North Carolina Department of Environment and Natural Resources

Beverly Eaves Perdue
Governor

Dee Freeman
Secretary

November 30, 2010

MEMORANDUM

TO: ENVIRONMENTAL REVIEW COMMISSION
The Honorable Pricey Harrison, Co-Chair
The Honorable Pryor Gibson, Co-Chair
The Honorable Bob Atwater, Co-Chair
The Honorable Dan Clodfelter, Co-Chair

FROM: Dee Freeman

SUBJECT: Draft 2010 Coastal Habitat Protection Plan (CHPP)

Pursuant to G.S. 143B-279.8, enclosed is the draft 2010 Coastal Habitat Protection Plan (CHPP) approved for your review. Please submit any comments or recommendations regarding the plan to Jimmy Johnson, CHPP Coordination (jimmy.johnson@ncdenr.gov or 252-948-3952) within 30 days from the date it is received by your office.

The overarching goal of the CHPP is long-term enhancement of coastal fisheries associated with each coastal habitat. The 2010 CHPP, the second iteration of the plan, updates information regarding the ecological functions, condition and threats to our coastal fish habitats. The department approves the updated recommendations of the 2010 CHPP and is committed to accomplishing these through continued development of implementation plans and interagency cooperation.

Enclosure

cc: Jimmy Johnson

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NORTH CAROLINA
COASTAL HABITAT PROTECTION PLAN

By

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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, 2011, the four Commissions and the Department of Environment and Natural Resources agree to continue preparing and adopting Coastal Habitat Protection Implementation Plans on a biannual cycle to accomplish the goals and recommendations of this plan. The Implementation Plans will establish priorities and identify actions to be taken within specified time periods, including measures of success. The Department and the four 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

____ __________
Chairman, Wildlife Resource Commission — Date

____ __________
Secretary, Department of Environment and Natural Resources — Date

ACKNOWLEDGEMENTS

In the process of obtaining updated information for the plan, and discussing priority issues and solutions related to CHPP implementation, a large number of people contributed information and reviewed drafts. This document would not have been possible without the assistance of these state and federal agency staff, university researchers, members of various NC regulatory commissions and advisory committees, nonprofit organizations and volunteers. Special thanks are given to Jimmy Johnson, CHPP coordinator, for providing support and advise, coordinating numerous CHPP Team and Steering Committee meetings, and keeping the plan on schedule. Also deserving special recognition are the CHPP Team, CHPP Steering Committee and reviewers who contributed their time and knowledge to this plan.

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EXECUTIVE SUMMARY

This document is intended as a resource and guide for implementation of the goals and recommendations included at the end of this summary and in Chapter 9 (Table 9.1).

North Carolina's coastal fisheries are among the most productive in the United States because of the diversity of habitats available in the largest estuarine system (2.3 million acres) of any single Atlantic coast state. The state's coastal fisheries also benefit from the location of North Carolina at the transition between mid-Atlantic and south Atlantic regions and a management system that supports active citizen participation. The current management system was developed following the decline of some important fish stocks 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 was considered 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.*** Unlike other planning efforts, the Fishery Reform Act mandated that three environmental regulatory commissions (Environmental Management, Coastal Resources, and Marine Fisheries Commissions) must adopt and implement the plan, thus requiring a coordinated management approach.

The purpose of the CHPP is to compile the latest scientific information on each habitat so that management needs can be identified to protect, enhance, and restore associated fish populations. The CHPP area includes all habitats within the coastal draining river basins in 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 plan is organized by six fish habitat categories - water column, shell bottom, submerged aquatic vegetation, wetlands, soft bottom, and hard bottom. Each habitat chapter includes information on the distribution, ecological function, status and trends, and threats to those habitats; and management needs to address the threats. The interdependence of these habitats and the need to manage them at an ecosystem level is discussed in the Ecosystem Management and Strategic Habitat Areas Chapter. CHPP goals and recommendations are included in the final chapter.

The first edition of the CHPP was adopted in December 2004, and published in January 2005. The recommendations provide the framework to guide CHPP implementation. Each participating division, commission and the Department agreed to develop bi-annual implementation plans. Implementation plans have been developed for the 2005-07, 2007-09, and 2009-2011 fiscal years. The Intercommission Review Committee (IRC), consisting of two members of each commission, was transformed into the CHPP Steering Committee (CSC) following CHPP adoption. The CSC's new charge was to meet quarterly and discuss progress in implementation, how to resolve complex habitat issues and exchange information on emerging issues. The CSC was also responsible for carrying back CHPP related information to their full commissions to enhance communication and coordination. The CSC asked the WRC to join their committee in 2009 as they saw increasing implementation actions that required coordination and cooperation with them. Other agencies participate in a non-obligatory manner, including the Division of Forestry, Ecosystem Enhancement Program (EEP), and Soil and Water Conservation Districts.

During the first five years of CHPP implementation, the CHPP was an active part of the decision making process for DENR, the divisions, and regulatory commissions. Numerous implementation actions were accomplished or begun. In the first year, most of the implementation work involved securing funding and positions to support implementation work. In the second year, many implementation actions were initiated and substantially advanced in the following year. Budget shortfalls somewhat constrained implementation success in 2008-2009. The CSC, in reviewing CHPP progress, concluded that the six most significant accomplishments and advancements of the CHPP were:

- Interagency coordination/cooperation – established a CHPP coordinator position, CHPP Steering Committee and interagency quarterly meetings
- Stormwater runoff management – adopted and implemented EMC Phase 2 and coastal stormwater rules
- Habitat mapping – initiated coastwide SAV mapping organized by APNEP workgroup, shellfish and shellfish closures mapping with new positions, SHA process to prioritize habitat areas, and shoreline mapping through grant funding
- Compliance monitoring – established new positions in multiple divisions, cross training marine patrol, increased permit fees and fines
- Beach nourishment management – drafted the Beach and Inlet Management Plan through grant funding, and adopted CRC sediment criteria rules
- Oyster reef restoration – established new positions and funding for sanctuary development and monitoring, construction of a shellfish hatchery, and creation of an oyster shell recycling program

The FRA required that the CHPP be reviewed and updated every five years. The updated CHPP follows the same organizational format as the initial plan, with additional focus on fisheries ecosystem management. The following information is a brief summary of the 2010 CHPP, highlighting new information, status, accomplishments, and priority research and management needs.

Habitat maps throughout the plan were updated to include newly mapped areas (foldout map). While much progress has been made on mapping, about 10% of shell bottom remains to be mapped, updated SAV maps are incomplete, more detailed mapping of nearshore hard bottom is needed, and wetland and bathymetry maps are in need of updating.

Since 2005, land-use patterns continued to change with population growth along the coast. During and just after completion of the first CHPP, there was a coastal boom in development. Rapidly accelerating property values made once small coastal mainland counties targets for large new developments. Marketed as the "Inner Banks", Pamlico, Chowan, Bertie, Washington, Brunswick, and Down East Carteret counties experienced rapid increase in population and subsequent decline in farmland, fish houses, and water access. While coastal North Carolina has historically supported a strong commercial fishing industry, the past five years showed a decline of about 10% in the number of licensed commercial fishermen (~ 8565 in 2008) and a 13% decline in fish dealers (~738 in 2008). Although commercial fishing has declined, recreational fishing has increased (~ 1.9 million anglers in 2007). The economic recession beginning in 2008 has greatly slowed new development. However, because population along the coast has been growing for decades, pollutants and habitat stressors from a diversity of sources remain a significant threat to coastal fish habitat.

The **water column** is the habitat in which all fish live, and the physico-chemical characteristics of specific waterbodies determine the fish assemblages that will utilize it. The DWQ use support assessments are used to assess status of water quality. The last available assessment (2004-2006) indicated little change in impairment. However, DWQ ambient monitoring coverage for estuaries remains low and only about 30% of freshwater streams are assessed where the majority of ambient stations are located. Fish kill events, which can be an indication of eutrophication, hypoxia, or toxic chemical issues, did not show an increasing trend over the past five years, though total mortality of fish was greater in recent years. Drought conditions from 2006-2008, reducing stormwater runoff, could have contributed to good water quality during the past few years. There was however an increase in reported wastewater treatment plant Notices of Violation and sewage spills, which contribute substantially to pollutant loading in coastal waters. Completion of several studies indicates that sea level rise is expected to increase in North Carolina at least 1 m per 100 yr. The effect of this rise, along with other weather changes associated with climate change will have a great influence on water quality, salinity, water depth, and temperature, all of which will alter fish distribution and abundance. Accomplishments of the CHPP which will benefit the water column include adoption of coastal stormwater rules by EMC, designation of Anadromous Fish Spawning Areas by MFC and WRC, additional DWQ , DCM, and Forestry compliance positions, advancements in swine farm wastewater management, and removal of two dams and USACE funding for dam modification to allow fish passage past Lock and Dam 1 on the Cape Fear River. Continued priority management needs include removing obstructions to anadromous fish passage, improving water monitoring coverage in gap areas identified by modeling, and developing tools (i.e., TMDLs) to address cumulative impacts. Emerging management needs include reducing pollutant loading from wastewater (including endocrine disrupting chemicals) through increased treatment and prevention of spills and violations, conducting research on rapid infiltration systems before further use, developing rules to enhance physical and water quality characteristics for designated Anadromous Fish Spawning Areas, and expanding the implementation of a drug take-back program to reduce endocrine disrupting chemicals in surface waters.

Shell bottom is both an important fish habitat and a historical fishery, requiring a careful balance in management. The ecological value of shell bottom has been recognized to be as or more significant than the fishery, due to the many species it supports and the ecosystem services it provides. Subtidal shell bottom habitat significantly declined in the 1900s due to previous oyster dredging practices and has not substantially recovered due to disease, sedimentation, declining water quality, and fishing gear impacts. Since the 2005 CHPP was completed, additional habitat was mapped by DMF (90% complete), but no comparisons were done to assess change. However oyster spatfall in northern areas improved slightly from 2003-2006 and spatfall in the southern areas continues to be stable. Fishery rules currently restrict all bottom disturbing gear from 36% of the shell bottom area year-round, Over 70% of shell bottom area have either trawling, dredging , mechanical shellfish harvest or a combination of these restrictions. Accomplishments of the 2005 CHPP regarding shell bottom include accelerated oyster shell recycling program, additional oyster sanctuary habitat designation/creation (from state appropriated funds and federal stimulus project), and several research studies on larvae dispersal and oyster restoration. Continued priorities include completing baseline mapping, refining programs for determining status and trends in shell bottom resources, and continuing scientifically based shell bottom restoration efforts. An emerging issue is the need for research on the effect and prevalence of endocrine disruptor chemicals on shellfish.

Submerged aquatic vegetation is another important fish habitat known to support a high diversity of invertebrates and fish, and provides valuable ecosystem services as a primary producer and water quality enhancer. New ecological information in the plan includes information on the light and optical water quality conditions needed and available for SAV growth in North Carolina. In addition, resource valuation studies indicate that the monetary value of the ecosystem services provided by SAV such as waste management, food production, and climate regulation are very high, making SAV habitat protection a priority. The major threats to SAV remain channel dredging and water quality degradation associated with excess nutrient and sediment accumulation. Since completion of the 2005 CHPP, coastwide imagery of SAV was obtained in 2007-2008 through a multi-agency effort. Preliminary delineation in Bogue and Core Sounds noted an increase in patchiness of SAV compared to historical maps. There were anecdotal reports of an increase in SAV abundance in low salinity areas and high salinity areas south of New River. The observed increase could be attributed to drought and lack of storms during that period. Although a quantified estimate of SAV abundance or change over time has not been completed in North Carolina, a metadata study found a global and national decline in SAV. Accomplishments of the 2005

CHPP that may benefit SAV include adoption of coastal stormwater rules by EMC, a modified SAV definition by MFC, and revised dock rules by CRC. Continued priority needs include completing delineation of SAV imagery, and modeling water quality parameters necessary to identify potential SAV habitat for restoration and establishment of appropriate water quality standards. Emerging issues include developing comprehensive monitoring programs to determine trends, initiating monitoring of SAV indicators, and assessing sea level rise effects.

Wetlands are the fish habitat occupying the transition between land and water. By storing and filtering land runoff, they enhance coastal water quality and play a vital role in providing refuge and food for juvenile fish. It is estimated that over 95% of the commercial finfish and shellfish fisheries are dependent on wetlands for some portion of their life cycle. Like SAV, valuation studies indicate wetlands provide beneficial ecosystem services through water filtration, carbon sequestration, and production of food fish. Precolonial estimates of wetlands in North Carolina are approximately 7.2 million acres, and current estimates are approximately 5.1 million acres. No new mapping information was available since the 2005 CHPP. However, there is data suggesting a loss of marsh islands from erosion. Between 2001 and 2008 approximately 1,700 acres of permitted wetland impacts were documented. Conversion for development and shoreline alterations are the major cause of wetland loss. Wetland losses and gains through mitigation are difficult to track, but it appears that mitigation and restoration are currently preventing net loss of wetlands. Improvements in wetland restoration address some important CHPP recommendations. Continued priority needs include updating wetland and shoreline maps, improving mapping and tracking system for wetland loss by wetland types, and modifying shoreline stabilization techniques to maintain shallow nursery habitat and enhance riparian buffers. Emerging needs include developing CRC and DENR policies regarding sea level rise adaptations and revising land use planning guidelines, as well as considering alternative types of restoration/mitigation.

Soft bottom habitat is a key foraging habitat for juvenile and adult fish and invertebrates, and aids in storing and cycling of sediment, nutrients, and toxins between the bottom and water column. Shallow unvegetated bottom is particularly productive and, by providing refuge from predators, is an important nursery area. Species dependent on soft bottom include clams, crabs, flounder, and rays, although almost all fish will forage on microalgae, infauna, or epifauna on the soft bottom. Soft bottom habitat is dynamic and resilient to change, although it can be degraded by toxins, hypoxia, or dredging. There is minimal monitoring of sediment quality (i.e., contamination, nutrient enrichment). Since the 2005 CHPP, there has been a large increase in requests for federally authorized and locally funded beach nourishment projects. Large scale projects have been conducted or are underway at Bogue Banks, and Brunswick County beaches, and are in late planning stages for portions of Dare County and most of Topsail Island. Accomplishments of the 2005 CHPP that may benefit soft bottom include implementation of CRC sediment criteria rules, modification to CRC dock rules to protect PNAs, DCM development of a Beach and Inlet Management Plan, and research on the effect of hypoxia on fish productivity. Emerging priority needs include updating existing bathymetric maps, preventing hardened structures on ocean shorelines, and implementing regional sand management strategies of the 2009 Ocean Policy Report.

Low to high relief **hard bottom** in nearshore ocean waters adds to the diversity of North Carolina's waters. The hard bottom areas serve as secondary nursery areas for estuarine dependent reef fish such as black sea bass and gag. Little new information is available for this habitat. SEAMAP-SA has conducted some mapping, but it is limited in information on fish use or habitat description or quality. The largest threat to hard bottom is large scale beach nourishment projects where hard bottom occurs immediately offshore of the nourished beach or near borrow areas. Continuing priority needs include establishing baseline data on the extent and quality of ocean hard bottom & fish use, monitoring water quality trends in bottom waters of the coastal ocean, and monitoring the effect of beach nourishment projects on nearshore hard bottom.

Ecosystem management is an approach to maintaining or restoring the composition, structure, function, and delivery of ecosystem services that focuses on multiple interdependent species and/or habitats rather than single species or habitats. The 2010 CHPP, while looking at each habitat individually also examines the interrelationship among habitats. Almost all threats mentioned in the CHPP affected more than one habitat and all habitats are affected by more than one threat. The largest threat to coastal fish habitats is the cumulative impact of multiple threats. Similarly, no single habitat is the most ecologically important. Multiple habitats are needed to maintain the functions of the entire system. Areas having high quality, structurally complex and diverse habitats are known to support ecosystem stability and resilience and should be high priorities for protection and conservation. To accomplish this, the CHPP recommended identification of Strategic Habitat Areas, which are habitat complexes of exceptional habitat quality or that are particularly at risk due to imminent threat, rarity, or vulnerability. MFC approved a process in 2006, the first assessment (Region 1 - Albemarle Sound area) was completed in 2008, and the second assessment for Region 2 (Pamlico Sound, Pamlico and Neuse rivers) began in April 2010.

The 2010 CHPP identifies numerous management needs, some accomplished, others with progress, without progress, or newly identified. The CHPP staff and CSC reviewed these management needs to determine if the existing goals and recommendations established in the 2005 CHPP adequately addressed all the specific management needs. The results suggested some necessary revision of the goals/recommendation language. New recommendations are in bold italic font below. The goals and recommendations listed below will serve as the new guiding framework for CHPP implementation over the next five years.

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

1. Continue to enhance enforcement of, and compliance with, Coastal Resources Commission (CRC), Environmental Management Commission (EMC), Marine Fisheries Commission (MFC), and ***Wildlife Resources Commission (WRC)*** rules and permit conditions.
2. Coordinate and enhance water quality, physical habitat, and fisheries resource monitoring (including data management) from headwaters to the nearshore ocean.
3. Enhance and expand educational outreach on the value of fish habitat, threats from land-use and human activities, ***climate change***, and reasons for management measures.
4. Coordinate rulemaking and data collection for enforcement among regulatory commissions and agencies.
5. ***Develop and enhance assessment and management tools for addressing cumulative impacts.***
6. ***Enhance control of invasive species with existing programs.***

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

1. Support Strategic Habitat Area assessments by:
    a. Coordinating, completing, and maintaining baseline habitat mapping (including seagrass, shell bottom, shoreline, and other bottom types) using the most appropriate technology.
    b. Selective monitoring of the status of those habitats, and
    c. Assessing fish-habitat linkages and effects of land use and human activities on those habitats
2. Identify, designate, and protect Strategic Habitat Areas.

GOAL 3. ENHANCE HABITAT AND PROTECT IT FROM PHYSICAL IMPACTS

1. Expand habitat restoration in accordance with ecosystem restoration plans, including:
    a. Creation of subtidal oyster reef no-take sanctuaries.

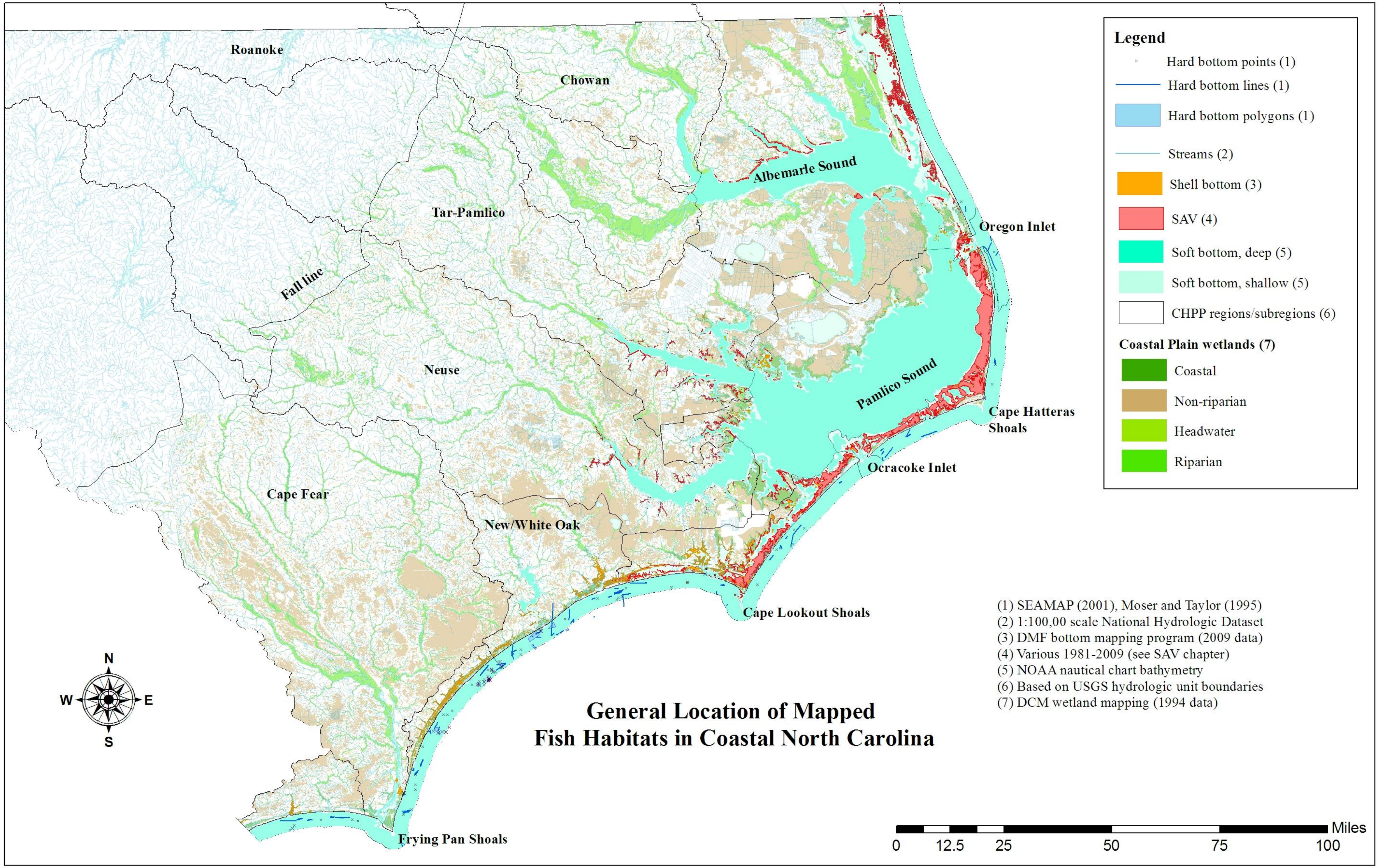
   b. Re-establishment of riparian wetlands and stream hydrology.
   c. Restoration of SAV habitat and shallow soft bottom nurseries.
   d. Developing compensatory mitigation process to restore lost fish habitat functions.
2. ***Sustain healthy barrier island systems by maintaining and enhancing ecologically sound policies for ocean and inlet shorelines*** and implement a comprehensive beach and inlet management plan that provides ecologically based guidelines to protect fish habitat and address socio-economic concerns.
3. Protect habitat from fishing gear effects through improved enforcement, establishment of protective buffers around habitats, modified rules, and further restriction of fishing gears, where necessary.
4. Protect estuarine and public trust shorelines and shallow water habitats by revising shoreline stabilization rules to include consideration of erosion rates and ***prefer*** alternatives to vertical shoreline stabilization measures ***that maintain shallow nursery habitat***.
5. Protect and enhance habitat for migratory fishes by:
   a. Incorporating the water quality and quantity needs of fish in water use planning and rule making.
   b. Eliminating or modifying obstructions to fish movements, such as dams and culverts, to improve fish passage.
6. ***Ensure that energy development and infrastructure is designed and sited in a manner that minimizes negative impacts to fish habitat, avoids new obstructions to fish passage, and where possible provides positive impacts.***
7. ***Protect important fish habitat functions from damage associated with activities such as dredging and filling.***
8. ***Develop coordinated policies including management adaptations and guidelines to increase resiliency of fish habitat to climate change and sea level rise***.

GOAL 4. ENHANCE AND PROTECT WATER QUALITY

1. Reduce point source pollution discharge by:
   a. Increasing inspections of discharge treatment facilities, collection infrastructure, and disposal sites.
   b. Providing incentives for upgrading all types of discharge treatment systems.
   c. ***Develop standards and treatment facilities that minimize the threat of endocrine disrupting chemicals on aquatic life***.
2. Adopt or modify rules or statutes to prohibit ocean wastewater discharges.
3. Prevent additional shellfish and swimming closures through targeted water quality restoration and 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.
4. Enhance coordination with, and financial/technical support for, local government actions to better manage stormwater and wastewater.
5. Improve strategies throughout the river basins to reduce non-point pollution and minimize cumulative losses of fish habitats through voluntary actions, assistance, and incentives, including:
   a. Improved methods to reduce pollution from construction sites, agriculture, and forestry.
   b. Increased on-site infiltration of stormwater.
   c. Documentation and monitoring of small but cumulative impacts to fish habitats from approved, un-mitigated activities.
   d. Encouraging and providing incentives for low impact development.
   e. Increased inspections of onsite wastewater treatment facilities.

f. Increased water re-use and recycling.

6. Improve strategies throughout the river basins to reduce non-point pollution and minimize cumulative losses of fish habitats through rule making, including:
    a. Increased use of effective vegetated buffers,
    b. Implementing and assessing coastal stormwater rules and modify if justified.
    c. ***Modified water quality standards that are adequate to support SAV habitat***.
7. 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, where necessary.
    c. Use improved siting criteria to protect fish habitat.
8. ***Maintain adequate water quality conducive to the support of present and future aquaculture***.



Roanoke
Chowan
Albemarle Sound
Tar-Pamlico
Oregon Inlet
Fall line
Neuse
Pamlico Sound
Cape Hatteras Shoals
Ocracoke Inlet
Cape Fear
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Cape Lookout Shoals
Frying Pan Shoals
N
W
E
S
Legend
Hard bottom points (1)
Hard bottom lines (1)
Hard bottom polygons (1)
Streams (2)
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SAV (4)
Soft bottom, deep (5)
Soft bottom, shallow (5)
CHPP regions/subregions (6)
Coastal Plain wetlands (7)
Coastal
Non-riparian
Headwater
Riparian
(1) SEAMAP (2001), Moser and Taylor (1995)
(2) 1:100,00 scale National Hydrologic Dataset
(3) DMF bottom mapping program (2009 data)
(4) Various 1981-2009 (see SAV chapter)
(5) NOAA nautical chart bathymetry
(6) Based on USGS hydrologic unit boundaries
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Miles
0 12.5 25 50 75 100

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CHAPTER 1. INTRODUCTION

HABITAT AND WATER QUALITY CONCERNS

North Carolina has the largest estuarine system of any state along the Atlantic coast. The numerous estuarine rivers, creeks, large sounds, inlets, and ocean bays create a diverse aquatic system totaling over 2.3 million acres in size. North Carolina is located at the convergence of the mid-Atlantic and south Atlantic biogeographical provinces, supporting a mix of both northern and southern fish species in North Carolina's waters. Because of this, the extensive amount of estuarine and marine waters, and the diversity and abundance of habitats occurring there, North Carolina's coastal fisheries are among the most productive in the United States.

However, pressures from development, loss of habitat, and water quality degradation appeared to be taking a toll on North Carolina's estuaries.in the late 1980s. Several major fish kills, associated with low oxygen events and diseases, such as *Pfeisteria*, occurred. Oysters were dying from diseases (Dermo and MSX). Sea turtle and marine mammal mortalities related to disease and fishing gear interactions were increasing. Several commercially and recreationally important fisheries were classified as overfished, including summer flounder, weakfish, river herring, and striped bass. All of these concerns resulted in conflicts between recreational and commercial fishermen and raised environmental concerns by the public.

Because of these concerns, the State of North Carolina, through the Governor and General Assembly, convened several high level panels during this period to examine coastal environmental and fishery management issues. Each has made numerous policy recommendations concerning improved management of fish habitat and water quality.

- The Governor's Blue Ribbon Panel on Environmental Indicators published a report and recommendations in December 1990 (C. Manooch/DMF, pers. com., 2004). This report, compiled by the Department of Environment, Health, and Natural Resources (now DENR) provided guidelines for developing a set of indicators to evaluate the status and trends of environmental quality within North Carolina.
- 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 to reevaluate coastal issues since the Coastal Area Management Act (CAMA), which established North Carolina's coastal zone management system under the CRC, was enacted 20 years ago. Recommendations of the report included restoration and protection of important fisheries habitats and impaired waters, the need to address nonpoint source pollution, 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).
- The Fisheries Moratorium Act, in 1994, established a steering committee to oversee study of fishery resources.

Up until this point, the majority of the panel recommendations were not implemented. However, most of the recommendations of the Fisheries Moratorium Act Steering Committee were included in the Fisheries Reform Act in 1997.

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 (G.S. 143B-279.8) requires preparation of Fishery Management Plans by the Division of Marine Fisheries and Coastal Habitat Protection Plans (CHPPs) by the North Carolina Department of Environment and Natural Resources. The goal of all Fishery Management Plans is to ensure the long-term viability of the State's commercially and recreationally significant species and fisheries. The Fishery Reform Act mandates that each plan include all pertinent fishery information as well as habitat and water quality considerations that are consistent with the Coastal Habitat Protection Plan. 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 CHPP is long-term enhancement of coastal fisheries associated with coastal habitats. The law specified that the CHPP 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. The intent of this tri-comission effort was to ensure consistent actions among commissions, as well as their supporting Department of Environment and Natural Resources (DENR) agencies. The public had become increasingly frustrated with the inability of multiple panels to successfully implement recommendations. However, the FRA clearly required that recommendations of the management plans be implemented. 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. Because the CHPP uniquely brings together three major regulatory commissions, the public has an expectation that positive actions would result from this effort.

1.3. AUTHORITY FOR MANAGEMENT AND PROTECTION OF PUBLIC TRUST RESOURCES

The Public Trust Doctrine provides the authority for the state to manage public trust resources. 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). 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 . . . 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).

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).

1.4 CHPP PROCESS

DMF staff, with assistance from the CHPP Development Team, completed drafting of the first CHPP in 2004. The CHPP team includes scientists and planners from DMF, DCM, DWQ, Division of Environmental Health (DEH), and WRC. An Intercommission Review Committee (IRC), consisting of two members from each of three commissions, the Marine Fisheries, Coastal Resources, and Environmental Management commissions, provided policy oversight, reviewed this plan, and developed the management recommendations (Street et al. 2005). After the IRC and DENR reviewed the draft plan, the Marine Fisheries, Coastal Resources, and Environmental Management Commissions separately approved of the plan and recommendations. Following that, each division and the Department compiled bi-annual implementation plans to accomplish recommendations within their authority. The IRC was slightly reorganized to reflect their new charge – to meet quarterly to discuss implementation progress, cross-cutting issues and facilitate CHPP implementation actions, as well as review future CHPP updates. Changes included renaming the group to the CHPP Steering Committee (CSC) and asking the Wildlife Resources Commission to join the CSC in 2009 since many of the implementation actions affect resources under their jurisdiction (see Appendix B for current CSC membership). In addition, other DENR division staff, such as Division of Environmental Health, Division of Forestry, Division of Water Resources, Division of Land Resources, Division of Soil and Water Conservation, and Ecosystem Enhancement Program were invited to participate at CSC meetings.

1.4. PURPOSE AND ORGANIZATION OF DOCUMENT

The purpose of the CHPP is to assimilate information on the environmental requirements, spatial distribution, ecological value, overall condition, and threats to coastal fish habitats and ecosystems, so that management needs can be identified to protect, enhance, and restore associated fisheries. The 2005 CHPP identified four overarching 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 updated 2010 CHPP follows the same organizational format as the initial 2005 plan, with updated information and additional focus on ecosystem integrity and Strategic Habitat Areas. The CHPP is organized 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 or gaps in the current management framework and are highlighted in the habitat chapters with *italics.* The threat sections are followed by a listing of habitat-specific management needs from the 2005 and 2010 CHPP, with a brief narrative on progress to date. A summary highlighting the most pressing management needs is provided at the end of each habitat chapter.

Following the habitat chapters, there is a discussion of ecosystem management and Strategic Habitat Areas (Chapter 8). The ecosystem management chapter will provide a cross-reference for threat-based information and a synthesis of information and recommendations regarding ecosystem-level management issues (i.e., cross-cutting threats, habitat trade-offs). The chapter will also summarize Strategic Habitat Area assessments and their role in ecosystem management.

The final chapter covers recommendations organized by CHPP goals. This chapter revisits the 2005 CHPP recommendations in light of new information presented in the update and discussions among the commissioners on the CSC. Each of the Commissions and the Department will use the threats discussion, management needs, and recommendations to develop and update coordinated coastal habitat implementation plans as provided in the Act.

1.6. ACCOMPLISHMENTS

After the CHPP was formally adopted in December of 2004, the commissions, their administrative divisions, and DENR developed and adopted bi-annual implementation plans during the summer of 2005. The implementation plans detailed more than 100 specific steps the Department, its agencies and their respective commissions would take during the 2005/06 – 2006/07 fiscal years to implement the CHPP recommendations. Following that, a second two year implementation plan was developed and adopted by the CSC for the 2007/08-2008/09. Many of the 07-09 implementation actions were continuations of ongoing activity. The 2007-2009 implementation plan includes proposed implementation actions and is available on the DMF website.

Over the past five years, implementation of the CHPP has been a significant part of the decision making process of DENR's divisions and regulatory commissions. All three commissions and their DENR

agencies actively used the CHPP and its recommendations as guidance in their regulatory and operational programs. Numerous implementation actions were accomplished or are underway.
The CHPP Steering Committee concluded that the six most significant accomplishments and advancements of the CHPP in the first five years included:

- Interagency coordination/cooperation – CHPP coordinator position established, CHPP Steering Committee and interagency quarterly meetings
- Stormwater runoff management – adoption of EMC Phase 2 and coastal stormwater rules
- Habitat mapping – SAV due to APNEP workgroup, shellfish and shellfish closures due to new positions, SHA process to prioritize habitat areas, shoreline mapping through grant funding
- Compliance monitoring – new positions in multiple divisions, cross training marine patrol, increased permit fees and fines
- Oyster reef restoration – new positions and funding for sanctuary development and monitoring, funding for construction of a shellfish hatchery, and creation of an oyster shell recycling program
- Beach nourishment management – development of the Beach and Inlet Management Plan through grant funding, and adoption of CRC sediment criteria rules

A common thread to all of these accomplishments was support from the Department and the General Assembly to implement these actions.

In the first fiscal year (2005-2006), most of the implementation measures were setting the stage to facilitate future actions. A CHPP coordinator position was created, the IRC was reorganized into the CHPP Steering Committee, and quarterly CHPP permit coordination meetings were established. Three DWQ, four DCM, three DEH-SS, and three DFR positions were funded by the General Assembly for compliance monitoring. Additionally, an agreement was established for Marine Patrol to regularly fly DCM compliance staff and to train officers how to report possible environmental violations. All of these actions were directed at improving effectiveness of existing rules and programs protecting coastal fish habitat (**Goal 1**). **Goal 2** called for identification and designation and protection of Strategic Habitat Areas. Before this could be done, mapping of CHPP habitats was needed. Three positions were appropriated to DMF to accelerate completion of shell bottom mapping. Elizabeth City State University, under a NOAA grant, began mapping SAV in Currituck Sound. CHPP staff, along with a SHA Advisory Committee, began developing the process to identify SHAs. To enhance habitat and protect it from physical impacts (**Goal 3**), DMF enhanced three existing oyster sanctuaries with more rock material and closed additional areas to mechanical shellfish harvesting. DCM began to formulate sediment compatibility rules, and NC Sea Grant formed a multi-slip docking facility advisory committee to discuss environmental issues related to multi-slip docking facilities and develop recommendations if needed to better protect fish habitat. To enhance and protect water quality (**Goal 4**), DWQ conducted a study, inspecting engineered stormwater structures, and surveyed stormwater outfalls draining into SA and ocean waters. In addition, DWQ, after hearing concerns of the CHPP Steering Committee and MFC Habitat and Water Quality Committee, began discussing the need for coastal stormwater rules.

In the second fiscal year (2006-2007), progress continued on the newly organized coordination meetings, and the appropriated positions were filled and began working. To further improve effectiveness of existing rules (**Goal 1**), CRC increased civil penalties to discourage violations. In addition NERRs hosted several workshops and outreach events on a variety of habitat and water quality protection topics. The major accomplishment toward identifying SHAs (**Goal 2**) was that an interagency SAV mapping workgroup was formed, with APNEP serving as the lead. An MOU was signed and the group began planning a coastwide mapping effort of SAV. Progress continued on shell bottom mapping and the SHA methodology process was completed and approved. For **Goal 3**, sediment compatibility rules were completed and approved, funding for the Beach and Inlet Management Plan was received, and the CRC

Estuarine Shoreline Stabilization scientific work group completed a report including recommendations regarding the placement and suitability of hardened shoreline structures. DCM received funding to map the shoreline and structures on it, an important precursor to managing shorelines. The CRC Estuarine Shoreline Stabilization Subcommittee reviewed the report and considered possible rule changes. Toward protection and enhancement of water quality (**Goal 4**), Phase II stormwater rules became effective, and DWQ drafted coastal stormwater rules went through the public hearing process.

In the third fiscal year (2007-2008), coordination and educational outreach continued for **Goal 1** and several efforts underway previously were substantially completed. Under **Goal 2**, the Interagency SAV Mapping Partnership pooled funding to acquire aerial imagery of SAV and the imagery was taken. The analysis of SHA Region 1 was well underway. In terms of enhancing and protecting habitat (**Goal 3**), the benefits of the additional resources for DMF's Resource Enhancement Section were beginning to be seen, with increased mapping of shell bottom, collection of recycled oyster shell, and monitoring and research of oyster sanctuaries. The MFC and the WRC designated Anadromous Fish Spawning Areas, an important step in protecting anadromous fish habitat. DMF began spawning and stream obstruction surveys, critical for prioritizing future habitat restoration. DCM began drafting of the Beach and Inlet Management Plan and received a Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) multi-agency grant to study shoreline stabilization and marsh sills. The most visible accomplishment of 2007-2008 was the adoption of coastal stormwater rules which went into effect in October 2008, after a huge effort was made by the DWQ, EMC, and Department as well as other supporting state agencies to keep the rules from being overruled due to opposing development interests (**Goal 4**). Other accomplishments in protecting and enhancing water quality included the formation of the Community Conservation Assistance Program with the Soil and Water Conservation Districts. This is the only program designed to address stormwater retrofitting from existing development. Other efforts included expansion of the areas that qualify for CREP funding, completion of three additional lagoon conversion projects, continuation of the swine lagoon buyout program, and additional equipment purchases by DFR to enhance forestry BMPs.

In 2008-2009, budget shortfalls constrained implementation success. Funding for two DCM positions (compliance education coordinator and Clean Marina Program) was rescinded, and the CHPP quarterly interagency meetings were cancelled due to travel restrictions. Similarly, funding approved by the legislature in the previous year to greatly accelerate oyster reef restoration was partially rescinded. The gain in funding to the program balanced out losses from DMF's budget, with the final result being a small net gain in resources for oyster restoration. Shell bottom and SAV mapping was slower than expected due to vacancies and the inability to fill positions. However, progress was still made.

Toward improving effectiveness of existing rules (**Goal 1**), DMF received approval for two grant funded positions dedicated to coastal permit review, and MFC approved a revised definition of SAV habitat, to improve effectiveness in protecting this habitat. Agencies worked together to ensure consistency among rules with this definition change. DWQ began reviewing coastal CAMA land use plans, sponsored workshops for local government and developers on the new stormwater rules, and hosted a Water Quality Monitoring Forum aimed at coordinating monitoring efforts. Regarding **Goal 2**, analysis for Strategic Habitat Areas in Region 1 was completed, areas were identified and approved by the MFC, and are being incorporated into DENR's Conservation Planning Tool. DMF completed spawning and obstruction surveys on the majority of the Chowan River system. Regarding **Goal 3**, enhancing and protecting habitat, sanctuary monitoring work continued and DWQ worked with DOT on a SAV and oyster habitat restoration and mitigation project in Currituck Sound. DWQ also established a compensatory mitigation database. DMF incorporated results of EEP and university research on compensatory mitigation to develop a MFC policy on compensatory mitigation which will hopefully encourage compensatory mitigation methods that successfully restore coastal watershed functions. DCM made major progress on drafting the Beach and Inlet Management Plan and delineating the coastal estuarine shoreline. Through

CHPP discussions, plans are underway to assess the success of existing marsh sills as alternatives to vertical stabilization structures, provide tools to the general public to educate them on the effects of shoreline stabilization and a range of management options, and to then revisit rules related to estuarine shoreline stabilization. CRC approved rules to better protect marshes from mowing, and reduce impacts from docks and piers. In terms of enhancing and protecting water quality (**Goal 4**), DWQ has begun reviewing several rules such as ocean stormwater discharges and marinas for adequacy in water quality protection. DWQ conducted a smart sponge pilot study to examine new ways to clean up stormwater, constructed four low impact development projects, and is developing a mitigation policy for intermittent streams. Additional resources were also appropriated to the Soil and Water for the Lagoon Conversion Program.

In summary, relative to other past planning efforts to protect North Carolina's coastal environment, the CHPP has been largely successful in implementing plan recommendations. The greatest accomplishments of the CHPP have been non-regulatory. Prior to making large management changes, positions and funding were needed to assess compliance of existing environmental rules, complete mapping of fish habitats, and educate the public on environmental issues. Multiple large grants have been awarded to state agencies and universities to conduct research or projects in support of the CHPP. Examples include DCM receiving funding for the BIMP, shoreline mapping, and the CICEET project looking at shoreline stabilization; APNEP coordinating the pooling of resources to map SAV coastwide; and universities receiving Fishery Resource Grants (FRGs) and Coastal Recreational Fishing License (CRFL) grants to collect needed habitat information. Much has been done in those areas, but work still remains. The passing of the coastal stormwater rules marks the largest regulatory change that the CHPP influenced. It occurred through the hard work of numerous DENR staff, commissioners and CHPP supporters such as environmental NGOs. With the exception of the EMC's coastal stormwater rules, rule changes for habitat protection occurred slowly and incrementally. Increased communication among divisions and commissions may have slowed down rule-making in some ways, but resulted in buy-in from other agencies and final products that are more consistent among divisions and commissions. Several large issues that involve regulations such as beach nourishment, estuarine shoreline stabilization, and protections for anadromous fish habitat are underway.

1.5. AREA DESCRIPTION

North Carolina's coast is framed by a chain of low-lying barrier islands extending from Virginia to Cape Fear. The barrier islands create large and productive sounds and estuaries behind them. Southwest of the Cape Fear River, dredging of the Atlantic Intracoastal Waterway (ICW) in the 1930s created an artificial extension of these barrier islands (Map 1.1a-b). The northern part of the natural barrier islands, the Outer Banks, separates the Albemarle-Pamlico sounds complex from the coastal ocean. The topography of the three major capes has a major influence on adjacent ocean circulation.

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 ocean and estuarine 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.

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 1.2), 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 CHPP area (coastal plain) includes all river basins flowing into North Carolina's coastal waters and the watersheds they drain. The Fall Line marks the upper extent of the CHPP area. The seaward extent of the CHPP area is the boundary of state territorial waters. In the 2005 CHPP, the coastal area was divided into 11 management units, closely following the river basin boundaries. The intent was to produce separate management plans for each of these units following completion of the CHPP. Subsequently, the CHPP Team and Steering Committee modified this organization into four management regions. These four regions were to be the basis for Strategic Habitat Area analyses to assess regional habitat condition and watershed issues. 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. Table 1.1 indicates the CHPP area is approximately 17% water (2,868,830 acres). Inlets at the boundaries between areas are shown separately since they influence both adjacent CHPP areas. 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 water area within CHPP management regions (based on USGS hydrologic unit boundaries and 1:24,000 scale shorelines).

CHPP regions	Major waterbodies	Total area (acres)	Water area (acres)	% water area
1	Albemarle/Currituck sounds, Chowan River	5,688,749	767,002	13
1/2	Oregon Inlet	54,777	52,927	97
2	Pamlico Sound, Neuse/Tar-Pamlico rivers	6,372,286	1,362,795	21
2/3	Ocracoke Inlet	37,165	36,640	99
3	Core/Bogue sounds, New/White Oak rivers	1,138,266	423,117	37
4	Cape Fear River, southern estuaries	3,483,211	226,349	6
Totals		**16,774,455**	**2,868,830**	**17**

To address local and watershed issues, a 2005 CHPP recommendation called for identification and designation of Strategic Habitat Areas. Four detailed regional analyses will be done to assess the condition and threats within these watersheds so that Strategic Habitat Areas can be identified at a landscape level for prioritized protection and restoration efforts. Boundaries of the four regional systems were based primarily on USGS 14-digit hydrologic units comprising hydrologically connected receiving waters and watersheds. The regions represent a continuum of aquatic habitats extending from coastal plain rivers through estuarine waters and passing into coastal ocean waters through dynamic inlet systems. 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 four regional systems and their boundaries approved by the CHPP Steering Committee are shown on Map 1.2. The regions are generally referred to as: Northern (Region 1), North-Central (Region 2), South-Central (Region 3), and Southern (Region 4). Because major inlet flow influences adjacent CHPP regions, some overlap between regions exist. To take this into account, Oregon and Ocracoke inlets have been tallied separately. The total hydrologic unit area and water area of the regions is approximated in Table 1.1.

1.5.1. 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 jobs, and the natural resources of the coastal areas (NOS 1990). North Carolina's coast has historically consisted of small residential communities and beach towns, with a tourism and retirement component. Quaint towns like Edenton, Beaufort, and Southport remain small but are growing. While some island towns have retained their relatively small summer cottage character (Ocracoke Island, Topsail Beach), others have shifted to large scale homes and multi-unit housing (Carolina Beach, Atlantic Beach, Hatteras Island). The largest coastal cities include Wilmington, Jacksonville, and New Bern. Military bases contribute significantly to the economy of the latter two. Large industries are relatively uncommon, and are primarily located near the port of Wilmington along the Cape Fear River. Population growth in coastal North Carolina has been driven by tourism and retirement communities, due to the high quality of NC's coastal resources. As population density increases, so does the potential for degradation of the natural environment by human activities (Cairns and Pratt 1992).

Population, density, and change in population from 1990 to projected 2010 numbers are shown in Table 1.2. In the twenty coastal counties, New Hanover County, followed by Onslow County continue to have the largest populations and densities in 2010. Brunswick County followed by Craven and Carteret counties had the next highest populations. Pasquotank, has a modest population but third densest population density. In both 2000 and 2010 the lowest populations and densities in eastern North Carolina (about 10 persons/mi^2) were in Tyrrell and Hyde counties, located on the Albemarle-Pamlico peninsula. This is about 100 times less dense than in New Hanover and about 20 times less than Onslow and Pasquotank counties. Although population density is increasing along the coast, many of the interior coastal plain counties like Cumberland, Pitt, and Johnston counties, had higher densities and similarly high growth rates. (Map 1.4), suggesting that some coastal pollution may be derived from these upstream sources.

The coastal counties that have undergone the greatest population change in the past ten years are Brunswick, Camden, Pender, and Currituck counties (Table 1.2). Growth over the past ten years ranged from 21-34% in those counties and was primarily the result of urban sprawl since all are within commuting distance of larger municipalities such as Wilmington, Jacksonville, and Norfolk Va. In the other coastal counties, population increased up to 18%, with the exception of Hyde, Washington, and Pamlico, where population declined slightly. For the past twenty years, the greatest population increases have occurred in the oceanfront counties. However, in the past ten years, the population increase in these areas slowed. The rate of county population change in the past ten years (2000-2010) was greater than the preceding ten years (1990-2000) in six counties, but slightly lower in fourteen. With the exception of Onslow County, which saw a major military base expansion, the other counties with greater population increases in the past ten years were located in non-oceanfront counties with relatively low populations on the north side of Albemarle Sound (Pasquotank, Perquimans, Camden, Hertford, and Bertie). This area and other western Albemarle-Pamlico counties have been marketed as the "Inner Banks" over the past five years by the real estate industry.

Municipalities on North Carolina's barrier islands have experienced great increases in population along the coast in the past twenty years (Table 1.3). Population increased by as much as 100-486% in some beaches from 1990 – 2000. However, as these islands become more densely built-out, growth rates have slowed some. From 2000-2007, 69% was the maximum population increase. Brunswick County beaches accounted for the majority of the largest population increases, while some of the older established beach communities such as Wrightsville and Atlantic Beach showed minimal new growth. Overall, the permanent population of all oceanfront municipalities declined in the last ten years. However, permanent dwelling units may have converted to seasonal rentals. Influx of tourists on barrier island beaches results in tremendous seasonal population fluctuations. Seasonal population estimates at beach towns are 3 – 59 times greater than their permanent population. These estimates do not include day trippers. In many of these municipalities, public facilities, including wastewater treatment systems, roads, and water supply systems, are being taxed to the limit (Steel 1991).

Since the 2005 CHPP was completed, patterns in coastal development have varied greatly. Prior to about 2002, coastal development appeared to be moderately increasing, primarily on the oceanfront communities, with some increase in the mainland communities as well. Between 2002 and 2006 a coastal boom in development escalated along the mainland waterfront as real estate prices rapidly increased. Termed as the "new waterfront" or the "Inner Banks", developers targeted these areas for extremely large developments, where one subdivision could almost double a town's population. In 2006, a survey by the News and Observer found that over 34,000 new homes in nearly 100 subdivisions and condominium projects were planned or under construction along the coast (www.newsandobserver.com/news/story/1139981.html). Pamlico, Chowan, Bertie, Washington, Brunswick, and Down East Carteret counties were among the coastal areas targeted for new large scale developments. Concerns rose over the potentially rapid change to rural coastal communities from the loss of farmland, fish houses, and public water access and the effect on the environment. Fish houses, struggling economically with falling seafood prices and rising fuel costs could sell their property for greater profits to developers. A study found that approximately one third of the fish houses open in 2000 had shut down by 2006 (Garrity-Blake and NC SeaGrant 2006). In 2008, sharply falling real estate prices and the recession lead to a major slow down in new development. Although some of the plans for property purchased by developers during the boom have been put on hold, land may have been zoned, platted, and/or permitted, allowing for future construction once economic conditions improve. The increase in population in these rural areas will require additional infrastructure (roads, schools, water and sewer facilities, electric transmission lines, etc.), which can result in loss or degradation 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).

Table 1.2. Human population, density, and growth in Coastal Plain counties of North Carolina, 1990 – 2010. (Source: NC Office of State Budget and Management, unpub. data.)

	1990		2000		2010 (projected)		1990-00	2000-10
COUNTY	Pop.	Persons/ mi^2	Pop.	Persons / mi^2	Pop.	Person s/ mi^2	Pop. change (%)	Pop. change (%)
CAMA counties								
Brunswick	50,985	82.33	73,143	118.10	110,293	130.23	43.5	33.7
Camden	5,904	24.57	6,885	28.65	9,919	41.23	16.6	30.6
Pender	28,855	33.16	41,082	47.22	55,188	63.45	42.4	25.6
Currituck	13,736	52.55	18,190	69.59	23,179	88.51	32.4	21.5
New Hanover	120,284	602.85	160,307	803.44	197,548	1031.34	33.3	18.9
Onslow	149,838	195.37	150,355	196.04	182,023	238.16	0.3	17.4
Pasquotank	31,298	137.96	34,897	153.83	41,529	183.04	11.5	16.0
Perquimans	10,447	42.28	11,368	46.00	13,461	54.48	8.8	15.5
Gates	9,305	27.29	10,516	30.84	11,828	34.74	13.0	11.1
Dare	22,746	59.33	29,967	78.17	33,073	86.26	31.7	9.4
Craven	81,812	115.12	91,436	128.66	99,211	139.89	11.8	7.8
Carteret	52,407	101.13	59,383	114.59	64,144	126.87	13.3	7.4
Hertford	22,317	63.01	22,601	63.81	23,663	67.02	1.3	4.5
Beaufort	42,283	50.83	44,958	54.05	46,877	56.18	6.3	4.1
Tyrrell	3,856	9.84	4,149	10.58	4,297	11.05	7.6	3.4
Bertie	20,388	29.16	19,773	28.28	20,152	28.82	-3.0	1.9
Chowan	13,506	78.19	14,526	84.09	14,763	85.60	7.6	1.6
Pamlico	11,368	33.40	12,934	38.00	12,871	38.24	13.8	-0.5
Washington	13,997	40.44	13,723	39.65	13,082	37.58	-2.0	-4.9
Hyde	5,411	8.75	5,826	9.43	5,448	8.89	7.7	-6.9
Total	710,743		826,019		982,549			
Other Coastal Plain Counties								
Johnston	81,306	102.18	121,965	153.28	174,876	221.02	50.0	30.3
Hoke	22,856	102.56	33,646	150.98	46,762	119.67	47.2	28.0
Harnett	67,833	113.20	91,025	151.90	116,342	195.54	34.2	21.8
Pitt	108,480	165.67	133,798	204.34	163,103	250.17	23.3	18.0
Greene	15,384	57.76	18,974	71.24	21,510	80.89	23.3	11.8
Sampson	47,297	49.96	60,161	63.55	67,493	71.44	27.2	10.9
Duplin	39,995	48.82	49,063	59.89	54,539	66.88	22.7	10.0
Nash	76,677	141.28	87,420	161.08	96,432	178.44	14.0	9.3
Wilson	66,061	176.54	73,814	197.25	81,097	220.27	11.7	9.0
Cumberland	274,713	427.25	302,963	471.18	323,472	496.13	10.3	6.3
Wayne	104,666	187.92	113,329	203.47	116,760	211.09	8.3	2.9
Columbus	49,587	487.97	54,749	538.77	55,430	59.14	10.4	1.2
Bladen	28,663	47.09	32,278	53.03	32,234	36.87	12.6	-0.1
Jones	9,361	19.75	10,381	21.90	10,312	21.90	10.9	-0.7
Lenoir	57,274	142.48	59,648	148.39	57,384	143.54	4.1	-3.9
Halifax	55,516	76.39	57,370	78.94	55,053	76.03	3.3	-4.2
Northampton	21,004	39.07	22,086	41.08	21,045	39.22	5.2	-4.9
Edgecombe	56,692	111.88	55,606	109.74	51,552	102.02	-1.9	-7.9
Martin	25,078	54.23	25,593	55.34	23,694	99.16	2.1	-8.0
Total	1,208,443		1,403,869		1,569,090			

Table 1.3. Changes in permanent population for barrier island municipalities, 1970 - 2007. (Sorted by percent increase in 2000-2007 population. Source: NC Office of State Planning

	Permanent population					
Municipality *	1970	April 1990	April 2000	July 2007	Percent increase:1990-2000	Percent increase: 2000-2007
Sunset Beach	108	311	1,824	3,090	486	69
Bald Head Island	*	78	173	251	122	45
Kure Beach	394	619	1,507	2,160	143	43
Caswell Beach	28	175	370	488	111	32
Carolina Beach	1,663	3,630	4,701	5,974	30	27
Surf City	166	970	1,393	1,766	44	27
Oak Island	493	4,550	6,571	8,261	44	26
Topsail Beach	108	346	471	575	36	22
Ocean Isle Beach	78	523	426	508	-19	19
Southern Shores	75	1,447	2,201	2,604	52	18
Holden Beach	136	626	787	931	26	18
Kitty Hawk	0	1,937	2,991	3,461	54	16
Kill Devil Hills	357	4,238	5,897	6,820	39	16
Nags Head	414	1,838	2,700	3,113	47	15
Emerald Isle	122	2,434	3,488	3,855	43	11
North Topsail Beach	*	947	843	898	-11	7
Pine Knoll Shores	62	1,360	1,524	1,601	12	5
Wrightsville Beach	1,701	2,937	2,593	2,710	-12	5
Atlantic Beach	300	1,938	1,781	1,799	-8	1
Indian Beach	48	153	95	88	-38	-7
Total	**6,253**	**40,788**	**53,859**	**50,953**		

* Excludes unincorporated townships, including Hatteras, Bodie, and Ocracoke Islands

The concern over loss of waterfront access led to a legislatively mandated Waterfront Access Study Committee which completed a report with recommendations in 2007 to examine the extent or potential of loss of diversity of uses and how those losses impact access to public trust waters, and recommendations to retain working waterfronts and public access, as well as to preserve North Carolina's coastal heritage. Some of those recommendations included extending eligibility of present use value taxation to working waterfront properties, increasing and utilizing funding from various existing programs to acquire and enhance public access, and establishing a Waterfront Access and Marine Industry (WAMI) Fund to purchase and develop working waterfronts. A $20 million trust fund was established by the legislature and the acquisition process was begun in 2008, and other recommendations are underway. The need to preserve waterfront access will remain a high priority as long as development along the coast continues to increase.

1.5.2. 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.

1.5.2.1. Fisheries

Authority to protect and conserve marine and estuarine resources and public trust resources resides in the Secretary of DENR (GS 143B-10) who has delegated it to the DMF director. The North Carolina MFC enacts rules to govern all fishing in coastal waters (GS 143B-279-8). 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 history of productive commercial and recreational fisheries is due not only to its large and diverse coastal ecosystem, but also to flexible and responsive management of coastal fisheries with extensive data collection and public participation, as well as a strong heritage of commercial and sport fishing throughout eastern North Carolina.

Coastal North Carolina has historically supported a vigorous commercial fishing industry. In the past five years, there has been a trend of declining numbers of commercial fishermen. Since 2000, the number of licensed commercial fishermen has declined by about 10% and the number of dealers by about 13%. In fiscal year 2008, there were 8711 commercial licenses issued with selling privileges (approximately 8565 commercial fishermen) and 738 licensed fish dealers throughout the coastal area. The annual ex-vessel value (paid to the fishermen, without any economic multipliers) has declined from about $100 million in 2000 to $82 million in 2008. The total economic impact from the commercial fishing industry in 2008 is still large however, estimated at $144 million. Dare, Carteret, and Hyde counties had the highest seafood landings by weight and value in 2008 (DMF 2009).

Table 1.4 Annual Atlantic coast commercial fisheries landings by state, 1997-2007 (thousands of pounds, sorted by average landings). (Source: National Marine Fisheries Service data)

State	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Average	%
Virginia	584,895	592,767	460,289	443,197	561,708	442,490	446,828	481,555	441,493	426,217	481,738	487,562	31
Massachusetts	229,915	257,438	198,877	187,861	242,066	243,824	295,439	336,948	337,214	383,466	303,006	274,187	17
Maine	246,344	184,103	229,633	226,849	239,868	197,057	224,106	208,405	214,820	234,275	176,006	216,497	14
New Jersey	175,172	197,550	168,974	171,804	168,403	162,175	170,132	185,615	156,961	175,759	153,965	171,501	11
North Carolina	228,433	180,238	153,310	155,214	139,277	159,557	139,215	136,444	79,154	68,641	62,900	136,580	9
Rhode Island	143,101	133,702	124,168	119,295	115,957	103,656	97,435	97,412	97,147	112,605	75,635	110,919	7
Maryland	76,599	61,479	66,419	48,913	55,536	53,185	49,350	49,507	67,460	51,216	50,102	57,251	4
New York	60,956	57,542	49,661	41,181	42,422	38,665	39,392	33,712	38,123	32,819	36,275	42,795	3
Florida (east coast)	32,719	29,959	30,417	40,607	37,130	32,221	34,855	41,824	23,113	26,342	24,483	32,152	2
Connecticut	19,072	17,625	18,430	19,563	18,687	16,177	16,420	21,150	13,628	11,746	10,263	16,615	1
New Hampshire	10,896	10,172	11,258	17,160	18,584	23,201	27,435	21,958	21,281	10,295	8,395	16,421	1
South Carolina	17,350	17,653	18,574	15,835	14,111	13,458	13,710	12,439	10,459	11,112	9,985	14,062	1
Georgia	14,511	13,196	12,250	9,694	9,036	9,563	8,942	6,341	9,697	7,747	7,180	9,832	1
Delaware	9,084	7,866	8,372	6,676	7,123	5,857	5,018	4,286	4,854	4,380	5,089	6,237	0
Total	**1,849,047**	**1,761,290**	**1,550,632**	**1,505,849**	**1,671,909**	**1,501,086**	**1,568,277**	**1,637,596**	**1,515,404**	**1,556,620**	**1,405,022**	1,592,612	**na**

*Source: National Marine Fisheries Service. Fisheries of the United States, annual reports.

Table 1.5. Annual Atlantic coast marine recreational fisheries harvest by state, 1997 - 2007 (thousands of pounds, sorted by average landings). (Source: National Marine Fisheries Service data.)

State	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Average	%
Florida (east coast)	24,179	21,017	25,859	29,408	29,517	22,080	25,948	22,379	20,925	25,381	27,986	24,971	19
North Carolina	19,703	15,370	18,034	22,699	24,146	17,879	22,010	25,352	23,933	24,878	23,349	21,578	16
New Jersey	19,921	13,632	14,181	24,645	22,323	15,541	17,152	17,879	19,033	20,596	16,654	18,323	14
Virginia	16,835	13,993	11,507	13,112	17,732	14,861	13,506	14,800	15,737	17,131	15,529	14,977	11
New York	12,476	8,458	9,733	17,050	11,127	12,467	18,770	12,325	13,155	14,097	17,665	13,393	10
Massachusetts	9,865	9,252	7,626	15,538	15,984	14,197	13,896	14,995	14,351	15,728	13,428	13,169	10
Maryland	8,238	8,311	5,396	8,872	8,366	7,102	10,622	5,293	8,608	8,306	9,302	8,038	6
Rhode Island	3,225	3,567	3,817	7,020	4,457	4,063	4,412	4,409	4,072	3,721	4,596	4,305	3
South Carolina	4,492	3,356	2,628	2,834	3,156	1,794	3,781	4,402	3,120	4,132	4,234	3,448	3
Connecticut	3,228	3,424	2,575	3,029	3,432	4,024	6,026	4,339	4,837	5,629	6,139	4,244	3
Delaware	2,751	2,463	2,021	3,486	3,246	3,486	1,827	1,801	2,213	2,569	1,823	2,517	2
Georgia	1,339	1,049	1,772	2,202	2,017	1,101	2,203	1,931	1,641	1,747	2,096	1,736	1
Maine	1,516	705	802	1,571	1,964	1,801	748	1,274	1,377	1,077	1,653	1,317	1
New Hampshire	1,479	588	833	1,074	2,150	1,104	1,451	869	1,726	1,714	1,512	1,318	1
Total	**129,247**	**105,185**	**106,784**	**152,540**	**149,617**	**121,500**	**142,352**	**132,048**	**134,728**	**146,706**	**145,966**	**133,334**	**na**

*Source: National Marine Fisheries Service. Fisheries of the United States, annual reports.

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. Other commercial fishermen have transitioned away from selling their catch, but continue to fish with a Recreational Commercial Gear License (RCGL) for personal pleasure. In 2008, there were 5113 RCGL licenses sold.

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 as far back as the 1930s (Godwin et al. 1971). While commercial fishing has declined in recent years, recreational fishing has increased as North Carolina's resident and visitor population has grown. Tens of thousands of private recreational boaters fish the coastal waters, while thousands more fish from the shore, piers, and other structures. In 2007, it was estimated that about 1.9 million anglers went fishing in coastal North Carolina, with a total of approximately 6.9 million recreational fishing trips (DMF 2008). This includes trips from land, private boat, and headboats, and both resident and non-resident fisherman. Diaby (1997) estimated that sport fishing contributed almost $75 million to the Carteret County economy, supporting over 1,800 jobs. In January 2007, GS 113-174 required establishment of a coastal recreational fishing license. This will allow better estimates of recreational fishing effort. In 2007, approximately 470,000 recreational fishing licenses were issued, of which approximately one third were for out-of –state visitors. Wake, New Hanover, Onslow, Carteret, and Brunswick counties accounted for the greatest number of licenses.

1.5.2.2. Protected species

North Carolina state law [G.S. 113-331] protects endangered, threatened, and special concern species of mammals, birds, reptiles, amphibians, freshwater fishes, freshwater and terrestrial mollusks, and freshwater and terrestrial crustaceans under the jurisdiction of the North Carolina Wildlife Resources Commission. The shortnose sturgeon (*Acipenser brevirostrum*) is listed as endangered at the state and federal levels. The Atlantic sturgeon (*Acipenser oxyrinchus*) is listed as special concern at the state level and as a candidate for listing at the federal level. A MFC rule [15A NCAC 3M .0508] prohibits possession of any sturgeon in North Carolina's coastal waters. Shortnose sturgeon and Atlantic sturgeon occur in riverine, estuarine and marine systems within the CHPP management area.

Beginning in 2004, the NC NHP decided to no longer track marine and estuarine fishes due to insufficient data, and difficulty of surveying and protecting fish species that occur in salt and brackish waters (LeGrand et al. 2008). The North Carolina Natural Heritage Program (NHP) had previously tracked five marine and estuarine fishes considered as significantly rare: spinycheek sleeper (*Eleotris pisonis*), lyre goby (*Evorthodus lyricus*), 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.

Other marine and estuarine species tracked 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, mollusks, and mammals tracked by NHP associated with salt marshes and other coastal wetlands [LeGrand et al. 2008 (NHP animals); Buchanan and Finnegan 2008 (NHP plants)]. Tracked 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*), which inhabit ocean beaches and inlet shorelines.

In addition to species tracked 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 novaeangliae*) 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 long-finned pilot whales (*Globicephala melas*).

1.6. STATUS OF FISHERIES

The current status of fisheries may in part be an indicator of habitat conditions or indicate the fisheries for whom it would be particularly important to minimize habitat degradation due to an already stressed fish population. The status of North Carolina's coastal fishery stocks are evaluated every year by DMF. A stock is defined as 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. This information is incorporated into MFC Fishery Management Plans to determine appropriate management actions and goals for a fishery.

Table 1.6 lists 5-year average landings in pounds of commercially and recreationally important fishery species during the previous CHPP cycle and in the last five years. Commercially, Atlantic menhaden, blue crab, Atlantic croaker, shrimp, and flounder have accounted for the most landings during both time periods. In the past five years, average landings of Atlantic menhaden greatly declined due to the closure of the single menhaden plant in North Carolina. Blue crab and shrimp landings declined, while Atlantic croaker slightly increased. Commercial catch of thirteen of the nineteen fishery species listed declined in the past five years. Recreationally, striped bass, spot, bluefish, snapper-grouper, and spotted seatrout accounted for the most landings in the past decade. Of the ten species listed with recreational data, landings of seven fishery species have increased in the past five years, including all of the most abundant. Summer flounder, Atlantic croaker, and red drum landings decreased slightly.

Stock status terms were modified by DMF in 2007 to better address the assignment of a status to stocks that have unapproved or no stock assessment, or whose stock assessments are too unreliable to determine a status. In addition, the term "Overfished" was changed to "Depleted" to address those stocks that may have other factors besides fishing contributing to low population abundances. Categories now include:

- **Viable -** Viable stocks exhibit stable or increasing trends in average length and weight, catch per unit effort, spawning stock biomass, juvenile abundance indexes based on historical averages, stable age structure that includes representatives of the older age classes, and stable or declining trends in fishing mortality. Stocks deemed recovered by a Division of Marine Fisheries (DMF), Atlantic States Marine Fisheries Commission (ASMFC), or regional Council fishery management plan (FMP) would be considered "viable". A stock is considered "recovered" when it has reached the target(s) for sustainable harvest, spawning stock biomass, spawning potential ratio, fishing mortality, size/age structure, or any other biological target required in an approved DMF, ASMFC and/or regional Council FMP. (No Overfishing; Not Overfished)[59]
- **Recovering -** Recovering stocks are those stocks that show marked and consistent improvement in the criteria listed for a "viable" stock. A "recovering" species may still be depleted but would be

[59] Overfishing/overfished designations result from completed stock assessments.

defined as one that, under a current plan, shows measurable and consistent improvement but has not yet reached the target(s) of a specific FMP. (No Overfishing; Overfished)*

- **Concern -** Stocks designated as "concern" are those stocks that exhibit increased effort, declining landings, truncated age distribution, or are negatively impacted by biotic and/or abiotic factors that cannot be controlled (example: water quality, habitat loss, disease, life history, predation, etc). Stocks with or without an approved stock assessment or FMP but are exhibiting declining trends may be classified as "concern". (Overfishing; Not Overfished)* Stocks whose assessments have unreliable benchmarks may also be classified as "concern" (Example: Overfishing can not be determined)
- **Depleted** – Depleted stocks are those stocks where the spawning stock abundance is below a predetermined threshold or where low stock abundance precludes an active fishery. Factors that can contribute to "depleted" status include but are not limited to fishing, predation, competition, water quality, habitat loss, recruitment variability, disease, or a combination of these factors. Determination is based on approved DMF, ASMFC, and/or regional Council FMPs and/or stock assessments. Species designated as "depleted" would be priority candidates for FMP development.
- **Unknown -** Stocks for which insufficient data are available to determine trends in effort, landings, age distribution, recruitment, etc. are classified as "unknown". Many stocks that have been designated as "unknown" have been picked up in DMF sampling programs that may result in sufficient data to designate a status in the future.

Of the fishery species listed in Table 1.6, comprising at least 25 fish stocks, eight stocks are Viable (32%), two are Recovering (8%), eight are Concern (33%), six are Depleted (24%), and one is Unknown (4%), as of 2008 (Table 1.7). Depleted stocks include black sea bass south of Hatteras, bay scallop, river herring (Albemarle stock), southern flounder, and striped bass (central/southern stock). Species that have demonstrated a decline in their stock status since the last CHPP include bay scallop, weakfish, spot, summer flounder, gag, and black sea bass north of Hatteras. Species with improved stock status include Atlantic croaker, bluefish, and striped mullet. Others remained the same. For more information on the status of individual fishery species, see the DMF website <http://www.ncdmf.net/stocks/index.html>).

Table 1.6. Average annual North Carolina landings for important commercial and recreational fishery species reported during the first (1997-2002) CHPP cycle and last five years. (Sorted alphabetically. Recreational landings include a+b1 landing type. Source: DMF fisheries landings data.)

Species	Average commercial fisheries landings			Average recreational fisheries landings			Lead FMP agency
	1997-2002 (lb)	2003-2007 (lb)	5 yr Change	1997-2002 (lb)	2003-2007 (lb)	5 yr Change	
American shad	233,718	268,359	+	Unknown	Unknown		ASMFC
Atlantic croaker	10,692,337	11,782,240	+	276,740	193,490	-	ASMFC
Atlantic menhaden	63,330,289	17,812,110	-	Unknown	Unknown		ASMFC
Bay scallops	39,903	2,855	-	Unknown	Unknown		DMF
Blue crab	47,673,736	29,819,727	-	Unknown	Unknown		DMF
Bluefish	3,240,218	3,038,788	-	838,102	1,141,502	+	ASMFC/NMFS
Hard clams	671,716	467,317	-	Unknown	Unknown		DMF
Oysters	234,445	379,268	+	Unknown	Unknown		DMF
Red drum	203,537	137,249	-	255,884	202,314	-	ASMFC/DMF
River herring	352,364	149,845	-	Unknown	Unknown		ASMFC / DMF
Shrimp	7,688,851	5,738,901	-	Unknown	Unknown		DMF < 3 mi, NMFS > 3 mi
Snapper/grouper / seabass	1,788,967	1,792,935	+	409,521	757,759	+	NMFS
Southern flounder	3,523,763	2,178,931	-	134,186	349,569	+	DMF
Spot	2,563,527	1,663,773	-	1,028,822	1,404,384	+	ASMFC
Spotted seatrout	290,303	225,873	-	419,273	618,003	+	ASMFC
Striped bass	555,421	639,960	+	663,626	2,364,036	+	ASMFC - ocean, DMF/WRC - internal waters
Striped mullet	2,311,092	1,649,147	-	Unknown	Unknown		DMF
Summer flounder	2,938,425	3,826,534	+	381,729	209921	-	ASMFC/NMFS
Weakfish	2,531,015	498,949	-	116,632	171,598	+	ASMFC/NMFS

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 and a fishing moratorium .

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 and stream obstructions and flow alterations.

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, 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 1.7. Trends in the stock status of important fishery species and stocks listed in Table 1.6. (1998 – 2010).

Species/stocks	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
American shad													
Atlantic croaker													
Atlantic menhaden													
Bay scallops							?	?	?				
Black sea bass (N. of Hatteras)										?	?		
Black sea bass (S. of Hatteras)													
Blue crab													
Bluefish													
Gag	?												
Oysters													
Red drum													
Reef fish													
River herring (Albemarle)													
Shrimp													
Southern flounder													
Spot													
Spotted seatrout													
Striped bass (Albemarle)													
Striped bass (except Ocean and Albemarle)													
Striped bass (Ocean)													
Striped mullet													
Summer flounder													
Weakfish													

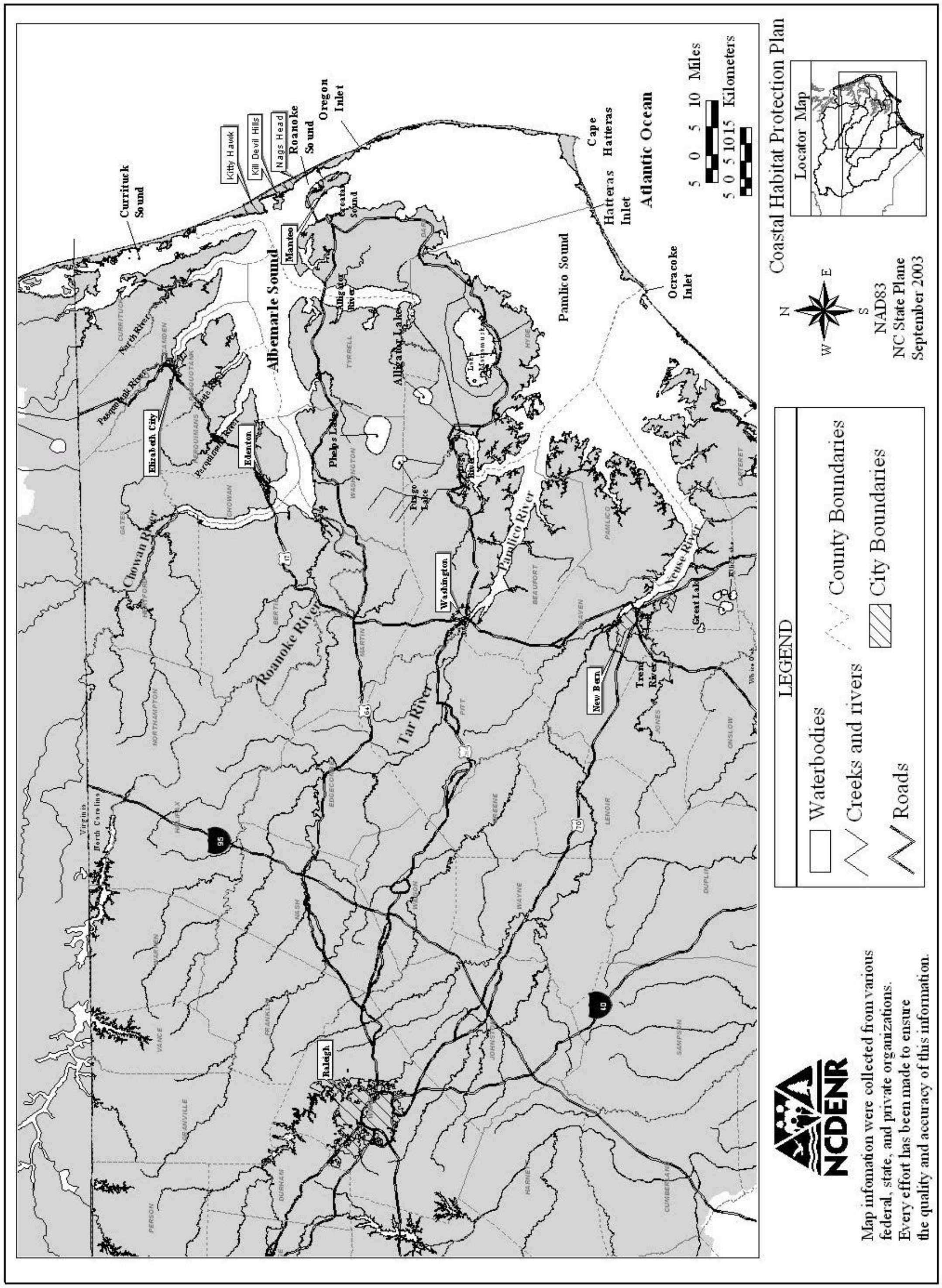
				?
Overfished	Concern	Recovering	Viable	Unknown

1.7. HABITAT CONCEPTS AND TERMINOLOGY

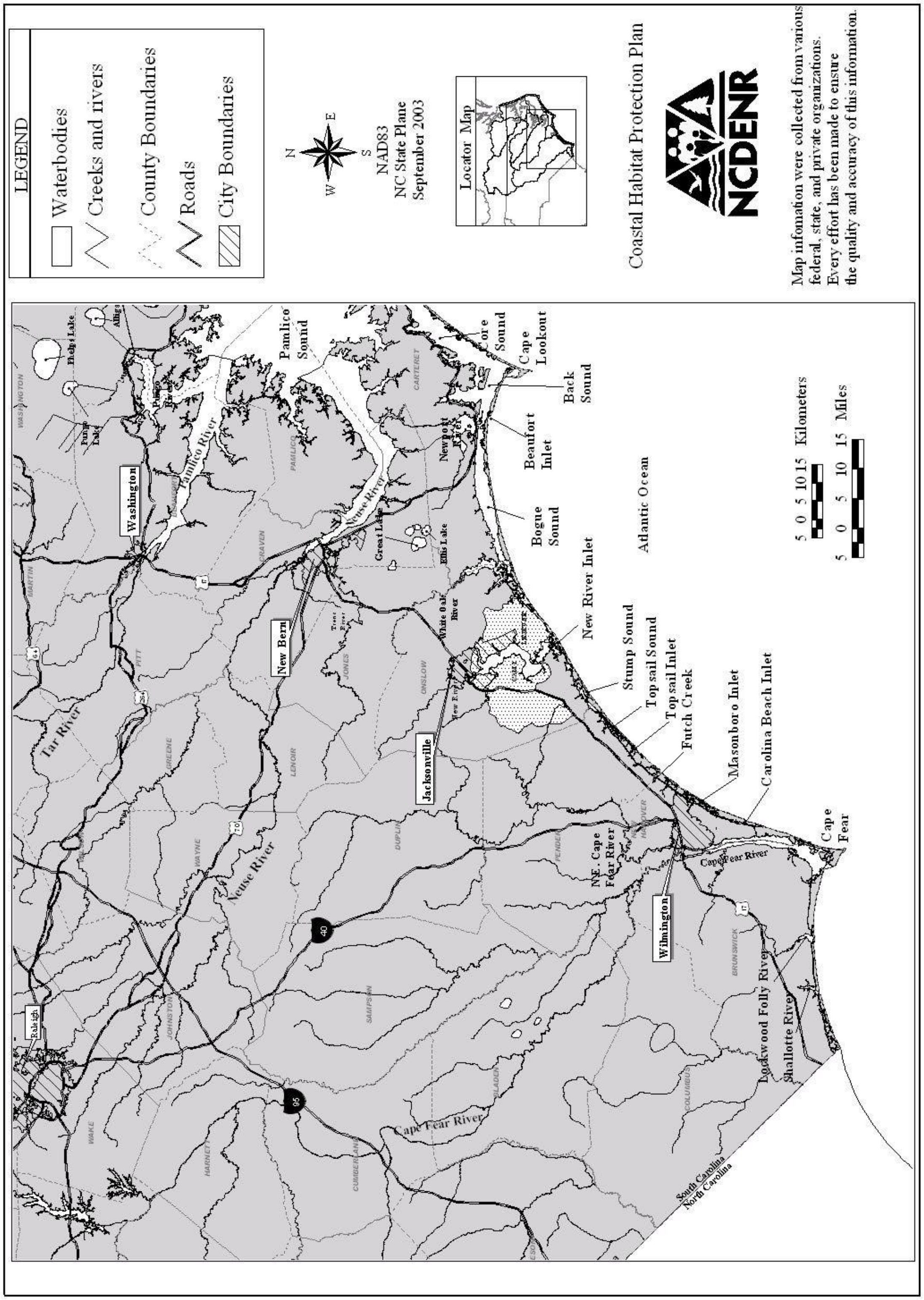
The following habitat chapters contain numerous technical terms and acronyms that may not be familiar to the average reader. A complete list of terms and acronyms is found in Appendix C.

Habitat is simply the place where an organism lives (Odum 1959). Fish Habitat (FH) is 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. 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, shell bottom, submerged aquatic vegetation (SAV), wetlands, and hard bottom.

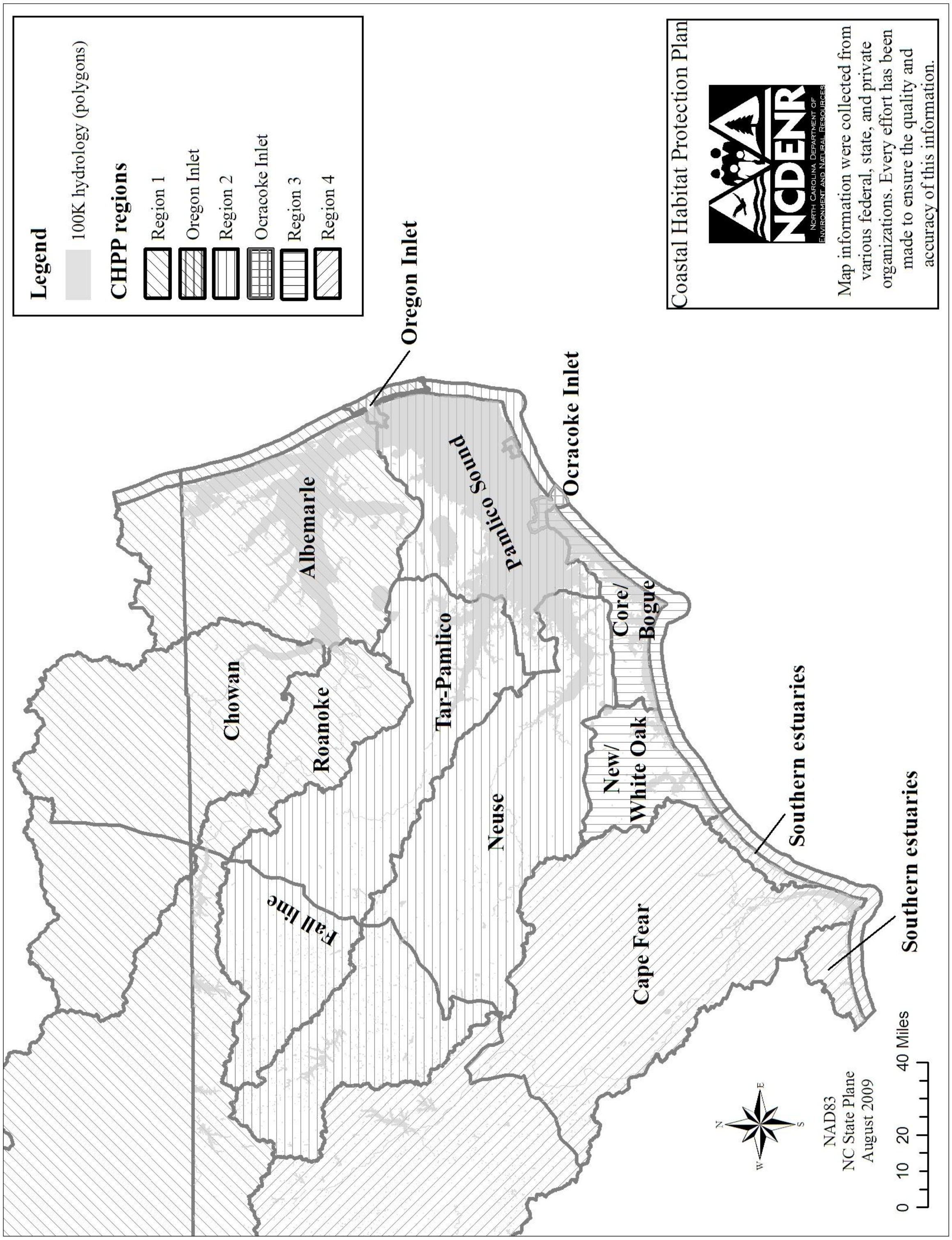
North Carolina's coastal fishery resources (the "fish") exist within a system of interdependent habitats that provide the basis for long-term fish production available for use by people (the "fisheries"). Most fish rely on different habitats throughout their life cycle (Figure 1.1); therefore, maintaining 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.



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



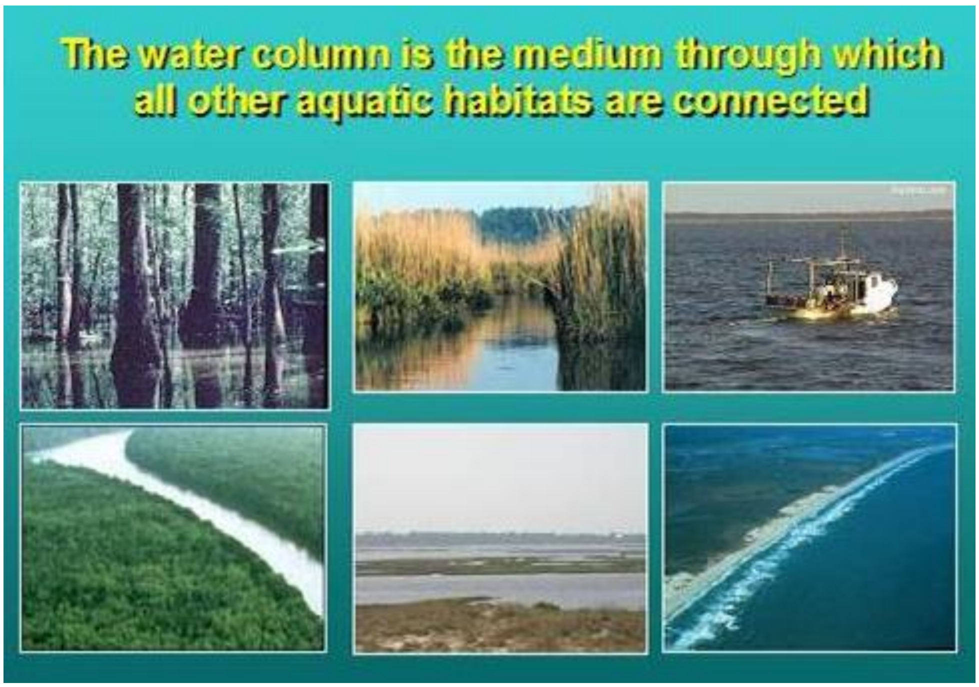
Map 1.1b. Hydrographic features in coastal North Carolina. (Data from 1:100,000 scale USGS topographic maps).



Map 1.2. The CHPP region and subregion boundaries (based on USGS hydrologic units), along with the fall line separating Coastal Plains and Piedmont physiographic regions.

CHAPTER 2. WATER COLUMN

The flow and quality of water in the water column are key factors linking fish, habitat, and people. The coastal fisheries ecosystem along the North Carolina coast is supported by a range of water column conditions. Water column properties that may affect fisheries resources include temperature, salinity, dissolved oxygen (DO), total suspended solids, nutrients (nitrogen, phosphorus), chlorophyll *a*, and pollutants (SAFMC 1998a). Other factors, such as depth, pH, water velocity and movement, and water clarity, also affect the distribution of aquatic organisms. Those properties are affected by growing development pressures along our coast as well as far inland. 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 to those characteristics.



2.1. DESCRIPTION AND DISTRIBUTION

Water column habitat is defined in this plan as "the water covering a submerged surface and its physical, chemical, and biological characteristics." The water column, defined as such, includes any area where surface waters exist for any length of time. The definition and focus of this chapter could be narrowed to include only public trust waters of North Carolina (see "Introduction" chapter for more information). This area includes surface waters up to the mean high water level (in tidal systems) or mean normal water level (in non-tidal systems). However, the area of fish utilization includes wetland areas and un-navigable streams subject to periodic flooding. Riverine, riparian wetlands are covered in the "Wetlands" chapter, whereas un-navigable streams are discussed wherever they coincide with Anadromous Fish Spawning Areas (see "Designations" section for more information).

The coastal aquatic ecosystem is divided among several river basins draining into North Carolina's estuarine and marine systems. Within a river basin, characteristics of the water column change markedly from the basin's extreme headwaters to the ocean. These factors also determine spatial and temporal differences in fish assemblage structure (reflected in "habitat requirements of aquatic life" section). Based on salinity and flow conditions, there are five major systems in coastal North Carolina (Cowardin et al. 1979).

1. **Creek and rivers** (riverine system) – All deepwater habitats contained within a channel; may have salinities in excess of 0.5 ppt.
2. **Lakes and ponds** (Lacustrine and palustrine systems, respectively) – isolated water bodies with salinity below 0.5 ppt and situated in a topographic depression or dammed river channel. Ponds are generally less than 8 ha in size and water depth is no greater than 2 m (6.6 ft). Lakes are generally greater than 8 hectares (20 acres) in size and deeper than 2 m (6.6 ft).
3. **Estuarine system** – Mixing area of saltwater and freshwater; tidally- and wind-influenced waters that are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the ocean, with ocean-derived water at least occasionally diluted by freshwater runoff from the land. The upstream and landward limit is where ocean-derived salts cause the water to have salinity 0.5 ppt during the period of average annual low flow. The seaward limit is an imaginary line closing the mouth of a river, bay, or sound.
4. **Marine system -** Open ocean overlying the continental shelf and coastline exposed to waves and currents of the open ocean shoreward to extreme high water of spring tides; or the seaward limit of the Estuarine System. Salinities exceed 30.

2.1.1. Creeks and rivers

The characteristics of river basins depend on climate, geology, topography, and land cover. The coastal plain has a basin slope of approximately one foot per mile (DWQ 1997a); higher in the southern portion and lower in the northern portion. The riverine system also changes as one moves from the headwater tributaries to mainstem channels. 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. Sluggish streams in sub-watersheds with flat topography and extensive riverine wetlands are often acidic with high inputs of dissolved organic matter (a condition known as "dystrophy"). Dystrophy also reduces the availability of nutrients for phytoplankton and dissolved oxygen for fish (Wetzel 2001). However, dystrophy does not imply poor water quality as native biological communities are adapted to such conditions in non-anthropogenically impacted such systems. *Dystrophic waters should be classified as "swamp waters" for the purpose of water quality standards* (See "Designations" section for more information)

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). Elevated discharge is a result of low temperatures and correspondingly low evapotranspiration rather than more rainfall. 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 1983 to 2008, annual discharge patterns within river basins appear to rise and fall on a 3-4 year cycle (Figure 2.2; see Map 2.1 for USGS stream gauge stations used).

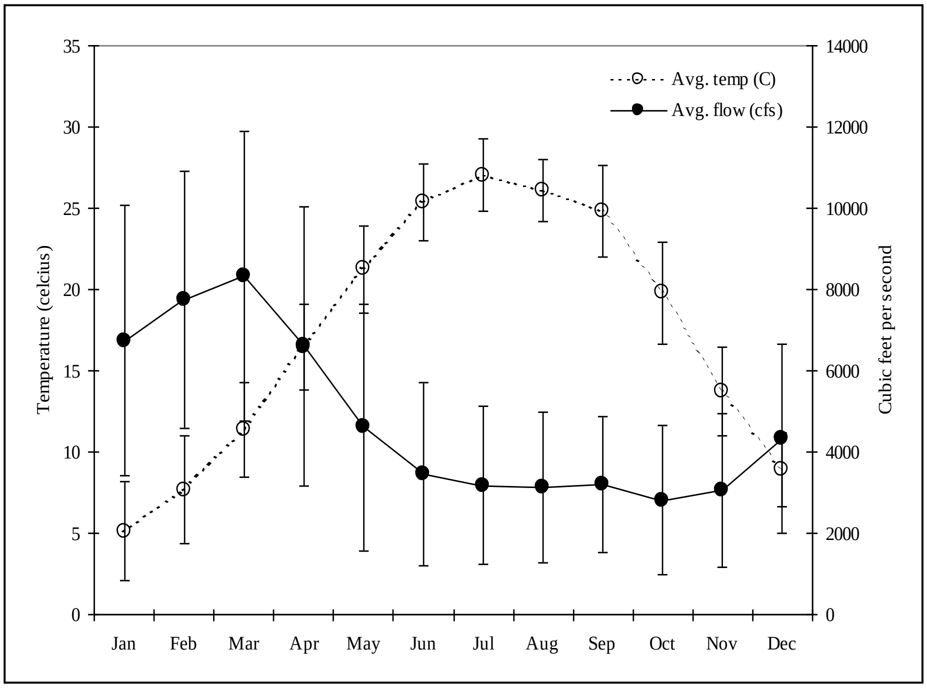


Figure 2.1. Average and standard deviation of monthly discharge (time period: 1969-1999, n = 1,464) and water temperature (time period: 1953-2001, data points per month = 52-123). [Source: USGS hydrologic monitoring stations on the lower Roanoke, Tar, Neuse, and Cape Fear rivers, North Carolina. (Station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

Five major riverine systems flow into North Carolina's coastal waters: the Chowan, Roanoke, Tar-Pamlico, Neuse, and Cape Fear (Map 1.1). Smaller, coastal plain systems include the blackwater tributaries of the Albemarle Sound, the New and White Oak rivers, and the coastal rivers of Lockwoods Folly and Shallotte rivers. Of the smaller systems, only the blackwater tributaries of the Albemarle Sound have a significant freshwater component. The New, White Oak, Lockwoods Folly, and Shallotte Rivers are primarily estuarine. The input from these riverine systems affects the quality and quantity of water in receiving estuarine systems.

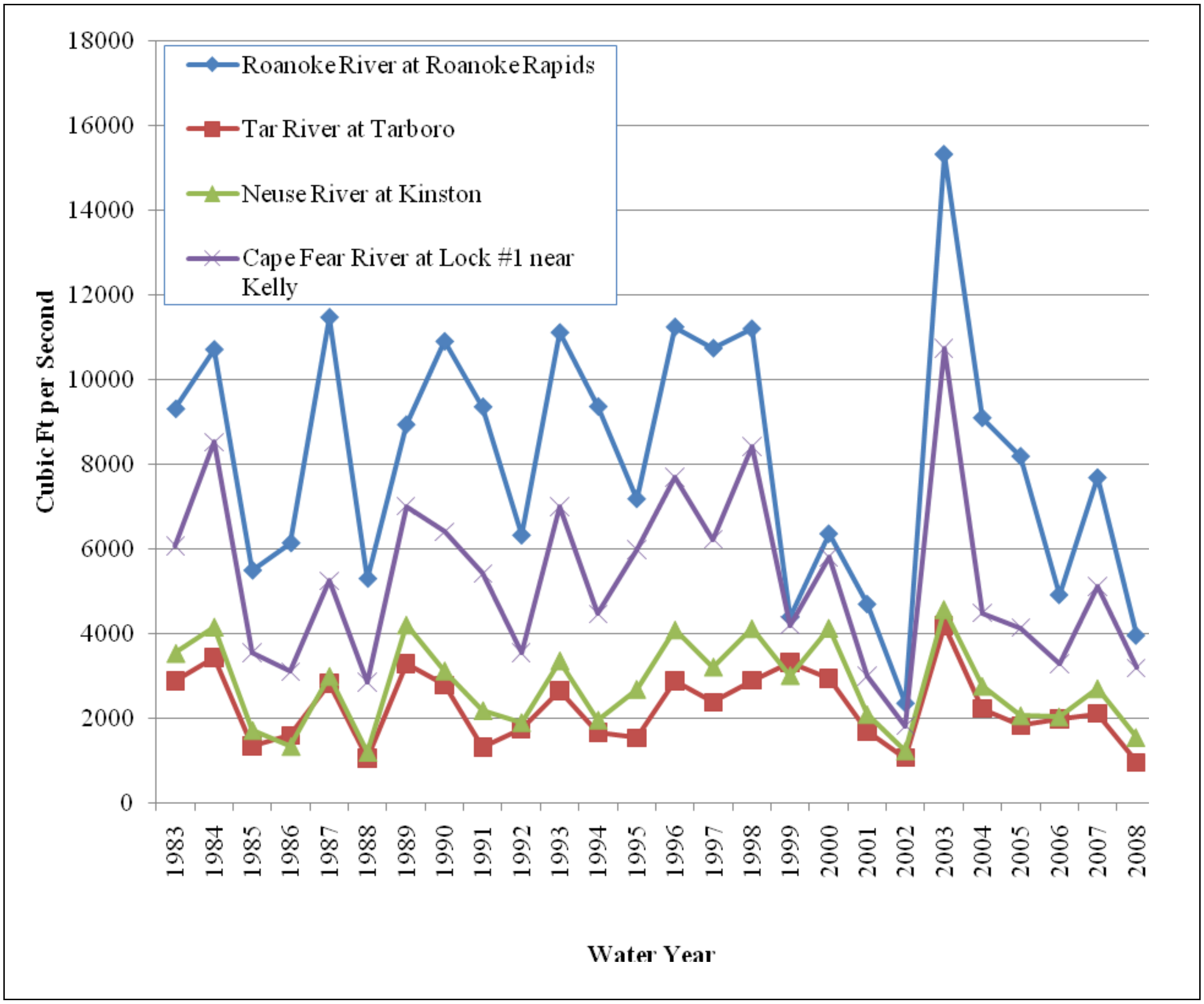


Figure 2.2. Average annual discharge in the Roanoke, Tar, Neuse, and Cape Fear rivers during water years 1983-2008, based on data from the USGS hydrologic monitoring stations. (Station locations are marked on Map 2.1)

2.1.2. Lakes and ponds

There are 16 natural lakes in North Carolina's coastal plain (Menhinick 1991). 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 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. The largest natural lake in North Carolina, Lake Mattamuskeet (41,084 acres), 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).

2.1.3. 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 lunar tides, prevailing winds, and density-layered flows. According to NOAA salinity maps, the 0.5 ppt-seawater zone, excluding coastal ocean waters, ranges from 2.0-2.1 million acres. These areas include only internal waters (excluding tidal wetlands) and a portion of Back Bay in Virginia. Coastal and Joint Fishing Water jurisdictions (excluding coastal ocean waters) include tidal wetlands for a total area of 2.2 million acres. A four-zone estuarine classification based on NOAA mapping is used in this document (Map 2.2a-b and Figure 2.3):

1. 0.5-5 (low-salinity)
2. 5-15 (moderate-salinity)
3. 15-25 (high-salinity)
4. 25-30 (inlet-salinity)

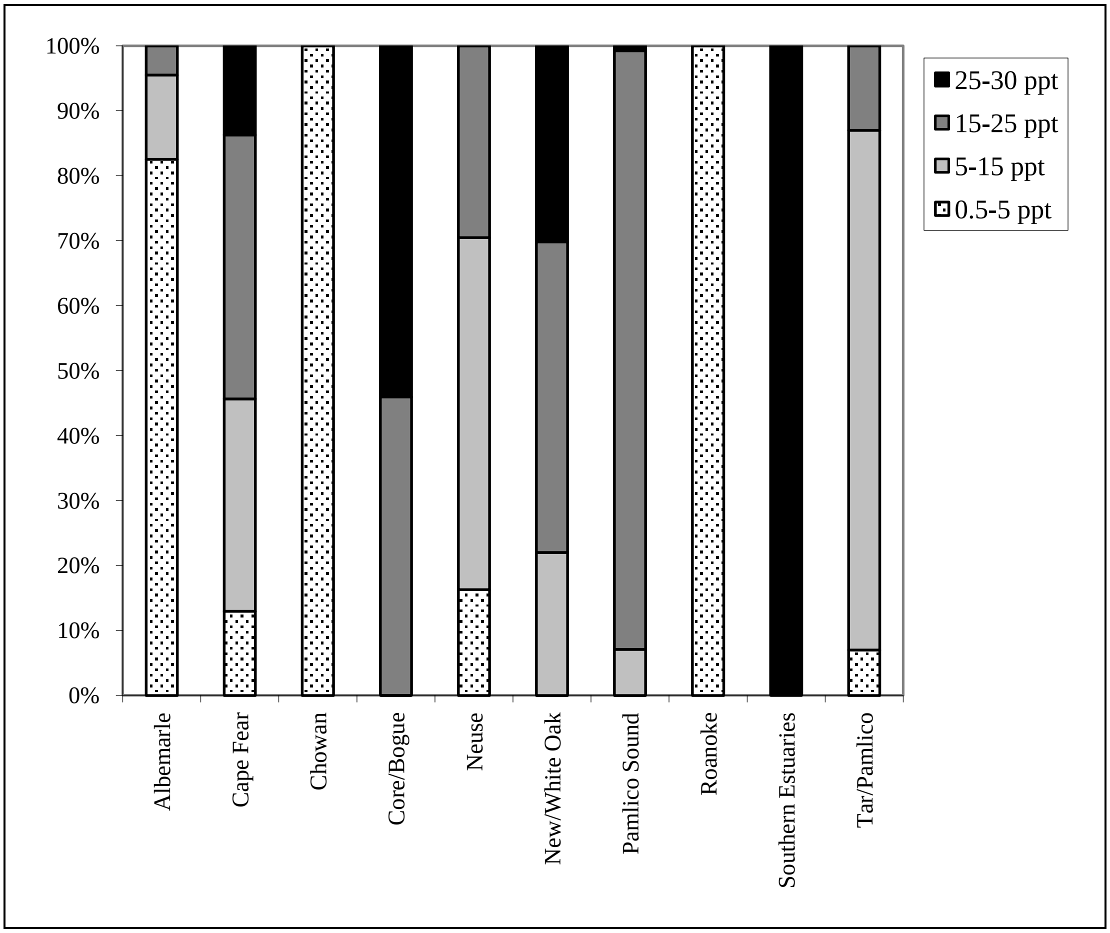


Figure 2.3. The relative proportion of estuarine salinity zones within CHPP subregions (excluding the coastal ocean). [Source: NOAA's 1:100,000 scale salinity mapping (Coastal Ocean Resource Assessment Program).]

Boundaries between salinity zones change in response to river flows, weather conditions, and tidal fluctuations. Flooding can result in fresh water expanding seaward over denser masses of water in the "mixing zone" (salinity 0.5-25 ppt). Conversely, dry weather can result in seawater advancing into typically freshwater areas. Estuarine salinities generally vary in accordance with the seasonal and annual pattern of river inputs depicted in Figures 2.1 and 2.2 and Maps 2.2a-b). 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. 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. Near inlets in the Albemarle-Pamlico system, lunar tides are the dominant influence on salinity variation and salinities vary between 25 and over 30 (Orlando et al. 1994). Dynamic inlet areas are typically the boundary of estuarine and marine systems.

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 are much greater (Reed et al. 2004, 2008). 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, or hypoxic bottom water in the summer, welling up along the leeward shore (Luettich et al. 1999; Borsuk et al. 2001). Wind tides also affect salinity in the estuary, by pushing high-salinity water from the ocean toward the estuary. One model of the Albemarle-Pamlico system predicts 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.

Estuarine salinities and circulation are reflected in the variable flushing rates of different estuarine systems. The Albemarle-Pamlico Estuarine system has a long flushing period (about 272 days) relative to the other North Carolina estuarine systems (Table 2.1). 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). 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. In the Pamlico-Pungo, Neuse, and New rivers, freshwater inflow is the dominant influence on salinity and water column mixing (Orlando et al. 1994), which is reflected in the higher flushing rates. The highest flushing rate of 14 days was in the Cape Fear estuary due to high river discharge directly to ocean waters, and low cross-sectional area.

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, Burkholder et al. 2004 – Albemarle Sound only)

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	597	318	214
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

2.1.4. Marine systems

Marine systems are defined as open ocean waters overlying the continental shelf and its associated high-energy coastline where salinities exceed 30 (Cowardin et al. 1979). Salinity, temperature, and circulation patterns in the marine system are affected by freshwater input, proximity to inlets, prevailing winds, major ocean currents, and shoals. The mix of factors results in generally uniform temperatures and salinities (from top to bottom) on the inner shelf during fall and winter (Menzel 1993). During summer, inner shelf waters are often stratified.

The effects of freshwater runoff are also most apparent near inlets and river mouths. Salinities and temperatures 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). 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. In contrast, the Neuse and Pamlico estuaries are almost entirely wind-influenced, with very little effect of tides.

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). 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.

The warm, north-flowing Gulf Stream and cool, south-flowing Virginia Coastal Labrador current meet near Cape Hatteras, separating mid- and south Atlantic waters. Warm Gulf Stream waters tend to elevate temperatures and salinities in the water column south of Cape Hatteras, and transport fish larvae from southern areas into North Carolina nearshore waters (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). These currents also interact with shoals extending roughly perpendicular from shore near capes and inlets along North Carolina's coastal ocean. Oceanic currents interacting with these shoals create upwellings of nutrient-rich bottom water. 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.

2.1.5. Fish assemblages by system

Salinity and proximity to inlets are the key factors shaping fish distribution in North Carolina estuaries (Ross and Epperly 1985; Noble and Monroe 1991; Szedlmayer and Able 1996). Salinity affects fish distribution according to physicochemical tolerances specific to a species or life stage. 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) (see Appendix D for scientific names of species). Inlet proximity affects the delivery of organisms from offshore spawning areas to their nearest intersection with estuarine nursery areas. A partial list of important fishery species in North Carolina coastal waters is shown in Table 2.2. Species are organized by salinity zone of spawning and nursery areas to give an indication of where species occur in coastal waters. The demersal/pelagic orientation of species and life stages is also listed for the table.

In low-salinity areas of coastal North Carolina, the fish community is dominated by freshwater and anadromous species (Table 2.2). In late winter, river herring (blueback herring and alewife), striped bass, Atlantic sturgeon, American shad, 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 (Sholar 1975, Marshall 1976, Sholar 1977, Fischer et al. 1979, Hawkins 1980). Residents of the low-salinity zone 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). The low-salinity zone is also occupied by the catadromous American eel. 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) also occupy the low-salinity zone (Table 2.2).

Unlike freshwater and low-salinity areas, the moderate- to high-salinity zone has very few and generally small resident species (i.e., gobies, anchovies, pipefish, grass shrimp, hogchokers) (Epperly and Ross 1986). Eastern oysters, bay scallops, and hard clams are the only fishery species that resides year-round in moderate- to high-salinity estuaries. During the growing season, these areas are dominated by the young of estuarine and marine spawning fishery species including Atlantic menhaden, spot, Atlantic croaker, southern flounder, striped mullet, blue crabs, red drum, and seatrout. Catadromous American eels migrate through the lower estuary in late summer to fall on their way to spawning in the Sargasso Sea. Anadromous fish migrate through these areas during their fall to early winter migration to the open ocean. Higher salinity regions of the estuary are also used by marine species including black sea bass, bluefish, juvenile gag, gulf flounder, summer flounder, pinfish, sheepshead, kingfish, and Spanish mackerel (Table 2.2). Other common inhabitants of the nearshore marine zone during the growing season include bottom fish such as kingfishes, Florida pompano, and dogfish sharks, along with more pelagic species like silversides, striped mullet, king mackerel, cobia, silversides. During late fall and winter, the nearshore marine zone is flooded with the post-juveniles of species reared in the estuary (i.e., southern flounder, Atlantic croaker, spot, shrimp, striped mullet, Atlantic menhaden, red drum, and seatrout) (Francesconi 1994, Hackney et al. 1996, Ross and Lancaster 1996).

Recent research in the Chesapeake Bay suggests a shifting pattern of dominance among spawning/nursery guilds in estuaries related to cycles of wet and dry climatic conditions (Wood and Austin 2009). The abundance of anadromous species (striped bass, river herring) was inversely correlated with abundance of shelf-spawning estuarine species (spot, Atlantic menhaden) using a long time series of fisheries-independent data (1968-2004). The data also suggested that recruitment dynamics were driven more by interannual variability than spawning stock biomass. Among species comprising spawning/nursery area guilds (i.e., river herring and striped bass), spawning stock biomass, predator-prey interactions, and differences in habitat availability can still be more significant sources of recruitment variation. The CHPP focuses primarily on habitat-mediated predator-prey interactions and other ecological functions of available habitat. Spawning stock/recruitment relationships are thoroughly evaluated for species subject to Fisheries Management Plans.

Table 2.2. Spawning location/strategy ("spawning/nursery guild") and vertical orientation of some prominent coastal fishery species.

Species*	Vertical orientation[1]	
	Demersal[2]	Pelagic
RIVERINE SPAWNING, FRESHWATER-LOW SALINITY NURSERY (ANADROMOUS)		
River herring (alewife and blueback herring)	**E**	**A, J, L**
American shad	**E**	**A, J, L**
Sturgeon (Atlantic and shortnose)[3]	A, J, E	
Hickory shad	**E**	**A, J, L**
Striped bass	A, J	E, L
MARINE SPAWNING, RIVERINE NURSERY (CATADROMOUS)		
American eel	A, J	E, L
ESTUARINE/INLET SPAWNING, ESTUARINE NURSERY		
Bay scallop	A, J, E	L
Hard clam	A J	E, L
Oyster	A, J	E, L
Blue crab	A, J, E	L
Cobia		**A, J, E, L**
Red drum	A, J	E, L
Spotted seatrout	A, J	E, L
Weakfish	A, J	E, L
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY		
Atlantic croaker	A, J	E, L
Atlantic menhaden		**A, J, E, L**
Shrimp	A, J, E	L
Southern flounder	A, J	E, L
Spot	A, J	E, L
Striped mullet	**A**	**J, E, L**
MARINE SPAWNING, HIGH SALINITY NURSERY		
Black sea bass	A, J	E, L
Bluefish		**A, J, E, L**
Florida pompano	A, J	E, L
Gag	A, J	E, L
Gulf flounder	A, J	E, L
King mackerel		**A, J, E, L**
Kingfish	A, J	E, L
Pinfish	A, J	E, L
Sheepshead	A, J	E, L
Spanish mackerel		**A, J, E, L**
Summer flounder	A, J	E, L

* Scientific names for species are listed in Appendix D. Pelagic species are **bolded**.
[1] Sources include Epperly and Ross (1986), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998), 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 occur primarily in the water column. A=adult, J=juvenile, L=larvae, and E=egg.
[3] Former fishery, but fishing moratorium since 1991

2.1.6. Fish habitat requirements

Within salinity zones, a specific combination of physical and chemical water quality parameters within the known tolerance range of the species is required for the water column to provide suitable habitat for various fish species. Those parameters include flow and water movement, pH, temperature, dissolved oxygen, and water clarity.

2.1.6.1. Flow and water movement

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.

Aquatic organisms rely on flow and water movement to: (1) distribute sediment and affect structures that serve as habitats (i.e., shell bottom, SAV, soft bottom) for many fish species (DMF 2003b), (2) cue spawning activity, and (3) transport/distribute eggs, larvae, and juveniles to the appropriate nursery area for optimum food availability and protection from predators. 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). Refer to, "Ecological role and function," sections for specific information on spawning and nursery habitat conditions.

As fish larvae grow in mobility, the nursery value of areas depends on complex biological interactions mediated by water movement and other parameters. 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.

2.1.6.2. pH

The pH of the water column is a basic chemical characteristic that affects egg development, reproduction, and the ability of fish to absorb dissolved oxygen (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 freshwaters. 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 organic matter content and buffering capacity of the water. Freshwaters with low buffering capacity and high organic matter (e.g., swampy creeks) can have very low pH (<5). The pH standard for surface freshwaters in North Carolina is between 6.0 and 9.0 depending on classification (see "Designations" section for more information). With dense plant growth, pH and dissolved oxygen may fluctuate dramatically between day and night. 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. Globally, ocean acidification impacts shell formation due to the increased carbon dioxide in the atmosphere. Carbon dioxide readily dissolves in the water creating carbonic acid, which lowers the pH and alters the saturation point of calcium carbonite and aragonite; the components used in making shell (See the hard bottom chapter).

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 and 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. Gerritsen et al. (1996) studied the effects of periodic acidification in headwater streams harboring spawning river herring. The acidification was attributed to rain storms in poorly buffered streams. Several coastal streams in the Chesapeake Bay watershed were monitored for pH and correlated with base-flow conditions, buffering capacity, and precipitation. These factors explained 74% of the variation in stream pH. The resulting risk assessment for the Chesapeake Bay predicted greater than 50% of streams would experience harmful pH levels during wet years. *A similar assessment of acidification risk should be conducted in Anadromous Fish Spawning Areas in North Carolina.*

2.1.6.3. 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. 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). See, “Ecological role and functions,” section for specific information on the spawning habitat of anadromous fish.

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/spottedseatrout.htm, January 2010).

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).

2.1.6.4. 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). Fish are also impacted by the increase in sulfide production associated with low dissolved oxygen 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).

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 2-4 mg/l, whereas spot and pinfish showed no preference. 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, and bluefish (Deubler and Posner 1963, Funderburk et al. 1991; Pattilo et al. 1997; Blanchet et al. 2001, Taylor and Miller 2001). 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, and yellow perch (Funderburk et al. 1991). The majority of species requiring high DO are pelagic species, although some prominent forage species can tolerate hypoxic conditions.

Among invertebrate species, mortality was reported 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. Carpenter and Cargo (1957, *in* Funderburk et al. 1991) documented 50% mortality of blue crabs at DO levels <2.0 mg/l. Another study reported total mortality of crabs after 3 hours in hypoxic conditions (DO < 0.5 mg/l) (De Fur et al. 1990 *in* Funderburk et al. 1991). The DO requirement of adult hard clams and brown shrimp is reported as >4 mg/l and 3-4 mg/l, respectively (Funderburk et al. 1991; Pattilo et al. 1997). Benthic hypoxia and anoxia degrade water column habitat by altering the behavior, growth, production, and survival of both benthic invertebrates and mobile vertebrates (Breitburg 1992).

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 during the growing season can also be fueled by nutrients and oxygen-consuming wastes, which result in excessive oxygen demand in the water column or sediment (see “Nutrients” section for more information). Algal production and microbial decomposition are enhanced in warm, nutrient-rich waters. Excessive algal production can deplete the water column of DO through nighttime plant respiration (DWQ 2000b). Excessive algal production creates labile organic biomass that dies and is consumed by microbial decomposition, creating a biochemical oxygen demand (BOD). Chlorophyll *a* concentrations and BOD have been strongly correlated in a variety of North Carolina coastal creeks, estuaries, lakes and rivers (Mallin et al. 2006). Warmer water, calm winds, and reduced freshwater inflow in the summer also reduces mixing and the corresponding aeration of the water column. 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).

Weather events can have varying impacts to water column habitat. Low-oxygen events frequently occur as a result of increased runoff and organic loading from heavy rainfall. Alternatively, hurricanes can flush out large quantities of organic matter that has accumulated in estuarine systems, reducing excessive nutrients that could otherwise fuel eutrophication over many years (Paerl et al. 2001, Burkholder et al. 2004).

2.1.6.5. 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 especially important for aquatic plant growth. Some amount of turbidity is natural in a water body, as it is related to nutrient inputs and productivity. Extreme turbidity is known to reduce light availability for plant growth, reduce visibility of pelagic food (Bruton 1985), and enhance temperature stratification. As a general rule, algae species can grow to a depth of 1% of surface light availability (Wetzel 2001). Submerged aquatic vegetation (SAV) has higher light requirements than microalgae and represents a more sensitive indicator of impaired light availability (see “Submerged aquatic vegetation” chapter for more information) where SAV is naturally occurring and non-invasive. For most visual fish predators, turbidity reduces 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, Reilly and Bellis 1983, Benfield and Minello 1996, Lindquist and Manning 2001). However, moderate turbidity can be beneficial to small or non-visually feeding fish afforded protection from visually feeding predators in shallow, food-rich areas (see "Ecological role and function" section on "Refuge" for information). Suspended particles causing turbidity also have physical effects on aquatic organisms explained in the "Sediment and turbidity" subsection of the "Water quality degradation – Causes" section.

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 by virtue of benthic-pelagic coupling. Benthic-pelagic coupling refers to the influence of the water column on the benthic community and sediments and vice versa (see "Soft bottom" chapter for more information), through integrated events and processes such as resuspension, settlement, and absorption (Warwick 1993).

2.2.1. Productivity

The potential productivity of fish and invertebrates in an aquatic system is determined by the assimilation of energy and nutrients by plants and other life at the base of the food chain. Productivity in the water column is derived from phytoplankton, floating plants, macroalgae, benthic microalgae, and bacterial decomposition of plants (detritus). The potential productivity of a habitat can indicate its relative value in supporting fish populations. 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 can support the majority of secondary production. Rivers play a dominant role in providing nutrients and flushing for downstream estuaries in the Albemarle, Tar-Pamlico, Pamlico, Neuse, and Cape Fear subregions. These nutrients, in turn, contribute to primary productivity and fish production. Mallin et al. (1993) demonstrated that primary productivity in the Neuse River estuary was strongly correlated with river discharge, which in turn was strongly correlated with nitrate and rainfall in the Neuse headwaters area. Arhonditsis et al. (2007) examined the spatiotemporal phytoplankton community patterns to assess underlying causal mechanisms in a freshwater–saltwater continuum, the Neuse River Estuary. Their modeling results indicated hydrologic forcing (mainly the river flow fluctuations) as a dominant factor in up-estuary processes that loosens the coupling between nutrients and phytoplankton. The switch from hydrologic forcing upstream to nutrient forcing downstream led to a phytoplankton accumulation in the mid- and down-estuary segments. This was more evident among diatoms, chlorophytes and cryptophytes, which exhibit opportunistic behavior (faster nutrient uptake and growth rates and tolerance to low salinity conditions) that allows them to dominate the phytoplankton community during high freshwater flows. Model results also showed a stronger association between phosphorus and total phytoplankton dynamics at the upstream freshwater locations. Both nitrogen and phosphorus played a significant role in the middle section of the estuary, while the nitrogen–phytoplankton relationship was stronger in the downstream meso-polyhaline zone. The research also provided evidence of a prolonged favorable environment for cyanobacteria going down-estuary, resulting in structural shifts on the phytoplankton assemblage through time.

In the mesohaline Neuse Estuary, Rothenberger et al. (2009a) used a continuous, long-term record of environmental data and phytoplankton species and assemblage structure to evaluate phytoplankton responses to changing environmental conditions, and potential environmental predictors of phytoplankton assemblage patterns. Their models indicated that phytoplankton assemblages were strongly related to temperature and total nitrogen to total phosphorus ratios. Inter-annual changes in river discharge influenced whether the phytoplankton assemblages were dominated by diatoms and photosynthetic flagellated algae, or by heterotrophic dinoflagellates. Overall, the data from this study suggested an increasingly important role of ammonium in controlling phytoplankton assemblage structure in the Neuse Estuary.

Studies of phytoplankton production in several NC and South Carolina estuaries have reported relatively high productivity, ranging from 67-500 g/C/m^2/y (Williams and Murdoch 1966; Thayer 1971; Sellner and Zingmark 1976; Peterson and Peterson 1979). 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 Estuary), whereas areas that are well flushed or unconstrained (e.g., Cape Fear River) support a much lower phytoplankton biomass and productivity.

However, phytoplankton productivity is 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 juvenile fish production is the major export (see “Wetland” chapter for more information).

Phytoplankton production in shallow estuaries can also be secondary to phytobenthic (microscopic plants that live on the bottom) production. 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. Other turbid estuaries also were found to have high primary productivity from resuspended benthic microalgae (Cloern 1987; Mallin et al. 1992; MacIntyre and Cullen 1996). The type and net productivity of a given estuary depends on water column conditions that also affect the relative proportion of wetlands, shallow soft bottom, SAV, shell bottom and deep water in the system.

In nearshore ocean waters, Menzel (1993) reported that primary production rates decreased significantly from the inner shelf to the outer shelf of the South Atlantic Bight. 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). Mallin et al. (1992) estimated that microalgal production can be at least 66% of the total annual primary production in coastal areas, the majority of which is contributed by benthic microalgae. 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.

Production levels in nearshore waters may increase by a factor of three to ten with warm core intrusions from the Gulf Stream (Signorini and McClain 2007). Upwellings, associated currents, and winds also transport floating *Sargassum* weed (from the Sargasso Sea) into nearshore coastal waters. 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.

2.2.2. 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 alewife, American shad, hickory shad, blueback herring, bay anchovy, silversides, Atlantic menhaden, striped mullet, bluefish, cobia, king mackerel, 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. Primarily demersal species/life stages also have water quality requirements documented in these sections.

Fish use of water column can be assessed using a variety of sampling methods. A recent application of hydroacoustics could prove useful for assessing pelagic fish abundances in similar areas of the state. Mitchell et al. (2007) tracked and attempted to identify fish during their anadromous spawning migration using hydroacoustics, fish wheels and shocking boats. Using acoustic signal strength differences Mitchell et al. (2007) was able to identify and estimate the number of anadromous fish (e.g. American shad, gizzard shad, and striped bass) migrating upstream to spawn in the Albemarle Sound and Chowan River.

2.2.2.1. 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 reach other habitats supporting other functions. The corridor function is particularly important for species whose life history spans more than one system (anadromous, catadromous, and marine spawning/estuarine nursery) (Table 2.2). 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 from spawning areas (see "Spawning" subsection for more information) to favorable nursery areas (see "Nursery" subsection for more information). The spatial and temporal interplay of factors triggering migration and the water column conditions needed for successful migration determine the degree of corridor function in an area. The primary conduits used by meroplankton and migrating fish include the ocean inlets and the network of channels draining the coastal region from riverine headwaters to downstream estuaries. The most variable connections occur in tributaries where local watershed conditions are isolated from the mixed conditions in the mainstem. These corridors are implied from the discussion of spawning and nursery areas below.

2.2.2.2. Spawning

During late winter and early spring, increasing light, flow, and temperature in freshwater creeks and rivers provides spawning habitat for resident freshwater and anadromous fish (Orth and White 1993) (Table 2.3). The reverse is true for marine spawning/estuarine nursery species as declining light, flow, and temperature in low salinity nurseries triggers spawning in the ocean during late fall and early winter. Species completing their life cycle in the inlet estuary system (i.e., red drum, seatrout, blue crab, eastern oyster) generally spawn during summer and fall. Specific conditions for spawning vary according to species and the mix of triggers for photoperiod, temperature/salinity change, and river discharge. When conditions are met for spawning, many fish species broadcast planktonic or semi-demersal eggs. Survival of the planktonic larvae (meroplankton) to free-swimming juveniles is affected by water quality, flow and circulation patterns in route to nursery areas. 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). Once the eggs are released into riverine waters, the survival of the developing larvae depends on reaching favorable nursery habitat conditions (see "Nursery" section for more information).

Table 2.3. 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.

Anadromous fish spawning

Anadromous fish species such as river herring (alewife and blueback herring), striped bass, and shads (hickory and American shad) use the riverine water column during spring to broadcast eggs, which develop as they float downstream. Current velocity, increasing light and temperature are all important cues for anadromous spawning activity (Klauda et al. 1991; Orth and White 1993) (Table 2.4). Sufficient rainfall during mid-February to mid-June is needed to provide suitable current velocities for spawning. The strongest currents are required by striped bass and blueback herring, whereas slower current velocities are needed for American shad and alewife (Funderburk et al. 1991). 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). Alewife spawn in lakes, slow-moving oxbows and small streams where the species co-occurs with blueback herring. Alewives spawn in water that is between 15cm and 3m deep, while blueback herring prefer deeper waters (Ross 1991). Blueback herring will use lentic (standing) water or lotic (moving) water as spawning habitat, while alewives will only use lentic (Walsh et al. 2005). Lake Mattamuskeet is a lentic system that historically supported significant anadromous alewife spawning runs (Winslow et al. 1983, Epperly 1985). Species also differ in whether they prefer the mainstem river or small tributary creeks for spawning. Mainstem spawners include American shad and striped bass (Funderburk et al. 1991). Blueback herring and alewife spawn in tributary creeks. For hickory shad, there is evidence of spawning in flooded tributaries in North Carolina and Virginia (Pate 1972, Funderburk et al. 1991). Species-specific spawning areas are included, but not differentiate, on designated Anadromous Fish Spawning Areas (See “Designations” section for more information). In terms of water quality, adequate DO levels in slow-moving backwaters are critical to spawning river herring because the eggs require >5 mg/l DO (Funderburk et al. 1991) (see “Dissolved oxygen” subsection of “Habitat requirements” section for more information). During their spawning migration, anadromous fish actively avoid waters with low DO and extremely high turbidity (Steel 1991).

Table 2.4. Physical spawning (adult) and egg development requirements for resident freshwater and 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)**		**Dissolved oxygen (mg/l)**		**Flow (cm/s)**	**Other parameters**
Species	**Adult**	**Spawn/ Egg**	**Adult**	**Spawn/ Egg**	**Adult**	**Spawn/ Egg**	**Spawning**	**Spawn/ Egg**
Alewife	[S] 0-5	[S] 0-5 [O] 0-2		[S] 11-28 [O] 17-21	[S] >3.6	[S] >4	[O] slow current	[S] Suspended solids <1000 mg/l
American shad	[S] 0-18	[S] 0-18	[S] 10-30	[S] 13.0-26.0	[S] >5		[S] 30-90	
Blueback herring	[S] 0-5	[S] 0-22 [O] 0-2		[S] 14-26 [O] 20-24	[S] >5		[O] strong current	[S] Suspended solids <1000 mg/l
Striped bass	[S] 0-5	[S] 0.5-10	[S] 20-22	[S] 12-24, [O] ~18-22	[S] >5		[S] 30.5-500, [O] 100-200	
Yellow perch	[S] 0-13	[S] 0-2	[S] 6-30		[S] >5			[S] Suspended solids <1000 mg/l
White perch	[S] 5-18	[S] 0-2	[S] 10-30	[S] 12-20	[S] >5			[S] Suspended solids <100 mg/l
Sturgeon, Atlantic	[S] 0 to >30	[S] 0-5	[S] 0 to >30	[S] 11-20				
Sturgeon, Shortnose	[S] 0 to >30	[S] 0-5	[S] 0 to >30	[S] 5-15				

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

Estuarine spawning

The estuarine spawning species are mostly resident forage finfish species that spawn in shallow water during the warmer months (Table 2.3). This group also includes some important shellfish species (e.g., oysters, hard clams, bay scallops, blue crabs) and sportfish (e.g., red drums, weakfish, spotted seatrouts, cobia) that spawn in deeper, flowing waters (Luczkovich et al. 1999; Powers and Gaskill 2004). Red Drum will spawn in high salinity nearshore waters, including inlets and estuaries (such as Pamlico Sound), in late summer (Murphy and Taylor 1990, Johnson and Funicelli 1991, Nicholson and Jordan 1994). These waters have the necessary conditions for the pelagic red drum eggs and larvae to be transported to the nursery grounds (Johnson 1978, Ross and Stevens 1992). Red drum larvae require water to have salinity greater than 25 ppt (Nelson et al. 1991).

Spawning for blue crabs, 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, DMF 2004a). Winds and currents carry the larvae resulting from spawning to nursery habitats in the estuary and nearshore ocean. Understanding water movements is therefore essential in understanding larval transport. Lipcius et al. (2008) discuss how one must understand habitat quality, larval dispersal, and population dynamics when trying to replenish a stock through a stock replenishment program. A stocking program fails if it supplies individuals to a habitat, and the individuals do not recruit to the spawning stock. It is also important to know where the spawning occurs. Blue crabs, for example, spawn near inlets from April-June and August-September (Table 2.3). Ballance and Eggleston (2008) studied oyster larvae transport and settlement in Pamlico Sound. The results suggest where to place source population for supplying recruits to other areas (see “Shell bottom restoration and enhancement” section of Shell Bottom chapter for more information). Successful movement of larvae through the inlets is also of great importance to North Carolina fisheries, particularly where inlets are limited, such as along the Outer Banks (see “Marine spawning” section for more information). The environmental requirements for successful spawning and egg development for estuarine spawners are shown in Table 2.5.

Table 2.5. 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)]

Species	Salinity (ppt)		Temperature (C)		Dissolved oxygen (mg/l)		Other parameters	
	Adult	Spawn/ Egg	Adult	Spawn/ Egg	Adult	Spawn/ Egg	Adult	Spawn/ Egg
Atlantic silversides		[O] ~30	[S] 14.5-30	[S] 15-30	[S] 1-3			
Bay anchovy	[S] o to >30	[S] 0.5 to >30	[S] 11-30	[S] 13-30	[S] >3			
Bay scallop	[S] >14	[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				
Blue crab	[S] 0-30	[S] 10-32, [O] 23-28	[S] 5-39	[S] 19-29	[S] >3			
Cobia	[S] 18 to >30	[S] >30	[S] 21 to >30	[S] 21 to >30				
Hard clam	[S] 10 to >30, [O] 24-28	[S] 18 to >30	[S] 16-30	[S] 16-30	[S] >5	[S] >0.2	[S] Suspended solids <44 mg/l	[S] Suspended solids <750 mg/l
Inland silversides		[S] 0-31.5	[S] 15-30	[S] 13-34, [O] 20-25	[S] >1.7			
Oyster	[S] 2 to >30, [O] 14-30	[S] 7.5-34, [O] 10-22	[S] 21-30	[S] 19-32	[S] >1			[S] Suspended solids <250 mg/l
Red drum	[S] 0 to >30, [O] 20-30	[S] 10-40, [O] 29-32	[S] 21-30	[S] 21-30	[S] >5			
Spotted seatrout	[S] 2 to >30, [O] 20-25	[S] 15-28, [O] ~28.1	[S] 16-30	[S] 16 to >30, [O] ~28				
Weakfish	[S] 1 to >30	[S] 12 to >30	[S] 10-30	[S] 18-24				

[S] = suitable, [O] = optimum

Marine spawning

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. There are basically two groups of marine spawners based on nursery area location: 1) Marine spawning, low-high salinity nursery, and 2) marine spawning, high salinity nursery (Table 2.3). The first group includes spot, Atlantic croaker, southern flounder, Atlantic menhaden, shrimp, and striped mullet spawning offshore from fall to late winter (Anderson 1958, Epperly and Ross 1986). The specific time of spawning is determined by coincidence of environmental conditions in the water column (Table 2.6). Their larvae are transported into the estuaries where they settle in nursery areas of low to high-salinity. The other group of marine spawners (pinfish, black sea bass, gag, kingfish) reproduces at various times, but their nursery habitat is limited to higher salinity areas. Evidence suggests that gag grouper will spawn offshore and larvae will spend some time in high salinity inlets before moving into estuaries (Keener et al. 1988). The DMF initiated a program in 2009 to study the ingress of gag larvae to estuaries near Masonboro Inlet in CHPP region 4 (Chip Collier/DMF, pers. com., September 2009). The study results are being used to calculate an annual index of abundance for larval gag grouper, among other things.

The larvae of both spawning/nursery area groups is affected by hydrodynamic conditions within oceanic inlets. Research projects conducted under the South Atlantic Bight Recruitment Experiment (SABRE) studied transport of winter-spawned fish larvae into the estuaries. They found larvae concentrated on the shelf in a narrow “withdrawal zone” upwind of an inlet within the 23-foot (7m) depth contour. When the ocean currents were appropriate, the larvae passed through the inlets. Even with the 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 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). The larvae of estuarine inlet spawners such as red drum, seatrout and blue crab are also affected by hydrodynamic conditions propagated through inlets.

Table 2.6. 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), Gilmore and Jones 1992, Pattilo et al. (1997), SAFMC (1998a), Wannamaker and Rice (2000), Blanchet et al. (2001), NOAA (2001), ASMFC species profiles]

	Salinity		**Temperature (C)**		**Dissolved oxygen (mg/l)**	
Species	**Adult**	**Spawn/ Egg**	**Adult**	**Spawn/egg**	**Adult**	**Spawn/ egg**
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY						
Atlantic croaker	[S] 0 to >30	[S] 18 to >30	[S] 5 to >30	[S] 16-25	[S] >5	
Atlantic menhaden	[S] 0 to >30	[S] 24 to >30	[S] 5-30	[S] 12-20	[S] >1.1	
Shrimp, brown	[S] 0.8-45, [O] 24-38.9	[S] >24	[S] 4-36, [O] 14.9-31	[S] 24 to >30	[S] 3-4	
Southern flounder	[S] 0 to >30	[S] 18 to >30	[S] 5 to >30	[S] 11-25	[S] >3	
Spot	[S] 0 to >30	[S] >30	[S] 0-25	[S] 16-25	[S] >2	
Striped mullet	[S] 0 to >30	[S] 18 to >30, [O] >30	[S] 5.9 to >30	[S] 10 to >30, [O] 21-24	[S] 1-3	[S] 3-4
MARINE SPAWNING, HIGH SALINITY NURSERY						
Black sea bass	[S] high salinity	[S] high, stable salinity	[S] >7			
Bluefish	[S] 7 to >30	[S] 26.6-34.9, [O] >30	[S] 12-29	[S] 16-30		
Gag	[S] high salinity		[S] >10.6			
Gulf flounder	[S] 6 to >30, [O] >20	[S] >22	[S] 8.3 to >30	[S] 16-25		
Pinfish	[S] 0 to >30	[S] 18 to >30	[S] 3.4 to >30	[S] 16-30	[S] >1	
Sheepshead	[S] 0.5 to >30	[S] >30	[S] 5-30, [O] 25	[S] 21-30		
Southern kingfish	[S] 0.5 to >30	[S] >30	[S] 11 to >30	[S] 16-25		
Spanish mackerel	[S] 18 to >30	[S] >30	[S] 20 to >30	[S] 20 to >30		
Summer flounder	[S] 5 to >30	[S] >30	[S] 0 to >30	[S] 14-17		

[S] = suitable, [O] = optimum

Beaufort, Ocracoke, and Oregon inlets support significant larval fish passage. Oregon Inlet, in particular, 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. Larval fish diversity passing through these inlets is very high. Sixty-one larval species have been found in Oregon Inlet, with Atlantic croaker and summer flounder being particularly abundant (Hettler and Barker 1993). Other larval species found in Oregon Inlet included bluefish, black sea bass, gray snapper, several flounder species, pigfish, pinfish, spotted seatrout, weakfish, spot, kingfish, red drum, mullet, and butterfish. Species' utilization and temporal trends in larval fish transport through Beaufort Inlet were documented by Peters et al. (1995) and Peters and Settle (1994). Table 2.7 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. 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 transport processes (Blanton et al. 1999, Churchill et al. 1999, Hare et al. 1999).

Table 2.7. 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**
Atlantic menhaden							
Summer flounder							
Southern flounder							
Spot							
Pinfish							
Gulf flounder							
Atlantic croaker							

Larval fish are also 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. During late fall and winter, estuarine-dependent species such as Atlantic menhaden, spot, and Atlantic croaker are an important component. Ichthyoplankton from estuarine-dependent species that spawn in the sounds and inlets 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. Current and wind patterns will have a strong effect on the recruitment and retention of various fish larvae from different offshore areas. 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).

2.2.2.3. Nurseries

Open water provides nursery habitat for most planktivorous larvae and many juvenile pelagic species (e.g., bluefish, river herring, menhaden, Spanish mackerel). The interactions of spawning locations, physical processes, environmental factors (salinity and temperature), chemical cues, and habitat preferences are primary factor determining larval settlement in estuaries (Luckenbach 1985, Peterson et al. 2000c, Brown 2002). The MFC designated Primary Nursery Areas as settlement areas for post-larvae of offshore winter spawners (See "Designations" section for more information). These areas total nearly

80,000 acres of coastal water column and tidal wetlands. The area of PNA represents 4% of the estuarine fishing water jurisdiction in North Carolina (76,719 acres / 1,872,773 acres). However, the percentage of estuarine shoreline as PNA designation is over 20% (1,673 miles / 7,102 miles). Nursery areas for other spawning/nursery area groups (i.e., anadromous) have not been specifically designated. Information concerning their initial settling location is presented here. Information on later juvenile stages is provided only for pelagic oriented species.

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).

Anadromous fish nurseries

Nursery habitat for anadromous fishes is generally downstream from spawning locations but still within the freshwater low-salinity system. The water quality requirements for anadromous fish larvae and juveniles inhabiting pelagic waters are listed in Table 2.8.

Table 2.8. 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		
Sturgeon, shortnose	[S] 0-5	[S] 0-5	[S] 5-15	[S] 0 to >30		
Sturgeon,Atlantic	[S] 0-5	[S] 0 to >30	[S] 11-30	[S] 0 to >30		
Yellow perch	[S] 0-2	[S] 0-5	[S] 10-30	[S] 10-30		[S] >5
White perch	[S] 0-2	[S] 0-3	[S] 12-20	[S] 10-30		[S] >5

[S] = suitable, [O] = optimum

Juvenile alewife and blueback herring in the Potomac River exhibited apparent upstream movement over the four months before emigration to nursery areas (Fay et al. 1983b). 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. While juvenile alewife were more abundant 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 were collected in upriver areas of the Tar River (CHPP Region 2) later in their maturity than blueback herring (Jones and Overton 2009). The results for juvenile blueback herring suggest a greater benefit from early arrival to higher salinity zones relative to juvenile Alewife. Jones and Overton (2009) also documented higher catch-per-unit-effort of larval river herring in "backwater" tributaries of the Tar River than in the mainstem. The peak abundances for both species in the meroplankton occurred in April and May. Recruitment of larval river herring in tributaries of the Chowan system is also related to flow conditions (O'Rear 1983). Walsh et al. (2005) observed an increase in the number of alewife larvae in 1997, when there was a large amount of wetlands flooded. Juvenile river herring migrate offshore 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).

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 waters (Funderburk et al. 1991). During winter, young striped bass may move even farther downstream and into deeper, high salinity water (Fay et al. 1983d, Hill et al. 1989). Water flow conditions are essential for recruitment for all life stages of striped bass (Hassler et al. 1981, Rulifson and Manooch 1990). In the Roanoke River, juvenile abundance indices (JAI) were highest when water flow was low to moderate (5,000-11,000 ft3/sec). When flow was above or below this range, JAI were low (Rulifson and Manooch 1990). 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) with a sandy bottom (Hill et al. 1989). During winter, young striped bass may move even farther downstream and into deeper, high salinity water (Fay et al. 1983d; Hill et al. 1989). Water flow regimes that minimize impacts to striped bass and other species were recommended in Manooch and Rulifson (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). Juvenile blueback herring will also make a nightly migration towards the surface. Juvenile river herring tend to be found higher in the water column than alewives as a way to possible reduce interspecies competition (Loesch et al. 1982, Loesch 1987). 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- and high -salinity nurseries

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 2.9). In Pamlico Sound, salinity and circulation patterns are the key physical conditions affecting the species composition occurring in juvenile nursery habitat (Ross and Epperly 1985, Noble and Monroe 1991). Low-salinity nurseries include the upper Pamlico Estuary, Pungo River, upper Neuse Estuary, the eastern portion of Albemarle Sound (including Croatan and Roanoke sounds), and the upper Cape Fear estuary. During spring through fall, pelagic species dominating shallow areas within these systems include juvenile Atlantic menhaden, striped mullet (Epperly and Ross 1986), silversides, and anchovies (Nelson et al. 1991). However, different species arrive in nursery areas at different times of the year and remain for variable periods. Post-larval striped mullet enter low-salinity nurseries primarily in winter (Nelson et al. 1991), whereas menhaden post-larvae arrive from February to June (Purvis 1976). Juvenile anchovies and silversides are generally year-long residents (Nelson et al. 1991). 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).

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). Nursery habitats for North Carolina juvenile weakfish are reported to be in deeper portions of coastal rivers, bays, sounds and estuaries (Mercer 1989, DMF unpublished program 195 data). As they grow, juvenile weakfish have been found to be most abundant in shallow bays or navigational channels that are characterized by moderate depths, slightly higher salinities, and areas with a sandy bottom (ASMFC 1996). See “Soft bottom” chapter for more information on nursery habitat for juvenile demersal fish.

Table 2.9. 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		

[S] = suitable, [O] = optimum

High-salinity nurseries

High-salinity nurseries (salinity greater than 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, protected waters of the high-salinity zone include mostly demersal species. The juveniles of pelagic species (Spanish mackerel, bluefish, 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 2.10. 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 Spanish mackerel appear (although rarely) in Bogue Sound in mid-May (Nelson et al. 1991).

Table 2.10. 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		

[S] = suitable, [O] = optimum

Some pelagic species, such as anchovies and king mackerel, rely on the nearshore boundaries of ocean water masses as nursery habitats (SAFMC 1998a). Pelagic species that use nearshore ocean waters as a nursery to some extent include butterfish, striped anchovy, striped mullet, and Atlantic thread herring (SEAMAP-SA 2000). Juveniles of other pelagic species, such as 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; Hackney 1996; DMF 2000a). Juvenile bluefish 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). The major recruitment period for juvenile fish to surf zone nurseries is late spring through early summer. Refer to the "Soft bottom" chapter for information on high-salinity nursery habitat for demersal fish.

2.2.2.4. Foraging

The primary food sources abundant in open waters are decayed plant material (detritus), phytoplankton, and zooplankton (including meroplankton). Most fish consume plankton at some point in their life cycle (larval stage in particular). Of the over 30 species listed in Table 2.2, nearly all larval stages eat phytoplankton or zooplankton. Resuspended benthic microalgae are also an important source of food (see "Soft bottom" chapter for more information). The diet of adult, pelagic filter-feeders (i.e., river herring, shads, Atlantic menhaden, striped mullet) includes zooplankton (the most common component), detritus, or phytoplankton (the least common). Filter-feeding pelagics may also consume benthic copepods, mysids, and amphipods as they rise through the water column at night (P. Peterson/UNC-IMS, pers. com., 2003). Other species are almost strictly piscivorous (i.e., striped bass, Spanish mackerel, king mackerel, bluefish). Young-of-year (YOY) bluefish feed predominately on fish species that are found throughout the water column. In 1992 and 1993, Buckel and Conover (1997) found clupeids, moronids, and bay anchovy (*Anchoa mitcheilli*) in a majority of the YOY stomachs that were sampled. A review of studies in Buckel et al. (2009) concluded very little overlap in the diet of juvenile bluefish and striped bass despite similar feeding ability. The non-overlap suggests differences in habitat use within the water column for juvenile bluefish and striped bass.

In freshwater streams, larval and juvenile American shad and blueback herring tend to feed on different sizes of zooplankton (Crecco and Blake 1983, Jenkins and Burkhead 1993). In years with a shortage of certain prey items, there is some overlap in the diets of larval American shad and river herrings as a result of interspecies competition (Crecco and Blake 1983). Zooplankton abundance for river herring in the Chowan River and tributaries is being studied as part of a Fisheries Resource Grant (S. Ensign/UNC-IMS, pers. com., January 2010). Monitoring results from April 2008 through May 2009 showed individuals per liter ranging from 21-42, which is approximate ten-fold higher than densities reported from the early 1980s (S. Mosley/NCSU, unpublished data). The preliminary data indicate a suitable abundance of zooplankton forage for river herring in the Chowan River and tributaries. However, the spatial and temporal coincidence of larval fish and zooplankton abundances remains an issue (B.J. Copeland/MFC, pers. com., March 2010).

Adult striped bass found in Albemarle Sound, Roanoke River, and Cape Fear River will feed primarily on clupeids (herrings, Atlantic menhaden, and shad) and engraulids during the summer and fall months (Trent and Hassler 1968; Manooch 1973; and Patrick and Moser 2001). In the winter and spring months adult striped bass will have a prey switch and feed predominately on invertebrates (i.e. amphipods and blue crabs) (Manooch 1973).

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) found the dominant food sources for menhaden were detritus in shallow estuarine systems and phytoplankton in coastal waters. Adult striped mullet in NC are opportunistic "interface feeders," feeding at the water surface, water bottom, or on the surface of objects. While feeding at these interfaces striped mullets will consume epiphytic microalgae and dissolved organic matter (DMF 2006b).

A large number of fish inhabit 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. Both striped bass and bluefish use the water column off the Outer Banks during winter, suggesting possible competition for resources. Buckel et al. (2009) postulated competitive exclusion as a contributing factor in a decline in bluefish recreational landings during the 1990s and early 2000s (Buckel et al. 2009). However, the results of laboratory experiments suggested no competitive interactions between adult bluefish and sub-adult striped bass in continental shelf waters.

2.2.2.5. Refuge

The refuge function of water column varies according to the relative area of open water, the depth, the distribution of water quality, and floating plants in a water body. Large expanses of open water can provide protection for forage species by reducing their encounter rate with predators. Juvenile fishes use shallow areas as refuge from larger predators. Spatial variability in dissolved oxygen and turbidity can provide a refuge function for pelagic forage species. 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). Turbidity in the water column can also provide refuge for prey species from visual predation (Ritchie 1972, Blader and Blader 1980, Boehlert and Morgan 1985, Bruton 1985, Miller et al. 1985). For example, bay anchovy may be attracted to more turbid areas for the refuge it provides (Livingston 1975). Utne-Palm (2002) found that increased turbidity may be more optimal for some species and size groups of 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 weed lines 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 hiding in and around *Sargassum*. This behavior prompts sport fishermen to target *Sargassum* patches. Casazza and Ross (2008) documented a higher diversity of species living in and around floating *Sargassum* mats relative to unvegetated open water habitat in the Gulf Stream off North Carolina.

2.3. STATUS AND TRENDS

Evaluating status and trends in water -column characteristics is a very difficult task. The number of independent monitoring agents, spatial distribution of monitoring sites, frequency of data collection, and parameters measures do not easily lend themselves to a comprehensive assessment of water quality. This section briefly describes current state water quality and fishery monitoring programs that help determine the status and trends of water column habitat in coastal North Carolina. However, the status and trends of water column are not described in terms of habitat distribution (unlike other habitats). The condition of waters is described in terms of physical and chemical conditions (e.g., nutrients, suspended sediment, toxins), indicators of pollution (e.g., chlorophyll *a*, fecal coliforms, fish kills), and status of pelagic fisheries (e.g., bluefish, Atlantic menhaden). Fish species and assemblages exhibit threshold responses to physical and chemical parameters (see "Habitat requirements" section for more information). Conditions of the water column that are outside the threshold tolerance or preference of fish are considered impaired, polluted, or otherwise not supporting fishery species.

In order to evaluate impairment of water quality/quantity for fishery species, one must understand the basic parameters as they relate to fish. Those parameters include: flow and water movement, pH, temperature, dissolved oxygen, and water clarity. The parameters also affect each other, causing a suite of water quality changes. The suites can be grouped into processes connecting the various parameters. Nutrient concentrations, biochemical oxygen demand, pH, suspended solids, water clarity, and temperature stratification are all related processes in eutrophication (see "Nutrients and eutrophication" section for more information). There is also the addition of chemicals that interact with biological processes (i.e., heavy metals, endocrine disrupting substances), causing unintended consequences (see "Toxic chemicals" section for more information). Excessive amounts of sediment from human activities on the land exacerbate the process of eutrophication and toxic contamination (see "Suspended sediment and turbidity" section for more information). Water flow and movement have a vital role in habitat distribution and connectivity, as well as distributing (dispersing/concentrating) the drivers of eutrophication and chemical pollution (see "Hydrologic modifications" section for more information).

2.3.1. Physical and chemical environment

The 2004 National Water Quality Inventory Report to Congress (http://www.epa.gov/owow/305b/2004report/) indicated polluted conditions in 44% of assessed streams, 64% of assessed lakes, and 30% of assessed estuaries, which is higher than the percentages found in the 2002 report (EPA 2002c). However, only 16%, 39%, and 29% of all streams, lakes, and estuaries were assessed, respectively. Although water quality monitoring data are abundant for North Carolina (Appendix E), differences in sampling methodology (i.e., duration, magnitude, parameters studied) complicate comparisons within and among river basins over time. However, information obtained from state-wide monitoring programs and research projects allows for some indirect evaluations. The status of water quality conditions in North Carolina's territorial 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); ambient water quality monitoring; lake monitoring data; United States Geological Survey (USGS) stream flow/quality stations; NPDES monitoring; Division of Environment and Health –Shellfish Sanitation (DEH-SS) sampling (fecal coliform concentrations) 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 use support status is "no data."

State-wide monitoring stations in the CHPP area include approximately 212 DWQ ambient stations (2009 - http://h2o.enr.state.nc.us/esb/ams.html), 76 USGS stream flow/quality stations (2009- http://wdr.water.usgs.gov/nwisgmap/), 651 NPDES sites (Cam McNutt/DWQ, unpublished data, 2006), 1020 DEH-SS growing area stations (Brad Pogue/DEH-SS, pers. com., October 2009), 241 DEH-SS recreational water quality stations (Erin Bryan-Millush/DEH-SS, pers. com., October 2009) and 22 Albemarle Pamlico National Estuarine Program (APNEP) Citizen's Water Quality Monitoring Stations[60] (2007- http://www.ecu.edu/icmr/cmn/Site_Locations.html). Stations monitoring water quality/quantity directly are concentrated in riverine and upper estuarine waters (Map 2.3). Only shellfish sanitation surveys and University research programs provide significant coverage of monitoring stations in lower estuarine and nearshore ocean waters. Water monitoring in offshore waters is conducted by various federal authorities and organizations (see http://secoora.org/about/observing-system-resources for more information).

Basic water quality monitoring is conducted in conjunction with fish sampling programs of the DMF. In 2009, DMF evaluated their fisheries independent monitoring programs and modified them to collect additional and consistent habitat data. The parameters measured include depth, water level, temperature, salinity, dissolved oxygen, sediment size, bottom composition, alteration state, and allowed fishing activities. Additional data elements collected include secchi depth, shoreline type, shoreline structure, land use, percent development, and SAV identification and density. Collectively, these programs cover a large area of coastal waters, though the coverage of any one program is limited. The DMF has also deployed nine continuous monitoring devices in the Chowan, Roanoke, Perquimans, Scuppernong, Pasquotank and Alligator Rivers, as part of ongoing river herring research (Sara Winslow/DMF, pers. com., 2009). These devices collect data every 2 hours, including water temperature, dissolved oxygen, salinity, pH and conductivity.

University research programs include those of the UNC-Chapel Hill's Institute of Marine Science, UNC Coastal Studies Institute, NCSU's Center for Applied Aquatic Ecology, UNC-Wilmington's Center for Marine Science, ECU's Interdisciplinary Institute for Coastal Science and Policy, and the Duke University Marine Lab. Research findings from these programs figure prominently in assessing the status of estuarine and nearshore ocean waters. These programs track water quality conditions, including nutrients and other factors, and examine the major processes affecting water flows and water quality in North Carolina's estuaries and coastal ocean.

Water quality standards and biotic integrity criteria are used as the, "measuring stick," in DWQ use-support assessments (http://h2o.enr.state.nc.us/csu/documents/ncactable290807.pdf, October 2009). Biotic integrity is determined from species composition and is evaluated in terms of biological diversity, sensitivity, and tolerance to anthropogenic stressors. The indices were developed and are primarily used on invertebrate and/or fish assemblages in freshwater streams. Evaluating biotic integrity in large rivers and estuaries has been problematic. Biotic integrity and water quality are used to evaluate aquatic life support in these systems. The water quality standards may vary according to the use supported (i.e., drinking water, shellfish harvest, primary recreation, aquatic life) and certain regulatory designations (see "Designations" section of this chapter for more information). Some basic standards for aquatic life support are listed in Table 2.11. Other supported uses and designations carry higher or lower standards.

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 in use support ratings 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

[60] State does not accept volunteer collected data. However, data may be used in litigation against polluters.

Use Support status of water bodies is referred to throughout this document as a general indicator of the current condition of some North Carolina streams flowing into coastal waters. However, use support impairment has a specific meaning relative to established water quality standards (Table 2.11) and does not necessarily reflect support for the coastal fisheries ecosystem. The DWQ's 2004 and 2006 use support assessments (http://h2o.enr.state.nc.us/tmdl/General_303d.htm) are reported here, along with a map of impaired waters for 2006 (Map 2.3).

Table 2.11. Basic 2009 water quality standards for freshwater and saltwater aquatic life support.

Parameters	**Freshwater Aquatic Life** *ug/l (unless noted)*	**Saltwater Aquatic Life** *ug/l (unless noted)*
Dissolved Oxygen	not less than 5.0 mg/L (N)*	not less than 5.0 mg/L (N)
pH	6.0-9.0 (N)*	6.8-8.5 (N)
Salinity		(N)
Solids, settleable	(N)	(N)
Solids, total suspended	(N)	10 mg/L in PNA
Temperature	(N)	(N)
Turbidity	50/25 NTU (N)	25 NTU (N)

(AL) Action Level Standard - See 2B .0211 for additional information (N) = Narrative standard See 2B .0211 and for WS: .0212, 0214,.0215, .0216 and.0218
* Standards are lower (pH >4.3) for Swamp Water classification.

The 2004 and 2006 reports indicate the amount (miles or acres) of waters assessed and impaired for use attainment, by river basin. The 2006 report assessed some uses on 31% of streams, 27% of estuarine creeks and shorelines, and 89% of estuarine and saltwater bays, inlets, and tidal areas (Table 2.12a-c). The percentages assessed were somewhat better than the national averages reported in 2004. However, 0% of North Carolina waters were assessed for all uses in 2006. Of the total stream mileage, 11-12% was impaired for at least one use in 2004 and 2006, respectively. The level of impairment among estuarine creeks and shorelines was 17%. For estuarine and saltwater bays, inlets, and tidal areas, the level was 5%. Based on the total assessment mileage/area, 32-39% of streams were impaired for at least one use in 2004 and 2006, respectively. A greater percentage of assessed estuarine creeks and shorelines were impaired (61%). Only 6% of assessed estuarine areas were classified as impaired. The percentage of assessed streams and estuaries in North Carolina classified as impaired in 2006 was less than the national averages for 2004. However, the DWQ assessment of estuaries reflected primarily use support for shellfish harvesting.

Table 2.12 (a). DWQ Use Support status for freshwater streams and shorelines (miles) in North Carolina coastal draining river basins (2004-2006). Note: numbers by category are additive.

River basin	Insufficient or no data to determine use attainment		Some uses assessed; assessed uses attained		At least one use impaired; TMDL needed		Aquatic life use impaired; biological integrity		At least one use impaired; no TMDL needed		All uses assess; all uses attained	
Year	**2004**	**2006**	**2004**	**2006**	**2004**	**2006**	**2004**	**2006**	**2004**	**2006**	**2004**	**2006**
Cape Fear	3,936	4,241	0	1,338	199	493	357	357	7	29	1,538	0
Chowan	518	622	150	46	105	104	31	31	0	0	0	0
Neuse	2,108	2,162	755	688	169	181	253	264	82	77	6	0
Pasquotank	338	442	101	0	40	31	0	4	0	0	0	0
Roanoke	1,495	1,722	369	228	242	228	21	21	0	14	0	0
Tar-Pamlico	1,697	1,685	0	684	13	43	67	75	0	0	555	0
White Oak	18	258	21	21	36	37	0	0	3	0	0	0
Total	10,110	11,132	1,396	3,005	804	1,117	729	752	92	120	2,099	0
%	66.4	69.0	9.2	18.6	5.3	6.9	4.8	4.7	0.6	0.7	13.8	0.0

Table 2.12 (b). DWQ Use Support status for estuarine creeks and shorelines (miles) in North Carolina coastal draining river basins (2006). Note: numbers by category are additive.

River Basin	Insufficient or no data to determine use attainment	At least one use impaired; TMDL needed	Some uses assessed; assessed uses attained	Aquatic Life use impaired; biological integrity	Shellfish use impaired; unfavorable for a TMDL	All uses assessed; all uses attained	At least one use impaired; no TMDL needed
Cape Fear	0	0	0	0	0	0	0
Chowan	0	0	0	0	0	0	0
Neuse	101	3	12	8	1	0	0
Pasquotank	9	0	0	0	0	0	0
Roanoke	0	0	0	0	0	0	0
Tar-Pamlico	64	1	15	0	0	0	0
White Oak	53	39	5	0	0	0	0
Total	227	43	32	8	1	0	0
%	73.0	13.8	10.3	2.6	0.3	0.0	0.0

Table 2.12 (c)…DWQ Use Support status for estuarine and saltwater bays, inlets, and tidal areas (acres) in North Carolina coastal draining river basins (2006). Note: numbers by category are additive.

River Basin	Some uses assessed; assessed uses attained	Insufficient or no data to determine use attainment	At least one use impaired; TMDL needed	At least one use impaired; no TMDL needed	Shellfish use impaired; unfavorable for a TMDL	All uses assessed; all uses attained	Aquatic Life use impaired; biological integrity
Cape Fear	18,253	639	9,129	0	3,732	0	0
Neuse	330,473	4,016	2,074	31,767	1,637	0	0
Pasquotank	689,888	215,219	6,807	21	4,525	0	0
Tar-Pamlico	645,071	4,933	9,955	3,417	218	0	0
White Oak	92,105	906	24,336	8,560	3,722	0	0
Totals	1,775,790	225,713	52,301	43,765	13,834	0	0
%	84.1	10.7	2.5	2.1	0.7	0.0	0.0

2.3.1.1. Causes of impairment

Among freshwater streams draining to coastal waters, the primary cause of impairment was low biological integrity scores (39% of impaired streams), followed by fish consumption advisories for mercury and/or dioxin (32% of impaired streams) (Table 2.13). Other causes for impairment (in descending order) included low dissolved oxygen (14%), low pH (7%), fecal coliform (4%), turbidity (3.6%), nutrients (1%), and copper (1%). The relative magnitude of causes also differed among river basins. For example, the Cape Fear River (CHPP region 4) suffers mostly from impaired biological integrity and fish consumption advisories. The Neuse River (CHPP region 2) is affected more by low DO and impaired biological integrity. The source of impairment in the Roanoke River (CHPP region 1) was primarily fish consumption advisories. Refer to relevant subsection in the threats section for more information on the causes of water quality impairment.

In downstream estuaries, the primary cause for impairment was listed as shellfish closures due to excess fecal coliform concentration (45% of impaired waters) followed by chlorophyll *a* (39% of impaired waters) (Table 2.14). Shellfishing areas must be closed to shellfish harvest when the median fecal coliform Most Probable Number (MPN) or the geometric mean MPN of water exceeds 14 per 100 milliliters [Commission for Health Services rule 15A NCAC 18A .0900]. While most strains offecal coliform 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 (see "Land-use and non-point sources" section for more information). In the Neuse River estuary, the largest cause of impairment was chlorophyll *a*. In the White Oak basin (CHPP region 3), the primary cause was shellfish closure due to fecal coliform concentrations. However, biological integrity of estuarine and marine systems was not assessed. Research regarding specific causes of impairment is presented in the "Water quality degradation" sections.

Table 2.13. Causes of DWQ use support impairment from 2006 assessment of freshwater streams and shorelines (miles).

River basin	Impaired biological integrity	Fish advisory (mercury or dioxin)	Low DO	Low pH	Fecal coliform	Turbidity	Nutrients	Copper	Other
Cape Fear	407	315	25	92	77	63	0	0	0
Chowan	31	40	44	42	0	0	22	0	0
Neuse	317	69	177	0	3	5	0	3	0
Pasquotank	4	0	31	20	0	0	0	0	0
Roanoke	42	240	10	0	0	14	0	11	0
Tar-Pamlico	89	29	14	0	14	0	0	0	0
White Oak	0	28	8	0	0	0	0	0	0
Total	890	721	309	154	94	82	22	14	0
Percentage	38.9	31.5	13.5	6.7	4.1	3.6	1.0	0.6	0.0

(a) The other category includes iron, zinc, aquatic weeds, chlorides, ammonia, toxicity, sediment, chlorophyll *a*, and unknown reasons.

Toxic chemical contamination was not evaluated by DWQ in estuarine and nearshore ocean waters (see "Toxic chemicals" section for more information). 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). The "Marinas and multi-slip docks" section has more information on pollutant contributions from such facilities.

Table 2.14. Causes of DWQ use support impairment from 2006 assessment of estuarine and saltwater bays, inlets, and tidal areas (acres).

River Basin	Shellfish closure: Fecal coliform	Chlorophyll *a*	Low DO	Low pH	Recreational posting: Enterococcus	Fecal coliform
Cape Fear	6501	0	6,527	6360*	97	0
Lumber	3606	0	0	0	0	0
Neuse	3711	31,767	0	0	0	0
Pasquotank	5089	0	6264	0	21	0
Tar-Pamlico	7516	6071	0	0	0	3
White Oak	28,058	8560	0	0	0	0
Totals	54,481	46,398	12,791	6,360	118	3
%	45.3	38.6	10.6	5.3	0.1	0.0

* Note: most of the low pH in this region is natural due to the predominantly blackwater streams and organic leachate, and is not necessarily harmful to native biota.

2.3.1.2. Sources of impairment

The sources of impairment were estimated for freshwater streams in the 2006 assessment report. Among impaired streams, the majority of sources for a cause were unknown (28% of impaired streams). The most common and known cause of impairment was agriculture and row crop production (21%) followed closely by permitted wastewater discharge (20%) (Table 2.15). Stormwater runoff from urban and built-upon areas was the source attributed to 11% of impaired streams. The relative contribution of sources also varied among river basins. In the Cape Fear River, permitted wastewater was the primary source of impairment. Agriculture was the primary source of impairment in the Neuse and Tar-Pamlico Estuaries. Atmospheric deposition was the primary source in the Roanoke River. Urban runoff was only the primary source of impairment in the White Oak basin. The largest contributions from urban runoff were in the Neuse and Tar-Pamlico basins. Refer to relevant subsections of the, “Threats and management needs,” section for more information on the sources of water quality impairment.

Table 2.15. Sources of DWQ use support impairment from 2006 assessment of freshwater streams and shorelines (miles).

River Basin	Source Unknown	Agriculture/ Row crop production	Wastewater, permitted	Runoff from urban & built-up areas (a)	Atmospheric deposition	Animal management/ Pasture (b)	Land application, permitted/ Non-discharge (c)	Construction/ Land disturbance (d)	Mining
Cape Fear	740	93	358	71	0	36	2	68	0
Chowan	0	44	66	0	38	0	2	0	0
Neuse	34	294	39	139	0	90	112	18	0
Pasquotank	0	48	20	11	0	35	15	0	0
Roanoke	0	18	49	18	207	0	0	0	14
Tar-Pamlico	85	148	78	77	0	0	18	0	0
White Oak	0	0	0	8	0	0	0	0	0
Totals	859	645	610	324	245	161	149	86	14
Percentage	27.8	20.9	19.7	10.5	7.9	5.2	4.8	2.8	0.5

(a) Runoff from urban & built up areas includes permitted stormwater from MS4s and industrial facilities, land development, urban development, and urban development/storm sewers.

(b) Animal management/pasture includes livestock access and off-farm animal holding/management.

(c) Land application, permitted/ Non-discharge systems includes concentrated animal feeding operations, intensive animal feeding operations and on-site wastewater.

(d) Construction/Land disturbance includes land clearing and road construction.

2.3.1.3. Assessment needs relative to aquatic life

Nearly 70% of freshwater streams in North Carolina are not assessed by DWQ due to lack of information. Continuous monitoring allows the observation of rapidly changing water quality and the cumulative affects on biological communities. The USGS water flow and quality stations represent the majority of continuous monitoring facilities in state waters maintained by government authorities. Most DWQ ambient sites do not acquire data on a continuous basis. *The portion of waters assessed for aquatic life support by DWQ and the coverage of continuous monitoring stations should be increased to create a more complete dataset of water quality on spatial and temporal scales.*

The index of biotic integrity (IBI) and *Ephemeroptera*/*Plecoptera*/*Trichoptera* (EPT) index are proxies for these cumulative effects. Developing indices for large rivers and estuarine waters has focused on freshwater mussel species and submerged aquatic vegetation (SAV) communities, respectively (see “Soft bottom” and “Submerged aquatic vegetation” chapters for more information). The APNEP’s development of ecological indicators yielded a number of metrics that could be used in large river and estuarine indices of biological integrity (http://www.apnep.org/index.html, October 2009). The topic of ecological indicators is discussed further in the, “Ecosystem management and Strategic Habitat Areas,” chapter.

Given adequate monitoring, there remains a need to develop water quality standards that more accurately reflect conditions necessary for supporting fishery species and communities (refer to the, "Water quality degradation," subsections of the threats section for more discussion). The ever present need for collaboration among independent monitoring agents also increases with the development of new and existing standards. The issues of coordination and collaboration were the subjects of a 2008 forum on water quality monitoring organized by DWQ and UNC-Charlotte (http://eao.uncc.edu/ncforwater/report_ncforwater2008.pdf, October 2009). The event was part of 2005 CHPP implementation. Gauging progress on this very complicated issue will be very difficult. The DWQ has stringent standards on what data can be included in their use-support assessments, and high quality data from University research programs is often unavailable due to publication requirements. However DWQ does include university data in basinwide assessments where possible, and should continue to work toward statewide coordinated monitoring among groups.

Other methods of estimating water quality may also be needed, considering the prohibitive cost of increasing the number of water monitoring stations. Modeling (based on climate, land cover, soil, hydrology and permitted development information) could be used to target watersheds for focused monitoring (refer to, "Water quality degradation" subsections of, "Threats and management needs," section for more discussion). However, monitoring only in areas where impairment is likely would result in a greater percentage of assessed waters listed for impairment. The selection of monitoring stations would need to reflect the proportion of projected water quality conditions among waters of the state. A proportional approach would support an accurate percentage of impaired waters.

2.3.2. Fish kills

According to NOAA, the leading cause of fish kill events in 22 coastal states from 1980 – 1989 was low DO (Lowe et al. 1991). In North Carolina, this has also been the case, as reported for the 1990s decade by Glasgow et al. (2001). In 2008, dissolved oxygen depletion was the reported cause of 28 of the 61 fish kill events statewide, resulting in mortality of 6,951,349 individuals, while toxic algal/phytoplankton blooms accounted for 6 kill events (DWQ 2008c). Other reported causes of fish kills included by-catch mortality, toxic spills, or other/unknown causes[61] (DWQ 2008c). Estuarine species most frequently reported included Atlantic menhaden, spot, flounder, and croaker. Total mortality from the 30 estuarine kills in 2008 was 7,380,580 individuals, the highest mortality ever since DWQ began reporting fish kills in 1996 (Figure 2.4). The sharp increase in mortality is attributed to the 2007 drought, meteorological factors, and extended calm weather conditions (DWQ 2008c). The greatest number of fish kills have been reported in the Neuse, Cape fear, and Tar-Pamlico rivers.

[61] Conditions such as bacterial, viral, parasitic, and fungal infections, ammonia toxicity, and sudden changes in temperature or salinity are also possible causes of fish kills.

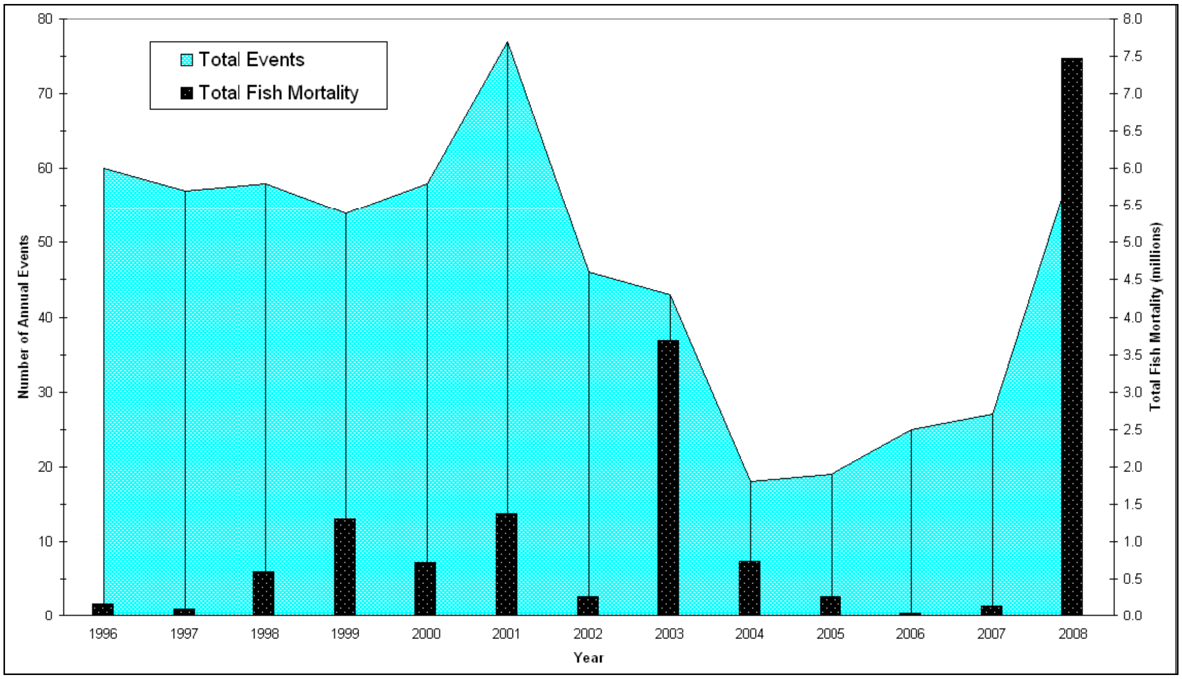


Figure 2.4. Annual fish kill events and mortality copied from DWQ (2008b).

