

North Carolina Coastal Habitat Protection Plan

By
Michael W. Street, Anne S. Deaton,
William S. Chappell, and Peter D. Mooreside

N. C. Department of Environment and Natural Resources
Division of Marine Fisheries
Morehead City, NC 28557

February 2005

NCDENR

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NORTH CAROLINA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES
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ADOPTION OF NORTH CAROLINA COASTAL HABITAT PROTECTION PLAN AND AGREEMENT TO PREPARE IMPLEMENTATION PLANS

The Chairmen of the North Carolina Environmental Management Commission, Coastal Resources Commission, and Marine Fisheries Commission affirm that their respective Commissions adopt the North Carolina Coastal Habitat Protection Plan, as provided in General Statute 143B-279.8.

We recognize the importance of North Carolina's coastal fisheries resources and the commercial and recreational fisheries they support. The continued existence and enhancement of these resources depend on the health of the aquatic habitats they occupy. We pledge to cooperatively manage these aquatic habitats to ensure the long-term viability of the coastal fisheries resources. We agree that these Commissions will work to accomplish the following goals:

GOAL 1 – Improve effectiveness of existing rules and programs protecting coastal fish habitats

GOAL 2 – Identify, designate, and protect strategic habitat areas

GOAL 3 – Enhance habitat and protect it from physical impacts

GOAL 4 – Enhance and protect water quality

By July 1, 2005, the three Commissions and the Department of Environment and Natural Resources will each prepare and adopt Coastal Habitat Protection Implementation Plans to accomplish the goals listed above. The Implementation Plans will establish priorities and identify actions to be taken within specified time periods, including measures of success. The Department and the three Commissions will review progress annually and revise their plans at least every five years.

_____ _____

Chairman, Environmental Management Commission Date

_____ _____

Chairman, Coastal Resources Commission Date

_____ _____

Chairman, Marine Fisheries Commission Date

_____ _____

Secretary, Department of Environment and Natural Resources Date

ACKNOWLEDGEMENTS

Scores of state and federal agency staff, administrators, and scientists; university researchers; and members of various North Carolina regulatory commissions and their advisory bodies have contributed to the successful completion of this document since planning formally began in 1998. The foresight of the North Carolina Moratorium Steering Committee in 1996, in recommending establishment of a Coastal Habitat Protection Plan (CHPP), provided the foundation for this effort. The North Carolina General Assembly adopted the Fisheries Reform Act, including a mandate for the Coastal Habitat Protection Plan, on14 August 1997, and Governor James B. Hunt, Jr. signed the Act a few hours later.

The Department of Environment and Natural Resources (DENR) established the Coastal Habitat Protection Plan Development Team in March 1998. The Team developed the program's guidelines, which were adopted by the Environmental Management (EMC), Marine Fisheries (MFC), and Coastal Resources (CRC) commissions in June of that year. The Team has continued to play a central role in preparation of the CHPP, providing technical and process advice, reviews and edits, and circulating drafts within their agencies for review, and we are most grateful for the Team's dedication and accomplishments. Team members have changed somewhat over the years, including the following persons (in addition to the authors): Katy West and Mike Marshall (Division of Marine Fisheries – DMF), Dianne Reid, Gloria Putnam, Bonnie Duncan, and Patricia MacPherson (Division of Water Quality – DWQ); Steve Underwood, Mike Lopazanski, and Patricia Hughes (Division of Coastal Management – DCM); Bennett Wynne (Wildlife Resources Commission – WRC); Steve Murphey, Jonathan Andre, and Shannon Jenkins (Division of Environmental Health – DEH); and Ronnie Smith (U. S. Fish and Wildlife Service). Elizabeth B. Noble (currently with Elizabeth City State University) and Christopher Perle are former members of the CHPP staff, and we are grateful for their contributions to the program and document.

The three regulatory commissions established the Intercommission Review Committee (IRC), comprised of two members from each of the commissions, in June 1998 to provide policy oversight for the CHPP process. Most members also reviewed and edited draft chapters of the CHPP, especially during 2003 – 2004. Most importantly, the IRC developed the recommendations contained in Chapter 9. Membership has also changed over the years, including the following individuals: Pricey Taylor Harrison, Lee Wynns, and David Beresoff (CRC); Charles H. (Pete) Peterson and Will Fowler (EMC); and Barbara Garrity-Blake, B. J. Copeland, Tim Nifong, and Willy Phillips (MFC). We thank these persons for their dedication to the CHPP process, perseverance, and ability to make the hard choices involved in developing the recommendations during 2004.

Secretary of the Department of Environment of Natural Resources (DENR), William G. Ross, Jr., has been a steadfast and vocal advocate for the CHPP, and we are indeed grateful for his support. Assistant Secretary Robin Smith has been the lead Department person for the CHPP. In this role she has earned our gratitude for attending innumerable meetings, reviewing the entire draft, and solving many difficult problems.

The CHPP program convened a meeting of about 50 scientists in February 2000. Deliberations produced excellent advice for the CHPP staff to use in organizing and preparing this document. Many of the scientists in attendance continued to participate in the CHPP program since that time by providing references and data, and reviewing draft material. Attendees are listed in the report of that meeting (Coastal Habitat Protection Plan Development Team. 2000. Coastal habitat protection plan program workshop on critical fish habitats: February 29, 2000 meeting summary. N. C. Department of Environment and Natural Resources, Division of Marine Fisheries, 31 p.).

Staff of the DENR Office of Conservation and Community Affairs made an important contribution to public understanding of the CHPP in 2004 by preparing an excellent and colorful non-technical CHPP

publication “Caring for Our Fisheries.” We thank Bill Crowell, Kelly Williams, and Janine Nicholson for their hard work on this report.

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Jeanne Hardy has been the CHPP secretary throughout the process, arranging dozens of meetings (often providing lunch), taking and summarizing notes, and keeping things on track. Sandra Williams has been an invaluable assistant to Jeanne, focusing especially on copying and organizing documents, including the several drafts of the CHPP, as well as making CHPP CDs and distributing the CHPP to hundreds of persons and organizations in North Carolina and elsewhere. Diana Heatwole pitched in to assist in copying the draft CHPP.

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EXECUTIVE SUMMARY

This document is intended as a resource and guide for implementation of the goals and recommendations in Chapter 9 (Table 9.2).

North Carolina's coastal fisheries are among the most productive in the United States because of the wide variety of habitats available, the largest estuarine system (2.3 million acres) of any single Atlantic coast state, location of North Carolina at the transition between mid-Atlantic and south Atlantic regions, and a management system that supports active citizen participation. The condition of some important fish stocks declined during the late 1980s and early 1990s (for example, river herring, weakfish, and summer flounder) as fish kills and water-borne disease outbreaks increased. Protection and enhancement of fish habitats utilized by such species would be especially beneficial in supporting stock recovery.

Recognizing the critical importance of healthy and productive habitats to produce fish for human benefits, the North Carolina General Assembly included a provision in the Fisheries Reform Act of 1997 instructing the Department of Environment and Natural Resources (DENR) to prepare Coastal Habitat Protection Plans (CHPPs). The legislative goal of the plans is long-term enhancement of coastal fisheries associated with each habitat.

A unique feature of the plans is that three regulatory commissions (Environmental Management, Coastal Resources, and Marine Fisheries Commissions) are to adopt and implement the plans, thus requiring a coordinated management approach. The plans are to include information on the description, distribution, function, status and trends of important habitats; threats to those habitats; and recommendations to address the threats. The CHPP area includes all eight of the river basins that drain to the coast of North Carolina. Because the Fall Line is the upper limit for migration of almost all coastal fisheries species, emphasis is placed on the area downstream from that point.

The DENR and Commissions began working on the plans in 1998. The comprehensive approach established by the General Assembly had never been used before in the United States, so the department tried several different approaches before deciding to use the six basic fish habitat types as the framework for the plans:

- Water column
- Shell bottom
- Submerged aquatic vegetation (SAV)
- Wetlands
- Soft bottom
- Hard bottom

Documented locations of selected fish habitats in eastern North Carolina are shown in the attached, foldout map. Once the habitat approach had been established, the DENR and Commissions moved on to address the tasks listed in the Act. After reviewing the results of hundreds of scientific studies and input from experts and citizens alike, it became even more apparent that North Carolina's coastal fish habitats are seriously threatened by many human activities. The water column and shell bottom are the most threatened habitats, shell bottom because there is so little of it left, and the water column because there are so many pollution sources. The greatest single threat to North Carolina's coastal fish habitats is probably stormwater runoff, which carries sediment, wastes, and chemical pollutants into coastal waters, reducing water clarity, promoting algal blooms, decreasing dissolved oxygen, and reducing the benefits that a healthy coastal system would provide to coastal residents and visitors. The threat of stormwater pollution is exacerbated by increased surface and groundwater withdrawals needed to meet the water needs of a growing population.

The CHPP development process identified hundreds of management needs. The three Commissions reviewed the threats, along with possible management actions to address them. The Commissions selected four general goals and a series of recommendations to reach each goal, as shown below. Implementation of these recommendations will involve new program activities and revised priorities for existing programs within DENR and other agencies. Significant new funding is essential. Prioritization of the recommendations will occur in each Commission's implementation plan to be developed in 2005.

GOAL 1. IMPROVE EFFECTIVENESS OF EXISTING RULES AND PROGRAMS PROTECTING COASTAL FISH HABITATS

- Enhance enforcement of, and compliance with, Coastal Resources Commission (CRC), Environmental Management Commission (EMC), and Marine Fisheries Commission (MFC) rules and permit conditions.
- Coordinate and enhance water quality, physical habitat, and fisheries resource monitoring (including data management) from headwaters to the nearshore ocean.
- Enhance and expand educational outreach on the value of fish habitat, threats from human activities, effects of non-native species, and reasons for management measures.
- Coordinate rulemaking and enforcement among regulatory commissions and agencies.

GOAL 2. IDENTIFY, DESIGNATE, AND PROTECT STRATEGIC HABITAT AREAS

- Evaluate potential Strategic Habitat Areas by:
    - Coordinating, completing, and maintaining baseline habitat mapping (including seagrass, shell bottom, and other bottom types) using the most appropriate technology,
    - Selective monitoring of the status of those habitats, and
    - Assessing effects of land use and human activities on those habitats.
- Identify and designate Strategic Habitat Areas using ecologically based criteria.
- Analyze existing rules and enact measures needed to protect Strategic Habitat Areas.
- Improve programs for conservation (including voluntary actions) and acquisition of areas supporting Strategic Habitat Areas.

GOAL 3. ENHANCE HABITAT AND PROTECT IT FROM PHYSICAL IMPACTS

- Greatly expand habitat restoration, including:
    - Creation of subtidal oyster reef no-take sanctuaries, and
    - Re-establishment of riparian wetlands and stream hydrology.
- Prepare and implement a comprehensive beach and inlet management plan that addresses ecologically based guidelines, socio-economic concerns, and fish habitat.
- Protect Submerged Aquatic Vegetation (SAV), shell bottom, and hard bottom areas from fishing gear effects through improved enforcement, establishment of protective buffers around habitats, and further restriction of mechanical shellfish harvesting.
- Protect fish habitat by revising estuarine and public trust shoreline stabilization rules using best available information, considering estuarine erosion rates, and the development and promotion of incentives for use of alternatives to vertical shoreline stabilization measures.
- Protect and enhance habitat for anadromous fishes by:
    - Incorporating the water quality and quantity needs of fish in surface water use planning and rule making, and

- Eliminating obstructions to fish movements, such as dams, locks, and road fills.

GOAL 4. ENHANCE AND PROTECT WATER QUALITY

Point sources

- Reduce point source pollution from wastewater by:
  - Increasing inspections of wastewater treatment facilities, collection infrastructure, and land disposal sites, and
  - Providing incentives for upgrading all types of wastewater treatment systems.
- Adopt or modify rules or statutes to prohibit ocean wastewater discharges.
- Prohibit new or expanded stormwater outfalls to coastal beaches and to coastal shellfishing waters (EMC surface water classifications SA and SB) except during times of emergency (as defined by the Division of Water Quality's Stormwater Flooding Relief Discharge Policy) when public safety and health are threatened, and continue to phase-out existing outfalls by implementing alternative stormwater management strategies.

Non-point sources

- Enhance coordination with, and financial/technical support for, local government actions to better manage stormwater and wastewater.
- Improve land-based strategies throughout the river basins to reduce non-point pollution and minimize cumulative losses to wetlands and streams through voluntary actions, assistance, and incentives, including:
  - Improved methods to reduce sediment pollution from construction sites, agriculture, and forestry,
  - Increased on-site infiltration of stormwater,
  - Documentation and monitoring of small but cumulative impacts to wetlands and streams from approved, un-mitigated activities,
  - Incentives for low-impact development,
  - Increased inspections of onsite wastewater treatment facilities,
  - Increased water re-use and recycling.
- Improve land-based strategies throughout the river basins to reduce non-point pollution and minimize cumulative losses to wetlands and streams through rule making, including:
  - Increased use of effective vegetated buffers,
  - Reduction of impervious surfaces where
  - feasible and reduction of the level of impervious surface allowable in the absence of
  - engineered stormwater controls,
  - Expansion of CAMA Areas of Environmental Concern (AECs) upstream and landward,
  - Consideration of erosion rates as an additional factor in the siting of structures along estuarine and public trust shorelines.
- Develop and implement a comprehensive coastal marina and dock management plan and policy for the protection of shellfish harvest waters and fish habitat.
- Reduce non-point source pollution from large-scale animal operations by the following actions:
  - Support early implementation of environmentally superior alternatives to the current lagoon and spray field systems as identified under the Smithfield Agreement and continue the moratorium on new/expanded swine operations until alternative waste treatment technology is implemented,
  - Seek additional funding to phase-out large-scale animal operations in sensitive areas and relocate operations from sensitive areas,
  - Use improved siting criteria to protect fish habitat.

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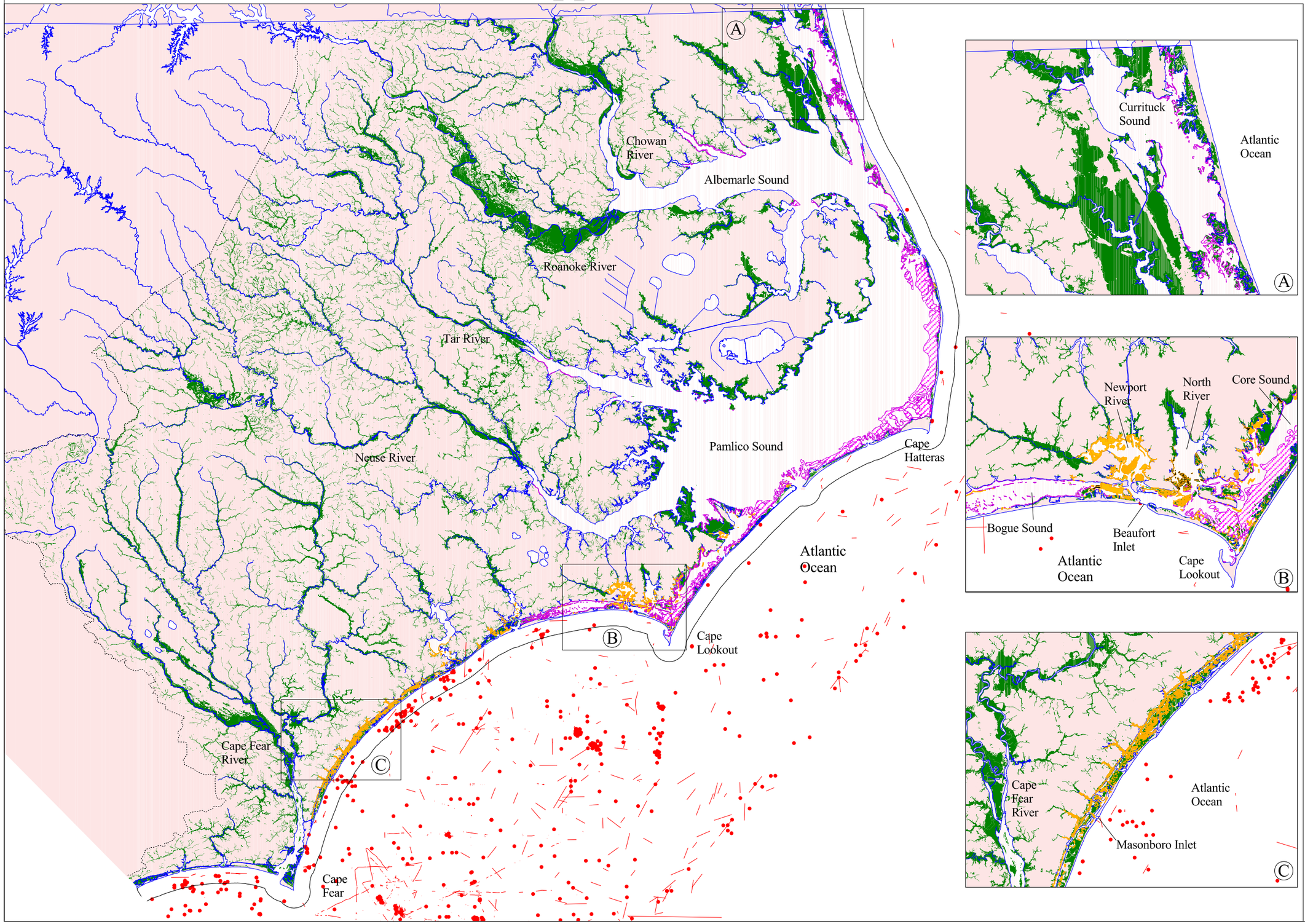
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General Location of Mapped Fish Habitats in Coastal North Carolina



HABITATS

- Rivers, Creeks and Streams
- Shell Bottom
- Riparian Wetlands
- Submerged Aquatic Vegetation
- Hardbottom

N

10 0 10 Kilometers

10 0 10 Miles

Locator map

Coastal Habitat Protection Plan

NCDENR

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

CHAPTER 1. INTRODUCTION

1.1. PUBLIC TRUST DOCTRINE

North Carolina state government applies the Public Trust Doctrine in management of its coastal lands, surface waters, and the resources in those waters. The Public Trust Doctrine states that "public trust lands, waters, and living resources in a State are held by the State in trust for the benefit of all the people, and establishes the right of the public to fully enjoy public trust lands, waters, and living resources for a wide variety of recognized public uses. The doctrine also sets limitations on the States, the public, and private owners, as well as establishing the responsibilities of the States when managing these public trust assets" (Coastal States Organization 1997).

The Constitution of North Carolina implements the Public Trust Doctrine in Article XIV, Section 5, which states: "It shall be the policy of this State to conserve and protect its lands and waters for the benefit of all its citizenry, and to this end it shall be a proper function of the State of North Carolina and its political subdivisions to acquire and preserve park, recreational, and scenic areas, to control excessive noise, and in every other appropriate way to preserve as a part of the common heritage of this State its forests, wetlands, estuaries, beaches, historical sites, open lands, and places of beauty."

Public trust resources include the waters to the upstream extent of navigation, including navigation by small recreational boats, such as canoes or kayaks [North Carolina Supreme Court (*Gwathmey v. State of North Carolina*, 342 N.C. 287, 464 S. E. 2d. 674, 1995)]; submerged lands beneath the waters up to the normal high tide line (or normal water level in areas not subject to lunar tides); and the fisheries resources within those waters (see definition below). Common public trust uses include navigation and commerce, fishing, bathing (swimming), and hunting. Under certain circumstances, private entities may own submerged lands, but public trust rights in the waters over those lands are not affected by such ownership.

The State can restrict exercise of public trust rights in the overall public interest. Such restrictions can be in the form of laws enacted by the North Carolina General Assembly or rules adopted as part of the North Carolina Administrative Code (NCAC) by regulatory commissions established by the General Assembly. A variety of regulatory commissions and administrative agencies established by the General Assembly have authority for management of North Carolina's coastal lands, waters, and fishes under state and federal laws. State authority generally applies within the boundaries of North Carolina, which extends from internal waters (creeks, rivers, and lakes) downstream through the coastal sounds, and into the Atlantic Ocean for three nautical (nm) or 3.45 statute miles from the state's Atlantic Ocean shoreline. Federal jurisdiction applies from that point out to 200 nm (230.16 statute miles) from shore, an area called the Exclusive Economic Zone (EEZ). Several state and federal agencies conduct major regulatory, research, and educational programs that affect North Carolina's coastal fisheries resources and their habitats (Appendix A).

1.2. THE FISHERIES REFORM ACT AND COASTAL HABITAT PROTECTION PLANS

On August 14, 1997, Governor James B. Hunt, Jr., signed the Fisheries Reform Act (FRA) into law, bringing to a close a three-year process of intense meetings, discussions and debates over the future of fisheries management in North Carolina. This far-reaching reform package was put together by a coalition of legislators, commercial and recreational fishermen, scientists, fisheries managers and conservationists, in order to ensure healthy fish stocks, the recovery of depleted stocks and the wise use of North Carolina's fisheries resources. The FRA (S.L.1997-400, H.B. 1097) includes a provision [General Statute (G.S.) 143B-279.8] for preparation of Coastal Habitat Protection Plans (CHPPs) by the North Carolina Department of Environment and Natural Resources. This section of the FRA resembles the federal Magnuson-Stevens Fishery Conservation and Management Act reauthorization of 1996 [also known as the Sustainable Fisheries Act (SFA)]. The SFA requires the regional fishery management councils and

National Marine Fisheries Service (NMFS) to amend federal fishery management plans to include provisions for the protection of "Essential Fish Habitat" (EFH) from federally funded activities. ***The legislative goal of the CHPPs is long-term enhancement of coastal fisheries associated with coastal habitats***. The CHPP is to identify threats and recommend management actions to protect and restore habitats critical to North Carolina's coastal fishery resources. The plans must be adopted by the Coastal Resources (CRC), Environmental Management (EMC), and Marine Fisheries (MFC) commissions. Once adopted, the plans will help to ensure consistent actions among commissions, as well as their supporting Department of Environment and Natural Resources (DENR) agencies. The passage of the FRA and the initiation of the CHPP program demonstrated the public desire and political will to better manage North Carolina's coastal fishery habitats.

Since the mid-1980s, the State of North Carolina, through the Governor and General Assembly, has convened several high level panels to examine coastal environmental and fishery management issues. Each has made numerous policy recommendations concerning improved management of fish habitat and water quality.

- The Final Report and Recommendations of the Governor's Blue Ribbon Panel on Environmental Indicators was published in December 1990 (C. Manooch, DMF, pers. com., 2004). This report provided guidelines for developing a set of indicators to evaluate the status and trends of environmental quality within North Carolina. Responsibility for the task was assigned to the state's Department of Environment, Health, and Natural Resources (now DENR). The report evaluates indicators in the following environmental areas: air quality, air radioactivity, and indoor radon; water quality, groundwater, and public water supplies; solid waste, hazardous waste, and low-level radioactive waste; marine fishery resources, shellfish growing areas, and wetlands.
- The Albemarle-Pamlico Estuarine Study (1987 – 1994) recommended numerous water quality, fishery management, and land use reforms in its Comprehensive Conservation and Management Plan, including retain, restore, and enhance water quality; conserve and protect vital fish and wildlife habitats; and restore or maintain fisheries (Waite et al. 1994).
- The North Carolina Coastal Futures Committee was established in recognition of the 20th anniversary of passage of the Coastal Area Management Act (CAMA), which established North Carolina's coastal zone management system under the CRC. The Committee's report cited the tremendous growth in population and use of coastal resources, and recommended a number of important actions, including restoration and protection of important fisheries habitats, the need to address nonpoint source pollution, restoration of impaired coastal waters, and protection of freshwater wetlands similar to existing protection of coastal wetlands (North Carolina Coastal Futures Committee 1994).
- The Blue Ribbon Advisory Council on Oysters recommended a major increase in planting of oyster cultch to help restore oyster resources as well as changes in management of oyster culture practices (Frankenberg 1995).
- Most of the recommendations of the Fisheries Moratorium Steering Committee were included in the FRA in 1997, including development of this CHPP. The report also recommended reform of North Carolina's coastal fisheries management system through the development of state Fishery Management Plans (FMPs) (MSC 1996).
- The CRC convened the Estuarine Shoreline Protection Stakeholders in 1999 to examine impacts of estuarine shoreline uses and water quality. The group's report included comprehensive recommendations to improve agency coordination, enhance basinwide water quality management, restoration of impaired waters, and reduction of point and nonpoint source pollution (North Carolina Estuarine Shoreline Protection Stakeholders 1999).

Thus, there is a rich history of citizen participation in examination of coastal habitat and water quality issues in recent years. Based on public comments received at 20 public CHPP meetings along the coast and inland during the summers of 2003 and 2004 (Appendix B1 and B2), results indicated considerable

frustration that many, repeated recommendations have not been implemented. Because the CHPP uniquely brings together three major regulatory commissions, the public has an expectation that positive actions will result from this effort.

While the MFC manages commercial and recreational fishing practices in coastal waters through rules implemented by the Division of Marine Fisheries (DMF), several other agencies directly and indirectly affect coastal fisheries and fish habitats. The EMC has wide-ranging authority over activities affecting water quality statewide. Rules adopted by the EMC govern point and nonpoint discharges, wastewater management, alteration of non-coastal wetlands, and stormwater management. The EMC is unique because its rules are implemented by several different DENR agencies, including the Division of Water Quality (DWQ), Division of Air Quality (DAQ), Division of Water Resources (DWR), and the Division of Land Resources (DLR). The DLR is also unique because it administers rules adopted by multiple regulatory commissions, including the EMC, Sedimentation Control Commission, and the Mining Commission. The CRC enacts rules to manage development and land disturbing activities along estuarine and ocean shorelines, shoreline stabilization, alteration of submerged bottoms and coastal wetlands, and marina construction. The Division of Coastal Management (DCM) implements rules adopted by the CRC. The N.C. Wildlife Resources Commission (WRC) has a direct role in the management of fisheries through the designation of primary nursery areas in Inland Waters, including many anadromous fish spawning areas, and regulation of fishing in those waters. There are a myriad of other state, federal, and interstate programs affecting coastal fisheries habitat in North Carolina (Appendix A).

This plan was written by DMF staff with assistance from the CHPP Development Team - scientists and planners from DMF, DCM, DWQ, Division of Environmental Health (DEH), and WRC (Appendix C). An Intercommission Review Committee (IRC), consisting of two members from each of the three commissions (Appendix C), provided policy oversight, reviewed this plan, and developed the management recommendations (Chapter 9.0).

1.3. PURPOSE AND ORGANIZATION OF DOCUMENT

The primary focus of this plan is describing habitats for coastal fisheries resources in eastern North Carolina, threats to those habitats, and management actions to address those threats. The CHPP identifies four goals for protection of coastal fisheries habitat:

1) Improve effectiveness of existing rules and programs protecting coastal fish habitats
2) Identify, designate, and protect all Strategic Habitat Areas
3) Enhance habitat and protect it from physical impacts
4) Enhance and protect water quality

The CHPP is built around six basic habitats utilized by coastal fishery species: water column, shell bottom, submerged aquatic vegetation (SAV), wetlands, soft bottoms, and hard bottoms. Within each of the following habitat chapters (Chapters 2 - 7), there is detailed information on the habitat's description, distribution, ecological role and functions for finfish and shellfish species (primarily fishery species, but also forage and protected species), status and trends, threats, and management needs. The term "management" is defined broadly to include regulatory, enforcement, research, monitoring, and restoration activities affecting coastal fish habitat. Management needs are based on documented inadequacies in the current management framework and are highlighted in the habitat chapters with *italics.* A summary highlighting the most pressing management needs is provided at the end of each habitat chapter. A chapter addressing strategic habitats (what they are and criteria for their designation) follows the habitat chapters (Chapter 8). The final chapter lists the most pressing management recommendations as developed by the IRC. Each of the Commissions will use the threats discussion, management needs, and recommendations to develop coordinated coastal habitat management strategies as provided in the Act. The DENR will also develop a coordinated strategy to implement the CHPP

recommendations.

1.4. AREA DESCRIPTION

The CHPP area includes all waters flowing into North Carolina's coastal waters and the watersheds they drain. Table 1.1 shows that the CHPP area is approximately 12% water (3,181,881 acres) and 88% land (24,229,770 acres). Maps 1.1a and 1.1b show this area, including water bodies, the main towns, roads and other local and regional features noted throughout the CHPP. Local and regional differences in habitat and associated fish species are determined by climate, geology, ground water and surface water hydrology, land use, and associated human population.

Table 1.1. The land and water areas for each North Carolina Coastal Habitat Protection Plan Management Unit. (Source: 1:100,000 scale USGS topographic quadrangle maps)

Management Unit	Land area		Water area		Total area (acres)
	Acres	% of total	Acres	% of total	
Albemarle	1,669,684	72	658,400	28	2,328,084
Cape Fear	5,795,998	99	64,973	1	5,860,970
Chowan	3,183,877	98	51,691	2	3,235,568
Coastal Ocean	15,374	2	724,842	98	740,216
Core/Bogue	188,976	53	167,998	47	356,974
Neuse	3,466,244	96	135,571	4	3,601,815
New/White Oak	481,345	93	38,449	7	519,794
Pamlico Sound	394,337	27	1,061,613	73	1,455,950
Roanoke	6,118,980	98	140,827	2	6,259,807
Southern Estuaries	253,227	95	14,425	5	267,652
Tar/Pamlico	2,661,729	96	123,092	4	2,784,821
Total	**24,229,770**	**88**	**3,181,881**	**12**	**27,411,651**

To address local and watershed issues, the CHPP program will also produce Management Unit (MU) plans, after the CHPP development, based primarily on the same watershed boundaries used by DWQ for Basinwide Water Quality Plans. Since the CHPP is focused on fish and fisheries, some minor boundary changes were made to reflect similarities in fish habitats, or in estuarine and coastal water body dynamics. A watershed approach is necessary because many fisheries rely on the interconnectivity of waters within a watershed, and most pollutants are conveyed into estuarine waters via upstream conduits. The eleven MU areas and their boundaries approved by the IRC are shown on Map 1.2. The units are Chowan, Albemarle, Roanoke River, Pamlico Sound, Tar-Pamlico, Neuse, Core/Bogue, New-White Oak, Cape Fear, Southern Estuaries, and Coastal Ocean. Most of the Chowan and Roanoke River MUs, and part of the Albemarle MU, are located in Virginia. The Coastal Ocean MU includes North Carolina's territorial waters and ocean front beaches. Among MUs, the largest area of water (1,061,613 acres) is in Pamlico Sound, and the smallest area (14,425 acres) is in the Southern Estuaries (Table 1.1).

Climate and weather

Weather conditions, especially temperature, precipitation, wind, and storms, exert major influences on the coastal area and fishery resources of eastern North Carolina. The climate along the North Carolina coast is strongly influenced by the Atlantic Ocean. North Carolina's coastal ocean includes the convergence between two major oceanic currents: the warm, north-flowing Gulf Stream and the cool, south-flowing Virginia coastal current (also called the Labrador Current). The Gulf Stream current moves within 10 – 12 mi (16.1 – 19.3 km) of the coast at Cape Hatteras before turning northeast toward Europe, bringing southern species (such as brown, white, and pink shrimp; king and Spanish mackerel; snappers and groupers; and calico scallops) to North Carolina's waters. The Virginian (Labrador) Current ends at the

Gulf Stream, supplying northern oceanic species (such as Atlantic mackerel, Atlantic herring, and Atlantic cod) to North Carolina.

The works summarized in Orlando et al. (1994) closely examined coastal wind patterns. These winds vary at basically three time scales: seasonal (>1 month); synoptic (3-20 days) due to the passage of weather systems; and diurnal (<1 day) due to changes in local sea breezes. Seasonal winds blowing in the South Atlantic Bight (SAB) (area from Cape Hatteras, N.C. to Cape Canaveral, F.L.) originate either from the Bermuda-Azores High in the North Atlantic or from a smaller high pressure area centered over the Ohio Valley (Ohio Valley High). During winter (November – February), winds flowing from the northwest gradually shift to the north. Winds are stronger in North Carolina than in states to the south during this season. During spring and summer, the dominant influence of the Ohio Valley High is replaced by the Bermuda-Azores High, resulting in winds from the west and southwest. West and southwest winds cause offshore movement of surface water and inshore movement of bottom water along much of the North Carolina coast, resulting in upwelling in some near-shore areas. Autumn winds (September – October) flow more from the northeast.

Storms can have a significant impact on the geology of the coastal area. Tropical storms can bring storm surges over 16 ft (4.9 m) above sea level along the south Atlantic coast (VIMS 1974 in Orlando et al. 1994), causing coastal flooding. Between 1950 and 1996, 14 hurricanes struck the North Carolina coast. More recently, hurricanes Bertha and Fran hit North Carolina in 1996. In 1997 and 1998, two more hurricanes affected the coastal area: Danny in July 1997 and Bonnie in August 1998. Three sequential storms affected the North Carolina coast during late August - October 1999 (Hurricanes Dennis and Floyd, and Tropical Storm Irene), inundating the region with up to 3.3 ft (1m) of rainfall, resulting in several weeks of flooding and major environmental and economic damage (Bales et al. 2000; Paerl et al. 2001). Similarly, “nor’easter” storms during fall through spring also cause coastal flooding. For example, the Good Friday storm of 1962 was one of the most severe storms recorded to strike the United States' Atlantic coast, causing severe damage from North Carolina to New England.

Geology and hydrology

A chain of low-lying barrier islands extending from Virginia to Cape Fear dominates the geology and surface water hydrology of North Carolina’s ocean coastline. Artificial barrier islands extending from the Cape Fear River to South Carolina were created by dredging the Atlantic Intracoastal Waterway (ICW) in the 1930s (Map 1.1b). The northern part of the natural barrier islands, the Outer Banks, separates the Albemarle-Pamlico sounds complex from the coastal ocean. Proceeding inland, eastern North Carolina's land area is divided between the Coastal Plain and Piedmont physiographic regions, with the majority of land in the Coastal Plain. These two regions are separated by the Fall Line (Map 1.3), where streams are characterized by falls and rapids. The Coastal Plain region extends from the seashore up to the Fall Line and varies in width from 120 to 160 mi (193.1 – 257.5 km). Streams in the western Coastal Plain have sandy bottoms. Going east, those sandy bottoms change to mud and clay in the eastern Coastal Plain, where there are extensive swamps and occasional large, shallow lakes (Menhinick 1991). The streams converge near the coast to form estuaries where fresh water mixes with salt water from the ocean. The Chowan, Roanoke, Tar-Pamlico, and Neuse rivers flow into the Albemarle-Pamlico estuarine system, the second largest estuary on the U.S. Atlantic coast. The Cape Fear River flows directly into the Atlantic Ocean.

The groundwater hydrology of coastal North Carolina is dominated by six major aquifers: the surficial, Yorktown, Black Creek, Castle Hayne, Cretaceous, and Peedee (Steel 1991; Giese et al. 1997). The various aquifers intersect the surface in zones running northeast to southwest. The Cretaceous aquifer is the most extensive and farthest west of Coastal Plain aquifers. The surficial and Yorktown are farthest east, and the Castle Hayne lies between the Yorktown and Cretaceous. The thickness of the aquifers varies from a several feet along the Fall Line, to more than 3000 m (9843 ft) at Cape Hatteras (Steel 1991).

Land use and human population

Estuarine and coastal areas contain some of the nation's most densely populated and rapidly growing areas (Beach 2002). Population density patterns reflect historical development and population pressures, location relative to transportation networks, and the natural resources of the coastal areas (NOS 1990). As population density increases, so does the potential for degradation of the natural environment by human activities (Cairns and Pratt 1992). In the year 2000, New Hanover County had the highest population density (803 persons/mi^2, Table 1.2) among the 20 coastal counties included in the Coastal Area Management Act (CAMA). Onslow, Pasquotank, Craven, Carteret, and Brunswick counties also had relatively high population densities (over 100 persons/mi^2). However, the highest-density areas in North Carolina were in the Piedmont region (Map 1.4), suggesting that at least some of the problem from highly mobile pollutants may be traced upstream. The lowest population densities in eastern North Carolina (about 10 persons/mi^2) were in Tyrrell and Hyde counties.

The human population of North Carolina's coastal area is growing rapidly. During the 1970s, counties within the Albemarle-Pamlico region grew at a rate below the statewide average, but in the 1980s, those counties exceeded the statewide average growth rate by 3.6% (Steel 1991). Growth rates were highest in oceanfront counties, except Hyde, in which all the oceanfront property is federally owned (Ocracoke Island lies within Cape Hatteras National Seashore). Combined population growth in the eight counties bordering the Atlantic Ocean (Currituck, Dare, Hyde, Carteret, Onslow, Pender, New Hanover, and Brunswick) has exceeded 20% per decade since 1970 (<http://data.osbm.state.nc.us/pls/linc>, 24 September 2003). During that period, population changes in those counties ranged from an increase of 91% (Dare County from 1970 to 1980) to a loss of 8% (Hyde County from 1980 to 1990). North Carolina's 44 Coastal Plain counties had a 16% population increase from 1990 to 2000 (1,919,186 to 2,229,888), compared to a 19% increase in non-Coastal Plain counties for the same time period. However, there was great variation among counties in the Coastal Plain (Map 1.5). As shown in Table 1.2, New Hanover, Pender, Currituck, Dare, and Brunswick counties had growth rates ranging from about 32 to 44%, while Onslow, Hertford, Washington, and Bertie counties had very low or negative growth rates (-3 to 1.3%).

The coastal counties of North Carolina experience tremendous seasonal population fluctuations due to the influx of tourists. The seasonal population of coastal cities and towns increased, on average, 54% from 1990 to 2000 (Table 1.3). These estimates do not include day visitors who come to the area, but do not stay overnight. The counties that border the ocean and sounds have the greatest population fluctuations due to tourism. In many of these counties, public facilities, including wastewater treatment systems, roads, and water supply systems, are being taxed to the limit (Steel 1991).

Table 1.2. Human population, density, and growth in Coastal Plain counties of North Carolina sorted by Coastal Area Management Act (CAMA) counties and other Coastal Plain counties, and growth during 1990 – 2000. (Source: North Carolina Office of State Budget and Management, unpub. data.)

	1990		2000		1990-2000	
COUNTY	Population	Persons/ mi^2	Population	Persons/ mi^2	Growth	% growth
CAMA counties						
Brunswick	50,985	82.33	73,143	118.10	22,158	43.5
Pender	28,855	33.16	41,082	47.22	12,227	42.4
New Hanover	120,284	602.85	160,307	803.44	40,023	33.3
Currituck	13,736	52.55	18,190	69.59	4,454	32.4
Dare	22,746	59.33	29,967	78.17	7,221	31.7
Camden	5,904	24.57	6,885	28.65	981	16.6
Pamlico	11,368	33.40	12,934	38.00	1,566	13.8
Carteret	52,407	101.13	59,383	114.59	6,976	13.3
Gates	9,305	27.29	10,516	30.84	1,211	13.0
Craven	81,812	115.12	91,436	128.66	9,624	11.8
Pasquotank	31,298	137.96	34,897	153.83	3,599	11.5
Perquimans	10,447	42.28	11,368	46.00	921	8.8
Hyde	5,411	8.75	5,826	9.43	415	7.7
Chowan	13,506	78.19	14,526	84.09	1,020	7.6
Tyrrell	3,856	9.84	4,149	10.58	293	7.6
Beaufort	42,283	50.83	44,958	54.05	2,675	6.3
Hertford	22,317	63.01	22,601	63.81	284	1.3
Onslow	149,838	195.37	150,355	196.04	517	0.3
Washington	13,997	40.44	13,723	39.65	-274	-2.0
Bertie	20,388	29.16	19,773	28.28	-615	-3.0
Other Coastal Plain Counties						
Johnston	81,306	102.18	121,965	153.28	40,659	50.0
Hoke	22,856	102.56	33,646	150.98	10,790	47.2
Harnett	67,833	113.20	91,025	151.90	23,192	34.2
Sampson	47,297	49.96	60,161	63.55	12,864	27.2
Pitt	108,480	165.67	133,798	204.34	25,318	23.3
Greene	15,384	57.76	18,974	71.24	3,590	23.3
Duplin	39,995	48.82	49,063	59.89	9,068	22.7
Nash	76,677	141.28	87,420	161.08	10,743	14.0
Bladen	28,663	47.09	32,278	53.03	3,615	12.6
Wilson	66,061	176.54	73,814	197.25	7,753	11.7
Jones	9,361	19.75	10,381	21.90	1,020	10.9
Columbus	49,587	487.97	54,749	538.77	5,162	10.4
Cumberland	274,713	427.25	302,963	471.18	28,250	10.3
Wayne	104,666	187.92	113,329	203.47	8,663	8.3
Northampton	21,004	39.07	22,086	41.08	1,082	5.2
Lenoir	57,274	142.48	59,648	148.39	2,374	4.1
Halifax	55,516	76.39	57,370	78.94	1,854	3.3
Martin	25,078	54.23	25,593	55.34	515	2.1
Edgecombe	56,692	111.88	55,606	109.74	-1,086	-1.9

As population increases, so does the need for infrastructure (roads, schools, water and sewer facilities, electric transmission lines, etc.) to support those people, sometimes resulting in loss of important habitats and supporting areas, such as wetlands and riparian forests (see Water Column and Wetland chapters for more information on changes in land cover). Land cover data reported by the federal National Resource Inventory (D. Good, U.S. Department of Agriculture, Natural Resource Conservation Service, pers. com., 2001) show that urban/built-up land increased in coastal river basins by 83% from 1982 to 1997 (Appendix D and E).

Despite the growth in urban/built-up areas, land cover in coastal North Carolina is still primarily forest (53%) and cultivated crops (21.5%) (Appendix D). Beach (2002) showed that increases in developed areas have far outpaced population growth in coastal areas nationwide, resulting in a greater habitat impact than population data alone suggest. Beach (2002) concluded that conversion of land in the coastal zone from open space (forest and agricultural uses) to urban/suburban uses was the primary threat to coastal water quality. As of 1997, urban/built-up land covered 2.9-19.6% of the land area in North Carolina's coastal river basins (Appendix D).

Table 1.3. Changes in permanent population, and seasonal population estimates for North Carolina's barrier islands, 1970 - 2000. (Sorted in order of descending percent increase in permanent population. Sources: North Carolina Office of State Planning; North Carolina State Library; and town officials, pers. com., 2001)

	Permanent population				Seasonal population	
Municipality	**1970**	**April 1990**	**April 2000**	**Percent increase: 1990-2000**	**Current seasonal estimate**	**Seasonal: permanent ratio**
Sunset Beach	108	311	1,824	486	15,000	8
Kure Beach	394	619	1,507	143	20,000	13
Bald Head Island	*	78	173	122	4,000	23
Caswell Beach	28	175	370	111	*	*
Kitty Hawk	0	1,937	2,991	54	19,759	7
Southern Shores	75	1,447	2,201	52	7,018	3
Nags Head	414	1,838	2,700	47	35,079	13
Oak Island	493	4,550	6,571	44	30,000	5
Surf City	166	970	1,393	44	20,000	14
Emerald Isle	122	2,434	3,488	43	35,000	10
Kill Devil Hills	357	4,238	5,897	39	40,473	7
Topsail Beach	108	346	471	36	1,500	3
Unincorporated Bodie Island	*	5,208	6,753	30	8,509	1
Carolina Beach	1,663	3,630	4,701	30	40,000	9
Holden Beach	136	626	787	26	*	*
Pine Knoll Shores	62	1,360	1,524	12	10,000	7
Ocracoke Township	*	690	769	11	*	*
Unincorporated Hatteras Island	*	3,833	4,001	4	24,901	6
Atlantic Beach	300	1,938	1,781	-8	35,000	20
North Topsail Beach	*	947	843	-11	4,800	6
Wrightsville Beach	1,701	2,937	2,593	-12	40,000	15
Ocean Isle Beach	78	523	426	-19	25,000	59
Indian Beach	48	153	95	-38	5,000	53
Total	**6,253**	**40,788**	**53,859**	**32**	**421,039**	**8**

* Lack of data

Fisheries and protected species

Throughout this plan, the term "fish" is used to include, "All marine mammals; all shellfish; all crustaceans and all other fishes" [G.S. 113-129 (7)]. Coastal fish species are grouped into three overlapping classes based on management considerations: 1) fishery species, 2) forage species, and 3) protected species.

- Fishery species are those finfish, crustaceans, and mollusks that may be harvested in North Carolina's Coastal and Inland Fishing Waters (DMF 2003a) by commercial and recreational fishermen. Habitats supporting fishery species are the primary focus of the CHPP.
- Forage species make up a significant portion of the diet of fishery species (e.g., killifish, grass shrimp, menhaden, mullet).
- Protected species meet two criteria: 1) listed according to state law [G. S. 113-331] or through the federal Endangered Species Act by the relevant state or federal agency or protected under the federal Marine Mammal Protection Act, and 2) require aquatic or wetland habitat within North Carolina's coastal river basins or nearshore ocean waters at some point in their life cycle. Protected species are important in the CHPP process because they can be indicators of ecological stress (Ricklefs 1993). In addition, their habitat needs provide support for designating strategic habitat in locations where the distribution of fishery and protected species overlap, as well as in upstream areas important for maintaining estuarine water quality.

Fisheries

Coastal fisheries are defined as, "Any and every aspect of cultivating, taking, possessing, transporting, processing, selling, utilizing, and disposing of fish taken in coastal fishing waters, whatever the manner or purpose of taking…" [G.S.113-129 (2)]. North Carolina is one of the nation's leading coastal fishing states. Reported landings by both commercial and recreational fishermen in North Carolina generally rank among the top Atlantic coast states every year (Tables 1.4 and 1.5). More than 90% of North Carolina's commercial fisheries landings and over 60% of the recreational harvest (by weight) are comprised of estuarine-dependent species (from DMF annual commercial and recreational fisheries landings data). These species depend on North Carolina's coastal sounds and rivers to complete their life cycle.

North Carolina's fisheries productivity is attributable to several factors:

- Vast estuarine system, the largest (about 2.3 million acres) of any single Atlantic coast state, provides the basis for a wide variety of fish stocks and the fisheries that depend on them.
- Location at the convergence of the South Atlantic and mid-Atlantic biogeographic provinces, with important features from both, including habitats, fish stocks, and fishing methods.
- Wide variety of habitats that support various life history stages of fisheries stocks, such as:
    - Extensive seagrass meadows;
    - Ocean hard bottoms (natural rock outcrops, coral encrusted reefs, shipwrecks, and one of the largest state-managed artificial reef systems in the United States);
    - Shell bottoms, especially oyster reefs;
    - Vast areas of biologically productive shallow waters overlying mud and sand bottoms;
    - Extensive coastal marshes; and
    - Riverine systems with large areas of productive bottomland hardwood forest, as well as adjacent swamp forests.
- Flexible and responsive fisheries management processes that provide for harvest under a fisheries management plan (FMP) system with extensive data collection and public participation.
- Strong heritage of commercial and sport fishing, including recreational use of commercial gears, throughout eastern North Carolina.

Table 1.4. Annual Atlantic coast commercial fisheries landings by state, 1997 - 2001 (thousands of pounds, sorted in descending order of average landings). (Source: National Marine Fisheries Service data)

State	1997	1998	1999	2000	2001	Total	Average	%	Rank
Virginia	584,895	592,767	460,289	443,197	561,708	2,642,856	528,571	32	1
Maine	246,344	184,103	229,633	226,849	239,868	1,126,797	225,359	14	2
Massachusetts	229,915	257,438	198,877	187,861	242,066	1,116,157	223,231	13	3
New Jersey	175,172	197,550	168,974	171,804	168,403	881,903	176,381	11	4
North Carolina	228,433	180,238	153,310	155,214	139,277	856,472	171,294	10	5
Rhode Island	143,101	133,702	124,168	119,295	115,957	636,223	127,245	8	6
Maryland	76,599	61,479	66,419	48,913	55,536	308,946	61,789	4	7
New York	60,956	57,542	49,661	41,181	42,422	251,762	50,352	3	8
Florida (east coast)	32,719	29,959	30,417	40,607	37,130	170,832	34,166	2	9
Connecticut	19,072	17,625	18,430	19,563	18,687	93,377	18,675	1	10
South Carolina	17,350	17,653	18,574	15,835	14,111	83,523	16,705	1	11
New Hampshire	10,896	10,172	11,258	17,160	18,584	68,070	13,614	1	12
Georgia	14,511	13,196	12,250	9,694	9,036	58,687	11,737	1	13
Delaware	9,084	7,866	8,372	6,676	7,123	39,121	7,824	0	14
Total	**1,849,047**	**1,761,290**	**1,550,632**	**1,505,849**	**1,671,909**	**8,334,726**	**1,666,945**	**na**	**na**

Table 1.5. Annual Atlantic coast marine recreational fisheries harvest by state, 1997 - 2001 (thousands of pounds, sorted in descending order of descending average landings). (Source: National Marine Fisheries Service, Fisheries Statistics and Economics Division, pers. com., 2003)

State	1997	1998	1999	2000	2001	Total	Average	%	Rank
Florida (east coast)	24,179	21,017	25,859	29,408	29,517	129,980	25,996	20	1
North Carolina	19,703	15,370	18,034	22,699	24,146	99,952	19,990	16	2
New Jersey	19,921	13,632	14,181	24,645	22,323	94,702	18,940	15	3
Virginia	16,835	13,993	11,507	13,112	17,732	73,179	14,636	11	4
New York	12,476	8,458	9,733	17,050	11,127	58,844	11,769	9	5
Massachusetts	9,865	9,252	7,626	15,538	15,984	58,265	11,653	9	6
Maryland	8,238	8,311	5,396	8,872	8,366	39,183	7,837	6	7
Rhode Island	3,225	3,567	3,817	7,020	4,457	22,086	4,417	3	8
South Carolina	4,492	3,356	2,628	2,834	3,156	16,466	3,293	3	9
Connecticut	3,228	3,424	2,575	3,029	3,432	15,688	3,138	2	10
Delaware	2,751	2,463	2,021	3,486	3,246	13,967	2,793	2	11
Georgia	1,339	1,049	1,772	2,202	2,017	8,379	1,676	1	12
Maine	1,516	705	802	1,571	1,964	6,558	1,312	1	13
New Hampshire	1,479	588	833	1,074	2,105	6,079	1,216	1	14
Total	**129,247**	**105,185**	**106,784**	**152,540**	**149,572**	**643,328**	**128,666**	**na**	**na**

Coastal North Carolina supports a vigorous commercial fishing industry. More than 7,500 licensed commercial fishermen sell their catches to over 800 dealers located throughout the coastal area. The annual ex-vessel value (paid to the fishermen, without any economic multipliers) is about $100 million. Diaby (1999) estimated that the commercial fishing industry generated more than 27,000 jobs in North Carolina, with an annual payroll exceeding $116 million. For 1994, Diaby (1997) estimated that commercial fishing supported about 4,900 jobs in Carteret County, with a total industry output of almost $46 million. Licensed North Carolina resident and non-resident commercial fishermen can participate in any fishery, except that non-residents may not harvest molluscan shellfish commercially.

Virtually all licensed commercial fishermen in North Carolina participate in several different fisheries during the course of a year [an "annual round" of work that, in total, provides for a year's employment and income (Johnson and Orbach 1996)]. Few can count on a full year's work in a single fishery. Most

fishermen own a variety of fishing gears, and many own several vessels, each rigged for different fisheries. The nature of the target species (growth, seasonal migrations), weather variations, rule changes and restrictions, and other variables require that successful commercial fishermen exhibit great adaptability. Many fishermen hold non-fishing jobs as part of their annual work cycle. In fact, some persons with a commercial fishing heritage, who make very little money from commercial fishing, instead earning most of their income in non-fishing occupations, consider themselves to be commercial fishermen.

Recreational fishing is very important economically and culturally in coastal North Carolina. There are records of surf fishing from the early colonial period. Surf fishing along the Outer Banks for red drum and bluefish was the subject of articles in sporting magazines in the 1930s (Godwin et al. 1971). Tens of thousands of private recreational boaters fish the coastal waters, while thousands more fish from the shore, piers, and other structures. Since 1997, about 1.6 million anglers (64% non-residents) have made about 5.4 million fishing trips each year in coastal North Carolina. Diaby (1997) estimated that sport fishing contributed almost $75 million to the Carteret County economy, supporting over 1,800 jobs.

Protected species

North Carolina state law [G.S. 113-331] protects endangered, threatened, and special concern species of mammals, birds, reptiles, amphibians, freshwater fishes, and freshwater and terrestrial mollusks under the jurisdiction of the North Carolina Wildlife Resources Commission (Appendix E). The North Carolina Natural Heritage Program (NHP) lists seven protected marine and estuarine fishes. The shortnose sturgeon (*Acipenser brevirostrum*) is listed as endangered at the state and federal levels. The Atlantic sturgeon (*Acipenser oxyrhynchus*) is listed as Special Concern for state and federal protection. An MFC rule [15A NCAC 3M .0508] prohibits possession of any sturgeon in North Carolina's coastal waters. There are five marine and estuarine fishes listed as significantly rare: spinycheek sleeper (*Eleotris pisonis*), lyre goby (*Evorthodus lyrinus*), marked goby (*Gobionellus stigmaticus*), freckled blenny (*Hypsoblennius ionthas*), and opossum pipefish (*Microphis brachyurus*). All five of these species occur in marine and estuarine systems of the Cape Fear MU. Shortnose and Atlantic sturgeon occur in riverine, estuarine and marine systems within the CHPP management area. Other marine and estuarine species listed by NHP include Florida manatee (*Trichechus manatus*), loggerhead sea turtle (*Caretta caretta*), green sea turtle (*Chelonia mydas*), hawksbill sea turtle (*Eretmochelys imbricata*), leatherback sea turtle (*Dermochelys coriacea*), and Kemp's ridley sea turtle (*Lepidochelys kempii*). There are also numerous birds, reptiles, and mammals listed by NHP associated with salt marshes and other coastal wetlands [LeGrand and Hall 1999 (NHP animals); Amoroso 1999 (NHP plants)]. Listed estuarine species include the Carolina diamondback terrapin (*Malaclemys terrapin centrala*), Carolina salt marsh snake (*Nerodia sipedon williamenglelsi*), and the federally listed piping plover (*Charadrius melodus*) inhabiting ocean beaches and inlet shorelines.

In addition to species listed by NHP, there are also species designated for protection under the Marine Mammal Protection Act (for example, bottlenose dolphin, *Tursiops truncatus*). Several species of marine mammals regularly utilize North Carolina's nearshore ocean waters as migratory corridors or nursery and feeding grounds. Northern right whales (*Balaena glacialis*), one of the world's most endangered species, migrate annually through North Carolina waters, between winter calving grounds along the Georgia coast and summer feeding areas from Cape Cod to the Bay of Fundy. Similarly, humpback whales (*Megaptera novaenagliae*) pass by offshore North Carolina during their annual journey between North Atlantic feeding grounds and winter calving areas off Hispanola. Bottlenose dolphin are year-round residents of the coastal ocean waters of North Carolina, and they utilize much of the estuarine system during the warmer months, going as far upstream as the lower Neuse River. Harbor porpoise (*Phocoena phocoena*) spend a part of each winter off the Outer Banks, as far south as Hatteras Bight, below Diamond Shoals. A number of other marine mammals occasionally utilize North Carolina's coastal waters, including pygmy sperm whales (*Kogia breviceps*) and pilot whales (*Globicephala melaena*).

1.5. STATUS OF FISHERIES

The current status of fisheries may be an indicator of the potential impacts of habitat degradation and loss. The status of North Carolina's coastal fishery resources is evaluated every year by DMF. Several pertinent definitions are provided for terms used in this section.

- Stock (<http://www.ncdmf.net/resource.htm>, 2002): A stock is a group of genetically similar fish that behave as a unit. Determining stock status requires long-term collection and subsequent analysis of data such as length, weight, age, catch, fishing effort, spawning stock biomass, juvenile abundance indices, fishing mortality, and natural mortality. All data are not available for all species, and there is no single measure or simple index that, by itself, describes the status of a given stock. Furthermore, information from a single year does not indicate stock status. Therefore, the stock status assigned for each coastal fishery stock is based on the available time-series of data.
- Fishery Management Plan (FMP): Plan for achieving specified management goals for a fishery. It includes data, analyses, and management measures for a fishery. The process for preparing FMPs in North Carolina was established by the FRA [G.S. 113-182.1]. The FRA states:
  > "[t]he goal of the plans shall be to ensure the long-term viability of the State's commercially and recreationally significant species and fisheries… Each plan shall…Contain necessary information pertaining to the fishery or fisheries, including… fishery habitat and water quality considerations consistent with Coastal Habitat Protection Plans …"
- Stock status descriptors used by DMF (<http://www.ncdmf.net/resource.htm>, 2003):
  - **Viable**: Viable stocks exhibit stable or significantly increasing trends in average length and weight, catch-per-unit-effort (CPUE), spawning stock biomass, juvenile abundance indices based on historical averages, stable age structure that includes representatives of the older age classes, and stable or declining trends in fishing mortality.
  - **Recovering**: Recovering stocks are those stocks previously listed as Overfished or Concern that show marked and consistent improvement in the criteria listed for a Viable stock. A recovering stock may still be Overfished but would show measurable and consistent improvement toward the target(s) established in the applicable FMP.
  - **Concern**: Stocks designated as Concern are those for which an assessment is incomplete or unavailable, but data show increased effort and landings, and/or a truncated age distribution. The nature of a given fishery may also be a reason for concern (such as the roe fishery for striped mullet). Stocks especially affected by diseases or adverse natural events may also fall into this category (for example, oysters). Species designated Concern may be reasonable candidates for FMP development if the concern is well documented and justified.
  - **Overfished**: Overfished stocks are classified based on stock assessments conducted by the DMF or some other recognized fisheries management authority. Species designated as Overfished are priority candidates for FMP development.
  - **Unknown**: Stocks for which insufficient data are available to conduct a scientifically valid stock assessment are classified as Unknown. When data for species that have been designated Unknown are subsequently collected in DMF sampling programs and analyzed, a different status may be assigned.

Based on a combination of fishery landings and value, dependence (or association) of the stock on specific habitats, and importance of management and environmental issues associated with the fisheries, the primary coastal fisheries species in North Carolina and their status are listed in Table 1.6 (<http://www.ncdmf.net/resource.htm>, 2003). Of the more than 25 species and at least 24 fish stocks listed in Table 1.6, eight stocks are Viable (33%), two are Recovering (8%), eight are Concern (33%), three are Overfished (13%), and three are Unknown (13%), as of 2003. The status of most stocks has been evaluated since 1997. Some stocks have shown signs of improvement from 1997 to 2003, while others have declined (Table 1.7). For example, southern flounder status has gone from Viable in 1998, to

Concern from 1999 to 2001, to Overfished in 2002 and 2003. Bay scallop status has also declined from Viable (1997-1999) to Concern (2000-2003). There have also been some improvements in stock status; summer flounder, weakfish, and Albemarle Sound striped bass have gone from Concern to Viable. For more information on the status of individual fishery species, see the DMF website (<http://www.ncdmf.net/stocks/index.html>).

While much of the concern over declining fish stocks has been attributed to overfishing, habitat loss and degradation can make a stock more susceptible to overfishing. The effect of habitat loss and degradation could be indicated by the lack of recovery of certain stocks after fishing pressure is reduced. For example, river herring stocks have not recovered despite reduced fishing effort in recent years. Although the role of environmental factors in the river herring decline is uncertain, the center of river herring abundance (Chowan and Roanoke rivers) has suffered from water quality problems since the 1970s.

Several species/fisheries with high landings are not discussed because they occur primarily outside the areas emphasized in the CHPP program, such as wahoo, tunas, sharks, and dolphin, which live most of their lives in the ocean. Among MUs, the primary fisheries vary according to the range of salinity present. For example, Table 1.6 shows that the primary fisheries in low salinity estuaries (Albemarle, Chowan, and Roanoke MUs) include river herring, catfishes (*Ictalurus* and *Ameiurus*), striped bass, white perch (*Morone americanus*), American eel, and American shad. In areas with moderate salinities (Neuse, Tar-Pamlico, and Pamlico Sound MUs), species such as blue crab, shrimp, and spot are dominant. In higher salinity estuaries (i.e., Core/Bogue) and the near shore ocean, the primary fisheries include Atlantic menhaden, flounders, hard clams, and shrimp.

Table 1.6. Average annual fisheries landings, fishery management plan (FMP) authority, stock status, and importance in Coastal Habitat Protection Plan management units in coastal North Carolina. (Sorted by descending commercial fisheries landings. Source: Division of Marine Fisheries commercial and recreational fisheries landings data.)

Species	Average commercial fisheries landings 1997-2002 (lb)	Average recreational fisheries landings 1997-2002 (lb)	Lead FMP agency	Stock status (2003)*	Management units										
					Albemarle	Cape Fear	Chowan	Coastal Ocean	Core/Bogue	Neuse	New/White Oak	Pamlico	Roanoke	S. Estuaries	Tar/Pamlico
Atlantic menhaden	63,330,289	Unknown	ASMFC	V				X	X	X		X			X
Blue crab	47,673,736	Unknown	DMF	C	X	X		X	X	X	X	X		X	X
Atlantic croaker	10,692,337	276,740	ASMFC	C	X			X	X	X		X			X
Shrimp	7,688,851	Unknown	DMF out to 3 miles, NMFS beyond 3 miles	V		X		X	X	X	X	X		X	X
Southern flounder	3,523,763	134,186	DMF	O	X				X	X	X	X		X	X
Bluefish	3,240,218	838,102	ASMFC/NMFS	R		X		X	X			X		X	
Summer flounder	2,938,425	381,729	ASMFC/NMFS	V		X		X	X			X			
Spot	2,563,527	1,028,822	ASMFC	V	X	X		X	X	X	X	X		X	X
Weakfish	2,531,015	116,632	ASMFC/NMFS	V	X			X	X	X		X			X
Striped mullet	2,311,092	Unknown	DMF	C	X	X		X	X	X	X	X		X	X
Snapper / grouper / seabass	1,788,967	409,521	NMFS	C				X							
Hard clams	671,716	Unknown	DMF	?		X			X		X	X		X	
Striped bass	555,421	663,626	ASMFC - ocean, DMF/WRC - internal waters	V-Ocean, Albemarle O-elsewhere	X		X	X		X			X		X
River herring	352,364	Unknown	ASMFC / DMF	O-Albemarle ?-elsewhere	X	X	X			X			X		
Spotted seatrout	290,303	419,273	ASMFC	V		X		X	X	X		X			X
Oysters	234,445	Unknown	DMF	C		X				X	X	X		X	
American shad	233,718	Unknown	ASMFC	C	X	X	X	X		X		X	X		X
Red drum	203,537	255,884	ASMFC/DMF	R		X		X	X	X	X	X		X	X
Bay scallops	39,903	Unknown	DMF	C					X						

*Stock status: V = viable, R = recovering, C = concern, O = Overfished, ? = Unknown

Table 1.7. Trends in the stock status of species and stocks listed in Table 1.6. (1997 – 2003).

Overfished	Concern	Recovering	Viable	Unknown

Species/stocks	1997	1998	1999	2000	2001	2002	2003
American shad							
Atlantic croaker							
Atlantic menhaden							
Bay scallops							
Black sea bass (North of Cape Hatteras)							
Black sea bass (South of Cape Hatteras)							
Blue crab							
Bluefish							
Gag							
Oysters							
Red drum (except Pamlico Sound)							
Red drum (Pamlico Sound)							
Reef fish							
River herring (Albemarle Sound)							
Shrimp							
Southern flounder							
Spot							
Spotted seatrout							
Striped bass (Albemarle Sound)							
Striped bass (except Ocean and Albemarle Sound)							
Striped bass (Ocean)							
Striped mullet							
Summer flounder							
Weakfish							

1.6. HABITAT CONCEPTS AND TERMINOLOGY

The following habitat chapters contain numerous technical terms and acronyms that may not be familiar to the average reader. A complete list of terms and acronyms is found in Appendix H.

Habitat is simply the place where an organism lives (Odum 1959). Fish Habitat (FH) is hereby defined as freshwater, estuarine, and marine areas that support juvenile and adult populations of economically important fish species (commercial and recreational), as well as forage species important in the food chain. Fish habitat also includes land areas that are adjacent to, and periodically flooded by, riverine and coastal waters. Fish occupy specific areas or sites where the conditions are suitable for growth, protection, and/or reproduction. A species' use of specific areas can depend on various factors, including life stage, time of day, and tidal stage. Together, these habitat areas form a functional and connected system that supports the fish from spawning until death.

The upstream boundary of coastal fish habitat in North Carolina is approximately the Fall Line separating the Coastal Plain and Piedmont physiographic regions (Map 1.3) because only one coastal migratory species (American eel, *Anguilla rostrata*) has been reported significantly above the Fall Line (Menhinick 1991). Within North Carolina's coastal ecosystem, six habitat types were distinguished based on similar physical properties, ecological functions, and habitat requirements for living components:

- Water column: The water covering a submerged surface and its physical, chemical, and biological characteristics.
- Shell bottom: Intertidal or subtidal bottom composed of shell concentrations, including living oysters (*Crassostrea virginica*), hard clams (*Mercenaria mercenaria*), or other shellfish (such as whelks). Also referred to as oyster bars, oyster beds, oyster rocks, oyster reefs, clam beds, and shell hash.
- Submerged aquatic vegetation (SAV): Bottom recurrently vegetated by living structures of submerged, rooted vascular plants, (including roots, rhizomes, leaves, stems, propagules), as well as temporarily unvegetated areas between vegetated patches.
- Wetlands: Section 404 of the Federal Water Pollution Control Act defines wetlands as: "areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in wet soil conditions." The CHPP will focus primarily on wetlands that are connected to coastal water bodies by surface water of sufficient depth to allow fish utilization. These "connected" wetlands are termed "riparian wetlands" in the CHPP because they border streams and other water bodies.
- Soft bottom: Areas of primarily unvegetated, unconsolidated sediment (particles smaller than rocks) beneath the water column, and not within other categories defined below.
- Hard bottom: Exposed areas of rock or consolidated sediments that may or may not be characterized by a thin covering of live or dead animals, generally located in the ocean rather than an estuary.

North Carolina's coastal fishery resources (the "fish") exist within a system of interdependent habitats that provide the basis for long-term fish production available for use by people (the "fisheries"). Most fish rely on different habitats throughout their life cycle (Figure 1.1); therefore, maintaining the health of an entire aquatic system is essential. The integrity of the entire system depends upon the health of areas and individual habitat types within the system. The areas that contribute most to the integrity of the system are another category of habitat termed Strategic Habitat Area. Strategic Habitat Areas (SHAs) are hereby defined as specific locations of individual fish habitat or systems of habitat that have been identified to provide critical habitat functions or that are particularly at risk due to imminent threats, vulnerability, or rarity. Criteria for delineation of SHAs are included in chapter 8.0 (Strategic Habitat Areas).

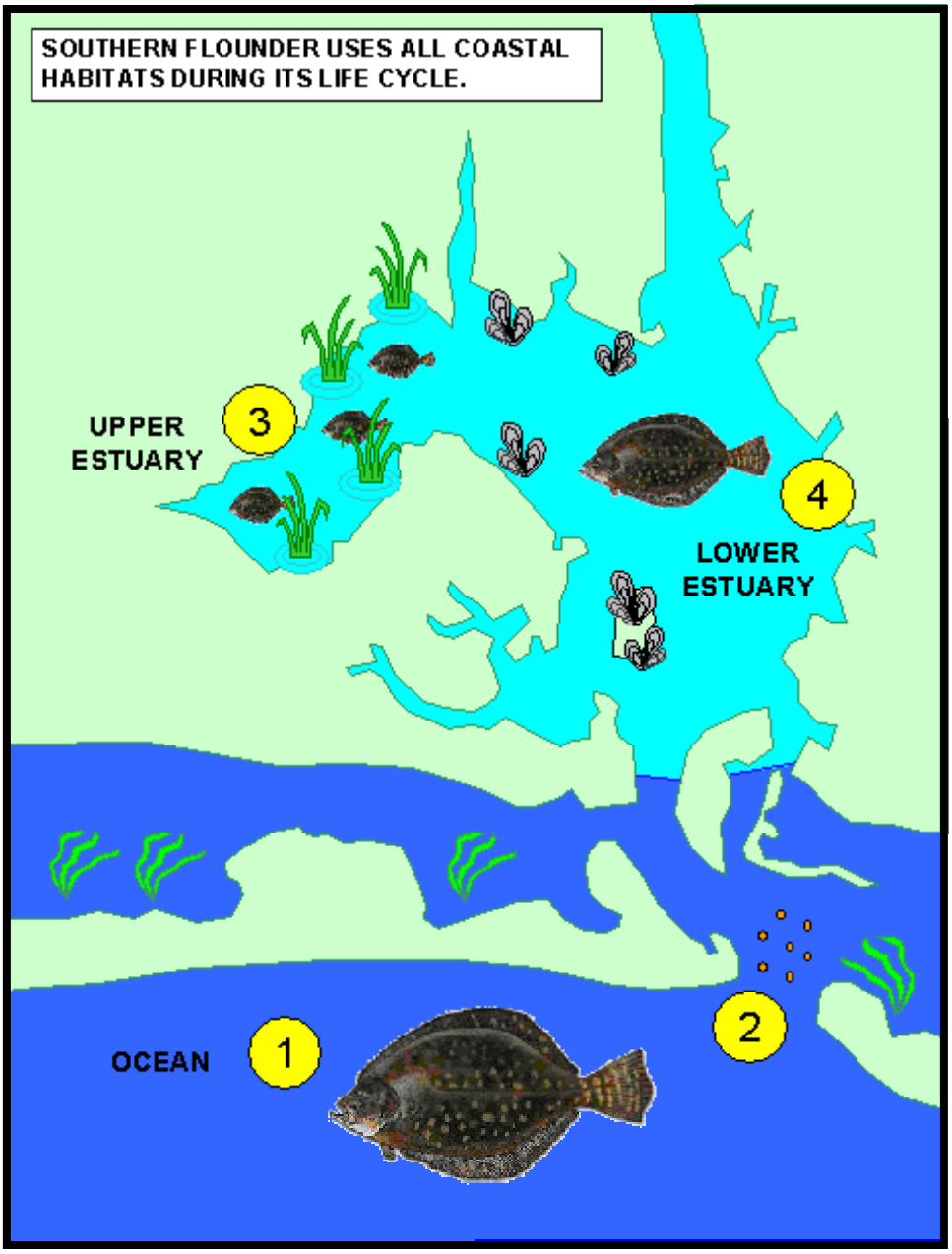


Figure 1.1. Life cycle of the southern flounder.
1 - Adults spawn in nearshore ocean waters during late winter months.
2 - Larvae drift inshore on currents, eventually passing through inlets and to the estuary beyond.
3 - Small juveniles settle out of the water column in upper, low-salinity estuaries containing marsh wetlands and shallow soft bottom habitat.
4 - As flounder grow, they begin to occupy deeper channels and the lower portion of the estuary. Juvenile flounder also move throughout the estuary, foraging on crabs and small fish living in oyster reefs and along the marsh edge. Once the juvenile flounder recruit to the adult population, the cycle is continued.

Ecological role and functions

The ecological role of each habitat is discussed in the habitat chapters that follow in terms of productivity and effect on overall water quality and quantity in an ecosystem. That discussion is followed by information on specific fish habitat functions. The general functions of habitat for fishery and forage species are grouped into the following categories:

- Refuge: Properties of the habitat that provide cover for organisms at various life stages to escape from predators and adverse environmental conditions. Structural refuge can also encourage attachment of colonizing sessile (stationary or non-mobile) organisms.
- Spawning: Properties of the habitat that provide the necessary conditions (substrate, temperature, flow, structure, etc.) for successful spawning of adults.
- Nursery: Properties of the habitat that provide a combination of refuge and foraging habitat resulting in successful development of subadult life stages of aquatic organisms. Nursery habitat can be further defined as habitats that contribute disproportionately to the production of individuals that recruit to adult populations (Beck et al. 2001).
- Foraging: Properties of the habitat that enhance growth of species' life stages through the presence, accessibility, and vulnerability of prey organisms.
- Corridor: Properties of the habitat that allow relatively safe passage (either active or passive) of species' life stages among foraging, spawning, and refuge areas. This function also addresses the connectivity of aquatic habitat and its effect on aquatic organisms.

Spatial scales

In ecological terms, spatial scales are differentiated by the variable resolution and extent of landscape features (such as a forest to a tree to an individual branch) and the manifestation of different biological, chemical, or physical patterns at those scales. For example, individual oyster shells, the spaces between them, and the water surrounding them could define a very fine scale. Small organisms relate to these crevices by selecting them over the surrounding unstructured bottom. The small organisms are relatively separate from what is happening in the entire watershed, although watershed patterns can affect them through the surrounding water. The entire watershed occupies a much larger scale in which anadromous fish, for example, require different areas depending on time of year and life stage. Regional scales encompass multiple watersheds and affect individual watersheds with similar climatic patterns and other large-scale phenomena. Highly migratory organisms like tunas, whales, and sea birds relate to habitat at regional scales while at the same time selecting fine-scale habitat characteristics at any specific point in time. There are basically three larger scales used to describe habitat and ecosystem organization and function in this document: regional, watershed, and site-specific.

- Regional scale is defined by large biogeographic regions, such as the mid-Atlantic and South Atlantic Bights or the Coastal Plain and Piedmont physiographic regions of eastern North America.
- Watershed scale is defined by CHPP management units or by other hydrologic units based on DWQ or U.S. Geological Survey (USGS) delineations. Nationally, the typical watershed covers 40,000 to 250,000 acres (USGS 2001).
- Site-specific scale is defined by DWQ as water bodies delineated on 1:24,000 scale hydrographic maps or by features named on NOAA nautical charts. Within a given area, a given habitat type may be dominant, but not continuous, such as patchy distribution of SAV. Specific habitat features change continually, especially at their edges. Beds of SAV expand and contract. Thus there is a high degree of natural variability within habitats.

Impacts, sources, and threats

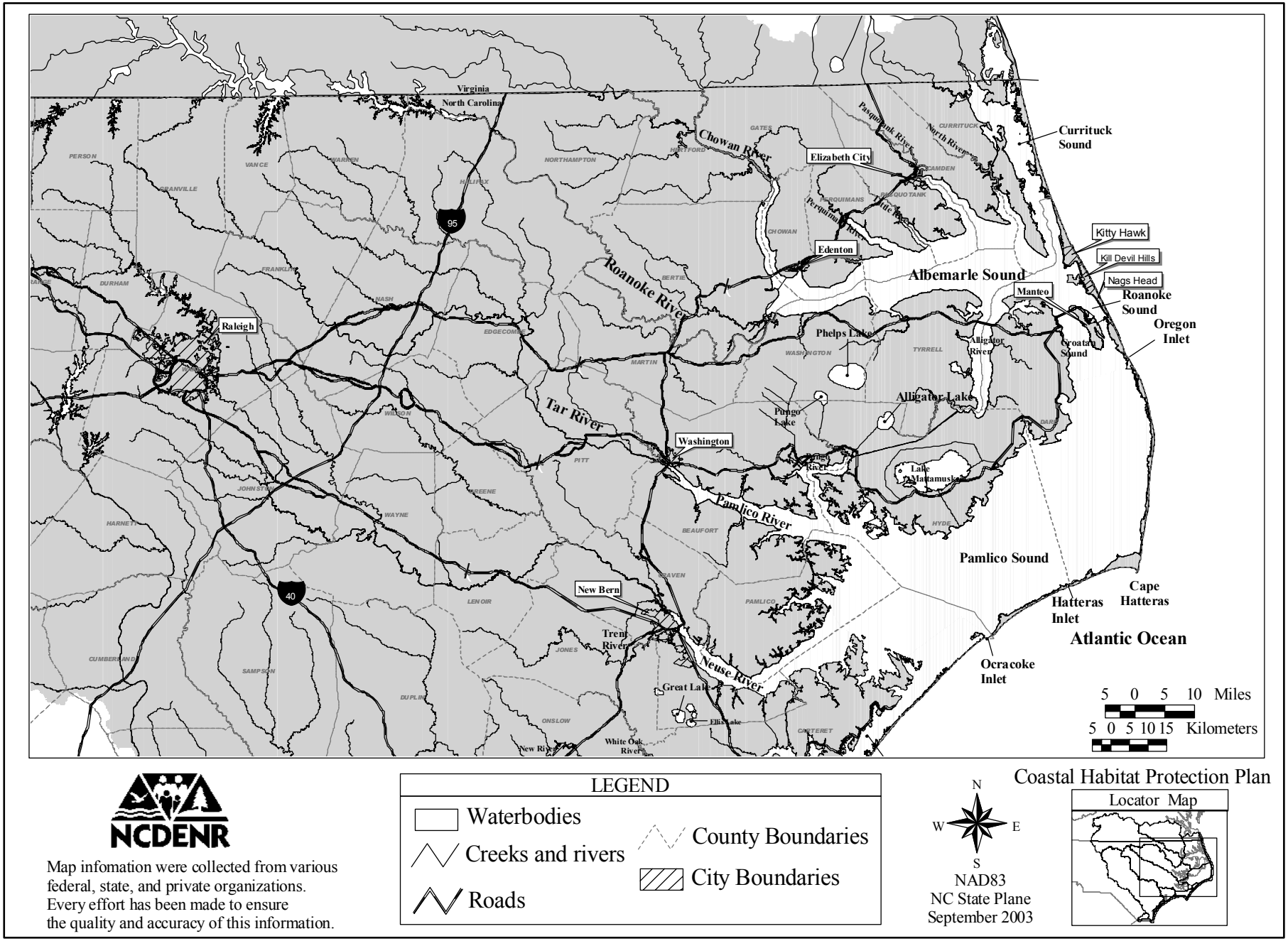
Coastal fisheries resources in North Carolina have evolved over geologic time to live within their existing conditions. Thus, they have adapted to the gradual climate shifts and episodic storm events that have

occurred through time. But these natural and gradual changes did not include the host of artificial chemicals, deforestation of riparian lands, stormwater runoff, nutrient enrichment, destruction of habitats, and highly effective fishing practices that have developed during the last century, and are so pervasive today. These threats to coastal fish habitat can be characterized by impacts types and sources.

Impacts are specific effects on habitat such as extremely low flow, nutrient enrichment, or erosion. These impacts have corresponding effects on living resources, which can be both positive and negative. Positive impacts can result from habitat preservation, enhancement, and restoration efforts. Negative impacts can result from habitat degradation and loss. Cumulative impacts are the combined outcome of numerous actions and stresses that alone may have relatively minor effects, but together lead to substantive habitat degradation or loss. Restoration of specific degraded habitats may cumulatively benefit dependent organisms.

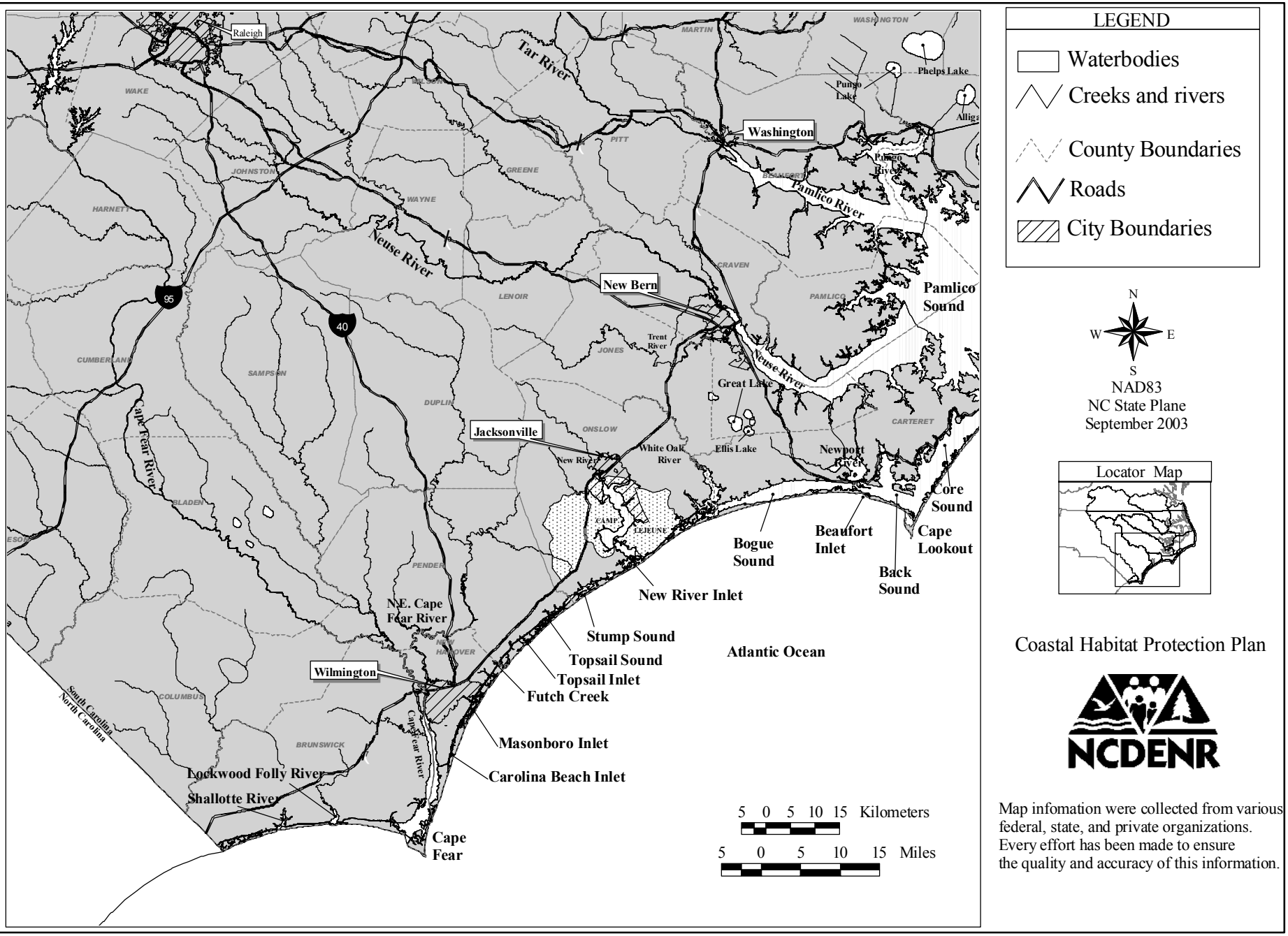
The overall effect of human-induced, habitat impacts on living resources has been expanding areas of low dissolved oxygen, coupled with nutrient enrichment and suspended sediment. Species that can tolerate the low dissolved oxygen, algae growth, and excess sediment thrive in degraded areas. These species include smaller, less desirable organisms such as comb jellies (Breitburg 1992; Breitburg et al. 1994) and toxic algae (Paerl 1982; Tester and Fowler 1990). In areas where there is no oxygen, only a few bacteria species can survive. Degraded areas not only impair fishery resources, but also impair other human uses such as swimming and drinking water supply.

Impact sources are natural events or human activities that can have individual or multiple effects. Impact from pollution originates from both point (outfall pipes, ditches) and nonpoint sources (stormwater runoff), primarily affecting water quality (the biological, chemical, and physical suitability of water relative to standards that support desirable living communities). Natural events and human activities also affect the physical habitat through storms, floods, construction activities, land clearing, and fishing.



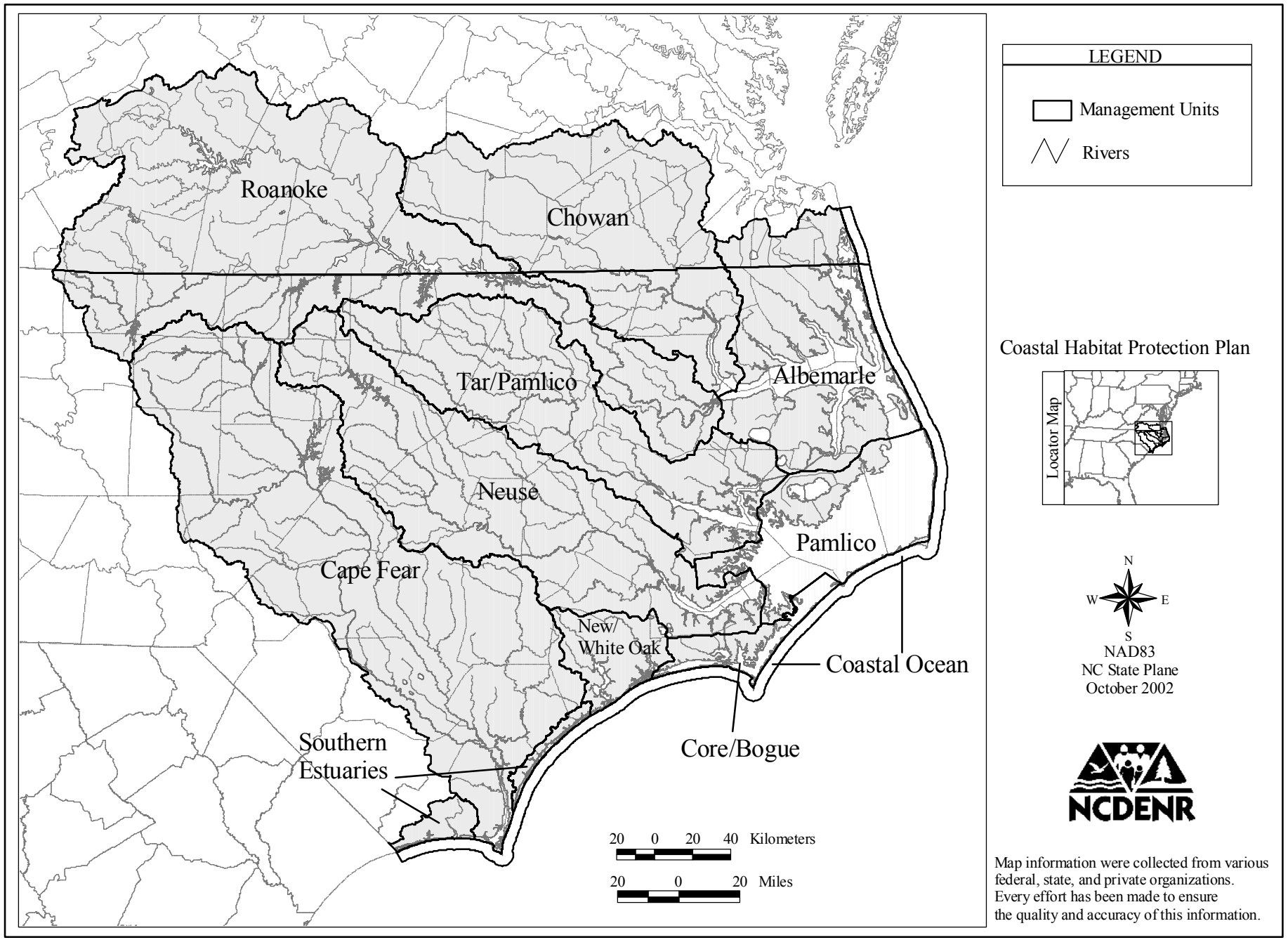
Map 1.1a. Hydrographic features in coastal North Carolina. (Data from 1:100,000 scale USGS topographic maps).

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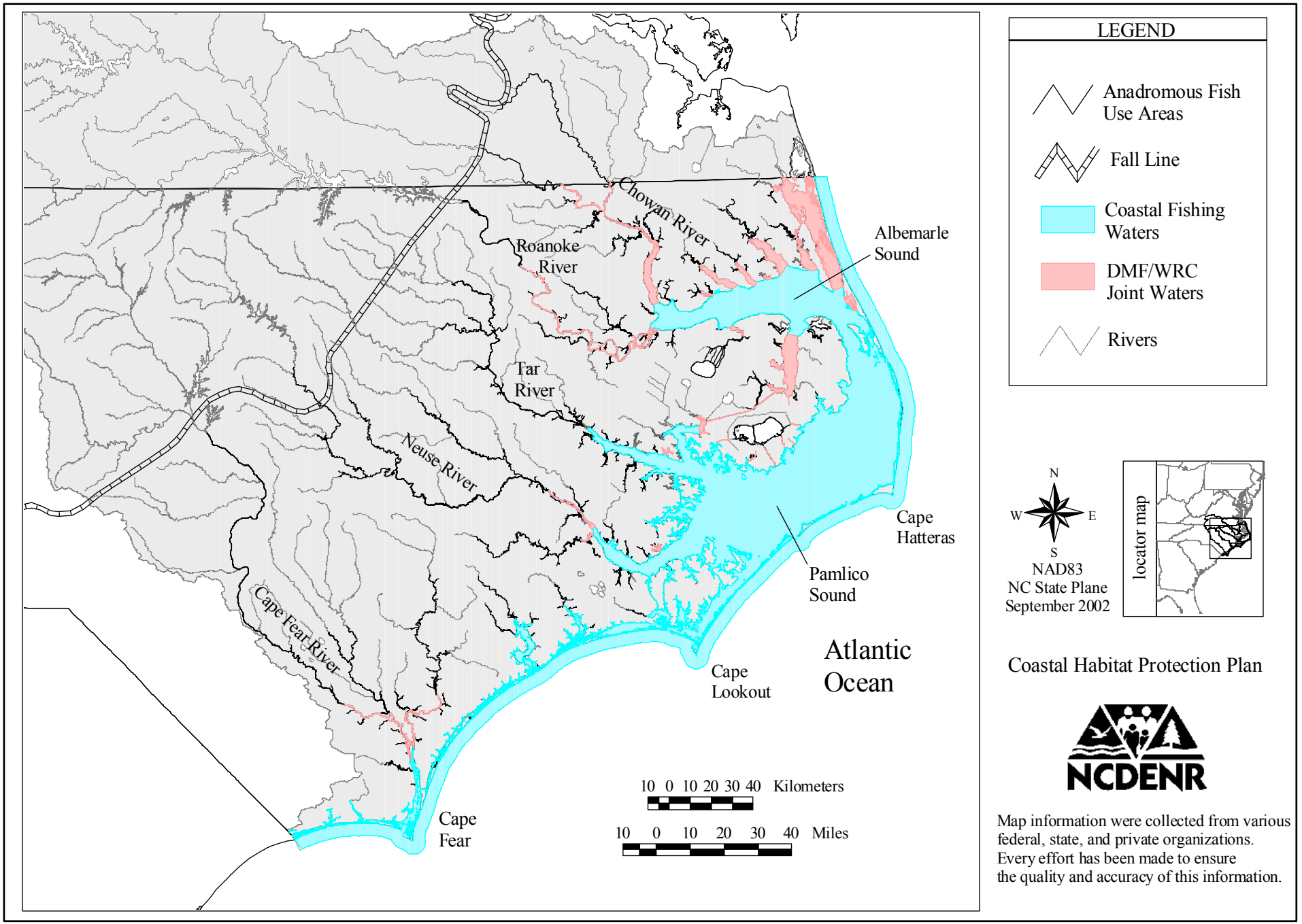
Map 1.1b. Hydrographic features in coastal North Carolina. (Data from 1:100,000 scale USGS topographic maps).

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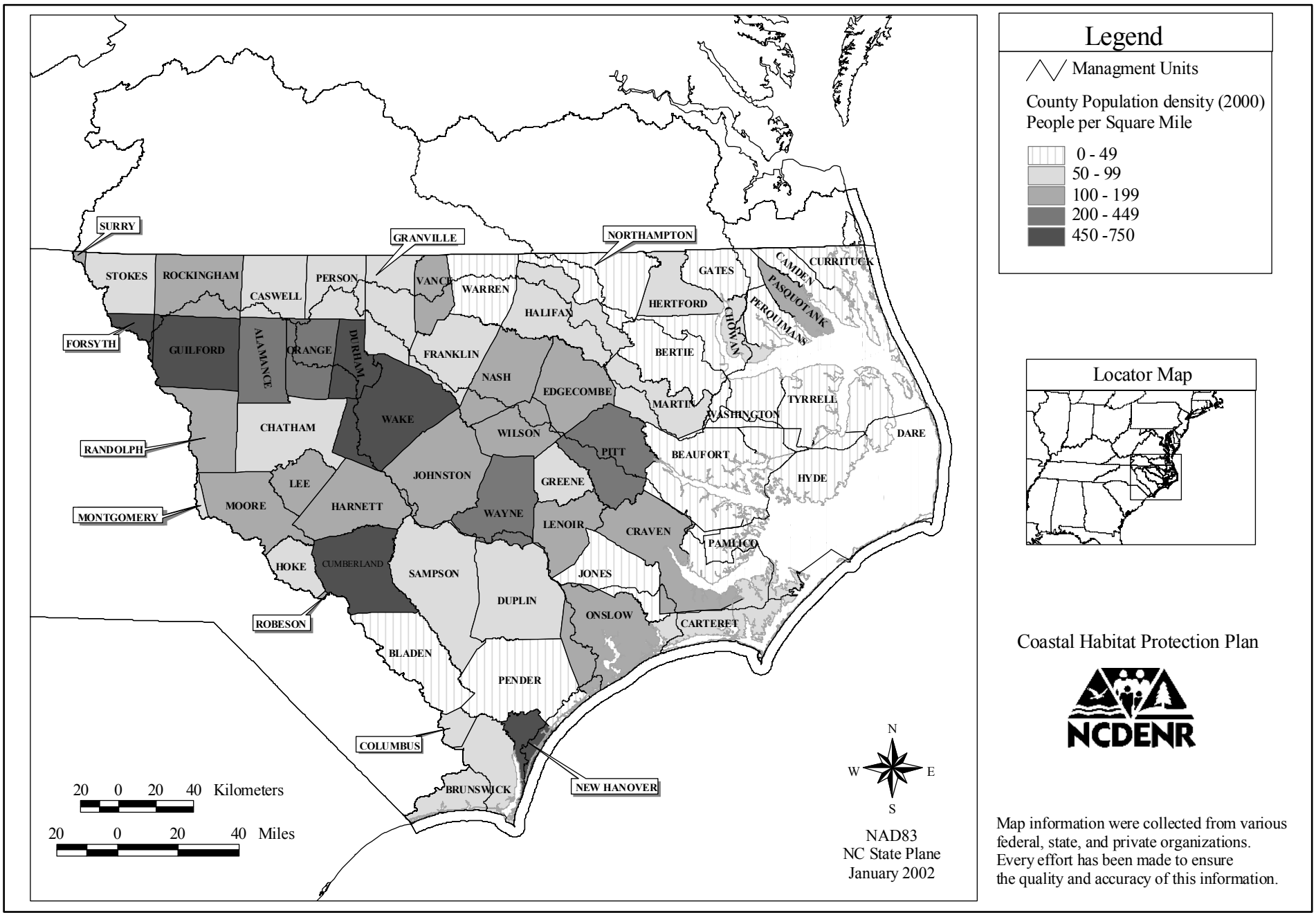
Map 1.2. North Carolina Coastal Habitat Protection Plan management unit boundaries

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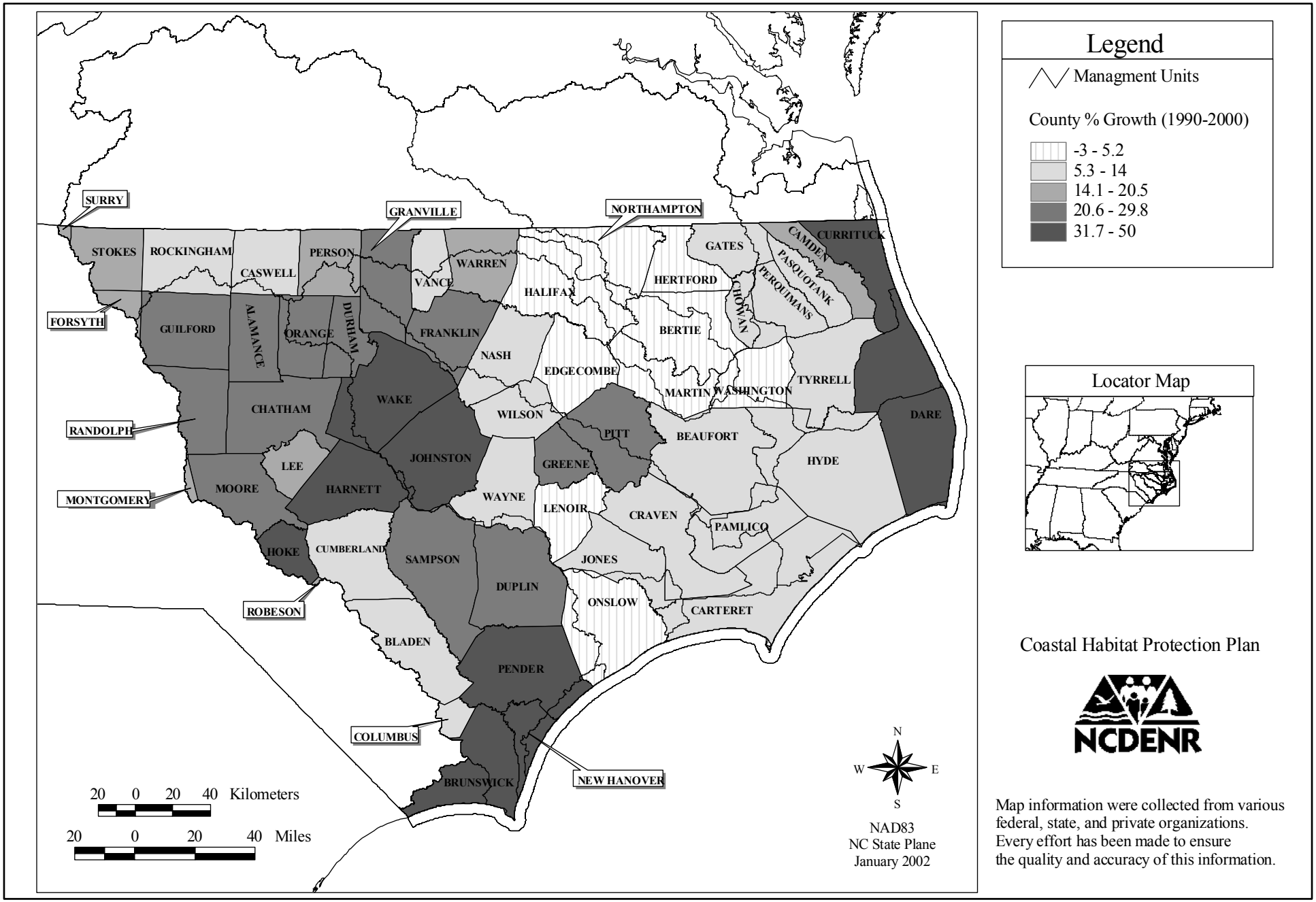
Map 1.3. Jurisdictional and effective boundaries of coastal fish habitat in North Carolina. [Anadromous fish use areas from North Carolina Division of Marine Fisheries data and Baker (1968), and fall line from Menhinick (1991)].

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Map 1.4. Density of human population in the Coastal Habitat Protection Plan area of North Carolina (2000).
(Data from the North Carolina Office of State Budget and Management (August 2001). Persons/mi2 includes only land areas.)

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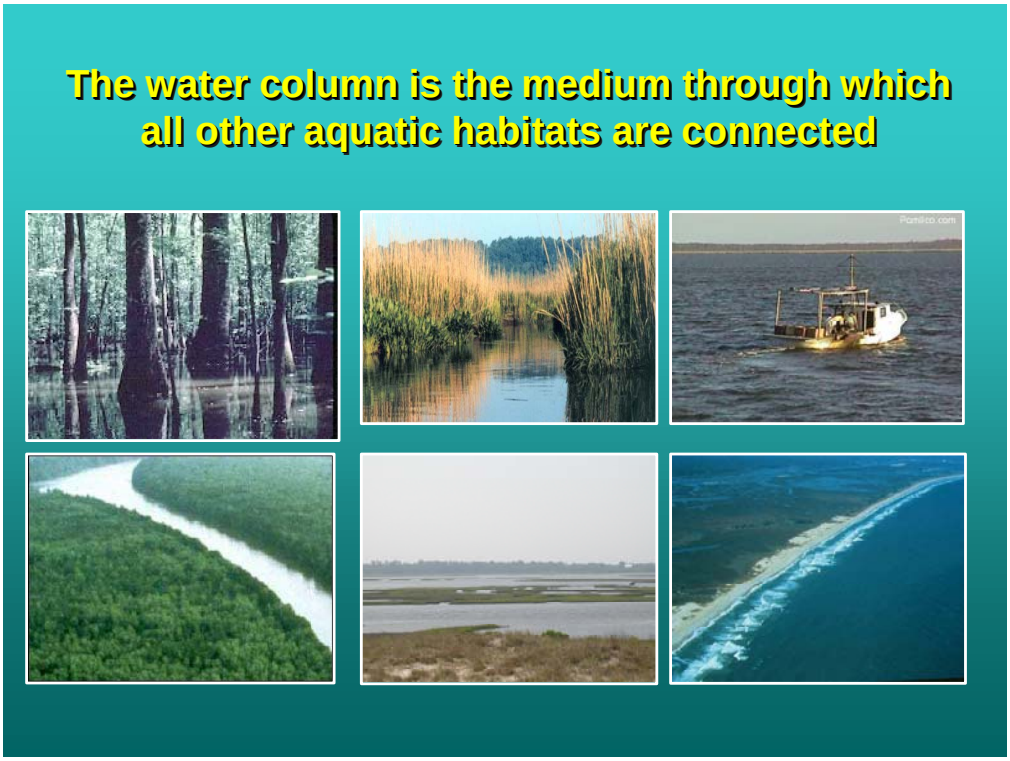


Map 1.5. Percent growth in human population by county in the Coastal Habitat Protection Plan area during 1990-2000.
[Data from the North Carolina Office of State Budget and Management (August 2001)].

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CHAPTER 2. WATER COLUMN

The quality of our coastal waters affects fish species diversity, production, and distribution but also living fish habitats, such as submerged aquatic vegetation and oyster beds (shell bottom). Water quality in the water column is a key factor that links fish, habitat, and people. That linkage is affected by growing development pressures along our coast as well as far inland, making the protection and enhancement of water quality for fisheries resources a challenging task. Determining the best course of action for enhancing water quality requires detailed knowledge of the water quality characteristics that various species require throughout their life cycle, along with the status, trends, and threats of those characteristics.



Water column habitat is defined in this plan as "the water covering a submerged surface and its physical, chemical, and biological characteristics." Differences in the chemical and physical properties of the water affect the biological components of the water column - including fish distribution. Water column properties that may affect fisheries resources include temperature, salinity, dissolved oxygen (DO), total suspended solids, nutrients (nitrogen, phosphorus), and chlorophyll *a* (SAFMC 1998a). Other factors, such as depth, pH, water velocity and movement, and water clarity, also affect the distribution of aquatic organisms.

Coastal fisheries habitat may be found both in waters that are privately owned and in waters that are held by the State for the use of the public. Private waters include many lakes, ponds, and some small streams. Public trust waters include all navigable waters and the lands beneath them, from the mean high water mark or mean water level, within State jurisdiction. The public has the right to use public trust waters for travel, recreation, and other activities (i.e., commercial and recreational fishing) that do not degrade acceptable public uses or biological and physical functions of those water bodies [CRC rule 15A NCAC 07H .0207(a)-(c)].

The Environmental Management Commission (EMC) classifies surface waters according to the best use of the water (e.g., water supply, aquatic life protection, and swimming) and adopts water quality standards intended to protect the designated uses. Supplemental surface water quality classifications provide additional protection to waters that have special physical, chemical, biological, or use characteristics. These standard and supplemental classifications are depicted in Maps 2.1a-b and 2.2a-b, and are also described below.

Primary Surface Water Classifications:
C or **SC***—Supporting secondary recreation (including swimming on an unorganized or infrequent basis); wildlife; fishing; fish and other aquatic life propagation and survival; agriculture and any other usage, except for primary recreation or water supply.
B or **SB***—Supporting primary recreation (including swimming on an organized or frequent basis) and all uses specified for Class C or SC (and not water supply use).
WS—Water supply in natural and undeveloped watersheds (WS-I), predominantly undeveloped watershed (WS-II), low to moderately developed watersheds (WS-III), and moderately to highly developed watersheds (WS-IV), plus former or industrial potable water supplies or waters upstream and draining to WS-IV waters (WS-V).
SA*—Commercial shellfishing waters and all Class SC and SB uses.
* = saltwater classification

Supplemental Surface Water Classifications:
ORW (Outstanding Resource Waters)—Unique and special waters that are of exceptional state or national recreational or ecological significance which require special protection to maintain existing uses. These waters have been identified as having excellent water quality in conjunction with at least one important resource value.
HQW (High Quality Waters)—Waters rated as excellent by DWQ; Primary Nursery Areas or other functional nursery area; Native and Special Native Trout Waters and their tributaries; WS-I, WS-II and SA waters and waters for which DWQ has received reclassification to WS-I or WS-II.
NSW (Nutrient Sensitive Waters)—Waters needing additional nutrient management due to their being subject to excessive growth of microscopic or macroscopic vegetation.
SW (Swamp Waters)—Waters with low velocities and other characteristics different from adjacent waterbodies (generally low pH, DO, high organic content).
FWS (Future Water Supply)—Water designated for future water supply use.
TR (Trout Waters)—Waters protected for natural trout propagation and stocked trout survival.

The Marine Fisheries Commission (MFC) designates areas subject to commercial and recreational fishing regulations (Map 1.3). The MFC and the Wildlife Resource Commission (WRC) also designate areas with ecological functions vital to fish and shellfish production, such as nursery and spawning areas for finfish and crustaceans (Maps 2.3 and 2.4).

Nursery areas: Those areas in which for reasons such as food, cover, bottom type, salinity, temperature and other factors, young finfish and crustaceans spend the major portion of their initial growing season [MFC rule 15A NCAC 03N .0102 (a)].
Primary nursery area: Those areas of the estuarine system where initial post-larval development takes place. These areas are located in the uppermost sections of a system where populations are uniformly very early juveniles [MFC rule 15A NCAC 03N .0102 (b)].
Secondary nursery areas: Those areas of the estuarine system where later juvenile development takes place. Populations are usually composed of developing sub-adults of similar size which have migrated from upstream primary nursery areas to the secondary nursery area located in the middle portion of the estuarine system [MFC rule 15A NCAC 03N .0102 (c)].
[Inland] primary nursery areas: Those [inland] areas inhabited by the embryonic, larval, or juvenile life stages of marine or estuarine fish or crustacean species due to favorable physical, chemical or biological factors [WRC rule 15A NCAC 10C.0502].
Anadromous fish spawning areas: Those areas where evidence of spawning of anadromous fish has been documented by direct observation of spawning, capture of running ripe females, or capture of eggs or early larvae [MFC rule 15A NCAC 03I .0101 (b) (20) (C)].
Anadromous fish nursery areas: Those areas in the riverine and estuarine systems utilized by post-larvae and later juvenile anadromous fish [MFC rule 15A NCAC 03I .0101 (b) (20) (D)].

The MFC and WRC habitat designations generally include a complex of habitats, of which the water column is one component. These definitions and classifications of water column habitat and their associated regulatory jurisdictions provide the authority for management actions.

2.1. DESCRIPTION AND DISTRIBUTION

The water column is the dominant component and bonding element of the entire coastal aquatic ecosystem, integrating aquatic influences from both land and sea [15A NCAC 07H .0206 (b)]. The coastal aquatic ecosystem is divided among several river basins draining into North Carolina's coastal area. Within a river basin, characteristics of the water column change markedly from the basin's extreme headwaters to the ocean. The primary variable that changes is salinity. Based on salinity variation, there are three major systems in coastal North Carolina: 1) fresh water, 2) estuarine, and 3) marine. To a large extent, differences in salinity determine the species found in coastal waters (Ross and Epperly 1985; Noble and Monroe 1991). Within each system, additional variation occurs as a result of water velocity, substrate, sediment transport, and depth.

Freshwater systems

Freshwater systems are generally considered to have salinity between 0 and 0.5 ppt (Cowardin et al. 1979; SAFMC 1998a; Map 2.5a-b). Freshwater water bodies include rivers, creeks, lakes, and ponds.

Rivers and creeks

The characteristics of river and creek water depend on climate, geology, topography, and land cover. The coastal plain is relatively flat, with a basin slope of approximately one foot per mile (DWQ 1997a), higher in the southern portion and lower in the northern portion. Streams in the coastal plain are often slow flowing, with extensive swamps, bottomland hardwood forest, and marshes in their floodplains (DWQ 1997a). These streams are often acidic from high inputs of dissolved organic matter, a condition known as "dystrophy" (Wetzel 2001). These "blackwater" systems often have moderate phytoplankton production, but, given a source of human-generated nutrients and an open canopy, shallow blackwater streams can support dense phytoplankton blooms (Ensign and Mallin 2001; Mallin et al. 2001a). Dissolved oxygen and pH are also influenced by dystrophy. Where slow-moving water bodies drain wetlands with decaying vegetation, the water column has high concentrations of dissolved organic carbon (humic acids), low pH, and low dissolved oxygen (DO). Water column characteristics change as one moves from the river's headwater tributaries to its mainstem channel. Changes include a shift to increasing turbidity, depth (Sheehan and Rasmussen 1993), phytoplankton abundance, and flooding frequency. There also tends to be a decrease in particle size of organic matter (Vannote et al. 1980), an increase in the importance of floodplain wetlands (Junk et al. 1989), and more continuous flow in downstream areas.

Rivers and creeks also exhibit seasonal variations in stream flow, suspended particle concentrations, and water temperature. Average monthly discharge among all coastal river basins peaks in March, declines throughout the summer and fall, and gradually increases again around November (Figure 2.1). This discharge pattern also corresponds with low and high-salinity time periods in downstream estuaries. Flow variability also follows the general discharge pattern, with the highest variability during March. Heavy spring flows carry relatively high sediment loads, which, in combination with spring algal blooms, result in increased turbidity. Water temperatures are generally highest from June to September (25-27º C) and lowest during December - January (5-9º C) (Figure 2.1). From 1969 to 1999, annual discharge patterns within river basins appear to rise and fall on a 2-5 year cycle (Figure 2.2; see Map 2.6 for USGS stream gauge stations used).

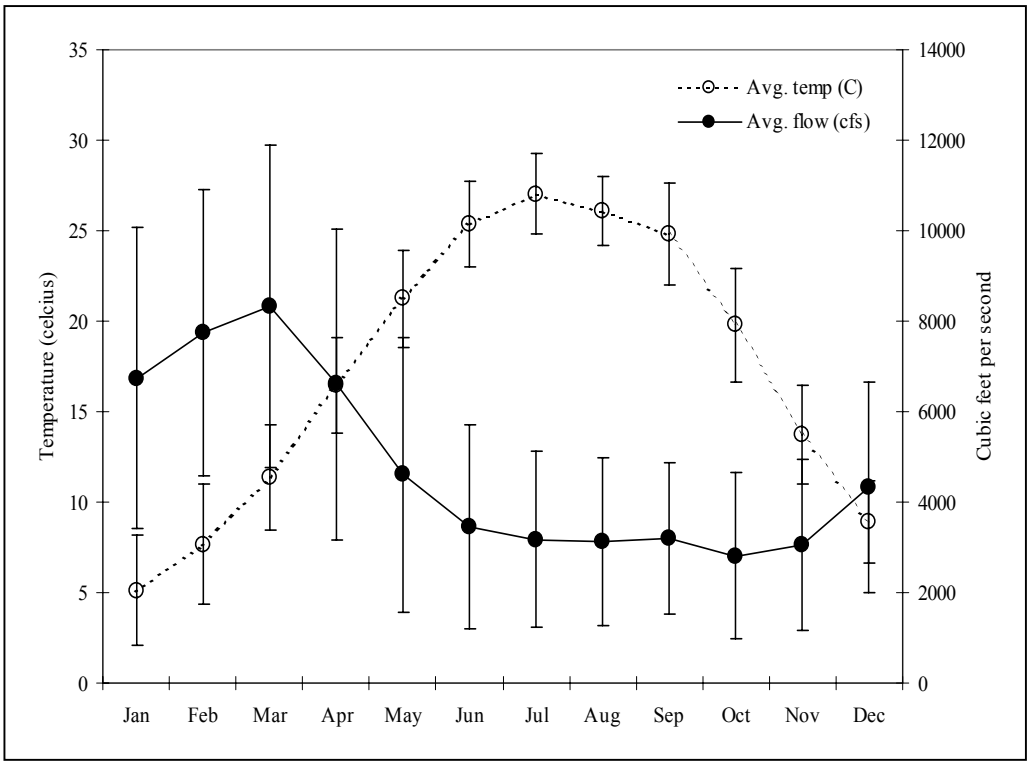


Figure 2.1. Average and standard deviation of monthly discharge (time period: 1969-1999, n = 1,464) and water temperature (time period: 1953-2001, data points per month = 52-123). [Source: USGS hydrologic monitoring stations on the lower Roanoke, Tar, Neuse, and Cape Fear rivers, North Carolina. (Station locations are marked on Map 2.6.)]

Five major riverine systems flow into North Carolina's coastal waters: Chowan, Roanoke, Tar-Pamlico, Neuse, and Cape Fear (Map 1.1). Smaller, coastal plain systems include the New and White Oak river basins, the blackwater rivers of the Pasquotank basin (Albemarle MU), and the coastal streams of the Lumber River basin (Southern Estuaries MU). Of the smaller systems, only the blackwater rivers of the Pasquotank basin (Albemarle MU) have a significant freshwater component. The New, White Oak, and coastal streams of the Lumber river (Southern Estuaries MU) basin are primarily estuarine.

The Chowan, Tar-Pamlico, Neuse, and Cape Fear rivers are contained entirely within the coastal plain and piedmont regions, while the Roanoke River flows from the mountains to the coastal plain region. With the exception of the Albemarle, Chowan and Roanoke basins, which originate in Virginia, all are located entirely within North Carolina. The Cape Fear River is the only major river system that flows directly into the ocean. The other riverine systems all discharge into coastal estuaries behind barrier islands.

The WRC has designated most of the main stem of the Roanoke, Tar, Neuse, and Cape Fear rivers within its jurisdiction as Inland Primary Nursery Areas (Map 2.4). The WRC has also designated certain inland waters near the coast as PNAs based on recommendations by DMF. While there are few MFC designated nursery areas within inland fishing waters, DMF sampling data show many of freshwater tributaries function as anadromous fish spawning and nursery areas.

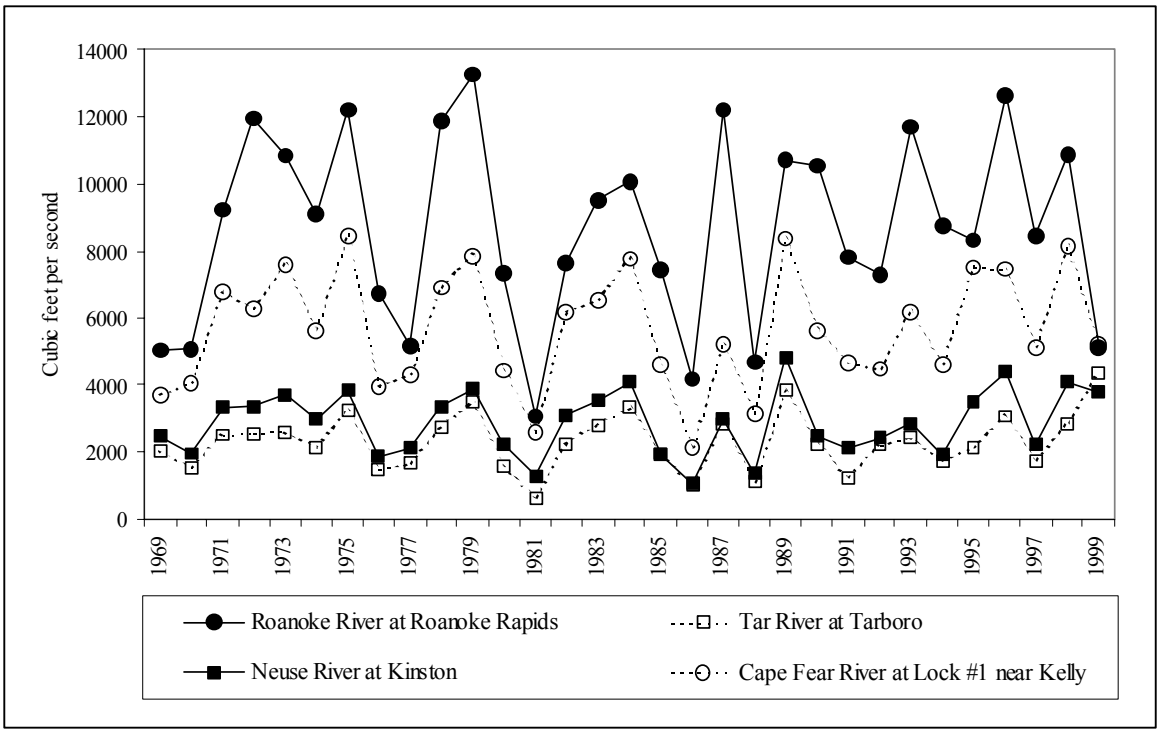


Figure 2.2. Average annual discharge in the Roanoke, Tar, Neuse, and Cape Fear rivers during 1969-2001 based on data from the USGS hydrologic monitoring stations. (Station locations are marked on Map 2.6)

Lakes and impoundments

The water column in lakes and ponds can be vertically stratified in temperature, DO, and related physical and chemical parameters. However, during strong winds or seasonal turnover (spring/fall), the water column's layers may become mixed so that there is less variability based on depth. Overall, water column characteristics in lakes depend on the lake's origin, underlying geology, and land cover in the watershed. Many natural lakes in North Carolina were formed by the solution of minerals in ground water (Menhinick 1991). They are shallow (maximum depth about 2 m) and generally circular (Crowell 1966). The Carolina Bays are an example of these systems. Most of these natural lakes, similar to coastal blackwater rivers and creeks, have low pH and are naturally dark in color from organic staining.

There are 16 natural lakes in North Carolina's coastal plain (Menhinick 1991). There are many other small natural ponds and impoundments. However, there are only a few lakes whose connection with coastal waters is unobstructed by a dam or other impassable feature. The lakes that directly connect to coastal waters include Alligator Lake, Great Lake, Ellis Lake, and Pungo Lake (Map 1.1). Lake Phelps has a sporadic connection to coastal water via several man-made canals. Except for Lake Phelps, which is designated as a State Park, these natural lakes are largely under federal government jurisdiction in Croatan National Forest and national wildlife refuges. The feeder creeks and canals flowing into them are partially under state and private ownership.

The natural coastal lakes range in size from 2,789 (Great Lake) to 41,084 acres (Lake Mattamuskeet). Lake Mattamuskeet, the largest natural lake in North Carolina, connects to coastal waters through several man-made drainage canals - a connection demonstrated by the frequent occurrence of adult blue crabs in the lake (Rulifson and Wall 1998). The canals draining Lake Mattamuskeet have historically supported significant anadromous alewife spawning runs that have shown signs of resurgence in recent years (Winslow et al. 1983; Epperly 1985; R. Rulifson, ECU, pers. com., 2002). There are research and

management activities currently underway to maintain and enhance the connections between Lake Mattamuskeet and other lakes on the Albemarle-Pamlico peninsula and coastal waters to benefit coastal fishery species utilizing these waters (R. Rulifson, ECU, pers. com., 2002).

Estuarine systems

Water column characteristics in estuaries are a dynamic mix of adjacent riverine and marine systems. Estuaries occupy the transition between freshwater and marine systems, where circulation patterns are determined by prevailing winds, buoyancy-driven flows, and lunar tides. Estuarine-dependent species comprise more than 90% of North Carolina's commercial fisheries landings and over 60% of the recreational harvest (by weight) (from DMF annual commercial and recreational fisheries landings data). This Plan uses three salinity zones[1] for simplicity and consistency with established definitions (Bulger et al. 1993):

- low-salinity (0.5-5 ppt) (also known as oligohaline)
- moderate-salinity (5-18 ppt) (also known as mesohaline)
- high-salinity (18-30 ppt) (also known as polyhaline)

Boundaries between salinity zones change in response to water flow, weather conditions, and tidal fluctuations. Flooding can result in fresh water expanding seaward over denser masses of water in the "mixing zone" (0.5-25 ppt). Conversely, dry weather can result in seawater advancing into typically freshwater areas. Less drastic are tidal changes resulting in periodic additions of seawater to the mixing zone. The mixing zone receives coarser-grained sediments, saline water, and migrating organisms from the flood tide, while the ebb tide brings finer-grained sediment, fresh water, nutrients, and organic matter (SAFMC 1998a). This dynamic system is mediated by a series of inlets along a chain of barrier islands separating the ocean from the adjacent estuary. Salinity in estuaries also varies in accordance with the seasonal pattern of river input depicted in Figure 2.1. Salinity within estuaries is generally lowest from December to early spring and highest from late spring to early fall (Orlando et al. 1994). Similarly, water temperatures are lowest during mid-winter and highest during the summer.

Pilkey et al.'s (1998) analysis of North Carolina's shore and barrier islands revealed much about the variation in salinity and tidal amplitude along North Carolina's coast due to the slope of the coast. Steeper slopes with relatively short basin profiles result in less river input and greater tidal amplitude from increasing oceanic influence. In these areas, numerous inlets develop along short barrier islands, protecting narrow, back barrier sounds. Small rivers draining these areas form trunk estuaries (drowned river estuaries perpendicular to the coast) where low volumes of organic-stained fresh water mix with seawater. As a result, small trunk estuaries exhibit a distinct salinity gradient from upstream fresh waters to the ocean, while narrow back barrier sounds maintain high salinities from regular lunar tides. Other areas have gentler slopes and relatively long basin profiles, with more river input and lower tidal amplitude from reduced seawater intrusion; such areas have few inlets and long barrier islands protecting extensive back barrier sounds with highly variable salinity. Large rivers flowing into the sounds form trunk estuaries with very low salinity.

Strong winds are a major component of water movement in large, irregularly flooded estuarine systems. At locations relatively isolated from inlets in the Albemarle-Pamlico Sound system, the effects of lunar tides are small (a few inches at most) whereas those of wind tides can be much greater (especially during storms). A strong wind tide often floods the windward shore, exposing bottom along the leeward shore. This situation can also result in colder, nutrient-rich water welling up along the leeward shore. Wind tides also affect salinity in the estuary, by pushing high-salinity water from the ocean toward the estuary.

[1] A five-zone scheme was used on existing salinity maps from NOAA: 1) 0-0.5 ppt (fresh water), 2) 0.5-5 ppt (low-salinity), 3) 5-15 ppt (moderate-salinity), 4) 15-25 ppt (high-salinity), and 5) >25 ppt (highest salinity) (Map 2.6). The low-salinity zone used in this document covers NOAA's zone (2) and the moderate-salinity zone covers NOAA's zone (3). The high-salinity zone is a combination of NOAA's high (4) and highest (5) salinity zones (15 to >25 ppt).

For example, one model of the Albemarle-Pamlico system indicates that southwesterly winds cause the formation of low-salinity plumes from Oregon Inlet seaward while wedge-shaped high-salinity plumes enter Pamlico Sound from Hatteras and Ocracoke inlets (Xie and Pietrafesa 1999). This hydrodynamic model predicted the opposite effect during cold fronts, when northwesterly winds caused a wedge-shaped, high-salinity plume on the sound side of Oregon Inlet.

Circulation, by wind or lunar tide, can increase DO levels in bottom water. But while lunar-driven systems receive regular circulation, wind-driven systems depend on variable weather conditions (Luettich et al. 1999; Borsuk et al. 2001). Irregular mixing can result in stratification of the water column and hypoxia or anoxia during periods of warm, calm weather. Anoxia can also develop with light winds if a strong vertical salinity gradient is present, especially during westerly winds.

Large back barrier sounds and trunk estuaries

Large back barrier sounds occur north of Cape Lookout and include Albemarle, Currituck, Croatan, Roanoke, and Pamlico sounds (Map 1.1). Large trunk estuaries flowing into these northern sounds include the Alligator, Pungo, Pamlico, and lower Neuse rivers. The Albemarle-Pamlico sound system (not including Core Sound) connects with nearshore ocean waters through Oregon Inlet in the north, and Hatteras and Ocracoke inlets in the south. These large sounds are of prime importance for North Carolina's fishery productivity. Small tributary estuaries in west and northwest Pamlico Sound provide important fish nursery habitat. Outstanding Resource Waters within these northern estuaries include the Alligator River and an area extending offshore from Swan Quarter National Wildlife Refuge. The Alligator River is also classified as Swamp Water. Nutrient Sensitive Waters include the Pamlico, Neuse, and Pungo rivers as well as southwest Pamlico Sound (Map 2.2a-b).

The Albemarle-Pamlico system has a long flushing period (about 272 days) relative to the other North Carolina estuarine systems. Since the large trunk estuaries flowing into Pamlico Sound flush more rapidly than Pamlico Sound, the sound acts as a settling basin for sediments and nutrients (Giese et al. 1979). Near inlets in the Albemarle-Pamlico system, lunar tides are the dominant influence on salinity variation and water column mixing (Orlando et al. 1994). Elsewhere, wind mixing is the dominant factor. Management of river flows can also affect salinity. Releases from Roanoke Rapids Lake and other Roanoke River reservoirs during low-flow periods are generally effective in keeping higher salinity waters out of Albemarle Sound (Giese et al. 1979), except during extreme droughts. Seasonal variation in fresh water has a major effect on salinity (Map 2.5a-b). Different salinity layers can occur in estuaries lacking a direct connection to the ocean, such as the Cape Fear and Northeast Cape Fear rivers (Orlando et al. 1994). Different salinity layers can also occur in Albemarle Sound during period of calm or high freshwater inflow (Steel 1991). Although the major factors driving large-scale salinity change are fairly simple in estuaries, the factors underlying smaller-scale horizontal and vertical variation can be very complex, both spatially and temporally.

Small back barrier sounds and trunk estuaries

South of Cape Lookout, back barrier sounds and trunk estuaries begin to narrow as the basin slope becomes steeper. Starting at Core Sound in the north, small back barrier sounds continue south with Bogue Sound and some very narrow sounds located between the small trunk estuaries of the New and White Oak estuaries and the more riverine lower Cape Fear River. Some of these smaller sounds are Stump Sound, Topsail Sound, Masonboro Sound, and Myrtle Grove Sound (Map 1.1). Other small trunk estuaries include the Newport and North rivers along Bogue and Back sounds. These small back barrier and trunk estuaries contain numerous designated nursery areas and Outstanding Resource Waters (Map 2.3a-b). The only Nutrient Sensitive Water among small back barrier sounds and trunk estuaries is the upper New River (DWQ, unpub. data).

In Bogue and Back sounds, lunar tides are the dominant influence on salinity and water column mixing

(Orlando et al. 1994) and flushing rates are faster than in the larger sounds. Winds and freshwater inflow are secondary influences on salinity variation, but may cause major seasonal differences in salinity.

During late winter (January-March) and summer (June-August), surface and bottom salinities are only weakly stratified in Bogue Sound. Large seasonal differences in surface salinity occur. The very small back barrier sounds found in the Southern Estuaries MU have high salinities year-long. In upper sections of the New River, freshwater inflow is the dominant influence on salinity (Orlando et al. 1994). In the lower New River estuary, lunar tides have the greatest influence on salinity variation. Spatial and temporal salinity variation in the New and White Oak rivers can be seen in Map 2.5a-b.

Cape Fear River estuary

The Cape Fear River is the only major river in North Carolina flowing directly into the ocean, making the Cape Fear River estuary unique among North Carolina estuaries. The lower river is essentially a large trunk estuary, but with a much steeper gradient in salinity than large trunk estuaries in the northern part of the coast. The upper Cape Fear estuary is composed almost entirely of low-moderate salinity fish nursery areas (Map 2.5a-b).

In the upper Cape Fear River estuary (north of Wilmington), seasonal patterns of freshwater inflow have the greatest influence on salinity (Orlando et al. 1994). Discharge from the principal rivers in the Cape Fear basin is three times greater during the high-flow period than during the low-flow period. Short-term increases in freshwater discharge also influence salinity in the upper estuary, displacing bottom water downstream and homogenizing the water column (Giese et al. 1979). In the lower and middle estuary, lunar tides have the dominant effect on salinity variation. Due to the relatively high discharge and low volume of the Cape Fear estuary, the flushing rate is approximately 14 days (Table 2.1), the most rapid turnover among major estuaries in North Carolina. Map 2.5a-b depicts the seasonal salinity in the Cape Fear River system.

Table 2.1. Hydrologic and hydrodynamic characteristics of major estuaries in North Carolina. (Note: flushing period = volume / average daily freshwater input; Source: Basta et al. 1990)

Estuary	Drainage area (mi^2)	Surface area (mi^2)	Avg. depth (ft)	Volume (billion ft^3)	Avg. daily freshwater input (100 cfs)	Flushing period (days)
Albemarle-Pamlico sounds*	29,600	2,949	13	1,081	460	272
Pamlico-Pungo River	4,300	166	9	44	46	111
Neuse River	5,600	173	12	55	62	103
Bogue-Core sounds and White Oak River	700	102	5	13	13	116
New River	500	32	6	5	8	72
Cape Fear River	9,100	38	11	12	101	14

* Includes Core Sound

Marine systems

Marine systems are defined as open ocean waters overlying the continental shelf and its associated high-energy coastline where salinities exceed 30 ppt (Cowardin et al. 1979). This Plan addresses the ocean waters within the State's territorial jurisdiction, which extends three nautical miles offshore.

The effects of tides and bottom friction are most evident near inlets and along the shoreline. Tidal amplitude along North Carolina's ocean shoreline is greatest in the southern coastal area where the

continental shelf is widest. The average tidal height in North Carolina is approximately 2 ft (0.6 m) near Cape Hatteras and 4.3 ft (1.3 m) near Cape Fear. A considerable amount of mixing is provided by the turbulence of twice-daily tides.

The effects of freshwater runoff are also most apparent near inlets and river mouths. Salinities are lowest in coastal marine systems during periods of maximum freshwater runoff in March (Figure 2.1). The Cape Fear River is a major source of direct river runoff into southern North Carolina's ocean waters. Low-salinity waters also enter the ocean through the multiple inlets along the coast and from southerly flow of Chesapeake Bay waters along the Outer Banks. The plume of lower-salinity Chesapeake Bay water is pushed southward by the southerly-flowing coastal frontal zone (CFZ).

Winds are important in all layers of the marine water column. Wind stress can alter or reverse the generally southern pattern of flow in the CFZ (Blanton et al. 1999). Winds can also mix and move water masses inshore. In the mid-Atlantic, waters from Gulf Stream intrusions move across the shelf at a rate of approximately 2-3 mi/day (3-5 km/day), and parallel to the coast at a rate of approximately 3-9 mi/day (5-15 km/day) (Hare et al. 1999). Georgian shelf waters flow into the Carolina Capes region during periods of persistent southwesterly winds, while Virginian coastal waters flow south across Diamond, and occasionally Lookout, shoals during periods of persistent northerly winds (Pietrafesa 1989). Current and wind patterns will have a strong effect on the recruitment and retention of various fish larvae from different offshore areas.

Major oceanic currents off North Carolina are the Gulf Stream and Virginia Coastal Labrador current. The warm, north-flowing Gulf Stream and cool, south-flowing Virginia Coastal Labrador current meet near Cape Hatteras, separating mid- and south Atlantic waters. The position of these major water masses is clearly seen in sea surface temperature data from satellite imagery (Map 2.7). Warm Gulf Stream waters tend to elevate temperatures and salinities in the water column south of Cape Hatteras (Menzel 1993). The cool, lower salinity Virginia Current runs along the northern shore of the Outer Banks, and tends to lower temperature and salinity of the water column (Pietrafesa 1989). Temperatures on the inner shelf are uniform throughout the water column in the fall and winter. During summer, inner shelf waters are often stratified (Menzel 1993). Gulf Stream waters are the transport mechanism for many larval fish species, nutrients, and phytoplankton into North Carolina's shelf waters (Govini and Spach 1999). The red tide episode that occurred in North Carolina coastal waters in 1987 was attributed to a Gulf Stream water intrusion, carrying the toxic dinoflagellate *Ptychodiscus brevis* (Tyler 1989).

Shoals extending roughly perpendicular from shore accompany capes and inlets along North Carolina's coastal ocean. Oceanic currents interacting with these shoals create upwellings of nutrient-rich bottom water. There is also a strong upwelling along the beaches north of Oregon Inlet during the summer caused by southwest winds, resulting in surface water temperature changes of 10°F (5.5°C) in one or two days. In offshore areas, the interaction of frontal zones and bottom topography can often result in nutrient-rich upwellings. Upwellings also recycle nutrients locked under a strong halocline. The most probable locations of upwellings and their associated blooms are around Cape Hatteras. Upwellings, associated currents, and winds can also transport phytoplankton and floating *Sargassum* weed (from the Sargasso Sea) into nearshore coastal waters.

Habitat requirements for aquatic life

Unlike other fish habitats, the water column will persist regardless of environmental conditions. However, the quality of the water column may not be suitable to support certain fish species or ecological functions. Fish and invertebrate species occur where physical and chemical characteristics (i.e., temperature, DO, salinity, clarity) suit their physiological requirements. The following paragraphs discuss the differentiation of fish community structure along important physical and chemical gradients in coastal North Carolina.

Salinity

The proportion of the different salinity-based systems within each CHPP management unit varies (Table 2.2). The Albemarle, Chowan, and Roanoke MUs are primarily freshwater and low-salinity systems, whereas Core/Bogue, Coastal Ocean, and Southern Estuaries MUs are primarily high-salinity estuarine or marine systems (Figure 2.3). The salinity characteristics of any given estuary are a major determinant of aquatic community composition.

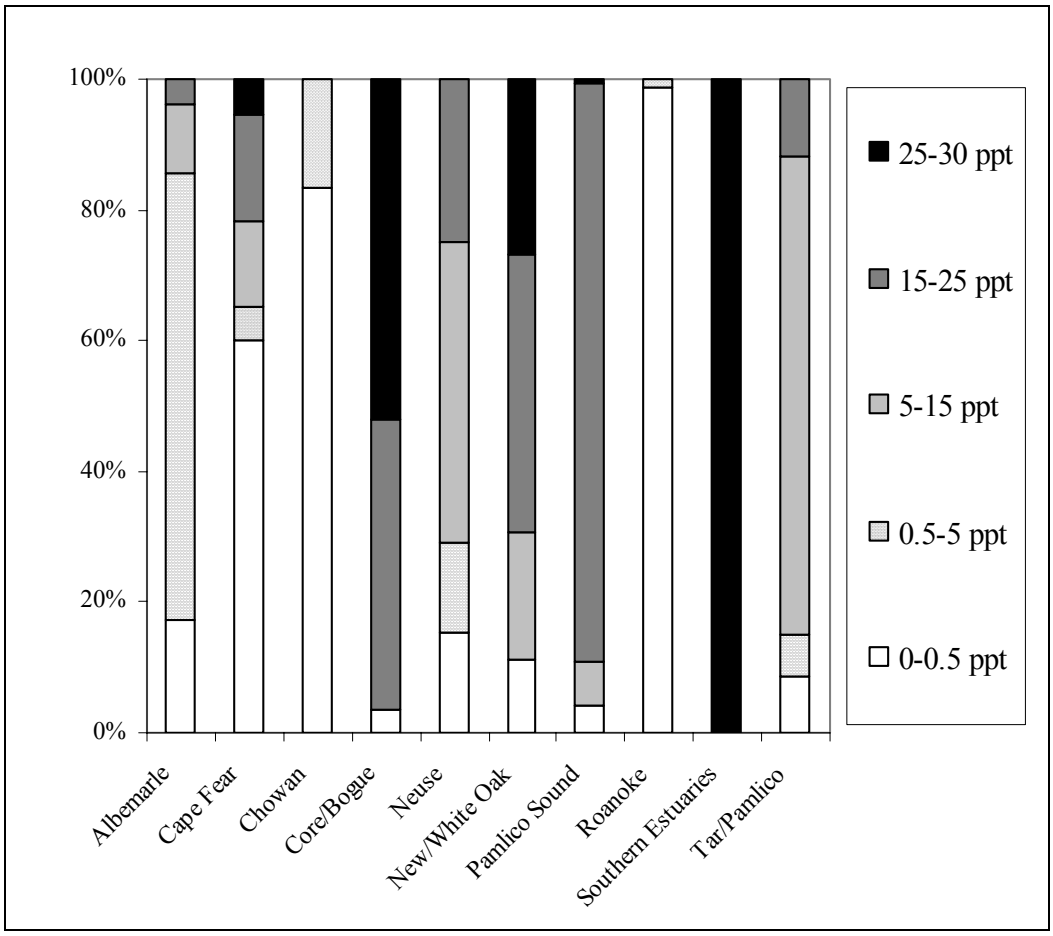


Figure 2.3. The relative proportion of average salinity zones within CHPP management units (excluding the coastal ocean). [Source: NOAA's 1:100,000 scale salinity mapping (Coastal Ocean Resource Assessment Program). The area for 0-0.5 ppt includes only mainstem rivers and lakes in the management unit.]

Salinity is among the key factors shaping fish communities in North Carolina estuaries (Ross and Epperly 1985; Noble and Monroe 1991). Some aquatic species are capable of tolerating large variations in salinity (e.g., blue crab), while others are capable of living in only a narrow salinity range (e.g., black sea bass). Salinity has a major role in the distribution of aquatic species (Szedlmayer and Able 1996). A partial list of important fish species[2] in North Carolina coastal waters is shown in Table 2.3. Species are organized by salinity zones of spawning and nursery areas to give an indication of where species occur in coastal waters.

[2] Scientific names for most species are listed in Appendix I.

In low-salinity areas of the Albemarle-Pamlico system, the fish community is dominated by freshwater and anadromous species (Table 2.3). In late winter, river herring (blueback herring and alewife), striped bass, Atlantic sturgeon, and other anadromous species migrate from the ocean and lower estuary to spawn upstream in freshwater areas. After spawning, the adults migrate back to the lower estuary or oceans, while the juveniles spawned in spring begin their seaward migration in late fall. This pattern holds for all the rivers in eastern North Carolina (Sholar 1975; Marshall 1976; Sholar 1977; Fischer et al. 1979; Hawkins 1980). The Albemarle-Pamlico system also has a resident population of striped bass that contributes little to the ocean migratory stock (Hassler et al. 1981; DMF 2003b).

Table 2.2. Area (acres) of average salinity zones in North Carolina Coastal Habitat Protection Plan management units (excluding the coastal ocean). [Source: NOAA's 1:100,000 scale salinity mapping (Coastal Ocean Resource Assessment Program)]

	Freshwater	Estuarine Salinity Zones				Total estuarine
Management unit	0-0.5 ppt[1]	0.5-5 ppt	5-15 ppt	15-25 ppt	25-30 ppt	acres
Albemarle	113,081	450,036	70,750	24,533	0	**545,320**
Cape Fear	38,934	3,364	8,521	10,580	3,574	**26,039**
Chowan	43,082	8,609	0	0	0	**8,609**
Core/Bogue	6,076	0	23	74,386	87,513	**161,921**
Neuse	20,904	18,648	62,156	33,863	0	**114,667**
New/White Oak	4,239	1	7,520	16,369	10,319	**34,210**
Pamlico Sound	42,842	97	71,921	939,104	7,651	**1,018,772**
Roanoke	138,821	2,006	0	0	0	**2,006**
Southern Estuaries	0	0	0	5	15,248	**15,253**
Tar/Pamlico	10,694	7,832	89,950	14,616	0	**112,397**
TOTAL	**418,673**	**490,593**	**310,840**	**1,113,455**	**124,305**	**2,039,194**

[1] The area for 0-0.5 ppt includes only mainstem rivers and lakes in the management unit.

In the Albemarle-Pamlico system, striped bass and American shad primarily use the Roanoke, Tar, and Neuse rivers (Steel 1991). River herring spawn in these rivers as well as most of the smaller tributaries of the Albemarle Sound system and the canals connecting Lake Mattamuskeet with coastal waters. River herring are also present in riverine waters south of the Albemarle-Pamlico system, where they have been studied in the New and White Oak rivers (Sholar 1975) and Cape Fear River (Sholar 1977; Fischer 1979; Rulifson et al.1982).

During spring and summer, juvenile and adult estuarine species spawned in high-salinity estuarine waters (e.g., blue crab, red drum, weakfish) or the nearshore ocean (e.g., Atlantic menhaden, Atlantic croaker, spot, southern flounder) occupy the low-salinity zone (Table 2.3). There are also some resident species that complete their entire life cycle in the low-salinity zone. Residents include estuarine species like bay anchovy but are dominated by freshwater species, such as white perch, yellow perch, catfishes, sunfishes, and minnows (Keefe and Harriss 1981; Copeland et al. 1983; Epperly 1984). Prominent species in this resident group include the spring-spawning white perch and white catfish (Keefe and Harriss 1981). Both species use the entire Chowan River and other areas as nursery habitat, but generally occupy deeper areas during winter (Hester and Copeland 1975). The low-salinity zone is also occupied by the catadromous American eel.

In moderate- and high-salinity estuarine zones, the young of offshore winter and spring spawners, such as Atlantic menhaden, spot, and Atlantic croaker, predominate (Table 2.3; refer to Nursery function section).

Table 2.3. Spawning location/strategy ("spawning guild") and vertical orientation of some prominent coastal fish and invertebrate species.

Species*	Vertical orientation[1]		Fishery [3]	Stock Status [4]
	Demersal[2]	Pelagic		
ANADROMOUS FISH				
River herring (alewife and blueback herring)	**E**	**A, J, L**	**X**	**O-Albemarle Sound, U-central/southern**
American shad	**E**	**A, J, L**	**X**	**Concern**
Sturgeon (Atlantic and shortnose)	A, J, E		X[5]	Overfished
Hickory shad	**E**	**A, J, L**	**X**	**Unknown**
Striped bass	A, J	E, L	X	V- Albemarle Sound, Atlantic Ocean, O- Central/Southern
CATADROMOUS FISH				
American eel	A, J	E, L	X	
ESTUARINE AND INLET SPAWNING AND NURSERY				
Bay anchovy		**A, J, E, L**		
Bay scallop	A, J, E	L		Concern
Grass shrimps	A, J, E	L		
Hard clam	A J	E, L	X	Unknown
Mummichog	A, J, E	L		
Oyster	A, J	E, L	X	Overfished
Silversides	**E**	**A, J, L**		
Black drum	A, J	E, L	X	
Blue crab	A, J, E	L	X	Concern
Cobia		**A, J, E, L**	**X**	
Red drum	A, J	E, L	X	Recovering
Spotted seatrout	A, J	E, L	X	Viable
Weakfish	A, J	E, L	X	Viable
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY				
Atlantic croaker	A, J	E, L	X	Concern
Atlantic menhaden		**A, J, E, L**	**X**	**Viable**
Shrimp	A, J, E	L	X	Viable
Southern flounder	A, J	E, L	X	Overfished
Spot	A, J	E, L	X	Viable
Striped mullet	**A**	**J, E, L**	**X**	**Concern**
MARINE SPAWNING, HIGH SALINITY NURSERY				
Black sea bass	A, J	E, L	X	O-south of Hatteras, V-north of Hatteras
Bluefish		**A, J, E, L**	**X**	**Recovering**
Florida pompano	A, J	E, L	X	
Gag	A, J	E, L	X	Viable
Gulf flounder	A, J	E, L	X	
King mackerel		**A, J, E, L**	**X**	**Viable**
Kingfish ("sea mullet")	A, J	E, L	X	Unknown
Pinfish	A, J	E, L	X	
Sheepshead	A, J	E, L	X	
Spanish mackerel		**A, J, E, L**	**X**	**Viable**
Summer flounder	A, J	E, L	X	Recovering

***** Scientific names for species are listed in Appendix I.

[1] Sources include Epperly and Ross (1986), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998a), NOAA (2001), USFWS species profiles (see literature cited: reference titles beginning with Species life histories and Environmental Requirements), and DMF (unpub. data).

[2] Demersal species live primarily in, on, or near the bottom while pelagic species (**bolded**) occur primarily in the water column. A=adult, J=juvenile, L=larvae, and E=egg.

[3] Existing commercial or recreational fishery. Fishery and non-fishery species are also important as prey.

[4] V = Viable, R = Recovering, C = Concern, O = Overfished, U = Unknown (DMF 2003a).

[5] Former fishery, but fishing moratorium since 1991

Common, year-round residents of the nearshore marine zone include bottom fish such as black sea bass, gag, kingfishes, dogfish sharks, and summer flounder, along with more pelagic species like Spanish mackerel, king mackerel, cobia, silversides, and bluefish. Juveniles and adults of these species are also common in the high-salinity estuarine zone (NOAA 2001). Many high-salinity estuarine species are also found in the nearshore ocean (e.g., red drum, spotted seatrout, weakfish, black drum). During late fall and winter, the nearshore marine zone is flooded with adult offshore spawning estuarine species like southern flounder, Atlantic croaker, spot, shrimp, striped mullet, and Atlantic menhaden. Florida pompano and Gulf kingfish are common species in the nearshore marine zone (primarily during the summer).

Temperature

Temperature patterns in North Carolina coastal waters affect fish distribution and functions. The North Carolina coast is located at the southern end of the cooler Mid-Atlantic Bight and the northern end of the warmer South Atlantic Bight, with Cape Hatteras marking the transition between these two major zones. As a result, some northern species are abundant in coastal ocean and estuarine waters north of Cape Hatteras, and some southern species are abundant south of Cape Hatteras. Predominantly northern fish include summer flounder, weakfish, spiny dogfish, and migratory striped bass, whereas primarily southern species include snappers, groupers, southern shrimps, and southern flounder.

In riverine systems, water temperature increases downstream from river headwaters to the estuary. The gradual increase in temperature is determined naturally by elevation, air temperature, shading, and water velocity. Temperature in riverine systems is one of the primary cues for anadromous fish spawning. For example, spawning of striped bass in coastal rivers is triggered by increasing water temperatures in early spring (Hill et al. 1989; Funderburk et al. 1991).

The greatest variation in temperature within North Carolina's estuaries occurs from season to season and is highly influenced by high spring flows in the rivers feeding the estuary (Figure 2.1). Apart from very high river flows, the temperature of upper estuarine waters is most affected by air temperatures. For example, average monthly temperatures in the Pamlico River estuary range from 41ºF (5ºC) in January to 81ºF (27ºC) in July and August, but in extreme conditions may range from 32º to 86ºF (0-30ºC) (Copeland et al. 1984). The seasonal temperature range of the Pamlico River estuary follows the average monthly temperature of upstream rivers very closely (Figure 2.1). Estuarine water temperature also responds to the tides (Peterson and Peterson 1979). In winter, water temperatures near ocean inlets rise abruptly with the incoming tide, whereas, during summer, the incoming tide is cooler (Peterson and Peterson 1979). Estuarine, and especially slow-moving or stationary, organisms have adapted to survive these short-term and seasonal conditions.

In general, all estuarine organisms can tolerate a very wide range of temperatures, if given adequate time to acclimate (Nybakken 1993). Organisms cannot readily adapt to a rapid increase or decrease in temperature. Early life stages of many species (e.g., clams, oysters, spot, croaker, flounder, menhaden) have a much narrower temperature tolerance than adults (Kennedy et al. 1974). If water temperature becomes too low, or falls too rapidly, there can be a fish kill of sensitive species like seatrout and red drum. Great variability in annual reported catch is typical for seatrout species and seems related to climatic conditions of the preceding winter and spring. Low catches follow severe winters; winter cold shock of juveniles and adults is cited as a primary factor in local and coast-wide declines in spotted seatrout (<http://www.ncdmf.net/stocks/spectrou.htm>, July 2003).

Temperature varies least in the marine system (Peterson and Peterson 1979; Nybakken 1993) and marine species tend to be less tolerant of temperature extremes and rapid changes in temperature. Water temperature is one of the most important factors in determining use of coastal ocean habitat by warm temperate and tropical species (SAFMC 1998a). Tropical species occur off the North Carolina coast where offshore bottom water temperatures range from approximately 52-81ºF (11–27ºC) (SAFMC 1998a). Temperatures less than 54ºF (12ºC) may result in the death of some tropical fish and

invertebrates (Wenner et al. 1984; SAFMC 1998a). Estuarine-dependent species in the nearshore ocean, such as black sea bass and southern flounder, have a broader temperature tolerance (Reagan and Wingo 1985; Steimle et al. 1999). Research in North Carolina marine waters has found that fish species composition at hard bottom shifted over a 15 year period, with an increase in tropical species and decrease in temperate species (Parker and Dixon 1998). The change in species composition was associated with global warming trends.

Dissolved oxygen

All fish and invertebrates require a minimum amount of dissolved oxygen (DO) to survive, and an even greater amount for growth and reproduction. Oxygen tolerance varies by organism type. Not accounting for mobility, fish are generally most sensitive to hypoxia (low dissolved oxygen; DO < 2 mg/l), followed by crustaceans and echinoderms, annelid worms, and mollusks (clams, oysters) (Gray et al. 2002). However, because highly mobile organisms can avoid areas of low DO, they are least affected by hypoxia. Although benthic invertebrates are fairly tolerant of low oxygen (Diaz and Rosenburg 1995), stationary invertebrates are helpless against prolonged anoxia. Therefore, DO is considered a critical factor affecting the survival of stationary benthic invertebrates and sedentary fishes and the distribution of mobile species (Seliger et al. 1985; Jordan et al. 1992; Eby et al. 2000; Buzzelli et al. 2002).

Growth of actively swimming fish is reduced at DO concentrations below about 6 mg/l, metabolism is reduced at 4.5 mg/l, and most fish cannot tolerate DO less than 2 mg/l (Gray et al. 2002). In tests comparing the response of selected juvenile estuarine fish (mummichog, juvenile spot, pinfish, Atlantic croaker, menhaden, white mullet, and brown shrimp) to hypoxia, Atlantic croaker and white mullet were more sensitive to low DO than spot and pinfish, and mummichog (a resident estuarine species) was the only species that did not avoid low oxygen (1 mg/l DO) (Wannamaker and Rice 2000).

Croaker and mullet preferred 4 mg/l to 2 mg/l, whereas spot and pinfish showed no preference. Although juvenile and adult mullet have more stringent oxygen needs, they can obtain additional oxygen by behavioral means (emerging from the water's surface by jumping, for example) and by producing more hemoglobin during warmer months (Cech and Wohlschlag 1982). Other species and life stages requiring DO levels greater than 3-4 mg/l include egg and larval striped mullet, larval spotted seatrout, juvenile river herring, southern flounder, bluefish, and adult brown shrimp (Deubler and Posner 1963; Funderburk et al. 1991; Pattilo et al. 1997; Blanchet et al. 2001; Taylor and Miller 2001) (Table 2.4). Species tolerating less than 3 mg/l, but greater than 1 mg/l DO, include Atlantic menhaden, bay anchovy, spot, oyster, pinfish, silversides, striped mullet, hogchoker, and larval red drum (Overstreet 1983; Funderburk et al. 1991; Pihl et al. 1991; Pattilo et al. 1997; Wannamaker and Rice 2000; Taylor and Rand 2003). Species and life stages requiring high DO levels (>4 mg/l) include larval alewife, yellow perch and blueback herring, and adult American shad, striped bass, white perch, yellow perch and hard clam (Funderburk et al. 1991). The majority of species requiring high DO are pelagic species, although some prominent forage species can tolerate hypoxic conditions.

Table 2.4. Minimum DO requirements for selected fish and invertebrate species of various life stages found in North Carolina. [Source: Funderburk et al. (1991), Pattilo et al. (1997), Wannamaker and Rice (2000), and Blanchet et al.(2001).]

Species	Dissolved oxygen requirements[1]		
	High (>4 mg/l)	Moderate (3-4 mg/l)	Low (1-3 mg/l)
Resident freshwater	A,L-yellow perch, A-white perch,		
Anadromous	L,E-alewife, A,L-blueback herring, A-American shad, A-striped bass	J-river herring (alewife, blueback herring)	
Estuarine and inlet spawning and nursery	A-hard clam	L-spotted seatrout	A-oyster, A-silversides, A-bay anchovy, J-mummichog, hogchoker, J-spotted seatrout, L-red drum
Marine spawning, low-high salinity nursery		J-southern flounder, A-brown shrimp, J-Atlantic croaker, L,E-mullet	Atlantic menhaden, spot, A,J-mullet,
Marine spawning, high salinity nursery		J-bluefish	pinfish

[1] A=adult, J=juvenile, L=larvae, E=egg

Light and water clarity

Water clarity is determined by the concentration of dissolved and suspended organic and inorganic particles in the water column. Water clarity and the resulting light availability in the water column are important to aquatic organisms for several reasons. The combination of increasing light, water velocity, and temperature during spring is the primary cue for upstream movement and spawning of anadromous fish (Klauda et al. 1991; Orth and White 1993). Extreme turbidity is known to reduce phytoplankton and submerged aquatic vegetation biomass, reduce visibility of pelagic food, reduce availability of benthic food due to smothering or bottom water hypoxia, and clog gill rakers and gill filaments (Bruton 1985). Turbidity also reduces a predator's visual range, which therefore reduces reactive distance (Barrett et al. 1992; Gregory and Northcote 1993), volume of water searched, and feeding efficiency (Moore and Moore 1976; Vingard and O'Brien 1976; Gardner 1981).

The estuarine water column typically has relatively high loading of suspended particles (phytoplankton, detritus, and/or sediment) and reduced water clarity (Nybakken 1993). Some species are adapted to turbid conditions, and the water clarity preference of many estuarine species at various stages of their life cycle is not known (Funderburk et al. 1991). Although excessive turbidity can be problematic, moderate turbidity in estuaries can be beneficial to small or non-visually feeding fish by affording protection from visually feeding predators in shallow, food-rich areas (Ritchie 1972; Blader and Blader 1980; Boehlert and Morgan 1985; Bruton 1985; Miller et al. 1985). Because there is an increased risk of predation in clear waters, some sedentary prey use cryptic coloration, bury under sand, or seek refuge in adjacent habitats to avoid detection. Distinctive aquatic communities can thus be found in turbid and clear water bodies. While water clarity could have an effect on fish species composition, it would be difficult to separate changes in species composition due to water clarity from correlated environmental changes such

as salinity, temperature, and depth. *Research is needed to quantify the relationship between water clarity and other parameters in order to evaluate the relative contribution of water clarity in determining fish community structure*.

Flow and water movement

Estuaries are mixing zones with complex water movements between fresh and salt water. The four principal factors that affect water movement in North Carolina's estuaries are: (1) rainfall (inflow), (2) wind, (3) lunar tides, and (4) density gradients (salinity and temperature) (DMF 2003b). In some freshwater rivers, flow may also be drastically affected by reservoir releases. Each creek, river, bay, or sound is uniquely different due to these four factors.

Flow and circulation patterns within North Carolina's estuaries are complex due to interacting physical, chemical, and biological factors. Variation in water flow occurs at a broad range of spatial scales in estuarine and marine systems. The interaction of topographic features (e.g., shoals, bays) and tidal or wind-driven circulation patterns creates large-scale (km) spatial variation (Xie and Eggleston 1999; Inoue and Wiseman 2000). At much smaller scales (<1m), topographic changes or the presence of bottom habitat structure (e.g., SAV, oyster reef, pilings, stumps, logs) can create areas of reduced and increased water velocity (Jokiel 1978; Gambi et al. 1990; Komatsu and Murakami 1994; Lenihan 1998). Temporal variation in flow is caused by regular tidal flushing or irregular circulation by the wind.

Each organism in an estuary relies upon certain circulation patterns to provide the conditions that it needs to flourish at a given life stage. Some conditions benefit one species or species' life stage more than others. The conditions needed by a species do not always occur at the same time and location each year due to variations in weather. However, the expansive nature of North Carolina's estuaries almost assures that proper conditions for a particular species will occur somewhere, but conditions may not be optimal in all locations (DMF 2003b).

The aquatic organisms that flourish in estuaries rely on flow and water movement to: (1) deliver the nutrients and physical water conditions for appropriate food and nursery area development at the opportune time; (2) keep eggs and larvae of pelagic spawners in suspension to enhance survival; (3) transport and distribute eggs, larvae, and juveniles to the appropriate nursery area for optimum food availability and protection from predators; and (4) distribute sediment and affect structures that serve as habitats (i.e., shell bottom, SAV, soft bottom) for many fish species (DMF 2003b).

High flows serve as a cue for spawning activity of anadromous fish, whereas low flows correspond to the growth and recruitment period of young fish (Orth and White 1993). Successful spawning of striped bass coincides with optimal water velocities between 3.3 and 6.6 ft/s (100-200 cm/s), while adult American shad prefer water velocities between 2 and 3 ft/s (61-91 cm/s) (Fay et al. 1983d; Mackenzie et al. 1985; Hill et al. 1989). Recruitment of larval river herring in tributaries of the Chowan system is also related to flow conditions (O'Rear 1983). However, water velocity is not the only cue for anadromous fish spawning; increasing light and temperature are also important factors.

Flows have a major effect on biological interactions. Powers and Kittinger (2002) found that blue crab predation on juvenile hard clams and bay scallops decreased with increasing water velocity, while whelk predation on bay scallops increased under the same treatment. Dilution of water-borne chemical cues was likely the reason for reduced blue crab predation (Powers and Kittinger 2002). Tamburri et al. (1996) found that chemical cues successfully induced larval settlement of oysters regardless of flow conditions. In another study, Palmer (1988) showed that higher current velocities increased erosion of small animals from below the sediment surface (meiofauna) into the water column, resulting in increased predation by spot (a more non-visual feeder). Species that rely primarily on visual cues would not be affected by dilution of chemical cues. However, all mobile aquatic organisms (including visual predators) also seek to minimize the energetic cost of movement through the water column while maximizing foraging

efficiency.

As fish grow and develop, flow regime requirements or preferences change (Ross and Epperly 1985). Larvae and juveniles generally prefer lower velocities than adults, enabling them to settle out and maintain their positions in the estuary. Consequently, juvenile, estuarine-dependent fish are highly abundant in shallow, side-channel habitats where velocities are low (Ross and Epperly 1985; Noble and Monroe 1991).

There is little information on flow preference of estuarine species. Hydrologic modifications can, in some situations, negatively impact optimum flow conditions for aquatic organisms (refer to threats section for more details). *Research is needed on the preferred flow regimes of estuarine species in order to refine distributional patterns and better understand the effect of hydrological modifications on fish species.*

pH

The pH of the water column is a basic chemical characteristic that affects egg development, reproduction, and the ability of fish to absorb DO (Wilbur and Pentony 1999). Among freshwater, estuarine, and marine systems, pH varies naturally, and the organisms of the aquatic community have adapted to that natural variation. However, most fish require pH >5 (Wilbur and Pentony 1999), within a possible range of 0 (extremely acidic) – 14 (extremely basic). The pH of seawater is the most stable among systems and varies between 7.5 and 8.5 (Nybakken 1993). The pH of estuaries depends on the dynamic mix of seawater and upstream fresh waters. In high-salinity estuaries with little river input (e.g., Core and Bogue Sound), pH is near that of seawater. Fresh water has the most variable pH, depending on the buffering, or acid controlling, capacity of the water and organic matter input. Freshwater water bodies with low buffering capacity and high organic matter (e.g., swampy creeks) can have very low pH (<5). The pH standard for surface fresh waters in North Carolina is between 6.0 and 9.0. The pH may fluctuate dramatically between day and night, associated with algal blooms. The pH can affect chemical cycling, availability, and ionic balance of compounds within the water column, some of which may be toxic to aquatic organisms under appropriate pH conditions, but have no effect otherwise.

The pH of the water is an important requirement for reproduction of estuarine organisms. For example, the optimum pH for normal egg development and larval growth of oysters occurs between 8.25 and 8.5 (Calabrese and Davis 1966; Calabrese 1972). Oysters also have an optimum pH of 7.8 for spawning and >6.75 for successful recruitment. Likewise, hard clam eggs and larvae require pH levels of 7.0-8.75 and 7.5-8.5, respectively, for the same functions (Funderburk et al. 1991). Anadromous fish species can generally tolerate fresh water with lower pH. For example, alewife eggs and larvae require pH between 5.0-8.5 pH and blueback herring eggs and larvae require pH levels between 5.7-8.5 (Funderburk et al. 1991). This pattern of pH requirements between systems also illustrates the adaptation of freshwater and estuarine organisms to their environment.

2.2. ECOLOGICAL ROLE AND FUNCTIONS

The water column is the lifeblood of aquatic ecosystems. It is the medium through which all other aquatic habitats are connected. As such, the water column provides a basic ecological role and function for organisms within it. The water column also provides other functions, both by itself and due to benthic-pelagic coupling. Benthic-pelagic coupling refers to the influence of the benthic community and sediments on the water column and, in turn, the influence of the water column on them, through integrated events and processes such as resuspension, settlement, and absorption (Warwick 1993).

Productivity

The potential productivity of fish and invertebrates in a system is determined by the assimilation of energy and nutrients by green plants and other life at the base of the food chain. The potential

productivity of a habitat can indicate its relative value in supporting fish populations. Although productivity in the water column is derived mostly from phytoplankton, it can also come from bacterial decomposition of plants (detritus), floating plants, and macroalgae. The foundation of riverine production during elevated flows is detritus from adjacent wetlands and fine particulate organic matter from upstream areas (Vannote et al. 1980; Junk et al. 1989). As flows decline through summer, phytoplankton can maintain its position in the water column and photosynthetic production supports the majority of secondary production. In some coastal rivers (e.g., Perquimans River), floating macrophytes such as duckweed can make up a significant portion of primary production during some years. Rivers play a dominant role in providing nutrients and flushing for downstream estuaries in the Albemarle, Tar-Pamlico, Pamlico, Neuse, and Cape Fear management units. These nutrients, in turn, contribute to primary productivity. The amount and type of production are determined by flushing (retention) and season.

Historically, phytoplankton productivity in estuarine systems was thought to be relatively low compared to that of other primary producers (Peterson and Peterson 1979). For instance, Marshall (1970) estimated that phytoplankton contributed only 50 g carbon/m^2/yr to New England's subtidal shoal waters, compared to a contribution of 125 g carbon/m^2/yr for all macrophytes. In the Newport River estuary near Beaufort, North Carolina, Williams and Murdoch (1966) and Thayer (1971) estimated that phytoplankton produce about 110 g carbon/m^2/yr. Subsequent research suggested a higher contribution to overall primary production from phytoplankton (Peterson and Peterson 1979). Sellner and Zingmark (1976) found phytoplankton production as high as 350 g carbon/m^2/yr in shallow tidal creeks and estuaries of South Carolina. Various data sources for North Carolina estimate phytoplankton productivity anywhere from 67 (Beaufort Channel adjacent estuaries) to 500 g carbon/m^2/yr (Pamlico River estuary) during the growing season. Mallin et al. (2000a) found that the highest phytoplankton production is in riverine estuaries where flushing is limited by extensive barrier islands (e.g., Neuse River), whereas areas that are well flushed or unconstrained (e.g., Cape Fear River) support a much lower phytoplankton biomass and productivity. Complex, estuarine creek/salt marsh systems generally have moderate phytoplankton productivity. Lucas et al. (1999) used a depth-averaged numerical model to predict the productivity of phytoplankton in an estuary with shallow shoals, deep channels, and variable turbidity and benthic grazing. The model predicted that phytoplankton growth rate was generally greater in deeper areas when benthic grazing is high and turbidity is low. Conversely, when turbidity was high and benthic grazing was low, phytoplankton growth rate was generally greater in shallow areas.

However, phytoplankton productivity is still generally considered secondary to detritus-based production in salt marsh-dominated estuaries (Peterson and Peterson 1979; Dame et al. 2000). A study conducted on a Georgia salt marsh found a net productivity of 6,850 kcal/m^2/year from emergent vegetation and only 1,600 kcal/m^2/yr from the various algae (Teal 1962). Compared to broad, open water areas, narrow tidal creeks and their associated marsh would likely contribute more detritus than phytoplankton. However, some research suggests that much of the detrital production from emergent vegetation remains in the marsh and that phytoplankton are the major production export (Haines 1979). Planktivorous fish (e.g., menhaden) and detritivores (e.g., shrimp) can also export production from shallow marsh creeks and bays to more open waters (SAFMC 1998a).

Phytoplankton production in shallow estuaries may also be secondary to phytobenthic (microscopic plants that live on the bottom) production. In North Carolina, benthic microalgal biomass frequently exceeds phytoplankton in the nearshore ocean water column by a factor of 10 to 100 (Cahoon and Cooke 1992). Based on relative rates of primary production and nutrient cycling, Webster et al. (2002) found that phytobenthos was the dominant primary producer in a shallow estuary where light was not limiting; however, these results may not be applicable to North Carolina estuaries with higher turbidity. Net productivity for any given estuary depends on the relative proportion of wetlands, shallow soft bottom, and water column in the system.

In nearshore ocean waters, the depth that light penetrates to allow photosynthesis (euphotic zone) may be quite shallow because of high turbidity and wind mixing. Proceeding offshore there is generally a sharp decrease in chlorophyll *a* where the water column becomes more stratified. Menzel (1993) reported that primary production rates decreased significantly from the inner shelf to the outer shelf of the South Atlantic Bight. Production levels may increase by a factor of three to ten with warm core intrusions from the Gulf Stream. Because these intrusions occur irregularly on the inner shelf zone, this nearshore area depends more on nutrients recycled or resuspended by wind or tidal forces (Menzel 1993). Zooplankton distribution is directly related to location of phytoplankton blooms. Cahoon et al. (1990) found that on the inner shelf in Onslow Bay, 80% of the chlorophyll *a* was associated with the sediment. Benthic microalgal biomass (36.4 mg chlorophyll *a*/m^2) always exceeded phytoplankton biomass (8.2 mg chlorophyll *a*/m^2) (Cahoon and Cooke 1992). Hackney et al. (1996) reported that, because of circulation patterns, inorganic nutrients could be resuspended and retained in sufficient amounts to allow localized phytoplankton blooms within the surf zone. Primary production within the water column can also come from macroalgae detached from hard substrate (e.g., *Enteromorpha*) or floating on the surface (e.g., *Sargassum*).

Fish utilization

Although all fish technically use the water column, this section focuses primarily on species associated with open water (pelagic) habitat. Pelagic species are those most commonly found near the surface of the water column and include the adult stages of alewife, American shad, hickory shad, blueback herring, bay anchovy, silversides, Atlantic menhaden, bluefish, cobia, and Spanish mackerel. In addition to these species, eggs and larvae of most fish species depend on the open water for passive transport and food (see Corridor and connectivity function).

Corridor and connectivity

The corridor function is the most basic function of the water column because the various life stages of fish species must move through it to utilize other habitats supporting other functions. The corridor function is particularly important for anadromous species such as river herring, shad, and striped bass, species that must migrate as adults from high-salinity waters, through estuarine waters, and upstream into freshwater systems to spawn in the spring. As a catadromous species, adult American eel must migrate from upstream freshwaters through estuarine waters to their spawning grounds in the Atlantic Ocean. The upstream limit of anadromous and catadromous fish migration in North Carolina is depicted on Map 1.3. All that is needed for transporting anadromous fish eggs and larvae to downstream nursery areas is relatively clear, unobstructed, and flowing water.

The large estuaries of North Carolina function as settling basins where coastal rivers meet the sea (Giese et al. 1979). As such, the flow of water between the rivers and the estuaries, and between the estuary and the ocean, must be maintained so that settlement of transported larvae to the estuary is successful. Nearly all fish and shellfish species in coastal North Carolina occupy the estuarine water column at some point in their life cycle. Meroplankton (organisms that spend only part of their life cycle in the plankton), in particular, rely on the corridor function of the water column to transport them to favorable nursery areas.

Common species inhabiting the Surf Zone
Atlantic menhaden, striped anchovy, bay anchovy, rough silverside, Atlantic silverside, Florida pompano, spot, Gulf kingfish, striped mullet, Spanish mackerel, flounders, bluefish, Atlantic sharpnose shark, red drum, sea robin, and skates

The surf zone and shallow intertidal waters are important corridors for seasonal fish migrations and for larval transport in and out of estuarine waters. Several studies have directly targeted surf zone fishes in North Carolina (Francesconi 1994; Hackney et al. 1996; Ross and Lancaster 1996). These studies reported 47 species in North Carolina's surf zone. About 130 species of fishes have been reported from

North Carolina through Georgia (Tagatz and Dudley 1961).

The surf zone is an important migratory path for larval and juvenile fish moving toward the estuaries in the winter and spring. Adult fish are thought to migrate close to shore in the surf zone during the fall migration offshore (Hackney et al. 1996). Adult fish abundance in the surf zone is highly seasonal with lowest abundance and diversity in the winter and maximum abundance and diversity in the late summer (Hackney et al. 1996). Maximum biomass occurs in the fall when juveniles are at peak sizes, and large schools of fish migrate from the estuaries along the beaches.

Larval fish are an important component of zooplankton in the coastal ocean water column. In Onslow Bay, Powell and Robbins (1998) documented a total of 110 families from ichthyoplankton samples. Estuarine-dependent species such as menhaden, spot, and Atlantic croaker are an important component of the ichthyoplankton during late fall and winter. These species spawn offshore and must be transported into estuaries through the water column. Ichthyoplankton from estuarine-dependent species that spawn in the sounds, inlets, and nearshore ocean waters during spring and early summer (e.g., pigfish, silver perch, weakfish) were also found in the ocean water column shortly afterward. Reef fish larvae were most abundant during spring, summer, and early fall. The frequent occurrence of larvae from deep-water oceanic species indicates that Gulf Stream waters transported those larvae to shelf waters off North Carolina.

Inlets are important corridors (or bottlenecks) through which many fish must successfully pass to complete their life cycles. Larval fish diversity in North Carolina's inlets is very high. Sixty-one larval species have been found in Oregon Inlet; Atlantic croaker and summer flounder were particularly abundant (Hettler and Barker 1993). Some of the other species included bluefish, black sea bass, gray snapper, several flounder species, pigfish, pinfish, spotted seatrout, weakfish, spot, kingfish, red drum, mullet, and butterfish. Beaufort, Ocracoke, and Oregon inlets also support significant larval fish passage, although Oregon Inlet may be especially important due to the great distance between it and adjacent inlets, its orientation along the shoreline, and the direction of prevailing winds. Oregon Inlet provides the only opening into Pamlico Sound north of Cape Hatteras for larvae spawned and transported from the Mid-Atlantic Bight.

Peters et al. (1995) and Peters and Settle (1994) documented species' utilization and temporal trends in larval fish transport through Beaufort Inlet. Table 2.5 depicts the time periods during which various larval species immigrated through the inlet. Over 52 taxa including 29 species were identified, although menhaden, spot, Atlantic croaker, and pinfish dominated the majority of the samples. Peak larval abundances for those species occurred between September and April.

Table 2.5. Peak larval abundance of seven important fish species near Beaufort Inlet. (Source: Peters et al. 1995)

	Month						
Species	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Menhaden							
Summer flounder							
Southern flounder							
Spot							
Pinfish							
Gulf flounder							
Atlantic croaker							

Research projects conducted under the South Atlantic Bight Recruitment Experiment (SABRE) studied transport of winter-spawned fish larvae into the estuaries. Larvae concentrate on the shelf in a narrow "withdrawal zone" upwind of an inlet within the 23-foot (7m) deep isobath. Upon the appropriate

conditions of ocean currents, the larvae pass through the inlets. Even during best wind and tidal conditions, only about 10% of the available larvae are successfully drawn into the inlet (Blanton et al. 1999). Larvae passing downwind and outside the narrow withdrawal zone pass seaward of the inlet shoals and, given the right conditions, will be transported into the next available inlet downstream. Churchill et al. (1999) noted that transport dynamics in the immediate vicinity of inlets are complex, and that larvae may also remain near an inlet or move in and out repeatedly before actually immigrating. However, since the along-shore flow component of the coast is four to five times greater than the cross-shelf component, larvae are highly dependent on being transported along the shore in a narrow zone and then injected through the inlet (Hare et al. 1999). Offshore-spawning, estuarine-dependent species include many of North Carolina's most important commercial and recreational fish species, such as menhaden, spot, Atlantic croaker, pinfish, flounders, shrimp, black sea bass, and gag. Red drum and blue crabs, which spawn in and near the inlets, also require transport of larvae through inlet systems. Consequently, successful movement of larvae through the inlets is of great importance to North Carolina fisheries, particularly where inlets are limited, such as along the Outer Banks.

Spawning

Fish that spawn in open waters generally broadcast planktonic eggs. Survival of these eggs is affected by flow and circulation patterns. With increasing light, flow, and temperature during the spring, open-water freshwater systems provide spawning habitat for resident freshwater and anadromous fish (Orth and White 1993).

Anadromous fish species such as river herring (alewife and blueback herring), striped bass, and shads (hickory and American shad) use the freshwater water column to broadcast eggs which develop as they float downstream. All of the life stages of these species use the water column as their primary habitat. Environmental conditions such as heavy rainfall, high water flow, and temperature affect anadromous fish life cycle stages and migration patterns in freshwater systems. Conditions for anadromous fish spawning are typically met from mid-February to mid-June in North Carolina (Table 2.6), although spawning periods vary according to species and drainage basin (Steel 1991). Sufficient rainfall is needed to provide suitable current velocities for spawning. The strongest currents are required by striped bass and blueback herring (Table 2.7). Slower current velocities are needed for American shad and alewife; alewife spawn in slow-moving oxbows and small streams, as well as fast-water sites. Adequate DO levels in slow-moving backwaters are critical to alewife spawning because the eggs require >5 mg/l DO (Funderburk et al. 1991) (Table 2.4). During their spawning migration, anadromous fish actively avoid waters with low DO and extremely high turbidity (Steel 1991).

Table 2.6. Spawning seasons for coastal fish and invertebrate species occurring in North Carolina that broadcast planktonic or semidemersal eggs. [Sources: USFWS species profiles (see literature cited: reference titles beginning with Species life histories and Environmental Requirements), DMF fishery management plans, Funderburk et al. (1991), Pattilo et al. (1997), Luczkovich et al. (1999), NOAA (2001), and DMF (2003a)]

	Winter			Spring			Summer			Fall		
Species	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
ANADROMOUS FISH												
Alewife		■	■	■	■							
American shad			■	■	■	■						
Blueback herring			■	■	■							
Striped bass			■	■	■	■						
ESTUARINE AND INLET SPAWNING AND NURSERY												
Atlantic silversides			▨	▨	▨	▨						
Bay anchovy				▨	▨	▨	▨	▨	▨	▨		
Bay scallop			▨	▨					▨	■	■	▨
Blue crab				■	■	■	▨	■	■			
Black drum				▨								
Cobia					▨	▨	▨	▨				
Hard clam					▨	▨	▨	▨	▨	▨		
Inland silversides			▨	▨	▨	▨	▨	▨	▨			
Oyster					▨	▨	▨	▨	▨	▨		
Red drum							▨	▨	▨			
Spotted seatrout				▨	▨	▨	■	▨	▨			
Weakfish				▨	■	■	▨	▨	▨			
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY												
Atlantic croaker	▨	▨	▨	▨	▨				▨	■	▨	▨
Atlantic menhaden	■	▨	▨								▨	■
Brown shrimp		■	■	▨						▨	▨	
Southern flounder	■	■	▨								▨	▨
Spot	■	▨									▨	■
Striped mullet	▨	▨	▨							■	■	▨
White shrimp					▨	■	▨					
MARINE SPAWNING, HIGH SALINITY NURSERY												
Black sea bass	▨	▨	■	■	■	▨						
Bluefish			▨	▨	▨	▨	▨	▨	▨	▨	▨	
Gag		■	■									
Gulf flounder	▨	▨									▨	▨
King mackerel						▨	▨	▨	▨			
Pinfish	▨	▨	▨							▨	▨	▨
Pink shrimp				▨	▨	▨	▨					
Sheepshead			▨	▨	▨							
Spanish mackerel					▨	▨	▨	▨	▨			
Southern kingfish				▨	▨	▨	▨	▨	▨			
Summer flounder	■	▨	▨								▨	■

Black squares indicate peak spawning. **Cross-hatched** squares indicate spawning period.

Table 2.7. Physical spawning and egg development requirements for anadromous fishes inhabiting coastal North Carolina. [Sources: Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998a), USFWS species profiles (see literature cited: reference titles beginning with Species life histories and Environmental Requirements), Wannamaker and Rice (2000), NOAA (2001).]

	Salinity (ppt)		Temperature (C)		Water velocity (cm/s)	Other parameters
Species	Spawning	Egg	Spawning	Egg	Spawning	Egg
Alewife	[S] 0-5	[S] 0-5 [O] 0-2	[S] 12-16	[S] 11-28 [O] 17-21	[O] slow current	[S] Suspended solids <1000 mg/l
American shad	[S] 0-18	[S] 0-18	[S] 11-25	[S] 13.0-26.0	[S] 30-90	
Blueback herring	[S] 0-5	[S] 0-22 [O] 0-2	[S] 14-17	[S] 14-26 [O] 20-24	[O] strong current	[S] Suspended solids <1000 mg/l
Striped bass	[S] 0-5	[S] 0.5-10	[S] 13-24 [O] ~18-22	[S] 12-23	[S] 30.5-500 [O] 100-200	

[S] = Suitable, and [O] = Optimum

The estuarine spawning species are mostly resident forage finfish species that spawn in shallow water during the warmer months (Table 2.6). This group also includes some important shellfish species (e.g., oysters, hard clams, bay scallop) and sportfish (e.g., red drum, weakfish, spotted seatrout, cobia) that spawn in deeper, flowing waters (Luczkovich et al. 1999; Powers and Gaskill 2004). Spawning for oysters, clams, and scallops is triggered primarily by increasing water temperatures during spring and/or decreasing water temperatures in fall (Fay et al. 1983c; Burrell 1986; Eversole 1987). Spotted seatrout, weakfish, and cobia spawn from spring to summer, and red drum in late summer (Table 2.6). The environmental requirements for successful spawning and egg development for estuarine spawners are shown in Table 2.8.

Table 2.8. Water quality requirements for spawning of fish and invertebrates in the estuarine waters of coastal North Carolina. [Source: USFWS species profiles (see literature cited: reference titles beginning with Species life histories and Environmental Requirements), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998a), Wannamaker and Rice (2000), NOAA (2001)]

	Salinity (ppt)		Temperature (C)		Other parameters	
Species	Spawning	Egg	Spawning	Egg	Spawning	Egg
Atlantic silversides		[O] ~30	[S] 14.5-30	[S] 15-30		
Bay anchovy	[S] 0.5 to >30	[S] 0.5 to >30	[S] 11-30	[S] 13-30		
Bay scallop		[S] 18-30	[S] >15 and <30	[O] 15-20	[S] Suspended solids <500 mg/l	
Black drum	[S] 5 to >30	[S] 8.8-34, [O] 23-34	[S] 16-25	[S] 16-20		
Cobia	[S] >30	[S] >30	[S] 21 to >30	[S] 21 to >30		
Hard clam	[S] 18 to >30	[S] 18 to >30	[S] 16-30	[S] 16-30		
Inland silversides	[S] 3.6-31.5	[S] 0-31.5	[S] 15-30	[S] 13-34, [O] 20-25		
Oyster	[S] 5 to >30	[S] 7.5-34, [O] 10-22	[S] 21 to 30	[S] 19-32		
Red drum	[S] 5 to >30	[S] 10-40, [O] 29-32	[S] 21-30	[S] 21-30		
Spotted seatrout	[S] 5 to >30	[S] 15-28, [O] ~28.1	[S] 16-30	[S] 16 to >30, [O] ~28		
Weakfish	[S] 5 to >30	[S] 5 to >30	[S] 16-30	[S] 16-30		

[S] = suitable, [O] = optimum

The marine spawning species generally spawn in locations where prevailing currents will carry their eggs and larvae to nursery areas within estuaries and nearshore ocean waters. Spot, Atlantic croaker, southern flounder, Atlantic menhaden, and striped mullet spawn offshore where they produce planktonic eggs and larvae from fall to late winter (Table 2.6) (Anderson 1958; Epperly and Ross 1986). Their larvae are transported into the estuaries where they settle in nursery areas with low to moderate-salinity. The spawning function of pelagic waters for demersal species is therefore limited to egg dispersal (discussed in Corridor section). The specific time of spawning is determined by coincidence of environmental conditions in the water column (Table 2.9). The other group of marine spawners reproduces at various times, but their nursery habitat is limited to higher salinity areas.

Table 2.9. Water quality requirements for fish spawning in the marine waters of coastal North Carolina. [Source: USFWS species profiles (see literature cited: reference titles beginning with Species life histories and Environmental Requirements), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998a), Wannamaker and Rice (2000), NOAA (2001)]

	Salinity (ppt)		Temperature (C)	
Species	**Spawning**	**Egg**	**Spawning**	**Egg**
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY				
Atlantic croaker	[S] 18 to >30	[S] high salinity	[S] 16-25	[S] 16-25
Atlantic menhaden	[S] 18 to >30	[S] 18 to >30	[S] 5-25	[S] 5-25
Southern flounder	[S] 18 to >30	[S] high salinity	[S] 11-25	[S] 5-30
Spot	[S] >30	[S] 30-35	[S] 16-25	[S] 16-25
Striped mullet	[S] 18 to >30	[S] 28-36.5, [O] 30-33	[S] 16-30	[S] 11 to >30
MARINE SPAWNING, HIGH SALINITY NURSERY				
Black sea bass		[S] Sensitive to		
Bluefish	[S] 18 to >30	[S] 26.6-34.9, [O] >30	[S] 21-25	[S] 16-30
Gulf flounder	[S] >30	[S] high salinity	[S] 16-25	[S] 16-25
Pinfish	[S] 18 to >30	[S] 0-43.8	[S] 16-30	[S] 16-30
Sheepshead	[S] >30	[S] >30	[S] 21-30	[S] 5 to >30
Southern kingfish	[S] >30	[S] >30	[S] 11-25	[S] 16-25
Spanish mackerel	[S] >30	[S] >30	[S] 21 to >30	[S] 21 to >30
Summer flounder	[S] >30	[S] >30	[S] 5-25	[S] 5-25

[S] = suitable, [O] = optimum

Nursery

Open water provides nursery habitat for most planktivorous larvae and many juvenile pelagic species (e.g., bluefish, river herring, menhaden, Spanish mackerel). The value of open water habitat for these species depends on the abundance and timing of planktonic food sources and their coincidence with required environmental conditions needed for growth during this critical time period. Areas that have been designated as Primary, Permanent Secondary, or Special Secondary Nursery Areas by the Marine Fisheries Commission are shown in Map 2.3a-b and total approximately 162,300 acres of coastal waters. Of this total, roughly 80,800 acres are Primary Nursery Areas, 35,000 acres are Permanent Secondary Nursery Areas, and 46,500 acres are Special Secondary Nursery Areas.

Anadromous fish nurseries

Nursery habitat for anadromous fishes is generally downstream from spawning locations but still within the freshwater low-salinity system. Alewife larvae in the Chesapeake Bay moved slightly downstream from spawning areas only where salinities were less than 12 ppt (Fay et al. 1983b). Juvenile alewife and blueback herring in the Potomac River exhibited apparent upstream movement over the four months before emigration. Both species were most abundant in surface waters through September. Juvenile blueback herring remained in the upper portion of the water column during their stay in nursery areas. Juvenile alewife, however, increased in abundance at a depth of 15 feet (4.6 m) and on the bottom for the two months prior to emigration (Warinner et al. 1969).

Juvenile alewife and blueback herring emigrate from freshwater/estuarine nursery areas by November of their first year of life (Burbidge 1974; Kissil 1974; Richkus 1975; O'Neill 1980). Heavy rainfall, high water flow, and sharp declines in water temperature have been found to influence the initiation of migration from nursery areas (Cooper 1961; Kissil 1974; Richkus 1975). The water quality requirements

for anadromous fish larvae and juveniles inhabiting pelagic waters are listed in Table 2.10.

Table 2.10. Larval and juvenile water quality requirements for anadromous fish species inhabiting coastal North Carolina. [Source: USFWS species profiles (see literature cited: reference titles beginning with Species life histories and Environmental Requirements), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998a), Wannamaker and Rice (2000), NOAA (2001)]

Species	Salinity (ppt)		Temperature (C)		Dissolved oxygen (mg/l)	
	Larvae	Juvenile	Larvae	Juveniles	Larvae	Juvenile
Alewife	[S] 0-3	[S] 0-5	[S] 8-31	[S] 10-28	[S] >5.0 mg/l	[S] >3.6
American shad	[S] 0-18	[S] 0-30	[S] 15.5-26.1	[S] 15.6-23.9		
Blueback herring	[S] 0 to 18	[S] 0-2	[S] 14-28	[S] 10-30	[S] >5.0 mg/l	[S] >3.6 mg/l
Striped bass	[S] 1.0-10.5	[S] 0-16	[S] 12-23	[S] 10-27		

[S] = suitable, [O] = optimum

Larval striped bass move downstream from spawning locations in the upper river during summer and early fall, where they inhabit shoal waters less than six feet deep (Funderburk et al. 1991). As the larvae grow into juveniles, they move progressively downstream, where they seem to prefer shallow-water, nearshore areas (Funderburk et al. 1991). During winter, young striped bass may move farther downstream and into deeper water (Fay et al. 1983d; Hill et al. 1989).

Juvenile American shad use the same general nursery areas as river herring, but the young shad prefer deeper pools away from the shoreline and occasionally move into shallow riffles (Funderburk et al. 1991). During summer, juvenile shad migrate from the bottom during the day to the surface at night (Loesch and Kriete 1984). A decrease in temperature during the fall and slight increases in river flow seem to trigger downstream movement of American shad (Funderburk et al. 1991). Nursery area surveys conducted by DMF noted decreased catch of juvenile shad in October on the Cape Fear River, Neuse River, and Albemarle Sound (Winslow 1990).

Low-high salinity nurseries

The interactions of spawning locations, physical processes, environmental factors (salinity and temperature), chemical cues, and habitat preferences are determining factors for the time and place of larval settlement in estuaries (Luckenbach 1985; Peterson et al. 2000c; Brown 2002). The total nursery area for larvae of most estuarine-dependent species extends from the spawning locations to juvenile nursery habitat. For species spawned offshore in winter, the larval (primary) nursery habitat extends from the inlet water column, across primarily inshore-flowing channels, to the upper reaches of estuaries. Survival to the juvenile life stage and beyond is then dependent on the estuarine nursery areas providing the biological, physical, and chemical characteristics needed for growth (Table 2.11).

In the Pamlico Sound, salinity and circulation patterns are the key physical conditions affecting the species composition occurring in juvenile nursery habitat (Noble and Monroe 1991). Low-salinity nurseries include the Pamlico, Pungo, and Neuse rivers, the eastern portion of Albemarle Sound (including Croatan and Roanoke sounds), and the upper Cape Fear estuary. During spring through fall, shallow areas within these systems are dominated by juvenile Atlantic menhaden, striped mullet (Epperly and Ross 1986), silversides, anchovies (Nelson et al. 1991), and demersal species such as Atlantic croaker, brown shrimp, blue crab, and southern flounder (Noble and Monroe 1991).

Table 2.11. Water quality requirements for selected larval and juvenile estuarine fish species inhabiting low – high estuarine nurseries in coastal North Carolina. [Source: USFWS species profiles (see literature cited: reference titles beginning with Species life histories and Environmental Requirements), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998a), Wannamaker and Rice (2000), NOAA (2001)]

	Salinity (ppt)		Temperature (C)		Dissolved oxygen (mg/l)	
Species	Larvae	Juvenile	Larvae	Juveniles	Larvae	Juvenile
ESTUARINE AND INLET SPAWNING AND NURSERY						
Bay anchovy	**[S] 0-15**	**[S] 9-30**	**[S] 15-30**	**[S] 10-30**		
Bay scallop	**[S] 22-35 [O] 25**	[S] 16-30	**[S] 16-30**	[S] 11 to >30		
Black drum	**[S] 0-36**	[S] 0-80 [O] 9-26	**[S] 11-16**	[S] 0 to >30		
Blue crab	**[S] >20**	[S] 2-21	**[S] 16-30**	[S] 16-30		
Cobia	**[S] 18 to >30**	**[S] 18 to >30**	**[S] 21 to >30**	**[S] 16 to >30**		
Grass shrimp	**[S] 15-46 [O] 20-25**	[S] 0-55 [O] 2-36		[S] 16 to >30		
Hard clam	**[S] 20-33 [O] 27-28**	[S] 12-33 [O] 22-28	**[S] 11 to >30**	[S] 0 to >30		
Inland silversides	**[S] 0-30 [O] 2-8**	**[S] 0-34.5**	**[S] 21-30**	**[S] 5-33 [O] 22-26.5**		**[S] >1.7**
Mummichog	**[S] 0 to >30**	[S] 0 to >30	**[S] 11-30**	[S] 5-30		[S] >1
Oyster	**[S] 12-27**	[S] 12-27	**[S] 19-32**	[S] 0 to >30		
Red drum	**[S] 8-36.4 [O] 20-40**	[S] 0-45 [O] >20	**[S] 16 to >30**	[S] 0 to >30	**[S] >1.8**	[S] 5.2-8.4
Spotted seatrout	**[S] 8-40 [O] 20-35**	[S] 0-48 [O] 8-25	**5 to >30**	[S] 5 to >30 [O] >28	**[S] >4**	
Weakfish	**[S] 5 to >30**	[O] 2-11	**[S] 11-30**	[S] 5 to >30		
MARINE SPAWNING AND LOW-HIGH SALINITY NURSERY						
Atlantic croaker	**[S] 1-21**	[S] 0-36.7 [O] 10-20	**[S] 11 to 25**	[S] 0.6-38		[S] >3-4
Atlantic menhaden	**[S] 1/2 to >30**	**[S] 0 to >30**	**[S] 0 to >30**	**[S] 0 to >30**		
Brown shrimp	**[S] 24-36**	[S] 0-45 [O] 10-20	**[S] 21 to >30**	[S] 0 to >30		
Southern flounder	**[S] 10-30**	[S] 2-60 [O] 2-37	**[S] 0-30**	[S] 0 to >30		[S] >3.7
Spot	**[S] 6-35 [O] 30-35**	[S] 0-36.2 [O] >10	**[S] 5-25**	[S] 0 to >30		
Striped mullet	**[S] 16-36.5 [O] 26-33**	**[S] 0-75 [O] 20-28**	**[S] 16-30**	**[S] 5 to >30**	**[S] ~4**	**[S] <4**
White shrimp	**[S] 0.4-37.4**	[S] 0.3-41 [O] <10	**[S] 11-30**	[S] 5 to >30		

Bold signifies life stage with pelagic orientation. [S] = suitable, [O] = optimum

Moderate-salinity areas include the bays and open waters of Pamlico Sound. In addition to juvenile species present in lower salinity areas, spotted seatrout, weakfish, silver perch, and red drum are also abundant in these moderate-salinity estuaries (Noble and Monroe 1991). Young weakfish and silver perch tend to occupy deeper waters of the moderate and high-salinity zones, while young blue crabs and other demersal species prefer shallow areas (Epperly and Ross 1986). There seem to be little or no data on the depth distribution for juvenile spotted seatrout in North Carolina. However, information from the Gulf coast suggests that the species prefers shallow, sheltered waters (Blanchet et al. 2001). The most common characteristics of water bodies supporting juvenile red drum in North Carolina are water depth (<16 feet or <5 m) and relative wind protection (Ross and Stevens 1992).

Different species arrive in nursery areas at different times of the year and remain for variable periods. For example, juvenile spot begin entering nursery areas in February (Steel 1991). Postlarval Atlantic croaker arrive over an extended period from August to May, with peak recruitment during winter and early spring

(Purvis 1976). Similar to Atlantic croaker, postlarval striped mullet enter low-salinity nurseries primarily in winter (Nelson et al. 1991). Menhaden postlarvae arrive in low-moderate salinity nurseries from February to June (Purvis 1976), whereas juvenile anchovies and silversides are generally year-long residents (Nelson et al. 1991). Juvenile brown shrimp are most abundant in moderate-salinity nurseries during spring to early fall (Nelson et al. 1991), migrating to higher salinity areas as they grow larger. By late fall, many of these nonresident estuarine fish migrate to the ocean or to deeper regions of the estuary to overwinter (Epperly and Ross 1986).

High-salinity nurseries

High-salinity nurseries (>18 ppt) include the eastern side of Pamlico Sound, Core and Bogue sounds, the mouth of the Cape Fear River, and the southern coastal estuaries. The dominant juvenile species in shallow waters of the high-salinity zone include pinfish, pink shrimp, black sea bass, gag, pigfish, red drum, gulf flounder, and summer flounder (Noble and Monroe 1991). Juvenile spot, brown shrimp, striped mullet, and southern flounder are also abundant in high-salinity estuaries (Epperly and Ross 1986), and juvenile red drum reach their highest abundance in this salinity zone (Nelson et al. 1991). With the exception of summer flounder (Powell and Schwartz 1977), these high-salinity species prefer protected, shallow waters over deeper areas. However, young Spanish mackerel, bluefish, and cobia prefer deeper, more open waters (NOAA 2001). The water quality requirements for larvae and juvenile species inhabiting high-salinity nurseries are listed in Table 2.12. As with juveniles in lower salinity areas, the timing of juvenile arrival in high-salinity nurseries depends on their preceding spawning conditions. Bluefish begin spawning in March, and their young become abundant in Bogue Sound (a high-salinity estuary) around mid-May (Nelson et al. 1991). Juvenile pinfish spawned offshore in winter become abundant in Bogue Sound by late March, and juvenile sheepshead spawned later in winter and early spring become abundant in Bogue Sound by April (Nelson et al. 1991). Spanish mackerel appear (although rarely) in Bogue Sound in mid-May (Nelson et al. 1991).

Table 2.12. Water quality requirements of selected larval and juvenile coastal estuarine fish species inhabiting high-salinity nurseries in coastal North Carolina. [Source: USFWS species profiles (see literature cited: reference titles beginning with Species life histories and Environmental Requirements), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998a), Wannamaker and Rice (2000), NOAA (2001)]

	Salinity (ppt)		**Temperature (C)**		**Dissolved oxygen (mg/l)**	
Species	Larvae	Juvenile	Larvae	Juveniles	Larvae	Juvenile
Black sea bass	**[S] 30-35**	[S] 8-38 [O] >18		[S] 5.6-30.4		
Bluefish	**[S] 26.7-38 [O] ~33**	**[S] 8-36.2**	**[S] 16-30**	**[S] 16-30**		**[S] >3-4**
Florida pompano	**[S] 31.2-37.7**	[S] 9.3-36.7, [O] >20		[S] 11 to >30		
Gulf flounder	**[S] >21**	[S] 6-35 [O] >20	**[S] 16-25**	[S] 5 to >30		
Pinfish	**[S] 0-43.8**	[S] 0-43.8 [O] >4	**[S] 16-30**	[S] 5 to >30		
Pink shrimp	**[S] 12-43**	[S] <1-47 [O] >20	**[S] 21-30**	[S] 0 to >30		
Sheepshead	**[S] 5-24.9**	[S] 0.3-43.8	**[S] 21-30**	[S] 21-30		
Spanish mackerel	**[S] 28-37.4**	**[S] 0.2-37 [O] >10**	**[S] 16-30**	**[S] 11 to >30**		
Summer flounder	**[S] 1/2 to >30**	[S] 0 to >30	**[S] 0 to >30**	[S] 0 to >30		
Southern kingfish	**[S] 5 to >30**	[S] 1/2 to >30	**[S] 11 to >30**	[S] 11 to >30		

Bold signifies life stages with a pelagic orientation. [S] = suitable, [O] = optimum

Data from the Estuarine Trawl Survey indicate that the diversity of juvenile species found in designated primary nursery areas is somewhat larger in waters north of Cape Lookout than south of Cape Lookout. From 1990 to 2002, an average of 68 species was collected from core sampling stations north of Cape Lookout during the months of May and June. During the same time span, an average of 55 species was collected south of Cape Lookout (DMF, unpub. data). The greater diversity in northern waters may be due to the larger variation in salinity regimes or its location at a major transition point for species distribution. North of the cape, the total number of observed species generally changed by less than 10 species from year to year. The number of species collected was lowest in 1992 (49 species) and highest in 1998 (83 species). Annual changes in observed species diversity south of Cape Lookout also appear to be relatively consistent (45 and 49 species were collected in 1999 and 2001, respectively).

Bluefish, Florida pompano and Gulf kingfish use the surf zone and nearshore ocean waters as a nursery (Hackney et al. 1996). Juveniles of these species tend to stay in one area and use the surf zone for an extended time (>25 days during the summer months) (Ross and Lancaster 1996). Some fish, such as anchovies and king mackerel, rely on the nearshore boundaries of ocean water masses as nursery habitats (SAFMC 1998a). Juveniles of other estuarine species, such as red drum, Spanish mackerel, bluefish, and black sea bass, use the surf zone and nearshore waters seasonally while migrating between estuarine and ocean waters (Godcharles and Murphy 1986; DMF 2000a). Pelagic species that use nearshore ocean waters as a nursery to some extent include butterfish, pinfish, striped anchovy, striped mullet, and Atlantic thread herring (F. Rohde, DMF, pers. com., 2001). The major recruitment period for juvenile fish to surf zone nurseries is late spring through early summer.

Foraging

The primary food sources abundant in open waters are decayed plant material (detritus), phytoplankton, and zooplankton. Most fish, during the larval stage in particular, consume plankton at some point in their life cycle. Of the 40 species listed in Table 2.3, nearly all larval stages eat phytoplankton or zooplankton. Resuspended benthic microalgae are also an important source of food.[3] The diet of juveniles and adults includes zooplankton (the relatively most common component), detritus, or phytoplankton (the least common). In addition, pelagic fish may consume benthic copepods, mysids, and amphipods as they rise through the water column at night (P. Peterson, UNC-IMS, pers. com., 2003). Some adult fish also forage on other fish. Overall, about 60% of juvenile species and 50% of adult species listed in Table 2.3 eat detritus, phytoplankton, zooplankton, or fish eggs/larvae (NOAA 2001).

In low-salinity estuaries and riverine systems, tributaries are the dominant source of water inputs. Because of this, the foundation of the food chain is typically incoming detritus from the watershed (Fairbanks 1963). Detritus comprises a large portion of the diet of small animals in the water column and on the bottom; these animals are in turn eaten by larger organisms. Estuarine and riverine fish can be characterized as omnivores and opportunistic feeders. Many fish, including the anadromous species, shift their food preferences as they grow. Most of the prey species important to finfish live in the water column. Some of the pelagic estuarine fish that feed on other fish in the water column include weakfish, bluefish, Spanish mackerel, and cobia (NOAA 2001).

Within an estuary, menhaden, anchovy, silversides, striped mullet, and other pelagic species use suspended organic matter exported from the adjacent marshes, SAV, and oyster reefs without physically occupying these structured bottom habitats (SAFMC 1998a). The relative contributions of detritus and phytoplankton between the estuarine and nearshore ocean ecosystem are demonstrated by the foraging behavior of Atlantic menhaden. Lewis and Peters (1994) confirmed that the dominant food source for menhaden was detritus in shallow, estuarine systems, but phytoplankton in coastal waters.

[3] Refer to the soft bottom section for more information on how soft bottom habitat contributes to water column productivity through benthic-pelagic cycling.

A large number of fish inhabits the marine water column as adults. Coastal pelagics, highly migratory species, and anadromous fish species are dependent on the water column for adequate foraging (Manooch and Hogarth 1983). The boundaries of water masses (coastal fronts) in the nearshore ocean are favorite foraging areas for mackerel and dolphin (SAFMC 1998a). King and Spanish mackerel feed on baitfish that congregate seasonally on shoals and natural and artificial reefs. National Marine Fisheries Service (SAFMC 1998a) has designated the cape shoals of North Carolina as Habitat Areas of Particular Concern (HAPC) for both mackerels. Anadromous species such as shad, river herring, and striped bass utilize the cape shoals as a staging area for migration along the coast. Large aggregations of striped bass have been documented, in the northern, nearshore coastal area of the state during winter months, feeding and resting prior to initiation of an extensive northward spawning migration (Holland and Yelverton 1973; Laney et al. 1999). This wintering ground is shared by the Chesapeake, Hudson, and Roanoke/Albemarle striped bass stocks, and is therefore important to the entire Atlantic coast population (Benton 1992). The water column off the Outer Banks during winter supports an abundance of anchovies and menhaden, weakfish and other sciaenids, on which the striped bass feed. Laney et al. (1999) considered the existence of an area with such abundant food sources to be critical for building energy reserves for successful migration and reproduction of striped bass.

Refuge

The water column provides a basic, but relatively minor, function as refuge for adult finfish and invertebrates. However, the water column does provide some indirect protection for forage species that need unobstructed, open water for protective schooling behavior. For example, silversides can create such dense schools that DO concentrations are low enough to repel predators (Fay et al. 1983a). Other areas of low DO can provide refuge for prey species whose predators are less tolerant of low DO. For example, copepods and zooplankton have a high tolerance for low DO, which could impact the food web in areas where the small invertebrates use low DO areas for refuge (Breitburg et al. 1997; Keister et al. 2000). Large expanses of open water can also provide protection for forage species by reducing their encounters with predators. Turbidity in the water column can provide refuge for prey species from visual predation (Bruton 1985) (refer to Light and water clarity section above). For example, bay anchovy may be attracted to more turbid areas for the refuge it provides (Livingston 1975). Snags from woody debris or overhanging branches extending from the shoreline provide excellent refuge for fish.

Deep water provides an important refuge from birds that feed in shallow water and protection from colder surface temperatures during winter. Deep, open-water habitats also provide refuge for fish and invertebrates during low tide (Ayvasian et al. 1992). Floating aquatic plants in fresh water such as duckweed may provide refuge for some open water fish. The value of floating plants has been evaluated in marine systems, where *Sargassum* floating in the water column supports a diverse assemblage of marine organisms, including at least 145 species of invertebrates, 100 species of fish, four species of marine turtles, and numerous marine birds (SAFMC 1998a). *Sargassum* is concentrated as small patches, large rafts, or weedlines at the convergence of water masses in the coastal ocean, such as those found along "tide lines" near coastal inlets. The greatest concentrations of *Sargassum* patches are found in the Sargasso Sea and on the outer continental shelf of the South Atlantic, although they can be pushed into nearshore waters by winds and currents. Large pelagic adult fish such as dolphin and sailfish feed on the small prey in and around *Sargassum*. This behavior prompts sport fishermen to target *Sargassum* patches.

Areas within the water column that have been found to have a particularly important ecological role or function include inlets, shallow nursery areas, and the nearshore surf zone. *These areas and others should be considered for designation as Strategic Habitat Areas*.

2.3. STATUS AND TRENDS

In North Carolina, news of massive fish kills, increasing events of oxygen depletion, and harmful algal blooms caused widespread concern over water quality and fisheries between the late 1980s and late 1990s. The catastrophic events that made news headlines have abated, but the concern over coastal water quality has not disappeared. There are many indications from a variety of sources that the nation's overall water quality is becoming increasingly degraded over time (EPA 2002c; Heinz Center 2002). In a recent EPA report on national water quality, using data through 2000, more than one third of the surveyed rivers and one half of all lakes and estuaries were too polluted for swimming or fishing (EPA 2002c; <http://www.epa.gov/305b/>, 2003). From 1998 to 2000, the percent of polluted streams increased from 35% to 39% and the percent of polluted estuaries increased from 44% to 51%.

This section briefly describes ongoing water quality and fishery monitoring programs that help determine the status and trends of water column habitat in North Carolina. Status and trends are described in terms of physical and chemical conditions (such as salinity and the presence of nutrients) and fisheries associated with the open water subsystem of water column (e.g., bluefish, Atlantic menhaden).[4]

Physical and chemical environment

Although water quality monitoring data are abundant for North Carolina (Appendix J), differences in sampling methodology, such as duration, magnitude, and parameters studied, complicate comparisons within and among river basins over time. However, information obtained from ongoing state and federal programs allows for some indirect evaluations. At the coast-wide level, water quality evaluations are conducted by DWQ and USGS. Detailed information on water quality within specific coastal river basins is available from DWQ's basinwide water quality plans (<http://h2o.enr.state.nc.us/basinwide/index.html>, 2004).

Statewide and regional water quality monitoring

The status of water quality conditions in North Carolina's coastal waters, as well as the probable causes of water quality problems, is determined primarily by DWQ's use support assessments. Water quality data are collected and summarized by river basin on five-year cycles. The information is used to assess whether waters are supporting their designated use (Use Support). Surface waters are assigned a use support status based on assessment of DWQ's biological sampling (benthic macroinvertebrates and fish); chemical and physical data from surface water monitoring; lake monitoring data; shellfish sanitation surveys; and other information. Impaired waters do not meet one or more water quality standards or some other criterion. If data are inconclusive for a determination of use support, the water body is not rated. Likewise, if no data are available, the water use support status is "no data."

Because of changes in methodology and in EPA requirements for assessing use support and improvements in analytical methodologies, current use support ratings cannot be directly compared to previous assessments, and trends cannot be readily identified. Division of Water Quality use support assessments give a snapshot of recent water quality conditions and can be used to determine where further studies or different management strategies are needed (DWQ 2000a). The DWQ Use Support status of water bodies is referred to throughout this document as a general indicator of the current condition of some North Carolina coastal waters.

The DWQ use support information reported in this document is taken from the 1998-1999 305(b) report (DWQ 2000a). In this report only one overall use support rating was given for individual water bodies. However, beginning with the 2000 Roanoke River Basin Plan, use support ratings are separated into six categories where applicable. Because of the rotation of river basin plan development, not all river basins

[4] Further information on threats and specific trends in water quality parameters is discussed in the threats section.

have been assessed with this different methodology. Therefore the 2000 305(b) report was used in the CHPP to briefly summarize and compare the general condition of all coastal river basins at one time period. Water quality data will be updated when the CHPP is updated.

The U.S. Geological Survey's National Water-Quality Assessment (NAWQA) was established in 1991 to evaluate the condition of the Nation's estuaries. The Albemarle-Pamlico Study Unit was one of 20 study areas evaluated nationwide. Data for the Albemarle-Pamlico study unit provide an assessment of water quality within each study unit by analysis of historical (pre-1992) and current (1992-95) water quality information. Surface water samples collected from the Coastal Plain and Piedmont and ground-water samples from the Coastal Plain of the Albemarle-Pamlico drainage area were analyzed to characterize current water quality conditions in the basin and identify potential problems in the study area. Because of potential human health and environmental implications, nutrients (nitrogen, ammonia, and phosphorus) and pesticides were the primary focus of the NAWQA effort (refer to Threats section). The study found that, although the water quality conditions tended to be more degraded than the national average, the fish communities were less degraded than the national average. This inconsistency could indicate that inappropriate measures were used to calculate a national fish community index, fish communities in the North Carolina study areas were relatively tolerant to water quality degradation, or there were flaws in the water quality testing.

Freshwater and estuarine water quality

As of 2002, surface water quality monitoring stations for freshwater areas within the CHPP area include approximately 145 DWQ ambient stations, 104 USGS stream gauges, 91 NAWQA stations, and 41 APNEP Citizen's Water Quality Monitoring Stations (Table 2.13, Map 2.8). Based on total watershed land areas, the mostly heavily sampled freshwater areas are located in the Neuse, Tar-Pamlico, and Cape Fear management units.

Table 2.14 shows the extent to which North Carolina's coastal rivers are able to support their intended uses. Of the total 15,771 freshwater stream miles in coastal river basins, 12,456 miles (94%) were rated by DWQ during 1995-1999. Of the 94% that were rated, 89% were fully supporting their intended uses; seven percent of streams were partially supporting and 1% were not supporting (DWQ 2000a). Current Use Support Assessments by DWQ do not use the "partially supporting" category. Of all monitored and evaluated streams, the river basin with the lowest percentage of fully supporting streams was the Chowan (42%). However, only about half of the stream waters were evaluated in the Chowan river basin primarily because of problems evaluating swamp waters. Recent refinements in the classifications of swamp waters in the Chowan River basin suggest less impairment (DWQ 2002b).[5]

Use-support evaluations in estuaries are based on 119 DWQ ambient stations, nine USGS stations, 31 Citizen's Water Quality Monitoring Stations, and other information sources (discussed below in Threats section). The typical coverage of monitoring stations in estuarine systems is somewhat less than in freshwater streams, particularly in Pamlico Sound, which has only five monitoring stations (Table 2.13). However, it is noteworthy that there are 1,263 DEH bacterial contamination-monitoring stations, which are often the primary basis for use-support ratings in estuaries (P. Fowler, DEH, pers. com., 2002). These DEH stations could provide a more balanced picture of coastal water quality than the lack of estuarine monitoring stations implies (to the degree that fecal coliform contamination indicated other forms of degradation). *There is a need to coordinate and enhance water quality, physical habitat, and fisheries resource monitoring efforts by DWQ, DMF, WRC, USFWS, USGS, NMFS, DEH, and others to determine status and trends of coastal waters and resources. There should also be concurrent efforts to provide a more thorough analysis of existing water quality data at multiple spatial and temporal scales.*

[5] Sources of impairment are discussed in the Threats section.

Table 2.13. Number of freshwater and estuarine surface water quality monitoring stations in North Carolina coastal drainages (as of 2002). The limit of estuarine waters was depicted using the spatial component of the salinity zone data presented in Table 2.2.

	Number of stations (freshwater/estuarine)[1]						TOTALS	
		USGS						
Management unit	DWQ ambient stations	Stream gauge	Water quality	Gauge + water quality	APNEP Citizens monitoring sites	Other[2]	freshwater stations	estuarine stations
Albemarle	1/12	1/0	0/0	2/2	2/20	0/X	12	37+
Chowan	11/3	2/0	0/0	0/0	12/1	X/0	34+	4
Roanoke	17/2	17/1	1/0	3/1	1/0	X/0	52+	4
Tar-Pamlico	20/26	14/0	0/0	0/0	17/5	0/X	67	31+
Pamlico Sound	0/3	0/0	0/0	0/0	0/2	0/X	0	5+
Neuse	30/25	32/1	0/2	3/1	9/17	0/X	117	64+
Cape Fear	61/4	37/0	0/0	0/0	0/0	29/24	127	28
Core/Bogue	0/12	0/0	0/0	0/0	0/10	0/X	0	22+
New/White Oak	3/17	1/0	0/0	0/0	0/1	0/8	5	26
Southern estuaries	2/16	0/0	0/0	0/0	0/0	8/29	2	45
TOTAL	**145/120**	**104/2**	**1/2**	**8/4**	**41/56**	**?**	**387+**	**187+**

[1] = See Appendix H for acronyms

[2] X = number uspecified or unknown, additional programs include:

Dare County Surface Water Monitoring program; ECU Institute of Coastal and Marine Resources stations; Neuse River MODeling and MONitoring Program; DEH microorganism contamination surveys; Discharge coalition monitoring sites; National Water Quality Assessment stations; FerryMon program; NCSU Center for Applied Aquatic Ecology; UNC-W's Lower Cape Fear Program, Tidal Creeks Program and Wilmington Watersheds Programs

Table 2.14. Use Support status for streams in each North Carolina portion of coastal river basins (1995-1999). (Note: DWQ no longer differentiates a "partially supporting" category, so data are not comparable with more recent data.)

		Use Support Totals (Miles)							
DWQ river basin	Total Stream Miles	Fully Supporting	% of rated	Partially Supporting	% of rated	Not Supporting	% of rated	Not Rated	% of total
Cape Fear	6,049	4,296	91	286	6	118	3	1,349	22
Chowan	788	332	72	129	28	0	0	327	41
Neuse	3,440	2,133	82	349	13	109	4	849	25
Pasquotank	478	360	88	45	11	3	1	70	15
Roanoke	2,389	1,974	91	185	9	0	0	230	10
Tar-Pamlico	2,335	1,780	96	78	4	2	0	475	20
White Oak	292	266	96	11	4	0	0	15	5
Total	15,771	11,141	89	1,083	9	232	2	3,315	6

Based on use-support ratings, the water quality of estuaries in North Carolina was considered in overall good condition in 1999 (DWQ 2000a). According to the DWQ 305(b) Report (DWQ 2000a), 96% of North Carolina estuaries were rated as fully supporting, with only 4% rated as partially supporting (Table 2.15). However, several changes in the use support assessment methodology will result in a substantial number of SA waters being downgraded to impaired for shellfish harvesting use support. The only ratings now used are fully supporting or impaired. Conditionally approved waters that in the past were rated as "fully supporting but threatened" or "partially supporting" are now rated as impaired. As an example, from 1995-1999, 10% of the rated waters in the White Oak River basin were classified as

partially supporting and 0% were classified as not supporting for overall use support; whereas in 2001, 24% were rated as impaired for shellfish harvest use support. The increase is primarily attributed to the change in methodology, rather than to additional shellfish closures.

Table 2.15. Use Support status for estuaries in each coastal river basin (1995-1999). (Note: DWQ now evaluates six separate use support rating categories for each river basin and has changed the use support classifications, so data are not comparable with more recent data.)

River Basin	Total acres	Use Support Totals (Acres)						Not Rated	% of total
		Fully Supporting	% of rated	Partially Supporting	% of rated	Not Supporting	% of rated		
Cape Fear	39,200	29,673	76	8,602	22	0	0	0	0
Lumber	4,800	2,178	45	2,622	55	0	0	0	0
Neuse	328,700	296,162	90	32,538	10	0	0	0	0
Pasquotank	868,800	862,813	99	5,987	1	0	0	0	0
Tar-Pamlico	634,000	622,420	99	8,280	1	0	0	3,300	1
White Oak	121,875	109,934	90	11,941	10	0	0	0	0
Total	**1,997,375**	**1,923,180**	**96**	**69,970**	**4**	**0**	**0**	**3,300**	**0**

Ocean water quality

There are a limited number of water quality monitoring stations in North Carolina's ocean waters. Since 2000 the University of North Carolina at Wilmington has maintained eight water quality monitoring stations in Onslow Bay and seven stations in Long Bay through the NOAA-supported Coastal Ocean Research and Monitoring Program (CORMP). There are also four NOAA Coastal-Marine Automated Network (C-MAN) stations in our coastal waters. The C-MAN stations are permanent automated climatic stations that typically record barometric pressure, wind direction, speed and gust, and air temperature. However, some C-MAN stations also measure seawater temperature, water level, wave height, relative humidity, precipitation, salinity, underwater light availability, and visibility. In North Carolina state waters, the only C-MAN station that measures water temperature is located off Cape Hatteras (see <http://www.ndbc.noaa.gov/Maps/Southeast.shtml>, 2003, for list of parameters measured by each C-MAN station). The EPA has three water quality sampling stations off the Outer Banks of North Carolina located approximately five nm off Currituck Beach, Sanderling, and Kitty Hawk. Parameters measured biannually since 1999 include total phosphorus, total nitrogen, chlorophyll *a*, and visibility (G. Gibson, EPA, pers. com., 2001). *To improve our understanding of current conditions in coastal waters, and the effect of estuarine inputs and human activities, water quality monitoring and research on coastal processes in North Carolina's nearshore ocean waters are needed.*

In 1997, the Division of Environmental Health, Shellfish Sanitation Office, began a recreational swimming water quality-monitoring program. The purpose of the program is to test for bacterial contamination (total coliform, fecal coliform, and *E. coli*) to determine safe conditions for swimmers. Bacterial contamination often comes from stormwater discharges along the ocean beaches. There are 33 ocean sampling stations in the northern region, 13 stations in the central region, and 22 in the southern section (Map 2.9a-c). Samples are taken from the surf zone where the public frequently swims. Stations are located near known stormwater outfalls and populated beach communities. In general, the results of the sampling have been within the SB water quality standards (less than geometric mean of 200/100 ml MF fecal coliform). It has been necessary, however, to post temporary precautionary swimming advisories along the coast following heavy rain events because of potential contamination from stormwater discharge onto the beach or into the water.

Fisheries associated with pelagic habitat

Trends in fish abundance may be an indication of changes in water quality. The status of open water fishery species is described in Table 2.3. Because many variables affect fish abundance, trends in stock status do not necessarily indicate a corresponding trend in water quality. The data necessary for evaluating trends in species abundance come from several sources:

- Fisheries-dependent data on commercial catch and effort (beginning in 1994 with the DMF trip ticket program).
- Fisheries-dependent data on commercial catch from fish house samples (since 1972 for many species).
- Creel survey data on recreational catch collected by NOAA (since 1979) and by DMF (since 1987).
- Fisheries-independent data from several coast-wide biological surveys (conducted by DMF from the early 1970s to the present).

The objective of these programs is to obtain biological and fisheries data on economically important fishes for use in fishery management decisions. Long-term trends in length, weight, and age for each stock are analyzed. The data collected provide information on species composition, relative abundance, distribution, migration, and seasonality of various fisheries. In riverine and estuarine waters, sampling focuses on juvenile estuarine and anadromous fish species, although data on adult fishes are collected from several fisheries. In ocean waters, the primary commercial fisheries sampled include the winter trawl (flynet and flounder trawl) and sink net fisheries. Other programs collect information on the snapper-grouper, coastal pelagic, red drum, beach seine and other fisheries, as well as catch and effort data. The information from the sampling programs is used in conjunction with commercial fishery landings data and recreational fishing surveys to evaluate stock status of important fishery species and to prioritize development of state fishery management plans. A stock status report is issued annually by the DMF.

Of at least eleven pelagic species identified in Table 2.3, eight species, comprising eight stocks, were evaluated for fishery status. Of the six stocks whose status was known, one was designated as Overfished, one as Concern, one as Recovering, and three as Viable (DMF 2003a). Specifically, the Albemarle Sound stock of alewife and blueback herring (classified jointly as "river herring" in the stock status report) was listed as Overfished, while the stock of American shad was identified as Concern. Bluefish were the only Recovering stock. Viable stocks included those of Atlantic menhaden, Spanish mackerel, and king mackerel. In summary, half of the pelagic fish stocks evaluated in 2003 were classified as Viable.

<u>DMF Fishery-independent surveys</u>

DMF conducts several monitoring programs to obtain information on the status of fish species. These programs include the estuarine trawl survey, the Pamlico Sound survey, and the juvenile anadromous survey. The estuarine trawl survey is conducted during May and June at 105 core stations in primary nursery areas. The Pamlico Sound survey samples in June and September at 50-52 random grid locations in Pamlico Sound, Pamlico River, and Neuse River. The juvenile anadromous survey, from June to October in western and central Albemarle Sound, includes trawl sampling for juvenile striped bass and seine sampling at 11 core stations for juvenile herring and 19 for striped bass. These surveys collectively provide information on the abundance and diversity of juvenile finfish in North Carolina's estuaries. Juvenile abundance indices (JAIs) are calculated as a standardized measure of catch per unit effort.

Figure 2.4 shows a sharp and consistent decline in blueback herring and a concurrent decline in the commercial catch of river herring beginning around 1986. River herring stocks in the Albemarle Sound Management Area are now considered Overfished and represent a collapsed fishery. The DMF River Herring FMP addressed habitat and water quality issues associated with these species (alewife and

blueback herring). Striped bass (Figure 2.5), in contrast to the river herring, indicate a stock that was Overfished during the early 1970s, but is now rapidly recovering as a result of improved management. As a result, both the juvenile abundance index and the commercial catch are increasing. It is important to note that quotas and other fishery management restrictions are limiting the annual commercial landings for both fisheries.

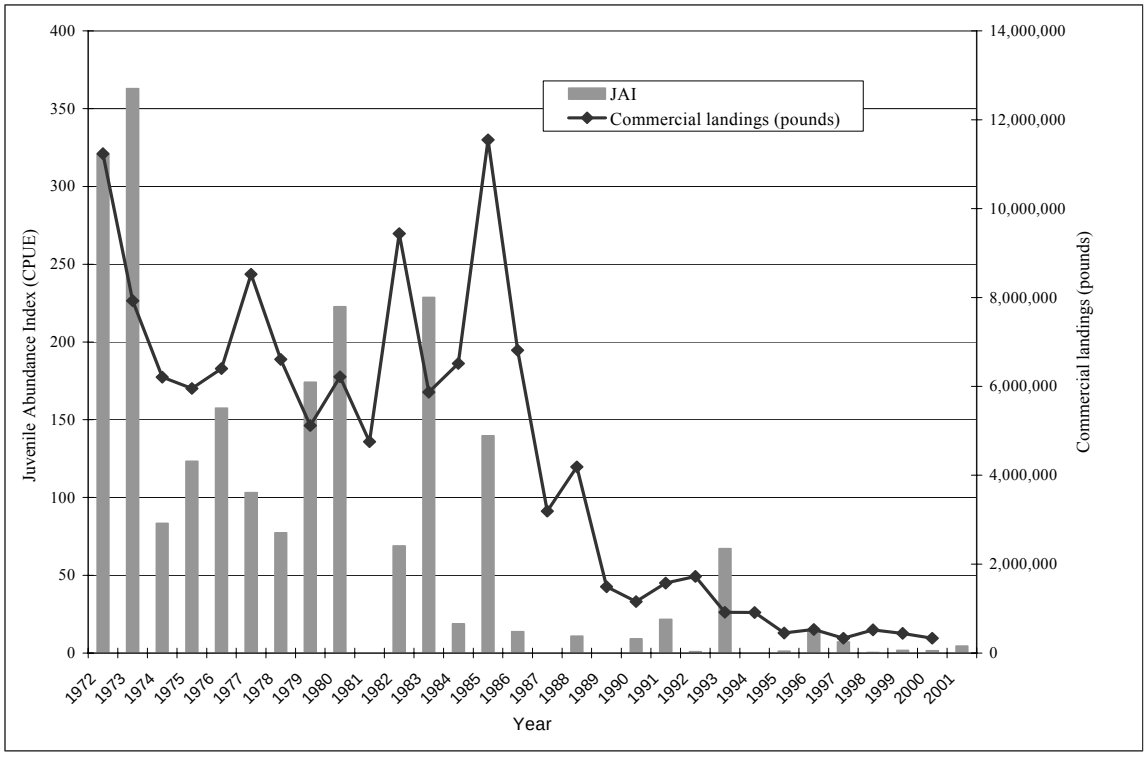


Figure 2.4. Annual North Carolina Division of Marine Fisheries juvenile abundance indices (seine survey) for blueback herring in the Albemarle Sound Management Area and total commercial landings of river herring (alewife and blueback herring), 1972-2001.

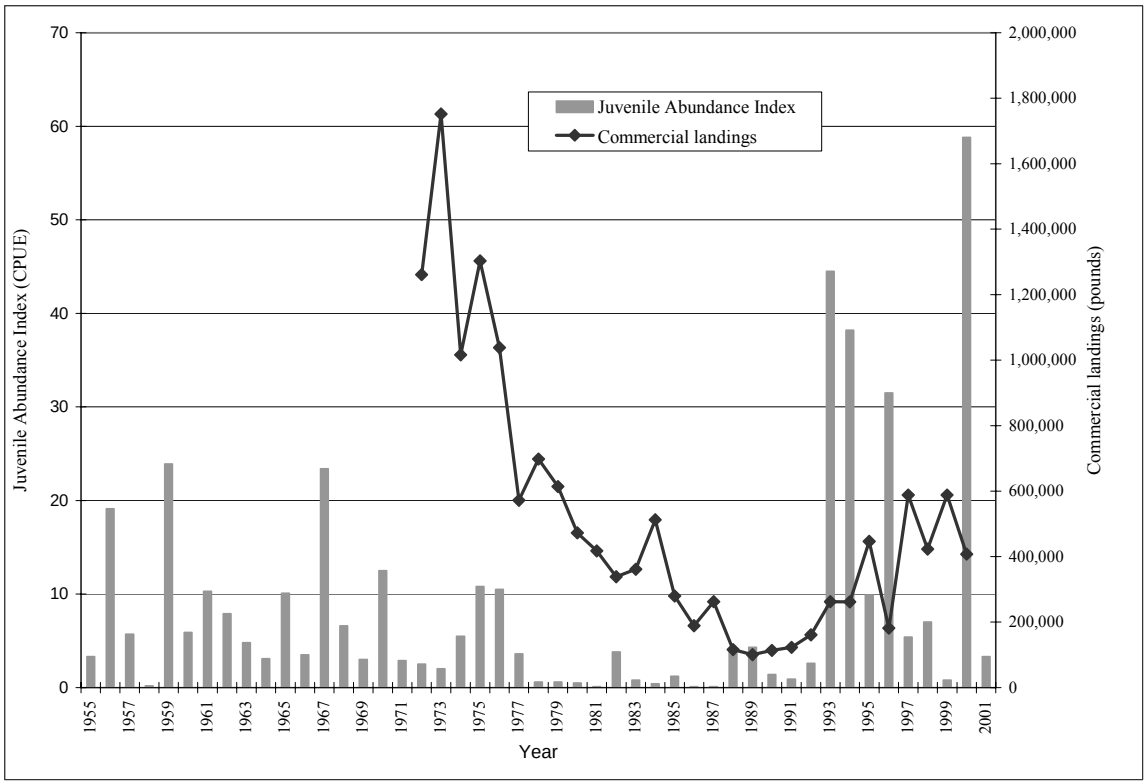


Figure 2.5. Annual DMF juvenile abundance indices of striped bass in the Albemarle Sound Management Area (1972-2001) and total commercial landings of striped bass (1972-2000).

In summary, only half of the predominantly pelagic stocks listed in Table 2.3 are considered Viable or Recovering. Of the stocks that have a status of Concern or Overfished, the majority are anadromous. Of those anadromous species, river herring (alewife and blueback herring) are the most threatened. For river herring, the suspected causes of stock reductions were both overfishing and degradation of water quality and quantity (DMF 2000c). The only estuarine species of concern was striped mullet. However, potential overfishing (not habitat degradation) is responsible for their concern status (R. Wong, DMF, pers. com., 2002). Juvenile abundance indices of common estuarine species do not indicate clear trends of increasing or decreasing abundance, except for pinfish, which had a large increase in the past few years. However, more apparent trends may be found analyzing data at the watershed or waterbody level (reserved for Management Unit plans).[6]

2.4. THREATS AND MANAGEMENT NEEDS

Human activities can negatively impact fish communities by altering naturally occurring water quality or flow conditions. Hydrological modifications—such as dam and culvert construction; surface water withdrawal; channelization; channel modification; streambank modification; and shoreline erosion—can obstruct fish passage or affect flow and quality of the water column. Pollutant loading from point or nonpoint sources affects the quality of the water column. Drainage projects and point source discharges can also affect the natural distribution and movement of water.

Excessive inputs of nutrients, bacteria, sediment, or toxins, from point or nonpoint sources alike, can lead to visible signs of habitat degradation, including algal blooms, hypoxia, and fish kills. Likewise,

[6] Trends in the condition of the water column will be discussed in the Threats section.

evidence of the diminished capacity and relative quality of fishery resources is indicated by increased disease incidence, decreased recruitment, lowered reproductive success, or reduced abundance of fish and invertebrates. Threats are organized and discussed in this section by hydrological modifications, water quality degradation, introduced species, and other threats.

The susceptibility of individual fish or invertebrates to threats in the water column will vary by species, lifestage, location, diet, residency, tolerance to change, and the cumulative impact from exposure to multiple stressors. The condition of the water column can affect all other coastal fish habitats. Therefore, identification and evaluation of threats to the water column will aid in protecting coastal fish habitats.

Hydrological modifications

The ability of various lifestages of fish species to move unobstructed through the aquatic system is a critical component of a healthy water column habitat. Physical structures not only obstruct fish passage but can also alter water flow. The natural flow patterns (volume and timing) of rivers or streams are important mechanisms for maintaining adequate oxygen, salinity, and temperature levels and for dissipating wastes throughout the watershed, including the downstream estuary (DMF 2003b). Unobstructed passage and natural flow patterns are crucial to anadromous species, since they travel great distances and their migration patterns are closely linked to flow conditions. Adult anadromous fish migrating upstream to spawning grounds are generally attracted to higher flows that typically occur in North Carolina rivers in late winter and early spring.[7] Flow pattern alterations, through surface water withdrawal, reservoir storage, or drainage/discharge, affect habitat conditions for anadromous and estuarine fish. Construction of dams, reservoirs, road fill, culverts, bridges, and shoreline stabilization structures can alter flow characteristics or obstruct fish passage. In addition, ground water withdrawals and channelization can alter natural flow patterns.

Flow regulation

Dams/impoundments

Dams have been constructed throughout N.C. to provide flood control, hydropower generation, water supply, irrigation, navigation, recreation, fish and wildlife ponds, debris and sediment control, and fire protection (DLR, unpub. data). The location of dams is shown in Map 2.10. The majority of dams in North Carolina occur in the upstream portions of estuaries, rivers, and streams. In the coastal plain, dams are most abundant in the upper reaches of the Cape Fear, Neuse, Tar-Pamlico, Roanoke, and Chowan rivers (Table 2.16). These structures primarily impact striped bass, river herring, sturgeon, and shad, migrating upstream to spawn, and the catadromous American eel migrating downstream to spawn. These species often migrate hundreds of miles to reach their traditional spawning sites in rivers, streams, and swamps. Eggs and larvae are less likely to survive if passage to their historical spawning areas is obstructed by dams or other alterations (Moser and Terra 1999). The level of impact on spawning and recruitment depends on the location of the dam, spawning grounds, and species requirements. Large dams located in the main stem of coastal rivers primarily impact striped bass, shortnose sturgeon, and Atlantic sturgeon, which spawn in these areas far upstream. Small millpond dams located along tributaries and narrow streams are more problematic for blueback herring and alewife (river herring), which spawn in the shallow upper reaches of streams or swamp waters. Movements of estuarine-dependent pelagic species, such as menhaden, and coastal pelagics, such as Spanish mackerel, are generally not impeded by dams, although water quality and flow characteristics can be affected in ways that impact them.

[7] Refer to Ecological Role and Function section for more on the importance of flow in anadromous fish spawning.

Table 2.16. Miles of stream that are partially or totally obstructed by dams, pipe culverts, or reinforced concrete box culverts, by Management Unit. (Source: N.C. Department of Transportation – culverts; N.C. Division of Water Resources – dams)

Management unit	Dams	Pipe culverts	Reinforced concrete box culverts
Cape Fear	1160	324	340
Neuse	596	154	219
Roanoke	445	101	78
Tar-Pamlico	241	83	124
Chowan	21	32	20
Southern estuaries	4	8	4
New-White Oak	4	19	8
Core-Bogue	1	8	0
Pamlico	1	5	2
Albemarle	0	27	16
Total	**2473**	**761**	**811**

Recently, efforts have been made to restore spawning habitat for anadromous species by removing dams that are no longer necessary. In 1997, the Quaker Neck Dam on the Neuse River near Goldsboro was removed, making an additional 74 miles of historic spawning habitat available upstream to the Milburnie Dam near Raleigh. Similarly, the Rains Mill Dam on the Little River in Johnston County was removed in 1999, opening an additional 49 miles of spawning grounds for anadromous species. After dam removal, striped bass spawned farther upstream and juvenile American shad used the entire river downstream of the fall line as a nursery area (Hightower and Jackson 2000). Nationwide, about 40 dams have been removed since 1999, and an additional 63 dams in 15 different states are scheduled for removal in 2002. One of these removals is located in a coastal North Carolina drainage, a tributary of Marks Creek in the Neuse River basin (Map 2.10). *This is a positive trend for fish habitat that should be continued*. It is estimated that 30% of the dams in the United States are no longer needed and are more costly to renovate and repair than to remove. Removal has demonstrated almost immediate positive benefits for migratory species (Hightower and Jackson 2000).

Where obstructions cannot be removed, fish passages can be constructed that allow fish to maneuver upstream. In the Chesapeake Bay region, several different types of fish passages are utilized (<http://www.chesapeakebay.net>, 2003). The Denil fishway, which is commonly used in Chesapeake Bay, consists of a series of sloped channels that allow the fish to swim over the dam or obstruction. Wooden baffles are placed at regular intervals within the channels to slow the velocity of the water. There are resting pools between each section of the fishway to conserve the energy of the migrating fish. The necessary slope and length of the fishway are determined by the swimming ability of the predominant species at the site. A fish lift or fish elevator is generally only used at very large obstructions. In this design, a flow of water guides the fish into a large hopper, which then raises the fish over the dam. At the top of the dam, the fish can be released into the river.

In the Cape Fear River, locking procedures were modified and a fishway was installed in 1997 to improve passage of anadromous fish (Appendix K). The U.S. Army Corps of Engineers (COE) has proposed constructing an artificial bypass channel around the lowermost dam (Lock and Dam # 1). The bypass will allow about 10% of the river flow to travel around the dam in a meandering channel that approximates a natural stream (COE 2002). It is not recommended that the dam itself be removed because saltwater intrusion would likely result, impacting the City of Wilmington's water supply. This stream restoration

project should greatly benefit habitat conditions for Atlantic and shortnose sturgeon, American shad, striped bass, American eel, blueback herring, and hickory shad stocks (COE 2002). Following the construction of the bypass channel, it is hoped that Lock and Dam #2 and 3 can be removed. *Restoration efforts through removal or modification of dam structures that impede migration of anadromous fish should remain a high priority to continue in North Carolina, focusing on the lowermost structures in rivers or streams, and advancing upstream. In particular, the Cape Fear system (i.e., Lock and Dam #1) should be a high priority, since striped bass, shortnose sturgeon, and Atlantic sturgeon have not recovered.*[8]

Water withdrawals

Water is withdrawn from surface and ground waters for multiple purposes (Table 2.17). Surface water is withdrawn for industrial uses (such as cooling water for nuclear and fossil fuel power plants), municipal water supply, crop irrigation, and other uses. Thermoelectric power generation accounts for the greatest amount of surface water withdrawals. Excluding thermoelectric use, non-agricultural industrial use accounts for the largest source of water withdrawal from both public water supply and self-supplied surface water. Domestic use is responsible for the second largest amount of water withdrawn. Public water supply systems withdraw primarily surface water (633 mgd) and a lesser amount of ground water (135 mgd).

Table 2.17. Most recent estimate of statewide water use compiled by the USGS in 1995, by type of use, in millions of gallons per day (mgd). (Source: DWR 2001)

Type of use	Self-supplied surface water	Self-supplied ground water	Public water supply (PWS)	Total
Domestic	0	172	332	504
Commercial	0.3	7.3	138	146
Industrial	308	61	193	562
Mining	4.3	11.7	-	16
Irrigation	181	57	-	238
Livestock	207	90	-	297
Thermoelectric	7,417	0.1	0.4	7,417
PWS losses	-	-	105	105
Total	8118	399	769	9,286

Most surface water withdrawals for power plants or water supply are located in fresh water and associated with a dam or reservoir. Although increasing numbers of potable water intakes are being located in the mainstem of coastal plain rivers (e.g., Neuse, Tar), in some large rivers, such as the Cape Fear, there is a considerable amount of water directly withdrawn from the river for industrial use. The quantity of water removed can be large enough to significantly affect river flow patterns below the intake. The impact of the withdrawal may be offset if treated wastewater or cooling water is discharged back into the same river system. Most cooling water is returned in close proximity to its source, reducing the effect on overall water quantity (DWR 2001). Interbasin transfers could result in large permanent flow reductions (DMF 2003b). Hydropower operations impact water flow conditions for anadromous species by severely altering natural discharge patterns over a short time period. For example, flows on the Roanoke River can increase from 2,000 cfs to up to 18,500 cfs within a few hours, causing rapid change in water depth and temperature, and can quickly affect water levels in adjacent floodplain forest (DMF 2003b). Such drastic changes in flow and temperature can have a major effect on spawning and egg development of anadromous species.

[8] Refer to Soft bottom chapter for more information on sturgeon.

Surface water withdrawal for municipal uses will likely become a major issue for future water conservation. Within the North Carolina portion of the Roanoke River basin, where over half of the total water use is currently derived from surface water, estimated water demand in 43 public water systems is projected to increase 55% by 2020 (DWQ 2001c). Similarly, overall demand for water from public sources is forecasted to grow 55%, 70%, and 73% by 2020 for the Tar-Pamlico, Neuse, and Cape Fear River basins, respectively, where surface water presently serves as the primary water supply (DWR 2001). At a minimum, public education is needed to encourage greater voluntary re-use and recycling of water within communities.

The amount of water withdrawn from surface and ground water is tracked through water withdrawal registrations. The Registration of Water Withdrawals and Transfers law (G.S.143-215.22H) requires users who withdraw predetermined amounts of ground and surface water in North Carolina to register annually with the Division of Water Resources (if non-agricultural) or with the Department of Agriculture and Consumer Services (if agricultural) (Table 2.18). Agricultural activities include those "directly related or incidental to the production of crops, fruits, vegetables, ornamental and flowering plants, dairy products, livestock, poultry, and other agricultural products" (G.S.143-215.22H). Because persons or entities who fall below the required use designations are exempt from registration, data obtained from Water Withdrawal Registrations represent fractional estimates of the total water usage.

Table 2.18. Surface and groundwater volumes requiring user registration inside and outside of Central Coastal Plain Capacity Use Area (CCPCUA), North Carolina.

	Gallons of water per day (gpd)	
User type	Inside CCPCUA	Outside CCPCUA
Non-agricultural	> 10,000	≥ 100,000
Agricultural	> 10,000	> 1,000,000

Within the coastal-draining river basins, surface water intakes are permitted in four river basins –Cape Fear, Roanoke, Tar-Pamlico, and Neuse (Table 2.19). The maximum permitted volume of water withdrawal ranges from 73 to 184 million gallons per day (mgd) in the Tar-Pamlico and Neuse, but is more than three times greater in the Cape Fear. The Cape Fear has 27 permitted intakes with a combined maximum flow of 406 mgd. However, these numbers exclude public water supply systems and hydropower facilities. Including public water supply intakes and hydropower facilities, there are at least 33 surface water intakes in the Cape Fear River basin (DWQ, unpub. data; Map 2.11). The North Carolina portion of the Roanoke River and entire Neuse River basin have a similar amount of maximum permitted volume of water withdrawal. Municipal water withdrawals are the largest threat to instream flow in the Cape Fear River. Some of the larger municipalities that receive water from these water intakes include Cary, Apex, Wake County, Fayetteville, and Wilmington. In the Roanoke, withdrawal for power plant use accounts for the majority of the water volume removed. Water withdrawals in the Tar-Pamlico and Neuse river basins are for a mixture of industrial and municipal water supplies. *More research is needed to assess the impact of water withdrawals on water column habitat and fish populations in the affected river basins*.

Table 2.19. Number of surface water intakes and maximum permitted volume of water that can be withdrawn daily (millions of gallons per day) for municipal surface water intake systems in CHPP MUs. (Source: DWR 2001 and DMF 2003b)

CHPP MU	Year of data	Number of surface water intakes	Maximum surface water flow (mgd)
Cape Fear	1997	27	405.90
Roanoke (North Carolina portion)	2000	26	147.08 [1]
Neuse	1997	11	183.70
Tar-Pamlico	1997	6	73.30

[1] This figure excludes public water systems and power generating facilities.

Withdrawal of groundwater from wells can also reduce river flows by reducing subsurface flow into adjacent rivers (Bair 1995; DMF 2003b). Removal of shallow groundwater can be particularly detrimental during low flow periods when subsurface flow is more critical to maintaining baseflow levels. Of the 50 inches of total precipitation per year in this area, it is estimated that approximately 22% enters streams through ground-water seepage, 2% seeps into large rivers and sounds, 10% becomes surface runoff, 66% evaporates, and only 2% percolates into confined aquifers (J. Bales, USGS, pers. com., 2001). These statistics emphasize the significance of ground water seepage in maintaining base flow in streams and the slow process of replenishing aquifers. Eastern North Carolina is experiencing a decline in the quantity of ground water. Between 1989 and 1998 in the Black Creek Aquifer, 10-year reductions in groundwater levels ranged between 3 ft in Greene County and 45 ft in Onslow County. Groundwater levels declined 27 ft decline in Craven County and 22 ft in Beaufort County (J. Bales, USGS, pers. com., 2001). *Assessments of groundwater water supplies in coastal counties should be made to determine what the environmental consequences will be if the increase in water withdrawals continues.*

Effective August 01, 2001, the Environmental Management Commission (EMC) designated 15 coastal counties as the Central Coastal Plain Capacity Use Area (CCPCUA)—Beaufort, Carteret, Craven, Duplin, Edgecombe, Greene, Jones, Lenoir, Martin, Onslow, Pamlico, Pitt, Washington, Wayne, and Wilson—and composed corresponding rules "to protect the long-term productivity of aquifers within the designated area [CCPCUA] and to allow the use of ground water for beneficial uses at rates which do not exceed the recharge rate of the aquifers within the designated area" [15A NCAC 2E .0501]. Specifically, to promote the sustainable use of groundwater, "adverse impacts" to existing aquifers are to be avoided or minimized. Examples of adverse impacts include dewatering (i.e., "when aquifer water levels are depressed below the top of a confined aquifer or water table declines adversely affect the resource"), saltwater encroachment, and land subsidence or sinkhole development [15A NCAC 2E .0502]. Farming- and non-farming-related users of surface water and groundwater within this area must register if they withdraw greater than 10,000 gpd (Table 2.18). Furthermore, in CCPCUA counties, any user of 100,000 gpd or more of groundwater is required to apply for and obtain a withdrawal permit. Quarterly reporting of groundwater withdrawals and monitoring of groundwater levels are then mandatory requirements for permitted users.

Rules also require reductions in withdrawals from the Peedee, Black Creek, Upper Cape Fear, and Lower Cape Fear aquifers, and are being implemented over a 16-year period. One implication is that the demand for high quality surface waters will gradually increase through time. However, permits are not currently required for surface water usage within the CCPCUA. In addition, "intermittent" users are exempted from the groundwater reduction requirements; "intermittent" is defined as "persons who withdraw ground water less than 60 days per calendar year; or who withdraw less than 15 million gallons of ground water in a calendar year; or aquaculture operations licensed under the authority of G.S. 106-761 using water for the initial filling of ponds or refilling of ponds no more frequently than every five years" [15A NCAC 2E .0507]. Although several coastal counties (e.g., Hyde, Tyrrell, Currituck, Brunswick, New Hanover) and adjacent aquifers (e.g., Castle Hayne) are omitted from the designated area, the CCPCUA provides a

potential foundation for comprehensive, regional conservation of aquifers.

Impingement and entrainment

Cooling water intake systems can cause mortality of fish and other aquatic life by pulling organisms into cooling water systems (entrainment) or trapping them on parts of the cooling water intake structure (impingement). Cooling water intake structures transport surface waters to the intake pump where the force of the water passing through the structure can cause the impingement of organisms. The organisms then suffocate because the water current prevents opening of their gill covers, or die from starvation, exhaustion, or descaling (ASMFC 2002). Fish impinged for a short period can survive or experience delayed mortality from the stress. Protected species, such as shortnose sturgeon, sea turtles, or manatees have also been trapped against or within intake structures. Usually only small organisms, including early life stages of fish and invertebrates, can pass through the mesh screens. The early life stages of fish are particularly vulnerable to damage because their soft tissues offer little protection against thermal or mechanical stress (EPA 2002b). Once entrained, organisms can be subjected to physical, thermal, and toxicity stresses. Studies have shown that very large numbers of fish larvae can be entrained through a power plant and that mortality is high, but varies by species and life stage. Entrainment survival studies found that mortality rates ranged from 2% for naked goby larvae to 97% for bay anchovy (ASMFC 2002). The primary concern of cooling water intake structures is the cumulative impact of multiple facilities on fish populations (ASMFC 2002). For example, in the Delaware Bay estuary, which has four power plant facilities, it was estimated that an average of 14.3 million fish/year were impinged and more than 616 million fish/year were entrained (EPA 2002b).

The ASMFC recently formed a Power Plant Panel to conduct a coast-wide assessment of the cumulative impact of power plant impingement and entrainment. The results of this workgroup will provide a method for estimating mortality rates based on loss estimates and power plant data. Also, EPA is developing national standards under section 316(b) of the Clean Water Act for cooling water intake structures to ensure that the location, design, construction, and water capacity reflect the best technology available to minimize adverse environmental impacts. Standards have already been developed for Phase I (new facilities), while Phase II standards for existing electric generating plants using large amounts of cooling water (>50 mgd) are under development. Phase III standards for existing plants that use smaller amounts of water will be developed last. There are 70 surface water intakes for water withdrawals in North Carolina. There are a particularly large number of intakes in the Cape Fear and Roanoke rivers (Table 2.19). In the lower Cape Fear River, a study at the Brunswick Steam Electric Plant found that the combined use of fish diversion structures, fine mesh screens, a fish return system, and flow minimization reduced the number of impinged or entrained larvae and fish by 40–70% (Thompson 2000). The study concluded that the plant operation did not have a significant adverse effect on the fisheries of the Cape Fear Estuary. *Until standards are implemented and effective exclusive technology is available, withdrawals should be reduced as much as possible during and following spawning season in areas known to be used by eggs, larvae, and early juveniles. This would include DMF designated PNAs and anadromous fish spawning and nursery areas that are currently being mapped by DMF staff.*

Status and trends in flow regulation

Of the North Carolina coastal river basins, flows are regulated through a combination of dams, reservoirs, and water withdrawals within the Chowan, Roanoke, Tar-Pamlico, Neuse, and Cape Fear river systems. Flows in the Pasquotank, New, White Oak, and Northeast Cape Fear are generally unregulated. All of these rivers historically supported striped bass and other anadromous fish populations (DMF 2003b). Alteration of natural flow patterns by operation of reservoirs and dams can negatively impact fish species. Water releases in the Roanoke River adversely affect flow conditions needed for some anadromous fish species and lower dissolved oxygen levels (Fay et al. 1983b,d; USFWS, unpub. letter 2001). Among other factors, low oxygen levels have been implicated in the decline of the Albemarle/Roanoke River stock of striped bass as well as in fish kill events (USFWS 1992). Water flow regimes that minimize

impacts to striped bass and other species were recommended in Manooch and Rulifson (1989). Status and trends in flow regulation (DMF 2003b) are detailed in Appendix K.

Efforts should continue to remove or modify the lowermost dams in the Cape Fear, Neuse, Tar-Pamlico, and Chowan rivers, in order to increase spawning habitat available to anadromous fish species. *Additionally, new dam construction should be avoided whenever possible or designed and sited to minimize impacts to anadromous fish use and to maintain appropriate flow conditions. Flow alterations that may significantly change the temporal and spatial features of inflow and circulation that are required for successful spawning of anadromous fish should be prohibited. A process that fully evaluates cumulative impacts from water withdrawals and other hydrological modifications should be developed and implemented.* There are several other options concerning flow regulation, listed in the Striped Bass FMP, which should be implemented (DMF 2003b):

- For free flowing rivers, work with water resources authorities in North Carolina and/or Virginia and South Carolina, as appropriate, to secure commitments for preservation of the unaltered flow regimes.
- For rivers which are presently dammed to such a degree that flow patterns depart significantly from a free flowing condition, require establishment of appropriate flow regimes for striped bass and other anadromous fish spawning and nursery areas, and work with the appropriate regulatory agencies to secure commitments for preservation of such regimes.
- Require water allocation for riverine fish habitat as part of the local water supply planning process and future water allocation processes.

Road fill and culverts

Road construction over rivers, streams, or wetlands often involves blockage of a portion of the original stream. Bridges are the preferred method of crossing over water and wetlands, since they disturb wetlands and obstruct water flow the least. However, bridges can narrow water passages (due to fill placed at the stream edge to support the structure), cause localized erosion, or alter current velocities. Culverts are a common, yet less expensive, alternative to bridges in small water bodies. Depending on the type of culvert and its location, water passages can be partially obstructed. Pipe and box culverts vary in dimensions, but are generally low and narrow passages that reduce light levels in the culverts and constrict water flow. Other concerns are the effects of increased current velocity, erosion around the pipe entrance, vibrations from road traffic, and improper placement of the pipe at height above the natural streambed (Mudre et al. 1985; Clay 1995). Any of these factors may prevent fish from entering the culverts and prevent migration to traditional spawning grounds. However, culvert designs have been improved to minimize impacts from current velocity and erosion (Moser and Terra 1999).

The effect of reduced light from culverts and bridges on river herring migratory behavior was examined in a study conducted in tributaries of Albemarle Sound and in the Neuse, Pamlico, and Cape Fear rivers in 1999 (Moser and Terra 1999). Results showed that river herring preferred to migrate through areas with some ambient lighting during the day, but required only a low amount of light – at least 1.4% of ambient light. Where lighting was less than 1.4% ambient conditions, avoidance was observed. Light measurements in the center of the structures were below this threshold in 6 ft diameter corrugated metal pipes and 6 ft by 6 ft box culverts. Sufficient light was available in 12 ft diameter pipes and bridges more than one meter above the water surface. Light was marginally adequate in bridges less than one meter above the water surface. Light penetrated approximately 10 ft inside the 6 ft diameter culverts. Since the average length of the 6 ft diameter pipes was 54 ft, approximately 30 ft in the center of the pipes was dark. Although culverts may reduce the number of herring passing upstream of the structures, some fish did successfully pass through culverts at night and, in some cases, under low light conditions (<1%) during the day. Culverts and bridge locations in North Carolina are shown in Map 2.12. Table 2.16 summarizes the number of dams and culverts in each CHPP MU.

In 1999, three hurricanes hit North Carolina within a four-week period, causing major flooding in the eastern part of the state. Although the hurricanes were natural events, the magnitude and duration of flooding and the associated human disaster were exacerbated by the extensive man-made modifications to the natural drainage systems (Riggs 2000). Modifications to the drainage system include dams, road blockages, stream channelization, dikes, ditching and draining of secondary floodplains and upland pocosins, and increased impervious surface (reduced infiltration and increased polluted runoff) resulting from urban development (Riggs 2000). In the aftermath of this flooding, it became apparent that culverts also severely slowed drainage pathways.

Because of the observed hydrological impacts, the MFC supported replacement of all temporary stream crossing structures with structures that were "herring friendly", including bridge piling structures and properly designed and situated box culverts. In 2001, an interagency team including staff from DOT, DENR, COE, and other state and federal agencies began meeting to discuss such changes, as well as other changes in permit processing improvements and mitigation. From this effort, the team established an Ecosystem Enhancement Program (EEP), which will manage watershed-based compensatory mitigation for the entire state, incorporating ongoing monitoring and management of mitigation projects, as well as emphasis on resource preservation and restoration of wetlands, streams, and other resources impacted by DOT projects. *Through this process, additional focus on restoring stream flow and fish habitat through the replacement of culverts with bridges should be accelerated. Funding should be allocated for replacing filled channels and streams with "fish friendly" culverts or bridges and upgrading existing culverts to "fish friendly" structures, prioritizing structures that are known to impede anadromous fish migration to spawning grounds, or have been found to be particularly problematic to the natural hydrology of a system.*

Transportation-related activities (e.g., road fill, diversion) have been responsible for altering thousands of stream acres per year, based on 401 water quality certifications (DWQ, unpub. data). The impacts have frequently occurred in headwater streams, which are known to assimilate many times more nitrogen than larger streams within a watershed (Peterson et al. 2001). Using a subset of 426 project records from 1987 to 2003, transportation-related activities accounted for 42% of the total stream distance impacted. The majority of impacts during the 2001/2002 fiscal year were to intermittent (often headwater) streams (WRP 2002). In previous years, the majority of impacts were in piedmont and large urban areas (WRP 2001). Some of the authorized stream impacts were offset by stream restoration. The net distance of stream impacted from 1999 to 2002 was 126,091 linear feet, a very small percentage of total stream mileage in coastal river basins. However, the total stream distance impacted does not address the concentration of impacted stream reaches, which could lead to localized degradation of water column functions for anadromous fish.

Channelization and ditching

Channelization is the deepening and straightening of a natural stream, or dredging of a new channel, to improve drainage of adjacent lands or for navigation (North Carolina Sea Grant 1997). These activities can affect the slope, depth, width, and roughness of the channel, disturbing the dynamic equilibrium of the stream. Channelized streams take up less land and allow adjacent wetlands to be drained and used for agriculture. Channelized streams are often deeper, with more extreme flows, less woody debris, and less variable depth than natural streams. These changes primarily affect smaller species and early life stages that use shallow stream margins, since these areas are reduced with channelization. Water in low slope areas can back up in the channel and overflow the banks during large storm events, allowing some continued function of the floodplain (North Carolina Sea Grant 1997).

Channelization has a number of impacts on the coastal aquatic environment. By removing the meanders of the channel and increasing the slope of the shoreline, water velocities in the altered stream are higher. Higher water velocity results in higher erosional-energy and downcutting of the channel, which in turn

prevents further meandering. Erosion often results in an increased sediment load in the channelized stream, which will be deposited downstream. In many channelized streams in the middle and lower coastal plain, storm flows are confined primarily to the main channel rather than passing through wetlands and achieving some filtration of pollutants and other wetland functions. In addition, the natural woody vegetation along the sides of the stream is often removed in the process of channelization. Consequently, loading and movement of sediment and other nonpoint source pollutants are often greater in channelized sections than natural streams, which can have negative impacts on water quality and therefore fish habitat (White 1996; EPA 2001). Nutrients, particularly nitrogen and phosphorus, may increase with channelization. Elevated water velocities can also deter or prevent movement of adult and juvenile fish. A study in the Tar River, for example, found that high water velocities in channelized sections of a stream prevented the entrance of adult and juvenile herring into those areas (Frankensteen 1976; DMF 2000c). Also, early larval river herring in the tributaries of the Chowan system were found to be highly associated with the stream edge and waters with minimum flow (O'Rear 1983). In addition, the spoil banks created by disposal of spoil along the shoreline prevent fish from accessing sloughs, floodplain forest, and other adjacent wetlands (DMF 2000c).

Due to their typically short length and relatively lower habitat quality, channelized streams generally support fewer fishery resources than unaltered, meandering streams. Several studies have found that the size, number, and species diversity of fish in channelized streams are reduced and the fisheries associated with them are less productive than those associated with unchannelized reaches of streams (Tarplee et al. 1971; Hawkins 1980; Schoof 1980). Pate and Jones (1981) compared nursery areas that were altered and unaltered by channelization and found that brown shrimp, spot, croaker, southern flounder, and blue crab were more abundant in nursery habitats with no man-made drainage. They attributed this to the unstable salinity conditions that occurred in areas adjacent to channelized systems following moderate to heavy rainfall (>1 inch/24 hr). Channelized streams have also been found to have less suitable spawning habitat and reduced recruitment success for anadromous species (Sholar 1975). These observed declines in habitat quality are attributed to the changes in flow characteristics, water quality, and decrease in structural complexity.

The amount of in-stream vegetation, woody debris, and streamside vegetation is generally reduced in channelized streams (DMF 2000c). Removal of in-stream vegetation and woody debris reduces the substrate for fertilized herring eggs, the protective cover for adult and juvenile fish, and habitat for invertebrates (DMF 2000c). Macroinvertebrate species richness, biomass, and production are higher on snags and debris than any other habitat in Coastal Plain streams. In the Satilla River, Georgia, a typical Coastal Plain river, 90% of the food items and 60% of prey biomass of most large fish are invertebrates dwelling on these habitats (Smock and Gilinsky 1992). Removal of large woody debris also contributes to accelerating water velocity. Streamside vegetation is important as a source of in-stream woody debris and shade from the overhanging tree canopy, which helps maintain cooler water temperatures. Clearing of the woody vegetation along the riparian shoreline will therefore result in less woody debris in the water, higher water temperatures, and reduced bank stability.[9] *De-snagging of woody debris from streams for navigation or other purposes should be minimized to enhance water column habitat value*.

The formation of new channels involves ditching or the creation of vegetated swales (very wide ditches with sloping banks) to control stormwater runoff for urban development, agriculture, or forestry. The ditches often connect and drain into headwaters, altering the natural hydrology of downstream systems. Ditches can degrade water quality and alter flow conditions by moving stormwater from uplands more rapidly, causing pulses of stormwater with lower salinity or high levels of sediment, nutrients, toxic chemicals, or bacteria (Heath 1975; Jones and Sholar 1981). In a Florida estuary, Serafy et al. (1997) found differences in fish community structure from stable-salinity habitats versus those adjacent to freshwater canals. The difference was attributed to the varying ability of species to adapt to salinity

[9] Refer to the Wetlands chapter of this plan for more information on the impacts of channelization to wetlands.

changes. For example, pinfish were more tolerant of salinity change than spotted seatrout. In tidal creeks with extensive channelization and ditching, the volume and speed of stormwater runoff increased considerably during storm events, and resulted in elevated fecal coliform levels (White et al. 2000).

In coastal North Carolina, channelization activities include drainage and flood control projects, clearing and de-snagging of freshwater streams, creation of ditches and canals for drainage of low-lying agricultural land, dredging of new navigation channels, maintenance dredging of existing channels, road construction, and residential development (DEHNR 1995b). Most streams in eastern North Carolina have been channelized to some extent (North Carolina Sea Grant 1997). North Carolina has a long history of stream channelization and drainage. Many of the original canals and waterways in North Carolina, dating to the 1770s, were constructed for inland navigation and drainage. In the late 1800s, a large portion of state-owned wetlands was sold for large-scale timber harvesting. This led to a need for additional drainage required for mechanized harvesting. In addition, a large network of canals and ditches was constructed to drain wetlands for agriculture, following World War II, primarily on the Albemarle-Pamlico Peninsula. These drained wetlands have become the most productive cropland in North Carolina, accounting for more than 50% of the total annual crop yield (North Carolina Sea Grant 1997). Much of the land around the Albemarle-Pamlico estuary is drained and must remain drained to accommodate existing agriculture and forestry. It is estimated that over two million acres of land have been drained and developed for agriculture and forestry along the North Carolina coast. Within every square mile of agricultural land in coastal North Carolina, there are estimated to be more than 20 miles of field ditches, collector canals, and main canals (Heath 1975; Daniel 1978). Many of the roads on the Albemarle-Pamlico Peninsula were constructed on top of spoil piles between canals to prevent flooding. Ditching of wetlands or uplands is also common in other areas of the coast for flood control and drainage. In many urbanized coastal areas, ditches are typically constructed along neighborhood streets, which drain to nearby coastal waters.

There are many policies currently in place that restrict new channelization. Stream channelization for flood control and drainage of low-lying farmland and mosquito ditching are no longer common practices. "Swampbuster" provisions of the 1985 Farm Bill prohibited the practice of draining wetlands for conversion to cropland. However, some stream channelization projects for agricultural drainage are still maintained in North Carolina by drainage districts (DEHNR 1995a). There have been no new drainage projects since the mid-1970s (Chicod Creek, Pitt and Beaufort counties, Tar-Pamlico MU). *New channelization projects should not be constructed unless found to be absolutely necessary and designed to minimize or adequately mitigate any negative habitat and water quality impacts.* Although channelization for flood control and drainage has greatly declined, the existing alterations continue to alter flow and salinity patterns. *Dechannelization of streams, particularly in areas historically utilized as fish nurseries, implementation of alternative drainage control practices, and acceleration of innovative BMP development are needed where feasible. Increased funding and educational outreach to farmers and other landowners are also needed for such projects.* These habitat enhancements could improve fish productivity and recruitment success.

Ditching for stormwater control and draining of wetlands are regulated by the state[10]. In 1999, DWQ adopted a wetland draining policy to ensure that required wetland conditions are maintained (<http://h2o.enr.state.nc.us/ncwetlands/ditch.html>, 1999). In addition, inspections were made of previously ditched wetlands to determine if the ditching was conducted in a manner that violated wetland standards. Of the 65 ditching projects inspected, there were 24 Notices of Violation issued (SCC 1999). Turbidity was the standard most frequently violated by ditching. Where violations occurred, property owners were required to restore the natural hydrology through the filling of the ditches. Approximately 50% of the ditched wetlands are to be restored, 22% are likely not to be restored, and the status of the remainder is undetermined (J. Steenhuis, DWQ, pers. com., 2002). Fishermen in Brunswick County

[10] Refer to Wetlands chapter for more information on ditching and draining.

reported to DMF staff that, for two or three years following the wetland ditching, there was a distinct absence of blue crabs and other finfish in a creek receiving newly ditched runoff (D. Beresoff, commercial fisherman, pers. com., 2003). In addition, dissolved oxygen levels were found to be very low in the creek (DMF, unpub. data). After several years, however, fishery landings appeared to return to levels similar to nearby unaffected areas. This may be because some of the ditches upstream of the creek had been in violation and DWQ ordered these to be restored. Other ditches, although not appearing to violate water quality standards, continue to transport stormwater into coastal waters. *Additional monitoring, paid for by the party responsible for the ditching, is needed to better assess impacts where extensive areas of wetlands were drained. More DWQ staff are needed to inspect for compliance with the wetland draining policy*.

Dredging (navigation channels and boat basins)

Dredging for navigation channels or boat basins involves deepening areas for boating or shipping. The most obvious impact of dredging is deepening of shallow water habitats. The conversion from shallow to deep water areas can result in a proportional loss of nursery habitat for some estuarine-dependent species (Rozas 1992). Habitat alteration from dredging may have been responsible for some major reductions noted in brown shrimp (-88%), blue crab (-75%), Atlantic croaker (-45%), and spot (-19%) following dredging for a marina site on Pierces Creek (Neuse River) (DMF, unpub. data). The reductions were probably caused by reduced primary production on the bottom and enhanced shallow-water access for predators.

Elevated turbidity during and after dredging can also affect juvenile fish by clogging gills, which can result in mortality or reduced feeding or movement (Ross and Lancaster 1996). Recruitment of invertebrate larvae, growth of filter feeding invertebrates, and visual foraging for prey by adult and juvenile fish are also affected by turbidity from dredging (Reilly and Bellis 1983; Hackney et al. 1996; Peterson et al. 2000a). Lindquist and Manning (2001) quantified the effect of dredging on visual foraging by Florida pompano. When pompano were exposed to turbidity levels of roughly 80 NTUs, predation on coquina clams and mole crabs decreased by 40.5% and 30%, respectively. This represents turbidity levels that are conservatively similar to what was generated by a nearby disposal project and substantially above natural turbidity conditions (340 NTUs near the discharge point; 59 NTUs 70 m downstream; 6 – 30 NTUs at upstream control site). There is also evidence that dredging certain areas has affected spawning of anadromous fish. The spawning of shortnose and Atlantic sturgeon in the Cape Fear river system appears to have been disrupted by dredging for the Wilmington Harbor (Moser and Ross 1995).

While turbidity from dredging may protect small or young fish from visual predators (Livingston 1975; Bruton 1985; Walsh et al. 1999), it may also expose them to heavy metals and other pollutants stored in the sediment[11]. Dredged channels act as sediment traps, accumulating fine silt and pollutants (DEHNR 1990). The fine material can easily be resuspended by boat wakes, wind, or periodic channel maintenance. Chemicals, metals, nutrients, and organic matter stored in the sediment can then re-enter the water column, causing short-term increases in turbidity, algal blooms, and biological oxygen demand (BOD) (Lalancette 1984). However, the chronic, short-term impacts of dredging could be minor compared to the effect of hurricanes on the water column and bottom. Hurricanes not only scour the bottom in some areas but also create bottom in others. Organisms living in the bottom are adapted to infrequent hurricane events. However, some organisms may not be adapted to the chronic disturbance near frequently dredged channels, especially in areas that are poorly flushed. Dredging coarse sediment in areas with strong currents has much less impact on water column habitat than dredging fine sediment in areas with little or no current. *New dredging in shallow, nearshore areas with fine sediment and low flushing should be discouraged.*

[11] Refer to: Corridor function subsection under Ecological Role and Function section; Light and water clarity subsection of Ecological Role and Function section; Toxic chemical subsection later in this section.

In some cases, dredging may actually be needed to improve circulation within a waterbody. The mouths of many creeks along the Atlantic Intracoastal Waterway have become nearly blocked with sediment from dredging and subsequent boat traffic. In 1995 and 1996, the mouth of Futch Creek, in New Hanover County, was dredged to increase flushing, lower bacteria levels, and improve water quality. Fecal coliform levels declined and additional acreage was opened to shellfish harvesting. The creek has continued to maintain good water quality, in terms of fecal coliform, since the mouth of the channel was dredged (Mallin et al. 2002a). Dredging may also benefit upper estuaries where the water column has been filled with sediment from land disturbing activities. The excavated sediment could then be put to some innovative use on the land it originated from. *Areas where dredging could enhance habitat should be identified for habitat restoration efforts.*

Dredging in estuarine waters is prohibited from April 1 to October 1 to avoid disturbing the bottom in nursery areas when juvenile fish are present, except in specific areas where dredging is allowed during the moratorium period. The COE maintains the federal waterways within North Carolina by dredging sediments from the channels with Government-owned sidecast and hopper dredges, industry-owned hydraulic pipeline dredges, and hopper dredges. The size and type of dredge to be used to perform the work are dependent on the channel dimensions and material disposal methods. Maintenance of the seven federal inlet channels is performed by a sidecast dredge or a small hopper dredge. Maintenance of the federal channels at Morehead City, Wilmington Harbor, and Oregon Inlet is conducted by hydraulic pipeline dredge or hopper dredge. Timing of all work is dependent upon the area to be maintained, the type of equipment to be used, and the anticipated environmental effects. Performing work with a hopper dredge requires consideration of possible impacts on endangered and threatened sea turtles.

Disposal of material is dependent on the type of dredge used to perform the work. Material dredged by sidecast is cast to either side of the channel. Hopper dredges place the material in the nearshore zone (10-18 foot contour), on the beach with direct pumpout capabilities, or in an EPA designated ocean dredged material disposal site. Material dredged by a hydraulic pipeline dredge may be placed on the nearby beaches or within a confined upland diked disposal site.

There are two major commercial shipping ports in North Carolina, located in Morehead City and Wilmington, which have extensive areas of dredged channels and basins. The dredged areas are as deep as 38 – 45 ft (11.6 – 13.7 m). Navigational channels were dredged through most major coastal water bodies in North Carolina by the COE in the 1930s to create the North Carolina portion of the Intracoastal Waterway. Dredging for access to other public facilities is also financed by the N.C. Division of Water Resources. The DOT also maintains most of the channels associated with the ferry system. Finally, there are dozens of privately maintained channels serving marinas and private docking facilities. The locations of ports and major navigational channels are shown in Map 2.13a-c. The primary dredging activities occurring within North Carolina's coastal waters are maintenance or improvement dredging of existing navigation channels (DEHNR 1995a). The maintenance frequency for most channels ranges from annually to intervals of 10 years or more.

Mining

In coastal North Carolina, there are surface, open pit mines for sand/gravel, crushed stone, and phosphate. Sand/gravel and crushed stone mines occur generally in upland areas, although some may be located in or adjacent to wetlands (M. Street, DMF, pers. com., 2004). Sand/gravel mines are the most common mine in coastal North Carolina (<http://www.geology.enr.state.nc.us/ Permitted%20Mines%201999-2000/permitte.htm>, June 2004). In CAMA counties during 2001, there were 249 permits for sand/gravel mining, seven permits for crushed stone mining, and two permits for phosphate mining. The two phosphate mining permits, totaling 15,952 acres, were for PCS Phosphate in Beaufort County. In the past, whole creeks were lost to PCS Phosphate's mining activities. The open pits created by coastal mines fill with groundwater that is often pumped into ditches and rivers (G. Cooper, DWR, pers. com.,

2004). The discharge can contain sediment, nutrients, and heavy metals. However, the discharge of pollutants from mines is undoubtedly small compared to stormwater runoff from farms and urban/developing areas. Among coastal mining operations, PCS Phosphate is the largest discharger. Before 1992, PCS Phosphate was discharging 50-60 million gallons/day of phosphate-rich water into Pamlico Sound (Steel 1991). This nutrient-rich effluent was contributing to eutrophication of the Pamlico River. Today, PCS Phosphate uses a water recycling process that has greatly reduced discharge of nutrients.

The focus of mining activities in coastal waters has been mostly limited to sand acquisition for beach nourishment projects. Dredge material from inlet and other navigation projects is also used for beach protection purposes.[12] In addition, there are currently two areas in North Carolina ocean waters that are used as sand sources (borrow areas), one off Carolina Beach and the other off Bogue Banks. Another borrow area has been proposed off Bodie Island. Impacts of dredging to intertidal beach, soft bottom, and hard bottom are discussed in those sections of the plan.

Log salvage operations are a form of mining involving removal of submerged logs from lakes, rivers, or estuaries. In North Carolina, log salvage operations have been permitted in the Cape Fear, Roanoke, and Perquimans rivers. The major concern with the removal of logs is the procedure's effect on water quality. The Log Salvage Policy Development Team was created by DENR, in response to growing interest by commercial operations in this industry, to assess the potential impacts of this activity and to establish the most appropriate permit process. Their habitat and water quality concerns included (DENR 2000c):

- Increased turbidity and sediment loading could negatively impact the integrity of anadromous fish spawning and nursery areas, SAV, and waters classified as NSW.
- Resuspension of sediments with toxic materials released into the water column could impact fishery resources or their prey.
- Where located above the surface, removal of woody debris and structure used by anadromous and resident fish reduces its habitat value.

Log salvage operations may also need to be restricted from anadromous fish nursery areas, due to the primarily freshwater distribution of those species. The Log Salvage Policy Development Team made recommendations to minimize adverse impacts to aquatic systems. Recommendations affecting water quality include:

- Preparing a programmatic EIS for log salvage operations as a comprehensive approach to provide sufficient information to decide permit approval.
- The DENR Secretary should adopt BMPs and operation conditions developed by the Team until appropriate policies can be implemented.
- Address impacts on a regional scale in North Carolina, with consideration of the variety of aquatic habitats and living resources.
- Log salvaging should be prohibited in areas with SAV or shell bottom. A seasonal moratorium should be established regionally, to avoid salvage operations during peak fish spawning and juvenile recruitment periods.

Jetties

Jetties can potentially interfere with the passage of larvae and early juveniles from offshore spawning grounds into estuarine nursery areas. Approximately 60 species of larval fish and 34 species of juvenile and adult fish have been documented moving through Beaufort Inlet, Ocracoke Inlet, and Oregon Inlet in the winter and an even greater number of species during the summer months (Hettler and Barker 1993; Peters et al. 1995). Successful transport of larvae from fish spawning on the continental shelf through the inlet occurred within a narrow zone parallel to the shoreline and was highly dependent on along-shore

[12] Refer to the Soft Bottom chapter for more detailed discussion of beach nourishment.

transport processes (Blanton et al. 1999; Churchill et al. 1999; Hare et al. 1999). Obstacles such as jetties adjacent to inlets block the natural passage for larvae into inlets and reduce recruitment success (Kapolnai et al. 1996; Churchill et al. 1997; Blanton et al. 1999). Impacts may be greatest in coastal areas like the Outer Banks, where there are few inlets. Offshore spawning, estuarine-dependent species that might be impacted by jetties include many of North Carolina's most important commercial and recreational fish species such as menhaden, spot, Atlantic croaker, shrimp, gag, black sea bass, and flounders.

Most of North Carolina's inlets do not have jetties. There is a long dual jetty system at Masonboro Inlet and single groins at Beaufort and Oregon inlets (Map 2.14). There is also a jetty at Cape Lookout, although it is not immediately adjacent to Barden's Inlet. The Oregon Inlet project proposed to lengthen the existing groin and add a similar jetty on the other side of the inlet. Miller (1992) and Settle (NMFS, unpub. data), in reviewing the potential impacts of a dual jetty system at Oregon Inlet, estimated that successful passage of winter-spawned, estuarine-dependent larvae through Oregon Inlet could be reduced 60-100%.

The jetty construction's effect on fisheries has been discussed and reviewed at length by the scientific community in association with the proposed construction of a dual jetty system at Oregon Inlet (COE 1999). In the latest EIS (COE 1999), The Fish and Wildlife Coordination Act Report concluded that the Oregon Inlet project should not be constructed because of, among other concerns, the impact of jetties on larval fish passage. Although there are conflicting opinions on the magnitude of fisheries impacts of a dual jetty system at Oregon Inlet, there is valid concern that construction of the structures would prevent some portion of ocean-spawned larvae from reaching estuarine nursery areas (COE 1999). Construction or lengthening of jetties, particularly where inlets occur infrequently along the coast (such as Oregon Inlet), could lower successful fish recruitment and fishery productivity (Kapolnai et al. 1996; Churchill et al. 1997; Blanton et al. 1999). *Construction of new or expanded jetties or groins along North Carolina's ocean shoreline should not be allowed until field research has been completed to assess the impact of jetties on successful larval passage through inlets into estuaries, particularly in Pamlico Sound where inlets are limited. Environmental outreach to the public, particularly commercial and recreational fishermen, regarding the effect of inlet stabilization on coastal fish habitat is needed to educate the public on this issue and gain support for maintaining natural barrier island processes.*

Shoreline stabilization

Shoreline stabilization using vertical structures, such as seawalls on the ocean shoreline or bulkheads on the estuarine shoreline, can impact the condition of the nearshore water column in several ways. During construction, soil disturbance may increase turbidity in adjacent waters and reduce light penetration. This can reduce primary productivity, interfere with respiration and feeding of fish and invertebrates, release heavy metals that may occur in the sediment, and smother aquatic vegetation (Watts 1987). Although shoreline stabilization structures may retain eroding sediments from land, the continual scouring of sediment at the base and downdrift of the structure may resuspend sediment, chronically elevating turbidity adjacent to bulkheads (Clark 1974; Watts 1987). The scouring action at the toe of seawalls and bulkheads results in deepening of the adjacent water, reducing or eliminating shallow water habitat preferred by many juvenile fish (SAFMC 1998a; DMF 2000a). *The state should enforce the prohibition of hardened structures on the oceanfront. In addition, existing seawalls and hardened structures on the oceanfront should be removed if they are more than 50% damaged and if removal will be beneficial to coastal fish habitat. Where shoreline stabilization structures such as rock revetments, sills, or bulkheads are allowed adjacent to fringing wetlands, permit conditions should require openings in the structures to allow adequate fish ingress and egress and water circulation. To minimize impacts to the water column and its functions, CRC estuarine shoreline stabilization regulations should be modified.* [13]

[13] Refer to the Wetlands and Soft Bottom chapters for more information on the impacts of shoreline stabilization to those coastal fish habitats and the status of this activity.

Water quality degradation

In addition to altering erosion and sedimentation dynamics, human activities can and often do change the chemistry of the water. Changes in chemistry causing degradation of water quality can originate from defined points such as industrial or wastewater discharges (point sources) or from land-use patterns contributing pollutants by sheet flow or through drainage features (nonpoint sources). The primary point source pollutants are oxygen-consuming wastes, nutrients, and toxins, including chlorine, ammonia, and metals. A National Pollutant Discharge Elimination System (NPDES) permit is needed for most point source discharges, and most NPDES discharges are treated municipal or industrial wastewater (Map 2.15).

Nonpoint source pollution is pollution that enters waters through diffuse sources with no defined point of entry. Nonpoint pollutants are generally carried into waters by rainfall, runoff, snowmelt, or air deposition. Stormwater drains and swales also carry polluted stormwater into coastal waters, but are technically considered nonpoint sources. Unlike point sources, nonpoint pollutant loading varies with weather patterns and land disturbance. The North Carolina Coastal Nonpoint Source Program categorizes nonpoint pollution by land activities:

- Hydromodification (drainage ditches)
- Agriculture
- Forestry
- Marinas
- Urbanization

Each activity associated with these categories can contribute multiple pollutants. Sediment and nutrients are most often associated with nonpoint source pollution, but other pollutants, including fecal coliform bacteria, toxic chemicals such as heavy metals, oil, and pesticides, may be carried into coastal waters as well (DWQ 2000a). The biological impacts and human sources associated with these pollutants are discussed below, as well as status and trends.

Land cover and water quality

Land cover and water quality within a watershed are closely linked (EPA 1992). Table 2.20 below provides a brief overview of some river basin characteristics (population, land cover), and major water quality problems that were noted in the summaries of the river basin plans. When considering the overall population of each river basin, the Neuse and Cape Fear river basins are the most densely populated, and the Chowan and Pasquotank are the least populated. The distribution of population is not even; there are areas of the coast that are extremely dense, while the overall population density for the river basin is relatively low. An example of this would be the Lumber, where population is quite dense on the coast of Brunswick County, but overall the river basin is much less densely populated. The impact of the population on fish habitat and water quality depends on the location of the development, use of the land, and the hydrography of the river basin.

Table 2.20. Overview of coastal river basin conditions based on population, land use, and major nonpoint water quality problems. (Source: DWQ Basinwide Plans 1999-2002)

River basin[1]	Population [2]	Population density (persons /mi^2) 1990	Major water quality problems noted in most recent basinwide plan	Land cover [3]		
				Type	% within basin (1997)	% change since 1982
Neuse (2002a)	1,320,379	211	Nutrient enrichment from urban build-up agriculture, hydromodifications Low DO Fecal coliform contamination	Urban/built	13.1	+ 89
				Cult. crop	23.9	- 17
				Uncult. crop	1.5	+ 311
				Pasture	3.7	+ 16.7
				Forest	44.9	- 7
				Federal	2.3	+11.6
				Other	10.6	+1.5
Cape Fear (2000c)	1,494,011	163	Large increase in urban development riparian vegetation, storms Large increase swine population Low DO	Urban/built	8.8	+ 43
				Cult. crop	18.2	- 8
				Uncult. crop	1.1	+ 18
				Pasture	4.8	- 3
				Forest	56.1	- 5
				Federal	0.0	0
				Other	8.8	+ 17
White Oak (2001a)	146,240	141	Fecal coliform contamination Increase in urban development	Urban/built	8.1	+ 81.6
				Cult. crop	4.9	- 15.1
				Uncult. crop	0.4	+ 490.0
				Pasture	0.4	+ 170.6
				Forest	29.1	- 9.7
				Federal	19.9	0
				Other	37.3	- 0.8
Roanoke (2001c)	335,194	107	Habitat degradation, erosion control Increasing development Water flow regulation	Urban/built	6.1	+ 132.8
				Cult. crop	17.0	- 21.8
				Uncult. crop	2.1	+ 86.1
				Pasture	3.9	- 21.2
				Forest	61.5	- 0.2
				Federal	0.9	+ 19.5
				Other	8.5	+ 17.7
Tar-Pamlico (1999a)	364,862	80	Low DO Fecal coliform contamination Nutrient enrichment	Urban/built	1.0	+ 62
				Cult. crop	22.0	- 7.7
				Uncult. crop		+ 158.9
				Pasture	3.0	- 15.1
				Forest	55.0	- 3.9
				Federal	0.0	0
				Other	20.0	
Lumber (1999b)	259,539	78	Large increase in Brunswick Co. population Large increase in swine population	Urban/built	6.0	+ 48.8
				Cult. crop	26.1	- 6.4
				Uncult. crop	0.7	- 0.7
				Pasture	1.5	- 16.7
				Forest	59.1	- 0.3
				Federal	0.8	0
				Other	5.9	+ 5.4
Chowan (2002b)	61,034	48	Nutrient enrichment from agriculture Habitat degradation Low DO and pH - swamp waters	Urban/built	2.8	+ 62.1
				Cult. crop	32.6	- 0.8
				Uncult. crop	0.2	+ 150.0
				Pasture	1.0	- 23.8
				Forest	54.9	- 1.0
				Federal	0.0	0
				Other	8.6	- 2.0
Pasquotank (2002c)	118,912	46	Fecal coliform contamination Increase in urban development	Urban/built	3.3	+ 86.2
				Cult. crop	21.3	- 11.4
				Uncult. crop	0.0	+ 10.0
				Pasture	0.3	+ 71.8
				Forest	23.9	- 26.5
				Federal	13.2	+ 293.3
				Other	37.9	- 0.5

[1] Year of most recent DWQ basinwide plan from which data taken noted in parentheses

[2] Population data for Tar-Pamlico, Lumber, White Oak are from 1990, while others are from 2000 census.

[3] Land cover data from USDA-NRCS, NRI. More current data for Lumber, Tar-Pamlico, and Cape Fear from 1992, others from 1997

Changes in land cover from 1982-1997 were estimated using land cover information provided by the National Resource Inventory (NRI) Program of the Natural Resources Conservation Service (NRCS). The NRI is a statistically based survey to assess conditions and trends of soils, water, and related resources on the nation's nonfederal rural lands (DWQ 2002a). The 1997 NRI database has been designed for use in detecting significant changes in land cover during the years 1982, 1987, 1992, and 1997 (<http://www.nrcs.usda.gov/technical/NRI/1997/national_results.html>, 2002). Land cover has shown significant changes in all river basins since 1982. The most significant and consistent change has been the large increase, ranging from 43 to 132%, in the amount of urban/built-upon areas. This is consistent with the evidence of increasing population. There have also been large increases in uncultivated cropland in most of the coastal river basins (10–490% increase). Uncultivated cropland includes summer crops that are fallow and crops that have permanent cover and are untilled, such as hay, sod, or blueberries. Spray irrigation fields associated with animal operations that grow grass and are not grazed are also included in this category. An increase in animal operations, vegetated buffers as agricultural BMPs, or unfavorable change in crop market conditions may account for some of this observed increase. In all river basins, forested land continues to comprise a significant portion of the land cover (24-61%), although the percentage of forested land has declined, ranging from a 0.2% decrease in Roanoke River basin to 26.5% decrease in the Pasquotank River basin.

Studies have indicated that substantial degradation of water quality and aquatic habitat occurs when impervious cover within a watershed reaches 10% (Beach 2002). The percentage of impervious surfaces in a watershed is a strong indicator of fecal coliform bacteria in surface waters (Mallin et al. 2000b). As vegetated areas are reduced, the ability of the land to absorb and filter stormwater runoff is reduced; flooding, bank erosion, and nonpoint runoff subsequently increase. More impervious surface also increases peak runoff in streams and reduces groundwater input for stream baseflow. Current DCM regulations have established a 30% limit on built-upon area per project within Areas of Environmental Concern [15A NCAC 07H .0209 (2)], while EMC limits on built-upon area under the low-density option vary by location and adjacent water classification from 12- 30%.

Areas of Environmental Concern (AECs) are the foundation of DCM's coastal development permitting program. The CRC designates areas as AECs to protect them from uncontrolled or incompatible development. There are four categories of AEC:

- The estuarine and ocean system
- The ocean hazard system
- Public water supplies
- Natural and cultural resources areas

Within the Areas of Environmental Concern, development requires a Coastal Area Management Act (CAMA) permit. The estuarine system, as defined by DCM rules, extends upstream to the dividing line between coastal and inland fishing waters. Within the Estuarine System is the Coastal Shoreline category that includes estuarine shorelines and public trust shorelines. Coastal Shorelines include all lands within 75 feet of the normal high water level of estuarine waters. Along Outstanding Resource Waters, the shoreline jurisdiction extends 575 feet landward of the normal high water level. Public Trust Shorelines include lands within 30 feet of the normal high water level of public trust waters located inland of the dividing line between coastal fishing waters and inland fishing waters (Figure 2.6).

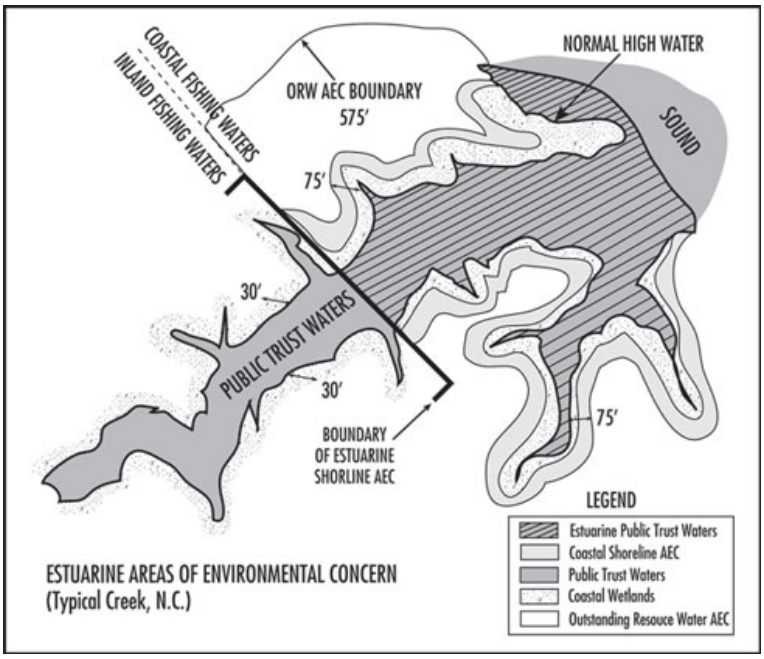


Figure 2.6. The location of Areas of Environmental Concern (AECs) along a typical creek in coastal North Carolina. (Source: <http://dcm2.enr.state.nc.us/Handbook/section2.htm>, 2003)

Rules applicable to CRC jurisdictional shorelines provide some additional water quality protection to adjacent and downstream habitat in coastal waters compared to most areas upstream and landward of CRC jurisdictional areas, unless designated as Nutrient Sensitive Waters, Outstanding Resource Waters, SA waters, or High Quality Waters. Nutrient management strategies for the Nutrient Sensitive Waters of the Tar-Pamlico, Neuse, and Chowan rivers include mandatory buffers and nutrient reductions from wastewater discharges, stormwater runoff, and agriculture. EMC rules in some areas[14] limit impervious cover adjacent to intermittent and perennial waters to varying levels. However there is no minimum vegetated buffer required in coastal draining watersheds that are not under the domain of CRC rules or EMC nutrient management strategies. Those rivers basins include the Cape Fear, Pasquotank, White Oak, and Roanoke, upstream and landward of coastal wetlands. Because CRC's coastal shoreline AEC is limited to only 75 ft in width from normal high water (575 ft adjacent to ORW), the CRC cannot regulate impervious surfaces on a watershed level and cannot guide development in all areas that affect coastal waters. *The estuarine shoreline AEC should therefore be widened and extended inland beyond the Inland Water jurisdictional line to at least the upstream boundary of coastal wetlands*[15]*. Establishment of development setbacks within AECs should also be considered as a tool in protecting water quality. To more effectively manage development in a manner that minimizes impacts to coastal fish habitat, a process to fully evaluate cumulative impacts of coastal development needs to be developed and implemented by the regulatory agencies.*

Table 2.21 shows the percent change of impervious cover in coastal river basins based on data from 1982 to 1997.[16] At that time, ten areas exceeded 10%—with the highest level of impervious cover, 24.8%—in the Upper Neuse. Overall, at least 16 of 25 (64%) USGS hydrologic units in coastal North Carolina currently fall below the 10% threshold. However, the relative amount of impervious surface on smaller

[14] Waters classified as HQW, ORW, or SA or small municipalities identified in Phase II Stormwater Rules (see Existing Management section later in this chapter).

[15] Refer to DCM's website for a description of current AEC categories (<http://dcm2.enr.state.nc.us/Handbook/handbook.htm>, 2001).

[16] The table uses a combination of urban/built-up lands and rural transportation corridors (road, highway and railroad rights-of-way) as a rough estimate of total impervious surface.

watersheds along the coast is not accounted for when averaging impervious cover across vast regions. Excess impervious cover in small watersheds could result in localized habitat and water quality degradation and closure of shellfish beds. The effect of impervious cover on water quality also depends on proximity to surface waters, drainage patterns, soils, and on-site storage of stormwater. Impervious surfaces having insufficient on-site storage of stormwater and located in drainage basins near the water have the greatest impact on water quality. *Coast-wide mapping of impervious cover is needed to evaluate watershed condition. The coast-wide mapping of impervious surfaces should be supplemented with data on local hydrology and on-site stormwater controls to more accurately reflect potential degradation of water quality.*

Between 1982–1997, the Middle Roanoke and Coastal Carolina-Sampit areas experienced the most growth (131-139%) in impervious surface (Table 2.21). Another coastal hydrologic unit with relatively high growth and percent impervious cover was Bogue-Core sounds (6-10% impervious and 94-116% growth). Most other coastal HUs had either low percent impervious cover and moderate growth (Lower Neuse, Pamlico and Albemarle Sound), very low percent impervious cover and high growth (Pamlico Sound), or high percent impervious cover and low growth (New River and portion of southern estuaries). If the rate of increase remains the same as 1982-1997, 17 of 25 HUs (68%) will have exceeded the 10% threshold by 2012. *These numbers suggest that water quality problems associated with development and excessive impervious cover will continue to worsen unless improved land-based strategies that reduce nonpoint source pollution are utilized at a local level. Voluntary strategies could include providing incentives for low impact development, improved BMPs and other techniques. Rule-making strategies may also be necessary to adequately retain stormwater on-site. This could be achieved through site design, construction of engineered storm water controls, or lower maximum amounts of impervious surfaces on developments choosing the low-density option for stormwater control. Phase II stormwater rules already recognize the need to limit impervious surfaces.*[17] *The EMC and CRC should consider 1) modifying rules regarding limits of built-upon area (low-density option) to be consistent with the scientific literature regarding water quality protection needs, or 2) modifying stormwater rules to require adequate retention or treatment of stormwater on-site, through alternative effective techniques.*

[17] Refer to Existing Management Measures for more information on Phase II stormwater permitting.

Table 2.21 Percent increase and percent coverage of the NRI's urban/built-upon + rural transportation land cover classes within North Carolina's coastal drainages.

USGS hydrologic unit	% increase (1982-1997)	% Urban/built-up and rural transportation[1]	
		1997 (measured)	2012 (predicted)
Upper Neuse	91.8	**24.8**	**47.6**
Haw	50.21	**23.8**	**35.7**
Carolina Coastal-Sampit	131.58	**20.5**	**47.5**
Upper Cape Fear	78.71	**15.1**	**27.0**
Deep	47.14	**13.2**	**19.4**
Upper Dan	87.04	**12.7**	**23.7**
New	33.23	**11.9**	**15.8**
Lower Tar	60.82	**11.8**	**19.0**
Upper Tar	81.03	**10.7**	**19.3**
Roanoke Rapids	77.55	**10.3**	**18.2**
Contentnea	51.27	9.5	**14.4**
Lower Cape Fear	66.5	9.4	**15.7**
Middle Neuse	43.03	8.9	**12.7**
Bogue-Core Sounds	89.58	6.8	**13.0**
Northeast Cape Fear	54.38	6.6	**10.2**
Middle Roanoke	139.22	6.2	**14.7**
Lower Dan	92.36	5.8	**11.2**
Lower Roanoke	41.02	5.8	8.1
Black	62.57	5.6	9.2
Lower Neuse	36.31	5.6	7.6
Pamlico	30.58	5.3	6.9
Meherrin	32.77	4.7	6.3
Albemarle	62.4	4.1	6.6
Chowan	33.33	3.9	5.2
Fishing	28	3.9	5.0
Pamlico Sound	83.72	1.3	2.4

[1]This land cover classification represents a close approximation of percent impervious cover, but could somewhat overestimate in some areas. USGS HUs in **bold** were >10% urban/built-up and rural transportation in 1997. USGS HUs in *italics* are predicted to reach >10% by 2012.

Maintaining riparian buffers is a proven watershed management tool that effectively reduces nonpoint source runoff into the water column, and positively influences aquatic habitat (Schueler 2003). Several studies evaluating the effectiveness of forested riparian buffers found that where quality riparian habitats were preserved, fish diversity could be maintained with up to 15% impervious cover in the watershed, and aquatic insect diversity could be maintained with as much as 30% impervious cover (Schueler 2003). Any activities which alter vegetated riparian habitat can affect water quality. In addition to clearing associated with development, logging operations, particularly clear cutting and stream crossing, can also cause considerable hydrological and water quality change to freshwater and brackish streams. A study of Goshen Swamp, a Coastal Plain blackwater stream that was clearcut, found that the clearcut caused violations of ambient N.C. water quality standards for turbidity, chlorophyll *a*, fecal coliform bacteria and DO compared with a control stream (Ensign and Mallin 2001). Despite a 10 m (33 ft) buffer left along the streambank, these violations occurred over a two-year period following the clearcut. The buffer was less than the state BMP recommending a 50 ft minimum buffer. Desbonnet et al. (1994) summarized studies documenting the different benefits of various buffer widths. Scientific literature suggests that minimum buffers between 26 ft (8m) and 75 ft (23 m) wide are needed to protect water quality and riparian habitat from logging impacts (Desbonnet et al. 1994; Ensign and Mallin 2001). In the Neuse,

Tar-Pamlico, and Catawba river basins, there is a mandatory buffer of 50 ft from mean high water, with exemptions for managed forests and selective harvesting of high value trees. *Ideally, mandatory buffer zones, of scientifically based and effective widths and configurations that protect habitat and water quality, should be required along all streams draining to coastal fish habitat in North Carolina.*

All forestry-related land-disturbing activities, regardless of river basin, must be conducted in accordance with Forestry Practice Guidelines Related to Water Quality [DENR rule 15A NCAC 01I .0101-0209] to qualify for exemption from Sedimentation Pollution Control Laws [G.S. 113A-52.01 (2)]. To remain exempt from the requirements associated with the Sedimentation Pollution Control Act, forestry activities must comply with certain performance standards, including establishment of Streamside Management Zones (SMZ). These zones are areas covered with vegetation on both sides of natural intermittent and perennial streams, rivers, ponds, and other water bodies where extra precautions are used during forestry operations to protect stream banks and water quality. In low slope areas (0-5%), the minimum recommended SMZ is 50 feet, which are not always followed according to Ensign and Mallin (2001). Along steeply sloping shorelines of public water supplies, the recommended SMZ is 200 feet. Roads are to be placed outside of the SMZ, and harvesting is limited so that the vegetation will trap and filter sediment and other pollutants before reaching the stream, maintain water quality, and provide riparian habitat and shade for fish.

In 1995, the DFR conducted a statewide survey of forestry BMP implementation and compliance. The results found overall compliance was 92% (Henson 1995). The lowest level of BMP compliance was on small non-industrial private forests. Compliance was significantly greater on sites having a professional forester involved with the operation. Although there was very high compliance with having a SMZ, some zones did not have adequate buffer widths, nor tree and/or ground cover, and thus, were not effective. The Division of Forest Resources inspects about 50% of all harvested sites for compliance with Forest Practice Guidelines Related to Water Quality (FPGs) (<http://www.dfr.state.nc.us/water_quality/wq_2000fpgreport.htm>, June 2004). The DFR asserts that complaints and observations of harvest operations catch the majority of violators. In FY 1998-1999, the compliance rate statewide for all sites inspected was 95.5%. Of those 4.5% that were out of compliance, the vast majority were brought into compliance. The remainder were referred to the appropriate agency for enforcement action. *Requiring professional foresters to be involved with the implementation of logging BMPs, even on small private forests, would enhance proper use of BMPs. In addition, notifying the Division of Forest Resources prior to initiating logging operations would facilitate BMP inspections and, hopefully, improve overall compliance. Educating owners of small non-industrial forests would also improve BMP implementation and success.*

Although forestry activities can cause short-term and localized water quality degradation, forest land cover likely provides the best combination of economic and environmental benefits. Mature forests can be occasionally harvested for economic benefit, while growing forests provide the best natural filters for stormwater runoff. However, the change from natural forested communities to managed forest lands in eastern North Carolina has resulted in a reduced diversity of wildlife habitats[18]. But regardless of forest type, a greater proportion of forest land cover will undoubtedly enhance coastal fish habitats.

Nutrients

Nutrients are chemical compounds or elements that are needed for growth of living organisms and are beneficial in appropriate amounts. Nitrogen and phosphorus are the major plant nutrients responsible for regulating growth of phytoplankton, algae, and other marine plants (DeAngelis et al. 1989). Most North Carolina estuaries already have relatively high nitrogen levels; adding nitrogen to those systems may degrade water quality. Freshwater systems tend to be limited in their ability to receive added phosphorus without adverse effects (North Carolina Sea Grant 1997). While a certain level of these nutrients is needed to support aquatic life, an overabundance of nutrients due to human activities often has a negative

[18] Consult the WRC's Comprehensive Wildlife Conservation Strategy (contact: salinda.daley@ncwildlife.org).

impact on the environment. Nutrient overenrichment and the resultant problems are called eutrophication.

Nutrient enrichment is a problem to coastal fish habitat for several reasons. Elevated nutrients can trigger a rapid increase in phytoplankton, resulting in algal blooms. Blooms tend to occur when water temperatures are warmer, water flow is slower, and where mixing of the water column is reduced due to salinity or temperature gradients. In freshwater areas, blue-green algae are usually associated with blooms, and they have lower nutritional value to aquatic life than other types of algae. In estuarine and marine waters, dinoflagellates are usually responsible for algal blooms (North Carolina Sea Grant 1997). With nutrient enrichment, there is a shift in the dominant plant community from slower growing SAV and perennial macroalgae to faster growing phytoplankton, microphytobenthos, and ephemeral macroalgae (Duarte 1995). Another direct effect of eutrophication on estuaries is the increased biological oxygen demand resulting from the sedimentation and resuspension of accumulating organic matter (Gray et al. 2002). Nutrient enrichment and algal blooms are therefore often accompanied by oxygen depletion.

Elevated levels of phytoplankton in the water column reduce water clarity. Reduced water clarity reduces successful feeding by some visually orienting fish (Peterson et al. 2000a). When light penetration is sufficiently reduced, survival and growth of submerged aquatic vegetation can also be impacted. Other indirect effects of nutrient enrichment include changes in the biomass, community structure, growth and reproduction rates of invertebrates, and change in the organic carbon inputs and biogeochemistry of the sediments (Cloern 2001). Algal blooms are also aesthetically undesirable to the public; the unpleasant odor and degraded visual appearance of the water's surface (green scum) discourages swimming, boating and fishing.

Some dinoflagellate species release toxic chemicals into the water column. Neurotoxins from algae, released into the water upon death, harm fish and shellfish by affecting their nervous systems and paralyzing their respiratory systems (Tyler 1989). Organisms such as clams, oysters, and some benthic fish can die of suffocation because of nervous system paralysis. Humans that eat contaminated seafood can also experience neurological symptoms (Tyler 1989). These blooms are sometimes referred to as "red tide" because the dinoflagellates can make the water appear red in color. In 1987, there was a large red tide event in North Carolina waters attributed to Gulf water intrusion into nearshore waters, carrying the toxic dinoflagellate *Karenia brevis* (Tyler 1989). This event resulted in contamination of shellfish and coastal fish consumption advisories for an extensive time period, significantly impacting several North Carolina fisheries. Globally, the incidence and frequency of red tides have increased in recent decades. Eutrophication is considered to be partially responsible for this increase, as well as transport of algal bloom species through ship ballast water (Hallegraeff 1998).

Another toxic dinoflagellate, *Pfiesteria piscicida*, may have contributed to a number of large fish kills in North Carolina estuarine waters since the late 1980s. Since then a second species, *Pfiesteria shumwayii,* has been discovered, and fish kills in Chesapeake Bay have been attributed to these organisms (Glasgow et al. 2001). *Pfiesteria* produces a toxin that could be responsible for large fish kills (Burkholder et al. 1992a). Other studies suggest that the mechanism of fish mortality in *Pfiesteria* is actually micropredation, rather than toxin release (Vogelbein et al. 2002). There is not full scientific consensus on the human effects of *Pfiesteria* exposure (Gratten et al. 1999; Rubin et al. 2001). Burkholder et al. (1995), Burkholder and Glasgow (1997), and Glasgow et al. (2001) provide data on numerous estuarine fish kill events, including number of fish killed, concentrations of *Pfiesteria*, DO and nutrients present at the site, whether toxicity of *Pfiesteria* was confirmed by subsequent laboratory bioassays, presence of lesions on fish, presence of other potentially toxic algal species, and water temperature. It is important to note that, since *Pfiesteria* abundance is stimulated by nutrient loading into estuaries, the occurrence of *Pfiesteria* is not independent of other eutrophication effects (Burkholder and Glasgow 1997; Glasgow et al. 2001). Low DO has also been documented to cause large fish kills in areas where *Pfiesteria* was also present (Paerl et al. 1998) (refer to oxygen depletion section). Conditions such as bacterial, viral,

parasitic, and fungal infections, ammonia toxicity, chemical pollutants, sudden changes in temperature or salinity, and bycatch from commercial fishing are also possible causes of fish kills.

Fish sampling was initiated in 1998 by DWQ, DMF and NCSU to determine the occurrence of and species impacted by *Pfiesteria* and ulcerative mycosis (UM) in three estuarine systems with a history of large fish kills – Neuse, Tar-Pamlico, and New rivers. Lesions were most common on menhaden and occurred on fish captured in areas with low to moderate salinities within the Pamlico River (Noga et al. 1989). Similar signs of disease were found on fish representing 19 species, including southern flounder, striped bass, weakfish, spot, croaker, silver perch, bluefish, pinfish, gizzard shad, and hogchoker. Both benthic and pelagic species were affected. The observed incidence of disease ranged from 10.0% in the Pungo River to 33.0% in the middle Pamlico River; 18.2% in the lower Neuse to 44.2% in the upper Neuse River; and 3.9% in the upper to 10.2% in the middle of the New River (DMF 2000b). Disease incidence was highest in May in all river systems, followed by the months of November and December. The presence of low DO, a stratified water column, increased phytoplankton, and active fertilizer application and pesticide spraying on farmland in the spring may have increased stress levels in fish, leading to increased disease in May (DMF 2000b). While skin ulcers were the most frequent abnormality observed in fish, fin erosion, abnormal pigmentation, tumors, skeletal abnormalities, and operculum damage were also reported.

Sources of nutrient enrichment

Nutrients enter surface waters from point and nonpoint sources. While point sources are highly regulated and effluent quality has improved over the years, nonpoint sources have only recently been recognized as significant contributors to eutrophication and are more difficult to control because of the diffuse pathways into coastal waters. Primary point sources of nutrients are (DWQ 2000b):

- Municipal wastewater and stormwater discharges; and
- Industrial wastewater discharges.

There are a total of 901 NPDES discharges into coastal waters covered by the CHPP management area (Map 2.15). Of these, 74 are major and 75 are minor municipal NPDES discharges. There are also 143 major and 609 minor non-municipal NPDES discharges within the CHPP management area. Non-municipal discharges include those from water treatment plants, fish houses, reverse-osmosis plants, phosphate mines and industrial activities. Nutrients also enter water from spills, plant failures, or inadequate treatment. In 2002, a relatively dry year, there were 2,047 spills reported from government or private waste collection systems that reached surface waters, totaling 56.9 million gallons (DWQ, unpub. data). In wet years, the totals are generally larger. Point source pollution was identified as a source of degradation for 36 percent of impaired streams in North Carolina (DWQ 2000a). *Loading of nutrients into coastal waters from mechanical failures, spills, and inadequate treatment must be reduced. This will require additional funding to upgrade plants and infrastructure. Increased inspections of sewage treatment facilities, collection infrastructure, land disposal sites, and onsite wastewater treatment facilities is needed.to identify and prioritize sites needing upgrades.*

There are numerous nonpoint sources of nutrients. Agriculture is believed to be the single largest contributor of nutrients in watersheds of the southeastern United States (SAFMC 1998a). The primary land use activities that contribute nonpoint delivery of nitrogen and phosphorus to North Carolina waters are (Steel 1991; USDA 1997; Spruill et al. 1998):

- Agricultural fertilizer from crop production;
- Livestock waste from concentrated animal operations;
- Urban development (lawns, pets, sewage, golf courses); and
- Air emissions from industry and vehicles.

Nutrients enter coastal waters through stormwater runoff, air deposition, groundwater discharge and rainfall. In the Albemarle-Pamlico system, nonpoint sources are estimated to account for the majority of the nutrient loading (94% for nitrogen and 84% for phosphorus) (Spruill et al. 1998). Precipitation accounts for about 20-30% of the total nitrogen inputs from nonpoint sources in the Albemarle-Pamlico basin (Spruill et al. 1998). Sources of nitrogen in the air and rain are vehicle exhaust, industrial emissions, and waste from animal operations (USGS 2003). Within the coastal river basins, 44.7% of the impaired miles of freshwater streams in 1998-1999 were related to agricultural runoff (cropland and animal operations) (Table 2.22).

Table 2.22. Miles and percent of impaired freshwater stream miles with identified nonpoint sources, by river basin (1995-1999). (Source: DWQ 2000a)

		River basin								
Nonpoint Sources		**Cape Fear**	**Chowan**	**Lumber**	**Neuse**	**Pasquotank**	**Roanoke**	**Tar-Pamlico**	**White Oak**	**Total**
Agricultural Runoff	Miles	139	88	0	335	48	85	28	0	**723**
	%	29.6	64.7	0.0	52.6	66.7	44.0	28.0	0.0	**44.7**
Forestry	Miles	0	0	0	34	0	40	0	0	**74**
	%	0.0	0.0	0.0	5.3	0.0	20.7	0.0	0.0	**4.6**
Construction/ development	Miles	15	0	0	65	12	0	0	0	**92**
	%	3.2	0.0	0.0	10.2	16.7	0.0	0.0	0.0	**5.7**
Urban Runoff	Miles	247	0	0	138	0	16	12	8	**421**
	%	52.6	0.0	0.0	21.7	0.0	8.3	12.0	72.7	**26.0**
Mining	Miles	12	0	0	0	0	4	0	0	**16**
	%	2.6	0.0	0.0	0.0	0.0	2.1	0.0	0.0	**1.0**
Land Disposal	Miles	0	0	0	0	12	1	0	0	**13**
	%	0.0	0.0	0.0	0.0	16.7	0.5	0.0	0.0	**0.8**
Hydro-modification	Miles	5	27	0	7	0	19	15	0	**73**
	%	1.1	19.9	0.0	1.1	0.0	9.8	15.0	0.0	**4.5**
Unknown/ other	Miles	52	21	0	58	0	28	45	3	**207**
	%	11.1	15.4	0.0	9.1	0.0	14.5	45.0	27.3	**12.8**
Total Impaired miles		**470**	**136**	**0**	**637**	**72**	**193**	**100**	**11**	**1619**

In a study of the Albemarle-Pamlico estuarine system, the four major river basins (Chowan, Roanoke, Tar-Pamlico, and Neuse) contained elevated concentrations of nitrogen and phosphorus (Spruill et al. 1998). Crop agriculture and animal operations were estimated to contribute approximately 50% of the nitrogen load and 75% of the phosphorus load. The effect of crop agriculture on water quality depends on the specific crops grown, weather, and the use of Best Management Practices (BMPs) (Steel 1991). The acreage of cultivated crop agriculture in coastal North Carolina has remained about the same or declined since the early 1980s. In addition, use of effective BMPs is increasing primarily due to availability of funds and technical assistance from multiple programs administered through the U.S. Department of Agriculture, Natural Resources Conservation Service, N.C. Department of Agriculture and Consumer Services, and N.C. Division of Soil and Water Conservation (DSWC). *However, because of the large percentage of nutrients attributed to crop agriculture, aggressive steps should continue to reduce nutrient loading.*

While crop production has declined in North Carolina's coastal plain, animal operations have greatly increased in the past 10-15 years (Table 2.23). The location of current animal operations is shown in Map

2.16. The primary types of animal operations using liquid waste-management systems are swine, cattle, and poultry. Swine operations are the most abundant and poultry the least abundant (Table 2.23). There are a total of 1,999 swine operations, with a design capacity of approximately 7 million animals, in the CHPP management area. The numbers of facilities and swine are greatest and most concentrated in the Cape Fear MU, followed by the Neuse, and Tar-Pamlico. Although relatively uncommon, cattle operations are most abundant in the Cape Fear, and poultry operations are most abundant in the Neuse. The Core/Bogue and Southern Estuaries MUs have a small number of animal operations. Nationally, North Carolina is one of the largest swine and poultry producing states, having undergone much growth in those industries in the past decade (Barker and Zublena 1995).

Table 2.23. Estimated number and capacity of animal operations within CHPP MUs. (Source: DWQ, unpub. data)

	Cattle			Poultry			Swine		
CHPP MU	# of Facilities	Design Capacity	Total Steady State Live Weight*	# of Facilities	Design Capacity	Total Steady State Live Weight*	# of Facilities	Design Capacity	Total Steady State Live Weight*
Albemarle	1	120	96,000	-	-	-	46	43,815	11,742,657
Cape Fear	48	15,062	18,001,400	-	-	-	1,158	4,702,601	679,649,855
Chowan	-	-	-	-	-	-	56	110,869	28,201,508
Core/Bogue	-	-	-	-	-	-	2	951	542,655
Neuse	9	1,699	2,006,600	3	190,000	760,000	501	1,659,072	254,123,458
New/White Oak	-	-	-	-	-	-	47	142,873	21,059,365
Pamlico	-	-	-	-	-	-	4	1,969	1,688,977
Roanoke	17	3,965	4,378,000	-	-	-	42	59,344	20,077,500
Southern estuaries	-	-	-	-	-	-	3	6,510	878,850
Tar/Pamlico	9	3,250	3,224,000	20	1,775,200	6,781,600	140	370,137	86,628,302
Total	**84**	**24,096**	**27,706,000**	**23**	**1,965,200**	**7,541,600**	**1,999**	**7,098,141**	**1,104,593,127**

* Total steady state live weight is a standardized measure in pounds calculated from number of animals.

The presence of concentrated animal operations on river floodplains has been shown to be a danger to fish survival and habitat suitability (Mallin et al. 2000a; Mallin et al. 2001c). Animal wastes are highly concentrated sources of nutrients, fecal coliform bacteria and other pathogenic microbes, and oxygen-consuming materials (Sobsey 1996; Burkholder et al. 1997; Mallin et al. 1997; Mallin et al. 2000a). Waste from animal operations is commonly discharged into lagoons, where it undergoes some anaerobic digestion and is then sprayed on fields. Pollutants may be transported into surface waters or groundwater if the lagoon ruptures, leaks or overflows. Pollutants can also enter groundwater beneath sprayfields and move laterally down slope toward streams (Mallin et al. 2000a). Between 1995 and 1999, multiple animal waste lagoon accidents and several hurricanes resulted in breaching, overtopping, and flooding of animal waste into coastal waters (Burkholder et al. 1997; Mallin et al. 1997; Mallin et al. 2000a). Lagoon waste also entered streams via spraying onto fields already saturated from rain (Mallin et al. 2000a; Mallin et al. 2001c). In 1995, the spilling of concentrated animal wastes into coastal waters in the lower Cape Fear and New Rivers resulted in anoxic and hypoxic conditions; high nitrogen and phosphorus concentrations; dense phytoplankton blooms, high bacteria levels, high turbidity, and fish kills (Burkholder et al. 1997; Mallin et al. 1997).

Groundwater can be contaminated through leaking lagoons (lined and unlined) or leaching of waste applied on sprayfields (Burkholder et al. 1997; Huffman 1999; Mallin 2000). An NCSU study found that 38% of older unlined lagoons leaked nitrogen into ground water at strong or very strong levels (Huffman 1999) and a DENR study found that approximately 25% of lined facilities also leaked nitrogen into groundwater, although sample size was very small (11 wells) (<http:www.p2pays.org/ref/13/12315.pdf>, 2004). Research has demonstrated that use of spray fields by concentrated animal operations chronically and significantly impact surface and groundwater resources due to surface runoff, subsurface flow, and air deposition (Stone et al. 1995; Gilliam et al. 1996). Increased levels of nutrients in the air and deposition into coastal waters have been associated with the substantial increase in livestock operations (Paerl and

Whitall 1999). Approximately two-thirds of the nitrogen in the swine excretions are emitted to the air due to the design of lagoon and sprayfield systems. Swine facilities are responsible for an estimated 20% of North Carolina's total atmospheric nitrogen compounds, 53% of which was contributed by eastern North Carolina alone (Paerl and Whitall 1999). Those compounds react with other constituents in the air and are deposited on land, vegetation, and water bodies.

The N.C. legislature has taken a number of steps to reduce water quality impacts from animal operations [15A NCAC 8F .0100-.0500]:

- Since 1997, operators at swine facilities with 250 or more animals are required to be trained.
- Beginning in 1996, new and expanding facilities are required to obtain permit.
- In 1997, DWQ was directed to inspect all animal waste management facilities annually.
- A moratorium on new or expanding swine operations was imposed in 1997 and has been extended several times. The moratorium currently extends to 2005.
- DENR was required to develop and adopt economically feasible odor control standards.

In addition, the Clean Water Management Trust Fund (CWMTF) provided funds to the Division of Soil and Water Conservation to buy out hog farms located in floodplains. To date, 14 swine operations have been bought out at cost of $5,737,500. In 2002 the Division of Soil and Water Conservation received a second grant of $6,062,000, which will be used to buy out approximately 11–12 additional operations (D. Williams, DLR, pers. com., 2002). *More funding is needed to buy out or relocate additional animal operations from environmentally sensitive areas. The moratorium should remain in effect until alternative waste treatment is implemented that will reduce pollutant loading to streams and nitrogen release into the air. In addition EMC should phase out use of waste lagoons or reclassify waste lagoon systems from nonpoint to point source discharges, and be permitted accordingly, as recommended in DENR's Neuse River Nutrient Sensitive Waters Management Strategy (DWQ 1997b).*

Research on cost-effective alternatives to the lagoon and sprayfield system is underway (D. Ramsey, DWQ, pers. com., 2002). As of 2004, several alternatives have been evaluated, but many are very costly and may not be economically feasible (P. Sherman, DWQ, pers. com., 2004). *Some environmentally superior alternatives to the current lagoon and spray field systems were identified in the Smithfield Agreement. The early implementation of these superior alternatives should be encouraged.*

Other ongoing initiatives to reduce water quality impacts from crop or animal agriculture include the Conservation Reserve Enhancement Program (CREP) and the Farmland Protection Program. CREP targets riparian protection and wetland restoration in river basins designated as Nutrient Sensitive Waters. Objectives include reducing sediment and nutrient impacts through installation of forested riparian buffers, grassed filter strips, wetland restoration BMPs, water control structures, and livestock exclusion. Landowners in the Neuse, Tar-Pamlico, and Chowan river basins and the Jordan Lake watershed are eligible to participate in CREP. The 2002 Farm Bill represents an unprecedented investment in conservation on private lands, committing over $13 billion nationally over a six-year period (USDA 2002). In 2002, The Farmland Protection Program allocated over $2 million to North Carolina and the Wetlands Reserve Program allocated $5 million. The funding will be used primarily to purchase conservation easements and provide technical and financial assistance to landowners to address wetland, wildlife habitat, soil, water, and other natural resource concerns. *Consideration should be given to a allocating a greater portion of agricultural conservation funds to the buy out or relocation of animal operations from sensitive areas, and for the purchase of conservation easements.*

These initiatives offer promise in reducing pollutant inputs from agriculture, but voluntary BMPs for agriculture have not been adequate to protect environmentally sensitive areas such as primary nursery areas (Preyer 1994). However, there has been some success reported for voluntary efforts by farmers to reduce nonpoint pollution in the Tar-Pamlico River basin (D. Williams, Div. of Soil and Water Conservation, pers. com., 2004). *Additional measures to reduce inputs from agriculture should be*

considered by the CRC, EMC, MFC, and NRCS, such as removing their exclusion of agriculture from CRC and EMC regulations, expansion of funding for BMPs and cost-share programs for nonpoint pollution control.

In June 2002, the N.C. General Assembly took a major step toward reducing nitrogen and sulfur emissions from power plants by enacting the "Clean Smokestacks" Act. The Air Quality/Electric Utilities law requires significant emissions reductions from coal-fired power plants in North Carolina. Under the Act, power plants must reduce their nitrogen oxide emissions 77% by 2009 and sulfur dioxide emissions 73% by 2013. The cuts in both SO_2 and NO_x emissions will improve respiratory conditions for North Carolina residents, as well as reduce acid rain and airborne deposition of nitrogen in coastal waters. Certain technologies used to reduce SO_2 and NO_x also reduce mercury emissions. A statewide mercury advisory currently warns against consumption of four ocean fish species (king mackerel, shark, swordfish, and tilefish) and three freshwater fish species (bowfin, chain pickerel, and largemouth bass) in eastern North Carolina because of high mercury levels. The Act also requires DENR to evaluate issues specifically related to the control of mercury and carbon dioxide emissions and make recommendations on the development of standards and plans to control these emissions.

Automobiles are the largest contributor of air pollution in North Carolina. This is attributed to increasing urban sprawl; members of a more dispersed human population typically drive longer distances per day in vehicles, contributing to increased nitrogen emissions. *The Division of Air Quality and DENR should implement the planned expansion of car inspections as soon as possible. In addition, North Carolina legislators, state agencies, and local governments should adopt coast-wide or state-wide "Smart Growth" policies that provide incentives and direct growth into more highly developed areas and preserve rural land uses.*

Nutrients are also transported into coastal waters through shoreline erosion processes. A study in the Chesapeake Bay region found that sediments from eroding high bank shorelines were significant sources of nitrogen and phosphorus loading (Ibison et al. 1992). The nutrient loading rates from highly eroding shorelines in the study varied considerably but were higher than that estimated from typical agricultural runoff. Adjacent land use was also a factor in nutrient loading concentrations in eroding sediments. In the Chesapeake study, sediment from active farms had the greatest average total nitrogen and phosphorus loading concentrations (Ibison et al. 1992). A study by UNC-W, in New Hanover County, found that soils under suburban and golf course grasses were highest in phosphorus, followed by soils in wet detention ponds and runoff channels. Soils in undisturbed forests had the least phosphorus associated with them (Mallin et al. 2002a). Their results indicated that fertilizer use was positively correlated with phosphorus levels. Both studies suggest that sites with high sediment loss and intense fertilizer use, such as agricultural land, golf courses, or manicured lawns, have high potential for nutrient contributions to the water column. *North Carolina's shorelines should be evaluated to identify potential hot spots of nutrient inputs from eroding shorelines. Additional education is also needed on proper application of fertilizers to reduce runoff of nutrients into coastal waters, targeting homeowners, golf course owners, and landscape businesses (Mallin and Wheeler 2000).* New Hanover County recently produced a publication entitled "Homeowner's Guide to Lawncare Best Management Practices" that offers information on proper dosages and methods of fertilizer application and other lawn care strategies. *Similar efforts are needed to reach and educate all fertilizer users throughout coastal North Carolina.*

Mallin and Wheeler (2000) studied the effect of golf courses in New Hanover and Brunswick counties on water quality in adjacent water bodies. This study found that ammonium and orthophosphate appeared to be fairly tightly bound to the soils and remained on site during normal base flow conditions. However, nitrate levels in streams leaving golf courses were greater than streams entering the courses. Nitrate levels at some sites were high enough to cause significant increases in phytoplankton biomass and algal blooms in the spring and summer. Nitrate levels varied widely and appeared to be related to stormwater management practices. Waters adjacent to golf courses having vegetated buffer zones, wet detention

ponds, and wooded wetland areas had considerably lower nutrient levels than sites without these landscape features and management tools (Mallin and Wheeler 2000). *BMPs, including vegetated buffers, detention ponds, and wetland areas, should be required on all new and existing golf courses draining to coastal waters to help reduce nutrient concentrations.*

Status and trends in nutrient enrichment

Nutrient levels can be measured directly (levels of nitrogen and phosphorus) or indirectly (chlorophyll *a* concentrations). Chlorophyll *a*, a component of most algae, is a commonly used indicator of algal biomass and relative nutrient levels. The North Carolina standard for chlorophyll *a* in lakes, reservoirs, and slow-moving waters not designated as trout waters is 40 μg/l. Concentrations greater than the standard are an indication of a nutrient problem and potential algal bloom. The miles of freshwater streams and acres of estuarine waters that were classified as impaired by chlorophyll *a* for the 1995-1999 time period are shown in Tables 2.24 and 2.25. In terms of measurements, the Neuse River has the most estuarine acres impacted by nutrients, followed by the Tar-Pamlico and White Oak river basins. In the freshwater portion of the river basins, the White Oak had the most stream miles impaired by chlorophyll *a*, followed by the Neuse and Cape Fear river basins. However, this is only one indicator of nutrient enrichment. For example, in the lower Cape Fear River, Mallin et al. (2001c) reported reasonably high nutrient levels in the river channels, but algal blooms rarely occurred. This was attributed to high flushing and reduced water clarity from turbidity and color, which reduced photosynthesis (Mallin et al. 2001c).

Table 2.24. Number and percentage of impaired freshwater stream miles by major pollutant causes and river basins,1995-1999. (Source: DWQ 2000a)

Major Causes		DWQ River Basin							
		Cape Fear	Chowan	Neuse	Pasquotank	Roanoke	Tar-Pamlico	White Oak	Totals
Ammonia (NH_3)	Miles	12	0	0	0	0	0	0	**12**
	%	3.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.9**
Fecal coliform	Miles	130	0	3	0	0	13	0	**146**
	%	32.2	0.0	0.7	0.0	0.0	16.3	0.0	**11.1**
Habitat Degradation[1]	Miles	284	4	164	0	38	0	0	**490**
	%	70.3	3.1	35.8	0.0	20.5	0.0	0.0	**37.3**
Low DO	Miles	0	46	132	40	24	13	8	**263**
	%	0.0	35.7	28.8	83.3	13.0	16.3	72.7	**20.0**
Chlorine	Miles	4	0	0	0	0	0	0	**4**
	%	1.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.3**
pH	Miles	0	51	7	28	0	0	0	**86**
	%	0.0	39.5	1.5	58.3	0.0	0.0	0.0	**6.5**
Turbidity	Miles	26	0	5	0	0	0	0	**31**
	%	6.4	0.0	1.1	0.0	0.0	0.0	0.0	**2.4**
Metals	Miles	0	0	0	0	13	0	0	**13**
	%	0.0	0.0	0.0	0.0	7.0	0.0	0.0	**1.0**
Chlorophyll a	Miles	1	0	7	0	0	0	11	**19**
	%	0.2	0.0	1.5	0.0	0.0	0.0	100.0	**1.4**
Total impaired miles		**404**	**129**	**458**	**48**	**185**	**80**	**11**	**1315**

[1] Habitat degradation is identified where there is a notable reduction in habitat diversity or change in habitat quality. This term includes sedimentation, bank erosion, channelization, scour, loss of pools or riffles, and loss of woody habitat.

Table 2.25. Number and percentage of impaired estuarine acres by major pollutant causes and river basins, 1995-1999. (Source: DWQ 2000a)

River Basin	Major Causes (Acres)		
	Fecal coliform	Low DO[1]	Chlorophyll a
Cape Fear	3,602	5,000	0
Lumber	2,622	0	0
Neuse	3,588	0	28,950
Pasquotank	4,862	1,125	0
Tar-Pamlico	4,825	0	3,455
White Oak	8,936	0	3,005
Totals	28,435	6,125	35,410
% PS or NS miles*	41	9	51

[1] DO = Dissolved oxygen

* PS = partially supporting, NS = not supporting

Another factor which affects chlorophyll *a* concentrations is tidal stage. A study of tidal creeks in New Hanover County found that chlorophyll *a* concentrations were greatest at mid to low tide (Mallin et al. 1999a). The reason for higher nutrient levels at lower tides was primarily attributed to the transporting of nutrients from the adjacent marsh and headwater areas. Headwater areas often have the highest chlorophyll *a* concentrations within a tidal creek (Laws et al. 1994; Mallin et al. 1996; Mallin et al. 1999a). Other studies have also found that falling tides transport algae from upstream to downstream sources (Litaker et al. 1987; 1993).

Based on NAWQA results from the mid-1990s, nutrient concentrations in the Albemarle-Pamlico basin were high relative to other areas in the country (Spruill et al. 1998). Several stations in the Neuse and Tar-Pamlico systems were among the highest 25–50% of stations sampled in the United States, with the Neuse River having the highest nitrogen and phosphorus yields. The lowest nutrient levels occurred in streams of the predominantly forested Chowan River basin. Permitted point sources (municipal wastewater treatment plants and industrial facilities) of nitrogen and phosphorus account for less than 5 percent of the nutrient source inputs in all basins. However, pollution from these sources enters directly into streams, contributing up to 20 percent of the in-stream nutrient load. Intensive agriculture, wastewater discharges, and urban runoff from Piedmont areas contributed to particularly high concentrations in the Neuse and Tar-Pamlico river basins. A geologic source also contributes to naturally high phosphorus in the Neuse and Tar-Pamlico.

Although nutrient levels were relatively high, the NAWQA study found that nitrogen and phosphorus concentrations in streams had shown a general decline since 1980 in all four basins. The decrease in nutrient levels was thought to be due to improved agricultural practices, the phosphate detergent ban in 1988, and improved water treatment practices. Although nutrient levels declined, they remained high enough in the Tar-Pamlico and Neuse river basins to continue causing algal blooms. In fact, the authors estimated that a 50% reduction of nitrogen and phosphorus concentrations in the Neuse River and a 30% reduction in the Tar River during summer months were needed to reach levels that will reduce the incidence of nuisance algal blooms and fish kills to more natural levels.

The National Oceanic and Atmospheric Administration's Estuarine Eutrophication Survey assessed the scale and scope of nutrient enrichment and eutrophication in the North Atlantic, South Atlantic and Gulf coasts (NOAA 1996). The report summarizes status and trends in tidal freshwater, mixing, and seawater zones of Albemarle-Pamlico sounds, Pamlico-Pungo rivers, Neuse River, Bogue Sound, New River, and Cape Fear River from 1970 to 1996. Medium or greater concentrations (>5 ug/l) of chlorophyll *a* occurred in 19 of 21 South Atlantic estuaries, and were most frequent in estuarine mixing zones (66% of the areas sampled). High (>20 ug/l) concentrations were reported periodically in 11 of 21 estuaries. Nuisance and toxic algae events occurred throughout all salinity zones in the South Atlantic but were concentrated in North Carolina estuaries (NOAA 1996). The upper Pamlico River and the Neuse River had increasing chlorophyll *a* concentrations in the mixing zone, while most others showed no trend or a decreasing trend, especially in the tidal freshwater and mixing zones (NOAA 1996). The only systems that did not have a problem with nuisance or toxic algae at that time were Bogue Sound and the Cape Fear River. The remaining systems reported algal blooms at least once during the course of the year. Some of the Albemarle-Pamlico system estuarine waters experienced the most severe problems. Because the Albemarle-Pamlico estuaries are wind driven systems and do not directly drain into ocean waters, tidal flushing is limited and weak. Consequently, nutrients and detrital matter are stored in the sediments, maintaining eutrophic conditions (Luettich et al. 1999).

The Neuse River MODMON research has found that riverine discharge, nutrient loading, and circulation (flushing and stratification) are strongly related and primarily determined by weather patterns. Irregular weather patterns and lack of long-term data complicate trend analysis. In addition, because of the shallow depth of the estuary, the bottom sediments store and release nutrients and carbon that can fuel algal blooms or low-oxygen events, independent of new sources, making it difficult to evaluate the

effectiveness of nutrient reductions and management actions (Luettich et al. 1999). Some important findings of the research pertinent to fish habitat include:

- Nitrogen loading has declined since 1999.
- Blooms in the upper system north of New Bern have declined. This is attributed to wastewater treatment plant improvements.

Priority research regarding nutrient enrichment, identified by the MODMON team, includes:

- Obtaining better information on rates of nutrient exchange, carbon processing and residence time in the estuarine system.
- Improving understanding of the transfer of nutrients and organic matter between primary producers, zooplankton, and benthic invertebrates; and fish to better assess the relationship among water quality, fish habitat and fish productivity.
- Developing a watershed model that tracks the fate and transformation of nitrogen through the watershed from the point of origin (i.e., outfall, stream edge, smoke stack) to the time it enters the estuary. The model should be used with water quality models to improve development and evaluation of management options.

A five-year study (1993-98) on nutrient loading and chlorophyll abundance in the Neuse River estuary by the NCSU Center for Applied Aquatic Ecology indicated a 14% reduction in phosphorus loading to the estuary, but increases in total nitrogen (+16%) and inorganic nitrogen (+38%) (Glasgow and Burkholder 2000). There was also a decrease in chlorophyll *a* concentrations over the period. Since that period and during the drought years 2000-2002, nitrogen loading stabilized but chlorophyll *a* increased by 25%. The authors recommended increased reduction of inorganic nitrogen inputs and co-management of phosphorus due to expanding swine production (285% increase observed from 1990-1999) and human population increase (17% increase observed from 1990-1999) in the watershed.

The Lower Cape Fear River Program (UNC-W) has monitored nutrients and other parameters since 1995. Total nitrogen was higher and more variable during 1996 and 1997 than in 1995, and leveled off between 1998 and 2001. This was thought to be due to flushing of accumulated organic matter from swamp waters into the channels during 1996 and 1997 hurricane seasons, reducing the excess organic nitrogen available during subsequent hurricanes (Mallin et al. 2001c). Total nitrogen loads were somewhat lower in blackwater rivers than in the mainstem Cape Fear River. In 2000-2001, nitrate levels, the main form of inorganic nitrogen in the lower Cape Fear River, were slightly lower than the five-year averages, except at three stations. Sources of high nitrate concentrations were nonpoint agriculture and animal waste drainage, and industrial and municipal wastewater discharges. Total phosphorus concentrations in 2000-2001 in riverine stations and the upper estuary were higher in 2000-2001 than the six-year average, while concentrations in the middle and lower estuary were lower. Like nitrogen, phosphorus was highest at upstream stations, declining in estuarine waters seaward to the ocean. At stations with high total phosphorus, industrial or municipal wastewater discharge was considered the primary source (Mallin et al. 2001c).

The Cape Fear Program's tidal creek monitoring found that nutrient loading was high enough in several of the creeks (Bradley and Hewlett creeks, both in southern estuaries MU) to support small algal blooms periodically. The high nutrient concentrations in Hewletts Creek were largely attributed to two golf courses that drain to the creek. Futch Creek has continued to maintain good water quality in terms of nutrients since the mouth of the channel was dredged in 1995–1996. Futch Creek and Pages Creek have the least development and impervious surfaces in their drainage area compared to the other creeks studied, and the least water quality degradation. *Areas like Futch or Pages Creek, that have relatively good water quality condition and are important nursery and shellfish producing areas, should be a high priority for water quality maintenance and protection through stormwater control BMPs, such as vegetative buffers and impervious surface limits and land conservation. Comprehensive sampling, similar to that done in the Tidal Creeks Program in New Hanover County, is needed for other tidal creeks*

in Brunswick, Pender and Onslow counties that are highly important nursery and shellfish areas.

Oxygen depletion and fish kills

Low-oxygen conditions can occur naturally in a system from flushing of swamp waters, which characteristically have low DO, or from stratification of the water column due to wind, temperature, and salinity conditions. However, low-oxygen conditions can also be fueled by nutrients and oxygen-consuming wastes, which result in excessive oxygen demand in the water column or sediment. Algal blooms deplete the water column of DO as respiration from the dense concentrations of plants consumes oxygen at night (DWQ 2000b). Dissolved oxygen can be further depleted as bacteria use oxygen to decompose the algae's organic material. The algal blooms may occur naturally in coastal waters or occur with greater frequency or intensity upon inputs of nutrients. Dissolved oxygen depletion in the water column occurs most often in summer. Warmer water holds less DO and increases microbial decomposition. In addition, warmer water, calm winds, and reduced freshwater inflow in the summer reduce mixing and aeration of water. The stratified bottom layer of water is prevented from receiving oxygenated surface waters and rapidly becomes depleted of oxygen. Shallow water estuaries with less frequent flushing often develop persistent stratification and bottom-water hypoxia that can last for weeks to months (Tenore 1972).

Low-oxygen events frequently occur as a result of increased runoff and organic loading from heavy rainfall. The habitat and fishery impacts of weather events can be either positive or negative. For example, hurricanes can flush out large quantities of organic matter that has accumulated in estuarine systems, temporarily causing low dissolved oxygen, but reducing excessive nutrients that could otherwise fuel eutrophication over many years.

Prolonged periods of hypoxia or anoxia can cause stress or mortality of many aquatic organisms. One of the most visible effects of oxygen depletion is a fish kill event. According to NOAA, the leading cause of fish kill events in 22 coastal states from 1980 – 1989 was low DO (Lowe et al. 1991). Atlantic menhaden and other small schooling fish were noted as the most affected in estuarine waters. In North Carolina, this has also been the case; in 2001 DWQ attributed 34% of the fish kills to low DO and 4% to algal or dinoflagellate blooms. Other reported causes of fish kills included bycatch mortality, extreme temperatures, waste, chemical, and pesticide spills (DWQ 2001b). Although *Pfiesteria*-like cells were identified with some fish kill events, toxic *Pfiesteria* was not reported as a cause in any of the 2001 fish kills (DWQ 2001b). Low oxygen has been identified as a major water quality problem in Chesapeake Bay for blue crabs, and low DO has local impacts on menhaden, bay anchovy, spot, white perch, and striped bass (<http://www.chesapeakebay.net/>, 2003). Although fish can migrate away from hypoxic areas and seek refuge in shallower oxygenated waters, wind-driven circulation can rapidly transport the hypoxic bottom-water into shallow waters, trapping fish and causing large fish kills of estuarine fish (Paerl et al. 1998).

From 1996 to 2000, the annual number of reported fish kill events remained fairly consistent, ranging from 54 to 60 per year, but increased to 77 in 2001 (DWQ 2001b). Coastal river basins account for the majority of these fish kills (Table 2.26). Some of the fish kills in 1996 were associated with Hurricanes Fran and Bertha (L. Henry, DMF, pers. com., 2003). Total fish mortality has varied annually but generally increased, with total mortality ranging from 92,000 in 1997 to over 1.3 million in 2001. July and August are the peak months of fish kill occurrence (DWQ 2001b).

Table 2.26. Fish kill events reported in the coastal river basins, 1996-2001. (Source: DWQ 2001b)

River basin	Year						
	1996	1997	1998	1999	2000	2001	Total
Neuse	14	12	8	16	23	37	110
Cape Fear	21	16	23	14	12	5	91
Tar-Pamlico	3	6	5	11	14	23	62
Pasquotank	10	2	8	2	0	1	23
White Oak	3	3	1	3	3	3	16
Lumber	4	3	5	0	2	0	14
Chowan	2	2	1	1	0	1	7
Roanoke	2	0	1	0	0	0	3
Total	**59**	**44**	**52**	**47**	**54**	**70**	**326**

In 2001, fish kills were concentrated in the Neuse (37 fish kill events) and the Tar-Pamlico river basins (23 events). Fish kills in the Neuse River were clustered in the upper sub-basins near Wake County and the lower sub-basins between New Bern and Minnesott Beach. Fish kills in the Tar-Pamlico River were clustered downstream of Washington and around the Pungo River. Map 2.17 shows the location of fish kills within the CHPP MUs from 1999-2001. Although fish kills have been reported in all of the eight coastal river basins between 1996 and 2001, the majority of the fish mortality occurred in the Neuse, Tar-Pamlico, and Cape Fear river basins (DWQ 2001b). Since 1999, the number of fish kill events in the Cape Fear system has declined while the Neuse and Tar-Pamlico systems have increased. In the coastal river basins, fish kills have been least abundant in the Roanoke and Chowan river basins.

Over twenty different fish species were identified in fish kills in 2001 by DWQ (Table 2.27). The suspected causes of the fish kills included low DO, algal blooms, chemical spills, bycatch, and hog lagoon spills, as well as unknown factors. Low DO accounted for 34% of the fish kills, while algal blooms were only reported as a factor in 4% of the events (DWQ 2001b).

Table 2.27. Fish species observed during 2001 fish kill events, from most frequently occurring to least. (Source: DWQ 2001b)

Estuarine		Fresh water	
Species	Events	Species	Events
Menhaden	32	Sunfish	29
Flounder	11	Catfish	15
Shad	9	Largemouth Bass	12
Croaker	8	Perch	11
Spot	7	Crappie	8
Pinfish	7	Carp	4
Mullet	4	Mosquitofish	3
Minnow	3	Pickerel	2
Anchovy	2	Gar	2
Bluefish	2	Eel	2
Killifish	2	Sucker	1
Spotted seatrout	1	Darter	1
Drum	1		

In addition to suffocation, fish are impacted by low-oxygen conditions due to an associated increase in sulfide production in bottom sediments. This combination of conditions is lethal to many benthic organisms (Tenore 1972), which can have significant effects on the aquatic food chain (Peterson et al. 2000a; Taylor and Eggleston 2000). Mortality began to occur after species were exposed to 0.5-1.0 mg/l oxygen for five days (90% mortality of blue crabs after exposure for about 3 days), although many species, such as the mud crab *Neopanope sayi*, the serpulid polychaete *Hydroides dianthus*, the polychaete *Sabellaria vulgaris*, and the hydroid *Obelia bicuspidata* survived in hypoxic waters for more than one week (Sagasti et al. 2001). Taylor and Eggleston (2000) found that low DO concentrations hindered the foraging abilities of blue crabs, and increased clam vulnerability since they moved higher to the sediment surface and increased siphon extension in response to low-oxygen conditions. Benthic hypoxia and anoxia degrade fish habitat by altering the behavior, growth, production, and survival of both benthic invertebrates and mobile vertebrates (Breitburg 1992).[19]

Status and trends of fish kills and dissolved oxygen

In freshwater streams, DWQ use support data indicate low DO as a major cause of impairment in the Neuse River basin (132 mi), Chowan River basin (46 mi), Pasquotank River basin (40 mi), Roanoke River basin (24 mi), Tar-Pamlico River basin (13 mi), and White Oak River basin (8 mi) (DWQ 2000a; Table 2.24). In estuarine waters, low DO was a major source of impairment in the Cape Fear (5,000 acres) and the Pasquotank river basins (1,125 acres) (Table 2.25). Although there is a direct relationship between eutrophication and low DO, use support data did not consistently show significant DO impairment where chlorophyll *a* impairment was high. This inconsistency may be due to highly variable and complex environmental conditions or DWQ monitoring limitations.

An analysis of DO data (<www.marine.unc.edu/neuse/modmon/results/results.htm>, 2003) from Neuse River MODMON stations indicated:

- Benthic and pelagic respiration are capable of fully depleting the oxygen pool in stratified bottom water in less than 5 days during summer months.
- Since the sediment oxygen demand (SOD) is much greater than biological oxygen demand (BOD) in the water column, the SOD and benthic fluxes will control how the estuary responds to long-term reductions in nutrient loads.
- Oxygen depletion is positively correlated with the accumulation of organic material in the sediments from water column production (algal blooms) or external organic matter loading and appropriate environmental conditions.
- Low-oxygen conditions occur more often and for longer duration in deeper portions of the water column. During the summer of 1997, these conditions caused lethal and sublethal stress of benthic infauna in the deeper sections of the estuary. The benthos affected included species that are important forage for demersal fish species, such as spot and croaker.

The Lower Cape Fear River Program (UNC-W) reported that low DO continues to be a major water quality problem in the river system, and an occasional problem in the tidal creeks system (Mallin et al. 2002a). More than one-third of the sites sampled on the Cape Fear River and its tributaries were impacted by low DO, with lower DO in the blackwater rivers than in the mainstem of the Cape Fear. Low DO in the blackwater systems occurs naturally because decaying vegetation on the swamp floor elevates BOD and consumes oxygen from the water. Oxygen levels are generally lowest during the summer and during hurricane years. Biochemical oxygen demand appears to be highly dependent on stream flow. BOD at most sites in 2000-2001 averaged around 1.0 mg/l. However, because river water quality was affected by hurricanes in three of the five years, the data are not thought to be representative of "background conditions," but do provide understanding of the system's response to storm events.

[19] Refer to the Soft Bottom chapter for additional information on the impact of nutrient enrichment, low oxygen, and dinoflagellate blooms on clams. The Shell Bottom chapter also contains information on the effects of eutrophication on fish habitat.

Recent research in Coastal Plain systems has determined that nitrogen and phosphorus loading to blackwater streams can lead to increased BOD (Mallin et al. 2001a). Nitrogen loading can cause algal blooms, which die upon entering deeper rivers and become sources of BOD. Phosphorus loading directly stimulates bacterial growth, which increases the BOD load, thus leading to reduced DO and degraded fish habitat.

In conclusion, low-oxygen conditions have been documented to cause fish kills in multiple river basins in North Carolina. While hypoxic and anoxic events can occur naturally, eutrophication aggravates low-oxygen conditions. *Coastal research and monitoring needs to continue to improve our understanding of the processes of hypoxia and anoxia and the effect on fish populations. Efforts to reduce nutrient loading from point and nonpoint sources in the Neuse, Tar-Pamlico, and Cape Fear river systems, where the largest number of fish kills have occurred, should continue and be increased as necessary.* Of these river systems, the Cape Fear is the only river that does not have Nutrient Sensitive Waters classification and associated nutrient reduction strategies. *Implementation of mandatory riparian buffers along the Cape Fear, as well as other strategies, should be considered.*

Sediments

The dynamic process in which the physical energy of waves, tides, and currents is transferred to the shoreline ultimately results in the erosion, transport and deposition of sediment in aquatic systems. Shorelines will respond differently to wave and current energy, depending on the source and magnitude of energy, topography of land, substrate, and vegetative cover. Shoreline erosion and sediment transport are ongoing natural processes (Riggs 2001). However, erosion and sediment loading can be accelerated by human activities and sea level rise. Excessive sediment loading is considered a pollutant in aquatic habitats.

High sediment levels in the water column increase turbidity. Increased turbidity reduces water clarity, which in turn reduces primary production by phytoplankton and submerged aquatic vegetation (SAV) (North Carolina Sea Grant 1997). The reduction in light availability due to turbidity is the primary limiting factor of SAV distribution.[20]

Excessive suspended sediments can impact aquatic animals by clogging gills and pores of juvenile fish and invertebrates, which can result in mortality or reduced feeding (Ross and Lancaster 1996). Increases in the amount of nonfood particles ingested by shellfish and polychaetes lowers the nutrient value of their diet and their growth rates (SAFMC 1998a). Excessive sediment loading from nonpoint sources can gradually fill in creeks and small waterbodies over time, reducing the depth and width of channels. This, in turn, alters currents and can bury benthic organisms, including entire oyster or mussel beds (Schueler 1997; P. Peterson, UNC-IMS, pers. com., 2003). Successful recruitment of invertebrate larvae may also be reduced (Reilly and Bellis 1983; Hackney et al. 1996; SAFMC 1998a; Peterson et al. 2000b; AFS 2003). Increased turbidity has been shown to lower feeding success and efficiency of adult and juvenile visually oriented predators such as bluefish, and pompano (Lindquist and Manning 2001), or to disrupt spawning migrations and social hierarchies (Reed et al. 1983).

Suspended sediment absorbs toxic chemicals, heavy metals, phosphorus, and bacteria, providing a mechanism for pollutants to be transported farther downstream, where they may be ingested by filter feeding fish and invertebrates (Steel 1991). Fecal coliform and other pathogenic bacteria also survive longer in turbid water (Schueler 1999). Sedimentation removes these pollutants from the water column but stores them indefinitely. For example, results from the MODMON project have estimated that the amount of nitrogen and organic carbon stored in the upper 2 cm of bottom sediments is ten times more than the amount of total nitrogen content in the entire 3-4 m water column (Luettich et al. 1999). Once

[20] Refer to the SAV section for more information on the relationship between sediment loading and SAV, and their status and trends.

bottom sediments are resuspended, the contaminants can be released back into the water column. As the oxygen of the water near the sediment interface is reduced, the release of phosphorus, iron, and manganese increases markedly (Wetzel 1983).

Sources of turbidity and sedimentation

The primary human sources of increased sediment loading include most land disturbing activities such as building and road construction, post-construction stormwater runoff from urbanized areas, agriculture, timber harvesting, animal operations, mining, and removal of vegetated buffers (DWQ 2000b). Dredging, mining, and boating activities resuspend bottom sediments. Bottom disturbing fishing activities that generate turbidity in the water column include bottom trawling, clam kicking, and hydraulic clam dredging.[21] Hydromodifications to stream channels also increase sediment loading. Municipal and industrial wastewater treatment discharges (point sources) can be a minor source of sediment. Of all the sources of sediment loading, sedimentation from agriculture has been cited as one of the largest contributors to water pollution in the southeastern states (SAFMC 1998a). The EPA concluded that siltation and nutrients impair more miles of assessed rivers and streams than any other pollutant, affecting 45% and 37% of impaired rivers and streams, respectively.

Streambank erosion can be accelerated by increased flow and velocity of stormwater runoff (Beach 2002) or from bank destabilization. In naturally forested systems of the southeast, there is very little surface runoff during and after a rainfall event, since the rainwater flows slowly over vegetated land, and infiltrates the soil (Beach 2002). Increasing impervious surfaces associated with urban/suburban development, recreational facilities, industrial/commercial activities, and land transportation result in higher volumes and rates of flow into receiving streams. Bank failures can occur when stream banks are subjected to high flows, intense or prolonged use by livestock, or vehicle crossings. Sediment inputs will generally be high where erosion rates are high and shorelines are unstable. Loss of buffer zones along streambanks can greatly contribute to bank erosion. Although shoreline stabilization with vertical structures may help retain sediments, erosion is often intensified adjacent to and in front of stabilized shorelines (Crowell 1998; Pilkey et al. 1998).

The rate of erosion and resulting sediment loading along North Carolina shorelines depends on shoreline orientation, fetch, water depth, bank height, sediment composition of bank, shoreline vegetation, presence of offshore vegetation, and boat wakes (Riggs 2001). In general, all of the Albemarle-Pamlico estuarine system is in a state of shoreline recession. South of Bogue Sound, erosion is severe only in portions of drowned river estuaries such as the Cape Fear, New, and White Oak rivers, and along the ICW and navigational channels. The remaining narrow, shallow estuaries are generally not eroding, as the marshes and flats vertically accrete sediment to keep up with rising sea level. Riggs (2001) mapped the shoreline types and shoreline areas where erosion was noticeable, and areas that had been significantly bulkheaded. Shoreline erosion rates have been estimated for portions of the coast by various studies including Stirewalt and Ingram (1974), USDA Soil Conservation Service (1975), Hartness and Pearson (1977), Riggs et al. (1978), and Hardaway (1980). Their results are summarized and compared in Riggs (2001). These studies are helpful in indicating where major erosion problems are occurring. *Updated and accurate coast-wide estuarine erosion rates are needed for the CRC and EMC in determining adequate development guidelines and regulations along the coast (DCM 2002).*

An important factor in sediment loading from shoreline erosion is the effect of global climate change on sea level rise (IPCC 1990). According to Riggs (2001), sea level is rising at a rate of approximately 1.01-1.5 ft/100 yr in North Carolina. If sea level continues to rise at the current rate, there is a 50% chance that by the year 2200, with the influence of global climate warming, the rate of sea level rise could increase two to three times greater than its current rate. An accelerated rate of sea level rise could adversely impact the water column by accelerating the rate of coastal erosion and land loss, submerging portions of

[21] The impact of these gears is dealt with in greater detail in the soft bottom section of this plan.

barrier islands, and increasing the loss of wetlands, which filter and trap sediment and other pollutants.

Status and trends in turbidity/sedimentation

North Carolina has no water quality standard for total suspended solids (TSS), but point source dischargers must meet minimum federal effluent guidelines of 30 mg/l for total suspended solids. Where effluent discharges to High Quality Waters (HQWs) that are primary nursery areas, the TSS limit is 10 mg/l; other HQWs have a TSS limit of 20 mg/l. Turbidity in streams is an indication of suspended sediment conditions and water clarity. The turbidity standard is 25 NTUs in estuaries and lakes/reservoirs not designated as trout waters, and 50 NTUs in other freshwater streams (DWQ 2000b). DWQ identified turbidity as a cause of use support impairment for the 1995 – 1999 period in portions of the Cape Fear and the Neuse River basins (Table 2.24).

Sediment impairment is also included in an evaluation of habitat degradation. The DWQ, in categorizing causes of use support impairment in freshwater streams, defines "habitat degradation" as a notable reduction in habitat diversity or change in habitat quality. Habitat degradation includes channelization, sedimentation, bank erosion, scour, loss of pools or riffles, and loss of woody habitat (DWQ 2000a). Habitat degradation was identified as a major cause of use support impairment in the Cape Fear, Neuse, Roanoke, and Chowan river basins for the 1995 – 1999 period (Table 2.24), with Cape Fear having the largest percentage of stream miles impaired by habitat degradation (284 mi., 70% of evaluated streams) and Chowan the least (4 mi., 3%). Of all major categories of use support impairment, habitat degradation accounts for the greatest overall cause of impairment in all coastal river basins combined (490 mi., 37%). Use support ratings for estuarine and coastal waters do not include habitat degradation or channelization, but agricultural and urban runoff are cited as possible sources of impairment in over half of all freshwater stream miles impaired (Table 2.22).

In addition to DWQ data, water quality information is available from federal and localized university monitoring programs. Results of the USGS NAWQA program stated that total suspended solids had decreased throughout the Albemarle-Pamlico drainage system from 1980 to 1995 (Spruill et al. 1998). Decreases in sediment and solids concentrations were probably a result of:

- Construction of new lakes, ponds, and beaver ponds in the basin, which trap solids,
- Improved agricultural soil management, including use of conservation tillage, and
- Improved wastewater management.

For the lower Neuse River, MODMON data indicated there is generally sufficient light (lack of turbidity) to support phytoplankton photosynthesis in the upper three meters of the water column (<http://www.marine.unc.edu/neuse/modmon/results/results.htm>, 2003). Based on results from UNC-W's Cape Fear Program in the lower Cape Fear River, turbidity appeared to be associated most with rainfall in the Piedmont and upper Coastal Plain and generally declined moving downstream, except at the maximum turbidity-mixing zone in the middle of the estuary (Mallin 2001c). Water clarity in 2000-2001 was higher than the six-year average at most stations, probably due to low river flow. Water clarity was lowest during late winter and early spring. Low water clarity is the primary reason for low phytoplankton production in the lower Cape Fear River (Mallin 2001c). In the tidal creeks monitored by UNC-W, turbidity was generally not a problem.

Sediment loads into coastal waters can be reduced through agricultural and urban BMPs. Agricultural BMPs include (DWQ 2000b; <http://www.chesapeakebay.net>, 2003):

- Stream bank fencing to keep livestock out of streams;[22]
- Planting vegetated buffer strips at the edge of crop fields;
- Strip cropping (different crops are alternated in rows through one field);

[22] Reduced soil loss by 40% and average sediment concentration during stormflow events by 60% (Owens et al. 1996).

- Conservation tillage (leaving unused plant material on the field);
- Sloped and vegetated ditch banks; and
- Water control structures.

Since stormwater is a major source of sediment in urban areas, structural or nonstructural urban BMPs can be used to reduce sediment loading (DWQ 2000b; <http://www.chesapeakebay.net>, 2003), including:

- Slope and vegetate ditch banks;
- Use of tree roots in stormwater ditches for stabilization;
- Streamside buffer zones;
- Riparian wetland restoration;
- Reduction of impervious surfaces to allow greater infiltration on land; and
- Breakwater or riprap stabilization where erosion rates are very high.

More stringent sediment controls on construction projects are still needed to reduce sedimentation in coastal waters. Several improvements and recommendations for improvements have been made by the EMC, SCC, and associated staff committees. DWQ reported to the EMC in 2002 that actions should be taken to strengthen groundcover requirements in the erosion and sedimentation control plans and improve enforcement of the erosion and sedimentation control law and rules. These recommendations (SCC 2003; B. Devane, DWQ, pers. com., 2003) included:

- *More expeditious application of land cover on disturbed sites*. Reduce the time that developers have to get groundcover in place following completion of each project phase involving grading from 15 to 10 working days, and from 30 to 21 calendar days, whichever is shorter[23]. Draft legislation was prepared but not introduced.
- An increase in the maximum penalty allowed for initial violations of the Sedimentation Pollution Control Act. Note: such a proposal was introduced in 2003 as part of House Bill 868 ("Improve Environmental Enforcement"); the bill passed the House but, in 2004, the Senate did not act on the bill (R. Smith, DENR, pers. com., 2004).
- An increase in the use of improved technologies to replace those now being used to control sedimentation and erosion.
- Support and encouragement by the EMC and SCC for issuing significant monetary penalties for all activities found to be in violation of their Stormwater Construction General Permit, Erosion and Sedimentation Control Plan, or the turbidity standard.

Vegetated buffers are another means of effectively trapping sediment before it reaches riverine and estuarine waters. Because buffers are beneficial in reducing not only sediment loading, but also nutrients and toxins, and benefit multiple coastal fish habitats, their use should be more widely practiced or required. Although definitions and characteristics of vegetated buffers vary, a buffer is generally a vegetated transitional zone, situated between upland land use and aquatic habitats, that functions as a filter of surface water runoff (Crowell 1998). Vegetated buffers are very effective in trapping sediment as well as other pollutants from stormwater runoff (Williams and Nicks 1988; Lee et al. 1989; Gilliam et al. 1994; Lowrance 1997; DWQ 2000b). Properly constructed vegetated buffers ranging from 5 - 185 m (15 - 600 ft) have been shown to remove as much as 90% of sediment and nitrate and up to 50% of phosphorus from stormwater runoff (Desbonnet et al. 1994). Relative effectiveness is dependent on buffer width, slope, soil type, vegetative cover, quality and flow of the runoff, and size of the drainage area. *Implementation of mandatory vegetated buffers along all coastal waters should be considered as a strategy for reducing sediment loading, the largest pollutant in N.C. coastal waters. Width and*

[23] It is important to note than only some areas on an active construction site can be vegetated. Those areas include stormwater pond banks and sloping areas around the edge of the construction site. Solutions to the grass cover issue could involve planting sod (grassed soil mats) instead of seed, and possibly dredging stormwater pond after construction to recover lost topsoil to use in sod production.

configuration of the buffers should be scientifically based and may need to be larger adjacent to strategic habitat areas.

Fecal coliform bacteria

Fecal coliform bacteria occur in the digestive tract of, and are excreted in the solid waste from, warm-blooded animals including humans, wildlife and domesticated livestock. While these bacteria are not harmful to humans or other animals, their presence in water or in filter-feeding shellfish may indicate the presence of other bacteria that are detrimental to human health (DWQ 2000b). Moreover, elevated levels of fecal coliform bacteria suggest that pollutants, such as nutrients, sediment, or toxins, may also be entering the water. Mallin et al. (2000b; 2001b), studying water quality in several tidal creeks in New Hanover County, found a positive correlation between fecal coliform abundance and turbidity, nitrate, and orthophosphate. The significant correlation between bacteria and sediment was most likely because fecal coliform bacteria tend to be associated with suspended particulate matter, and survive longer when in association with sediment particles (Mallin et al. 2000b). The positive relationship between coliform bacteria and nutrients was attributed to both pollutants being derived from the same sources in some instances. Also, some studies suggest that nutrient loading can stimulate growth and survival of fecal bacteria indicators (Evison 1988). *Any steps taken to reduce nonpoint sources of bacteria loading will at the same time reduce loading of other pollutants into coastal waters and improve water quality and habitat conditions.*

Because consumption of shellfish containing high levels of fecal coliform bacteria and associated pathogens can cause serious illness in humans, shellfish growing waters must be closed to shellfish harvest when fecal coliform counts increase above the standard 14 MFFCC/100ml [Commission for Health Services rule 15A NCAC 18A .0900], where MFFCC denotes "membrane filter fecal coliform count." The DEH also closes waters where a high potential for bacterial contamination exists, such as around marinas and point source discharges. Shellfish harvest closures have continued to occur over time (DMF 2001a), which has led to a reduction in available shellfish harvest areas. While closures may protect shell bottom habitat from harvesting, water quality degradation associated with high bacterial contamination is generally not advantageous for other aquatic organisms and fish. However, because shellfish filter organisms from the water column, unharvested shellfish may provide an important water quality enhancement function to the water column. *The effect of shellfish filtering capacities on water quality parameters, such as bacteria, nutrients and sediments, should be determined.*

Sources of bacterial contamination in estuarine waters

Fecal coliform originates from both point and nonpoint sources. Point sources for the purposes of shellfish area protection include NPDES wastewater discharges and other sources with identifiable origins, such as pipes emptying directly into coastal waters. Although the wastewater discharges are treated, closures are required around all NPDES wastewater discharges due to the possibility that mechanical failure could allow inadequately treated sewage to reach shellfish waters. There are five minor and three major municipal NPDES discharges located within 0.5 mi of SA waters (Map 2.18). There are also 39 minor and 10 major non-municipal wastewater discharges near SA waters. These include discharges from water treatment plants (regular and reverse-osmosis), fish houses, sand and phosphate mines, and miscellaneous industrial activities.

Current EMC rules discourage creation of new direct discharges into shellfish waters [EMC rule 15A NCAC 2B .0224]. In fact, there has been a trend to remove some direct discharges, such as in the New River, and dispose of treated effluent on land. Most wastewater discharges meet their permit limits. However, when wastewater treatment plants are found to be out of compliance with their permitted discharge limits, waters can become degraded. Facilities that are out of compliance are subject to civil penalties. *Additional funds and process changes are needed to allow local communities to more rapidly address repairs and upgrades to all aspects of the municipal waste systems, including collection and*

treatment systems.

Sanitary surveys conducted by DEH (Shellfish Sanitation and Recreational Water Quality Section) indicate nonpoint stormwater runoff is the primary cause of water quality contamination in more than 90% of the areas sampled (G. Gilbert, DEH, pers. com., 2002). Sources of bacteria and other contaminants carried into coastal waters via stormwater runoff and contributing to shellfish harvest closures identified by DEH and in numerous other studies (DEM 1994; Frankenberg 1995; Reilly and Kirby-Smith 1999; Schueler 1999; DMF 2001a) include:

- Residential and commercial development activities (urbanization);
- Construction of impervious structures (buildings);
- Roadways, parking lots, and driveways;
- Domestic pet waste;
- Unauthorized discharges of sewage effluent;
- Failing on-site sewage systems or subsurface flow from drainfields;
- Mechanical failure of centralized sewage treatment plants or lift stations;
- Marinas;
- Animal operations;
- Agricultural croplands;
- Mechanical forest harvesting;
- Hydrologic alteration (e.g., channelization, ditching, bulkheading, canals) from multiple land uses;
- Wetland loss and degradation associated with multiple land uses; and
- Wildlife.

To prevent fecal coliform contamination from on-site sewage systems, periodic inspections of on-site systems should be conducted at frequencies recommended by DEH. In addition, siting of subsurface disposal systems in soils adjacent to coastal waters should be reevaluated and revised if necessary to protect water quality.

The primary way in which urban nonpoint runoff reaches coastal waters is from storm drain outlets, residential lawns, driveways, and streets (Schueler 1999). Bacterial concentrations in stormwater discharging from storm drains has been found to be at least an order of magnitude higher than any other individual source in a watershed, indicating that the storm drain system is the most concentrated bacterial source in the watershed (Schueler 1999). Therefore, bacterial contamination tends to come from local, rather than from upstream, sources. Once in the water, bacteria can be transported downstream, but are relatively short-lived. These bacteria die more quickly when exposed to sunlight or high salinity water. Elevated bacterial levels have been positively correlated with high rainfall (low salinity), increased turbidity and suspended solids, and low temperature (Schueler 1999). Bacterial life is extended under low temperature, low salinity, and low light conditions and may be transported with sediment (DEM 1994; White et al. 2000). Fecal coliform bacteria may also be transported to shellfish-growing waters through subsurface flow. Onsite wastewater disposal systems with less than 10 cm distance (about 4 in) between the water table and the drainage trench may contribute to bacterial contamination of the surrounding groundwater and transport to adjacent surface waters (Reilly and Kirby-Smith 1999).

A number of watershed studies have been conducted to identify specific sources of bacterial contamination in a watershed. The primary causes for bacterial contamination from studies in N.C. coastal waters are listed in Table 2.28. The cause of impairment varies and is often due to a combination of factors. When hydrological alterations (i.e., ditching and draining) occur, many wetland and stream functions are removed, increasing the delivery rate of nonpoint source runoff, and decreasing the time available for bacteria to be filtered out (DEM 1994; White et al. 2000). The forestry and agricultural BMPs that were in place during these studies did not prevent fecal coliform standards from being

exceeded (DEM 1994; Mallin et al. 1997).

Table 2.28. Primary causes of fecal coliform impairment in localized North Carolina studies.

Waterbody, CHPP MU	Primary causes of impairment	Reference
South River, Neuse MU	Hydrologic modifications for logging, agriculture, and development; animal grazing at stream edge	DEM 1994
Jumping Run Creek, Core-Bogue MU	Channelization, ditching, bulkheading	White et al. 2000
North River, Core-Bogue MU	Hydrologic modifications; pet and wildlife waste	Reilly and Kirby-Smith 1999
Tidal creeks, Southern Estuaries MU	Increasing impervious surfaces and population	Mallin et al. 2001b
N.E. Cape Fear River, Cape Fear MU	Swine waste lagoon spills and ruptures	Mallin et al. 1997

Some recommendations from the above referenced bacteria tracking studies for reducing fecal coliform contamination include:

- Improve enforcement of existing Forestry Practice Guidelines and BMPs.
- Implement more effective BMPs for forestry and agriculture, particularly where extensive hydrological modifications exist.
- Require advance notice before any timber harvest in close proximity to coastal waters.
- Implement innovative wetland restoration and stormwater retention techniques (bioretention areas, peat and sand filters, and constructed wetlands) to slow, capture, and filter stormwater runoff.
- Work with owners of small animal farms to restrict livestock and their waste from direct access to stream waters.
- Educate homeowners on how and why to properly dispose of pet waste.

The control of fecal coliform bacteria sources before they reach shellfish waters is the simplest and most cost effective measure for restoring water quality (Reilly and Kirby-Smith 1999). However, to effectively reduce bacteria loading, the site-specific sources must be identified. Collaborative research is underway by NCSU and NOAA to determine accurate and cost effective methods of bacterial source tracking (M. Fulton, NOAA, pers. com., 2003). *DENR should support this research since it is needed for successful restoration of bacteria impaired waters.*

In urban areas, the percentage of impervious surfaces in a watershed has been found to be a strong indicator of fecal coliform abundance (Mallin et al. 2000b). Removing vegetated areas reduces the natural filter and groundwater recharge capability of the land and forces water into areas of smaller pervious surfaces. These smaller surfaces are then overwhelmed by high volumes of water, leading to standing water and flooding. As the amount of impervious surface increases, so does the amount of runoff and flooding. Mallin et al. (1998; 2001b) examined the effects of land-use practices on water quality in New Hanover County and found a statistically significant relationship between percent impervious surface cover and fecal coliform concentrations among several tidal creek systems ($r^2 = 0.95$) (Figure 2.7).

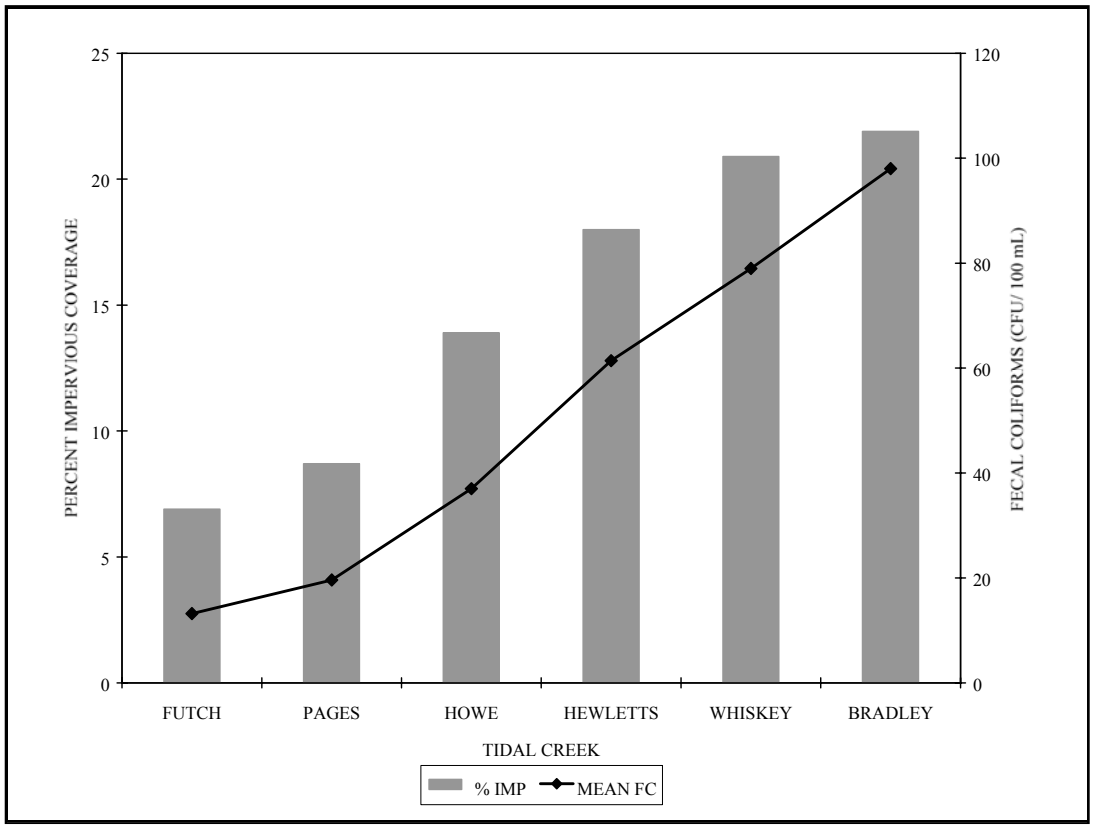


Figure 2.7. Percent watershed impervious surface coverage versus geometric mean fecal coliform bacteria counts for six New Hanover County tidal creeks. (Source: modified from Mallin et al. 2001b)

Several studies have found that acceptable water quality for shellfishing occurs when the proportion of impervious surface on a watershed is less than 10% (Schueler 1994; Arnolds and Gibbons 1996; Mallin et al. 2000b; Barnes et al. 2001). Significant water quality and habitat degradation occurred where impervious surface exceeded 20%. A strong relationship has also been found between human population growth and closed shellfishing areas (Maiolo and Tschetter 1981; Mallin et al. 2001b; Mallin et al. 2000b). The use of stormwater BMPs in some watersheds has not been demonstrated to reduce the negative impacts of high impervious surfaces (Schueler 2003). *Modification of local or state stormwater rules limiting built upon area for new development adjacent to all coastal waters to less than approximately 12% (for the low density option) would be a scientifically based means of preventing additional water quality degradation.*

Alternatively, scientifically based performance standards regarding the quantity and quality of stormwater coming off a site could be established, but careful maintenance and monitoring would be necessary. The ability of stormwater controls to reduce impacts associated with increasing impervious surfaces has been difficult to quantify since stormwater controls are generally not installed consistently across an entire local watershed, vary in type and quality of construction and maintenance, and may not have been designed specifically to protect aquatic habitat or prevent downstream erosion (Schueler 2003). Several studies evaluating effectiveness of stormwater ponds in small watersheds were unable to detect major differences in insect diversity between streams with and without stormwater ponds. Other studies evaluating larger watersheds detected small positive effects when impervious cover did not exceed 5-20%. These studies concluded that the use of effective stormwater treatments could allow an increase in maximum impervious cover by as much as 5%, and still maintain aquatic insect diversity (Schueler 2003).

While new development needs to be regulated to prevent further degradation, it is just as important to address impacts from existing development. Stormwater runoff from state roads and urban/suburban built upon areas could be reduced by retrofitting with adequate stormwater controls. *Innovative solutions for improving stormwater control on existing roads and built-upon areas are needed to completely address the issue of stormwater pollution in degraded waters.*

Status and trends in fecal contamination in estuarine waters

There has been a continual increase in fecal coliform contamination with increasing human population along the North Carolina coast (Maiolo and Tschetter 1981; Mallin et al. 2001b). As of 2002, 263 of 776 estuarine areas (SA waters) were on the 303(d) list because of fecal coliform contamination. The DWQ 305(b) report listed 28,435 acres (of approximately 2 million acres) of estuarine area impaired by fecal coliform contamination in coastal North Carolina (Table 2.25). If the contamination is mostly from stormwater flow and other anthropogenic sources, the location of these impaired waters could indicate other nonpoint pollutants.

Trends in shellfish harvest closures reflect trends in fecal coliform contamination. Over 364,325 ac of coastal (salt and brackish) waters were closed to shellfish harvesting in North Carolina in 2002 due to high levels of fecal coliform or the potential risk of bacterial contamination (immediately around wastewater treatment plant discharges) (DEH, unpub. data). Of this total, approximately 56,446 ac of closed shellfish waters are suitable for shellfish production. These closures have primarily affected the central and southern areas of the coast. In more recent years, additional closures have also been made in and around the Pamlico Sound (DMF 2001a). Fecal coliform abundance tends to be highest upstream and in shallow creeks and waterbodies; contamination decreases downstream and in larger open waterbodies. The areas prone to high fecal coliforms are also typically areas where shell bottom habitat is concentrated.

Between 1983 and 1985, there was a sharp decline in the acreage of estuarine SA waters that were permanently closed to shellfish harvesting (Figure 2.8). This decline was attributed to increased sampling efforts and refinements in growing area classifications by DEH (i.e., conditionally approved, open or closed), and to reductions in point source discharges in coastal waters. From 1985 through 1995 shellfish closures continually increased. Between 1995 and 2000, the total acreage of shellfish closures has fluctuated; since 2000, totals have changed only slightly.



Figure 2.8. Acreage of North Carolina shellfish waters permanently closed to shellfish harvest during 1982-2002. (Source: N.C. Division of Environmental Health, Shellfish Sanitation and Recreational Water Quality Section, unpub. data)

In addition to the 56,446 ac that are permanently closed to shellfishing, other areas are temporarily closed during periods of high rainfall. For example, a rainfall of 1.5 inches in a 24-hour period can cause temporary shellfish harvest closures. Closures last from several days to more than a month. Large storms, such as hurricanes, result in harvest closures covering much larger areas, sometimes including all of North Carolina's estuarine waters. The conditionally approved areas are concentrated in the Core-Bogue, New-White Oak, and Southern Estuaries management units (Map 2.19a-c). Within these watersheds, permanent closures are most common in the upper reaches of tidal creeks and rivers, with conditionally approved areas occurring downstream of those areas or in the upper portions of less degraded creeks. As temporary closures have increased in frequency and duration, they have become an issue of great concern to the public, particularly in the southern area of the coast.

There are approximately 2,010 ac of shell bottom in the mapped areas that are currently unharvestable most of the time due to outright prohibitions or restrictions based on bacterial concentrations (classified as "prohibited" or "conditionally approved closed"). On average, an additional 2,823 ac of shellfish waters are closed to harvest for some portion of the year ("conditionally approved open" areas), representing approximately 39% of the mapped shell bottom (12,502 acres). *Restoration efforts to reduce fecal coliform levels should target concentrated areas of shell bottom or other Strategic Habitat Area. Focusing on areas less degraded (conditionally approved areas, recently experiencing increased closures), rather than areas that have been permanently closed for many years, could also result in a greater success in habitat enhancement.*

Approximately 1,157 ac of ORW waters have been closed to shellfish since 1990. These closures have been in tributaries of Middle Sound, Stump Sound, and Topsail Sound in the Southern Estuaries MU; western Bogue, Core, and Back sounds in the Core-Bogue MU; and Swan Quarter and Juniper bays in the Pamlico Sound MU. As development activities continue, so will the number of shellfish area closures,

unless changes are made to the manner in which land is developed and stormwater runoff is managed. *New or expanded stormwater outfalls to coastal shellfishing waters should be prohibited by the EMC and existing outfalls should be phased out*. Reclamation of closed areas will also become more difficult as population pressures increase. *Coordination and enhancement of rule enforcement and compliance review capabilities within DENR agencies is needed to fully enforce existing statutes and rules and minimize further water quality degradation*.

Water quality monitoring in tidal creeks in the southern portion of the coast indicates that bacterial contamination is widespread and chronic, from both point and nonpoint sources (Mallin et al. 2002b). In 1995 and 1996, the mouth of Futch Creek, in New Hanover County, was dredged to increase flushing, lower bacteria levels, and improve water quality. Fecal coliform levels declined and additional acreage was opened to shellfish harvesting. The creek has continued to maintain good water quality, in terms of fecal coliform, since the mouth of the channel was dredged (Mallin et al. 2002b). However, this type of water quality enhancement does not reduce the amount of pollutants entering the creeks. *Restoration of waters impaired by fecal coliform bacteria should be addressed through reductions in nonpoint source loading as well as enhancement of natural water flow conditions*.

Fecal coliform contamination in ocean waters

In the surf zone and nearshore ocean waters, fecal coliform contamination primarily comes from nonpoint runoff of stormwater. There are currently no direct discharges of treated or raw sewage to North Carolina's ocean waters. Wastewater in the coastal region is generally managed by septic systems or centralized collection and treatment facilities and package treatment plants that discharge on land or to estuarine waters. Systems that discharge into coastal rivers indirectly affect ocean waters by degrading estuarine waters that ultimately flow into the ocean. Centralized collection and treatment facilities treat their waste to kill fecal coliform prior to discharge. An important concern, however, is capacity of the collection and treatment systems to handle the rapid and expanding development in the coastal area. Collection and treatment systems are sometimes overloaded due to increasing development, heavy rainfall and infiltration and improper planning. Most problems occur during this overload period, when sewers overflow or sewage is inadequately treated. Septic systems also fail where they are not properly sited or constructed, the soil is not suitable, or they are improperly maintained (North Carolina Ocean Resources Task Force 1995).

As the coastal population continues to grow, there will be an increasing demand for local governments and the state to evaluate alternative wastewater treatment and disposal methods, including ocean outfalls. Currently, there are several studies underway in the central coastal region to recommend wastewater disposal strategies. A major concern regarding ocean outfalls, along with other sewage treatment alternatives that may remove constraints to development, is the cumulative and secondary impacts of increasing development (North Carolina Ocean Resources Task Force 1995). For example, the extent of onshore development could impact estuarine and ocean resources through associated nonpoint sources of pollution, degrading coastal water quality. *Given the role of public infrastructure (i.e., sewage treatment capacity) in coastal development, the siting process for infrastructure should consider restriction from areas that would impact sensitive fish habitats and supporting areas.*

Ocean dumping of sewage has led directly to incidents of beach pollution in several states, including New York, New Jersey, California, and Florida (Moore 1992). Adverse impacts to the fishing industry have also been documented to occur in association with dumping of sewage sludge and industrial wastes in ocean waters (Cross et al. 1985). *Offshore wastewater discharges should be prohibited in North Carolina to minimize water quality degradation*.

Stormwater runoff is currently the largest concern regarding bacterial contamination in ocean waters. The stormwater inputs are primarily a health concern due to bacterial contamination, but can also increase loading of nutrients and toxins into the surf zone. There are approximately 13 identified stormwater

outfalls that discharge directly onto the beach near or lower than the mean high tide line; there are several others that discharge behind the primary dune (Maps 2.9a-c). Samples from the catch basins have found extremely high bacteria levels in the stormwater (J. Potts, DEH, pers. com., 2003). Hanby Beach, Carolina Beach, Emerald Isle, Atlantic Beach, and Kill Devil Hills have had precautionary advisories posted due to discharge of stormwater. Hanby Beach has a permanent point source precautionary advisory because the opening of the pipe is in the water, making it impossible to see when the pipe is discharging. All of these communities, with the exception of Emerald Isle, are served by municipal or privately operated wastewater treatment systems. Centralized sewage systems have had secondary impacts to water quality and habitat by indirectly permitting denser development than would be allowed if using individual septic systems. Dense development results in increased impervious surface area and stormwater runoff.

Beach communities appear to be increasingly using "temporary" pumping of stormwater to the beach as a solution to flooding. The runoff during heavy rain events floods the streets; such flooding is largely the result of filling of wetlands, excessive impervious surface, and lack of upland stormwater retention areas. Until recently, there were no specific stormwater rules prohibiting or regulating pumping of stormwater onto the beach or into the surf zone. Any discharge into the ocean without a permit is prohibited (E. Beck, DWQ, pers. com., 2003) [NCGS 143-214.2] and any source of pollution that precludes using the waters for purposes identified in its water quality classification (i.e., swimming in SB waters) is prohibited [15A NCAC 2B.0222(2)]. In October 2003, DWQ implemented a stormwater flooding relief discharge policy. It states that, for chronic stormwater flooding, the Division staff will review proposals and work with the Shellfish Sanitation Section to ensure that water quality standards will not be impacted. Public entities are advised that non-discharge alternatives, such as pumping stormwater behind a foredune or to another land surface, are preferable to discharging directly to state waters. The town of Emerald Isle is in the process of developing such an alternative. After years of frequent emergency pumping of floodwater to the ocean, the Town recently decided to purchase a 40-acre wetland parcel that will remain undeveloped. Stormwater from flooded streets and yards will be pumped to this existing wetland site. The Town also plans to pump groundwater from the town to the wetland parcel to lower the groundwater table and increase the storage capacity around the developed portion of the town. In addition, Emerald Isle is developing a town ordinance for new development that would require the first two inches of rain to be retained on a lot, prohibit excessive removal of vegetation due to the development, and require retention of vegetated buffers along drainage ways where feasible (<http://www.emeraldisle-nc.org>, 2004). The Cape Fear Council of Governments has also developed a proposed alternative to the current practice of direct stormwater discharge onto beaches at Kure Beach. The Council is seeking funding through the Clean Water Management Trust Fund and other sources to construct a network of wetlands (totaling approximately 20 acres) and reroute stormwater through it, eventually discharging to a canal that drains to the Cape Fear River (SC waters).

Water pollution in nearshore ocean waters is becoming increasingly problematic along the entire nation's coast. In 2000, there were reported to be nearly twice as many beach closings and advisories in the United States as in 1999. The most frequent cause of closures or advisories was stormwater runoff (<http://www.nrdc.org/>, 2001). The apparent increase in closings, however, may be due to improved or expanded monitoring along the oceanfront. *Additional permits for stormwater outfalls on ocean beaches or nearshore waters should be prohibited by the EMC[24] or the stormwater should be treated to acceptable water quality levels prior to discharging. Alternative stormwater management strategies should be implemented, similar to the efforts underway by Emerald Isle, to phase out existing stormwater outfalls and encourage land application.*

[24] Except during times of emergency when public safety and health are threatened.

Potential sources of water quality degradation include leaching from failing or improperly functioning sewage systems or drainfields, or where septic systems become exposed or located below mean high water due to erosion. Storm-damaged septic tanks may cause contamination for a short but concentrated period in localized areas. Table 2.29 shows the number of septic tanks in need of repair, replacement, or relocation following Tropical Storm Dennis and Hurricane Floyd. In the past, the eastern ends of Ocean Isle and Holden Beach have had to relocate septic tanks and homes on a regular basis following large storm events. Leakage from systems either with inadequate setbacks from ocean waters due to erosion or not designed to handle heavy use by renters may cause gradual contamination to nearshore waters. Recent research has demonstrated that septic tank leakage in this area has caused elevated fecal coliform and nutrient loading to nearby streams and tidal creeks (Cahoon et al. 2003). *More detailed monitoring is needed to assess the extent oceanfront septic systems are causing degradation to nearshore coastal waters*.

Table 2.29. Number of known coastal septic tanks damaged by Hurricane Floyd or Tropical Storm Dennis (August – October 1999) in need of repair, replacement or relocation. (Source: D. Moffitt, DCM, pers. com., 2002)

	Number of septic tanks damaged	
Beach community	Post-Trop Storm Dennis	Post-Hurricane Floyd
Nags Head	35	
Rodanthe	6	
Buxton	1	
Atlantic Beach	2	
Pine Knoll Shores		3
Emerald Isle		31
Oak Island		114
Holden Beach		36
Total	44	184

The DEH Shellfish Sanitation and Recreational Water Quality Section of DENR has the responsibility for initiating a recreational water quality-monitoring program in ocean and estuarine waters. The primary purpose of the program is to protect public health. In 2000, the Beaches Environment Assessment and Coastal Health (BEACH) Act was implemented for the purposes of improving the quality of beaches and coastal recreation water.

The Act allocates funding for states in the form of grants to:

- Develop or revise water quality criteria and standards;
- Implement studies to assess potential human health risk from exposure to pathogens;
- Develop appropriate and effective indicators and methods for improving detection in coastal recreational waters of the presence of harmful pathogens; and
- Improve monitoring and public notification programs.

Implementation of this act will provide much needed information on the water quality condition of North Carolina's coastal waters and the impact of coastal development and other activities on water quality. The Beaches Act provided additional funding to allow for more beach sampling in North Carolina. There are currently 225 stations in ocean and estuarine waters that are sampled at different frequencies. Following EPA recommendations, *Enterococci* is used as the indicator organism for contamination. Sites are ranked as Tier I to III based on the level of swimming use, with specific standards at each tier for the acceptable level of *Enterococci.* If the swimming standard is exceeded, warning signs are posted temporarily at swimming sites.

Toxic chemicals

A toxic substance is defined in the North Carolina Administrative Code [15A NCAC 2B. 0202(36)] as "any substance or combination of substances … which after discharge and upon exposure, ingestion, inhalation, or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, has the potential to cause death, disease, behavioral abnormalities, cancer, generic mutations, physiological malfunctions (including malfunctions or suppression in reproduction or growth) or physical deformities in such organisms or their offspring or other adverse health effects." Potentially toxic chemicals found in the water column include heavy metals, pesticides, dioxins, petroleum hydrocarbons (e.g., oil), polycyclic aromatic hydrocarbons (PAHs), chlorine, polychlorinated biphenyls (PCBs), antifoulants, ammonia and pharmaceuticals. Many of these chemicals occur naturally (e.g., heavy metals), while others are created almost entirely by humans (e.g., pesticides). Below is a brief description of these chemicals:

- Heavy metals - Metals that have a density of at least five times that of water. These include mercury, nickel, lead, arsenic, cadmium, aluminum, iron, platinum and copper. Nonpoint sources of heavy metal inputs include municipal and agricultural runoff, contaminated groundwater and sediments, industrial shipping, recreational boating, and atmospheric deposition (Wilbur and Pentony 1999). Point sources of heavy metals include industrial discharges, power plants, ocean disposal of dredged material, and marine transportation (e.g., hull paints containing butyltin compounds to hinder biofouling).
- Pesticides - Chemical compounds that are typically composed of chlorinated hydrocarbons and are used as herbicides, insecticides, and wood preservatives for agriculture, aquaculture, and urban/suburban development. Examples of pesticides are aldrin, atrazine, chlordane, fenvalerate, permethrin, toxaphene, and DDT.
- Dioxins - By-products of pesticide production, high temperature-combustion processes, and chemical bleaching of pulp in paper production (DWQ 1997a). Dioxins are also present as trace impurities in some commercial products.
- Petroleum hydrocarbons - Compounds found in fuel-related products such as gas, oil, and grease. There are over 100 hydrocarbon compounds in gasoline as well as numerous additives. Lubricant oil also contains elements such as zinc, sulfur, and phosphorus (Jackivicz and Kuzminski 1973).
- Polycyclic aromatic hydrocarbons (PAHs) - A group of over 100 different chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances like tobacco or charbroiled meat. Compounds in the PAH group are found in coal tar, crude oil, creosote, and roofing tar, but a few are used in medicines or to make dyes, plastics, and pesticides (<http://www.atsdr.cdc.gov/tfacts69.html>, October 2002).
- Chlorine - Biocide and bleaching agent sometimes used to disinfect waste and pool water, clean clothes, and wash boats and other surfaces.
- Polychlorinated biphenyls (PCBs) - Organic chemicals containing chlorine that have properties that make them useful for many industrial and commercial applications like electrical, heat transfer, and hydraulic equipment; in paints, plastics and rubber products; in pigments, dyes and carbonless copy paper and many other areas.
- Antifoulant paints - Paints used on vessel hulls to prevent covering by marine organisms such as barnacles (Milliken and Lee 1990). Copper and organotin (e.g., Tributyltin or TBT) compounds are the most common ingredients in antifouling paints.
- Ammonia - Form of nitrogen that comes from concentrated animal operations, cleaning products, and point source dischargers. Ammonia is also a highly toxic waste product of living organisms.
- Pharmaceuticals and personal care products - "[a] broad collection of substances [that] refers, in general, to any product consumed by individuals for personal health or cosmetic reasons", such as antidepressant medications and oral contraceptives (<http://www.epa.gov/nerlesd1/chemistry/pharma/faq.htm>, July 2004).

Effects of toxic chemicals on fish

There are many factors affecting a chemical's toxicity to marine organisms. Some species or life stages are more sensitive than others. Eggs, and larvae in particular, are generally more sensitive to toxics than adult and juvenile life stages because they have more permeable membranes and less developed detoxifying systems (EPA 1985; Weis and Weis 1989; Funderburk et al. 1991; Gould et al. 1994). For example, larval striped bass are less tolerant of copper sulfate ($CuSO_4$) than juveniles (Kaumeyer and Setzlter-Hamilton 1982). Individuals of these early life stages often float in the water column, where toxic chemicals are more available for uptake. Because of their water column orientation, early life stages of fish are the primary focus of this section.

Regardless of the life stage affected, some chemicals are more inherently toxic to organisms than others. For example, some pesticides and metals (i.e., toxaphene, TBT, mercury) cause acute mortality to fish or shellfish at very low concentrations (approximately 1 part per billion or less), whereas others (i.e., chromium, atrazine) can cause toxic effects only at much higher concentrations (>10,000 parts per billion) (Funderburk et al. 1991). The effect on organisms also varies according to the physical and chemical properties of the water column in which they live; higher salinity water can neutralize more dissolved chemicals than fresh water, making these toxics less biologically available for uptake. There are other physiochemical conditions that can either increase or decrease toxicity of a given chemical. For example, copper is less toxic in the presence of dissolved organic matter. Cadmium toxicity, on the other hand, decreases as salinity increases due to binding to chloride.

Many toxic chemicals (especially heavy metals) are readily adsorbed on small sediment particles and eventually removed from the water column (Butler 1971; Wolfe and Rice 1972; Vandermeulen and Mossman 1996; <http://www.atsdr.cdc.gov/tfacts69.html>, October 2002). Adsorption on sediment particles allows some toxic chemicals to continue contaminating sediments until they degrade into less harmful substances. Bottom feeding fish may therefore be more affected by feeding on benthic organisms than from ambient chemical concentrations in the water column (Funderburk et al. 1991). However, the smaller fraction of highly soluble toxic chemicals present in the water is more bioavailable and therefore more toxic to aquatic life.

Toxic chemicals can also affect growth, reproduction, and behavior, resulting in a reduction of stock viability (Weis and Weis 1989; Wilbur and Pentony 1999; DeFur and Foersom 2000). These effects include abnormal cell division of embryos, reduced survival of embryos, malformation of larvae, and slowed development (Weis and Weis 1989). Some toxic chemicals may disrupt endocrine secretions (i.e., hormones) of aquatic organisms, which could have a corresponding effect on natural biological properties (Wilbur and Pentony 1999; <http://ca.water.usgs.gov/pnsp/rep/carp2/ abs.html>, 2002). In the Chesapeake Bay, male catfish exhibited arrested or indeterminate sexual development when their tissue contained significant concentrations of PCBs, organotins, mercury, DDT, and DDT metabolites (DeFur and Foersom 2000). Small amounts of pharmaceuticals such as Prozac and birth-control drugs are also finding their way into U.S. rivers and streams (<http://toxics.usgs.gov/pubs/OFR-02-04/index.html>, 2004). In mosquitofish, exposure to anti-depressant drugs caused delayed sexual maturation (<www.cnn.com/2003/TECH/science/11/14/coolsc.frogs.fish/index>, November 2003). The prevalence, sources and entire effects of hormone-altering chemicals in North Carolina are currently unknown. *More research is needed on the subject of hormone-altering chemicals in surface waters.*

Given all these factors, determining the effect of toxins on organisms and populations is a complex and difficult problem. The effects of toxic chemicals on oyster beds and bottom species are discussed later in the Shell Bottom and Soft Bottom chapters, respectively. This section primarily covers the effect of toxic chemicals on pelagic species of various life stages.

The acute and chronic toxicity of selected chemicals on a few pelagic species are listed in Table 2.30. The effects of environmental pollutants on early fish life stages are listed in Appendix L. Based on the limited number of chemicals for which data are available, the water quality standard is less than the acute and chronic toxicity level for the selected pelagic species and early fish life stages. However, these data are mostly from anadromous species and based on laboratory tests to determine acute levels of mortality, which are difficult to translate into ecosystem-level effects in very complex chemical and biological environments (Weis and Weis 1989; Funderburk et al. 1991).

Table 2.30. Literature values (micrometers/liter) for measured toxicity of selected chemicals on selected pelagic species. (Sources: DWQ water quality standard and Funderburk et al. 1991)

	Water quality standard[1]		Acute / chronic or sublethal toxicity[2]		
Chemical	Freshwater	Saltwater	**Atlantic menhaden**	**American shad**	**Striped bass**
Heavy metals					
Arsenic	50	50			20,248[a]/ ND
Cadmium	2	5			8.3[a], 38[b]/2
Chromium VI	50	20			16,370[a], 58,000[b]/ND
Copper	7 (AL)	3 (AL)	610/ND		54[a]/ND
Lead	25 (N)	25 (N)		<10/ND	
Mercury	0.012	0.025			90[a]/5
Zinc	50 (AL)	86 (AL)		<30/ND	322[a]/430
Pesticides (Chlorinated hydrocarbons)					
Aldrin	0.000136	0.000136			8[b]/ND
Chlordane	0.000588	0.000588			12/ND
Dieldrin	0.00144	0.00144			20/ND
Toxaphene	0.0002	0.0002			5[a], 5.8[b]/ND
Other chemicals					
Trialkyltin	0.008	0.002	4.5/ND		<2.0/25

[1] AL = Values represent action levels as specified in [2B .0211 & .0220]; N = There is also a narrative description of limits in [2B .0211]; ND = no data.

[2] The values are meant to provide a relative indication of potential effect. End times and exposure times vary, and life stages were pooled for calculating means.

[a] Toxicity tests conducted in freshwater, [b] Toxicity tests conducted in saline water

Because toxic contaminant concentrations (especially heavy metals) in the sediment far exceed concentrations in the water column (Steel 1991), resuspension can be a major problem in areas where fine-grained sediments predominate. These fine-grained sediments are common in sheltered creeks and small trunk estuaries, or in the deeper regions of larger estuaries. Heavy metal contamination in these areas is of particular concern because they cover the majority of designated nursery areas, where young fish gravitate in spring and summer. Heavy metals and other volatile chemicals are most toxic in freshwater systems. Therefore, anadromous and low-salinity nursery areas are probably the most sensitive to heavy metal contamination. Documented concentrations of toxic chemicals in the sediment were the highest in low-salinity areas with limited tidal flushing and high river discharge (Riggs et al. 1989; Riggs et al. 1991; Hackney et al. 1998). The problem is further intensified by the timing of most heavy metal inputs, which occur during the period of heaviest runoff and pollutant loading (during spring), and the arrival of many larvae and juvenile to the nursery areas.

The coincidence of heavy runoff, pollutant loading, and fish use of nursery habitat is also a potential problem when pesticides that are primarily dispersed in spring (predominantly herbicides). The concentration of atrazine and other herbicides in the Albemarle-Pamlico system was highest in late May and early June and decreased gradually until September; a seasonal pattern of pesticide concentration coinciding with seasonal patterns of pesticide use (<http://nc.water.usgs.gov/albe/pubs/

ALBEetroabs.htm>, 2002). However, toxic effects may be less significant if the arrival of larvae is preceded by a major flushing event. Considering the typically high freshwater flows that occur during spring, this pattern may also demonstrate the acute toxicity and rapid sedimentation of many pesticides.

Aside from the direct impact of toxins on aquatic organisms, there is also the ability of toxic chemicals, especially heavy metals and dioxins, to accumulate in the tissue of animals at higher trophic levels (i.e., bioaccumulation), which can cause health problems in human consumers (Wilbur and Pentony 1999). Fish consumption advisories are often the result of chemical contamination. This primarily affects large fish occupying higher trophic levels, and the effect is not limited to freshwater species. There is currently fish consumption "advice" for mercury in sharks, swordfish, tilefish, king mackerel, bowfin, largemouth bass, and chain pickerel caught in waters south and east of Interstate 85 (<http://www.epi.state.nc.us /epi/fish/>, 2003). Site-specific advisories for dioxin have been given for Albemarle Sound, lower Roanoke River, and Welch Creek in Beaufort, Martin, and Washington counties.

Sources of toxic chemical pollution

Due to the settling of suspended particles in estuaries, heavy metals, dioxin, and PAH contamination usually reflects localized impacts from point and nonpoint sources, although high flow events can result in resuspension and redeposition of metal-contaminated sediments far from their original sources (Steel 1991). Riggs et al. (1989) found the highest concentration of toxic chemicals in the sediment near point sources and on the surface sediment. The concentration of toxic chemicals in deeper sediment cores was as much as 100 times less than surface concentrations.

Upon entering the water column, many organic compounds will not persist for very long because of their inability to blend, volatility, and biodegradability, or due to the effects of weathering (Jackivicz and Kuzminski 1973). The organic molecules that do persist either remain suspended in the water column, concentrate on the surface, or settle to the bottom. The portion of oil that reaches the bottom may persist for several years (Olsen et al. 1982). Lead compounds from gasoline additives have a tendency to sink to the bottom (Chmura and Ross 1978). The degradation (half-life) of pesticides such as malathion, parathion, endosulfan, fenvalerate, chlorpyrifos-methyl, methanidathion, and diazinon in seawater ranges from 2.2-17 days (Walker 1977; Cotham and Bidleman 1989; Lacorte et al. 1995). However, the toxicity and longevity of degradation products must also be considered in evaluating water quality.

Activities contributing to heavy metal contamination include urban/suburban sprawl, dock and marina development and operation, boating activity, dredge spoil disposal, automotive transportation, industrial shipping, industrial emissions, and pesticide use (Wilbur and Pentony 1999). Potential sources of heavy metals from these activities include anti-fouling paint, zinc plates on boats, fuel, runoff from parking lots or other road surfaces, and wood preservatives leached from dock structures (EPA 1985; Marcus and Stokes 1985; Sanger and Holland 2002). Mercury and arsenic are no longer used in antifouling paints due to their toxicity (Bellinger and Benham 1978). Tributyltin (TBT), another toxic metal compound used in antifouling paints, was restricted on non-military vessels by the Organotin Antifouling Paint Control Act of 1988 (Milliken and Lee 1990). The use of TBT-containing paints for coating the hulls of military vessels has been either officially discontinued or is currently in the process of being phased out.[25] Ports are also a potential source of toxins. Increased boat traffic and transport of petroleum products and other toxic materials increase the chance of spillage into the water column.

[25] Currently, most Navy, MSC [Military Sealift Command], USCG [United States Coast Guard], and Army ships have steel hulls with copper-based antifouling paints. Paints containing tributyltin (TBT) are still found on some aluminum-hulled small craft because some copper-based paints are incompatible with aluminum hulls. Currently, TBT-based antifouling paints are found on approximately 10-20% of small boats and craft with aluminum hulls. The numbers of vessels from the respective Armed Forces branches estimated to have TBT coatings are: Navy-56, USCG-50, MSC-0, Air Force-50, Army-11 (U.S. Navy and EPA 1999). It is unknown how many of these vessels have operated or presently operate in North Carolina waters, or if the policy regarding TBT use has changed since the date of the reference's publication.

Runoff from impervious surfaces such as roads and parking lots appears to be one of the major sources of heavy metals in estuaries and nearshore ocean waters. A study in the lower San Francisco Bay found that half of the cadmium and zinc in the bay came from tire wear (Beach 2002). Lead originated primarily from diesel-fueled vehicles and half the copper in the bay was derived from brake pad wear. An additional 25% of the copper came from atmospheric emissions. In Maryland, a study of suburban watersheds with little industrial activity found that metals from lawns, roads, and automobiles accumulated in sediments at levels toxic to aquatic life (Hartwell et al. 2000). In the Charleston, S.C. area, Lerberg and Holland (2000) found a strong correlation between increasing impervious surface coverage in tidal creek watersheds and the cumulative level of contaminants in tidal creek sediments. *Because pollutants associated with roads, parking lots, and associated transportation are a significant source of toxins and other contaminants to the water column, efforts should be taken by DOT to minimize impacts by 1) designing roads to retain stormwater runoff in natural and vegetated upland or wetland areas; 2) designing roads and parking lots to minimize impervious surfaces; 3) improving water flow through transportation structures; 4) monitoring of BMPs; and 5) incorporating BMP design criteria to enhance control of bacteria.*

Studies of heavy metal concentrations in the sediments of the Pamlico and Neuse Rivers found surface sediments in the vicinity of known point sources significantly more enriched than subsurface sediment in the Neuse River (Riggs et al. 1989; Riggs et al. 1991). In the Pamlico River, heavy metal enrichment was generally less severe than in the Neuse River. In the Pamlico and Neuse rivers, individual waste treatment plants, marinas, industrial plating facilities, and military facilities were identified as probable sources of heavy metal enrichment (Steel 1991). *Determining the distribution and concentration of heavy metals and other toxins in bottom sediments throughout the coast is needed to comprehensively assess potential threat to the water column*.