2.3.3. Fisheries associated with pelagic habitat

It is difficult to attribute changes in fish abundance to changes in habitat due to the large and specific datasets needed for analyses and the influence on non-habitat factors. The analysis needs accurate density estimates for fish species and size classes among accurately delineated habitat types over a time series to predict fish – habitat relationships. In some studies adequate information was sufficient to draw relationships between habitat trends and population (Rozas et al. 2007).

There are also non-habitat factors affecting fish populations (i.e., fishing mortality). In North Carolina, estimated fishing mortality and juvenile abundance indices are used by the DMF to determine the status of fishery stocks. Stock status evaluations may also suggest habitat issues for concern or depleted species. Of the 10 pelagic species and 14 stocks identified in Table 2.2, seven species (blueback herring, alewife, American shad, striped bass, Atlantic menhaden, bluefish, and striped mullet), comprising eleven stocks, were evaluated for fishery status. Depleted stocks include river herrings in Albemarle Sound and striped bass south of Albemarle Sound (DMF 2009). Viable stocks include that of striped bass in Albemarle Sound and the ocean, Atlantic menhaden, and bluefish. American shad was the only pelagic species in the concern category. In summary, less than half the pelagic fishery stocks assessed were considered depleted in 2008. For detailed information on trends in pelagic species abundance, consult the relevant FMP (http://www.ncdmf.net/fmps/index.html). Pelagic species, being less dependent on structured habitats, and highly mobile, may be less vulnerable to habitat degradation, unless it results in severe water quality degradation.

Habitat loss has been implicated in the decline of river herring, along with several other factors (DMF 2007 – river herring FMP). Hydrologic modifications in Albemarle Sound-draining watersheds have substantially reduced the amount of tributary spawning habitat available to river herring (refer to "Hydrologic modifications" subsection of threats section for more discussion). Habitat loss has also been implicated in the precipitous decline of other anadromous species within the north Atlantic basin (Limburg and Waldman 2009). Restoration and protection of river herring spawning and nursery habitat is a major focus of the water column chapter as a whole.

2.3.4. Water column restoration and enhancement

Restoring water column habitat addresses a history of stream, wetland and riparian buffer alteration on the landscape. The restoration of wetlands is discussed in the wetland chapter. Stream and upland buffer restoration are covered in this section. Restoration efforts may occur as a result of mitigation requirements or proactive watershed restoration plans. There are mitigation requirements for impacted streams and buffers (Tar and Neuse rivers only) similar to impacting wetlands. The permitted alteration of streams and buffers is tracked by the Wetlands/401 Unit of the DWQ. The need for a USACE Section 404 permit authorizing the fill or alteration of wetlands, streams, or buffers triggers the 401 Water Quality Certification process by the DWQ. However, projects impacting less than 150 linear feet of stream are not required to notify DWQ and represent an unknown loss of stream segments. The loss of streams refers to altered hydrologic conditions affecting water quality (i.e., buffer impact, dredge and fill). The intent of mitigation is to maintain natural hydrologic conditions and associated water quality. Watershed restoration plans may target streams and shorelines impaired by non-point sources of pollution. Point source pollution is addressed by National Pollution Discharge Elimination System (NPDES) permit requirements and Total Maximum Daily Load (TMDL) allocations (see “Water quality degradation” section for more information). Impoundment effects on water quality have only recently been included as a potential violation of the Clean Water Act (http://act.americanrivers.org/site/DocServer/04-1527o.pdf?docID=4142, 2006). Managing hydrologic obstructions as an integral part of water column restoration is discussed in the “Hydrologic modifications” section.

The amount of stream and riparian buffer impacts and corresponding mitigation were reported by the Wetland Restoration Program (WRP) from 1999-2003. Thereafter, the Ecosystem Enhancement Program has reported stream and buffer mitigation assets. The 2002-2003 WRP report documented 103.75 acres of buffer impacts since 1998. There were 102.19 acres in the Neuse River basin and 1.56 in the Tar-Pamlico River basin. The corresponding mitigation assets included 177.7 acres in the Neuse River basin. The 2003-2004 EEP report documented an additional 82.41 acres of buffer impacts in the Cape Fear, Neuse, and Tar-Pamlico river basins. The corresponding mitigation was 139.25 acres, for a net gain of 56.84 acres. The need for mitigating buffer impacts came about with implementation of the Tar-Pamlico and Neuse river Nutrient Reduction Strategies (see “Non-point source management” section for more information). After 2004, the EEP reports are presented differently and do not include the amount of buffer impacts and corresponding impacts. The assets are reported as gross and used assets based on mitigation needs of the Department of Transportation (DOT) and other permit applicants. The assets are reported as stream feet and wetland acres.

Reported stream impacts in coastal draining river basins increased gradually from 1999 to 2003, based on WRP reports (Figure 2.5). Annual permitted impacts increased from 58,342-ft (11 mi) to 90,000-ft (17 miles) over a period of 5 years. The majority of the permitted losses required mitigation. The total length of impacted streams from 1999-2003 was 385,386-ft (73 miles, or 14 miles/year). The majority of impacts occurred in the Cape Fear and Neuse river basins (Figure 2.6). Relatively small amounts of stream impact were permitted in other coastal draining river basins.

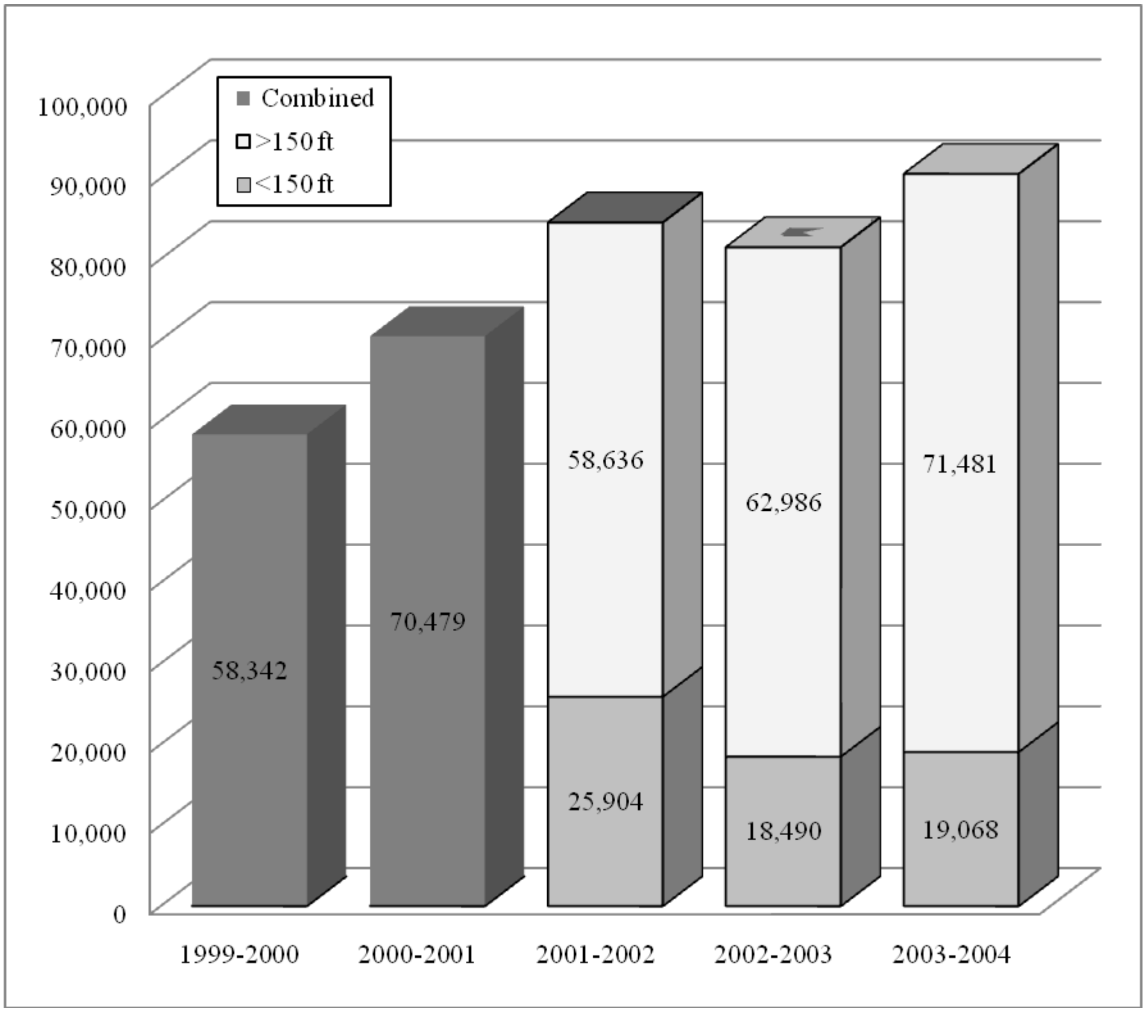


Figure 2.5. Stream feet impacted, by fiscal year, in coastal draining river basins (WRP 2000-2004).

The majority of impacts occurred in the piedmont and mountain regions of the state and in urban areas. The State of North Carolina did not require mitigation for impacts to intermittent streams (prior to 2009), but impacts to these streams were reported and represent some of the reported losses. As of 2009, the DWQ requires mitigation for impacting a cumulative total of greater than 150 linear feet of intermittent and/or perennial streams (John Dorney/DWQ, pers. com., August 2009). However, the permitting is only applied to streams as they were mapped on USGS topographic quadrangles. The DWQ is currently re-mapping stream channels with more accurate methods and LIDAR imagery. The re-mapping of intermittent and perennial streams should help identify more stream areas subject to permit requirements.

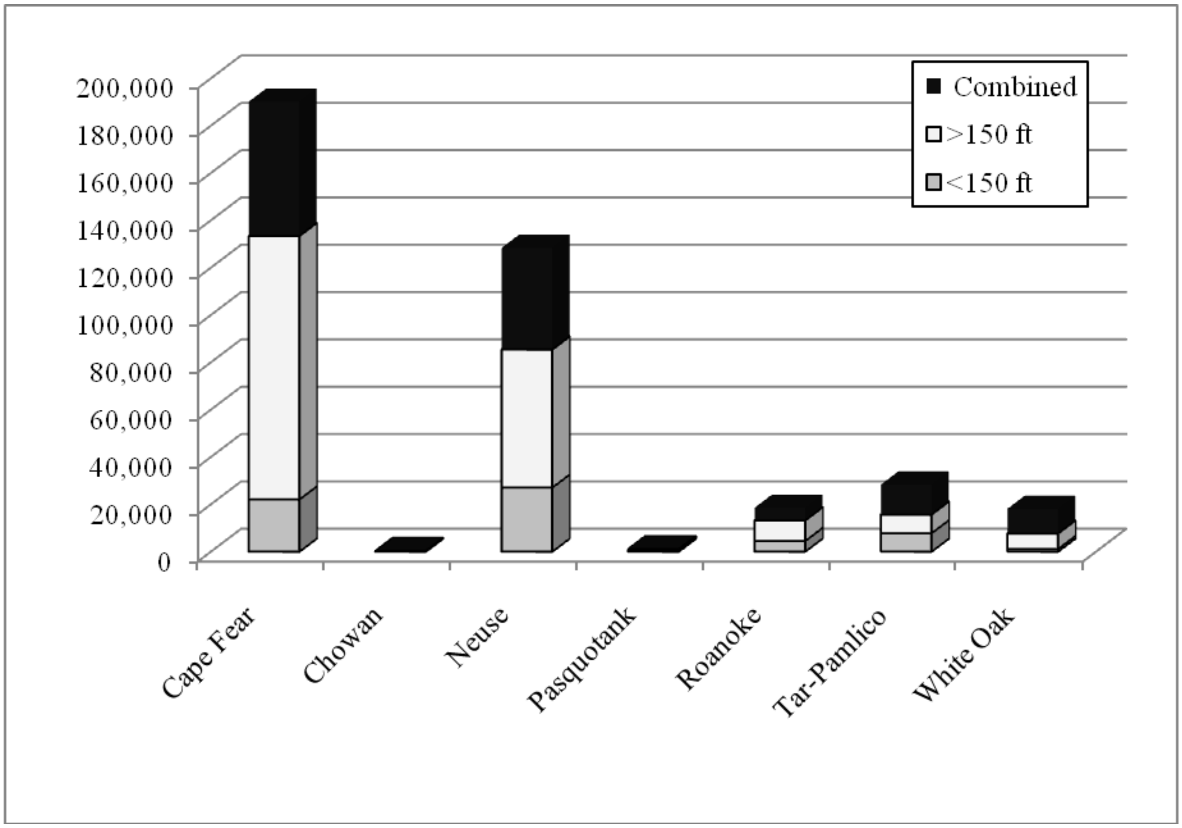


Figure 2.6. Stream feet impacted, by river basin, in North Carolina (WRP 2000-2004).

Including applied mitigation, there were net regulatory losses of streams every year from 1999 to 2003 (Table 2.16), for a total unmitigated loss of 179,276 feet (34 miles). These losses were partially offset by some voluntary creation or restoration of streams. During fiscal years 1999-2003, 33,800 feet (6 miles) of streams were voluntarily restored or created in coastal river basins for the purpose of mitigation banking. The 2004-2008 EEP reports summarize mitigation assets in terms of gross and remaining (after required mitigation is applied). The mitigation for streams includes restoration, enhancement, and high quality preservation. The remaining assets represent progress that EEP has achieved to produce mitigation in advance of permits. The 2007-2008 EEP report indicated a net gain in linear feet for stream available for mitigating future impacts. In coastal draining river basins, 52 miles of stream restoration assets were available for mitigation in fiscal year 2007-2008. Considering all the projects in an active monitoring stage, the EEP reported greater than 90% success for stream geomorphic criteria (channel dimension, profile, substrate, engineered structure stability). This is a slight improvement over the previous year's statistics. In FY 2008-2009, the EEP reported a 95% compliance rate for mitigating permitted stream impacts (EEP 2009). The mitigation compliance reported for nutrient offsets and riparian buffer varied from 66% to 100%. The lowest mitigation compliance for riparian buffers was in the Tar-Pamlico (66%), whereas Nitrogen offset compliance was lowest in the Neuse (69%).

Table 2.16. Stream mitigation in coastal draining river basins (WRP 2000-2004).

Fiscal Year	Regulatory gains or losses (linear feet)	Non-regulatory gains restoration/creation (linear feet)	Net gains/losses (linear feet)
1999-2000	-31,595	1,400	-30,195
2000-2001	-47,120	1,000	-46,120
2001-2002	-47,376	30,000	-17,376
2002-2003	-23,230	1,400	-21,830
2003-2004	-29,955	0	-29,955
TOTAL	-179,276	33,800	-145,476

Since its inception, EEP has utilized its planning processes (River Basin Restoration Priorities and Local Watershed Plans) to implement mitigation projects in the watersheds of greatest need. In 2009-2010, EEP reevaluated its planning processes to ensure that current watershed planning methods comply with the 2008 federal mitigation rule (33 CFR Parts 325 and 332). Based upon this review, EEP updated its processes and developed standardized methodologies that address federal requirements for a watershed approach and incorporate lessons learned.

In accordance with the Compensatory Planning Framework (CPF) of EEP's Draft In Lieu Fee Instrument, EEP prioritizes compensatory mitigation activities first in a local watershed plan (LWP) developed by EEP or a watershed plan developed by other state, federal, tribal and/or local government agencies or appropriate non-governmental organization. If a watershed plan developed by an outside entity does not meet EEP's six element criteria (outlined in CPF), EEP builds upon the existing planning effort in order to ensure it complies with EEP's watershed plan criteria. If a watershed plan is not available in the 8-digit catalogue unit (CU) of impact, and EEP determines substantial compensatory mitigation is required, EEP will initiate a new LWP. If compensatory mitigation requirements are too small to justify development of a new LWP and a watershed plan does not currently exist, EEP will focus projects within the Targeted Local Watershed (TLW) for that particular CU. Projects that are not located in an LWP or TLW will be reviewed by the IRT and at a minimum should reference the most recent RBRP for a particular basin and state how the proposed mitigation project addresses the restoration goals for that particular CU.

To some degree, the EEP also strives to restore watersheds above and beyond mitigation requirements. The EEP continues to use and develop Local Watershed Plans to focus restoration work guided by local interest and support for developing a plan, information on water quality degradation (restoration potential), In-Lieu-Fee mitigation, and compensatory mitigation needs of the DOT (http://www.nceep.net/services/lwps/localplans.htm, November 2009) (Map 2.4). The EEP also encourages other government entities and funding organizations to consider implementing watershed improvement projects within the targeted watersheds as well as maximize state, federal and local funding sources based on multiple watershed planning objectives[62]. 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. The DMF's on-going effort to locate and designate Strategic Habitat Areas for coastal and marine fishery species should complement land-based watershed restoration plans. The SHA priorities are currently being incorporated in EEP's coastal River Basin Restoration Priorities, starting in the Chowan River (R. Breeding/EEP, pers. com., March 2010). However, the application of SHA and Local

[62] The list of funding sources and watershed planning objectives include various city/county governments, the Clean Water Management Trust Fund (CWMTF), Division of Soil and Water Conservation, U.S. Geological Survey, Natural Heritage Program, Wildlife Resources Commission, and Division of Water Quality Section 319 Grant Program.

Watershed Plan priorities at different scales, addressing different goals, suggests a need to place both planning efforts under the larger umbrella of DENR strategic planning. *The CHPP agencies (DMF, DCM, DWQ, WRC) and EEP should meet to determine how SHA and LWP methodologies complement and contribute to complementary goals of the North Carolina Department of Natural Resources.*

Sudduth et al. (2007) provides an excellent study of stream restoration practices in the southeastern United States. The study compared nationwide and state-level databases documenting stream restoration projects. The states included were Georgia, Kentucky, North Carolina, and South Carolina. North Carolina figured prominently in the study; having the majority of projects represented (502 of 860). The study looked at number of projects per 1,000 km of stream, length of projects, cost of projects, goals for restoration, measures of success, associated monitoring, and site location criteria. The results for the southeast were compared to nationwide data included in the National River Restoration Science Synthesis (NRRSS). The number of projects per kilometer of stream was generally less than the national average (8.3 per 1,000 km), though North Carolina was very close to the national average. North Carolina also had the second highest percentage being monitored at 36%. The positive differences for North Carolina were attributed to the Clean Water Management Trust Fund (NCCWMTF), the EEP, and the monitoring required to earn mitigation credit. However, there were some problems identified for stream restoration practices in the southeast. One of the most significant problems was the 50% of projects not following a watershed assessment and the even lower percentage following a watershed management plan. The most common reason for choosing a site was available land opportunities and not the potential ecological benefit of restoration. As of February 2010, EEP has instituted 559 projects. These projects include projects that pre-dated EEP and its current watershed planning processes. Of these projects, 60% are located in TLWs and 19% are located in local watershed planning areas. This percentage is expected to grow as EEP implements more projects that developed within EEP's current watershed planning and project implementation processes (Map 2.4). *More incentives are needed to generate conservation/restoration opportunities in areas with the most ecological benefit of restoration.*

Other important programs restoring streams and riparian buffers include the Conservation Reserve Enhancement Program (CREP) and Agriculture Cost-share Program (ACSP) administered by the State Division of Soil and Water Conservation (DSWC). The CREP was designed to pay farmers who place marginal land overlapping stream riparian zones into conservation easements. From 1983-2008, the CREP has restored and protected 32,000 riparian acres and 883 stream miles in coastal draining river basins of North Carolina (http://www.enr.state.nc.us/dswc/pages/annual%20report.pdf, November 2009) via temporary or permanent easements. In 2008, a total 1,358 acres were enrolled protecting 37 miles of stream not including CREP and ACSP (Sudduth et al. (2007). These data could be obtained from individual county offices and were thus not included in the regional NRRSS database.

2.3.5. Designations

2.3.5.1. Regulatory

Surface waters are provided varying levels of protection through designated EMC water classifications. The 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. The standard and supplemental classifications, are described below.

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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

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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).
TR (Trout Waters)—Waters protected for natural trout propagation and stocked trout survival.

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Most streams are classified as C (73%), followed by WS (18%). The greatest total length of streams occurred in the coastal plains portion large riverine systems. The majority of water bodies in the coastal plains were classified as SA (61%), followed by SB (16%) and SC (16%). Most of the SA waters were in the central coast due to Pamlico Sound. The distribution of fresh- and saltwater classifications follows the approximate boundary of salinity zones (see "Description and distribution" section for more information).

The most widely distributed supplemental classification for streams was NSW at 49% of total stream mileage (48% in the coastal plains and 50% in the piedmont) (Table 2.17). In the coastal plains, there were also a large number of streams classified as swamp water (54%) of coastal plain streams). Nearly all the ORW streams were located in the coastal plains. The majority of NSW streams were in Neuse and Tar-Pamlico watersheds. Most of the swamp streams could be found in regions with large riverine systems.

The largest number of ORW streams was in coastal plain portions of regions 1 and 4. The NSW classification was also the most common among water bodies in the coastal plain (28%), followed by ORWs (9%) and Swamp waters (7%) (Table 2.18). Most of the ORW water bodies were in the central coast due to the large sounds (Core, etc.), whereas the majority of NSW water bodies were in the Neuse and Pamlico estuaries. The Albemarle Sound system had the majority of Swamp water acreage.

Table 2.17. Supplemental EMC/DWQ classification of streams in CHPP management regions.

Phys. Region	CHPP region	EMC/DWQ Supplemental Classification (miles)				
		ORW	HQW	NSW	Sw	Tr
Coastal Plains	1	195	1	1,479	2,182	0
	2	20	46	8,361	4,901	0
	3	22	29	392	7	0
	4	207	202	2	4,386	0
	ALL	444	278	10,235	11,476	0
Piedmont	1	2	0	10	0	149
	2	0	0	4,597	30	0
	4	0	201	2,112	100	0
	ALL	2	201	6,719	130	149
TOTAL	ALL	445	479	16,953	11,606	149

Table 2.18. Supplemental EMC/DWQ classification of rivers, lakes, and estuaries in CHPP management regions.

Phys. region	CHPP region	EMC/DWQ Supplemental Classifications (acres)				
		ORW	HQW	NSW	Sw	Tr
Coastal Plains	1	43,717	33	49,158	91,318	0
	2	35,276	871	459,579	45,076	0
	2/3	3,403	0	5,082	0	0
	3	112,954	1,656	61,447	210	0
	4	2,181	172	0	11,939	0
Piedmont	1	0	0	6	0	10
	2	0	0	23,346	0	0
	4	0	910	22,573	300	0
TOTAL	ALL	197,531	3,642	621,193	148,843	10

The Marine Fisheries Commission (MFC) designates areas subject to commercial and recreational fishing regulations. 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. These definitions and classifications of water column habitat and their associated regulatory jurisdictions provide the authority for management actions. These areas may also be recognized by the EMC for enhanced water quality standards, or by CRC for more protective coastal development standards. Primary Nursery Areas, in particular, are considered High Quality Waters for the purpose of water quality standards, and have dredging restrictions by EMC and CRC (see “Dredging (navigation channels and boat basins)” section for map references). Designated Inland Primary Nursery Areas and Anadromous Fish Spawning Areas have not been recognized for specific water quality standards. In 2008, the MFC and WRC joined in designating Anadromous Fish Spawning Areas (MFC rule 15A NCAC 03R .0115 and WRC rule 15A NCAC 10C .0603) (see “Flow regulation” section for map references).

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 (PNA): 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 (SNA): 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 (IPNA): 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 (AFSA): 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)].

There are relatively few PNAs in CHPP region 1, but a relatively large number of IPNAs. There are roughly equal areas of PNA in regions 2, 3, and 4, while most permanent SNAs are located in region 2 (Table 2.19). Special SNAs were not included in Table 2.19 due to the temporary protection offered. There are approximately 162,000 acres of PNA and SNAs (Permanent and Special) in North Carolina Coastal Fishing Waters (including both water and wetlands). Anadromous fish spawning areas cover 17% and 10% of streams/shorelines and water bodies, respectively, in coastal plain portions of CHPP regions. Most AFSAs are located in the Albemarle region (70%) and include the mainstem Chowan River, Alligator River, and Phelps Lake. The WRC has also designated most of the main stem of the Roanoke, Tar, Neuse, and Cape Fear rivers within its jurisdiction as Inland Primary Nursery Areas. While there are no MFC designated nursery areas within inland fishing waters, DMF sampling data show many of the freshwater tributaries function as Anadromous Fish Nursery Areas. The WRC has designated certain inland waters near the coast as IPNAs based on recommendations by DMF. *The location and designation of Anadromous Fish Nursery Areas is an important management need.*

Table 2.19. MFC and WRC fish habitat designations in CHPP management regions. Note: the area of PNA, Permanent SNA, and IPNA does not include tidal areas between the mean high water (or normal water level) and the apparent shoreline (i.e., wetland edge). The miles of AFSA includes both streams and shorelines.

Phys. region	**CHPP region**	**PNA (acres)**	**PSNA (acres)**	**IPNA (acres)**	**AFSA (miles)**	**AFSA (acres)**
Coastal Plains	1	166	168	16,269	2,413	153,894
	2	12,166	46,875	8,985	1,450	49,995
	3	14,557	0	700	101	829
	4	14,786	292	4,391	821	13,491
Piedmont	1	0	0	303	0	2
	2	0	0	0	55	375
	4	0	0	634	0	0
TOTAL	ALL	41,675	47,336	31,283	4,840	218,586

2.3.5.2. Non-regulatory

Some streams and riparian buffers are protected by virtue of public ownership. Larger water bodies, such as lakes, may be surrounded by lands managed for conservation. Except for Lake Phelps, which is designated as a State Park, the natural lakes in North Carolina are largely under federal government jurisdiction in Croatan National Forest and national wildlife refuges (Pocosin Lakes and Mattamuskeet). The feeder creeks and canals flowing out of them are partially under state and private ownership. However, no one can own public trust bottom in navigable waters (except in rare cases of submerged land claims or King's Grants); the government holds the submerged land in public trust (see Introduction chapter for more information). Small streams can be owned if they are not considered navigable. Some of these streams are within lands owned by non-profit groups, government agencies, land trusts, municipalities, and private citizens for the purpose of conservation.

The GIS data layer for lands managed for conservation and open space is based on multiple source layers (http://www.nconemap.com/nconemap_meta/lmcos_faq.htm, November 2009). Partners in the creation of this data layer included the Department of Environment and Natural Resources (the Division of Parks and Recreation, the Wildlife Resources Commission, the Division of Coastal Management, and the Conservation Tax Credit program), the State Property Office, the Land Trust for North Carolina and its associated land trusts, the Department of Agriculture and Consumer Services, the Clean Water Management Trust Fund, the Conservation Fund, the Nature Conservancy, the US Forest Service, the US Fish and Wildlife Service, the NC GAP Analysis program, and the Triangle J Council of Governments and its associated local governments. However, not all land that has recreational, historic, scenic and natural resource value is defined as "open space and preserved farmland" for this project[63]. Approximately 9% of streams in coastal draining river basins (in the coastal plains) are protected in lands managed for conservation (CGIA 2002 data) (Table 2.20). *Rates and trends in land conservation and development could be tracked and compared to predict future landscape characteristics, and water quality impacts, and determine conservation actions needed.* Protection of water quality through land acquisition and deed obligations is a passive and less controversial approach to management of non-point sources of water pollution than regulations.

The North Carolina Department of Environment and Natural Resources (NCDENR) recognizes the need to coordinate statewide conservation efforts and developed the One NC Naturally Conservation Planning Tool (CPT) to streamline the process of identifying and prioritizing natural areas for conservation. The need for a tool became evident after the North Carolina General Assembly established the goal of permanently protecting one million acres of natural lands by the end of 2009. The state managed to achieve over half of the one million acres in the allotted time http://www.onencnaturally.org/pages/CPT_Detailed_Report.html, January 2010. The CPT approach is based on the "Green Infrastructure" principle, which emphasizes the importance of maintaining an interconnected network of natural areas for maintaining ecosystem stability. The tool can be used to pinpoint areas that are already protected as well as "gap" areas in ecosystem connectivity. The geospatial data layers supporting the tool are separated them into six classifications considered equally valuable: biodiversity/wildlife habitat, open space/conservation, water services, farmland, forestry lands, and marine/estuarine (see "Ecosystem management and Strategic Habitat Areas" chapter for more information).

[63] The Lands Managed for Conservation and Open Space database does NOT include privately owned green spaces, homeowner association green spaces, public leases of private land, school yards, university and college campus land, athletic fields, golf courses, utility-owned land, privately owned forests, prison property, university campuses, research farms or military bases. Private land that is leased or managed by the state for gameland reserves is not included in the database and does not count toward the Million Acre goal. These types of property all have value as areas that are free of buildings and parking lots, but they lack the permanency and purposes required for this project's working definitions.

Table 2.20. Coastal streams miles in lands managed for conservation (CGIA 2002 data). Note: Column sorted in order of descending total stream miles.

CHPP region	Federal	State	Private	Conservation group	Land Trust	Municipal	Other public	Local	Other non-profit	County	TOTAL
1	635.3	202.4	61.7	32.5	0	0.6	0	0	0	0	932.6
1/2	0.9	0	0	0	0	0	0	0	0	0	0.9
2	348.9	101.4	3.7	0	8.8	13.5	14.8	0	5.3	0	496.5
2/3	0.8	0	0	0	0	0	0	0	0	0	0.8
3	267.3	14	3.2	7.1	6.3	0.4	0	0.8	0	0.1	299.3
4	56.6	158.5	30.6	9.8	26	3	0	8	0.7	0.2	293.3
ALL	1,309.90	476.4	99.3	49.4	41.1	17.5	14.8	8.8	6	0.3	2,023.40

2.4. THREATS AND MANAGEMENT NEEDS

Human activities can negatively impact fish communities by altering naturally occurring flow and/or water quality conditions. Hydrological modifications – such as dam and culvert construction; water withdrawal; channelization; channel modification; stream bank modification; and shoreline erosion – can obstruct fish passage and/or affect flow and quality of the water column. Pollutant loading from point or nonpoint sources affects the quality of the water column. Excessive inputs of nutrients, bacteria, sediment, toxins or biochemical agents (i.e., endocrine disrupting substances), from point or nonpoint sources alike, can lead to visible signs of habitat degradation, including algal blooms, hypoxia, fish kills, and/or deformed fish. Threats are organized and discussed in this section by hydrological modifications, water quality degradation, non-native /nuisance species, and sea level rise/climate change.

2.4.1. Hydrological modifications

2.4.1.1. Flow regulation

Dams and water withdrawals modify the quantity of water in coastal North Carolina waters according to the water demands of a growing population. Flow regulation is a side-effect of road fill and culverts, channelization and drainage, and other hydrologic modifications.

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 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 watersheds. These structures primarily impact anadromous fish and the catadromous American eel spawning migrations (Maps 2.5a-b). 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). In the coastal plains portion of CHPP Region 1, approximately 18% (2,369 miles) of National Hydrologic Dataset (NHD) streams (13,070 miles) appear blocked by an impoundment, based on SHA Assessment results (see "Ecosystem management and Strategic Habitat Areas" chapter for more information). The Chowan subregion of Region 1 had the largest percent of dam-obstructed streams at 38%. Table 2.21 tallies the number of dams, locks, and culverts in CHPP regions and subregions.

Table 2.21. Number of documented obstructions (i.e., dams, locks, culverts) in coastal plains portion of CHPP regions based on data from Virginia Game and Inland Fisheries (1983 data), Collier and Odum (1989), Moser and Terra (1999), Department of Transportation (2003 data), Division of Water Resources (2003 data), and USACE obstructions inventory (2009 data). Note: Structures duplicated in different datasets were consolidated into one dataset.

CHPP Region	**Subregion**	**Dam/impoundment**	**Beaver dam***	**Lock***	**Storm gate***	**Vegetation***	**Culvert (unspecified)**	**Pipe culvert**	**Box culvert****
1	Albemarle	2	0	1	4	2	33	39	3
	Chowan	95	1	0	0	0	25	46	5
	Roanoke	28	0	0	0	0	29	32	0
	TOTAL	*125*	*1*	*1*	*4*	*2*	*87*	*117*	*8*
2	Neuse	113	0	0	0	0	119	139	1
	Pamlico Sound	1	0	0	0	0	15	9	0
	Tar/Pamlico	73	0	0	0	0	95	68	0
	TOTAL	*187*	*0*	*0*	*0*	*0*	*229*	*216*	*1*
3	Core/Bogue	1	0	0	0	0	0	8	0
	New/White Oak	5	0	0	0	0	8	24	0
	TOTAL	*6*	*0*	*0*	*0*	*0*	*8*	*32*	*0*
4	Cape Fear	191	0	0	0	0	104	176	1
	Southern estuaries	3	0	0	0	0	1	6	0
	TOTAL	*194*	*0*	*0*	*0*	*0*	*105*	*182*	*1*
ALL	**TOTAL**	**512**	**1**	**1**	**4**	**2**	**429**	**547**	**10**

* Collier and Odum (1989) only
** Moser and Terra (1999) only

Alteration of natural flow patterns by operation of reservoir dams can also impact conditions needed for successful spawning of anadromous species. Water releases in the Roanoke River have adversely affected flow conditions needed for some anadromous fish species and lowered dissolved oxygen levels (Fay et al. 1983b,d; USFWS, unpub. letter 2001). Among other factors, low oxygen levels were implicated in the decline of the Albemarle/Roanoke River stock of striped bass as well as in fish kill events (USFWS 1992). Other regulated rivers in coastal North Carolina include the Chowan, Tar-Pamlico, Neuse, and Cape Fear systems. All of these rivers historically supported striped bass and other anadromous fish populations (DMF 2003b).

Concern for anadromous fish spawning resulted in a cooperative agreement between the USACE, NCWRC, NCDMF, and the operators of Kerr Reservoir to store and release water between April 1 and June 15 when stored water is available (>299.5 ft msl) in the reservoir (P. Kornegay/WRC, pers. com., December 2008). When Kerr's elevation drops below 299.5 ft msl, the USACE will endeavor to store water and release it during peak spawning periods for anadromous species. Releases from downstream Roanoke Rapids Reservoir are regulated by Dominion Power Company, who has agreed to not release peaking flows from April to June 15. Dominion also agreed to re-release the exact "spawning flows" released by the USACE from Kerr Reservoir.

The USACE recently undertook a Neuse River Basin Study for which the WRC recommended the following flow guidelines for anadromous species. The guidelines were based spring striped bass and American shad survey work by the WRC. The guidelines have not been put into use (Bennett Wynn/WRC, pers. com., December 2008). Currently, the Army Corps' Falls Lake project is operated to meet a 184 cfs minimum flow target at the Clayton gage from November 1 to March 30. The rest of the year, a 254 cfs minimum target at Clayton is used. Since winter flows usually exceed 184 cfs, for practical purposes the target can be considered to be 254 cfs. While these targets take into account water quality and fish spawning, a primary concern is having water levels high enough to cover the many downstream water users' intake pipes.

In the Cape Fear River basin, the USACE operates Jordan Lake to meet a minimum flow target of 550 cfs at the Lillington gage. This target is sufficient for downriver water users and also generally maintains flow over the downstream Locks and Dams to the extent fish kills are prevented. Enhanced fish passage at the Locks and Dams may justify revision of this target, however (Bennett Wynn/WRC, pers. com., December 2008). There is no federal project on the Tar River, so the USACE has no specific mechanism for regulating flows in this basin. It is widely recognized, however, that the Tar can experience extremely low flows during drought conditions. The City of Greenville is initiating an instream flow study for the Tar River to address future water availability from this surface water source. Habitat and water quality needs will likely be considered in this study. Hopefully, flow targets will be developed from the study that accommodate the needs of anadromous fish (Bennett Wynn/pers.com., December 2008).

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, reclaiming 74 miles of historic spawning habitat available upstream to the Milburnie Dam near Raleigh (Map 2.5b). 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). The 2005 removal of Lowell Mill Dam in Johnston County, the most downstream dam on the Little River (tributary of the Neuse), provided 130 newly opened river miles of the Little River and its tributaries. The largest dam removal project ever in North Carolina, the Carbonton Dam removal in Lee, Moore and Chatham Counties, took place in December 2005 and opened up 10 miles of the Deep River (Cape Fear subregion, Piedment physiographic region).

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 allowing species to migrate further upstream to reclaimed habitat (Hightower and Jackson 2000, Bowman 2001, Burdick and Hightower 2006). Although dam removal reopens substantial migratory fish habitat, it also eliminates the created reservoir habitat, disrupts downstream aquatic communities, releases a substantial amount of sediment and any associated heavy metals, toxic chemicals, and nutrients, allows opportunities for invasive species on reservoir sediments, and will ultimately impact other fisheries and their habitats (Stanley and Doyle 2003). *Further research is encouraged to monitor impacts of dam removal on downstream fisheries and habitats. Removing unnecessary dams should be* *undertaken with consideration for both upstream and downstream impacts. A prioritized list of dams for removal or modification should also be compiled by state and federal resource agencies. The highest priorities for dam removal are Milburnie Dam on the mainstem Neuse River and the remaining dam on the Little River near Goldsboro (Atkinson Mill Dam), in the Neuse subregion (M. Wicker/USFWS, pers. com., March 2010).*

Where obstructions cannot be removed, fish passages (i.e. step-pool, roughened channels, and hybrid fishways) can be constructed that allow fish to maneuver upstream. When designing a fishway, the species present and the environmental conditions must be taken into account in order to ensure fish migration can and will occur. 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. Moser et al. (2000) investigated the success of American shad using Lock #1 and fish passages on the Cape Fear River using acoustic tags from 1996 to 1998. During the time period of this study Moser et al. (2000) observed a range of 18 to 61% of American shad moving upstream of the lock. In this study they found more fish migrating upstream utilizing the navigation lock instead of the fish passage as a result of design flaws in the fish passageway. The U.S. Army Corps of Engineers (COE) was required to enhance fish passage around the lowermost dam (Lock and Dam # 1) as mitigation for the deepening of the Wilmington Harbor dredging project and resulting sturgeon impacts, which finished in 2004. Removal of the dam was discussed but the City of Wilmington was strongly opposed to that because their water intake is just upstream of the dam. They were concerned that dam removal would lower water levels and increase salt content, impacting their water supply. The USACE then considered constructing an artificial bypass to allow a portion of the river flow to travel around the dam in a meandering channel that approximates a natural stream (USACE 2002), but met resistance from the adjacent land owner. The current proposal is to construct a rock ramp in front of the dam. However, the USACE has yet to receive funding for the required mitigation, due to budget restraints. The USACE received federal stimulus funding to fill the scour hole and build fish passage at Lock and Dam #1. Completion of a fish passage at Lock and Dam 1 would greatly benefit habitat conditions for Atlantic and shortnose sturgeon, American shad, striped bass, American eel, blueback herring, and hickory shad stocks (USACE 2002). Following the construction of a fish passage, natural resource agencies would like to remove or construct fish passage structures at Lock and Dam #2 and 3. *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.*[64] *State and federal agencies should work together to secure grant or other funding for fish passage restoration.*

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*

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

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.

Water withdrawals

Water is withdrawn from surface and ground waters for multiple purposes. 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 (Table 2.22). Excluding thermoelectric use, non-agricultural industrial use accounted for the largest source of water withdrawal from both public water supply and self-supplied surface water in 1995 (Street et al. 2005). Public water supply (including residential, commercial, and industrial uses) is responsible for the second largest amount of water withdrawn at 873 million gpd. Public water supply systems withdraw primarily surface water (698 mgd) and a lesser amount of ground water (174 mgd). Water treatment plants mark the general location of surface water withdrawals for public water supply (Map 2.6). Documented water use in the state has risen from 9,286 to 10,863 mgd from 1995-2008 (an increase of 1,577 mgd in 13 years).

Cooling water intake systems (CWISs) for power plants affect aquatic ecosystems by pulling organisms into water intake systems (entrainment) or trapping them on parts of the intake structure (impingement) (Greene et al. 2009). 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 de-scaling (ASMFC 2002b). 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.

Table 2.22. Most recent (2008) estimate of statewide water use compiled by the Division of Water Resources, by type of use, in millions of gallons per day (mgd). (Source: D. Rayno/DWR unpublished data, 2009)

Type of use	Ground Water	Surface Water	Total
Domestic self-supply (estimated)[1]	171	0	171
Industrial	45.5	169.5	215
Mining	105.9	35.3	141
Golf Courses	7.3	22.2	29
Agriculture/Aquaculture	96.3	131.8	228
Thermoelectric	0	9,206	9,206
Public Water Supply[2]	173.9	698.8	873
Total[3]	600	10,263	10,863

[1] Domestic self-supply estimated at 70 gallons per person per day for 26.5% of the 2008 state population of 9,227,016.
[2] Includes residential, commercial, institutional, and industrial uses supplied by community water systems reporting water use to DWR.
[3] Use in other categories derived from data submitted to the Division of Water Resources and Dept. of Agriculture and Consumer Services.

Entrainment survival studies found that mortality rates ranged from 2% for naked goby larvae to 97% for bay anchovy (ASMFC 2002b). The primary concern with cooling water intake structures is the cumulative impact of multiple facilities on fish populations (ASMFC 2002b). 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). Devices including electrical screens, air bubble curtains, lights, high-frequency sound, chemicals, and lights have been developed as a "warning" system to deter fish from intake systems (Martin et al. 1994, Greene et al. 2009). 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 Areas.*

The ASMFC formed a Power Plant Panel in 2000 to conduct a coast-wide assessment of the cumulative impacts of power plant impingement and entrainment. The results of this workgroup provided a method for estimating mortality rates based on loss estimates and power plant data. In 2004, the EPA developed 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 were developed for Phase I (new facilities) and Phase II (existing power plants using large amounts of cooling water) and finalized by February 2004 (http://www.epa.gov/waterscience/316b/phase2/phase2final-fs.pdf, January 2010). The final rules for

Phase II included impingement requirements to reduce the number of organisms pinned against parts of the intake structure to be reduced by 80 to 95 percent from uncontrolled levels. Entrainment requirements called for a 60 to 90% reduction in number of aquatic organisms drawn into the cooling system. The rule also included several compliance alternatives for large power plants. Phase III standards (existing facilities that withdraw at least 2MGD) were discussed in 2006, but the EPA decided that due to cost restraints it would be best to handle each case individually. In 2007 the EPA suspended the Phase II rules affecting existed CWISs following a ruling by the U.S. Circuit Court of Appeals.

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. In addition to altering flow downstream, water intakes placed behind dams can impede efforts to restore fish passage. 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). During low flow conditions, such as drought, returned wastewater can comprise a significant portion of the river's flow. Interbasin transfers could result in large permanent flow reductions (DMF 2003b).

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 N.C. Department of Agriculture and Consumer Services (if agricultural) (Table 2.23). 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 falling below the required use designations are exempt from registration, data obtained from Water Withdrawal Registrations represent only part of the total water usage.

Table 2.23. 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 2.24). Permitted withdrawals include community water systems, thermoelectric generation, agricultural operations, golf courses, quarries, and non-electric generating industrial operations. The maximum permitted volume of surface water withdrawal from community water systems ranges from 69 to 338 million gallons per day (mgd) among the four river basins. The largest amounts of community withdrawal are in the Cape Fear and Neuse basins. Withdrawals for thermoelectric generation are much greater than withdrawals for community water systems (Table 2.24). The Cape Fear and Roanoke have the largest quantity of withdrawals for thermoelectric generation. Withdrawals for other uses range from 14 to 122 mgd among river basins. The total quantity of surface water withdrawals from Table 2.24 sources is over 5,000 mgd in the specified coastal draining river basins. Additional surface water use from agriculture and aquaculture was reported by the Department of Agriculture and Consumer Services (Table 2.25). The additional sources add 59 mgd to the total quantity of surface water withdrawn in the Cape Fear, Roanoke (NC portion), Neuse, and Tar-Pamlico subregions. However, the reported withdrawals represent some degree of under-reporting. *More research is needed to assess the impact of water withdrawals on water column habitat fish populations, or the ability to remove obstructions to fish passage in the affected river basins. New large volume surface water intakes should not be permitted behind dams in areas that would prevent stream passage restoration, where the dam has been identified as a priority for removal.*

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 eastern North Carolina, it is estimated that approximately 22% enters streams through ground-water seepage, 1% seeps into large rivers and sounds, 10% becomes surface runoff, 66% evaporates, and only 1% percolates into confined aquifers (Giese et al. 1997). 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, particularly in deep aquifers historically used for water supplies. Between 1989 and 1998 in the Black Creek Aquifer, 10-year delines 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 availability in coastal counties should be made to determine what the environmental consequences will be if the increase in water withdrawals continues.* As deep aquifers are restricted for use, as has occurred in the CCPCUA, there will likely be a shift to surface water and alluvial aquifer systems (T. Spruill/USGS. Pers. com., March 2010). Because shallow aquifers are the principal sources of baseflow to streams and rivers, these should be the focus of impact assessments. In lower sections of large rivers increased demand is likely to induce saltwater where towns and cities are located

Table 2.24. Current (2008) surface water withdrawals and relevant capacities derived from data reported to DENR-Division of Water Resources and Department of Agriculture and Consumer Services Agricultural Statistics for CHPP subregions. (Source: D. Rayno/DWR, unpublished data, 2009)

	Community Water Systems*		**Thermoelectric Generation**		**Other Uses****	
CHPP subregion	**No. of systems**	**treatment capacity (MGD)**	**No. of facilities**	**withdrawal capacity (MGD)**	**No. of systems**	**withdrawal capacity (MGD)**
Cape Fear	22	337.6	4	2334.4	21	122.8
Roanoke (NC portion)	8	68.7	3	1763.1	7	32.3
Neuse	11	219.1	1	31.7	11	91.7
Tar-Pamlico	7	84.5	0	0	6	13.8
TOTALS	*48*	*709.776*	*8*	*4129.23*	*45*	*260.613*

*Data submitted to DWR in Local Water Supply Plans for water systems supplying residential, commercial, institutional and industrial users

** Other Uses includes agricultural operations, golf courses, quarries, and non-electric generating industrial operations

Effective August 01, 2002, the Environmental Management Commission (EMC) designated 15 coastal counties as the 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 2.23). Outside of 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. As of 2009, North Carolina Cretaceous aquifers have been providing 51% (on average between 2002 and 2009) of the reported public supply needs in the CCPCUA (DWR 2009).

Table 2.25. Current (2008) water withdrawals registered for agriculture and aquaculture with the Department of Agriculture and Consumer Services and no included in Table 2.24. (Source: D. Rayno/DWR, unpublished data, 2009) Note: An explanation of this data can be found at the "2008 Water Use" link at http://www.ncagr.gov/stats/index.htm

CHPP subregion	Unique Operations	Annual Average Daily Use: Ground Water (MGD)	Annual Average Daily Use: Surface Water (MGD)	Total Withdrawal Capacity (MGD)
Cape Fear	511	10.96	26.73*	428.19
Roanoke (NC portion)	86	0.87*	9.05	91.91
Neuse	250	5.36	12.05	149.28
Tar-Pamlico	131	2.45	11.25*	160.5
TOTAL	*976*	*19.64*	*59.08*	*829.88*

*May represent under reporting of actual use due to data disclosure limitations of authorizing legislation

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. As a result DWR issued 54 permits in 2008 requiring a 75% reduction of the Black Creek and Upper Cape Fear aquifers by 2018.

Water withdrawal for municipal uses will likely become a major issue for future water conservation. With North Carolina' population expected to increase from 8.5 million people in 2005 to 12 million by 2030, the consumption of surface water is estimated to increase from 244.5 to 335 billion gallons /year (NCREDC 2005). 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 current frequency of droughts and forecasted increases with climate change (see “Climate change” section for more information) could also exacerbate water supply issues (NWF 2008). The major droughts that occurred during 2000-2002 and 2007-2008 are captured on Figure 2.2. The drought of 2007-08 was the worst in North Carolina since recordkeeping began on the subject in 1895. The drought started Feb. 13, 2007, creeping from the mountains to the coast as a lack of rainfall depleted stream flows and reservoirs to record low levels. The drought prompted many towns to enact mandatory and voluntary water conservation restrictions and helped bring about a state law that makes state and local officials better prepared to respond to future droughts. The cycle of flood and drought years has a significant impact on the cyclic nature of plant life growing in the water column. For example, the high abundance of SAV documented in 2007-2008 was encouraged by the relatively clear water and cloud-free days associated with minimal rainfall conditions (see “Submerged aquatic vegetation” chapter for more information on SAV status and trends).

An emerging issue since the 2005 CHPP is the effect of dewatering on estuarine waters. Dewatering is often done in association with mining, to temporarily lower the water table. Large amounts of fresh water are discharged. Where the water is discharged to SA waters, there is concern regarding the effect of the dewatering on salinity in adjacent and downstream waters. Excessive decrease or rapid change in salinity can be detrimental to juvenile fish and shellfish. *To properly review mining applications, more information is needed on the expected effect of the freshwater discharge on the salinity of receiving waters.* Large amounts of dewatering are also required when utilizing a new type of wasterwater treatment system known as rapid infiltration system. In this centralized wastewater treatment system, treated effluent is discharged into a storage pond. Wells are installed around the pond for dewatering, lowering water table levels and allowing room for the treated effluent to filter down. Not only will large amounts of freshwater be discharged to an adjacent stream, there is concern that over time, the groundwater will be contaminated with the effluent, and then discharged to the stream as freshwater (L. Willis/DWQ, pers. com. 2010). This new technology is being increasingly used. *Research on the potential ecological impact of this type of wastewater system needs to be assessed further before widespread use.*

2.4.1.2. Road fill and culverts

Based on analysis of NC DENR and NC DOT records, it has been estimated that the state loses, on average, about 500 acres of wetlands per year, mostly from road construction (see “Status and trends” section of the Wetlands chapter for more information). Road construction over rivers, streams, or wetlands often involves blockage of a portion of the original stream channel and floodplain. Bridges may cross over the water or culverts may be constructed under the road, depending on the size of stream and associated wetlands. In the past, bridges were constructed by filling the adjoining wetlands and creating a narrow channel for water passage. Current wetland protection rules and DOT policies discourage placing fill in adjoining wetlands, thus requiring bridges to span a longer distance in some areas. Culverts have been placed on small streams bisecting the road/rail network. 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 to some degree. Both bridge channels and culverts narrow water passages (due to fill placed at the stream edge to support the structures), slowing drainage, altering water velocities and causing localized erosion (Mudre et al. 1985, Clay 1995, Riggs 2000). Any of these factors may prevent fish from entering the culverts to reach otherwise suitable spawning grounds. Placing the culverts at the wrong elevation or slope can also prevent passage during certain flow conditions. In 1997, a multi-disciplinary committee comprised of members from the DMF, WRC, NMFS, USFWS, DEM (Division of Environment Management), and the DOT developed guidelines for minimizing the impact of bridge and culvert infrastructure on anadromous species. The guidelines pertain to “blue line” streams in the Coastal Plains, and include the following stipulations:

- Avoidance of instream work during the spring migration period, defined as occurring from February 15 to June 15,
- Preference for bridges and other channel spanning structures over road fill and culverts,
- Requirement that proposed openings allow passage of the average historical spring flows without adversely altering flow velocity ("adverse" not defined), and a
- Requirement to place culvert bottoms below the stream bed

Fish migration may also be hampered by reduced light in culverts and under bridges. Moser and Terra (1999) studied the effect of, "light in the pipe," on river herring migratory behavior in tributaries of Albemarle Sound and in the Neuse, Pamlico, and Cape Fear rivers. Results showed that river herring preferred to migrate through areas with a minimum light level – 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.

Because of the observed hydrological impacts and light reduction, 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, USACE, 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 the Ecosystem Enhancement Program (see "Wetland restoration and enhancement" section of the "Wetland" chapter for more information).

According to DOT, there are numerous aging culverts and bridges in need of replacement. Because of this increase, DOT formed an interagency permit group to discuss streamlining the permit process for bridge and culvert replacement to reduce permit process time and expense. With culverts being much cheaper to install than bridges, economics may discourage upgrading culverts to bridges. *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. Partnering with resource agencies, NGOs, and regional conservation groups such as Albemarle-Pamlico Conservation and Communities Collaborative (AP3C), Cape Fear Arch, and Onslow Bight Partners to assist with any associated costs should be considered.*

Since 2005, some research and monitoring of culverts and anadromous fish passage has been conducted. Environmental Defense (ED) is finalizing a report using a GIS-based tool to identify the most valuable spawning and nursery habitats for river herring in coastal watersheds. The model was tested within the North Carolina portion of the Chowan River basin. A two-part habitat suitability analysis was conducting starting with an expert workshop and resulting criteria applied to 1:24,000 scale (USGS) hydrology and DCM wetland type maps. The area selected covered streams and adjoining floodplain wetlands up to the point of major fragmentation of riparian wetland habitats. Duke University Marine Lab's Geospatial Analysis Program conducted the second part of suitability analysis with GIS modeling of the following components:

1. Determination of river herring habitat:
   a. Construction of high resolution drainage network based on LIDAR floodplain mapping;
   b. Determination of suitable river herring habitat patches using DCM's Coastal Region Evaluation

of Wetland Significance dataset. Then confirming suitability with DMF data on river herring spawning locations (Street et al. 1975, Johnson et al. 1977, Winslow et al. 1983, Winslow et al. 1985, Winslow and Rawls 1992);
   c. Identification of restorable and enhanceable river herring habitat patches using DCM's Potential Restoration and Enhancement Site Mapping;
2. Delineation and description of buffer areas around suitable and restorable river herring habitat using STATSGO soil database and 1996 statewide land cover data;
3. Identification and incorporation of obstacles to habitat using statewide dams database, bridge and culvert data from DOT, and other obstructions data from Collier and Odum (1989)

In the summer of 2007, a field assessment was conducted to evaluate a subset of the obstructions. A total of 62 sites were randomly selected and visited to confirm the physical presence of structures (bridges and culverts) and to judge the degree to which each structure presented an obstacle to river herring movement. A total of 14 bridges, 30 pipe culverts and 14 box culverts were visited. Criteria established by Moser and Terra (1999) were used to determine whether the bridges and culverts posed challenges to herring movement. The results of the field assessment indicated that none of the 14 bridges assessed as an obstruction to river herring. All but one of the culverts was less than twelve feet in diameter; therefore the vast majority of culverts were obstructions. The findings were applied to the GIS model; all culverts were classified as obstructions and all bridges were not. Applying the model to the Chowan River Basin assessment area, there were a total of 91 obstructions (dams and culverts) yielding 8,587 acres of suitable river herring habitat and 1,163 acres of restorable/enhanceable habitat are inaccessible to herring. This corresponds to an equivalent of 28% of the total 5,920 drainage network stream miles being blocked from river herring access in the Chowan River study area. The model is intended to help resource managers select the best opportunities for habitat preservation or restoration projects. The DWQ does not consider culverts bisecting anadromous spawning areas as a source of impairment and thus EEP does not include culvert removal as a restoration target for local watershed plans. *The DWQ should consider including culverts obstructing suitable anadromous fish spawning habitat as a source of water column impairment, and culvert removal as a restoration credit for the EEP and DOT. The EEP could then include such proactive restoration options in its overall mission to mitigate and restore lost ecosystem functions.*

Strategic Habitat Area assessment in CHPP Region 1 (Albemarle Sound and tributaries), a larger area than the ED study, generated a GIS coverage of possible and documented culverts forming the upstream limit of unobstructed creeks. Sources of culvert data included the DOT, Collier and Odum (1989), Moser and Terra (1999), and a GIS analysis intersecting streams (1:100,000 scale National Hydrologic Dataset) and unbridged roads. Based on this data, there were nearly 9,000 culverts and possible culverts in Region 1 (including Virginia). Ninety eight percent of the culverts were located with GIS analysis and therefore undocumented. Based on culvert locations, the amount of obstructed lowland streams[65] (both natural and ditched) in Region 1 could be as much as 5,027 miles (63% of all lowland streams in Region 1). The figures go up only slightly when dam and lock obstructed areas are included. However, it should be noted that total mileage of streams varies according to the mapping scale. The EDF study represents a very fine scale representation of the stream network, including many more low order streams. The locations of culverts and storm gates on AFSAs are shown on Maps 2.5a-b and inventoried in Table 2.21.

In an ongoing effort to locate obstructions and impedances to river herring passage, the DMF also conducted surveys on the lowest downstream culvert, or primary culvert, in Chowan and Meherrin River tributaries (beginning in 2007). Such work has resulted in the removal of one culvert blocking river herring migration at the mouth of Brooks Creeks, a tributary of the Wiccacon River in the Chowan river basin (K. Rawls/DMF, pers. com., February 2010). Information collected included; culvert type, material, dimensions, water depth, distance between water level and top/bottom of culvert, water level

[65] The lowest of three elevation categories found in the coastal plains of North Carolina, based on natural breaks.

and water body width. *The results of the EDF study and DMF field surveys should be used to determine priorities for culvert removal.* The need for priorities was highlighted when American Rivers came to DMF for suggestions on where to fund a culvert or dam removal project (L. Batt/American Rivers/pers. com., February 2010).

2.4.1.3. Channelization and drainage

Channelization is the deepening and straightening of a natural stream. Ditching involves the creation of new channels for draining adjacent lands. These activities can affect the slope, depth, width and roughness of the channel, thus changing the dynamic equilibrium of the stream and associated wetlands. Channelized streams are deeper, more variable in flow, and less variable in depth than natural streams (Orth and White 1993). Both channelization and ditching increase channel cross-section and flow capacity, thus reducing the frequency of overbank flow events that allow wetland filtration and fish access to the riparian wetlands (DMF 2000b). Consequently, loading and movement of sediment and other nonpoint source pollutants are often greater in channelized streams than in natural streams (White 1996; EPA 2001). The banks created by disposal of spoil along the shoreline further prevent fish from entering the adjacent wetlands (see “Channelization/ditching” section of “Wetland” chapter for more information). Ditches and canals (large ditches) have been constructed primarily in uplands, previously filled wetlands, and wetlands (both riparian and non-riparian). Ditching of riparian wetlands is no longer allowed without a permit and possible mitigation (see “Status and trends” section of “Wetland” chapter for more information). Ditching is discussed further in the “Land-use and non-point sources” section of this chapter.

The impacts of channelization primarily affects smaller species and life stages (i.e., larval river herring) using wetlands and shallow stream margins (O’Rear 1983); habitats that are reduced or made inaccessible by channelization. Elevated water velocities in channelized streams 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 2000b). 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).

Channelized streams have also been found to have less suitable spawning habitat and reduced recruitment success for anadromous species (Sholar 1975). The amount of in-stream vegetation, woody debris, and streamside vegetation is generally reduced in channelized streams resulting in reduced substrate for fertilized herring eggs, the protective cover for adult and juvenile fish, and habitat for invertebrates (DMF 2000b). Macroinvertebrate species richness, biomass, and production are higher on snags and debris than any other habitat in Coastal Plain streams (Smock and Gilinsky 1992). Removal of large woody debris also contributes to accelerating water velocity. Excessive woody debris can also hamper upstream fish migration and downstream water conveyance, suggesting a need for threshold criteria. Municipalities often view “naturalized channels” as a problem that will increase flooding. As channelized streams have aged, there is increasing interest in clearing them out for flood control. Education to local government is needed on the negative ecological impacts of de-snagging and proper techniques. *De-snagging of woody debris in AFSAs should be conducted in accordance with, “Stream Obstruction Removal Guidelines,” published by the American Fisheries Society in 1983. Guidelines for woody debris removal in streams are also provided at http://www.americanwhitewater.org/content/Wiki/stewardship:woody_debris*

Most streams in eastern North Carolina have been channelized to some extent (NC Sea Grant 1997). North Carolina has a long history of stream channelization and drainage. However, documentation of historic drainage activities has not differentiated between channelized streams and artificial drainage channels (see “Land use and non-point sources” section for more information on ditching). No new channelization projects have occurred since the 1970’s (Chicod Creek, Pitt and Beaufort counties, Tar-Pamlico subregion). However, maintenance of existing channels in agricultural drainage districts (DEHNR 1995a) is a recurring issue in permit decisions. There are over 200 miles of channelized streams in CHPP region 1 (3% of all lowland streams in region), based on Strategic Habitat Area (SHA) assessment (Map 2.7). Many of these old channels have re-naturalized and are now supporting river herring migration (Sara Winslow/DMF, pers. com., Nov. 2007). So far, the DMF has successfully opposed the maintenance of re-naturalized channels. *Channelization regulations could be modified to discourage or prevent maintenance of previously un-navigable and re-naturalized channels in Anadromous Fish Spawning Areas and Primary Nursery Areas.*

2.4.1.4. Dredging (navigation channels and boat basins)

Dredging of canals, channels, and boat basins involves land excavation or deepening areas for boating or drainage. Excavation of coastal wetlands has also been done to control mosquitoes; a practice that is no longer permitted. The most obvious impacts of dredging are the deepening of shallow water habitats and the creation of artificial channels.

Deepening of shallow-water habitats can result in a loss of nursery habitat for some estuarine-dependent species (Rozas 1992). For this reason, CAMA rules restrict new dredging in MFC-designated Primary Nursery Areas. Dredged channels may also accumulate fine silt and pollutants that can be easily resuspended by boat wakes, prop wash, strong winds, and/or channel maintenance (DEHNR 1990). Chemicals, metals, nutrients, and organic matter stored in the sediment can then re-enter the water column, causing short-term increases in toxicity, turbidity, algal blooms, and biological oxygen demand (BOD) (Lalancette 1984). Habitat alteration from dredging may have been responsible for 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) (Street et al. 2005). However, turbidity from dredging may also protect small or young fish from visual predators (Livingston 1975; Bruton 1985; Walsh et al. 1999). Recruitment of invertebrate larvae, growth of filter feeding invertebrates, and visual foraging for prey by adult fish are also affected by turbidity from dredging (Reilly and Bellis 1983; Hackney et al. 1996; Peterson et al. 2000a, Lindquist and Manning 2001). 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.* These areas are likely to include Anadromous Fish Nursery Areas that have yet to be designated.

Fish species attracted to the topography of dredged canals and basins, can be adversely impacted by altered water quality conditions that occur there. Major canals connecting estuarine areas and coastal lakes attract fish and sometimes create stressful temperature and oxygen conditions where storm gates prevent water movement during low flows (Wilson Laney/USFWS, pers. com., February 2009). The USFWS and WRC are investigating gate technologies that allow passage of fish even during low flow periods. Dead-end canals and upland boat basins may also be isolated from riverine flow, causing stagnation during even normal flows. The CRC currently requires flow studies and facility designs that minimize stagnation (i.e., basin no deeper than connecting water body). However, some canals augment existing nursery habitat where they form the headwaters of PNAs and SNAs. A visual GIS evaluation of over 2,400 fish nursery areas (PNA, SNA and IPNAs) suggested that about 40 designated areas were actually drainage canals (DMF unpublished data, December 2008). *Canals classified as fish nursery habitat should receive the same consideration in permit decisions as naturally occurring designated areas.* Equal protection is justified by a history of unmitigated loss of shallow water habitat to shoreline development. Upland boat basins in nursery habitat may also attract larvae and juveniles. In CHPP region 1 there are nearly 200 miles of canals and boat basins, based on SHA assessment. These 200 miles are in addition to the nearly 8,000 miles of lowland streams in Region 1.

While dredging has water quality impacts, it has been used in some instances to enhance water quality by improving circulation. The mouths of many creeks along the Atlantic Intracoastal Waterway have shoaled in with sediment from suspension and settlement of sediment from dredging and boat wakes. 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, Mallin et al. 2008). However, when Bald Head creek was similarly dredged to reduce bacterial contamination, the dredging was unsuccessful and resulted in no water quality improvements (R. Carpenter/DMF, pers. Com. 2009).

Navigational channels were dredged through most major coastal water bodies in North Carolina by the USACE 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 maintains most of the channels associated with the ferry system. And there are dozens of privately maintained channels serving marinas and private docking facilities. The two major commercial shipping ports in North Carolina, located in Morehead City and Wilmington, have extensive areas of dredged channels and basins (38 – 45 ft deep). The locations of dredge channels, marinas, and 10-slip docks are shown in Map 2.8a-ba-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.

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 USACE 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. Timing of all work is dependent upon the area to be maintained, the type of equipment to be used, and the anticipated environmental effects. Disposal of material is dependent on the type of dredge used to perform the work. Material dredged by sidecast is deposited on 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. Beneficial uses of dredge spoil include in enhancement and restoration of marsh islands being lost to sea level rise and the interruption of barrier island over -wash with beach-front development (see "Wetland" and "Submerged Aquatic Vegetation" chapters for more information).

2.4.1.5. 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). The open pits created by coastal mines fill with groundwater that is often pumped into ditches and rivers during excavation (G. Cooper/DWR, pers. com., 2004). Many mine sites are in the vicinity of rivers and estuaries (http://www.dlr.enr.state.nc.us/pages/permittedmines.html, November 2009). The discharge can contain sediment, nutrients, and heavy metals. *Although mining was the source implicated in only 0.5% of impaired streams in coastal draining river basins in the DWQ (2006) Integrated 305(b)/303(d) report, if* *more resources could be applied to required monitoring, checking for compliance, or encorporating monitoring results in the BIMS, then perhaps the impacts from mining would traceable.*

Sand/gravel mines are the most common mine in coastal North Carolina. Data from DLR for 2009 indicate 634 active and inactive mines in the CHPP management area, with 302 located in CAMA counties. Of the 271 active mines in CAMA counties, there are 262 permits for sand/gravel mining, 8 permits for crushed stone mining, and 1 permit for phosphate mining. The number of mines in CAMA counties has changed very little since 2000. The phosphate mining permit, includes 12,140 acres along and within the Pamlico River in Beaufort County, is now owned by PCS Phosphate, (see "Mining" section of "Wetland" chapter for more information). The phosphate mine is the largest wastewater discharger among all coastal NC mining operations. In addition to substantial stream and wetland impacts due to excavation, before 1992, this mine was discharging 50-60 million gallons/day of phosphate-rich water into Pamlico Sound contributing to eutrophication of the Pamlico River (Steel 1991). Since 1992, PCS Phosphate uses a water recycling process that has reduced discharge of nutrients by over 90% (USACE/PCS Phosphate DEIS, 2006).

In addition to open pit mining near rivers and ditches, there is also mining of marine soft bottom for beach nourishment sand (see "Soft bottom" chapter for more information on beach nourishment) and mining riverine soft bottom near old saw mills for ancient logs. Log salvage operations have been permitted in the Cape Fear, Roanoke, and Perquimans rivers (Street et al. 2005). The Log Salvage Policy Development Team was created by DENR in 1999, 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 (DENR 2000c). The removal of ancient logs removal large woody debris from the system and may impact water quality of anadromous fish habitat. Log salvaging in areas of contaminated sediment could allow pollutants to re-enter the water column. However, this resuspension of sediment is a temporary impact from a relatively minor industry.

2.4.1.6. Jetties and groins

Jetties and groins are both hardened structures positioned perpendicular from shore to control sand movement. In association with inlets, these structures can potentially interfere with the passage of larvae and early juveniles from offshore spawning grounds into estuarine nursery areas because successful transport of larvae through the inlet occurs within a narrow zone parallel to the shoreline and is highly dependent on along-shore 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). Offshore spawning, estuarine-dependent species that could 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 (see "Marine spawning" subsection of "Ecological Role and Function" section for more information).

Impacts from jetties and groins may be greatest in coastal areas like the Outer Banks, where there are few inlets. 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 Environmental Impact Statement (USACE 1999) for the Oregon Inlet project concluded the jetties should not be constructed because of, among other concerns, the impact of jetties on larval fish passage. Although there is uncertainty regarding the magnitude of fisheries impacts, jetties and groins would likely reduce larval recruitment into estuarine nurseries (Kapolnai et al. 1996; Churchill et al. 1997; Blanton et al. 1999). *Research is needed to determine when and where recruitment to adult fish stocks is limited by larval ingress to estuarine nursery habitats. Without conclusive research, changes to North Carolina's policy on prohibition of* *shoreline hardening structures on the oceanfront should be considered very carefully*.

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, and a groin field on Bald Head Island (see Map 6.3a-c in the Soft Bottom chapter). There is also a jetty at Cape Lookout, although it is not immediately adjacent to Barden's Inlet. State law currently prohibits the construction of groins for shoreline protection along North Carolina's ocean beaches. However, pressure from littoral local governments and resulting legislative action has re-opened the possibility of groins for protecting beach property. Session Law 2009-479 mandated that the CRC conduct a study on the feasibility advisability of the use of terminal groins, and present a report to the Environmental Review Commission and the General Assembly by April 1, 2010. The bill directs the CRC to consider the effectiveness of terminal groins constructed in North Carolina and other states in controlling erosion, scientific data regarding the impact of terminal groins on the environment and natural wildlife habitats, and information on the economics of terminal groins. The study will compile information on the effectiveness and impacts of five existing groin structures at five inlets: Oregon Inlet and Beaufort Inlet in NC, Amelia Island/Nassau Sound, northeast Florida, and Captiva Island and St John's Pass, west coast Florida. *The long-term consequences of hardened structures on larval transport and recruitment should be thoroughly assessed.*

Environmental outreach regarding the effect of inlet stabilization on coastal fish habitat is needed to educate public stakeholders (fishing communities and coastal property owners) on this issue and gain support for maintaining natural barrier island processes.

2.4.1.7. 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 by scouring along the toe and sides of the structure. Other impacts are to adjoining wetlands, SAV, and shallow soft bottom. The impacts of stabilization along the estuarine and ocean shoreline are primarily discussed in the "Wetland" and "Soft bottom" chapters, respectively.

2.4.1.8. Fishing gear impacts

Fishing gear is not a major threat to the condition of the water column. Mobile bottom disturbing gear can resuspend sediment and associated contaminants in the sediment, causing temporary turbidity (see soft bottom chapter for more information). Corbett et al (2004) in examining the effect of trawling on water quality, found that trawling increased total suspended sediment 1.5 – 3 times above background concentrations for less than one day, and had minor impacts on nutrient and chlorophyll *a* concentrations. Wind forced water circulation played a greater role in mixing the water column and altering nutrient and sediment characteristics of the water.

Entanglement gear, such as gill nets, do not cause bottom disturbance and are size selective, allowing smaller species to pass through. However, certain sized gill nets can unintentionally capture larger non-targeted species. DMF data has found that the large mesh gill net fishery in certain locations and times was resulting in sea turtle deaths. The gill nets in these cases are impeding the function of the water column as a corridor for migration of protected species. *DMF is actively working to address this situation and should develop a comprehensive plan to minimize impacts to protected species*.

2.4.2. Water quality degradation- Sources

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 pollutants are oxygen-consuming wastes, nutrients, suspended sediment, and toxins (including chlorine, ammonia, and metals). A National Pollution Elimination System (NPDES) permit is needed for individually significant point source discharges, and most NPDES discharges are treated municipal or industrial wastewater. 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, groundwater seepage, or atmospheric deposition. Unlike point sources, nonpoint pollutant loading varies with weather patterns and land disturbance. The concentration of point source pollutants in streams tends to increase under low flow or drought conditions.

Tracking sources of pollutants is generally more difficult than measuring pollutants levels in the water. The difficulty is implied by the unspecified source of pollutants in 28% of streams and 100% of estuaries in coastal draining river basins of North Carolina. Of the 72% of streams with specified sources of impairment, 27% were point sources and 73% were non-point sources. The USGS and University research programs have attempted to allocate nutrient sources in the Albemarle-Pamlico and Cape Fear systems, where there is extensive water quality monitoring (see “Nutrients and eutrophication” section for more information). *Pollution source/pollutant contribution modeling should be used to support DWQ assessment of impairment sources. Such modeling should also be used to evaluate impairment where water quality data is lacking. The attribution of pollution sources is a vital component in developing Local Watershed Plans and TMDLs, which could be applied to the management of cumulative impacts.*

2.4.2.1. Point sources

Discharges that enter surface waters through a pipe, ditch, or other well-defined point of discharge are broadly referred to as “point sources.” By this definition, point sources include not only industrial and municipal discharge pipes, but also the myriad of ditches draining coastal watersheds and some marina basins. The regulatory definition is based on state and federal wastewater and stormwater rules and includes municipal (city and county) and industrial wastewater treatment plants, small domestic wastewater treatment systems, and reverse osmosis water treatment plants (see “Other causes of water quality degradation” for more information). As exemplified by recent studies in the Neuse River basin, in watersheds with increasing human population such point sources continue to be large contributors to nutrient loading to estuarine waters (Rothenberger et al. 2009b). Point source dischargers in North Carolina must apply and obtain a National Pollutant Discharge Elimination System (NPDES) permit, and comply with applicable Nutrient Management Strategies and stormwater rules (see “Non-point source management” subsection of “Land-use and non-point sources” section for more information). Discharge permits are issued under the NPDES program, delegated to the DWQ by the Environmental Protection Agency (EPA). The NPDES program also has non-discharging and stormwater components, which address primarily water treatment (see “Water withdrawal” section for more information), groundwater remediation, and non-point source pollution (see Land use and non-point sources” section for more information). As of 2009, the NPDES general permit for discharging stormwater also includes marinas as a point source.

Point sources of pollution discharges are managed by NPDES permit conditions, Total Maximum Daily Load (TMDL) allocations and Notices and Violation (NOV). Permit conditions require discharges to maintain water quality standards at the outlet pipe. Failing to meet water quality standard could lead to a NOV. Load limits are also placed on point sources with specific TMDLs allocations. In 2002, the DWQ set a goal of developing TMDLs for all impaired waters within 10 years of their first placement on the North Carolina 303(d) list (http://h2o.enr.state.nc.us/tmdl/General_TMDLs.htm, November 2009). The TMDLs for impaired waters are currently at many different stages on the path to EPA approval. Some require additional data collection to adequately define the problem in TMDL terms. Some require more outreach to increase stakeholder involvement. Others need to have a technical strategy budgeted, funded, and scheduled. Some are ready for EPA submittal. Having defined pollutant allocations maintaining water quality conditions is a vital tool for coastal habitat protection. However, the water quality standards and available monitoring do not necessarily correspond to the needs of sensitive estuarine indicators (i.e., submerged aquatic vegetation; see "Assessment needs relative to aquatic life" section and "Submerged Aquatic Vegetation" chapter for more information). Further comparison of water quality standards and water quality needs for estuarine aquatic life is provided in the following sections on nutrients, sediment, and toxic chemicals.

In the CHPP management area, there are 317 and 181 permitted discharges of municipal/domestic and industrial wastewater, respectively (Table 2.26). Over half the NPDES discharges are in the coastal plains (Map 2.6). Permitted wastewater accounted for 20% of impaired streams in coastal draining river basins in 2006 (see "Status and trends" section for more information). The contribution of permitted wastewater to shellfishing closures was not listed in the 2006 DWQ assessment. The DEH requires closures around all NPDES wastewater discharges due to the possibility that mechanical failure could allow inadequately treated sewage to reach shellfish waters. However, the DEH automatically closes waters to shellfish harvesting in most marina basins due to high potential for shellfish contamination. Sanitary surveys conducted by DEH (Shellfish Sanitation and Recreational Water Quality Section) implicated permitted discharges and marina closures as the primary source of microbial contamination in about 10% of shellfishing areas sampled (G. Gilbert/DEH, pers. com., 2002). 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.

There are also episodic discharges of raw sewage into estuarine waters resulting in elevated biological oxygen demand and microbial contamination. From 2002-2009, the amount of sewage spilled in coastal waters ranged from 0.5 million to over 10 million gallons per year (Table 2.27, DWQ unpublished data, 2009). In wet years, the totals are generally larger due to storm sewer overflows. Counties with over one million gallons spilled in a year included Pasquotank, Onslow and New Hanover. The volume of spills is estimated by the violators and is probably underestimated (K. Glazier/DWQ, pers. com., December 2009). *Loading of pollutants 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 are needed to identify and prioritize sites needing upgrades.*Since the 2005 CHPP, Wilmington and New Hanover County experienced a series of large spills due to failing infrastructure and high usage. A 3,000,000 gallon raw sewage spill into Hewletts Creek resulted in strong hypoxia and large fish kills, algal blooms from nutrient inputs, fecal microbial contamination of the water and sediments, waterfowl kills (presumably from pathogenic microbes) and lengthy shellfishing and swimming waters closures (Mallin et al. 2007). The city was issued multiple fines and now has a SOP. Work is partially completed to upgrade sewer lines. DWQ's strict enforcement helped facilitate getting infrastructure improvements completed.*Enforcement of high fines should be consistently used by DWQ to encourage proactive maintenance of sewage infrastructure and plants.* In 2010, HB 1746 established a Water Infrastructure Information Needs Task Force to develop a statewide survey on water and wastewater infrastructure needs, and develop a plan to address resources and funding needed for that.

Table 2.26. NPDES permits in coastal draining river basins of North Carolina (2006 data).

CHPP Region[1]	Physiographic region	Class	Wastewater: Municipal large	Wastewater: Municipal <1MGD	Wastewater: 100% Domestic <1MGD	Industrial Process & Commercial	TOTAL
1	Coastal Plains	Major	6	1	0	8	15
		Minor	0	10	8	13	31
	Piedmont	Major	4	0	0	9	13
		Minor	0	5	24	9	38
2	Coastal Plains	Major	14	0	0	16	30
		Minor	0	17	10	33	60
	Piedmont	Major	16	0	0	1	17
		Minor	0	4	40	6	50
3	Coastal Plains	Major	2	0	0	1	3
		Minor	0	4	23	4	31
4	Coastal Plains	Major	14	0	0	25	39
		Minor	0	18	17	22	57
	Piedmont	Major	21	0	0	8	29
		Minor	0	7	52	26	85
Coastal Plains TOTAL		Major	36	1	0	50	87
		Minor	0	49	58	72	179
		ALL	36	50	58	122	266
Piedmont TOTAL		Major	41	0	0	18	59
		Minor	0	16	116	41	173
		ALL	41	16	116	59	232
TOTAL			77	66	174	181	498

[1] Region 1 contains Chowan, Roanoke, and Albemarle subregions; Region 2 contains Tar-Pamlico, Pamlico Sound, and Neuse subregions; Region 3 contains Core/Bogue and New/White Oak subregions; Region 4 contains Cape Fear and southern estuaries subregions.

There are also notices of violation (NOVs) and civil penalty assessments issued from effluent measurements at permitted wastewater discharges. The violations were for a variety of EMC standard violations. Some of the most commonly violated standards were for Biological Oxygen Demand (BOD), Chlorine, fecal coliforms, and dissolved oxygen. The number of violations appears to be increasing through time, though some of the change is related to improvements in monitoring (B. Diuguid and M. Matthews/DWQ, pers. com., March 2010) (Table 2.28). Coastal counties with over 100 violations in a year include Perquimans, Dare, Craven, Onslow, and New Hanover. North Carolina currently requires Best Practicable Technology for wastewater treatment. Advanced treatment methods, especially biological nutrient removal (BNR), do exist that lower effluent limits and can remove other pollutants that currently aren't treated (ex. pharmaceuticals). *To improve water quality in North Carolina surface waters, the state should move toward requiring Best Available Technology (BAT) for wastewater treatment, rather than Best Practicable Technology (BPT). WWTPs that currently have BATs in place should be required or provided incentives to actually utilize this technology.*

Table 2.27. Sewage spills, in 1,000s of gallons, reaching surface waters in Coastal counties from 2002-2009 (K. Glazier/DWQ, unpublished data, December 2009).

CHPP region	County	2002	2003	2004	2005	2006	2007	2008	2009
1	Bertie	1	34	16	13	58	2	2	5
	Camden	0	0	0	1	0	0	2	0
	Chowan	0	0	0	5	129	0	0	55
	Currituck	0	0	0	0	0	2	0	0
	Hertford	17	100	0	0	1	0	0	406
	Hyde	0	0	0	0	0	0	0	134
	Pasquotank	55	851	5	6,194	268	3	2	5
	Perquimans	0	0	0	16	86	0	8	141
	Tyrrell	0	0	0	0	0	0	0	1
	Washington	0	3	0	41	38	8	6	34
1-2	Dare	0	2	1	2	0	21	1	0
2	Beaufort	1	31	74	49	211	2	76	273
	Craven	35	986	97	211	319	61	123	33
	Pamlico	0	1	1	2	7	16	0	3
3	Carteret	64	198	0	214	190	395	33	0
	Onslow	383	18	223	27	164	266	3,609	113
4	Brunswick	1	12	1	136	7	2	0	200
	New Hanover	25	86	539	4,705	6,776	45	36	19
	Pender	1	0	36	1	1	0	0	41
TOTAL		581	2,322	994	11,618	8,256	824	3,898	1,463

Ocean outfalls discharge stormwater or cooling water to the ocean. There are 15 active ocean outfalls along the coast. Eight stormwater outfalls are in Dare County, one is in Kure Beach, five are in Emerald Isle, and one is in Atlantic Beach. There is one cooling water discharge with small amount of treated wastewater in Brunswick County (Progress Energy). EMC rules (Article 21) prohibits discharge of wastes to open waters of the Atlantic Ocean unless permitted by a rule of the Commission. *The 2009 Ocean Policy Report (NC Sea Grant 2009) recommended that no new or expanded ocean outfalls for stormwater or wastewater be permitted, and existing stormwater ocean outfalls should be decommissioned in a phased out approach*.

Table 2.28. Notices of Violation and civil penalty assessments issued to NPDES permittees from reporting years 2002-2009 in coastal counties (K. Glazier/DWQ, unpublished data, December 2009).

CHPP Region	County	2002	2003	2004	2005	2006	2007	2008	2009
1	Bertie	3	7	8	21	3	24	26	33
	Camden	1	6	8	1	2	7	5	4

	Chowan	10	0	2	32	29	4	10	27
	Currituck	3	0	0	2	3	1	5	16
	Gates	29	9	11	9	15	0	11	6
	Hertford	0	4	0	0	0	0	0	0
	Pasquotank	33	30	50	84	6	4	3	17
	Perquimans	1	7	3	0	0	188	61	40
	Tyrrell	10	2	6	5	9	0	10	10
	Washington	32	20	18	6	21	11	30	41
1-2	Dare	18	14	54	108	61	45	3	18
2	Beaufort	8	26	10	74	23	8	7	22
	Craven	29	88	120	28	61	33	51	107
	Hyde	3	5	8	18	12	12	16	11
	Pamlico	1	0	2	2	3	19	8	30
3	Carteret	3	25	5	18	17	28	18	170
	Onslow	48	84	91	74	158	171	354	433
4	Brunswick	19	40	23	56	44	17	48	79
	New Hanover	20	27	31	37	15	111	183	157
	Pender	2	0	0	0	2	4	4	3
TOTAL		273	394	450	575	484	687	853	1224

2.4.2.2. Marinas and multi-slip docking facilities

Marinas are neither clearly point nor clearly non-point sources of pollution. 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 are located immediately adjacent to shorelines where upland pollutants coming from boats, parking lots and hull maintenance areas can often flow directly into coastal waters. Documented adverse environmental impacts include microbial contamination, dissolved oxygen deficiencies and high concentrations of toxic metals in the water column and bottom (NCDEHNR 1990, McAllister et al. 1996). There are typically CCA-treated boards on docking facilities and bulkheads, and antifouling paints on the boats moored in those docking facilities (see Soft bottom chapter for primary discussion of marina, dock, and bulkhead impacts on benthic organisms). 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. In addition, marina facilities include boat workshops, wash-down facilities, and parking lots located immediately adjacent to coastal waters. Although marinas were implicated in a relatively small area of shellfishing closures (see "Point sources" section for more information), development pressures associated with them can be more threatening (e.g., increased boating, upland development, and shoreline stabilization). Boats within marinas or anchored outside of marinas can be sources of fecal microbial contamination (from boat head discharge) to nearby recreational waters, as has been determined recently for the Town of Wrightsville Beach (Sobsey et al. 2003; Mallin et al. 2009).

Since the 2005 CHPP, DWQ obtained additional information on toxin inputs associated with marinas. Marinas, boatyards, and boat manufacturers often provide services such as boat maintenance, wastewater pumpout, pressure washing, sanding, and painting that can lead to introduction of toxins into adjacent waters. To assess the types of activities ongoing in marina facilities along the coast and potential water quality concerns, DWQ conducted a survey of 141 marina facilities in the 20 coastal counties in 2007 (DWQ 2008b). Of 112 marinas and 52 boatyards, 51 were permitted by a NPDES stormwater permit and 29% of the facilities inspected, generated process wastewater from pressure washing or rinsing activities. Levels of copper, iron, zinc, and aluminum in the wastewater were significantly elevated, and lead, nickel, chromium, arsenic, and cadmium were elevated to a lesser extent. High metal concentrations were attributed to sloughing of residual paints from boat hulls during washing, with pressure washing contributing significantly greater loading of copper, zinc, and aluminum. Boats with "bottom paint" designed to prevent marine life growth on boat hulls, have the highest concentrations of metals in process wastewater, compared to water from boats without bottom paint. The DWQ report concluded that due to the extremely high concentrations of metals in the powerwashing process wastewater, and since the majority of these operations were located immediately adjacent to coastal surface waters, the environmental effects of these wastewater streams was a significant concern. *The report recommended that wastewater generated from marinas, boatyards, and manufacturers should be addressed, to prevent process wastewater from mixing with storm event water by:*

1) *Elimination of the waste stream*
2) *The use of other medias (sanding, sand blasting–provided the dry product is captured)*
3) *Recycle systems*
4) *Industrial pretreatment and connection to a publicly owned treatment works (POTW)*
5) *Development of a non-discharge waste system for hand washing operations*
6) *Development of new service industry designed to collect, treat, perhaps recycle residual metals, and/or to use these process waters in other industrial production processes.*

To address the concerns of the study, DWQ decided to use education and outreach to the marina industry to provide guidance about how this industry can reduce its impacts to water quality from boat -cleaning operations. These materials are located at the http://h2o.enr.state.nc.us/ws/marinas.htm. The wash water created from pressure washing and hand washing is defined as a type of wastewater, and therefore must be handled and treated per the wastewater permitting requirements. Discharging this wastewater to surface waters without a permit is prohibited and is not allowed in SA waters.

Marinas and boatyards that provide services for boat maintenance, repairing, or building are required to obtain an NPDES Stormwater General Permit called the NCG190000. This permit was renewed on October 1, 2009 and contains a few additions and changes that were partially affected by the DWQ study in 2008. This permit, forms, and the additions and changes to this permit can be found on the Technical Bulletin provided at http://h2o.enr.state.nc.us/su/Forms_Documents.htm#stormwaterGP. They are as follows:

- Twice per year analytical monitoring of pH, Oil & Grease, Total Suspended Solids (TSS), Copper, Aluminum,Lead, and Zinc.
- Refinements and clarifications to the SPPP requirements; refer to Part II, Section A.
- Tiered response requirements for benchmark exceedences based on analytical results beginning with the monitoring in Year 3 – Period 1 (Sample 5), and direction to notify the Regional Office in the event of four benchmark exceedances. Benchmarks are not limits.
- Twice per year qualitative monitoring during a representative storm event.
- Requirement to use forms provided by the Division to record qualitative monitoring results.
- Requirement to submit an annual monitoring summary to the DWQ Regional Office (RO).
- Develop a Solvent Management Plan (Part II, Section A).

While education and outreach are a first step, the extremely high concentrations of pollutants found in marina wash water make it imperative that this wastewater stream be properly treated and not allowed to enter surface waters. DWQ will continue the compliance inspections at marinas and boatyards throughout the state. *DWQ should continue to strive to reach compliance with stormwater and wastewater regulations at marinas and boatyards, through regulatory and non-regulatory measures.*

Specific Coastal Area Management Act (CAMA) regulations regarding marina siting are designed to minimize impacts to estuarine resources, such as shell bottom and Primary Nursery Areas. The Division of Environmental 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, marinas may still be 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 (see "Microbial contamination" section of the Shell Bottom chapter for more information). 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)]. Only maintenance dredging of existing channels (pre-CAMA) is allowed through PNAs [CRC 07H .0208 (b)(1)(J)].

The DCM administers the NC Clean Marina program as a voluntary initiative designed to recognize marina operators for their efforts toward environmental stewardship by implementing Clean Marina practices. It also gives boaters a way of identifying marinas that are promoting environmental stewardship and following best management practices. The NC Clean Marina Program was begun in 2000 with funding from the NC Coastal Nonpoint Source Program, however, program growth was hampered by the lack of dedicated full-time staff to manage the daily activities of the initiative. In 2007, the DCM increased efforts to support and enhance program growth through the creation of a year-long dedicated staff position. The temporary position facilitated program development by traveling coast-wide to increase marina certifications, market the program, present educational workshops and materials, increase boater awareness and recertify existing Clean Marinas. Unfortunately, the Division is unable to continue funding for this position and maintain the program at that level of involvement with coastal marinas. *Funding should be secured for a Clean Marina Coordinator in order to maintain this voluntary initiative.*

Current marina development tends to occur in lower salinity areas given existing saturation of marinas in high-salinity estuarine waters. From 1990-2002, the number of CRC marina permits issued per year declined, with a corresponding increase in smaller docking facility permits. This decline was in part due to stringent permitting regulations and an increase in smaller docking facilities (see "Multi-slip docking facilities" section for more information). As of 2009, there are at least 117 public marinas bordering North Carolina coastal waters (Table 2.29), which is about 1 marina per 50 miles of shoreline. The majority of marinas are clustered in high salinity waters (61), followed by transitional (38) and low salinity (18) (Map 2.8a-b). The greatest numbers of marinas (in descending order) occur in Core/Bogue, Southern Estuaries, and Neuse subregions. In high and transitional salinity zones, there are currently 30 marinas located within 500 meters of a PNA. Marinas in low-salinity areas are often on smaller water bodies that may include designated Anadromous Fish Spawning Areas (AFSAs), Inland Primary Nursery Areas (IPNAs), or undesignated anadromous fish nursery areas (see "Designations" subsection of "Status and trends" section). There were 18 marinas located within 500 meters of designated AFSAs.

The threat posed to spawning anadromous fish depends on the design of the marina basin. The DWQ tends to prefer marina boat basins 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 young freshwater and anadromous species while also flushing out pollutants. Marina basins created in upland areas may attract fish larvae and juveniles while accumulating pollutants. Fish kills are often spotted in off-channel habitats where the morphology of the shoreline creates a virtual trap for pelagic species such as menhaden (see “Fish kills” subsection of “Status and trends” section for more information). *Studies are needed to compare use of both upland and open water basins by young anadromous fish. To protect designated AFSAs and IPNAs from marina impacts, dredging for new marina construction and other marina-related activities should be managed to minimize alteration of these important functional areas.*

Table 2.29. Number of public marinas (WRC coastal boating guide 2009) within 500m of high (>15 ppt), low (<0.5 ppt), and transitional salinity zones in coastal North Carolina.

CHPP Region	Within 500-m of:			High salinity	Transitional	Low salinity	TOTALS
	AFSA	PNA	SNA				
1	-	-	-	0	4	1	**5**
	-	-	X	0	1	0	**1**
	-	X	X	0	1	0	**1**
	X	-	-	1	0	13	**14**
2	-	-	-	6	13	2	**21**
	-	-	X	0	5	0	**5**
	-	X	-	0	5	0	**5**
	-	X	X	0	2	0	**2**
3	-	-	-	24	0	0	**24**
	-	-	X	1	1	0	**2**
	-	X	-	4	1	0	**5**
	-	X	X	1	0	0	**1**
	X	X	-	0	1	0	**1**
4	-	-	-	11	1	1	**13**

	-	-	X	1	0	0	**1**
	-	X	-	11	0	0	**11**
	-	X	X	1	0	0	**1**
	X	X	-	0	3	1	**4**
TOTALS	**18**	**31**	**14**	**61**	**38**	**18**	**117**

An emerging concern is the proliferation of non-marina docking facilities (3-10 slips), also referred to as multi-slip docking facilities (MSDFs), in developing coastal subdivisions that may result in cumulative impacts to coastal fish habitat due to concentrated development. 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. Permit records indicate that, from 1990 to 2002, DCM issued an average of 538 permits per year along the coast for individual piers and 67 permits/year for MSDFs (Street et al. 2005). While the number of new and expanding marinas declined during 1990-2002, the number of smaller docking facilities increased and has since shown large annual fluctuation. The Division of Environmental Health's Shellfish Sanitation and Recreational Water Quality Section (DEH-SS) has a database for tracking of marinas (both private and public) and large MSDFs (8-10 slips) along SA, SB, or SC waters. Database records indicate there are currently a total of 201 large MSDFs and 445 marinas along estuarine waters in North Carolina (Table 2.30). Based on the shoreline miles for SA, SB, and SC waters, there is approximately one large MSD or marina facility for every 7 miles of shoreline. The facilities are concentrated in CHPP regions 3 (Core/Bogue) and 4 (Southern Estuaries), and there were generally twice as many marinas as small docking facilities. The number of piers and docks with fewer than 10 slip are generally not represented in the DEH-SS database (S. Jenkins/DEH-SS, pers. com., February 2010).

Table 2.30. Number of docking facilities along SA, SB, and SC waters with >10 slips (marinas) and 8-10 slips (DEH-SS, unpublished data, December 2009).

CHPP Region	**Subregion**	**Number of slips**		**TOTALS**
		8-10	**>10**	
1	Albemarle	18	48	66
2	Neuse	24	54	78
	Pamlico Sound	20	35	55
	Tar/Pamlico	10	17	27
3	Core/Bogue	51	128	179
	New/White Oak	22	41	63
4	Cape Fear	5	10	15
	Southern estuaries	51	112	163
TOTALS		201	445	646

Kirby-Smith and White (2006) examined the relationships among estuarine shellfish closures due to fecal coliform contamination, adjacent shoreline land uses (including non-marina docking facilities, undeveloped shoreline, old developed shoreline, new developed shoreline, and marinas), and environment (precipitation events). The 1-year study was conducted in a developing watershed of a small estuary in central North Carolina. Microbial contamination levels were measured from samples taken bi-weekly (summer) and monthly (other seasons). Results indicated that old developed shoreline has the highest bacterial counts followed by newly developed shoreline, marinas, and non-marina docking facilities. The top three failed to meet NC shellfishing standards, and less than half of the 10-slip marina sites failed to meet standards. Water level from wide tides was strongly correlated with bacteria levels in the OD, undeveloped, and non-marina docking facilities. The investigators speculated that inundation of wildlife habitat and animal feces was the cause. Weekend boat use had no effect on bacterial counts in this relatively remote area. The researchers stated a need to sample pollutant levels using a strategy to separate local sources from more remote sources to focus limited restoration/mitigation efforts more effectively.

As part of 2005-07 CHPP implementations, a workgroup was established to examine the issue of marinas and multi-slip docking facilities. The Sea Grant Marina Advisory Group completed its report on Multi-slip docking Facilities (MSDFs) and provided recommendations to the CRC in 2007. The report resulted in a revised application form for MSDFs (DCM-MP-4) designed to capture information that can be used to assess the impacts of individual projects. Other recommendations of the study that have been partially addressed include protecting working waterfronts and public access, and collecting baseline mapping of sensitive habitats. Recommendations that remain to be addressed include:

- *Research on cumulative impacts of these small docking facilities and associated development on pollutant concentrations in the water column,*
- *Review and development of cumulative impact assessment techniques*
- *Once additional information is obtained, development standards for MSDFs, such as limiting in shallow ecologically sensitive waters, may be considered.*
- *Develop educational materials for property owners, developers, and realtors on ecological concerns of docking facility construction*

The research could be part of a large study predicting receiving water quality from watershed characteristics (see "Land use and non-point sources" section for more information). The results could help in defining a rule limiting the ratio of developed public trust bottom to undeveloped shoreline near shallow nursery habitats.

2.4.2.3. Land use and non-point sources

Land cover and water quality within a watershed are closely linked. The impact of land-uses on fish habitat and water quality depends on the location of specific land-uses in the context of watershed hydrology, which is affected by land surface characteristics (i.e., slope, elevation, soil type) and local weather conditions (i.e., prevailing winds, precipitation, evapotranspiration). The focus of this section is primarily the delivery of nutrients, sediment, and toxic chemicals to receiving water (see following sections on nutrients, sediment, and toxic chemicals for more information on impacts). The 2006 National Land Cover Dataset (NLCD) was not available for use in the 2010 CHPP; consequently this data has not changed since the 2005 CHPP. Table 2.31 below provides a brief overview of 2001 land-use/land-cover in CHPP subregions. Developed areas are characterized by a high percentage (30 percent or greater) of constructed materials. Grassland, Forest, and Shrubland include upland habitat, while wetlands include periodically saturated areas with more than 20% vegetative cover.

Table 2.31. Land cover and CHPP regions and subregions based on 2001 NLCD.

	Region 1			Region 2			Region 3		Region 4	
NLCD land cover	**Chowan**	**Roanoke**	**Albemarle**	**Tar-Pamlico**	**Neuse**	**Pamlico Sound**	**Core/Bogue**	**New/White Oak**	**Cape Fear**	**Southern Estuaries**
Open water	5.8%	2.6%	32.4%	4.9%	4.2%	73.2%	45.6%	7.9%	1.7%	6.9%

Developed	2.0%	2.4%	0.9%	2.3%	4.7%	0.2%	2.0%	5.5%	4.6%	18.2%
Barren Land	0.0%	0.2%	0.2%	0.1%	0.2%	0.1%	1.4%	0.6%	0.3%	1.0%
Transitional	0.7%	1.1%	0.1%	1.2%	0.9%	0.0%	0.1%	1.5%	1.1%	0.0%
Upland Forests	45.9%	61.3%	11.0%	44.3%	41.6%	3.5%	15.3%	45.9%	54.5%	28.0%
Scrubland	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	4.2%
Grassland/ herbaceous*	0.2%	0.2%	0.1%	0.2%	0.4%	0.0%	0.3%	1.1%	0.3%	10.2%
Planted/ cultivated	28.6%	20.0%	24.3%	29.9%	29.6%	6.5%	12.7%	10.6%	23.0%	8.7%
Wetlands	16.8%	12.2%	31.2%	17.3%	18.3%	16.4%	22.6%	27.0%	14.5%	27.0%

* Mostly "Urban/recreational grasses" subclass

The developed, grassland/herbaceous (urban/recreational grasses), planted/cultivated, and upland forests (silviculture portion) can be sources of pollution. The most developed CHPP subregions (in descending order) were the Southern Estuaries (18.2%), New/White Oak (5.5%), Neuse (4.7%), and Cape Fear (4.6%). Planted or cultivated lands were the most widespread among subregions. The greatest percentages of planted/cropland area (in descending order) were in the Tar-Pamlico (30%), Neuse (30%), Chowan (29%), Albemarle (24%), Cape Fear (23%), and Roanoke (20%) subregions. Urban/recreational grasses (i.e., golf courses) were a significant percentage (10%) of only the Southern Estuaries subregion.

Pollutants from non-point sources are delivered to receiving waters through atmospheric deposition (including air-borne particles, gases, and precipitation), surface drainage, and groundwater seepage. Whereas surface drainage and groundwater seepage can be linked to water quality conditions downstream, the contribution from atmospheric deposition is more difficult to trace. Sources of atmospheric pollutants include vehicle exhaust, industrial emissions, and waste from animal operations (Walker et al. 2000; USGS 2003). Atmospheric deposition was the source implicated in 7.9% of impaired coastal draining streams in North Carolina (DWQ 2006). The greatest number of streams impaired from atmospheric deposition occurred in the Roanoke river basin. A significant portion of nutrient pollution has also been attributed to atmospheric sources (see “Nutrients and eutrophication” section for more information).

Septic systems that discharge on land near the water can be another source of non-point pollution. Septic systems can fail during heavy rain events or 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). Degradation of water quality occurs with waste leaching from failing or improperly functioning drainfields, or where septic systems become exposed or located below mean high water due to erosion. Storm-damaged septic tanks may also cause contamination for a short but concentrated period in localized areas. Over 200 damaged septic systems were reportedly damaged after Hurricanes Dennis and Floyd (D. Moffitt/DCM, pers. com., 2002). 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. Cahoon et al. (2006) demonstrated that septic tank leakage in this area has caused elevated fecal coliform and nutrient loading to nearby streams and tidal creeks. *More detailed monitoring is needed to assess the extent oceanfront septic systems are causing degradation to nearshore coastal waters.*

The Shellfish Sanitation & Recreational Water Quality Section within the Division of Environmental Health documents some failing septic systems along SA, SB, and SC waters as part of their pollution source surveys for shellfish growing areas. The shoreline surveys are conducted adjacent to estuarine waters and within certain watersheds in coastal North Carolina. Malfunctioning wastewater systems such as failing septic systems and gray water discharges as defined in 15A NCAC 18A .1961(a) are identified and referred to the local Health Department for corrective action. Onsite wastewater issues can be a significant pollution source in localized areas but remain a small number relative to the number of inspections made and when compared to other pollution sources. Historically, the percentage of onsite wastewater issues found during shoreline surveys averages to be 1% to 4% of inspections made (S. Jenkins/DEH-SS&RWQ, pers. com., August 2010).

To reduce pollutant loading from septic systems, the town of Nags Head implemented a Septic System Inspection and Tank Pumping Program. This program provides incentives for properly maintaining and repairing septic systems. The town provides free system inspections and offers a $30 credit for having a tank pumped as a result of the septic inspection. They also have a low-interest loan program for those needing to repair or replace their system. The town also maintains a database to track failures, site use, age of systems, size of tanks, and other information. The program has been very successful and popular with the community. *This program could be used as a model for other coastal communities to follow*.

Agricultural sources accounted for 20.9% (row crop production) and 10% (animal management/pastures and concentrated feeding operations) of stream impairment in 2006 (Table 2.15). Aquaculture was not specifically listed as a source of impairment. The greatest agriculture impacts were assessed in the Neuse (496 stream miles), Tar-Pamlico (166 miles), and Cape Fear (131 miles) subregions. These subregions are also in the top 5 for percentage of agricultural land cover (Table 2.31). The water quality impacts of silviculture operations are included with land disturbances implicated in <3% of impaired streams in coastal draining river basins in 2006. Runoff from impervious surfaces was implicated in 10.5% of impaired streams; mostly in the Neuse (139 miles), Tar/Pamlico (77 miles), and Cape Fear (71 miles) river basins. The Southern Estuaries (part of Cape Fear river basin) had the greatest percentage of developed land-use among CHPP subregions.

Ditches, canals, and vegetated swales (wide, shallow ditches with sloping banks) are watershed features constructed for surface drainage (Map 2.7). These artificial drainage features 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, Maxted et al. 1997; Serafy et al. 1997, White et al. 2000; Cahoon et al. 2006). Pate and Jones (1981) compared nursery areas that were unaltered and anthropogenically altered by upland drainage (ditching) 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). The observed declines in habitat quality were attributed to the changes in flow characteristics, water quality, and decrease in structural complexity. After several years, however, fishery landings appeared to return to levels similar to nearby unaffected areas. The recovery could be related to required wetland and stream restoration in the affected watershed (see "Status and trends" section of the "Wetland" chapter for more information).

On the Pamlico-Albemarle Peninsula, ditch networks through peatlands have replaced intermittent streams that were historically important to spawning river herring (both in the stream and associated floodplain and as pathways to natural lakes) (M. Wicker/USFWS, pers. com., February 2010). For example, the ditching and canal works around Lake Phelps have replaced the seasonal overflow channels that once existed to concentrate river herring passage into the lake. The USFWS has expressed some interest in consolidating overflow from the lake into one major canal (i.e., Bee Tree Canal) to promote fish passage (M. Wicker/USFWS, pers. com., February 2010). Ditching through "peatlands" can also enhance the release of stored carbon, nitrogen, and mercury (Di Giulio and Ryan 1987; http://www.ces.ncsu.edu/nreos/forest/feop/AWC2009/proceedings/Ward.html, February 2010). Restoring hydrology to drained peatlands can prevent these additional pollution source from entering coastal waters or the atmosphere. The retention of carbon in restored peatlands bolsters sequestration efforts aimed at reducing climate change impacts (Henman and Poulter 2008). The TNC's climate change adaption study funding by Duke Power (in cooperation with USFWS) includes the restoration of peatland hydrology as a integral part of overall site restoration (B. Boutin/TNC, pers. com., 2009). The project is located on the Pamlico-Albemarle Peninsula.

Water-dependent development, such as dredged navigation channels, boat basins, marinas, docks, engineered shoreline stabilization also contribute to non-point runoff pollution in the water column. The altered hydrology of dredged channels and boat basins and resulting impact on water quality was discussed in the, "Hydrologic modifications," section.

Land use trends

Much of the land around the Albemarle-Pamlico Estuarine System is drained and remains drained to accommodate existing agriculture and silviculture. It is estimated that over two million acres of land have been drained and developed for agriculture and silviculture 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) (Map 2.7). However, North Carolina agriculture and silviculture lands are currently being replaced with developed land uses (ENCRPC 2007). Agricultural lands include cropland, pastureland, animal operations, and land-based aquaculture. According to the US Department of Agriculture's 2007 agriculture census, farmland area in North Carolina has declined from 9.0 to 8.5 million acres during 2002-2009. For animal operations, the number of swine has remained around 10,000,000 since 1997 (http://www.nass.usda.gov/Statistics_by_State/North_Carolina/index.asp), the year the moratorium on new or expansion of swine farms began. For the silviculture industry, ownership has declined by one-third from 1990 to 2002 (http://srsfia2.fs.fed.us/states/nc/NCFACT~1.PDF, August 2010).

Ditching and drainage is also associated with development and related infrastructure. Many of the roads on the Albemarle-Pamlico Peninsula were constructed on top of spoil piles between canals to prevent flooding. In many urbanized coastal areas, ditches are typically constructed along neighborhood streets, which drain to nearby coastal waters. These drainage features often connect into headwaters, altering the natural hydrology of downstream systems.

Unlike agriculture and silviculture, developed land uses have been steadily increasing. Table 2.32 shows the percent change of urban/built-upon and transportation classifications in 12-digit USGS hydrologic units (HUs) from 1982 to 1997 (http://www.nc.nrcs.usda.gov/technical/nri/). This was the most recent NRI data available for comparison. Overall, at least 10 of 26 (38%) USGS hydrologic units in coastal North Carolina fell below the 10% threshold in 1997, with the highest level of built-upon area (24.8%) in the Upper Neuse. The Middle Roanoke and Coastal Carolina-Sampit areas experienced the most growth (131-139%) in built-upon areas. Another coastal hydrologic unit with relatively high growth and percent built-upon area was Bogue-Core sounds (6-10% impervious and 94-116% growth). Most other coastal HUs had either low percent built-upon area and moderate growth (Lower Neuse, Pamlico and Albemarle Sound), very low percent built-upon area and high growth (Pamlico Sound), or high built-upon area 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.

Rothenberger et al. (2009b) found that in the upper Neuse watershed over the ten-year period, total urban land cover more than doubled (from 5% to 12%), and high-density urban areas tripled. Suburban sprawl (low- to medium-density urban as 10-70% impervious surface area) increased by 150%. The major change in land use for the mid- to lower watershed was in the form of agriculture: croplands decreased from 23% to 7% of total agriculture, while swine production agriculture increased 285%. These changes were related to water quality changes in the river and estuary (below).

A means of assessing more recent change in developed land use is through the distribution of stormwater permits issued from 2001-2009 (Table 2.33), since this permit is required for all developments disturbing more than one acre of land. The number of stormwater permits issued in CAMA coastal counties has increased from over 500/year (2001-2004) to around 800/year (2005-2009). The highest ranking counties in terms of permits per square mile were New Hanover, Onslow, Brunswick, Carteret, and Dare counties. Comparing the rankings for 2000 population density and 2001-2009 permit density suggests rapidly growing areas, in terms of built-upon area. The counties ranking lower in 2000 population and higher in permits included (in descending order) Pamlico, Hyde, Currituck, Dare, and Carteret counties. These counties represent rapidly growing areas of the Inner and Outer Banks.

Table 2.32. Percent increase and percent coverage of urban/built-upon + rural transportation land cover classes within North Carolina's coastal drainages (http://www.nc.nrcs.usda.gov/technical/nri/).

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.

Table 2.33. Stormwater permits by CAMA county and approximate CHPP region (K. Glazier/DWQ, unpublished data, December 2009). Also includes rank (1=highest quantity) density of people (2000) and permits (2001-2009), for comparison.

CHPP region	CAMA county	2001	2002	2003	2004	2005	2006	2007	2008	2009	RANK Person/ mi^2 (2000)	RANK permits/ mi^2 ('01-'09)
1	Bertie	4	2	4	7	16	8	10	7	9	**18**	**18**
	Camden	11	6	6	9	5	7	8	6	11	**17**	**14**
	Chowan	5	4	4	6	7	7	8	12	10	**7**	**11**
	Currituck	20	17	21	30	31	35	38	26	25	**9**	**6**

	Gates	1	1	2	0	1	2	1	4	1	**16**	**20**
	Hertford	4	4	1	7	9	7	7	5	10	**10**	**15**
	Pasquotank	16	14	23	18	36	31	25	16	30	**3**	**7**
	Perquimans	7	7	4	11	19	9	14	4	8	**13**	**13**
	Tyrrell	5	3	3	4	2	3	3	3	8	**19**	**19**
	Washington	6	6	3	4	4	0	8	6	3	**14**	**16**
1-2	Dare	50	52	50	45	36	26	48	45	41	**8**	**5**
2	Beaufort	27	23	28	16	34	30	51	30	41	**11**	**12**
	Craven	42	42	29	28	72	83	72	72	64	**4**	**8**
	Hyde	6	9	5	3	12	8	7	6	9	**20**	**17**
	Pamlico	8	5	12	7	17	20	32	24	14	**15**	**9**
3	Carteret	46	53	59	75	47	61	66	92	76	**6**	**4**
	Onslow	64	69	96	71	87	129	138	164	138	**2**	**2**
4	Brunswick	66	68	89	97	118	148	182	167	116	**5**	**3**
	New Hanover	115	115	116	124	118	170	182	216	183	**1**	**1**
	Pender	22	33	34	32	55	48	41	38	42	**12**	**10**
TOTALS		**525**	**533**	**589**	**594**	**726**	**832**	**941**	**943**	**839**	**na**	**na**

Studies comparing land use and water quality

A study by Mallin et al. (2009b) compared water quality in three oligohaline tidal creeks of varying impervious voverage, designated urban, suburban and agricultural creeks. In general the most urbanized creek had the highest suspended sediments, orthophosphate, BOD, surfactants, fecal bacteria and chlorophyll *a*, while the agricultural/forestry watershed had the highest total organic carbon. The comparative impact of agriculture and development was studied by USGS in conjunction with USACE plans to implement a restoration project in Currituck Sound (D. Piatkowski/USACE, pers. com., November 2009). Water quality monitoring was conducted in 2006-2007 at various locations in both the main body and selected tributaries of Currituck Sound. The monitored parameters included salinity, nutrients, chlorophyll *a*, and water clarity. Water quality modeling using SWAT[66] was conducted in tributaries with urban and agricultural drainage areas. Preliminary results revealed very little difference in measured parameters between the two tributaries. However, the precipitation inputs were averages that diminish the impact of storm events in these very sluggish coastal streams. Riparian wetlands were also abundant along the lower portion of the tributaries; likely intercepting nutrients from upland pollution sources. Furthermore, the conditions in the respective watersheds did not include major construction activities over a long time series. Concurrent monitoring in the main body of Currituck Sound recorded lower water clarities than tributaries, suggesting a resuspension problem in this wind-swept, low salinity and shallow estuary. The nutrient levels measured in Currituck Sound did not indicate over-enrichment relative to the indicator metric: SAV habitat suitability (see "Submerged aquatic vegetation" chapter for more information). The USACE workgroup is currently developing defensible criteria for choosing between restoration site alternatives (D. Piatkowski/USACE, pers. com., November 2009).

By developing a statistical model that integrates a decade of available land use/land cover data and water quality data, Rothenberger et al. (2009b) found that total phosphorus concentrations were significantly higher during summer in sub-basins with high densities of wastewater treatment plants (WWTPs) and confined swine feed operations (CSFOs). Nitrate was significantly higher during the winter season in sub-basins with high numbers of WWTPs, and organic nitrogen concentrations were higher in sub-basins with higher agricultural land coverage. Overall, wastewater discharges in the upper watershed and intensive swine agriculture in the lower watershed were the highest contributors of nitrogen and

[66] Modeling tool simulates stream output based on precipitation, drainage and land-use characteristics

phosphorus to the Neuse.

Whereas other studies of agricultural land use and water quality have focused on nutrients (see "Nutrients and eutrophication" section for more information), studies of development impacts have focused more on overall habitat degradation. Studies have indicated that substantial degradation of water quality and aquatic habitat occurs when impervious cover (i.e., roads, roofs, parking lots) within a watershed reaches 10-20% (Schueler 1994; Arnolds and Gibbons 1996; Mallin et al. 2000b; Barnes et al. 2001; Beach 2002). Significant water quality and habitat degradation occurred where impervious surface exceeded 20%. As vegetated areas are replaced, the ability of the land to absorb and filter stormwater runoff is reduced; flooding, bank erosion, and runoff subsequently increase. More impervious surface also increases peak runoff in streams and reduces groundwater input for stream base-flow. Line and White (2007) compared runoff from two similar drainage areas in the Piedmont physiographic region of North Carolina. The drainage areas were very different in terms of developing land use. Runoff volume, sediment, and nutrient export were measured in both drainages for 5.6 years. In the developing drainage area, there was a 68% increase in runoff volume, 0% change in base-flow contribution (as a % of overall discharge), 95% increase in exported sediment, and 66-88% increase in nutrient export, compared to the undeveloped drainage. In the undeveloped drainage area, there were 30 meter riparian buffers and no animal operations confounding the analysis.

Over the past three decades there has been a drop in the value of the clam and oyster harvest in North Carolina of approximately $10,000,000 annually; much of this drop can be attributed to increased closures of shellfish beds due to microbial contamination (Mallin 2009). Human population growth and percentage of impervious surfaces in a watershed is a strong indicator of fecal coliform bacteria and associated pollutants in surface waters (Maiolo and Tschetter 1981, Mallin et al. 2001b, Mallin et al. 2000b; Mallin 2009). Mallin et al. (1998, 2001b) examined the effects of land-use practices on water quality in New Hanover County and found a statistically significant relationship between percent impervious surface cover and fecal coliform concentrations among several tidal creek systems ($r^2 = 0.95$) (Figure 2.7). Increased human population supplies the human and domestic animal sources for fecal bacteria, while impervious surface provide the means of conveyance of such microbes into coastal waters. In a study of 22 tidal creek watersheds in the Charleston, S.C. area Holland et al. (2004) likewise found a similar statistical relationship. Both the North and South Carolina studies indicated that fecal bacteria contamination became an important polluting factor once impervious surface coverage reached > 10% of the watershed (Mallin et al. 2001; Holland et al. 2004). Sanitary surveys conducted by DEH (Shellfish Sanitation and Recreational Water Quality Section) implicate nonpoint stormwater runoff as the primary cause of microbial contamination in more than 90% of the shellfishing areas sampled (G. Gilbert/DEH, pers. com., 2002). There are numerous studies tracking specific sources of microbial contamination in North Carolina waters (DEM 1994, Mallin et al. 1997, White et al. 2000, Reilly and Kirby-Smith 1999, Mallin et al. 2001b, Mallin et al. 2002b, Coulliette and Noble 2008, DiDonato et al. 2009). Source tracking studies are needed for the development of TMDLs. Fecal coliform concentration tends to be highest upstream and in shallow creeks and water bodies; decreasing downstream and in larger open water bodies. The areas prone to high fecal coliforms are also typically areas where shell bottom habitat is concentrated (Table 2.34; see "Microbial contamination" section of Shell bottom chapter for more information).

Table 2.34. Recent coverages of shellfish density by harvest water closure area.

Status	≥ 1 shellfish/m^2	<1 shellfish/m^2
Approved	5,419.8	3,002.0
Conditionally approved - closed	774.2	85.09
Conditionally approved – open	3,369.9	1,211.4
CSHA - prohibited	2,268.0	624.9

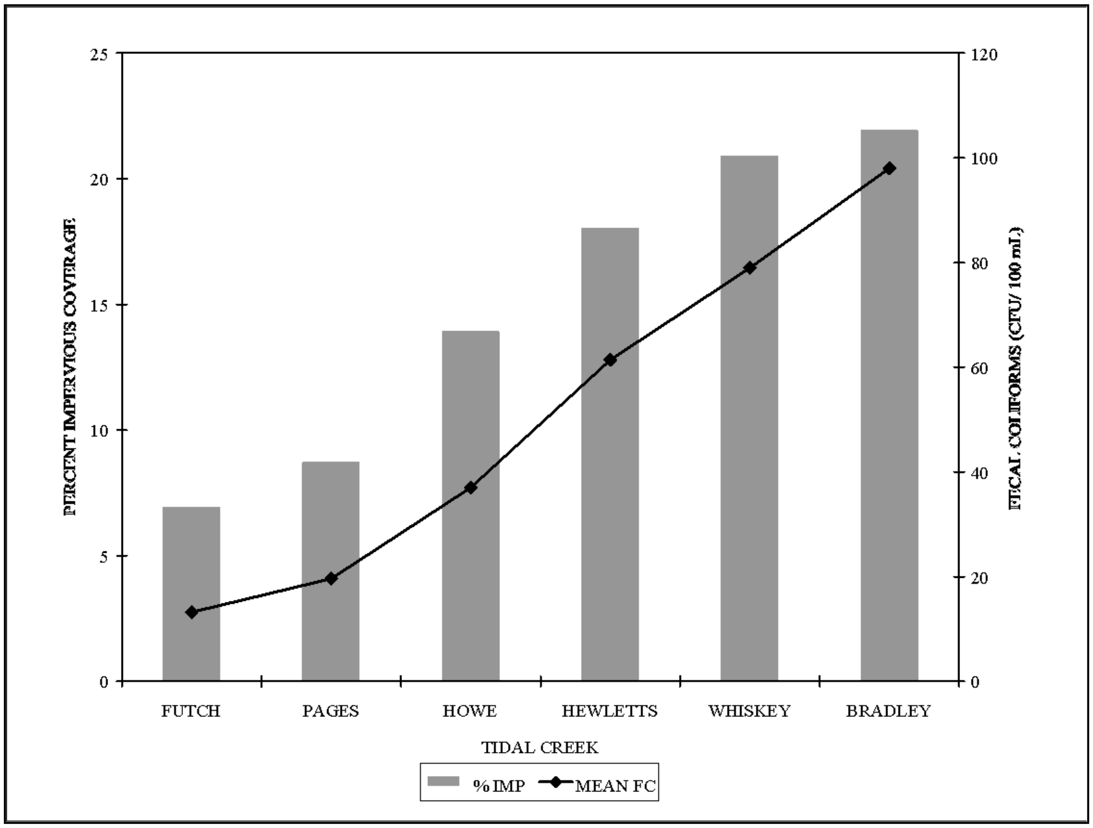


Figure 2.7. Percent watershed impervious surface coverage versus geometric mean fecal coliform bacteria counts for six New Hanover County tidal creeks. (Source: modified from Mallin et al. 2001b)

Elevated levels of fecal coliform bacteria have also been correlated with other water quality parameters such as nutrients, suspended sediments, turbidity, or toxins (Schueler 1999, Mallin et al. 2000b, 2001b Mallin et al. 2009b). Chlorophyll *a* levels, in particular, have been correlated strongly with both bacterial production (literature review in Apple et al. 2008) and nutrient loading (see "Status and trends in nutrient enrichment" for more information). Survival of fecal coliform bacteria is enhanced with low temperature, low salinity, and low light conditions associated with suspended sediment (DEM 1994, Mallin et al. 2000b, White et al. 2000). 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). The strong statistical relationships between fecal bacteria and suspended sediments and turbidity argue for measures to control the runoff of suspended sediments into coastal waters (Mallin et al. 2009b); thus, 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. *Efforts to reduce fecal coliform levels should target pollution sources upstream of significant shell bottom resources in conditionally approved open (i.e., less degraded) areas (see "Microbial contamination" section of "Shell bottom" chapter for more information) in order to maximize the probability of successful restoration*.

Maintaining riparian buffers is a proven watershed management tool that effectively reduces nonpoint source runoff into the water column, and positively influences aquatic habitat (Lee et al. 1989, Zirschky et al. 1989, Groffman et al. 1991, Desbonnet et al. 1994, Gilliam et al. 1994, Lowrance 1997, Mallin and Wheeler 2000, 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). However, the use of BMPs in some watersheds has not been demonstrated to reduce the negative impacts of high impervious surfaces (Schueler 2003). This could be attributed to improper installation or maintenance of stormwater BMPs. Stream riparian zone alterations associated with development and silviculture operations can also cause considerable hydrological and water quality changes in receiving waters. Ensign and Mallin (2001) found violations of ambient NC water quality standards for turbidity, chlorophyll *a*, fecal coliform bacteria and DO after clear cutting around a Coastal Plain blackwater stream (Goshen Swamp) compared with a control stream. Despite a 10-m (33-ft) buffer left along the stream bank, these violations occurred over a two-year period following the clear cut. The buffer was less than the recommended BMP of 50 ft.

The effectiveness of buffers 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). 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). 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 predicted increases in impervious surface (Tables 2.32 and 2.33) and population (Table 1.2) suggest a corresponding increasing in associated water quality problems. However, the land-use data does not account for the location and effectiveness of riparian buffers and engineered stormwater controls and thus represents a "worst case" scenario. When averaging impervious cover across vast regions, the relative amount of impervious surface on smaller watersheds is also not accounted for. 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, and soils types. Impervious surfaces having insufficient on-site storage of stormwater and located in drainage basins near the water have the greatest impact on water quality. A comprehensive model of pollution sources to predict water quality requires regular mapping/monitoring of pollution sources (including silviculture, agriculture, and impervious surfaces), riparian zone conditions, stormwater control measures, climactic events, flushing rates, and measured pollution levels.

Non-point source management

Managing the human activities contributing to non-point source pollution is the intent of various state stormwater permits, nutrient management strategies, CAMA land use plans, and best management practices for different land uses. The stormwater programs are charged with controlling stormwater runoff from new development activities such that water quality standards for DWQ classifications are maintained (see "Stormwater program overview" and "Coastal Stormwater Program" sections for more information). Nutrient management strategies are a suite of rules designed to control nutrient enrichment in sensitive waters (see "Nutrient Reduction Strategies" section for more information). The CAMA land use plans can assist local communities in developing land-use ordinances. Finally, best management practices (BMPs) are techniques, measures or structural controls that are used for a given set of conditions to manage the quantity and improve the quality of non-point source runoff in the most cost-effective manner. Best management practices can be applied to any source of pollution (i.e., managed forestland, croplands, aquaculture, pasturelands, construction sites).

Stormwater program overview

Stormwater regulations vary across the state according to DWQ water classifications, municipalities, and counties. Coastal stormwater rules apply to the 20 coastal counties (Figure 2.8). Statewide stormwater management includes specific rules for NPDES Phase I and II municipalities, Nutrient Sensitive Waters of the Neuse and Tar-Pamlico, and Outstanding Resource Waters. However, these areas do not cover the entire state. The only stormwater regulations that apply to the entire state address impervious parking lots (DWQ 2009b). Other stormwater management in the gap areas is voluntary, though mandatory Erosion and Sediment Control Plans provide some stormwater protection (see "Sediment/turbidity" section for more information). Stormwater programs in North Carolina and their requirements are listed in Table 2.35.

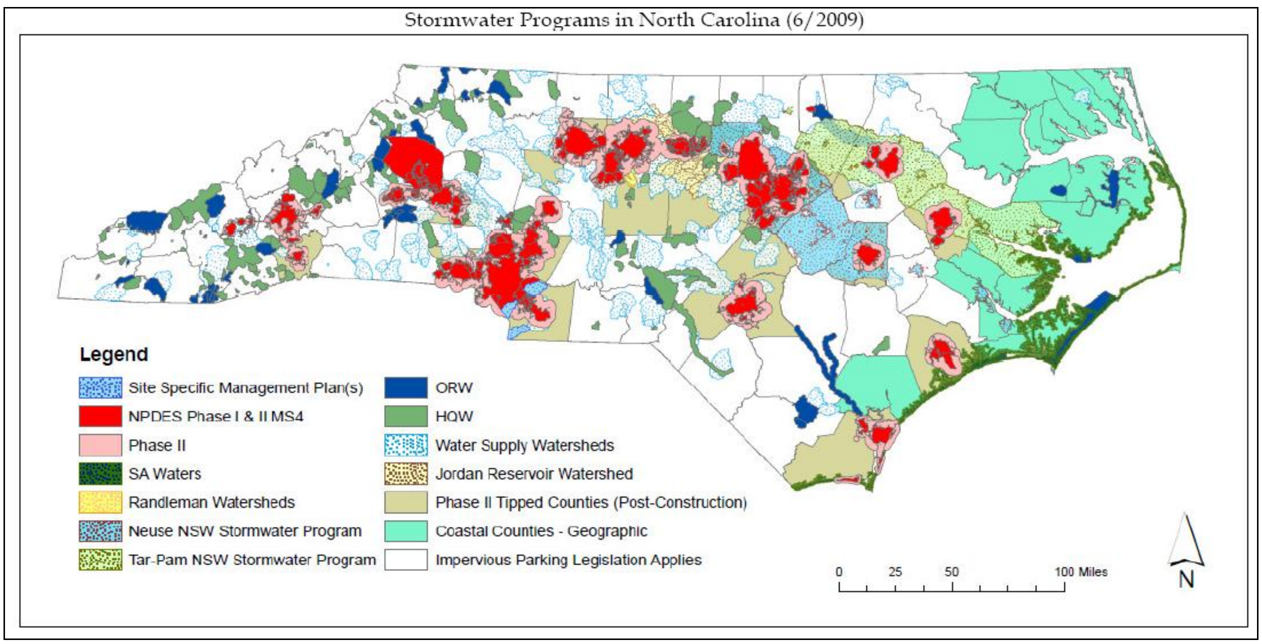


Figure 2.8. Stormwater programs and where their requirements apply (map copied from DWQ 2009b).

Table 2.35. Stormwater management programs and requirements in North Carolina. Table derived from DWQ (2009b).

Requirements	State S//W	SA	ORW	Neuse & Tar-	Phase II	USMP

				Pamlico NSW		
Permitting authority	DWQ-RO	DWQ-RO	DWQ-RO	Local govt	Note 12	Local govt
Low density max. (BUA) (1)	24%	12%	12%	N/A	24%	
High density max. (BUA) (2)	No Max	No Max	25%	N/A	No Max	
Setback/buffer	50' (note 13)	50' (note 13)	50' (note 13)	50' RB	30'	30' *
S/W control reg. for high density (3)	1.5"	Note 14	Note 14	Peak reduction	1" (Note 15)	1.5" R/O
TSS removal requirement	85%	85%	85%	N/A	85%	85%
Stormwater drawdown req. (4)	Note 4	Note 4	Note 4	Note 4	Note 4	Note 4
Vegetated conv. for low density (5)	Yes	Yes	Yes	N/A	Yes	N/A
Deed/property restrictions req. (6)	Yes	Yes	Yes	N/A	Yes	Yes
Infiltration systems req. for S/W control		Note 8				
No new or expanded S/W discharges		Applies				
Nitrogen loading limits (9, 10)				Yes	Note 9, 10	Note 9, 10
Phosphorus loading limits (11)				Yes	Note 10	Note 10

BUA-built-upon area, DWQ-RO-Division of Water Quality-Regional Office, NSW-Nutrient Sensitive Waters, ORW-Outstanding Resource Waters, RB-Riparian Buffer, R/O-runoff, SA-Saltwater "A" classification (shellfishing), S/W-stormwater, TSS-Total Suspended Solids, USMP-Universal Stormwater Management Program, HQW-High Quality Waters

(1) Low-density limits are represented in the table in terms of maximum built-upon area percentage. In addition, a two-dwelling-unit-per-acre limit may be used in lieu of this percentage

(2) High-density limits are represented in maximum built-upon area percentage only. No dwelling-unit-per-acre apply.

(3) Stormwater control requirement: 1.5-inch storm. For SA and ORW water see Note 15. For the Neuse and Tar-Pamlico stormwater programs (peak reduction), there shall be no increase in peak flow leaving the site from the predevelopment condition for the 1-year, 4-hour storm.

(4) Drawdown requirement: Runoff volume drawdown time varies between programs but must be a minimum of 24-48 hours (depending on the program), but not more than 120 hours, many differ based on BMP selected.

(5) The low-density option requires the use of vegetated conveyances to the maximum extent practicable and shall not have a discrete collection system.

(6) Where applicable, deed or property restrictions and protective covenants are required by the locally issued permit and incorporated by the development to ensure that subsequent development activities maintain the development consistent with the approved plans. For the 20 coastal counties and Phase II projects, this must be recorded prior to issuance of a certification of occupancy.

(7) Cluster development is defined in 15A NCAC 02B .0202 (16) as the following: "The grouping of in order to conserve land resources and provide for innovation in the design of the project including minimizing stormwater runoff impacts.

(8) For 20 Coastal Counties must meet requirements of Section 2 (b)(1)(c) of SL 2008-211

(9) The Neuse stormwater nutrient loading limits specified in 15A NCAC 2B .0235 apply in the applicable affected local governments within the Neuse river basin.

(10) The Tar-Pamlico stormwater nutrient loading limits specified in 15A NCAC 2B .0258 apply in the applicable affected local governments within the Tar-Pamlico river basin.

(11) No low/high density designation for USMP; no maximum BUA, except within 575' of SA waters, maximum BUA is 36.

(12) DWQ-RO or location government (see http: //h2o.enr.state.nc.us/su/msi_maps.htm)

* Neuse and Tar-Pamlico setbacks are 50' riparian buffers.

(13) 50' vegetated buffer for new development and 30' vegetated buffer for redevelopment

(14) The greater of: 1.5" R/O; or Pre/Post Difference for the 1-year, 24-hour storm

(15) In the 20 Coastal Counties, as local government's Phase II NPDES permits are renewed the post-construction requirements will be updated to meet those in 2008-211.

Coastal stormwater program

The Coastal Stormwater Program is administered by the DWQ Regional Offices. Any development in the 20 coastal counties that requires a Coastal Area Management Act (CAMA) major permit or a Sedimentation/Erosion Control Plan must obtain a stormwater management permit. CAMA permits are required in Areas of Environmental Concern (AECs). Major permits are necessary for activities that require other state or federal permits, for projects that cover more than 20 acres, or for construction covering more than 60,000 square feet. Applications for major permits are reviewed by 10 state and four federal agencies before a decision is made. The CRC designates areas as AECs to protect them from uncontrolled or incompatible development in 20 coastal counties within CAMA jurisdiction. The estuarine system, as defined by DCM rules, extends upstream to the dividing line between coastal and inland fishing waters. The Estuarine System is the Coastal Shoreline category 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. Specific stormwater requirements vary according to adjoining water classification and distance from mean high water.

Rules applicable to CRC jurisdictional shorelines provide some additional water quality protection to coastal receiving waters compared to waters upstream and landward of CRC jurisdictional areas, unless those waters are designated Nutrient Sensitive Waters (NSW), Outstanding Resource Waters (ORW), or High Quality Waters (HQW). Nutrient management strategies for NSWs (Tar-Pamlico, Neuse, and Chowan rivers) include mandatory buffers and nutrient reductions from wastewater discharges, stormwater runoff, and agriculture (see “Neuse and Tar-Pamlico Nutrient Reduction Strategies” for more information). State-wide stormwater rules of the Environmental Management Commission (EMC) limit impervious cover adjacent to intermittent and perennial waters depending on their designation as NSW, ORW, SA, or NPDES Phase II stormwater municipality. However there is no minimum vegetated buffer required in coastal draining watersheds that are not under the domain of CRC rules or EMC special designations. Those river basins include portions of the Cape Fear and Roanoke, outside of the 20 CAMA counties.

Prior to October 2008, the coastal stormwater rules for low-density development allowed 25% built-upon area next to SA waters and ORWs. The inadequacy of that threshold is supported by numerous studies. The studies were, in turn, supported by the increase in conditional shellfish harvest closures through time (Street et al. 2005), despite stormwater regulations in place prior to late 2008. Following Street et al. (2005), the DWQ conducted a study of shellfish closures in five shellfish creeks in New Hanover County. The study found significant increases in conditionally closed shellfish harvesting waters between 1988 and 2005 (Tom Reeder/DWQ, pers. com., 2007; see also Mallin 2009). The implementation of existing stormwater rules was apparently ineffectiveness at preventing shellfish closures in North Carolina’s highest quality waters. Since 2004, there has been nearly 2,000 additional acres of water permanently closed to shellfish harvesting in North Carolina, occurring mostly in 2006 (Table 2.36).

Table 2.36. Acres of shellfish closures in SA waters from 2004 to 2009 (B. Pogue/DEH-SS, unpublished data 2010). Note: In 2007, the DEH-SS section started calculating acreage figures from GIS whereas prior acreage figures were hand tallied using a planimeter on NOAA Charts. Please be aware that the 2007 data will be slightly higher than previous data calculated by hand.

Classification	Dec-04	Dec-05	Dec-06	Dec-07	Dec-08	Dec-09
Approved	1,423,046	1,423,046	1,421,833	1,421,551	1,421,489	1,421,450
Conditionally Approved- Open	43,833	43,833	42,831	43,294	43,280	43,531
Conditionally Approved- Closed	12,116	12,116	13,166	12,782	12,782	12,562
CSHA- Prohibited	62,575	62,575	63,740	63,943	64,019	64,027
Additional Acreage Permanently Closed (Net)[1]	NA	0	2,215	-182	77	-212

[1] Included Conditionally Approved-Closed and CSHA-Prohibited.

To address the demonstrated inadequacy of existing regulations, new stormwater rules were developed and came into effect in October 2008 (Senate Bill 1967). The changes are highlighted in Table 2.37 for lands within one half mile of SA water and within 575 feet of ORWs. The most significant change was the reduction in built-upon area from 25% to 12%, in accordance with study results. The calculation of impervious surface was also changed to exclude coastal wetland area from the denominator[67]. Prior to 2008, all wetland area was excluded from the calculation,making it difficult to build on lots with any coastal wetland area. The inclusion of wetland area along with the reduction in total built-upon area allowed, may allow development of more lots but on a smaller area . Building on lots with coastal wetlands may now require a higher use of engineered stormwater controls.

Table 2.37. Stormwater rules for areas with one half mile of SA waters and within 575 feet of ORWs (http://h2o.enr.state.nc.us/su/documents/CoastalRuleComparisonChart2008.pdf).

Requirements	Pre-2008	Post-2008
Low density threshold	Built-upon area of 25% or less	Built upon area of 12% or less (max. built-upon area of 25% for ORW)
Stormwater control for high density projects	Control and treat runoff from the first 1.5 inches of rainfall.	Control and treat runoff generated by 1.5 inches of rainfall - OR - the difference in runoff from the pre and post development conditions for the 1-year, 24-hour storm (whichever is greater)
Discharge	No discharge for the first 1.5 inches of rainfall	No new points of discharge for the design storm (see above)
Types of stormwater controls	Infiltration is the only control allowed	All types of stormwater controls are allowed, with some restrictions

Whereas stormwater regulations target new development, it is just as important to address existing development and post-construction compliance. Retrofitting with adequate stormwater controls could reduce stormwater runoff from state roads and older urban/suburban built upon areas. The only stormwater retrofit program available to communities is the Conservation Assistance Program (CCAP) administered by the Division of Soil and Water Conservation (DSWC). *The CCAP program should be fully utilized in addressing the issue of stormwater pollution from existing development*. Post-construction compliance is an important issue supported by CHPP recommendations. Enhancing enforcement of, and compliance with, agency environmental rules and permit conditions was a major action item under Goal #1 of the 2005 CHPP. Subsequent implementation plans called for a taskforce to

[67] Coastal wetlands comprise only 10-20% of all wetlands in the coastal counties

coordinate interagency compliance monitoring. Membership on the taskforce included DWQ, DCM, DMF, WRC, and DEH-SS. Some of the members were hired with the help of CHPP recommendations calling for increased compliance monitoring. The effort to improve compliance monitoring was also supported by recent DWQ studies.

The first DWQ study examined compliance with State Stormwater permit conditions in 5 selected counties in southeastern North Carolina (http://h2o.enr.state.nc.us/nps/CNPSCP/documents/WIROStormwaterStudy2005andaddendum.pdf, December 2009). Within those counties, 524 stormwater permit sites were investigated in 2005. The full compliance rates for permitted projects with detention ponds and low-density sites were 26.9% and 34.9% respectively, and 30.7% for all projects. Non-compliance was primarily due to improper maintenance for detention ponds, and improper installation for low density sites. The percentage of maintenance violations for detention ponds was 32.5%, nearly twice that of low-density projects (14.5%). This potentially indicates detention ponds are a more complex and potentially more costly measure to maintain. Conversely, low-density projects failed more often to properly install the required stormwater control measures. The results were even poorer for the 6 infiltration systems examined; 100% were in reporting violation, 83% were not installed correctly, and 50% were not maintained according to permit conditions. To improve compliance, DWQ recommended increasing the number of compliance evaluation inspections, enhancing design certifications and deed restriction compliance, and educating permittees on maintenance expectations. As part of CHPP implementation, DWQ did receive 2 new stormwater compliance positions. *However, the need still exists for DWQ to educate permittees about the proper construction, maintenance, and installation time of stormwater ponds to help control run-off from construction sites.*

A follow-up study was conducted in the same 5 counties (http://h2o.enr.state.nc.us/nps/CNPSCP/documents/StormwaterComplianceProjectProgressReport.Sept07.pdf, December 2009). In total, the study examined 74 High Density stormwater permits expiring in 2007 and requiring inspections. As of September 2007, 34 of the 74 permitted sites had been inspected. Key findings were that two stormwater facilities that were approved have not been built, three sites were found to be compliant and 29 were out of compliance. The primary reason for non-compliance was poor or no maintenance. Both DWQ studies included recommendations for improving compliance. Those recommendations were incorporated in the final report from the Compliance Coordination Taskforce completed in mid-2009 (A. Haines, S. Jenkins/DEH-SS, pers. com., 2009). *Recommendations of the Compliance Coordination report should be a high priority for CHPP implementation.* Implementing measures to enhance permit compliance is also a high priority in the DENR Strategic Plan.

Despite improvements in stormwater regulations and compliance monitoring, the ability of stormwater controls to reduce impacts associated with increasing impervious surfaces remains difficult to quantify considering they 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). *The effectiveness of new coastal stormwater regulations in maintaining water quality and preventing further shellfish closures should be evaluated by DWQ and DEH-SS. Areas where data is lacking, including water quality in stormwater ponds and mining effluent, may require new studies to determine what DWQ monitoring requirements should include.*

Nutrient Reduction Strategies

Nutrient reduction strategies include both regulations associated with Nutrient Sensitive Waters and concentrated animals operations. In 1979, the Chowan River was first to be designated Nutrient Sensitive Water. Nutrient reduction strategies in the Chowan River basin–which have been in place for over 20 years–have had some success. The following strategies were recommended to reduce point and nonpoint phosphorus and nitrogen inputs (DWQ 2002b):

- 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.

Since nutrient reduction strategies were implemented, some 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 2002b). Current water quality conditions in the Chowan River are considered good, though a large portion of Swamp Waters makes comprehensive evaluation difficult (DWQ 2007). Researchers at the UNC-IMS have documented nitrogen concentrations 60% lower than in the early 1980s (S. Ensign/UNC-IMS, unpublished data, January 2010). Despite the reduced nutrient levels, measured chlorophyll *a* and dissolved oxygen concentrations exceeded North Carolina water quality standards on occasion in the mainstem Chowan River at Shingle Island and Bennetts Creek. Stations in the upper Wiccacon River and upper Bennetts Creek were in violation 60% and 80% of time, respectively. The data indicate serious impediments to spawning and juvenile river herring, particularly in the upper tributaries of the Chowan River.

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 total nitrogen 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 silviculture 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] 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.

The Neuse and Tar-Pamlico riparian buffer rules were designed based on the zonation scheme in Lowrance (1997). 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 is 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 the buffer rules to be critical to successfully reducing nitrogen (see "Status and trends" and "Nutrients and eutrophication" sections for information on water quality assessments).

The Nutrient Reduction Strategies in the Neuse and Tar-Pamlico have resulted in the targeted 30% reductions from point source dischargers and agriculture, though the overall goal of a 30% reduction in receiving waters has not been met (DWQ 2009a; H. Patt/DWQ , pers. com., January 2010). Updates from the Tar/Pamlico Basin nutrient reduction strategy can be found at the DWQ website (http://h2o.enr.state.nc.us/nps/documents/LoadSumTabl-Running2008.pdf, January 2010). Each of the fifteen local governments covered under the Neuse Stormwater Rule have adopted and are implementing ordinances and programs that in addition to requiring the nutrient export goal be met, carry out public education activities, and identify and remove illegal discharges (DWQ 2009). The disparity between source reductions of nutrients and measured concentrations of nutrients in the water column suggests a "lag-time" while excess nutrients stored in sediment are released. This "lag-time" suggest a longer time frame for realizing water quality improvements resulting from source reductions.

A statistical analysis of a comprehensive, 10-year data set on the Neuse River estuary demonstrated that over this period total phosphorus and total nitrogen concentrations significantly decreased, there was no change in nitrate concentrations, but ammonium concentrations significantly increased by 500% (Burkholder et al. 2006). Escalating ammonium in the Neuse Estuary is especially problematic because ammonium is the preferred source of nitrogen by many phytoplankton species, including certain harmful species whose increased abundance has been related to the increasing ammonium (Rothenberger et al. 2009a). This study also found a significant decrease in dissolved oxygen concentrations. Increased ammonium from concentrated animal feeding operations was a likely cause of the ammonium increases, contributing to algal bloom increases. It is notable that during this same period the Cape Fear River system also experienced a significant increase in ammonium, especially in the CAFO-rich Northeast Cape Fear and Black Rivers (Burkholder et al. 2006).

The NSW might be expanded to consider nutrient enrichment at larger spatial scales. For example, the riverine flows of the Cape Fear and Roanoke River discourage algae blooms and low dissolved oxygen, despite high nutrient loading to receiving waters (i.e., coastal ocean and Albemarle Sound). Dafner et al. (2007) measured nutrient concentrations in coastal and shelf waters of the Cape Fear River estuary (CFRE) and found significant removal of inorganic nutrients in wetland-fringed tributaries of the CFRE. These fringing wetlands are therefore helping to improve coastal ocean water quality.

Managing concentrated animal operations is an important component of overall nutrient management strategies. 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 was last extended to 2007.
- DENR was required to develop and adopt economically feasible odor control standards
- In 2007, the General Assembly passed Senate Bill 1465, the NC Swine Farm Environmental Performance Standards Act

The 2007 Swine Farm Act prohibited new lagoon and sprayfield systems, established a lagoon conversion cost-share program, and established a swine farm methane capture pilot program. New or expanding swine operations are required to have specified waste treatment systems that meet stringent health and environmental standards.

One recent study found that swine operation wastes have lower nutrient concentrations than in the past (Casteel 2007). Using data from 1999-2006 collected by the NC Department of Agriculture, researchers found that concentrations of almost all nutrients measured in waste were far lower than the values obtained by Barker and Zublena (1995) from 1980-1991 (Casteel, 2007). This study updated these default nutrient values to be used in calculations for NC farm nutrient/waste management plans. The change was attributed to more efficient feed practices. *If lower nutrient concentrations allow greater sprayfield application, there should be corresponding groundwater monitoring to verify nutrient levels are not increasing.*

A number of programs have provided funds for buyout of swine operations, close inactive lagoons, install BMPs, preserve or restore riparian buffers, streams, wetlands, and other natural resource concerns. These programs include:
- Clean Water Management Trust Fund (CWMTF)
- Division of Soil and Water Conservation
- Environmental Enhancement Grants Program (EEG)
- Conservation Reserve Enhancement Program (CREP)
- Farmland Protection Program

CAMA Land-Use Plans

A land-use plan is a collection of policies and maps that serves as a community's blueprint for growth (http://dcm2.enr.state.nc.us/planning/about.htm, December 2009). These plans are a fundamental element of coastal management in North Carolina. The Coastal Area Management Act requires each of the 20 coastal counties to have a local land-use plan in accordance with guidelines established by the Coastal Resources Commission. Each land-use plan includes local policies that address growth issues such as the protection of productive resources (i.e., farmland, forest resources, fisheries), desired types of economic development, natural resource protection and the reduction of storm hazards. Once a land-use plan is certified by the CRC, the Division of Coastal Management uses the plan in making CAMA permit decisions and federal consistency determinations. Proposed projects and activities must be consistent with the policies of a local land-use plan, or DCM cannot permit a project to go forward. At the local level, land-use plans provide guidance for both individual projects and a broad range of policy issues, such as the development of regulatory ordinances and public investment programs.

By 1997, 72 cities and towns had adopted their own plans, although CAMA does not require them to do so. By 1999, each of the 20 coastal counties, and numerous towns, had updated its plan four times, improving the quality of the plan with each update (http://dcm2.enr.state.nc.us/planning/LUP%20Submittal_Approval_website.pdf, December 2009). Land-use planning provides one of the best opportunities for public involvement in the coastal land-use issues.

Best Management Practices

Silviculture, agriculture, and mining are generally exempt from stormwater permit requirements if there are assurances of BMP implementation. Silviculture and agriculture are only required to comply with Nutrient Sensitive Strategies in the Neuse, Tar-Pamlico, and Chowan river basins (see "Nutrient Reductions Strategy" section for more information). Construction site preparations have BMPs associated with mandatory Erosion and Sediment Control Plans. A listing and description of non-point source management programs for silviculture, agriculture, and other land-uses can be found in the DWQ's Citizen's Guide to Water Quality (http://h2o.enr.state.nc.us/basinwide/WQ citizen guide on the web.pdf, December 2009).

Silviculture

In North Carolina, forestry (silviculture) related site-disturbing activities must comply with the performance standards described in the state water quality regulations (15A NCAC 01I .0100 - .0209) entitled the *Forest Practices Guidelines Related to Water Quality*, abbreviated as FPG's. The statewide FPG's are incorporated as part of the N.C. Sedimentation Pollution Control Act, (GS113A-52.1) and cover the full spectrum of forestry activities, including a section that describes requirements for establishing a Streamside Management Zone (SMZ) along intermittent streams, perennial streams, and perennial waterbodies; refer to the N.C. Division of Forest Resources (NCDFR) Web site for citations of the FPG's: http://dfr.nc.gov/publications/Forestry%20Leaflets/WQ01.pdf

In addition to the statewide FPG's, forestry activities also must comply with the 50-foot riparian buffer protection and maintenance rules described by the nutrient sensitive water strategies within the Catawba River basin; Neuse River basin; Tar-Pamlico River basin; Jordan Lake watershed; Randleman Lake watershed; and similar state rules for the Goose Creek watershed. And, there are two General Statutes related to the prohibition of obstructing streams, ditches and drainages (GS77-13, GS77-14) which must be followed when conducting forestry activities. The NCDFR inspects forestry sites across the state for compliance with the aforementioned rules and laws. Of the over 3,000 sites inspected each year from 2005-2009, compliance with forestry rules and laws has increased from 95-97% (T. Gerow/DFR, unpublished data, March 2010). To learn more about FPG's refer to this Web site: http://dfr.nc.gov/water_quality/fpg_bmp_differences.htm

During 2006, a comprehensive multi-year stakeholder-driven revision of North Carolina's forestry Best Management Practices (BMPs) was completed. The forestry BMP manual outlines recommendations that may be implemented as a means to promote compliance with the FPG's, as well as other water-quality regulations. The manual goes into detail regarding the inter-relationships between BMPs, soil conservation, and water quality. The SMZ-width recommendations now include more options based upon site-specific variables. While the primary objective of establishing a SMZ is for water quality protection, a well-managed SMZ can provide multiple benefits, including wildlife cover and habitat; recreation; aesthetic visual screens; and windbreaks. Generally, harvesting is allowed within a SMZ, but should occur in a low-impact manner that maintains the integrity of the soil and water resources.

In addition, an entire chapter of the forestry BMP manual is dedicated to forested wetlands and provides a summary of regulations, guidance and recommended measures to implement when conducting silvicultural activities in wetlands. Silvicultural activities in wetlands are governed under Section 404 of the federal Clean Water Act, and there are mandatory federal BMPs for activities related to road construction and mechanical site prep. These requirements, along with additional wetland-related BMPs are described in Chapter 6 of the forestry BMP Manual: http://dfr.nc.gov/publications/WQ0107/BMP_chapter06.pdf

While the implementation of forestry BMPs is voluntary in North Carolina, the NCDFR conducts periodic site survey assessments to determine the degree of BMP implementation. A 2005 report summarizes the results from BMP surveys that were completed from 2000 to 2003 across the state, with selected highlights noted below:

- 565 logging sites evaluated
- 82% statewide average BMP implementation rate
- 85% coastal area average BMP implementation rate
- 87% piedmont area average BMP implementation rate
- 69% mountain area average BMP implementation rate
- Practices in need of improvement: stream crossings; skid trails; site rehabilitation.

Copies of the report are available from the NCDFR and from the Web site noted below. As of March 2010, data analysis and report development is underway for the second round of these periodic BMP surveys. This second round was undertaken between 2006 and 2008, and evaluated more than 200 logging sites. The NCDFR expects to complete and produce this final report by mid-2010 and will post this report to the 'Water Quality' portion of the Web site: http://dfr.nc.gov/water_quality/water_quality.htm. Additional periodic BMP surveys are being planned for the foreseeable future, with the third round of surveys expected to begin in 2010.

Ongoing efforts of education, training, and on-site technical assistance are employed to reach landowners, loggers, and others who may need to understand FPGs, BMPs and the multitude of water quality regulations that affect forestry operations in North Carolina. Some examples of accomplishments from the N.C. Division of Forest Resources since the previous CHPP include:

- Production and distribution of two stream crossing BMP training videos that were used to train over 1,000 loggers statewide through the ProLogger Program.
- Production and distribution of one logging skid trail BMP training video that was used to train over 1,000 loggers statewide through the ProLogger Program.
- Acquisition and deployment of portable bridges for loggers to protect stream and ditch crossings. These bridges are staged or available for use across the 20 coastal counties.
- Implementation of a comprehensive forest-water quality and nonpoint source educational program at Clemmons Educational State Forest in Clayton which includes an outdoor water quality classroom, a river basin observation deck, and two workbook modules.
- Establishment of a paired-watershed research study in the upper Neuse River basin to monitor the effectiveness of riparian buffers and BMPs during forest harvesting.

The N.C. Division of Forest Resources recognizes that water-resource issues continue to dominate the areas of concern regarding land use practices, including forestry. The NCDFR also recognizes that a new set of challenges is facing the forestry community, as land-use development expands into areas that have traditionally been rural, agriculture and/or forested. Bridging the gap between traditional forest management practices, and traditional arboricultural urban forestry practices will be needed to address the transition of forested watersheds from rural, to suburban, to urbanized areas. Strategies for continuing efforts and exploring new opportunities are outlined below.

- *Create and implement a Forest Watershed Assistance Program that would provide enhanced water resource technical assistance to forestland owners in targeted watersheds.*
- *Create and implement an Urban Forest Watershed Management Program that would explore and implement opportunities to incorporate forestry-related management practices with low-impact development (LID), green infrastructure, and traditional nonpoint source stormwater control measures.*
- *Continue periodic BMP implementation surveys and monitoring of BMP effectiveness to ascertain trends in forest harvest activities, especially with questions concerning the harvesting of forest biomass, as well as evaluate the BMPs that were revised in 2006.*

- *Create an online GIS-based preharvest planning tool that would allow users to gain access to volumes of data related to soils, water resources, aerial imagery and other information that would be worthwhile for planning their harvest.*
- *Pursue opportunities for regulatory reform that would standardize the SMZ and/or riparian buffer requirements for forestry activities, in an effort to enhance performance on the ground and streamline the regulatory framework that governs forestry in the state.*
- *Continue to pursue the establishment of a Water Quality Forester position in areas of the state that do not have such a position. For eastern North Carolina, the gaps in coverage are the Fayetteville District (middle Cape Fear area), and the Fairfield District (Albemarle-Pamlico peninsula area). In western North Carolina, the gaps in coverage are the Asheville District and Sylva District.*
- *Develop BMPs related to water handling and the use of water resources for the purposes of suppressing and controlling peat-fueled wildfires based upon the lessons learned from the 2008 Evans Road Fire and similar wildfires in recent years.*
- *Develop threshold criteria for determining at what point a non-compliant forestry operation directly contributes to a degradation or loss of in-stream aquatic habitat that is sufficient to warrant restoration or remediation of the impacted water resource.*

Agriculture

Agricultural non-point source pollution is managed primarily through voluntary participation. The approach is supported by financial incentives, technical and educational assistance, research, and regulatory programs. Financial incentives are provided through North Carolina's Agriculture Cost Share Program administered by the Division of Soil and Water Conservation. The Cost Share program was authorized in 1983 as a pilot program to address nonpoint source problems in the NSWs of Jordan Lake, Falls Lake, and the Chowan River covering 16 counties. The program has been extended to all 96 Soil and Water Conservation Districts that includes all 100 counties. In addition, use of effective BMPs is enhanced by 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. *Increased monitoring of runoff, both groundwater and surface water, will be needed to evaluate effectiveness of BMPS or any management procedure implemented.*

Construction

Construction site BMPs (i.e., groundcover on slopes) are implemented with Erosion and Sediment Control Plans (ESCPs) required for projects impacting >1 acre. The DWQ reported to the EMC in 2002 that actions should be taken to strengthen groundcover requirements in the ESCPs and improve enforcement of the erosion and sedimentation control law and rules. The Sediment Control Act was amended in 2007 in accordance with some recommendations. The time that developers have to stabilize graded slopes was reduced from 30 to 21 calendar days. And the maximum civil penalty allowed for initial violations of the Sedimentation Pollution Control Act increased from $500 to $5000 per day in violation. For additional information, the "North Carolina Erosion and Sediment Control Planning and Design Manual" provides a comprehensive description of construction site BMPs (http://www.dlr.enr.state.nc.us/pages/publications.html).

2.4.3. Water quality degradation – Causes

The previous section covered the major sources and management of composite pollution (i.e., point source discharge, marina "hot spots," non-point sources) causing impairment based on existing water quality standards. The following section covers the specific ecological impacts and causes of nutrient enrichment, turbidity, toxic chemicals, desalinization, and marine debris in North Carolina coastal waters. The section may also compare existing water quality standard to the levels suggested in the primary literature.

2.4.3.1. Eutrophication and oxygen depletion

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). While a certain level of these nutrients is needed to support aquatic life, an overabundance of nutrients, or eutrophication, due to human activities often leads to increased primary production resulting in algal blooms (Nixon 1995). Nixon (1995) defines eutrophication as ''an increase in the rate of supply of organic matter to an ecosystem'' and points out that that most common form of eutrophication is nutrient enrichment. Andersen et al. (2006), defines eutrophication as “the enrichment of water by nutrients, especially nitrogen and/or phosphorus and organic matter, causing and increased growth of algae and higher forms of plant life to produce an unacceptable deviation in structure, function, and stability of organisms present in the water and to the quality of the water concerned, compared to reference conditions”. Nixon (2009) re-emphasizes that while nutrient enrichment is the most common cause of eutrophication, it is not the only one. It is important to separate the process of eutrophication from its causes and consequences.

Algal blooms are typically composed of phytoplankton (but sometimes include macroalgal species) at hundreds to thousands of cells per milliliter. When these blooms die off and settle through the water column, bacterial decomposition of the available organic matter drives respiratory uptake of dissolved oxygen (DO). In several types of coastal water bodies BOD5 (labile BOD) has been positively correlated with chlorophyll *a* biomass (Mallin et al. 2006). The blooms themselves can deplete the water column of DO through the nighttime respiration of dense algal concentrations. This increase in biological oxygen demand causes low dissolved oxygen levels (hypoxia or anoxia) in poorly-mixed, stratified water columns where oxygen is not being replaced through exposure to the air or resupply through photosynthesis (Diaz 2001). Increased oxygen demand can also result from the resuspension of un-decomposed or partially decomposed organic matter that previously settled to the bottom (Gray et al. 2002). Finally, BOD concentrations have been positively correlated with rainfall in a series of tidal creeks in New hanover County, and BOD was correlated with suspended solids as well (Mallin et al. 2009a). It is interesting to note that longer-term BOD (BOD20) was more strongly correlated with suspended sediments than five-day BOD, indicating that particulate matter (refractory material) entrained in runoff is an important BOD source involved in hypoxia, in addition to the more labile algal blooms.

Algal blooms tend to occur when water flow is slow and where mixing of the water column is reduced due to salinity and/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 and other flagellated algae are usually responsible for algal blooms (Smayda 1989, NC Sea Grant 1997, Mallin et al. 2000a). 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). The Chowan-Roanoke-Albemarle system is generally phosphorus-limited for phytoplankton growth, whereas phytoplankton growth in both the Tar-Pamlico and the Neuse Estuaries is generally limited by the levels of nitrogen- (Lin et al., 2007), or, in the Neuse, co-limited by both N and P (Rudek et al. 1991).

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) (see “Light and water clarity” subsection of “Status and trends” section for more information). 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 that harm fish and shellfish by affecting their nervous systems and paralyzing their respiratory systems (Tyler 1989). The chemicals released either inhibit ion channels in cell membranes or protein functions. Many fish kills have been attributed to toxic algal blooms and associated ulcerative mycosis (see "Status and trends" section for more details).

There are many potentially toxic algal species (Burkholder 1998). Species, though species often associated with fish kills in the estuarine and marine waters have included dinoflagellates such as *Karena brevis* (one major event in 1987), *Karlodinium veneficum*, *Pfiesteria piscicida,* and *Pfiesteria shumwayae* (Tyler 1989, Burkholder et al. 1995, Burkholder and Glasgow 1997, Glasgow et al. 2001, Hall et al. 2008). *Karenia brevis* blooms, sometimes referred to as "red tides" because the dinoflagellates can make the water appear red in color, impact benthic organisms through suffocation and nervous system paralysis (Tyler 1989). *Karlodinium veneficum*, found in the Neuse Estuary in 2006, causes fish kills at high cell concentrations (10,000 cells/ml or more), and is able to out-compete other co-occurring dinoflagellates, perhaps because of the production of karlotoxins that are known to act as grazing deterrents in addition to being toxic to fish (Hall et al. 2008). *Pfiesteria* spp. and *Karlodinium veneficum*, as well as various other algae that can harm fish, have been shown to be stimulated by nutrient pollution (Lewitus et al. 1999; Glibert et al. 2006; Burkholder et al. 2008).

Pfiesteria piscicida and *Pfiesteria shumwayae* are potentially toxic dinoflagellates that were related to certain fish kills in North Carolina and Maryland estuaries during the 1990s (Glasgow et al. 2001). *Pfiesteria* toxins were recently characterized by Moeller et al. (in 2007), who found that when combined with metals, the free radicals were found to be highly toxic, but ephemeral in nature and thus, very difficult to isolate. Moeller et al. (2007) reported that the combination of exposure to sunlight and metals is likely to control the presence or absence of the toxins. Low DO has been documented to cause large fish kills in areas where *Pfiesteria* was also present (Burkholder and Glasgow 1997, Paerl et al. 1998, Burkholder et al. 1999).

Fish kills are often accompanied by ulcerative mycosis (a certain type of fish skin lesions), which has been attributed to *Pfiesteria* spp. and other toxic algae, various protozoan fish parasites, mycobacteria, and physical stressors , and various other chemical poisons or toxins (Glasgow et al. 2001; Blazer et al. 1999; Jacobs et al. 2009; Noga et al. 1996, Noga 2000). *Pfiesteria piscicida* has been found to cause rapid erosion of fish cells and ulcerations on living fish (Parrow et al. 2005, Burkholder et al. 2005). Hackney et al. (1998) noted that high numbers of menhaden with lesions were found in estuarine areas containing high concentrations of toxic substances such as toxic metals, DDT, and PCBs. Recently, based on samples of skin ulcers of Atlantic menhaden (*Brevoortia tyrannus*) from populations found in the Pamlico and Neuse River estuaries, Vandersea et al. (2006) reported that the fungal pathogen *Aphanomyces invadans* (water mold) was the primary ethiological agent in ulcerative mycosis. However, the study results are based on 50 samples taken in very recent years; no samples were used from the 1990s or early 2000s.

Several NC estuarine environments are characterized by slowly moving, poorly flushed waters with high level of nutrients, which offer ideal conditions for various algae, fungi, and bacteria to thrive. These organisms promote low dissolved oxygen in the water that can lead to fish kills, and some of these microbes can also attack fish and shellfish directly (e.g. Springer et al. 2002, Shumway et al. 2006, Vandersea et al. 2006), compounding the impact of eutrophication on fisheries.

Coastal research and monitoring needs to continue to improve our understanding of all of the processes of eutrophication and the effects on fish populations.

Sources of nutrient enrichment

The majority of nutrient pollution to the Albemarle-Pamlico system has been linked to agriculture; including cropland, pastureland, and animal operations (Stone et al. 1995; Gilliam et al. 1996; Burkholder et al. 1997; Huffman 1999; Paerl and Whitall 1999; Mallin et al. 2000a; Mallin et al. 2001c; Cahoon and Ensign 2004; Rothenberger et al. 2009b). 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 atmospheric deposition (Stone et al. 1995; Gilliam et al. 1996; Burkholder et al. 2007a; Costanza et al. 2008a). Other sources include golf courses and atmospheric deposition from industry.

The presence of concentrated animal operations on river floodplains has been shown to be a danger to fish survival and habitat suitability (Burkholder et al. 1997, Mallin et al. 2000a,; Mallin et al. 2001c). Animal wastes are highly concentrated sources of nutrients, organic matter, fecal coliform bacteria, andpathogenic microbes (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 wastes 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 coastal New River watersheds resulted in anoxic and hypoxic conditions,; high nitrogen and phosphorus concentrations,; dense phytoplankton blooms, high fecal coliform bacteria levels, high turbidity, and fish kills (Burkholder et al. 1997; Mallin et al. 1997). A growing concern is the release of pharmaceuticals, antibiotics and other veterinary drugs from CAFOs into the environment (Burkholder et al. 2007a).

Groundwater can be contaminated through leaking lagoons (lined and unlined) or leaching of waste applied on sprayfields (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). Paerl and Whitall (1999) found that 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. Empirically-verified modeling results from Costanza et al. (2008a) indicated a small portion of CAFOs contributes disproportionately to atmospheric deposition of Nitrogen in the Albemarle-Pamlico Sound. The study estimated that 14-37% of the state receives 50% of the state's atmospheric Nitrogen deposition from CAFO lagoons. *The authors suggested stronger waste management and emission standards for CAFOs in certain areas of the Coastal Plains.*

The discharge from coastal aquaculture facilities are also a source of nutrients. This issue was raised by the MFC Habitat and Water Quality Committee due to high chlorophyll *a* concentrations at the discharge sites. To address this new source of nutrient enrichment, the DWQ developed a Schedule of Compliance (SOC) calling for the preparation of Farm Management Plans that minimize water quality impacts during the life of the SOC (DWQ staff , pers. com., October 2008). The Farm Management Plans would be followed by a Final Solution Plan designed to resolve all water quality impacts on the chlorophyll *a* standard. The first five striped bass operations have submitted Farm Management Plans and are preparing Final Solution Plans that analyze impacts and specify how to treat, reuse, and irrigate discharge water as much as possible. To be eligible for an NPDES permit, the aquaculture facilities will conduct an 18 month study on water quality impacts/effluent characterization at various ages of operation. Once the process is complete for first five, other facilities will have to comply. The Division of Soil and Water Conservation has also convened a workgroup to identify ways they Agriculture Cost Share Program can assist aquaculture facilities with effective discharge BMPs.

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 total particulate nitrogen (N) and phosphorus (P) loading (Ibison et al. 1992). The N and P loading rates from highly eroding shorelines in the study varied considerably but were higher than that estimated from typical agricultural runoff. *North Carolina's shorelines should be evaluated to identify potential hot spots of nutrient inputs from bank erosion.*

Mallin and Wheeler (2000) studied the effect of golf courses in New Hanover and Brunswick counties on water quality in adjacent water bodies. Although this study found that ammonium and orthophosphate was tightly bound to the soils, nitrate levels in the streams increased as they flowed through the courses and in some places caused increases in phytoplankton biomass and algal blooms. The authors concluded that 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). Another study, 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 (Mallin et al. 2002a). Soils in undisturbed forests had the least phosphorus associated with them. Their results indicated that fertilizer use was positively correlated with phosphorus levels. Unfortunately, Nutrient Reduction Strategies apply to golf course in only the Neuse and Tar-Pamlico river basins, where the percent cover of urban/recreation grasses is relatively low (see "Land-use and non-point sources" section for more information). The highest percent cover of urban/recreational grasses was in the southern estuaries subregion (part of Cape Fear River basin), where only stormwater rules apply. These studies suggest that sites with high sediment loss and intense fertilizer use, such as agricultural lands, CAFOs, golf courses, or manicured lawns, have high potential for nutrient contributions to the water column. *Additional education is needed on proper application of fertilizers to reduce runoff of nutrients into coastal waters, targeting homeowners, golf course owners, and landscape businesses in non-NSW watersheds (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.*

Nutrients can also enter the water column habitat through atmospheric deposition from industries other than agriculture and CAFOs. In June 2002, the NC 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.

Automobiles contribute to air pollution across North Carolina. Increasing air pollution from automobiles could be attributed to increasing urban sprawl; as members of a more dispersed human population typically drive longer distances per day in vehicles, contributing to increased nitrogen emissions. The relative increase in urban built-upon areas may also be contributing excess nutrients during extreme weather events. Engelhaupt (2008) compared nitrogen release in urban areas and agriculture lands and found that urban areas were shown to become a bigger contributor when rainfall patterns were more variable. Specifically, the study documented a 50% decrease in nitrogen retention during wet years. Forests and agricultural lands largely kept their nitrogen-retaining ability.

Status and trends in nutrient enrichment

Nutrient enrichment in Albemarle-Pamlico estuarine system and the subsequent effects on phytoplankton populations and water quality parameters has been observed by many researchers since the 1970s, Changes in these parameters were linked to anthropogenic nutrient loading events including changes in agricultural fertilizer use, the phosphate detergent ban, overall improvements to WWTPs, upstream dam construction as well as to discharge fluctuations caused by hurricanes and droughts (Stanley and Hobbie 1981, Christian et al. 1991, Boyer et al. 1993, Stanley 1993, Stow et al. 2001, Paerl et al. 2004) Since the phytoplankton blooms seen in NC estuaries resulted from nutrient enrichment, measures of chlorophyll *a*, a photosynthetic pigment found in all algae and most cyanobacteria, is a commonly used indicator of algal biomass, primary production, and eutrophication.

Paerl et al. (2004, 2007) found that depending on seasonal hydrologic cycles and episodic (hurricane) events, phytoplankton community structure differed substantially. They argue that since phytoplankton are relatively easy to detect, identify, and quantify, conduct a large share of primary production, and are sensitive to diverse environmental stressors, they can be valuable indicators of eutrophication (Paerl et al. 2007). Andersen et al. (2006), argues that measuring primary production should be “mandatory” in monitoring coastal waters for eutrophication. It should be noted, however, that the sampling frequency and location have a major influence on the data because of the high variation in the system.

In the lower Cape Fear River, Mallin et al. (2001c) reported 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). 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; Mallin et al. 2004). In continental-draining tidal creeks, phytoplankton growth in the lower reaches is limited by nitrogen, while in the upper reaches it can be limited by phosphorus at times due to elevated nitrate inputs, or even by light through self-shading of the algae (Mallin et al. 2004). Other studies have also found that falling tides transport algae from upstream to downstream sources (Litaker et al. 1987; 1993).