Copper, chromium, and arsenic (known collectively as CCA) comprise the most common wood preservative in the U.S. (Weis and Weis 1994). CCA-treated wood preservative has been shown to leach copper, chromium VI, and arsenic into adjacent sediments and to impact marine benthos (Weis and Weis 1994; Weis et al. 1998). Among CCA chemicals, copper appears to have the most toxic effect on marine organisms and also consistently appears to leach the greatest amount (Weis and Weis 1994). The area of significantly elevated heavy metal concentrations in the sediment can extend as much as 10 m beyond CCA-treated shoreline structures (Weis and Weis 1994; Weis et al. 1998). EPA is requiring new labeling on all CCA products specifying that no use of CCA be allowed after December 2003. The wood-treating industries had already made a voluntary decision to transition away from use of arsenic treated wood. However, according to the CCA Compliance Strategy developed by the Office of Enforcement and Compliance Assurance (OECA) (<http://www.epa.gov/pesticides/factsheets/chemicals/cca_strategy5.pdf>, June 22, 2004), the CCA prohibition excludes "wood for marine construction" (i.e., subject to immersion or exposed to salt water or brackish water) and pertains only to wood "intended for most [but not all] residential settings" (<http://www.epa.gov/pesticides/factsheets/chemicals/cca_qa.htm>, August 2004). Moreover, "existing stocks of [CCA-treated] wood may be sold by retailers until such stocks are exhausted, and consumers may continue to buy and use the wood for as long as it is available" (<http://www.epa.gov/pesticides/factsheets/chemicals/cca_guidance_q_a.htm>, August 2004). The effect of toxic chemical leaching from wood is primarily a problem along poorly flushed, freshwater and low-salinity areas. Furthermore, alternative wood preservatives containing copper or other chemicals may have similar toxicity to marine organisms. *Any new wood preservative products should be evaluated for impacts to marine benthos, including oysters. Ultimately, research is needed to determine if marina basins in freshwater and low-salinity areas actually produce enough toxic chemicals, at the right time, to impact fish populations.*

Marinas and multi-slip docking facilities

Marina basins and their associated facilities combine many sources of toxic contamination. There are typically CCA-treated boards on docking facilities and bulkheads, and antifouling paints on the boats moored in those docking facilities. Marinas are also a source of chronic, low-level oil and gas pollution from spills that sometimes occur at their pumping stations. Although there are permit requirements for oil spill containment in marinas, there are no requirements for chronic oil pollution. ***The impact of chronic oil pollution on nursery areas is unknown and needs future research.*** In addition, marina facilities include boat workshops and parking lots located immediately adjacent to coastal waters. By themselves, marinas pose relatively little threat to coastal fish habitats. However, development pressures associated with them can be more threatening (e.g., increased boating, upland development, and shoreline stabilization).

The Coastal Resources Commission (CRC) defines a marina as "any publicly or privately owned dock, basin or wet boat storage facility built to accommodate more than 10 boats and providing permanent or temporary docking space, dry stack storage, haul-out facilities or repair services" (<http://dcm2.enr.state.nc.us/Handbook/section4.htm>, 2003).

Marinas have historically been most concentrated around high- and moderate-salinity estuarine areas (Maps 2.18a-d). According to permit records, there are approximately 440 existing marinas and community docking facilities along North Carolina's coastal waterways, with a total of 1,851 wet slips (DCM, unpub. data). Carteret County has the most marinas (approximately 100), followed by New Hanover County (80 marinas). Onslow, Beaufort, Dare, and Brunswick counties have approximately 30 to 40 marinas each. The highest marina concentrations are found in the Southern Estuaries (4 mi. of shoreline/marina) and Core/Bogue (5 mi. of shoreline/marina) management units.

Specific CAMA regulations exist regarding marina siting to minimize impacts to estuarine resources, such as shell bottom and human health. DEH rules require that waters adjacent to marinas have a buffer of closed shellfishing areas, of varying distances, around them. For purposes of this rule, DEH defines "marina" as "any water area with a structure (dock, basin, floating dock, etc.) which is utilized for docking or otherwise mooring vessels and constructed to provide temporary or permanent docking space for more than 10 boats" [15A NCAC 18A.0901]. Development that results in new shellfish closures is generally not permitted. However, there are still marinas being developed in closed shellfishing waters, which may lead to further degradation in waters already closed to shellfishing or to increase the size of the area closed.

There are also CRC regulations that address marina siting in designated primary nursery areas (PNAs). Current CRC regulations prohibit construction of new marinas in designated PNAs if new dredging is required, but allow siting of marinas in PNAs if no new dredging is required [15A NCAC 07H .0208 (b)(5)(B)]. However, upland basins requiring an access channel through a PNA are given a variance by CRC if the dredging will not result in significant degradation of existing fishery and wetland resources and basin design provides adequate flushing [CRC 07H .0208 (b)(5)(A)]. Maintenance dredging of existing channels is also allowed through PNAs [CRC 07H .0208 (b)(1)(J)]. Current marina development tends to be occurring in lower salinity areas because many areas adjacent to high-salinity estuarine waters are already developed. These low-salinity areas are often smaller waterbodies that are important but are undesignated as nursery areas for anadromous and other fish. ***To protect anadromous fish spawning and nursery areas from marina impacts, dredging for new marina construction and other marina-related activities that negatively impact these fish functions should be restricted.*** Map 2.4 shows some freshwater areas that have been designated as Inland PNAs by the WRC. These include mainstem sections and tributaries of the Cape Fear, New, Neuse, Tar-Pamlico, Alligator, Roanoke, and North rivers, and Currituck Sound [15A NCAC 10C .0503]. The WRC-designated nursery areas are given the same consideration as MFC-designated PNAs by the CRC. However, only a small portion of these is located within CAMA jurisdiction. These inland PNAs are currently not recognized as HQW in EMC

regulations. *Waters designated as Inland PNAs by WRC should be considered for reclassification to HQW by EMC, as was done for MFC-designated PNAs. Formal criteria need to be developed to classify and protect anadromous fish spawning areas that will be recognized by DWQ.*

Considering the localized effect of many toxic pollutants, marinas and possibly "non-marinas" (small docking facilities) located near sensitive nursery areas pose a particular concern. Of the marinas in coastal waters, 51 are located within 100 m of a MFC-designated Primary Nursery Area. Few Primary Nursery Areas in freshwater and low-salinity areas have been designated by DMF. Although anadromous fish use areas have been located by DMF, designation of anadromous fish spawning areas needs to be completed. Until these important freshwater and low-salinity areas are designated, they remain vulnerable to toxic chemical pollution and other habitat impacts associated with marina development. *Designation of specific anadromous fish spawning and nursery areas and possibly additional Inland PNAs needs to be completed along the entire coast to provide protection from marina development and other potential threats*.

The issue of marina siting is complex and design preferences may differ between agencies due to each agency's primary responsibilities. For example, DWQ tends to prefer marinas designed with open water basins to enhance flushing, while DCM tends to prefer marinas designed as upland basins with a dredged connecting channel to minimize impacts to shoreline vegetation and obstruction of navigational access. Open water basins may encourage use by juvenile freshwater and anadromous species [26], but also enhance flushing of heavy metal contaminants. If upland basins accumulate toxins and attract young fish and shellfish, they could have a more negative impact on fisheries than open water basins. *Studies are needed to compare use of both upland and open water basins by young fish. Development of a comprehensive marina policy to address appropriate design, siting, operation and maintenance procedures, and cumulative impacts is needed to thoroughly address these and other impacts of marinas. This should consider, among other things, requiring the use of oil-absorbing materials around fuel and docking stations and shoreline habitat (i.e., wetlands, soft bottom). Support of the Clean Marinas Program through additional staff resources and incentives would benefit coastal fish habitat. The cumulative impact of clustered marinas should also be assessed*. The DWQ is drafting a marina action plan that could address many of the issues involved in developing a comprehensive marina policy (G. Putnam, DWQ, pers. com., 2002).

An emerging problem is the proliferation of small docking facilities, also referred to as non-marina boating facilities (1-10 boat slips), in developing coastal subdivisions. DCM permit records indicate that, from 1990 to 2002, DCM issued an average of 538 permits per year along the coast for individual piers; 67 permits/year issued for non-marinas; and 10 permits/year issued for new or expanding marinas (Figure 2.9). These numbers are only estimates since they include repairs and replacements and may slightly overstate new marina/dock construction (D. Huggett, DCM, pers. com., 2003). The total number of marinas permitted/year has declined since 1990 and 1991 (31 and 16 permits/year, respectively) to about 6-13 per year. This decline is in part due to stringent permitting regulations and an increase in smaller docking facilities. The greatest numbers of permitted boating facilities with fewer than 10 slips since 1990 are in Carteret (164 permits), New Hanover (139 permits), and Dare (116 permits) counties. While the number of new and expanding marinas has declined over the years (Figure 2.9), the number of smaller docking facilities increased in the late 1990s and has shown large annual fluctuation since. The Division of Environmental Health's Shellfish Sanitation Branch is in the process of making a database to improve tracking of small docking facilities (1-10 slips) (S. Murphey, DEH, pers. com., 2001). Given the potential for degradation of nursery area function, *DENR should consider a temporary moratorium on all new small docking facilities (1-10 slips) and marinas, excluding individual private docks, until a comprehensive marina management system for all counties is developed.*

[26] Refer to Nursery function section.

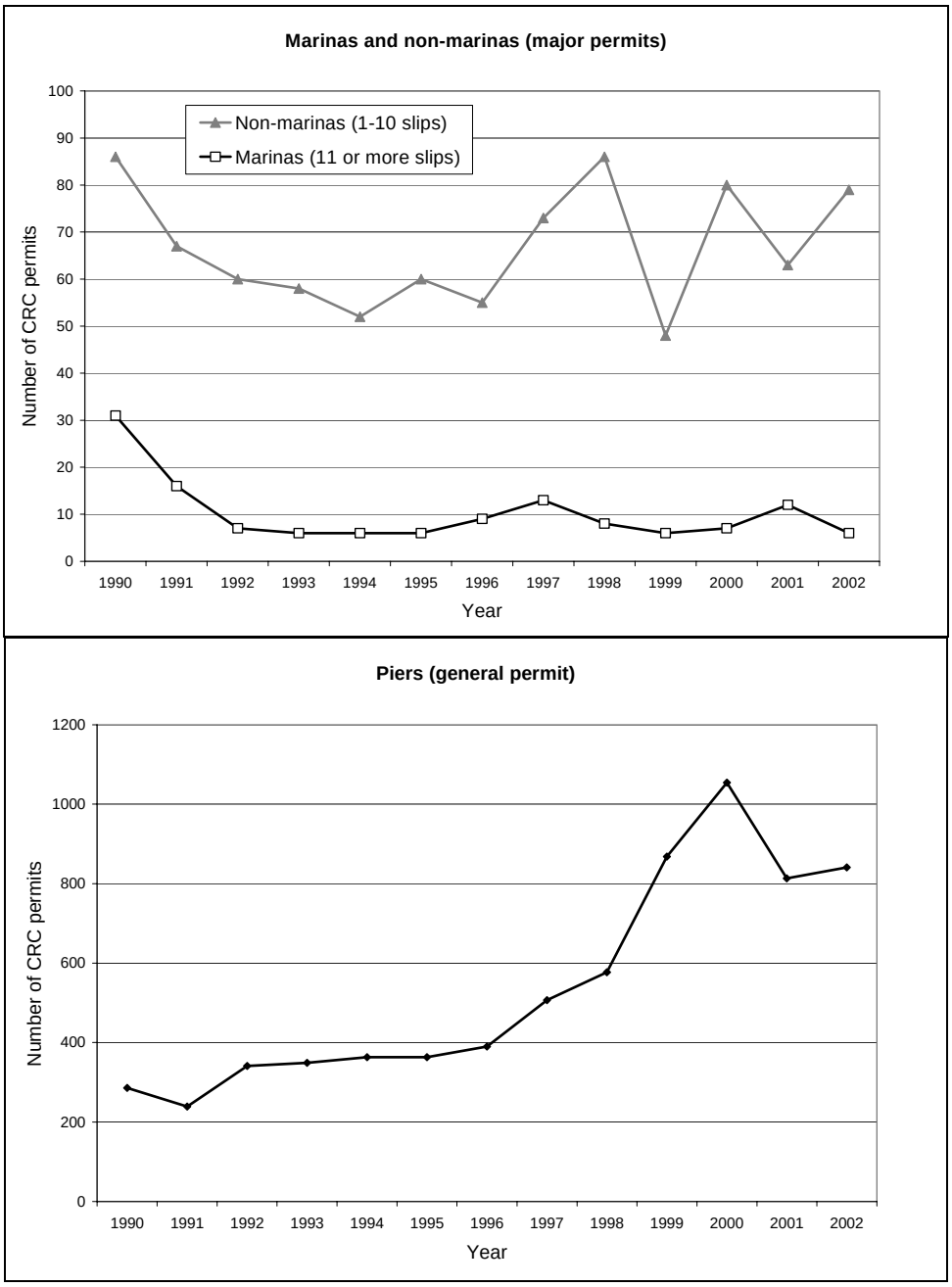


Figure 2.9. Annual number of CAMA permits issued by CRC for piers, non-marinas, and new or expanded marinas.

Small docking facilities (1-10 slips) may result in cumulative impacts to coastal fish habitat. Development often concentrates adjacent to areas with water access and docking facilities. The combination of heavy metal contamination from shoreline structures, antifoulant paints, bilge water, marine sewage, and stormwater runoff from roads, driveways, ditches, and adjacent development, could lead to significant degradation of primary nursery area functions. However, there is little documented proof of such degradation. *There is a need to study the cumulative impact of these small docking facilities and associated development on toxic chemical concentrations in the water column. The study should also compare higher and lower salinity nursery areas.* The results could help in defining a rule limiting the ratio of developed public trust bottom to undeveloped shoreline near shallow, nursery habitats. There is already a CAMA rule affecting marina development by limiting the ratio of developed shoreline to undeveloped shoreline along the coastal shoreline AEC [15A NCAC 07H .0208(b)(5)], but its adequacy in preventing cumulative impacts is unverified.

Pesticide spraying

Cropland agriculture has been a consistent source of pesticides in streams, as cropland coverage has grown relatively little from 1982-1997 (Table 2.20). From 1992-1994, water samples from the Tar-Pamlico drainage basin were analyzed for 46 agricultural herbicides, insecticides, and pesticide metabolites as part of the NAWQA program (Woodside and Ruhl 2001). Although the pesticides with the highest estimated use were the compounds detected most frequently, there was not a strong correlation between estimated use and detection frequency (Woodside and Ruhl 2001). This was probably due to a number of pesticides whose estimated use was unknown (e.g., prometon). The concentration of many herbicides was greatest in spring and summer, during and immediately following application periods. The seasonal pattern of concentration was less evident for the insecticides prometon, diazinon, and chlorpyrifos (Woodside and Ruhl 2001).

Another potentially increasing threat is the effect of pesticide application over shallow water in and adjacent to wetlands to reduce mosquito levels. The Environmental Protection Agency, hoping to stem the rapid spread of West Nile virus, has recently modified pesticide use procedures to allow some spraying of pesticides over water (contrary to the pesticide label instructions) to kill mosquitoes, without having to get a permit under the Clean Water Act (<http://www.enn.com/news/wire-stories/2002/10/10112002/ap_48678.asp>, October 2002). However, these mosquito control agents can be non-selective, and are known to harm or kill larval aquatic invertebrates and fish (Weis and Weis 1989; Milam et al. 2000), which is the reason they are not labeled for use over open water. *Pesticides should always be applied according to label instruction, regardless of whether a permit is required or not*.

Milam et al. (2000) evaluated the toxicity of several popular mosquito control agents on non-target zooplankton and fish species (minnows and mosquitofish). Exposures required to kill mosquito larvae were as much as 31.4 µg/l for Dursban®, malathion, Permanone®, Abate®, Scourge®, B.T.I., and Biomist®, whereas >2.7 µg/l of these chemicals resulted in substantial mortality (Milam et al. 2000). Only malathion killed mosquito larvae before it killed mosquitofish (Milam et al. 2000). However, malathion was also identified as the cause of 64% of the pesticide-related fish kills in U.S. coastal areas between 1980 and 1989 (Key et al. 1998). The disparity between toxicity of malathion on moquitofish and pesticide-related fish kills could be the result of variable sensitivity among fish species. The toxicity of malathion was tested on grass shrimp in moderate salinity water (20 ppt) and found to be highest for newly hatched larvae (Key et al. 1998). However, the doses used to evaluate toxicity (up to 30 µg/l l) were much higher than were required to kill mosquito larvae in fresh water (1 µg/l). It may be that salinity has a buffering effect on the toxicity of malathion to both fish and mosquito larvae. *Research is needed to identify those pesticides safe for spraying over open waters and, for those pesticides whose toxicity is impacted by salinity, appropriate application rates for controlling mosquitoes.*

There are also natural pesticides and bacteria that can be used for mosquito control (Buchsbaum 1994). The bacterium *Bacillus thuringiensis israelensis* (B.T.I.) is more specific to mosquito larvae and less toxic than malathion. There is also the Integrated Pest Management approach that allows natural predators of mosquito larvae (e.g., mosquitofish, killifish) access to breeding areas. However, allowing fish access to breeding areas could disrupt or eliminate amphibians dependent on the exclusion of fish predators for their survival.

Pesticide spraying over agricultural crops is another source of pesticides in the water column. Some fish kills in coastal rivers have been found to be related to crop spraying. Pesticides can enter the water through runoff or directly due to drift from aerial applications. The North Carolina Department of Agriculture and Consumer Services administers and enforces the N.C. Pesticide Law of 1971 and N.C. Pesticide Board-adopted regulations, including crop spraying practices. The purpose of the N.C. Pesticide Program is to protect public health and safety and to promote continued environmental quality by minimizing and managing risks associated with the legal use of pesticides. Policies on drift from aerial applications will affect the potential for toxin contamination in coastal waters and associated chronic and acute effects on fish populations.

The N.C. Pesticide Board has rules regarding aerial spraying that prohibit the application of pesticides under conditions that result in drift and adverse effects to non-target areas. Deposition of pesticides labeled toxic or harmful to aquatic life is not permitted in or near waterbodies. Another aerial rule states that no pesticide shall be deposited onto any non-target area in such a manner that it is more likely than not to cause an adverse effect, unless such aquatic life is the intended target of the pesticide. An inspector will investigate whenever there is an allegation of pesticide drift to non-target sites to determine whether the pesticide was applied according to the label. *Although safeguards are in place, the N.C. Pesticide Board's policies on drift should be assessed and modified if necessary to ensure adequate protection of aquatic life and water quality*.

Recent research indicates that wetlands receiving drainage laden with toxic chemicals may indirectly impact estuarine food chains by accumulating toxic chemicals in the bacterial component of detritus, which is not affected by toxic chemicals (<http://es.epa.gov/ncer/ final/grants/96/ecoass/alberts.html>, May 2003). These toxic chemicals are then exported from the wetland to accumulate in the tissue of higher animals in the food chain. Therefore, toxic chemicals may not only accumulate through sediment pathways[27], but also through the water column in the form of floating detritus.

Status and trends in toxic chemical pollution

Several coastal studies have examined toxic chemical contamination in North Carolina's estuaries. One study of bottom sediments throughout coastal North Carolina waters found the following chemicals to be most abundant between 1994 and 1997 (in order of descending concentration): PAHs, nickel, arsenic, DDT, chromium, PCBs, and mercury. Over 1.5 billion pounds of PCBs were produced in the U.S. before they were banned in 1977. The presence of PCBs and DDT in the sediment therefore provides evidence of their persistence in the environment (Hackney et al. 1998). The study also found concentrations of other heavy metals such as antimony, copper, lead, cadmium, silver, and zinc. The sediment in 13.4% of estuarine sites sampled was nearly devoid of life during harsh summer conditions, according to the survey.

Although potentially toxic levels of trace chemicals were found in bottom sediments throughout North Carolina coastal waters, their presence also reflects the quality of the overlaying water column. Based on historical data (1950-1993) from the EPA's Storage and Retrieval System (STORET), the most common pesticides in surface water of the Albemarle-Pamlico system were atrazine and aldrin (<http://nc.water.usgs.gov/albe/pubs/ALBEetroabs.htm>, 2002). The Water Data Storage and Retrieval

[27] Refer to Soft bottom chapter.

System maintained by USGS indicated relatively high concentrations of atrazine, alachlor, metalachlor, prometon, metribuzin, and metribuzin over the same time period. The herbicide atrazine is known to cause embryonic deformities in channel catfish exposed to 0.4 mg/l (Weis and Weis 1989). In total, there were 45 pesticides detected in waters of the Albemarle-Pamlico system, out of a total of 47 pesticides analyzed (<http://nc.water.usgs.gov/albe/pubs /circ1157/nawqa91.6.htm>, 2002).

The highest contamination levels were found in low-salinity areas with limited flushing and high river discharge (e.g., upper estuaries) (Hackney et al. 1998). This trend in toxic chemical pollution has been affected by severe weather striking the North Carolina coast. For example, after flooding accompanying Hurricane Floyd in 1999, pesticide concentrations in upper Pamlico River estuary declined by a factor of ten, while concentrations in the lower estuaries had increased slightly (D. Shay, NCSU, pers. com., 2002). One year following Floyd, however, the overall concentration of current-use pesticides was comparable to pre-hurricane levels (D. Shay, NCSU, pers. com., 2002).

Based on recent DWQ evaluations, heavy metals were a cause for impairment in 13 freshwater stream miles (DWQ 2000a). The DWQ also identified chlorine as the source of impairment in four freshwater stream miles (<1% of total rated) in coastal river basins and ammonia (NH_3) in 12 freshwater stream miles (Table 2.24). The EMC has established a water quality standard of 17 μg/L for total residual chlorine (TRC), effective April 1, 2003. The Committee's move to adopt a freshwater standard for total residual chlorine is driving the implementation of TRC effluent limitations for facilities that use chlorine or a chlorine derivative for disinfection. Such a limit may necessitate the use of a dechlorinating agent such as sulfur dioxide or a sulfite derivative. Alternative means of disinfection, such as an ultraviolet system, may be encouraged for new or expanding facilities to reduce the use of chlorine disinfection.

Toxic chemical contamination was not evaluated by DWQ in estuarine and nearshore ocean waters. However, based on a study in 1988, DWQ found concentrations of heavy metals within water quality standards in SA waters near marinas (DWQ 1990). This study also detected unidentified organic compounds (e.g., pesticides, PAHs, PCBs) at every marina examined, although the concentrations did not represent a violation of water quality standards. The current standards do not completely eliminate risk because: (1) values are not established for many toxic chemicals; (2) mixtures and breakdown products are not considered; (3) the effects of seasonal exposure to high concentrations have not been evaluated; and (4) some types of potential effects, such as endocrine disruption and unique responses of sensitive species, have not yet been assessed (<http://water.usgs.gov/pubs/circ/circ1225/html/human.htm>, 2002). *These considerations should be a topic of future research.*

The precautionary principle regarding toxic chemical contamination should be used when data are lacking on their effects. Ideally, the fewer types and quantities of toxic chemicals to enter into the environment, the better (DeFur and Foersom 2000). Given time and normal ecological processing, some highly contaminated sites will be covered and no longer accessible, while biological agents will slowly process other sites. Lead and other heavy metals will not degrade, and dioxin only degrades slowly. *These factors should be considered when determining what chemical quantities should be allowed in the water.*

Other sources of water quality degradation

Desalination plants and marine debris are two other threats to the water column. Removal of brackish water for desalination and use as a municipal water supply is a more recent activity that has potential impacts to water quantity or quality (Copeland 1967). In rapidly developing coastal counties where wells are drawing deeper into saltier groundwater, desalination of surface waters provides another source of drinking water. There are several existing desalination facilities and some proposed facilities. The first desalination plants in North Carolina discharge wastewater into the Atlantic Ocean and sounds where the receiving area had equal or higher salinity than the effluent. Newer facilities are moving more inland to less saline waters. For example, the DWQ recently issued an NPDES permit for a proposed facility in Camden County that would discharge 430,000 gallons of salt water (~13 ppt) into the Pasquotank River,

where salinities range from 2-5 ppt. As of 2001, there were at least three proposed desalination plants for North Carolina, in addition to 11 existing plants in the coastal area (L. Henry, DMF, pers. com., 2003). Two of these existing plants are located in freshwater areas (L. Henry, DMF, pers. com., 2003).

Effluent from desalination in freshwater areas could create isolated pockets of higher salinity water with very low diversity of species, the majority of which occupy lower trophic levels. The reduction in species diversity and isolation from the surrounding aquatic community would constitute a loss of habitat. Moreover, under natural circumstances, vertical stratification in the estuarine water column due to salinity differences creates conditions favorable to low DO, which serve to degrade bottom habitat, cause stress or mortality in benthic species, and force mobile species to move (Stanley and Nixon 1992, Buzzelli et al. 2002). Similar conditions may occur artificially through effluent release in fresh water. *However, research is needed to determine if effluent from desalination plants could create the predicted effect.* Even if aquatic organisms were able to adjust to salinity changes, they may also face an imbalance of ions that would make adjustment even more difficult (Copeland 1967; Florida DEP 1995; Goodfellow et al. 2000). Florida Department of Environmental Protection (1995) indicated that ionic imbalance could be toxic to mysid shrimp, which are an important food item in the diet of many freshwater fish species found in coastal North Carolina (Adams 1976; Whitehead 1985; Robins and Ray 1986; Page and Burr 1991; Bowman et al. 2000).

Aside from the stress of salinity change and ionic imbalance on organisms, other concerns (from Pantell 1993) include the effect of:

- Chlorine and other biocides used to clean pipes and other equipment and sometimes to pretreat the feedwater;
- Temperature of discharge waters above those of receiving waters;
- Turbidity levels from discharge above those of receiving waters;
- Oxygen levels of discharge waters below those of receiving waters;
- Chemicals from pretreatment of the feedwater such as biocides, sulfur dioxide, coagulants-e.g., ferric chloride, carbon dioxide, polyelectrolytes, anti-scalants-e.g., polyacrylic acid, sodium bisulfite, antifoam agents, and polymers;
- Chemicals used in flushing the pipelines and cleaning the membranes in reverse osmosis (RO) plants such as sodium compounds, hydrochloric acid, citric acid, alkalines, polyphosphate, biocides, copper sulfate, and acrolein;
- Organics and metals contained in the feedwater and concentrated in the desalination process; and
- Metals that are picked up by the salty effluent touching facility components and pipelines.

The MFC has strongly objected to the presence of desalination plants in low-salinity areas due to the potential impacts and the lack of information on physical and chemical characteristics of the saline discharge. Recommendations for permitting desalination plants were presented in a draft report assembled by the Water Treatment Plant Workgroup (L. Henry, DMF, pers. com., 2002). The report identified specific information needed to evaluate the potential impact of the discharge:

- Additional information from applicant;
- Location of project and discharge;
- Ambient water quality at discharge location;
- Proposed designed flow;
- Type of treatment process (e.g., reverse osmosis, cation exchange);
- Proposed water source;
- Dilution modeling;
- Chemical cleaning procedures; and
- Ratio of potable water to concentrate.

Using the above information and their own data/analysis, permit review agencies can evaluate the impacts

on habitat and water quality. *Based on the results of dilution modeling, basic water quality parameters (flow, temperature, pH, and DO) should be identified for the applicant to monitor (<http://h2o.enr.state.nc.us/NPDES/documents.html>, 2004). If the data indicate the presence of pollutants in the discharge water, toxic chemical monitoring and toxicity testing should be required. Nutrients and ammonia should be monitored if a mass balance approach indicates excess nutrients. Finally, biological monitoring of the macrobenthic community should be required on facilities discharging more than 0.5 million gallons per day*. If the facility can demonstrate that their discharge is not significantly impacting the physical, chemical, and biological environment, further monitoring could be discontinued.

Trash and other waste that is carried into the water (marine debris) accidentally or intentionally is a threat to fishery resources due to entanglement and ingestion. Entanglement can strangle or injure organisms, or impair mobility. Ingestion of plastic resin pellets, plastic bags, and other packaging by marine life can impede feeding and breathing. A 1997 study found that at least 267 species were affected by marine debris, including numerous fish, invertebrates, sea turtles, and marine mammals (Laist 1997). In 1998, the amount of trash dumped at sea was more than twice the weight of the total U.S. fishery catch (<http://www.cmc-ocean.org/mdio>, December 01, 2000). Plastics comprise about 90% of debris found floating in the water (<http://marine-litter.gpa.unep.org/facts/what-where.htm>, November 02, 2002). Surveys indicate that water based sources of trash include cruise ship operations, recreational boating, commercial fishing, offshore oil drilling, and military vessel operations. Land based sources include storm drains, sewer outfalls, and general littering. *Incentives are needed to encourage removal and proper disposal of derelict fishing gear. In addition, public education is needed to discourage littering from land or water based activities*.

Non-native or nuisance species

There is widespread documentation that non-native/nuisance species can out-compete some native species, altering the established ecosystem, habitat, and eventually water quality (Mallin et al. 2001c). Foreign organisms in the discharge of ships' ballast water at or near ports have resulted in the introduction and spread of non-native invertebrates, such as zebra mussels and toxic dinoflagellates. Hallegraeff (1998) linked a global increase in the frequency, intensity, and geographic distribution of paralytic shellfish poisoning (a human illness resulting from consumption of shellfish contaminated with certain red tide toxins) with increased translocation of non-native dinoflagellate species via ships' ballast and import/export of shellfish products. In Australia, the sudden appearance of toxic dinoflagellate cysts was tied to exportation of woodchips (Hallegraeff 1998), an industry currently active in North Carolina. In the Chesapeake Bay and North Carolina, where the potent toxic dinoflagellate *Pfiesteria piscidia* has been reported, there is concern that the organism may disperse to unaffected areas via ballast water. Possible ballast water treatment options include chemical treatment with chlorine or hydrogen peroxide, electric shocking, ozonation, heat ($35 – 45^{o}$ C), deoxygenating, ballast water exchange, or reballasting. Of these alternatives, heating may be the most effective and environmentally friendly. Ballast water contamination is a worldwide maritime issue that must be addressed on an international scale, but may also be partially addressed on a regional scale. *Until treatment of ballast water is required and implemented, monitoring of port waters for algal blooms is recommended to minimize risks of introduction elsewhere (Hallegraeff 1998).* Currently the U.S. Coast Guard requires vessels to carry out an open ocean exchange of ballast water. However, this does not effectively remove or kill all organisms in the tanks (USCG 2003, unpub. doc). In 2003, the Coast Guard, under authority in the National Invasive Species Act of 1996, proposed requiring a mandatory national ballast water management program for all vessels having ballast water tanks that operate in U.S. waters and /or enter U.S. waters after operating beyond the exclusive economic zone (EEZ). Vessels entering U.S. waters after operating beyond the EEZ would be required to do one or more of the following:

- Perform complete ballast water exchange in an area no less than 200 nautical miles from any shore;
- Retain ballast water onboard the vessel;

- Use an alternative environmentally sound method of ballast water management approved by the Coast Guard; and/or
- Discharge ballast water to an approved reception facility.

DENR should work with the North Carolina Port Authority and the U.S. Coast Guard to ensure compliance with these proposed rules.

Existing management measures

There are many management initiatives that are already underway to improve conditions in the water column. Some of these programs, BMPs, and other management measures have already been mentioned. Appendix J contains a list of over 100 existing state and federal agency programs that may affect water quality. This list was compiled during the Estuarine Shoreline Protection Stakeholders Process in 1999 to identify various governmental programs that in some way affect water quality and to determine where gaps exist or better coordination is needed. The scope of their authority, the pollutants they may affect, and a brief description are included. Some of the larger efforts are discussed below.

Stormwater Management Program

The State Stormwater Management Program was established in the late 1980s under the authority of the North Carolina Environmental Management Commission (EMC) and North Carolina General Statute 143-214.7. This program, codified in 15A NCAC 2H .1000, affects development activities that require either a Erosion and Sediment Control Plan (for disturbances of one or more acres) or a CAMA major permit within one of the following areas:

- The twenty coastal (CAMA) counties, and/or
- Development draining to Outstanding Resource Waters or High Quality Waters.

The State Stormwater Management Program requires developments to protect these sensitive waters by maintaining low- and high-density options for stormwater management, varying with water quality classification. Low-density options include limits on the maximum amount of built-upon area (or pervious surfaces), type of development (single-family residential rather than commercial), and requiring vegetative buffers and the transport of runoff through vegetative conveyances:

- Low-density built-upon area limits for High Quality Waters and freshwater ORWs are 12% or less or single family residential development on lots of one acre or more [EMC 15A NCAC 02H .1006 and .1007].
- Low-density built-upon area requirements for saltwater ORWs and areas within 0.5 mi of and draining to SA waters are 25% or less built-upon area or single-family residences on lots of 0.33 acre or more [EMC 15A NCAC 02H .1005].
- Low-density built-upon area requirements for coastal counties adjacent to waters that are not classified as ORW, SA, or HQW waters are 30% or less or single family residences on lots 0.33 acres or more [EMC 15 NCAC 02H .1005].

Development adjacent to HQW, ORW, and SA waters must also:

- Maintain a 30 ft wide vegetative buffer, and
- Transport stormwater runoff primarily by vegetated conveyances (i.e., vegetated swales are permitted, but direct pipes are not).

If low-density design criteria cannot be met, then high-density development requires the installation of structural best management practices (BMPs) to collect and treat stormwater runoff from the project. High-density BMPs must control the runoff (depending on the receiving stream classification) from the 1 in (HQW and freshwater ORWs) or 1.5 in (ORW and SA waters) storm event and remove 85% of the total suspended solids. However, within 575 ft of the shoreline adjacent to designated saltwater ORWs, development activities must comply with the low-density option.

The Stormwater Management Program's goals are achieved through Phase I and II Stormwater permits. The Phase I permitting program for stormwater discharges was established in 1990. Phase I focuses on site and operations planning to reduce pollutant sources from certain industrial facilities, construction activities that disturb five or more acres of land, and municipal separate storm sewer systems (MS4s) serving populations of 100,000 or more (based on 1990 census data). The large MS4s in North Carolina coastal drainages include the cities of Raleigh, Fayetteville, and Greensboro. Construction activities disturbing more than one acre require an Erosion and Sediment Control Plan approved by the Division of Land Resources.

The Phase II program requires NPDES permits for smaller MS4s in federally designated urbanized areas. A small MS4 could also be pulled into the Phase II program through state designation or in response to a petition. State designations will be considered in conjunction with updates of the State's river basin plans. Federal rules require the State to consider for designation, as a minimum, all municipalities with a combined population of 10,000 or more and a density of 1,000 people per square mile. Other communities can be placed under the program as a rule-making petition to the EMC where there are significant water quality concerns (<http://www.epa.gov/owm/sw/phase2>, 2003). Regulated small MS4s were required to apply for stormwater permits by March 2003. Minimum requirements include:

- Public education and outreach on stormwater impacts;
- Public involvement and participation;
- Illicit discharge detection and elimination;
- Control of stormwater runoff at construction sites; and
- Post-construction stormwater management for new development and redevelopment pollution prevention for municipal operations.

To comply with the post-construction rules, local governments will have to adopt development ordinances and administer local programs that assure that new development does not cause unacceptable stormwater pollution. For example, local governments will be denied the required Phase II permit if they cannot demonstrate their stormwater programs are adequate in protection of shellfish harvesting. To be in compliance, local governments do not have to eliminate all pollutants, but must reduce the discharge of pollutants to the "maximum extent practical." The Phase II permit can require certain BMPs that are known to be effective in achieving Clean Water Act requirements in order to meet this minimum standard. As part of the Phase II stormwater regulations, local governments will have to map all stormwater outfalls in their communities. These outfalls are defined as any ditch or culvert that discharges stormwater pollution to surface waters such as creeks, sounds, or the ocean. The quality of the stormwater will have to comply with downstream water quality standards.

In July 2004, the N.C. General Assembly adopted legislation further defining the requirements of North Carolina's Phase II stormwater program. The legislation set out the criteria for designating additional Phase II communities, established minimum requirements for local Phase II stormwater programs, and addressed other Phase II implementation issues. The legislation refers back to temporary rules adopted by the EMC in October 2002 for model stormwater standards that local programs must meet or exceed. Under those standards, the local government must address post-construction runoff from all new development disturbing more than one acre. The model stormwater practices generally do not require engineered stormwater controls for low-density development (defined as no more than 24% built-upon area), so long as all built-upon area is setback at least 30 feet from surface waters and stormwater moves through vegetated conveyances. High density development (exceeding 24% built-upon area) would be required to include stormwater controls capable of treating the excess stormwater runoff leaving the site in a 1-year, 24-hour storm (as compared to pre-development conditions) and designed to provide 85% average annual removal of total suspended solids. Additional stormwater controls may be needed to address specific water quality problems in a given community.

Neuse and Tar-Pamlico Nutrient Reduction Strategies

In response to the large number of fish kills in the Neuse River in the summer of 1995 and other concerns over deteriorating water quality, the General Assembly enacted a law into statute that required a 30% reduction in the 1995 nutrient levels in the Neuse River basin by 2003. To meet this requirement, five "Nutrient Reduction Strategies" were developed and made effective as of 1997. Similar rules were implemented for the Tar-Pamlico river basin in 2000. The rules include:

- Riparian buffer protection rule,
- Wastewater discharge rule,
- Agriculture rule,
- Nutrient management rule, and
- Stormwater rule.

Agriculture and forestry are affected by the agriculture rule [15A NCAC 2B .0238] and the nutrient management rule [15A NCAC 2B .0232]. The agriculture rule gives farmers several options. They may participate in developing a Local Nitrogen Reduction Strategy where specific plans for each farm are developed, or implement standard BMPs such as buffers and water control structures. The nutrient management rule applies to anyone applying fertilizer on 50 or more acres of land, such as cropland, golf courses, recreational land, nurseries, or residential or commercial lawns. This rule requires training in nutrient management or development of a nutrient management plan. The wastewater discharge rule [15A NCAC 2B .0234] and stormwater rule [15A NCAC 2B .0235] will target reductions in nutrients from point and nonpoint urban development, respectively. The wastewater discharge rule allocates a total maximum discharge limit for the basin and divides that amount among different discharger groups. Dischargers also have the option to establish a nitrogen trading coalition, a group that collectively meets a nitrogen limit, determined by the EMC, equal to the combined nitrogen limits of its members (<http://h2o.enr.state.nc.us/nps/pt-sourc.htm>, 2003). The stormwater rule applies to certain large and rapidly growing communities in an effort to reduce urban stormwater runoff. Local governments are required to develop stormwater plans for new development, educate the public on stormwater issues, identify and remove illegal discharges, and identify existing development that could be retrofitted.

Although various concepts have been applied to riparian buffers, they are generally defined (Crowell 1998; <http://www.chesapeakebay.net/pol/interim.htm>, 2000) as permanently vegetated areas between a water body and upland land use that are designed to:

- Prevent upland sources of pollution from reaching surface waters by trapping, absorbing, and filtering sediments, nutrients, chemicals, and fecal bacteria.
- Maintain the natural morphology and ecosystem role of stream channels and shorelines (erosion and flood control).
- Protect fish and wildlife by supplying food, cover, and thermal protection.
- Protect other coastal habitats such as wetlands, SAV, and shell bottom through water quality and flow enhancement.

Ideally, no development is allowed in a buffer. Numerous scientific studies have documented that vegetated buffers are highly effective in removing sediment, nutrients, bacteria, heavy metals, and other chemicals from stormwater runoff (Lee et al. 1989; Zirschky et al. 1989; Groffman et al. 1991; Desbonnet et al. 1994; Gilliam et al. 1994). However, the effectiveness is dependent on the width, slope, soil type, vegetative cover, quantity and quality of the stormwater runoff, and size of the drainage area (Crowell 1998). In 1998, DCM staff compiled an extensive bibliography on reported pollutant removal effectiveness of various buffer widths and recommended buffer widths for various environmental objectives (Crowell 1998). The widths range from 2 to 178 m, depending on the objective and the desired amount of pollutant removal.

Forested riparian buffers are considered to deliver the greatest range of environmental benefits of any

type of stream buffer (Lowrance 1997; <www.chesapeakebay.net/pol/interim.htm>, 2003). Unlike most other BMPs, riparian forest buffers accomplish multiple habitat benefits while also improving water quality. Since forested buffers are thought to remove some nutrients that grasses cannot, a three-zone riparian buffer concept was proposed for the Chesapeake Bay region to maximize buffer benefits (Lowrance 1997):

- **Zone 1** functions as an extension of the water body. Undisturbed woody vegetation remains to stabilize sediments, reduce flooding, provide woody debris, and remove some pollutants.
- **Zone 2** consists of a managed forest, where trees remain but can be managed. The primary function of this zone is removal of pollutants from surface and groundwater, while allowing some economic benefits.
- **Zone 3** may contain grass filter strips, level spreaders or other features. This zone is needed to slow runoff, infiltrate water, and filter sediment and other pollutants.

The Neuse and Tar-Pamlico riparian buffer rules were designed with this concept in mind. Zone 1 must be a 30 ft wide forested area, beginning at mean high water (MHW), where the first 10 ft remain completely undisturbed, and the other 20 ft may have limited thinning of trees. Landward of this, Zone 2 must be 20 ft wide and have dense plant cover where no fertilizer use or development are allowed. The rule applies to all perennial and intermittent streams, lakes, ponds, and estuaries. All man-made ditches are exempt from this rule [EMC rule 15A NCAC 02B .0233 (6)]. The EMC considers this rule to be critical to successfully reducing nitrogen. *Thorough evaluation of water quality conditions and effectiveness of the nutrient reduction strategies should be performed in the Neuse River in 2006 and the Tar-Pamlico River in 2007/2008 and rules modified as necessary to achieve nutrient reduction goals.*

Although there are many unanswered questions regarding the effectiveness of the Nutrient Sensitive Waters (NSW) regulations in the Neuse and Tar river basins, including the 50 ft riparian buffer, nutrient reduction strategies in the Chowan River basin–which have been in place for over 20 years–have had some success. In 1979, the Chowan River basin was the first river basin to be designated as NSW. Since nutrient reduction strategies were implemented, reductions in nutrient loads have been achieved and algal blooms have been reduced in frequency and duration. The Chowan River basin met the goal of a 20% nitrogen reduction. Total phosphorus was reduced by 29% in the same time period, although the goal was 35% (DWQ 2001a). The following strategies were recommended to reduce point and nonpoint phosphorus and nitrogen inputs (DWQ 2001a):

- Convert point source discharges to land application systems.
- Require point source effluent limits of 1 mg/l for phosphorus and 3 mg/l for nitrogen in the North Carolina portion of the basin.
- Target funds from the Agriculture Cost Share Program to implement BMPs for agricultural nonpoint sources. From 1995 to 2000, over $1,942,634 of Agriculture Cost Share funds were directed to the Chowan basin.

Although a 50 ft buffer is not in place in the Chowan, this river basin has the lowest basin population (North Carolina portion only), second lowest population density, and lowest projected population increase relative to other coastal river basins (Table 2.20). This river basin also has extensive riparian wetland vegetation to filter pollutants from upland activities. In addition, net loss of wetlands from dredge and fill activities in the Chowan River basin, as determined from 401 permits issued, appears to have decreased since 1995. Additional information on wetland impacts and mitigation in all of the coastal river basins is provided in the Wetlands chapter of this plan. Although the Chowan River basin is very different from the other coastal river basins, it is an example of how nutrient reduction strategies can successfully improve water quality.

Coast-wide Buffer Rule

The CRC adopted a 30 ft buffer as part of the Coastal Shoreline AEC in August 2000 for all new

development in the 20 coastal counties governed by CAMA. This buffer begins at the water's edge, and allows clearing of vegetation as long as no soil disturbance occurs. Although this buffer will certainly have positive environmental benefits throughout the coast, the science suggests that it will be inadequate in significantly reducing pollutant loading from nonpoint runoff (Lee et al. 1989; Zirschky et al. 1989; Groffman et al. 1991; Desbonnet et al. 1994; Gilliam et al. 1994; Lowrance 1997).

Additional actions are needed to increase the preservation and establishment of riparian forest buffers in other river basins to maintain and improve the condition of coastal waters. Highest priority should be in coastal waters where fish kills are documented, shellfish harvesting is threatened or closed, where there are primary nursery areas, and where the most pristine waters are located nearest to productive fisheries. The Neuse and Tar-Pamlico riparian buffer rules could be expanded to these areas. Additional incentive-based approaches, such as tax credits for preserving unmowed vegetated buffers, should be developed and implemented. Another means of preserving highly sensitive undeveloped shoreline vegetation is through establishment or enhancement of state/local land acquisition programs.

Local initiatives

There are many local monitoring and management initiatives that have been implemented to protect sensitive resources. University and citizen water quality monitoring programs have already been discussed in the text. Other county programs are focusing on educating the public on the value of riparian buffers, developing watershed management plans, acquiring conservation easements, and restoring wetlands and riparian streams to improve water quality. *The successes of these local projects need to be well publicized to promote similar local and multiple agency projects in other areas. In addition, conservation easements need to be enforced to ensure effectiveness. Land use planning and implementation equivalent to that required by CRC in CAMA counties should be required in all coastal-draining river basins, as recommended by the Estuarine Shoreline Protection Stakeholders group in 1999.*

Needed management measures

In summary, there are many possible actions at state, local, and federal levels that could be taken to improve multiple water quality parameters. *Before implementing new measures, actions should focus on improving the effectiveness of existing regulations and water quality monitoring programs so that status and trends can be accurately assessed. Efforts should continue to reduce point source discharges and improve the quality of discharge effluent. To reduce nonpoint loading of nutrients, sediments, bacteria, and toxins into the water column, a broad range of strategies should be implemented, including:*

- Accelerate land preservation and restoration activities;
- Improve and implement land use planning strategies;
- Reduce nonpoint runoff from agriculture and silviculture practices; and
- Expand or implement public outreach on coastal fish habitat, threats, and actions to reduce negative impacts.

2.5. SUMMARY OF WATER COLUMN CHAPTER

The water column habitat surrounds and supports all aquatic organisms and connects all coastal fish habitats. Consequently, clean and healthy waters are critical to the overall viability of coastal fish habitats and aquatic organisms. The general distribution of fish within the water column is determined by the physical and chemical properties of each unique water body (e.g., salinity, temperature), while the abundance, diversity, and health of coastal fish and invertebrates are strongly influenced by water quality conditions (e.g., oxygen, turbidity, nutrients). The water column provides the necessary medium for spawning and transport of eggs and larvae to habitats favorable for survival and growth. In addition, coastal waters are an important source of primary production, providing food for the survival of early life stages of aquatic organisms. Another critical function of the water column is to support other important

food sources for pelagic species, such as river herring, bluefish, and Spanish mackerel, and to serve as a critical corridor for migration. Particularly important areas of the water column include inlets, shallow estuarine nursery areas, anadromous fish spawning and nursery areas, and the nearshore surf zone.

Well-documented occurrences of low oxygen events, fish kills, and harmful algal blooms during the 1980s and 1990s provided visible indicators that coastal waters were declining in quality. Although severe water quality problems are variable and appear to have diminished in recent years, many coastal waters remain impaired. The primary threats to the water column are hydrological modifications and water quality degradation.

The hydrology of North Carolina has been altered dramatically, with over 2,000 dams obstructing and modifying water flow to the coast, numerous surface water withdrawals, and extensive channelization of streams. Physical obstructions in streams from structures such as dams and road crossings (fill causeways, culverts), as well as alteration of flow conditions, are a major threat to anadromous fish species, some of which are classified as Overfished by Division of Marine Fisheries (American shad, the central/southern stock of striped bass, and the Albemarle Sound stock of river herring). Removing obstructions and restoring flow in streams and rivers have been highly successful in some areas for restoring striped bass and American shad populations and should continue to be a high priority.

Water quality degradation affects aquatic organisms in many ways. Excessive sediment loading increases turbidity and sedimentation, which can result in a decrease in biological productivity, clogging of fish gills, reduced recruitment of invertebrates, increased mortality, and filling in of rivers and creeks. Important fishery and prey species in North Carolina that are impacted by alterations or degradation of the water column include pelagic-oriented species such as blueback herring, American shad, striped bass, Atlantic menhaden, bluefish, and anchovies. The condition of the water column also influences other coastal fish habitats. For example, waters depleted of oxygen can result in extensive mortality of individuals inhabiting shell bottom and soft bottom communities. Moreover, excess sedimentation and turbidity can shade submerged vegetation, while the associated sediment can smother hard bottom communities.

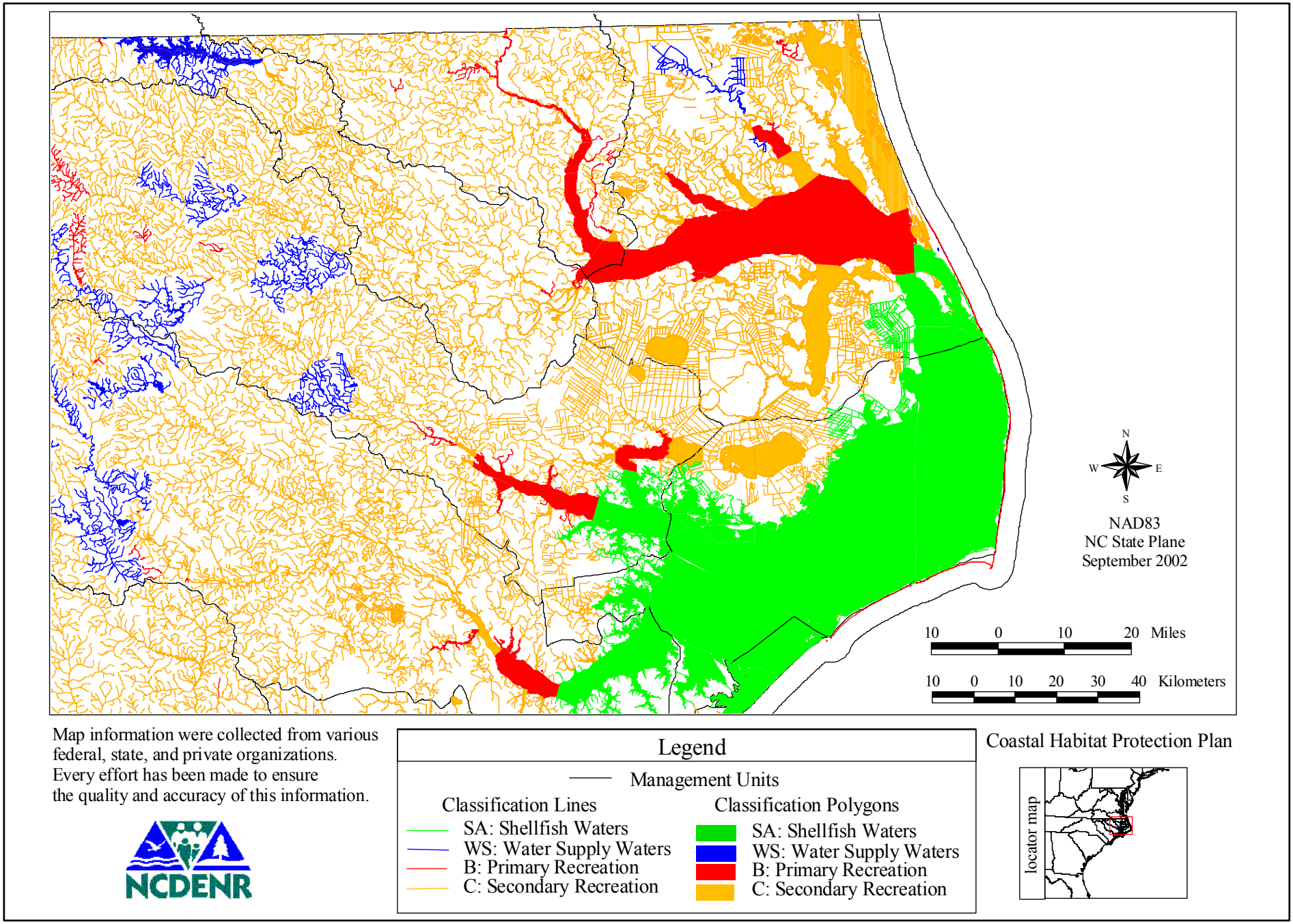
Primary sources of sediment are nonpoint runoff from land disturbance associated with building and road construction and agricultural drainage. A predicted increase in the rate of sea level rise will accelerate coastal erosion and impact sedimentation-related issues. Division of Water Quality data show the greatest impairment to coastal freshwater streams is due to not only excessive sediment loading but also low dissolved oxygen.

Low dissolved oxygen has been responsible for many fish kills in coastal river basins, especially the Neuse, Cape Fear, and Tar-Pamlico. The estuarine species most frequently affected by fish kills have been menhaden and flounder; the most frequently reported freshwater species have been sunfish and catfish. Such oxygen depletion can occur naturally, but is greatly aggravated and intensified by eutrophication. This excessive loading of nutrients can also contribute to toxic algal blooms and may contribute to *Pfiesteria* outbreaks. Primary sources of excessive nutrients in the water column include point source wastewater discharges, and nonpoint runoff from crop agriculture, animal operations, urban development, and air emissions from industries and vehicles. Another serious concern for estuarine and ocean water quality is bacterial contamination, both for habitat and health reasons. Fecal coliform contamination in estuarine waters is a major cause of water quality impairment, originating primarily from nonpoint sources. Bacterial contamination has resulted in consistent increases in shellfish harvest closures over time, including closures in Outstanding Resource Waters, North Carolina's highest quality waters (over 1,000 acres closed in ORW waters since 1990). When stormwater is discharged on ocean beaches, it contaminates the surf zone with not only bacteria, but also a variety of other toxins. Runoff from roads, agriculture, and marina-related activities are common sources of toxins in coastal waters. While toxins are a concern to the water column, these pollutants tend to settle and become incorporated

into soft bottom habitat relatively quickly, where they can be resuspended or can adversely affect organisms in the bottom sediments.

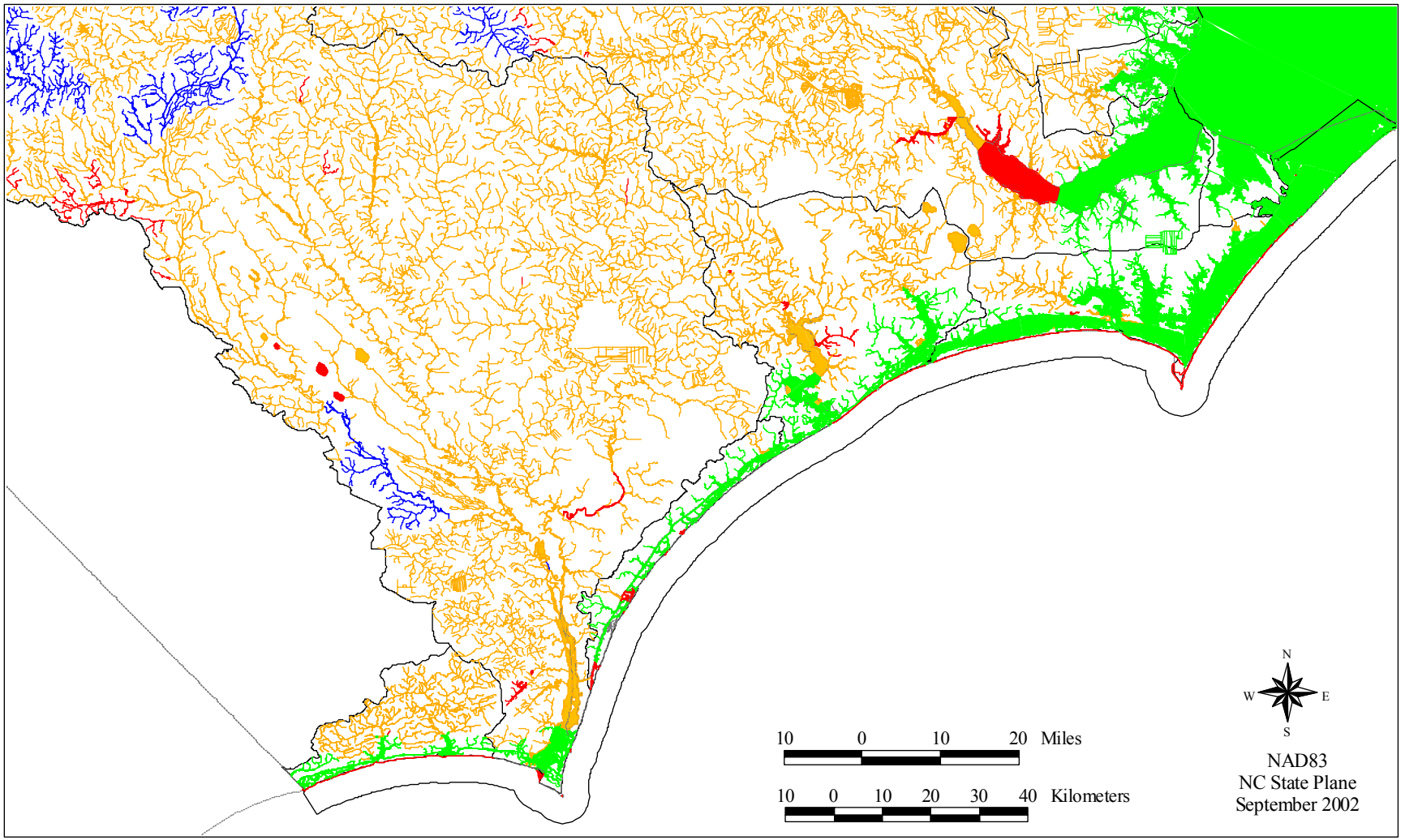
Sediment, nutrient, bacteria, and toxin loading must be reduced by addressing multiple sources. These include improvement and continuation of urban and agricultural BMPs, more stringent sediment controls on construction projects, and additional buffers along coastal waters.

Water column habitat is required for the survival, growth and reproduction of fish and it greatly influences all other coastal fish habitats. Therefore, efforts are needed to minimize threats and enhance water quality wherever possible, particularly within and adjacent to designated Strategic Habitat Areas.



2.1a. Surface water classifications of the North Carolina Environmental Management Commission in eastern North Carolina (1997 classification).

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Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

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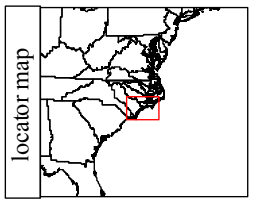
Legend

Management Units

Classification Lines
- SA: Shellfish Waters
- WS: Water Supply Waters
- B: Primary Recreation
- C: Secondary Recreation

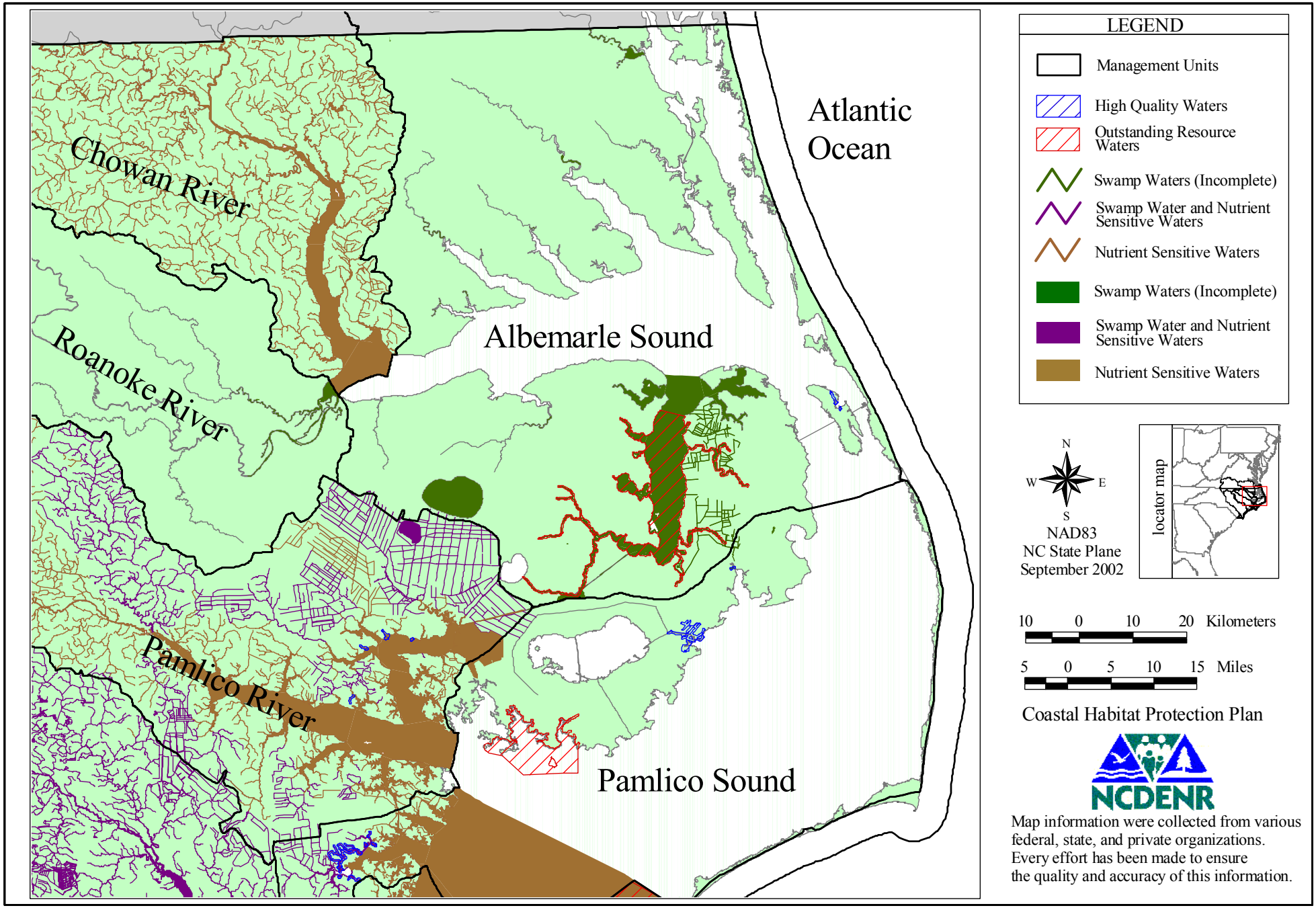
Classification Polygons
- SA: Shellfish Waters
- WS: Water Supply Waters
- B: Primary Recreation
- C: Secondary Recreation

Coastal Habitat Protection Plan



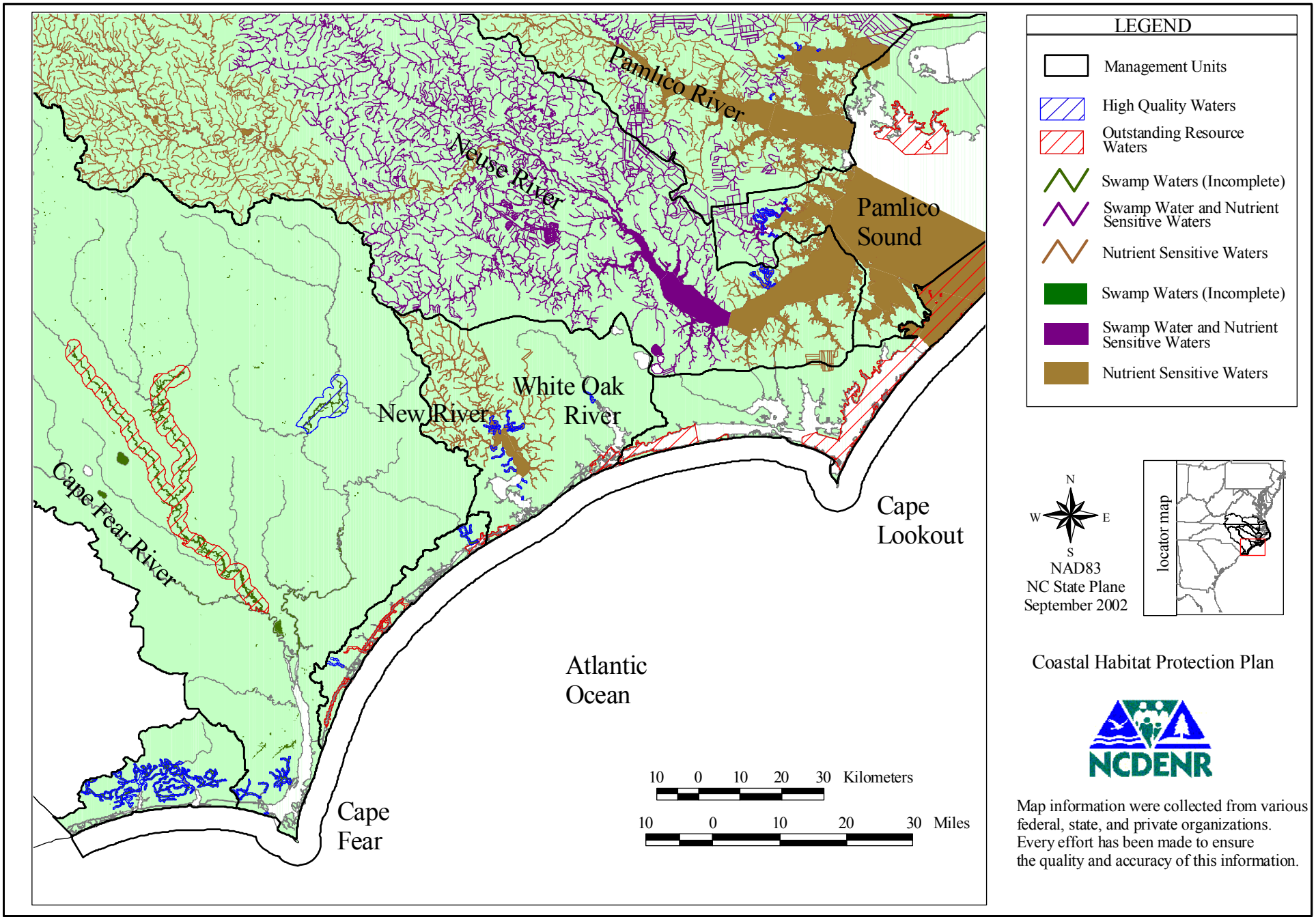
2.1b. Surface water classifications of the North Carolina Environmental Management Commission in eastern North Carolina (1997 classification).

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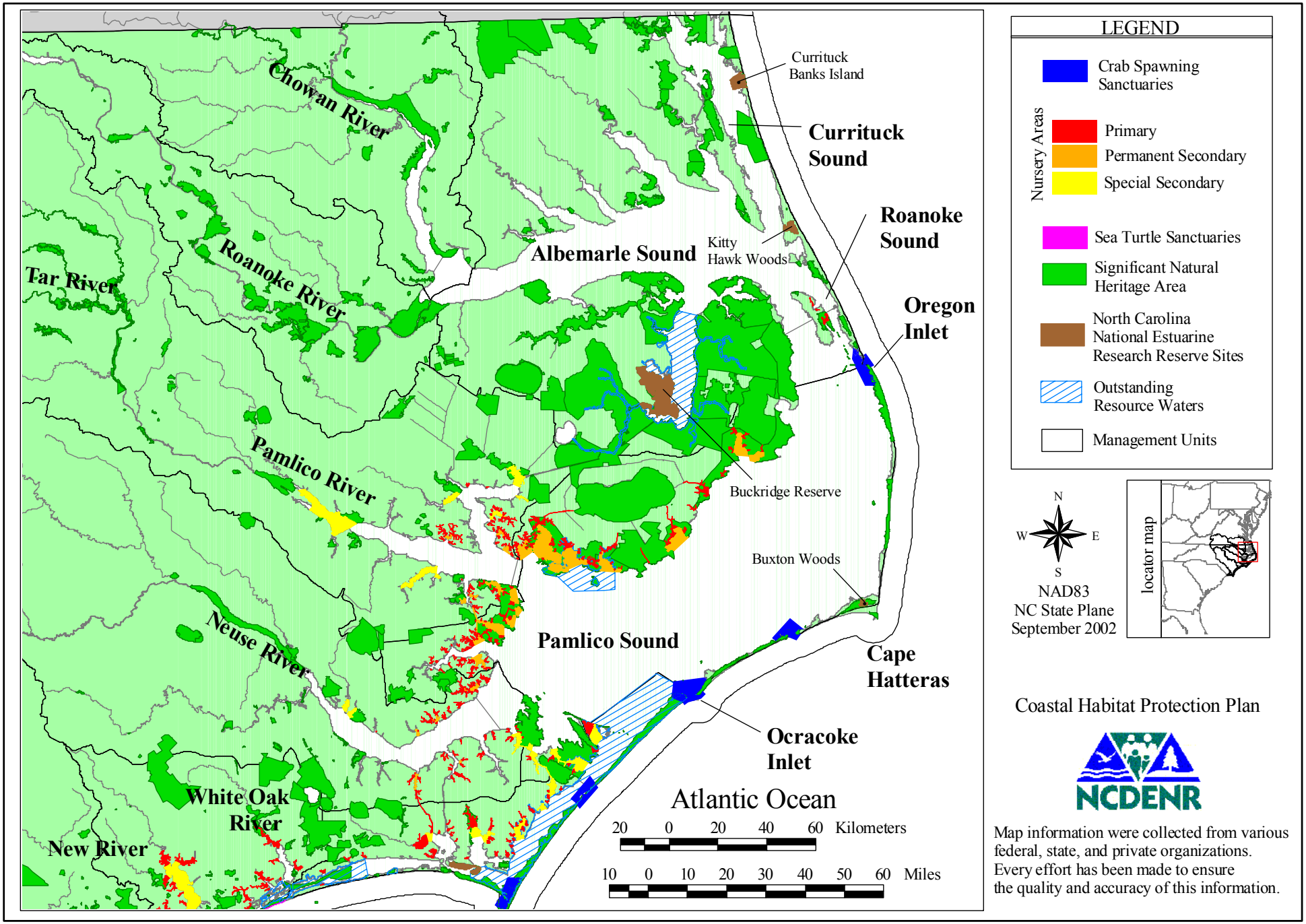
Map 2.2a. Supplemental surface water classifications of the NC Environmental Management Commission in eastern North Carolina (1997 classification)

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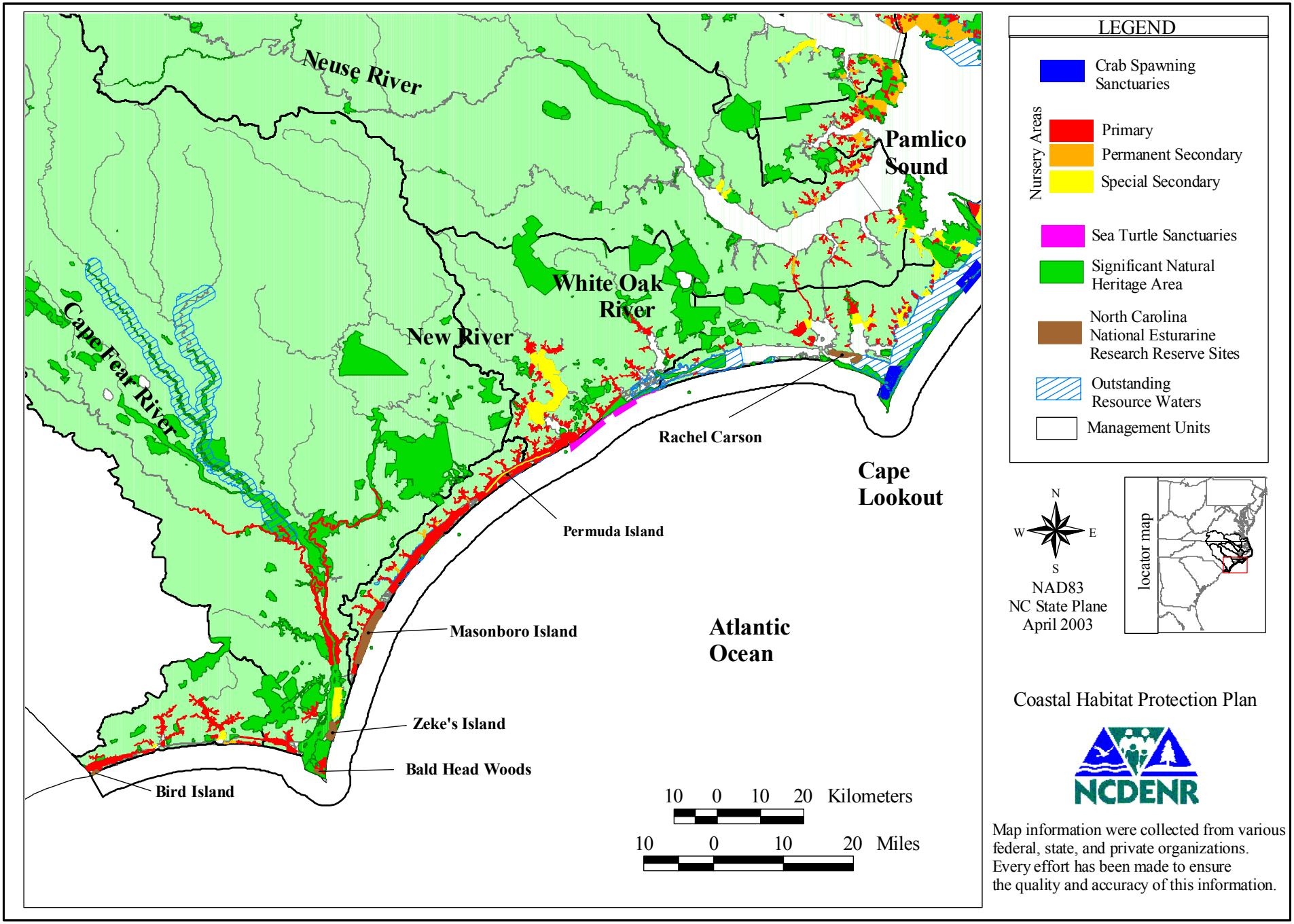
Map 2.2b. Supplemental surface water classifications of the NC Environmental Management Commission in eastern North Carolina (1997)

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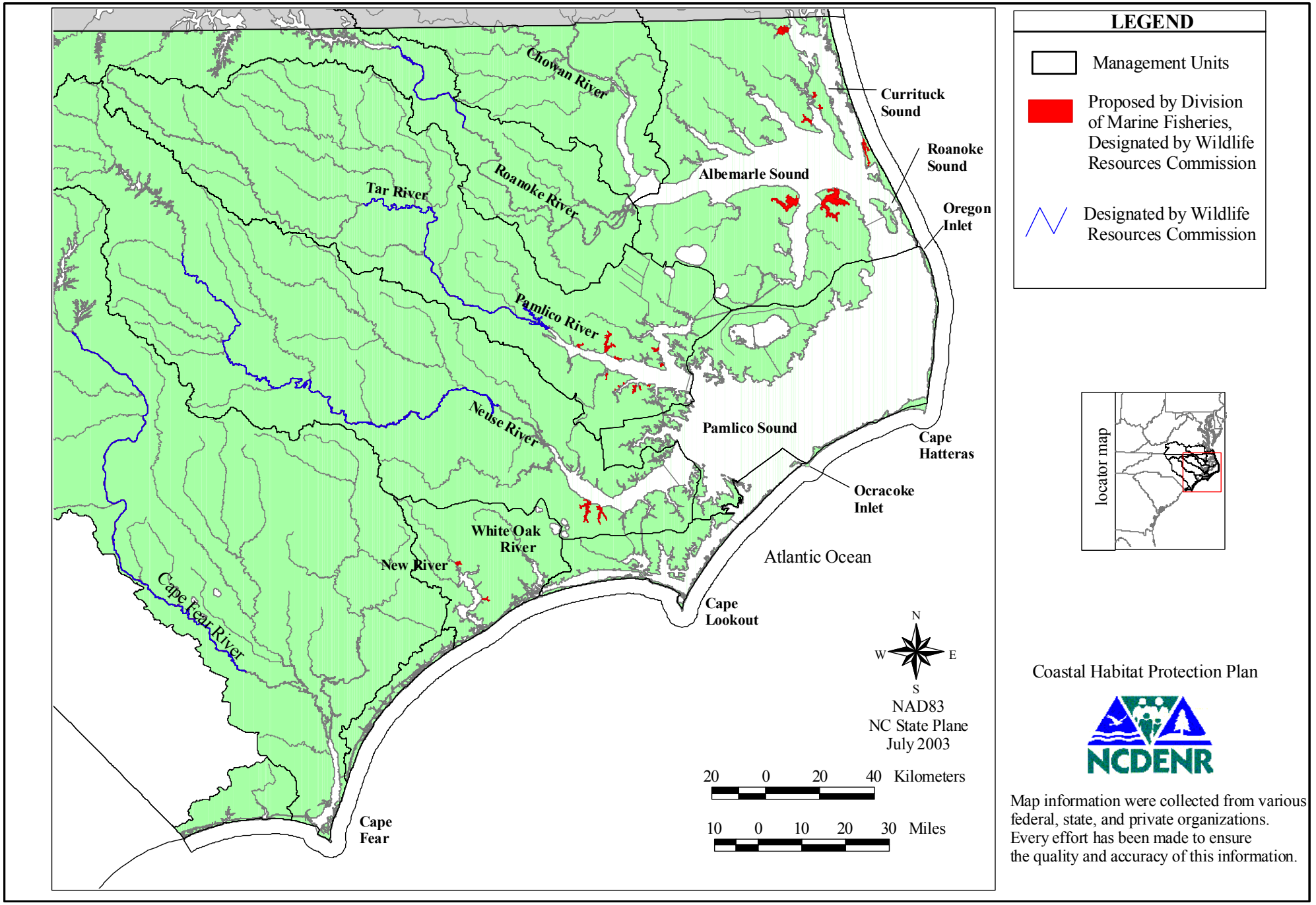
Map 2.3a. Designated protected habitat areas in eastern North Carolina north of Cape Lookout (map themes from BasinPro3 software).

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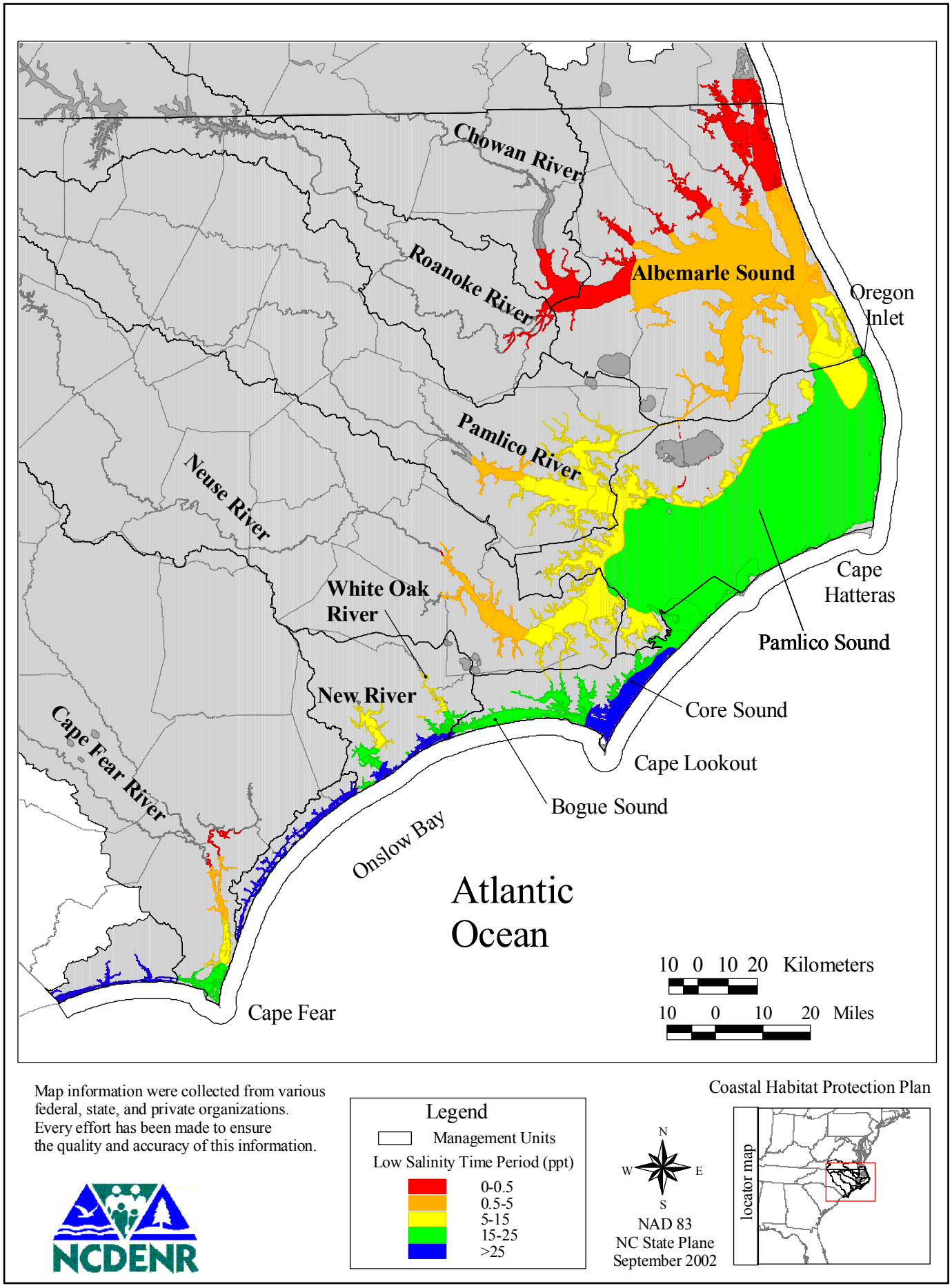
Map 2.3b. Designated protected habitat areas in eastern North Carolina south of Cape Lookout (map themes from BasinPro3 software).

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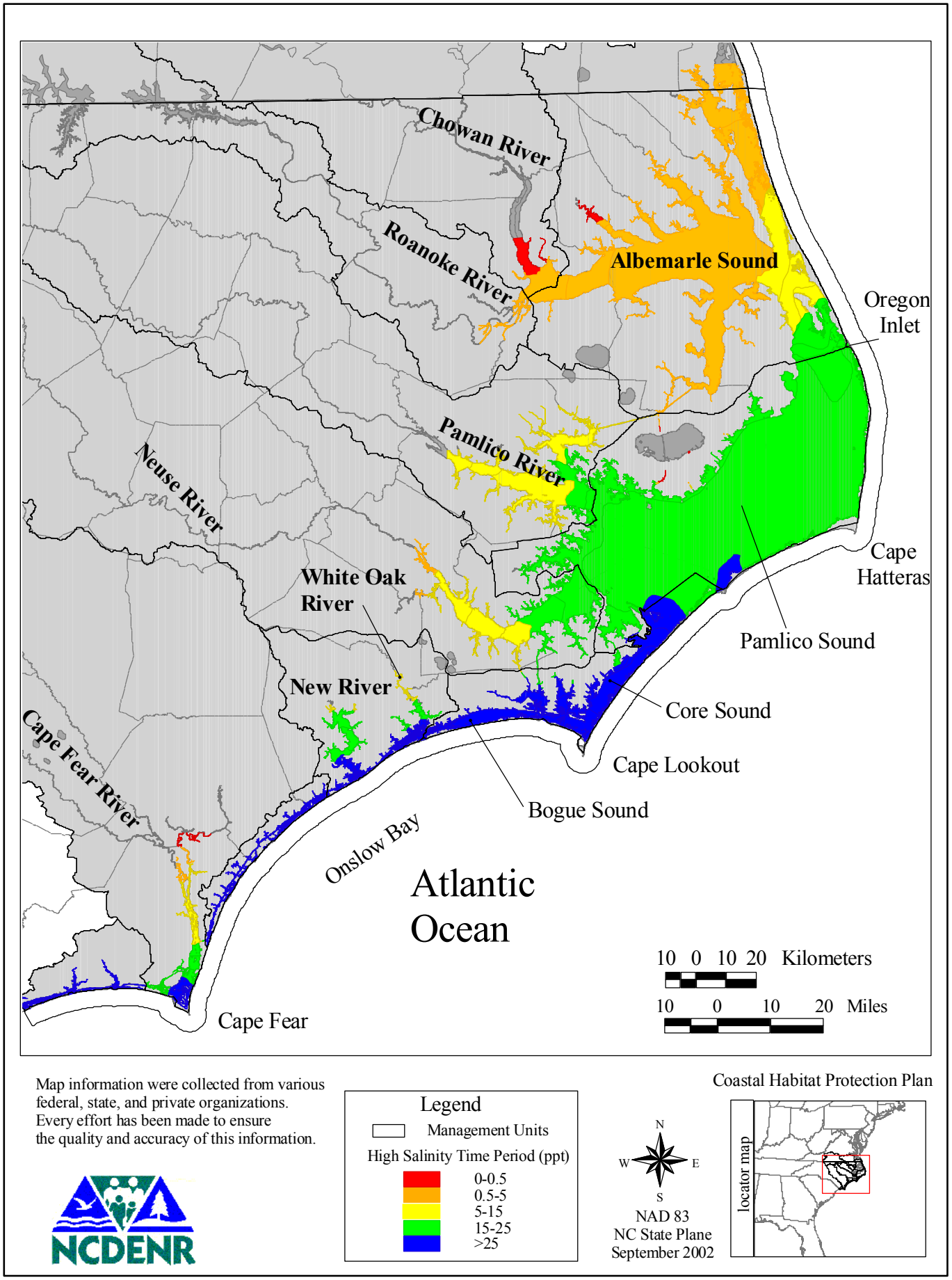
Map 2.4. Inland primary nursery areas designated by the Wildlife Resources Commission [WRC rule: 15A NCAC 10C .0503].

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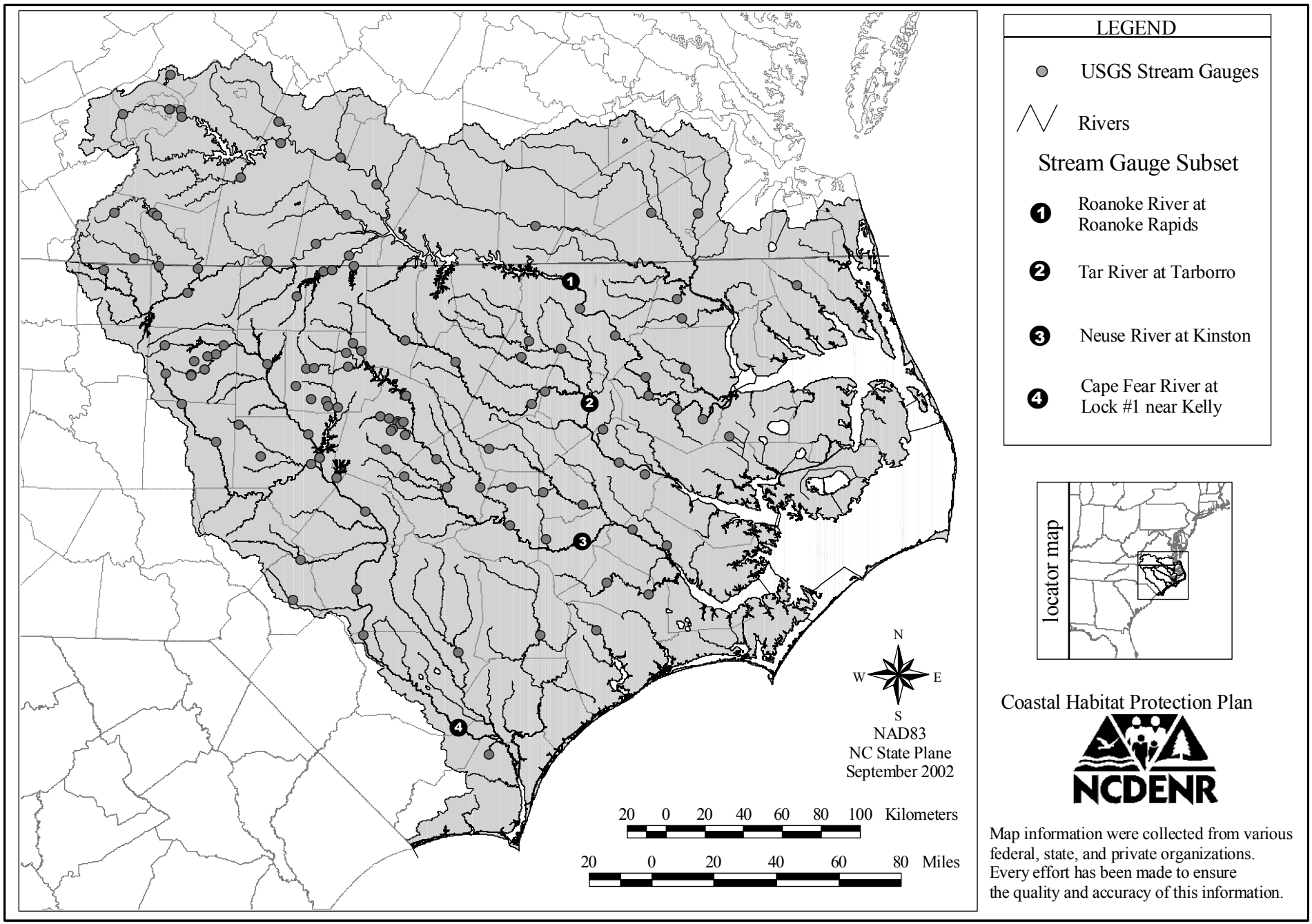
Map 2.5a. Winter and spring salinity zones in eastern North Carolina (derived from Orlando et al. 1994).

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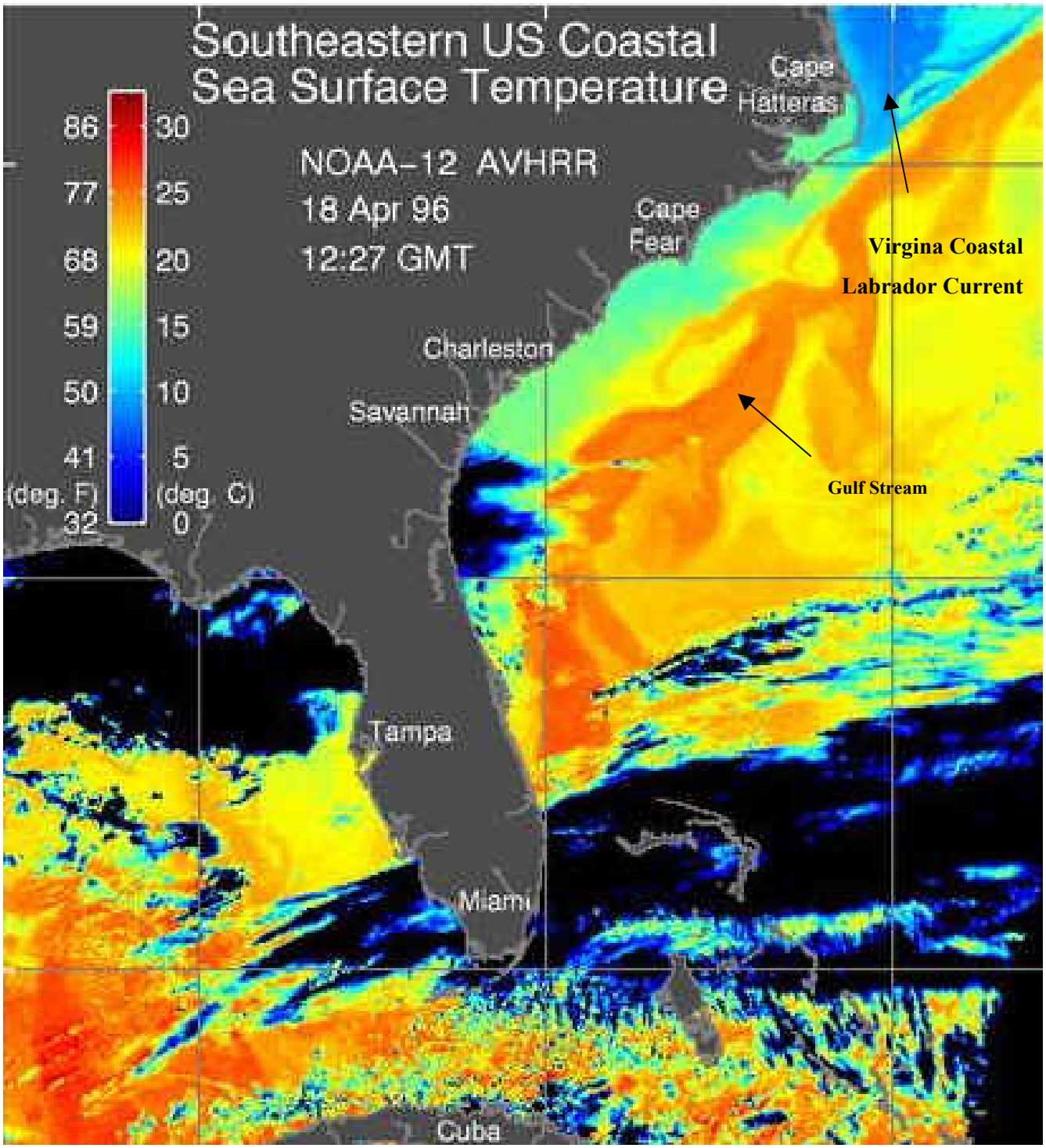
Map 2.5b. Summer and fall salinity zones in eastern North Carolina (derived from Orlando et al. 1994).

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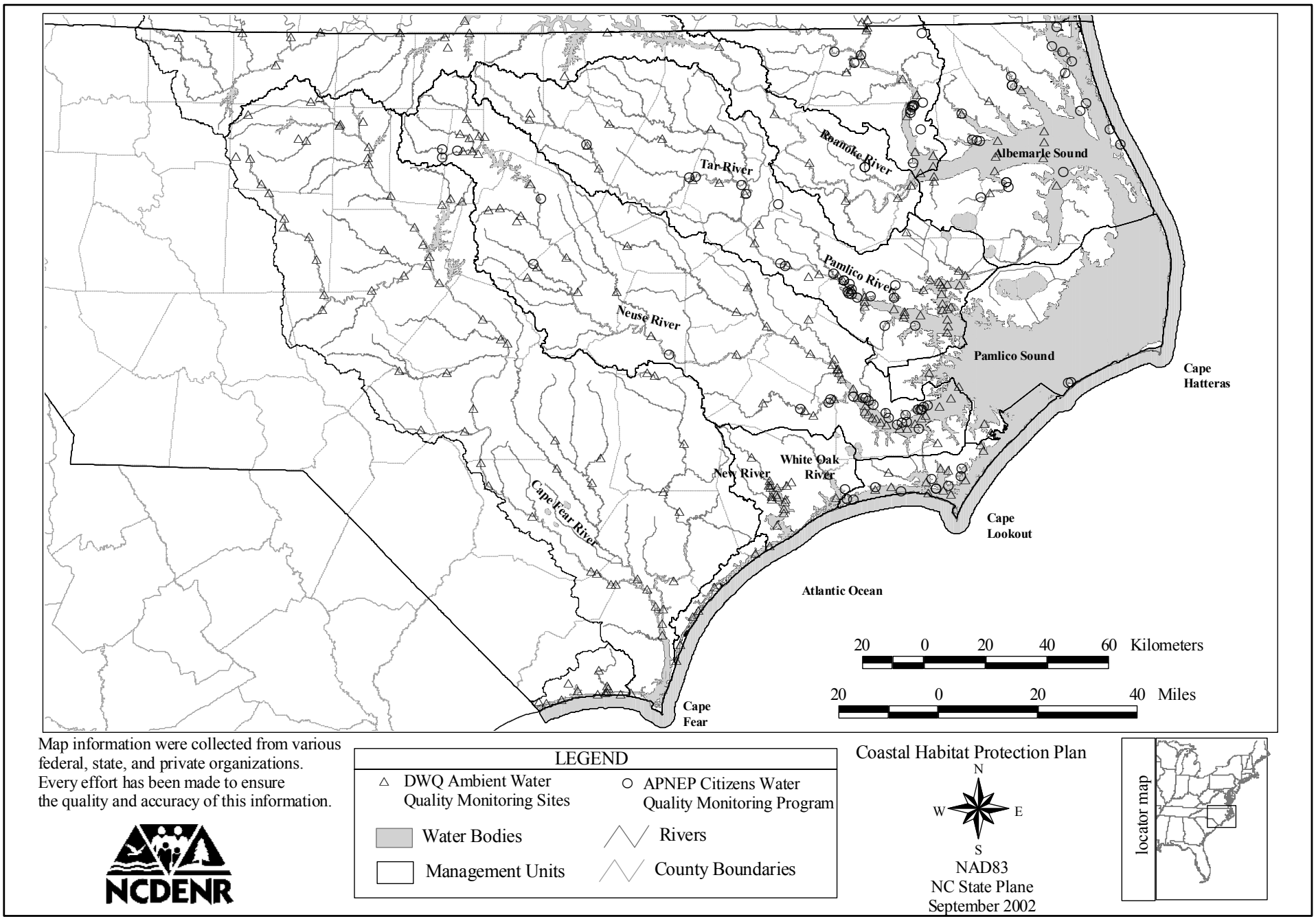
Map 2.6. Locations of US Geological Survey stream gauge stations in the area included in the NC Coastal Habitat Protection Plan (source: BasinPro3 software).

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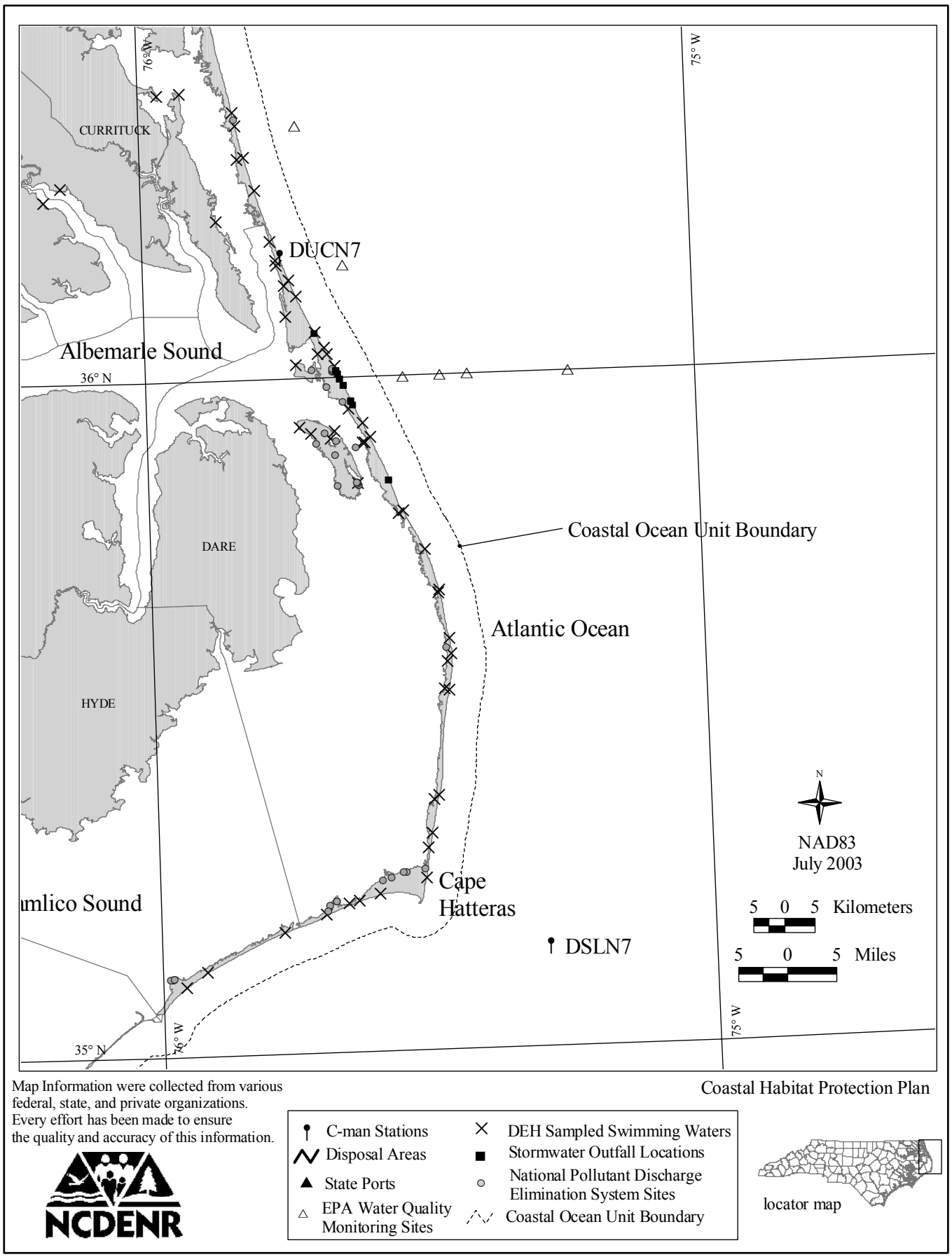
Map 2.7. Satellite imagery of sea surface temperature of North Carolina ocean waters, depicting position of the Virginia Current and Gulf Stream (Source: NOAA web site).

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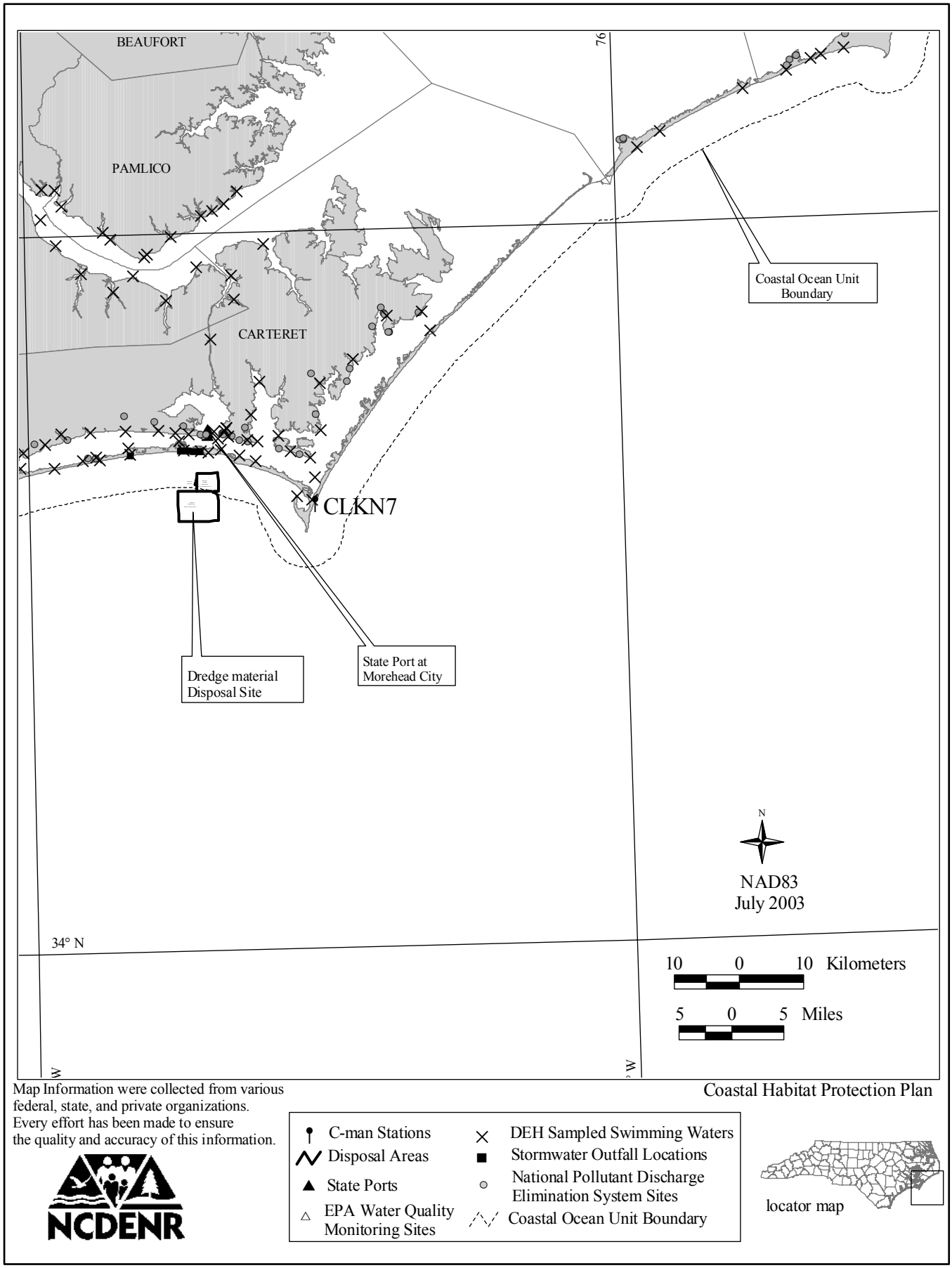
Map 2.8. Water quality monitoring stations within N.C. Coastal Habitat Protection Plan area (source: NC CGIA BasinPro3 software).

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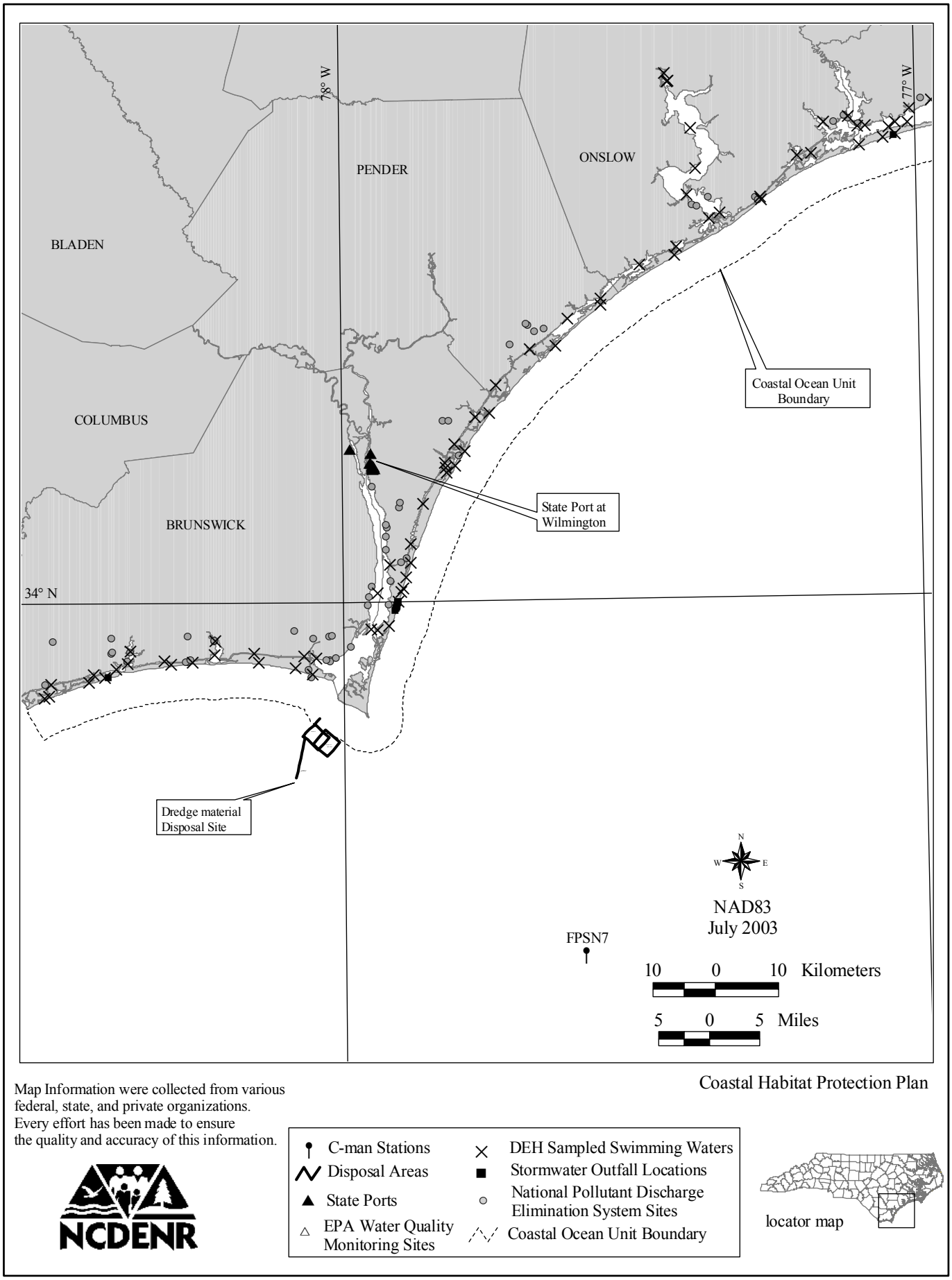
2.9a. Water quality monitoring stations and potential water quality threats in coastal North Carolina north of Ocracoke Inlet

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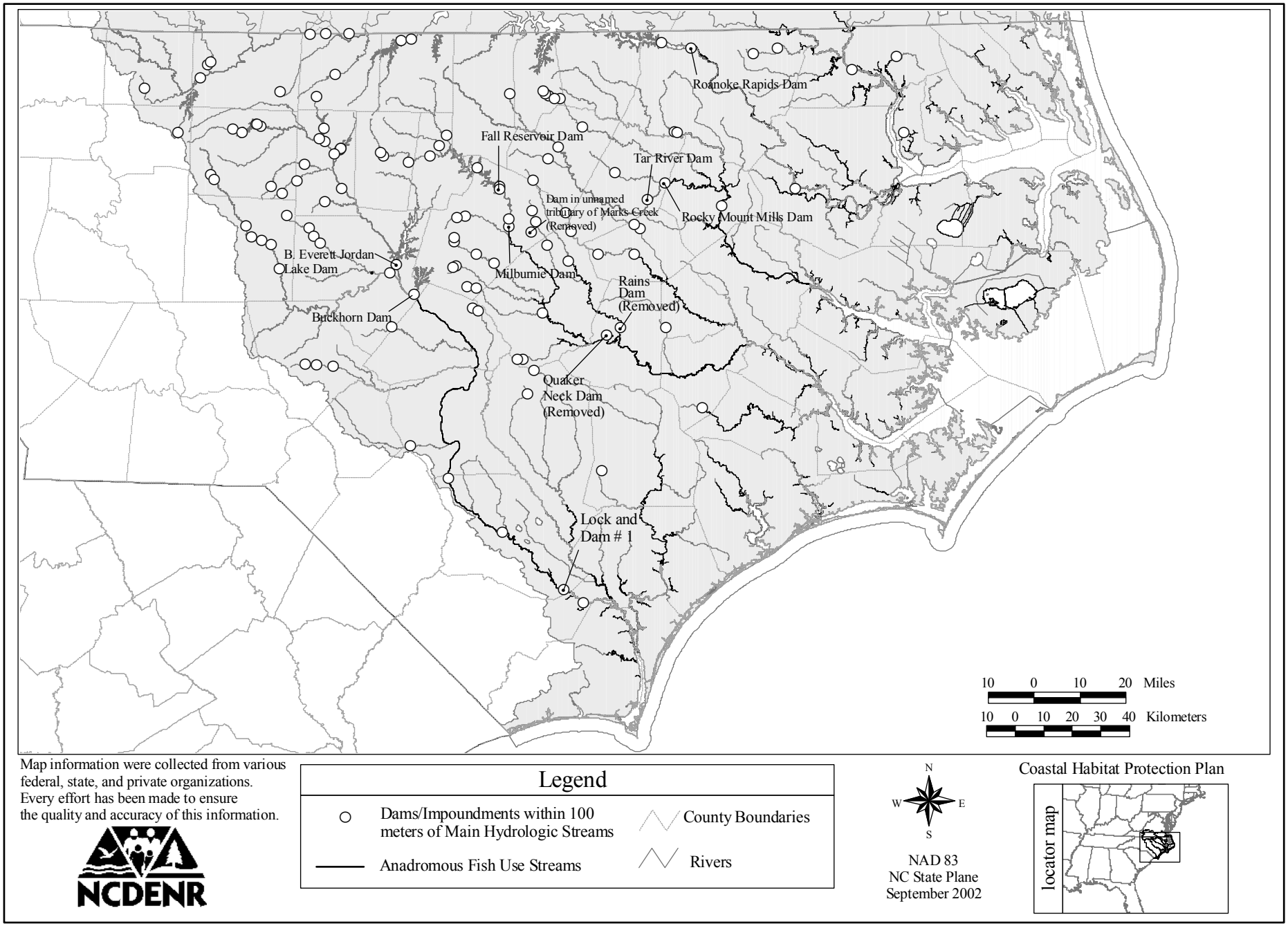
Map 2.9b. Water quality monitoring stations and potential water quality threats in coastal North Carolina from Bogue Sound to Ocraco

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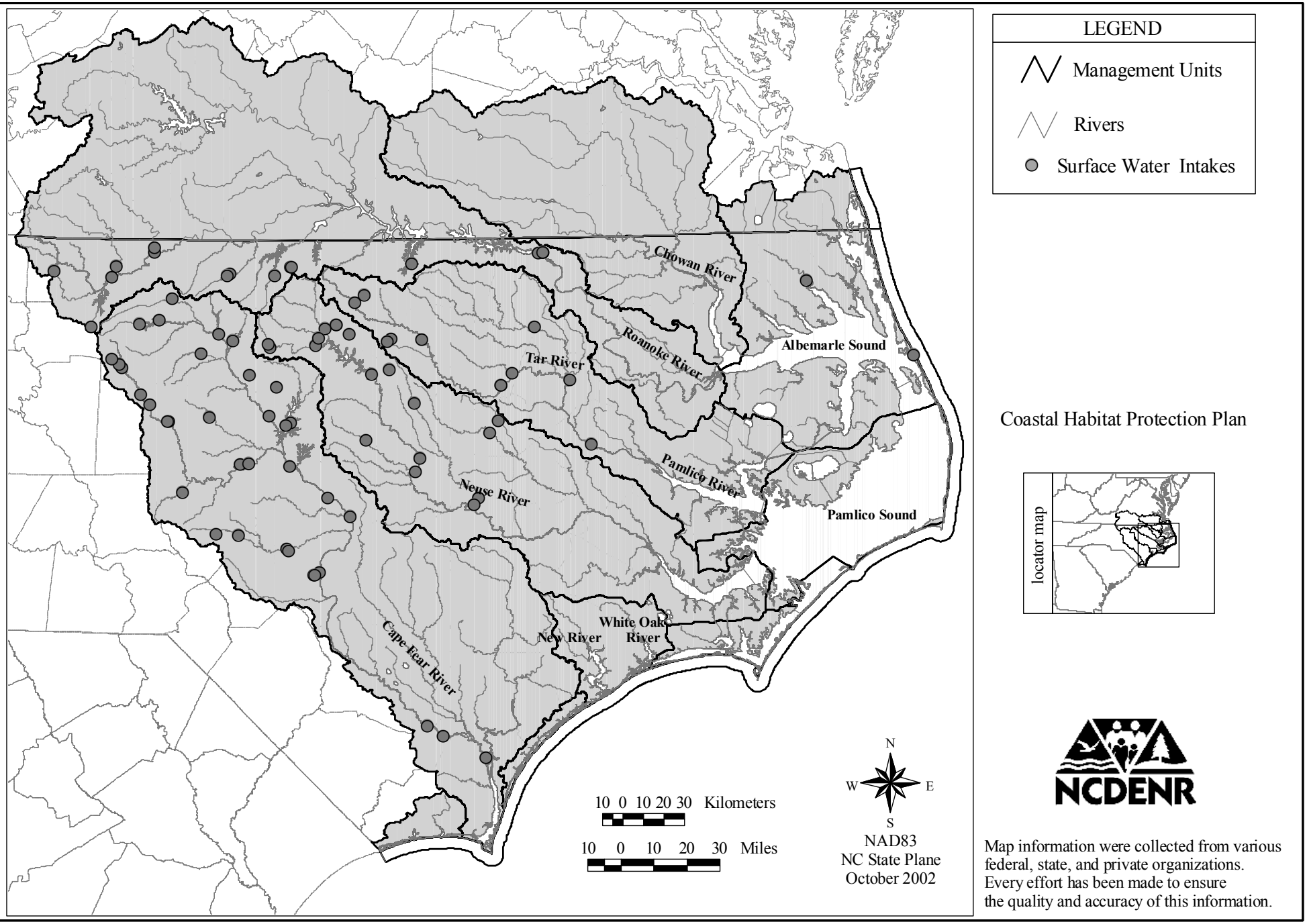
Map 2.9c. Water quality monitoring stations and potential water quality threats in coastal North Carolina south of Bogue Sound

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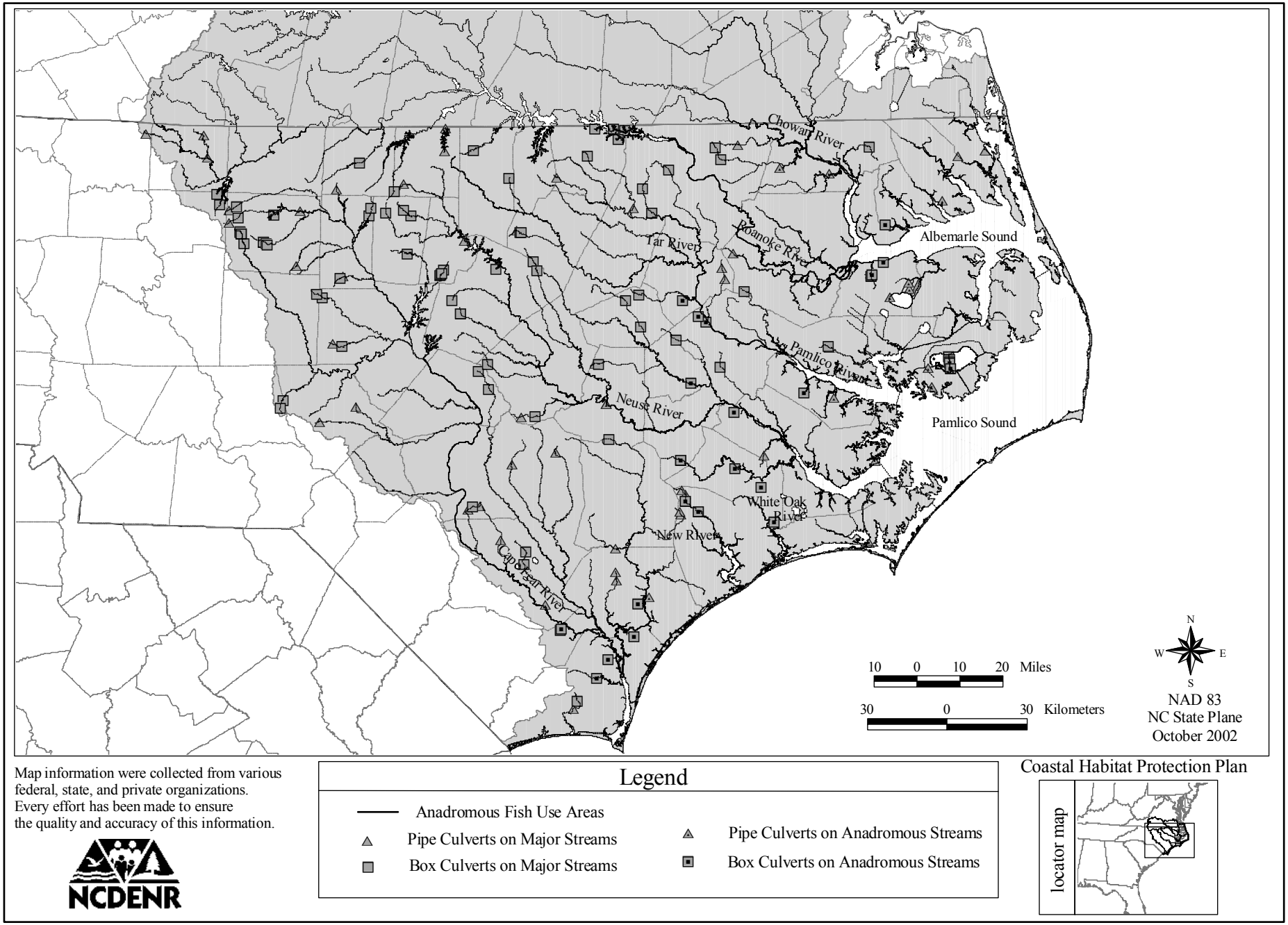
Map 2.10. Location of dams on large creeks and rivers in coastal North Carolina drainages (from BasinPro3 software).

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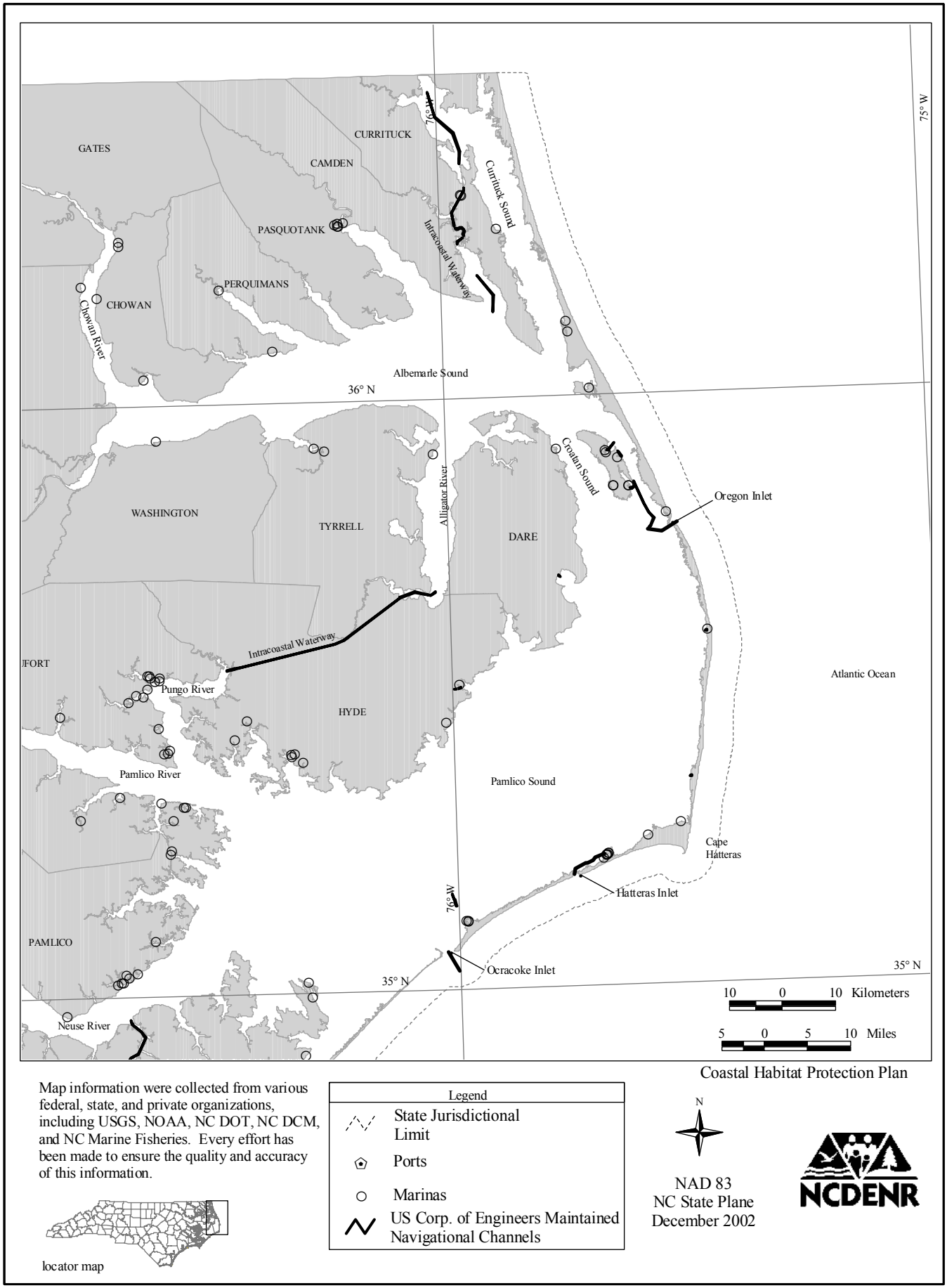
Map 2.11. Location of registered surface water intakes in North Carolina coastal river basins (from BasinPro3 software).

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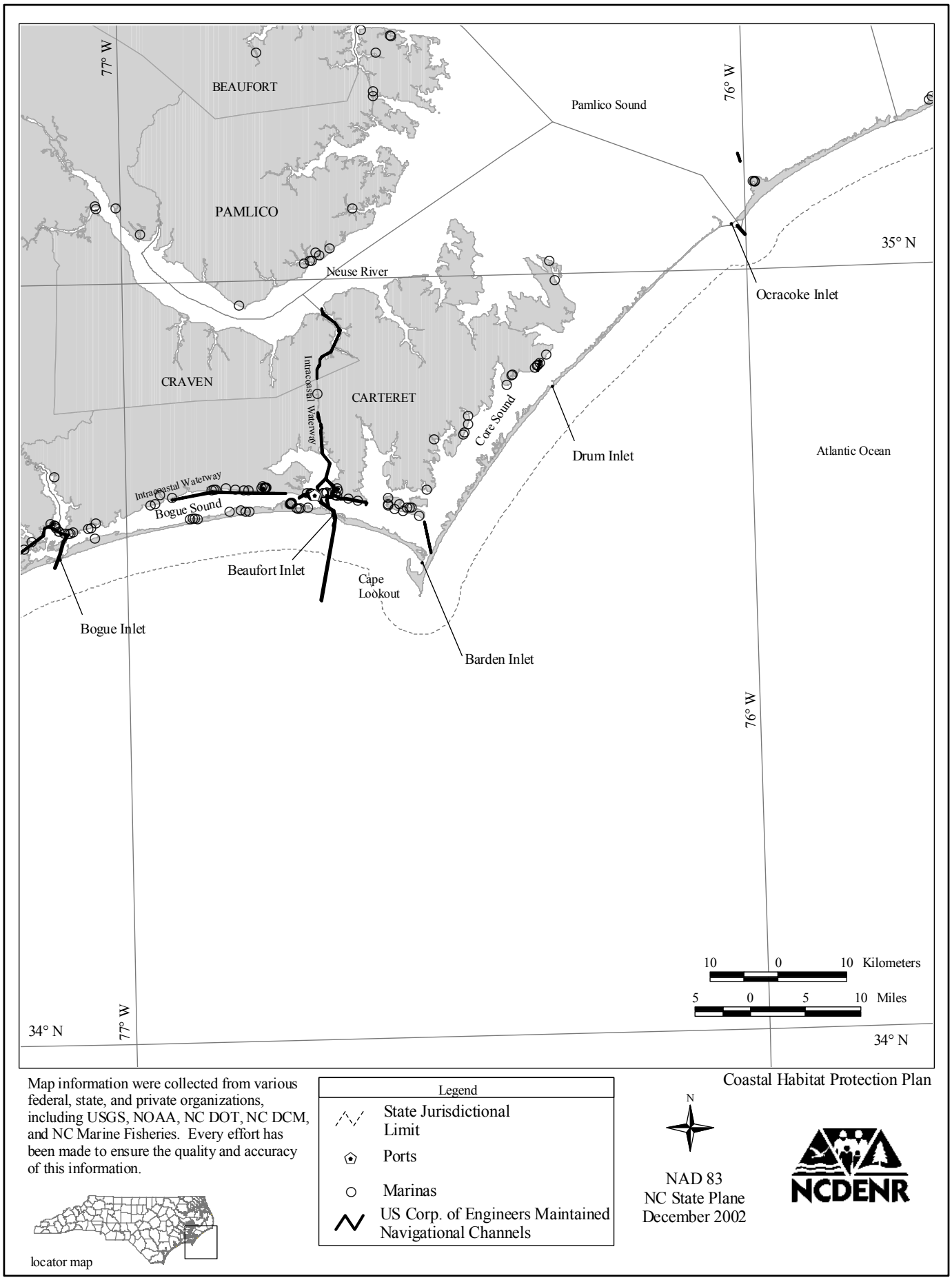
Map 2.12. Location of pipes and culverts on major streams in coastal North Carolina drainages.

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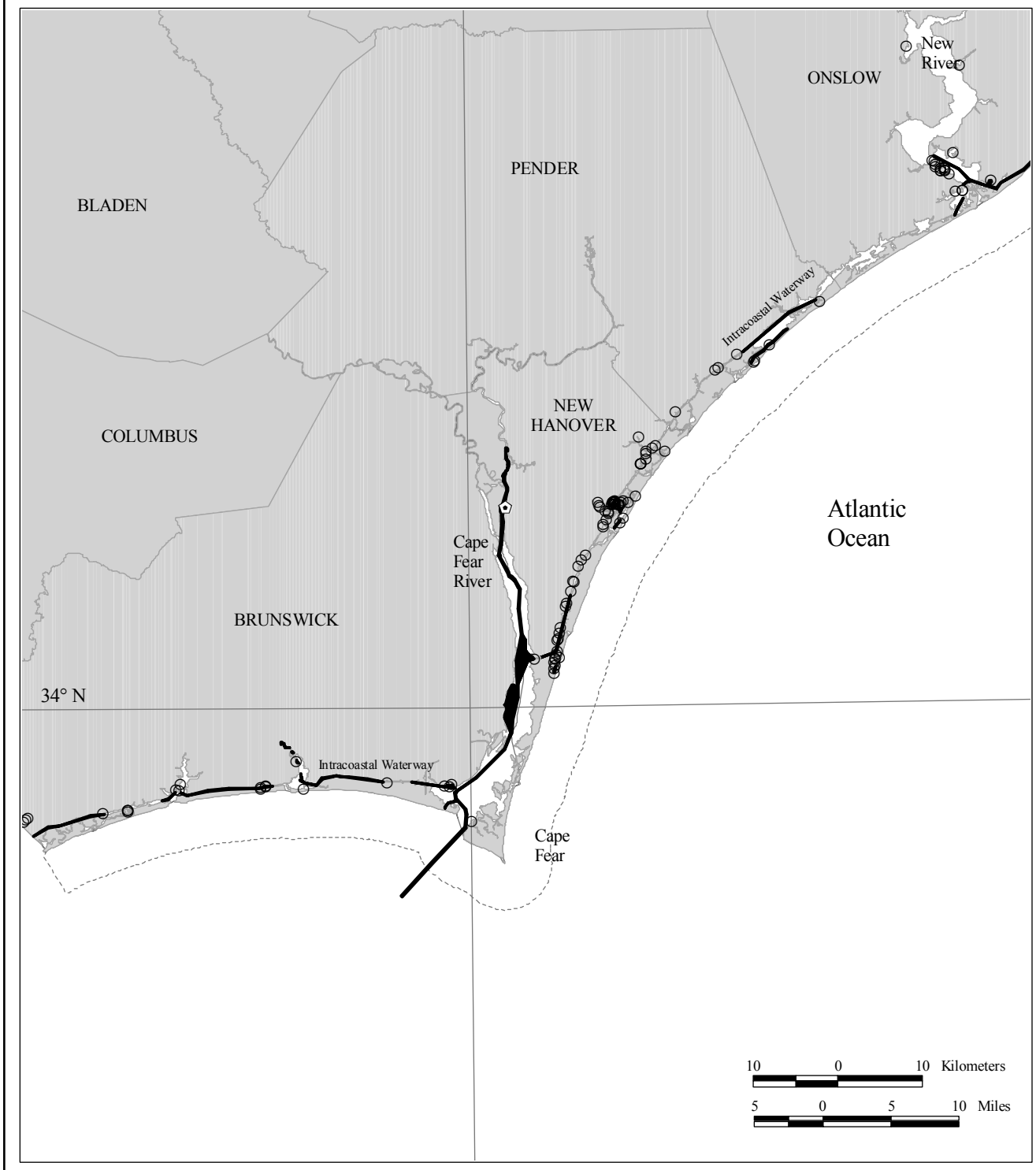
Map 2.13a. US Army Corps of Engineers maintained navigation channels in coastal North Carolina from Virginia to Ocracoke Inlet

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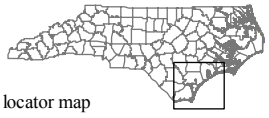


Map 2.13b. US Army Corps of Engineers maintained navigation channels in coastal North Carolina from: Ocracoke Inlet to Bogue Inlet

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Map information were collected from various federal, state, and private organizations, including USGS, NOAA, NC DOT, NC DCM, and NC Marine Fisheries. Every effort has been made to ensure the quality and accuracy of this information.



Legend

- State Jurisdictional Limit
- Ports
- Marinas
- U.S. Army Corps of Engineers maintained navigational channels

Coastal Habitat Protection Plan

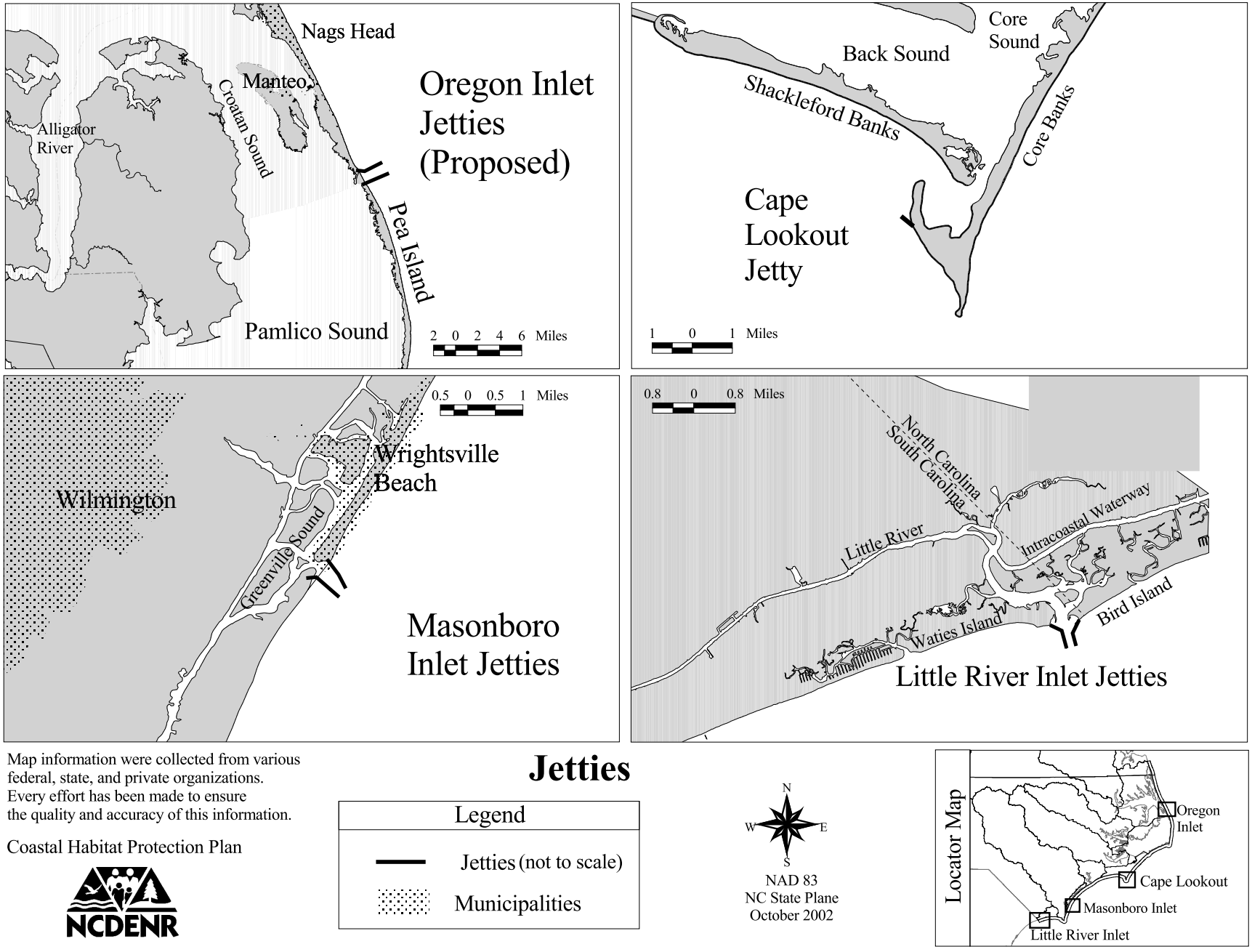
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NAD 83
NC State Plane
December 2002

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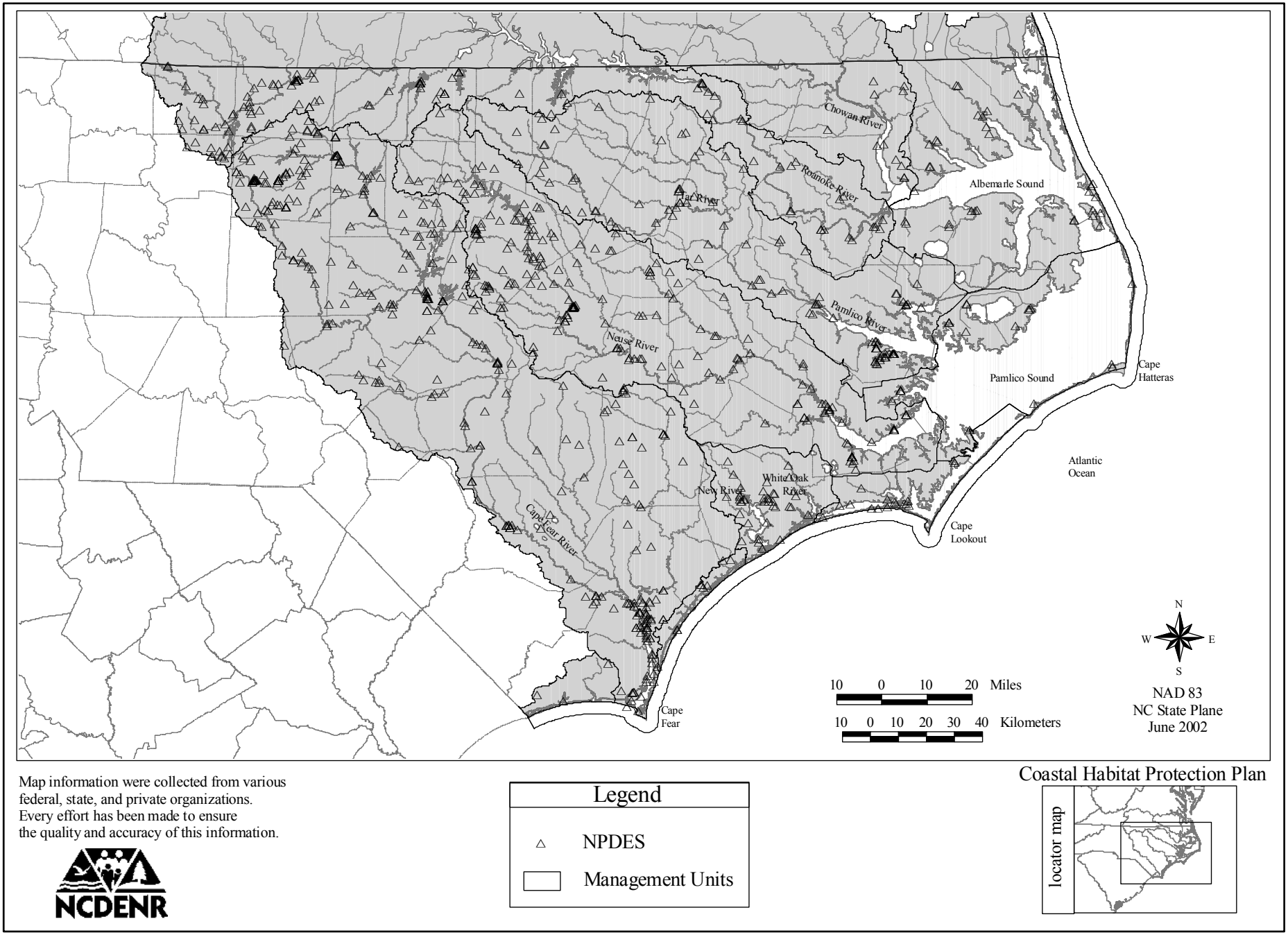
Map 2.13c. U.S. Army Corps of Engineers maintained navigation channels in coastal North Carolina from Bogue Inlet to South Carolina

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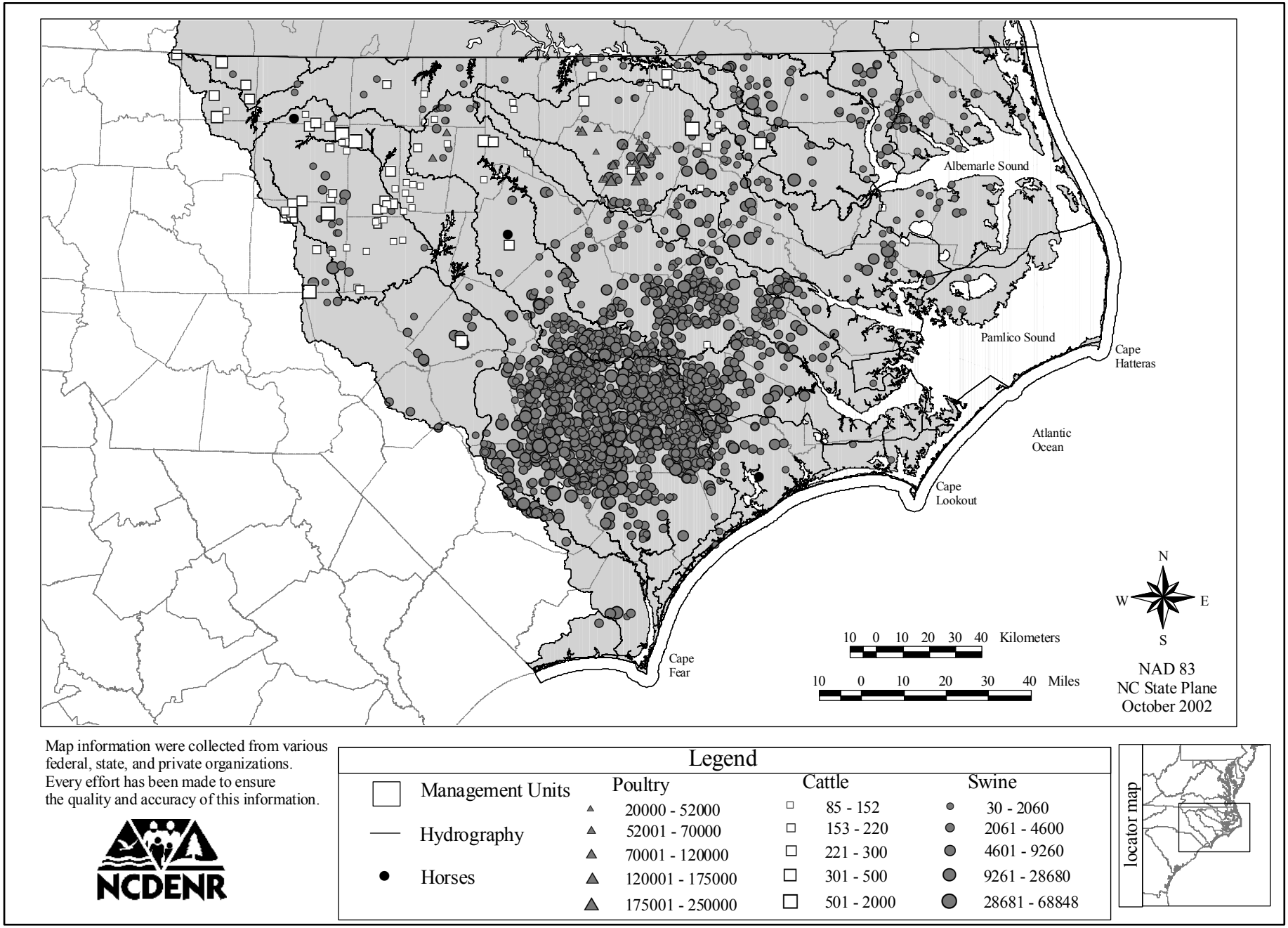
Map 2.14. Location of ocean jetties along the North Carolina coast.

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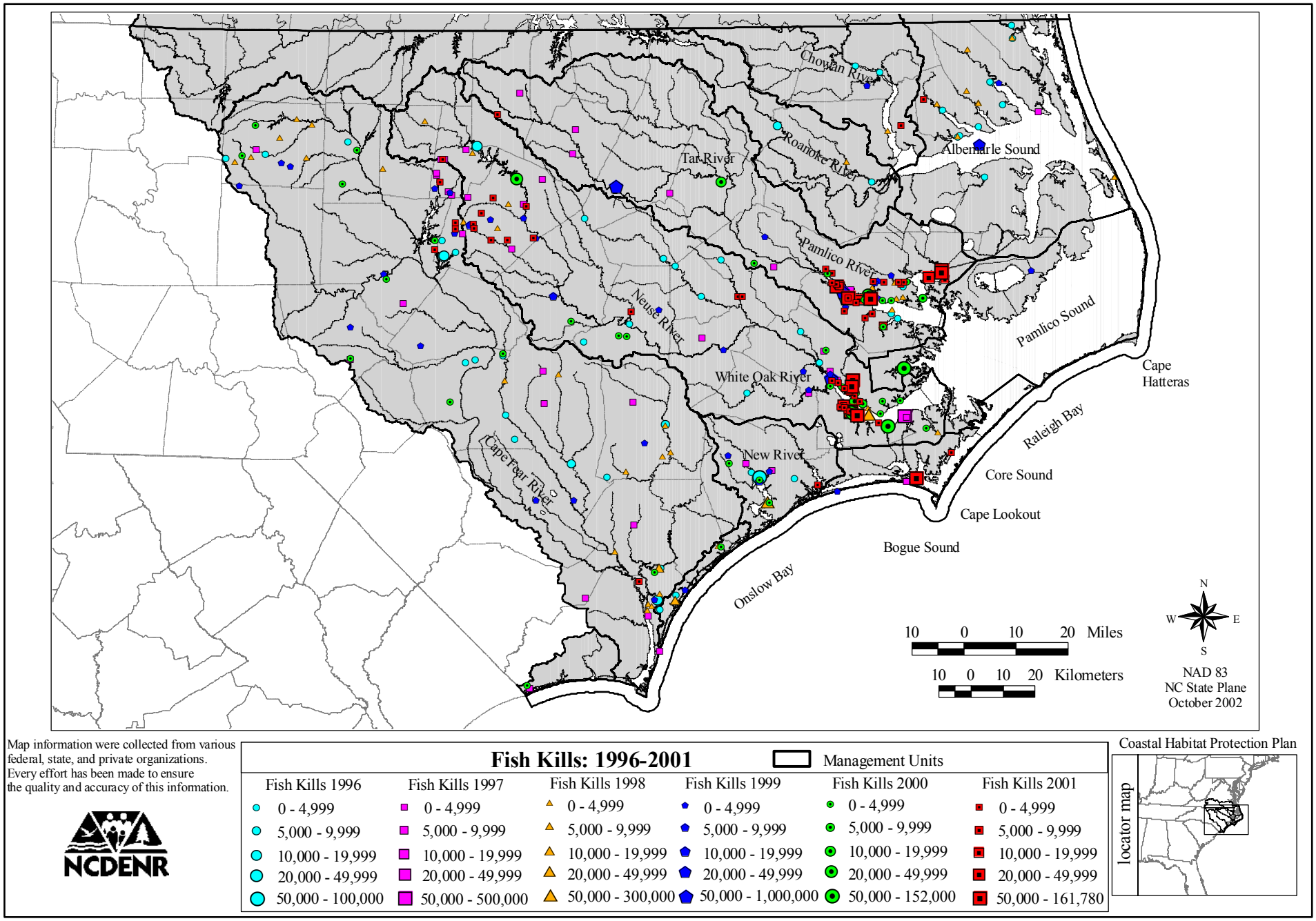
Map 2.15. Location of point source discharges permitted by the North Carolina Division of Water Quality (source: NC CGIA BasinPro3 software).

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Map 2.16. Location of registered animal operations in eastern North Carolina watersheds (source: NC Center for Geographic Information and Analysis BasinPro3 software, numbers of animal).

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Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

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Fish Kills: 1996-2001

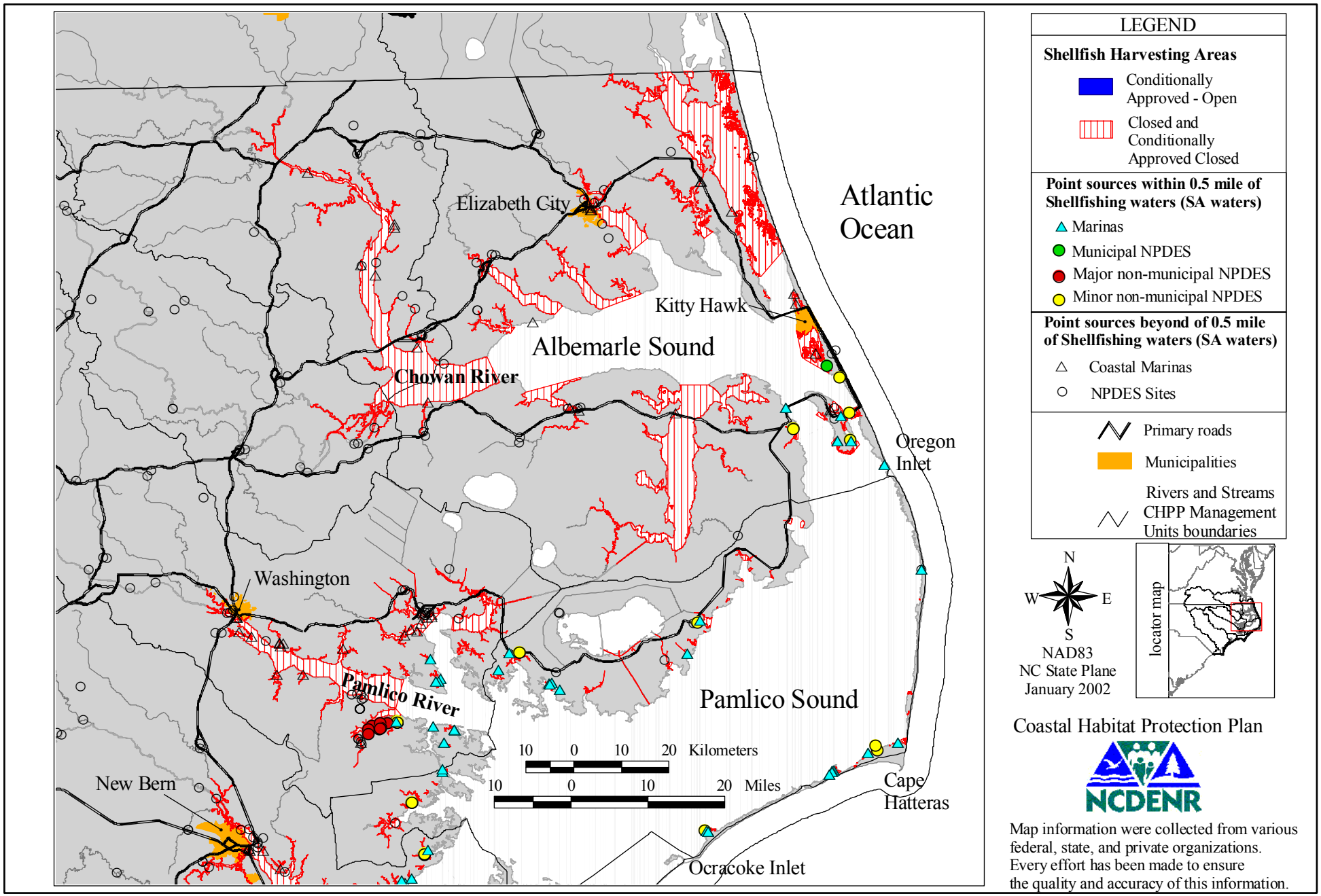
Management Units

Fish Kills 1996	Fish Kills 1997	Fish Kills 1998	Fish Kills 1999	Fish Kills 2000	Fish Kills 2001
0 - 4,999	0 - 4,999	0 - 4,999	0 - 4,999	0 - 4,999	0 - 4,999
5,000 - 9,999	5,000 - 9,999	5,000 - 9,999	5,000 - 9,999	5,000 - 9,999	5,000 - 9,999
10,000 - 19,999	10,000 - 19,999	10,000 - 19,999	10,000 - 19,999	10,000 - 19,999	10,000 - 19,999
20,000 - 49,999	20,000 - 49,999	20,000 - 49,999	20,000 - 49,999	20,000 - 49,999	20,000 - 49,999
50,000 - 100,000	50,000 - 500,000	50,000 - 300,000	50,000 - 1,000,000	50,000 - 152,000	50,000 - 161,780

Coastal Habitat Protection Plan

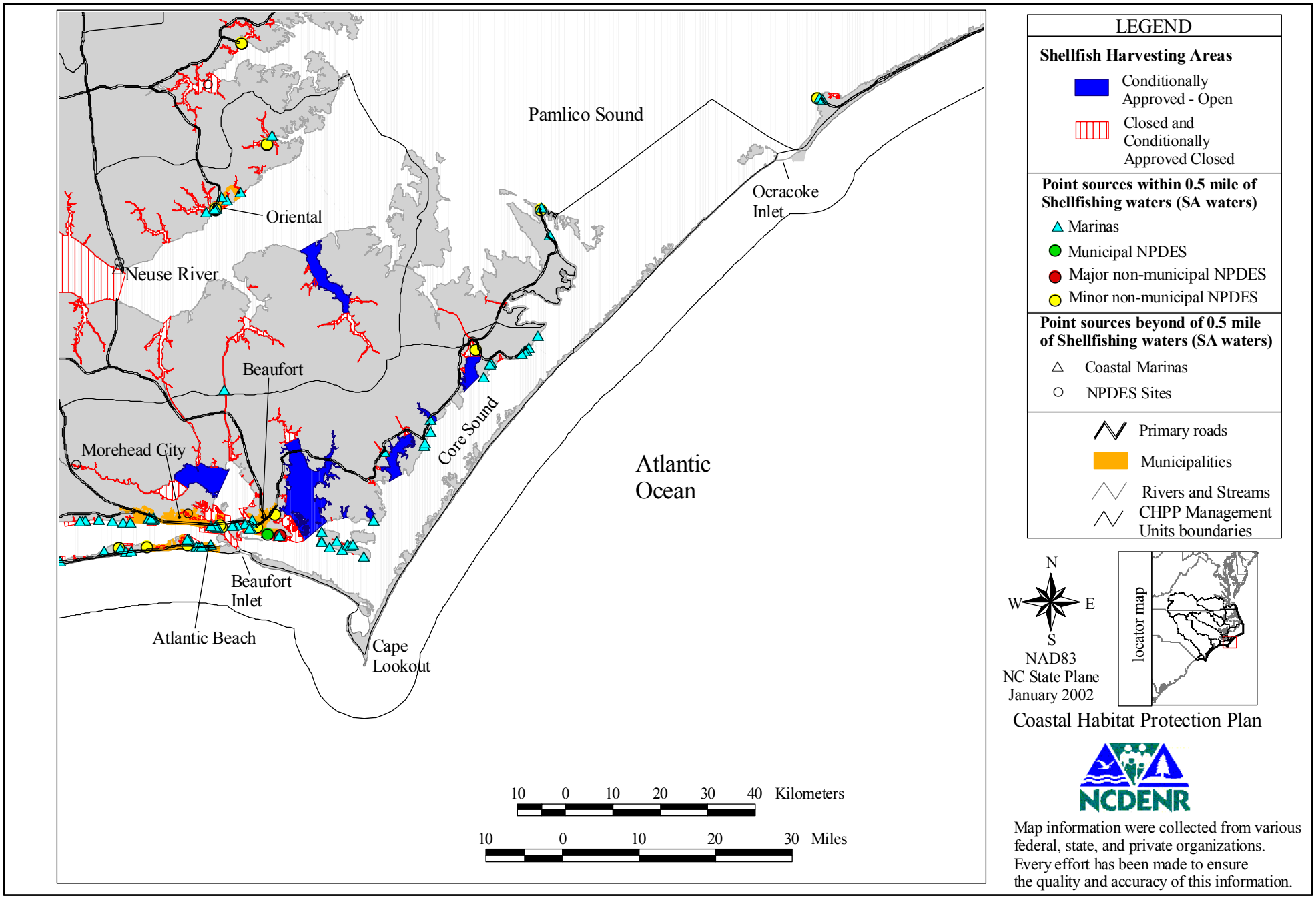
Map 2.17 Location of reported fish kills, 1996-2001 (source: DENR-DWQ Environmental Sciences Branch)

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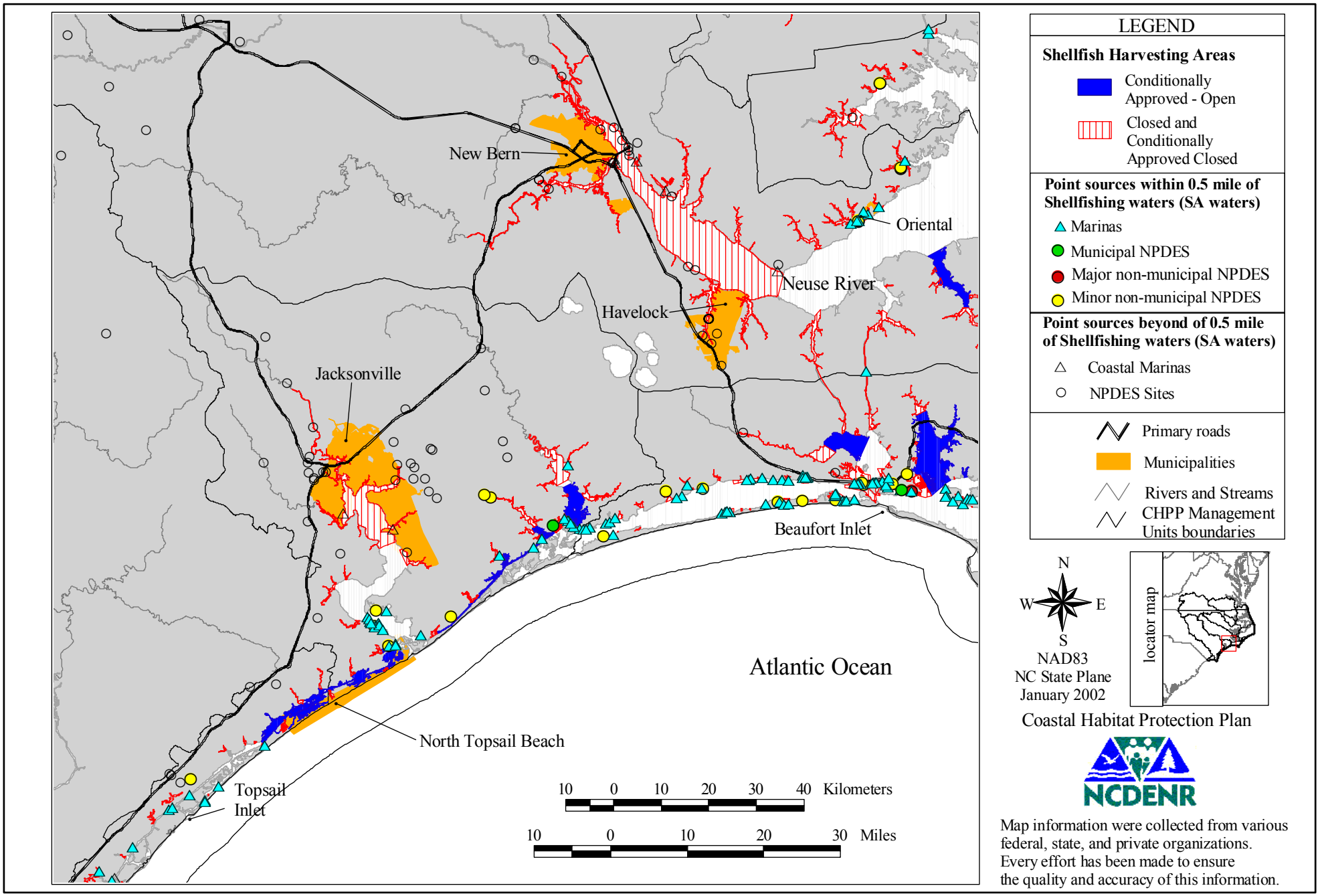
Map 2.18a---Locations of marinas and National Pollution Discharge Elimination System discharges in relation to North Carolina Division of Environmental Health shellfish harvesting areas - Virginia state line to Ocracoke Inlet

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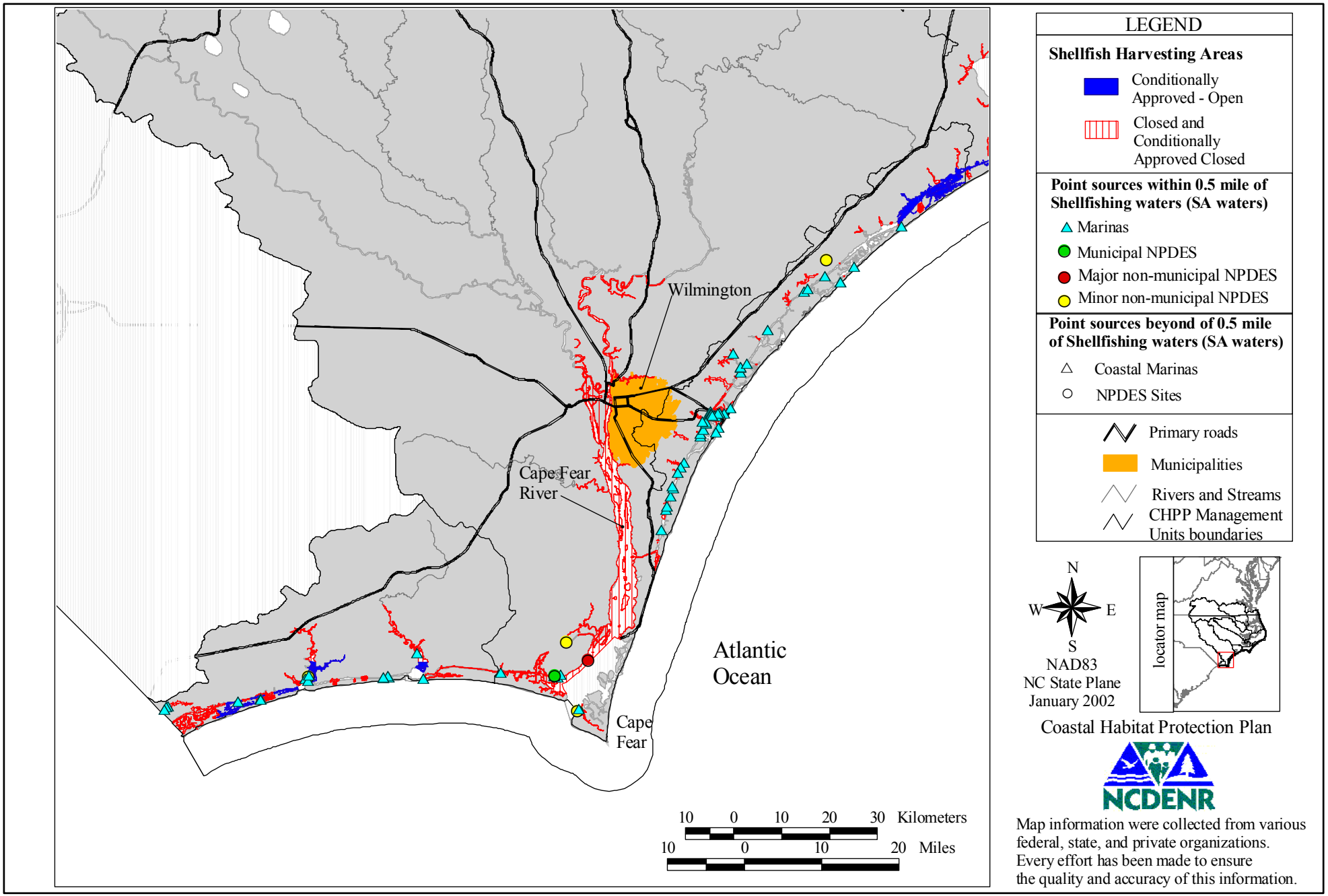
Map 2.18b ---Location of National Pollution Discharge Elimination System marinas and discharges in relation to North Carolina Division of Environmental Health shellfish harvesting areas - Ocracoke Inlet to Beaufort Inlet

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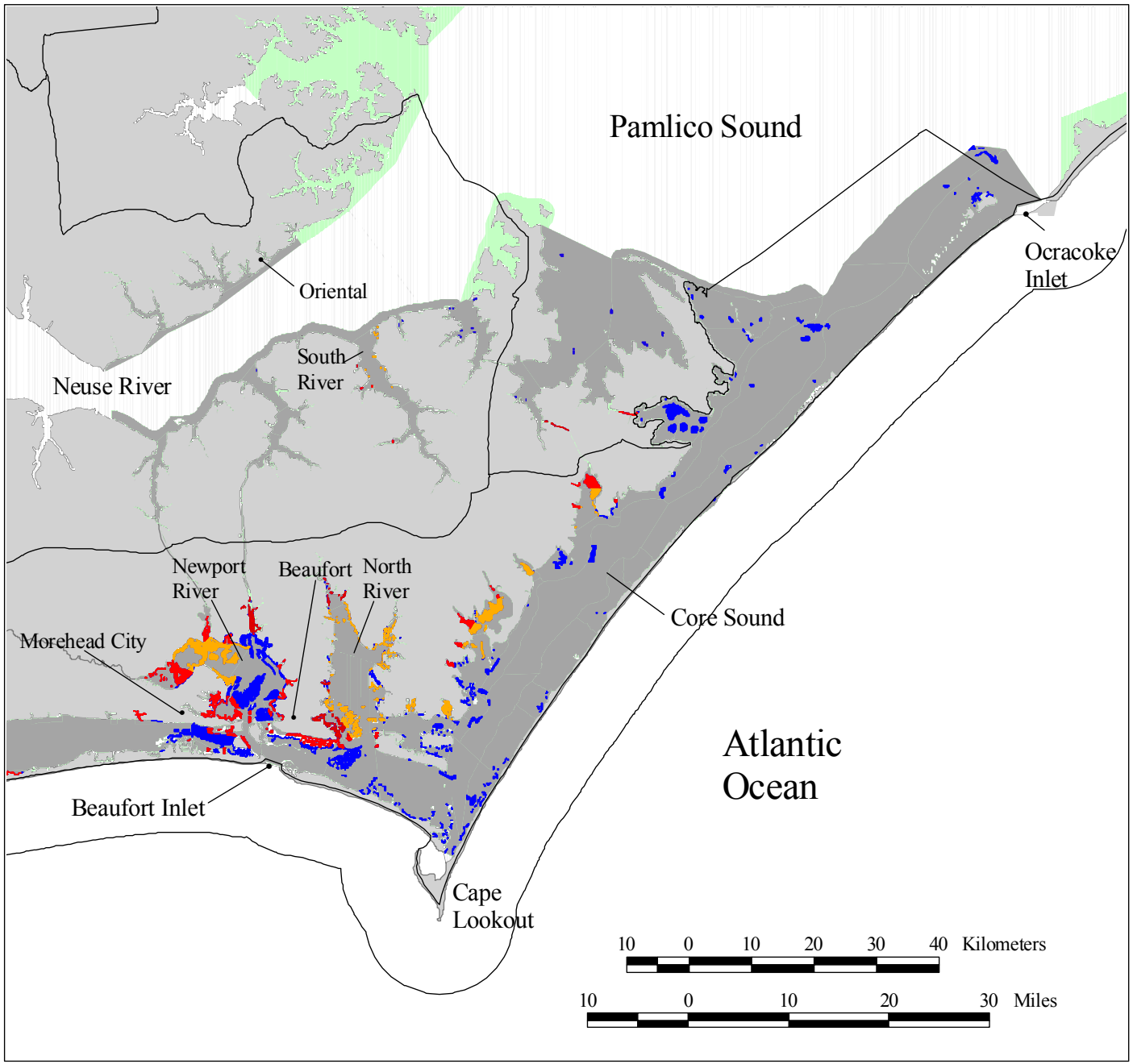
Map 2.18c---Location of National Pollution Discharge Elimination System marinas and discharges in relation to North Carolina Division of Environmental Health shellfish harvesting areas - Beaufort Inlet to Topsail Inlet

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Map 2.18d --Location of National Pollution Discharge Elimination System marinas and discharges in relation to North Carolina Division of Environmental Health shellfish harvesting areas - Topsail Inlet to South Carolina state line

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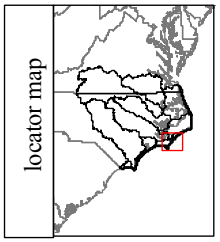
LEGEND

Shell bottom:

- Within Closed and Conditionally Approved Closed Areas
- Within Conditionally Approved Open Areas
- Within Approved Areas
- Shellfish Mapping Study Areas: Mapped
- Shellfish Mapping Study Areas: Not Yet Mapped
- Rivers and Streams
- CHPP Management Unit boundaries

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NC State Plane
January 2002



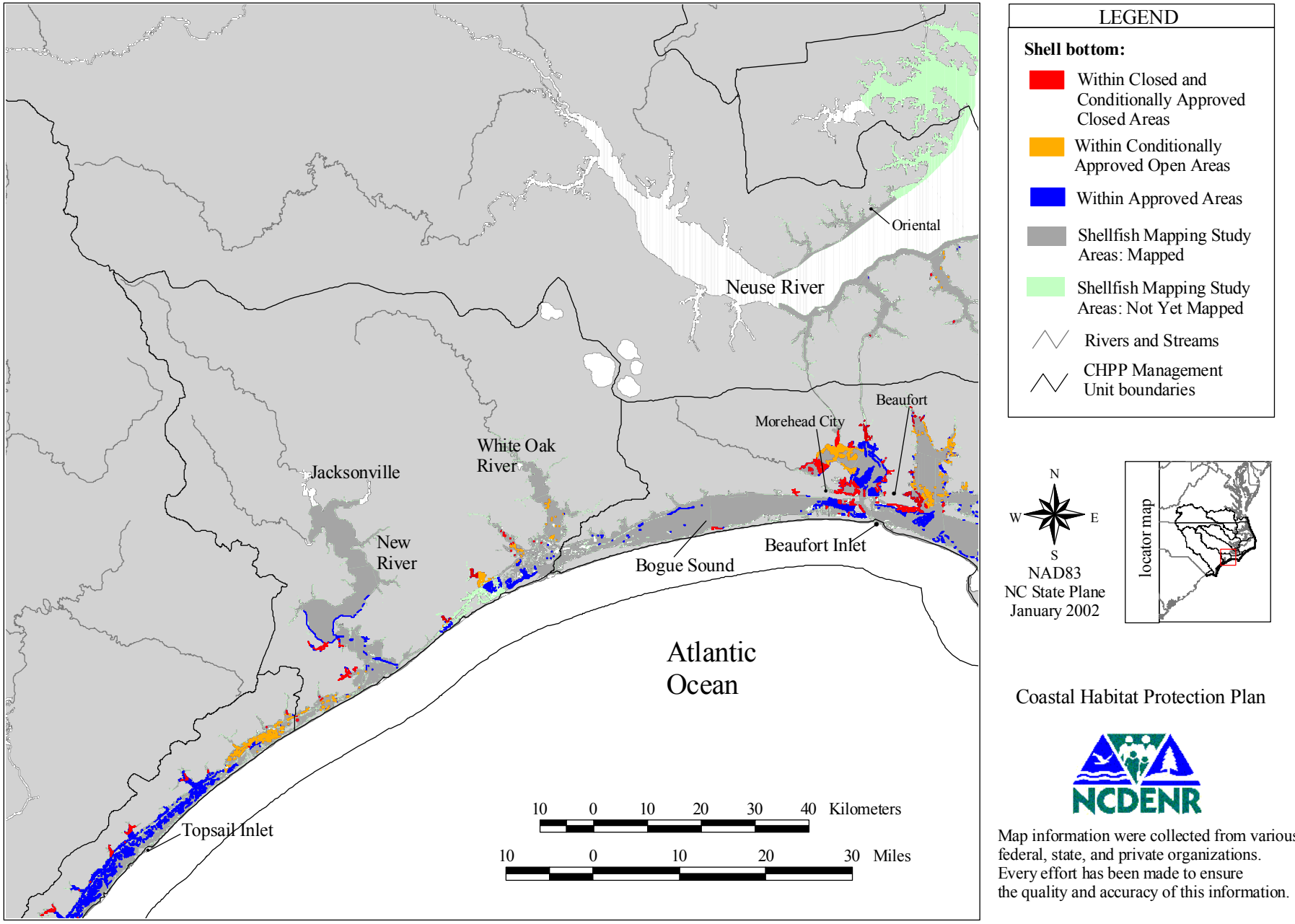
Coastal Habitat Protection Plan

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Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

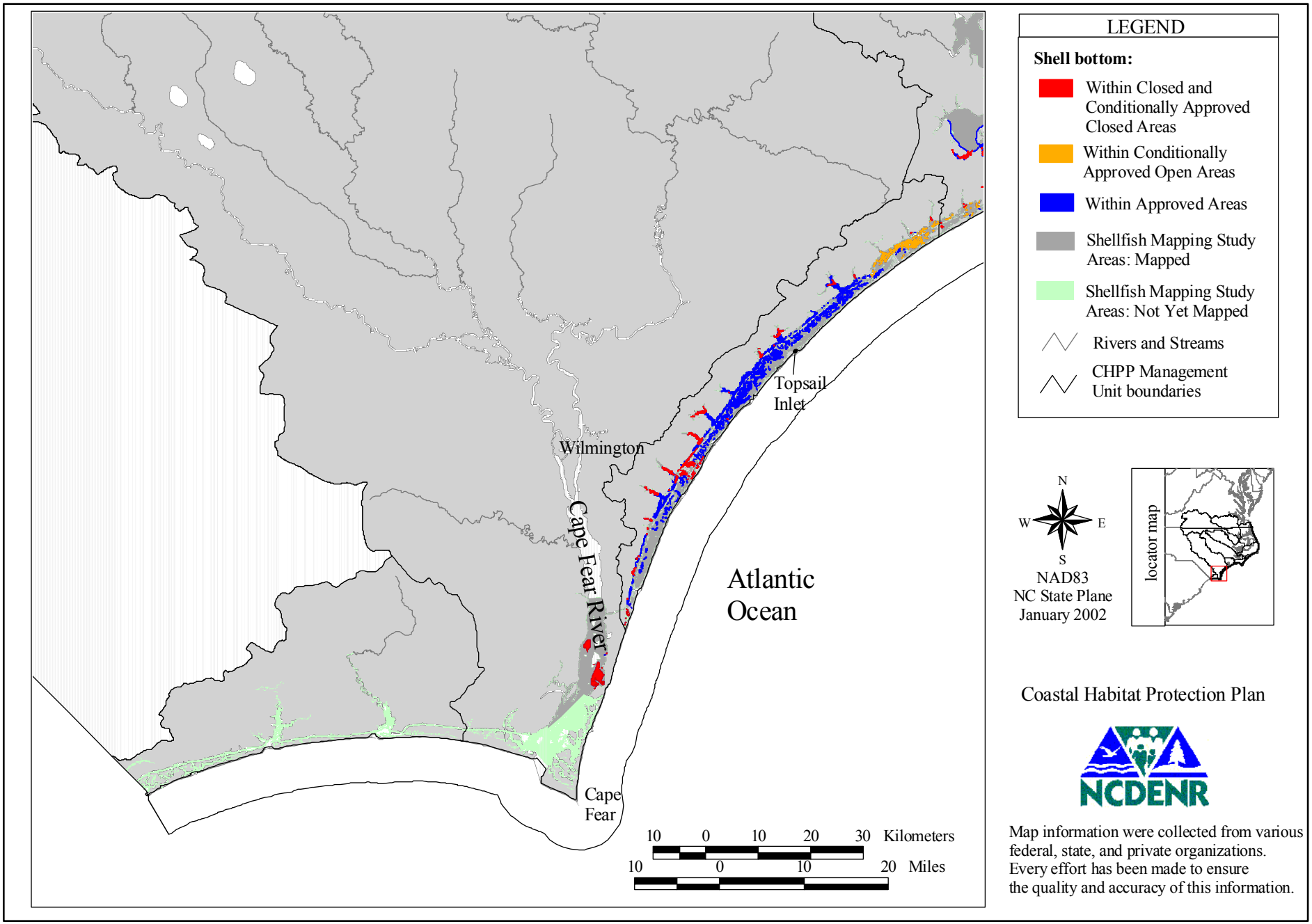
Map 2.19a---Extent of shell bottom within North Carolina Division of Environmental Health Shellfish Area designations - Ocracoke Inlet to Beaufort Inlet

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Map 2.19b--- Extent of shell bottom within North Carolina Division of Environmental Health Shellfish Area designations - Beaufort Inlet to Topsail Inlet

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Map 2.19c ---Extent of shell bottom within North Carolina Department of Environmental Health Shellfish Area designations -Topsail Inlet to South Carolina

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CHAPTER 3. SHELL BOTTOM

3.1. DESCRIPTION AND DISTRIBUTION

Definition

For the purposes of this plan, shell bottom is defined as "estuarine intertidal or subtidal bottom composed of surface shell concentrations of living or dead oysters (*Crassostrea virginica*), hard clams (*Merceneria merceneria*), and other shellfish." The definition is limited to estuarine waters and habitats because North Carolina's economically significant shellfish resources and their fisheries are entirely estuarine, although many species of molluscan shellfish live in fresh water and nearshore ocean waters.

In the 1990s, fisheries management agencies began to formally recognize shell bottom habitat as critical to fisheries production. The North Carolina Marine Fisheries Commission (MFC), South Atlantic Fishery Management Council (SAFMC), and Atlantic States Marine Fisheries Commission (ASMFC) all recognize the importance of shell bottom. Some define shell bottom largely by reference to the economic value of living shellfish, while others include the ecological functions of all shell bottom.

Shell bottom is especially important as a fish spawning and nursery area, as well as protecting nearby shorelines and seagrass beds from erosion.



Description

Common terms used to describe shell bottom habitats in North Carolina are "oyster beds," "oyster rocks," "oyster reefs," "oyster bars," and "shell hash." Shell hash is a mixture of sand or mud with gravel and/or unconsolidated broken shell (clam, oyster, scallop, and/or other shellfish). Shell bottom can be natural or man-made. Cultch material (hard material to which oysters attach) can consist of oyster, clam, or scallop shells; gravel or marl; or other hard materials. Cultch exists naturally, as shell hash and oyster rocks. It is also planted by DMF's Shellfish Rehabilitation Program to enhance and restore estuarine shell bottom in order to increase oyster spat settlement and growth, and to promote settlement and survival of hard clams. Participants in the shellfish lease program often use cultch in their aquaculture operations.

The horizontal area of shell bottom habitat ranges in size from a few square yards of scattered shell clumps to acres of living oysters and dead shells. The habitat can also consist of many square miles of shell hash more than a yard deep. A good example of shell hash bottom habitat is present in New River, North Carolina.

Shell bottom is both intertidal and subtidal and can consist of fringing or patch reefs (Coen et al. 1999). In North Carolina, oysters accumulate on existing oyster beds, outcroppings of fossil shell beds, as well as on wedge rangia, hard clam, and bay scallop shell beds (DMF 2001a). Oysters attach to exposed roots at the margin of salt marsh, pilings, seawalls, and rip-rap. Intertidal oyster reefs in North Carolina were characterized into three "landscapes" or combinations of adjacent habitats (Bahr and Lanier 1981; Grabowski et al. 2000). These were:

- Salt marsh landscape – on the edges and points of salt marsh away from seagrass beds
- Seagrass landscape – nestled between seagrass beds and salt marshes
- Mud flat landscape – on mud flats isolated from vegetative structure

Intertidal oyster reefs in the central and southern estuarine systems may only be a few oysters thick. However, subtidal oyster mounds in Pamlico Sound may have been several meters tall (Lenihan and Peterson 1998).

Habitat requirements

Oysters are the principal builders of natural shell bottom in North Carolina's estuaries. Marshall (1995) identified the most critical habitat for oyster populations as oyster beds and rocks, which the oysters themselves form by the accumulation of shells and oysters over time. The North Carolina Oyster Fishery Management Plan also recognized that the condition of oyster beds or rocks is the most important factor affecting oyster stock abundance because the shell material on those rocks is the most abundant and preferred substrate for the settlement of larval oysters (DMF 2001a).

The oyster's reproductive, morphological, physiological and behavioral adaptations have, in the past, allowed it to persist in immense numbers throughout the estuary (Kennedy 1991). The normal growing temperatures for eastern oyster range from 10 to 30°C (Burrell 1986). Their optimum salinity ranges from 14 to 30 ppt (Castagna and Chanley 1973). The optimum salinity for oyster larvae is somewhat lower than normal growing salinities for spat and adults (Loosanoff 1953; Chanley 1958; Davis 1958). Studies have shown that lower salinities combined with higher temperatures increases oyster mortality (Loosanoff 1953; Funderburk et al. 1991). Oyster distribution and abundance in low salinity waters are therefore limited by salinity and high temperature. However, predation by boring sponges, oyster drills, whelks, annelid worms, and starfish is also reduced in low salinity waters (Gunter 1955; Bahr and Lanier 1981). Increased mortality in the upper and lower regions of the estuary leaves moderate salinity areas with the highest abundance of subtidal oysters in North Carolina. Oyster growth in the intertidal waters varies significantly with temperature, tidal flows, and food quality and availability.

Oxygen levels and suspended sediment can affect survival and viability of oysters. Dissolved oxygen (DO) less than 1 to 2 mg/l is generally lethal or harmful to oysters, depending on the time of exposure and life stage of the oyster. Oyster eggs are affected most by suspended sediment, while larvae are slightly more turbidity tolerant, and adult oysters have significantly greater tolerance for suspended matter.[28]

Although oysters can tolerate extremes in salinity, temperature, turbidity and low dissolved oxygen, spawning success requires optimum salinities, temperatures and good water currents to disperse the larvae. Successful spat settlement and survival requires refuge from predators (Bartol and Mann 1999; Coen et al. 1999); clean, firm surfaces, preferably oyster shell (Kennedy et al. 1996); and good water circulation (Burrell 1986). Adult oysters also require adequate water circulation to deliver food and

[28] Studies have found that suspended sediment concentrations of 250 mg/L resulted in 27% mortality in oyster eggs, 500 mg/L resulted in 69% mortality, and 1000 mg/L caused 97-100% mortality (Davis and Hidu 1969a). Larvae were slightly more turbidity tolerant, with 50% mortality occurring at 1000 to 1500 mg/L after 12 days of exposure. These researchers also documented growth reductions in oyster larvae at suspended sediment concentrations of 750 mg/L. Concentrations above 750 mg/L are representative of the amount of turbidity caused by storms or dredging activities (Davis and Hidu 1969a). Adult oysters are able to feed in water containing up to 0.4 g/l of suspended matter (Nelson 1938; Nelson 1960).

oxygen and to remove wastes and sediment.

For subtidal oyster reefs, vertical height affects growth and survival rates for individual oysters by maximizing circulation benefits (Lenihan and Peterson 1998; Lenihan et al. 1999; Peterson et al. 2000a). The vertical structure of oyster reefs physically locates the oysters off the bottom to avoid anoxic water (Lenihan and Peterson 1998) or smothering by sediment (Coen et al. 1999). Lower reefs may be exposed to higher sedimentation rates and increased exposure to anoxia resulting in higher mortality rates.

Distribution

The primary shell-building organism in North Carolina estuaries, the eastern oyster, ranges from the Gulf of St. Lawrence in Canada through the Gulf of Mexico to the Bay of Campeche, Mexico and to the West Indies (Bahr and Lanier 1981). To the degree commercial fishery landings may indicate abundance, the highest documented oyster abundance along the Atlantic coast is in the Chesapeake Bay (DMF 2001a). Historically, Maryland's landings of 15 million bushels dwarfed North Carolina's highest annual oyster landings of 1.8 million bushels in 1902 (DMF 2001a).

Oysters are found along a majority of the North Carolina coast from extreme southeastern Albemarle to the estuaries of the southern part of the state to the South Carolina border (DMF 2001a). Oyster reefs occur at varying distances up North Carolina's estuaries, depending upon salinity, substrate, and flow regimes. In the wind-driven Pamlico Sound system north of Cape Lookout, oyster reefs consist overwhelmingly of subtidal beds. South of Cape Lookout, subtidal rocks also occur in the New, Newport, and White Oak rivers (DMF 2001a). Extensive intertidal oyster rocks occur in North Carolina's southern estuaries, where the lunar tidal ranges are higher. Substantial shell hash is present in New River, eastern Bogue Sound, and along the edges of many streams and channels, such as portions of the Atlantic Intracoastal Waterway (ICW) in the southern coastal area.

In the Albemarle-Pamlico estuary, oysters are concentrated in the lower portion of Pamlico Sound tributaries, along the western shore of Pamlico Sound, and to a lesser extent behind the Outer Banks. (Epperly and Ross 1986) (Map 3.1).

Shellfish habitat and abundance mapping

The DMF Shellfish Habitat and Abundance Mapping Program began creating detailed bottom type maps in 1988. These maps are being compiled using standardized surveys from the South Carolina border north through Core Sound, along the perimeter of Pamlico Sound, and in Croatan/Roanoke sounds (Map 3.2). The program delineates all bottom habitats, including shell bottom, and samples the density of oysters, clams, and bay scallops in these habitats. This program has differentiated 24 different bottom types based on combinations of depth, bottom firmness, vegetation density, and density of surface shells. This program defines shell habitat (shell bottom) as significant cover (>30% of bottom) of living or dead shells. Some of the other fish habitats mapped by the program include salt marsh, submerged aquatic vegetation, and soft bottom. A stratified random sampling design is used to provide statistically sound shellfish density estimates by area and habitat.

As of January 2003, mapping has been completed from Carolina Beach to Ocracoke Inlet, including Core Sound. The following specific areas have also been mapped: Shallowbag Bay, portions of Pamlico Sound in the vicinity of Oregon Inlet, and South River (Carteret County) (Map 3.2). This area represents approximately 42% (222,643 acres) of the total area (about 530,000 acres) intended for mapping (Map 3.2). As of 2003, West Bay in southwestern Pamlico Sound has also been completed.

Of the entire area mapped by January 2003 (222,643 acres), approximately 6% (12,502 acres) of the bottom was classified as shell bottom (Table 3.1). The Southern Estuaries have the greatest proportion of shell bottom (17%) of the areas mapped to date. Private shellfish leases were delineated but not included

in these estimates. Shellfish leases cover additional shell bottom areas in the Core/Bogue (357 acres) and New/White Oak (498 acres) of the shellfish mapping study area. As of January 2003, there were 281 shellfish leases in coastal North Carolina occupying 2,079 ac, which comprises less than 1% of the shellfish mapping study area.[29]

Table 3.1. Shell bottom habitat mapped within Coastal Habitat Protection Management Units by the North Carolina Division of Marine Fisheries' Shellfish Habitat and Abundance Mapping Program (January 2003).

	Total area mapped[1]		Shell bottom (intertidal)		Shell bottom (subtidal)		Total shell bottom
Management unit	acres	% complete	acres	% complete	acres	% complete	acres
Albemarle	1,687	2.8	0	0.0	33	1.9	32.8
Core/Bogue	148,994	94.7	1,875	1.3	5,420	3.6	7,294.6
Neuse	3,120	13.3	0	0.0	26	0.8	25.9
New/W. Oak	34,495	94.4	346	1.0	333	1.0	679.5
Pamlico	8,498	3.8	22	0.3	93	1.1	114.7
Southern Estuaries	25,603	82.6	2,577	10.1	1,775	6.9	4,352.1
Coastal Ocean	246	56.2	0	0.2	2	0.8	2.3
Total *	**222,643**	**41.9**	**4,820**	**2.2**	**7,681**	**3.5**	**12,501.8**

[1] Percent (%) is the amount of shell bottom/total area mapped within each MU. Total mapping study area is shown on Map 3.2.

The highest average shellfish density (45.5 shellfish/m^2) within the mapped area was in the Core/Bogue MU. Maps 3.3a-c show the spatial distribution of shellfish density on shell bottom.[30]

3.2. ECOLOGICAL ROLE AND FUNCTIONS

Ecosystem enhancement

Water Quality Enhancement

The direct and indirect ecosystem services of the oyster reef, such as filtering capacity, transfer of production between bottom and water column, nutrient dynamics and sediment stabilization, have been largely ignored or underestimated (Coen and Luckenbach 1998). The ASMFC reports that shell bottom provides food, refuge and nursery grounds for coastal fisheries. Shell bottom also indirectly benefits the fisheries by providing water filtration. Kennedy (1991) suggested that the filtering activities of the massive concentrations of oysters historically present in the Chesapeake Bay might have resulted in different assemblages of plankton, with fewer sea nettles, microplankton and bacterioplankton. Before the end of the 19th century, oysters in the Chesapeake Bay could filter the entire volume of the bay in a little more than three days (Newell 1988). Newell's estimate of the filtering capacity of Chesapeake Bay oyster populations in 1988 was 325 days. Other researchers agree that the loss of oyster populations removes one potentially important means of controlling nuisance phytoplankton blooms and other negative impacts of nutrient enrichment and coastal eutrophication (Officer et al. 1982; Dame et al. 1984; Lenihan and Peterson 1998; Coen et al. 1999; Jackson et al. 2001). Jackson et al. (2001) attributed much of the decline in water quality in Pamlico Sound and Chesapeake Bay to loss of bio-filtration capacity attributable to the drastic decline (>90%) in oyster biomass.

[29] However, the contribution of shellfish leases to overall shell bottom is unknown because they contain areas that do not meet the definition of shell bottom. So the estimates for overall shell bottom coverage are somewhat underestimated.
[30] More information on the distribution of shell bottom is provided in the Status and trends section (3.3).

Shell bottom enhances water quality by transferring phytoplankton production to benthic production through filter feeding (Officer et al. 1982; Cloern 2001; DMF 2001a; Newell et al. 2002). Increased shell bottom and oyster biomass reduce the impacts of eutrophication. After being recycled by oysters, nutrients are deposited around the base of oyster beds where nitrogen is removed (Newell et al. 2002). The organic deposits from oyster filtering can be released by erosion, sediment reworking by animals, or resuspension with possible uptake by adjacent SAV (Peterson and Peterson 1979). With more nutrients denitrified or stored in the sediment, the frequency of hypoxia (<2 mg/l of dissolved oxygen) and anoxia (no dissolved oxygen) events in the water column should decrease. The oyster shells themselves also store carbon in the form of calcium carbonate (Hargis and Haven 1999). The sequestered carbon is thus taken out of atmospheric circulation, serving as one means to partially offset the observed trend of increasing concentrations of CO_2, an important greenhouse gas associated with global warming.

Habitat Modification

The oyster's structural modification of habitat is important to the estuarine system. As shell bottom increases, wave energy decreases, stabilizing sediment and decreasing erosion (Lowery and Paynter 2002). High-relief shell bottom alters currents and water flows, influencing patterns of fish settlement, predation and predator feeding success (Breitburg et al. 1995; Coen et al. 1999). On the down-current side of the reef, flow velocity is reduced and larval fish species can maintain their positions during the high-flow portions of the tidal cycle (Breitburg et al. 1995). Oyster reefs can also constrict tidal flow to certain areas, resulting in island formation (Bahr and Lanier 1981). By reducing wave energy along the shoreline, shell bottom aids in stabilizing creek banks and reducing salt marsh erosion (Bahr and Lanier 1981; Dame and Patten 1981; Marshall 1995; Breitburg et al. 2000).

The presence of shell bottom reduces turbidity by filtering water and physically trapping and stabilizing large quantities of suspended sediment and organic matter with the shell structure (Haven and Morales-Alamo 1970; Dame et al. 1989; Coen et al. 1999; Grabowski et al. 2000). This, in turn, improves water clarity, which increases productivity of the water column and SAV. The reduction in turbidity has a positive effect on SAV by increasing light penetration to the plants, creating more suitable conditions for SAV growth, survival, and expansion (Meyer and Townsend 2000). As an example, prior to large-scale losses of shell bottom in the Chesapeake Bay, bay waters were reported to be much less turbid than current conditions, which allowed submerged aquatic vegetation to thrive (Coen et al. 1999; Jackson et al. 2001). Because of these ecosystem benefits provided by oysters to other habitats, Lenihan and Peterson (1998) proposed that oysters might now be more economically valuable as a habitat than a fishery.

Productivity

Primary producers on shell bottom include algae (epiphytic microalgae, attached macroalgae) and organic films of bacteria and fungi. These organisms provide food for resident secondary consumers. Many crab species (including the mud crabs and pea crab), barnacles, soft-shelled clams, hard clams, mussels, anemones, polychaetes, amphipods, hydroids, bryozoans, flatworms, mussels, and sponges make up the oyster reef community. All of these species recycle nutrients and organic matter and many become prey for finfish, shrimps and blue crab (Bahr and Lanier 1981). Grass shrimp (*Palaemonetes* spp.), an important link in food webs, prefer oyster reefs to other surfaces when avoiding predators (Posey et al. 1999). Resident species (e.g., gobies) are significant zooplankton predators.

Live oyster shell bottom also enhances secondary productivity in the estuary by providing hard, complex substrate, allowing colonization by an abundance of plants and animals on the shell substrate. This in turn supports many resident and transient fish and invertebrates that are ecologically and economically important.

Fish utilization

Shell bottom provides critical fisheries habitat not only for oysters, but also for recreationally and commercially important finfish, other mollusks, and crustaceans. The ecological functions of oyster reefs related to oyster production are well known and accepted (Coen et al. 1999). These functions include aggregation of spawning stock, chemical cues for successful spat settlement, and refuge from predators and siltation. Oysters have also been described as "ecosystem engineers that create biogenic reef habitat important to estuarine biodiversity, benthic-pelagic coupling, and fishery production"[31] (Lenihan and Peterson 1998).

Data quantifying fish use of habitats vary from presence/absence and numerical abundance, to actual fish production value. In North Carolina, 18 fishery species have been documented utilizing both natural and restored oyster reefs in Pamlico Sound, including Atlantic croaker, southern flounder, Spanish mackerel, spotted seatrout, weakfish, American eel, and black sea bass (Lenihan et al. 2001). Numerical abundance and production compared to other habitats provides additional information on the importance of habitat for fish. The species found most abundantly on oyster reefs compared to adjacent soft bottom were silver perch, sheepshead, pigfish, pinfish, toadfish, and Atlantic croaker. Southern flounder was collected on both oyster reefs and adjacent soft bottom areas, while bluefish and Atlantic menhaden were not collected near oyster reefs (Lenihan et al. 2001).

Several studies have found higher abundance and diversity of fish on shell bottom than adjacent soft bottom, particularly pinfish, blue crabs, and grass shrimp (Harding and Mann 1999; Posey et al. 1999; Lenihan et al. 2001). A study in Back Sound also found that crabs were more abundant on shell bottom than restored SAV beds (Elis et al. 1996). Breitburg (1998) concluded that the importance of shell bottom to highly mobile species is very likely underestimated, partially due to the difficulty in sampling oyster beds.

Peterson et al. (2003a) estimated the amount of fish production that shell bottom provides in addition to adjacent soft bottom habitats. Using results from numerous studies, they compared the density of fish at different life stages on oyster reefs and adjacent soft bottom habitats. The published growth rates of species were then used to determine the amount of production gained from shell bottom. The species were separated into recruitment-enhanced, growth-enhanced, and not enhanced groups. Recruitment-enhanced species are those having early life stages showing almost exclusive association with shell bottom. For other species with higher abundance in shell bottom, diet and life history studies were used to determine the fraction of their production associated with the consumption of shell bottom-enhanced species. Species consuming relatively more shell bottom-enhanced species were classified as growth-enhanced. Analysis of the studies revealed that every $10m^2$ of newly constructed oyster reef in the southeast United States is expected to yield a benefit of an additional 2.6 kg of fish production per year for the lifetime of the reef (Peterson et al. 2003a).[32]

Fish that utilize shell bottom can be classified into three categories: resident, transient, and facultative (Coen et al. 1999; Lowery and Paynter 2002). Resident species live on shell bottom and depend on it as their primary habitat. Transient species are wide-ranging species that use shell bottom for refuge and forage along with other habitats. Facultative species depend on shell bottom for food, but utilize other

[31] Benthic-pelagic coupling refers to the transfer of production from the oyster beds to the mobile species foraging on the beds (Lenihan and Peterson 1998), benefiting both estuarine and ocean fisheries. It also refers to the transfer of phytoplankton production and other fine particulates to the bottom.

[32] For individual species, the amount of additional production ranged from 0.08 (spottail pinfish) - 158.80 (bay anchovy) fish/$10m^2$. Of the 53 species of fish and shellfish for which data were available, ten were recruitment-enhanced and ten were growth-enhanced. About half of the 20 shell bottom-enhanced species were fishery species (sheepshead, black sea bass, gray snapper, white perch, gag, pigfish, southern flounder, and tautog). The recruitment-enhanced species included stone crabs, sheepshead, blennies/gobies, skilletfish, gray snapper, gag, toadfish, and tautog. Growth enhanced species included bay anchovy, black sea bass, sheepshead minnow, spottail pinfish, silversides, white perch, pigfish, and southern flounder.

habitats with vertical relief or shelter sites.

At least seven fish species have been identified as resident species—naked goby, striped blenny, feather blenny, freckled blenny, skilletfish, and oyster toadfish (Coen et al. 1999, Lowery and Paynter 2002). These species were also considered recruitment-enhanced by Peterson et al. (2003a). Resident fish are important prey for transient and facultative predator species (Coen et al. 1999). For example, Breitburg (1998) found high densities of juvenile striped bass (15.4 individuals/m^2 of reef surface) aggregating near the reef surface feeding on naked goby larvae congregated on the down-current side of the reef. Other common predator species sampled on oyster reefs in North Carolina are red and black drum, Atlantic croaker, sheepshead, weakfish, spotted seatrout, summer and southern flounder, blue crab, and oyster toadfish. Of these species, however, only sheepshead, southern flounder, and oyster toadfish were considered shell bottom-enhanced by Peterson et al. (2003a). Production of black drum, Atlantic croaker, blue crab, and summer flounder were classified as not enhanced by shell bottom. Oyster reefs in higher salinity waters are critical habitat for predators such as juvenile gag, snappers (*Lutjanus* spp.) and stone crab (Wenner et al. 1996; Peterson et al. 2003a).