NAWQA results from the mid-1990s in the Albemarle-Pamlico system found that the Neuse Basin had the highest nitrogen and phosphorus concentrations due to intensive agriculture and urban runoff while the lowest concentrations occurred in the forested Chowan Basin (Spruill et al. 1998). Although nitrogen and phosphorus concentrations in streams had shown a general decline since 1980 in all four basins, concentrations are still such that continue to cause to algal blooms in the Tar-Pamlico and Neuse river basins. The decrease in nutrient levels was likely due to improved agricultural practices, the phosphate detergent ban in 1988, and improved water treatment practices. 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 (Spruill et al. 1998).

A geologic source also contributes to naturally high phosphorus in the Neuse and Tar-Pamlico. Fear et al. (2007) worked in areas high in organic sediments and reported that submerged groundwater discharge in the Neuse Estuary represented a small part of watershed nitrogen and phosphorus loading, 0.8% and 1.0%, respectively. Similar measurements reported in Spruill and Bratton (2008) indicated 4% and 5% of N and P originating from ground water. However, Null et al. (2009) measured ten-fold higher concentrations of ammonium in nearshore sandy sediments of that estuary than in the overlying water column, and significant seasonal groundwater input to porewaters. They conclude that groundwater is an important mechanism forcing nutrients from porewaters to the overlying water column in this shallow lagoonal estuary.

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 summarized 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 high concentrations (>5 µg/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). 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. All systems reported nuisance or toxic algal blooms at least once during the course of the year except Bogue Sound and the Cape Fear River (NOAA 1996). This survey was a part of the National Estuarine Eutrophication Assessment (NEAA) Program that was designed to improve monitoring and assessment efforts to develop models and tools for successful management of eutrophication (Whitall et al. 2007). The NOAA (1996) survey of these estuaries was updated by Bricker et al. (2007), and North Carolina estuaries were evaluated similarly as in the earlier assessment. Conditions were predicted to worsen in 65% of the assessed estuaries in the future, especially in shallow, poorly flushed estuaries such as the Albemarle-Pamlico in North Carolina.

For 17 years ongoing, NCSU Center for Applied Aquatic Ecology's (CAAE) Neuse River Monitoring and Research Program has tracked riverine discharge, dissolved oxygen throughout the water column, phytoplankton assemblages, phytoplankton biomass, fecal coliform bacteria densities, suspended sediment loads, and nutrient concentrations and loads in the mesohaline Neuse Estuary (e.g. Burkholder et al. 2004, 2006). Important findings contributed by this effort that are pertinent to fish health and fish habitat include:

- Long-term analysis of land use changes in the Neuse watershed showed that urban/suburban development and associated runoff and sewage inputs are the most important contributors to water quality degradation in the upper watershed, whereas industrialized swine agriculture is the most important contributor to water quality degradation in the middle and lower watershed (Rothenberger et al. 2009b).
- Total nitrogen loading declined over the period from 1994 to 2009, but at the same time, ammonium has increased. Ammonium is an important form of nitrogen that is preferred by many phytoplankton species.
- Algal biomass (as chlorophyll *a*) has significantly increased in both the oligohaline and mesohaline estuary from 1993 to 2009, despite management efforts to control algal biomass by reducing the total nitrogen load. The significant trend upward in algal biomass appears to be related to nonpoint source pollution (Burkholder et al. 2006)
- Bottom-water dissolved oxygen has significantly decreased in the mesohaline estuary from 1993

to 2009, reflecting a status of chronic eutrophication of this system. This trend indicates, as do the significant trends upward in chlorophyll *a* and ammonium, that the Neuse Estuary is sustaining progressive, increased habitat degradation for fish and other beneficial aquatic life.
- Fish kills have not declined in the Neuse Estuary over this period, despite management actions to reduce total nitrogen loading, our data support DWQ's having reported that 2008-2009 marked record fish kill years. While drought years sometimes have sustained more fish kills, this dataset showed that fish kills may also be significantly affected by pollutant loadings and the degree of flushing by major storms (Burkholder et al. 2004).
- Co-management of both nitrogen and phosphorus, and major reductions in inputs from nonpoint as well as point sources, are needed (Glasgow and Burkholder 2000) to reverse water quality degradation in this estuary

The ongoing (1997 to the present), Neuse River Modeling and Monitoring Project (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 in this dataset complicate trend analysis. 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). 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 were:
- Nitrogen loading had declined since 1999 and blooms in the upper Neuse River Estuary (NRE) north of New Bern have declined. This is attributed to upstream wastewater treatment plant improvements.
- The mesohaline portion of the estuary has persistent salinity stratification and regular phytoplankton blooms due to nutrient enrichment
- The increased hurricane frequency since the mid-1990s has resulted in decreased upstream N and P concentrations due to increased flushing
- Benthic and pelagic respiration is capable of fully depleting the oxygen pool in stratified bottom water in less than 5 days during summer months. Primary production is largely influenced by the amount of freshwater flushing of the estuary. Large amounts of discharge move the largest measures of algal biomass far downstream while droughts result in high algal biomass far upstream.
- 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. 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 (Luettich et al. 2000, Buzzelli et al. 2001, Paerl et al. 2009)

The Lower Cape Fear River Program (UNC-W) has monitored nutrients and other parameters since 1995. In 2008, chronic or periodic high nitrate levels were found at a number of stations. There were considerably more algal blooms than the previous two years, most likely due to low flow throughout 2008 (Mallin et al. 2008). Low flow is also the likely explanation for annual mean turbidity levels being much lower than the long-term average. Dissolved oxygen levels were similar to the annual average in the river channel but lower in the blackwater creeks. These "blackwater" systems often have low to 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). The Lower Cape Fear River Program (UNC-W) uses its data, along with that of DWQ's Basinwide Assessments, to give ratings for each parameter in each sub-basin in the Lower Cape Fear. This effort provides a detailed description of the changes occurring in each sub-basin and could be used for planning efforts.

The Cape Fear Program's tidal creek monitoring has found that nutrient loading is high enough in several of the creeks to support small algal blooms periodically. In 2006-2007, the three creeks that have the most development and impervious surfaces in their drainage area, had the worst water quality degradation. Of the 11 tidal creeks monitored in 2008, five were reported to have good water quality, often attributed to low development and impervious surfaces (Mallin et al. 2008). The new stormwater rules made effective in October 2008 should help maintain water quality in the creek with good water quality (see "Non-point source management" subsection of "Land-use and non-point sources" section for more information). C*omprehensive water quality monitoring is needed in other tidal creeks that are highly important nursery and shellfish areas.*

In the Cape Fear River Estuary (CFRE), highest concentrations of all individual N and P compounds measured in coastal and shelf waters were found in the upper parts of each tributary. There has been a significant increasing trend, as mentioned earlier, in ammonium concentrations in areas of the Cape Fear watershed that are rich in CAFOs (Burkholder et al. 2006). The lower parts of estuaries and surface shelf waters were characterized by oceanic surface values, indicating removal of N and P downstream in all tributaries. Despite a high level of anthropogenic pressure on the uppermost coastal waters, significant amounts of the inorganic N and P load are retained within estuarine and nearshore waters without reaching the shelf (Dafner et al. 2006). Lin et al. (2008) found that light limitation controls phytoplankton growth in the upper CFRE while nutrient availability limits growth in the lower estuary during low flow periods, as in the coastal ocean. Their model predicted that in low flows, light limitation decreases and phytoplankton growth increased, while in high flows residence time was shorter, light availability was reduced, and less nutrients were consumed. This study, along with others, highlights the importance of discharge on residence time, light availability, and nutrient uptake by phytoplankton in NC estuaries (Christian et al. 1991, Paerl et al. 2009).

A recent analysis of hypoxia, nitrogen loadings, and fisheries landings in 30 estuaries worldwide, suggests that hypoxia does not typically reduce system-wide fisheries landings below what would be predicted from nitrogen loadings. There was also no correlation found between N loading and the spatial extent of hypoxia. Although compensatory mechanisms limit the translation of local-scale effects of hypoxia to the scale of the whole system, hypoxia should still be considered in fisheries management strategies (Breitburg et al. 2009).

However, fisheries landings are not the only measure of ecosystem integrity and resilience. Other studies have indicated a fundamental change in trophic structure and species composition as eutrophication intensifies (Jackson et al. 2001, Kemp et al. 2005). Jackson et al. (2001) found that the combined effects of eliminating a particular species/trophic level and adding excessive amounts of nutrients and sediments, greatly alters relative community composition and allows for extreme eutrophication-related events that may not have occurred unless both conditions were present. They argue that overfishing, both the elimination of top predators as well as structural bottom impacts may actually be a precondition to eutrophication, disease, and microbial outbreaks. They propose that large scale oyster reef restoration in temperate estuaries to increase water filtration may be required, in addition to nutrient input reduction, for significant reduction in eutrophication to be achieved (Jackson et al. 2001, Boesch et al. 2001, and Peterson et al. 2001). In a review of eutrophication in Chesapeake Bay, VA, Kemp et al. (2005) note that declines in eastern oyster stocks may have exacerbated eutrophication in the estuary. They conclude that while overall fisheries production may not have been effected, there have been fundamental shifts in trophic and habitat structures (Kemp et al. 2005).

2.4.3.2. Suspended sediment and turbidity

The dynamic process in which the physical energy of waves, tides, and currents is transferred to stream, estuarine, and ocean shorelines 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. The affects of light availability on aquatic organisms and other basic water quality parameters (i.e., temperature, pH, dissolved oxygen) were discussed in the preface for "Status and trends." Here we discuss the physical effects of suspended sediment and turbidity on aquatic organisms and the synergy of sediment additions with eutrophication and toxic contamination in North Carolina coastal and estuarine waters.

Excessive suspended sediments can directly 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). Auld and Schubel (1978) demonstrated reducing hatching success and reduced larval fish survival with increased turbidity for several fisheries species in the Chesapeake Bay. Increases in the amount of nonfood particles ingested by suspension-feeding shellfish and polychaetes lower the nutrient value of their diet and their growth rates (Reilly and Bellis 1983, Benfield and Minello 1996, SAFMC 1998a; Lindquist and Manning 2001). Turbidity has also been found to disrupt spawning migrations and social hierarchies (Reed et al. 1983) and results in decreased combined fish biomass (Aksnes 2007). Peterson and Manning (2001) found that high turbidity (~100 NTUs) resulted in 25% reduction in growth by *Donax variabilis* and 30-40% reduced feeding rate by Florida pompano in experimental wave tanks.

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). In a set of North Carolina oligohaline tidal creeks Mallin et al. (2009a) found that both TSS and turbidity were strongly correlated with fecal bacteria, phosphate, and BOD, and that TSS and turbidity were strongly correlated with rainfall events. 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 bottom sediments are resuspended, 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 2001).

Excessive sediment loading from nonpoint sources can gradually fill in creeks and small water bodies 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 in the upper estuary (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, http://www.fisheries.org/Public_Affairs/Policy_Statements).

Sources of turbidity and sedimentation

Sources of deposited or re-suspended sediment include land-disturbing activities, dredging for navigation channels and boat basins, mining, beach nourishment, boating activities, and bottom-disturbing fishing gear. 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 (see "Land-use and non-point sources" for information on status and trends for these activities).

- Dredging for navigation channels and boat basins causes re-suspension of bottom sediments and additions of sediment from disturbed uplands (see “Dredging (navigation channels and boat basins)” and “Water-dependent development” sections for information on status and trends for these activities).
- Mine dewatering is another source of land-based sediment (see “Mining” subsection of “Hydrologic modifications” section for information on status and trends for mining).
- Beach nourishment activities redistribute sediment between ocean shoreline and estuarine/offshore borrow sites (see “Beach nourishment” section of “Soft bottom” chapter for more information).
- Bottom fishing gear and boating activities primarily re-suspend bottom sediments (see “Boating activity” section of “Submerged aquatic vegetation” chapter for more information).
- Bottom disturbing fishing activities that generate turbidity in the water column include bottom trawling, clam kicking, and hydraulic clam dredging (see “Soft bottom” chapter for more information on fishing gear impacts).
- Municipal and industrial wastewater treatment discharges (point sources) can be a minor source of sediment (see “Point sources” subsection of “Water quality degradation – Source” section for information on status and trends).

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. However, since the amount of land in agriculture is declining, with a corresponding increase in development, the sediment contributions from these activities could be changing (see “Land-use and non-point sources” for more information).

Stream bank 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 development result in higher volumes and rates of flow into receiving streams. Bank failures are likely to occur when stream banks are subjected to high flows, when stabilizing vegetation is removed or not present, and at livestock or vehicle crossings. Sediment inputs will generally be high where erosion rates are high and shorelines are unstable. 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). In Piedmont NC, Line and White (2007) found that as land cover change progressed from forested/agriculture to a residential development in a small drainage area, there were increased runoff volumes (68% higher) and TSS (95%) compared to a similar undisturbed drainage area (see “Land-use and non-point sources” section for more information). The Line and White study also supports the likelihood of urban development eventually outpacing agriculture as a source of sediment pollution. The effectiveness of stormwater regulations, Erosion and Sediment Control Plans, and land-use BMPs will modify the relative contributions of agriculture and residential development (see “Nonpoint source management” section for more information).

Corbett et al. (2009) found that sediment accumulation rates in two small tributaries of the Neuse River Estuary are 0.2-0.5 cm/yr, indicating sediment retention. They explain that estuaries in the southeastern U.S. are lined with tributaries and marshes that widen as they join the trunk estuary (see “Soft bottom” chapter for information on sedimentation and resuspension in mainstem estuaries). These areas act as temporary storage of sediment from the watershed and deliver sediment to the estuary only during high flows and/or storm events. In disturbed watersheds, these tributaries accumulate a large amount of sediment that can become storage for contaminants, nutrients, and organic matter.

Another important factor in sediment loading from shoreline erosion is the effect of global climate change on sea level rise and resulting accelerated erosion (IPCC 2007). The accelerated erosion stems from submerging portions of barrier islands (see "Soft bottom" chapter for more information on ocean shoreline erosion and sea level rise), increased erosion along previously protected shorelines, and increasing loss of wetlands trapping sediment and other pollutants (see "Wetland" chapter for more information on estuarine shoreline change with sea level rise and erosion).

Status and trends in turbidity/sedimentation

Sediment and suspended solids 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 reservoirs, ponds, and beaver ponds in the basin, which trap solids,
- Improved agricultural soil management, including use of conservation tillage, and
- Improved wastewater management.

In the lower Neuse River Estuary, UNC's 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 UNCW's Cape Fear Program in the lower Cape Fear River, annual mean turbidity in 2008 was much lower than the long-term average due to low rainfall and discharge (Mallin et al. 2008). As expected, the highest turbidities, which were only 25 NTUs, were found in the upper estuary and decreased downstream, with the lowest in the blackwater tributaries. In the tidal creeks monitored by UNC-W, turbidity was generally not a problem during the time period sampled.

The NCSU CAAE conducted decadal trend analysis of suspended solids loads to the mesohaline Neuse Estuary and showed a significant trend downward (24% decrease) in suspended solids loads during 1994-2003 (Burkholder et al. 2006). The resulting increased light availability, together with the striking increase in ammonium concentrations, likely are both contributing to the significant trend upward in chlorophyll *a* that the estuary has sustained.

Although the two commonly measured water quality parameters are water column turbidity (NTU) and total suspended solids (TSS), correlations can be misleading due to the light scattering characteristics of the suspended particles (Newcombe and MacDonald, 1991; Davies-Colley and Smith, 200; Fries et al. 2007). Fries et al. (2007) suggested that, under certain conditions, either of these measures could represent a proxy for runoff and provide rapid measures of identifying suspensions dominated by various particles (phytoplankton, runoff particles, or resuspended sediments). This knowledge could then be used to help identify the source and predict water quality consequences of particle suspensions found.

2.4.3.3. 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." Many of these chemicals occur naturally (e.g., heavy metals), while others are created almost entirely by humans (e.g., pesticides). Potentially toxic chemicals found in the water column include:

- 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, copper- and organotin -based antifoulants, 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). Hydrocarbons enter surface waters through stormwater runoff, boat use, and fuel spills.
- 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).
- Biocides- chlorine and other disinfectants 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. PCBs are used in plasticizers and flame retardants.
- Plasticizers and flame retardants - Plasticizers (containing bisphenol A) are used to soften PVC and used in storage containers and other items. Flame retardants are used in building materials such as insulation, electric cable insulation, electronics, motor vehicles, household furnishings, plastics and polyurethane foams. These chemicals are being found increasingly in surface waters (Kuiper et al. 2007; Kimbrough et al. 2008), bioaccumulate in organisms, and disrupt endocrine processes (www.epa.gov).
- 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 referring to any product consumed by individuals for personal health or cosmetic reasons, such as over -the-counter drugs like ibuprofen, prescription drugs such as antibiotics, antidepressants and oral contraceptives, caffeine, nicotine, disinfectants, and fragrances in products like shampoo and detergent (<http://www.epa.gov).

many factors affect a given 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. Human -introduced chemicals can damage aquatic organisms directly by causing mortality or indirectly by altering endocrine related growth and reproductive processes.

Regardless of the life stage affected, some chemicals are inherently more 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.

While some toxins will remain in aqueous form in the water column, others, 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). Adsorption on sediment particles allows some toxic chemicals to accumulate and continue contaminating sediments until they degrade into less harmful substances. Refer to the soft bottom chapter for information on sources and effects of heavy metal and hydrocarbon impacts to bottom feeding fish. However when these chemicals are re-suspended, they become biologically available to pelagic species as well and can be incorporated into fish tissue through absorption or diet. Upon entering the water column, many organic compounds will break down and not persist indefinitely (Jackivicz and Kuzminski 1973).

Toxicity and bioaccumulation

The acute and chronic toxicity of selected chemicals on a few pelagic species are listed in Table 2.38. The effects of environmental pollutants on early fish life stages are listed in Appendix F. 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). For many organic wastewater compounds, thresholds for aquatic organisms are not yet known and standards have not been established.

In addition to 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. Mercury is one toxin known to bioaccumulate in fish. The EPA has some recent guidance documents regarding the assessment of chemical contamination for use in fish advisories (EPA 2000b, 2000c).

Table 2.38. Current water quality standards and literature values (micrometers/liter) for measured toxicity of selected chemicals on selected pelagic species. (Sources: 2009 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 (N)	5 (N)			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	0.002	0.003			8[b]/ND
Chlordane	0.004	0.004			12/ND
Dieldrin	0.002	0.002			20/ND
Toxaphene	0.0000002	0.0000002			5[a], 5.8[b]/ND
Other chemicals					
Trialkyltin	0.07	0.007	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

Natural sources of atmospheric mercury include volcanoes, geologic deposits of mercury, and volatilization from the ocean. Anthropogenic sources of mercury include chlor-alkali plants, coal combustion and ash containment facilities, waste incinerators, metal smelting and emissions from cement plants. Atmospheric deposition is the dominant source of mercury over most of the landscape. Once in the atmosphere, mercury is widely disseminated and can circulate for years, accounting for its wide-spread distribution. Emissions from cement plants are a major producer of mercury and recent work for a proposed cement plan on the Northeast Cape Fear found that a large portion of the emissions would precipitate out over the surrounding wetlands and waters. Elevated methylmercury has been found in fish tissue of several species in the lower Cape Fear watershed and several miles are listed as impaired for mercury by DWQ. One major source of the contamination was a former chlor-alkali manufacturing plant (HolttraChem facility) used to provide chlorine gas, caustic soda, and bleach to the adjacent International Paper facility. The lagoons holding process water and the plant were highly contaminated with mercury. The site is now designated as a Superfund site, removal of the waste has been underway since 2003. *Additional industrial emissions of mercury would be detrimental to fish populations in this area and should be highly limited.*

Another emerging source of toxic contamination was documented recently in reports concerning coal ash containment facilities in coastal North Carolina and elsewhere (Stant 2010; http://www.publicintegrity.org/assets/pdf/CoalAsh-Doc1.pdf). The reports document toxic leachate from these facilities at very high concentrations in the receiving waters. The levels of some deadly pollutants, such as arsenic, cadmium, lead, selenium, and other toxic metals were as much as 145 times greater than federal discharge standards. The results from 31 such facilities have strengthened the case for releasing delayed federal regulations on coal ash containment facilities. Two active facilities in North Carolina were located in coastal draining river basins; one operated by Progress Energy near the Cape Fear River, and another located near Swift Creek in the Neuse River Basin. Among other things, the delayed federal regulations would require flue-gas desulfurization controls (scrubbers). Progress Energy has opted to close all of its coal-fired power plants that do not have the scrubbers. The company decided that it was cheaper to close them than to install the necessary retrofits (http://progress-energy.com/aboutus/news/article.asp?id=22982. March 2010). The company has plans to build cleaner, natural gas-powered plants to replace some of the lost capacity. Cleaning up coal ash containment facilities is supported by CHPP goals and objectives to protect water quality.

Once in surface waters, bacteria that process sulfate can take up inorganic mercury, convert it to methyl mercury through metabolic processes, and be consumed by the next higher level in the food chain. Eventually, methyl mercury accumulates higher trophic species. Mercury can settle on the bottom and become buried by sediment or be resuspended into the water column. In a US study, blackwater coastal plain streams draining forested wetlands in the southeast tended to have the highest concentrations of mercury in fish tissue (Scudder et al. 2009). Studies have documented that the Cape Fear system has favorable conditions for conversion to methylmercury and for retention in the system (Schneider 2009). Fish consumption advisories in North Carolina can be found at http://www.rabies.ncdhhs.gov/epi/fish/current.html. There is a statewide mercury advisory and site specific advisories for PCBs, dioxin, and other toxins. Site-specific advisories for dioxin have been given for Albemarle Sound, lower Roanoke River, and Welch Creek in Beaufort, Martin, and Washington counties, due to a former paper mill plant. There is also 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. In addition to bioaccumulating, both inorganic and organic mercury have been reported to be lethal to fish and invertebrates in low concentrations and cause various physiological, reproductive, and biochemical abnormalities at sublethal concentrations (Boening 2000). Temperature, pH, salinity, and DO will affect toxicity values.

Endocrine Disruptors

Since the 2005 CHPP, more information is available that residuals of many new compounds (emerging contaminants) used today in products that improve our lifestyle, such as mosquito control chemicals, antibiotics, cleaning supplies, hand sanitizer, flea control, and lawn pesticides and herbicides, and others, can enter the environment and have significant environmental and human health effects. These “emerging contaminants” have been identified in wastewater, surface, and groundwater in the United States and other countries (Shea et al. 2001; Kolpin et al. 2002; Giorgino et al. 2007) and may act as endocrine disrupting chemicals.

Endocrine disrupting chemicals (EDCs) are hormonally active chemicals that alter growth, development, reproductive or metabolic processes, adversely affecting the organism, its progeny, and/or stock viability (Weis and Weis 1989; Wilbur and Pentony 1999, DeFur and Foersom 2000). EDCs may include some, but not necessarily all industrial chemicals, pesticides, metals, flame retardants, plasticizers, disinfectants, prescription medications such as antibiotics and hormones, and some pharmaceuticals and personal care products. While the public may realize that pesticides and heavy metals from industrial and car emissions may be dangerous, it is less known that seemingly benign products such as caffeine, ibuprofen, antibacterial soap, and byproducts from plastic bottles and upholstery materials are entering coastal waters and may be adversely affecting the growth and reproduction of aquatic organisms. Some examples of the effects that have been documented as a result of exposure to these contaminants include: decreases in reproduction, altered sexual development or “gender bending”, environmental antibiotic resistance to one or more antibiotics, and changes in population structure or localized extinction of some species. These chemicals are human generated and are very persistent in the environment. They may be active at very low levels (P. McClellan-Green/NCSU, pers. comm. 2009). The majority of these chemicals are not removed with most types of tertiary wastewater treatment and enter waters through effluent discharges (Giorgino et al. 2007). They can also enter surface waters through urban and agricultural runoff.

Numerous aquatic and marine species suffer adverse effects following chemical exposure because of their diverse pathways for exposure, their methods of uptake, and their individual metabolism. The effects seen in individuals that are higher on the food chain and exposed to higher levels of contaminants are readily noticeable. However, those organisms inhabiting the lower reaches of the food chain, i.e. the invertebrates, are often overlooked. The levels of chemicals entering aquatic ecosystems through hazardous spills have decreased over time and most exposures currently occur through a low level chronic uptake. In addition, levels of active chemicals that accumulate in the environment are now known to affect invertebrates at much lower concentrations than previously considered. The types of endocrine disrupting and newly emerging contaminants encountered by invertebrates, including marine invertebrates, are similar to those encountered by terrestrial organisms. These include metals, pesticides, various organic compounds (PAHs, PCBs, steroids, etc) and pharmaceuticals and personal care products (Damstra et al. 2002; P. McClellan-Green/NCSU, pers. com., 2009).

The divergent nature of endocrine systems found in invertebrates serves to complicate the analysis of potential risk following exposure to endocrine active compounds. At least eight different types of hormones are active in the endocrine systems of eukaryotic organisms. These endocrine systems are many times inter-related and dependent upon one another for function and signaling capacity. Their end function can be carried out through direct action or through circulating levels of the various endocrine compounds. Invertebrates are unique in that their endocrine systems control not only sexual development and reproduction but also growth, molting, limb regeneration, diapause, metamorphosis, pigmentation, immune function and the production of pheromones (B. Roer, pers. com., 2009). For the most part, these aspects of endocrine regulation while they may be susceptible to the effects of environmental contaminants have not been fully examined and their influence on population structure and population stability unknown.

The prevalence and effects of endocrine disrupting chemicals in North Carolina is largely unknown. The U.S. Geological Survey conducts a nationwide monitoring program looking for a large variety of chemicals in selected sampling stations and has found widespread occurrence of organic wastewater compounds in rivers and streams. Kolpin et al. (2002), in sampling 30 states for organic wastewater compounds, reported at least one organic wastewater compound detected in 80 percent of the sampled streams. Organic wastewater compounds included chemical widely used by households, industry, and agriculture, sterols, pharmaceuticals, and antibiotics. These wastes may enter surface waters through agricultural or urban runoff or wastewater effluent. Other studies have found presence of organic wastewater compounds in wastewater effluent and elevated concentrations downstream of wastewater effluents in West Virginia (Chambers and Leiker 2006) Georgia (Frick and Zaugg 2003), lower Mississippi ecosystem (Shae et al. 2001), Colorado (Sprague and Battaglin 2005) and South Dakota (Sando et al. 2005). In North Carolina, the USGS conducted a limited amount of monitoring for endocrine disrupting chemicals in freshwater reaches of the Tar, Neuse, and Cape Fear river basins (Giorgino et al. 2007; M. Giorgino/USGS, pers. com., 2009). Prescription drugs (antibiotics and other medications), non-prescription drugs, flame retardants, plasticizers, fragrances, pesticides, detergent metabolites, antimicrobial agents, and other suspected endocrine disruptors were detected. In the areas sampled in North Carolina, pharmaceuticals, followed by flame retardants and plasticizers were the most frequently detected wastewater compounds. While some of the sites were downstream of wastewater discharges, others were in areas receiving runoff from agriculture and urban development as well. North

Carolina's estuaries were not targeted in these studies.

Typical municipal wastewater treatment processes are not capable of removing hormones, antibiotics, and other EDCs, making sewage effluent a major source. The current recommended federal policy for disposal of unused drugs is to flush medicines down the toilet or mix with cat litter and take to a landfill. Hospitals also routinely dump expired and unused medications into the wastewater system. The NC Department of Agriculture and Consumer Services (NCDACS) has been working to add a Prescription Drug Collection and Disposal Program to their Pesticide Disposal Assistance Program for the citizens of North Carolina. The concept is that when residents come to a One Day Pesticide Disposal Collection Event, run by NCDACS, they could dispose of unused herbicides or pesticides they could also bring unused over the counter (OTC) or prescription medications. These could be dropped into a drum of reagent directly by each individual, so that there is no risk of inappropriate re-use of medications. The drum of reagent is secured for final incineration. There is support for a program like this as an initial option for the disposal of household pharmaceutical product wastes, until take-back programs can be established. However, because of the current federal policy, approval is needed from the federal Drug Enforcement Administration (DEA). Other states have managed to institute some type of drug take-back program. *Assistance and support is needed from the Attorney General's office to implement a take-back program in North Carolina.*

In 2008, the MFC established an Endocrine Disrupting Chemical workgroup to discuss what was known regarding the effects of EDCs on coastal fishery species, and status of these chemicals in estuarine waters. The group consisted of university scientists, USGS scientists, and staff from DEH, DWQ, NCDA, and DMF. *They compiled a white paper with recommendations. The workgroup recommended that to assess potential impact of endocrine disruptors in North Carolina's estuaries, a site-specific, compound specific monitoring program is needed. The program should include:*

1) estuarine monitoring of the concentration and prevalence of priority chemicals of concern with possible focus on the Neuse River system,
2) specific research on the effects of chemicals on fishery species, particularly blue crab, oysters, and fish,
3) education and outreach regarding proper disposal of pharmaceuticals, pesticides and antibiotics, including what existing waste management and recycling programs are available,
4) expand the NC Pesticide Disposal Assistance Program to include unused and outdated pharmaceuticals, and
5) a plan for removal of chemicals from wastewater and runoff.

The NC Division of Water Quality could expand its sampling program to include collection of water samples for analyses, with USGS laboratories conducting the analyses. Critical chemicals should be selected for analyses, rather than analyzing for everything. Chemicals like fipronil (frontline), bisphenol A (certain plastics), alpha and beta estrodiol (hormones), antibiotic degradation products, alachlor and other high-use pesticides, juvenile hormone analogs (mosquito control), etc. should be prime candidates. A monitoring task force comprised of USGS, DWQ, DMF, NCDA, Shellfish Sanitation, as well as representative researchers, could identify a list of most likely problematic chemicals.

Crustaceans

Numerous studies have been done assessing the effect of hormone-like substances, insecticides, and juvenile hormone insecticides (interrupt the insect life cycle) on crustaceans, including amphipods, copepods, grass and mysid shrimp, crabs, and lobster. Over the past two decades, scientists began to observe so-called "intersex" individuals among crustacean (e.g. shrimp, crabs, lobsters) populations (Zou and Fingerman 1999; Ford et al. 2004; Brian 2005). These individuals were generally males that exhibited female sexual characteristics. The incidence of intersex males was associated with areas downstream from urban wastewater outflows. Other observed impacts associated with human hormones and hormone-like substances include toxicity, increases in female/male sex ratios, molting enzyme abnormalities, abnormal larval development, and altered egg production and maturation. Analysis of the wastewater and subsequent controlled experiments indicated that the cause of these developmental abnormalities was due to both human sex hormones (predominantly estrogen – naturally occurring and from birth control and hormone replacement sources) and compounds that mimicked the structure of these sex hormones (including many insecticides and other agricultural chemicals).

Crustaceans, being bound by a rigid exoskeleton, must molt (shed the outer skeleton) in order to grow. Mating and reproduction, in addition to larval development, are intimately tied to molting and growth. For example, many crabs and lobsters can only mate when the females have just molted. Many of the hormones that control molting and reproduction in crustaceans are steroids that bear a structural resemblance to human reproductive hormones like estrogen. Thus estrogenic and estrogen-like compounds have the potential to affect molting, growth, mating, reproduction, and development of crustaceans (B. Roer/UNCW, pers. com. 2009).

The past few decades have also seen the emergence of insecticides that mimic insect juvenile hormones. Juvenile hormone maintains larval characteristics when insects molt, preventing the development of the adult, reproductive form. Insects and crustaceans are closely related, and crustaceans employ a hormone similar in both form and function to insect juvenile hormone. Thus, the juvenile hormone (JH) analog insecticides have the potential to adversely affect reproduction and development in commercially important crustacean species (e.g. blue crabs, shrimp, and lobsters) (McKinney 2005, Turberty and McKinney 2005). In North Carolina, one of the JH analog insecticides (methoprene) is widely used against mosquitoes and fleas.

Other studies have examined the effects of non-hormonal insecticides used in agriculture (i.e., dieldrin, heptachlor, lindane, endosulfan) on crustaceans (water fleas, crabs, and lobsters). Similar to hormone effects, these studies found molting enzyme abnormalities, increase in male/female sex ratios, intersex males, and toxicity (Ayaki et al. 2005, Waddy et al. 2002).

Molluscs

Decreased reproduction, increased vitellogenisis, and sperm abnormalities have been documented in oysters, clams, and scallops exposed to human hormones or hormone-like substances (Gagne et al. 2002, Matozzo and Marin 2008, Wang and Croll 2006, Canesi et al. 2008). Exposure to insecticides via agricultural runoff also decreased reproduction and filtration, and caused gonad atrophy and abnormal larval development in oysters, snails, clams and scallops (Wessel et al. 2007, Anguiano-Vega et al. 2007). Exposure to organics and metals had the same consequences (Curiewx-Belfond 2001, Cju et al. 2003, Smaoui-Damak et al. 2006, Choy et al. 2007, Wintermyer and Copper 2007). In other studies that looked at effects from mixed contaminants associated with marina harbor pollutants and sewage effluent, altered sex ratios, impaired immune function, delayed growth and development, and decreased reproduction were observed in mussels (Gagne et al. 2002, Gagne et al. 2007).

Fish

In the past decade, there have been increasing number of studies examining the effects of EDC on fish, but most have focused on freshwater species. 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). Other studies have found altered sex hormone levels associated with PCB and mercury contamination downstream of wastewater treatment plants (Baldigo et al. 2006). Kuiper et al. (2007) examined the effect of flame retardants on flounder and found limited endocrine effects. Studies in multiple regions of the United States (Potomac River, Colorado, lower Mississippi River systems) have found similar effects from human hormones on fish (mosquitofish, largemouth bass, white suckers, catfish, carp, gar) as invertebrates, including intersex, gonad deformities, delayed maturation, and asynchronous ovarian development (Shae et al. 2001; Woodling et al. 2006, Blazer et al. 2007, Fong and Molnar 2008, Hinck et al. 2009, Iwanowicz et al. 2009). Kidd et al. (2007) found that not only did exposure of fish (fathead minnow) to estrogens and mimics downstream of wastewater outfalls cause feminization of males, the reproductive alterations led to a near extinction of the population, suggesting that EDC impacts can affect the sustainability of wild fish populations.

Pesticides

Pesticides and herbicides can be toxic to aquatic organisms or act as endocrine disruptors. In a review of pesticide toxicity on aquatic microorganisms, DeLorenzo et al. (2001) documented a great deal of variability in the toxicity of even a single pesticide among microbial species. The authors also stressed considering the toxicity of pesticide mixtures and interaction with nutrients. Pesticides and herbicides tend to be greatest where agricultural runoff is present, but are also are attributed to urban runoff from residential and golf course-related lawn care. More information is available on golf course runoff in the nutrient section**.** Pesticides and herbicides may be more concentrated and problematic to fish when heavy runoff from spring rains coincides with juvenile fish nursery use in shallow waters 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). Many of the chemicals used today are EDCs (Damstra et al. 2002).

The most commonly applied pesticides in agricultural areas of the North Carolina Coastal Plain include the herbicides atrazine and metolachlor (McCarthy 2002, McCarthy et al. 2007). These pesticides also were among the most frequently detected pesticides in streams of the Tar-Pamlico River Basin (Woodside and Ruhl 2001). For example, atrazine was detected in 38 – 92 percent of samples annually collected in the Tar-Pamlico basin during 1992 – 2001, and metolachlor was detected in 73 – 100 percent of the samples each year during the same period (Woodside and Ruhl 2001, McCarthy, 2002). McCarthy et al. (2007) reported that more than 1,230 kg of active ingredient of atrazine and 902 kg of active ingredient of metolachlor were applied annually in Beaufort County, North Carolina, which is likely typical of agricultural counties in eastern North Carolina.

Another potentially increasing threat is the effect of mosquito spraying over shallow water s and wetlands. The U.S. 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://cfpub.epa.gov/NPDES/HOME.CFM?PROGRAM_ID=41). 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. The toxicity of several common mosquito control pesticides on non-target zooplankton and fish species (minnows and mosquitofish) has been investigated (Milam et al. 2000). Malathion was 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 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) 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.*

Juvenile hormone analogs (JHA) are a substance used as insecticides to alter molting cycles and disrupt the normal growth and development of targeted pests. The use of JHA is commonly used for the control of insects in general mosquitoes, fleas, and fire ants. Of the various products, S-methoprene appears to be the JHA with the greatest potential to contaminate NC surface water based on registered uses as a mosquito/midge control product and as an animal feed supplement (B. Bruss/NCDACS, pers. com., 2009). Subsequent efforts are needed to refine the details of product use to prevent its transport into surface waters. *Education and enforcement to ensure proper application of pesticides according to label instruction, is needed.*

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.

Crop 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 water bodies. 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*.

Fossil fuels

Although fish that utilize the water column are highly mobile and can migrate from oil affected areas, fisheries can still be adversely impacted by oil. With oil present in the water column, water quality begins to degrade, making fauna more susceptible to other stress factors such as disease (Giles et al. 1978). In tank experiments mullet, *Mugil cephalus,* had outbreaks of fin rot (vibrio) when exposed to varying amounts of oil (Giles et al. 1978).

After an oil spill, oil will begin to evaporate and be broken down by varying microbes or by the use of dispersants. As the oil breaks down PAHs become available in the water column were they are taken up through fish gills and mouths and eventually excreted in bile (Jung et al. 2009). Chemically dispersed oil can greatly affect larval development of fishes. McIntosh et al. (2010) showed that the level of toxicity on larval fish development varied depending on the exposure duration and the amount of time post fertilization with the youngest being the most sensitive. The presence of oil can prevent fish eggs from hatching, limiting the growth rate of small fish, and can prevent fish from returning to previously utilized spawning habitat (Peterson 2001 and Peterson et al. 2003b). After exposing larval herring to crude oil, Incardona et al. (2009) observed a cardiac arrhythmia in 100 % of the exposed larvae. Together, there are indications that all of these affects have some part in the collapse of the Pacific herring (*Clupea pallasi*) (Hulson et al. 2008; Thorne and Thomas 2008).

In pond experiments, compared to control ponds, there was a 44 to 65 % reduction in primary production and a 30 to 50 % reduction in respiration two weeks after crude oil was introduced into ponds (De La Cruz 1982). After two months there was a 17 % and 7 % lower level of primary production and respiration, respectively, when compared to the control ponds (De La Cruz 1982). This is important to note since primary production reduces the potential for hypoxic and anoxic conditions (as described in other parts of this chapter).

Tar balls, are partially degraded patches of oil that may drift in currents and wash onto the shoreline or become entangled in macroalgae drift lines. Tar balls have been observed in various aquatic species including loggerhead turtles (Witherington 2002), yellowfin tuna [(*Thunnus albacares*) Manooch and Mason 1983] and *Coryphaena hippurus* (Manooch et al. 1984). Manooch et al. (1984) goes as far as saying that due to the presence of manmade debris in *Coryphaena hippurus* stomachs they could be indicator species for offshore water quality.

Most of the information presented above comes from one time spill events that had a finite amount of oil. Additonal impacts to other habitats and their residents are discussed in subsequent chapters. In the case of continuously flowing oil from a leaking well, it is important that the source of oil is stopped and not allowed to flow free so recovery can occur. As a result of oil contamination, commercial and/or recreational fisheries may be closed as a result of PAH uptake. In order to determine if an area can be reopened baseline samples are needed of pre-impact conditions. In NC, DMF and Shellfish Sanitation are collecting samples of crustaceans, mollusks, and finfish to have such a baseline in preparation of a potential oil spill that reaches and impacts NC. NCDENR have been working with various federal agencies in order to have a response plan in case of such an emergency with the US Coast Guard and NC Division of Emergency Management being the lead agencies. Due to the high potential impacts associated with deepwater drilling, *there should be a continued ban of oil and gas drilling in off North Carolina waters.*

Other toxins

Polymers are organic compounds such as polyacrylamides (PAM) and the Smart Sponge that have recently begun to be used as soil erosion control techniques. These substances are synthetic and designed to increase the soil's available pore volume infiltration, increase flocculation of suspended sediments, increase retention of sediment, oil and gas products, and in some cases, bacteria as well. The chemical can be incorporated into fiber check dams, filter bags, or applied directly to a side bank or ditch. These products can be used as BMPs for disturbed soil areas that discharge to a sediment trap or basin. Since the chemicals have been found to be toxic to aquatic organisms, improper application or degradation over time could result in toxic products entering surface waters and impacting the nervous system of aquatic organisms. DWQ is implementing more stringent turbidity limits on construction site general permits that go into effect for sites over 20 acres by 2011 and over 10 acres by 2014. *Since the use of this new technology is expected to increase rapidly, there is an urgent need for research to assess the impacts of polymers on aquatic estuarine life.*

Status and trends in toxic contamination

Because contaminants often settle out into sediment in close proximity to their origin, status and trends of sediment contamination can be an indicator of what has occurred in the water column in the past (see “Soft bottom” chapter for more information).

2.4.3.4. Other causes of water quality degradation

Desalination plants and marine debris are two other threats to the water column.

Saline discharge

Withdrawals of brackish water for desalination and use as a municipal water supply is an activity that has potential impacts to water quantity or quality (Copeland 1967). In rapidly developing coastal counties where adequate volumes of shallow fresh groundwater is not available, desalination of saltier groundwater provides another source of drinking water. Effluent from desalination (membrane filtration) and water softening (ion exchange) treatment plants discharged into fresh surface water environments could create isolated pockets of higher salinity water with very low diversity of species, the majority of which occupy lower tropic levels. The reduction in species diversity and isolation from the surrounding aquatic community would constitute a loss of habitat. Even under natural circumstances, vertical salinity stratification in the estuarine water column creates unfavorable low dissolved oxygen (DO) conditions, which serves 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 a salt water effluent release into fresh water. Currently, DWQ general permits restrict flow in HQW and PNA to no more than 50% of the 7Q10, but there is no 7Q10 calculated for tidal creeks, which results in no flow restrictions in these areas. In some waters, unrestricted effluent flow from a desalination water treatment plant could greatly affect water column salinity, as well as ammonia, pH and temperature. 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). Other potential effects of the hypersaline effluent are listed in Pantell (1993).

Currently, in coastal NC, there are 16 reverse osmosis desalination facilities and several proposed facilities. Most of the older desalination plants in the coastal area are low volume and discharge wastewater into the Atlantic Ocean and sounds where the receiving waters had lower or higher salinity than the effluent. Several of the existing low volume plants are located in freshwater areas. However, some of the newer high volume facilities are moving more inland to less saline waters. For example, the DWQ issued an NPDES permit for a facility in Camden County that discharges 300,000 gallons/day of saltwater (salinity ~10-15 ppt) into the Pasquotank River, where salinities range from 1-4 (Rulifson et al. 2006a, Rulifson et al. 2006b). The Camden County facility is also located in an Anadromous Fish Spawning Area.

Due to concerns with two proposed high volume (1.67 MGD discharge) reverse osmosis (desalinization) water treatment plants located in Albemarle Sound at the mouth of North (Currituck Mainland) and Little (Pasquotank) rivers, government agencies requested a one-year, pre-construction and a two-year post-discharge study of potential effects. During the pre-construction study, water quality, mixing potential, and aquatic life conditions at the proposed discharge sites and the existing Camden County facility were evaluated relative to control areas (Rulifson et al. 2006a, Rulifson et al. 2006b). The Camden County discharge was used as a model to predict potential impacts at the proposed sites. Bi-monthly samples taken from surface and bottom waters (depth approximately 2 meters) at 13 sites around the discharge pipe and at proposed sites were analyzed for major elements and nutrients. All major elements of the whole effluent were quantified instead of relying on TDS or conductivity to indicate water quality.

Ambient conditions were also assessed at each location. Data analyses included contour maps and profiles of ion concentrations, analysis of mineral saturation, sediment grain-size and organic-content analysis. The effluent plume was detected in bottom waters as increased concentrations of major elements (only within 50 meters of the pipe). The plume shifted its position frequently, presumably with prevailing wind and current conditions. Surface waters were not noticeably affected and showed less variable chemistry than bottom waters. No samples, including those around the Camden discharge, showed harmful ratios (15:1) of calcium (Ca) and sodium (Na) to aquatic animals. Of the major-elemental ratios, only bicarbonate (alkalinity) to chloride ($HCO3^-$: Cl^-) ratio was significantly higher than ambient ratios and this was only for a few bottom samples nearest the discharge pipe. The ammonium ($NH4^+$) levels were significantly higher than ambient levels within a few meters of the discharge pipe. However, no algal blooms were observed due to the highly stained water at the Camden discharge site. There were also no significant reductions in the abundance of benthic organisms around the discharge location. The researchers concluded there would be only minor impacts at the proposed discharge sites along the more saline and higher energy shoreline of Albemarle Sound. Despite NCDMF's ongoing concern, commitments and evaluations planned for the two-year post-discharge studies at the Currituck Mainland and Pasquotank reverse osmosis discharge sites have been abandoned by the two counties, and NCDWQ has issued discharge permits without adequate instream monitoring.

Proposals to locate large saline discharges (>0.5 million gallons/day) in low energy/salinity areas should include specific information to evaluate the impacts (Water Treatment Plant Workgroup report, Lynn Henry/DMF, pers. com., 2002):

- 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 Rulifson et al. (2006a,b) studies and the above site specific information, permit review agencies can evaluate the singular and cumulative impacts of desalinization facilities on aquatic organisms.

Marine debris

Trash and other waste that is carried into the water (marine debris) accidentally or intentionally are 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 2000). Plastics comprise about 90% of debris found floating in the water (http://marine-litter.gpa.unep.org/facts/what-where.htm, November 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.

Agency programs and Organizations such as NOAA's Marine Debris Program (http://marinedebris.noaa.gov/welcome.html), and The Ocean Conservancy (TOC) (http://www.oceanconservancy.org/site/PageServer?pagename=issues_debris) are actively involved in monitoring and clean-up efforts. The TOCs Marine Debris Index documents the results of recent cleanup efforts around the world (http://www.oceanconservancy.org/pdf/2009_Marine_Debris_Index.pdf). In addition to the national programs, North Carolina Big Sweep is a state-wide nonprofit organization whose mission is a litter–free environment. NC Big Sweep conducts year-round education to prevent litter and coordinates the North Carolina Big Sweep, the North Carolina component of the International Coastal Cleanup – an event in which volunteers from all 100 counties in the State and approximately 90 countries worldwide come together to clean up our land and waterways. The most abundant trash items in U.S. waters were related to shoreline and recreational activities. Other categories include ocean/waterway activities, smoking activities, dumping activities, and medical/personal hygiene. The United Nations Environmental Program's Global Initiative on Marine Litter provides an effective framework for conducting regional activities addressing marine litter around the world, including those of the 12 participating Regional Seas programs (UNEP 2009). *At the state level, education and incentives are needed to encourage removal and proper disposal of derelict fishing gear and other waste from water-dependent activities.*

2.4.4. Non-native, invasive, or nuisance species

There is widespread documentation that some non-native species can out-compete native species, altering the established ecosystem, habitat, and eventually water quality (Mallin et al. 2001c, Burkholder et al. 2007b). In the water column, these invasive species tend to be transported and introduced by ship's ballast, fishing gear, and through association with another non-native species.

The "water mold," *Aphanomyces invadans,* reported to be a major cause of the characteristic, deeply penetrating lesions that commonly afflict Atlantic menhaden in NC estuaries, is an invasive species from the western Pacific. This fungal pathogen infects schooling species in low-salinity or fresh water. It is held responsible for ulcerative fish diseases around the world, including red spot disease (RSD) in Australia, epizootic ulcerative syndrome (EUS) in Asia, and mycotic granulomatosis (MG) in Japan. It is suspected that *Aphanomyces invadans* was introduced to the US via another infected invasive species, such as the northern snakehead fish (*Channa argus*) from northern China, because the genetic make-up of the two strains of water mold have been found to be identical (Blazer et al. 2002).

Foreign organisms in the discharge of ships' ballast water at or near ports have resulted in the introduction and spread of non-native invertebrate animals, algae, bacteria, and 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 dinoflagellate cysts was tied to exportation of woodchips (Hallegraeff 1998), an industry currently active in North Carolina.

The Australian spotted jellyfish, *Phyllorhiza punctata*, was found in Bogue Sound and Sunset Beach, NC in 2007. This jellyfish has an average diameter of around 50 cm and can consume a large amount of plankton, eggs, and larvae in the water column. The large size has also resulted in the fouling of fishing gear in the Gulf of Mexico, where they are thought to have arrived in the US either attached to ships or in ship ballast.

In 2004, the Coast Guard published regulations establishing a national mandatory ballast water management (BVM) program and penalties for ships headed to the U.S. that fail to submit a ballast water management reporting form. These regulations also require vessels to maintain a ballast water management plan that is specific for that vessel and assigns responsibility to the master or appropriate official to understand and execute the ballast water management strategy for that vessel. These regulations also increased the number of vessels subject to these provisions by expanding the reporting and the recordkeeping requirements on ships, increasing the Coast Guard's ability to determine the patterns of ballast water movement as required by National Invasive Species Act of 1996. This final rule in 2004 changed the national voluntary BWM program to a mandatory one, requiring all vessels equipped with ballast water tanks and bound for ports or places of the United States to conduct a mid-ocean ballast water exchange (BWE), retain their ballast water onboard, or use an alternative environmentally sound BWM method approved by the Coast Guard (USCG 2009a).

Currently, the U.S. Coast Guard is proposing new regulations that include the treatment of ballast water and propose a ballast water discharge standard. They found that 60% of US ships do not travel 200 nautical miles from shore, as required in the current rules for BWE, and BWE was not always effective in removing non-native organisms (USCG 2009b). The proposed regulations include ballast water discharge standards, composed of concentration limits of various organisms, as a quantifiable measure of ballast composition that can be used to verify compliance and effectiveness of the treatment systems (USCG 2009a). *DENR should work with the U.S. Coast Guard to encourage support for these proposed rules.*

Some of the most likely methods of treating ballast water include hypochlorite generators, filters and UV light treatment, and deoxygenation. Other ballast water treatment options include chemical treatment with chlorine or hydrogen peroxide, electric shocking, ozonation, heat (35 – 45^{o} C), and reballasting. 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 (Burkholder et al. 2007b, and references therein).

The 2010 Ocean Policy Report, produced by the Ocean Policy Steering Committee, DCM, and Sea Grant, identified marine aquaculture as an emerging issue in which the primary concern was the introduction on non-native species into endemic environments due to incidental escapement of farmed fish. The report recommended that the state conduct a technical assessment of the feasibility of marine aquaculture in North Carolina's coastal ocean waters and if the federal government passes a national offshore aquaculture act, that North Carolina policies be developed as part of the Coastal Management consistency process.

2.4.5. Sea level rise and climate change

The Wetland chapter contains the primary discussion of sea level effects along the North Carolina coast. Other chapters contain information on climate change that is specific to biological features of a habitat (i.e., SAV, estuarine shellfish, ocean hard bottom). This chapter covers the changes in distribution of basic water quality parameters (i.e., temperature, pH, salinity, etc.) and anticipated changes in fish community distribution. The affects of local climate warming in coastal North Carolina are expected to be relatively severe, given the state's position at the boundary between the North and South Atlantic Bights. Based on a history of measurement data, there is an anticipated rise in both temperature[68] and sea level[69] for the immediate future (Bin et al. 2007; UNC-W report to UNC president 2008; ECU 2008). Long-term changes in temperature and salinity suggest expansion of some species at the expense of others. There is also a predicted increase in storm events and other extreme weather (i.e., drought). So there are several dimensions of change bearing on fish communities in North Carolina estuaries that favor resilient species with warmer temperature and higher salinity preferences. *Analysis and monitoring of long-term trends in estuarine salinity and temperature is needed to evaluate the impact of sea level rise and climate change on fishery resources in North Carolina.*

[68] International Panel on Climate Change scenarios predict a future increase of 1.1◦–6.4◦C during the twenty-first century (IPCC 2007).

[69] Sea-levels are rising at a rate of at least 2 mm/yr (IPCC 2007), though local SLR rates vary widely and can be as high as 10 mm/yr (Scavia *et al.* 2002 in Crain et al. 2009).

Variations in the predicted rate of rise could also have major implications for the current distribution biological communities. If the rate of sea level rise increases too quickly, coastal wetland accretion may not keep pace (see “Wetland” chapter for more information). There may also be an increasing frequency of inlet breaches along the barrier islands. The proliferation of inlets along the Outer Banks could significantly increase salinities in Pamlico Sound and tributaries. Even without the persistence of new inlets, there will be increasing flow through existing inlets and elevated water levels. The proportion of depth zones may also change as coastal wetlands are submerged. All these factors (depth, flow, temperature, salinity) are very basic in determining both species distribution and other water quality parameters[70]. The loss of barrier islands, reductions in wetlands, and increase in flushing could also reduce the productivity of the estuarine nursery areas. Increased runoff from predicted increased storms, loss of wetlands, and septic systems located increasingly close to the shoreline and water table due to sea level rise could result in more degraded water quality. Acidification of ocean waters could also impact calcareous plankton (coccolithophores, foraminifera), which would have major implications on the marine food web, particularly in high latitude areas (Raven et al. 2005).

Nye et al. (2009) evaluated changes in fish species distribution from 1968 to 2007 with concurrent climate changes. The changes included a rise in temperature and changes in oceanographic oscillations. The study tested the hypothesis that such changes in the Northeast United States continental shelf ecosystem have caused a change in the distribution of marine fish. Trends in the annual abundance of 36 fish stocks were related to depth of occurrence, mean temperature, and area occupied. Many stocks spanning several taxonomic groups, life-history strategies, and fishing pressure exhibited a northern shift in their center of biomass, most with a simultaneous increase in depth, and a few with corresponding expansion of their northern range. However, the changes were highly dependent on the location of stocks. Stocks located in the southern extent of the survey area exhibited much greater northward shifts in biomass and some occupied increasingly greater depths, relative to northern stocks. The northward shift in biomass of alewife and American shad are of particular interest to North Carolina inshore fisheries. Overall, large-scale temperature increases and changes in circulation, represented by the Atlantic Multidecadal Oscillation, was the most important factor associated with shifts in the mean center of stock biomass. *Restoration goals for anadromous stocks should be adjusted to reflect the shifting distribution of species with climate change.*

2.4.6. Management and research needs and accomplishments

The management needs noted by italics in the 2005 CHPP were addressed to some degree during 2005-2010. Some needs are considered accomplished, whereas others are considered ongoing with or without progress. Emerging management needs are new or significantly modified from their 2005 versions and may or may not be refined and adopted as actions in the 2009-2011 CHPP implementation plans. Discontinued needs includes those recommendations from Street et al. (2005) that were omitted from the chapter update for various reasons (i.e., included in another chapter as part of primary discussion, need discontinued, considered minor, redundant, or too general). The subheadings reflect these distinctions.

2.4.6.1. Research needs and progress (2005-2010)

Accomplished research needs

1. 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.* **The latest**

[70] Apple et al. (2008) analyzed water quality data from various National Estuarine Research Reserves to verify the relationships among basic water quality parameters. The analysis shows the inverse relationships between temperature and dissolved oxygen, and salinity/pH and nitrogen.

bacterial source tracking research listed in "Studies comparing land-use and water quality" section.

2. 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.* **A research project was conducted on existing and proposed saline discharges in low salinity systems of the Albemarle Sound (see "Saline discharge" subsection of "Other causes of water quality degradation" section for more information).**

Research needs with progress

1. *There is a need to study development patterns around marinas in high and low salinity waters and the cumulative impact of docking facilities and associated development on toxic chemical and other contaminant concentrations in the water column.* **Partial progress with study results (see "Marinas and multi-slip docking facilities" section for more information).**

2. *Coastal research and monitoring needs to continue to improve our understanding of the processes of hypoxia and anoxia and the effect on fish populations.* **Partial progress with latest research (see "Nutrients and eutrophication" section for more information.**

Research needs without progress

1. *More research is needed to assess the impact of water withdrawals on water column habitat and fish populations in the affected river basins*. **No specific progress; related to monitoring stream flow and water supplies (see "Water withdrawal" section for more information).**

2. *Studies are needed to compare use of both upland and open water basins by young anadromous fish. To protect designated AFSAs and IPNAs from marina impacts, dredging for new marina construction and other marina-related activities should be managed to minimize alteration of these important functional areas.* **No specific progress; see "Marinas and multi-slip docking facilities" section for context.**

3. *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.* **No specific progress; see "Pesticide" subsection of "Toxic chemicals" section for context."**

Emerging research needs

1. *A similar assessment of acidification risk should be conducted in Anadromous Fish Spawning Areas in North Carolina.* **See "pH" subsection of "Fish habitat requirements" section for context.**

2. *Further research is encouraged to assess impacts of dam removal on downstream fisheries and habitats.* **See "Dams/impoundments" subsection of "Hydrologic modifications" section for context.**

3. *Research on the potential ecological impact of this type of wastewater system (mine discharge) needs to be assessed further before widespread use.* **See "Water withdrawals" subsection of "Hydrologic modifications" section for context.**

4. *Research is needed to determine when and where recruitment to adult fish stocks is limited by larval ingress to estuarine nursery habitats. Without conclusive research, changes to North Carolina's policy on prohibition of shoreline hardening structures on the oceanfront should be considered very*

carefully. **See "Jetties and groins" subsection of "Hydrologic modifications" section for context.**

5. *The long-term consequences of hardened structures on larval transport and recruitment should be thoroughly assessed.* **See "Jetties and groins" subsection of "Hydrologic modifications" section for context.**

6. *Develop a comprehensive model of pollution sources predicting water quality based on regular mapping/monitoring of pollution sources (including silviculture, agriculture, and impervious surfaces), riparian zone conditions, stormwater control measures, climactic events, flushing rates, and measured pollution levels.* **See "Water quality degradation – sources" section for context.**

7. A Sea Grant study assessing impacts of multi-slip docking facilities recommended the following research:
   a. *Cumulative impacts of these small docking facilities and associated development on pollutant concentrations in the water column,*
   b. *Review and development of cumulative impact assessment techniques*

   See "Marinas and multi-slip docking facilities" section for context.

8. *The effectiveness of new coastal stormwater regulations in maintaining water quality and preventing further shellfish closures should be evaluated by DWQ and DEH-SS. Areas where data is lacking, including water quality in stormwater ponds and mining effluent, may require new studies to determine what DWQ monitoring requirements should include.* **See "Coastal stormwater program" subsection of "Non-point source management" section for context.**

9. *Since the use of this new technology is increasing, more research is needed to assess the impacts of polymers on aquatic estuarine life.* **See "Other toxins" subsection of "Toxic chemicals" section for context.**

10. *The EDC workgroup recommended a site-specific, compound specific monitoring program is needed to assess potential impact of endocrine disruptors in North Carolina's estuaries. The program should include the following research components:*
    a. *estuarine monitoring of the concentration and prevalence of priority chemicals of concern with possible focus on the Neuse River system,*
    b. *specific research on the effects of chemicals on fishery species, particularly blue crab, oysters, and fish,*

    See "Status and trends in toxic chemical" subsection of "Toxic chemical contamination" section for context.

11. *Analysis and monitoring of long-term trends in estuarine salinity and temperature is needed to evaluate the impact of sea level rise and climate change on fishery resources in North Carolina.* **See "Sea-level rise and climate change" section for context.**

2.4.6.2. Management needs and progress (2005-2010)

Accomplished management needs

1. *Formal criteria need to be developed to classify and protect Anadromous Fish Spawning Areas that will be recognized by DENR agencies.* **Anadromous Fish Spawning Areas have been designated by the MFC and WRC (see "Designations" subsection of "Status and trends" for more information).**

2. *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.* **Nutrient Reduction Strategies have shown signs of success (see "Nutrient**

reduction strategies" subsection of "Nonpoint source management" section for more information).

3. *These impervious surface 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.[71] 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*. **Stormwater rules have been improved to address increasing shellfish harvest water closures (see "Coastal Stormwater program" subsection of "Non-point source management" section for more information).**

4. *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.* **Implementation of BMPs has been improved (see "Best management practices" subsection of "Non-point source management" section).**

5. *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).* **Management of animal waste has improved (see "Nutrient reduction strategies" subsection of "Non-point source management" section for more information).**

6. *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.* **Management of animal waste has improved (see "Nutrient reduction strategies" subsection of "Non-point source management" section for more information).**

7. *Consideration should be given to a allocating a greater portion of agricultural conservation funds to the buyout or relocation of animal operations from sensitive areas, and for the purchase of conservation easements.* **Management of animal waste has improved (see "Nutrient reduction strategies" subsection of "Non-point source management" section for more information).**

8. *More stringent sediment controls on construction projects are still needed to reduce sedimentation in coastal waters.* **Management of sediment from construction sites has improved (see "Best management practices" subsection of "Non-point source management" section for more information).**

9. *More expeditious application of land cover on disturbed sites.* **Management of sediment from construction sites has improved (see "Best management practices" subsection of "Non-point source management" section for more information).**

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

10. *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.* **Stormwater rules have been improved to address increasing shellfish harvest water closures (see "Coastal Stormwater program" subsection of "Non-point source management" section for more information).**

11. *New or expanded stormwater outfalls to coastal shellfishing waters should be prohibited by the EMC and existing outfalls should be phased out.* **Stormwater rules have been improved to address increasing shellfish harvest water closures (see "Coastal Stormwater program" subsection of "Non-point source management" section for more information).**

12. *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).* **Management of ballast water has changed (see "Non-native, invasive, or nuisance species" section for more information).**

13. *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.* **Evaluations have been conducted and results are presented (see "Nutrient reduction strategies" subsection of "Non-point source management" section for more information).**

Management needs with progress

1. *Dystrophic waters should be classified as "swamp water" for the purpose of water quality standards.* **The DWQ continues to evaluate coastal streams for swamp water classification (see "Creek and rivers" subsection of "Description and distribution" section for context).**

2. *There is also a need to increase the coverage of continuous water quality monitoring stations.* **Some progress has been made on deployment of continuous water quality monitoring stations by state authorities (see "Status and trends" section for more information).**

3. *Public education is needed to encourage greater voluntary re-use and recycling of water within communities.* **The drought of 2007-08 led to restriction in water use and incentives for wise use of water (see "Water withdrawals" subsection of "Hydrologic modifications" section for more information).**

4. *Channelization regulations could be modified to discourage or prevent maintenance of previously un-navigable and re-naturalized channels in Anadromous Fish Spawning Areas and Primary Nursery Areas (AFSAs).* **Though regulations have not been modified, objections to maintenance dredging in re-naturalized AFSAs have prevented renewed alteration (see "Channelization and drainage" subsection of "Hydrologic modifications" section for more information).**

5. *More detailed monitoring is needed to assess the extent oceanfront septic systems are causing degradation to nearshore coastal waters.* **Some progress has been made with DEH-SS shoreline surveys. See "Point sources" section for context.**

6. *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.[72] *Removing unnecessary dams should be undertaken with consideration for both upstream and downstream impacts*. **Some dams have been removed after the reporting in Street et al. (2005) (see "Dams/impoundments" subsection of "Hydrologic modifications" section for more information.**

7. *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.* **An assessment has been conducted (see "Water withdrawals" subsection of "Hydrologic modifications" section for more information).**

8. *Through the EEP 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. Partnering with resource agencies, NGOs, and regional conservation groups such as AP3C, Cape Fear Arch, and Onslow Bight Partners to assist with any associated costs should be considered.* **Progress has been made (see "Road fill and culverts" subsection of "Hydrologic modification" section for more information).**

9. *New dredging in shallow, nearshore areas with fine sediment and low flushing should be discouraged.* **CAMA rules restrict new dredging in MFC-designated Primary Nursery Areas. However, similar yet undesignated areas are not specifically protected (see "Dredging (navigation channels)" subsection of "Hydrologic modification" section for more information).**

Management needs without progress

1. *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.* **No major dams have been constructed on North Carolina coastal rivers since 2003 (see "Dams/impoundments" subsection of "Hydrologic modifications" section for more information).**

2. *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.* **No specific progress (See "Water withdrawals" subsection of "Hydrologic modifications" section for context).**

3. *Environmental outreach regarding the effect of inlet stabilization on coastal fish habitat and ecosystem processes is needed to educate public stakeholders (fishing communities and coastal property owners) on this issue and gain support for maintaining natural barrier island processes*. **No specific progress (see "Jetties and groins" subsection of "Hydrologic modification" section for more information).**

4. *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.* **No specific progress (see "Point sources" subsection of "Water quality degradation – sources" section for**

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

context).

5. *Loading of pollutants into coastal waters from mechanical failures, spills, and inadequate treatment must be reduced. This will require additional funding to upgrade plants and infrastructure.* **No specific progress (see "Point sources" subsection of "Water quality degradation – sources" section for context).**

6. *To protect designated AFSAs and IPNAs from marina impacts, dredging for new marina construction and other marina-related activities should be managed to minimize alteration of these important functional areas.* **No specific progress (see "Marinas and multi-slip docking facilities" section for more information).**

7. *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).* **No specific progress (see "Nutrients and eutrophication" subsection of "Water quality degradation – causes" section for context).**

8. *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.* **No specific progress (see "Nutrients and eutrophication" subsection of "Water quality degradation – causes" section for context).**

9. C*omprehensive water quality monitoring is needed in other tidal creeks that are highly important nursery and shellfish areas.* **No specific progress (see "Nutrients and eutrophication" subsection of "Water quality degradation – causes" section for context).**

10. *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*. **No specific progress (see "Pesticides" subsection of "Toxic chemicals" section for more context).**

11. *Education and incentives are needed to encourage removal and proper disposal of derelict fishing gear and other debris from water-dependent activities.* **No specific progress (see "Marine debris" subsection of "Other causes of water quality degradation" section for context).**

Emerging management needs

1. *Given adequate monitoring, there remains a need to develop water quality standards that more accurately reflect conditions necessary for supporting fishery species and communities* (refer to the, "Water quality degradation," subsections of the threats section for more discussion). **See "Assessment needs relative to aquatic life" subsection of "Status and trends" section for context.**

2. *The CHPP agencies (DMF, DCM, DWQ, WRC) and EEP should meet to determine how SHA and LWP methodologies complement and contribute to complementary goals of the North Carolina Department of Natural Resources.* **See "Water column restoration and enhancement" subsection of "Status and trends" section for context.**

3. *More incentives are needed to generate conservation/restoration opportunities in areas with the most ecological benefit of restoration.* **See "Designations" subsection of "Status and trends" section for context.**

4. *Identify and designate Anadromous Fish Nursery Areas for consideration in permit decisions.* **See "Designations" subsection of "Status and trends" section for context.**

5. *Track the rates and trends in land conservation and development to predict future landscape characteristics and water quality impacts, and determine conservation actions needed.* **See "Designations" subsection of "Status and trends" section for context.**

6. *Compile a prioritized list of dams for removal or modification that would benefit recovery of anadromous species. The next highest priority for dam removal could be removal of the remaining dam on the Little River near Goldsboro , in the Neuse subregion (M. Wicker/USFWS, pers. com., March 2010).* **See "Dams/impoundments" subsection of "Hydrologic modifications" section for context.**

7. *State and federal agencies work together to secure grant or other funding for fish passage restoration.* **See "Dams/impoundments" subsection of "Hydrologic modifications" section for context.**

8. *New large volume surface water intakes should not be permitted behind dams in areas that would prevent stream passage restoration, where the dam has been identified as a priority for removal.* **See "Water withdrawals" subsection of "Hydrologic modifications" section for context.**

9. *To properly review mining applications, more information is needed on the expected effect of the freshwater discharge on the salinity of receiving waters.* **See "Water withdrawals" subsection of "Hydrologic modifications" section for context.**

10. *Consider including culverts obstructing suitable anadromous fish spawning habitat as a source of water column impairment, and culvert removal as a restoration credit for the EEP and DOT. The EEP could then include such proactive restoration options in its overall mission to mitigate and restore lost ecosystem functions.* **See "Road fill and culverts" subsection of "Hydrologic modifications" section for context.**

11. *The results of the EDF study and DMF field surveys should be used to determine priorities for culvert removal.* **See "Road fill and culverts" subsection of "Hydrologic modifications" section for context.**

12. *Canals classified as fish nursery habitat should receive the same consideration in permit decisions as naturally occurring designated areas.* **See "Channelization and drainage" subsection of "Hydrologic modifications" section for context.**

13. *De-snagging of woody debris in AFSAs should be conducted in accordance with, "Stream Obstruction Removal Guidelines," published by the American Fisheries Society in 1983. Guidelines for woody debris removal in streams are also provided at http://www.americanwhitewater.org/content/Wiki/stewardship:woody_debris.* **See "Channelization and drainage" subsection of "Hydrologic modifications" section for context.**

14. *Although mining was the source implicated in only 0.5% of impaired streams in coastal draining river basins in the DWQ (2006) Integrated 305(b)/303(d) report, if more resources could be applied to required monitoring, checking for compliance, or incorporating monitoring results in the BIMS, then perhaps the impacts from mining would traceable.* **See "Mining" subsection of "Hydrologic modifications" section for context.**

15. *Environmental outreach regarding the effect of inlet stabilization on coastal fish habitat is needed to educate public stakeholders (fishing communities and coastal property owners) on this issue and gain support for maintaining natural barrier island processes.* **See "Jetties and groins" subsection of "Hydrologic modifications" section for context.**

16. *DMF is actively working to address this situation and should develop a comprehensive plan to*

minimize impacts to protected species. **See "Fishing gear impacts" section for context.**

17. *Pollution source/pollutant contribution modeling could be used to support DWQ assessment of impairment sources. The attribution of pollution sources is a vital component in developing Local Watershed Plans and TMDLs - the current management tools for addressing cumulative impacts. Such modeling could also be used to evaluate impairment where water quality data is lacking.* **See "Water quality degradation - sources" section for context.**

18. *Enforcement of high fines should be consistently used by DWQ to encourage proactive maintenance of sewage infrastructure and plants.* **See "Point sources" subsection of "Water quality degradation - sources" section for context.**

19. *To improve water quality in North Carolina surface waters, the state should move toward requiring Best Available Technology for wastewater treatment, rather than Best Practicable Technology.* **See "Point sources" subsection of "Water quality degradation - sources" section for context.**

20. *WWTPs that currently have BATs in place should be required or provided incentives to actually utilize this technology.* **See "Point sources" subsection of "Water quality degradation - sources" section for context.**

21. *Funding should be secured for a Clean Marina Coordinator in order to maintain this voluntary initiative.* **See "Marinas and multi-slip docking facilities" subsection of "Water quality degradation – sources" section for context.**

22. *The report recommended that wastewater generated from marinas, boatyards, and manufacturers should be addressed, to prevent process wastewater from mixing with storm event water by:*
    a. *Elimination of the waste stream*
    b. *The use of other medias (sanding, sand blasting–provided the dry product is captured)*
    c. *Recycle systems*
    d. *Industrial pretreatment and connection to a publicly owned treatment works (POTW)*
    e. *Development of a non-discharge waste system for hand washing operations*
    f. *Development of new service industry designed to collect, treat, perhaps recycle residual metals, and/or to use these process waters in other industrial production processes.*
    g. **See "Marinas and multi-slip docking facilities" subsection of "Water quality degradation – sources" section for context.**

23. *DWQ should continue to strive to reach compliance with stormwater and wastewater regulations at marinas and boatyards, through regulatory and nonregulatory measures.* **See "Marinas and multi-slip docking facilities" subsection of "Water quality degradation – sources" section for context.**

24. *A Sea Grant study assessing impacts of multi-slip docking facilities recommended the following:*
    a. *Once additional information is obtained, development standards for MSDFs, such as limiting in shallow ecologically sensitive waters, may be considered.*
    b. *Develop educational materials for property owners, developers, and realtors on ecological concerns of docking facility construction*
    c. **See "Marinas and multi-slip docking facilities" subsection of "Water quality degradation – sources" section for context.**

25. *Efforts to reduce fecal coliform levels should target pollution sources upstream of significant shell bottom resources in conditionally approved open (i.e., less degraded) areas (see "Microbial contamination" section of "Shell bottom" chapter for more information) in order to maximize the probability of successful restoration.* **See "Studies comparing land-use and water quality" subsection of**

"Land-use and non-point sources" section for context.

26. *The need still exists for DWQ to educate permittees about the proper construction, maintenance, and installation time of stormwater ponds to help control run-off from construction sites.* **See "Coastal stormwater program" subsection of "Non-point source management" section for context.**

27. *The Community Conservation Assistance Program should be fully utilized in addressing the issue of stormwater pollution from existing development*. **See "Coastal stormwater program" subsection of "Non-point source management" section for context.**

28. *Recommendations of the Compliance Coordination report should be a high priority for CHPP implementation.* **See "Coastal stormwater program" subsection of "Non-point source management" section for context.**

29. *If lower nutrient concentrations allow greater sprayfield application, there should be corresponding groundwater monitoring to verify nutrient levels are not increasing (T. Spruill/USGS, pers. com., March 2010).* **See "Nutrient reduction strategies" subsection of "Non-point source management" section for context.**

30. *Increased monitoring of runoff, both groundwater and surface water, will be needed to evaluate effectiveness of BMPS or any management procedure implemented.* **See "Best Management Practices" subsection of "Non-point source management" section for context.**

31. *Create an online GIS-based preharvest planning tool that would allow users to gain access to volumes of data related to soils, water resources, aerial imagery and other information that would be worthwhile for planning their harvest.* **See "Best Management Practices" subsection of "Non-point source management" section for context.**

32. *Create and implement a Forest Watershed Assistance Program that would provide enhanced water resource technical assistance to forestland owners in targeted watersheds.* **See "Best Management Practices" subsection of "Non-point source management" section for context.**

33. *Create and implement an Urban Forest Watershed Management Program that would explore and implement opportunities to incorporate forestry-related management practices with low-impact development (LID), green infrastructure, and traditional nonpoint source stormwater control measures.* **See "Best Management Practices" subsection of "Non-point source management" section for context.**

34. *Pursue opportunities for regulatory reform that would standardize the SMZ and/or riparian buffer requirements for forestry activities, in an effort to enhance performance on the ground and streamline the regulatory framework that governs forestry in the state.* **See "Best Management Practices" subsection of "Non-point source management" section for context.**

35. *Continue to pursue the establishment of a Water Quality Forester position in areas of the state that do not have such a position. For eastern North Carolina, the gaps in coverage are the Fayetteville District (middle Cape Fear area), and the Fairfield District (Albemarle-Pamlico peninsula area). In western North Carolina, the gaps in coverage are the Asheville District and Sylva District.* **See "Best Management Practices" subsection of "Non-point source management" section for context.**

36. *Develop BMPs related to water handling and the use of water resources for the purposes of suppressing and controlling peat-fueled wildfires based upon the lessons learned from the 2008 Evans Road Fire and similar wildfires in recent years.* **See "Best Management Practices" subsection of**

"Non-point source management" section for context.

37. *Develop threshold criteria for determining at what point a non-compliant forestry operation directly contributes to a degradation or loss of in-stream aquatic habitat that is sufficient to warrant restoration or remediation of the impacted water resource.* **See "Best Management Practices" subsection of "Non-point source management" section for context.**

38. *Continue periodic BMP implementation surveys and monitoring of BMP effectiveness to ascertain trends in forest harvest activities, especially with questions concerning the harvesting of forest biomass, as well as evaluate the BMPs that were revised in 2006.* **See "Best Management Practices" subsection of "Non-point source management" section for context.**

39. *The authors suggested stronger waste management and emission standards for CAFOs in certain areas of the Coastal Plains.* **See "Sources of nutrient enrichment" subsection" of "Eutrophication and oxygen depletion" section for context.**

40. *Education and enforcement to ensure proper application of pesticides according to label instruction, is needed.* **See "Pesticides" subsection of "Toxic chemicals" section for context.**

41. *Assistance and support is needed from the Attorney General's office to implement a drug take-back program in North Carolina.* **See "Endocrine disruptors" subsection of "Toxic chemicals" section for context.**

42. *The NC Division of Water Quality could expand its sampling program to include collection of water samples for analyses, with USGS laboratories conducting the analyses. Critical chemicals should be selected for analyses, rather than analyzing for everything. Chemicals like fipronil (frontline), bisphenol A (certain plastics), alpha and beta estrodiol (hormones), antibiotic degradation products, alachlor and other high-use pesticides, juvenile hormone analogs (mosquito control), etc. should be prime candidates. A monitoring task force comprised of USGS, DWQ, DMF, NCDA, Shellfish Sanitation, as well as representative researchers, could identify a list of most likely problematic chemicals.* **See "Endocrine disruptors" subsection of "Toxic chemicals" section for context.**

43. *The EDC workgroup recommended the following management needs:*
    a. *education and outreach regarding proper disposal of pharmaceuticals, pesticides and antibiotics,including what existing waste management and recycling programs are available,*
    b. *expand the NC Pesticide Disposal Assistance Program to include unused and outdated pharmaceuticals, and a plan for removal of chemicals from wastewater and runoff.*

    See "Status and trends in toxic chemical" subsection of "Toxic chemical contamination" section for context.

44. Due to the high potential impacts associated with deepwater drilling, *there should be a continued ban of oil and gas drilling in off North Carolina waters.* **See "Fossil fuels" subsection of "Toxic chemicals" section for context.**

45. *DENR should work with the U.S. Coast Guard to encourage support for these proposed rules.* **See "Non-native, invasive, or nuisance species" section for context.**

46. *Restoration goals for anadromous stocks should be adjusted to reflect the shifting distribution of species with climate change.* **See "Sea level rise and climate change" section for context.**

47. *The 2009 Ocean Policy Report (NC Sea Grant 2009) recommended that no new or expanded ocean outfalls for stormwater or wastewater be permitted, and existing stormwater ocean outfalls should be*

decommissioned in a phased out approach. **See "Point sources" subsection of "Water quality degradation – sources" section for context.**

2.5. SUMMARY OF WATER COLUMN CHAPTER

The water column connects and affects all other fish habitats, emphasizing the need for ecosystem management in aquatic systems. Environmental conditions of the water column, including salinity, temperature, flow, pH, nutrients, and dissolved oxygen are the primary factors determining the distribution and abundance of coastal fish species and communities. Seasonal and annual variation in these factors is affected by both climatic cycles and anthropogenic stressors. Some of the pelagic species dependent on the water column include blueback herring, alewife, shad, menhaden, striped bass, bluefish, and Spanish mackerel. New ecological information since the 2005 CHPP includes information on additional research regarding diet studies of some pelagic species and distribution of anadromous fish using acoustic methods.

The status and trends of water column are described in terms of physical and chemical conditions (e.g., nutrients, suspended sediment, toxins), indicators of pollution (e.g., chlorophyll *a*, fecal coliforms, fish kills), and status of pelagic fisheries (e.g., bluefish, Atlantic menhaden). These parameters can change very quickly through time at any given location due to natural or anthropogenic causes, making monitoring the status and trends of this habitat very difficult. In addition, changes in monitoring methods over time make trend analysis challenging. The status and trends in water column condition are evaluated by both government regulatory programs and University programs. Though quantifying management and water quality trends is difficult, there was notable information added for the period from 2003-2009. Since the 2005 CHPP, comprehensive water quality monitoring coverage for estuaries remained low, with the exception of a few a DMF stations added in the Albemarle Sound region. Monitoring for microbial contamination of shellfish harvesting waters remained the most abundant measurements of estuarine water quality but is limited in the parameters monitored. There was little change in the amount of DWQ assessed stream impairment from 2004 to 2006 (2008 assessment not available), though only about 30% of streams and shorelines assessed. The percentage assessed is greater for estuaries, primarily due to monitoring for microbial contamination in shellfish harvesting waters. A major drought from 2007-2008, the worst recorded since 1895, most likely had an effect on coastal water quality in the past five years. River discharges were below normal from 2006 to 2008. High abundance of SAV reported in 2007-2008 and minimal change in water quality impairment may be partially due to low runoff conditions during drought. Salinities were also higher in coastal rivers, bringing estuarine fish further upstream.

Fish status is also used as an indicator of water column condition. Total reported fish kill events did not rise in the past five years above a 2001 maximum. However, the total mortality of fish reported has increased from 1996-2008. In terms of stock status, less than half of assessed pelagic fishery stocks in 2009 were considered depleted, which is a modest improvement over the 2003 assessment (Street et al. 2005). The depleted status of river herring continues to provide a target for restoration and enhancement efforts.

The cumulative effect of human activities that alter naturally occurring flow and/or water quality continue to influence the water column, which in turn can negatively impact fish communities. Hydrological modifications, such as dam and culvert construction, water withdrawal, channelization, channel modification, stream-bank modification, and shoreline erosion can obstruct fish passage and/or affect flow and quality of the water column. Since the 2005 CHPP a small amount of progress was made in removing physical obstructions. Two dams were removed in the Neuse and Cape Fear in 2005 opening a total of 140,000 additional miles of habitat in the Piedmont physiographic region. There was also some groundtruthing of culvert obstructions in the Chowan River system. Federal stimulus funding was approved in 2010 to construct a rock ramp fish passage at Lock and Dam #1 on the Cape Fear River, which will significantly improve fish access. Permitted stream impacts associated with development steadily increased from 1999-2004 with a corresponding low percentage of mitigation. However, the 2008-09 EEP report indicated a surplus of restoration projects available for mitigation. However, there was substantial disparity between the location stream restoration activities and local watershed plans. The EEP has adapted its planning and implementation processes to address the disparity.

Other human activities from point or nonpoint sources result in excessive inputs of nutrients, bacteria, sediment, toxins or biochemical agents (i.e., endocrine disrupting substances), which can lead to visible signs of habitat degradation, including algal blooms, hypoxia, fish kills, and/or deformed fish. Weather patterns such as storm events and droughts, which may be exacerbated by global warming, can alter water column conditions in a manner that stresses aquatic organisms. In the past five years, there was an increase in reported notices of violation (NOVs) for effluent measurements at permitted wastewater discharges, though improvements in monitoring could be responsible. There was also a substantial amount of sewage spills occurring, especially during wet years. Pollutant loading from these point sources must be addressed. The past five years was marked by a development boom along the coast and especially in the Inner Banks. Based on stormwater permits issued from 2001-2009, the top five counties for permit density include New Hanover, Onslow, Brunswick, Carteret, and Dare. The lowest 2001 population density and highest post-2001 permit density was in Pamlico county (part of the "Inner Banks"), indicating an area undergoing rapid growth. The rapid growth will likely contribute to increased nonpoint source runoff. Although the economic recession in 2009 has slowed growth, many previous undeveloped areas were rezoned and platted to permit development when economic conditions improve. In 2008, a DWQ marina study found that the wash water created from pressure washing and hand washing was resulting in extremely high concentrations of metals in the wastewater streams and should therefore be defined as a wastewater, and handled and treated per the wastewater permitting requirements. However, difficulties remain in how to handle this waste.

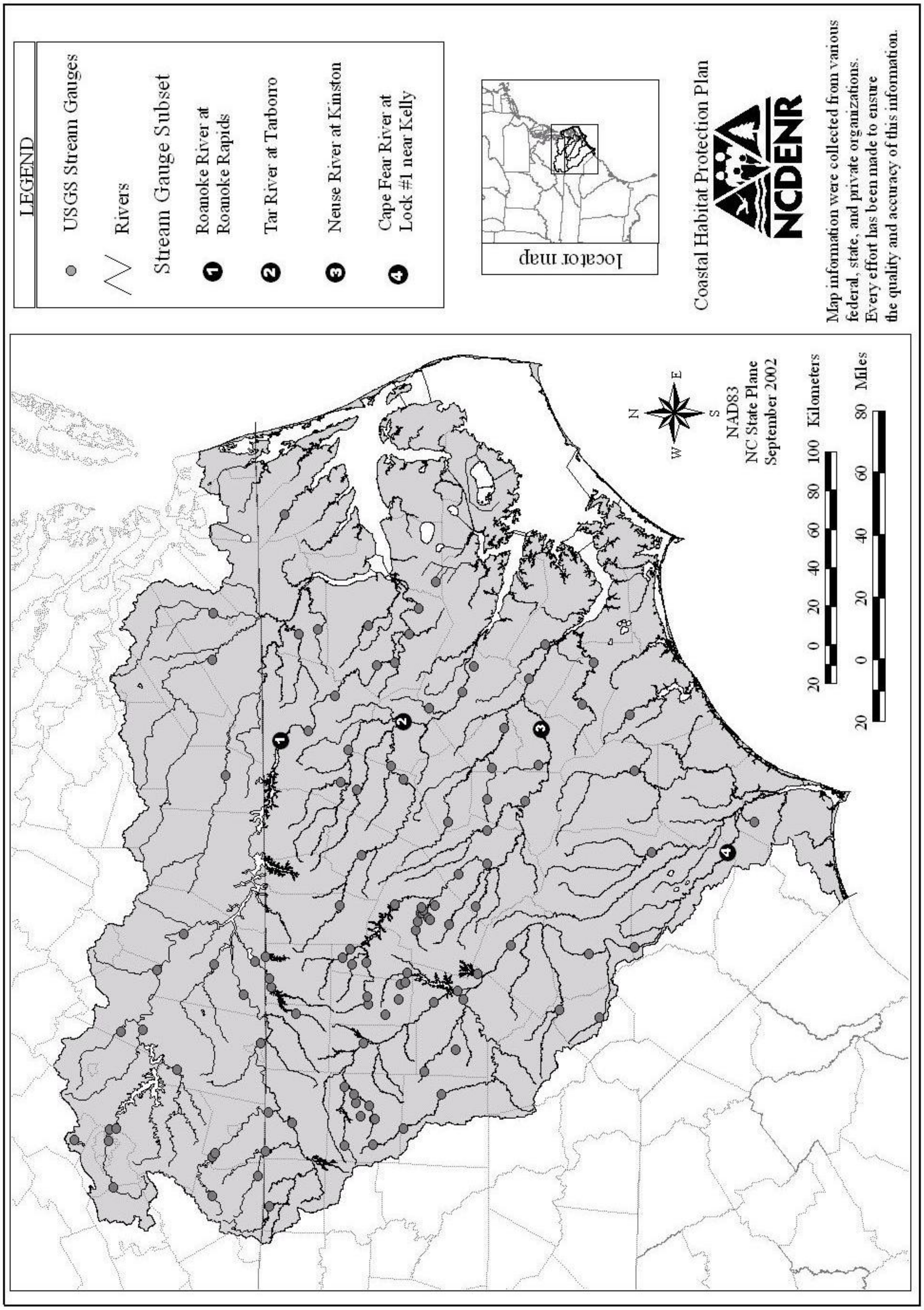
The most significant accomplishment related to the water column was the adoption of the revised 2008 coastal stormwater rules. The rules require decreased built-upon area next to SA waters and ORWs from 25 to 12% to further reduce run-off from new development, and expand the stormwater control methods that can be used. Other accomplishments included the designation of Anadromous Fish Spawning Areas by MFC and WRC, establishment of additional staff positions for compliance with EMC rules and Division of Forestry BMPs, and improvements to sediment management on construction sites. Progress was made to prevent additional pollution from swine farms. In 2007, the General Assembly passed Senate Bill 1465, the NC Swine Farm Environmental Performance Standards Act that prohibited new lagoon and sprayfield systems, established a lagoon conversion cost-share program, and established a swine farm methane capture pilot program. New or expanding swine operations are required to have specified waste treatment systems that meet stringent health and environmental standards. However, there are many existing hog lagoons in flood plains or near coastal waters that need to be relocated or converted. Since the 2005 CHPP, monitoring indicates the Nutrient Reduction Strategies in the Neuse and Tar-Pamlico have resulted in the targeted 30% reductions from point source dischargers and agriculture, though in 2010, the overall goal of a 30% reduction in receiving waters has not been met. Additionally, there has been a significant increase in ammonium in the water column of the Neuse River estuary (as well as the Cape Fear River estuary).

Emerging research needs include assessing the risk of acidification on anadromous fish spawning and larval development, determining when and where recruitment is limited by larval transport into estuaries, and the long-term effect of hardened structures on larval transport and recruitment. Development of cumulative impact assessment techniques is greatly needed, as well as assessment of the effectiveness of the coastal stormwater rules and the effect of new erosion control materials (polymers). The increasing evidence of endocrine disrupting chemicals in surface waters nationwide suggests a need to monitor

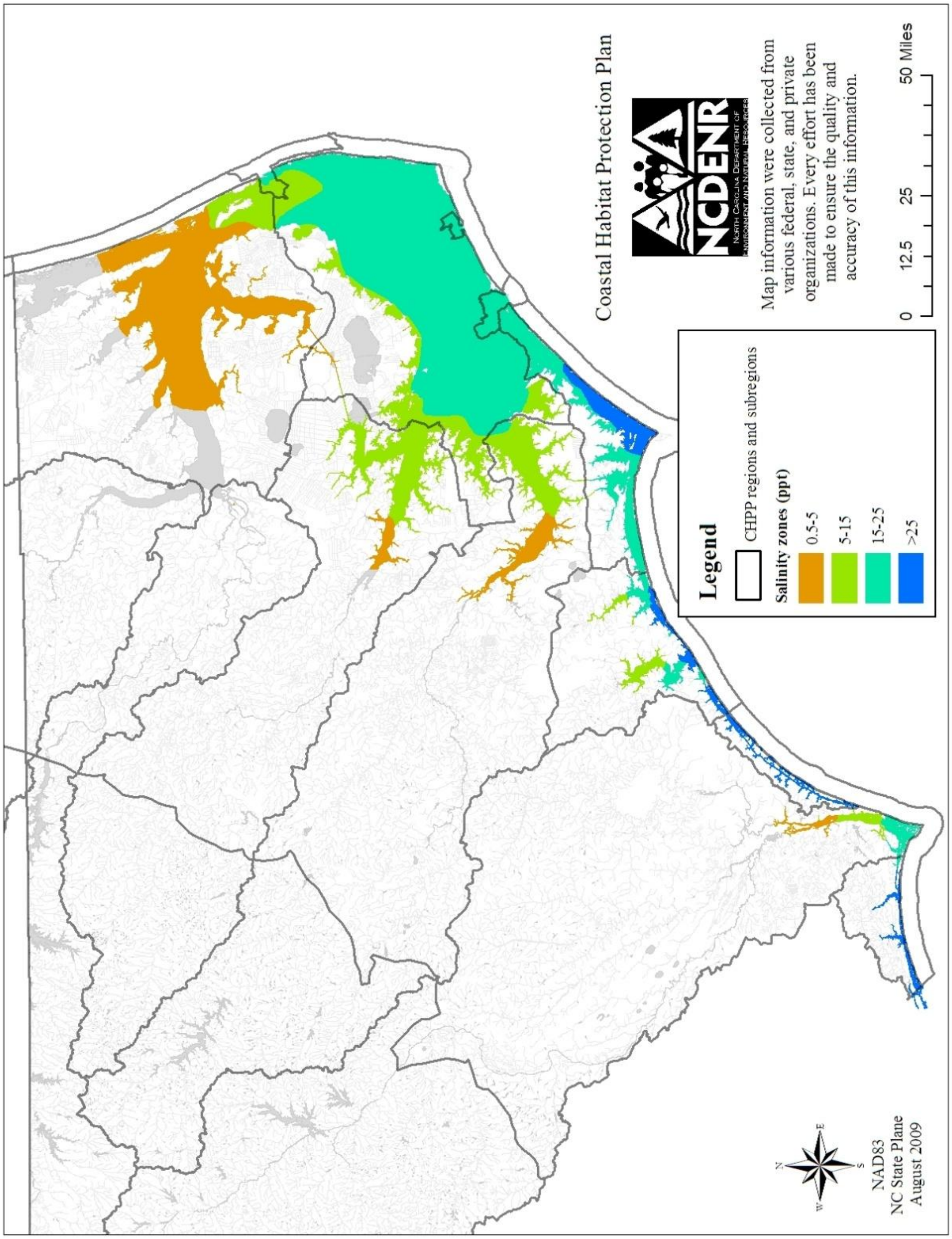
North Carolina coastal waters for such chemicals and conduct further research on the effects of various chemicals on fish and invertebrates, as well as research on wastewater treatment methodology to remove EDCs from sewage effluent. Emerging management needs include prioritizing dams and culverts for removals or modifications and initiating removal, shift toward requiring Best Available Technology for wastewater treatment rather than Best Practicable Technology to improve water quality, and reviewing and modifying as needed water quality standards that accurately reflect conditions necessary to support fish species and habitats. DWQ should develop a means to enforce prevention of marina washwater from entering surface waters and continue education on proper construction and maintenance of stormwater ponds and erosion control structures to control runoff at construction sites. In addition, educational outreach on proper disposal of pharmaceuticals and pesticides, and development of a drug take-back program through NC Pesticide Disposal Assistance Program, drug stores, or hospitals is needed to minimize introduce of EDCs into surface waters. Changes in water temperature, salinity, water levels and weather patterns associated with climate change and sea level rise will affect water quality, flows, and fish distribution. The state should take steps to implement adaptive management measures to minimize expected impacts.

In updating the chapter, many of the very general, minor, or redundant research and management needs were discontinued. Of the remaining 2005 CHPP research and management needs, progress was made on more than half of both categories. However, there were 44 new or clarified research (10) and management (34) needs identified, indicating new challenges for future water quality protection and restoration efforts. Some priority management needs include:

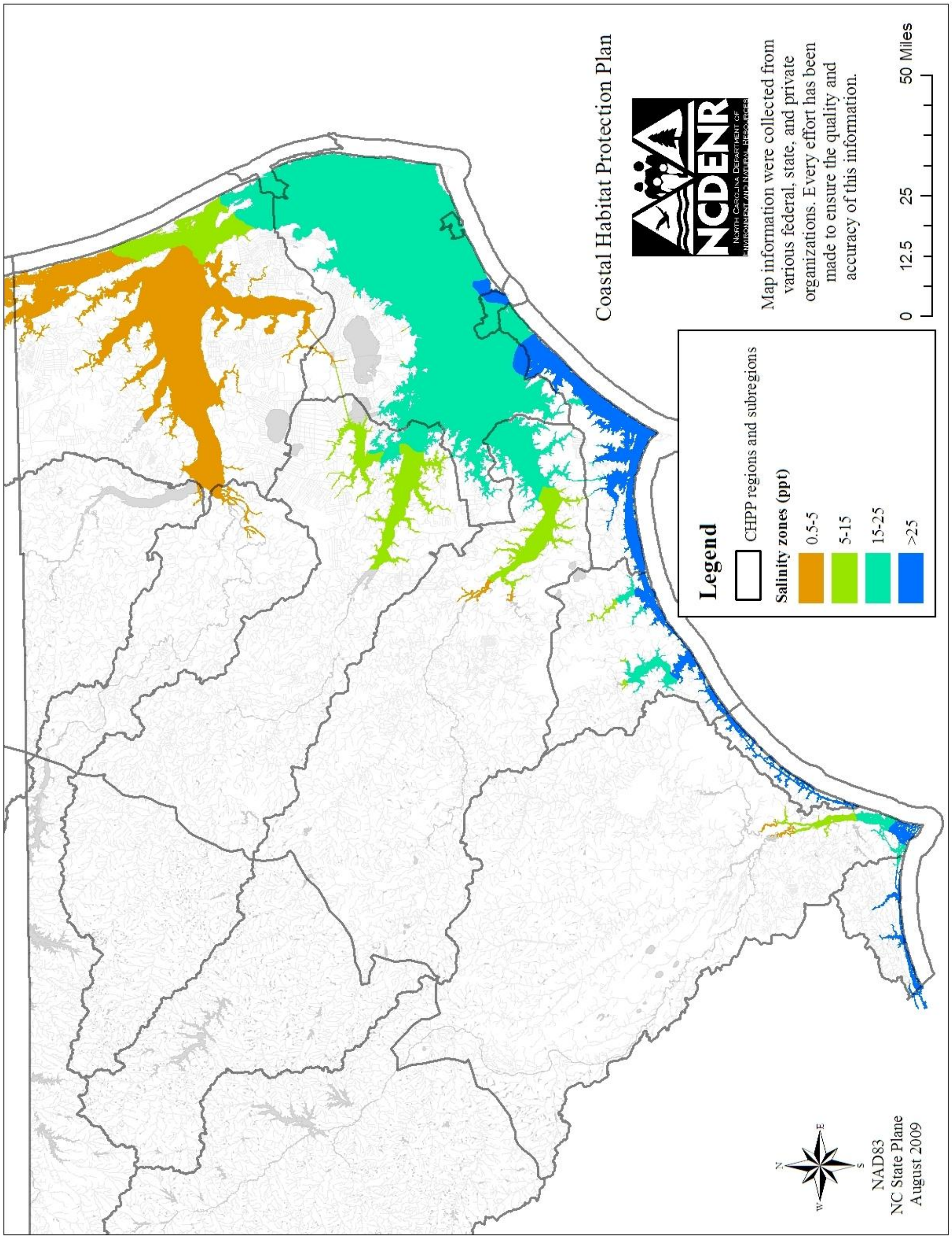
- Removal of unnecessary obstructions to anadromous fish passage,
- Use of current land-use, shoreline development, and point source data to model water quality /quantity impacts,
- Improve water monitoring coverage and suite of measurements taken in gap areas identified by modeling, and
- Enhance regulatory tools (i.e., Local Watershed plans, TMDLs) to address cumulative impacts.



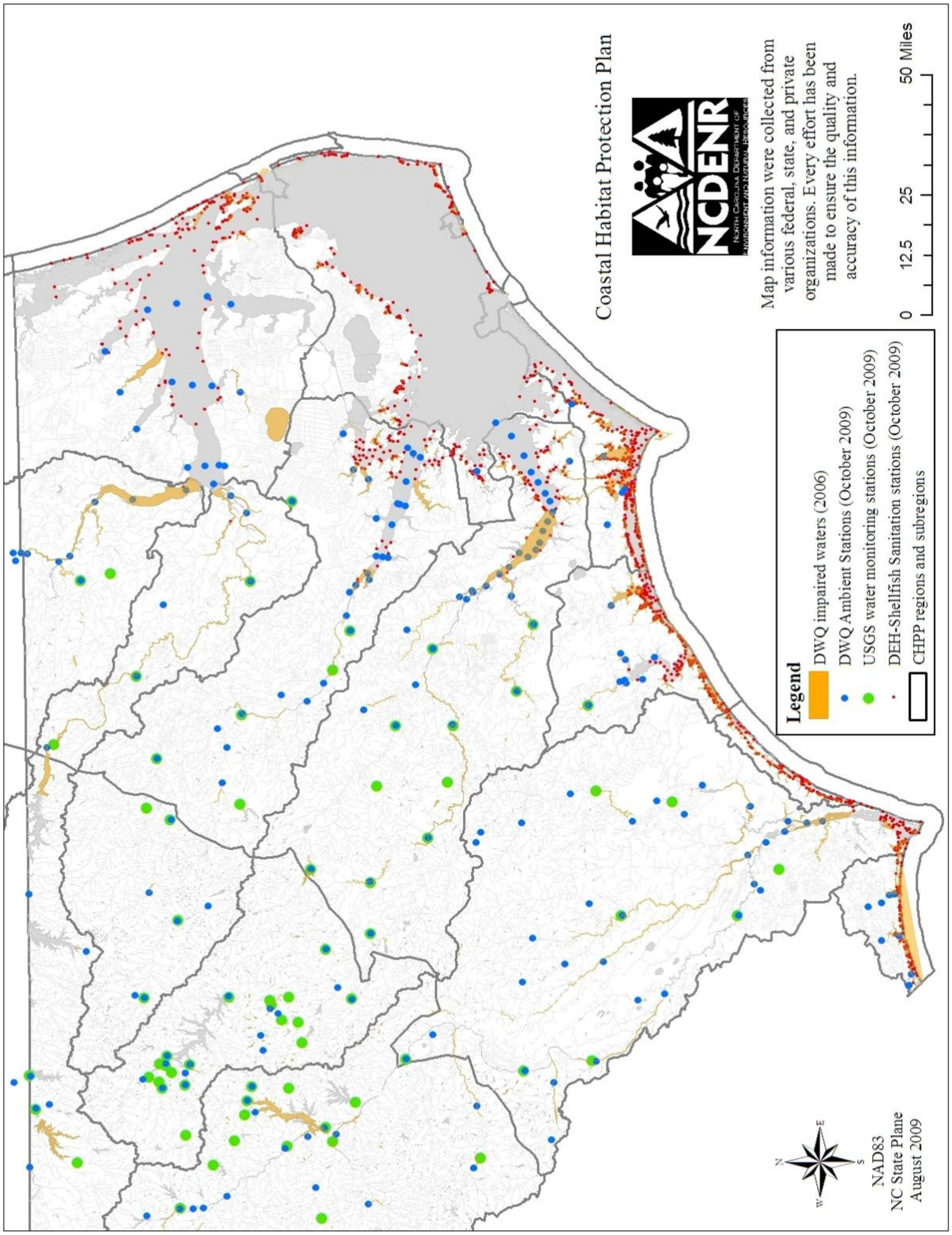
Map 2.1. Location of U.S. Geological Survey stream gauge stations in the coastal draining river basins of North Carolina. Note: Numbered gauges are associated with Figures 2.1 and 2.2.



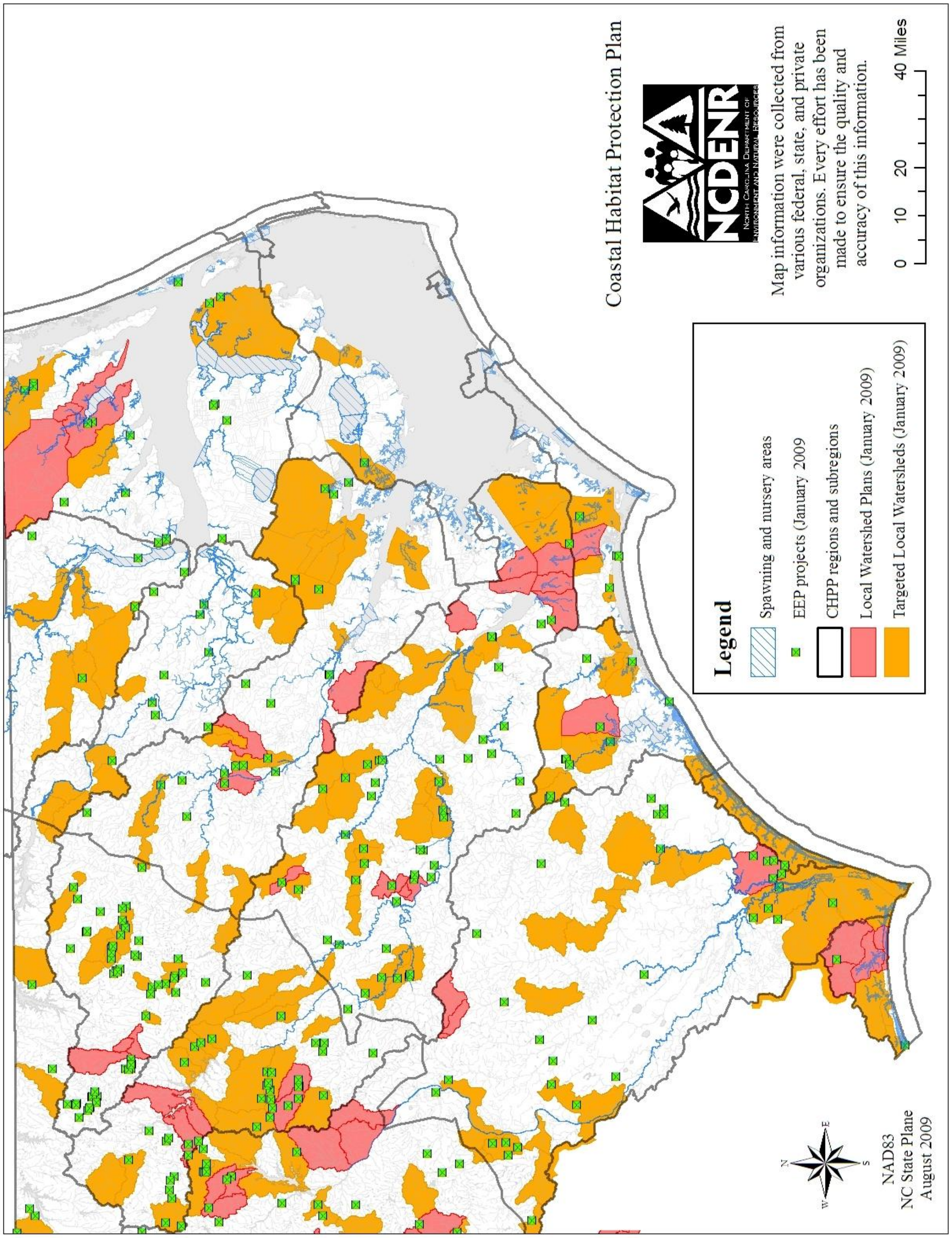
Map 2.2a. Winter and spring salinity zones in eastern North Carolina (derived from Orlando et al. 1994)



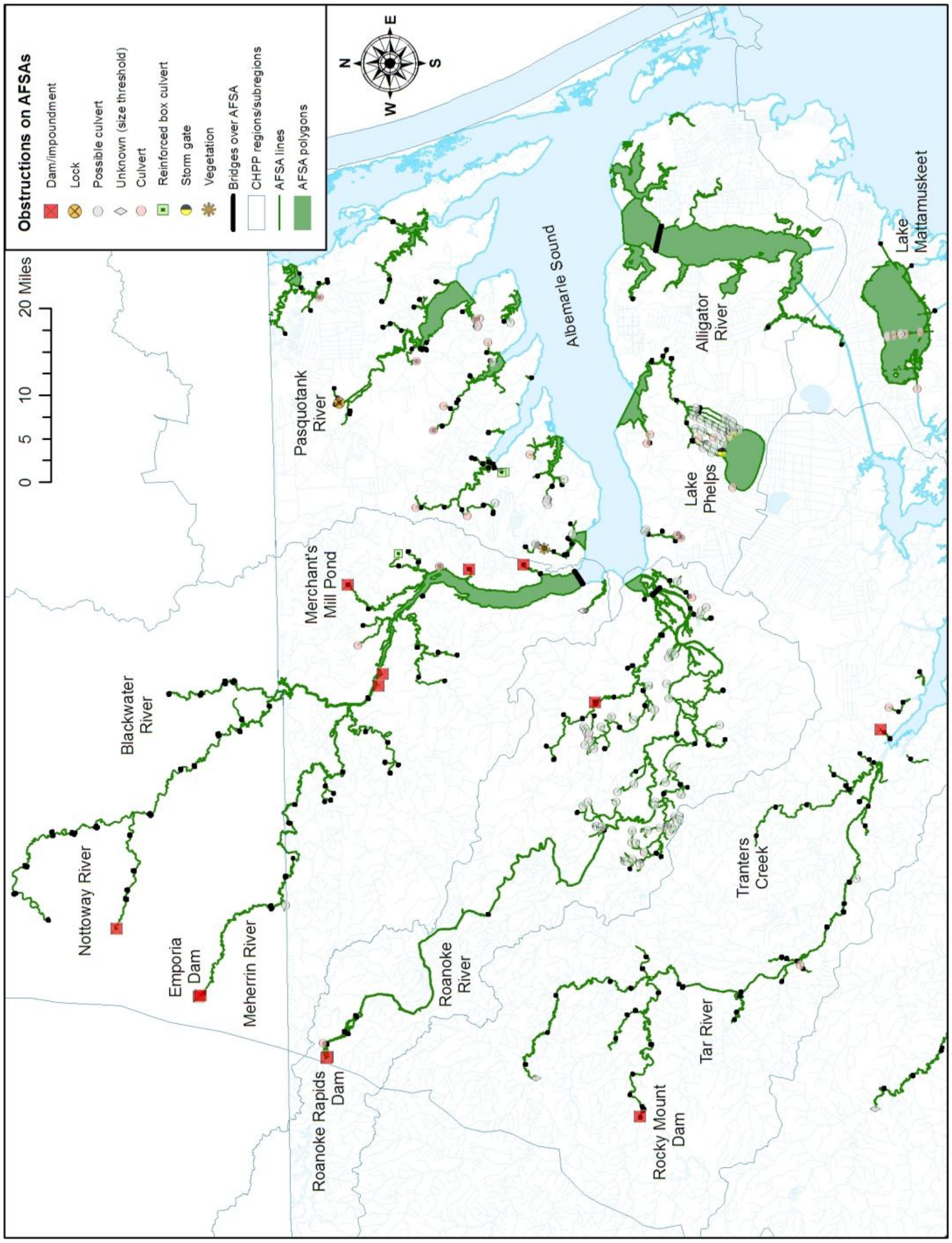
Map 2.2b. Summer and fall salinity zones in eastern North Carolina (derived from Orlando et al. 1994).



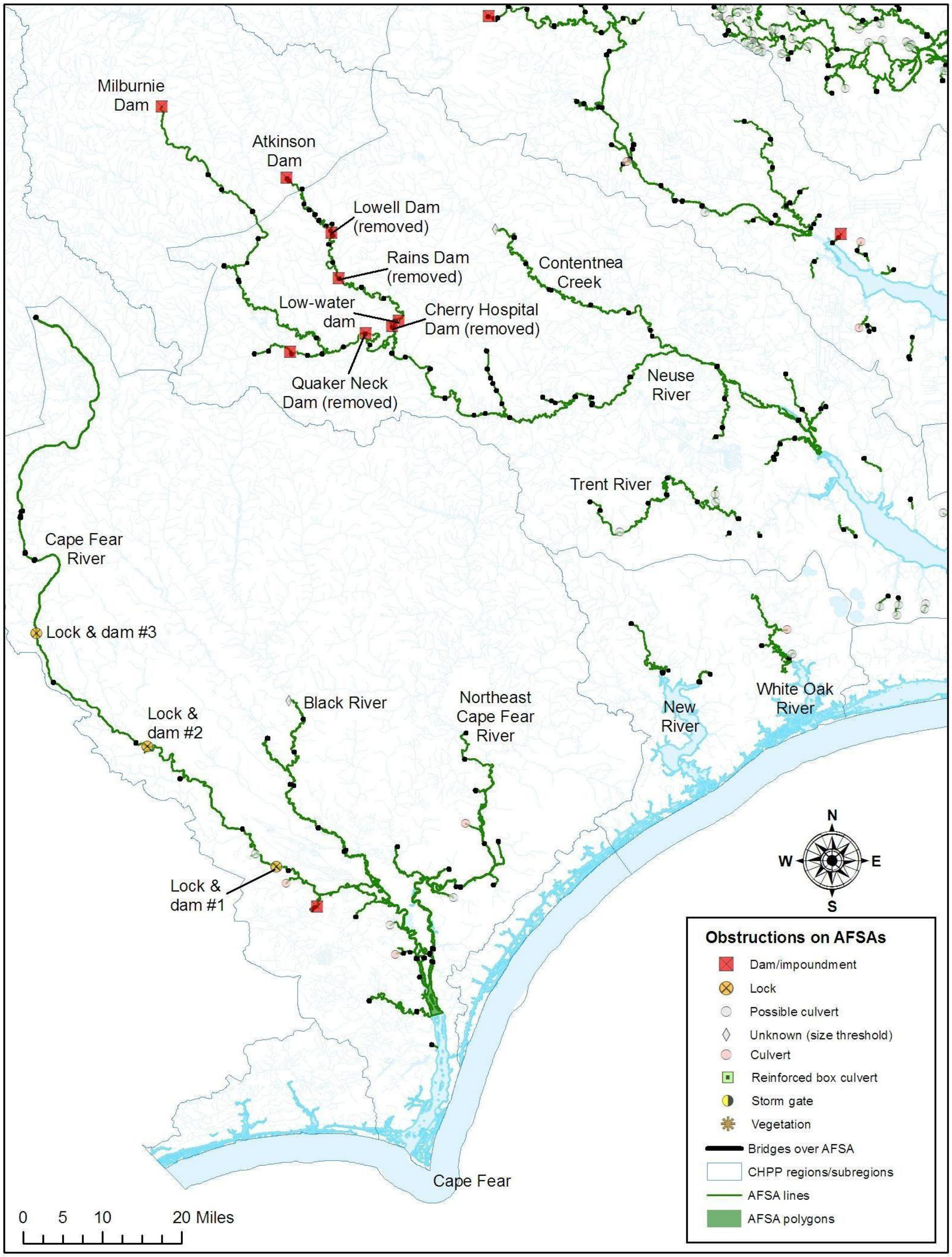
Map 2.3. Current water quality monitoring stations and 2006 impaired waters in coastal draining river basins of North Carolina.



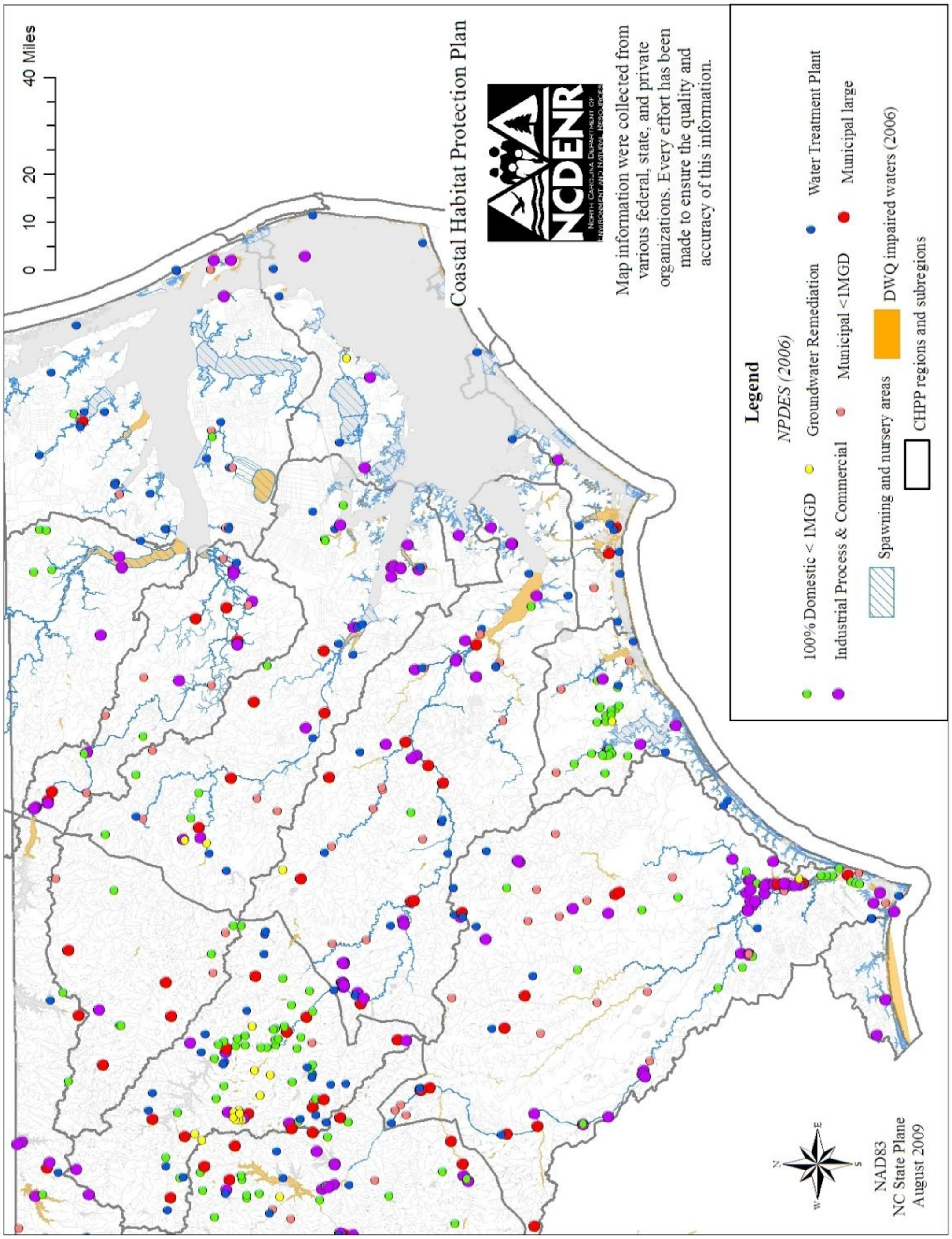
Map 2.4. Targeted Local Watersheds, Local Watershed Plans and Ecosystem Enhancement Program (EEP) project inventory relative to fish spawning and nursery areas (MFC/WRC designations).



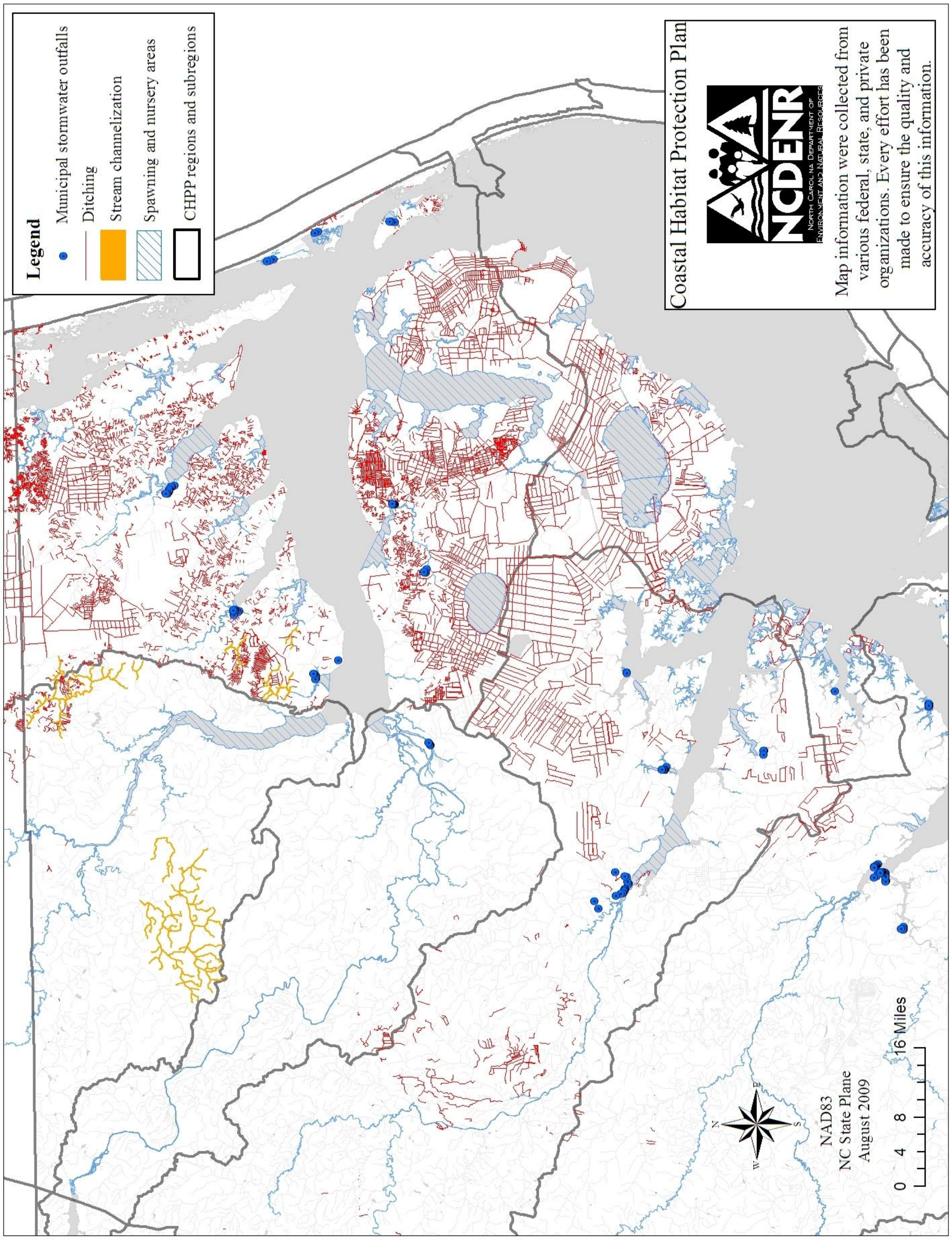
Map 2.5a. Documented water control structures in the North Carolina coastal plains (northern regions) relative to Anadromous Fish Spawning areas (AFSAs). Data from Virginia Game and Inland Fisheries (1983 data), Collier and Odum (1989), Moser and Terra (1999), Department of Transportation (2003 data), Division of Water Resources (2003 data), and USACE obstructions inventory (2009 data).



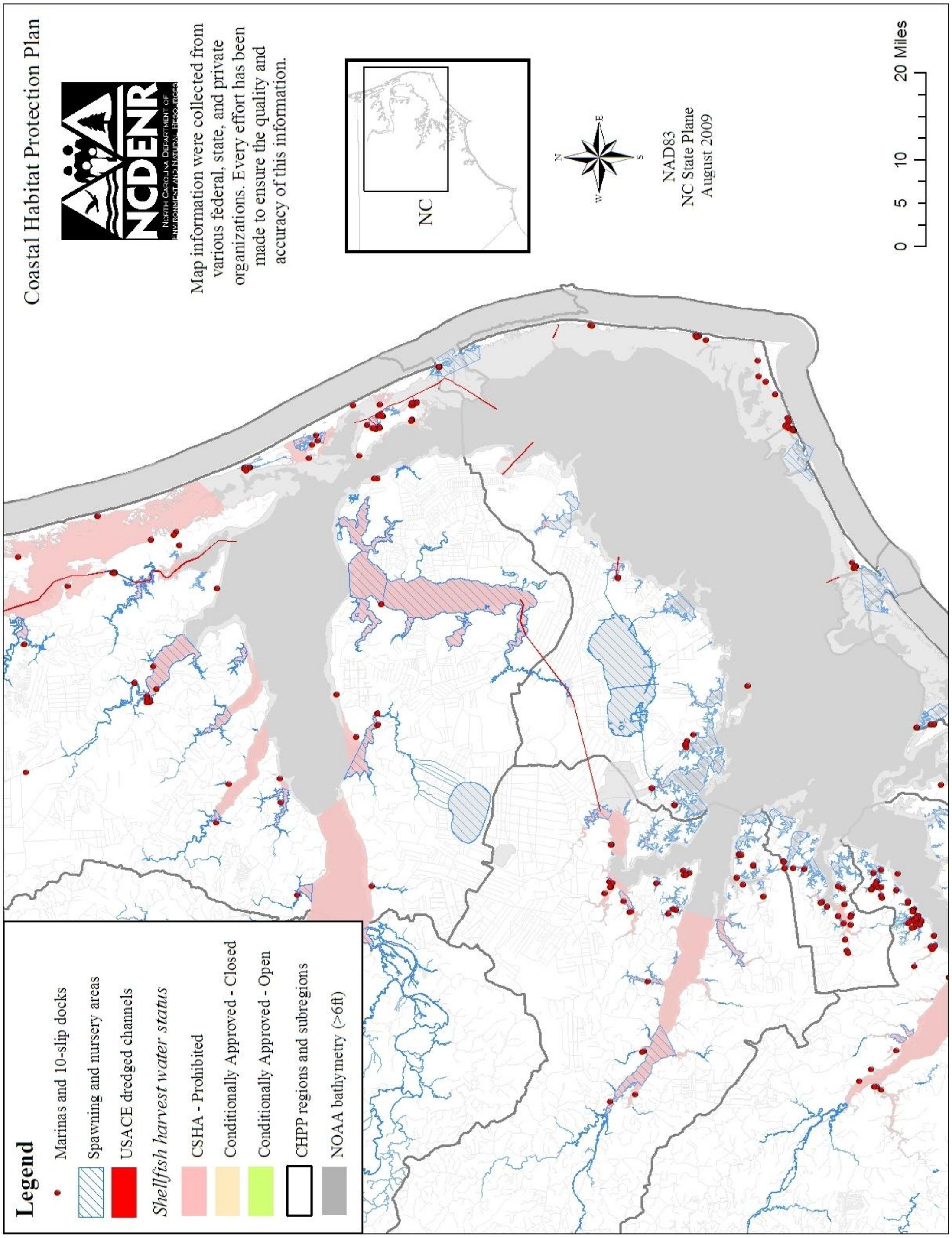
Map 2.5b. Documented water control structures in the North Carolina coastal plains (southern regions) relative to Anadromous Fish Spawning Areas (AFSAs). Data from Virginia Game and Inland Fisheries (1983 data), Collier and Odum (1989), Moser and Terra (1999), Department of Transportation (2003 data), Division of Water Resources (2003 data), and USACE obstructions inventory (2009 data).



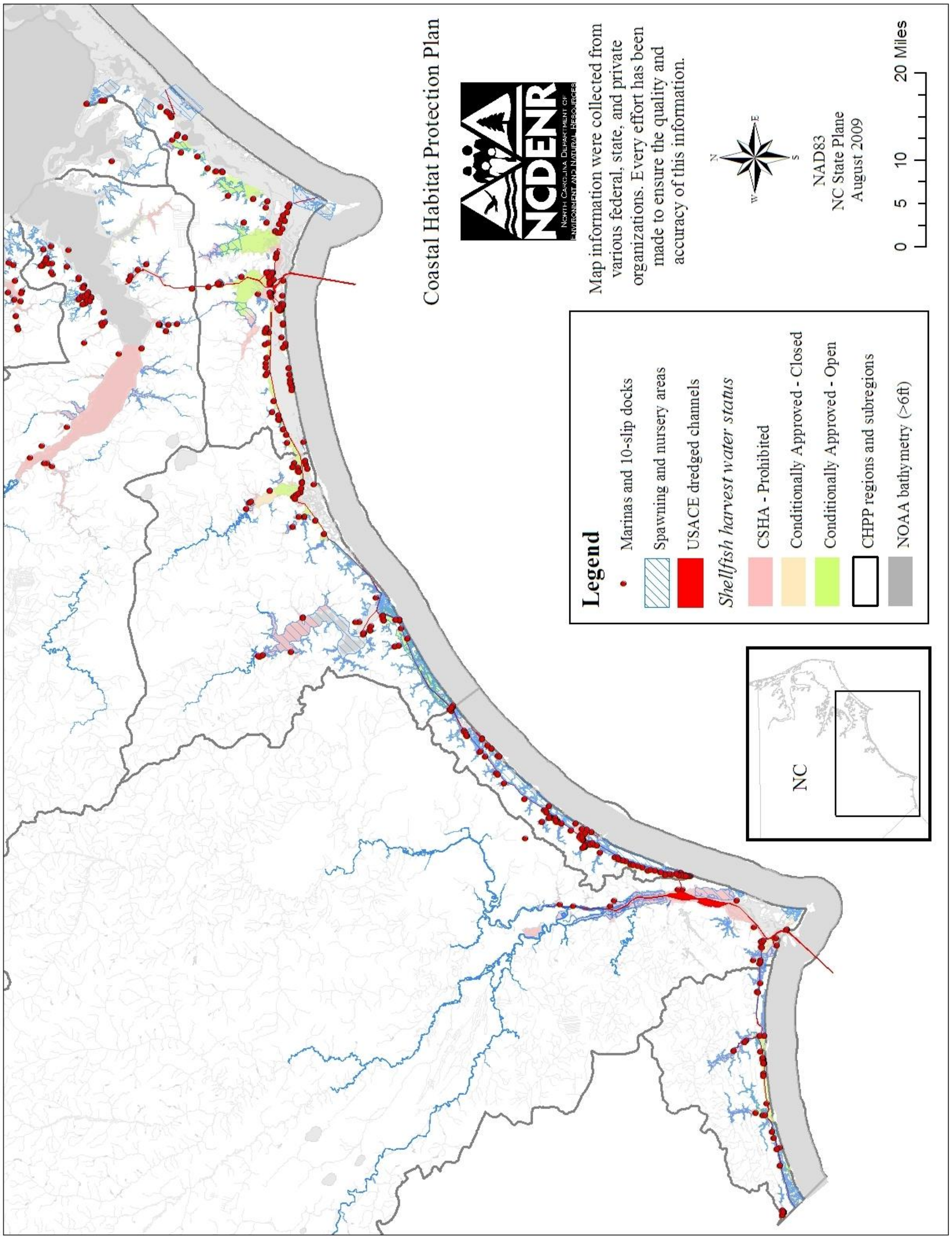
Map 2.6. Location of NPDES permits (DWQ 2006 data) relative to fish spawning and nursery areas.



Map 2.7. Ditches, channelization, and some municipal stormwater outfalls (DWQ 2006 data) in Albemarle Pamlico region of eastern North Carolina. Hydrographic data from 1:100,000 scale National Hydrologic Dataset (ditching) and Natural Resource Conservation Service (channelization).



Map 2.8a. Dredged channels (USACE 2003 data), marinas (WRC and DEH-SS 2009 data), 10-slip docks (DEH-SS 2009 data) and fish spawning and nursery areas.



Map 2.8b. Dredged channels (USACE 2003 data), marinas (WRC and DEH-SS 2009 data), 10-slip docks (DEH-SS 2009 data) and fish spawning and nursery areas.

CHAPTER 3. SHELL BOTTOM

3.1. DESCRIPTION AND DISTRIBUTION

3.1.1. Definition

Shell bottom is defined by Street et al. (2005) 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." Although molluscan shellfish are also present in freshwater and the nearshore ocean, the definition is limited to estuarine waters because North Carolina's economically significant shellfish resources and their fisheries are entirely estuarine.

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

3.1.2. Description

Shell bottom habitats are commonly referred to as "oyster beds," "oyster rocks," "oyster reefs," "oyster bars," and "shell hash." While most of these terms describe concentrations of living and dead oysters, shell hash refers to an accumulation of unconsolidated broken shell (oyster, clam, bay scallop and/or other shellfish) on sand or mud substrates. Shell bottom is both intertidal and subtidal, and can consist of fringing or patch oyster reefs, surface aggregations of living shellfish, and shell accumulations (Coen et al. 1999; ASMFC 2007). The vertical relief of shell bottom varies significantly between intertidal and subtidal habitats. In North Carolina, intertidal oyster reefs in the central and southern estuarine systems may be a few oysters thick, while subtidal oyster mounds in Pamlico Sound may have been several meters tall (Lenihan and Peterson 1998). The horizontal extent of shell bottom habitat ranges in size from a few square meters of scattered shell to acres of living and dead oysters. Additionally, the habitat can consist of many square miles of shell hash more than a yard deep.

Cultch material, including shell hash, existing oyster rocks, marl, or other hard materials, provide oysters and other shellfish with important substratum for settlement, attachment, refuge, and accumulation. Although cultch exists naturally, the North Carolina Division of Marine Fisheries (DMF) Shellfish Rehabilitation Program uses cultch planting to enhance and restore estuarine shell bottom in order to increase oyster spat and hard clam settlement and survival. Oysters and other shellfish also use exposed roots at the margin of salt marsh, pilings, seawalls, and rip-rap as attachment sites (DMF 2008a).

3.1.3. Habitat requirements

Although numerous species of molluscan shellfish contribute surface shell material to the estuarine environment, oysters in particular dominate shell bottom habitat in North Carolina's estuaries. Oyster beds and rocks are the most critical habitat for oyster populations, as they provide the most abundant and preferred substrate (oyster shell) for larval settlement (Marshall 1995; Kennedy et al. 1996; DMF 2008a). While oysters colonize a wide variety of locations within the estuary, their distribution and abundance is generally limited by ambient physicochemical conditions. Optimal growth conditions for adult oysters and oyster spat exist at temperatures between 10 and 30°C (Burrell 1986), salinities ranging from 14 to 28 ppt (Quast et al. 1988; Shumway 1996) and dissolved oxygen levels above 1-2 mg O_2 l^{-1} (Funderburk et al. 1991). Oysters can survive for up to 5 days in waters with < 1 mg O_2 l^{-1} (Sparks et al. 1958). Several studies have found that the combination of low salinities and high temperatures increase oyster mortality (Loosanoff 1953; Funderburk et al. 1991), while predation rates are highest in near seawater conditions (Gunter 1955; Bahr and Lanier 1981). The combination of these two factors effectively concentrates subtidal oysters in moderate salinity areas of North Carolina estuaries. Intertidal oyster growth and distribution is generally less influenced by predation and more influenced by exposure, tidal flows and food availability.

Other factors, such as turbidity and circulation patterns can have profound effects on oyster survival and viability. Oyster eggs have experienced over 50% at suspended sediment concentration >500 mgl^{-1}, while oyster larvae are slighter more tolerant with 50% mortality occurring from 100-150 mgl^{-1} (Davis and Hidu 1969a; Funderburk et al. 1991). Good water circulation is of critical importance for larval dispersal and successful spat settlement (Burrell 1986). Adult oysters also require adequate circulation to deliver food and oxygen and to remove wastes and sediment. For subtidal oyster reefs, the vertical height of the oyster rock maximizes circulation benefits by physically locating the oysters off the bottom to avoid anoxic water (Lenihan and Peterson 1998) or sedimentation (Coen et al. 1999).

3.1.4. 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; Carlton and Mann 1996; Carriker and Gaffney 1996; MacKenzie 1997; Jenkins et al. 1997). 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 Sound to the estuaries of the southern part of the state along the South Carolina border (DMF 2001a). Oyster reefs occur at varying distances upstream in 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 beds 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).

3.1.4.1. Shellfish habitat and abundance mapping

The DMF Shellfish Habitat and Abundance Mapping Program began creating detailed bottom type maps of the estuarine system in 1988. These maps are being compiled using standardized survey methods from the South Carolina border north through Core Sound, along the perimeter of Pamlico Sound, Lower Neuse River, Lower Pamlico River, Pungo River and in Croatan/Roanoke sounds (Map 3.2). The program delineates all bottom habitats, including shell bottom, with field surveys, 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 shells (surface or subsurface). This program defines shell present strata as significant cover (>30% of bottom) of living or dead shells on the surface or in the substrate. Some of the other habitats mapped by the program include salt marsh, where the intertidal fringe is habitat for shellfish, submerged aquatic vegetation, and soft bottom. A stratified random sampling design is used to provide statistically valid shellfish density estimates by area and habitat.

The CHPP implementation plan of 2005 called for accelerating the mapping of shell bottom. The Department was able to secure funding in the legislative budget to support four new shellfish mapping technician positions, as well as a GIS analyst. From January 2003 to November 2008, Resource Enhancement staff has mapped 270,920 additional acres of bottom, primarily in Pamlico, Carteret, Brunswick, Onslow, Dare, and Hyde counties (B. Conrad/DMF, pers. com., 2009). The only areas that have not been mapped are a portion of the waters in Brunswick County, northwest Pamlico Sound nearshore and tributaries (mainland Hyde County from Spencer Bay to Far Creek), Pamlico Sound areas around Ocracoke Island, and subtidal oyster beds in Pamlico Sound with depths over twelve feet. With current staffing, DMF now plans to map all of these areas less than 12ft deep on a five year cycle. (B. Conrad, DMF, pers. com., 2008). Resource Enhancement also plans to implement mapping of the Pamlico Sound subtidal oyster beds with depths greater than twelve feet in the future, using acoustic sonar technology when additional funding and manpower become available.

As of November 2008, 90% (493,563 acres) of the total area intended for mapping (543,169 acres <12 feet deep) has been completed. Military restricted areas, lease areas, and major navigation channels are excluded from the mapping effort. Of the entire area mapped during Iteration 1, approximately 2.24% (11,052 acres) of the bottom was classified as shell bottom (Table 3.1 and Maps 3.3a-c). The southern estuaries have the greatest relative area of shell bottom (16% - mostly intertidal) among the areas mapped to date. Cape Fear had the greatest relative area of subtidal shell bottom (12%). The largest areas of subtidal shell bottom was in Core/Bogue Sound (5,586 ac), followed by Southern Estuaries (1,159 ac), New/White Oak (1,090 ac), and Pamlico Sound (857 ac). The vast majority of intertidal shell bottom was mapped in the Southern Estuaries (2,782 ac) and Core/Bogue (1,938 ac) subregions. Due to the sampling method and because not all shell bottom is inhabited by living oysters, these estimates of shell bottom abundance represent potential habitat where salinities are suitable for larval settlement, and do not take into account oyster beds in deep water (> 12 ft) outside of bottom mapping areas, such as those known in Pamlico Sound. Estimated densities of living shellfish on shell bottom are included on Maps 3.3a-c. The shellfish densities sampled in shell present strata/area combinations were applied to the entire strata within an area to create the maps of shellfish densities on shell bottom. Estimated densities suggest the additional ecological functions of living shellfish where shell bottom has been mapped.

As of January 2007, there were 160 shellfish lease areas mapped in coastal North Carolina waters occupying 880 acres, which comprises less than 1% of the Shellfish Habitat and Abundance Mapping Program focus area.[73] For the entire coast, including locations outside the Shellfish Habitat and Abundance Mapping Program focus area, there were 1,935 acres reserved as shellfish leases (DMF

[73] 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 probably underestimated.

2008a).

Table 3.1. Shell bottom habitat mapped by the North Carolina Division of Marine Fisheries' Shellfish Habitat and Abundance Mapping Program by CHPP subregions (Nov. 2008).

CHPP subregions (region)	Area Intended for Mapping* (acres)	Acres Mapped	% Mapped	Mapped Shell Bottom (subtidal) Acres	Mapped Shell Bottom (subtidal) % of mapped	Mapped Shell Bottom (intertidal) Acres	Mapped Shell Bottom (intertidal) % of mapped	Total Shell bottom
Albemarle (1)	56,807.84	56,807.84	100%	466.31	0.82%	40.89	0.07%	507.2
Oregon Inlet (1/2)	7,793.41	7,793.41	100%	104.7	1.34%	2.87	0.04%	107.57
Eastern Coastal Ocean (2)	4,393.84	4,393.84	100%	0	0.00%	0	0.00%	0
Tar Pamlico (2)	45,832.67	45,832.67	100%	397.47	0.87%	0	0.00%	397.47
Neuse (2)	20,615.41	20,615.41	100%	43.02	0.21%	0	0.00%	43.02
Pamlico Sound (2)	214,145.48	165,153.16	77%	856.61	0.52%	67.41	0.03%	924.02
Ocracoke Inlet (2/3)	2,925.54	2,361.26	84%	67.43	2.86%	9.67	0.33%	77.1
Core/Bogue (3)	149,240.65	149,240.65	100%	5,585.63	3.74%	1,938.72	1.30%	7,524.36
New/White Oak (3)	41,217.41	41,217.41	100%	1,089.65	2.64%	379.6	0.92%	1,469.25
South Eastern Coastal Ocean (3)	196.96	147.78	75%	1.75	1.18%	0.38	0.19%	2.13
Southern Estuaries (4)	27,252.38	23,315.31	86%	1,159.65	4.97%	2,782.21	10.21%	3,941.86
Cape Fear (4)	16,663.73	6,218.11	44%	768.9	12.37%	15.69	0.09%	784.59
South Coastal Ocean (4)	7.68	0	0%	0	0.00%	0	0.00%	0
Total	**543,169.22**	**493,563.45**	**90.87%**	**10,541.12**	**2.14%**	**5,237.44**	**1.06%**	**15,778.56**

*Not including areas that can not be mapped due to military prohibitions, leases or bridge restrictions/ depth/hazards.

3.2. ECOLOGICAL ROLE AND FUNCTIONS

3.2.1. Ecosystem enhancement

3.2.1.1. Water Quality Enhancement

Shell bottom provides direct and indirect ecosystem services that benefit coastal fisheries through water filtration, benthic-pelagic coupling, and sediment stabilization (Coen et al. 1999; Newell 2004; ASMFC 2007; Coen et al. 200). The filtering activities of oysters and other suspension feeding bivalves remove particulate matter (both organic and inorganic), phytoplankton, and microbes from the surrounding water column (Coen et al. 1999; Wetz et al. 2002; Nelson et al. 2004; Newell 2004; Coen et al. 2007; Wall et al. 2008). Fouling organisms on shell bottom are often suspension feeders as well and contribute to the water filtration capacity of this habitat (ASMFC 2007). Small-scale additions of oysters in tidal creeks of North Carolina have been demonstrated to reduce total suspended solids and chlorophyll *a* concentrations downstream of transplanted oyster reefs (Nelson et al. 2004). In addition, laboratory investigations have found that environmentally realistic densities of oysters, hard clams, and blue mussels (*Mytilus edulis*) lower chlorophyll *a* concentrations and increase light penetration to levels that facilitate the growth of

SAV (Wall et al. 2008).

Modeling efforts of the effects of oyster filtration on water quality in Chesapeake Bay have suggested that oysters play an important role in determining water clarity, phytoplankton biomass, and dissolved oxygen (DO) dynamics in that system (Newell and Koch 2004; Cerco and Noel 2007). Cerco and Noel (2007) found that a tenfold increase in oyster biomass would result in a system-wide reduction of chlorophyll *a* concentration by 1 mg m^{-3}, an increase in deepwater DO by 25 g m^{-3}, and a 20% increase in summer SAV biomass. Newell and Koch (2004) came to similar conclusions for the addition of oysters, suggesting that a modest increase in oyster biomass in Chesapeake Bay would reduce suspended sediment concentrations by an order of magnitude and increase the depth at which SAV was predicted to grow, but found that the influence of hard clams on reducing turbidity was much less than oysters due to their lower weight-specific filtration rate. The results of water quality models such as these and *in situ* measurements of filtration capacities has lead numerous authors conclude that oysters exert top-down grazer control of phytoplankton blooms (Coen et al. 1999; Newell 2004; Newell and Koch 2004; Cerco and Noel 2007; Coen et al. 2007). However, several investigators have recently questioned the validity of this conclusion stating that oyster filtration rates have been overestimated due to spatial and temporal mismatches between oyster and phytoplankton biomass and the lack of filtration access to all but the shallow bay water (Pomeroy et al. 2006; Fulford et al. 2007). Nevertheless, filtration by oysters has been demonstrated to improve water quality and clarity in both laboratory and field settings (Coen et al. 1999; Wetz et al. 2002; Nelson et al. 2004; Newell 2004; Coen et al. 2007; Wall et al. 2008). *An economic analysis is needed that compares the cost-saving of oyster restoration and sanctuary development with that of wastewater treatment capacity, along with the added fishery production of associated finfish species and oyster harvest in the remaining open shellfish harvesting waters*. The results of one such analysis are pending (J. Grabowski/GMRI, pers. com., January 2009).

Shell bottom also enhances water quality through coupling benthic and pelagic processes (Newell et al. 2002; Newell 2004; Porter et al. 2004; Newell et al. 2005; ASMFC 2007; Coen et al. 2007; DMF 2008a). Suspension feeding bivalves consume particles suspended in the water column, while accumulating biodeposits on the sediment surface (Newell 2004; Porter et al. 2004; Newell et al. 2005). The nitrogen (N) and phosphorous (P) excreted by the bivalves can become buried in the sediment or may be lost via bacterially mediated nitrification-denitrification (Newell et al. 2002; Newell 2004; Porter et al. 2004; Newell et al. 2005). The net ecosystem loss of N and P results in bottom-up nutrient control of phytoplankton production through alterations in nutrient regeneration processes (Newell 2004; Newell et al. 2005). However, bivalve biodeposits can be released back into the water column by erosion, sediment reworking by animals, or resuspension with possible uptake by adjacent SAV and phytoplankton (Peterson and Peterson 1979; Newell 2004).

3.2.1.2. Habitat Enhancement

The structural relief shell bottom provides plays an important role in the estuarine system. High relief shell bottom alters currents and water flows, and physically traps and stabilizes large quantities of suspended solids, reducing turbidity (Dame et al. 1989; Coen et al. 1999; Lenihan 1999; Grabowski et al. 2000). In addition, intertidal shell bottom, specifically oyster reefs, protects shoreline habitats from waves and currents, which aids in creek bank stabilization and reduction of salt marsh erosion (Bahr and Lanier 1981; Dame and Patten 1981; Marshall 1995; Breitburg et al. 2000; Henderson and O'Neil 2003; Piazza et al. 2005; ASMFC 2007). By decreasing erosive forces, intertidal oyster reefs reduce vegetative losses and, in some instances, promote marsh accretion (Meyer and Townsend 2000; Piazza et al. 2005; ASMFC 2007). In North Carolina, Meyer et al. (1997) found that placement of oyster cultch along the lower intertidal fringe of *Spartina* marshes resulted in net sediment accretion, while noncultched shorelines eroded. Additional studies in the Gulf of Mexico and along the Atlantic coast have also suggested the value of shell bottom for shoreline protection and erosion control, indicating lower erosion rates at shorelines protected by intertidal oyster reefs as compared to unprotected locations (Piazza et al. 2005; ASMFC 2007).

3.2.2. Productivity

Primary production on shell bottom is comprised of modest production from macroalgae, microphytobenthos, and organic biofilms. These organisms provide food for resident secondary consumers. The low primary productivity on oyster reefs reflects the importance of exogenous sources of primary production, such as phytoplankton, to this habitat. Meta-analysis of estuarine habitat productivity ratios indicated secondary production on oyster reefs was an order of magnitude greater than production in *Spartina* marshes, soft bottom, SAV, and mangrove forests (Peterson et al. in prep.). The high secondary productivity of this habitat was attributed to the high biomass of the oysters themselves and other macroinvertebrates inhabiting oyster reefs. In addition, tertiary production of nektonic organisms was found to be more than two times higher on oyster reefs than in *Spartina* marshes, soft bottom, and SAV, indicating the importance of this habitat for higher order consumers. 6

3.2.3. Fish utilization

Shell bottom has been widely recognized as essential fish habitat (EFH) for oysters and other reef-forming mollusks (Coen et al. 1999; ASMFC 2007). The functional value of shell bottom for oysters includes aggregation of spawning stock, chemical cues for successful spat settlement, and refuge from predators and siltation (Coen et al. 1999). As a reef matures, a complex habitat with greater reef height and more interstitial spaces for recruiting oysters to settle is created. This has led numerous authors to describe oysters as ecosystem engineers in recognition of the importance of the biogenic reef structure to estuarine biodiversity, fishery production, water quality, and hydrodynamic processes (Lenihan and Peterson 1998; Gutierrez et al. 2003; Dame 2005; Brumbaugh et al. 2006).

In addition to its role as EFH for oysters, shell bottom also provides critical fisheries habitat for ecologically and economically important finfish, mollusks, and crustaceans. In North Carolina, well over 40 species of fish and decapod crustaceans have been documented using natural and restored oyster reefs including American eel, Atlantic croaker, Atlantic menhaden, black sea bass, sheepshead, spotted seatrout, red drum, and southern flounder (Coen et al. 1999; Lenihan et al. 2001; Peterson et al. 2003a; Grabowski et al. 2005; ASMFC 2007). These documented species include 12 ASMFC-managed species and 7 SAFMC-managed species, suggesting the importance of this habitat for recreational and commercial fisheries. However, the most abundant species on oyster reefs are generally small forage fishes and crustaceans, such as pinfish, gobies, grass shrimp, and mud crabs (Coen et al. 1999; Minello 1999; Posey et al. 1999; Plunket and La Peyre 2005; ASMFC 2007). These small fish and crustaceans are important prey items in the diet of larger recreationally and commercially important fishes that make foraging excursions to this habitat, reflecting the aforementioned importance of shell bottom to fisheries production.

Fish that utilize shell bottom can be classified into three categories: resident, facultative resident, and transient species (Coen et al. 1999; Lowery and Paynter 2002; ASMFC 2007). Resident species use shell bottom as their primary habitat and depend on the availability of this habitat for breeding, feeding, and refuge from predation. Facultative resident species are generally associated with structured habitats including shell bottom and depend on this habitat for food. Transient species are wide-ranging species that use shell bottom for both refuge and forage grounds, but do not necessarily depend on this habitat. While oyster reef residents often dominate in sheer abundance, transients are frequently the most diverse. Peterson et al. (2003) 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 results grouped species into three categories: recruitment enhanced, growth enhanced, and not enhanced (relative to soft bottom habitat). Recruitment and growth enhancement are discussed in the nursery and foraging sections, respectively.

A partial list of finfish and macroinvertebrates documented from collections on shell bottom is provided in Table 3.2. Those species that use shell bottom as spawning, nursery, forage, or refuge grounds are identified. Although more than 30 species are listed in Table 3.2, this list is by no means all encompassing.

3.2.4. Specific biological functions

3.2.4.1. Refuge

The complex three-dimensional structure of shell bottom provides valuable refuge habitat for larval, juvenile, and adult finfish and macroinvertebrates (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; Grabowski and Powers 2004; Posey et al. 2004; Soniat et al. 2004; Grabowski and Kimbro 2005; Hughes and Grabowski 2006). Often, oyster reefs provide the only source of structural refuge habitat in submerged areas of estuaries (Grabowski et al. 2000). Oyster reefs also represent the dominant structural habitat in the mid-intertidal to shallow subtidal zone of estuarine waters where SAV is absent (e.g. southern North Carolina to Florida) (Eggleston et al. 1998; Posey et al. 1999). The interstitial spaces between shells and within the shell matrix of oyster reefs are critical to the survival of recruiting oysters and other small, slow-moving macrofauna, such as polychaete worms, crabs, hard clams, and amphipods (Zimmerman et al. 1989; SAFMC 1998a; Bartol and Mann 1999; Coen et al. 1999; Soniat et al. 2004; Grabowski and Kimbro 2005; Hughes and Grabowski 2006; F et al. 2006). Mud crabs, a dominant component of the oyster reef macrofaunal assemblage, utilize shell bottom as refuge from oyster toadfish, blue crabs, and wading birds (Meyer 1994; Grabowski and Kimbro 2005). However, mud crabs also function as an important intermediate predator, foraging on juvenile hard clams within oyster reefs (Grabowski and Powers 2004; Posey et al. 2004). Predation pressure by oyster toadfish has been documented to reduce mud crab foraging on juvenile hard clams, thus increasing the refuge value of oyster reefs for juvenile hard clams and highlighting the complexity of interactions dictating the significance of shell bottom as refuge (Grabowski and Kimbro 2005). Previous investigations have also documented the importance of shell bottom for predation protection of adult and juvenile hard clams, citing increased survival in shell bottom habitats as compared to open soft bottom (Peterson et al. 1995).

To take advantage of the hard clam-oyster shell refuge relationship, DMF specifically manages some intertidal oyster cultch planting sites in the southern coastal area for harvesting both oysters and hard clams. Once 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. Subsequent to the clam harvest, the areas are re-planted with cultch, and the two-year cycle begins again (Marshall et al. 1999; DMF 2008a).

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.

	Shell Bottom Functions [1]						
Species*	**Refuge**	**Spawning**	**Nursery**	**Foraging**	**Corridor**	**Fishery [2]**	**2010 Stock Status[3]**
ANADROMOUS & CATADROMOUS FISH							
American eel	**X**		**X**	**X**	**X**	**X**	**U**
Striped bass			**X**	**X**		**X**	**V- Albemarle Sound, Atlantic Ocean, D-Central/Southern**
ESTUARINE AND INLET SPAWNING AND NURSERY							
Black drum				**X**		**X**	
Blue crab	**X**	**X**	**X**	**X**	**X**	**X**	**C**
Oyster	**X**	**X**	**X**	**X**		**X**	**C**
Gobies/blennies	**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**
Spotted seatrout				**X**		**X**	**D**
Stone crab	**X**		**X**	**X**		**X**	
Weakfish	X		X	X	X	X	D
MARINE SPAWNING , LOW-HIGH SALINITY NURSERY							
Atlantic croaker				X		X	C
Brown shrimp	**X**		**X**	**X**	**X**	**X**	**V**
Southern flounder				**X**		**X**	**D**
Spot	X		X	X	X	X	C
Striped mullet				X		X	V
MARINE SPAWNING , HIGH SALINITY NURSERY							
Black sea bass	**X**		**X**	**X**	**X**	**X**	**C- north of Hatteras, D- south of Hatteras**
Gag	**X**		**X**	**X**	**X**	**X**	**C**
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	R

* 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. 2003a; Barrios 2004; ASMFC 2007; A. Barrios unpub. data

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

[3] V=viable, R=recovering, C=Concern, D=Depleted, U=unknown ().

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

3.2.4.2. Spawning

Shell bottom resident species, such as oyster toadfish, gobies, grass shrimp, and hard clams, have been documented to use oyster reefs for reproduction (Hardy 1978a-b, Johnson 1978; Coen et al. 1999; NOAA 2001; Tolley and Volety 2005). Many of these residents use the interstitial spaces within and between the shells as nesting sites and attach their eggs to the shell surface (Coen et al. 1999). Recent research has suggested that estuary-spawning transient species use shell bottom for spawning purposes as well. In the Neuse River estuary, spawning aggregations of red drum and spotted seatrout were found to frequently occur over subtidal oyster beds, although a distinct preference for this habitat in comparison to soft bottom was not found (Barrios 2004; Barrios-Beckwith et al. 2006; A. Barrios unpub. data). *More research is needed on the functional value of oyster reefs as spawning habitat for estuary-spawning transient species in North Carolina*.

3.2.4.3. Nursery

Shell bottom serves as valuable nursery habitat for numerous juvenile finfish and macroinvertebrates (Daniel 1988; Orterga and Sutherland 1992; Minello 1999; Grabowski et al. 2000; Lehnert and Allen 2002; Grabowski et al. 2005; ASMFC 2007; Shervette and Gelwick 2008). Species considered, "recruitment-enhanced," by shell bottom (relative to soft bottom) include stone crabs, sheepshead, blennies/gobies, skilletfish, gray snapper, gag, toadfish, and tautog (Peterson et al. 2003a). Both juvenile oysters and hard clams settle on shell bottom, taking advantage of the protection this habitat provides (Wells 1957; MacKenzie 1977; Peterson 1982; Nestlerode et al. 2007; DMF 2008a; DMF 2008b). Survival of juvenile oysters post-settlement is often higher on oyster shell as compared to other shell substrates due to the structural complexity oyster shell affords (Nestlerode et al. 2007). Juvenile stone crabs occur almost exclusively on shell bottom in areas where other sources of hard substrate are rare to absent (Minello 1999; Lowery and Paynter 2002). Megalopal stone crabs key in on the chemical signals of the oyster themselves and associated biofilms as a cue for settlement (Krimsky and Epifanio 2008). The nursery area function of shell bottom for resident finfish was demonstrated by Lehnert and Allen (2002) who found abundances of juvenile naked goby (*Gobiosoma bosc*), oyster toadfish (*Opsanus tau*), and crested blenny (*Hypleurochilus geminatus*) to be higher on shell bottom than on adjacent mud and sand bottom habitats.

Commercially and recreationally important finfish, such as black sea bass, gag, snappers, and sheepshead also use shell bottom as nurseries (Grabowski et al. 2000; Lenihan et al. 2001; Lehnert and Allen 2002; Lowery and Paynter 2002; Levin and Hay 2003; Peterson et al. 2003a; Grabowski et al. 2005; SAFMC 2007a). The ASMFC and SAFMC consider shell bottom as important nursery habitat for juveniles of these species (SAFMC 1998a; Lowery and Paynter 2002; ASMFC 2007; SAFMC 2007a). Grabowski et al. (2005) found that juvenile gag and grey snapper were some of the most abundant species on intertidal oyster reefs in Middle Marsh, North Carolina, and that the abundances of these species were higher than on the adjacent mud flat. Lehnert and Allen (2002) reported that black sea bass and groupers were nearly 500 times more abundant on shell bottom as compared to adjacent soft bottom habitats, leading these authors to suggest that oyster reefs function as EFH for those species.

3.2.4.4. Foraging

Numerous aquatic organisms use shell bottom as foraging grounds during one or more of their life stages (Loosanoff 1965; Eggleston 1990; Mann and Harding 1997; Grabowski et al. 2000; Lenihan et al. 2001; Peterson et al. 2003a; ASMFC 2007; Simonsen 2008). Species considered, "growth-enhanced," by shell bottom (relative to soft bottom) include bay anchovy, black sea bass, sheepshead minnow, spottail pinfish, silversides, white perch, pigfish, and southern flounder (Peterson et al. 2003a). The structure shell bottom provides concentrates prey organisms and attracts predators. Both mud and blue crabs forage heavily on oyster reefs, functioning as important predators of oyster spat and juvenile hard clams

(Menzel and Hopkins 1955; Krantz and Chamberlin 1978; Eggleston 1990; Mann and Harding 1997; Coen et al. 1999; Grabowski and Powers 2004; Posey et al. 2004; Grabowski and Kimbro 2005). In the Gulf of Mexico, oysters and other reef associated bivalves were documented to comprise over one third of the diet of juvenile and adult black drum (Brown et al. 2008). Stomach content analysis of fishes collected in association with oyster reefs in the Neuse River and Middle Marsh, North Carolina, indicated preferential foraging on reef-associated fish, crustaceans, and mollusks (Grabowski et al. 2000; Lenihan et al. 2001). Studies in Louisiana and Chesapeake Bay found that dietary breadth of spotted seatrout, bluefish, and Atlantic croaker was greater over oyster reefs than adjacent soft bottom (Harding and Mann 2001; Simonsen 2008). Recently, the ASMFC has recognized the importance of shell bottom as foraging grounds for economically and ecologically important species, noting that 17 of the 22 ASMFC-managed species use shell bottom for this purpose (ASMFC 2007).

3.2.4.5. Corridor and Connectivity

Shell bottom has been suggested to serve as a corridor to other habitats, such as salt marsh and SAV, for finfish and macroinvertebrates (Coen et al. 1999; Micheli and Peterson 1999; Grabowski et al. 2000). Several authors have found that the proximity and connectivity of intertidal oyster reefs to other habitats, specifically SAV, affect fish and blue crab utilization patterns and the functional value of those reefs (Micheli and Peterson 1999; Grabowski et al. 2000). Nevertheless, there is a general paucity of information documenting the corridor function of shell bottom habitat. *Further research is needed on the corridor function of intertidal oyster reefs and the importance of connectivity to SAV and salt marsh for fisheries production.*

3.3. STATUS AND TRENDS

3.3.1. Status of shell bottom habitat

Status and trends of shell bottom can be assessed by examining changes in abundance and distribution over time. Other indicators could include changes in associated fishery landings, extent of shell bottom in protective designations, extent of disease, and change in recruitment indices (spatfall).

During the colonial period in the Mid-Atlantic, oyster reefs occurred so extensively that they were considered to be a hazard to navigation (Newell 1988). Street et al. (2005) and DMF (2001a, 2008a) have summarized the historical losses of oyster reefs in North Carolina, primarily in the Pamlico Sound region. Winslow (1889) documented the historical distribution of oyster beds in North Carolina in 1886-1887. Although the Winslow methods differed from today’s methods, those early estimates indicated a greater distribution and abundance of oyster reefs in Croatan, Roanoke, Pamlico, and Core sounds. In this area, Winslow (1889) estimated roughly 8,328 acres of public and private oyster beds (0.6% of the bottom) and 20,554 acres of potential “public oyster grounds.” Since the DMF Shellfish Habitat and Abundance Mapping Program has not completed mapping within this region, and methods differed, a comparison cannot be done. However, in the North River, where Winslow estimated 553 acres of natural and private oyster beds, DMF estimated 445 acres in the 1990s.

In Pamlico Sound, large changes in the abundance of oyster rocks since the 1880s were documented by Ballance (2004). Using new technologies to locate some of the subtidal reefs in Pamlico Sound reported by Winslow (1889), Ballance found that many of the once productive high profile reefs of the 1880s consisted of low profile, shell rubble, low density reefs, or had been completely buried by sediment. Ballance (2004) also found that the larger solid reefs tended to have less live oysters, which was attributed to the ease of locating these reefs by fishermen. The DMF has used the results of that study to guide oyster restoration activities.

Studies in riverine systems 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). *Re-mapping of the bottom is needed to accurately evaluate changes in distribution and density of oysters. In the future, change analysis in a subset of areas remapped by DMF, particularly where major changes are suspected, is needed to assess trends in this habitat.* Currently, there are no plans to conduct change analysis before mapping of the entire bottom area is completed. The Resource Enhancement Section estimated that increases in staffing through CHPP implementation and changes in methodology will enable each region of the coast to be remapped on five year cycles (B. Conrad/DMF, pers. com. 2008). *New technology should be investigated that will further reduce time of mapping and enhance mapping products.*

Harvest data (fishery-dependent data) has been used as an indicator of overall change in oyster abundance due to the lack of fishery-independent information. Based on harvest data, North Carolina oyster stocks were in a state of decline for most of the 20th century (DMF 2001a). High landings around 1890 associated with introduction of the oyster dredge were followed by sharp declines in landings around 1918 due to restrictions in the oyster dredging and size limits. Data on landings by gear type indicate that, between 1887 and 1960, most oysters were harvested by dredge when compared to all hand methods (Chestnut 1955; DMF 2001a). Poor harvesting practices are believed to be the primary cause of initial degradation and loss of shell bottom habitat in the Pamlico Sound area (DMF 2001a; Jackson et al. 2001).

Since 1991, oyster stocks and harvests from Pamlico Sound have collapsed due to high mortalities from disease and low spawning stock biomass (DMF 2001a). However, harvest of oysters has risen slightly since 2002 (DMF 2008a) (Figure 3.1). Oyster dredges are still used in some central coastal areas but are not permitted in the southern portion of the state. Between 1994 and 2002, oyster dredge fishery landings 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. Between 2002 and 2007, oyster dredging trips have generally increased with increasing harvest, while hand harvest trips have remained fairly constant (DMF 2008a; DMF 2008c). However, we cannot infer that oyster populations are increasing from harvest data alone.

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. However, in open areas, fishing effort via hand harvest is high as intertidal oyster beds typical of the southern coast are easily accessible. In general, cumulative and secondary effects from severe disease infestations, coupled with continued decline in suitable habitat, have seriously impacted oyster stocks.[74]

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

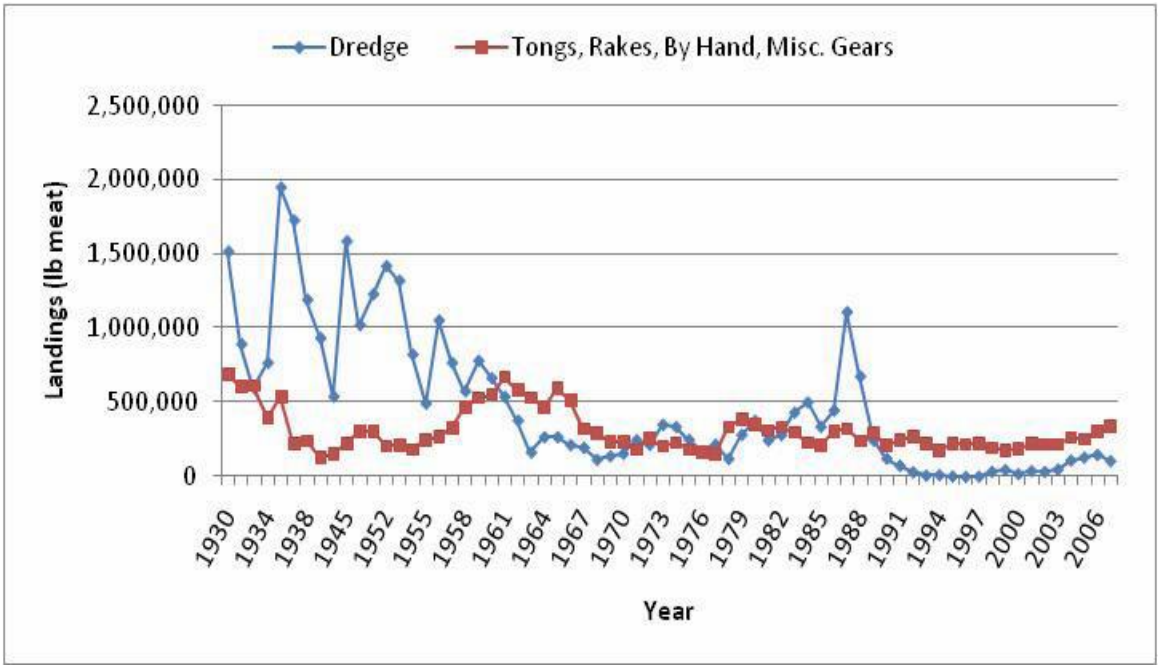


Figure 3.1. Commerical oyster landings (in pounds of meat) by gear type from 1930 to 2007. [Source: DMF 2008c]

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 2008a) (Figure 3.2). However, data since 1999 show an increase in spatfall (Figure 3.2). 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 2008a), or to physical damage from dredging (Marshall et al. 1999). *Although there has been no reported decline in spatfall in the southern coastal region of North Carolina* (R. Carpenter/DMF, pers. com., 2002), *more information is needed to determine trends in spatfall in this area over time*.

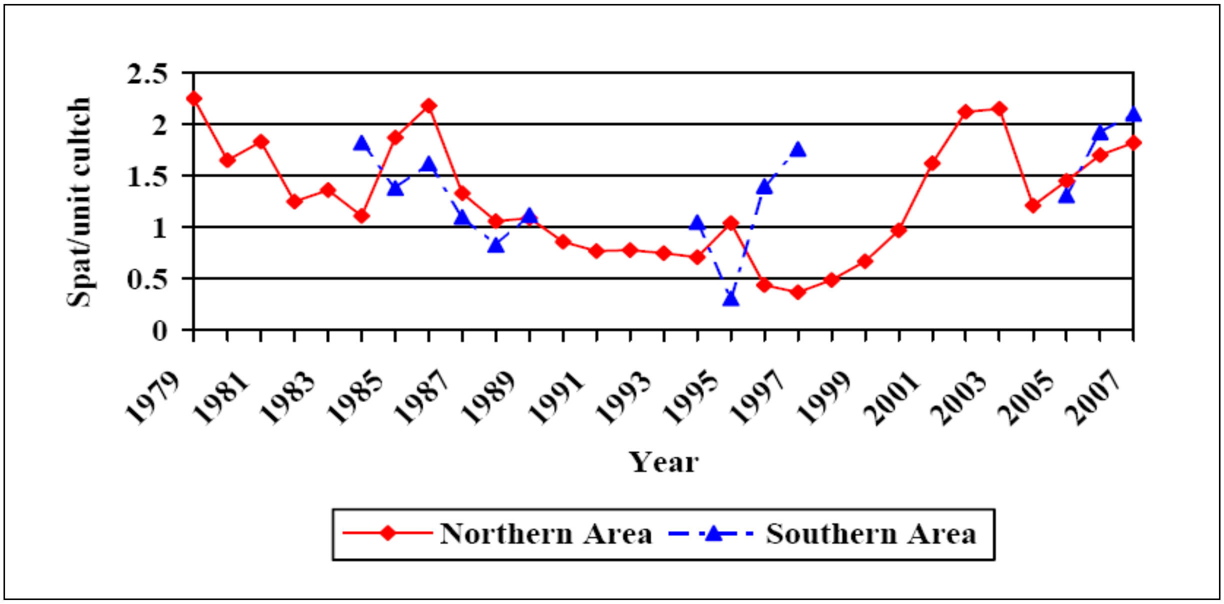


Figure 3.2. Northern and southern area (separated by Newport River) average oyster spatfall per unit cultch, 1979–2007. [Source: DMF 2008a]

3.3.2. 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, the utility of inferences is severely limited because the majority of shell bottom loss is thought to have occurred before detailed fishery harvest statistics were collected (prior to 1972). The DMF juvenile finfish surveys use seines and bottom trawls, which are ineffective for sampling in oyster beds. University researchers have conducted some research targeting fish use of shell bottom (see “For ecosystem enhancement” section below), although there is no monitoring on a regular basis. *Fishery-independent sampling on oyster reefs using appropriate sampling gear is needed to monitor juvenile and adult fish abundance in shell bottom.* Recent fishery harvest statistics may also provide a benchmark for future analysis, especially trip ticket data collected since 1994.

Of at least twenty five species (including oysters) showing higher relative abundance in shell bottom as compared to other habitats (bolding in Table 3.2), thirteen species, comprising at least fifteen stocks, were evaluated for fishery status in 2010 (http://www.ncdmf.net/stocks/2010NCDMF%20StockStatusReport.pdf). Of the thirteen stocks whose status was known, four were designated Depleted, six were Concern, two were Recovering, and three were Viable. Specifically, the southern flounder stock, the central-southern stock of striped bass, weakfish, spotted seatrout and the black sea bass stock south of Cape Hatteras are classified as Depleted; blue crab, oyster, spotted seatrout, Atlantic croaker, spot, gag, sheepshead, and the black seas bass stock north of Cape Hatteras are classified as Concern; and red drum and southern flounder are classified as Recovering. Viable stocks include brown and pink shrimp, striped mullet, and the ocean and Albemarle Sound stocks of striped bass. The stock status of hard clams, stone crabs, black drum and other shell bottom-associated fishery species is unknown. Since 2003, there have been more stocks added to the list of concern and a corresponding reduction in the number of stocks considered viable (Street et al. 2005). However, a change in stock status does not necessarily suggest any relationship to changing habitat conditions. The change in stock status only stresses the importance of protecting shell bottom as a habitat for species of concern.

Stock status of Concern or Depleted could be attributed to a variety of causes ranging from habitat loss, disease, and overfishing, to annual variation in environmental conditions. Compounding this uncertainty is the fact that status of some shell bottom-associated species, such as hard clams and black drum, is currently unknown. *More information on the status of hard clams, black drum, and other fishery and resident non-fishery species (i.e., oyster toadfish) as indicators of shell bottom conditions is needed. 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.* 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.*

3.3.3. Shell bottom enhancement and restoration

Restoration efforts are a form of oyster management designed to address the precipitous decline in oyster harvest and associated population size. However, the nature of oyster enhancement and restoration efforts has changed through the years. The earliest restoration efforts were directed at fishery enhancement, whereas recent efforts also included no-take sanctuaries and mitigation projects.

3.3.3.1. For fishery enhancement

The Shellfish Rehabilitation Program has contributed to the restoration of depleted oyster grounds through the planting of cultch material and seed oysters (Chestnut 1955). State-sponsored cultch plantings begin in 1915. Between 1915 and 1934, a total of 1,856,379 bushels of shells and seed oysters were planted in North Carolina’s estuaries. The Shellfish 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 3.3). 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 (Street et al. 2005). While some cultch plantings target soft bottom to create additional shell bottom habitat, other plantings are replenishments of older existing plantings, making it impossible to estimate how much shell bottom has been created over time.

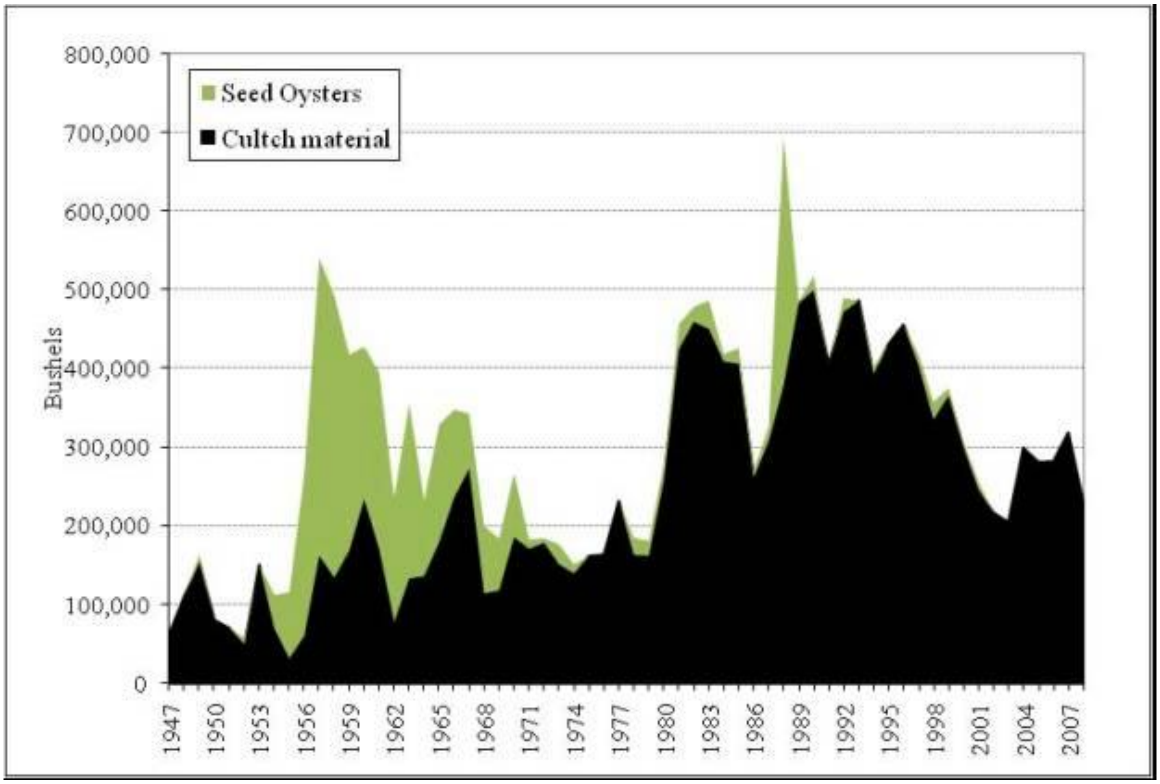


Figure 3.3. North Carolina oyster rehabilitation activities for 1947 – 2007 (data stacked to show cumulative total). The peak in 1988 was due to special state disaster funding during the red tide of 1987-88. [Sources: Marshall et al. 1999; DMF unpub. data]

The majority of cultch planting sites during 1990-1994 were in Pamlico Sound, lower Neuse River and lower Pamlico River (Marshall et al. 1999). Most of these sites were "new" plantings on soft bottom (Marshall et al. 1999). The same general areas were also planted from 1998-2008 (Maps 3.4a-b). 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, mechanical 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 (closed to harvest) 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, or seed management areas (C. Hardy/DMF, pers. com., 2008).

Funding for the acquisition of cultch material was drastically cut in the 1990 budget for DMF. As a result, cultch plantings had declined to around 200,000 bushels by 2002 (Figure 3.3). And until 2005, the DMF possessed more planting capacity than available cultch material (Street et al. 2005). Then in 2005 and 2006, legislative actions to support CHPP implementation accelerated the acquisition of cultch material. Those actions included funding for a dedicated shell recycling coordinator, additional public recycling sites and some important legislation. The shell recycling program had started in 2004 using local coordinators to collect discarded shells from individuals and businesses. The shells were then transferred to stockpile facilities before being planted in new or expanding cultch planting sites. The program started out slow with only about 1,000 bushels donated in 2004. The amount of cultch collected was secondary to the public awareness gained from a shell recycling program. Since 2005, contributions have increased each year to nearly 30,000 bushels in 2007 (S. Varnum/DMF, pers. com., 2008). The following statutes also encouraged voluntary shell recycling:

- General Statute 105-130.48: A taxpayer who donates oyster shells to the Division of Marine Fisheries is eligible for a state tax credit of one dollar ($1.00) per bushel of oyster shells donated. This act will remain in effect until tax year 2011.
- General Statute 130A-309.10(f): No person shall knowingly dispose of oyster shells in solid waste landfills.
- General Statute 136-123(b): No landscaping or highway beautification project undertaken by the Department of Transportation (DOT) or any other unit of government may use oyster shells as a ground cover. The DOT or any other unit of government that comes into possession of oyster shells shall make them available to the Department of Environment and Natural Resources, Division of Marine Fisheries, for use in any oyster bed revitalization programs or any other program that may use the shells.

The shortfalls in cultch planting material are primarily offset with the purchase of limestone marl for subtidal reefs. Thus, legislative actions in 2005 have allowed DMF to reach operational capacity (C. Hardy/DMF, pers. com., 2008). The legislative actions also followed recommendations and proposed actions in the 2005-2007 CHPP implementation plans. Maps 3.4a-b show the cultch planting sites from 1998 to 2007.

During 2007, over 200,000 bushels of cultch were distributed among nearly 50 sites. However, management of these sites varies. There are basically three management designations for cultch planting sites: (1) Research Sanctuary, (2) Seed Management Area, or (3) Shellfish Management Area. The Research Sanctuary designations are discussed in the following section. Shellfish Management Areas are designated under proclamation authority of the Fisheries Director [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 Shellfish Management Areas and, unless open by proclamation, they are closed to all shellfish harvest. Cultch planting sites in the Pamlico Sound have not been designated as Shellfish Management Areas 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). South of Pamlico Sound there are numerous Seed Management Areas and Shellfish Management Areas (Map 3.4a-b).

3.3.3.2. For ecosystem enhancement

The primary purpose of the DMF cultch-planting program since it began has been oyster fishery enhancement, which primarily provides temporary habitat value. Recent research showing the important ecological and economic value of oyster reefs (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) has prompted DMF enhancement efforts to broaden their primary focus to include ecosystem enhancement. Grabowski et al. (2000) 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. 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 finfish fisheries landings from restored reefs was greater than the oyster harvest value for both intertidal and subtidal shell bottoms. Peterson et al. (2003) 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. Analysis of the studies revealed that every 10 m^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).

The aforementioned research supported the development of Oyster Sanctuaries and Shellfish Management Areas for large, mature oysters (Maps 3.4a-b), in addition to cultch planting sites for oyster fisheries enhancement. Large oysters are known to be more viable than their smaller (younger) counterparts (DMF 2008a). They are assumed to be disease-resistant and have the potential to establish these traits in populations beyond sanctuary boundaries. This in turn could have long-term benefits on a sustainable fishery. Although still open to debate, relaying large surviving oysters to sanctuaries could promote characteristics needed to suppress the trends in *Perkinsus marinus* (Dermo) mortality. Another strategy would be to plant hatchery-reared disease resistant oysters on sanctuaries on the premise that they will pass their resistance on to wild populations. Currently, there are no state operated hatcheries for shellfish restoration in North Carolina (DMF 2008a). However, in 2008, per recommendations from the General Assembly, the DMF was provided \$4.3 million to build an oyster research hatchery at the University of North Carolina at Wilmington. The money was designated for construction cost only. *Additional funding is needed to staff and operate the oyster hatchery facility.*

As of 2008, the DMF has established and developed nine Oyster Sanctuaries encompassing 4.6 – 47.7 acres each, totaling 167.9 acres, of which approximately 42.8 acres have substrate for oyster attachment (Map 3.4a-b). The sanctuaries are located around Pamlico Sound and constructed of multiple, high profile mounds using mostly Class B Riprap (limestone marl) and the use of shell and seeded shell as part of the research needs. The Nature Conservancy (TNC), the North Carolina Coastal Federation (NCCF), the National Marine Fisheries Service (NMFS) Hurricane grant 2001-2006, state appropriations through DMF, and other mitigation sources provided funding. Current plans for expansion include an additional sanctuary along northwestern Pamlico Sound funded to NCCF and DMF by Coastal Recreational Fishing License revenue (S. Slade/DMF, pers. com., 2008). Oyster Sanctuaries are designated and delineated under North Carolina Marine Fisheries Rule 15A NCAC 03R .0117 and are protected from damaging harvest practices under rule 15A NCAC 03K .0209.

Some factors considered in the selection of sites for Oyster Sanctuaries include depth, bottom type, salinity, currents, cover or cultch necessary for shellfish growth, presence of larvae, and proximity to SAV, salt marsh, fish nursery areas, or Military Protected Areas. There is currently a NMFS-Sea Grant Fellowship project (NA08OAR4170764) developing other criteria for placement of sanctuaries based on larval transport (Eggleston et al. 2008). Oyster Sanctuaries are monitored by DMF staff to:

- Establish the effectiveness of the different types of cultch materials,
- Determine the recruitment, survival, and growth potential of each sanctuary on an annual basis,
- Determine the best water characteristics for long-term oyster growth in Pamlico Sound, and
- Characterize habitat utilization by sessile organisms in Pamlico Sound.

Seven of the nine Oyster Sanctuaries were monitored by DMF in 2007-2008. There is also a General Assembly funded two-year project underway that includes monitoring of fish predation on young oysters in Oyster Sanctuaries (principal investigator: C. Peterson, UNC-CH). In addition, a CRFL supported (\$132,242) project has recently been approved to examine how planting size for oyster seed influences seeding success on constructed oyster reefs at three sites in the Pamlico Sound (principal investigator: C. Peterson, UNC-CH). In an effort to further expand monitoring efforts, the DMF is working to assign different researchers to different sanctuaries (C. Hardy/DMF, pers. com., 2008).

The placement of sanctuaries by DMF has primarily focused on Pamlico Sound due to the large historic loss of oyster reefs in this area, as well as the sizeable amount of oysters in areas closed to harvest south of Pamlico Sound by reason of pollution. However, there are some cultch planting sites in the central and southern regions sponsored by various non-profit organizations, a University, and one coastal community (Map 3.4b). These sites are designated as Research Sanctuaries [MFC rule 15A NCAC 03I .0109] or Shellfish Management Areas [MFC rule 15A NCAC 03K .0103] under proclamation authority of the Fisheries Director. The North Carolina Coastal Federation (NCCF) has sponsored most of the sites. The NCCF sites are located in Williston Creek (Research Sanctuary), Everett Bay (Shellfish Management Area), Hewlett's Creek (Shellfish Management Area), New River near Sneads Ferry (Research Sanctuary), Dicks Bay in Myrtle Grove Sound (Research Sanctuary), and Alligator Bay (Shellfish Management Area) (Map 3.4a-b). The sites are monitored for three years after planting. The parameters measured include oyster density and abundance, epifaunal coverage, bed height and rugosity, and selected water quality measurements. Other sponsors and sites include:

- the St. James Plantation (golf course community), which built two large reefs (Research Sanctuaries) in Brunswick County that now serve as spat monitoring stations;
- the University of North Carolina at Wilmington, which has Research Sanctuaries in Spicer Bay/Kings Creek and Everett Bay; and
- Pender Watch and TNC, which have sponsored two sites that will be designated as Shellfish Management Areas in closed shellfish harvesting waters (S. Taylor/DMF, pers. com., 2008).

To provide better long-term protection for oysters, DMF (2008a) recommended that stakeholders and legal counsel investigate the feasibility of conservation leasing whereby environmental groups are allowed to lease coastal submerged lands and utilize portions of the water column for long term habitat restoration or enhancement projects rather than close these areas to any potentially damaging harvest practice through short-term proclamation only.

Researchers in Chesapeake Bay have recommended that 10% of the total shell bottom area be managed as sanctuaries to provide a means to restore this habitat closer to its original distribution and abundance (DMF 2008a). This equates to about 832 acres in North Carolina based on an estimate of total (mostly subtidal) shell bottom by Winslow (1889). Given no other caveats, at the current rate of sanctuary development, it could take over 100 years to reach a goal of 10%. However, other Marine Fisheries Commission (MFC) rules restricting mechanical bottom disturbing gear also provide varying levels of protection to other areas of shell bottom (see Threats-mobile disturbing fishing gear section). These areas serve as partial sanctuaries and should be included in the total area of shell bottom within protective designations.

Recent increases in funding for the Oyster Sanctuary program could accelerate the creation of sanctuaries (S. Slade/DMF, pers. com., 2008). However, it should be noted that there is less suitable habitat for oyster reef restoration than existed in the late 1880s, so the goal of restoring shell bottom to its original distribution and abundance is in all likelihood unrealistic. The causes of habitat unsuitability include sedimentation, hypoxic waters, and other water quality degradation (Ballance 2004). Many of the 1880 shell beds re-located by Ballance (2004) were covered in layers of sediment. There have also been changes in the hydrology and water quality covering oyster rocks that were lost due to poor harvest practices (refer to section on Water quality degradation). A more current comprehensive estimate of shell bottom abundance will be available when DMF bottom mapping is complete in late 2009 (B. Conrad/DMF, pers. com., 2008).

3.3.3.3. For mitigation

The first focused oyster reef restoration project in North Carolina occurred in 1992-1993 when 13 acres of oyster producing habitat were created on an existing, degraded reef 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 this site as part of a mitigation agreement with the U.S. Army Corps of Engineers (COE). Additional projects creating more than 70 acres of shell bottom have been planned with the USACE (Marshall et al. 1999), but are currently on hold until project details are agreed upon (C. Hardy/DMF, pers. com., 2008). *An improved mitigation policy is needed to identify mitigation needs, increase mitigation efficiency, and reduce project timelines*. The DMF has also performed mitigation projects for the North Carolina Department of Transportation (DOT) (Marshall et al. 1999). Since 1999, there have been at least three mitigation projects funded by various entities targeting the Crab Hole Oyster Sanctuary in northern Pamlico Sound (C. Hardy/DMF, pers. com., 2008). These mitigation projects resulted in an additional 12.65 acres of shell bottom created. The mitigated impacts included:

- Impacts from Highway 64 bridges in Dare County; DOT/Division of Coastal Management (DCM) provided funding in 2003 for the construction of 17 cultch mounds.
- Prop dredging by a crew with DOT (Ferry Division) in Currituck Sound; DOT provided funding in 2006 for the construction of 55 cultch mounds.
- Habitat lost due to Pirate's Cove development on Roanoke Island; conservation funds for mitigation were provided in 2007 for the construction of 26 cultch mounds.

The DCM does not allow mitigation to impact shell bottom for privately funded projects. In other words, direct impacts to shell bottom habitat are not allowed by DCM rules. *Where any depletion or loss of shell bottom is allowed, agencies should consider requiring mitigation. The EEP is developing an out-of-kind crediting system that could be employed in mitigating the permitted loss of shell bottom to water dependent development.*

3.3.3.4. Planning efforts

To coordinate various organizations' interests with DMF restoration work, a steering committee was established by the NCCF to draft an oyster restoration plan for North Carolina. The need for a comprehensive oyster restoration plans was also noted in Street et al. (2005). Some of the recommendations from the NCCF plan are reflected in the previous sections, as well as in the 2007-2009 CHPP implementation plan (See http://www.nccoast.org/publication/oysterplan/index_html for the final NCCF plan). The recommendations of interest involve cooperation and coordination between DMF and other organizations. The continuing development of financial, jurisdictional, and technical partnerships will undoubtedly help in reaching oyster protection and restoration goals. There are numerous organizations that play a role in the development and monitoring of shell bottom enhancement and restoration.

- The North Carolina Clean Water Management Trust Fund, NOAA's Community-based Restoration Fund, and Sea Grant FRGs provide funding for projects.
- University researchers and knowledgeable citizens provide guidance for site placement, seeding, and subsequent monitoring.
- Non-governmental organization, such as TNC and NCCF, help with all phases of a project (planning, funding, site development, monitoring, etc.).
- The North Carolina Division of Environmental Health (DEH) Shellfish Sanitation and Recreational Water Quality Program provides shellfish harvest closure information.
- The Ecosystem Enhancement Program local watershed plans prioritize shellfish waters affected by road construction and develop appropriate mitigation credits.
- The North Carolina Division of Water Quality (DWQ) basinwide plans help identify waters that are becoming more or less degraded.

- The State of North Carolina and USACE basin studies help evaluate sites for restoration potential.

One must also consider the added benefit of oyster restoration for other habitat types. There is a positive synergy between SAV growth, marsh formation, and shell bottom development (see Ecosystem enhancement section). So the above restoration efforts apply not only to shell bottom, but also riparian wetlands, and SAV.

Another aspect of oyster restoration involves watershed restoration and/or enhancement, a necessary component of any water-based restoration initiative (see "Water column restoration and enhancement" section of Water column chapter for more information). There are numerous planning efforts that prioritize lands for conservation/restoration, which could open the possibility for oyster restoration downstream.

- The North Carolina Department of Environment and Natural Resources (DENR) Conservation Planning Tool can help prioritize statewide conservation of both terrestrial and aquatic habitats. This strategic planning effort was meant to be a "one stop shop" for various conservation plan priorities based on multiple federal, state, nonprofit, and private programs.
- The Coastal Area Management Act (CAMA) land use plans could balance economic development with oyster restoration activities within their jurisdiction.
- The Ecosystem Enhancement Program local watershed plans can prioritize wetland mitigation sites based on oyster restoration potential downstream.
- The Onslow Bight Initiative plans can help prioritize conservation of both terrestrial and aquatic habitats in that particular region.
- Albemarle-Pamlico Conservation and Communities Collaborative (AP3C) developed by institutions interested in balancing the long-term conservation of natural systems with opportunities for the well-being of all the region's citizens coordinate efforts.
- Cape Fear Arch Conservation Collaborative - a partnership of organizations and individuals interested in protecting this region while balancing the needs of man and nature.

Appropriate DENR staff should continue to participate in collaborative efforts to plan, develop, and monitor the biological effectiveness of oyster enhancement and restoration activities.

3.3.4. Designated areas

Special designations may provide additional protection for shell bottom above the default level of protection granted wherever they occur. State designations protecting Shell bottom in public trust waters fall into basically three categories: (1) water quality protection, (2) physical habitat protection, and (3) both water quality and physical habitat. Water quality designations include Outstanding Resource Waters, High Quality Waters, Nutrient Sensitive Waters, and Water Supply Water I & II. These designations are described in the "Designations" section of the "Water Column" chapter. Physical habitat protections include trawling and mechanical methods prohibited areas, Crab Spawning Sanctuaries, Oyster Sanctuaries, Shellfish Management Areas, and Military Prohibited Areas. Both physical and water quality protections are afforded to open shellfish harvesting waters and Primary Nursery Areas. The protections are described later in reference to particular threats. The vast majority of mapped Shell bottom occurs within one or more designations providing some degree of additional protection, based on GIS analysis comparing SAV maps and regulatory designations (DMF unpublished data, July 2009).

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.

3.4.1. Physical threats and hydrologic modifications

3.4.1.1. 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, boat ramps, docks, piers, and bulkheads. Although the construction of water-dependent structures may actually increase substrate for oysters, negative impacts from such activities generally outweigh the benefits. Projects involving channel dredging for navigational purposes can remove, damage, or degrade existing shell bottom if permit reviewers, including DMF, NMFS, and N.C. Wildlife Resource Commission (WRC), do not advise against damaging project alternatives when making habitat value determinations. 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 (PNAs) are currently protected from dredging projects for deep-water access. However, some areas with extensive shell bottom habitat are not so explicitly protected from dredging. Oyster beds in closed shellfishing waters, which can provide similar habitat functions to those in open waters, are particularly vulnerable to loss and degradation from marina–associated impacts, unless significant adverse impacts to viable shell bottom can be identified by permit reviewers.

Turbidity and siltation over shell bottom can also occur from increased boating activity once a given marina or dock project is completed. Scouring of the bottom by frequent boat traffic causes resuspension of fine sediments, which is similar to the effect of dredging on nearby oyster beds. The associated boat wakes increase wave energies and shoreline erosion, and promote the development of dead margins along intertidal reefs (Grizzle et al. 2002; Walters et al. 2003; Wall et al. 2005). In a study of recruitment and survival of oysters in Mosquito Lagoon, Florida, Wall et al. (2005) found that reefs adjacent to areas with intense boating activity (i.e. those containing dead margins) had higher sediment loads, relative water motion, and juvenile oyster mortality than pristine reefs. Other studies in this same system have indicated reef migration away from the ICW, as well as total reef destruction in response to increased boating activity since the mid twentieth century (Grizzle et al. 2002). Current (2009) Coastal Resources Commission (CRC) marina siting rules discourage significant degradation of existing shellfish resources [CRC rule 15A NCAC 07H .0208].

Marinas can also negatively impact shell bottom through increased runoff from associated development and discharges from boats (see Water quality degradation section). Due to the potential for physical and water quality impacts, a variety of rules apply to development of new marinas in shellfishing waters. 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 Environmental Management Commission (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, the marina does not require a status review if the receiving waters are closed to shellfishing. This policy may unintentionally promote additional development, rather than restoration, in areas with degraded water quality, and can result in further degradation of water quality, as well as physical degradation of shell bottom habitat. Marinas may also be allowed in freshwater areas upstream of shellfishing waters, which may export toxins, microbes, and other contaminants downstream. Another issue is the similar effect of numerous multi-slip docking facilities in an area. Multi-slip docking facilities do not meet the definition of a marina and may be allowed in open shellfishing waters, after consultation with the DMF and other agencies, if no significant adverse impact can be demonstrated by permit reviewers. However, it is very difficult to determine when and where one additional multi-slip dock will cause a closure. The accumulation of multi-slip docking is therefore difficult to control based solely on potential to close shellfish waters. The accumulation of multi-slip facilities has been linked with shellfish harvest area closures (see "Water quality degradation-sources" section of Water column chapter for more information). *A threshold contamination level is needed to cap multi-slip docking facilities in open shellfish harvesting waters.*

A variety of work 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). As part of 2005-07 CHPP implementations, a workgroup was established to examine the issue of marinas and multi-slip docking facilities. The Sea Grant Marina Advisory Group completed its report on Multi-slip docking Facilities (MSDFs) and provided recommendations to the CRC in 2007. The report resulted in a revised application form for MSDFs (DCM-MP-4) designed to capture information that can be used to judge the impacts of projects. The CRC has also proposed changes to dock and piers rules which give property owners greater flexibility in docking facilities (8 sq. ft./linear ft. shoreline) and provides better protection of shallow water habitat by including minimum water depth for docks permitted under a general permit (2 ft) and minimum water depth for floating docking facilities under the general permit if located in a PNA, in SAV, or in shell bottom (18 in).

Bulkheads and other shoreline stabilization structures can also impact oyster populations. The placement of bulkheads along eroding shorelines causes scouring of sediment at the base and downdrift of the structure (Clark 1974; Watts 1987). The loss of fringing wetlands waterward of structures (see "Wetlands" chapter) can also mean the loss of associated oyster beds. However, shoreline structures may also provide substrate for oyster attachment, depending on the material used. One alternative to traditional shoreline stabilization in tidal estuarine waters involves the placement of oyster bags just above mean low water. It is well know that oyster spat prefer settlement on oyster shells compared to other hard structures. The addition of oyster shell bags may be a preferred alternative to other materials where engineered structures are considered necessary. The issue of shoreline stabilization is examined more closely in the "Wetlands" chapter.

3.4.1.2. Fishing gear impacts

Mobile bottom disturbing fishing gear

Mechanical fishing gear includes any gear that is towed or run by engine power, including oyster dredges, hydraulic clam dredges and clam kicking gear, bottom trawls, and patent tongs. Over-harvesting and habitat destruction from excessive 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 Carolina. Although other factors had contributed to the decline in the oyster fishery, dredging and tonging had the greatest impact on the physical structure of reefs in Chesapeake Bay (Hargis and Haven 1988; Rothschild et al. 1994). One full season of simulated oyster dredge harvesting effort reduced the mean height of high profile oyster mounds by 30% (Lenihan and Peterson 1998; DeAlteris et al. 1999).

Oyster harvesting reduces the vertical relief of subtidal oyster reefs (Marshall 1954) and oyster dredging results in several additional negative habitat impacts, including scattering and removing shell and oysters and destabilizing the shell structure (Lenihan and Peterson 1998; Lenihan et al. 1999). These harvesting effects result in reduced spawning stock biomass, reduced substrate availability for recruitment, reduced structural complexity utilized for refuge and foraging by juvenile fish and crustaceans, and decreased resistance to disease. [75]

Between the 1970s and 1990s, the negative impact of oyster dredging and other mechanical methods on shell bottom was recognized, and areas were designated where all mechanical methods for shellfish harvest were prohibited by rules of the MFC Areas [MFC rules 15A NCAC 03N .0104 and .0105, 03J .0103, 3J .0104] (Maps 3.5a-b). These methods include towed dredges, hydraulic dredges, patent tongs, rakes powered by an engine, and clam kicking. In October 2004, additional areas in the Pamlico Sound system were prohibited to mechanical harvest (DMF 2008a). These additional areas are located primarily in the upper portion of Pamlico Sound tributaries and small bays. The majority of larger bays along Pamlico Sound remain open to mechanical harvest methods (Map 3.5a-b).

Although the use of oyster dredges has been limited by the MFC in recent years due to habitat impacts (DMF 2008a), historically fished subtidal oyster beds have not recovered (Lenihan and Peterson 1998), and oysters are still listed as a species of concern in the 2008 DMF stock status report (DMF 2008d). Degraded water quality, partially due to reduced filtration by oysters after stocks were reduced, and increased disease occurrence from environmental stress are thought to have prevented full recovery (Lenihan and Micheli 2000; Jackson et al. 2001). The extent of dredge damage to shell bottom depends on trip duration and frequency, as well as the amount of oyster reef area worked over time (Powell et al. 2001). Some of the damage is mitigated through re-planting with cultch at 3-4 year time intervals (Map 3.4a).

Trawling for shrimp, crabs, and finfish, 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 living shell bottom habitat.

There are several different fishing gear restrictions and designations that limit some or all bottom disturbing gears permanently or seasonally (Table 3.3). On nearly 400,000 acres or 70% of the bottom mapping area, trawling, oyster dredging, or mechanical shellfish harvesting is prohibited (Table 3.3). However, only 36% of the bottom mapping area is protected from all these bottom disturbing gear year-round. This protected area includes PNAs, Shellfish Management Areas, and locations where No Trawl Areas or Secondary Nursery Areas (SNAs) overlap with Mechanical Methods Prohibited (Map 3.5a-b, Table 3.3). South of Pamlico Sound, a significant portion of the bottom mapping area is closed to oyster dredging but not to trawling. However, trawling generally occurs in deeper channels, avoiding the majority of the oyster beds, which are intertidal. Wherever bottom disturbing gears are allowed in subtidal oyster habitat, creation, maintenance, and re-establishment of oyster beds may be deterred. Bottom disturbing gear is problematic where deepwater oyster restoration is occurring or natural processes favor re-establishment of deepwater oyster beds.

In other areas, such as Special SNAs and Crab Spawning Sanctuaries (47,423 acres, 8% of bottom mapping area), trawling or dredging is prohibited at certain times of the year. In military designations,

[75] See disease section for more information

the federal government has the authority to allow or prohibit all or some fishing activities on a case-by-case basis. Mechanical clam harvesting and crab dredging are severely limited and are only allowed in specific defined areas, usually on soft bottom habitat. Permanent shellfish harvest closures due to polluted waters, prevent harvest of shellfish with any gear. Many of these closed waters overlap with PNAs or SNAs, where dredging and trawling for fish species is also prohibited. Closed and conditionally approved closed shellfish harvesting waters contribute 18,159 acres (~3% of Shellfish Habitat and Abundance Mapping Program focus area) to the area prohibited to bottom disturbing methods.

Table 3.3. Amount of bottom habitat mapped (acres) by the North Carolina Division of Marine Fisheries Shellfish Habitat and Abundance Mapping Program within areas receiving specific North Carolina Marine Fisheries Commission designations that restrict fishing activities (as of September 2008).

Bottom disturbing fishing gear prohibited	Acres within the bottom mapping area	Portion of bottom mapping area (%)
Only oyster dredging[1]	152,247	25.68%
Only trawling[2]	20,525	3.46%
Only shrimp trawling	30,471	5.14%
Both trawling and oyster dredging[3]	214,308	36.15%
Other MFC designations		
Crab Spawning Sanctuaries	17,673	2.98%
Military designations	24,051	4.06%
Seed Management Areas	628+	>0.11%
Planted Shellfish Management Areas and oyster sanctuaries[4]	100+	<0.01%
Special Secondary Nursery Areas	29,750	5.02%

[1] Designations include Primary Nursery Areas and Mechanical Methods Prohibited

[2] Designations include Permanent Secondary Nursery Areas and Trawl Net Prohibited

[3] PNAs + overlap of SNAs or No Trawling Areas with Mechanical Methods Prohibited areas

[4] Some sanctuaries are located outside the shellfish bottom mapping area.

With 36% of the Shellfish Habitat and Abundance Mapping Program focus area (potential shellfish habitat) permanently protected from the major bottom disturbing gears, the level of protection is above the recommended average (20-30%) in marine protected area literature (NRC 2001). However, these protected areas are not evenly distributed throughout the coast (nearly 100% of shell bottom in the southern region is protected from dredging). In addition, this protecetion does not prevent habitat losses from hand harvest, water-dependent development, and water quality degradation. *Once shell bottom mapping for the Pamlico Sound is complete, the portion of high (oyster) density, subtidal shell bottom open and closed to trawling and dredging should be determined.*

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. Oyster mortality was attributed to incidental shell damage and sedimentation from harvesting. Conversely, oyster harvesting had little effect on clam populations. The DMF conducted field investigations on the impact of clamming on oyster beds in a Carteret County creek, and the effectiveness of designating Shellfish Management Areas, where clamming was prohibited from December to March, and oystering was limited to hand harvest (Noble 1996). The DMF found that the structural integrity and oyster abundance on most of the surveyed oyster rocks were good and, in most cases, had improved following the implementation of the Shellfish Management Area restrictions. Because restrictions were successful in curbing the destruction and deterioration of oyster rocks, the Shellfish Management Area designation was extended to other waters to protect shell bottom habitat, with several locations periodically marked for closure by proclamation of the Fisheries Director (C. Caroon/DMF, pers. com., 2008).

Noble (1996) 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. Clamming on oyster beds is primarily a concern for open harvesting areas south of Core Sound (DMF 2008a). Oyster rocks are protected from mechanical harvest of clams and bull rakes by MFC rules [15A NCAC 03K .0304 and 03K .0102]. The DMF has also designated some areas as Shellfish Management Areas where enhancement activities are conducted (shell is added and/or oysters are transplanted) and oystering and clamming are restricted or prohibited, except by proclamation. (Map 3.4a-b). However, there are very few oyster beds posted as Shellfish Management Areas anywhere in the state due to the localized nature of such destructive harvesting, as well as limited enforcement capabilities. *Creation of additional Shellfish Management Areas in locations of intense hand harvest would reduce habitat damage and enhance spatfall of oysters and clams.*

There are currently over 628 acres of Seed Management Areas south of Bogue Sound that are part of the DMF Shellfish Habitat and Abundance Mapping Program focus area (Table 3.3). There are also oyster Seed Management Areas at the south end of Roanoke Island in Cedar Bush Bay, and in Bay River at Spencer Point. Oyster/Research Sanctuaries and Shellfish Management Areas cover over 200 acres in coastal waters and over 100 acres in the Shellfish Habitat and Abundance Mapping Program focus area (Table 3.3). Currently, almost 90% of the bottom mapping area is open to hand harvest methods.

3.4.2. Water quality degradation

Degradation of the water column affects all living habitats features of the coastal aquatic ecosystem. Whereas the primary discussion of water quality degradation resides in the “Water Column” chapter, the major water quality issues for shell bottom are summarized in this section.

3.4.2.1. Nutrient and eutrophication

Anthropogenic nutrient loading from expanding urban, agricultural, and industrial development can indirectly impair shell bottom habitat by stimulating nuisance phytoplankton blooms and causing episodic oxygen depletion. Recent research indicates that the magnitude of eutrophication in coastal waters has increased globally over the past century (Paerl et al. 1995; NRC 2000; CENR 2003; Selman et al. 2008). Increasing eutrophication, in turn, has caused the frequency, duration, and spatial extent of hypoxia (< 2 mg O_2 l^{-1}) and anoxia (0 mg O_2 l^{-1}) to intensify in many estuaries due to increased biological oxygen demand (Lenihan and Peterson 1998; CENR 2003; Diaz and Rosenberg 2008; Selman et al. 2008). Prolonged periods of hypoxic conditions can cause mass mortalities of oysters and other shellfish, and can significantly decrease oyster spatfall (Sparks et al. 1958; Widdows et al. 1989; Baker and Mann 1992; Lenihan and Peterson 1998). The detrimental effects of oxygen depletion are exacerbated on fishery-disturbed oyster beds where reduced reef heights increase exposure of oysters and other sessile invertebrates to bottom water hypoxia/anoxia (Lenihan and Peterson 1998; Kirby and Miller 2005).

Data have shown that eutrophication, as indicated by nutrient levels and high chlorophyll *a* concentrations, is a concern in North Carolina coastal waters. According to the most recent draft DWQ integrated 305(b) and 303(d) report (DWQ 2008a), there are approximately 43,870 acres of coastal waters impaired by excessive chlorophyll *a* levels. Additionally, 1441.5 acres of shellfish producing (SA) waters are impaired by low dissolved oxygen (< 5 mg O_2 l^{-1}), an indication of excessive nutrients. In an Environmental Protection Agency (EPA) sponsored four-year study in North Carolina, low dissolved oxygen and low infaunal communities within SA waters were most frequently reported in Pamlico River and the lower portion of Neuse River where nutrient loading has been problematic (Hackney et al. 1998).

Eutrophic conditions can also trigger harmful algal blooms (HABs) (CENR 2003; Selman et al. 2008). Algal toxins associated with HABs affect the nervous system of fish and shellfish, inhibiting respiration (Tyler 1989). Oysters, clams, and other benthic organisms eventually die of suffocation because of nervous system paralysis. In laboratory trials, significant mortality of oyster embryos was documented when exposed to the toxic dinoflagellate *Karlodinium veneficum* (Stoecker et al. 2008). It was suggested that survival and maturation of oyster embryos and larvae may be reduced when spawns coincide with high density *K. veneficum* blooms during the summer months. Exposure of oysters to laboratory cultures of *Heterosigma akashiwo* caused significant long-term sublethal physiological effects, including hepatopancreas lysosomal destabilization, which can compromise oyster resilience to other environmental stressors (Keppler et al. 2005). Other shellfish, such as the bay scallop, are also vulnerable to the negative effects of HABs. Research during an outbreak of the red tide *Karenia brevis* in North Carolina documented recruitment failure, as well as widespread adult mortality of bay scallops in Bogue and Back sounds (Summerson and Peterson 1990).

Multiple sources and activities contribute to excessive nutrient loading of surface waters, including agricultural fertilizer use, sewage discharge, industrial effluent, filling of wetlands, loss of riparian buffers, stormwater runoff from developed areas, ditching, channelization, and atmospheric nitrogen deposition from fossil fuel combustion and animal operations (Cooper and Brush 1991; Paerl et al. 1995; CENR 2003; Selman et al. 2008). Catastrophic weather events, such as hurricanes, tropical storms, and nor'easters, can also greatly increase delivery of nutrients to coastal waters. High volume discharge of nutrient-laden floodwaters following Hurricanes Fran and Bertha in 1996 and Hurricanes Dennis, Floyd, and Irene in 1999 resulted in large-scale hypoxia in the Neuse, Tar, Cape Fear, and Lumber Rivers, as well as in Pamlico Sound (Mallin et al. 1999b; Bales et al. 2000; Paerl et al. 2001). Although hypoxic conditions often occur naturally following such weather events due to flushing of swamp waters and heavy precipitation, environmental damage was exacerbated by failure of animal waste lagoons and municipal and private wastewater-treatment facilities, allowing large quantities of organic waste to enter coastal waters (Mallin et al. 1999b). *Excessive nutrient loading from wastewater-treatment facilities, animal operations, and other sources must be reduced upstream of shell bottom habitat in order to minimize hypoxia-induced mortality of shellfish and associated organisms.*

Several initiatives have already been taken to reduce nutrient levels in coastal North Carolina. The North Carolina General Assembly established the Lagoon Conversion Program [SL 2007-0523] in which, among other things, grants are provided to assist in the conversion of animal waste management systems that serve swine farms from anaerobic lagoons to innovative animal waste management systems. The EMC has designated a number of coastal river basins as Nutrient Sensitive Waters, requiring removal of wastewater discharges and other management actions to reduce nutrient inputs. The EMC has also mandated a 30% reduction in nitrogen loading in the Neuse and Tar-Pamlico river basins from regulated sources. Effective October 1, 2008, new Coastal Stormwater Rules [SL 2008-211] require more stringent stormwater controls for development within 0.5 mi of, and draining to, SA waters. High-density development projects in these areas must control and treat runoff generated by 1.5 in of rainfall or the excess runoff (as compared to pre-development conditions) generated by the 1-year, 24 hour storm (whichever is greater), while low-density development projects must maintain a maximum built upon area of 12% or less. A 50-ft vegetative setback from mean high water was also mandated for all new development within the 20 coastal counties to increase the filtration function of these buffers. Nutrient loading in watersheds draining to shell bottom habitat, however, remains an issue. *Reductions in nutrient loads draining to coastal shellfish waters must be achieved by increasing inspections and improving maintenance of sewage treatment facilities, collection infrastructure, and on-site wastewater systems.*[76]

3.4.2.2. Sedimentation and turbidity

Excessive turbidity and sedimentation can have profound effects on oyster health and viability. As suspended sediment disperses 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 clog the gills of shellfish, increase survival time of pathogenic bacteria, or increase ingestion of non-food particles (SAFMC 1998a). Oyster eggs and larvae are most sensitive to suspended sediment loading (Davis and Hidu 1969a).

Sediment has been considered the largest cause of water quality degradation in the Albemarle-Pamlico estuarine area (DEM 1989). In 2008, 12,017 saltwater acres (sounds, ocean) and 11 saltwater miles (tidal creeks) were impaired due to turbidity (DWQ 2008a). This amount of impairment represents less than 1% of the total saltwater acres and stream miles in North Carolina. However, turbidity is only sparsely measured in estuarine and marine waters. *There remains a need to enhance monitoring of turbidity in estuarine waters and in the adjacent nearshore ocean.*

There are many 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, and 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). There was also a recent FRG project (03-EP-03) that found many historic oyster bed foundations silted over (Ballance 2004). Use of bottom disturbing fishing gear, including hydraulic clam dredges, clam trawls (kickers), and shrimp and crab trawls can also increase turbidity and sedimentation on and adjacent to oyster reefs. *Restoration activities should be planned to restore natural hydrology, dredge excess sediment, reduce the sources of excess sediment, and plant oysters on historic oyster bed foundations.*

Sediment in excessive amounts is also problematic because it transports pathogenic microorganisms and toxic chemicals in stormwater, and allows the bacteria to persist longer in the water column than such bacteria would live in clear waters (Schueler 1999; Fries et al. 2008; Jartun et al. 2008). See the microbial and chemical contamination sections below for more information on pathogenic microbes and toxic chemicals. The issue of sedimentation in streams is more thoroughly discussed in the "Water Column" chapter.

3.4.2.3. Microbial contamination

Elevated levels of fecal coliform bacteria in shellfish and adjacent waters do not harm oysters or clams. Such levels indicate contamination of waters, shellfish, and sediments from warm-blooded animal waste.

[76] See the Water Column chapter for more information on water quality degradation affecting shell bottom.

Because of the sources and pathways of fecal coliform, high bacteria levels are an indication that other 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. 2000a; 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 DEH shellfish harvest closure areas provide oysters protection from harvesting in North Carolina. Based on surveys and bacterial sampling, the DEH may recommend waters as closed to shellfish harvesting, on either a full-time basis (permanent closure) or rainfall-dependent basis (conditionally approved). 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). Some closed shellfish harvesting water may therefore have significant habitat value as shell bottom. Research is currently underway to address the question of oyster condition in closed areas and evaluate the potential function of closed areas as sanctuaries in the southern region (T. Alphin/UNC-W, pers. com., 2008). Similar work is needed in closed areas of the central and northern regions. In the mean time, some non-government organizations have sponsored Research Sanctuaries in closed areas (see “Shell bottom enhancement and restoration” subsection). Construction of sanctuaries in closed areas could highlight those robust oyster populations in permit decisions. *Identifying oyster beds with robust oyster populations in closed shellfish harvesting areas will help permit reviewers evaluate marina projects in shellfish harvesting waters. Protecting oyster beds in closed harvesting area may also be more acceptable to oyster harvesters who have seen a growing area of closures over the years.* The general location of high quality oyster beds in shellfish growing areas was assessed and summarized in Haines (2004).

3.4.2.4. Toxic chemicals

Toxic chemicals include any substance or combination of substances that can cause adverse health effects to oysters and other aquatic organisms. Such chemicals include heavy metals, petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), dioxins, pesticides, antifoulants, and pharmaceuticals. Heavy metals and PAHs are of particular concern with regard to oyster resources due to bioaccumulation and human health concerns (Huanxin et al. 2000; Sanger and Holland 2002; O’Conner and Lauenstein 2005). Many of these toxic chemicals enter estuarine waters through urban stormwater runoff and accumulate in adjacent sediments (Dauer et al. 2000; Williamson and Morrisey 2000; Hwang and Foster 2006; Jartun et al. 2008). Spills and releases of industrial effluent and waste can allow toxic chemicals to occur in acutely toxic concentrations.

Oyster embryos and larvae are more sensitive to toxic chemical effects than adults and juveniles, which are generally more tolerant of contaminants than most estuarine species (Funderburk et al. 1991). The substances having the greatest chronic (sublethal) effect on oysters include tributyltin, heavy metals, petroleum hydrocarbons, PCBs, and dioxins (Funderburk et al. 1991; Chu et al. 2003; Wintermyer and Cooper 2007; Ivanina et al. 2008). Acute and chronic toxicity of certain toxic chemicals to oysters and hard clams, as well as the current North Carolina saltwater surface water quality standards [EMC rule 15A NCAC 02B .0200], are listed in Table 3.4. Current surface water quality standards are sufficiently stringent to protect these species. For those toxicants with no listed standard, EMC rule 15A NCAC 02B .0208 allows for the calculation of criteria to prevent chronic toxicity.

Several studies have documented the effects of toxins associated with placement of docks and marinas on the estuarine environment (Wendt et al. 1990; Steel 1991; Sanger and Holland 2002; Kelty and Bliven 2003; Sanger et al. 2004). Contaminants entering estuarine waters from such development, such as heavy metals and PAHs, can cause acute toxicity (mortality) and sublethal stress on oysters and other estuarine benthos. Research conducted in South Carolina found that densities of oyster spat were significantly reduced at marina sites as compared to controls (Wendt et al. 1990). During the summer months, increased marina activity intensified tissue concentrations of several PAHs in marina-associated oysters. Copper concentrations in oyster tissue were also 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).

Table 3.4. Comparison of acute and chronic (sublethal) toxicity (μg/l) levels for oysters and clams with North Carolina's 2007 saltwater surface water quality standards.

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	-	-	-	50
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	-	-	-	20
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 (polychlorinated biphenyl)	10	13.9	-	-	0.001
Permethrin (insecticide)	>1,000	-	-	-	[2]
Toxaphene (insecticide)	23	40	<250	1,120	0.0002
Tributyltin (antifoulant)	1.5	0.7	0.05	0.08	0.007
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 (2008), 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.

The extent of contamination from Copper/Cromium/Arsenic (CCA) could be significant, considering the quantity of treated timber used by the marine construction industry for bulkheads, docks, and marinas (Weis and Weis 1994). Although the toxicity of treated wood decreases over time, with most leaching occurring in the first five to six days (Sanger and Holland 2002), dock pilings and bulkheads are periodically replaced, providing a continual source of newly treated wood in coastal waters. Effective December 31, 2003, the EPA mandated that no wood treater or manufacturer may treat wood with CCA for residential uses, with certain exceptions. This CCA prohibition excludes "wood for marine construction" (i.e., subject to immersion and/or salt or brackish water splash) (<http://www.epa.gov/oppad001/reregistration/cca/ cca_strategy5.pdf >, October 2008). Moreover, alternative wood preservatives such as alkaline copper quaternary (ACQ), copper boron azole (CBA), ammoniacal copper zinc arsenate (ACZA), and creosote may have similar toxicity to marine organisms. Spot (*Leiostomus xanthurus*) exposed to creosote-derived PAH concentrations as low as 320 µg/l exhibited fin erosion and skin lesions (Sved et al. 1992). *Any new wood preservative product should be evaluated for impacts to marine organisms, including oysters.*[77] *Furthermore, recycled plastics, concrete, and natural rock are non-wood alternatives that do not require any chemical preservatives and should be recommended for use in future water-dependent development projects.*

Endocrine disrupting chemicals

There is increasing concern regarding the presence and effects of endocrine disrupting chemicals (EDC) entering surface waters of freshwater, brackish, and marine environments (Cooper et al. 2008). EDCs are exogenous substances that alter an organism's reproductive physiology and morphology (WHO 2002). EDCs include natural and synthetic estrogens, dioxins, PCBs, as well as other chemicals. These chemicals originate mostly from wastewater-treatment plant discharge and industrial effluent, but sources also include runoff from animal operations and use of sewage sludge as fertilizers (Cooper 2008). EDCs have been found to have significant negative effects on oyster gametogenesis and reproductive success (Chu et al. 2003; Wintermyer and Cooper 2007). Exposure of oysters to relatively low concentrations of PCBs in a laboratory setting resulted in decreased lipid metabolism, altered spawning and diminished oocyte development (Chu et al. 2003). Similarly, at concentrations as low as 2 ppt, dioxin has been documented to cause decreased oyster fertilization success and veliger development (Wintermyer and Cooper 2007). A recent study conducted in Taylor's Creek near Beaufort, North Carolina found increasing proximity to a wastewater-treatment facility associated with declines in oyster fecundity (Romano 2007; P. McClellan-Green/NCSU, unpub. data).

The extent and magnitude of EDC contamination in North Carolina's estuaries is currently unknown. However, this knowledge is necessary to assess the seriousness of potential adverse impacts on the native oyster population. U.S. Geological Survey (USGS) monitoring in upper portions of coastal rivers (Neuse and Cape Fear rivers) indicates that a broad range of endocrine disrupting chemicals were present at low concentrations (Giorgino et al. 2007). *An EDC monitoring program should be established through cooperative efforts of DMF, DWQ, Shellfish Sanitation, USGS, and the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) to determine the presence and concentrations of selected chemicals in North Carolina's coastal waters, beginning in the Neuse River estuary. Additionally, funding from FRGs and other programs is needed to provide support for further research on oysters and their response to EDCs at critical life stages.*

Fossil fuels

Exposure to hydrocarbons can be toxic to or alter proper development of oyster embryos and larvae (Geffard et al. 2003). Consequently, oyster spat development on shell material covered in petroleum products has been shown to decline, although barnacles tended to flourish due to the reduced competition (Smith and Hackney 1989; Roberts et al. 2008). Generally, oysters can recover from spills as long as they are small scale (i.e. a small leak), but with larger spills during the period of highest settlement recovery may be hindered by the presence of oil (Hulathduwa and Brown 2006).

Shellfish are known to be good indicators of contaminants due to their ability to accumulate chemicals, including PAH in their soft tissue (Jackson et al. 1994). Blue mussels, *Mytilus edilus,* have shown a

[77] See Soft bottom chapter for management needs concerning toxic contaminants affecting benthic invertebrates.

slowed growth rate when exposed to oil. This reduced growth rate was due in part to a reduced feeding rate and food absorption efficiency (Widdows et al. 1987). In laboratory experiments oysters showed a reduced filtration rate when exposed to PAH (Mu-Chan et al. 2007). Although oil can have negative impacts on shellfish, laboratory experiments have shown that shellfish have the ability to eliminate levels of PAH once removed from contaminated water and placed in clean water (Enwere 2009). These results are consistent with other studies showing shellfish eliminating PAH levels in varying time periods (2-120 days) depending on the type of oil and the length of exposure (Pruell et al. 1986; Boehm et al. 1998; McIntosh et al. 2004; and Richardson et al. 2005). It is important to note that monitoring has to be complete to reduce the chances of PAHs, a known carcinogen, entering the market through commercial fisheries. With continued monitoring these levels can be assessed to determine if shellfish are safe for human consumption.

3.4.3. Diseases and microbial stressors

The protozoan pathogens *Perkinsus marinus* (Dermo) and *Haplosporidium nelsoni* (MSX) have caused significant oyster mortality throughout the species' geographic range (Andrews 1988; Hargis and Haven 1988; Kennedy 1996; Lenihan et al. 1999). Although MSX can infect all ages of oysters (Andrews 1966; Barber et al. 1991), Dermo infects a disproportionate amount of larger, more fecund individuals (Mackin 1951; Ray 1954; Andrews and Hewatt 1957). Once infected, oysters suffer reduced growth, poor condition, and diminished reproductive capacity (Ray and Chandler 1955; Haskin et al. 1966; Ford and Figueras 1988; Ford and Tripp 1996). Eventually, mortality results as a consequence of tissue lysis and occlusion of hemolymph vessels.

Infection rates of both pathogens generally increase with water temperature and salinity (Paynter and Burreson 1991; Ewart and Ford 1993; La Peyre et al. 2006). Salinities below 10 ppt are energetically stressful to Dermo and are lethal to MSX when persisting for two weeks or more (VIMS 2002; La Peyre et al. 2006; DMF 2008a). Reduced salinities associated with freshet events have been found to decrease pathogen prevalence and infection intensities, resulting in low oyster mortality and good growth (La Peyre et al. 2003; Tarnowski 2005). In contrast, elevated salinities during drought years allow for infection intensification (Rebach 2005) and range expansions into areas where Dermo and/or MSX had been rare or absent (Burreson and Ragone Calvo 1996; Tarnowski 2003). In spite of severe to extreme drought conditions in North Carolina from 2007 to 2008, Dermo infection intensity was low and disease-related oyster mortality was, on average, negligible (DMF, unpub. data). Nevertheless, Dermo prevalence, infection intensity, and disease-related oyster mortality may increase significantly if optimum conditions for parasitic growth and dispersal continue to persist (DMF 2008a).

Although both Dermo and MSX have been documented in North Carolina's estuaries, Dermo has been responsible for the majority of adult oyster mortality in recent years (DMF 2008a). Intense hurricane activity and the associated heavy rainfall experienced in North Carolina since 1996 has periodically reduced salinities in Pamlico Sound, and consequently, the occurrence of MSX in that area (DMF 2008a). Conversely, Dermo prevalence has remained near 100% coastwide during that same time period (Fig. 3.4), although disease-related mortality has been relatively low (DMF 2008a). It is interesting to note that the recovery of oyster recruitment during 2000-2006 coincided with a very low occurrence of high level Dermo infections (DMF 2008a), indicating possible pathogen regulation of spawning stock and recruitment potential. Some research results suggest that North Carolina oysters are developing an increased resistance to Dermo infections (Brown et al. 2005), but more testing is needed.

Environmental stressors, such as low dissolved oxygen, sediment loading, and anthropogenic pollution, increase the susceptibility of oysters to parasitism and disease (Barber 1987; Kennedy 1996; Lenihan et al. 1999). Research on experimental subtidal oyster reefs in the Neuse River estuary (Lenihan et al. 1999) found that oysters with the highest Dermo prevalence, infection intensity, and mortality were located at the base of reefs, where currents and food quality were lowest and sedimentation rates highest. Oysters located at the crest of reefs, however, were much less susceptible to parasitism and Dermo-related mortality. *Maintenance of high-profile oyster rocks is, therefore, critical for subtidal oysters to perform their ecological functions, as well as provide resources for harvest*.

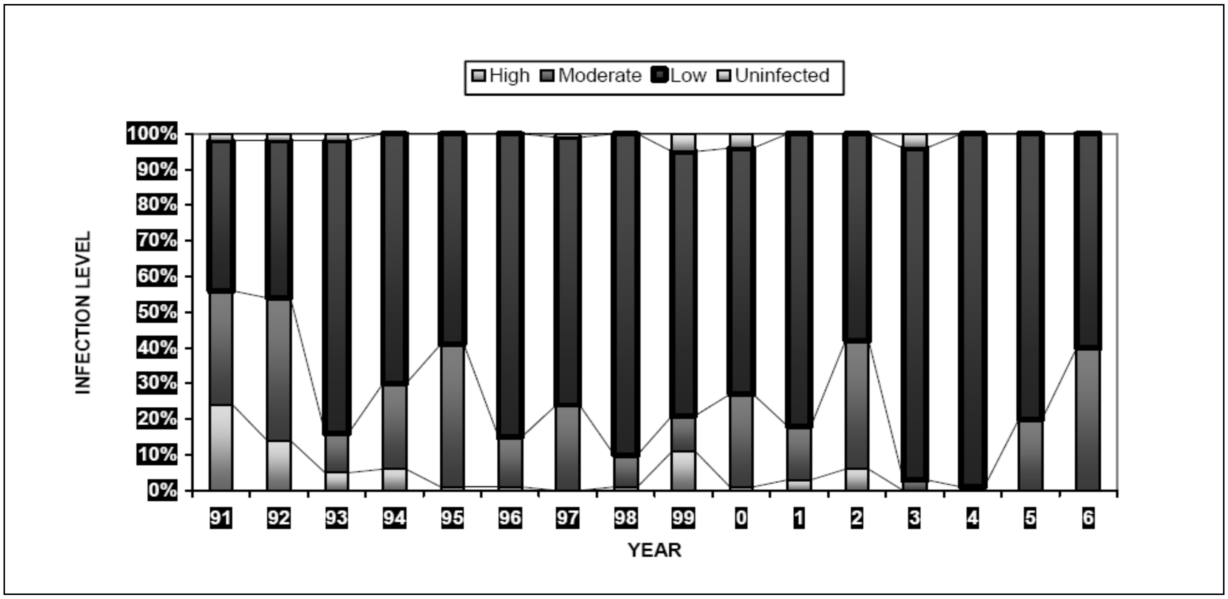


Figure 3.4. Infection categories and proportion of individuals infected by *Perkinsus marinus* in North Carolina 1991-2006. [Source: DMF 2008a]

Changes to environmental conditions as a result of anthropogenic activities can also affect disease-related oyster mortality. Activities such as inlet dredging for navigational channels artificially increase salinities (SAFMC 1998a), creating conditions more favorable to oyster pathogens. In North Carolina, both Cape Fear and Beaufort inlets have been extensively deepened for navigational access to state ports. Shellfish waters adjacent to these inlets are especially vulnerable to increases in salinity. However, inlet deepening may also improve tidal flushing in the immediate area. High flushing rates have been speculated as the major cause of higher survival of oysters in the southern estuaries at Dermo infection intensities similar to Pamlico Sound stocks (DMF 2008a). *The relationship between channel deepening, saltwater intrusion, flushing rates, and oyster mortality must be evaluated in order to determine appropriate management action.*

Although countless oysters are exposed to disease during one or more stages of their life history, some are able to survive and reproduce. These “disease resistant” individuals are important to the survival and recovery of oyster populations in North Carolina (Breitburg et al. 2000). Harvest of large mature oysters that have survived disease infections, however, selectively removes this disease resistant genotype from the population. *Oyster Sanctuaries and restoration sites should be seeded with disease resistant oysters in an effort to enhance oyster survivability and provide disease resistant broodstock for repopulating highly impacted areas*.

3.4.4. Non-native, invasive, or nuisance species

Non-native species introductions are a growing and imminent threat to living aquatic resources throughout the United States. The accidental or intentional introduction of such species puts the health and viability of North Carolina shell bottom habitat at risk. Non-native species enter North Carolina waters by means of vectors, such as discharge of ballast water, releases from aquaria and mariculture facilities, and boat movement from areas outside the state (North Carolina Sea Grant 2000; Carlton 2001). These organisms are then able to disperse through river systems and created waterways. State laws and rules of several commissions are in place to control intentional introductions of organisms not native to North Carolina. Proposals to introduce non-native species into North Carolina coastal waters, or species native to North Carolina when the individuals in question originate outside North Carolina, are subject to MFC rule 15A NCAC 3I .0104. A written application must be submitted to the Fisheries Director with sufficient information for the Director to "determine the level of risk to any native marine resource or the environment."

Bioinvasions of zebra mussels (*Dreissena polymorpha*) have not been reported in North Carolina as of yet, but they have been found in Virginia and Tennessee, as well as 23 other states (Benson and Raikow 2008). The rapid rate that this non-native has spread in the United States has led researchers to presume that zebra mussels are likely to invade all southeastern states eventually, with negative impacts to the native freshwater and low salinity mollusks (Neves et al. 1997). Zebra mussels are notorious for their biofouling capabilities, frequently clogging water intake pipes and smothering native mussels and large crustaceans (i.e., crayfish) (Benson and Raikow 2008). It is estimated that 13 species of native freshwater mussel could be extirpated from North Carolina streams and rivers if zebra mussels were to invade, and among those, four species could become extinct (North Carolina Sea Grant 2000). 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).

The substantial decline of North Carolina's native oyster population has prompted resource managers to consider the introduction of non-native oysters for fishery restoration and ecosystem enhancement (DMF 2008a). While some oyster introductions have revived or expanded oyster fisheries (e.g. Europe and Australia) (Shatkin et al. 1997), others have failed or caused problems (Andrews 1980; DMF 2008a). The deadly oyster disease MSX was introduced with attempts to establish Pacific oyster (*Crassostrea gigas*) populations along the Atlantic coast of the United States (Burreson 1997; Richards and Ticco 2002). If native oyster stocks cannot recover naturally, however, establishment of a non-native oyster population could provide complex structure for fish habitat, water filtration functions, and preserve a traditional North Carolina fishery.

Although several candidates for non-native oyster introduction have been considered, the Suminoe oyster (*Crassostrea ariakensis*) has proven most promising (USACE 2008; DMF 2008a). Laboratory and field trials have consistently shown rapid growth and survival of *C. ariakensis* under a suite of environmental conditions typical of estuaries in the Middle and South Atlantic Bights (Richards and Ticco 2002; NRC 2003; Bishop and Peterson 2005; Peterson 2005; Bishop and Peterson 2006a; VIMS 2007). Overboard tests in Newport River, North Carolina found that *C. ariakensis* was able to provide ecosystem services, such as enhancement of benthic secondary production and water filtration functions, similar to that of native oysters without substantial ecological costs (Peterson 2005). *C. ariakensis* was also documented to have a significant level of tolerance to the parasite-induced diseases Dermo and MSX during initial studies in the Chesapeake Bay (Richards and Ticco 2002; USACE 2008; Paynter et al. 2008). However, recent investigations have shown that *C. ariakensis* can acquire advanced Dermo infections capable of causing substantial mortality (Moss et al. 2006; Schott et al. 2008). Additionally, the Suminoe oyster is highly vulnerable to a novel haplosporidium parasite *Bonamia* spp. (Audemard et al. 2008a; Audemard et al. 2008b; Carnegie et al. 2008), as well as predation by blue crabs (Bishop and Peterson 2006b), *Polydora* spp. infestations (Bishop and Peterson 2005), and the ichthyotoxic dinoflagellate *Karlodinium veneficum* (Brownlee et al. 2006; Brownlee et al. 2008). These susceptibilities potentially limit the ecological and economic benefits of Suminoe oyster introduction.

Introduction of non-native oysters remains a subject of much debate and uncertainty. A draft

Programmatic Environmental Impact Statement (PEIS) was recently completed by the USACE concerning the use of non-native oysters for fishery and ecosystem restoration in the Chesapeake Bay (USACE 2008). Although recommendations have yet to be made, the draft PEIS does highlight three alternatives to investigate more thoroughly. One option calls for native oyster aquaculture and enhanced efforts to restore native oyster populations. Another calls for enhanced native restoration efforts and aquaculture, as well as large-scale aquaculture of sterile triploid Suminoe oysters. A third option contains all the recommendations of the second but would also introduce fertile diploid Suminoe oysters with the intention of creating a self-sustaining wild population. All three options include a temporary moratorium on the harvest of wild oysters, with a compensation program for watermen. Nevertheless, concerns over non-native oyster introduction remain, including competition with native oysters, cross-fertilization (reducing viability of spat and decreasing reproductive success), long-term survival of introduced species, and introduction of non-native pests with the introduced oysters (USACE 2008; DMF 2008a). Policy makers are faced with a dilemma of 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). In November 2008, the MFC decided to write a letter commenting on the PEIS, expressing concern that an introduction of non-native oysters into the Chesapeake Bay would likely result in an unwanted introduction in North Carolina waters. *The MFC should continue to support the use of native oysters in Oyster Sanctuaries, cultch plantings, and other restoration efforts rather than non-native introductions to enhance oyster resources until appropriate scientific and socioeconomic data are available that strongly support any other actions*.

3.4.5. Sea level rise and climate change

Global climate change has potentially profound implications for shell bottom habitat in North Carolina. Long-term changes in temperature regimes, precipitation/streamflow patterns, and sea level can alter shellfish distributions, growth, reproduction, and survival (Hofmann and Powell 1998; Dekshenieks et al. 2000; Najjar et al. 2000; Scavia et al. 2002; Wood et al. 2002; Lawrence and Soame 2004; Oviatt 2004; Harley et al. 2006; Kimmel and Newell 2007). Temperature increases may initially benefit oysters and other shellfish, allowing for increased filtration and growth rates (Powell et al. 1992; Grizzle et al. 2003), a longer spawning season, a shorter duration of the planktonic larval phase (Dekshenieks et al. 1993), and range expansion of lower latitude species (Scavia et al. 2002; Oviatt 2004). However, sustained deviations from normal temperature patterns amplify the susceptibility of oysters to environmental stressors (Hofmann et al. 1999; Najjar et al. 2000; McLaughlin and Jordan 2003; Ford and Chintala 2006; Lannig et al. 2006). Lannig et al. (2006) found that increasing the temperature of cadmium polluted water resulted in increased mortality and lowered condition of oysters. Temperature elevation has also been associated with an increased prevalence and infection rate of the oyster parasites MSX and Dermo (Hofmann et al. 1999; Najjar et al. 2000; McLaughlin and Jordan 2003; Ford and Chintala 2006). High temperatures inflate proliferation rates of these pathogens, triggering widespread epizootic conditions (Hofmann et al. 1999; McLaughlin and Jordan 2003; Ford and Chintala 2006). Extensive infections can result in mass mortality of mature oysters, potentially impacting the viability and distribution of shell bottom habitat. Higher temperatures may also decouple environmental cues for reproduction and optimal larval conditions by inducing spawning earlier in the season (Harley et al. 2006), which could result in a temporal mismatch between larval production and food supply. *The likely effect of temperature-induced early season reproduction on subsequent spatfall should be evaluated*.

Although current climate models disagree on whether precipitation in North Carolina will increase or decrease in the years to come (EPA 1998; Munger and Shore 2005), both scenarios threaten the health and viability of shell bottom habitat. Changing precipitation patterns influence freshwater inflow, nutrient delivery, and salinity regimes (Najjar et al. 2000; Scavia et al. 2002). Increased precipitation would cause an upsurge in freshwater inflow and a subsequent decline in estuarine salinity. At salinities < 10 ppt, oysters become physiologically stressed, and filtration and respiration rates are reduced

(Loosanoff 1953; Shumway and Koehn 1982; Hofmann and Powell 1998). Prolonged exposure to salinities <5 ppt can result in mass oyster mortalities, especially when combined with higher temperatures (Burrell 1986; Hofmann and Powell 1998; Funderburk et al. 2001). Dekshenieks et al. (2000) found that a simulated increase of freshwater inflow in Galveston Bay, Texas resulted in substantial declines in oyster larvae production and larval survivorship. An escalation in the frequency and/or duration of precipitation events, therefore, may be detrimental to the health of oyster reefs, particularly for those currently near their lower salinity tolerance limit.

Increased precipitation and freshwater inflow can also cause water column stratification and nutrient enrichment via runoff (Najjar et al. 2000; Scavia et al. 2002; Wood et al. 2002). These two factors in concert provide conditions necessary for the development of persistent areas of hypoxia or anoxia. Although oysters are generally tolerant to low DO conditions, mortality occurs when exposed to sustained hypoxic/anoxic conditions (Lenihan and Peterson 1998).

Decreased precipitation, on the other hand, would greatly reduce freshwater inflows, increasing estuarine salinity. Higher salinities would initially be somewhat physiologically beneficial to oysters through an increase in filtration and growth rates, and reproduction (Castagna and Chanley 1973; Dekshenieks et al. 1993; Dekshenieks et al. 2000). However, salinities above 15 ppt increase the susceptibility of oysters to pathogens (Paynter and Burreson 1991; Lenihan et al. 1999; Wood et al. 2002; McLaughlin and Jordan 2003) and predators (Gunter 1955; Bahr and Lanier 1981). Nevertheless, Dekshenieks et al. (2000) reported that mortality associated with increased Dermo infection was offset by the positive effects of higher salinity under simulated low freshwater inflow conditions, resulting in a 101-200% increase in the oyster population. *It is essential to gain a better understanding of forecasted changes in estuarine salinities in North Carolina to more accurately predict the effects on shell bottom distribution and health*.

A particularly notable effect of climate change is a rise in sea level. Sea level rise is a second order response, whose rate is dependent on atmospheric temperature and the dynamics of polar ice masses (IPCC 2007). Current accelerated rates of sea level rise predominantly threaten intertidal oyster reefs, which may not be able to migrate landward quickly enough to maintain their intertidal position or may be impeded by land-based development. In a study of sea level rise in southwest Florida, M. Savarese (unpub. data) found that present-day rates of sea level rise are comparable to those in the late Holocene prior to 4500 ybp (years before present). Intertidal oyster reefs were found to be short-lived and not very extensive during that time period. It was suggested that if accelerated sea level rise rates continue, intertidal oyster reef development may decline. Still, current intertidal reefs may be able to persist subtidally if submerged by a rise in sea level. Subtidal reefs have, however, been suggested to be subject to higher rates of predation by boring sponges, oyster drills, and blue crabs (Burrell 1986), potentially limiting the ability of intertidal reefs to invade the subtidal. The increase of salinity associated with sea level rise can also allow for range extensions of predators that prefer higher salinities into areas which were once seldom impacted by predation. Submerging of intertidal reefs may also cause a disconnect in the corridor function between the reefs and the adjacent tidal marsh, thus reducing habitat quality for fishes and macroinvertebrates that use intertidal reefs as way stations during flood tides.

An emerging issue associated with climate change is the decline in ocean pH resulting from human emissions of carbon dioxide (Feely et al. 2004; Orr et al. 2005; Harley et al. 2006; IPCC 2007; Guinotte and Fabry 2008). This acidification is caused by an increased amount of CO_2 dissolved in ocean waters, which lowers the pH, decreases the availability of carbonate (CO_2^{-3}) ions, and lowers the saturation state of the major carbonate minerals (Feely et al. 2004; Orr et al. 2005). Exposure of calcifying organisms, such as oysters, to seawater less than a pH of 7.5 can considerably reduce their rates of calcification, diminishing growth rates, hindering larval development and settlement, and even resulting in dissolution of adult calcareous shells (Gazeau et al. 2007; Kurihara et al. 2007; Kurihara et al. 2008). Such changes can slow reef development and maturation, as well as increase the susceptibility of mature oysters to predation. Thus, in an environment with declining pH, the density and distribution of shell bottom is likely to also decline, leading to greatly reduced habitat complexity and biodiversity loss (Orr et al. 2005). *More research is needed to examine the potential ecological effects of declining ocean pH on shell bottom in North Carolina under environmentally realistic scenarios*.

3.4.6. Management needs and accomplishments

The management needs noted by italics in the 2005 CHPP were addressed to some degree during 2005-2010. Some of the needs were refined and adopted as actions in the multi-agency CHPP implementation plans (IPs). There were also shell bottom-related actions that came directly from the implementation plans, without a specific call in the 2005 CHPP. However, numerous IP actions affect multiple habitats (see "Introduction" chapter) and will not be duplicated here. Only shell bottom-focused actions from the IPs are listed in the "Needs and progress" sections. Emerging management needs are included without a reference and may or may not be refined and adopted as actions in a 2009-2011 CHPP implementation plans.

3.4.6.1. Research needs and progress (2005-2010)

Accomplished research needs

1. *Research on the impact of dock-associated boating on shell bottom habitat.* **Some new research is presented in the "Water dependent development" section.**

Needs with progress

Needs with no progress

1. *Research 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.* **No specific progress. However, there has been more research on the cumulative affect of oyster filtering capacity on large water bodies (see "Ecosystem enhancement" section).**

Emerging needs

1. *An economic analysis is needed that compares the cost saving of oyster restoration and sanctuary development with that of wastewater treatment capacity, along with the added fishery production of associated finfish species and oyster harvest in the remaining open shellfish harvesting waters*. The results of one such analysis are pending (J. Grabowski/GMRI, pers. com., January 2009). **See "Ecosystem enhancement" subsection of "Ecological role and functions" section for context.**

2. *More research is needed on the functional value of oyster reefs as spawning habitat for estuary-spawning transient species in North Carolina*. **See "Specific biological functions" subsection of "Ecological role and functions" section for context.**

3. *Further research is needed on the corridor function of intertidal oyster reefs and the importance of connectivity to SAV and salt marsh for fisheries production.* **See "Specific biological functions" subsection of "Ecological role and functions" section for context.**

4. *A threshold contamination level is needed to cap multi-slip docking facilities in open shellfish harvesting waters*. **See "Water-dependent development" subsection of "Threats and management needs" section for more context.**

5. *The effect of temperature-induced early season reproduction on subsequent spatfall should be evaluated*. **See "Sea-level rise and climate change" section for context.**

6. *Funding from FRGs and other programs is needed to provide support for further research on oysters and their response to EDCs at critical life stages.* **See "Toxic chemical" subsection of "Threats and management needs" section for context.**

7. *It is essential to gain a better understanding of forecasted changes in estuarine salinities in North Carolina to more accurately predict the effects on shell bottom distribution and health*. **See "Sea-level rise and climate change" section for context.**

8. *More research is needed to examine the potential ecological effects of declining ocean pH on shell bottom in North Carolina under environmentally realistic scenarios*. **See "Sea-level rise and climate change" section for context.**

3.4.6.2. Management needs and progress (2005-2010)

Accomplished management needs

1. *Creation of additional "no take" subtidal oyster sanctuaries.* **There has been significant progress in this area (see "Shell bottom enhancement and restoration, For ecosystem enhancement" section, subsection).**

2. *More planting and longer protection of sites in Pamlico Sound to offset declining spatfall. Restoration efforts must use knowledge of larval availability in order to be most effective.* **There are now more sanctuaries in Pamlico Sound (see "Shell bottom enhancement and restoration" section) and spatfall has improved (see "Status of shell bottom habitat" section).**

3. *Increasing funding for acquisition of cultch material to more efficiently use the existing planting capabilities of DMF.* **There has been significant progress in this area (see "Shell bottom enhancement and restoration, For fishery enhancement" section, subsection).**

4. *Use DMF pilot project methodology for assessing shoreline hardening for a larger portion of the coast to spatially delineate and quantify where and how much of the shoreline is hardened.* **Coast-wide shoreline mapping, by type and structures, is being conducted by DCM (see "Water dependent development" section).**

5. *Developing a coastal marina policy that encompasses all associated regulatory activities conducted within the DENR.* **There has been some progress in regulating multi-slip docks (see "Water dependent development" section).**

6. *Construction of oyster sanctuaries in locations of historic abundance and restriction of trawling over restored shell bottom to restore shell bottom in 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.* **Additional Oyster Sanctuaries have been constructed in locations where trawling was allowed (see "Shell bottom enhancement and restoration, For ecosystem management" section, subsection). There are very few areas where trawling is prohibited but dredging is not (see "Mobile bottom disturbing fishing gear" subsection).**

7. *Adoption of criteria to designate additional areas where mechanical harvest methods are prohibited.* **Additional areas were closed to mechanical harvest methods in Pamlico Sound (see "Mobile bottom disturbing fishing gear" section).**

Needs with progress

1. *Creation of additional Shellfish Management Areas to reduce habitat damage and enhance*

spatfall of oysters and clams in areas where hand-harvesting activity is intense. **Additional Research Sanctuaries have been created south of Cape Lookout (see "Shell bottom enhancement and restoration, For ecosystem enhancement" section, subsection).**

2. *Evaluating the value of closed shellfishing waters as oyster sanctuaries.* **An assessment of shellfish resources in growing areas (including closed waters) was summarized in Haines (2004). See "Microbial contamination" subsection of "Water quality degradation" section for context.**

3. *Maintaining high profile Oyster Sanctuaries and restoration sites and seeding them with disease resistant oysters in an effort to enhance oyster survivability and provide disease resistant broodstock for repopulating highly impacted areas.* **Oyster Sanctuary program develops and maintains high profile reefs. The production of disease-resistant oysters may come about with construction and operation of a state oyster hatchery (see "Emerging needs" section). See "Diseases and microbial stressors" section for context.**

Needs with no progress

1. *Re-mapping of the bottom to accurately evaluate changes in distribution and density of oysters. In the future, change analysis in a subset of areas remapped by DMF, particularly where major changes are suspected, is needed to assess trends in this habitat.* **Neither base map nor repeat mapping is complete. However, the bottom mapping program has made significant progress (see "Distribution" section).**

2. *Fishery-independent sampling on oyster reefs using appropriate sampling gear to monitor juvenile and adult fish abundance in shell bottom.* **No specific progress. However, the DMF Resource Enhancement section is planning a sampling program to track juvenile fish abundance in and around oyster sanctuaries (Greg Bodnar/DMF Resource Enhancement, pers. com., February 2009). See "Status of associated fishery species" section for context.**

3. *More information on the status of hard clams, black drum, and other fishery 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.* **No specific progress. However, the aforementioned DMF sampling program will address this management need as well. See "Status of associated fishery species" section for context.**

4. *Developing an overall strategy for shell bottom restoration as the effort expands.* **There is no overall strategy for shell bottom restoration. However, there are somewhat coordinated planning efforts directing oyster restoration activities (see "Shell bottom enhancement and restoration, Planning efforts" section, subsection).**

5. *Evaluating the relationship between channel deepening, saltwater intrusion, flushing rates, and oyster mortality in order to determine appropriate management action.* **No specific progress. See "Diseases and microbial stressors" section for context.**

Emerging needs

1. *New technology should be investigated that will further reduce time of mapping and enhance mapping products.* **See "Status of shell bottom habitat" section for context.**

2. *Although there has been no reported decline in spatfall in the southern coastal region of North Carolina (R. Carpenter/DMF, pers. com., 2002), more information is needed to determine trends in spatfall in this area over time.* **See "Status of shell bottom habitat" section for context.**

3. *Additional funding is needed to staff and operate the oyster hatchery facility.* **See "For ecosystem enhancement" subsection of "Shell bottom enhancement and restoration" for context.**

4. *An improved mitigation policy for shell bottom is needed to identify mitigation needs, increase mitigation efficiency, and reduce project timelines.* **See "For mitigation" subsection of "Shell bottom enhancement and restoration" for context.**

5. *Where any depletion or loss of shell bottom is allowed, agencies should consider requiring mitigation. The EEP is developing an out-of-kind crediting system that could be employed in mitigating the permitted loss of shell bottom to water dependent development.* **See "For mitigation" subsection of "Shell bottom enhancement and restoration" for context.**

6. *Appropriate DENR staff should continue to participate in collaborative efforts to plan, develop, and monitor the biological effectiveness of oyster enhancement and restoration activities.* **See "Planning efforts" subsection of "Shell bottom enhancement and restoration" section for context.**

7. *Once shell bottom mapping for the Pamlico Sound is complete, the portion of high (oyster) density, subtidal shell bottom open and closed to trawling and dredging should be determined.* **See "Mobile bottom disturbing fishing gear" subsection of "Fishing gear impacts" section for context.**

8. *There remains a need to enhance monitoring of turbidity in estuarine waters and in the adjacent nearshore ocean.* **See "Sediment and turbidity" subsection of "Water quality degradation" section for context.**

9. *Restoration activities should be planned to restore natural hydrology, dredge excess sediment, reduce the sources of excess sediment, and plant oysters on historic oyster bed foundations.* **See "Sediment and turbidity" subsection of "Water quality degradation" section for context.**

10. *Identifying oyster beds in closed shellfish harvesting areas with robust oyster populations will help permit reviewers evaluate marina projects in shellfish harvesting waters. Protecting oyster beds in closed harvesting area may also be more acceptable to oyster harvesters who have seen a growing area of closures over the years.* **See "Microbial contamination" subsection of "Water quality degradation" section for context.**

11. *Recycled plastics, concrete, and natural rock are non-wood alternatives that do not require any chemical preservatives and should be recommended for use in future water-dependent development projects.* **See "Toxic chemicals" subsection of "Water quality degradation" section for context.**

12. *An EDC monitoring program should be established through cooperative efforts of DMF, DWQ, Shellfish Sanitation, USGS, and the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) to determine the presence and concentrations of selected chemicals in North Carolina's coastal waters, beginning in the Neuse River estuary.* **See "Toxic chemicals" subsection of "Water quality degradation" section for context.**

13. *The MFC should continue to support the use of native Oyster Sanctuaries, cultch plantings, and other restoration efforts rather than non-native introductions to enhance oyster resources until appropriate scientific and socioeconomic data are available that strongly support other actions.* **See Non-native, invasive, or nuisance species" section for context.**

3.5. SHELL BOTTOM SUMMARY

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 buffering presence of oysters also benefits the leeward establishment of other habitats, such wetlands and SAV.

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 2006. However, oyster harvest and spatfall in northern areas has improved slightly from 2003-2006 (attributed to reduced mortality from Dermo). Most shell bottom losses were due to a history of dredging activity on subtidal beds in Pamlico Sound, lower Neuse River, and lower Pamlico River.

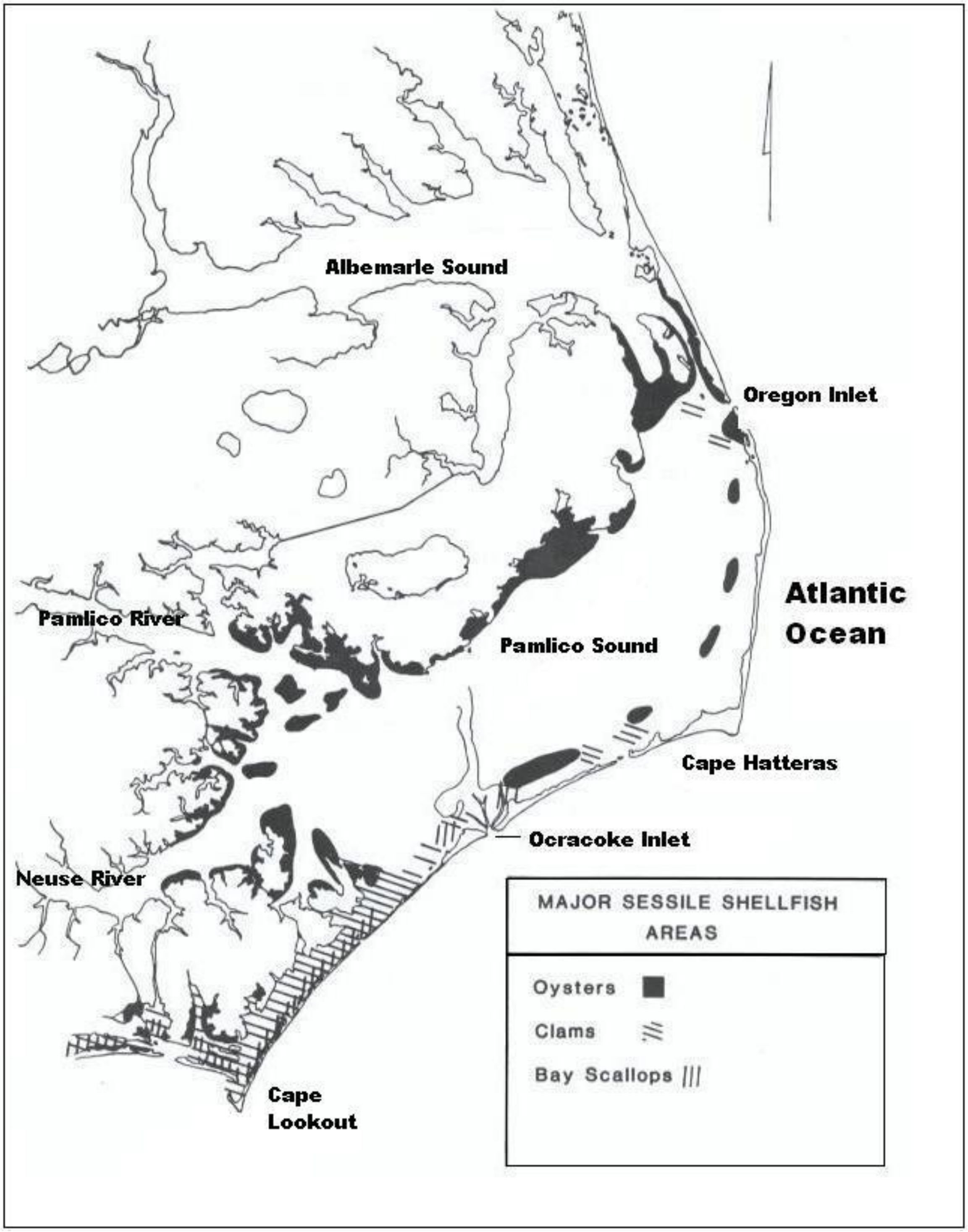
As of November 2008, nearly 400,000 acres or 70% of the DMF Shellfish Habitat and Abundance Mapping Program focus area is closed to either trawling, dredging, and/or mechanical shellfish harvesting. However, only 36% of the bottom mapping area is protected from all mobile bottom disturbing gear year-round. As of November 2008, the bottom mapping program has covered 493,563 acres (90%) of the area intended for mapping. The DMF Shellfish Habitat and Abundance Mapping Program focus area does not include the deeper subtidal bottom of the larger sounds, although these areas are the target of future mapping efforts. The additional positions and resources received from the legislature for shell bottom mapping in 2005 enabled the DMF bottom mapping program to accelerate and nearly complete mapping and initiate remapping the entire area on five year cycles. This effort allows not only monitoring of shell bottom distribution, but also SAV and fringing wetlands in SA waters of the state.

Whereas mechanical harvesting of oysters has been greatly restricted, recovery of oysters is limited by degraded water quality, sedimentation on overharvested reef foundations, endocrine disrupting chemicals, periodic disease mortality, and trawling activity over suitable oyster habitat. Sea-level rise and associated changes in salinity and ocean pH could have major impacts on living oyster populations. The loss of shell bottom habitat could be particularly damaging to associated fishery stocks that are classified as Depleted by DMF, such as southern flounder, black sea bass south of Cape Hatteras, or the central/southern stock of striped bass. The protection and restoration of living oyster beds is therefore critical to the restoration of numerous fishery species, as well as proper functioning and protection of surrounding coastal fish habitats.

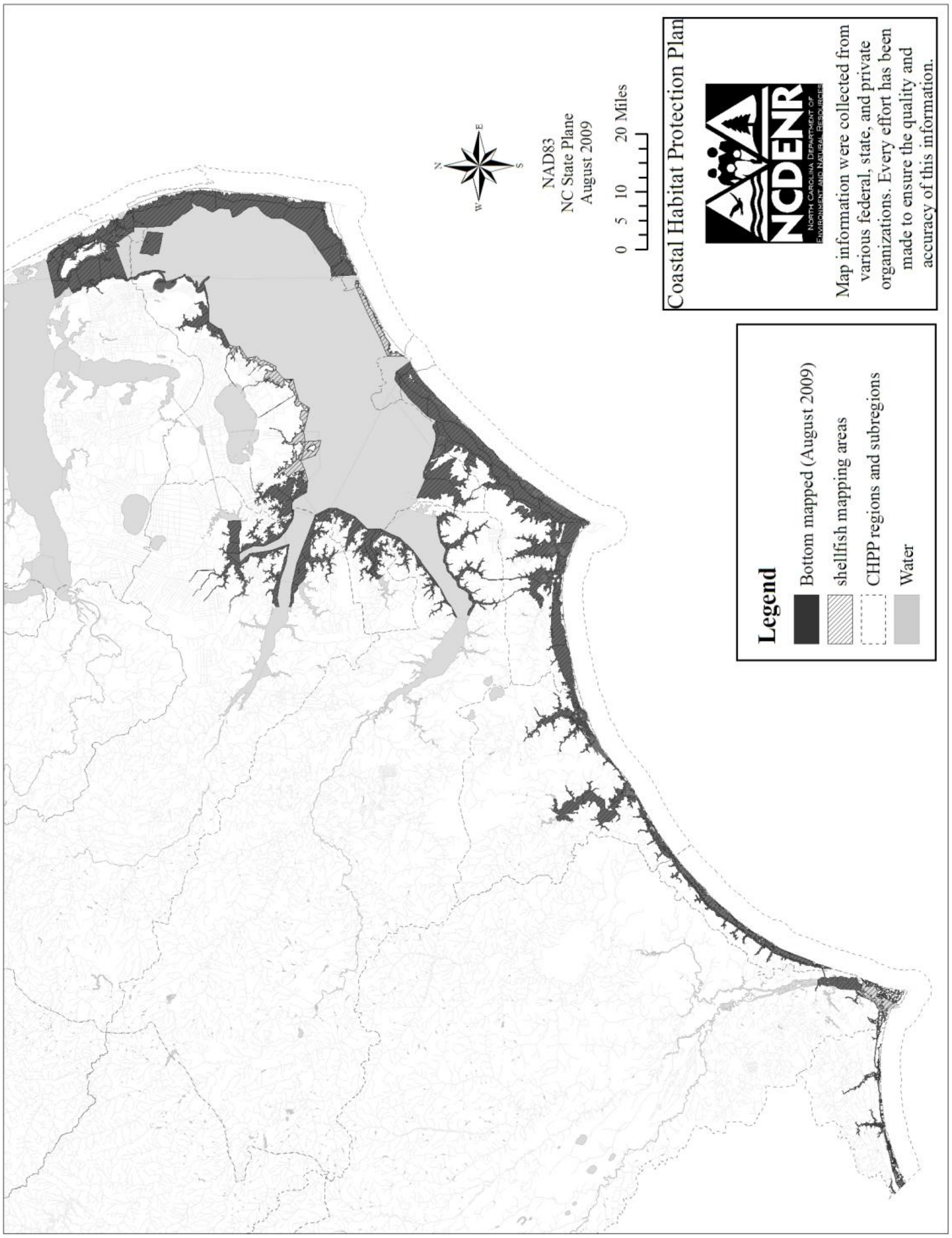
Efforts to restore oysters began in 1947 and have continued at various levels since then. Through CHPP implementation, a significant amount of additional funds were allocated to enhance oyster sanctuary development and monitoring. Historically, oyster restoration was managed for oyster fishery enhancement. Current efforts are a mix of fishery enhancement and ecosystem enhancement with sanctuary development. There are currently nine oyster sanctuaries spread throughout Pamlico Sound, which the DMF monitors for their viability and ecosystem benefits, and there are plans for establishing more using Coastal Recreational Fishing License revenue. Further restoration activities may require restoring natural hydrology, dredging excess sediment, reducing the sources of excess sediment, and planting oysters on historic oyster bed foundations.

In updating the chapter, many of the very general, minor, or redundant research and management needs were discontinued. Of the remaining 2005 CHPP research (2) and management needs (15), eight (1 research, 7 management) were considered accomplished and discontinued. There were also three renewed management needs with progress and five without progress. However, 20 new or clarified research and management needs were also identified. Major themes of the current management needs include:

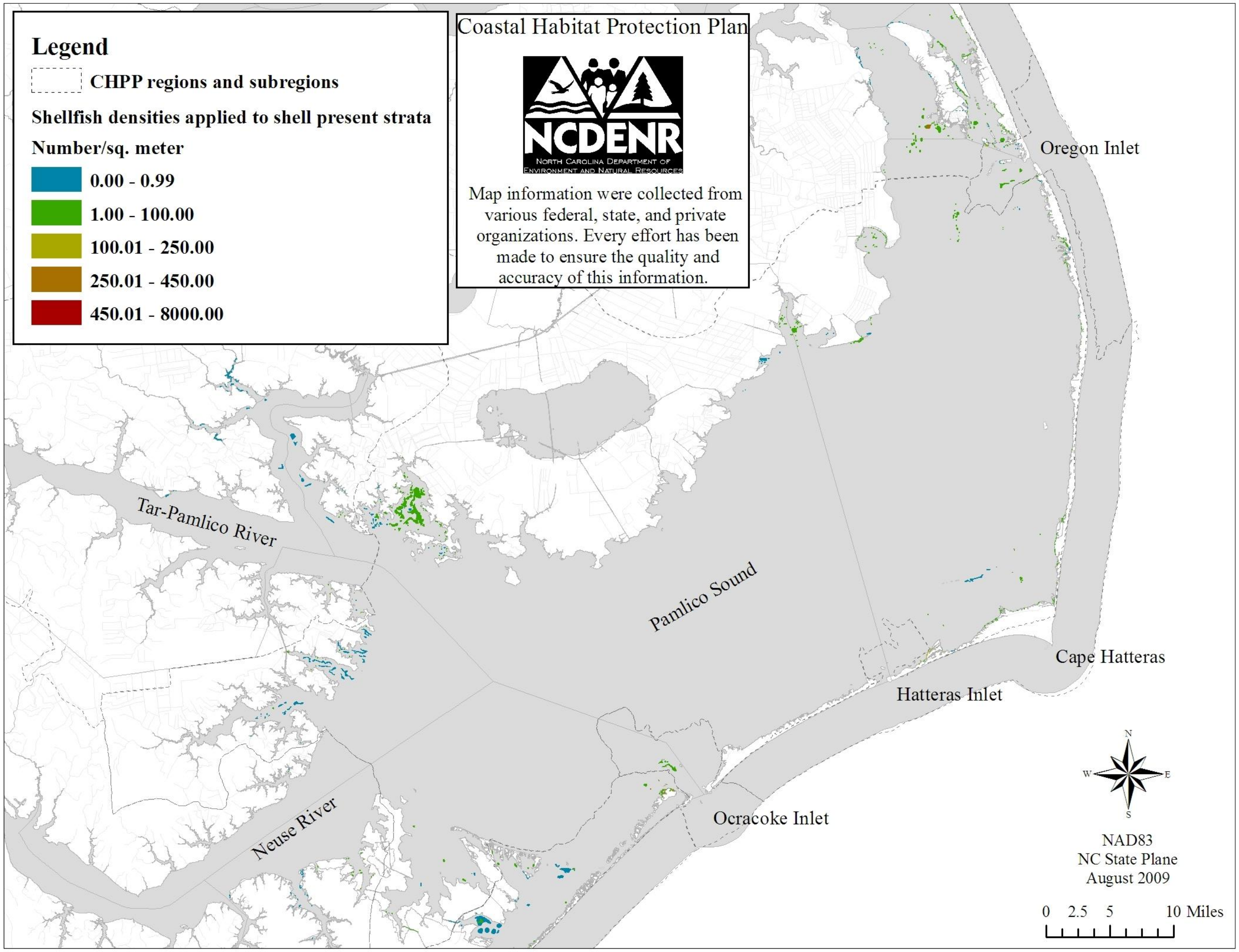
1. Refining programs for determining status and trends in shell bottom resources;
2. Continuing shell bottom restoration efforts guided by planning efforts, spat source-destination models and suitable habitat locations; and
3. Monitoring the effects of endocrine disruptor compounds on shell bottom resources



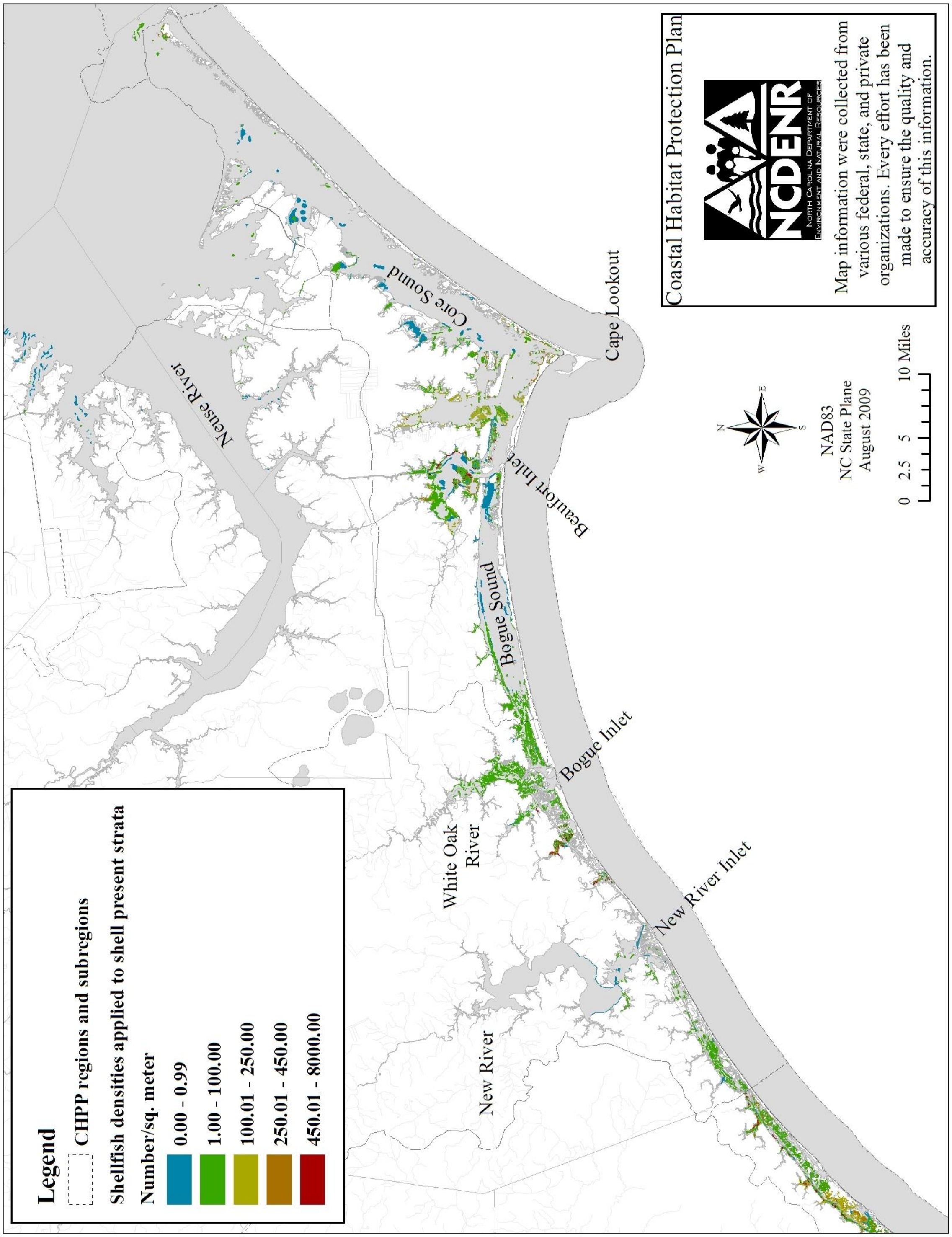
Map 3.1. General distribution of eastern oysters, hard clams, and bay scallops in the Albemarle-Pamlico estuarine system. [Source: Ross and Epperly 1986]



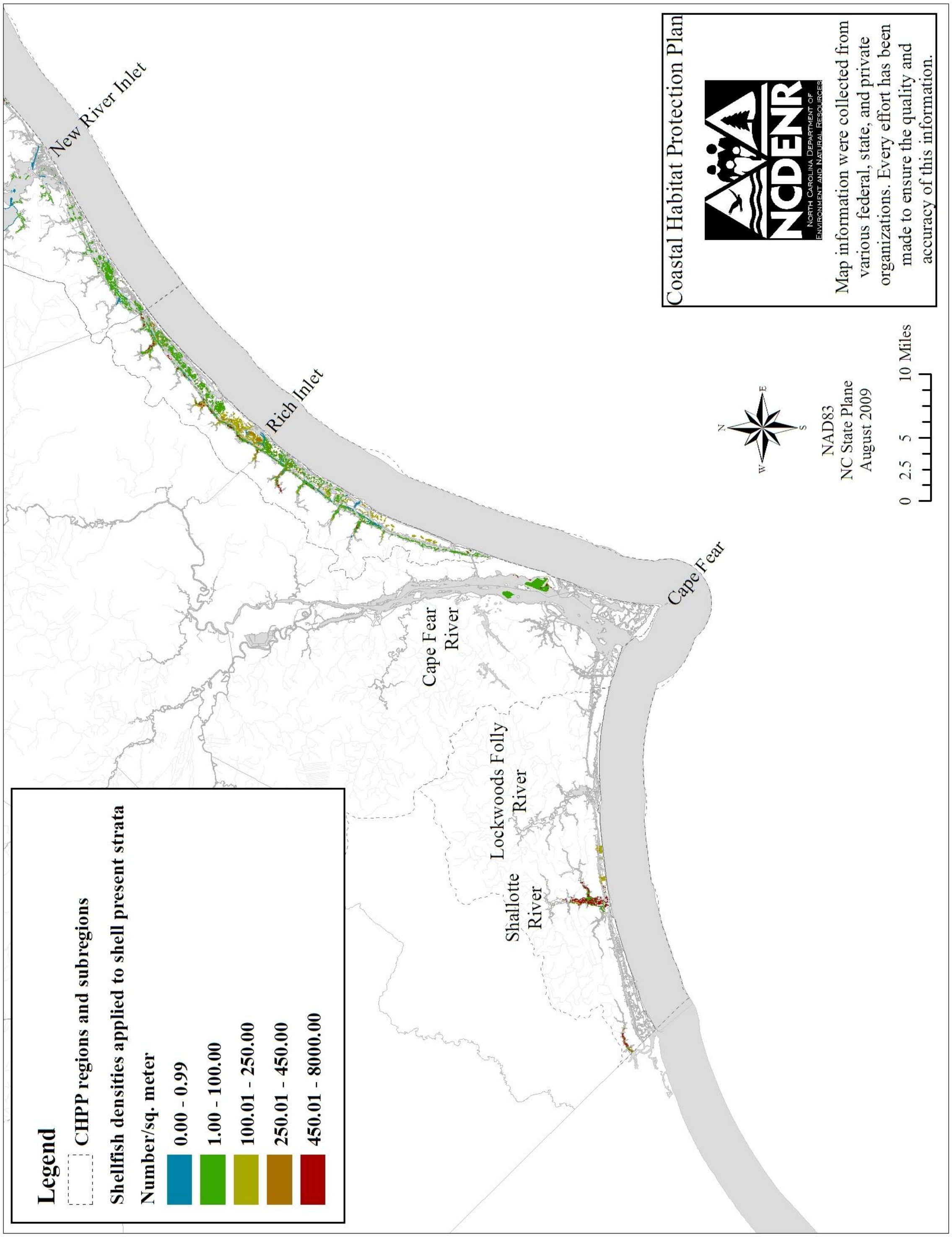
Map 3.2. Areas for which the bottom type has been mapped or is planned for mapping by the DMF's bottom mapping program (August 2009).



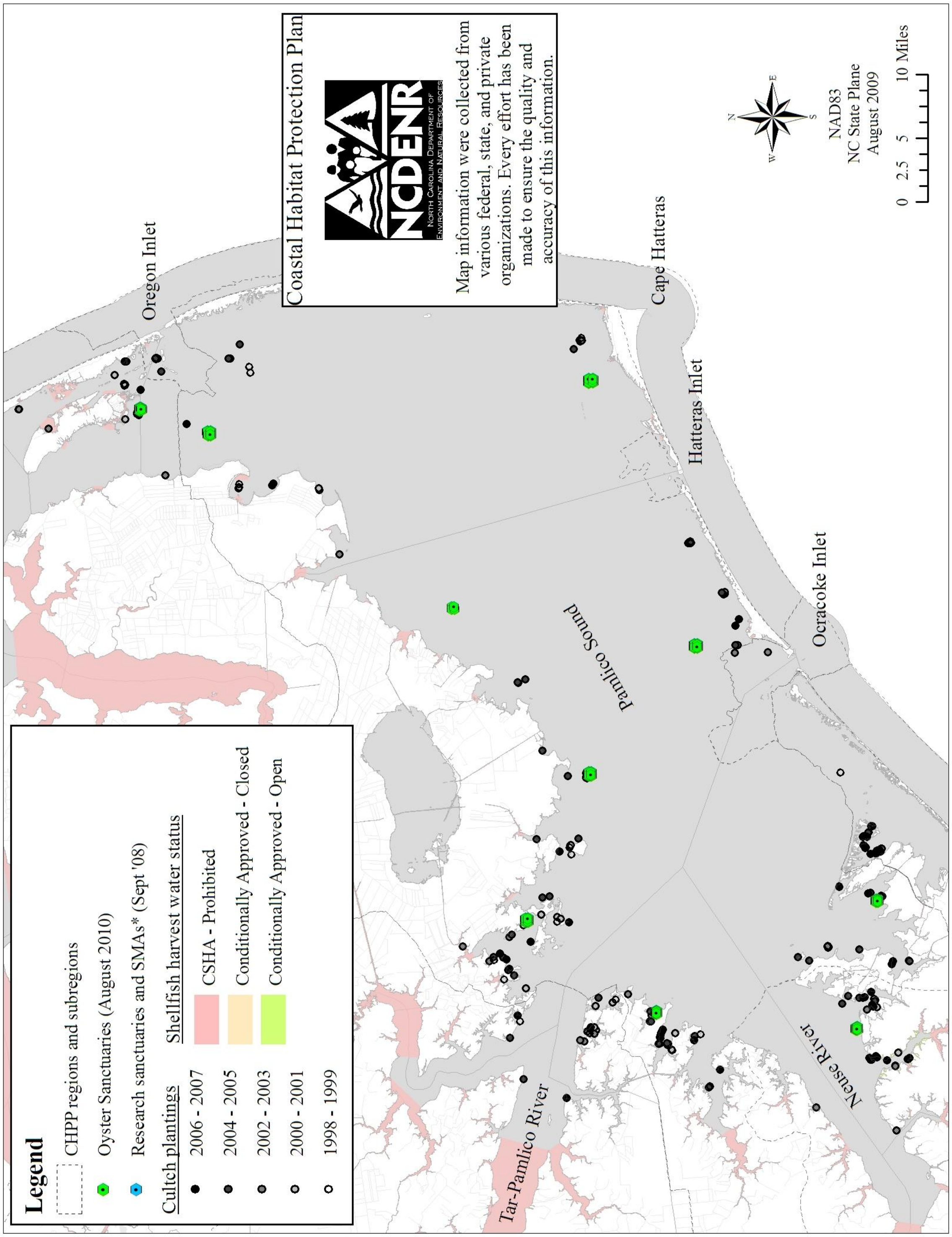
Map 3.3a. Estimated density of living shellfish in completed portions of the bottom mapping area from Roanoke Island to northern Core Sound (August 2009). Note: Absence of mapped shell bottom is not evidence of absence.



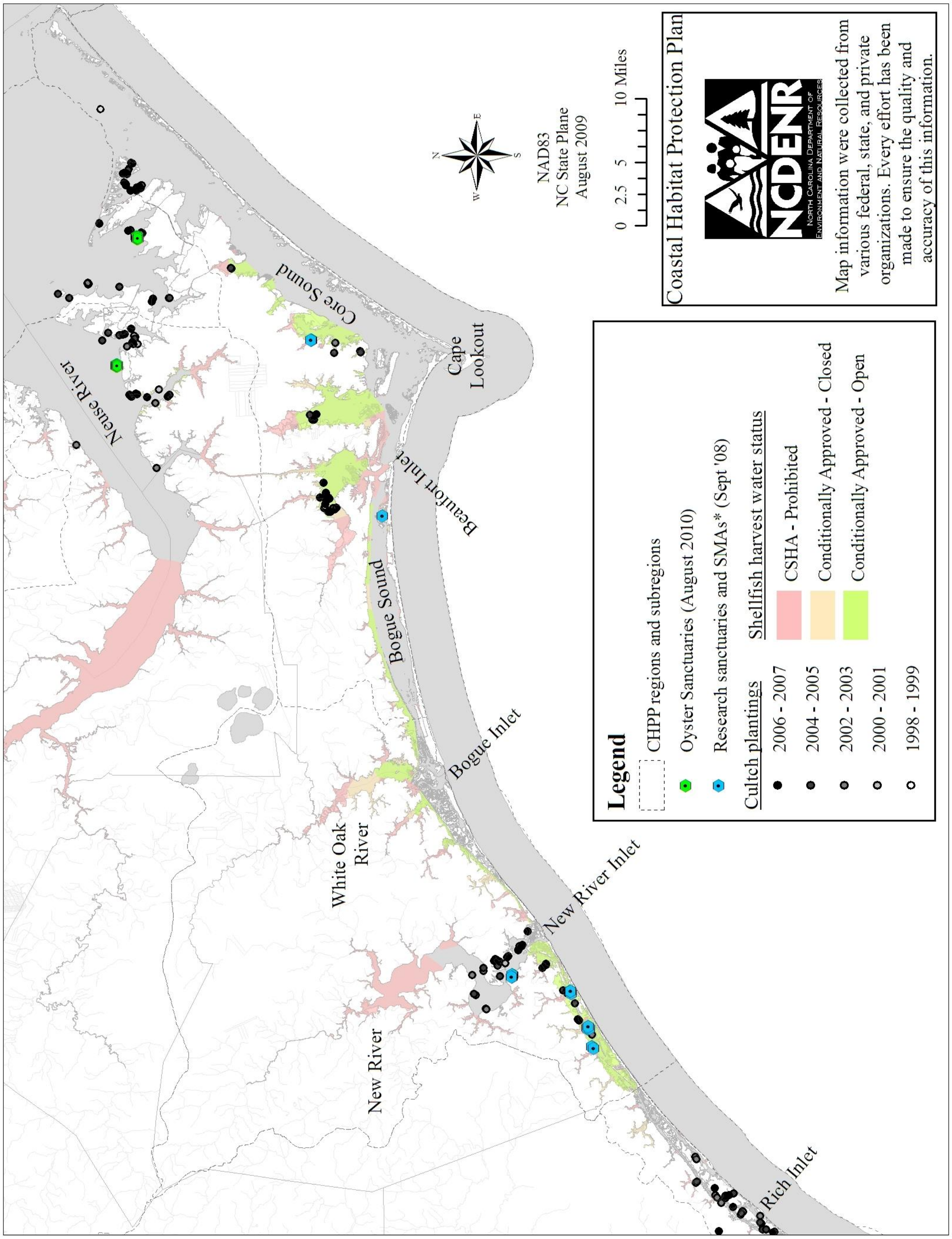
Map 3.3b. Estimated density of oysters in completed portions of the bottom mapping area from southern Core Sound to Surf City (August 2009). Note: Absence of mapped shell bottom is not evidence of absence.



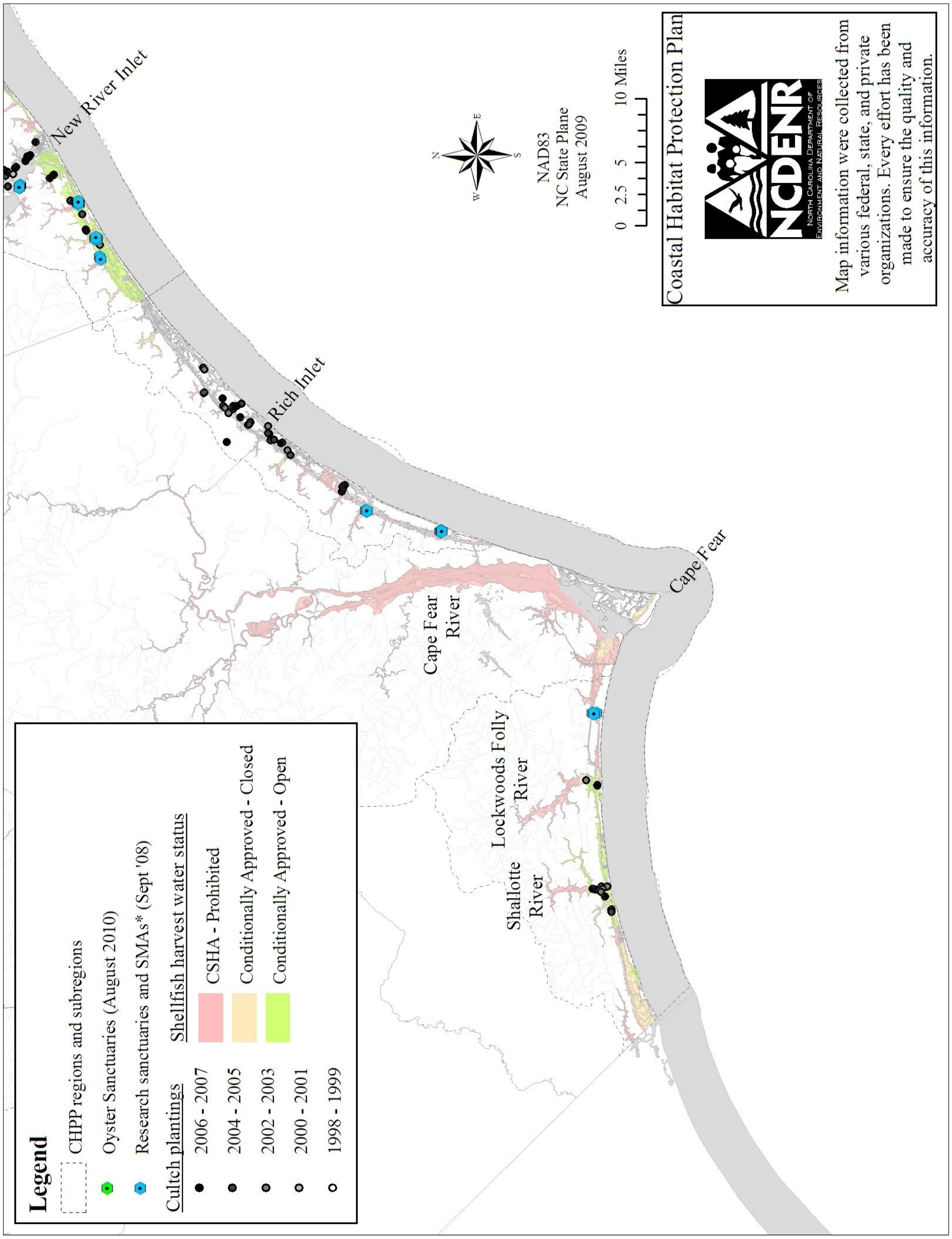
Map 3.3c. Estimated density of oysters in completed portions of the bottom mapping area from Surf City to Shallotte River (August 2009). Note: Absence of mapped shell bottom is not evidence of absence.



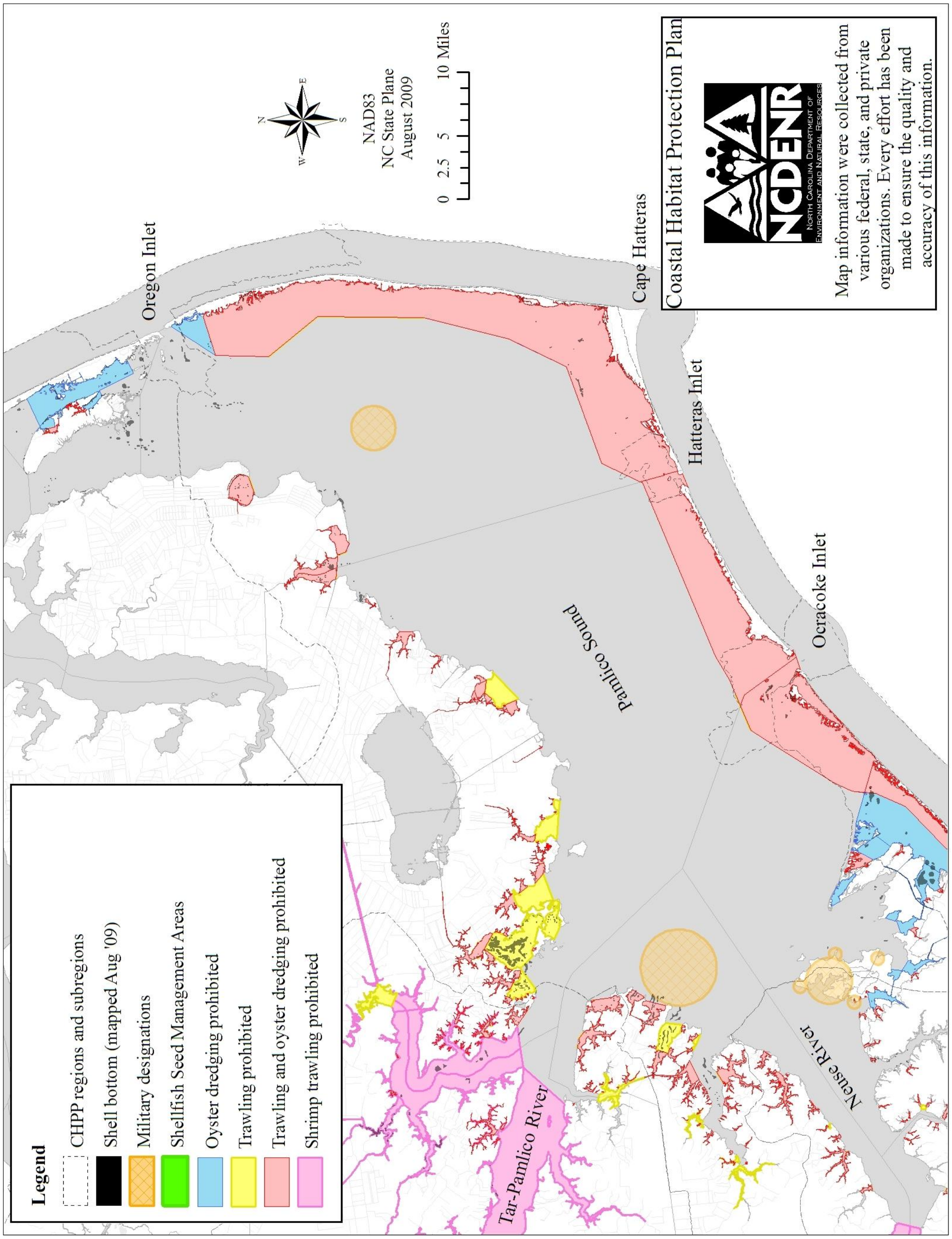
Map 3.4a. Location of cultch planting sites (1998-2007), shellfish management areas and research sanctuaries (2008), and oyster sanctuaries (2007, 2008) from Roanoke Island to northern Core Sound.



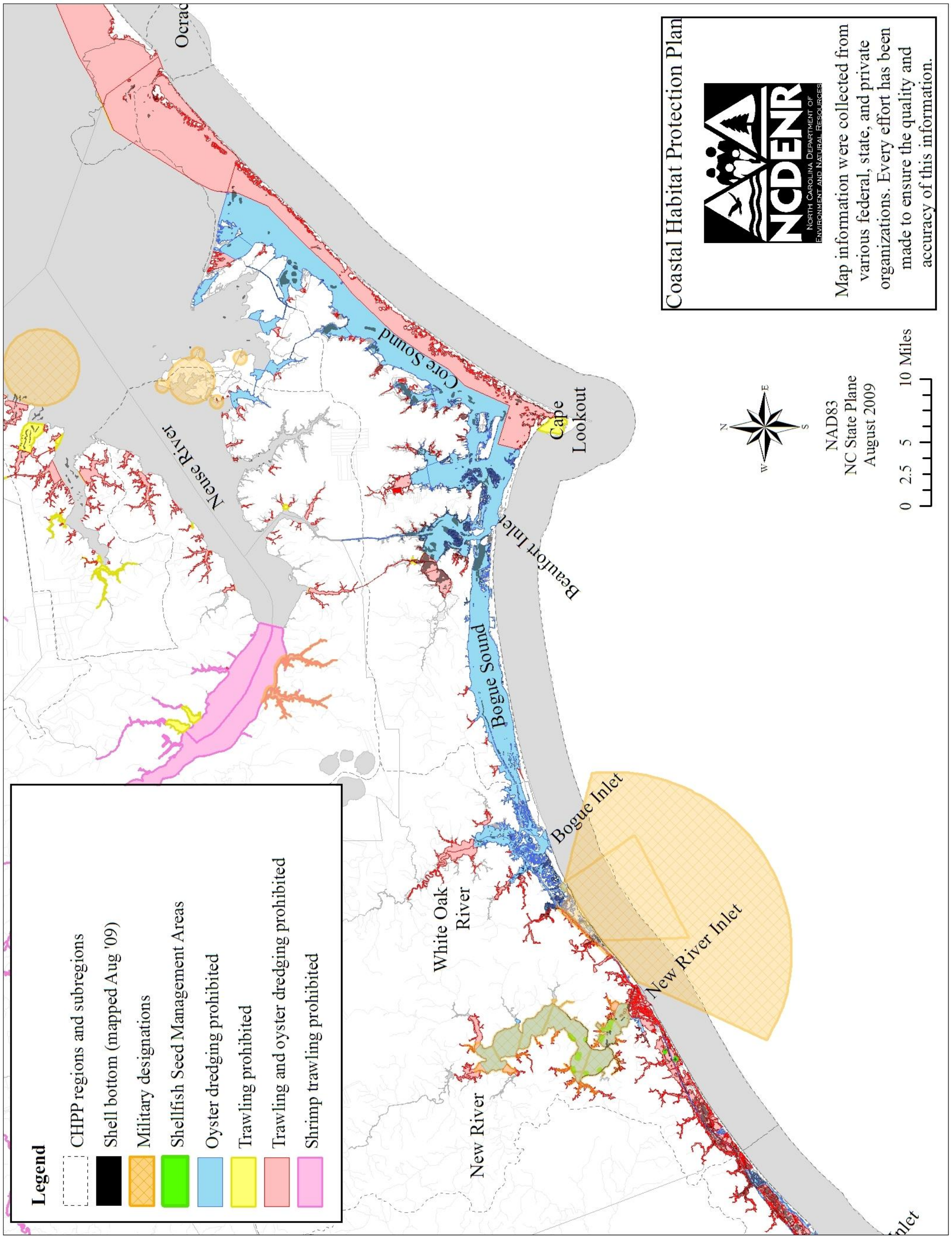
Map 3.4b. Location of cultch planting sites (1998-2007), shellfish management areas and research sanctuaries (2008), and oyster sanctuaries (2007, 2008) from southern Core Sound to Surf City.



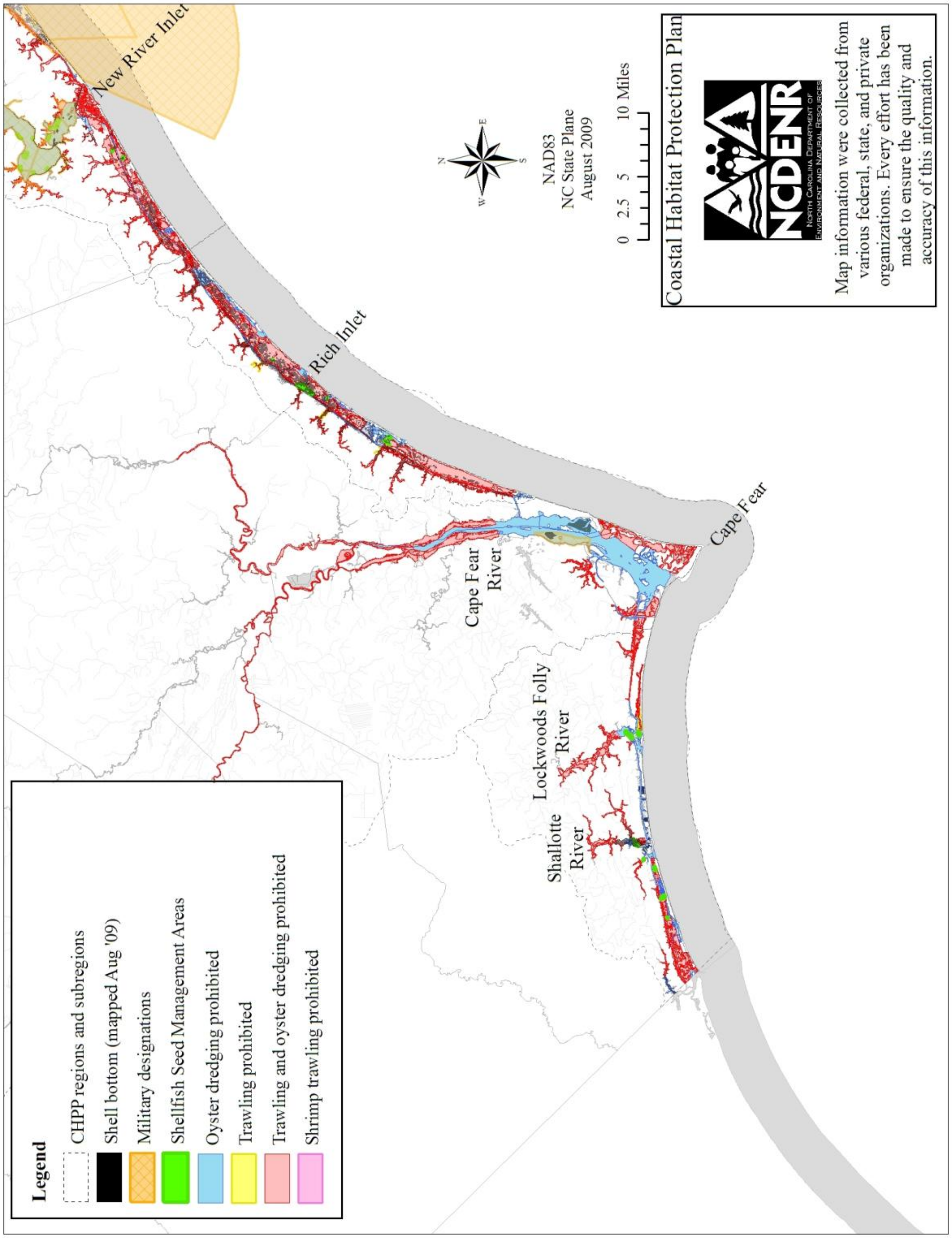
Map 3.4c. Location of cultch planting sites (1998-2007), shellfish management areas and research sanctuaries (2008), and oyster sanctuaries (2007, 2008) from Surf City to Shallotte River.



Map 3.5a. Areas prohibited to dredging and/or trawling from Roanoke Island to northern Core Sound (as of 2008).



Map 3.5b. Areas prohibited to dredging and/or trawling from southern Core Sound to Surf City (as of 2008).



Map 3.5c. Areas prohibited to dredging and/or trawling from Surf City to Shallotte River (as of 2008).

CHAPTER 4. SUBMERGED AQUATIC VEGETATION

4.1. DESCRIPTION AND DISTRIBUTION

4.1.1. 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) define SAV habitat as submerged lands that:

> "(i) are vegetated with one or more species of submerged aquatic vegetation including bushy pondweed or southern naiad (*Najas guadalupensis*), coontail (*Ceratophyllum demersum*), eelgrass (*Zostera marina*), horned pondweed (*Zannichellia palustris*), naiads (*Najas* spp.), redhead grass (*Potamogeton perfoliatus*), sago pondweed (*Stuckenia pectinata*, formerly *Potamogeton pectinatus*), shoalgrass (*Halodule wrightii*), slender pondweed (*Potamogeton pusillus*), water stargrass (*Heteranthera dubia*), water starwort (*Callitriche heterophylla*), waterweeds (*Elodea* spp.), widgeongrass (*Ruppia maritima*) and wild celery (*Vallisneria americana*). These areas may be identified by the presence of above-ground leaves, below-ground rhizomes, or reproductive structures associated with one or more SAV species and include the sediment within these areas; or
>
> (ii) have been vegetated by one or more of the species identified in Sub-item (4)(i)(i) of this Rule within the past 10 annual growing seasons and that meet the average physical requirements of water depth (six feet or less), average light availability (secchi depth of one foot or more), and limited wave exposure that characterize the environment suitable for growth of SAV. The past presence of SAV may be demonstrated by aerial photography, SAV survey, map, or other documentation. An extension of the past 10 annual growing seasons criteria may be considered when average environmental conditions are altered by drought, rainfall, or storm force winds." [2009 MFC rule 15A NCAC 03I .0101 (4)(i)].

SAV is an underwater forest for juvenile fish and small invertebrates and a barometer of water quality.

Submerged aquatic vegetation is included as fish habitat areas under MFC rules [2009 MFC rule 15A NCAC 03I .0101 (4)]. The MFC definition was modified as above since the 2005 CHPP as part of CHPP implementation to include low salinity species and address difficulties in identification of SAV habitat. The definition went into effect in April 2009. The former definition required the presence of leaves, shoots, or rhizomes. However because the presence of SAV vegetation varies seasonally and inter-annually, a one-time inspection could result in improper habitat determination. The modified definition allows SAV habitat to include either areas where SAV vegetation is present during the active growing season, or there is past documentation or professional knowledge of SAV in the area within the past ten years. A concern with the new definition arises for SAV habitat that has not been mapped or otherwise documented within the last 10 years. Although documentation of past occurrence may be limited, it can be taken into account where available and should improve over time. Regular mapping and monitoring of SAV habitat is consequently imperative for proper identification of SAV habitat. In areas appearing suitable for SAV, SAV surveys are required during the active growing season. To ensure consistency in identifying SAV habitat among agencies (an action in the 2007-09 CHPP Implementation Plan) CRC rules were modified to reference the MFC definition.

4.1.2. Description

Submerged aquatic vegetation habitat includes marine, estuarine and riverine vascular plants that are rooted in sediment. Although SAV occurs intertidally in high salinity regions, the plants are generally submerged and cannot survive if removed from the water for an extended 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). Because the plants are rooted in anaerobic sediments, they need to produce a large amount of oxygen to aerate the roots, and therefore have the highest light requirements of all aquatic plants (including phytoplankton, macroalgae, floating leaf plants, etc.). Reproduction occurs both sexually and asexually (i.e., vegetatively).

There are three basic types of SAV communities in North Carolina, all of which are important to coastal fisheries – (1) high salinity or saltwater (18-30 ppt), (2) moderate salinity or brackish (5-18 ppt), and (3) freshwater - low salinity (0-5 ppt) . High salinity estuarine species that occur in North Carolina include eelgrass (*Z. marina*) and shoalgrass (*H. wrightii*). 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 (*R. maritime)* grows best in moderate salinity but has a wide salinity range and grows from low to high salinity environments. The co-occurrence of these three SAV species is unique to North Carolina, resulting in high coverage, both spatially and temporally, of shallow bottoms in North Carolina's estuaries (Ferguson and Wood 1994). Freshwater – low salinity SAV species in North Carolina are diverse and 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). Submerged aquatic vegetation covers areas that vary in size from small isolated patches of plants less than a meter (<3 ft) in diameter to continuous meadows covering many acres.

Habitat for SAV 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.

The three-dimensional shape of SAV habitat can be quite variable, ranging from highly mounded, patchy beds several meters wide, to more contiguous, low-relief beds (Fonseca et al. 1998). Leaf canopies formed by the SAV 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). Despite the difficulty of defining the boundaries of SAV beds, unvegetated bottom between nearby adjacent patches is included as a component of patchy SAV habitat since rhizomes and/or seedlings may be present and the beds “move” around with patterns of sediment erosion and deposition (Fonseca et al. 1998).

4.1.3. 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 reaching the bottom, and moderate to negligible current velocities or turbulence (Thayer et al. 1984; Ferguson and Wood 1994). While this is generally true for all SAV species, individual species vary in their occurrence along gradients of salinity, depth, and water clarity (Table 4.1). Field sampling of SAV beds in in the Albemarle-Pamlico estuarine system between 1988 and 1991 found that occurrence of SAV was related to water depth, water clarity as measured by secchi depth, and salinity. 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 SAV, since they were found in areas of similar water depths to high salinity grasses, but secchi depths were lower (Ferguson and Wood 1994). This conclusion supports other research (Funderburk et al. 1991) showing that salt/brackish SAV requires slightly greater water clarity (secchi depth >1.0 m, or 3.28 ft) than freshwater SAV (secchi depth >0.8 m or 2.63 ft).

The primary factors controlling distribution of SAV are water depth, sediment composition, currents/wave energy, and the penetration of photosynthetically active radiation (PAR) through the water column (Goldsborough and Kemp 1988; Duarte 1991; Kenworthy and Haunert 1991; Dennison et al. 1993; Stevenson et al. 1993; Gallegos 1994; Moore et al. 1996; Virnstein and Morris 1996; Moore et al. 1997; Koch 2001; French and Moore 2003; Havens 2003; Kemp 2004; Cho and Poirrier 2005; Duarte et al. 2007; Biber et al. 2008). At a minimum, high salinity SAV leaves require 15-25% of incident light (Dennison and Alberte 1986; Kenworthy and Haunert 1991; Bulthius 1994; Fonseca et al. 1998). Low salinity species have generally lower light requirements (9-13%) than high salinity grasses (Funderburk et al. 1991; Fonseca et al. 1998; EPA 2000a; Kemp et al. 2004). For comparison, phytoplankton in the water column requires only 1% of light available at the surface (Fonseca et al. 1998). The light requirements of SAV species can be expressed as percent of surface light, light attenuation coefficient ($K_d m^{-1}$), or secchi depth (m). Table 4.2 summarizes what is known about the growing season and light requirements of North Carolina SAV species. The amount of light penetrating through the water column is partitioned into two categories: light required through the water column, and light required at leaf. The “light required at leaf” refers to the amount of water column light that can penetrate epibiota to the leaf surface. If less light is available, photosynthesis is limited, reproduction may be inhibited, and growth and survival of the submerged vegetation cannot be sustained.

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 (18-30 ppt)						
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)
MODERATE SALINITY (5-18 ppt)						
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)
FRESHWATER -LOW SALINITY (0-5 ppt)						
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)

Table 4.2. Light requirements for SAV species found in coastal North Carolina. [Funderburk et al. 1991; EPA 2000a; Kemp et al. 2004]

SAV salinity categories	Light required at leaf (%)	Light required through water (%)
Moderate - high salinity (5-30 ppt)	>15	>22
Freshwater-low salinity (0-5ppt)	>9	>13

Light penetration is affected by epibiotic growth and 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 (Kemp et al. 2004; Biber et al. 2008). Dissolved organic matter affects light penetration by coloring the water. 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.

Suitable or potential SAV habitat can be determined by modeling habitat requirements. This could be done by simply selecting shallow bottom with appropriate substrate or could be further refined through modeling of additional bio-optical parameters and wave exposure. Turbidity, total suspended solids (TSS), Chlorophyll *a*, and dissolved organic matter are the optically active constituents (OACs) typically measured to determine light available in the water column above the substrate (Biber et al. 2008). In the mid-Atlantic, 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 15μg/l (Kemp et al. 2004). However, another study indicated that high salinity SAV requires chlorophyll *a* < 10 μg/l and turbidity <1 ntu (Gallegos 1994). Bio-optical models predicting light attenuation under various environmental conditions have been calibrated for the Chesapeake Bay (Gallegos 2001), Indian River Lagoon in Florida (Gallegos and Kenworthy 1996), and North River in North Carolina (Biber et al. 2008). In North Carolina, the North River was chosen because it exhibited a broad range of depths and salinities representing the Albemarle-Pamlico estuarine system. In the North River, the bio-optical model predicted a deeper depth distribution (1.7 m MSL) for SAV than was observed (0.87 m MSL). The reason SAV was not found as deep as predicted may be due to confining hydrographic features, currents, epiphytic growth, substrate composition, or overestimation of colonization depth (Duarte 1991; Kemp et al. 2004; Bradley and Stolt 2006; Biber et al. 2008).

Kemp et al. (2004) developed a relationship to estimate epiphytic material and its associated light attenuation. The estimation required input data on light attenuation in the water column, TSS, dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphorus (DIP). In the Chesapeake Bay, epiphytic growth contributed 20-60% additional light attenuation in low salinity areas and 10-50% in moderate to high salinity areas (Kemp et al. 2004). From that, the amount of needed DIN and DIP was determined (~ 0.15 mg/l DIN; 0.01-0.02 mg/l DIP) (Sand-Jensen 1977; Funderburk et al. 1991; Kemp et al. 2004). However, the majority of nitrate used by SAV is derived from the sediment, rather than the water column (Thayer et al. 1984), suggesting the importance of substrate fertility in SAV distribution. Once light attenuation at both leaf and water column is determined, a maximum depth of SAV can be estimated. The actual distribution of potential habitat for SAV also depends on the distribution of substrate compositions, current velocities, and wave exposure during the growing season.

Contiguous beds of eelgrass or other species of SAV rarely occur in high energy areas or where currents are strong (>20-40 cm/s) (Thayer et al. 1984; Fonseca et al. 1998). Work conducted in Core Sound by Fonseca and Bell (1998) found that percent cover of SAV, bed perimeter to area ratio, sediment organic content, and percent silt/clay declined with increased wave exposure and currents. *A simple model to predict potential SAV habitat in North Carolina would be helpful for identification and protection of this important habitat where it has not been mapped or otherwise documented recently (within the past 10 years).* To make the most accurate prediction of SAV habitat, the bio-optical model (calibrated for North Carolina) should include adjustments for epiphytic growth, substrate composition, currents and wave energies at a location. However, the data needs for such an analysis are not satisfied by either current spatial data on bathymetry or available spatial/temporal data on physicochemical conditions. Refer to the soft bottom and water column chapters for information on bathymetric data and physicochemical monitoring stations, respectively.

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 two submerged grasses common to high salinity estuarine waters (Hurley 1990; Bergstrom et al. 2006).

4.1.3.1. High salinity SAV/seagrasses (18-30ppt)

- 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 thoughout the growing season, 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* and *Ruppia* 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).
- 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). May co-occur with *Zostera* and *Ruppia* and dominates mid-summer through fall in North Carolina, after which *Zostera* becomes relatively more predominant (Thayer et al. 1984).

4.1.3.2. Moderate salinity/brackish SAV (5-18ppt)

- Widgeon grass (*Ruppia maritima*): Tolerates a wide range of salinity regimes, from slightly brackish to high salinity, but grows best in moderate salinity. Found growing with eelgrass and shoalgrass, as well as low salinity species like redhead grass. 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. It reproduces sexually in summer and disperse by seed.

4.1.3.3. Freshwater-low salinity SAV (0-5ppt)

The following species typically grow best in fresh to low salinity waters, but also grow occasionally in moderately brackish waters up to about 15 ppt.

- 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.
- 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.
- 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. *Myriophyllum 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].
- Bushy Pondweed or Southern Niad (*Najas quadalupensis*): Present in small freshwater streams. Also tolerates slightly brackish waters. Sand substrates are preferred, but the species can grow in muddy soils. *Najas* spp. requires less light than other SAV species.
- 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.

4.1.4. Distribution

The dynamic nature of SAV beds has important implications for mapping and monitoring work. The distribution, abundance, and density of SAV varies seasonally and among years (Thayer et al. 1984; Dawes et al. 1995; 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). 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).

SAV habitat occurs 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. Along the Atlantic coast, North Carolina supports more SAV than any other state, except for Florida (Funderburk et al. 1991; Sargent et al. 1995). The 2005 CHPP reported that, based on interpretation and field verification 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). Other mapping efforts included Carroway and Priddy (1983) in Core and Bogue Sounds and DWQ (1998) in the Neuse River system. In addition to mapped SAV, Davis and Brinson (1989) surveyed and described the distribution of SAV in Currituck Sound and the Western Albemarle-Pamlico Estuarine System.

Since 2005, some additional mapping efforts have added over 20,000 acres of mapped vegetated areas, suggesting SAV habitat covers over 150,000 acres in coastal North Carolina (Map 4.1). The additional mapping efforts include the following:

- DMF (North Carolina Division of Marine Fisheries) Bottom Mapping Program - http://www.ncdmf.net/habitat/shellmap.htm *Maps based on interpolated transect data.
- ECSU (Elizabeth City State University) Mapping Program - http://www.ecsu.edu/ECSU/AcadDept/Geology/GEMSNewHomePageS05/index.htm *Maps based on aerial photography.
- NCSU (North Carolina State University) – Dr. Eggleston (http://www4.ncsu.edu/~dbeggles/) *Maps based on aerial photography.
- DWQ Rapid Response Teams - http://www.esb.enr.state.nc.us/prrt.html *Maps based on interpolated transect data.

An inventory of all SAV mapping and monitoring efforts is provided at (http://www.ncdmf.net/habitat/chpp28.html, June 2009). When considering only mapping data, the area of SAV habitat in North Carolina covers approximate 20% of the shallow (<6 foot) littoral zone within the area mapped[78], and approximately 5% of the total water area. Of course, the spatial distribution of SAV coverage varies within and among regions, corresponding generally to the relative area of shallow estuarine waters (Table 4.3).

SAV habitat in coastal North Carolina occurs mostly along the estuarine shoreline of the Outer Banks (Pamlico and Core/Bogue sounds), with sparse cover along much of the mainland shores of the estuarine system (Ferguson et al. 1989). As the systems become more riverine (i.e., tributaries of Albemarle Sound), freshwater SAV is locally abundant in larger blackwater streams and rivers, but rare in small

[78] Based on digitizing contours from the depth points drawn on NOAA nautical charts.

blackwater streams (Smock and Gilinsky 1992) due to shading from forested wetlands and irregular flows typical of low order streams. Freshwater SAV can also be extensive in some low-salinity back bays and lagoons (Moore 1992) such as Currituck Sound and in coastal lakes, such as Lake Mattamuskeet (not included in the area estimate of SAV habitat). Estuarine SAV occurs sporadically west of Bogue Inlet to the border with South Carolina, but these areas had not been suitably photographed in the early 1990's (Ferguson and Wood 1994). Small areas of SAV habitat have been observed in the past by DMF biologists in the New River, Alligator and Chadwick bays, Topsail Sound and inside Rich's Inlet (DMF southern district office staff, pers. com., 2002). More recent imagery and monitoring has verified the presence of patchy SAV beds south of Bogue Sound (S. Chappell and A. Deaton/DMF, pers. observation).

Table 4.3. Estimated acreage of mapped SAV habitat within regions of North Carolina. The area estimates are from a mosaic of mapping efforts spanning a time period from 1981-2008.

CHPP regions	Major waterbodies	SAV area (acre)	<6 foot area (% SAV)	Total water area (% SAV)
1	Albemarle/Currituck sounds, Chowan River	21,577	240,471 (9%)	767,002 (3%)
1/2	Oregon Inlet	2,124	10,043 (21%)	52,927 (4%)
2	Pamlico Sound, Neuse/Tar-Pamlico rivers	87,241	251,477 (35%)	1,362,795 (6%)
2/3	Ocracoke Inlet	3,740	14,459 (26%)	36,640 (10%)
3	Core/Bogue sounds, New/White Oak rivers	40,042	154,492 (26%)	423,117 (9%)
4	Cape Fear River, southern estuaries	0	37,800 (0%)	226,349 (0%)

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. Submerged aquatic vegetation is recognized as an essential fish habitat because of five interrelated features – primary production, structural complexity, modification of energy regimes, sediment and shoreline stabilization, and nutrient cycling. Water quality enhancement and fish utilization are especially important ecosystem functions of SAV relevant to the enhancement of coastal fisheries.

The economic value of ecosystem services provided by SAV habitat has been reported to be very large. Costanza et al. (1997) estimated that the average global value of annual ecosystem services of seagrass and algal beds was $3,801 trillion/yr. Their estimate took into account services such as climate regulation, erosion control, waste treatment, food production, recreation, and others. Compared to the total global gross national product of $18 trillion per year, this is a significant amount of services that would otherwise have to be paid for. However, the monetary estimate of SAV services did not account for the lesser value of alternative habitats, such as subtidal soft bottom. While estimated ecosystem services of subtidal soft bottom are reportedly less than SAV (Eyre and Ferguson 2002; Piehler and Smyth in press), there is much more of this habitat (see "Soft bottom" chapter for more information). Despite the correction, SAV habitat provides proportionately greater ecosystem services than subtidal soft bottom.

4.2.1. Productivity

SAV habitat is dominated by dense stands of vascular plants, their associated epiphyte communities, as well as benthic micro- and macroalgae. These grasses produce large quantities of organic matter under optimum conditions. Estimates of daily production for eelgrass beds rank among the most productive of marine plant habitats (Thayer et al. 1984; Peterson et al. 2007; Hemminga and Duarte 2000; Larkum et al. 2006). The typical biomass of growing eelgrass beds (leaves, roots, and rhizomes) in North Carolina was reported as 57–391 g (dry weight)/m^2 (Thayer et al. 1984; Twilley et al. 1985). The majority of biomass was contained in the roots (45-285 g m^{-2}). The productivity of eelgrass beds in North Carolina was reported as 1.05-1.32 g C m^{-2} d^{-1} (Thayer et al. 1984). Based on a compilation of published research (Peterson et al. 2007), the annual primary production estimates for eelgrass surpassed intertidal Spartina, intertidal soft bottom, subtidal soft bottom, and shell bottom. The relative productivity of SAV suggests its importance as a source of secondary production. The components of SAV habitat production include epiphytes, above-ground biomass, below-ground biomass, epibenthic algae, and water column phytoplankton.

Contributions of the various components of SAV productivity varies by species, salinity type, and location throughout the growing season (Stevenson 1988). In general, high salinity grasses have more annual production than freshwater SAV where they develop greater standing crops and have more capacity to store biomass in extensive root and rhizome systems. Stevenson (1988) reported high salinity SAV production at >10 g C m^{-2} d^{-1} and low salinity SAV production at <5 g C m^{-2} d^{-1}. Attached epiphytes contribute substantially to the total productivity of SAV beds (Koch 2001) and are an important food source for fish and invertebrates. While early stages of epiphytic growth increase primary productivity of the habitat, later stages can may impede SAV growth and density due to competition for light, nutrients, and carbon (Thayer et al. 1984; Koch 2001). Excessive epiphytic and macrophytic growth can result in loss of SAV (Hauxwell et al. 2000; McGlathery 2001) (see "Water quality degradation, nutrients" section). Dillon (1971) and Penhale (1977) estimated that epiphytes (macroalgae) constitute 10-25% 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). Freshwater and high salinity grasses also vary in growing season (see "Habitat description" and "Habitat requirements" sections), suggesting temporal variation in productivity.

Because of their high rates of primary production and particle deposition, SAV beds are important sources and sinks for nutrients (SAFMC 1998a). Thayer et al. (1984) concluded that SAV beds in high velocity areas are sources (exporters) of organic matter, while SAV in low current areas are sinks (importers) of organic matter. Exported matter represents a large portion of total SAV production in high salinity 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. 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; Kenworthy and Thayer1984).

4.2.2. Ecosystem enhancement

Because SAV are rooted in the substrate and provide semi-permanent structures in estuaries and coastal rivers, system enhancement is one of their more important ecological functions. Some of these functions include (Thayer et al. 1984; SAFMC 1998a):

- Accelerated deposition of sediment and organic matter,
- Physical binding of sediments beneath the canopy,
- Nutrient cycling between the water column and sediments, and
- Modification of water flow and reduction in wave turbulence,

These functions improve water quality in estuaries 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 (Dennison et al. 1993; Virnstein and Morris 1996; Biber et al. 2008). Moore (2004) studied the effect of SAV beds on water quality inside compared to outside the bed in Chesapeake Bay. During spring (April – June), the rapidly growing SAV beds were a sink for nutrients, suspended solids, and phytoplankton. The beds began to die as the summer progressed, releasing sediment and nutrients to the surrounding water. The improvements in water quality were not measureable until SAV biomass exceeded 50-100 g (dry weight) m^{-2} or 25-50% vegetative cover. The rapid uptake of nutrients by growing SAV was reflected in a 73% decline in nitrate levels inside the bed compared to outside. A threshold coverage and density of SAV is needed to ensure bed survival through high levels of spring turbidity (Moore et al. 1997; Moore 2004). Beds of SAV can also enhance grazing on phytoplankton by providing a daytime refuge for planktonic filter feeders (Scheffer 1999). Scheffer (1999) synthesized an extensive literature resource to model the effect of SAV density on planktivore abundance. The analysis suggested a threshold level of SAV density and grazing pressure where phytoplankton can be reduced to very low levels.

Aquatic grasses, by absorbing moderate wave energy (Fonseca 1996a), buffer nearshore turbulence and reducing erosion along adjacent shorelines, improves water clarity, and helps stabilize marsh edge habitat (Stephan and Bigford 1997). 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).

4.2.3. Fish utilization

Many fish 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. Because of the temporal abundance patterns among SAV species, refuge and foraging habitat are provided almost year-round for estuarine-dependent species (Steel 1991). In addition to natural fluctuations in 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, Heck et al. 2008; Hovel et al. 2002).

The SAFMC considers SAV Essential Fish Habitat (EFH) for red drum; brown, white, and pink shrimp; and species in the snapper-grouper complex. 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 SAV-enhanced species and species utilizing SAV habitat in North Carolina is compiled in Table 4.4.

4.2.3.1. Moderate-high salinity SAV

In brackish and high salinity estuaries, fish and invertebrates use seagrass, to varying extents, as nursery, refuge, foraging, and spawning locations. Studies in eelgrass beds in the Newport River estuary and 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 SAV 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). Composition of long haul seine catches sampled by DMF reported at least 49 adult fish species collected over SAV 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). Spotted seatrout (*Cynoscion nebulosus*), are highly dependent on the quantity and quality of seagrass habitat (Vetter 1977), and bay scallops occur almost exclusively in seagrass beds (Thayer et al. 1984).

Table 4.4. Partial list of species documented to use submerged aquatic vegetation habitat.

Species*	SAV Functions [1]					2010 Stock status [2]
	Refuge	Spawning	Nursery	Foraging	Corridor	
ANADROMOUS & CATADROMOUS FISH						
River herring (blueback herring and alewife)	X		X	X	X	D-Albemarle Sound, U-Central/Southern
Striped bass				X		V- Albemarle Sound, Atlantic Ocean, D-Central /Southern
Yellow Perch		**X**				**C**
American eel	X		X	X	X	U
ESTUARINE AND INLET SPAWNING AND NURSERY						
Bay scallop	**X**	**X**	**X**	**X**		**R**
Blue crab	**X**		**X**	**X**	**X**	**C**
Grass shrimp	**X**		**X**	**X**		
Hard clam	**X**		**X**	**X**		**U**
Red drum	**X**		**X**	**X**	**X**	**R**
Spotted seatrout	**X**		**X**	**X**	**X**	**D**
Weakfish	X		X	X	X	D
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY AREA						
Atlantic croaker	X		X	X	X	C
Atlantic menhaden	X		X	X	X	V
Brown shrimp	**X**		**X**	**X**	**X**	**V**
Southern flounder			X	X		D
Spot	X		X	X	X	V
Striped mullet	X		X	X	X	V
White shrimp	X		X	X	X	V
MARINE SPAWNING, HIGH SALINITY NURSERY						
Black sea bass	X		X	X	X	D- south of Hatteras, C- north of Hatteras
Bluefish			X	X		V
Gag	X		X	X	X	C
Kingfish spp.	X		X	X	X	U
Pinfish	**X**		**X**	**X**	**X**	
Pink shrimp	**X**		**X**	**X**	**X**	**V**
Smooth dogfish				**X**		
Spanish mackerel			X	X		V
Summer flounder			X	X		R

* Scientific names listed in Appendix D. 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] V=viable, R=recovering, C=Concern, D=Depleted, U=unknown (http://www.ncdmf.net/stocks/index2k10.html)

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 SAV beds compared to unvegetated bottom (Thayer et al. 1975; Summerson and Peterson 1984; Thayer et al. 1984; Heck et al. 1989; Ross and Stevens 1992; Irlandi 1994; ASMFC 1997a; Wyda et al. 2002; Hirst and Attrill 2008). 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). Wyda et al. (2002) found significantly higher abundance, biomass, and species richness of fish at sites with high levels of seagrass habitat (biomass >100 wet g m^{-2}; density > 100 shoots m^{-2}) than sites with low-absent eelgrass (biomass <100 wet g m^{-2}; density <100 shoots m^{-2}). The sites with low-absent SAV biomass and density also had higher proportions of pelagic species than sites with high SAV biomass and density. 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). In Back Sound, N.C., Elis et al. (1996) found that fish and shrimp were more abundant on artificial SAV beds than on shell bottom. 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 inhabiting seagrass beds (such as crustaceans and pipefish) with decreases in seagrass coverage, while larger demersal predatory fish (such as toadfish and sharks) increased. Similarly, increases in seagrass 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).

Some studies have shown a linkage between the abundance and species composition of fish and the quantity and/or quality of seagrass beds. 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 habitat complexity (biomass >100 wet g/m^2; density >100 shoots/m^2) compared to sites with reduced habitat complexity (Wyda et al. 2002). Abundance, biomass, and species diversity were also more variable at sites with reduced SAV complexity. Sites with lower habitat complexity also had a greater proportion of pelagic species than bottom, structure-oriented species. In North Carolina, comparison of pink shrimp densities in continuous and patchy SAV beds found significantly greater shrimp densities in continuous beds than in patchy grass beds (Murphey and Fonseca 1995). Although patchy beds did not support as great a density of shrimp, they still functioned as important habitat for pink shrimp (Murphey and Fonseca 1995). Hirst and Attrill (2008), in examining benthic invertebrate composition, found that the size of the SAV patch did not impact the level of increased invertebrate diversity – presence of SAV alone significantly increased diversity.

Hovel et al. (2002) examined the effect of SAV bed structure (percent cover and total linear edge), local-scale ecological attributes (shoot density, shoot biomass, percent organic matter), and elements of physical setting (water depth and wave energy regime) on fish and shellfish densities in Core and Back Sound, North Carolina. The surveys were conducted in two consecutive years in both spring and fall. Wave energy regime and SAV shoot biomass had the most influence of species densities. Other factors explained little of the variation in species densities. Processes operating at larger than local spatial scales (e.g., larval delivery by currents) were evident between sites with high and low faunal abundance (western vs. eastern Core Sound). The results support treating all moderate-high salinity SAV within different regions equally in terms of fish and shellfish use.

4.2.3.2. Freshwater-low salinity SAV

Less information is available on fish use in low-salinity SAV habitat. Fish abundance and size has been shown to be greater in freshwater and low-salinity systems with submerged aquatic vegetation than in similar systems devoid of SAV (Randall et al. 1996; http://www.fao.org/DOCREP/006/X7580E/X7580E10.htm, August 2007). In Currituck Sound, Borawa et al. (1979) observed an increase in fish abundance from approximately 1,000 to more than 15,000 fish hectare^{-1} after *Myriophylum spicatum* became established. However, the size of fish declined drastically. Another study in the Potomac River (VA) found densities of fish in SAV habitat that were 2-7 times higher than areas without SAV (Killgore et al. 1989). Floating leaf aquatic vegetation is particularly important in freshwater systems such as the Roanoke River (Cooper et al. 1994). Common species using freshwater SAV is shown below and in Table 4.4. Species that utilize freshwater SAV include not only freshwater species but certain estuarine species and anadromous fish species (Rozas and Odum 1987; SAFMC 1998a; NOAA 2001). The most commonly occurring include:

Freshwater	Estuarine	Anadromous
Minnows	Juvenile menhaden	Striped bass
Juvenile American eel	Spot	Shad (American and hickory)
Pirate perch	Blue crab	River herring
Inland silversides	Grass shrimp	
Yellow perch	Bay anchovy	
Largemouth bass	Striped mullet	
Bluegill (bream)	Tidewater silverside	
White perch		

4.2.4. Specific biological functions

4.2.4.1. 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). Light levels are reduced within the canopy as well, further concealing small prey (SAFMC 1998a). 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. In addition, cryptic species that have the ability to change color use camouflage to decrease their visibility within the SAV habitat. The roots and rhizomes of SAV also provide a substrate matrix for meiofauna [79] and macrofauna [80] (Kenworthy and Thayer 1984). Hard clams, for example, are significantly more abundant in SAV beds than in adjacent unvegetated bottom due to differences in food supply, predation, and sediment stability (Peterson and Peterson 1979; Peterson 1982; Irlandi 1994, 1997).

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; Rooker et al.1998 for juvenile red drum). Estuarine-dependent spring-summer spawners (i.e., red drum, seatrout) 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).

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. Matilla et al. (2008) found that SAV beds of various densities equally increased survival of shrimp from predators compared to unvegetated bottom. In freshwater systems, excess

[79] Very small benthic animal, 0.1 – 0.5 mm in size, about the size of a sand grain, important food source for larval fish
[80] Small benthic animal larger than 0.5 mm in size; e.g., mole crabs, amphipods

vegetation can actually hamper movement and foraging efficiency of large predatory fish, resulting in a stunted fish population (Colle and Shireman 1980). Based on investigation of 60 Florida lakes, Hoyer and Canfield (1993) concluded that total harvestable fish biomass (per unit of adjusted Chlorophyll *a*) is maximal when the percent coverage of SAV ranged from 20-40%. However, large opportunistic predators such as largemouth bass can thrive at <20% SAV coverage, as long as higher nutrient levels are maintained and sufficient nursery habitat is available (Hoyer and Canfield 1996). Percent coverage of SAV in North Carolina estuaries is much lower than 20%, and cannot reach >40% given the proportion of shallow and deep waters (Table 4.3).

Seagrass, particularly eelgrass, may also provide overwintering habitat for some estuarine species. Pink shrimp have been collected in SAV during winter months in North Carolina sounds (Williams 1964; Purvis and McCoy 1972) . The presence of SAV in the winter is thought to contribute to the pink shrimp's ability to survive, supporting the spring pink shrimp fishery (Murphey and Fonseca 1995), which 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).

4.2.4.2. Spawning

It is difficult to discern species whose reproduction is more successful in SAV than in other habitats. Preference for spawning in SAV could be assumed for species found exclusively in SAV habitat. The bay scallop is one estuarine species that occurs almost exclusively in high salinity SAV beds (Thayer et al. 1984). The presence of spawning adults is therefore dependent on high salinity SAV. There are few other year-round estuarine residents found almost exclusively in moderate-high SAV. However, many species benefit from the close proximity of spawning and SAV nursery areas (see "Nursery" function section below). Seasonal patterns of reproduction and development of many temperate fishery species also coincide with seasonal abundance of seagrass (Stephan and Bigford 1997).

Freshwater fish spawning preferentially on or near SAV include common carp, crappie, yellow perch and chain pickerel (Balon 1975; Graff and Middleton 2000). The roots and stems of the submerged vegetation provide substrate for attachment of eggs. As with high salinity SAV, many species benefit from the close proximity of spawning areas and SAV nursery area (see "Nursery" function section below). *Research is needed to assess the effect of SAV proximity to spawning areas on juvenile production.*

4.2.4.3. Nursery

Submerged aquatic vegetation is considered a nursery habitat for numerous species of fish and invertebrates along the Atlantic coast (Thayer et al. 1984). The roots and stems of SAV provide ideal protection and foraging habitat for developing fish and invertebrate larvae (Ambrose and Irlandi 1992; SAFMC 1998a). Important commercial and recreational species present in SAV as juveniles in the spring and early summer include gag, black sea bass, snappers, weakfish, spotted seatrout, bluefish, mullet, spot, Atlantic croaker, red drum, flounders, southern kingfish, hard clam, and herrings (Rooker et al. 1998, SAFMC 1998a). Estuarine-dependent reef fish (i.e., gag, black sea bass) use seagrass meadows as juveniles, prior to moving offshore (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). In North Carolina, where SAV is present year-round, some larval and early juvenile finfish, molluscan, and crustacean species are present in SAV habitat much of the year (SAFMC 1998a). Offshore, winter-spawning species such as spot, croaker, shrimp, and pinfish inhabit SAV habitat as early juveniles in winter and early spring (Rooker et al. 1998).

While some juveniles of a species have been documented occurring in SAV, other species show some preference for SAV habitat over other habitat types. Minello (1999) summarized information on densities of juvenile fisheries species (<100 mm TL) in shallow-water estuarine habitats (marsh edge, SAV, and soft bottom) of Texas and Louisiana, which showed highest densities of pink shrimp and red drum in SAV habitat. Submerged aquatic vegetation has been recognized as critical nursery habitat for pink shrimp in North Carolina (Murphey and Fonseca 1995). For juvenile red drum in Galveston Bay, Stunz et al. (2002) reported measuring increased growth rates in SAV enclosures compared to other habitat enclosures (shell bottom, wetland edge, and soft bottom). 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 during summer months and in grass beds that are close to spawning areas (Zieman 1982; DMF, unpub. data). Juvenile red drum were also 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 SAV behind the Outer Banks (DMF 2001c). More rigorous analysis of DMF data, including both juvenile abundance and concurrent habitat measurements, indicated a higher affinity to seagrass for both age-1 and age-2 red drum (Bachelor et al. 2009).

Other species showing some preference for SAV habitat include brown shrimp, bay scallop, hard clams, and blue crabs. Clark et al. (2004) compared the density of juvenile brown shrimp in various habitats (marsh edge, SAV, and soft bottom) using 16 years of data for Galveston Bay. The results indicated a preference of marsh and SAV over soft bottom, with SAV selected over marsh where both habitats co-occurred. 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[81] (Thayer et al. 1984; Stephan and Bigford 1997).

Juvenile blue crabs prefer shallow water areas with structures, including SAV, tidal marsh, shell bottom and detritus (Etherington and Eggleston 2000). In the Albemarle-Pamlico system, the majority of initial recruitment of juvenile crabs occurs in SAV 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). 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). Hovel (2003) correlated the survival of juvenile blue crabs to SAV landscape characteristics such as patch size, patch isolation, and proximity to edge in Back Sound, North Carolina. The results indicated that juvenile blue crab survival was positively correlated with patch area and was negatively correlated with seagrass shoot biomass.

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). Hoyer and Canfield 1996 determined that although adult largemouth bass can thrive with very little SAV coverage, adequate nursery habitat must

[81] Recruitment = 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.

be available for juveniles. Paller (1987) determined that the standing stock of larval fish in freshwater SAV beds 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). Hirst and Attrill (2008) found that a decrease in patch size (increase in fragmentation) did not affect the invertebrate biodiversity. These findings suggest that habitat fragmentation could have a varying effect on recruitment, depending on the species.

4.2.4.4. Foraging

The majority of macrofauna in SAV habitat forage on secondary production from epibiotic communities, benthic algae, organic detritus, and bacteria rather than direct consumption of SAV (Day 1967; Adams and Angelovic 1970; Carr and Adams 1973; Meyer 1982; SAFMC 1998a). 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). In contrast, there are numerous air-breathing species grazing directly on SAV that include migratory birds (e.g., black brant, *Branta bernicla;* Canada goose, *Branta canadensis;* and widgeon, *Anas penelope*), green sea turtles, and West Indian manatees (SAFMC 1998a). Green sea 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, greatly reducing the input of organic matter and nutrients to sediments near the SAV (Ogden 1980). Dramatic declines in eelgrass abundance have also been documented following the over-winter foraging activity of Canadian geese (River and Short 2007). Due to the geese consuming plant meristems, sexual reproduction of the remaining eelgrass was minimal the following summer. 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 [82] (Jackson et al. 2001). The balancing of SAV abundance and grazer populations is another example of ecosystem management.

Large predatory fish, such as Atlantic stingrays, flounders, bluefish, sandbar and other sharks, weakfish, red drum, spotted seatrout, and blue crabs, are attracted to SAV beds for their concentrations of juvenile fish and shellfish (Thayer et al. 1984). Though large shellfish predators represent 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). Overharvesting predators of shellfish consumers (i.e., large coastal sharks) could therefore lead to increasing damage on their foraging habitat (Myers et al. 2007).

4.2.4.5. 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% compared to areas 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 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

[82] see Threats section

adjacent to the marsh edge. These findings indicate that SAV provided a safe passage and offered additional food resources (Irlandi and Crawford 1997). 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 (i.e., juvenile red drum, seatrout) that are more susceptible to predation in open water. *Research is needed on the relationship between juvenile Sciaenid abundance and connectivity among nursery habitats and spawning area.*

4.3. STATUS AND TRENDS

4.3.1. 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). Scientific studies indicate a global and national trend of declining SAV habitat (Orth et al. 2006; Waycott et al. 2009). Orth et al. (2006) summarized status and trends information on SAV at a global scale and found reports of large-scale SAV losses in the European Mediterranean, Japan, and Australia. Reports of SAV recovery were very low by comparison. Waycott et al. (2009) showed seagrasses disappearing at rates similar to coral reefs and tropical rainforests based on more than 215 studies and 1,800 observations dating back to 1879. The compilation of studies shows a 29% decline in known SAV extent since 1879. The study also indicated an acceleration of loss since 1940 (7%/yr, up from <0.9%/yr prior). In North America, 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 on 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.

Trend data on SAV distribution in North Carolina are either limited to qualitative information for broad areas or quantitative information for selected areas of the coast. The qualitative information includes:

- Elderly fishermen and fishermen's journal accounts from the late 1800s describe extensive beds of SAV in many coves along mainland Pamlico Sound where it was absent in the late 1990's (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. Healthy eelgrass beds were generally re-established by the 1960s.
- In the upstream half of the Pamlico River estuary, tidal freshwater SAV was common until the mid-1970s (Davis and Brinson 1976; Davis and Brinson 1990). During the mid-1980's, SAV in western Albemarle Sound and Neuse River declined significantly (Davis and Brinson 1990).
- During the 1990's, Mallin et al. (2000a) reported extensive losses of eelgrass beds along the intracoastal waterway (Morehead City area) and near the Harker's Island mainland. There was also a major die-off of SAV in the Perquimans River after Hurricane Floyd in 1999 (S. Chappell/DMF, pers. observation). But there was also a resurgence of SAV during the 1990's in some locations. The resurgence was implied by complaints about abundant SAV around docks in the Neuse River and fishermen's anecdotal accounts in the Pamlico River (Mallin et al. 2000a).
- 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).
- In 2007 and 2008, DMF biologists reported extensive SAV growth throughout the estuarine

system (attributed primarily to drought conditions and lack of major storm events).

Quantitative information on SAV status and trends comes in basically 3 forms: 1) station monitoring, 2) transect monitoring, and 3) areal coverage monitoring (i.e., mapping). The earliest data on SAV status and trends comes come from a history of station and transect monitoring in Currituck Sound (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. Before 1962, native sago pondweed and wild celery were the dominant and subdominant SAV species. By 1973, Eurasian watermilfoil had replaced sago pondweed as the dominated aquatic plant species, followed by bushy pondweed. After a severe storm in 1978, bushy pondweed was virtually eliminated, and total macrophyte biomass was 42% less than in 1973. 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. The monitoring transects referenced in Davis and Brinson (1983) were revisited in recent years by the Marine Environmental Science Program at Elizabeth City State University (Liz Noble, unpublished data 2006) and USACE (report pending). It is apparent from the historical record that SAV coverage and biomass are greatly affected by weather events, site conditions, and human activities that affect turbidity and salinity (see “Threats and management needs” sections). This relationship is true not only for Currituck Sound, but also for other coastal water bodies containing SAV. *In order to quantify trends in SAV abundance, regular mapping efforts of all or a subset of the habitat are needed in addition to monitoring data from stations and transects. Monitoring should focus on SAV in the most vulnerable locations (close to land where water quality degradation and shoreline development impacts greatest, edge of southern and western distribution range) and in areas of current or former importance to bay scallops.*

Coast-wide aerial photography of SAV combined with on-site sampling is the standard method for mapping SAV in Chesapeake Bay and elsewhere. The relatively short history of SAV mapping in North Carolina estuaries started in 1981 with digitizing from aerial photographs of Core and Bogue sounds (Carroway and Priddy 1983). The largest mapping coverage (Albemarle-Pamlico estuarine system) over the shortest time period (1983 – 1992) was completed by NOAA and published in Ferguson and Wood (1994)[83]. Since then, comparable repeat mapping is available for the Neuse River, Currituck Sound, and

[83] An inventory of SAV mapping and monitoring efforts is provided at (http://www.ncdmf.net/habitat/chpp28.html, June 2009).

Back Bay (Virginia). The Neuse River was remapped in 1998 by DWQ, and the Currituck Sound and Back Bay were remapped by ECSU in 2003. However, basic change analysis has only been completed for the Neuse River (DWQ 1998). The DWQ assessment was conducted using aerial photography and field verification methods similar to those of Ferguson and Wood (1994). 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 differences in methodology, any change in coverage cannot be determined with certainty. In 2006, NOAA acquired SAV imagery of Core and Bogue Sound and completed digitizing in 2009 (Don Field/NOAA, pers. com., August 2009). The multiple years of data for Bogue and Core Sound (Carroway and Priddy 1983; Ferguson and Wood 1994) suggest the possibility of change analysis. However, conducting SAV change analysis in different areas should be undertaken with careful consideration of annual differences in growth-integrated environmental conditions. Undigitized imagery is also available for the purpose of SAV mapping and change analysis. The earliest such imagery was funded by DOT in 2004, for the Pea Island Area in northern Pamlico Sound. However, field verification data is lacking for the area and time period.

Prior to 2007, the mapping and monitoring of SAV was sporadic and piece meal, resulting in the lack of a comprehensive baseline dataset for SAV distribution. Comprehensive mapping of SAV habitat in coastal North Carolina was initiated in 2007 by a joint effort of federal and state agency and academic institutions (http://www.apnep.org/pages/sav.html, June 2009). The SAV Partnership began in summer 2001 when Region 5 (Virginia) staff of the U.S. Fish and Wildlife Service (FWS) needed matching non-federal funds to secure an agency grant. The outcome of their initial inquiry was the formation of a SAV Working Group, whose common goal was to pool resources from organizations with a common interest in assessing SAV habitat along the North Carolina and southeast Virginia coastal region. The first aerial surveys in support of this goal were flown during fall 2003 in the northernmost portion of the region. The Ablemarle-Pamlico National Estuarine Program (APNEP) became the lead coordinator in summer 2004. During this period the Working Group began the process of creating a Memorandum of Understanding to formalize agency interactions for implementing a combined effort map and monitor SAV habitat. Beginning in winter 2006, meetings were scheduled on a regular (quarterly) basis and agenda topics expanded beyond mapping and monitoring to include assessment, restoration, policy, and outreach. The Memorandum of Understanding was signed by all signatories in fall 2006, thus creating the Partnership.