There is some variation in fish use among salinity gradients as well. Oyster reefs in higher salinity waters tend to support a greater number of associated species than reefs in lower salinity waters (Sandifer et al. 1980). Studies summarized by Coen et al. (1999), which included work in North Carolina, identified 72 facultative, resident and transient fish species in close proximity to oyster reefs. The ASMFC-managed species categorized as transient and also important to North Carolina's coastal fisheries are American eel, Atlantic croaker, Atlantic menhaden, black sea bass, bluefish, red drum, spot, striped bass, summer flounder, tautog, and weakfish. Only black sea bass and tautog were considered shell-bottom enhanced by Peterson et al. (2003a).

A partial list of macrofaunal species observed in collections from oyster habitat is provided in Table 3.2. Those species that use shell bottom as spawning and/or nursery areas are identified, as are those species that forage on shell bottom habitat and/or use it as a refuge (SAFMC 1998a; Lenihan et al. 1998; Coen et al. 1999; Grabowski et al. 2000). More than 30 species are listed in Table 3.2, and there are many more not listed, emphasizing the importance of shell bottom as fisheries habitat.

Table 3.2. Partial listing of finfish and shellfish species observed in collections from shell bottom in North Carolina, and ecological functions provided by the habitat.

Species*	Shell Bottom Functions [1]					Fishery [2]	Stock Status [3]
	Refuge	Spawning	Nursery	Foraging	Corridor		
ANADROMOUS & CATADROMOUS FISH							
American eel	X		X	X	X	X	U
Striped bass			**X**	**X**		**X**	**V- Albemarle Sound, Atlantic Ocean, O- Central/Southern**
ESTUARINE AND INLET SPAWNING AND NURSERY							
Anchovies (striped, bay)		**X**	**X**	**X**			
Blennies	**X**	**X**	**X**	**X**			
Black drum				**X**		**X**	
Blue crab	**X**	**X**	**X**	**X**	**X**	**X**	**C**
Oyster	**X**	**X**	**X**	**X**		**X**	**C**
Gobies	**X**	**X**	**X**	**X**			
Grass shrimp	**X**	**X**	**X**	**X**			
Hard clam	**X**	**X**	**X**	**X**		**X**	**U**
Mummichog	X	X			X		
Oyster toadfish	**X**	**X**	**X**	**X**		**X**	
Red drum	**X**		**X**	**X**	**X**	**X**	**R**
Sheepshead minnow		**X**		**X**			
Silversides				**X**			
Skilletfish	**X**		**X**	**X**			
Spotted seatrout				**X**		**X**	**V**
Stone crab	**X**		**X**	**X**		**X**	
Weakfish	X		X	X	X	X	V
MARINE SPAWNING , LOW-HIGH SALINITY NURSERY							
Atlantic croaker				X		X	C
Brown shrimp	**X**		**X**	**X**	**X**	**X**	**V**
Southern flounder				**X**		**X**	**O**
Spot	X		X	X	X	X	V
Striped mullet				X		X	C
MARINE SPAWNING , HIGH SALINITY NURSERY							
Atlantic spadefish						X	C [4]
Black sea bass	**X**		**X**	**X**	**X**	**X**	**V- north of Hatteras, O- south of Hatteras**
Gag	**X**		**X**	**X**	**X**	**X**	**V**
Gulf flounder						X	
Pigfish				**X**		**X**	
Pinfish	**X**		**X**	**X**	**X**	**X**	
Pink shrimp	**X**		**X**	**X**	**X**	**X**	**V**
Sheephead	**X**		**X**	**X**	**X**	**X**	**C [4]**
Spanish mackerel						X	V
Summer flounder	X			X	X	X	V

* Scientific names listed in Appendix I. Names in **bold** font are species whose relative abundances have been reported in the literature as being generally higher in shell bottom than in other habitats. Note that lack of bolding does not imply non-selective use of the habitat, just a lack of information.

[1] Sources: Pattilo et al. 1997; SAFMC 1998; Lenihan et al. 1998, 2001; Coen et al. 1999; Grabowski et al. 2000; Peterson et al. 2003

[2] Existing commercial or recreational fishery. Fishery and non-fishery species are also important as prey

[3] V=viable, R=recovering, C=Concern, O=overfished, U=unknown (DMF 2003a).

[4] Status of reef fish complex as a whole. Sheepshead and Atlantic spadefish have not been evaluated in NC.

Refuge

The complex three-dimensional shell habitats provide food, refuge, and attachment areas for larval, juvenile, adult, and spawning finfish, crustaceans and mollusks (Arve 1960; Wells 1961; MacKenzie 1983; Zimmerman et al. 1989; Meyer et al. 1996; Breitburg 1998; Lenihan et al. 1998; Coen et al. 1999; Harding and Mann 1999). Oyster reefs provide more area for attachment of oysters and other sessile organisms. More habitat niches occur in oyster reefs than on the surrounding flat or soft bottom habitats. Bartol and Mann (1999) found the quality and quantity of interstitial spaces (spaces between the shells within the shell matrix) to be critical to recruiting oysters, as well as to the survival of other oyster reef species. Survival was greater in the interstitial spaces than at the reef surface.

The crevices in shell bottom provide refuge for small, slow-moving macrofauna, such as polychaete worms, blue crabs, hard clams, amphipods and other species (Zimmerman et al. 1989; SAFMC 1998a). Mud crabs utilize shell bottom as refuge from oyster toadfish, blue crabs and wading birds (Meyer 1994). While crabs utilize the shell structure to hide from predators in the day, sampling found that they migrate to the open mud flats at night to feed (Grabowski et al. 2000). Competition for shell bottom habitat as refuge is greatest within similar size categories of fauna (Coen et al. 1999).

Shell bottom substrates provide significant protection from predators for adult and juvenile hard clams. Peterson et al. (1995) reported that young clams survived better in shell bottom than open soft bottom areas. The DMF specifically manages some intertidal oyster cultch planting sites in the southern coastal area to take advantage of this hard clam–oyster shell relationship. After oysters are harvested off the planted site, the areas are opened specifically for clam harvest by hand gears. Fishermen dig under the cultch to take high concentrations of hard clams that recruited under the oyster shell. Once the clam harvest is over, the areas are re-planted with cultch, and the two-year cycle begins again.

Subtidal oyster reefs may be relatively more important to commercially important finfish than intertidal reefs, because subtidal reefs often provide the only structured habitat in submerged areas (Grabowski et al. 2000). In contrast, intertidal reefs are often surrounded by other structured habitats, such as salt marshes and SAV beds. From southeastern North Carolina to northern Florida, where SAV does not occur, shell bottom represents the dominant structural habitat in the mid-intertidal to shallow subtidal waters (Posey et al. 1999). In other intertidal estuaries in North Carolina where little or no SAV is present, shell bottom also provides critical structural refuge, along with salt marsh (Eggleston et al. 1998).

Spawning

Resident species, such as gobies (naked and green), Atlantic midshipman, and northern pipefish depend on shell bottom as breeding habitat (Hardy 1978a, 1978b; Johnson 1978; Coen et al. 1999). Other species documented to spawn on shell bottom include the oyster toadfish, mummichog, sheepshead minnow, eastern oyster, grass shrimp, and hard clams (NOAA 2001). Toadfish attach their eggs to the underside of oyster shells, whereas gobies, blennies, and skilletfish place their eggs in recently dead oyster shell (Coen et al. 1999). Well-developed oyster reefs with clean oyster shells in a variety of sizes were shown to accommodate reproduction by the greatest densities of all resident species (Breitburg 1998).

Nursery

Shell bottom protects oyster spat and other juvenile bivalves, finfish and crustaceans from predators. Juvenile clams, in particular, settle in shell substrate for the protection it provides (Wells 1957; MacKenzie 1977; Peterson 1982; DMF 2001b). The nursery area function of shell bottom was demonstrated by Eggleston et al. (1998) who found that juvenile blue crabs and grass shrimp were equally abundant on shell bottom and SAV in Back Sound, North Carolina. Twelve of the 18 mobile and economically important coastal fisheries species sampled by Lenihan et al. (2001) on natural and restored oyster reefs in Pamlico Sound were juveniles.

In a study where shell structure was added to mud flat reefs, juvenile fish abundance increased on the augmented reefs compared to surrounding soft bottom (Grabowski et al. 2000). The study also found that this initial increase was higher than increases that occurred when SAV and/or salt marsh were added in the same area. The ASMFC considers shell bottom as important nursery habitat for juvenile fish such as sheepshead, gag, snappers, stone and blue crabs, and penaeid shrimps (Lowery and Paynter 2002). An analysis by Peterson et al. (2003a) confirmed that sheepshead, gag, and stone crab were recruitment enhanced, as well as many non-fishery species, including anchovies, blennies, gobies, oyster toadfish, and skilletfish.

While oyster reefs are the most recognized shell bottom habitat, shell hash concentrations on tidal creek bottoms provide important nursery habitat for young fish. For example, the preferred habitat of juvenile drum species in South Carolina is high marsh areas with shell hash and mud bottoms (Daniel 1988). However, the extent of shell hash in North Carolina tidal creeks is currently unknown; known locations of shell hash include concentrations along the Intracoastal Waterway. The nursery value of designated nursery areas could be enhanced by low-density plantings of cultch material. However, the enhancement of fish stocks provided by planting could be negated if recruitment is not limiting the adult population. *The recruitment enhancement provided by low-density cultch planting in nursery areas should be evaluated.*

Foraging

Shell bottom provides important foraging area for a variety of aquatic organisms. Fish, shrimp and crabs forage on the worms, algae, crustaceans, mollusks, and other invertebrates present on and in shell bottom habitat. Concentrations of prey organisms among the shell attract both specialized and opportunistic predators. Eggs from oysters and other organisms, and larvae from species belonging to the oyster shell bottom community, are eaten by protozoans, jellyfishes, ctenophores, hydroids, worms, mollusks, adult and larval crustaceans, and fishes (Loosanoff 1965). Blue crabs forage heavily on oyster reefs (Menzel and Hopkins 1955; Krantz and Chamberlin 1978; Mann and Harding 1997). Stomach contents of common finfish predators sampled near shell bottom in Middle Marsh, North Carolina, included fish, shrimp, tanaids, amphipods, isopods, polychaetes, bivalves, gastropods, and tunicates, as well as plant, algal and detrital material (Grabowski et al. 2000).

Grabowski et al. (2000) calculated an index of reef affinity (association) for fish species and analyzed the relative proportion of stomach contents originating from oyster reef versus non-reef habitats. Results showed:

- Pigfish and pinfish foraged more on reefs (amphipods, bivalves, gastropods and polychaetes).
- The ubiquitous spot foraged on both reef and non-reef habitats.
- Gulf and southern flounder foraged on species slightly more common on reefs.
- Blacktip sharks, spotted seatrout, and bluefish exhibited a feeding preference for oyster reef prey (fish, shrimp and crabs).
- Red drum foraged slightly more off reefs.
- Blacknose sharks rarely foraged on reef habitats.

The growth-enhanced species/groups identified in Peterson et al. (2003a) included sheepshead minnow, silversides, pigfish, southern flounder, and black sea bass. These results differ somewhat from those of Grabowski et al. (2000). The discrepancies between Peterson et al. (2003a) and Grabowski et al. (2000) could be due to regional differences in fish habitat use, or other unknown factors. Sheepshead also have an affinity for slow or sessile invertebrates found abundantly on shell bottom (Pattilo et al. 1997).

Corridor and Connectivity

Shell bottom serves as a nearshore corridor to other fish habitats, such as salt marsh and SAV for finfish and crustaceans; therefore, it plays a significant ecological role in landscape-level processes (Coen et al.

1999; Micheli and Peterson 1999). Vicinity (isolation) and connectivity of intertidal oyster reefs to other fish habitats, especially SAV, are two factors that affect fish utilization of shell bottom. For example, connectivity of oyster reefs to SAV enhanced blue crab predation, whereas isolation of oyster reefs enhanced hard clam survivorship (Micheli and Peterson 1999). In Middle Marsh, North Carolina, gag, gray snapper, and spottail pinfish preferred shell bottom habitat adjacent to SAV beds (Grabowski et al. 2000), allowing access to both refuge and prey.

3.3. STATUS AND TRENDS

Status of shell bottom habitat

During the colonial period in the mid-Atlantic, oyster reefs grew so extensively that they were considered to be a hazard to navigation (Newell 1988). U.S. Navy Lieutenant Francis Winslow documented the historical distribution of oyster beds in North Carolina in 1886-1887. Winslow (1889) surveyed 1,325,419 acres in 17 areas extending from Croatan and Roanoke sounds west to the lower Pamlico and south to the eastern edge of Bogue Sound, and located 8,328 acres of public and private oyster beds (0.6% of the bottom). Allowing for expansion of oyster beds, Winslow et al. (1889) also located 20,554 acres of "public oyster grounds." In the North River estuary of Carteret County, Winslow (1889) found 243 acres of natural oyster beds, 310 acres of private beds, and about 600 acres of additional public oyster grounds. In the same general area during the 1990s, the DMF Shellfish Habitat and Abundance Mapping Program estimated there were 445 acres of shell bottom. The DMF mapping program includes scattered, individual shellfish and shellfish clusters as shell bottom, while Winslow (1889) only counted shellfish clusters, making comparisons difficult. DMF's Shellfish Mapping data on shellfish cluster abundance are therefore more inclusive than the Winslow data. *However, DMF mapping data could be analyzed by shellfish density to approximate changes in abundance.*

Other studies suggest that viable oyster beds have been displaced downstream roughly 10-15 miles in the Pungo, Pamlico, and Neuse rivers since the late 1940s (Jones and Sholar 1981; Steel 1991). The DMF's Shellfish Habitat and Abundance Mapping Program has not yet mapped these estuarine systems, as mapping existing shell bottom for protection is prioritized. Current priority for the Shellfish Mapping Program is the lower Neuse River, followed by areas to the north. Because this detailed mapping process is time consuming, *change analysis would need to be limited to a subset of priority areas. Priorities should be based on a combination of functional significance, economic value, and the magnitude of growth and development threatening the area.*

The status of shell bottom can also be evaluated using area-specific oyster harvest and effort data, fishery-independent sampling data, or site-specific studies on reproduction, growth, and recruitment. Based on harvest data, North Carolina oyster stocks were in a state of decline for most of the 20th century (DMF 2001a). North Carolina's oyster landings have generally declined from a peak coinciding with the introduction of the oyster dredge in 1889 to today's low harvest (Figure 3.1). Data on landings by gear type indicate that, between 1887 and 1960, most oysters were harvested by dredge when compared to all hand methods (DMF 2001a). Chestnut (1955) reported that 90% of the oysters landed in North Carolina came from dredging operations in the Pamlico Sound. These harvesting practices were the primary cause of initial degradation and loss of shell bottom habitat in the Pamlico Sound area (DMF 2001a; Jackson et al. 2001).

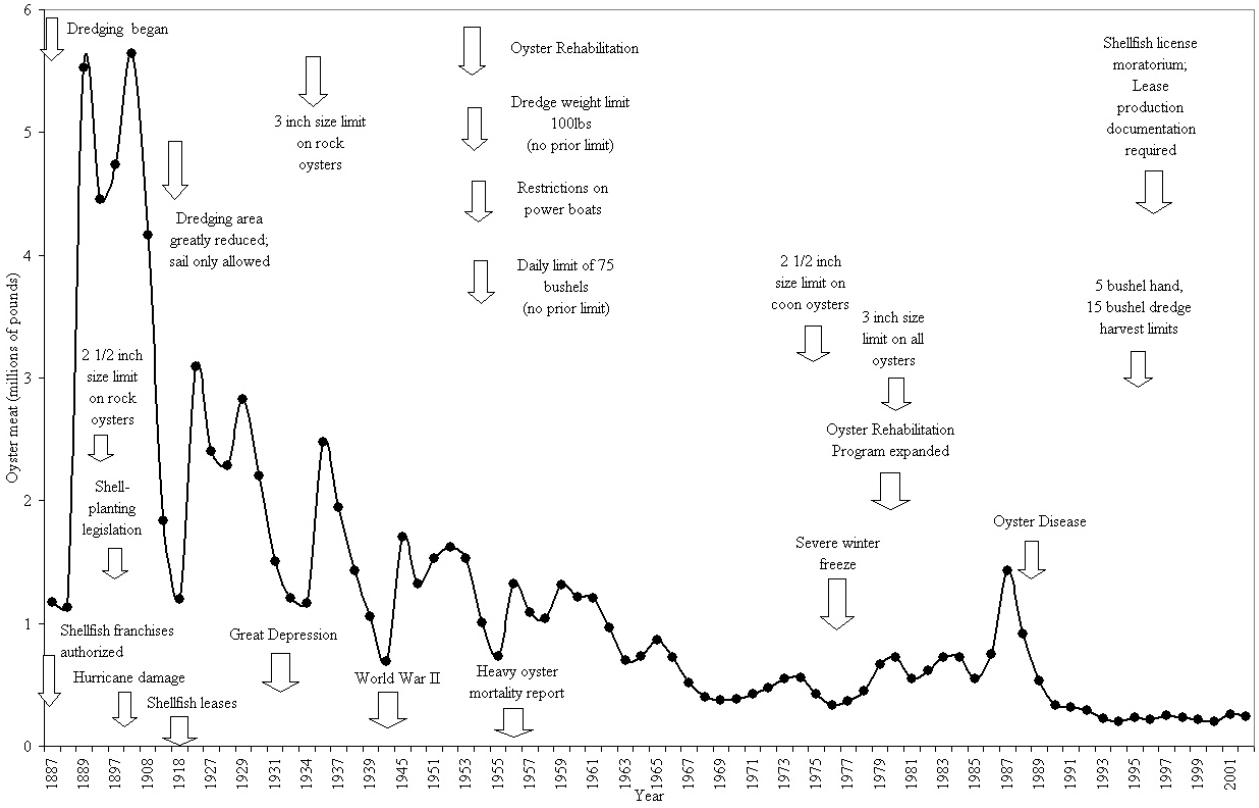


Figure 3.1. Historical, social, economic, and regulatory factors affecting the North Carolina oyster fishery, 1887-1999 (Source: DMF 2001a).

Since 1991, oyster stocks and harvests from Pamlico Sound have collapsed due to high mortalities from disease and low spawning stock biomass (DMF 2001a). Oyster dredges are still used in the fishery in Pamlico Sound and its tributaries, but are not permitted in the southern portion of the state. Since 1994, oyster dredge fishery landings have accounted for only 1% to about 21% of the annual oyster catch. Landings data indicate that, since 1997, oyster harvest has remained fairly constant at around 50 pounds of oyster meat landed per oyster dredging trip, while the number of trips, although generally increasing, has fluctuated between 3 and 943 (Figure 3.2).

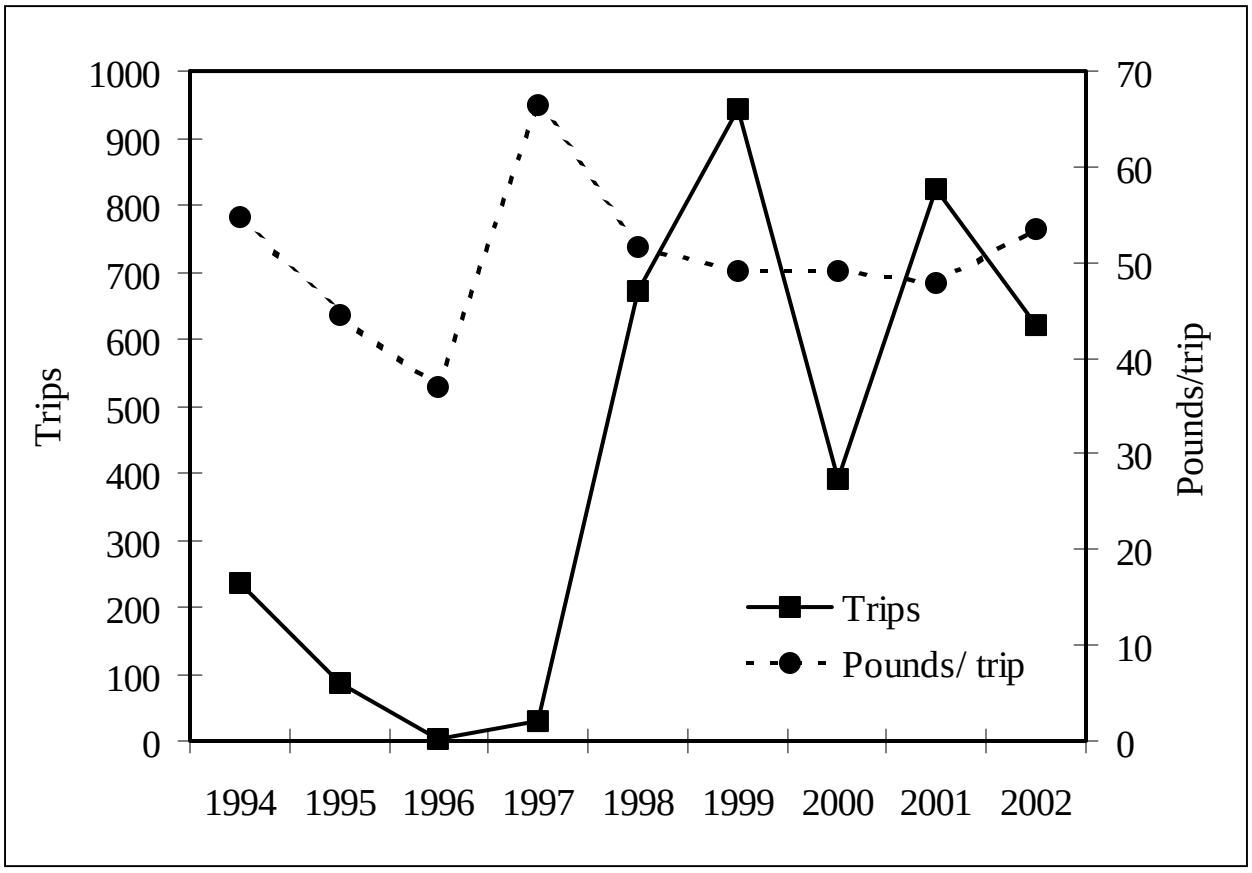


Figure 3.2. Oyster dredge effort by trips in North Carolina and pounds of oyster meat landed per trip during 1994-2000 (DMF, unpub. data).

Oyster populations in the southern portion of the coast have suffered only moderately from disease and, due to a prohibition on the use of mechanical oyster harvest methods south of Pamlico Sound, these populations have not been impacted by those methods (DMF, unpub. data). The harvest of oysters in this area is primarily limited by availability of open areas, since harvest closures have increased over time due to pollution, fishing effort is high, and oyster beds are easily accessible. In North Carolina coastal waters overall, cumulative and secondary effects from severe disease infestations, coupled with continued decline in suitable habitat, have seriously impacted oyster stocks.[33]

Average oyster spatfall in the Pamlico Sound area for the 1989–1999 period was less than half the value for the 1979–1988 period (DMF 2001a) (Figure 3.3). Unpublished DMF spatfall data for cultch planting sites over the past 24 years indicate a decline in maximum spatfall relative to similar surveys reported by Chestnut (1955). Some researchers suspect that oysters are becoming spawner-limited, while others attribute the decline to stress and mortality from infectious diseases that affect primarily larger, more fecund (egg-producing) adults (Choi et al. 1994; Lenihan et al. 1999; DMF 2001a), or to physical damage from dredging (Marshall et al. 1999). However, there has been no reported decline in spatfall in the southern coastal area of North Carolina (R. Carpenter, DMF, pers. com., 2002).

[33] Fishing gear and disease impacts are given a more thorough discussion in the Section 3.4 (Threats and Management Needs).

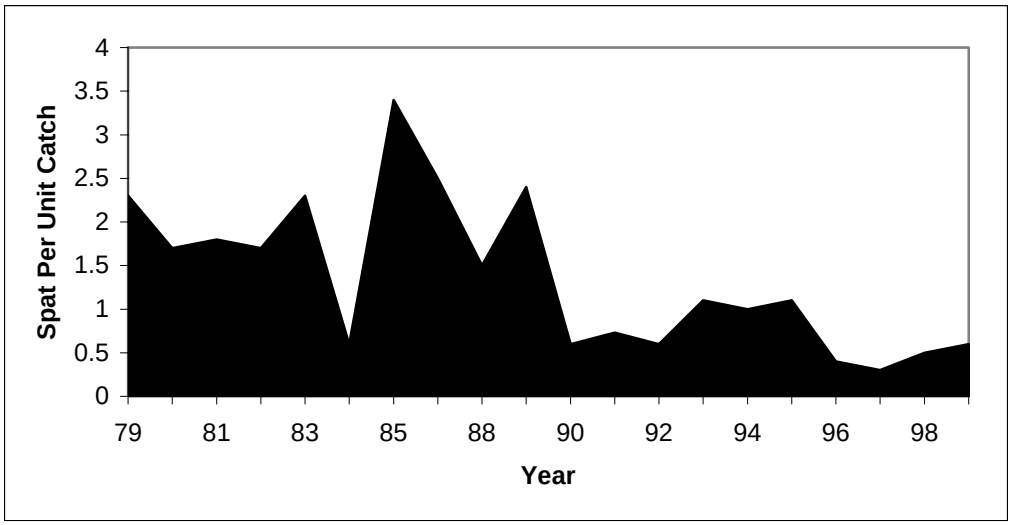


Figure 3.3. Pamlico Sound area average oyster spatfall per unit catch, 1978–1999 (DMF, unpub. data).

Status of associated fishery stocks

Based on the link between fishery species and shell bottom established in Section 3.2, some inferences can be made using the status and trends of fishery species that are highly dependent on shell bottom habitat (bolded species in Table 3.2). However, utility of the inferences is severely limited because the majority of shell bottom loss occurred before detailed fishery statistics were collected (prior to 1972). Another problem is the difficulty of sampling in oyster beds. The DMF's juvenile surveys use seines and bottom trawls, which are ineffective for sampling in oyster beds. *Appropriate sampling gear should be used to gather baseline data on juvenile abundance in shell bottom areas.* Recent fishery statistics provide a benchmark for future analysis, especially trip ticket data collected since 1994.

Of at least twenty-eight species (other than oysters) showing some preference for shell bottom (Table 3.2) habitat, ten species, comprising at least thirteen stocks, were evaluated for fishery status. Of the eleven stocks whose status was known, three were designated Overfished (27%), one was Concern (9%), one was Recovering (9%), and six were Viable (55%) (Figure 3.4). Specifically, the southern flounder stock, the central-southern stock of striped bass, and the black sea bass stock south of Cape Hatteras are classified as Overfished; blue crab and red drum are classified as Concern and Recovering, respectively (DMF 2003a). Viable stocks include spotted seatrout, shrimp, gag, the ocean and Albemarle Sound stocks of striped bass, and the black sea bass stock north of Cape Hatteras. The stock status of hard clams, stone crabs, black drum and other shell bottom-associated fishery species is unknown.

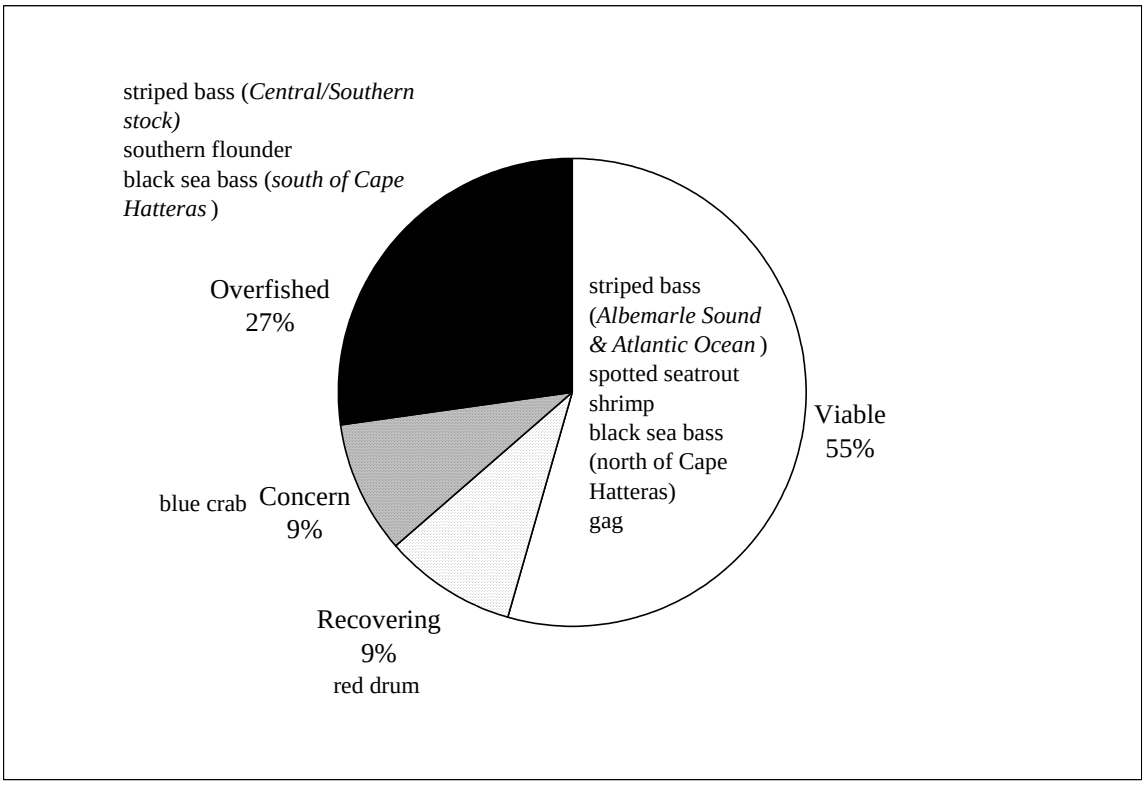


Figure 3.4. Percent of fish stocks showing some preference for shell bottom habitat that were classified as Overfished, Concern, Recovering, or Viable in the 2003 DMF Stock Status Report.

Unviable stock status could be attributed to a variety of causes ranging from habitat loss, disease, and overfishing, to annual variation in climatic conditions. Compounding this uncertainty is the fact that status of shell bottom-associated species, such as hard clams, sheepshead, and black drum, is currently unknown. *More information is needed on the status of hard clams, sheepshead, black drum, and resident non-fishery species (i.e., oyster toadfish) as indicators of shell bottom conditions. Due to the limitations of using fisheries-dependent data (landings data) to indicate stock trends, fisheries independent-data should be collected for these species to develop independent indices.* Status and trends of hard clams are currently being evaluated by DMF. The capacity of shell bottom habitat to affect water quality and overall community structure would probably be the best indicator of status and trends in shell bottom habitat. *However, before this function could be used as an indicator, research is needed on the critical amount and quality of living and dead shell bottom in a water body below which significant changes in biotic community structure occur.*

Shell bottom restoration

State efforts to restore oyster habitat and enhance oyster fishery production began around the turn of the century (Marshall et al. 1999). These efforts relied mostly on planting a variety of natural cultch, including oyster, clam, and scallop shells, and, more recently, limestone marl. Experimental oyster cultch plantings began in 1900, and state-sponsored cultch planting began in 1915 (Marshall et al. 1999). Between 1915 and 1934, a total of 1,856,379 bushels of shells and seed oysters were planted in North Carolina's estuaries. The Oyster Rehabilitation Program officially began in 1947 and resulted in planting 838,088 bushels of shell and 350,734 bushels of seed oysters over its first 10 years. Since 1970, North Carolina has relied almost exclusively on cultch planting as a means of enhancing oyster production (Figure 3.5). From 1958 to 1994, 12,475,000 bushels of shell material were planted, for an annual

average of 337,162 bushels (Marshall et al. 1999). Over the entire period of cultch planting from 1915-1994, about 15 million bushels of oysters were planted in North Carolina waters. This volume of shells would contain the equivalent of 4.5 billion 2-inch oyster shells. Using a minimum 30% area coverage (100 2-inch shells/m^2) as defining shell bottom, the volume of shell cultch planted from 1915-1994 could cover as much as 11,120 acres (45,000,000 m^2). However, this is an overestimate of actual shell bottom area gained, because the shell plantings consist of piles of variable thickness rather than a single uniform layer. Also, many of the cultch areas are replanted due to flattening by waves and/or commercial harvesting. Despite these planting efforts, the oyster harvest continued to decline (Marshall et al. 1999).

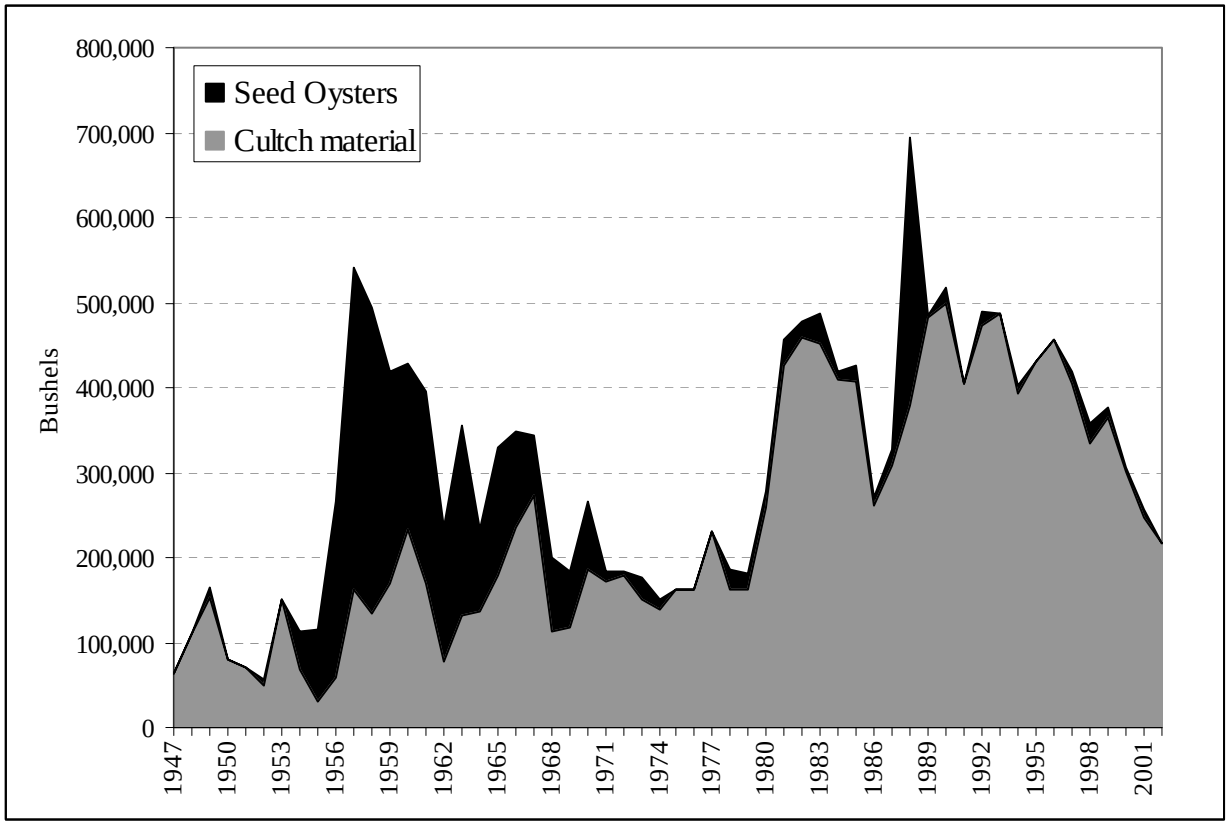


Figure 3.5. North Carolina oyster rehabilitation activities for 1947 – 1994 (data stacked to show cumulative total). The peak in 1988 was due to special state disaster funding during the red tide of 1987-88. (Source: Marshall et al. 1999)

Similar to natural shell bottom, restored oyster reefs provide bottom habitat for economically important species (Breitburg 1998; Lenihan et al. 1998; Coen et al. 1999; Harding and Mann 1999; Grabowski et al. 2000; Lenihan et al. 2001; Peterson et al. 2003a). Recent studies have examined the habitat value of constructed oyster reefs compared to natural oyster reefs. The researchers found that landscape characteristics seemed to influence fish species' relative abundance (i.e., connectivity with SAV and/or salt marsh). Fish abundance was significantly greater on restored oyster reefs adjacent to SAV than on mud flat and/or salt marsh restored reefs (Grabowski et al. 2000). Restored intertidal oyster reefs produced significantly more economically valuable oysters ($95.68/10 m^2) than estimates of oyster production on subtidal reefs ($11.61/10 m^2). The value of legal oysters present on mud flat reefs ($129.38/10 m^2) exceeded that for oysters on salt marsh ($50.50/10 m^2) or SAV restored reefs ($24.25/10 m^2). They estimated that the long-term value of commercial fisheries landings from restored reefs was greater than the oyster harvest for both intertidal and subtidal shell bottoms.

The habitat benefits of cultch plantings may only be limited or temporary if the shell bottom is removed or damaged by towed fishing gears or other harvesting gears (Marshall et al. 1999). Cultch plantings in the southern areas (Onslow, Pender and New Hanover counties) are frequently replanted after harvesting to replenish cultch material for recruitment (Marshall et al. 1999). It generally takes about 3-4 years before oysters on planted sites reach harvestable size in the Pamlico Sound system, while oysters reach the minimum legal size of 3 inches in about two years in the southern coastal area. Faster growth in this area is due to higher rates of water exchange caused by greater tidal flow than in most of Pamlico Sound. The increased flow brings in more food and prevents oxygen depletion problems.

The majority of cultch planting sites during 1990-1994 were in Pamlico Sound, lower Neuse River and lower Pamlico River (Marshall et al. 1999). The same general areas were also planted in 2001 and 2002 (Maps 3.4a-b). Most of the recent (2001-2002) oyster restoration effort has been conducted in large bays around Pamlico Sound and in smaller tributaries of other estuaries (Maps 3.4a-b). The majority of these sites are "new" plantings on basically barren sediment (Marshall et al. 1999). Criteria for site selection include suitable sediment types, currents, protection from storm damage, historical productivity, salinity patterns, and existing shellfish concentrations. The presence of bottom disturbing fisheries, such as trawling, hydraulic clamming, and long haul seining, is also considered. Recommended sites for cultch plantings are often narrow bands of mixed sand and mud sediment between shallow, hard, nearshore sediment and soft offshore sediment. In deep water, large oyster mounds are constructed to increase recruitment and reduce effects of low oxygen on the bottom. The planting sites are monitored for oyster recruitment and survival over a period of three years (DMF 2001a). Using vessels currently in operation, cultch can be planted in water as shallow as two feet (Marshall et al. 1999). Since the early 1980s, the DMF has concentrated primarily on cultch plantings and small-scale, high quality seed transplanting activities, also referred to as the "relay program." In the relay program, oysters are removed from dense oyster populations in prohibited areas and relocated to open harvest areas with depleted resources. The relay program is very small and concentrated in the south, where there is very little effect on the seed source areas (M. Street, DMF, pers. com., 2003).

The primary purpose of the DMF cultch-planting program since it began has been oyster fishery enhancement. The DMF enhancement efforts have also been directed at providing stable long-term oyster habitat because research in recent years shows that oyster reefs have important ecological and economic value as coastal fisheries habitat. This broadening of focus for the protection/restoration program has occurred since the late 1990s. As of 2001, there were five constructed/artificial reef sanctuaries in North Carolina located in Bogue Sound, West Bay (Tump Island), Deep Cove (Swan Quarter), Croatan Sound, and behind Hatteras Village (DMF 2001a). Work is currently underway to enhance several existing restoration sites and create additional sites. These areas are no-take, no-disturbance sanctuaries (C. Hardy, DMF, pers. com., 2002). In other states, sanctuaries are a major component of restoration efforts (CBP 2000). *Creation of additional "no take" subtidal oyster sanctuaries has been recommended by Frankenberg (1995), the Chesapeake Research Consortium (1999), and Lenihan et al. (1998).*

There are multiple ecological benefits of constructed and natural oyster sanctuaries, including the following (Breitburg et al. 2000):

- Protection of brood stock,
- Enhancement of oyster populations in surrounding harvested areas through larval dispersion,
- Protection of disease-resistant oysters, improving the genetic pool for disease resistance, and
- Protection of associated fisheries and other organisms from predation through development and maintenance of maximum vertical relief and structural complexity.

The first true oyster reef restoration project in North Carolina occurred in 1992-1993 when 13 acres of oyster producing habitat were created as mitigation for the loss of 16 acres of estuarine bottoms and 1.5 acres of wetlands in Roanoke Sound (Marshall et al. 1999). The DMF is monitoring the site as part of a

mitigation agreement with the U.S. Army Corps of Engineers (COE). More recently, the DMF has performed mitigation projects for the North Carolina Department of Transportation, and additional projects creating more than 70 acres of shell bottom are planned with the COE (Marshall et al. 1999). Research is continuing on how to better construct these sites to provide effective oyster habitat. *However, in the Pamlico Sound region where spatfall continues to decline (Marshall et al. 1999), more planting and longer protection of sites may be required to achieve the same results as previous restoration efforts. Restoration efforts must use knowledge of larval availability in order to be most effective.* In southern waters, the amount of shell habitat is generally stable, but the amount of harvestable area is decreasing as closures increase because of contamination from storm water runoff (R. Carpenter, DMF, pers. com., 2002).

Restoration of shell bottom is also undertaken by non-profit groups. One such project has been initiated in Pamlico Sound by The Nature Conservancy, in cooperation with NOAA's Community-Based Restoration Program and several partners. The goal of the Project is to enhance the biological diversity of Pamlico Sound by establishing a self-sustaining complex of living oyster reefs throughout the estuary. The Conservancy has enlisted the cooperation of marine scientists to ensure the most up-to-date techniques for siting, construction, and management are used. Some criteria for site selection include depth, salinity, shellfishing-prohibited status, disease-resistant salinities, reef footprints, presence of larvae, and proximity to SAV, salt marsh, fish nursery areas, or Military Protected Areas. States and territories containing anadromous, estuarine, and marine species are eligible to compete for Community-Based Restoration grants typically ranging from $25,000 to $75,000.[34] *As the number of oyster restoration projects grows, the need for an overall strategy for shell bottom restoration also increases.*

Any expansions of the current restoration/enhancement effort will require additional sources and funding for oyster cultch or limestone marl. Funding for the acquisition of cultch material was drastically cut in DMF's 1990 budget. As a result, the DMF currently has more planting capability than available cultch material. *Funding for acquisition of cultch material must be increased to more efficiently use the existing planting capabilities of DMF.* The DMF began a voluntary shell-recycling program in 2004 using local coordinators to collect discarded shells from individuals and businesses. The shells are later transferred to stockpile facilities before being planted in new or expanding oyster sanctuaries. The amount of cultch volunteered could somewhat offset the amount of funding needed for additional cultch material. However, the amount of cultch volunteered is probably secondary to the public awareness gained from a shell-recycling program.

3.4. THREATS AND MANAGEMENT NEEDS

Although shell bottom consists of both living and non-living shell material, annual recruitment of live shellfish is needed to sustain the supply of shell material and three-dimensional structure of oyster reefs. Therefore, any activities that directly remove or destroy live shellfish, or indirectly prevent or slow growth and survival, are threats to shell bottom habitat. Mollusks that contribute shell material include oysters, hard clams, bay scallops, as well as many non-fishery species. Since oysters are the dominant contributor to shell bottom, the threats discussed below focus primarily on oyster reefs.

Physical threats

Mobile bottom disturbing fishing gear

Mechanical fishing gear includes any gear that is towed or run by engine power including dredges, hydraulic clam dredges, clam kicker, bottom trawls, or patent tongs. Over-harvesting and habitat destruction from oyster dredging were the initial causes for the large-scale decline in oyster resources from approximately the late 1800s to the mid-1900s, particularly in the northern portion of North

[34] For information on guidelines and requirements for the grants, visit <http://www.conserveonline.org>, or the NOAA Fisheries Restoration Center at <http://www.nmfs.noaa.gov/habitat/restoration>.

Carolina. Although other factors had contributed to the decline in the oyster fishery, tonging and dredging had the greatest impact on the physical structure of the reefs (Hargis and Haven 1988; Rothschild et al. 1994). One full season of oyster dredge harvesting effort reduced the mean height of restored subtidal oyster reefs by 30% (Lenihan and Peterson 1998; DeAlteris et al. 1999). Because of this high removal rate, DMF has added shell to heavily fished subtidal areas approximately every 3 to 4 years to maintain the fishery (Frankenberg 1995).

Oyster dredges reduce the vertical relief of subtidal oyster reefs resulting in several negative habitat impacts (Lenihan and Peterson 1998; Lenihan et al. 1999):

- Scattering of shell and oysters into less suitable substrates.
- Destabilization of the reef structure, which increases vulnerability to damage by future storms.
- Removal of live and dead oysters and portions of the upper layers of the shell which:
  - Decreases potential number of spawning adults (spawning stock biomass).
  - Decreases area available for settlement by oyster larvae.
  - Subjects newly settled oysters to lower oxygen and increased sediment due to lower depth in water column.
- Reduction in the small spaces within the oyster reef that function as refuge and foraging areas for juvenile fish.
- Decreased resistance to disease [35].

Between the 1970s-1990s, the negative impact of the oyster dredge on shell habitat was recognized, and areas were designated where all mechanical methods for shellfish harvest were prohibited (Maps 3.5a-c). These mechanical methods include towed dredges, hydraulic dredges, patent tongs, rakes powered by engine, and clam trawling ("kicking" clams with vessel propellers so they are caught in a small trawl).

Trawling, dredging, and all mechanical shellfish harvest methods are prohibited in MFC designated Primary Nursery Areas (PNAs), and trawling is prohibited in permanent Secondary Nursery Areas and Shellfish Management Areas [MFC rules 15A NCAC 03N .0104 and .0105, 03J .0103], protecting shell bottom in these shallow water areas. The rules defining nursery areas have been in effect since 1977. Maps 3.5a-c depict the areas where trawling and dredging are not allowed by MFC rules (including PNAs, mechanical harvest prohibited areas, SAV beds). However, trawling over bottom in tributaries of Pamlico Sound, where productive oyster beds once existed, continues, possibly preventing oysters from reestablishing in part of their historic range (Frankenberg 1995). *Construction of oyster sanctuaries in locations of historic abundance and restriction of trawling over restored shell bottom are necessary to restore shell bottom in these northern subtidal areas*. There are also areas where trawling is prohibited, but oyster dredging is not. *Oyster dredging in these areas should also be prohibited.*

Use of oyster dredges has been severely limited by the MFC in recent years due to habitat impacts. However, the historic subtidal oyster beds have not recovered (Lenihan and Peterson 1998). Degraded water quality, partially due to reduced filtering by oysters after stocks were greatly reduced, and increased disease occurrence from environmental stress are thought to have prevented full recovery (Lenihan and Micheli 2000; Jackson et al. 2001). Approximately 222,224 acres of shellfish bottom in the Neuse, Pamlico, Tar-Pamlico, and Albemarle MUs are open to oyster dredging at least temporarily. Forty-five percent of this area is within the Pamlico Sound MU. Oyster dredging is prohibited in the southern portion of the state's estuarine waters because the majority of shell bottom resources south of Pamlico Sound are intertidal.

Considering the average number of oyster dredge trips reported from 1994 through 2000, there has been approximately 1 trip/year for every 380 acres of the shellfish mapping study area open to dredging. The total amount of damage to shell bottom depends on the effect of each trip and the relative amount of shell

[35] see discussion under "Disease"

bottom within the mapping area. *One of the recommendations of the North Carolina Oyster Management Plan is the adoption of criteria to designate additional areas where mechanical harvest methods are prohibited (DMF 2001a).* The new additions are intended to protect shellfish beds in potential hand harvest areas.

Trawling for shrimp, crabs, and finfish, and long haul seining and dredging for crabs have similar types of habitat impacts as oyster dredges, but at reduced levels of disturbance (DMF 2001a). The weight and movement of trawl doors or chain towed across the seafloor can disrupt the structure of the oyster mound, removing the upper layers of shells or scattering oysters (DMF 2001a). Long haul seines dragged through shell bottom can also damage oyster mound structures by entangling, uprooting, and scattering shell. Frankenberg (1995) studied the state of the oyster fishery and concluded that, because of its intensity, trawling had a significant negative impact on live shell bottom habitat. Illegal trawling in prohibited areas can also be a problem, and the penalties for getting caught are minimal. *Stronger penalties are needed for trawling over oyster rocks, where prohibited by the MFC.*

There are approximately 16,000 trips annually with these gears, primarily (>70%) shrimp trawling (DMF, unpub. data). About 75% of the trips occur in estuarine waters, and the rest are mainly within the Territorial Sea. Virtually all shrimp and crab trawling occurs on sand/mud bottoms. Shell bottom is protected from bottom trawling in trawl net prohibited areas [MFC rule 15A NCAC 3J .0104]. Furthermore, it is illegal to use trawls on shell bottom designated as Shellfish/Seed Management Areas [MFC rule 15A NCAC 03K .0103(b)]. These areas are designated by proclamation and must be marked with signs or buoys. The DMF lacks the resources to mark, maintain, and enforce restrictions on all shell bottoms. *Additional marking of productive shell bottom would provide increased protection of this habitat from destructive fishing gears. However, additional law enforcement resources are necessary to mark and enforce increased closed areas.*

Hand harvest

The harvest of clams or oysters by tonging or raking on intertidal oyster beds causes damage to not only living oysters but also the cohesive shell structure of the reef (Lenihan and Peterson 1998). This destruction has been an issue where oysters and hard clams co-exist, primarily around the inlets in the northern part of the state and on intertidal oyster beds in the south (DMF 2001a). Studies by Noble (1996) and Lenihan and Micheli (2000) quantified the effects of oyster and clam harvest on oyster rocks. The former study found that the density of live adult oysters was significantly reduced where clam harvesting occurred. Mortality was attributed to oysters being cracked or punctured and subsequently dying or being eaten by predators, or by being smothered beneath sediments associated with clam digging. Conversely, oyster harvesting had little effect on clam populations. DMF conducted field investigations of the status of oyster rocks in Ward Creek, Carteret County, to assess the destruction of oyster rocks by individuals taking clams by legal hand harvest methods (Noble 1996). The 1995 survey determined that the oyster rocks had been impacted and, subsequently, the affected portion of Ward Creek was designated a shellfish management area and was temporarily closed to clamming from December 1995 to March 1996. Oysters could only be harvested by hand in the Ward Creek shellfish management area during the 1995–1996 oyster season. Based on visual inspection and field sampling in 1996, the structural integrity and oyster abundance on six of the eight oyster rocks surveyed were good and, in most cases, had improved following the implementation of the shellfish management area restrictions. Because the restrictions were successful in curbing the destruction and deterioration of Ward Creek oyster rocks, it was recommended that the shellfish management area designation be continued to protect oyster rock habitat in Ward Creek. The investigators concluded that, by preventing the destruction of oyster rocks, optimum substrate for oyster-spat settlement and critical habitat for other estuarine species would be preserved.

The MFC has recognized that clamming can have a negative impact on oyster habitat and has adopted rules that prohibit the harvest of clams on posted oyster beds and restrict the areas and gear that can be

used to take clams and oysters (DMF 2001b). The posting of all natural oyster beds has never been attempted, because of the large number of areas that would have to be posted and the lack of sufficient resources and enforcement to keep them marked. The DMF has designated some areas as Shellfish Management Areas where enhancement activities are conducted (shell is added and/or oysters are transplanted) and clamming is restricted or prohibited. Existing Shellfish Management Areas, about 752 acres of shell bottom, are shown in Map 3.4a-b. *Creation of additional Shellfish Management Areas would reduce habitat damage and enhance spatfall of oysters and clams in areas where hand-harvesting activity is intense. More enforcement would also be needed to enforce the restrictions associated with Shellfish Management Areas.*

Water-dependent development

Water-dependent development includes any permanent, man-made structures that are designed for access to the water (Kelty and Bliven 2003). These include marinas, docks, piers, and bulkheads. Although the construction of water-dependent structures may actually increase substrate for oysters, activities associated with water-dependent development can harm shell bottom. Dredging of channels for navigational purposes can remove, damage, or degrade existing shell bottom. Dredging creates turbidity that can clog oyster gills or cover the oysters completely. Even low levels of siltation affect growth of oyster beds by reducing larval attachment. Although there are no major new channels being constructed at this time in North Carolina's estuarine waters, maintenance dredging, construction of new marinas and docking facilities, and new dredging for deep water access continue to be potential problems. Primary Nursery Areas are currently protected from dredging projects for deep-water access. However, there are other areas with shallow oyster beds that are not protected from such dredging. Oyster beds in closed shellfishing waters are particularly vulnerable to loss and degradation from marina dredging. *These areas should be evaluated for protection as Strategic Habitat Areas.*

Turbidity and siltation over shell bottom can also occur from increased boating activity near the marina or dock. Boats running in shallow water cause resuspension of fine sediments, which is similar to the effect of dredging on nearby oyster beds. However, the impact of both dredging and boating activity on oysters has been difficult to quantify (Kelty and Bliven 2003). Current (January 2003) CRC marina siting rules discourage significant degradation of existing shellfish resources [CRC rule 15A NCAC 07H .0208]. Marina siting data collected by DCM during 1994-1995 indicate that 44% of the 182 coastal marinas adjacent to mapped bottom areas were located within 100 m (328 ft) of shell bottom (DCM, unpub. data), indicating the potential for shell bottom to be affected by marina-related activities.

Marinas can also negatively impact shell bottom through water quality degradation due to increased runoff and erosion from adjacent developed areas and discharges from boats.[36] Due to the potential for physical and water quality impacts, a variety of rules apply to development of new marinas. The DCM is responsible for permitting marinas under the CAMA. The CAMA permitting process requires coordination with DEH, DMF, DWQ, and other state and federal agencies. If the marina is located in waters that would be classified as shellfishing waters (SA) by the EMC, then a review of the status of the waters is required. If the waters are currently classified as open to shellfishing, then DWQ would recommend denying the permit to protect the designated use of those waters. However, if the waters are closed to shellfishing or not classified as SA, then the marina may be allowed. This policy can unintentionally result in degraded areas being targeted for additional development and further degradation, rather than restoration. *A variety of working groups have recommended the development of a coastal marina policy that encompasses all associated regulatory activities conducted within the DENR (NC Coastal Futures Committee 1994, Waite et al. 1994). Development of this policy continues to be a management need.*

[36] Water quality impacts are discussed under "Water quality degradation."

Scouring of the bottom by frequent boat traffic associated with dock concentrations can have an effect similar to dredging. Unlike marinas, individual docks and piers can be built in open shellfish waters. Dock proliferation in coastal waters is a growing concern for resource managers. Concerns raised at a NOAA workshop regarding environmental impacts of boating associated with small docks and piers included erosion of marsh edge and tidal flats, and resuspension of sediment and resulting turbidity (Kelty and Bliven 2003). The workshop participants agreed that boating traffic associated with docks is far from a benign influence on aquatic and marine environments. *Evaluation of the impact of dock-associated boating on shell bottom habitat is therefore a research need. Prohibiting construction of docks or replacement of severely damaged docks (>50%) in documented shellfish beds may be required to minimize degradation and loss of habitat.*

Water quality degradation

Sediment

In addition to direct physical damage to the shell mound structure, bottom disturbing fishing gear, including hydraulic clam dredges, clam trawls (kickers), and shrimp and crab trawls can impact oyster reefs indirectly by re-suspending sediment. As sediment disperses away from the disturbance and settles to the bottom, it can bury oyster larvae, adults, or shell, deterring successful recruitment of larvae due to lack of an exposed hard substrate (Coen et al. 1999). Excessive sedimentation can also harm shellfish by clogging gills, increasing survival time of pathogenic bacteria, or increasing ingestion of non-food particles (SAFMC 1998a). Oyster eggs and larvae are most sensitive to suspended sediment loading (Davis and Hidu 1969a). Sediment was listed by DWQ as a problem parameter for 964 miles of North Carolina waterways in 125 water bodies, including 25 water bodies in the Cape Fear River basin, 18 in the Neuse River basin, and 11 in the Tar-Pamlico River basin in 1998-1999 (DWQ 2000a). All of these river basins contain shell bottom habitat.

There are many other sources of human-induced turbidity and sediment pollution. Any activity that involves clearing of vegetation, grading, and ditching of land can potentially increase erosion and sediment loading in stormwater runoff. These activities include, but are not limited to, construction of residential, commercial, or transportation structures; forestry harvesting; and agricultural activities. Increased sedimentation in headwaters from upland development has caused environmental stress and possibly some mortality to upstream oyster stocks (Ulanowicz and Tuttle 1992; Mallin et al. 1998). There is anecdotal evidence that sedimentation from upstream development (primarily road construction) has silted over numerous oyster beds in trunk estuaries such as the Newport River, where Cross Rock (a large oyster rock) has been buried under 1-2 feet of soft sediment (P. Pate, DMF, pers. com., 2004; C. Peterson, UNC-CH, pers. com., 2004). *Improved voluntary and regulatory land use strategies must be implemented to reduce nonpoint source pollution in coastal waters and subsequent habitat degradation*. *Mitigation should be required from upstream development projects that result in habitat loss downstream*. Shoreline erosion increases the amount of sediment transported into the estuarine system. While bulkheads can retain some upland sediment, such structures can increase erosion at the base of and downstream from the hardened structures, causing chronic increased turbidity in those areas.[37]

Sediment in excessive amounts is also a problem because it transports fecal coliform in stormwater farther downstream and allows the bacteria to persist longer in the water column than such bacteria would live in clear waters (Schueler 1999). While fecal coliform bacteria do not affect the viability of oysters, pathogenic bacteria can make oysters unfit for human consumption. Sediment was the largest cause of water quality degradation in the Albemarle-Pamlico estuarine area (DEM 1989).

[37] The Water Column chapter contains a more thorough discussion of sedimentation and turbidity.

Nutrients

Increased nutrient loading can indirectly damage live shell bottom by increasing the occurrence of plankton blooms and low oxygen events. Research indicates that the magnitude and frequency of eutrophication in coastal waters has increased (Paerl et al. 1995; NRC 2000). Increasing eutrophication, in turn, has caused the frequency, duration, and spatial scale of low or no oxygen events (hypoxia and anoxia, respectively) to intensify over time in many estuaries (Lenihan and Peterson 1998). Prolonged periods of low oxygen conditions in the water column can cause mass mortality of fishery-disturbed oyster beds or the non-mobile organisms attached to them. Dissolved oxygen concentrations less than 2 mg/l are fatal to sessile biota and stressful to most motile finfish and shellfish species (Sparks et al. 1958; Funderburk et al. 1991; Paerl et al. 2001). Low dissolved oxygen can occur naturally when the water column becomes stratified (not wind mixed) and biological processes deplete oxygen.

In the Neuse River estuary in 1993, Lenihan and Peterson (1998) found that protracted hypoxia/anoxia caused mass mortality of oysters, other invertebrates, and fishes on a low profile oyster reef at all water depths greater than 5 m. Occupancy of crab burrows on an oyster reef decreased from 100% at all depths prior to hypoxia to 0% at 6 m from the water's surface, 75% at 4 m, and 80% at 3 m immediately after a hypoxic event. Mobile invertebrates such as mud crabs (*Panopeus herbstii*) avoided oxygen depletion by moving upward on the reef where possible. As the frequency of hypoxic events increases, food availability for species that forage on oyster reefs, such as red drum, weakfish, summer flounder, spot, Atlantic croaker, striped bass, and black sea bass, will decrease, particularly in deeper habitats and where oyster reef height has been reduced by fishing efforts.

Data have shown that eutrophication, as indicated by nutrient concentrations and high chlorophyll *a* concentrations, is a concern in North Carolina coastal waters. According to the DWQ 305(b) report (DWQ 2000a), there are approximately 35,410 acres of waters impaired by excessive chlorophyll *a* levels. In an EPA sponsored four-year study in North Carolina, low dissolved oxygen (DO) (potentially related to eutrophication) and low infaunal communities within shellfish waters were most frequently reported in Pamlico River and the lower portion of Neuse River (Hackney et al. 1998). One site in Alligator Bay and another at the mouth of Cape Fear River also had moderate contamination and low DO.

There are multiple sources and activities that contribute to excessive nutrient loading of surface waters, including fertilizer use, discharge of animal and human waste, filling of wetlands, loss of riparian buffers, increased stormwater runoff from developed areas, ditching and channelization, and atmospheric nitrogen deposition from animal operations, internal combustion engines, and industrial burning (Cooper and Brush 1991; Paerl et al. 1995). Catastrophic weather events, such as hurricanes, can also greatly increase delivery of nutrients to coastal waters. The Neuse and Tar rivers carried the equivalent of over half their normal nitrogen and phosphorus loads during one month of flooding following Hurricane Floyd during September–October 1999 (Bales et al. 2000). High volumes of floodwater discharge following the hurricanes and other tropical storms in North Carolina in the 1990s resulted in large-scale events of hypoxia in estuarine waters. In the estuaries of the Cape Fear River, hypoxia (0–2 mg/L) persisted for several weeks following Hurricane Fran and Bertha in 1996 (Mallin et al. 1999b).

Similarly, bottom water hypoxia, followed by increased algal blooms and fish disease, occurred in Pamlico Sound following Hurricanes Dennis, Floyd, and Irene in 1999 (Paerl et al. 2001). Salinity and light penetration also decreased temporarily in both areas. These effects often occur naturally following hurricanes because of the large quantities of swamp water flooding and heavy precipitation. However, environmental damage was considerably increased due to failure of municipal and private waste treatment systems and subsequent sewage diversions into rivers, as well as breaching, overtopping, or flooding of swine waste lagoons by river water, allowing large quantities of swine waste to enter coastal waters (Mallin et al. 1999b). *Nitrogen, phosphorus and sediment loading from waste treatment facilities, animal operations and other sources must be reduced upstream of shell bottom habitat to minimize mortality to*

shellfish and associated organisms. Construction of high profile oyster reefs in deeper waters is needed to serve as refuge areas during low oxygen events.

Several initiatives have already been taken to reduce nutrient levels in some areas of the coast. The EMC has designated several coastal river basins as Nutrient Sensitive Waters, requiring removal of wastewater discharges and other management actions to reduce nutrient inputs (Maps 2.2a-b). The EMC initiated a 50-ft streamside buffer and mandated a 30% reduction in nitrogen loading in the Neuse and Tar-Pamlico river basins. Several mitigation and restoration projects have been constructed in these river basins, as well. A 12.4 acre tidal wetland was constructed at a large row crop farm in 1999 adjacent to the South River. This stream drains to the lower Neuse River in the vicinity of past algal blooms, anoxia and hypoxia events, and fish kills. Results from 2000 and 2001 indicate that the wetland area effectively reduced nitrogen in runoff by approximately 30% (Poe et al. 2002). *Efforts in wetland restoration, shoreline conservation (vegetative buffers, setbacks), and stormwater management should be a priority in watersheds draining to shell bottom habitat, particularly where oxygen and nutrient problems have been documented. Nutrient loading from point sources must also be reduced through increased inspections and maintenance of sewage treatment facilities, collection infrastructure, and on-site wastewater systems. In systems with an abundance of "black waters" (or swamp water), such as the lower Cape Fear River, investigations should focus on separating nutrient impacts on DO from impacts due to inflow of low DO swamp waters.*[38]

Toxic chemicals

Toxic chemicals can enter estuarine waters and accumulate in the sediment or in filter-feeding shellfish at concentrations that are reported to cause biological effects to oysters and other organisms. Under some conditions, such as spills, toxic chemicals may occur in acutely toxic concentrations. Heavy metals, petroleum products, chlorinated hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), and pesticides (organophosphates) can enter estuarine waters from stormwater runoff in developed areas (Dauer et al. 2000; Williamson and Morrisey 2000). Heavy metals and PAHs may be of particular concern with regard to oyster resources due to bioaccumulation and human health concerns (Sanger and Holland 2002).

Oyster embryos and larvae are more sensitive to toxic chemical effects than adults and juveniles, which are generally more tolerant of contaminants than other estuarine species (Funderburk et al. 1991). Oyster larvae are very sensitive to mercury and silver, and moderately sensitive to copper and zinc. Oyster larvae are relatively insensitive to other heavy metals and most of the pesticides tested (Funderburk et al. 1991). The substances having the most chronic effect on oysters include tributyltin, a few heavy metals, and petroleum hydrocarbons. For acute toxicity and sublethal effects on juvenile oysters, chlorinated pesticides and PCB (such as Arochlor 1016) are thought to be most damaging. Acute toxicity and chronic or sublethal effects of certain toxic chemicals to oysters and clams, as well as the current North Carolina saltwater surface water quality standards [EMC rule 15A NCAC 02B .0200], are listed in Table 3.3. In most cases, existing surface water quality standards are sufficiently stringent to protect these species. There are a couple of pesticides listed in the table for which there is no standard. However, EMC rule 15A NCAC 02B .0208 allows for the calculation of criteria to prevent chronic toxicity due to any toxicant not listed in the rules.

[38] See the Water Column chapter for more information on water quality degradation affecting shell bottom.

Table 3.3. Comparison of acute toxicity and chronic or sublethal toxicity (µg/l) for oyster and clams with North Carolina's saltwater surface water quality standards of the North Carolina.

Contaminant	Eastern oyster (µg/l)[1]		Hard clam (µg/l)[1]		N.C. surface saltwater standards (ug/L)
	Acute	Chronic	Acute	Chronic	
Aldrin (insecticide)	15	0.1	-	202.5	0.003
Arsenic (metaloid)	7500	-	-	-	10
Atrazine (herbicide)	>30,000	>10,000	-	-	[2]
Cadmium (heavy metal)	2579/39	39	-	-	5
Chlordane (insecticide)	8	6	-	-	0.004
Chromium VI (heavy metal)	10,300	-	-	-	50 (as total)
Copper (heavy metal)	38	50	22	25	3
Dieldrin (insecticide)	67	13	-	-	0.0002
Lead (heavy metal)	2450	-	780	-	25
Mercury (heavy metal)	8	12	20	14	0.025
PCB (polychlorinatedbiphenyl)	10	13.9	-	-	0.000079
Permethrin (insecticide)	>1,000	-	-	-	[2]
Toxaphene (insecticide)	23	40	<250	1,120	0.0002
Tributyltin (antifoulant)	1.5	0.7	0.05	0.08	0.002 (as trialkyltin includes tributyltin)
Zinc (heavy metal)	263	200	190	-	86

[1] Geometric means of literature values from Funderburk et al. (1991).
[2] No numeric standard in rules at this time (2002), but currently use "no toxics in toxic amounts" Environmental Management Commission rule 15A NCAC 2B .0208 to control for substances not listed in the rules.

Several studies have documented the effects of toxins associated with marinas on the estuarine environment (Wendt et al. 1990; Steel 1991; Sanger and Holland 2002). Heavy metals and PAHs can cause acute toxicity (mortality) and sublethal stress on oysters (all life stages) and other benthos and fish prey organisms. These toxic chemicals can inhibit reproductive development, release of gametes, fertilization, larval development, and growth of juvenile oysters.

The primary biological effect on oysters from marinas examined in South Carolina was a significant reduction in the density of recruited oyster spat at the marina sites compared to control sites (Wendt et al. 1990). No effect was observed on reproduction (reproductive cycle and gonadal index) or the condition of adult oysters. Three PAHs were detected in marina sediments at concentrations known to be carcinogenic. During the summer months, with increased activity at the marina, several PAHs were detected in oyster tissue at greater levels than occurred at control sites. Copper concentrations in oysters were considerably higher at the marina than at control sites. Other data from South Carolina showed that concentrations of copper and zinc in oysters were elevated above statewide averages around a large shipyard and boat repair complex (SC DHEC 1987).

Leaching of wood preservatives from dock and bulkhead structures may also contaminate live oysters. Chromated copper arsenate (CCA), the most common wood preservative in the United States, consists of copper, chromium, and arsenic. This wood preservative has been shown to leach those heavy metals into adjacent sediments and impact marine benthos (Weis and Weis 1994; Weis et al. 1998). The toxicity of copper, chromium, and arsenic to aquatic organisms is well known (Weis et al. 1998) and all three metals are listed as priority pollutants by the EPA (Hingston et al. 2001). Copper appears to have the most toxic

effect on marine organisms and also consistently appears to leach the greatest amount (Weis and Weis 1994).

Weis et al. (1995) found that oysters living on CCA-treated wood in a residential canal had fifteen times more copper (~ 200 μg/g wet weight) and 2-3 times more arsenic than reference oysters, and significantly more digestive system malfunctions. Copper is known to cause this pathology (Weis et al. 1995). Sediment contaminated with CCA has caused toxicity and some mortality to oysters, amphipods, polychaetes, fiddler crabs, mud snails, fish embryos, and sea urchin (Weis et al. 1998). Elevated concentrations of metals and reduced abundance and diversity of the benthic community were found to extend approximately 10 meters from CCA treated bulkheads and one meter from docks, decreasing with distance from the structure (Weis and Weis 1994; Weis et al. 1998). Sediment contamination was higher in a residential bulkheaded canal than adjacent to bulkheaded open water.

The extent of sediment contamination from CCA could be significant considering the magnitude of preserved timber used in the marine environment for bulkheads, docks, and marinas (Weis and Weis 1994). A pilot study conducted by DMF along approximately seven miles of estuarine shoreline in the southern portion of the coast (Pages Creek and Intracoastal Waterway) found that approximately 21% of the shoreline within the study area was hardened in 1984. By 2000, 37% of the shoreline in the same area was hardened. Because a small proportion (<5% in 1984 and 2000) of structure identified in the pilot study as hardened included non-wooden structures (e.g., boat ramps and rip-rap), the reported percentages may slightly overestimate the total extent of the shoreline exposed to CCA. Nevertheless, the most affected area of shoreline was along the waterway, where boat wakes and greater fetch increase erosion problems. In this area, 54% of the project area was hardened. However, even along a protected creek with a wide marsh fringe and little obvious erosion problems, 38% of the shoreline has been hardened. Along Yeopim Creek, a tributary of Albemarle Sound, approximately 1% of the shoreline was hardened in 2000. *This methodology for assessing shoreline hardening could be used for a larger portion of the coast to spatially delineate and quantify where and how much of the shoreline is hardened.*

Toxicity of wood decreases with time, about 50% each day after immersion, with most leaching occurring in the first five to six days (Sanger and Holland 2002), and 99% of the leaching completed in three months. However, dock pilings and bulkheads are replaced periodically, providing a continual source of newly treated wood in coastal waters. The EPA is requiring new labeling on all CCA products specifying that no use of CCA will be allowed after December 2003. In February 2002, the wood-treating industries made a voluntary decision to transition away from use of arsenic treated wood (CCA) by the end of 2003. However, according to the CCA Compliance Strategy developed by the Office of Enforcement and Compliance Assurance (OECA) (http://www.epa.gov/pesticides/factsheets/chemicals/cca_strategy5.pdf , June 2004), the CCA prohibition excludes "wood for marine construction" (i.e., subject to immersion or exposed to salt water or brackish water), and pertains only to wood "intended for most [but not all] residential settings" (<http://www.epa.gov/pesticides/factsheets/chemicals/cca_qa.htm>, August 2004). Moreover, "existing stocks of [CCA-treated] wood may be sold by retailers until such stocks are exhausted, and consumers may continue to buy and use the wood for as long as it is available" (<http://www.epa.gov/pesticides/factsheets/chemicals/cca_guidance_q_a.htm>, August 2004). Furthermore, alternative wood preservatives containing copper or other chemicals may have similar toxicity to marine organisms. *Any new wood preservative products should be evaluated for impacts to marine benthos, including oysters*[39].

Fecal coliform bacteria

Elevated levels of fecal coliform bacteria in shellfish and adjacent waters do not kill oysters or clams. Such levels indicate contamination of waters, shellfish, and sediments from warm-blooded animal waste. Because of the sources and pathways of fecal coliform, high bacteria levels are an indication that other

[39] See Water Column chapter for management needs concerning toxic contaminants affecting shell bottom.

water quality problems may also exist that could impact growth, survival, reproduction, or recruitment of fisheries resources and potentially impact human health through harvest and consumption of contaminated shellfish. Water quality monitoring in several tidal creeks in New Hanover County found a positive correlation between fecal coliform abundance and turbidity, nitrates, and orthophosphates (Mallin et al. 2000b; 2001b). There was also a correlation between levels of fecal coliform and levels of other pollutants such as toxins and sediment. Similar spatial patterns of increased fecal coliform as well as increased nitrates, chlorophyll *a*, and, to some extent, turbidity, were observed at upstream locations in the same study. Highest concentrations at upstream areas were attributed to proximity to development sources and reduced flushing and dilution compared to higher salinity waters near the ICW (Mallin et al. 1998). The majority of fecal coliform contamination has been attributed to nonpoint stormwater runoff (DEM 1994; Frankenberg 1995; Schueler 1999; Reilly and Kirby-Smith 1999; DMF 2001a).

The relative importance of other nonpoint sources of fecal coliform pollution has also been investigated. For example, Mallin and Wheeler (2000) found that runoff from golf courses was not a significant source of fecal coliform bacteria to tidal creeks in southeastern North Carolina, although they did contribute to elevated nutrient levels in the water.[40]

Disease

When oysters suffer physiological stress induced by extreme environmental conditions, such as low dissolved oxygen or poor water quality, they become more susceptible to parasitism and disease, such as Dermo and MSX (Lenihan et al. 1999). The parasites *Perkinus marinus* (Dermo) and *Haplosporidium nelsoni* (MSX) have caused significant oyster mortality (Andrews 1988; Hargis and Haven 1988; Kennedy 1996; Lenihan et al. 1999). Disproportionate infection of larger, more fecund (egg producing) oysters (Mackin 1951; Ray 1954; Andrews and Hewatt 1957) may at least partially explain the decline in reproduction and subsequent spatfall that has occurred since 1988 (Marshall et al. 1999), prompting major concerns for oysters as a natural and economic resource.

Dermo has been responsible for the majority of adult oyster mortalities in North Carolina in recent years. Although reported to occur in this state in the 1950s (Chestnut 1955), disease assessments were not attempted until large-scale oyster mortalities occurred during late 1988. Dermo was found at nine of 11 sampling sites, while MSX was found at the other two. While both MSX and Dermo have been documented, Dermo was the major cause of adult mortalities (DMF 2001a). Oysters typically begin suffering Dermo-related mortality at the age of two years or approximately 2.5 inches in shell height (DMF 2001a). Rates of Dermo infection in oysters generally increase with water temperature and salinity (Paynter and Burreson 1991). The highest rates of infection occur where salinity ranges from 16 – 20 ppt (Lenihan et al. 1999). The MSX dies when salinities are below 10 ppt for at least two weeks. Heavy rainfall from the several hurricanes in North Carolina during 1996-1999 reduced Pamlico Sound salinities, and consequently, the occurrence of MSX in that area (DMF 2001a).

Location and severity of Dermo infection have varied over the years, but were as high as 98 – 100% through much of the 1990s. It became evident that oysters in the smaller, saltier southern estuaries had higher survival rates and infection rates similar to those occurring in Pamlico Sound oysters. Conditions in these small, high salinity areas with high tidal flow may inhibit mortality by flushing out parasites at a high rate and/or having salinities too high for the Dermo parasite (DMF 2001a). A possible link among low DO, increased availability of iron, and increased parasite activity supports this concept, because these estuaries rarely experience low DO events (DMF 2001a).

Research on experimental oyster reefs in the Neuse River and Pamlico Sound (Lenihan et al. 1999) found that oysters at the base of the reefs, where currents were slowest, food quality lowest, and sedimentation

[40] A more in-depth discussion of fecal coliform is provided in the Water Column chapter.

rates highest, had the highest prevalence and intensity of infection with Dermo. In the areas studied, adequate height of the shell bottom structures was necessary for the oysters to grow well and survive disease and pollution. The upper portions of taller structures also allowed a safe refuge for mobile invertebrates and fish when low oxygen events occurred. *Maintenance of high-profile oyster rocks is critical for subtidal oysters to perform their ecological functions, as well as provide resources for harvest.*

Human activities that artificially increase salinity can also indirectly cause additional mortality of oysters from Dermo. Such activities include inlet deepening for navigational channels (SAFMC 1998a) and extensive withdrawal of groundwater and surface water during drought conditions. Cape Fear and Beaufort inlets have been extensively deepened for access to the state ports. Shellfish waters in these areas are the most vulnerable to increases in salinity. *The relative contribution of channel deepening to saltwater intrusion and subsequent oyster mortality must be evaluated in order to determine appropriate management action.*

To protect and restore the oyster resource of the Chesapeake Bay by minimizing the spread of Dermo, a group of scientists from North Carolina, Virginia, and Maryland recommended that a policy be established whereby infected oysters would not be moved into salinities lower than where they set or into areas where disease levels were low, and optimally, infected oysters would not be moved at all (Chesapeake Research Consortium 1999). However, other scientists feel that Dermo is now so widespread that relocation of oysters is not a problem.

Some oysters, although exposed to disease, are able to survive. These "disease resistant" individuals are important to the survival and recovery of oyster populations in North Carolina (Breitburg et al. 2000). Harvesting of large oysters or relaying of large oysters from closed to open harvest areas selectively eliminates this disease-resistant genetic pool from the populations. *Establishment of oyster sanctuaries seeded with disease-resistant brood stock or allowed to naturally develop disease-resistant oysters would enhance the oyster's ability to survive and provide disease-resistant broodstock for repopulating highly impacted areas.*

Introduced and nuisance species

Nuisance and non-native aquatic species are becoming more of a problem throughout the United States. North Carolina shell bottom is at risk from the accidental or intentional introduction of these species. Non-native species enter North Carolina waters through river systems, created waterways such as the ICW, ships discharging ballast water of foreign origin, boats entering North Carolina waters from other areas, and the sale of live fish and shellfish for bait or aquaculture (North Carolina Sea Grant 2000). Oysters have already been impacted by the introduction of the parasites Dermo and MSX. It is suspected that the MSX parasite was introduced with Pacific oysters (*Crassostrea gigas*) (DMF 2001a). Intentional introductions of non-native species are covered under state laws and rules of several commissions. Proposals to introduce organisms not native to North Carolina into the coastal waters of North Carolina, or organisms native to North Carolina when the individuals in question originate outside North Carolina, are subject to MFC rule 15A NCAC 3I .0104. An applicant must submit a written application to the Fisheries Director with sufficient information for the Director to "determine that the action will not pose a significant danger to any native marine resource or the environment." The Director can require an applicant to conduct analyses to aid in evaluation of the application, and hold public meetings concerning the proposal. The Fisheries Director determines whether or not to issue the requested permit.

Zebra mussels (*Dreissena polymorpha*) have not been reported in North Carolina, but have been found in northern Virginia and 20 other states (<http://nas.er.usgs.gov/zebra.mussel/>, 2004). Due the rapid rate that this non-native has spread in the United States since first found in 1986, researchers feel that zebra mussels are likely to infest all southeastern states eventually, with negative impacts to the native freshwater and low salinity mollusks (Neves et al. 1997). Zebra mussels frequently clog intake pipes and

smother native mussels and large crustaceans (i.e., crayfish). Most estuarine shell bottom (oyster beds) would not be affected, however, since the upper salinity tolerance limit of zebra mussels is <10 ppt (North Carolina Sea Grant 2000). Although the spread of zebra mussels in Lake Erie has improved water clarity, the effect on most fish populations is still largely unknown (<http://nas.er.usgs.gov/zebra.mussel/docs/sp_account.html>, January 2004). Planktivorous species and life stages would most likely be affected due to competition with the mussel. North Carolina Sea Grant has pursued multi-state and regional efforts to address the issue of aquatic nuisance species introduction and dispersal, primarily through education on the ecological impacts and methods to prevent or control dispersion (North Carolina Sea Grant 2000). It is estimated that 13 species of freshwater mussel could be extirpated from North Carolina streams and rivers if zebra mussels were to invade (North Carolina Sea Grant 2000). Among those native mussel species, four species could become extinct.

As North Carolina's oyster populations have declined, interest in establishing a non-native oyster population has grown. While some oyster introductions have revived or expanded oyster fisheries in some parts of the world (especially in Europe), others have failed or caused problems, such as the destruction of native species by exotic diseases (Andrews 1980; DMF 2001a). If the native oyster stocks cannot recover naturally, establishment of non-native oyster populations could provide complex structure for fish habitat (if the introduced species were reef-builders - some oysters are not), water filtration functions, and preserve a traditional North Carolina fishery.

The Pacific oyster (*Crassostrea gigas*) and Suminoe oyster (*Crassostrea ariakensis*) have been the leading candidates for non-native introductions. Researchers have conducted overboard tests in North Carolina with Pacific oysters and work is underway with the Suminoe oyster (C. Peterson, UNC-CH, pers. com., 2002). The shells of Pacific oyster were found to be too thin to resist predation by native oyster drills (DeBrosse and Allen 1996). The Suminoe oyster has proven more promising. Laboratory and field studies conducted on *C. ariakensis* in Chesapeake Bay indicate rapid growth and survival under a wide range of coastal and estuarine conditions (Richards and Ticco 2002). *C. ariakensis* also shows greater disease resistance than native oysters.

There is currently much debate and uncertainty regarding the introduction of non-native oysters (Richards and Ticco 2002). Concerns include long-term survival of introduced species, competition with native oysters, unknown reef-building attributes, cross-fertilization with native species (reducing viability of spat and decreasing reproductive success), and introduction of non-native pests with the introduced oysters (DMF 2001a). Policy makers are being faced with a dilemma of incomplete knowledge of the species' life history, lack of consensus among scientists regarding the impact of non-native oysters on Atlantic coastal ecosystems, and pressure from commercial and economic interests to revive a once prosperous oyster industry (Richards and Ticco 2002). *The DMF Fishery Management Plan for Oysters (DMF 2001a) recommended that testing continue on aquaculture use of non-spawning, non-native oysters before decisions are made opposing or supporting introduction.*

A comprehensive study of non-native oyster introductions was completed by the National Research Council of the National Academy of Science in 2003 (NRC 2003). The study identified concerns that should be addressed by decision-makers when the introduction of a non-native oyster is under consideration. The concerns included:

- Viability of introduced stocks in Atlantic coast waters
- Co-introduction of new pathogens and parasites
- Economic and social impacts of a non-native oyster introduction
- Adequacy of regulatory and institutional structure for monitoring and overseeing the interjurisdictional aspects of open water aquaculture

The study concluded that *C. ariakensis* is probably well suited for growth and reproduction in the Chesapeake Bay and similar estuarine habitats on the Atlantic coast. The risk of introducing non-native

pathogens and parasites could be reduced by following International Council for Exploration of the Seas protocols. However, it will not be easy for the oyster industry to adapt to dependence on hatchery production of Asian oysters. Furthermore, the existing regulatory and institutional framework was found inadequate for handling interjurisdictional issues. Based on this evaluation, limited aquaculture of triploid oysters was considered the most defensible management option. Other options included prohibition of non-native oyster introduction and introduction of reproductive diploid oysters. The principal recommendation from NRC (2003) was to establish standards and protocols for non-native oyster aquaculture that minimize and monitor the unintentional release of reproductive *C. ariakensis*. *The recommendations provided in NRC (2003) should be considered in developing a comprehensive oyster restoration plan.*

Existing management measures

No amount of oyster restoration will erase the effect of continuing pollution of aquatic systems (Boesch et al. 2001). *Therefore, both restoration efforts and water quality management actions reducing direct and indirect shell bottom loss and degradation are necessary to enhance coastal fish habitat.* Several existing management actions provide some protection or enhancement of shell bottom habitat, including shellfish size and harvest limits, habitat restoration, and closure of areas to harvest or use of certain fishing gears. By EMC rules, all shellfish waters with significant resources are classified as SA waters and are, by definition, High Quality Waters (HQW). In addition, some waters that are classified SA also carry the Outstanding Resource Waters (ORW) classification based on recreational or environmental special uses. These waters are afforded additional protection from construction and runoff under EMC, CRC and Sedimentation Control Commission rules. Maps 2.3a-b show HQW and ORW areas for the CHPP area. The HQW and ORW areas cover 8% and 24% of the shellfish mapping study area, respectively. A total of 142,017 acres out of 362,450 acres of ORW in the CHPP MUs are within the DMF shellfish mapping study area. Of the total bottom area mapped by DMF to date (January 2003), 55% (126,583 acres) is classified ORW.

Under MFC rules, oyster reefs are protected from early harvest by size limit and culling tolerance rules [MFC rule 15A NCAC 03K .0202]. By rule, the minimum size at which oysters can be harvested is based on shell lengths not less than 2.5 in. The Fisheries Director has, by proclamation (an administrative order authorized by the MFC), further restricted harvest to oysters of at least 3 inches in length. The intent of the size limit is to allow oysters to spawn before they are removed from the population, as well as to protect sublegals as fecundity increases (C. Hardy, DMF, pers. com., 2002). Oysters reach sexual maturity in their first year and harvestable size in about 3-4 years in Pamlico Sound (Ortega et al. 1990). This size limit provides some protection for young oysters throughout their range in North Carolina and for beds of stunted oysters along the boundary of their range. Stunted oyster beds occur where the salinity range is only marginally suitable for larval survival and growth.

Some planted areas can be designated by proclamation of the Fisheries Director as “Shellfish/Seed Management Areas” (SSMAs) [MFC rule 15A NCAC 03K .0103]. These areas include shellfish populations or shellfish enhancement projects that may produce commercial quantities of shellfish or shellfish suitable for transplanting as seed [MFC rule 15A NCAC 03K .0103a]. Use of trawl nets, long haul seines, and swipe nets is prohibited in SSMAs and, unless open to oyster harvest by proclamation, they are closed to all oyster harvest. There are currently 628 acres of SSMA in the Southern Estuaries and New/White Oak MUs that are part of the DMF shellfish mapping study area (Table 3.4). Cultch planting sites in the Pamlico Sound have not been designated as SSMAs because of the difficulties in enforcing the prohibition of shellfish harvesting on these areas (i.e., small numbers of Marine Patrol Officers patrolling large water bodies (M. Marshall, DMF, pers. com., 2002)).

In addition to protection from certain fishing gears in Shellfish/Seed Management Areas, shell bottom is also protected from shellfish harvest in military restricted areas. These areas have served as target and bombing ranges since the World War II period. Military restricted areas cover 24,051 acres of the

shellfish mapping study area, and all of these areas have been mapped (Table 3.4). Other area designations protecting shell bottom from specific fishing gear impacts include nursery areas, mechanical oyster harvest prohibited areas, trawl net-prohibited areas, and crab spawning sanctuaries. These areas cover more than half of the shellfish bottom mapping area, leaving the largest unrestricted areas in west and northwest Pamlico Sound, the lower Pamlico and Neuse rivers, and around Roanoke Island (Maps 3.5a-c). A number of cultch planting sites in the Pamlico Sound area are also closed to mechanical harvest by proclamation annually (Map 3.4a), although none have been designated shellfish management areas (DMF 2001a). *Given adequate enforcement capabilities, additional cultch enhanced and naturally occurring shell bottom (intertidal and subtidal) should be designated as DMF Shellfish Management Areas to protect them from fishing gear impacts.*

Table 3.4. Amount of bottom habitat mapped (acres) by the North Carolina Division of Marine Fisheries Shellfish Habitat and Mapping Program within areas receiving specific North Carolina Marine Fisheries Commission designations that restrict fishing activities (as of January 2003).

Marine Fisheries Commission restricted fishing area designation	Amount within the shellfish bottom mapping area	Currently mapped area	% complete
Crab spawning sanctuaries	17,673	12,831	73%
Mechanical clam harvest areas	39,446	29,878	76%
Mechanical oyster harvest prohibited	289,617	169,925	59%
Military restricted areas	24,051	24,051	100%
Permanent Secondary nursery areas	34,825	243	1%
Primary nursery areas	46,941	31,045	66%
Shellfish/seed management areas (SSMA)	628	489	78%
Special secondary nursery areas	30,686	21,889	71%
Taking crabs with dredges	43,318	2,044	1%
Trawl nets prohibited	138,812	37,959	27%

Another designation that indirectly provides protection from harvesting in North Carolina is the Division of Environmental Health's (DEH) shellfish harvest closure areas. Based on surveys and bacterial sampling, the DEH may designate waters as closed to shellfish harvesting, on either a full-time basis (permanent closure) or rainfall-dependent basis (conditionally approved). Maps 2.19a-c show the extent of shell bottom within the various DEH shellfish area designations. It should be noted that significant portions of closed shellfish waters are located in areas not suitable for shellfish propagation and maintenance due to low salinity levels or other conditions. There are also some closed areas that have robust oyster populations (C. Peterson, UNC-CH, pers. com., 2003). *The value of closed shellfishing waters as oyster sanctuaries should be evaluated*.[41]

3.5. SUMMARY OF SHELL BOTTOM CHAPTER

Shell bottom habitat is unique because it is the only coastal fish habitat that is also a fishery species (oysters). The ecological value of shell bottom has only recently been recognized to be as or more significant than the fishery itself, since it provides numerous habitat and water quality functions that are vital for fishery and non-fishery species. The ability of shell bottom to withstand moderate turbidity levels allows oysters to clear the water column, encouraging growth of SAV and benthic microalgae. Oysters, SAV, and benthic microalgae quickly process dissolved and suspended material from the water column, thus facilitating the estuaries' role in storage and cycling of nutrients. This process reduces the

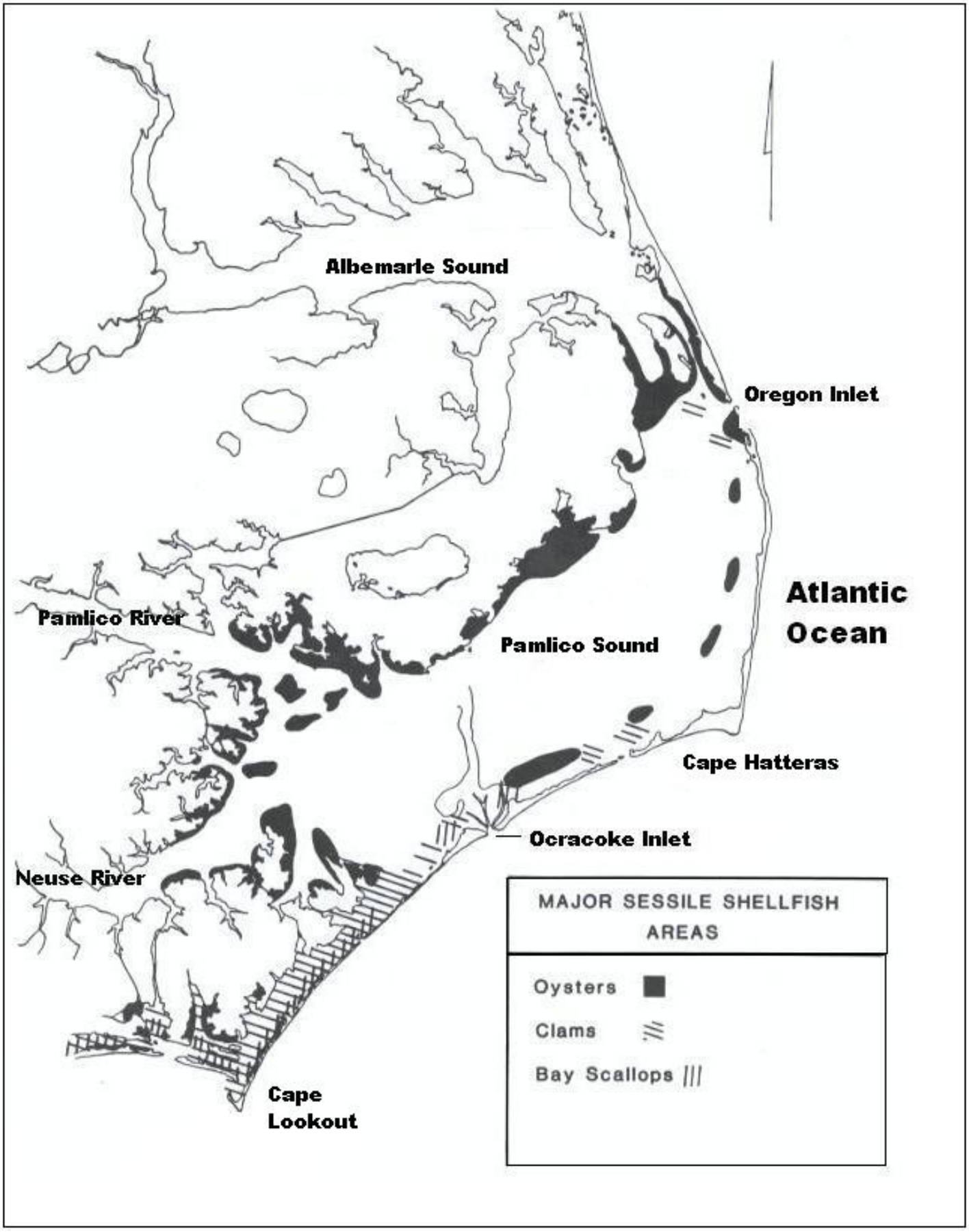
[41] More discussion of trends related to the DEH areas is provided in the Water Column chapter.

likelihood of coastal eutrophication and its detrimental effects on fish and fisheries. Oyster beds also increase shoreline complexity, can alter circulation patterns, and enhance fish use of marsh edge habitat. Shell bottom also provides hard structure for attachment of diverse invertebrate species and protective cover for small mobile finfish and invertebrates. Gobies, blennies, hard clams, mud crabs, blue crabs, anchovies, oyster toadfish, and sheepshead are a few of the typical residents of oyster reefs. Research has shown that abundance and production of numerous fishery and prey species are enhanced more by shell bottom than by the surrounding soft bottom. Some of the important fishery species whose production is enhanced by shell bottom include hard clam, black sea bass, gag, tautog, and southern flounder. Shell bottom is federally designated as a Habitat Area of Particular Concern for estuarine dependent snapper-grouper species. The restoration of living oyster beds is therefore critical to the proper functioning and protection of surrounding coastal fish habitats and numerous fishery species.

Shell bottom habitat declined for most of the 20th century. The current distribution of shell bottom has shrunk to a mere fraction of its historical range, when oyster rocks were so abundant that they were considered a hazard to navigation. Anecdotal information suggests that oyster beds have been displaced roughly 10-15 miles (16-24 kilometers) downstream in the Pamlico and Neuse estuaries and completely covered by sediment in other areas. Furthermore, North Carolina's commercial oyster landings have declined about 90% from 1889 to today's low harvest. Most shell bottom losses have been subtidal beds in Pamlico Sound, where DMF has also found declines in spatfall. Although mechanical harvesting of oysters has been greatly restricted, reefs have not recovered, possibly due to stress from water quality degradation and increased occurrence of disease (Dermo, MSX). The loss of habitat could be particularly damaging to fishery stocks associated with shell bottom that are classified as Overfished by DMF, such as southern flounder, black sea bass south of Cape Hatteras, or the central/southern stock of striped bass.

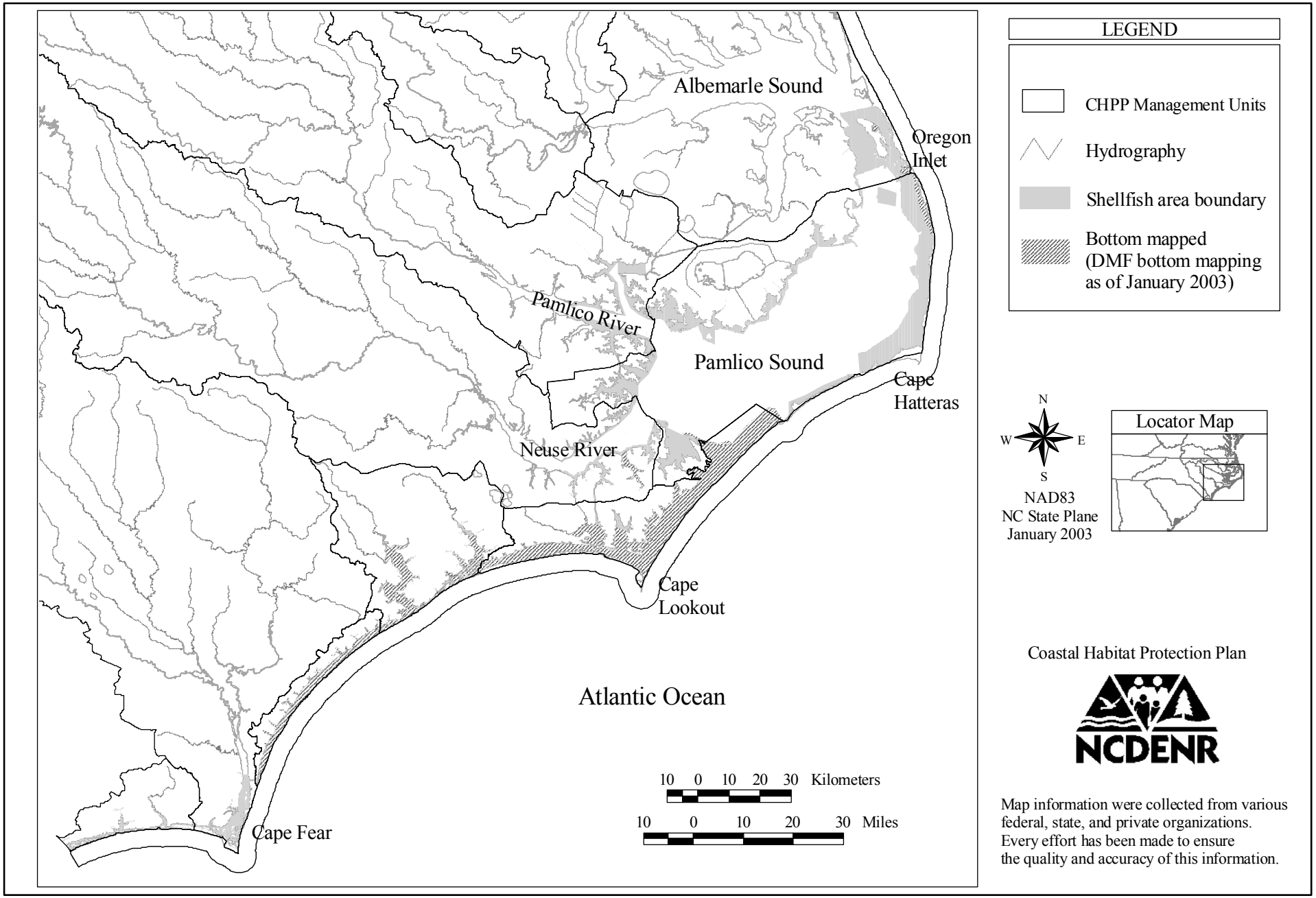
Oyster dredging, beginning in 1889, is believed to be the major cause of the initial decline in shell bottom. Today the dredge harvest has greatly diminished in North Carolina, although about 42% of shallow estuarine bottom (where oysters could live) is still open to mechanical harvest methods, all in Pamlico Sound. Dredging removes oysters and reduces the vertical profile of oyster rocks, increasing the susceptibility of remaining shell bottom at that location to low dissolved oxygen and possible mortality. Hand harvest methods for oysters and clams can also be destructive, but on a much smaller scale. Other bottom disturbing fishing gears, such as trawls, prevent the establishment of oyster reefs in areas within their historic range. Dredging for navigation channels or marina basins also impacts shell bottom. The downstream displacement of oysters in the Neuse and Pamlico rivers is probably the result of extensive drainage networks designed to increase the flow of stormwater (fresh water) into coastal waterways, decreasing salinity in the downstream portions of those rivers. While drainage for agriculture has changed little, drainage for urban/suburban development is increasing steadily. Runoff from agriculture, urban/suburban development, and transportation infrastructure carries sediment, nutrient, and toxic chemical pollutants. Sediment, the number one pollutant of waterways in the United States, clogs oyster gills and buries shells. Excess nutrients can fuel algal blooms and low dissolved oxygen events, and in turn, cause mortality of benthic organisms on deep, subtidal shell bottom. Heavy metals, petroleum products, pesticides, and other toxic chemicals in the runoff can kill sensitive oyster larvae.

To offset the decline in oyster habitat, restoration efforts were begun in 1958, and some protected areas have been established. While almost all work in the past has focused on restoring oysters for harvest, some recent efforts have been designed to restore or enhance shell bottom for habitat purposes. However, the magnitude of losses still greatly exceeds gains from restoration. Large areas of shell bottom habitat are still unprotected from direct physical removal or damage via human-related activities, as well as from indirect damage from water quality degradation. In order to restore shell bottom habitat, the destruction of oyster beds from fishing practices, channel or marina dredging, and pollutant loading must be reduced and oyster habitat restoration must increase significantly.



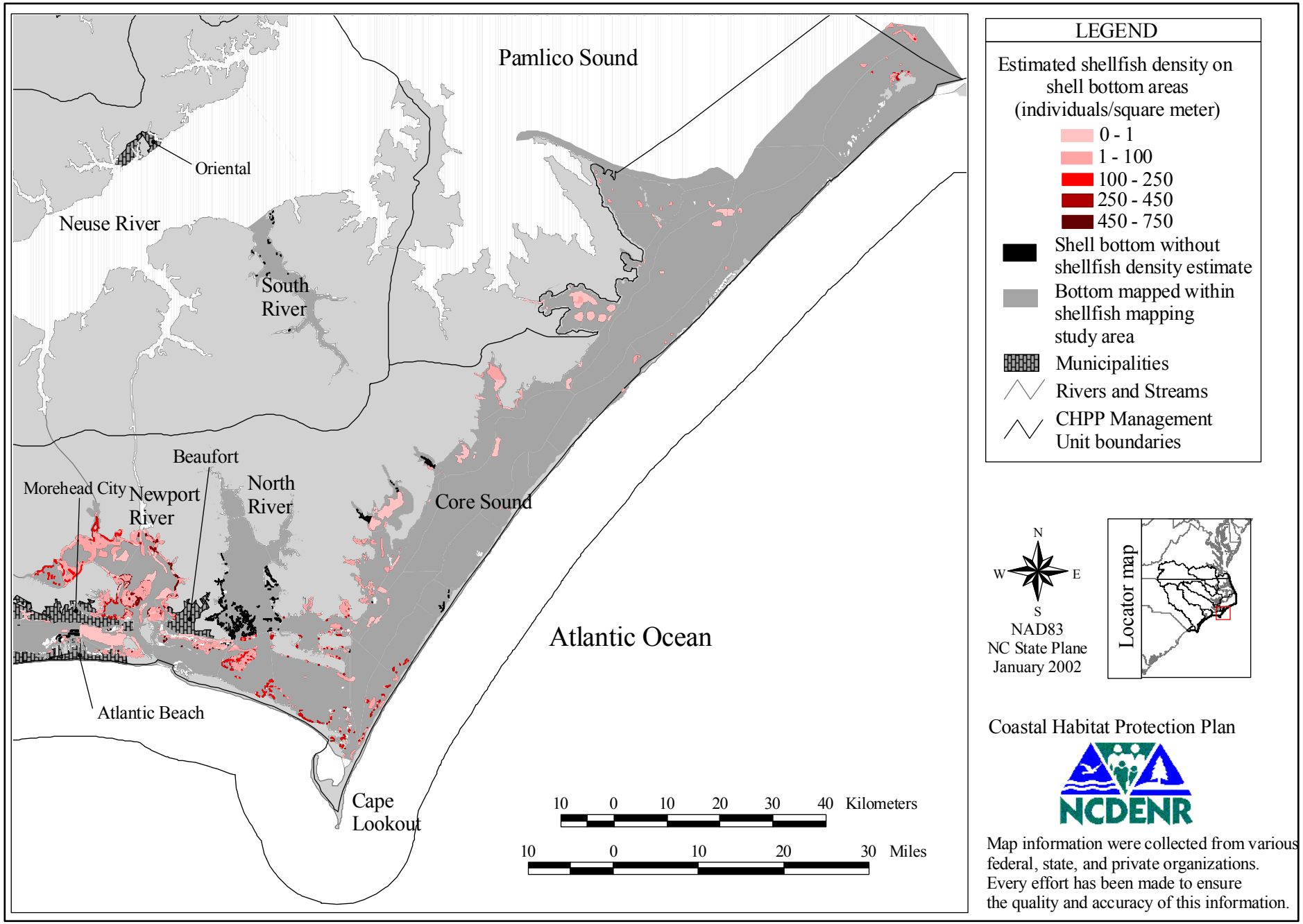
Map 3.1—Distribution of eastern oysters, hard clams, and bay scallops in the Albemarle-Pamlico estuarine system (from Ross and Epperly 1986)

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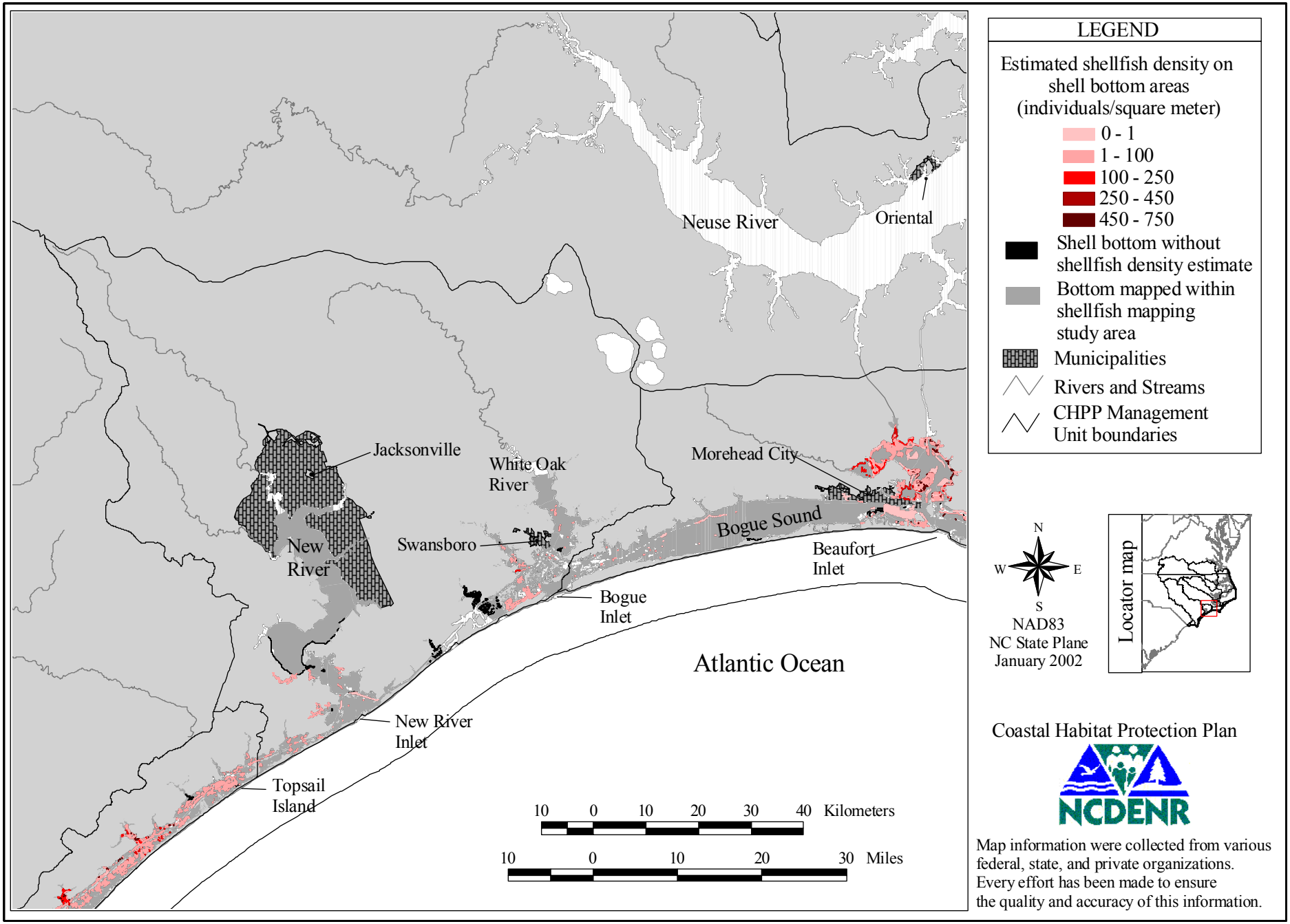
Map 3.2-Areas for which the bottom type has been mapped or will be mapped by the North Carolina Division of Marine Fisheries' Shellfish Habitat and Abundance Mapping Program.

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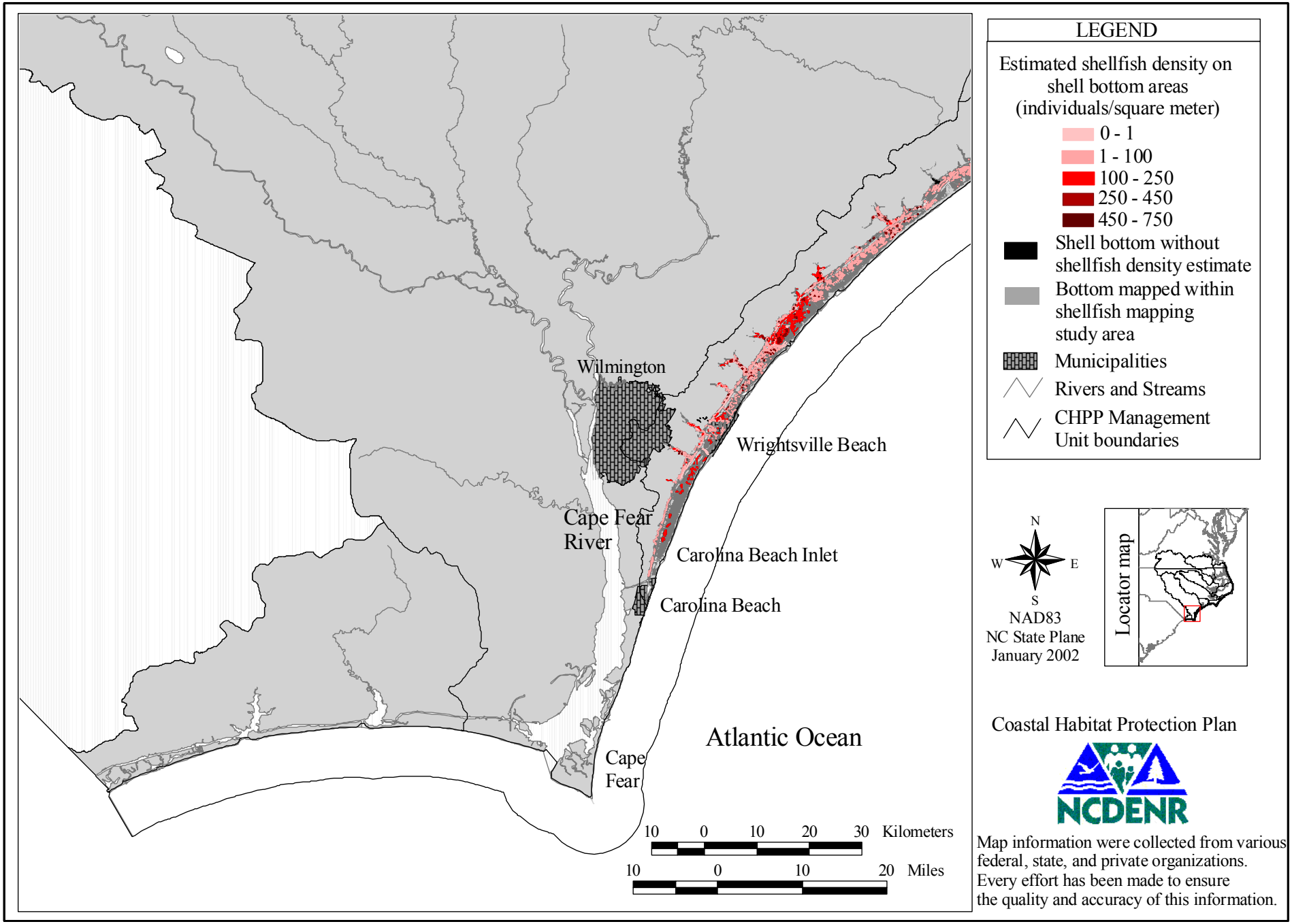
Map 3.3a. Estimated density of shellfish in estuarine waters from Ocracoke Inlet to Atlantic Beach, North Carolina

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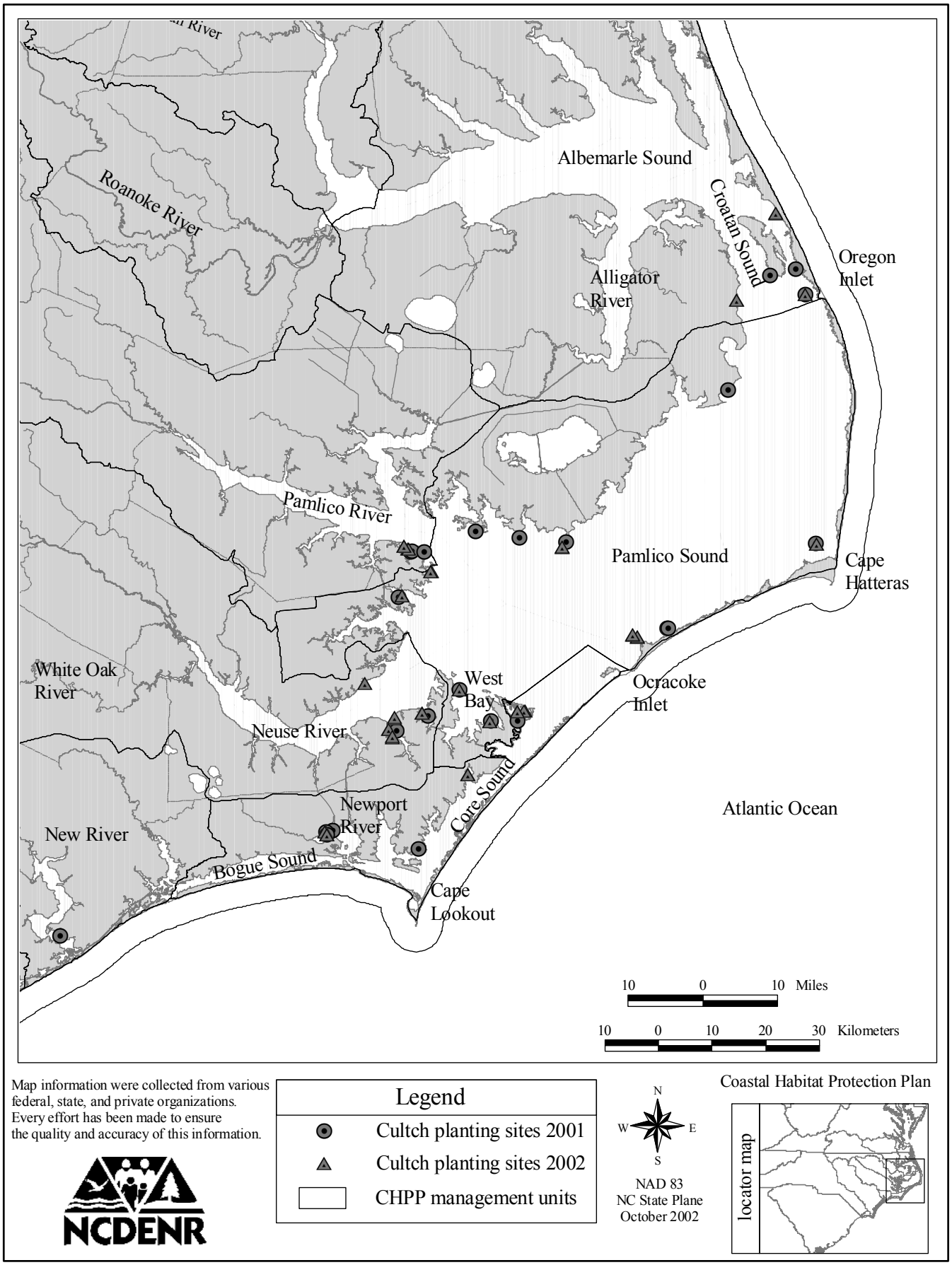
Map 3.3b. Estimated density of shellfish in estuarine waters from Beaufort Inlet to Topsail Island, North Carolina

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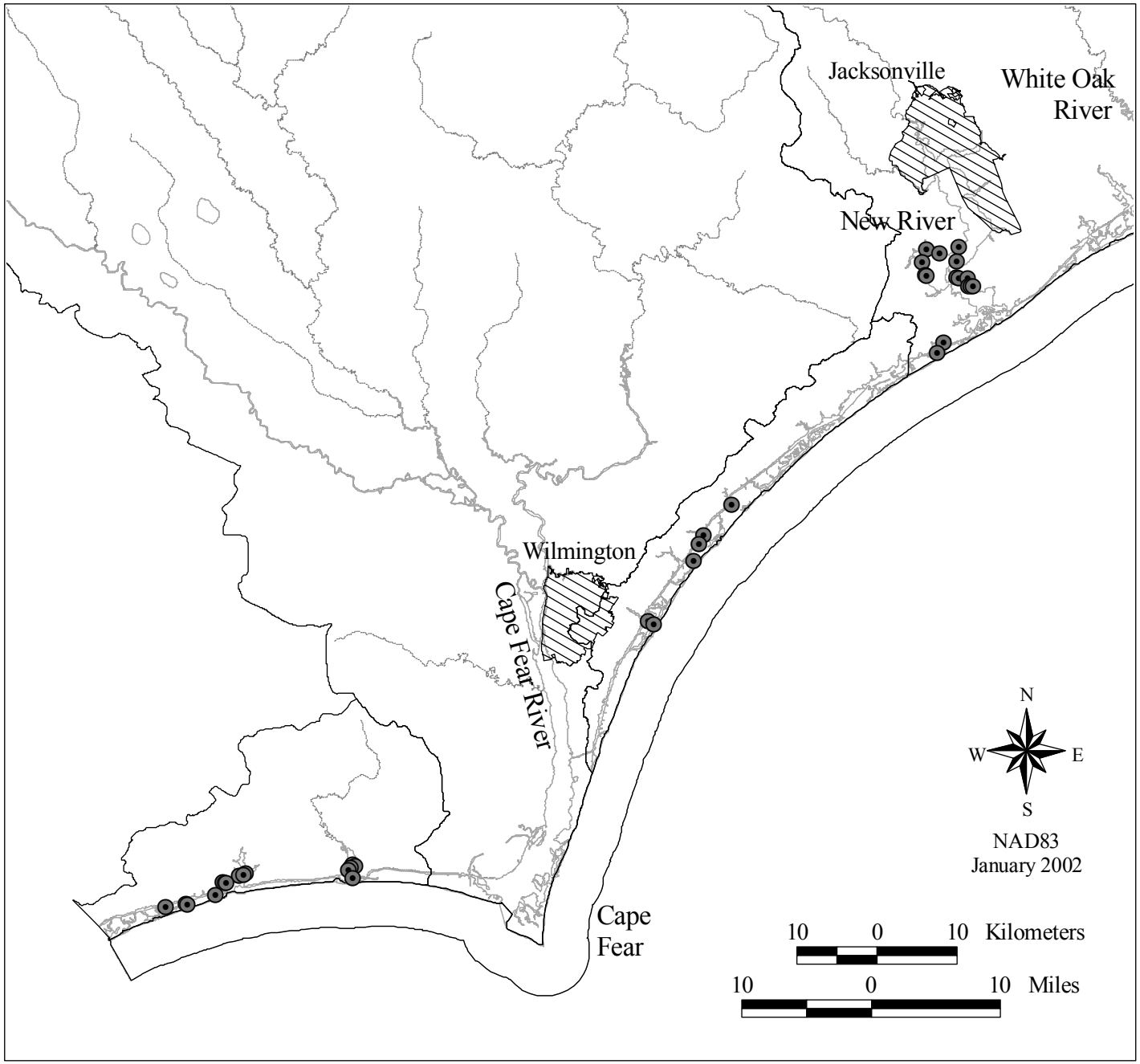
Map 3.3c. Estimated density of shellfish in estuarine waters from Topsail Island, North Carolina to the South Carolina border

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Map 3.4a---Locations where the North Carolina Division of Marine Fisheries planted oyster cultch during 2001 and 2002 in estuarine waters from New River northward

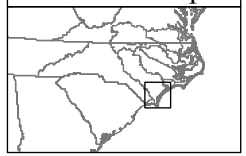
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LEGEND

- CHPP Management Units
- Shell Seed Managment Locations
- Hydrography
- Municipalities

Locator Map



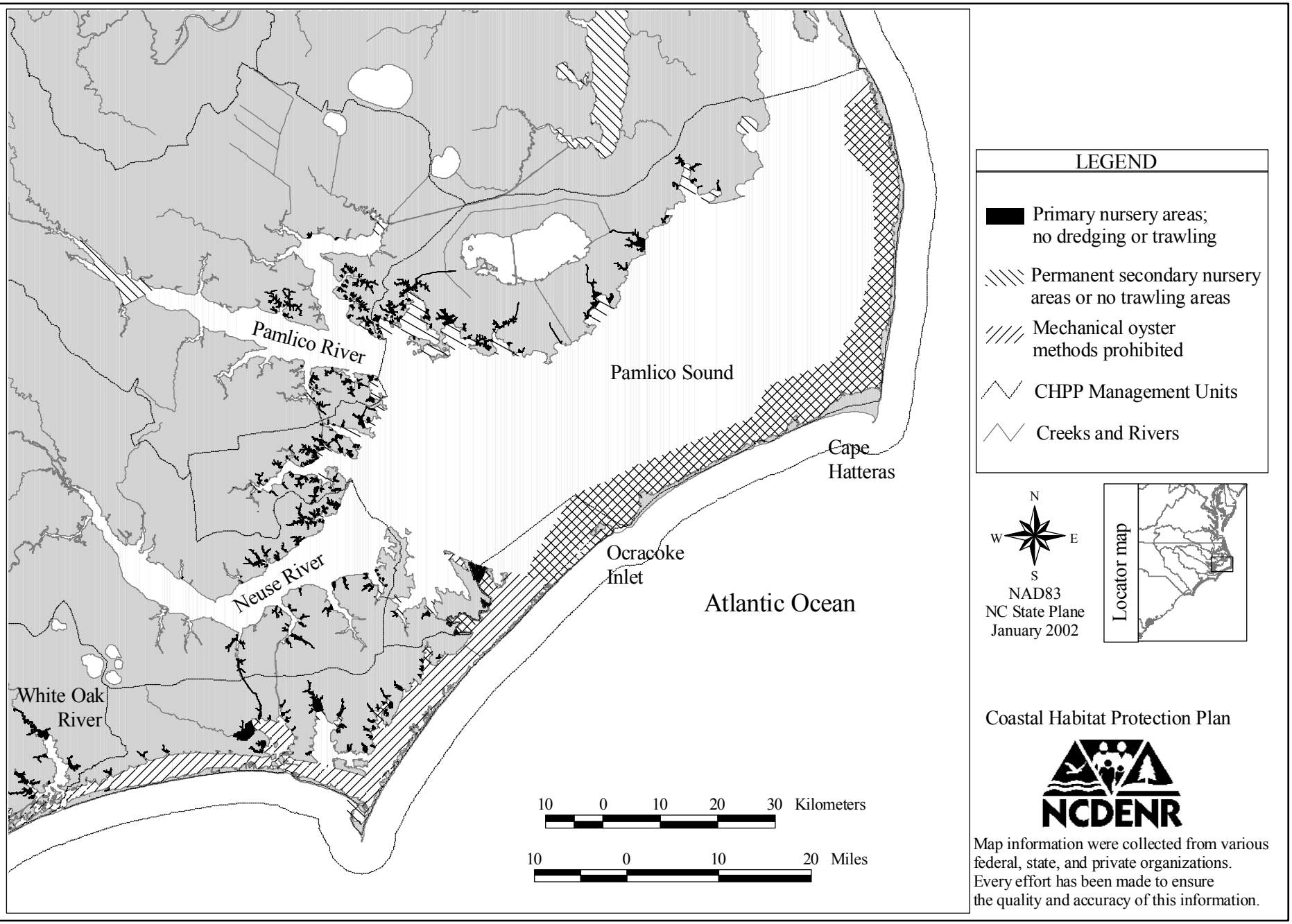
Coastal Habitat Protection Plan

NCDENR

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

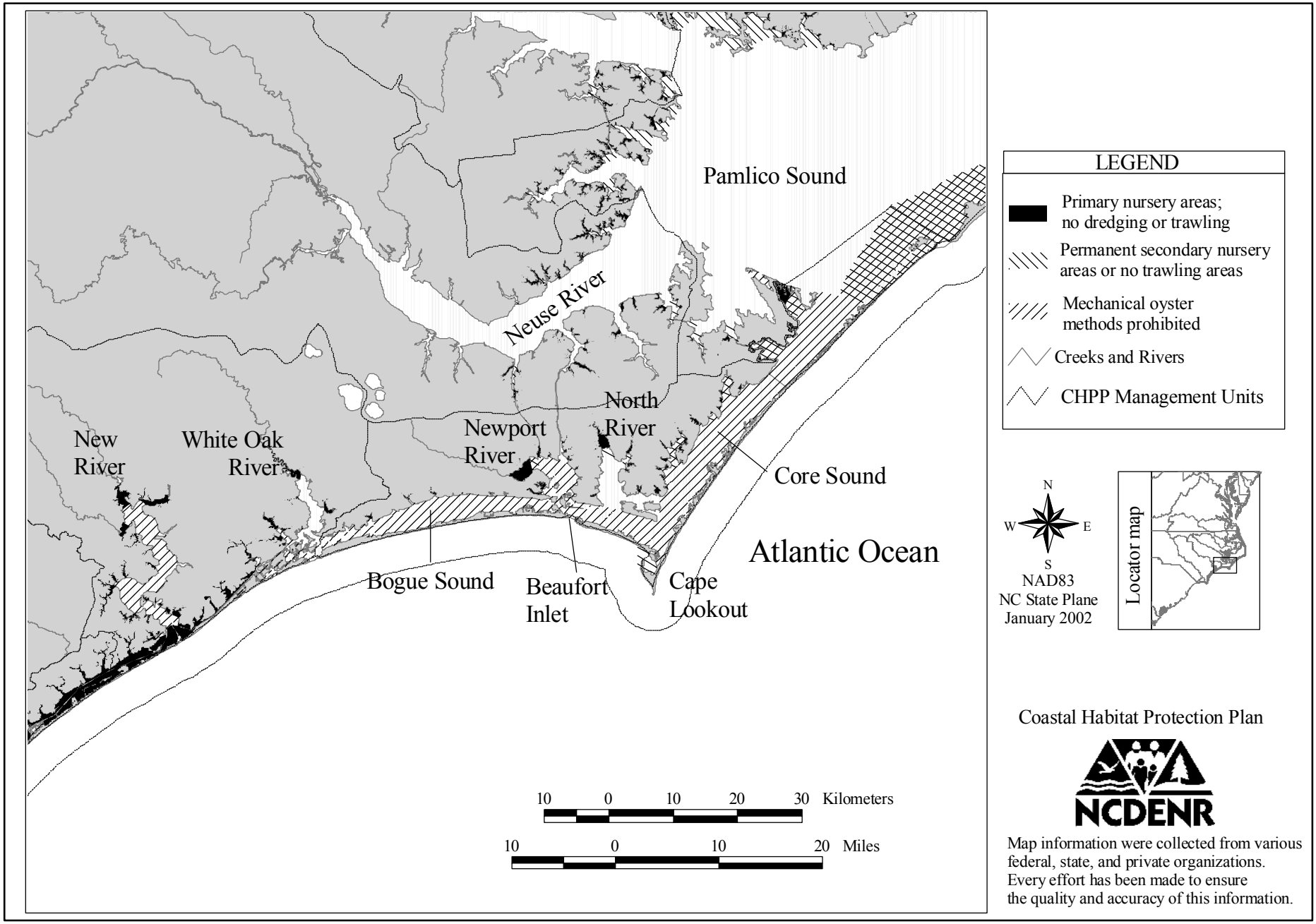
Map 3.4b---Existing North Carolina Division of Marine Fisheries Shell Seed Management areas (also cultch planting sites)

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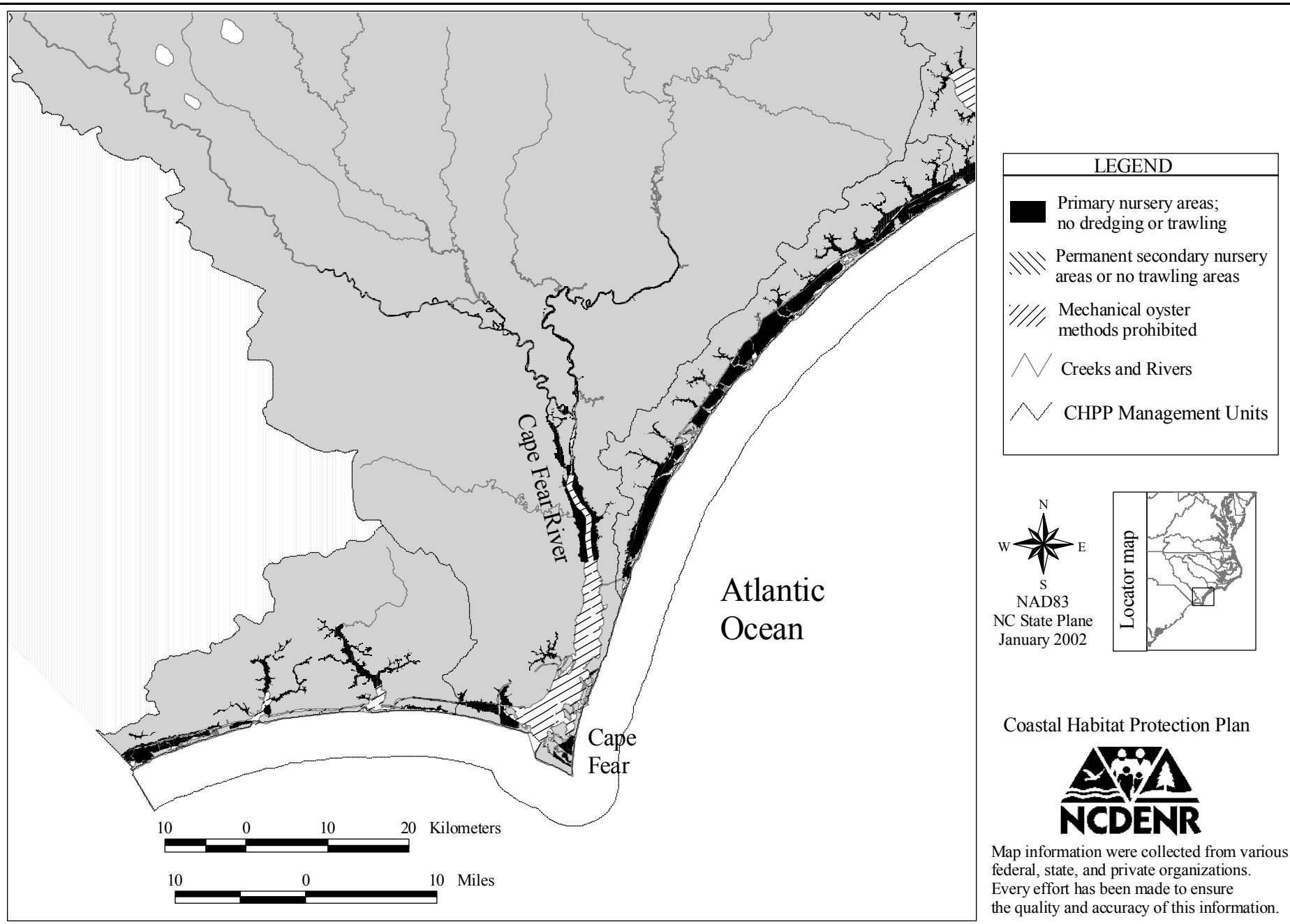
Map 3.5a---Areas where mechanical oyster harvesting and bottom trawling are prohibited in the Pamlico Sound system, North Carolina

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Map 3.5b---Areas where mechanical oyster harvesting and bottom trawling are prohibited in the central coastal area of North Carolina

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Map 3.5c---Areas where mechanical oyster harvesting and bottom trawling are prohibited in the southern coastal area of North Carolina

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CHAPTER 4. SUBMERGED AQUATIC VEGETATION

4.1. DESCRIPTION AND DISTRIBUTION

Definition

Submerged aquatic vegetation (SAV) is a fish habitat dominated by one or more species of underwater vascular plants. The North Carolina Marine Fisheries Commission (MFC) and Coastal Resources Commission (CRC) define SAV as:

"…those habitats in public trust and estuarine waters vegetated with one or more species of submerged vegetation such as eelgrass (*Zostera marina*), shoalgrass (*Halodule wrightii*), and widgeon grass (*Ruppia maritima*). These vegetation beds occur in both subtidal and intertidal zones and may occur in isolated patches or cover extensive areas. In either case, the bed is defined by the presence of above-ground leaves or the below-ground rhizomes and propagules together with the sediment on which the plants grow. In defining beds of submerged aquatic vegetation, the Marine Fisheries Commission recognizes the Aquatic Weed Control Act of 1991 (G.S. 113A-220 et. seq.) and does not intend the submerged aquatic vegetation definition and its implementing rules to apply to or conflict with the non-development control activities authorized by that Act" [MFC rule 15A NCAC 03I .0101 (20)(A) and CRC rule 15A NCAC 07H .0208 (6)].

Although not specifically listed in the definitions, SAV beds may also be vegetated with freshwater species such as native wild celery (*Vallisneria americana*) and sago pondweed (*Potamogeton pectinatus*). Submerged aquatic vegetation is included as a Critical Habitat Area under MFC rules [MFC rule 15A NCAC 03I .0100 (b)(20)]. The SAFMC classifies SAV as Essential Fish Habitat for peneaid shrimp, red drum, and snapper/grouper species. Although the MFC and CRC definitions may include areas with only SAV roots or propagules, SAV habitat could also occur on bottom temporarily lacking any SAV structures between patchy SAV beds or where conditions are currently unfavorable for growth, but have historically supported SAV. Therefore, for purposes of this plan, SAV habitat is defined as "bottom recurrently vegetated by living structures of submerged, rooted vascular plants, (i.e., roots, rhizomes, leaves, stems, propagules), as well as temporarily unvegetated areas between vegetated patches."

SAV is an underwater forest for juvenile fish and small invertebrates and a barometer of water quality.



Description

Submerged aquatic vegetation habitat includes marine, estuarine and riverine vascular plants that are rooted in sediment. Although SAV sometimes occurs intertidally or extends to the water's surface, these plants are generally submerged and cannot survive if removed from the water for any length of time (Hurley 1990). Leaves and stems have specialized thin-walled cells (aerenchyma) with large intercellular air spaces to provide buoyancy and support in an aquatic environment. Leaves and stems are generally thin and lack the waxy cuticle found in terrestrial plants. The lack of a waxy cuticle increases the exchange of water, nutrients, and gases between the plant and the water (Hurley 1990). The extensive root and rhizome system anchors the plants, and also absorbs nutrients (Thayer et al. 1984). Reproduction occurs both sexually and asexually (i.e., vegetatively).

Habitat for SAV in North Carolina consists of two types of SAV communities, both of which are important to coastal fisheries – one in higher salinity estuarine waters and another in lower salinity to freshwater systems (Table 4.1). Estuarine species that occur in North Carolina include eelgrass (*Z. marina*), shoalgrass (*H. wrightii*), and widgeon grass (*R. maritima*). Eelgrass is a temperate species at the southern limit of its Atlantic coast range in North Carolina. In contrast, shoalgrass is a tropical species that reaches its northernmost extent in the state. Widgeon grass has a wide salinity range and grows in both fresh water and high salinity environments, although it occurs most commonly in moderate salinities (about 15 ppt). The co-occurrence of these three SAV species is unique to North Carolina, resulting in high coverage of shallow bottoms in North Carolina's estuaries (Ferguson and Wood 1994). These three species form biological and physical assemblages referred to as seagrass meadows (SAFMC 1998a). Seagrass meadows are often defined by a visible boundary marking unvegetated and vegetated bottom varying in size from small isolated patches of plants less than a meter (<3 ft) in diameter to continuous meadows covering many acres. Low salinity species that occur in North Carolina include native wild celery (*V. americana*), non-native Eurasian milfoil (*Myriophyllum spicatum*), bushy pondweed (*Najas guadalupensis*), redhead grass (*P. perfoliatus*), and sago pondweed (*P. pectinatus*) (Ferguson and Wood 1994). There is slightly greater SAV species diversity in coastal riverine systems than marine systems in North Carolina (Odum et al. 1984).

Seagrass habitat supports other types of aquatic plants in addition to submerged grasses. Macroalgae (benthic, drift, and floating forms) often co-occur with SAV and provide similar ecological services, but the plant taxa have distinctly different growth forms and contrasting life requirements (SAFMC 1998a). Macroalgae grow faster than SAV and do not require unconsolidated substrate for anchoring extensive root systems. Because of this growth pattern, macroalgae do not provide as much sediment stabilization as submerged rooted vascular plants. Their leaves are also less rigid than those of submerged rooted vascular plants, thus reducing their function as substrate for attachment and as a source of friction for sediment deposition. Macroalgal genera include salt/brackish (*Ulva, Codium, Gracilaria, Enteromorpha*) and freshwater (*Chara* and *Nitella*) species. Macroalgae common to the rivers of the Albemarle Sound system include the charophytes (*Chara* spp.). In addition, the macroalgae *Ectocarpus* and *Cladomorpha* grow on salt marsh flats (Mallin et al. 2000a) and in association with SAV beds (Thayer et al. 1984).

Epibiota are another important component of SAV habitat. Epibiota are organisms that attach or grow on the surface of a living plant and may or may not derive nutrition from the plant itself. Micro- and macroalgae (i.e., seaweed) can grow on the leaves of SAV. Invertebrates attached to the SAV leaves include protozoans, nematodes, polychaetes, hydroids, bryozoans, sponges, mollusks, barnacles, shrimps and crabs.

Table 4.1. Average environmental conditions at locations where submerged aquatic vegetation occurred in coastal North Carolina, 1988-1991. [Source: Ferguson and Wood 1994]

	Environmental parameter					
	Salinity (ppt)		Secchi depth m (ft)		Water depth m (ft)	
SAV species	Range	Average	Range	Average	Range	Average
HIGH SALINITY SEAGRASS						
Eel Grass	10 - >36	26	0.3 - 2.0 (1.0 - 6.6)	1.0 (3.3)	0.4 - 1.7 (1.3 - 5.6)	1.2 (3.9)
Shoal Grass	8 - >36	25	0.4 - 2.0 (1.3 - 6.6)	1.0 (3.3)	0.1 - 2.1 (0.3 - 6.9)	0.8 (2.6)
Widgeon Grass	0-36	15	0.2 - 1.8 (0.7 - 5.9)	0.7 (2.3)	0.1 - 2.5 (0.3 - 8.2)	0.8 (2.6)
LOW SALINITY SEAGRASS						
Redhead Grass	0-20	1	0.4 - 1.4 (1.3 - 4.6)	0.9 (3.0)	0.4 - 2.4 (1.3 - 7.9)	0.9 (3.0)
Wild Celery	0-10	2	0.2 - 2.0 (0.7 - 6.6)	0.6 (2.0)	0.2 - 2.3 (0.7 - 7.6)	1.0 (3.3)
Eurasian Watermilfoil	0-10	2	0.2 - 1.4 (0.7 - 4.6)	0.6 (2.0)	0.5 - 2.4 (1.6 - 7.9)	1.1 (3.6)
Bushy Pondweed	0-10	1	0.2 - 2.0 (0.7 - 6.6)	0.7 (2.3)	0.5 - 1.7 (1.6 - 5.6)	1.0 (3.3)
Sago Pondweed	0-9	2	0.2 - 0.4 (0.7 - 1.3)	0.3 (1.0)	0.6 - 0.9 (2.0 - 3.0)	0.8 (2.6)

The three-dimensional shape of SAV habitat can be quite variable, ranging from highly mounded, patchy beds several yards wide, to more contiguous, low-relief beds (Fonseca et al. 1998). Leaf canopies formed by the seagrasses range in size from a few inches to more than three feet (0.91 m) tall. The structural complexity of an SAV bed also varies somewhat because of the growth form of the species present (SAFMC 1998a). While leaf density tends to be higher in contiguous beds than in patchy SAV habitat, below-ground root mass is often higher in patchy beds (Fonseca et al. 1998). Patchiness in seagrass bed distribution can result from new beds sprouting from seed or from existing beds that are fragmented by high wave energy or currents (Thayer et al. 1984). The rate that an area of unvegetated bottom can become vegetated may vary on the scale of days or decades, depending on the species and the physical conditions (Fonseca et al. 1998). Consequently, to maintain patchy seagrass beds, an area of shallow soft bottom must be maintained that is at least two times greater than the area of actual SAV coverage (Fonseca et al. 1998). Despite the difficulty of defining the boundaries of seagrass beds, unvegetated bottom between nearby adjacent patches is included as a component of patchy SAV habitat since rhizomes may be present and the beds "move" around with patterns of sediment erosion and deposition (Fonseca et al. 1998). Patchy habitats provide many ecological functions similar to continuous beds (Murphey and Fonseca 1995; Fonseca 1996b).

The dynamic nature of seagrass beds has important implications for fisheries habitat. Seagrass habitat can change at a scale of hours to decades (Fonseca et al. 1998; SAFMC 1998a). Therefore, one should

consider historical as well as current SAV occurrence to determine locations of viable seagrass habitat (SAFMC 1998a). Seagrass abundance and biomass fluctuate seasonally (Dawes et al. 1995). In North Carolina, annual meadows of eelgrass are common in shallow, protected estuarine waters in the winter and spring when water temperatures are cooler. However, in the summer when water temperatures are above 25 – 30°C (77 – 86°F), shoalgrass is more abundant, and eelgrass thrives only where water temperatures are lower (i.e., deeper areas and tidal flats with continuous water flow (SAFMC 1998a).

Habitat requirements

Beds of SAV occur in North Carolina in subtidal, and occasionally intertidal, areas of sheltered estuarine and riverine waters where there is unconsolidated substrate (loose sediment), adequate light exposure on the bottom, and moderate to negligible current velocities or turbulence (Thayer et al. 1984; Ferguson and Wood 1994). The factors generally considered to limit the success of SAV are light, salinity, wave energy, and nutrients. Specific habitat requirements for individual species are presented in Table 4.1.

The primary factor controlling distribution of SAV is the penetration of light through the water column (Goldsborough and Kemp 1988; Duarte 1991; Kenworthy and Haunert 1991; Dennison et al. 1993; Stevenson et al. 1993; Virnstein and Morris 1996). Availability of light to SAV is determined by water clarity, also known as "transparency." Water clarity can be quantified indirectly by measuring turbidity (nephelometric turbidity units or NTU) or secchi depth (maximum depth where a standard object can be seen by the human eye), or directly by measuring the amount of sunlight that penetrates through the water and reaches the leaves of underwater grasses. At a minimum, seagrasses require 15-25% of the light that is available on the water's surface to reach them (Dennison and Alberte 1986; Kenworthy and Haunert 1991; Bulthius 1994; Fonseca et al. 1998). If less light is available, photosynthesis is limited, reproduction may be inhibited, and growth and survival of the submerged vegetation can not be sustained.

Water clarity can be reduced by natural substances in the water column, such as dissolved organic matter (e.g., humics), suspended particulate matter (e.g., sediment and minerals), detritus, and algae. As the water column becomes more turbid and less transparent, light attenuation (absorption and scattering of light by particles in the water column) increases. Water color also affects light penetration. For example, dissolved organic matter such as tannic acid (produced naturally in swamp waters via breakdown of detritus) and lignins (produced naturally as well as artificially, such as through wood pulp mill processing) strongly absorbs blue light. Seagrasses generally cannot survive below a certain depth because of light limitations. Therefore, as water clarity declines, SAV beds in deeper waters are lost first. In coastal North Carolina, SAV can grow in water up to 2.5 m (8.20 ft) deep and secchi depths averaging approximately one meter (3.28 ft) (Ferguson and Wood 1994) (Map 4.1).

Light and water quality requirements for SAV in Chesapeake Bay were reevaluated and revised in 2000 by the Chesapeake Bay Program in a technical synthesis (EPA 2000). These requirements are listed in Table 4.2 by salinity regime. The primary limiting factor is light; sufficient light must reach the SAV so that photosynthesis can occur. The EPA partitions available light into two categories. The "water column light requirement" refers to the amount of light penetrating through the water column. The "light at leaf requirement" refers to the amount of light that can penetrate the leaf surface due to epibiotic coverage. Environmental conditions that allow adequate light penetration for SAV survival are total suspended solids (TSS) less than 15 mg/l and chlorophyll *a* less than 15*u*g/l. No secchi depth or turbidity values were recommended. In contrast, preliminary bio-optical modeling suggests that the water conditions required for seagrass survival may be less stringent in North Carolina's North River relative to conditions in the Chesapeake Bay (P. Biber, NMFS, pers. com., 2003). Specifically, the maximum values of TSS and chlorophyll *a* that can occur at any given depth and still allow SAV survival may be somewhat higher than that needed in Chesapeake Bay. Greater tidal current magnitude (causing the prolonged suspension of relatively larger particles) and decreased absorption/scattering capacity of phytoplankton species and sediment types specific to North Carolina may be responsible for the observed regional differences (P. Biber, NMFS, pers. com., 2003). Given certain combinations of turbidity and nutrients, North Carolina's

current standards may not be adequate to sustain SAV (P. Biber, NMFS, pers. com., 2003). *Additional estuaries should be modeled to determine environmental requirements for SAV over a broader scale and to determine if changes in EMC water quality standards are needed.*

Table 4.2. Recommended primary and secondary submerged aquatic vegetation habitat requirements for the Chesapeake Bay and its tidal tributaries classified by salinity regimes. [Source: Funderburk et al. 1991; EPA 2000]

Salinity regime (ppt)	SAV growing season	Primary Requirements		Secondary Requirements[2]			
		"Light at leaf" requirement[1]	Water column light requirement[1]	Total suspended solids (mg/l)	Chlorophyll *a* (ug/l)	Dissolved inorganic phosphorus (mg/l)	Dissolved inorganic nitrogen (mg/l)
Tidal fresh	April-October	>9%	>13%	<15	<15	<0.02	none
0.5 - 5.0	April-October	>9%	>13%	<15	<15	<0.02	none
5.0 - 18.0	April-October	>15%	>22%	<15	<15	<0.01	<0.15
18.0 - 30+	March-May, Sept.-Nov.	>15%	>22%	<15	<15	<0.02	<0.15

[1] Assessed with percent light at the leaf and percent light through the water parameters. All habitat requirements are independent of restoration depth.
[2] Secondary requirements are used to determine possible reason for non-attainment of primary requirement.

Field sampling of SAV beds in North Carolina between 1988 and 1991 found that occurrence of SAV in the study area was related to water depth, water clarity as measured by secchi depth, and salinity. This study did not measure light attenuation or percent light availability (Ferguson and Wood 1994). Environmental conditions where SAV species occurred are listed in Table 4.1. In the area sampled, average depth of SAV occurrence ranged from 2.63–3.94 ft (0.8–1.2 m), depending on the species. The maximum depth of observed presence, regardless of species, was 7.87 ft (2.4 m) (Ferguson and Wood 1994). Data indicated that freshwater SAV had a somewhat greater tolerance to turbidity than salt and brackish seagrasses, since they were found in areas of similar water depths to high salinity grasses, but secchi depths were less (Ferguson and Wood 1994). This feature supports other research (Funderburk et al. 1991) showing that salt/brackish seagrasses require slightly greater water clarity (secchi depth >1.0 m, or 3.28 ft) than freshwater SAV (secchi depth >2.63 ft or 0.8 m).

Other physical and chemical factors that impact SAV include salinity, nutrients, and wave exposure. The average salinity for freshwater SAV is between 1 and 2 ppt, while the average salinity for salt/brackish SAV ranges from 15 to 26 ppt (Ferguson and Wood 1994) (Table 4.1). Widgeon grass occurs in both high and low salinity waters, with an average salinity of 15 ppt. Salt/brackish SAV requires less than 0.15 mg/l of dissolved inorganic nitrogen and less than 0.01 mg/l of dissolved inorganic phosphorus (Funderburk et al. 1991). The majority of nitrate used by SAV is derived from the sediment, rather than the water column (Thayer et al. 1984). Contiguous beds of eelgrass or other species of SAV rarely occur in windswept areas or where currents are strong (>20-40 cm/s) (Thayer et al. 1984; Fonseca et al. 1998). Work was done in Core Sound by Fonseca et al. (1998) to analyze the effect of wave exposure and currents on SAV coverage. They found significant relationships, with percent cover of SAV decreasing with increasing relative wave exposure indices or current speed. *This information could be used to determine habitat suitability for SAV restoration in Core Sound. A similar process could be conducted in other areas, particularly low salinity areas, where large losses of SAV have historically occurred. Alternative measures of restoration site suitability could be investigated in areas where the Fonseca wave exposure model has yet to be tested (P. Biber, NMFS, pers. com., 2003; <http://www.marine.unc.edu/Paerllab/research/seagrass/field_experiments.htm>, 2003).*

Below is a brief description of the habitat and plant characteristics of the five submerged grasses common to North Carolina's brackish to freshwater systems and the three submerged grasses common to high salinity estuarine waters (Hurley 1990). Widgeon grass is included with high salinity grasses, but it can tolerate low salinity as well.

High salinity grasses

- Eelgrass (*Zostera marina*): Grows in fine muds, silts, and loose sand in high salinity waters and can tolerate high energy waters (Thayer et al. 1984). Reproduces vegetatively from October to June, and sexually from December to April. Present primarily as a seed-bank from July to November (P. Biber, NMFS, pers. com., 2003). Rhizomes rarely deeper than 5 cm (1.97 inches). Can spatially coexist in beds with *Halodule* in North Carolina, but is dominant from winter to summer, with lower densities during summer months relative to that of *Halodule* (Thayer et al. 1984).
- Widgeon grass (*Ruppia maritima*): Tolerates a wide range of salinity regimes. Slightly brackish to moderately brackish and high salinity. Found growing with eelgrass. Widgeon grass is more common in shallow areas, with eelgrass in deeper waters. Spreads vegetatively from creeping rhizome during April - October. Rare occurrence reported in fresh water. While more common on sandy substrates, is also found on soft, muddy sediments. High wave action damaging to slender stems and leaves.
- Shoalgrass (*Halodule wrightii*): Forms dense beds and can occur in very shallow water. Known for its relative tolerance to desiccation (drying out) once rooted. Rhizomes situated fairly shallow in sediment and may extend into the water column with attached shoots. Almost exclusively vegetative (asexual) reproduction from April through October and sexually on a very rare basis in spring and summer (J. Kenworthy and P. Biber, NMFS, pers. com., 2003). Due to its clonal reproductive strategy, genetic diversity may be quite limited and, as such, populations may be at particular risk to changing estuarine conditions (P. Biber, NMFS, pers. com., 2003). May co-occur with *Zostera* and dominates mid-summer through fall in North Carolina, after which *Zostera* becomes relatively more predominant (Thayer et al. 1984).

Low salinity grasses

- Bushy Pondweed or Southern Niad (*Najas quadalupensis*): Present in small freshwater streams. Also tolerates slightly brackish waters. Sand substrates preferred. Can grow in muddy soils. *Najas* spp. requires less light than other SAV species.
- Wild celery (*Vallisneria americana*): Primarily a freshwater species occasionally found in moderately brackish waters. Coarse silt to slightly sandy soil. Tolerant of murky waters and high nutrient loading. Can tolerate some wave action and currents compared to more delicately leaved and rooted species. Similar in appearance to eelgrass.
- Sago pondweed (*Potamogeton pectinatus*): Fresh to moderately brackish. Tolerates waters with high alkalinity. Associated with silt-mud sediments. Long rhizomes and runners provide strong anchorage to the substrate. Capable of enduring stronger currents and greater wave action than most other SAV.
- Redhead grass (*Potamogeton perfoliatus*): Found in fresh to moderately brackish and alkaline waters. Grows best on firm muddy soils and in quiet waters with slow-moving currents. Because of its wide leaves more susceptible to being covered with epibiotic growth then the more narrow leaved species. Securely anchored in the substrate by its extensive root and rhizome system.
- Eurasian watermilfoil (*Myriophyllum spicatum*): This species inhabits fresh to moderately brackish waters. Affinity for water with high alkalinity and moderate nutrient loading. Grows on soft mud to sandy mud substrates in slow moving stream or protected waters. Not tolerant of strong tidal currents and wave action. Over-wintering lower stems provide early spring cover for fish fry before other SAV species become established. *M. spicatum* is a non-native, invasive species, estimated to cover over 4000 acres in Currituck and Albermarle sounds during the 1990s

(DWR 1996), and is classified by the North Carolina Board of Agriculture as a Class B noxious weed [02 NCAC 48A .1702].

Distribution

Seagrasses occur along the entire east coast of the United States, with the exception of South Carolina and Georgia, where high freshwater input, high turbidity, and large tidal amplitude (vertical tide range) inhibit their occurrence. The published estimate for estuarine SAV in North Carolina is approximately 200,000 acres (80,937 hectares (ha)) (Field et al. 1988 and Orth et al. 1990; cited in Ferguson and Wood 1994), or about 7% of the estuarine bottom in North Carolina. Based on interpretation and ground-truthing by NOAA of remotely-sensed imagery taken during 1985-1990, the total area of visible SAV was approximately 134,000 acres (Ferguson and Wood 1994). Since these surveys were conducted at least 14 years prior to 2004, the current spatial distribution and acreage of SAV in the area sampled are likely to vary. In general, along the Atlantic coast, North Carolina supports more SAV than any other state, except for Florida (Table 4.3). Based on Ferguson and Wood (1994), areas of visible SAV were mapped as follows:

SAV Distribution in North Carolina	
Eastern Pamlico Sound	90,000 acres (36,421.71 ha)
Core Sound	19,938 acres (8,068.62 ha)
Albemarle Sound	4,439 acres (1,796.39 ha)
Croatan-Roanoke sounds	926 acres (374.74 ha)
Neuse River estuary	91 acres (36.83 ha)
Pamlico River estuary	378 acres (152.97 ha)
Western Pamlico Sound	83 acres (33.58 ha)

Table 4.3. Estimated spatial coverage of submerged aquatic vegetation in coastal waters of mid- and south Atlantic states.

	SAV		
State	**acres**	**hectares**	**Source**
Florida	2,658,290	1,075,772	Sargent et al. (1995)
North Carolina	200,000	80,937	Field et al. 1988 and Orth et al. 1990; cited in Ferguson and Wood (1994)
Chesapeake (VA and MD)	59,300	23,998	Funderburk et al. (1991)

In 1981, visible SAV in Core and Bogue sounds covered 19,458 acres (7,874.37 ha) within a total water area of 104,840 acres (42,427.24 ha) (19% SAV coverage; Carraway and Priddy 1983). However, acreage for these areas may be underestimated, particularly in low salinity riverine areas, since aerial photography at the scale utilized (1:24,000) may not be able to detect some SAV due to the relatively small patch size and high turbidity of the water.

Physical and chemical conditions of the Albemarle-Pamlico estuarine system provide suitable habitat conditions for SAV growth. The extensive barrier islands of the Outer Banks protect the east side of Pamlico Sound and other smaller sounds within the Albemarle-Pamlico estuary. Tides and currents are primarily wind-driven. The western shorelines of the sounds are less protected from the wind, but, because of the reduced currents and tidal amplitude, they also support SAV growth where water depth is shallow enough and water quality conditions allow. Aside from physical and chemical limitations, survival of SAV can be affected by excessive covering of drifting macroalgae or epiphytes, and disease outbreaks like eelgrass wasting disease (Stephan and Bigford 1997). In Florida Bay, uncommon yet

large-scale grazing events by urchins (Rose et al. 1999) restricted seagrass distribution. It is unknown if similar overgrazing incidents by these or other organisms have affected seagrasses, recently or historically, in North Carolina.

SAV habitat in coastal North Carolina occurs mostly in sandy and muddy sediment and high salinity waters along the estuarine shoreline of the Outer Banks, with sparse cover along much of the mainland shores of the estuarine system (Ferguson et al. 1989). Within the Coastal Plain, freshwater SAV is locally abundant in some larger blackwater streams and rivers, but is rare in small blackwater streams (Smock and Gilinsky 1992) due to shading from forested wetlands and irregular flows typical of low order streams. Freshwater SAV can be extensive in some low-salinity back bays and lagoons (Moore 1992), and may also occur in coastal lakes such as Lake Mattamuskeet.

Limited SAV distribution and lower species diversity of SAV have been associated with areas of low salinity (5–18 ppt) (Ferguson and Wood 1994). Seagrasses in these regions may be limited by long wind fetch (the horizontal distance over which wind blows, creating waves), lack of protected shallow bottom, extreme currents, reduced light availability, and excessive nutrient enrichment. Shoalgrass or eelgrass were not observed in western Pamlico Sound or the Pamlico or Neuse estuaries despite acceptable salinity ranges. The presence of SAV in low salinity waters (<5 ppt) of Albemarle and Currituck sounds and their tributaries was relatively low (Ferguson and Wood 1994). Map 4.2 shows SAV areas mapped by Carraway and Priddy (1983) and Ferguson and Wood (1994). The area of SAV habitat within CHPP management units is presented in Table 4.4.

Table 4.4. Submerged aquatic vegetation (SAV) coverage within Coastal Habitat Protection Plan management units (MU) based on mapping work of Carraway and Priddy (1983) and Ferguson and Wood (1994).

	SAV		Total Water*		
MU	acres	hectares	acres	hectares	% SAV
Albemarle	13638	5519	604417	244599	2.26
Core/Bogue	36189	14645	167946	67966	21.55
Neuse	96	39	112817	45655	0.08
Pamlico	83403	33752	1020522	412991	8.17
Tar/Pamlico	392	159	117123	47398	0.33
Total	133718	54114	2022825	818608	6.61

* Water area includes broad, open waters detected on 1:100,000 scale USGS topographic maps

Estuarine SAV occurs sporadically west of Bogue Inlet to the border with South Carolina, but these areas have not been suitably photographed (Ferguson and Wood 1990). Small areas of SAV habitat have been observed in the past few years by DMF biologists in the New River, Alligator and Chadwick bays, Topsail Sound and inside Rich's Inlet (M. Allison, DMF, pers. com., 2002). Other studies reporting distribution of salt/brackish SAV include Davis and Brinson (1983) for Currituck Sound, Brinson and Davis (1976) for the Chowan River, and DWQ (1998) for the Neuse River. The U.S. Fish and Wildlife Service's National Wetland Inventory (NWI) Program has mapped some SAV in inland fresh waters. However, this information has not been summarized by CHPP management unit or region.

4.2. ECOLOGICAL ROLE AND FUNCTIONS

Submerged aquatic vegetation provides important structural fish habitat and other important ecosystem functions in estuarine and riverine systems in coastal North Carolina. The SAFMC (1998a) recognized SAV as an essential fish habitat because of five interrelated features of seagrass meadows – primary production, structural complexity, modification of energy regimes, sediment and shoreline stabilization,

and nutrient cycling. Water quality enhancement and fish utilization are especially important functions of SAV relevant to the enhancement of coastal fisheries.

Productivity

Seagrass habitat is dominated by dense stands of primary producers – underwater grasses. These grasses produce large quantities of organic matter. Estimates of daily production for eelgrass beds rank among the most productive of marine plant habitats (Thayer et al. 1984). The typical biomass of growing SAV beds (leaves + rhizomes) in North Carolina was reported as 57–391 g (dry weight)/m^2 (Thayer et al. 1984; Twilley et al. 1985). Primary productivity is derived approximately equally from above-ground and below-ground growth.

Because of their high rates of primary production and particle deposition, SAV beds are important nutrient sources (nutrients are exported from the bed to other users) and sinks (nutrients are retained within the bed by the plant structure (leaves and roots), especially during high growth periods (SAFMC 1998a)). Thayer et al. (1984) concluded that SAV beds in high velocity areas are sources of organic matter, while SAV in low current areas are sinks of organic matter (detritus). Important sources of organic matter produced by SAV habitat include the SAV plant tissue, epibiotic organisms attached to SAV leaves, microalgae and macroalgae present on sediments among SAV plants, and dissolved organic matter released during metabolism (SAFMC 1998a). Ultimately, large amounts of nutrients, originally retained by SAV, are exported via secondary production and trophic interactions by animals as they depart nursery areas following larval and juvenile development (Thayer et al. 1984).

Attached epibiota contribute substantially to the total productivity of SAV beds (Thayer et al. 1984) and are an important food source for fish and invertebrates. Approximately 25% of the average annual above-ground biomass of an eelgrass bed in the Newport River was attributable to epiphytes (Penhale 1977). In certain instances, total biomass of epibiota can actually exceed that of the SAV leaves to which the epibiota are attached. While they may increase primary productivity of the habitat, epibiota may also significantly reduce productivity of individual plants if coverage is too extensive (Thayer et al. 1984). Dillon (1971) estimated that epiphytic macroalgae constitute 10% of the total SAV biomass in a North Carolina estuary, although seasonal variability in macroalgal abundance corresponds to seasonal fluctuations in eelgrass biomass (Thayer et al. 1975; Penhale 1977).

Exported matter represents a large portion of total SAV production in salt/brackish SAV beds in North Carolina (Thayer et al. 1984). When grasses die and decompose, the detrital material is broken down by invertebrates, zooplankton and bacteria, and energy is transferred through the estuarine detrital food web. Because SAV breaks down much slower than algae, SAV decomposition generally does not cause anoxic conditions (Hurley 1990). Decomposed SAV matter and its associated bacteria are actually of greater importance as a food source for fish than the living SAV leaves (Thayer et al. 1984).

Ecosystem enhancement

System enhancement includes any positive effect on other habitats provided by proximity to SAV. Because seagrasses are rooted in the substrate and provide long-term submerged structure in estuaries and coastal rivers, system enhancement is one of their more important ecological functions. Some of these functions include (SAFMC 1998a):

- Modification of water flow and reduction in wave turbulence,
- Accelerated deposition of sediment and organic matter,
- Physical binding of sediments beneath the canopy, and
- Nutrient cycling between the water column and sediments.

The network of leaves, stems, and roots of an SAV bed oxygenate the surrounding water, filter and trap sediments, and utilize excess nutrients (nitrogen and phosphorus) dissolved in the water (Thayer et al.

1984). These processes increase water clarity and improve conditions for further SAV growth. The absorption of excess nitrogen and phosphorus by SAV can reduce the frequency of nuisance algal blooms and resultant anoxic waters when the blooms die off and decay (Thayer et al. 1984). During active periods of growth and leaf turnover, nutrients cycle rapidly between plant tissues and the organisms that feed upon them. This retention and controlled release of nutrients improves water quality down current and also provides a stable foraging base for herbivores, detritivores, and secondary consumers (Thayer et al. 1984).

Suspended sediment is removed from the water column when the frictional drag of water flowing over the leaves and stems reduces water velocity and wave energy, allowing sediment to settle out of the water column. Roots bind and stabilize the substrate, partially inhibiting bottom sediments from being resuspended (Thayer et al. 1984; SAFMC 1998a). This deposition enhances the productivity, stability, and biodiversity of SAV. The rhizomes and roots of SAV stabilize the substrate and form large pools of organic matter and structural matrices supporting many species that live in the sediment (Kenworthy and Thayer 1984). Particle deposition and burial, as well as formation of organic matter in the sediment, facilitate temporary and permanent retention of nutrients within SAV beds by the roots and rhizomes (Thayer et al. 1984; SAFMC 1998a). These functions improve water quality down current of the bed by removing suspended solids from the water column, improving water clarity, and adding dissolved oxygen. The presence of SAV is both a maintainer and indicator of good water quality (Virnstein and Morris 1996; R. Ferguson, NMFS, pers. com., 2000). *However, the exact relationship between the extent of SAV coverage and water quality is unknown and requires research.*

Seagrasses have a stabilizing effect on substrate and nearby shorelines by absorbing wave energy (Fonseca 1996a). By buffering nearshore turbulence, SAV beds reduce erosion along adjacent shorelines, which also helps stabilize marsh edge habitat (Stephan and Bigford 1997). Where water turbulence is too great for SAV to persist, its buffering capacity over time may be limited (Thayer et al. 1984). Although oyster reefs are relatively more resilient to turbulence than SAV beds, both oyster reefs and SAV beds provide, among other ecosystem functions, shoreline protection (Day et al. 1989; Fonseca 1996a).

Fish utilization

Many species occupy SAV at some point in their life cycle (Thayer et al. 1984). However, the importance of SAV depends on its relative contribution to a particular species' refuge, spawning, nursery, foraging, and corridor needs. For instance, some species use SAV directly as a food source (consumption of living plant material) while other species rely on SAV indirectly, by hunting for prey along the edge of the beds, or finding refuge from predation while foraging within the beds.

Submerged aquatic vegetation was classified as "Essential Fish Habitat" (EFH)[42] by the SAFMC (1998a) due to its habitat heterogeneity, plant biomass, and surface area, all of which enhance animal abundances. Because of the different temporal abundance patterns in SAV species, feeding habitat and refuge for fish and shellfish are provided almost year-round for estuarine-dependent species (Steel 1991). In North Carolina, the species for which SAV is considered EFH include red drum; brown, white, and pink shrimp; and species in the snapper-grouper complex. While bay scallops are not managed by the SAFMC, the SAV habitat that bay scallops share with federally managed species is technically considered EFH (K. Abrams, NOAA, pers. com., 2003). Several important forage species also depend on SAV habitat. The two EFH categories for SAFMC-managed species are salt/brackish and freshwater SAV.

Salt/brackish grasses

In brackish and high salinity estuaries, fish and invertebrates use SAV, to varying extents, as nursery, refuge, foraging, and spawning locations. Studies in eelgrass beds in the Newport River estuary and

[42] EFH is defined by SAFMC as those waters and substrate necessary to fish for spawning breeding, feeding, or growth to maturity.

vicinity reported between 39 and 56 fish species during regular monitoring conducted in the 1970s (Thayer et al. 1975; Adams 1976; Thayer et al. 1984). Results from DMF's juvenile fish sampling in seagrass beds in eastern Pamlico and Core sounds found over 150 species of fish and invertebrates from 1984 to 1989, of which 34 fish and six invertebrate species were important commercial species (DMF 1990). Adult fish as well as juveniles utilize grass beds. Composition of long haul seine catches sampled by DMF reported at least 49 adult fish species collected over seagrass beds in eastern Pamlico Sound (DMF 1990). In addition to fish, over 70 benthic invertebrate species have been reported from eelgrass beds along the east coast (Thayer et al. 1984). Bay scallops occur almost exclusively in SAV beds (Thayer et al. 1984), and spotted seatrout (*Cynoscion nebulosus*), an important recreational and commercial species in North Carolina, is also highly dependent on the quantity and quality of SAV habitat (Vetter 1977). Species whose relative abundances at some life stage are generally higher in SAV than in other habitats, or otherwise show some preference for SAV, are referred to as "SAV-enhanced." A partial list of species utilizing SAV habitat in North Carolina is compiled in Table 4.5.

Several studies along the coasts of the Atlantic Ocean and the Gulf of Mexico have demonstrated significantly greater species richness and numerical abundance of organisms in seagrass beds compared to unvegetated bottom (Thayer et al. 1975; Summerson and Peterson 1984; Heck et al. 1989; Ross and Stevens 1992; Irlandi 1994; ASMFC 1997a; Wyda et al. 2002). In Back Sound, N.C., a study found that fish and shrimp were more abundant on artificial SAV beds than on shell bottom (Elis et al. 1996). In the Newport River estuary (Core/Bogue MU), rough silverside (*Membras martinica*) and smooth dogfish (*Mustelus canis*) were classified as abundant in SAV beds, but were rare or absent in marsh channel and intertidal flats (Thayer et al. 1984). Blue crabs and pink shrimp were significantly more abundant in SAV beds than in adjacent shallow non-vegetated estuarine bottoms in North Carolina, Alabama, and Florida (Williams et al. 1990; Murphey and Fonseca 1995). In the Chesapeake Bay region, juvenile crabs grow faster, occur more densely, and have higher survival rates in SAV beds (Heck and Orth 1980; Chesapeake Bay Commission 1997). In addition to natural fluctuations in SAV coverage and density, the utilization of SAV by fish and invertebrates differs spatially and temporally due to species distribution ranges, time of recruitment, and life histories (Nelson et al. 1991).

Some studies have shown a linkage between the abundance and species composition of fish and the quantity and quality of SAV. Abundance, biomass, and species richness of fish assemblages in two spatially distant areas of the Mid-Atlantic Bight (Buzzards Bay and Chesapeake Bay) were significantly higher at sites with higher levels of seagrass complexity (biomass >100 wet g/m^2; density >100 shoots/m^2) compared to sites with reduced seagrass complexity (Wyda et al. 2002).

Table 4.5. Partial list of species documented to use submerged aquatic vegetation habitat.

Species*	SAV Functions [1]					Fishery [2]	Stock status [3]
	Refuge	Spawning	Nursery	Foraging	Corridor		
ANADROMOUS & CATADROMOUS FISH							
River herring (blueback herring and alewife)	X	X	X	X	X	X	O-Albemarle Sound, U-Central/Southern
Sturgeon spp.				X		X [4]	O
Striped bass				X		X	V- Albemarle Sound, Atlantic Ocean, O- Central / Southern
American eel	X		X	X	X	X	U
ESTUARINE AND INLET SPAWNING AND NURSERY							
Bay scallop	**X**	**X**	**X**	**X**		**X**	**C**
Blue crab	**X**		**X**	**X**	**X**	**X**	**C**
Grass shrimp	**X**	**X**	**X**	**X**			
Hard clam	**X**		**X**	**X**		**X**	**U**
Red drum	**X**		**X**	**X**	**X**	**X**	**R**
Rough silverside	**X**	**X**	**X**	**X**			
Spotted seatrout	**X**		**X**	**X**	**X**	**X**	**V**
Weakfish	**X**		**X**	**X**	**X**	**X**	**V**
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY AREA							
Atlantic croaker	**X**		**X**	**X**	**X**	**X**	**C**
Atlantic menhaden	X		X	X	X	X	V
Brown shrimp	**X**		**X**	**X**	**X**	**X**	**V**
Southern flounder			X	X		X	O
Spot	X		X	X	X	X	V
Striped mullet	**X**		**X**	**X**	**X**	**X**	**C**
White shrimp	X		X	X	X	X	V
MARINE SPAWNING , HIGH SALINITY NURSERY							
Black sea bass	X		X	X	X	X	O- south of Hatteras, V- north of Hatteras
Bluefish			X	X		X	R
Gag	**X**		**X**	**X**	**X**	**X**	**V**
Tautog	**X**		**X**	**X**	**X**	**X**	**O**
Kingfish spp.	X		X	X	X	X	U
Pinfish	**X**		**X**	**X**	**X**	**X**	
Pink shrimp	**X**		**X**	**X**	**X**	**X**	**V**
Sheepshead	X		X	X	X	X	C [5]
Smooth dogfish				**X**		**X**	**O**
Spanish mackerel			X	X		X	V
Summer flounder			**X**	**X**		**X**	**V**

* Scientific names listed in Appendix I. Names in **bold** font are species whose relative abundances have been reported in the literature as being generally higher in SAV than in other habitats. Note that lack of bolding does not imply non-selective use of the habitat, just a lack of information.

[1] Sources: ASMFC (1997a), Thayer et al. (1984), NOAA (2001), Peterson and Peterson (1979), NMFS (2002), and SAFMC (1998)

[2] Existing commercial or recreational fishery. Fishery and non-fishery species are also important as prey

[3] V=viable, R=recovering, C=Concern, O=overfished, U=unknown (DMF 2003a).

[4] Species under harvest moratorium

[5] Status of reef fish complex as a whole. Sheepshead has not been evaluated in NC.

Abundance, biomass, and species diversity at sites with reduced seagrass complexity were more variable than at sites with high seagrass complexity. Sites with lower SAV complexity also had a greater proportion of pelagic species than bottom, structure-oriented species. In Florida Bay, changes in animal abundances were compared between the 1980s and 1990s when significant changes in SAV coverage also occurred (Matheson et al. 1999). The major change observed was a decrease in abundance of small fish and invertebrates that live within the seagrass canopy (such as crustaceans and pipefish) with decreases in SAV coverage, while larger demersal predatory fish (such as toadfish and sharks) increased. Similarly, increases in SAV density were characterized by significant increases in crustaceans. In another study in Florida Bay, greater reductions in pink shrimp abundance occurred in seagrass die-off areas relative to adjacent undamaged or recovering areas (Roblee and DiDomenico 1992). In North Carolina, comparison of pink shrimp densities in continuous and patchy seagrass beds found significantly greater shrimp densities in continuous beds than in patchy grass beds (Murphey and Fonseca 1995). Although patchy seagrass beds did not support as great a density of shrimp, they still functioned as important habitat for pink shrimp (Murphey and Fonseca 1995). The presence of SAV may be the reason pink shrimp can overwinter and survive, supporting a spring pink shrimp fishery in North Carolina (T. Murphey, DMF, pers. com., 2003). The pink shrimp fishery comprises a large portion of North Carolina's annual shrimp landings. In contrast, in South Carolina and Georgia, where no SAV is present, pink shrimp comprise an extremely small portion of the shrimp landings. Similarly, survival of blue crabs in a New Jersey estuary was attributed to the ability of the species to overwinter in SAV (Wilson et al. 1990).

Freshwater grasses

In coastal riverine systems, such as the Chowan River, finfish, shellfish, and crustaceans utilize SAV as nursery areas for refuge and protection, particularly minnows, killifish, juvenile striped bass, largemouth bass, and molting/soft shelled blue crabs (Hurley 1990). Floating leaf aquatic vegetation is particularly important in freshwater systems such as the Roanoke River (Cooper et al. 1994). Freshwater SAV is also an important habitat for estuarine species, in streams and some lakes, such as Lake Mattamuskeet. Common species using freshwater SAV is shown below and in Table 4.5. *More research is needed to improve scientific understanding of the relationship of SAV to fresh and brackish water fish species.*

COMMON FISH SPECIES THAT UTILIZE FRESHWATER SAV

(Sources: Rozas and Odum 1987; SAFMC 1998a; NOAA 2001)

Freshwater species

In freshwater streams and lakes

Minnows
White perch
Juvenile American eel
Pirate perch
Inland silversides
Yellow perch
Largemouth bass
Bluegill ("bream")

Estuarine species

In freshwater streams

Juvenile menhaden
Spot
Blue crab
Grass shrimp
Bay anchovy

In freshwater lakes

Striped mullet
Tidewater silverside
White perch

Anadromous Species

Striped bass
Shad (American and hickory)
River herring

Specific biological functions

Refuge

The physical structure of SAV conceals prey from visual detection, restricts the pursuit and capture of prey by predators and protects small organisms from adverse weather conditions (Savino and Stein 1989; SAFMC 1998a; Rooker et al. 1998). High densities of seagrass shoots and increased plant surface area inhibit predator efficiency and provide shelter to prey (Coen et al. 1981 for grass shrimp; Prescott 1990 for bay scallops; Orth 1992 for blue crabs). Moreover, the predation mortality rate of red drum in unvegetated habitat was up to four times greater than that observed in SAV habitat (Rooker et al. 1998). Light levels are reduced within the canopy as well, further concealing small prey (SAFMC 1998a). In addition, cryptic species that have the ability to change color use camouflage to decrease their visibility within the SAV habitat.

Since beds of SAV can be as tall as one meter (3.28 ft), their leaf canopies provide a three-dimensional structure containing a large volume of sheltered water. The blades of SAV can increase the available surface area for colonization by an order of magnitude when compared to adjacent unvegetated habitats (SAFMC 1998a). In the sediment, the roots and rhizomes of SAV also provide a matrix for meiofauna [43] and macrofauna [44] (Kenworthy and Thayer 1984). Organisms utilize the leaves, roots, and rhizomes, as well as the space between shoots, for refuge from predators and adverse environmental conditions (SAFMC 1998a). Hard clams are significantly more abundant in SAV beds than in adjacent unvegetated bottom due to changes in food supply, predation, and sediment stability (Peterson and Peterson 1979; Peterson 1982; Irlandi 1994, 1997).

The refuge value of SAV also depends on its corresponding value for predators. For example, benthic macroinvertebrates can be more vulnerable to crab predation in SAV because crabs use SAV for refuge from avian predators (Skilleter 1994; Micheli and Peterson 1999; Beal 2000). Summerson and Peterson (1984) hypothesized that nocturnal bottom predators living on sand flats use SAV during the day to avoid their own predators. Predator–prey interactions in SAV habitat are a function of canopy structure, shoot and blade density, and surface area (SAFMC 1998a). Moreover, the relative value of SAV as refuge is also likely to change over time, not only with seasonal patterns of SAV abundance (Prescott 1990) but also during the course of the day. As previously mentioned, mobile epibenthic[45] organisms that typically hide from predators in seagrass beds during daylight may later feed and successfully avoid visually-searching predators on unvegetated flats under the cover of darkness (Summerson and Peterson 1984).

Spawning

Coastal aquatic species that spawn in SAV include blueback herring, mummichog, bay scallop, grass shrimp, and rough silversides (Stephan and Bigford 1997; NOAA 2001). The roots and stems of SAV also provide substrate for attachment of eggs and invertebrates (such as barnacles, sea squirts, and bryozoans). Seasonal patterns of reproduction and development of many temperate fishery species coincide with seasonal abundance of seagrass (Stephan and Bigford 1997). Estuarine-dependent spring-summer spawners utilize SAV habitat in the spring and summer for forage and refuge, residing there prior to emigrating to the mouths of bays and rivers, inlets, or coastal ocean shelf waters to spawn (SAFMC 1998a; Luczkovich et al. 1999). Some of these species include red drum, weakfish, spotted sea trout, silver perch, and southern kingfish. *Additional research is needed on how SAV affects spawning success of these or other species.*

Nursery

Submerged aquatic vegetation is a primary nursery habitat for numerous species of fish and invertebrates

[43] Very small benthic animal, 0.1 – 0.5 mm in size, about the size of a sand grain, important food source for larval fish
[44] Small benthic animal larger than 0.5 mm in size; e.g., mole crabs, amphipods
[45] Organism that lives at the surface of the bottom, as opposed to burrowed below bottom; e.g., starfish, flounder

along the Atlantic coast (Thayer et al. 1984). Important commercial and recreational species present in SAV as juveniles in the spring and early summer include gag, black sea bass, snappers, weakfish, bluefish, mullet, spot, Atlantic croaker, red drum, flounders, and herrings (SAFMC 1998a). The roots and stems of SAV provide ideal protection and food for developing fish and invertebrate larvae (Ambrose and Irlandi 1992; SAFMC 1998a). Larvae of spring-summer spawning fish (such as anchovies, gobies, pipefish, spotted seatrout, weakfish, hard clams and southern kingfish) use SAV habitat (SAFMC 1998a). In North Carolina, where SAV is present year-round, some larval and early juvenile finfish, molluscan, and crustacean species are also present much of the year (SAFMC 1998a). Both bay scallops and hard clams attach to seagrass blades temporarily before settling on the bottom (Thayer et al. 1984; SAFMC 1998a). While hard clams also utilize other substrates, such as oysters and shell hash, bay scallops almost exclusively utilize seagrass, and are therefore highly dependent on its existence for successful recruitment[46] (Thayer et al. 1984; Stephan and Bigford 1997). Juvenile blue crabs prefer shallow water areas with structure, including SAV, tidal marsh, shell bottom and detritus (Etherington and Eggleston 2000). In the Albemarle-Pamlico system, the majority of initial recruitment occurs in seagrass beds around inlets behind the Outer Banks, unless there is a major storm event. In years with large storm events, crabs are dispersed into additional lower salinity habitats (Etherington and Eggleston 2000). At sites near Ocracoke and Hatteras inlets, the density of juvenile blue crabs increased significantly with increasing seagrass blade length, but not with biomass or shoot abundance (Etherington and Eggleston 2000). *More research is needed on the use of SAV for larval fish and invertebrate settlement and as a nursery; by determining optimal conditions for such species, additional success criteria may be developed for seagrass restoration projects.*

Several groups of fish use SAV as nursery habitat. Spot, croaker, shrimp, and pinfish are estuarine-dependent offshore spawners that inhabit SAV habitat as early juveniles in winter and early spring. Submerged aquatic vegetation has been recognized as critical nursery habitat for pink shrimp in North Carolina (Murphey and Fonseca 1995). Silver perch, spotted seatrout, and red drum are estuarine spawners, and their juveniles are present later in the spring and in the summer. Estuarine-dependent reef fish use seagrass meadows as juveniles, prior to moving offshore. For example, juvenile gag (*Mycteroperca microlepis*) use SAV habitat for refuge and foraging on crustaceans before moving to offshore hard bottom as a secondary nursery area (Ross and Moser 1995). Juvenile sheepshead (<50 mm or <2.17 in) and juvenile gray snapper also utilize SAV beds (Pattilo et al. 1997). However, juvenile gray snapper are rare in most interior waters of North Carolina, and they are common only in Pamlico Sound from July to November (Nelson et al. 1991).

Some studies have found that juvenile red drum, as well as pink shrimp and sand seatrout (*Cynoscion arenarius*) were more abundant in SAV beds compared to marsh edge, inner marsh, shell bottom, or shallow non-vegetated bottoms (Minello 1999); other studies disagree (Stunz et al. 2002). The degree of preference by red drum for SAV is somewhat uncertain since they also utilize estuaries lacking SAV, such as in the southern portion of North Carolina and South Carolina. However, red drum eggs, larvae, postlarvae, and juveniles have been documented in SAV beds in North Carolina which is particularly important as a foraging area for young (1-2 year old) red drum (Mercer 1984; Reagan 1985; Ross and Stevens 1992). Abundance of juvenile red drum in SAV beds varies seasonally and spatially, being more common in grass beds during summer months and in grass beds that are close to spawning areas (Zieman 1982; DMF, unpub. data). Also, juvenile red drum were more abundant in edge habitat with patchy grass coverage than in homogeneously vegetated sites (Mercer 1984; Reagan 1985; Ross and Stevens 1992). Data from DMF red drum seine surveys and tagging studies indicate high abundance of late young of year red drum in shallow high salinity grass beds behind the Outer Banks (DMF 2001c). Rooker et al. (1998) also examined post-settlement patterns by several species in SAV habitat and found densities of red drum, spotted seatrout and silver perch were highest for very small individuals (4-8 mm or 0.1-0.3 in). These fish utilized SAV habitat at smaller sizes and remained in SAV longer than spot and croaker. Spot and

[46] Successful settlement, and in some cases metamorphosis, of pelagic larvae into their juvenile habitat. Also refers to successful movement of juveniles into adult habitat or fishery.

croaker seemed to utilize SAV habitat more as temporary residents, migrating to alternate habitats shortly after their arrival (Rooker et al. 1998).

Studies have shown that recruitment of small juvenile fishes corresponded to periods of greatest SAV coverage (SAFMC 1998a). In freshwater SAV beds, Paller (1987) determined that the standing stock of larval fish was 160 times higher than in adjacent open waters, and that larvae would concentrate in the interior of aquatic beds rather than in the transition zones between habitats. This difference suggests that large SAV beds provide better refuge for larvae than an equivalent area of patchy SAV. Several studies in estuarine SAV beds also found that juvenile hard clams, pink shrimp, and blue crabs were more abundant in large or continuous SAV beds than in small or patchy SAV beds, whereas the opposite was found for adult pink shrimp and grass shrimp (Murphey and Fonseca 1995; Irlandi 1997; Eggleston et al. 1998). This finding suggests that habitat fragmentation could have a significant impact on recruitment of some species.

Noble and Monroe (1991) analyzed environmental variables associated with relative abundance and diversity of juvenile finfish and crustacean from the DMF nursery area database for the Albemarle-Pamlico estuarine area. Critical habitat criteria, based on core group characterizations, were developed to better define and protect critical fishery habitats functioning as nursery areas for economically important finfish and crustaceans. The study recommended classifying a "new type" of nursery area characterized by higher salinities, SAV presence, and a somewhat different species composition than the typical Albemarle-Pamlico Peninsula nursery areas (such as Rose Bay). *Criteria should be developed and implemented to assist with designation of SAV beds as Strategic Habitat Areas by the MFC.*

Foraging

Submerged aquatic vegetation supports numerous complex food webs and serves as a foraging area for fish and invertebrate species. Nutrient sources associated with SAV include, but are not limited to, dissolved organic matter, epibiota, plants and animals living on and in the sediment surrounding SAV rhizomes, and living SAV tissues (Adams and Angelovic 1970; Thayer et al. 1975; SAFMC 1998a). The majority of organisms in SAV habitat utilize secondary production from epibiotic communities, benthic algae, organic detritus, and bacteria rather than direct consumption of SAV (Day 1967; Adams and Angelovic 1970; SAFMC 1998a).

Benthic invertebrates (e.g., worms, snails) and fish graze on other benthic animals that live in the sediment among SAV roots and stems. These small invertebrates and fish, in turn, provide food for larger fish and shellfish adapted to feed upon them. Benthic algae are important forage items for pelagic-feeding planktivorous fishes (such as silversides) that inhabit the grass beds at night (Meyer 1982). Eelgrass and shoalgrass are highly productive (Thayer et al. 1984), and their stems and leaves provide an important substrate for attachment by small organisms that contribute to the overall productivity of the system and serve as forage for larger organisms (Carr and Adams 1973).

Only a few fish species are known to consume submerged grasses directly. These include pinfish (*Lagodon rhomboides*), spot (*Leiostomus zanthurus*), filefish (*Monocanthus hispidus*), and toadfish (*Opsanus tau*). However, SAV comprised only 1 – 12% of their diet (Thayer et al. 1984). Rather than direct grazing, most fish and invertebrates benefit from SAV indirectly by foraging on small plants and animals associated with the vegetation. In contrast, many species of birds (e.g., black brant, *Branta bernicla;* Canada goose, *Branta canadensis;* and widgeon, *Anas penelope*) graze directly on freshwater SAV. The green sea turtle and West Indian manatee consume salt/brackish SAV (SAFMC 1998a). Green turtles appear to be more abundant in seagrass than in unvegetated areas in North Carolina, based on data from incidental occurrence in pound nets (SAFMC 1998a). Abundant green turtles closely crop seagrass and greatly reduce the input of organic matter and nutrients to sediments (Jackson et al. 2001). An absence of SAV grazers can result in excessive growth and accumulation of substrate suitable for

proliferation of slime mold, which is largely responsible for SAV wasting disease [47] (Jackson et al. 2001).

Fisheries production by SAV results primarily from predator consumption of the plants and animals that live on the seagrass (leaves and roots/rhizomes), benthic algae, and organic detritus (SAFMC 1998a). Large predatory fish, such as Atlantic stingrays, flounders, bluefish, sandbar and other sharks, weakfish, red drum, spotted seatrout, and blue crabs eat small fish, crustaceans and invertebrates that live in seagrass beds (Thayer et al. 1984). Although large finfish predators represent only a small proportion of the fish biomass in SAV habitat, they can be important in structuring seagrass communities and, at times, can uproot grasses or alter the substrate (e.g., cownose ray; Orth 1975).

Corridor and connectivity

For some species, such as blue crabs, SAV can function as a safe corridor between habitats, thereby reducing predation (Micheli and Peterson 1999). In marshes where adjacent SAV was removed, the abundance of grass shrimp declined 27% and was significantly higher where SAV was not removed (Rozas and Odum 1987). Submerged aquatic vegetation adjacent to marshes also provides a refuge at low tide for organisms associated with marsh edge habitat at high tide (Rozas and Odum 1987). Consequently, the catch of fish was also higher at sites with both marsh and SAV, rather than at marsh-dominated sites. In a North Carolina estuary where SAV occurred adjacent to intertidal marsh, pinfish showed more movement, were more abundant, and weighed more than those in areas where SAV was not present adjacent to the marsh edge. These findings indicate that SAV provided a safe passage and offered additional food resources (Irlandi and Crawford 1997). Similarly, another study in North Carolina found that adult fish abundances were greater where marsh, seagrass, and oyster reefs co-occurred, rather than areas with shell bottom alone or shell bottom with marsh (Grabowski et al. 2000). The corridor function of SAV may also apply to other small predators that are more susceptible to predation in open water. Although red drum have a strong association with marsh edge habitat in Gulf coast estuaries (Minello 1999; Stunz et al. 2002), information is lacking for North Carolina. *Examination of the relationship between juvenile red drum abundance in SAV and marsh edge habitat and the effect of spatial connectivity on habitat use should be conducted to support management of this important species.*

4.3. STATUS AND TRENDS

Status of submerged aquatic vegetation habitat

When SAV beds are subjected to human-induced impacts in addition to natural stressors, large-scale losses of SAV may occur (Fonseca et al. 1998). Such losses of seagrass beds have been as high as 50% in Tampa Bay, 43% in northern Biscayne Bay, and 30% in the northern portion of Indian River Lagoon (all in Florida), and as much as 90% in Galveston Bay, Texas, and Chesapeake Bay (Taylor and Saloman 1968; Kemp et al. 1983; Pulich and White 1991; Smith 1998). In North Carolina, SAV loss has not been quantified, but anecdotal reports indicate that the extent of SAV may have been reduced by as much as 50%, primarily from the mainland side of the coastal sounds (North Carolina Sea Grant 1997; J. Hawkins, DMF, pers. com., 2003; B.J. Copeland, MFC, pers. com., 2003). However, since low salinity SAV tends to exhibit large fluctuations from year to year, and because no mapping has been conducted to quantify the reported SAV changes, the extent of loss is uncertain.

In North Carolina, data on trends in SAV distribution are limited to qualitative information or only certain areas of the coast. For example, while SAV currently is concentrated along the sound side of the Outer Banks (Ferguson et al. 1989), elderly fishermen and fishermen's journal accounts from the late 1800s describe extensive beds of SAV in many coves along the mainland where it is absent today (Mallin et al. 2000a). Seagrass wasting disease devastated eelgrass populations throughout the North Atlantic, including North Carolina, between 1930 and 1933, dramatically disrupting estuarine systems. Higher

[47] see Threats section

water temperatures apparently stressed the seagrasses, making them more susceptible to the slime mold protist *Labryinthula* (Steel 1991). Healthy eelgrass beds were generally re-established by the 1960s. Some specific information on SAV changes in Currituck Sound and the Tar-Pamlico and Neuse rivers is given below and is depicted in Table 4.6.

Table 4.6. Timeline of major trends in abundance of submerged aquatic vegetation (SAV) in North Carolina estuaries. [Source: Davis and Brinson 1990; Steel 1991]

Year	Changes in submerged aquatic vegetation in coastal North Carolina
1918 - 1919	Major decline in Currituck Sound due to turbidity from opening Albemarle and Chesapeake Canal
1930	Major decline in eelgrass in Pamlico, Core, and Bogue sounds from seagrass wasting disease
1952	Full recovery in Currituck Sound from improved management of canal locks
1955	Four hurricanes cause major loss to SAV in Currituck Sound, but it recovers within two years
1960	Eelgrass in Pamlico, Core, and Bogue sounds mostly recovered from seagrass wasting disease
1962	Decline in native freshwater species in Currituck Sound due to saltwater intrusion and displacement by non-native Eurasian watermilfoil
1975	SAV common in upper Pamlico River estuary
1985	Significant declines in SAV in upper Pamlico River estuary (1% of pre-1970s levels), western Pamlico Sound, and Neuse River estuary due to excessive sediment loading
1990	Improved erosion control methods and/or weather patterns result in slight recovery of SAV in Neuse and Pamlico estuaries
2002	Reports of increased SAV in Albemarle Sound, possibly due to drought conditions improving water clarity

Currituck Sound has a significant historical record of observations and/or biomass of brackish water SAV (Davis and Brinson 1983). Studies have documented the status of SAV in Currituck Sound since 1909, including a major decline around 1918 attributed principally to increased turbidity (Bourn 1932; Davis and Brinson 1983). The locks of the Albemarle and Chesapeake Canal were opened during this period (Davis and Brinson 1983). This canal connects the Norfolk (Virginia) Harbor at the mouth of the Chesapeake Bay with Currituck Sound, by way of the North Landing River. From 1914 to 1918 the canal was deepened and widened, and the North Landing River was dredged extensively. In 1932, operation of the canal locks was modified, improving the situation, and the SAV began to recover. Submerged vegetation had fully recovered by 1951, with the highest production of submerged aquatic plants in the Currituck-Back Bay system since 1918 (Davis and Brinson 1983). During 1954 and 1955, the occurrence of four hurricanes along the North Carolina coast increased turbidities via sediment suspension and resulted in widespread destruction of plant beds (Dickson 1958). Submerged vegetation in other hurricane-impacted areas of North Carolina may have been similarly affected. However, the SAV community recovered rapidly, as growth was considered good in 1957 (Davis and Brinson 1983). After a severe nor'easter storm in 1962, saltwater intrusion in the sound raised the average salinity slightly (4.4 ppt) and caused major reductions in freshwater SAV biomass (Davis and Brinson 1983). Another likely factor contributing to reductions in northern Currituck Sound was the accumulation of silty, semiliquid dredge spoil in the North Landing River and the resulting turbidity (Davis and Brinson 1983).

As the native SAV beds recovered after 1962, Eurasian watermilfoil (a non-native species) began to spread across Currituck Sound from its northern extremities (Davis and Brinson 1983). The spread of the

exotic plant was probably encouraged by improved water clarity caused by dry conditions and higher salinities after 1962 (Davis and Brinson 1983). Before 1962, native sago pondweed and wild celery were the dominant and subdominant SAV species (Davis and Brinson 1983). By 1973, Eurasian watermilfoil had replaced sago pondweed as the dominated aquatic plant species, followed by bushy pondweed (Davis and Brinson 1983). After a severe storm in 1978, bushy pondweed was virtually eliminated, and total macrophyte biomass was 42% less than in 1973 (Davis and Brinson 1983). Again, the reductions in SAV biomass were associated with extreme turbidity and turbulence associated with the severe weather during the early growing season in 1978. It is apparent from this historical record that SAV coverage and biomass are greatly affected by weather events, site conditions, and human activities that affect turbidity and salinity. This relationship is true not only for Currituck Sound, but also for other coastal water bodies containing SAV.

In the upstream half of the Pamlico River estuary, SAV was common until the mid-1970s (Davis and Brinson 1976; Davis and Brinson 1990). By 1985, SAV biomass had been reduced to about 1% of its pre-1970s biomass (Davis and Brinson 1990). Tidal freshwater SAV (primarily wild celery) was historically abundant in western Pamlico Sound (Copeland et al. 1984), and to a lesser extent, the Neuse River, with pondweeds (*Potamogeton* spp.) and widgeon grass also common (Steel 1991). Submerged aquatic vegetation in these areas declined significantly during the mid-1980s, under excessive sediment loading, and then experienced a resurgence as modest improvements in erosion control promoted an increase in water clarity (Mallin et al. 2000a). This information is derived mostly from many recent complaints about abundant SAV around dock areas (Neuse) and from visual observations and fishermen's anecdotal accounts (Pamlico) (Mallin et al. 2000a). *Regular mapping efforts should confirm the status of SAV in western Pamlico Sound and its tributaries. Ideally, the experimental design should allow inference regarding the cause of any observed changes.*

In 1998, presence and distribution of SAV in the Neuse River estuary were assessed by DWQ, in coordination with NMFS and EPA using aerial photography and field ground-truthing (DWQ 1998). The study area extended from the N.C. Highway 43 bridge north of New Bern downstream to Rattan Bay where the river opens to Pamlico Sound, about 48 river miles (77 km). Distribution of SAV in the Neuse River estuary is shown in Maps 4.3a and 4.3b. Eleven species of SAV were documented at the sample sites. The SAV occurred in multiple small patches along both the north and south shorelines of the Neuse River and its tributaries in water depths ranging from 0.5 to 1.4 m (1.6 – 4.6 ft). Roughly 514 acres (208 ha) of SAV were delineated. North of New Bern, *Nuphar lutea* was the prevalent species found. In the middle of the river, where most SAV occurred, coontail or hornwort (*Ceratophyllum* sp.) was the most common species, followed by wild celery. The largest patch of SAV occurred on the south shore of the river, downstream of the mouth of the Trent River. This large patch was dominated by wild celery. In the lower portion of the river, widgeon grass was most common. Results showed that SAV was present at four of five areas that had supported SAV in 1991, indicating there has not been a major decline in SAV abundance over the seven-year period on the Neuse. More SAV was identified in 1998 than in 1991. However, because of the different methodologies used, change in coverage cannot be accurately assessed.