The APNEP then allocated $160,000 toward contracting out imagery for 2007-08. The FWS, DMF, DENR, and NOAA contributed an additional $130,000. The NOAA representative took the lead on imagery specifications and securing the contract. The DMF was responsible for verifying water clarity conditions, coordinated field survey efforts and conducting the photo-interpretation. A stratified random sampling design was used to conduct 1,250 field surveys to accompany the 1-m resolution imagery. The strata consisted of previously vegetated and nonvegetated bottom less than 6 feet deep. The DMF conducted the majority of field surveys, with the remaining stations covered by ECU, ECSU, DWQ, DOT, WRC, NERR, FWS, and DCM. Over 90% of the flight lines were covered in 2007, with the remaining area flown in 2008. Digitizing SAV polygons on the imagery is currently discontinued due to a staff position vacancy and freeze on hiring. The SAV Partnership is looking into other locations to house a GIS analysis for digitizing SAV polygons from the imagery (Joe Luczkovich/ECU, pers. com., May 2009).

While a quantified change analysis is not available, preliminary review of core areas of SAV, such as behind the Outer Banks in Pamlico Sound and Core Sound do not indicate large change since previous imagery for those areas in 2004 (D. Field/NOAA, pers. com, 2010). However, there may have been a shift to increased patchiness of previously dense beds in Bogue Sound. Observations of DENR field staff have noted SAV presence in previously unvegetated areas in some of the low salinity systems and southern range of SAV, which may be related to improved water clarity associated with the coastwide drought in 2007-2008.

A comprehensive SAV monitoring program must employ methods covering the range of water quality conditions where SAV grows in North Carolina. The relatively shallow estuarine waters of North Carolina vary in optical properties from highly organic stained in the coastal rivers to clear saline behind the barrier islands. Ferguson and Wood (1994) noted the difficulty in digitizing SAV beds in turbid, low salinity waters. Aerial reconnaissance conducted during 2005 revisited some field-verified SAV beds in the upper Neuse River and found most of the beds indistinguishable from the air (S. Chappell/DMF and J. Green/DWQ, pers. observation). The low visibility in riverine areas from the air presents a challenge to periodic areal monitoring of SAV coverage in the state. Other comprehensive SAV monitoring methods are being investigated to address the issue. The APNEP was awarded a North Carolina Coastal Recreational Fishing License grant from the DMF and WRC for a 2-year project to establish a protocol for sampling submerged aquatic vegetation in the field. This field sampling will use underwater video and acoustic equipment to compare methodology and be complementary to the aerial imagery acquired in 2007-2008. The project will attempt to provide a rigorous statistical evaluation of annual changes in SAV abundance and develop a standardized method of field monitoring SAV in North Carolina. Partnering organizations for this grant include APNEP, NOAA, NCSU, and ECU. *The results of this new SAV monitoring research should be evaluated for broader application in the estuary as a whole.*

There have been several smaller mapping projects involving various techniques. DMF's Bottom Mapping Program and DWQ's Rapid Response Program map SAV by delineating bottom type strata boundaries along transect lines and interpolating. The DMF has been mapping subtidal vegetated strata in moderate to high salinity waters since 1989. Bottom mapping personnel also comprised a large portion of the field survey crew working with the 2007-2008 aerial imagery. The DWQ started mapping freshwater and low salinity SAV in western Pamlico Sound tributaries in 2005. However, there has been no repeat sampling of areas mapped using transect-based interpolation methods. The DMF also surveys for SAV presence and density in conjunction with selected fisheries monitoring programs. The NEER is also monitoring SAV on their reserves as part of 2005 CHPP implementation. *Local and regional monitoring programs should eventually be coordinated with a comprehensive SAV monitoring program.*

4.3.2. Status of associated fishery stocks

It is very difficult to attribute changes in fish abundance to changes in habitat due to the difficulty of achieving the data needs for such an analysis. The analysis needs accurate density estimates for fish species and size classes among accurately delineated habitat types over a time series to predict fish – habitat relationships. Assessments have been attempted for peneaid shrimp and red drum. The habitat relationships of fishery species and life stages were used to estimate population densities of brown shrimp by Clark et al. (2004), and priorities for habitat protection by Levin and Stunz (2005) in Galveston Bay. Clark et al. (2004) used the density of juvenile brown shrimp in different habitats to estimate an overall population size of 1.3 billion in Galveston Bay. Levin and Stunz (2005) estimated that habitat for red drum larval and juveniles should be given the highest priority for protection. Such analyses have not been conducted in North Carolina. *Research is needed to quantify habitat relationships of fisheries species and life stages in North Carolina in order to estimate population sizes and determine habitat protection priorities.*

Fish-habitat change analysis is also difficult because of the confounding effect of fishing on fish populations. In North Carolina, estimated fishing mortality and juvenile abundance indices are used by the DMF to determine the status of fishery stocks. Stock status evaluations may also suggest habitat issues for concern or depleted species. Of the species identified in Table 4.4 with a preference for SAV habitat, 8 stocks were evaluated for fishery status[84]. The hard clam was assigned an Unknown status. Of the remaining 7 stocks with a designated status, one was designated Depleted (spotted seatrout), two were Concern (yellow perch, blue crab), two were Recovering (red drum, bay scallop), and two were Viable (brown shrimp, pink shrimp) (http://www.ncdmf.net/stocks/2010NCDMF%20StockStatusReport.pdf). 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 Depleted or Concern, by maximizing recruitment and productivity. *More fishery-independent information and habitat change analysis are needed to evaluate the effect of SAV-coverage on the abundance of fish and invertebrates.*

4.3.3. Submerged aquatic vegetation restoration and enhancement

Although protection, rather than mitigation or restoration, is the more environmentally sound and a less costly management approach for long-term enhancement of SAV habitat, restoration and/or enhancement is possible in areas of recovering SAV abundance or where human impacts have physically removed the vegetation (Fonseca et al. 1998, SAFMC 1998a, Treat and Lewis 2006, Orth et al. 2006). Restoration in the latter case requires only replacing SAV where it had recently existed. Successfully restoring SAV to areas where it is not currently present depends on conditions at the site throughout the year.

As SAV grows and spreads, it creates a feedback loop of increasing resilience to perturbation and improving habitat conditions for itself, up to a point (see “Diseases and microbial stressor” section for more information). This positive feedback suggests a critical mass of SAV, above which, the vegetation is less susceptible to periodic disturbances (Moore et al. 1997; Moore 2004). Recent research examining the water treatment capacity of SAV beds (see “Ecosystem enhancement section” for more information) observed water quality benefits at bed densities of 50% or greater. The actual density, extent and location of SAV needed to establish resilience and ecological functions depends on the corresponding quality and quantity of water circulating through the system. To use an analogy, dirtier water needs a larger filter to prevent clogging. Successful restoration efforts will establish an SAV coverage during optimum conditions that is sufficient to allow recovery after natural perturbations to the system. In areas of recovering SAV abundance, restoration and enhancement techniques can be used to accelerate the recovery of SAV toward some critical density and coverage. Hard clam restoration could be one possible means of enhancing water quality for SAV growth. SAV has been observed expanding adjacent to some clam aquaculture leases in Virginia and North Carolina. This suggests that by seeding areas adjacent to SAV with hard clams, the filter feeders will reduce suspended sediment and nutrients. *Research is needed on the feasibility of hard clam augmentation for the purpose of water quality based restoration of SAV.*

In suitable habitat areas, SAV can recover quickly after a natural disturbance. In more human-altered areas, SAV may recover very slowly or not at all. Water-based restoration efforts are warranted in areas where SAV is very slow to recover. A perfect example of slow recovery may be occurring in Back Bay, Virginia, just north of Currituck Sound. Throughout most of the 20th Century, Back Bay and Currituck Sound garnered a reputation for excellent hunting and fishing along the East Coast. This began to change during the 1970s. Annual Mid-winter Waterfowl Surveys coupled with Back Bay NWR aerial waterfowl surveys revealed a decline in waterfowl populations during the early 1970s (Baker et al. 2006) in the system. The decline was linked to significant reductions in the distribution and abundance of freshwater and low salinity SAV throughout the Bay. Unfortunately, systematic water quality monitoring was not in place in Back Bay; so the cause of the decline could not be correlated with data. However, the decline corresponded to major landscape changes in the northwestern portion of Back Bay’s watershed during the 1970s and 1980s, as new housing developments and farming activities increased. A similar decline was noticed about ten years later in the Knotts Island Bay-Currituck Sound (Baker et al. 2006), immediately

[84] Refinement of the ecological role and function section lead to a reduction in documentation of SAV-enhanced species noted in the 2005 CHPP (Street et al. 2005).

south of Back Bay.

The SAV in Back Bay-Currituck Sound was mapped by ECSU in 2003 and again by the APNEP SAV partnership in 2007. The 2003 imagery and field verification indicated a very low abundance of SAV in the Back Bay portion of the system (Noble and Hall 2005). A very low abundance of SAV was also indicated from ECSU transect monitoring of Back Bay during 2006 (Noble and Mohr 2008). However, the imagery from 2007 and observations during 2008 suggest a substantial increase in SAV abundance from 2003-2008 (J. Gallegos/USFWS, pers. observation). The increase in SAV is an encouraging sign for the multiple federal and state agencies interested in restoring the SAV resources of Back Bay (i.e., USACE, USFWS, Virginia Game and Inland Fisheries (VDGIF), APNEP). The VDGIF is pursuing a pilot project to enhance SAV habitat in Back Bay with the use of strategically placed turbidity curtains (C. Boyce/VDGIF, pers. com., May 2009). The VDGIF is seeking information regarding potential habitat locations, effective planting techniques, and seed/rhizome dispersal patterns.

Given the range of environmental conditions at a site, modeling potential habitat must indicate both habitat suitability and probability of occurrence. Restoration efforts could then move out from locations of highest probability. Probabilities are indicated by the pattern of SAV recovery in a water body. The reported spread of SAV in Perquimans River after Hurricane Floyd occurred upstream from the lower reaches of the rivers, near the main body of Albemarle Sound (S. Winslow/DMF, pers. com.). A recovery pattern was also suggested in the Neuse River from small, sunlit coves and tributaries having a consistent coverage of SAV (J. Paxon/DWQ, pers. com.). The observed patterns suggest core areas of abundance from which to launch restoration efforts. Research in Chesapeake Bay observed eelgrass seeds settling rapidly with the waves and currents to disperse only a few meters from the seed sources (Orth et al. 1994). However, other SAV species may differ in their dispersion range, suggesting a pattern of succession in species composition during recovery. *Research is needed to verify where recovery of SAV is occurring and if there is a spatial (and species) 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. In the mean time, Back Bay/Currituck Sound should serve as a test case for re-establishing SAV in a recovering/recoverable ecosystem ..*

Land-based restoration may also be possible in locations of historical SAV abundance where it is currently absent or severely reduced (even in the best of years). Improving the quality of water circulating through the system will mitigate the need for extensive water-based restoration of SAV. A good example of land-based restoration facilitating SAV restoration is occurring in Wilson Bay, New River. The Wilmington USACE-Jacksonville SAV Restoration project (Section 206) has done a lot of work restoring water quality, wetland, and oysters in Wilson Bay. And there are plans to establish SAV in the system (C. Wilson/USACE, pers. com., 2009) where it currently exists upstream and downstream. The restoration was made possible by removing or diverting polluted effluent entering the bay (Mallin et al. 2005). A nursery facility on Wilson Bay is producing plants for restoration, with technical assistance from the Chesapeake Bay Program (Dr. Deborah Shafer and Steve Ailstock). The project employs annual seed collections from areas of high SAV abundance for growing rooted transplants for restoration (P. Donovan-Potts, pers. com., June 2009).

The facility on Wilson Bay could also be expanded to supply SAV transplants for other project areas. Other projects with an SAV restoration component include USACE's Festival Park & Wanchese Marsh Restoration Projects on Roanoke Island, USFWS's Monkey Island Restoration in Currituck Sound (shoreline protection component could include SAV restoration as wave buffers), DWR's Silver Lake Harbor estuarine shoreline restoration project, and the town of Kitty Hawk's proposal to protect an eroding marsh shoreline where SAV is abundant offshore (need to avoid, mitigate and/or monitor SAV impacts). In 2007, Elizabeth City State University (ECSU) was granted $59,834 to evaluate restoration opportunities in Currituck Sound and Back Bay (J. Gallegos/USFWS, pers. com., November 2009).

ECSU faculty investigators Elizabeth Brinker and Dr. Maurice Crawford are tasked with: (1) producing digital polygon maps of potential SAV restoration sites in Currituck Sound and Back Bay; (2) completing some experimental SAV plantings in Currituck Sound to assess plant survival, vigor, and feasibility of SAV restoration efforts in Back Bay and Currituck Sound; (3) calibrating the Kemp et al. (2004) algorithm and/or other light attenuation models; (4) producing a GIS data layer of the bathymetry of Currituck Sound and Back Bay, and (5) hosting a workshop at ECSU to communicate SAV restoration techniques to State, Federal, and Non-governmental agency staff. ECSU will also produce a final report on SAV restoration techniques and recommendations for re-establishment of SAV in Currituck Sound and Back Bay. As of October 2009, ECSU has completed bathymetric transects of Currituck Sound and Back Bay and has established reference and transplants sites in Coinjock Bay (Currituck Sound). Transplanting efforts in 2008 met with limited success, whereas 2009 efforts exhibited survival and growth attributed to retention of transplanted sediment (Brinker and Crawford 2009). Lessons learned and data accumulated from the Coinjock Bay restoration site will be applied to proposed expanded restoration efforts. Back Bay is targeted as the high priority for a restoration site. The results from Brinker and Crawford study could also be used in SAV restoration for mitigation in low salinity areas.

Compensatory mitigation is often required for major shoreline development projects involving direct removal of SAV. The mitigation is required by the USACE's enforcement of Clean Water Act Section 404 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. Though in practice, mitigation is only designed to replace an acreage equal to or greater than that which was lost or impacted (see "Wetland enhancement and restoration" section of "Wetlands" chapter for more information). So mitigation activities should represent very little net change is SAV coverage, if the restored habitat is functionally equivalent to what was lost. Mitigation may also be required by enforcement actions, such as the recent (2004) case of unpermitted dredging in northern Currituck Sound by DOT.

Mitigation for impacts to SAV is only allowed by CRC rules if the activity associated with the proposed project will have public benefits that outweigh the short or long range adverse impacts. Otherwise, direct impacts to SAV are not allowed by DCM policies and CRC rules. Most permitted impacts have involved transportation (bridge construction) or navigation (channel dredging). 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 documented in Carteret and two in Onslow counties between 1978 and 1991. Three projects were done as N.C. Department of Transportation (DOT) mitigation, while the others were research projects conducted by NOAA. A total of 1.95 acres (0.79 ha) of bottom was restored to SAV by these projects. The general criteria for determining success was defined 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). Of the 14 sites, 11 were considered "successful."

Since 1991, there have been four more DOT projects involving some level of SAV impacts/mitigation: Neuse River bridge, Chowan River US 17 bridge, Wright Memorial bridge from Currituck to Dare county, (D. Huggett/DCM, pers. com., August 2009), and the illegal dredging of a channel off Corolla's Heritage Park (see "Dredging (navigation channels and boat basins)" section for more information). The impacts were estimated at 1-2 acres for each project, and the mitigation was almost always out-of-kind. Some mitigation was also required for at least two private projects. The Sandy Point Development near Edenton impacted around 3-4 acres of SAV habitat, with mitigation occurring adjacent to the site. The Joseph Thompson Project in Dare County involved moving a navigation channel away from SAV habitat. Mitigation for this project involved transplanting SAV into the old channel area. The DCM generally does not permit projects with direct SAV impacts, therefore negating the need for restoration/mitigation (D. Huggett/DCM, pers. com., August 2009).

Techniques and success criteria for SAV restoration have been developed and evaluated by the NOAA's Coastal Ocean Office (Fonseca et al. 1998) and others (Orth et al. 1994; Smart et al. 1998; Boustany 2003; Ailstock and Shafer 2006; Treat and Lewis 2006). However, a detailed description of the various restoration techniques and specific success criteria will not be discussed here. The APNEP SAV Partnership is developing an action plan for SAV restoration activities in North Carolina and southeastern Virginia, with guidance from the Chesapeake Bay experience (Orth et al. 2002). Some important action items for the plan include developing a central database of SAV restoration projects, a central repository for mapping/monitoring data, and some means of coordinating research, monitoring, and restoration activities among multiple agencies and conservation organizations. *The plan for SAV restoration should also be coordinated with other habitat restoration plans and activities.*

Any plan for SAV restoration should include target goals for measuring progress toward some end point. Setting goals based on historical abundance has been suggested (Street et al. 2005). However, setting goals based on historical abundance may not be justified given an evolving system. Setting restoration goals based on potential habitat maps and projected water quality improvements would be more justifiable (see "Habitat requirements" section for more information on modeling potential habitat). An accurate map of potential habitat could guide restoration work aimed at accelerating SAV recolonization after a period of low abundance due to unfavorable or extreme conditions. *The SAV restoration action plan should include restoration goals based on potential habitat maps and projected water quality improvements (see "Water column restoration and enhancement" section of water column chapter for more information).*

4.3.4. Designated areas

Strong regulations are in place to protect SAV, particularly from physical damage. Special designations may provide additional, indirect protection for native SAV above the regulatory protection granted wherever they occur. State designations protecting SAV in public trust waters fall into basically three categories: (1) water quality protection, (2) physical habitat protection, and (3) both water quality and physical habitat. EMC rules related to water quality designations such as Outstanding Resource Waters, High Quality Waters, Nutrient Sensitive Waters, and Water Supply Water I & II protect water quality, which in turn benefits SAV. These designations are described in the "Designations" section of the "Water Column" chapter. MFC designations such as trawling and mechanical methods prohibited areas, Crab Spawning Sanctuaries, Oyster Sanctuaries, Shellfish Management Areas, and Military Prohibited Areas provide protection from fishing gear damage. CRC rules (general use standards 7 H .0208) require activities in public trust waters, such as navigation channel dredging and marina siting, to avoid significant adverse impacts to SAV habitat, as defined by the MFC. Both physical and water quality protections are afforded to open shellfish harvesting waters and Primary Nursery Areas. At the federal level, the South Atlantic Fishery Management Council (SAFMC) classifies SAV as Essential Fish Habitat for peneaid shrimp, red drum, and snapper/grouper species. The protections are described later in reference to particular threats. The vast majority of mapped SAV occurs within one or more designations providing some degree of additional protection, based on GIS analysis comparing SAV maps and regulatory designations (DMF unpublished data, July 2009).

4.4. THREATS AND MANAGEMENT NEEDS

Natural events, human activities, and global climate change influence the distribution and quality of SAV habitat. Natural events may include regional shifts in salinity because of drought or excessive rainfall, animal foraging, storm events, cold temperatures or disease. 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 inflict damage or mortality on SAV directly, as well as by indirectly influencing future survival, reproduction or establishment through alteration of habitat conditions (e.g., increased turbidity via sediment resuspension). SAV is also vulnerable to water quality degradation, and in particular to suspended sediment, due to its relatively high light requirements (see "Habitat requirements" section for more information). Human impacts to SAV habitat have been documented and summarized by the Chesapeake Bay Program (CBP 1995), Atlantic States Marine Fisheries Commission (ASMFC 1997a), South Atlantic Fisheries Management Council (SAFMC 1998a), NOAA (Thayer et al. 1984; Fonseca et al. 1998) and others (Funderburk et al. 1991; Mallin et al. 2000; Orth et al. 2006). The most recent synthesis of research describes a global crisis for seagrass ecosystems (Orth et al. 2006; Waycott et al. 2009). Climate change and sea-level rise could cause large-scale losses of SAV habitat due to rising temperatures, water levels, and a collapse of the barrier island system (see "Sea-level rise and climate change" section for more information). The situation for North Carolina SAV will be described using these sources, in addition to permitted impacts documented by regulatory agencies, and personal observations.

4.4.1. Physical threats

4.4.1.1. Water dependent development

Dredging (navigation channels and boat basins)

Dredge and fill activities are considered the primary physical threat to SAV (Orth et al. 2006). Dredging for creation or maintenance of navigational channels and inlets resulted in degradation or elimination of SAV habitat. 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). 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 more 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.[85] SAV habitat can also be destroyed if dredged material is placed directly on shallow soft bottom where it could grow. However, placement of dredge spoil is restricted to upland sites except on subtidal bottom where spoil islands are permitted. The current permit process should prevent spoil islands being placed on SAV habitat. However, dredge spoil could also be used in deeper water to create SAV habitat. The beneficial use of dredge material is addressed in the wetlands and soft bottom chapters.

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; Duarte et al. 2005). North Carolina's ports in Wilmington and Morehead City are small in comparison. The Wilmington port resides in the turbid, riverine section of the Cape Fear River where suitable habitat for SAV is lacking. 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. Dredged channels connecting marinas and small docking facilities (including boat ramps) to major navigation channels are another source of SAV habitat loss and degradation. Maps 2.13a-c (Water Column chapter) shows the location of ports, navigational channels (both dredged and undredged), boat ramps, marinas, and multi-slip docking facilities in coastal North Carolina. Some artificial channels bisect uniformly shallow areas with SAV beds on both sides, indicating a possibly unmitigated loss of SAV habitat (S. Chappell/DMF, pers.

[85] Refer to the "Habitat Requirements" section for the light and sediment conditions needed for SAV colonization

observation). Restoration goals could be established for historic losses of dredged SAV habitat, by using the 2007-08 SAV imagery and GIS data for marinas, boat ramps, small boat basins, and navigation channels to calculate the amount of dredged area.. This would provide a conservative starting point for SAV restoration compared to other methods for determining restoration goals (i.e., predicted changes in water quality are uncertain, as is the historic distribution of SAV).

Coastal Management rules and policies require aligning dredge channels to avoid submerged aquatic vegetation, as defined by the MFC [CRC rule 15A NCAC 7H .0208(b)(1)]. In the past, to satisfy these criteria, the permit process would work with the applicant to locate the proposed area for dredging between visible patches of SAV. As part of CHPP implementation the MFC modified the definition of SAV habitat to take into account growing seasons and inter-annual variability. CRC modified their rules to refer to the MFC definition. With this modified definition effective in 2009, regulatory and review agencies, now assess past and current occurrence of documented SAV coverage within the past 10 years (see “Definition” section for more information) when siting coastal development projects to avoid areas of SAV habitat. However, some areas of historic SAV occurrence can still be dredged if they are “essential to maintain a traditional and established use” based on meeting four criteria [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 that 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 a disposal area in accordance with Part (b)(1)(B) of this rule without impacting adjacent nursery areas and submerged aquatic vegetation as defined by the MFC; (iv) the original depth and width of a human-made or natural channel shall not be increased to allow a new or expanded use of the channel.”

Although the USACE maintains 6,992 acres (2,829.56 ha) of navigation channels in coastal North Carolina (USACE, unpub. data, 2003), 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). Some of these channels are adjacent to or bisect SAV occurrence (Maps 4.3a-b), suggesting the potential for historic and/or indirect impacts. New dredging projects that could potentially impact SAV continue to be proposed. Some of the major projects (proposed, permitted, or discussed) with SAV considerations included:

- Relocation of ferry landing on north end of Ocracoke Island -
- Realignment of existing navigation channel through Bogue Inlet -
- Town of Southern Shores (Dare County) -
- Sandy Point Development (Chowan County) -
- Sunset Village (Dare County) - Mitigation/restoration
- Kitty Hawk Landing HOA(Dare county) – currently proposed
- Craven Board of Education – boat ramp with SAV

Alternative proposals often require weighing the impact on one habitat versus another (see “Ecosystem management and Strategic Habitat Areas” chapter for discussion of habitat trade-offs). As the coast becomes more developed, additional projects involving SAV impacts will likely be proposed. *The DMF and MFC should continue to use existing permit review to prevent or limit as much as possible direct or indirect impacts to SAV from all dredge and fill projects.*

There is also some degree of illegal propeller dredging (i.e., “kicking”) where large boats are docked in very shallow water. One notable case of illegal dredging occurred in 2004 when a DOT work boat kicked 2 feet of sediment to create a 5 foot deep channel through shallow water and SAV in Currituck Sound (S. Mitchell/DOT, pers. com., 2009). The intent was to deepen an existing channel in order to accommodate a pedestrian ferry to Currituck's Heritage Park in Corolla. Permits for the project had previously been denied by DCM to protect shallow nursery habitat in the area. The CRC's current rules and regulations adequately addressed the situation and DCM staff handled a complicated enforcement case appropriately, ensuring all impacted SAV habitat was restored (M. Lopazanski/DCM, pers. com., January 2010). The DOT efforts to restore SAV in the affected area have been successful (S. Mitchell/DOT, pers. com., July 2009).

Shoreline stabilization

The primary discussion of shoreline stabilization occurs in the Wetlands chapter and includes information on SAV impacts. Hardened vertical structures in moderate-energy environments can potentially degrade shallow SAV habitat by increasing wave energy, turbidity, and water depth. Scouring, deepened water, and reduced water clarity due to suspended sediments degrade optimal conditions for SAV growth. One specific observation was noted by ECU researchers conducting a video and acoustic assessment of SAV near Sandy Point on Albemarle Sound. A graduate student working with Dr. Joe Luczkovich noticed a conspicuous contraction and degradation of SAV habitat along hardened portions of the shoreline relative to natural shoreline. Dr. Luczkovich has considered investigating the observation further. *The relationship between SAV habitat characteristics and associated shoreline types should be investigated further.*

In comparing impacts of vertical versus non-vertical structures, there are habitat trade-offs that can make one alternative more ecologically beneficial than another. For example, bulkheads placed to prevent upland erosion typically increase the depth of shallow nearshore soft bottom, resulting in a loss of shallow soft bottom areas near SAV. In contrast, non-vertical structures, while not causing as much scouring and deepening, may require placement of rock structure further out onto submerged lands, resulting in loss of SAV habitat under the subtidal footprint of the sill. However, the gain of marsh habitat and increased stormwater runoff control landward of the sill may enhance water quality for SAV (see "Ecosystem enhancement" section of "Wetland" chapter for more information). The issue of habitat trade-offs is explored further in the "Ecosystem management and Strategic Habitat Areas" chapter.

Marinas and docks

The CRC requires marinas to be sited in non-wetland areas in deep waters that don't require dredging and shall not disturb SAV as defined by the MFC. The CRC's preference is for upland basins, where SAV may become established. However, upland 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). Vertical shoreline stabilization and docking facilities associated with marinas may also impact SAV. Recent rule changes by the CRC state that, "Piers and docking facilities located over shellfish beds or submerged aquatic vegetation (as defined by the Marine Fisheries Commission) may be constructed without prior approval from the Division of Marine Fisheries or the Wildlife Resources Commission (whichever is applicable) if the following two conditions are met: (1) Water depth at the docking facility is equal to or greater that two feet of water at normal low water level or normal water level (whichever is applicable). (2) The pier and docking facility is located to minimize the area of submerged aquatic vegetation or shellfish beds under the structure" [CRC rule 15A NCAC 07H.1205(h)]. The location of marinas, boat basins, and public boat access areas relative to SAV is depicted in Maps 2.13a-b of the Water Column chapter.

Shading from docks also results in loss of SAV beneath the dock structures (Loflin 1995; Beal and Schmit 1998; Shafer 1999; Connell and Murphey 2004). 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). These small individual losses of SAV may seem insignificant, but they can have significant cumulative impacts. *The overall significance of dock shading on SAV should be assessed by comparing concurrent maps of shoreline structures and SAV habitat.*

A study by NCDMF in 2002-2003 (Connell and Murphey 2004) found reduced shoot density and coverage of SAV under docks compared to pre-construction conditions, indicating shading impacts. 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. Burdick and Short (1999) identified dock height, orientation, and width as the most important factors affecting SAV survival under a dock Plank spacing was of some but less importance. Their assessment in Massachusetts recommended that docks be built less than 2 m wide, oriented within 10 degrees of north-south, be at least 3 m above the bottom, and add 0.4 m in dock height for every additional m in width. The impact of dock structures on SAV habitat in North Carolina could be minimized given sufficient height of dock structures above the water surface. CRC dock rules were modified in 2009 providing some additional protection for SAV by requiring applications for docking facilities over SAV in less than 2 ft of water (MLW) to be reviewed by the state resource agencies. *Where SAV habitat is evident, additional permit conditions regarding dock design should be considered on a case by case basis to maximize light penetration below docks.* Minimum height requirements are not without precedent in the Atlantic region. State regulations in Maryland, Virginia, Florida and Rhode Island as well as federal regulations have stringent restrictions on constructing piers over SAV, often requiring the applicant to pier out past the SAV, specifying width and height standards, and prohibiting or limiting new dredging in SAV habitat (Orth et al. 2002; DMF unpub. report 2008- tech guidance doc for sav). In Florida aquatic preserves, guidelines for dock construction require 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).

In addition to direct damage from docks and marinas, indirect damage to MFC-defined SAV habitat 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. The potential for boating-related damage increases as additional docks and marinas are constructed along the coast.

As part of 2005-07 CHPP implementation, a workgroup was established to examine the issue of marinas and multi-slip docking facilities in North Carolina. The Sea Grant Marina Advisory Group completed its report on Multi-slip docking Facilities (MSDFs) and provided recommendations to the CRC in 2007. The report resulted in a revised application form for MSDFs (DCM-MP-4) designed to capture information that can be used to judge the impacts of projects. The CRC has also proposed changes to the rules regarding the general permit conditions for dock and piers which give property owners flexibility in docking facilities (8 sq. ft/linear ft shoreline) and provides better protection of shallow water habitat by requiring minimum water depth for docks permitted under a general permit (2 ft) and minimum water depth for floating docking facilities under the general permit if located in a PNA, in SAV, or in Shell bottom (18 in between bottom of floating dock and substrate). Where these conditions aren't met, the applicant may apply for a permit through the major permit process. Pre-existing rules limited dock lengths to no more than 25% of a water body's width (with some exceptions), and not extending into navigation channels or beyond the length of other piers along the same shoreline.

The cumulative impacts from dock structures in rapidly developing coastal areas must also be considered. The DCM has the authority to deny coastal development permits based on the comments of other DENR review agencies relative to cumulative impacts. However, the research and modeling tools necessary for review agencies 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.* Subdivisions choosing community docks over individual docks could minimize the cumulative impact of dock structures on SAV and other aquatic habitats (see “Water dependent development” section of “Water column” chapter for more information).

Infrastructure

Infrastructure is generally defined as a conduit spanning the length between supply and demand locations (i.e., bridges, power lines, fiber optic cables, pipelines). Infrastructure can be an SAV issue where the structures overshadow or replace SAV habitat with hard substrate (see “Ecosystem management and Strategic Habitat Areas” chapter for further discussion of habitat trade-offs) or require dredging to lay cables or pipes. *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 (Street et al. 2005).*

In North Carolina, proposed and completed bridge projects can and have resulted in loss and degradation of SAV habitat. The Highway 17 By-pass Bridge over the Neuse River at New Bern resulted in a loss of SAV habitat and subsequent mitigation (referenced in “Submerged aquatic vegetation restoration and enhancement” section). The bridge constructed over Croatan Sound in 2002 managed to avoid all mapped SAV habitat in the area. The pending replacement of Bonner bridge over Oregon Inlet could cause direct impacts to the grass beds in the area, as well as indirect impacts from changing current patterns and scouring. The current status of the Oregon Inlet bridge replacement remains in the plan development phase (A. Deaton/DMF, pers. com., July 2009). A new bridge was also proposed to cross the middle of Currituck Sound (Street et al. 2005). The proposed location is just north of the largest concentration of SAV in Currituck Sound. As of July, 2009, the Mid-Currituck Bridge is still proposed by the NC Turnpike Authority and will be funded “privately” (Sara Winslow/DMF, pers. com., July 2009). The EIS is being finalized and will be out for review soon.

Infrastructure can also be an SAV issue where development of alternative energy sources is considered water-dependent (i.e., requires location in public trust waters). The conduit for transferring the energy produced in the estuary may intersect SAV habitat. There is an increasing interest in the development of wind farms in Albemarle and Pamlico sounds, as well as off the coast of Cape Hatteras and Cape Lookout, as these areas have some of the most abundant wind resources in the state (<http://www.ncsc.ncsu.edu/programs/NCPWR50m7May04.pdf>, 2009). Although wind farms are generally considered a source of “green” energy, the construction of towers and infrastructure can impact immediate and adjacent marine or estuarine habitats (Byrne Ó Cléirigh et al. 2000). While current CRC rules prohibit the placement of wind turbines in state waters as they are not considered water-dependent structures, the CRC has taken steps to amend these rules (M. Lopazanski/DCM, pers. com., January 2010). The proposal currently under consideration would declare wind energy facilities of three MW or larger to be water dependent structures. *Should the State consider locating a wind facility in state or federal waters, proper placement of energy infrastructure is necessary to minimize potential impacts to SAV habitat and minimize conflicts with existing activities*.

4.4.1.2. Boating activity

Direct physical impacts from propeller scarring, vessel wakes, and mooring scars have 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). Large holes 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). Where prop scarring is extensive and SAV beds destabilized, the ecological value of the SAV habitat is reduced (Fonseca et al. 1998). A study in Florida found that fish abundance was not significantly different between scarred and unscarred seagrass beds, but that severe scarring leading to complete bed removal could affect nekton (Bell et al. 2002).

In Florida, boats 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; Moore et al. 1997). 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 (see "Introduction" chapter on population trends), so will the number of boats. 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. *Clearly marked navigation channels, boater training, and SAV education materials would help boaters avoid SAV beds.* Educational material targeting boaters include an excerpt in the coastal boating guides describing the value of SAV habitat for fishery species and the threats posed by careless boating activity (http://www.ncwildlife.org/fs_index_05_boating.htm, May 2009). Broader educational outreach for CHPP implementation was undertaken by the NC-NERR and the DMF. There is also an outreach subcommittee of the SAV partners workgroup chaired by NC-NERR staff. The DCM has a *Boater's Guide to Protecting Coastal Resources* briefly mentions boating impacts to SAV (http://www.nccoastalmanagement.net/Marinas/BoaterGuide2004.pdf). This document could be enhanced to provide better education to NC's recreational boaters.

4.4.1.3. 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 4.5.

Table 4.5. 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
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. Auster and Langton 1999, ASMFC 2000, and Collie et al. (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. 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). High turbidity from frequent use of bottom-disturbing fishing gear can reduce water clarity, affecting SAV growth, productivity, and in some cases, survival.

Regulatory designations protecting SAV from fishing gear include crab spawning sanctuaries, mechanical methods prohibited areas, military protected areas, Shellfish Management Areas, Oyster Sanctuaries, Primary Nursery Areas (PNA), Secondary Nursery Areas (SNA), Special Secondary Nursery Areas (SSNA), and trawl net prohibited areas protect SAV in those areas from potential physical disturbance associated with bottom fishing gear (Maps 3.5a-c of the “Shell bottom” chapter). Crab spawning areas protect an area from crab dredging, crab trawling, and other methods disturbing the substrate. Oyster dredging is restricted in Mechanical Methods Prohibited areas, Oyster Sanctuaries and PNAs. Fishing activities in military protected areas are by permission only. Trawling of all kinds is prohibited in Shellfish Management Areas, Oyster Sanctuaries, PNAs, SNAs, and periodically in SSNAs. Trawl net prohibited areas apply to trawling of all kinds, whereas some areas are closed to shrimp trawling only (Maps 3.5a-c of the “Shell bottom” chapter). Areas open to clam trawling (“kicking”) were delineated to avoid SAV impacts. The efficiency of most mechanical fishing gears is reduced when pulled through dense SAV beds, therefore discouraging the practice. Only scallop dredging is both conducted and allowed in SAV habitat. Hand assisted methods (rakes <12 inches wide and <6 pounds, tongs) are prohibited in established SAV beds [MFC rule 15A NCAC 03K .0102 and 15A NCAC 03K .0304].

Areas closed to both oyster dredging and trawling protect 70% of mapped SAV in coastal North Carolina (Table 4.6). An additional 10% of SAV is protected from oyster dredging only. The area of SAV protected from only trawling or shrimp trawling was <1%. Crab Spawning Areas protected 5% of mapped SAV followed by Special Secondary Nursery Areas at 2%. Military designations and planted Shellfish Management Areas and Oyster Sanctuaries protect <1% of SAV. Areas open to hand harvest (approved, conditionally approved-open, and conditionally approved-closed) include 134,812 acres (90%) of mapped SAV. However, high densities of shell bottom and SAV do not generally overlap.

Though a large portion of SAV is protected from dredging and trawling, the spatial distribution of protection leaves some areas relatively unprotected. The great majority of SAV beds along the eastern perimeter of the Albemarle-Pamlico system are protected within these areas. However, trawling is technically allowed over much of the SAV present in western Core Sound, southern Bogue Sound, both sides of Roanoke Sound, and along the shoreline of West Bay in the southern Pamlico Sound area (Maps 3.5a-c of the "Shell bottom" chapter). Exceptions occur within PNAs, along the northern shoreline of Bogue Sound and one small area in western Bogue Sound (DMF 2007 - Bay Scallop FMP). However, the majority of trawling in Bogue and Core sounds occurs in or near the Atlantic Intracoastal Waterway, with some commercial trawling during the high tide in shallow regions outside the ICW. Eleuterius (1987) noted that shallow SAV beds were not affected by trawling except during high tides when beds were more accessible. Most of the SAV occurring in western portions of the Albemarle-Pamlico system is protected from shrimp trawling. However, crab trawling is allowed in the Pungo River, upper Neuse and Pamlico rivers (Maps 3.5a-c of the "Shell bottom" chapter). The number of participants and trips for crab trawling has been declining in recent years; 1,780 trips in 2004 to only 157 trips in 2007 (DMF 2008c). Cunningham et al. (1992) reported that peeler crab trawls (16-20 feet in head rope length) are pulled in shallow areas such as creeks and grass beds. However, only a small portion of peeler crabs landings are from trawls (DMF 2004a).

Table 4.6. Amount of mapped SAV within areas receiving specific North Carolina Marine Fisheries Commission designations that restrict fishing activities (as of September 2008).

Bottom disturbing fishing gear prohibited	**Acres of SAV covered**	**Percent of mapped SAV**
Only oyster dredging[1]	15,556	10%
Only trawling[2]	552	<1%
Only shrimp trawling	1,142	<1%
Both trawling and oyster dredging[3]	105,601	70%
Other MFC designations		
Crab Spawning Sanctuaries	7,684	5%
Military designations	80	<1%
Planted Shellfish Management Areas and Oyster Sanctuaries	19	<1%
Special Secondary Nursery Areas	2,683	2%

[1] Designations include Primary Nursery Areas and Mechanical Methods Prohibited

[2] Designations include Permanent Secondary Nursery Areas and Trawl Net Prohibited

[3] PNAs + overlap of SNAs or No Trawling Areas with Mechanical Methods Prohibited areas

As part of 2005 CHPP implementation, the DMF prepared maps identifying areas where allowed use of bottom disturbing fishing gear does or could overlap with sensitive estuarine habitat (CHPP IP database 2009 – Action #223). The largest spatial gap in SAV protection from fishing gear impacts was in northern Pamlico Sound where dredging for crabs is allowed [MFC rule 15A NCAC 03R.0109]. This area included SAV beds in the sound immediately west of Pea Island National Wildlife Refuge. 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. In 2004, the MFC removed the portion of crab dredge area that overlapped with the no trawl area in northeastern Pamlico Sound. This was one of the earliest accomplishments of the 2005 CHPP. The shrimp (3/06), bay scallop (11/07), and oyster

FMP (6/08) also identified and resolved some of the conflicts. No trawl areas were expanded along the banks side of northern Core Sound, and no shrimp trawl areas were established in the Pamlico, Neuse, and Pungo rivers (DMF 2006a) (Maps 3.5a-c of the "Shell bottom" chapter). The MFC supported modifying no trawl areas as needed to protected SAV habitat (DMF 2007a) and expanded Mechanical Methods Prohibited areas in Pamlico Sound (DMF 2008a).

Scallop dredging

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 opening of the scallop dredging season now corresponds to high tide, and is often limited to hand harvest.

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, ranging from about 201,000 lb (91,172.07 kg) in 1995 to only 19,000 lb (8,618.26 kg) in 2002. There have been no trips documented for scallop dredging in North Carolina since 2003 (DMF 2008c) due to a harvest moratorium. Most of the catch is now taken by hand when the season is opened by proclamation. The projected impact of intense scallop dredging on juvenile scallops prompted Bishop et al. (2005) to recommend only hand harvesting methods for bay scallops. The season is opened for a specified area when DMF biologists determine there is a sufficient population (see DMF 2007a for more information). Annual monitoring of bay scallop populations not only provides data for fisheries management actions, but also provides information on a sensitive environmental indicator.

Mechanical clam harvesting

Mechanical clam harvesting methods include clam dredging and clam trawling (kicking). Clam dredging can cause severe impacts to SAV. There are basically two types of clam dredges: basic and hydraulic. The impacts of and restrictions on basic clam dredging is similar that of oyster dredging. Hydraulic dredges direct 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. The reported number of participants, vessels, and trips for clam dredging include both basic and hydraulic dredging (DMF 2008c). There were 768 clam dredge trips in 1995 and only 344 in 2007. The number of trips declined markedly after 2004. However mechanical clam harvesting in close proximity to SAV could cause turbidity impacts.

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 behind a vessel. The vessel's propeller backwash is directed into the bottom and displacing the substrate so that the buried clams are collected in the trawl (Guthrie and Lewis 1982). Most kicking activities are restricted to depths less than 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 for three reasons: (1) kicking techniques were first experimented with in eastern North Carolina during the 1940s, (2) almost 150 kicking vessels operated in 1980 in Carteret County alone, and (3) 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, Newport, North, New, and White Oak rivers, and southeastern Pamlico Sound. 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 has been declining from around 1,000 trips (1996-1999) to 214 trips in 2007 (DMF 2008c). High salinity SAV species are more likely to be impacted by mechanical clamming practices due to the location of the fishery. As a part of CHPP implementation, the clam kicking area was modified by proclamation to clearly avoid all SAV and oysters beds and establish a buffer of 50-100 feet between the gear and habitat. *If this buffer appears inadequate, DMF should modify it to an effective and scientifically based distance (CHPP IP database 2009 – Action #71).*

4.4.2. Water quality degradation

Degradation of the water column affects all living habitat features of the coastal aquatic ecosystem. Submerged aquatic vegetation, in particular, is highly dependent on water quality conditions. Whereas the primary discussion of water quality degradation resides in the "Water Column" chapter, the major water quality issues for SAV are summarized in this section.

4.4.2.1. Nutrient 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 attributed to large-scale nutrient enrichment and sedimentation, which reduces light penetration to the leaf (Twilley et al. 1985; Orth et al. 1986; Goldsborough and Kemp 1988; Kenworthy and Haunert 1991; Funderburk et al. 1991; Dennison et al. 1993; Stevenson et al. 1993; Durako 1994; Orth et al. 2006; Steward and Green 2007). Nutrient enrichment and/or increased sediment loads impact light at leaf for SAV by:

- Reducing water clarity with suspended sediment or phytoplankton associated with algal blooms that absorb light rays prior to reaching SAV blades,
- Increasing epiphytic coverage, sedimentation, or covering by drift algae on the SAV blades (Virnstein and Morris 1996), and
- Diminishing dissolved oxygen concentrations as photosynthesis from SAV beds decrease,

coupled with increasing concentrations of hydrogen sulfide resulting in toxicity (Dennison et al. 1993; Fonseca et al. 1998).

In addition to epiphytic growth, eutrophication of shallow estuaries can lead to the proliferation of extensive thick unattached mats of ephemeral macroalgae over and around SAV, often filamentous or sheet-like bloom forming green and brown algae (*Ulva*, *Cladophora, Chaetomorpha, Gracilaria*, *Ectocarpus*) (McGlathery 2001). Some of these macroalgal species are also epiphytes (Neckles et al. 1993). Studies have found that macroalgae biomass was directly related to increased nutrient levels (Neckles et al. 1993; Valiela et al. 1997) and that SAV loss (density and productivity) increased with increasing macroalgae, particularly the macroalgal canopy height (Hauxwell et al. 2000). Where eelgrass loss occurred due to macroalgal cover, nitrogen loading rates were 30 kg/ha/yr in the urbanized watershed, compared to 5 kg/ha/yr in the forested watershed. Once heavy macroalgal blooms die off, they decompose rapidly, increasing nutrient levels in the water column, which stimulates phytoplankton production and further light reductions. Low grazing pressure has also been shown to lead to increased epiphytic biomass on SAV, and may have a greater effect than nutrient enrichment (Neckles et al. 1993). Monitoring of the epiphytic and macrophytic algal community has been used as an indicator of SAV condition and anthropogenic impacts in some areas (Dunn et al. 2008). *Epiphytic and macroalgal cover should be considered as a monitoring parameter for SAV in North Carolina.*

Nutrient concentrations could indicate eutrophic conditions favoring faster-growing epiphytic algae over SAV. In freshwater lakes, algae begin to dominate SAV at phosphorus concentrations greater than 50 mg/l (McComas 2003). Nutrients also adsorb to sediment particles, which contribute to turbidity and reduced water clarity. 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 of algal biomass (e.g. phytoplankton), by measuring the green pigments contained in plants in the water column. Higher abundances of Chlorophyll *a* indicate an increasing dominance of algae and phytoplankton around SAV in the water column.

Research has shown that elevated nitrogen concentrations not only affect SAV through light reduction from phytoplankton and epiphyte biomass, 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 indicate that of the three species studied, eelgrass would be most impacted by eutrophication.

Nutrient concentrations (mainly phosphorus and nitrogen) and dissolved or suspended matter (organic or inorganic) can also affect the distribution and condition of SAV beds (see “Habitat requirements” section for more information). Even before nutrient and sediment enrichments from human activities, SAV distribution and abundance expands and contracts naturally with climatic conditions (i.e., storms, droughts) since these weather patterns alter timing and magnitude of nutrient, sediment and freshwater inputs. The specific effects of human-caused eutrophication on SAV 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). Early season pulses of turbidity can also affect SAV survival along the river continuum where conditions are suitable later in the growing season (Moore et al. 1997). Therefore, optimal criteria for preventing eutrophication and sedimentation vary by salinity, species, time of year, and specific location of SAV beds.

Threshold nutrient and sediment concentrations for SAV growth have been provided in the literature (Funderburk et al. 1991; Fonseca et al. 1998; McComas 2003; Kemp et al. 2004). The threshold values vary among freshwater, moderate and high salinity SAV, with freshwater-low salinity SAV having slightly higher tolerance for nutrient concentrations. Table 4.7 provides those threshold values for dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), total suspended solids (TSS), and Chlorophyll *a* (proxy for nutrient concentrations). Table 4.8 provides the North Carolina water quality classifications and standards that most closely match these parameters. There is no official standard for light attenuation in North Carolina. However, several water quality standards can be used as indicators of light conditions, including turbidity, total suspended solids, and chlorophyll *a* levels (EPA 2000a). Other standards affecting SAV growth include dissolved oxygen and nitrate. However, the standards are sometimes different among DWQ water body classifications (Table 4.8). The water quality parameters are measured periodically by DWQ at fixed stations concentrated in riverine systems of the coast (Street et al. 2005). There are relatively few water quality stations in the estuarine system (see “Water column” chapter for more information). Regulations on wastewater discharge, development density, buffer requirements, erosion and sediment controls, best management practices, and landfill restrictions may also affect light conditions in receiving waters with SAV (see “Water column” chapter for more information). However, the effect of regulations on water clarity can only be measured in terms of a water quality standard.

Table 4.7. Threshold nutrient and sediment concentrations for SAV. [Funderburk et al. 1991; Fonseca et al. 1998; EPA 2000a; Kemp et al. 2004]

SAV salinity categories	**Growing season**	**Total suspended solids (mg/l)**	**Dissolved inorganic Nitrogen (mg/l)**	**Dissolved inorganic Phosphorus (mg/l)**	**Chlorophyll a (mg/l)**
High salinity (18-30 ppt)	March-May, September-November	<15	<0.15	<0.01	<15
Moderate salinity (5-18 ppt)	April-October	<15	<0.15	<0.01	<15
Freshwater-low salinity (0-5ppt)	April-October	<15	-	<0.02	<15

In comparing current North Carolina water quality standards to SAV habitat requirements, the standard for chlorophyll *a* is higher (40 mg/l vs. <15 mg/l). The standard for TSS is also higher, but to a lesser degree and applies only to discharges (20 mg/l vs. <15 mg/l) (Table 4.8). Given the current standards for water quality in North Carolina, the system is not being managed to support SAV requirements even with continuous monitoring of parameters. There are basically two alternatives for supporting SAV habitat via standards monitoring: (1) lowering existing standards pertaining to light attenuation, or (2) including a light attenuation standard. *A study is needed to evaluate the feasibility of implementing adequate water quality standards for supporting SAV habitat.* The study would include selecting representative locations for monitoring the standards, when and how often to measure the standard, what constitutes a 303(d) listing, and additional cost estimates. Another important question affecting feasibility would be where to apply the enhanced standards (e.g., Outstanding Resource Waters, NSWs, High Quality Water, Strategic Habitat Areas). Areas not meeting the standard could then be targeted by DWQ for Total Maximum Daily Load (TMDL) development (for nutrient and sediment standards). With or without an official standard, the need for restoration requires an attribution of cause regarding a degraded parameter. Because degraded light attenuation in a system can be due to variable precipitation and/or storm events as well as nutrient and sediment additions by humans, the use of water quality standards is complicated.

Table 4.8. North Carolina Environmental Management Commission classifications and standards (mg/l) related to SAV presence and condition (May 2007).

Standards/ regulations	Supplemental Classifications			Salt water		Fresh water
	ORW	HQW (salt or freshwater)	NSW	SA	SB, SC	Aquatic life (B, C)
Dissolved oxygen (mg/l)	*	6	*	6	5	5
Nitrate (mg/l)	*	-	*	-	-	-
Turbidity (NTU)	*	25	*	25	25	50
Total suspended solids (mg/l)**	*	20	*	20	-	(narrative)
Chlorophyll *a* (mg/l)	*	40	*	40	40	40

* Determined by primary classifications (SA – SC and C) or site-specific management strategies developed by EMC through rule-making.
** Applies to discharges only

Another factor complicating the use of water quality standards is the natural cycle of SAV expansion and contraction in aquatic systems. Establishment of new SAV in an area requires more stringent water quality conditions than maintaining or expanding existing SAV due to water quality enhancement provided by the existing SAV (see "Ecosystem enhancement" section for more information). Loss or contraction of SAV habitat, whether from physical impacts or water quality degradation, leads to a cascade 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). Future SAV restoration may also be confounded by the loss of existing beds, which increases sediment resuspension and turbidity (P. Biber/NMFS, pers. com., 2003). Therefore higher water quality conditions may be needed for survival of newly restored SAVthan for survival of existing vegetation due to the synergistic effect on water quality. Therefore, management efforts should focus on protecting and enhancing existing SAV habitat and preventing any additional direct or indirect losses.

The presence of SAV can, in itself, be valuable as a sensitive indicator of water quality (Dennison et al. 1993). 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 rates have been determined 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.

Further research in Indian River lagoon has addressed setting load limits for nutrients and suspended solids based on seagrass depth-limit targets (Steward and Green 2007). Total Maximum Daily Loads were calculated based on regressing total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) loading [log (kg ha-1 yr-1)] against seagrass depth limits (percent of depth limit targets). Calculating TMDLs for SAV in North Carolina would require coordinated multi-year monitoring of: (1) SAV depth and distribution, and (2) nutrient and sediment loading. However, TMDLs should only be developed for areas where light attenuation is strongly affected by watershed pollutant loading (i.e., NSWs). A multi-year protocol for detecting annual changes in SAV distribution in North Carolina is being developed jointly by APNEP, NOAA, ECU, and NCSU (see "Status and trends" section for more information). The primary discussion of nutrient and sediment monitoring is in the "Water column" chapter.

In Chesapeake Bay, cooperative efforts by scientists, managers, and politicians have worked for over two decades to protect and restore SAV (Orth et al. 2002). Chesapeake Bay Agreements in 1983, 1987, and 2000 as well as other related ongoing efforts have established policies and regulations to protect and restore SAV through adaptive management. Research and modeling was conducted to determine light and water quality standards needed to sustain SAV and evaluate point and nonpoint pollutant loading reductions needed to achieve these conditions. Despite the enormous efforts, success in terms of water quality improvements and SAV habitat increases has been limited.

Knowing that water quality degradation is the largest contributor to declines in SAV, and that North Carolina's growing coast will likely lead to additional water quality degradation, North Carolina needs to investigate the best method to protect SAV habitat from water quality degradation.

4.4.2.2. Toxic chemicals

Herbicides

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). Some SAV species may even be viable candidates for monitoring hydrophobic organochlorines (cis- and trans-chlordane, dieldrin, and polychlorinated biphenuls). Along the tidal Potomac River, Hopple and Foster (1996) found toxic concentrations in Hydrilla beds similar to surrounding riverine sediment. 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. The following section ("Introduced and nuisance species") includes more information on toxic chemicals effects on SAV.

Fossil fuels

Oil spills can have negative impacts on SAV in several ways. SAV can be smothered and die by high concentrations of oil. In lesser concentrations oil may leave a "burnt" look on SAV blades, but this is a temporary effect since new leaf production continues once oil concentrations subside (Jacobs 1980). In lower concentrations of oil SAV can have a reduced photosynthetic rate as a result of oil toxicity. Oil may also have sublethal effects by accumulating PAH in seagrasses reducing its tolerance to other stress factors (as described in above sections) potentially leading to death of the SAV (Zieman et al. 1984).

Although in most field studies of oil effects on SAV and the associated fauna there is seldom pre-event data, many studies compare oil affected sites versus non affected sites or observe trends over a period of time. After the 'Exxon Valdez' spill Jewett et al. (1999) observed lower abundance of amphipods at oil affected sites than those not affected as well a higher numbers of certain polychaetes species. The reduced number of amphipods may be caused by the acute toxicity of oil, while the increased number of polychaetes may be from the increased amount of detritus from the dead/decaying SAV. This shift in the benthic invertebrates may cause a shift in the food web. These results have been observed in other studies such after other spills such as the 'Amico Cadiz' (Dauvin 1982). Dispersants may be useful in the cleanup of oil, but they may be detrimental to SAV. Edwards et al. (2003) showed dispersants encourage the breakdown of SAV's waxy cuticle, allowing greater penetration of oil into SAV blades.

4.4.3. Non-native, invasive, or nuisance species

There is a general perception by some of the public that all SAV is a nuisance. Grass blades may get in boat propellers, water intakes, or entangle or weigh down fishing gear. Aesthetically, swimmers may prefer a sand bottom to a grass bottom. 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). Native species may also be more resilient to long-term patterns in temperature, salinity and energy regime.

The Division of Water Resources, under the Aquatic Weed Control Act of 1991 [General Statute 113A-220 ff; DENR rules 15A NCAC 02G .0600], manages the North Carolina Aquatic Weed Control Program (AWCP) [86], 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 program's focus is determined by public notices, which are primary directed at vegetation problems in impoundments (mostly hydrilla in Lake Gaston) (R. Emens/DWR, pers. com., May 2009). Program staff ("the Weed Team") work with local governments to provide technical and financial assistance (50:50 cost share). The Weed Team conducts a site assessment using the DENR list of noxious aquatic weeds (includes Hydrilla, Elodea, water hyacinth, Eurasian watermilfoil, alligator weed, purple loostrife, brittle naiad, and Phragmites) to identify projects for assistance. The species most pertinent for DMF in 2010 included *Alternanthera philoxeroides* (alligator weed), *Myriophyllum spicatum* (Eurasian milfoil), and *Phragmites australis*. Hydrilla was reported for the first time in the Chowan River. Aquatic herbicides may be used to kill the nuisance vegetation. Herbicides used include copper-based compounds (cheap but results in water use restrictions), 2-4-Dichlorophenoxyacetic acid (2-4-D), and/or SONAR (expensive but can be used with no water use restrictions). The Weed Control Program also posts signs at boat ramps warning of the danger in spreading noxious weeds to other systems. *Signs could also be posted to educate the public on the value of native aquatic plants.*

The most troublesome species in low salinity, estuarine waters is Eurasian watermilfoil. Weed control activities in coastal waters are primarily focused on this species. Control activities target areas where native species are not the dominant species based on site assessments (R. Emens/DWR, pers. com., May 2009). The AWCP may consult with DENR resource management agencies in assessing coastal sites

[86] http://www.ncwater.org/Education_and_Technical_Assistance/Aquatic_Weed_Control/

concerning any impacts on native SAV. A recent consultation involved the area of Kitty Hawk Bay where treatments of dense Eurasian milfoil stands resulted in a significant reduction of milfoil coverage (R. Emens/DWR, pers. com., August 2009). *The Weed Team also observed native species resilience to 2-4-D treatments of milfoil and would like to test the observation further (R. Emens/DWR., pers. observation, May 2009).* The AWCP, in cooperation with the Town of Kill Devil Hills intends to continue monitoring the milfoil infestation and conduct spot treatments on an as needed basis. *Long-term management and restoration of SAV habitat should include replacement of Eurasian watermilfoil with native species throughout the estuary.* However, because milfoil is providing habitat for important fishery species, treatment of milfoil should only be conducted where milfoil occurs as a dense monoculture and native species are minimally or not present. The AWCP staff agreed to consult with regional DMF staff prior to chemical applications in public trust waters to ensure that fish habitat impacts are minimized, and should continue to do so.

To spray submerged or emergent vegetation in public trust waters, one must be licensed for herbicide spraying and have a special certification for public water spraying (B. Bruss/Dept of Agriculture, pers. com. 2009). The spraying must be done according to the label and overspray to unintentional areas would be a violation of the label. Only state agencies or local government are allowed to have the public water certification. Possible violations are investigated by the Dept. of Agriculture on request. In 2008 property owners in a private subdivision treated a large area of public trust waters independently, without having proper certification or consulting with DWR or DMF staff. As a result, a large area of native and non-native SAV species was obliterated. G.S. 113-300.1 states that WRC has authority to regulate, prohibit or restrict use of poisons or pesticides severely affecting wildlife resources (includes SAV as resource), as long as the rules do not conflict with the Pesticide Law of 1971 or Structural Pest Control Act of 1955. Furthermore, an Attorney General review in 1995 found that MFC had authority under 143B-289.3(b) to regulate use of pesticides on SAV. EPA is in the process of requiring a NPDES permit for any spraying of aquatic pesticides and herbicides over or near public trust waters. NC DWQ is in the process of developing the permit. However, the exemption thresholds will be fairly high and the permit will not address the spraying of native vegetation. *Legislation is needed to prohibit chemical treatment of native vegetation in estuarine waters, due to its high value as fish habitat*.

Another introduced species affecting SAV is the grass carp, which is often stocked in ponds and impoundments for nuisance weed control. Grass carp have escaped from stocked ponds and reservoirs into some river systems in North Carolina. The escaped carp can have a significant impact on native freshwater SAV in receiving waters. 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.
Nuisance species, from the perspective of SAV habitat, may or may not be introduced. Examples include macroalgae and the "animal grass" (a bryozoan) that sometimes overwhelms SAV in high salinity waters (Trish Murphy/DMF, pers. com., 2007). Excessive macroalgae growth (drift algae or epiphytic), has been shown to negatively impact productivity of SAV (Kemp et al. 2004). The animal grass infestations observed in 2007 were identified as the Sauerkraut bryozoan, *Zoobotryon verticillatum* (Beth Burns/DMF, pers. com., October 2007). The overabundance of animal grass appears to occur in drought years in high salinity areas. Though *Z. verticillatum* competes with SAV for space and interferes with certain fisheries activities, it also filters large quantities of water to provide a function similar to living oyster reefs. *Research is needed to determine the ecological role and effects of animal grass on SAV beds and related fish communities in North Carolina.*

4.4.4. Diseases and microbial stressors

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*. Vergeer et al. (1995) later confirmed a decline in the microbial defenses of seagrass with increasing temperature. The primary factor enhancing microbial defenses was increasing light intensity, which is related to both water quality and self-shading. Jackson et al. (2001) suggested that declining grazer abundance has caused, among other things, a self-shading stressor for dense seagrass beds. 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). 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 and loss of ecosystem services. 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 periodic basis to assess the status of wasting disease and its association with human-induced stresses.*

Another microbial stressor on SAV could be the gall-like growths on widgeon grass observed in low salinities areas such as Blounts Bay on the Tar River (C. Wilson/USACE, pers. com., April 2008). The effects of the gall-like growths on widgeon grass in Blounts Bay are unknown. However, the 2009 disappearance of widgeon grass in Blounts Bay may suggest a causal link (Jill Paxon/DWQ, pers. com., 2009). *Research is needed to determine effects of gall infections on SAV beds and related fish communities in North Carolina.*

4.4.5. Sea level rise and climate change

The “Wetlands” chapter contains the primary discussion of sea level rise and its effect on coastal habitats. Changing temperature and salinity patterns with climate change are discussed primarily in the “Water column” chapter. Specific issues and effects of sea level rise and climate change on SAV habitat in North Carolina are discussed in this section. The effects/issues include:

1. The significant impact of increasing CO_2 concentrations on growth of CO_2-limited seagrass species (Palacios and Zimmerman 2007);
2. Shifting relative abundance and distribution of eelgrass and shoal grass with increasing temperature (Micheli et al. 2008).
3. The importance of seagrass genetic diversity in providing resilience to heat waves and other extreme climate conditions (Ehlers et al. 2008);
4. Loss of marsh and barrier island windbreaks and subsequent loss of sheltered SAV habitat (D. Piatkowski /USACE, pers. observation, 2009).
5. Deepening of waters adjacent to hardened shoreline (see “Shoreline stabilization” section of Wetlands chapter) exacerbated by predicted increases in the severity and frequency of large storm events (IPCC 2007).

Palacios and Zimmerman (2007) compared the growth of eelgrass with various levels of CO_2 enrichment. The results indicated significantly higher reproductive output, below-ground biomass and vegetative production of new shoots at 33% surface irradiance at leaf. The results suggest an increasing CO_2 content in the atmosphere and ocean surface will increase the area-specific productivity of seagrass meadows. This also suggests the value of seagrass beds in sequestering carbon. However, warming trends pose a threat to eelgrass growing near its southern limits in North Carolina. There is some evidence of declining summer densities and biomass of eelgrass in Bogue Sound at sites that were monitored between 1985 and 2004 (Micheli et al. 2008). The study also found that an increase in shoal grass compensated for the eelgrass decline, but invertebrate diversity and abundance declined. In a study looking at the role of eelgrass genetic diversity on their resilience to temperature extremes, the results suggested a reduction in seagrass resilience to climate change with alterations that tend to reduce genetic diversity (Ehlers et al. 2008). *Site monitoring of SAV should include species composition and genetic diversity to track the potential impacts of climate change*. North Carolina is uniquely situated to conduct such research.

The reduction in extent of marsh islands described in the wetlands chapter was observed by USACE managers working in Currituck Sound and associated with loss of SAV (D. Piatkowski /USACE, pers. observation, 2009). Marsh islands provide shelter from the wind and waves during the growing season for SAV. The shrinking of marsh islands is caused by sea level rise, erosion, and the interruption of barrier island over-wash by oceanfront development (see “Soft bottom” chapter for more information). *The relationship between marsh island extent and quality of surrounding SAV beds should be investigated further.*

Seagrass habitat, as one of the most productive systems in the world, is considered an important carbon dioxide sink relative to other terrestrial and aquatic habitats. Because the plants have a slow turnover rate, the leaves degrade slowly, and a large part of the carbon production is put into the below-ground rhizome system, seagrasses have a large capacity for accumulation and storage of carbon. It is estimated that seagrass habitat is responsible for about 15% of the total carbon storage in the ocean while occupying a lesser portion of the seafloor (Pidgeon 2009; UNEP 2009). *To sustain the carbon sink service provided by submerged grasses, the habitat must be preserved, with management efforts focused on maintaining environmental conditions (nutrient and sediment concentrations) needed for SAV growth (Bjork et al. 2008).*

4.4.6. Management needs and accomplishments

The global and nationwide trend of declining SAV habitat (Orth et al. 2006; Waycott et al. 2009), coupled with recognition of its ecological importance, has led several regional and state resource management agencies to develop protective management policies for SAV habitat, including Atlantic States Marine Fisheries Commission, South Atlantic Fishery Management Council, Chesapeake Bay Program, and Rhode Island Coastal Resources Management Program. Virginia and Maryland, through the Chesapeake Bay program, developed a guidance document for SAV (EPA 1995) and Rhode Island Coastal Resources Management Program has definitions, findings, policies, and standards regarding activities that can impact SAV (http://www.edc.uri.edu/Eelgrass/300_18.pdf). Both documents address identification and protection of both existing and historically occurring SAV habitat, recommend SAV mapping, require surveys of the SAV habitat during appropriate growing seasons, require buffers around identified grass beds, and restrict certain specific activities from occurring in or over SAV habitat. Chesapeake Bay implements a tiered approach in SAV habitat protection, based on the documented bottom information available. 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 (Appendix G). The policy includes the following guidelines:

- *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 and/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) have been fairly consistent with this policy. Substantial progress has been made on the majority of these guidelines, but there are others that have not yet been addressed.

The management needs noted by italics in the 2005 CHPP were addressed to some degree during 2005-2010. Some needs are considered accomplished, whereas others are considered ongoing with or without progress. Emerging management needs are new or significantly modified from their 2005 versions and may or may not be refined and adopted as actions in the 2009-2011 CHPP implementation plans. Discontinued needs includes those recommendations from Street et al. (2005) that were omitted from the chapter update for various reasons (i.e., included in another chapter as part of primary discussion, need discontinued, considered minor, redundant, or too general). The subheadings reflect these distinctions.

4.4.6.1. Research needs and progress (2005-2010)

Accomplished research needs

1. *Model a wide range of estuaries to determine environmental requirements for SAV over a broader spatial and temporal scale to determine if changes in EMC water quality standards are needed.* **The relationship between water quality and SAV has been examined sufficiently in North Carolina, the Chesapeake Bay, and Florida (see "Habitat requirements" and "Water quality degradation" sections for more information and context).**

2. *Examine the relationship between juvenile red drum abundance in SAV and marsh edge habitat and the effect of spatial connectivity on habitat use to support management of this important species.* **Conclusive research has been conducted (see "Nursery" subsection of "Specific biological functions" section for more information and context).**

Research needs with progress

1. *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. 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 (Street et al. 2005).* **The DMF habitat section assembled an inventory of water quality monitoring stations to help determine if conditions could be modeled throughout the estuary – part of mapping potential habitat for SAV. The results show that water quality data are few and far between, especially in estuarine waters (see "Habitat requirements" section). Relating land-use characteristics to downstream water quality in a hydrodynamic model could be the most cost effective means of locating potential SAV habitat – existing WQ monitoring stations could be used to calibrate the model.**

2. *Determine the relationship between changing SAV coverage and water quality conditions (Street et al. 2005).* **There has been some research in North Carolina, Virginia and Florida relating SAV habitat characteristics to water quality measurements (see "Habitat requirements" and "Ecosystem enhancement" sections).**

3. *DENR should work with NMFS to determine what levels of TSS, chlorophyll a and other parameters are needed to achieve desired water clarity (Street et al. 2005).* **The latest research is presented in the "Nutrient and sediment" subsection of the "Water quality degradation" section.**

4. *Determine if adequate light is available beneath North Carolina docks, given the CRC's current siting criteria. The criteria should be evaluated to determine if changes would be needed to allow the minimum amount of light for SAV growth (Street et al. 2005).* **A study by NCDMF in 2002-2003 (Connell and Murphey 2004) found reduced shoot density and coverage of SAV under docks compared to pre-construction conditions (see "Marinas and docks" subsection of "Water dependent development" section).**

5. *Develop criteria to designate of SAV beds as a component of Strategic Habitat Areas (Street et al. 2005).* **The DMF has also developed criteria for designating Strategic Habitat Areas that capture the vast majority of low and high salinity SAV and assesses potential alteration from fishing gear, among other factors (see "Ecosystem management and Strategic Habitat Areas" chapter for more information).**

Research needs without progress

1. *Verify if a recovery of SAV has occurred and determine if there is a spatial pattern of that recovery. If there is a pattern, special monitoring and protection should be afforded those core areas from which SAV begins its recolonization (Street et al. 2005). In the mean time, Back Bay/Currituck Sound should serve as a test case for re-establishing SAV in a recovering/recoverable ecosystem.* **No specific progress. See "Submerged aquatic vegetation restoration and enhancement" section for more information.**

2. *Assess the cumulative impacts of dock placement (i.e., shading, boating activity, associated development) on SAV habitat in selected water bodies (Street et al. 2005).* **No progress, but anticipated completion of shoreline mapping and structures inventory will help DCM and other permit review authorities evaluate cumulative impacts (see "Marinas and docks" subsection of "Water dependent development" section for more information).**

3. *Conduct research to determine the relative fishery value of Eurasian watermilfoil compared to native vegetation (Street et al. 2005).* **No specific progress. See "Introduced and nuisance species" section for more information.**

Emerging research needs

1. *A simple model to predict potential SAV habitat in North Carolina would be helpful for identification and protection of this important habitat where it has not been mapped or otherwise documented recently (within the past 10 years).* **See "Habitat requirements" section for more information.**

2. *Research is needed on how much SAV proximity affects juvenile production from spawning areas.* **See "Spawning" subsection of the "Specific biological functions" section for more information.**

3. *Research is needed on the relationship between juvenile Sciaenid abundance and connectivity among nursery habitats and spawning areas.* **See "Corridor and connectivity" section for more information.**

4. *Research is needed to determine the habitat preferences of other fisheries species and life stages in North Carolina in order to estimate population sizes and determine habitat protection priorities.* **See "Status of associated fishery stocks" section for more information.**

5. *More fishery-independent information and habitat change analysis are needed to evaluate the effect of SAV-coverage on the abundance of fish and invertebrates.* **See "Status of associated fishery stocks" section for more information.**

6. *The relationship between SAV habitat characteristics and associated shoreline types should be investigated further.* **See "Shoreline stabilization" subsection of the "Water dependent development" section for more information.**

7. *Research is needed to estimate the loss of SAV habitat from apparent dredging using the 2007-08 SAV imagery and GIS data for marinas, boat ramps, small boat basins, and navigation channels. The results of such research could be used to set restoration goals addressing historic losses of SAV habitat to dredging.* **See "Dredging (navigation channels and boat basins)" subsection of the "Water dependent development" section for more information.**

8. *The overall significance of dock shading on SAV should be assessed by comparing concurrent maps of shoreline structures and SAV habitat.* **See "Marinas and docks" subsection of the "Water dependent development" section for more information.**

9. *The Weed Team observed native species resilience to 2-4-D treatments of milfoil and would like to test the observation further (Rob Emens/DWR., pers. observation, May 2009).* **See "Introduced and nuisance species" section for more information.**

10. *Research is needed to determine the ecological role and effects of animal grass on SAV beds and related fish communities in North Carolina.* **See "Introduced and nuisance species" section for more information.**

11. *Research is needed to determine effects of gall infections on SAV beds and related fish communities in North Carolina.* **See "Diseases and microbial stressors" section for more information.**

12. *The relationship between marsh island extent and quality of surrounding SAV beds should be investigated further.* **See "Sea level rise and climate change" section for more information.**

13. *Epiphytic and macroalgal cover should be considered as a monitoring parameter for SAV condition in North Carolina.* **See "Water quality degradation, nutrients" section, subsection for more information.**

14. *Research is needed on the feasibility of hard clam augmentation for the purpose of water quality based restoration of SAV.* **See "Status and trends, SAV restoration" section, subsection for more information.**

4.4.6.2. Management need with progress (2005-2010)

Accomplished management need

1. *Ensure consistency in habitat definitions among agencies and commissions (CHPP IP database 2009 – Action #152).* **MFC approved revised definition of SAV habitat in 2009. CRC references definition in revised General and Specific Use Standards for Development. See "Definition" section for more information.**

2. *Evaluate the boundaries of No Trawl Areas and adjusting, if necessary, to adequately protect all high salinity SAV beds from both direct and indirect impacts, such as turbidity. Additional law enforcement may be needed to enforce buffers necessary to protect SAV from gear-induced turbidity (Street et al. 2005).* **The DMF prepared maps identifying areas where allowed use of bottom disturbing fishing gear does or could overlap areas with sensitive estuarine habitat. The Shrimp FMP (2007), Bay scallop FMP (2007) and oyster FMP (2008) identified and resolved gear/habitat conflicts (i.e., crab dredging in Oregon Inlet overlapping SAV). See "Fish gear impacts" section for more information.**

3. *Modify clam kicking and hydraulic dredging areas by proclamation to clearly avoid all SAV and oyster beds and allow a buffer of 50-100 ft between mechanical shellfish gear and SAV and shell bottom. The size of the buffer may be modified if supported by scientific studies.* **Done for Core Sound in 2006. The MFC also closed >30,000 acres in Pamlico Sound tributaries to mechanical shellfish harvest in 2005. See "fishing gear impacts" section for more information.**

4. Provide 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 (Street et al. 2005). **Broader educational outreach for CHPP implementation was undertaken by the DCM NERR and the DMF. There is also an outreach subcommittee of the SAV partners workgroup chaired by NC-NERR staff. See "Boating activity" section for more information.**

5. Conduct educational outreach to increase awareness by the boating public of the ecological value of SAV and the damaging effects of boat propellers on SAV habitat (Street et al. 2005). **Educational material targeting boaters includes an excerpt in the coastal boating guides describing the value of SAV habitat for fishery species and the threats posed by careless boating activity (http://www.ncwildlife.org/fs_index_05_boating.htm and http://www.nccoastalmanagement.net/Marinas/BoaterGuide2004.pdf, May 2009).**

6. *Conduct a review of current chlorophyll, TSS, and turbidity standards to determine if they are appropriate for the protection of SAV in North Carolina waters*. **A review is provided in the "Nutrients and sediment" subsection of the "Water quality degradation" section.**

7. *Ensure that chemical removal of European watermilfoil and other non-native vegetation does not also eradicate native species in the process (Street et a. 2005).* **The DWR Weed Team is consulting with DENR resource management agencies as part of their site assessments. See "Introduced and nuisance species" section for more information.**

Management needs with progress

1. *To quantify trends in SAV abundance, regular mapping efforts of all or a subset of the habitat is needed in addition to monitoring data from stations and transects (Street et al. 2005).* **The mapping was coordinated through the Albemarle-Pamlico National Estuary Program (APNEP), in partnership with multiple agencies. A multi-agency MOU was signed in 2006; state and federal funds were allocated for SAV aerial photography in 2007; sampling protocols were developed in 2006-2007, and image acquisition was completed in 2007-2008. However, the imagery has not been classified due to loss of staff position. See "Distribution" section for more information.**

2. *Require compensatory mitigation where impacts to SAV are unavoidable. Initiate restoration programs to recoup and/or enhance lost SAV habitat (Street et al. 2005).* **DWQ worked with DOT on a SAV and oyster habitat restoration and mitigation project in the Currituck Sound. Restoration work has been completed and monitoring continues to assess the success of the project. EEP has initiated internal research to determine the functional value of SAV restoration. EEP will review the DCM permitting requirements involving impacts to SAV. EEP will incorporate SAV restoration recommendations into the non-traditional mitigation strategy to be proposed to the PACG in the following year. See "Submerged aquatic vegetation restoration and enhancement" section for more information.**

3. *Use existing permit review and issuing authorities to provide more protection of SAV by addressing both direct and indirect impacts from dredge and fill projects (Street et al. 2005).* **Change in SAV definition and dock rules has helped improve protection, but is an ongoing battle with progress difficult to quantify. See "Channel dredging" subsection of "Water dependent development" section for more information.**

4. *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 (Street et al. 2005)* **Ongoing need with the placement and replacement of bridges in coastal North Carolina. See "Infrastructure" subsection of "Water dependent development" section for more information.**

Management needs without progress

1. *Conduct regular monitoring of SAV beds to assess their changing distribution and condition (Street et al. 2005). The DMF and NERR will initiate SAV monitoring of sentinel sites.* **Initial concepts have been discussed at the APNEP SAV Partners meetings. Monitoring activities are dependent on identification of funding; a multi-agency team of SAV researchers (NOAA, ECU, NCSU) submitted a CRFL proposal for testing long term field monitoring of SAV in Aug. '08, but no SAV monitoring plan has been established. NC-NERR sites may be included in monitoring sites if the project is selected for funding. See "Status and trends" section for more information.**

2. *Conduct additional juvenile fish sampling stations in SAV habitat (Street et al. 2005).* **No specific progress. However, the DMF Resource Enhancement section is planning a sampling program to track juvenile fish abundance in and around oyster sanctuaries (Greg Bodnar/DMF Resource Enhancement, pers. com., February 2009). The sampling will be conducted in SAV, shell bottom, and soft bottom habitats.**

3. *Periodically assess the level of prop scar damage on SAV habitats. 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 persistent SAV beds to avoid (Street et al. 2005).* **No specific progress. See "Boating activity" section for more information.**

4. *Focus management efforts on protecting (and enhancing) existing SAV habitat and preventing any additional direct or indirect losses (Street et al. 2005).* **Direct losses of habitat areas meeting the definition of SAV are strongly discouraged by permitting authorities. If losses are unavoidable, publicly funded projects are required to mitigate for the losses whereas privately funded project may be asked to include a mitigation plan. Indirect losses due to changes in water quality are more difficult to project. See "Nutrients and sediments" subsection of "Water quality degradation" section for more information.**

5. *The need and feasibility for a water quality standard for light attenuation should be further investigated to provide a pro-active target or standard for protection and restoration of SAV (Street et al. 2005).* **The need for a water quality standard is demonstrated in the "Water quality degradation" section. See "Nutrient and sediment" subsection of "Water quality degradation" section for more information.**

6. *Knowing that water quality degradation is the largest contributor to declines in SAV, and that North Carolina's growing coast will likely lead to additional water quality degradation, North Carolina needs to investigate the best method to protect SAV habitat from water quality degradation* **(See "Nutrients and sediments" subsection of "Water quality degradation" section for more information).**

7. *Include replacement of Eurasian watermilfoil with native species as an objective in SAV management and restoration plans.* **No specific progress. The need is predicated on research demonstrating the value of milfoil as fish habitat. See "Introduced and nuisance species" section for more information.**

8. *Conduct regular monitoring of submerged grasses for wasting disease and its association with human-induced stresses (Street et al. 2005).* **No specific progress. See "Diseases and microbial stressors" section for more information.**

Emerging management needs

1. *Local and regional monitoring programs should eventually be coordinated with a comprehensive SAV monitoring program.* **See "Status and trends" section for more information.**

2. *The results of this new SAV monitoring research should be evaluated for broader application in the estuary as a whole.* **See "Status and trends" section for more information.**

3. *Monitoring should focus on SAV in the most vulnerable locations (close to land where water quality degradation and shoreline development impacts greatest, edge of southern and western distribution range) and in areas of current or former importance to bay scallops.* **See "Status of submerged aquatic vegetation" section for more information.**

4. The APNEP SAV Partnership is developing an action plan for SAV restoration activities in North Carolina and southeastern Virginia, with guidance from the Chesapeake Bay experience (Orth et al. 2002). *The plan for SAV restoration should also be coordinated with other habitat restoration plans and activities.* **See "Submerged aquatic vegetation restoration and enhancement" section for more information.**

5. *The SAV restoration action plan should include restoration goals based on potential habitat maps and projected water quality improvements.* **See "Submerged aquatic vegetation restoration and enhancement" section for more information.**

6. *Where SAV habitat is evident, additional permit conditions regarding dock design should be considered on a case by case basis to maximize light penetration below docks.* **See "Marinas and docks" subsection of the "Water dependent development" section for more information.**

7. *Should the State consider locating a wind facility in state or federal waters, proper placement of energy infrastructure is necessary to minimize potential impacts to SAV habitat and minimize conflicts with existing activities.* **See "Infrastructure subsection of the Water Dependent Development" section for more information.**

8. *Clearly marked navigation channels, boater training/licensing, and SAV education materials would help boaters avoid SAV beds.* **See "Boating activity" section for more information.**

9. *If this buffer appears inadequate, DMF should modify it to an effective and scientifically based distance.* **See "fishing gear impacts" section for more information.**

10. *Site monitoring of SAV should include species composition and genetic diversity to track the potential impacts of climate change.* **See "Sea level rise and climate change" section for more information.**

11. The Weed Control Program also posts signs at boat ramps warning of the danger in spreading noxious weeds to other systems. *Signs could also be posted to educate the public on the value of native aquatic plants.* **See "Non-native, invasive, or nuisance species" section for more information.**

12. *Legislation is needed to prohibit chemical treatment of native vegetation in estuarine waters, due to its high value as fish habitat*. **See "Non-native, invasive, or nuisance species" section for more information.**

13. *To sustain the carbon sink service provided by submerged grasses, the habitat must be preserved, with management efforts focused on maintaining environmental conditions (nutrient and sediment concentrations) needed for SAV growth (Bjork et al. 2008).* **See "Sea level rise and climate change" section for more information.**

4.5. SUMMARY OF SUBMERGED AQUATIC VEGETATION CHAPTER

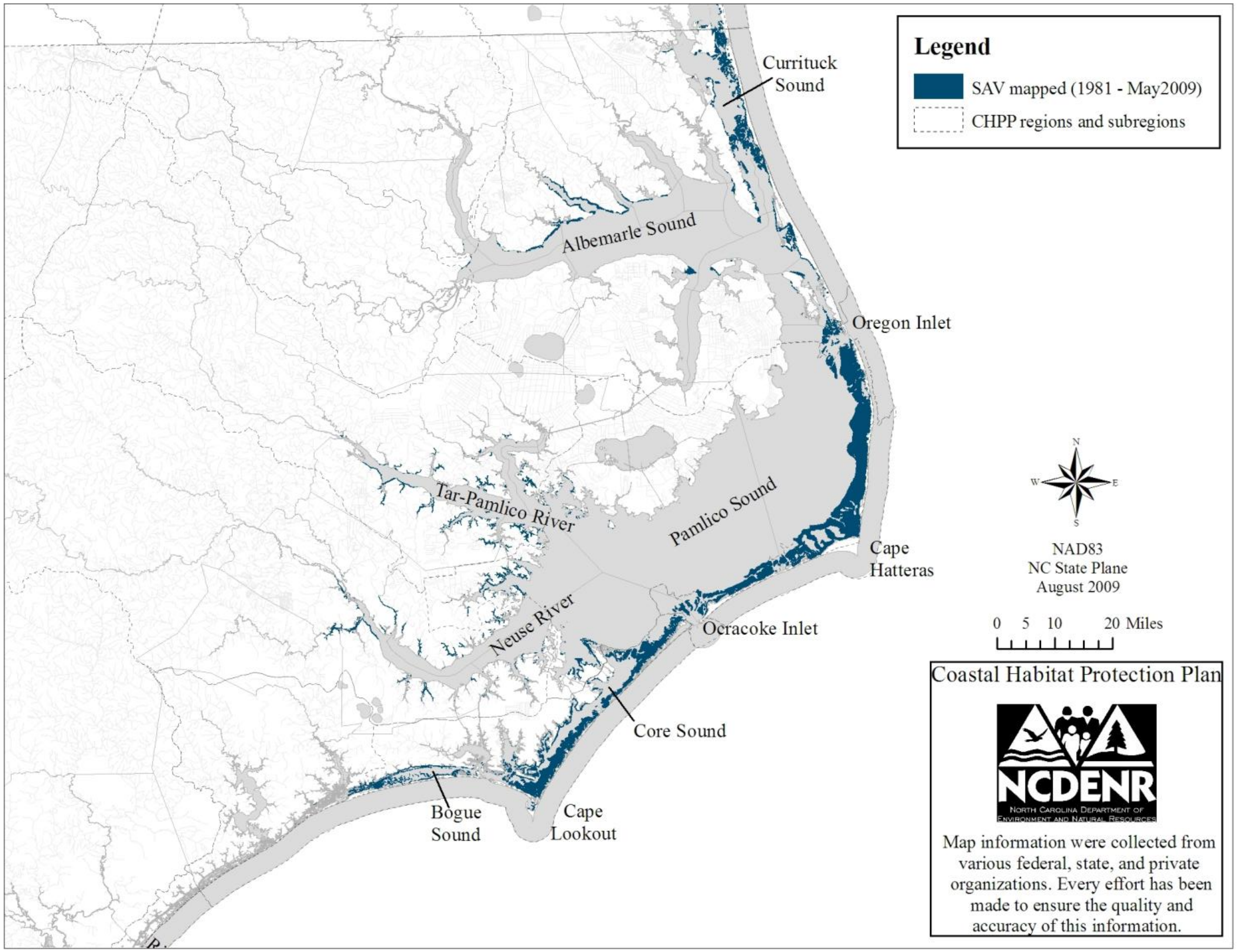
The ecological importance of SAV habitat is well documented in the literature. Some additional research since the 2005 CHPP has looked at fish use of SAV of various patchiness or density and found that SAV presence, regardless of the bed shape or density, supports a greater diversity and abundance of organisms than unvegetated bottom, although some species favor certain SAV habitat characteristics over others. Valuation studies indicate that the monetary value of the ecosystem services provided by SAV is very significant. With North Carolina having the second largest amount of SAV on the east coast, protection and enhancement of this resource should be a high priority for the state. The major threats to SAV habitat remain channel dredging and water quality degradation from excessive nutrient and sediment loading. An emerging issue that could have large consequences on SAV is the effect of sea level rise associated with global climate change.

The 2010 CHPP provides additional information on habitat requirements and distribution of SAV. The light requirements of SAV groups (based on salinity) are now well established and documented in this chapter. Since the 2005 CHPP, coastwide imagery of SAV was obtained in 2007-2008, with delineation delayed due to staff vacancies (a state/federal cooperative mapping effort). Digitizing SAV polygons on the imagery is in progress. Additional mapping in western Pamlico Sound, Neuse River, and Tar/Pamlico River by the DMF and DWQ have increased the total area of mapped SAV to over 150,000 acres. While a quantified change analysis is not available, there appeared to be an increase of SAV in some of the low salinity systems and southern range of SAV, which may be related to improved water clarity associated with the coastwide drought in 2007-2008. Preliminary review of core areas of SAV, such as behind the Outer Banks in Pamlico Sound and Core Sound do not indicate large change. However, there may have been a shift to increased patchiness of previously dense beds in Bogue Sound. Mapping SAV using aerial imagery to assess status and trends is a large and difficult task that must be augmented with monitoring.

Some annual monitoring of SAV presence and species composition is being done, but is not being applied to a coastwide analysis of annual change in distribution and abundance. A cooperative agency/academic research project (funded by Coastal Recreational Fishing License dollars) is underway and investigating methods to employ for SAV change analysis. Less rigorous analysis of change has been conducted for the Currituck Sound and Back Bay system, where restoration plans are being developed by the USACE in consultation with other resource management agencies and University researchers. The SAV in these systems is currently recovering naturally, but could benefit from restoration/enhancement work to build more resilience during less favorable conditions in the future. With better information available on light and other habitat requirements of SAV, it may be possible to manage water quality for protection of SAV. The 2010 CHPP provides information on techniques to identify potential SAV habitat so that these areas can be targeted for protection and restoration. However, the bathymetric data and existing network of water quality monitoring stations remain inadequate for coastwide modeling SAV habitat suitability. The state of North Carolina would have to commit substantial resources to adequately manage SAV habitat through regular monitoring, mapping, and development of SAV specific water quality standards such as has been done in the Chesapeake Bay and regions of Florida.

Over half of the research and management needs identified in the 2005 CHPP have advanced to some degree. Nine were accomplished, nine others had significant progress, and eleven had no action. Of the research needs, the most significant advancement is information regarding the bio-optical habitat requirements of SAV. Numerous management needs were accomplished while some are ongoing and require continued effort and funding. The most significant management accomplishment was obtaining aerial imagery to map all SAV along the coast. However progress to get the SAV imagery delineated has been delayed due to staffing shortages and budget issues. There are also 13 and 12 emerging or modified research and management needs, respectively.

Progress since the 2005 CHPP included an updated, regulatory definition of SAV habitat that should further reduce piecemeal loss and degradation of SAV habitat from water dependent development. There are also more areas of SAV habitat closed to bottom disturbing fishing gear, and fishing gear buffer boundaries were re-evaluated and are being enforced. Direct dredge and fill impacts to existing and historic SAV are being avoided to a greater extent, due to improved education and commitment of the permitting agencies, revisions to the MFC definition of SAV habitat and revisions of the CRC dock rules. So the management of SAV habitat loss to individual, direct impacts has improved, while management of cumulative impacts continues to be an issue. Steps have been taken to reduce nutrient and sediment loading from nonpoint sources through implementation of coastal stormwater rules. Though water quality degradation affects large areas of SAV habitat, monitoring of water quality standards continues to only marginally reflect support of SAV habitat requirements. There remains a need for improved water quality standards and monitoring for SAV habitat. Some research in underway looking at various monitoring methods however. Educational awareness of the value of SAV habitat remains a great need.



Map 4.1. Location of mapped submerged aquatic vegetation (SAV) habitat in coastal North Carolina (1981-2009). See "Distribution" section for mapping efforts included. Note: Absence of SAV beds in a given area does not suggest actual presence/absence of SAV because surveys have not been conducted in all areas.

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 2000). 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 support vital nursery areas and serve as the primary buffer between land and water-based impacts.

5.1. DESCRIPTION AND DISTRIBUTION

5.1.1. 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[29] (i.e., marsh grasses) can be found - generally <6ft (2m) below mean low water during the growing season. The EMC and federal regulatory definitions include non-tidal freshwater wetlands not subject to CRC rules. The CRC defines coastal wetlands 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" [15A NCAC 07H .0205(a)]. For the purpose of DCM permitting actions salt marshland or other marsh are defined as containing any of the following species: smooth or salt water Cordgrass (*Spartina alterniflora*), Black Needlerush (*Juncus roemerianus*), Glasswort (*Salicornia* spp.), Salt Grass (*Distichlis spicata*), Sea Lavender (*Limonium* spp.), Bulrush (*Scirpus* spp.), Saw Grass (*Cladium jamaicense*), Cattail (*Typha* spp.), Salt-Meadow Grass (*Spartina patens*) and Salt Reed-Grass (*Spartina cynosuroides*) [N.C.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 referred to as "riparian wetlands" in the CHPP because they border streams and other water bodies.

[29] For the purpose of this plan, emergent vegetation includes (rooted) floating leaf aquatic plants (i.e., lily pads).

5.1.2. 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.

- **Salt/brackish marshes,** classified as a coastal wetland by DCM, is a herbaceous plant community subjected to tidal inundation and defined by containing one of the following plant species: 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 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.
- **Estuarine forested wetlands** are a tree-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). 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.

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.

- **Freshwater marshes** are defined as herbaceous areas that are flooded for extended periods during the growing season (Sutter 1999). 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[30]. 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 floodplain and shoreline areas of coastal rivers.

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. Headwater swamps are wooded, riverine systems along small, intermittent or perennial 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.

[30] Cowardin et al. (1979): Semi-permanently flooded = water covers the land surface throughout the growing season in most years. Seasonally flooded = water covers the land surface for most of the growing season, but is usually absent by the end of the season in most years.

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, such as the pocosins adjacent to the Alligator and Northeast Cape Fear rivers have surface drainage to coastal waters (Brinson 1991) and the center of Cedar Island NWR (M. Brinson/ECU, pers. com., June 2009). The center of the refuge has rainwater killifish, yet it is only connected during storm tides (1 mile from the shore). Most of the marsh has 'resident" populations of mummichog that do not exchange with the estuary. However, the primary focus of this chapter is the riparian wetlands found in estuarine and riverine systems.

5.1.3. Habitat requirements

5.1.3.1. Estuarine wetlands

Salt-brackish marsh occupy wetland areas at salinities from 0.5 to >35 ppt in North Carolina (Wiegert and Freeman 1990). Salt marsh occurs in salinities >15 ppt (eastern Pamlico Sound, Core/Bogue sounds, etc.) and brackish marsh occurs from 0.5-15 ppt (Albemarle Sound, western Pamlico sound, etc.) (see "Water Column" chapter for salinity zone maps). Within these salinity ranges, salt-tolerant 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 builds side banks of higher elevation (low marsh) and coarser particle size than the sediments in the marsh interior (high marsh). Fringing salt marshes bordering larger water bodies exhibit different patterns of sediment accretion and particle size (Currin et al. 2008; Morgan et al. 2009).

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 bank composition, shoreline vegetation, and presence of offshore vegetation (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 or otherwise sheltered estuaries are eroding at very low rates, allowing the marshes and flats to vertically accrete sediment to keep up with rising sea level. Riggs (2001) mapped the shoreline types and shoreline areas where erosion was noticeable (see "Sea level rise and climate change" section for more information on erosion). Channels through marsh platforms form from micro-differences in sediment elevation and accretion patterns (Pratolongo et al. 2009 in Perillo et al. 2009).

The zonation of marsh vegetation in tidal systems is largely determined by variations of salinity and drainage of sediment porewater (Wiegert and Freeman 1990). Porewater salinity in the low marsh bank 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. Few species can survive in the low marsh because of high porewater salinity and frequent inundation. In the high marsh, frequent precipitation (and occasionally groundwater) creates salinities that may be low enough to support shrubs and other plants intolerant of high salinities (i.e., wax myrtle, groundsel-tree, and marsh elder) in low marsh. However, very high salinity sediments devoid of vegetation (i.e., salt pans) may develop in mid-marsh areas where shallow, salt ponds evaporate between periods of high water (Pratolongo et al. 2009). Frequency and depth of inundation increase with increasing proximity to inlets, modified somewhat by prevailing wind patterns. Porewater salinity and inundation frequency in coastal wetlands areas also vary with seasonal and annual changes in precipitation and relative sea level (see “Sea level rise and climate change” section for graph of annual changes in sea level).

5.1.3.2. Riverine wetlands

Swamp forests and freshwater marshes occupy riverine wetland areas at salinities less than 0.5 ppt. Hydrology in riverine systems may be tidal or non-tidal depending on proximity to ocean inlets and elevation gradient (Perillo et al. 2009). In North Carolina, tidal freshwater wetlands occur in the Cape Fear, New, and White Oak rivers. Though small in relative area to other wetlands, tidal freshwater wetlands occupy a unique hydrogeomorphic setting at the upper limit of tidal influence (tidal range 0.1-0.5 m) where brackish water meets downstream flow from nontidal rivers (Perillo et al. 2009). The development of tidal freshwater marshes is similar to that of salt/brackish marsh. However, tidal freshwater marshes have more diverse plant communities than salt/brackish marsh due to increased soil aeration and lack of salinity stress (Odum et al. 1984; Perillo et al. 2009).

The hydrology of non-tidal freshwater wetlands is more variable than tidal wetlands that receive regular inundation. Consequently, these communities are adapted to survive in varying water levels. In inland marshes water levels are determined by the type of water body in which they occur, whereas in isolated marshes they are controlled more by the balance of precipitation and evapotranspiration than connection to larger water bodies (Mitsch and Gosselink 1993).

Riverine swamp forests typically develop along low lying margins of rivers and lakes where they receive seasonal flooding (Wharton et al. 1982). 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). Riverine swamp forests are semi-permanently to permanently flooded. Overbank flooding and surface and groundwater discharge are likely sources of inundation in riverine swamp forests (Wharton et al. 1982). 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. 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 (Winner and Simmons 1977; Wharton et al. 1982). When the mainstem channel is low, water level in blackwater streams is controlled more by local precipitation. The timing and duration of flooding in the different riverine wetlands will affect the type and regularity of fish use. The seasonal (winter-spring) inundation of swamps bordering blackwater streams allows temporary use by opportunistic fish at high mainstem river flows.

5.1.3.3. 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 located along the upper reaches of first order streams. They are critical in buffering potentially harmful effects of land use that generate high levels of sediment and nitrate loading. They are the first line of defense for the protection of the waters further downstream.

5.1.4. Distribution

There has been no new coastwide mapping of wetland distribution since the last CHPP. The DCM mapping effort 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 unaltered riparian and non-riparian wetlands, respectively, in the CHPP management area. Riparian and non-riparian wetlands therefore covered 8.9% and 14.5% of the regions for SHA assessment. 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. The range of mapped wetland acreage does not include small wetland areas and narrow fringing wetlands less than 30 meters wide. Some overestimation also occurs where small creeks and ponds are located within the wetland area.

Riverine wetlands were the most abundant of the three riparian wetland classes (i.e., estuarine, riverine, and headwater) at 30.70% of all mapped wetlands (Table 5.1). Estuarine wetlands came in a distant second at 6.55%, and headwater wetlands barely registered at <1%. Riparian wetlands are not distributed evenly along the coast (Map 5.1a-d). The Cape Fear subregion of CHPP region 4 contained the largest area of riparian wetlands, followed by the Neuse and Albemarle (Figure 5.1). The greatest proportions of estuarine wetlands were in Core-Bogue, Southern Estuaries, and Pamlico subregions, whereas the Roanoke, Cape Fear, and Neuse had the highest proportion of riverine wetlands (Figure 5.1). The Chowan, Roanoke, and coastal Ocean subregions are the only areas without any mapped estuarine wetlands. All types of riverine wetlands occurred throughout all subregions except the coastal ocean.

<u>5.1.4.1 Salt/brackish marsh</u>

- The total area of unaltered salt/brackish marsh in coastal North Carolina was 199,068 acres in 1994, which comprised 15% of riparian wetland types (Table 5.1).
- The greatest acreage (89,224 acres) of salt/brackish marsh was in CHPP region 2 (Pamlico Sound and tributaries).

<u>5.1.4.2. Estuarine shrub/scrub</u>

- There was a total of 28,291 acres of estuarine shrub/scrub habitat, which comprised 2.1% of riparian wetland areas.
- The greatest acreage (8,279) of estuarine shrub/scrub habitat was in CHPP region 2.

<u>5.1.4.3. Estuarine forests</u>

- There was a total of 968 acres of estuarine forest, comprising less than 1% of riparian wetlands.
- The greatest acreage of estuarine forested wetlands was in CHPP region 2.

<u>5.1.4.4. Freshwater marsh (riparian only)</u>

- Freshwater marsh covered a total area of 16,960 acres and comprised 1.3% of riparian wetlands (Table 5.1).
- The greatest acreage (10,608) of freshwater marsh was in CHPP region 4 (Cape Fear River and southern estuaries).

<u>5.1.4.5. Riverine forested wetlands (riparian only)</u>

- The combined total acreage of bottomland hardwood forest and riverine swamp forest was 1,052,556, which comprised 79.2% of all riparian wetlands.

- The greatest area (407,109 acres) of bottomland hardwood and riverine swamp forest was in CHPP region 1 (Albemarle Sound and major tributaries).

5.1.4.6. Headwater swamps (riparian only)

- The total area of headwater swamps was 31,088 acres, which comprised 2.3% of all riparian wetlands.
- The greatest acreage of headwater swamps (14,673 acres) was in CHPP region 2.

Accurate and up-to-date mapping of wetland types is needed for North Carolina. As of March 2009, there has been no repeat mapping of wetlands in coastal North Carolina since 1994. However, there are plans to update the NWI maps with LIDAR and multispectral imagery (Julia Harrell/DENR, pers. com., March 2009). The National Landcover Dataset (NLCD) for 2006 will also be available sometime in 2009. According to the 2001 NLCD, there were 2,867,548 acres of wetlands in coastal draining river basins of North Carolina (excluding Lumber River), and 5,132,634 acres in the entire state. The error of the 2001 NLCD is still being determined (http://www.epa.gov/mrlc/nlcd-2001.html, April 2009). The classification error (by pixel) of the wetland classes on the 1992 NLCD for North Carolina was 32% (http://landcover.usgs.gov/accuracy/table5.php, April 2009). So the actual amount of wetlands in coastal draining river basins of North Carolina was between 1,949,933 and 3,785,164 acres in 2001, assuming the accuracy is equal to that of 1992 classification.

Table 5.1. Total acreage of unaltered riparian and non-riparian wetland types by CHPP region. [Source: DCM wetland mapping data (1994).]

Hgm[1]	DCM wetland type	CHPP Regions (acres)[2] 1	1/2	2	2/3	3	4	Total acres (by type)	% of wetland area
Estuarine	Estuarine Forest	231	0	524	0	135	79	968	0.03%
	Estuarine Shrub/Scrub	8,058	53	12,066	2	6,990	1,121	28,291	0.81%
	Salt/Brackish Marsh	42,869	425	89,224	40	36,136	30,375	199,068	5.71%
	Hgm total	51,158	478	101,813	42	43,261	31,575	228,327	6.55%
Headwater	Freshwater Marsh	0	0	4	0	0	1	5	0.00%
	Hardwood Flat	0	0	0	0	0	31	31	0.00%
	Headwater Swamp	6,819	0	14,669	0	3,349	6,214	31,051	0.89%
	Managed Pineland	0	0	0	0	0	0	0	0.00%
	Hgm total	6,819	0	14,673	0	3,349	6,246	31,088	0.89%
Riverine	Bottomland Hardwood	71,539	0	105,887	0	8,183	40,789	226,398	6.50%
	Freshwater Marsh	2,475	0	3,529	0	344	10,608	16,955	0.49%
	Hardwood Flat	0	0	24	0	0	10	34	0.00%
	Managed Pineland	0	0	45	0	24	58	128	0.00%
	Maritime Forest	4	0	0	0	0	0	4	0.00%
	Pine Flat	0	0	67	0	0	0	67	0.00%
	Riverine Swamp Forest	335,570	0	244,634	0	26,558	219,397	826,158	23.71%
	Hgm total	409,587	0	354,186	0	35,109	270,862	1,069,744	30.70%
Flat/ depression-al	Bottomland Hardwood	0	0	58	0	0	246	304	0.01%
	Depressional Swamp Forest	122,485	0	55,900	0	5,608	31,371	215,364	6.18%
	Freshwater Marsh	5,331	0	6,685	0	662	3,019	15,696	0.45%
	Hardwood Flat	44,095	0	66,114	0	8,229	46,040	164,477	4.72%
	Managed Pineland	201,831	0	337,060	0	85,901	329,020	953,812	27.37%
	Maritime Forest	1,788	7	1,610	0	146	0	3,551	0.10%
	Pine Flat	37,748	0	100,575	0	44,861	112,825	296,009	8.49%
	Pocosin	103,106	0	159,903	0	74,555	169,124	506,688	14.54%
	Hgm total	516,384	7	727,905	0	219,962	691,643	2,155,901	61.86%
Total acres (by region)		983,949	485	1,198,577	42	301,680	1,000,327	3,485,060	100%
Percent wetlands in region		26.0%	0.9%	18.8%	0.1%	26.5%	28.7%	23.4%	na

[1] Hydrogeomorphic class

[2] 1 = Albemarle Sound and tributaries, 1/2 = Oregon Inlet, 2 = Pamlico Sound and tributaries, 2/3 = Ocracoke Inlet, 3 = Core/Bogue and New/White Oak estuaries, and 4 = Cape Fear River and southern estuaries

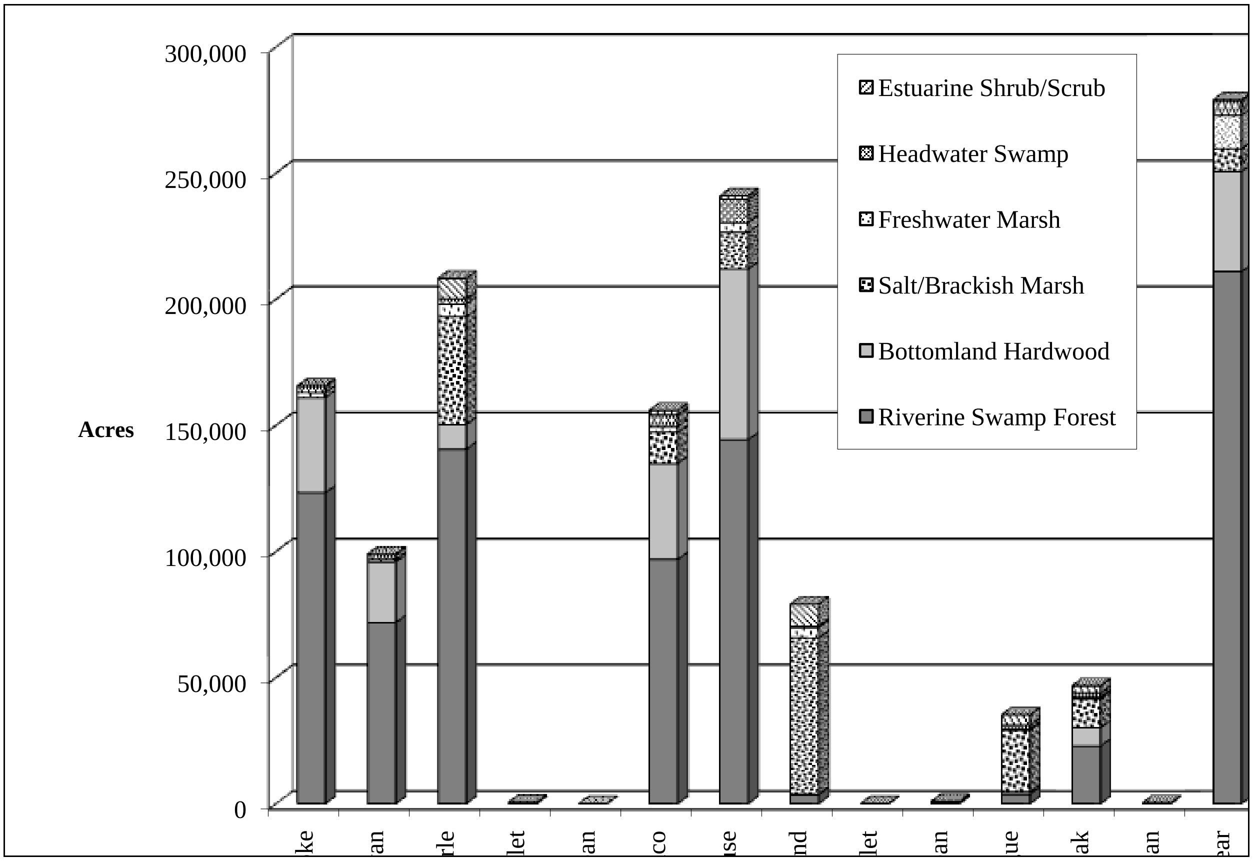


Figure 5.1.Relative amount and proportion of unaltered riparian wetland types among CHPP subregions. [Source: DCM wetland mapping data (1994).]

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. Since the last CHPP there has been some additional research on the economic value of wetlands and the critical importance of even a narrow fringe of wetland edge for fish utilization and erosion control.

5.2.1. 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 stored floodwater equivalent to about 60 days of river discharge before European settlement. 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.

Reduced extent of coastal wetlands[31] has also been linked to increased hurricane damage. Costanza et al. (2008b) estimated that a loss of 1 acre of coastal wetlands resulted in a $13,360 loss of gross domestic product. The study also estimated that coastal wetlands in the U.S. could provide as much as $23.2 billion, per year, in storm protection services.

Rooted vegetation stabilizes unconsolidated sediment, buffering erosive forces and improving water clarity for SAV and benthic microalgae (Mitsch and Gosselink 1993, Riggs 2001). Studies have shown that even narrow (7-25m), marsh borders reduce incoming wave energy by 60-95% (Knutson et al. 1982; Morgan et al. 2009). The buffering of sediment-laden water also causes deposition of suspended solids (inorganic sediment and organic matter) among the vegetation (Mitsch and Gosselink 1993). Leonard and Croft (2006) quantified the relationship between flow velocity, turbulence, and sediment deposition/retention in salt/brackish marsh vegetation. The buffering effect of wetland vegetation also reduces sediment additions from upland areas creating 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.*

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). Kao et al. (2001) and Kao and Wu (2001) quantified the percent of pesticides and nutrients treated by a wetland in the North Carolina mountains with a hydraulic retention time of 10.5 days. The wetland completed removed Atrazine (a pesticide) pollution from the upstream agricultural lands. Once adsorbed to sediment particles in low-oxygen (anaerobic or reducing) sediment, ammonia and nitrate (organic waste or fertilizer) is transformed into nitrogen gas (Mitsch and Gosselink 1993). Nitrogen processing in wetlands may prevent nutrient over-enrichment and resulting oxygen stress in receiving waters. 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).

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). 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). Over the long term, marshes are effectively sinks where they are not losing material from erosion (Mark Brinson/ECU, pers. com., June 2009). The most active uptake and retention of nutrients in riverine systems can be found in headwater wetlands (Peterson et al. 2001, http://www2.ncsu.edu/ncsu/CIL/WRRI/reports/report317.html, 2003, Meyer et al. 2007). Retention and controlled release of particles, toxic chemicals and nutrients can improve water quality downstream. Therefore, forested wetlands and marshes upstream influence the potential for erosion, flooding, sedimentation, algal blooms, and fish kills downstream.

Though flat/depressional or non-riparian wetlands are not used by fish, they can have a significant effect on water quality in public trust waters. Pocosins cover a vast continuous expanse of the coastal North Carolina landscape and are connected to surface waters through shallow aquifers. These facts suggest that pocosins are connected to regulated tributary waters of the United States (Richardson 2003). A survey of USACE personnel in North Carolina indicated that most pocosins are considered hydrologically connected to regional water supplies where they dominate the landscape (Richardson 2003).

[31] Not necessarily "Coastal wetlands" as defined in CRC rule.

Only recently have studies revealed the importance of freshwater and coastal marshes in storing silicon, which is critical for benthic diatom production (Hackney et al. 2000; Struyf et al. 2005). Tidal marshplants store silica in their tissues until it is liberated by decomposition into surface waters. Maintaining high concentration of silica is important because it supports a high abundance of diatoms, which are critical for secondary production of commercial fish and crustaceans (Hackney et al. 2000). Tidal marshes are also an important source of silicon for diatoms in freshwater systems (Struyf et al. 2005). In tidal freshwater systems of the Schelde estuary (Belgium), nearly half of silicon recycling was performed by marsh grasses, based on comparing import and export rates during the spring and summer.

5.2.2. 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). Inundated wetland plants also exude dissolved organic substances contributing to epiphytic growth on their stems and leaves (Mitsch and Gosselink 1993) and to the dissolved organic matter content of the water column.

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). Discounting 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 to 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, with higher temperatures (allowing faster decomposition) and frequent inundation increasing the export rate.

5.2.3. 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). The use of wetlands by finfish and shellfish is presented first, followed by documentation of specific functions for selected species.

5.2.3.1. 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 spawned in deeper waters that use marsh habitat as nursery or foraging areas (i.e., red drum, flounder, spot, croaker). Among transient species, some prefer the edge of salt/brackish marsh (i.e., red drum, flounder) while others are found on unvegetated bottom near the edge (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).

A study in South Carolina looking at the relationship between depth and movement of nekton at different tide stages found a consistent pattern of resident species entering early in the rising tide followed by transient species entering during the mid to late tide (Bretsch and Allen 2006). The depth of migrations among species were also consistent between creeks, days (within months), and years. The only variation occurred as the summer progressed, with some species (i.e., spot, mullet, pinfish) moving into deeper water. This pattern of nekton migration is probably similar to that of North Carolina salt marshes.

5.2.3.2. 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).

Table 5.2. Partial listing of fish and their use of wetland habitat in coastal North Carolina.

Species*	Wetland Functions [1] Nursery	Foraging	Refuge	Spawning	Corridor	Fishery [2]	2010 Stock Status [3]
RESIDENT FRESHWATER OR BRACKISH							
White perch						X	U
Yellow perch	X					X	C
Catfish						X	U
ANADROMOUS AND CATADROMOUS							
American eel		X	X		X	X	U
Sturgeon spp.	X	X	X		X	X [4]	D
River herring	**X**	**X**	**X**	**X**	**X**	**X**	**D-Albemarle Sound, U-Central/Southern**
Striped bass	X	X	X		X	X	V-Albemarle Sound, Atlantic Ocean, D-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**	**D**
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**	**D**
Spot	**X**	**X**	**X**		**X**	**X**	**C**
Striped mullet	**X**	**X**	**X**		**X**	**X**	**V**
MARINE SPAWNING, HIGH SALINITY NURSERY							
Black sea bass	X	X	X		X	X	D - south of Hatteras, C- north of Hatteras
Pinfish	**X**	**X**	**X**		**X**	**X**	
Summer flounder	**X**	**X**	**X**		**X**	**X**	**R**

* Scientific names listed in Appendix D. 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, D=Depleted, U=Unknown (http://www.ncdmf.net/stocks/2010NCDMF%20StockStatusReport.pdf)
[4] Fishery species under harvest moratorium

5.2.3.3. Bottomland hardwood and riverine swamp forest

There is a strong relationship between fishery yields and forested river floodplains (Wharton 1982, Junk et al. 1989, 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 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). Similar studies of fish use on river floodplains in North Carolina has not been conducted (literature search in March, 2009). Fish use of riverine forested wetlands is generally restricted to periods of seasonal inundation. Some exceptions to this general pattern occur. The riverine wetlands below Lock and Dam #1 on the Cape Fear River receive regular tidal inundation (C. Hackney/UNC-W, pers. com., 2003). 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).

5.2.3.4. Flat/depressional wetlands

Fish use of normally isolated wetlands (i.e., pocosins along the Alligator and Northeast Cape Fear rivers) depends on many factors. Pocosins that are located directly adjacent to salt/brackish marsh or other riparian wetlands are potential fish habitat. 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).

5.2.4. Specific biological functions

5.2.4.1. 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 2000). Nursery habitat is not only provided by the dense structures, but also by the shallow depth and expanse of water itself, which provides refuge from aquatic fish predators (review in Rozas and Odum 1987). The avoidance of shallow water by large, deep-bodied aquatic predators is a common behavior, which indirectly protects smaller fish. 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).

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. Marsh wetlands are a vital component of estuarine nursery habitat, while 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).

Many 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 (lower salinity) or lowermost (higher salinity) reaches of estuarine creek systems (Ross 2003). The peak of juvenile settlement generally occurs in spring through early summer, depending on 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).

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. In higher salinity marshes of the Pamlico Sound, spotted seatrout, weakfish, silver perch, and red drum are also abundant (Noble and Monroe 1991). 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 marsh edge habitat compared to inner marsh, shell bottom, SAV, and shallow, non-vegetated bottom (Minello 1999). Resident estuarine species, such as gulf killifish and sheepshead minnow, were most abundant in high marsh (Rozas and Zimmerman 2000).

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, red drum, and southern flounder (Tagatz and Dudley 1961; Noble and Monroe 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. The most abundant species were spot, grass shrimp, bay anchovy, and Atlantic menhaden. They also reported three seasonal peaks in abundance: (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.

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).

Bottomland hardwood and riverine swamp forest

Forested wetlands are important nursery areas for anadromous and resident freshwater species (Wharton et al. 1982; DMF 2000b). 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 2000b). 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). Sections of the Missouri River with accessible floodplains 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).

5.2.4.2. 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. Study results from the southeastern United States suggest that blue crab predation on plant-eating snails (*Littorinid* spp.) may prevent the snail from overgrazing the marsh grass (Silliman and Bertness 2002). A more recent study (Tyrrell et al. 2008) observed greater snail damage on *S. alterniflora* in more stressful conditions associated with sea-level rise (i.e., longer inundation periods, lower elevation, poorer drainage).

Detritus and bacteria 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 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).

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). Deegan et al. (2000) concluded that secondary production derived from salt marsh vegetation occurs in close proximity to the marsh, indicating the possibly minor flux of salt marsh organic matter to offshore habitats. Salt marsh support of offshore fisheries is more likely indirect through export of juvenile fish. 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* species." However, 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). 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 than 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.

5.2.4.3. Refuge

Many small resident species, such as grass shrimp and killifish, find refuge from predators and adverse weather conditions on and among the dense leaf canopies found in marshes (Mitsch and Gosselink 1993; Pattilo et al. 1997; SAFMC 1998a; Rozas and Zimmerman 2000; Graff and Middleton 2000). Clark et al. (2003) highlighted 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.

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 preference of largemouth bass, bluegill, and other freshwater ambush predators for vegetated habitat (review in Savino and Stein 1989).

5.2.4.4. 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. Numerous freshwater riverine species use riparian swamps as a spawning habitat (Wharton et al. 1982). River herring are an important coastal species that spawn adhesive eggs in flooded swamps, oxbows, and along stream edges (Wharton et al. 1982; DMF 2000b). Spawning of river herring in North Carolina occurs during elevated spring flows from March through May in small tributaries (DMF 2000b). The DMF surveyed river herring spawning activity (eggs, larvae, spawning adults) through riverine forested wetlands in the early 1970's and again in 2008-2009. The data from the original survey was used to map and officially designated Anadromous Fish Spawning Areas in 2008 [North Carolina Rules for Coastal Fishing Waters 2009 - 15A NCAC 03I .0101 (4) (b)]. Spawning hickory shad are thought to use flooded swamps and tributaries of the main river (Pate 1972; Funderburk et al. 1991). Pate (1972) collected hickory shad larvae and eggs in flooded swamps and sloughs off of the mainstem of the Neuse River.

The structural complexity of vegetation and intertidal submersion regime in salt/brackish marsh provides 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 (see "Water column" chapter). Nevertheless, many of the species spawning in wetlands are also important food items for transient fishery species.

5.2.4.5. 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 1999). Studies comparing fish and shellfish densities in tidal creeks with and without adjacent SAV beds found that pinfish and grass shrimp numbers greatly declined in tidal creeks without subtidal SAV (Rozas and Odum 1987; Irlandi and Crawford 1997). 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. Subtidal structures (i.e., SAV, large woody debris) near freshwater wetlands may serve a similar corridor function in wind tidal systems of Pamlico and Albemarle Sound. Wetlands can also enhance the foraging function of adjacent habitats. Micheli and Peterson (1999) found that marsh edge provided a corridor function for blue crabs foraging on nearby subtidal oyster reefs. *These studies show the importance of considering optimal locations for habitat restoration/creation projects.*

5.3. STATUS AND TRENDS

5.3.1. History of loss and regulatory action

5.3.1.1. Historic loss of wetland habitat

Past studies have estimated that North Carolina had about 7.2 million acres of wetlands prior to European colonization, of which 95% occurred in the Coastal Plains (DWQ 2000a). Dahl (1990) estimated that by the mid-1980s, only about 50% of these wetlands remained. The trend in wetland loss for North Carolina mirrors national trends (Dahl 1990). DWQ also estimated wetland losses but concluded that approximately 66% of North Carolina's original wetland extent remains and 83% of its original salt marsh, bottomland hardwood, and swamp forests still remain (Table 5.3) (DWQ 2000a). However, the 83% figure is only a rough estimate because the DWQ study did not distinguish between depressional (non-riparian) 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 acreage of 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				Reference[2]
		Original Extent[1]	1990's	Change	% remaining	
Non-riparian	Pine savannah	3,643,000	28,000	-3,615,000	1%	Leonard, pers. com.
	Pocosin	1,366,000	655,000	-711,000	48%	DWQ 1993
	Wet pine flatwood	0	2,212,000[3]	2,212,000		DWQ 1993
Riparian	Bottomland hardwood	1,481,000	1,207,000	-274,000	81%	DWQ 1993
	Salt marsh	209,000	183,000	-26,000	88%	Cashin 1992
	Swamp forest	476,000	413,000	-63,000	87%	DWQ 1993
TOTAL		7,175,000	4,706,000	-2,469,000	66%	DWQ 1993

[1] Based on descriptions of native vegetation found on hydric soils from SCS county soil surveys from the 1950s to 1980's.
[2] These references did not use the same methods and are not directly comparable.
[3] Based on original extent of pine savannahs.

The major causes of wetland loss and degradation have 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. Drainage districts currently maintain the old drainage canals for croplands (DEHNR 1995a). About one-third of the loss of wetlands has occurred since 1950 (Bales and Newcomb 1996). From the 1950's to early 1990's, 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 material between canals so the road would remain relatively dry and accessible for year-round use. Ditching of wetlands was also common in other areas of the coast for flood control and drainage up until the mid-1970's. 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, CHPP region #2).

The DCM wetland maps use three modifiers to indicate human disturbance: 1) partially drained, 2) cutover, or 3) cleared (Sutter 1999). 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). Cutover wetlands are wet areas in which satellite imagery from 1994 indicates a lack of wetland vegetation where it was present in 1988. Cleared wetlands were NWI[32] wetland areas (excluding marsh) for which satellite imagery indicated a lack of vegetation in both 1988 and 1994 (Sutter 1999). Cutover wetlands have likely retained wetland hydrology and soil characteristics, while cleared and drained wetlands are probably no longer functional wetlands.

[32] The NWI wetlands in coastal North Carolina were delineated from 1:58,000 scale color infrared aerial photography from the early 1980's.

Using the DCM modifiers for human disturbance, more non-riparian wetlands have been impacted than riparian wetlands. As of 1994, 98,673 and 387,498 acres of coastal/riparian and non-riparian wetlands, respectively, were mapped as degraded or modified (Tables 5.4 and 5.5)[33]. Among coastal/riparian wetland types, salt/brackish was most often modified by drainage, followed by riverine swamp forest, and bottomland hardwood forests (Table 5.4 and Maps 5.1a-d). During 1988-1994, the rates of cutover for riparian and non-riparian wetlands were 2,919 and 6,719 acres/year, respectively. Areas classified as human impacted on the DCM wetlands coverage have physically disturbed wetlands, but the area is still a wetland. Impoundments and some cutovers are included in this category, as well as other disturbed areas, such as power lines. The total area of human impacted wetlands in the North Carolina coastal plain was 415,013 acres (244,751 acres of riverine, 1,496 acres of headwaters, and 168,750 acres of flat/depressional).

Table 5.4. Altered coastal and riparian wetland types in CHPP regions. [Source: DCM wetland mapping (current as of 1994).]

Coastal and riparian wetlands	**Cleared[1]**	**Cutover[2]**	**Drained[1]**	**Total altered area (ac)**	**% Altered [3]**
Bottomland Hardwood	4,183	7,840	13,548	25,571	10.14%
Estuarine Forest	0	5	19	24	2.42%
Estuarine Shrub/Scrub	318	535	2,195	3,048	9.73%
Freshwater Marsh	0	0	2,550	2,550	7.24%
Headwater Swamp	822	2,853	2,583	6,258	16.77%
Riverine Swamp Forest	2,985	6,280	22,715	31,980	3.73%
Salt/Brackish Marsh	0	0	29,242	29,242	12.81%
Total altered area (ac)	8,308	17,513	72,852	98,673	6.84%
% Altered [3]	0.58%	1.21%	5.05%	6.84%	na

[1] NWI wetland areas (excluding marsh) for which satellite imagery indicated a lack of vegetation in both 1988 and 1994.

[2] Impacted from 1988-1994

[3] Calculated using [total altererd area]/[altered wetland area + unaltered wetland area]*100

In addition to conversion to agriculture, silviculture, and upland development, many coastal 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). Many acres of wetlands were dredged for the Intracoastal Waterway (1930s), boat basins, and connecting channels before dredge and fill laws were implemented.

[33] Does not include degradation or modification of fringing wetlands less than 30 meters wide.

Table 5.5. Altered non-riparian wetland types in CHPP regions. [Source: DCM wetland mapping (current as of 1994).]

Non-riparian wetlands	Cleared[1]	Cutover[2]	Drained[1]	Total altered area (ac)	% Altered [3]
Depressional Swamp Forest	3,755	5,686	61,830	71,271	24.86%
Hardwood Flat	8,091	13,388	70,536	92,015	35.87%
Maritime Forest	142	138	17	297	7.71%
Pine Flat	4,610	15,748	95,933	116,291	28.20%
Pocosin	1,986	5,356	100,282	107,624	17.52%
Total altered area (ac)	18,584	40,316	328,598	387,498	24.62%
% Altered [3]	1.18%	2.56%	20.88%	24.62%	na

[1] NWI wetland areas (excluding marsh) for which satellite imagery indicated a lack of vegetation in both 1988 and 1994.

[2] Impacted from 1988-1994

[3] Calculated using [total altererd area]/[altered wetland area + unaltered wetland area]*100

5.3.1.2. Regulatory response to historic losses

Development activities impacting 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 Coastal Zone Management Act of 1972 (Bales and Newcomb 1996); the Food Security Act of 1985; the Emergency Wetlands Resources Act of 1986; and the Food, Agriculture, Conservation, and Trade Act of 1990.

The 1899 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 impounding, deepening, filling, excavating, and placement of structures. Section 404 of the 1972 Clean Water Act requires that the USACE regulate the discharge of dredge or fill material into “Waters of the United States” (current definition includes riparian, estuarine, and headwater wetlands). Permit applications for activities affecting Waters of the United States are decided after consultation with the U.S. Environmental Protection Agency (EPA), U.S. Fish and Wildlife Service (FWS), National Marine Fishery Service (NMFS), and state agencies (Mitsch and Gosselink 1993). Of course, these agencies can only recommend denial of a permit. The USACE is not required to take their advice. However, the EPA has statutory authority to designate wetlands subject to permits, and also has veto power on the Corp’s decisions. 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 were exempt from such permits (Bales and Newcomb 1996). The “Swampbuster” provisions of the Food Security Act of 1985 and its amendments reduced the agricultural exemptions. “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. The majority of wetlands lost to agriculture most likely occurred before 1985. Estimates of historical trends indicate a notable alteration of wetland areas in forested areas (Table 5.4 and 5.5) in the past, much of which may be attributed to forestry activities. However, given the lack of current and reliable data sources related to forested wetland status, we can only speculate about the current level of silviculture alteration of wetland areas. Nonetheless, it is widely recognized than in order to maintain the exemptions under Section 404, a land-use activity must not result in the immediate or gradual conversion of a wetland to a non-wetland.

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 may 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. A sample list of other activities covered under federal general permits includes:

- 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.
- Stream and wetland restoration

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 established in North Carolina under the NC Coastal Area Management Act (CAMA) of 1974. The Division of Coastal Management (DCM) was later established as the operational arm of the CRC. Rules promulgated by the CRC apply to North Carolina's 20 coastal counties. Prior to the NC CAMA, dredging and filling of coastal waters was regulated under the NC Dredge and Fill Law.

The CRC rules 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 narrowest fringing wetlands [CRC rule 15A NCAC 07H .0208 (b) (1) (A-C)]. Furthermore, CRC rules require that bulkheads 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[34]. This will result in a cumulative loss of freshwater wetlands and will impede the ability of the estuarine marsh to migrate landward with sea level rise.

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 some of the public as "taking" of property that should be discontinued or compensated for financially. 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 lead to increasing reliance on land acquisition and direct incentives for protecting remaining wetlands. Increasing public awareness of wetlands benefits (i.e., reducing flood levels,

[34] 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 criterion for mitigation when dealing with designated unique wetlands [EMC rule 15A NCAC 02H .0506(e)].

velocities, and damage) encourages greater acceptance of wetland regulations, as well as voluntary actions.

5.3.1.3. Recent loss of wetland habitat (1994-present)

Within coastal draining river basins, 401-permitted wetland impacts over a period of eight fiscal years (FY 1999/2000-2007/2008) indicate a potential conversion of 1,613 wetland acres to non-wetlands (Figure 5.2). Approximately 25% of these wetland impacts did not require mitigation. Among coastal draining river basins, the Cape Fear had the most impacts, followed by the Neuse and Pasquotank (Figure 5.3). 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 (flat/depressional) lost after repeal of the federal Tulloch Rule (see "Regulatory response to recent losses" section). However, most of this acreage had its hydrology restored through an intensive state and federal enforcement effort (see "Wetland enhancement and restoration" section). There is also an unquantified amount of wetland acres lost each year to the indirect effects of bulkheads (see "Shoreline Stabilization" section) as well as unauthorized and/or small projects not requiring notification of DWQ[35]. Thus, the amount of impacted wetland acres may be underestimated. The DWQ is working to resolve the issue of tracking unauthorized and cumulative, small impacts (EEP 2004).

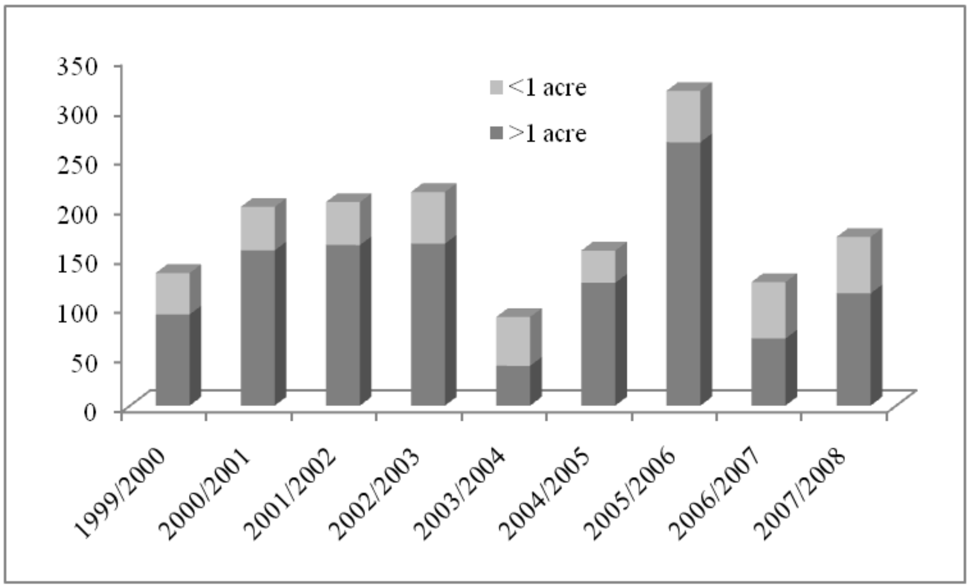


Figure 5.2. Total 401 Permitted Wetland Impacts (acres) during FY 1999/2000-2007/2008 in the seven coastal draining river basins (excluding the Lumber River basin) by fiscal year. Note: These data are for permanent wetland loss and do not include impacts from CAMA, Corps of Engineers Nationwide Permits 12, 27 and 33, and Corps of Engineers Regional General Permit 030 since these impacts are temporary, impacts to water (e.g., drainage), or impacts for wetland creation, restoration, or enhancement.

[35] Impacts to wetlands less than 1/3 acres (east of I-95) or 1/10 acre (west of I-95) and not designated as unique wetlands, or adjacent to ORW, SA, WS-I, WS-II, or contiguous with a state or national Wild and Scenic River (http://h2o.enr.state.nc.us/ncwetlands/rd_wetlands_certifications.htm, February 2009).

Since 2003, the EEP no longer summarized wetland losses by river basin. The EEP only tracks gross mitigation requirements and credits for restoration, enhancement, and high quality preservation. It is very difficult to extract and summarize aggregate information from the BIMS database containing both 401 and CAMA permit records (A. Mueller/DWQ 401 Wetlands Unit, pers. com., March 2009). The ability to summarize and aggregate data on permitted wetland impacts is essential for conducting a cumulative impacts assessment. Though cumulative impact assessment is required by CRC rules, it is often not fully assessed by review agencies because of the difficulty and uncertainty associated with the analysis. *To facilitate cumulative impacts assessment, there should be a central database for recording 404, 401 and CAMA permits that is easy to aggregate and summarize. Necessary fields for the database would include accurate geographic coordinates for impacts and parcel identification numbers. Inclusion of accurate geographic coordinates in the database could simplify data collection.* The DCM's Coastal Development Activity and Impact Tracking System (CDAITS) is an attempt at providing such a database. The database is currently available but includes only general permits. *Other issues hampering management of cumulative impacts include the development of threshold values (for shoreline development) similar to the impervious surface limits in EMC's new stormwater rules. There must also be a means to limit impacts at larger than parcel scales.*

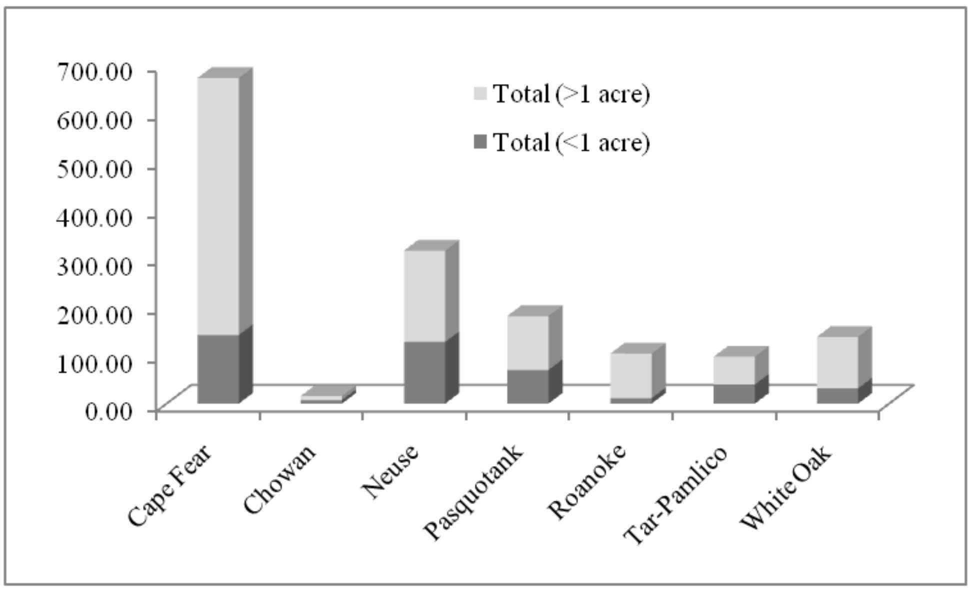


Figure 5.3. Total 401 permitted wetlands impacts (acres) during FY 1999/2000-2007/2008 by coastal draining river basin. Note: These data are for permanent wetland loss and do not include impacts from CAMA, Corps of Engineers Nationwide Permits 12, 27, and 33, and Corps of Engineers Regional General Permit 030 since these impacts are temporary, impacts to water (e.g., drainage), or impacts for wetland creation, restoration, or enhancement.

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 coastal draining river basins (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.

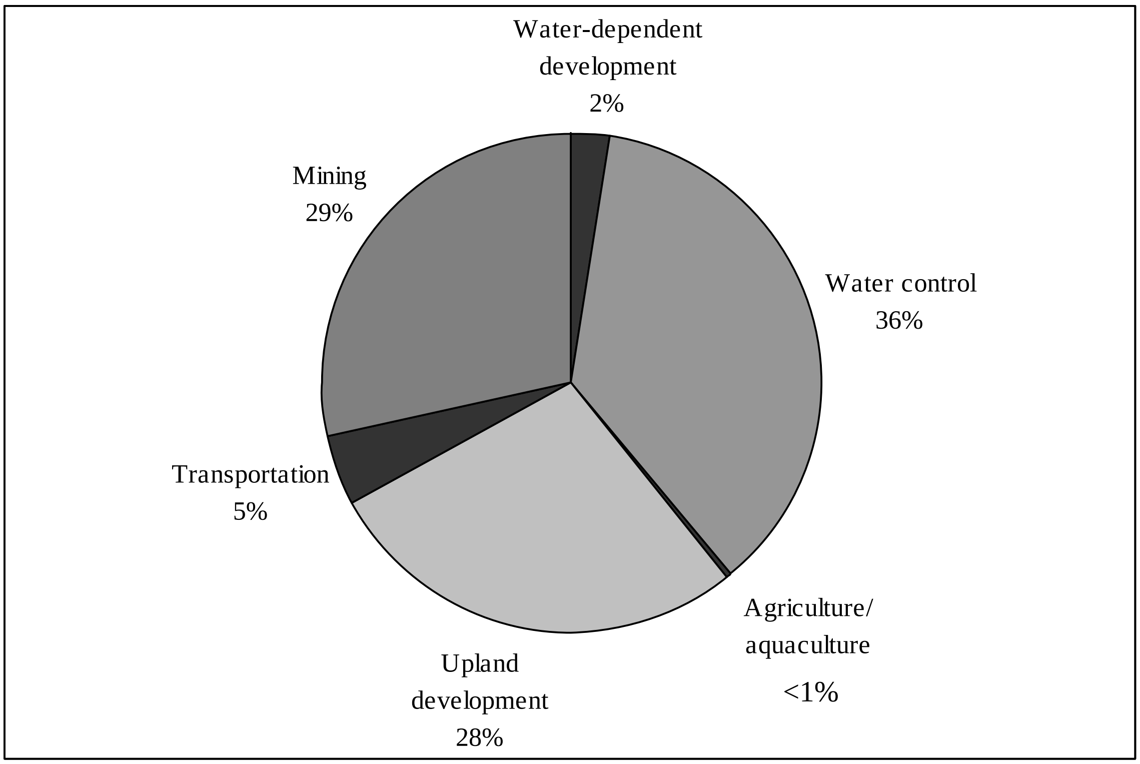


Figure 5.4. Sources of wetland impact in eastern North Carolina. [Source: subset of DWQ Section 401 certification records (1997-2003), with location coordinates within CHPP management units.]

The 1997-2003 trend in wetland loss showed water control projects as the major source of wetland impacts (36% of impacted acres) (Figure 5.4, 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 5.4). However, 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).

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). However, wetland areas are not lost where wetland accretion keeps pace with sea level rise (see "Sea level rise and climate change" section for more information).

5.3.1.4. Regulatory response to recent losses

Between 1993 and 1998, the Tulloch rule gave the USACE authority to regulate ditching and draining of wetlands by preventing the removal of material that could fall back into the wetland. 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 Tulloch rule in June 1998, the USACE lost authority to issue permits for wetland ditching unless spoil was actually 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. The EMC then 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. The DWQ created two stormwater compliance positions in 2007 that were filled in 2008, to inspect for compliance with water quality standards, including wetland draining. The positions are located in Washington and Wilmington, respectively.

In 1995, the COE and EPA issued a joint guidance memo <http://www.epa.gov/owow/wetlands/guidance/silv2.html> that specifies how mechanical site preparation forestry activities must be conducted in order to maintain the silvicultural exemption under Section 404 of the Clean Water Act. This joint guidance memo describes six 'mandatory' best management practices (BMPs) for conducting mechanical site preparation for the establishment of pine plantations. However, this guidance memo also describes nine wetland types in which a *permit is required* to conduct such site preparation activities; these wetland types are listed below:

1. Permanently flooded, intermittently exposed, and semi-permanently flooded wetlands
2. Riverine Bottomland Hardwood wetlands
3. White Cedar swamps
4. Carolina Bay wetlands
5. Non-riverine Forest Wetlands
6. Low Pocosin wetlands
7. Wet Marl forests

8. Tidal freshwater marshes
9. Maritime grasslands, shrub swamps and swamp forests

It could be implied that after 1995, any silvicultural site preparation activity for the establishment of pine plantations in the above nine types of wetlands should not have taken place without applicable permits.

The following case demonstrates how the silvicultural (forestry) exemption can be abused by a landowner and/or company who ultimately does not have an interest in maintaining sustainable forestry operations. In a 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 flat/depressional wetland 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. However, minor drainage- as described for silvicultural purposes in the Code of Federal Regulations 33CFR323.4 – is categorized, treated, and regulated as a nonpoint source contributor of pollution. 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. *Any ditching activity resulting in excess pollutant discharge to 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 small drainage projects, in addition to traditional point source discharges (i.e., wastewater treatment plants).*

In order for forest roads in wetlands to maintain the silvicultural exemption under Section 404, there are fifteen required practices that must be implemented, as described in Code of Federal Regulations 33 CFR Part 323.4 - "Discharges not requiring permits", http://www.saw.usace.army.mil/wetlands/authority.html#Code%20of%20Federal%20Regulations. In addition to these federal rules, in 2004 the Wilmington District of the USACE issued an information document that contains specific recommendations related to the construction of forest roads in wetlands of North Carolina regarding compliance under Section 404 (http://www.saw.usace.army.mil/WETLANDS/Policies/Forest%20Road%20Guidance-final-11-9-2004.pdf). Finally, in 2006 the NC Division of Forest Resources completed a multi-year effort to coordinate and publish a revised North Carolina Forestry Best Management Practices (BMP) Manual (http://www.dfr.state.nc.us/water_quality/bmp_manual.htm). This comprehensive manual was developed through a multi-disciplinary technical advisory group and incorporates extensive information and recommendations for conducting forestry activities in wetlands, including citations of the applicable federal and state laws that effect forestry activities (refer to "Best management practices" subsection of Section 2.4.2.3. for more information on forestry management).

5.3.2. Status of associated fishery stocks

It is very difficult to attribute changes in fish abundance to changes in habitat for several reasons. A major difficulty arises in achieving the data needs for such an analysis. The analysis needs accurate density estimates for fish species and size classes among accurately delineated habitat types over a time series to predict fish – habitat relationships. A study in Galveston Bay was able to predict a substantial decline in shrimp and blue crab populations following a decline in salt marsh edge relative to open water (Rozas et al. 2007). Such an analysis has not been conducted in North Carolina.

There are also non-habitat factors affecting fish populations (i.e., fishing mortality). In North Carolina, estimated fishing mortality and juvenile abundance indices are used by the DMF to determine the status of fishery stocks. Stock status evaluations may also suggest habitat issues for concern or depleted species. Of the fishery stocks with higher relative abundance in wetlands (Table 5.2), six are Depleted, five are Concern, two are Recovering, and five are Viable (http://www.ncdmf.net/stocks/2010NCDMF%20StockStatusReport.pdf). There are an approximately equal number of Viable and Concern stocks showing some preference for wetland habitat. The wetland-enhanced[36] stocks listed as Depleted were river herring (alewife and blueback herring in Albemarle Sound), sturgeon sp., CSMA striped bass, southern flounder, spotted seatrout and black seabass (South of Hatteras). Wetland-enhanced species of Concern included yellow perch, blue crab, Atlantic croaker, spot, and black seabass (North of Hatteras) The two Recovering species are red drum and summer flounder. The Viable species were striped bass (ASMA and Atlantic Ocean migratory stocks), Atlantic menhaden, shrimp and striped mullet. 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. Therefore, protection or enhancement of wetland habitat can be especially beneficial to wetland-enhanced species classified as Depleted or Concern, by maximizing recruitment and productivity. *More fishery-independent information and habitat change analysis are needed to determine the effect of wetland-coverage on the abundance of fish and invertebrates.*

5.3.3. Wetland enhancement and 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). The Clean Water Act (CWA) of 1972 and subsequent agreements (MOAs) between the EPA and USACE develop requirements to compensate for wetlands lost to authorized dredge and/or fill activities. Permit applicants are required to avoid, minimize, or compensate for lost wetlands and their associated water quality functions. The USACE may issue permits to dredge or fill wetlands considered "Waters of the United States." As currently defined, Waters of the United States do not include isolated wetlands (i.e., flat/depressional). In response, the Environmental Management Commission has adopted rules governing the impact to isolated wetlands. DWQ administers these rules. Permitting impacts to salt/brackish marsh is handled through CAMA major permits, which include 404 and state 401 permit conditions. However, each permit authority has a slightly different jurisdiction in terms of wetland type and mitigation requirements (Table 5.6).

The 1990 MOA between the USACE and EPA (http://www.wetlands.com/fed/moafe90.htm, February 2009) states a preference for in-kind, on-site mitigation where permit conditions require compensation. To date, avoidance and minimization have received far less policy attention than mitigation by the USACE (Hough and Robertson 2009). A new USACE/EPA rule finalized in April 2008 specifies the following order of preference: (1) mitigation bank credits, (2) in-lieu fee credits, (3) permittee responsible under a watershed approach, (4) permittee responsible in-kind and on-site, and (5) permitee responsible off-site and/or out of kind (http://www.epa.gov/owow/wetlands/pdf/wetlands_mitigation_final_rule_4_10_08.pdf, June 2009). The USACE (Section 404) and DWQ (Section 401) use the mitigation types in Table 5.6 for determining in-kind. Where on-site mitigation cannot be achieved, off-site mitigation is allowed within the same 8-digit USGS hydrologic unit (HU) and preferred within the same 14-digit HU. Mitigation may include restoration, enhancement, creation, or preservation of wetlands.

- Restoration is the re-establishment or rehabilitation of wetlands or stream hydrology and wetlands vegetation into an area where wetland conditions (or stable stream bank and stream channel conditions) have been lost or degraded (http://www.nceep.net/resources/glossary.pdf, February 2009). Re-establishment and rehabilitation are specifically differentiated in a 2002 regulatory guidance letter (http://www.fws.gov/habitatconservation/RGL2-02.pdf, June 2009).

[36] Wetland-enhanced species are those showing some documented preference for wetland habitat.

- Enhancement refers to actions taken to increase or enhance wetland functions through the manipulation of either vegetation or hydrology, but not both; an example would be the filling in of ditches in a previously drained wetland area.
- Creation is the establishment of wetlands or stream hydrology and wetlands vegetation into an area where wetland conditions (or stable stream bank and stream channel conditions) were not lost.
- Preservation is the long-term protection of an area with high habitat and/or water quality protection value (e.g., wetland, riparian buffer), generally effected through the purchase or donation of a conservation easement by/to a government agency or non-profit group (e.g., land trust); such areas are generally left in their natural state, with minimal human disturbance or land-management activities.

The types of wetland mitigation count differently toward replacing lost wetland functions. The guidelines for awarding credit for mitigation types are (www.saw.usace.army.mil/WETLANDS/Notices/2008/PnforMitigation6-3-2008.pdf, February 2009):

- 1 acre of restoration is equal to 1 restoration equivalent
- 2 acres of enhancement is equal to 1 restoration equivalent
- 3 acres of creation is equal to 1 restoration equivalent
- 5 acres of preservation is equal to 1 restoration equivalent
- Enhancement, creation, or preservation can only be employed after planning at least one acre of restoration.

Table 5.6. Wetland mitigation types and their associated permitting authorities (www.saw.usace.army.mil/WETLANDS/Notices/2008/PNforMitigationChanges6-3-2008.pdf, February 2009).

		Minimum area threshold for mitigation (acres)		
Mitigation type	**DCM wetland types**	**CAMA**	**401**	**404**
CAMA coastal wetland	Estuarine - Salt/brackish marsh	1	0	0.1
Riverine	Riverine - swamp forest, freshwater marsh	na	1	0.1
Riparian	Riverine - bottomland hardwood forest, headwater wetland	na	1	0.1
Non-riparian wetter variety	Flat/depressional - swamp forest, pocosins, estuarine forested or shrub-scrub	na	1	na
Non-riparian, drier variety	Flat/depressional - pine flat, hardwood flat	na	1	na

In North Carolina, state-sponsored restoration began in 1996 with the establishment of the Wetland Restoration Program (NCWRP), which was later expanded to form the Ecosystem Enhancement Program (EEP) in 2003. The purpose of both programs was/is to restore, enhance, preserve, and create wetlands, streams, and riparian buffers throughout North Carolina. The WRP/EEP restoration activities were primarily undertaken as mitigation for past, present, or future (anticipated) losses of wetland acreage.

However, a 2002 study 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. Thus, 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. The EEP follows a more rigorous process for monitoring mitigation success than the WRP (refer to section on the "North Carolina Ecosystem Enhancement Program" below).

The early years of the WRP were devoted to the development of local watershed plans (LWPs). The DWQ basin-wide assessment reports were used to identify targeted local watersheds for development of local watershed plans (LWP). The development of LWPs was described in a Department of Environment and Natural Resource (DENR) Memorandum of Understanding (MOU) with the Department of Transportation (DOT). The MOU allowed DENR, through the WRP, to help the DOT mitigate environmental impacts associated with highway construction projects. The watershed restoration plans were developed to identify the coincidence of restoration needs and opportunities on the scale of 14-digit hydrologic units. The local watershed approach was considered the preferred alternative to distributing restoration projects randomly throughout a river basin. By concentrating several projects within a small watershed, water quality improvement can more readily be achieved.

Through the local watershed planning process, WRP/EEP conducts watershed characterization and field assessment tasks to identify critical stressors in local watersheds. The WRP/EEP planners and their consultants coordinate with local resource professionals, local governments, and local citizens to identify optimal watershed projects and management strategies to address the major functional stressors identified. The LWPs prioritize restoration/enhancement projects, preservation sites, and best management practices (BMP) that will provide water quality and hydrologic improvement, habitat protection and other environmental benefits to the local watershed. The restoration strategies included in LWPs are not limited to the scope of WRP/EEP's mission (i.e., wetland restoration and mitigation). The strategies include stormwater management projects, water supply protection strategies, land use planning guidelines and best management practices for reducing sediment pollution and soil erosion. The development of Local Watershed Plans is essential for the restoration of degraded watersheds because restoration projects alone may not improve water quality to use-support standards. The WRP/EEP works closely with local governments, nonprofit groups and organizations to develop and implement the plans. The LWP recommendations are implemented at the local level through a consensus-building and stakeholder-driven process. The WRP/EEP is committed to funding restoration projects identified in the LWPs through payments made to the Wetlands Trust Fund to satisfy compensatory mitigation requirements.

The WRP/EEP is required by statute to report on both compensatory and non-compensatory (i.e., non-regulatory) restoration work accomplished in North Carolina annually. The total compensatory mitigation in North Carolina coastal river basins during fiscal years 1999-2003 was approximately 957.36 acres (WRP 2001, 2002, 2003, EEP 2004) (Table 5.7). There was also a large amount of voluntary creation or restoration of wetlands. During fiscal years 1999-2003, 3,740 acres of wetlands were voluntarily restored or created in coastal river basins for the purpose of mitigation banking.

Table 5.7. Net regulatory (compensatory mitigation) and non-regulatory (voluntary restoration/creation) wetland gains in coastal river basins from 1999-2003. Note: NC coastal river basins do not include the Lumber. (Sources: WRP 2001, 2002, 2003; EEP 2004).

Fiscal year	Non-regulatory gains (acres)	Regulatory gains (acres)	Total gains (acres)
1999/2000	9	151	160
2000/2001	2	289	291
2001/2002	6	196	202
2002/2003	35	225	260
2003/2004	3,688	97	3,785
TOTAL	3,740	957	4,697

5.3.3.1. North Carolina Ecosystem Enhancement 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 memorandum of agreement (MOA). However, EEP does not coordinate all mitigation activities. Coastal wetland impacts requiring a 401 consistency or 404 permit are mitigated primarily on-site by private restoration companies (Rob Breeding/EEP, pers. com., February 2009). An estimated 80% of all wetland mitigation in North Carolina has been covered by the EEP (Jim Stanfill/EEP, pers. com., February 2009)

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. The EEP continues to use and develop Local Watershed Plans to focus restoration work guided by local interest and support for developing a plan, information on water quality degradation (restoration potential), In-Lieu-Fee mitigation needs due to development (where mitigation banks are unable to provide credit) and compensatory mitigation needs of the DOT. The EEP also encourages other government entities and funding organizations to consider implementing watershed improvement projects within the targeted watersheds as well as maximize state, federal and local funding sources based on multiple watershed planning objectives[37]. 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.

Since 2004, the EEP records annual mitigation by gross assets divided among 12 categories of wetland mitigation types. Projects are listed as assets when land has been secured and the design has been initiated. The mitigation associated with a specific project may change slightly during design, construction, and monitoring. Only at project closeout are the exact mitigation asset amounts and types determined by the regulatory agencies. Due to the sequence of events, there will occasionally be

[37] The list of funding sources and watershed planning objectives include various city/county governments, the Clean Water Management Trust Fund (CWMTF), Division of Soil and Water Conservation, U.S. Geological Survey, Natural Heritage Program, Wildlife Resources Commission, and Division of Water Quality Section 319 Grant Program.

reductions in a particular mitigation type. For example if a project was dropped, the design was adjusted, the construction varied from the design, the monitoring showed that the project was producing more or less than expected, or it was determined that another mitigation type was needed, the end mitigation results would be different than originally planned (Jim Stanfill/EEP, pers. com., February 2009). The total mitigation assets in coastal drainage river basins in FY 2004/2005 were 12,741 acres (Table 5.8). When restoration equivalents are calculated[38], the total mitigation assets were 8,311 acres in FY 2004/2005. By 2007/2008, the adjusted mitigation assets were over 10,000 acres, for a regulatory gain of nearly 2,000 acres. However, only 70% of those mitigation assets have been constructed. Additional mitigation assets available from private mitigation banks cover an estimated 20% of total assets not accounted for by the EEP (http://www.saw.usace.army.mil/wetlands/Mitigation/mitbanks.html, July 2009).

Table 5.8. Gross mitigation assets (planned and constructed) available from EEP in coastal draining river basins of North Carolina from FY 2004/2005 to 2007/2008 (EEP 2005, 2006, 2007, 2008). Note: The Lumber is not included in NC coastal river basins. The 'Total – adjusted' is calculated using the equation: [Preservation/5] + [Creation/3] + [Enhancement/2] + [Restoration/1].

	Gross mitigation asset (acres)			
Mitigation type	**2004/2005**	**2005/2006**	**2006/2007**	**2007/2008**
Coastal marsh				
Preservation	186	205	205	371
Enhancement	80	80	86	86
Creation	40	40	31	20
Restoration	52	52	24	14
Non-riparian				
Preservation	1,388	4,879	5,547	5,347
Enhancement	2,234	1,145	2,220	2,319
Creation	157	157	13	15
Restoration	4,298	4,670	4541	4,621
Riparian				
Preservation	2,159	2,808	3,650	3,810
Enhancement	259	496	495	489
Creation	38	80	87	78
Restoration	1,850	2,366	2,213	2,041
Total - unadjusted	12,741	16,978	19,113	19,211
Total – adjusted	8,311	9,620	11,757	10,066

On a statewide level, EEP reports success for advance mitigation (EEP 2008, 2009). In other words, the amount of mitigation assets exceeds the amount of required mitigation. As of FY 2008-2009, the program reports a mitigation compliance rate of 96% for wetland impacts. However, much of the current advance mitigation is focused in particular HUs, whereas the mitigation needs are spread more evenly across the state. Thus, while some HUs have already achieved advanced mitigation, others will require additional mitigation credits over the coming years.

Not counting mitigation assets, the total wetland area in North Carolina has declined from 7,175,000 acres (1950's) to 5,132,634 acres (2001), for a total loss of over 2 million acres (30% of 1950's wetland area). Table 5.9 summarizes what has been documented regarding wetlands losses in North Carolina.

[38] Calculated using the equation: [Preservation/5]+[Creation/3]+[Enhancement/2]+[Restoration/1]

Table 5.9. Estimated wetlands acreage (1950's-2001), and 401 permitted impacts in North Carolina. Note: small or unauthorized wetlands impacts and net losses due to erosion are not included in the 401 permitted impacts.

1950's wetland acres[1]	1994 wetland acres (DCM)[2] +/- 11%	2001 wetland acres (NLCD)[3] +/- 32%	401 permitted impacts (FY 2001/2002 – 2007/2008)[3]
7,175,000	3,485,060	2,867,548	1,613

[1] Based on descriptions of native vegetation found on hydric soils from SCS county soil surveys from the 1950s. The estimated acreage of coastal plain wetlands would be 90% or 6,457,500 acres.
[2] Covers only CHPP management regions (coastal plain portion of coastal draining river basins).
[3] Covers only coastal draining river basins (excluding Lumber River). The entire state had 5,132,634 acres of wetlands, according to the 2001 NLCD.

5.3.3.2. Other initiatives

Federal, state, local, and private organizations and individuals conduct voluntary initiatives independent of EEP local watershed plans. However, the EEP encourages these wetland restoration organizations and individuals to join them in collaborative efforts to protect and restore strategic wetland resources. 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 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 2008, total program enrollment in North Carolina had exceeded 34,148 acres (http://www.nrcs.usda.gov/Programs/WRP/2008_ContractInfo/CumulativeContractInfo2008.html, February 2009). Based on the enrollment from 1992-2008, the Wetland Reserve Program in North Carolina has added about 2,000 acres of wetland restoration and protection per year.

To guide both regulatory and non-regulatory wetland conservation and restoration efforts, DENR has developed a conservation planning tool incorporating the latest GIS information supporting prioritization of areas based on a myriad of program objectives[39]. Refer to the 'Ecosystem management and strategic habitat areas' chapter for more comprehensive information on conservation planning.

5.3.3.3. Evaluating mitigation/restoration efforts

The rate of wetland losses and gains documented by permit records and WRP/EEP reports does not account for functional equivalency, which is the replacement of full ecological functions specific to a wetland type. The criteria for successful mitigation should reflect the ecologic functions that needed replacing. The North Carolina Wetlands Assessment Method (NC WAM) provides the current guidance for evaluating functional replacement (http://h2o.enr.state.nc.us/ncwetlands/rd_pub_not.html, March 2009). The monitoring associated with EEP mitigation projects continues for at least 5 years, or until success criteria are achieved (EEP 2005). Success criteria for wetlands includes a minimum stem density of 260 per acre at year 5, and a specified percent saturation or inundation during the growing season (consecutive days) reflecting conditions on a reference wetland considered in-kind mitigation (EEP 2008). In addition, please note that DWQ is conducting a random survey of mitigation success across the state which will be completed in early 2010. We will then be able to use the results of that work to determine mitigation success rates for all mitigation providers (J. Dorney/DWQ, pers. com., June 2009).

[39] http://www.onencnaturally.org/Conservation_Planning_Tool.html

In FY 2007-08, the EEP had 238 projects in some phase of monitoring, closeout, or long-term management. Most projects were in monitoring phases of years 1 through 5. These projects totaled 13,401 acres of wetland restoration, enhancement, and preservation (EEP 2008). Considering all the projects in active monitoring, the collective success rate was 90% for achieving vegetative and hydrologic criteria. However, the development of restoration success criteria for different types of wetlands continues. In late 2008, the DWQ completed a three year, in-depth study of headwater wetlands to supply specific success criteria for headwater wetland restoration (Baker et al. 2009).

Currently, wetland losses and gains are tracked, by in-kind mitigation types (Table 5.8), on an acre-for-acre basis. The specific wetland type lost is not always mitigated by the same wetland type. There is only incidental consideration for maintaining the natural diversity 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. The EEP currently reports mitigation assets using a subset of hydrogeomorphic classes (Table 5.8); riverine and headwater wetlands are lumped into the riparian class. *Headwater wetlands restoration should be tracked separately from other riparian wetlands because of their vulnerability and relative importance in denitrification (see 'Ecosystem enhancement' subsection of the 'Ecological role and function' section).* This point is important and should be discussed among involved agencies (i.e., EEP, NCDOT, USACE).

For many coastal watersheds, in-kind mitigation opportunities (i.e. salt marsh restoration) are limited. To address this issue, the EEP contracted with East Carolina University to develop a rapid assessment process for coastal watersheds and compensatory mitigation that is consistent with the goals of the Coastal Habitat Protection Plan. The 2007-09 CHPP implementation plan called for developing an innovative system for out-of-kind mitigation credit that includes aquatic habitat restoration. Currently, the mitigation of lost wetlands with restored wetlands is relatively clear and direct. Mitigating lost wetlands with SAV restoration, for example, is not considered "in-kind" even if similar functions are supported. If the function is simply water quality improvement, the out-of-kind mitigation may be justified by the regulatory goal of improving water quality (per the Clean Water Act). One drawback of this interpretation occurs where the re-establishment of aquatic habitat is dependent on watershed improvements. In this case, mitigating lost wetlands upstream with SAV downstream would be unsuccessful without improving water quality. In other words, restoring watersheds is required before restoring the lost aquatic habitat associated with water quality degradation.

The results of the ECU study are available at http://www.nceep.net/services/lwps/pull_down/by_basin/WhiteOak_RB.html. The report describes an approach to determining out-of-kind mitigation credit based on indicators of:

- Hydrologic regime functions such as riparian condition, extent of ditching, wetland conversion, land-use effects on runoff, and watershed impervious surface.
- Materials flux/pollution functions such as land-use effects on nutrient loading, point sources of pollution, and concentrated sources of pollution
- Aquatic habitat functions such as near-shore pollution, shellfish water closures, eutrophication, toxic chemicals, impediments to anadromous fish migration, impediments to circulation, and maintained channels, trawl areas, and SAV scars.

This assessment approach helps locate the biggest problems in a watershed, thus revealing qualitative criteria for mitigation success anywhere in the watershed. Unfortunately, difficulty arises in assigning mitigation success criteria for improvements in a qualitative indicator score. The Strategic Habitat Areas (SHAs) approach involves similar indicators of function, but attempts to find the highest quality habitat for marine and coastal fishery species across a much larger area (see 'Ecosystem management and Strategic Habitat Areas' chapter for more information). The DMF's on-going effort to locate and designate SHAs for coastal and marine fishery species should complement land-based watershed restoration plans. The SHA priorities are currently being incorporated in EEP's coastal River Basin Restoration Priorities, starting in the Chowan River. However, the application of SHA and Local Watershed Plan priorities at different scales, addressing different goals, suggests a need to place both planning efforts under the larger umbrella of DENR strategic planning. *The CHPP agencies (DMF, DCM, DWQ, WRC) and EEP should meet to determine how SHA and LWP methodologies complement and contribute to complementary goals of the North Carolina Department of Natural Resources.*

In 2009, the MFC approved a compensatory mitigation policy that endorses the concept developed by the ECU study. This change is being incorporated into the MFC's existing 1999 "Policies for Protection and Restoration of Marine and Estuarine Resources and Environmental Permit Review and Commenting" (Appendix H). Based on our evolving understanding of the needs of compensatory mitigation to protect and enhance the quality of coastal waters and watersheds, the focus and goals of compensatory mitigation should shift from the current no net loss goal to one that allows an array of options to be applied. The policy recommends:

1) Establishing goals for coastal wetlands based on desired outcomes - protection/restoration of shellfishing waters, PNAs, SAV beds, etc.;
2) Identifying watersheds/areas where these goals can be realistically achieved. The Strategic Habitat Area assessments can be used to identify such locations
3) Utilizing the Rapid Watershed Assessment Procedure (or other assessment methods) to assess watershed condition and identify problems/solutions;
4) Evaluating and authorizing compensatory mitigation projects based on their ability to contribute to goals established for coastal watersheds. Projects that provide functional replacement, e.g., increased water retention/storage through the use of BMPs, may be approved if documentation is provided that the projects are the most effective mechanism to achieve the goals established for a watershed;
5) Implementing monitoring to support data acquisition necessary to support the SHA process and the effectiveness of projects that have been implemented;
6) Seek funding from all available sources (compensatory mitigation, CWMTF, 319, etc.) to fully implement protection/restoration strategies in coastal watersheds.

Esty (2007) examined the practice of mitigation in detail at the national level. Basically two types of mitigation were described: (1) individual mitigation with constructed wetlands, and (2) mitigation banking in which developers purchase credits from companies (mitigation banks) that have restored or created wetlands deemed acceptable as mitigation. Esty (2007) then quoted a 2001 study by the National Research Council estimating the country was loosing 60,000 acres of wetlands annually, despite mitigation efforts. He goes on to say most mitigation sites are subject to no more than 5 years of oversight. Numerous studies have documented replication of natural wetlands functions that require greater than 5 years to realize (Burchell et al. 2007; Bruland et al. 2006; Bruland and Richardson 2005a; Bruland and Richardson 2005b; Zheng et al. 2004; Craft et al. 2003; Craft and Sacco 2003; Desmond et al. 2002; Craft et al. 2002). Wetland vegetation and hydrology usually develop within 5 years, whereas soil properties take much longer. The major concern implied by Esty was a lack of adequate criteria for success and the resulting accountability. *Given a limited time to monitor for success, criteria should focus on identifying trajectories of functional development that include wetland soil development. In other words, are the functions developing to fully replace that of lost wetlands within a reasonable timeframe?* Recent literature summarizing the state of coastal wetland research and restoration should help in identifying trajectories of functional development (Perillo et al. 2009).

5.3.4. Designated areas

5.3.4.1. Regulatory

Several state regulatory designations provide some level of protection for wetlands:

- Coastal Shoreline Areas of Environmental Concern (CRC rule)
- Estuarine Water Area of Environmental Concern (CRC rule)
- Outstanding Resource Waters (EMC rule)
- Buffer rules for Nutrient Sensitive Waters (EMC rule)
- Water Supply Waters I & II (EMC rule)
- Unique Wetlands (EMC rule)
- Approved Shellfishing Waters (MFC rule)
- Primary Nursery Areas (MFC/WRC rule)
- Wild and Scenic Rivers (state government designation administered by the Division of Parks and Recreation administration)

The CRC-designated Estuarine Shoreline Area of Environmental Concern (AECs) extend 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 (ORWs). The Public Trust Shoreline AEC is adjacent to public trust waters and runs inland from the line separating Coastal and Inland Fishing Waters, and extends landward 30 feet from the high water mark. Coastal Shoreline AEC includes the Public Trust Shoreline AEC and the Estuarine Waters AEC. These areas, along with adjacent public trust water, contain the vast majority of salt/brackish marsh in the state. Only water-dependent activities are allowed in this area, and they require a Coastal Area Management Act (CAMA) permit. . Development projects any coastal marsh will require a CAMA permit, USACE permit and DWQ 401 consistency most of the time unless the project meets certain exemptions as defined by the USACE. Projects affecting >1 acre of 404 wetlands (including coastal wetlands) require mitigation by DWQ. The USACE can require mitigation, preservation, restrictive covenances, or some combination of these for any wetland impact due to no net loss policies. Dredging of wetlands is at times permitted through the major permit process. Narrow, fringing wetlands less than 1 acre (per lot) are particularly vulnerable to loss without compensation. *The importance and vulnerability of fringing coastal marsh merits decreasing the minimum area and/or length requirement for mitigation. Protecting or restoring fringing marsh is especially important where adjacent slopes allow landward migration with sea level rise (see "Sea level rise and climate change" section for more information).*

Outstanding Resource Waters (ORWs) and their 575 foot buffer from mean high water encompass approximately 6% of the riparian wetland habitat in coastal North Carolina, the majority of which is salt/brackish marsh and riverine swamp forest. These ORW areas also cover 2% of non-riparian wetlands. There is no size threshold for permitting wetland impacts adjacent to ORWs, Water Supply Waters I & II, or Unique Wetlands. In or near these designations, any development project impacting wetlands must acquire a permit of some kind, and a permit requirement means documentation. See the Water Column chapter for a description of Water Supply Waters I & II. Unique Wetlands (UWL) are a supplemental classification for wetlands of exceptional state or national ecological significance. These wetlands may include wetlands that have been documented to the satisfaction of the EMC as habitat essential for the conservation of state or federally listed threatened or endangered species. However, Unique Wetlands will likely not be designated on private lands without the approval of the landowner. According to the DWQ Wetlands Unit, approximately 66% of known potential UWL acres are managed by three state and federal agencies (Ed Schwartzman/DWQ, unpublished data). The remaining 34% are managed by a variety of public and private entities (i.e., municipal governments, land trust, and private owners).

Waters designated as Primary Nursery Areas (PNAs) by the MFC or WRC (in CAMA counties) 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. The CRC has also implemented a minimum depth requirement, effective July 2009, for boat docks in Primary Nursery Areas, SAV, shell bottom, and soft bottom habitat that may inhibit some dock construction and associated boating impacts on wetlands landward of these areas (see 'Water-dependent development' section for more information). Approved Shellfish Harvesting Waters are designated by MFC based at the recommendations of DEH-SS. Approved Shellfish Harvesting Waters protect wetlands by prohibiting new marina construction that could result in loss of harvestable waters [CRC rule 15A NCAC 07H .0208 (b)(5)(E)] and, incidentally, fringing wetlands.

Wild and Scenic Rivers is a state and federal government designation intended to protect certain free flowing rivers or segments with outstanding natural, scenic, educational, recreational, geologic, fish and wildlife, historic, scientific or other cultural values. There are three river classifications: Natural, Scenic, and Recreational river areas. This classification is administered by the NC Division of Parks and Recreation. There is no size threshold for requiring permits adjacent to state or federal Wild and Scenic Rivers. Therefore, all wetland impacts along Wildlife and Scenic Rivers should be documented.