Some recent, unquantified changes have been noted in SAV distribution and abundance in the Albemarle Sound area and Bogue Sound. Several large eelgrass beds have disappeared in the Intracoastal Waterway in the Morehead City area (Core/Bogue MU) following intensive use of herbicides to control macroalgal growth over the last ten years (Mallin et al. 2000a). During that same time period, large SAV beds near Harkers Island (Core/Bogue MU) have also disappeared following construction activity (Mallin et al. 2000a). In 1988, the shallow waters of Perquimans River were overgrown with dense stands of Eurasian watermilfoil and other species (Steel 1991) (Map 4.2). After Hurricane Floyd in 1999, those dense stands of milfoil had disappeared. Local commercial fishermen reported that the blue crabs had disappeared along with the grass. In 2002, DMF biologists noted high abundance of SAV throughout many shallow water areas of Albemarle Sound and its tributaries, especially in Perquimans River (S. Winslow, DMF, pers. com., 2002). The SAV was reportedly spreading upstream from the lower reaches of the rivers, near

the main body of Albemarle Sound. *Research is needed to verify if a recovery of SAV has occurred and to determine if there is a spatial pattern of that recovery. If there is a pattern, special monitoring and protection should be afforded to those core areas from which SAV begins its recolonization.*

Coast-wide aerial photography of SAV combined with on-site sampling is the standard method for mapping SAV in coastal North Carolina and Chesapeake Bay. The method was last used in North Carolina in the late 1980s to early 1990s (Ferguson and Wood 1994). Regular aerial photography and mapping of the coastal area would provide the necessary information to determine status and trends in SAV distribution, coverage, and health over the long-term. *Coast-wide mapping should be repeated at regular intervals using similar methodology to the early 1990s mapping to determine the current location and quantity of SAV coverage and compare changes over time. In addition to maps of current SAV coverage, a comprehensive map of all potential SAV habitat should also be developed.*

A process to calculate relative wave exposure indices has been completed by NMFS for Core and Back sounds. This process allows identification of areas that have physical characteristics, such as water depth, wave exposure, and currents that are suitable for SAV colonization, which could include SAV habitat. *This process should be conducted in other areas of the coast to identify potential restoration sites for SAV.*

Status of associated fishery stocks

Inadequate data are available to assess if trends in SAV-enhanced fishery species are related to changes in SAV coverage. Of the species identified in Table 4.5 with a preference for SAV habitat, 13 stocks were evaluated for fishery status. The hard clam was assigned an Unknown status. Of the remaining 12 stocks with a designated status, two were designated Overfished (17%), four were Concern (33%), one was Recovering (8%), and five were Viable (42%) (SAFMC 2002; DMF 2003a; Figure 4.1). Specifically, smooth dogfish and tautog were listed as Overfished. The SAV-enhanced stocks given a Concern status included bay scallop, blue crab, Atlantic croaker, and striped mullet. Viable and Recovering stocks included red drum, spotted seatrout, weakfish, shrimp (brown and pink combined), gag, and summer flounder. Whereas much of the cause of declining stock status is attributed to overfishing, habitat loss and degradation can make a stock more susceptible to overfishing. Therefore, protection or enhancement of SAV habitat can be especially beneficial to SAV-enhanced species classified as Overfished or Concern, by maximizing recruitment and productivity.

Trends in fishery data indicate a decline in catch and effort for some prominent SAV-enhanced species. Landings data for bay scallops indicate a long-term decline in catch and effort (Figure 4.2). However, landings and fishery independent sampling indicated that this annual stock showed improved recruitment in Core and Bogue sounds in 2002 (DMF, unpub. data). Blue crabs also appear to be experiencing long-term declines in catch and effort, and possibly reduced abundance in some regions. More fishery-independent information and habitat change analysis are needed to determine the effect of SAV-coverage on the abundance of fish and invertebrates. *To obtain needed information on use and trends of fish utilization in SAV habitat, DMF staff should assess where additional juvenile fish sampling stations are needed and add these to existing sampling programs. Research should be conducted to better assess the relationships of bay scallop and blue crab to SAV and to investigate if long-term declining trends in these fisheries are related to declines in or degradation of SAV.*[48]

[48] Relationships can be generally inferred from habitat studies, which are covered in the Ecological role and function section.

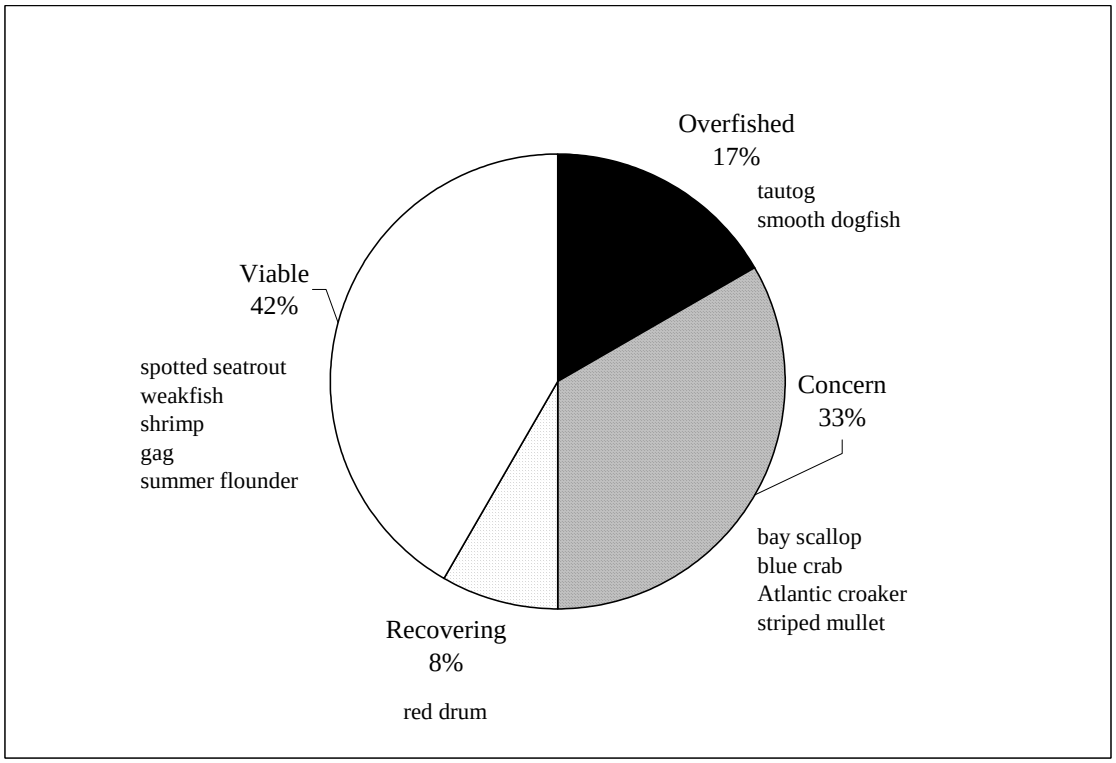


Figure 4.1. Percent of SAV-enhanced fishery stocks classified as Overfished, Concern, Viable, or Recovering in the 2003 stock status report. [Source: DMF 2003a]

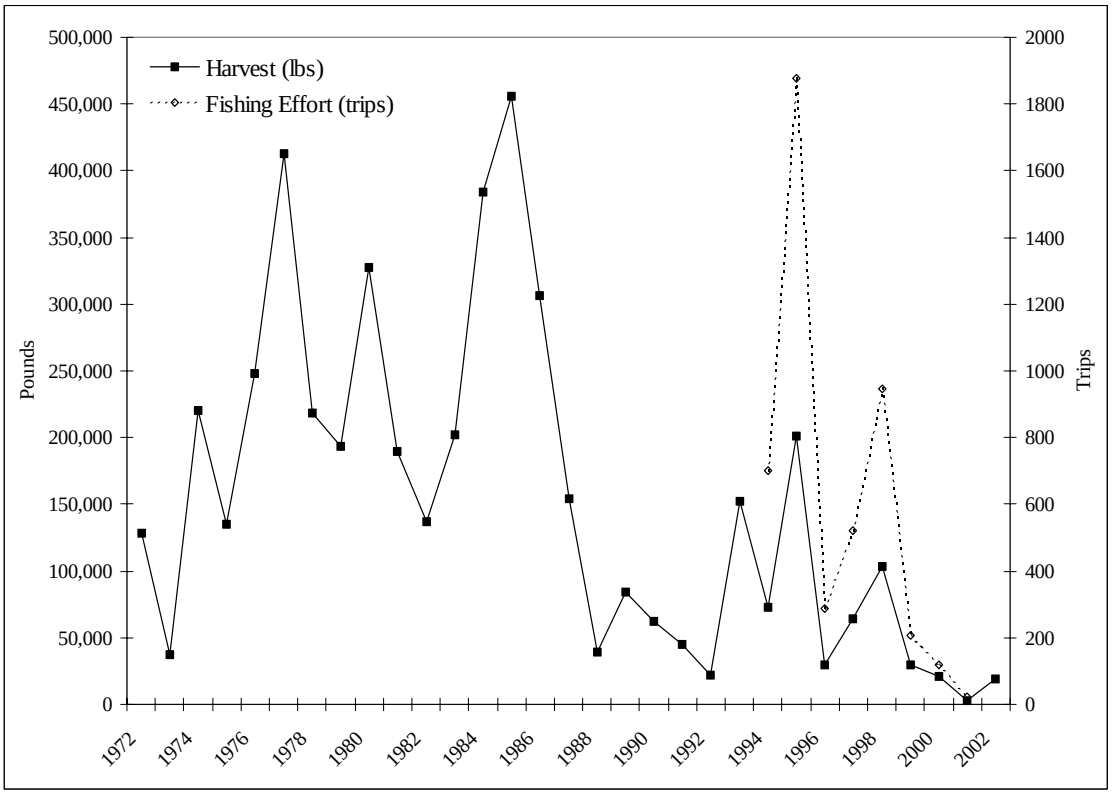


Figure 4.2. Annual commercial landings and fishing effort for bay scallops, 1972 – 2002. [Source: DMF, unpub. data]

Submerged aquatic vegetation restoration

Although protection, rather than mitigation or restoration, is the more environmentally sound and less costly management approach for long-term enhancement of SAV fisheries habitat (SAFMC 1998a), restoration of SAV beds in areas that historically supported this habitat is possible to offset past losses. Seagrass restoration techniques have been developed and evaluated by the NMFS. Depending on environmental variables, a similar faunal community can return, at the earliest, within two years (Fonseca et al. 1998). The success of replanting efforts is often gauged by an evaluation of "functional equivalency." As defined by Fonseca et al. (1998), an area has achieved functional equivalency when "a restored or mitigated system attains [ecological] functions the same as those of an unimpacted system in a similar setting." According to the authors, an impacted seagrass bed has the potential to become functionally equivalent, but not identical, to an undisturbed seagrass bed if a) it is at least equal in space to that of the original area prior to disturbance and b) the seagrass species composition is unchanged and persists after the disturbance. Based on review by Fonseca et al. (1998), the time needed to attain functional equivalency for seagrasses ranges dramatically, from less than two to more than 31 years. Seagrass shoot densities and canopy height can be used to determine when a restoration project has reached functional equivalency (Fonseca et al. 1998). Studies in Florida have found that SAV shoot densities approximately one third as dense as a natural bed supported similar animal densities (Fonseca 1996a; Fonseca 1996b). In North Carolina, beds having 30-40% SAV coverage had penaeid shrimp densities virtually indistinguishable from beds with continuous cover (Murphey and Fonseca 1995). The size of the restored SAV bed can also affect fish utilization. Some organisms, such as larval fish, juvenile blue crabs, and juvenile hard clams, were more abundant in large, contiguous beds than in smaller, patchy beds (Paller 1987; Irlandi 1997; Eggleston et al. 1998). However, even SAV habitats as small as 1-2 m^2 have significantly greater numbers of fish, shrimp, and crabs than found in adjacent sand areas (Fonseca et al. 1998).

Reference materials discussing planting techniques emerged prior to and during the 1970s, but major attention and financial support to study seagrass restoration did not develop until the early 1990s (Fonseca et al. 1998). Prior to that time, the variable track records of SAV mitigation projects, many of which were unpublished or not subject to peer review, discouraged its establishment as a management tool, even though suitable planting methods were available (Fonseca et al. 1998). There have been both failures and successes in seagrass planting (Stein 1984; Thayer et al. 1985). If SAV is not present in an area because of water quality conditions (e.g., insufficient light, excess nutrients), establishment of planted submerged grasses, without improving water quality, is likely to be unsuccessful. Furthermore, EPA (2000) stated that water quality conditions needed to restore underwater grasses are likely to be more stringent than conditions needed to support existing healthy SAV beds. Maintenance of existing beds should, therefore, be a higher priority than restoration. In order to maintain existing SAV habitat, more stringent water quality standards need to be established in those areas. [49]

Restoration of submerged aquatic vegetation is generally conducted for compensatory mitigation, mitigation banking, or research purposes. Benefits of SAV restoration include fish habitat enhancement, sediment and shoreline stabilization, and water quality enhancement. Compensatory mitigation is the replacement of a natural resource, such as a bed of SAV destroyed or severely degraded by a permitted action. Such replacement is often required by the enforcement of Section 404 of the Clean Water Act by the U.S. Army Corps of Engineers (COE) or by state regulations enforced by other regulatory agencies (DCM, DWQ). The intent is replacement of ecological functions such as water quality, habitat, and hydrology. Mitigation is usually also meant to replace an acreage equal to or greater than that which was lost or impacted (<http://dcm2.enr.state.nc.us >, May 2002). Based on data available through the Internet on SAV restoration and mitigation (<http://dcm2.enr.state.nc.us/ims/restsites/srchall.htm>, May 2002), there were 12 SAV restoration projects in Carteret and two in Onslow counties between 1978 and 1991. Of these 14 sites, 11 were considered "successful".

[49] This approach is discussed in the water quality threats section.

Specifically, "success criteria" were identified by DCM as "those conditions which must be met for a mitigation site to be considered successful in order to receive a permit to impact those wetlands…[and the criteria] may include any combination of the following and often include all of the following: vegetation establishment, wildlife use and a hydrologic regime that is characteristic of the target wetland type" (<http://dcm2.enr.state.nc.us/Wetlands/defs.htm#habitat type>, Spring 2004). Three projects were done as N.C. Department of Transportation (DOT) mitigation, while the others were research projects conducted by NMFS. A total of 1.95 acres (0.79 ha) of bottom was restored to SAV by these projects. This area is relatively small compared to restored shell bottom areas. Seagrass restoration projects tend to be more limited due to the relatively high water quality conditions needed for survival of the plants. *Restoration goals for SAV habitat should be established, including goals for SAV acreage, abundance, and species diversity, considering historical distribution and estimates of potential habitat. However, protection of existing SAV beds should be given a high priority.*

4.4. THREATS AND MANAGEMENT NEEDS

Natural events and human-related activities may negatively impact the distribution and quality of SAV. Natural events may include regional shifts in salinity because of drought or excessive rainfall, animal foraging, storm events, cold temperatures or disease.[50] Human-related activities can be broken into two basic categories: physical and water quality. Submerged aquatic vegetation is extremely susceptible to physical disturbance because of its vulnerable location in shallow nearshore waters. Physical threats can negatively affect SAV by inflicting damage or mortality directly, as well as by indirectly influencing future survival, reproduction or establishment through alteration of preferred conditions (e.g., increased turbidity via bottom sediment resuspension). SAV is vulnerable to water quality degradation, and in particular to sedimentation, primarily because of its relatively high light requirements (Fonseca et al. 1998). Moreover, the timing of anthropogenic impacts can have important ramifications for SAV. For example, disturbances that remove eelgrass and their surrounding sediment during the summer and fall months may have the added consequences of eliminating the seed bank that will produce future season's plants and of reducing genetic diversity (P. Biber, NMFS, pers. com., 2003). Human-related impacts to SAV habitat have been documented and summarized by the ASMFC (ASMFC 1997a), the Chesapeake Bay Program (1995), NMFS (Thayer et al. 1984; Fonseca et al. 1998), and others. Much of the information on threats is from these sources.

Physical threats

Channel dredging

Dredging and filling activities were at one time considered to have the greatest detrimental impact on SAV (Thayer et al. 1984). Dredging for creation or maintenance of navigational channels and inlets resulted in removal or destruction of existing grass beds. The change in bottom depth, bottom sediment characteristics, and water clarity that accompanies dredged channels prevents or discourages future growth or establishment of SAV (Stevenson and Confer 1978; Funderburk et al. 1991). SAV habitat can be destroyed if dredged material is placed directly on existing SAV. Potential SAV habitat can also be eliminated if unvegetated soft bottom is filled and converted to an upland spoil island, or dredged to an excessive water depth. The increased water depth in dredged channels reduces light penetration to the bottom, limiting the ability of SAV to colonize the area. In addition, dredged channels tend to refill with finer sediments (Thayer et al. 1984; Bishof and Kent 1990) that are easily resuspended by currents or boat wakes. The resulting chronic elevated turbidity and sedimentation can reduce light penetration to levels that reduce or eliminate productivity of adjacent grass beds and make colonization of unvegetated areas difficult (Thayer et al. 1984). Turbidity from dredging of fine sediments, such as mud bottom, is usually more severe and persistent than dredging of coarse sand bottom.[51]

[50] Changes in SAV coverage due to changing salinity patterns were discussed in the Status and Trends section.
[51] Refer to the "Habitat Requirements" section for the light and sediment conditions needed for SAV colonization

Loss of SAV habitat from dredge and fill activities has been particularly severe in bays with major ports or metropolitan areas, such as Tampa Bay, Galveston Bay, and Chesapeake Bay (Taylor and Saloman 1968; Thayer et al. 1984). North Carolina's ports in Wilmington and Morehead City are small in comparison. No SAV occurs in the vicinity of the Wilmington port. In contrast, considerable SAV loss may have occurred in Morehead City when the port's turning basins and access channels were originally dredged, given that nearby, similar yet undredged areas within Bogue Sound support SAV. Maps 4.5a-b show the location of the ports, navigational channels and marinas in coastal North Carolina and their proximity to SAV. Because almost all of the eastern shoreline of Core Sound and the southern shoreline of Back Sound are undeveloped (Shackleford and Core banks), the grass beds in that area have not been highly impacted by channel dredging, marinas, or docks.

Current state and federal regulations minimize impacts to SAV from permitted dredge and fill activities, particularly those associated with private development, and have reduced the severity of this threat (SAFMC 1998a). Although dredging is currently prohibited in SAV beds, maintenance excavation "essential to maintain a traditional and established use" is approved if four criteria are met [15A NCAC 07H .0208]: "(i) the applicant demonstrates and documents that a water-dependent need exists for the excavation; (ii) there exists a previously permitted channel which was constructed or maintained under permits issued by the State or Federal government (if a natural channel was in use, or if a human-made channel was constructed before permitting was necessary, there shall be clear evidence that the channel was continuously used for a specific purpose); (iii) excavated material can be removed and placed in an approved disposal area without significantly impacting adjacent nursery areas and beds of submerged aquatic vegetation; (iv) the original depth and width of a human-made or natural channel will not be increased to allow a new or expanded use of the channel."

Although the COE maintains 6,992 acres (2,829.56 ha) of navigation channels in coastal North Carolina (COE, unpub. data), the quantity dredged in a typical year will likely amount to less than 1,000 acres, the majority of which is restricted to maintenance dredging in deep water ports and ocean inlets (J. Sutherland, DWR, pers. com., 2004). Nevertheless, some of these channels may be adjacent to or bisect SAV occurrence (Maps 4.5a-b). New public dredging projects that could potentially impact SAV continue to be proposed. For example, relocation of a ferry landing at the north end of Ocracoke Island might require dredging a new access channel through seagrass. Realignment of an existing navigational channel through Bogue Inlet as part of the Emerald Isle beach nourishment project could destroy existing SAV habitat directly and indirectly through changes in scouring patterns of inlet currents. Alternative proposals often require weighing the impact of one habitat versus another. As the coast becomes more developed, additional projects involving SAV impacts are likely to occur. *The DMF and MFC should continue to use existing permit review authorities and CRC and EMC should provide more protection to SAV within existing permitting authority to prevent or limit as much as possible direct or indirect impacts to SAV from all dredge and fill projects.*

Infrastructure

Other public works projects that can impact SAV include placement of infrastructure, such as bridge supports and fiber optic cables, on submerged lands. Bridge construction and replacement have resulted in SAV loss in several areas of Florida (Fonseca et al. 1998). In North Carolina, two bridge projects on the Outer Banks could result in SAV loss. Replacement of the Oregon Inlet bridge with a new bridge and extended causeway behind Pea Island could cause direct impacts to the grass beds west and south of the current bridge, as well as indirect impacts from changing current patterns and scouring. Also, a new bridge is proposed to cross the middle of Currituck Sound. The proposed location is in the vicinity of the largest concentration of SAV in Currituck Sound, but the project is in the early stages of development and could change substantially. Laying of fiber optic cables across submerged bottom can also damage SAV

where trench excavation is used (Nero 2001).[52] Impacts to SAV can be minimized by use of directional drilling technology. This method involves drilling a small tunnel under the seafloor instead of dredging a trench from the seafloor surface. *Infrastructure projects that require SAV impacts should be avoided. Where impacts are unavoidable, SAV losses should be minimized and adequately compensated through mitigation, using methods recommended by NMFS for SAV restoration or creation. Such projects should be monitored over time to determine persistence of restored SAV beds.*

Boating activity

Direct physical impacts from propeller scarring, vessel wakes, and mooring scars have recently been identified nationally as a major and growing source of SAV loss (Sargent et al. 1995; ASMFC 1997a; Fonseca et al. 1998). Propeller scarring of SAV occurs when outboard vessels travel through water that is shallower than the draft of the boat. The propeller cuts the plants' leaves, roots, and stems, as well as creates a narrow trench through the sediment. The damaged area is referred to as a "prop scar" (Sargent et al. 1995). A "blow hole" may also be excavated where boaters attempt to rapidly power off the shallow bottom (Kenworthy et al. 2000). Mechanical disturbance to sediments damages the plant's rhizomes, which reduces plant abundance and cover for extensive periods of time, sometimes for many years. Recovery of SAV can take anywhere from two to 10 years, depending on the SAV species and local conditions, or in some cases, the habitat may never recover (Zieman 1976; ASMFC 2000). Once started, SAV damage can increase beyond the initial footprint of the prop scar due to physical scouring by tidal currents, storms, or biological disturbance such as crab and ray burrowing (Patriquin 1975; Townsend and Fonseca 1998). As long as the affected areas are unvegetated, their ecological value is reduced (Fonseca et al. 1998).

In some areas, particularly in Florida, watercraft have severely scarred seagrass beds (Sargent et al. 1995). Prop scarring was identified as an increasing problem in some areas of Chesapeake Bay as well (Funderburk et al. 1991). In both locations, increasing occurrence of prop scarring was associated with an increasing human population, as well as an increasing number of registered vessels (Hurley 1990; Sargent et al. 1995). Preliminary aerial observations of high salinity grass flats in North Carolina indicate that damage to SAV from propeller scarring is currently not a significant problem. However, as the human population along North Carolina's coast increases, so will the number of boats. From 1990 to 2000, the permanent population of Dare County, which borders most of the high salinity SAV in Pamlico Sound, increased by 31%, while the population of Carteret County, bordering Core and Bogue sounds, increased by 13% (Table 1.2). In addition, the seasonal (summer) population in barrier island municipalities jumped three to as much as 53 times more than the permanent population in 2000 (Table 1.3). Many of the seasonal visitors are also recreational boaters. The permanent population adjacent to waters with low salinity SAV has also increased at varying rates. Along the western shore of Pamlico Sound, population increased 12% in Craven County, 14% in Pamlico County, and 6% in Beaufort County. In northeastern North Carolina, the permanent population of Currituck County grew by 32%, while the counties along tributaries of Albemarle Sound increased by 7-16%. During this same time period, the number of registered boats in North Carolina increased by about 40% (Figure 4.3). As the number of boaters in North Carolina continues to increase, the potential for damage to SAV via prop scarring is likely to increase, as has happened in Florida and Virginia. *Educational outreach is needed to increase awareness by the boating public of the ecological value of SAV and the damaging effects of boat propellers to SAV habitat. The level of damage to SAV from prop scarring should be assessed periodically. In areas where boating activity is found to cause significant SAV impacts, navigational markers should be installed to clearly delineate navigational channels to be used or SAV beds to avoid.*

[52] More information on the use of fiber optic cables in fish habitats is included in the hard bottom chapter of the CHPP

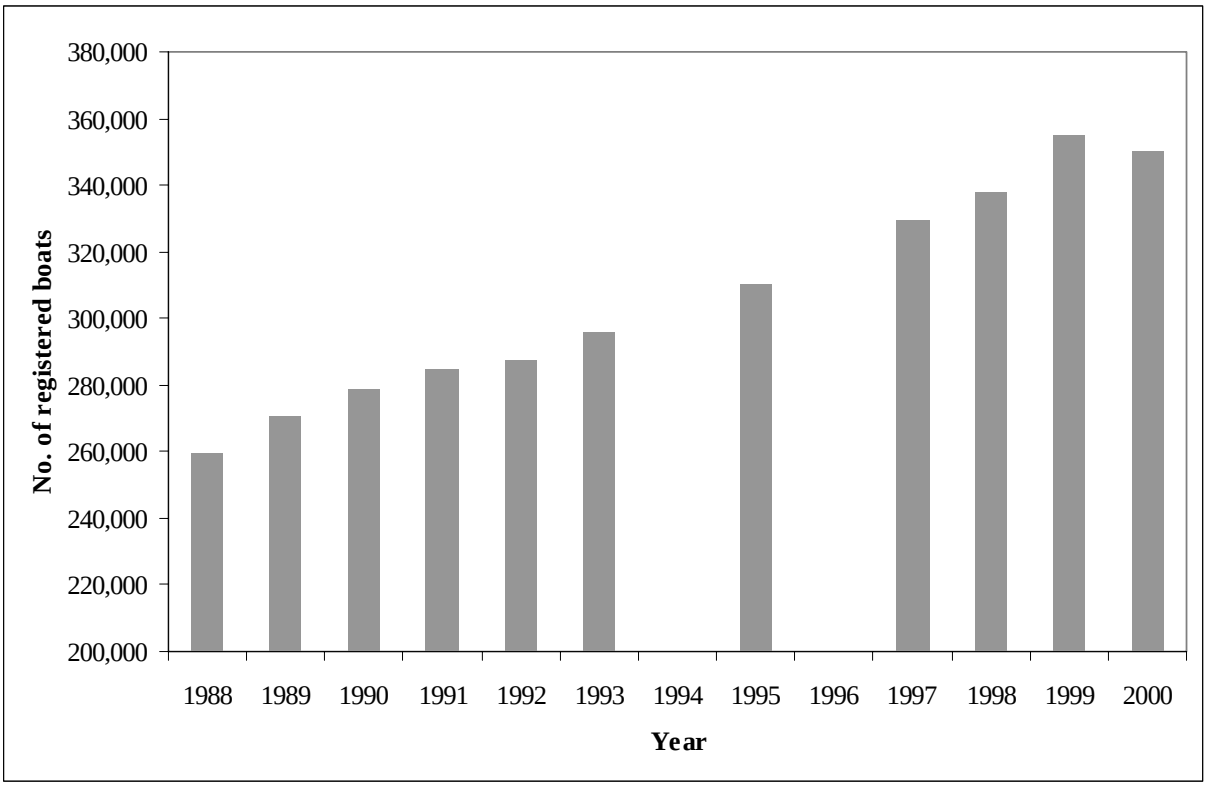


Figure 4.3. Total number of registered boats in North Carolina (no data for 1994 and 1996). [Source: C. Murphey, North Carolina WRC, 2001]

Marinas and docks

Marinas and docks impact SAV in several ways. During construction, placement of pilings or dredging of basins may destroy SAV. Once dredged, boat basins, like navigational channels, reduce light availability at the seafloor because of the increased depth, or change the sediment composition so that SAV cannot survive or recruit into the area (Stevenson and Confer 1978). Shoreline hardening structures associated with docking facilities (bulkheads) impact SAV by increasing wave energy and scour along the shoreline where SAV may occur, and by reducing shallow water habitat where SAV exists or could potentially colonize (Funderburk et al. 1991).

Shading from docks also results in loss of SAV beneath the dock structures. In a study in the Indian River Lagoon, Florida, light availability was reduced under docks that were 3 ft (0.91 m) and 5 ft (1.52 m) high to 11 and 14% of ambient light, which is less than the minimum amount needed (15-25%) for growth and survival of seagrass (Beal and Schmit 1998). Light availability increased with increasing dock elevation, and was significantly greater under the higher dock (5 ft or 1.52 m). The Florida Department of Environmental Protection (unpub. data) assessed the impact of dock shading to SAV in Palm Beach County, Florida, and found that 45% of surveyed docks had SAV around them but no SAV under them. Shading effects extended 1–3 m (3.28 - 9.84 ft) to either side of the docks. Seagrass presence was strongly correlated with dock height for docks ranging from 0–5.5 ft (1.68 m) above mean high water (MHW). Other studies in Florida found significantly less SAV under docks than in adjacent unshaded areas (Loflin 1995), and no seagrasses under docks having light levels less than 14% of surface irradiance (Shafer 1999). Offshore mooring of boats for extended periods of time in one location has also been shown to result in SAV loss in a circular area beneath the boat due to shading or damage from anchor and chain movement (Fonseca et al. 1998). These small individual losses of SAV may seem insignificant, but they can have significant cumulative impacts. The location of marinas and public boat

access areas relative to SAV is depicted in Maps 4.5a-b.

In addition to direct damage from docks and marinas, indirect damage to SAV can result from boating activity associated with these structures. Shoals and other shallow bottoms supporting SAV may become scarred as boating activity to and from the docking areas increases. Boat wakes can destabilize and erode SAV beds, or resuspend sediment, reducing light penetration. As additional docks and marinas are constructed along the coast, the potential for boating-related damage increases. Based on marina records from DCM and SAV distribution maps, there are at least 104 marinas within 0.5 mi (0.81 km) of mapped SAV beds (Maps 4.5a-b). *Direct, indirect, and cumulative impacts to SAV and other habitats from marina and dock siting should be minimized. Development of a comprehensive state marina policy is needed to achieve this objective.*

Along the southeast coast of Florida, there are stringent standards for dock construction to minimize impacts to SAV. In John Pennekamp Coral Reef State Park in the Florida Keys, docks are prohibited over park bottom because of the documented impacts to SAV from construction, shading, and boating activity associated with the docks (R. Skinner, F.L. Park Service, pers. com., 2002). In other areas, the total square footage, width, or minimum height is limited. In aquatic preserves, guidelines for dock construction at one time required that access piers be five feet (1.52 m) above MHW with half inch (1.27 cm) deck spacing to allow more light to reach beneath the structure (Beal 1999). A minimum water depth of four feet (1.22 m) mean low water (MLW) at the dock end is required in most areas, and in some areas, a dock may not be permitted if deep-water access is not available (minimum of 4 ft [1.22 m] water depth MLW from dock to offshore waters).

In North Carolina, the depth of water at the dock end is not considered in CRC rules. With some exceptions, dock length is limited to no more than 25% of a water body's width, and cannot extend into navigation channels and should not extend beyond the length of other piers along the same shoreline. To minimize shading effects to wetland plants, CRC rules require a dock height of at least three feet (0.91 m) above the wetland substrate, and a pier width of no greater than six feet (1.83 m) [CRC rule 15A NCAC 07H.0208 (6)]. However, there is no requirement for height above the water surface. Total shading of the bottom by piers and docks is limited by a requirement that pier surface area associated with a given waterfront lot may not exceed a combined total area of four square feet per linear foot of adjacent shoreline. *Research is needed to determine if adequate light is available beneath North Carolina docks, given the current CRC dock siting criteria. These criteria should be evaluated to determine if existing requirements are adequate for SAV survival and growth and what changes would be needed to allow at least the minimum amount of light beneath docks. The permit requirements for docks and piers may need to be changed accordingly.*

The cumulative impacts from dock structures in rapidly developing coastal subdivisions must also be considered. The DCM has the authority to deny coastal development permits based on cumulative impacts. However, the research and modeling tools necessary to determine criteria for denial are lacking. *Any research and modeling effort conducted on dock impacts should address the cumulative impact of shading, turbidity, boater access, and other impacts on the quality and quantity of SAV beds.*

Fishing gear impacts

Several bottom disturbing fishing gears have the potential to destroy or damage SAV. The ASMFC SAV policy (ASMFC 1997b) urged development of technical guidelines and standards to objectively determine fishing gear impacts and develop standard mitigation strategies, in cooperation with NMFS and FWS. In North Carolina, the Fisheries Moratorium Steering Committee's Habitat Subcommittee identified specific habitat impacts from various commercial and recreational fishing gears used in North Carolina waters, and made recommendations to minimize such impacts (MSC 1996). The Fisheries Moratorium Steering Committee presented the summary of findings to the Joint Legislative Commission on Seafood and Aquaculture of the General Assembly. Fishing gear found to be potentially damaging to SAV is listed in

Table 4.7.

Table 4.7. Fishing gears used in North Carolina identified as potentially damaging to submerged aquatic vegetation habitat. [Source: MSC 1996]

Severe damage	Moderate damage	Low damage or unsure
Oyster dredge	Crab trawl	Long haul seine
Crab dredge	Clam Tongs	Otter trawl
Hydraulic clam dredge		Clam hand rake
Clam trawl (kicking)		Bay scallop dredge (very little)
Bull rake		

Damage from fishing gear varies in severity. Shearing or cutting of the leaves, flowers, or seeds, and uprooting of the plant without major disruption of the sediment, are most often caused by dragging or snagging of gear, such as long haul seines or bottom trawls (ASMFC 2000). Bull rakes and large oyster tongs can uproot SAV and cause substantial damage, while hand rakes are more selective and cause less damage (Thayer et al. 1984). Shearing of above ground plant biomass does not necessarily result in mortality of SAV, but productivity is reduced since energy is diverted to replace the damaged plant tissue, and the nursery and refuge functions are reduced in the absence of structure. Some fishing practices can cause severe disruption of the sediment and damage the roots of SAV. The ASMFC (2000) discussed several impacts of fishing gears on SAV. Belowground effects, such as those from toothed dredges, heavy trawls, and boat propellers, may cause total loss of SAV in the affected area, requiring months to years to recover. SAV can be buried by excessive sedimentation associated with trawling, dredging, and propeller wash. High turbidity from use of bottom-disturbing fishing gear can reduce water clarity, affecting SAV growth, productivity, and in some cases, survival.

All toothed dredges can cause severe damage when pulled through SAV. Dredges, like trawls, are dragged across the bottom and organisms are caught in a net or cage. Oyster and crab dredges are essentially the same gears, although a few fishermen may use longer teeth to take blue crabs. Both oyster and crab dredges are limited to a weight of 45.36 kg (100 lb) in North Carolina [MFC rule 15A NCAC 03J .0303 (a)]. Oyster and crab dredges have a metal frame less than 1.52 m (5 ft) wide to hold the net open and a blade at the bottom of the frame to which teeth are attached for digging the target species out of the bottom (crabs) or breaking them off from adjoining material (oysters). Qualitatively, damage to eelgrass meadows caused from unspecified dredges used to harvest shellfish was surpassed only by damage associated with propellers (Thayer et al. 1984). Because oyster and crab dredges affect bottom structure, there are strict limits on their use in North Carolina.

Use of crab dredges is restricted to an area in northern Pamlico Sound west of Oregon Inlet [MFC rule 15A NCAC 03R.0109]. In recent years, crabs have not been dredged from areas where SAV was present. However, the designated area overlaps with SAV habitat and could become a problem. Based on SAV data from the late 1980s and early 1990s (Ferguson and Wood 1994), there are 15,560 acres (6,296.91 ha) of SAV within the designated crab dredging area. Crab dredge effort is very low, with roughly 10 crab dredge trips annually in recent years. Use of oyster dredges is currently restricted to parts of Pamlico Sound and its tributaries. The majority of high salinity SAV occurs in areas where the mechanical methods for oyster harvesting are prohibited. However, brackish and freshwater SAV in western Pamlico Sound is generally unprotected from dredging, except in PNAs and SNAs.[53] However, there has been relatively little oyster dredging in the Neuse or Pamlico rivers in recent years, indicating that most potential problems are in Pamlico Sound. Submerged aquatic vegetation will not be able to recolonize areas that historically supported SAV if they continue to be dredged. *Research is needed to determine*

[53] The cumulative number of oyster dredge trips reported in Pamlico Sound varies annually: 224 trips (1997), 1,298 trips (1998), 239 trips (1999) and 691 trips (2000) (DMF, unpub. data).

where there is suitable potential SAV habitat along the mainland shorelines of the Albemarle-Pamlico system for the purpose of establishing defined SAV restoration goals. Once determined, oyster dredging should be prohibited from areas targeted for SAV restoration.

Bay scallop dredges, in contrast to oyster and crab dredges, cause less severe damage to SAV because they are smaller (not over 50 lb (22.68 kg)) and have no teeth. They are intended to glide along the substrate surface, taking bay scallops lying on the surface within SAV beds. Bay scallops depend on SAV for initial post-larval setting, so they are strongly associated with SAV beds. An evaluation of impacts to eelgrass (*Zostera marina*) from bay scallop dredging in North Carolina found that scallop dredging over grass beds significantly reduced the biomass, surface area, and shoot density of eelgrass (Fonseca et al. 1984). The impacts were more severe in soft bottom compared to harder bottom. Full recovery was estimated to take up to two years. Because bay scallop populations in North Carolina typically spawn between August and December (Fay et al. 1983c), eelgrass leaves are most needed for attachment of juveniles (the next season's scallop crop) during the winter, which is also the time of maximum fishing effort (Fonseca et al. 1984). However, most damage observed by DMF staff has not been from the dredge, but from propeller scarring while pulling the dredge, particularly when the season opening coincides with low tide (T. Murphey, DMF, pers. com., 2002).

The area fished with bay scallop dredges in the Albemarle-Pamlico region (Cunningham et al. 1992) encompasses approximately 46,000 acres (18,615.54 ha) of mapped SAV in eastern Pamlico, Core, Back, and Bogue sounds. Bay scallop landings have been quite variable in recent years, ranging from about 201,000 lb (91,172.07 kg) in 1995 to only 19,000 lb (8,618.26 kg) in 2002. Bay scallops are an annual crop with availability dependent on the previous year's spawning success and survival. Therefore, fishing effort is also quite variable. Reported scallop dredging trips in Core and Bogue sounds have generally declined from 1994 to 2000, peaking at around 1,800 trips in 1995 and falling to fewer than 15 trips annually by 2002 (DMF, unpub. data). Bay scallop dredges accounted for 62-92% of the harvest during 1994-1998, but only 38% in 1999, and 3% in 2000. Most of the catch is now taken by various hand methods. The low dredge effort is due to very short periods of time open for dredging and reduced bay scallop stocks in recent years. To reduce SAV impacts, DMF allows hand harvest methods for bay scallops early in the season, followed by proclamations to open scallop dredging later in the season, starting on a high tide. This management practice is based on the presumption that the majority of the scallops have been hand harvested in the shallow beds prior to allowing dredging. By opening the first day of dredging on a rising or high tide, damage to SAV by propeller scarring from dredging vessels is minimized because the water depth is approaching or at its maximum (T. Murphey, DMF, pers. com., 2002). At that time, dredgers can harvest the few scallops hypothetically remaining in the shallow beds and then, during the course of the day, move out to the deeper water. *Research should be conducted to determine whether gear impacts or other factors are causing the decline observed in bay scallop landings that was discussed in the Status and Trends section. If current bay scallop harvesting methods are found to negatively impact SAV and bay scallop populations, the DMF and MFC should consider rotation of fishing areas, as recommended in Fonseca et al. (1984), or other fishery management techniques.*

Hydraulic clam dredging can cause severe impacts to SAV. This gear directs high-pressure water jets into the bottom to blow surface sediment away and expose clams. The clams are then captured by the dredge head and brought to the surface on a conveyor belt. Hydraulic dredges dig trenches in the bottom, create mounds of discarded material, and redistribute bottom material (Adkins et al. 1983). When hydraulic clam dredging occurs in SAV beds, it digs up all vegetation in a swath approximately three feet (0.91 m) wide (ASMFC 2000). Hydraulic clam dredging can also significantly increase local turbidity (ASMFC 2000). Because of the severe impacts on the bottom, the MFC and DMF restrict use of this gear to open sand and mud bottoms, including areas frequently dredged as navigation channels, such as sections of the Atlantic Intracoastal Waterway. This gear is not allowed in SAV or oyster beds and the restrictions are strictly enforced. On average, about 38 vessels make more than 600 hydraulic clam dredge trips to harvest about 72,000 lb (32,658.65 kg) of clam meats annually (DMF, unpub. data).

Another method of mechanical clamming is clam kicking. Several kicking techniques have been developed over time (e.g., anchor, bedstead, oyster drag, clam trawl); each technique uses different gear but all rely on propeller backwash to expose clams buried in the sediment to facilitate their harvest (Guthrie and Lewis 1982). The most prevalent technique currently employed in North Carolina is the clam trawl, in which a small, heavily weighted trawl is towed approximately 15 feet (4.6 meters) behind a kicking vessel (Guthrie and Lewis 1982). These vessels are modified or weighted so that the stern is low in the water, to achieve a more efficient angle and depth at which to force or deflect the propeller backwash into the bottom, thereby displacing the substrate so that the buried clams are collected in the trawl (Guthrie and Lewis 1982). Although the size of associated nets and trawl boards varies according to boat size and water depth, most kicking activities are restricted to depths below about 10 feet (3 m) (Guthrie and Lewis 1982). Some areas where this method is used (open waters of Core Sound, southeast Pamlico Sound) contain clams that otherwise might not be harvested because the areas are exposed to the wind, making it difficult for fishermen to use clam tongs. The methods and gears associated with kicking can also cause severe damage to SAV. Peterson et al. (1987) found that clam kicking reduced plant biomass in eelgrass and shoalgrass beds. Loss of SAV biomass and time needed for recovery increased as intensity of clam kicking increased (Peterson et al. 1987). The probability of historic damage to SAV via kicking seems likely to be high, given that kicking techniques were first experimented with in eastern North Carolina during the 1940s, that almost 150 kicking vessels operated in 1980 in Carteret County alone, and that kicking vessels tend to operate in shallow waters (Guthrie and Lewis 1982).

Because of the severe disturbance to the bottom, clam kicking is restricted to open sand areas in Core and Pamlico sounds, and Newport, North, New, and White Oak rivers (Maps 4.4a-b). The fishery is managed intensively, with strong enforcement to prevent clam kicking outside the designated areas. Much of the designated mechanical clamming areas have SAV in close proximity to them, so vessels that fish illegally outside the open areas may severely impact SAV. Turbidity generated by clam kicking may also affect adjacent SAV beds. Annual effort in this fishery varies.[54] During 1994 - 2000, clam kicking accounted for about 6-12% of the annual commercial hard clam harvest in North Carolina. Mechanical clamming, including kicking and dredging, accounts for about 21% of annual hard clam landings. High salinity SAV species are more likely to be impacted by mechanical clamming practices due to the location of the fishery.

The Fisheries Moratorium Steering Committee (MSC 1996) recommended that existing areas for mechanical harvest remain, but not be expanded. However, opening a new mechanical harvest area in southeast Pamlico Sound was raised as an issue during development of DMF Hard Clam FMP. The area selected contained SAV, particularly in the shallower water. The final DMF Hard Clam FMP (DMF 2001b) added this location as a new mechanical clam harvest area, but restricted harvest to deeper waters where SAV was not present. This new area in southeast Pamlico Sound will be rotated with existing mechanical harvest areas in Core Sound to allow recovery of clam populations in each area. Turbidity and non-compliance with area restrictions could potentially damage surrounding SAV. *Turbidity impacts to SAV at this new location and other existing mechanical harvest areas should be assessed through water quality monitoring.*

Hand gears can also cause varying amounts of damage, but generally to smaller areas than mechanical gears. A hand clam rake looks similar to a garden rake, usually with nine teeth or less. Clam rakes are pulled through the sediment to obtain clams; different techniques are associated with different types of rakes, which reach different depths (Peterson et al. 1983). A bull rake is a large heavy clam rake having 18 to 24 teeth and a basket attached behind the teeth to catch the harvested clams. The length and spacing of the teeth are designed to prevent harvest of undersized clams. Clam tongs, similar to oyster tongs, are a pair of rakes attached to the end of two long poles which are fastened together like a pair of scissors.

[54] Clam kicking effort: 640 trips (1994), 824 trips (1995), 1095 trips (1996), 1116 trips (1997), 1083 trips (1998), 1162 trips (1999) and 364 trips (2000) (DMF, unpub. data).

Bull rakes and large clam tongs can uproot SAV and cause substantial damage to grass beds, while hand rakes are smaller and lighter in weight, and cause less damage. (Thayer et al. 1984). A comparison of the impact of bull rakes and hand rakes on SAV found that a bull rake removed over 80% of the shoots, roots, and rhizomes in a completely raked area, while a hand rake removed 55% of shoots and 37% of roots and rhizomes (Peterson et al. 1983).

Hand clam rakes are used to take intertidal clams during all tidal stages, but are used mostly by recreational clammers during low tide (Cunningham et al. 1992). Clamming with hand rakes occurs in areas around Ocracoke Inlet in eastern Pamlico Sound and in the higher salinity sounds, rivers, and creeks from Core Sound south through Brunswick County. Bull rakes are used by commercial clam fishermen in the same general area, primarily in deeper water (such as New, White Oak, Newport, and North rivers) or during colder months. Many of the bull rake areas are in close proximity to significant SAV beds. Clam tonging occurs primarily in limited areas where there is very little known SAV. Current MFC rules prohibit use of bull rakes and clam tongs in SAV [MFC rule 15A NCAC 03K.03049 (a) (2)]. Use of hand rakes and clamming by hand are allowed.

Long haul seines have been reported to cause little or no damage to SAV. A long haul seine is a long (more than 1,000 yd or 914.4 m) net that hangs in the water from the surface to the bottom. The top of the net is suspended at the surface with floats, and the bottom line ("leadline") is weighted so that it will skim the estuarine bottom. Both ends are pulled slowly through the water by boats until the end of the "haul" (Guthrie et al. 1973; DeVries 1981). The extent of damage from haul seining is dependent upon seine length, weight, and the density and height of the SAV. Possible damage includes shearing of the leaves or reproductive structures.

Long haul seine fishing is used in Croatan and Roanoke sounds; northern and eastern portions of Pamlico Sound along the Outer Banks; portions of the Pamlico River estuary, including the Pungo River and adjacent areas of western Pamlico Sound; and also in portions of the Neuse River estuary, West Bay, Core and Back sounds, and North River (Cunningham et al. 1992). These areas include approximately 78,148 acres (31,625.37 ha) of mapped SAV. The Fisheries Moratorium Steering Committee (MSC 1996) recommended that research be conducted to assess bottom damage associated with long haul seines. A study conducted in Chesapeake Bay found no detectable effect from this gear on plant height, density, or species composition of brackish SAV (wild celery and *Hydrilla*) in Chesapeake Bay (Sadzinski et al. 1996), indicating no need for further restrictions to protect SAV. However, use of the gear differs between North Carolina and Chesapeake Bay, with much larger nets used in North Carolina. Peak use of long haul seines occurred during the 1970s and 1980s, with far less effort in recent years (about 50–60 crews active during the peak, down to 20–25 crews by the early 1990s (DMF 1993)). Trip ticket data indicate that the number of seine trips has fallen by more than half from the 1994–1996 period to the 2000–2002 period (DMF, unpub. data).

An otter trawl is another gear that may impact SAV. A trawl consists of a conical net towed behind a fishing vessel at various locations in the water column. Most types of trawls used in North Carolina are held open by water pressure against a pair of "otter boards" or "doors" attached to the front of the net. Bottom trawls used to catch shrimp, crabs, and finfish are towed along the bottom, and both the bottom weighted line ("leadline") at the opening of the net and part of the doors dig into the bottom. Many shrimp trawl fishermen attach a "tickler" chain in front of the leadline to cause shrimp to jump off the bottom in front of the net. The tickler chain also digs into the bottom to some degree.

Many studies have shown that trawling can have severe impacts to sensitive bottom habitats (Auster and Langton 1999, Collie et al. 2000). Because almost all shrimp and crab trawling occurs on sand/mud bottoms, the least complex bottom types, habitat impacts may be relatively low (Auster and Langton 1999). Where trawling does occur over SAV, impacts may occur from the dragging of the net across the seafloor and the digging of the trawl doors into the sediment (ASMFC 2000). It is estimated that the

maximum cutting depth for otter trawl doors ranges between about an inch and a foot (2.54–30.48 cm) when used in depths over about 100 ft (30.48 m) (ASMFC 2000), although such deep water does not occur in North Carolina's estuaries. The variation is due to differences in gear weight, bottom hardness, and towing warp to depth ratio (a measure of the force of the gear). Trawl doors were found to penetrate the bottom more than the rest of the gear (ASMFC 2000). Crab trawling impacts to SAV are expected to be more severe than shrimp trawling because of the heavy chain used on the bottom line. However, far fewer crab trawl trips (about 2,000) occur annually than estuarine shrimp trawl trips (about 10,000).

The greatest use of trawls in North Carolina is in the shrimp fishery, with about 13,000 trips annually during 2000–2002. About 75% of the trips occur in estuarine waters, and the rest are mainly within the U.S. Territorial Sea (0-12 nautical miles or 22.22 km). Shrimp trawls are used primarily in Croatan, Roanoke, and Pamlico sounds; the Pamlico, Pungo, Bay and Neuse rivers; and in Core, Back, and Bogue sounds, including the New, White Oak, Newport, and North rivers (Cunningham et al. 1992). The areas open to trawling cover approximately 20,035 acres (8,107.88 ha) of mapped SAV. Trawling is not allowed in designated Primary or Secondary Nursery Areas (PNA, SNA) or No Trawl Areas (NTA) (Maps 3.5a-c). Low-salinity SAV beds occurring along the western shoreline of Pamlico Sound and its tributaries are protected from trawling primarily by the PNA and SNA regulations. The No Trawl Areas primarily protect high salinity SAV located along the eastern edge of Pamlico Sound, and a few areas along the western shoreline of Pamlico Sound, as well. Trawling is also prohibited in Currituck and Albemarle sounds. Core Sound and a large portion of Bogue Sound, which both contain significant amounts of SAV, are open to trawling. The average annual harvest of shrimp in Core and Bogue sounds is about 893,000 and 338,000 pounds (405,057.99 and 153,314.22 kg), respectively. The harvest indicates a substantial trawl fishery in these areas.

Fishery restrictions already exist for most of the gears used in North Carolina that are potentially damaging to SAV. Based solely on numbers of trips and SAV acres covered, trawling in Core and Bogue sounds has the greatest potential for significant fishing gear impacts on SAV. However, without knowing the specific areas affected per fishing trip, it is difficult to evaluate the impact of these fishing gears on SAV habitat. *Field studies are needed to assess the effect of shrimp and crab trawling on SAV in North Carolina, particularly in Core and Bogue sounds. In addition, the boundaries of No Trawl Areas should be evaluated and adjusted, if necessary, to adequately protect all high salinity SAV beds and provide a buffer of unvegetated area to reduce turbidity impacts. Additional law enforcement may be needed to enforce buffers around SAV.*

In identifying potentially damaging fishing gear, the ASMFC recognized that varying physiological and habitat requirements of the different species of marine, fresh, and brackish water SAV affects their susceptibility to damage and their ability to recover (ASMFC 2000). Characteristics of concern include light requirements, location of asexual and sexual reproductive structures, dependence on sexual or asexual reproduction for maintenance and growth of beds, and ability to recover from plant damage. Species having higher light requirements (i.e., eelgrass) or whose growth and vegetative reproduction are primarily above ground or just below the sediment surface (i.e., pondweed) are more vulnerable to above-ground disturbance (ASMFC 2000). Seagrass beds composed of species that rely primarily on vegetative spreading (asexual reproduction) recover more slowly (many years) than those with species that rely more heavily on seed set and sexual reproduction (1–2 growing seasons) (Fonseca et al. 1998).

Many factors affect recovery, including the magnitude of the injury, the amount of stored energy reserves in the plant, seed or tuber set before disturbance, and local environmental conditions. Taking as many factors as possible into account, the SAV workgroup of the ASMFC estimated the relative ability of different SAV species to recover from physical impacts. The overall recovery potential of species occurring in North Carolina are listed in Table 4.8. Species having moderate potential for recovery are more sensitive to disturbance than those with high potential for recovery. No species occurring in North Carolina were listed as having a low potential for recovery.

Table 4.8. Estimated recovery potential of selected species of submerged aquatic vegetation occurring in North Carolina. [Source: ASMFC 2000]

Moderate Recovery Potential	High Recovery Potential
Eelgrass	Shoalgrass
Wild celery	Widgeon grass
Redhead grass	Horned pondweed
Sago pondweed	Common elodea

Water quality degradation

Nutrients and sediment

While physical damage to SAV beds generally occurs in a discrete area and within discrete time periods, water quality degradation can cause SAV loss over less defined and much larger areas and time periods. The majority of SAV loss is now considered to result from large-scale nutrient enrichment (causing enhanced epiphytic and phytoplanktonic growth) and sedimentation, which result in reductions in water transparency and light penetration (Goldsborough and Kemp 1988; Kenworthy and Haunert 1991; Funderburk et al. 1991; Dennison et al. 1993; Stevenson et al. 1993). Catastrophic losses of seagrass beds have been correlated with these water quality problems in Virginia and Florida waters (Twilley et al. 1985; Orth et al. 1986; Durako 1994). Nutrient enrichment and/or increased sediment loads impact SAV growth, survival, and productivity by:

- Increasing chronic turbidity in the water column from suspended sediment or phytoplankton associated with algal blooms,
- Increasing epiphytic loads, sedimentation, or covering by drift algae on the SAV blades, and
- Diminishing dissolved oxygen concentrations as photosynthesis decreases, coupled with increasing concentrations of hydrogen sulfide resulting in toxicity (Dennison et al. 1993; SAFMC 1998a; Fonseca et al. 1998).

The effects of human-related eutrophication on seagrass survival are dependent on the growth periods and environmental requirements of the dominant species, and the timing and duration of the water quality problem (Burkholder et al. 1994). Eutrophication effects are generally most severe in sheltered habitats with reduced tidal flushing where nutrient loadings are concentrated and frequent, and where temperature fluctuations may be greater (Burkholder et al. 1994). Therefore, optimal criteria for preventing eutrophication vary by salinity, species, time of year, and specific location of SAV beds.

Decreased water clarity due to dissolved organic matter, suspended particulate matter, detritus, or algae that is suspended in the water column has a major effect on SAV distribution[55]. In addition to light attenuation in the water column, sedimentation and algal growth on the surface of grass blades (epiphytes) also reduce light reaching the surface of SAV (Virnstein and Morris 1996). Because algal growth is directly related to dissolved nutrient concentrations, epiphyte loads are considered to be caused by excessive nutrients in the water column.

Loss of SAV habitat, whether from physical impacts or water quality degradation, leads to a "snowball effect" of additional habitat and water quality degradation (Durako 1994; Fonseca et al. 1998). In the absence of SAV, the ability of the rooted grasses to bind sediment and baffle wave action is reduced, which results in sediment destabilization and increased turbidity. The destabilized bottom can result in accelerated shoreline erosion, putting more sediment into the water, decreasing water clarity further. These effects, in turn, can lead to additional SAV loss above and beyond the initial impact area or reduce the rate of recolonization (Durako 1994; Fonseca 1996b). Large-scale losses of SAV are particularly problematic because the rate of recovery (measured in the scale of years) often cannot keep up with the

[55] see Habitat requirements section.

rapid rate of losses (occurring within weeks or months) (Fonseca et al. 1998). Furthermore, future seagrass restoration may be confounded by the loss of existing seagrass beds, which increases sediment resuspension and turbidity (P. Biber, NMFS, pers. com., 2003). *Therefore, management efforts should focus on protecting existing SAV habitat and preventing any additional direct or indirect losses.*

Several water quality variables can be used as indicators of light conditions, including turbidity, total suspended solids, chlorophyll levels, and color (EPA 2000). Turbidity is a measure of the reduced transparency of water due to suspended or dissolved substances, while total suspended solids is a measure of the density of suspended solids in the water column. Chlorophyll *a* is a measure of the abundance and variety of phytoplankton in the water column. Chlorophyll levels may have the greatest impact on SAV in spring and summer (EPA 2000). Color is an indication of the amount of dissolved organic matter in the water.

In North Carolina, there is no official standard for light attenuation or light availability. There are EMC standards for other light associated parameters including turbidity, total suspended solids, and chlorophyll *a*. The standards for water clarity parameters are listed in Table 4.9 for the different water quality classifications. Waters classified as Nutrient Sensitive Waters (NSW) in the CHPPs area include the Neuse, Tar-Pamlico, and Chowan river basins, and the New River watershed within the White Oak River basin. In general, no increase in background nutrient levels is allowed within NSW waters unless preventing the increase would result in serious economic hardship, would not endanger human health and safety, or is due to natural variations. In both the Tar-Pamlico and Neuse basins, nitrogen limits were placed on point source discharges, and BMPs were established with the goal of reducing annual nitrogen loading by 30% of the amount occurring during a selected past year (DWQ 2000b). In the Chowan River basin, the updated 1990 NSW strategies called for reducing nitrogen inputs from all sources by 20%, as well as targeting BMP implementation. In the New River, nitrogen limits were placed on point source discharges, no new discharges were permitted, and expansions of existing facilities were allowed only if there was no increase in permitted loading of oxygen-consuming waste.

High Quality Waters include all waters designated SA for harvesting of shellfish, as well as Primary Nursery Areas designated by the MFC. Standards for those waters are shown in Table 4.8. For Outstanding Resource Waters, standards are based on the primary classification of those waters or if the standards are found to be insufficient to protect the ORW resource(s), then site-specific standards may be developed as part of the management strategy and rule-making process.

In the Chesapeake Bay, a multi-state and federal effort is underway to restore Chesapeake Bay water quality and SAV, in part by defining specific water quality criteria for water clarity, chlorophyll *a*, and dissolved oxygen as part of the process of maintaining and restoring SAV and other habitat. These parameters were considered the best and most direct measure of the effects of excessive nutrient and sediment pollution on SAV and other resources (<http://www.chesapeakebay.net/>, 2002).

In comparing current North Carolina water quality standards to those proposed for the Chesapeake Bay, North Carolina's chlorophyll *a* standard is higher (40 μg/l vs. <15 μg/l), while the TSS standard is very similar (10-20 mg/l vs. <15 mg/l) (Tables 4.2 and 4.9). The EPA did not list a standard for turbidity for the Chesapeake Bay (EPA 2000). Historically, water clarity standards have been based on phytoplankton requirements, which are much lower than that required for submerged grasses–only approximately one percent of incident light, compared to 15–25% (Kenworthy and Haunert 1991). Research is currently being conducted at NMFS in Beaufort to determine specific light requirements for SAV in North Carolina's estuaries and the relationship between light attenuation and other water quality parameters (P. Biber, NMFS, pers. com., 2004). Preliminary results indicate that, given certain combinations of turbidity and nutrients, North Carolina's current standards may not be adequate to sustain SAV (P. Biber, NMFS, pers. com., 2004). *Modifications may be needed to regulations and monitoring programs to improve their effectiveness for SAV protection. A review of current chlorophyll, TSS, and turbidity standards*

should be conducted to determine if they are appropriate for the protection of SAV in North Carolina waters. DENR should work with NMFS to determine what levels of TSS, chlorophyll a and other parameters are needed to achieve desired water clarity. The need and feasibility (scientific defensibility and "implementability") for a water quality standard for light attenuation should be investigated to provide a pro-active target or standard for protection and restoration of SAV.

Minimal water quality monitoring is conducted in Pamlico and Core sounds by DWQ, where the vast majority of SAV coverage occurs. The North Carolina light-associated water quality standards adopted by the EMC that apply directly to SAV are shown in Table 4.9. *Once the appropriate water quality conditions for protection of SAV are determined, DWQ should evaluate whether current sampling locations and methods are sufficient in estuarine waters to monitor the suitability of water quality conditions for SAV survival and growth. Monitoring should be conducted in waters with SAV habitat to ensure that the standards and conditions are being met. If additional monitoring is needed, establishment of continuous monitoring stations should be considered. In either case, priority should be given to those areas already classified NSW.*

Table 4.9. North Carolina Environmental Management Commission standards for light-associated parameters by North Carolina surface water quality classifications.

	Supplemental Classifications			**Salt water**			**Fresh water**
Parameter	ORW	HQW (salt or freshwater)	NSW	SA	SB	SC	Aquatic life
Turbidity (NTU)	**	25	**	25	25	25	50
Total dissolved solids (mg/l)*	**	10 – in PNAs; 20 – other	**	10 – in PNAs; 20 – other	30	30	20
Chlorophyll *a*	**	40	**	40	40	40	40

* Applies to discharges only

** Determined by primary classifications (SA – SC and C) or site-specific management strategies developed by EMC through rule-making.

In North Carolina, between 1995 and 1999, chlorophyll *a* concentrations at or above the state surface water quality standard of 40 μg/L were identified as one of the major causes of impairment in the freshwater portions of the Neuse and White Oak river basins (Table 4.10) and in the saltwater portions of the Neuse, Tar-Pamlico, and White Oak river basins. During calendar year 2000, 183 algal bloom samples were received from the basins included in the CHPPs area.[56] The Neuse (Maps 4.3a-b), Tar-Pamlico and White Oak river basins support SAV habitat, and at one time supported larger grass bed areas. Since some SAV is present in the shallow portions of the Neuse and portions of the White Oak river basins, and water quality data indicate some level of eutrophication exists, nutrient levels may be limiting survival or expansion of SAV in these areas. *These areas should be a high priority for monitoring of SAV and water clarity.*

Research has shown that elevated nitrogen concentrations not only affect SAV through light reduction, but may actually be toxic to eelgrass. In laboratory experiments, long-term exposure of eelgrass to enriched nitrate concentrations was lethal at enrichment levels ranging from 3.5 – 35 μM water column NO_3^-- Nd^{-1} (Burkholder et al. 1992b). In another experiment with eelgrass, nitrogen enrichment (10 μM water column NO_3^-- Nd^{-1} for 14 wk) significantly lowered shoot production compared to control plants without nitrogen enrichment (<2 μM water column NO_3^-- Nd^{-1}) (Burkholder et al. 1994). In contrast, growth in shoalgrass and widgeon grass was stimulated by similar nutrient enrichment conditions (Burkholder et al. 1994). Widgeon grass shoot production actually increased by 300%. These results

[56] 50 samples from the Tar-Pamlico River Basin, 79 from the Neuse River Basin.

indicate that of the three species studied, eelgrass would be most impacted by eutrophication. The results also suggest that shoalgrass or widgeon grass might be successfully established by transplanting efforts in areas where eelgrass beds have been lost (Burkholder et al. 1994). More research is needed on the effect of nutrient enrichment on other brackish and freshwater species of SAV.

Table 4.10. Major causes of use support impairment in freshwater streams by coastal draining river basin, 1995-1999[1] [Source: DWQ 2000a]

		DWQ River Basin							
Major Causes		**Cape Fear**	**Chowan**	**Neuse**	**Pasquotank**	**Roanoke**	**Tar-Pamlico**	**White Oak**	**Totals**
Ammonia (NH_3)	Miles	12	0	0	0	0	0	0	**12**
	%	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
Fecal coliform	Miles	130	0	3	0	0	13	0	**146**
	%	32.2	0.0	0.7	0.0	0.0	16.3	0.0	11.1
Habitat Degradation[1]	Miles	284	4	164	0	38	0	0	**490**
	%	70.3	3.1	35.8	0.0	20.5	0.0	0.0	37.3
Low DO	Miles	0	46	132	40	24	13	8	**263**
	%	0.0	35.7	28.8	83.3	13.0	16.3	72.7	20.0
Chlorine	Miles	4	0	0	0	0	0	0	**4**
	%	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
pH	Miles	0	51	7	28	0	0	0	**86**
	%	0.0	39.5	1.5	58.3	0.0	0.0	0.0	6.5
Turbidity	Miles	26	0	5	0	0	0	0	**31**
	%	6.4	0.0	1.1	0.0	0.0	0.0	0.0	2.4
Metals	Miles	0	0	0	0	13	0	0	**13**
	%	0.0	0.0	0.0	0.0	7.0	0.0	0.0	1.0
Chlorophyll a	Miles	1	0	7	0	0	0	11	**19**
	%	0.2	0.0	1.5	0.0	0.0	0.0	100.0	1.4
Total impaired miles		**404**	**129**	**458**	**48**	**185**	**80**	**11**	**1315**

[1] Habitat degradation is identified where there is a notable reduction in habitat diversity or change in habitat quality. This term includes sedimentation, bank erosion, channelization, scour, loss of pools or riffles, and loss of woody habitat.

Over the past several decades, there have been some nutrient reductions in waters supporting SAV due to improvements in wastewater treatment systems (Glasgow and Burkholder 2000), the 1988 ban on phosphorus-detergents (<http://pubs.er.usgs.gov/pubs/cir/cir1157>, June 2002) and more stringent water quality and management strategies in NSW areas (DWQ 1997b). Despite efforts to reduce nutrient loading, nutrient concentrations will continue to fluctuate as bottom sediments containing nutrients are resuspended into the water column and stormwater runoff introduces additional nutrients, varying with rainfall and runoff patterns. In addition, increasing population along the coast potentially increases nutrient loading into wastewater systems and nonpoint runoff. Nutrient and sediment levels may be preventing recovery of SAV in areas that historically supported SAV. The edges of existing SAV beds mark the general transitional area where water quality conditions become adequate to support SAV (Virnstein and Morris 1996). *To restore SAV habitat in fresh and estuarine systems where it historically occurred, management strategies should focus on water quality improvements at the edges and upstream of SAV occurrence.*

Suspended sediment, suspended solids, and dissolved solids concentrations have decreased throughout the Albemarle-Pamlico watershed from 1980 to 1995 (<http://water.usgs.gov/pubs/circ/circ1157

/nawqa91.9.html>, June 2002). Decreasing concentrations of suspended solids in the sounds and estuaries may not adequately improve water clarity for SAV growth if nutrient levels remain high. As a result, reduction of nutrients will be even more important in controlling water clarity conditions for SAV.

Increased sediment and nutrient loading in the water column can enter coastal waters from point source discharges, nonpoint stormwater runoff, or resuspension of bottom sediments. Specific sources that contribute to increased sediment loading include construction activities, unpaved roads, road construction, golf courses, uncontrolled urban runoff, mining, silviculture, row crop agriculture, and livestock operations (DWQ 2000b). Urbanization can increase the flow and velocity of stormwater runoff, which in turn leads to increased stream bank erosion. Stream bank erosion is a significant source of sediment loading (DWQ 2000b). Specific sources that contribute to increased nutrient loading include agricultural and urban runoff, wastewater treatment plants, forestry activities, and atmospheric deposition. Nutrients in point source discharges are from human waste, food residues, cleaning agents, and industrial processes. The primary contributors of nutrients from nonpoint sources are fertilizer and animal wastes (DWQ 2000b).

Addressing wetland and riparian restoration and management can reduce the effects of nonpoint pollution on water quality. Reductions in sediment or nutrient loading, particularly in river basins draining to the northern two-thirds of the coast (Albemarle Sound south through Topsail Sound), would help maintain or improve water clarity and light conditions needed for SAV growth and survival. *Nonpoint source loading of nutrients and sediment could be reduced through multiple strategies, including preservation and restoration of upland and wetland riparian habitats, modifications in land use regulations and agricultural BMPs. Conservation priorities should be set for land acquisition programs which will aid in protecting Strategic Habitat Areas.*[57] *Nutrient and sediment reduction goals should be established by the EMC to achieve the minimum of 15-25% light availability at depth requirement for SAV growth. An increase in staffing to fully implement and enforce existing stormwater and other nonpoint source-related regulations is needed to achieve this goal.*

Implementation of NSW rules for the Neuse, Tar-Pamlico, Chowan, and New rivers by the EMC are positive steps needed for nutrient and sediment reductions from both point and nonpoint sources. Goals and strategies vary, but in general aim to obtain nutrient reductions ranging from 20 to 40% of a targeted previous year, depending on the river basin. In addition, implementation of the CRC's coast-wide 30 ft (9.14 m) buffer rule [CRC rule 15A NCAC 07H .0209 (d)(10)], and EMC's 50 ft (15.24 m) buffer [58] in the Neuse and Tar-Pamlico river basins [EMC rule 15A NCAC 02B.0232 and 2B.0229] should aid in reducing nonpoint pollution. *The New River nutrient management strategy [EMC rule 15A NCAC 02B.0223] was heavily focused on point sources and should be revisited to determine what additional controls, such as buffers, might be necessary to achieve continued water quality improvements.*

The presence of SAV can, in itself, be valuable as a sensitive indicator of water quality (Smith et al. 1981; Valiela et al. 1990). In the Indian River Lagoon, Florida, where stormwater runoff has caused large SAV losses, SAV is used as a barometer of overall water quality conditions because of its sensitivity to water quality, the ecological value and functions it provides, and its importance as a keystone species for numerous other species (Virnstein and Morris 1996). To manage the lagoon, light attenuation models have been developed that link water quality to seagrass health. From the information obtained, pollution load reduction goals were developed to maintain and extend SAV coverage to historically occurring depths. Seagrass acreage and density were used as the measures of success. The conceptual model was based on the following relationship, which is supported in the scientific literature (Virnstein et al. 1983; Thayer et al. 1984; Gilmore 1995):

[57] Because nonpoint source pollution also affects other habitats as well, including oyster reefs, soft bottom, tidal marsh, and the water column, this topic is discussed in more detail in the Water Column habitat section of this plan.

[58] First 30 ft (9.14 m) from water must remain forested and undisturbed and the next 20 ft (6.10 m) must have at least grass vegetation.

Proper watershed management → Adequate water quality → Healthy SAV coverage → High biological productivity and diversity → Healthy fish populations

The SAFMC SAV policy (1998a) encourages long-term trend analyses to monitor distribution and abundance of SAV. *An approach similar to that used in Indian River Lagoon and the Chesapeake Bay, where the condition of water quality, SAV, and fish populations are linked in monitoring and management, would be useful for protection of SAV habitat in North Carolina.*

Toxic chemicals

Herbicides are the primary toxic chemical known to have negative impacts to SAV (Funderburk et al. 1991). Herbicides enter riverine and estuarine waters from agricultural runoff and other sources. The most common agricultural herbicides used in Chesapeake Bay were atrazine, simazine, diquat, paraquat, and linuron. Research in Chesapeake Bay found that concentrations of the toxins in the water column were seldom high enough to damage SAV beds. In addition, SAV recovery was rapid following exposure to low concentrations of herbicides (Funderburk et al. 1991). However, impacts to SAV from sporadic or localized pulses of higher concentrations are not known, and could potentially cause problems.

While most agricultural herbicides come in contact with SAV indirectly through runoff, there are other chemicals specifically developed for aquatic weed control in freshwater and brackish systems. These chemicals are designed to be short-lived and should not persist in the water for long periods of time. Aquatic herbicides are at times used to intentionally kill SAV that is considered a nuisance. The Division of Water Resources, under the Aquatic Weed Control Act of 1991, manages the North Carolina Aquatic Weed Control Program, under direction from the Aquatic Weed Control Council. This program primarily focuses on non-native invasive species in freshwater lakes, ponds, and rivers. Some of the annual control activities occur in fresh and low salinity waters used by anadromous fishes and blue crabs, including the Albemarle Sound system.

The non-native European watermilfoil is the most troublesome SAV species in low salinity waters. It sometimes forms dense beds that can interfere with boating in local areas. Native submerged grasses may be impacted indirectly where occurring near treated areas or directly when herbicides are used by the general public. There is a general perception by some of the public that SAV is a nuisance. Grass blades may get in boat propellers, or entangle or weigh down fishing gear. Aesthetically, swimmers may prefer a sand bottom to a grass bottom. *Permitting for chemical removal of European watermilfoil and other non-native vegetation should be carefully restricted where native species co-occur to prevent non-target impacts. More education on the value of SAV to the health of North Carolina's estuaries and fisheries is needed to modify attitudes toward this habitat and improve individual and community stewardship of SAV.*

Introduced and nuisance species

The North Carolina Aquatic Weed Control Program is mandated by the North Carolina Aquatic Weed Control Act of 1991 [General Statute 113A-220 ff; DENR rules 15A NCAC 02G .0600] to assist local governments with aquatic weed problems affecting public waters. (<http://www.ncwater.org/Education_and_Technical_Assistance/Aquatic_Weed_Control/>, May 2002). Primary species targeted for control under the Program include:

- Giant salvinia (*Salvinia molesta*)
- Hydrilla (*Hydrilla verticellata*)
- Alligator weed (*Alternantherea philoxeroides*)
- Eurasian watermilfoil (*Myriophyllum spicatum*)

The above mentioned species, in addition to Elodea (*Lagarosiphon* spp.) and Water hyacinth (*Eichhornia azurea*), are classified as Noxious Aquatic Weeds under section .0602 of the Act. These highly invasive non-native species form dense beds in the water, which can make swimming, fishing, and boating difficult; clog water intake systems for municipalities and industries; and impede water flow in drainage canals (<http://www.ncwater.org/Education_and_Technical_Assistance/ Aquatic_Weed_Control/>, May 2002). Moreover, dense beds of Eurasian watermilfoil, a submerged rooted grass, can cause the water column to become anoxic at night, which can stress fish or cause fish to leave the area (T. West, ECU, pers. com., 2003). Although these nuisance species do provide some beneficial fish functions, such as refuge and sediment stabilization, they can also negatively impact SAV habitat by shading or out-competing other native species, which may have greater value to fish as a food source or refuge area (DWR 1996). *Long-term management and restoration of SAV habitat should include replacement of Eurasian watermilfoil with native species. The DENR should coordinate with the Division of Water Resources to ensure that native species are not targeted for removal. Research is also needed to determine the relative fishery value of Eurasian watermilfoil compared to native vegetation.*

While most introductions of non-native fish have little noticeable effect on habitat, grass carp can have a significant impact on submerged grass beds. Grass carp is a non-native species that has escaped from stocked ponds and reservoirs into some river systems. North Carolina requires that only sterile triploid grass carp be used for stocking because of their potential damage to submerged vegetation. However, a recent study in the Chesapeake Bay found that although stocking of sterile grass carp has been required for over 20 years, 18% of the non-native grass carp were not sterile (Schultz et al. 2001). Non-native species may also be introduced through unintentional releases from aquaculture and live bait facilities. *Policies should be developed by state agencies overseeing aquaculture and bait facilities to prevent such releases into coastal waters*.

Other threats

Seagrass wasting disease is a natural event that has affected SAV in North Carolina and may occur when SAV is stressed. Historic population losses of large vertebrate grazers may have, among other consequences, increased seagrass vulnerability to infection by pathogens (Jackson et al. 2001). It was suspected, but never proven, that the slime mold protist, *Labryinthula,* was the cause of the wasting disease event that devastated eelgrass populations throughout the North Atlantic between 1930 and 1933, dramatically disrupting estuarine systems (Steel 1991). Higher water temperatures apparently stressed the seagrasses, making them more susceptible to *Labryinthula*. Healthy eelgrass beds were generally reestablished by the 1960s. More recently, similar large-scale die-offs of eelgrass from Nova Scotia to Connecticut, and turtle grass in Florida Bay have been attributed to *Labryinthula* (Short et al. 1987). Eelgrass infected with *Labryinthula* was also found near Beaufort, North Carolina in the 1980s (Short et al. 1987). Recent studies indicate that characteristics of wasting disease are appearing in some eelgrass beds in southern Core Sound, Back Sound and Bogue Sound (SAFMC 1998a). Submerged aquatic vegetation is less susceptible to infection by the pathogen in low salinity waters (Short et al. 1987). Potential impacts in North Carolina include reductions in bay scallops and other fisheries resources, and large reductions in migratory waterfowl populations. Although the current infections have not caused catastrophic declines in eelgrass populations such as those which occurred in the 1930s, the disease is a potential threat to coastal fisheries should large-scale mortalities occur. *Submerged grasses need to be monitored on a regular basis to assess the status of wasting disease and its association with human-induced stresses.*

Existing management measures

Regulatory designations of coastal waters can either protect or potentially allow degradation of SAV habitat. The MFC-designated crab spawning sanctuaries, mechanical oyster harvest prohibited areas, military restricted areas, fish nursery areas, and trawl net prohibited areas protect SAV in those areas from

potential physical disturbance associated with bottom fishing gear (Maps 3.5a-c). The great majority of SAV beds along the eastern perimeter of the Albemarle-Pamlico system are protected within these areas. However, SAV occurring in the western portion of the Albemarle-Pamlico system is generally not within these gear-restricted areas. Moreover, the likelihood of sedimentation and eutrophication is relatively greater on the sounds' western perimeter due to the closer proximity of river discharge. Although SAV functions as a nursery for many economically important species, SAV is predominantly absent from designated fish nursery areas. In particular, most of the high salinity SAV beds are not designated Primary Nursery Areas. *The DMF should develop criteria for designating Strategic Habitat Areas and designate SAV areas that meet those criteria.*

The largest spatial gap in SAV protection from fishing gear impacts is in northern Pamlico Sound where dredging for crabs is allowed. This area includes SAV beds in the sound immediately west of Pea Island National Wildlife Refuge. There are smaller areas of unprotected SAV along both the eastern and western sides of Roanoke Sound and along the shoreline of West Bay in the southern Pamlico Sound area. The extensive SAV beds of Core and Bogue sounds are protected from mechanical oyster methods, but not from trawling or from bay scallop dredging. Area designations that could result in SAV impacts include mechanical clam harvest areas and areas where trawling and bay scallop dredging occur. Most of the designated mechanical clam harvest areas are not located where SAV is found (Maps 4.4a-b). Areas open to trawling generally do not support SAV, since SAV is limited in occurrence to shallow water. However, SAV does occur in Core and Bogue sounds where trawling and bay scallop dredging are allowed. *The DMF should assess the effect of trawling and dredging activities in Core and Bogue sounds on SAV. The DMF should also assess where additional protective distances are needed between SAV and bottom disturbing fishing methods, including clam trawling (kicking), oyster dredging, crab dredging, bay scallop dredging, and bottom trawling.*

There are several regulations and designations that provide some direct and indirect protection of SAV beds. Area designations that provide water quality protection for SAV include Primary Nursery Areas (PNAs), High Quality Waters (HQWs), and Outstanding Resource Waters (ORWs). The CRC prohibits new dredge and fill activities in areas with SAV, but maintenance dredging of existing permitted navigation channels is allowed. Rules of the CRC do not allow authorization of projects that can violate water quality standards of estuarine resources, including SAV and PNAs [CRC rule 15A NCAC 07H .0207]. CRC rules state that activities directly impacting SAV, such as dredging or construction of docking facilities, should be avoided [CRC rule 15A NCAC 07H .0209(d)(4)]. Waters designated as PNAs by the MFC, or that have a special water quality classification by the EMC, such as ORW, are given additional consideration for impacts by DCM prior to issuing development permits. Despite these additional considerations, permits that result in cumulative impacts to SAV, particularly from dock construction, continue to be authorized (T. Murphey, DMF, pers. com., 2002).

Several Outstanding Resource Waters (classified by the EMC) have significant SAV coverage. The ORW designation carries with it more site-specific management strategies based on the resources to be protected, as well as some minimum requirements for discharges and development. For example, new development adjacent to ORW waters must comply with specified stormwater provisions [EMC rule 15A NCAC 2H .1007] and non-discharge permits are required to meet reduced loading rates and increased buffer zones. Outstanding Resource Waters and their more stringent water quality standards, as adopted by the EMC, cover approximately 25% of the mapped SAV habitat in coastal North Carolina. Submerged aquatic vegetation habitat within ORWs is located in Core Sound, western Bogue Sound, and the lower White Oak River (Maps 2.3a-b). *The remaining 75% of mapped SAV should be evaluated for designation as Outstanding Resource Waters or Strategic Habitat Areas to invoke adequate protective measures.*

Because development and associated impacts occur in areas adjacent to existing ORWs, such as in the Bogue Sound area, the designation of waters alone will not effectively protect habitats unless the rules associated with those designations are adequate and enforced. *The effectiveness of ORW and HQW rules*

in protecting SAV and other habitats should be examined and strengthened as necessary. The EMC, CRC, and MFC should develop appropriate management strategies that maintain water quality at a level that adequately protects SAV.

In 2003 the MFC adopted a policy statement for protection of SAV habitat. The document summarizes the habitat value of SAV and provides management guidelines for protection of SAV, to aid in development of habitat protection and fishery management plans. These management needs are listed below.

- *In order to delineate and assess the distribution and health of SAV habitat, SAV beds need to be mapped and monitored. The saltwater end of coastal waters supports eelgrass, widgeon grass and shoalgrass, and the freshwater end supports several species of freshwater SAV.*
- *Minimize nutrient and sediment loading to coastal waters that support existing SAV to protect adequate water quality as defined by water-column clarity in standard measurement units.*
- *All SAV needs to be protected from all bottom-disturbing fishing and recreational gear. Sufficient buffer zones surrounding SAV beds should also be protected from disturbance to prevent impacts of sediments on growing SAV.*
- *Provide adequate safeguards to prevent direct (or indirect) impacts from development projects adjacent to or connected to SAV.*
- *Assess cumulative impacts of land use and development changes in the watershed affecting SAV to identify the potential impact. Require identification of cumulative impacts as a condition of development of permit applications.*
- *Require compensatory mitigation where impacts are unavoidable. Initiate restoration programs to recoup an/or enhance lost SAV habitat.*
- *Educate landowners adjacent to SAV, boaters, and other potential interested parties about the value of SAV as a habitat for many coastal fishes and invertebrates.*

Commission actions (MFC, CRC, and EMC) should be consistent with this policy.

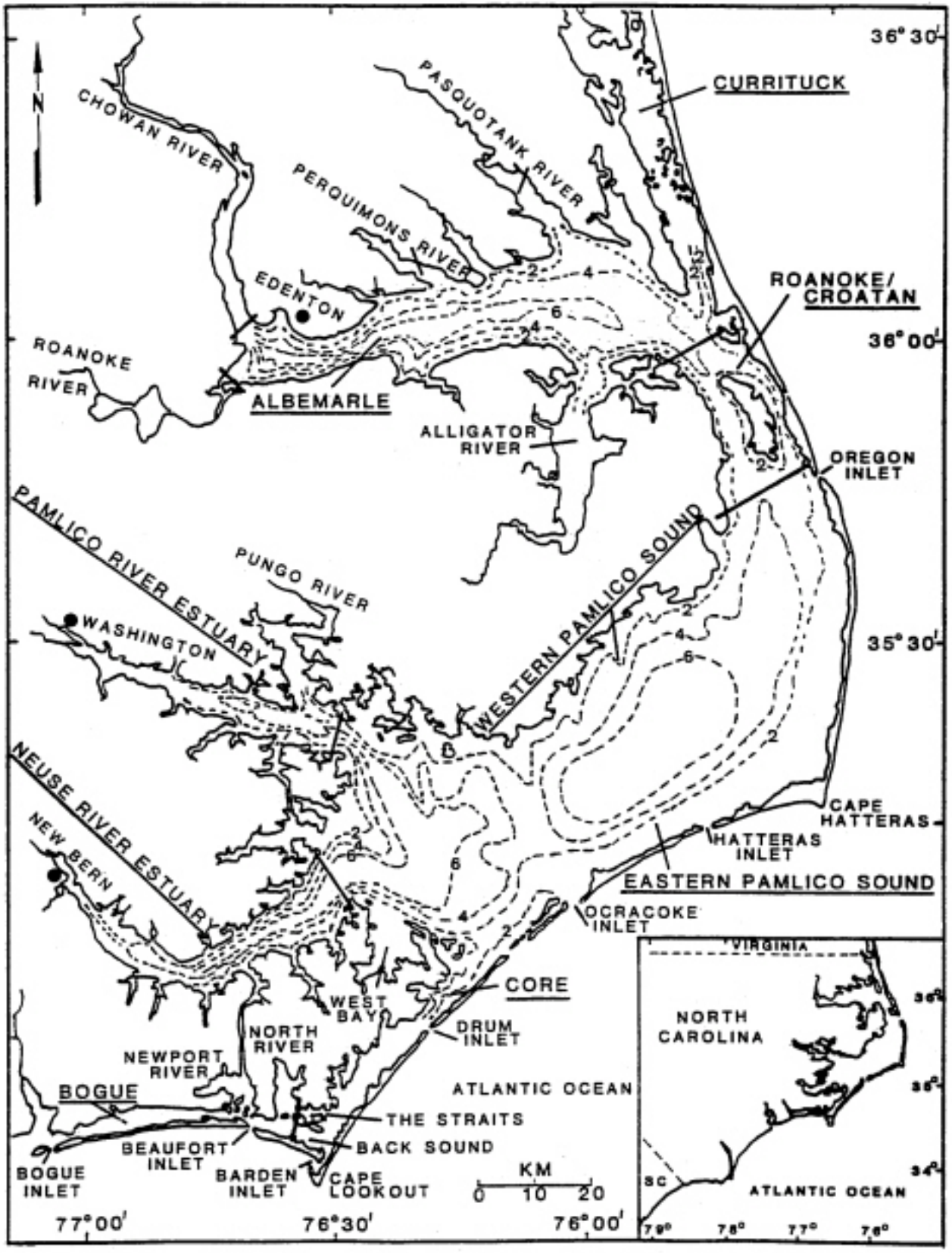
4.5 SUMMARY OF SUBMERGED AQUATIC VEGETATION CHAPTER

Submerged aquatic vegetation is an extremely valuable fish habitat that occurs in North Carolina's coastal estuarine and freshwater systems. Because light is the primary limiting factor affecting its distribution, SAV is restricted to relatively shallow waters. Submerged aquatic vegetation provides ecosystem functions similar to shell bottom, such as enhancing water quality through stabilizing and trapping sediment, reducing wave energy, cycling nutrients within the system, and providing structure for invertebrate attachment and refuge from predators. Seagrasses also produce large quantities of organic matter, which supports a complex food base for coastal fishes and other organisms. This habitat is especially valuable as a nursery and refuge from larger predators for the young of many important commercial and recreational fishery species. Bay scallops, pink shrimp, hard clams, gag, black sea bass, summer flounder, and others are typically associated with high salinity SAV. Juvenile striped bass, striped mullet, brown and white shrimp, Atlantic croaker, and others frequently use low salinity grasses. Red drum and blue crabs are among several species that rely upon both low and high salinity grasses at different stages of their life cycles. The high fisheries value of this habitat has been well established by the scientific community, and SAV is federally designated as a Habitat Area of Particular Concern for penaeid shrimp, blue crab, and red drum.

Historical accounts indicate that there have been large-scale losses of SAV in North Carolina's low salinity tributaries on the mainland side of Pamlico Sound and along much of the shoreline of western Albemarle Sound, while the high salinity grass beds to the east appear relatively stable. Loss of low salinity SAV habitat could negatively affect stocks of striped mullet, Atlantic croaker, and blue crab, which were classified as Concern by DMF in 2003. Impacts to high salinity SAV beds could be especially detrimental to bay scallops and black sea bass (south of Hatteras), which are currently listed as

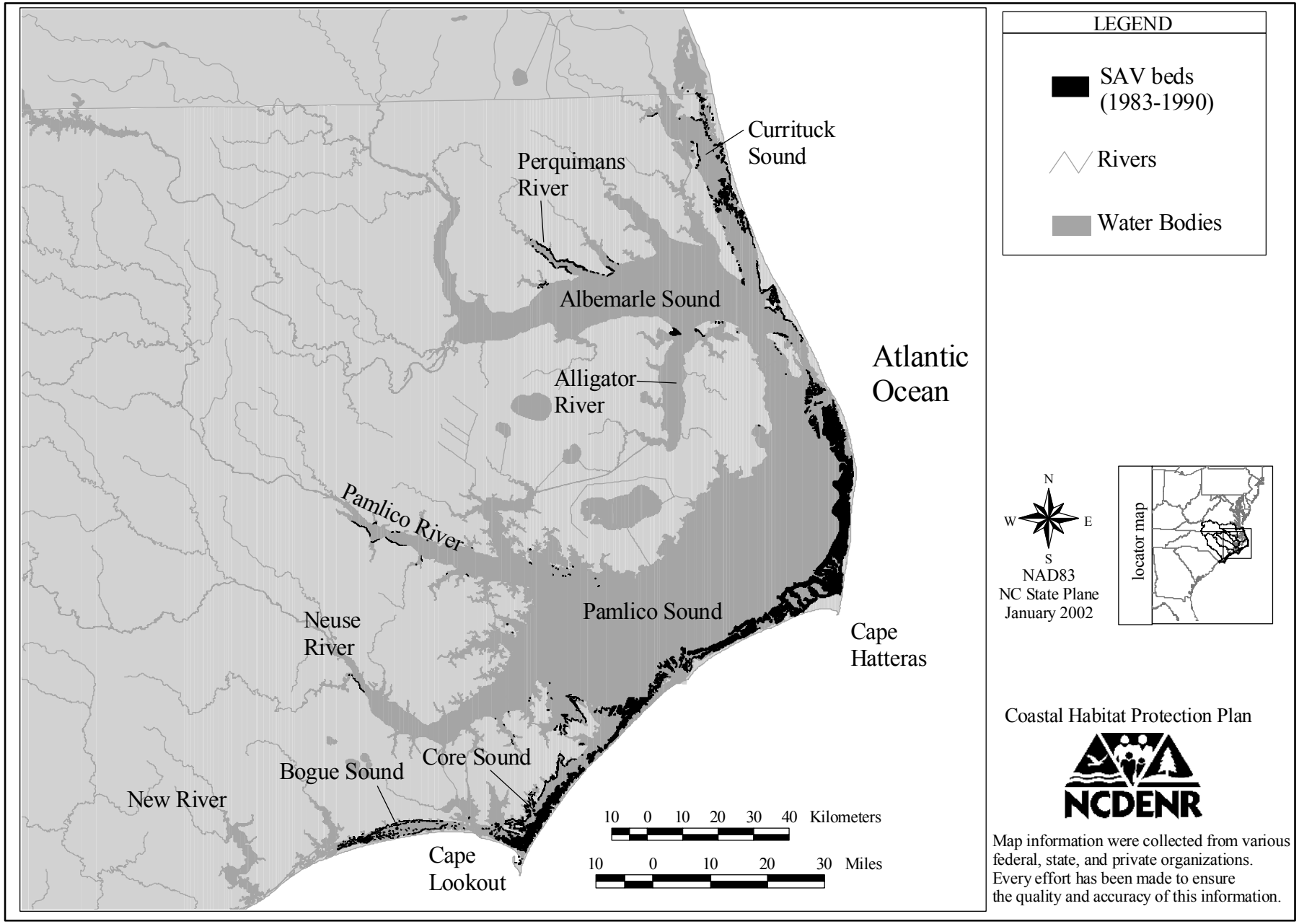
Overfished. Protection, enhancement, and restoration of this habitat are high priorities for recovery of those species and for sustained health of many others.

The major threat to SAV is large-scale nutrient enrichment and sediment loading, which increases turbidity, reduces light penetration, and subsequently impacts SAV growth, survival, and productivity. In North Carolina, most of the low salinity areas that have experienced large reductions in SAV coverage are also designated Nutrient Sensitive Waters. Major contributors of nutrients and sediments include point source discharges, nonpoint runoff (from crop agriculture, animal operations, urban and road construction, and impervious surfaces) and resuspended sediments (from bottom disturbing fishing gear and channel dredging). There are also activities that threaten the physical structure of SAV. Dredging for navigational channels, marinas, or infrastructure such as bridges or cables can result in large, direct losses of SAV. Docks constructed over SAV can cause immediate loss during construction or gradual loss due to shading effects. Boating activity in shallow vegetated waters can damage SAV from propeller damage to SAV. Bottom disturbing fishing gears used within or near SAV habitat, such as oyster and crab dredges, hydraulic clam dredges, clam trawls, and bull rakes, may cause significant damage to SAV habitat. As human population, boating activity, fishing pressure, and shoreline development increase, losses of SAV are likely to continue if steps are not actively taken to protect SAV and maintain suitable water quality conditions. State and local managers need to ensure that 1) SAV habitat is not physically impacted by water-dependent activities and 2) water quality (especially clarity) is enhanced to allow persistence of existing SAV and re-colonization of former habitat.



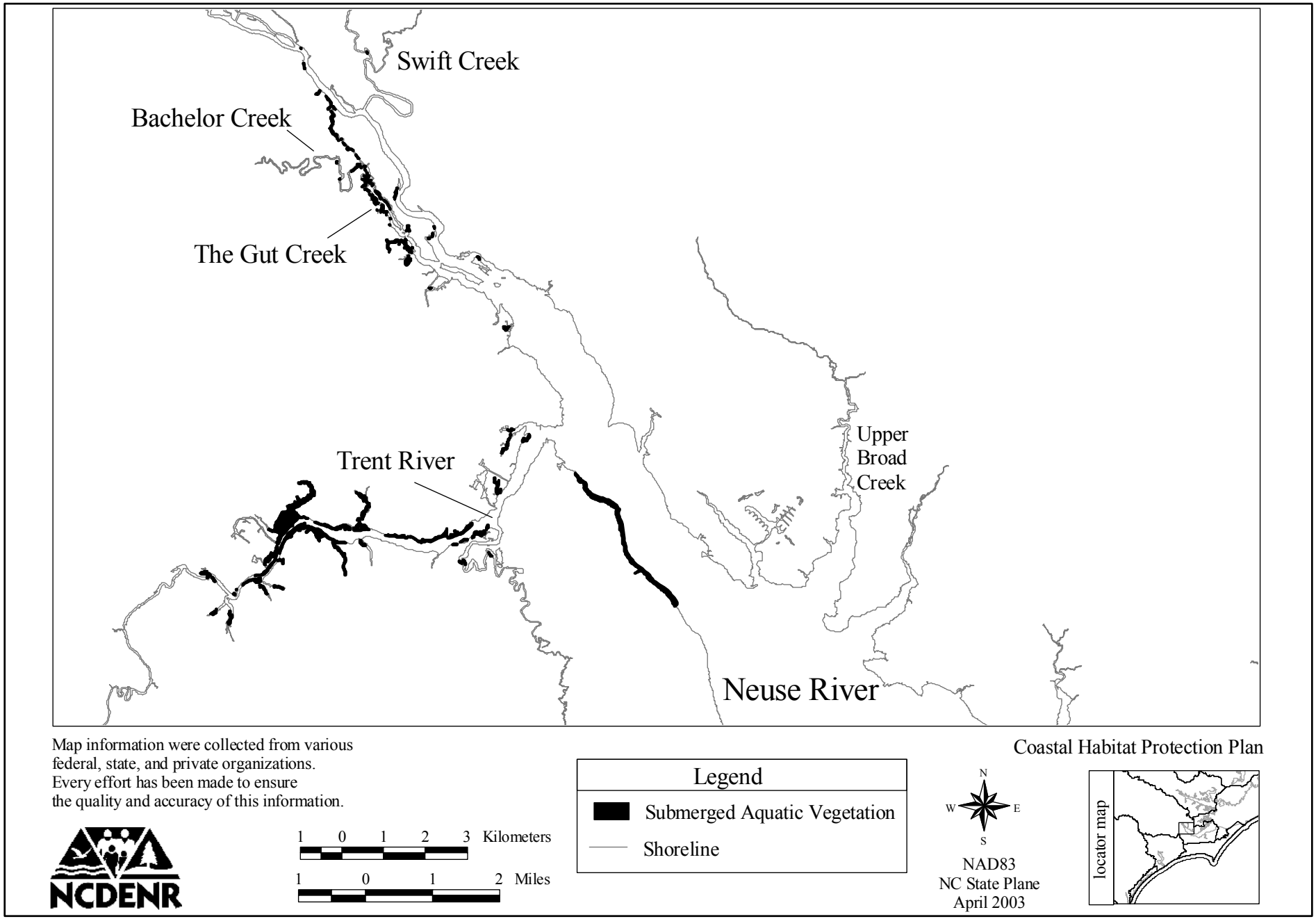
Map 4.1. Depth contours (meters) of the Albemarle-Pamlico Sound system, North Carolina (from Ferguson and Wood 1994).

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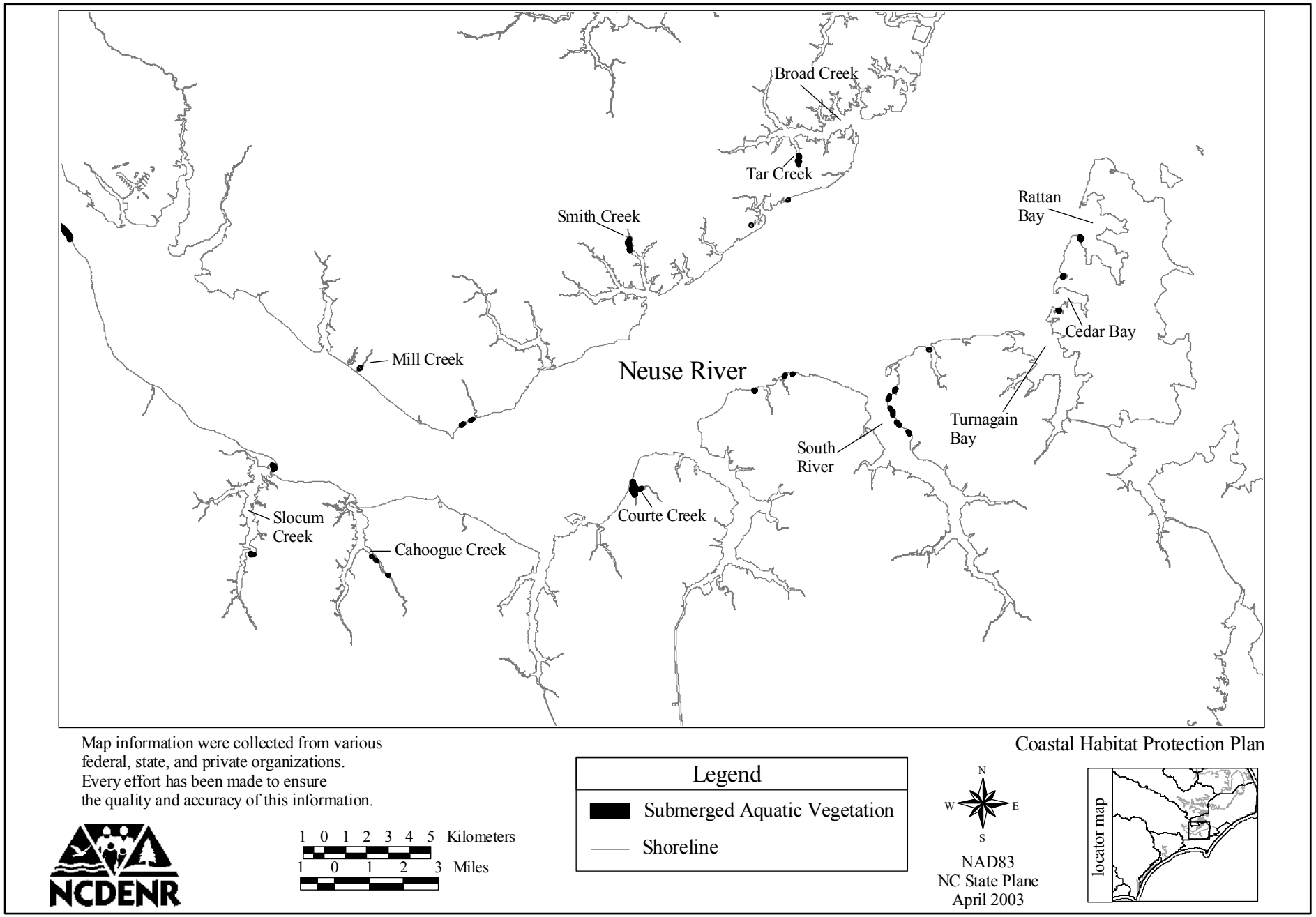
Map 4.2. Location of known of submerged aquatic vegetation (SAV) habitat in coastal North Carolina (from Ferguson and Wood 1994; Carraway and Priddy 1983).
Note: absence of SAV beds in a given areas does not suggest actual presence/absence of SAV because surveys have not been conducted in all areas.

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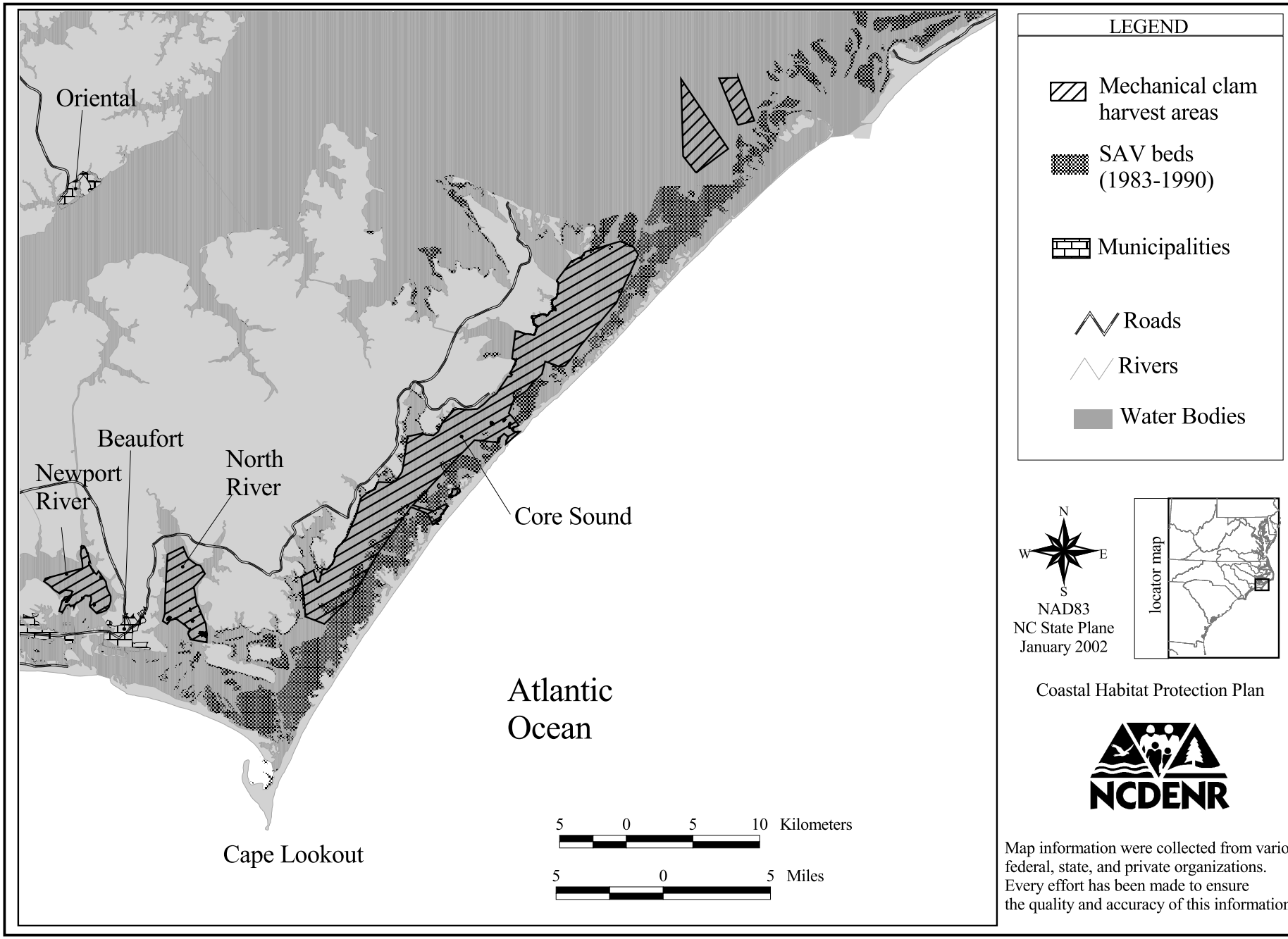
Map 4.3a. Distribution of submerged aquatic vegetation in the Neuse River estuary in 1998 (From DWQ 1998).

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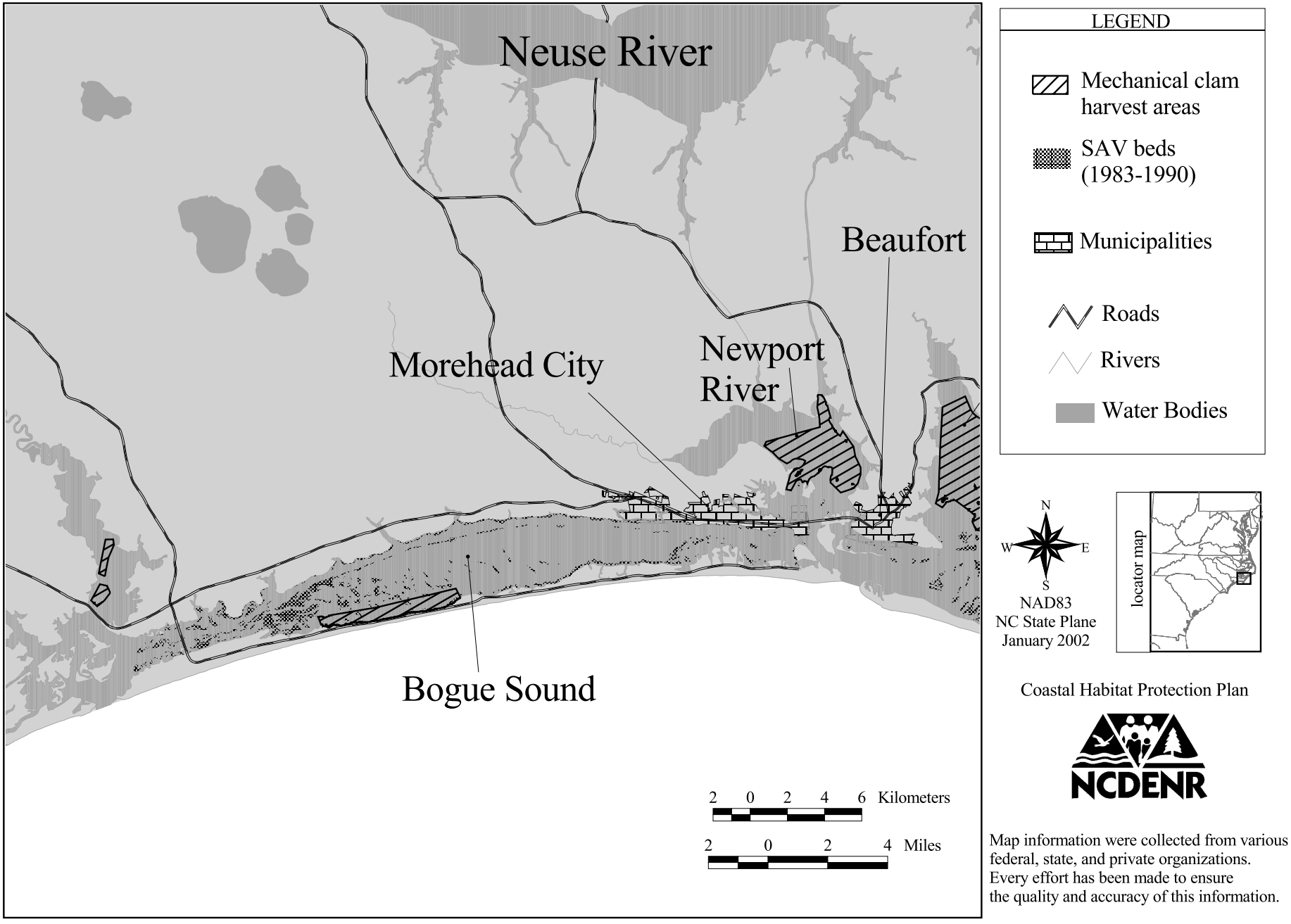
Map 4.3b. Distribution of submerged aquatic vegetation in the Neuse River estuary in 1998 (From DWQ 1998).

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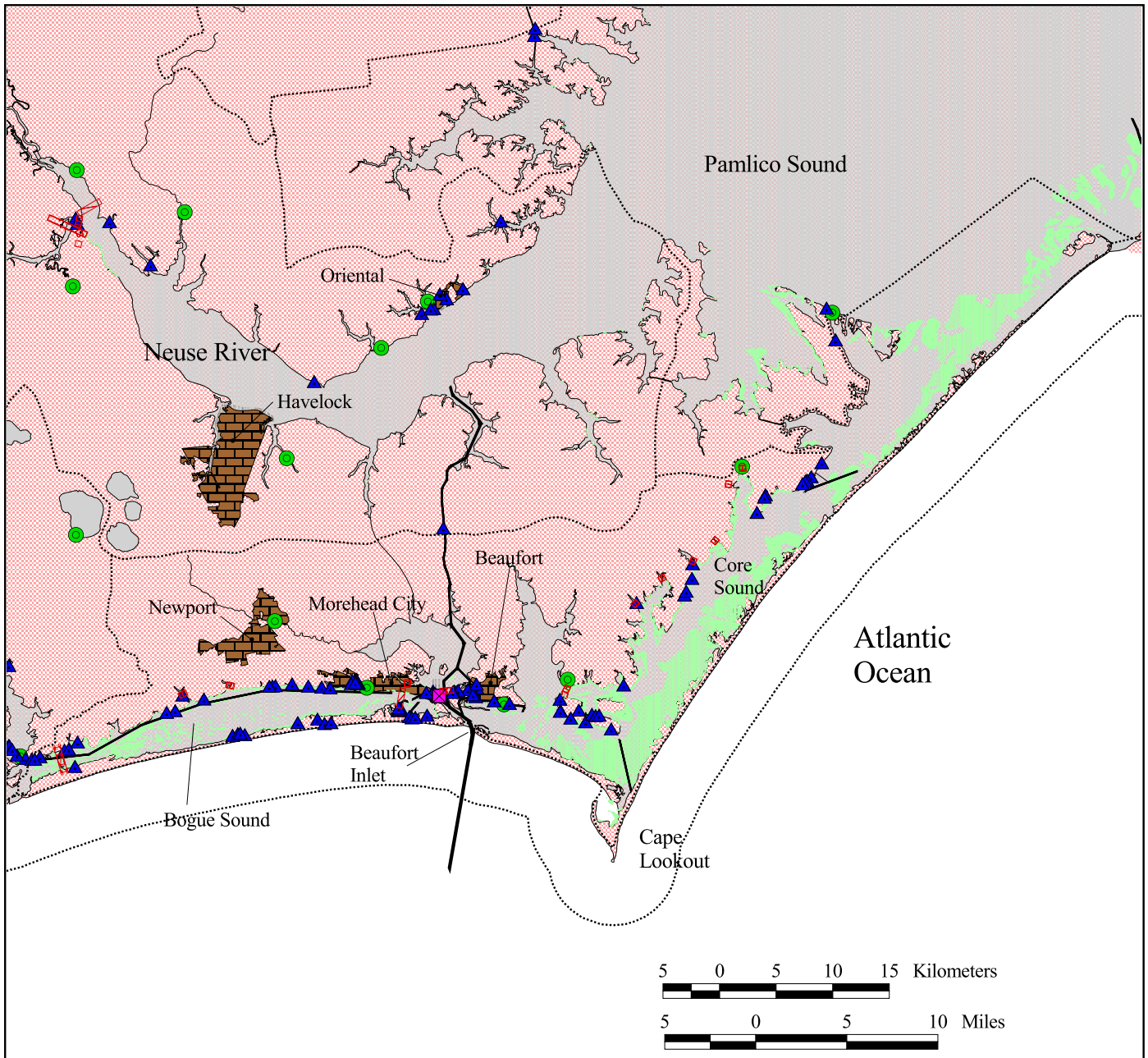
Map 4.4a. Location of mechanical clam harvesting areas relative to submerged aquatic vegetation habitat in the Core Sound area of North Carolina.

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Map 4.4b. Location of mechanical clam harvesting areas relative to submerged aquatic vegetation habitat in the Bogue Sound area of North Carolina.

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LEGEND

- State ports
- Coastal marinas
- Public boat access site
- Bridges within 1-km of SAV
- COE maintained channels
- SAV beds (1983-1990)
- CHPP management unit boundaries
- Municipalities

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NAD83
NC State Plane
January 2002

locator map

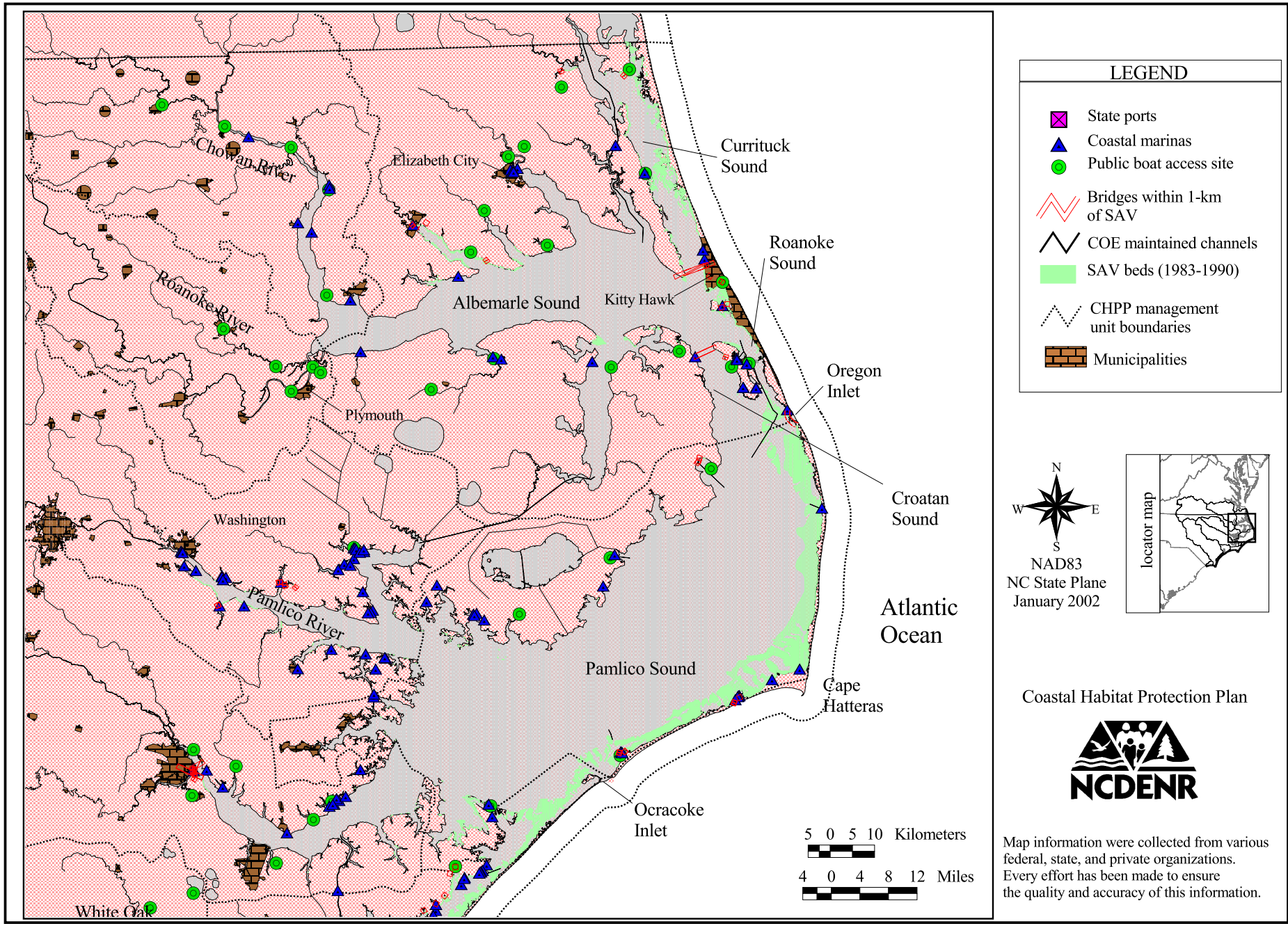
Coastal Habitat Protection Plan

NCDENR

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

Map 4.5a. Locations of marinas, boating access sites and other man-made facilities relative to beds of submerged aquatic vegetation in the Core-Bogue sounds and lower Neuse River areas of North Carolina

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Map 4.5b. Locations of marinas, boating access sites and other man-made facilities relative to beds of submerged aquatic vegetation in the Albemarle-Pamlico sound systems of North Carolina

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CHAPTER 5. WETLANDS

Wetlands are widely recognized as habitats vital to fisheries production in North Carolina and elsewhere (Mitsch and Gosselink 1993; Graff and Middleton 2003). This chapter defines and describes wetland habitats found in coastal North Carolina and documents their current distribution, ecological role, biological function, current status, trends, threats, and management needs.

Coastal wetlands border vital nursery areas and serve as the primary buffer between land and water-based impacts.



5.1. DESCRIPTION AND DISTRIBUTION

Definition

Wetlands are wet areas commonly referred to as swamps or marshes. Wetlands, as defined by federal regulations [40 CFR 230.3(t)] and EMC rules [15A NCAC 2B .0202(71)], are "…areas that are inundated or saturated by an accumulation of surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions." The boundary between wetlands and deepwater habitat (i.e., submerged aquatic vegetation) is defined as the maximum depth where rooted emergent vegetation (i.e., marsh grasses) can be found - generally <6ft (2m) below mean low water during the growing season (Figure 5.1). The EMC and federal regulatory definitions include nontidal freshwater wetlands not subject to CRC rules. The CRC refers to coastal wetlands as "marshlands," defined as "any salt marsh or other marsh subject to regular or occasional flooding by tides, including wind tides (whether or not the tide waters reach the marshland areas through natural or artificial watercourses), provided this shall not include hurricane or tropical storm tides" [G.S. 113-229(n)(3)]. The CHPP will focus primarily on wetlands that are connected to coastal water bodies by surface water of sufficient depth to allow fish utilization. These "connected" wetlands are hereby termed "riparian wetlands" because they border streams and other water bodies.

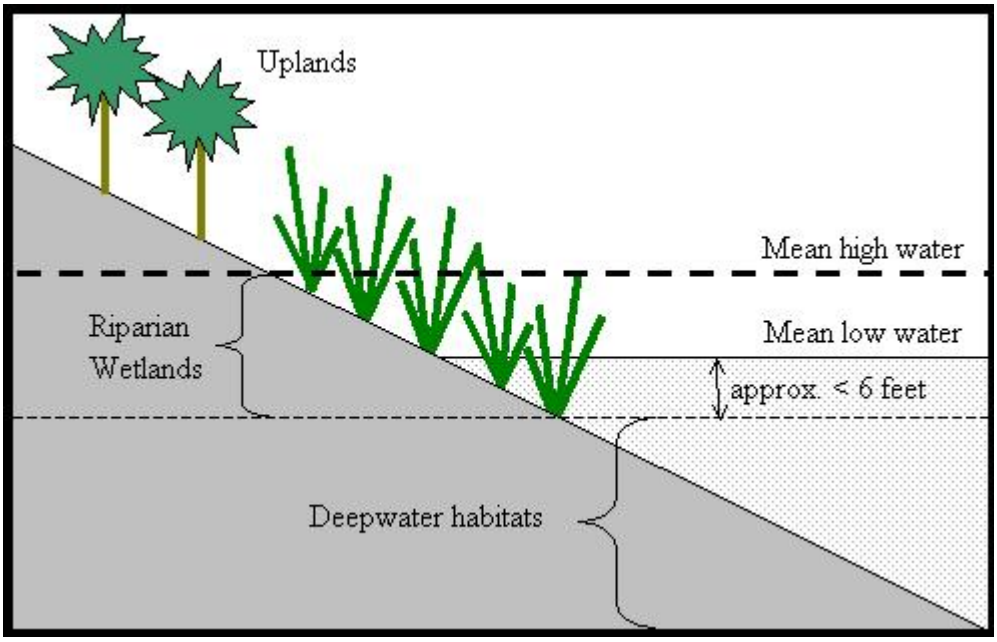


Figure 5.1. Graphic depiction of the conceptual boundaries among riparian wetlands, uplands, and deepwater habitats.

Description

Riparian wetlands can be differentiated into four broad wetland classes based on their landscape position within drainage networks (hydrogeomorphology): estuarine, riverine, headwater, and flat/depressional (Sutter 1999).

- **Estuarine wetlands** are generally found along the margins of estuaries and sounds. Estuarine wetlands include salt/brackish marsh, estuarine shrub/scrub and estuarine forests.
- **Riverine wetlands** are those in which hydrology is determined or heavily influenced by proximity to a perennial stream of any size. Overbank flow from the stream exerts considerable influence on the hydrology of larger streams. Riverine wetlands include freshwater marshes, bottomland hardwood forest, and riverine swamp forest.
- **Headwater wetlands** exist in the uppermost reaches of local watersheds upstream of perennial streams. Headwater systems may contain channels with intermittent flow, but the primary sources of water input are precipitation, overland runoff, and groundwater discharge rather than overbank flow from a stream.
- **Flat/depressional wetlands** are generally not in direct proximity to surface water. While they are isolated from or hydrologically disconnected from surface water, the hydrology of depressional wetlands is primarily determined by groundwater discharge, overland runoff, and precipitation. Flat/depressional wetlands include pocosins, pine flats, depressional swamp forest, hardwood flats, maritime swamp forests, and some managed pinelands. They are also referred to as non-riparian wetlands.

While fish occupy riverine and estuarine wetlands (Map 5.1a-d) during periods of regular inundation, headwater and flat/depressional wetlands (Map 5.2) are generally not directly utilized by fish. However, there are some exceptions. The pocosins adjacent to the Alligator and Northeast Cape Fear rivers have surface drainage to coastal waters (Brinson 1991). However, the primary focus of this chapter is the riparian wetlands found in estuarine and riverine systems.

Estuarine wetlands

- **Salt/brackish marsh** is defined by DCM using the CAMA definition for coastal wetlands. Salt/brackish marsh is therefore defined by the plant species it contains: smooth cordgrass, black needlerush, glasswort, salt grass, sea lavender, bulrush, saw grass, cattail, salt-meadow grass, and salt reed-grass [G.S. 113-229(n)(3)].
- **Estuarine forested wetlands** are subject to occasional flooding by tides, including wind tides (whether or not the tide waters reach the marshland areas through natural or artificial watercourses). Examples include pine-dominated communities with rushes in the understory or fringe swamp communities, such as those that occur along large back barrier estuaries like Albemarle and Pamlico sounds. Estuarine forested wetlands are common in upper estuarine sections of coastal rivers.
- **Estuarine shrub/scrub** is any shrub/scrub dominated community subject to occasional flooding by tides, including wind tides (whether or not the tide waters reach the marshland areas through natural or artificial watercourses). Typical species include wax myrtle and eastern red cedar. Examples include areas along the sound shorelines of barrier islands.

Riverine wetlands

- **Freshwater marshes** are defined by DCM as herbaceous areas that are flooded for extended periods during the growing season. Included are marshes within lake systems, managed impoundments, some Carolina Bays, and other non-tidal marshes (i.e., marshes which do not fall into the salt/brackish marsh category). Typical communities include species of sedges, millets, rushes and grasses that are not specified in the coastal wetlands regulations. Also included are giant cane, arrowhead, pickerelweed, arrow arum, and smartweed. Such marshes occur in the coastal waters of the Trent River near New Bern and along parts of the Cape Fear and Northeast Cape Fear rivers.
- **Bottomland hardwood forests** and **riverine swamp forests** are generally forested, or occasionally shrub/scrub, communities usually occurring in floodplains, that are semi-permanently to seasonally flooded. Bottomland hardwood forests contain mostly oaks (overcup, water, laurel, swamp, chestnut), sweet gum, green ash, cottonwoods, willows, river birch, and occasionally pines, while riverine swamp forests contain generally cypress, black gum, water tupelo, green ash and red maple. These swamps occur throughout the shoreline areas of coastal rivers.

Headwater wetlands

- **Headwater swamps** are wooded, riverine systems along small, intermittent tributary streams. Headwater swamps include hardwood-dominated communities with soil that is moist most of the year. Channels receive their water from overland flow and rarely overflow their banks.

Flat/depressional wetlands

- **Non-riverine swamp forests** are very poorly drained, non-riverine forested, or occasionally shrub/scrub, communities which are semi-permanently to temporarily flooded. Typical species include cypress, black gum, water tupelo, green ash and red maple (Sutter 1999).
- **Pocosins** are palustrine shrub/scrub communities (i.e., non-estuarine shrub/scrub) dominated by evergreen shrubs, often mixed with pond or loblolly pines. Pocosins typically occur on saturated, acid, nutrient poor, sandy or peaty soils; usually removed from large streams, and subject to periodic burning.
- **Wet forested flats** are poorly drained interstream flats not associated with rivers or estuaries. They are seasonally saturated by high water table or poor drainage. Species vary greatly but often include sweet gum and red maple. This category includes some hardwood flats, pine flats, and pine plantations.
- **Maritime Swamp Forests** are forested communities characterized by stunted growth due to the stresses imposed by its proximity to salt spray from the ocean. Typical vegetation includes live oak, red cedar, red maple, and swamp tupelo.

Habitat requirements

Estuarine wetlands

Salt/brackish marsh plants grow at salinities from 0.5 to >35 ppt (Wiegart and Freeman 1990). Within this salinity range, salt marsh plants persist in low-energy protected areas where the rate of sediment building (accretion) exceeds the rate of sediment loss (through erosion) or subsidence (Mitsch and Gosselink 1993). Inorganic sediments are deposited by river currents, tidal creeks and ocean overwash on and adjacent to the marsh platform (Wiegert and Freeman 1990; Mitsch and Gosselink 1993). Deposition from sediment-laden creek water causes side levees of higher elevation (low marsh) and coarser particle size than the sediments in the marsh interior (high marsh).

Erosion and sedimentation are natural processes that can result in changing distributions of marsh vegetation. The rate of erosion is dependent on shoreline orientation, fetch, water depth, bank height, sediment composition of bank, shoreline vegetation, presence of offshore vegetation, and boat wakes (Riggs 2001). In general, all of the Albemarle-Pamlico estuarine system, which is a drowned river system, is in a state of shoreline recession (Riggs and Ames 2003). South of Bogue Sound, estuarine erosion is severe only in portions of drowned river estuaries such as the Cape Fear, New, and White Oak rivers, and along the ICW and navigational channels. The remaining narrow, shallow estuaries are generally not eroding, as the marshes and flats vertically accrete sediment to keep up with rising sea level. Riggs (2001) mapped the shoreline types and shoreline areas where erosion was noticeable. Shoreline erosion rates have been estimated for portions of the coast by various studies including Stirewalt and Ingram (1974), USDA Soil Conservation Service (1975), Hartness and Pearson (1977), Riggs et al. (1978), and Hardaway (1980). Their results are summarized and compared in Riggs (2001). These studies are helpful in indicating where major erosion problems are occurring.

The zonation of vegetation in salt/brackish marsh is largely determined by variations of salinity and drainage of sediment porewater (Wiegert and Freeman 1990). Porewater salinity in the levees tends to remain similar to that of adjacent estuarine waters because of the frequent exchange of water and better internal drainage (due to coarser sediment) than the more isolated high marsh. Porewaters of the short cordgrass zone often are hypersaline during times of warm, dry weather, high rates of evapotranspiration, and minimal water exchange. In the high marsh, precipitation (and groundwater occasionally) creates salinities that may be low enough to support shrubs and other plants intolerant of high salinities (wax myrtle, groundsel-tree, and marsh elder). Some species are restricted in the low marsh because of high porewater salinity, frequent inundation, and high-sulfide porewaters associated with frequent inundation. Consequently, there is greater species richness in the high marsh because of the less stressful conditions.

Riverine wetlands

The development of tidal freshwater marshes is similar to that of salt/brackish marsh. Freshwater marshes have a higher number of plant species than their salt/brackish counterpart due to lower salinity in freshwater areas (Mitsch and Gosselink 1993; SAFMC 1998a). Tidal freshwater marshes can also be divided into low and high zones. Species in low marshes are more fleshy and succulent (e.g., arrowheads, pickerel weed, wild rice) than those in the high marsh (e.g., cattails, reeds). Competition and inundation frequency and duration are among the most important factors determining the presence and zonation of tidal freshwater marsh, although variation in salinity along stream margins reduces the number of species (Odum et al. 1984). Tidal freshwater marsh plants are usually more sensitive to toxic levels of soluble iron, manganese, or sulfide compounds that can accumulate in tidal freshwater marsh soils and can be excluded by levels of these substances that have little effect on typical salt/brackish marsh species (Odum et al. 1984).

The plant community in nontidal (inland) freshwater marshes is very similar to its tidal counterpart. However, the hydrology of nontidal wetlands is more variable than tidal wetlands that receive regular

inundation. Water levels in inland marshes are determined by the type of water body in which they occur. Water levels in isolated marshes within a small watershed are controlled more by the balance of precipitation and evapotranspiration than anything else (Mitsch and Gosselink 1993).

Riverine swamp forests typically occur along low lying margins of rivers and lakes where they receive seasonal flooding (Wharton et al. 1982). Fish use of flooded riverine forested wetlands depends on the timing and duration of inundation. The frequency and magnitude of flooding in swamp forests depends on the land use characteristics of the watershed, bank height, the degree of stream channelization, and tidal influence. Depth and duration of flooding determine whether an area is bottomland hardwood forest or swamp forest. Bottomland hardwood and swamp forest wetlands are generally irregularly to seasonally flooded (Sutter 1999). Overbank flooding and surface and groundwater discharge are likely sources of inundation in riverine swamp forests (Wharton et al. 1982). The source of inundation varies with the type of river or stream. Wetlands adjacent to large rivers receive overbank flow from flood pulses or tidal flows, whereas water level in small blackwater tributaries is influenced more by groundwater discharge and local precipitation (Wharton et al. 1982). For example, the water budget of a small blackwater stream (Creeping Swamp) in coastal North Carolina showed that water loss consisted of 61% evapotranspiration, followed by baseflow (20%), overland runoff (17%) and seepage to groundwater (2%) (Winner and Simmons 1977). The relatively low input from overland flow allows the mainstem river to have more influence on small blackwater streams at high river flows. When the mainstem channel is low, water level in blackwater streams is controlled more by local precipitation. The sporadic inundation of swamps bordering blackwater streams allows temporary use by opportunistic fish at high mainstem river flows.

Headwater swamps

The requirements of headwater swamps are similar to small tributary streams referenced above. The main difference between riverine forested wetlands and headwater wetlands is their position in the watershed: headwater wetlands are the highest hydrologic points in the watershed.

Distribution

By 1994, the DCM had used GIS technology to map and classify wetlands in the 20 coastal counties using National Wetland Inventory (NWI) maps, Natural Resource Conservation Service digital soils maps, satellite imagery (1988, 1994), and hydrography maps as source data (Sutter 1999). Analyses showed there were a total of 1.3 and 2.2 million acres of riparian and non-riparian wetlands, respectively, in the CHPP management area of those counties. The classification error for wetlands was approximately 11% (Shull 1999), making the total figure for wetlands acreage in coastal North Carolina between 3.1 and 3.9 million acres.

Riparian wetlands covered 7% of the land area in coastal river basins of North Carolina in 1994, and riverine forested wetlands was the most abundant class of the three riparian wetland classes (Table 5.1). Riparian wetlands are not distributed evenly among CHPP management units (MUs) (Map 5.1a-d). The Cape Fear MU contained the largest area of riparian wetlands, followed by the Neuse and Albemarle (Figure 5.2). The greatest proportions of estuarine wetlands were in Core-Bogue, Southern Estuaries, and Pamlico MUs, whereas the Roanoke, Cape Fear, and Neuse had the highest proportion of riverine wetlands (Figure 5.2). The greatest percentage of total land cover in riparian wetlands was in the Southern Estuaries MU (13%), where the dominant wetland type was salt/brackish marsh (Table 5.1).

Salt/brackish marsh

- The total area of salt/brackish marsh in coastal North Carolina was 198,168 acres in 1994, which comprised 17% of all riparian wetland types.
- The greatest acreage (63,601 acres) of salt/brackish marsh was in the Pamlico MU.
- Salt/brackish marsh occurs in all the CHPP management units except the Chowan, Roanoke, and

Table 5.1. Total acreage of riparian wetland types by CHPP management unit. [Source: DCM wetland mapping data (current as of 1994).]

Management Unit	Riparian Wetlands							% of total land area
	Estuarine			Riverine				
	Salt/Brackish Marsh	Estuarine Forest	Estuarine Shrub/Scrub	Freshwater Marsh	Bottomland Hardwood	Riverine Swamp Forest	Headwater swamps	
Albemarle	44,758	231	8,279	4,897	8,890	140,501	2,200	**11.3**
Cape Fear	9,640	18	363	13,443	40,018	211,888	5,606	**4.9**
Chowan	0	0	0	1,028	24,868	74,974	2,143	**11.8**
Core-Bogue	22,274	57	4,048	325	941	3,768	1,696	**9.7**
Neuse	14,386	26	1,367	3,878	68,175	146,400	9,283	**7.0**
New/ White Oak	9,143	71	2,242	665	7,134	22,229	1,530	**8.5**
Pamlico	63,601	303	8,802	4,105	254	616	611	**5.5**
Roanoke	0	0	0	1,888	37,788	123,045	2,477	**7.4**
S. estuaries	21,996	66	1,115	302	1,387	9,002	824	**13.2**
Tar/ Pamlico	12,370	193	1,658	2,272	38,127	97,258	4,789	**5.8**
Total	**198,168**	**965**	**27,874**	**32,803**	**227,582**	**829,681**	**31,159**	**6.9**
% of wetland types	**14.7**	**0.1**	**2.1**	**2.4**	**16.9**	**61.5**	**2.3**	**na**

Coastal Ocean.

Estuarine shrub/scrub

- There was a total of 27,874 acres of estuarine shrub/scrub habitat in North Carolina in 1994, which comprised 2% of riparian wetland areas (Table 5.1).
- The greatest acreage (8,279) of estuarine shrub/scrub habitat was in the Albemarle MU.
- Estuarine shrub/scrub habitat is not present in the Chowan and Roanoke MUs.

Estuarine forests

- There was a total of 965 acres of estuarine forest in the CHPP management area, comprising less than 1% of the riparian wetlands (Table 5.1).
- The greatest acreage of estuarine forested wetlands was in the Albemarle and Pamlico MUs (231 and 303 acres, respectively).
- Estuarine forest wetlands are not present in the Chowan and Roanoke MUs.

Freshwater marsh

- Freshwater marsh covered a total area of 32,803 acres in 1994 and comprised 2% of these riparian wetlands (Table 5.1).
- The greatest acreage (13,443) of freshwater marsh was in the Cape Fear MU.
- Freshwater marsh occurred in all CHPP MUs except the Coastal Ocean.

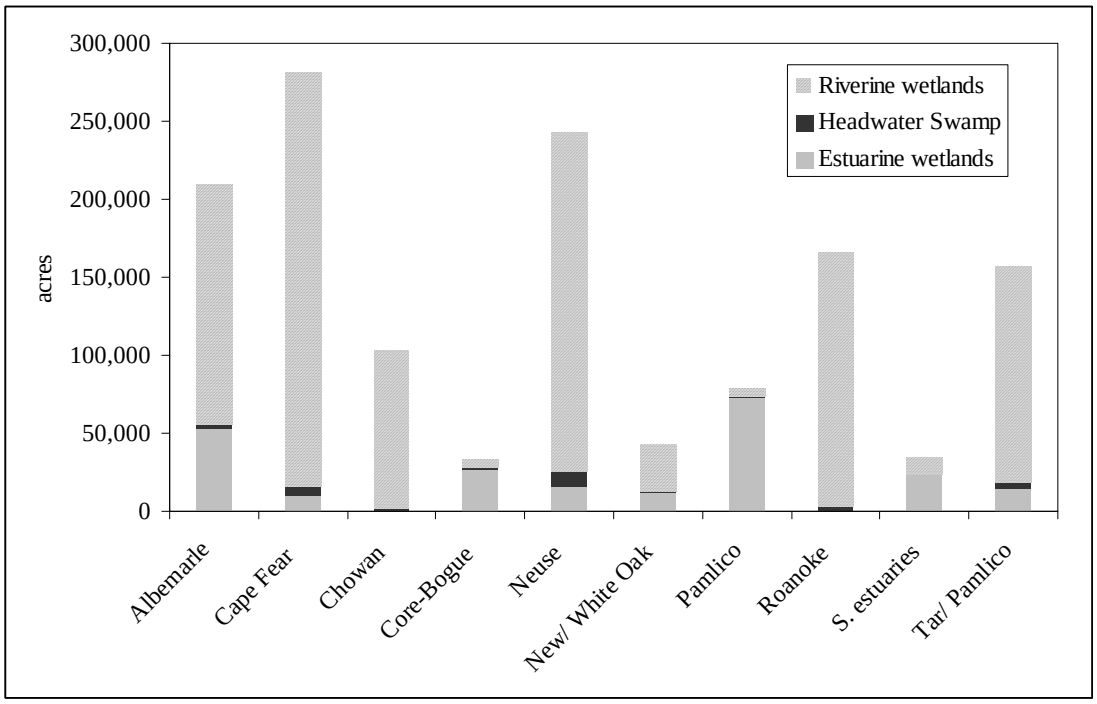


Figure 5.2. Relative amount and proportion of these riparian wetland classes among CHPP management units. [Source: DCM wetland mapping data (current as of 1994).]

Bottomland hardwood and riverine swamp forests

- The combined total acreage of bottomland hardwood forest and riverine swamp forest in 1994 was 1,057,263, which comprised 78% of all riparian wetlands in the CHPP management area (Table 5.1).
- The greatest area (251,906 acres) of bottomland hardwood and riverine swamp forest was in the Cape Fear MU (Table 5.1).
- Bottomland hardwood forests occur in all MUs except the Coastal Ocean.

Headwater swamps

- The total area of headwater swamps in the CHPP management area in 1994 was 31,159 acres, which comprised 2% of all riparian wetlands (Table 5.1).
- The greatest acreage of headwater swamps was in the Neuse (9,283 acres), Cape Fear (5,606 acres), and Tar-Pamlico MUs (4,789 acres).
- Headwater wetlands occur in all CHPP MUs except the Coastal Ocean.

5.2. ECOLOGICAL ROLE AND FUNCTIONS

Wetlands are well known for the ecological services they provide. Wetland services improve the quality of adjacent habitats with their capacity for water control and filtration. They can also protect upland habitats from erosion. Wetlands play a vital role in providing abundant food and cover for juvenile and adult finfish and shellfish. Support and documentation of these important functions are provided in this section.

Ecosystem enhancement

The flood control and water quality benefits of wetlands have been extensively studied (Mitsch and Gosselink 1993). By spreading and slowing flood waters, wetlands decrease flooding in adjacent upland areas and downstream areas. Some wetlands can store flood waters and slowly release it to surface and groundwater systems during periods of low flow (Mitsch and Gosselink 1993). Bottomland hardwood forest along the Mississippi River before European settlement stored floodwater equivalent to about 60 days of river discharge. The storage capacity of these wetlands today has been reduced to about 12 days (Mitsch and Gosselink 1993). Consequently, flooding has increased along the lower Mississippi River. Mitsch and Gosselink (1993) concluded that wetlands reduce downstream flooding most effectively with (1) increasing wetland area, (2) increasing distance of wetland downstream, (3) increasing size of flood, (4) increasing proximity to upstream wetlands, and (5) decreasing upstream storage such as reservoirs.

An important water quality benefit of wetlands is their ability to foster settlement from sediment-laden water, resulting in deposition of suspended solids (inorganic sediment and organic matter) among the vegetation (Mitsch and Gosselink 1993). Under favorable conditions, toxic chemicals and nutrients (especially phosphorus) are also retained in some wetlands due to adsorption to sediment particles (Wolfe and Rice 1972; Mitsch and Gosselink 1993). Rooted vegetation stabilizes unconsolidated sediment, reducing erosion and turbidity in adjacent aquatic habitats. Along eroding estuarine shorelines, wetlands also provide an important buffer against wave-induced turbulence (Riggs 2001). The buffering effect of wetland vegetation improves water clarity for submerged vegetation and benthic algae (Mitsch and Gosselink 1993) while also reducing sediment additions necessary for creation of new shallow water habitat (Rogers and Skrabal 2001). Consequently, both wetland and non-wetland shorelines play an important role in maintaining the function of the estuarine system. *Maintaining a natural proportion and relative position of wetland and non-wetland shorelines will be a vital component of habitat restoration and management.*

Another water quality benefit of wetlands stems from their low-oxygen soil (anaerobic or reducing). Anaerobic soils play a vital role in the nitrogen cycle by transforming ammonia and nitrate (organic waste product or fertilizer) into nitrogen gas (denitrification) (Mitsch and Gosselink 1993). In agricultural watersheds receiving fertilizer-enriched runoff, denitrification plays a important role in the world's nitrogen balance (Mitsch and Gosselink 1993). Nitrogen cycling is important to fisheries because high concentrations of nitrate can be toxic to fish, and nitrogen over-enrichment can result in algal blooms and hypoxia that contribute to stress and fish kills. Even moderate hypoxia can result in death of benthic invertebrates (Diaz and Rosenburg 1995; Taylor and Eggleston 2000; Sagasti et al. 2001), a major food source for crabs and demersal fish (Taylor and Eggleston 2000). Temporary and permanent retention of nutrients, such as phosphorus, are facilitated by particle deposition and burial as well as formation of organic matter in the sediment by roots and rhizomes (Mitsch and Gosselink 1993). Forested (streamside) wetlands in agricultural drainages have been shown to remove approximately 80% of the phosphorus and 90% of the nitrogen from the water (<http://www.epa.gov/owow/wetlands/facts/fact3.html>, July 2001). Stream headwaters are the site of most active uptake and retention of nutrients in riverine systems (Peterson et al. 2001). A study of denitrification in a headwater creek (Culvert Creek, North Carolina) found that marsh vegetation had the greatest potential for denitrification, compared to marsh sediment and flashboard risers (water control structures) (<http://www2.ncsu.edu/ncsu/CIL/WRRI/reports/report317.html>, 2003). The combination of nutrient uptake and retention makes headwater wetlands very important in controlling nutrient enrichment downstream.

Mitsch and Gosselink (1993) concluded that nutrients are probably stored in salt/brackish marshes fringing estuaries with limited water circulation (i.e., back barrier sounds), whereas wetlands in funnel-shaped (trunk) estuaries export more nutrients. There is also evidence that salt/brackish marshes act as a source of nutrients during the growing season and a sink in winter and spring (Woodwell et al. 1979). Compared to plant uptake, however, leakage of nitrogen from a Georgia salt marsh was small (Haines

1979). Nitrogen uptake in salt/brackish marsh is, on average, somewhat less than that in freshwater marshes (Mitsch and Gosselink 1993). The nutrients are also released by erosion and decomposition of wetland vegetation. Retention and controlled release of particles, toxic chemicals and nutrients can improve water quality downstream. Therefore, if bottomland hardwood forests or headwater swamps are lost upstream, the potential for erosion, flooding, sedimentation, algal blooms, and fish kills increases downstream.

Productivity

Because of the abundant supply of water, nutrients, and sunlight, wetland plant communities can be one of the most biologically productive ecosystems in the world (Teal 1962; Teal and Teal 1969; Mitsch and Gosselink 1993; SAFMC 1998a). Some of the high primary production (creation of organic compounds through photosynthesis) of wetland vegetation is transferred to adjacent aquatic habitats via detritus and microalgae (Peterson and Howarth 1987; Wiegert and Freeman 1990; Mitsch and Gosselink 1993). However, wetland plant species vary in their rate of decomposition, with leafy, succulent, low vegetation decomposing the quickest and woody, high vegetation the slowest (Mitsch and Gosselink 1993). Therefore, production from vegetation in woody, forested wetlands is converted more slowly into detritus than vegetation in marsh wetlands with leafy, succulent vegetation. Inundated wetland plants also exude dissolved organic substances contributing to epiphytic growth on their stems and leaves (Mitsch and Gosselink 1993).

Salt/brackish marsh growth in the low marsh is limited by self-shading, where other habitat requirements are met, whereas growth in the high marsh can be affected by a number of factors, including high salinity, sulfides, scarcity of iron, and lack of nitrogen (Wiegert and Freeman 1990). Accounting for phytoplankton in the water column and algae on the sediment surface, productivity of low marsh (*Spartina alterniflora*) in a Georgia tidal creek was 1,539 g carbon/m^2/yr while production in the high marsh was somewhat lower (about 1,350 g carbon/m^2/yr) (Wiegert and Freeman 1990). In North Carolina, Stroud (1976) reported somewhat higher salt/brackish marsh production in low marsh (1660 g carbon/m^2/yr), but much lower production in the high marsh (750 g carbon/m^2/yr). In both North Carolina and Georgia, above ground production was about 20% greater than below-ground production (Mitsch and Gosselink 1993).

Primary production in salt/brackish marshes is converted into fish production through several pathways. Using sulfur, carbon, and nitrogen isotopes to trace organic matter flow in the salt marsh estuaries of Sapelo Island, Georgia, Peterson and Howarth (1987) found two major sources of organic matter used in fish production: *Spartina* (detritus) and algae. The relative importance of each source is determined by the feeding mode, size, location, and trophic position of the marsh and estuarine consumers (Peterson and Howarth 1987). For example, benthic microalgae probably support herbivorous snails, whereas detritus supports sheepshead minnows, mummichogs, and their prey. Attached algae can be found on the marsh grass itself, the intertidal mudflats, and the shallow subtidal bottom near the marsh. Pinckney and Zingmark (1993) compared production rates of benthic microalgae in various bottom types in an estuarine system (North Inlet, South Carolina). Short *Spartina* marsh accounted for the greatest amount of microalgal productivity (44.6%) in the system, followed by intertidal mudflats (22%), tall *Spartina* marsh (18%), and shallow subtidal bottom (<1 m mean low water) (13%). Sand flats accounted for only 3% of the total annual microalgal production (Pinckney and Zingmark 1993).

Productivity in riverine forested wetlands in North Carolina has been reported to be much lower than in salt/brackish marsh, representing about 523-677 g carbon/m^2/yr of leaf and twig litter (Brinson 1977; Mulholland 1979). However, the total production of forested wetlands may be similar to that of salt/brackish marsh when stem growth and below ground production are taken into account. The export of detritus from these riverine forested wetlands can be significant (Mitsch and Gosselink 1993). Mulholland and Kuenzler (1979) found that organic export was higher from river basins containing more deepwater swamps than other riparian habitats. From a Louisiana swamp forest, Day et al. (1977)

measured an export rate of 10.4 g carbon/m^2/yr. By contrast, salt/brackish marshes can have an organic export rate as high as 100 g carbon/m^2/yr (Wiegert et al. 1981). However, export rates in swamp forest can vary greatly with submersion regime and temperature. For example, higher temperatures (allowing faster decomposition) and frequent inundation increase the export rate of tidal swamp forests in tidal fresh waters of the Cape Fear River.

Fish utilization

It is estimated that over 95% of the finfish and shellfish species commercially harvested in the United States are wetland-dependent (Feierabend and Zelanzy 1987). Wetlands provide numerous ecological services to coastal fishes (Table 5.2). For example, one of the most important characteristics of riparian wetlands are their combination of shallow water and thick vegetation, which provides nursery habitat for young fish. The use of wetlands by finfish and shellfish is presented first, followed by documentation of specific functions for selected species.

Salt/brackish marsh

Finfish and shellfish using salt/brackish marsh fall into several categories based on location and timing of use. Year-round residents of the marsh include small forage species such as killifish, mummichogs, sheepshead minnows, gobies, grass shrimp, bay anchovies, and silversides (SAFMC 1998a). Transient species include those spawning near the marsh, but inhabiting deeper channels (i.e., river herring), and those spawned in deeper waters using marsh habitat as nursery or foraging areas. Among transient species, some prefer the edge of salt/brackish marsh (i.e., red drum, flounder) while others are found near marsh edge on unvegetated bottom (i.e., spot, croaker). Some species are not found in the marsh, but derive substantial food resources from the marsh plants as detritus (i.e., menhaden; Lewis and Peters 1994) or from microalgae produced on the marsh surface. Of fishery species in North Carolina, penaeid shrimp and red drum are considered critically linked to marsh edge habitat (SAFMC 1998a)[59].

Freshwater marsh

Fishery and forage fish inhabiting tidal and non-tidal freshwater marshes include largemouth bass, bluegill, warmouth, black crappie, chain pickerel, southern flounder, white perch, mummichog, bay anchovy, inland silversides, river herrings, striped bass, and sturgeon (Mitsch and Gosselink 1993). The nature and degree of association with freshwater marsh habitat depend on the species. For example, striped bass and river herring are not only abundant along marsh edge, but also in open water areas adjacent to the marsh edge. Bluegill, black crappie, largemouth bass, and warmouth are found almost exclusively near shoreline structures such as marsh grass. Mosquitofish are an important forage species and a “mosquito control agent” closely associated with freshwater marsh habitat (Odum et al. 1984).

[59] More information on salt/brackish marsh can be found in the Nursery function section of this chapter.

Table 5.2. Partial listing of fish and their use of wetland habitat in coastal North Carolina.

Species*	Wetland Functions [1]					Fishery [2]	Stock Status [3]
	Nursery	Foraging	Refuge	Spawning	Corridor		
ANADROMOUS AND CATADROMOUS FISH							
American eel		X	X		X	X	
Sturgeon spp.	X	X	X		X	X [4]	O
River herring (alewife & blueback herring)	**X**	**X**	**X**	**X**	**X**	**X**	**O-Albemarle Sound, U-Central/Southern**
Striped bass	X	X	X		X	X	V-Albemarle Sound, Atlantic Ocean, O-Central/Southern
ESTUARINE AND INLET SPAWNING AND NURSERY							
Atlantic rangia clam	X	X	X	X			
Banded killifish	**X**	**X**	**X**	**X**			
Bay anchovy	X	X		X			
Blue crab	**X**	**X**	**X**		**X**	**X**	**C**
Cobia	X	X			X	X	
Grass shrimp	**X**	**X**	**X**	**X**			
Mummichog	**X**	**X**	**X**	**X**			
Naked goby	X	X	X	X			
Red drum	**X**	**X**	**X**		**X**	**X**	**R**
Sheepshead minnow	**X**	**X**	**X**	**X**			
Silversides	X	X		X			
Spotted seatrout	**X**	**X**	**X**		**X**	**X**	**V**
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY							
Atlantic croaker	**X**	**X**	**X**		**X**	**X**	**C**
Atlantic menhaden	X	X			X	X	V
Shrimp	**X**	**X**	**X**		**X**	**X**	**V**
Southern flounder	**X**	**X**	**X**		**X**	**X**	**O**
Spot	**X**	**X**	**X**		**X**	**X**	**V**
Striped mullet	**X**	**X**	**X**		**X**	**X**	**C**
MARINE SPAWNING, HIGH SALINITY NURSERY							
Black sea bass	X	X	X		X	X	O- south of Hatteras, V- north of Hatteras
Pinfish	**X**	**X**	**X**		**X**	**X**	
Summer flounder	**X**	**X**	**X**		**X**	**X**	**V**

* Scientific names listed in Appendix I. Names in **bold** font are species whose relative abundances have been reported in the literature as being generally higher in wetlands than in other habitats. Note that lack of bolding does not imply non-selective use of the habitat, just a lack of information.

[1] Sources: Wharton et al. 1982; Odum et al. 1984; Wiegert and Freeman 1990; Mitsch and Gosselink 1993; Micheli and Peterson 1999; Minello 1999; NOAA 2001.

[2] Existing commercial or recreational fishery. Fishery and non-fishery species are also important as prey.

[3] V=Viable, R=Recovering, C=Concern, O=Overfished, U=Unknown (DMF 2003a)

[4] Fishery species under harvest moratorium

Bottomland hardwood and riverine swamp forest

There is a strong relationship between fishery yields and forested river floodplains (Mitsch and Gosselink 1993). A study on the Suwanee River floodplain (Florida/Georgia) found that fish production was much greater in floodplain sloughs than in the main river (Holder et al. 1970). A similar study of fish standing stock on river floodplains in North Carolina has not been conducted. Fish use of riverine forested wetlands is generally restricted to periods of seasonal inundation, which occurs mostly during winter and

spring. By contrast, riverine wetlands below Lock and Dam #1 on the Cape Fear River receive regular tidal inundation (C. Hackney, UNC-W, pers. com., 2003). Seasonal flooding in riparian forested wetlands also increases the productivity of riverine systems by connecting the mainstem river with the abundant organic material found on forested floodplains (Wharton 1982; Junk et al. 1989). For example, numerous studies have shown a correlation between sunfish and largemouth bass spawning success and the timing and extent of floodplain inundation (Wharton et al. 1982). In North Carolina, seasonal high water in riverine systems generally occurs from winter to spring. Summer conditions (falling water levels, increasing temperatures, and low dissolved oxygen) exclude most fish from forested wetlands areas. Only fish adapted to low oxygen conditions continue to inhabit wetland areas as long as they contain water (i.e., bowfin, gar, mudminnows, killifish; Wharton et al. 1982). A study on fish use of creek floodplains in North Carolina documented several common species using channels in the floodplain (Walker 1984). Those species included several small sunfish species, redfin pickerel, bowfin, brown bullheads, redear sunfish, pumpkinseed, bluegill sunfish, green sunfish, and small forage species (e.g., shiners, darters, killifish, and crayfish). Estuarine-dependent species found on river floodplains include hickory shad, blueback herring (Wharton et al. 1982), and alewife (SAFMC 1998a). The tidal swamp forests in the Cape Fear estuary are also inhabited by blue crabs and other transient estuarine species (C. Hackney, UNC-W, pers. com., 2003).

Flat/depressional wetlands

Fish use of normally isolated wetlands (i.e., pocosins along the Alligator and Northeast Cape Fear rivers) depends on many factors. A study conducted on the Savannah River floodplain found that fish use was limited to wetlands that dried infrequently, were most connected to intermittent water bodies, and had an elevation closest to the nearest permanent water body (Snodgrass et al. 1996). Pocosins that are located directly adjacent to salt/brackish marsh or other riparian wetlands are potential fish habitat. Biotic interactions and characteristics of the wetlands had relatively less influence on fish community structure than the wetland's landscape position. The study also noted that only widespread, colonizing species were correlated with landscape position, suggesting more complicating factors controlling colonization rates (i.e., variation in water level more related to local rainfall than overflow). *As sea level continues to rise and low-lying pocosins near coastal North Carolina waters transform into marshes, they will become more important as primary nursery areas for estuarine-dependent fish (Brinson 1991). Therefore, a similar study should be conducted in North Carolina to determine what pocosin areas are actually used by fish, and the contribution of those fish to overall production in the estuary.*

Specific biological functions

Nursery

The large expanses of shallow water and thick vegetation found in riparian wetlands provide abundant food and cover for larval, juvenile and small organisms (Graff and Middleton 2003). Nursery habitat is not only provided by the dense structures, but also by the shallow depth of water itself, which provides refuge from aquatic fish predators (review in Rozas and Odum 1987). The aversion to shallow water among large, deep-bodied aquatic predators is a common behavior, which indirectly protects smaller fish.

Salt/brackish marsh

Along with the shallow soft bottom and shell hash areas they border, salt/brackish marshes along the North Carolina coast are probably the most recognizable nursery habitat for estuarine-dependent species. The majority of Primary and Secondary Nursery Areas designated by the MFC are located in soft bottom areas surrounded by salt/brackish marsh. Even though salinity and transport mechanisms are the key physical factors affecting the species composition in nursery habitats in Pamlico Sound and its tributaries (Ross and Epperly 1985; Noble and Monroe 1991; Ross 2003), marsh wetlands are a vital component of estuarine nursery habitat. Minello et al. (2003) concluded that the relative nursery value of salt marshes in Atlantic coast estuaries appears to be higher than open water, but lower than submerged aquatic

vegetation.

Most of the juveniles of fishery species found in salt/brackish marsh nurseries were spawned offshore during winter. The larvae were transported through inlets and into estuarine waters where they settled in the upper (low salinity) or lowermost (high salinity) reaches of estuarine creek systems (Ross 2003). The peak of juvenile settlement generally occurs in spring through early summer, although the peak is correlated more with water temperature (Ross and Epperly 1985). Settlement in upper reaches is particularly beneficial to spot and croaker, where growth and survivorship are enhanced compared to lower reaches (Ross 2003). If movement to general regions of the estuary is largely passive (Pietrafesa et al. 1986; Pietrafesa and Janowitz 1988), the viability of spot and croaker stocks could be reduced by hydrodynamic conditions resulting in more settlement to lower regions of the estuary (Ross 2003). This settlement pattern could also occur in other estuarine-dependent species.

According to DMF's juvenile abundance survey data, the dominant species in high salinity marshes behind the Outer Banks and Core Sound include pinfish, pink shrimp, black sea bass, gag, pigfish, red drum, gulf flounder, and summer flounder (Noble and Monroe 1991). However, the primary nursery habitat in these areas is submerged aquatic vegetation. Juvenile spot, brown shrimp, striped mullet, and southern flounder are abundant along the western shores of Pamlico and Core sounds and their tributaries (Epperly and Ross 1986; Noble and Monroe 1991). In the Newport River estuary, juvenile southern flounder showed a distinct preference for marsh edge habitat over other habitats, but only during fall (Walsh et al. 1999). The juvenile southern flounder were most abundant in more turbid, upper regions of the estuary.

During spring through fall, brackish marshes in the Albemarle-Pamlico estuary are dominated by juvenile Atlantic menhaden, striped mullet (Epperly and Ross 1986), silversides, anchovies (Nelson et al. 1991) and more demersal species such as Atlantic croaker, brown shrimp, blue crab, and southern flounder (Noble and Monroe 1991). In higher salinity marshes of the Pamlico Sound, spotted seatrout, weakfish, silver perch, and red drum are also abundant (Noble and Monroe 1991). Juvenile red drum reach their highest abundance in brackish marsh (Tagatz and Dudley 1961; Nelson et al. 1991; C. Peterson, UNC-CH, pers. com., 2003). Fish use of low salinity (brackish) marsh habitat in estuaries of North Carolina was studied by Rozas and Hackney (1984), who found a combination of freshwater and estuarine species in low-salinity, intertidal creeks. The most abundant species were spot, grass shrimp, bay anchovy, and Atlantic menhaden. They also reported three seasonal peaks in abundance in low salinity marshes: (1) spring peak with influx of juvenile spot, Atlantic menhaden, Atlantic croaker, and southern flounder; (2) summer peak of grass shrimp; and (3) fall peak of bay anchovies and grass shrimp.

A study in Galveston Bay, Texas, found that juvenile brown shrimp, white shrimp, blue crab, spotted seatrout, and southern flounder were most abundant along salt/brackish marsh edge habitat compared to inner marsh, shell bottom, SAV, and shallow, non-vegetated bottom (Minello 1999). In another Texas estuary, low marsh supported higher abundances of brown shrimp, blue crabs, daggerblade grass shrimp, white shrimp, and striped mullet, although there was little difference between low and high marsh for white shrimp and striped mullet (Rozas and Zimmerman 2000). Resident estuarine species, such as gulf killifish and sheepshead minnow, were most abundant in high marsh.

Habitat types derived from salt/brackish marsh (i.e., peat blocks) can also provide important nursery habitat for certain species. Peat blocks are generally found along eroding marsh shorelines, where they serve as firm substrate for the attachment of sessile invertebrates and refuge for juvenile blue crabs in western Pamlico Sound (D. Eggleston, NCSU, pers. com., 2001). Szedlmayer and Able (1996) found that, in a New Jersey estuary, juvenile black seabass were more abundant in sponge-peat habitats (associated with eroding marsh) compared to eelgrass beds, upper estuary, subtidal creeks, marsh channels, and open bay areas.

Freshwater marsh

Studies documenting the use and significance of freshwater marsh for larval and juvenile fish in North Carolina are lacking. Freshwater marshes comprise only a very small portion of riparian wetlands in coastal North Carolina. A study conducted in Virginia found that larvae and juvenile fish represented 79% and 59% of the total number of fish collected at tidal freshwater and salt marsh sites, respectively (Yozzo and Smith 1997). McIvor and Odum (1987) found reduced predation by large carnivorous fish in the shallow water (<3ft or <1m) of freshwater tidal creeks, possibly due to unfavorable water quality, the physical constraints of shallow water, and/or increased predation from predatory birds (i.e., herons).

Bottomland hardwood and riverine swamp forest

Forested wetlands are important nursery areas for anadromous and resident freshwater species along coastal rivers and creeks in North Carolina (Wharton et al. 1982; DMF 2000c). Forested wetlands are also important for some transient estuarine species (i.e., spot, croaker, southern flounder, blue crab) in the lower Cape Fear River (Mallin et al. 2001c; C. Hackney, UNC-W, pers. com., 2003). The timing and extent of flooding are critical to fish use of bottomland hardwood and riverine swamp forest. Larval and juvenile river herring have been collected near flooded riverine wetlands in North Carolina (DMF 2000c). Studies of larval fish abundance and diversity on Mississippi River floodplains suggested that nearly 50% of fish species inhabiting the river used the floodplain as a nursery (Gallagher 1979). Unchannelized sections of the Missouri River produced 2 to 2.5 times more fish than channelized sections (Groen and Schmulbach 1978). In general, vegetated shoreline inundation during spring and early summer has been correlated with increased year-class strength of largemouth bass, sunfish, and yellow perch (Nelson and Walburg 1977; Strange et al. 1982; Ploskey 1986).

Foraging

Salt/brackish marsh

Few aquatic species feed directly on living plant tissue in salt/brackish marsh (i.e., periwinkle), and their productivity is very low compared to that of detritivores and consumers of microalgae (Wiegert and Freeman 1990; Steel 1991; SAFMC 1998a). However, biotic interactions with primary consumers can result in degradation or loss of wetlands. Recent study results from the southeastern United States suggest that blue crab predation on plant-eating snails may prevent the snail from overgrazing the marsh grass (Silliman and Bertness 2002).

Detrital and bacterial production from salt/brackish marsh exhibit some of the highest recorded values per unit area of any ecosystem in the world (Wiegert and Evans 1967). Slow-moving or sessile species residing in salt/brackish marsh and contributing to secondary production include fiddler crabs, mud snails, amphipods, oysters, clams, and ribbed mussels (Wiegert and Freeman 1990). Based on data from Georgia marshes, biomass of these resident species exceeded 15 g carbon/m^2, and consisted of 80-200 fiddler crabs, 400-700 periwinkle snails or mud snails, and 7-8 mussels (Wiegert and Freeman 1990). The resident estuarine fishes (i.e., killifish, grass shrimp, sheepshead minnow) are an important link between estuarine production and transient predatory fish populations (Wiegert and Freeman 1990; Kneib 1997). Salt-brackish marsh edge also provides important feeding areas for blue crabs, red drum, flounder, seatrout and other large predators searching the edge of complex structure near deeper water, as illustrated by greater predation on grass shrimp with increasing depth in shallow-estuarine water (Clark et al. 2003).

It has been estimated that 45% of salt marsh production is exported to the estuarine system in the form of detritus, dissolved organic matter, and transient nekton (i.e., grass shrimp and killifish; Teal 1962). The biomass of secondary production going in and out with the tide (fish, shrimp) is less well known than resident species biomass (Kneib and Wagner 1994). The exported production of brown and white shrimp is probably the best known and most significant to coastal fisheries (Turner 1977; Wiegert and Freeman 1990). The estimated yield of shrimp from North Carolina was 107 lb per acre of intertidal vegetated

bottom (Turner 1977), where intertidal vegetation included "salt marsh macrophytes, *Spartina* spp. [and] *Juncus* spp.." However, recent research suggests that wetlands vary greatly in their role as exporters or importers of organic matter (Wiegert and Freeman 1990). This variation could be the result of variable erosion or deposition rates among seasons or wetland areas.

Freshwater marsh

Compared to salt/brackish marsh, most living vegetation in freshwater marshes can be more readily consumed by insects, crayfish, muskrats, waterfowl, and carp (Mitsch and Gosselink 1993; SAFMC 1998a). However, herbivory is still minor in freshwater marshes (Mitsch and Gosselink 1993). Together with phytoplankton and benthic algae, organic matter from the emergent vegetation is the source of primary production in freshwater marshes. The export of this production (in the form of particulate detritus) to other systems is less understood than that of salt marshes (Mitsch and Gosselink 1993), but is probably similarly affected by the rates of erosion and water exchange between wetlands and open water systems. Because many freshwater marshes in North Carolina generally occur in slow-moving, backwater areas, export of detritus is probably less significant compared to salt marshes.

The detritus that remains in the marsh provides food for meio- and macrobenthic communities consisting of nematode worms, chironomid fly larvae, mysids, snails, and amphipods (Odum et al. 1984; Mitsch and Gosselink 1993; SAFMC 1998a). The macrobenthic community, in turn, provides abundant food for small fish, grass shrimp, crayfish, crabs, and waterfowl. Large fish feeding within the marsh include chain pickerel, bowfin, and gars (Odum et al. 1984). Many other large, aquatic predators (i.e., largemouth bass, crappie) feed along the edge of freshwater marshes where there is deep water nearby for refuge (Odum et al. 1984).

Bottomland hardwood and riverine swamp forest

Although riverine forests contain vast stores of organic matter, much of it is not rapidly converted into particulate organic matter for secondary production (Mitsch and Gosselink 1993) because woody material and leaves break down more slowly than succulent vegetation in marshes. In spite of this, riverine forested wetlands still produce abundant invertebrate food, such as copepods, ostracods, amphipods, isopods, oligochaetes, flatworms, crayfish, and terrestrial insects (Wharton et al. 1982; Mitsch and Gosselink 1993). Fish species and life stages adapted for feeding in riverine swamp forests include adult mosquitofish, gar, bowfin, carp and chain pickerel, along with early life stages of many other species (Wharton et al. 1982; Mitsch and Gosselink 1993). Other species, such as largemouth bass and catfish, are opportunistic predators within the flooded forest.

Refuge

Adult or small aquatic organisms find refuge from predators and adverse weather conditions on and among the dense leaf canopies found in salt/brackish and freshwater marshes (Mitsch and Gosselink 1993; SAFMC 1998a; Graff and Middleton 2003). Many small resident species, such as grass shrimp and killifish, reside within emergent stands of vegetation (Pattilo et al. 1997; SAFMC 1998a; Minello 1999; Rozas and Zimmerman 2000). A recent study on predation risk and prey distribution in shallow-water estuarine habitats found that predation on grass shrimp increased with increasing depth during the day, and decreased across all depths at night (Clark et al. 2003). The study's results highlight the importance of a refuge from predation during the daytime and a relaxation of predation at night. Large, somewhat less mobile organisms also find refuge in the vegetation. For example, Micheli and Peterson (1999) found that adult blue crabs utilized marsh edge habitat in preference to unvegetated, open water habitat in a North Carolina estuary, presumably as refuge from predation.[60]

[60] The refuge function of marshes for juvenile species is discussed in the nursery function section.

The structure provided by freshwater marsh vegetation and forested wetland margins provides excellent refuge for sunfish, crappie, largemouth bass, and other ambush predators, as well as slow-moving benthic invertebrates (e.g., crayfish). Numerous studies have documented the vegetated habitat preference of largemouth bass, bluegill, and other freshwater ambush predators (review in Savino and Stein 1989).

Spawning

The stems and leaves of wetland vegetation provide a surface for attachment of eggs. The combination of egg-laying structures, abundant food and relative scarcity of predators (Power et al. 1995) in seasonally flooded wetlands makes them an ideal spawning area. River herring are an important coastal species that spawn adhesive eggs in flooded swamps, oxbows, and along stream edges (Wharton et al. 1982; DMF 2000c). Spawning of river herring in North Carolina occurs during elevated spring flows from March through May in small tributaries (DMF 2000c).

The structural complexity of marsh vegetation and intertidal submersion regime in salt/brackish marsh provide spawning habitat for forage species such as killifish (including mummichogs), silversides, gobies, and grass shrimp (Anderson 1985; Pattilo et al. 1997). The number of species spawning in salt marsh habitat is low compared to the number of estuarine species spawning offshore and in deep channel habitat (Table 2.3). Nevertheless, many of the species spawning in wetlands are also important food items for transient fishery species.

Corridor and connectivity

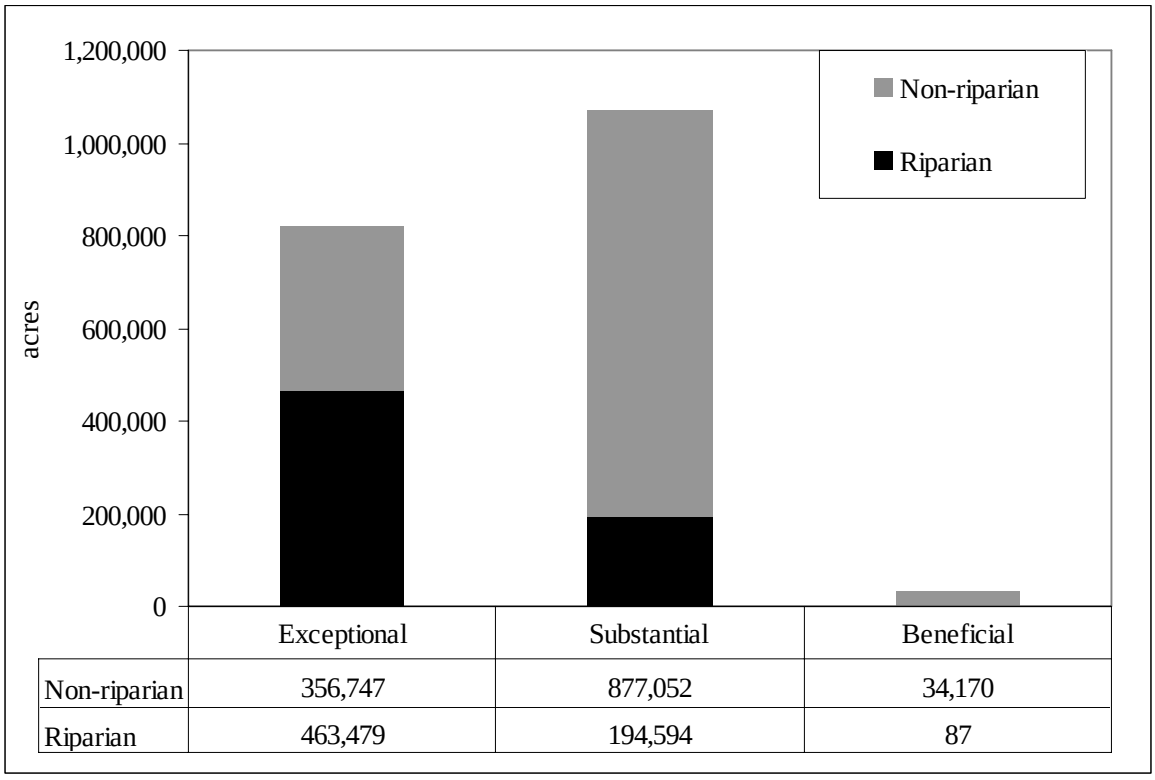
Within the marsh, elevation and proximity to open water are important influences on the distribution of fish. Rozas and Odum (1987) found that shallow water and greater distance from deep water typically meant lower abundance of large predatory fish (Rozas and Odum 1987). Marsh edge is also more utilized when adjacent to SAV or shell beds where small organisms can take refuge at low tide (Rozas and Odum 1987; Irlandi and Crawford 1997; Micheli and Peterson 1998). Increased utilization is possible because small organisms need to move only a short distance to return to the marsh at high tide. Rozas and Odum (1987) compared fish and shellfish densities in tidal creeks with and without adjacent SAV beds. They found that grass shrimp numbers greatly declined when artificial SAV was removed from a tidal creek. However, fish numbers (mostly mummichogs and banded killifish) were not significantly reduced. The results suggest a higher relative importance of wetland vegetation near SAV beds for grass shrimp. Irlandi and Crawford (1997) found that pinfish were more than twice as abundant in intertidal marshes adjacent to SAV beds than in marshes adjacent to completely unvegetated bottom. The movement of pinfish between the intertidal marsh and subtidal grass beds could provide an important link in the transfer of secondary production from the marsh to adjacent aquatic habitats, and vice versa. Micheli and Peterson (1998) found that marsh edge provides corridor function by facilitating the access of blue crabs to oyster reefs and enhancing the intensity of predation on smaller macroinvertebrates. Isolated oyster reefs had higher densities of those smaller macroinvertebrates. *These studies show the importance of considering optimal locations for SAV and wetland restoration/creation projects.*

Functional significance

Functional value of wetlands was incorporated into DCM's North Carolina Coastal Region Evaluation of Wetland Significance (NC-CREWS), which is a GIS wetland functional assessment model. The primary objective of the NC-CREWS wetland functional assessment is to provide users with information about the relative ecological importance of wetlands for use in planning and the overall management of wetlands. Thirty-eight separate wetland functions were used to evaluate each mapped wetland area within the 20 coastal counties. Each wetland is given a rating of "Exceptional", "Substantial", or "Beneficial" Functional Significance. The overall rating was based on individual ratings for nonpoint source function, floodwater cleansing, landscape and watershed attributes, surface runoff storage, floodwater storage, shoreline stabilization, terrestrial wildlife habitat functions, and aquatic life habitat functions (Sutter 1999). NC-CREWS provides an excellent rating system, but it was not specifically

developed to locate the best habitat for coastal fisheries. Wetland properties such as primary production, structural complexity, depth and submersion regime were not included in this particular model. However, the 'aquatic life habitat functions' component of CREWS provides an area within which coastal fish habitat can be found. The aquatic life habitat function of NC-CREWS includes anadromous fish, other fish species, and amphibian/invertebrate habitat (Sutter 1999).

The NC-CREWS categories corresponded fairly well to riparian and non-riparian habitat categories used in CHPPs. Riparian wetlands included the following DCM wetland types: salt/brackish marsh, freshwater marsh, estuarine shrub/scrub, bottomland hardwood, riverine swamp forest, headwater swamp, and estuarine forest. Most intact riparian wetlands were rated "Exceptional" in function (Figure 5.3). The majority of non-riparian wetlands were rated as "Substantial." There were virtually no riparian wetlands in the "Beneficial" significance category. *The significance of riparian wetlands further justifies the need to enhance their protection*.



	Exceptional	Substantial	Beneficial
Non-riparian	356,747	877,052	34,170
Riparian	463,479	194,594	87

Figure 5.3. Results from North Carolina Coastal Region Evaluation of Wetland Significance (NC-CREWS) in CAMA counties grouped by CHPP riparian and non-riparian wetland categories. [Source: DCM wetlands data (current as of 1994)]

5.3. STATUS AND TRENDS

Status of wetland habitat

Various estimates have been made of the original extent of North Carolina's wetlands. The DWQ and North Carolina Water Resources Research Institute staff have examined hydric soils from the published and draft county soil surveys (DWQ 2000a). These studies estimate that North Carolina had about 7.2 million acres of wetlands prior to European colonization. Of that original extent, 95% was in the Coastal Plains. In another study, Dahl (1990) estimated that by the mid-1980s, only about one-half of North Carolina's original wetlands remained. The trend in wetland loss for North Carolina mirrors national

trends (Dahl 1990).

According to DWQ (2000a), approximately 66% of North Carolina's original wetland extent remains and 83% of its original salt marsh, bottomland hardwood, and swamp forest (Table 5.3). However, the 83% figure is only a rough estimate because the DWQ study did not distinguish between depressional and riverine swamp forest. Pocosins have suffered even greater losses (48% remaining from the 1950s). The figures also do not account for wetland losses after 1993. The amount for remaining wetlands in North Carolina will be updated later in this chapter with more recent permit statistics.

Table 5.3. North Carolina wetland acreage estimates. [Source: NC Division of Water Quality 305(b) report (DWQ 2000a)]

Wetland type		Wetland Acreage			
		Original Extent[1]	1990's	Change	% remaining
Non-riparian	Pine savannah	3,643,000	28,000	-3,615,000	1%
	Pocosin	1,366,000	655,000	-711,000	48%
	Wet pine flatwood	0	2,212,000[2]	2,212,000	
Riparian	Bottomland hardwood	1,481,000	1,207,000	-274,000	81%
	Salt marsh	209,000	183,000	-26,000	88%
	Swamp forest	476,000	413,000	-63,000	87%
TOTAL		7,175,000	4,706,000	-2,469,000	66%

[1] Based on descriptions of native vegetation found on hydric soils from SCS county soil surveys from the 1950s.
[2] Based on original extent of pine savannahs.

The DCM wetlands types use three modifiers to indicate human disturbance: 1) partially drained, 2) cutover, or 3) cleared. These modifiers were not meant to account for all wetlands modified or "lost." The inclusion of modifiers was simply a way to show how some of the wetlands remaining today have been degraded or modified (M. Lopazanski, DCM, pers. com., 2003). According to U.S. Fish and Wildlife Service's National Wetlands Inventory maps, partially drained wetlands are, or have been, partially ditched/drained. Cutover wetlands are wetland areas in which satellite imagery from 1994 indicates a lack of vegetation where it was present in 1988. Cleared wetlands are areas containing hydric soils for which satellite imagery indicated a lack of vegetation in both 1988 and 1994. Cutover wetlands have likely retained wetland hydrology and soil characteristics, while cleared and drained wetlands are probably no longer functional wetlands.

Using the DCM modifiers for human disturbance, more non-riparian wetlands have been lost than riparian wetlands. As of 1994, 98,773 and 387,498 acres of riparian and non-riparian wetlands, respectively, were mapped as degraded or modified (Tables 5.4 and 5.5). Among riparian wetland types, riverine swamp forests were most often mapped as modified by drainage, followed by salt/brackish marshes, and bottomland hardwood forests (Table 5.4 and Maps 5.1a-d). A quantifiable trend in wetland degradation is apparent for cutover wetlands. During 1988-1994, the rates of cutover for riparian and non-riparian wetlands were 2,919 and 6,719 acres/year, respectively (DCM, unpub. data). Although wetland hydrology and soil are maintained in these areas, the trees will take years to recover.

Table 5.4. Acres of modified riparian wetland types in coastal area. [Source: DCM wetland mapping (current as of 1994).]

Riparian wetlands	Bottomland Hardwood	Estuarine Forest	Estuarine Shrub/Scrub	Freshwater Marsh	Headwater Swamp	Riverine Swamp Forest	Salt/Brackish Marsh	Total area
Cleared[1]	4,183	0	318		822	2,985		**8,308**
Cutover[2]	7,840	5	535		2,853	6,280		**17,513**
Drained[1]	13,548	19	2,195	2,550	2,583	22,715	29,242	**72,852**
TOTAL	**25,571**	**24**	**3,048**	**2,550**	**6,258**	**31,980**	**29,242**	**98,673**

[1] Unknown time period of impact; current as of 1994

[2] Impacted from 1988-1994

Table 5.5. Acres of non-riparian wetland types impacted in 1994 in coastal areas. [Source: DCM wetland mapping (current as of 1994).]

Non-riparian wetlands	Depressional Swamp Forest	Hardwood Flat	Maritime Forest	Pine Flat	Pocosin	Total area
Cleared[1]	3,755	8,091	142	4,610	1,986	**18,584**
Cutover[2]	5,686	13,388	138	15,748	5,356	**40,316**
Drained[1]	61,830	70,536	17	95,933	100,282	**328,598**
TOTAL	**71,271**	**92,015**	**297**	**116,291**	**107,624**	**387,498**

[1] Unknown time period of impact; current as of 1994

[2] Impacted from 1988-1994

Within DWQ coastal river basins, Clean Water Act section 401-permitted wetland impacts over a period of four fiscal years (1997-2001) indicate a potential conversion of 3,817 wetland acres to non-wetland uses (Figure 5.4). Losses in fiscal years 1999/2000 and 2000/2001 were relatively small compared to 1997/1998 and 1998/1999. The relatively large losses in those earlier years resulted from two large projects (Buckhorn Reservoir in Wilson County and Global Transpark in Lenoir County). However, it should be noted that section 401 water quality certifications (from DWQ) precede section 404 permits (from the U.S. Army Corps of Engineers or COE) that may never be issued. In addition, some permitted impacts never occur. There were an additional 11,580 acres of pocosin wetland (non-riparian) lost after repeal of the federal Tulloch Rule[61]. However, most of this acreage had its hydrology restored through an intensive state and federal enforcement effort. There are also an unknown number of wetland acres lost each year from unauthorized projects and small projects not requiring confirmation by DWQ. Thus, the

[61] See "Land use and wetland conversion" section for more information

amount of impacted wetland acres may be underestimated. The DWQ is working to resolve the issue of tracking unauthorized and cumulative, small impacts (DWQ 2000a).

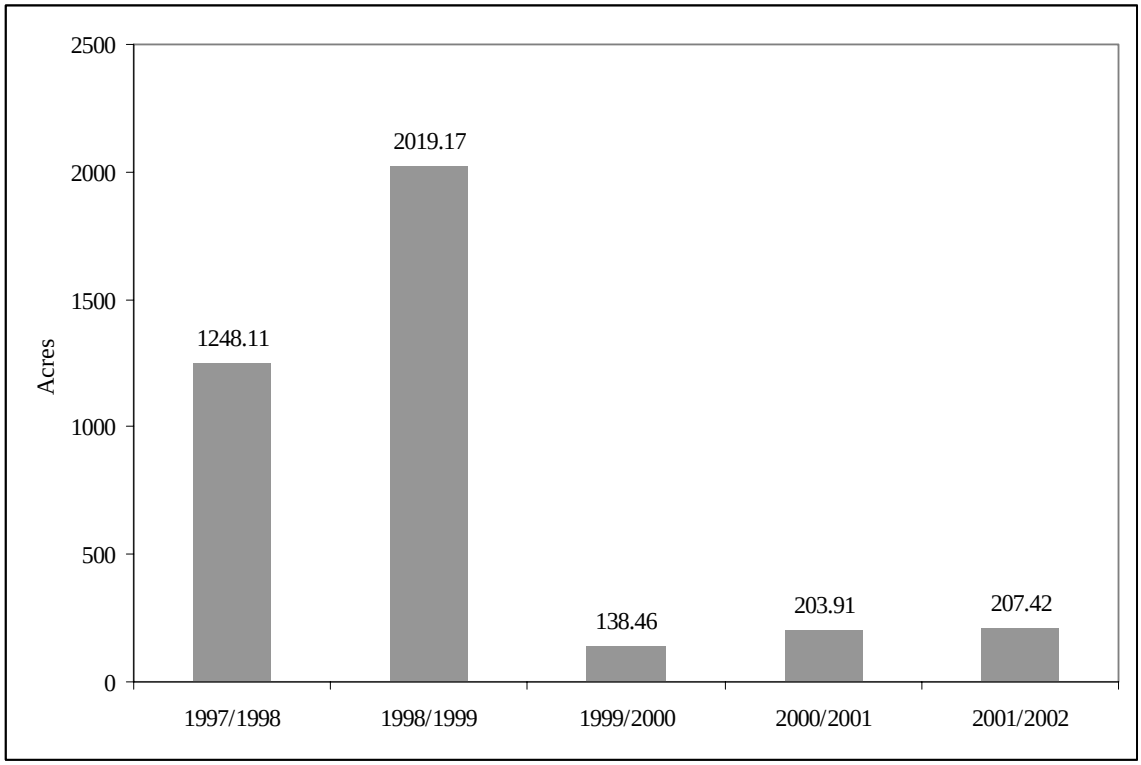


Figure 5.4. Total DWQ 401 Permitted Wetland Impacts (acres) during 1997-2002 in the seven Coastal river basins (excluding the Lumber River basin). Note: These data are for permanent wetland loss and do not include impacts from CAMA, Corps of Engineers Nationwide Permits 12 and 33, and Corps of Engineers Regional General Permit 030 since these impacts are temporary or are impacts to water (e.g., drainage).

In addition to conversion caused directly by humans, wetlands are also being lost to erosion resulting from sea level rise and shoreline hardening (Riggs 2001). Based on a recent study of 21 field sites and then extrapolated to the entire length of estuarine shoreline in northeastern North Carolina, annual wetland losses are approximately 802 acres/year, most of which are mainland brackish marsh habitat (Riggs and Ames 2003). When the cumulative effects of permitted wetlands impacts from 1997 to 2001, unpermitted wetland impacts (after repeal of Tulloch Rule), estimated coastal erosion loss from 1993 to 2001, and total estimated wetland losses prior to 1993 (DWQ 2000a) are added together, the total loss of wetlands in DWQ coastal river basins could be as much as 2,491,515 acres (1993-2002). This total estimated wetland loss still leaves 65% of the estimated original extent of wetlands in North Carolina (DWQ 2000a). However, this figure does not account for wetlands gained through restoration or creation, either by natural processes or restoration/creation effort. It also does not account for losses between 1993 and 1997 that were not attributable to erosion.

Status of associated fishery stocks

Of the ten fishery stocks with higher relative abundance in wetlands (Table 5.2), two are Overfished, three are Concern, one is Recovering, and four are Viable. There are an approximately equal number of Viable and Concern stocks showing some preference for wetland habitat. The two wetland-enhanced[62]

[62] Wetland-enhanced species are those showing some documented preference for wetland habitat.

stocks listed as Overfished were river herring (alewife and blueback herring in Albemarle Sound) and southern flounder. Wetland-enhanced species of Concern included blue crab, striped mullet, and Atlantic croaker.[63] The one Recovering species was red drum. The Viable species were spotted seatrout, spot, summer flounder, and shrimp.

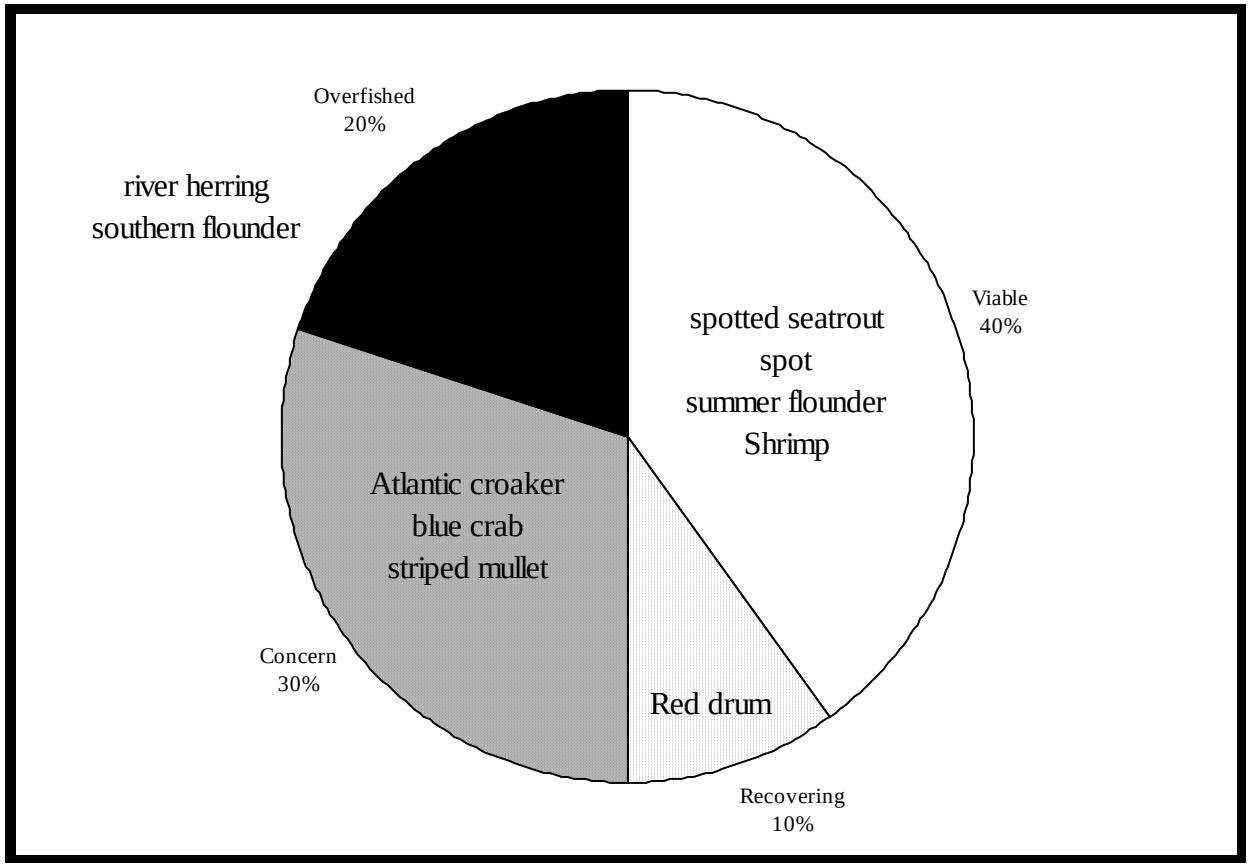


Figure 5.5. Percent of wetland-enhanced fish stocks classified as Overfished, Concern, Recovering, or Viable in the 2003 North Carolina Division of Marine Fisheries stock status report (DMF 2003a).

While most of the concern over declining fish stocks has focused on overfishing, habitat loss and degradation can also prevent recovery or make a stock more susceptible to overfishing. For example, impassable obstructions of migratory corridors to spawning grounds can prevent stock recovery despite fishing restrictions. In other cases, regional reductions or loss of one habitat can make a stock more susceptible to overfishing by reducing the diversity or total amount of suitable habitat available. *A strategy for enhancing fisheries, as required by the Fisheries Reform Act of 1997, must therefore involve both habitat protection/enhancement and prevention/reduction of overfishing.*

Wetland restoration

The loss of wetlands and need for alternative pollution control methods prompted restoration/creation efforts beginning in the late 1980s and early 1990s (Mitsch and Gosselink 1993). Actual restoration of wetlands is accomplished through compensatory mitigation and voluntary initiatives. The purpose of compensatory mitigation is to replace wetland functions that are lost through permitted impacts to

[63] A more detailed evaluation of wetland-enhanced species and their status can be found in the Chapter 6 (i.e., nursery area statistics).

wetlands (WRP 2002). Many wetland restoration projects involve simply restoring the natural hydrologic condition, while others include greater design considerations. Depending on the purpose of restoration/creation, design considerations include hydroperiod, nutrient/pollutant loading rates, seasonal flood pulses, flow patterns, water retention times (Mitsch and Gosselink 1993), and/or soil type.

While there have been many successful projects implemented nationwide, there have been failures attributed to lack of proper hydrology (Mitsch and Gosselink 1993). More recent studies in North Carolina found that mitigation sites restored by the N.C. Department of Transportation (DOT) relied too much on hydrologic criteria, leading to reduced survivorship of planted seedlings in some excavated areas with non-wetland soil (Rheinhardt and Brinson 2002). They also found that reference sites were rarely utilized in measuring the success of restoration. Presently, all DOT monitoring is stopped after permit conditions are satisfied. With these considerations in mind, it will be difficult to determine gains in wetland acreage. *Rheinhardt and Brinson (2002) encouraged long-term monitoring of restoration projects using success criteria based on hydrology, soil, and vegetation characteristics at established reference sites.*

North Carolina Wetlands Restoration Program

The North Carolina Ecosystem Enhancement Program (EEP) was established in July 2003 as an innovative program to restore, enhance, and protect the State's wetlands and waterways. The Ecosystem Enhancement Program combines an existing wetlands restoration initiative by the Department of Environment and Natural Resources (Wetlands Restoration Program) with ongoing efforts by the N.C. Department of Transportation to offset unavoidable environmental impacts from transportation-infrastructure improvements. The U.S. Army Corps of Engineers joined as a sponsor in the historic agreement. The mission of the EEP is to restore, enhance, preserve and protect the functions associated with wetlands, streams and riparian areas, including but not limited to those necessary for the restoration, maintenance and protection of water quality and riparian habitats throughout North Carolina's 17 river basins[64]. To accomplish this mission, the WRP works closely with the DWQ and other resource agencies to identify watersheds (14-digit hydrologic units) in each river basin that exhibit both the need and opportunity for restoration. These areas are called "Targeted Local Watersheds" and receive priority for WRP planning and restoration project funds. Based primarily on water quality, habitat, land cover, and public comment, staff identify "Targeted Local Watersheds" that are believed to be the best areas for the program to implement wetland, stream, and riparian restoration projects, and nutrient reduction projects. The goal is to concentrate multiple projects within small watersheds to address real watershed degradation symptoms instead of isolated problem areas scattered more broadly across a basin or larger watershed. This focus works toward implementing long-term watershed restoration and protection benefits. The WRP encourages other government entities and funding organizations to consider implementing watershed and habitat improvement projects within these areas as well as maximize state, federal and local funding sources based on multiple watershed planning objectives. Multiple complementary projects focused in small watersheds will provide the greatest ecological benefit to North Carolina's streams, rivers, lakes, estuaries, and wetlands. This approach also helps maximize program funds and programmatic benefits, creating an environment for partnership and collaboration among various state, federal and local programs.

Compensatory mitigation[65] is often required with the issuance of a 401 Water Quality Certification and/or

[64] More information on EEP website (www.nceep.net).

[65] The data presented in this section are based on the Division of Water Quality's Wetlands/401 Unit's Water Quality Certification Database. This database tracks wetland and streams losses that are authorized through the issuance of a 401 Water Quality Certification. Issuance of a 401 Water Quality Certification is required before the Corps of Engineers can issue a Section 404 Permit authorizing the fill or alteration of wetlands and/or streams. Although in the majority of cases the impacts authorized by the 401 Water Quality Certification are consistent with the impacts authorized by the Section 404 Permit, the amount of impact authorized by the Section 404 Permit may be less than that authorized by the 401 Water Quality Certification and, in some cases, a Section 404 Permit may never be issued. In addition, the authorized impacts may not occur during this

Section 404 permit to impact wetlands. However, not all project impacts are mitigated with the creation or restoration of wetlands. Based on compensatory mitigation requirements, permittees may choose to conduct the compensatory mitigation themselves, request to make a payment to the DENR Wetlands Trust Fund for Compensatory Mitigation, or purchase credits from private mitigation banks (if the impacts occur within their mitigation service area). Donation of land for wetlands restoration or creation also satisfies wetland mitigation requirements [EMC rule 15A NCAC 02R .0403 (e)(1-2)]. Land donations preserving wetlands do not satisfy the rule. *Land acquisition for preservation should also be an option for wetlands mitigation. However, the amount of land preserved should be more than the area impacted because the preservation will not offset the adverse impact.* Preservation of high quality lands is an option to meet compensatory mitigation needs in advance of expected impacts during the Ecosystem Enhancement Program's Transition Period (July 2003-July 2005). Preservation sites are intended to supplement achieving compliance with compensatory mitigation requirements.

The WRP is required by statute to report on both compensatory and non-compensatory (i.e., non-regulatory) restoration work accomplished in North Carolina annually. In fiscal year 2001-2002, eighty-one 401 Water Quality Certifications issued statewide required wetland or stream mitigation. Of those, 69% were satisfied through payment to the Wetlands Trust Fund. Compensatory mitigation requirements for 7% were satisfied through payment to private mitigation banks, while the remaining 23% conducted compensatory mitigation on-site. The amount of compensatory mitigation in North Carolina coastal river basins during fiscal years 1999-2002 was approximately 650 acres (WRP 2000, 2001, 2002) (Table 5.6). During that same time period, there were 550 acres of wetlands impacted in coastal river basins[66]. There is also some voluntary creation or restoration of wetlands. During fiscal years 1999-2002, 17.25 acres of wetlands were voluntarily restored or created in coastal river basins through non-regulatory restoration practices (i.e., North Carolina Coastal Federation projects funded by Clean Water Management Trust Fund).

Table 5.6. The amount (acres) of compensatory mitigation and non-regulatory gains (voluntary restoration/enhancement) in coastal river basins from 1999-2002. (Sources: WRP 2000, 2001, and 2002)

Fiscal year	Non-regulatory Gains-Restoration/ Creation	Compensatory mitigation	Total
1999/2000	9.25	150.40	159.65
2000/2001	2.00	288.60	290.60
2001/2002	6.00	195.65	201.65
TOTAL	17.25	634.65	651.90

The WRP evaluates the costs of restoration projects on an annual basis. These costs can vary based on site conditions and restoration methods. Based on two riparian wetland projects in fiscal year 2001-2002, the cost of restoration in 2002 was $20,000-25,000/acre (WRP 2002). The cost includes site identification, site acquisition, project design, construction management, site restoration, post monitoring, and long-term management. The cost of restoring 4.11 acres of coastal wetlands in 2002 was even higher at $101,148/acre.[67]

fiscal year and in some cases may never occur. The DWQ is increasing its efforts to monitor and track the impacts that actually occur.

[66] The total number of wetlands impacted includes impacts of less than one acre. Impacts of less than one acre do not require compensatory mitigation as a condition of the 401 Water Quality Certification, though they may result in a substantial loss of wetland resources (WRP 2002).

[67] For additional information regarding 401/404 compensatory mitigation requirements, visit DWQ's website at <http://h2o.enr.state.nc.us/ncwetlands/>. For additional information concerning the WRP, visit <http://h2o.enr.state.nc.us/wrp/>.

The rate of wetland loss documented by 401 permit records does not account for functional equivalency, which is the replacement of full ecological functions specific to a wetland type. Currently, wetlands losses and gains are tracked on an acre-for-acre basis. The wetland type lost is not always mitigated by the creation of a similar wetland type. In fact, there is little consideration for maintaining a natural mix of wetland types on the landscape. *Rheinhardt and Brinson (2002) recommended the tracking of restoration efforts by river basin and hydrogeomorphic class so that restoration can maintain a balanced distribution of classes on the landscape.* For example, the loss of riverine wetlands in the Neuse River basin should be mitigated by the creation or restoration of riverine wetlands in the Neuse River basin. The new Ecosystem Enhancement Program is tracking restoration efforts associated with Department of Transportation projects.[68]

Other initiatives

Federal, state, local, and private organizations and individuals conduct voluntary initiatives. The Wetlands Reserve Program of the Food, Agriculture, Conservation, and Trade Act of 1990 authorized the U.S. Department of Agriculture (USDA) to purchase easements from landowners who agree to protect or restore wetlands. The goal of USDA's Pilot Wetlands Reserve Program was to restore one million acres of cultivated crops to wetlands by 1995 (Bales and Newcomb 1996). The USDA pays 75% of the restoration cost to landowners, and NRCS and FWS assist in completing the restoration plans. As of 2001, there were more than 6,500 restoration projects nationwide that encompassed nearly 1,075,000 acres (NRCS 2002). By 1992, there were about 15,000 acres of cultivated land enrolled in the North Carolina program (Bales and Newcomb 1996). By 2002, total program enrollment in North Carolina had exceeded 26,000 acres (NRCS 2003). Project costs vary throughout the country. In 2001, the average cost of purchasing and restoring a permanent easement was approximately $1,200 per acre. The average cost of purchasing and restoring a 30-year easement was around $770 per acre. Restoration cost-share agreements, which do not include easement acquisition costs, averaged around $450 per acre (NRCS 2003).

The Conservation Reserve Enhancement Program (CREP) is another state/federal program intended to improve not only wetlands, but also other riparian habitats in North Carolina. The program is focused on impaired water bodies in the Chowan, Neuse, and Tar-Pamlico river basins, and the Jordan Lake area (all Nutrient Sensitive Waters). The program can pay up to $50,000 per person, per fiscal year to replace marginal agricultural land with forested riparian buffers, grassed filter strips or wetlands. For the enrollment of 100,000 acres in North Carolina, federal and state obligations over a 15-year period are approximately $275 and $54 million, respectively (<http://www.fsa.usda.gov/crpstorpt/CREP/default .htm>, April 2003). During 1999-2003, 19,081 acres were enrolled in this program in North Carolina (calculated from USDA website, April 2003). However, the proportion of this acreage in wetland restoration or creation was not reported.[69]

In addition to the programs discussed above, other state programs involved in the restoration of wetlands include DWQ's 319 Program, Clean Water Management Trust Fund, and the Division of Water Resources' Grant Program (WRP 2002).[70]

[68] See "Recent trends" subsection under "Land use and wetland conversion" below for more information.
[69] More information on the CREP program can be found on the USDA's website (<http://www.fsa.usda.gov/dafp/cepd/crpinfo.htm>).
[70] Information on these programs is provided on the WRP website (<http://h2o.enr.state. nc.us/wrp/index.htm>).

Existing management measures

Legislation and regulatory programs

Alteration or destruction of wetlands are currently regulated by federal and state agencies. Numerous federal regulations and incentives affecting wetlands were included in the River and Harbors Act of 1899; the Clean Water Act of 1972 (and its amendments); the Food Security Act of 1985; the Food, Agriculture, Conservation, and Trade Act of 1990; the Emergency Wetlands Resources Act of 1986; and the Coastal Zone Management Act of 1972 (Bales and Newcomb 1996).

The River and Harbors Act gives the COE the authority to regulate certain activities in navigable waters. These activities include some that can damage or destroy wetlands such as diking, deepening, filling, excavating, and placement of structures. Section 404 of the Clean Water Act requires that the COE regulate the discharge of dredge or fill material into wetland areas. Permit applications are reviewed by the U.S. Environmental Protection Agency (EPA) and U.S. Fish and Wildlife Service (FWS). The Corps can deny the permit based on FWS or NMFS recommendation. States were given the authority to approve, apply conditions to, or deny 404 permits by Section 401 of the Clean Water Act. The authority is applied in North Carolina by DWQ with the 401 Water Quality Certification program.

While issuance or denial of Section 404 permits are the most widely used federal management tools protecting wetlands, most farming, ranching, and silviculture activities are exempt from such permits (Bales and Newcomb 1996). These exemptions were reduced by the "Swampbuster" provisions of the Food Security Act of 1985 and its amendments. "Swampbuster" provisions discourage (through financial disincentives) the draining, filling, or other alterations of wetlands for agricultural use. However, there are exemptions from the disincentives if the farmer agrees to restore the altered wetland or some other wetland area converted to agriculture. Cutover wetlands impacts between 1988 and 1994 are likely the result of silviculture operations.

There are also section 404 and 401 general permits issued for projects causing minimal individual and cumulative environmental impacts. These permits are important because the activities they cover do not require wetland restoration. The most frequently used, but no longer issued, 404 general permit is Nationwide Permit 26, which applied to wetland fills less than 10 acres in size. This permit had the following general conditions: (1) the wetland must be located adjacent to a stream and above headwaters, or (2) the wetland must be isolated (equivalent to flat/depressional hydrogeomorphic class). Nationwide Permit 26 probably contributed primarily to loss of flat/depressional wetlands noted earlier in the Status and Trends section. Some other activities covered under federal general permits include:

- Fish and wildlife harvesting,
- Survey activities,
- Minor road crossings,
- Modifications of existing marinas,
- Maintenance dredging of existing basins,
- Boat ramps with no discharge to wetlands, and
- Cleanup of hazardous and toxic waste.

The Emergency Wetlands Resources Act of 1986 required states to address wetland protection in their Comprehensive Outdoor Recreation Plans in order to qualify for federal funding. Other wetland protection incentives were provided by the Coastal Zone Management Act, which required coastal states to adopt coastal zone management programs in order to be eligible for federal funding and technical assistance. As a result, the Coastal Resources Commission (CRC) was subsequently established in North Carolina. The DCM was later established as the operational arm of the CRC. Rules promulgated by the CRC apply to North Carolina's 20 coastal counties.

Within coastal counties, the CRC forbids projects that can violate water quality standards of estuarine

resources, including coastal wetlands [CRC rule 15A NCAC 07H .0207]. The CRC rules also state that activities directly impacting wetlands shall not have significant adverse impacts. The CRC prohibits disposal of fill in coastal wetlands and dredging activities in all but the most narrow fringing wetlands [CRC rule 15A NCAC 07H .0208 (b) (1) (A, C)]. Furthermore, CRC rules require that bulkheads and riprap be constructed landward of coastal wetland areas. However, CRC and EMC rules allow bulkhead backfilling of small, freshwater wetlands landward of coastal wetlands following the size threshold criteria for permitting wetland impacts[71], resulting in a cumulative loss of wetlands that might provide for marsh migration with sea level rise. *To minimize these losses, all but the most miniscule of wetland impacts should be subject to permitting.*

Encouraged by the progress of wetland regulations, "No Net Loss" policies were developed by the federal government in the late 1980s (Wiebe and Heimlich 1995). But despite their achievements, wetland regulations are still considered by the public a "taking" of property that should be discontinued or financially compensate the landowner. The central problem of wetland protection remains how to protect wetlands for public benefit when the majority of converted or remaining wetlands are privately owned. These factors have led to increasing reliance on land acquisition and direct incentives for protecting remaining wetlands. Increasing public awareness of wetlands benefits (i.e., reducing flood levels, velocities, and damage) encourages greater acceptance of wetland regulations, as well as voluntary actions.

State and federal regulatory designations

Several state regulatory designations provide additional protection of wetlands, such as area designations for:

- Estuarine Shoreline Areas of Environmental Concern [CRC rule 15A NCAC 07H .0205-207];
- Nutrient Sensitive Waters [EMC rule 15A NCAC 02B .0101(e)(3)];
- Primary Nursery Areas [MFC rule 15A NCAC 03N .0102(a)];
- Shellfishing Waters [EMC rule 15A NCAC 02B .0101(d)(3)];
- High Quality Waters [EMC rule 15A NCAC 02B .0101(e)(5)];
- Outstanding Resource Waters [EMC rule 15A NCAC 02B .0101(e)(4)].

The CRC-designated Estuarine Shoreline Area of Environmental Concern (AECs) extends landward 75 feet from the high water mark along estuarine shorelines, upstream to the line separating Coastal and Inland Fishing Waters (Figure 2.6 in Chapter 2). The Estuarine Shoreline AEC increases to 575 feet along shorelines of EMC-designated Outstanding Resource Waters. Any development planned within this area must obtain a Coastal Area Management Act (CAMA) permit. Hard surfaces, such as buildings, paved parking lots and roads, must cover no more than 30% (25% along ORWs) of the project area within the Area of Environmental Concern, unless the development incorporates an innovative design that provides stormwater protection equal to or exceeding the protection of the 30% limitation. However, certain activities (i.e., agriculture and silviculture) not involving excavation or filling of coastal wetlands are exempt from a CAMA permit. The Coastal Shoreline AEC, which includes estuarine and public trust shorelines to the upstream extent of navigable waters, also includes a 30-foot buffer from high tide elevation in which only water-dependent uses are allowed. However, the vegetation in this buffer does not have to be natural, and it can be mowed. There are exemptions allowing non-water dependent structures within 30 feet of the high water mark. For example, the full buffer is not required if it would preclude the placement of residential structures on a lot, parcel, or tract that was platted before June 1,

[71] Projects impacting less than 1/3 acre of wetland within 50 feet of the high water line are exempt from 401 water quality certifications, as well as projects impacting less than 1 acre within 150 feet of the high water line [EMC rule 15A NCAC 02H .0506 (c)(2)]. There is no minimum area criteria for mitigation when dealing with designated unique wetlands [EMC rule 15A NCAC 02H .0506(e)]. However, unique wetlands will likely not be designated on private lands without the approval of the land owner.

1999 (if certain criteria are met) [CRC rule 15A NCAC 7H .0209 (e)(1)]. There are also exemptions for lots platted before June 1, 1999 or surrounded by existing development [CRC rule 15A NCAC 07H .0209 (e)(2)(A)].

Along Nutrient Sensitive Waters in the Tar-Pamlico and Neuse river basins, the EMC has established a buffer width of 50 feet directly adjacent to intermittent streams, perennial streams, lakes, ponds, and estuaries, excluding wetlands [EMC rule 15A NCAC 02B .0233 (3)]. The first 30 feet of the buffer (Zone 1) must be virtually undisturbed natural vegetation. However, within the 20 CAMA counties, Zone 1 is measured from the landward edge of coastal wetlands [EMC rule 15A NCAC 02B .0233 (4)(a)(iii)]. The zone of undisturbed natural vegetation could therefore include some freshwater wetlands not covered under CRC rules. The second 20 feet of the buffer (Zone 2) can be mowed grass and/or harvestable trees. While the buffer rules for Nutrient Sensitive Waters provide more protection for wetlands than CRC buffer rules, there are many exemptions [EMC rule 15A NCAC 02B .0233 (6)]. Most of the exemptions (over 35 in all) are for infrastructure associated with development (e.g., utility lines, drainage ditches, roads/bridges).

Waters designated as PNAs by the MFC are given additional consideration of impacts by DCM prior to issuing development permits. Only maintenance dredging is allowed, and only within existing basins and channels. There are no other special requirements on water-dependent, development-related activities in wetlands surrounding PNAs (i.e., bulkheads, piers). However, all designated PNAs and SA waters are classified HQW and receive additional protection from discharge and development under EMC and CRC rules. Rules dealing with approved Shellfishing Waters protect wetlands by prohibiting new marina construction that could result in loss of some fringing wetlands and increased boat traffic and associated impacts [CRC rule 15A NCAC 07H .0208 (b)(5)(E)].

All coastal areas classified as Outstanding Resource Waters also have significant wetland coverage. Outstanding Resource Waters and their more stringent regulations [EMC rule 15A NCAC 02B .0225 (e)] encompass approximately 6% of the riparian wetland habitat in coastal North Carolina, the majority of which is salt/brackish marsh and riverine swamp forest. Those areas also cover 2% of non-riparian wetlands. There is also a larger Area of Environmental Concern (extending 575 feet from mean high water) adjacent to ORW waters, within which there is a built-upon area limit of 25% [CRC rule 15A NCAC 07H .209 (g)]. The limit on impervious surfaces could help prevent loss of wetlands within the AEC. *The effectiveness of ORW-related rules in protecting wetlands and other habitats should be examined and changed as necessary. Appropriate management strategies should be developed by the EMC, MFC and CRC to protect wetland areas designated as Strategic Habitat Areas by the MFC.*

The federal government protects wetlands by designating them Essential Fish Habitat (EFH). The designation of EFH for coastal wetlands means several things. First, the regional fishery management councils must identify measures to conserve, restore, or enhance Essential Fish Habitat. They must also recommend actions that will minimize the adverse effects of fishing on habitat. Most recommendations target federal agencies (i.e., Corps of Engineers or Environmental Protection Agency) whose projects may affect fish habitat. Basically, any state or federal activity that could harm habitat for federally managed fish stocks is subject to review by NMFS (NOAA Fisheries). Federally managed fish stocks include those occurring in federal waters (i.e., tuna, sharks, panaeid shrimp, red drum). Coastal wetlands are designated EFH for red drum and shrimp. Areas of EFH requiring the most protection are termed Habitat Areas of Particular Concern (for more information see Chapter 8).

Land ownership and management

In addition to regulatory designations, wetlands also receive protection by virtue of ownership and management. Protected lands are owned and managed by federal, state, county, and municipal governments, as well as conservation organizations, other nonprofit organizations and land trust properties. These protected lands cover 217,289 ac of riparian wetlands and 434,746 ac of non-riparian

wetlands, representing approximately 16 and 26% of all riparian and non-riparian wetlands, respectively, in coastal North Carolina.[72] Based on the amount of 1994 wetlands within protected areas, 74% of wetlands are not protected by land ownership, although this amount does not account for regulatory restrictions and area designations on lands not managed for conservation. It also does not include lands with restoration cost-share agreements in the Wetland Reserve Program.

Within areas protected by conservation ownership and management, some wetlands types are more represented than others. Of the riparian wetland types, estuarine shrub/scrub, salt/brackish marsh, and estuarine forests are the most protected (28-52%; see Table 5.7). The riparian freshwater wetlands are relatively less protected (7-28%). Among hydrogeomorphic categories, headwater wetlands receive the least protection (6%). Most headwater wetlands are outside of estuarine shoreline AECs, and thus are not protected by CRC use standards. Projects impacting these small wetlands may often require only a

Table 5.7. The amount and percentage of each wetlands type in eastern North Carolina within protected lands. Only undisturbed wetlands indicated on DCM GIS mapping of the Coastal Plains are included. (Source: CGIA's BasinPro3 coverage, "Land Managed for Conservation")

Wetland class	Wetland type	Protected (ac)	Total (ac)	% Protected
Riparian	Salt/Brackish Marsh	74,038	198,168	37.36
	Estuarine Shrub/Scrub	14,417	27,874	51.72
	Estuarine Forest	274	965	28.38
	Freshwater Marsh	9,091	32,803	27.71
	Bottomland Hardwood	16,301	227,582	7.16
	Riverine Swamp Forest	101,400	829,681	12.22
	Headwater Swamp	1,769	31,159	5.68
	TOTAL RIPARIAN	*217,289*	*1,348,232*	*16.12*
Non-riparian	Pocosin	299,225	507,117	59.01
	Maritime Swamp Forest	1,666	3,438	48.46
	Non-riverine Swamp Forest	101,154	215,305	46.98
	Pine Flat	74,912	296,591	25.26
	Hardwood Flat	15,041	165,077	9.11
	Managed Pineland	58,943	954,336	6.18
	TOTAL NON-RIPARIAN	*550,941*	*2,141,864*	*25.72*
TOTAL		**768,230**	**3,490,096**	**22.01**

general permit and no mitigation, or they may be exempt from a permit due to small size. Although there are no accurate records on the type of wetlands impacted by 401 Water Quality Certifications, headwater wetlands are believed to be one of the most heavily impacted wetland types (J. Dorney, DWQ, pers. com., 2003). *Due to the relative threat to, and ecological importance of, headwater wetlands, they should receive higher priority in wetland preservation/restoration efforts.*[73]

Statewide Wetland and Streams Management Strategy

In 1997, DENR received a grant from the EPA to develop a comprehensive, statewide plan to improve and simplify North Carolina's wetland and stream protection policies. The EPA provides financial, technical, and planning assistance to states interested in developing statewide wetland conservation plans. The EPA strongly supports development of statewide wetland conservation plans because these plans

[72] This information was obtained by overlaying DCM wetlands data with "Land Managed for Conservation" coverage from BasinPro3 (software developed by the North Carolina Center for Geographic Information and Analysis).
[73] Wetland acquisition and conservation programs are listed in Appendix J.

give states a framework to protect, restore, and create wetlands in an effective and efficient manner.

The objective of this strategy was to identify opportunities to make wetland, stream, and riparian buffer protection programs and conservation approaches work more efficiently and effectively in North Carolina. In 1999, a stakeholder Advisory Committee was convened to develop the strategy. The major stakeholder groups represented on the Advisory Committee include: agriculture, forestry, environmental groups, academics, industry, development, private consulting, local government, the COE, EPA, the Natural Resources Conservation Service, and North Carolina departments of Environment and Natural Resources, Transportation, Agriculture, and Commerce. Through a series of both private and public meetings, the committee identified eight priority issues that were further investigated by a smaller Technical Work Group in May 2000. These priority issues have been published in the Statewide Wetland and Stream Management Strategy (<http://h2o.enr.state.nc.us/ncwetlands/about.htm>, 2004) and are shown below:

- Unique wetlands – Examine the regulatory authority of the EMC and DWQ for unique wetlands, develop policy interpretations for definitions, and develop a list of candidate sites or a process to determine potential sites.
- Wetland and stream mitigation – Develop flexible wetland and stream mitigation options.
- Local government roles – Examine the involvement of local governments in wetland management/protection and develop potential mechanisms to encourage involvement.
- Wetland preservation – Inventory existing wetland preservation activities in North Carolina, develop wetland preservation goals, and examine mechanisms to encourage involvement.
- Wetland mapping – Examine existing and planned wetland mapping efforts, determine need for additional and improved mapping, explore mechanisms to carry out new mapping efforts, and examine the role of Geographic Information Systems in wetland and stream management.
- Environmental education – Examine existing wetland and stream education programs and activities, determine need for additional education opportunities, and recommend new and improved education activities.
- Regulatory structure and process – Examine the 401 Water Quality Certification Program's strengths and weaknesses, develop options to address weaknesses, and develop options for clarification.

Net loss

During 1999-2002, 651.90 acres of wetlands were created or restored in coastal river basins. Over that same time period, there have been 549.79 acres of permitted wetlands impacts (Figure 5.4) and an estimated 2,406 acres of coastal wetland lost to erosion (802 ac/yr x 3 yr). So the rate of wetland creation/restoration would appear to surpass the rate of loss from direct human causes. However, the total permitted impacts do not include the cumulative impact of very small losses that go untracked by permit authorities. *A study should be conducted to determine the cumulative impact of small wetland losses on the distribution and abundance of wetland types in a watershed. The cumulative loss could then be related to the nature and extent of development pressure in the watershed in order to formulate a model predicting untracked losses in other watersheds. But regardless of empirical evidence, small cumulative impacts may have a negative impact on fish habitat. Rules should be modified to reduce net loss of riparian wetlands from small cumulative dredge and fill projects (i.e., lower size threshold of wetland impacts that require permit or mitigation).*

5.4. THREATS AND MANAGEMENT NEEDS

Physical threats

Because physical alterations primarily impact wetlands, land use changes associated with population growth are the primary cause of wetland habitat loss today (Dahl 2000). Large-scale draining and ditching are prevalent agricultural impacts, whereas deforestation and fill are associated with silviculture

activities and upland development. Shoreline stabilization is primarily a coastal phenomenon. Dredging access channels for upland boat basins can destroy wetlands, while bulkheading can increase erosion along adjacent wetland shorelines. The direct effects of land use changes and hydrologic modifications on riparian wetlands are discussed in the following sections.

Land use and wetland alteration

Historical conversions

The major cause of wetland loss and degradation has been conversion to agriculture, silviculture and upland development (including road construction). In the late 1800s and early 1900s, the greatest losses resulted from ditching and draining for agriculture. Several large agricultural drainage projects occurred during that period (Heath 1975), resulting in an estimated 1 million miles of drainage ditches and canals throughout the Coastal Plains of North Carolina (Wilson 1962). Much of the land around the Albemarle-Pamlico estuary was drained and must remain drained to accommodate existing agriculture and forestry. About one-third of the loss of wetlands has occurred since 1950 (Bales and Newcomb 1996). After 1950, conversion to managed forest and agriculture accounted for 53% and 42%, respectively, of wetland losses (Bales and Newcomb 1996). Many of the roads on the Albemarle-Pamlico Peninsula were constructed on top of spoil piles between canals to prevent flooding on the roads. Ditching of wetlands or uplands is also common in other areas of the coast for flood control and drainage. In many urbanized coastal areas, ditches and swales are typically constructed along neighborhood streets. The ditches often connect and drain into headwaters, which alters the natural hydrology of downstream systems (Pate and Jones 1981).

Many government policies restrict ditching and draining of wetlands. Drainage of low-lying farmland funded by the USDA's Natural Resources Conservation Service (NRCS) and mosquito ditching are no longer common practices. "Swampbuster" provisions of the 1985 Farm Bill discouraged the practice of draining wetlands for conversion to cropland. However, drainage channels for croplands are still maintained by drainage districts (DEHNR 1995a). Except for a short period from 1998 to 2000, there have been no new large-scale wetland drainage projects since the mid-1970s (Chicod Creek, Pitt and Beaufort counties, Tar-Pamlico MU). Prior to 1998, ditching/draining of wetlands was regulated by the COE. At that time, ditching required a federal 404 permit with a DWQ 401 certification, to ensure that water quality standards were not violated. When the federal court overturned the federal Tulloch rule in June 1998, the COE lost authority to issue permits for wetland ditching unless spoil was placed on adjacent wetlands. As a result, thousands of acres of wetlands were drained, primarily in Brunswick, New Hanover, and Pender counties (J. Steenhuis, DWQ, pers. com., 2002). Approximately 9,500 acres of wetlands were impacted in Brunswick County alone (DWQ 1999), and a total of approximately 11,580 acres of wetlands were impacted in the Coastal Plain. These losses are in addition to 401 Water Quality certification records. In Brunswick, New Hanover, Pender, and Onslow counties, 24% of the ditching was reported as forestry-related, 6% as agriculture-related, and 70% was done for development or other purposes (J. Steenhuis, DWQ, pers. com., 2002).

In 1999, the State of North Carolina determined that wetlands ditching and draining activities fall under its authority, constituting an illegal activity if proper approval is not obtained. In 1999, EMC adopted a wetland draining policy to ensure that required wetland conditions are maintained (<http://h2o.enr.state.nc.us/ncwetlands/ditch.html>, 1999). In addition, inspections were made of previously ditched wetlands to determine if the ditching was conducted in a manner that violated wetland standards. Where violations occurred, property owners were required to restore the natural hydrology through the filling of the ditches. Approximately 50% of the ditched wetlands have been restored, 22% are likely not to be restored, and the status of the remainder is undetermined (J. Steenhuis, DWQ, pers. com., 2002). Many of the remaining ditches, although not appearing to be violating water quality standards, continue to transport stormwater into coastal waters. *Additional monitoring is needed to better assess impacts where extensive areas of wetlands were drained. More DWQ staff are needed to inspect for compliance with water quality standards, including wetland draining.*

A violation of the Clean Water Act occurs if any wetland area benefiting water quality is converted to uplands, without a permit. The Corps of Engineers and EPA signed a Memorandum of Agreement describing the types of wetlands in which mechanical forestry site preparation activities required a permit (<http://www.epa.gov/owow/wetlands/guidance/silv2.html>, June 2004). The resulting list included all riparian wetlands. Prior to the memorandum, forestry operations were exempt from 401 or CAMA permits when the hydrology of the wetland area was maintained. The forestry exemption can be an issue when there is dispute concerning how forestry operations alter different wetlands types. Altering some wetland types would have a negative impact on downstream water quality (i.e., riparian wetlands), while altering other types would have little effect on water quality (i.e., some isolated wetlands). If a forestry operation allowed the exemption to alter a wetland benefiting water quality, and later sold the property to someone claiming the site had become an upland, the development may have been exempt from water quality permits and mitigation requirements. The Memorandum of Agreement between the COE and EPA should prevent mechanical forestry operations from altering any riparian wetland without obtaining a 404 permit or 401 Water Quality certification.

In a recent court case related to the drainage activities during 1998-2000, a development company claimed the forestry exemption when it ditched and drained over 200 acres of wetlands in Onslow county (N.C. Shellfish Growers Association and NCCF vs. Holly Ridge Associates; U.S. District Court for the Eastern District of North Carolina, Eastern Division, No. 02cv0053). The judge said the ditches and the site itself were all "point sources" of stormwater and sediment pollution, and therefore required discharge permits under the Act – even if the activities were for forestry purposes. In a related state case, an administrative judge ruled there was no credible evidence that the ditching and drainage were for the purpose of forestry. Holly Ridge Associates was found in violation of the Clean Water Act for not obtaining a CAMA permit, a 401 Water Quality Certification, and an NPDES discharge permit. Barring successful appeal[74], the latter case should prevent other land development and forestry companies from ditching or draining riparian wetlands without NPDES permits. *Any ditching activity resulting in nonpoint source pollution in North Carolina's rivers and sounds should require an NPDES permit. The EMC's constraints on discharges in SA waters could then be extended to drainage projects, in addition to traditional point source discharges (i.e., wastewater treatment plants).*

The cutover wetland acreage from 1988 to 1994, noted in the Status and Trends section (above), was likely the result of silviculture operations. The alterations occurred in both forested riparian and non-riparian wetlands (17,513 and 40,316 acres, respectively; Tables 5.4 and 5.5). The majority of alterations were to non-riparian forested wetlands. Using the rate of cutover impacts from 1988 to 1994, approximately 21,000 more acres of riverine forested wetland may have been impacted from 1994 to 2003. As long as wetland hydrology is maintained, this is a relatively minor issue. If upland development replaced these cutover riparian wetlands, there could have been a violation of the Clean Water Act.

In addition to conversion to upland development, agriculture, and silviculture, many wetlands were also converted to deepwater habitat. Based on national trends during the mid-1970s, the major source of coastal wetland loss was conversion to deep water habitat (e.g., boat basins, navigation channels), followed by upland development (Hefner and Brown 1985). The CRC currently prohibits dredging through all but the most narrow fringing marshes [CRC rule 15A NCAC 07H .0208 (b)(1)(A)]. Many acres of wetlands were dredged for the Intracoastal Waterway (1930s), boat basins, and connecting channels before dredge and fill and CRC rules were implemented. The primary dredging activities still occurring within North Carolina's coastal waters are maintenance or improvement dredging of existing navigation channels (DEHNR 1995a). These projects have a relatively minor effect on existing wetlands. However, small non-coastal wetlands, contiguous to coastal wetlands, are still lost to the backfilling of

[74] As of August 16, 2004, Holly Ridge Associates is appealing the court decision.

bulkheads.

Recent trends

To examine recent trends in wetland conversion, an analysis of wetland impact sources was performed on approximately 6% of the total number of 401 certification records from the DWQ database, covering a time period from 1997 to 2003 (1,213 of 18,700 total records). The data were filtered to include only those records within CHPP management units (based on geographic coordinates) having a date, project type (excluding wetland restoration/creation), and area impacted (DWQ, unpub. data). The analysis is unbiased toward certain impact types assuming the data represent a random subsample. Impact source categories for analysis of 401 permit records consist of the following:

- *Water control* includes the construction of impoundments, reservoirs, ditches, canals, water intakes, storm drains, stormwater ponds, and other activities designed to alter water flows. Note: some water control projects are related to transportation.
- *Upland development* includes isolated ponds, residential lots, commercial facilities, utility cables/pipelines, wastewater treatment plants, schools, churches, and other activities converting wetland habitat to uplands or supporting upland development.
- *Mining* includes quarry and sand pit construction or expansion, and other mining sources.
- *Agriculture/aquaculture* activities include irrigation ponds, farm construction, clearing land for animal operations, fish hatcheries, fish farms, spray fields, and similar activities that disturb wetland hydrology. Note: most agriculture activities are exempt from requiring 401 permits.
- *Transportation* includes construction of roads, highways, bridges, and culverts.
- *Water-dependent development* includes piers, docks, marinas, navigation channels, boat ramps, shoreline stabilization structures, channel relocation, and similar activities and structures associated with waterways.

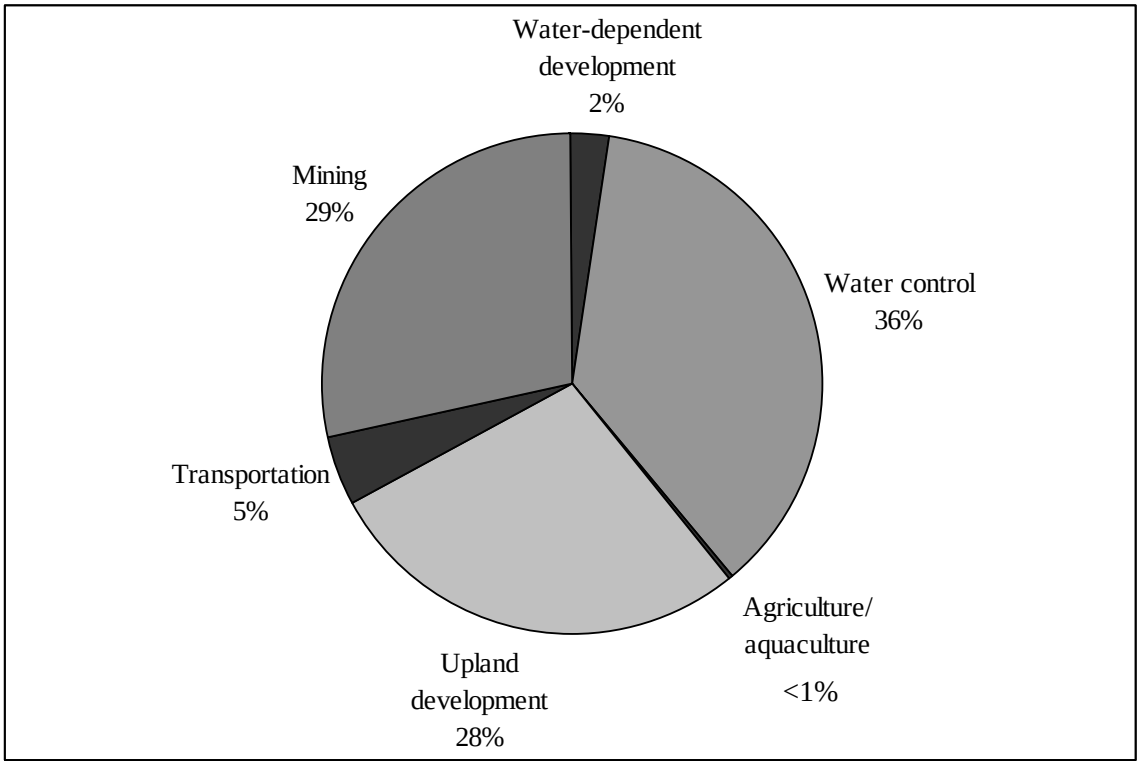


Figure 5.6. Sources of wetland impact in eastern North Carolina. [Source: subset of DWQ Section 401 certification records (1997-2003), with location coordinates within CHPP management units.]

The most recent trends (1997-2003) in wetland loss show water control projects as the major source of wetland impacts (36% of impacted acres) (Figure 5.6), followed by mining (29%) and upland development (28%). The vast majority of mining impacts occurred during a single project in 1997 when PCS Phosphate was issued a permit to destroy 1,268 acres of wetlands in Beaufort County (U.S. District Court for the Eastern District of North Carolina, Eastern Division, No. 02cv0053). Activities least impacting wetlands included agriculture/aquaculture (<1%), transportation (5%), and water-dependent development (2%) (Figure 5.6).

Projects by N.C. Department of Transportation accounted for 23% of permitted wetlands impacts during 1997-2003, based on 11% of 18,700 permit records (DWQ, unpub. data). The DOT spends more than $80 million each year mitigating the impact of bridges and other road crossings on wetlands (*Water Resources Research Institute News*, March/April 2003), causing considerable delays in road construction. In recognition of the problems resulting from these delays, DOT, DENR, and COE have developed a program to improve efficiency and provide sufficient mitigation, the Ecosystem Enhancement Program (EEP). The new program, established through an agreement among agencies, brings together mitigation staff from the WRP and DOT under DENR's umbrella. The EEP will estimate potential wetland impacts very early in the roadway planning process (*Water Resources Research Institute News*, March/April 2003). Prior to mitigation, potential impacts will be evaluated in a watershed context, having targeted priority areas for mitigation efforts. Functional assessment will be conducted prior to the permitting process for the transportation project. Priorities will be consistent with DWQ basinwide planning reports, Coastal Habitat Protection Plans, and Wetland Restoration Plans. Once in place, mitigation projects will be monitored to determine their effectiveness in replicating wetland functions. *Eventually, the EEP should include mitigation planning for upland development and other approaches to habitat enhancement, restoration, and preservation.*

Shoreline stabilization

Shoreline stabilization is modification of the natural shoreline to prevent or reduce landward migration of the shoreline. The purpose of shoreline stabilization is protection of man-made structures and property, including natural features. As shoreline development increases in conjunction with rising sea level, waterfront structures will be threatened more often and property owners will likely have greater interest to protect their property. Shoreline stabilization in estuarine areas generally utilizes hard stabilization techniques. Bulkheads are the primary hard stabilization structure.

Construction of seawalls and jetties are primarily oceanfront practices; they are discussed in the Soft Bottom and Water Column chapters (Chapters 2 and 6). Soft stabilization includes beach bulldozing or beach nourishment, which are also discussed in the Soft bottom chapter (Chapter 6). This section will discuss the extent of estuarine shoreline stabilization that has already occurred in North Carolina, impacts of this activity on riparian wetlands, and management needs to reduce or minimize such impacts.

Physical and biological effects

Hard stabilization techniques have fairly severe impacts on coastal habitat, including accelerated erosion, loss of shallow intertidal bottom, loss of fringing marshes, increased scouring and turbidity in nearshore waters, and obstruction to fish migration where structures are perpendicular to the shoreline (Walton and Sensabaugh 1979; Pilkey and Wright 1989; Pilkey et al. 1998; Peterson et al. 2000c). Two managed fishery species strongly linked to fringing marsh are penaeid shrimp and red drum (SAFMC 1998a). Other important estuarine-dependent fish species that utilize wetlands during larval and juvenile life stages include gag, snapper, Spanish mackerel, striped bass, and river herring (SAFMC 1998a). Degradation and loss of wetland habitat from shoreline hardening impacts these species, as well as many others.

Bulkheads impact wetlands in several ways. During construction, heavy equipment and backfilling may

destroy vegetation above the high water line (wetland and transitional wetland plants), where bulkhead construction is allowed. Along the CRC's Estuarine Shoreline AEC, a 30 foot buffer above the high water line is established in which only water-dependent uses are allowed ([CRC rule 15A NCAC .07H .0209] provides exceptions to the buffer requirement). Rather than allowing natural vegetation to recolonize the area, property owners generally plant landscape scrubs and lawn grasses. These plants are not as effective at deterring erosion or reducing and cleansing stormwater as natural vegetation. Increased nutrients and toxins from fertilizers and pesticides used on the lawn enter the water with the runoff (Watts 1987). Bulkheads also prevent shoreward migration of fringing wetlands as sea level rises, resulting in eventual drowning and loss of existing wetlands (Titus 1988).

McDougal et al. (1987) found that nearshore wave impact increases as the horizontal length of the structure increases. Therefore, the cumulative effect of multiple, contiguous bulkheads has a greater impact on adjacent natural shoreline habitat than the effect of individual structures that are spatially distinct. Scouring action at the toe of bulkheads results in deepening of the adjacent water, thus reducing or eliminating intertidal habitat. Shallow water habitat is also reduced because the bulkhead structure prevents transport of sediment to other areas (Riggs 2001). The added turbulence at the base of bulkheads prevents vegetation from reestablishing after construction (Knutson 1977). Garbisch et al. (1973) showed that marsh vegetation waterward of bulkheads experienced a 63% mortality post-construction due to stress from increased turbulence and scour. This loss of habitat reduces benthic food resources for juvenile, anadromous, estuarine-dependent, and surf fish, as well as shore birds, which are highly dependent on shallow intertidal habitat for feeding (Byrne 1995; DMF 2000a; Peterson et al. 2000c). The deepening also increases the feeding efficiency of large piscivorous fish on small and juvenile fish that occupy the shallow waters adjacent to the structure (Rozas 1987).

Several studies have documented lower relative abundance and diversity of invertebrates and juvenile fish adjacent to bulkheaded shorelines compared to unaltered marsh, beach, or forested wetland habitats:

- Peterson et al. (2000c): On the Gulf coast, the most abundant species groups along unaltered marsh and beach shorelines (including habitat for penaeid shrimp, crabs, gobies, grass shrimp, drums species, and shad/herring species) were least abundant along bulkhead or rubble shorelines. In addition, diversity was lowest adjacent to bulkheads.
- Byrne (1995): In a Barnegat Bay lagoon, New Jersey, littoral fish and shrimp abundance were consistently and significantly lower at bulkheaded sites. The differences were attributed to lower levels of structural complexity, since SAV, macrophytic algae, snags, overhanging and submerged branches, and woody debris were absent from the bulkheaded sites, but present at the unaltered sites.
- Ellifrit et al. (1972): Fewer clams (*Venerupis japonica*) were present near bulkheaded areas compared to natural areas. The difference was attributed to less favorable conditions for settling and survival of clam larvae.
- Gilmore and Trent (1974): For all groups combined, benthic organisms were numerically and volumetrically less abundant in bulkheaded canals than in natural marshes. Crustaceans were over three times less abundant.
- Mock (1966): Brown and white shrimp abundance was 80% less in front of a bulkheaded shoreline compared to naturally vegetated shoreline. The difference was attributed to lower abundance of organic detritus and benthic macroinvertebrates, deeper water, and less intertidal vegetation.
- Bulkheads reduce or degrade spawning and nursery habitat for anadromous fish (SAFMC 1998a; DMF 2000a). Cumulative impacts of bulkheads have been specifically cited as a contributing factor to the decline of chinook salmon on the Pacific coast (Taylor 1999).
- O'Rear (1983) found that early larval river herring in the tributaries of the Chowan system were highly associated with the stream edge and waters with minimum flow. Shoreline hardening impacts the stream edge on which these larvae depend, and can accelerate flow, thereby making areas adjacent to bulkheads less suitable for use by larval or juvenile anadromous fish.

Most of the studies on the biological impact of bulkheads on fish and their habitat were not conducted in North Carolina. However, a recent study by the WRC (Waters and Thomas 2001) examined impacts of bulkheads and other hardened shorelines (i.e., rock revetments) on fish utilization in northeastern North Carolina waters, particularly spawning success and juvenile recruitment of anadromous fish species. They found significantly lower abundance and species diversity of fish adjacent to bulkheads, compared to forested wetland shoreline and rip rap. The study also found higher abundances of juvenile fish along rip-rap and natural shoreline than along bulkheads, and a comparable number of quality size gamefish. The difference in juvenile abundance was attributed to both greater complexity of rip-rap and natural shoreline, and their location near shallower water. These results indicate a reduction in nursery function along bulkheaded shorelines.

Vertical hardened structures are also problematic for marine species that move between water and land during their life cycle. Along the estuarine shoreline, bulkheads are a physical barrier to animals such as the eastern mud turtle, yellow-bellied turtle, and northern diamondback terrapin (a species of "concern" in North Carolina) that live and feed in the marsh, but nest above the high tide line (Ernst and Barbour 1972).

Cumulative effects

North Carolina's policies and rules for estuarine erosion management allow landowners to protect their property from erosion, while attempting to minimize the impacts of erosion control structures. Past and current CRC rules have greatly reduced losses of wetlands and shallow bottom by restricting placement of vertical structures in or seaward of coastal wetlands, and restricting backfilling of the associated landward wetlands. Although currently used techniques may effectively protect waterfront property, immediate and long-term impacts to wetlands often occur, and alteration of sediment supply affects natural shoreline processes and wetland migration. In addition, bulkheads are sometimes permitted and constructed where an erosion problem is not evident. The DCM is working towards permitting stabilization methods only where an identifiable erosion problem occurs. *Better criteria to define an "erosion problem" and aid in proper utilization of erosion control structures are needed and should be developed by the DCM and CRC.*

While a single bulkhead may have little effect on adjacent habitat, the cumulative impact of multiple bulkheads along estuaries can result in significant habitat degradation. Between 1984 and 2000, DCM issued permits to bulkhead approximately 457 miles of shoreline (11.7% of the estimated 3,900 miles of estuarine shoreline). During this time period, the amount of bulkheading permitted annually along the coast has ranged from eight to 91 miles (Figure 5.7). These numbers must be considered with caution since there may be data entry errors. In addition, the CAMA permits include repairs, replacements, or projects that may not have been done or completed. Numbers appear to increase sharply from 1997 to 2000, probably due to the large number of repairs following a series of damaging hurricanes (during 1996 – 1999) and to the strong economy of the mid-1990s. The highest number of bulkhead permits issued annually occurred in 1999. The total amount of bulkheading per county has ranged from less than one mile in Gates County to 109 miles in Beaufort County and 79 miles in Dare County (Figure 5.8). Beaufort, Dare, Carteret, and Currituck counties have the greatest total lengths of permitted bulkheads. In these counties, the percent of hardened shoreline along major waterbodies ranges from roughly 8% to 32%. Because of the limitations of the current database on bulkheading, and the potential impacts to habitat, particularly nursery areas, *there is a need to more accurately assess where and how much of the estuarine shoreline is hardened. With more accurate information, the level of impact to marine resources can be assessed.*

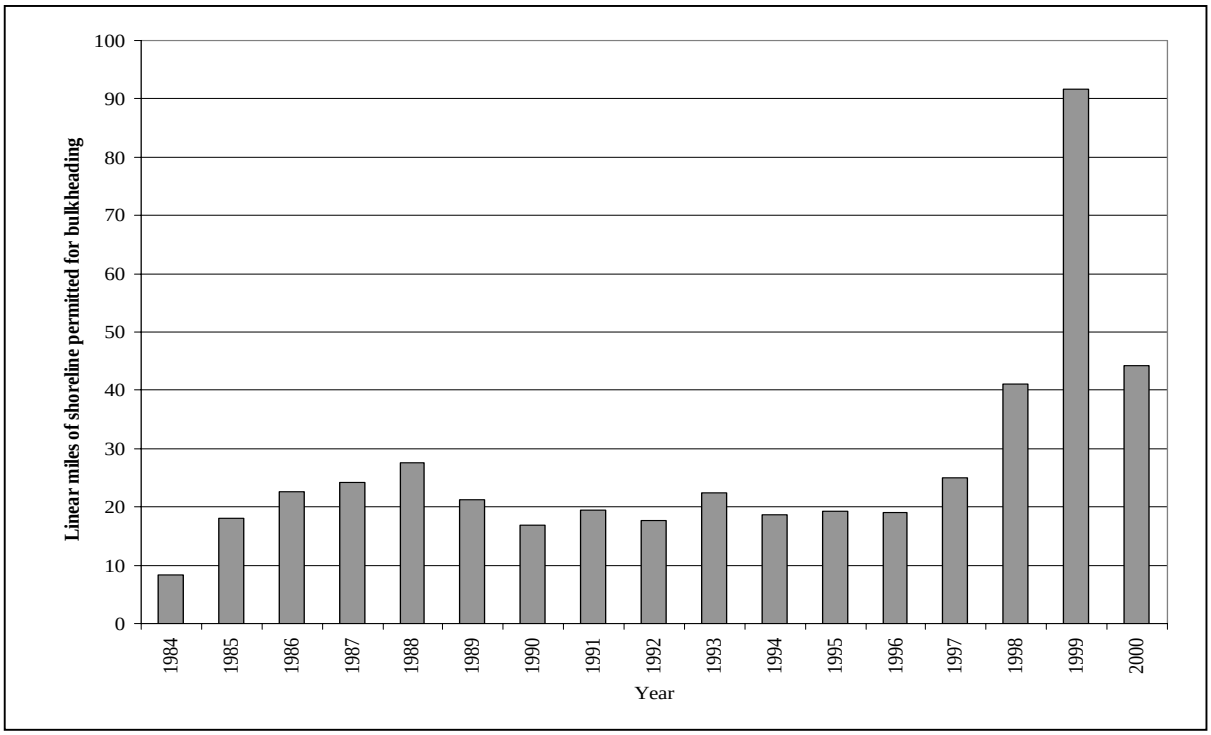


Figure 5.7. Linear miles of bulkheading authorized by Division of Coastal Management permits annually, 1986-2000. (Source: DCM, unpub. data)

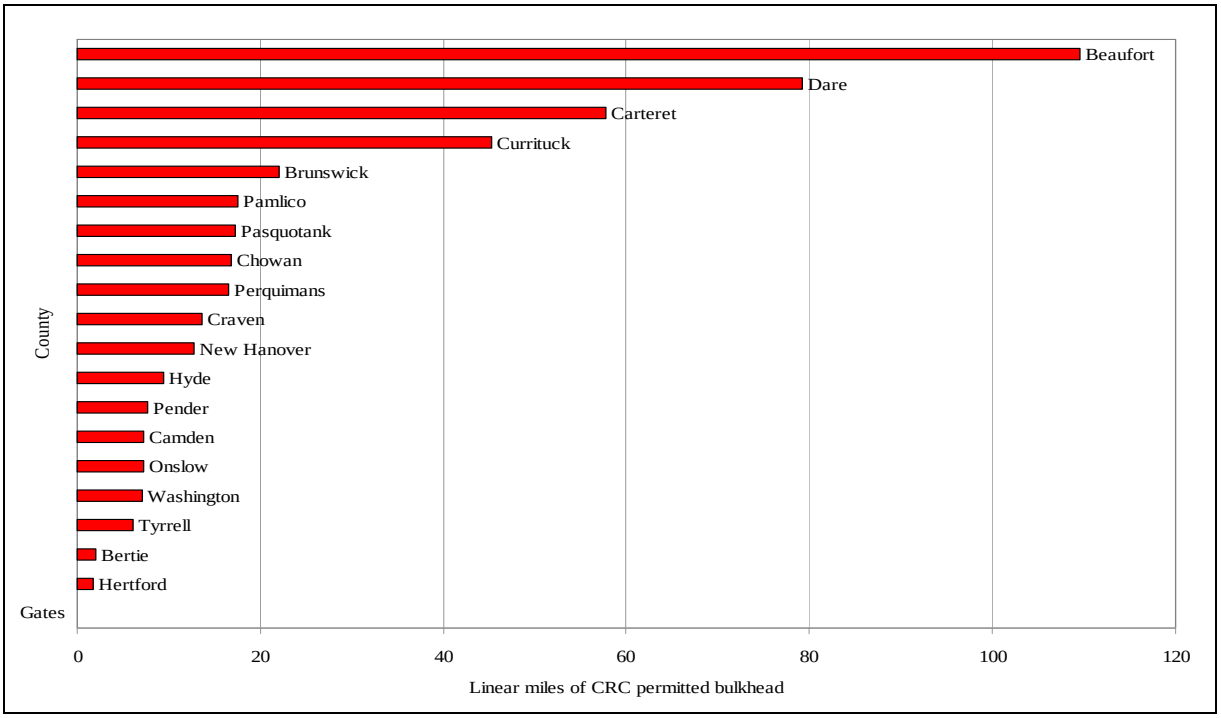


Figure 5.8. Linear miles of bulkheading authorized by Division of Coastal Management permits during 1986-2000. (Source: DCM, unpub. data)

A pilot study conducted by DMF along approximately seven miles of estuarine shoreline in the southern portion of the coast (Pages Creek and Intracoastal Waterway in New Hanover County) found that approximately 21% of the shoreline within the study area was hardened in 1984. By 2000, 37% of the shoreline in the same area was hardened. The most affected area of shoreline was along the ICW, where boat wakes and greater fetch increase erosion problems; 54% of the area examined was hardened. However, even along a protected creek (Pages Creek) with a wide marsh fringe and little obvious erosion, 38% of the shoreline has been hardened. Along Yeopim Creek, a tributary of Albemarle Sound, approximately 1% of the shoreline was hardened in 2000. *The methodology used for assessing shoreline hardening (examination of aerial photographs) could be used for a larger portion of the coast to spatially delineate and quantify where and how much of the shoreline is hardened.*

Although CRC rules state that sloping riprap or vegetation, rather than vertical seawalls/bulkheads, should be used where possible [CRC rule 15A NCAC 07H .0200 (7)(E)], bulkheads continue to be constructed at a rate greater than that associated with alternative shoreline protective methods. Recognizing the extensive, and at times inappropriate, use of bulkheads in North Carolina's estuaries, DCM modified the permitting process in 2001, requiring a General Permit for bulkhead construction less than 500 linear ft (rather than an exemption) and a Major Permit for those greater than 500 linear ft. Also, in 2000, the Estuarine Shoreline Stabilization Subcommittee was established by the CRC to review the estuarine shoreline rule development process. Although not yet adopted by the CRC, the Subcommittee developed a set of principles and concepts to guide further development of any shoreline stabilization rule changes:

1) The State of North Carolina has the authority under CAMA and the Dredge and Fill Act to regulate placement and installation of shoreline stabilization measures.
2) Only property owners with demonstrable erosion problems* may be eligible to obtain a permit to stabilize the shoreline. * CRC will define "erosion problem".
3) Stabilization techniques should be appropriate for site and erosion forces present.
4) Measures with the least adverse environmental effects are preferred (General preference for soft structures).
5) The goals of establishing standards for estuarine and public trust shorelines are:
   a) To safeguard and perpetuate the natural productivity and biological, economic and aesthetic values of natural ecological conditions of the estuarine system (Protection of Habitat and Water Quality).
   b) To insure that the development or preservation of the land and water resources of the coastal area proceed in a manner consistent with the capability of the land and water for development, use, and preservation based on ecological considerations (Appropriate Development For Site).
   c) To insure the orderly and balanced use and preservation of our coastal resources on behalf of the people of North Carolina and the nation (Protection of Public Trust and Private Property Rights).
6) CRC will create development standards for stabilization technique/measures:
   a) Soft Measures
      i) Grading and Planting
      ii) Wetland Planting
   b) Hard Measures
      i) Bulkheads
      ii) Groins and Jetties
      iii) Breakwaters
      iv) Sills
      v) Revetments
      vi) Wave-boards (wooden breakwaters)
   c) Combinations
7) Stabilization measures shall be located as far landward as feasible.
8) CRC will set standards for existing stabilization projects:
   a) Allowing for tying with existing stabilization projects and adjoining lots
   b) Allowing for hardened structures on constructed canals and basins
   c) Allowing in kind/in place repair
   d) Allowing for in kind/in place replacement
9) Allow for larger footprint for riprap for achieved desired slope (1 : 1 ½).
10) CRC will attempt to keep criteria and standards simple to understand and implement.
11) CRC will gather public input on the above principles and provide guidance on the concepts prior to DCM developing draft rule text.

In addition, a science-based panel, the Estuarine Biological and Physical Processes Work Group, was formed by DCM to develop recommendations for shoreline stabilization rules that adequately take into account and reflect the dynamic nature of the estuarine system (DCM 2002). The approach the group took was to evaluate which erosion control methods would be effective on various shoreline types, considering the ecological functions of each shoreline type. Wetland shoreline categories included swamp forest and marsh shorelines, and sediment banks with a marsh or swamp forest fringe. Erosion control options included vegetative planting, beach fill, marsh toe revetment, rock sill, wood or rock breakwater, gabions, groins, riprap, and bulkheads. Non-vertical structures, such as rock sills, oyster reefs or marsh toe revetments, where suitable for erosion control, can have more habitat advantages than vertical structures, since they provide three dimensional structure and areas of refuge for fish and invertebrates. A channel left between sills allows juvenile fish access to the inner marsh. However, even this structure can increase erosion on adjacent shorelines, albeit much less than on shorelines next to

bulkheads. Marsh grass planting creates the least erosion along adjacent shorelines, but offers the least protection of property. Advantages and disadvantages of each effective erosion control method were discussed and the preferred methods that minimize impacts to the hydrological, biogeochemical, and ecological functions of each specific shoreline type were ranked. For example, adjacent to a high bluff with a sand fringe, a bulkhead structure may be preferred over a rip-rap rock structure. However, along a low-lying upland with a marsh fringe, a wood or rock structure on the waterward edge of the marsh would be preferred over a wood or rock structure on the upland edge of the marsh, and bulkheads would not be an appropriate option. This effort is still underway and needs review by the Estuarine Shoreline Stabilization Subcommittee once complete (DCM 2002).

The CRC should revise estuarine shoreline management rules using best available scientific information, including the recommendations from the Estuarine Shoreline Biological and Physical Processes Work Group to minimize impacts to natural shoreline and nearshore fish habitat functions. As part of the process of modifying shoreline management rules, accurate estuarine shoreline erosion rates are needed to aid in identifying "erosion problems," determining adequate shoreline setbacks, and determining appropriate erosion control methods where necessary. Wherever possible, sections of estuarine, non-vegetated shoreline with very little hard stabilization should remain unaltered to provide "new" sediment for shallow water habitats (Riggs 2001). Some consideration should also be given to the type of material used in rock structures because oysters more readily colonize oyster cultch material or limestone marl, than granite.

Impervious surfaces

The increase of impervious surface in coastal North Carolina causes loss and degradation of both riparian and non-riparian wetlands. Impervious surfaces affect wetlands indirectly by preventing infiltration into the soil and shallow groundwater tables, thus reducing discharge to certain groundwater-dependent wetlands. The increased peak flow in urbanized watersheds (Schueler 1994) can result in greater bank erosion and channel incision in riparian wetlands located near impervious surfaces and their associated drainage networks.[75]

Channelization and ditching

Channelization is the deepening and straightening of a natural stream or dredging of a new channel for the primary purpose of improving drainage of adjacent lands (NC Sea Grant 1999). These activities can affect the slope, depth, width and roughness of the channel, thus changing the dynamic equilibrium of the stream (including associated wetlands). Channelized streams are deeper, more variable in flow, and less variable in depth than natural streams (Orth and White 1993). These differences affect primarily smaller species and life stages using wetlands and shallow stream margins, habitats that are reduced by channelization. In many channelized streams in the middle and lower Coastal Plain, storm flows are confined primarily to the main channel rather than passing through wetlands. This change greatly reduces the natural beneficial functions of wetlands to filter pollutants and regulate water flow between uplands and coastal waters. In addition, the riparian zone (including the natural woody vegetation along the sides of the stream) is often removed in the process of channelization (NRC 2002). Consequently, loading and movement of sediment and other nonpoint source pollutants are often greater in channelized streams than in natural streams, which can have negative effects on water quality and fish habitat (White 1996; EPA 2001). Channelization also increases channel cross-section and flow capacity, thus reducing the frequency of overbank flow events that allow fish access to the wetlands. The remaining wetlands exist with an altered hydrology, relying more on overland flow from upland areas and groundwater discharge, and/or overbank flow from unchannelized stream segments nearby.

[75] Refer to Chapter 2 for more information on impervious surfaces.

Although new channelization for flood control and drainage has greatly decreased, the existing alterations continue to alter flow and salinity patterns.[76] *Dechannelization of streams, restoration of wetland hydrology, use of alternative drainage techniques, and on-site BMPs are therefore needed to maintain and restore wetlands, flows and salinity patterns in downstream areas. In addition, increased funding and educational outreach to farmers and other landowners are needed for projects that restore natural stream and wetland functions.*

Dredging for navigation

Dredging impacts wetlands indirectly by limiting the amount of shallow water habitat available for colonization. The spoil from dredging can also be used to create shallow water habitat. At a number of sites, the COE has established wetlands as part of their management of dredge spoil islands; the spoil islands in Pamlico Sound west of Oregon Inlet are good examples. However, CRC rules generally require confining all dredging material to an upland area landward of regularly or irregularly flooded marsh [15A NCAC 07H .0208]. In recent years, cooperative interagency projects have resulted in some beneficial uses of dredge materials, such as creation of marsh and water bird nest sites.

Boating

The most detrimental effect of boating on wetlands is probably loss of vegetation from wave action. The actual impact of boat wakes on wetlands has not been quantified (SAFMC 1998a; Riggs 2001). Erosion from boat traffic along the Intracoastal Waterway and elsewhere is readily observable and is likely responsible for substantial (or just localized) loss of fringing wetland habitat (Riggs 2001). The loss of fringing wetland can result in increased erosion of waterfront property along the Intracoastal Waterway. As the human population of coastal North Carolina increases, so will the impact of boater-induced wave turbulence. The number of registered boats in North Carolina increased by 26% from 1990 to 2000 (see Figure 4.3 in Chapter 4). *There is a need to amend WRC no wake zone authority to include consideration for erosion in strategic wetland areas*. Currently, the issue of human safety is the only issue driving the WRC's authority (habitat protection is not a consideration). *There should also be increased public awareness of the impact of boat wakes on wetland shorelines.*

Marinas, docks, and piers

Direct impacts to wetlands through marina construction are minimized since current CRC rules encourage marina construction in upland basins. Marinas, docks, and piers can impact wetlands indirectly by shading and associated boat traffic. Shading results in the loss of plant growth and vigor beneath the dock structures. A study in South Carolina compared stem densities of *Spartina* under docks with stem densities five meters away from docks (Sanger and Holland 2002). The results of the study indicated an average reduction in stem density of 71% under the docks. The study concluded that although shading of *Spartina* by docks reduces stem density, the total impact on wetland habitat was minor. It was estimated that by the year 2010, only 0.02 to 0.24% of the total salt marsh area in South Carolina would be affected by dock shading. However, local effects in areas with many docks could be significant.

The number of pier general permits issued in coastal North Carolina has risen from about 250 in 1990, to about 800 in 2002 (DCM, unpub. data; Figure 5.9). Additional numbers of large piers are also constructed every year throughout the coastal area. To minimize shading effects in North Carolina, CRC rules require a dock height of three feet above wetland substrate, and a pier width of no greater than six feet. As in South Carolina, the impact of dock and pier shading on wetland vegetation on a coast-wide basis may be minor at present, but the impact will likely increase over time as more piers are constructed.

[76] See Chapter 2 section on channelization and ditching.

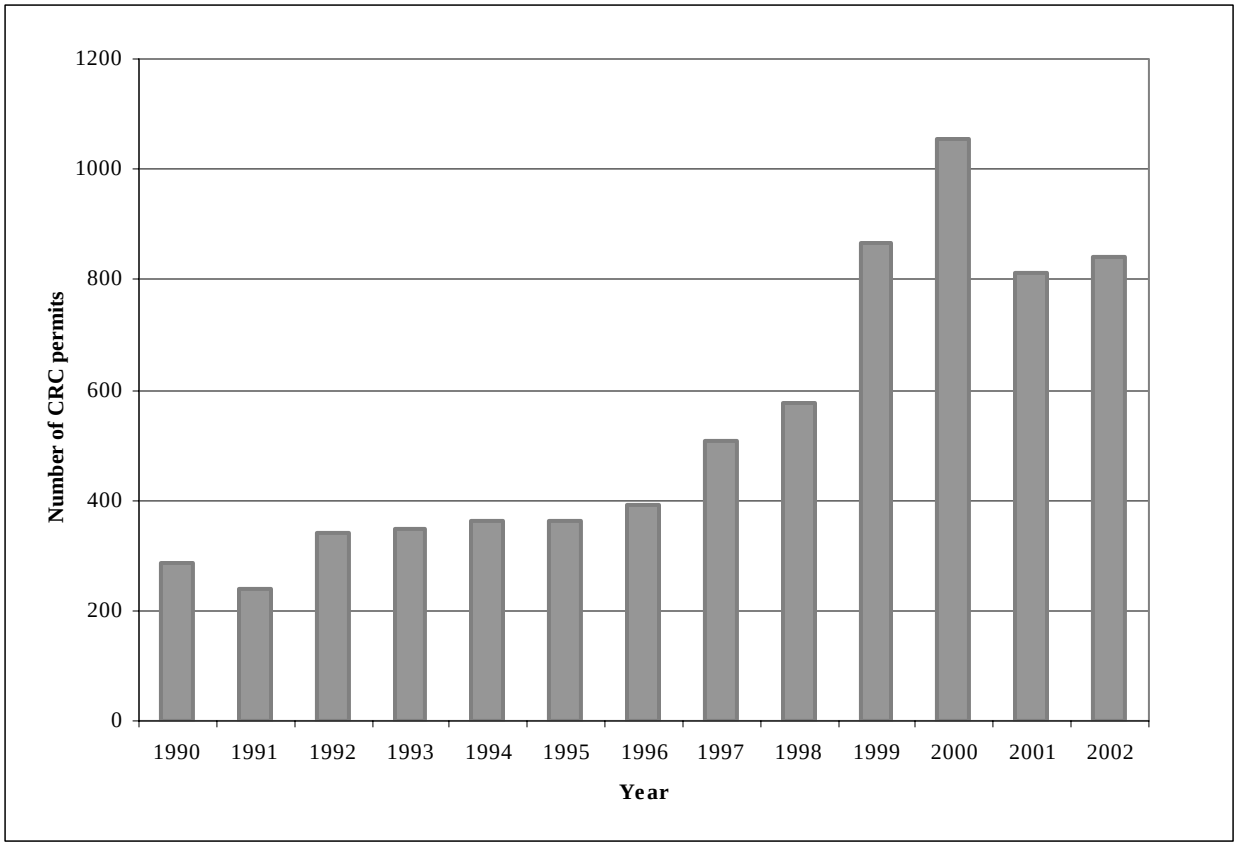


Figure 5.9. Annual number of CAMA general permits issued by the North Carolina Division of Coastal Management for piers, 1990-2002. (Source: DCM, unpub. data)

Water quality degradation

Excess nutrients can result in undesirable changes in the wetland plant community (Lamers et al. 2002). The effect of changes in the plant community on fish use of wetlands is unknown. However, the effect of excess nutrients on fish use of wetlands could be problematic. Algal blooms in and around emergent vegetation can cause very low dissolved oxygen levels at night, resulting in fish kills (see Chapter 2).

Another potential issue regarding the water quality of wetlands (especially freshwater marsh) is sulfate (SO_4^{-2}), a water-soluble, abundant form of sulfur that commonly occurs in nature (e.g., soil and minerals). Elevated sulfate concentrations can enter surface waters and eventually reach wetlands from a number of man-made sources, including: runoff from mining and agriculture, industrial waste discharge and atmospheric deposition (Lamers et al. 2001; EPA 2002a; Lamers et al. 2002). Sulfates are used in a variety of industries, including, but not limited to, mining, processing (e.g., wood pulp, metal finishing, leather), sewage treatment, and manufacturing (e.g., chemical, dye, glass, textile, soap, insecticide, fungicide) (Greenwood and Earnshaw 1984). Approximately 30% of sulfate in groundwater may be from the atmosphere, while the remaining 70% is from organic processes (EPA 2002a). In contrast, Moore (1991) reported that greater than 45% of sulfates detected in rivers originated from human activities. Dissolved or free sulfide (HS^-) can be highly toxic to rooted plants in freshwater wetlands where there is an insufficient amount of iron (Fe). Typically, sulfate-reducing bacteria convert sulfate to hydrogen sulfide (H_2S), pyrite (FeS_2), or iron sulfide (FeS). Sulfate over-enrichment may cause HS^- to accumulate in sediments, and the subsequent toxicity leads to rooted plant communities composed of a few highly sulfur-tolerant species. The effect of these changes in plant community structure on fish use of marsh wetlands is unknown. Lamers et al. (2002) demonstrated that FeS_x oxidation during desiccation, FeS_x

oxidation due to nitrate pollution, and atmospheric sulfur (S) pollution threatened the water quality of freshwater wetlands via eutrophication and HS^- accumulation. The degree of HS^- accumulation did not vary among wetland soil types with different humus profiles (Lamers et al. 2001). *The susceptibility of freshwater wetlands to sulfate pollution should be evaluated in coastal North Carolina. Results should provide the measure of iron concentrations in wetland sediment necessary to evaluate susceptibility.*

Introduced and nuisance species

A major non-native species issue concerning wetlands is the spread of *Phragmites* species (common reed) into salt/brackish marsh areas (Weinstein and Balletto 1999). Since the early 1900s, *Phragmites australis* has been replacing other salt/brackish marsh vegetation along the Atlantic coast at a rate of about 1% to 6% of the marsh surface per year (Weinstein and Balletto 1999). *Phragmites* forms dense, monotypic stands of vegetation that could alter fish use of the marsh. Recent research comparing fish use of *Phragmites* and *Spartina* marsh in New Jersey found no distinct habitat preference among large fish and decapod crustaceans (e.g., shrimp) (Able and Hagan 2000). On the other hand, *Phragmites* had a negative effect on larval and juvenile fish abundance (Able and Hagan 2000; Able et al. 2003). A study in Connecticut salt marshes found no difference between use of reed-dominated tidal marshes and typical tidal marsh vegetation by mummichogs (Fell et al. 1998).

Sea level rise and storm events

Rising sea level is a major threat to coastal wetlands in North Carolina. Analyses of data from tide gauge stations in Hampton, Virginia, and Charleston, South Carolina, from 1921 to 2000 (Riggs 2001), show sea level rising along the Atlantic coast by about 3.35 mm per year (1.1 ft per 100 years). Gauge data specific to North Carolina are available only for 20 years, but suggest a slightly greater rate of approximately 4.57 mm per year (1.5 ft per 100 years). The combination of sea level rise and storm events causes erosion of wetlands at a rate of approximately 802 acres/year (Riggs 2001). The importance of coastal erosion is further emphasized by the relatively low amount of permitted coastal wetland impacts from 1999 to 2002 (WRP 2001), compared to estimated erosion losses. Compared to sea level rise, the rate of wetland building or accretion is slightly less, but of the same order of magnitude: approximately 1.20 mm per year (Hackney and Cleary 1987). Loss of wetlands from sea level rise is exacerbated along steeply sloping shorelines or where wetland migration is otherwise restricted (i.e., where bulkheads are present). A recent study of salt marsh response to sea level rise in New England found that low marsh vegetation (*Spartina alternaflora*) was replacing high marsh vegetation (*Spartina patens*, *Distichlis spicata*, and *Juncus gerardi*) (Donnelly and Bertness 2001). If the rate of sea level rise increases significantly over the next century, many low marsh areas in New England and elsewhere will likely drown (Donnelly and Bertness 2001). *Buyers and owners of coastal property should be aware of sea level rise and the potential for loss of wetlands and property. Updated and accurate coast-wide estuarine erosion rates are needed for the CRC and EMC to determine adequate development guidelines and rules along the coast (DCM 2002). Priorities for coastal wetland protection should also acknowledge sea level rise, and protect gently sloping areas upland of coastal wetlands to allow for landward migration of coastal wetlands with sea level rise.*

Tropical storm surge events can degrade or erode low salinity wetlands by bringing in high salinity water, as well as flooding from rainfall. Freshwater species cannot tolerate high salinity, while salt/brackish species cannot tolerate the freshwater flooding, resulting in a total loss of wetland vegetation in some areas (Baldwin and Mendelssohn 1998). With rising sea level, the impact of storm events on dieback of coastal wetlands can be substantial (Riggs 2001). Loss of wetlands due to increasing salinity and flooding has been documented in Louisiana estuaries (Webb 1997). Loss of wetlands from storm surge events and erosion in North Carolina (Riggs 2001) did not distinguish losses due to vegetation dieback from overall erosion. Vegetation dieback is important because it could actually accelerate erosion of coastal wetlands. *Research is needed on site-specific erosion and accretion rates and their relationship with sea level rise and storm events (Brinson and Moorhead 1989). Specific research is also needed to*

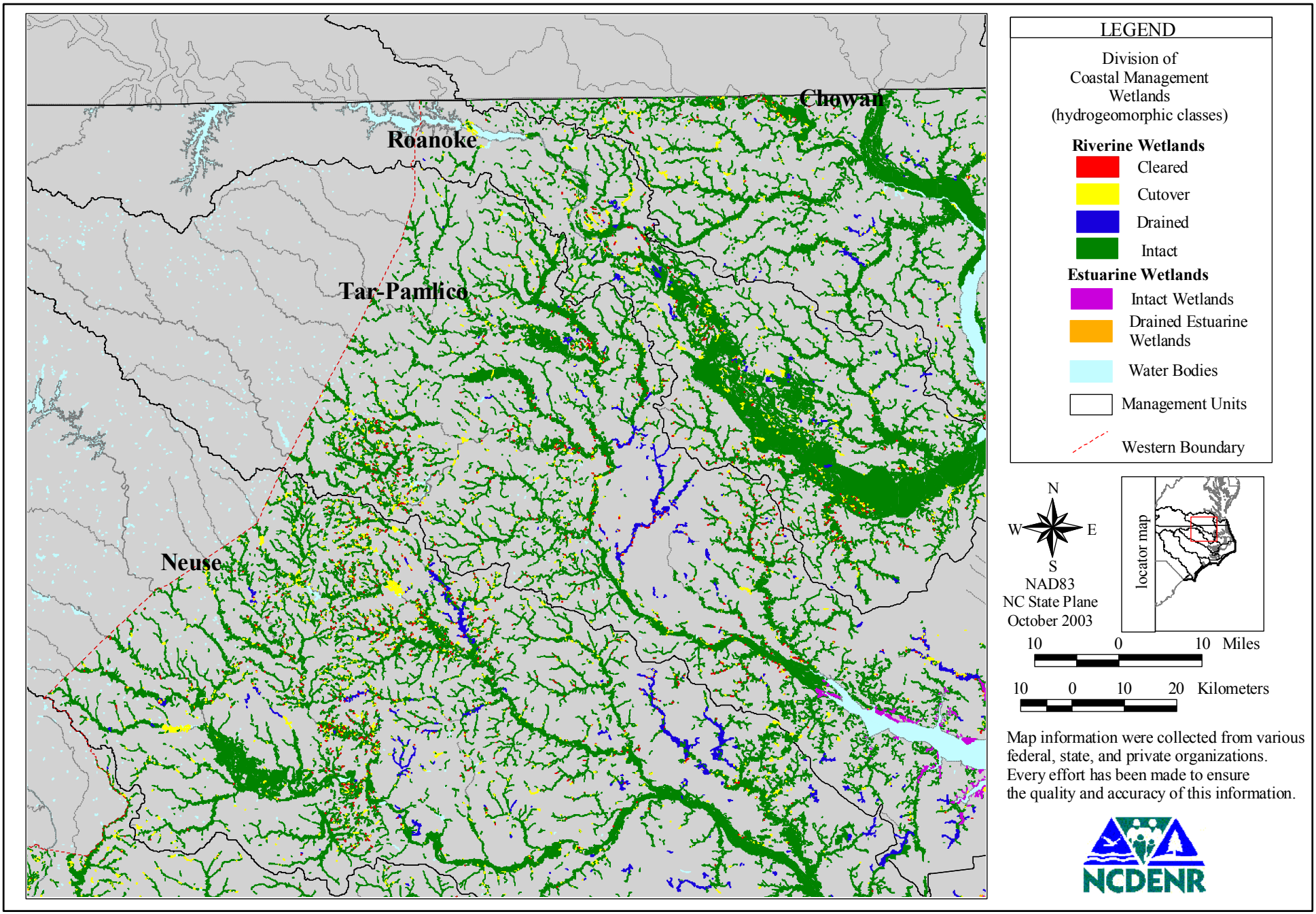
determine processes that control the upper limits of peat accumulation, which is the foundation of coastal wetland development in the Albemarle-Pamlico system (Moorhead and Brinson 1995).

5.5. SUMMARY OF WETLANDS CHAPTER

Wetland habitat is unique among the coastal fish habitats because it is not entirely submerged but occurs in and above the water. There are many different types of wetlands throughout the coast, many bordering the rivers and sounds, while others are hydrologically isolated. While each wetland type is unique, these different types provide similar ecological functions. Wetlands are highly effective and well recognized for their value as a natural filter, trapping and filtering pollutants from upland runoff; as well as serving to buffer the effects of floods by storing, spreading, and slowing stormwater runoff. Like SAV, wetlands are highly productive biologically, but because of their expansive coverage and biomass, produce much more organic matter, which is broken down and utilized by multiple species adjacent to wetlands and elsewhere. It has been estimated that over 95% of the United States' commercially harvested finfish and shellfish are wetland dependent. The combination of shallow water and thick vegetation provides excellent nursery habitat for juvenile fish. The majority of MFC-designated Primary Nursery Areas consists of wetlands and adjacent shallow water and soft bottom. Fish found commonly in or near freshwater marshes and swamps include bluegill, largemouth bass, river herring, and striped bass. In and adjacent to estuarine wetlands, killifish, spot, red drum, flounder, penaeid shrimp, striped mullet, pinfish, blue crab, and other species are abundant. In addition to supplying food and acting as nursery habitat for numerous species, riparian wetlands also provide a relatively safe corridor for fish moving among the other nearshore habitats.

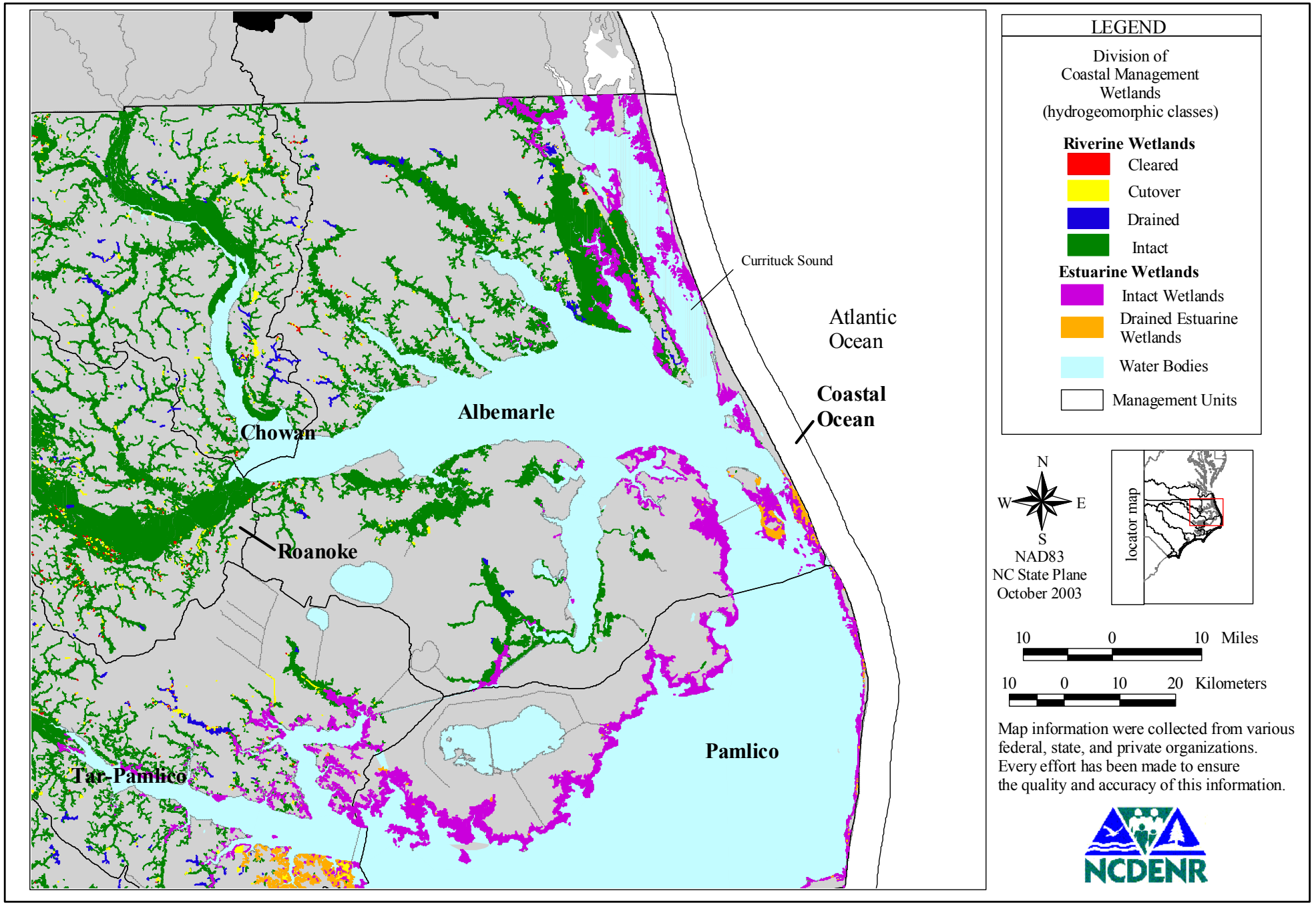
It is estimated that as much as 40-50% of North Carolina's original wetland coverage has been lost, primarily due to ditching, channelization, and filling for agriculture and development. From the early 1800s to the early 1900s, agriculture accounted for the majority of wetland losses. From about 1950 to the 1990s, conversion to forestry and agriculture accounted for 53% and 42% of wetland losses in North Carolina. Although the rate of wetland loss has slowed, losses continue to occur. Mitigation for permitted losses and voluntary restoration efforts in some areas have partially offset some recent losses, but the type of wetland gained is often not equivalent to what was lost. Degradation and loss of wetlands can impact many species, including overfished stocks of river herring and southern flounder, as well as stocks designated with the Concern status such as blue crab and striped mullet.

There are multiple threats to wetland habitat today, primarily due to physical destruction and hydrological alteration. Ditching and draining for development, construction of new dams, mining activity, and filling for new development accounted for the majority of permitted wetland losses in recent years. Construction of roads, infrastructure, and water dependent-development, including dredging for marinas and navigation channels, also results in smaller, site-specific losses and contributes to cumulatively large wetland losses. Estuarine shoreline stabilization causes gradual, long-term wetland loss by limiting sediment inputs needed for maintenance and expansion of wetlands, and by blocking landward migration as sea level rises. Because wetlands are critical to a large number of fishery species, but have been greatly reduced in spatial coverage from their original extent, ongoing initiatives such as wetland restoration, land acquisition and preservation, and agricultural cost-share BMPs need to be enhanced. There should also be additional initiatives implemented to protect and enhance wetland habitat. The many fishery and water quality functions provided by wetlands make their preservation and restoration along North Carolina's coast a high priority for protection of all coastal fish habitats.



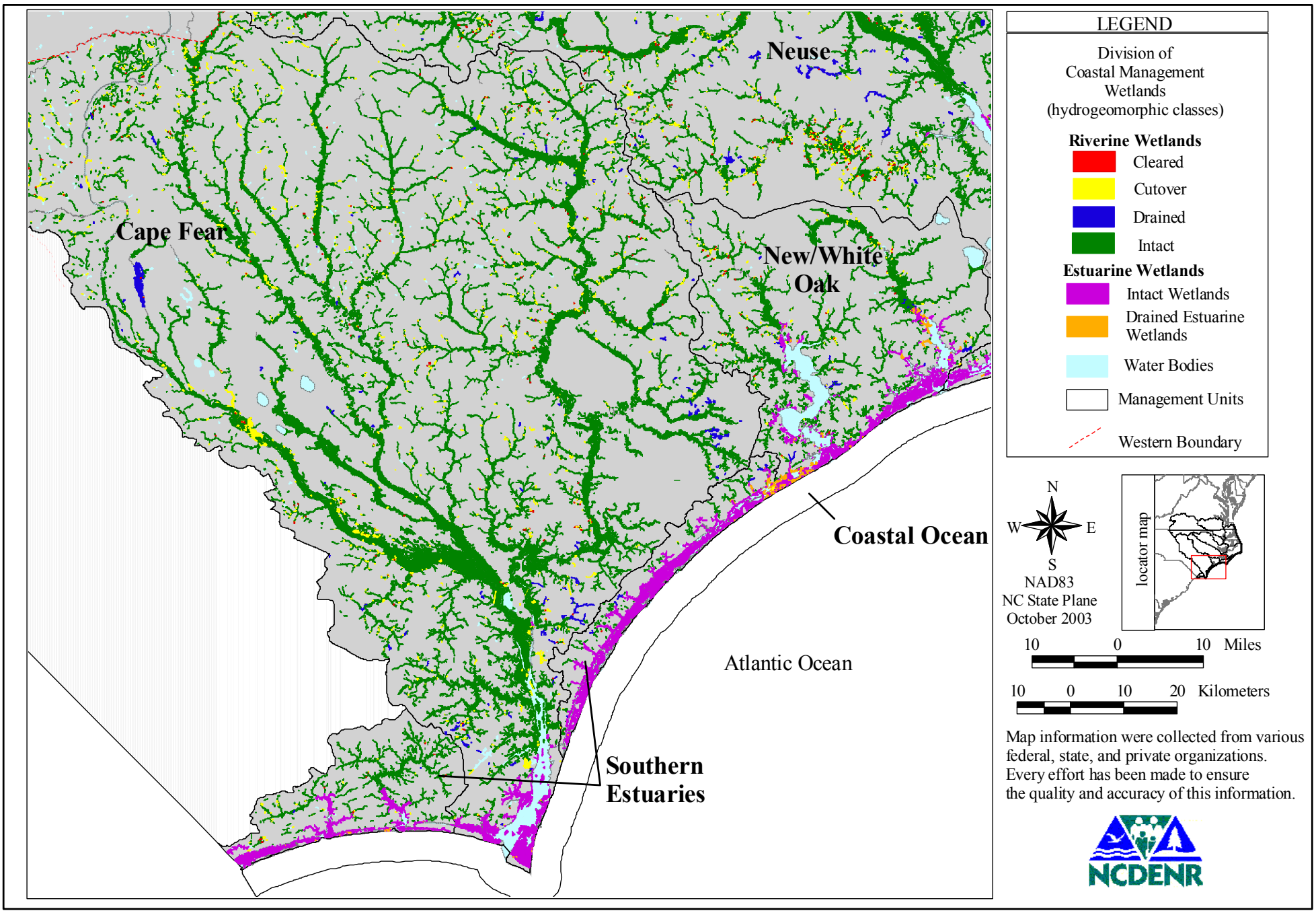
Map 5.1a. Location of riparian wetland areas derived from maps produced by DCM (1994) in the upper areas of the Roanoke, Tar-Pamlico, Neuse and Chowan basins.

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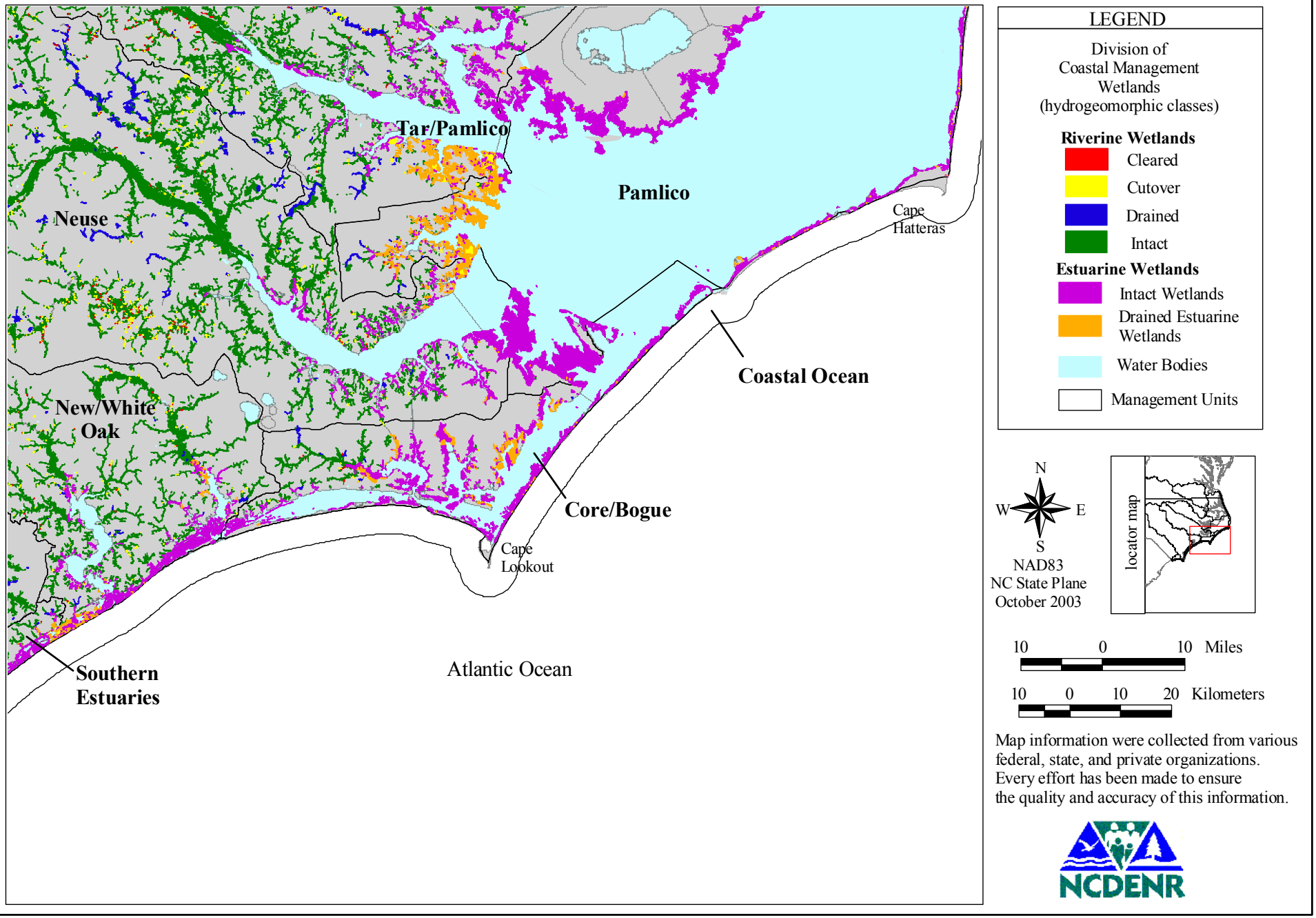
Map 5.1b. Location of riparian wetland areas derived from maps produced by DCM (1994) in northeastern North Carolina.

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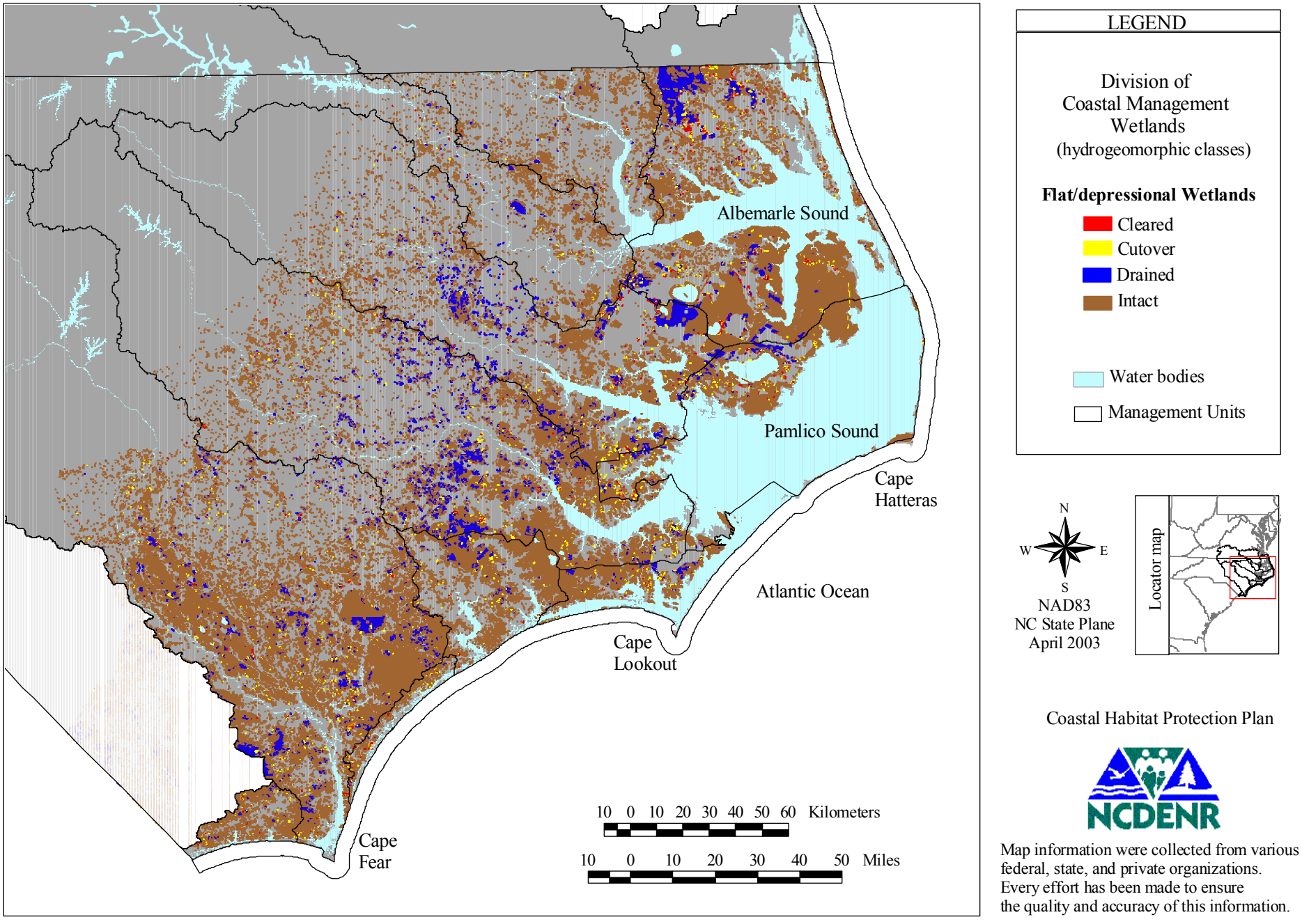
Map 5.1c. Location of riparian wetland areas derived from maps produced by DCM (1994) in southeastern North Carloina.

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Map 5.1d. Location of riparian wetland areas derived from maps produced by DCM (1994) in central coastal area of North Carolina.

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Map 5.2. Location of flat/depressional wetland areas derived from maps produced by DCM (1994).

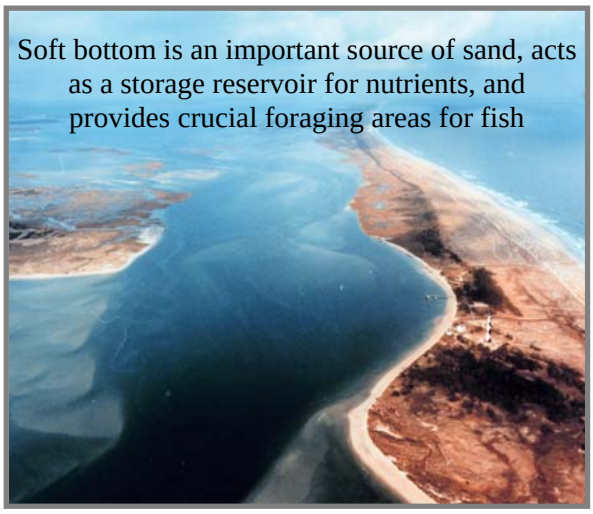
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CHAPTER 6. SOFT BOTTOM

6.1 DESCRIPTION AND DISTRIBUTION

Definition

Soft bottom habitat is unconsolidated, unvegetated sediment that occurs in freshwater, estuarine, and marine systems. The MFC, CRC, or EMC do not specifically define soft bottom or unvegetated bottom in their regulations. The SAFMC defines one type of soft bottom, tidal flats, as "dynamic features of coastal landscapes whose distribution and character may change with shifting patterns of sediment erosion and deposition." This definition could in fact apply to all soft bottom. However, the CHPP definition of soft bottom includes deeper subtidal bottom as well as shallow bottom areas. Although soft bottom as a habitat type is not specifically designated or protected by any of North Carolina's regulatory commissions, it is an important component of MFC designated Primary Nursery Areas (PNAs), Anadromous Fish Spawning Areas, and Anadromous Nursery Areas.



Soft bottom is an important source of sand, acts as a storage reservoir for nutrients, and provides crucial foraging areas for fish

Habitat requirements

Soft bottom has only one habitat requirement – sediment supply. Environmental characteristics, such as sediment grain size and distribution, salinity, dissolved oxygen, and flow conditions, will affect the condition of the soft bottom habitat and the type of organisms that utilize it. Nevertheless, the habitat itself will persist regardless of its condition unless it becomes starved for sediment or is colonized by other organisms, transforming it into another habitat such as SAV or shell bottom. Refer to the threats section for more information on alterations to soft bottom habitat.

Description and distribution

Although soft bottom habitat is defined as "unvegetated" and lacks visible structural habitat, the surface sediments support an abundance of microscopic plants; numerous burrowing animals are hidden below the surface (Peterson and Peterson 1979). The characteristic common to all soft bottom types is the mobility of unconsolidated, uncemented soft sediment (Peterson and Peterson 1979). Soft bottom habitat can be characterized by geomorphology (the shape and size of the system), sediment type, water depth, hydrography (riverine, intertidal, or subtidal), and/or salinity regime (DENR 2000a). Soft bottom habitat types in North Carolina's coastal waters can be categorized as the following:

Freshwater
- unvegetated shoreline
- river, creek, and lake bottom

Estuarine
- intertidal flats and unvegetated shoreline
- subtidal bottom in rivers, creeks, and sounds

Marine
- intertidal beach
- subtidal bottom

It is important to understand the physical and chemical properties of soft bottom habitat since these affect the benthic organisms that inhabit these areas and, in turn, their value as fish habitat. The physical and chemical character of all soft bottom is determined by the underlying geology, basin morphology, and associated physical processes (Riggs 1996). Geologically, North Carolina's coast can be divided into distinct northern and southern provinces that are approximately separated by Cape Lookout (Riggs 1996; Pilkey et al. 1998). In the northern province, sediment formations generally consist of a thick layer of unconsolidated muds, muddy sands, sands, and peat sediments. A gently sloping depositional basin formed north of Cape Lookout. The low slopes of the northern province are characterized by an extensive system of drowned river estuaries (i.e., Albemarle Sound, Neuse River), long barrier islands, and few inlets (Map 6.1 a-e). In contrast, the southern coastal province has only a thin and variable layer of surface sands and muds, with many areas of exposed rock outcrops in marine waters. The southern province also has a steeper sloping shoreline, resulting in narrow estuaries (e.g., Topsail Sound, Batts Mill Creek), short barrier islands, and numerous inlets (Map 6.1 a-e). These geomorphic features, in turn, affect sediment deposition and the character of soft bottom habitat.

Freshwater bottom

Freshwater bottom includes the bottom sediments of freshwater rivers, creeks, and lakes. These areas were described in the Water Column chapter and are shown in Map 2.5a-b. Properties of the soft bottoms within a river system depend primarily on the origin of sediment inputs but also on elevation gradient, flow conditions, riparian cover, local geology, and water column characteristics. Upstream sources of sediment inputs into riverine systems include erosion of sediment bank shorelines, flushing of swamp forests and other wetlands, and transport of suspended sediment from upstream riverine flood waters (Riggs 1996). Bottom composition generally ranges from more consolidated material upstream (bedrock, boulders) to less consolidated material downstream (gravel, sand). Because freshwater rivers and creeks are eroding through older sediment banks, there tends to be a deep main channel dominated by medium-to-coarse grained sand with varying amounts of detritus. Shallow flats may exist on one or both sides of the channel. Sediment on these flats tends to consist of a layer of fine sandy mud on top of older sediments (Riggs 1996). Where the channel bed is relatively deep or wide, pools form and water velocity slows, allowing finer particles to settle (sand, silt). Where the channel bed is relatively narrow or shallow, riffles and runs occur and water velocity increases, leaving only the heaviest particles on the bottom (boulder, cobble). Dissolved oxygen in flowing waters is generally high, leading to aerobic surface sediments.

In freshwater lakes, like Lake Mattamuskeet, the shallow bottom around the shoreline is often unvegetated due to shoreline erosion, high wind exposure, or low water clarity (from turbidity or organic staining). In sheltered areas, however, the bottom may be covered by submerged aquatic vegetation. In deeper areas of lakes, the bottom is unvegetated because of low light availability. These deeper waters may become stratified during summer, causing anoxia or hypoxia on the bottom (Mitsch and Gosselink 1993).

Estuaries and sounds - intertidal flats, unvegetated shoreline and subtidal bottom

Sediment composition of soft bottoms in estuaries and sounds varies with geomorphology and position within the estuary. The basin morphology of most northern estuaries in North Carolina is similar to a shallow, flat-bottomed dish with a small lip around the perimeter (Pilkey et al. 1998). The estuarine shoreline is a cut bank with a narrow and shallow perimeter platform (the lip) that slopes gradually away from the shoreline to approximately 3-7 ft (1.5-2 m) deep, and then more abruptly to the floor of the central basin. The central basins deepen gradually from the inner estuary to the outer estuary from about 12 – 23 ft deep (4 to 7 m). The central basins become shallow near the mouths of the estuaries due to formation of sandy bars, and behind the barrier islands due to storm overwash and transport of sand from the inlets. Coarse sands are concentrated on the shallow perimeter platforms, shoals, and inlet mouths, while fine sediments such as organic rich mud (ORM) are concentrated in the deeper central basins and downstream channels (Wells 1989; Riggs 1996; Pilkey et al. 1998) (Map 6.2). General bottom topography of estuarine water bodies is shown in Map 4.1. The relationship between sediment composition and water depth is evident when comparing Map 4.1 and Map 6.2. The width and thickness of ORM increase as the estuary widens and deepens in the downstream direction, since the fine sediments are easily suspended and transported away from high energy waters (Riggs 1996).

Soft bottoms in the northern geologic province, including the Albemarle-Pamlico Estuarine System, consist of four general types of sediment: sand, peat, inorganic mud, and ORM (Wells 1989; Riggs 1996). Sands are derived from erosion of the sediment bank shorelines and shallow perimeter platform throughout the estuaries. Sand is also transported into the lower portion of the estuaries from barrier island overwash and transport through the inlets. Peats (sediments with more than 40% organic matter) are derived from flushing of organic matter from wetlands and erosion of wetland shorelines. Inorganic muds consist of several clay minerals, primarily derived from suspended sediment transported from riverine flood waters to the estuarine system. Organic rich mud is the most extensive sediment type in North Carolina's estuaries. It is composed of 5 to 40% organic matter (most commonly about 10%), mixed with inorganic clay (approximately 76%) and quartz sand (approximately 13%). Organic rich mud comprises approximately 70% of the sediment in North Carolina's estuarine system and is primarily concentrated in the central basins of the sounds.

Soft bottom in the southern estuarine system is dominated by sloped mudflats on the perimeter and interior of the smaller estuaries (i.e., White Oak River, Pages Creek) (Pilkey et al. 1998). The mudflats are riddled with tidal channels and support extensive salt marshes. In the lower estuary, sand is transported into the estuaries from the numerous inlets and barrier island overwash. In the upper estuary, small blackwater streams carry relatively low sediment loads into these estuaries, but the water contains large quantities of dissolved organic matter that give it a brown tea color. The Cape Fear River, unlike the other smaller river systems in the Southern Province, transports large sediment loads from eroding clay sediments of the Piedmont to the lower estuary.

Unvegetated shorelines occur where wave energy prevents colonization by plants and there is a gently sloping area for sand to build upon (Riggs 2001). The shoreline provides an area to absorb the physical energy from waves, tides, and currents, protecting upland areas. Although unvegetated nontidal shorelines are ordinarily exposed from water, and therefore not used by fish, the dynamic processes of erosion and sediment deposition affect the composition and supply of sediment in adjacent shallow water habitats. This in turn affects the type and productivity of the benthic invertebrate community. For example, unvegetated sediment bank shorelines are generally eroding and sandy, providing a source of sand to adjacent waters (Riggs 2001). Sand deposits from inlet flood tide deltas and overwash events on back barrier islands form shallow sand flats behind the islands. In contrast, marsh or swamp forest shorelines are generally not eroding and have a high organic content, thus providing fine organic sediments to adjacent waters. Several shoreline erosion studies have been conducted along North Carolina's coast that provide information on the character and condition of intertidal, shoreline, and shallow subtidal soft bottom and were compiled and summarized in Riggs (2001).

Intertidal flats are the unvegetated bottoms of estuaries and sounds that lie between the high and low tide lines. These flats occur along mainland or barrier island shorelines or can emerge in areas unconnected to dry land. Intertidal flats are most extensive where tidal range is greatest, such as near inlets and in the southern portion of the coast. Because the influence of lunar tides is minimal in the large sounds (e.g., Pamlico, Albemarle, and Currituck), true intertidal flats are not extensive, except for the area immediately adjacent to inlets (Peterson and Peterson 1979). Sediment composition on intertidal shorelines tends to shift from coarser, sandy sediment on higher portions of the shoreline, with greater wave energy, to finer, muddier sediments in the lower portion of the shoreline, with relatively less wave energy (Peterson and Peterson 1979). Conditions on intertidal flats are physically stressful for associated marine organisms. Drastic fluctuations in salinity, water and air temperature (in addition to air and wind exposure) occur during each tidal cycle. Due to physiological restraints and limited water depth, some mobile organisms are restricted to deeper waters or adjacent habitats to avoid the stressful extremes associated with low tide. However, the sediment provides a buffer from changes in temperature and salinity in the water column for benthic infauna (Peterson and Peterson 1979).

The inlets separating North Carolina's barrier islands are part of a sand-sharing system among the islands, estuaries, and nearshore ocean. Intertidal flats or deltas form on the ebb and flood sides of inlets as sediments shift with tides and waves. Sediments in the vicinity of inlets are typically composed of coarse sands and shell fragments (Peterson and Peterson 1979). Ebb-tidal and flood-tidal deltas (i.e., the seaward and estuarine shoals of an inlet, respectively) are formed by waves and currents, and may contain large volumes of sand. Intense wave and current energy cause the flats to continually change, erode, and reform. The high instability of the ebb and flood tide deltas makes colonization by benthic invertebrates difficult (Peterson and Peterson 1979). Inlets are classified as stable, migrating, or ebb-tidal delta breaching (Fitzgerald et al. 1978). Unstable inlets may form extensive spits, tidal deltas, and sand bars, creating bathymetric complexity (or differences in water depth) in nearshore waters that attract certain fish species. The process of channel realignment and abandonment provides a mechanism for large sandbar complexes to move onto the adjacent barrier islands, supporting productive intertidal beach communities (Cleary and Marden 1999).

There are currently 20 inlets in North Carolina that connect estuarine waters to the sea (Map 6.3 a-c). Ten of these inlets originated as a result of storm breaches across barrier spits or islands and remain spatially unstable, including Oregon and Mason inlets (Cleary and Marden 1999). Mason Inlet, which has been migrating south rapidly, was artificially relocated in the winter of 2002. Mad and New (Corncake) inlets closed following the hurricanes of the last few years, and Old Drum Inlet reopened. A new inlet breached between Hatteras and Frisco during Hurricane Isabel in 2003, but was refilled by the United States Army Corps of Engineers (COE). There are nine larger inlet systems, including Ocracoke, Bogue, and the Cape Fear River inlets, which occupy ancient river channels. Two other inlets were artificially created: Drum and Carolina Beach inlets. Although originating as a storm-related breach, Tubbs Inlet was artificially relocated in 1970.

Ocean intertidal beaches and subtidal bottom

The locations of major marine intertidal and subtidal topographic features, such as beaches, inlets, inlet-associated ebb-tidal deltas, and shoals, are indicated in Map 6.1 a-e. The seafloor off the North Carolina coast is part of the Atlantic continental shelf, which slopes gradually from the coastline before dropping off steeply at approximately the 160–250 ft (50–75 m) isobath where the continental slope begins. In North Carolina, the continental shelf is relatively narrow, approximately 16 mi (30 km) off Cape Hatteras, 32 mi (60 km) off Cape Lookout, and about 49 mi (90 km) off Cape Fear. Water depth at the seaward limit of state territorial waters ranges from 50–70 ft (15–21 m) (Map 6.1 a-e). Because North Carolina is located at a transition between two major physiographic and zoogeographic zones, the marine subtidal bottom supports a high diversity of invertebrates.

North of Cape Hatteras, the shoreline and adjacent shoals tend to be linear, the shelf is relatively steep, and the bottom consists of a regional depositional basin known as the Albemarle Embayment, resulting in few exposed rock outcrops. Several prominent shoals, such as Wimble, Kinnekeet, and Platt shoals, also occur in this region, as well as a series of prominent ridges and swales that are spaced about 1,300–2,000 ft (400–600 m) apart, with mean relief of 3–23 ft (1–7 m), averaging 6–10 ft (2–3 m) in height (Inman and Dolan 1989; Rice et al. 1998). Shoals closest to shore, such as Wimble and Kinnekeet shoals, tend to be oriented at a 20–30° angle from the coastline, while those farther offshore run more parallel to the coast (MMS 1993).

The coastline south of Cape Hatteras consists of a series of arcs, dominated by three major capes (Hatteras, Lookout, and Fear) and three associated bays (Raleigh, Onslow, and Long) (Map 6.1 a-e). Long Bay continues into South Carolina to Cape Romain. Large shoals extend across the shelf from each cape (Diamond, Lookout, and Frying Pan shoals) for more than 11 mi (20 km). South of Cape Hatteras, the continental shelf has a greater amount of exposed rock outcroppings and is intersected with younger sediments originating from filled ancient river valleys (Riggs et al. 1995). The rock outcroppings are discussed in the hard bottom chapter of this plan.

The continental shelf off North Carolina has a relatively low supply of incoming sand, due to low direct river input, entrapment of most river-borne sediment in the upper estuaries and sounds, and minimal sediment exchange between adjacent shelf embayments (Riggs et al. 1998). The shoreface is the generally concave, upward surface extending from the surf zone to the point where the slope matches that of the continental shelf (Thieler et al. 1995). The base of the shoreface off North Carolina occurs at approximately 33–40 ft (10–12 m) water depth. The shoreface represents the area of active beach sand movement. Six classes of shoreface systems were recognized by Riggs et al. (1995) based on differences in the underlying geology. The nature of these shorefaces affects the geologic composition of the surface and underlying substrate of the subtidal bottom and shoreline and partially explains the patterns of localized erosion or deposition.

The intertidal zone of oceanfront barrier island beaches is the area periodically exposed and submerged by waves, varying with frequency and with lunar tide cycles. In this high energy area, waves continually rework and sort sediment by grain size. The uprush of water carries sediment onto the beach, with larger sediments deposited first and finer-grained sediment carried farther landward. The backwash carries some sediment back into the water. Because of this regular high wave energy, as well as occasional storm events associated with extreme wave action, the intertidal beach and surf zone typically have rapid scour and fill events. The sediments are generally much coarser, more highly sorted, and contain less organic matter than in protected estuarine intertidal flats (Donoghue 1999).

The surf zone is the shallow subtidal area of breaking waves seaward of the intertidal beach. Within the surf zone, longshore sandbars frequently develop and shift seasonally in response to wave energy. Seaward of the surf zone, the subtidal bottom consists of a series of minor ridges and swales. Ripple scour depressions, ranging from 130–330 ft (40–100 m) in width and up to 3 ft (1 m) in depth, occur along the southern portion of the coast and are perpendicularly oriented to the beach, extending to the base of the shoreface (Thieler et al. 1995; Reed and Wells 2000). These features are located adjacent to areas experiencing chronic severe beach erosion, and may be indicative of rapid offshore transport of sand during storms (Thieler et al. 1995).

Three major shoals extend perpendicular to Cape Hatteras, Cape Lookout, and Cape Fear: Diamond Shoals, Cape Lookout Shoals, and Frying Pan Shoals, respectively. Water depth on the shoals ranges from 2–18 ft (0.6–5.5 m), in contrast to adjacent waters that are 20–40 ft (6–12 m) deep. Due to an interest in beach nourishment projects for Dare County, Boss and Hoffman (2000) collected detailed information on the sand resources of North Carolina's Outer Banks, including specific data about Diamond Shoals. Diamond Shoals extend approximately 11 nautical miles (nm) (20 km) and are about

5.5 nm (11 km) wide. The estimated total volume of sand on the shoal was at least 1.66 billion cu yd, with approximately 256 million cu yd within state waters (Boss and Hoffman 2000). As such, cape shoals are major sand resources for coastal processes. Detailed mapping of the bottom has been done in other areas of the coast to varying extent with different techniques. *The results of these studies need to be compiled in a comprehensive and comparable manner to evaluate changes and trends in substrate character, as well as the feasibility of beach nourishment projects.*

6.2 ECOLOGICAL ROLE AND FUNCTIONS

Community structure

Freshwater

The freshwater benthic community varies greatly from extreme headwaters to mainstem rivers and may be more similar to that found in inland lake bottoms than in estuaries. Green algae and diatoms are more common than dinoflagellates (Rulifson et al. 1986). In headwater streams, algal production is negligible where there is complete tree canopy cover and the benthic community consists largely of organisms that break down and collect detritus. As the canopy opens up downstream, algae grazers and detritivores increase in abundance (Vannote et al. 1980). Mussels are an important component of the invertebrate community in freshwater soft bottom. There are over 60 species of freshwater mussels in North Carolina. The distribution and diversity of native freshwater mussels have been in a state of decline in North Carolina as well as in other southeastern states. The freshwater Asiatic clam (*Corbicula fluminea*), introduced about 50 years ago, has become a prominent component of many rivers (Lauritsen and Moxley 1983). Ecological problems associated with this non-native species include alteration of the benthic substrate, and competition with native mussels and other mollusks (Devick 1991). Zebra mussels (*Dreissena polymorpha*) have not been reported in North Carolina, but have been found in Virginia and 20 other states. Due the rapid rate that this non-native species has spread in the United States since first found in 1986, researchers feel that zebra mussels are likely to infest all southeastern states eventually, with negative impacts to the native mollusks (Neves et al. 1997). Freshwater benthic sampling, conducted by DWQ in all of North Carolina's river basins, provides detailed information on the abundance and diversity of benthic species present in the freshwater portion of North Carolina's coastal rivers.

Estuarine

Benthic microalgae are a key part of the food chain in estuarine soft bottom habitat. Benthic microalgae are microscopic photosynthetic algae that live in the top few millimeters of the surface of soft bottom (Miller et al. 1996). Because the unvegetated bottom appears barren, but is actually rich in photosynthetic algae, MacIntyre et al. (1996) referred to benthic microalgae as "The Secret Garden." Benthic microalgae on sand, mud flats, and subtidal bottom are composed primarily of benthic diatoms and blue green algae, with benthic dinoflagellates and filamentous green algae also present (Peterson and Peterson 1979). Dense mats of blue green algae sometimes form in protected higher portions of intertidal flats, giving the sediment surface a dark brown or blue-green appearance, which can form a crusty mat when dry at low tides (Peterson and Peterson 1979). Diatom mats are more abundant in the lower intertidal zone (Peterson and Peterson 1979). Benthic microalgae can either be attached to sediment particles or be mobile, migrating vertically through the sediment. Productivity depends on photosynthesis by these microalgae, which can only occur in sediments having adequate light penetration (MacIntyre et al. 1996). Photosynthetically active light generally penetrates only about 2-3 mm into the sediment, but can reach 5-20 mm in sandy, high energy environments.

Most benthic invertebrates inhabiting soft bottom live in the sediment (infauna), as opposed to the bottom's surface (epifauna), because of the high mobility of sediments (Peterson and Peterson 1979). These animals are classified by size and feeding mode. Microfauna are the very small protozoans (< 0.06 mm). Meiofauna are about 0.06 – 0.40 mm in size (the size of a sand grain), and include nematodes and

copepods. Both microfauna and meiofauna are important grazers on benthic microalgae and bacteria. Macrofauna (>0.5 mm) contribute the most to infaunal biomass and include organisms such as amphipods, polychaetes, mollusks, echinoderms, and crustaceans (Peterson and Peterson 1979). These macrofauna may be deposit feeders or suspension feeders (Peterson and Peterson 1979; Miller et al. 1996). Deposit feeders ingest sediment and detrital deposits and assimilate bacteria, fungi, and microalgae from them. Compared to detritus and larger plants, microalgae may be a nutritionally richer food source for benthic invertebrates (Miller et al. 1996). Deposit feeders include mud snails, many polychaete worms, and certain bivalve clams and crustaceans.

Suspension feeders capture particles suspended in the water column. Common suspension feeders are bivalves such as the hard clam (*Mercenaria mercenaria*) and razor clam (*Tagelus plebeius*), and some polychaete worms (Miller et al. 1996). When sediment is resuspended, the benthic microalgae become available to the suspension feeders (Miller et al. 1996). A large proportion of intertidal bivalves' diet has been shown to consist of suspended benthic microalgae, particularly when chlorophyll concentrations in the water column are low (Page and Lastra 2003). While resuspended benthic microalgae can be beneficial to the invertebrate community as an additional food source, excessive suspended sediment and associated algae have been found to reduce growth rates and survival of macrofauna, such as hard clams (Bock and Miller 1995). Although the abundance of food sources affects invertebrate populations, benthic predators (such as spot and pinfish) were found to have a larger influence on soft bottom community composition and biomass relative to that of nutrient availability (Posey et al. 1995).

Larger, mobile invertebrates live on the surface of soft bottom. Fiddler crabs (*Uca* spp.) congregate on intertidal flats foraging for microalgae and detritus, and amphipods and insects also graze on the flats. On submerged flats and shallow bottom, blue crab (*Callinectes sapidus*) is an important predator. Other mobile invertebrates include horseshoe crab (*Limulus polyphemus*), whelks (*Busycon* spp.), tulip snails (*Fasciolaria* spp.), moon snails (*Polinices duplicatus*), penaeid shrimp (*Penaeus* spp.), hermit crabs (*Pagurus* spp., *Petrochirus* spp., and *Clibanarius vittatus*), sand dollars (*Mellita quinquiesperforata*), and spider crabs (*Libinia* spp.). Overall, estuarine soft bottom supports a high diversity of benthic invertebrates, with over 300 species documented in the southern portion of North Carolina (Hackney et al. 1996).

Marine

On oceanfront beaches, most benthic animals in the intertidal zone consist of infaunal burrowing forms. A diverse assemblage of meiofauna (0.06 – 0.4 mm in size) occurs in the lower beach community and acts as an important food source for many juvenile fish (Levinton 1982; Hackney et al. 1996). A relatively low diversity of macrofauna (>0.5 mm in size) (~ 20 – 50 species) exists in the intertidal beach compared to estuarine intertidal flats (~ 300 – 400 species) (Hackney et al. 1996). The dominant macrofauna by biomass in North Carolina's oceanfront intertidal beaches are mole crabs (*Emerita talpoida*) and coquina clams (*Donax variablis, D. parvula*) (Hackney et al. 1996; Donoghue 1999). Several species of amphipods and the spionid polychaete (*Scolelepis squamata*) have been reported as highly abundant on some beaches as well (Lindquist and Manning 2001).

Polychaete worms, isopods, mollusks, echinoderms, amphipods, and other crustaceans occur in sediments in the oceanfront intertidal beaches, cape and ebb tide shoals, surf zone and other subtidal bottom (Jutte 1999; Peterson et al. 1999). Three general groups of polychaetes occur in intertidal beaches (Hackney et al. 1996): a) burrowing deposit feeders, including thread worms (*Lumbrineris* sp., *Scolelepsis* sp.), and red-lined worms (*Nepthys* sp.); b) suspension feeders; and c) tube building burrow dwellers, such as plumed worms (*Diopatra* sp.) and lugworms (*Arenicola* sp.). Offshore sand bottom communities along the North Carolina coast are relatively diverse habitats containing over a hundred polychaete taxa (Lindquist et al. 1994; Posey and Ambrose 1994). Tube dwellers and permanent burrow dwellers are important benthic prey for fish and epibenthic invertebrates. These species are also most susceptible to sediment deposition, turbidity, erosion, or changes in sediment structure associated with sand mining

activities, compared to other more mobile polychaetes (Hackney et al. 1996). In South Carolina, 243 species of benthic invertebrates were documented in the nearshore subtidal bottom (Van Dolah et al. 1994). Polychaetes and amphipods were the most abundant, although oligochaetes, bivalves, and crabs were also highly represented (Van Dolah et al. 1994). On ebb tide deltas, polychaetes, crustaceans (primarily amphipods), and mollusks (primarily bivalves) were the most abundant infauna, while decapod crustaceans and echinoderms (sand dollars) dominated the epifauna. Because periodic storms can affect benthic communities along the Atlantic coast to a depth of about 115 ft (35 m), the soft bottom community tends to be dominated by opportunistic taxa that are adapted to recover relatively quickly from disturbance (Posey and Alphin 2001). Many faunal species documented on the ebb tide delta are important food sources for demersal predatory fishes and mobile crustaceans, including spot, croaker, weakfish, red drum, and penaeid shrimp. These fish species congregate in and around inlets during various times of the year (Peterson and Peterson 1979), presumably to enhance successful prey acquisition and reproduction.

Four species of sea turtles (loggerhead, green, leatherback, and Kemp's ridley) currently nest on the beaches of North Carolina, although the loggerhead accounts for the majority of nesting activity. Kemp's ridley and leatherback nesting events are quite rare. Generally between 400 and 1000 marine turtle nests are documented per year in North Carolina (WRC, unpub. data). Successful nesting requires sufficient area of supratidal dry beach, adequate softness of sand to facilitate digging, ability of turtle to reach the nesting site without obstructions such as seawalls or fencing, and the ability of the site to avoid inundation throughout the nesting season. Sea turtles prefer to nest on wide sloping beaches or near the base of the dunes. The composition, color, and grain size of the beach sand affect the incubation time, sex, and hatching success of turtle hatchlings (Crain et al. 1995).

Over 147 species of birds have been documented roosting, feeding, or nesting on the beach and dune systems of North Carolina (<http://plover.fws.gov>, 2001). These systems are especially important for migratory shorebirds and colonial water birds. These birds forage and nest on the beach and overwash areas. Overwash events usually occur during storm events or in low areas during spring high tide conditions when seawater flows through the primary dune line, spreading out sand from the beach and dunes. Recently created overwash fans are generally unvegetated and function similar to the beach community. The sandflats, mudflats, and flattened dunes created by these overwashes are essential for several species of wildlife endemic to our coastal systems, including shorebirds and colonial water birds. In particular, the Wilson's plover and the federally threatened piping plover are both dependent on hurricanes and storms to provide the washovers they need as nesting habitat (D. Allen, WRC, pers. com., 2002). The least tern, common tern, and black skimmer are listed by the State as species of special concern, while the gull-billed tern is designated by the State as threatened.

Productivity

Freshwater and estuarine

Production of organic matter in North Carolina's estuarine system is derived from several primary producers, including phytoplankton in the water column, detritus from wetlands and submerged grasses, and benthic microalgae and macroalgae on soft bottoms and other structure (Currin et al. 1995; Wainright et al. 2000). Of these, benthic microalgae have only recently been recognized as an important source of primary production in estuarine systems (Cahoon and Cooke 1992; Pinckney and Zingmark 1993; de Jong and Van Beusekom 1995; MacIntyre et al. 1996). Benthic microalgae are the major food source for deposit feeders such as mud snails, certain bivalve clams, and many polychaete worms (MacIntyre et al. 1996). Chlorophyll *a* biomass and carbon productivity rates are often used as indicators of overall productivity. In North Carolina estuaries, values for chlorophyll *a* biomass from soft bottom has varied widely but generally ranged from 10-90 mg/m^2 (Posey et al. 1995). Similar ranges were found in other Atlantic coast states (Table 6.1). Production rates in North Carolina are thought to be similar to that reported for Delaware and South Carolina (Table 6.1) (C. Currin, NMFS, pers. com., 2004). In flowing

freshwater creeks and rivers, little information is available in the scientific literature on benthic productivity. In general, primary production in these freshwater areas is greatest in shallow, well-illuminated benthic substrates.

Table 6.1. Benthic productivity estimates in Virginia and Delaware (Chesapeake Bay), North Carolina (Masonboro Sound), and South Carolina (North Inlet Estuary).

Region	Chl. *a* biomass (mg/m^2)	Carbon production ($g\ C/m^2/yr$)	Reference
Virginia	5 – 65	-	Rizzo and Wetzel (1985)
Delaware	-	79 – 99	Rizzo and Wetzel (1985)
North Carolina	10 – 90	-	Posey et al. (1995)
South Carolina	20 – 110	56 – 234	Pinckney and Zingmark (1993)

The most productive estuarine bottom, in terms of benthic microalgae, tends to be protected and shallow areas with muddy/fine sand (Pinckney and Zingmark 1993; MacIntyre et al. 1996). Productivity is generally lower in exposed areas, deep areas, or on coarse sand bottom (Chester et al. 1983; Sundback et al. 1991; MacIntyre et al. 1996). In the upper reaches of the estuary, where the bottom consists of soupy mud/silt, productivity declines because of the instability of the fine sediment and greater frequency of high turbidity (M. Posey, UNC-W, pers. com., 2003). Many of the typically productive areas of soft bottom, in terms of benthic microalgae, are also productive fish nursery areas. In shallow intertidal bottom, primary production may be greater than in the water column, while in deeper subtidal bottom, benthic production may be slightly less than in the water column (MacIntyre et al. 1996). In the Newport River estuary, benthic diatoms were found to be resuspended into the water column following wind or rain events, greatly altering the composition and abundance of plankton in the water column (Tester et al. 1995). Since there is a large and ongoing exchange of sediment, algae, and nutrients between the soft bottom and water column (benthic-pelagic coupling), especially in shallow waters, it is difficult to distinguish between productivity in the water column versus soft bottom (Cahoon and Cooke 1992; MacIntyre et al. 1996).

Factors that control the magnitude and variability of benthic primary productivity on soft bottom include temperature, light availability, sediment grain size, and community biomass (amount of chlorophyll present) (Pinckney and Zingmark 1993; Barranguet et al. 1998; Cahoon et al. 1999; Guarini et al. 2000). Since the depth to which benthic microalgae photosynthesize is determined by light, most researchers consider light the major factor affecting primary production rates (MacIntyre et al. 1996). Nutrients are not thought to limit productivity in soft bottom habitat because bacteria quickly convert detritus to inorganic nutrients (remineralization), making nutrients readily available in the sediment (Peterson and Peterson 1979; Admiraal et al. 1982).

In addition to primary productivity from benthic microalgae, organic matter on soft bottom habitat is derived from detrital matter from marsh vegetation, submerged grasses, and macroalgae that settles on soft bottoms (Currin et al. 1995; Wainright et al. 2000). In a South Carolina estuary, benthic microalgae accounted for approximately 22 – 38% of the primary production, with marsh vegetation accounting for approximately 30 – 59% and phytoplankton accounting for approximately 15 – 27%. The relative contribution of different primary producers varies by the diet preference of individual fish or invertebrate species, their position within the estuary, and seasonal and episodic weather conditions (Tester et al. 1995; Wainright et al. 2000; Page and Lastra 2003). Each source of primary production contributes to the estuarine food web. This web supports large numbers of benthic invertebrates, which are the primary food base for North Carolina's bottom feeding larval, juvenile, and adult fish and invertebrates (Peterson and Peterson 1979).

Marine

In the surf zone, inorganic nutrients are continually resuspended by wave action and retained by circulation patterns in sufficient amounts to create localized phytoplankton blooms, particularly composed of diatoms (McLachlan et al. 1981; Hackney et al. 1996). This self-sustaining nutrient input drives phytoplankton production, which supports intertidal filter feeders and, consequently, high concentrations of baitfish and estuarine dependent fish migrating through the shallow waters of the surf zone. Benthic invertebrates in the subtidal bottom of the surf zone and inlets provide an important link between primary producers and predators, such as demersal fish and crustaceans. Many of these predators have high economic value in recreational and commercial fisheries. Peterson and Peterson (1979) compiled a list of the diets of many common fish that forage in the intertidal flats. Some of the species that forage on benthic invertebrates in the surf zone and shoals include inshore lizardfish, pompano, pigfish, pinfish, spot, kingfish, red drum, Atlantic croaker, northern sea robin, and summer flounder. Additional information on fish utilization of the surf zone is discussed in the water column chapter of this plan.

Benthic microalgae on subtidal bottom in the coastal ocean are an important source of primary production. Viable chlorophyll *a* occurs in sediments across the continental shelf in Onslow Bay (Cahoon et al. 1990). Studies in Onslow Bay have found that roughly 80% of the chlorophyll *a* in the bay was associated with microalgae in or on the sediment. Benthic microalgal biomass (36.4 mg chlorophyll *a*/m^2) exceeded phytoplankton biomass (8.2 mg chlorophyll *a*/m^2). Gross benthic microalgal production averaged 24.9 mg carbon/m^2/hr, compared to 27.4 mg carbon/m^2/hr integrated water column phytoplankton production (Cahoon and Cooke 1992). Benthic microalgal production also surpassed integrated phytoplankton production primarily in the summer months, when light flux to the bottom is greater and phytoplankton biomass is generally lower. Pennate diatoms dominate the benthic microflora. These microalgae are grazed by demersal zooplankton, meiobenthos, and other macrofauna.

Ecosystem enhancement

Soft bottom plays a very important role in the ecology of estuarine ecosystems as a storage reservoir of chemicals and microbes. Intense biogeochemical processing and recycling establish a filter to trap and reprocess watershed-derived natural and human-induced nutrients and toxic substances. These materials may pass through an estuary (Matoura and Woodward 1983), become trapped in the organic rich oligohaline (low salinity) zone (Sigels et al. 1982; Imberger et al. 1983), or migrate within the estuary over seasonal cycles (Uncles et al. 1988). The fate of the materials depends upon salinity gradients, which are driven by freshwater discharges, density stratification, and formation of salt wedges (Matson and Brinson 1985, 1990; Paerl et al. 1998). Density gradients (stratification) hamper mixing and oxygen exchange of sediments and water in bottom waters with overlying oxygenated waters, leading to depletion of dissolved oxygen in bottom water (Malone et al. 1988).

In North Carolina's slow-moving, expansive estuaries, nutrients and organic matter from the watershed runoff and phytoplankton production are stored in the soft bottoms. Depending upon freshwater discharge and density stratification, these materials are recycled within the sediments via microbial activities and from the sediments into the overlying waters. Increased inflows of nutrients exacerbate the process, leading to more rapid and expanding dissolved oxygen depletion. In organic enriched oligohaline zones (e.g., Pamlico and Neuse River estuaries), nutrient-induced recycling results in higher microbial activity and oxygen depletion (B.J. Copeland, NCSU, pers. com., 2004).

Although soft bottom habitat is composed of unconsolidated shifting sediments, colonization by benthic microalgae reduces the extent to which sediment is resuspended at low velocities, stabilizing bottom sediments and reducing turbidity in the water column (Holland et al. 1974; Underwood and Paterson 1993; Yallop et al. 1994; Miller et al. 1996). In spite of this, microalgae cannot stabilize sediments under intense or prolonged disturbance conditions, such as during large storm events or in the surf zone (Miller 1989). Structure from tube dwelling invertebrates also helps to bind the sediment (Peterson and Peterson

1979), while filtering activity of dense aggregations of suspension feeders (hard clams) clears significant amounts of plankton and sediment from the water column and improves water clarity (Miller et al. 1996). Yet, because of the absence of large, extensive structure, soft bottom provides relatively less stabilization benefits than other estuarine habitats.

Intertidal shorelines, flats, tidal deltas, and sand bars along the ocean shoreline buffer and modify wave energy, reducing shoreline erosion. Alterations to the ebb and flood tide deltas can result in significant changes in the adjacent barrier island shorelines. Flood-tidal deltas are an important source of sand, which allows barrier island migration to respond to sea level rise (Cleary and Marden 1999). The soft bottom associated with inlets has a great influence on overall barrier island dynamics.

Fish utilization

Like the water column, soft bottom is used to some extent by almost all native coastal fish species in North Carolina. However, certain species are better adapted to, characteristic of, or dependent on shallow unvegetated bottom. Flatfish, rays, and skates are well suited for utilization of soft bottom. Juvenile and adult fish species that forage on the rich abundance of microalgae, detritus, and small invertebrates are highly dependent on the condition of soft bottom. Table 6.2 summarizes important fishery and nonfishery species that are dependent on subtidal bottom for some portion of their life history and the ecological function of the soft bottom habitat.

Foraging

One of the most important functions of soft bottom habitat is as a foraging area. Members of several trophic levels in the benthic community benefit directly or indirectly from a) the high concentrations of organic matter transported to and produced on soft bottom and b) the numerically abundant, diverse invertebrate fauna associated with soft bottom – including herbivores (e.g., planktonic and benthic algal feeders), detritivores, predators of benthic invertebrates and fish (secondary consumers), and predators of those predators (tertiary consumers) (Peterson and Peterson 1979).

Table 6.2. Partial list of common or important fish species occurring on soft bottom habitat in riverine, estuarine, and ocean waters, and ecological functions provided to those species. Bolded species indicate relatively higher association on soft bottom habitat.

	Soft bottom functions [1]						
Species*	**Spawning**	**Nursery**	**Foraging**	**Refuge**	**Corridor**	**Fishery [2]**	**Stock status [3]**
ANADROMOUS SPAWNING							
Atlantic sturgeon	**X**	**X**	**X**		**X**	**X[4]**	**O**
Shortnose sturgeon	**X**	**X**	**X**		**X**	**X[4]**	**O**
ESTUARINE AND INLET SPAWNING AND NURSERY							
Blue crab	X	X	X	X		X	C
Hard clam	**X**	**X**	**X**	**X**		**X**	**U**
Hermit crab spp.	**X**	**X**	**X**				
Horseshoe crab	**X**	**X**	**X**			**X**	
Mud crab spp.	**X**	**X**	**X**				
Mummichug	**X**	**X**	**X**				
Naked goby	X	X	X				
Red drum	**X**	**X**	**X**			**X**	**R**
Sheepshead minnow	**X**	**X**	**X**				
Silver perch	X	X	X			X	
Striped killifish	X	X	X				
Whelks	X	X	X			X	
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY							
Atlantic croaker		**X**	**X**			**X**	**C**
Bay whiff		**X**	**X**	**X**	**X**		
Blackcheek tonguefish	**X**	**X**	**X**	**X**	**X**		
Hogchoker	**X**	**X**	**X**	**X**	**X**		
Penaeid shrimp (brown, white, pink)		**X**	**X**	**X**	**X**	**X**	**V**
Southern flounder		**X**	**X**	**X**	**X**	**X**	**O**
Spot		**X**	**X**			**X**	**V**
Striped mullet		**X**	**X**			**X**	**C**
MARINE SPAWNING, HIGH SALINITY NURSERY							
Atlantic stingray	**X**	**X**	**X**	**X**	**X**	**X**	
Coastal sharks [5]	**X**	**X**	**X**			**X**	**O**
Cownose ray	**X**	**X**	**X**	**X**	**X**	**X**	
Florida pompano		**X[6]**	**X**			**X**	
Fringed flounder		**X**	**X**	**X**	**X**		
Gulf flounder		**X**	**X**	**X**	**X**	**X**	
Gulf kingfish		**X[6]**	**X**			**X**	**U**
Smooth dogfish	X	X	X			X	U
Spiny dogfish		X	X			X	O
Striped anchovy		**X[6]**	**X**				
Summer flounder	**X**	**X**	**X**	**X**	**X**	**X**	**V**

* Scientific names listed in Appendix I. Names in **bold** font are species whose relative abundances have been reported in the literature as being generally higher in soft bottom than in other habitats. Note that lack of bolding does not imply non-selective use of the habitat, just a lack of information.

[1] Sources: Peterson and Peterson (1979); Thorpe et al. (2003); Manooch (1984); Hildebrand and Schroeder (1972); Lippson and Moran (1974); Wang and Kernehan (1979)

[2] Existing commercial or recreational fishery. Other species important to the system as prey items.

[3] V = viable, R = recovering, C = concern, O = overfished, U = unknown (DMF 2003a)

[4] Former fishery, but fishing moratorium since 1991

[5] Incl. Atlantic sharpnose, blacknose, blacktip, bonnethead, dusky, sandbar, scalloped hammerhead, and spinner sharks

[6] Uses surf zone almost exclusively as nursery area

Both plankton and benthic feeding herbivorous fish are found in abundance on intertidal flats. Schools of baitfish, small pelagic fish that tend to group together, are common over subtidal soft bottom and very abundant on shallow intertidal flats. These baitfish, such as anchovies, killifish, and menhaden, feed on the abundant supply of phyto- and zooplankton in the water column, but also consume resuspended benthic algae, microfauna, and meiofauna (Peterson and Peterson 1979). Although the majority of detritivores of the soft bottom habitat are invertebrates, striped mullet, white mullet, and pinfish also feed on detritus on subtidal bottom and intertidal flats. Other fish species use detritus as an alternate food source when preferred items are not available.

Most fish that forage on soft bottom are predaceous. Predators of benthic invertebrates include juveniles and adults of the following species (Peterson and Peterson 1979; Bain 1997):

- rays and skates,
- flatfish (southern flounder, summer flounder, hogchoker, tonguefish),
- several species of drum (spot, Atlantic croaker, red drum, kingfishes, silver perch),
- Florida pompano,
- pigfish,
- sea robins,
- lizardfish,
- spadefish,
- gobies, and
- shortnose and Atlantic sturgeons.

The compressed body forms of flatfish, rays, and skates assist in prey acquisition and predator avoidance on shallow intertidal flats (Peterson and Peterson 1979). For example, flounder forage on shallow flats by laying still, by concealing themselves under a thin layer of sediment, or by changing skin color. Small flatfish, including the bay whiff, fringed flounder, hogchoker, and tonguefish, feed mostly on copepods, amphipods, mysids, polychaetes, mollusks, and small fish. By way of comparison, summer and southern flounder primarily consume fish, such as silversides and anchovies, as well as shrimp and crabs, small mollusks, annelids, and amphipods (Peterson and Peterson 1979). Various rays excavate large pits while feeding, creating slightly deeper pockets of water that other fish and invertebrates use as refuge. Mollusks, annelids, crustaceans, and fish comprise the typical diet of rays.

To avoid predation, small fish commonly feed on open, unvegetated bottom at night and hide near structure during the day (Peterson and Peterson 1979). Larger predators that feed on smaller, benthic-feeding fish and invertebrates typically move onto the flats during high water to feed on schools of fish. These predators include sharks (sandbar, dusky, smooth dogfish, spiny dogfish, Atlantic sharpnose, scalloped hammerhead), drum (weakfish, spotted seatrout), striped bass, and estuarine dependent reef fish (black sea bass, gag grouper, sand perch, sheepshead) (Peterson and Peterson 1979; Thorpe et al. 2003).

Due to their size and shape, small baitfish and flat bodied rays, skates, and flounders have a feeding advantage over other fish in that they can forage on intertidal flats for greater amounts of time than larger fish. These fish groups are considered to be most characteristic of intertidal flats and would be most affected by habitat degradation and loss of intertidal flats from dredging, filling, bulkheading, or other anthropogenic causes (Peterson and Peterson 1979).

Fish species and age composition over soft bottom vary seasonally. Baitfish are present on shallow flats throughout the year. In the spring, large schools of baitfish are joined by juvenile fish that were spawned offshore in the winter (spot, Atlantic croaker, menhaden). In the summer, these species remain abundant on shallow unvegetated bottom; flatfish and rays also appear at this time. By fall, fish species diversity is at a maximum since summer residents and fall migrants are both present. Migratory fish feeding on the soft bottom include bluefish, striped mullet, kingfish, spotted seatrout, red drum, and many others

(Peterson and Peterson 1979).

Ocean subtidal bottom serves as important foraging grounds for numerous fish species, particularly for Florida pompano, red drum, kingfish, spot, and Atlantic croaker, weakfish, and striped bass. Many commercially or recreationally important fish and invertebrate species, such as red drum, striped bass, shrimp, and summer flounder, are caught while they aggregate and feed over subtidal bottom in nearshore ocean waters. These species appear to be strongly associated with distinct topographic features of the subtidal bottom, such as the cape shoals, channel bottoms, sandbars, and sloughs. *The natural processes that create these features need to be maintained. Additional public outreach is needed to emphasize the importance of natural barrier island and estuarine processes.*

The food resources present in and on soft bottom are needed to support hard bottom fish species. Demersal zooplankton and infaunal macroinvertebrates from sand substrate have been found to be a quantitatively important component of many species' diets and an important link to reef fish production (Cahoon and Cooke 1992; Thomas and Cahoon 1993; Lindquist et al. 1994). Reef species documented foraging over sand bottom away from the reef include tomtate (*Haemulon aurolineatum*), whitebone porgy (*Calamus leucosteus*), cubbyu (*Equetus umbrosus*), black sea bass (*Centropristis striata*), and scup (*Stenotomus chrysops*) (Lindquist et al. 1994). Therefore, benthic microalgal production on the subtidal bottom of Onslow Bay, as well as other similar shelf habitats, is an important component to the continental shelf productivity and is an important link to the ecology of hard bottom habitats[77].

Spawning

Many demersal fish spawn over various areas of soft bottom habitat in North Carolina's coastal waters (Table 6.2). In fresh water, resident species such as largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*) spawn on shallow flats where they lay eggs in bowl-shaped nests. Eggs may be dependent on the small structure available on the unvegetated bottom, such as emerging worm tubes or woody debris, to hold them in position. Since all life stages of freshwater resident fish (spawning adults, eggs, larvae, juveniles) remain near the same area of soft bottom habitat, they are relatively more vulnerable to degraded soft bottom habitat conditions than migratory species. Anadromous species, such as Atlantic and shortnose sturgeon (*Acipenser oxyrinchus oxyrinchus* and *A. brevirostrum*, respectively), spawn in upper freshwater portions of coastal rivers (Moser and Ross 1995).

Estuarine spawners include resident fish and invertebrates, as well as migratory fish that are summer estuarine spawners. Estuarine resident species include common invertebrates that occupy the intertidal flats, like hard clams, whelks, snapping shrimp, and hermit crabs. Small schooling baitfish such as mummichogs and striped killifish spawn in the marsh edges near soft bottom (Hildebrand and Schroeder 1972; Manooch 1984). Species of flatfish, including the windowpane, and hogfish have been reported to spawn on estuarine soft bottom (Hildebrand and Schroeder 1972; Manooch 1984).

Summer estuarine spawners include several species of drum. Weakfish and silver perch were documented spawning in deep estuarine channels near Pamlico Sound inlets (Ocracoke and Hatteras inlets) and in deep areas of Pamlico Sound from May to September, peaking in May and June (Luczkovich et al. 1999a). Spotted sea trout spawn on the east and west sides of Pamlico Sound during a similar time period, with peak activity observed around July. Specific spawning areas for spotted sea trout identified on the west side of Pamlico Sound were Rose Bay, Jones Bay, Fisherman's Bay, and Bay River (Luczkovich et al. 1999a). Red drum were documented spawning in the mouth of the Bay River on the west side of Pamlico Sound, and in estuarine channels near Ocracoke Inlet (Luczkovich et al. 1999a). Blue crabs also spawn near inlets in summer (DMF 2000d).

Several species of sharks pup in North Carolina's nearshore ocean waters. North of Cape Hatteras,

[77] Refer to Hard bottom Chapter, Ecological role and function for additional information.

pupping of spiny dogfish over subtidal bottom has been documented in winter months (W. Laney, USFWS, pers. com., 2003). Subtidal bottom in the southern portion of North Carolina state waters serves as pupping grounds for the Atlantic sharpnose shark (*Rhizoprionodon terraenovae*), bonnethead shark (*Sphyrna tiburo*), blacknose shark (*Carcharhinus acronotus*), spinner shark (*C. brevipinna*), dusky shark (*C. obscurus*), and, to a lesser extent, blacktip shark (*C. limbatus*), sandbar shark (*C. plumbeus*), and scalloped hammerhead shark (*S. lewini*). Most neonate (newborn) sharks were found in June and July (Beresoff and Thorpe 1997; Thorpe et al. 2003).

Most ocean spawning activity by estuarine dependent species occurs beyond state waters during the winter months. However, eggs and larvae are carried in the water column by currents through nearshore state waters and inlets to estuarine nursery areas. Important spawning aggregations of summer flounder occur on Wimble, Platt, and Kinnekeet shoals off the Outer Banks, in state and federal waters from November to March, peaking near January in North Carolina (MAFMC 1998). Locations of summer flounder spawning aggregations are linked to environmental conditions, such as water temperature and wind direction, and are generally concentrated north of Cape Hatteras, but extend to Cape Lookout.

Nursery

Shallow soft bottom habitat, usually adjacent to wetlands, is utilized as a nursery for many species of juvenile fish. The shallow unvegetated bottom provides an abundance of food and is inaccessible to larger predators. Shallow unvegetated flats have been documented as being particularly important nursery habitats for juvenile summer and southern flounder (Burke et al. 1991; Walsh et al. 1999). A partial list of species that use soft bottom habitat as a nursery area is included in Table 6.2. Studies and ongoing DMF juvenile fish monitoring have found that shallow unvegetated bottom supports high abundances of juvenile fish, composed of relatively few species but which have similar life histories and feeding patterns (Ross and Epperly 1985).

The dominant juvenile species utilizing shallow soft bottom estuarine nursery areas are estuarine dependent winter spawners. Most of the species spawn offshore during the winter. The larvae are transported through inlets into estuarine waters. For many species, the uppermost area of shallow creek systems corresponds to where larval settlement of winter spawned species occurs – the primary nursery areas (Weinstein 1979; Ross and Epperly 1985). However, in tributaries on the western side of Pamlico Sound, such as Neuse, Pamlico, Bay and Pungo rivers, larval settlement tends to occur in lower portions of the creeks. Unlike larval settlement in areas south of Pamlico Sound, salinity is low in the upper reaches of the Sound's tributaries and this may deter larval settlement in those areas. Abundance of juvenile species in estuarine nursery areas peaks between April and July and is correlated with water temperatures (Ross and Epperly 1985). As fish grow, they move to deeper waters and areas lower in the estuary.

Analysis of fishery independent trawl sampling data, from shallow creeks and bays in Pamlico Sound tributaries, found 78 different fish and invertebrate species over a two-year period (Ross and Epperly 1985). Eight species comprised more than 97% of the total fish abundance. Data from DMF's ongoing juvenile fish monitoring program, which began in 1971, show that the same eight species continue to dominate North Carolina's estuaries (Ross and Epperly 1985). This long-term database provides fishery independent information on species composition and abundance to identify primary and secondary nursery areas. From 1990 to 2003, the eight species that were the most abundant in both the northern and southern sampling sites were:

- spot
- pinfish
- brown shrimp
- Atlantic croaker
- bay anchovy

- blue crab
- silver perch
- Atlantic menhaden

In addition, southern flounder and white shrimp were among the most abundant species sampled in the northern and southern areas, respectively. From 1990 to 2003, a total of 178 species was collected and identified from the juvenile fish monitoring stations throughout the coast (DMF, unpub. data). Because sampling is not conducted year-round, it is probable that this figure underestimates the true number of species present. The annual number of species has ranged from 49 to 83 species per year north of Cape Lookout, and from 45 to 60 species per year south of Cape Lookout (DMF, unpub. data). The consistent abundance of several species over time is an indication that these areas continue to function as healthy nurseries. *Temporal and spatial expansion of juvenile fish sampling would provide additional information on trends in juvenile fish utilization of soft bottom and other habitats, especially summer and fall spawning species, which are generally not present at existing sampling stations during May and June.*

Statistical analyses of DMF's juvenile fish data in the Pamlico Sound system identified specific fish groupings or associations (Ross and Epperly 1985; Noble and Monroe 1991). From the latter analysis, four geographically distinct groupings of juvenile fish species occur in the Pamlico estuarine system (Table 6.3). Menhaden and spot were omitted from the analysis because they were so abundant in all areas that they masked other species abundance trends. Group 1 occurred in the Pamlico, Pungo, and Neuse rivers, and along eastern Albemarle Sound. Group 2 occurred in the western bays of Pamlico Sound. Group 3 was located in the shallow area behind the Outer and Core banks, from Oregon Inlet south to Cape Lookout. Group 4 was located along the western shore and tributaries of Core Sound (Table 6.3). Fish groupings in Pamlico Sound appeared to be affected by Bluff Shoal, which runs across the sound in a southeast-northwest direction from around Ocracoke Inlet north to Bluff Point. Bluff Shoal effectively separates Pamlico Sound into distinct basins of differing depth and sediment composition and alters larval settlement patterns into the sound. Distinct fish species groupings are found north and south of the shoal (Ross and Epperly 1985). Salinity was the most important abiotic variable affecting species composition (Noble and Monroe 1991). Groups 1, 2, and 4 occurred where the bottom consisted primarily of shallow unvegetated sediment, while group 3 occurred in SAV beds.

Table 6.3. Dominant juvenile fish species groupings found in the Pamlico Sound system by biotic cluster analysis of juvenile fish data (Noble and Monroe 1991).

Group	Location	Dominant fish species	Primary Habitat
1	Pamlico, Pungo, Neuse rivers, eastern Albemarle Sound	Atlantic croaker, brown shrimp, blue crab, southern flounder	Shallow unvegetated sediment
2	Western bays of Pamlico Sound	Species above + weakfish, spotted seatrout, silver perch	Shallow unvegetated sediment
3	Behind the Outer and Core banks	Pinfish, pink shrimp, black sea bass, gag, pigfish, red drum	SAV beds
4	Western shore and tributaries of Core Sound	Summer and southern flounder, brown shrimp	Shallow unvegetated sediment

In the southern portion of the coast, DMF biologists have found that juvenile fish tend to be most abundant in shallow waters with unvegetated muddy sediment (J. Schoolfield, DMF, pers. com., 2003). The dominant, demersal, juvenile species in coastal waters south of the Pamlico system were also found behind Core Banks and the Outer Banks. Although black sea bass and gag are not very common, brown shrimp, white shrimp, striped mullet, spot, and menhaden are more common in the southern estuaries (R. Carpenter, DMF, pers. com., 2003).

Many areas used as nurseries by estuarine dependent fish have been designated as Primary or Secondary Nursery Areas by MFC (Maps 2.3 and 2.4 in Chapter 2). However, there are other areas of soft bottom that function as nurseries but are undesignated. Benthic anadromous fish, such as Atlantic and shortnose sturgeon, use freshwater soft bottom as a nursery. *The specific locations of anadromous fish spawning areas need to be designated by the MFC and adequately protected*. Nearshore ocean subtidal bottom is also a nursery area for summer flounder and shark species. The primary nursery grounds for coastal shark species is in the vicinity of where pupping occurs. Small coastal sharks that use this habitat for a nursery area include spinner (*C. brevipinna*), blacknose (*C. acronotus*), and dusky (*C. obscurus*) sharks (Beresoff and Thorpe 1997; Thorpe et al. 2003). Juvenile Atlantic sturgeon and spiny dogfish, both demersal feeders with Overfished fishery status, have been documented over nearshore subtidal bottom between Oregon Inlet and Kitty Hawk during winter months (Cooperative Striped Bass Tagging Program, unpub. data). Subtidal bottom, particularly the surf zone, is also a nursery area for Florida pompano, southern and gulf kingfish (Hackney et al. 1996).

Refuge

Soft bottom habitat can provide refuge to some organisms in some locations through predator exclusion. Shallow, intertidal flats may be inaccessible to large fish predators and therefore protect small and juvenile fish and invertebrates (Peterson and Peterson 1979; Ross and Epperly 1985). Consequently, juvenile fish recruit into the shallowest portions of the estuary first. Many invertebrates, including hard clams, can avoid predation by burrowing into the sediment (Luettich et al. 1999). Flatfish, such as flounder and rays, and other small cryptic fish, like gobies, can bury slightly into the sediment, camouflaging themselves from predators (Peterson and Peterson 1979). Nonetheless, soft bottom habitat in deep water is a vulnerable place for small fish and invertebrates that cannot burrow. For example, flounders also camouflage themselves in the sediment to ambush prey (Walsh et al. 1999). Because of this, many fish in subtidal water will venture out to feed on the open bottom only at night (Summerson and Peterson 1984).

Corridor and connectivity

Freshwater and estuarine soft bottom channels are the highways for migrating adult demersal fish species to and from other estuarine habitats and the ocean. Demersal feeding anadromous fish, such as sturgeon and striped bass, require a corridor of soft bottom to reach upstream spawning areas. Inlets act as conduits for exchange of sediment, water, and marine organisms between the estuaries and the ocean. Because large fish are less likely to be consumed as prey, they can travel relatively safely over less turbid sand flats and in channels of the middle and lower estuaries (Walsh et al. 1999). Smaller flatfish tend to be more abundant in the shallower uppermost portion of the estuary, where salinities are low, turbidity high, and sediments muddy with high detritus content (Walsh et al. 1999).

While connectivity among structured habitat patches, such as SAV, wetlands, and shell bottom, facilitates movement of blue crabs and other mobile predators through an estuary, a few meters of unvegetated bottom can act as a barrier to movement (Micheli and Peterson 1999). Such barriers can be beneficial to small invertebrates by potentially obstructing predator dispersal and reducing predation risk. Small crabs, gastropods, and infaunal bivalves, such as hard clams, were more abundant, denser, and had higher survival rates on isolated oyster beds (at least 10-15 m of unvegetated bottom between habitats) than on oyster beds adjacent to salt marsh or SAV (Micheli and Peterson 1999). Blue crab predation on infaunal bivalves was greater along vegetated edges of salt marshes and seagrass beds than in unvegetated intertidal flats (Micheli and Peterson 1999). Although structural habitat separations by unvegetated soft bottom may benefit the survival or viability of infaunal populations, fish and crustacean productivity may be enhanced by connectivity of structured estuarine habitats (Micheli and Peterson 1999). These habitat-mediated predator/prey interactions point out the importance of maintaining the integrity of an entire estuarine system.

6.3 STATUS AND TRENDS

Status of soft bottom habitat

Since standardized or comprehensive baseline mapping of soft bottom habitat has not been completed, and because sediments shift and move over time, it is currently not possible to quantify how the extent and condition of the habitat has changed through time. The loss of more structured habitat, such as SAV and shell bottom, has undoubtedly led to gains in soft bottom habitat, but the low quality of areas gained may not be considered beneficial to the ecosystem as a whole. The general type and condition of shorelines in the Albemarle-Pamlico region and Bogue Sound, as well as the rough location of eroding and stabilized shorelines in these areas, were summarized by Riggs (2001). The primary alterations to soft bottom habitat are associated with dredging for navigational channels and marina basins. Refer to the threats section for more information.

Status of associated fishery stocks

Fishery independent monitoring programs

The DMF began a juvenile fish monitoring program (Estuarine Trawl Survey) in 1971. This long-term database provides fishery independent (data gathered independent of the fishery) information on species composition and abundance to identify primary and secondary nursery areas, shallow soft bottom habitat usually surrounded by wetlands. The Pamlico Sound Survey is another long-term monitoring program used to calculate juvenile abundance indices in Pamlico Sound and the lower portion of the Pamlico and Neuse estuaries. Data from this survey are compared to results from the Estuarine Trawl Survey and are also used as an indicator of young of year class strength. Juvenile abundance indices (JAI) are calculated from these sampling programs for major fish and invertebrates. The JAI is the annual geometric mean (weighted by strata) of the number of individuals per tow for young of the year fish or invertebrates. The JAI is considered an accurate indicator of recruitment and year-class strength for many species, including southern flounder (DMF 2003c). The information is used to determine stock status of fishery species by various fishery management agencies. Juvenile abundance indices are also used as a criterion to qualify an area as a designated Primary or Secondary Nursery Area. Designated areas are monitored regularly to provide long-term information on status and trends in recruitment of the dominant estuarine dependent species. Both surveys are critical components to stock assessments since they are independent of commercial or recreational fisheries (DMF 2003c). Trends in juvenile abundance indices may indicate change in the habitat conditions (DMF 2003c). However, consistent and comparable JAI data are only available to about 1990 and, prior to this time, considerable habitat losses and changes occurred.

Flatfish are closely linked to soft bottom habitat and juvenile abundance indices from the Estuarine Trawl Survey for southern flounder and hogchoker are shown in Figure 6.1. Southern flounder is a commercially and recreationally important fishery species, while hogchoker is a non-fishery species found in northern and southern estuaries of the state. The JAIs for both species have followed similar temporal patterns, varying between 0.5 to 2.5. Both species had peak JAIs in 1996. JAI of southern flounder experienced large declines in 1997, 1998, and 2002; notably, a 16.7% decline was recorded between 2001 and 2002. The 2002 stock status report stated that the estimated population biomass of this species had declined by 32% over the past decade (DMF 2003a). Hogchoker JAI also declined to low levels in 1998, showed some improvement in 1999, but has remained relatively low since 2000. These results indicate that recruitment of both fishery and non-fishery flatfish species has been variable over time and strongly influences annual JAIs. However, hogchoker has exhibited greater recovery following years with low JAIs than southern flounder. Both species have exhibited relatively low JAIs since 1996.

Trends in JAI of Atlantic croaker from both the Estuarine Trawl Survey and the Pamlico Sound Survey are very similar (Figure 6.2). Atlantic croaker is a benthic feeding fish that could be affected by changes in soft bottom habitat, such as reductions in benthic food sources due to toxicity or anoxia in sediments. Annual trends in juvenile abundance of both surveys are very similar. Sizes of fish collected in the

Pamlico Sound Survey were larger, accurately reflecting that juvenile fish first settle in the primary nursery areas and later move into the sound. Both juvenile abundance indices for Atlantic croaker experienced large fluctuations and are currently near their lowest recorded levels in the past 12 years. According to the DMF 2002 stock status report, there are some signs of recovery, such as increased commercial CPUE, increased landing size, and improved age structure (multiple year classes), but JAIs remain below average and landings in estuarine waters have not returned to historical levels. An ASMFC FMP was created in 1987 and was reviewed most recently in 1998. Research needs, including a coast-wide stock assessment, have been completed and are being reviewed by ASMFC. The stock assessment determined that Atlantic croaker is a recruitment-driven stock, where biomass and landings fluctuate in response to large year classes.

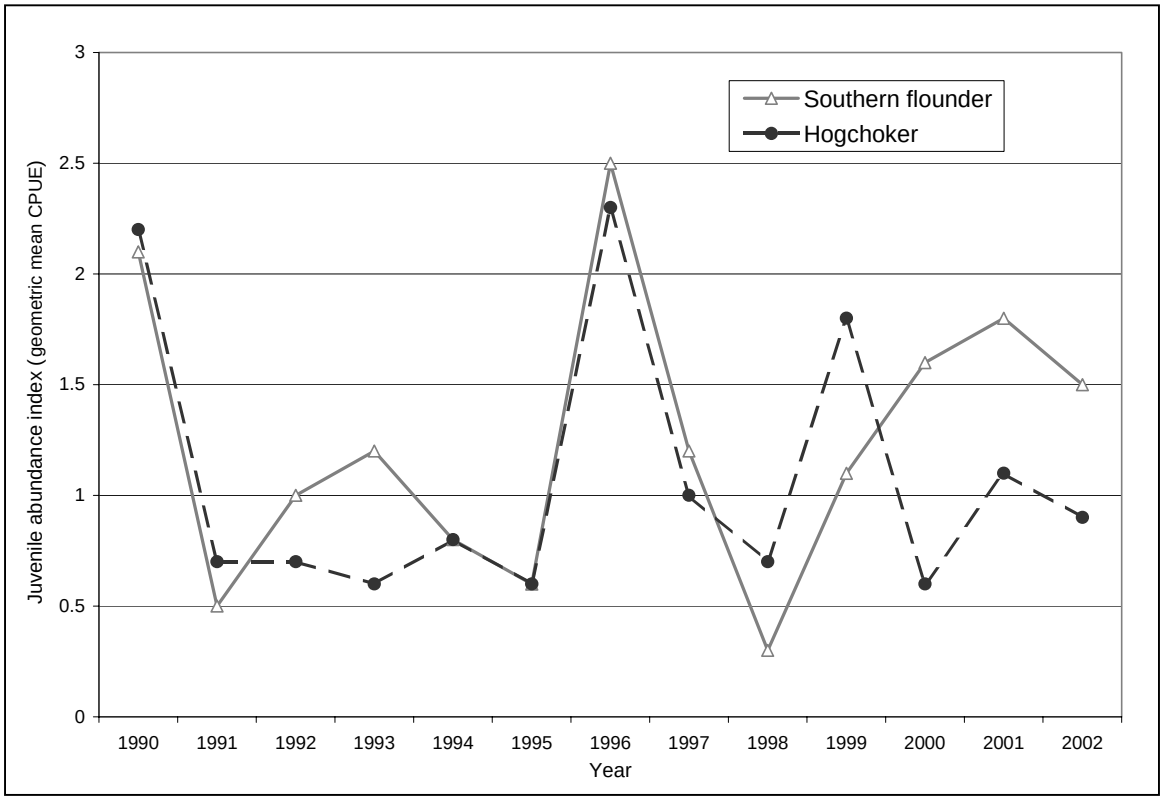


Figure 6.1. Southern flounder and hogchoker juvenile abundance indices (geometric mean CPUE) from two DMF juvenile fish sampling programs, core stations sampled in May and June for each program pooled (Estuarine Trawl Survey and the Pamlico Sound Survey), 1990-2002.

Hard clams, although also present in shell bottom and SAV habitats, require soft bottom habitat for burrowing. Because clams remain fairly stationary and are filter feeders, they may be vulnerable to habitat degradation, such as sediment contamination or sedimentation. The status of the hard clam stock is currently unknown due to lack of adequate data (DMF 2001b). However, using trip ticket data, DMF (2001b) concluded that hand harvest of clams appeared to be stable, but that clam abundance, in areas where mechanical clam harvest occurred, appeared to decline from 1994 to 1999. MFC recommended that mechanical harvest limits in Core Sound be further restricted. *Reducing the area available to mechanical clam harvesting is another means of protecting clam stocks and would also provide additional habitat protection.*

Twelve of 18 soft bottom associated fishery species (bolded species in Table 6.2) were evaluated by DMF for stock status in 2002. Of these twelve species, two (17%) were of unknown status. Of the ten stocks whose status is known, three (30%) were classified as Viable, one (10%) was Recovering, two (20%)

were of Concern, and four (40%) were Overfished (Table 6.2, Figure 6.3). Viable species included shrimp, spot, and summer flounder; red drum was a Recovering species. Overfished species included Atlantic and shortnose sturgeons, southern flounder, and coastal sharks. The species listed as Concern include striped mullet and Atlantic croaker.

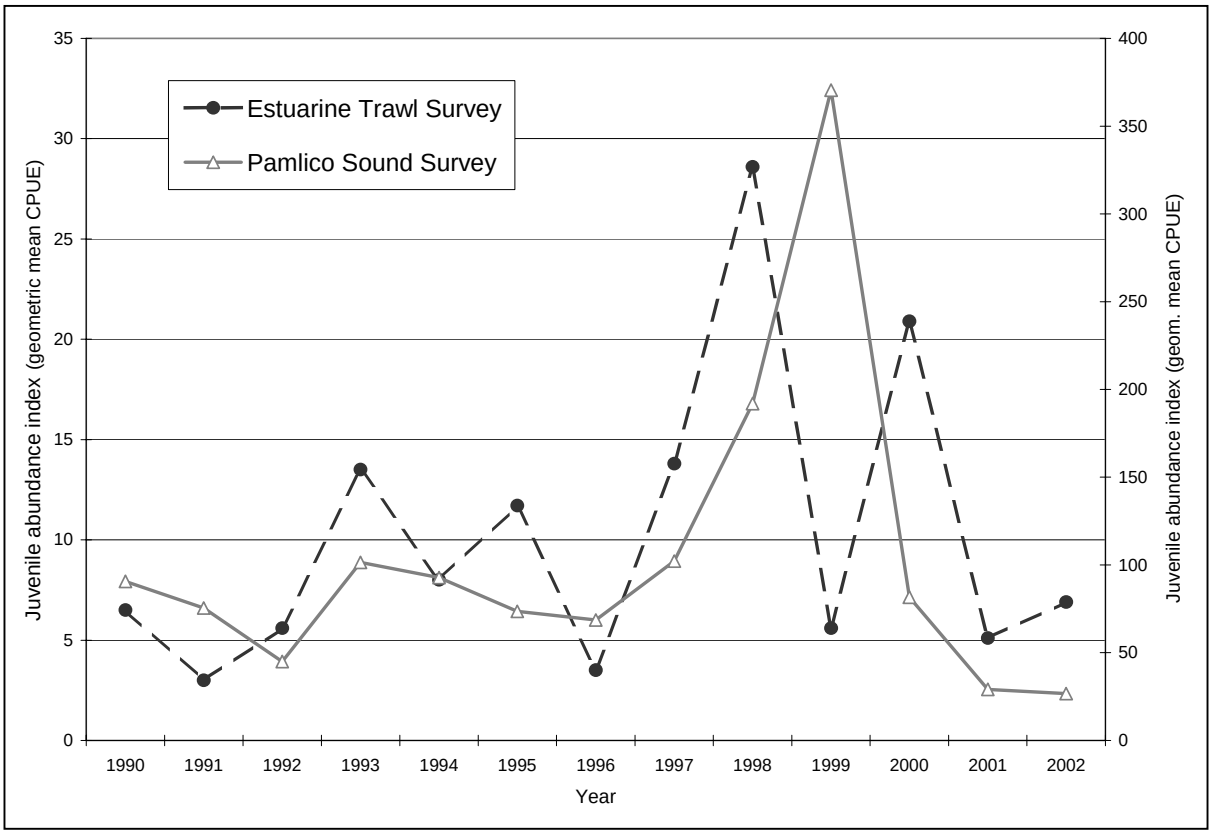


Figure 6.2. Atlantic croaker juvenile abundance indices (geometric mean CPUE) from two DMF juvenile fish sampling programs, core stations sampled in May and June for each program pooled (Estuarine Trawl Survey and the Pamlico Sound Survey), 1990-2002.

Both sturgeons historically supported a valuable commercial fishery; however, landings declined dramatically by the early 1900s. Shortnose sturgeon is currently a federally listed endangered species and Atlantic sturgeon is considered threatened in North Carolina (Ross et al. 1988). Atlantic and shortnose sturgeon have not shown signs of recovery despite a fishing moratorium in North Carolina since 1991, indicating that habitat and water quality issues are also affecting recovery. Potential habitat issues could include reduction of benthic food sources in fresh water due to eutrophication or toxin contamination, or degradation of spawning and nursery habitat from channel obstructions, channelization, and sedimentation.

Coastal shark species, such as sand bar sharks, Atlantic blacktips, Atlantic sharpnose, hammerheads, and duskys, are slow growing and mature late, making them more vulnerable to overfishing. Federal and state harvest restrictions have been in place since 1993, but there has not been evidence of recovery. Degradation of nearshore marine bottom from beach nourishment or nonpoint runoff could potentially impact pupping and nursery areas.

The Overfished status of southern flounder is due in part to overfishing but may also be related to habitat issues in the low salinity estuaries. Severe hypoxic events and anoxia can directly affect populations of southern flounder through mortality from suffocation and indirectly from reduced growth rates, loss of

preferred prey (mortality of benthic community), changes in activity patterns, or disease. The Division is currently working on a Fishery Management Plan for southern flounder.

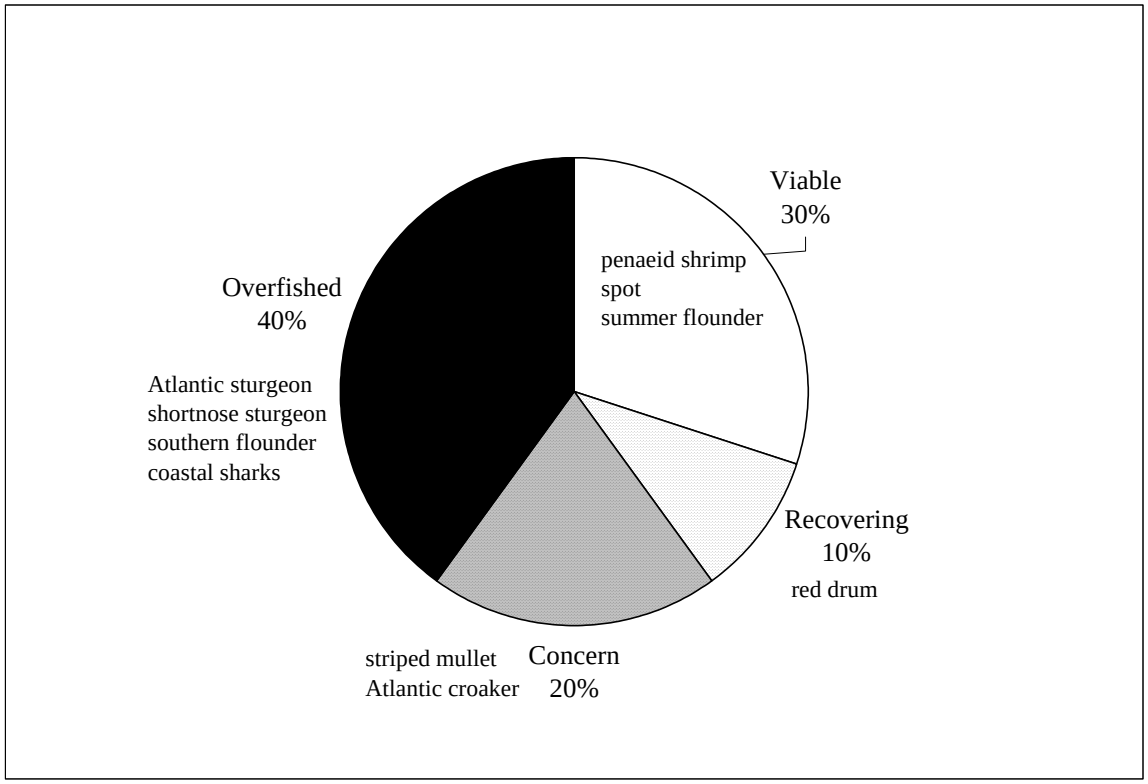


Figure 6.3. Percent of soft bottom dependent fishery species classified as Overfished, Concern, Recovering, or Viable in the DMF 2003a stock status report, N = 10 (DMF 2003a).

Striped mullet are of concern primarily due to an increase in associated fishing effort. A juvenile abundance index is currently not available for striped mullet and more biological information is needed to determine habitat threats. The Division is currently working on a Fishery Management Plan for striped mullet. Atlantic croaker is listed as Concern because JAIs and estuarine landings have remained low. *All three commissions should work together to address habitat issues that will protect or enhance southern flounder, sturgeon, and shark habitat.*

From 1968 to 1981, monthly fish surveys by DMF were conducted in coastal ocean waters but have since been discontinued. Currently in coastal waters of North Carolina, fishery-independent data are available from shallow water trawl surveys conducted by the Southeast Area Monitoring and Assessment Program – South Atlantic (SEAMAP-SA). SEAMAP is a cooperative state/federal/university program that was first implemented in the southeastern United States in 1983 and is coordinated by ASMFC. SEAMAP currently provides the only region-wide standardized surveys for monitoring long-term status and trends of demersal fish and invertebrate populations that utilize marine soft bottoms as well as other habitats. The SEAMAP study area includes inner (4m depth contour) and outer (10m depth contour) strata stations in Long Bay, Onslow Bay, and Raleigh Bay in North Carolina.

Since 1990, 141 species were found in all three bays. Many of the dominant species are also dominant in estuarine waters. In examining data from 1990 to 2000, spot and Atlantic croaker consistently comprised a large portion of the catch in all bays and years. Spot is generally most abundant in Long Bay and accounted for 20 to 50% of the catch in most years in the three bays. Other abundant species included

striped anchovy, squid, pinfish, and porgies.

Since 1990, species diversity from the shallow (approximately 4m) strata sampling sites has been highest in Long Bay (124 – 147 species) and lowest in Raleigh Bay (81 – 104 species). The total number of species collected in each bay has only fluctuated slightly from year to year, and appears fairly stable over time. Densities in Long Bay ranged from 212 individuals/hectare (ind./ha) in 1993 and 2000 to 511 ind./ha in 1991. Long Bay and Onslow Bay had very similar densities of fish and fluctuations in abundance. Fluctuations in fish density among years were greatest in Raleigh Bay. These data indicate strong inter-annual variation in year class abundance but demonstrate no clear trends.

Trends in annual catch per tow, or CPUE, of demersal species from SEAMAP data are an indicator of relative abundance of late juvenile and adult species. Annual trends in catch per tow for summer and southern flounder, striped anchovy, and southern kingfish were examined since the flounders are strongly associated with estuarine and marine soft bottom and latter two species are common in the surf zone and nearshore waters. Of these four species, SEAMAP bottom trawl data indicate a decline in abundance only for southern flounder (Figure 6.4). Southern flounder CPUE has shown a general decline since its peak abundance from about eight fish/tow in 1992 to two fish/tow in 2002. Southern flounder spend more time in low salinity estuarine waters than summer flounder, and therefore may be more affected by estuarine habitat and water quality changes. The decline noted in southern flounder CPUE is consistent with DMF's stock status for this species. While DMF's stock status report indicates that the decline in population biomass is primarily due to overfishing (DMF 2003a), habitat degradation, such as toxin contamination of bottom sediments or bottom anoxia and benthic kills, could add additional stress to the species, delaying recovery.

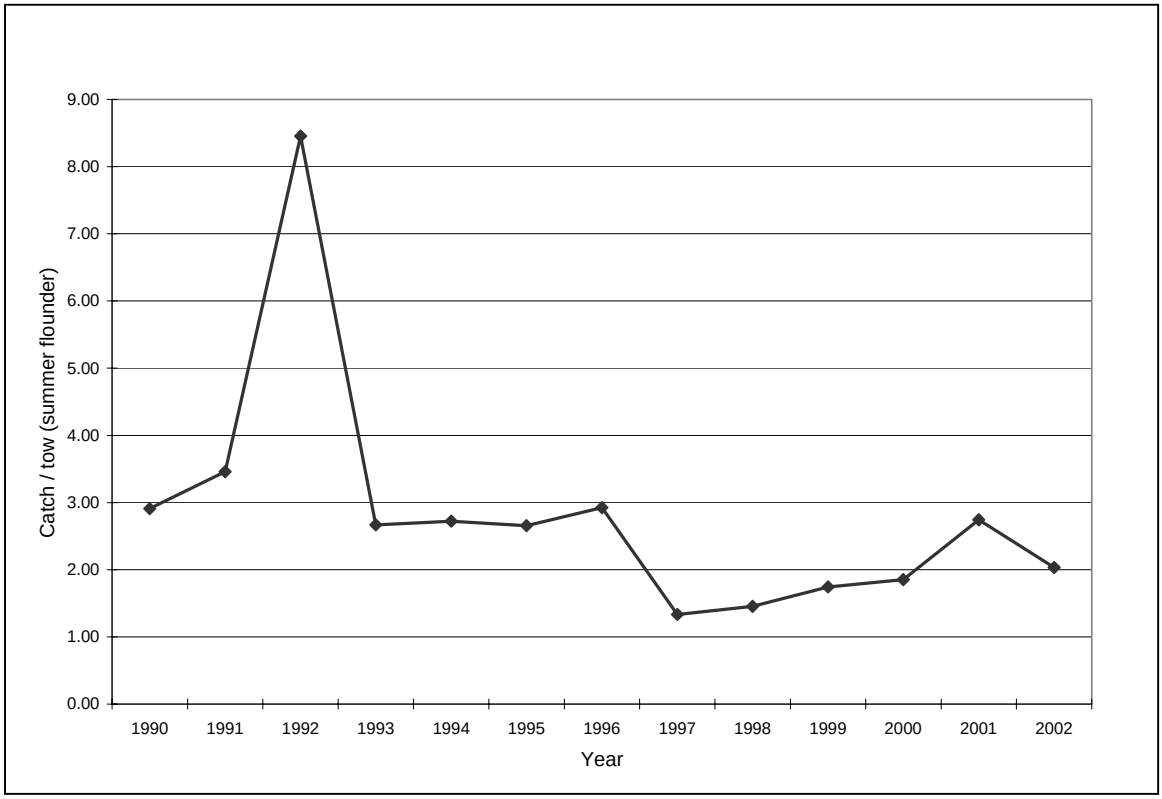


Figure 6.4. Annual CPUE of southern flounder collected in nearshore coastal ocean waters, by fishery independent SEAMAP-SA trawl surveys, 1990-2002.

Designated areas

There have been some federal actions taken to designate and protect certain portions of soft bottom habitat in coastal ocean waters. The SAFMC designated all coastal inlets as Habitat Areas of Particular Concern (HAPC) for blue crab, estuarine-dependent snapper-grouper species, penaeid shrimp, and red drum. The sandy shoals of Cape Hatteras, Cape Lookout, and Cape Fear are designated as HAPC for all coastal migratory pelagics, including king mackerel, Spanish mackerel, dolphin, and cobia. In May 2000, Presidential Executive Order 13158, Marine Protected Areas, was implemented. The order mandated strengthening of the management, protection, and conservation of existing marine protected areas and establishing or expanding additional marine protected areas. Marine protected areas (MPA) were defined as "any area of the marine environment that has been reserved by Federal, State, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein" (Federal Register 2000). Among the many agencies cited in the order, the Environmental Protection Agency (EPA), relying on existing Clean Water Act authorities, is required to identify and prioritize natural and cultural resources for additional protection, propose science-based protocols for monitoring and evaluating marine protected areas, and propose science-based regulations to ensure appropriate protection of habitat and water quality standards. These actions may provide additional protection for North Carolina's marine soft bottom habitat, as well as hard bottom and other ocean habitats. State agencies are in the process of compiling an inventory of existing marine managed areas prior to assessing the need and feasibility of establishing new MPAs in North Carolina. Also, there are approximately 160 mi of federally or state owned barrier islands along the 320 mi of ocean shoreline. This includes all or portions of eight (of 23) barrier islands or peninsulas. Intertidal beaches adjacent to these areas are protected from most development associated threats.

6.4 THREATS AND MANAGEMENT NEEDS

Physical threats

Of the coastal habitats in North Carolina, soft bottom is probably the most resilient to physical alterations because of its lack of structure and dynamic nature. However, because this habitat plays a vital role as nursery and foraging grounds for fish and invertebrate species, it is important that threats to soft bottom are identified and addressed. Human activities that can physically impact soft bottom habitat include dredge and fill activities, marinas and docks, shoreline stabilization, and use of bottom disturbing fishing gear.

Dredging

Existing dredged navigational channels and basins are necessary to sustain current boating and fishing activities and provide access to state ports for transport of commerce. However, dredging activities do affect physical and biological features of soft bottom communities. New dredging for navigational channels or marina construction can alter topographic and hydrologic features that attract fish for feeding, refuge, or spawning, and modify sediment grain characteristics (SAFMC 1998a). Dredging removes all benthic infauna from the affected areas immediately, reducing food availability temporarily to bottom feeding fish and invertebrates, including southern and gulf kingfish, Florida pompano, spot, Atlantic croaker, flounder, and shrimp (Hackney et al. 1996; Peterson et al. 2000a). Whether the magnitude of prey reduction limits fish growth, reproduction or survival depends on the species' diet preference, foraging range, mobility, abundance of prey elsewhere, and extent and location of other benthic disturbing activities. Inlet dredging in winter can kill or displace female blue crabs that are burrowing in the inlet sediments. Disturbance associated with inlet dredging can also deter or alter summer spawning activity of red drum, weakfish, spotted seatrout, silver perch, and blue crab (Luczkovich et al. 1999a; DMF 2000d). Spawning activity around the inlets occurs from May through October, depending on the species (refer to spawning table in the Water Column chapter). Because spawning activity occurs at night, daytime dredging may not be a problem. However, there are also possible indirect effects associated with dredging, such as reductions in benthic prey availability and alterations of the acoustic environment (J. Luczkovich, ECU, pers. com., 2003).

Impacts in the water column associated with dredging induced turbidity were discussed in the water column chapter of the plan. Turbidity, however, also affects benthic invertebrates in the soft bottom. For example, mole crabs were killed by excess turbidity generated during a beach nourishment project in Atlantic Beach (Reilly and Bellis 1983). Growth of coquina clams was significantly reduced when exposed to elevated turbidity (Lindquist and Manning 2001). The invertebrates and fish associated with inlet subtidal bottoms, tidal deltas, meandering channels, and shallow shoals have adapted to that specific environment and to its natural disturbance regimes. *More research is needed to assess direct and indirect dredging impacts on blue crabs and inlet spawning species.*

Map 2.13 a-c depicts the location of the major navigational channels in North Carolina's coastal waters. Soft bottom habitat in the southern portion of the coast has been highly modified by navigational dredging and associated spoil islands. Immediate effects to soft bottom from original dredging have recovered. The current system of navigational channels is necessary to maintain boating and fishing activities, and in some cases, may be beneficial by enhancing flushing. Many of the dredged channels were originally chosen because they were naturally deeper. While fish have adapted to these channels, creation of additional navigational channels and basins would require dredging in shallow and productive habitat areas. Converting shallow bottom into deeper basins and channels can reduce primary and secondary productivity of the bottom (Wendt et al. 1990). *Commenting and permitting agencies should continue to use their existing authorities to a) minimize new dredging of shallow soft bottom habitat, b) prevent direct impacts from dredge and fill projects, and c) limit as much as possible indirect impacts to shallow soft bottom or other habitats.*

Log salvage is another form of dredging that causes disturbance of soft bottom and water column habitat. However, the magnitude of disturbance is much less than that created by dredging of a permanent channel or basin. Refer to the water column chapter for more information on this activity.

Mining

Mining or mineral extraction is another dredging activity that has potential habitat impacts. Phosphate deposits, of sufficient quality and quantity to be potentially exploitable, have been identified within the Pungo River geological formation in Onslow Bay (Map 6.4). The formation occurs beneath the Pamlico River, extends beneath ocean soft bottom from Bogue Banks southwest to Frying Pan Shoals, is approximately 150 km long and 40 km wide, and covers approximately 6,000 km^2 (Powers et al. 1990). The largest deposit occurs at Frying Pan Shoals, seaward of state jurisdiction, and is potentially available to dredge mining. Other phosphate deposits, referred to as the Northeast Onslow Bay phosphate district, occur immediately off Bogue Banks within and seaward of state jurisdiction. Because of its proximity to shore and a deep-water port, the economic potential of mining these deposits is high. In addition, other minerals occur in offshore sediments (as phosphate mining byproducts) including trace elements, radioactive substances like uranium and phosphogypsum, heavy minerals such as titanium, zirconium, aluminosilicates, and valuable metals such as gold and silver (Riggs and Manheim 1988). Currently no mining is ongoing in North Carolina waters, although the potential for such activities exists. Continued cooperation between COE, DWQ 401 staff, CAMA, and others responsible for review of mining projects is necessary to protect and mitigate against soft bottom and other habitat impacts.

Dredge material disposal on subtidal bottom

Deposition of dredge material from navigational channel maintenance on estuarine or coastal dredge disposal sites, ebb tidal deltas, or other areas of subtidal bottom results in increased turbidity, temporary reduction in and slow recovery of the abundance and diversity of benthic invertebrates (SAFMC 1998a). In estuarine waters, dredge material islands, also referred to as spoil islands, were often created adjacent to the dredged navigational channels. Subsequent maintenance dredging deposits new material onto these islands. The majority of the dredge material islands were produced when the ICW was first created in the 1930s. The creation of permanent dredge islands a) reduced the amount of available underwater habitat (including soft bottom), b) changed the natural hydrology of the surrounding waterbodies, and c) had a relatively more profound effect on the smaller waterbodies of the southern coast. However, the islands can provide beneficial nesting bird habitat and fringing wetland habitat along the perimeter. *A state policy on dredge material management, that a) minimizes impacts to coastal fish habitat, including soft bottom habitat, and b) is consistent with federal existing guidelines, should be developed.*

In ocean waters, dredge disposal occurs in both offshore, designated disposal sites and in nearshore waters and ebb tide deltas. Offshore sites are in federal waters in depths greater than 30 ft, whereas nearshore areas are in state waters in depths less than 30 ft deep. Sediment deposited in nearshore waters and on ebb tide deltas is incorporated into the beach profile and is discussed further in the beach nourishment section. The rate of bottom recovery will depend on the volume discharged, characteristics and similarity of the dredge material, hydrography of the disposal area, time of year, and the resulting turbidity (Windom 1976; SAFMC 1998a). Disposed dredge material that contains elevated levels of toxic contaminants may have adverse impacts on the benthic community. There are two EPA approved and designated ocean dredge material disposal sites off North Carolina, one off Beaufort Inlet and one off Cape Fear River Inlet. Both are located just seaward of the state territorial seas.

Marinas and docks

Soft bottom habitat may be affected by marina and dock facilities through alteration of the shoreline configuration, circulation patterns, and, subsequently, changes in bottom sediment characteristics (Wendt et al. 1990). Because benthic microalgae, an important component of primary production in soft bottom

habitat, are light dependent, bottom sediments in dredged marinas will have reduced light availability due to the deeper water depth and shading from docking structures. There are few studies that examine the effect of marinas and boating activity on benthic productivity. A study estimating macroalgal and microalgal productivity before and after construction of a marina in Long Island Sound found that microalgal production on soft bottom would decline by 48% post construction and macroalgal production would decline by 17%, due to changes in depth, light, and hard structures (Ianuzzi et al. 1996). However, the authors concluded that some of this loss would be offset by additional microalgal production on hard structures in the marina.

Operation of a marina can also affect productivity of the soft bottom community due to introduction of heavy metals, hydrocarbons, and bacteria (Chmura and Ross 1978; Marcus and Stokes 1985; Voudrias and Smith 1986). In a South Carolina estuary, distinct differences were found in the benthic community at a marina compared to the control site (Wendt et al. 1990). The marina appeared to favor the occurrence of infaunal burrowers over infaunal tube dwellers. Overall, there was greater abundance of deposit feeders at the marina. The authors concluded that the presence of docks and pilings may have resulted in greater habitat complexity and therefore greater diversity of sessile and motile epifauna. However, the study did find a lower abundance of several pollution sensitive species at the marina, indicating some environmental degradation, which could affect the food chain. Faunal differences were attributed to the finer grained sediments occurring in the marina and proximity to hard structures.

While the higher concentration of organic matter contributed to a greater abundance of certain deposit feeders, certain species were excluded from the marina. While the additional colonization of non-mobile epifauna on dock structures within the marina may provide additional biotic diversity and a food source for some fish, high densities of fouling organisms (tunicates, barnacles, bryozoans) in marinas can reduce dissolved oxygen levels due to high respiration rates (Wendt et al. 1990). Toxic substances in fouling organisms bioaccumulate and can become concentrated in successively higher levels of the aquatic food chain (Nixon et al. 1973; Marcus and Stokes 1985). Both PAHs and heavy metals were found to be significantly higher in bottom sediments in the marina compared to the control site. Heavy metals and hydrocarbons are toxic to many soft bottom dwelling invertebrates and benthic feeding fish (Weis and Weis 1989). The effect of toxins from marinas or other sources is discussed in more detail in the toxins section. *Stringent efforts are needed to prevent toxic contamination of sediments from marinas to reduce impacts to soft bottom productivity. Toxic sources at marinas should also be addressed.*

In another study in South Carolina, differences in the benthic community in areas with no, low, and high densities of docks were examined. Similar to the other South Carolina study, some pollution sensitive species of polychaetes were more abundant at control sites than high dock sites (Sanger and Holland 2002). Areas in the high dock category usually had the lowest values of benthic abundance. Three species (*S. benedicti, T. acutus, P. cornuta*), in addition to the total number of organisms, had a significant correlation to docks, with the abundance of organisms decreasing as the number of docks increased (Sanger and Holland 2002). Total fish and crustacean abundance, including bay anchovy, silver perch, spot, and brown shrimp, were highest in the no dock category, but were not significantly correlated with dock number (Sanger and Holland 2002). This study also found that shading from docks decreased stem density of *Spartina alterniflora* by 70%, which was comparable to studies in Virginia and other areas of the United States. This reduction can lower the overall productivity in the vicinity of marinas and multi-docking facilities. Overall productivity in a marina can also be reduced by effects on associated wetland and shell bottom communities. Refer to these sections for more information related to marina and dock impacts.

Several studies indicate that marinas and concentrations of individual docks have potential to alter soft bottom habitat, particularly shallow water habitat, in ways that can reduce productivity of the system as a whole. Marina siting issues were discussed in the earlier water column chapter, and the location of marinas in North Carolina was shown in Map 2.18 a-c. The majority of docking facility permits are for

individual piers. The number of individual pier permits issued annually by the CRC, with the exception of 2001, has continually increased in the coastal counties through 2000 (Figure 2.9, water column chapter). Since then, the number of permits issued annually has dropped below 1999 levels to around 800 per year. The DCM estimates that approximately 10% of these piers do not have boats associated with them and are used solely for fishing, swimming, view, etc. The large increase in permit numbers from 1999 to 2000 is at least partially due to large numbers of repair or replacement requests following hurricane damage. If properly designed and located, individual piers do not pose a large threat to soft bottom habitat. However, when docks are permitted in very shallow areas, moored boats or floating docks may actually sit on the bottom for a large portion of a tidal cycle (up to 12 hr) or cause considerable turbidity or prop dredging when attempting to motor to deeper waters (F. Rohde, DMF, pers. com., 2003). Either situation can significantly reduce primary or secondary productivity (F. Rohde, DMF, pers. com., 2003). There is currently no minimum water depth required to receive a dock permit. *Dock siting criteria should include a minimum water depth to prevent boats or floating docks from sitting directly on soft bottom or other benthic habitats*.

Multi-docking facilities (10 slips or less according to the CRC definition) may be a greater threat to soft bottom habitat due to the number of these facilities and their concentration in shallower areas than typical marinas. However, by concentrating boat use, overall impacts may be less than what would be needed to serve the same number of boats with individual piers at individual residences. Also, because boat use is concentrated, other areas of the shoreline, including wetland and shell bottom habitats, may not be impacted by docking related activities. There are about five to eight times more permits issued annually for small multi-docking facilities (non-marinas, 1-10 slips) than marinas (> 10 slips). The annual number of non-marinas has generally increased since 1996 (Figure 2.9, water column chapter). The annual number of permits issued for new or expanding marinas has remained fairly stable over the past ten years. As waterfront property becomes increasingly developed, requests for new piers and marinas in shallower and less suitable locations will increase. *A comprehensive dock and marina policy is needed to address appropriate design, siting, operation, maintenance procedures, and cumulative impacts to minimize impacts to soft bottom and other fish habitats. Research on the impacts of these parameters is needed.*

Shoreline stabilization

Different shoreline stabilization strategies are effective under different environmental conditions, with varying effects on soft bottom and other habitats. Strategies range from soft techniques such as marsh planting to engineered hard stabilization techniques. Estuarine and ocean shoreline stabilization are discussed separately below.

Estuarine and riverine shoreline stabilization

In North Carolina, estuarine and riverine shoreline stabilization has traditionally utilized hard structures such as bulkheads, rock revetments or riprap, sills, breakwaters, groins, or combinations thereof. Bulkheads are the most commonly used structure. Beach nourishment is generally not utilized. Although excessive sediment loading is considered a water quality issue, erosion of sediments is a natural process that provides sand for maintenance of beaches, wetlands, and shallow water habitat. When this sand supply is cut off by a hard structure under rising sea level conditions, the long-term results are a net loss of beach and intertidal shoreline and the deepening of shallow water habitat. High quality intertidal shoreline and shallow water habitat serve as important nursery, feeding, and spawning grounds to many economically and biologically valuable fish species in North Carolina. Multiple studies have shown that the diversity and abundance of invertebrates and juvenile fish are reduced adjacent to bulkheaded areas (Mock 1966; Ellifrit et al. 1972; Gilmore and Trent 1974; O'Rear 1983; Byrne 1995; Peterson et al. 2000c; Waters and Thomas 2001). In the 2003 legislative session, House Bill 1028 was approved, which allows the CRC to establish a general permit for construction of offshore parallel rock sills for estuarine shoreline protection. Prior to this, a major permit was required for such activity, while construction of a bulkhead required a general permit. *A comprehensive examination and revision of current CRC shoreline*

stabilization rules using best scientific information are still needed to minimize impacts from this activity to soft bottom, particularly intertidal estuarine shorelines. Research is needed to determine 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 while also providing habitat value. Refer to the wetlands chapter for additional information of the impact of shoreline stabilization to that habitat.

An additional concern of wooden bulkheads is the toxicity of preserved wood to certain aquatic organisms. Estuarine and riverine bottom may be contaminated by wooden bulkheads treated with copper, chromium, and arsenic (CCA). These elements are leached from CCA-treated wood, gradually accumulate in adjacent sediments, and have the capacity to harm marine benthos (Weis and Weis 1994; Weis et al. 1998). The toxicity of these metals to aquatic organisms is well recorded and all three are listed as priority pollutants by the EPA (Hingston et al. 2001). Copper appears to have the most toxic effect on marine organisms and is consistently released in the largest relative amount (Weis and Weis 1994).

Studies have documented significantly elevated concentrations of metals and reduced abundance and diversity of the benthic community extending approximately 30 ft (10 m) from bulkheads treated with CCA, decreasing with distance from the structure (Weis and Weis 1994; Weis et al. 1998). Benthic organisms that were lethally or sublethally impacted included macroalgae, amphipods, polychaetes, oysters, fiddler crabs, sea urchins, mud snails, and fish embryos. Sediment contamination has been documented to be higher in a residental bulkheaded canal than adjacent to bulkheaded open water (Weis and Weis 1995). Concentrations decreased more rapidly with distance from bulkhead in the open water system. Weis et al. (1995) found that oysters living on CCA-treated wood in a residential canal had 15 times more copper (~ 200 μg/g wet weight), two to three times more arsenic, and significantly more degeneration of digestive gland diverticula than compared to that of reference oysters. Copper is known to cause this pathology. Although bioaccumulation has been observed in shellfish and other invertebrates grazing on CCA contaminated algae or bivalves, similar biomagnification in fish has not been documented for these elements (Weis and Weis 1999). The extent of sediment contamination from CCA could be significant, considering the magnitude of preserved timber used in the marine environment for bulkheads and docks (Weis and Weis 1994). Toxicity of wood decreases with time but CCA can continue leaching for many years. In addition, bulkheads need to be replaced periodically, providing a continual source of newly treated wood in coastal waters. Rock sills and revetments are non-wood alternatives that do not require any chemical preservatives. *Any new wood preservative products should be evaluated for toxicity to marine benthic organisms and juvenile fish. When formulating revisions to CRC's shoreline stabilization regulations and guidelines, CRC should take into account the impact of sediment contamination and potential toxicity of wood preserved bulkheads on marine organisms.*

Oceanfront shoreline hardening

Shoreline hardening, or hard stabilization, involves construction of hard immovable engineered structures, such as seawalls, rock revetments, jetties, and groins. Seawalls and rock revetments run parallel to the beach. Seawalls are vertical structures, constructed parallel to the ocean shoreline, and are primarily designed to prevent erosion and other damage due to wave action. Revetments are shoreline structures constructed parallel to the shoreline and generally sloped in such a way as to mimic the natural slope of the shoreline profile and dissipate wave energy as the wave is directed up the slope. Breakwaters are structures constructed waterward of, and usually parallel to, the shoreline. They attempt to break incoming waves before they reach the shoreline, or a facility (e.g., marina) being protected. Jetties and groins are manmade structures constructed perpendicular to the beach, with jetties usually being much longer and located adjacent to inlets. The primary purpose of jetties and groins is to create or widen beaches by capturing sand moving along the shoreline (littoral drift).

It is now well accepted that hard stabilization techniques along high energy ocean shorelines will accelerate erosion in some location along the shore, resulting in the eventual loss of beach and intertidal

bottom as well as increased scouring and chronic turbidity in the surf zone (Walton and Sensabaugh 1979; NRC 1995; Pilkey et al. 1998; Peterson et al. 2000a). Recognizing that hardened structures destroy recreational beaches and the intertidal zone, four states have prohibited shoreline armoring: Maine, Rhode Island, South Carolina, and North Carolina (effective in North Carolina since 1985).

Only a relatively small amount of North Carolina's ocean shoreline is hardened compared to other states, having roughly 6% of the developed shoreline hardened (Pilkey et al. 1998). In contrast, South Carolina, Florida (Atlantic coast), and New Jersey have 27%, 45%, and 50% of their respective shorelines covered with some form of hard stabilization. Of all hardened structures, seawalls are the greatest threat to beach erosion and degradation of the intertidal beach (Pilkey et al. 1998). Moreover, the areal loss of beach at hardened shorelines is often managed by implementing nourishment projects, possibly having additional damage to subtidal bottom. In addition to causing erosion on downdrift beaches and accelerating the need for beach nourishment projects, jetties obstruct fish passage through adjacent inlets (Blanton et al. 1999). Jetties in some locations may therefore be the most directly detrimental shoreline stabilization structure to coastal fish habitat (for more information, refer to water column threats section). In the 2003 legislative session, House Bill 1028 was approved, putting into law the CRC prohibition on construction of permanent erosion control structure on an ocean shoreline. *Prohibition of shoreline hardening of the oceanfront should continue to be enforced for overall protection of barrier island processes, nearshore soft bottom communities, and associated fish species.*

Soft stabilization on oceanfront shorelines

Because hard stabilization is currently prohibited in North Carolina, the only beach stabilization techniques available to local communities are soft techniques, such as beach nourishment and beach bulldozing. Beach nourishment is the introduction of new sand to dry and intertidal beach and adjacent shallow waters from upland areas, navigational channels, inlet systems, or submerged mine sites to restore or enlarge a beach. There are generally two categories of COE projects that result in sand being put on beaches: disposal projects and storm damage reduction projects. Disposal projects are generally much smaller in magnitude than storm damage reduction projects, and can be expected to have a smaller impact on fish habitat. Sand bypassing is a type of disposal project where sand is moved around physical barriers, such as a jetty or deep port, that interrupt the natural littoral drift along the shoreline.

Beach bulldozing, also referred to as beach scraping, is a method of short-term erosion protection that has been used in North Carolina for approximately 40 years. Beach bulldozing is the process of mechanically redistributing beach sand from the lower portion of the intertidal beach to the upper portion of the dry beach to create or enhance the primary dune. In contrast to beach nourishment, new sediment is not added and the existing beach is not widened. Because beach bulldozing only utilizes sand on-site, the impacts of this soft technique are less, relative to those from beach nourishment (Pilkey et al. 1998). *The effectiveness and cumulative impact of this activity should be assessed and appropriate guidelines should be included in a coastal beach management plan.*

Soft stabilization offers an alternative to hard stabilization that has less severe habitat impacts to soft bottom and some positive effects. For example, wider beaches from properly constructed beach nourishment projects can enhance sea turtle nesting habitat and protect oceanfront development that is important to North Carolina's economy. However there are potential biological impacts to soft bottom habitat, depending on specific factors of the project and site, which should be considered.

Beach nourishment impacts at mining areas

Mining is defined under the Mining Act (G.S. 74-48 and G.S. 47-49) as "the breaking of surface soil in order to facilitate or accomplish extraction or removal of mineral, ores, or other solid matter." Whether the purpose is beach nourishment, channel maintenance, or mineral extraction, the consequences of mining activities have similar effects upon the habitat. Dredging of subtidal bottom initially causes

mortality of benthic organisms within the dredged area and causes elevated turbidity in an extended area, which may also result in negative impacts. Physical recovery of mining sites in nearshore areas and shoals can be a slow process, but is quite variable. In South Carolina, comparison at multiple mine sites found that sediment refilling took from two to at least 12.5 years at various mine sites. Because mine sites often refill with finer-grained material than was originally present (NRC 1995; Van Dolah et al. 1998), post-dredging turbidity may remain high indefinitely (Peterson et al. 2000). Since these areas often refilled with a more fine-grained, muddy sediment, most sites became unsuitable as future sand sources and altered benthic species recruitment patterns (Van Dolah et al. 1992; Van Dolah et al. 1998; Jutte et al. 2001a). Use of ebb or flood tidal deltas and nearshore sandbars as a sand source for nourishment projects removes sand from the inlet system, alters the sediment budget, and may result in accelerated erosion from adjacent beaches (Wells and Peterson 1986). Roessler (1998) also suggested that the major cause of beach erosion on Bogue Banks was the removal of sediment from the longshore system due to the intense dredging and deepening of Beaufort Inlet for access to the state port at Morehead City. Sand from that dredging operation has at times been taken out of the inlet, hence out of the longshore system, and disposed of offshore beyond the active beach profile. Biological recovery rates of mined sites vary, but generally are longer than those reported at the intertidal beach disposal sites, and in some cases may be altered indefinitely (Table 6.4).

Table 6.4. Reported biological recovery time at mine sites

Location	Mine site recovery time	Reference
North Carolina	6 – 18 months	Posey and Alphin 2001
South Carolina	3 – 6 months	Van Dolah et al. 1992
South Carolina	2 – 12.5 years	Van Dolah et al. 1998
South Carolina	11 – 14 months	Jutte et al. 2001b
South Carolina	14 – 17 months	Jutte et al. 2001a
New Jersey	18 – 30 months	COE 2001
location undisclosed	> 12 months	NRC 1995

Van Dolah et al. (1998) observed significant changes in the species composition of the recruited benthos, shifting from a dominance by amphipods to mollusks. During the time period monitored (> 12.5 years), the original species composition within the affected area was never restored due to the change in substrate composition (Van Dolah et al. 1998). Mining activities that changed bottom sediment composition were often associated with impacts of the greatest magnitude and most prolonged recovery, typically occurring in areas with little sand movement, with deep mine pits, or that were previously mined (Saloman et al. 1982; COE 2001). Comparison of mine areas and control sites associated with a storm damage reduction project at Carolina Beach found few statistically significant differences in species abundance 0.5 and 1.5 years after sediment removal (Posey and Alphin 2001). However, after sediment removal, dominant species composition at the mine site was more dissimilar to the control site than before sediment removal. The authors concluded that year to year variability in the benthic community, in addition to multiple hurricanes during the monitoring period, made effects from the project difficult to determine, suggesting that the effect of beach nourishment is minimal compared to the natural variability of the system (Posey and Alphin 2001; Posey and Alphin 2002). Observed recovery at this site was more rapid than expected, due in part to the configuration of the mine areas. The mine area was long (3 mi), relatively wide (0.5 mi), and, most importantly, not excessively deep (5-10 ft deep) (M. Posey, UNC-W, pers. com., 2003). At mine sites monitored off New Jersey, infaunal assemblages (diversity) recovered within one year after disturbance, while biomass and taxonomic richness took 1.5 to 2.5 years to fully recover (COE 2001). Because material was removed from a topographically diverse bottom, a deep pit was not created, leading the authors to conclude that time to recovery was reduced. In addition, strong water currents and dynamic sand movement in the project area facilitated more rapid infilling.

Repeated use of a mine site for beach nourishment is generally not possible since the excavated areas tend

to refill with more muddy substrate or have not completely refilled prior to the next renourishment interval (3 – 8 year cycles). Because of the slow recovery and change in sediment composition, Van Dolah et al. (1998) stated that nearshore mine areas must be viewed as a non-renewable resource and as the regions most impacted by beach nourishment projects (R. Van Dolah, SC DNR; pers. com., 2002). The benthic community appeared to recover more quickly where hopper dredges were used rather than pipeline dredges (Jutte et al. 2001a). Locating mine sites at specific soft bottom locations known to support seasonal aggregations of demersal fish, such as the critical overwintering area off the Outer Banks for juvenile Atlantic sturgeon, spiny dogfish, and striped bass, could negatively impact those species. Mine sites established on ebb and flood tide deltas may recover relatively faster due to nearby longshore sediment transport. However, these deltas serve as important feeding sites to a number of commercially and recreationally important species, including red drum, striped bass, spot, Atlantic croaker, weakfish, blue crabs, and shrimp, and serve as spawning sites for red drum, weakfish, spotted sea trout, and blue crab. Removal of a major component of their diet could negatively impact these species (Peterson et al. 1999). Factors that appeared to maximize biological recovery rates include:

- Shallow excavation of mine areas,
- Use of topographic highs, and
- Location in areas of high sand movement.