5.3.4.2. Non-regulatory

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 322,493 ac of riparian wetlands and 747,295 ac of non-riparian wetlands, representing approximately 20 and 27% of all riparian and non-riparian wetlands, respectively, in coastal North Carolina (Table 5.10). Based on the amount of 1994 wetlands within conservation lands, 76% of riparian and non-riparian 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 wetland types are more represented than others. Of the unaltered hydrogeomorphic wetland categories, estuarine and flat/depressional were most represented in conservation lands (46.51 and 27.90%, respectively; see Table 5.10). Unaltered headwater wetlands have the lowest percent within conservation lands (8.33%), followed by riverine wetlands (16.83%). Most headwater wetlands do not contain CAMA coastal wetlands or are outside of estuarine shoreline AECs, and thus are not protected by CRC use standards. Projects impacting wetlands outside of CAMA counties or without coastal wetland species may often require only a 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 401 Wetlands Unit, pers. com., 2003). Headwater wetlands are separated from flat/depressional or non-riparian wetlands by their intersection with 1st order watersheds indicated on USGS 7.5 minute quadrangles. The DWQ is currently re-mapping headwater stream watersheds with more accurate methods and LIDAR imagery. *The re-mapping of headwater streams should be used to identify headwater wetlands as a new category for tracking impacts and restoration work.*

Restoration/enhancement opportunities may exist for altered wetlands located within conservation lands (Table 5.10). The most opportunities for wetland restoration/enhancement occur where wetlands were cleared or drained. Of the cleared estuarine (349 ac), headwater (874 ac), and riverine (7,586 ac) wetlands, there is approximately 54, 10, and 2% within conservation lands, respectively. Ten percent of the cleared flat/depressional wetlands are located within conservation lands. Of the drained estuarine (31,292 ac), headwater (2,724 ac), and riverine (45,043 ac) wetlands, there is approximately 14, 2, and 5% within conservation lands, respectively. Twenty two percent of the drained flat/depressional wetlands are located within conservation lands. *Restoring altered wetland areas within conservation lands would be more readily compatible with existing uses than analogous efforts on other private lands. A good example was recent funding of $1 million donated from Duke Energy to The Nature Conservancy for climate change research and adaptation on North Carolina's Albemarle Peninsula. The pilot project will focus on the effects of rising sea levels on the Alligator River National Wildlife Refuge.*

Table 5.10. The amount and percentage of each hydrogeomorphic wetland class in eastern North Carolina located within lands managed for conservation (http://www.onencnaturally.org/Conservation_Planning_Tool.html, February 2009). Alteration types are explained in the 'Historic loss of wetland habitat' section of this chapter.

Hydrogeomorphic wetland category	**Alteration type**	**Wetlands in conservation lands (acres)**	**Total wetland acres**	**Wetlands in conservation lands (%)**
Estuarine	Unaltered	106,207.43	228,348.92	46.51
	Cleared	188.93	348.64	54.19
	Cutover	254.88	617.32	41.29
	Drained	4,416.97	31,292.78	14.11
Flat/depressional	Unaltered	656,383.90	2,352,952.22	27.90
	Cleared	1,938.11	19,426.14	9.98
	Cutover	3,584.35	45,295.56	7.91
	Drained	81,772.08	365,005.21	22.40
	Impacted	3,616.23	15,677.50	23.07
Headwater	Unaltered	2,819.37	33,843.18	8.33
	Cleared	35.87	873.67	4.11
	Cutover	40.62	3,073.50	1.32
	Drained	48.26	2,723.65	1.77
	Impacted	3.40	138.97	2.44
Riverine	Unaltered	202,292.36	1,201,728.66	16.83
	Cleared	117.16	7,586.23	1.54
	Cutover	622.77	16,084.40	3.87
	Drained	2,164.82	45,042.65	4.81
	Impacted	3,280.16	22,738.20	14.43
Total Riparian		322,492.98	1,594,440.77	20.23
Total Non-riparian		747,294.67	2,798,356.63	26.70
Total		1,069,787.65	4,392,797.39	24.35

5.4. THREATS AND MANAGEMENT NEEDS

5.4.1. Physical threats and hydrologic modifications

Land use changes associated with population growth have been and continue to be the primary anthropogenic cause of wetland habitat loss (Dahl 2000). The Status and Trends section covers the history of wetland losses associated with land use changes, and the regulatory structures designed to achieve a goal of "no net loss. The cumulative and largely unmitigated impact of water dependent development on fringing wetlands continues to be the major issue facing wetlands in the past five years and is discussed in the following sections.

Other physical threats to wetlands and their use by fish include construction of marinas and docks, associated boating activity, infrastructure development, stormwater conveyance, mining for minerals, obstructions to fish passage and water withdrawals.

5.4.1.1. Water-dependent Development

Dredging (navigation channels and boat basins)

Dredging for navigational channels or boat basins can result in an unmitigated direct loss of wetlands, as well as indirect impacts from dredging of adjacent shallow soft bottom, limiting the amount of shallow water habitat available for future wetland colonization. The CRC rules require confining all dredging material to an upland area landward of regularly or irregularly flooded marsh [15A NCAC 07H .0208]. The spoil from dredging could also be used to create shallow water habitat. At a number of sites, the USACE has established wetlands as part of their management of dredge spoil islands; the spoil islands in Pamlico Sound (west of Oregon Inlet) and Cape Fear River are good examples. 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.

Where barrier islands have been developed, back barrier marshes are more likely to be sediment starved, since actions are usually taken to prevent or undo overwash of ocean sand to the estuarine shoreline through actions such as beach bulldozing, inlet closing, dune construction, and beach nourishment. Croft et al. (2006) studied the effect of placing dredged material on sediment-starved back barrier marshes in southeastern North Carolina. The study questioned whether sediment additions could offset submergence without negatively affecting wetland functions. A clean sediment layer up to 10cm thick was added to both deteriorating and non-deteriorating marshes. The sediment additions increased the stem densities of marsh grass in deteriorating marshes, but the effect was only temporary. The deteriorating sites gradually returned to pre-fill conditions due to bioturbation and sedimentation. The addition of sediment on non-deteriorating marshes had little effect on the wetland functions measured. Another study (La Peyre et al. 2009) tested whether a thin layer of dredge material would increase elevation and create favorable soil conditions for marsh enhancement. The vegetative response to sediment addition was minimal on wetland areas. However, the addition of sediment into the interior ponds resulted in increased vegetation cover and productivity. *The enhancement or creation of marsh islands should accompany the net loss of marsh islands to deterioration with sea level rise (see "Sea level rise and climate change" section).*

The dredging and deepening of inlets can also increase salt water intrusion, causing a change in wetland species composition along the boundary between salt/brackish marshes and riverine swamp forests. Beaufort and Cape Fear River inlets have been dredged to a depth of more than 50 ft for port access. The deepening of the Lower Cape Fear River caused a large conversion of tidal/riverine swamp forests to salt/brackish marsh (Hackney et al. 2007).

Shoreline stabilization

Shoreline stabilization is modification of the natural shoreline using hardened structures or organic materials to prevent or reduce erosion. The purpose is to stabilize and protect shorefront lands, including natural features, as well as man-made structures. As shoreline development increases, rising sea level will threaten more waterfront property, likely increasing the number of landowners with an interest to protect their shorefront from erosion. North Carolina's policies and rules for estuarine shoreline stabilization allow landowners to protect their property from erosion, while attempting to minimize the impacts of erosion control structures on natural resources. Traditional shoreline stabilization methods in estuarine and riverine areas of North Carolina consist of hard stabilization, mainly bulkhead construction near the high water line. This section will discuss the impacts of estuarine and riverine bulkheading on riparian wetlands, an alternative "living shoreline" approach, the extent of shoreline stabilization that has already occurred in North Carolina, and management needs to reduce or minimize impacts. Stabilization methods, including construction of seawalls and jetties, beach bulldozing, and beach nourishment, are discussed further in the Soft Bottom chapters (Chapters 6).

Vertical stabilization techniques can have fairly severe impacts on coastal habitats, including accelerated erosion, loss of shallow intertidal bottom, loss of fringing marshes, and increased scouring and turbidity in nearshore waters (Walton and Sensabaugh 1979; Pilkey and Wright 1989; Pilkey et al. 1998; Rogers and Skrabal 2001; Bozek and Burdick 2005; DCM 2006; NRC 2007; Bilkovic and Roggero 2008). Current CRC rules attempt to prevent or limit environmental impacts of vertical stabilization on wetlands by specifying that bulkheads be constructed landward of significant marshland or marsh grass fringes [CRC rule 15A NCAC 07H .0208 (b)(7)(B)]. Furthermore, the general permit for bulkheads and riprap [CRC rule NCAC 07H .1105] requires their placement landward of all wetland vegetation at the approximate high water mark. During construction, use of heavy equipment and backfilling above the high water line, the location where bulkhead construction is allowed by CRC [CRC rule 15A NCAC 07H .0208 (b)(7)(A)], may destroy wetlands and transitional vegetation. However, marine contractors often use BMPs such as mattgin across wetlands to minimize impacts (Ted Tyndall/DCM, pers. com., September 2009), Rather than allowing native vegetation to recolonize, property owners generally replant the required 30 ft buffer along the estuarine shoreline AEC [CRC rule 15A NCAC 07H .0209 (d)(10)] with landscape scrubs and lawn grasses. These plants are not as effective at reducing and treating stormwater laden with nutrients and toxins as natural vegetation, and are less apt at deterring erosion (Watts 1987; CBF 2007; NRC 2007). *Use of native vegetation in the 30 ft buffer along the estuarine shoreline AEC would minimize stormwater runoff and erosion landward of shoreline stabilization structures, and would be consistent with the Neuse and Tar-Pamlico River Basin Nutrient Sensitive Waters management strategies [EMC rules 15A NCAC 02B .0233 and 15A NCAC 02B .0259]*.

Once bulkhead construction is complete, changes in hydrography and geomorphology often follow with resultant negative effects on shallow nursery habitats. Scouring action at the toe of bulkheads erodes the shoreline, undercuts the living root mass of marsh grasses, and deepens the adjacent water, thus reducing or eliminating vegetated and unvegetated intertidal, and/or shallow subtidal habitat (Riggs 2001; Bozek and Burdick 2005; Berman et al. 2007). Garbisch et al. (1973) showed that marsh vegetation waterward of bulkheads experienced 63% mortality post-construction due to stress from increased turbulence and scour. The change in hydrography and deepened water at the base of bulkheads prevent wetland vegetation from reestablishing once lost (Knutson 1977; Berman et al. 2007). As sea level rises, bulkheads also obstruct shoreward migration of fringing wetlands, resulting in the eventual drowning and loss of wetland vegetation, particularly in the upper transition zone (Boorman 1992; Titus 1998; Bozek and Burdick 2005; NRC 2007). Construction of bulkheads also reduces shallow water habitat along mainstem shorelines by preventing transport of sediment fromadjacent shorelines to their adjoining intertidal and shallow subtidal zones (Riggs 2001; NRC 2007). The transport of sediment from upstream sources primarily contributes to delta formation in the upper portion of estuarine systems. *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).

Degradation and loss of wetlands from shoreline stabilization affects many fishery species linked to this habitat (see "Ecological role and function" section), including penaeid shrimp, red drum, spotted seatrout, gag grouper, snapper, Spanish mackerel, striped bass, and river herring (SAFMC 1998a; SAFMC 2008a). Bulkhead-induced loss of wetlands and shallow intertidal habitat reduces aquatic food resources for anadromous, estuary-dependent, and surf fishes, as well as shore birds (Byrne 1995; Peterson et al. 2000c; Toft et al. 2004; Seitz et al. 2006; Bilkovic et al. 2006; Toft et al. 2007; Partyka and Peterson 2008). Deepening of waters adjacent to the bulkhead structure allows large piscivorous fish access to previously shallow nursery areas, enhancing their feeding efficiency on small and/or juvenile fishes looking for shallow water (Rozas 1987). Bulkheads also degrade spawning and nursery habitat for many species, including river herring and striped bass, which utilize the vegetated marsh edge (O'Rear 1983; SAFMC 1998a; DMF 2004-striped bass fmp; DMF 2007b). Vertical structures may remove narrow marsh fringes, thereby making areas adjacent to bulkheads less suitable as nurseries, even where SAV or oysters are present offshore.

Numerous studies have documented lower relative abundance and diversity of fishes and invertebrates adjacent to bulkheaded shorelines compared to unaltered marsh, beach, or forested wetland habitats:

- Bilkovic and Roggero (2008): In James River, Virginia, fish community integrity was reduced along bulkheaded shorelines with both low and high upland development as compared to natural and riprap shorelines with low upland development. Species diversity was also lower along bulkheaded shorelines with many tidal marsh species absent from this habitat.
- Partyka and Peterson (2008): In the Pascagoula River estuary, Mississippi, epifaunal-nekton and infaunal species richness and density were always greater at natural shore types than hardened ones.
- Bilkovic et al. (2006): In the Chesapeake Bay, a benthic index of biological integrity and an abundance biomass comparison of the macrobenthic community was reduced significantly when the amount of developed shoreline exceeded 10%.
- Seitz et al. (2006): In the lower Chesapeake Bay, bivalve abundance and diversity were higher in subtidal habitats adjacent to natural marsh than those adjacent to bulkheaded shorelines. Fish and blue crab density and diversity also tended to be highest adjacent to natural marsh shorelines than in bulkhead habitats.
- Peterson et al. (2000c): On the Gulf coast, the most abundant fauna along unaltered marsh and beach shorelines, including penaeid shrimp, blue crab, naked goby, grass shrimp, drums, Gulf menhaden, and bay anchovy, were least abundant along bulkhead or rubble shorelines. In addition, diversity was lowest adjacent to bulkheads.
- Mock (1966), Ellifrit et al. (1972), Gilmore and Trent (1974), and Byrne (1995): These studies conducted in other states along Atlantic, Gulf, and Pacific coasts found significantly lower littoral fish and/or benthic invertebrate abundances along bulkheaded sites relative to natural shoreline.
- Waters and Thomas (2001) examined fish utilization adjacent to bulkheads and other hardened shorelines (i.e. rock revetments) in northeastern North Carolina waters, focusing mainly on spawning success and juvenile recruitment of anadromous fish species. The study found lower numbers and diversity of fish along bulkheaded shorelines than along forested wetland and riprap shorelines, with particularly low numbers of juvenile anadromous fish. The difference in juvenile abundance was attributed to both the greater complexity of riprap and natural shorelines, and their location near shallower water. These results suggest a reduction in nursery function along bulkheaded shorelines for juvenile anadromous fishes in North Carolina.

Bulkhead construction is also problematic for aquatic species that move between water and land during their life cycle. These vertical structures are a physical barrier to animals such as the eastern mud turtle, yellow-bellied turtle, diamondback terrapin (North Carolina special concern species), and American alligator (Federally threatened) that live and feed in the estuarine and riverine waters, but nest above the high tide line (Ernst and Barbour 1972; Rosenburg 1994; Brennessel 2007; USFWS 2008).

Although the effect of a single bulkhead on the adjacent habitat complex may be comparatively small, the cumulative impact of multiple bulkheads can result in significant habitat degradation with associated ecosystem effects (NRC 2007). McDougal et al. (1987) found that nearshore wave impact increases in relation to the horizontal length of the bulkhead structure. This higher wave energy renders the waterward and surrounding areas unsuitable for wetland vegetation. Therefore, multiple, contiguous bulkheads have a greater impact on the adjacent natural shoreline than that of spatially distinct structures.

The cumulative impact of multiple bulkheads can also cause serious problems for wetland-dependent fishes. *A study should be conducted to quantify the cumulative impact of shoreline hardening on wetland vegetation and habitat-mediated predator-prey interactions in North Carolina estuarine waters. The results of such a study could then be developed into a model to predict a threshold value for the allowable extent of shoreline hardening in a particular water body, after which, changes in community composition and ecosystem services are likely to occur.*

Because of the documented ecological problems associated with vertical hardening of estuarine shorelines, the 2005 CHPP recommended that public trust and estuarine shoreline stabilization rules be revised, using the best available information, considering estuarine erosions rates, and development and promotion of incentives for alternatives to vertical shoreline stabilization measures. This has been a topic of several CHPP Steering Committee meetings over the past five years. Several alternatives to traditional vertical stabilization have been developed that use a natural "living shorelines" approach to reduce the habitat and ecosystem impacts of shoreline erosion control (Broome et al. 1992; Rogers and Skrabal 2001; Berman et al. 2007; CBF 2007; NRC 2007). These alternative methods fall into one of three categories: (1) nonstructural, (2) structural, and (3) hybrid.

A softer, non-vertical approach can be implemented in low-energy environments and uses natural vegetation (wetland and terrestrial), biodegradable organic materials such as natural fiber logs (bio-logs), and/or SAV to protect the shoreline from erosion (Broome et al. 1992; Rogers 1994; Rogers and Skrabal 2001; Berman et al. 2007; CBF 2007). This approach creates the least erosion along adjacent shorelines, but offers the least protection of property in higher energy environments. In high-energy environments, a structural approach is typically used whereby a series of detached offshore breakwaters seeded with oysters dissipate wave energy, thus protecting the natural beach shoreline and/or marsh plantings (Rogers and Skrabal 2001; Berman et al. 2007; CBF 2007). Riprap and wetland toe riprap revetments are other non-vertical structural techniques that can be used in moderate to high energy environments and provide some habitat benefit while stabilizing the shoreline. Where appropriate, these "living shorelines" provide similar erosion control capabilities to other hard stabilization techniques, while preserving, creating, or maintaining valuable wetland and shallow intertidal habitat for aquatic flora and fauna (Piazza et al. 2005; DCM 2006; Currin et al. 2008). Hybrid stabilization (marsh sill) is more appropriate in low to moderate-energy environments and involves the use of segmented sills, jetties, or groins to anchor nonstructural materials in place (Broome et al. 1992; Rogers and Skrabal 2001; Berman et al. 2007; CBF 2007). Nursery functions of a living shoreline are supported where diffuse access to landward marshes and marsh ponds is designed in the construction. Focused access through solitary passages in the sill may concentrate predatory fish, thus diminishing the nursery function of the sill-protected marshes. *Habitat-mediated predator-prey interaction along both living shorelines and bulkheads should be studied.*

In North Carolina, Currin et al. (2008) found no significant difference in the mean number of fish, crabs, or shrimp between stone sill-protected and natural marshes. In addition, the study found that sediment accretion rates in marshes protected by a stone sill were 1.5- to 2-fold greater than in controls. Because of these findings, the authors cautioned that use of a "living shoreline" could result in replacing soft bottom with artificial hard substrate and could potentially increase the elevation of the marsh, thus altering the overall ecosystem services provided. Another conflict exists where the extended subtidal footprint of a sill covers shallow unvegetated habitat and SAV growing just below the normal high water line. The loss of SAV beds to the rock sill would constitute a direct impact on the habitat. However, living shorelines should also improve water quality passing through them, thus enhancing growth of SAV in receiving waters. The sill-protected marsh could also provide ecosystem services similar to a marsh protected by fringing oyster beds. Living shorelines often require habitat trade-offs, but can result in long-term habitat benefits. *There is a need for 1) the regulatory and resource management agencies to consider and acknowledge through the permit review process the long-term benefits of alternative non-vertical stabilization methods, 2) an assessment of the ecological impacts of sills compared to vertical structures,* *and 3) incentives to use non-vertical structures where appropriate. It is equally important to educate the public on the pluses and minuses of living shorelines, and their availability as an erosion control alternative. And finally, there is a need to determine a way to modify CRC and EMC shoreline stabilization regulations in a manner that is logistically manageable and effectively results in permitting of the least environmentally damaging shoreline stabilization structures wherever possible.*

Between 1984 and 2000, DCM issued permits to bulkhead approximately 457 miles of shoreline, which is about 5% of the estimated 9,000 miles of estuarine shoreline[40] (S. Geis and B. Bendell/DCM, pers. com., June 2009). However, there can be local concentration of stabilization that is much higher than 5% (DMF unpublished data, Corbett et al. 2008). During this 17- year time period, the amount of bulkheading permitted annually along the coast has ranged from eight to 91 miles. These numbers must be considered with caution since there may be data entry errors and the CAMA permits include repairs, replacements, or projects that may not have been done or completed. In addition there have been changes regarding the process for permitting bulkheads over the years[41], which could change the number of projects requiring a permit. Approximately 206 (45%) of these miles were processed under a major permit, with the other 55% processed as GPs. 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. Beaufort, Dare, Carteret, and Currituck counties have the greatest total lengths of permitted bulkheads. In these counties, the percent bulkheading along major water bodies ranged from roughly 8% to 32%. However, the percentages were based a lower mileage of estuarine shoreline used in the 2005 CHPP (estimated 3,900 miles of estuarine shoreline).

To receive a general permit for a bulkhead, the structure must be located landward of all wetlands and if waterward of NWL or NHW line, there must be an erosion problem evident on the site. From 2001 to 2008, 143 miles of bulkhead were authorized under GP permits, averaging 18 mi/year (Figure 5.5). In comparison, from 1984 to 2000, the amount of bulkhead authorized under GP permits average 15 mi/yr. The rate of bulkhead mileage permitted by GP has varied over time. In the past five years (2004-2008), a total of 98 miles of bulkhead was permitted in coastal counties. In the previous five year period (1999-2003) 86 miles were permitted, and five years prior to that (1994-1998), 68 miles were permitted. These numbers, as previously stated, include both new bulkheads and repairs of existing bulkheads. A mapping effort by DCM is currently underway to spatially delineate the entire estuarine shoreline of North Carolina, in which the location and extent of estuarine shoreline modified with engineered structures (i.e. bulkheads, riprap revetments, etc.) will be identified (Geis and Bendell 2008). With this information, the level of impact to coastal habitats and associated aquatic flora and fauna can be better assessed.

[40] Number of miles highly dependent on scale of delineations and the boundaries placed to separate marine, estuarine, and riverine systems.

[41] Rule 7K .0203 changed in 2002 (Ed Brooks/DCM/ pers. com., 2003). Prior to that, bulkheads above MHW and not affecting wetlands were exempt and not in the database. After that, they were handled by field reps, mostly as GPs.

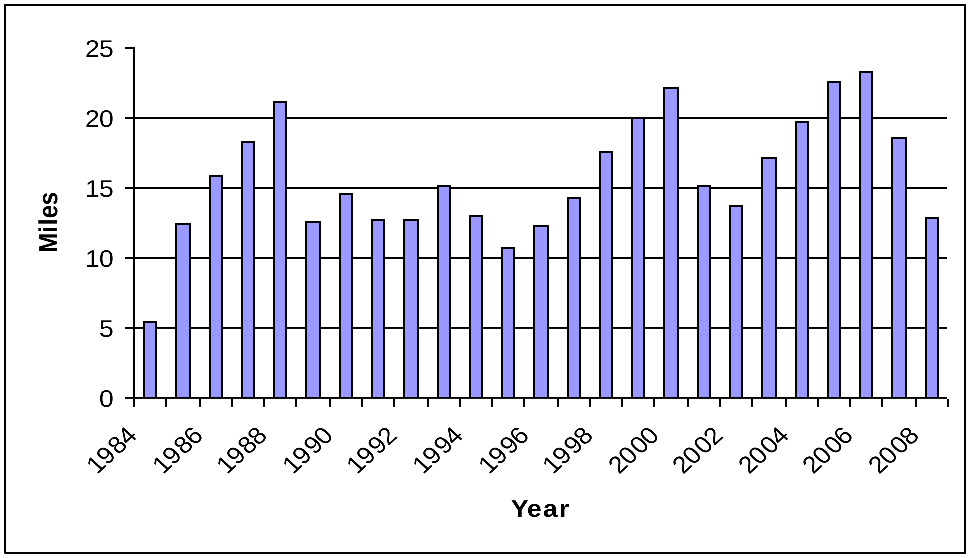


Figure 5.5. Linear miles of bulkheading authorized through a Division of Coastal Management general permit annually, 1984-2008. [Source: DCM, unpub. data]

Although CRC rules state that sloping riprap, gabions, or vegetation, rather than vertical seawalls/bulkheads, should be used where possible [CRC rule 15A NCAC 07H .0208 (b)(7)(E)], bulkheads continue to be constructed at a rate greater than that associated with alternative shoreline protection methods. In addition, bulkheads are sometimes permitted and constructed where an erosion problem is not evident. A pilot study conducted by DMF along approximately seven miles of estuarine shoreline in New Hanover County found that roughly 38% of the shoreline along a protected creek (Pages Creek) with a wide marsh fringe and little obvious erosion had been hardened by 2000. The DCM is working towards matching the appropriate stabilization technique with shoreline types. *Better criteria to define an "erosion problem" and aid in proper utilization of erosion control structures are needed and should be developed by DCM and the CRC.*

The DCM modified the permitting process in 2002, requiring a General Permit for bulkhead construction less than 500 linear ft (rather than an exemption above NWL or NHW) and a Major Permit for those greater than 500 linear ft. In addition, an Estuarine Shoreline Stabilization Subcommittee was established by the CRC in 2000 to review issues associated with the estuarine shoreline rule development process. To guide the Subcommittee on the development of shoreline stabilization rules that adequately take into account the dynamic nature of the estuarine system and consider the benefits and impacts of various shoreline stabilization methods on biological communities and physical processes, DCM formed a science-based panel, the Estuarine Biological and Physical Processes Work Group, in 2002 (DCM 2006). The approach the took was to evaluate which erosion control methods, including land planning, vegetation control, beach fill, sills, groins, breakwaters, sloped structures (i.e. riprap revetments or cast concrete), and seawalls/bulkheads, would be appropriate for various shorelines, considering the ecological functions and values of each North Carolina shoreline type. Wetland shoreline categories included swamp forest and marshes with oysters or mudflats, and sediment banks with a marsh or swamp forest fringe.

In 2005, CHPP implementation actions directed the CRC to re-establish the Estuarine Shoreline Stabilization Subcommittee and charged them with revising the estuarine shoreline stabilization rules to encourage alternatives to vertical structures. In order to accomplish this goal, the Subcommittee updated a set of principles and concepts, originally developed in 2000, to guide further development of any shoreline stabilization rule changes (Figure 5.8). The Work Group completed their report in August 2006 (DCM 2006) and presented their findings to the Subcommittee. Advantages and disadvantages of each effective erosion control method on various shoreline types 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. For all estuarine shoreline types, the number one recommendation was adequate land planning (i.e. leave the land in its natural state) (DCM 2006). The Subcommittee also drafted several changes to the estuarine shoreline stabilization rules to promote responsible use of shoreline stabilization structures. The CRC adopted these rule changes for groins, sheet pile sills, and riprap revetments for wetland protection effective February 2009 [CRC rule 15A NCAC 07H .1100] (B. Bendell/DCM, pers. com., effective July 2009). The changes include increasing the permit fee to $400.00 for the construction of any bulkhead, and positioning bulkheads at approximate NHW. An attempt was made to require placement of bulkheads more landward of NHW, but the DWQ brought up a potential conflict with their buffer rules.

Although sill-marsh “living shorelines” were encouraged through CRC permit requirements and fees, such techniques are rarely selected by property owners. The general permit for marsh sills has more conditions than the corresponding general permit for bulkheads and may require engineered plans. There are also relatively few examples of marsh sills to show land owners and marine contractors with an interest in shoreline stabilization. There are a total of 27 marsh sill projects permitted, and most of those permitted are in Carteret County (S. Geis and B. Bendell/DCM, pers. com., June 2009). In 2009, the DCM developed a decision making tool (web based and paper brochure) to assist property owners in making appropriate shoreline stabilization decisions based upon their shoreline and adjacent water characteristics (B. Bendell/DCM, pers. com., June 2009). It leads property owners through a series of questions to determine which stabilization technique may be the most appropriate for their shoreline. However, the CRC does not mandate use of any particular technique. *There remains a need to inform managers and the public about the hydrological, biogeochemical, ecological, and aesthetic benefits of alternative stabilization methods*. Accurately assessing the pros and cons of various structures requires information on depth/elevation profiles, current habitat distributions (including sediment types), tidal ranges, and wave exposures along the shoreline exhibiting erosion. Ideally, the most beneficial structure in terms of both resilience to erosion and ecological function will be permitted. *If depletion or loss of shallow/intertidal habitats is allowed, agencies should consider requiring mitigation. The EEP is developing an out-of-kind crediting system that could be employed in mitigating the permitted loss of shallow/intertidal habitats to shoreline stabilization construction and associated impacts.*

A review of the permits approved for marsh sill, or living shoreline, projects in North Carolina since 2000 was completed by DCM staff in July 2009. There were 19 projects established by major permit and 9 projects under the new general permit. The major permit projects were an average length of 370 feet, while the general permit projects averaged 114 feet, and the average height of all projects was 0.5 feet above MHW (B. Bendell/DCM, pers. com., 2009). Overall, the amount of shallow bottom converted to marsh habitat was approximately equal to the amount of shallow bottom covered by rock sill. The state will be conducting an on-site evaluation of marsh shill projects in fall 2009 to further evaluate their erosion control effectiveness and impacts on adjacent habitats and property. Also in 2009, the NC DSWC - Community Conservation Assistance Program (CCAP) added Marsh Sills as one of their BMPs. This BMP will reimburse up to 75% with a $5000 cap to allow for an incentive to property owners to install Marsh Sills. It includes both rock (.2700) and sheetpile (.2100) sills and can be permitted through either the Major or General Permit process. There are specific guidelines, but generally speaking if the structure is permitable through DCM’s program it qualifies for CCAP funding.

1. The State of North Carolina has the authority under CAMA and the Dredge and Fill Law to regulate placement and installation of shoreline stabilization measures.

2. Stabilization techniques should be appropriate for site and erosion forces present.

3. Measures with the least adverse environmental effects are preferred.

4. 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).

5. CRC will create development standards for stabilization technique/measures.
   a. Soft Measures
      i. Beach fill
      ii. Vegetation Planting
   b. Hard Measures
      i. Bulkheads
      ii. Groins
      iii. Breakwaters
      iv. Sills
      v. Revetments
      vi. Wave-boards (wooden breakwaters)
   c. Combinations

6. Stabilization measures shall be located as far landward as feasible.

7. CRC will set standards for existing stabilization projects:
   a. Allowing for tying with existing stabilization projects and adjoining lots
   b. Allowing for vertical structures on constructed canals and basins
   c. Allowing in kind/in place repair
   d. Allowing for in kind/in place replacement

8. CRC will attempt to keep criteria and standards simple to understand and implement.

9. CRC will gather public input on the above principles and provide guidance on the concepts prior to DCM developing draft rule text.

10. Most shorelines erode. Erosion rates vary greatly due to shoreline type and their location.

Box 5.1. Coastal Resources Commission concepts/principles for estuarine shoreline stabilization policy assessment and development. [Source: DCM 2006]

Marinas and docks

Direct impacts to wetlands through marina construction are minimized with CRC rules encouraging marina construction in upland basins [15A NCAC 7H .0208(b)(5)]. Some wetland impacts still occur where CRC rules allow dredging an access channel through narrow, fringing wetlands. 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. In Georgia two studies similarly found a reduction of approximately 50% in vegetation stem density under docks, resulting in 21-37% reduction in biomass and carbon production per meter square, and estimated that change to cause a 0.5-0.9 g dw nekton/m^2 reduction in total annual primary nekton production (Alexander and Robinson 2004; 2006). Because of the increasing proliferation of docks in Georgia, the study concluded that the cumulative effect from dock shading on critical fish nursery areas should be further assessed. The percent of North Carolina salt marshes covered by piers is difficult to determine due to technical difficulties in querying the permit database. Data on pier permits issued from 1990 to 2002 showed an increase from about 250 to about 800 (DCM, unpub. data; Figure 5.6). However, the portion of these pier permits issued for re-construction (versus new construction) was unspecified, making it impossible to know exactly how many docks currently exist. DCM is in the process of spatially identifying all docking structures during their process of delineating the estuarine shoreline (Geis and Bendell 2008). Division records indicate that about 1,400 permits are issued annually for docks and piers. Of this total, approximately 150 permits are for floating structures in PNA, SAV, or shellfish areas, approximately half of which (75) are in water that is less than two feet deep, representing ~8% of permits in sensitive areas (Mike Lopazanski/DCM, pers. com., April 2009).

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 over coastal wetlands. The impact of dock and pier shading on wetland vegetation on a coast-wide basis may be minor at present, but the impact will increase over time with a greater number of piers. A variety of work groups have recommended the development of a coastal dock and marina policy that encompasses all associated regulatory activities conducted within DENR (NC Coastal Futures Committee 1994, Waite et al. 1994). As part of 2005-07 CHPP implementation, a workgroup was established to examine the issue of marinas and multi-slip docking facilities. The Sea Grant Marina Advisory Group completed its report on Multi-Slip Docking Facilities (MSDFs) and provided recommendations to the CRC in 2007. The report resulted in a revised application form for MSDFs (DCM-MP-4) designed to capture information that can be used to judge the impacts of projects. The CRC has also adopted changes to dock and pier rules, effective July 2009, which give property owners flexibility in docking facilities (8 sq. ft./linear ft. shoreline) while limiting the overall area of the dock structure, and provides better protection of shallow water habitat by including minimum water depth for docks permitted under a general permit (2 ft) and minimum water depth for floating docking facilities under the general permit if located in a PNA, in SAV, or in Shell bottom (18 in). A minimum water depth requirement discourages dock construction along wetland shorelines in shallow, nursery areas.

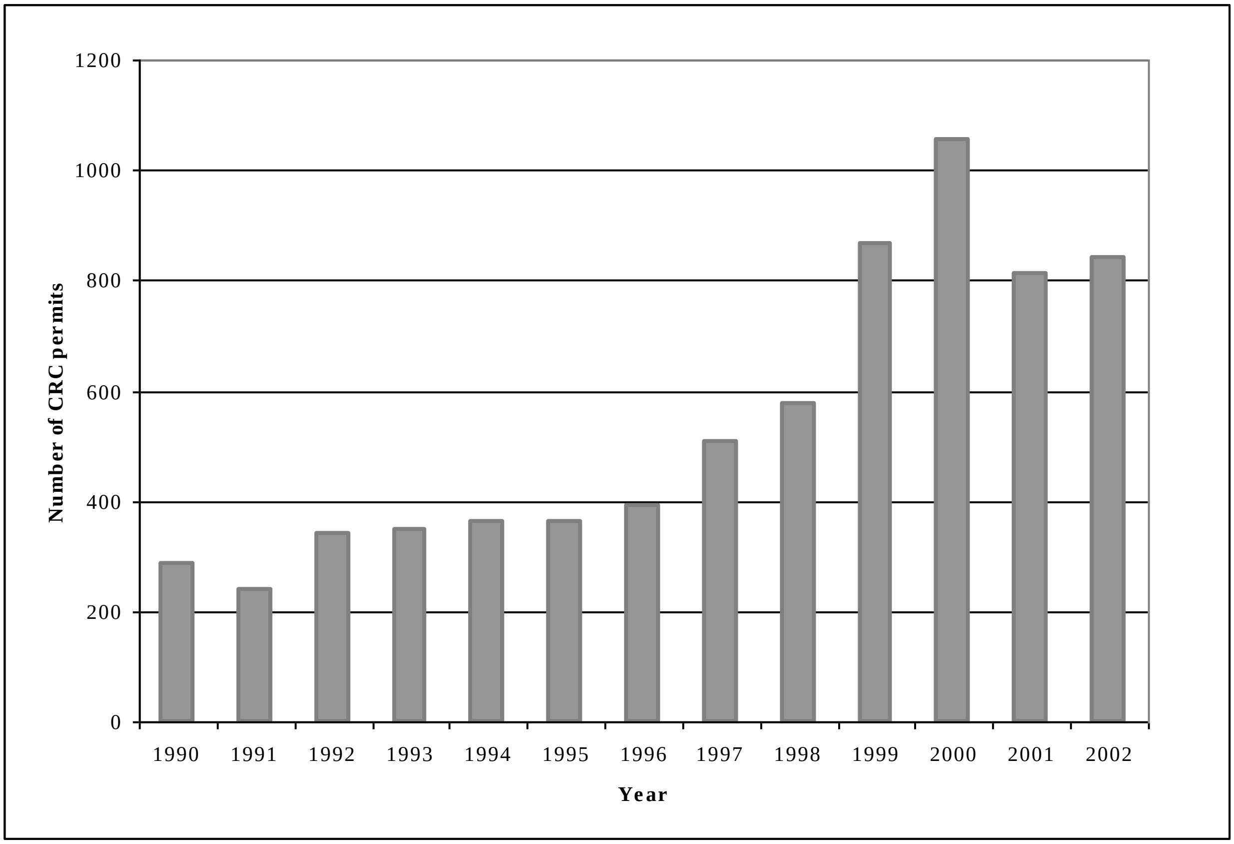


Figure 5.6. Annual number of CAMA general permits issued by the North Carolina Division of Coastal Management for piers, 1990-2002. (Source: DCM, unpub. data)

Infrastructure

Infrastructure is generally defined as a conduit spanning the length between supply and demand locations (i.e., power lines, sewer lines, water lines). Infrastructure can be a wetlands issue where development of alternative energy sources is considered water-dependent (i.e., requires location in public trust waters). The conduit for transferring the energy produced offshore will undoubtedly intersect coastal wetlands.

There is an increasing interest in the development of offshore wind farms in Albemarle and Pamlico sounds, as well as off the coast of Cape Hatteras and Cape Lookout, as these areas have some of the most abundant wind resources in the state (<http://www.ncsc. ncsu.edu/programs/NCPWR50m7May04.pdf>, 2009). Although offshore wind farms are generally considered a source of "green" energy, the construction of towers and infrastructure can impact immediate and adjacent marine or estuarine habitats (Byrne Ó Cléirigh et al. 2000). Current CRC rules prohibit the placement of wind turbines in state waters as they are not considered water-dependent structures [15A NCAC 07H. 0208]. *Should the State consider locating a wind facility in state or federal waters, proper placement of energy infrastructure is necessary to minimize potential impacts to wetland habitat and minimize conflicts with existing activities*.

5.4.1.2. Upland development

The increase of impervious surface in coastal North Carolina causes loss and degradation of both riparian and non-riparian wetlands. Nearly 30% of wetland impacts from 1997-2003 were related directly to upland developments and associated impervious surfaces (Figure 5.4). 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.[42] Stormwater control may include the creation of infiltration systems that function like non-riparian wetlands. However, wet infiltration systems should not be confused with wetlands used to mitigate for the loss of natural wetlands under permitting provisions (http://h2o.enr.state.nc.us/su/PDF_Files/SW_Documents/BMP_Manual.PDF, March 2009).

The coastal stormwater rules made effective October 1, 2008 (Senate Bill 1967) also enhanced protection of CAMA coastal wetlands. For the 20 coastal counties, the vegetative setback requirement from mean high water was increased from 30 to 50 feet for both new development and re-development. This will protect wetlands 50 feet landward of the mean high water line. This area includes the high marsh as well as some non-coastal wetlands. The CAMA coastal wetlands are also not included in the calculation of impervious surfaces limits. The exclusion of coastal wetlands from the equation will likely inhibit development on small lots with a large proportion of coastal wetlands area. But the exclusion does not necessarily protect narrow fringing wetlands.

Marsh mowing, a practice conducted by some property owners, can be detrimental to the ecological integrity of the wetland if conducted repeatedly with the intention of altering the wetland substrate. Property owners mow the marsh for various reasons, including enhancing the view to the water or to give the appearance to prospective property buyers of being uplands. Repeated mowing can elevate the marsh over time, converting it to uplands through the continued deposition of cuttings. In 2009, the CRC adopted rule changes to restrict how and when marsh can be mowed to maintain the viability of the vegetation. While this is an improvement, a mowed marsh will not be as effective for fish use, erosion control, or filtration of runoff.

5.4.1.3. 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 adjacent to South Creek and Pamlico River estuary were lost to PCS Phosphate's mining activities. The mining company is currently trying to expand its operation into more wetland areas in the vicinity. The Certification issued by DWQ would allow the company to mine an additional 11,000 acres over 35 years. The mining will affect 4.8 miles of streams and 3,900 acres of wetlands, representing the largest destruction of wetlands ever permitted in North Carolina. The mitigation effort could also be the largest ever conducted in North CarolinaThe USACE issued a permit allowing reduced wetland impacts in June 2009 after consulting EPA and PCS Phosphate. Mitigation, generally at a 2:1 ratio, is being provided by the company under oversight of the Corp of Engineers and Division of Water Quality and is required for the lost streams and wetlands.

5.4.1.4. Channelization and drainage

Channelization is the deepening and straightening of a natural stream. Ditching involves the creation of new channels for draining adjacent lands. These activities can affect the slope, depth, width and

[42] Refer to Chapter 2 (Water Column) for more information on impervious surfaces.

roughness of the channel, thus changing the dynamic equilibrium of the stream and 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 or made inaccessible by channelization (see "Channelization and drainage" section of "Water column" chapter for more information). Channelization 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. These changes greatly reduce the natural beneficial functions of wetlands to filter pollutants and regulate water flow between uplands and coastal waters. 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 downstream (White 1996; EPA 2001).

Although new channelization for flood control and drainage has greatly decreased, the existing alterations continue to alter flow and salinity patterns until natural stream morphology is restored. No new channelization projects have occurred since the 1970's. However, maintenance of existing channels is a recurring issue in permit decisions. Many of the old channels in CHPP Region 1 have re-naturalized and are now supporting river herring migration (Sara Winslow/DMF, pers. com., Nov. 2007). So far, the DMF has successfully opposed the maintenance of re-naturalized channels. *Channelization regulations could be modified to discourage or prevent maintenance of previously un-navigable and re-naturalized channels in Anadromous Fish Spawning Areas and Primary Nursery Areas.*

Far more wetland acres have been affected by ditching than by channelization. The DCM's wetland mapping from 1994 documented over 72,000 acres of drained riparian wetlands and 328,000 acres of drained non-riparian wetlands in coastal North Carolina. The DCM wetland maps show drainage impacting 5% and 21% of riparian and non-riparian wetlands, respectively (Tables 5.4 and 5.5). Since 1995, large areas of riparian wetlands could not be legally drained without a permit and mitigation requirements. The determination of drainage impacts has also improved since 1995. Skaggs et al. (2005) modeled the affect of drainage ditch depth and spacing on wetland hydrology in order to set criteria for both impacts and restoration.

Evans et al. (2007) summarized seven drainage restoration projects implemented in North Carolina from 1995 to 2006. The results showed nitrogen reductions in the receiving water of 20-70% with in-stream and constructed stormwater wetlands. Reconnecting the river and floodplain reduced peak flows and reduced flooding in unchannelized sections downstream. There was also a comparative cost assessment for the projects relative to traditional drainage practices. The restoration and alternative drainage projects were more expensive and resulted in 2-3 times more land being taken out of production. However, the benefits were improved water quality, lower peak flows, and enhanced habitat for wildlife. The monetary value of improved water quality, flood control, and wildlife habitat was not figured into the comparison.

5.4.1.5. Obstructions

Obstructions, such as dams and culverts, affect wetlands both upstream and downstream. Upstream wetlands may become inaccessible to anadromous fish and downstream wetlands may receive less surface water from upstream sources during relatively dry periods. The Roanoke River in CHPP Region 1 has been regulated by a series of dams since the 1950's. The upstream dams are causing extended flooding during the growing season of riverine forested wetlands downstream – an area identified by The Nature Conservancy, the U.S. Fish and Wildlife Service, and the State of North Carolina as a critical natural resource for conservation (Pearsall et al. 2005). A coalition of public agencies and private organizations is cooperating with dam managers to establish an adaptive management program that will enable riverine forested wetlands in the lower Roanoke to regenerate and continue supporting associated biota (i.e., river herring) (Pearsall et al. 2005). Of all the connected wetlands[43] in CHPP region 1 (including both North Carolina and Virginia), approximately 6% (72,132 acres) were obstructed by impoundments (http://www.ncdmf.net/habitat/miscdownloads/SHA_region1_report_11_20_08.pdf, March 2009). The amount of downstream wetland area affected by impoundments is more difficult to determine. The data on impoundment locations was acquired from the N.C. Division of Water Resources, U.S. Army Corp of Engineers, Collier and Odum (1989), and the NWI modifier "impounded" modifier.

Culverts, if improperly designed, primarily obstruct fish passage to upstream tributaries and riparian wetlands and can alter the hydrology of upstream wetlands. The location of culverts in Region 1 was based on culverts and bridge data from N.C. Department of Transportation, Collier and Odum (1989), Moser and Terra (1999) and the intersection of streams and roads without a bridge or documented culvert. The topic of culverts is discussed in more detail in the 'Water Column' chapter.

5.4.1.6. Water withdrawals

Ground or surface water withdrawals can lower water tables, thus drying out wetland areas. Considering that most riverine wetland communities are controlled by their response to flooding (Townsend 2001b), the impact of water withdrawals may only be temporary (until the next flood). Water withdrawal impacts receive more attention in the 'Water Column' chapter.

5.4.1.7. Boating activity

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 (ICW) and elsewhere is readily observable and is likely responsible for substantial loss of fringing wetland habitat (Riggs 2001). Cowart and Currin (unpublished data) documented relatively severe erosion rates along the ICW in the New River Estuary (see "Sea level rise and climate change" section for more information). As the human population of coastal North Carolina increases, so will the impact of boater-induced wave turbulence between boating access points (i.e., ramps, docks, marinas) and major navigation channels. According to WRC records, there were approximately 108,100 vessels registered in the coastal counties in 2008 (see Table 5.11). Counties with the greatest number of boats are in the tidally driven southern counties of New Hanover, Carteret, Brunswick, and Onslow counties. Craven, Beaufort, Dare and Pender counties also have a considerable number of registered vessels. Boats less than 16 feet comprise over one third of all vessels, and boats 19 to 23.9 feet were the second most common boat size, accounting for 24% of all vessels. Currently, the issue of human safety is the only issue driving the WRC's authority to establish no-wake zones (habitat protection is not a consideration). *No-wake zones should be considered where they protect wetlands and other habitats along quiet shorelines with significant, nearshore boat activity.*

[43] Includes riparian wetlands and adjoining non-riparian wetlands

Table 5.11. Number of registered recreational boats of different length categories in the 20 coastal counties of North Carolina, 2008 (WRC, unpub. data).

County	Number of boats per boat length interval (feet)							
	< 16 Ft	16 - 16.9 Ft	17 - 17.9 Ft	18 - 18.9 Ft	19 - 23.9 Ft	24 - 30 Ft	> 30 Ft	Total
New Hanover	5,784	1,965	2,090	1,588	4,606	1,613	347	17,993
Carteret	3,797	1,308	1,423	1,280	4,799	1,511	362	14,480
Brunswick	4,971	1,532	1,099	1,006	2,414	873	155	12,050
Onslow	3,972	1,212	1,254	958	2,176	586	109	10,267
Craven	3,472	866	932	806	2,383	714	190	9,363
Beaufort	2,926	829	717	766	1,853	647	164	7,902
Dare	2,075	592	502	566	1,951	736	116	6,538
Pender	2,851	944	682	484	1,163	325	65	6,513
Currituck	1,677	508	473	499	945	263	22	4,387
Pamlico	1,314	313	301	282	823	430	117	3,580
Pasquotank	1,047	262	264	235	614	188	19	2,629
Perquimans	898	177	165	170	469	174	23	2,076
Chowan	738	190	208	198	489	113	26	1,962
Bertie	743	280	251	166	330	52	9	1,831
Hertford	599	208	173	163	291	58	6	1,498
Washington	531	184	143	142	250	73	9	1,332
Camden	547	129	117	120	282	100	16	1,311
Gates	521	144	129	105	180	26	2	1,107
Hyde	253	97	70	81	176	53	17	747
Tyrrell	197	88	57	53	101	25	12	533
TOTAL	**38,913**	**11,828**	**11,050**	**9,668**	**26,295**	**8,560**	**1,786**	**108,099**

5.4.2. Water quality degradation

Of all the CHPP habitats, wetlands are the most resilient to water quality degradation, due to their position both in and above the water column. Wetlands are also known for their water treatment capabilities (see ‘Ecosystem enhancement’ section). 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).

5.4.2.1. Sulfate enrichment

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. 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 (literature search, March 2009). Results should provide the measure of iron concentrations in wetland sediment necessary to evaluate susceptibility.*

5.4.2.2. Fossil fuels

Wetland plants can be smothered by oil that reaches the shoreline. As these plants are covered with oil they will die which may eventually lead to increased shoreline erosion rates due to the decreased root density (Peacock 2007; Culbertson et al. 2008). In these low energy anaerobic areas, oil can persist for long periods of time. In Wild Harbor, Massachusetts residual oil and the effects of the *Florida* barge spill were still evident 40 years after the spill occurred (Teal et al. 1978; Sanders et al. 1980; Teal et al. 1992; Reddy et al. 2002; Frysinger et al. 2003; Peacock et al. 2005; Slater et al. 2005; Culberson et al. 2007a, b). Elevated levels of crude oil have been shown to not only decrease plant stem density but also reduce photosynthesis rates and shoot height (Lin and Mendelssohn 2008). With these negative impacts caused by oil, the marshes may not be able to migrate with the rising sea level or export nutrients to the coastal aquatic systems which provide for the entire food chain (Culbertson 2008). This is important to note since many of NC's Primary Nursery Areas are bordered by extensive wetlands.

Chemical dispersants can be used to reduce the impacts of oil on wetlands, but they may have negative effects on the fauna in the area (i.e. slowed growth rate and reduced respiration). Page et al. (2002) experimentally observed no differences between wetlands affected by oil and chemical dispersed oil, but chemically dispersed oil was washed away easier than non-treated. As with all habitats that are affected by oil it is important to note that the extent of the impacts will vary depending on the type of oil.

In estuarine waters, tidal marsh is the highest priority for protection, followed by intertidal oyster beds. Because of their structural complexity, they support a diversity of small organisms that can be adversely impacted by petroleum products and would be extremely difficult to clean up if necessary. Those marshes designated by MFC as Primary and Secondary Nursery Areas represent a subset of particularly productive areas of marsh and/or oyster beds that would be of greatest importance for protection. In order to restore coastal wetlands several reports propose varying methods to aid in recovery. These methods include planting new plants, adding fertilizers or tilling/mixing the sediments (Lin and Mendelssohn 1998; Lin and Mendelssohn 2008). Most of the information presented above comes from one time spill that had a finite amount of oil. In the case of continuously flowing oil from a damaged well, it is important that the source of oil is stopped and not allowed to flow free so recovery can occur. *There should be a continued ban of oil drilling off North Carolina waters.*

5.4.3. Non-native, invasive, or 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. Research in the northeast and mid-Atlantic found that there was not a clear observed effect on shrimp, mummichogs, and large fish when the non-native vegetation initially invaded a native *Spartina alterniflora* marsh (Fell et al. 1998; Able and Hagan 2000; Meyer et al. 2001), but as the vegetation becomes more established, the substrate becomes elevated, flattened, with fewer depressions for holding water (Rooth and Stevenson 2000; Able et al. 2003). Higher elevations and dense vegetation associated with Phragmites marshes have also been linked to lower benthic microalgal biomass in New Jersey marshes, which in turn altered the structure of the food web supporting mummichogs (Currin et al. 2003). Another study in Chesapeake Bay (Posey et al. 2003) compared benthic communities associated with *P. australis* and *S. alterniflora* microhabitats (high marsh, low marsh, rivulets, and hummocks). In the system and scale studied, the differences in plant species did not strongly affect benthic infaunal communities. Weis and Weis (2003) observed similar results for nekton use, but reduced larval mummichog abundance in *P. australis* compared with *S. alterniflora*. They also observed somewhat denser growth of epifauna on *S. alterniflora* compared to *P. australis*. Rooth and Stevenson (2000) working in a salt marsh on the Maryland Eastern Shore of Chesapeake Bay found significantly greater rates of mineral and organic sediment deposition in a *P. australis* marsh than in a *Spartina* spp. marsh. They concluded that the rapid litter accumulation and the below-ground accumulation from root biomass were responsible for rapid and substantial increase in substrate elevation over short time periods. The elevation increase appears to modify the habitat to be less accessible to estuarine species over relatively short time periods. *More research is needed on the long-term impact of Phragmites invasions on estuarine fish use.*

5.4.4. Sea level rise and climate change

Rising sea level is a major threat to coastal and riparian 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 Coastal Hazard Advisory Committee of the CRC was tasked by the CRC with providing input on DCM's sea-level rise initiative in late 2009. The Committee completed a report providing the most current sea-level rise projections for North Carolina. The report considered a one meter (39 inch rise) rise in 100 years to be most likely because it only requires the linear relationship between temperature and sea level noted in the 20th century to remain valid for the 21st century (Rahmstorf, 2007). The anticipated one meter includes the projected impact of melting glaciers on sea-levels in North Carolina. The Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC 2007) estimated that global average sea levels will rise from 0.18 to 0.59 m (0.59 – 1.92 feet) by the year 2100 (Fitzgerald et al. 2008). The report did not include the potential for additional sea level rise caused by melting glaciers in Greenland and Antarctica.
Rising sea levels will inundate large areas of the Pam-Albemarle peninsula, causing a positive feedback of carbon emissions from the drowning peat lands (Henman and Poulter 2008). Salt-intrusion into freshwater peats could also accelerate collapse of peat lands following a shift in decomposition from methanogenesis to sulfate reduction, as SO_4^{-2} becomes more abundant [Hackney and Yelverton 1990]. Rising sea levels not only cover low-lying areas, but also redistribute sediment as barrier islands attempt to migrate landward in order to conserve mass through offshore and onshore sediment transport. The number and size of inlets will likely increase through time with sea level rise, causing potentially major changes in salinity distribution (Riggs and Ames 2003). Coastal marshes may keep pace with sea levels rise according to their rate of accretion, which is largely determined by depth of mean high water inundation, vegetation density, atmospheric CO_2 and total suspended solids in flood water (Langley et al. 2009). Marsh areas are lost if their accretion rate falls behind sea level rise. As the proportion of marsh declines relative to open water, tidal exchange increases such that sand deposition in tidal deltas and erosion of adjacent barrier islands are elevated (Fitzgerald et al. 2008).

Not accounting for marsh migration/accretion, the combination of sea level rise and storm events causes erosion of wetlands at a rate of approximately 802 acres/year in North Carolina (Riggs 2001). However, the rate of erosion varies according to shoreline orientation, fetch, water depth, bank height, sediment composition of bank, shoreline vegetation, presence of offshore vegetation, and boat wakes. Riggs (2001) mapped the shoreline types and shoreline areas where erosion was noticeable, and areas that had been significantly bulkheaded. 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. 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) and their results are summarized and compared in Riggs (2001). These studies are helpful in indicating where major erosion problems are occurring.

Wang and Allen (2008) detected shoreline change on the Pamlico-Albemarle peninsula using satellite radar data from 1994 to 2006. The results indicated no significant losses on the north and south shorelines, and a significant landward migration of shoreline along the eastern portion of the peninsula. The rate of shoreline recession along the eastern shore peaked at 11 meters per year. In the Neuse River estuary, Corbett et al. (2008) measured an average erosion rate of approximately 1 foot per year over a 40 year time period. Every shoreline type (i.e., marsh, beach, bluff) was eroding to some degree in the estuary. In some locations, erosion rates were greater than 10 feet per year. A very small amount of shoreline accretion occurred in upper tributary reaches of the Neuse estuary. The accretion in upper tributaries suggests their importance in maintaining wetlands coverage with sea level rise. Corbett et al. (2008) also mapped structures for shoreline stabilization (i.e., bulkheads, riprap, sills, and groins) and found they covered 30% of the estuarine shoreline. The structures were located along the open estuarine shoreline of the river and not in the tributaries. As sea level rises, the impacts of more vertical structures on shallow nursery areas and narrow fringing wetlands will be exacerbated.

Shoreline erosion rates have also been estimated in the New River Estuary (NRE) using aerial photography (Cowart and Currin, unpublished data; RTI International. 2009). Using 2004 and 1956 aerial photography, shoreline-change rates within the NRE ranged from -2.33 m/yr to 1.06 m/yr with a mean rate of -0.28m/yr. When the tributaries and main trunk of the NRE are compared, the tributaries exhibit a lower mean erosion rate (-0.15 m/yr) with a much smaller range (-1.13 m/yr to 0.69 m/yr) compared to the trunk of the estuary, which had a mean shoreline-change rate of -0.38 m/yr and ranged from -2.33 m/yr to 1.06 m/yr. The shoreline-change rates and width of the Intracoastal Waterway (ICW) were analyzed from Brown's Inlet south to the NRE using 1938, 1956, 1989, and 2004 aerial photography. Over the time series analyzed, the ICW width increased from a mean of 65.2 m in 1938 to 151.8 m in 2004. The shoreline-change rates along the ICW within the same area over the same time series ranged from -1.67 m/yr to 0.18 m/yr with a mean of -0.66 m/yr. The relatively severe erosion along the ICW was presumable from boat wakes and bank slumping (C. Currin/NOAA, pers. com., June 2009).

While the Albemarle-Pamlico Estuarine System is highly vulnerable to erosion due to the coast’s low elevation, geomorphology, and erosion rates (Riggs 2001), shoreline erosion has also been documented in the southern portion of North Carolina. A study in the Topsail Sound area of Pender County, documented an 18.7% loss of marsh acreage and concurrent increase in open water, over a 49 year period (NC SeaGrant, unpublished data, 2009). Concern over erosion has led many waterfront property owners to try to stop the loss of their property through shoreline stabilization, primarily bulkheading. *Buyers and owners of coastal property should be aware of sea level rise and the potential for loss of wetlands and property. 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 and land acquisition 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. CRC and DENR policies need to be developed regarding sea level rise adaptations and revise CRC land use planning guidelines.*

The U.S. Environmental Protection Agency (EPA), in collaboration with the U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA), collaborated on a 784 page report that discusses the impacts of sea-level rise on the physical characteristics of the coast, on coastal communities, and the habitats that depend on them. The report, Coastal Sensitivity to Sea-level Rise: A Focus on the Mid-Atlantic Region examines multiple opportunities for governments and coastal communities to plan for and adapt to rising sea levels, and is available online at <http://www.climatescience.gov/Library/sap/sap4-1/final-report/>. The report listed six key findings:

1. In the short time frame of a few decades, negative consequences of climate change may be avoided or minimized by enhanced efforts in managing traditional stressors of estuarine ecosystems through existing best management practices (BMPs).
2. Many management adaptations to climate change can be achieved at modest expense by strategic shifts in existing practices.
3. The appropriate time scale for both planning and implementing new management adaptations requires considering and balancing multiple factors.
4. To minimize negative consequences of climate change beyond a few decades, planning for some future management adaptations and implementing other present management adaptations is necessary now.
5. Even with sufficient long-term planning and enhancing short-term resilience by instituting BMPs, dramatic long-term losses in ecosystem services are inevitable and will require tradeoffs among services to protect and preserve.
6. Establishing baselines and monitoring ecosystem state and key processes related to climate change and other environmental stressors is an essential part of any adaptive approach to management.

The EPA also created a "Climate Ready Estuaries" program that works with the National Estuary Programs and other coastal managers to: 1) assess climate change vulnerabilities, 2) develop and implement adaptation strategies, 3) engage and educate stakeholders, and 4) share the lessons learned with other coastal managers (<http://www.epa.gov/cre/>, April 2009).

There are numerous projects currently investigating the impacts of climate change on coastal ecosystems.

- Corbett et al. (2008) was part of a larger, NOAA-funded project involving various Universities and locations in North Carolina (<http://www.cop.noaa.gov/stressors/climatechange/current/slr/overview.html>, April 2009).
- As part of its Living Coasts Program, The Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) awarded $715,178 to North Carolina NERR and NOAA's Center for Coastal Fisheries and Habitat Research to evaluate the costs and benefits of different approaches to erosion prevention along the North Carolina coast (<http://ciceet.unh.edu/news/releases/shoreline/index.html>, April 2009). The project is focused on understanding the environmental and economic tradeoffs of alternative erosion control measures with climate change and sea level rise. The work is a collaboration among representatives of local, state, and federal agencies, coastal property owners, academic institutions, and nonprofits.
- The state of North Carolina has received $5 million for a statewide risk assessment and mitigation strategy demonstrating the potential impacts of climate change-induced sea level rise (<http://www.fema.gov/news/newsrelease.fema?id=47583>, April 2009). The N.C. Division of Emergency Management is managing the study.
- The Department of Defense Strategic Environmental Research and Development Program (SERDP) has funded a multi-disciplinary research project with the goal of developing an ecosystem management plan for Marine Corps Base Camp Lejeune, which is located along the New River Estuary. As part of this research effort, investigators from NOAA's Center for Coastal Fisheries and Habitat Research and the University of South Carolina will be examining the response of coastal wetlands to sea level rise, and investigating developing a model to predict the role of wind waves and boat wakes on estuarine shoreline erosion

(<http://dcerp.rti.org/Portals/0/DCERP_Executive_Summary_FINAL.pdf>). The results of these projects will provide valuable information for devising management strategies to face climate change.

5.4.5. Management needs and accomplishments

The management needs noted by italics in the 2005 CHPP were, or will be, addressed to some degree during 2005-2010. Some of the needs were refined and adopted as actions in the multi-agency CHPP implementation plans (IPs). There were also wetland-related actions that came directly from the implementation plans, without a specific call in the 2005 CHPP. However, the majority of IP actions affect either water column (see "Water column" chapter) or multiple bottom habitats (see "Ecosystem management and strategic habitat areas" chapter) and will not be duplicated here. Only wetland-focused actions from the IPs are listed in the "Needs and progress" sections. Emerging management needs are included without a reference and may or may not be refined and adopted as actions in the 2009-2011 CHPP implementation plans.

5.4.5.1. Research needs (2005-2010)

Needs with progress

1. *Research site-specific erosion and accretion rates and their relationship to sea level rise and storm events (Street et al. 2005).* **Recent studies have determined site-specific erosion rates in some parts of coastal North Carolina (see Section 5.4.4 Sea level rise and climate change).**

Needs with no progress

1. *Examine the effectiveness of ORW-related rules for protected wetlands (changing if necessary) (Street et al. 2005).* **No specific progress. However, the new stormwater rules provide some protection for wetlands by decreasing the % impervious surface allowed and excluding coastal wetland acreage from the calculation of impervious surface (see Section 5.4.1.2. Upland development).**

2. *Examine the cumulative impact of unmitigated wetland losses on overall wetland area in a watershed (Street et al. 2005).* **No specific progress. However, sea level rise and coastal erosion studies suggest a substantial unmitigated loss of wetlands (see Section 5.4.4 Sea level rise and climate change and the "Shoreline stabilization" subsection of Section 5.4.1.1. Water-dependent Development).**

3. *Develop better criteria for defining an "erosion" problem in order to prevent unnecessary structures (Street et al. 2005).* **No specific progress (see the "Shoreline stabilization" subsection of Section 5.4.1.1. Water-dependent Development).**

4. *Evaluate the susceptibility of freshwater wetlands to sulfate pollution (Street et al. 2005).* **No specific progress (see Section 5.4.2. Water quality degradation).**

Emerging needs

1. *More fishery-independent information and habitat change analysis are needed to determine the effect of wetland-coverage on the abundance of fish and invertebrates.* **See "Status of associated fishery species" section for context.**

2. *Given a limited time to monitor for restoration success, criteria should focus on identifying trajectories of functional development that include wetland soil development. In other words, are the functions developing to fully replace that of lost wetlands within a reasonable timeframe.* **See Section 5.3.3.3. Evaluating mitigation/restoration efforts.**

3. *A study should be conducted to quantify the cumulative impact of shoreline hardening on wetland vegetation and habitat-mediated predator-prey interactions in North Carolina estuarine waters. The results of such a study could then be developed into a model to predict a threshold value for the allowable extent of shoreline hardening in a particular water body, after which, changes in community composition and ecosystem services are likely to occur*. **See the "Shoreline stabilization" subsection of Section 5.4.1.1. Water-dependent Development.**

4. *More research is needed on the long-term impact of Phragmites invasions on estuarine fish use*. **See Section 5.4.3. Non-native, invasive, or nuisance species.**

5.4.5.2. Management needs (2005-2010)

Accomplished management needs

1. *Include land acquisition as an option for wetlands mitigation (Street et al. 2005).* The EEP considers preservation a mitigation option (**see Section 5.3.3. Wetland enhancement and restoration**).

2. *Establish success criteria for restoration projects that do not rely too much on hydrologic criteria (Street et al. 2005).* **The EEP has improved their monitoring of restoration projects (see Section 5.3.3.3. Evaluating mitigation/restoration efforts.**

3. *Conduct additional monitoring of drained wetlands for compliance with water quality standards (Street et al. 2005).* **More DWQ staff were hired to check compliance with stormwater permit conditions (see Section 5.3.1.4. Regulatory response to recent losses).**

4. *Include mitigation planning for upland development, and other approaches to habitat enhancement, restoration, and preservation (Street et al. 2005).* **EEP covers mitigation needs of upland development via "in lieu fee" program (see "Wetland enhancement and restoration" section). Alternative mitigation strategies designed to improve water quality have also been explored (see Section 5.3.3.3. Evaluating mitigation/restoration efforts).**

5. *Track restoration efforts by river basin and hydrogeomorphic class (Street et al. 2005).* **The EEP currently tracks restoration efforts by river basins and 3 hydrogeomorphic categories (coastal, riparian, and non-riparian). Headwater wetland mitigation is a type of riparian wetland is not specifically tracked (see Section 5.3.3.3. Evaluating mitigation/restoration efforts).**

Needs with progress

1. *Give higher priority for headwater wetlands in preservation/restoration efforts (Street et al. 2005).* **The coastal headwater stream mitigation guidance has been modified and finalized by the Corps of Engineers and DWQ and is now being implemented across the outer coastal plain. In addition, including headwater wetlands as an "in-kind" mitigation type will put this hydrogeomorphic class in the accounting system (see Section 5.3.3.3. Evaluating mitigation/restoration efforts).**

2. *Conduct an assessment of where and how much of the estuarine shoreline is hardened (Street et al. 2005).* **The DCM is currently delineating shoreline types for the entire estuarine system of North Carolina (see the "Shoreline stabilization" subsection of Section 5.4.1.1. Water-dependent Development).**

Needs with no progress

1. *These studies show the importance of considering optimal locations for habitat restoration/creation projects.* **See "Corridor and connectivity" section for context.**

2. *Implement comprehensive planning for wetland preservation and restoration that includes dechannelization of streams, restoration of wetland hydrology, use of alternative drainage techniques, on-site BMPs, and outreach to private owners of wetland resources (Street et al. 2005).* **No specific progress. However, there are projects conducting comprehensive and proactive watershed restoration on lands managed for conservation (see Section 5.3.4.2. Non-regulatory).**

3. *Amend "No Wake" zone authority to include consideration for erosion along normally low-energy shorelines (Street et al. 2005).* **No specific progress (see Section 5.4.1.7. Boating related**

4. *Increase public awareness of boat wakes on wetland shoreline (Street et al. 2005).* **No specific progress (see Section 5.4.1.7. Boating related).**

5. *Maintain a natural proportion and relative position of wetland and non-wetland shorelines. Wherever possible, sections of estuarine, non-vegetated shoreline with very little hard stabilization should remain unaltered to provide "new" sediment for shallow water habitats (Street et al. 2005).* **No specific progress (see the "Shoreline stabilization" subsection of Section 5.4.1.1. Water-dependent Development).**

6. *Require an NPDES permit for ditching activities resulting in excess pollutant discharge to coastal North Carolina waters (Street et al. 2005).* **No specific progress (see Section 5.3.1.4. Regulatory response to recent losses).**

7. *Inform buyers and owners of coastal property about sea level rise and resulting loss of wetlands and property (Street et al. 2005).* **No specific progress. However, recent publications, workshops, meetings, and television programs provide an ample source of information on the impacts of sea level rise (see Section 5.4.4. Sea level rise and climate change).**

8. *Acknowledge sea level rise in prioritizing coastal wetland protection and land acquisition efforts (Street et al. 2005).* **No specific action at the agency level. However, there are agency studies underway to help determine priorities (see Section 5.4.4. Sea level rise and climate change).**

Emerging needs

1. *Accurate and up-to-date mapping of DCM wetland types is needed for North Carolina.* **Refer to section 5.1.4., "Distribution," for a discussion of the current mapping available and potential improvements.**

2. *Headwater wetlands restoration should be tracked separately from other riparian wetlands because of their vulnerability and relative importance in denitrification.* **See Section 5.2.1., "Ecosystem enhancement" for context.**

3. *To facilitate cumulative impacts assessment, there should be a central database for recording 404, 401 permits similar to the CDAITS database being developed for CAMA permits. Necessary fields for the database would include accurate geographic coordinates for impacts and parcel identification numbers.* **See Section 5.3.1.3., "Recent loss of wetland habitat (1994-present)" for context.**

4. *Other issues hampering management of cumulative impacts include the development of threshold values (for shoreline development) similar to the impervious surface limits in EMC's new stormwater rules. There must also be a means to limit impacts at larger than parcel scales.* **See Section 5.3.1.3., "Recent loss of wetland habitat (1994-present)" for context.**

5. *Location of Strategic Habitat Areas should also be coordinated with local watershed planning to facilitate the linkage between watershed improvement efforts and management of sensitive aquatic habitats (i.e., SAV, oysters) downstream.* **See Section 5.3.3.3., "Evaluating mitigation/restoration efforts" for context**.

6. *The re-mapping of headwater streams should be used to identify headwater wetlands as a new category for tracking impacts and restoration work.* **See Section 5.3.4.2. Non-regulatory for context.**

7. *Restoring altered wetland areas within conservation lands would be more readily compatible with existing uses than analogous efforts on other private lands.* **See Section 5.3.4.2. Non-regulatory for context.**

8. *Use of native vegetation in the 30-foot buffer along the estuarine shoreline AEC would minimize stormwater runoff and erosion landward of shoreline stabilization structures, and would be consistent with the Neuse and Tar-Pamlico River Basin Nutrient Sensitive Waters management strategies [EMC rules 15A NCAC 02B .0233 and 15A NCAC 02B .0259].* **See the "Shoreline stabilization" subsection of Section 5.4.1.1. Water-dependent Development for context**.

9. *There is a need for 1) the regulatory and resource management agencies to consider and acknowledge through the permit review process the long-term benefits of alternative non-vertical stabilization methods, 2) an assessment of the ecological impacts of vertical structures, and 3) incentives to use non-vertical structures where appropriate.* **In 2009, the NC Division of Soil and Water Conservation - Community Conservation Assistance Program (CCAP) added Marsh Sills as one of their supported BMPs (see the "Shoreline stabilization" subsection of Section 5.4.1.1. Water-dependent Development).**

10. *It is equally important to educate the public on the benefits and advantages of alternatives to vertical stabilization.* **See the "Shoreline stabilization" subsection of Section 5.4.1.1. Water-dependent Development for context**.

11. *There is a need to determine a way to modify CRC and EMC shoreline stabilization regulations in a manner that is logistically manageable and effectively results in permitting of the least environmentally damaging shoreline stabilization structures wherever possible.* **The CHPP Steering Committee is in the discussion phase of dealing with this issue but no significant improvement has occurred yet. DCM has produced a brochure/website key to assist property owners in matching the appropriate shoreline stabilization technique to their shoreline type (see the "Shoreline stabilization" subsection of Section 5.4.1.1. Water-dependent Development).**

12. *If depletion or loss of shallow/intertidal habitats is allowed, agencies should consider requiring mitigation. The EEP is developing an out-of-kind crediting system that could be employed in mitigating the permitted loss of shallow/intertidal habitats to bulkhead construction and associated impacts.* **See the "Shoreline stabilization" subsection of Section 5.4.1.1. Water-dependent Development for context.**

13. *There is also a need to inform managers and the public on the hydrological, biogeochemical, ecological, and aesthetic benefits of alternative stabilization methods.* **See the "Shoreline stabilization" subsection of Section 5.4.1.1. Water-dependent Development for context.**

14. *Should the State consider locating a wind facility in state or federal waters, proper placement of energy infrastructure is necessary to minimize potential impacts to wetland habitat and minimize*

conflicts with existing activities. **See the "Infrastructure" subsection of Section 5.4.1.1. Water-dependent Development for context.**

15. *Modify EMC regulations to discourage or prevent maintenance of previously un-navigable and re-naturalized channels in Anadromous Fish Spawning Areas and Primary Nursery Areas.* **See Section 5.4.1.4. Channelization and drainage for context.**

16. *There should be a continued ban of oil drilling off North Carolina waters.* **See Section 5.4.2.2. on fossil fuels for context.**

17. *The importance and vulnerability of fringing coastal marsh merits decreasing the minimum area and/or length requirement for mitigation. Protecting or restoring fringing marsh is especially important where adjacent slopes allow landward migration with sea level rise.* **See Section 5.4.4. Sea level rise and climate change for context**.

18. *The enhancement or creation of marsh islands should accompany the net loss of marsh islands due to deterioration with sea level rise.* **See Section 5.4.4. Sea level rise and climate change for context.**

19. *Develop CRC and DENR policies regarding sea level rise adaptations and revise CRC land use planning guidelines.* **See Section 5.4.4. Sea level rise and climate change for context.**

5.5. WETLANDS CHAPTER SUMMARY

Wetland services improve the quality of adjacent upland and open-water habitats with their capacity for water storage, filtration, and protection from erosion. Wetlands also play a vital role in providing abundant food and cover for juvenile and adult finfish and shellfish. It is estimated that over 95% of the finfish and shellfish species commercially harvested in the United States are wetland-dependent. The large expanses of shallow water and thick vegetation characterizing wetlands provide nursery habitat for numerous fishery species, and ecosystem enhancement value for the entire system. The value of wetland has even been extended to waste treatment and storm protection services for humans.

The 2001 National Land Cover Dataset indicates that approximately 3 million acres in coastal draining river basins of North Carolina (excluding the Lumber River) and 5.1 million acres in the entire state. Pre-colonial estimates of wetland area for the entire state are approximately 7.2 million acres. Between 2001 and 2008, there were nearly 1,700 acres of permitted wetland impacts in coastal draining river basins. More accurate mapping of wetland types has not been conducted since the 1994, suggesting the need to revisit mapping of wetland types.

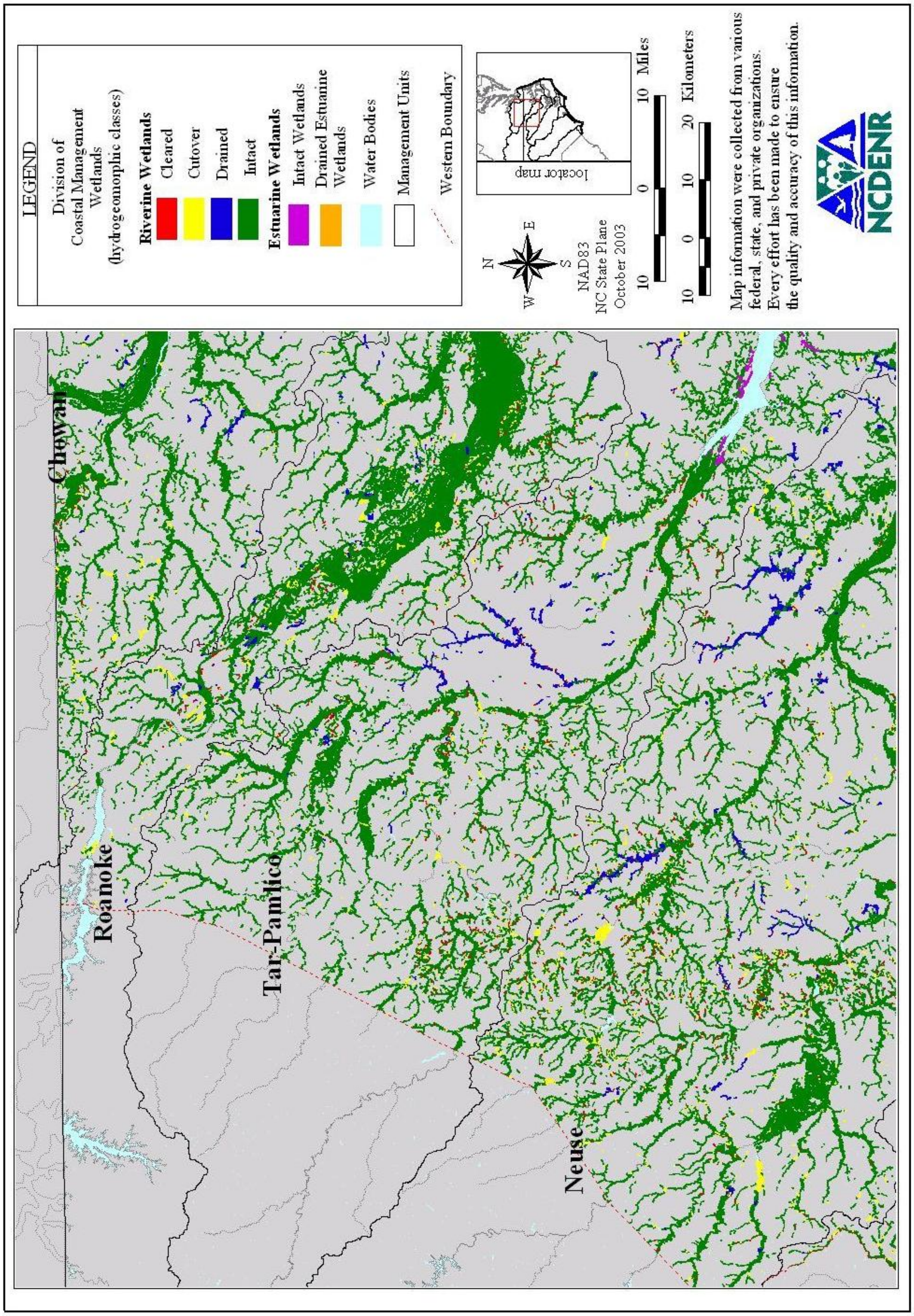
Land use and shoreline changes associated with population growth have been and continue to be the primary anthropogenic cause of wetland habitat loss. The indirect, cumulative and largely unmitigated impact of water dependent development nearshore habitats continues to be a major issue facing riparian wetlands. The presence of bulkheads along the estuarine shoreline exacerbates the degradation and loss of fringe wetlands and other shallow water habitats. Recent research provides site-specific evidence of the widespread erosion and shoreline stabilization in the Neuse River estuary. Other parts of the North Carolina coast are experiencing similar widespread erosion and conversion of wetlands to open water. As normal water levels rise, wetlands will need space to migrate inland or they will be converted to another habitat. Additional threats to wetlands and their use by fish include construction of marinas and docks, associated boating activity, infrastructure development, stormwater conveyance, mining for minerals, obstructions to fish passage and water withdrawals.

The EEP currently has more mitigation assets (restoration, enhancement, creation, and preservation) than the permitted losses recorded (not counting advance mitigation) and reports a success rate of 90% for EEP mitigation projects. Although it appears that "No Net Loss" of wetlands is being achieved by the wetland permitting programs in North Carolina, the restored wetlands may not be of equivalent function or location to prevent localized impacts. There are also losses of wetlands that are not captured by regulatory programs and therefore not mitigated for. These losses are from net erosion with sea-level rise and storm events, unauthorized impacts, and impacts too small to require a permit or mitigation. Loss of wetland function also occurs from non-native species invasions, such as *Phragmites* spp., resulting in reduced biodiversity and potential impacts on fish nursery functions. Mitigating for a history of wetland alterations may be possible with opportunities such as wetland restoration on conservation lands, re-building marsh islands, and constructing living shorelines.

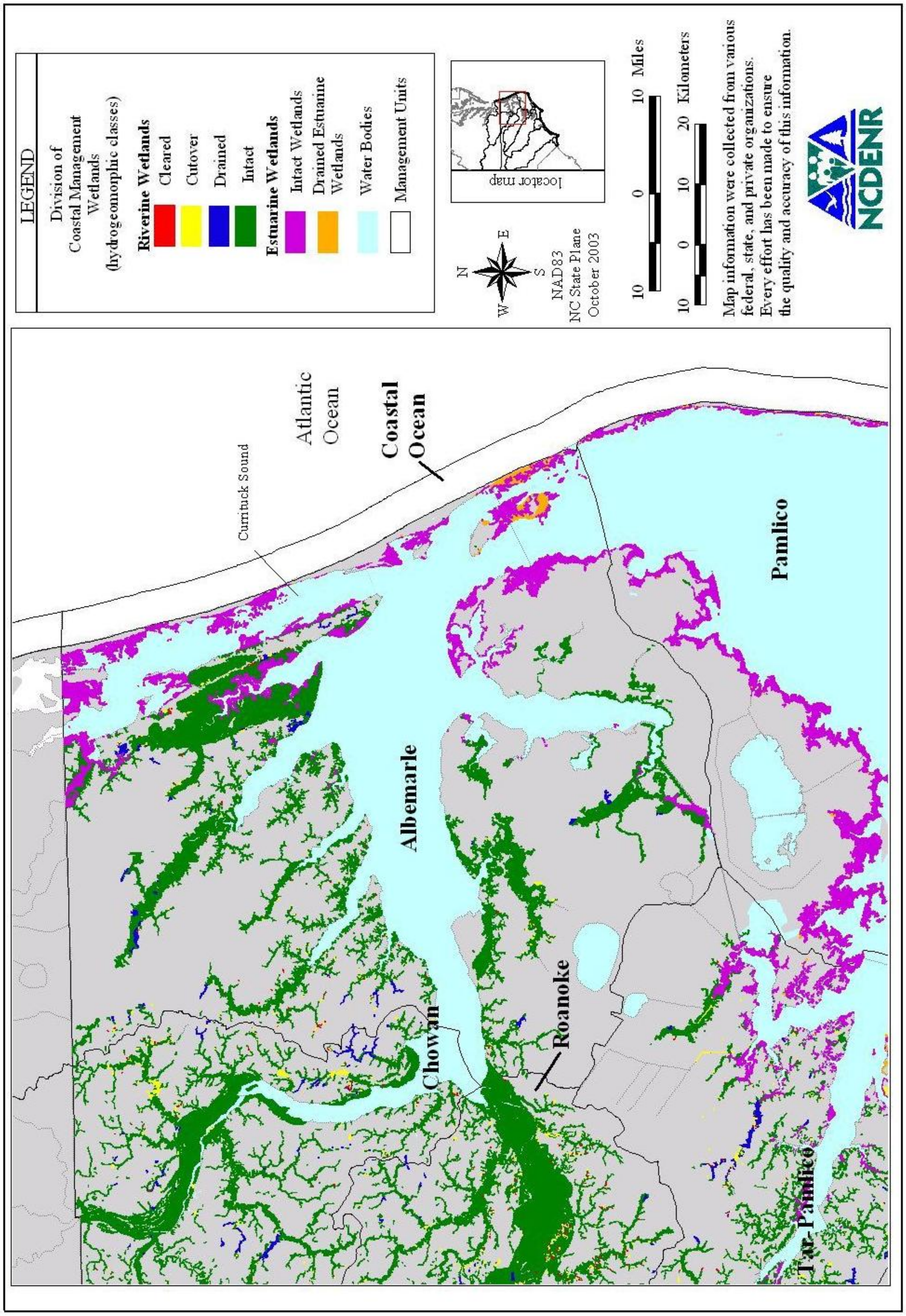
Some progress has been made in almost half of the management needs identified in the 2005 CHPP. Many of the management needs are ongoing and require continued effort and funding. There have been incremental improvements in the rules governing shoreline development and how it contributes to the unmitigated loss of wetlands. There are numerous research, planning, and restoration efforts designed to address the unmitigated loss of wetlands with the interruption of natural shoreline migration processes during this period of rising sea level. Wetland restoration project through EEP are designed, located, tracked and monitored with more detail. Both regulatory changes and coordinated mitigation and restoration opportunities are needed to foster a trajectory of sustainable human development that recognizes the role of wetlands in sustainability.

In updating the chapter, many of the very general, minor, or redundant research and management needs were discontinued. Of the remaining 2005 CHPP research and management needs (20), five management needs were considered accomplished and discontinued. Of the renewed needs, one research need had progress while the other five did not. There were also two renewed management needs with progress and eight without progress. However, 22 new or clarified research and management needs were also identified. Some of the highest priority management needs for wetlands include:

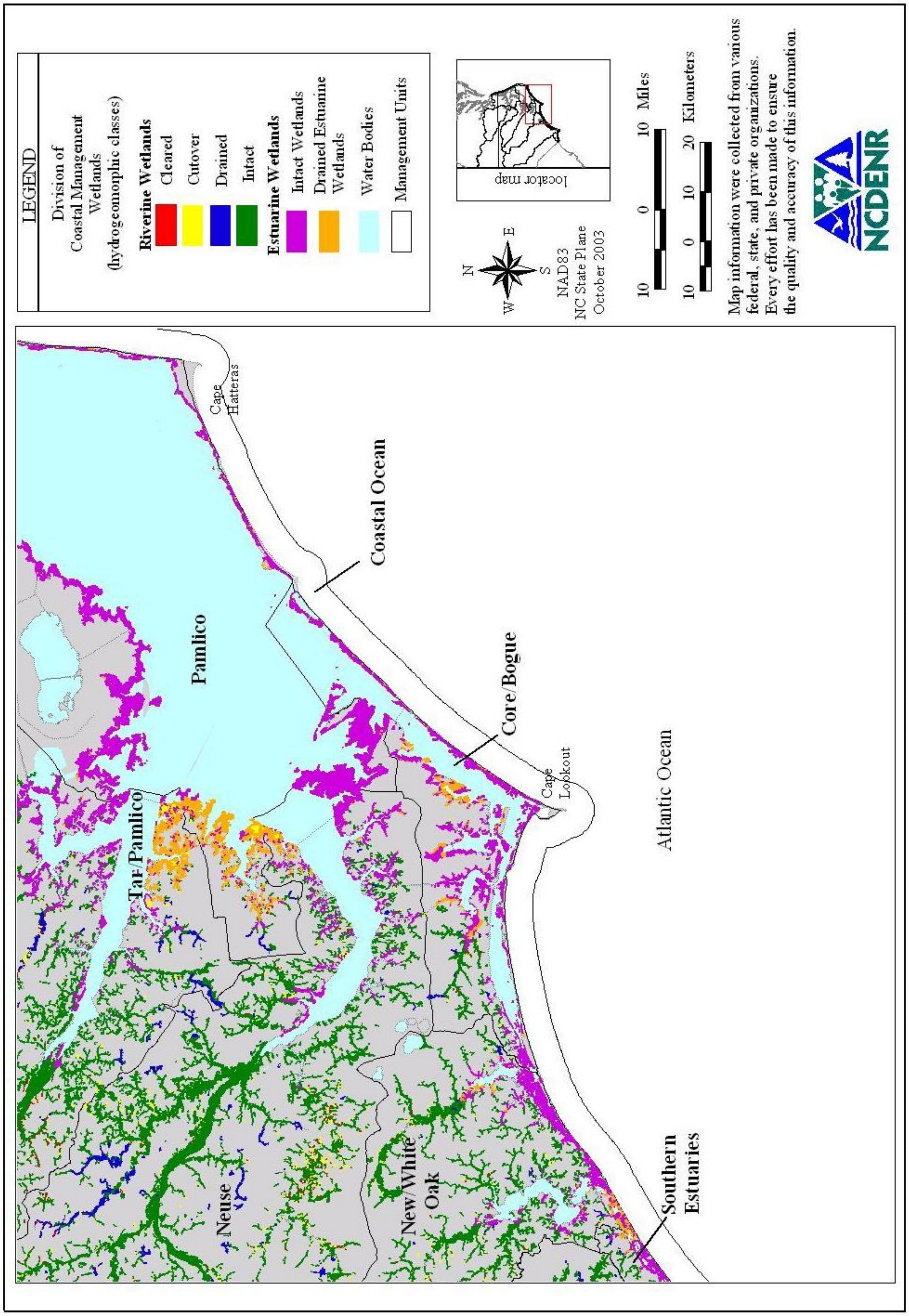
1. A mapping and tracking system for wetland loss by wetland types;
2. Incentives for using alternative shoreline stabilization techniques compatible with riparian buffer requirements;
3. Further development of success criteria for wetland restoration and consideration of alternative types of restoration/mitigation
4. Developing coastal management policies and guidelines regarding sea level rise.



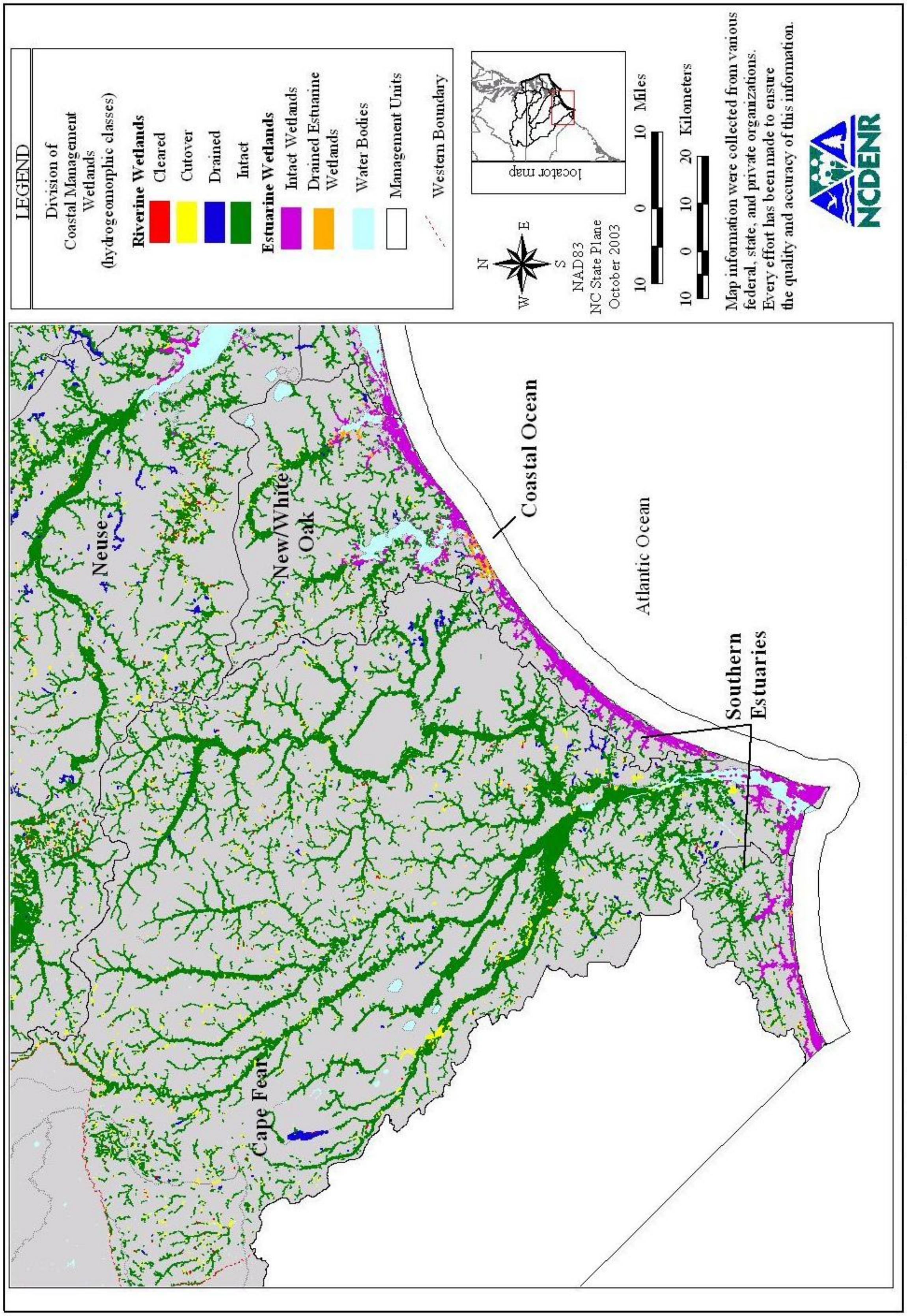
Map 5.1a. Location of riparian wetland areas derived from maps produced by DCM (1994) in northwestern North Carolina.



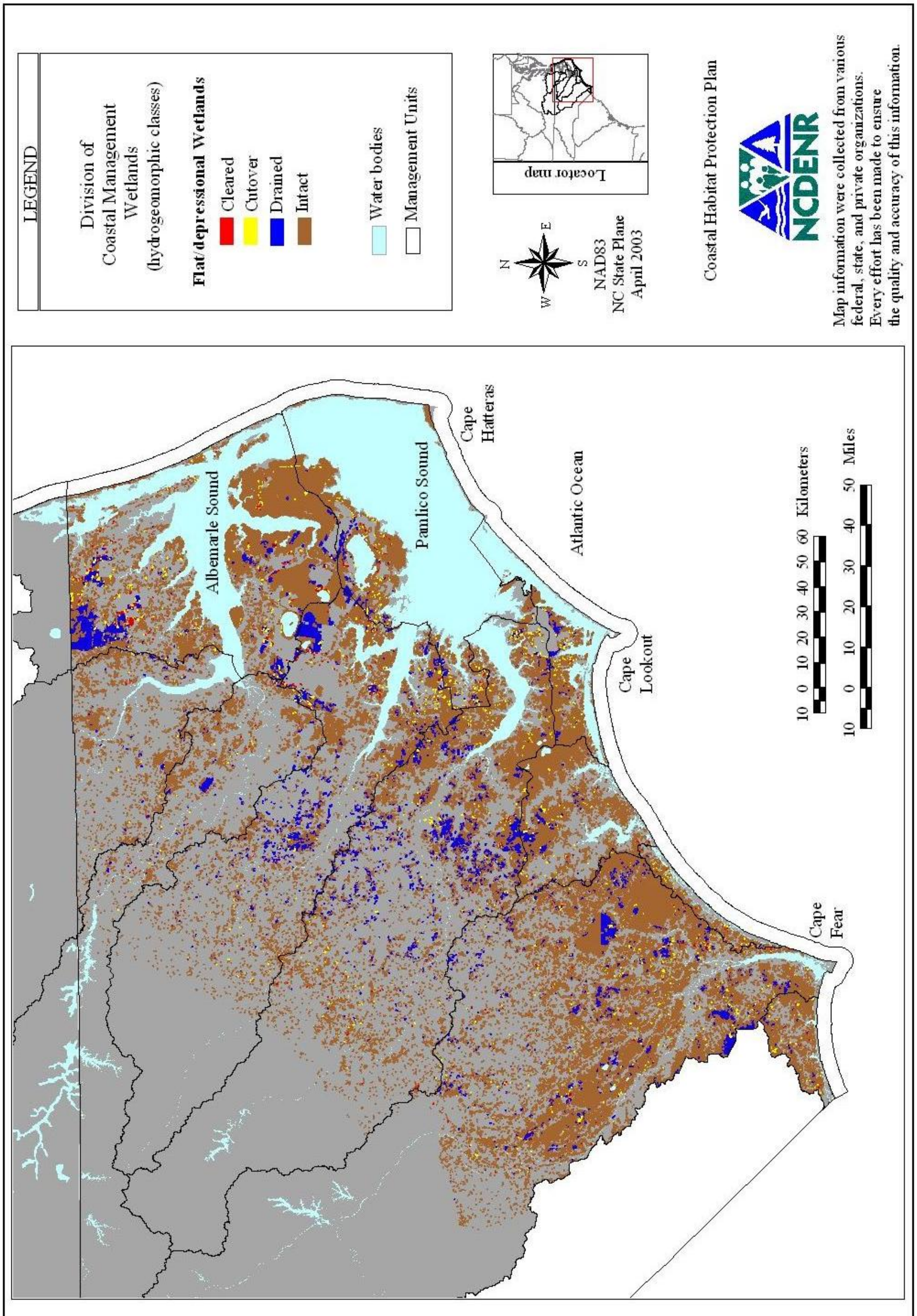
Map 5.1b. Location of riparian wetland areas derived from maps produced by DCM (1994) in northeastern North Carolina.



Map 5.1c. Location of riparian wetland areas derived from maps produced by DCM (1994) in southcentral North Carolina.



Map 5.1d. Location of riparian wetland areas derived from maps produced by DCM (1994) in southeastern North Carolina.



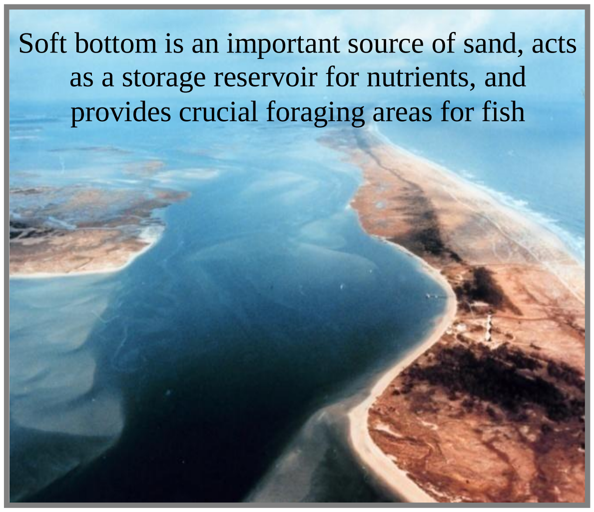
Map 5.2. Location of flat/depressional wetland areas derived from maps produced by DCM (1994).

CHAPTER 6. SOFT BOTTOM

6.1 DESCRIPTION AND DISTRIBUTION

6.1.1. Definition

Soft bottom habitat is defined by Street et al. (2005) as "unconsolidated, unvegetated sediment that occurs in freshwater, estuarine, and marine systems." This definition includes both deeper subtidal bottom as well as shallow intertidal flats.



6.1.2. Habitat requirements

The only requirement for the presence and persistence of soft bottom is 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 use it. However, the habitat itself will persist regardless of its condition unless it becomes sediment starved or is colonized by organisms, such as oysters or SAV, which can transform soft bottom into another habitat.

6.1.3. Description and distribution

The characteristic common to all soft bottom is the mobility of unconsolidated, uncemented sediment (Peterson and Peterson 1979). Soft bottom habitat in North Carolina's coastal waters can be characterized by geomorphology, sediment type, water depth, hydrography, and/or salinity regime, and can be categorized into 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

Soft bottom covers approximately 1.9 million acres, or 85% of the total bottom area, in North Carolina's coastal waters, excluding the coastal ocean. An estimate for its area in North Carolina's marine waters is not feasible due to the uncertainty of the extent of hard bottom. As part of NC Strategic Habitat Area (SHA) assessments, soft bottom area has been described for Region 1 (Albemarle Sound to Northeastern coastal ocean) and Region 2 (Pamlico Sound to ocean). Refer to, "Ecosystem Management and Strategic Habitat Areas" chapter for more information regarding SHAs. In region 1, there is an estimated 852,346 acres of soft bottom within a total habitat area (water and adjoining wetlands) of 2,162,142.77 acres (soft bottom = approximately 39 percent). Shallow (<6ft) bottom habitat (mostly soft bottom) covers 17-37% of the total bottom area in CHPP regions (Table 6.1). Shallow bottoms occupy the largest proportion of bottom area in Regions 1 and 3. In all regions, there is a much larger area of deeper bottom below the sunlit portion of the water column. However, measuring the distribution of depth zones and bottom features is hampered by the lack of current bathymetry maps. For example, the data used to map bathymetry in Pamlico Sound ranged from 1913-1980 http://estuarinebathymetry.noaa.gov/southatlantic.html , February, 2010). There have been water body-specific efforts to construct updated bathymetry in New River (J. McNinch/USACE, pers. com., April 2010) and Currituck Sound (E. Brinker/ECSU, pers. com., April 2010), but no comprehensive mapping of estuarine waters. *There should be a cooperative effort to update existing NC estuarine bathymetric maps.*

Table 6.1. Estimated acreage of shallow and deep bottom habitat within CHPP regions of North Carolina (bathymetry derived from NOAA navigation charts).

CHPP regions	Major waterbodies	Shallow (<6 ft)		Deep (>6 ft)	
		acres	%	acres	%
1	Albemarle/Currituck sounds, Chowan River	240,471	31	526,531	69
2	Pamlico Sound, Neuse/Tar-Pamlico rivers	251,477	18	1,111,318	82
3	Core/Bogue sounds, New/White Oak rivers	154,492	37	268,625	63
4	Cape Fear River, southern estuaries	37,800	17	188,549	83

The physical and chemical character of all soft bottom habitats is determined by the underlying geology, basin morphology, and associated physical processes (Riggs 1996; Riggs and Ames 2003). Geologically, North Carolina's coast can be divided into distinct northern and southern provinces that are separated (approximately) by Cape Lookout (Riggs 1996; Pilkey et al. 1998; Riggs and Ames 2003). In the northern province, sediment formations generally consist of a thick layer of slightly consolidated to unconsolidated muds, muddy sands, sands, and peat sediments. 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 surficial sands and mud, with underlying rock platforms. The southern province also has a steeper sloping shoreline, resulting in narrow estuaries (e.g., Topsail Sound, Stump Sound), short barrier islands, and numerous inlets (Map 6.1 a-e). The geologic differences results in dissimilar sediment supplies and physical oceanographic conditions, thus affecting the characteristics of each province's soft bottom habitat.

6.1.3.1. Freshwater soft bottom

Properties of freshwater soft bottom not only depend on the origin of sediment inputs, but also on the prevailing 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 flood waters (Riggs 1996; Riggs and Ames 2003). Bottom composition generally ranges from more consolidated material (bedrock, boulders) upstream to less consolidated material (gravel, sand) downstream. Because freshwater rivers and creeks are eroding through older sediment banks, there tends to be a deep main channel dominated by medium-grained to coarse-grained sand with varying amounts of organic detritus. Shallow flats may exist on one or both sides of the channel, consisting 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 (sand, silt) to settle. Where the channel bed is relatively narrow or shallow, riffles and runs occur and water velocity increases, leaving only the heaviest particles (boulder, cobble) on the bottom.

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, shallow bottom may become covered by submerged aquatic vegetation, assuming appropriate water clarity conditions exist (see "Submerged aquatic vegetation" chapter for more information).

6.1.3.2. Estuarine soft bottom

Sediment composition in estuaries and sounds varies greatly with geomorphology and estuarine position. The basin-scale formation of most estuaries in the northern geologic province of North Carolina is similar to a flat-bottomed dish with a narrow and shallow perimeter lip or platform, providing ample space for sediment deposition (Pilkey et al. 1998; Riggs and Ames 2003). Soft bottoms in this region, including the Albemarle-Pamlico Estuarine System, consist of three general sediment types: sand, organic rich mud (ORM), and peat (Wells 1989; Riggs 1996). Coarse sands, derived from erosion of sediment bank shorelines and transport from barrier island overwash or through inlets, are concentrated on the shallow perimeter platforms, shoals, and at inlet mouths (Wells 1989; Riggs 1996; Pilkey et al. 1998) (Map 6.2a-b). Organic rich mud, the most pervasive sediment that comprises approximately 70% of the sediment in North Carolina's estuarine system, generally fills the deeper central basins and downstream channels of sounds and rivers (Wells 1989; Riggs 1996; Pilkey et al. 1998; Riggs and Ames 2003) (Map 6.2a-b). Since fine sediments are easily suspended and transported away from high energy waters, the width and thickness of ORM increase as the estuary widens and deepens in the downstream direction (Riggs 1996; Riggs and Ames 2003). Peats, sediments with more than 50% organic matter, form either in the swamp forests of riverine floodplains or in coastal marshes (Riggs and Ames 2003).

Soft bottoms in the estuarine systems of the southern geologic province are dominated by sloped mudflats on the perimeter and interior of small estuaries (i.e., White Oak River, Pages Creek) (Pilkey et al. 1998). Coarse sands are concentrated in the lower portion of these estuaries and are transported into the systems via inlets and barrier island overwash. Small blackwater streams carry relatively low sediment loads into the upper portion of the southern estuaries where ORM dominates, but the water does contain large quantities of dissolved organic matter that give it a brown tea color (Riggs and Ames 2003). In contrast, the Cape Fear River, the only major trunk estuary in North Carolina that discharges directly into the Atlantic Ocean, transports large sediment loads from erosion of clay Piedmont soils to the lower portion of the river basin (Riggs and Ames 2003).

Unvegetated estuarine shorelines occur where wave energy prevents colonization by plants and there is a gently sloping area for sediment to build upon (Riggs 2001). These sediment bank shorelines are generally eroding and sandy, providing a source of sand to adjacent waters. In contrast, marsh or swamp forest shorelines are eroding to a lesser degree 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 and were compiled and summarized in Riggs (2001). Due to wave energy, sediments can have long-shore or cross-shore transport. Sediments undergoing long-shore transport move parallel to the shoreline where sediments can be deposited on adjacent beaches. Cross-shore transport will move sediments onshore or offshore creating an equilibrium beach profile.

Estuarine intertidal flats are unvegetated bottoms that occur along shorelines or unconnected, emergent sediment banks between the high and low tide lines. Intertidal flats are most extensive where tidal range is greatest, such as near inlets and along 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 areas immediately adjacent to an inlet (Peterson and Peterson 1979). Sediment composition on intertidal flats tends to shift from coarser, sandy sediment on the landward fringe, to finer, muddier sediments on the waterward fringe (Peterson and Peterson 1979).

Tidal deltas form as sediments shift with tides and waves on the ebb and flood sides of the inlets separating North Carolina's barrier islands. Sediments in the vicinity of inlets are typically composed of coarse sands and shell fragments (Peterson and Peterson 1979). Intense wave and current energy cause the flats to continually change, erode, and reform. Inlets are classified as stable, migrating, or ebb-tidal delta breaching (Fitzgerald et al. 1978). 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 21 inlets in North Carolina that connect estuarine waters to the ocean (Map 6.3 a-c). Eleven of these inlets originated as a result of storm breaches and remain spatially unstable, including Oregon and Mason inlets (Cleary and Marden 1999; Mallinson et al. 2008). Ophelia Inlet breached southwest of Drum Inlet during Hurricane Ophelia in 2005, and has since been expanding, nearly merging with Drum Inlet (Mallinson et al. 2008). There are nine larger inlet systems, including Ocracoke, Bogue, and the Cape Fear River inlets, which occupy ancient river channels. Several others have been artificially created (e.g. Carolina Beach Inlet) or artificially relocated (e.g. Tubbs Inlet).

6.1.3.3. Ocean soft bottom

North Carolina's marine soft bottom is part of the Atlantic continental shelf, which slopes gradually away from oceanfront beaches before dropping off steeply at the 160–250 ft isobath, where the continental slope begins (Map 6.1 a-e). The intertidal zone of oceanfront beaches is the area periodically exposed and submerged by waves and tides. In this high energy area, waves continually rework and sort sediment by grain size, with larger sediments deposited first and finer-grained sediment carried farther landward. Sediments are generally much coarser, more highly sorted, and contain less organic matter than that found on protected estuarine intertidal flats (Donoghue 1999).

Seaward of the intertidal beach in the shallow subtidal area of breaking waves lies the surf zone. Within this zone, longshore sandbars frequently develop and shift seasonally in response to wave action. Ripple scour depressions, ranging from 130–330 ft in width and up to 3 ft in depth, occur along the southern portion of the coast and are perpendicularly oriented to the beach (Thieler et al. 1995; Reed and Wells 2000). These features are located adjacent to areas experiencing chronic beach erosion, and may be indicative of rapid offshore transport of sand during storms (Thieler et al. 1995).

Extending from the surf zone to the point where the slope matches that of the continental shelf is the generally concave, upward surface called the shoreface (Thieler et al. 1995). The base of the shoreface off North Carolina occurs at approximately 33–40 ft water depth and 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 composition of the surface and underlying substrate and partially explains the patterns of localized erosion or deposition.

The continental shelf off North Carolina is relatively narrow, approximately 16 mi off Cape Hatteras, 32 mi off Cape Lookout, and about 49 mi off Cape Fear. North of Cape Hatteras, the shelf is relatively steep, the coastline tends to be linear, and the bottom consists of a regional depositional basin known as the Albemarle Embayment. Several prominent shoals, including Wimble, Kinnekeet, and Platt shoals, occur in this region, as well as a series of ridges and swales that are spaced about 1,300–2,000 ft apart (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). In contrast to that found to the north, the continental shelf south of Cape Hatteras is less steep and the coastline 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). Large shoals also occur in this region and extend across the shelf from each cape (Diamond, Lookout, and Frying Pan shoals) for more than 11 mi. Water depth on the shoals ranges from 2–18 ft, while adjacent waters are 20–40 ft deep. This region is generally sediment starved due to low direct river input and minimal sediment exchange between adjacent shelf embayments (Riggs et al. 1998).

6.2 ECOLOGICAL ROLE AND FUNCTIONS

6.2.1. Ecosystem enhancement

Soft bottom plays an important role as a storage reservoir of chemicals and microbes in coastal ecosystems. Intense biogeochemical processing and recycling allow for deposition and resuspension of natural and human-induced nutrients and toxic substances (Fear et al. 2005; Smith and Benner 2005; Sutula et al. 2006). These materials may pass through an estuary (Matoura and Woodward 1983), become trapped in the organic rich oligohaline zone (Sigels et al. 1982; Imberger 1983), or migrate within the estuary over seasonal cycles (Uncles et al. 1988). The fate of the materials depends upon freshwater discharges, density stratification, and formation of salt wedges (Matson and Brinson 1985; Matson and Brinson 1990; Paerl et al. 1998). Density stratification hampers mixing and oxygen exchange of sediments with overlying oxygenated waters, often leading to benthic hypoxia (Malone et al. 1988; Buzzelli et al. 2002; Lin et al. 2006).

In slow-moving, expansive estuaries, such as the Albemarle-Pamlico Estuarine System, nutrients and organic matter from 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 resuspended into the overlying waters (Fear et al. 2005). In organic enriched oligohaline zones (e.g., Pamlico and Neuse River estuaries), weather-induced recycling results in higher microbial activity and associated oxygen depletion (Buzzelli et al. 2002; MacPherson et al. 2007).

Colonization of soft bottom by benthic microalgae reduces the extent to which sediment is resuspended at low water flow velocities, stabilizing the bottom and reducing turbidity in the water column (Holland et al. 1974; Underwood and Paterson 1993; Yallop et al. 1994; Miller et al. 1996). However, microalgae cannot stabilize sediments under intense or prolonged disturbance conditions, such as during large storm events or in the surf zone (Miller 1989). 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. Flood-tidal deltas are an important source of sand, which allows barrier island migration to respond to sea level rise (Cleary and Marden 1999). Alterations to these deltas can result in significant changes in the adjacent barrier island shorelines.

6.2.2. Productivity

6.2.2.1. Freshwater and estuarine

Although soft bottom habitat is defined as "unvegetated," the surface sediments support an abundance of benthic microalgae that are an important source of primary production (Peterson and Peterson 1979; Cahoon and Cooke 1992; Pinckney and Zingmark 1993; Currin et al. 1995; MacIntyre et al. 1996; Cahoon et al. 1999; and Litvin and Weinstein 2003). Benthic microalgae including diatoms, dinoflagellates, and blue green algae, that live in the top few millimeters of the surface of soft bottom (Peterson and Peterson 1979; Miller et al. 1996). Benthic microalgae often support the base of the soft bottom food-web (Mallin et al. 2005) and are the major food source for deposit feeders such as mud snails, bivalve clams, and polychaete worms (MacIntyre et al. 1996). Values for benthic chlorophyll *a* biomass (an indicator of overall productivity) in North Carolina estuaries have been reported to range from 10-90 mg m^{-2} (Posey et al. 1995) and are similar to those found in other Atlantic coast states (Table 6.2). Little information is available on benthic productivity in coastal freshwater creeks and rivers. In general, primary production in these areas is greatest in shallow, well-illuminated benthic substrates.

Table 6.2. Benthic productivity estimates as measured by chlorophyll *a* biomass in Virginia (Chesapeake Bay), North Carolina (Masonboro Sound), and South Carolina (North Inlet Estuary).

Region	Chl. *a* biomass (mg m^{-2})	Reference
Virginia	5 – 65	Rizzo and Wetzel (1985)
North Carolina	10 – 90	Posey et al. (1995)
South Carolina	20 – 110	Pinckney and Zingmark (1993)

The most productive estuarine bottom, in terms of benthic microalgae, tends to be in shallow, protected areas with muddy/fine sand (Pinckney and Zingmark 1993; MacIntyre et al. 1996), while productivity in exposed or deep areas, or on coarse sand bottom tends to be low (Chester et al. 1983; Sundback et al. 1991; MacIntyre et al. 1996). In some locations, primary production on shallow intertidal bottom may be greater than that in the water column (MacIntyre et al. 1996). Following wind or rain events, benthic diatoms can be resuspended, greatly altering the composition and abundance of phytoplankton (Tester et al. 1995). Since there is a large and ongoing exchange of materials between soft bottom and the water column (benthic-pelagic coupling), it is often difficult to distinguish differences in productivity between the two habitats (Cahoon and Cooke 1992; MacIntyre et al. 1996). Factors that control the magnitude and extent of benthic primary production include temperature, light availability, sediment grain size, and community biomass (Pinckney and Zingmark 1993; Barranguet et al. 1998; Cahoon et al. 1999; Guarini et al. 2000). Light availability is considered by most researchers to be the major factor affecting primary production rates (MacIntyre et al. 1996), while other factors including nutrient availability are not thought to be limiting (Peterson and Peterson 1979; Admiraal et al. 1982). Photosynthetically active light generally penetrates only about 2-3 mm into the sediment, but can reach 5-20 mm in sandy, high energy environments.

Organic matter on soft bottom habitat arrives in the form of detritus originating from marsh grass, submerged aquatic vegetation, and macroalgae(Currin et al. 1995; Wainright et al. 2000; Litvin and Weinstein 2003). The relative contribution of different primary producers to overall secondary production varies by the diet of individual fish or invertebrate species, their position within the estuary, and seasonal or episodic weather conditions (Tester et al. 1995; Wainright et al. 2000; Page and Lastra 2003; Galvan et al. 2008).

6.2.2.2. Marine

Benthic microalgae are also an important source of primary production on marine soft bottom. Viable chlorophyll *a* occurs in sediments across the continental shelf of North Carolina (Cahoon et al. 1990). Studies in Onslow Bay have found that roughly 80% of chlorophyll *a* was associated with microphytobenthos and its biomass (36.4 mg m^{-2}) generally exceeded that of phytoplankton (8.2 mg m^{-2}) (Cahoon and Cooke 1992). Recently, McGee et al. (2008) discovered obligate benthic diatoms living on the upper continental slope offshore from North Carolina, in waters as deep as 191 m. This discovery increases the estimated total benthic primary production in that area of the continental margin by about 14%.

In the surf zone, wave action is generally too great to allow for the development of productive benthic microalgae communities. However, this wave action continually re-suspends inorganic nutrients in sufficient amounts to create localized phytoplankton blooms composed primarily of diatoms (McLachlan et al. 1981; Hackney et al. 1996). This self-sustaining nutrient input and associated phytoplankton production supports intertidal filter feeders and, consequently, high concentrations of fish migrating through the shallow waters of the surf zone.

6.2.3. Benthic community structure

6.2.3.1. 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. In headwater streams, the benthic community consists largely of organisms that break down and collect detritus associated with the dense tree canopy cover. As the canopy opens up downstream, algae grazers and detritivores increase in abundance (Vannote et al. 1980). Freshwater benthic sampling conducted by DWQ in all of North Carolina's river basins provides more detailed information on the abundance and diversity of benthic species present in the freshwater portion of North Carolina's coastal rivers. Common coastal freshwater invertebrates include mayfly and caddisfly larvae, leeches, chironomids, beetles, dragonfly larvae, and crayfish. Hyland et al. (2004) found that oligochaetes, insect larvae, gammaridean amphipods, and larval *Coelotanypus* spp. dominate the tidal freshwaters of the Chowan River.

Mussels are also an important component of the coastal freshwater invertebrate community on soft bottom (Hyland et al. 2004), with over 60 species of freshwater mussels in North Carolina. However, the distribution and diversity of native freshwater mussels have been in a state of decline as of late. The freshwater Asiatic clam (*Corbicula fluminea*), introduced about 50 years ago, has become a prominent component of many coastal rivers (Lauritsen and Moxley 1983; Hyland et al. 2004), resulting in alteration of the benthic substrate and competition with native mollusks (Devick 1991).

6.2.3.2. Estuarine

Estuarine soft bottom supports a high diversity of benthic invertebrates, with over 400 species documented in North Carolina waters (Hackney et al. 1996; Hyland et al. 2004). Most benthic invertebrates inhabiting soft bottom live in the sediment (infauna), as opposed to the sediment surface (epifauna), because of the high mobility of this habitat (Peterson and Peterson 1979). On intertidal flats, the sediment provides a buffer from drastic fluctuations in salinity, water temperature, and air temperature (in addition to air and wind exposure) during each tidal cycle, allowing infauna to flourish under these normally stressful conditions (Peterson and Peterson 1979). Infauna can be separated into three distinct size classes: microfauna, meiofauna, and macrofauna. Microfauna are comprised of very small protozoans (< 0.06 mm) and include foraminifera and ciliates. Meiofauna, such as nematodes and copepods, are about 0.06 – 0.50 mm in size (the size of a sand grain) and generally live within the interstitial spaces of sands or within the top centimeter of muds. Both microfauna and meiofauna are important grazers on estuarine microphytobenthos 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).

Benthic infauna may also be classified by feeding mode, specifically as deposit feeders or suspension feeders (Peterson and Peterson 1979; Miller et al. 1996). Deposit feeders include mud snails, polychaete worms, and certain bivalve clams and crustaceans that ingest sediment and detrital particles, and assimilate the associated bacteria, fungi, and microalgae. Suspension feeders capture particles suspended in the water column and include bivalves such as the hard clam (*Mercenaria mercenaria*) and razor clam (*Tagelus plebeius*), and some polychaete worms (Miller et al. 1996). A large proportion of suspension feeders' diet may consist of resuspended benthic microalgae, particularly when chlorophyll *a* concentrations in the water column are low (Miller et al. 1996; Page and Lastra 2003).

Benthic epifauna consist of larger, mobile invertebrates that live on the surface of soft bottom. Fiddler crabs (*Uca* spp.), amphipods, and insects congregate on intertidal flats, foraging for microalgae and detritus. On submerged flats and shallow bottom, the blue crab (*Callinectes sapidus*) functions as an important predator and scavenger. Other mobile epifauna include horseshoe crabs (*Limulus polyphemus*), whelks (*Busycon* spp.), tulip snails (*Fasciolaria* spp.), moon snails (*Polinices duplicatus*), penaeid shrimp, hermit crabs (*Pagurus* spp., *Petrochirus* spp., and *Clibanarius vittatus*), sand dollars (*Mellita quinquiesperforata*), and spider crabs (*Libinia* spp.).

6.2.3.3. Marine

Benthic invertebrate species composition and diversity varies greatly from oceanfront beaches to subtidal marine soft bottom. A diverse assemblage of meiofauna (0.06 – 0.5 mm) occurs in the intertidal zone of the lower beach (Levinton 1982; Hackney et al. 1996), while a relatively low diversity of macrofauna (> 0.5 mm) (~ 20 – 50 species) exists (Hackney et al. 1996). The dominant macrofauna in North Carolina's oceanfront intertidal beaches are mole crabs (*Emerita talpoida*), coquina clams (*Donax variablis, D. parvula*), several species of haustoriid amphipods, and the spionid polychaete *Scolelepis squamata* (Hackney et al. 1996; Donoghue 1999; Lindquist and Manning 2001; Peterson et al. 2006).

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. Offshore sand bottom communities along the North Carolina coast have been reported to contain over 600 species of benthic invertebrates (Posey and Alphin 2002), with over 100 polychaete taxa (Lindquist et al. 1994; Posey and Ambrose 1994). Posey and Alphin (2002) found that polychaetes dominated the benthic invertebrate assemblage on soft bottom offshore from Kure Beach, although bivalves, crabs, and amphipods were also highly represented. On ebb tide deltas, spionid and oweniid polychaetes, haustoriid and phoxocephalid amphipods, venus clams, tellin clams, and lucina clams are the dominant infauna (Bishop et al. 2006), while decapod crustaceans and echinoderms (sand dollars) are abundant epifauna. Given that 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; Posey and Alphin 2002).

6.2.4. Fish utilization

Like the water column, soft bottom is used to some extent by almost all native coastal fishes in North Carolina. Estuary-dependent migratory species, including spot, Atlantic croaker, and penaeid shrimp are common components of the estuarine soft bottom during summer and fall (Weinstein 1979; Epperly 1984; Ross and Epperly 1985; Noble and Monroe 1991; Ross 2003). Spot and Atlantic croaker also frequent shallow (< 10 m) nearshore soft bottom, where they dominate the benthic fish assemblage (Wenner and Sedberry 1989). Certain species, such as flatfish, skates, and rays, are best adapted to, characteristic of, or dependent on shallow unvegetated bottom (Peterson and Peterson 1979; Burke et al. 1991; Walsh et al. 1999; Schwartz 2003). Habitat utilization patterns by fishes on soft bottom are primarily related to season and ontogenetic stage (Walsh et al. 1999; Ross 2003). Table 6.3 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.

Table 6.3. 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.

Species*	Soft bottom functions [1]					2010 Stock status [2]
	Spawning	Nursery	Foraging	Refuge	Corridor	
ANADROMOUS SPAWNING						
Atlantic sturgeon	X	X	X		X	D
Shortnose sturgeon	X	X	X		X	E
ESTUARINE AND INLET SPAWNING AND NURSERY						
Hard clam	X	X	X	X		U
Hermit crab spp.	X	X	X			
Horseshoe crab	X	X	X			
Mud crab spp.	X	X	X			
Mummichug	X	X	X			
Red drum	X	X	X			R
Sheepshead minnow	X	X	X			
Whelks	X	X	X			
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY						
Atlantic croaker		X	X			C
Hogchoker	X	X	X	X	X	
Penaeid shrimp		X	X	X	X	V
Southern flounder		X	X	X	X	D
Spot		X	X			C
Striped mullet		X	X			V
MARINE SPAWNING, HIGH SALINITY NURSERY						
Atlantic stingray	X	X	X	X	X	
Coastal sharks[3]	X	X	X			C
Cownose ray	X	X	X	X	X	
Florida pompano		X	X			
Gulf flounder		X	X	X	X	
Gulf kingfish		X	X			U
Smooth dogfish	X	X	X			
Spiny dogfish		X	X			V
Striped anchovy		X	X			
Summer flounder	X	X	X	X	X	R

* Scientific names listed in Appendix D. 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: Hildebrand and Schroeder (1972); Lippson and Moran (1974); Peterson and Peterson (1979); Wang and Kernehan (1979); Manooch (1984); Thorpe et al. (2003)

[2] V = Viable, R = Recovering, C = Concern, D = Depleted, U = Unknown (DMF 2009), E= federally and state listed as endangered (http://www.ncdmf.net/stocks/2010NCDMF%20StockStatusReport.pdf)

[3] Incl. Atlantic sharpnose, blacknose, blacktip, bonnethead, dusky, sandbar, scalloped hammerhead, and spinner sharks

6.2.5. Specific biological functions

6.2.5.1. Foraging

One of the most important functions of soft bottom habitat is as a foraging area. In freshwater reaches, high concentrations of organic matter and the associated secondary production (i.e. benthic invertebrates) support a diverse array of freshwater fishes. Several species of coastal freshwater fishes, including yellow perch (*Perca flavescens*), bluegill (*Lepomis macrochirus*), and channel catfish (*Ictalurus punctatus*), rely heavily on benthic food resources, such as mayfly nymphs, chironomids, corixids, and tendipedid larvae, for maintaining elevated growth rates (Bailey and Harrison 1948; Flemer and Woolcott 1966; Lott et al. 1996; Schaeffer et al. 2000). In North Carolina, largemouth bass (*Micropterus salmoides*) and white catfish (*Ameiurus catus*) have been reported to forage on both benthic-associated crustaceans and fishes in oligohaline, intertidal rivulets of the upper Cape Fear River Estuary (Rozas and Hackney 1984).

Reliance on benthic productivity for food is not unique to freshwater areas. Members of several trophic levels, including primary, secondary, and tertiary consumers, benefit directly or indirectly from detrital and benthic microalgal production, as well as the numerically abundant and diverse invertebrate fauna associated with estuarine soft bottom (Peterson and Peterson 1979). On shallow intertidal flats, planktonic and benthic feeding herbivorous fish, such as anchovies, killifish, and menhaden, consume phyto- and zooplankton in the water column, as well as resuspended benthic algae, microfauna, and meiofauna (Peterson and Peterson 1979). While numerous fish species use detritus as an alternate food source when preferred items are not available, striped and white mullet feed preferentially on detritus collected on estuarine soft bottom.

Most fish that forage on estuarine soft bottom are predators of benthic invertebrates. These fish include juvenile and adult rays, skates, flatfish, drums, pigfish, sea robins, lizardfish, gobies, and sturgeons (Peterson and Peterson 1979; Bain 1997). Larger piscivorous fishes typically move onto estuarine flats during high water to feed on schools of baitfish. These predators include sharks (sandbar, dusky, smooth dogfish, spiny dogfish, Atlantic sharpnose, and scalloped hammerhead), drum (weakfish and spotted seatrout), striped bass, and estuary-dependent reef fish (black sea bass, gag grouper, sand perch) (Peterson and Peterson 1979; Thorpe et al. 2003). Flatfish, rays, and skates are particularly adapted to forage on shallow intertidal flats due to their compressed body forms (Peterson and Peterson 1979). Small flatfish, (i.e. bay whiff, fringed flounder, hogchoker, and tonguefish), feed mostly on copepods, amphipods, mysids, polychaetes, mollusks, and small fish. Summer and Southern flounder, larger flatfish primarily consume fish, such as silversides and anchovies, as well as shrimp and crabs, small mollusks, annelids, and amphipods (Peterson and Peterson 1979; Burke 1995). These larger flatfish will ambush their prey by blending into the bottom sediments or by slowly stalking prey items (Sharf et al. 2006). Various rays excavate large pits while searching for mollusks, annelids, crustaceans, and benthic fish prey (Cross and Curran 2004). In the Chowan Creek Channel, SC Cross and Curran (2004) observed an average of 17.8 % of the intertidal surface was disturbed by pit formation not including excavation piles. *Due to the increasing numbers of rays in NC, the impact of ray foraging pits in NC waters should be examined.*

Ocean soft bottom, particularly in the surf zone, and along shoals and inlets, serves as an important feeding ground for numerous fishes that forage on benthic invertebrates (Peterson and Peterson 1979). These predators generally have high economic value as recreational and commercial fisheries, and include Florida pompano, red drum, kingfish, spot, Atlantic croaker, weakfish, Spanish mackerel, and striped bass. Many of these species congregate in and around distinct topographic features of the subtidal bottom, such as the cape shoals, channel bottoms, sandbars, sloughs, and ebb tide deltas during various times of the year, presumably to enhance successful prey acquisition or reproduction. *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.*

Hard bottom fishes are also supported by the food resources present in and on soft bottom. Demersal zooplankton and infauna from sand substrate have been found to be an 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).

6.2.5.2. Spawning

Many demersal fish spawn over soft bottom habitat in North Carolina's coastal waters (Table 6.2). In freshwater, largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*) spawn on shallow flats where they lay eggs in bowl-shaped nests. Longnose gar occasionally spawn in the depressions made by these fishes, exploiting the brood care afforded by nest-defending species. Anadromous fishes, such as Atlantic and shortnose sturgeon (*Acipenser oxyrinchus oxyrinchus* and *A. brevirostrum*, respectively), will spawn in the upper freshwater portions of coastal rivers (Moser and Ross 1995).

In estuarine reaches, resident fish and invertebrates, as well as seasonal migratory fish spawn over soft bottom, particularly in summer. Resident flatfish, including hogchokers and tonguefish, use subtidal estuarine soft bottom as spawning grounds (Hildebrand and Schroeder 1972; Manooch 1984). Estuarine invertebrates, like hard clams, whelks, and hermit crabs use the intertidal flats that they inhabit as their primary spawning habitat. Migratory estuarine spawners, including several species of drum, predominately spawn over soft bottom during the summer months. Spotted seatrout spawn on the east and west sides of Pamlico Sound during a similar time period, with peak activity observed around Rose Bay, Jones Bay, Fisherman's Bay, and Bay River (Luczkovich et al. 1999a; Luczkovich et al. 2008). Red drum were also 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; Luczkovich et al. 2008). The evidence for blue crabs spawning in inlet areas was enough to warrant their protection as Crab Spawning Sanctuaries (DMF 2004 – blue crab FMP).

Several species of estuary-dependent fishes use ocean soft bottom as critical spawning habitat during winter, primarily seaward of state waters. Eggs and larvae of these species are carried by currents through nearshore state waters and inlets to estuarine nursery areas. Important spawning aggregations of summer flounder occur during winter on Wimble, Platt, and Kinnekeet shoals off the Outer Banks (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.

Nearshore ocean waters in North Carolina also serve as important pupping grounds for several species of sharks. North of Cape Hatteras, pupping of spiny dogfish over subtidal bottom has been documented in winter months (ASMFC 2002a). 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 from this area are found in June and July (Beresoff and Thorpe 1997; Thorpe et al. 2003).

6.2.5.3. Nursery

Shallow soft bottom, usually adjacent to wetlands, is utilized as a nursery for many species of juvenile fish (Table 6.2). This habitat provides an abundance of food and is relatively inaccessible to larger predators. Shallow unvegetated flats have been documented as being a particularly important nursery habitat for summer and southern flounder, spot, Atlantic croaker, and penaeid shrimp (Weinstein 1979; Burke et al. 1991; Walsh et al. 1999; Ross 2003). Ongoing DMF juvenile fish monitoring has found that shallow unvegetated bottom supports an abundance of juvenile fish, composed of relatively few species that have similar life histories and feeding patterns (Ross and Epperly 1985).

The dominant fishes using shallow estuarine soft bottom as nursery areas are estuary-dependent species, which primarily spawn offshore in winter. For many species, the uppermost reaches of shallow creek systems correspond to the site of larval settlement, i.e. the primary nursery areas (Weinstein 1979; Ross and Epperly 1985). However, in tributaries far removed from ocean inlets, such as Neuse, Pamlico, Bay and Pungo rivers, larval settlement tends to occur in lower reaches of the system. Abundance of juvenile species in estuarine nursery areas generally peaks between April and July and is correlated with water temperatures (Ross and Epperly 1985). As they grow, fish move to deeper waters and areas farther down-estuary.

In the early 1980s, fishery independent data from shallow creeks and bays in Pamlico Sound documented 78 fish and invertebrate species over a two-year period (Ross and Epperly 1985). Eight species, including spot, bay anchovy, Atlantic croaker, Atlantic menhaden, silver perch, blue crab, brown shrimp, and southern flounder, comprised more than 97% of the total nekton 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 nekton assemblage, with pinfish and white shrimp also among the most abundant species collected. The consistency of catch characteristics during 1990-2008 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.*

Historical analyses of DMF's juvenile fish data in the Pamlico Sound system have found significant geographical differences in the fish assemblages (Ross and Epperly 1985; Noble and Monroe 1991). Noble and Monroe (1991) identified four distinct groupings of juvenile fish (Table 6.4), with salinity functioning as the primary abiotic variable structuring species composition. Fish assemblages in Pamlico Sound also have been found to be affected by Bluff Shoal, which runs across the sound from around Ocracoke Inlet north to Bluff Point. Bluff Shoal effectively splits Pamlico Sound into separate basins of differing depth and sediment composition, causing distinct fish assemblages to occur north and south of the shoal (Ross and Epperly 1985).

Table 6.4. 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

Soft bottom in freshwater areas and the nearshore ocean also function as valuable nursery habitat for numerous fish species. Benthic anadromous fish, such as Atlantic and shortnose sturgeon, use freshwater soft bottom as a primary nursery during spring and summer. In the nearshore ocean, subtidal soft bottom is used extensively as a nursery area for coastal sharks, such as spinner (*C. brevipinna*), blacknose (*C. acronotus*), and dusky (*C. obscurus*) sharks (Beresoff and Thorpe 1997; Thorpe et al. 2003). Ocean soft bottom, particularly the surf zone, is also a nursery area for Florida pompano, and southern and gulf kingfish (Hackney et al. 1996). Juvenile Atlantic sturgeon and spiny dogfish, both demersal feeders, have been documented over nearshore subtidal bottom between Oregon Inlet and Kitty Hawk during winter months (Cooperative Striped Bass Tagging Program, unpub. data). In New Jersey, Able et al. (2009), observed recently hatched juvenile fish in the surf zone during the spring and summer months.

6.2.5.4. Refuge

Shallow soft bottom, such as intertidal flats, can provide refuge to small and juvenile fish and invertebrates through exclusion of large fish predators (Peterson and Peterson 1979; Ross and Epperly 1985). Consequently, juvenile fish benefit from settling in the shallowest portions of the estuary first. Many fish and invertebrates, including hard clams, flatfish, skates, rays, and other small cryptic fish, like gobies, avoid predation by burrowing partially or completely into the sediment, thus camouflaging themselves from predators (Peterson and Peterson 1979; Luettich et al. 1999). Deep water soft bottom habitat may be a treacherous environment for small fish and invertebrates, particularly for those that cannot burrow. These areas are generally the most accessible to large piscivorous fishes and because of this, many fish venture out on the open bottom only at night (Summerson and Peterson 1984).

6.2.5.5. Corridor and connectivity

Numerous migrating juvenile and subadult demersal fishes use soft bottom as corridors for movement from freshwater and estuarine nursery habitats to the coastal ocean. As fishes grow, they slowly move from up-estuary primary nurseries down estuary to secondary nurseries and eventually out into the coastal ocean. Because large fish are less likely to be consumed as prey, they can travel relatively safely over the less turbid sand flats and channels of the middle and lower estuary (Walsh et al. 1999). However, juvenile summer flounder were found in higher density in muddy bottoms that were adjacent to wetlands, than areas in sandy bottoms (Walsh et al. 1999). In fact, substrate type is the most important factor influencing juvenile summer flounder habitat (Burke 1991 and Burke et al. 1991). Anadromous fish, including sturgeon and striped bass, also require a corridor of soft bottom to reach upstream spawning areas.

While connectivity among structured habitat patches, such as SAV, wetlands, and shell bottom, facilitates movement of mobile predators, 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. In Back Sound, North Carolina, Micheli and Peterson (1999) documented higher densities and survival rates of small crabs, gastropods, and infaunal bivalves on isolated oyster reefs (at least 10-15 m of unvegetated bottom between habitats) than on oyster beds adjacent to salt marsh or SAV. Blue crab predation on infaunal bivalves was greater along vegetated edges of salt marshes and SAV than on unvegetated intertidal flats (Micheli and Peterson 1999). Although structural habitat separations by unvegetated soft bottom may benefit the viability of infaunal populations, fish and crustacean productivity may be enhanced by connectivity of structured estuarine habitats (Micheli and Peterson 1999).

6.3 STATUS AND TRENDS

6.3.1. 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, wetlands, 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.

6.3.2. Status of associated fishery stocks

<u>6.3.2.1. Fishery independent monitoring programs</u>

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. Although the data is not discussed here, the Pamlico Sound Survey is another long-term monitoring program used to calculate juvenile abundance indices (JAI) in Pamlico Sound and the lower portion of the Pamlico and Neuse estuaries. JAI, the annual geometric mean (weighted by strata) of the number of individuals per tow for young of the year fish and invertebrates, are calculated from these sampling programs for important fish and invertebrate species. The JAI is considered an accurate indicator of recruitment and year-class strength for many recreational and commercially important species (DMF 2003c). The information is used to determine stock status of fishery species by various fishery management agencies. JAI 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. Trends in JAI may indicate change in the habitat conditions (DMF 2003c). However, consistent and comparable JAI data are only available since 1990 and, prior to this time, considerable habitat losses and changes occurred. Habitat information has been collected by NCDMF for the Estuarine Trawl survey since the beginning, while this information has only been collected for Pamlico Sound Trawl Survey since 2009. Currently a Sea Grant project is being completed by East Carolina University researchers examining the impacts of land use change on several species of fish and invertebrates using NCDMF Estuarine Trawl Survey data (J. Luczkovich/ECU, pers. com., 2009).

Several species are closely linked to soft bottom habitat and juvenile abundance indices from the Estuarine Trawl Survey for recreationally and commercially important species (i.e. southern flounder , spot, and Atlantic croaker) are shown in Figure 6.1 and 6.2. Southern flounder JAIs have varied between 1 and 8.1 with peak JAIs in 1996 and 2003 (Figure 6.1). While there were large declines in 1997, 1998, 2002 and 2004 through 2006. Atlantic croaker and spot are benthic feeding fish that could be affected by changes in soft bottom habitat, such as reductions in benthic food sources due to toxicity or anoxic conditions in sediments. The JAI for Atlantic croaker from the Estuarine Trawl Survey has fluctuated between 8.6 and 97.1 while spot have fluctuated between 50 and 350 (Figure 6.2). An Atlantic croaker ASMFC FMP was completed in 1987 and is in the process of being updated in 2009. The stock assessment determined that Atlantic croaker is a recruitment-driven stock, where biomass and landings fluctuate in response to large year classes. Research priorities for Atlantic croaker include determining the impacts of any dredging activity (i.e. for beach re-nourishment) on all life history stages of croaker (ASMFC 2009).

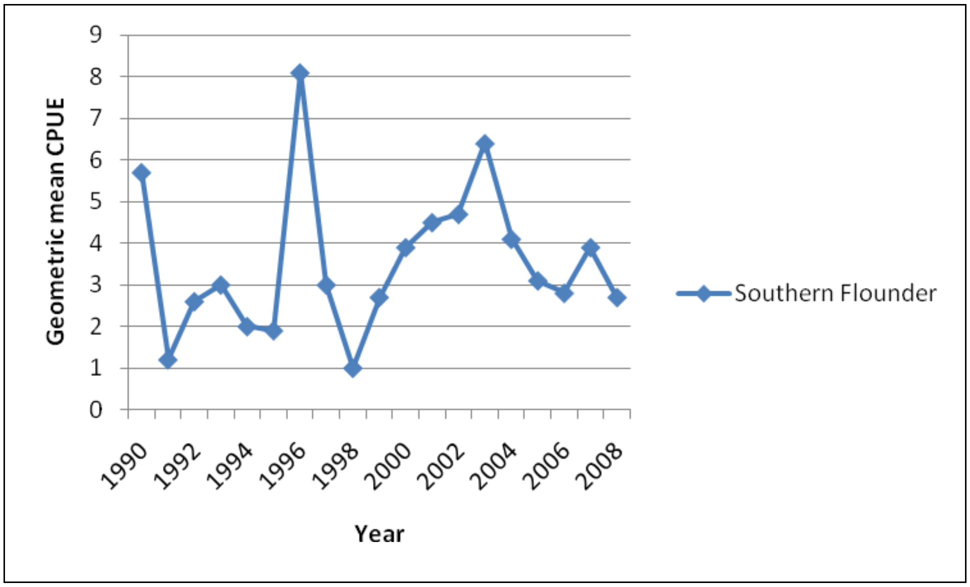


Figure 6.1. Southern flounder juvenile abundance indices (geometric mean CPUE) from DMF Estuarine trawl survey, core stations sampled in May and June, 1990-2008.

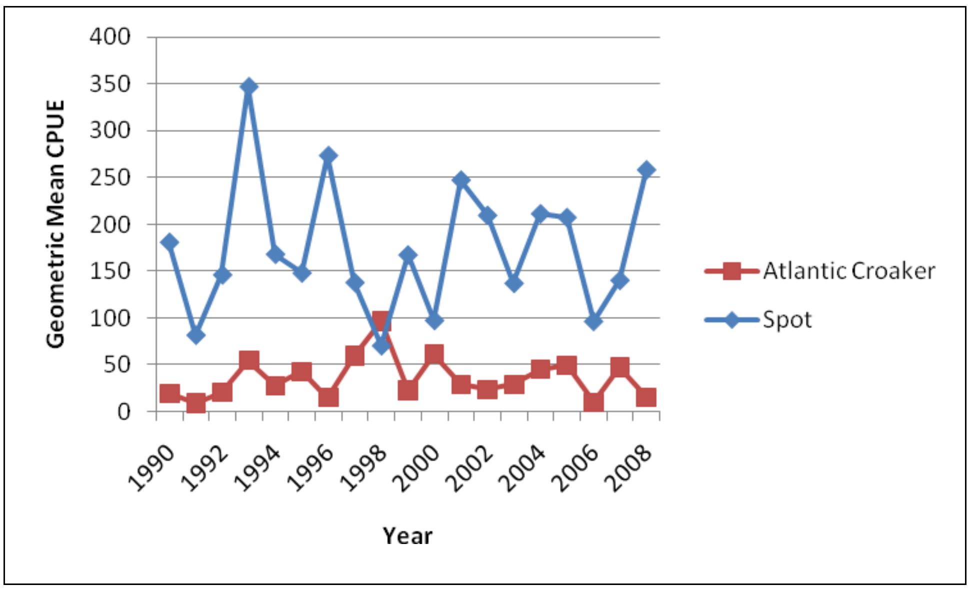


Figure 6.2 Spot and Atlantic croaker juvenile abundance indices (geometric mean CPUE) from DMF Estuarine trawl survey core stations sampled in May and June (1990-2008).

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 currently provides the only region-wide standardized surveys for monitoring long-term (1983-present) 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.

The status of benthic macroinvertebrate populations is another measure of soft bottom conditions. 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 2009). 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. From 1978 to 2001 *Mercenaria mercenaria* recruitment in central North Carolina decreased 65-72% while fishing pressure for hard clams has continued to increase (Peterson 2002). *Reducing the area available to mechanical clam harvesting is another means of protecting clam stocks, particularly in location within close proximity of SAV habitat*.

In 2010 the stock status of twelve of 18 soft bottom associated fishery species (bolded species in Table 6.2) were evaluated by NCDMF (http://www.ncdmf.net/stocks/2010NCDMF%20StockStatusReport.pdf). Of these twelve species, two (17%) were of unknown status. Of the ten stocks whose status is known, two (20%) were classified as Viable, two (20%) were Recovering, four (40%) were of Concern, and two (20%) were Overfished (Table 6.2,). Viable species included penaied shrimp and striped mullet; red drum and summer flounder were Recovering. Depleted species included Atlantic and shortnose sturgeons and southern flounder. The species listed as Concerned include blue crab, Atlantic croaker, spot, and coastal sharks.

Atlantic sturgeon has 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). In 2009, the Atlantic sturgeon has been petitioned to be classified as a federally endangered species. A decision on this petition should be reached in 2010. Despite a fishing moratorium in North Carolina since 1991 both sturgeon species have not shown signs of recovery, 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. The Cape Fear River and Albemarle Sound are the only estuaries in NC that presently show evidence of spawning for the Atlantic sturgeon. The Interstate Fishery Management Plan for Atlantic sturgeon has listed dredging as a major concern (ASMFC 1998) to essential habitat for sturgeon.

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 Depleted status of southern flounder is due in part to overfishing but may also be related to habitat issues in the low salinity estuaries. Dredging (navigational and fishery) and inlet stabilization are listed as threats to Southern flounder habitat in the NCDMF 2005 FMP. 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 updating the southern flounder Fishery Management Plan in 2009.

Striped mullet are of concern primarily due to an increase in associated fishing effort. The Division developed a Fishery Management Plan for striped mullet in 2005. As a result of the 2005 FMP, one objective is to “Restore, improve, and protect critical habitats that affect growth, survival, and reproduction of the North Carolina striped mullet stock" (DMF 2005-Striped mullet FMP). Atlantic croaker is listed as Concern because JAIs and estuarine landings have remained low.

6.3.3. 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. In 2004, DCM compiled an inventory of existing marine managed areas prior to assessing the need and feasibility of establishing new MPAs in North Carolina. In 2004, there were 84 state sites, 13 de facto sites, and 7 federal sites in the Marine Managed Area (MMA) inventory that were located within North Carolina; with a proposal to include three more federal sites (Trappe 2004). Additionally, 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.

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, Anadromous Nursery Areas, and crab spawning sanctuaries (See "Designation" section of Water Column chapter for more information). Most of the North Carolina PNAs have soft muddy bottoms that are surrounded by marshes and wetlands (<http://www.ncfisheries.net/habitat/pna.htm>, 2009).

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>, 2009). 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>, 2009) for maps of the designated areas.

6.4. THREATS AND MANAGEMENT NEEDS

Although the soft bottom habitat is always changing, there are several threats to the overall habitat stability. These threats may be direct impacts to the soft bottom or they may affect water quality thereby altering the soft bottom community. As people continue to live in coastal North Carolina, there will be continued channel dredging, dock construction, shoreline stabilization, and commercial fishing. These methods may all potentially be detrimental to the soft bottom habitat. Water quality will also continue to be affected by increased nutrient input and heavy metal contamination.

6.4.1. Physical threats

6.4.1.1. Water-dependent development

Dredging (navigation channels and boat basins)

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 2000c). Spawning activity around the inlets occurs from May through October, depending on the species (Table 2.3 in Water Column chapter). Because spawning activity occurs at night, daytime dredging may have less of an effect. 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., 2009). While new dredging is prohibited in designated Primary Nursery Areas, and seasonally restricted in Anadromous Fish Spawning Areas, similar restrictions do not exist for undesignated anadromous fish nursery areas, which require shallow bottom habitat. Some anadromous species also require shallow bottom for spawning. *Permitting agencies should avoid or minimize dredging projects in Anadromous Fish Spawning Areas and important associated anadromous fish nursery areas.*

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. In order to reduce the effects of sedimentation on benthic invertebrates the USACE dredging procedures include dredging during outgoing tides. *More research is needed to assess direct and indirect dredging impacts on blue crabs and inlet spawning species*.

Map 2.8 a-b 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 may require dredging in shallow, undesignated nursery habitats. Converting shallow bottom into deeper basins and channels is likely to reduce primary and secondary productivity of the bottom (Wendt et al. 1990). As of November 2009, the USACE had completed 5 navigational dredging maintenance projects in NC, while 17 projects were ongoing or scheduled to start in the 2009 fiscal year. *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.*

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 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 (Parnell et al. 1986).

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. Sidecast dredging only occurs within shallow inlet systems in North Carolina with course grained sediment in order to minimize turbidity impacts and keep littoral sediment within the system. No open water sidecast dredging occurs in estuarine areas with fine grained sediments and subsequent high turbidity concerns. Hopper dredges also take dredged material from navigational channels and dispose of the sediment within designated dredged material disposal sites. All littoral material dredged with a hopper is disposed within designated nearshore disposal areas to keep the material within the littoral system in accordance with state requirements. 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). According to Bolam and Rees (2003) the recovery time for macrobenthos varied (greater than 1 year), but was related to how stable the environment is, the more stable prior to deposition, the longer the recovery time. All other offshore disposal is in accordance with EPA requirements for designated Offshore Dredged Material Disposal Sites (ODMDS). Currently there are three designated EPA approved ocean dredge material disposal sites off North Carolina, one off Beaufort Inlet and two off Cape Fear River Inlet (Maps 6.3a-c). All three are located just seaward of the state territorial seas (http://www.epa.gov/region4/water/oceans/sites.html#wilmington 2010). A significant amount of sediment testing, including bioassays, is conducted on dredged material before being placed in designated ODMDS sites; therefore, contaminated sediments are not authorized for ocean disposal. Disposed dredge material that contains elevated levels of toxic contaminants may have adverse impacts on the benthic community through bioaccumulation (Winger et al. 2000).

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 (Iannuzzi 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 (polycyclic aromatic hydrocarbons) 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 (Wendt et al. 1990), some pollution sensitive species of polychaetes were more abundant at control sites than at 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.

The presence of docks can alter the young-of-year fish population present. In the Hudson River, New York and New Jersey, Able et al. (1998) examined the impacts docks had on the YOY fish population present under docks. Although most YOY fish tend to utilize complex habitats for refuge from predators, several studies found fewer fish that feed using sight under piers than in adjacent areas (Able et al 1998 and Duffy-Anderson et al. 2003). This difference may be due to light not penetrating under the pier. YOY winter flounder *(Psuedopleuronectes americanus)*, (a species similar to southern flounder) had faster growth rates and consumed more prey in caged areas at pier edges than those under piers (Duffy-Anderson and Able 1999).

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 water column chapter, and the location of marinas in North Carolina was shown in Map 2.8 a-b. 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). 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. Based on DEH-SS shoreline surveys in SA, SB, and SC waters, there is approximately one multi-slip docking facility[44] for every 7 miles of shoreline in coastal North Carolina (see “Marinas and multi-slip docking facilities” section of Water Column chapter for more information). 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 navigable waters (SAFMC 2009). Either situation can significantly reduce primary or secondary productivity (F. Rohde/DMF, pers. com., 2009). Recent rule changes by the CRC, allow for piers and docking facility to be constructed if the following two conditions are met: (1) Water depth at the docking facility is equal to or greater that two feet of water at normal low water level or normal water level (whichever is applicable). (2) The pier and docking facility is located to minimize the area of submerged aquatic vegetation or shellfish beds under the structure” [CRC rule 15A NCAC 07H.1205(h)]. The general permit requirements also include a minimum water depth of 18 inches when a floating dock is proposed over PNA, shellfish, or SAV. *Dock siting criteria should include a minimum water depth over all habitats to prevent boats or floating docks from sitting directly on shallow soft bottom.*

Multi-slip 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 currently more marinas than multi-slip docking facilities along estuarine shorelines (see “Marinas and multi-slip docking facilities” section of Water Column chapter for more information). As waterfront property becomes increasingly developed, requests for new piers, docks, and marinas in shallower and less suitable locations will likely increase (see “Marinas and mult-slip docking facilities” section of Water Column chapter for more information). *Research is needed on the cumulative impact of docks and marinas on soft bottom and other fish habitats*

[44] Includes both marinas and multi-slip docking facilities

in North Carolina.

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. 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, which impacts the function of intertidal shoreline and shallow water habitat as nursery, feeding, and spawning grounds to fish species in North Carolina. Multiple studies have shown that the diversity and abundance of invertebrates and juvenile fish is lower adjacent to bulkheaded areas than natural shorelines (Mock 1966; Ellifrit et al. 1972; Gilmore and Trent 1974; O'Rear 1983; Byrne 1995; Peterson et al. 2000c; Waters and Thomas 2001; Seitz et al. 2006; Bilkovic and Roggero 2008; Partyka and Peterson 2008). Deepening of waters adjacent to the bulkhead structure allows large piscivorous fish access to previously shallow nursery areas, enhancing their feeding efficiency on small and/or juvenile fishes looking for shallow water (Rozas 1987). Non-vertical structures, such as marsh sills, offer an alternative to bulkheads that may have less long-term impact on shallow soft bottom habitat, as well as wetlands and submerged aquatic vegetation. However the larger footprint of a marsh sill can result in some habitat tradeoff from soft bottom to wetlands and rock and/or oysters. 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. Despite this incentive, only 12 general permits and 22 major permits have been issued for marsh sill construction. Refer to the wetlands chapter for additional information on the impact of shoreline stabilization to that habitat, efforts agencies have taken to revise shoreline stabilization rules to minimize impacts from shoreline hardening, and remaining management needs that should be implemented.

An additional concern of wooden bulkheads is the toxicity of preserved wood to certain aquatic organisms. Chemically treated wood is also used for dock and marina construction. 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 (i.e. oysters, amphipods, polychaetes, fiddler crabs, mud snails, fish embryos, and sea urchin) (Weis and Weis 1994 and Weis et al. 1998). 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 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).

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). (refer to wetlands chapter on DCM shoreline study to assess extent of shoreline alterations) Toxicity of wood decreases with time but CCA can continue leaching for many years. In addition, bulkheads and docks need to be replaced periodically, providing a continual source of newly treated wood in coastal waters. In 2003, the EPA required new labeling on all CCA products specifying use restrictions. The lumber industry voluntarily agreed to eliminate use of CCA for residential use, although CCA is still being used in certain marine and industrial applications. Local home stores or lumberyards now sell lumber treated with less toxic alternatives such as amine copper quat (ACQ), copper azone (CA). Alternative wood preservatives containing copper or other chemicals may have similar toxicity to marine organisms. Rock sills and revetments are non-wood shoreline stabilization alternatives that do not require any chemical preservatives. *Due to the toxic sediment contamination associated with pressure treated wood, revised shoreline stabilization rules should require or encourage use of non-wood materials or wood that is not toxic to benthic organisms. Any new wood preservative products should be evaluated for toxicity to marine benthic organisms and juvenile fish.*

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 are located adjacent to inlets with the purpose of maintaining navigation in the inlet by preventing sand from entering it. In contrast, terminal groins are structures built at the end of a littoral cell to trap and conserve sand along the end of the barrier island, stabilize inlet migration, and widen a portion of the updrift beach. Terminal groins are designed so that when the area behind the groin fills in with sand, additional sand will go around the structure and enter the inlet system.

It is well accepted that hard stabilization techniques along high energy ocean shorelines will accelerate erosion in some location along the shore as a result of the longshore sediment transport being altered (Defeo et al. 2009). The hydromodifications resulting from coastal armouring modifies sediment grain size, increases turbidity in the surf zone, narrows and steepens beaches, and results in reduced intertidal habitat and diversity and abundance of macroinvertebrates (Walton and Sensabaugh 1979; NRC 1995; Dolan et al. 2004: 2006; Pilkey et al. 1998; Peterson et al. 2000a; Miles et al. 2001; Dugan et al. 2008 ; Walker et al. 2008; Riggs and Ames 2009). A study looking at the effect of a short groin (95m) on the benthic community found that the groin created a depositional condition on one side of the structure and erosion on the other, and macroinvertebrate diversity and abundance was significantly reduced within 30 m of the structure, as sand particle size and steepness increased (Walker et al. 2008). The change in benthic community was attributed to the change in geomorphology of the beach. Hard structures along a sandy beach can also result in establishment of invasive epibenthic organisms (Chapman and Bulleri 2003). A secondary impact of hardened structures is that the areal loss of beach resulting from hardening of shorelines is often managed by implementing nourishment projects, possibly having additional damage to subtidal bottom (Riggs et al. 2009). Anchoring inlets also prevents shoal formation and diminishes ebb tidal deltas, which are important foraging grounds for many fish species. Recognizing that hardened structures are damaging to 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).

Perhaps the greatest impact of terminal groins and jetties results in the long-term effect on barrier islands and the effect that will have on marine and estuarine ecosystems. By stabilizing the inlet, inlet migration and overwash processes are interrupted, causing a cascade of other effects (Riggs and Ames 2009). In the case of Oregon Inlet, the terminal groin anchored the bridge to Pea Island and stopped the migration of the inlet on the south side. But the continuing migration of the north end of Bodie Island led to an increased need for inlet dredging. The combination of reduced longshore transport of sediment due to the groin and the post-storm dune construction to open and protect the highway prevented overwash processes that allow Pea Island to maintain its elevation over time. With overwash processes disrupted, the beach profile has steepened, and the island has flattened and narrowed, increasing vulnerability to storm damage (Dolan et al. 2006; Riggs and Ames 2009; Riggs et al. 2009). At Oregon Inlet and Pea Island, the accelerated need for beach replenishment is further aggravated by the need to maintain Hwy 12 on the narrowing beach. From 1983 to 2009 approximately 12.7 million cubic yards of sand have been added to the shoreline within three miles of the terminal groin (Riggs and Ames 2009). Dolan (2006) documented that the large volumes of sand replenishment in this area, required to maintain the channel, protect the road, and maintain a beach have resulted in a significant reduction in grain size and reduction in mole crab abundance. Mole crabs are considered an important indicator of beach conditions due to their importance in the food web as prey for shorebirds and surf fish. In addition to causing erosion on downdrift beaches, altering barrier island migration processes, and accelerating the need for beach nourishment projects, jetties obstruct larval fish passage through adjacent inlets (Blanton et al. 1999). Disruption of larval transport is discussed in detail in the water column threats section.

In contrast, where natural coastal barrier island processes, such as overwash and the opening, closing, and shifting of inlets have occurred without manipulation, the islands have grown in width and elevation and migrated. Core Banks and Drum Inlet are an example of one of a barrier island with inlets that opened and closed throughout time (Mallinson et al. 2008). Drum Inlet initially opened in 1899, but closed and reopened multiple times during storm events. It is possible that several other areas that have historically had inlets will again in the future (i.e. Buxton Inlet, New Inlet, and Isabel Inlet) (Mallinson et al. 2008). When inlets open, the new sediment deposition of a flood tide delta aids barrier island migration and widening. *Where new inlets form, Mallison et al.(2008) recommended that allowing the inlets to remain open even if temporarily until a substantial flood tide delta forms, would allow for long-term maintenance and stability of the barrier island.* Ferries could be used on a temporary basis to allow critical transportation to continue.

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. Existing seawalls and revetments in North Carolina were constructed prior to CAMA (eg. Atlantic Beach) or were for the purpose of protecting historic structures (eg. Ft. Fisher). Existing jetties in North Carolina occur at Masonboro and Barden's inlets, terminal groins occur at Oregon and Beaufort inlets, and small groin fields were constructed at Bald Head Island and Hatteras Island.

Use of sandbags is a temporary method of erosion control that are permitted for protection to imminently threatened structures (shoreline less than 20 feet from structure) while their owners seek more permanent solutions, such as beach nourishment or relocation of the structure. While filled with sand, these bags are stacked and act like a seawall, although they can be removed more easily. Sandbag walls may remain in place for up to two years if the protected structure is 5,000 square feet or less, or for up to five years if the structure is larger than 5,000 square feet. Sandbags also may remain in place for up to five years – regardless of the protected structure's size – if the community in which it is located is taking part in a beach nourishment project. Sandbags may remain in place indefinitely if they have become covered with sand and stable natural vegetation. However, if a storm exposes them, they must be removed if their time period has expired. However, there has been difficulty in enforcing removal of temporary sandbags. As of July 2008, there were a total of 381 total sandbag structures on record, 150 of which were still installed with an expired removal date (K. Richardson/DCM, pers. com. 2009). In 2008, the CRC instructed all property owners with exposed sandbags that had exceeded their time limit to remove the bags. However, Session Law 2009-479 intervened on this action by implemented a moratorium on the removal of sandbags.

In the 2003 legislative session, House Bill 1028 was approved, putting into law the CRC prohibition on construction of permanent erosion control structures on ocean shorelines. However, there has been lobbying efforts by special interests to weaken this law by allowing the use of terminal groins. In 2009, Session Law 2009-479 mandated that the CRC 1) shall not order the removal of sandbags if actively pursuing a beach nourishment or inlet relocation project; and 2) shall conduct a study on the feasibility and advisability of use of terminal groins as an erosion control device at the end of a littoral cell or inlet, and present a report to the Environmental Review Commission and the General Assembly by April 1, 2010.

CRC and DCM contracted the study out to Moffitt and Nichols. The goals of the study were to:

- Characterize physical and environmental impacts of terminal groin structures,
- Determine engineering techniques used to construct terminal groins including those which may help minimize impacts on adjacent shorelines,
- Determine economic impacts of shifting inlets as well as potential construction/maintenance costs of terminal groin structures, and
- Determine whether the construction of terminal groins is both feasible and advisable in North Carolina, and if so, what are the types of locations where such structures function as designed with minimal impacts.

These questions were to be answered by assessing five existing terminal groins which had available data and were located in a similar environment as North Carolina's beach community. The study sites included Oregon Inlet and Beaufort Inlet in NC, Amelia Island/Nassau Sound in northeast Florida, and Captiva Island and St John's Pass, on the west coast of Florida. The study documented that constructing terminal groins resulted in the need for periodic nourishment behind the structures, where it had previously been futile due to dynamic inlet processes (Moffatt and Nichol 2010). Without nourishment, erosional impacts to adjacent beach areas would occur. This means that construction of terminal groins create a condition of long-term mandatory maintenance, increasing the expensive of beach management. The study found that the groins did reduce erosion rates immediately adjacent to the structure, but there was evidence of increased erosion about two miles downdrift, and on the opposite side of the inlet. However, effects were inconclusive because of simultaneous inlet dredging and sand disposal. The CRC terminal groin subcommittee concluded that use of terminal groins may be feasible but not advisable due to environmental consequences, expense, and large uncertainty of long-term impacts. However, the CRC voted to state that the study was inconclusive and therefore could not recommend for or against their use. *Because there is strong evidence available on the potential ecological impacts of hardened structures ,* *large uncertainty on the environmental impacts of terminal groins specifically, and no clear economic benefit from inlet stabilization, North Carolina should not reverse its position or policies on ocean shoreline hardening.* The long-term consequences of hardened structures on larval transport and recruitment should also be thoroughly assessed prior to approval of such structures (refer to water column chapter for details). Overall, the scientific evidence does not support changing North Carolina's policy on prohibition of shoreline hardening structures on the oceanfront.

Soft stabilization on oceanfront shorelines

Soft stabilization techniques available for oceanfront erosion control include beach bulldozing and beach nourishment. 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 largest biological impact of beach bulldozing appears to be reduction in ghost crab populations on the dry beach (Peterson et al. 2000b). 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; McNinch 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. There is also a federal bulldozing moratorium in NC from May 1 to November 15 to protect sea turtles.

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 USACE projects that result in sand being put on beaches: disposal projects and Coastal storm damage reduction projects. Disposal projects are placement of dredged material from maintenance dredging of navigation channels. Specifically, they do not include an engineered and constructed profile designed for protection purposes. Rather, the intent is to take dredged material from navigation dredging and place it on the recipient site. Disposal projects are generally smaller in magnitude than storm damage reduction projects, and can be expected to have a smaller impact on fish habitat. The sand source for disposal projects is inlet dredging. 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. Storm damage reduction projects have used sand from dredged channels, offshore borrow areas, ebb tide delta shoals, or inlet relocation. Erosion rates near inlets tend to be large and variable due to the natural migration processes of barrier islands. Because of that and the associated risk near inlets, CRC has designated Inlet Hazard Areas along barrier islands. Greater setbacks are required in these areas. Beach nourishment is generally not recommended immediately adjacent to the inlet because of the dynamic nature of the area and the expected low retention time of sand.

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) 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. Jay Bird Shoals, an ebb tide shoal off of the Cape Fear River, will be used as a mine site for Bald Head Island beaches in 2010. This shoal and adjacent waters are known for high fish productivity and diversity. The effect of the mining on this shoal or the adjacent downdrift Oak Island are unknown. It is also unknown what effect use of the cape shoals would have on fish productivity or how long recovery would take. 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	USACE 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; USACE 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 (USACE 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. Another potential concern of sand mining is impacts to nearby hardbottom from physical damage or elevated turbidity during the mining. Along many of the beaches in Onslow and Long Bays, low to high profile hardbottom is scattered along the coast, making mining without impacting hardbottom difficult.

Repeated use of a mine site for beach nourishment is generally not possible refilling of the borrow area with finer sediment or insufficient sand in the borrow areas 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 region’s 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). Hopper dredges tend to have long shallow dredge cuts and unimpacted ridges between cuts which facilitate recruitment into dredged areas while pipeline dredges have deep cuts. 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.

Since the 2005 CHPP, there has been increased interest from barrier island municipalities in use of the cape shoals as a sediment source for beach nourishment projects. Boss and Hoffman (2000) collected detailed information on the sand resources for 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. Research on Cape Lookout Shoal found that the cape associated shoals act as a barrier to longshore transport, diverting southerly flow of water and sediment seaward in a tidal-driven headland flow, resulting in net sediment transport and deposition onto the shoal. The shoals are maintained by this sediment transport and serve as a long-term sink for littoral sediment and limits exchange between adjacent littoral cells and shelf regions (McNinch and Wells 1999; McNinch and Luettich 2000).

Due to the increased interest in long-term storm damage reduction projects, there are also several projects requesting use of borrow areas in nearshore subtidal bottom for large storm reduction projects. This includes the Bogue Banks, Nags Head, Topsail Beaches, and Brunswick Beaches projects that are at various stages of the permit process. *When mine areas are necessary for beach nourishment projects, guidelines should strongly encourage siting protocol that maximize biological recovery rates, do not degrade critical fish foraging areas, do not impact hard bottom, and minimize impacts to longshore transport processes.* Many steps are already taken to minimize environmental impacts. State or National Environmental Policy Act (SEPA or NEPA) documents, likely including Environmental Impact Statements (EIS) or Environmental Assessments (EA), must be completed and reviewed prior to these projects being permitted. A memorandum of agreement between DCM and USACE 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 I). Existing CRC rules (15A NCAC 07H .0208(b)(12)(A)(iv)) require a 500 m buffer between dredging and high relief hard bottom. High relief is defined as relief greater than or equal to 0.5 m per 5 m of horizontal distance. Research has shown that there is a halo area around hard bottom which reef fish use as a foraging area to derive a significant portion of their diet. The halo distance was estimated to extend about 500 m from exposed hard bottom of any relief (Lindquist et al. 1994). *Because of this, the 2009 Ocean Policy report (NC Sea Grant 2009) recommended that CRC rule language be modified to require a 500 m dredging buffer around all hard bottom areas, including those of low relief that are periodically buried with thin ephemeral sand layers.*

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).

Factors likely affecting the recovery time of the intertidal beach community include:

- compatibility of deposited material with native sand (sediment grain size)
- seasonal timing of nourishment
- time period between renourishment events on an individual site volume, depth, and length of sand
- alteration of the beach geomorphology
- location placed on the beach
- longshore transport conditions (higher transport results in more rapid recruitment

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).

Table 6.5. Reported biological recovery times at nourished ocean beaches.

Locaton	Biological recovery following beach nourishment	Reference
Bogue Banks, NC	Mole crabs recovered within months, coquina clams and amphipods failed to initiate recovery after one growing season. No follow up sampling.	Peterson et al. 2006
Bogue Banks, NC	On ebb tide delta, where sediment deposited, significant coarsening of sediment, and reductions in spinoind polychaetes after 8 mo.	Bishop et al. 2006
Bald Head Island, Caswell Beach, Oak Island, NC	Coquina clams, mole crabs - > 1 year. Abundance declined 1 – 10 times from control. Most severe reductions and longest times of recovery due to season of project – greatest in spring and summer, except Oak Island coquina clams recovered within 1 year - timing of sand deposition allowed summer recruitment.	Versar 2003
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.	USACE 2001

Similarity between native and introduced sediments is considered to be the most important factor determining the rate of recovery of beach invertebrate populations following nourishment (Nelson 1993; Peterson et al. 2000). Due to these problems, the 2005 CHPP had recommended that more specific minimum and maximum grain size standards were needed. Recognizing the ecological problems of sediment incompatibility, and problems resulting from projects at Pine Knoll Shores and Oak Island, the CRC, through recommendations of the CRC Coastal Hazards Science Panel, worked to modify CRC rules regarding sediment compatibility to be more specific and effective. New rules became effective in February 2007.

The season and time period between renourishment events are also important factors that affect the rate of recovery of the beach community (Dolan et al. 1992; Donoghue 1999; Versar 2003). At the Brunswick Beaches project, conducted as part of the Cape Fear harbor deepening project, sand was placed sequentially from east to west: Baldhead Island in spring 2001, Caswell Beach in summer 2001, Oak Island in fall 2001, and Holden Beach in winter 2002. Impacts were observed immediately to the intertidal beach community at all beaches, but the severity of invertebrate reductions and time to recovery was the greatest at beaches nourished in the spring and summer (Versar 2003). 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 and limits on time of year, linear length, and interval between nourishment to enhance recovery of the benthic community. The CRC's beach nourishment rules should be evaluated and modified in a comprehensive manner as needed to minimize overall impacts from this activity. Comprehensive monitoring to assess the impact of each project should be required of the applicant to* *determine if and how nourishment practices should be modified. Additional research is also needed to more clearly quantify the cumulative impact of nearshore dredge disposal on fish populations*.

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; USACE 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). Although USACE (2001) did not observe a significant change in the surf zone fish population, they stated that due to the inter-annual variability of surf zone fishes, a change would only be observed if a catastrophe occurred. 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. Although, there has been few studies examining the direct effects of beach nourishment on pelagic fish, several studies have examined the impacts on pelagic fish prey items (i.e. polychaetes, copepods, and mollusks). Peterson (2000) concluded that nourishment projects should be ceased in April or May (warm season) to reduce the effects of nourishment on *Domax* and *Emerita* populations. For further discussion on nourishment impacts on invertebrates, refer to the beach nourishment impacts on the intertidal beach section.