When mine areas are necessary for beach nourishment projects, guidelines should strongly encourage siting protocol that maximizes biological recovery rates and does not degrade critical fish foraging areas. Many steps are already taken to minimize environmental impacts. Environmental Impact Statements (EIS), Environmental Assessments (EA), Findings of No Significant Impact (FONSI), State Environmental Policy Act (SEPA) documents, or National Environmental Policy Act (NEPA) documents must be completed and reviewed. A memorandum of agreement between DCM and COE provides for a coordinated permit review process between state and federal agencies (Federal Consistency Program). A federal project cannot begin unless DCM finds that it is consistent with state policies. Other agencies are given an opportunity to comment on projects as well. The MFC adopted a beach nourishment policy in 2000 to guide the permitting process to more fully consider fish habitat impacts (Appendix N).

Beach nourishment impacts at intertidal beach and adjacent subtidal bottom

Biological impacts of sediment disposal to the intertidal beach community have been studied by Reilly and Bellis (1983), Van Dolah et al. (1992), Hackney et al. (1996), Donoghue (1999), Jutte et al. (1999), Peterson et al. (2000b), and others. Studies of dredge disposal and storm damage reduction projects demonstrated an almost complete initial reduction in the number of benthic invertebrates in the intertidal zone, as well as in the subtidal zone and dry beach, immediately following the disturbance. The effect on smaller meio- and microfauna is unknown. The rate of reported biological recovery on nourished intertidal beaches has varied from about one month to one year, but in some cases longer (Table 6.5).

Table 6.5. Reported biological recovery times at nourished ocean beaches.

Locaton	Biological recovery following beach nourishment	Reference
Atlantic Beach, N.C.	More than 3 months. Coquina clams in nearshore overwintering bottom killed initially by turbidity; delayed recruitment and repopulation; Haustoriid amphipods had not recovered after 3 months. Polychaete *S. squamata* recovered 15 – 30 days post nourishment.	Reilly and Bellis 1983
Atlantic Beach, N.C.	Densities of mole crabs and coquina clams were 86 – 99% lower than control sites, 5 – 10 weeks post-nourishment, during mid-summer.	Peterson et al. 2000b
North Topsail, N.C.	After 1 year, mole crab, coquina clam, and amphipod abundance remained significantly less than at control sites and body size was significantly smaller. Polychaetes increased in abundance.	Lindquist and Manning 2001
Pea Island N.W.R., N.C.	2 – 9 months for coquina clams and mole crabs.	Donoghue 1999
Hilton Head, S.C.	Density and diversity returned to levels similar to control sites in 6 months.	Van Dolah et al. 1992
Folly Beach, S.C.	2 – 5 months, depending on benthic group and site, polychaetes recruiting earlier than mollusks.	Jutte et al. 1999
Panama City, F.L.	Large reductions in abundance and diversity remained after 2 years.	Rakocinski et al. 1993
Manasquan, N.J.	Abundance, biomass, and diversity completely recovered after 6.5 months. Recovery quickest when filling completed before low point in seasonal infaunal abundance and where grain size of fill material matched natural beach.	COE 2001

Factors likely affecting the recovery time of the intertidal beach community include:

- compatibility of deposited material with native sand (sediment grain size)
- volume of sand
- depth of filled sand
- length of area covered
- time of year
- time period between renourishment events on an individual site
- alteration of the beach geomorphology
- location placed on the beach

In the studies referenced above and others, biological impacts persisted longer when supplemented sand was either coarser (Rakocinski et al. 1993; McLachlan 1996; Rakocinski et al. 1996; Peterson et al. 2000a) or finer (Gorzelany and Nelson 1987; NRC 1995) than the existing sand. Increased grain size of the beach can result in significant reduction in species richness and abundance by 1) limiting body size, 2) limiting burrowing performance and other functions in some species, and 3) changing the beach condition to a higher energy swash zone (McLachlan 1996). A decrease in grain size impacts the benthos by 1) smothering organisms, 2) clogging gills from sediment plumes, and 3) decreasing the interstitial space between sediment grains available to small burrowing invertebrates (Rakocinski et al. 1996). Current CRC rules state that sediment grain size shall be equal to or larger than that found naturally at the site. *More specific minimum and maximum grain size standards are needed to minimize biological impacts*.

The time period between renourishment events is also an important factor for successful recovery. Lindquist and Manning (2001) found that at a beach where dredge material was placed between April and June, and redeposited the following year (April – June), the abundance of the mole crabs, coquina clams, and amphipods was significantly lower than that of the control beach after one year. Also, mole crabs and coquina clams were significantly smaller in size than at control sites, indicating that repeated disturbance from beach disposal (once a year) prevented full recovery of the populations. Peterson et al. (2000b) also argued that recovery could be accelerated if projects were timed to occur before spring recruitment of benthos.

Dredge material from inlet dredging is often placed in nearshore water (< 30 ft deep) within the beach profile to enhance sand supply on the beach. Such sand placement in nearshore waters can delay the duration and reduce the magnitude of the benthos reduction on the beach, but cause additional impacts to subtidal bottom (Donoghue 1999). Monitoring of a nearshore disposal project that occurred on an ebb tide delta near Beaufort Inlet in March – April found that after eight months (December), infaunal invertebrates were only 50% as dense as that of the original benthic community, but mobile epifauna had fully recovered (Peterson et al. 1999). In the following two months (December – February), density estimates doubled, as new recruits rapidly entered the area (Peterson et al. 1999). Projects timed to occur in the winter, prior to peak infauna larval recruitment in the summer and fall, will speed up the recovery of intertidal benthic organisms within the impacted area (Donoghue 1999).

In summary, several conditions appear to minimize biological impacts of nourishment projects to the intertidal beach community. These include, but are not limited to:

- Use of sand similar in grain size and composition to original beach sands (specific minimum and maximum standard needed).
- Restrict beach nourishment to winter months to minimize mortality of infauna and enhance recovery rates of intertidal benthic organisms, an important prey source for many surf fish (Donoghue 1999).
- Limit time interval between projects to allow full recovery of benthic communities (1-2 years, depending on timing of project and compatibility of sediment).
- Limit linear length of nourishment projects to provide undisturbed area as a source of invertebrate colonists for the altered beach, and a food source for fish.

The extent of biological impacts from beach nourishment activities is determined not only by these individual conditions, such as grain size, time of project, and frequency of reapplication, but also by combinations of factors. *Because of the potential impact of beach nourishment and dredge disposal on soft bottom communities, there is a need for a coast-wide Beach Management Plan that carefully reviews cumulative impacts of activities and provides ecologically based guidelines, including sediment compatibility standards, to minimize cumulative impacts. The CRC's beach nourishment rules should be evaluated and modified in a comprehensive manner as needed to minimize overall impacts from this activity. Additional research is also needed to more clearly quantify the cumulative impact of nearshore dredge disposal on fish populations.*

The largest biological impact of beach bulldozing appears to be reduction in ghost crab populations on the dry beach (Peterson et al. 2000b). Lindquist and Manning (2001) found no significant impact on dominant beach invertebrates associated with beach bulldozing. No decline in surf fish or shorebird use at or adjacent to scraped beaches was observed. Peterson et al. (2000b) found that beach bulldozing at Bogue Banks reduced the width of the intertidal beach, shifted sediment composition, and immediately reduced abundance of benthic organisms. Because of the relatively quick recovery on intertidal and shallow subtidal benthic communities and the relatively small area that occurs in subtidal waters, fish impacts from bulldozing should be less than other beach management activities. However, beach scraping has not been shown to provide any erosion control benefit, and has actually increased wind erosion of sand where created dunes were left unvegetated (Kerhin and Halka 1981; Tye 1983; McNish and Wells 1992; Peterson et al. 2000b). The CRC modified specific conditions for beach bulldozing in

2000 which should help minimize biological impacts if properly enforced, including time windows for work to be completed, maximum depth of scraping, and replanting of dunes.

Beach nourishment impacts on fish

Fish may be impacted by beach nourishment due to reduction in food availability, alteration of preferred topographic features, disturbance prior to or during spawning, or reduced visibility. Fish and invertebrate species that spend considerable time in the surf zone and feed on benthic invertebrates, such as Florida pompano, gulf kingfish, Atlantic croaker, spot, and shrimp, would be most vulnerable to beach nourishment activities. Some studies have found insignificant impact to fish populations (Van Dolah et al. 1994; COE 2001) or a temporary increase (Saloman 1974). This may be 1) due to release of nutrients and infauna during dredging, 2) because resident fish are wide-foraging, or 3) because migratory fish spend only a portion of their life cycle at the mine site or target beach (Greene 2002). Other researchers suggest that fish are dependent on the amount of available habitat and that any loss represents a decrease in production (Peterson et al. 2001). Unfortunately, very little monitoring has been done at the level needed to adequately assess and detect the impacts of nourishment projects on fish distribution, feeding, growth, or survival.

A New Jersey study examined surf zone fish distribution, abundance, and diet in response to ongoing nourishment projects (COE 2001). In the immediate vicinity, abundance of bluefish, a visual feeder, decreased and northern kingfish, a benthic feeder, appeared to increase. However, no long-term trends were detected in distribution or abundance. Stomach content analyses of kingfish and silversides did not suggest differences in prey availability between control and project sites. This study concluded that "because inter-annual variation of surf zone fish community dynamics is considerable, it is unlikely that anything other than catastrophic environmental impacts on surf zone fish populations would be evident (COE 2001)."

In North Carolina, the effects of a Brunswick County beach nourishment project on surf fish, benthic invertebrates, and water quality, were evaluated from March 2001 to May 2002 (COE 2003). Sand from the lower Cape Fear River dredging project was placed on Bald Head Island, Caswell Beach, Oak Island, and Holden Beach. Seining and trawling before and after the project found no significant differences in fish abundance or diversity among disturbed, undisturbed, and reference sites during any season. This was attributed to the high mobility and schooling behavior of the dominant fish species (anchovies and drum family), resulting in clustered and variable distribution. Although statistically not significant, gulf kingfish were less abundant at the disturbed sites than the undisturbed sites. The decline was thought to be at least partially due to the reduced availability of benthic invertebrates preferred by gulf kingfish (COE 2003). The intertidal benthic community was the most directly impacted by the beach nourishment project. Analysis of the effects of this project was limited by problems with the statistical design (COE 2003). Sample size was often insufficient to calculate confidence limits, partly due to uneven sampling among treatments (disturbed, undisturbed, reference). *Adequate monitoring of the effects of beach nourishment on the soft bottom community and associated surf fish populations is increasingly important as the number of beach nourishment projects increase and should be required for all large-scale or long-term nourishment projects.*

Status of beach nourishment from navigational dredge disposal projects

The COE is charged to maintain North Carolina's navigable inlets and ocean channels through dredging as necessary. Navigational dredging in inlets by the COE is allowed at any time of the year and is not subject to any mandatory dredging moratoria unless sea turtle take quotas are exceeded. Industry-owned hopper dredges working in the Wilmington and Morehead City port areas and Oregon Inlet have a voluntary dredge window of January 1 – May 31, to minimize taking of turtles (T. Wilder, COE, pers. com., 2003).

Maintenance of the seven federal inlet channels is performed by a sidecast dredge or a small hopper dredge. Maintenance of the federal channels at Morehead City, Wilmington Harbor, and Oregon Inlet is conducted by hydraulic pipeline dredge or hopper dredge. Timing of all work is dependent upon the area to be maintained, the type of equipment to be used, and the anticipated environmental effects. Performing work with a hopper dredge requires consideration of possible impacts on endangered and threatened sea turtles.

Material from dredge disposal projects is put on or adjacent to ocean beaches in close proximity to the dredged site, or in an EPA designated ocean dredge material disposal site. Beaches receiving sand from dredged inlets and adjacent waterways are indicated in Table 6.6 and Map 6.3 a-c. Sand from these projects usually only covers a relatively short linear length of the beach (< one mile), generally close to the inlet where the sand originated. The amount of sand deposited and the frequency of dredging vary between sites and with each dredging event (Table 6.6). There are 51 miles of beach designated and approved for dredge disposal, but only about 16 miles of beach receive dredge material (T. Wilder, COE, pers. com., 2003). Areas receiving dredge disposal include several locations on Hatteras Island, south end of Ocracoke Island, Core Banks, both ends of Bogue Banks, Onslow Beach, several locations on Topsail Island, Wrightsville Beach, Masonboro Island, north end of Carolina Beach, Caswell Beach, Oak Island, east end of Ocean Isle Beach, and both ends of Bald Head Island. In addition, privately owned Figure 8 Island has received nourishment projects periodically, most recently in 2002 from the Mason Inlet relocation project.

Table 6.6. Ongoing COE dredge disposal projects on North Carolina ocean beaches (Source: T. Wilder, COE, pers. com., 2003).

Dredging Project	Disposal location	Approved disposal limits (mi)	Actual disposal limits (mi)	Estimated quantity (cu. Yd.)
Avon Harbor vicinity, Avon	Hatteras Island, south of Avon Harbor and extend north.	3.1	0.4	< 50,000 every 5-6 yr.
Rodanthe Harbor vicinity, Rodanthe	Extends from south end of Pea Island NWR to south of Rodanthe Harbor.	0.9	0.4	<100,000 every 5-6 yr
Rollinson channel/ Hatteras	Hatteras Island south of Hatteras Harbor and extends 5.85 mi north of Frisco.	5.9	0.4	<60,000 every 2-3 yr
Silver Lake	Southwest end of Ocracoke Island.	0.4	0.4	<50,000 every 2-3 yr
Oregon Inlet	Pea Island south from Oregon inlet.	3.0	1.5	300,000 / year
Drum Inlet	Core Banks, extending 1 mi either side	2.0	1	298,000 initial, 100,000 maint.
Morehead City	Bogue Banks, from Beaufort Inlet west to Coral Bay Club, Pine Knoll Shores	7.3	5.2	3,500,000 every 8-10 yr.
AIWW	Pine Knoll Shores	2.0	0.4	<50,000 every 5-6 yr.
AIWW Bogue Inlet	Bogue Banks from Bogue Inlet east to Emerald Point Villas	1.0	0.4	<100,000 / year
AIWW	Camp Lejeune, from Browns Inlet west	1.6	1	<200,000 every 2-3 yr
AIWW, New River Inlet	N. Topsail Beach from inlet west to Maritime Way	1.5	0.8	<200,000 / yr
AIWW	Surf City opposite N.C. 50 bridge	1.0	0.04	<75,000 every 5-6 yr (only used in 1996)
AIWW	Topsail Island, Queen's Grant	0.6	0.6	<50,000 every 5-6 yr
AIWW, Topsail Inlet and Topsail Creek	Topsail Beach, north of Topsail Inlet	1.0	0.4	<75,000 / yr
AIWW, Mason Inlet crossing	North end Wrightsville Beach 2000' from Mason Inlet	0.4	0.4	<100,000 (not scheduled)
Masonboro sand bypassing	North end Masonboro Island, south from Masonboro Inlet	1.2	1	500,000 every 4 yr
AIWW, Carolina Beach Inlet, Snows Cut	South end Masonboro Island, from Carolina Beach Inlet north	1.3	0.4	<50,000 / yr
AIWW	North end of unincorp. Carolina Beach, south of Carolina Beach Inlet to town limit	0.8	0.4	<100,000 / yr
Cape Fear River, Wilmington Harbor	Bald Head Island	3.0		Approx. 1,000,000 / 2 yr.- total for Bald Head, Caswell, and eastern Oak Island
Cape Fear River, Wilmington Harbor	Caswell Beach and eastern part of Oak Island	4.7 mi initially, 2.8 mi./2 yr		
Cape Fear River, Wilmington Harbor	Sea Turtle Restoration Site, Oak Island (Continuing Authorities Project)	2.4		Only received one time from initial dredging
Cape Fear River, Wilmington Harbor	Oak Island, west of sea turtle project	4.9		Only received one time from initial dredging
Cape Fear River, Wilmington Harbor	Holden Beach	2.0		Only received one time from initial dredging
AIWW Cape Fear River to SC line	East end Ocean Isle Beach	0.6	0.6	<100,000 every 1-2 yr; 250,000 if Lockwood Folly Inlet dredged (every 8-10yr)
Total		**50.7**	**16.14**	

Status of beach nourishment from storm damage reduction projects

Storm damage reduction projects involve dredging sand specifically to increase the width and height of the beach and dunes to reduce storm damage to infrastructure and private property adjacent to the beach. To implement a federally authorized and subsidized storm damage reduction project, local governments must follow a lengthy process that can take up to 10 years to initiate. A local government must first identify an erosion problem and request a study by the COE to determine if and how a project could be

conducted. Numerous regulations and policies guide permit review and authorization, although protection of fish habitat is not the primary consideration. DMF and other agencies are given an opportunity to comment to DCM and the COE on the potential impacts of a project to fisheries, fish habitat, and other environmental concerns. The MFC adopted a beach nourishment policy in 2000 to guide the permitting process to more fully consider fish habitat impacts (Appendix N).

The frequency and magnitude of beach nourishment on developed beaches have increased over time. From the 1960s to 2000, only nine miles of beach (3% of the ocean shoreline) had ongoing storm damage reduction projects - Wrightsville Beach, Carolina Beach, and Kure Beach (Table 6.7; Map 6.3 a-c). These projects were initially authorized and begun in the 1960s, although the first nourishment project in Wrightsville Beach occurred in 1939 (COE 1992). With the exception of Currituck County where there have been no nourishment projects, Onslow County has had the least beach renourishment, with only one small project in the 1990s. Currently there are 16 mi (5%) of beach along North Carolina's coast that have authorized and funded storm damage reduction projects ongoing. An additional 35 mi (11%) of beaches have authorization to conduct projects, and 104 mi of additional beaches (33%) are at some stage of requesting long-term beach nourishment (storm damage reduction projects). This includes all of Hatteras and Ocracoke islands because of the DOT NC 12 study, but it is likely that only a small part of these islands would actually be nourished (J. Sutherland, WRC, pers. com., 2004). Beach renourishment of federally authorized storm reduction projects generally occurs on three or four year intervals. Potentially 155 mi or 48% of North Carolina's beaches could be renourished regularly if resources existed, and these beaches could be potentially impacted by such activities. This does not include approximately 16 mi of beach renourished periodically by disposal from channel, inlet, and port dredging. There are approximately 160 mi of federally or state owned barrier islands along the 320 mi of ocean shoreline where storm damage reduction projects would be unlikely.

Table 6.7. North Carolina beach communities with federally authorized or requested storm damage reduction projects (does not include beach disposal from navigational dredging projects). [Source: COE, unpub. doc., 2003.]

Beach	Project length (miles)		
	Existing	Authorized	Requested/Under study
S. Kitty Hawk & N. Kill Devil Hills		4.5	2.2
Nags Head		10.5	
Hatteras Island			53 (NC 12 project)
Ocracoke Island			17 (NC 12 project)
Bogue Banks, excluding Atlantic B.			17
Onslow Beach		1.0	
North Topsail Beach			4
Surf City			5.5
Topsail Beach		3	5.5
Figure 8 Island	2		
Wrightsville Beach	3 (every 4 yrs)		
Carolina and Kure Beach	6 (every 3 yrs)		
Caswell Beach, southern part of Oak Island		7.3	
Holden Beach		5.7	
Ocean Isle	5.3		
Sunset Beach		2.7 (needs re-evaluation)	
Total	**16.3**	**34.7**	**104.2**

Preliminary examination of commercial gill net landings data for demersal feeding surf fish in counties with differing levels of beach nourishment activity indicates some relationship may exist between beach nourishment events and low landings (DMF, unpub. data). However, more information and analysis are needed to determine if beach nourishment events negatively impact surf fish abundance, CPUE, or landings. Given the increasing numbers of existing and requested nourishment projects over time, the cumulative impacts of activities on the intertidal and subtidal communities are also expected to increase. *To adequately and correctly assess the direct and cumulative impacts of beach nourishment activities on fish, their habitat, and biological recovery rates, thorough monitoring must be conducted.* Increasing use of beach nourishment may have a cumulative impact on fish productivity of nearshore waters through impacts on the benthic community and alteration of natural barrier island processes. *Because the demand for beach nourishment has increased in recent years, due in part to the state's prohibition of shoreline hardening, there is a need to complete a comprehensive beach management plan to provide guidelines to minimize long-term impacts. In addition, multi-agency efforts should be made to educate local government officials and the general public (since these groups initiate and drive the demand for beach nourishment) on natural hazards and other factors associated with dynamic coastal systems.*

Fishing gear impacts

The extent of habitat damage from fishing gear varies greatly with the gear type, habitat complexity, and amount of gear contact. While MFC rules are designed to minimize commercial fishing gear impacts to fisheries habitat, these restrictions primarily focus on restricting the use of highly destructive bottom disturbing gear from most structural habitats such as oyster or SAV beds. Soft bottom habitat, because of its low structure and dynamic nature, has historically been considered the most appropriate location to use bottom disturbing gear. There are some fishery rules that restrict bottom disturbing gears in soft bottom

habitat, since DMF research found that their use disturbed soft bottom substrate. These include prohibition of trawls, dredges, and long haul seines in PNAs [15A NCAC 3N .0104] and prohibition of trawls or mechanical shellfish gear in crab spawning sanctuaries [15A NCAC 3L .0205] in the five northern-most inlets of North Carolina during the blue crab spawning season (March-August).

Fishing related impacts to fish habitat have been reviewed and compiled in federal fishery management plans for managed species and have been summarized in fishery management plans by SAFMC and MAFMC, as well as by MSC (1996), Auster and Langton (1999), DMF (1999), and Collie et al. (2000). A legislative report to the Moratorium Steering Committee (MSC 1996) compiled a list of the gears used in North Carolina waters and their probable impacts (Appendix O). The gears with the greatest potential for damage to soft bottom or other habitats include dredges and trawls. The impacts of these gears and where they are used are discussed below.

Dredging

Of gears used in North Carolina, dredges are considered to be the most habitat destructive (DeAlteris et al. 1999; Collie et al. 2000). Oyster and crab dredging are conducted in limited areas in northern Pamlico Sound and its tributaries. Oyster dredging is conducted over shell bottom and was discussed in detail in the shell bottom chapter. Crab dredging is allowed in one area in northern Pamlico Sound (approximately 100,653 acres), primarily on soft bottom (Map 6.5), and is opened by proclamation from January 1 to March 1. Crab dredges are similar to oyster dredges, although the dredge teeth are sometimes longer on the crab dredge. Because of the gears' teeth, crab and oyster dredges can dig deep into the sediment and cause extensive sediment disturbance. Crab dredges are limited to a weight of 100 lbs and can only be used in January and February [15A NCAC 3L .0203]. Mechanical methods, as well as trawls and pots, for the taking of crabs are prohibited in designated Crab Spawning Sanctuaries from March through August. In recent years, fishing effort has been very low, with fewer than 10 crab dredge trips reported per year. Although the amount of fishing effort is low, this gear is documented to cause significant damage (DeAlteris et al. 1999; Collie et al. 2000). *Because less habitat damaging methods are available for harvesting crabs, MFC should prohibit crab dredging.*

There are two types of scallop dredges used in North Carolina. Bay scallop dredges are used in SAV beds. Refer to the SAV chapter for more information on this gear. Sea scallop dredges are used occasionally in the coastal ocean off Cape Lookout. Studies have found that scallop dredges cause extensive damage to hard bottom and significantly reduce habitat complexity on soft bottom and shell hash bottom (Auster et al. 1996; Currie and Parry 1996). Habitat complexity is reduced through flattening of mounds, filling of depressions, dispersing shell hash, and removing small biotic cover such as hydrozoans and sponges (Auster et al. 1996). Sea scallop dredging primarily occurs in deep coastal waters north of North Carolina. Dredging for sea scallops off North Carolina has been a sporadic fishery, primarily located in federal waters. Since 1994, commercial landings of sea scallop meats have been very low, ranging from 13,815 lb in 1999 to 206,790 lb in 1995 (DMF 2001c). Because of the location of the fishery and the low level of effort, no additional restrictions appear to be needed.

Hydraulic clam dredging and clam kicking were described in detail in the SAV chapter. Mechanical clamming, including kicking and dredging, accounts for approximately 21% of the annual hard clam landings (DMF, unpub. data). The dredging and kicking activity creates trenches and mounds of discarded material in soft bottom habitat, redistributing and resuspending sediment (Adkins et al. 1983). Water jets from the hydraulic dredge can penetrate 18 inches into bottom sediments, and uproot any living structure present (Godcharles 1971). Dredge tracks can remain present from a few days to more than one year and recolonization by vegetation can take months to begin. Recruitment of clams and other benthic invertebrates does not appear to be affected by hydraulic dredging (Godcharles 1971). Because of the severe impacts to habitats, both hydraulic clam dredging and clam kicking are restricted to open sand and mud bottoms, including areas frequently dredged as navigational channels. The locations where mechanical clam harvest is allowed are shown in Map 6.5. There are approximately 39,517 acres that are

potentially available to mechanical clam harvest in portions of Core, Bogue, and Pamlico sounds, Newport, North, White Oak, and New rivers, and a portion of the ICW in Topsail Sound. The majority of mechanical harvest areas are located in Core Sound (29,951 acres). These fisheries may be opened by proclamation between Dec 1 and March 31. At this time, no changes are necessary to protect soft habitat because of the low frequency of the activity and dynamic nature of the habitat. However, some changes are needed to better protect SAV and are discussed in that chapter.

Bottom trawling in estuarine waters

Bottom trawling is used more extensively than dredges on soft bottom habitat in both estuarine and coastal ocean waters. Bottom trawling in estuarine waters is used primarily to catch shrimp, although some crab trawling is also conducted. Flounder trawling is restricted to ocean waters. Bottom trawls are conical nets that are towed behind a fishing vessel, held open by water pressure against a pair of "otter boards" or "doors" that are attached to the front of the net. Three components of a bottom trawl can dig into the sediment: the doors, the weighted line at the opening of the net, and the tickler chains (which are sometimes added in front of the net to improve the harvest).

Impacts of shrimp and crab trawling in estuarine waters were reviewed and compiled by DMF (1999), at the request of the MFC and were reported to the General Assembly's Joint Legislative Commission on Seafood and Aquaculture. This report found that trawling can impact fish habitat by altering the physical structure or biological components of soft bottom. Pulling trawl nets across soft bottom reduces habitat complexity by (Auster and Langton 1999):

- directly removing or damaging epifauna
- removing benthic invertebrates which produce structure like burrows and pits
- smoothing sediment features of the seafloor, such as sediment ridges and contours

Gear contact can uproot and remove plants and invertebrates attached to the seafloor, such as algae, sponges, worm tubes, and SAV, and can expose them to predators. This structure, although small relative to other benthic habitats, is important to certain species, such as *Sabellaria* worms, for recruitment (Wilson 1968). Gear effects on bottom were described in the SAV chapter and in ASMFC (2000). Trawl doors penetrate more than the rest of the gear and will penetrate deeper in muddy substrates. The change and reduction in the structural complexity of the seafloor and increase in turbidity from trawling can reduce feeding success of filter feeding invertebrates due to gill clogging, or increase predation due to increased exposure and reduced cover. Clam trawling (clam kicking) causes severe disturbance to bottom sediments. However, a study in North Carolina found no significant effect of this fishing activity on recruitment of hard clams or abundance of other benthic invertebrates in unvegetated sandy bottom (Peterson et al. 1987).

Reduced diversity and abundance of some benthic taxa are commonly observed in areas experiencing intense fishing activities (Auster and Langton 1999). A shift in dominant species and a reduction in community stability may also occur. Long-lived species, which take more time to recover from fishing disturbance, may be temporarily or indefinitely replaced by short-lived species. Sediment resuspension by trawling can significantly increase the suspended sediment load (turbidity) over soft bottom on the outer shelf. Increased turbidity reduces light penetration and consequently reduces primary productivity of benthic microflora on the seafloor as well as phytoplankton in the water column (Auster and Langton 1999). Decreased primary productivity will affect demersal zooplankton that, in turn, support higher trophic layers. A reduction in filter feeders on the subtidal bottom can result in reduced water clearing capacity in the water column (Auster and Langton 1999). However, given the frequency, magnitude, and location of trawling, it is unknown whether these events are having a significant negative impact on soft bottom habitat in North Carolina's estuarine system. Trawling can affect primary productivity of both soft bottom and water column by (DMF 1999):

- stimulating chemical exchange between resuspended sediment and the water column

- increasing turbidity and reducing light availability at the surface of soft bottom
- reducing primary production of benthic microalgae

Increased chemical exchange between bottom sediments and the water column (benthic-pelagic coupling) can have positive and negative effects on estuarine systems. Nutrients released into the water column can greatly increase nitrogen and phosphorus levels, stimulating phytoplankton growth, as well as enhancing secondary productivity of herbivorous zooplankton and larger prey (DMF 1999). Eventually, the remains of plankton and other organisms will settle, adding to the food available to benthic deposit feeders. However, if large amounts of organic matter are resuspended, the subsequent increase in plankton can reduce water oxygen levels, causing hypoxia and anoxia (West et al. 1994; Paerl et al. 1998). By resuspending sediments, trawling can make inorganic and organic pollutants (e.g., heavy metals and pesticides, respectively) available in the water column (Kinnish 1992; DMF 1999). Such toxins can negatively affect productivity and may also accumulate in organisms through food chain interactions.

While some consider trawling to be physically disruptive to the bottom and potentially harmful to the benthic community due to gear damage, sedimentation, predation exposure, and reduction in benthic primary production (Auster and Langton 1998), others feel that trawling may mimic natural disturbances and stimulate benthic production, enhancing fish production. In a literature review of the effects of trawling in estuarine waters, DMF (1999) noted that multiple studies demonstrated the presence and absence of long-term effects of trawling in estuarine waters. No or minimal long-term impacts were reported in MacKenzie (1982), Van Dolah et al. (1991), and Currie and Parry (1996). Of these studies, Van Dolah et al. (1991) was located closest to North Carolina, in a South Carolina estuary. After five months of trawling, Van Dolah et al. (1991) found no significant change in abundance, diversity, or composition of soft bottom habitat. Studies which have found long-term habitat impacts include Bradstock and Gordon (1983), Brown (1989), Collie et al. (1997), and Engel and Kvitek (1998).

The DMF trawl report recommended that additional studies be done in North Carolina estuarine waters to better assess the impact of trawling on the estuarine environment. *Further analysis is needed to identify the location, duration, and initiation of trawling over soft bottom habitat as well as over structured habitats, such as shell bottom and SAV. It is also important to quantify the effects of trawling on the habitat.* Specific research needed to evaluate the habitat impacts of trawling include (DMF 1999):

- *Determine the intensity, duration, and spatial scale of trawling effort in different regions of North Carolina.*
- *Determine turbidity levels generated by different gear configurations and the subsequent rates of redeposition.*
- *Determine the physical effect of natural forms of disturbance to compare significance of trawling effects.*
- *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.*
- *Measure in situ rates of growth, mortality, and recruitment of selected benthic organisms that are exposed to trawling.*
- *Evaluate the effect of trawling on benthic algal growth and primary productivity overall.*
- *Determine the impact of trawling on secondary productivity.*

Attempting to answer questions in the DMF trawl report, Cahoon et al. (2002) studied changes in benthic microalgae, demersal zooplankton, and benthic macroalgae (important food sources for recreationally and commercially important species) in the Pamlico River estuary in 1999-2000. Demersal zooplankton include small crustaceans, nematodes, and other animals that are important grazers of benthic microalgae and prey for larger fish and invertebrates. Experimental trawling was conducted to document natural seasonal changes in the benthic community, examine changes before and after experimental trawling, and compare regularly trawled and untrawled areas. No significant differences were recorded in benthic algal

biomass prior to and after experimental trawling. In comparing commercially trawled and untrawled areas, benthic microalgae were more abundant in the untrawled sites. This could be because benthic algae in trawled areas are resuspended into the water column. Nematodes, an important food source for shrimp, were the most abundant demersal organism found. The authors concluded that, because the soft bottom community in shallow systems is frequently subjected to disturbance (such as exposure to waves and currents), trawling was not detrimental (Cahoon et al. 2002). However, since the experimental treatment consisted of one trawling pass, observed changes do not accurately reflect those consistent with chronic trawling. A key issue in determining if trawling is having a negative impact to soft bottom communities is the frequency and intensity of disturbance. *Further analysis is needed to spatially quantify where, how often, and when trawling occurs in specific areas of soft bottom habitat.*

The impact of trawling and associated bottom changes on fish populations also depends in part on each species' habitat dependence (Auster and Langton 1998). Where a life stage of a demersal species is highly dependent (obligate) on the structural components of a habitat where trawling occurs, particularly for recruitment, there is a greater potential for that species to be impacted by trawling (Auster and Langton 1998). However, if individuals can move to and survive in alternative habitats, impacts may be less severe (i.e., adult flounder foraging over ocean bottom can occupy other habitats) (DMF 1999). Primary nursery areas and inlets are described as "recruitment bottlenecks" for estuarine dependent species in DMF (1999). Since larval flounder, shrimp, and Atlantic croaker must pass through inlets and recruit to shallow PNAs, trawling impacts in inlets and PNAs could be greater than trawling in ocean waters. *Protection of these "recruitment bottlenecks" from trawling or other impacts is therefore very important for estuarine dependent fish and invertebrates.* The current MFC restrictions on trawling protect PNAs. However, there are productive shallow water areas of soft bottom that are not designated as primary or secondary nursery areas but still serve as important habitat to many juvenile fish and invertebrates. *Shallow areas where trawling is currently allowed should be re-examined to determine if additional restrictions are necessary*. There are also other non-habitat related concerns regarding trawling in estuarine waters, including bycatch or socio-economic reasons which may warrant additional restrictions on trawling in estuarine waters. *However, further studies are needed to more accurately assess if trawling is having a negative effect on soft bottom habitat and justify if additional closures are necessary for habitat concerns*.

Bottom trawling in ocean waters

Many studies have been conducted around the world assessing the effect of trawling on soft bottom habitat in offshore waters. A thorough review of literature on fishing impacts to continental shelf benthos quantified impacts via a meta-analysis, examining data derived in part from studies of otter trawl effects on subtidal bottom in eastern North America (Table 6.8) (Collie et al. 2000). Some of their conclusions included:

- Otter and beam trawling were found to have fewer negative impacts on benthos than intertidal or scallop dredging or intertidal raking.
- In subtidal bottom, sand habitats were the least impacted, and muddy sand and gravel the most impacted.
- In muddy sand, polychaetes and large bivalves were most negatively impacted. Smaller bodied organisms are displaced by pressure waves in front of fishing gear.
- Depth and scale of fishing had insignificant effect on initial impact but significant effect on recovery. Recovery is slower where the spatial scale of impact is larger and in deeper waters where the bottom is more stable.
- Recovery was most rapid in less physically stable habitats such as sandy bottom (recovery in sand, estimated from modeling, was approximately 100 days).
- Benthos most impacted were Anthozoa (corals and anemones) and Malacostraca (crabs, amphipods), while copepods and ostracods were least impacted.
- Benthos had more negative responses to chronic disturbances than to acute disturbances.

- Epifaunal organisms are less abundant in areas subjected to intensive bottom fishing.
- Results suggested that fish and benthos in areas heavily fished would shift from communities dominated by high biomass species towards those with high abundance of small-sized organisms.
- *Large- scale long-term experiments with and without fishing pressure are needed, rather than short-term small-scale studies, to examine and better quantify cumulative fishing impacts and recovery patterns*.

Table 6.8. Trawl impact studies on the continental shelf of eastern North America.

Reference	Habitat	Depth (m)	Recovery Period (days)
Van Dolah et al. (1991)	Hard bottom	20	365
Kaiser and Spencer (1996)	Gravel	94	n/a
Van Dolah et al. (1991)	Sand	20	180
Van Dolah et al. (1991)	Sand	8	180
Auster et al. (1996)	Sand	30	3,650

These conclusions suggest that the dynamic soft bottom community found in nearshore ocean communities is less impacted by trawling and recovers much quicker than in estuarine systems. However, some long-term impacts to the benthic community may occur, especially to the epibiota, depending on the frequency of trawling and site-specific characteristics.

Status and trends of estuarine and ocean trawling

Trawling is primarily allowed in relatively deeper soft bottom areas. Map 3.5a-c (from shell bottom chapter) shows the areas where trawling is currently not allowed in estuarine waters. Use of trawl nets is not allowed in Albemarle Sound and is not allowed for taking of finfish in internal (estuarine) waters [15A NCAC 3L .0205, 15A NCAC 3J .0104(a&b)]. Shrimp trawling is not allowed in primary or secondary nursery areas [15A NCAC 3N .0105], or in No Trawl Areas [15A NCAC 3R .0106]. In North Carolina, bottom trawling in ocean waters is prohibited over hard bottom but is allowed over most soft bottom communities. Trawling is prohibited in military prohibited areas [15A NCAC 3I .0110 and 3R .0102], a designated sea turtle sanctuary seaward of Onslow Beach from June 1 to August 31 [15A NCAC 3I .0107 and 3R .0101], within 0.5mi of the beach from Virginia to Oregon Inlet [15A NCAC 3J .0202], and in designated crab spawning sanctuaries from March 1 to August 1 [15A NCAC 3L .0205]. Map 6.6 a-c shows areas where trawling and some other gears are restricted over soft bottom in ocean waters. The purpose of these regulations is to protect spawning areas and reduce bycatch or user conflicts.

Annual effort with various commercial trawling gears in North Carolina waterbodies is shown in Table 6.9 (DMF, unpub. data). Commercial shrimp trawling accounts for the majority of trawl trips (92% in 2002) (Table 6.9). About 75-80% of shrimp trawl trips occur in estuarine waters, with the remainder in ocean waters, primarily within state territorial seas (<3 mi offshore) off the central and southern coast of North Carolina. Total annual shrimp trawling effort has decreased since 1995 by about 5,500 trips. Total annual shrimp trawling effort has fluctuated with shrimp abundance but appears to have gradually declined since 1994. However, the lower commercial fishing effort observed from 1999 – 2002, when compared to earlier years, is thought to be mostly due to a change in licensing procedure (R. Carpenter, DMF, pers. com., 2004). In 1999, a recreational commercial gear license became available to fishermen. Under this license, shrimp may be caught recreationally using a trawl, but cannot be sold. Some fishermen, with previously held commercial licenses , switched from standard commercial gear licenses (SCGL) to recreational commercial gear licenses (RCGL). Effort from RCGL licenses are not included in the data shown in Table 6.9. In 2002, approximately 5000 trips for shrimp were reported (DMF, unpub. data).

Regionally, shrimp trawling effort has generally been greatest in Core and Bogue sounds and associated estuaries (3,400-7,200 trips/year) (Table 6.9). Pamlico Sound and associated rivers and estuaries account

for the second largest number of trawl trips per year, ranging from 2,900-5,500 trips/year. In 2000 and 2002, however, the Pamlico region accounted for slightly more trips than the Core/Bogue waters. Decreased effort in Core/Bogue sounds is not attributed to changes in shrimp management or habitat condition. In ocean waters, shrimp trawling is highly concentrated in the southern portion of the state (Onslow through Brunswick counties), primarily in the summer (approximately 2,300-3,400 trips/year). In contrast, the annual effort has ranged from 137 to 457 trips per year in the central district (Carteret County) and from 2 to 69 trips per year in the northern district (Virginia state line through Hyde County). Commercial shrimp trawl effort has remained relatively stable over time in the southern portion of the state.

Over 99% of crab trawling occurs in estuarine waters, while all directed flounder trawling (specially targeting flounder) occurs in ocean waters (i.e., no directed trawling for finfish is allowed in internal waters). The majority of crab trawling occurs in Pamlico Sound and adjacent estuarine rivers, followed by Core/Bogue sounds and estuaries. Flounder trawling effort occurs primarily in the northern and central portions of North Carolina's coastal waters. Effort in the northern district has varied from 14 trips in 1994 to 123 trips in 2002. In the central district, trips seem to be declining over time, with a peak of 95 trips in 1996 and 19 trips in 2002 (Table 6.9). Overall, current bottom trawling effort in estuarine waters for all fishery species is greatest in Pamlico Sound and associated estuaries.

Table 6.9. Annual number of trips reported for shrimp, crab, and flounder trawls in estuarine and ocean waters [1], 1994-2002 (DMF, unpub. data).

Shrimp trawl								
	Estuarine rivers and sounds				State ocean waters (< 3 mi.)			
Year	Albemarle estuaries	Core/Bogue estuaries	Pamlico estuaries	Southern estuaries	Northern district	Central district	Southern district	Total
1994	2	7,186	4,869	3,066	3	223	3,409	18,758
1995	0	7,252	5,185	3,361	41	316	3,414	19,569
1996	32	6,070	2,903	2,352	13	327	2,630	14,327
1997	1	5,745	4,790	2,722	23	229	2,742	16,252
1998	0	4,679	1,864	2,053	2	376	2,834	11,808
1999	1	4,868	4,105	2,178	18	457	3,468	15,095
2000	1	3,462	5,556	1,946	69	311	2,657	14,002
2001	0	3,534	3,211	1,273	6	137	2,528	10,689
2002	3	3,763	4,917	1,622	2	210	2,384	12,901

Crab trawl								
	Estuarine rivers and sounds				State ocean waters (< 3 mi.)			
Year	Albemarle	Core/Bogue	Pamlico	Southern	Northern district	Central district	Southern district	Total
1994	12	238	3,523	36	2	13	0	3824
1995	0	207	1,895	102	0	1	0	2205
1996	9	197	4,058	51	0	2	0	4317
1997	0	657	4,193	198	0	0	0	5048
1998	1	542	5,103	63	1	0	0	5710
1999	0	410	3,127	32	0	0	0	3569
2000	1	265	1,985	50	0	0	0	2301
2001	1	397	2,093	107	0	0	0	2598
2002	7	87	811	79	0	0	0	984

Flounder trawl								
	Estuarine rivers and sounds				State ocean waters (< 3 mi.)			
Year	Albemarle	Core/Bogue	Pamlico	Southern	Northern district	Central district	Southern district	Total
1994	0	0	4	1	14	35	0	54
1995	0	1	13	6	43	45	0	108
1996	0	1	5	0	17	95	0	118
1997	0	0	11	2	22	46	0	81
1998	0	0	1	0	115	87	0	203
1999	0	0	0	0	99	70	0	169
2000	0	0	0	0	84	22	0	106
2001	0	0	0	0	74	30	0	104
2002	0	0	0	0	123	19	0	142

[1] Albemarle Area: Albemarle Sound, Currituck Sound, and all tributaries of Albemarle Sound.
Pamlico Area: Pamlico, Croatan, and Roanoke sounds; Pamlico, Bay, Neuse, and Pungo rivers.
Core/Bogue Area: Core and Bogue sounds; Newport, White Oak, and North rivers.
Southern Area: Masonboro, Stump, and Topsail sounds; Cape Fear, New, Shallotte, and Lockwood Folly rivers; ICW.
Northern district ocean waters: Virginia line through Hyde County.
Central district ocean waters: Carteret County.
Southern district ocean waters: Onslow County to the South Carolina line.

Water quality degradation

The condition of soft bottom is determined by the character and quality of bottom sediments and the quality of the overlying water column. Solids and organic matter in the water column eventually settle out and become a part of the soft bottom habitat. However, soft bottom sediments can also be

resuspended by disturbances (e.g., storms and human activities such as dredging). The cycling of material between the bottom and the water column was discussed previously in this chapter and in the water column chapter. In general, bottom sediments tend to act more as a sink than a source with regards to benthic-pelagic coupling. Aquatic organisms can accumulate pollutants from the sediment or the water column. Because water quality inevitably affects soft bottom (i.e., anoxia in the water column leads to increased production of hydrogen sulfide (H_2S), a gas that is toxic to aquatic life, in bottom sediments), many of the same threats to the water column are threats to soft bottom. The primary pollutants of concern to soft bottom are discussed below.

Toxic chemicals

Toxic chemicals that tend to accumulate in bottom sediments include:

- heavy metals
- polycyclic aromatic hydrocarbons (PAHs)
- petroleum hydrocarbons
- pesticides
- polychlorinated biphenyls (PCBs)
- ammonia

Of the heavy metals, arsenic, copper, cadmium, chromium, nickel, lead, zinc, tin, and mercury are among the greatest concerns. While toxins can fluctuate between the sediment and water column, concentrations of toxic chemicals tend to accumulate in sediments to several orders of greater magnitude than overlying waters (Kwon and Lee 2001). The bioavailability and transport of a chemical depend on the form of the chemical incorporated into the sediments, the feeding habits and condition of aquatic organisms, and the physical and chemical conditions of the environment. Because toxins can accumulate and persist over time, chemicals that have been banned since 1977, such as DDT, Diedrin, and TBT, continue to be found in sediments (Marburger et al. 2002). Toxic chemicals can become active in soft bottom sediment or overlying waters through several mechanisms, including resuspension from natural weather events or human activities. Toxins can also be active in surface waters, when dry sediment is hydrated from rainfall or runoff, toxic chemicals in the soils become oxidized, and heavy metals are released and transported downstream by heavy rains or water movements. Also, several studies have shown that mercury and other metals are released from peat soils subjected to intensive drainage (Evans et al. 1984; Gregory et al. 1984).

Because low concentrations of heavy metals in the water column can be easily incorporated into fine-grained sediment, chemicals can accumulate in the sediment to toxic levels and be resuspended into the water column (Riggs et al. 1991). Studies have shown that fine-grained sediments are the primary reservoir for heavy metals, particularly organic rich muds (ORM) (Riggs et al. 1991). Since organic rich muds are the most extensive sediment type in North Carolina's estuaries and since many primary nursery areas are composed of ORM, resuspension of contaminated ORM sediments in PNAs is of particular concern.

Contaminated sediments affect benthic feeding fish and invertebrates in several ways. Some toxins can inhibit or alter reproduction and development of marine and aquatic organisms, or cause mortality in some situations (Weis and Weis 1989; Gould et al. 1994). Large spills of toxic chemicals, such as pesticides or petroleum products, can result in fish kill events. In North Carolina, spills of pesticide, chlorinated water, and sewage waste were responsible for 8% of fish kill events in 2001 (DWQ 2001b)[78]. Some heavy metals and pesticides cause hormone alterations that affect reproduction (Wilbur and Pentony 1999). Certain PAHs have been shown to cause mutations or cancer in fish (White and Triplett 2002). Documented effects of PAHs to flatfish include DNA damage, liver lesions, and impacts on

[78] Other suspected causes reported: unknown (46%), dissolved oxygen (34%), blooms (4%), other (9%), and bycatch (1%).

growth and reproduction (Johnson et al. 2002).

Early life stages (embryos and larvae) of fish are most susceptible to toxins (Funderburk et al. 1991; Gould et al. 1994; Rice et al. 2001). Visible indications of heavy contamination are development of lesions, deformities, and tumors on fish or high mortality rates of larvae. Anadromous fish larvae are particularly sensitive to many toxins (Funderburk et al. 1991). In Alaskan waters, salmon eggs and larvae were killed or exhibited damage for up to four years following long-term exposure to low concentrations of weathered crude oil, and migrating salmon fry had reduced growth rates and population reductions (Rice et al. 2001). See Appendix L for more information on toxicity thresholds for early life stages of fish. Mollusks are known to be very sensitive to petroleum products, pesticides, and TBT, with relatively low levels of exposure affecting reproduction, tissue development, growth, and survival (Funderburk et al. 1991) (refer to shell bottom chapter for toxicity levels). Because macrobenthic invertebrate diversity significantly declines with increasing sediment contamination (Weis et al. 1998; Brown et al. 2000; Dauer et al. 2000), food resources for benthic feeders may be limited in areas having significant contamination.

Lethal and sublethal levels of toxicity are known for some benthic aquatic species. However, most information comes from acute toxicity tests conducted in laboratory settings on standard test species. Data are lacking on chronic or sublethal toxicity levels for many important fishery species and interactions of contaminants in the field. Following oil spills, sub-lethal levels of contamination can delay population recovery due to indirect effects, and may lead to increased fish mortality where predation risk is size-dependent (Peterson et al. 2003b). *More information is needed on the in situ effects of various contaminant levels, in combination with other contaminants and existing environmental stressors, to many important fish species in North Carolina.*

While some aquatic organisms experience mortality from exposure to toxins, chemicals may bioaccumulate to toxic levels within surviving organisms and pass through the food chain. Multiple studies have shown clear connections between concentrations of toxins in sediments and those in benthic feeding fish and invertebrates (Kirby et al. 2001; Marburger et al. 2002). Heavy metal contamination of sediments has been documented to result in elevated trace metal concentrations in benthic feeding striped mullet, shrimp, oysters, and flounder (Kirby et al. 2001; Livingstone 2001). Largemouth bass and catfish, stocked in a restored and flooded freshwater wetland, had high concentrations of organochlorine (chlordane, DDT, dieldrin) and internal contaminants were significantly correlated to contaminant levels in the sediment (Marburger et al. 2002). Toxic contaminants are also considered one of the most serious threats to native freshwater mussels, which are the most imperiled fauna in North America (Keller 1996).

The bioaccumulation of toxins in fish may pose a risk to human health. High levels of mercury have been found in four saltwater fish species (sharks, swordfish, tilefish, and king mackerel) and three freshwater species (bowfin, largemouth bass, and chain pickerel). Fish consumption advisories have been posted for all of these species (<http://www.epi.state.nc.us/epi/fish/current.html>, 2003). The saltwater fish consumption advisory for sharks, swordfish, tilefish, and king mackerel covers the entire state of North Carolina and much of the lower East Coast. The fish advisory for bowfin, largemouth bass, and chain pickerel extends south and east from Interstate 85. In addition, several site-specific advisories exist (<http://www.epi.state.nc.us/epi/fish/current.html>). Limits on consumption of catfish and carp due to dioxin contamination exist for Albemarle Sound, the lower portion of Roanoke River from Williamston to the mouth of Albemarle Sound, all of Welch Creek, a tributary of Roanoke River, and Walters Lake, a reservoir.

Toxic chemicals come from localized point sources as well as diffuse nonpoint sources. Point sources include industrial and municipal waste discharges. Nonpoint sources of toxins include urban runoff containing household and yard chemicals, roadways, marinas and docks, boating activity, runoff from agriculture and forestry, industrial emissions, spills from industrial shipping, and dredge spoil disposal (Wilbur and Pentony 1999). Refer to the water column chapter for more detailed information on the

sources of toxic chemicals.

The extent of sediment contamination in North Carolina coastal waters is not well known. Sediment sampling is not conducted by the DWQ since there are no sediment standards in the state. Studies examining sediment contamination at sites in North Carolina soft bottom have found various levels of contamination. The EPA Environmental Monitoring and Assessment Program surveyed 165 sites within North Carolina's sounds and rivers during 1994-1997 to evaluate condition of bottom sediments (Hackney et al. 1998). Highest contamination levels occurred in low salinity areas with low flushing and high river discharge. Benthic communities were dominated by tolerant opportunistic species and low species richness. Laboratory bioassays showed that sediments from many sites were toxic to biological organisms. However, because of the low sample size, frequency of sampling, and the confounding effects of hypoxia in areas sampled, results from this study may not accurately assess the condition of North Carolina sediments (C. Currin, NOAA, pers. com., 2003).

Concentrations of heavy metals in the Neuse and Pamlico estuaries have been assessed (Riggs et al. 1989; Riggs et al. 1991). In the Neuse River, surface sediments were found to contain elevated levels of several heavy metals, including zinc, copper, lead, and arsenic. Furthermore, 17 areas between New Bern and the mouth of the river were identified as "contaminated areas of concern". The contaminated sites were primarily attributed to permitted municipal and industrial treatment plant discharges. Marinas were also found to contribute substantial amounts of copper and variable amounts of zinc and lead. Nonpoint sources were more difficult to evaluate. In the Pamlico River, heavy metal contamination was less severe, although arsenic, cobalt, and titanium exceeded the levels found in the Neuse River. These studies suggest that sediment contamination in some estuarine areas, especially those where both organic rich mud and waste water discharges are present, may be significant and could affect fish populations and the base of their food chain. *To better determine if contaminated sediment is a significant threat to coastal fish habitat, the distribution and concentration of heavy metals and other toxic contaminants in freshwater and estuarine sediments need to be adequately assessed and areas of greatest concern need to be identified. Continued minimization of point and nonpoint sources of toxic contaminants is vital for protecting not only soft bottom but also the other fisheries habitat.*

Nutrients

Increased nutrient loading and accumulation in bottom sediments are other concerns to this habitat. The effects of nutrient enrichment are complicated by additional stressors, such as toxins or hydrological modifications, and by benthic-pelagic coupling (Riedel et al. 2003). High concentrations of organic material in bottom sediments serve as continual sources of additional nutrients to the water column, which can fuel algal blooms. In the shallow Neuse River estuary, high but variable rates of exchange of nutrients between the water column and soft bottom were noted, with soft bottom efficiently storing and providing nutrients that can fuel algal blooms that may lead to hypoxia (Luettich et al. 1999). When nutrient loading reductions occur, a decline in nutrient levels may not be observed in a water body until the nutrient supply in the sediment is depleted (Luettich et al. 1999), making management strategies difficult to evaluate in the short term. Work is currently underway to determine the contribution of resuspended nutrients from bottom sediments to phytoplankton production (<http://www.marine.unc.edu/Paerllab/research/mudboy>, 2003). *Long-term monitoring is required, in combination with management actions that reduce discharge concentrations, to determine effectiveness and future management needs.*

Soft bottoms in North Carolina's estuaries tend to store nutrients for several reasons (Peterson and Peterson 1979). Small clay sized sediment particles that are abundant in ORM adsorb nutrients readily. In addition, suspension feeding invertebrates remove nutrients and particles from the water column which later are transformed and deposited on the bottom as feces (a process known as biodeposition). These nutrients can become stored in the sediment, but later can be resuspended into the water column, maintaining nutrient concentrations at high levels in estuarine waters. The ebb and flood circulation

increases the residence time of particles in estuarine waters, further retaining nutrients in the system (Peterson and Peterson 1979). Extensive monitoring in the Neuse River revealed that large quantities of nutrients were stored in the sediment. Refer to the water column chapter for detailed discussion of the sources and status of nutrient enrichment in the water column.

Oxygen-depleted sediment

Adequate supply of dissolved oxygen is critical to survival of sessile benthic invertebrates and fish living on or in soft bottom habitat. In freshwater systems, low oxygen levels resulting from eutrophication has been suggested as an important source of mortality in mussels (Neves et al. 1997). In mesohaline estuaries, low oxygen events occur when the water column becomes stratified for a long period, particularly during summer in areas of deeper water (Tenore 1972). If stratification persists, hypoxic events in the water column can cause changes in the physical and chemical conditions at the sediment-water interface, lead to stress or mortality of benthic organisms, and reduce species richness (Tenore 1972). In the benthic community, polychaetes tend to be most tolerant to low oxygen, followed by bivalves and then crustaceans (Diaz and Rosenberg 1995). Severe oxygen depletion in the sediment also results in release of toxic levels of sulfide into bottom waters (Luettich et al. 1999).

Mass mortality of benthic infauna due to anoxia and toxic sulfide levels has been documented in the deeper portions of the Neuse River estuary, in association with stratification of the water column in the summer (Lenihan and Peterson 1998; Luettich et al. 1999). During these events, oxygen depletion caused mass mortality of infauna such as clams and worms. Epifauna like oysters and mud crabs and some benthic fish, like blennies, also died when adequate tall refuge (oyster reefs) with oxygenated water was not available (Lenihan and Peterson 1998). More mobile benthos, such as blue crabs, left their burrows when oxygen was not available and moved to shallower or higher areas. In 1997 during a large hypoxic event in the Neuse River estuary, the abundance and biomass of *Macoma balthica* and *M. mitchelli*, the dominant benthic invertebrates and critical food sources for demersal fishes such as spot and croaker, declined by 90 - 100% over a 100 km^2 area (Buzelli et al. 2002). The areas of high benthic mortality coincided with the area estimated to have been the most severely oxygen depleted.

Low oxygen in bottom sediments can also affect the primary productivity of soft bottom and predation on the benthic community. Benthic microalgae are limited to oxygenated sediments (MacIntyre et al. 1996). During a severe anoxic event, mortality of benthic microalgae can occur, due to anaerobic sediments and the higher turbidity that often accompanies the stratification of the water column (M. Posey, UNC-W, pers. com., 2003). Predation on members of the benthic community by species such as flounder, spot, blue crab, and croaker generally increases in the short-term since burrowing organisms tend to move into the shallowest sediment layers to avoid sulfide release and lack of oxygen in deeper sediments (Luettich et al. 1999). However, the overall reduction in prey could decrease long-term fish production (P. Peterson, UNC-CH, pers. com., 2004). Results from statistical modeling, utilizing field data from the Neuse River, indicated that benthic invertebrate mortality, resulting from intensified hypoxia events, reduced total biomass of heterotrophs (demersal predatory fish and crabs) during the summer by 51% in 1997 and 17% in 1998 (Baird et al. 2004). The decrease in available energy (fewer benthic invertebrates) greatly reduced the ecosystem's ability to transfer energy to higher trophic levels at the time of year most needed by juvenile fish (Baird et al. 2004).

When the benthic community is depleted by a low oxygen event, the pattern of recolonization of the soft bottom will affect higher trophic levels differently over time (Luettich et al. 1999). Opportunistic, fast-growing species of polychaetes and copepods will begin to recolonize the bottom first. Juvenile clams and larger polychaetes will recruit afterwards. The various successional stages may affect or benefit different benthic feeders to differing extents. For example, early successional communities composed of very small, shallow-burrowing opportunists (capitellid worms) and meiofauna may favor small species, such as penaeid shrimp and larval and juvenile croaker and red drum, but not provide food for large adult fish species. Partially recovered benthic communities consisting of polychaetes and small juvenile clams

could benefit demersal species like spot, croaker, and blue crab. A fully recovered community with deep burrowing polychaetes and large clams might benefit adult spot and hogchoker but not benefit shrimp (Luettich et al. 1999).

While hypoxia and anoxia can occur naturally, they can also be attributed, in part, to anthropogenic changes in the system, including excess nutrient and organic loading from waste discharges, nonpoint runoff, streambank erosion, and sedimentation (Schueler 1997). In the Neuse River system, MODMON studies found that the sediment oxygen demand is much greater than the biological oxygen demand in the water column. Oxygen depletion in the water column was positively correlated with accumulation of organic material in the sediments (Luettich et al. 1999). Site-specific information on sediment condition is generally lacking in other areas of North Carolina. Several studies have indicated that the frequency, duration, and spatial extent of low oxygen events have increased over the years due to increasing eutrophication of coastal waters from human and animal waste discharges, greater fertilizer use, loss of wetlands, and increased atmospheric nitrogen deposition (Cooper and Brush 1991; Dyer and Orth 1994; Paerl et al. 1995; Buzelli et al. 2002). *More information is needed to understand the consequences on the estuarine food web and to what extent anoxia is impacting the soft bottom community.* As hypoxia and anoxia of bottom sediments become more frequent, the quality of soft bottom habitat will deteriorate. *Efforts are needed to reduce anthropogenic nutrient loading, particularly in systems that have a history of hypoxia and anoxia.* Fish kill events that have been attributed to low oxygen can be used as an indication of these hot spot areas.

Turbidity and sedimentation

Organisms in soft bottom habitat are adapted to shifting and changing sediments. Shoreline erosion and stormwater runoff transport sediment into coastal waters, which helps maintain shallow water habitat. However, when sedimentation is excessive, there can be negative impacts. Impacts of sedimentation include (Schueler 1997):

- Physical smothering of benthic invertebrates
- Reduced survival of fish eggs
- Destruction of fish spawning areas in freshwater streams
- Elimination of sensitive species such as anadromous fish or darters
- Increase in sediment oxygen demand and depletion of oxygen
- Decline in freshwater mussels
- Reduced channel capacity, and subsequent acceleration of downstream bank erosion and flooding

The primary areas that are adversely affected by sedimentation are freshwater systems and upstream estuarine systems. The effects of sedimentation can be very gradual. Excessive deposition of sediments in a stream over time causes the depth and velocity to decrease and the width to increase. Consequently, the number and depth of riffle pools, and the temperature gradients within them, decrease. These riffle pools are important habitat for some fish species, such as minnows and darters (AFS 2003). The deposition of silt and fine sediment in gravel bottom rivers and streams fills the interstices of the gravel, and can decrease dissolved oxygen content if the organic content is high. Most North Carolina coastal rivers and streams do not consist of gravel substrate, however.

Excess sedimentation can reduce or eliminate aquatic insect larvae from stream bottoms (AFS 2003). These larvae are the basic fish food source in freshwater streams, and impacts to them can affect the productivity of associated fish species (AFS 2003). High levels of suspended sediment in an estuarine or marine habitat can greatly reduce successful settlement of larval clams and oysters, and can smother other benthic invertebrates (AFS 2003). In some areas, historic oyster bars have been completely covered with fine sediment and mud (P. Peterson, UNC-CH, pers. com., 2004). Refer to the water column chapter for information on habitat degradation from sedimentation and options for addressing sedimentation.

Excessive sedimentation has been cited as the major cause of freshwater mussel decline in the United States since the late 1800s (Neves et al. 1997; Box and Mossa 1999). Poor land use practices, including construction and road building activities, agriculture, forestry, dams, reservoirs, and channelization are among the causes cited for sedimentation (Neves et al. 1997; Box and Mossa 1999). Because freshwater mussels are dependent on specific host fish to complete their reproductive cycle, changes in resident fish populations, due to dams, channelization, or other habitat alterations, jeopardize survival of mussels (Neves et al. 1997). The decline in mussel populations in North Carolina is considered severe (Neves et al. 1997). Over 50% of approximately 60 native freshwater mussels are designated as Endangered, Threatened, or of Special Concern within the state and approximately 22 of these occur within coastal draining river basins (Neves et al. 1997; <http://www.ncwildlife.org>, April 2004). The Tar River spiny mussel (*Elliptio steinstansana*) and dwarf wedgemussel (*Alasmidonta heterodon*) are federally and state endangered species that occur in the upper Tar and Neuse rivers, respectively (<http://www.ncwildlife.org>, April 2004). Since these species are highly sensitive to water quality and habitat degradation, freshwater mussels are often considered an excellent early biological indicator of freshwater stream condition.

Existing management measures

The majority of the management measures discussed in the water column and other habitat chapters would also benefit soft bottom by reducing loading of point and nonpoint pollutants. Recently, several actions have been taken regarding beach nourishment and management of intertidal and subtidal ocean soft bottom habitat. The North Carolina General Assembly enacted House Bill 1840 in the 2000 Session, which required DENR to prepare a Beach Management Plan (DENR 2000b) and make recommendations on several related policy issues. This plan was to be completed by April 2001, although no funding was allocated for this task. *Completion of a beach management plan using the best scientifically based information could be helpful in directing beach nourishment activities in a manner that minimizes impacts to the soft bottom community.*

In addition, the Legislative Research Commission studied the cost, need, and feasibility of beach nourishment, and submitted a report to the 2001 Session of the General Assembly on Coastal Beach Movement, Beach Renourishment, and Storm Mitigation as mandated by the 1999 General Assembly (Legislative Research Commission 2001). The focus of this report was on economics more than environmental impacts, however. As impacts from beach nourishment are increasingly documented and the magnitude of this activity increases, the scientific community has expressed concern regarding the long-term consequences to fish habitat. An environmental forum on beach nourishment was held in April 2001 by the North Carolina Coastal Federation to compile information and knowledge of scientists on beach nourishment and associated impacts to the marine and estuarine environment. In 2000, the MFC adopted a beach nourishment policy that provides specific suggestions and guidance to agencies concerning the effects of beach nourishment on fisheries stocks and the habitats on which they depend. Policies call for avoidance, minimization, and mitigation for impacts that do occur, monitoring to document pre- and post- conditions, and assessments that take cumulative impacts into account (Appendix K).

In July 2001, the USFWS designated 1,798 miles of intertidal and supratidal (dry) beaches and dunes to the mean low water (MLW) in eight states as Critical Habitat for the wintering population of piping plover (*Charadrius melodus*). Critical Habitat is defined in the Endangered Species Act as a specific geographic area that is essential for the conservation of a threatened or endangered species and that may require special management and protection (<http://endangered.fws.gov/listing/critical_habitat.pdf>, 2004). This may include suitable habitat that is not currently occupied by the species but is needed for its recovery, thereby providing more habitat protection. Federal agencies are required to consult with the USFWS to ensure that any federal actions do not adversely modify Critical Habitat functions, including areas not currently occupied by a designated species. This action, by providing protection to wintering habitat, also protects intertidal benthos, which will benefit foraging habitat for piping plover as well as

benthic feeding surf fish. There are 18 designated areas in North Carolina, primarily inlet systems and adjacent shoals and spits. Refer to website (<http://plover.fws.gov>, 2003) for maps of the designated areas.

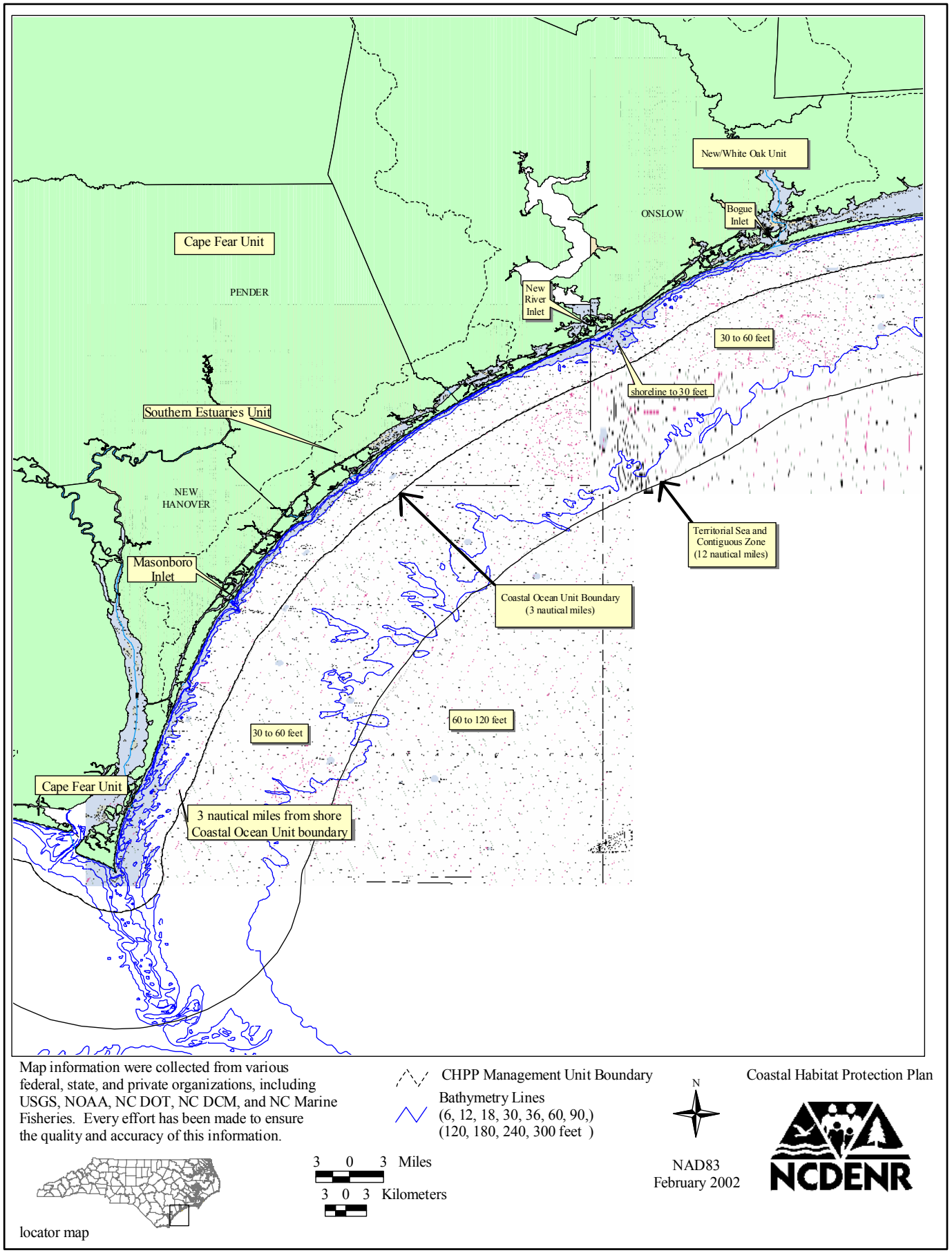
Another federal initiative that provides resource protection to ocean soft bottom habitat is the Coastal Barrier Resources Act (COBRA). Initiated in 1982, COBRA (16 U.S.C. 3501-3510) generally restricts federal spending for establishment or expansion of infrastructure (roads, wastewater systems) and disaster relief funds in high-risk coastal areas. It also prohibits federally guaranteed low-cost flood insurance from designated areas that might contribute to development on designated undeveloped barrier islands. The restrictions are intended to discourage unwise development in ecologically sensitive areas. In North Carolina, some of the areas requesting storm damage reduction projects (portions of Cape Hatteras and North Topsail Beach) are located within federally designated COBRA sites (Map 6.3 a-c). This act demonstrates an innovative strategy to protect undeveloped natural resources through economic disincentives, while imposing no new regulations on how an individual may develop their land. *Funding for beach nourishment in designated COBRA areas should not be supported by state or local funds*.

6.5 SUMMARY OF SOFT BOTTOM CHAPTER

Soft bottom habitat is the unvegetated bottom sediment in all coastal systems, and includes features such as inlets, shoals, channel bottoms, intertidal ocean beaches, and cape shoals. Soft bottom plays a key role in primary productivity in shallow estuarine and marine systems. This habitat strongly influences the water column through dynamic cycling processes, storing and releasing nutrients and chemicals over time. Other ecosystem functions of soft bottom include the reduction of physically destructive storm effects on oceanfront beaches, and providing sand sources for barrier island and inlet migration. Soft bottom habitat is particularly important as a foraging area for all size ranges of bottom feeding fish and invertebrates, such as blue crabs, shrimp, flounders, striped mullet, spot, croaker, and kingfish. Burrowing mollusks (e.g., hard clams, coquina clams), flatfishes (e.g., southern flounder, hogchoker) and baitfish (e.g., striped mullet) are highly associated with shallow soft bottom, while larger benthic feeding predators (e.g., weakfish, coastal sharks, sturgeons) typically utilize deeper soft bottom areas. Valued fishery species that depend on healthy soft bottom habitat include hard clams, shrimp, blue crabs, southern flounder, Atlantic croaker, striped mullet, kingfish, and spot. Of these, the DMF stock status of Atlantic and shortnose sturgeons, southern flounder, and coastal sharks was Overfished. Striped mullet and Atlantic croaker were listed as Concern. The Atlantic sturgeon, which is classified as Overfished, has been under a fishing moratorium since 1991 but has not shown signs of recovery. Coastal inlets have been federally designated as Habitat Areas of Particular Concern for blue crab, estuarine-dependent snapper and grouper, penaeid shrimp, and red drum.

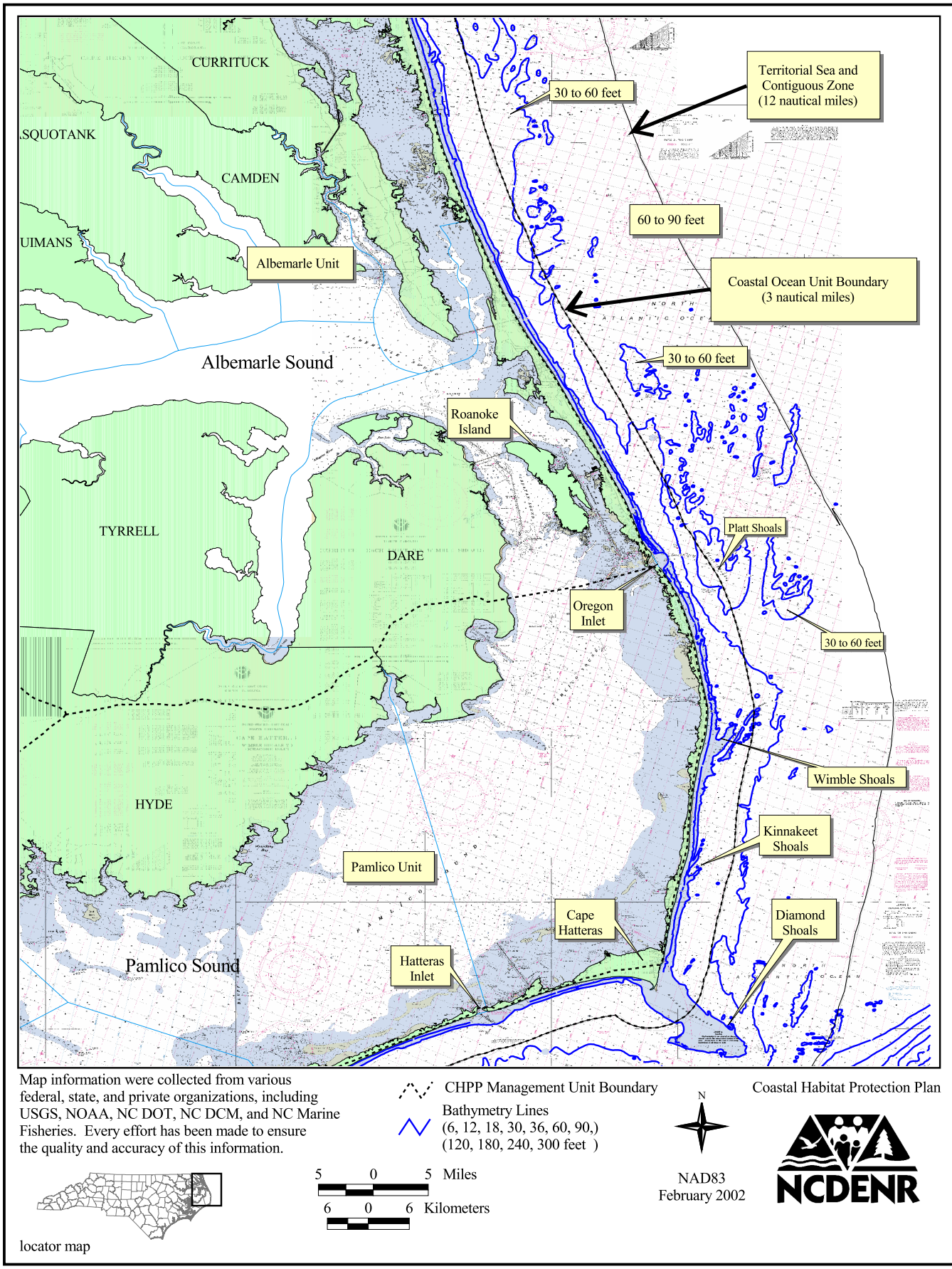
Inadequate data are available to clearly indicate the current condition of soft bottom habitat. Fortunately this habitat is relatively resistant to a changing environment. This is the most abundant submerged coastal fish habitat, and estuarine acreage of soft bottom has undoubtedly increased over time as shell bottom, SAV, and wetland habitats have declined.

Threats of greatest concern include large-scale alterations such as dredging of productive shallow bottom areas, construction of marinas and docks, bottom dredge and trawl fisheries in estuarine waters, and large-scale beach nourishment. Depletion of oxygen and toxic contamination of bottom sediments are the major water quality concerns since those conditions can cause mortality or poor recruitment of benthic invertebrates, which in turn can affect food availability for numerous benthic feeding invertebrates and fish. Therefore, minimizing dredging of productive shallow bottom, properly managing beach nourishment to maintain healthy benthic communities in the surf zone, and reductions in nutrient and toxin loading in all coastal waters are the primary management needs for soft bottom.



Map 6.1a. Location of marine topographic features, southern coastal area of North Carolina.

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Map information were collected from various federal, state, and private organizations, including USGS, NOAA, NC DOT, NC DCM, and NC Marine Fisheries. Every effort has been made to ensure the quality and accuracy of this information.

CHPP Management Unit Boundary

Bathymetry Lines
(6, 12, 18, 30, 36, 60, 90,)
(120, 180, 240, 300 feet)

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Coastal Habitat Protection Plan

NCDENR

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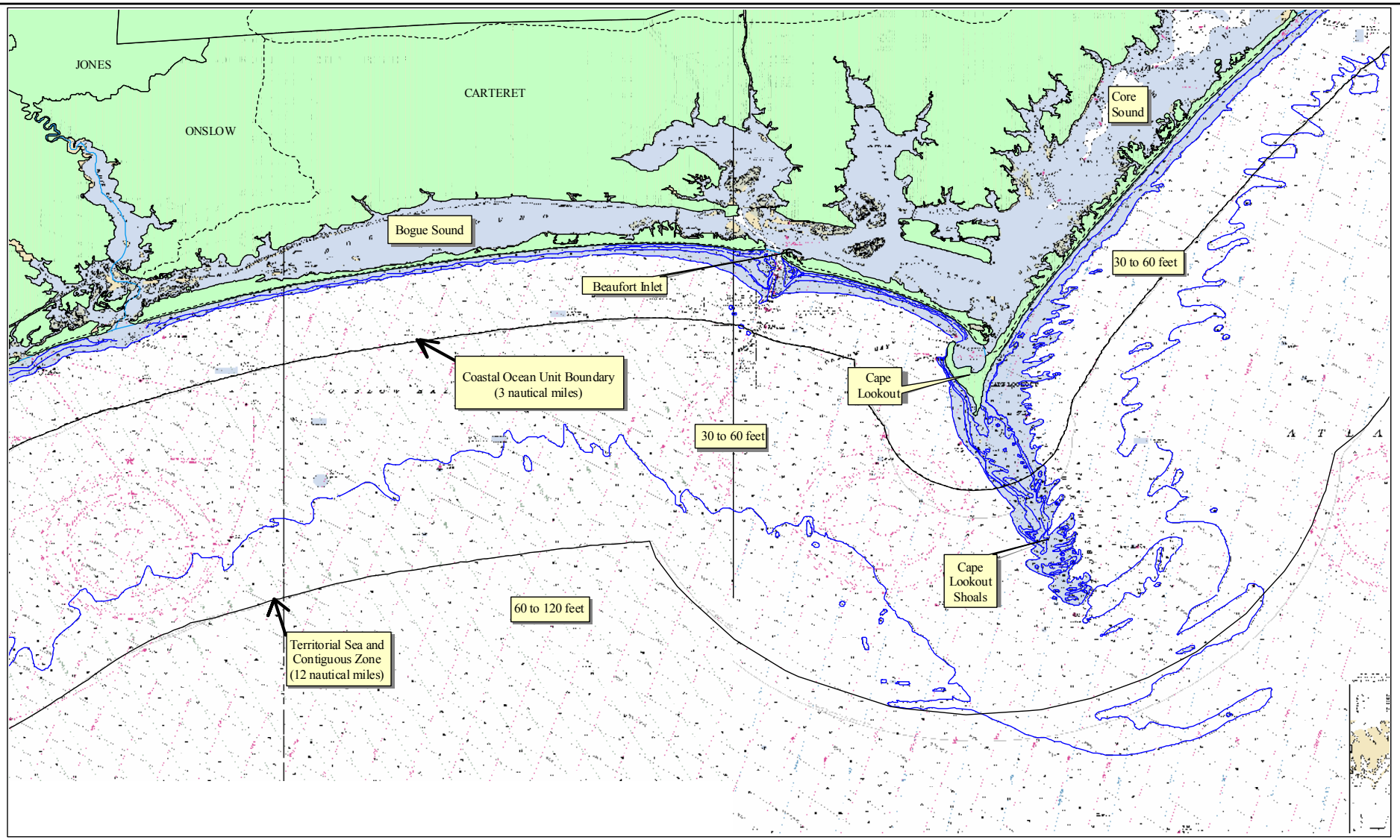
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Map 6.1b. Location of marine topographic features, northern coastal area of North Carolina.

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Map information were collected from various federal, state, and private organizations, including USGS, NOAA, NC DOT, NC DCM, and NC Marine Fisheries. Every effort has been made to ensure the quality and accuracy of this information.



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CHPP Management Unit Boundary

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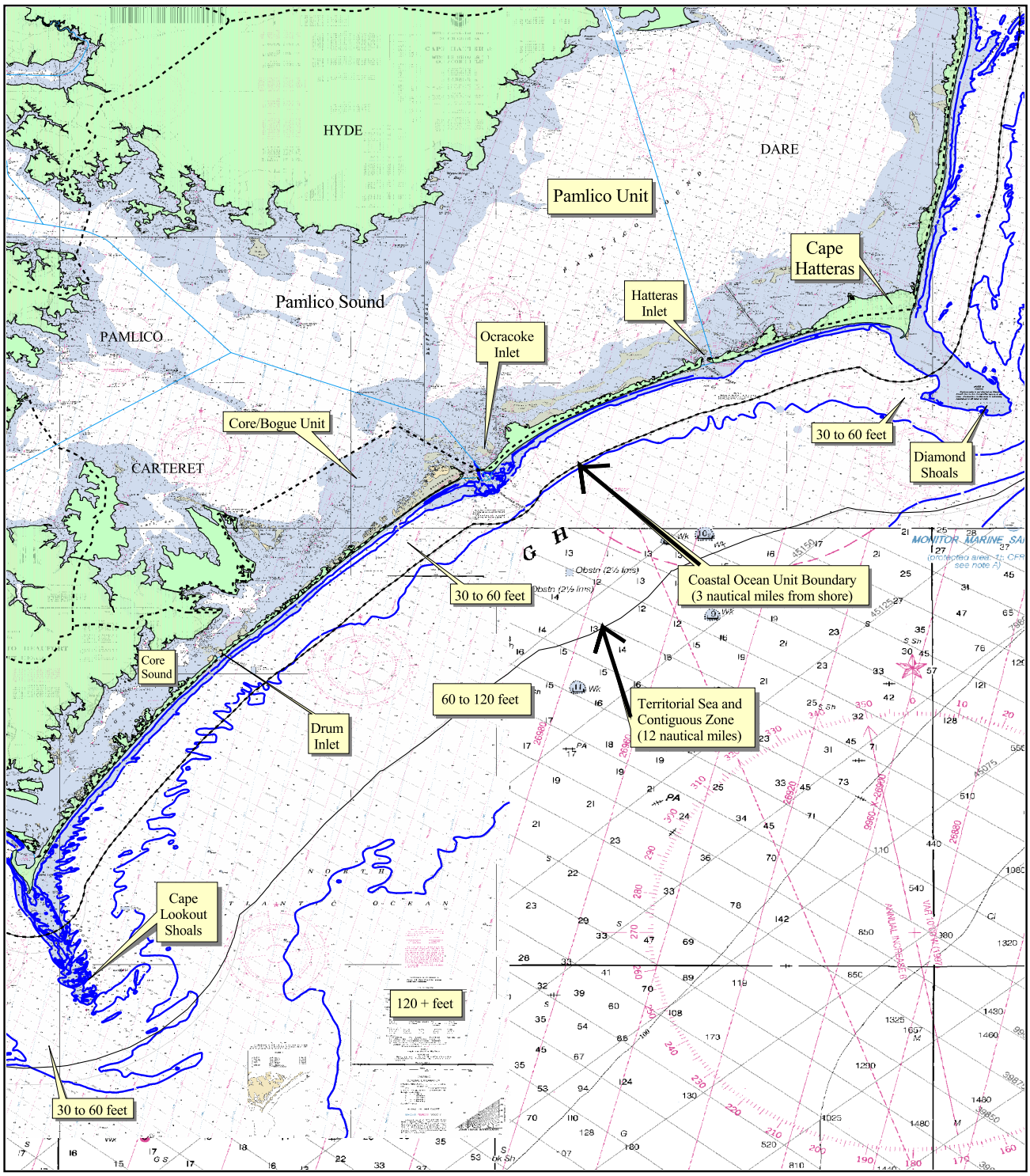
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Coastal Habitat Protection Plan

NCDENR

Map 6.1c. Location of marine topographic features in the Cape Lookout area of North Carolina.

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Map information were collected from various federal, state, and private organizations, including USGS, NOAA, NC DOT, NC DCM, and NC Marine Fisheries. Every effort has been made to ensure the quality and accuracy of this information.

CHPP Management Unit Boundary

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Coastal Habitat Protection Plan

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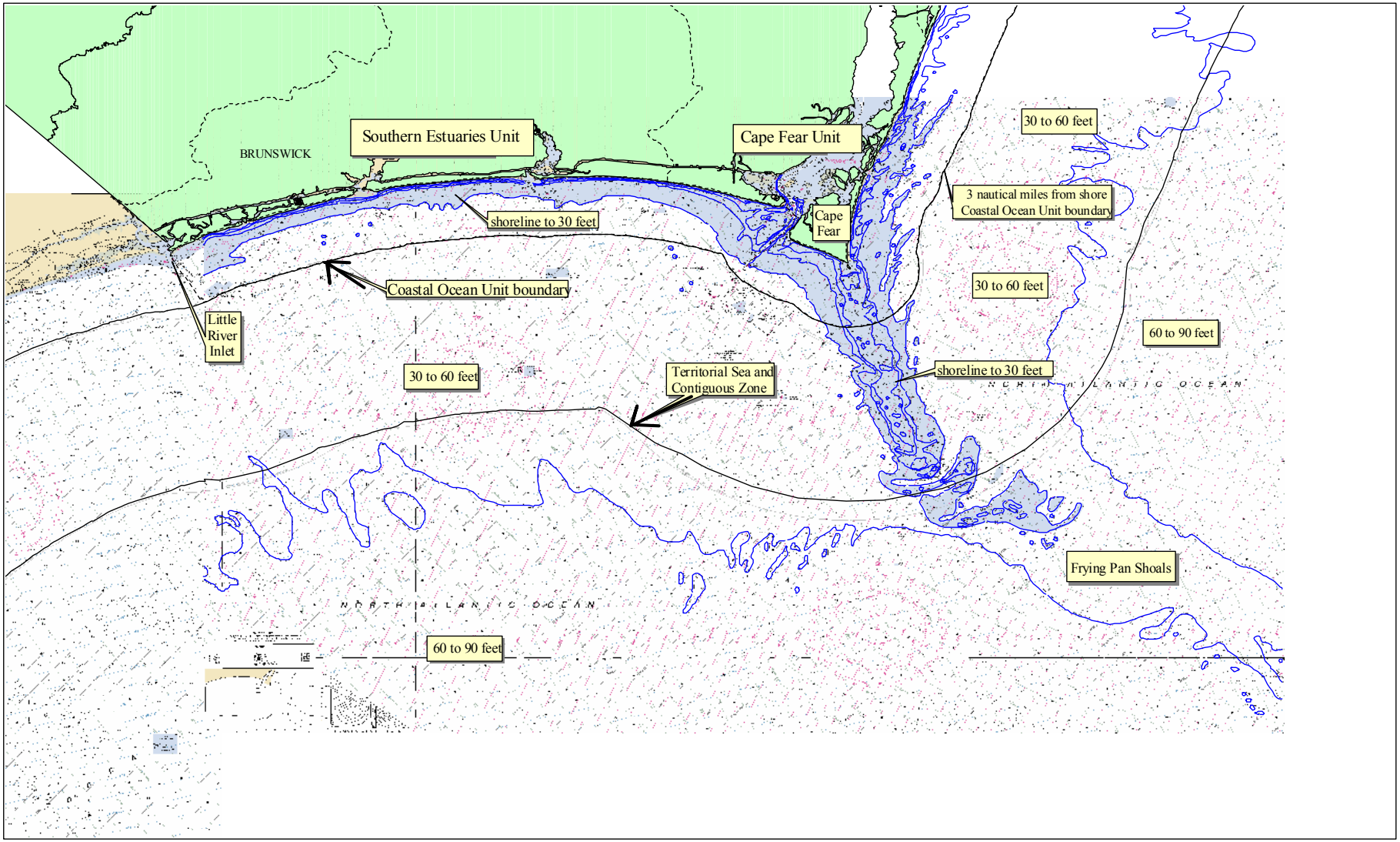
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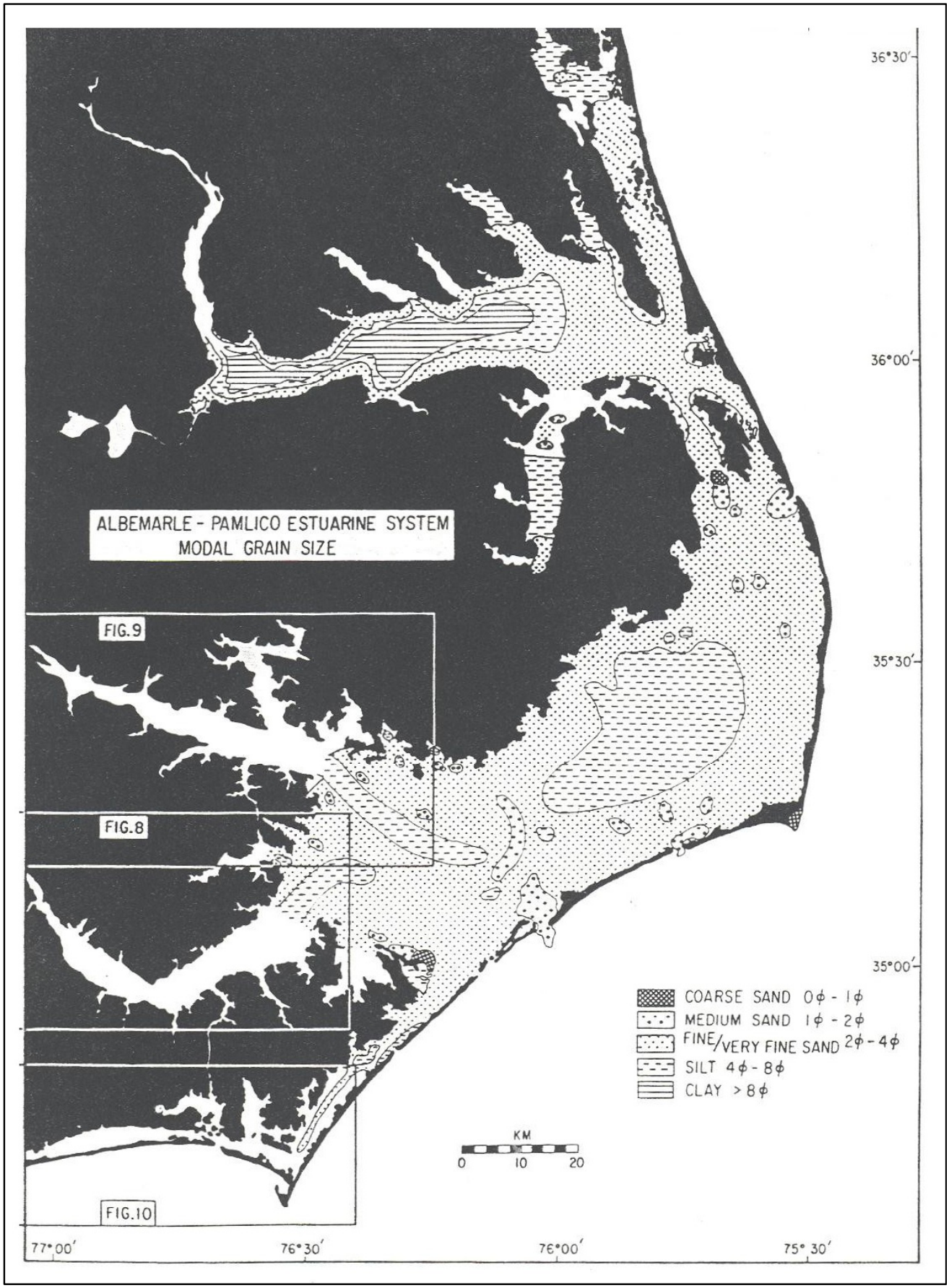
Map 6.1d. Location of marine topographic features between Cape Lookout and Cape Hatteras, North Carolina.

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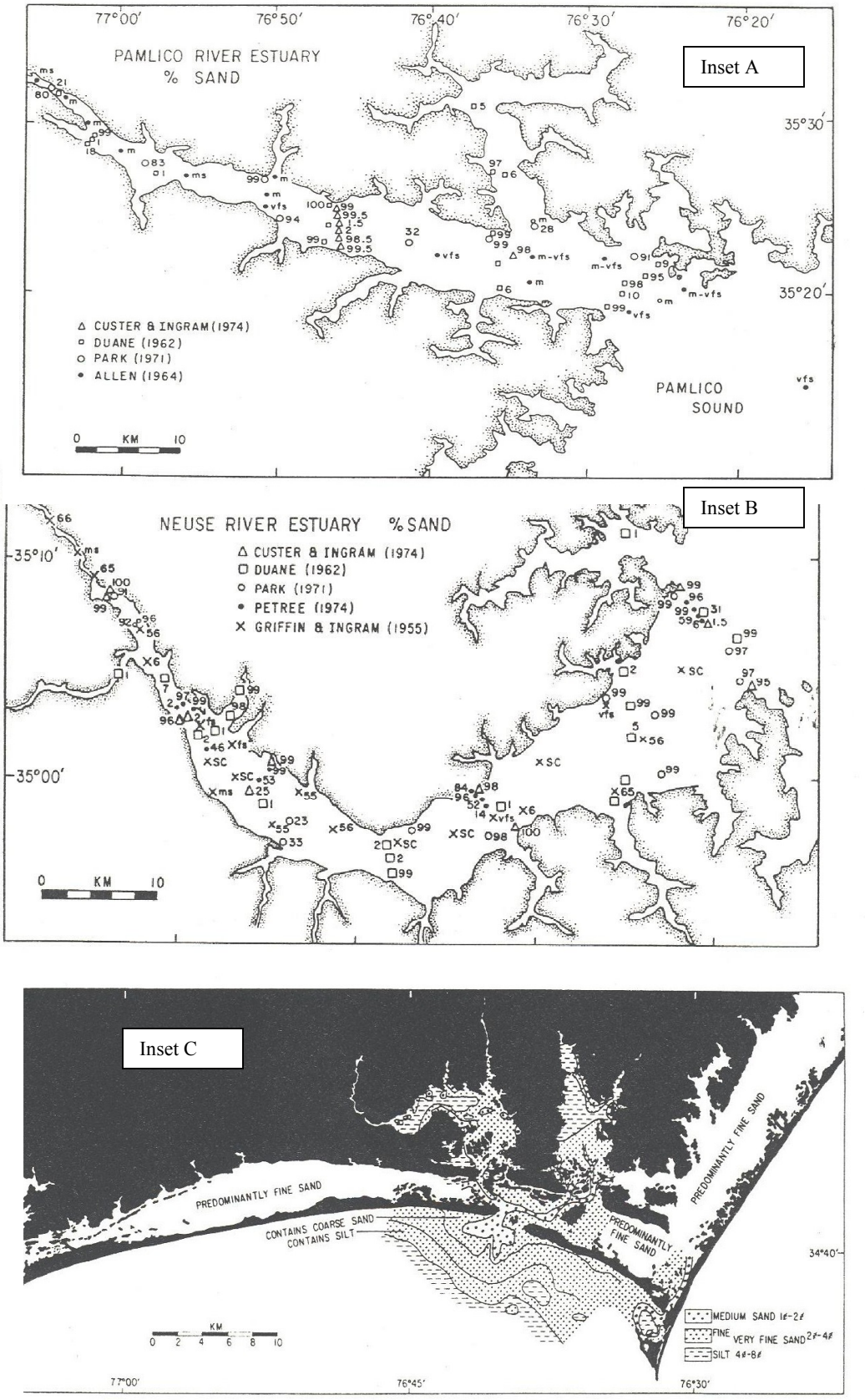
Map 6.1e. Location of marine topographic features in the Cape Fear Area, North Carolina.

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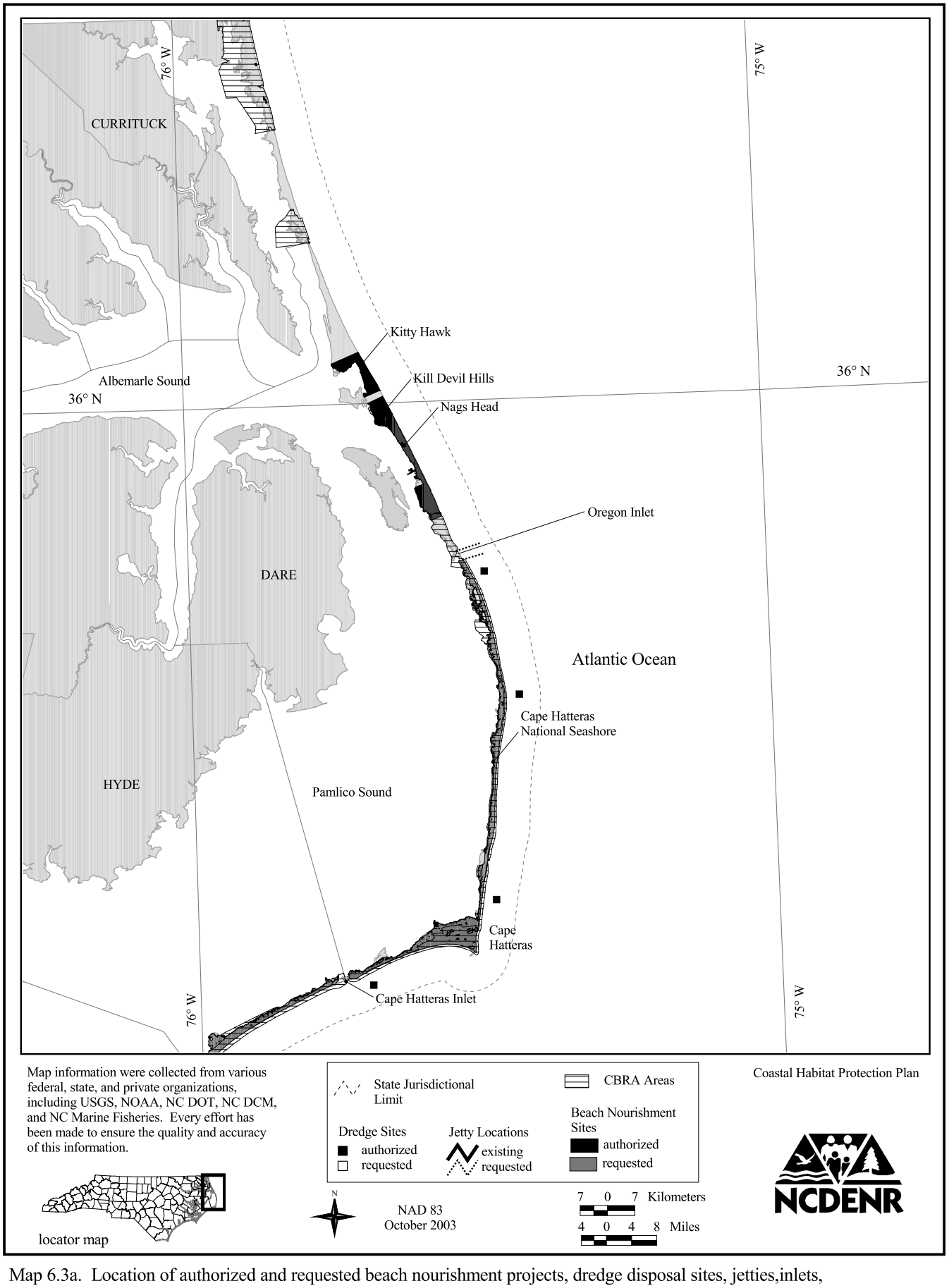
Map 6.2a. Sediment composition in the Albemarle-Pamlico estuarine system.
Inset A = Tar-Pamlico, Inset B = Neuse, Inset C= Bogue (Wells 1989)

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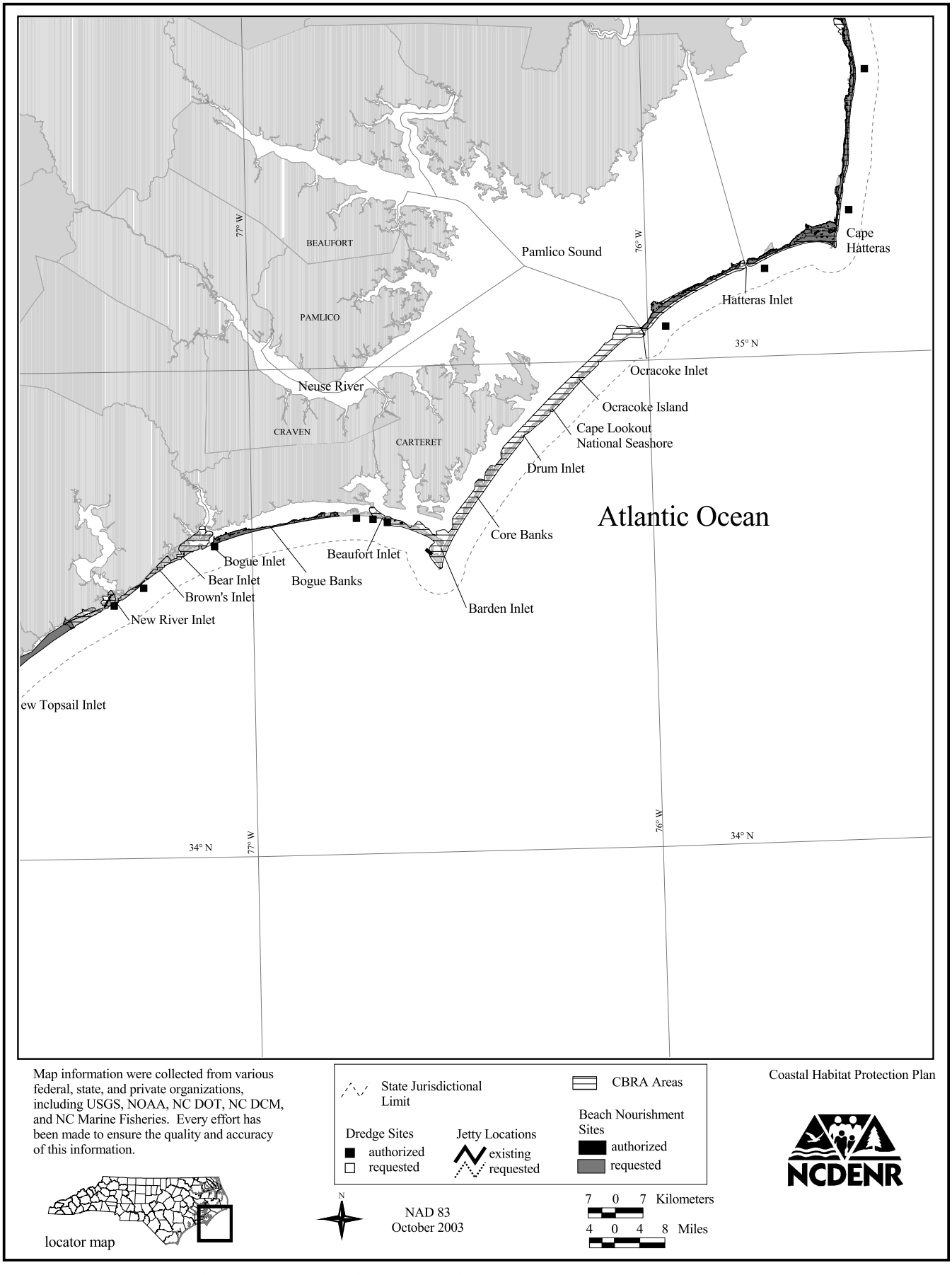
Map 6.2b. Insets. Sediment composition in the Tar-Pamlico, Neuse, and Core/Bogue estuaries (Wells 1989). Numbers = % sand, M= mud, SC=silty clay, VFS= very fine sand, MS= medium sand.

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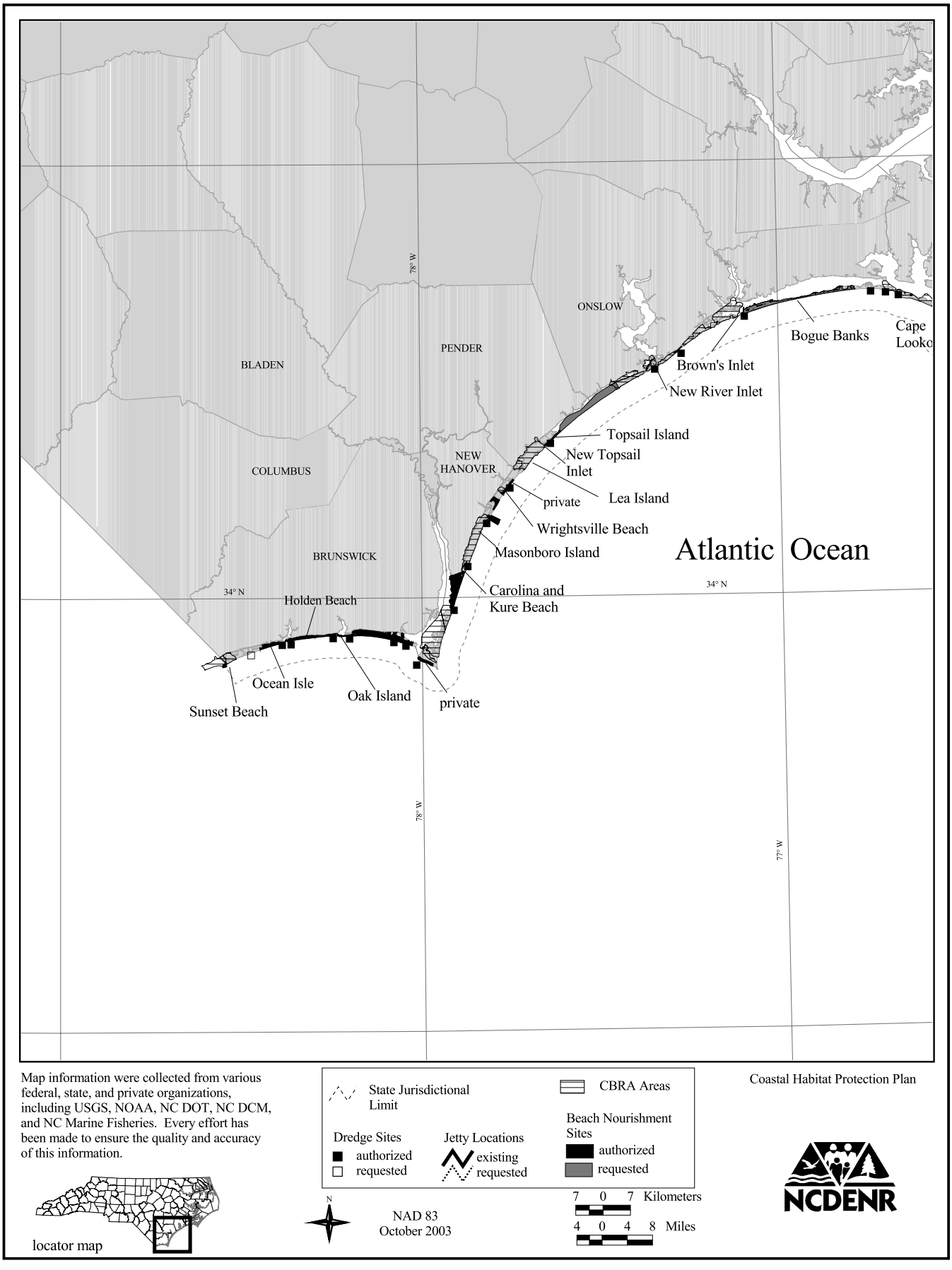
Map 6.3a. Location of authorized and requested beach nourishment projects, dredge disposal sites, jetties,inlets, and designated CBRA sites, northern coastal area of North Carolina.

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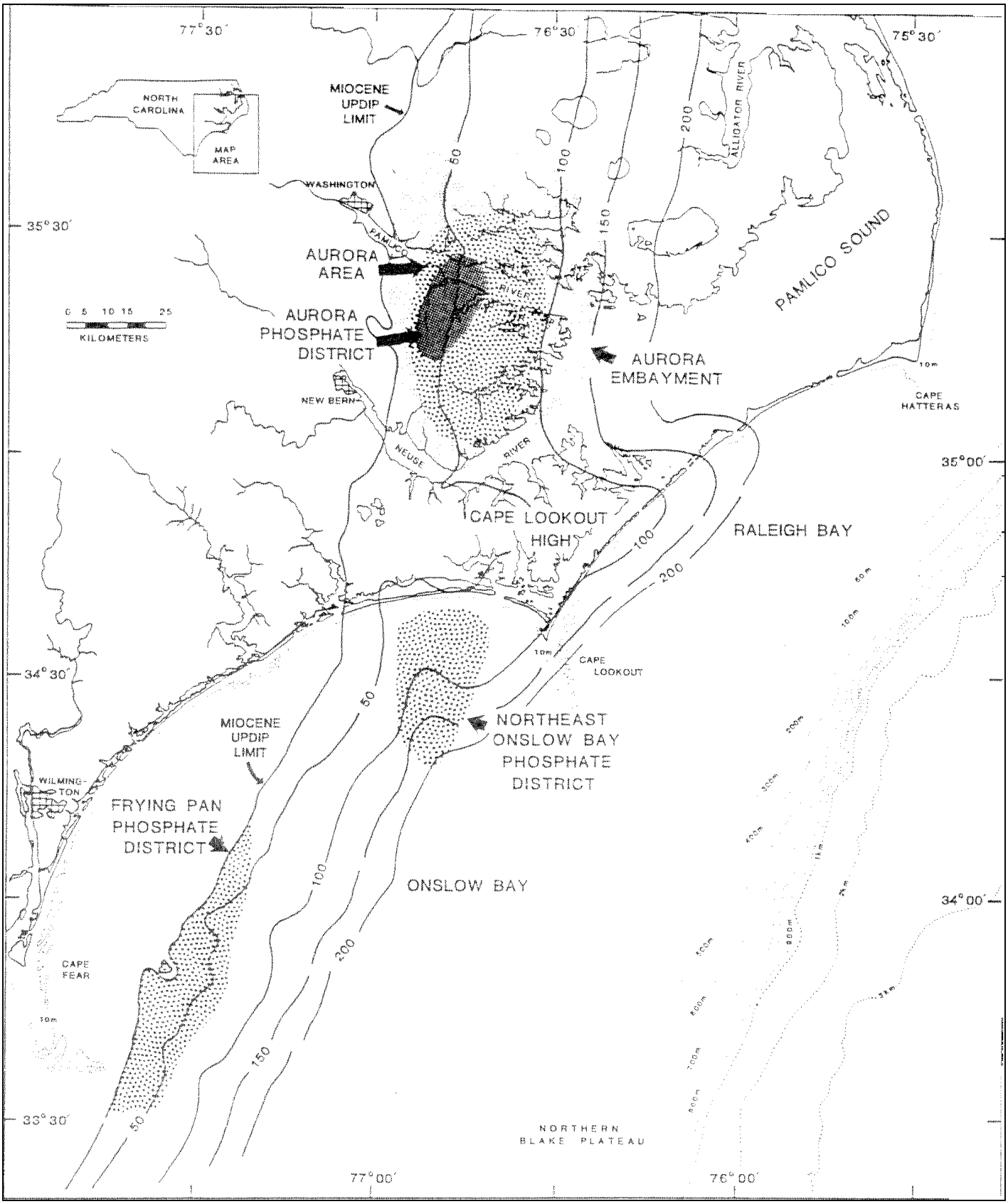
Map 6.3b. Location of authorized and requested beach nourishment projects, dredge material disposal sites, jetties, inlets, and designated CBRA sites, central coastal area of North Carolina.

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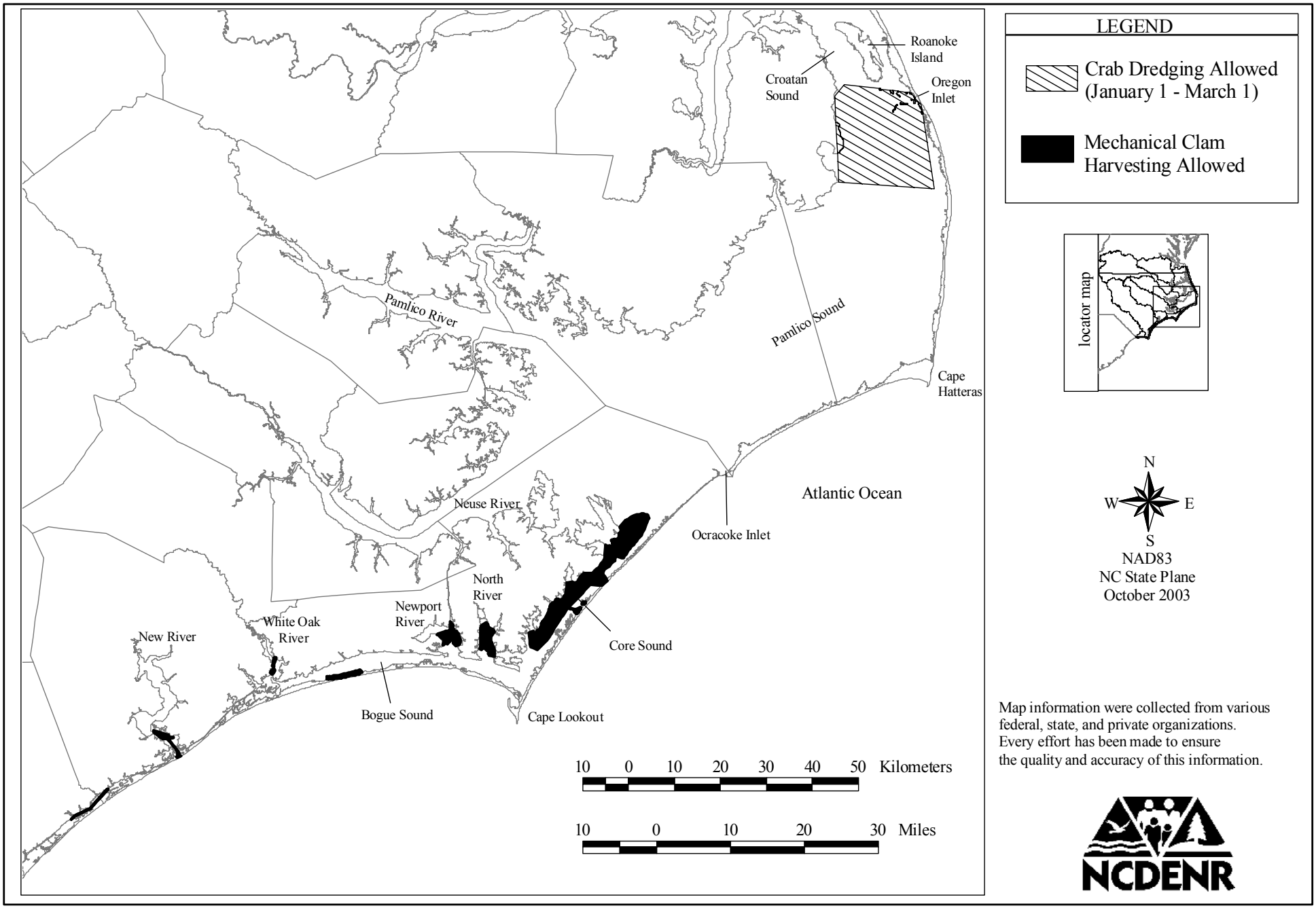
Map 6.3c. Location of authorized and requested beach nourishment projects, dredge material disposal sites, jetties, inlets, and designated CBRA sites, southern coastal area of North Carolina.

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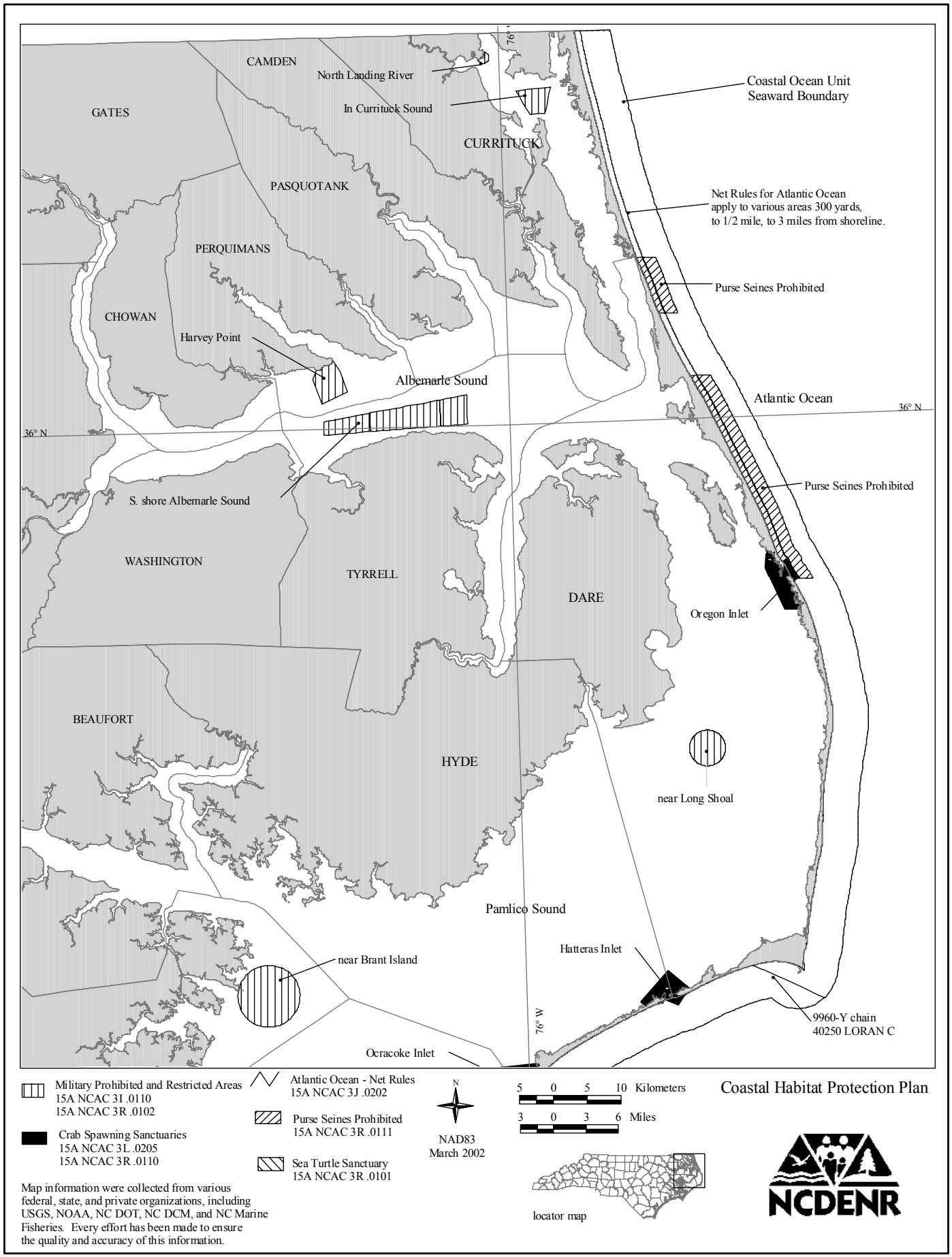
Map 6.4. Location of phosphate districts (known concentrations of phosphate deposits) on the continental shelf off North Carolina. (from Riggs and Manheim - 1988).

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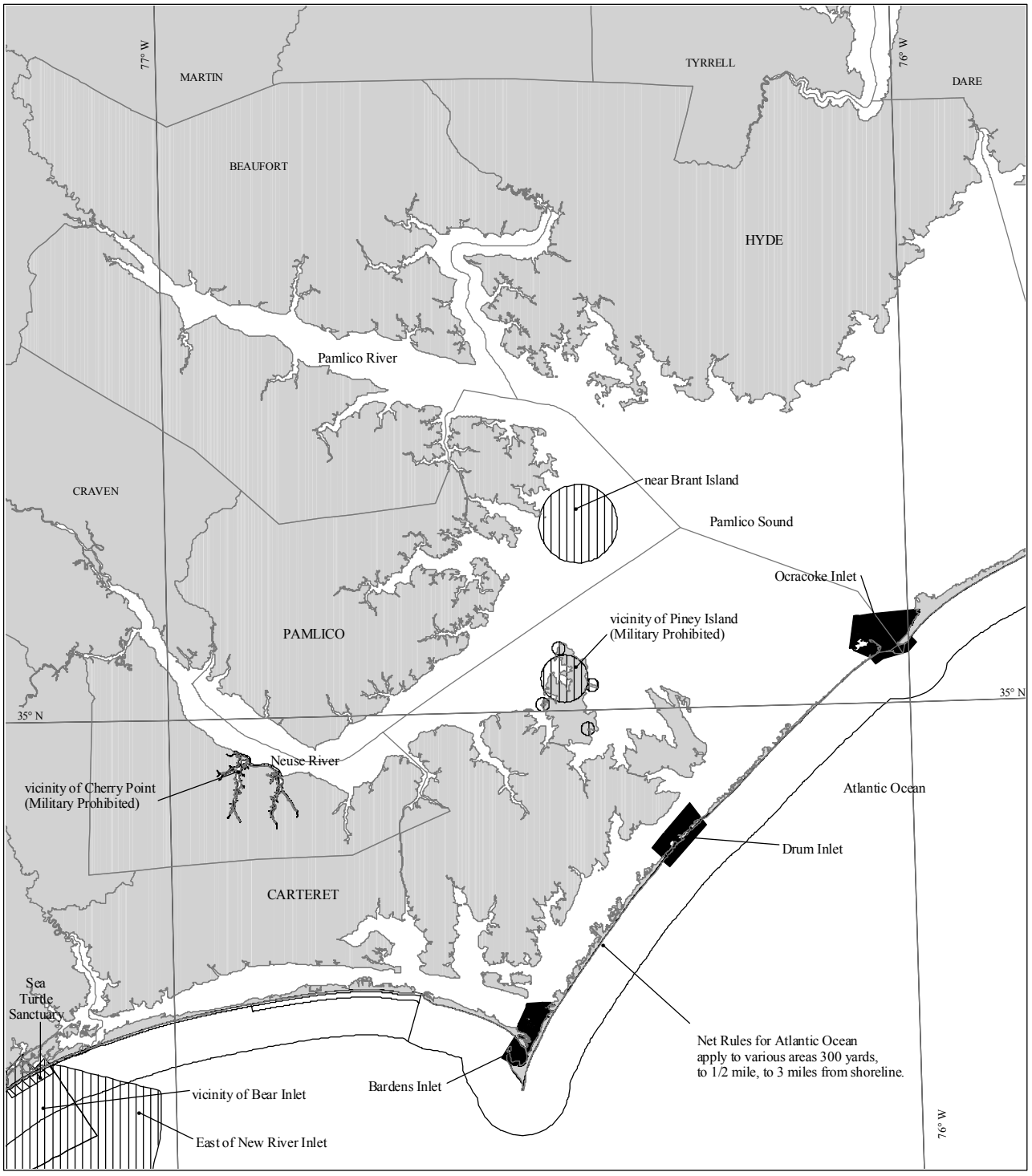
Map 6.5. Areas where mechanical harvest for clams (clam kicking, hydraulic dredge) and crabs (crab dredge) is authorized in estuarine waters of North Carolina.

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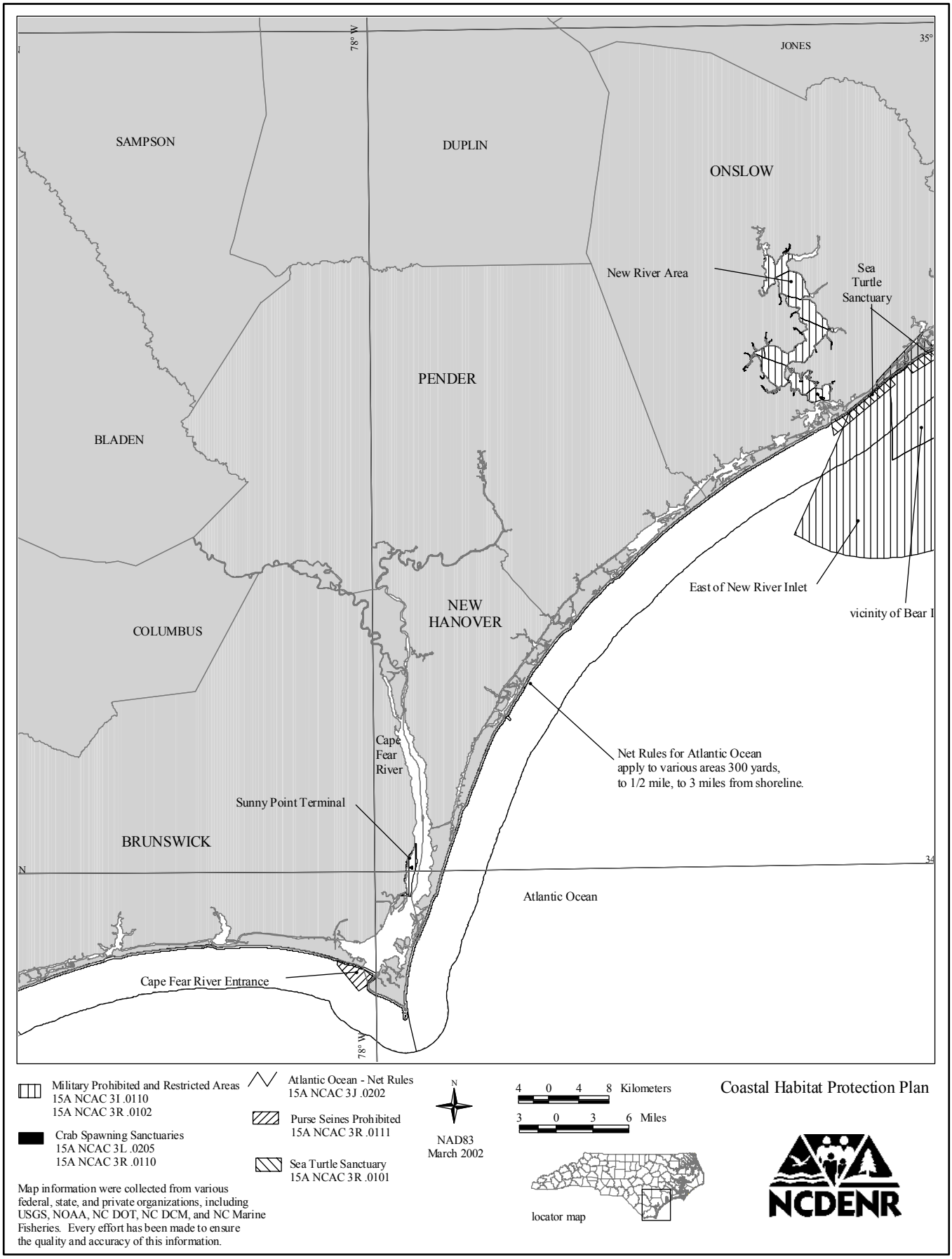
Map 6.6a. North Carolina Marine Fisheries Commission fishing gear restrictions in coastal waters, northern coastal area.

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Map 6.6b. North Carolina Marine Fisheries Commission fishing gear restrictions in coastal waters, central coastal area.

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Map 6.6c. North Carolina Marine Fisheries Commissions fishing gear restrictions in coastal waters, southern coastal area.

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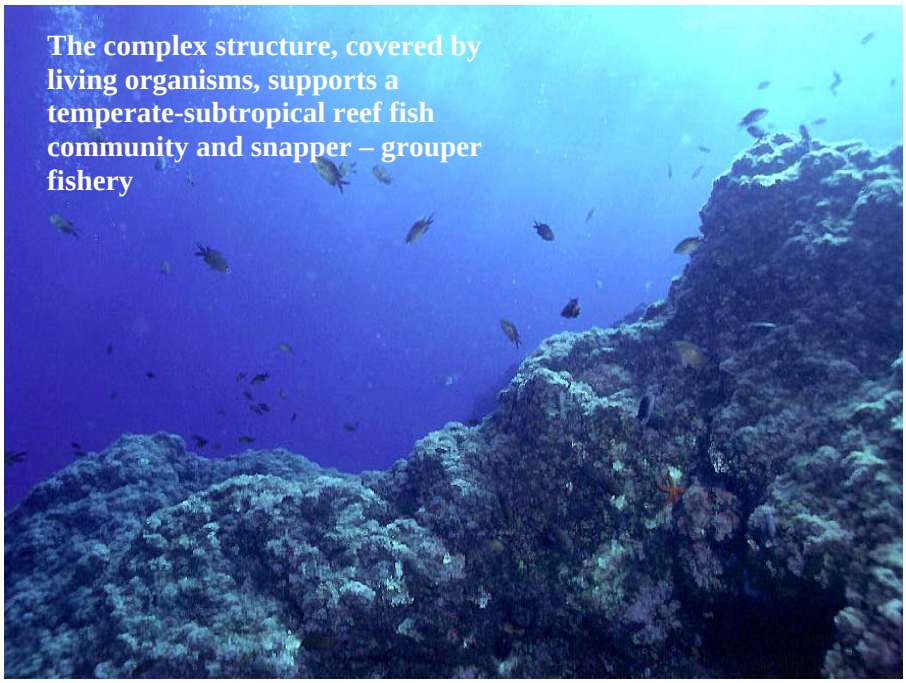
CHAPTER 7. HARD BOTTOM

7.1. DESCRIPTION AND DISTRIBUTION

Definition

Hard bottom refers to a classification of coral communities that occur in temperate, subtropical, and tropical regions that lack the coral diversity, density, and reef development of other types of coral communities (SAFMC 1998a). For the purposes of the CHPP, hard bottom habitat is defined as "exposed areas of rock or consolidated sediments, distinguished from surrounding unconsolidated sediments, which may or may not be characterized by a thin veneer of live or dead biota, generally located in the ocean rather than in the estuarine system."

Man-made structures, such as artificial reefs, wrecks, and jetties, provide additional suitable substrate for development of hard bottom communities. Artificial reefs are structures constructed or placed in waters for the purpose of enhancing fishery resources and providing opportunities for commercial and recreational fisheries. Although the purpose of artificial reef placement is primarily fishery enhancement, colonization of the structures by marine life results in establishment of hard bottom habitat. Vessels that have run aground or sunk and remain on the seafloor can also provide a base for hard bottom communities. These sites are separate from the DMF-managed artificial reef sites.



Description

Natural hard bottom varies in topographic relief from a relatively flat, smooth surface to a scarped ledge having up to 10 m of vertical, sloped, or stepped relief. The exposed areas of rock outcrop or relic reef are colonized to a varying extent by algae, sponges, soft coral, hard coral, bryozoans, polychaete worms, and tunicates, which in turn support a large diversity of fish (SAFMC 1998a). Hard bottom is also referred to as "live rock" or "live bottom" because of the abundance of live plants and invertebrates that typically attach to or bore into hard substrate. Erosion of the hard substrate through the long-term actions

of colonizing organisms results in overhanging hard bottom ledges and undercut sloped scarps (Riggs et al. 1995). Rock outcrops, particularly those with low relief, can become buried and unburied by the natural processes of sand movement across the seafloor (SEAMAP-SA 2001). When hard substrate is exposed, a live bottom community may develop on the hard surfaces and persist for many years, later becoming covered by varying thicknesses of sand (SEAMAP-SA 2001). Areas of compacted or sheered mud and sediment also function as consolidated hard bottom (Riggs et al. 1995).

Artificial reefs can be constructed of many different materials. In North Carolina, surplus vessels, steel boxcars, concrete pipe, concrete rubble, boat molds, tires, and surplus military aircraft have been used for artificial reefs. In addition, concrete structures specifically designed and constructed to provide complex habitat (domes, igloos) are used by DMF. In total, artificial reefs provide roughly 2.75 million ft^2 (47 acres) of hard surface area (DMF 1995). This area is equivalent to approximately 2% of the natural hard bottom occurring in Raleigh and Onslow bays. The DMF Artificial Reef Program is responsible for deployment and maintenance of the sites, following the guidelines of the DMF Artificial Reef Master Plan (DMF 1988). In addition to the DMF's artificial reefs, the U.S. Army Corps of Engineers (COE) constructed a large artificial reef off the Cape Fear River, known as the Wilmington Offshore Fishery Enhancement Structure, using rock dredged during deepening of the Cape Fear River shipping channel. Comprised of approximately 800 barge-loads of rock and rubble piled in rows, this structure is currently being disrupted by relocation of the Cape Fear River shipping channel. The North Carolina Department of Cultural Resources, Underwater Archeology Unit, estimates there are more than 1,000 sunken vessels along the North Carolina coast dating from the days of the earliest European explorers to the present (<http://www.arch.dcr.state.nc.us/UW-LIGIT.HTM>, 2003). Documented wrecks include World War II German U-boats, gunboats, tankers, freighters, barges, and wooden and iron-hulled steamers. The abundance of shipwrecks off the North Carolina coast provides additional structure available as hard bottom habitat.

Jetties are man-made structures consisting of large boulders placed perpendicular to the shoreline, usually near inlets, for the primary purpose of stabilizing navigational channels. Because jetties emerge above the water line, they support both intertidal and subtidal hard bottom communities. Groins are similar to jetties, but are generally smaller. They may be constructed to stabilize a marina entrance or navigational channel or used as an erosion control device to trap sand and stabilize the shoreline. Community composition and fish utilization of jetties were described in Hay and Sutherland (1988) and are discussed in section 7.2, Ecological role and functions.

Habitat requirements

The primary requirement for this habitat is exposed hard substrate. Bottom water temperatures at hard bottom habitats in the ocean off North Carolina range from approximately 11 to 27º C. Salinity is generally around 35 ppt with little fluctuation. The composition of invertebrate, algal, and fish communities varies with temperature and depth. Although hard bottom is similar to other coral reef communities, the hard bottom community in warm-temperate regions such as North Carolina is physically stressed by changes in water masses and seasonal fluctuations in water temperature and light penetration (Kirby-Smith 1989). Because of this stress, hard coral and reef fish abundance and diversity in temperate hard bottom are limited and often vary by season.

Distribution

Hard bottom is the most widely distributed coral community in the South Atlantic Bight. It occurs in both warm-temperate and tropical areas, although it is less extensive in the northern end of its range (North Carolina). Along the south Atlantic states, hard bottom ranges from the shoreline and nearshore (within the state's three-mile jurisdictional limit) to beyond the continental shelf edge (>200 m deep). It tends to occur in clusters across the shelf in specific areas (SEAMAP-SA 2001). Estimates of the percent cover of hard bottom vary greatly along the south Atlantic coast between Cape Canaveral and Cape Hatteras.

From Cape Hatteras to Cape Fear, it was estimated that approximately 14% (roughly 504,095 acres) of the bottom between 27 and 101 m water depth consisted of hard bottom; between Cape Fear and Cape Canaveral, 30% (roughly 1,829,321 acres) of the seafloor was hard bottom (Parker et al. 1983). Approximately 7–10% of the hard bottom habitat is estimated to be one meter or more in relief (Parker et al. 1983).

Hard bottom mapping

In 1985, the Southeast Area Monitoring and Assessment Program—South Atlantic (SEAMAP-SA) began a large-scale initiative to identify and map all known hard bottom and coral reef areas in the South Atlantic Bight. A final report and ArcView GIS CD were completed in 1998 and updated in 2001 (SEAMAP-SA 2001). The majority of the data used to identify hard bottom was based upon the relative presence of indicator species in traps or trawls or on sidescan sonar records (73%). The SEAMAP Bottom Mapping Workgroup identified 177 South Atlantic Bight reef species that indicate reef habitat. The remaining data came from video and diver observations. The majority of identified sites was located in federal waters off North Carolina (> three nautical miles (nm) from shore). Because of the ephemeral nature of low-relief hard bottoms (uncovered and covered by storm-induced shifting sands) and the difficulty of distinguishing soft bottom from low-relief hard bottom using seismic data, the amount of hard bottom habitat identified in this program was most likely an underestimate (SEAMAP-SA 2001).

Hard bottom and artificial reef sites identified by SEAMAP in both state and federal waters are shown in Map 7.1, along with some of the known wrecks. Hard bottom outcrops are most concentrated in Onslow and Long bays. In federal waters, concentrations occur offshore between Shallotte Inlet and the Cape Fear River. In Onslow Bay, hard bottom is most concentrated from Frying Pan Shoals north to Masonboro Inlet, from New Topsail Inlet to Brown's Inlet, and from Bogue Inlet east to Cape Lookout Shoals. In Raleigh Bay, there are two concentrations of hard bottom - one east of Lookout Shoals and another south of Diamond Shoals. Within North Carolina state territorial waters, using point data, the SEAMAP database identified 19 natural hard bottom sites and 16 possible hard bottom sites. In addition, line data from trawls identified 29 hard bottom sites and 59 possible sites.[79]

A follow-up study compiling hard bottom locations in the nearshore ocean waters of North Carolina identified additional sites not included in the SEAMAP-SA database (Map 7.1, Table 7.1) (Moser and Taylor 1995). The study relied on surveys of researchers, dive professionals, and fishermen. Some of these sites may be duplicates of those identified by SEAMAP-SA, due to different sources and slightly different coordinates. A total of 198 hard bottom positions was identified; some were point data, while others represented transects or areas. Over 92% of the identified hard bottom in North Carolina waters are south of Cape Lookout, particularly in the southern half of Onslow Bay and in northern Long Bay. Concentrations of hard bottom occur seaward of inlets, including Shallotte, Lockwood's Folly, New, Carolina Beach, Masonboro, New Topsail, New River, and Bogue inlets. There are outcrops of moderate-to-high relief in shallow water near the shoals of Cape Fear and Cape Lookout. Moser and Taylor (1995) estimated that the majority of the bottom in state territorial waters from 1) mid-Onslow Beach to south of New Inlet and 2) the area from Yaupon Beach west to Tubbs Inlet is comprised of hard bottom that is covered with a thin layer of sand.

[79] The lengths of the trawl lines vary, and some lines may actually represent several transects of one area. Similarly, some hard bottom lines may overlap with hard bottom points.

Table 7.1 Hard bottom and possible hard bottom locations in North Carolina by coastal bay. [Source: Point and line data identified by SEAMAP-SA (2001). Results from Moser and Taylor (1995) in parentheses.]

Bottom Type	Long Bay	Onslow Bay	Raleigh Bay	North of Hatteras	Total
Hard bottom (point)	2 (19)	14 (58)	1 (4)	2 (3)	19 (86)
Hard bottom (line)	3 (6)	25 (39)	1 (2)	0 (2)	29 (49)
Possible hard bottom (point)	1	8	3	4	16
Possible hard bottom (line)	5	37	12	5	59
Total	11 (25)	84 (97)	17 (6)	11 (5)	123 (135)

Twenty sites were reported as high-profile relief, defined by Moser and Taylor (1995) as vertical relief greater than two meters. Two of these sites, one off Carolina Beach and one off New River, are extensive in both area and topographic relief; these areas are particularly close to shore, making them more vulnerable to land-based, fishing, and boating-related impacts. A unique intertidal and subtidal coquina rock outcrop extends from the beach into the surf zone at Fort Fisher. This unique habitat supports a diversity of organisms such as starfish, anemones, sea urchins, crabs, octopi, and numerous fish species.

Distribution of man-made hard bottom

There are 11 artificial reefs of varying construction located in North Carolina State ocean waters, 28 in federal ocean waters (Map 7.1), and seven in estuarine waters. The estuarine artificial reefs are located in Pamlico Sound, Albemarle Sound, Neuse River, and Pamlico River. The artificial reef program periodically adds material to the 39 existing ocean sites, rather than creating new reefs. Gentile (1992) listed 46 documented wrecks in North Carolina waters south of Hatteras Inlet. The majority of the wrecks is located northeast and west of the mouth of the Cape Fear River (Map 7.1). There are many more wrecks in federal waters, with concentrations around the three cape shoals. There are also two jetty systems and three groin systems along the ocean shoreline. The groins are located on the south side of Oregon Inlet, off the former site of the Cape Hatteras Lighthouse, and at the west side of Beaufort Inlet. There is a single jetty at the west side of Cape Lookout; Masonboro Inlet has jetties on both sides–one attached to Wrightsville Beach and the other attached to Masonboro Island. The Little River Inlet, which is the state boundary between North and South Carolina, also has a dual jetty system, but both structures are located in South Carolina. There are also numerous small groins and jetty systems in estuarine waters, but these features have not been mapped.

For the purposes of this document, estuarine shell bottom (e.g., oyster reefs, beds, bars) is not categorized as hard bottom habitat. Although technically a "hard" substrate that shares some characteristics with hard bottom (e.g., three-dimensional structure), shell bottom differs in its formation, spatial distribution, function, and species composition from those of oceanic hard bottom; it is classified as a distinct habitat type[80]. In addition, shell bottom can be either inter- or subtidal, whereas hard bottom is typically subtidal (with the single exception of the exposed coquina outcrops near Fort Fisher).

7.2. ECOLOGICAL ROLE AND FUNCTIONS

Productivity

Exposed hard substrate (whether rock outcrops, jetties, artificial materials, or semi-compacted sediments) provides surface area for colonization by invertebrates and algae. Hard substrate with vertical relief or irregular surface areas provides more complex habitat, allowing a greater variety of species to coexist (Wenner et al. 1984). This "live bottom" structure, in turn, provides a source of abundant food and

[80] Refer to the Shell Bottom chapter (Chapter 3) .

protective cover for numerous fishes. These areas may be quite small and isolated and have been considered oases of productivity surrounded by less productive unconsolidated ocean bottom (SAFMC 1998a). The extent and diversity of colonization vary among sites due to topography, habitat diversity, currents, light availability, and location on the shelf. Studies that have documented the composition and diversity of the communities on hard bottom in North Carolina include MacIntyre and Pilkey (1969), Schneider (1976), Peckol and Searles (1984), Kirby-Smith (1989), and COE (1992). Most of the locations examined in these studies were located beyond the three-mile state boundary.

The dominant colonizing organisms on hard bottom in North Carolina are macroalgae (Peckol and Searles 1984), ranging from 10 to 70% of the biotic cover, and varying among seasons and years. Perennial and crustose brown and red algae were the dominant algal forms, including *Lobophora variegata*, *Lithophyllum subtenellum*, *Zonaria tournefortii*, and *Gracilaria mammillaris*. In nearshore waters (< one nm from shore), between Rich Inlet and Brown's Inlet, large amounts of seaweed grow on and between hard bottom areas during the summer. The algae consist of several types and species, including the brown algae, *Sargassum filipendula* and *Dictyopteris membranacea*, and the red algae, *Halymenia* sp. and *Gracilaria* sp. (DMF 2001d). Sargassum (*S. filipendula*) is common in nearshore and offshore waters, and on jetties. Hay and Sutherland (1988) documented several other species on jetties. Roughly 150 species of macroalgae were identified on hard bottom in North Carolina; the majority was red algae (Rhodophyta) (Schneider 1976). Onslow Bay had a higher diversity of species, which was attributed to more available hard substrate (Schneider 1976). The shallow inshore flora consisted of a large component of northern-distributed species, while offshore areas supported more tropical flora. Offshore areas had the greatest abundance of macroalgae, due to the high proportion of suitable substrate, greater relief on the shelf break, and mild water temperatures throughout the year. Of the offshore species, 66% were at their northern limit of distribution in Onslow Bay, and 2% were at their known southern distributional limit (Schneider 1976). The latter include *Arthrocladia villosa, Gigartina stellata*, and *Polysiphonia harveyi*. The presence of macroalgae from the shoreline to beyond the shelf break indicates that light and nutrient availability do not limit primary production on hard bottom off North Carolina (Cahoon and Cooke 1992).

Community structure

Non-mobile, attached invertebrates accounted for 10% or less of the biotic cover on hard bottom off North Carolina (Peckol and Searles 1984). The most abundant non-mobile invertebrates were the soft corals, *Titandeum frauenfeldii* and *Telesto fructiculosa,* and the hard coral, *Oculina arbuscula*. Sea urchins (*Arbacia punctulata* and *Lytechinus variegatus*) were the most common mobile invertebrates. Species composition of invertebrates occurring at hard bottom sites in South Carolina and Georgia were studied by Wenner et al. (1984). Study results using dredge and trawl samples showed that sponges, bryozoans, corals, and anemones[81] dominated the large macroinvertebrate collection in terms of numbers and species diversity during all seasons. Sponges were the most important invertebrate group overall on the inner shelf, comprising 60–78% of the total biomass. Tunicates, anthozoans, and mollusks also contributed substantially (Wenner et al. 1984). Species characteristic of the inner shelf sites included the sponges, *Homaxinella waltonsmithi, Spheciospongia vesparium, Cliona caribbaea*, and *Halichondria bowerbanki*; the echinoderms, variegated urchin (*Lytechinus variegatus*), purple sea urchin (*Arbacia punctuata*), *Encope michelini*, and *Ocnus pygmaeus*; the bryozoan, *Membranipora tenuis*; and the decapod crustacean, *Synalpheus minus*. Grab samples of small invertebrates showed that polychaetes were the most diverse and abundant group, followed by mollusks, and amphipods[82] (Wenner et al. 1984).

Kirby-Smith (1989) studied hard bottom communities at nearshore and offshore reefs in North Carolina. Community structure varied with season, depth, and distance from the shelf edge. Diversity and

[81] sponges (89 Porifera taxa); bryozoans (91 Bryozoa taxa); and corals and anemones (70 Cnidaria taxa)

[82] polychaetes (285 species, 72% of total individuals); mollusks (251 species, 4.3% of total individuals); and amphipods (100 species, 13% of total individuals)

abundance of invertebrates were greater in the spring and fall than in winter and summer, attributed to spring and fall plankton blooms. The inner shelf sites, in approximately 16–27 m water depths, had somewhat lower diversity than mid- or outer shelf sites. Mollusks, followed by polychaetes, and then amphipods were dominant in the number of observed species.

Due to cooler water temperatures and greater temperature fluctuations, the species composition of hard bottom communities in nearshore waters is less tropical in nature compared to that farther offshore or south of North Carolina (Kirby-Smith 1989). Furthermore, at natural and artificial reefs in Onslow Bay, seaweed species outcompeted a hard coral (*Oculina arbuscula*), limiting its growth and recruitment and largely restricting its distribution to deeper, poorly lit habitats via competitive exclusion (Miller and Hay 1996). Because of these conditions, hard bottom in North Carolina's state territorial sea is colonized by hard and soft corals to a lesser extent than offshore or more southern areas. Two species of reef building corals that have been documented on North Carolina hard bottom are *Solenastrea hyades* and *Siderastrea siderea*. These species occurred on rock outcrops at depths of 20 to 26 m in Onslow Bay approximately 32 km offshore (MacIntyre and Pilkey 1969). Other species of coral reported for North and South Carolina include the hard corals, ivory bush coral (*Oculina arbuscula*), *Oculina varicosa*, *Astrangia danae*, *Phyllangia americana*, *Balanophyllia floridana*, and the soft corals, sea whip (*Leptogorgia virgulata*), *Telesto* spp., *Lophogorgia* spp., *Titanideum frauenfeldii*, and *Muricea pendula* (Wenner et al. 1984; Hay and Sutherland 1988).

Ecosystem enhancement

In addition to providing habitat for an abundance of reef organisms and fish, hard bottoms, through bioerosion, are a source of sand production for sediment-starved sections of the continental shelf, such as Onslow and Long bays. Riggs et al. (1995) described three primary groups of bioeroders: rock boring bivalves, burrowing shrimp, and macroalgae. These animals and plants tend to occur in or on hard bottom of different hardnesses and slopes. Some species, like the rock boring bivalve *Jouanettia quillingi* and burrowing shrimp *Upogebia* sp., occur on muddy sandstones, while macroalgae tend to colonize Pleistocene limestone. The larvae of rock boring bivalves erode rock by excavating a hole chemically (through secretion of acid) or mechanically (through abrasion from their hard shell). Over time, multiple tunnels from clams eventually weaken the rock until chunks break off, leaving a fresh rock surface for more clam larvae to settle on and bore into. Macroalgae erode rock when their roots (holdfasts) are torn off the rock surface by storms and strong water currents, carrying away small pieces of rock. The decomposition of calcareous macroalgae plant material also produces sediment. Rates of sediment production from bioerosion increase with increasing softness of rock substrate, varying from 5.5 $kg/m^2/yr$ on vertical and sloped Miocene mudstone hard bottom, to 0.4 $kg/m^2/yr$ on vertical and sloped Pleistocene limestone, and 0.03 $kg/m^2/yr$ on flat Plio-Pleistocene limestone. These processes also enhance the structural complexity of the hard bottom outcrops, which promotes diversity of fish habitat within the reef (Riggs et al. 1995).

Fish utilization of natural hard bottom

Because of their structural complexity, more permanent nature, and high functional diversity, hard bottom areas of relatively high relief are particularly important to a variety of fish and invertebrate species. Fish comprise a major portion of the animal biomass on hard bottom, and they are an important component of the overall trophic structure (Jaap 1984). Numerous studies have examined fish assemblages on natural and artificial reef habitats in North Carolina (Huntsman and Manooch 1978; Miller and Richards 1980; Grimes et al. 1982; Lindquist et al. 1989; Potts and Hulbert 1994; Parker and Dixon 1998). With the exception of Hay and Sutherland (1988), who described fish utilization at jetties in North Carolina, all of these studies, including those at the inner shelf, were conducted seaward of state territorial waters. *Fish studies specific to nearshore hard bottom (within state territorial waters) are needed to better understand the dependence of fish species on this habitat.*

Natural hard bottoms off the Carolina coasts support large populations of offshore reef fish, temperate, and coastal pelagic species. In one study along the North and South Carolina coasts, 47 tropical and subtropical resident reef fish species were found on inshore hard bottom (<18 m water depth), and almost twice as many occurred farther offshore (18–110 m water depth). The fauna of hard bottom is characterized by wrasses, damselfish, snappers, grunts, parrotfish, and sea basses. Inshore hard bottom communities support large numbers of more temperate fish species, such as black sea bass (*Centropristis striata*), spottail pinfish (*Diplodus holbrookii*), and estuarine-dependent migratory species (Huntsman and Manooch 1978). A list of species reported for North and South Carolina inshore hard bottom is provided in Table 7.2.

Water temperature and topography are the most important factors in determining use of habitat by warm-temperate and tropical hard bottom species (Wenner et al. 1984; SAFMC 1998a). Temperatures less than 12º C may result in the death of some tropical fish and invertebrate species. Lindquist et al. (1989) reported 32 species at inner shelf hard bottom sites in North Carolina, approximately five miles from shore. Commonly occurring and numerically abundant species for both natural and artificial reefs were, in order of decreasing abundance:

- round scad (*Decapterus punctatus*)
- tomtate (*Haemulon aurolineatum*)
- spottail pinfish (*Diplodus holbrookii*)
- black sea bass (*Centropristis striata*)
- slippery dick (*Halichoeres bivittatus*)

Other common species included scup (*Stenotomus chrysops*), juvenile grunts, pigfish (*Orthopristis chrysoptera*), cubbyu (*Equetus umbrosus*), and belted sandfish (*Serranus sublgiarius*). Fish composition varied due to seasonal inshore migrations of tropical and subtropical species, fishing pressure, and microhabitat differences.

In general, most reef fish are carnivores (Jaap 1984). Benthic invertebrates are therefore very important as energy assimilators and food sources for reef fish (Jaap 1984). A partial list of the most important fish species that utilize hard bottom in North Carolina's state territorial waters and the function the habitat provides is given in Table 7.3.

Table 7.2. Fishes occurring at inshore hard bottom in North Carolina and South Carolina coastal waters. [Sources: Grimes et al. 1982; Powell and Robins 1998; DMF, unpub. data]

Family	Scientific name	Common name
Carcharhinidae	*Carcharhinus falciformis*	Silky shark
Muraenidae	*Gymnothorax nigromarginatus*	Blackedge moray
Ophichthidae	*Ophichthus ocellatus*	Palespotted eel
Engraulidae	*Anchoa* sp.	Anchovy
Synodontidae	*Synodus foetens*	Inshore lizardfish
	Trachinocephalus myops	Snakefish
Batrachoididae	*Opsanus pardus*	Leopard toadfish
Antennaridae	*Antennarius ocellatus*	Ocellated frogfish
Gadidae	*Urophycis earlii*	Carolina hake
Ophidiidae	*Rissola marginata*	Striped cusk-eel
Sygnathidae	*Hippocampus erectus*	Lined seahorse
	Sygnathus sp.	Pipefish
Serranidae	*Centropristis ocyurus*	Bank sea bass
	C. striata	Black sea bass
	Dermatolepis inermis	Marbled grouper
	Diplectrum formosum	Sand perch
	Epinephelus adscensionis	Rock hind
	E. drummondhayi	Speckled hind
	E. morio	Red grouper
	E. fulva	Coney
	E. guttatus	Red hind
	Mycteroperca microlepis	Gag
	M. phenax	Scamp
	M. venenosa	Yellowfin grouper
	Petrometopon cruenatatum	Graysby
	Serranus subligarius	Belted sandfish
Priacanthidae	*Pristigenys alta*	Short bigeye
	Priacanthus creuntatus	Glasseye snapper
Apogonidae	*Apogon pseudomaculatus*	Twospot cardinalfish
Pomatomidae	*Pomatomus saltatrix*	Bluefish
Carangidae	*Alectis crinitus*	African pompano
	Caranx ruber	Bar jack
Lutijanidae	*Lutjanus analis*	Mutton snapper
	L. campechanus	Red snapper
	L. griseus	Gray snapper
	Decapterus punctatus	Round scad
Pomadasyidae	*Haemulon aurolinearum*	Tomtate
	H. plumieri	White grunt
	Orthpristis chrysoptera	Pigfish
Sparidae	*Diplodus holbrookii*	Spottail pinfish
	Archosargus probatocephalus	Sheepshead
	Calamus leucosteus	Whitebone porgy
	Stenotomus chrysops	Scup
Sciaenidae	*Equetus umbrosus*	Cubbyu
	Cynoscion regalis	Weakfish
Labridae	*Haliochores bivittatus*	Slippery dick
Ephippidae	*Chaetodipterus faber*	Atlantic spadefish
Clinidae	*Paraclinus* sp.	Blennies
Gobiidae	*Ioglossus calliurus*	Blue goby
Bothidae	*Paralichthys dentatus*	Summer flounder
	Paralichthys lethostigma	Southern flounder

Table 7.3. Habitat utilization, stock status, and use of important fish species that occupy hard bottom areas in North Carolina's nearshore ocean waters.

Species*	Hard bottom Functions [1]					Fishery [2]	Stock status [3]
	Refuge	Spawning	Nursery	Foraging	Corridor		
MARINE SPAWNING, LOW - HIGH SALINITY NURSERY							
Atlantic croaker	X			X		X	C
Inshore lizardfish	X	X	X	X		X	
Southern kingfish	X			X		X	U
Spot	X			X		X	V
Striped mullet	X		X	X		X	C
Weakfish	X			X		X	V
MARINE SPAWNING, HIGH SALINITY NURSERY							
Black sea bass [4]	**X**	**X**	**X**	**X**	**X**	**X**	**O- south of Hatteras, V- north of Hatteras**
Bluefish	X			X		X	R
Damselfish (mult. spp.)	**X**	**X**	**X**	**X**			
Florida pompano	X			X		X	
Gag [4]	**X**		**X**	**X**	**X**	**X**	**V**
Gobies (multiple spp.)	**X**	**X**	**X**	**X**			
Gulf kingfish	X			X		X	U
King mackerel	X			X		X	V
Pigfish	**X**	**X**	**X**	**X**		**X**	
Planehead filefish	**X**	**X**	**X**	**X**			
Sand perch	X	X	X	X		X	
Scup [4]	**X**	**X**	**X**	**X**		**X**	**R**
Smooth dogfish	X			X		X	U
Spiny dogfish	X			X		X	O
Spottail pinfish	**X**	**X**	**X**	**X**		**X**	
Summer flounder	X			X		X	R
Tautog [4]	**X**		**X**	**X**	**X**	**X**	**O**
Wrasses (several species)	**X**	**X**	**X**	**X**			
MARINE REEF FISH COMPLEX							
Atlantic spadefish	**X**	**X**	**X**	**X**		**X**	C- reef fish complex as a whole in NC. Individual species have not been evaluated in NC.
Greater amberjack	X			X		X	
Round scad	**X**		**X**	**X**			
Sheepshead	**X**	**X**	**X**	**X**		**X**	
Tomtate	**X**	**X**	**X**	**X**		**X**	
White grunt	**X**	**X**	**X**	**X**		**X**	
Whitebone porgy	**X**		**X**	**X**		**X**	

* Scientific names listed in Appendix I. Names in **bold** font are species whose relative abundances have been reported in the literature as being generally higher in hard bottom than in other habitats. Note that lack of bolding does not imply non-selective use of the habitat, just a lack of information.

[1] Powell and Robins 1998; Grimes et al. 1982; F. Rohde, DMF pers. com. 2003

[2] Commercially or recreationally caught species. Other species are important to the ecosystem as prey

[3] V = Viable, R = Recovering, C = Concern, O = Overfished, U = Unknown (DMF 2003).

[4] Part of the reef fish complex but evaluated separately by DMF for stock status

Refuge and foraging

Hard bottom provides protective cover and foraging areas for an abundance of organisms, supporting high fish productivity. Nearshore hard bottom habitats can support over thirty times as many individuals per transect as natural sand habitats (Lindeman 1997). Consequently, natural reefs can sustain greater fish stocks (270 to 5,279 kg/ha) compared to non-reef open shelf bottom (6.3 to 46.3 kg/ha) (Huntsman 1979). In general, natural and artificial reefs support similar fish species assemblages (Ambrose and Swarbrick 1989). The abundance of fish on hard bottom and artificial reefs is related to the amount and type of structural complexity of the reef (Potts and Hulbert 1994; Carr and Hixon 1997). Rocky structures that have more available complex space resources consistently supported a more abundant and diverse resident fish community than less complex structures. In addition, multiple small hard bottom areas surrounded by sand habitat supported greater fish abundance and diversity than one large area of equal material, suggesting the importance of habitat variety to overall ecosystem quality (Bohnsack et al. 1994; Auster and Langton 1999). This research suggests that artificial refugia would be beneficial for enhancement of fish productivity and ecosystem value. An artificial refugia site is an artificial reef that is designated as a no-take area, to provide unfished habitat to aid in stock recovery, conduct research, and test effectiveness of enforcement. *Construction of artificial refugia (no-take artificial reefs) or designation of existing artificial reefs as refugia (no-take, Marine Protected Areas) should be considered to enhance fisheries productivity.*

Spawning

Hard bottom provides not only refuge and foraging areas, but also spawning areas. Most reef fish spawn in aggregations in the water column above the reef, and the eggs remain planktonic during development (Jaap 1984). The timing of egg release is often triggered by dusk, night, or the tides, probably to reduce risk from predation. Nearshore hard bottom has been identified as a spawning site for some reef species. Species known to spawn on nearshore hard bottom include black sea bass (*Centropristis striata*) and sand perch (*Diplectrum formosum*) between January and June (Powell and Robins 1998). Sheepshead (*Archosargus probatocephalus*), Atlantic spadefish (*Chaetodipterus faber*), seaweed blenny (*Parablennius marmoreus*), inshore lizardfish (*Synodus foetens*), and several species of damselfish, wrasses, and gobies (*Ioglossus calliurus* and others) are also thought to spawn on inshore hard bottom (F. Rohde, DMF, pers. com., 2001). *More research is needed concerning spawning on, and recruitment to, nearshore hard bottom to understand the importance of this habitat and document trends in fish utilization.*

Nursery

Nearshore and inner shelf hard bottom areas serve as important settlement and nursery habitat for immigrating larvae of many important fisheries species. Powell and Robbins (1998) collected larvae from 22 reef-associated families adjacent to hard bottom habitat in Onslow Bay. Planehead filefish, *Monacanthus hispidus*; the blenny, *Parablennius marmoreus*; the goby, *Loglossus calliurus*; tomtate; white grunt; snappers including vermilion snapper, *Rhomboplites aurorubens*; black sea bass; bank sea bass; sand perch; spottail pinfish; and whitebone porgy were commonly collected. These species are thought to have been spawned in Onslow Bay in somewhat deeper water and recruited locally to nearshore hard bottom (Powell and Robins 1998). Additional species that are not generally reef-associated were also collected adjacent to hard bottom, including estuarine-dependent and oceanic species. It is unclear how planktonic larvae recruit to hard bottom habitat, except that recruitment is dependent on water circulation patterns transporting larvae to suitable habitat (Jaap 1984). Hard bottom habitat with vertical relief provides a variety of microhabitats, allowing a diversity of fish to recruit to the structure. Higher food availability in structure-rich hard bottoms, as well as properly managed artificial reefs, may result in increased growth rates, as well as increased survival.

Nearshore hard bottom also serves as intermediate nursery habitat for late juveniles emigrating out of the estuaries (Lindeman and Snyder 1999). In North Carolina, this group of fishes includes black sea bass,

gag, red grouper, sheepshead, Atlantic spadefish, bank sea bass, and gray snapper, which are estuarine-dependent as early juveniles, moving offshore to hard bottom habitat as older juveniles. Juvenile red snapper and mutton snapper have also been documented in North Carolina's estuaries to a lesser extent (DMF, unpub. data). Species migrating offshore benefit from structure-rich hard bottom by using it for refuge from predators and foraging on the high abundance of invertebrates and macroalgae. Lindeman and Snyder (1999) found that over 80% of the individual fish at hard bottom sites on the southeast coast of Florida were early life stages. The study documented more than 20 species of newly settled stages, including several species of grunts and snappers. In North Carolina, the patchy distribution and limited extent of hard bottom suggest that habitat availability may limit survival of early stages of reef fish, giving available hard bottom habitat particularly high value (P. Parker, NMFS, pers. com., 2002).

Fish utilization of man-made structures

The composition and density of fish at artificial reefs tend to be similar to those at natural hard bottom sites when occurring in similar environmental conditions (Huntsman and Manooch 1978; Miller and Richards 1980; Bohnsack et al. 1994; Potts and Hulbert 1994). Studies comparing fish utilization of shipwrecks and artificial reefs of various designs found that all structures supported similar species composition (Stephan and Lindquist 1989). Species composition, relative abundance, and catch-per-unit-effort (CPUE) on artificial reef sites are documented periodically by DMF (DMF 1998; DMF 2002). In 1997, an assessment of the effectiveness of differently constructed artificial reefs found species assemblages to be similar on reefs composed of concrete pipes, cans, or domes. However, the assessment also found that CPUE was 71 – 85% greater on natural reefs than nearby artificial reefs (DMF 1998), possibly because natural hard bottom habitat is inherently more complex than artificial structures.

DEMERSAL SPECIES	**PELAGIC SPECIES**
Inshore reefs (< 30 m depth)	Inshore reefs (< 30 m depth)
Pinfish Pigfish Black sea bass Longspine porgy Whitebone porgy Tomtate Tautog Atlantic spadefish Sheepshead Weakfish Flounders Spot Atlantic croaker Kingfish White grunt	Amberjacks Barracuda Bluefish Bonito Cobia King mackerel
Offshore reefs (> 30 m depth)	Offshore reefs (> 30 m depth)
Groupers Porgies Triggerfish Snappers	Dolphin Sailfish Wahoo Yellowfin tuna

Jetties offer some of the same habitat functions for fishery resources that natural hard bottoms and artificial reefs provide. The hard surface and irregular relief of the rocks provide shelter and food for the colonized plants and animals, which, in turn, serve as prey for higher order invertebrates and fishes. Hay and Sutherland (1988) described fish composition at jetties in North Carolina and South Carolina as a

subset of those fish found on offshore hard bottoms and estuarine oyster reefs. The majority of fish moved to deeper water in the winter, gradually returning to inshore habitats as waters warmed in spring. The abundance of *Sparidae* species, such as pinfish, spottail pinfish, and sheepshead, was positively correlated with vegetative cover on the hard bottom. Hay and Sutherland (1988) categorized five general fish groups:

- Small cryptic resident fish, such as blennies and gobies;
- Numerically dominant species that migrate offshore in colder months, such as pinfish, spottail pinfish, black sea bass, and pigfish;
- Predatory pelagic species, such as bluefish, and Spanish and king mackerels;
- Fish attracted to jetties during their northerly migration in spring or southerly migration in fall, such as smooth dogfish (*Mustelus canis*); and
- Tropical species that occur as strays during warmer months, such as butterflyfishes (Chaetodontidae) and sergeant majors (*Abudefduf saxatilis*).

Although jetties provide habitat for some fish, the species that utilize them do not require jetties for survival since they are attracted from other existing natural habitats, such as hard bottom and estuarine oyster reefs. Because of impacts of these artificial structures on intertidal beach and water column functions[83], oceanfront jetties should not be considered as a habitat enhancement tool.

7.3. STATUS AND TRENDS

Status of hard bottom habitat

The condition of this habitat is of particular importance to estuarine-dependent snapper-grouper species that utilize North Carolina's shallow hard bottom habitat as "way stations" or protective stopping points as they emigrate offshore to deeper hard bottom. Protection of the shallow hard bottom habitat in state territorial waters is essential for successful protection of the estuarine-dependent snapper-grouper species and the associated fisheries that primarily occur on hard bottom in federal waters. The offshore snapper-grouper fishery is of great importance to North Carolina's commercial and recreational fisheries because of the market value of the fish, the number of recreational participants, and the associated businesses it supports. The snapper-grouper fishery had an annual market value of $3.6 million between 1992 and 2001 (DMF, unpub. data). For the years 1997–2001, DMF and NMFS records show 10,817 trips annually by private and charter boats and another 1,049 by headboats.

Nearshore reefs, although adversely impacted to various degrees by man, are in good condition overall (SAFMC 1998b). Good information exists on the distribution of hard bottom (Moser and Taylor 1995; SEAMAP-SA 2001). However, there is very little information available to evaluate the status and trends of hard bottom habitat in North Carolina state territorial waters. Anecdotal information from fishermen and local residents in New Hanover County suggests that nearshore hard bottom sites in the 1960s and earlier are now completely covered in sand, and that the abundance of fish along the shore and nearshore areas is much reduced.

Status of associated fishery stocks

Reef fish harvested commercially or recreationally are managed collectively as the reef fish complex or Snapper-Grouper management unit. There are 73 species in this complex, including snappers, groupers, sea bass, porgies, triggerfishes, grunts, jacks, and others. Only some of these species are found on North Carolina's nearshore hard bottoms. Information is available on the status of many reef fish species through federal, state, and interstate stock assessments. Fishery-dependent data are collected on reef fish by DMF's Offshore Live Bottom Fishery Program (DMF biological database program 438/448). Fishery-independent status and trends data on reef fish are also available for a portion of North Carolina from the

[83] see Water Column (2.0) and Soft Bottom (6.0) chapters

Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP) conducted by the South Carolina Department of Natural Resources (SCDNR). This program has conducted standardized groundfish (bottom fish) surveys since 1973 utilizing a variety of fishing gears. Since 1983, surveys have been conducted using fish traps and long lines from Cape Lookout south to Ft. Pierce, Florida. Sampling occurs on mid-shelf live bottom and shelf-edge reef habitats in water from 16 m to more than 92 m deep. Species composition, fish length, and fish weight are recorded to determine community structure, biomass estimates, distribution, and relative abundance of the more abundant species. In addition, CPUE is calculated for vermilion snapper, red porgy, white grunt, gray triggerfish, and black sea bass (SCDNR, unpub. data). Although sampling occurs seaward of state waters, this program provides valuable information for state and federal stock assessments of reef fish, including species that utilize nearshore hard bottom and estuarine waters in North Carolina.

Most major South Atlantic reef fish stocks are considered fully utilized or over-utilized (NMFS 2002). Of 73 managed species in the South Atlantic Snapper-Grouper management unit, including black sea bass, 14 species were classified as Overfished in 2001 by the NMFS, nine were not Overfished, and 50 were Unknown (NMFS 2002).[84] Red porgy, speckled hind, red snapper, and snowy grouper are a few of the reef species classified as Overfished that occur in North Carolina.

In North Carolina, the reef fish complex as a whole was classified as Concern by DMF in 2002 (DMF 2003a). For stock status of individual reef species, DMF defers to SAFMC. Of the twelve fishery stocks listed in Table 7.3 that are highly associated with inshore hard bottom in North Carolina, six stocks have been evaluated by DMF. Two stocks were reported as Overfished (tautog and black sea bass south of Hatteras), one was Recovering (scup), two were Viable (gag and black sea bass north of Hatteras) and the reef fish complex was reported as Concern (Figure 7.1). The reef fish complex includes numerous individual species, of which at least ten species are common in North Carolina. SAFMC evaluates many of the species within the complex individually, and has reported some as overfished and others as viable. However, DMF has reported the complex as a whole to be of Concern, unless individually evaluated. Gag was upgraded by DMF in 2002 from the Overfished category to Viable. Black sea bass north of Cape Hatteras was upgraded from Overfished to Viable, based on the Northeast Fishery Science Center spring survey. Black sea bass south of Cape Hatteras was downgraded to Overfished based on the SAFMC stock assessment, which indicated low spawning stock biomass and heavy fishing exploitation. Approximately 74% of black sea bass landed in North Carolina are caught south of Hatteras.

[84] Overfished is defined as "a stock size was below a prescribed biomass threshold" (NMFS 2002) and Unknown is defined as "no recent assessment was conducted or insufficient information about this stock exists to make a determination" (NMFS 2003).

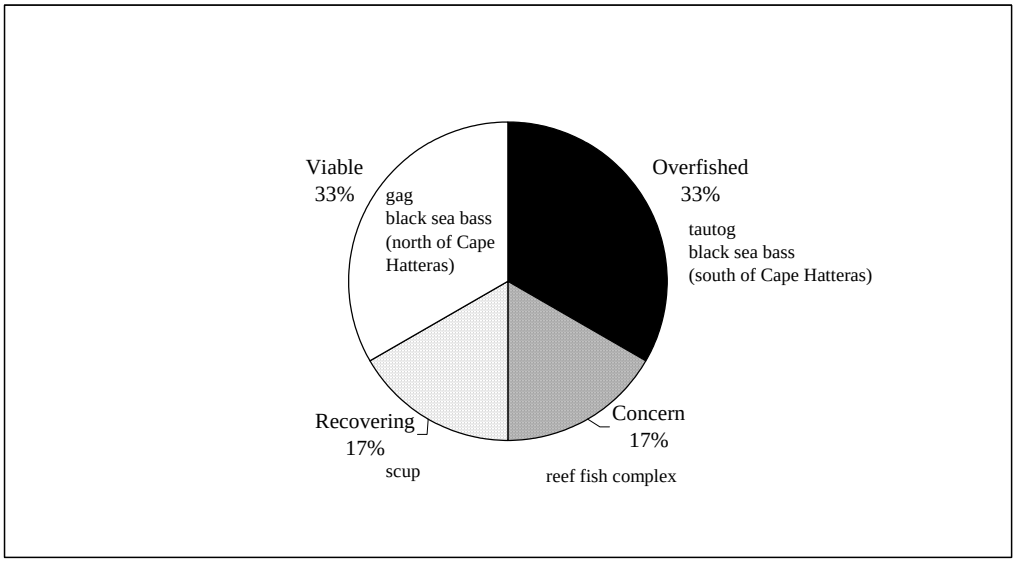


Figure 7.1. Percent of hard bottom associated fish stocks classified as Overfished, Concern, Recovering, or Viable in the 2003 DMF Stock Status Report. Individual species in the reef fish complex and common to North Carolina are listed in Table 7.3.

Although most of the overfished species are caught primarily in federal waters, many are highly dependent on the shallow hard bottom habitat in state waters as primary and secondary nursery areas. The status of gag and black sea bass is particularly important because they are highly dependent on nearshore hard bottom and estuarine habitats as primary and secondary nursery areas and for providing migratory corridors as species move offshore as individuals age. The apparent vulnerability of reef species to overfishing is attributed to their long lives, slow growth, ease of capture, large size, and delayed sexual maturity. *The MFC should consider designating inshore hard bottoms (within State Territorial Seas) as Strategic Habitat Areas because of their importance as secondary nursery habitats and migratory corridors for black sea bass, gag, and other reef fish species.*

Because of concern for the overfished status of major stocks of the snapper-grouper complex and failure of those stocks to adequately recover despite extensive changes in fishing regulations, the SAFMC is considering establishment of Marine Protected Areas (MPAs) in the south Atlantic area. The primary purposes for MPA designation by the Council would be to protect important known grouper spawning aggregations and prevent overfishing, particularly for deepwater species. One deepwater site is currently being considered in federal waters off North Carolina in Onslow Bay, east of Cape Fear. A shallow water site near Cape Lookout has been proposed as an artificial refugia location. An artificial refugia site is an artificial reef that is designated as a no-take area, to provide unfished habitat to aid in stock recovery, to conduct research, and to test effectiveness of enforcement. *Within this area, program sponsors should construct numerous small complex sites surrounded by open areas to mimic natural nearshore hard bottoms and maximize habitat utilization.*

Overfished stocks can be particularly vulnerable to changes in the quantity or quality of habitat. While some research in Florida has indicated that habitat is not limiting and reef fish population is controlled primarily by recruitment success (Bohnsack 1996; Grossman et al. 1997), these studies may not be applicable to North Carolina, where hard bottom is much less abundant. In North Carolina, there appears to be a direct relationship between the amount of hard bottom and the number of reef fish. Of the three bays in North Carolina, Onslow Bay has more hard bottom than Long Bay or Raleigh Bay and also has the greatest amount of reef fish (P. Parker, NMFS, pers. com., 2002). This relationship implies that increased habitat quantity would result in more or larger populations of reef fish. *Field experiments using*

a Before-After-Control-Impact Paired Series (BACIPS) design may be able to compare differences in fish abundance between undisturbed reefs (control sites) and areas with recently-added artificial structure (experimental sites) (Osenberg et al. 2002).

Hard bottom restoration

Artificial reefs can potentially enhance fish production by increasing foraging, spawning, and refuge habitat (Grossman et al. 1997). However, there is some concern among fishery scientists that the structures may only concentrate available biomass rather than increase regional productivity (Carr and Hixon 1997). Artificial reefs are most effective at increasing production where reef habitat is limiting, when fishing effort is low, and when a large stock reservoir exists (Bohnsack 1996; Grossman et al. 1997). However, the results of studies attempting to determine if habitat is limiting are mixed. Although coral-eating fishes have been shown to decrease in abundance with decreasing live coral coverage, a similar relationship with fish-eating fishes, such as snappers and groupers, has not been observed (Grossman et al. 1997). The latter group is the more common type of reef fish in North Carolina and the primary target of anglers.

Artificial reefs must be properly designed, sited, and managed to successfully increase production of benthic (bottom-dwelling organisms) biomass and fish populations (DMF 1988). If habitat is limiting, artificial reefs that are not marked for fishing exploitation could serve as artificial refugia, providing beneficial habitat functions that could enhance local populations of reef fishes. Also, small complex structures that mimic natural hard bottom may be better for overall recruitment and enhance juvenile habitat and survival, while larger structures may be better for attracting large predators and enhancing fishing (Bohnsack et al. 1994). One ongoing problem that the DMF has experienced with artificial reefs is the failure of some designs to remain assembled and in position. Early reefs composed of tires have broken apart during storms, and the tires have washed up on beaches and obstructed commercial fishing trawls. More recent artificial reefs constructed of concrete and pipes appear to remain in position as designed (DMF 1995). The DMF Artificial Reef Master Plan provides recommendations for design and siting of artificial reefs (DMF 1988). Some of the recommendations that pertain to habitat enhancement include:

- Materials used should not be toxic to the environment;
- Materials used must be stable and durable;
- Materials used should provide the degree of habitat complexity and profile appropriate for the targeted reef species;
- Artificial reefs should be designed to increase surface area and interstitial space by addition of rock, concrete, or other suitable materials to barges and stripped vessels that lack structural complexity;
- Trolling alleys, reef clusters, and reef sanctuaries should be incorporated into reef complex designs;
- Artificial reefs should not be sited where natural hard bottom exists, in high-energy environments, or where traditional commercial fishing activities occur;
- Enhancement of existing artificial reef sites should be a higher priority than construction of new artificial reef sites;
- If artificial reefs are used to replace natural reef habitat that has been damaged or destroyed, they should be designed and constructed to provide proven biologically productive habitat.

High numerical abundance of fish may not necessarily be associated with increased production, survivorship, or species richness. The attraction-production debate regarding artificial reef fish assemblages is not yet resolved (Bohnsack 1989; Pickering and Whitmarsh 1996; Carr and Hixon 1997; Rilov and Benayahu 2000). *Additional research is needed to determine if and to what extent artificial reefs in North Carolina simply concentrate available fish or effectively increase fish biomass.*

7.4. THREATS AND MANAGEMENT NEEDS

Dredging and beach nourishment

In evaluating habitat condition for the snapper-grouper fishery, SAFMC concluded that dredging near or on hard bottom is potentially the most damaging physical human activity to this habitat (SAFMC 1998b). Dredging can be associated with creation or modification to navigational channels, or removal of sediment for beach nourishment projects. Dredging impacts to hard bottom habitat include the following (SAFMC 1998b):

- Dislocation of corals or colonized rock (live rock) and cuts through live tissue that lead to infection or mortality;
- Sedimentation that stresses corals and other sessile invertebrates, causing mortality if the deposited sediment can not be displaced, which in turn may also displace reef fishes;
- Elevated turbidity for extended periods may continue to stress hard bottom organisms, potentially decreasing survival over time;
- Movement of fill material from beaches by waves and currents can result in increased turbidity at and sedimentation on nearby hard bottom sites.

At beach nourishment projects in Florida, added sand was transported offshore from the beach by cross-shelf currents, covering hard bottom habitat (Marsh and Turbeville 1981; Lindeman and Snyder 1999). Studies off Wrightsville Beach and Atlantic Beach demonstrated how sediment was transported from the nourished beaches across the shoreface in southeastern and central North Carolina waters (Thieler et al. 1995; Thieler et al. 1998; Reed and Wells 2000). Hard bottom was observed to be buried by nourishment sands in the Wrightsville Beach area (R. Thieler, USGS, pers. com., 2001). Commercial fishermen in the Wrightsville Beach area, where beach nourishment has been conducted regularly since the 1960s, reported that nearshore hard bottom areas that were once productive fishing areas are now covered in sand (public comment at SAFMC public meeting on MPAs, Wrightsville Beach, 2001; B. Cleary, UNC-W, pers. com., 2001). These areas are no longer fished due to poor yield. In Florida, Lindeman and Snyder (1999) observed dramatic decreases in numerical abundance of fish species and individuals following the burial of hard bottom habitat via sand transported from an augmented beach. The cumulative number of species detected 12 months prior to and 15 months after site burial decreased by nearly one order of magnitude, from 54 to eight species, respectively (Lindeman and Snyder 1999). The average number of individual fish recorded per transect also declined, from 38 (pre-burial) to less than one (post-burial) (Lindeman and Snyder 1999). Side-scan monitoring was conducted off South Carolina to look at the effect of Myrtle Beach nourishment projects on nearshore hard bottom. Little to moderate change in percent of seafloor with exposed hard bottom or rocky substrate was observed at most sites within two years of the project's completion (Ojeda et al. 2001). Two areas immediately seaward of the nourished beach showed a 20% net loss of hard bottom. This loss was offset by a net gain in hard bottom habitat of about 10% in another area, due to local redistribution of sand. Available data from the study indicated that the nearshore loss of hard bottom seaward of the project was due to localized introduction of new sand from beach fill, but was only somewhat greater than the natural variability occurring from shifting sands (Ojeda et al. 2001).

Dredging large navigation channels through ocean bottom is limited to the entrance channels leading to North Carolina's state ports in Wilmington on the Cape Fear River and in Morehead City on the Morehead City channel. The dredged channels in the ocean lead into the Cape Fear and Beaufort inlets, respectively. Hard bottom is located in close proximity to the Wilmington channel. In 2002, the navigation channel was rerouted as part of a project to deepen the river channel and port and create a new offshore dredge material disposal site. The proposed route was altered to avoid dredging through hard bottom (F. Rohde, DMF, pers. com., 2002). Dredging and stabilization of other inlets can also potentially impact hard bottom when these activities occur close to shore, such as at New River, Masonboro, or Shallotte inlets. Turbidity and sedimentation associated with dredging may also have indirect effects on

hard bottom in the vicinity of dredge sites.

In North Carolina, the frequency and magnitude of beach nourishment have increased over time.[85] If all requested and proposed projects are eventually authorized and conducted, a maximum of 155 miles (48% of ocean shoreline) could be affected and potentially degraded, excluding the beaches nourished periodically from channel and inlet dredging. All of the existing projects and the majority of the newly authorized projects are located south of Cape Lookout where hard bottom is most abundant, especially in the nearshore area. *The transport of sand from nourished beaches over time should be monitored. Future research should attempt to determine if the probability or extent of burial are affected by sand volume, type, or grain size, by the time-of-year of project initiation, or by the distance between nourished beach and hard bottom. A DENR Beach Management Plan should be developed and implemented which includes specific guidelines to minimize impacts to hard bottom from nourishment projects.*

Fishing and diving

Commercial fishing

Bottom longlines, dredges, fish traps, and bottom trawls can cause rapid and extensive physical damage to living and non-living components of hard bottom (SAFMC 1998b). In a comparative analysis of benthic fishing activities, the largest relative declines in benthic species richness and total numbers of individuals were associated with intertidal dredging (Collie et al. 2000). Fishing gear dragged across the bottom causes direct damage and mortality by breaking attached benthic organisms, such as sponges, anemones, and corals, or outcrop structures from the seafloor. Damage is especially extensive where the bottom is uneven and there is a concentration of coral and other invertebrates. The removal of structure and attached benthic organisms decreases species diversity and reduces structural complexity of hard bottom (Watling and Norse 1998). Dragged gear also indirectly damages bottom habitat by increasing the vulnerability of injured organisms to subsequent diseases and predation, smothering invertebrates with sediment (Auster and Langton 1999), and partially or completely destroying burrows and tubes constructed by invertebrates (Watling and Norse 1998). Trawling also results in an immediate reduction of mobile benthic invertebrates (e.g., crabs and polychaete worms) on and adjacent to hard bottom, reducing food resources available to other reef organisms.[86]

Roller-rigged trawls are a specific type of trawl with large rubber discs that is designed to roll over hard bottom habitat without becoming entangled. A study in South Carolina on the effects of roller-rigged trawls found that 32% of the sponges, 30% of the hard corals, and 4% of the soft corals at a hard bottom site were damaged by a single tow (Van Dolah et al. 1987). Damaged individuals require years to completely regenerate to their initial, pre-disturbance sizes, due to the organisms' slow growth rates (Van Dolah et al. 1987). Another study evaluated impacts from a roller-framed shrimp trawl and found that 50% of the sponges, 80% of the hard corals, and 40% of the soft corals were damaged (Tilmant 1979). In addition, catch rates of all animal groups declined over a five-year period; fewer animals may have been available to be caught due to past trawling effort.

Of the fishing gears that can potentially damage hard bottom, longlines, dredges, and fish traps are of minimal concern because they are used little or not at all in North Carolina state waters. There is currently no active dredge fishery in North Carolina's intertidal or subtidal ocean waters. Use of bottom longlines was prohibited by federal regulations in depths of less than 50 fathoms (300 ft) throughout the South Atlantic area as part of Amendment 4 of the Snapper Grouper Fishery Management Plan in 1991 to reduce fishing mortality and habitat damage. Fish traps can cause significant damage if placed on or dragged through hard bottom. However, federal regulations (Amendment 4, Snapper-Grouper Fishery Management Plan) prohibited the use of large fish traps in 1991. Smaller sea bass pots are allowed if equipped with escape vents and biodegradable panels to release undersize fish and eliminate waste from

[85] Refer to the soft bottom threats section for status, trends, and location of beach nourishment activity, Map 6.2.
[86] Refer to Appendix L for a list of the fishing gears used in North Carolina waters and their probable habitat impacts.

lost pots ("ghost fishing"). Only a relatively small number of black sea bass pots are placed in state territorial waters. Between 1994 and 2000, the total number of fish pot trips in state territorial waters ranged from 40 to 94 (DMF, unpub. data). Fish pots are more commonly used in federal waters and may have a greater impact to hard bottom in those areas.

Bottom trawling is conducted in North Carolina state ocean waters extensively for shrimp and to a lesser extent for flounder. Shrimp trawl effort in the ocean is most concentrated in the southern district of North Carolina (Onslow, Pender, New Hanover, and Brunswick counties), where hard bottom is most abundant (Figure 7.2). Flounder trawling in the ocean occurs in the northern (Currituck, Dare, Hyde counties) and central (Carteret County) districts, primarily north of Cape Hatteras. The number of flounder trawl trips during 1994–2000 has ranged from 49 to 204 trips/year, while the number of shrimp trawl trips has ranged from 2,500 to 3,500 trips/year (DMF, unpub. data). The extent that trawls contact and damage hard bottom in North Carolina is not known. Because the irregular hard surfaces of hard bottom can tear nets and damage expensive gear, fishermen generally try to avoid those areas. Roller-rigged trawls have been prohibited by federal regulations for targeting snapper-grouper since 1989. In addition, ocean trawling is prohibited within one-half mile of the ocean shoreline from Oregon Inlet north to the Virginia border [MFC rule 15A NCAC 3J.0202]. Trawling is also restricted in many other areas, as provided by MFC rules (MFC 2001). *While there is potential for damage, research is needed to determine if and to what extent hard bottom is being damaged by trawling activity in North Carolina, particularly shrimp trawls in the southern portion of the coast. The specific locations of trawl trips should be mapped. To assess potential effects of trawling, experimental trawls of predetermined duration, magnitude, and frequency should be conducted in a previously untrawled hard bottom location. The MFC should consider designating nearshore ocean hard bottoms as Strategic Habitat Areas due to their importance as secondary nursery habitat and corridors for gag, black sea bass, and other fisheries resources.*

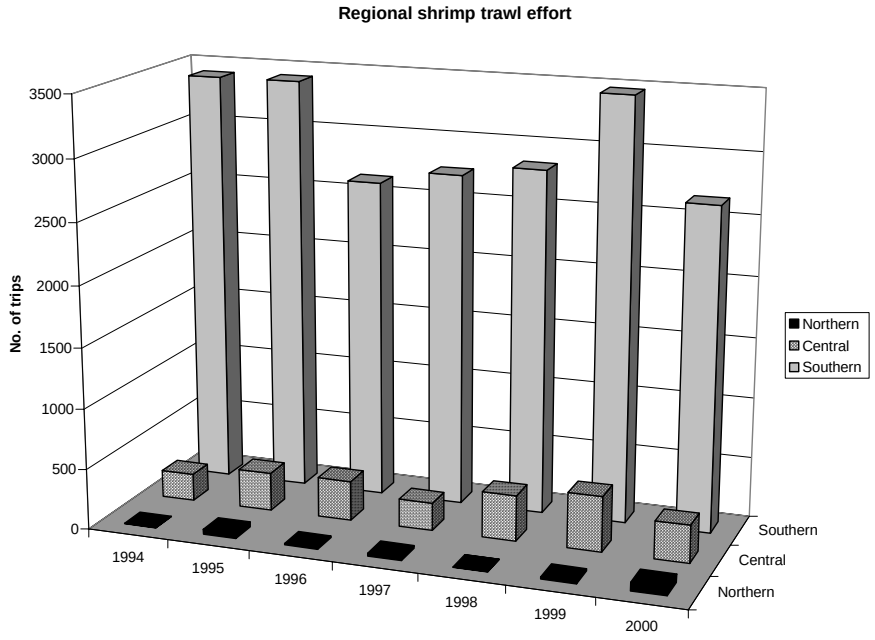


Figure 7.2a. Shrimp and flounder trawl fishing effort (number of trips) in North Carolina's nearshore ocean waters (0-3 miles from shore), 1994–2000, by coastal region. [Source: DMF, unpub. data]

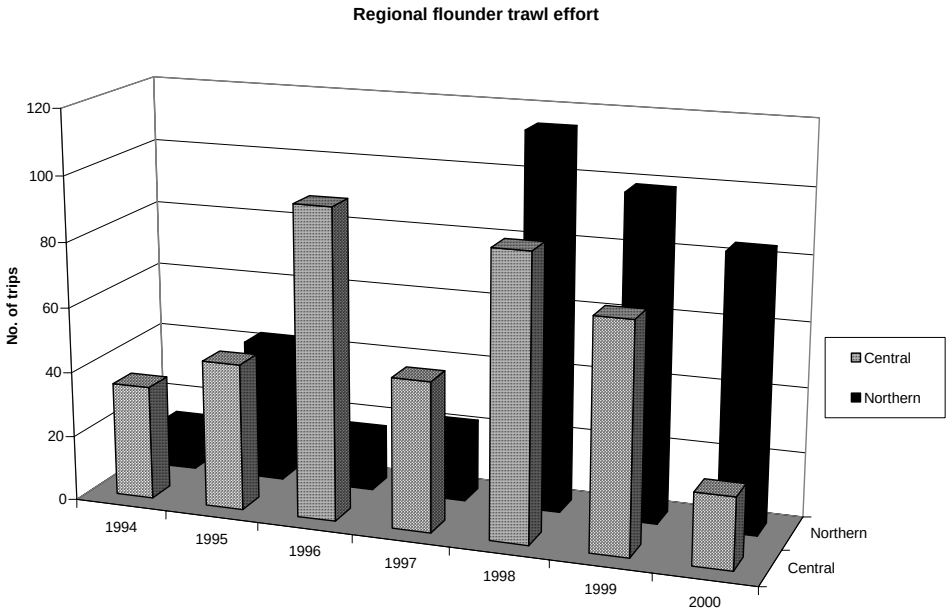


Figure 7.2b. Shrimp and flounder trawl fishing effort (number of trips) in North Carolina's nearshore ocean waters (0-3 miles from shore), 1994–2000, by coastal region. [Source: DMF, unpub. data]

Recreational fishing

Direct impacts of hook and line gear on hard bottom habitat are considered low. Recreational fishing was identified at a NMFS conference as a major concern because of the large number of participants in the fishery (Hamilton 2000). There were more than six million sport fishing trips in coastal North Carolina in 2001, including more than 500,000 by private boats and charter boats in the ocean. Federal headboat survey data indicate that, additionally, there were more than 1,000 headboat fishing trips in North Carolina's ocean waters south of Cape Hatteras during 2001, involving about 32,000 angler-days (R. Dixon, NMFS, pers. com., 2002). Hard bottom and artificial reef species are targeted by many recreational fishermen, and may receive concentrated use, leading to unknown cumulative impacts. Anchors and chains from recreational or commercial boats can break corals and other organisms and create lesions, leading to infection (SAFMC 1998b). In addition to habitat damage caused by anchors and chains, lost fishing gear (e.g., line, wire leaders, hooks, sinkers) and discarded rubbish (especially plastics) can entangle or be ingested by marine life, including bottom dwelling organisms. Roughly 52% of marine debris identified in U.S. waters originated from recreational vessels (UNESCO 1994). Chemical contamination from lost lead sinkers is also a concern. *Monitoring of hard bottom is needed to assess the level of impact from hook and line fishing. Educating anglers on the impacts of anchor damage, lost fishing gear, and discarded litter to hard bottom habitat and associated species would be helpful in reducing those impacts.* Finally, overfishing of large reef fish predators can indirectly damage hard bottom habitat by creating an imbalance of trophic structure, reducing the quality and productivity of the habitat (NMFS 1999). *This issue is best addressed through fishery management plans, rather than the CHPP process.*

Recreational diving

Diving activities can also damage hard bottom. Divers can kick or overturn corals and live rock, which results in habitat damage. Harvest of live rock for the aquarium trade was found to cause extensive destruction and loss of hard bottom, with additional damage when chemicals were used (SAFMC 1998b). The MFC prohibits harvest or possession of coral or live rock [MFC rule 15A NCAC 3I .0116]. The

Carteret County area has been rated as one of the premier offshore diving areas in the United States, especially for wreck diving. Recreational spearfishing with power heads has damaged corals where diving activity was concentrated. In North Carolina, however, damage from diving activity is probably minimal due to the relatively low numbers of divers in the inshore areas.

Infrastructure

A relatively new threat to hard bottom comes from the installation or maintenance of fiber optic cables and pipelines placed across oceans and waterways. Cables are increasingly used to transmit telecommunications over long distances and pipelines are used to transport gas products. Since 1988 when the first fiber optic cable was laid across the Atlantic Ocean, an estimated 230,000 miles of oceanic cable have been installed (Nero 2001). Fiber optic cables are generally laid directly on the seafloor, and routed into a dredged or bored trench, conduit, or access hole where the cable comes onshore (landing site). Once the access hole or conduit is in place and buried, maintenance or placement of new cables involve dredging these holes back open. While cables are currently being placed under estuarine and inland waters as part of a combined natural gas pipeline and cable project, there are no fiber optic cables located in the ocean off North Carolina at this time (<http://www.telegeography.com/products/map_cable/index.php>, August 2004).

Environmental concerns to hard bottom associated with laying cables or pipelines identified by Nero (2001) and Blue Atlantic Transmission System (2003) include:

- During installation, cable "sweeping" and crushing of hard bottom communities can occur, even when pre-construction evaluations and analyses of alternative proposed routes are conducted.
- During repairs, grappling to recover and repair damaged cable has the potential to cause additional impacts to hard bottom resources. The repaired cable is generally not returned to its original location, potentially impacting additional bottom areas.
- When directional drilling (drilling a tunnel under the seafloor) for the landing sites encounters certain subsurface conditions, the pressurized fluid mud used to lubricate the drill hole can escape into the water column. The escaped fluids may cause turbidity plumes and subsequent burial or smothering of sensitive hard bottom resources, and release potentially toxic compounds.
- Sedimentation or excessive suspended sediment can cover hard bottom or impact filter feeders.
- Pipes or cables may restrict or alter invertebrate movement on the seafloor due to physical barrier of the pipe, noise, vibrations, magnetic fields or other biochemical influences.

These cables and pipes may also pose a conflict for recreational and commercial fishing activities, as well as beach nourishment borrow areas. Permit authority for fiber optic cable corridors in the ocean is vested in the Corps of Engineers, with state review under the DCM consistency process. The ASMFC recommended that offshore corridors be pre-identified and evaluated for environmental impacts and conflicts. The ASMFC also recommended that monitoring be conducted to assess damage and recovery of habitat (Nero 2001). *North Carolina should coordinate with ASMFC, other states, and the communications companies to manage the placement of fiber optic cables in North Carolina offshore waters in a manner that minimizes impact to hard bottom and minimizes conflicts with existing activities.*

Water quality degradation

The quality of water at nearshore hard bottom sites is important since fisheries species are most sensitive to toxics and other pollutants during the first months of life. The effect of polluted waters on a given species depends on its life history and feeding behavior. According to the SAFMC (1998b), the primary threats to offshore water quality at hard bottom sites are oil and gas development, offshore dumping, and discharge of contaminants from river and estuarine systems.

The last active offshore oil and natural gas leases in state or federal waters off N.C. were relinquished in November 2000 (<http://www.gomr.mms.gov/homepg/offshore/atlocs/atocsfax.html>, 2003). Several

companies, including Amerada Hess, Chevron, Conoco, Marathon, Mobil, Occidental Petroleum Corporation (OXY), and Shell have held interests, singly or jointly, in the Manteo Exploration Unit, a submerged area comprised of 21 lease blocks located approximately 44.8 statute miles northeast of Cape Hatteras (Vigil 1998). Currently, a federal moratorium on oil exploration and development of the eastern U.S. seaboard is in effect until 2012 (<http://dcm2.enr.state.nc.us/Facts/offshore.htm>, 2003). *However, it would be beneficial for the state to develop and implement a policy to prohibit oil and gas drilling in North Carolina's coastal waters, to ensure protection of hard bottom and water column habitats.*

Offshore dumping of dredged material occurs at designated sites in federal waters seaward of the Morehead City and Wilmington ports. A new, enlarged "Ocean Dredge Material Disposal Site" (ODMDS) is being developed by COE off the mouth of Cape Fear River in close proximity to natural hard bottom. The ship channel re-alignment goes through an artificial reef established a few years ago by COE. *Adequate monitoring should be conducted prior to creation and during use of this ODMDS to determine its effect on hard bottom habitat.*

Studies in the Mediterranean Sea examining the effect of pollution on hard bottom benthic communities found that total species richness, abundance, and diversity declined with increasing influence of multiple sources of pollution (Hong 1983) and echinoderm richness and density decreased with proximity to industrial sewage outfalls (Hermelin et al. 1981). Current state (EMC) policies prevent wastewater discharge into the Atlantic Ocean. The only exception to this restriction is the discharge off Oak Island of heated flow-through, non-contact cooling water from a nuclear power plant. *Because nearshore hard bottoms are so vulnerable to damage from physical and water quality changes, this policy should be maintained.*

Hard bottom can be degraded not only by point discharges but by outflowing estuarine and river waters. The effect of estuarine waters on hard bottom in North Carolina's ocean waters is largely unknown since little monitoring has been conducted. In 1999, UNC-W began a Coastal Ocean Monitoring Program (COMP) to assess physical, chemical, and biological properties of the Cape Fear River water plume, extending into Long Bay, and waters in Onslow Bay. Results following Hurricane Floyd found that approximately 200 mi^2 of coastal ocean waters were affected for approximately one month, in terms of turbidity and nutrient levels (<http://rover.phy.uncwil.edu/onslow/CFRPlume/>, 2004). In comparing water quality in nearshore ocean waters in Long Bay, where there is a large riverine influence, to Onslow Bay, where there is minimal riverine influence, the Long Bay stations had four to seven times greater chlorophyll and nitrate concentrations than stations in Onslow Bay (<http://www.uncw.edu/cmsr/cormp/results.htm>, 2003). Hard bottom is concentrated in Long Bay and the south end of Onslow Bay, where riverine influence has been noted (Map 7.1c). Declines in estuarine water quality are therefore most likely to impact hard bottom in that area. *Monitoring of hard bottom should be initiated and coordinated with UNC-W or other ocean water quality monitoring programs to determine the effects of estuarine water quality, particularly nutrient and sediment loading, on hard bottom.*

Hard bottom in close proximity to shore is more vulnerable to coastal pollution from point and nonpoint discharge of sewage, industrial waste, and stormwater runoff than offshore hard bottom. Stormwater runoff and discharge of nutrient-rich estuarine waters can increase nutrient levels in coastal ocean waters. Problem levels of nutrients have generally not been found in North Carolina's coastal ocean waters. However, water quality sampling in the ocean waters is extremely limited.[87] Residues of the organochlorine pesticides DDT, PCB, dieldrin, and endrin have been found in gag, red grouper, black grouper, and red snapper, indicating that toxins from stormwater runoff are a potential threat to the hard bottom community (SAFMC 1998b). *Additional water and tissue sampling at hard bottom sites are needed to determine if the benthos of the hard bottom community or the surrounding waters exhibit levels*

[87] Refer to the Water Columnchapter for more information on water quality.

that exceed designated levels of concern.

Existing management measures

Man-made structures functioning as hard bottom have been given varying levels of designation and protection. In 1975, the wreck of the USS Monitor, a Civil War ironclad located off Cape Hatteras in federal waters, was designated as the first national marine sanctuary. Within North Carolina state territorial waters, the USS Huron, a popular wreck located just 250 yards off the beach in Dare County, was designated by the state as a historic shipwreck preserve (Map 7.1). Despite some concern regarding the effectiveness of artificial reefs, all artificial reefs, along with all natural hard bottom, have been designated by the NMFS as Essential Fish Habitat (EFH). All SAFMC-designated Artificial Reef Special Management Zones (SMZs) are also Habitat Areas of Particular Concern (HAPC) under authority of the federal Sustainable Fisheries Act of 1996 (SAFMC 1998b). Artificial reef SMZs are designated areas surrounding artificial reef sites where certain fishing restrictions or regulations may apply (DMF 1988). The purpose of the designation is to prevent extremely efficient fishing gear from being used on the sites, so that user conflicts are reduced, the resource is used in an orderly manner, biological production is optimized, fish stocks are maintained, and recreational fishing is protected (DMF 1988). There are 21 SMZs in the South Atlantic: seven off Georgia, 11 off South Carolina, one shared by Georgia and South Carolina, and two off Florida. There are no SMZs in North Carolina waters. Fishery management plans adopted by the South Atlantic Council include HAPC designations, which are then put into effect through federal regulations implemented and enforced by NMFS.

Natural hard bottom is protected through several state and federal designations. Certain hard bottom areas were designated as federal Habitat Areas of Particular Concern based on four criteria: 1) importance of ecological functions; 2) sensitivity to human degradation; 3) probability and extent of effects from development; and 4) rarity of the habitat. In North Carolina, all of the nearshore hard bottom areas, two specific offshore areas in Onslow Bay (Ten Fathom Ledge and Big Rock), and the entire shelf break have been given this designation for snapper-grouper (SAFMC 1998a). Approximately 150 reef-associated species have been documented from Ten Fathom Ledge and Big Rock (SAFMC 1998a). Inshore hard bottom (<18 m water depth) is thought to support similar fish species as those documented at Ten Fathom Ledge (P. Parker, NMFS, pers. com., 2001).

The N.C. Natural Heritage Program inventories, catalogues, and facilitates protection of the rarest and most outstanding elements of natural diversity in the state. The program designates rare or significant plants, animals, or natural communities, which consequently merit protection or special consideration when making land use and conservation decisions. Currently, four hard bottom ledges within state territorial waters (Map 2.3) have been designated by this state program as Significant Natural Heritage Areas (SNHA) (Natural Heritage Program, unpub. data). These areas include rock outcrops off Bogue Banks (two acres), New River Inlet (1300 acres), South Topsail Island (38 acres), and Masonboro Island (50 acres). There is also one designated intertidal rock outcrop community—the Fort Fisher Coquina Rock outcrops (47 acres). These and other nearshore hard bottom areas are particularly vulnerable to impacts from on-shore land development activities. *These areas should be designated as Strategic Habitat Areas and considered for additional protection under the recent federal Executive Order 13158, which calls for strengthening and expansion of Marine Protected Areas in the United States or through additional state actions specifically designed to protect those sites.*

Several state and federal regulations provide protection for hard bottom habitat. Since 1995, DMF has prohibited directed harvest of all coral or any live rock in North Carolina state waters [MFC rule 15A NCAC 3I .0116]. In addition, any live rock or coral which is harvested incidentally with any gear must be returned immediately to the waters where taken. Similar NMFS regulations exist for federal waters. There are a few areas where hard bottom is present and trawling is restricted. This includes the military prohibited and restricted areas and sea turtle sanctuary that are both located in the ocean seaward of Onslow Beach [15A NCAC 3I .0110, 15A NCAC 3I .0107].

Despite the live rock prohibition, hard bottom structure can still be damaged or killed accidentally by certain commercial and recreational fishing gear and boating equipment. Although there is potential for damage, there has been no documentation that fishing gear currently used in North Carolina is damaging hard bottom. An absence of data on past conditions and current fishing and boating effects prevents accurate identification of potential damage to nearshore hard bottom. *Monitoring of hard bottom condition in nearshore waters, as well as fish utilization of the habitat, is the first step in evaluating impacts of fishing gear or threats to that habitat.*

A series of federal regulatory actions have been taken by NMFS to protect hard bottom habitat (SAFMC 1998b). Management measures from the snapper-grouper FMP and subsequent amendments focused on prevention of overfishing through harvest and gear limitations:

- Amendment 1 (1989) addressed habitat damage through prohibition of trawling gear (roller-rigged trawls) for the harvest of species in the snapper-grouper fishery south of Cape Hatteras (SAFMC 1998b);
- Amendment 2 to this plan (1994) prohibited collection of live rock in federal waters. State rules were implemented in 1995 to be consistent with this federal regulation;
- Amendment 4 (1991) prohibited use of fish traps in federal waters, with the exception of black sea bass traps north of Cape Canaveral, Florida. Fish traps cannot be used in North Carolina ocean waters to target snapper-grouper [15A NCAC 3M .0506(s)(1)]. These rules limit the potential number of traps and associated impacts to hard bottom in North Carolina. The majority of black sea bass traps are located beyond state waters. Bottom longlines are allowed in south Atlantic federal waters. Collecting corals and use of chemicals are regulated by NMFS pursuant to the 1982 SAFMC Coral Fishery Management Plan (SAFMC 1998b).

Use of Marine Protected Areas has proven effective in habitat protection and fishery enhancement in several areas of the world. A recent study of 89 marine reserves showed that fish and marine life quickly recovered when protected by establishment of marine reserves (Halpern 2003), and organisms within the protected areas repopulated adjacent waters (AAAS 2001; Roberts et al. 2001). In New Zealand, overfished snapper populations increased by 40 times within a few years of its establishment, compared to populations outside a reserve. Fish populations tripled in a St. Lucia reserve within three years. North Atlantic sea scallop populations were 14 times greater inside a reserve than outside it after five years of closure. Estuarine waters near Cape Canaveral that were closed to fishing for over 30 years had 3–12 times greater relative fish abundance than adjacent fished areas (Roberts et al. 2001). In addition, preliminary results from establishment of several no-take reserves in the Florida Keys in 1995 indicate reduced habitat damage and improvement in some reef fish populations, particularly yellowtail snapper and spiny lobster.

Since multiple harvest and gear regulations have not appeared to adequately improve the status of reef fish species in the Snapper-Grouper fishery, and additional species have become overfished, the SAFMC has considered use of Marine Protected Areas as a possible management tool since 1992 (SAFMC 1998b; SAFMC 2001). Marine Protected Areas are considered most effective at protecting species with restricted geographical movements typical of most reef animals or where habitat is limiting (Bohnsack 1993). Creation of MPAs can be a valuable tool for the prevention of or recovery from overfishing. They also protect, and potentially improve, reef habitat previously subjected to physical damage. Finally, MPAs protect age structure, biodiversity, and genetic diversity of fish stocks within their boundaries. Based on the 1992 scoping process, input from SAFMC advisory panels and committees, and an ongoing public involvement process, the SAFMC will likely use some form of MPAs as a fishery management tool in the south Atlantic. There has been little discussion concerning establishment of reserves through state management. The MFC has the authority to establish no-take areas. The Fisheries Director may prohibit or restrict taking of fish and use of any equipment in and around any artificial reef or research sanctuary subject to some conditions [15A NCAC 3I .0109]. Many areas within state waters, such as

primary nursery areas, are already protected from certain fishing activities through MFC rules. For example, trawling is prohibited in over 46% of North Carolina's estuarine waters. *Hard bottom designated as Strategic Habitat Areas could be considered for incorporation into an MPA to provide protection from fishing gear impacts.*

Two federal Executive Orders issued in 1997 and 2000 also support and encourage establishment of MPAs. In 1997, Executive Order 13089 authorized establishment of a multi-agency task force to direct coral reef conservation in the United States (63 FR 32701–32703, 1998). This task force is exploring recommendations for establishment of MPAs to protect coral reef ecosystems. Establishment of MPAs was being considered at Gray's Reef National Marine Sanctuary in Georgia waters (SAFMC 2001). In 2000, Executive Order 13158 directed federal agencies to strengthen the management, protection, and conservation of existing marine protected areas and establish new or expanded MPAs through the creation of a scientifically-based comprehensive national system of MPAs representing diverse marine ecosystems (Federal Register 2000). The MPA executive order calls for:
Integrated assessments of ecological linkages among MPAs;
Biological assessment of the minimum area of "No Take" zones needed to preserve representative habitats in different geographic areas of the marine environment;
An assessment of threats and gaps in levels of protection to natural and cultural resources;
Practical science-based criteria and protocols for monitoring and evaluating the effectiveness of MPAs;
Identification of emerging threats and user conflicts affecting MPAs and appropriate, practical, and equitable management solutions, including effective enforcement strategies to eliminate or reduce such threats and conflicts; and
Assessment of the economic effects of the preferred management solutions.

The DMF should investigate the law enforcement needs necessary to implement MPAs or similar actions for the protection of hard bottom habitat and associated fisheries.

Water quality protection for hard bottom habitat may also result from Executive Order 13158. In addition to establishment of MPAs through NMFS, the order instructs the Environmental Protection Agency (EPA) to identify areas warranting additional protection from pollution and enhancement of water quality standards, and to "propose new science-based regulations, as necessary, to ensure appropriate levels of protection for the marine environment" (Federal Register 2000). The Executive Order also requires the Department of Commerce and the Department of the Interior to consult with relevant states, and to seek expert advice and recommendations of non-federal scientists and resource managers, and other interested organizations through an advisory committee. More information on MPAs is available on the web (<http://www.mpa.gov>, 2003).

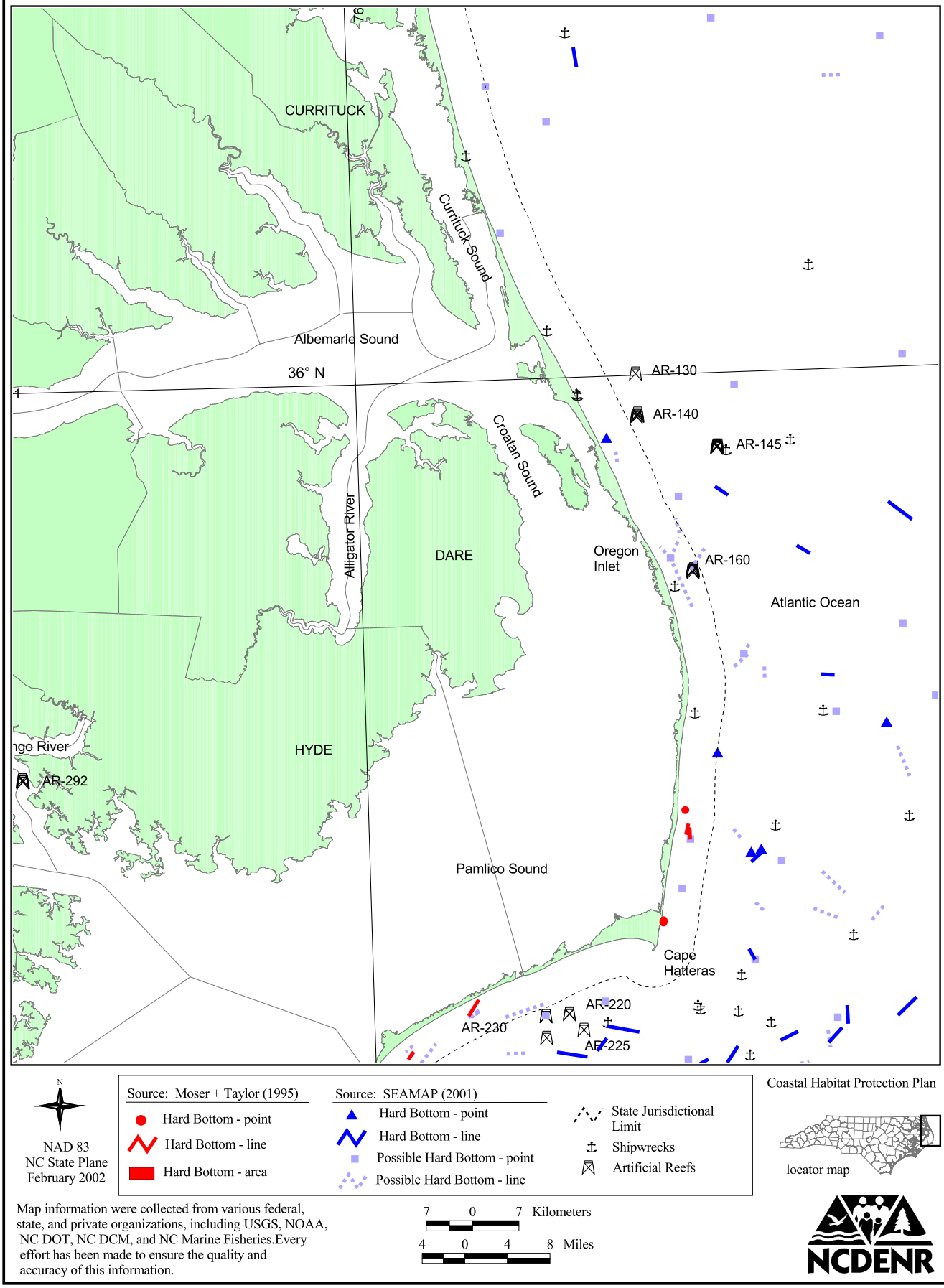
7.5 SUMMARY OF HARD BOTTOM CHAPTER

Hard bottom is valuable to fish because it provides structural complexity for foraging and refuge in marine waters. The presence of ocean hard bottom, along with appropriate water temperatures, allows for the existence of a temperate-to-subtropical reef fish community and a snapper-grouper fishery in North Carolina. Many economically important species and many non-fishery species spawn on nearshore hard bottoms, including black sea bass, Atlantic spadefish, sheepshead, tomtate, white grunt, pinfish, pigfish, damselfish, blennies, sand perch, and inshore lizardfish. Nearshore hard bottoms within North Carolina's ocean waters also serve as important nursery areas for these species as well as provide important secondary nursery habitat for estuarine-dependent fish, such as gag, and black sea bass, as the fish move between estuarine areas and offshore reef areas. All nearshore hard bottoms have been federally designated as Habitat Areas of Particular Concern for the snapper-grouper complex.

Although the current distribution of hard bottom habitat has been mapped, little is known about the biological condition of specific hard bottom sites or how it is changed over time. Wrecks and artificial

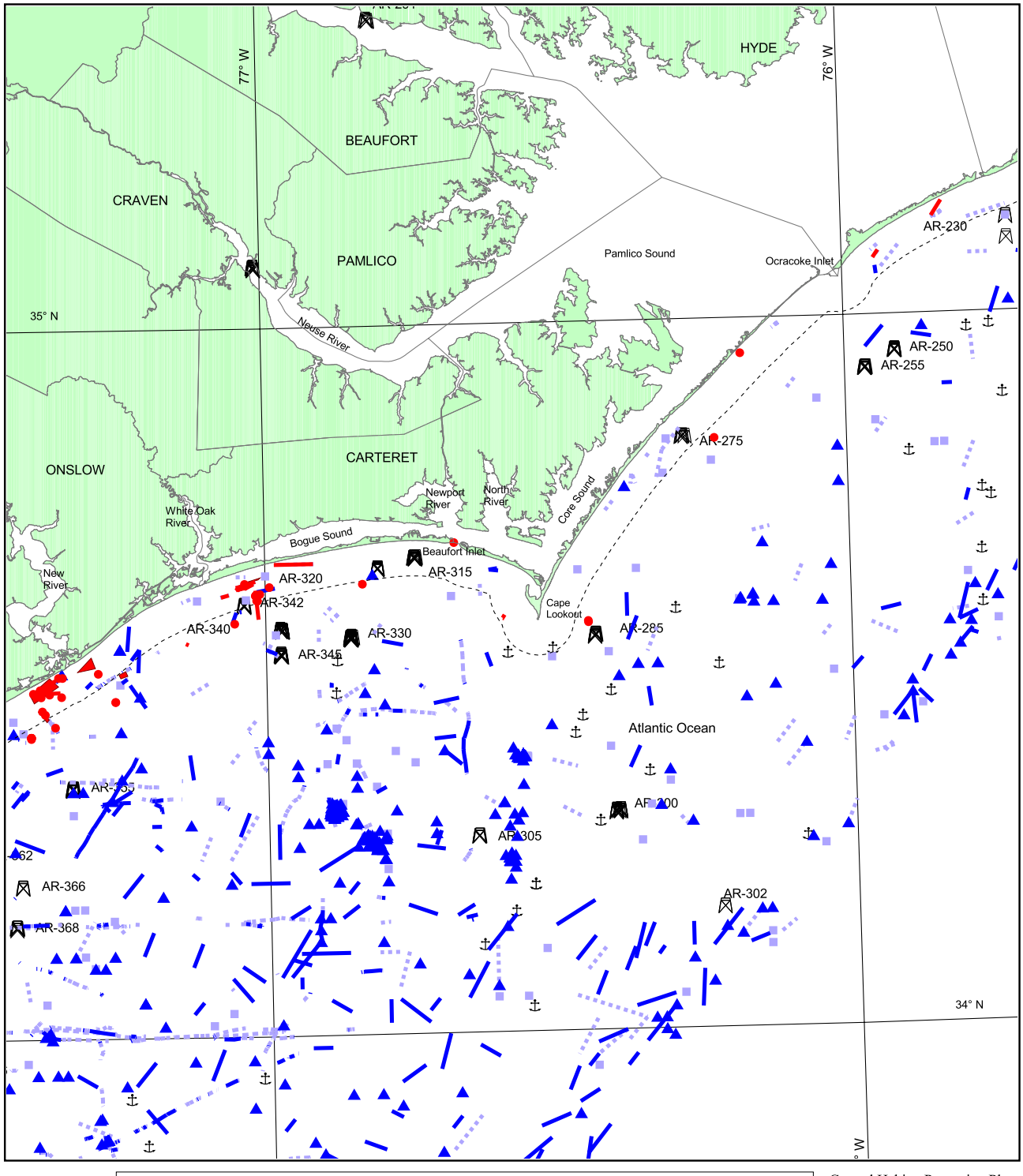
reefs are beneficial since they add to the total amount of hard structure available to marine organisms and may reduce fishing pressure on natural reefs.

Because of the lack of baseline information on the biological functioning of nearshore hard bottom, the primary management needs for this habitat are continued research and monitoring to determine specific functional importance, determination of status and trends, and protection of existing hard bottom habitats from degradation or destruction. Threats to nearshore hard bottom in North Carolina include beach nourishment, channel dredging, bottom-disturbing fishing gear, and water quality degradation. Channel dredging can directly remove hard bottom habitat or increase turbidity to damaging levels. Sand transported from nourished beaches can cover up hard bottom structure. Bottom-disturbing fishing gear and related equipment, such as bottom trawls and boat anchors, can uproot coral and damage the structure of hard bottom. Excess nutrients, sediments, or toxins can impact growth or survival of the invertebrates living on hard bottom structure. Water quality degradation to hard bottom originates from nonpoint sources, such as oil and gas from boating activity, oil spills, and nutrient, sediment, or toxin loading from estuarine and riverine discharges. The quality of estuarine waters discharging into marine waters may have the largest overall effect on hard bottom, and can be addressed through the management needs discussed in the other estuarine habitat sections.



Map 7.1a. Location of hard bottom, possible hard bottom, shipwrecks, and artifical reefs in state and federal waters off North Carolina - northern coast

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NAD 83
NC State Plane
February 2002

Source: Moser + Taylor (1995)
- Hard Bottom - point
- Hard Bottom - line
- Hard Bottom - area

Source: SEAMAP (2001)
- Hard Bottom - point
- Hard Bottom - line
- Possible Hard Bottom - point
- Possible Hard Bottom - line

- State Jurisdictional Limit
- Shipwrecks
- Artificial Reefs

Coastal Habitat Protection Plan

locator map

Map information were collected from various federal, state, and private organizations, including USGS, NOAA, NC DOT, NC DCM, and NC Marine Fisheries.Every effort has been made to ensure the quality and accuracy of this information.

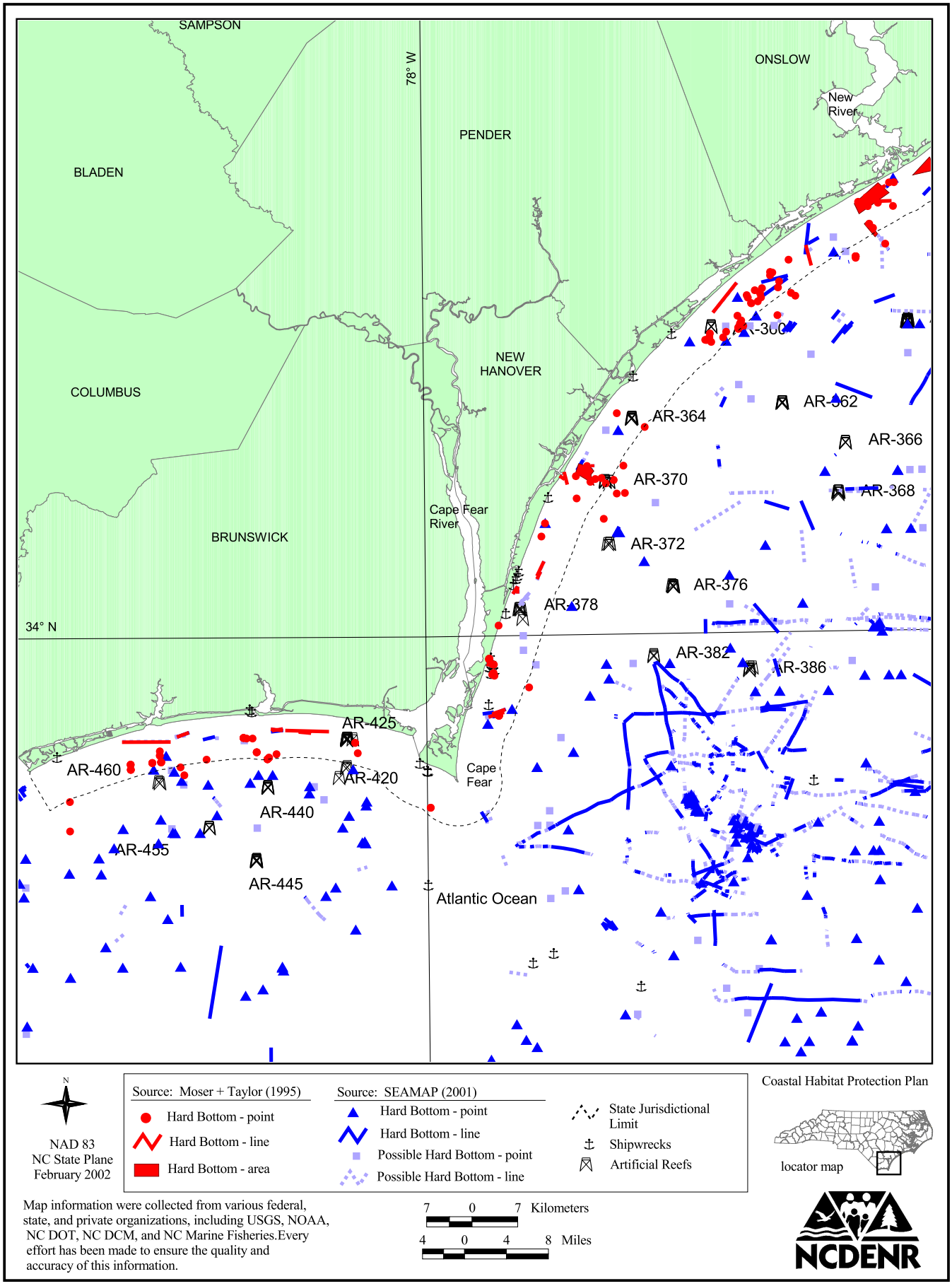
7 0 7 Kilometers

4 0 4 8 Miles

NCDENR

Map 7.1b. Location of hard bottom, possible hard bottom, shipwrecks, and artificial reefs in state and federal waters off North Carolina - central coast.

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Map 7.1c. Location of hard bottom, possible hard bottom, shipwrecks, and artificial reefs in state and federal waters off North Carolina - southern coast.

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CHAPTER 8. STRATEGIC HABITAT AREAS

While recognizing that all fish habitat is important, scientific data show that certain areas contribute disproportionately more to the viability of fishery and forage stocks, and populations of protected species. These areas of high importance should be the primary focus of habitat protection efforts. While the locations of many Strategic Habitat Areas (SHAs) in North Carolina are currently unverified, some are known (i.e., Primary Nursery Areas). Basic criteria for their location are presented in this chapter. This chapter also provides guidance for the identification, delineation, and designation processes. Location and delineation of these areas will be addressed in the eleven Management Unit plans following adoption of this Coastal Habitat Protection Plan.

8.1. DEFINITION

In 1998, the CRC, EMC, and MFC approved the following definition for Strategic Habitat Areas (SHAs):

"Specific locations of individual fish habitats or systems of fish habitats that have been identified to provide exceptional habitat functions or that are particularly at risk due to imminent threats, vulnerability, or rarity. These may include areas previously delineated by other state or federal agencies (AECs, HAPCs, ORWs, for example), or others as deemed necessary in an approved CHPP. Strategic Habitat Areas allow for site-specific management measures to be recommended."

As noted in the SHA definition, management measures will be site-specific based on the fish population dependence on the habitat and the threats to habitat function. Some measures may be broader reaching than others due to the extent of SHAs in a particular Management Unit. As SHAs are identified, each commission and agency involved with activities impacting those areas will determine appropriate regulatory and non-regulatory actions necessary to protect these sites.

8.2. SYSTEM RELATIONSHIPS

In order to locate and delineate SHAs, the relationships among habitats must be considered. While all fish habitats are of ecological value to fish, numerous studies from a variety of areas show that certain spatial relationships among habitats maximize their ecological value to species in those habitats. For example, the overall abundance and biomass of finfish and other animals in tidal freshwater and estuarine creeks are enhanced by proximity of SAV beds to the marsh edge and depth of adjacent creeks (Rozas and Odum 1987a; Ellis 1995; Irlandi and Crawford 1997). Open-water zooplankton are more vulnerable to predation in close proximity to SAV beds providing refuge for small planktivorous fish than zooplankton occurring well away from such areas (SAFMC 1998a). In a Texas estuary, densities of small invertebrates (worms, shellfish, insects) in soft bottom are highest adjacent to emergent salt marsh vegetation in the spring (Rozas and Zimmerman 2000). Species using rocky outcrops in North Carolina marine systems were supported by benthic production from adjacent soft-bottom habitat (Posey and Ambrose 1994). Another example of the synergistic effect of habitat diversity is the co-occurrence of oyster reefs and SAV. In turbid areas with reduced SAV coverage, addition or enhancement of oyster reef habitat facilitates filtration of suspended particles from the water column, enhancing light penetration and improving conditions for SAV. Expansion of SAV habitat can lead to increased production of many fishes and invertebrates dependent on that habitat. These studies show how individual habitats can have a greater value to fish production as part of a system or complex of habitats than as isolated sites.

While delineating complexes of related bottom features is important, it is only part of Strategic Habitat Area delineation. Water circulation patterns play a crucial role in larval settlement and post-larval migration to nursery areas. Maintaining water flow among SHAs is therefore an important aspect of SHA management. The water column surrounding bottom features is also affected by water circulation patterns and land use/land cover characteristics affecting the source of that water. Habitat fragmentation

is a well-recognized problem affecting terrestrial wildlife populations (Saunders et al. 1991). In aquatic systems, Turner et al. (1999) found that SAV patch isolation had a significant influence on benthic community composition, suggesting that habitat fragmentation degrades aquatic systems as well as terrestrial systems. *Therefore, consideration should be given to reducing habitat fragmentation in the process of SHA designation.*

8.3. EXISTING HABITAT DESIGNATION AND PROTECTION PROGRAMS

There are no designated Strategic Habitat Areas in North Carolina at this time. However, several different approaches are used in North Carolina to identify, delineate, and designate ecologically important habitat areas. At the federal level, the Magnuson-Stevens Fishery Conservation and Management Act Reauthorization of 1996 [the Sustainable Fisheries Act (SFA)] requires the National Marine Fisheries Service (NMFS) to amend federal Fishery Management Plans (FMPs) to include provisions for protection of "Essential Fish Habitat" (EFH), defined as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." In North Carolina, salt marshes, oyster reefs, and seagrass beds are designated EFH for red drum and penaeid shrimp, species managed cooperatively by state and federal authorities. Similar to CHPP Strategic Habitat Areas, federal "Habitat Areas of Particular Concern" (HAPCs) are designated for areas of EFH that are particularly important for managed species or species complexes (SAFMC 1998a). North Carolina Primary Nursery Areas, first designated by the MFC in 1977, are similar in concept to HAPCs. However, the NMFS has designated very few HAPCs (none in North Carolina), while the MFC/DMF and WRC have designated tens of thousands of acres as nursery areas in North Carolina (see below). The state designations are well accepted by the various state and federal regulatory and permitting agencies, as well as by the public.

While the concept of HAPC is similar to that of CHPP Strategic Habitat Areas, there are some important differences. First, measures protecting HAPC are focused on federally funded activities. The scope of HAPC protection is also specific to individual species or groups of similar species and, therefore, does not take a watershed-based approach. For oceanic species managed by the federal government (e.g., tunas), this approach presents no obstacle, but for anadromous (e.g., American shad) and estuarine-dependent (e.g., southern flounder) species, which are of primary importance in North Carolina, the watershed approach best captures the nature of threats and impacts, as well as opportunities for restoration, enhancement, and preservation. Finally, the federal FMPs and their implementing rules do not apply to fishery species managed primarily under state authorities (e.g., oysters, spot).

The MFC and WRC have designated nursery areas since 1977 and 1990, respectively, based on field sampling. Approximately 162,000 acres of Coastal Fishing Waters are currently designated by the MFC as Primary, Secondary, and Special Secondary Nursery Areas. About 10,000 acres of Inland Fishing Waters in the coastal area are designated as Inland Primary Nursery Areas, as well as the following areas of the four main rivers draining to North Carolina's coast:

- Roanoke River, U.S. 258 bridge to Roanoke Rapids Dam (35.5 stream miles, 57.1 km)
- Tar-Pamlico River, railroad bridge at Washington to Rocky Mount Mill Dam (90.2 stream miles, 145.2 km)
- Neuse River, Pitchkettle Creek to Milburnie Dam (160.6 stream miles, 258.4 km)
- Cape Fear River, Lock and Dam #1 to Buckhorn Dam (126.7 stream miles, 203.9 km).

Strategic Habitat Areas are not the same as MFC-defined "Critical habitat areas" [MFC Rule 15A NCAC 3I .0101(20)]. Strategic Habitat Areas may include critical habitat areas, but all critical habitat areas may not be SHAs. The term "Strategic Habitat Areas" is also used to avoid confusion with the term "Critical Habitat" used in the federal Endangered Species Act. There are currently no specific protections for MFC-designated Critical habitat areas within EMC or CRC rules. There are, however, specific protections for designated nursery areas included in the rules of all three commissions. For example, a MFC rule [15A NCAC 3N .0104] prohibits use of trawls, dredges, long haul and swipe seines, and

mechanical shellfishing gears in Primary Nursery Areas (PNAs). Once an area has been designated as a PNA by the MFC, the area also comes under protection of existing CRC rules [15A NCAC 07H .0208] and EMC rules [EMC rule 15A NCAC 02B .0301(c)] that protect physical and water quality parameters of PNAs as a class.

Four classes of Critical habitat areas were defined by a MFC rule in the early 1990s [MFC Rule 15A NCAC 3I (20) – submerged aquatic vegetation, shellfish producing areas, anadromous fish spawning areas, and anadromous fish nursery areas], but no specific areas have yet been designated under that rule. The DMF is currently delineating anadromous fish spawning areas based on sampling conducted from the early 1970s to the present for presentation to the MFC. Although neither CRC nor EMC rules offer any specific protection for anadromous fish spawning or nursery areas, regulatory protections exist for other critical habitat areas, such as submerged aquatic vegetation and shellfish producing areas. Beds of submerged aquatic vegetation are protected from the direct impacts of dredging and trawling (in some locations [MFC rule 15A NCAC 3J .0104]), and open shellfish harvesting areas are protected from new marina pollution and wastewater discharges [CRC rule 15A NCAC 07H.0208(5) (E)]. (More information regarding protection of fish habitat types is provided in Chapters 2 – 7). The piecemeal protection of individual habitat types fails to provide the holistic approach needed to protect entire systems of interdependent habitat. Designation and protection of Strategic Habitat Areas are meant to remedy this problem.

8.4. LOCATION AND DESIGNATION PROCESS

Strategic Habitat Areas will be delineated and recommended for designation in CHPP Management Unit plans. To protect these areas, the CRC, EMC, and MFC would enact appropriate management measures following the Administrative Procedures Act (G.S. 150B) for rulemaking. Recommendations for designation of SHAs will be developed based on existing DMF procedures for identifying PNAs and similar procedures by the other commissions and agencies. Government agencies or private parties may suggest potential areas. The process for identifying and designating SHAs should include the following tasks:

- ***Gather data and information to locate potential Strategic Habitat Areas*** by completing and maintaining habitat mapping (including seagrass, shell bottom, and other bottom types) using the most appropriate technology, monitoring the status of those habitats, and assessing the effects of land use and human activities on those habitats. Data on specific habitat areas (such as small watersheds, bays, or creek segments), fish populations and other natural resources, and potential threats in or near those specific habitat areas, will be compiled, including assessment of linkages between habitats and fisheries resources. Staff will evaluate indicators of biological or ecosystem health and integrity; distribution, status, and trends of the habitat; and threats to habitat quality and quantity.
- ***Identify Strategic Habitat Areas using ecologically based criteria*** developed from information gathered in step 1**.** The checklist outlined in section 8.5 should be utilized in identifying SHAs.
- ***Develop a spatial database for each proposed SHA.*** The boundaries of each SHA will be mapped and entered into a DENR Geographic Information System (GIS) database. The spatial database will also include habitat types, fish populations and other natural resources, existing protected areas (state, federal and local agencies' designated areas), and potential threats, as well as supporting research and sampling information.
- ***Present recommended Strategic Habitat Areas for designation by the appropriate commission***. These recommendations will be part of the report associated with the proposed SHA.

Once an area is designated, existing rules and voluntary initiatives pertinent to that area should be compared to potential threats in order to identify any gaps in protecting its current strategic functions. This evaluation could lead to new rules to protect the area, or modifications of existing management

activities (i.e., enforcement, education, land acquisition).

8.5. STRATEGIC HABITAT AREA CHECKLIST

1. The area provides exceptional habitat function for coastal fisheries resources and/or related forage species. The coastal fisheries and forage species and stocks to be considered include the following:
    a. All coastal fisheries species for which North Carolina, interstate, or federal FMPs have been adopted by the MFC, WRC, Atlantic States Marine Fisheries Commission (ASMFC), South Atlantic Fishery Management Council (SAFMC), or Mid-Atlantic Fishery Management Council (MAFMC),
    b. Other species that support important commercial and recreational fisheries in coastal North Carolina,
    c. Forage species important in the diets of the above species
2. The area is documented by specific data or scientific studies as highly important for spawning, nursery, foraging, corridor, or refuge functions.
3. Qualitative information indicates the area is highly important for spawning, nursery, foraging, corridor, or refuge functions.
4. The area is documented by specific data or literature as highly important based on
    a. High and consistent species abundance
    b. High and consistent species diversity
5. The area has been documented to provide important functions for state or federally listed protected aquatic animal or plant species.
6. The area is particularly vulnerable to human impacts or is rare (i.e., uncommon, limited geographic range).
7. The area is at particular risk due to demonstrable threats, as indicated by local development patterns, land use plans, or other applicable information.
8. The area is within an existing state, federal, or local government aquatic area designated to provide some level of protection against degradation or loss (designating authority in parentheses):
    a. Primary nursery areas (MFC)
    b. Critical habitat area (MFC)
    c. Inland primary nursery areas (WRC)
    d. Crab spawning sanctuaries (MFC)
    e. Outstanding Resource Waters (EMC)
    f. Wetlands of exceptional functional significance (DCM)
    g. Habitat areas of particular concern (NMFS)
    h. Significant natural heritage areas (Natural Heritage Program)
    i. Sea turtle sanctuaries (MFC)
    j. North Carolina coastal reserves (CRC)
    k. National estuarine research reserves (NMFS)
9. Marine protected areas (NMFS)
10. The site is within an area set aside for natural resource management or protection (designating authority in parentheses):
    a. State parks, natural and scenic rivers (North Carolina General Assembly)
    b. National parks and seashores (United States Congress)
    c. National wildlife refuges (United States Congress)
    d. National forests (United States Congress)
    e. State game lands (WRC)

CHAPTER 9. MANAGEMENT RECOMMENDATIONS

9.1 INTRODUCTION

The discussions of the six major habitat types in the preceding chapters demonstrate the importance of coastal fish habitats, threats to those habitats, and the need to take actions to achieve the stated goal of the Coastal Habitat Protection Plan as provided by the North Carolina General Assembly: "long-term enhancement of coastal fisheries associated with each coastal habitat." This chapter provides management recommendations based on scientific studies cited in chapters 2 – 7, deliberations of the Environmental Management, Coastal Resources, and Marine Fisheries commissions, and citizen input (verbal comments received in person or by telephone; written comments received in person or via mail and e-mail) from two series of well-attended public meetings (20 in all) held during the summers of 2003 and 2004, as well as additional comments obtained during the CHPP process.

The public cited coastal development as the issue most needing immediate attention, followed by enforcement of existing statutes, rules, and permit conditions, and then environmental education and research. Threats associated with development included polluted stormwater runoff, wastewater discharges, and wetland filling. Meeting attendees agreed that existing laws and rules might be sufficient for habitat protection, but that they are not adequately enforced largely due to insufficient staffing and resources. Educating the public about the importance of coastal habitats and the threats they face was repeatedly mentioned as being critical for successful habitat protection and enhancement.

9.2 THREATS

The CHPP law specifically requires identification of "existing and potential threats to the habitats" and "actions to protect and restore the habitats" (G.S. 143B-279.8). Threats to coastal fish habitat come from many sources and usually affect more than one habitat. Table 9.1 provides a listing and evaluation of the principal threats to the six types of coastal fish habitats identified previously in this report. The water column and shell bottom are the most threatened habitats (shell bottom because there is so little of it, and the water column because there are so many pollution sources). All habitats are subject to multiple threats.

Table 9.1. Evaluation of specific threats to coastal fish habitats based on hydrologic, physical, and water quality alterations. Darker shading indicates greater impact[1].

ACTIVITY TYPE	THREAT / ACTIVITY	Coastal Fish Habitats[1]					
		Water column	Shell bottom	SAV	Wetlands	Soft bottom	Hard bottom
AGRICULTURE/ AQUACULTURE RELATED	Animal operations						
	Aquaculture (incl. discharges, exotic species)						
	Cropland						
	Forestry						
WATER CONTROL	Dams						
	Water withdrawal						
DEVELOPMENT RELATED	Urban/suburban construction activities						
	Urban stormwater runoff (impervious surface)						
	On-site wastewater disposal						
	Permitted industrial wastewater discharges						
	Permitted domestic wastewater discharges						
	Waste disposal (landfills, ocean dumping)						
	Fiber optic cables/utility pipelines						
	Estuarine shoreline stabilization						
	Ocean shoreline hardening						
	Ocean beach nourishment						
TRANSPORTATION RELATED	Impervious roadways						
	Culverts, bridges, and fill (physical blockages)						
FISHING RELATED	Bottom trawl						
	Clam trawl (clam kicking)						
	Toothless dredge (bay scallop)						
	Toothed dredge (crab and oyster)						
	Long haul seines						
	Pots (crab)						
	Rakes, tongs						
	Rod and reel						
NAVIGATION RELATED	Marinas and docks (construction, assoc. NPS)						
	Ports (incl. exotic species via ballast water)						
	Boating activity						
	Channel and inlet dredging						
	Dredge material disposal (on submerged land)						
MINING RELATED	Phosphate and other minerals						
	Log salvage						
	Oil and gas exploration/drilling						
OTHER	Sea level rise						
	Storm events						
	Disease						
	Introduced or nuisance species						
	Marine debris/litter						

[1]Impact ranking: Black - severe; Dark gray - moderate; Light gray - minor; White - none, unknown or potential

Broad coast-wide threats to fish habitat identified below were discussed throughout the plan as they apply to each coastal fish habitat. These threats are well documented, as indicated by the literature citations shown below and as previously discussed in chapters 2 – 7:

- Fishing gear impacts: Negative impacts of fishing gear on habitat have been the subject of numerous studies (Adkins et al. 1983; Van Dolah et al. 1991; Dorsey and Pederson 1992; Collie 1997; Auster and Langton 1999; ASMFC 2000). Effects include uprooting vegetation, breaking physical structures, and digging and suspending sediment. Oyster dredging, in particular, may have played a significant role in the eutrophication of Pamlico Sound (Jackson et al. 2001).
- Marina and dock siting, and boating: The cumulative effects of increasing boater access facilities and associated boating activities are a concern due to documented negative impacts from operation of individual boats (Lockwood 1990; Milliken and Lee 1990; Wisby and Lopazanski 1995; Stephan and Bigford 1997; Crawford et al. 1998; Fonseca et al. 1998; SAFMC 1998a) and access facilities (Allen and Hardy 1980; DWQ 1990; Wendt et al. 1990; DEHNR 1991; Weis and Weis 1994; Wisby and Lopazanski 1995; McAllister et al. 1996; SAFMC 1998a; Weis et al. 1998). Some effects include disturbance and removal of sediment, changes in currents, and degradation/loss of wetlands and SAV.
- Shoreline stabilization: The increasing modification of natural shorelines to prevent or reduce landward migration of the shoreline (a natural process) is a major concern documented in numerous studies (Mock 1966; Ellifrit et al. 1972; Garbisch et al. 1973; Gilmore and Trent 1974; Knutson 1977; Walton and Sensabaugh 1979; O'Rear 1983; Reilly and Bellis 1983; Pilkey and Wright 1989; Van Dolah et al. 1992; Byrne 1995; Hackney et al. 1996; Pilkey et al. 1998; SAFMC 1998a; Titus 1998; Donaghue 1999; Jutte et al. 1999; Taylor 1999; Cahoon et al. 2000; Peterson et al. 2000c; Waters and Thomas 2001). These modifications often result in loss of wetlands and shallow water habitats, reduced fish diversity and abundance, and changes in runoff patterns.
- Nonpoint source (NPS) pollution: While great advances in the control and reduction of point source pollution have been made in the past 25 years (<http://www.epa.gov/OWOW/NPS/facts/point1>, 2002), NPS pollution has become the most widespread source of water quality degradation in North Carolina's streams and estuaries (DWQ 2000a). The impacts and contribution of nonpoint source pollutants have been well documented (DEHNR 1995b; Mallin et al. 1997; SAFMC 1998a; Paerl et al. 1999; Mallin et al. 2000). Some impacts include reduced availability of dissolved oxygen, reduced water clarity, and excessive nutrients that trigger algal blooms.
- Habitat loss: The physical degradation and loss of habitat is the most widespread source of impairment in coastal North Carolina streams (DWQ 2000a). Sources of physical degradation and loss include:
    - Dredging and draining of wetlands (Sutter 1999; Dahl 2000; DWQ 2000a);
    - Conversion of habitat to impervious surfaces (Mallin et al. 1998; Mallin et al. 2000; White et al. 2000; Natural Resources Conservation Service (NRCS), unpub. data); and
    - Installation of dams, culverts, bulkheads (Mock 1966; Ellifrit et al. 1972; Garbisch et al. 1973; Gilmore and Trent 1974; Knutson 1977; Walton and Sensabaugh 1979; O'Rear 1983; Reilly and Bellis 1983; Pilkey and Wright 1989; Van Dolah et al. 1992; Byrne 1995; Hackney et al. 1996; Pilkey et al. 1998; SAFMC 1998a; Titus 1998; Donaghue 1999; Jutte et al. 1999; Taylor 1999; Cahoon et al. 2000; DMF 2000a; Peterson et al. 2000a; DCM, unpub. data), and jetties (Kapolnai et al. 1996; Churchill et al. 1997; Blanton et al. 1999).
- Shellfish harvest area closures: The increasing closure to harvest of shellfishing waters has been correlated with increasing coastal development and stormwater runoff (Maiolo and Tschetter 1981; DEM 1994; Frankenberg 1995; Reilly and Kirby-Smith 1999; DWQ 2001a; and DMF 2001a,b). Although such closures have no direct impact on shellfish (only human harvest is affected), presence of indicator bacteria is strongly correlated with presence of other pollutants and nutrients (Mallin et al. 2000b, 2001b).

In spite of the great stresses on North Carolina's coastal ecosystem, it has proven to be quite resilient, and

it is generally healthy (DWQ 2000a). However, the number of water bodies showing danger signs is growing as human activities further stress the coastal area (Maiolo and Tschetter 1981; DWQ 2000a). The trend toward a largely degraded coastal ecosystem is alarming and must be reversed. A major purpose of the CHPP is to implement strategies to halt habitat degradation and promote restoration.

9.3 RECOMMENDATIONS

The CHPP development process identified hundreds of management needs, as shown in chapters 2 – 7. The members of the three Commissions reviewed the issues, along with suggested management actions to address those needs. The Commissions selected four general goals and a series of recommended actions to reach each goal, as shown below and in Table 9.2. The goals and recommendations shown below are not listed in any kind of priority order. Implementation of any of the recommendations below through specific rules or policies may involve further discussion with stakeholders and, in some cases, the balancing of competing ecological and economic values.

GOAL 1. IMPROVE EFFECTIVENESS OF EXISTING RULES AND PROGRAMS PROTECTING COASTAL FISH HABITATS

Every year, an average of more than 100 acres of Outstanding Resource Waters (the highest quality waters in North Carolina) are closed permanently to shellfish harvest, and miles of previously unaltered estuarine shoreline are artificially hardened with vertical shoreline stabilization structures. Thousands of acres of farmland and forests are uprooted, developed, and paved annually, and nutrient-contaminated Public Trust waters suffer from low oxygen events and fish kills. Existing rules and programs have had only limited success in protecting and enhancing coastal fish habitats and fisheries resources. The following non-regulatory actions must be taken for existing management strategies to be effective:

- Enhance enforcement of, and compliance with, Coastal Resources Commission (CRC), Environmental Management Commission (EMC), and Marine Fisheries Commission (MFC) rules and permit conditions.
- Coordinate and enhance water quality, physical habitat, and fisheries resource monitoring (including data management) from headwaters to the nearshore ocean.
- Enhance and expand educational outreach on the value of fish habitat, threats from human activities, effects of non-native species, and reasons for management measures.
- Coordinate rulemaking and enforcement among regulatory commissions and agencies.

GOAL 2. IDENTIFY, DESIGNATE, AND PROTECT STRATEGIC HABITAT AREAS

Growing resident and visitor populations in coastal North Carolina will further stress productive coastal habitats and fisheries resources through expansion of support services and infrastructure. Inland development degrades the water quantity and quality of streams that flow to the coastal sounds, as do increased boating and some fishing activities. Certain areas are especially important to fish production, and others are particularly vulnerable to these threats. Greater protection for these "Strategic Habitat Areas" must be a high priority in order to maintain a healthy coastal ecosystem. The following regulatory and non-regulatory management actions should be implemented:

- Evaluate potential Strategic Habitat Areas by:
    a) Coordinating, completing, and maintaining baseline habitat mapping (including seagrass, shell bottom, and other bottom types) using the most appropriate technology.
    b) Selective monitoring of the status of those habitats.
    c) Assessing effects of land use and human activities on those habitats.
- Identify and designate Strategic Habitat Areas using ecologically based criteria.
- Analyze existing rules and enact measures needed to protect Strategic Habitat Areas.

- Improve programs for conservation (including voluntary actions) and acquisition of areas supporting Strategic Habitat Areas.

GOAL 3. ENHANCE HABITAT AND PROTECT IT FROM PHYSICAL IMPACTS

Studies estimate that up to 50% of North Carolina's original wetlands have been destroyed since colonial times. Development continues to cause degradation and permanent loss of coastal and non-coastal wetlands. Significant negative impacts to wetlands may occur through a combination of larger projects that require state and federal permits and numerous small, unrecorded actions. Regardless of magnitude, each impact contributes to the cumulative loss of habitat functions and biological productivity. Shell bottoms (oyster reefs) in coastal North Carolina were decimated by uncontrolled fishing methods more than a century ago, and later by construction of the Atlantic Intracoastal Waterway in the 1930s. Since that time, hurricanes, mechanical harvest methods, small scale dredging and filling projects, and diseases and parasites have continued to reduce remaining shellfish bottoms, particularly subtidal oyster beds in the Pamlico Sound system, and impede establishment of new shell bottoms. Submerged aquatic vegetation (SAV, seagrass) in low salinity areas, such as Albemarle Sound and western Pamlico Sound, has all but disappeared. Submerged aquatic vegetation is highly vulnerable to physical disturbances, as well as to water quality degradation, especially turbidity. Strong management actions are necessary to reverse historic and current habitat losses and restore wetlands, shellfish beds, and SAV. The following regulatory and non-regulatory measures are recommended:

- Greatly expand habitat restoration, including:
    a) Creation of subtidal oyster reef no-take sanctuaries.
    b) Re-establishment of riparian wetlands and stream hydrology.
- Prepare and implement a comprehensive beach and inlet management plan that addresses ecologically based guidelines, socio-economic concerns, and fish habitat.
- Protect Submerged Aquatic Vegetation (SAV), shell bottom, and hard bottom areas from fishing gear effects through improved enforcement, establishment of protective buffers around habitats, and further restriction of mechanical shellfish harvesting.
- Protect fish habitat by revising estuarine and public trust shoreline stabilization rules using best available information, considering estuarine erosion rates, and the development and promotion of incentives for use of alternatives to vertical shoreline stabilization measures.
- Protect and enhance habitat for anadromous fishes by:
    a) Incorporating the water quality and quantity needs of fish in surface water use planning and rule making.
    b) Eliminating obstructions to fish movements, such as dams, locks, and road fills.

GOAL 4. ENHANCE AND PROTECT WATER QUALITY

Because all fish habitats are connected through the water column, maintaining and restoring water quality is the basic component of habitat protection and enhancement. Runoff from developed lands (structures, parking lots, roads, residential yards), agricultural fields and facilities, and some intensively managed forests carries excess nutrients into surface waters, which can lead to algal blooms that reduce water clarity and lower dissolved oxygen in the water column. Turbidity from runoff can suppress SAV growth, cause low oxygen events leading to fish kills, and cause mortality of organisms in the bottom community, including oysters. Excess sediment clouds the water, reduces SAV growth and survival, fills in creeks and small water bodies with silt, and degrades spawning and nursery habitats. Heavy metals and pesticides transported into the water with storm water can accumulate in the bottom sediments and organisms. Through the food chain, such pollutants may contaminate fish, affecting their survival and growth, and making them unsafe for human consumption. Runoff also carries fecal material to surface waters after rain events, requiring closure of tens of thousands of acres of shellfishing waters to harvest in order to protect human health.

Spills and other failures of municipal and on-site wastewater treatment facilities and infrastructure often send sewage pollution downstream, contributing to algal blooms, and causing shellfishing closures and restrictions on swimming in public waters. Some coastal towns dispose of stormwater on the ocean beaches, while others drain it to the ocean or estuaries. These discharges degrade water quality, leading to shellfishing closures and notifications warning of possible public health dangers from contact with contaminated water. These warnings have a detrimental effect on tourism. Marinas also degrade water quality and restrict use of Public Trust waters via mandatory shellfish harvest closures. Large-scale animal farming expanded rapidly in eastern North Carolina in the 1990s, and management of hog waste became a major environmental problem. Current methods generally used for hog waste management can greatly increase nutrient loading to adjacent waters through excessive spraying on fields, aerial deposition, and spills. The following regulatory and non-regulatory management measures are necessary to address a diversity of point and non-point pollution sources:

Point sources

- Reduce point source pollution from wastewater by:
    a) Increasing inspections of wastewater treatment facilities, collection infrastructure, and land disposal sites.
    b) Providing incentives for upgrading all types of wastewater treatment systems.
- Adopt or modify rules or statutes to prohibit ocean wastewater discharges.
- Prohibit new or expanded stormwater outfalls to coastal beaches and to coastal shellfishing waters (EMC surface water classifications SA and SB) except during times of emergency (as defined by the Division of Water Quality's Stormwater Flooding Relief Discharge Policy) when public safety and health are threatened, and continue to phase-out existing outfalls by implementing alternative stormwater management strategies.

Non-point sources

- Enhance coordination with, and financial/technical support for, local government actions to better manage stormwater and wastewater.
- Improve land-based strategies throughout the river basins to reduce non-point pollution and minimize cumulative losses to wetlands and streams through voluntary actions, assistance, and incentives, including:
    a) Improved methods to reduce sediment pollution from construction sites, agriculture, and forestry.
    b) Increased on-site infiltration of stormwater.
    c) Documentation and monitoring of small but cumulative impacts to wetlands and streams from approved, un-mitigated activities.
    d) Incentives for low impact development.
    e) Increased inspections of onsite wastewater treatment facilities.
    f) Increased water re-use and recycling.
- Improve land-based strategies throughout the river basins to reduce non-point pollution and minimize cumulative losses to wetlands and streams through rule making, including:
    a) Increased use of effective vegetated buffers.
    b) Reduction of impervious surfaces where feasible and reduction of the level of impervious surface allowable in the absence of engineered stormwater controls.
    c) Expansion of CAMA Areas of Environmental Concern (AECs) upstream and landward.
    d) Consideration of erosion rates as an additional factor in the siting of structures along estuarine and public trust shorelines.
- Develop and implement a comprehensive coastal marina and dock management plan and policy for the protection of shellfish harvest waters and fish habitat.
- Reduce non-point source pollution from large-scale animal operations by the following actions:
    a) Support early implementation of environmentally superior alternatives to the current

lagoon and spray field systems as identified under the Smithfield Agreement and continue the moratorium on new/expanded swine operations until alternative waste treatment technology is implemented.

b) Seek additional funding to phase-out large-scale animal operations in sensitive areas and relocate operations from sensitive areas.

c) Use improved siting criteria to protect fish habitat.

9.4. POSSIBLE FUNDING SOURCES

Implementation of the above recommendations will involve new program activities and revised priorities for existing programs within DENR and other agencies. Significant new funding is essential to expand and improve enforcement and compliance monitoring to fully implement existing laws and rules. Coordinating and expanding DENR biological, physical, and water quality monitoring and data management within the eight coastal river basins will provide local and state environmental managers and regulatory commissions, as well as the development, agriculture, and forestry communities, with data and analyses necessary to make informed decisions, and to evaluate the effects of those decisions. Implementation of coordinated interagency management requires a significant infusion of personnel, equipment, and operations monies. These funds must be considered as an investment in greatly enhanced environmental productivity that will benefit all citizens and provide important dividends over the long-term. Possible funding sources listed below are suggestions only. No specific proposals have been developed, although the Saltwater Fishing License enacted by the North Carolina General Assembly in July 2004 includes a provision to fund habitat restoration activities.

- Request expansion funds from the North Carolina General Assembly.
- Dedicate funds collected through sale and renewal of a Coastal Recreational Fishing License to manage coastal fish habitats.
- Dedicate funds collected through sale and renewal of a Coastal Recreational Fishing License to environmental education and outreach.
- Incorporate CHPP recommendations into North Carolina Clean Water Management Trust Fund priorities.
- Establish severance fees for commercial extraction of non-renewable, natural resources from coastal lands and waters and utilize such funds to enhance, protect, restore, and manage coastal fisheries resource habitats.
- Support protection, enhancement, restoration, and management of coastal fish habitats by establishing a Coastal Fish Habitat Protection Fund supported by impact fees on development in the vicinity of coastal fish habitats.
- Work with the DENR Ecosystem Enhancement Program to implement coastal habitat restoration projects.
- Develop partnerships to restore and protect coastal fish habitats through private and federal programs, such as the FishAmerica Foundation, Restore America's Estuaries, NOAA Restoration Center, and the U.S. Fish and Wildlife Service.
- Seek direct federal funding through the U.S. Congress, similar to funding provided for the Chesapeake Bay program.

Table 9.2 Recommended actions to protect, enhance, restore, and manage habitats important for North Carolina's coastal fisheries resources.

Reference No.	Recommended actions to protect, enhance, restore, and manage coastal fish habitats	Responsible commission or agency [Lead group(s) in bold]	Require rule making?
	GOAL 1. IMPROVE EFFECTIVENESS OF EXISTING RULES AND PROGRAMS PROTECTING COASTAL FISH HABITATS		
1.1	Enhance enforcement of, and compliance with, Coastal Resources Commission (CRC), Environmental Management Commission (EMC), and Marine Fisheries Commission (MFC) rules and permit conditions.	**CRC/DCM**, **EMC/DWQ**, **MFC/DMF**, CHS, SCC, WRC, DFR, DLR, S&WCC	No
1.2	Coordinate and enhance water quality, physical habitat, and fisheries resource monitoring (including data management) from headwaters to the nearshore ocean.	**DENR**, DMF, DWQ, DCM, WRC	No
1.3	Enhance and expand educational outreach on the value of fish habitat, threats from human activities, effects of non-native species, and reasons for management measures.	DENR	No
1.4	Coordinate rulemaking and enforcement among regulatory commissions and agencies.	EMC, CRC, MFC, DENR, WRC, SWCC, DFR	No
	GOAL 2. IDENTIFY, DESIGNATE, AND PROTECT STRATEGIC HABITAT AREAS		
2.1	Evaluate potential Strategic Habitat Areas by a) coordinating, completing, and maintaining baseline habitat mapping (including seagrass, shell bottom, and other bottom types) using the most appropriate technology, b) selective monitoring of the status of those habitats, and c) assessing effects of land use and human activities on those habitats.	**MFC/DMF**, CRC/DCM, DENR	No
2.2	Identify and designate Strategic Habitat Areas using ecologically based criteria, analyze existing rules and enact measures needed to protect Strategic Habitat Areas, and improve programs for conservation (including voluntary actions) and acquisition of areas supporting Strategic Habitat Areas.	**DENR**, CRC, EMC, MFC, WRC	Yes

Reference No.	Recommended actions to protect, enhance, restore, and manage coastal fish habitats	Responsible commission or agency [Lead group(s) in bold]	Require rule making?
	GOAL 3. ENHANCE HABITAT AND PROTECT IT FROM PHYSICAL IMPACTS		
3.1	Greatly expand habitat restoration, including a) creation of subtidal oyster reef no-take sanctuaries, and b) re-establishment of riparian wetlands and stream hydrology.	**DMF**, EEP, CRC	No
3.2	Prepare and implement a comprehensive beach and inlet management plan that addresses ecologically based guidelines, socio-economic concerns and fish habitat.	**CRC/DCM,** EMC/DWQ, MFC/DMF, DWR, WRC, DENR	Yes
3.3	Protect Submerged Aquatic Vegetation (SAV), shell bottom, and hard bottom areas from fishing gear effects through improved enforcement, establishment of protective buffers around habitats, and further restriction of mechanical shellfish harvesting.	MFC/DMF	Yes
3.4	Protect fish habitat by revising estuarine and public trust shoreline stabilization rules using best available information, considering estuarine erosion rates, and the development and promotion of incentives for use of alternatives to vertical shoreline stabilization measures.	CRC/DCM	Yes
3.5	Protect and enhance habitat for anadromous fishes by a) incorporating the water quality and quantity needs of fish in surface water use planning and rule making, and b) eliminating obstructions to fish movements, such as dams, locks and road fills.	**DENR**, EMC, DWQ, DWR, WRC, DMF	Yes
	GOAL 4. ENHANCE AND PROTECT WATER QUALITY		
4.1	Reduce point source pollution from wastewater by a) increasing inspections of wastewater treatment facilities, collection infrastructure, and land disposal sites, and b) providing incentives for upgrading all types of wastewater treatment systems.	**EMC**, DWQ, CHS, DEH	No
4.2	Adopt or modify rules or statutes to prohibit ocean wastewater discharges.	**EMC**	Yes

Reference No.	Recommended actions to protect, enhance, restore, and manage coastal fish habitats	Responsible commission or agency [Lead group(s) in bold]	Require rule making?
	GOAL 4. ENHANCE AND PROTECT WATER QUALITY (*continued*)		
4.3	Prohibit new or expanded stormwater outfalls to coastal beaches and to coastal shellfishing waters (EMC surface water classifications SA and SB) except during times of emergency (as defined by the Division of Water Quality's Stormwater Flooding Relief Discharge Policy) when public safety and health are threatened, and continue to phase-out existing outfalls by implementing alternative stormwater management strategies.	**EMC**, DWQ, CRC, DCM, CHS, DEH	Yes
4.4	Enhance coordination with, and financial/technical support for, local government actions to better manage stormwater and wastewater.	**DENR**, DWQ, DCM, DEH	No
4.5	Improve land-based strategies throughout the river basins to reduce non-point pollution and minimize cumulative losses to wetlands and streams through voluntary actions, assistance, and incentives, including a) improved methods to reduce sediment pollution from construction sites, agriculture, and forestry, b) increased on-site infiltration of stormwater, c) documentation and monitoring of small but cumulative impacts to wetlands and streams from approved, un-mitigated activities, d) incentives for low-impact development, e) increased inspections of onsite wastewater treatment facilities, and f) increased water re-use and recycling.	**DENR**, EMC, CRC, DWQ, DCM, SCC, DLR, S&WCC, DS&WC, Dept. of Agriculture & Consumer Services, DFR	No
4.6	Improve land-based strategies throughout the river basins to reduce non-point pollution and minimize cumulative losses to wetlands and streams through rule making, including a) increased use of effective vegetated buffers, b) reduction of impervious surfaces where feasible and reduction of the level of impervious surface allowable in the absence of engineered stormwater controls, c) expansion of CAMA Areas of Environmental Concern (AECs) upstream and landward, and d) consideration of erosion rates as an additional factor in the siting of structures along estuarine and public trust shorelines.	**EMC**, **CRC**, DWQ, DCM, SCC, DLR	Yes
4.7	Develop and implement a comprehensive coastal marina and dock management plan and policy for the protection of shellfish harvest waters and fish habitat.	**CRC/DCM**, EMC, DWQ, DMF, WRC	Yes

Reference No.	Recommended actions to protect, enhance, restore, and manage coastal fish habitats	Responsible commission or agency [Lead group(s) in bold]	Require rule making?
	GOAL 4. ENHANCE AND PROTECT WATER QUALITY (*continued*)		
4.8	Reduce non-point source pollution from large-scale animal operations by the following actions: a) support early implementation of environmentally superior alternatives to the current lagoon and spray field systems as identified under the Smithfield Agreement and continue the moratorium on new/expanded swine operations until alternative waste treatment technology is implemented, b) seek additional funding to phase-out large-scale animal operations in sensitive areas and relocate operations from sensitive areas, and c) use improved siting criteria to protect fish habitat.	**General Assembly**, **DENR**, EMC, DWQ, S&WCC, DS&WC, Dept. of Agriculture & Consumer Services	Yes

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APPENDIX A:
STATE, FEDERAL, AND INTERSTATE AUTHORITIES AFFECTING COASTAL FISH HABITAT IN NORTH CAROLINA

Public Trust Doctrine - Implemented as part of North Carolina's constitution; applied in management of North Carolina's coastal lands, surface waters, and the resources in those waters. The doctrine states that "public trust lands, waters, and living resources in a State are held by the State in trust for the benefit of all the people, and establishes the right of the public to fully enjoy public trust lands, waters, and living resources for a wide variety of recognized public uses. The doctrine also sets limitations on the States, the public, and private owners, as well as establishing the responsibilities of the States when managing these public trust assets" (Coastal States Organization 1997).

North Carolina General Assembly - Enacts statutes affecting all of North Carolina. State laws and rules implementing those laws cannot overrule federal laws. However, state actions can be more restrictive than federal rules for environmental protection.

North Carolina Fisheries Reform Act of 1997 (FRA) - Includes a provision [G.S. 143B-279.8] for preparation of Coastal Habitat Protection Plans (CHPPs) by the N.C. Department of Environment and Natural Resources (DENR), with adoption and implementation by three regulatory commissions and their administrative agencies.

Magnuson-Stevens Fisheries Conservation and Management Act of 1976 - The basic law giving the federal government fisheries management authority in the ocean. The reauthorization law (in 1996) is known as the Sustainable Fisheries Act (SFA), which established the basis for federal designation of Essential Fish Habitat (EFH).

National Marine Fisheries Service (NMFS) - The agency in the National Oceanic and Atmospheric Administration (NOAA) charged with principal responsibilities for management of the Nation's fisheries and fish habitat in the oceans beyond individual states' jurisdictions. Federal fishery management plans must include provisions for the protection of Essential Fish Habitat (EFH) from negative impacts from federally funded activities.

Coastal Resources Commission (CRC) - One of three North Carolina regulatory commissions that must adopt CHPPs and implement their recommendations. The CRC enacts rules to manage development and land disturbing activities along estuarine and ocean shorelines, shoreline stabilization, alteration of submerged bottoms and coastal wetlands, and marina construction. The Division of Coastal Management (DCM), an agency of the N.C. Department of Environment and Natural Resources, implements CRC rules.

Environmental Management Commission (EMC) - One of North Carolina regulatory commissions that must adopt CHPPs and implement their recommendations. The EMC has wide-ranging authority over activities affecting water quality statewide. Rules adopted by the EMC govern point and nonpoint discharges, wastewater management, alteration of non-coastal wetlands, and stormwater management. Several different DENR agencies implement EMC rules, including the divisions of Water Quality (DWQ), Air Quality (DAQ), Water Resources (DWR), and Land Resources (DLR) of the N.C. Department of Environment and Natural Resources.

Marine Fisheries Commission (MFC) - One of three North Carolina regulatory commissions that must adopt CHPPs and implement their recommendations. The MFC manages commercial and recreational fishing practices in coastal waters through rules implemented by the Division of Marine Fisheries (DMF), an agency of the N.C. Department of Environment and Natural Resources.

Intercommission Review Committee (IRC) - A committee of two members from each of the three regulatory commissions (EMC, CRC, MFC), who reviewed the CHPP and developed the management recommendations.

Division of Marine Fisheries (DMF) - DENR agency that implements MFC rules affecting commercial and recreational fishing practices in coastal waters, including rules governing effects of fishing practices on fish habitats. The DMF also conducts extensive monitoring and research programs concerning fish stocks, landings statistics, licensing, and enforcement, and prepares and implements state fishery management plans.

Division of Water Quality (DWQ) - One of the DENR agencies that implements rules of the Environmental Management Commission to govern point and nonpoint discharges into surface waters, wastewater management, alteration of non-coastal wetlands, and stormwater management. The DWQ conducts an extensive statewide water quality monitoring program, manages permit programs for wetlands impacts and wastewater discharges, and prepares and implements basinwide management plans.

Division of Air Quality (DAQ) - One of the DENR agencies that implements rules of the Environmental Management Commission to govern discharges of particulates and gases into the atmosphere. The DAQ operates a statewide network to monitor air quality.

Division of Water Resources (DWR) - One of the DENR agencies that implements rules of Environmental Management Commission pertaining to use of water resources and water supply. The DWR manages state grant programs for water resource development projects, such as navigation and ocean beach nourishment.

Division of Land Resources (DLR) - The DLR administers rules adopted by Sedimentation Control Commission to control sediment transport from land development, as well as rules of the N.C. Mining Commission. The DLR administers the State's dam safety program, and also includes the N.C. Geological Survey and the N.C. Geodetic Survey.

Division of Coastal Management (DCM) - DENR agency that implements rules adopted by the CRC to manage development and land disturbing activities along estuarine and ocean shorelines, shoreline stabilization, alteration of submerged bottoms and coastal wetlands, and marina construction through permit programs. The DCM also sponsors and conducts research and analysis concerning coastal erosion and wetlands mapping.

Wildlife Resources Commission (WRC) - The state agency charged with management of inland fisheries, hunting, and management of wildlife, including birds and protected species. The WRC has authority over most anadromous fish spawning areas in coastal rivers and creeks. The WRC conducts fisheries research on a statewide basis.

APPENDIX B1:

Coastal Habitat Protection Plan
Public Meeting Data Analysis

A Report on the Input Received at Public Meetings
July – September 2003

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January 2004

INTRODUCTION

The North Carolina General Assembly enacted the Fisheries Reform Act in August 1997. One of its major provisions is a requirement that the North Carolina Department of Environment and Natural Resources (DENR) prepare Coastal Habitat Protection Plans (CHPPs). The stated CHPPs goal is to enhance the coastal fisheries associated with each habitat. The divisions of Marine Fisheries, Coastal Management, and Water Quality were given the major responsibilities for writing the plans. A unique feature of the law is that three state regulatory commissions (Coastal Resources, Environmental Management, and Marine Fisheries) must adopt the plans. Once adopted, the Commissions' actions are to be consistent with the plans. The Commissions are to adopt the initial plan by the end of December 2004.

In order to educate the public about the CHPP, DENR initiated a public outreach effort during the summer of 2003. This effort included a short video to introduce the public to the CHPP initiative, an informational brochure, a twelve-page newspaper tabloid, and a series of ten public meetings. The video was made available to Coastal Resources Advisory Council (CRAC) members and others for viewing at county commission meetings, town council meetings and other public gatherings. The video was also sent to local cable TV outlets, and given on request to interested groups. Over 200 copies of the video were distributed. A total of 250,000 copies of the newspaper tabloid, which described the six important fish habitats and threats to them, were distributed to coastal newspapers and to a limited statewide distribution through targeted mailings. DENR also held ten public meetings (see table below), gathering almost 1,000 written comments from over 500 participants.

Summary of Data for CHPP Public Meetings, July – September, 2003

Location	Date	Attendance	Number of comments
Raleigh	July 23, 2003	38	70
Mooresville	July 24, 2003	30	61
Supply	July 29, 2003	38	82
Wilmington	July 30, 2003	78	173
Dixon	August 12, 2003	52	127
Beaufort	August 13, 2003	92	154
Manteo	August 19, 2003	64	87
Edenton	August 20, 2003	32	52
Washington	September 9, 2003	59	94
Bayboro	September 10, 2003	44	66
Totals		527	966

SUMMARY OF PERCEIVED THREATS TO COASTAL HABITAT

Meeting participants were asked to comment on the threats to coastal fisheries identified in the handout given to them (Attachment 1), and to include additional threats of which they were aware. Additional threats to coastal fisheries habitats identified during the public meetings included unsustainable development, inadequate enforcement of existing environmental laws and rules, and boating and fishing practices.

About one-third of the comments (324) dealt with development issues. Polluted stormwater runoff (45 comments), sewage discharges (41), and filling wetlands (35) were the major development threats cited by the public during the meetings.

It should be noted that 137 comments cited inadequate enforcement of existing rules, with 27 stating that penalties for violating environmental standards were either too low or should be increased. Some participants (21) also felt that enforcement staff levels at the regulatory agencies were inadequate to enforce existing rules and statutes.

Fishing and boating were also identified as threats to habitat (128 comments). Fifty-six comments cited boat wakes and other boating practices as major threats, while 27 comments identified specific fishing gear as a threat.

Specific development-related threats included 19 comments referencing land-use planning, and four comments identifying golf courses. Other threats identified at the meetings included: silviculture (11), aquaculture (9), air pollution (5), overfishing (4), and phosphate mining (1).

SUMMARY OF SUGGESTED ACTIONS

In addition to identifying threats to coastal fisheries, the meeting participants were asked for solutions to address the specific threats. Educating the public about the importance of coastal habitats and the threats they face was the most commonly cited suggestion.

More emphasis on enforcement of existing laws and rules was the second most popular “fix” that participants recommended. Eighty-six comments noted that critical habitats must be preserved or restored.

Other solutions offered numerous times by citizens attending the meetings included: increased funding to state agencies responsible for protecting habitats (29 comments); better cooperation among state and federal agencies (26); and more funding for land acquisition (14).

Hundreds of specific, individual actions were also suggested, ranging from establishing a citizens’ hotline, to better emissions standards for cars and boats, to restoring oyster reefs. An appendix to this report that includes the complete list of comments from the meetings is available at the Division of Marine Fisheries’ web site (http://www.ncfisheries.net/habitat/chpp1.htm) or on request (CHPPs@ncmail.net, or telephone 252-726-7021).

RESPONSE SUMMARY GROUPINGS

Comments were further grouped into the following nine categories in order to identify and portray trends in the nature of the comments submitted.

1. Common themes
2. Top responses ranked statewide (regardless of meeting location)
3. Top responses ranked by meeting location
4. Institutional: staffing, funding, interagency cooperation, senior-level support
5. Regulatory: rules, policies, compliance and enforcement
6. Implementation: public outreach, public-private partnerships, continuous improvement
7. Recommendations by the Commissions' (Environmental Management Commission or EMC, Coastal Resources Commission or CRC, Marine Fisheries Commission or MFC) areas of jurisdiction
8. Recommendations outside the Commissions' *(EMC, CRC, MFC)* areas of jurisdiction: agriculture, silviculture, planning and zoning, U.S. Army Corps of Engineers, local government, school/education programs, U.S. military
9. Recommendations by habitat type

1. Common themes
This category lists the most frequent themes within each of the major issue areas.

Development – wastewater management, land use planning, wetlands protection, impervious cover, beach nourishment

Education and Research – school programs, homeowner education, decision maker education, natural and social science research to inform rulemaking

Enforcement – consistent enforcement of rules and penalties (e.g., curtail the influence of politics on variances from CRC rules); focus on existing rules rather than on creating new ones; increase enforcement staff and agency funding levels

Boating and Fishing – Require coastal recreational fishing licenses; ban or further limit the use of certain commercial fishing gear (e.g., trawl nets and dredges); further limit commercial fishing grounds (e.g., ban in estuarine waters); expand no wake zones; ban or further limit the use of personal watercraft (e.g., jet skis) especially in shallow waters; improve access to and reliability of sewage pumpout stations

Agriculture and Silviculture – subject agriculture and silviculture to Coastal Area Management Act (CAMA) rules; gradually eliminate hog farms from the coastal zone or require more stringent waste management; expand the oyster restoration program; apply forestry best management practices (BMPs)

Agency Cooperation – continue and expand existing cooperation among relevant agencies; streamline customer service

2. Response rankings statewide (regardless of meeting location)
This category ranks the three most common issue areas of concern on a statewide basis, with the number of times each was mentioned (in parentheses). For further details about the comments submitted on each issue, see the full list of comments in the Appendix.

#1:	Development controls	(324)
#2:	Enforcement and Compliance	(130)
#3:	Education and Research	(124)

The volume and pace of coastal development were cited in most meeting locations to be the biggest threats to coastal habitat, needing the most immediate and concerted attention. Actions to alleviate the effects of development were the most frequent recommendations. Within the development category, better handling of stormwater and wastewater was the most common concern, including sewage treatment, construction runoff, and discharge into public trust waters.

Enforcement of existing laws was the next most common area for desired action. The responses reflect a widespread opinion that existing laws are sufficient to improve habitat condition, but that they are not being enforced to their full extent.

Also notable for the frequency with which it was mentioned was boat operations, including a desire to establish more "No Wake Zones," to limit use of 2-stroke boat engines and personal watercraft (e.g., jet skis), and to better manage the disposal of marine sewage.

The Education and research theme was the third most common category for recommended action. Respondents concluded that much more education is required, targeting local decision-makers as well as the general public of all ages. Education topics would include the types of human activity that affect coastal habitat, the value in protecting habitat, and an explanation of how existing and proposed regulations work to protect the resource.

3. Top 3 responses by meeting location

This category lists the three most common issues of concern at each public meeting location. For further details about the comments submitted on each issue, see the full transcript of comments in the Appendix.

Site (# of attendees)	**Issue** (# of times mentioned)
Bayboro (44):	Development (23), Agriculture and Silviculture (11), Education and Research (8)
Beaufort (92):	Development (64), Enforcement (26), Boating and Fishing (25)
Edenton (32):	Education and Research (14), Enforcement (13), Development (9)
Dixon (52):	Development (44), Boating and Fishing (26), Enforcement (15)
Manteo (64):	Development (16), Education and Research (14), Enforcement (9)
Mooresville (30):	Boating and Fishing (19), Development (13), Enforcement (9)
Raleigh (38):	Development (28), Agriculture and Silviculture (11), Boating and Fishing (9)
Supply (38):	Development (35), Enforcement (15), Education and Research (11)
Washington (59):	Development (35), Education and Research (19), Agriculture and Silviculture/ Boating and Fishing (8)
Wilmington (78):	Development (57), Enforcement (27), Boating and Fishing (22)

4. Institutional: staffing, funding, interagency cooperation, and senior-level support

This category describes the main institutional needs that were identified.

Respondents that addressed the levels of enforcement staffing and resources were in agreement that the current levels are insufficient to ensure satisfactory compliance with existing laws, given the volume of activity on the coast. Respondents were supportive of increasing the staff and funding dedicated to enforcement and compliance.

Respondents acknowledged the cooperation taking place among the three Commissions and their staffs. Recommendations include extending the opportunity for early participation to other state agencies that will have some impact upon the success of the CHPP, and streamlining the customer response setup to deliver one-stop shopping for members of the public who want to get involved.

5. Regulatory: rules, policies, compliance and enforcement
This category describes the main suggestions concerning the Commissions' (EMC, CRC, MFC) legislative and regulatory programs.

There is the widespread belief that existing laws are not being fully enforced, and recognition among respondents that the lack of adequate staffing and resources is a major contributor to this shortcoming. Respondents were also concerned that certain laws were not being fairly and uniformly applied – the perception being that politically connected property owners received more favorable treatment on CRC variance requests and softer penalties for violating coastal rules. There was not a general feeling that existing laws are *in*adequate for coastal protection. Alternately, several respondents commented that there is not a good public understanding of what laws do exist and why.

6. Implementation: public outreach, public-private partnerships, continuous improvement
This category shows the main recommendations regarding CHPP implementation and quality control.

Education and research were repeatedly mentioned as central components for success of the CHPP. Recommendations included efforts to partner with primary and secondary schools to introduce environmental stewardship curricula, partnering with universities on research, and engaging in concerted educational outreach to private citizens and public sector employees.

7. Common recommendations by Commissions' (CRC, EMC, MFC) areas of jurisdiction
This category relates common recommendations that pertained specifically to any of the three Commissions' (CRC, EMC, MFC) jurisdictions, e.g., CAMA permitting, stormwater management, and fishing regulation.

CRC – Strengthen application of CRC rules, including tougher variance criteria for development in the buffer; phase out bulkheads – move towards living shorelines and riprap; strengthen disaster mitigation especially on the oceanfront by mandating greater setbacks and larger lots; reduce impervious cover by phasing in pervious materials; stop all beach nourishment; ensure more sewage pumpouts are available to boaters, and that they work; provide public education outreach; support more thorough and consistent enforcement of CRC rules; increase penalties for violations; ensure better interagency collaboration;

EMC – Complete Phase II Stormwater process; bring septic and sewer systems up to a higher standard; improve ability to handle/treat sewage overflows; end practices that send untreated stormwater to public waters (ocean, sound, rivers, etc.); provide public education outreach; fully enforce existing rules; increase penalties for violations; ensure better interagency collaboration;

MFC – Improve or restrict the use of non-selective commercial gear, particularly trawl nets and dredges; ban or further limit trawling and gill netting in estuarine waters; expand the oyster restoration program for water quality benefits; provide public education outreach; continue to develop more selective, less disturbing commercial gear; fully enforce existing rules; increase penalties for violations; ensure better

interagency collaboration.

8. Recommendations outside Commissions' (CRC, EMC, MFC) areas of jurisdiction: agriculture, silviculture, planning and zoning, U.S. Army Corps of Engineers, local government, school/education programs, U.S. military
This category lists common recommendations that fall outside of the three Commissions' (EMC, CRC, MFC) direct control.

Bring agriculture and forestry under CAMA jurisdiction; phase out hog farms and waste lagoons from the coastal zone; finalize and adopt the coastal recreational fishing license (CRFL); divert funds from beach nourishment to purchasing threatened properties; control the use of fertilizers; ban landfills in [drained] wetlands; require basin-wide land use planning that meshes with local plans and strict CAMA standards; establish more no wake zones; phase out 2-stroke boat engines in favor of 4-stroke engines; require inlet dredging only on low (ebb) tides; increase enforcement personnel and budget; prevent General Assembly from making last-minute changes to rules.

9. Common recommendations by habitat type
This category lists specific recommendations that were offered regarding the six habitat classes: Water Column, Shell Bottom, Submerged Aquatic Vegetation, Wetlands, Soft Bottoms, and Ocean Hard Bottom.

Water Column – plant oysters to filter out nutrients; allow dredging only on a falling (ebb) tide so that sediments flush oceanward; lessen the amount of pollutants, nutrients and sediments that come from point and nonpoint sources

Shell Bottom – increase the amount of effort dedicated to rebuilding and expanding oyster reefs; lessen the amount of pollutants, nutrients and sediments that come from various sources

Submerged Aquatic Vegetation (SAV) – ban equipment and practices such as jet skiing and trawling that damage SAV; lessen the amount of pollutants, nutrients and sediments that come from various sources

Wetlands – enforce "no net loss" rule; increase investment in wetland restoration; purchase lands for preservation; phase out bulkheads; lessen the amount of pollutants, nutrients and sediments that come from upland sources

Soft Bottoms – limit disturbing activities such as clam kicking and dredging; lessen the amount of pollutants, nutrients and sediments that come from various sources

Ocean Hard Bottom – ban or severely limit beach nourishment, which would lessen the need for dredging; modify or curtail the use of disturbing commercial fishing gear that directly and indirectly impacts the habitat; lessen the amount of nutrients and sediments that come from ocean outfalls and other inland sources

ATTACHMENT 1

List of threats to coastal fish habitats distributed for discussion at North Carolina Coastal Habitat Protection Plan public meetings, summer 2003.

Coastal Habitat Protection Plans (CHPPs) – Public Meeting

Coastal Fisheries Habitats

Water column – The water in a river, sound or ocean and its physical, chemical and biological properties
Shell bottom – Intertidal and subtidal bottoms made up to shells or living oysters, clams or other shellfish
Submerged aquatic vegetation – Underwater beds of rooted plants, called sea grass, or macro algae
Wetlands – Areas that are inundated enough to support plants normally adapted to saturated soils
Soft bottoms – Sand and mud bottoms with no vegetation
Ocean hard bottoms – Exposed areas of rock or hard sediment in the ocean

THREATS TO COASTAL FISH HABITATS
AGRICULTURE/AQUACULTURE RELATED
Excessive Sedimentation and Turbidity
Excess Nutrients
Harmful Bacteria (animal operations)
Invasive Species
Filling and Draining Wetlands
Stormwater Runoff
WATER CONTROL
Alteration of the Natural Flow of Water (dams, water withdrawal, channelization)
DEVELOPMENT RELATED
Toxins
Excessive Sedimentation and Turbidity
Roads/Highways (including culverts, bridges)
Harmful Bacteria
Stormwater Runoff
Wastewater Discharges
Filling and Draining Wetlands
Beach Nourishment
Shoreline Stabilization (bulkheads, rip rap)
BOATING AND FISHING RELATED
Fishing Gear
Marinas and Docks
Ports
Boat Operations (Wakes, Prop Damage, Boat Anchors)
Dredging
MINING RELATED
Sand and Gravel
Oil and Gas Exploration

APPENDIX B2:

Coastal Habitat Protection Plan
Public Meeting Data Analysis

A Report on the Input Received at Public Meetings
July – August 2004

Prepared by

North Carolina Department of Environment and Natural Resources
Division of Coastal Management

August 2004

I. Introduction

The North Carolina General Assembly enacted the Fisheries Reform Act in August 1997. One of its major provisions is a requirement that the North Carolina Department of Environment and Natural Resources (DENR) prepare Coastal Habitat Protection Plans (CHPPs). The stated CHPPs goal is to enhance the coastal fisheries associated with each habitat. The divisions of Marine Fisheries, Coastal Management, and Water Quality were given the major responsibilities for writing the plans. A unique feature of the law is that three state regulatory commissions (Coastal Resources, Environmental Management, and Marine Fisheries) must adopt the plans. Once adopted, the Commissions' actions are to be consistent with the plans. The Commissions are to adopt the initial plan by the end of December 2004. An Intercommission Review Committee (IRC), comprised of two members of each of the commissions, oversaw the development of the plan and was responsible for drafting recommendations.

During the summer of 2003, the Department conducted a major effort to educate and solicit public input for development of the Coastal Habitat Protection Plan. The focus of the 2003 public meetings was to explain the CHPP to the public, describe the state's coastal habitats and the threats to them, and to get the public's input about perceived threats and possible solutions. The Department held a series of ten public meetings, and distributed over 200 copies of an introductory video, 15,000 informational brochures, and 250,000 copies of a newspaper tabloid. Over 500 citizens attended the public meetings, almost 1,000 written comments were received, and the CHPP was widely discussed in local and regional news media. A primary message conveyed at these meetings was that public comment would be incorporated into the draft CHPP. The Department also made it clear that there would be another series of public meetings in the summer of 2004 to give citizens an opportunity to see how their comments have been incorporated into the plan and allow them to comment on forthcoming recommendations.

The Department held a second round of public meetings in the summer of 2004 — ten meetings geared towards the general public, as well as five additional meetings to solicit comments from targeted stakeholder groups that seemed to be under-represented at the 2003 meetings, including realtors, homebuilders, local governments, and agriculture and forestry interests. The 2004 public meetings focused on soliciting public response to the recommendations drafted by the IRC and whether or not the recommendations would be effective in meeting the goals of the CHPP. These meetings attracted over 500 people, who submitted 276 completed questionnaires (see Attachment 1) and over 700 written comments. As in 2003, the Department assured the meetings' attendees that comments would be incorporated in the CHPP and the accompanying draft recommendations. The CHPP has undergone revisions reflecting the comments received during this second round of public input (see Attachment 2) and the targeted interest group meetings (see Attachment 3), as have the recommendations.

The meeting dates and locations, the attendance at each meeting, and the number of completed comment questionnaires returned are shown in Table 1. A summary of the five meetings held in July and August for targeted stakeholder groups is shown in Table 2. One additional meeting is to be scheduled in September for a targeted stakeholder group in the northern coastal area.

Table 1. Locations and other data for the Coastal Habitat Protection Plan public meetings, Summer 2004

Location	Date	Attendance	# of Questionnaires Completed
Manteo	July 13	45	30
Edenton	July 14	27	22
Jacksonville	July 19	30	19
Beaufort	July 21	47	43
New Bern	July 22	36	29
Bolivia	July 27	28	17
Wilmington	July 28	100	50
Washington	July 29	60	32
Mooresville	August 3	7	5
Raleigh	August 4	50	29
Totals		**430**	**276**

Table 2. Locations and other data for the Coastal Habitat Protection Plan stakeholder meetings, Summer 2004

Location	Date	Attendance	Stakeholder Group
Wilmington	July 8	18	Business Alliance for a Sound Economy
New Bern	July 29	32	N.C. Coastal Communities Coalition
New Bern	August 2	9	N.C. Fisheries Association
Raleigh	August 5	4	N.C. Forestry Association
Raleigh	August 5	16	N.C. Soil & Water Conservation Comm. Technical Review Committee
Total		**79**	

II. Summary of Written Responses

Attendees at the 2004 public meetings received a form that included the CHPP draft recommendations and columns to fill in to (1) indicate if the draft recommendations would likely help achieve the plan's goals, and (2) rank their top three overall recommendations, as well as to provide additional comments. Participants provided about 700 individual written comments at the meetings, in addition to their evaluation of the efficacy of the recommendations and their priorities.

About 64% of the attendees turned in a response form. Overall, 90% of respondents indicated that the draft recommendations would contribute to reaching the CHPP goals, ranging from a low of 81% for recommendations **4E2 - Improve land-based strategies to reduce non-point pollution and minimize cumulative losses to wetlands and streams through rule making, including: more stringent impervious surface limits** to a high of 99% for recommendation **1A - Enhance enforcement of, and compliance with, Coastal Resources Commission (CRC), Environmental Management Commission (EMC), and Marine Fisheries Commission (MFC) rules and permit conditions**. Thus, even the recommendations that generated the greatest opposition were supported by at least 80% of those persons who provided written comments.

The following recommendations were ranked as the three most important overall for success of the CHPP (indicated as the highest priority by the most respondents):

> *1(A) Enhance enforcement of, and compliance with, Coastal Resources Commission (CRC), Environmental Management Commission (EMC), and Marine Fisheries Commission (MFC) rules and permit conditions (99% support).*
>
> *1(C) Enhance and expand educational outreach on the value of fish habitat, threats from human activities, effects of non-native species, and the reasons for management measures (93% support).*
>
> *4(A)(1) Reduce point source pollution from human sewage by increasing inspections of sewage treatment facilities, collection infrastructure, and land disposal sites (93% support).*

Respondents also indicated which of the recommendations they felt would contribute the least towards success of the CHPP. The following three recommendations received the least support:

> *4(E)(2) Improve land-based strategies to reduce non-point pollution and minimize cumulative losses to wetlands and streams through rule making, including more stringent impervious surface limits (81% support).*
>
> *4(E)(3) Improve land-based strategies to reduce non-point pollution and minimize cumulative losses to wetlands and streams through rule making, including expansion of Areas of Environmental Concern (AECs) upstream and landward (82% support).*
>
> *4(D)(3) Improve land-based strategies to reduce non-point pollution and minimize cumulative losses to wetlands and streams through voluntary actions, Best Management Practices (BMPs), and incentives, including documentation and monitoring of small but cumulative impacts to wetlands and streams resulting from un-permitted/un-mitigated activities (82% support).*

III. Comments on Individual Goals

Goal 1: Improve Effectiveness of Existing Rules & Programs Protecting Coastal Fish Habitats

An average of 237 respondents (95%) felt that these recommendations would help achieve Goal 1 (Table 3). Recommendation **1A - Enhance enforcement of, and compliance with, Coastal Resources Commission (CRC), Environmental Management Commission (EMC), and Marine Fisheries Commission (MFC) rules and permit conditions** was perceived as the most effective, with 99% of respondents agreeing that it was beneficial. Recommendation **1D - Coordinate rulemaking and enforcement among regulatory commissions and agencies** was ranked as the least effective under this goal, with 8% of respondents challenging its usefulness.

Table 3. Summary of comments on Goal 1 recommendations

Recommendation	Recommendations helpful?		Overall Rankings (# of votes)		
	Yes	No	1	2	3
1A	237 (99%)	2	61	24	14
1B	240 (96%)	11	21	23	32
1C	239 (93%)	19	29	26	24
1D	233 (92%)	20	21	21	23

Meeting attendees expressed strong support (39% of Goal 1 written comments) for enhanced education efforts (20%) and better enforcement of existing rules (19%). Many respondents believe that understanding the regulations will improve compliance and make enforcement seem fairer since the rules would be more widely known. The third most common written comment called for improved coordination among permitting and regulatory agencies (13% of Goal 1 comments).

Goal 1 comments also revealed skepticism (6% of comments) about the feasibility of fulfilling this goal. Respondents questioned whether there is sufficient political will to fully enforce existing rules, and whether programs and enforcement will be adequately funded.

Goal 2: Identify, Designate and Protect Strategic Habitat Areas (SHAs)

An average of 212 respondents (93%) felt that these recommendations would help achieve Goal 2 (Table 4). Recommendation **2A1 - Gather information to identify Strategic Habitat Areas by: coordinating, completing, and maintaining habitat mapping (including seagrass, shell bottom, and other bottom types) using the most appropriate technology** was perceived as the most effective, with 98% of respondents agreeing that it was beneficial. Recommendation **2B - Identify and designate Strategic Habitat Areas using ecologically based criteria** was ranked as the least effective under this goal, with 11% of respondents challenging its usefulness.

Table 4. Summary of comments on Goal 2 recommendations

Recommendation	Recommendations helpful?		Overall Rankings (# of votes)		
	Yes	No	1	2	3
2A1	227 (95%)	12	18	7	5
2A2	225 (95%)	12	4	6	9
2A3	219 (91%)	21	6	3	3
2B	227 (89%)	27	9	23	18
2C	232 (91%)	23	13	18	18
2D	230 (92%)	21	21	20	19

Written comments on this goal showed little consensus. The most frequent comment was whether this goal was necessary and feasible (11% of Goal 2 comments) while 9% of the comments supported increased funding for land conservation.

Other comments on this goal advised DENR to proceed with implementation instead of conducting further studies, that individual property rights should be preserved, public trust access should be maintained, and that new Strategic Habitat Areas (SHAs) should be coordinated with existing programs and designations. Respondents also indicated that any new SHA should be afforded strict protection, including a ban on trawling.

Goal 3: Enhance Habitat and Protect it from Physical Impacts

An average of 200 respondents (91%) felt that these recommendations would help achieve Goal 3 (Table 5). Recommendation **3A - Greatly expand habitat restoration, including: 1. creation of subtidal oyster reef no-take sanctuaries and 2. re-establishment of riparian wetlands and stream hydrology** was perceived as the most effective with 93% of respondents agreeing that it was beneficial. Recommendation **3B - Prepare and implement a coast wide beach and inlet management plan that requires ecologically based guidelines for minimization of impacts to fish habitat, while addressing socio-economic concerns** was ranked as the least effective under this goal, with 15% of respondents challenging its usefulness.

Table 5. Summary of comments on Goal 3 recommendations

Recommendation	Recommendations helpful?		Overall Rankings (# of votes)		
	Yes	No	1	2	3
3A1	220 (93%)	16	4	9	4
3A2	209 (90%)	24	10	6	4
3B	202 (85%)	37	22	15	16
3C	228 (92%)	20	19	23	22
3D	218 (90%)	24	11	24	16
3E1	219 (93%)	17	0	5	5
3E2	194 (87%)	30	3	3	8

Other comments received for Goal 3 covered feasibility, trawling, estuarine buffers and beach nourishment. Some respondents believed that this goal might be unnecessary, and questioned whether it is feasible to implement (16% of Goal 3 comments). An equal number of comments called for bans on trawling and mechanical shellfish harvest for inshore waters (16% of Goal 3 comments).

Increased limits on coastal development was supported by 14% of the comments, including tighter restrictions within buffers and setbacks, and 9% of the comments supported more attention to the positive and negative effects of beach nourishment. There was little consensus in other comments on this goal.

Goal 4: Enhance and Protect Water Quality

An average of 195 respondents (89%) felt that these recommendations would help achieve Goal 4. Recommendation **4G4 - Reduce non-point source pollution from concentrated animal operations by the following actions: use improved siting criteria to protect fish habitat** was perceived as the most effective, with 98% of respondents agreeing that it would be beneficial. Recommendation **4E2 - Improve land-based strategies to reduce non-point pollution and minimize cumulative losses to wetlands and streams through rule making, including: 2. more stringent impervious surface limits** was ranked as the least effective, with 19% of respondents challenging its usefulness.

Table 6. Summary of comments on Goal 4 recommendations

Recommendation	Recommendations helpful?		Overall Rankings (# of votes)		
	Yes	No	1	2	3
4A1	239 (93%)	17	23	16	5
4A2	232 (93%)	17	9	7	9
4B	221 (90%)	24	8	9	6
4C	215 (92%)	18	12	12	15
4D1	224 (94%)	15	8	13	11
4D2	223 (91%)	21	6	4	6
4D3	191 (82%)	43	4	6	3
4D4	214 (89%)	26	8	7	7
4D5	215 (90%)	23	1	4	1
4D6	203 (88%)	28	4	4	6
4E1	199 (83%)	42	14	6	5
4E2	191 (81%)	45	5	6	6
4E3	195 (82%)	44	4	5	4
4E4	195 (83%)	40	2	5	5
4F	194 (85%)	33	1	2	5
4G1	230 (90%)	25	16	18	11
4G2	216 (88%)	30	7	4	14
4G3	209 (85%)	37	13	10	11
4G4	217 (98%)	5	5	6	4

The most frequent comment on this goal was a need to reduce pollution from farming and development (11%). Other frequent comments included:

- Strengthen stormwater regulations and enforcement (8%)
- Encourage new pollution control technologies (7%)
- Increase public education efforts (7%)
- No need for more regulations; enforce existing rules (7%)
- Provide incentives for low-impact development and voluntary compliance with existing regulations (6%)
- Strengthen enforcement of buffer rules — fewer variances (5%)

IV. Summary

The public provided more than 700 written comments to the North Carolina Department of Environment and Natural Resources on the draft recommendations of the North Carolina Coastal Habitat Protection Plan at 10 meetings in the eastern and central parts of the state during July and August 2004. Overall, more than 90% of the comments indicated support for the recommendations. Even those recommendations generating the most opposition were still supported by 80% of the meetings' attendees.

Recommendations that would not require new rules garnered the greatest support, including those dealing with improved enforcement, education, and coordination. Programs to restore oyster beds and riparian wetlands and stream flow were also strongly supported.

While recommendations for stricter impervious surface limits, extending AECs inland, and conducting cumulative impact assessments received the most direct opposition, each of these recommendations was still supported by over 80% of respondents.

V. Response to Public and Interest Group Meetings

In response to the comments received at the 2004 public meetings and the targeted interest group meetings, numerous changes have been made to the text of the CHPP and the recommendations in particular. Some of the highlights are indicated below.

One major text change has been in the sections discussing the threats from forestry activities. The CHPP cites forestry as a major threat to water quality. Data from the most recent 303 (d) listing requirement of the Clean Water Act show that it is an order of magnitude less than agriculture and development. The text in the CHPP has been changed to reflect this.

There was much confusion about how increased impervious surface limits would be applied and a lot of apprehension about the effects on property owners. It was also noted that the recommendations did not acknowledge the use of engineered systems to minimize the effects on water quality due to increased impervious surface coverage. The recommendation has been changed to incorporate the use of engineered systems and recognize that increased limits on impervious surfaces may not be feasible in all situations.

Written comments indicated some confusion over the buffers currently in place and what the CHPP recommendation (larger buffers) were calling for – larger than what? While the recommendation still does not state a specific width, it was changed to call for the increased use of effective buffers.

Several comments recommended stakeholder involvement in the implementation of specific recommendations as well as economic analyses. Since stakeholder groups and economic concerns are relative to many of the recommendations, the IRC chose to address them in the text of the document as a preface to the recommendations. "*Implementation of any of the recommendations below through specific rules or policies may involve further discussion with stakeholders and, in some cases, the balancing of competing ecological and economic values.*"

In response to meetings with local governments, a new recommendation added "Enhance coordination with, and financial/technical support for, local government actions to better manage stormwater and wastewater." This recommendation is an attempt to recognize the efforts currently undertaken by local governments to manage stormwater and protect water quality.

Several changes were made to recommendations dealing with non-point source pollution. "Improve land-based strategies <u>throughout the river basins</u> to reduce non-point pollution and minimize cumulative losses to wetlands and streams through voluntary actions, assistance, Best Management Practices (BMPs) and

incentives, including…" The IRC wanted to make it clear that these recommendations, as does the CHPP itself, applies to the entire river basins and not just the coastal counties.

Attachment 1. CHPP Public Meeting Comment Form (Summer 2004)

SUMMARY OF CHPP RECOMMENDATIONS	Will the recommendations help reach the goal?		Rank top three among all recommendations
	YES	*NO*	
Goal 1: Improve Effectiveness of Existing Rules & Programs Protecting Coastal Fish Habitats			
A. Enhance enforcement of, and compliance with, Coastal Resources Commission (CRC), Environmental Management Commission (EMC), and Marine Fisheries Commission (MFC) rules and permit conditions.			
B. Coordinate and enhance water quality, physical habitat, and fisheries resource monitoring (including data management) from headwaters to the nearshore ocean.			
C. Enhance and expand educational outreach on the value of fish habitat, threats from human activities, effects of non-native species, and the reasons for management measures.			
D. Coordinate rulemaking and enforcement among regulatory commissions and agencies.			
Comments or suggested recommendations:			
Goal 2: Identify, Designate & Protect Strategic Habitat Areas (SHAs)			
A. Gather information to identify Strategic Habitat Areas by:			
1. coordinating, completing, and maintaining habitat mapping (including seagrass, shell bottom, and other bottom types) using the most appropriate technology,			
2. monitoring the status of those habitats, and			
3. assessing effects of land use and human activities on those habitats.			
B. Identify and designate Strategic Habitat Areas using ecologically based criteria.			
C. Analyze existing rules and enact measures needed to protect Strategic Habitat Areas.			
D. Improve programs for conservation (including voluntary actions) and acquisition of areas supporting SHAs.			
Comments or suggested recommendations:			

SUMMARY OF CHPP RECOMMENDATIONS	Will the recommendations help reach the goal?		Rank top three among all recommendations
	YES	*NO*	
Goal 3: Enhance Habitat and Protect it from Physical Impacts			
A. Greatly expand habitat restoration, including:			
1. creation of subtidal oyster reef no-take sanctuaries and			
2. re-establishment of riparian wetlands and stream hydrology.			
B. Prepare and implement a coast wide beach and inlet management plan that requires ecologically based guidelines for minimization of impacts to fish habitat, while addressing socio-economic concerns.			
C. Protect Submerged Aquatic Vegetation (SAV), shell bottom, and hard bottom areas from fishing gear effects through improved enforcement, establishment of protective buffers around habitats, and further restriction of mechanical shellfish harvesting.			
D. Protect fish habitat by revising estuarine and public trust shoreline stabilization rules using best available information, considering estuarine erosion rates, and the development and promotion of incentives for use of alternatives to vertical shoreline stabilization measures.			
E. Protect and enhance habitat for anadromous fishes by:			
1. incorporating the water quality and quantity needs of fish in surface water use planning and rule making and			
2. eliminating obstructions to fish movements, such as dams, locks and road fills.			
Comments or suggested recommendations:			

Attachment 1 (continued)

SUMMARY OF CHPP RECOMMENDATIONS	Will the recommendations help reach the goal?		Rank top three among all recommendations
	YES	*NO*	
Goal 4: Enhance and Protect Water Quality			
Point Source			
A. Reduce point source pollution from human sewage by:			
1. increasing inspections of sewage treatment facilities, collection infrastructure, and land disposal sites and			
2. providing incentives for upgrading all types of wastewater treatment systems.			
B. Adopt or modify rules or statutes to prohibit ocean wastewater discharges.			
C. Prohibit new or expanded stormwater outfalls to coastal beaches and to coastal shellfishing waters (EMC surface water classifications SA and SB), and continue to phase-out existing outfalls by implementing alternative stormwater management strategies.			
Nonpoint Source			
D. Improve land-based strategies to reduce non-point pollution and minimize cumulative losses to wetlands and streams through voluntary actions, Best Management Practices (BMPs), and incentives, including:			
1. improved methods to reduce sediment pollution from construction sites, agriculture, and forestry,			
2. increased on-site infiltration of stormwater,			
3. documentation and monitoring of small but cumulative impacts to wetlands and streams resulting from un-permitted/un-mitigated activities,			
4. incentives for low-impact development,			
5. enhanced inspections of onsite wastewater treatment facilities, and			
6. increased water re-use and recycling.			

Attachment 1 (continued)

SUMMARY OF CHPP RECOMMENDATIONS	Will the recommendations help reach the goal?		Rank top three among all recommendations
	YES	*NO*	
Goal 4: Enhance and Protect Water Quality (continued)			
E. Improve land-based strategies to reduce non-point pollution and minimize cumulative losses to wetlands and streams through rule making, including:			
1. larger vegetated buffers,			
2. more stringent impervious surface limits,			
3. expansion of Areas of Environmental Concern (AECs) upstream and landward, and			
4. establishment of setbacks along estuarine and public trust shorelines.			
F. Develop and implement a comprehensive coastal marina and dock management plan and policy to prevent closures of shellfish harvest waters and minimize cumulative impacts on fish habitat			
G. Reduce non-point source pollution from concentrated animal operations by the following actions			
1. continue the moratorium on new/expanded swine operations until alternative waste treatment technology is implemented,			
2. use a greater percentage of agricultural conservation funds to phase-out concentrated animal operations in sensitive areas and relocate operations from sensitive areas,			
3. mandate the phase-out of waste lagoons by a specific deadline, and			
4. use improved siting criteria to protect fish habitat.			
Comments or suggested recommendations:			

Attachment 1 (continued)

Attachment 2. Major changes to CHPP Public Draft 7-01-04

EXECUTIVE SUMMARY

- Large, foldout map of habitat types

WATER COLUMN CHAPTER

- Chapter 2, Section 2.4, Hydrologic modification/Dredging (navigation channels and boat basins)
- Chapter 2, Section 2.4, Water quality degradation/Land cover and water quality
- Chapter 2, Section 2.4, Water quality degradation/Nutrients/Sources of nutrient enrichment
- Chapter 2, Section 2.4, Water quality degradation/Sediments/Status of turbidity/sedimentation
- Chapter 2, Section 2.4, Water quality degradation/Fecal coliform bacterial contamination in estuarine waters
- Chapter 2, Section 2.4, Water quality degradation/Fecal coliform bacterial contamination in ocean waters
- Chapter 2, Section 2.4, Water quality degradation/Toxic chemicals/Sources of toxic chemical pollution
- Chapter 2, Section 2.4, Existing management measures/Stormwater management program
- Chapter 2, Section 2.5, Water column summary
- Chapter 3, Section 3.2, Fish utilization/Nursery

SHELL BOTTOM CHAPTER

- Chapter 3, Section 3.3, Status of associated fishery stocks
- Chapter 3, Section 3.4, Water quality degradation/Toxic chemicals

SAV CHAPTER

- Chapter 4, Section 4.4, Physical threats/Channel dredging

SOFT BOTTOM CHAPTER

- Chapter 6, Section 6.2, Ecological role and function/Community structure/marine
- Chapter 6, Section 6.3, Status and trends/Designated areas
- Chapter 6, Section 6.4, Physical threats/Dredging
- Chapter 6, Section 6.4, Physical threats/Shoreline stabilization/Soft stabilization

RECOMMENDATIONS <whole chapter>

Attachment 3. Comments from Interest Groups – 8/10/04 Memorandum from Mike Street to IRC

Memo To: IRC
From: Mike Street
Subject: Possible additional CHPP recommendation changes
Date: 10 August 2004

Based on comments received at public meetings, interest group meetings, e-mail, and written statements since the meeting with Pres Pate, Charles Jones, and Steve Wall on 4 August 2004, some additional possible changes to CHPP recommendations are provided below.

- Specifically include stakeholder process in SHA (Goal 2), beach nourishment (Goal 3), and marina planning (Goal 4).
- Because the legislative moratorium applies only to large-scale swine operations, change a) under Goal 4 (large-scale animal operations) back to "swine."
- Comments from David Williams (Div. Soil & Water Conservation), supported by Jim Cummings (Assistant Commissioner, Dept. of Agriculture and Consumer Affairs), also address concerns in the non-point source pollution and large-scale animal operations recommendations.
    - For voluntary NPS actions:
        - a) "Increased incentives and technical assistance for and promotion of" …
        - b) Delete reference to "agriculture conservation funds" and insert "Continue and expand voluntary efforts" to …
        - Add a new g) "Increased incentives for establishing riparian buffers and restoring prior converted wetlands."
    - For large-scale animal operations:
        - Replace c) lagoon phase-out with "Develop and provide incentives and infrastructure to implement effective alternative uses for animal derived-nutrients as described in the Soil and Water Conservation Commission's State Plan for Managing Animal Manures and Animal-Derived Nutrients Produced in North Carolina (http://www.enr.state.nc.us/DSWC/pages/state%20nutrient%20plan.pdf) and be consistent with the process for implementing environmentally superior technologies between the N.C. Attorney General and Smithfield Foods, Premium Standard Foods, and Frontline Farmers."

This last comment is extremely long and complex, potentially replacing the simple concept of eliminating swine waste lagoon/spray field systems. But there is information, and the A-G agreement is in place. I have taken a quick look at the referenced S&WC report, and I lack the background to judge it. So we really need advice here.

Please contact me if you have any questions.

cc: Bill Ross, Robin Smith, Dempsey Benton, Dan Oakley, Steve Wall
Pres Pate, Charles Jones, Alan Klimek
CHPP Development Team

APPENDIX C:
INTERCOMMISSION REVIEW COMMITTEE AND
COASTAL HABITAT PROTECTION PLAN DEVELOPMENT TEAM

Intercommission Review Committee (Two members each from MFC, EMC, CRC)

Current members as of June 1, 2004

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CHPP Development Team (Scientists and planners from DMF, DCM, DWQ, DEH, and WRC)

Current members as of June 1, 2004

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Appendix D: Land cover descriptions (Source: DWQ Basinwide Plans)

Natural Resources Inventory land cover type	Land cover descriptions
Cultivated cropland	Harvestable crops including row crops, small-grain and hay crops, nursery and orchard crops, and other specialty crops.
Uncultivated cropland	Summer fallow or other cropland not planted.
Pastureland	Includes land that has a vegetative cover of grasses, legumes and/or forbs, regardless of whether or not it is being grazed by livestock.
Forest land	Land at least 10% stocked by single-stemmed trees of any size which will be at least 4 meters at maturity, and land bearing evidence of natural regeneration of tree cover. The minimum area for classification of forestland is 1 acre, and the area must be at least 1,000 feet wide.
Urban and built-up	Includes airports, playgrounds with permanent structures, cemeteries, public administration sites, commercial sites, railroad yards, construction sites, residences, golf courses, sanitary landfills, industrial sites, sewage treatment plants, institutional sites, water control structure spillways and parking lots. Including highways, railroads and other transportation facilities if surrounded by other urban and built-up areas. Tracts of less than 10 acres that are completely surrounded by urban and built-up lands.
Other	Rural transportation: Consists of all highways, roads, railroads and associated right-of-ways outside urban and built-up areas; private roads to farmsteads; logging roads; and other private roads (but not field lanes).
	Small water areas: Waterbodies less than 40 acres; streams less than 0.5 miles wide.
	Minor land: Lands that do not fall into one of the other categories.

Appendix E: Land Cover by Management Unit shown as acreage (1000s) and percentage of total by river basin.
(Sources: National Resource Inventory, unpub. data. See Appendix F for map representation of USGS hydrologic units.)

USGS hydrologic unit (CHPP MU)	Year	Land cover types						Total
		Cultivated crop	Un-cultivated crop	Pasture	Forest	Urban/ built-up	Other land cover[1]	
Albemarle (95% of Albemarle MU and 5% of Chowan MU)	1982	493.2	0	3.9	668.7	36.9	198.3	1401.0
	1987	498.9	1	5.4	552.9	50.2	292.4	1400.8
	1992	443.5	0.1	7.8	487.3	58.8	402.0	1399.5
	1997	437.1	0.1	6.7	491.7	68.7	395.0	1399.3
% of total land cover	1997	31.2	0.0	0.5	35.1	4.9	28.2	100.0
% Change	1982-97	-11.4	na	71.8	-26.5	86.2	99.2	-0.1
Bogue-Core Sounds (100% of Bogue-Core MU, 30% of Pamlico MU, and 50% of New-White Oak MU)	1982	54.3	0	1.7	159.6	25.2	201.6	442.4
	1987	56.8	0	1.7	156.3	32.6	195.1	442.5
	1992	50.4	0	1.7	146.9	46.6	197.1	442.7
	1997	45.5	5	1.7	144.4	51	195.1	442.7
% of total land cover	1997	10.3	1.1	0.4	32.6	11.5	44.1	100.0
% Change	1982-97	-16.2	na	0.0	-9.5	102.4	-3.2	0.1
(Cape Fear)	1982	1177	44.6	297	3531.7	370	351.5	5771.8
	1987	1138.4	40.8	304.8	3461.1	435.6	382.1	5762.8
	1992	1077.5	69	277.4	3395.7	517.2	423.3	5760.1
	1997	947.1	143.4	301.1	3312.2	627.6	426.9	5758.3
% of total land cover	1997	16.4	2.5	5.2	57.5	10.9	7.4	100.0
% Change	1982-97	-19.5	221.5	1.4	-6.2	69.6	21.5	-0.2
Chowan, Meherrin, Nottaway (95% of Chowan MU)	1982	265.4	0	10.5	448.4	14	32.9	771.2
	1987	265.3	0	10.6	445.9	17.3	32.2	771.3
	1992	262.5	1.5	9	446.2	20	32.1	771.3
	1997	263.3	1.5	8	444	22.7	31.4	770.9
% of total land cover	1997	34.2	0.2	1.0	57.6	2.9	4.1	100.0
% Change	1982-97	-0.8	na	-23.8	-1.0	62.1	-4.6	0.0

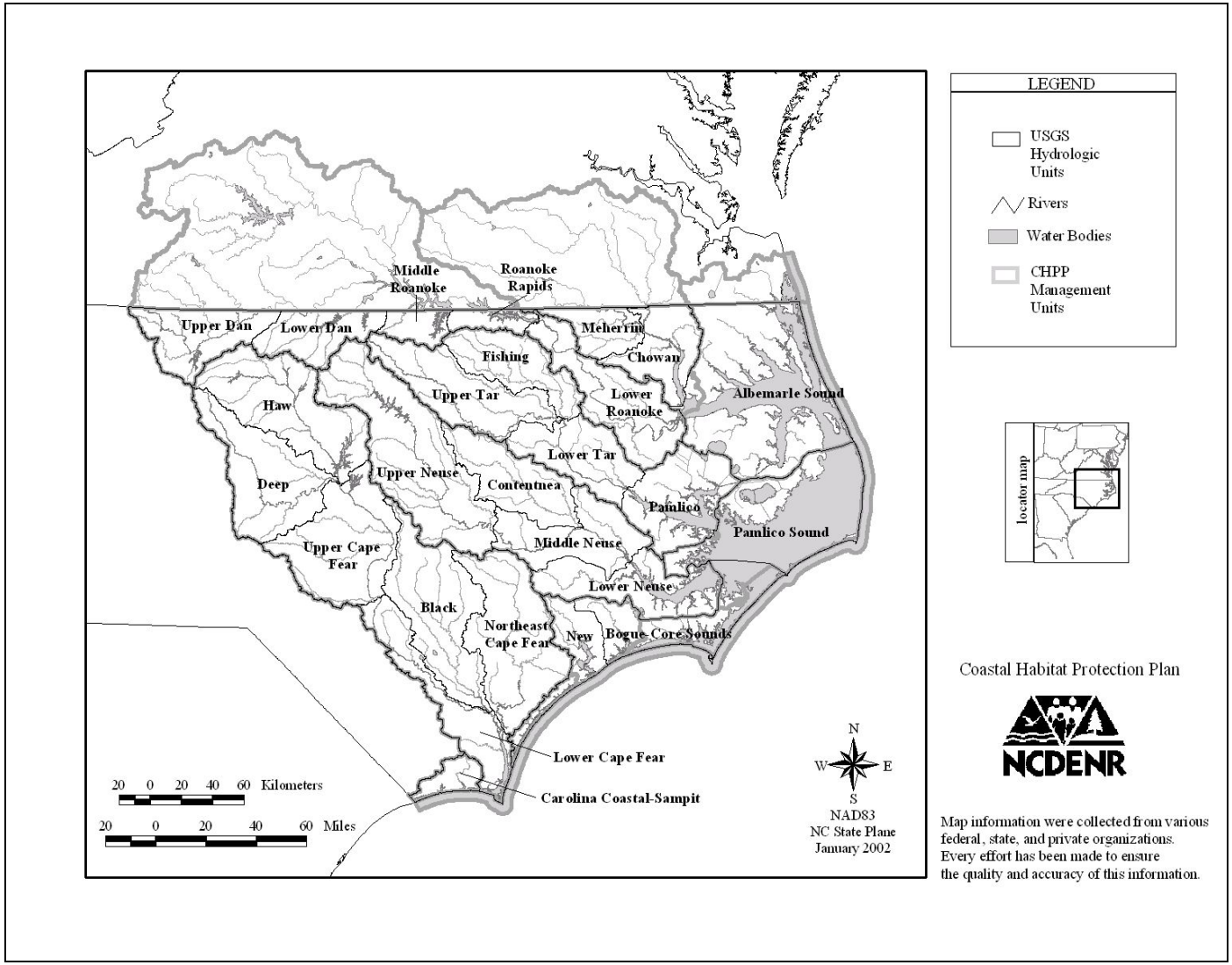
[1] Includes minor land uses, rural transportation, federal lands, and Conservation Reserve Program lands (See Appendix D for explanation)

USGS hydrologic unit (CHPP MU)	Year	Land cover types						Total
		Cultivated crop	Un-cultivated crop	Pasture	Forest	Urban/ built-up	Other land cover[1]	
(Neuse)	1982	1054.4	13.1	116.7	1769.4	254.1	235.3	3443.0
	1987	1028.3	32.3	105.3	1697.2	326.3	249.1	3438.5
	1992	985.4	35.1	108.5	1669.4	391.1	247.8	3437.3
	1997	874.7	53.9	136.2	1641.5	481	247.3	3434.6
% of total land cover	1997	25.5	1.6	4.0	47.8	14.0	7.2	100.0
% Change	1982-97	-17.0	311.5	16.7	-7.2	89.3	5.1	-0.2
New (50% of New-White Oak MU and 40% of Southern Estuaries MU)	1982	12.7	0	0	221.7	28.9	58.7	322.0
	1987	12.7	0	0	217	33.6	58.7	322.0
	1992	12.4	0	0.1	214.5	35.9	59.0	321.9
	1997	12.4	0	4.2	207.4	38.6	59.2	321.8
% of total land cover	1997	3.9	0.0	1.3	64.4	12.0	18.4	100.0
% Change	1982-97	-2.4	na	na	-6.5	33.6	0.9	-0.1
Pamlico Sound (70% of Pamlico MU)	1982	77	0	0	142.6	5.5	137.0	362.1
	1987	59.1	0	0	124.5	9.5	169.0	362.1
	1992	55.8	0	0	120	11	175.3	362.1
	1997	55	0	0	118.1	13.1	175.9	362.1
% of total land cover	1997	15.2	0.0	0.0	32.6	3.6	48.6	100.0
% Change	1982-97	-28.6	na	na	-17.2	138.2	28.4	0.0
(Roanoke)	1982	478.7	24.8	111.8	1377.4	54.9	98.3	2145.9
	1987	437.3	16.2	118.3	1396.6	76.5	100.3	2145.2
	1992	399.1	38.1	102.1	1380.9	105.5	119.9	2145.6
	1997	381	47	87.8	1370.1	129.6	129.0	2144.5
% of total land cover	1997	17.8	2.2	4.1	63.9	6.0	6.0	100.0
% Change	1982-97	-20.4	89.5	-21.5	-0.5	136.1	31.2	-0.1

[1] Includes minor land uses, rural transportation, federal lands, and Conservation Reserve Program lands (See Appendix D for explanation)

USGS hydrologic unit (CHPP MU)	Year	Land cover types						Total
		Cultivated crop	Un-cultivated crop	Pasture	Forest	Urban/ built-up	Other land cover[1]	
Carolina Coastal-Sampit (50% of Southern Estuaries MU)	1982	17.9	0.8	2.5	120.3	13.7	8.9	164.1
	1987	11	0	5.4	110.1	27.8	9.7	164.0
	1992	10.9	0	5.4	109.3	27.9	10.5	164.0
	1997	10.1	0	5.3	105.9	32.1	10.5	163.9
% of total land cover	1997	6.2	0.0	3.2	64.6	19.6	6.4	100.0
% Change	1982-97	-43.6	-100.0	112.0	-12.0	134.3	18.0	-0.1
Fishing, Lower Tar, Pamlico (100% of Tar-Pamlico MU)	1982	846.2	5.8	94.9	1422.5	90.8	163.9	2624.1
	1987	823.9	2.7	87.1	1427.4	114.7	167.3	2623.1
	1992	782.3	19	81.8	1412.3	139.9	187.4	2622.7
	1997	714.5	27.7	118.9	1390	170	198.7	2619.8
% of total land cover	1997	27.3	1.1	4.5	53.1	6.5	7.6	100.0
% Change	1982-97	-15.6	377.6	25.3	-2.3	87.2	21.2	-0.2
TOTAL AREA	1982	4476.8	89.1	639	9862.3	894	1486.4	17447.6
	1987	4331.7	93	638.6	9589	1124.1	1655.9	17432.3
	1992	4079.8	162.8	593.8	9382.5	1353.9	1854.4	17427.2
	1997	3740.7	278.6	669.9	9225.3	1634.4	1869.0	17417.9
% of total land cover	1997	21.5	1.6	3.8	53.0	9.4	10.7	100.0
% Change	1982-97	-16.4	212.7	4.8	-6.5	82.8	25.7	-0.2

[1] Includes minor land uses, rural transportation, federal lands, and Conservation Reserve Program lands (See Appendix D for explanation)



Appendix F: Map of U.S. Geological Survey (USGS) hydrologic units and CHPP management units.

Appendix G: State protected species. [Source: N.C. Natural Heritage Program (2001)]

Associated Habitat	Taxonomic group	Endangered	Endangered-Special Concern	Threatened	Threatened-Special Concern	Special Concern	Candidate	Candidate-Special Concern	Significantly rare
Aquatic	Amphibian	.	.	.	.	1	.	.	.
	Crustacean	.	.	.	.	.	.	.	2
	Fish	5	.	1	.	13	.	.	1
	Insect	.	.	.	.	.	.	.	26
	Mammal	1	.	.	.	.	.	.	.
	Mollusk	4	.	9	.	5	.	.	5
	Moss	.	.	.	.	.	1	.	.
	Reptile	3	.	2	.	2	.	.	.
	Vascular Plant	1	.	3	.	.	6	.	11
	Subtotals	14	0	15	0	21	7	0	45
Wetland	Amphibian	.	.	1	.	4	.	.	3
	Bird	3	.	2	.	6	.	.	17
	Crustacean	.	.	.	.	.	.	.	2
	Insect	.	.	.	.	.	.	.	25
	Lichen	.	.	.	.	.	.	.	1
	Liverwort	.	.	.	.	.	1	.	4
	Mammal	.	.	1	.	3	.	.	2
	Mollusk	.	.	1	.	.	.	.	.
	Moss	.	.	.	.	.	1	.	2
	Reptile	.	.	2	.	2	.	.	5
	Vascular Plant	18	1	11	2	.	56	1	69
	Subtotals	21	1	18	2	15	58	1	130
Totals		35	1	33	2	36	65	1	175

Appendix H: *Part 1 (Acronyms)*

Acronym	Meaning
A	One of the three primary surface water classifications established by the EMC
AAAS	American Association for the Advancement of Science
ACOE	United States Army Corps of Engineers (see "COE" and "USACOE" below)
ADCP	Acoustic Doppler Current Profiling
AEC	Area of Environmental Concern
AFS	American Fisheries Society
AIWW	Atlantic Intracoastal Waterway (see "ICW" below)
APES	Albemarle-Pamlico Estuarine Study
APNEP	Albemarle-Pamlico National Estuary Program
ASMFC	Atlantic States Marine Fisheries Commission
B	One of the three primary surface water classifications established by the EMC
BACIPS	Before-After-Control-Impact Paired Series
BEACH	Beaches Environmental Assessment and Coastal Health Act of 2000
BMPs	Best Management Practices
BOD	Biological Oxygen Demand
BRACO	Blue Ribbon Advisory Council on Oysters
C	One of the three primary surface water classifications established by the EMC
CAAE	Center for Applied Aquatic Ecology at North Carolina State University
CAMA	Coastal Area Management Act
CBF	Chesapeake Bay Foundation
CCA	Copper, chromium, and arsenic
C-CAP	Coastal Change Analysis Program
CCPCA	Central Coastal Plain Capacity Use Area
cfs	Cubic feet per second
CFZ	Coastal frontal zone
CGIA	Center for Geographic Information and Analysis
CHAs	Critical Habitat Areas
CHPP	Coastal Habitat Protection Plan
CHS	Commission for Health Services
C-MAN	Coastal-Marine Automated Network
CMSR	Center for Marine Science Research at the University of North Carolina - Wilmington

Acronym	Meaning
COBRA	Coastal Barrier Resources Act
COE	United States Army Corps of Engineers (see "ACOE" above and "USACOE" below)
COMP	Coastal Ocean Monitoring Program
CORMP	Coastal Ocean Research and Monitoring Program
CPUE	Catch per unit effort
CRAC	Coastal Resources Advisory Council
CRC	Coastal Resources Commission
CREP	Conservation Reserve Enhancement Program
CREWS	Coastal Region Evaluation of Wetland Significance
CWMTF	Clean Water Management Trust Fund
DAQ	Division of Air Quality
DCM	Division of Coastal Management
DDD	1,1-dichloro-2,2-bis(p-chlorophenyl)ethane
DDE	1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene
DDT	Dichlorodiphenyltrichloroethane
DEH	Division of Environmental Health
DEH - SS	Division of Environmental Health - Shellfish Sanitation
DEHNR	Department of Environment, Health and Natural Resources
DEM	Division of Environmental Management
DENR	Department of Environment and Natural Resources
Dermo	*Perkinus marinus*
DFR	Division of Forest Resources
DLR	Division of Land Resources
DMF	Division of Marine Fisheries
DNA	Deoxyribonucleic acid
DO	Dissolved oxygen
DOT	Department of Transportation
DSWC	Division of Soil and Water Conservation
DWQ	Division of Water Quality
EA	Environmental Assessment
ECU	East Carolina University
EEP	Ecosystem Enhancement Program
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat

Acronym	Meaning
EIS	Environmental Impact Statement
EMAP	Environmental Monitoring and Assessment Program
EMC	Environmental Management Commission
EO	Executive Order
EPA	United States Environmental Protection Agency (see "USEPA" below)
FC	Fecal coliform bacteria
FLDEP	Florida Department of Environmental Protection
FMP	Fishery Management Plan
FONSI	Findings of No Significant Impact
FPGs	Forestry Practice Guidelines
FRA	Fisheries Reform Act
FWS	United States Fish & Wildlife Service (see “USFWS” below)
FWS	Future Water Supply
FY	Fiscal year
GIS	Geographic Information System
GS	General Statute
HAPC	Habitat Area(s) of Particular Concern
HB	House Bill
HQW	High Quality Waters (EMC supplemental water quality classification)
HU	Hydrologic unit
ICW	Atlantic Intracoastal Waterway (see "AIWW" above)
IRC	Intercommission Review Committee
JAI	Juvenile abundance index
LC50	Lethal concentration 50%
MAFMC	Mid-Atlantic Fishery Management Council
MARMAP	Marine Resources Monitoring, Assessment, and Prediction Program
MFC	Marine Fisheries Commission
mgd	Million gallons per day
MHW	Mean high water
MLW	Mean low water
MMS	Minerals Management Service
MODMON	Neuse River Estuary Modeling and Monitoring project
MPA	Marine Protected Area
MS4s	Municipal separate storm sewer systems

Acronym	Meaning
MSC	Moratorium Steering Committee
MSX	*Haplosporidium nelsoni*
MU	Management Unit
NAWQA	National Water Quality Assessment
NCAC	North Carolina Administrative Code
NCDEHNR	North Carolina Department of Environment, Health and Natural Resources
NCDOT	North Carolina Department of Transportation
NCGS	North Carolina General Statute
NCSU	North Carolina State University
NCWRP	North Carolina Wetlands Restoration Program
NHP	Natural Heritage Program
NM	Nautical mile
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NPDES	National Pollution Discharge Elimination System
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NRI	National Resource Inventory
NSW	Nutrient Sensitive Waters (EMC supplemental water quality classification)
NTA	No Trawl Areas
NTU	Nephelometric turbidity unit
NWI	National Wetland Inventory
NWR	National Wildlife Refuge
OECA	Office of Enforcement and Compliance Assurance
ODMDS	Ocean Dredge Material Disposal Site
ORM	Organic rich mud
ORW	Outstanding Resource Waters (EMC supplemental water quality classification)
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PNA	Primary Nursery Area
ppm	Parts per million
ppt	Parts per thousand
PWS	Public Water Supply

Acronym	Meaning
RCGL	Recreational Commercial Gear License
RO	Reverse osmosis
SA	One of the three primary surface water classifications for coastal waters established by the EMC
SAB	South Atlantic Bight
SABRE	South Atlantic Bight Recruitment Experiment
SAFMC	South Atlantic Fishery Management Council
SAV	Submerged aquatic vegetation
SB	One of the three primary surface water classifications for coastal waters established by the EMC
SB	Senate Bill
SBFMP	Striped Bass Fishery Management Plan
SC	One of the three primary surface water classifications for coastal waters established by the EMC
SCC	Sedimentation Control Commission
SCGL	Standard Commercial Gear License
SCDHEC	South Carolina Department of Health and Environmental Control
SCMRD	South Carolina Marine Resources Division
SEAMAP	Southeast Area Monitoring and Assessment Program
SEAMAP-SA	Southeast Area Monitoring and Assessment Program - South Atlantic
SECC	Sedimentation and Erosion Control Commission
SEPA	State Environmental Policy Act
SFA	Sustainable Fisheries Act
SHA	Strategic Habitat Area
SL	Session Law
SMZ	Federal Artificial Reef Special Management Zone
SMZ	Streamside Management Zone
SNA	Secondary Nursery Area
SNHA	Significant Natural Heritage Area
SOC	Schedule of Compliance
SOD	Sediment Oxygen Demand
SSMAs	Shellfish/Seed Management Areas
SSR	Stock Status Report
STORET	Storage and Retrieval System
SW	Swamp waters (EMC supplemental water quality classification)
TBT	Tributyltin
TL	Total length

Acronym	Meaning
TMDL	Total Maximum Daily Load
TR	Trout waters (EMC supplemental water quality classification)
TRC	Total residual chlorine
TSS	Total suspended solids
UM	Ulcerative mycosis
UNC	University of North Carolina
UNC-IMS	University of North Carolina - Institute of Marine Science
UNC-W	University of North Carolina - Wilmington
USACOE	United States Army Corps of Engineers (see "ACOE" and "COE" above)
USC	United States Code
USCG	United States Coast Guard
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency (see "EPA" above)
USFWS	United States Fish & Wildlife Service
USGS	United States Geological Survey
UV	Ultraviolet light
VIMS	Virginia Institute of Marine Science
WRC	Wildlife Resources Commission
WRP	Wetland Restoration Program
WS	Water Supply (EMC supplemental water quality classification)

Appendix H: *Part 2 (Definitions)*

Term	Description
Accretion/accrete	Natural process by which marshes build in elevation with rising water level.
Adsorption	Chemical attachment to a particle.
Aerenchyma	Specialized thin-walled cells with large air spaces between them to provide buoyancy and support in an aquatic environment.
Anadromous	Fish species that migrate from the ocean to fresh water streams, lakes, and wetlands to spawn .
Anaerobic/reducing	Condition of the water column without oxygen.
Anoxia	Absence of oxygen.
Anthropogenic	Human-like or caused by humans.
Baseflow	Sustained low flow of a stream which is often due to groundwater inflow to the stream channel.
Benthic	Associated with the bottom under a water body.
Benthic-pelagic coupling	The influence of the benthic community and sediments on the water column, and, in turn, the influence of the water column on the benthic community and sediments, through integrated events and processes such as resuspension, nutrient cycling, settlement, and absorption .
Biomass	Weight of living material, usually expressed as a dry weight, in all or part of an organism, population, or community. Commonly presented as weight per unit area, a biomass density.
Biotic interactions	The physical interactions among organisms (i.e., predation, spawning, competition).
Buffer	A vegetated transitional zone between upland areas and aquatic habitats, which functions as a filter of surface water runoff.
Catadromous	Fish species that migrate from fresh waters through to spawning areas in the ocean.
Catch per unit effort	Amount of fish (numbers or weight) caught by a standard amount of fishing, such as pounds per trip.
Compensatory mitigation	The restoration, creation, enhancement, or, in exceptional cases, preservation of wetlands and/or other aquatic resources for the purpose of compensating for unavoidable impacts from human activities.
Critical habitat area	Habitat areas that are vital for spawning, early growth and development, and/or the entire life cycle of marine and estuarine fish species (MFC rule 15A NCAC 3I .0101 (20) defines critical habitat areas generally, along with specific definitions for submerged aquatic vegetation, shellfish beds, anadromous fish spawning areas, and anadromous fish nursery areas).
Demersal	Fish species that live primarily on or near the bottom.
Denitrification	Biochemical reduction , primarily by microorganisms, of nitrogen from nitrate (NO_3^-) eventually to molecular nitrogen (N_2).
Desiccation	Removal of water from organic material.
Detritivores	An organism that feeds on freshly dead or partially decomposed organic matter.
Detritus	Fragments of plant material occurring in the water during the process of decomposition by bacteria and fungi.
Drowned river system	An estuary that originated as a river basin flooded by rising sea level.
Embayment	A bay or bay-like waterbody.
Emergent vegetation	Non-woody wetland vegetation rooted in shallow water having leaves protruding above the water.

Term	Description
Energy regimes	Refers to the timing and magnitude of wave impact on and near a shoreline.
Epibenthic	Living on the surface of the bottom.
Epibiota	Organisms living on a relatively stationary surface.
Estuarine and ocean waters	All the waters of the Atlantic Ocean within the seaward boundary of North Carolina and all the bays, sounds, rivers, and tributaries thereto seaward of the dividing line between coastal fishing waters and inland fishing waters.
Estuary	A dynamic coastal water body in which fresh water from rivers and creeks mixes with ocean waters.
Euphotic zone	Portion of the water column in which light penetrates sufficiently to allow photosynthesis.
Eutrophication	Process of enrichment of a water body with excessive nutrients to the extent that abnormal algae blooms occur and community structure changes.
Evapotranspiration	The combination of water transpired from vegetation and evaporated from the soil and plant surfaces.
Extirpation	To destroy totally; extermination.
Functional equivalence	Refers to different characteristics that provide the same function in a system.
Hard bottom habitat	Exposed areas of rock or consolidated sediments, distinguished from surrounding unconsolidated sediments, which may or may not be characterized by a thin veneer of live or dead biota, generally located in the ocean rather than in the estuarine system.
Herbivory	Consuming living plants or their parts.
Heterogeneity	The variety of qualities found in an environment (habitat patches) or a population (genotypic variation).
Hydric soils	A soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part.
Hydrodynamic conditions	How the water is moving or circulating through a body of water.
Hydrogeomorphology	The characteristics of aquifers transmitting groundwater.
Hypoxia	Condition in which the level of dissolved oxygen in the water column is below that necessary to fully support normal biological functions, resulting in stress for the natural community.
Ichthyoplankton	Fish eggs and larvae that drift with the currents near the water's surface.
Impoundment	Water body created or modified by a barrier or dam which purposefully or unintentionally obstructs the outflow of water. This could include man-made dams and beaver dams.
Interbasin transfers	Artificial movement of water from one river basin to another, generally through pipelines or canals.
Inundation	Covering with water.
Isobath	Lines on a map or graph connecting points with the same water depth.
Light attenuation	The reduction of radiant energy (light) with depth, by both scattering and absorption mechanisms.
Light availability	The amount of light present at a given depth.
Macroalgae	Large algae visible to the naked eye, such as sea lettuce and kelp.

Term	Description
Macrofauna	The larger animals such as adult crabs and fish.
Macrophyte	Plant large enough to be visible to the naked eye.
Marine systems	Open ocean waters overlying the continental shelf and its associated high-energy coastline where salinities exceed 30 ppt.
Meiofauna	Microscopic animals that live in the upper layers of sediment.
Meroplankton	Organisms that spend only part of their life cycle in the plankton.
Mesohaline	Moderate salinity waters (5-18 ppt).
Nekton	Free-swimming organisms that live in the water column.
Oligohaline	Low salinity waters (0.5-5 ppt).
Peat blocks	Old marsh beds on which the vegetation has died, leaving a mass of decomposed roots. Along eroding shorelines, they are created when the banks cave in.
Pelagic	Fish species that live primarily up in the water column.
Phytobenthic	Refers to microscopic plants that live on the bottom.
Phytoplankton	Microscopic plants that float in the water column.
Plankton	Small organisms that live in the water column, generally near the surface, including eggs, larvae, and adults; they may float with the currents, or have some control over their movements.
Polyhaline	High salinity waters (18-30 ppt).
Porewater	Water found among the air spaces in soil.
Primary production	The accumulation of energy and nutrients by green plants and other life forms that do not consume other life forms to survive (autotrophs).
Propagules	A plant seed or spore.
Public trust waters	All navigable waters within state jurisdiction and the lands thereunder, below the mean high water line or mean water level.
Recruitment	Number of fish hatched or born in any year that survive to reproductive size; also, the number of individuals that reach a harvestable size, a particular size or age, or a size captured by a particular fishing gear.
Rhizomes	Underground plant stem that can give rise to a new plant above the surface.
Riparian wetlands	Wetlands that are connected to coastal water bodies by surface water of sufficient depth to allow fish utilization.
Sciaenids	Family of fishes that includes the drums and croakers
Secondary production	The accumulation of energy and nutrients by organisms consuming green plants or other autotrophs.
Sedimentation	Soil that is washed into coastal waters by runoff waters. The source of sedimentation could be land-disturbing human activities or natural events.
Sessile	Stationary or non-moving.
Siltation	Process of filling a water body with sediments.
Silviculture	The branch of forestry dealing with the development and care of forests.
Sinks	Habitats where certain organisms have a higher mortality rates and production rate (i.e., areas that are heavily fished or otherwise dangerous).

Term	Description
Slough	A stagnant, backwater area associated a swamp.
Strategic Habitat Areas (SHAs)	Specific locations of individual fish habitats or systems of fish habitats that have been identified to provide exceptional habitat functions or that are particularly at risk due to imminent threats, vulnerability, or rarity.
Submersion regime	The frequency and depth of flooding over a given bottom area.
Subsidence	Natural degradation of marsh wetlands to open waters.
Substrate	A submerged surface, usually associated with the bottom.
Surface incident light	The amount of light hitting a surface.
Temporal abundance	The variation in abundance of a given organism through time.
Tidal amplitude	Vertical distance between the high and low points of lunar tides.
Total suspended solids	A measure of suspended particles (i.e., sediment, phytoplankton) in the water column.
Trophic position	An organisms position on the food chain (top predator vs. plant eater).
Trunk estuaries	Coast-perpendicular, drowned river estuaries.
Turbidity	Reduced water clarity caused by sediment or other particulates suspended in the water column.
Unconsolidated substrate	Substrate with at least 25% cover of particles smaller than stones, and vegetative cover less than 30% (Cowardin et al. 1979).
Vegetated swales	Very wide ditches with sloping banks constructed to gradually convey storm water to surface waters.
Water clarity	A measure of the depth to which light penetrates the water column .
Wetlands	Areas that are inundated or saturated by an accumulation of surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.
Wind fetch	Distance over which the wind has blown uninterrupted by land, over water.
Zoogeographical	Related to the geographic distribution of animals.

Appendix I: Common and scientific names of selected fish and invertebrates cited in this document

Common name	***Scientific name***	**Common name**	***Scientific name***
Alewife	*Alosa pseudoharengus*	Greater amberjack	*Seriola dumerili*
American eel	*Anguilla rostrata*	Gulf flounder	*Paralichthys albigutta*
American shad	*Alosa sapidissima*	Hard clam	*Mercenaria* spp.
Atlantic croaker	*Micropogonias undulatus*	Hermit crab	*Pagurus bernhardus*
Atlantic menhaden	*Brevoortia tyrannus*	Hickory shad	*Alosa mediocris*
Atlantic spadefish	*Chaetodipterus faber*	Horseshoe crab	*Limulus polyphemus*
Atlantic stingray	*Dasyatis sabina*	Inland silverside	*Menidia beryllina*
Atlantic sturgeon	*Acipenser oxyrhynchus*	Inshore lizardfish	*Synodus foetens*
Banded killifish	*Fundulus diaphanus*	King mackerel	*Scomberomorus cavalla*
Bay anchovy	*Anchoa mitchilli*	Kingfish	*Menticirrhus* spp.
Bay scallop	*Argopecten irradians*	Mantis shrimp	*Squilla empusa*
Bay whiff	*Citharichthys spilopterus*	Moon snail	*Polinices duplicatus*
Black drum	*Pogonias cromis*	Mummichog	*Fundulus heteroclitus*
Black sea bass	*Centropristis striata*	Naked goby	*Gobiosoma bosc*
Blackcheek tonguefish	*Symphurus plaqiusa*	Oyster	*Crassostrea virginica*
Blue crab	*Callinectes sapidus*	Oyster toadfish	*Opsanus tau*
Blueback herring	*Alosa aestivalis*	Pinfish	*Lagodon rhomboides*
Bluefish	*Pomatomus saltatrix*	Pink shrimp	*Penaeus duorarum*
Brown shrimp	*Penaeus aztecus*	Planehead filefish	*Stephanolepis hispidus*
Cobia	*Rachycentron canadum*	Red drum	*Sciaenops ocellatus*
Cownose ray	*Rhinoptera bonasus*	Rough silverside	*Membras martinica*
Florida pompano	*Trachinotus carolinus*	Round scad	*Decapterus macarellus*
Fringed flounder	*Etropus crossotus*	Sand perch	*Diplectrum formosum*
Gag	*Mycteroperca microlepis*	Scup	*Stenotomus chrysops*
Grass shrimp	*Palaemonetes* spp.	Sheepshead	*Archosargus probatocephalus*
Sheepshead minnow	*Cyprinidon variegatus*	Stone crab	*Menippe mercenaria*
Shortnose sturgeon	*Acipenser brevirostrum*	Striped anchovy	*Anchoa hepsetus*
Silver perch	*Bairdiella chrysoura*	Striped bass	*Morone saxatilis*
Skilletfish	*Gobiesox strumosus*	Striped mullet	*Mugil cephalus*
Smooth dogfish	*Mustelus canis*	Summer flounder	*Paralichthys dentatus*
Southern flounder	*Paralichthys lethostigma*	Tautog	*Tautoga onitis*
Southern kingfish	*Menticirrhus americanus*	Tomtate	*Haemulon aurolineatum*
Spanish mackerel	*Scomberomorus maculatus*	Weakfish	*Cynoscion regalis*
Spiny dogfish	*Squalus acanthias*	Whelks	*Busycon* spp.
Spot	*Leiostomus xanthurus*	White grunt	*Haemulon plumieri*
Spottail pinfish	*Diplidus holbrooki*	White shrimp	*Penaeus setiferus*
Spotted seatrout	*Cynoscion nebulosus*	Whitebone porgy	*Calamus leucosteus*

Appendix J: Existing state and federal agency programs that may affect water quality. (Source: Estuarine Shoreline Protection Stakeholders Report 1999)

Program type	Organization	Program/Policy/Act	Affected impact[1]	Authority[2]	Geographic jurisdiction[3]	Issue Permits / Rules	Enforcement	Review Permits	Planning	Technical Assistance	Monitor	Research	Education	Start Year
Federal Government	Council on Environmental Quality	National Environmental Policy Act	F,N,S,T	S	N	X			X	X				1972
	Environmental Protection Agency	Clean Air Act	T,N	S	N	X	X	X	X	X	X	X	X	1970
		Clean Water Act	F,S,N,T	S	N	X	X	X	X	X	X	X	X	1977
		Insect, Fungi, & Rodenticide Act	T	S	N	X	X			X	X	X	X	1972
		Office of Wetlands, Oceans&Watersheds	F,S,N,T	S,R	N	X	X	X	X	X	X	X	X	1977
		Oil Pollution Act	T	S	N	X	X		X	X	X	X	X	1990
		Pollution Prevention Act	T	S	N			X	X	X	X		X	1990
		Safe Drinking Water Act	F,S,N,T	S	N	X	X			X	X	?	X	1974
	Nat. Oceanic & Atmospheric Adm.	Coastal Non-point Source Prog.	F,N,S,T	S	N				X	X	X			1990
		National Marine Fisheries Service	F,N,S,T	S,E	N			X		X	X	X		

[1] F = Fecal coliforms, S = Sediment, N = Nutrients, T = Toxics, Q = Water quality/flow
[2] S = Statutory, R = rules, C = Conservation, E = Research, V = Voluntary, * = Federally mandated state program
[3] C = 20 coastal counties, S = Statewide, N = National

Program type	Organization	Program/Policy/Act	Affected impact[1]	Authority[2]	Geographic jurisdiction[3]	Issue Permits / Rules	Enforcement	Review Permits	Planning	Technical Assistance	Monitor	Research	Education	Start Year
Federal government	US Army Corps of Engineers	N/A	F,N,S,T	S	N	X	X	X						1899
	US Coast Guard	N/A	F,N,S,T	S	N		X							
	US Dept. of Agriculture	Conservation Reserve Enhance. P.	N,F,S,T	V,C	C				X	X				1999
		Conservation Reserve Program	N,F,S,T	V,C	S				X	X				
		Environ. Quality Incentives P.	N,F,S,T	V,C	S				X	X				1996
		Farmland Protection Program	N,F,S,T	V,C	S				X	X				
		Flood Risk Reduction Program	N,F,S,T	V,C	S				X	X				
		Wetlands Reserve Program	N,F,S,T	V,C	S				X	X				
		Wildlife Habitat Incentives P.	N,F,S,T	V,C	S				X	X				
	US Fish & Wildlife Service	Endangered Species Act	S,N,T	S	N	X	X	X	X	X	X	X	X	1973

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Program type	Organization	Program/Policy/Act	Affected impact[1]	Authority[2]	Geographic jurisdiction[3]	Issue Permits / Rules	Enforcement	Review Permits	Planning	Technical Assistance	Monitor	Research	Education	Start Year
Federal government	U.S. Fish & Wildlife Service	Fish & Wildlife Coordination Act	F,S,N,T	S	N			X	X					1934
		Magnuson-Stevens Cons./Mgmt.	F,S,N,T	S	N	X	X	X	X	X	X	X	X	1996
	US Forest Service	American Heritage Rivers Initiative	S	V,C	N				X	X				1997
		Technical Develop. & Planning P.	S	V,C	N				X	X		X	X	
Private organization	Conservation Trust for NC	N/A	F,N,S,T	C	S				X					
	The Nature Conservancy	N/A	F,N,S,T	C	N				X	X	X	X	X	
State government	NC Clean Water Management Trust Fund	Clean Water Mgmt Trust Fund	N,T,S,F	S,C	S					X			X	1996
	NC Dept. of Administration	SEPA Program	N,T,S,F	S*	S			X	X					1971
	NC Dept. of Agriculture	Aquaculture and Natural Res. Div.	F,N,S,T	S	S			X	X	X			X	1975

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Program type	Organization	Program/Policy/Act	Affected impact[1]	Authority[2]	Geographic jurisdiction[3]	Issue Permits / Rules	Enforcement	Review Permits	Planning	Technical Assistance	Monitor	Research	Education	Start Year
State government	NC Dept. of Agriculture, Agronomic Division	N/A	F,N,S,T	S	S					X	X	X	X	1938
	NC Dept. of Commerce	Business & Industry Dev. P., etc.		S	S				X	X				1971
	NC Dept. of Commerce, Div. Of Community Assistance	N/A		S	S				X	X				1971
	NC Dept. of Transportation	Statewide Planning Branch	S,T,N	S	S				X	X				
	NC Div. Of Highways	Soil and Water Engineering Prog.	S,N,T	S,R	S				X	X				
		Wetland Restoration Program	S,N,T	S	S				X		X			
	NC Division of Air Quality	Air Emissions Permitting Program	N,T,S	S,R*	S	X	X	X	X	X	X			1971
		Ambient Air Quality Monitoring P.	N,T,S	S	S					X	X		X	1971
		Compliance Program	N,T,S	S,R*	S		X			X	X			1971

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Program type	Organization	Program/Policy/Act	Affected impact[1]	Authority[2]	Geographic jurisdiction[3]	Issue Permits / Rules	Enforcement	Review Permits	Planning	Technical Assistance	Monitor	Research	Education	Start Year
State government	NC Division of Air Quality	Odor Control/Animal Operations P.	N	S,R	S	X		X	X	X	X			1971
		Planning Section	N,T,S	S,R*	S	X		X	X	X			X	1971
		Public Outreach Program	N,T,S	S,C	S					X	X		X	1990
	NC Division of Coastal Management	Coastal Reserves Program	F,S,N,T	S,C	C				X		X	X	X	1989
		Development Permitting (AEC) P.	F,S,N,T	R	C	X	X	X		X				1974
		Dredge & Fill Permitting Program	S,N,T	R	S	X	X	X		X				1970
		Federal Consistency Program	F,S,N,T	R	C		X		X	X				1974
		Land-use Planning Program	F,S,N,T	S	C			X	X	X				1974
		Marine Sewage Pumpout Program	F,T,N	S	C					X		X	X	1994
		Ocean Res. Mgmt./OCS Program	F,S,N,T	S*	C			X	X	X				1993
		Wetland Mapping Program		S,C	C				X	X				1992

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Program type	Organization	Program/Policy/Act	Affected impact[1]	Authority[2]	Geographic jurisdiction[3]	Issue Permits / Rules	Enforcement	Review Permits	Planning	Technical Assistance	Monitor	Research	Education	Start Year
State government	NC Division of Environmental Health	On-site Wastewater Program	F,N	S,R	S	X		X		X			X	1977
	NC Division of Environmental Health	Public Health Pest Mgmt. Program	S	R	S	X	X	X		X	X		X	1957
		Public Water Supply Program	Q	R	S	X	X	X	X	X	X		X	
		Shellfish Sanitation Program	F	S,R	C	X		X	X	X	X	X	X	1930s
	NC Division of Forestry Resources	Forest Practices Guidelines	S,N	R	S				X	X			X	1990
		Forestry BMPs	S,N	V	S				X	X			X	
		Forest Stewardship Program	S,N	V	S				X	X			X	1990
		Forest Land Enhancement Program	S,N	V	S				X	X			X	
		Forest Development Program	S,N	V	S					X				?
	NC Division of Land Resources	Dam Safety Permits Program	S	S/R	S	X	X	X						1967
		Mining Permits Program	S	S/R	S	X	X	X						1973
		Sedimentation/ Erosion Control P.	S	S/R	S	X	X	X	X	X				1974
	NC Division of Marine Fisheries	Coastal Habitat Protection Program	F,N,S,T	S	S				X					1999

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Program type	Organization	Program/Policy/Act	Affected impact[1]	Authority[2]	Geographic jurisdiction[3]	Issue Permits / Rules	Enforcement	Review Permits	Planning	Technical Assistance	Monitor	Research	Education	Start Year
State government	NC Division of Marine Fisheries	Fisheries Management Section	F,N,S,T	S,R	C			X	X	X	X	X		1822
		Permit Review Program	F,N,S,T	S	S			X						1984
	NC Division of Parks and Recreation	Natural Heritage Program	N	S,E,C	S				X	X	X		X	1979
	NC Division of Soil and Water Conservation	319 Coordinating Program	N,T,S,F	V,C	S					X				1997
		Agriculture Cost-share Program	N,T,S,F	V,C	S					X			X	1980s?
		Neuse R. Rules Coordinating P.	N,T,S,F	V,C	C				X	X			X	1996
		Operational Reviews Program	N,T,S,F	R	S			X	X	X	X		X	
		Pamlico R. Rules Coordinating P.	N,T,S,F	V,C	C				X	X			X	1996
		Soil survey Program	S	S	S				X	X	X		X	1938
	NC Division of Waste Management	Hazardous Waste Program	T	SF/R	S	X	X			X				1980
		Solid Waste Management Program	T	S/R	S	X	X			X	X			1989
		Superfund Program	T	SF	S			X		X				1980

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Program type	Organization	Program/Policy/Act	Affected impact[1]	Authority[2]	Geographic jurisdiction[3]	Issue Permits / Rules	Enforcement	Review Permits	Planning	Technical Assistance	Monitor	Research	Education	Start Year
State government	NC Division of Waste Management	Underground Storage Tank Prog.	T	S/R	S	X	X			X				1983
	NC Division of Water Quality	303(d) TMDL Program	F,N,S,T	R*	S	X			X	X	X			1997
		404/401 Wetlands Program	F,N,S,T	R*	S	X	X	X		X				1973
		Albemarle-Pamlico Program	F,N,S,T	S,R*	C				X	X				1987
		Basinwide Mgmt. Plans Program	F,N,S,T	S*	S				X	X			X	1993
		Construction Grants & Loan P.	F,N	S*	S				X	X				
		NC 319 Program	F,N,S,T	S*	S				X	X				1990
		Neuse R. Rapid Response Prog.	F,N,S,T	S,E	C						X		X	?
		Non-discharge Program - Sewage	F,N	R	S	X	X	X	X	X				rev. 1997
		NPDES Program – Stormwater	F,N,S,T	S,R*	S	X	X	X	X	X			X	?
		NPDES Program – Wastewater	F,N	S,R*	S	X	X	X	X	X			X	1973

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Program type	Organization	Program/Policy/Act	Affected impact[1]	Authority[2]	Geographic jurisdiction[3]	Issue Permits / Rules	Enforcement	Review Permits	Planning	Technical Assistance	Monitor	Research	Education	Start Year
State government	NC Division of Water Quality	Nutrient Sensitive Waters Program	F,N	S,R	C	X			X		X			1979
		Pamlico R. Rapid Response Prog.	F,N,S,T	S,E	C						X		X	1996
		State Stormwater Mgmt. Program	F,N,S,T	R	S	X	X	X	X	X			X	rev. 1997
		Unified Watershed Asses. Program	F,N,S,T	R*	S	X			X	X	X			1998
		Use Restoration Waters Program	F,N,S,T	S*	S	X			X	X				1998
		Water Quality Monitoring Program	F,N,S,T	S	S					X	X			1973
		Wetlands Restoration Program	F,N,S,T	S	S				X	X	X		X	1996
		WQ Std. / Classification Program	F,N,S,T	R*	S	X			X		X			1976
	NC Division of Water Resources	Aquatic Weed Control Program	T	S	S					X				1982
		Interbasin transfer certificate	Q	R	S	X		X		X				1993
		NC Rivers Assessment	F,N,S,T	S	S				X		X		X	1997

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Program type	Organization	Program/Policy/Act	Affected impact[1]	Authority[2]	Geographic jurisdiction[3]	Issue Permits / Rules	Enforcement	Review Permits	Planning	Technical Assistance	Monitor	Research	Education	Start Year
State government	NC Division of Water Resources	Project Stream Watch	F,N,S,T	S	S						X		X	1978
		Project WET	F,N,S,T	S	S								X	1993
		Streamflow modification notification	Q	S	S	X		X		X				1977
		Water Res. Dev. Grant Program	S,T	S	S					X				1979
		Water Supply Planning Program	Q	S	S				X	X	X		X	1992
		Water Use Permit	Q	R	S	X								1967
		Water withdrawal / transfer	Q	R	S	X		X		X				1991
	NC Wildlife Resources Commission	Habitat Conservation Program	N,T,S,F	S*	S			X	X	X			X	1989

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Appendix K: Status and trends in flow regulation

The status and trends in regulation of flow for North Carolina's coastal rivers are summarized below (adapted from DMF 2002a).

Chowan River Basin

Dams

- One hydropower dam on the Meherrin River in Emporia, Virginia, has effectively blocked anadromous fish movement for over 90 years. In 1990, a fish elevator or lift was constructed at the Emporia Dam to facilitate migration of American shad and river herring upstream. The lift's effectiveness is unknown due to small sample size of tagged individuals recaptured. For information, please see the following web sites: <http://www.sdafs.org/meetings/98sdafs/clupeids/simmonds.htm> <http://www.dgif.state.va.us/fishing/lakes/emporia_reservoir/index.html> <http://www.sdafs.org/meetings/98sdafs/clupeids/simmonds.htm>.
- The lowermost dam on the Nottoway River is the Baskerville Mill Dam, which restricts the historical migratory range of striped bass in that river.

Surface water withdrawal

- There is one municipal intake for Norfolk, Virginia, from Blackwater River; the remainder are only for agriculture. Because small agricultural withdrawals do not need a permit, they are not accounted for in the total water withdrawals.

Roanoke River Basin

Dams

- There are several large dams upstream of Roanoke Rapids, including the Lake Gaston Dam, John H. Kerr Dam, Hyco Dam, Mayo Dam, Smith Mountain Lake Dam, Leesville Dam, Philpott Lake Dam, Avalon Dam and Pinnacles Dam (DWQ 2001c; Pearsall et al. [no date]; <www.rrba.org/facts.htm>). Completed in 1952 and operated by the U.S. Army Corps of Engineers (COE), the Kerr Dam created the largest reservoir in the system, covering approximately 48,900 ac (19,789 hectares) (<http://epec.saw.usace.army.mil/kerrdesc.txt>). The Roanoke Rapids Dam is the lowermost dam on the main stem of the river, and there are no power plants downstream of its location. Numerous small municipal water supply dams and old mill dams exist on the river's tributary streams.

The Roanoke River Water Flow Committee

- The Committee, including state and federal government representatives, academics, local officials and residents, and corporate interests, was established in 1988 to address flow issues. A new flow regime was developed and implemented during striped bass spawning periods, which, along with state fishery management efforts, has resulted in greatly improved juvenile striped bass recruitment (Manooch and Rulifson 1989). However, outside of the striped bass spawning period (April 1–June 15), flows remain altered by hydropower peaking operations. New FERC license for Gaston and Roanoke Rapids dams will expand the spawning period into March.

Surface water withdrawal

- There are 26 registered water withdrawals in the North Carolina portion of the basin. Of these, 16 are surface water withdrawals (DWQ 2001c).
- Water supply demand is expected to increase greatly within the basin, and other basins are also considering the river as a potential water supply source. Withdrawal for power plant use accounts for the majority of the water volume removed, although most is eventually returned to the system.

Tar-Pamlico River Basin

Dams

- Tar River Dam/ Reservoir controls downstream releases; the reservoir is water supply for the city of Rocky Mount.
- Rocky Mount Mills Dam, a hydropower facility, is the lowermost dam on the Tar River. It is an obstruction to migrating striped bass, American shad, hickory shad, and blueback herring during the spring spawning season (Collier and Odom 1989) (Map 2.11).

Surface water withdrawal

- There are several municipal surface water withdrawals (including Enfield, Greenville, Louisburg, Rocky Mount, Tarboro) and numerous agricultural withdrawals.
- Of the 60 water withdrawals registered in the basin (39 agricultural, 21 non-agricultural), 51 are surface water withdrawals (DWQ 2003).
- Surface water withdrawals are projected to increase because of demand and because the basin is partially located within the Central Coastal Plain Capacity Use Area (CCPCUA). Ground water use within the CCPCUA, so demand for surface water as a replacement source will grow.

Neuse River Basin

Dams

- Removal of Quaker Neck Dam in 1998 opened access to 74 additional miles of upstream river habitat for migrating anadromous fish each spring.
- Milburnie Dam, a small hydropower facility near Raleigh, is now the lowermost dam on the Neuse River (Map 2.11).
- Falls Dam/Reservoir is managed by the COE for flood control, municipal water supply, water quality enhancement downstream, and recreation. Currently, discussions are underway between WRC and COE to stabilize downstream flows to benefit spawning by anadromous species in the Neuse River.

Surface water withdrawal

- There are numerous agricultural and municipal water supply withdrawals from the main stem of the river, as well as from many of its tributaries, including the cities of Durham, Raleigh, Smithfield (in addition to a separate intake for Johnston County), Goldsboro, and Wilson.
- Surface water withdrawals are projected to increase due to demand. The CCPCA rules will also affect portions of this river basin, including Carteret, Craven, Jones, Lenoir,

Pamlico, Pitt, Wayne, and Wilson counties. As of 2003, an application was in process for withdrawal of 60 million gallons per day from the Neuse River in Lenoir County to replace existing ground water supplies.

- Of the 176 registered water withdrawals in the Neuse River basin, excluding 78 public water systems, 51 are surface water withdrawals (DWQ 2002).

Cape Fear River Basin

Dams

- The three COE Lock and Dams, constructed for navigation between 1915 and 1934 (Moser et al. 2000), are the lowermost obstructions to fish passage. However, in 1997, efforts to improve anadromous fish passage were made at Lock #1, including the use of fish-locking cycles or lockage to facilitate fish migration during the spawning period and the construction of a steppass Denil fishway (Moser et al. 2000). Sonic tracking of American shad revealed varying proportions (ranging from 18% in 1997 to 63% in 1998) of successful upstream passage of tagged individuals during Lock # 1 operation (Moser et al. 2000). By way of comparison, passage efficiency of adult shad was relatively lower at the fishway (Moser et al. 2000). In general, efficiency of fish passage was improved by a) increasing the frequency of lockage events per day, b) extending lockage duration to include more of the spawning season, and c) encouraging fish entrance into the lock via attractant flows (Moser et al. 2000). Buckhorn Dam is the lowermost complete barrier to fish migration. Striped bass tagged by DMF in the lower Cape Fear River near Wilmington have been recaptured just below this obstruction. Although the hydropower facility at the Buckhorn Dam no longer operates, the dam continues to provide a pool for cooling water for a nearby coal-fired power plant.
- B. Everett Jordan Dam/Reservoir is located well upstream of the lock and dam system. It provides water for Holly Springs, Apex, Cary, Durham, Morrisville, and Chatham, Orange, and Wake counties. (<www.ncwater.org/ReportsandPublications>).

Surface water withdrawal

- There are numerous municipal water withdrawals, and they are the largest threat to instream flow in the Cape Fear river basin.
- In 1999, there were 57 registered water withdrawals in the basin (DWQ 2000c).
- Surface water withdrawals are projected to increase 39% by 2010, excluding new permitted withdrawals. Municipalities dependent on water withdrawals include Cary, Apex, Orange County, Wake County – Research Triangle Park, Fayetteville, Fort Bragg, Wilmington, and the lower Cape Fear Water and Sewer Authority.

Appendix L: Effects of environmental pollutants on fish early life stages
[modified from Weis and Weis (1989), Key et al. (2000); "exp" = "exposure"]

Chemicals	Effect on fish			Water quality standards (ug/l) for aquatic life	
	Test organism	Test	Results	Salt-water	Fresh-water
Benzo[a] Pyrene (B[a]P)					
Methylmercury	Mummichog	unspecified exp.	Abnormal cell division of embryos		
Chlorine					
Chlorine, total residual	Striped bass	0.07 mg/l exp.	3.5% of embryos hatched and malformation of surviving hatchlings	na	17 (AL)
		0.01 mg/l exp.	23% of embryos hatched		
		0.15 mg/l exp.	Embryo mortality noted in combination with temperature change of 2^{o}C.		
	Spotted seatrout	unspecified exp.	Greater resistance of embryos than larvae		
	Striped bass, white perch, blueback herring, silversides	0.3 mg/l exp.	Lethal to embryos		
Herbicides					
Atrazine	Channel catfish	0.4 mg/l exp.	Embryo deformities		na
Diquat	Mummichog	0.01-10mg/l exp.	Fry neurologically impaired after embryo exposed		
Trifluraline	Sheepshead minnow	unspecified exp.	Embryo deformities		
PCBs					
Aroclor 1016	Sheepshead minnow	>32 ug/l exp.	Total mortality of embryos and fry		
Aroclor 1242	Fathead minnow	<5.4 ug/l exp.	No effect on embryos		
Aroclor 1254	Sheepshead minnow	10 ug/l exp.	Reduced survival rate of embryos		

Chemicals	Effect on fish			Water quality standards (ug/l) for aquatic life	
	Test organism	Test	Results	Salt-water	Fresh-water
Aroclor 1254	Sheepshead minnow	>0.1 ug/l exp.	Reduced fry survival		
		0.14 ug/l exp.	Adult exposure and reduced survival of embryos and fry		
Pesticides					
Aldicarb (Temik)	Fathead minnow	<320 ug/l exp.	No effect		
	Fathead minnow	156 ug/l exp.	100% larvae mortality in 30-day test		
Carbaryl (Sevin)	Silversides	10 ug/l exp.	Embryo malformations		
	Killifish	10 ug/l exp.	Arrested embryo development, embryos transferred to clear water after continuous exp. had abnormalities		
DDT	Killifish	1mg/l exp.	Hatchlings with tail deformities	0.001	0.001
		0.1 ug/l exp.	Slowed development of embryos		
	Silversides	25 ug/l exp.	Embryo malformations		
	Yellow perch	unspecified exp.	No fin ray asymmetry		
Dieldrin	Winter flounder	>1.74 ng/g eggs	Eggs not fertilized	0.0002	0.002
		39 ug/l exp.	50% mortality		
Endrin	Sheepshead minnow	0.31 ug/l	Embryo stunting, some mortality, and lower fertility of adults	0.002	0.002
Fenoprop (Kuron)	Bluegill	>10 ug/l exp.	100% mortality of hatchlings		
Fenvalerate	Sheepshead minnow	3.9 ug/l exp.	Reduced hatchling survival		
	Fathead minnow	0.43 ug/l exp.	Unspecified negative effect on larvae		
Fonofos	Fathead minnow	<80 ug/l exp.	No effect		
		33 ug/l exp.	100% larvae mortality in 30-day test		
Kelthane (Dicophol)	Fathead minnow	125 ug/l exp.	Delayed and reduced hatching, survivors deformed and died		
		39 ug/l exp.	50% mortality		

Chemicals	Effect on fish			Water quality standards (ug/l) for aquatic life	
	Test organism	Test	Results	Salt-water	Fresh-water
Kepone	Sheepshead minnow	1.9 ug/l exp.	16% arrested development of embryos		
	Fathead minnow	0.31ug/l exp.	Reducing hatching success		
Lindane	Caranx	unspecified exp.	Premature hatching and fry deformities	0.004	0.01
Malathion	Silversides	10 ug/l exp.	Embryo malformations		
Methoxychlor	Winter flounder	>1.74 ng/g eggs	Eggs not fertilized	0.03	0.03
		39 ug/l exp.	50% mortality		
Mirex	Fathead minnow	2,3,7 ug/l exp.	Increased viability of hatchlings	0.001	0.001
		13,34 ug/l exp.	No effect		
Parathion	Mummichog	10 ug/l exp.	Arrested embryonic development, 50% of embryos exposed for 3 days and returned to clean water had malformations	0.178	0.013
Permethrin	Sheepshead minnow	22 ug/l exp.	Reduced hatchling survival		
		2.2 ug/l exp.	Reduced hatchling size		
Permethrin biomist	Gambusia	25,114 mg/l	48 h LC_{50}		
Permethrin-Permanone	Gambusia	0.0027 mg/l	48 h LC_{50}		
Pyrethroids	Sheepshead minnow	0.06 ug/l exp.	Reduced fish weight		
Temephos	Gambusia	0.014-0.039 mg/l	48 h LC_{50}		
Petroleum hydrocarbon					
Toluene	Fathead minnow	30-45 mg/l exp.	Embryonic malformations	na	11
Water soluable fraction of No. 2 fuel oil	Mummichog	unspecified exp.	Malformation of larvae and decreased time to hatching of embryos, increased toxicity noted at suboptimal water conditions		

Chemicals	Effect on fish			Water quality standards (ug/l) for aquatic life	
	Test organism	Test	Results	Salt-water	Fresh-water
Water soluable fraction of No. 2 fuel oil	Mummichogs, sheepshead minnow	12 ppm	100% mortality of hatchlings		
		6 ppm	50% mortality of hatchlings		
		1,4 ppm	Stimulated hatching		
Wood preservative					
Pentachlorophenol	Fathead minnow	128 ug/l exp.	Reduced larval survival		
		>73 ug/l exp.	Reduced growth of larvae		

Appendix M: Land protection and conservation programs in the North Carolina coastal river basins by eligible land types and conservation techniques (DENR 1999). Eligible land types include agricultural (A), forested (F), wetlands (W), prior converted wetlands (PCW), riparian areas (R), and residential (RES).

Eligible Land Types	Federal and State Programs/Nonprofit/Private Organizations/Land Trusts	Donation	Purchase	Conservation Easement	Lease	Management Agreement	Restoration	Other
A, PCW, R	Conservation Reserve Program (USDA NRCS)				X	X	X	
A, PCW, R	Continuous Conservation Reserve Program (USDA NRCS)				X	X	X	
A, W	Debt Cancellation Conservation Contact Program (USDA FSA)					X		
A,F,PCW,R	Environmental Quality Incentives Program (USDA NRCS)					X		
A, F, W, PCW, R, RES	North American Wetlands Conservation Act (USFWS)	X	X	X		X	X	X
PCW, R	Wetlands Reserve Program (USDA NRCS)			X			X	
A, F, PCW, RES	Wildlife Habitat Incentives Program (USFWS)					X	X	
A, PCW, R	NC Agriculture Cost Chare Program (DENR DSWC)						X	
A, F, W, PCW, R, RES	NC Clean Water Management Trust Fund (DENR)		X	X		X	X	X
A, PCW	Conservation Reserve Enhancement Program (USDA FSA and DENR DSWC)			X	X	X	X	
A, F, W, PCW, R, RES	Conservation Tax Credit Program (DENR)	X	X	X				
A, F, W, PCW, R	NC Forest Development Program (DENR DFR)					X		
F, R	Forest Land Enhancement Program (DENR DFR)					X	X	X
F, R	Forest Legacy (USDS FS)		X	X		X		
A, F, W, PCW, R	Forest Management Technical Assistance (DENR DFR)					X		X
F, W, R	Forest Practice Guidelines/BMP's (DENR DFR)							X
F, W, R	Forest Stewardship Program (USFS, DENR DFR)					X		X
W, R	Public Trust / Submerged Lands Program (DENR DMF)	X						
F, W, R	Registry of Natural Heritage Areas (DENR DPR)			X		X		
R	Rivers Assessment (DENR DWR)							
A, F, W, PCW, R, RES	NC Wetlands Restoration Program (DENR DWQ)	X	X	X			X	
A, F, W, R	Conservation Trust for North Carolina	X	X	X	X	X		X
A, F, W, PCW, R, RES	NC Coastal Federation	X	X	X			X	
A, F, W, R, RES	NC Local and Regional Land Trusts (20)	X	X	X	X	X	X	X
F, W, R	NC Chapter of The Nature Conservancy	X	X	X				

APPENDIX N:

NORTH CAROLINA MARINE FISHERIES COMMISSION

POLICIES FOR THE PROTECTION AND RESTORATION
OF MARINE AND ESTUARINE RESOURCES
FROM BEACH DREDGING AND FILLING
AND LARGE-SCALE COASTAL ENGINEERING

NORTH CAROLINA MARINE FISHERIES COMMISSION HABITAT AND WATER QUALITY
STANDING ADVISORY COMMITTEE: NOVEMBER 6, 2000
NORTH CAROLINA MARINE FISHERIES COMMISSION:
NOVEMBER 16, 2000

Policy Context

This document establishes the policies of the North Carolina Marine Fisheries Commission (Commission) regarding protection and restoration of the state's marine and estuarine resources associated with beach dredge and fill activities, and related large-scale coastal engineering projects. The policies are designed to be consistent with the overall habitat protection policies of the Commission, adopted April 13, 1999, as amended February 17-18, 2000, as follows:

It shall be the policy of the North Carolina Marine Fisheries Commission that the overall goal of its marine and estuarine resource protection and restoration programs is the long-term enhancement of the extent, functioning and understanding of those resources.

Toward that end, in implementing the Commission's permit commenting authority pursuant to N.C.G.S. §143B-289.52(a)(9), the Chairs of the Habitat and Water Quality Standing Advisory Committee, in consultation with the Commission Chair, shall, to the fullest extent possible, ensure that state or federal permits for human activities that potentially threaten North Carolina marine and estuarine resources:

> (1) are conditioned on (a) the permittee's avoidance of adverse impacts to marine and estuarine resources to the maximum extent practicable; (b) the permittee's minimization of adverse impacts to those resources where avoidance is impracticable; and (c) the permittee's provision of compensatory mitigation for all reasonably foreseeable impacts to marine and estuarine resources in the form of both informational mitigation (the gathering of base-line resource data and/or prospective resource monitoring) and resource mitigation (in kind, local replacement, restoration or enhancement of impacted fish stocks or habitats); and

(2) result, at a minimum, in no net loss to coastal fisheries stocks, nor functional loss to marine and estuarine habitats and ecosystems.

The findings presented below assess the marine and estuarine resources of North Carolina which are potentially threatened by activities related to the large-scale movement of sand in the coastal ocean and adjacent habitats, and the processes whereby those resources are placed at risk. The policies established in this document are designed to avoid, minimize and offset damage caused by these activities, in accordance with the laws of the state and the general habitat policies of this Commission.

Marine and Estuarine Resources At Risk from Beach Dredge and Fill Activities

The Commission finds:

1. In general, the array of large-scale and long-term beach alteration projects currently being considered for North Carolina together constitute a real and significant threat to the marine and estuarine resources of the United States and North Carolina.

2. The cumulative effects of these projects have not been adequately assessed, including impacts on public trust marine and estuarine resources, use of public trust beaches, public access, state and federally protected species, state critical habitats and federal essential fish habitats.

3. Individual beach dredge-and-fill projects and related large-scale coastal engineering activities rarely provide adequate assessment or consideration of potential damage to fishery resources under state and federal management. Historically, emphasis has been placed on the logistics of sand procurement and movement, and economics, with environmental considerations dominated by compliance with limitations imparted by the Endangered Species Act for sea turtles, piping plovers and other listed organisms.

4. Opportunities to avoid and minimize impacts of beach dredge-and-fill activities on fishery resources, and offsets for unavoidable impacts have rarely been proposed or implemented.

5. Large-scale beach dredge and fill activities have the potential to cause impacts in four types of habitats:

    a. waters and benthic habitats near the dredging sites;
    b. waters between dredging and filling sites;
    c. waters and benthic habitats near the fill sites; and
    d. waters and benthic habitats potentially affected as sediments move subsequent to deposition in fill areas.

6. Certain nearshore habitats are particularly important to the long-term viability of North Carolina's commercial and recreational fisheries and potentially threatened by large-scale, long-term or frequent disturbance of sediments:

    a. inlets;
    b. the swash and surf zones and beach-associated bars; and
    c. underwater soft-sediment topographic features, both onshore and offshore
    d. underwater hard-substrate topographic features.

7. Large sections of North Carolina waters potentially affected by these projects, both individually and collectively, have been identified as Essential Fish Habitats (EFH) by the South Atlantic Fishery Management Council (SAFMC) and the Mid-Atlantic Fishery Management Council (MAFMC). Affected species under federal management include:

    a. summer flounder (various nearshore waters, including the surf zone and inlets; certain offshore waters);
    b. bluefish (various nearshore waters, including the surf zone and inlets);
    c. red drum (ocean high-salinity surf zones and unconsolidated bottoms to a depth of 50 meters);

d. several snapper and grouper species (live hard bottom from shore to 600 feet, and – for estuarine-dependent species [e.g., gag grouper and gray snapper] – unconsolidated bottoms and live hard bottoms to the 100 foot contour);
e. spiny dogfish (various coastal waters from the surf zone to 200 miles);
f. black sea bass (various nearshore waters, including unconsolidated bottom and live hard bottom to 100 feet, and hard bottoms to 600 feet);
g. penaeid shrimps (offshore habitats used for spawning and growth to maturity, and waters connecting to inshore nursery areas, including the surf zone and inlets);
h. coastal migratory pelagics (sandy shoals of capes and bars, barrier island and ocean-side waters from the surf zone to the shelf break inshore of the Gulf Stream; all coastal inlets);
i. corals of various types (hard substrates and muddy, silty bottoms from the subtidal to the shelf break);
j. calico scallops (unconsolidated bottoms northeast and southwest of Cape Lookout in 62-102 feet);
k. sargassum (wherever it occurs out to 200 miles);
l. many large and small coastal sharks, managed by the Secretary of the Department of Commerce (inlets and nearshore waters, including pupping and nursery grounds).

8. Beach dredge and fill projects also potentially threaten important fish habitats for anadromous species under federal, interstate and state management (in particular, inlets and offshore overwintering grounds), as well as essential overwintering grounds and other critical habitats for weakfish and other species managed by the Atlantic States Marine Fisheries Commission and the State of North Carolina. The SAFMC identified for anadromous and catadromous species those habitats that have been EFH if there had been a council plan (inlets and nearshore waters).

9. Many of the habitats potentially affected by these projects have been identified as Habitat Areas of Particular Concern by the SAFMC. The specific fishery management plan is provided in parentheses:

    a. all nearshore hard bottom areas (SAFMC, snapper-grouper);
    b. all coastal inlets (SAFMC, penaeid shrimps, red drum, and snapper-grouper);
    c. near-shore spawning sites (SAFMC, penaeid shrimps, and red drum)
    d. well-known seafloor features, including the Point, Ten Fathom Ledge and Big Rock (SAFMC, snapper-grouper, coastal migratory pelagics, and corals);
    e. pelagic and benthic sargassum (SAFMC, snapper-grouper);
    f. sandy shoals of Cape Lookout, Cape Fear, and Cape Hatteras (SAFMC, coastal migratory pelagics) and;
    g. Bogue Sound and New River Estuary (SAFMC, coastal migratory pelagics).

10. Habitats likely to be affected by beach dredge and fill projects include many being recognized in North Carolina Fishery Management Plans as important for state-managed species. Many of these habitats are in the process of being recognized as Critical Habitat Areas by the Commission, in either FMPs or in Coastal Habitat Protection Plans. Examples include:

    a. inlets (Blue Crab FMP, Red Drum FMP, River Herring FMP);
    b. oceanic nearshore waters (Blue Crab FMP, Red Drum FMP); and
    c. many others as FMPs and CHPPs are adopted over the coming years.

11. Recent work by scientists in east Florida has documented exceptionally important habitat

values for nearshore, hard-bottom habitats often buried by beach dredging projects, including use by over 500 species of fishes and invertebrates, and juveniles of many reef fishes. Equivalent scientific work is just beginning off North Carolina, but life histories suggest that similar habitat use patterns will be found.

Threats to Marine and Estuarine Resources from Beach Dredge and Fill Activities

The Commission finds that beach dredge-and-fill activities and related large-scale coastal engineering projects (including inlet alteration projects) threaten the marine and estuarine resources of North Carolina through the following mechanisms:

1. Direct mortality and displacement of organisms at and near sediment dredging sites;
2. Alteration of seafloor topography and associated current and waves patterns and magnitudes at dredging areas;
3. Alteration of seafloor sediment size-frequency distributions at dredging sites, with secondary effects on benthos at those sites;
4. Elevated turbidity and deposition of fine sediments down-current from dredging sites;
5. Direct mortality and displacement of organisms at initial sediment fill sites;
6. Elevated turbidity in and near initial fill sites, especially in the surf zone, and deposition of fine sediment down-current from initial fill sites;
7. Alteration of near-shore topography and current and waves patterns and magnitudes associated with fill;
8. Movement of deposited sediment away from initial fill sites, especially onto hard bottoms;
9. Alteration of large-scale sediment budgets, sediment movement patterns and feeding and other ecological relationships, including the potential for cascading disturbance effects;
10. Alteration of large-scale movement patterns of water, with secondary effects on water quality and biota;
11. Alteration of movement patterns and successful inlet passage for larvae, post-larvae, juveniles and adults of marine and estuarine organisms;
12. Alteration of long-term shoreline migration patterns (inducing further ecological cascades with consequences that are difficult to predict); and
13. Exacerbation of transport and/or biological uptake of toxicants and other pollutants released at either dredge or fill sites.

Commission Policies for Beach Dredge and Fill Projects and Related Large Coastal Engineering Projects

The Commission establishes the following general policies related to large-scale beach dredge-and-fill and related projects, to clarify and augment the general policies already adopted on April 13, 1999:

1. Projects should fulfill the Commission's general habitat policy by avoiding, minimizing and offsetting damage to the marine and estuarine resources of North Carolina;

2. Projects should provide detailed analyses of possible impacts to each type of Essential Fish Habitat (EFH), with careful and detailed analyses of possible impacts to Habitat Areas of Particular Concern (HAPC) and Critical Habitat Areas (CHA), including short and long term, and population and ecosystem scale effects;

3. Projects should provide a full range of alternatives, along with assessments of the relative impacts of each on each type of EFH, HAPC and CHA;

4. Projects should avoid impacts on EFH, HAPCs and CHAs that are shown to be avoidable through the alternatives analysis, and minimize impacts that are not;

5. Projects should include assessments of potential unavoidable damage to marine resources, using conservative assumptions;

6. Projects should be conditioned on the avoidance of avoidable impacts, and should include compensatory mitigation for all reasonably predictable impacts to the marine and estuarine resources of North Carolina, taking into account uncertainty about these effects. Mitigation should be local, up-front and in-kind wherever possible;

7. Projects should include baseline and project-related monitoring adequate to document pre-project conditions and impacts of the projects on the marine and estuarine resources of North Carolina;

8. All assessments should be based upon the best available science, and be appropriately conservative so as to be prudent and precautionary; and

9. All assessments should take into account the cumulative impacts associated with other beach dredge-and-fill projects in North Carolina and adjacent states, and other large-scale coastal engineering projects that are ecologically related.

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Appendix O: Impacts to fish habitat from commercial and recreational fishing gears used in coastal North Carolina (adapted from Moratorium Steering Committee (1996)).

Fishing method	Habitat Impacts and Recommendations
Bay Scallop Dredge: A fairly lightweight (not>50 lbs.) steel frame, without teeth, used in estuarine waters, and that has an attached, nylon webbing bag to accumulate the catch.	The use of patent tongs is thought to have a major effect on shellfish beds and the bottom generally. Recommend collection of information on this gear, e.g., the habitat impact experiences of other states which have or are presently allowing use of patent tongs.
Beach Seine: Net generally used to corral mullets. A beach seine can also be used on such fish as striped bass and spot. Sometimes a beach seine is used in conjunction with a "stop" net. Net usually spread round fish with a boat and then pulled to the shore. Pulling power can be by hand or by vehicle. This is one of the most historic methods of fishing.	No known habitat impacts. No recommendations at this time.
Bull Rake: A large, heavy clam rake, usually having eighteen (18) to twenty-eight (28) teeth. Handles range from ten (10) feet to forty (40) feet long.	Bull rakes have severe habitat impacts when used on oyster rocks, and can damage SAV beds. Recommend that bull rake clamming on marked oyster grounds and SAV beds be prohibited.
Butterfly Trawl: In this gear, a solid frame holds a modified trawl in the top of the water column, acting like a channel net. Its use generally requires a good tidal flow and it is normally used only at night.	Little known habitat impact. Skimmer trawls are generally okay to use in SAV beds, but should not be used in oyster grounds. Recommend that trawls be prohibited in marked oyster grounds and that the more widespread use of this gear be promoted in estuarine waters.
Cast Net: Small net thrown by hand and used to catch "schooled fish", such as mullet, and used by bait-fish dealers and individual fishermen to net bait-fish and shrimp.	No known habitat impacts. No recommendations at this time.
Channel Net: A passive gear built like a shrimp trawl that is anchored in a specific area. Channel nets are used to catch shrimp in areas with strong tidal flow, which is required to hold the net open.	No known habitat impacts. No recommendations at this time.
Clam Kickers: Generally refers to the use of the propeller of a boat to blow the mud/silt off the clams and into a trawl having a heavy steel cage or bag made of rings. The gear is chained so that it plows up the clams as it is towed behind the vessel. Often the stern of the vessel is loaded so that the propeller "wash" is directed at a downward angle.	The use of this gear has severe impacts upon SAV beds and oyster grounds. Recommend that areas that may be used by these dredges not be expanded in public trust areas. However, employment in mariculture operations to recover shellfish crops should be considered a viable use of the gear if leases are located in an area where the gear is already allowed, if adjacent leases would not be affected. Permits should be issued by the division of Marine Fisheries on a case-by-case basis. During the oyster season, legal size oysters caught incidental to clamming should be allowed to be retained.
Clam Tongs: Hand held steel "forceps", used to recover clams from any and all types of bottom. Clam tong teeth tend to be longer and more closely spaced than the teeth on oyster tongs.	Habitat impacts of oyster dredges can be significant. Historically, such dredges have been used only on bottoms that were oyster beds. Dredges can plow down any mounds of shellfish and should not be allowed for use in SAV beds. Recommend maintaining present limits on usage and that steps be taken to ensure that the gear is used with adequate consideration of its habitat impacts.
Crab Dredges: A crab dredge is much like an oyster dredge, except perhaps with longer teeth, and is used to dredge crabs from the bottom sediments during the winter months. Crab dredges are used in northern North Carolina waters from Long Shoal north.	Habitat impacts from the use of crab dredges can be significant, and the gear causes severe damage on oyster grounds or in SAV beds. Recommend that the current restrictions on the use of this gear be maintained, and that steps be taken to ensure that crab dredges are used with adequate regard to their effects on coastal fishery habitats.

Fishing method	Habitat Impacts and Recommendations
Crab Pot: A wire trap similar to a fish pot. This is the usual method for catching crabs in North Carolina.	Very little habitat impact. Main habitat impact is from discarded bait cartons. It is generally okay to use crab pots in SAV beds, PNAs , or oyster grounds. Anecdotal reports indicate the use of anti-fouling solution or "cleansing" solutions aboard boats or near the waters edge to treat crab pots. Also anecdotal evidence exists to indicate that zinc used in crab pots to minimize rusting may contribute to heavy metal pollution in estuarine systems. Recommend: (1) a requirement that bait boxes be returned to shore; (2) a requirement that biodegradable escape panels be used in crab pots [Note: There is work being done that indicates that "tagged" crabs left in a crab pot with no food subsequently appear in other baited pots]; (3) prohibition of the use of any anti-fouling solution aboard a vessel or within seventy-five (75) feet of the shoreline; and (4) a study of the effects of zinc used to coat crab pots in terms of estuarine pollution.
Crab Trawl: A trawl consisting of larger mesh nets made like a shrimp trawl. The basic equipment is the same as a shrimp trawl except that the bottom leading edge of the trawl is laced with several loops of heavy chain so that the crabs are "plowed" out of the bottom where they have embedded themselves.	For all bottoms, the severity of habitat impacts from the use of shrimp trawls is related to the size of the doors. Damage to oyster grounds is generally moderate to high. Studies are inconclusive on the question of whether trawling in other areas has significant habitat impacts. Recommend continuation of prohibition of trawling in marked oyster grounds. A study of the impact of trawling on different types of habitat should also be conducted.
Dip Nets/Pier Net: Hand nets that are not usually used to catch fish by themselves, but rather, are used as tools in conjunction with other fishing gears. For example, a flounder fisherman may use a dip net to scoop up a flounder that is in his net but appears ready to fall out, or a fisherman may use a pier net to bring up catches of mullet too large to lift without danger of splitting his cast net, or to lift other species to keep from breaking the line of his fishing rod. However, large dip nets are used to catch river herring and shad in coastal streams.	No known habitat impacts. No recommendations at this time.
Eel Pot: A wire trap that looks like a crab pot, but has smaller wire mesh.	No known habitat impacts. If escape panels are used, the lost pots become habitat. Okay to use in SAV beds or oyster grounds. Recommend that biodegradable escape panels be required for eel pots.
Electric Shocking: Refers to the use of mechanical devices that generate an electric current into coastal fishing waters, which stun the fish and cause them to rise to the surface. The practice of electric shocking is currently allowed only in a portion of the Cape Fear River, where it is used to catch catfish.	Habitat effects on this practice are unknown, but would seem to potentially be significant. Recommend that this practice continue to be prohibited in North Carolina.
Estuarine Gill Net: A major gear used in North Carolina's internal coastal waters that captures fish by entangling them when they swim into the net. The next is often anchored to the bottom or attached to stakes. In some fisheries, gill nets are fished by drifting with the current. A variety of mesh sizes are used to take spot, flounder, American shad, river herring, mullet, striped bass and many other species. This gear is often used by recreational fishermen.	Estuarine gill nets have negligible habitat impacts. Such gear can be safely used in PNAs, SNAs and SAV beds. Proper identification of gear owners should be emphasized, along with regular tending of the fear to avoid wastage of fish. No recommendations at this time.
Explosives: Pyrotechnic devices, such as dynamite, used to create a concussion, which causes the stunned or dead fish to rise to the surface where they are gathered. The use of explosives to fish is not legal in North Carolina	No known habitat impacts. No recommendations at this time.
Fish Pot: A wire trap having directed (one-way) openings whereby fish may enter to get to bait. Fish pots are generally used in the ocean harvesting of black sea bass. Fish pots are also used to harvest catfish in the Albemarle Sound area.	Very little habitat impact. Impact can increase in coral formations. "Lost" pots become habitat when used correctly with biodegradable panels. Pots in estuarine waters do not adversely affect oyster grounds or SAV beds. Recommend that biodegradable escape panels be required for all fish pots.
Fish Trawls/Flynets: Usually large trawl nets, generally fished in ocean waters. Fish trawls may drag on the bottom, but also may utilize "mid-water technology." Fish trawling is not allowed in inside waters in North Carolina.	No known habitat impacts, but complaints have been received of float nets being used in a manner that blocks navigation channels, and of failure to yield to boat traffic. Recommend that float netters be required to yield to boat traffic.
Float Netting: This is done when a shrimp trawler "floats" its doors so that it can act as a butterfly or channel net, usually occurring in ebb tidal flow and at night.	No known habitat impacts, but there have been complaints that these netters have failed to yield to boat traffic when working the Atlantic Intracoastal Waterway and marked channels. Recommend that the use of butterfly trawls be promoted, with a requirement that netters must yield to all boat traffic when utilizing navigation channels

Fishing method	Habitat Impacts and Recommendations
Fyke Net: A usually round net having a series of throats. Tyke nets are primarily used in the upper reaches of estuaries.	No known habitat impacts. No recommendations at this time.
Gig: A spear with or without barbed points at its tip, used mostly to spear flounder at night, using underwater lights.	No known habitat impacts. No recommendations at this time.
Hand Clam Rake: A tool that usually has nine (9) teeth or less, and looks a lot like a garden rake. Most rakes have a handle, but they can consist merely of "metal fingers" that rest at the wrist and extend over the fingers. Clam rakes can be utilized to "scratch" for clams under water or for "signing" on tidal flats at low tide.	Very little habitat impact in most areas, but slight impacts occur in SAV beds. Clam rakes are difficult to use on most oyster rocks, but impact can be great when used to pull oysters into piles in order to get at the clams beneath. Recommend that: (1) no rakes be allowed in marked oyster rocks/beds {these oyster areas would be designated "clam seed management areas"}; and (2) during the normal oyster season, clams should be allowed as an unlimited, approved, incidental catch when harvesting oyster.
Hand Clamming: Refers to the clamming method wherein clammers are in the water on their hands and knees feeling for clams. Clammers typically use latex gloves as protection for their hands, but can use the "metal hands" noted under "Clam Rake", above.	Very little known habitat impact. Hand clamming in generally okay in SAV beds. Recommend that hand clamming on marked oyster grounds be prohibited except as part of the normal oyster season.
Hand Seine: Small mesh net used to catch bait. Usually pulled by hand, but sometimes a boat is used to spread the seine.	No known habitat impacts. Recommend increasing allowable hand seine sizes to thirty (30) feet.
Hook and Line: The customary “rod and reel” method of fishing, used as the “up and down” bottom rig in the reef fish fishery. “Electro-mate” reels are customarily used for rapid line retrieval.	Virtually no habitat impacts, but see comments at right on monofilament fishing line and other relevant equipment. No recommendations at present.
Hydraulic Clam Dredge: Gear generally used to harvest clams, that employs a conveyer system that can be lowered to the bottom where jets of water uncover the clams. These dredges are allowed only in "mechanical clamming" areas. The gear is also used by mariculturists to harvest shellfish crops from their public bottom leases.	The use of purse seines has no habitat impacts as the net is fished entirely within the water column. No recommendations at this time.
Long haul seine: Usually a long seine, heavily leaded (weighted) and dragged by boats in estuarine waters to catch fish.	Some damage to SAV beds may occur from the heavily leaded bottom line being dragged through the grass beds. Damage to SAV beds by the boat motor propellers may be significant in shallow waters. There is concern over the use of this gear in PNAs (where use is currently prohibited) and near oyster rocks. Recommend: (1) a study be implemented to determine the actual bottom damage and whether the damage is short-term or long-lasting; (2) all oyster grounds, PNAs, and SAV beds be permanently marked: and (3) a study be conducted into the effects of long haul seine activities in these areas.
Long-line System: Fishing lines used for top-water, underwater or bottom fishing.	Virtually no habitat impacts when used as a top-water gear. Impact of bottom gear can range from minor on sand bottoms to significant when used in live rock (coral) formations. Recommend that bottom gear should be prohibited in coral formations.
Ocean Drift Net: Usually a monofilament gill net constructed so as to be tended from the top down. Ocean drift nets generally utilize a larger mesh size than bottom fishing nets. There is very little, if any, use of this gear in the ocean off North Carolina.	No known habitat impacts. No recommendations at this time.
Ocean Sink Gill Net: These are offshore gill nets that may be heavily anchored or not, as is appropriate to the area and fishery.	Sink nets have very little habitat impact unless gear becomes entangled with live rock formations. Lost or discarded webbing can become a danger for continued fishing until webbing becomes encrusted. Recommend better, more positive identification of net owners.
Otter Trawl: A cone-shaped net fashioned in one of the many patterns of "Otter Trawls", used primarily in North Carolina to catch shrimp. The gear is pulled from behind or alongside a vessel using "doors" or "gates" to keep the trawl open. The doors are sized (18" x 36" to 40" x 120") and weighted (50 lb. to 500 lb.) in direct ratio to the size of the trawl. Trawls skim the bottom, and shrimp are made to "pop" up into the net by a "tickler" chain pulled just ahead of the bottom line. Trawl doors ride along the bottom.	
Oyster Dredge: Usually heavy, large-toothed cages towed by a vessel to recover oysters from deeper waters. Oyster dredges are currently allowed only in Pamlico Sound, with a one hundred-(100) pound weight limit.	These dredges have severe habitat impacts. Recommend that dredges continue to be prohibited in estuaries and on live bottom formations offshore [Note: This fishery is regulated under a federal FMP, and its impacts are not presently an issue in NC].

Fishing method	Habitat Impacts and Recommendations
Oyster Tongs: Hand held steel "forceps", typically used while standing in a boat to recover oysters from water ranging in depth from that barely deep enough to float a boat to then 910) to twelve (12) feet.	Some habitat impact in SAV beds. Impacts on oyster beds may be negated if clam and oyster seasons are combined at some future point. Recommend that clam tongs be prohibited on marked oyster rocks except during oyster harvest season.
Patent Tongs: Very large steel "forceps" typically used to recover oysters from deep water.	The use of clam kicking has severe habitat impact on all bottoms. The gear causes severe damage to SAV beds and to oyster rocks. Recommend that gear continue to be prohibited in SAV beds and over marked oyster grounds.
Pound Net: A passive gear using netting "leads", which the fish travel along to a net "pound", where they are captured. Captured fish can be culled alive. Mesh size in the pound can be fish size selective. This gear known also as "weirs", and is one of the oldest methods of fishing. Some states have specific laws protecting weirs.	No known habitat impacts. The poles used to support the pound net leads and pound are permanent structures that can themselves become habitat, but abandoned or broken-off poles can become a hazard to navigation. No recommendations at this time.
Purse Seine: Large net used to catch menhaden. A menhaden school is surrounded by the purse et and a large weight is then dropped to close, or "purse", the bottom of the net.	
Sea Scallop Dredge: An extremely heavy steel cage similar to an oyster dredge that drags the bottom and is used in the ocean. These dredges are intended for use only on beds of scallops at sea.	Very little habitat impact. It is generally okay to use these dredges in SAV beds over a short scallop season. No recommendations at this time.
Shrimp Pot: A wire trap used as a special type of underwater trap or pot to catch shrimp.	No known habitat impacts. Okay to use in SAV beds, PNAs, or oyster grounds. No recommendations at this time.
Skimmer Trawl: A trawl net that utilizes a solid frame and a flat offshore "foot" in order to push a trawl through the water without using doors. Use of this gear is limited to areas where the depth of the water is no more than the size of the metal frame. Its use is highly successful in the "white shrimp" fishery.	The use of crab trawls has severe impacts on all bottoms, causing great damage to oyster grounds and moderate to severe damage in SAV beds. Crab trawling results in substantial sedimentation in the trawled area. Recommend that crab trawls be prohibited in marked oyster grounds. Because of heavy chain at the mouth of these trawls, there was much concern over potential damage to SAV beds. For that reason, also recommend a study of the effects of crab trawling on SAV beds.
Spear: Similar to a gig, but usually single pronged, used by underwater divers using scuba gear.	No known habitat impacts. No recommendations at this time.
Stop Net: [See "Beach Seine", above] A term used for large mesh nets that are set out of "run" perpendicular to the beach. Stop nets are not intended to catch anything themselves, given that the mesh size in these nets is from six (6) to ten (10) inches. During the night, migrating mullet (or other fishes) gather against the stop net, which they perceive as an obstruction to travel. Other species may either swim through the stop net or go around it. A beach seine is used to gather the fish "encamped" at the stop net site. A recent DMF study showed that ninety-five percent (95%) of the fish "encamped" at the stop net are mullet.	Use of this gear can seriously damage live rock formations. Recommend the continued prohibition of use in inside (internal) coastal waters. Federal rules should address the use of flynets in the EEZ.
Trammel Net: A multi-walled net usually made with two outer walls of large mesh (6" to 12" stretch or more" made of heavy gauge monofilament, and an inner wall of small mesh monofilament. A fish "pockets" itself between the walls.	Only impact is from lost or discarded nets. Recommend that better, more positive identification of net owner be required.
Trolling Gear: Fishing lines attached to a reel or directly to a boat and "trolled" through the water. Used when fishing for king mackerel, tuna, etc.	No known habitat impacts. No recommendations at this time.
Trot Line: Lines used in estuarine waters to catch crabs and fish, consisting of a long multi- or monofilament line baited at intervals, with or without hooks, used much like an ocean long-line.	No known habitat impacts. No recommendations at this time.

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