A New Jersey study examined surf zone fish distribution, abundance, and diet in response to ongoing nourishment projects (USACE 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 (USACE 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 (USACE 2003; Versar 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 (USACE 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 (USACE 2003; Versar 2003). Sample size was often insufficient to calculate confidence limits, partly due to uneven sampling among treatments (disturbed, undisturbed, reference). Research is currently being conducted by UNC-Wilmington investigating the effects of beach nourishment on the nursery function of the surf zone by comparing fish and invertebrate assemblages, density and nutritional condition of juvenile Florida pompano and gulf kingfish. Initial findings indicate that fish composition and diet differed significantly at nourished beaches compared to unnourished beaches, potentially affecting diet and growth (Lipton et al. 2010; Perillo and Lankford 2010). *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 disposal from navigational dredge disposal projects

The USACE is charged to maintain North Carolina's navigable inlets and ocean channels through dredging as necessary. Navigational dredging in inlets by the USACE 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 are requested to refrain from using hopper dredges in the December to March time period to ovoid the taking of sea turtles. These take can jeopardize the future of that and future dredging projects. (J. Richter/USACE, pers. com., 2009).

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. The USACE has no anticipated impacts from the dredging aspect of hydraulic dredge jobs, but beach disposal is conditioned to avoid/minimize impacts to all flora and fauna, specifically turtles, piping plovers and seabeach amaranth (J. Richter 2009).

Material from navigation dredging 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 (J. Richter/USACE, pers. com., 2009). Areas receiving dredge disposal include several locations on Hatteras Island, south end of 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, east end of Holden beach and both ends of Bald Head Island. In addition, privately owned Figure 8 Island has received nourishment projects periodically.

Table 6.6. Ongoing USACE dredge disposal projects on North Carolina ocean beaches (Source: J. Richter/USACE, pers. com., 2009).

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 coastal storm damage reduction projects

Coastal 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 USACE to determine if and how a project could be conducted. While designing these projects avoiding and minimizing environmental impacts is a primary consideration. DMF and other agencies are given an opportunity to comment to DCM and the USACE 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 I).

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 (USACE 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 14.2 mi of beach along North Carolina's coast that have authorized and funded storm damage reduction projects ongoing. Additionally beach renourishment projects are under development for Bogue Banks, Oak Island/ Caswell/ Holden, Bodie Island, and Topsail Island (Table 6.7). All of Hatteras and Ocracoke islands are also under consideration 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 beaches with periodic 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. Along with the federally funded USACE coastal storm reduction projects, there are several beaches that have or in the process of privately funding beach nourishment projects (including but not limited to Nags Head, Surf City, North Topsail Beach, Bogue Banks, Figure 8 Island, and Bald Head Island) (Table 6.8). These privately funded projects must undergo an USACE permit review, and are considered one time projects.

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. 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.

Due to the increasing interest by municipalities in beach nourishment of some kind, it was evident that a plan was needed to provide guidelines on how to manage a limiting resource in an effective and environmentally sensitive manner. DWR and DCM agreed to collaboratively develop a Beach and Inlet Management Plan (BIMP) in part, to address the CHPP recommendation to prepare a BIMP that addresses ecologically based guidelines, socio-economic concerns and fish habitat. In addition, in 2000, House Bill 1840 required DENR to develop a multiyear beach management and restoration strategy, and in 2005 the GA commissioned a study of the cost and management issues related to maintaining NC's shallow draft navigation channels. The purpose of the BIMP was to compile data, define regional sand management regions, and develop management strategies to assist with the decisions and review process associated with beach nourishment activities. The plan will also assist DWR in developing funding priorities for beach nourishment projects, and be an educational tool for legislators.

Table 6.7. North Carolina beach communities with federally authorized or requested storm damage reduction projects by the USACE (does not include beach disposal from navigational dredging projects). [Source: DWR, unpub. doc., 2009.]

Project Name	County	Local Sponsor	Length of Beach (miles)	Project Status
Bogue Banks	Carteret	Carteret County (Towns of Atlantic Beach, Pine Knoll Shores, Salter Path, Indian Beach, and Emerald Isle	TBD	Study on-going, expected completion in FY2012 if Federal funding appropriated
Brunswick County Beaches GRR (Oak Island/Caswell/Holden	Brunswick	Brunswick County (Town of Oak Island, Town of Caswell Beach, and Town of Holden Beach), N.C.	TBD	Re-evaluation study on-going, expected completion in FY2011 if Federal funding is appropriated
Dare County Beaches (Bodie Island)	Dare	Dare County (Towns of Kitty Hawk, Kill Devil Hills, and Nags Head	TBD	Study complete, awaiting funding for engineering & design
Surf City and North Topsail Beach	Onslow	Town of North Topsail Beach	TBD	Study on-going, expected completion in FY2010 if Federal funding appropriated
	Pender	Town of Surf City	TBD	
West Onslow Beach (Topsail Island)	Pender	Town of Topsail Beach	TBD	Re-evaluation study on-going, expected completion in FY2010 if Federal funding is appropriated
Brunswick County Beaches (Ocean Isle)	Brunswick	Town of Ocean Isle Beach	5.3	Active 50 year project (ends 2051). Next renourishment scheduled for 1st quarter 2010
Carolina Beach and Vicinity (Area South Portion)	New Hanover	Town of Kure Beach	3.4	Active 50 year project (ends 2048). Next renourishment scheduled for 1st quarter 2010
Carolina Beach and Vicinity (Carolina Beach Portion)	New Hanover	Town of Carolina Beach	2.7	Active 50 year project (ends 2015). Next renourishment scheduled for 1st quarter 2010
Wrightsville Beach	New Hanover	Town of Wrightsville Beach	2.8	Active 50 year project (ends 2036). Next renourishment scheduled for 1st quarter 2010

Table 6.8 North Carolina beach communities with non-federally authorized or requested storm damage reduction projects (does not include beach disposal from navigational dredging projects). [Source: D. Piatkowski/USACE, pers. com.., 2010.]

Project Name	**County**	**Local Sponsor**	**Length of Beach** [2]
Town of Nags Head - Beach Nourishment Project	Dare	Offshore Borrow Areas	10
Emerald Isle FEMA Project	Carteret	USACE ODMDS – Morehead City Port Shipping Channel	4
Bogue Banks FEMA Project	Carteret	USACE ODMDS – Morehead City Port Shipping Channel	13
Bogue Banks Restoration Project – Phase I – Pine Knoll Shores and Indian Beach Joint Restoration	Carteret	Offshore Borrow Areas	7
Bogue Banks Restoration Project – Phase II – Eastern Emerald Isle	Carteret	Offshore Borrow Areas	6
Bogue Banks Restoration Project – Phase III– Bogue Inlet Channel Realignment Project	Carteret	Offshore Borrow Areas	5
North Topsail Dune Restoration (Town of North Topsail Beach)	Onslow/ Pender	Upland borrow source near Town of Wallace, NC	NA
North Topsail Beach Shoreline Protection Project	Pender	New River Inlet Realignment and Offshore Borrow Area	11
*Topsail Beach - Beach Nourishment Project	Pender	New Topsail Inlet Ebb Shoal and Offshore Borrow areas	6
*Figure Eight Island	New Hanover	Banks Channel and Nixon Channel	3
*Rich Inlet Management Project	Pender	Relocation of Rich Inlet	NA

With approximately 50 % of North Carolina's ocean shoreline in state or federal ownership, the remaining 50% are developed. Of those, 80 mi of shoreline in the recent past have been managed, and potentially 80 mi more may be managed in the future. The state funding required to maintain potentially 160 mi of beach would be huge. With that in mind, theBIMP may recommend establishment of a dedicated fund, and a regional commission to coordinate and facilitate projects. As of February 2010, the BIMP was drafted but not finalized.

In 2008 an Ocean Policy Steering Committee was formed to reexamine ocean resource issues and update existing policies on ocean uses. In April 2009 DCM published an ocean policy report (NC Sea Grant

2009) which identified five emerging resource policy issue areas and provides recommendations for changes to state policy that ensure North Carolina will be responsive with adaptive rule language as the ocean climate continues to experience technological, social, and economic change. Sand resource management was identified as an emerging issue. The report recommended:

- Identification of regional available sand sources
- Development of a state-level comprehensive plan to protect beaches and inlets
- Comprehensive management of inlet tidal delta sand sources
- Preventing loss to the barrier island system of sand in inlet channels
- Amendment to rules regarding dredging around hard bottom areas
- Incorporation of a sea level rise component to CAMA land use plans

All of the sand management recommendations of the Ocean Policy Report should be implemented. The first four items should be addressed in the BIMP.

6.4.1.2. Infrastructure

Oil and gas development

As described in the water column and hard bottom section, oil and natural gas drilling can be a major threat to the ocean environment. Specifically, oil drilling can affect the soft bottom community by altering both the inter and sub-tidal soft bottom habitat. Sub-tidal habitat can be directly influenced by moving or removing soft sediments during the drill process. This removal process can potentially create disturbances similar to those caused by soft bottom dredging impacts. As a result of offshore drilling there is a possibility of increased levels of pollutants and changes in the bottom composition (sediment characteristics and water movement) that can alter the nearby benthic community (Olsgard and Gray, 1995; Kennicutt et al., 1996; Barros et al., 2001). Studies have found diversity lowest adjacent to oil/gas platforms, with increasing diversity the further you traveled from the platforms (Kingston 1992; Daan and Mulder 1996; and Peterson et al. 1996). Although these results have been observed, other studies believe these changes are influenced by differences in depth, sediment characteristics, distance from shore, interannual variability, or the presence of previously unavailable hard substrate (Hernández et al. 2005 and Terlizzi et al. 2008). A common theme throughout this research is that in order to determine the effects of drilling on soft bottom benthos, information regarding pre-drilling, during, and post drilling conditions, as well as the use of control sites. In 2009 the General Assembly formed a Legislative Research commission Advisory Subcommittee on Offshore Energy Exploration to examine the impacts of offshore energy in North Carolina. For further discussion refer to the “Infrastructure” section of the Hard Bottom chapter.

The potential for an oil spill can be detrimental to the entire ecosystem. Not only can ocean habitats be impacted by released oil, estuarine habitats can also be affected if the spill occurs in or is transported through the inlets to estuarine waters. In North Carolina, as a result of wind and water movement, the first habitat point of contact for oil floating on the waters surface in the ocean environment is the intertidal beaches and flats. Although most of North Carolina’s coastal beaches are high energy areas, oil spills can cause closures of beaches and fishing activities. In the areas where there is low flow, oil can persist for decades (Peterson 2001 and Peterson et al. 2003b). The presence of oil in soft bottom sediments can prevent fish eggs from hatching, limiting the growth rate of small fish, and prevents fish from returning to previously utilized spawning habitat (Peterson 2001 and Peterson et al. 2003b). It is important to note, that these impacts can be caused by other sources such as shipping vessels running aground and leaking oil or gas.

Wind Energy

Wind farms are discussed in further detail in the hard bottom section, while this section focuses on the potential impacts on soft bottom and the associated fauna. Duke Energy Progress is proposing to construct a wind turbine field in either Pamlico Sound or off of the coast of North Carolina and run underground power lines from the turbines to land. In areas where there is soft bottom, pilings may be driven deep into the bottom sediments (approximately 30 to 35 meters). This practice can act similarly to that of driving pilings into the substrate (i.e. oil/gas platforms, docks, or bridges) or like a platform itself (modifying sediment composition or water movement). Cables will then be run from the structures to a facility were the electricity will be distributed. Putting pilings and cables in soft bottom habitat will immediately crush or kill benthic invertebrates and remove soft bottom habitat that was previously available. In order to minimize these impacts cables should be below the surface using directional boring methods. Although hard bottom habitat will be created, the benthic community will change from infaunal bivalves and annelid worms to epifaunal bivalves and algae, altering the food web (see “Ecosystem management and Stragetic Habitat Areas” for discussion of habitat trade-offs). The practice of driving pilings into the soft bottom can also have a negative effect on sound producing fish, mammals, and turtles causing them to leave the immediate area while pilings are being installed. In preliminary work, Wahlberg and Westerberg (2005) estimated that fish were only affected by the sound produced by wind mills up to 4 m away when winds were above $13 m\ s^{-1}$. Wahlberg and Westerberg (2005) go on to state that these wind turbines are masking communication sounds (i.e. mating and warning) and orientation signals. Underground energy cables are known to give off an electrical charge that can alter fishes’ migration patterns. Studies have shown different species (including the American eel, *Anguilla rostrata*) to be effected by these electrical charges (Rommel and McCleave 1973 and Öham et al. 2007).

While current CRC rules prohibit the placement of wind turbines in state waters as they are not considered water-dependent structures, the CRC has taken steps to amend these rules (M. Lopazanski/DCM, pers. com., January 2010). The proposal currently under consideration would declare wind energy facilities of three MW or larger to be water dependent structures. *Should the State consider locating a wind facility in state or federal waters, proper placement of energy infrastructure is necessary to minimize potential impacts to SAV habitat and minimize conflicts with existing activities*.

The 2009 Ocean Policy Steering Committee made several recommendations regarding ocean based alternative energy, primarily regarding review and modification of legal structure as needed to support alternative energy development. Other alternative energy industries that could develop in the future include wave energy, current energy, and tidal energy.

6.4.1.3. Off-road vehicles

The use of off-road vehicles (ORV) has been allowed in designated beach areas of North Carolina. These ORV have been shown to increase the loss of sediment from intertidal shoreline and negatively affect intertidal fauna (Schlacher and Thompson 2008). Fauna can be affected directly by being crushed by ORVs, or indirectly by altering the sediment composition and behavior (Schlacher and Thompson 2008). On the Cape Hatteras National Seashore Hobbs et al. (2008) observed a decrease in the number of ghost crabs (*Ocypode quadrata*) in areas that had been previously closed to ORV. This is important to note since ghost crabs have been described to be indicator species of anthropogenic influences on coastal shorelines (Steiner and Leatherman 1981; Neves and Bemvenuti 2006; and Hobbs et al. 2008). In Australia, low volumes of ORVs (5 passes through an area) were found to crush large numbers of surf clams (*Donax deltoi*) (Schlacher et al. 2008). As the number of trips increased more surf clams were crushed (Schlacher et al. 2008). On Fire Island, NY, ORVs were estimated to deliver large amounts of sand to the swash zone contributing to the overall erosion rate (Anders and Leatherman 1987). It is unclear of whether or not the sand is lost from the long shore sediment transport. In North Carolina, the National Park Service regulates where ORVs are permitted to drive on beach. Current regulations include restrictions to keep ORVs above the wrack line (which protect intertidal fauna) and out of important nesting areas for birds and other fauna. *The National Park Service should continue to restrict ORV beach access to areas that will not negatively influence soft bottom fauna.*

6.4.2. Mining/salvage

6.4.2.1. Minerals

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.

6.4.2.2. Logs/pilings

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.

6.4.3. 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 shallow soft bottom functions (i.e., nursery characteristics). 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) (Map 3.5a-c in the Shell Bottom chapter).

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. 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.

6.4.3.1. Mobile bottom disturbing gear

Dredging

Even with a low fishing effort, dredges are considered to be the most habitat destructive fishing gear (DeAlteris et al. 1999; Collie et al. 2000). Oyster dredging is conducted over shell bottom and was discussed in detail in the shell bottom chapter. Crab dredging is allowed in one area of primarily soft bottom in northern Pamlico Sound (approximately 100,653 acres) (Map 6.5), and is opened by proclamation from January 1 to March 1 [15A NCAC 3L .0203]. 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. 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. *Because less habitat damaging methods are available for harvesting crabs, MFC should consider if prohibition of crab dredging is advisable.*

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; Løkkeborg 2005). Due to a decline in bay scallops, a moratorium was in place from 2005 through 2008. Sea scallop dredging is a sporadic fishery, primarily occurring in deep coastal waters (federal) north of North Carolina. Since 1994, commercial landings of sea scallop meats have been very low, ranging from 13,815lb in 1999 to 512,624lb in 2001 (DMF, unpub. data). 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. 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). 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.

Bottom trawling

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

Trawl doors were shown to bring a high number of infaunal bivalves to the sediment surface (Gilkenson et al. 1998) and Sanchez et al. (2000) observed more annelids in a muddy bottom after trawling had occurred in the Mediterranean Sea. This is important to note since in Kaiser and Spencer (1996) observed a large number of benthic organisms that are damaged by trawls in the diets of demersal fish scavengers after a trawl has been pulled through an area. Studies in areas that are consistently trawled have shown otter trawls to have a negative effect on the nematode (a food source for fishery species) community by reducing abundance, production, and genus richness in areas that are not susceptible to environmental stresses (i.e. wind events) (Hinz et al. 2008). Gear contact can uproot and remove invertebrates attached to the seafloor, such as sponges and worm tubes and can expose them to predators.
The change and reduction in the structural complexity of the seafloor and increase in turbidity from frequent trawling can reduce feeding success of filter feeding invertebrates due to gill clogging, or increase predation due to increased exposure and reduced cover. A reduction in filter feeders on the subtidal bottom may also result in reduced water clearing capacity in the water column (Auster and Langton 1999). The 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, supports higher trophic layers. The sediment composition of the bottom may also change with frequent trawling. Due to the close relationship between sediment size and benthic community structure, this sediment shift will alter the benthic community (Thrush and Dayton 2002). Reduced diversity and abundance of some benthic taxa are commonly observed in areas experiencing intense fishing activities (Auster and Langton 1999; Thrush et al. 2006). 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. 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 also affect primary productivity through the connection of bottom and water column processes (DMF 1999). 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). The increased plant growth can reduce light penetration to the bottom and extent to effects of trawling in an area beyond the episodic increases in turbidity. 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. On the contrary, several studies have found trawling to have long-term habitat impacts (Bradstock and Gordon 1983, Brown 1989, Collie et al. 1997, Engel and Kvitek 1998). Benthic community recovery time greatly depends on the effort and intensity of trawls in a given area (Watling and Norse 1998, Auster and Langton, 1999). The recovery time tends to vary depending on the amount of natural disturbances in the area (weather or macrofaunal). In the Gulf of Maine, the recovery time after trawling over a mud bottom was 3 months, possibly due to the presence of burrowing megafauna that naturally disturb the bottom (Simpson and Watling 2006).

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 includes 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. It is also important to quantify the episodic and chronic effects of trawling on nursery functions in different estuarine settings.*

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 to larval fish in inlets and PNAs could be greater than trawling in ocean or deep estuarine 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*.

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 6.9) (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 6.9. Soft bottom trawl impact studies on the continental shelf of eastern North America.

Reference	Habitat	Depth (m)	Recovery Period (days)
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. Repeated and prolonged trawling over muddy ocean bottom will negatively influence the benthic fauna, decreasing the abundance and diversity of epifauna invertebrates, possibly altering the marine food web (Hinz et al 2008).

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 for the taking of finfish in internal (estuarine) waters [15A NCAC 3L .0205, 15A NCAC 3J .0104(a&b)]. Shrimp trawling is allowed, except in primary or secondary nursery areas [15A NCAC 3N .0105], or in No Trawl Areas [15A NCAC 3R .0106] (Map 3.5a-c in the Shell Bottom chapter). 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]. The purpose of these regulations is to protect functional habitat areas and reduce bycatch or user conflicts.

Annual effort with various commercial trawling gears in North Carolina waterbodies is shown in Table 6.6 (DMF, unpub. data). Commercial shrimp trawling accounts for the majority of all trawl trips (92% in 2002). 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 estuarine shrimp trawling effort has ranged from 2,944 in 2005 to 15,791 in 1995. The total number of estuarine shrimp trawl trips has not exceeded 10,000 trips since 2002. Prior to 2002, the number of estuarine shrimp trawl trips declined to below 10,000 during two years, 1998 and 2001. 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 6.10. In 2002, approximately 5,000 trips for shrimp were reported (DMF, unpub. data).

Regionally, the shrimp trawling effort has generally been greatest in Core and Bogue sounds and the associated estuaries (3,400-6,783 trips/year) (Table 6.10). Estuarine rivers and sounds represent 60 to 99 % of NC shrimp trawls. 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. However in 2000, 2002, 2006, 2007, and 2008, the Pamlico region accounted for 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 34 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 district 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. The number of crab trawl trips has decreased dramatically since 2004 as crab trawlers have switched to other fisheries such as scallop trawling in Virginia (S. McKenna/NCDMF, pers. com., 2009). Flounder trawling effort occurs primarily in the northern district of North Carolina's coastal waters. Effort in the northern district has varied from 7 trips in 1997 to 134 trips in 1999 (Table 6.10). Overall, current bottom trawling effort in estuarine waters for all fishery species is greatest in Pamlico Sound and associated estuaries.

Table 6.10. Annual number of trips reported for shrimp, crab, and flounder trawls in NC estuarine and ocean waters <3 miles [1], 1994-2008 (DMF, unpub. data). Trawling is not permitted in Albemarle Sound.

Shrimp Trawl

Year	Estuarine Rivers and Sounds			State Ocean Waters (<3mi.)	
	Core/Bogue	Pamlico	Southern	Northern District	Southern District
1994	6783	4870	3461	0	2
1995	6979	5186	3626	34	661
1996	5749	2903	2672	19	2233
1997	5411	4790	3056	23	2529
1998	4547	1864	2185	2	2820
1999	4406	4082	2617	5	3839
2000	3245	5513	2157	12	2999
2001	3319	3180	1487	0	2654
2002	3548	4883	1834	2	2596
2003	3484	1752	1660	1	2810
2004	1731	2728	985	10	2781
2005	1262	861	821	0	1535
2006	791	1819	693	7	2316
2007	743	2923	830	7	2189
2008	651	2720	855	8	1684

Crab Trawl

Year	Estuarine Rivers and Sounds			State Ocean Waters (<3mi.)	
	Core/Bogue	Pamlico	Southern	Northern District	Southern District
1994	236	3524	38	0	0
1995	206	1897	103	0	0
1996	190	4058	58	1	1
1997	647	4193	208	0	0
1998	517	5103	88	1	0
1999	407	3104	35	0	0
2000	265	1910	47	0	0
2001	396	2034	107	0	0
2002	85	805	79	0	0
2003	113	1474	105	0	0
2004	402	1210	163	0	0
2005	163	823	125	0	6
2006	51	245	5	0	0
2007	61	96	0	0	0
2008	41	273	0	0	0

Flounder Trawl

Year	Estuarine Rivers and Sounds			State Ocean Waters (<3mi.)	
	Core/Bogue	Pamlico	Southern	Northern District	Southern District
1994	0	4	1	0	0
1995	1	13	6	30	20
1996	1	5	0	31	61
1997	0	11	2	7	57
1998	0	1	0	117	50
1999	0	0	0	134	18
2000	0	0	0	102	4
2001	0	0	0	78	26
2002	0	0	0	131	10
2003	0	0	0	62	0
2004	0	0	0	22	4
2005	0	0	0	11	0
2006	0	0	0	23	0
2007	0	0	0	67	2
2008	0	0	0	20	4

[1]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: North of Cape Hatteras.

Southern district ocean waters: South of Cape Hatteras.

Active Gillnet Techniques

Although gillnets are a passive fishing gear, they can be made active by dragging weighted objects to "scare" fish into gillnets. These objects (including weights, chains, and cinder blocks) may weigh anywhere between 5 and 29 pounds and may disturb the soft bottom habitat in a manner similar to a small trawl door or a toothless scallop dredge. In 2007, the NCDMF became aware of fishermen utilizing active gillnets in PNAs in the Spot, Mullet, Flounder, and Specked trout gillnet fisheries. Although there was no specific rule against active gillnets in PNAs, all bottom disturbing gears are prohibited. According to MFC rule 15A NCAC 03J .0103, the fisheries director may limit the use of gillnets and the means/methods they are fished. While the NC Marine Patrol have observed active gillnets in PNAs in the Central and Southern districts of NC, they found it to be more prevalent in the Southern district (DENR 2008). Currently, there is a NC Seagrant Fisheries Resource Grant investigating the impacts of active gillnets on PNAs. Results of this study are expected to be complete in June of 2010. *The impacts of active gillnets on soft bottom should continue to be investigated.*

6.4.4. 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.

6.4.4.1. Eutrophication and Oxygen Depletion

The primary discussion of eutrophication resides in the "Water quality degradation – causes" section of the Water Column chapter. The enrichment of bottom sediment is discussed in this section.

While a certain level of these nutrients is needed to support aquatic life, an overabundance of nutrients, or eutrophication, due to human activities often leads to increased primary production resulting in algal blooms and hypoxic bottom water (Nixon 1995). The effects of nutrient enrichment on soft bottom habitat are also 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. 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). The ebb and flood of tides 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.

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 and cause 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 (see "Non-point source management" section of Water Column chapter for related information). In an effort to reduce the amount of run-off from farming and animal feed operations, the EMC approved a rule [15A NCAC 02T .1310-.1311] in 2008 designed to increase monitoring of the Nitrogen, Ammonia, fecal coli form, and chlorine. *Long-term monitoring is required, in combination with management actions that reduce discharge concentrations, to determine effectiveness and future management needs*.
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. Powers et al. (2005) linked the decrease of *Macoma balthica* to a diet switch in Atlantic croaker. As a result of less *M. balthica*, croaker tended to consume more polychaetes and plants, providing evidence of a change in the food web.

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 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). Seitz et al. (2003) observed blue crabs (*Callinectes sapidus*) and Baltic clams (*Macoma balthica*) in cages in the Chesapeake Bay under normal and hypoxic conditions. Under hypoxic conditions Seitz et al. (2003) showed that crabs had reduced feeding efficiency and trophic transfer from the clams.

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 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 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). Research is ongoing at NCSU looking at the effect of hypoxic events in the Neuse River on fish displacement, foraging, growth and survival (B.J. Copeland/MFC, pers. com. April 2010). The research results suggest that the energy utilized by fish to avoid hypoxia and find adequate food impacts fish growth and productivity. *More information is needed to understand the consequences on the estuarine food web and to what extent anoxia is impacting the soft bottom community*. Refer to Water Column chapter for more information on eutrophication and oxygen depletion.

6.4.4.2. Sedimentation and turbidity

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). 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).

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 including (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 (Rodriguez et al. 2006). 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 2009). 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 2009). 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.

6.4.4.3. Toxic chemicals

The primary discussion of toxic chemicals resides in the Water Column chapter. This section focuses on the storage and release of chemicals stored in soft bottom habitat.

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). Multiple studies have examined the toxic chemical contamination in North Carolina's estuaries. One study of bottom sediments throughout coastal North Carolina waters found PAHs, nickel, arsenic, DDT, chromium, PCBs, and mercury to be the most abundant chemicals between 1994 and 1997 (in order of descending concentration) (Hackney et al. 1998). The study also found concentrations of other heavy metals such as antimony, copper, lead, cadmium, silver, and zinc. According to the survey, sediment in 13.4% of estuarine sites sampled was nearly devoid of life during harsh summer conditions. 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. 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. Toxic chemicals that tend to accumulate in bottom sediments include:

- heavy metals
- polycyclic aromatic hydrocarbons (PAHs)
- petroleum hydrocarbons
- pesticides
- polychlorinated biphenyls (PCBs)
- ammonia

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)[45]. 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). Lethal and sublethal levels of toxicity are known for some benthic aquatic species. 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. See Appendix F

[45] Other suspected causes reported: unknown (46%), dissolved oxygen (34%), blooms (4%), other (9%), and bycatch (1%).

for more information on toxicity thresholds for early life stages of fish. 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, on survival, growth, and reproduction of 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 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) corresponding 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). In high concentrations copper and ammonia, by-products of water treatment outfalls, can be fatal to freshwater bivalves (Ward et al. 2007). For further discussion on toxicity in fishes, refer to “Toxic chemical section” of the Water Column chapter.

Fossil fuels

Anthropogenic sources of hydrocarbons include burning of fossil fuels, the marine industry (boat maintenance/activity), urban/suburban sprawl, dock and marina development and operation, automotive transportation, and industrial emissions (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).

Hydrocarbons are derived from fuel emissions, runoff from roads, spills from boats and fuel facilities. Runoff from impervious surfaces such as roads and parking lots appears to be one of the major sources of heavy metals and hydrocarbons in estuaries and nearshore ocean waters. It was estimated that in the United States, 11 million gallons of oil enters surface waters through runoff every eight months, equivalent to the Exxon Valdez-size oil spill (PEW Ocean Commission report; http://www.pewtrusts.org/our_work_report_detail.aspx?id=30009&category=130). The major source of this oil appears to be from cumulative oil drips on roadways and dumping of waste crankcase oil (Latimer et al. 1990). 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 in streams (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.

Heavy metals

Anthropogenic sources of metals include industrial ore processing, chemical production, agriculture, the marine industry (boat maintenance/activity), urban/suburban sprawl, dock and marina development and operation, dredge spoil disposal, automotive transportation, atmospheric deposition, and industrial emissions (Wilbur and Pentony 1999). Of the heavy metals, arsenic, copper, cadmium, chromium, nickel, lead, zinc, tin, and mercury are among the greatest concerns. 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. 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). Nunes et al (2008) showed that in areas with a high concentration of heavy metals studies surface deposit feeders and herbivores decreased in abundance, while subsurface deposit feeders have increased in areas of high concentration of heavy metals (Nunes et al. 2008). Because low concentrations of heavy metals in the water column can be easily incorporated into organic rich mud (ORM), chemicals can accumulate in the sediment to toxic levels and be resuspended into the water column (Riggs et al. 1991, Steel 1991).

Fine-grained sediments are common in sheltered creeks and small trunk estuaries, or in the deeper regions of larger estuaries. The highest contamination levels were found in low-salinity areas with limited flushing and high river discharge (e.g., upper estuaries) (Riggs et al. 1989, Riggs et al. 1991, Hackney et al. 1998). Some heavy metals and pesticides can cause hormone alterations that affect reproduction (Wilbur and Pentony 1999). Heavy metals in these areas are of particular concern because they cover the majority of designated anadromous and low-salinity nursery areas, where young fish gravitate in spring and summer. *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*.

Heavy metal concentrations have been measured in Durham Creek, Porter Creek, South Creek, Pamlico River, Jacks Creek, Huddles Cut, and Tooley Creek by PCS as part of their permit compliance. Arsenic, cadmium, molybdenum, selenium, and zinc were all found to be higher in concentration than continental crust concentrations (CZR 1999). The presence of these heavy metals has been directly linked to shell disease in blue crabs (*Callinectes sapidus*) found in the Pamlico River (Weinstein et al. 1992).

Steps have been made to reduce heavy metal input into the aquatic system. 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.[46] .

PAHs, PCBs, and pesticides

Polycyclic aromatic hydrocarbons (PAHs) are 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. Polychlorinated biphenyls (PCBs) are 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. PCBs are used in plasticizers and flame retardants.

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 growth and

[46] 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.

reproduction (Johnson et al. 2002). Several pesticides also have been detected in sediments of the Albemarle-Pamlico estuary (Hyland et al 2000). 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). As a result of offshore transport and atmospheric deposition, pesticides, PAH, and PCBs have been found 32km off of the coast of Georgia in the Grey's Reef Marine Sanctuary (Hyland et al. 2006). Refer to the water column chapter for more detailed information on the sources of toxic chemicals.

Status of sediment contamination

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. Although the NCDWQ does not sample sediments for heavy metals in NC coastal waters, they require that dredging applicants sample for heavy metals under certain circumstances (i.e. historically commercial ports). The NCDWQ requires heavy metal sampling so that if dredging does occur in an area with contaminated sediments proper dredging and disposal methods can be utilized. A complete list of DWQ pollutant standards can be found in the DWQ surface water and wetlands standard "redbook", but the pollutants that are sampled include but are not limited to Mercury, Selenium, and Cadmium (http://portal.ncdenr.org/c/document_library/get_file?folderId=285750&name=DLFE-8513.pdf, August 2010).

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). The sediment in 13.4% of estuarine sites sampled was nearly devoid of life during harsh summer conditions, according to the survey. 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. Hyland et al. (2000) sampled 174 station from 1994-1997, from these stations Hyland estimated less than 10 percent of North Carolina estuaries are contaminated by toxins. 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. 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).

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. Corbett et al. (2009) investigated the presence of heavy metals in Slocum Creek, Hancock Creek, and the adjacent Neuse River Estuary, finding higher concentrations of the heavy metals in the portions of the creeks with low sedimentation rates. Additionally, Corbett et al (2009) observed little to no macrofauna in sediment cores where the heavy metal concentrations were high.

Heavy metal and toxin concentrations have been monitored yearly by NOAA's mussel watch monitoring program since 1986 (Kimbrough et al. 2008). In NC, there are 10 sites (Roanoke Sound, Pamlico Sound, Cape Fear River, and Beaufort Inlet areas) that the heavy metal levels found in the eastern oyster *Crassostrea virginica* are monitored (Lauenstein et al. 2002). For more information regarding toxins see water column and oyster sections. *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.*

Resident Time

Chemical contamination may reside in soft bottom sediments for any period of time. The residence time depends on the specific chemical. 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. 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. Shae/NCSU, pers. com., 2002). One year following Floyd, however, the overall concentration of current-use pesticides was comparable to pre-hurricane levels (D. Shae/NCSU, pers. com., 2002). Toxins can accumulate and persist over time, chemicals that have been banned since 1977 (e.g. DDT, Diedrin, and TBT) continue to be found in sediments (Hackney et al. 1998; Marburger et al. 2002).

6.4.4.4. Sewage Spill

Sewage spills and overflows can cause an influence in nutrient and fecal coliform bacteria concentrations in the water column and soft bottom habitats. These higher than normal concentrations can contribute to anoxic conditions (refer to eutrophication section) that can cause fish kills to bottom feeding fish and soft bottom invertebrates. Both the nutrients and bacteria can settle out of the water column into the sediments and remain for several weeks where they will be subject to resuspension (Mallin et al. 2007). These elevated levels of fecal coliform can create shellfish closure areas as mandated by the Shellfish Sanitation and Recreational water quality section of NCDENR, due to the potential human health issues. For further discussion refer to the Shell bottom and Water Column Chapter.

6.4.5. Non-native, invasive, and nuisance species

The presence of non-native species poses a threat to soft-bottom habitat, by out-competing native species for food and habitat. An introduced species that have an influence on soft bottom habitats found in coastal North Carolina is a red algae (*Gracilaria vermiculophylla*).

The red algae *Gracilaria vermiculophylla*, originally described from East Asia, is believed to occur in NC's southeastern estuaries (Freshwater et al. 2006). It was observed fouling nets and water intakes and growing on mudflats in Masonboro Sound in 2000. If confirmed it will be the seventh red algae reported in NC. It is associated with human-related mechanisms of dispersal, likely in fouled fishing gear or boats (Freshwater et al. 2006). It has also been reported as abundant along saltmarsh borders and mudflats in Virgina (Thomsen et al. 2009). It is expected that the primary mode of dispersal is through oyster transplants because it is not generally found in ships ballast and is abundant on Virginia oyster reefs (Thomsen et al. 2007).

6.4.6. Climate change and sea level rise

Anticipated climate change is expected to affect soft bottom environmental conditions, thus altering the biological community. These changes include a rise in sea surface temperatures, intensification of tropical storms, larger and more extreme waves and storm surges, and altered nutrient run-off (IPCC 2007).

The expected changes from climate change will facilitate an increase erosion rate of the intertidal soft bottom. Using diatoms to model former sea levels, Horton et al. (2006) observed a rise of 0.7m over approximately the past 150 years. As sea level rises (SLR) erosion will continue to occur at intertidal shorelines. Research has stated that if all conditions remain the same as sea level rises, the intertidal beach will move landward and upland (Brunn Rule) (Zhang et al. 2004). Using data from the mid nineteenth century to 2004, Zhang et al. (2004) observed approximately 24% of the NC coast that is not influenced by coastal engineering projects or inlets to be eroding by at a rate of 0.32 m/y. Development has increased in coastal communities not allowing the intertidal zones to move landward. In an attempt to reduce the effects of this landward movement, developers have been utilizing varying shoreline stabilization methods. In NC, the coastal hazards science panel has been issued the task of presenting the NC CRC with scientific data and recommendations regarding the hazards of SLR on the coastal community. The science panel has estimated a sea level rise of approximately 1meter by 2100. Currently, the international best practice is using setbacks, not allowing development landward from the first line of stable, natural vegetation (Defeo et al. 2009). In NC, the CRC determines setbacks for single family homes by multiplying the average annual erosion rate by 30, or the set back must be at least 60ft.

Schlacher et al. (2008) summarized the 2006 Sandy Beach Ecology Symposium (Vigo Spain) workshops, describing the loss of habitat and associated biota as the most severe and immediate effect of climate change. As a result, Schlacher (2004) states that there is a need to expand the understanding of how climate change will influence sandy beaches. These research needs include:

- long-term studies on communities and populations that quantify ecological responses to changes in beach morphology and variability
- key ecological traits of individual species (i.e. dispersal abilities, reproductive strategies, thermal tolerance, etc.)
- ability of species to adapt or acclimatize
- metapopulation studies
- realized and predicted geographic range shifts of biota
- habitat requirements of iconic and threatened species (birds, turtles, fish)
- identification of indicator species and their efficacy in monitoring the effects of climate change on sandy beaches
- linkages across ecosystems – ecotonal coupling (e.g. dunes, estuaries, reefs)
- ecological consequences of alternative societal responses to erosion and shoreline retreat (e.g. do nothing, retreat ⁄ setback, nourish, armour)
- scale-dependency and cumulative effects of societal responses to beach erosion
- effects of management interventions to sea-level rise and beach erosion on critical linkages of sandy beaches with adjacent systems (dunes, nearshore, estuaries)
- efficacy of mitigation, rehabilitation and restoration measures
- impacts on economically important fisheries species on beaches

Increasing water temperatures and sea level rise are thought to influence aquatic community structure. Although the biological changes that might occur from sea level rise are difficult to predict, researchers expect the settlement of non-native species to increase, shift in prey availability, and changes to the nutrient flux originating from upland areas to occur (Stachowicz 2002, Diederich 2005, Büttger et al.

2008). As sea level rises, certain species of mollusks found in the intertidal zone may become unavailable to certain bird species. As this shift occurs the mollusks will become more readily available to predatory fish in subtidal zones (Reise and van Beusekom 2008). Many experts expect tropic and sub-tropic species (Smith et al. 2000) to move north to the sub-arctic as a result of this warming trend. In southeastern NC, researchers have observed an increase in the number of benthic invertebrates (e.g. Carribean crabs, bivalves, snails, and polychaetes) from waters further south (UNCW 2008). This trend has already been observed in geologic records from the Pleistocene Epoch (Palumbi and Kessing 1991, Dayton et al. 1994, King et al. 1995).

Currently, researchers are working on five independent projects that have been examining the impacts of sea level rise in NC as part of North Carolina Sea Level Rise project. Refer to the Wetlands chapter for a comprehensive list of sea-level rise and climate change projects/initiatives occurring in North Carolina. Of these projects, researchers at UNC-CH are modeling estuarine habitat (including intertidal and subtidal soft bottom) response to sea level rise (http://www.cop.noaa.gov/stressors/climatechange/current/SLRabstracts.html#peterson, 2009). This project is scheduled to be completed by FY2010. *Research needs to continue to investigate the impacts of climate change on the soft bottom habitat and the associated fauna. This should include effects on productivity*.

As the climate changes, more severe and frequent storms are predicted to occur. Sediment erosion and run-off is expected to increase with the climate changes. After hurricane activity occurs in the Neuse River Estuary (NRE), phytoplankton dynamics are altered through nutrient. These high levels of nutrients can create soft bottom hypoxic conditions (Paerl et al. 2006). Hurricanes may alter the benthic community, by changing the community structure as a result of salinity changes and hypoxic conditions (Mallin and Corbett 2006). The increase hurricane events can cause inlets to open and close, effecting NC's estuaries (refer to Water Column chapter for more information).

6.4.7. Management needs and accomplishments

Some of the management needs from the 2005 CHPP were refined and adopted as actions in the multi-agency CHPP implementation plans (IPs). The status of 2005 research and management needs is listed below, along with new emergine needs. Emerging needs includes new issues and previously existing actions that were extensively reworded in the 2010 draft, and therefore considered "new". Research and management needs are classified as accomplished, with progress, without progress, emerging, or discontinued because they were found to be redundant or too general or minor.

6.4.7.1. Research needs (2005-2010)

Accomplished and discontinued research needs

n/a

Research needs with progress

1. *Further analysis is needed to spatially quantify where, how often, and when trawling occurs in specific areas of soft bottom habitat. It is also important to quantify the episodic and chronic effects of trawling on nursery functions in different estuarine settings.* **Some new research presented in "Bottom trawling" subsection of "Mobile bottom disturbing gear" section.**

2. *More information is needed to understand the consequences on the estuarine food web and to what extent anoxia is impacting the soft bottom community.* **Some research has been done by NCSU, Jim Rice on effect of hypoxia on fish displacement and growth.**

Research needs without progress

1. *Research that quantifies the cumulative impact of dock and marina policies on soft bottom and other fish habitats.* **Research conducted regarding the cumulative impact of microbial contamination from multiple docks in an area (See "Marinas and docks" section of Water Column chapter for more information).**

Emerging research needs

The following needs are quoted or paraphrased from the text.

1. *There should be a cooperative effort to update existing NC estuarine bathymetric maps.* **See "Distribution" section for more information.**

2. *The long-term consequences of hardened structures on larval transport and recruitment should also be thoroughly assessed prior to approval of such structures (groins or jetties).* **See "Oceanfront shoreline hardening" for context.**

3. *The impacts of active gillnets on soft bottom should continue to be investigated.* **NC Sea Grant has funded a Fisheries Resource Grant to investigate the impacts of active gillnets on PNAs, report pending (see Mobile bottom disturbing gear" section for context).**

4. *Research needs to be conducted to investigate the impacts of climate change on the soft bottom habitat and fauna. This should include effect on productivity.* **NC researchers are investigating the impacts of sea level rise as part of the North Carolina Sea Level Rise Project. The DCM coastal hazards science panel has been discussing the issues of sea level rise on NC coastal areas. Refer to "Climate change and sea level rise" section for context.**

5. *Due to the increasing numbers of rays in NC, the impact of ray foraging pits in NC waters should be examined.* **See foraging section.**

6.4.7.2. Management Needs (2005-2010)

Accomplished and discontinued management needs

1. *Designating the specific locations of anadromous fish spawning and nursery areas by the MFC and adequately protected*. **Anadromous Fish Spawning Areas have been designated by the MFC and WRC (see "Designations" section of Water Column chapter for more information).**

2. *More specific minimum and maximum grain size standards for beach nourishment that minimize biological impacts*. **CRC has implemented effective sediment criteria rules (see "Beach nourishment impacts on intertidal beach and adjacent subtidal bottom" section for more information).**

Management needs with progress

1. *Reducing the area available to mechanical clam harvesting is another means to protect clam stocks and provide additional habitat protection*. **Ongoing DMF effort to adjust boundaries with expansion of SAV (see "Status of associated fishery stocks" section for more context.**

2. *Commenting and permitting agencies should continue using 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.* **Ongoing (see "Dredging (navigation channels and boat basins)" section for more information).**

3. *Completing 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. Conditions should include sediment compatibility, restricting time of nourishment, interval between nourishment events, and linear length of projects to enhance recovery of the benthic community. **The coastwide Beach and Inlet Management Plan has been drafted and pending review and finalization (see "Status of beach nourishment from storm damage reduction projects" section for more information).**

4. *Encourage sand mining guidelines for beach nourishment that maximize biological recovery rates and do not degrade fish habitat functions*. **Increased need due to storm damage projects using offshore borrow areas. See "Beach nourishment impacts at mining sites" for context. May be addressed in BIMP.**

5. *Re-examining shallow areas where trawling is currently allowed to determine if additional restrictions are necessary*. **Some areas were re-examined for the 2004 shrimp FMP http://www.ncdmf.net/download/shrimpfmp2004finial.pdf. See "Mobile bottom disturbing gear" section for context.**

6. *Additional public outreach to emphasize the importance of natural barrier island and estuarine processes.* **ECU has produced several publications on barrier island migration and shoreline stabilization of estuarine and ocean shorelines. See "Foraging" function subsection of "Ecological role and functions" section for context.**

7. *Including minimum water depth criteria for siting docks in shallow nursery habitats.* **Minimum water depth included for structured habitat and PNAs (see "Marinas and docks" section for context.**

Management needs without progress

1. *Expanding temporal and spatial sampling of juvenile fish to 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.* **See "Nursery" function subsection of "Ecological role and functions" section for context.**

2. *More research to assess direct and indirect dredging impacts on blue crabs and other inlet spawning species*. **See "Dredging (navigation channels and boat basins)" section for context.**

3. *Developing 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*. **The "Dredge material disposal on subtidal bottom" for context.**

4. *Due to the toxic sediment contamination associated with pressure treated wood, revised shoreline stabilization rules should require or encourage use of non-wood materials or wood that is not toxic to benthic organisms. Any new wood preservative products should be evaluated for toxicity to marine benthic organisms and juvenile fish.* **See "estuarine and riverine shoreline stabilization" section for context.**

5. *Adequate monitoring of the effects of beach nourishment projects on the soft bottom community and associated surf fish populations. The monitoring should assess the direct and cumulative impact of beach nourishment activities on fish, their habitat, and biological recovery rates.* **See "Beach nourishment impacts on intertidal beach and adjacent subtidal bottom" for context.**

6. *Because less habitat damaging methods are available for harvesting crabs, MFC should consider if*

prohibition of crab dredging is advisable. **See "Mobile bottom disturbing gear" section for context.**

7. *Protection of "recruitment bottlenecks" from trawling or other impacts is very important for estuarine dependent fish and invertebrates.* **See "Bottom Trawling" section for context.**

8. *More information on the in situ effects of various contaminant levels, in combination with other contaminants and existing environmental stressors, on survival, growth, and reproduction of many important fish species in North Carolina.* **See "Toxic chemicals" section for context.**

9. *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.* **See "Toxic chemicals" section for context.**

Emerging management needs

1. *Where new inlets form, recommend allowing inlets to remain open even if temporarily until a substantial flood tide delta forms. This will allow for long-term maintenance and stability of the barrier island.* **See "Oceanfront shoreline hardening for context.**

2. *The natural processes that create these features (shoals, sand bars, sloughs, and tidal deltas, that surf fish utilize) need to be maintained.* **See "Foraging" subsection of "Specific biological functions" section for context.**

3. *Because there is strong evidence available on the potential ecological impacts of hardened structures, large uncertainty on the environmental impacts of terminal groins specifically, and no clear economic benefit from inlet stabilization, North Carolina should not reverse its position or policies on ocean shoreline hardening. Overall, the scientific evidence does not support changing North Carolina's policy on prohibition of shoreline hardening structures on the oceanfront.* **See "Oceanfront shoreline hardening" for context.**

4. In an effort to reduce the amount of run-off from farming and animal feed operations, the EMC approved a rule [15A NCAC 02T .1310-.1311] in 2008 designed to increase monitoring of the Nitrogen, Ammonia, fecal coli form, and chlorine. *Long-term monitoring is required, in combination with management actions that reduce discharge concentrations, to determine effectiveness and future management needs*. **See "Eutrophication and oxygen depletion" section for context.**

5. *Efforts should be taken by state agencies to assist with creating Ecosystem Sensitivity Index (ESI) maps of NC.* **NCDMF is currently cooperating with NOAA to create maps showing the presence of fauna collected by NCDMF sampling surveys (see "Toxic chemicals" section for context).**

6. *The National Park Service should continue to restrict ORV beach access to areas that will not negatively influence soft bottom fauna.* **See "Offshore Vehicles" section for context.**

7. *Should the State consider locating a wind facility in state or federal waters, proper placement of energy infrastructure is necessary to minimize potential impacts to SAV habitat and minimize conflicts with existing activities.* **See "Wind Energy" section for context**

8. *Permitting agencies should avoid or minimize dredging projects in Anadromous Fish Spawning Areas and undesignated but important associated anadromous fish nursery areas.* **See "Dredging (navigation channels and boat basins)" section for context.**

9. *Dock siting criteria should include a minimum water depth over all habitats to prevent boats or floating docks from sitting directly on shallow soft bottom.* **See "Marinas and docks" subsection of "Water dependent development" section for context.**

10. *All of the sand management recommendations of the Ocean Policy Report should be implemented.* The first four items should be addressed in the BIMP. **See "Shoreline stabilization" subsection of "Water dependent development" section for context.**

11. *Because of this, the 2009 Ocean Policy report (NC Sea Grant 2009) recommended that CRC rule language be modified to require a 500 m dredging buffer around all hard bottom areas, including those of low relief that are periodically buried with thin ephemeral sand layers.* **See "Shoreline stabilization" subsection of "Water dependent development" section for context.**

6.5 SUMMARY OF SOFT BOTTOM CHAPTER

There are a variety of soft bottom habitat types, ranging from intertidal ocean beaches, to sound bottoms and mud flats. Soft bottom is an important source of primary (benthic microalgae) and secondary (infauna and epifauna) productivity, and therefore the primary foraging habitat for many species. Soft bottom also plays an important role in the ecosystem by storing and releasing nutrients and chemicals into the water column. Shallow soft bottom serves as important nursery areas for many species, especially spot, croaker, flounder, Penaeid shrimp, and blue crabs. Shallow riverine waters function as spawning areas for some anadromous fish species and inlet channels are often spawning areas for species like blue crab, speckled sea trout and red drum. Other species highly associated with soft bottom include shortnose sturgeon in riverine waters, hard clams, and coastal sharks, kingfish, and Florida pompano in marine waters. It is estimated that roughly 17-37% of soft bottom is less than six feet deep, although bathymetric maps need updating.

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. With the increased effort to map SAV, hard, and shell bottom habitats in NC, a better understanding of the extent of soft bottom habitat is available. This increased effort to map NC habitats has included updating both Nursery and Anadromous Fish Spawning Areas designations. Species that are highly dependent on soft bottom with depleted stock status in 2009 include Atlantic sturgeon and southern flounder. Those with concern stock status are croaker, spot, and coastal sharks. Shortnose sturgeon is not classified since they are federally listed as endangered and there is a fishing moratorium on the species.

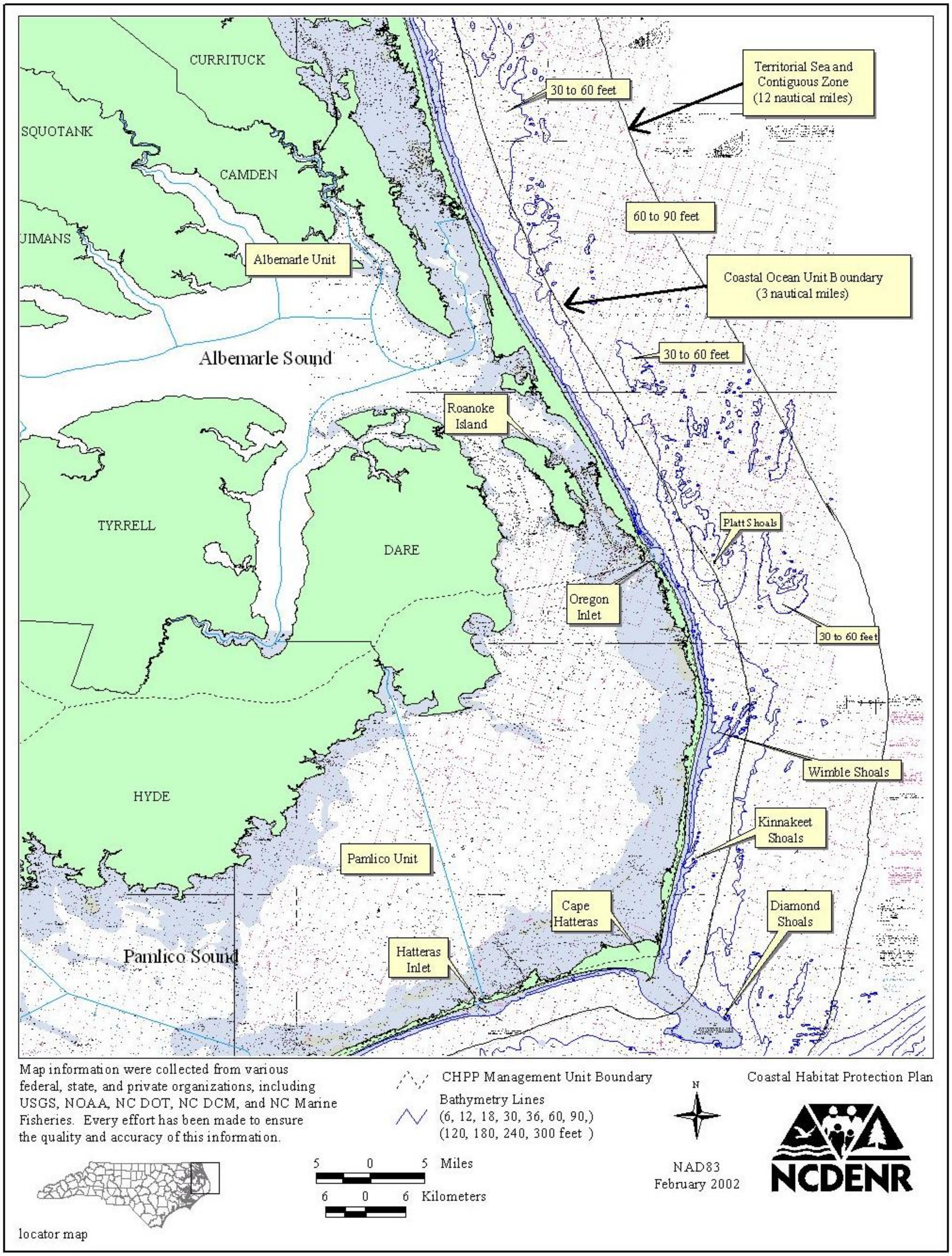
In estuarine and fresh waters, a significant threat to shallow soft bottom habitat is channel dredging, as the need for boat access continues to growToxin contamination of bottom sediments, particularly where sediments are fine and flushing is low, can have a negative impact on the benthic community and entire food chain in fresh and estuarine waters particularly. Although many toxic chemicals and metals that are harmful to aquatic fauna have been banned from being used in the aquatic environment, they have remained in soft bottom sediments. In order to fully understand the extent of this issue, chemical analyses need to be performed on NC estuarine and marine sediments to determine the heavy metal and toxin distribution and their effect on aquatic organisms. Potential oil and gas development and infrastructure in NC waters could introduce another source of toxin contamination. There needs to be a complete understanding of the impacts on the soft bottom habitat and the associated organisms, as well as other habitats. Eutrophication can also be problematic by exasperating hypoxia and mortality of the benthic community.

On the oceanfront, shoreline stabilization is a large and growing threat . Since the last CHPP, there have been increased requests by beach communities along the coast for large-scale storm damage reduction projects and inlet relocation projects, including Dare and Brunswick counties, Bogue Banks and Topsail Island. These projects are requesting use of offshore borrow areas for a sand source. There has also been a shift to more communities requesting privately funded nourishment projects, due to unavailability of federal funds in a short time frame. Private projects have been done or are in planning stages for approximately 65 mi of beach. There has also been increased interest in using ebb tidal deltas and the cape shoals as a sand source for nourishment projects. An emerging issue for this habitat since the 2005 CHPP is the consideration by the legislature to reverse the State's long standing policy against ocean shoreline hardening due to severe erosion on portions of some developed islands and private interests to protect the affected homes and infrastructure.

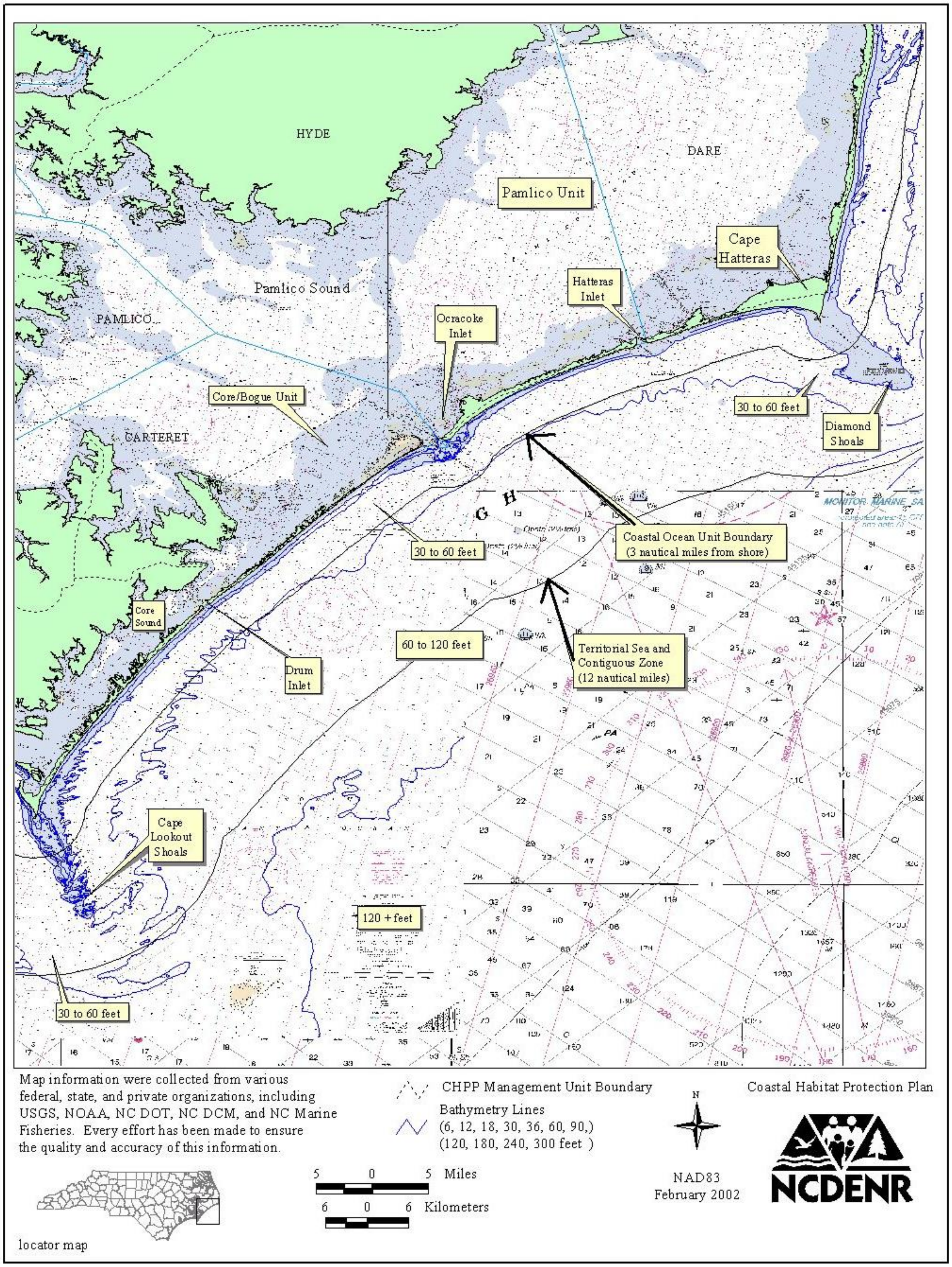
As a result of the 2005 CHPP, approximately one third (11) of the 35 research and management needs(excluding new emerging items) have had some progress in being addressed. Three management needs were accomplished, but six management needs and two research needs are ongoing and require continued effort and funding. There were 10 management and research needs that were not addressed, and 14 were discontinued due to duplication, vagueness, or lack of supporting information. Since the 2005 CHPP, 14 additional emerging research and management needs were identified. These needs include understanding the long-term effects of climate change, sea level rise, and construction of wind energy facilities. Climate change and sea level rise, are directly linked to the soft bottom habitat threat of shoreline stabilization. With the threat of sea level rise, there will continue to be a desire to utilize varying methods to stabilize the shoreline. As these structures continue to be built we must fully understand both the positive and negative effects they have on the ecosystem as a whole.

Accomplishments related to soft bottom include designation of anadromous fish spawning areas by the MFC and WRC, new CRC rules regarding sediment criteria for beach nourishment and additional conditions on siting of docking facilities over designated Primary Nursery Areas. Other progress underway includes additional MFC restrictions on bottom disturbing gear over shallow soft bottom, preparation of a draft Beach and Inlet Management Plan, research on the effect of hypoxia on fish productivity, and some additional public outreach on the importance of natural barrier island and estuarine processes by ECU. Initial progress has been made regarding improvements to estuarine shoreline stabilization rules, primarily through development of outreach products, discussions of the issue with scientists and managers, research on effects of various shoreline stabilization structures on habitat and associated fauna. Even though several needs have been addressed since 2005, there is more to be done.

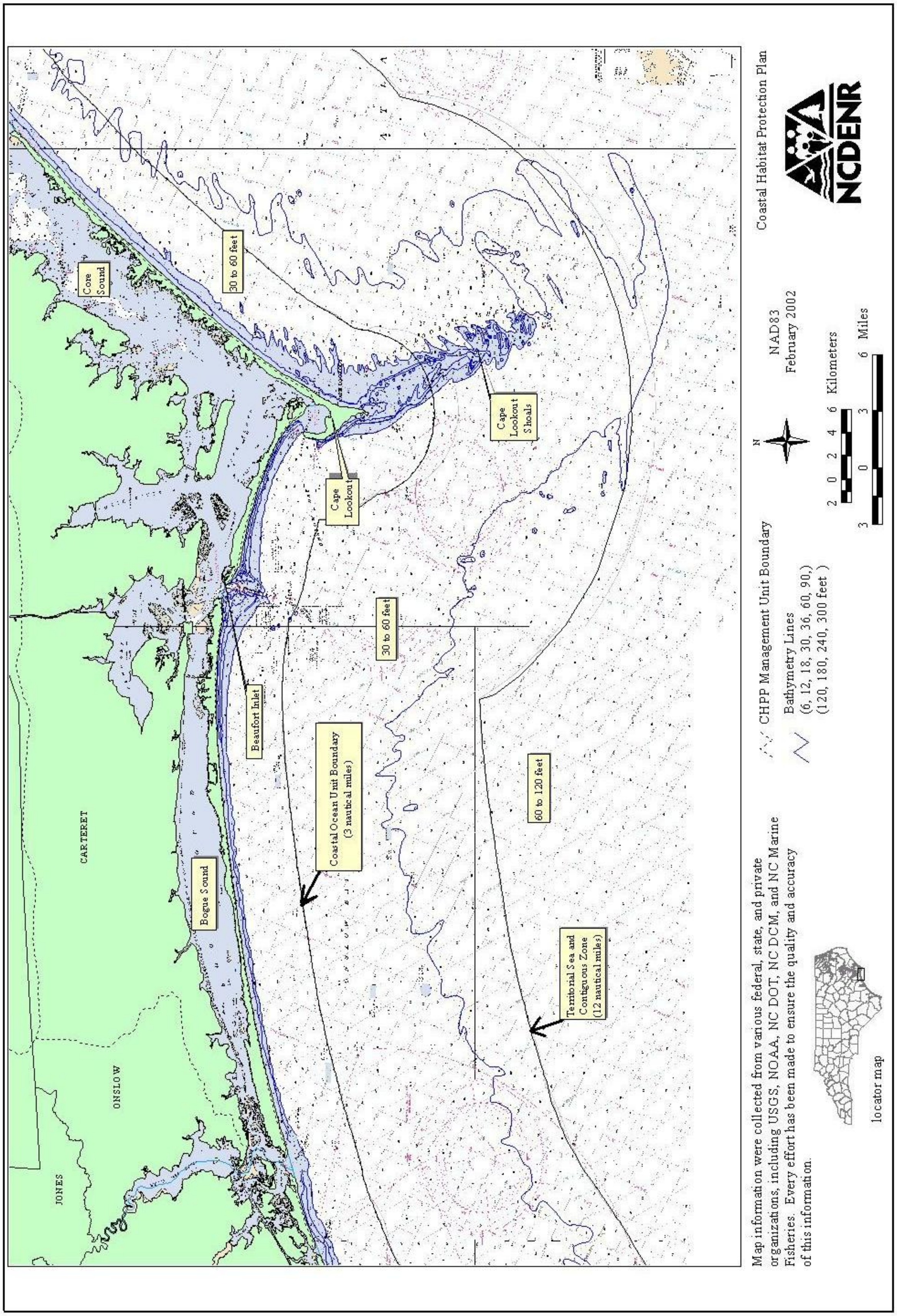
Emerging needs for this habitat include preventing hardened structures along ocean shorelines and inlets, modifying post-storm practices to allow newly formed inlets to temporarily remain open to form flood tide deltas, restricting dredging or implementing other needed management actions to protect designated Anadromous Fish Spawning Areas, and implementing the sand management strategies of the 2009 Ocean Policy Report, including rule changes regarding dredging near hard bottom. In order to continue to preserve the soft bottom habitat and associated fauna there needs to be a continued effort to address the research and management needs outlined in this document. Informed decisions can be made as we expand on the available information regarding the soft bottom habitat and its response to its threats.



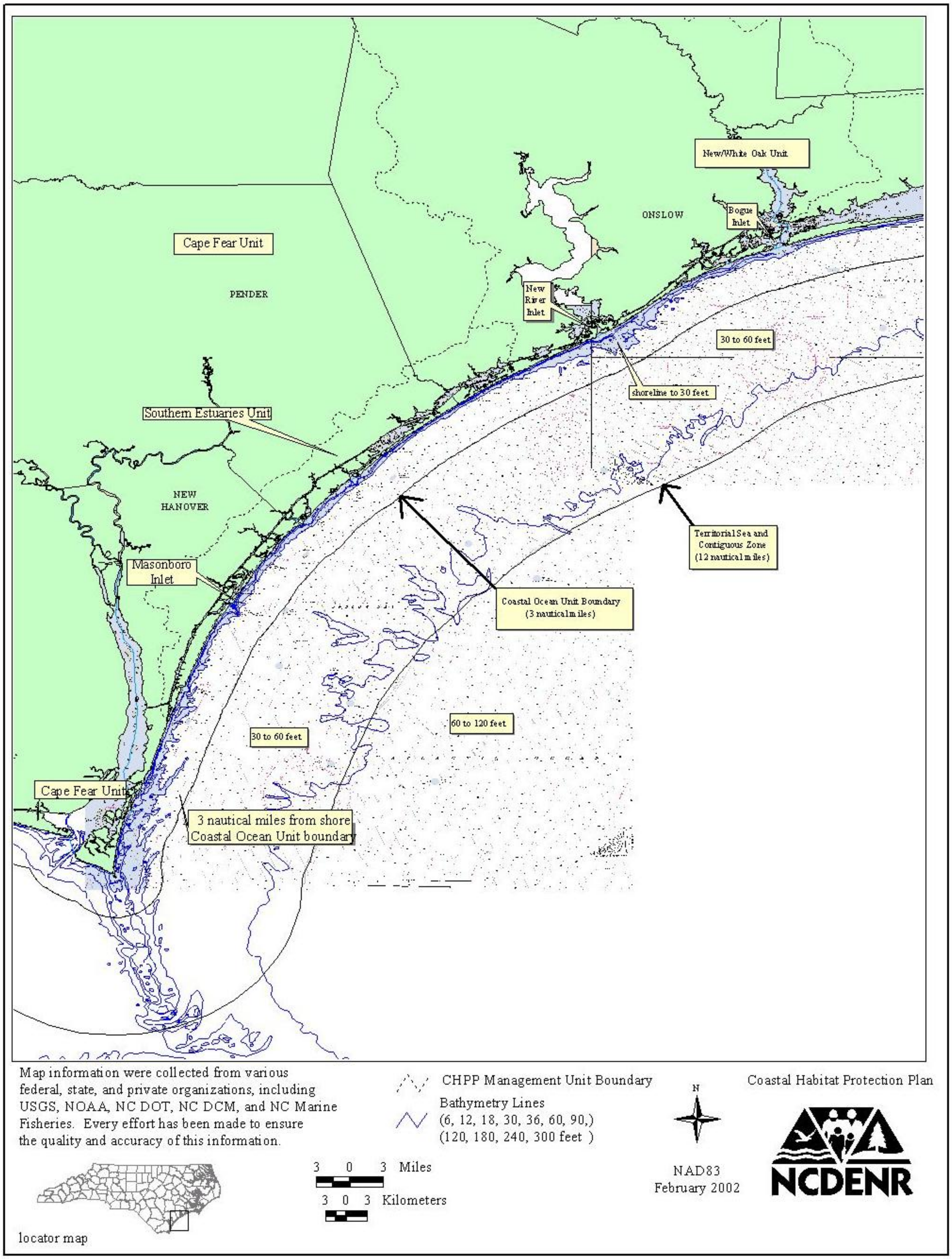
Map 6.1a. Location of marine topographic features, northeastern coast of North Carolina.



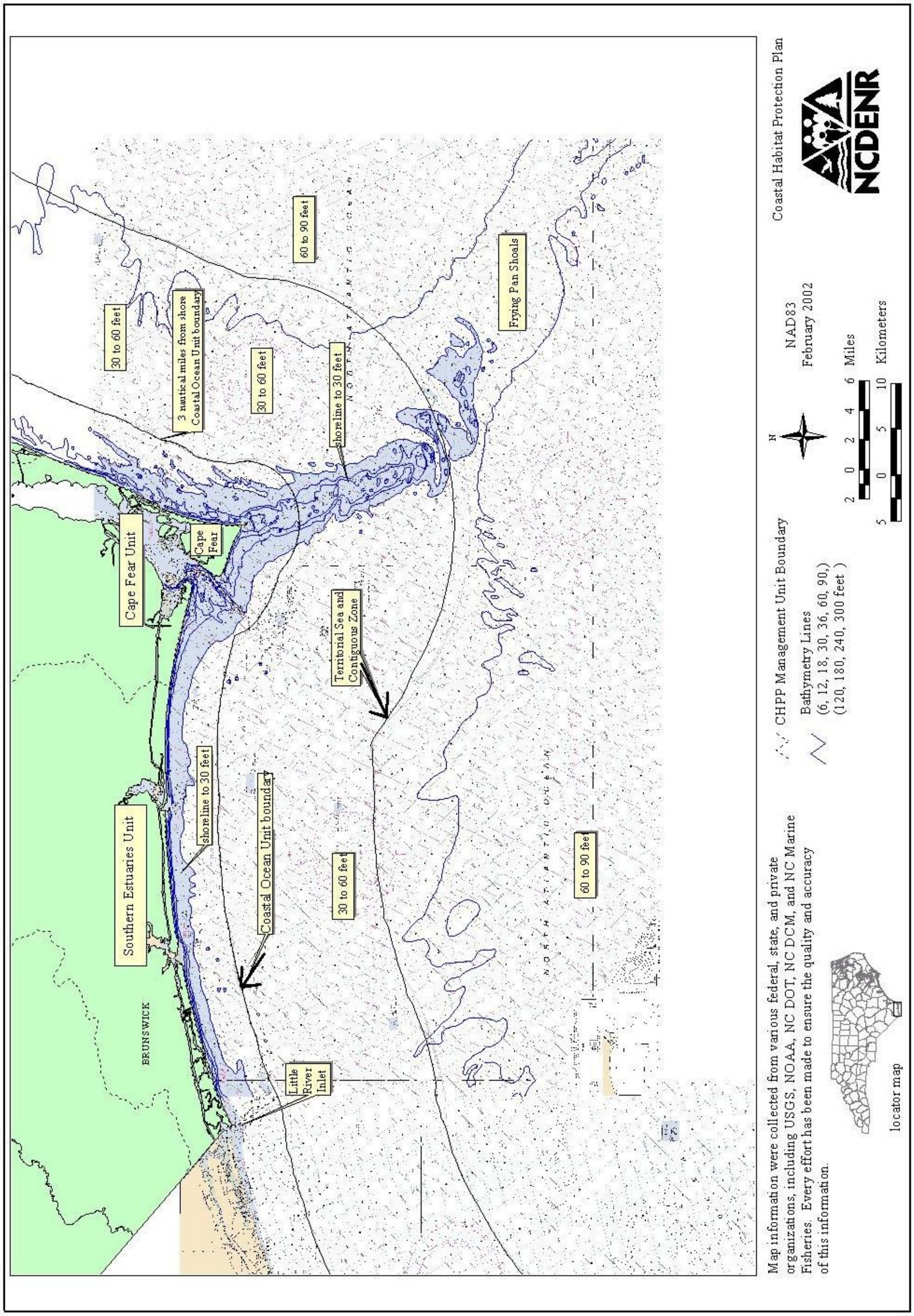
Map 6.1b. Location of marine topographic features, central coast of North Carolina.



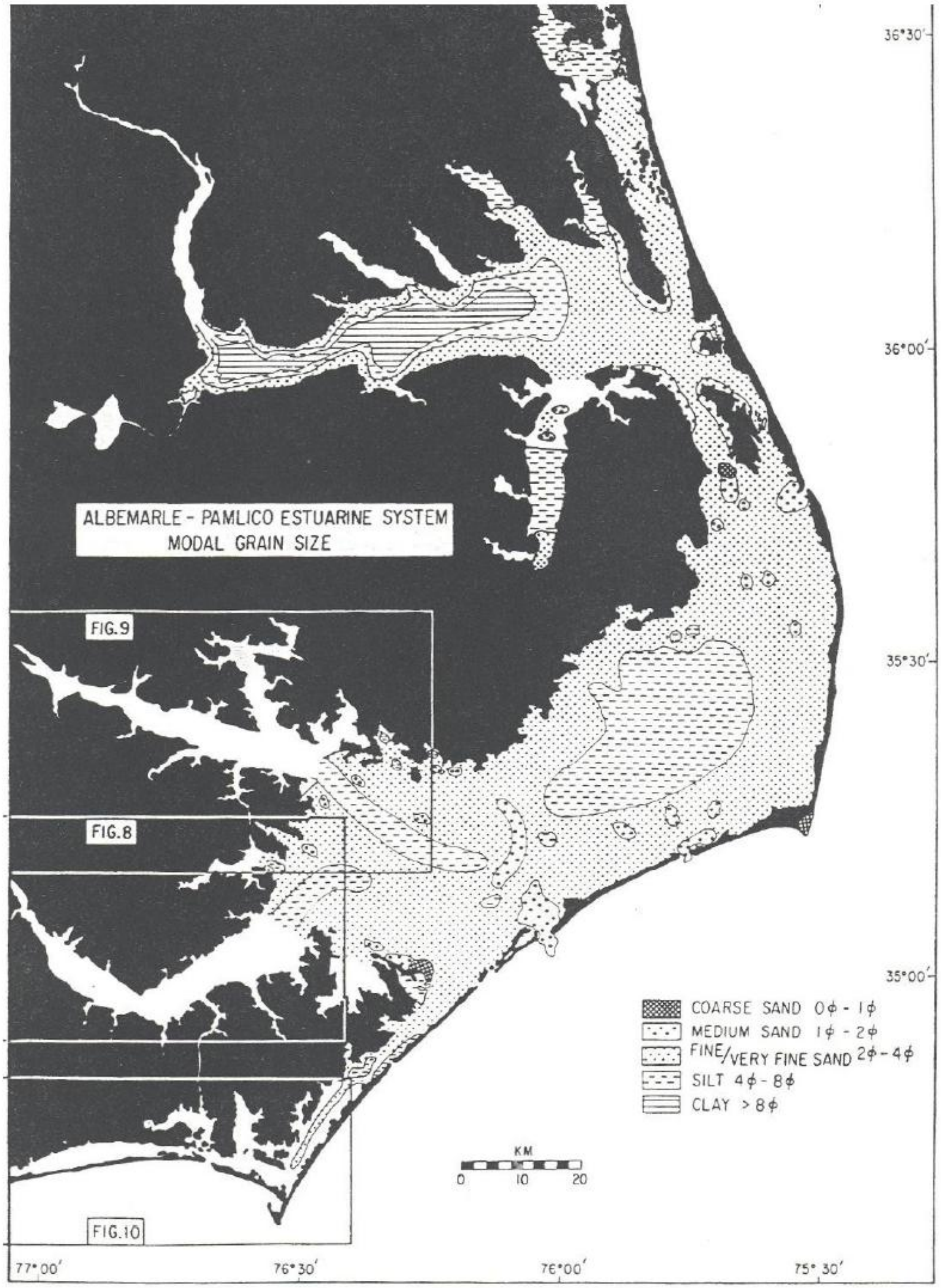
Map 2.1c. of marine topographic features, southcentral coast of North Carolina.



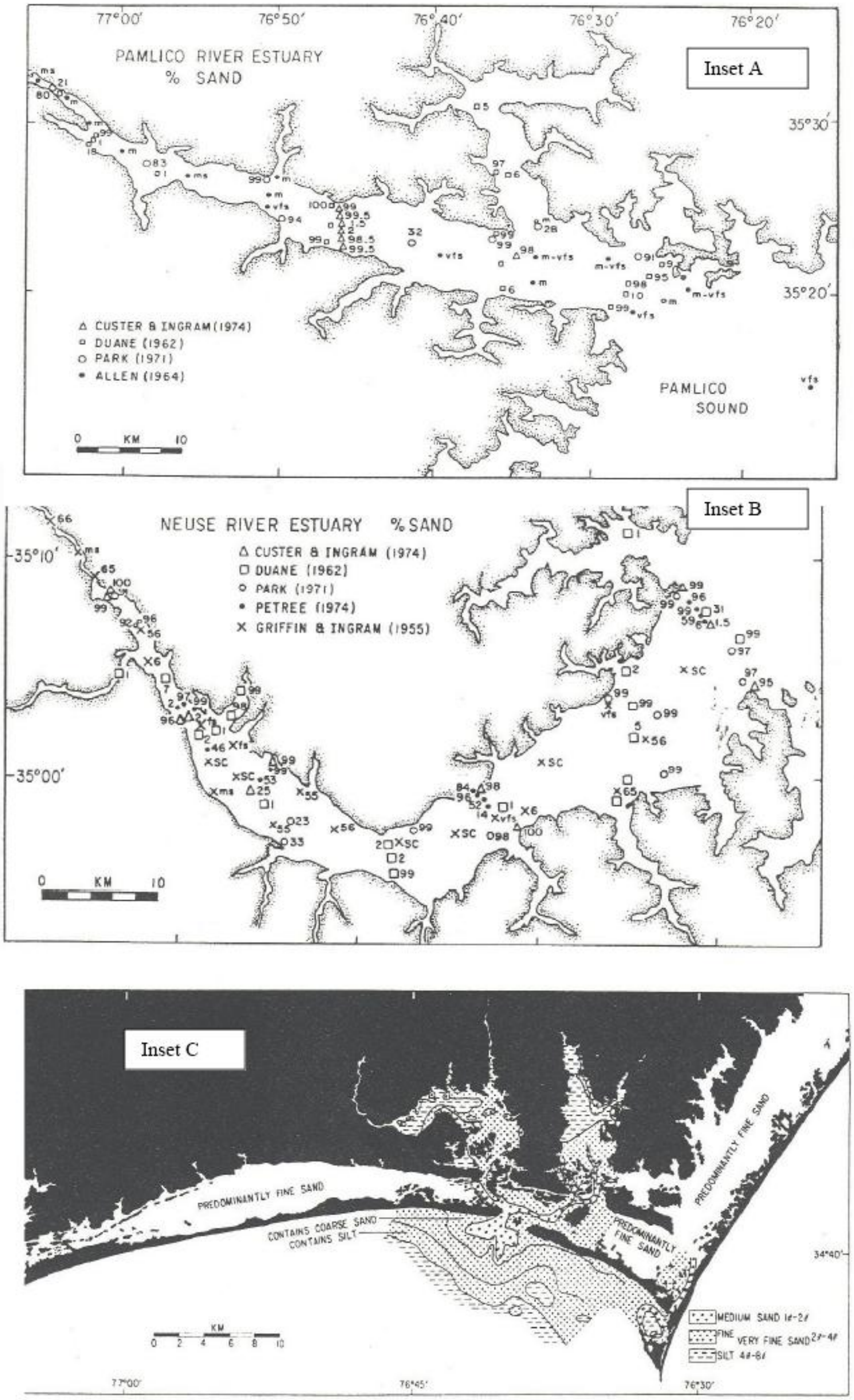
Map 6.1d. Location of marine topographic features, southeast coast of North Carolina.



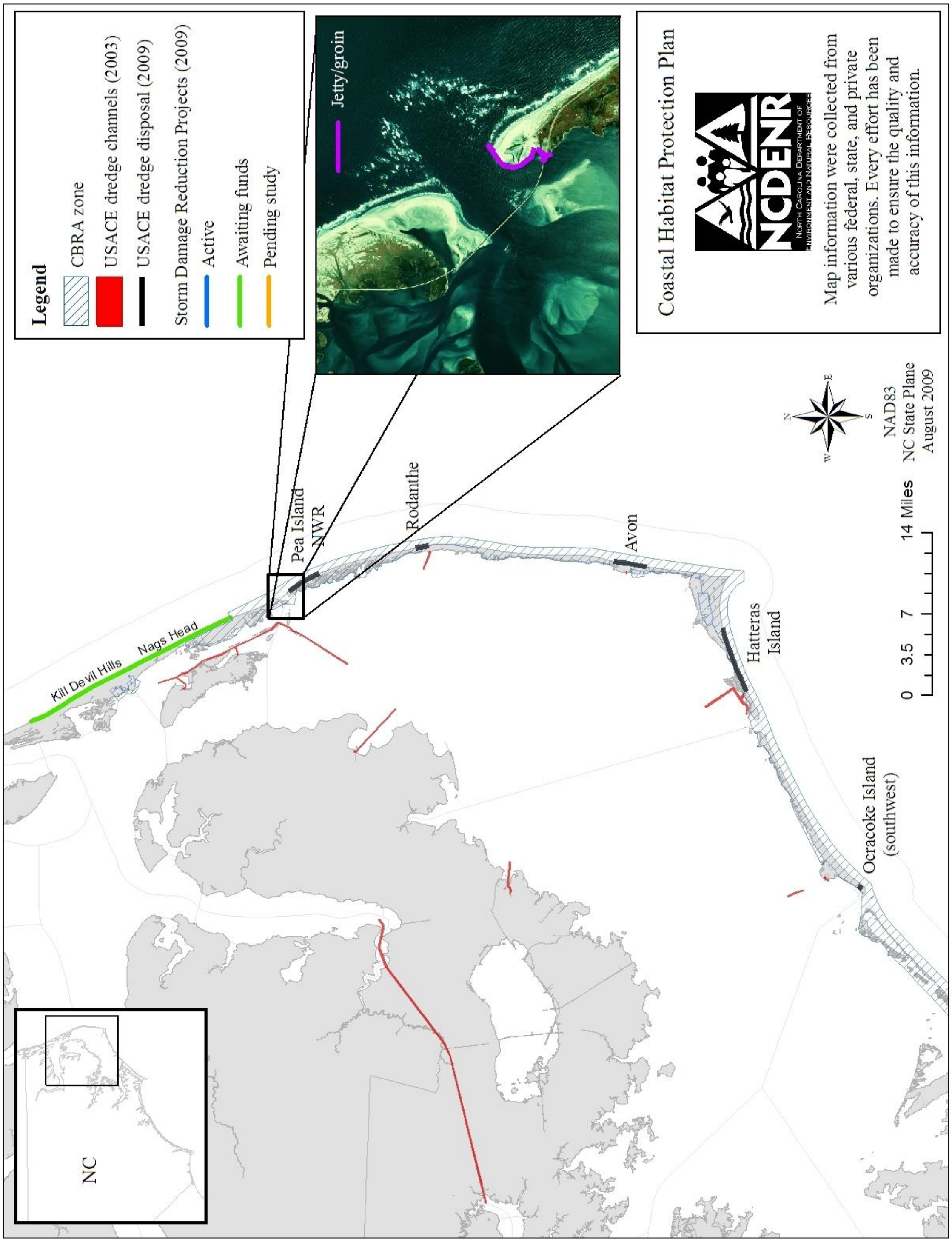
Map 6.1e. Location of marine topographic features, south coast of North Carolina.



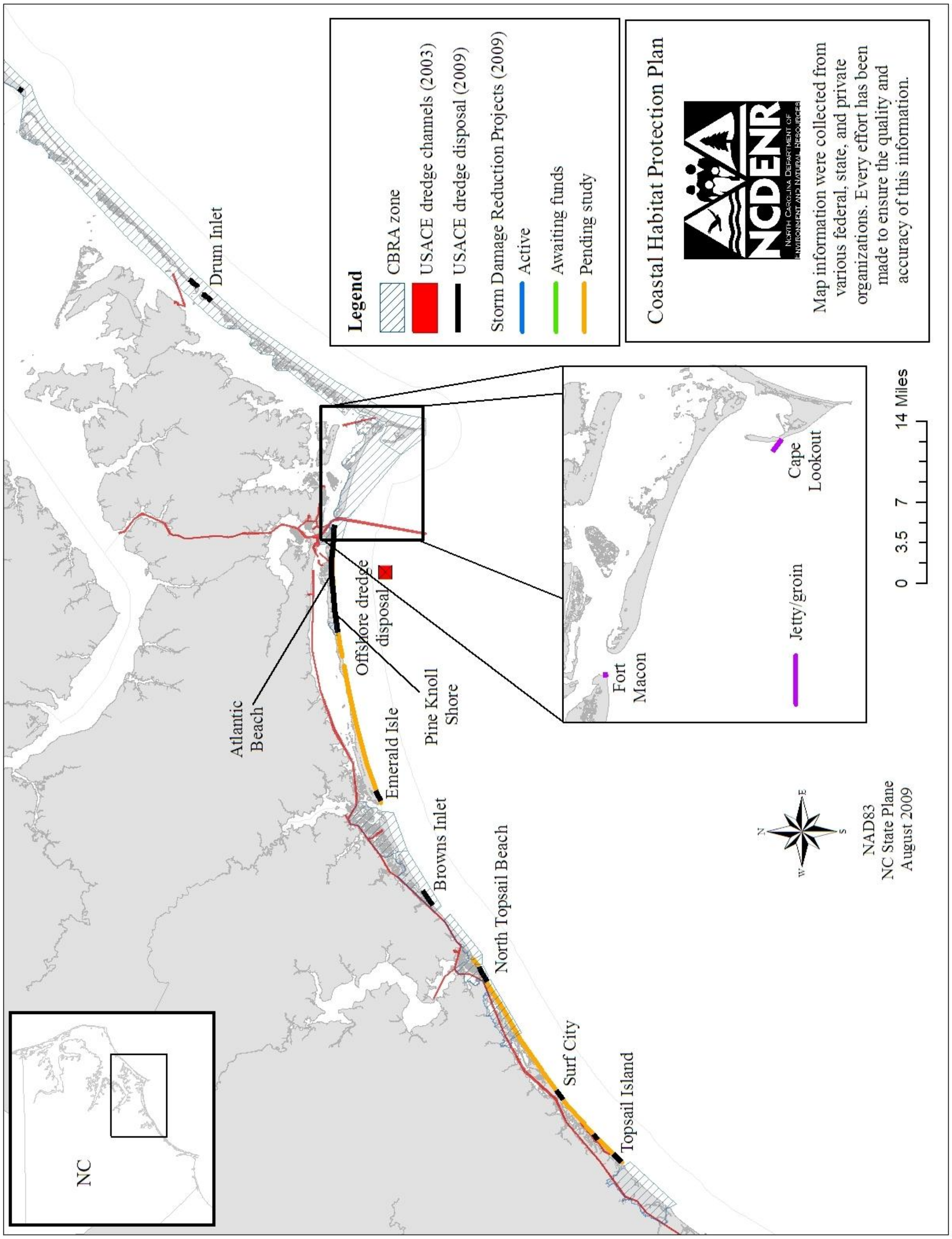
Map 6.2a. Sediment composition in the Albemarle-Pamlico estuarine system. Inset A = Tar-Pamlico, Inset B = Neuse, Inset C= Bogue (Wells 1989). Numbers = % sand, M= mud, SC=silty clay, VFS= very fine sand, MS= medium sand).



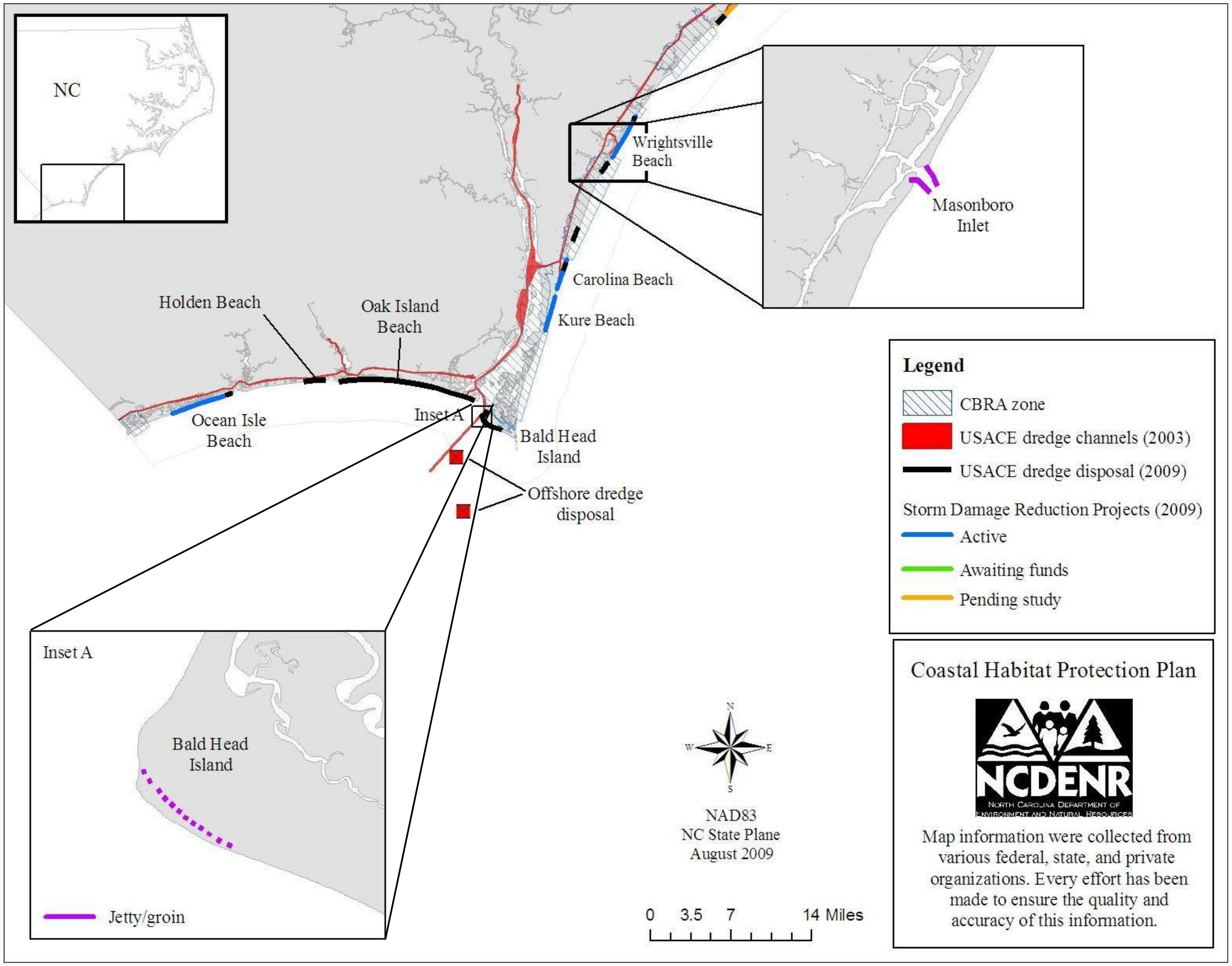
Map 6.2b. Sediment composition in the Tar-Pamlico, Neuse, and Core/Bogue estuaries (Wells 1989). Numbers = % sand, M= mud, SC=silty clay, VFS= very fine sand, MS= medium sand.



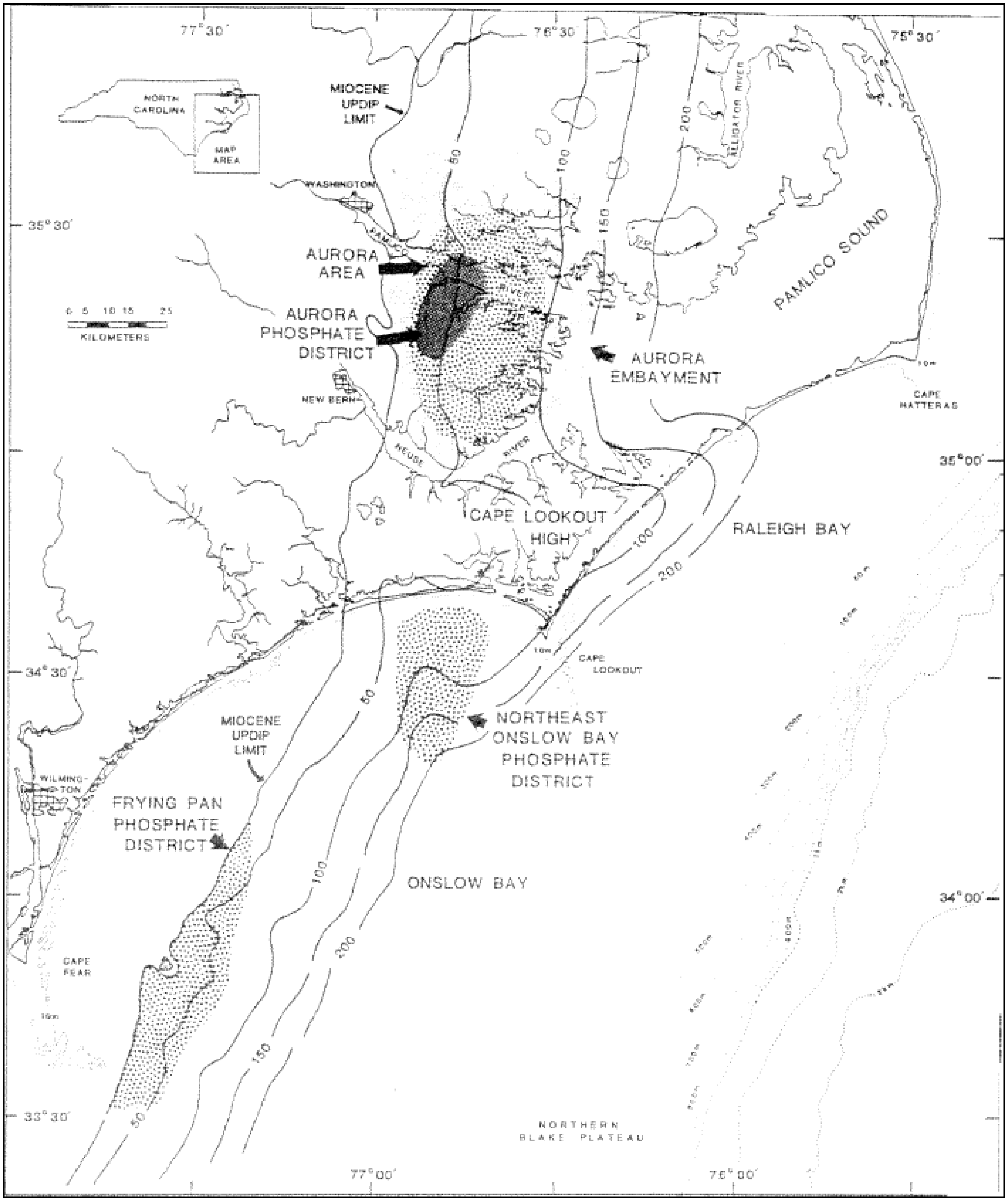
Map 6.3a. Location of Storm Damage Reduction projects (active, awaiting funding, or pending study), dredge disposal sites (approved areas), jetties, groins, and designated CBRA zones, northern coastal area of North Carolina.



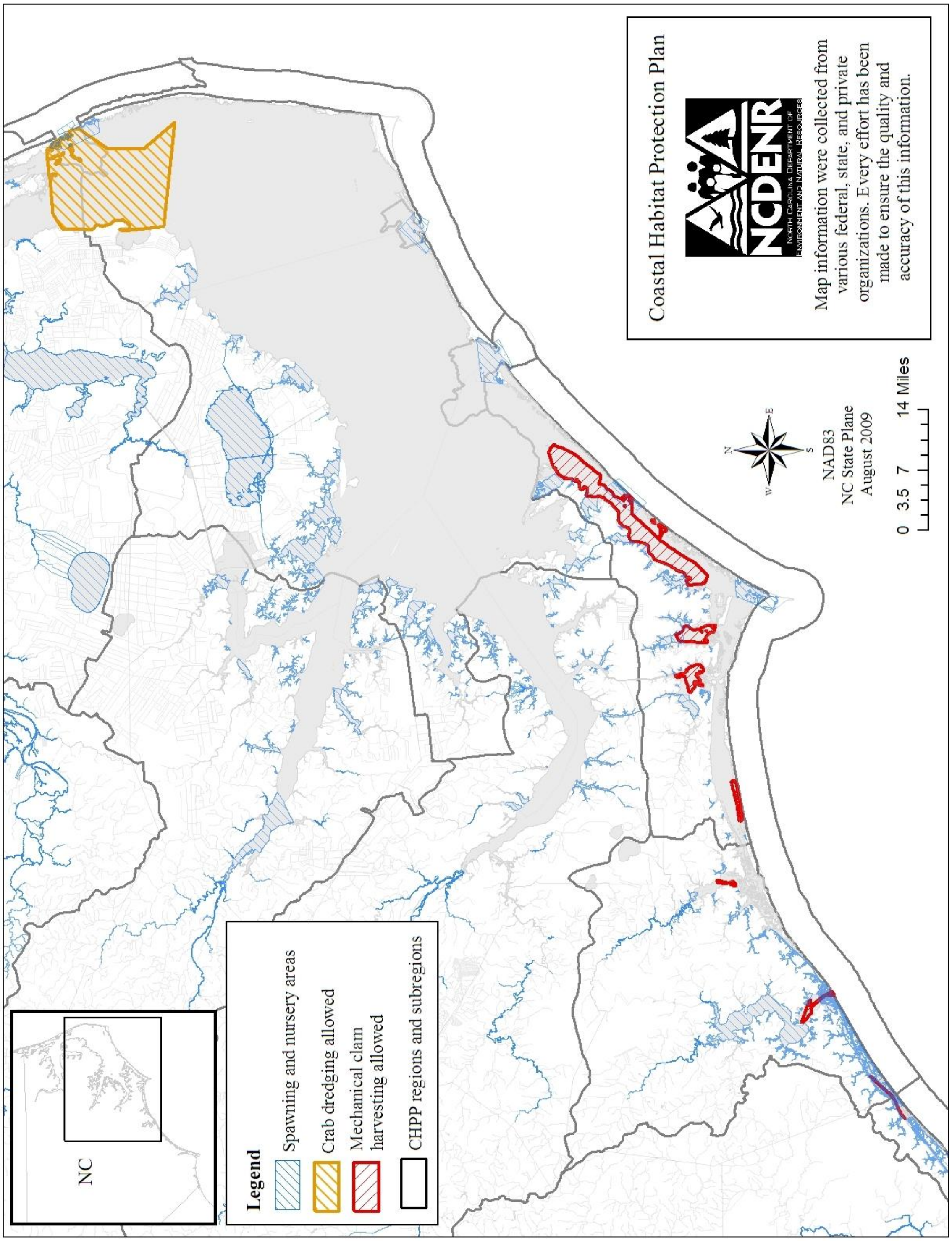
Map 6.3b. Location of Storm Damage Reduction projects (active, awaiting funding, or pending study), dredge disposal sites (approved areas), jetties, groins, and designated CBRA zones, central coastal area of North Carolina.



Map 6.3c. Location of Storm Damage Reduction projects (active, awaiting funding, or pending study), dredge disposal sites (approved areas), jetties, groins, and designated CBRA zones, southern coastal area of North Carolina.



Map 6.4. Location of phosphate districts (known concentrations of phosphate deposits) on the continental shelf off North Carolina (from Riggs and Manheim 1988).



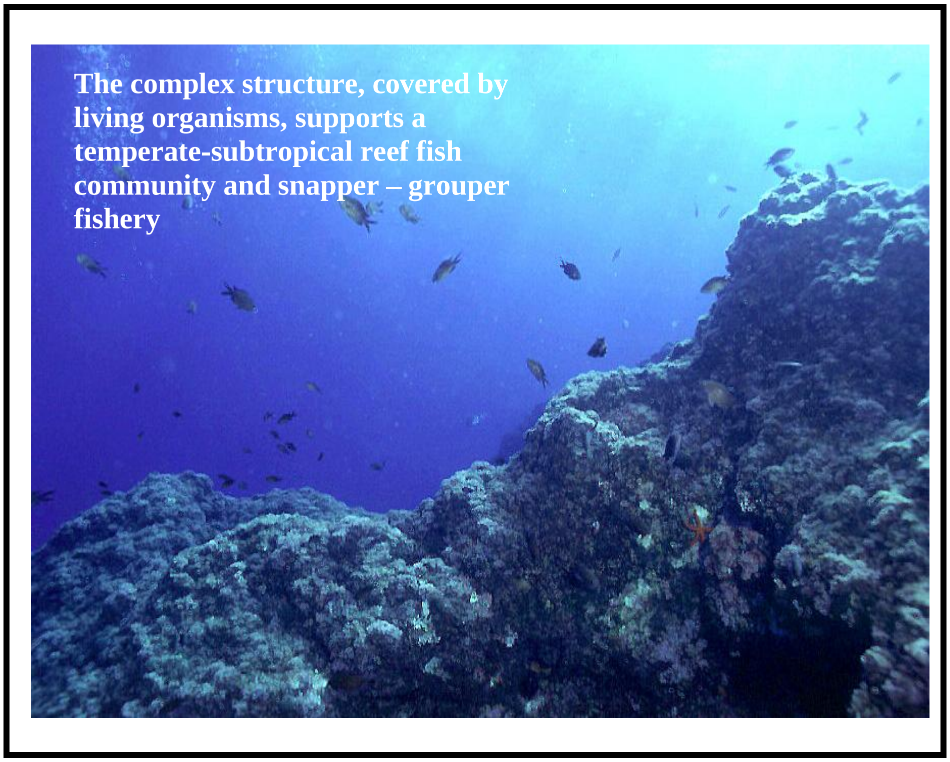
Map 6.5. Areas where mechanical harvest for clams (clam kicking, hydraulic dredge) and crabs (crab dredging) is authorized in estuarine waters of North Carolina.

CHAPTER 7. HARD BOTTOM

7.1. DESCRIPTION AND DISTRIBUTION

7.1.1. Definition

Hard bottom habitat is defined by Street et al. (2005) 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." In addition to areas of natural hard bottom, man-made structures, including artificial reefs, shipwrecks, and jetties, provide additional substrata for the development of hard bottom communities.



7.1.2. Description

Natural hard bottom, also referred to as "live rock" or "live bottom," consists of exposed rock outcrops or relic reef colonized to a varying extent by algae, sponges, soft coral, hard coral, and other sessile invertebrates (SAFMC 1998a; SAFMC 2008a). Hard bottom habitats vary in topographic relief from relatively flat outcrops with gentle slopes to a scarped ledge with up to 10 m of vertical, sloped, or stepped relief (Barans and Henry 1984; Riggs et al. 1996). Bioerosion of the hard substrate by encrusting organisms produces large-scale morphological features, including overhangs and undercut sloped scarps (Riggs et al. 1996; Riggs et al. 1998). Low-relief outcroppings may be subject to intermittent burial and exposure through the natural distribution of ephemeral sand bodies (SEAMAP-SA 2001). Areas of compacted or sheered mud sediments also function as hard bottom habitat (Riggs et al. 1996).

Artificial reefs are structures constructed or placed in waters for the purpose of enhancing fishery resources. Colonization of artificial reefs by algae, invertebrates, and other marine life results in establishment of additional hard bottom habitat. In North Carolina, artificial reefs have been constructed from surplus vessels, steel boxcars, concrete pipe, concrete rubble, rock, boat molds, tires, and surplus military aircraft. Concrete domes and igloos specifically designed to provide structurally complex habitat (i.e. Reef Balls ™) have also been used for artificial reef construction. The DMF Artificial Reef Program is responsible for deployment and maintenance of artificial reef sites in state and federal waters, following the guidelines of the DMF Artificial Reef Master Plan (DMF 1988). Shipwrecks off the North Carolina coast also provide added structure available as hard bottom habitat. Documented wrecks include World War II German U-boats, gunboats, tankers, freighters, barges, sailing ships, and wooden and iron-hulled steamers.

Jetties and groins are man-made rubble (e.g. large boulder) structures built perpendicular to the shoreline and designed to retard the littoral transport of sediments. Jetties are usually constructed at 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 but shorter than jetties, and their primary purpose is to trap sand, not maintain the channel. The degree of colonization of these hard structures by attached invertebrates and algae depends primarily on location, flow characteristics, and water quality conditions. Bridge and pier pilings, as well as other concrete structures in high salinity estuarine waters, also provide suitable substrate for hard bottom communities.

7.1.3. Habitat requirements

The primary requirement for the formation and stability of hard bottom habitat is exposed areas of hard substrate. Species composition and abundance of algae, invertebrates, and reef fishes at hard bottom habitats in the ocean off North Carolina vary with temperature and depth. Bottom water temperatures at these habitats range from approximately 11º to 27º C. Temperatures less than 12°C may result in the death of tropical species of invertebrates and fishes. Changes in water masses, seasonal fluctuations in water temperature, and light penetration physically stress the hard bottom community in North Carolina (Kirby-Smith 1989), limiting the abundance and diversity of hard coral and reef fish.

7.1.4. Distribution

Hard bottom occurs in both warm-temperate and subtropical areas of the South Atlantic Bight, although it is less extensive in the northern end of its range (North Carolina). This habitat extends from the shoreline and nearshore (within the state's three-nautical mile jurisdictional limit) to beyond the continental shelf edge (>200 m deep), generally occurring in clusters in specific areas (SEAMAP-SA 2001). Parker et al. (1983) estimated that hard bottom accounts for approximately 14% (504,095 acres) of the substratum between 27 and 101 m water depth from Cape Hatteras to Cape Fear, and 30% (1,829,321 acres) between Cape Fear and Cape Canaveral.

7.1.4.1. Hard bottom mapping

Several efforts have been undertaken to map hard bottom resources in coastal waters of the southeastern United States. In 1985, the Southeast Area Monitoring and Assessment Program—South Atlantic (SEAMAP-SA) began an initiative to identify the location and extent of hard bottom and coral reef habitats throughout the South Atlantic Bight to water depths of 200 m. Data used to identify hard bottom was based upon the presence of indicator species in traps or trawls, sidescan sonar records, and video and diver observations. The amount of hard bottom habitat documented by this program was most likely an underestimate due to the ephemeral nature of low-relief hard bottoms and the difficulty of distinguishing bottom type using seismic data (SEAMAP-SA 2001).

Locations of natural hard bottom and artificial reef sites documented by SEAMAP-SA (2001) in both state and federal waters are shown in Map 7.1, along with some of the known shipwrecks. The majority of natural hard bottom outcrops identified are located in federal waters (> three nautical miles (nm) from shore) of Onslow and Long bays. Concentrations of hard bottoms in Long Bay occur between the Cape Fear River mouth and Shallotte Inlet. In Onslow Bay, hard bottom is most concentrated from Bogue Inlet east to Cape Lookout Shoals, from Brown's Inlet south to New Topsail Inlet, and from Masonboro Inlet to Frying Pan Shoals. Hard bottom in Raleigh Bay is most concentrated east of Cape Lookout Shoals and south of Diamond Shoals. Within state territorial waters, the SEAMAP-SA (2001) database identified 48 natural hard bottom sites and 75 possible hard bottom sites using point and line data, with the majority of sites occurring in Onslow Bay (Table 7.1).[47]

Table 7.1. Hard bottom and possible hard bottom locations in North Carolina state territorial waters 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)

Recently, SEAMAP-SA expanded their efforts to synthesize existing data on bottom habitat distributions for water depths between 200 and 2000 m within the U.S. Exclusive Economic Zone (EEZ) of the South Atlantic Bight (SEAMAP-SA 2004; Udouj 2007). Similar to that done for shallower waters, data used to identify deepwater hard bottom included visual observations, presence of invertebrate indicator species in trawls, traps or dredges, and geological records (SEAMAP-SA 2004). The SEAMAP-SA Deepwater Bottom Mapping Project identified 34 natural hard bottom sites in the waters off North Carolina, many of which are concentrated in Onslow Bay (Udouj 2007). These sites include the proposed Cape Lookout and Cape Fear Deepwater Coral Habitat Areas of Particular Concern (CHAPC) (Ross 2006; Partyka et al. 2007; SAFMC 2008b).

In addition to the large-scale SEAMAP-SA mapping efforts, Moser and Taylor (1995) compiled information on the distribution of hard bottom in the nearshore ocean waters of North Carolina using surveys of local researchers, dive professionals, and fishermen. A total of 198 hard bottom positions were identified with several sites not included in the SEAMAP-SA (2001) database (Map 7.1, Table 7.1). Over 92% of the identified nearshore hard bottom is south of Cape Lookout, predominantly in the southern half of Onslow Bay and in northern Long Bay. Concentrations of nearshore hard bottoms occur seaward of inlets, including Bogue, New River, New Topsail, Masonboro, Carolina Beach, Lockwood's Folly and Shallotte inlets. Twenty of the identified nearshore hard bottom sites were reported as high-profile relief, defined by Moser and Taylor (1995) as vertical relief greater than two meters, with several sites, specifically those off Carolina Beach and New River, extensive in both area and topographic relief. Outcroppings of moderate-to-high relief occur in shallow waters near the shoals of Cape Fear and Cape Lookout. Vast areas of low-relief hard bottom, intermittently covered with a thin layer of sand, occur extensively from 1) mid-Onslow Beach to south of New River Inlet and 2) Yaupon Beach west to Tubbs Inlet (Moser and Taylor 1995). At Fort Fisher, a unique intertidal and subtidal coquina rock outcrop extends from the beach into the surf zone.

Several localized mapping efforts have provided detailed information with regards to the extent of hard bottom habitats in specific areas of the North Carolina coast (Crowson 1980; Lombardero et al. 2008). These mapping efforts have primarily focused on nearshore resources in the vicinity of Surf City and New River Inlet. Extensive low to high-relief hard bottom outcrops have been identified in these areas.

[47] Line data represents information from trawls. 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.

Crowson (1980) found that much of the nearshore low-relief hard bottom in the proximity of New River Inlet was partially covered by a thin layer of sand. In boring for compatible sand sources for Brunswick County beach nourishment, the US Army Corps of Engineers (USACE)has identified several areas of low-relief hard bottom seaward of Oak Island, Holden Beach, and Ocean Isle (USACE, unpub. data).

7.1.4.2. Distribution of man-made hard bottom

There are 47 DMF-managed artificial reefs of varying construction in North Carolina, of which 29 are located in federal ocean waters, 11 in state ocean waters (Map 7.1), and seven in estuarine waters.[48] The DMF Artificial Reef Program generally adds material to the 40 existing ocean sites, rather than creating new reefs, although new reefs are created on occasion. In addition to the DMF-managed artificial reefs, the USACE constructed an artificial reef off the Cape Fear River using rock dredged during deepening of the shipping channel. The North Carolina Department of Cultural Resources, Underwater Archaeology Branch, estimates there are over 1,000 sunken vessels off the North Carolina coast dating back to the earliest period of European exploration (<http://www.archaeology. ncdcr.gov/ncarch/underwater/ underwater.htm>, 2008). The majority of shipwrecks are in federal waters, with concentrations around the three cape shoals. Gentile (1992) listed 46 documented wrecks in waters south of Hatteras Inlet, with most located northeast and west of the mouth of the Cape Fear River (Map 7.1). There are also two jetty systems and three groin systems along the North Carolina ocean shoreline. A single jetty is situated on the west side of Cape Lookout, while Masonboro Inlet has jetties on both sides–one attached to Wrightsville Beach, and the other attached to Masonboro Island. The groins are located on the south side of Oregon Inlet, off the former site of the Cape Hatteras Lighthouse, and on the west side of Beaufort Inlet. Numerous small groins and jetty systems are in estuarine waters as well, but these features have not been mapped.

7.2. ECOLOGICAL ROLE AND FUNCTIONS

7.2.1. Ecosystem enhancement

Hard bottoms, through bioerosion, contribute significant volumes of new sand to sediment-starved sections of the North Carolina continental margin, such as Onslow and Long bays (Riggs et al. 1996; Riggs et al. 1998). Three primary groups of bioeroders, including rock boring bivalves, burrowing shrimp, and macroalgae, physically and/or chemically degrade hard bottom of different hardnesses and slopes (Riggs et al. 1998). Larvae of rock boring bivalves erode mostly muddy sandstones by chemically (i.e. secretion of acid) or mechanically (i.e. abrasion from their hard shell) burrowing through sections of rock. Over time, multiple tunnels weaken the rock until chunks break off, leaving a fresh surface for more bivalve larvae to settle on and bore into. Macroalgae erode rock (primarily Pleistocene limestone) when storms and strong water currents dislodge their holdfasts from the rock surface, removing small pieces of rock along with the plant itself. Rates of sediment production from bioerosion vary with respect to substrate type, ranging from 5.5 kg/m^2/yr on vertical and sloped Miocene mudstone to 0.03 kg/m^2/yr on flat, highly lithified Plio-Pleistocene limestone (Riggs et al. 1998). These processes also enhance the structural complexity of the hard bottom outcrops, which promotes diversity of fish habitat within the reef (Riggs et al. 1996; Riggs et al. 1998).

7.2.2. Productivity

Exposed hard substrate provides stable attachment surfaces for colonization by sessile marine invertebrates and algae. The vertical relief and irregularity of hard bottom structure affords greater habitat complexity, allowing more species to coexist (Wenner et al. 1984; Fraser and Sedberry 2008). Areas of exposed hard bottom may be quite small and isolated, and have been considered oases of productivity surrounded by less productive unconsolidated ocean bottom (SAFMC 1998a; SAFMC

[48] The Shell Bottom chapter (3.0) covers estuarine reefs located in salinities suitable for oysters.

2008a). Species diversity and extent of colonization on temperate hard bottom vary with topography, environmental conditions, and distance from shore. Much of the research on hard bottom communities in North Carolina has been focused on locations beyond the three-mile state boundary (MacIntyre and Pilkey 1969; Schneider 1976; Peckol and Searles 1984; Kirby-Smith 1989).

Macroalgae are the dominant colonizing organisms on North Carolina hard bottoms, ranging from 10% to 70% of the biotic cover (Peckol and Searles 1984). Roughly 150 species of encrusting macroalgae have been identified, with the greatest diversity occurring in Onslow Bay (Schneider 1976). Perennial and crustose brown and red algae, including *Sargassum filipendula*, *Dictyopteris membranacea*, *Lobophora variegata*, *Lithophyllum subtenellum*, *Zonaria tournefortii*, and *Gracilaria mammillaris* are dominant algal forms (Schneider 1976; Peckol and Searles 1984; Renaud et al. 1997; Mallin et al. 2000a; DMF 2001d). The shallow inshore flora consist largely of temperate species, while offshore areas support more tropical flora (Searles 1984). The greatest abundance of macroalgae occurs at offshore habitats due to the high proportion of suitable substrate, greater relief on the shelf break, and mild water temperatures. Of the offshore species, 66% are at their northern limit of distribution in Onslow Bay, and 2% are at their known southern distributional limit (Schneider 1976).

7.2.3. Benthic community structure

Attached, sessile invertebrates account for 10% or less of the biotic cover on hard bottom in North Carolina (Peckol and Searles 1984). Peckol and Searles (1984) reported that the soft corals *Titandeum frauenfeldii* and *Telesto fructiculosa*, and the hard coral *Oculina arbuscula* were the most abundant non-mobile invertebrates, while sea urchins (*Arbacia punctulata* and *Lytechinus variegatus*) were the most common mobile invertebrates. In a study of hard bottom communities at nearshore and offshore reefs, Kirby-Smith (1989) found that benthic community structure varied with season, depth, and distance from the shelf edge. Inner shelf sites, in approximately 16–27 m water depths, had somewhat lower diversity than mid- or outer shelf sites. Regardless of location, mollusks, polychaetes, and amphipods were dominant in the number of species observed.

Wenner et al. (1984) reported that sponges, bryozoans, corals, and anemones[49] dominated the large macroinvertebrate community in terms of numbers and species diversity during all seasons at hard bottom sites in South Carolina and Georgia. Sponges comprised 59–78% of the total invertebrate biomass on the inner shelf, although tunicates, anthozoans, and mollusks also contributed substantially. Species which typified inner shelf sites included the sponges *Homaxinella waltonsmithi, Spheciospongia vesparium, Cliona caribbaea*, and *Halichondria bowerbanki*; the echinoderms *Lytechinus variegatus, Arbacia punctuata*, *Encope michelini*, and *Ocnus pygmaeus*; the bryozoan *Membranipora tenuis*; and the decapod crustacean *Synalpheus minus*. Polychaetes were the most diverse and abundant group of small invertebrates, followed by mollusks, and amphipods.[50]

Species composition of hard bottom communities in the nearshore waters of North Carolina is less tropical in nature compared to that farther offshore or to the south due to cooler water temperatures and greater temperature fluctuations (Kirby-Smith 1989; Fraser and Sedberry 2008). Furthermore, macroalgae outcompetes the hard coral *Oculina arbuscula* at nearshore reefs in Onslow Bay, limiting its growth and recruitment, as well as restricting its distribution to deeper, poorly lit habitats via competitive exclusion (Miller and Hay 1996). Because of these conditions, hard bottom in state territorial waters is colonized to a lesser extent by hard and soft corals than offshore or more southern areas. Offshore hard bottom, however, appears to offer suitable habitat for two species of tropical reef building corals: *Solenastrea hyades* and *Siderastrea siderea*. These species grow on flat rock outcrops in Onslow Bay at

[49] sponges (89 Porifera taxa); bryozoans (91 Bryozoa taxa); and corals and anemones (70 Cnidaria taxa)
[50] polychaetes (285 species, 72% of total individuals); mollusks (251 species, 4.3% of total individuals); and amphipods (100 species, 13% of total individuals)

depths of 20 to 40 m approximately 32 km offshore (MacIntyre and Pilkey 1969; MacIntyre 2003). Other species of coral reported in North and South Carolina include the hard corals *Oculina arbuscula, Oculina varicosa, Astrangia danae, Phyllangia americana, Balanophyllia floridana*, and the soft corals *Leptogorgia virgulata*, *Telesto* spp., *Lophogorgia* spp., *Titanideum frauenfeldii*, and *Muricea pendula* (Wenner et al. 1984; Hay and Sutherland 1988).

Unique and productive hard bottom communities are also found on the slope off North Carolina (> 250 m water depth) (Ross 2006; Partyka et al. 2007; Ross and Nizinski 2007). Because these habitats seem to be at their northern limit of distribution in Onslow Bay, they may be distinct in biotic resources as well as habitat expression. The hard coral *Lophelia pertusa* is the dominant macroinvertebrate, although the colonial corals *Madrepora oculata* and *Enallopsammia profunda* as well as a variety of solitary corals, sponges, and anemones are also abundant. Overall, species diversity of these deep water habitats increases south of Cape Fear (Partyka et al. 2007; Ross and Nizinski 2007). The Galatheid crab *Eumunida picta*, brisingid basket star *Novodinia antillensis*, and the brittle star *Ophiacantha bidentata* typify the mobile invertebrate community in the deep water reefs off North Carolina (Ross 2006).

7.2.4. Fish utilization of natural hard bottom

Fish comprise a significant proportion of the faunal biomass on hard bottom and are an important component of the overall trophic structure (Jaap 1984; Thomas and Cahoon 1993; Steimle and Zetlin 2000). Habitat utilization patterns by hard bottom fishes are primarily determined by water temperature and topography (Wenner et al. 1984; SAFMC 1998a; SAFMC 2008a). Temperatures less than 12º C may result in the death of some tropical species, while hard bottoms with relatively high relief support a greater abundance and diversity of fishes because of their structural complexity and more permanent nature (Huntsman and Manooch 1978). Studies that have examined fish assemblages on hard bottom habitats in North Carolina include Huntsman and Manooch (1978), Miller and Richards (1980), Grimes et al. (1989), Clavijo et al. (1989), Lindquist et al. (1989), Potts and Hulbert (1994), Parker and Dixon (1998), Quattrini et al. (2004), Quattrini and Ross (2006), Ross and Quattrini (2007), and Shertzer and Williams (2008). All of these studies, however, were conducted seaward of state territorial waters, including those at sites on the inner shelf. *Research specific to nearshore hard bottom (i.e. within state territorial waters) is needed to better understand the dependence of fishes on this habitat.*

Natural hard bottoms off the North Carolina coast support large populations of tropical, subtropical, and warm-temperate reef fish, as well as numerous coastal pelagic species. Along the coasts of North and South Carolina, well over 150 species of reef fish have been documented on inshore, offshore, and shelf-edge hard bottoms, with species richness and diversity increasing with distance from shore (Huntsman and Manooch 1978; Grimes et al. 1989; Clavijo et al. 1989; Lindquist et al. 1989; Parker and Dixon 1998, Quattrini et al. 2004; Quattrini and Ross 2006; Ross and Quattrini 2007). Documented species include wrasses, damselfish, snappers, grunts, porgies, and sea basses. Generally, inshore hard bottoms support a higher proportion of temperate fishes, such as black sea bass (*Centropristis striata*), spottail pinfish (*Diplodus holbrookii*), and estuary-dependent migratory species (Huntsman and Manooch 1978; Grimes et al. 1989). A list of species reported at nearshore hard bottom in North and South Carolina is provided in Table 7.2.

Table 7.2. Fishes occurring at nearshore hard bottom in North Carolina and South Carolina coastal waters. [Sources: Grimes et al. 1989; 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
	Decapterus punctatus	Round scad
Lutjanidae	*Lutjanus analis*	Mutton snapper
	L. campechanus	Red snapper
	L. griseus	Gray snapper
Haemulidae	*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
	Tautoga onitis	Tautog
Ephippidae	*Chaetodipterus faber*	Atlantic spadefish
Blenniidae	*Parablennius* sp.	Blennies
Gobiidae	*Ioglossus calliurus*	Blue goby
Paralichthyidae	*Paralichthys dentatus*	Summer flounder
	Paralichthys lethostigma	Southern flounder

Lindquist et al. (1989) reported 30 species in 14 families at a natural inner shelf (~5 miles from shore) hard bottom site in Onslow Bay, North Carolina. Commonly occurring and numerically abundant species were, in order of decreasing abundance, are juvenile grunts, round scad, tomtate, spottail pinfish, and black sea bass.

Other common species included slippery dick (*Halichoeres bivittatus*), scup (*Stenotomus chrysops*), pigfish (*Orthopristis chrysoptera*), cubbyu (*Equetus umbrosus*), belted sandfish (*Serranus sublgiarius*), and sand perch (*Diplectrum formosum*). Species composition at this reef varied due to seasonal inshore migrations of tropical and subtropical fishes. 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 7.3. Habitat utilization, stock status, and use of important fish species that occupy hard bottom areas in North Carolina's nearshore (≤ 3 nm from shore) ocean waters.

	Hard bottom Functions [1]						
Species	**Refuge**	**Spawn ng**	**Nursery**	**Foraging**	**Corridor**	**Fishery [2]**	**2009 Stock status [3]**
MARINE SPAWNING, HIGH SALINITY NURSERY							
Black sea bass [4]	**X**	**X**	**X**	**X**	**X**	**X**	**D- S of Cape Hatteras, C- N of Cape Hatteras**
Bluefish	X			X		X	V
Damselfish (mult. spp.)	**X**	**X**	**X**	**X**			
Gag [4]	**X**		**X**	**X**	**X**	**X**	**C**
Gobies (multiple spp.)	**X**	**X**	**X**	**X**			
King mackerel	X			X		X	C
Pigfish	**X**	**X**	**X**	**X**		**X**	
Planehead filefish	**X**	**X**	**X**	**X**			
Scup [4]	**X**	**X**	**X**	**X**		**X**	**V**
Spottail pinfish	**X**	**X**	**X**	**X**		**X**	
Summer flounder	X	X		X		X	R
Tautog	**X**		**X**	**X**	**X**	**X**	
Wrasses (mult. spp.)	**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 D. 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, D = Depleted, U = Unknown

(http://www.ncdmf.net/stocks/2010NCDMF%20StockStatusReport.pdf).

[4] Part of the reef fish complex but evaluated separately by DMF for stock status

7.2.5. Fish utilization of man-made structures

When occurring in similar environmental conditions, the composition and density of fish at artificial reefs tend to be similar to those at natural hard bottoms (Huntsman and Manooch 1978; Miller and Richards 1980; Ambrose and Swarbrick 1989; Lindquist et al. 1989; Bohnsack et al. 1994; Potts and Hulbert 1994). Species composition, relative abundance, and catch-per-unit-effort (CPUE) at artificial reef sites in North Carolina are documented periodically by DMF (DMF 1998; DMF 2002). An evaluation of the effectiveness of different artificial reef materials found species assemblages to be similar on reefs constructed with concrete pipes or domes. However, the evaluation also found that CPUE was 71 – 85% greater on natural reefs than nearby artificial reefs (DMF 1998). A more recent assessment conducted between 2001 and 2005 found that CPUE by number and weight of recreationally important demersal target species, including grouper (*Epinephelus* and *Mycteroperca*), black sea bass, snapper (*Lutjanus spp*), vermilion snapper (*Rhomboplites aurorubens*), gray triggerfish (*Balistes capriscus*), porgies (*Calamus and Pagrus*), and flounder (*Paralichthys spp*), were similar, if not higher at artificial reef sites compared to adjacent natural reefs (DMF, unpub. data), possibly reflecting the naturalization of artificial substrata over time. Several studies have reported that multiple artificial patch reefs surrounded by sand habitat support 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; Jordan et al. 2005).

Jetties provide some of the same habitat functions for fishery resources as natural hard bottoms and artificial reefs. The fish community found at jetties in North Carolina is a subset of that found on offshore hard bottoms and estuarine oyster reefs (Lindquist et al. 1985; Hay and Sutherland 1988). Most fishes are absent from inshore jetty habitats in the winter, gradually returning as waters warm in spring. Hay and Sutherland (1988) grouped fishes documented on jetties in North and South Carolina into five general categories based on their mobility, association with structure, and seasonality of jetty occupancy:

- Small cryptic resident fishes, such as blennies and gobies;
- Numerically dominant fishes that migrate offshore in winter, such as pinfish, spottail pinfish, black sea bass, and pigfish;
- Predatory pelagic fishes, such as bluefish, Spanish mackerel, and king mackerel;
- Fishes attracted to jetties during their seasonal migrations, such as smooth dogfish (*Mustelus canis*); and
- Tropical fishes that occur as strays during summer, such as butterflyfishes and surgeonfishes.

Although jetties provide suitable habitat for some structure-oriented fish, the species that utilize them do not require jetties for survival since they are attracted from existing natural hard bottom and estuarine oyster reefs.

7.2.6. Specific biological functions

7.2.6.1. Refuge and foraging

The complex three-dimensional structure of hard bottom provides protective cover for numerous organisms (Huntsman and Manooch 1978; Potts and Hulbert 1994; Mallin et al. 2000a; Quattrini and Ross 2006; Fraser and Sedberry 2008; Kendall et al. 2008). Hard bottom habitats are often the only source of structural refugia in open shelf waters. The abundance of fish on hard bottom is related to the amount and type of structure of the reef habitat (Huntsman and Manooch 1978; Potts and Hulbert 1994; Kendall et al. 2008). Rocky faces with more complexity consistently support a greater abundance and diversity of resident reef fish than less complex habitats.

The structure provided by hard bottom also concentrates prey resources and attracts predators. In general, most reef fish are carnivores (Jaap 1984; Sedberry and Cuellar 1993; Lindquist et al. 1994; Goldman and Sedberry 2006). Benthic invertebrates are therefore very important as energy assimilators and food sources for reef fish (Jaap 1984). Lindquist et al. (1994) found that black sea bass, scup, and cubbyu forage extensively on both reef and adjacent soft bottom invertebrates at a nearshore hard bottom site off the North Carolina coast. Posey and Ambrose (1994) documented significant reductions in soft bottom macroinvertebrate densities within 10 m of an inner shelf reef due to the foraging activity of several reef fishes. These finding suggest that, in addition to reef-associated invertebrates, sand substrata organisms around reefs function as valuable prey for reef fishes.

The abundance of prey and extent of structural refugia afforded by hard bottom in turn supports high fish productivity. Nearshore hard bottom can support over thirty times as many individuals per transect as adjacent sand habitats (Lindeman 1997). Accordingly, natural reefs 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).

7.2.6.2. Spawning

Hard bottom also functions as crucial spawning areas for numerous species of fish and invertebrates. Most reef fish spawn in aggregations in the water column above the reef surface (Jaap 1984). The timing of egg release is often triggered by nightfall or tide stage, probably to reduce the risk of predation. While offshore and shelf-edge reefs have been documented as important spawning habitat for species of the snapper-grouper complex (Wyanski et al. 2000; White and Palmer 2004; Burton et al. 2005; Burgos et al. 2007), nearshore hard bottom provides valuable spawning sites for smaller and more temperate reef species. Species known to spawn on nearshore hard bottom include black sea bass and sand perch (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 nearshore hard bottom (F. Rohde/DMF, pers. com., 2001). *More research is needed concerning spawning activity on, and recruitment to, nearshore hard bottom to understand the importance of this habitat and document trends in fish utilization*.

<u>7.2.6.3. Nursery</u>

Nearshore and inner shelf hard bottom serves as important settlement and nursery habitat for the larvae and early juveniles of many reef fishes. In a study of the abundance and distribution of ichtyoplankton adjacent to hard bottom in open shelf waters (< 55 m water depth) in Onslow Bay, Powell and Robbins (1998) collected the larvae of 22 reef-associated families. Planehead filefish (*Monacanthus hispidus*), the blenny *Parablennius marmoreus*, the goby *Ioglossus calliurus*, black sea bass, sand perch, and several species of grunts, snappers, and wrasses were commonly collected. These taxa are thought to spawn in somewhat deeper waters of Onslow Bay and recruit locally to nearshore hard bottom (Powell and Robins 1998). Although the mechanisms of recruitment to hard bottom habitats are generally unclear, it is apparent that successful recruitment depends on water circulation patterns transporting larvae to suitable habitat (Jaap 1984).

<u>7.2.6.4. Corridor and connectivity</u>

Nearshore hard bottom also serves as a migratory corridor for the late juveniles of estuary-dependent reef fishes (Lindeman and Snyder 1999; Baron et al. 2004). In North Carolina, these species include black sea bass, gag, red grouper, sheepshead, Atlantic spadefish, bank sea bass, and gray snapper, which use estuarine habitats as early juveniles and move to offshore hard bottom with growth. Red snapper and mutton snapper juveniles have also been documented in North Carolina's estuaries to a lesser extent (DMF, unpub. data). Juveniles migrating offshore benefit from the structural refugia and high abundance of prey organisms provided by nearshore hard bottoms. Several studies on the southeast coast of Florida have reported that early life stages represent over 80% of the individuals at nearshore hard bottom sites (Lindeman and Snyder 1999; Baron et al. 2004). These assemblages were primarily dominated by juvenile grunts, wrasses, and damselfish. In North Carolina, the patchy distribution and limited extent of nearshore 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).

7.3. STATUS AND TRENDS

7.3.1. Status of hard bottom habitat

The condition of shallow hard bottom in North Carolina state territorial waters is of particular importance to the health and stability of estuary-dependent snapper-grouper species that utilize this habitat as "way stations" or protective stopping points as they emigrate offshore. Because of the high market value, number of recreational participants, and associated businesses, the offshore snapper-grouper complex supports productive commercial and recreational fisheries. Between 2005 and 2007, the North Carolina commercial snapper-grouper fishery harvested an average of 1,148,152 lbs of fish at an annual market value of over $3.1 million (DMF 2008c). During those same years, recreational fisherman (including private boats, charter boats and headboats) harvested an average of 687,216 lbs of fish in the snapper-grouper complex.

Nearshore hard bottoms are generally considered to be in good condition overall (SAFMC 1998b). Although adequate information exists on the distribution of hard bottom off the North Carolina coast (Moser and Taylor 1995; SEAMAP-SA 2001; Udouj 2007), little information is available to evaluate the status and trends of hard bottom habitat in state territorial waters. Anecdotal information from fishermen and local residents in coastal North Carolina suggests that many known nearshore hard bottom sites in the mid-twentieth century are now completely covered by sand, and that the abundance of fish in these areas is much reduced. *An extensive and regular survey of nearshore hard bottom distribution and quality is needed to better evaluate status and trends of both habitat and biological communities.*

7.3.2. Status of associated fishery stocks

Commercially or recreationally harvested reef fish are managed collectively as the reef fish complex or Snapper-Grouper management unit, which includes 73 species of snappers, sea basses and groupers, porgies, tilefishes, grunts, triggerfishes, wrasses, spadefish, wreckfish, and jacks. Management authority is shared by NMFS, SAFMC, and DMF/MFC. Of these species, only some are found on hard bottoms in North Carolina state territorial waters. Information is available on the status of many reef fishes through state, interstate, and federal stock assessments. Fishery-dependent data on reef fish are collected by the DMF Offshore Live Bottom Fishery Program (DMF biological database program 438/448). Fishery-independent data on reef fish abundance and community structure are also available for a portion of North Carolina from the Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP), a cooperative fisheries project of the Marine Resources Research Institute (MRRI) of the South Carolina Department of Natural Resources (SCDNR). This program has conducted standardized groundfish (bottom fish) surveys from Cape Lookout, North Carolina south to Ft. Pierce, Florida since 1972 using a variety of fishing gears. Sampling occurs on mid-shelf and shelf-edge reef habitats in water depths of 16 m to more than 92 m. Although sampling is focused seaward of state waters, this program provides valuable information for stock assessments of reef fishes, including species that utilize nearshore hard bottom in North Carolina.

Most major South Atlantic reef fish stocks are considered fully utilized or over-utilized (NMFS 2008). Of 73 managed species in the South Atlantic Snapper-Grouper management unit, three species were classified as “Overfished” in 2007 by the NMFS, four were “Not Overfished”, and 66 were “Unknown” (NMFS 2008).[51] Overfished species included snowy grouper, black sea bass, and red porgy. In addition, 10 species were reported to be subject to Overfishing, 13 were not subject to Overfishing, and the status of 50 species was Unknown (NMFS 2008). *More data are needed for evaluating the stock status of species in the reef fish complex off North Carolina.*

In North Carolina, the reef fish complex as a whole was classified as Concern by DMF in 2009 (DMF 2009). The reef fish complex includes numerous species, of which at least ten are common in North Carolina state territorial waters. For stock status of individual reef fishes, DMF defers to SAFMC Southeast Data, Assessment, and Review (SEDAR) stock assessments. Of the species listed in Table 7.3 that are highly associated with nearshore hard bottom in North Carolina, five stocks have been evaluated by DMF. One stock was reported as “Depleted” (black sea bass south of Cape Hatteras) in 2010 and three were reported as Concern (black sea bass north of Cape Hatteras, gag, and reef fish complex) (http://www.ncdmf.net/stocks/2010NCDMF%20StockStatusReport.pdf). Scup were considered Viable in 2010.

Although most exploited reef fish species are caught primarily in federal waters, several, such as gag and black sea bass, are highly dependent on nearshore hard bottom as primary and secondary nursery areas,

[51] Overfished is defined as a stock size below an established biomass threshold and Unknown is defined as a stock for which no recent assessment was conducted or insufficient information about the stock exists to make a determination (NMFS 2008).

and for providing migratory corridors as individuals move offshore with age. The apparent vulnerability of reef fishes to overfishing is attributed to their long lives, slow growth, large size, delayed sexual maturity, ease of capture, and preference for patchy hard bottom habitats. *Nearshore hard bottoms (within state territorial waters) should be considered for nomination 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, as well as valuable foraging habitat for flounder, mackerel, and weakfish.*

The status and health of reef fish stocks in North Carolina may be particularly subject to changes in the quantity or quality of habitat. Although some research in Florida has indicated that habitat is not limiting and reef fish populations are 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 extensive. 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 Carolina Bays, 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 larger populations of reef fish.

7.3.3. Hard bottom enhancement

Artificial reefs may enhance fish production by providing additional foraging, spawning, and refuge habitat, increasing an area's carrying capacity (Bohnsack 1989; Grossman et al. 1997; Lindberg 1997; Brickhill et al. 2005). They are most effective at bolstering production where reef habitat is limiting, when a large stock reservoir exists, and when fishing effort is low (Bohnsack 1996; Grossman et al. 1997; Powers et al. 2003). Powers et al. (2003) estimated that annual fish productivity was 32% greater at artificial reefs protected from fishing as compared to those subject to fishing pressure. This 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 an 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.*

High numerical abundance of fish, however, may not necessarily be associated with increased production. There is some concern among fishery scientists that artificial reefs only concentrate available biomass rather than increase regional productivity. This attraction-production debate is yet to be resolved (Bohnsack 1989; Bohnsack et al. 1994; Pickering and Whitmarsh 1996; Carr and Hixon 1997; Grossman et al. 1997; Lindberg 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.*

Artificial reefs must be properly designed, sited, and managed to successfully increase production of benthic organisms and fish populations (DMF 1988; Gregg 1995; Brickhill et al. 2005; Strelcheck et al. 2005). Small, complex structures that mimic natural hard bottom may be better for recruitment and enhance juvenile survival, while larger structures may be better for attracting large predators and enhance fishing opportunities (Bohnsack et al. 1994; Jordan et al. 2005; Lindberg et al. 2006). One ongoing problem that the DMF has experienced with artificial reefs is the failure of some designs, such as those composed of tires, to remain assembled and in position. More recent artificial reefs constructed of concrete pipes and domes appear to be sufficiently stable and durable when deployed (DMF 1995; Gregg 1995). The DMF Artificial Reef Master Plan provides siting guidelines and construction standards for artificial reefs in North Carolina (DMF 1988). Some of the recommendations that pertain to habitat enhancement include:

- North Carolina's artificial reef program should <u>NOT</u> use materials that:
    - Are toxic to the environment.

  - Are not stable and may move off-site.
  - Are not durable and will have a short lifespan in the ocean.
- 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.
  - The seafloor would not support proposed reef structures.
  - High-energy environments exist.
  - Traditional commercial fishing activities occur.
  - They would be a navigation or liability hazard.
- 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 (DMF 1988).

In 2009, the DMF Artificial Reef Program shifted its focus toward development of estuarine artificial reefs. The Artificial Reef Program, in association with the Oyster Sanctuary Program[52], will develop nursery habitat evaluation and enhancement projects for estuary-dependent reef fishes, including gag and black sea bass. Addition and enhancement of estuarine artificial reefs may increase fish production on nearshore and offshore hard bottoms by providing additional estuarine nursery habitats, potentially increasing the number of recruits.

7.3.4. Designated areas

Natural hard bottom is protected through both state and federal designations. The N.C. Natural Heritage Program inventories, catalogues, and supports conservation of the rarest and most outstanding elements of natural diversity in the state. The program designates rare or significant plants, animals, or natural communities that merit special consideration when making land use and conservation decisions. Four hard bottom sites within state territorial waters (Map 2.3) have been designated by this program as Significant Natural Heritage Areas (SNHA) (Natural Heritage Program, unpub. data). These include rock outcrops off Bogue Banks (two acres), New River Inlet (1300 acres), South Topsail Island (38 acres), and Masonboro Island (50 acres). In addition, the intertidal Fort Fisher Coquina Rock outcrops (47 acres) were also designated as SNHA. *These and other nearshore hard bottoms should be considered for nomination as Strategic Habitat Areas because of their natural significance and vulnerability to impacts from on-shore land development activities*.

Certain natural hard bottoms have been designated as federal Essential Fish Habitat-Habitat Areas of Particular Concern (EFH-HAPC) 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, The Point, Ten Fathom Ledge (Onslow Bay), Big Rock (Onslow Bay), and the entire shelf break have been given this designation for the snapper-grouper complex (SAFMC 1998a; SAFMC 2008b). In addition, the SAFMC has proposed the establishment of deepwater Coral Habitat Areas of Particular Concern (CHAPCs) to protect what is currently thought to be the largest contiguous distribution (>23,000 square miles) of deepwater coral ecosystems in the world (SAFMC 2008b). The proposed CHAPCs include two locations in Onslow Bay, North Carolina: the Cape Lookout *Lophelia* Bank (122 square miles) and the Cape Fear *Lophelia* Bank

[52] See Shell Bottom chapter (2.0) for more information on the Oyster Sanctuary Program.

(52 square miles). The Cape Lookout *Lophelia* Bank encompasses two large *Lophelia* coral mounds, with the main mound rising 80 meters (262 ft.). More than 54 species of deepwater reef fishes have been documented along this bank. The Cape Fear *Lophelia* Bank also includes mounds rising nearly 80 meters (262 ft.) and exhibits some of the most vertically rugged habitat of any deep water reef in North Carolina. Over 12 fish species have been documented along this bank, including many larger deepwater reef fishes. In addition, the Cape Fear *Lophelia* Bank is the only location in North Carolina where wreckfish have been observed (Ross 2006; SAFMC 2008b).

In 2000, federal Executive Order 13158 directed federal agencies to strengthen the management, protection, and conservation of existing Marine Protected Areas (MPAs), and establish new or expanded MPAs through the creation of a scientifically-based comprehensive national system of MPAs representing diverse marine ecosystems (65 FR 34909). In response to this directive and because of concern for major stocks of the snapper-grouper complex that are undergoing overfishing and/or overfished, and failure of those stocks to adequately recover despite extensive changes in fishing regulations, the SAFMC established several Marine Protected Areas (MPAs) in the South Atlantic Bight through Amendment 14 to the South Atlantic Snapper Grouper Fishery Management Plan (SAFMC 2007). The NMFS issued a final rule to implement Amendment 14 effective February 2009 (74 FR 1621-1631), officially creating eight Type II MPAs in which fishing for or possession of South Atlantic snapper-grouper species are prohibited, but other types of fishing, such as trolling, are allowed. Use of MPAs has proven effective in habitat protection and fishery enhancement, particularly for species with restricted geographical movements typical of most reef fishes (Bohnsack 1993). A study of 89 marine reserves world-wide showed that fish and other 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). The primary purpose for MPA designation by the SAFMC is to protect a portion of the population and habitat of long-lived, slow growing, deepwater snapper-grouper species from directed fishing pressure to achieve a more natural sex ratio and age and size structure within the proposed MPAs, while minimizing adverse social and economic effects (SAFMC 2007). In North Carolina, the Snowy Grouper Wreck MPA (150 square miles) was established in federal waters of Onslow Bay, east of Cape Fear. This location was once the site of a known spawning aggregation of snowy grouper, and supports numerous speckled hind, gag, red porgy, red grouper, graysby, and hogfish, as well as tuna, dolphinfish, wahoo, and marlin.

Although the MFC has the authority to establish no-take areas within state jurisdictional waters, there has been little discussion concerning establishment of nearshore hard bottom reserves through state management. 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 [MFC Rule 15A NCAC 3I .0109]. Many areas within state waters, such as primary nursery areas, are already protected from certain fishing activities through MFC rules. *Nearshore hard bottom nominated as Strategic Habitat Areas should be considered for designation as MPAs, either through state or federal avenues, to provide some protection from fishing gear impacts and enhance fish production.*

Man-made structures functioning as hard bottom have also been given varying levels of designation and protection. In 1975, the wreck of the USS Monitor, a Civil War ironclad located in federal waters off Cape Hatteras, was designated as the first national marine sanctuary. Within North Carolina state territorial waters, the USS Huron, a popular wreck located 250 yards off the beach in Dare County, was designated by the state as a historic shipwreck preserve (Map 7.1). Furthermore, all artificial reefs, along with all natural hard bottoms have been designated by the NMFS as Essential Fish Habitat (EFH).

7.4. THREATS AND MANAGEMENT NEEDS

7.4.1. Water-dependent development

7.4.1.1. Dredging (navigation channels and boat basins)

Dredging near or on hard bottom is potentially the most damaging physical human activity to this habitat (SAFMC 1998b). Navigational dredging is associated with the creation of, or modification to, shipping channels. Dredge gear impacts hard bottom directly by dislodging corals or colonized rock (live rock), as well as injuring live tissue, which may lead to infection or mortality (SAFMC 1998b). The disposal of dredged sediments on Ocean Dredged Material Disposal Sites (ODMDS) may, through sediment dispersal from the ODMDS, bury adjacent hard bottom habitat, resulting in long-term loss of sessile biota and associated finfishes (Crowe et al. 2006). Even if hard bottom is not buried, increased sedimentation stresses corals and other sessile invertebrates, and may result in decreased productivity or death if the organisms cannot purge the sediments deposited on them (SAFMC 1998b; Crowe et al. 2006). Silt generated by dredging may remain in the area for long periods and continue to impact hard bottom when resuspended during storms.

Dredging of large navigation channels through oceanic bottoms in North Carolina is limited to the entrance channels leading to the state ports in Wilmington and Morehead City via Cape Fear and Beaufort inlets, respectively. Although hard bottom is found in the general vicinity of both port entrance channels, it is particularly abundant in the ocean adjacent to the Port of Wilmington. In 2002, the Wilmington channel was rerouted as part of a project to deepen the river channel and port, and create a new ODMDS. The proposed route was, however, altered to avoid dredging through hard bottom (F. Rohde/DMF, pers. com., 2002). Dredging and stabilization of other inlets, such as New River, Masonboro and Shallotte inlets, can also potentially impact hard bottom through direct removal of hard bottom resources, as well as increased turbidity and sedimentation in the vicinity of dredge sites.

7.4.1.2. Shoreline stabilization

Due to the economic and recreational value of beaches, several different erosion control measures have been used to protect coastal property and structures from continued erosional loss of protective shorelines and dunes (ASMFC 2002a). The most common method of combating ocean shoreline retreat is beach nourishment, in which sediments from a dredge site (e.g. nearshore ocean or inlet) or land-based source are placed on the shoreface in order to build the beach profile and extend it seaward (ASMFC 2002a; Peterson and Bishop 2005). However, these dredge-and-fill projects can have deleterious effects on nearshore hard bottom if sited inappropriately (Blair et al. 1990). Similar to that for navigational dredging, dredging of ocean borrow areas can directly impact hard bottom via mechanical removal of hard corals, soft corals, sponges, algae, and other benthic organisms. In addition, these organisms may be fractured (e.g. hard corals), injured (e.g. soft corals and sponges), or silted over, reducing the health and productivity of hard bottom resources. Current CRC rules prevent dredging activities within a 500 m buffer of significant biological communities, such as high relief hard bottom areas [CRC Rule 15A NCAC 07H .0208(b)(12)(A)(iv)]. Under this rule, "high relief" is defined as relief greater than or equal to one-half meter per five meters of horizontal distance. However, research by Lindquist et al. (1994) suggests that reef fishes derive a significant portion of their nutritional requirements within a 500 m "halo" of any exposed hard bottom. Because of this finding, the Ocean Policy Steering Committee (OPSC), a group established by DCM to examine North Carolina's emerging ocean policy issues, has recommended in their draft report that a 500 m dredging buffer should be established around all hard bottom areas, including those periodically buried with thin, ephemeral sand layers (DCM 2009). In the past few years beach nourishment planning efforts have attempted to mine closer than this distance due to the difficulty of finding an area of sand not within the hard bottom buffer. *Using the recommendations from the OPSC, the CRC should modify existing rules pertaining to mining of submerged lands to require a 500 m dredging buffer around any exposed hard bottom, thus minimizing potential impacts to fish* *habitat functions. Furthermore, these buffers should be enforced.*

The subsequent addition of sand to the shoreface can also negatively affect nearshore hard bottom through direct burial and sediment redistribution. At a beach nourishment project site in Florida, Lindeman and Snyder (1999) observed dramatic decreases in fish species and numerical abundance of individuals following the burial of nearshore hard bottom. The number of species detected 12 months prior to and 15 months after burial decreased by nearly one order of magnitude, from 54 to eight species (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). At several other beach nourishment projects in Florida, added sand was documented to redistribute offshore from the beach via cross-shelf currents, covering hard bottom habitat (Marsh and Turbeville 1981; Continental Shelf Associates 2002). Studies off Wrightsville Beach and Atlantic Beach, North Carolina documented movement of sands from the nourished beaches across the shoreface (Thieler et al. 1995; Thieler et al. 1998; Reed and Wells 2000), with hard bottom becoming buried by nourishment sands in the vicinity of Wrightsville Beach (R. Thieler/USGS, pers. com., 2001). Commercial fishermen in the Wrightsville Beach area, where nourishment has been conducted regularly since the 1960s, reported that nearshore hard bottoms that were once productive fishing areas are now covered in sand and are no longer fished due to poor yield (W. Cleary/UNC-W, pers. com., 2001). Ojeda et al. (2001) found little to moderate change in percent of seafloor with exposed hard bottom or rocky substrate within two years of a nourishment project off Myrtle Beach, South Carolina. 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).

In North Carolina, the frequency and magnitude of beach nourishment activities (including dredged material from navigational channels placed on beaches) have increased over time.[53] The cumulative length of shoreline affected by ocean beach management projects is approximately 176 miles or about 55% of the North Carolina ocean coastline (ASMFC 2002a). The majority of nourishment projects (existing, authorized, and requested) are located south of Cape Lookout where hard bottom is most abundant, especially in the nearshore. *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, and/or by the distance between nourished beach and hard bottom.*

7.4.1.3. Energy infrastructure

A newly developing threat to hard bottom comes from the opportunity for oil and natural gas exploration on the outer continental shelf (OCS). During 2008, a federal moratorium on offshore drilling for oil and natural gas, which covered much of the OCS in the Atlantic and Pacific oceans, was lifted. This opened the majority of federal waters, including those off the coast of North Carolina, to future oil and natural gas exploration, development, and production. Such activities can have detrimental effects to hard bottom habitat. The direct impact of oil and natural gas development on hard bottom is physical in nature, in which organisms and hard substrate are damaged or dislodged from the platform anchor site, or smothered by sediments from the disposal of drilling muds (Lissner et al. 1991; Boehm et al. 2001). The disturbance from drilling reduces, at least temporarily, natural habitat complexity, and species richness and diversity. Site-specific recovery from such disturbances may take years to decades and is dependent on the vertical relief of the hard substrate and growth characteristics of the local organisms (Lissner et al. 1991). In addition to physical impacts, disposal of drilling muds, as well as produced formation water (oily water produced after separation from oil) can cause acute or chronic toxic effects to hard bottom

[53] Refer to the Soft Bottom chapter threats section for status, trends, and location of beach nourishment activity.

organisms and reef fishes (Lissner et al. 1991; Hyland et al. 1994; Holdway 2002). Exposure to toxins associated with drilling activities have been found to cause adult mortality, tissue loss, and reduced relative viability of corals, and altered liver enzyme activities in reef fish living in close proximity to oil producing platforms (Holdway 2002). *Drilling on or in the vicinity of hard bottom resources on the OCS of North Carolina should be prohibited to minimize potential impacts to ecologically productive hard bottoms and there dependent biological communities*.

The last active offshore oil and natural gas leases in the federal waters off North Carolina were relinquished in November 2000 (<http://www.gomr.mms.gov/homepg/offshore/atlocs/atocsfax.html>, 2008). Several companies, including Amerada Hess, Chevron, Conoco, Marathon, Mobil, Occidental Petroleum Corporation (OXY), and Shell 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). The current federal Minerals Management Service (MMS) 5-year Lease Program, which consists of the schedule for lease sales, as well as the size and location of blocks offered, took effect July 2007 and runs through June 2012. The Program includes a special interest sale scheduled for 2011 of about 2.9 million acres in the Mid-Atlantic Planning Area, 50 miles offshore the coast of Virginia and approximately 25 miles north of the North Carolina-Virginia border. Under the authority of the Outer Continental Shelf Lands Act, CAMA consistency process, and CRC administrative rule on coastal energy policies (15A NCAC 7M .0400), North Carolina submitted comments on the proposed Program in which concerns were raised regarding the effects on fisheries, fisheries habitat, tourism, and continued dependency on fossil fuels, and that by virtue of proximity, North Carolina would be subject to direct adverse impacts of such a sale, with no commensurate benefit. The MMS, at the request of the federal government, developed a new draft 5-year Lease Program in January 2009 that could replace or supersede the remaining portion of the current Program if implemented. *North Carolina should continue to be engaged in the MMS 5-year Lease Program and any proposed OCS energy development project.*

In addition to oil and natural gas exploration, there is an increasing interest in the development of offshore wind farms off the coast of Cape Hatteras and Cape Lookout, as well as in Albemarle and Pamlico sounds, as these areas have some of the most abundant wind resources in the state (<http://www.ncsc.ncsu.edu/programs/NCPWR50m7May04.pdf>, 2009). Although offshore wind farms are generally considered a source of "green" energy, the construction of foundations for turbine towers can impact immediate and adjacent marine habitats (Byrne Ó Cléirigh et al. 2000). Changes to the natural seabed structure can alter the composition and biomass of macroalgae, sessile invertebrates, and fish (Byrne Ó Cléirigh et al. 2000; Wilhelmsson and Malm 2008). A study in the Baltic Sea found that the presence of turbine foundations affected the assemblage of invertebrates and algae colonizing adjacent natural hard bottom areas, resulting in an increased abundance of blue mussels and decreased abundance of algae (Wilhelmsson and Malm 2008). These structures may also pose a conflict for commercial fishing activities, as well as beach nourishment borrow areas. CRC is in the process of modifying their rules to include wind turbines as water-dependent structures [15A NCAC 07H. 0208]. *Should the State consider siting a wind facility in state or federal waters, proper placement of turbine foundations is necessary to minimize potential impacts to hard bottom habitat and minimize conflicts with existing activities*.

In 2009 the North Carolina General Assembly formed a Legislative Research commission Advisory Subcommittee on Offshore Energy Exploration. The Advisory Subcommittee is studying:

1) The implications of leasing federal waters off North Carolina's coast in the Atlantic Outer Continental Shelf to energy companies for oil and natural gas exploration.
2) Relevant federal law and the legal authority of the State of North Carolina with regard to offshore drilling.
3) The potential impacts on the nation's energy supply, including documenting the best unbiased estimates available for what oil and natural gas might exist.

4) The potential financial impact of proposed exploration on the State of North Carolina, including effects on the economy, tourism, the commercial fishing industry, the impacts of a more industrial coastline, and ensuring a share of State profits.
5) The environmental impacts of exploration on North Carolina's coastline, including possibilities of spills, effects on water quality, air quality, marine life, and contributions to global climate change.
6) The environmental impacts of the infrastructure that would be associated with exploration and drilling for oil and natural gas.

The committee is working on developing final recommendations to the state, which will likely include the need to work with MMS to achieve the best overall outcome for the state of North Carolina and the need for additional information.

Associated with offshore energy development, as well as the expansion of high-speed transoceanic telecommunications, comes the need for installation or maintenance of cables and pipelines placed across oceans and waterways. Cables and pipelines are generally laid directly on the seafloor, and routed into a dredged or bored trench, conduit, or access hole where they come onshore (landing site). Once the access hole or conduit is in place and buried, maintenance or placement of new cables or pipelines involves dredging these holes back open. Current CRC rules prohibit structures, such as cables and pipelines, from coming onshore on oceanfront beaches [15A NCAC 07H. 0300].

Environmental concerns to hard bottom associated with laying cables or pipelines identified by Nero (2001) and Blue Atlantic Transmission System (2003) include:
- Cable “sweeping” and crushing of hard bottom communities during installation or repairs.
- Escape of pressurized fluid mud used to lubricate the drill hole for directional drilling (drilling a tunnel under the seafloor) may cause turbidity plumes and subsequent burial or smothering of sensitive hard bottom resources.
- Restriction or alteration of macrofaunal movement due to physical barriers, noise, vibrations, or magnetic fields.

North Carolina should coordinate with federal agencies, other states, and private companies with offshore infrastructure interests to manage the placement of cables and pipelines in North Carolina offshore waters in a manner that minimizes impact to hard bottom and minimizes conflicts with recreational and commercial fishing.

7.4.2. Boating activity

7.4.2.1. Anchoring and diving

Boating related activities, such as anchoring or diving on hard bottom, can also damage this habitat. Anchors and chains from recreational or commercial boats can damage corals and other benthic organisms, creating lesions and leading to infection (SAFMC 1998b). Divers can kick or overturn corals and live rock, which results in habitat damage. Recreational spearfishing with power heads also can damage corals where diving activity is concentrated (SAFMC 1998b). In North Carolina, however, damage from recreational diving is probably minimal due to the relatively low numbers of divers in the nearshore areas.

Diver harvest of live rock for the aquarium trade was found to cause extensive destruction and loss of hard bottom, with additional damage occurring when chemicals were used (SAFMC 1998b). Several state and federal regulations provide protection for hard bottom habitat from such destructive harvest techniques. Since 1995, North Carolina has prohibited directed harvest of all coral or any live rock in state waters [MFC rule 15A NCAC 3I .0116]. In addition, any live rock or coral incidentally harvested with any gear must be returned immediately to the waters where it was taken. Similar NMFS regulations exist for federal waters, which prohibit the collection of live rock, stony corals and black corals, fire coral and hydrocorals and two species of seafans (SAFMC 1982; SAFMC 1994). However, NMFS may issue permits to take prohibited coral for scientific, research, and educational purposes, and for use of allowable chemicals and harvest of octocorals.

7.4.3. Fishing gear impacts

7.4.3.1. Mobile bottom disturbing gear

Bottom trawls, dredges and other mobile gears can cause rapid and extensive physical damage to living and non-living components of hard bottom (SAFMC 1998b; Auster and Langton 1999; Freese 2001; NRC 2002; Reed et al. 2007; Wells et al. 2008). Dragged fishing gear directly removes or damages attached benthic organisms, such as sponges, corals and macroalgae, often leading to mortality. These gear types also displace outcrop structures from the seafloor. Damage from mobile gear is especially extensive where the bottom is uneven and there is a concentration of epiflora and/or epifauna. The removal of structure and attached biota decreases species richness and diversity, and reduces habitat complexity (Watling and Norse 1998; Auster and Langton 1999; NRC 2002). In addition, indirect damages to hard bottom habitat occur through altered trophic linkages and nutrient cycles, as well as an increased vulnerability of injured organisms to subsequent diseases and predation (Auster and Langton 1999; NRC 2002). Trawling, in particular, 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.[54]

Although most trawls and dredges are generally not towed over hard bottom, one type of trawl was designed specifically for use in this habitat. Roller-rigged trawls are equipped with large rubber discs to roll over hard bottom without becoming entangled. Several studies have noted significant damage to sponges, hard corals, and soft corals at hard bottom locations where roller-rigged trawls had been used (Tilmant 1979; Van Dolah et al. 1987). While many sponges and corals can recover, at least partially, within one year following trawling, it may require several years for some species to completely regenerate to their initial, pre-disturbance sizes due to slow growth rates (Van Dolah et al. 1987). To address the potential for extensive hard bottom degradation, roller-rigged trawls have been prohibited by federal regulations for the harvest of snapper-grouper south of Cape Hatteras since 1989 (SAFMC 1998b).

Bottom trawling is conducted extensively in North Carolina state ocean waters, in particular for shrimp and, to a lesser extent, for flounder. Shrimp trawl effort in the ocean is most concentrated in the southern region of North Carolina (Onslow, Pender, New Hanover, and Brunswick counties), where hard bottom is most abundant (Fig. 7.1a). Flounder trawling in the ocean occurs in the northern (Currituck, Dare, and Hyde counties) and central (Carteret County) regions, but is most concentrated north of Cape Hatteras (Fig. 7.1b). The number of ocean flounder trawl trips during 1994–2007 has ranged from 11 to 202 trips/year, while the number of ocean shrimp trawl trips has ranged from approximately 1,500 to almost 4,000 trips/year (DMF, unpub. data).[55] Several state rules provide protection for nearshore hard bottom habitat from the potential impacts of ocean trawling. Current MFC rules prohibit trawling within one-half mile of the ocean shoreline from the Virginia border south to Oregon Inlet [15A NCAC 3J.0202], as well as within the military danger zone and restricted area, and sea turtle sanctuary, both located seaward of Onslow Beach [15A NCAC 3I .0110, 15A NCAC 3I .0107]. However, trawling is not restricted at most locations in the nearshore ocean waters of Onslow and Long bays, where the majority of nearshore hard

[54] Refer to Appendix O for a list of the fishing gears used in North Carolina waters and their probable habitat impacts.
[55] Number of trips calculated as those landed in Currituck, Dare, Hyde, Carteret, Onslow, Pender, New Hanover, and Brunswick counties only. Trips in the ocean (0-3 miles) landed in other counties are not included in the present analysis.

bottom is concentrated. 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. *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. In addition, nearshore ocean hard bottoms should be considered for nomination as Strategic Habitat Areas due to their importance as secondary nursery habitats and corridors for gag, black sea bass, and other fisheries resources.*

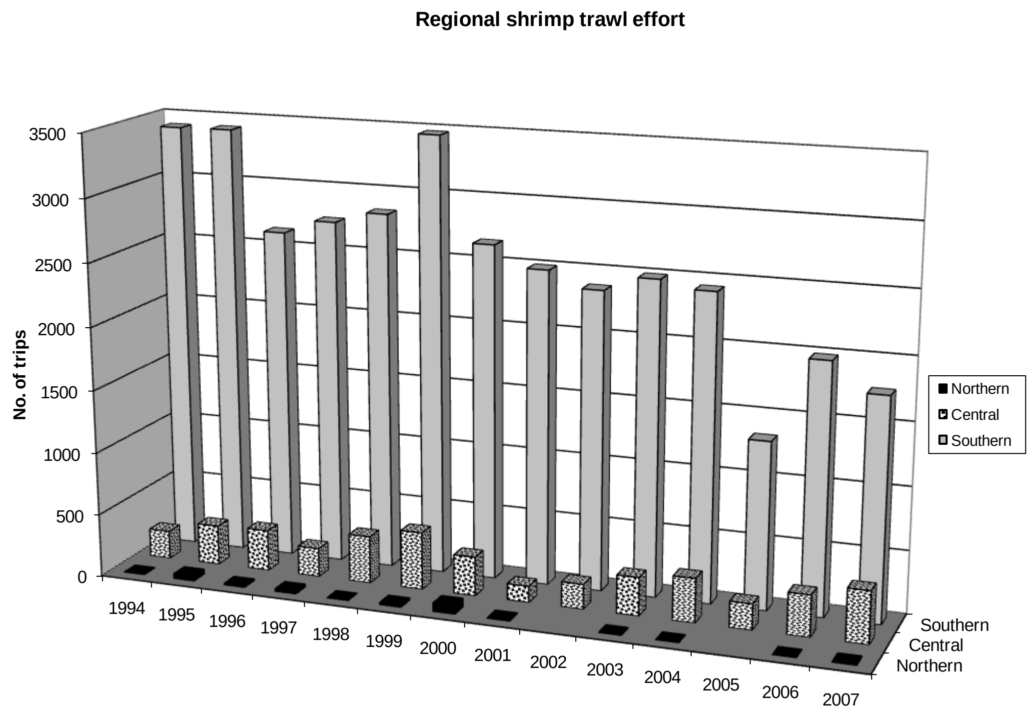


Figure 7.1a. Shrimp trawl fishing effort (number of trips) in North Carolina's nearshore ocean waters (0-3 miles from shore), 1994–2007, by coastal region. [Source: DMF, unpub. data]

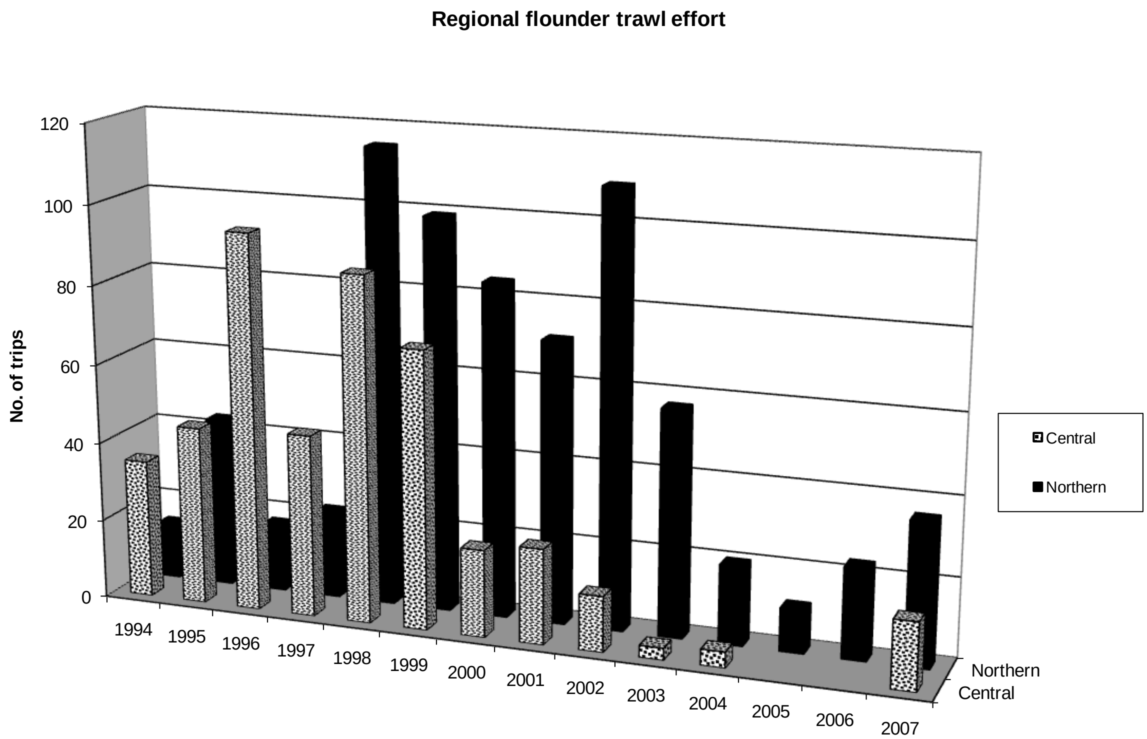


Figure 7.1b. Flounder trawl fishing effort (number of trips) in North Carolina's nearshore ocean waters (0-3 miles from shore), 1994–2007, by coastal region. [Source: DMF, unpub. data]

7.4.3.2. Passive capture techniques

Bottom longlines and fish traps can also physically damage the structure of hard bottom, as well as injure or kill the associated sessile biota (SAFMC 1998b). However, these passive fishing gears are of minimal concern because they are not used extensively or at all in North Carolina state 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 were also prohibited in all federal waters through Amendment 4, with the exception of smaller black sea bass pots, which are allowed if equipped with escape vents and biodegradable panels to release undersize fish and eliminate waste from lost pots ("ghost fishing"). In North Carolina state territorial waters, fish traps cannot be used to target snapper-grouper [15A NCAC 3M .0506(s)(1)], but are allowed for black sea bass. Nevertheless, black sea bass pots are more commonly used in federal waters and may have a greater impact to hard bottom in those areas.

7.4.3.3. Rod and reel

Although direct impacts of rod and reel 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). Reef fishes are targeted by many recreational fishermen and their habitat may receive concentrated use, leading to unknown cumulative impacts. Lost fishing gear (e.g., line, wire leaders, hooks, sinkers) and discarded rubbish (especially plastics) can entangle or be ingested by marine life (Sheavly 2007), as well as cause tissue abrasions and partial colony mortality of sessile invertebrates (Chiappone et al. 2005). Roughly 18% of marine debris identified in U.S. waters is comprised of ocean-based items, including clumps of fishing line, and floats and buoys (Sheavly 2007).

Bauer et al. (2008) found that at Gray's Reef National Marine Sanctuary, the presence and abundance of marine debris, particularly hook and line fishing gear, was directly related to observed recreational boating and fishing activity. In the Florida Keys National Marine Sanctuary, hook and line fishing gear represented 87% of the marine debris removed from about 6.2 acres of hard bottom habitat, although less than 0.2% of the available milleporid hydrocorals, stony corals, and gorgonians were adversely affected (Chiappone et al. 2004; Chiappone et al. 2005). In addition to the potential physical effects of discarded fishing gear, chemical contamination from lost lead sinkers is also a concern. *Monitoring of hard bottom is needed to assess the level of impact from rod and reel fishing. Educating anglers on the impacts of lost fishing gear and discarded litter to hard bottom and associated species would be helpful in reducing those impacts.*

7.4.4. Water quality degradation

Since snapper-grouper species are most sensitive to toxins and other pollutants during early life stages (SAFMC 1998b), it is essential to maintain good water quality at critical nursery habitats, including nearshore hard bottoms. The effect of degraded water quality on a given species depends primarily on its life history (Schaaf et al. 1987; Schaaf et al. 1993), as well as feeding behavior and diet at all life stages. With the exception of oil and gas development,[56] the primary threats to water quality at hard bottom sites are ocean dumping and coastal pollution from discharge of sewage, stormwater runoff, herbicides, and pesticides (SAFMC 1998b).

Offshore dumping of dredged material occurs at designated sites in federal waters and must be conducted pursuant to the Water Resources Development Act Amendments of 1992 to the Marine Protection, Research, and Sanctuaries Act of 1972 for the management and monitoring of ocean disposal activities. This law requires that ocean dredged material disposal will not unreasonably degrade the marine environment. In North Carolina, three ODMDS exist: one seaward of the Port of Morehead City and two seaward of the Port of Wilmington (COE and EPA 1996; COE and EPA 1997; COE and EPA 2002). While no hard bottoms have been identified in the vicinity of the Morehead City ODMDS (COE and EPA 1997), extensive hard bottom resources have been found within one nautical mile of both Wilmington ODMDS (COE and EPA 1996; COE and EPA 2002), suggesting the potential for water quality impacts on natural hard bottoms neighboring these sites. However, prior to disposal, any fine-grained sediments which are dredged are chemically and biologically tested to ensure the environmental integrity of an ODMDS. *The COE should continue environmental monitoring during use of the two Wilmington ODMDS to determine their effect on adjacent hard bottom habitat and report monitoring results.*

Point discharges of wastewater and sewage can also negatively impact the health and stability of hard bottom. Several studies of hard bottom communities in the Mediterranean found that species richness, abundance, and diversity of corals and echinoderms declined with increasing proximity to sources of pollution (Hong 1983; Hermelin et al. 1981). Terlizzi et al. (2002) reported that a sewage outfall on the southern Apulian coast of Italy negatively influenced the natural distribution pattern of filamentous green algae. At the same location, reef fish assemblages differed between the sewage-impacted site and adjacent controls, with more planktivorous and detritivorous fishes at the sewage outfall (Guidetti et al. 2003). Current North Carolina state (EMC) policies prevent wastewater discharge into the Atlantic Ocean, with one exception: the discharge off Oak Island of heated flow-through, non-contact cooling water from the Brunswick Steam Electric Plant. *Because nearshore hard bottoms are so vulnerable to damage from changes in water quality, this "non-discharge" policy should be maintained.*

Hard bottom can be degraded not only by point discharges, but also by outflowing pollutants from estuarine and river waters. The effect of these non-point outflows on hard bottom off the coast of North

[56] Refer to the Energy Development section for more information on the effects of oil and gas development.

Carolina is largely unknown since little monitoring has been conducted. In 1999, UNC-W began the Coastal Ocean Monitoring Program (COMP), currently known as the Coastal Ocean Research and Monitoring Program (CORMP), which focused on ocean processes in the coastal ocean off southeastern North Carolina. Among other things, this project investigated the chemical and biological effects of the Cape Fear River's plume on the nearshore ocean, as well as responses of the plume to major storm events. Results following Hurricane Floyd found that approximately 200 mi^2 of coastal ocean waters were affected by elevated turbidity and nutrient levels for approximately one month (Cahoon et al. 2001). In comparing water quality of nearshore ocean waters in Long Bay, which is heavily influenced by the Cape Fear River's plume, to Onslow Bay, where riverine influence is minimal, Dafner et al. (2007) found dissolved organic nitrogen and phosphorous concentrations 2–3 times higher and chlorophyll *a* concentrations 5–10 times higher in Long Bay than in Onslow Bay. Nearshore hard bottom is highly concentrated in Long Bay (Map 7.1c), suggesting that declines in estuarine water quality are 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 pollutants than offshore hard bottom. Stormwater runoff and discharge of nutrient-rich estuarine waters can increase nutrient levels, potentially resulting in nuisance algal blooms. Problem levels of nutrients have generally not been found in North Carolina's coastal ocean waters, although, water quality sampling in these areas is extremely limited.[57] Residues of the organochlorine pesticides DDT, PCB, dieldrin, and endrin have been found in gag, red and black grouper, and red snapper (Stout 1980), indicating that toxins from stormwater runoff are a potential threat to the hard bottom community. *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 that exceed designated levels of concern.*

7.4.5. Non-native, invasive, or nuisance species

A relatively new threat to hard bottom ecosystem health and biodiversity is the successful invasion of Indo-Pacific lionfish (*Pterois volitans*/*miles* complex) in the South Atlantic Bight (Whitfield et al. 2002; Meister et al. 2005; Hamner et al. 2007; Whitfield et al. 2007). Lionfish were first documented in marine waters off North Carolina in 2000; by 2001, lionfish could be found at eight hard bottom locations (Whitfield et al. 2002). Documented sightings and collections indicate that lionfish distribution may be continuous from Cape Hatteras to the North Carolina-South Carolina Border (Meister et al. 2005; Whitfield et al. 2007), with abundances comparable to many native grouper species (Whitfield et al. 2007). Such a successful invasion is likely to impact natural hard bottom communities through direct predation, competition, and overcrowding (Whitfield et al. 2007). On natural and artificial reef patches in the Bahamas, Albins and Hixon (2008) found predation by a single lionfish at each patch reef reduced net recruitment of native fishes by a mean of 28.1 fish per reef over five weeks, representing an average reduction in net recruitment of 79%. This finding suggests that an increasing lionfish population on North Carolina hard bottoms has the potential to decrease the abundance of juvenile reef dwelling species, as well as increase the competition with native piscivores for this important food resource. Although there are few documented natural predators of the lionfish, several individuals have been found in the stomachs of native groupers in the Bahamas (Maljkovic and Van Leeuwen 2008). However, such large piscivores are systematically targeted by commercial and recreational fisheries which remove a significant portion of the population, and thus are not likely to substantially reduce the effects of lionfish on Atlantic hard bottom communities. Staff at thehe NOAA Center for Coastal Fisheries and Habitat Research have been conducting studies on lionfish to better understand lionfish distribution, density, life history, temperature tolerances, and genetics. NOAA also encourages reporting of all lionfish captured

[57] Refer to the Water Column (2.0) chapter for more information on water quality.

by rod and reel, as well as sightings by SCUBA divers. The information gained will be used to determine, and possibly mitigate, potential ecosystem and fisheries impacts due to the presence of lionfish. *Further information on Indo-Pacific lionfish biology and competitive/predatory interactions with native fish species is needed. Although complete eradication of lionfish in the marine waters off the North Carolina coast is unlikely, focused lionfish control efforts in strategic locations are needed to reduce the likelihood of potentially detrimental ecological effects.*

7.4.6. Climate change

Rapid increases in atmospheric carbon dioxide (CO_2) concentrations over the past century have led to global climatic changes (Harley et al. 2006; IPCC 2007). Because of this atmospheric increase, global air and ocean temperatures have risen by 0.4–0.8°C (IPCC 2007). This warming trend is expected to accelerate in the current century (IPCC 2007), with implications for hard bottom health and community structure. A study of hard bottom ledges off the North Carolina coast over a 15 year period reported an increased prevalence of tropical reef fishes and a decreased abundance of temperate species (Parker and Dixon 1998). The authors speculated that the observed shift in reef fish community structure was most likely in association with warmer winter bottom water temperatures allowing for range extensions of tropical species. An additional study on North Carolina outer shelf hard bottoms documented four tropical reef fishes new to continental United States waters and range extensions for ten tropical species (Quattrini et al. 2004), potentially indicating that species composition of reef fishes has become more tropical in nature. Such changes in reef fish community structure can have profound impacts on hard bottom by altering the trophic structure, thus changing habitat quality and productivity.

Perhaps the most insidious but poorly understood implication of atmospheric CO_2 loading on hard bottom habitat is that of ocean acidification (Harley et al. 2006; Kleypas et al. 2006; IPCC 2007). Ocean acidification is caused by an increased amount of CO_2 dissolved in ocean waters, which lowers the pH, decreases the availability of carbonate (CO_3^{-2}) ions, and lowers the saturation state of the major carbonate minerals (Feely et al. 2004; Orr et al. 2005). This process can have severe consequences for marine calcifying organisms that inhabit hard bottom in North Carolina, such as hard corals, gorgonians, coralline algae, mollusks, sponges, echinoderms, and calcitic plankton, such as such as foraminifera and coccolithophorids (Feely et al. 2004; Orr et al. 2005; Kleypas et al. 2006; Hoegh-Guldberg et al. 2007). Decreased carbonate ion concentrations considerably reduce the calcification rates of marine invertebrates and algae that build carbonate structures, diminishing growth rates, and increasing susceptibility to predation (Feely et al. 2004; Kleypas et al. 2006; Roberts et al. 2006; Hoegh-Guldberg et al. 2007). In addition, calcifying organisms may be unable to maintain exoskeletal structures in waters that are undersaturated with respect to carbonates, ultimately resulting in dissolution of their calcium carbonate skeletons (Orr et al. 2005). Thus, facing a rapidly acidifying ocean, the density and diversity of hard corals, gorgonians, coralline algae, mollusks, sponges, and other calcifying organisms on hard bottoms are likely to decline, leading to greatly reduced habitat complexity and biodiversity loss, including losses of reef-associated fish and invertebrates (Orr et al. 2005; Hoegh-Guldberg et al. 2007). *More research is needed to examine the potential ecological effects of ocean acidification on nearshore hard bottom in North Carolina*.

7.4.7. Management needs and accomplishments

The management needs noted by italics in the 2005 CHPP were addressed to some degree during 2005-2010. Some of the needs were refined and adopted as actions in the multi-agency CHPP implementation plans (IPs). There were also hard bottom-related actions that came directly from the implementation plans, without a specific call in the 2005 CHPP. However, the majority of IP actions affect either water column (see “Water column” chapter) or multiple bottom habitats (see “Ecosystem management and strategic habitat areas” chapter) and will not be duplicated here. Only hard bottom-focused actions from the IPs are listed in the “Needs and progress” sections. Emerging management needs are included without a reference and may or may not be refined and adopted as actions in 2009-2011 CHPP implementation plans.

7.4.7.1. Research needs and progress (2005-2010)

Accomplished or discontinued needs

1. *Investigate fish use of nearshore hard bottom (Street et al. 2005).* **There is additional research available from other states. See "7.2. Ecological role and functions" for more information.**

2. *Investigate spawning on, and recruitment to, nearshore hard bottom to understand the importance of this habitat and document trends in fish utilization (Street et al. 2005).* **There is additional research on offshore spawning activity. See "7.2.6. Specific biological functions" for more information**.

Needs with progress

None

Needs without progress

1. *Conduct further research to determine if and to what extent artificial reefs in North Carolina simply concentrate available fish or effectively increase fish biomass (Street et al. 2005).* **No specific progress. See "7.2.5. Fish utilization of man-made structures" for more information.**

2. *Conduct research 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 (Street et al. 2005).* **No specific progress. See "7.4.3.1. Mobile bottom disturbing gear" for more information.**

3. *Coordinate 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 (Street et al. 2005).* **No specific progress. See "7.4.4. Water quality degradation" for more information.**

4. *Conduct additional water and tissue sampling at hard bottom sites to determine if the benthos of the hard bottom community or the surrounding waters exhibit levels that exceed designated levels of concern (Street et al. 2005).* **No specific progress. See "7.4.4. Water quality degradation" for more information.**

Emerging needs

1. *Further information on Indo-Pacific lionfish biology and competitive/predatory interactions with native fish species is needed. Although complete eradication of lionfish in the marine waters off the North Carolina coast is unlikely, focused lionfish control efforts in strategic locations are needed to reduce the likelihood of potentially detrimental ecological effects.* **See "7.4.5. Non-native, invasive, or nuisance species" for more information.**

2. *More research is needed to examine the potential ecological effects of ocean acidification on nearshore hard bottom in North Carolina.* **See "7.4.6. Climate change" for more information.**

7.4.7.2. Management needs and progress (2005-2010)

Accomplished or discontinued needs

None

Needs with progress

1. *Monitor the transport of sand from nourished beaches over time. 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 (Street et al. 2005).* **See "Soft bottom" chapter, "Water dependent development" section for information on North Carolina's Beach and Inlet Management Plan.**

2. *Require adequate monitoring prior to creation and during use of the Ocean Dredged Material Disposal Site (ODMDS) off Cape Fear River to determine its effect on nearshore hard bottom habitat (Street et al. 2005).* **Prior to disposal, any fine-grained sediments which are dredged are chemically and biologically tested to ensure the environmental integrity of an ODMDS.** *The USACE should continue environmental monitoring during use of the two Wilmington ODMDS to determine their effect on adjacent hard bottom habitat (Street et al. 2005).* **See "7.4.4. Water quality degradation" for more information.**

3. *Designate hard bottom within State Natural Heritage Areas as Strategic Habitat Areas for consideration of 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 (Street et al. 2005).* **The SAFMC identified several Marine Protected Areas (MPAs) in offshore federal waters through Amendment 14 to the South Atlantic Snapper Grouper Fishery Management Plan. The NMFS issued a final rule to implement Amendment 14 officially creating eight Type II MPAs in which fishing for or possession of snapper-grouper species are prohibited, but other types of fishing, such as trolling, are allowed. No specific progress with regard to state action. However, the MFC has the authority to establish no-take areas over nearshore hard bottom in North Carolina state waters. See "7.3.4. Designated areas" for more information.**

Needs without progress

1. *Construct artificial refugia (no-take artificial reefs) or designate existing artificial reefs as refugia (no-take, Marine Protected Areas) to enhance fisheries productivity (Street et al. 2005).* **No specific progress. See "7.3.3. Hard bottom enhancement" for more information.**

2. *Construct numerous small complex sites surrounded by open areas to mimic natural nearshore hard bottoms and maximize habitat utilization at a shallow, nearshore site near Cape Lookout (Street et al. 2005).* **No specific progress. See "7.3.4. Designated areas" for more information.**

3. *Designate 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 (Street et al. 2005).* **Strategic Habitat Area assessments have not progressed to regions with significant hard bottom resources. See "7.3.4. Designated areas" for more information.**

4. *Monitor hard bottom 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 (Street et al. 2005). **No specific progress. However, there are some monitoring results from other states on the prevalence of marine debris in marine protected areas. See "7.4.3.3. Rod and reel" for more information.**

5. *Develop and implement a state policy to prohibit oil and gas drilling in North Carolina's coastal waters, to ensure protection of hard bottom and water column habitats (Street et al. 2005).* **During 2008, a federal moratorium on offshore drilling for oil and natural gas, which covered much of the OCS in the Atlantic and Pacific oceans, was lifted. This opened the majority of federal waters, including those off the coast of North Carolina, to future oil and natural gas exploration, development, and production. There are emerging management needs related to lifting moratorium.**

6. *Ensure state cooperation 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 (Street et al. 2005).* **No specific progress. Current CRC rules prohibit structures, such as cables and pipelines, from coming onshore on oceanfront beaches. See "7.4.1.3. Energy " for more information.**

7. *Maintain the state policy on waste water disposal in nearshore ocean waters to protect hard bottom vulnerable to damage from physical and water quality changes (Street et al. 2005).* **No changes. However, there is additional research on the impact of waste water disposal on nearshore hard bottom. See "7.4.4. Water quality degradation" for more information.**

8. *Consider designating nearshore hard bottoms in Strategic Habitat Areas as MPAs, either through state or federal avenues, to provide some protection from fishing gear impacts and enhance fisheries production (Street et al. 2005).* **Strategic Habitat Area assessments have not progress to regions with significant nearshore hard bottom resources. See "7.3.4. Designated areas" for more information.**

Emerging needs

1. *An extensive and regular survey of nearshore hard bottom distribution and quality is needed to better evaluate status and trends.* **See "7.3.1. Status of hard bottom habitat" for context.**

2. *More data is needed for evaluating the stock status of species in the reef fish complex off North Carolina.* **See "7.3.2. Status of associated fishery stocks" for context.**

3. *Using the recommendations from the Ocean Policy Steering Committee, the CRC should modify existing rules pertaining to mining of submerged lands to require a 500 m dredging buffer around any exposed hard bottom, thus minimizing potential impacts to fish habitat functions. Furthermore, these buffers should be complied with.* **See "7.4.1.2. Shoreline stabilization" for context.**

4. *Drilling on or in the vicinity of hard bottom resources on the Outer Continental Shelf (OCS) of North Carolina should be prohibited to minimize potential impacts to ecologically productive hard bottoms.* **See "7.4.1.3. Energy " for context.**

5. *North Carolina should continue to be engaged in the Minerals Management Service 5-year Lease Program and any proposed OCS energy development project.* **See "7.4.1.3. Energy " for context.**

6. *Should the State consider siting a wind facility in state or federal waters, proper placement of turbine foundations is necessary to minimize potential impacts to hard bottom habitat and minimize conflicts with existing activities.* **See "7.4.1.3. Energy " for more information.**

7.5 HARD BOTTOM SUMMARY

Hard bottom is valuable to fish because it provides oases of structural complexity for foraging and refuge in marine waters. The presence of ocean hard bottom off North Carolina, along with appropriate water temperatures, allows for the existence of a temperate-to-subtropical reef fish community and a snapper-grouper fishery. Many fishery and 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 also serve as nursery areas for these species and provide important secondary nursery habitat for estuary-dependent fish, such as gag and black sea bass, as they move between the estuary and offshore reef areas. Because of their importance as spawning, nursery, and foraging habitat, all of the nearshore hard bottoms off North Carolina have been federally designated as Habitat Areas of Particular Concern for the snapper-grouper complex.

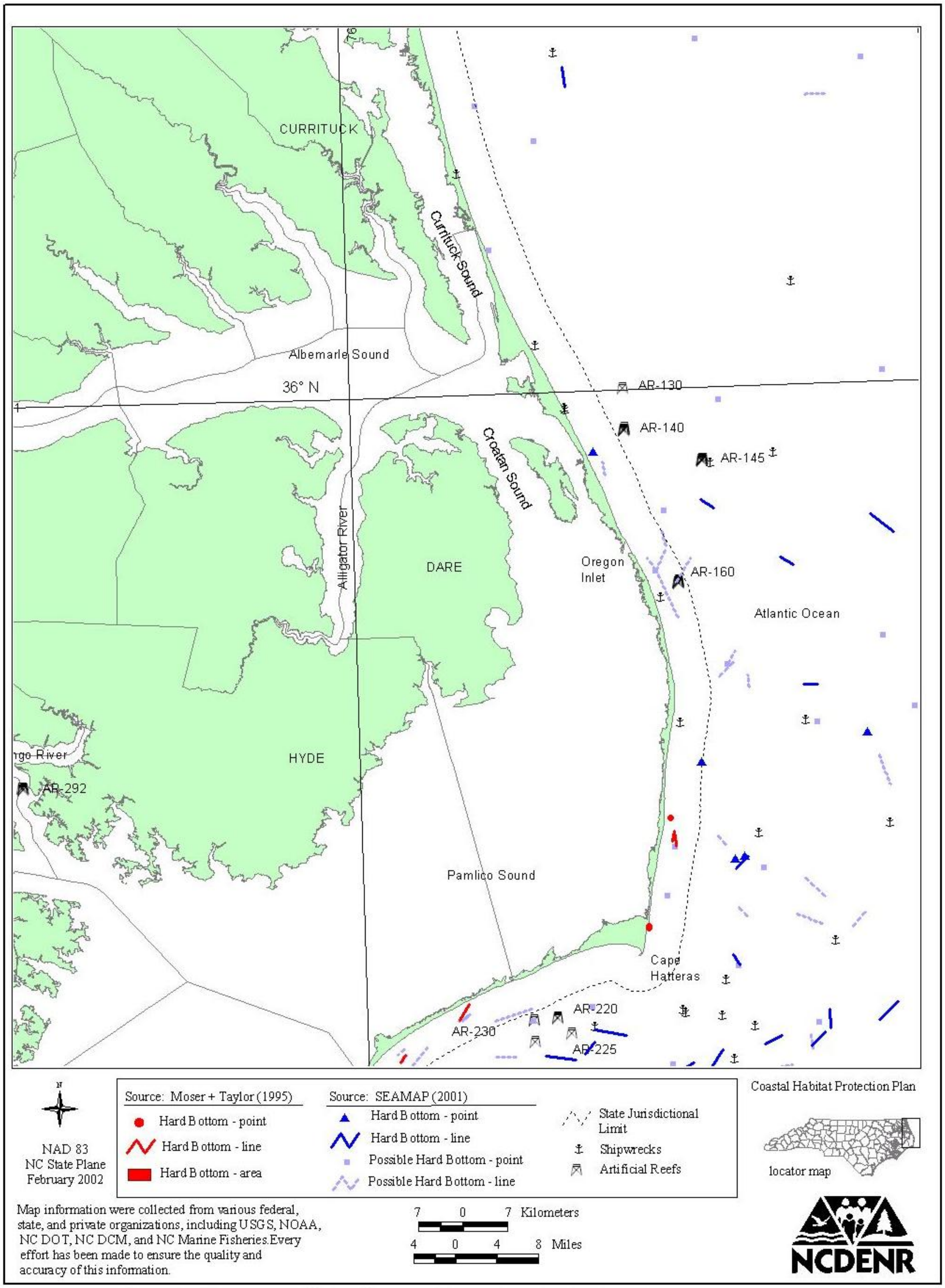
While the distribution of hard bottom off the North Carolina coast was mapped in the 1990s, little is known about the biological condition of specific hard bottom sites or how hard bottom distribution or quality has changed over time. However, an increase in beach nourishment activities, which require an environmental assessment, have resulted in new information on localized hard bottom distribution and condition. Although not natural, wrecks and state-maintained artificial reefs 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, the primary management need for this habitat is continued research and monitoring specific to nearshore hard bottom to determine its functional importance. In addition, extensive and regular surveys of nearshore hard bottom distribution and quality are needed to determine status and trends. It is also essential to provide continual and expanding protection of existing hard bottom habitats to protect these areas from further degradation or destruction.

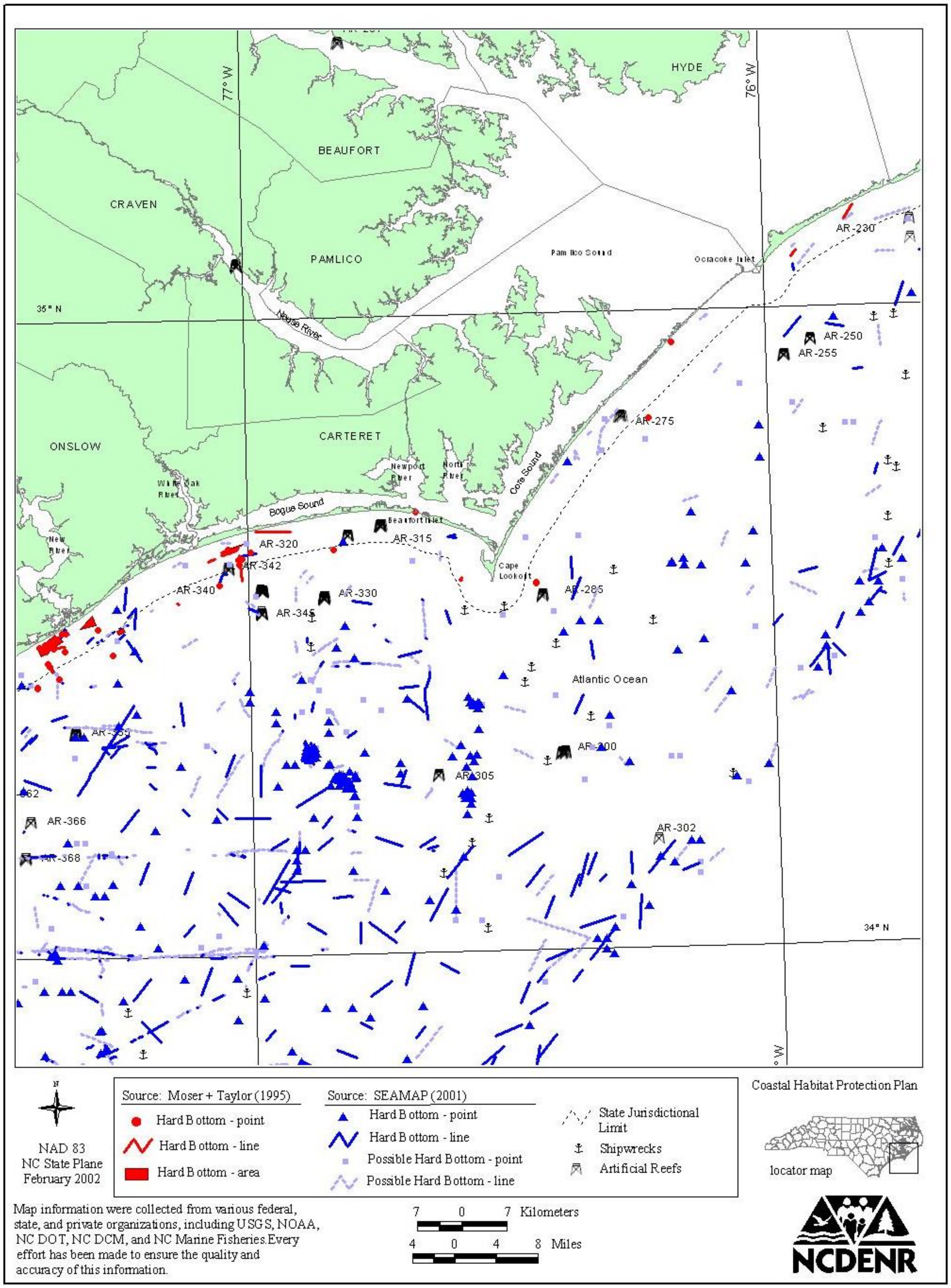
Several threats continue to pose an issue for nearshore hard bottom in North Carolina, including channel dredging, beach nourishment, bottom-disturbing fishing gear, and water quality degradation. Channel dredging can directly remove hard bottom habitat or increase turbidity to problematic levels. Sand transported from nourished beaches can cover up hard bottom structure. Bottom-disturbing fishing gear, such as bottom trawls and dredges, 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 boating activity and estuarine or riverine discharges. The quality of waters discharging into marine areas may have a large overall effect on hard bottom, and can be addressed through the management needs discussed in the other estuarine habitat sections.

In addition to the above, several new and recently recognized threats jeopardize the health of hard bottom off North Carolina and have emerging management and research recommendations associated with them. These include offshore energy development, invasive species, and climate change. Offshore drilling for oil and natural gas can damage or dislodge corals, sponges, and algae at the platform anchor site, while disposal of drilling muds, as well as produced formation water (oily water produced after separation from oil), can cause acute or chronic toxic effects to hard bottom organisms and reef fishes. The invasion of the Indo-Pacific lionfish in marine waters off North Carolina will likely impact natural hard bottom communities through direct predation, competition, and overcrowding. Perhaps the largest threat to hard bottom health and stability comes from climate change. As global temperatures rise, tropical organisms may invade North Carolina hard bottoms with greater frequency, altering the natural trophic structure. Increasing atmospheric CO_2 concentrations decrease carbonate ion concentrations considerably, thus reducing the calcification rates of hard bottom invertebrates and algae that build carbonate structures and increasing their susceptibility to predation.

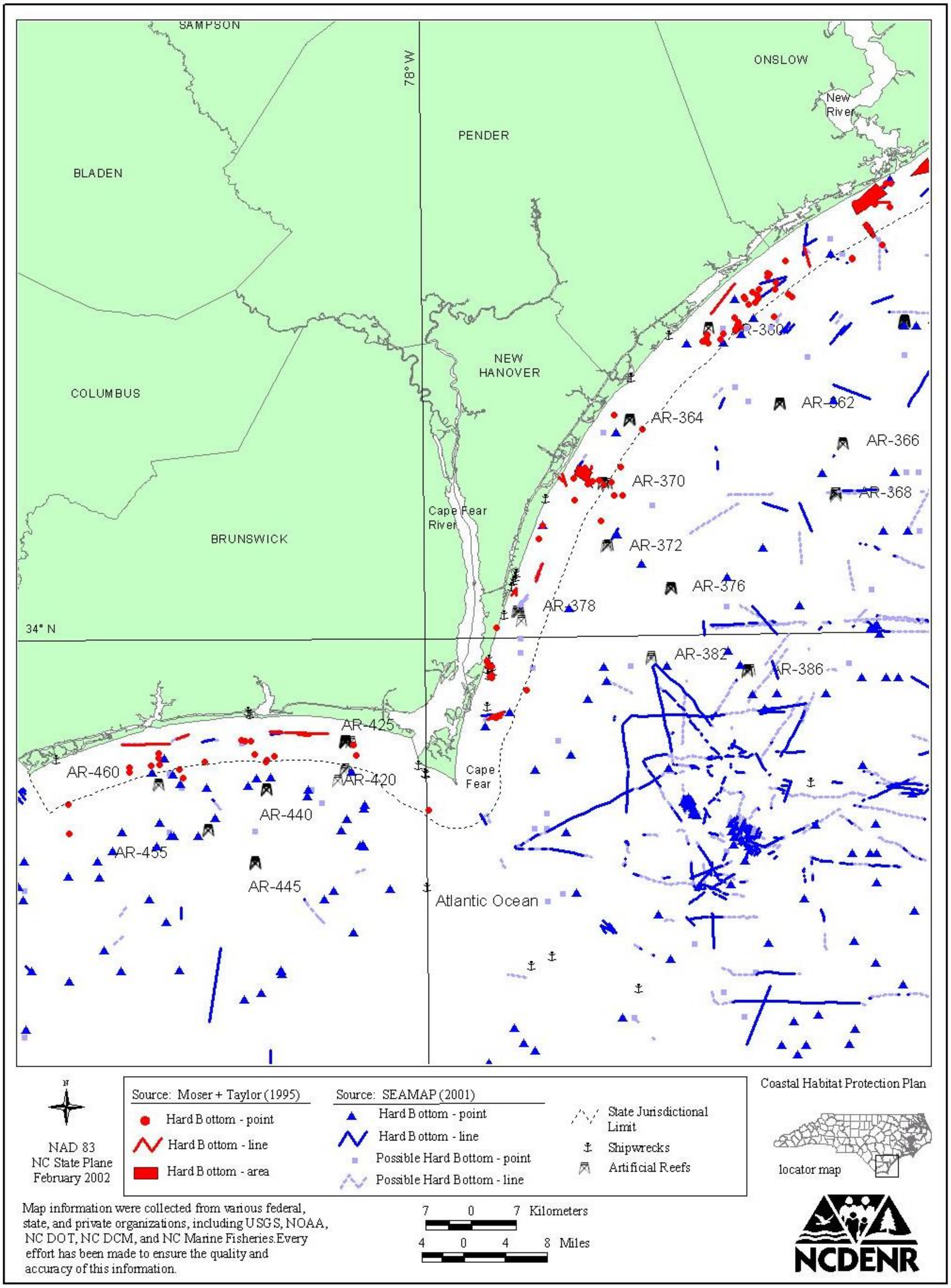
As a result of the 2005 CHPP, 3 of the 17 research and management needs have had some progress in being addressed. The 3 needs that have had some progress are all management recommendations. Two needs from the 2005 CHPP have been addressed or discontinued. Since the 2005 CHPP, there have been 10 emerging research and management recommendations added that include understanding climate change, invasive species, status of hard bottom-enhanced fishery species, and energy infrastructure. Of the 3 needs with progress, 2 are related to dredging and nourishment, while the third relates to designating strategic habitat areas.



Map 7.1a. Location of hard bottom, possible hard bottom, shipwrecks, and artificial reefs in state and federal waters off North Carolina - northern coast.



Map 7.1b. Location of hard bottom, possible hard bottom, shipwrecks, and artificial reefs in state and federal waters off North Carolina - central coast.



Map 7.1c. Location of hard bottom, possible hard bottom, shipwrecks, and artificial reefs in state and federal waters off North Carolina - southern coast.

CHAPTER 8. ECOSYSTEM MANAGEMENT AND STRATEGIC HABITAT AREAS

Ecosystem management is defined as an approach to maintaining or restoring the composition, structure, function, and delivery of services of natural and modified ecosystems that integrates ecological and socioeconomic perspectives within a geographic framework, for the goal of achieving sustainability. Ecosystem management, as a concept, is a broadening of the narrow focus of single species, single habitat, or single threat management to consider multiple species and habitats that are interdependent. An ecosystem approach is necessary given the interrelationships among species, habitats, and threats. Thus, any management activity that considers multiple species, habitats, and/or threats could be considered ecosystem management. 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 8.1); 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.

In recent years, there has been increasing awareness of the need to manage aquatic resources on an ecosystem scale (Beck et al. 2000; NRC 2001; http://www.safmc.net/Portals/0/FEP/FisheryEcosystemPlanApril2009Final.pdf, August, 2010). To address habitat biodiversity within the South Atlantic, the SAFMC is adopting an ecosystem approach to fisheries management with the development of a Fishery Ecosystem Plan (FEP) and Comprehensive Ecosystem-Based Amendment (CE-BA) that will amend all the Council's Fishery Management Plans. Other regional initiatives, such as the Southeast Aquatic Resource Partnership (SARP) developed a habitat plan (SARP 2008) that provides regional watershed conservation and restoration targets. Ecoregional assessments have been conducted in over half of the ecoregions of the United States to develop conservation priorities (Beck et al. 2000) for regional funding sources. The North Carolina Department of Environment and Natural Resources has developed a conservation planning tool (CPT) to provide guidance for both aquatic and terrestrial conservation efforts in the state (see "Designations" section of Water Column chapter for more information on the CPT).

One of the most challenging aspects of ecosystem management is the setting of management priorities, objectives and measures of success. Success criteria could take the form of indicator metrics and threshold values. The APNEP is currently developing indicator metrics for the Albemarle-Pamlico region (Dean Carpenter/APNEP, pers. com., 2009). However, there is also a need to set threshold values that reflect a fundamental, destabilizing shift in ecosystem function. The finding of fundamental indicators with threshold values is an essential goal of ecosystem management research (Grossman et al. 2006). Without indicator metrics and threshold values, the management of ecosystems has relied upon maintenance of ecosystem characteristics (i.e., no net loss of wetlands). Because climate change may alter ecosystem characteristics, a shift in maintenance goals based on predicted changes may need to be considered (see "Sea level rise and climate change" sections of habitat chapters). Research suggests that even minute changes in temperature, salinity, and other basic parameters can have major impacts on biological community structure (Apple et al. 2008; Baird 2009).

One fundamental metric of ecosystem assessment is biodiversity and the richness of genetic information it represents (literature review in Airoldi et al. 2008). By fostering enhanced species diversity, structurally complex habitats add resilience and efficiency to ecosystems in the face of changing conditions. Less complex habitats favor generalist, colonizing species forming relatively disorganized systems with more biomass in microbial pathways (Baird 2009). Hypoxia in the Neuse River, for example, can shift biomass away from the benthic invertebrates (fish food) and more into the phytoplankton and microbial decomposers. Increasing abundances of toxic algae and pathogenic microbes have also been associated with nutrient enrichment and hypoxia (Jackson et al. 2001). Carbon-building, structurally complex habitats in shallow water (i.e., SAV, shell bottom, marsh) also provide greater denitrification services compared to deeper, less structured habitats (Piehler and Smyth in press), suggesting their importance as waste treatment facilities. The value of services, in terms of nutrient trading rates, ranged from $1000-2000/acre/year over subtidal bottom.

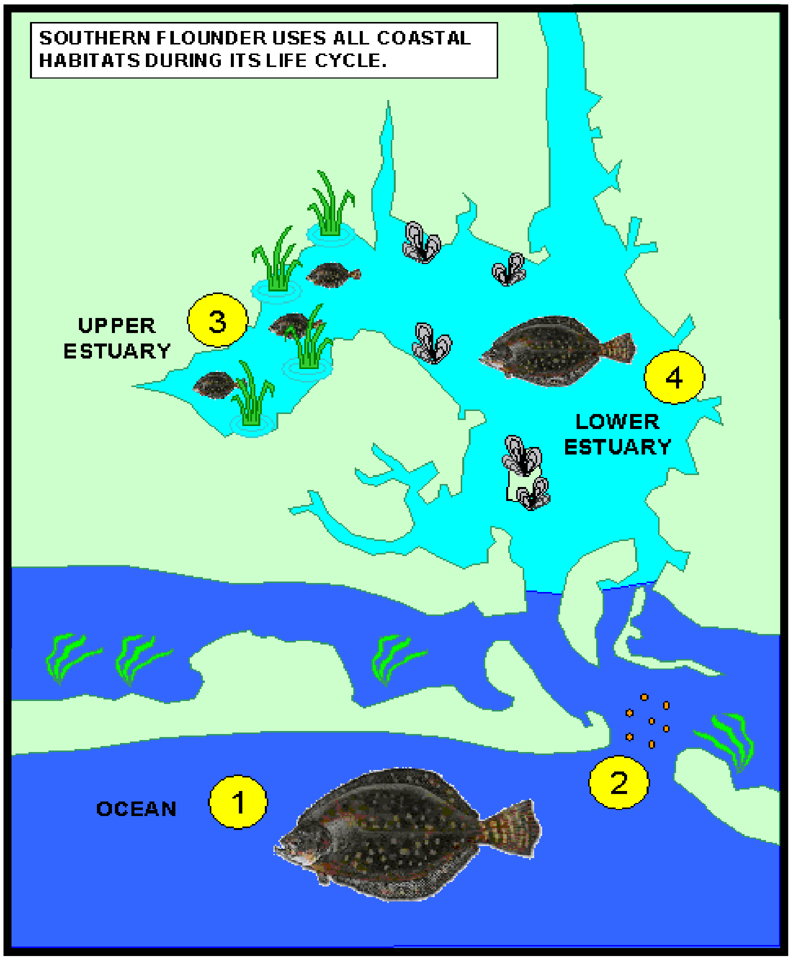


Figure 8.1. Life cycle of the southern flounder.

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.

There is abundant evidence that structurally complex habitats (i.e., SAV, shell bottom, hard bottom, wetlands) are becoming more rare across the globe, with a corresponding increase in less structured habitats (i.e., soft bottom) (Airoldi et al. 2008). The changes have been linked to coastal development, overfishing, and eutrophication described in the CHPP habitat chapters. With persistent overfishing and loss of structural habitats, an ecosystem can change its stabilizing processes to reach an alternative stable state (Beisner et al. 2003; Briske et al. 2008). Once an Alternative Stable State (AltSS) is reached, restoration to a former state can be more difficult. However, an AltSS is only one of many possible behaviors based on a review of AltSS literature (Schroder et al. 2005). Whereas vulnerability or proximity to AltSS is lacking in evidence, maintaining bio-diversity and structurally complex habitat is undoubtedly a stabilizing influence. Human activities that degrade biodiversity and structurally complex habitats are therefore destabilizing ecosystems.

THREATS AND CUMULATIVE IMPACTS

The previous habitat chapters cover the effects of individual human activities as threats to a single habitat. However, threats often affect multiple habitats, with a corresponding impact on bio-diversity and ecosystem function. Threats affecting a single habitat have indirect impacts on other habitats depending on their proximity and ecosystem enhancement services (see "Ecosystem enhancement" sections of habitat chapters). For example, reductions in wetland area and filter-feeding shellfish could degrade water quality conditions needed for SAV growth. There are also multiple threats affecting habitat areas that are not necessarily confined to individual property boundaries. A good example is the indirect relationship between degraded water quality along an individual shorefront property and the cumulative contribution of pollution sources upstream of the property (see "Water quality degradation - sources" section of the Water Column chapter for more information). The management of cumulative impacts is an area lacking in state regulatory authority and practices due to the lack of an effective assessment methodology and management tools. The state's best attempts at managing cumulative impacts have been the coastal impervious surface limits, development of Local Watershed Plans (EEP) and Total Maximum Daily Loads (DWQ), and acquisition of lands managed for conservation. Though required in the permit process, assessment of cumulative impacts as the basis for determining significant adverse impacts is rarely put forward due to the limitations of existing data, lack of threshold values, and anticipated legal challenges. However, a precedent has been set with the application of impervious surface limits to individual lots, though no limits have been placed on a hydrologic unit basis.

A review of top threats to coastal marine ecosystems across the globe listed habitat loss, overexploitation, eutrophication and hypoxia, pollution, invasive species, altered salinities, altered sedimentation, climate change, ocean acidification, and disease (Crain et al. 2009). The threats were not habitat-specific, unlike the CHPP, which discusses threats in each habitat chapter (for continuity). In the 2005 CHPP, a threats table was produced to evaluate the relative threat of various anthropogenic activities to fish habitats in North Carolina. From that table, it was evident that most threats affected more than one habitat and all habitats were affected by multiple threats. The original table has been modified to provide a cross-reference for locating all the information on each threat discussed among the habitat chapters (Table 8.1). The primary discussion of individual threats can be found in the habitat chapter they most affect. The table also includes the relative severity of a threat to each habitat. Some alteration sources and/or impacts clearly threaten the entire ecosystem. The most "cross-cutting" threats include climate change/sea level rise, water quality degradation from nutrients and toxins, dredging for navigation, water dependent development, and non-native/invasive/introduced species. The synergy of these threats may also exacerbate or mitigate the individual impacts discussed in the habitat chapters. This is particularly true for sea-level rise and climate change.

The impacts of sea level rise are most apparent along the estuarine and ocean shoreline, where management decisions regarding water dependent development can profoundly impact nearshore habitats (both landward and waterward of shoreline). For this and other reasons, climate change and associated sea level rise are now recognized as a priority issue for DENR strategic planning. The DENR climate change initiative includes comprehensive strategies across programs that effectively identify and address potential impacts to the environment and natural resources that DENR is charged with protecting (J. Nicholson/DENR, pers. com., February 2010). In the effort to proactively prepare for sea level rise, DENR has established a working group with representatives from OCCA, DCM, APNEP, DWQ, DMF, and Natural Heritage Trust Fund. This group will work with external agencies such as NOAA and Sea Grant, to develop coordinated policies, land use planning guidelines and other recommendations that will increase the resiliency of estuarine and coastal lands to changing climate and associated impacts.

Table 8.1. Threat sources, impact severities (both measured and potential), and documentation in the habitat chapters. The primary discussion of a threat is indicated by which chapter(s) it receives the most attention. Note: X = discussed as a section heading, XX = primary discussion of threat affecting multiple habitats. Shading = relative severity of impact; 0% = no impact/unknown, 25% = minor, 50% = moderate, 75% = major.

Threat category	Source and/or impact	Water column	Shell bottom	SAV	Wetlands	Soft bottom	Hard bottom
Physical threats/ hydrologic modifications	Boating activity	-	X	X	X	-	X
	Channelization	X	-	-	X	-	-
	Dredging (navigation channels, boat basins)	X	X	X	X	X	X
	Fishing gear impacts	X	X	X	-	X	X
	Infrastructure (i.e., pipelines)	-	-	X	X	X	X
	Jetties and groins	X	-	-	-	XX	-
	Mining	X	-	-	X	X	-
	Obstructions (dams, culverts, locks)	XX	-	-	X	-	-
	Estuarine shoreline stabilization	X	X	X	XX	X	-
	Ocean shoreline stabilization	-	-	-	-	XX	X
	Upland development	-	-	-	X	-	-
	Water withdrawals	XX	-	-	X	-	-
Water quality degradation-sources	Land use and non-point sources	X	-	-	-	-	-
	Water dependent development (marinas and docks)	XX	X	X	X	X	-
	Point sources	X	-	-	-	X	-
Water quality degradation-causes	Marine debris	X	-	-	-	-	-
	Microbial contamination	XX	X	-	-	-	-
	Nutrients and eutrophication	XX	X	X	X	X	X
	Saline discharge	X	-	-	-	-	-
	Suspended sediment and turbidity	XX	X	X	-	X	-
	Toxic chemicals	X	X	X	X	X	X
Disease and microbial stressors		-	X	X	-	-	-
Non-native, invasive or nuisance species		X	X	X	X	X	X
Sea-level rise/climate change		X	X	X	XX	X	X

STRATEGIC HABITAT AREAS

An important step toward developing ecological thresholds in hydrologic units is the selection of exceptional areas to protect, enhance, or restore. The areas that contribute most to the integrity of the system are the category of habitat termed Strategic Habitat Area (SHAs). Strategic Habitat Areas are 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. Location and designation of SHAs is an attempt to identify such exceptional areas within the coastal fisheries ecosystem. Exceptional habitat areas are relatively unaltered and represent a proportion of habitat types to maintain[58]. The amount to maintain is adjusted up or down from 30%, based on relative ecological importance, rarity, vulnerability, sensitivity to alteration, and/or historic losses.

The process for locating and designating SHAs can be downloaded from the DMF website (http://www.ncdmf.net/habitat/miscdownloads/FINAL_MFC_SHAreport12-6-06.pdf). Using this process and several refinements, the first of four regional assessments was completed and presented to the Marine Fisheries Commission in January 2009. Through the analysis, maps of habitats and relative alteration levels are produced, and a network of exceptional areas are selected as SHAs (Maps 8.1 and 8.2). The designation of SHAs was postponed until field verification could be conducted. In the meantime, Region 1 SHAs (Albemarle Sound and tributaries) and supporting data are used in conservation planning (at the DENR level) and as information for the CHPP update. There are also Sea Grant research fellowships supporting SHA assessments. The first project was conducted for Region 1 comparing DMF sampling data and proximity to altered habitats. The results indicated some correlations between juvenile fish data and cumulative alteration within a 0.5 kilometer radius, with low fish abundance where alteration levels were greater (http://www.ncdmf.net/habitat/miscdownloads/SHA_region1_report_11_20_08.pdf). Current research and assessment work is focused on SHA region 2 (Tar-Pamlico, Neuse, and Pamlico Sound subregions). *The SHA assessment for Region 2 should be complete by late 2010; Regions 3 and 4 should be completed by late 2011 (Map 1.2 of the Introduction chapter). Additional research is needed to verify the relative impact and distribution of cumulative alterations affecting the selection of areas.*

The input data and results of SHA assessment should help permit reviewers in assessing cumulative impacts and deciding habitat trade-offs acceptable for development projects. One could estimate how much more altered an area would get with the addition of proposed structures. The habitat trade-off issue is exemplified by the criteria required for constructing marsh-sills instead of vertical bulkheads. In this case, the exchange of soft bottom with shell bottom and wetlands could be justified by comparing representation levels in the region. The question to ask is whether the loss of soft bottom habitats would result in those habitats not meeting their representation levels in the SHA network. The addition of habitats with higher representation levels (i.e., shell bottom and wetlands) and less over-representation could be applied to restoration goals for those habitats in the area. *A basic need of SHA assessment continues to be the development of accurate and contemporary distribution maps for habitats (see "Distribution" sections of habitat chapters for specific recommendations) and threats (see "Threats and management needs" sections of habitat chapters for specific recommendations).*

The EEP, along with permitting agency input, is currently developing criteria for out-of-kind restoration credits based on projected improvements in downstream water quality[59]. This is fundamentally an ecosystem approach to maintaining water quality and associated bottom habitats with permitted impacts. The SHA approach could provide some input regarding the maintenance of habitat diversity in a restoration crediting system (see "Wetland enhancement and restoration" section of Wetlands chapter for more information).

OTHER HABITAT DESIGNATIONS AND PROTECTION PROGRAMS

While Region 1 SHAs have been identified and approved under the CHPP, they have not been placed in agency rule due to the need to develop site specific management plans for each SHA that will determine if

[58] In the SHA region 1 (Albemarle Sound and tributaries), there were 42 habitat types and 18 alteration factors.
[59] The EEP contracted with East Carolina University to develop a rapid assessment process for coastal watersheds and compensatory mitigation that is consistent with the goals of the Coastal Habitat Protection Plan. The 2007-09 CHPP implementation plan called for developing an innovative system for out-of-kind mitigation credit that includes aquatic habitat restoration. http://www.nceep.net/services/lwps/pull_down/by_basin/WhiteOak_RB.html

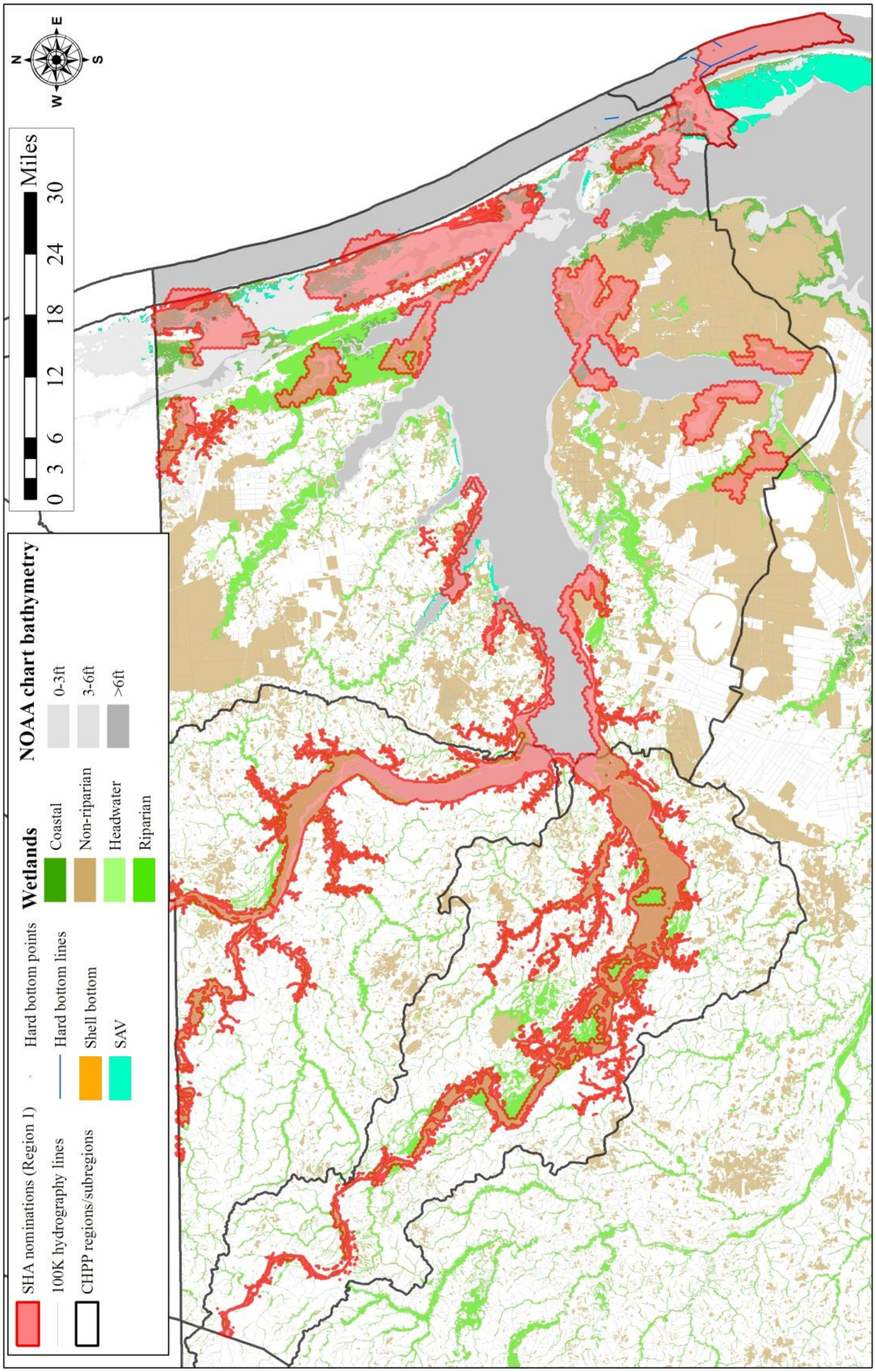
regulatory actions or restrictions are needed. There are however, several different existing designations used in North Carolina that identify, delineate, and designate functionally important habitat areas. At the federal level, the Magnuson-Stevens Fishery Conservation and Management Act Reauthorization 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.

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:

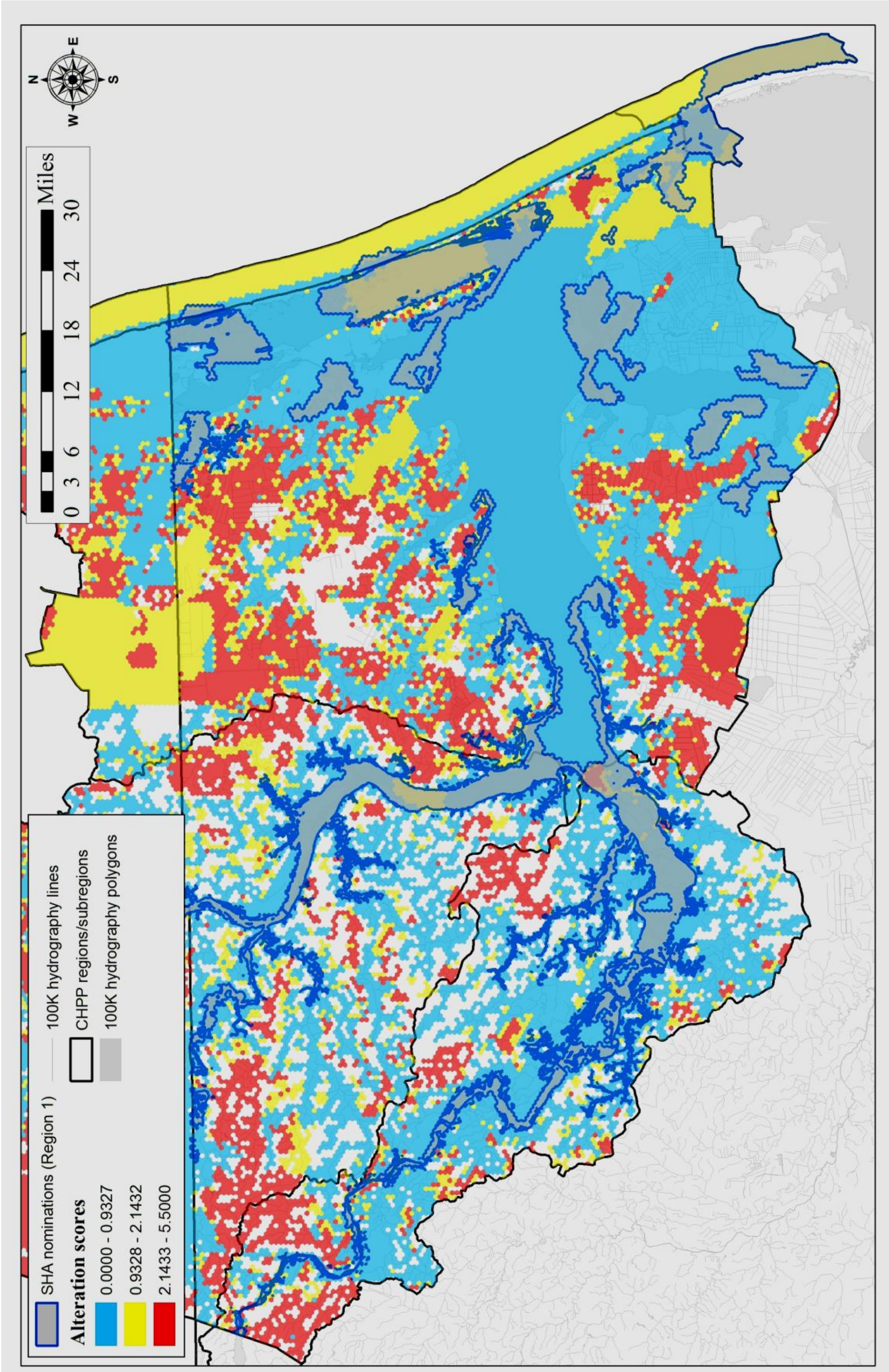
- Roanoke River, U.S. 258 bridge to Roanoke Rapids Dam (35.5 stream miles, 57.1 km)
- Tar-Pamlico River, railroad bridge at Washington to Rocky Mount Mill Dam (90.2 stream miles, 145.2 km)
- Neuse River, Pitchkettle Creek to Milburnie Dam (160.6 stream miles, 258.4 km)
- Cape Fear River, Lock and Dam #1 to Buckhorn Dam (126.7 stream miles, 203.9 km).

There are specific protections for designated nursery areas included in the rules of all three commissions. For example, an 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.

The existing rule definitions for various fish habitats were revised by the Marine Fisheries Commission in April 2009 [MFC Rule 15A NCAC 03I .0101(4)]. The word "critical" was omitted since all fish habitats, under the ecosystem concept, are critical to a properly functioning system as a whole. The DMF also delineated in rule anadromous fish spawning areas based on sampling conducted from the early 1970s to the present. Although neither CRC nor EMC rules offer any specific protection for anadromous fish spawning areas, regulatory protections exist for other fish habitats, 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). Designation and protection of Strategic Habitat Areas was meant to improve on the piecemeal protection of individual habitats and functional areas.



Map 8.1. Strategic Habitat Area nominations presented and approved by the Marine Fisheries Commission in January 2009.



Map 8.2. Total alteration scores calculated from 18 individual alteration factors coinciding with habitat targets in the Albemarle Sound region.

CHAPTER 9. MANAGEMENT RECOMMENDATIONS

9.1 INTRODUCTION

The discussions of the six major habitat types and habitat systems 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 – 8, deliberations of the Environmental Management, Coastal Resources, Marine Fisheries and Wildlife Resources commissions, and citizen input (verbal comments received in person or by telephone; written comments received in person or via mail and e-mail) from three public meetings held during the summer of 2010, as well as additional comments obtained during the CHPP process. The commission representation formed the CHPP Steering Committee or CSC (Appendix B).

9.3 PUBLIC INPUT

In 2003 and 2004, 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.

The public meetings in 2010 focused on what was done to address the recommendations in the 2005 CHPP and getting input on emerging and continuing priority issues of the 2010 CHPP. Three meetings were held in Morehead City (June 8), Wilmington (june 4), and Manteo (June 17). Two letters were also received during the comment period, which closed on July 30, 2010. Groups represented at the public meetings or through comments included Pender Watch, North Carolina Coastal Federation, and Business Alliance for a Sound Economy (BASE). When asked what they considered the highest priority recommendations, answers included continuing to enforce existing rules, address cumulative impacts, prevent pollution, endocrine disruptors, no offshore drilling, increase adaptation to sea level rise, greater encouragement and interagency cooperation to implement Low Impact Development (LID) techniques to meet stormwater rule goals, since they are considered the best available technology standard for reducing polluted stormwater runoff. Another comment noted the need for more specific recommendations to address failing septic systems since that is a factor in stormwater runoff, as well as funding for enforcement of existing rules.

There is currently an ongoing DENR Interagency Inspection Task Force, lead by Shellfish Sanitation Office, to examine the issue of compliance and inspections to reduce nonpoint pollution from failing septic systems and other sources. Recommendations 4.5d and 4.6b address LID, but more coordination and outreach efforts are needed to increase use. This could be addressed through establishment of a CSC workgroup rather than modification of the existing recommendations. Substantive public comments and CSC consensus regarding possible modifications to recommendations included:

Rec # 3.2 – specifically state to maintain the state law banning hardened structures on ocean shorelines, rather than leaving the language vague as currently worded. This would be consistent with the literature findings in the CHPP. The recommendation was not changed due to a CSC member objection.

> CSC response (Commissioner Bob Emory): "The committee is aware that the CRC study on terminal groins was inconclusive and our recommendation to the General Assembly was similarly inconclusive. As a matter of fact, at the CRC's next meeting there will be a discussion regarding

just exactly what our recommendation meant. There is significant disagreement among some Commissioners. My support for retaining a hardened structure ban aside, a definitive statement in the CHPP report would meet resistance from CRC members; I honestly don't know how many at this point."

Rec # 3.4 – strengthen the wording to simplify and promote use of marsh sills and other alternatives by stating these structures should be preferred rather than just considered. This is supported in the CHPP literature and would be consistent with the conclusions of the Estuarine Biological and Physical Processes Work Group report. The MFC's Habitat and Water Quality Advisory Committee revised wording was accepted by the CSC:

Protect estuarine and public trust shorelines and shallow water habitats by revising shoreline stabilization rules that include consideration of erosion rates and prefer alternatives to vertical shoreline stabilization measures that maintain shallow nursery areas.

Rec. # 3.6 – reword to clearly state that offshore drilling is incompatible with NC's coastal policy because of potential habitat effects. Due to the Deepwater Horizon oil spill, additional research on the effect of oil spills is estuarine waters was done and incorporated into the CHPP text. The literature has documented negative effects to the water column, estuarine wetlands, shellfish, and SAV, as well as ocean hard bottom, and soft bottom. The recommendation was not changed due to a CSC member objections.

CSC response (Commissioner Anna Beckwith): "I would be cautious about the oil drilling. While I personally oppose drilling for oil off our coast and would personally love to see <a recommendation change>, I would be concerned that it would be considered an emotional reaction to the current situation." (Commissioner Bob Emory) "I prefer to leave the energy development language as it is, without making a statement about banning offshore oil exploration. We should be informed by upcoming investigation in the Gulf."

9.2 RECOMMENDATIONS

The 2010 CHPP update identifies numerous management needs as either accomplished, progressing, without progress, or emerging/clarified, as shown in the "Management needs and accomplishments" sections of chapters 2 – 7. Major accomplishments and progress on 2005 CHPP goals and recommendations was presented in the Introduction chapter. There were also numerous discontinued items because they were found to be redundant, too vague, or insignificant. The management needs information was summarized for the CSC in March 2010. The CHPP staff reviewed the 2010 management needs to determine if the existing goals and recommendations established in the 2005 CHPP adequately addressed all the specific management needs. The results suggested some necessary revision of the goals/recommendation language. The CSC reviewed the changes during their subsequent meeting in April. The revised goals and recommendations are listed below and in Table 9.1, in no particular order of priority.

Making further progress on the goals and recommendations will require the continuing development of CHPP Implementation Plans (IPs). The IPs are developed on a 2-year schedule and include action items for all the participating commissions and their supporting agencies. Prior IPs have included numerous items that address the 2005 goals and recommendations but were not specifically included as management needs in the habitat chapters. The management needs italicized in the habitat chapters are therefore included as a guide for developing implementation actions that combine the influences of opportunity, importance to fish habitat, and socio-economic realities. Some action items in the 2009-2011 CHPP Implementation Plan are listed and described in Appendix J. Contact the DMF Habitat Section (1-252-808-8066) for the most up-to-date Implementation Plans.

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

During the 2005 public meetings, the most common request was to enforce existing rules before implementing new rules. With additional coordination, enforcement, and education, many of the existing rules and programs regarding habitat protection could be much more effective. Despite progress made on this goal during 2005-2010, the following actions are still needed for existing management strategies to be effective:

- Continue to enhance enforcement of, and compliance with, Coastal Resources Commission (CRC), Environmental Management Commission (EMC), Marine Fisheries Commission (MFC), and Wildlife Resources Commission (WRC) 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 land-use and human activities, climate change, and reasons for management measures.
- Coordinate rulemaking and data collection for enforcement among regulatory commissions and agencies.

Some management needs identified in the 2010 CHPP suggested the inclusion of additional recommendations under the goal of improving existing rules and programs. The new recommendations include:

- Develop and enhance assessment and management tools for addressing cumulative impacts.
- Enhance control of invasive species with existing programs.

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

To identify and protect Strategic Habitat Areas in a science based manner, mapping and monitoring of all fish habitat is necessary to assess distribution and condition. Research is also needed on the effect of anthropogenic activities on fish habitat, as well as ecological linkages between fish and habitat. With mapping, monitoring, and ecological and threats assessments available, SHAs can be accurately identified. Strategic Habitat Area assessments and subsequent nominations are not yet completed. The need for more up-to-date data on habitat distribution and quality, along with current alterations to the habitat, is a major theme of the CHPP update. The following regulatory and non-regulatory management actions continue to be recommendations:

- Support Strategic Habitat Area assessments by:
  - Coordinating, completing, and maintaining baseline habitat mapping (including seagrass, shell bottom, shoreline, and other bottom types) using the most appropriate technology.
  - Selective monitoring of the status of those habitats, and
  - Assessing fish-habitat linkages and effects of land use and human activities on those habitats
- Identify, designate, and protect Strategic Habitat Areas.

GOAL 3. ENHANCE HABITAT AND PROTECT IT FROM PHYSICAL IMPACTS

Large historical losses of wetlands, oysters, and SAV have occurred in North Carolina in the past from various causes. Habitats continue to be degraded or lost at a smaller but cumulatively significant scale from certain development, water dependent and fishing activities. Direct and indirect impacts may occur due to unauthorized impacts, impacts too small to require a permit, indirect and unmitigated impacts of permitted activities, and unsuccessful mitigation. The following regulatory and non-regulatory measures continue to be recommendations:

- Expand habitat restoration in accordance with ecosystem restoration plans, including:
  - Creation of subtidal oyster reef no-take sanctuaries.
  - Re-establishment of riparian wetlands and stream hydrology.
  - Restoration of SAV habitat and shallow soft bottom nurseries.
  - Developing compensatory mitigation process to restore lost fish habitat functions.
- Sustain healthy barrier island systems by maintaining and enhancing ecologically sound policies for ocean and inlet shorelines and implement a comprehensive beach and inlet management plan that provides ecologically based guidelines to protect fish habitat and address socio-economic concerns.
- Protect habitat from fishing gear effects through improved enforcement, establishment of protective buffers around habitats, modified rules, and further restriction of fishing gears, where necessary.
- Protect estuarine and public trust shorelines and shallow water habitats by revising shoreline stabilization rules to include consideration of erosion rates and prefer alternatives to vertical shoreline stabilization measures that maintain shallow nursery habitat.
- Protect and enhance habitat for migratory fishes by:
  - a) Incorporating the water quality and quantity needs of fish in water use planning and rule making.
  - b) Eliminating or modifying obstructions to fish movements, such as dams and culverts, to improve fish passage.

Some management needs identified in the 2010 CHPP suggested the inclusion of additional recommendations under the goal of protecting habitat from physical impacts. The new recommendations include:

- Ensure that energy development and infrastructure is designed and sited in a manner that minimizes negative impacts to fish habitat, avoids new obstructions to fish passage, and where possible provides positive impacts.
- Protect important fish habitat functions from damage associated with activities such as dredging and filling.
- Develop coordinated policies including management adaptations and guidelines to increase resiliency of fish habitat to climate change and sea level rise.

GOAL 4. ENHANCE AND PROTECT WATER QUALITY

Because all fish habitats are connected and influenced by the water column, maintaining and restoring water quality is the basic component of habitat protection and enhancement. Water quality stressors include toxins, excess nutrients and sediment, and bacteria. Sources of these stressors include nonpoint runoff from land-based activities, point source discharges, and spills and failures of wastewater treatment. Alterations to water flow through intakes, discharges, impoundments and obstructions can also degrade habitat functions. Despite numerous improvements in the management of water-born pollutants, there continue to be areas for improvement, as well as emerging issues. Additional recommendations are related to the emerging threat of endocrine disrupting chemicals. The following regulatory and non-regulatory management measures are still necessary to address a diversity of point and non-point pollution sources:

Point sources

- Reduce point source pollution discharge by:
  - a) Increasing inspections of discharge treatment facilities, collection infrastructure, and disposal sites.
  - b) Providing incentives for upgrading all types of discharge treatment systems.

c) Develop standards and treatment facilities that minimize the threat of endocrine disrupting chemicals on aquatic life.

- Adopt or modify rules or statutes to prohibit ocean wastewater discharges.
- Prevent additional shellfish and swimming closures through targeted water quality restoration and 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 strategies throughout the river basins to reduce non-point pollution and minimize cumulative losses of fish habitats through voluntary actions, assistance, and incentives, including:
    a) Improved methods to reduce pollution from construction sites, agriculture, and forestry.
    b) Increased on-site infiltration of stormwater.
    c) Documentation and monitoring of small but cumulative impacts to fish habitats from approved, un-mitigated activities.
    d) Encouraging and providing incentives for low impact development.
    e) Increased inspections of onsite wastewater treatment facilities.
    f) Increased water re-use and recycling.
- Improve strategies throughout the river basins to reduce non-point pollution and minimize cumulative losses of fish habitats through rule making, including:
    a) Increased use of effective vegetated buffers,
    b) Implementing and assessing coastal stormwater rules and modify if justified.
    c) Modified water quality standards that are adequate to support SAV 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, where necessary.
    c) Use improved siting criteria to protect fish habitat.

A management need identified by the CHPP Steering Committee was included as an additional recommendation under the goal of protecting habitat from water quality impacts. The new recommendation was to:

- Maintain adequate water quality conducive to the support of present and future aquaculture.

9.3 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.
- Apply for grant funding collected through sale and renewal of a Coastal Recreational Fishing License for applicable research on fish habitat
- Utilize existing environmental education and outreach programs
- Incorporate CHPP recommendations into North Carolina Clean Water Management Trust Fund priorities.
- 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.
- Seek regional funds available through participation in National Fish Habitat Initiative partnerships and alliances.
- Apply for grant funding through other environmental and habitat restoration grants.
- 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.
- Establish a Coastal Fish Habitat Protection Fund supported by impact fees on development in the vicinity of coastal fish habitat

Table 9.1. Recommendations for the long-term enhancement of coastal fisheries associated with coastal habitats. Note: * signifies new recommendation.

Reference No.	Recommended actions to protect, enhance, restore, and manage coastal fish habitats	Responsible commission or agency [Lead group(s) in bold]	Progress
GOAL 1. IMPROVE EFFECTIVENESS OF EXISTING RULES AND PROGRAMS PROTECTING COASTAL FISH HABITATS			
1.1	Continue to enhance enforcement of, and compliance with, Coastal Resources Commission (CRC), Environmental Management Commission (EMC), Marine Fisheries Commission (MFC), and Wildlife Resource Commission (WRC) rules and permit conditions.	**CRC/DCM**, **EMC/DWQ**, **MFC/DMF**, CHS, SCC, WRC, DFR, DLR, S&WCC	☑
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	☑
1.3	Enhance and expand educational outreach on the value of fish habitat, threats from land-use and human activities, climate change and reasons for management measures.	**DENR**, WRC	☑
1.4	Coordinate rulemaking and data collection for enforcement among regulatory commissions and agencies.	EMC, CRC, MFC, DENR, WRC, SWCC, DFR	☑
1.5*	Develop and enhance assessment methodology and management tools for addressing cumulative impacts.	**CRC/DCM**, **EMC/DWQ**, **MFC/DMF**, CHS, SCC, WRC, DFR, DLR, S&WCC, APNEP, DENR	☑
1.6*	Enhance control of invasive species with existing programs.	DENR, WRC	☑
GOAL 2. IDENTIFY, DESIGNATE, AND PROTECT STRATEGIC HABITAT AREAS			
2.1	Support Strategic Habitat Area assessments by: a) coordinating, completing, and maintaining baseline habitat mapping (including seagrass, shell bottom, shoreline, and other bottom types) using the most appropriate technology b) selective monitoring of the status of those habitats c) assessing fish-habitat linkages and effects of land use and human activities on those habitats.	**DMF**, DCM, DWQ, DENR, WRC	☑

Reference No.	Recommended actions to protect, enhance, restore, and manage coastal fish habitats	Responsible commission or agency [Lead group(s) in bold]	Progress
2.2	Identify, designate, and protect Strategic Habitat Areas .	**DENR**, CRC/DCM, EMC/DWQ, MFC/DMF, WRC	☑
GOAL 3. ENHANCE HABITAT AND PROTECT IT FROM PHYSICAL IMPACTS			
3.1	Expand habitat restoration in accordance with restoration plan goals, including: a) creation of subtidal oyster reef no-take sanctuaries b) re-establishment of riparian wetlands and stream hydrology c)* restoration of SAV habitat and shallow soft bottom nurseries d)* develop compensatory mitigation process to restore lost fish habitat function	**DMF**, EEP, CRC, WRC?	a) ☑ b) ☑ c) ☑ d) ☑
3.2	Sustain healthy barrier island systems by maintaining and enhancing ecologically sound policies for ocean and inlet shorelines and implement a comprehensive beach and inlet management plan that provides ecologically based guidelines to protect fish habitat and address socio-economic concerns.	**CRC/DCM,** EMC/DWQ, MFC/DMF, DWR, WRC, DENR	☑
3.3	Protect habitat from fishing gear effects through improved enforcement, establishment of protective buffers around habitats, modified rules and further restriction of fishing gear where necessary.	**MFC/DMF**	☑
3.4	Protect estuarine and public trust shorelines and shallow water habitats by revising shoreline stabilization rules to include consideration of erosion rates and prefer alternatives to vertical shoreline stabilization that maintain shallow nursery habitats.	**CRC/DCM, DWQ/EMC**	☑
3.5	Protect and enhance habitat for migratory fishes by: a) incorporating the water quality and quantity needs of fish in water use planning and rule making. b) eliminating or modifying obstructions to fish movements, such as dams and culverts, to improve fish passage.	**DENR**, EMC, DWQ, DWR, WRC, DMF	a) ☑ b) ☑
3.6*	Ensure that energy development and infrastructure is designed and sited in a manner that minimizes negative impacts to fish habitat, avoids new obstructions to fish passage, and where possible provides positive impacts.	CRC/DCM, EMC/DWQ	☑
3.7*	Protect important fish habitat functions from damage associated with activities such as dredging and filling.	CRC/DCM, EMC/DWQ	☑

Reference No.	Recommended actions to protect, enhance, restore, and manage coastal fish habitats	Responsible commission or agency [Lead group(s) in bold]	Progress
3.8*	Develop coordinated policies including management adaptations and guidelines to increase resiliency of fish habitat to climate change and sea level rise.	DENR, WRC	☐
GOAL 4. ENHANCE AND PROTECT WATER QUALITY			
4.1	Reduce point source pollution discharges by a) increasing inspections of wastewater treatment facilities, collection infrastructure, and disposal sites, b) providing incentives for upgrading all types of discharge treatment systems, and c)* developing standards and treatment methods that minimize the threat of endocrine disrupting chemicals on aquatic life.	**EMC/** DWQ, CPH/DEH	a) ☑ b) ☑ c) ☐
4.2	Adopt or modify rules or statutes to prohibit ocean wastewater discharges.	**EMC**	☐
4.3	Prevent additional shellfish closures and swimming advisories through targeted water quality restoration and 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, CPH/DEH, CRC/ DCM	☑
4.4	Enhance coordination with, and financial/technical support for, local government actions to better manage stormwater and wastewater.	**DENR**, DWQ, DCM, DEH	☑
4.5	Improve strategies throughout the river basins to reduce non-point pollution and minimize cumulative losses of fish habitat through voluntary actions, assistance, and incentives, including a) improved methods to reduce pollution from construction sites, agriculture, and forestry, b) increased on-site infiltration of stormwater, c) documentation and monitoring of small but cumulative impacts to fish habitats from approved, un-mitigated activities, d) encouraging and providing 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	a) ☑ b) ☑ c) ☑ d) ☑ e) ☑ f) ☑

Reference No.	Recommended actions to protect, enhance, restore, and manage coastal fish habitats	Responsible commission or agency [Lead group(s) in bold]	Progress
4.6	Improve strategies throughout the river basins to reduce non-point pollution and minimize cumulative losses of fish habitat through rule making, including a) increased use of effective vegetated buffers, b)* implement and assess coastal stormwater rules and modify if justified. c)* modify water quality standards to adequately support SAV habitat.	**EMC**, **CRC**, DWQ, DCM, SCC, DLR	a) ☑ b) ☑ c) ☐
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 where necessary c) use improved siting criteria to protect fish habitat.	**General Assembly**, **DENR**, EMC, DWQ, S&WCC, DS&WC, Dept. of Agriculture & Consumer Services	a) ☑ b) ☑ c) ☑
4.7*	Maintain adequate water quality conducive to the support of present and future aquaculture.	**DENR**	☐

LITERATURE CITED

AAAS (American Association for the Advancement of Science). 2001. Worldwide network of no-takes proposed at American Association for the Advancement of Science. AAAS, San Francisco, CA, 2p.

Able, K. W., D.H. Wilber, A. Muzeni-Corino, and and D.G. Clarke. 2009. Spring and summer larval fish assemblages in the surfzone and nearshore off northern New Jersey, USA. Estuaries and Coasts 33: 211-222.

Able, K. W., J.P. Manderson, and A.L. Studholme. 1998. The distribution of shallow water juvenile fishes in an urban estuary: The effects of manmade structures in the lower Hudson River. Estuaries 21(48): 731-744.

Able, K. W. and S.M. Hagan. 2000. Effects of common reed (*Phragmites australis*) invasion on marsh surface macrofauna: response of fishes and decapod crustaceans. Estuaries 23(5): 633-646.

Able, K. W., S.M. Hagan, and S.A. Brown . 2003. Mechanisms of marsh habitat alteration due to *Phragmites*: response of young-of-the-year mummichog (*Fundulus heteroclitus*) to treatment for *Phragmites* removal. Estuaries 26(2B): 484-494.

Adams, S. 1976. The ecology of eelgrass, *Zostera marina* (L.), fish communities. I. Structural analysis. Journal of Experimental Marine Biology and Ecology 22: 269-291.

Adams, S. and J. Angelovic. 1970. Assimilation of detritus and its associated bacteria by three species of estuarine animals . Chesapeake Science 11(4): 249-254.

Adkins, B. E., R.M. Harbo, and N. Bourne. 1983. An evaluation and management considerations of the use of a hydraulic clam harvester on intertidal clam populations in British Columbia. Canadian Manuscript Reports Fisheries Aquatic Science 1716: 38.

Admiraal, W., H. Peletier, and H. Zomer. 1982. Observations and experiments on the population dynamics of epipelic diatoms of an estuarine mudflat. Estuarine Coastal and Shelf Science 14: 471-487.

AFS (American Fisheries Society). 2003. AFS policy statement #4: Sedimentation. http://www.fisheries.org/Public_Affairs/Policy_Statements, 9/30/2003.

Ailstock, S. and D. Shafer. 2006. Protocol for large-scale collection, processing, and storage of seeds of two mesohaline submerged auqatic plant species. U.S. Army Engineer Research and Development Center, Vicksburg, MS, SAV Technical Notes Collection (ERDC/TN SAV-06-3) , 7 pp.p.

Airoldi, L., D. Balata, and M.W. Beck. 2008. The gray zone: relationships between habitat loss and marine diversity and their applications in conservation. Journal of Experimental Marine Biology and Ecology 366: 8-15.

Aksnes, D. L. 2007. Evidence for visual constraints in large marine fish stocks. Limnology and Oceanography 52(1): 198-203.

Albins, M. A. and M.A. Hixon. 2008. Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral reef fishes. Marine Ecology Progress Series 367: 233-238.

Alexander, C. R. and M.H. Robinson. 2004. GIS and field-based analysis of the impacts of recreational docks on the salt marshes of Georgia. Skidaway Institute of Oceanography and Applied Coastal Research Laboratory, Georgia Southern University, Savannah, GA, 40 pp.p.

Alexander, C. R. and M.H. Robinson. 2006. Assessing the impacts of floating docks on bottom character and benthic productivity in coastal Georgia. Skidaway Institute of Oceanography and Applied Coastal Research Laboratory, Georgia Southern University, Savannah, GA, 54 pp.p.

Ambrose, R. and S. Swarbrick. 1989. Comparison of fish assemblages on artificial and natural reefs off the coast of southern California. Bulletin of Marine Science 44(2): 718-733.

Ambrose, W. G. Jr. and E.A. Irlandi. 1992. Height of attachment on seagrass leads to trade-off between growth and survival in the bay scallop *Argopecten irradians*. Marine Ecology Progress Series 90(1): 45-51.

Anders, F. J. and S.P. Leatherman. 1987. Distrubance of beach sediment by off-road vehicles. Environmental Geology and Water Sciences 9(3): 183-189.

Andersen, J. H., L. Schluter, and G. Aertebjerg. 2006. Coastal eutrophication: recent developments on definitions and implications for monitoring strategies. Journal of Plankton Research 28(7): 621-628.

Anderson, G. 1985. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico)--grass shrimp. U.S. Fish and Wildlife Service, Biological Report USFWS/BR-82(11.35) , 377p.

Anderson, W. W. 1958. Larval development, growth, and spawning of striped mullet (*Mugil cephalus*) along the South Atlantic coast of the United States. Fishery Bulletin 144: 501-519 .

Andrews, J. D. 1966. Oyster mortality studies in Virginia. V. Epizootiology of MSX, a protistan pathogen of oysters. Ecology 47 (1): 19-31.

Andrews, J. D. 1980. A review of introductions of exotic oysters and biological planning for new importations. Marine Fisheries Review 42: 1-11.

Andrews, J. D. 1988. Epizootiology of the disease caused by the oyster pathogen, *Perkinsus marinus*, and its effects on the oyster industry. American Fishery Society Special Publication 18: 47-63.

Andrews, J. D. and W.F. Hewatt. 1957. Oyster mortality studies in Virginia II. The fungus disease caused by *Dermocystidium marinum* in oysters in Chesapeake Bay. Bay Ecology Monographs 27: 1-26.

Anguiano-Vega, G., R. Liera-Herrere, E. Rojas, and C. Vazquez-Boucard. 2007. Subchronic organismal toxicity, cytotoxicity, genotoxicity, and feeding response of Pacific oyster (*Crassostrea gigas*, Thunberg 1795) to lindane(y-HCH) exposure under experimental conditions. Environmental Toxicology and Chemistry 26: 2192-2197.

Apple, J. K., E.M. Smith, and T.J. Boyd. 2008. Temperature, salinity, nutrients, and the covariation of bacterial production and chlorophyll *a* in estuarine ecosystems . Journal of Coastal Research 55: 59-75.

Arhonditis, G. B., C.A. Stow, H.W. Paerl, L.M. Valdes-Weaver, L.J. Steinberg, and K.H. Reckhow. 2007. Delineation of the role of nutrient dynamics and hydrologic forcing on phytoplankton patterns along a freshwater-marine continuum. Ecological Monitoring 208: 230-246.

Arnolds, C. L. and C.J. Gibbons. 1996. Impervious surface coverage - the emergence of a key environmental indicator. Journal of the American Planning Association 62: 243-258.

Arve, J. 1960. Preliminary report on attracting fish by oyster shell plantings in Chincoteaque Bay, Maryland. Chesapeake Science 1(1): 58-65.

ASMFC (Atlantic States Marine Fisheries Commission). 1996. Amendment #3 to the interstate fisheries management plan for weakfish. Atlantic States Marine Fisheries Commission, Washington, DC, 66p.

ASMFC (Atlantic States Marine Fisheries Commission). 1997a. Atlantic coastal submerged aquatic vegetation: a review of its ecological role, anthropogenic impacts, state regulation, and value to Atlantic coastal fisheries. unpub. rep., ASMFC Habitat Management Series #1 , 78p.

ASMFC (Atlantic States Marine Fisheries Commission). 1997b. Submerged aquatic vegetation policy. Unpub. rep., ASFMC Habitat Management Series #3 , 9 p.

ASMFC (Atlantic States Marine Fisheries Commission). 2000. Evaluating fishing gear impacts to submerged aquatic vegetation and determining mitigation strategies. ASFMC Habitat Management Series 5 , 38p.

ASMFC (Atlantic States Marine Fisheries Commission). 2002a. Beach nourishment: a review of the biological and physical impacts. ASMFC, Washington DC, ASMFC Habitat Management Series #7 , 174p.

ASMFC (Atlantic States Marine Fisheries Commission). 2002b. How are cooling water intake structures at power plants impacting fish? Habitat Hotline Atlantic 9(1): 8.

ASMFC (Atlantic States Marine Fisheries Commission). 2007. The importance of habitat created by molluscan shellfish to managed species along the Atlantic coast of the United States. Habitat Management Series 8 , 108p.

ASMFC (Atlantic States Marine Fisheries Council). 1998. Amendment 1 to the Interstate Fishery ManagementPlan for Atlantic Sturgeon . Washington DC, 59p.

Audemard, C., R.B. Carnegie, M.J. Bishop, C.H. Peterson, and E.M. Burreson. 2008a. Interacting effects of temperature and salinity on *Bonamia* sp. parasitism in the asian oyster *Crassostrea ariakensis*. Journal of Invertebrate Pathology 98(3): 344-350.

Audemard, C., R.B. Carnegie, N.A. Stokes, M.J. Bishop, C.H. Peterson, and E.M. Burreson. 2008b. Effects of salinity on *Bonamia* sp. survival in the asian oyster *Crassostrea ariakensis*. Journal of Shellfish Research 27(3): 535-540.

Auld, A. H. and J. R. Schubel. 1978. Effects of suspended sediment on fish eggs and larvae: A laboratory assessment. Estuarine and Coastal Marine Science 6(2): 153-164.

Auster, P. J. and R.W. Langton. 1999. The effects of fishing on fish habitat. p. 150-187 *in* L. Benaka (ed.). Fish habitat: essential fish habitat and rehabilitation. American Fisheries Society, Bethesda, MD , Symposium 22 , 459 p.

Ayaki, T., Y. Kawauchino, C. Nishimura, H.Ishibashi, and K.Arizono. 2005. Sexual Disruption in the Freshwater Crab (Geothelphusa dehaani). Integrative and Comparative Biology 45(1): 39-42.

Bachelor, N. M., L.M. Paramore, J.A. Buckel, and J.E. Hightower. 2009. Abiotic and biotic factors influence the habitat use of an estuarine fish. Marine Ecology Progress Series 377: 263-277 .

Bahr, L. N. and W.P. Lanier . 1981. The ecology of intertidal oyster reefs of the South Atlantic coast: a community profile. U.S. Fish and Wildlife Service Biological Reports, FWS/OBS-81/15 , 105p.

Bailey, R. M. and H.M. Harrison Jr. 1948. Food habits of the southern channel catfish (*Ictalurus lacustris punctatus*) in Des Moines River, Iowa. Transactions of the American Fisheries Society 75(1): 110-138.

Bain, M. B. 1997. Atlantic and shortnose sturgeon of the Hudson River: a common and divergent life history attributes. Environmental Biology of Fishes 48(1-4): 347-358.

Bair, E. S. 1995. Hydrogeology. p. 285-310 *in* A.D. Ward and W.J. Elliot (eds). Environmental Hydrology. CRC Press, Inc., Boca Raton, FL, 462 p.

Baird, D. 2009. An assessment of the functional variability of selected coastal ecosystems in the context of local environmental changes. ICES - Journal of Marine Science 66: 1520-1527.

Baker, S. M. and R. Mann. 1992. Effects of hypoxia and anoxia on larval settlement, juvenile growth, and juvenile survival of the oyster *Crassostrea virginica*. Biological Bulletin 182(2): 265-269.

Baker, V., R. Savage, C. Reddy, and M. Turner. 2009. Development of a Wetland Monitoring Program for Headwater Wetlands in North Carolina. North Carolina Division of Water Quality, Raleigh, NC, Final Report of EPA Grant CD 974260-01 , 388 p.

Baldigo, B. P., R.J. Sloan, S.B. Smith, N.D. Denslo, V.S. Blazer, and T.S. Gross. 2006. Polychlorinated biphenyls, mercury, and potential endocrine disruption in fish from the Hudson River, New York. Aquatic Sciences 68: 206-228.

Bales, J. D., C.J. Oblinger, and A.H. Sallenger. 2000. Two months of flooding in eastern North Carolina, September-October 1999. U.S. Geological Survey, Raleigh, NC, 47p.

Bales, J. D. and D.J. Newcomb. 1996. North Carolina wetland resources. p. 297-302 *in* R.M. Hirsch (dir). National Water Summary on Wetland Resources. U.S. Geological Survey, Atlanta, GA, USGS Water-Supply Paper 2425 .

Ballance, E. S. 2004. Using Winslow's 1886 NC oyster bed survey and GIS to guide future restoration projects. North Carolina Sea Grant, Fisheries Resource Grant Final Report #03-

EP-03 , 22p.

Ballance, E. S. and D.B. Eggleston. 2008. Oyster dispersal and metapopulation dynamics in Pamlico Sound: Part II, settlement, survival and spawning potential. DMF FRG 06-EP-03, 33p.

Balon, E. K. 1975. Reproductive guilds of fishes: a proposal and definition. Journal of Fisheries Research Board of Canada 32(6): 821-864.

Barans, C. A. and V.J. Henry Jr. 1984. A description of the shelf edge groundfish habitat along the southeastern United States. Northeast Gulf Science 7: 77-96.

Barber, B. J. 1987. Influence of stress on disease susceptibility. p. 82-85 *in* Fisher, W. S. and Figueras (eds.), A. J. Marine Bivalve Pathology. Maryland Sea Grant, College Park, MD.

Barber, R. D., S.A. Kanaley, and S.E. Ford. 1991. Evidence for regular sporulation by *Haplosporidium nelsoni* (MSX) (Ascetospora: Haplosporidiidae) in spat of the American oyster, *Crassostrea virginica*. Journal of Eukaryotic Microbiology 38(4): 305-306.

Barker, J. C. and J.P. Zublena. 1995. Livestock manure nutrient assessment in North Carolina. Proceedings of the 7th International Symposium on Agricultural and Food Processing Wastes, Chicago 18-20 June 1995 : 98-106.

Barnes, K. B., J.M. Morgan III, and M.C. Roberge. 2001. Impervious surfaces and the quality of natural and built environments. Department of Geography and Environmental Planning, Towson University, Baltimore, Md, 28p.

Baron, R. M., L.K.B. Jordan, and R.E. Spieler. 2004. Characterization of the marine fish assemblage associated with the nearshore hardbottom of Broward County, Florida, USA. Estuarine Coastal and Shelf Science 60(3): 431-443.

Barranguet, C., J. Kromkamp, and J. Peene. 1998. Factors controlling primary production and photosynthetic characteristics of intertidal microphytobenthos. Marine Ecology Progress Series 173: 117-126.

Barrett, J. C., G.D. Grossman, and J. Rosenfield. 1992. Turbidity-induced changes in reactive distance of rainbow trout. Transactions of the American Fisheries Society 121: 437-443.

Barrios, A. T. 2004. Use of passive acoustic monitoring to resolve spatial and temporal patterns of spawning activity for red drum, *Sciaenops ocellatus*, in the Neuse River Estuary, North Carolina. North Carolina State University, Raleigh, NC, 97 p.

Barrios-Beckwith, A., G. Beckwith, and P. Rand. 2006. Identification of critical spawning habitat and male courtship vocalization characteristics of red drum, *Sciaenops ocellatus*, in the lower Neuse River Estuary of North Carolina. North Carolina Division of Marine Fisheries, Morehead City, NC, 05-EP-05 , 39p.

Barros F., A. J. Underwood, and M. Lindegarth. 2001. The influence of rocky reefs on structure of benthic macrofauna in nearby soft-sediments. Estuarine, Coastal and Shelf Science 52: 191-199.

Bartol, I. K. and R. Mann. 1999. Small scale patterns of recruitment on a constructed intertidal reef:

the role of spatial refugia. p. 159-170 *in* M. Luckenbach, R. Mann and J. Wesson eds. Oyster reef habitat restoration: a synopsis and synthesis of approaches. Virginia Institute of Marine Science Press, Gloucester Point, VA.

Basta, D. J., M.A. Warren, T.R. Goodspeed, C.M. Blackwell, T.J. Culliton, J.J. McDonough III , M.J. Katz, D.G. Remer, J.P. Tolson, C.J. Klein, S.P. Orando Jr., and D.M. Lott. 1990. Estuaries of the United States, vital statistics of a national resource base. National Ocean Service, NOAA, U.S. Department of Commerce, Rockville, MD, A Special NOAA 20th Anniversary Report , 79p.

Bauer, L. J., M.S. Kendall, and C.F.G. Jeffery. 2008. Incidence of marine debris and its relationship with benthic features in Gray's Reef National Marine Sanctuary, Southeast USA. Marine Pollution Bulletin 56: 402-413.

Beach, D. 2002. Coastal sprawl : the effects of urban design on aquatic ecosystems in the United States. Pew Oceans Commission, Arlington, VA, 32p.

Beal, B. F. 2000. The importance of temporal and spatial replication of field experiments: effects of seagrass cover on the growth and survival of cultured juveniles of the soft-shell clam, *Mya arenaria*, and hard clam, *Mercenaria mercenaria*. Shellfish Research 19(1).

Beal, J. L. 1999. The effects of dock height and alternative construction measures on light irradiance (PAR) and seagrass (*Halodule wrightii* and *Syringdium filiforme*) cover. Florida Department of Environmental Protection, Divisions of Marine Resources, unpub. rep. 10p.

Beal, J. L. and B.S. Schmit. 1998. The effects of dock height and alternative construction measures on light irradiance (PAR) and seagrass (*Halodule wrightii* and *Syringdium filiforme*) cover. Florida Center for Environmental Studies, Ft. Lauderdale, Fl, Abstracts from the Workshop on subtropical and tripical seagrass management ecology: responses to environmental stress , 2p.

Beck, M. W., M. Odaya, J. Bachant, B. Keller, R. Martin, C. Porter, and G. Ramseur. 2000. Identification of priority sites for conservation in the northern Gulf of Mexico: an ecoregional plan. The Nature Conservancy, Arlington, VA.

Beisner, B. E., D.T. Haydon, and K. Cuddington. 2003. Alternative stable states in ecology. Frontiers in Ecology and the Environment 1(7): 376-382.

Bell, S. S., M.O. Hall, S. Soffian, and K. Madley. 2002. Assessing the impact of boat propeller scars on fish and shrimp utilizing seagrass beds. Ecological Application 12(1): 206-217.

Bellinger, E. G. and B.R. Benham. 1978. The levels of metals in dock-yard sediments with particular reference to the contributions from ship-bottom paints. Environmental Pollution 15: 71-81.

Benfield, M. C. and T. J. Minello. 1996. Relative effects of turbidity and light intensity on reactive distance and feeding of an estuarine fish. Environmental Biology of Fishes 46: 211-216.

Benson, A. J. and D. Raikow. 2008. *Dreissena polymorpha*. USGS Nonindigenous Aquatic Species Database, Gainsville, FL, <http://nas.er.usgs.gov/queries/FactSheet.asp?speciesID=5> .

Benton, J. C. 1992. Estimates of total mortality, migration, and length-age composition of Atlantic striped bass, offshore mixed stocks from 1988 to 1992. USFWS, Unpub. rep. 15p.

Beresoff, D. and T. Thorpe. 1997. Gill net selectivity for coastal shark species. NC Sea Grant, FRG 97FEG-10 , 1p.

Bergstrom, P. W., R.F. Murphy, M.D. Naylor, R.C. Davis, and J.T. Reel. 2006. Underwater Grasses in Chesapeake Bay and Mid-Atlantic Coastal Waters, Guide to Identifyinf Submerged Aquatic Vegetation. Maryland Sea Grant College, 76p.

Berman, M., H. Berquist, J. Herman, and K. Nunez. 2007. The Stability of Living Shorelines - An Evaluation. Center for Coastal Resources Management, Virginia Institute of Marine Science, Glouster Point, VA, Final report to NOAA/NOAA Chesapeake Bay Program Office , 36p.

Biber, P. D., C.L. Gallegos, and W.J. Kenworthy. 2008. Calibration of a bio-optical model in the North River, North Carolina (Albemarle-Pamlico Sound): a tool to evaluate water quality impacts on seagrass. Estuaries and Coasts: J CERF 31: 177-191.

Bilkovic, D. M. and M.M. Roggero. 2008. Effects of coastal development on nearshore estuarine nekton communities. Marine Ecology Progress Series 358: 27-39.

Bilkovic, D. M., M. Roggero, C.H. Hershner, and K.H. Havens. 2006. Influence of land use on macrobenthic communities in nearshore estuarine habitats. Estuaries and Coasts 29(6B): 1185-1195.

Bin, O., C. Dumas, B. Poulter, and J. Whitehead. 2007. Measuring the impacts of climate change on North Carolina coastal resources. East Carolina University, Greenville, NC, 101p.

Bishof, D. and S. Kent. 1990. Preliminary report - the effects of propeller-dredging on benthic macrofauna in shallow seagrass beds in the Florida Keys. Fl Department of Environmental Regulation, Unpub. rep. 10p.

Bishop, M. J. and C.H. Peterson. 2005. Constraints to *Crassostrea ariakensis* aquaculture: season and method of culture strongly influence success of grow-out. Journal of Shellfish Research 24(4): 995-1006.

Bishop, M. J. and C.H. Peterson. 2006a. Direct effects of physical stress can be counteracted by the indirect: invertebrate growth on a tidal elevation gradient. Oecologia 147(3): 426-433.

Bishop, M. J. and C.H. Peterson. 2006b. When r-selection may not predict introduced-species proliferation: predation of a nonnative oyster. Ecological Applications 16(2): 718-730.

Bishop, M. J., C.H. Peterson, H.C. Summerson, and D. Gaskill. 2005. Effects of harvesting methods on sustainability of a bay scallop fishery: dredging uproots seagrass and displaces recruit. Fishery bulletin 103(4): 712.

Bishop, M. J., C.H. Peterson, H.C. Summerson, H.S. Lenihan, and J.H. Grabowski. 2006. Deposition and long-shore transport of dredge spoils to nourish beaches: Impacts on benthic infauna of an ebb-tidal delta. Journal of Coastal Research 22(3): 530-546.

Bishop, M. J., S.P. Powers, H.J. Porter, and C.H. Peterson. 2006. Benthic biological effects of seasonal hypoxia in a eutrophic estuary predate rapid coastal development. Estuarine Coastal and Shelf Science 70(3): 415-422.

Blader, S. J. M. and T.G. Blader. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. Journal of Fish Biology 17: 143-162.

Blair, S. M., B.S. Flynn, and S. Markley. 1990. Characteristics and assessment of dredge related mechanical impact to hard-bottom reef areas off northern Dade County, Florida. p. 5-20 *in* Jaap (ed.), W. C. Diving for science. American Academy of Underwater Sciences, Costa Mesa, CA, Proceedings of the American Academy of Underwater Sciences Tenth Annual Scientific Diving Symposium, Oct 4-7 St. Petersburg, Fl .

Blanchet, H., M.V. Hoose, L. McEachron, B. Muller, J. Warren, J. Gill, T. Waldrop, J. Waller, C. Adams, R.B. Ditton, D. Shively, and S. VanderKooy. 2001. The spotted seatrout fishery of the Gulf of Mexico, United States: A regional management plan. Gulf State Marine Fisheries Commission, Ocean Springs, MI, NOAA Publication Number 87 .

Blanton, J. O., F.E. Werner, A. Kapolnai, B.O. Blanton, D. Knott, and E.L. Wenner. 1999. Wind-generated transport of fictitious passive larvae into shallow tidal estuaries. Fisheries Oceanography 8(2): 210-223.

Blazer, V. S., J.H. Lilley, W.B. Schill, Y. Kiryu, C.L. Densmore, V. Panyawachira, and S. Chinabut. 2002. *Aphanomyces invadans* in Atlantic Menhaden along the East Coast of the United States. Journal of Aquatic Animal Health 14: 1-10.

Blazer, V. S., L.R. Iwanowicz, D.D. Iwanowicz, D.R. Smith, JA. Yound, and J.D. Hedrick. 2007. Intersex (testicular oocytes) in smallmouth bass from the Potomac River and selected nearby drainages. Journal of Aquatic Animal Health 19: 242-253.

Blazer, V. S., W.K. Vogelbein, C.L. Densmore, E.B. May, J.H. Lilley, and D.E. Zwerner. 1999. *Aphanomyces* as a cause of ulcerative skin lesions of menhaden from Chesapeake Bay tributaries. Journal of Aquatic Animal Health 11: 340-349.

Blue Atlantic Transmission System. 2003. Proceedings of a workshop on the potential effects of the construction and operation of subsea pipelines on lobster movement and behavior. Unpub. doc., Rhode Island, 152p.

Boehlert, G. W. and J.B. Morgan. 1985. Turbidity enhances feeding abilities of larval pacific herring, *Clupea harengus pallasi*. Hydrobiologia 123: 161-170.

Boehm, P., D. D. Turton, A. A. Raval, D. Caudle, D. French, N. Rabalais, R. Spies, and J. Johnson. 2001. Deepwater Program: Literature Review, Environmental Risks of Chemical Products Used in Gulf of MexicoDeepwater Oil and Gas Operations, Volume I: Technical Report. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA, OCS Study MMS 2001-011 , 326p.

Boehm, P. D., S.D. Page, W.A. Burns, A.E. Bence, and P.J. Mankiewicz. 1998. Resolving the origin of the petrogenic hydrocarbon background in Prince William Sound, Alaska. Environmental Science and Technology 35: 471-479.

Boening, D. W. 2000. Ecological effects, transport, and fate of mercury: a general review. Chemosphere 40: 1335-1351.

Boesch, D. F., R.B. Brinsfield, and R.E. Magnien. 2001. Chesapeake Bay eutrophication. Journal of

Environmental Quality 30: 303-320.

Bohnsack, J. A. 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behaviorial preference? Bulletin of Marine Science 44(2): 631-645.

Bohnsack, J. A. 1993. Marine reserves: they enhance fisheries, reduce conflicts, and protect resources. Oceanus 36(3): 63-71.

Bohnsack, J. A. 1996. Maintenance and recovery of reef fishery productivity. p. 284-313 *in* N.V. Polunin and C.M. Roberts (eds.). Reef fisheries. Chapman and Hall, London.

Bohnsack, J. A., D.E. Harper, D.B. McClellan, and M. Hulsbeck. 1994. Effects of reef size on colonization and assemblage structure of fishes at artificial reefs off Southeastern Florida, USA. Bulletin of Marine Science 55(2-3): 796-823.

Boorman, L. A. 1992. The environmental consequence of climate change on British salt marsh vegetation. Wetlands Ecology and Management 2(1/2): 11-21.

Borawa, J. C., J.H. Kerby, T. Huish, and A.W. Mullis. 1979. Currituck Sound fish populations before and after infestation by Eurasian water-milfoil. Procs. Ann. Conf. SE Assoc. Fish and Wildlife Agencies 32: 520-528.

Borsuk, M. E., C.A. Stow, R.A. Leuttich, H.W. Paerl, and J.L. Pickney. 2001. Modelling oxygen dynamics in an intermittently stratified estuary: estimation of process rates using field data. Estuarine Coastal and Shelf Science 52: 33-49.

Boss, S. K. and C.W. Hoffman. 2000. Sand resources of the North Carolina Outer Banks. University of Arkansas and North Carolina Geological Survey, Final Report prepared for the Outer Banks Task Force and the North Carolina Dept of Transportation . 43p.

Bourn, W. S. 1932. Ecological and physiological studies on certain aquatic angiosperms. Contributions Boyce Thompson Institute 4 : 425-496.

Boustany, R. G. 2003. A pre-vegetated mat technique for the restoration of submerged aquatic vegetation. Ecological Restoration 21(2): 87-94.

Bowman, R. E., C.E. Stillwell, W.L. Michaels, and M.D. Grosslein. 2000 . Food of Northwest Atlantic fishes and tow common species of squid. National Marine Fisheries Service, NOAA, NMFS-NE-155 , 19p.

Bowman, S. W. 2001. American Shad and Striped Bass Spawning migration and Habitat Selection in the Neuse River, North Carolina . Thesis, North Carolina State University, Raleigh, N.C.

Boyer, J. N., R.R. Christian, and D.W. Stanley. 1993. Patterns of phytoplankton in primary production in the Neuse River Estuary, North Carolina, USA. Marine Ecology Progress Series 97: 287-297.

Boyer, J. N., R.R. Christian, and D.W. Stanley. 1993. Patterns of phytoplankton primary productivity in the Neuse River Estuary, NC, USA. Marine Ecology Progress Series 97: 287-297.

Bozek, C. M. and D.M. Burdick. 2005. Impacts of seawalls on saltmarsh plant communities in the

Great Bay Estuary, New Hampshire USA. Wetlands Ecology and Management 13: 553-568.

Bradley, M. P. and M.H. Stolt. 2006. Landscape-level seagrass-sediment relations in a coastal lagoon. Aquatic Botany 84: 121-128.

Breitburg, D. L. 1992. Episodic hypoxia in Chesapeake Bay: interacting effects of recruitment behavior, and physical disturbance. Ecological Monographs 62(4): 525-546.

Breitburg, D. L. 1998. Are three dimensional structure and healthy oyster populations the key to an ecologically interesting and important fish community. *in* M.W. Luckenbach, R. Mann and J. A. Wesson eds. Oyster reef habitat restoration. A synopsis and synthesis of approaches. Virginia Institute of Marine Science Press.

Breitburg, D. L., D.W. Hondorp, L.A. Davias, and R.J. Diaz. 2009. Hypoxia, nitrogen, and fisheries: integrating effects across local and global landscapes. Annual Review of Marine Science (1): 329-349.

Breitburg, D. L., L.D. Coen, M.W. Luckenbach, R. Mann, M. Posey, and J.A. Wesson. 2000 . Oyster reef restoration: convergence of harvest and conservation strategies. Journal of Shellfish Research 19(1): 371-377.

Breitburg, D. L., N. Steinberg, S. DuBeau, C. Cooksey, and E.D. Houde. 1994. Effects of low dissolved oxygen on predation on estuarine fish larvae. Marine Ecology Progress Series 104(3): 235-246.

Breitburg, D. L., T. Loher, C.A. Pacey, and A. Gerstein. 1997. Varying effects of low dissolved oxygen on trophic interactions in an estuarine food web. Ecological Monographs 67(4): 489-507.

Brennessel, B. 2007. The Northern Diamondback Terrapin Habitat, Management and Conservation. Northeast Diamondback Terrapin Working Group, Norton, MA.

Bretsch, K. and D. M. Allen. 2006. Tidal migrations of nekton in salt marsh intertidal creeks. Estuaries and coasts 29(3): 474-486.

Brian, J. V. 2005. Inter-population variability in the reproductive morphology of the shore crab (Carcinus maenas): evidence of endocrine disruption in a marine crustacean? Marine Pollution Bulletin 50: 410-416.

Bricker, S. B., B. Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks, and J. Woerner . 2007. Effects of Nutrient Enrichment in the Nation’s Estuaries: A Decade of Change. NOAA Coastal Ocean Program Decision Analysis Series No. 26. National Centers for Coastal Ocean Service, Silver Spring, MD, 328p.

Brickhill, M. J., S. Y. Lee, and R. M. Connolly. 2005. Fishes associated with artificial reefs: attributing changes to attraction or production using novel approaches. Journal of Fish Biology Supplement B: 53-71.

Brinker, E. L. and M. Crawford. 2009. SAV restoration research in Coinjock Bay. Elizabeth City State University, Elizabeth City, NC, October , 14p.

Brinson, M. M. 1977. Decomposition and nutrient exchange in litter in an alluvial swamp forest. Ecology 58: 601-609.

Brinson, M. M. 1991. Landscape properties of pocosins and associated wetlands. Wetlands 11: 441-465.

Briske, D. D., B.T. Bestelmeyer, T.K. Stringham, and P.L. Shave. 2008. Recommendations for develoment of resilience-based state-and-transition models. Rangeland Ecology and Management 61(July): 359-367.

Broome, S. W., S.M. Rogers Jr., and Ernest D. Seneca. 1992? Shoreline Erosion Control Using Marsh Vegetation and Low-cost Structures. NOAA, 20p.

Brown, B. L., A.J. Butt, S.W. Shelton, D. Meritt, and K.T. Paynter. 2005. Resistance of Dermo in eastern oysters, *Crassostrea virginica* (Gmelin), of North Carolina but not Chesapeake Bay heritage. Aquaculture Research 36(14): 1391-1399.

Brown, C. A. 2002. The transport of fish larvae to estuarine nursery areas: a modeling study. Dissertation Abstracts International Part B: Science and Engineering 62(7): 3099.

Brown, K. M., G.J. George, G.W. Peterson, B.A. Thompson, and J.H. Cowan Jr. 2008. Oyster predation by black drum varies spatially and seasonally. Estuaries and Coasts 31(3): 597-604.

Brown, S. S., G.R. Gaston, C.F. Rakocinski, and R.W. Heard. 2000. Effects of sediment contaminants and environmental gradients on macrobenthic community trophic structure in Gulf of Mexico estuaries. Estuaries 23(3): 411-424.

Brownlee, E. F., A.R. Place, H. Nonogaki, J.E. Adolf, S.G. Sellner, and K.G. Sellner. 2006. *Crassostrea ariakensis* and *C. virginica* responses to ichthyotoxic *Karlodinium veneficum*. Journal of Shellfish Research 25(2): 714.

Brownlee, E. F., S. G. Sellner, K. G. Sellner, H. Nonogaki, J. E. Adolf, T. R. Bachvaroff, and A. R. Place. 2008. Responses of *Crassostrea virginica* (Gmelin) and *C. ariakensis* (Fujita) to bloom-forming phytoplankton including ichthyotoxic *Karlodinium veneficum* (Ballantine). Journal of Shellfish Research 27(3): 581-591.

Bruland, G. L. and C.J. Richardson. 2005a. Hydrologic, edaphic, and vegetative responses to microtopographic reestablishment in a restored wetland. Restoration Ecology 13(3): 515-523.

Bruland, G. L. and C.J. Richardson. 2005b. Spatial variability of soil properties in created, restored, and paired natural wetlands. Soil Science Society of American Journals 69(1): 273.

Bruland, G. L., C.J. Richardson, and S.C. Whalen. 2006. Spatial variability of denitrification potential and related soil properties in created, restored, and paired natural wetlands. Wetlands 26(4): 1042-1056.

Brumbaugh, R. D., M.W. Beck, L.D. Coen, L. Craig, and P. Hicks. 2006. A practitioners' guide to the design and monitoring of shellfish restoration projects: an ecosystem approach. The Nature Conservancy, Arlington, VA, 28p.

Bruton, M. N. 1985. The effect of suspensoids on fish. Hydrobiologia 125: 221-241.

Buchanan, M. and J.T. Finnegan. 2008. 2008 Natural Heritage Program list of the rare plant species of North Carolina. NC Natural Heritage Program, Raleigh, NC.

Buchsbaum, R. 1994. Management of coastal marshes. p. 331 *in* D.M. Kent (ed). Applied Wetlands Science and Technology. CRC Press, Boca Raton, FL.

Buckel, J. A. and D.O. Conover. 1997. Movements, feeding periods, and daily ration of piscivorous young-of-the-year bluefish, *Pomatomus saltatrix,* in the Hudson River estuary. Fishery bulletin 95(4): 665-679.

Buckel, J. A., J.P. Pessutti, J.E. Rosendale, and J.S. Link. 2009. Interactions between bluefish and striped bass: behavior of bluefish under size- and number-impaired conditions and overlap in resource use. Journal of Experimental Marine Biology and Ecology 368: 129-137.

Bulthius, D. A. 1994. Light environment/implications for management. p. 23-27 *in* S. Wyllie-Echeverria, A. M. Olson and M. J. Hershman eds. Seagrass Science and Policy in the Pacific Northwest: Proceedings of a seminar Series. U.S. Environmental Protection Agency, (SMA). EPA 910/r-94-004 , 63 p.

Burbidge, R. G. 1974. Distribution, growth, selective feeding and energy transformations of young-of-the-year blueback herring in the James River, Virginia. Transactions of the American Fisheries Society 103 : 297-311.

Burchell, B. R., R.W. Skaggs, C.R. Lee, S. Broome, G.M. Chescheir, and J. Osborne . 2007. Substrate organic matter to improve nitrate removal in surface-flow constructed wetlands. Journal of Environmental Quality 36(1): 194-207.

Burdick, D. M. and F.T. Short. 1999. The effects of boat docks on eelgrass beds in coastal waters of Massachusetts. Environmental Management 23: 231-240.

Burdick, S. M. and J.E. Hightower. 2006. Distribution of Spawning Activity by Anadromous Fishes in an Atlantic Slope Drainage after Removal of a Low-Head Dam. Transactions of the American Fisheries Society 135: 1290-1300.

Burgos, J. M., G. R. Sedberry, D. M. Wyanski, and P. J. Harris. 2007. Life history of the red grouper (*Epinephelus morio*) off the coasts of North Carolina and South Carolina. Bulletin of Marine Science 21: 45-65.

Burke, J. S. 1991. Influence of abiotic factors and feeding on habitat selection of summer and southern flounder during colonization of nurery grounds. North Carolina State University, Raleigh, NC, 97 p.

Burke, J. S. 1995. Role of feeding and prey distribution of summer and southern flounder in selection of estuarine nursery habitats. Journal of Fish Biology 47(3): 355-366.

Burke, J. S., J.M. Miller, and D.E. Hoss. 1991. Immigration and settlement pattern of *Paralichthys dentatus* and *P. lethostigma* in an estuarine nursery ground, North Carolina, USA. Netherlands Journal Sea Research 27: 393-405.

Burkholder, J., D. Eggleston, H. Glasgow, C. Brownie, R. Reed, G. Melia, C. Kinder, G. Janowitz, R. Corbett, M. Posey, T. Alphin, D. Toms, N. Deamer, and J. Springer . 2004. Comparative impacts of two major hurricane seasons on the Neuse River and western Pamlico Sound. Proceedings of the National Academy of Sciences (USA) 101: 9291-9296.

Burkholder, J. M. 1998. Implications of harmful microalgae and heterotrophic dinoflagellates in management of sustainable marine fisheries. Ecological Applications 8(1 Supplement): 37-62.

Burkholder, J. M., A.S. Gordon, P.D. Moeller, J.M. Law, K.J. Coyne, A.J. Lewitus, J.S. Ramsdell, H.G. Marshall, N.J. Deamer, S.C. Cary, J.W. Kempton, S.L. Morton, and P.A. Rublee. 2005. Demonstration of toxicity to fish and to mammalian cells by *Pfiesteria* species: Comparison of assay methods and multiple strains. Proceedings of the National Academy of Sciences 102: 3471-3476.

Burkholder, J. M., B. Libra, P. Weyer, S. Heathcote, D. Kolpin, P.S. Thorne, and M. Wichman . 2007a. Impacts of waste from concentrated animal feeding operations on water quality. Environmental Health Perspectives 115: 308-312.

Burkholder, J. M., D.A. Dickey, C. Kinder, R.E. Reed, M.A. Mallin, G. Melia, M.R. McIver, L.B. Cahoon, C. Brownie, N. Deamer, J. Springer, H. Glasgow, D. Toms, and J. Smith . 2006. Comprehensive trend analysis of nutrients and related variables in a large eutrophic estuary: A decadal study of anthropogenic and climatic influences. Limnology and Oceanography 51: 463-487.

Burkholder, J. M., G.M. Hallegraeff, G. Melia, A. Cohen, H.A. Bowers, D.W. Oldach, M.W. Parrow, M.J. Sullivan, P.V. Zimba, E.H. Allen, and M.A. Mallin . 2007b. Phytoplankton and bacterial assemblages in ballast water of U.S. military ships as a function of port of origin, voyage time and ocean exchange practices. Harmful Algae 6: 486-518.

Burkholder, J. M. and H.B. Glasgow Jr. 1997. *Pfiesteria piscicada* and other *Pfiesteria*-like dinoflagellates: behavior, impacts, and environmental controls. Limnology and oceanography 42: 1052-1075.

Burkholder, J. M., H.B. Glasgow Jr., and C.W. Hobbs. 1995. Distribution and environmental conditions for fish kills linked to a toxic ambush predator dinoflagellate. Marine Ecology Progress Series 124: 43-61.

Burkholder, J. M., H.B. Glasgow Jr., and J.E. Cooke. 1994. Comparative effects of water-column nitrate enrichment on eelgrass *Zostera marina*, shoalgrass *Halodule wrightii*, and widgeongrass *Ruppia maritima*. Marine Ecology Progress Series 105: 121-138.

Burkholder, J. M., K.M. Mason, and H.B. Glasgow Jr. 1992b. Water-column nitrate enrichment promotes decline of eelgrass *Zostera marina* : Evidence from seasonal mesocosm experiments. Marine Ecology Progress Series 81(2): 163-178.

Burkholder, J. M., M.A. Mallin, and Jr. H.B. Glasgow. 1999. Fish kills, bottom-water hypoxia, and the toxic *Pfiesteria* complex in the Neuse River and Estuary. Marine Ecology Progress Series 179: 301-310.

Burkholder, J. M., M.A. Mallin, H.B. Glasgow Jr. , L.M. Larsen, M.R. McIver, G.C. Shank, N.

Deamer-Melia, D.S. Briley, J. Springer, B.W. Touchette, and E.K. Hannon. 1997. Impacts to a coastal river and estuary from rupture of a swine waste holding lagoon. Journal of Environmental Quality 26: 1451-1466.

Burkholder, J. M., P.M. Glibert, and H.M. Skelton . 2008. Mixotrophy, a major mode of nutrition for harmful algal species in eutrophic waters. Harmful Algae 8: 77-93.

Burrell, V. G. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic) -- American oyster. US Fish and Wildlife Service, Biological Report 82(11.57) , 17p.

Burreson, E. M. 1997. Molecular evidence for an exotic pathogen: Pacific origin of *Haplosporidium nelsoni* (MSX), a pathogen of Atlantic oysters. p. 62 *in* Pascoe (ed.), M. 10th International Congress of Protozoology. University of Sydney, Sydney, Australia.

Burreson, E. M. and L. M. Ragone Calvo. 1996. Epizootiology of *Perkinsus marinus* disease in Chesapeake Bay, with emphasis on data since 1985. Journal of Shellfish Research 15: 17-34.

Burton, M. L., K. J. Brennan, R. C. Munoz, and R. O. Parker. 2005. Preliminary evidence of increased spawning aggregations of mutton snapper (*Lutjanus analis*) at Riley's Hump two years after establishment of the Tortugas South Ecological Reserve. Fishery Bulletin 103(2): 404-410.

Butler, P. A. 1971. Influence of pesticides on marina ecosystems. Proceedings of the Royal Society of London 177(1048): 321-329.

Buzzelli, C. P., Jr. R.A. Luettich, H.W. Paerl, J. Fear, J. Fleming, L. Twomey, E. Cleseri, M.J. Alperin, and C.S. Martens. 2001. Neuse River Estuary modeling and monitoring project phase 2: monitoring of hydrography and water quality, circulation, phytoplankton physiology, and sediment-water coupling. Water Resources Research Institute.

Buzzelli, C. P., R.A. Luettich Jr., S.P. Powers, C.H. Peterson, J.E. McNinch, J.L. Pinckney, and H.W. Paerl. 2002. Estimating the spatial extent of bottom water hypoxia and habitat degradation in a shallow estuary. Marine ecology progress series 230: 103-112.

Byrne, D. M. 1995. The effect of bulkheads on estuarine fauna: a comparison of littoral fish and macroinvertebrate assemblages at bulkheaded and non-bulkheaded shorelines in a Barnegat Bay Lagoon. Second Annual Marine Estuarine Shallow Water Science and Management Conference : 53-56.

Byrne O Cleirigh Ltd - Ecological Consultancy Services Ltd (EcoServe) - School of Ocean and and Earth Sciences - University of Southampton. 2000. Assessment of Impact of Offshore Wind Energy Structures on the Marine Environment. The Marine Institute, 42p.

Büttger, H., H. Asmus, R. Asmus, C. Buschbaum, S. Dittmann, and G. Nehls. 2008. Community dynamics of intertidal soft-bottom mussel beds over two decades. Netherlands Journal of Sea Research 27: 23-26.

Cahoon, L. B. and S. H. Ensign. 2004. Spatial and temporal variability in excessive soil phosphorus levels in eastern North Carolina. Nutrient Cycling in Agroecosystems 69: 111-125.

Cahoon, L. B., J.C. Hales, E.S. Carey, S. Loucaides, K.R. Rowland, and J.E. Nearhoof. 2006. Shellfish closures in southwest Brunswick County, North Carolina: Septic tanks vs. storm-water runoff as fecal coliform sources. Journal of Coastal Research 22: 319-327.

Cahoon, L. B. and J.E. Cooke. 1992. Benthic microalgal production in Onslow Bay, North Carolina, USA. Marine Ecology Progress Series 84: 185-196.

Cahoon, L. B., J.E. Nearhoof, and C.L. Tilton. 1999. Sediment grain size effect on benthic microalgal biomass in shallow aquatic ecosystems. Estuaries 22(3B): 735-741.

Cahoon, L. B., M.A. Mallin, F.M. Bingham, S.A. Kissling, and J.E. Nearhoof. 2001. Monitoring the Coastal Ocean: Responses to Hurricane Floyd. p. 247-253 *in* Maiolo, J. R., J.C. Whitehead, M. McGee, L. King, J. Johnson, and H. Stone (eds.). Facing Our Future: Hurricane Floyd and Recovery in the Coastal Plain. Coastal Carolina Press, Wilmington, NC.

Cahoon, L., D.G. Lindquist, and I.E. Clavijo. 1990. "Live bottoms" in the continental shelf ecosystem: A misconception?. Diving for science. Proceedings of the American Academy of Underwater Sciences Tenth Annual Scientific Diving Symposium, Oct 4-7 St. Petersburg, Fl : 39-47.

Calabrese, A. 1972. How some pollutants affect embryos and larvae of the American oyster and the hard shell clam. Marine Fisheries Review 34: 66-77.

Calabrese, A. and H.C. Davis. 1966. The pH tolerance of embryos and larvae of *Mercenaria mercenaria* and *Crassostrea virginica*. Biology Bulletin 131: 427-436.

Canesi, L., C. Borghi, C. Ciacci, R. Fabbri, L.C. Lorusso, L. Vergani, A. Marcomini, and G. Poiana. 2008. Short-term effects of environmentally relevant concentrations of EDC mixtures on *Mytilus galloprovincialis* digestive gland. Aquatic Toxicology 87: 272-279.

Carlton, J. T. 2001. Introduced Species in U.S. Coastal Waters: Environmental Impacts and Management Priorities. Pew Oceans Commission, Arlington, VA, 28p.

Carlton, J. T. and R. Mann. 1996. Transfers and world wide distributions. p. 691-706 *in* Kennedy, V. S., R. I. E. Newell, and A.F. Eble (eds.) . The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant College, University of Maryland, College Park, Maryland.

Carnegie, R. B., N.A. Stokes, C. Audemard, M. J. Bishop, A. E. Wilbur, T. D. Alphin, M. H. Posey, C. H. Peterson, and E. M. Burreson. 2008. Strong seasonality of *Bonamia* sp. infection and induced *Crassostrea ariakensis* mortality in Bogue and Masonboro Sounds, North Carolina, USA. Journal of Invertebrate Pathology 98(3): 335-343.

Carr, M. H. and M. A. Hixon. 1997. Artificial reefs: the importance of comparisons with natural reefs. Fisheries 22(4): 28-33.

Carr, W. and C. Adams. 1973. Food habits of juvenile marine fishes occupying seagrass beds in the estuarine zone near Crystal River, Florida. Transactions of the American Fisheries Society 102(3): 511-540.

Carraway, R. J. and L.J. Priddy. 1983. Mapping of submerged grass beds in Core and Bogue Sounds, Carteret County, North Carolina, by conventional aerial photography. CEIP Report No. 20 , 88p.

Carriker, M. R. and P.M. Gaffney. 1996. A catalogue of selected species of living oysters (Ostreacea) of the world. p. 1-18 *in* Kennedy, V. S., R. I. E. Newell, and A. F. Eble (eds.). The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant College, University of Maryland, College Park, Maryland.

Casazza, T. L. and S.W. Ross. 2008. Fishes associated with pelagic Sargassum and open water lacking *Sargassum* in the Gulf Stream off North Carolina. Fisheries Bulletin 106: 348-363.

Castagna, M. and P. Chanley. 1973. Salinity tolerance of some marine bivalves from inshore and estuarine environments in Virginia waters on the western Mid-Atlantic coast. Malacologia 12: 47-96.

Casteel, S. N., B. Cleveland, D. Osmond, and C. Hudak-Wise. 2007. North Carolina trends in animal waste concentrations. ASA-CSSA-SSSA International Conference .

CBF (Chesapeake Bay Foundation). 2007. Living shorelines for the Chesapeake Bay watershed. Annapolis, MD, 10p.

CBP (Chesapeake Bay Program). 1995. Guidance for protecting submerged aquatic vegetation in Chesapeake Bay from physical disruption. US Environmental Protection Agency, Annapolis, Md, EPA 903-R-95-013 , 15p.

CENR (Committee on Environment and Natural Resources). 2003. An Assessment of Coastal Hypoxia and Eutrophication in U.S. Waters. National Science and Technology Council Committee on Environment and Natural Resources, Washington, D.C., 76p.

Cerco, C. F. and M.R. Noel. 2007. Can oyster restoration reverse cultural eutrophication in Chesapeake Bay? Estuaries and Coasts 30(2): 331-343.

Chambers, D. B. and T.J. Leiker. 2006. A reconnaissance for emerging contaminants in the South Branch Potomac River, Cacapon River, and Williams River basins, West Virginia, April-October 2004. US Geological Services, USGS Open file report 2006-1393 .

Chapman, M. G. and F. Bulleri. 2003. Intertidal seawalls - new features of landscape in intertidal environments. Landscape and Urban Planning 62: 159-172.

Chesapeake Bay Commission. 1997. Chesapeake Bay blue crab fishery management plan. Chesapeake Bay Program Office, US EPA, Annapolis, MD, 102p.

Chester, A. J., R.L. Ferguson, and G.W. Thayer. 1983. Environmental gradients and benthic macroinvertebrate distributions in a shallow North Carolina estuary. Bulletin of Marine Science 33(2): 285-295.

Chestnut, A. F. 1955. The distribution of oyster drills in North Carolina. Proceedings of the National Shellfishing Association 46: 134-139.

Chiappone, M., H. Dienes, D. W. Swanson, and S. L. Miller. 2005. Impacts of lost fishing gear on coral reef sessile invertebrats in the Florida Keys National Marine Sanctuary. Biological Conservation 121(2): 221-230.

Chiappone, M., D. W. Swanson, S. L. Miller, and H. Dienes. 2004. Spatial distribution of lost fishing gear on fished and protected offshore reefs in the Florida Keys National Marine Sanctuary. Caribbean Journal of Science 40(3): 312-326.

Chmura, G. L. and N.W. Ross. 1978. Environmental impacts of marinas and their boats. Rhode Island Sea Grant, Narragansett, RI, P675; RIU-T-78-005 .

Cho, H. J. and M.A. Poirrier. 2005. Vegetation habitat based on studies in Lake Pontchartrain, Louisiana. Restoration Ecology 13(4): 623-629.

Choi, K.-S., E.N. Powell, D.H. Lewis, and S.M. Ray. 1994. Instantaneous reproductive effort in female American oysters, *Crassostrea virginica,* measured by a new immuno- precipitation assay. Biological Bulletin 186: 41-61.

Choy, E. J., Q. Jo, J. Moon, C. Kang, and J. Kang. 2007. Time-course uptake and elimination of benzo(a)pyrened and its damage to reproductive outputs of Pacific oyster, *Crassostrea gigas*. Marine Biology 151: 157-165.

Christian, R. R., J.N. Boyer, and D.W. Stanley . 1991. Multiyear distribution patterns of nutrients within the Neuse River Estuary, North Carolina. *Marine Ecology Progress Series* 71: 259-274.

Chu, F. E., P. Soudant, and R.C. Hale. 2003. Relationship between PCB accumulation and reorductive output in conditioned oysters *Crassostrea virginica* fed a contaminated algal diet. Aquatic Toxicology 65(3): 293-307.

Chu, F. L. E., P. Soudant, and R.C. Hale. 2003. Relationship between PCB accumulation and reproductive output in conditioned oysters *Crassostrea virginica* fed a contaminated algal diet. Aquatic Toxicology 65(3): 293-307.

Churchill, J. H., F.E. Werner, R. Luettich, and J.O. Blanton. 1997. Flood tide circulation near Beaufort Inlet, NC: implications for larval recruitment. Estuaries 22(in press).

Churchill, J. H., R.B. Forward, R.A. Luettich, J.J. Hench, W.F. Hettler, L.B. Crowder, and J.O. Blanton. 1999. Circulation and larval fish transport within a tidally dominated estuary. Fisheries Oceanography. 8 (Suppl. 2): 173-189.

Clark, J. 1974. Coastal ecosystems, ecological considerations for management of the coastal zone. The Conservation Foundation, Washington D.C.

Clark, K. L., G.M. Ruiz, and A.H. Hines. 2003. Diel variation in predator abundance, predation risk and prey distribution in shallow-water estuarine habitats. Journal of Experimental Marine Biology and Ecology 287(1): 37-55.

Clark, R. D., J.D. Christensen, M.E. Monaco, P.A. Caldwell, G.A. Matthews, and T.J. Minello. 2004. A habitat-use model to determine essential fish habitat for juvenile brown shrimp (Farfantepenaeus aztecus) in Galveston Bay, Texas. Fisheries Bulletin 102: 264-277.

Clavijo, I. E., D.G. Lindquist, S.K. Bolden, and S.W. Burk. 1989. Diver inventory of a midshelf reef fish community in Onslow Bay, N.C.: preliminary results for 1988 and 1989. p. 59-66 *in* Lang, M. A. and Jaap (eds.), W. C. Diving for Science...1989. American Academy for

Underwater Sciences, Costa Mesa, California.

Clay, C. H. 1995. Design of fishways and other fish facilities. Lewis Publishers, Boca Raton, Florida, 248p.

Cleary, W. J. and T. P. Marden. 1999. A pictorial atlas of North Carolina inlets. NC Sea Grant, Raleigh, NC, UNC-SG-99-04 , 51 p.

Cloern, J. E. 1987. Turbidity as a control on phytoplankton biomass and productivity in estuaries. Continental Shelf Research 7(11-12): 1367-1381.

Cloern, J. E. 2001. Our evolving conceptual model of the coastal eutrophication problem. Marine Ecology Progress Series 210: 223-253.

Coen L., K. Heck, and L. Abele. 1981. Experiments on competition and predation among shrimps of seagrass meadows. Ecology 62 (6): 1484-1493.

Coen, L. D., R.D. Brumbaugh, D. Bushek, R. Grizzle, M.W. Luckenbach, M.H. Posey, S.P. Powers, and S.G. Tolley. 2007. Ecosystem services related to oyster restoration. Marine Ecology Progress Series 341: 303-307.

Coen, L. E., M.W. Luckenbach, and D.L. Breitburg. 1999. The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. p. 438-454 *in* L.R. Benaka (ed.). Fish habitat: Essential fish habitat and rehabilitation. American Fisheries Society, Bethesda, MD, Symposium 22 , 459 p.

Colle, D. E. and J.V. Shireman. 1980. Coefficients of condition for largemouth bass, bluegill, and redear sunfish in hydrilla-infested lakes. Transactions of the American Fishery Society 109: 521-531.

Collie, J. S., S.J. Hall, M.J. Kaiser, and I.R. Poiners. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. Journal of Animal Ecology 69: 785-798.

Collier, R. S. and M.C. Odom. 1989. Obstructions to anadromous fish migration. US Fish and Wildlife Service , Raleigh, NC, Project No. 88-12 , 29p.

Connell, B. and T. Murphey. 2004. A preliminary evaluation on the effects of dock shading on density and coverage of shoal grass (Halodule wrightii) in Bogue Sound, North Carolina. North Carolina Division of Marine Fisheries, Morehead City, NC, 12p.

Continental Shelf Associates, I. 2002. Second post-nourishment monitoring survey of nearshore hard bottom habitats south of Fort Pierce Inlet Fort Pierce, Florida. unpub. report, 29p.

Cooper, E. R., T.C. Siewicki, and K. Phillips. 2008. Preliminary risk assessment database and risk ranking of pharmaceuticals in the environment. Science of the Total Environment 398: 26-33.

Cooper, J. E., S.F. Wood, and R.A. Rulifson. 1994. Extent of water lily (*Nuphar lutea*) beds and their use by larval fishes in the Roanoke River, North Carolina. Journal of the Elisha Mitchell Scientific Society 110(2): 84-96.

Cooper, R. A. 1961. Early life history and spawning migration of the alewife, *Alosa pseudoharengus*. M.S. Thesis, University of Rhode Island, 58 p.

Cooper, S. R. and G.S. Brush. 1991. A 2500 year history of anoxia and eutrophication in the Chesapeake Bay. Science 254: 992-1001.

Copeland, B. J. 1967. Environmental characteristics of hypersaline lagoons. Contributions in Marine Science 4: 207-218.

Copeland, B. J., R. Hodson, and S.R. Riggs. 1984. The ecology of the Pamlico River, North Carolina: an estuarine profile. U.S. Fish and Wildlife Service Biological Reports FWS/OBS-82/06 , 83p.

Copeland, B. J., R. Hodson, S.R. Riggs, and J.E. Easley Jr. 1983. The ecology of Albemarle Sound, North Carolina: an estuarine profile. U.S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-83/01 , 68p.

Corbett, D. R., J.P. Walsh, and K. Marciniak. 2009. Temporal and spatial variability of trace metals in sediments of two adjacent tributaries of the Neuse River Estuary, North Carolina, USA. Marine Pollution Bulletin 58(11): 1739-1759.

Corbett, D. R., J.P Walsh, L. Cowart, S.R. Riggs, D.V. Ames, and S.J. Culver. 2008. Shoreline change within the Albemarle-Pamlico estuarine system, North Carolina. East Carolina University, Greenville, NC, 10p.

Corbett, D. R., T. West, L. Clough, and H. Daniels. 2004. Potential impacts of bottom trawling on water column productivity and sediment transport processes. NC SeaGrant, Raleigh, NC, NC SeaGrant Project No. 01-EP-04 , 57p.

Costanza J.K., S.E. Marcinko, A.E. Goewert, and C.E. Mitchell. 2008a. Potential geographic distribution of atmospheric nitrogen deposition from intensive livestock production in North Carolina, USA. Science of the Total Environment 398: 76-86.

Costanza, R., O. Perez-Maqueo, M.L. Martinez, P. Sutton, S.J. Anderson, and K. Mulder. 2008b. The value of coastal wetlands for hurricane protection. Ambio 37(4): 241-248.

Costanza, R., R d'Arge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253-260.

Cotham, W. E. and T.F. Bidleman. 1989. Degradation of malathion, endosulfan, and fenvalerate in seawater and seawater/sediment microcosms. Journal of Agriculture and Food Chemistry 37: 824-828.

Coulliette, A. D. and R.T. Noble. 2008. Impacts of rainfall on the water quality of the Newport River Estuary (Eastern North Carolina, USA). Journal of Water and Health 6(4): 473-482.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Department of Interior Fish and Wildlife Service, Washington, D.C., FWS/OBS-79/31 .

Craft, C. and J. Sacco. 2003. Long-term succession of benthic infauna communities on constructed *Spartina alterniflora* marshes. Marine Ecology-Progress Series 257: 45-58.

Craft, C., P. Megonigal, S. Broome, J. Stevenson, R. Freese, J. Cornell, L. Zheng, and J. Sacco. 2003. The pace of ecosystem development of constructed *Spartina alterniflora* marshes. Ecological Applications 13(5): 1417-1432.

Craft, C., S. Broome, and C. Campbell. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restoration Ecology 10(2): 248-258.

Crain, C. M., B.S. Halpern, M.W. Beck, and C.V. Kappel. 2009. Understanding and managing human threats to the coastal marine environment. The Year in Ecology and Conservation Biology: New York Academy of Science 1162: 39-62.

Crecco, V. A. and M.M. Blake. 1983. Feeding ecology of coexisting larvae of American shad and blueback herring in the Connecticut River. Transactions of the American Fisheries Society 112: 498-507.

Croft, A. L., L.A. Leonard, T.D. Alphin, L.B. Cahoon, and M.H. Posey. 2006. The effects of thin layer sand renourishment on tidal marsh processes: Masonboro Island, North Carolina. Estuaries and Coasts 29(5): 737-750.

Crowe, S. E., P.C. Jutte, R.F. Van Dolah, P.T. Gayes, R.F. Viso, and S. E. Noakes. 2006. An Environmental Monitoring Study of Hard Bottom Reef Areas Near the Charleston Ocean Dredged Material Disposal Site . U.S. Army Corps of Engineers, Charleston, SC, 123p.

Crowell, B. 1998. Estuarine shoreline initiative: memorandum to the Coastal Resources Commission . DCM, Raleigh, NC, 16p.

Crowson, R. A. 1980. Nearshore rock exposures and their relationship to modern shelf sedimentation Onslow Bay, North Carolina. M.S. Thesis, East Carolina University, Greenville, NC, 128 p.

Culbertson, J. B., I. Valiela, M. Pickart, E.E. Peacock, and C.M. Reddy. 2008. Long-term consequences of residual petroleum on salt marsh grass. Journal of Applied Ecology 45: 1284-1292.

Cunningham, P. A., R.J. Curry, R.W. Pratt, S.J. Stichter, K. West, P. P. L. Mercer, S. Sherman, B. Burns, and S. Winslow. 1992. Watershed planning in the Albemarle-Pamlico Estuarine System, Report No. 5 - fishing practices mapping . Report No. 92-05 , 227p.

Curieux-Belfond, O. L., S. Moslemi, M. Mathieu, and G.E. Seralini. 2001. Androgen metabolism in oyster *Crassostrea gigas*: evidence for 17B-HSD activities and characterization of an aromatase-like activity inhibited by pharmacological compounds and a marine pollutant. Journal of Steroid Biochemistry and Molecular Biology 78: 359-366.

Currie, D. R. and G.D. Parry. 1996. Effects of scallop dredging on a soft sediment community: a large-scale experimental study. Marine Ecological Progress Series. 134: 131-150.

Currin, C. A., P.C. Delano, and L.M. Valdes-Weaver. 2008. Utilization of a citizen monitoring protocol to assess the structure and function of natural and stabilized fringing salt marshes in North Carolina. Wetlands Ecology and Management 16: 97-118.

Currin, C. A., S.C. Wainright, K.W. Able, M.P. Weinstein, and C.M. Fuller. 2003. Determination of food web support and trophic position of the mummichog, *Fundulus heteroclitus*, in New Jersey smooth cordgrass (*Spartina alterniflora*), common reed (*Phragmites australis*), and restored salt marshes. ESTUARIES 26(2B): 495-510.

Currin, C. A., S.Y. Newell, and H.W. Paerl. 1995. The role of standing dead *Spartina alterniflora* and benthic microalgae in salt marsh food webs: considerations based on multiple stable isotope analysis. Marine Ecology Progress Series 121: 99-116.

CZR Incorporated. 1999. Final Report for the cadmium and other metals study on and adjacent to PCS phosphate reclamation areas)R-1, R-2, R-3, and the Charles Tract. Wilmington, NC.

Dafner, E. V., M.A. Mallin, J.J. Souza, H.A. Wells, and D.C. Parsons. 2007. Nitrogen and phosphorus species in the coastal and shelf waters of southeastern North Carolina, Mid-Atlantic US coast. Marine Chemistry 103(3-4): 289-303.

Dahl, T. E. 1990. Wetlands - losses in the United States, 1780's to 1980's. U.S. Fish and Wildlife Service, Washington, D.C., Report to Congress , 13p.

Dahl, T. E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. U.S. Fish and Wildlife Service, Washington, D.C.

Dame, R. 2005. Oyster reefs as complex ecological systems. p. 331-343 *in* R. Dame and S. Olenin (eds.). The comparative roles of suspension-feeders in ecosystems. Springer, The Netherlands.

Dame, R., M. ALber, D. Allen, A. Chalmers, R. Gardner, G. Gilman, B. Kjerfve, A. Lewitus, M. Mallin, C. Montague, J. Pinckney, and N. Smith. 2000. Estuaries of the South Atlantic coast of North America: their geographic signatures. Estuaries 23: 793-819.

Dame, R. F. and B.C. Patten. 1981. Analysis of energy flows in an intertidal oyster reef. Marine Ecology Progress Series 5: 115-124.

Dame, R. F., J.D. Spurrier, and T.G. Wolaver . 1989. Carbon, nitrogen, and phosphorus processing by an oyster reef. Marine Ecology Progress Series 54: 249-256.

Damstra, T. 2003. Endocrine disruptors: the need for a refocused vision. Toxicological Sciences 74: 231-232.

Daniel III, C. C. 1978. Land use, land cover, and drainage on the Albemarle-Pamlico Peninsula, eastern North Carolina, 1974. USGS, Washington, DC, Rep. No. 78-134 .

Daniel III, L. B. 1988. Aspects of the biology og juvenile red drum, *Sciaenops ocellatus* and spotted seatrout, *Cynoscion nebulosus* (Pisces: Sciaenidae) in South Carolina. M.S. Thesis, College of Charleston, Charleston, SC, 58 p.

Dann, R. and M. Mulder. 1996. On the short-term and long-term impact of drilling activities in the Dutch sector of the North Sea. ICES Journal of Marine Science 23: 1036-1044.

Dauer, D. M., J.A. Ranasinghe, and S.B. Weisberg. 2000. Relationships between benthic community condition, water quality, sediment quality, nutrient loads, and land use patterns in Chesapeake Bay. Estuaries 23(1): 80-96.

Dauvin, J. C. 1982. Impact of *Amoco Cadiz* oil spill on the muddy fine sand *Abra alba* and *Melina palmate* community from the Bay of Morlaix. Estuary Coast Shelf Science 14: 517-531.

Davies-Colley, R. J. and D.G. Smith. 2001. Turbidity, suspended sediment, and water clarity: a review. Journal of the American Water Resources Association 37(5): 1085-1101.

Davis, G. J. and M.M. Brinson. 1976. Submersed macrophytes of the Pamlico River estuary. Water Resources Institute of North Carolina, Raleigh, NC, Report No. 112 , 202p.

Davis, G. J. and M.M. Brinson. 1983. Trends in submerged macrophyte communities of the Currituck Sound: 1909-1979. Journal of Aquatic Plant Management 21: 83-87.

Davis, G. J. and M.M. Brinson. 1989. Submerged aquatic vegetation of the Currituck Sound and the western Albemarle-Pamlico estuarine study. NC Department of Environment, Health, and Natural Resources, Raleigh, NC, Report .

Davis, G. J. and M.M. Brinson. 1990. A survey of submersed aquatic vegetation of the Currituck Sound and the Western Albemarle-Pamlico estuarine system. DNRCD, Albermarle-Pamlico Estuarine Study Project No. 89-10 , 135p.

Davis, H. C. and H. Hidu. 1969a. Effects of turbidity-producing substances in sea water on egg and larvae of three genera of bivalve mollusks. Veliger 11: 316-323.

Dawes, C. J., D. Hanisak, and W.J. Kenworthy . 1995. Seagrass biodiversity in the Indian River Lagoon. Bulletin of Marine Science 57: 59-66.

Day, J. 1967. The biology of Knysna Estuary, South Africa. p. 397-407 *in* G. H. Lauff (ed.). Estuaries.

Day, J., C. Hall, W. Kemp, and A. Yanez-Arancibia (eds). 1989. Estuarine ecology. John Wiley & Sons, Inc. New York, NY, 558p.

Day, J. W. Jr., T.J. Butler, and W.G. Conner. 1977. Productivity and nutrient export studies in a cypress swamp and lake system in Louisiana. p. 255-269 *in* M. Wiley (ed.). Estuarine Processes. Academic Press, New York, NY, II .

Dayton, P. K., B.J. Mordida, and F. Bacon. 1994. Polar marine communities. American Zoologist 34: 90-99.

DCM (North Carolina Division of Coastal Management). 2006. The North Carolina Estuarine Biological and Physical Processes Work Group's Recommendations for Appropriate Shoreline Stabilization Methods for the Different North Carolina Estuarine Shoreline Types North Carolina Division of Coastal Management . Raleigh, NC, 49p.

DCM (North Carolina Division of Coastal Management). 2009. Developing a Management Strategy for North Carolina's Coastal Ocean: report of the Ocean Policy Steering Committee. North Carolina Department of Environment and Natural Resources, Raleigh, NC, 116p.

De La Cruz, A. A. 1982. Effects of oil on phytoplankton metabolism in natural and experimental estuarine ponds. Marine Environmental Research 7: 257-263.

DeAlteris, J., L. Skrobe, and C. Lipsky. 1999. The significance of seabed disturbance by mobile fishing gear relative to natural processes: A case study in Narragansett Bay, Rhode Island. American Fisheries Symposium 22: 14.

DeAngelis, D. L., P.J. Mulholland, A.V. Palumbo, A.D. Steinman, M.A. Huston, and J.W. Elwood. 1989. Nutrient dynamics and food-web stability. Annual Review of Ecology and Systematics 20: 71-95.

Deaton, A., S. Chappell, and K. West. 2006. Process for identification of Strategic Habitat Areas in coastal North Carolina. North Carolina Division of Marine Fisheries, Morehead City, NC, 54p.

Deegan, L. A., J.E. Hughes, and R.A. Rountree. 2000. Salt marsh ecosystem support of marine transient species. p. 333-365 *in* Weinstein, M. P. and D.A. Kreeger. Concepts and controversies in tidal marsh ecology. Kluwer Academic Publishers, The Netherlands, 875 p.

Defeo, O., A. McLachlan, D.S. Schoeman, T.A. Schlacher, J. Dugan, A. Jones, M. Lastra, and F. Scapini. 2009. Threats to sandy beach ecosystems: a review. Estuarine, Coastal and Shelf Science 81: 1-12.

Defeo, P. K., D.S. Schoeman, J. D. T.A. Schlacher, A. Jones, M. Lastra, and F. Scapini. 2009. Threats to sand beach ecosystem: A review. Estuarine, Coastal and Shelf Science 89(1-2): 1-12.

DeFur, P. L. and L. Foersom. 2000. Toxic chemicals: can what we don't know harm us? Environmental Research Section A 82: 113-133.

DEHNR (NC Dept. of Environment Health and Natural Resources). 1990. North Carolina coastal marinas: water quality assessment. DEHNR, Raleigh, NC, 90-01 , 69p.

DEHNR (NC Dept. of Environment Health and Natural Resources). 1995a. North Carolina coastal nonpoint pollution control program. Volume VI: hydromodification. DEHNR, Raleigh, NC, p.

Dekshenieks, M. M., E.E. Hofmann, and E.N. Powell. 1993. Environmental effects on the growth and development of eastern oyster, Crassostrea virginica (Gmelin, 1791), larvae: a modeling study. Journal of Shellfish Research 12(2): 241-254.

Dekshenieks, M. M., E.E. Hofmann, J.M. Klinck, and E.N. Powell. 2000. Quantifying the effects of environmental change on an oyster population: a modeling study. Estuaries 23(5): 593-610.

DeLorenzo, M. E., G.I. Scott, and P.E. Ross. 2001. Toxicity of pesticides to aquatic microorganisms: a review. Environmental Toxicology and Chemistry 20: 84-98.

DEM (NC Division of Environmental Management). 1989. North Carolina nonpoint source assessment report. NC Natural Resources and Community Development, Raleigh, NC, Report No. 89-02 .

DEM (NC Division of Environmental Management). 1994. An examination of fecal coliform bacteria levels in the South River, Carteret County, NC. NC DEHNR, DEM, Raleigh, NC, 71p.

Dennison, W. C., R.J. Orth, K.A. Moore, J.C. Stevenson, V. Carter, S. Kollar, P.W. Bergstrom, and R.

Batiuk. 1993. Assessing water quality with submerged aquatic vegetation. Bioscience 43: 86-94.

Dennison, W. C. and R.S. Alberte. 1986. Photoadaptation and growth of *Zostera marina* L. (eelgrass) along a depth gradient. Journal of Experimental Marine Biology and Ecology 98: 265-282.

DENR (NC Department of Environment and Natural Resources). 2000c. Log Salvage Policy Development Team. Log Salvage Final Report . DENR, Raleigh, NC.

DENR (North Carolina Department of Environmental and Natural Resources). 2008. Gill net operation disturbance in Primary Nursery Areas, Issue Paper. North Carolina Division of Marine Fisheries, Morehead City, NC.

Desbonnet, A., P. Pogue, D. Reis, J. Boyd, J. Willis, and M. Imperial. 1994. Vegetated buffers in the coastal zone - a summary review and bibliography. University of Rhode Island Graduate School of Oceanography, Narragansett, RI, Coastal Resources Center Technical Report No. 2064 , 72p.

Desmond, J. S., D.H. Deutschman, and J.B. Zedler. 2002. Spatial and temporal variation in estuarine fish and invertebrate assemblages: analysis of an 11-year data set. Estuaries 25(4A): 552-569.

Deubler, E. F. Jr. and G.S. Posner. 1963. Response of postlarval flounders to water of low oxygen concentration. Copeia : 312-317.

Devick, W. S. 1991. Patterns of introductions of aquatic organisms to Hawaiian freshwater habitats. American Malacological Bulletin. New directions in research, management and conservation of Hawaiian freshwater stream ecosystem. Proceedings of Freshwater Stream Biology and Fisheries Management Symposium Special Edition No. 2: 7-39.

Di Giulio, R. T. and E.A. Ryan. 1987. Mercury in soils, sediments, and clams from a North Carolina peatland. Water, Air, and Soil Pollution 33: 205-219.

Diaz, R. J. 2001. Overview of hypoxia around the world. Journal of Environmental Quality 30(2): 275-281.

Diaz, R. J. and R. Rosenberg. 1995. Marine benthic hypoxia: a review of its ecological effects and the behavioral response of benthic macrofauna. Oceanography and Marine Biology Annual Review 33: 245-303.

Diaz, R. J. and R. Rosenberg. 2008. Spreading dead zones and consequences for marine ecosystems. Science 321(5891): 926-929.

Dickson, A. W. 1958. Some ecological observations in Currituck Sound. North Carolina Wildlife Resources Commission, Raleigh, NC, Mimeo. Report , 11p.

DiDonato, G. T., J.R. Stewart, D.M. Sanger, B.J. Robinson, B.C. Thompson, and R. F. V. D. A.F. Holland. 2009. Effects of changing land use on the microbial water quality of tidal creeks. Marine Pollution Bulletin 58: 97-106.

Diederich, S., G. Nehls, J.E.E. van Beusekom, and K. Reise. 2005. Introduced Pacific oysters

(*Crassostrea gigas*) in the northern Wadden Sea: invasion accelerated by warm summers? Helgoland Marine Research 59: 97-106.

Dillon, C. R. 1971. A comparative study of the primary productivity of estuarine phytoplankton and macrobenthic plants. Ph.D. Dissertation, University of North Carolina - Chapel Hill, Chapel Hill, NC, 112 p.

DMF (North Carolina Division of Marine Fisheries). 1988. North Carolina artificial reef master plan. DMF, Morehead City, NC, 57 p.

DMF (North Carolina Division of Marine Fisheries). 1990. Justification for submerged aquatic vegetation critical habitat designation. DMF, Unpub. rep. 15p.

DMF (North Carolina Division of Marine Fisheries). 1995. North Carolina artificial reef guide. DMF, Morehead City, NC, 75 p.

DMF (North Carolina Division of Marine Fisheries). 1998. North Carolina artificial reef monitoring and evaluation. DMF, Morehead City, NC, Annual Performance Report, Grant F-41-7 , 15p.

DMF (North Carolina Division of Marine Fisheries). 1999. Shrimp and crab trawling in North Carolina's estuarine waters. DENR, Morehead City, NC, Report to NC Marine Fisheries Commission , 121p.

DMF (North Carolina Division of Marine Fisheries). 2000a. Red drum fishery management plan. DMF, Morehead City, NC, 106p.

DMF (North Carolina Division of Marine Fisheries). 2000b. North Carolina Fishery Management Plan for Albemarle Sound area river herring. NC Division of Marine Fisheries, Morehead City, NC, . 126p.

DMF (North Carolina Division of Marine Fisheries). 2000c. Blue crab fishery management plan. NC DENR, DMF, Morehead City, NC, 171p.

DMF (North Carolina Division of Marine Fisheries). 2001a. North Carolina oyster fishery management plan. N.C. Department of Environment and Natural Resources, Division of Marine Fisheries, 225 p.

DMF (North Carolina Division of Marine Fisheries). 2001b. North Carolina hard clam fishery management plan. N.C. Department of Environment and Natural Resources, Division of Marine Fisheries, 164 p.

DMF (North Carolina Division of Marine Fisheries). 2001c. Assessment of North Carolina commercial finfisheries, 1997-2000. North Carolina Division of Marine Fisheries, Morehead City, NC.

DMF (North Carolina Division of Marine Fisheries). 2001d. Application for renewal of incidental take permit number 1008 under the Endangered Species Act of 1973. DMF, Morehead City, NC.

DMF (North Carolina Division of Marine Fisheries). 2002. North Carolina artificial reef monitoring and evaluation. DMF, Morehead City, Annual Performance Report Grant F-41-11 , 15p.

DMF (North Carolina Division of Marine Fisheries). 2003a. North Carolina Stock Status Report, 2002. DMF, Morehead City, NC.

DMF (North Carolina Division of Marine Fisheries). 2003b. Draft NC striped bass development team issue paper . DMF and NC WRC, Morehead City, NC, Water flow issues , 32 p.

DMF (North Carolina Division of Marine Fisheries). 2003c. Survey of population parameters of marine recreational fishes in North Carolina, annual progress report, Grant F-42, Jan-Dec 2002 . DMF, Morehead City, NC, 49p.

DMF (North Carolina Division of Marine Fisheries). 2004. Blue crab fishery management plan. NC DENR, DMF, Morehead City, NC, 230p.

DMF (North Carolina Division of Marine Fisheries). 2004a. North Carolina blue crab fishery management plan. NC Division of Marine Fisheries, Morehead City, NC, 671p.

DMF (North Carolina Division of Marine Fisheries). 2004b. North Carolina estuarine striped bass fishery management plan for the Albemarle Sound area and Central/Southern area. N.C. Department of Environment and Natural Resources, Division of Marine Fisheries , Morehead City, N.C., 374p.

DMF (North Carolina Division of Marine Fisheries). 2005. North Carolina striped mullet fishery management plan . N.C. Department of Environment and Natural Resources, Division of Marine Fisheries , Morehead City, N.C.

DMF (North Carolina Division of Marine Fisheries). 2006a. North Carolina shrimp fishery management plan. NC Division of Marine Fisheries, Morehead City, NC, 390p.

DMF (North Carolina Division of Marine Fisheries). 2006b. North Carolina striped mullet fishery management plan. NC Division of Marine Fisheries, Morehead City, NC, 207p.

DMF (North Carolina Division of Marine Fisheries). 2007a. North Carolina bay scallop fishery management plan. NC Division of Marine Fisheries, Morehead City, NC, 198p.

DMF (North Carolina Division of Marine Fisheries). 2007b. North Carolina Fishery Management Plan for Albemarle Sound area river herring. NC Division of Marine Fisheries, Morehead City, NC, .

DMF (North Carolina Division of Marine Fisheries). 2007c. North Carolina river herring fishery management plan amendment I. N.C. Department of Environment and Natural Resources, Division of Marine Fisheries , Morehead City, N.C., 311p.

DMF (North Carolina Division of Marine Fisheries). 2008a. North Carolina oyster fishery management plan amendment II. NC Division of Marine Fisheries, Morehead City, NC, 282p.

DMF (North Carolina Division of Marine Fisheries). 2008b. North Carolina hard clam fishery management plan. NC Division of Marine Fisheries, Morehead City, NC, 314p.

DMF (North Carolina Division of Marine Fisheries). 2008c. North Carolina License and Statistics Section Summary Statistics of License and Permit Program, Commercial Trip Ticket Program, Marine Recreational Fishery Statistics Survey, Recreational Commercial Gear Survey, Striped

Bass Creel Survey in the Central and Southern Management Area. DMF, Morehead City, NC, 430p.

DMF (North Carolina Division of Marine Fisheries). 2009. Stock status of important coastal fisheries in North Carolina, 2009. DMF, Morehead City, NC.

Dolan, R., C. Donoghue, and D. Stewart. 2006. Long-term impacts of tidal inlet bypasing on the swash zone filter feeder *Emerita talpoida*, Oregon Inlet and Pea Island, North Carolina. Shore and Beach 74(1): 23-27.

Dolan R., S. Dofflemeyer, C. Donoghue, and J. Jones-Smith. 2004. Analysis of changes in the beach sediment and beach-face organisms associated with sand bypassing from the Oregon Inlet and Pea Island, North Carolina, 1990-2002. Coastal Research Associates Report, 71pp.

Dolan, R. E., J. Fucella, and C. Donoghue. Monitoring and analysis of beach renourishment placed on Pea Island, NC, Alligator River National Wildlife Refuge 1991-1992. USFWS, Alligator River National Wildlife Refuge, Manteo, NC.

Doney, S. C., V.J. Fabry, R.A. Feely, and J.A. Kleypas. 2009. Ocean acidification: the other CO_2 problem. Annual Review of Marine Science 1: 169-192.

Donoghue, C. R. 1999. The influence of swash processes on *Donax variabilis* and *Emerita talpoida*. PhD Dissertation, University of Virginia, Charlottesville, Va, 197 p.

Duarte, C. M. 1991. Seagrass depth limits. Aquatic Botany 40: 363-377.

Duarte, C. M. 1995. Submerged aquatic vegetation in relation to different nutrient regimes. Ophelia 41: 87-112.

Duarte, C. M., J. Borum, T.T. Short, and D.I. Walker. 2005. Seagrass Ecosystems: Their global status and prospects. *in* Polunin NVC (ed). Aquatic ecosystems: trends and global prospects. Cambridge Univ. Press.

Duffy-Anderson, J. T., J.P. Manderson, and D.W. Able. 2003. A characterization of juvenile fish assemblages around man-made sturctures in the New York-New Jersy Harbor Estuary, U.S.A. Bulletin of Marine Science 72(3): 877-889.

Duffy-Anderson, J. T. and K.W. Able. 1999. Effects of municipal piers on the growth of juvenile fishes in the Hudson River Estuary: A study across a pier edge. Marine Biology 133(3): 409-418.

Dugan, J. E., D.M. Hubbard, I. Rodil, D.L. Revell, and S. Schroeter. 2008. Ecological effects of coastal armoring on sandy beaches. Marine Ecology 29: 160-170.

Dunn, A. E., D.R. Dobberfuhl, and D.A. Casamatta. 2008. A survey of algal epiphytes from *Vallisneria americana* Michx. (Hydrcharitaceae) in the Lower St. John's River, Florida. Southeastern Naturalist 7(2): 229-244.

Durako, M. J. 1994. Seagrass die-off in Florida Bay (USA): changes in shoot demographic characteristics and population dynamics in *Thalassia testudinum*. Marine Ecology Progress Series 110: 59-66.

DWQ (North Carolina Division of Water Quality). 1990. North Carolina coastal marinas: water quality assessment. DEHNR, Division of Water Quality, Raleigh, NC, 90-01 , 69p.

DWQ (North Carolina Division of Water Quality). 1997. Chowan River Basinwide Water Quality Management Plan. North Carolina Division of Water Quality - Water Quality Section, Raleigh, NC.

DWQ (North Carolina Division of Water Quality). 1998. Neuse River estuary SAV ground-truthing study. DWQ, Unpub. Rep. 11p.

DWQ (North Carolina Division of Water Quality). 1999. Lumber River Basinwide Water Quality Plan. N.C. Department of Environment and Natural Resources, Raleigh, NC, http://h20.enr.state.nc.us/nep/tarpamlico_river_basin.htmp.

DWQ (North Carolina Division of Water Quality). 2000a. Water quality progress in North Carolina in 1998-1999, 305(b) report. DENR, Division of Water Quality, Raleigh, NC, 34p.

DWQ (North Carolina Division of Water Quality). 2000b. A citizen's guide to water quality management in North Carolina. DENR, Div. Water Quality, Planning Branch, Raleigh, NC, 156p.

DWQ (North Carolina Division of Water Quality). 2001a. White Oak River Basinwide Water Quality Plan. N.C. Department of Environment and Natural Resources, Raleigh, NC, http://h20.enr.state.nc.us/nepp.

DWQ (North Carolina Division of Water Quality). 2001b. Annual report of fish kill events. DENR, Raleigh, NC, 10p.

DWQ (North Carolina Division of Water Quality). 2006. North CarolinaWater Quality Assessment and Impaired Waters List (2006 Integrated 305(b) and 303(d) Report). North Carolina Divion of Water Quality, Raleigh, NC, 94p.

DWQ (North Carolina Division of Water Quality). 2007. Chowan River Basinwide Water Quality Management Plan. North Carolina Division of Water Quality - Water Quality Section, Raleigh, NC.

DWQ (North Carolina Division of Water Quality). 2008a. Draft North Carolina Water Quality Assessment and Impaired Waters List (2008 Integrated 305(b) and 303(d) Report). N.C. Department of Environment and Natural Resources, Division of Water Quality, Raleigh, NC.

DWQ (North Carolina Division of Water Quality). 2008b. Marinas, boatyards, and boat manufacturers: an account of services, activities, stormwater, and process wastewater in the twenty coastal counties in North Carolina. NC DWQ, Raleigh, NC, 35p.

DWQ (North Carolina Division of Water Quality). 2008c. Annual report of fish kill events. North Carolina Division of Water Quality, Raleigh, NC, 26p.

DWQ (North Carolina Division of Water Quality). 2009a. Neuse River Basinwide Water Quality Plan. North Carolina Division of Water Quality, Raleigh, NC.

DWQ (North Carolina Division of Water Quality). 2009b. North Carolina Stormwater Best

Management Practices manual. North Carolina Division of Water Quality, Raleigh, NC, 102p.

DWR (North Carolina Division of Water Resources). 1996. Economic and environmental impacts of N.C. aquatic weed infestations. North Carolina Department of Environment, Health and Natural Resources.

DWR (North Carolina Division of Water Resources). 2001. North Carolina state water supply plan. DENR, Raleigh, NC.

DWR (North Carolina Division of Water Resources). 2009. Central Coastal Plain Capacity Use Area Status Report. N.C. Department of Environment and Natural Resources, Raleigh, N.C., August .

Eby, L., L. Crowder, and C. McClellan. 2000. Neuse River estuary modeling and monitoring project Stage 1: effects of water quality on distribution and composition of the fish community. Water Resources Research Institute, Raleigh, NC, Report N. 325-C , 2p.

ECU (East Carolina University) faculty. 2008. Global warming and coastal North Carolina: A Response in Two Parts from East Carolina University to Senator Marc Basnight's Request Concerning Global Warming. 32p.

Edwards, K. R., J.E. Lepo, and M.A. Lewis. 2003. Toxicity comparison of biosurfactants and synthetic surfactants used in oil spill remediation to two estuarine species. Marine Pollution Bulletin 46: 1309-1316.

EEP (Ecosystem Enhancement Program). 2004. Ecosystem Enhancement Program, 2003-2004 Annual Report. N.C. Department of Environment and Natural Resources, Wetlands Restoration Program, Raleigh, NC, . 31p.

EEP (Ecosystem Enhancement Program). 2005. Ecosystem Enhancement Program, 2004-2005 Annual Report. N.C. Department of Environment and Natural Resources, Wetlands Restoration Program, Raleigh, NC, . 48p.

EEP (Ecosystem Enhancement Program). 2006. Ecosystem Enhancement Program, 2005-2006 Annual Report. N.C. Department of Environment and Natural Resources, Wetlands Restoration Program, Raleigh, NC, . 62p.

EEP (Ecosystem Enhancement Program). 2007. Ecosystem Enhancement Program, 2006-2007 Annual Report. N.C. Department of Environment and Natural Resources, Wetlands Restoration Program, Raleigh, NC, . 94p.

EEP (Ecosystem Enhancement Program). 2009. Ecosystem Enhancement Program, 2008-2009 Annual Report. N.C. Department of Environment and Natural Resources, Wetlands Restoration Program, Raleigh, NC, .

Eggleston, D. B. 1990. Foraging behavior of the blue crab, Callinectes sapidus, on juvenile oysters, Crassostrea virginica: effects of prey density and size. Bulletin of Marine Science 46(1): 62-82.

Eggleston, D. B., L.L. Etherington, and W.E. Elis. 1998. Organism response to habitat patchiness: species and habitat-dependent recruitment of decapod crustaceans. Journal of Experimental

Marine Biology and Ecology 223(1): 111-132.

Ehlers, A., B. Worm, and T.B.H. Reusch. 2008. Importance of genetic diversity in eelgrass Zostera marina for its resilience to global warming. Marine ecology progress series 355: 1-7.

Eleuterius, L. 1987. Seagrass ecology along the coasts of Alabama, Louisiana, and Mississippi. p. 11-24 *in* M.J. Durako, R. C. Phillips and R. R. Lewis III eds. Proceedings of the symposium on subtropical–tropical seagrasses in the Southeastern United States. Florida Marine Resources Publication, St Petersburg, FL, 42 .

Elis, W. E., D.B. Eggleston, L.L. Etherington, C.P. Dahlgren, and M.H. Posey. 1996. Patch size and substrate effects on macrofaunal recruitment. p. 94 *in*: Abstracts from Twenty-fourth Annual Benthic Ecology Meeting.

Ellifrit, N. J., M.S. Uoshinaka, and D.W. Coon. 1972. Some observations of clam distribution at four sites on the Hook Canal, Washington. Proceedings of the National Shellfish Association 63: 7.

ENCRPC (Environment North Carolina Research and Policy Center). 2007. Losing our natural heritage: development and open space loss in North Carolina. Environment North Carolina Research and Policy Center, Raleigh, NC, April , 28p.

Engelhaupt, E. 2007. In a changing climate, cities worsen water quality. Environmental Science and Technology August: 5836.

Ensign, S. E. and M.A. Mallin. 2001. Stream water quality following timber harvest in a Coastal Plain swamp forest. Water Research 35: 3381-3390.

Enwere, R. 2009. Environmental risk management of contamination of marine biota by hydrocarbons specifically those arising following an oil spill. Dissertation, Robert Gordon Universit, Aberden, 283 p.

EPA (U.S. Environmental Protection Agency). 1985. Coastal marinas assessment handbook. EPA, Atlanta, GA, 904/6-85-132 .

EPA (U.S. Environmental Protection Agency). 1992. National water quality inventory: 1990 report to Congress. U.S. Environmental Protection Agency, Washington, DC, EPA-503-9-92-006 .

EPA (U.S. Environmental Protection Agency). 1995. National water quality inventory: 1994 report to Congress. EPA, Washington, DC, 841-R-95-005 , 123p.

EPA (U.S. Environmental Protection Agency). 1998. Climate Change and North Carolina. EPA, Washington, D.C., EPA 236-F-98-007q , 4p.

EPA (U.S. Environmental Protection Agency). 2000a. Chesapeake Bay submerged aquatic vegetation water quality and habitat based requirements and restoration targets: a second technical synthesis, Executive Summary. US EPA, Annapolis, Md, 19p.

EPA (U.S. Environmental Protection Agency). 2000b. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Vol. 1: Fish Sampling and Analysis. United States Environmental Protection Agency, Office of Water, Washington, D.C., EPA-823-B-00-

007 .

EPA (U.S. Environmental Protection Agency). 2000c. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Vol. 2: Risk Assessment and Fish Consumption Limits. United States Environmental Protection Agency, Office of Water, Washington, D.C., EPA-823-B-00-008 .

EPA (U.S. Environmental Protection Agency). 2001. Hydromodification chapter factsheet. http://www.epa.gov/OWOW/NPS/MMGI/hydro.html, 12/2001.

EPA (U.S. Environmental Protection Agency). 2002a. Drinking water advisory: consumer acceptability advice and health effects analysis on sulfate. U.S. Environmental Protection Agency, Washington, D.C., EPA 822-R-02-033, Contract Number 68-C-01-002, Work Assignment Number: B-02 .

EPA (U.S. Environmental Protection Agency). 2002b. National Pollutant Discharge Elimination System - proposed regulations to establish requirements for cooling water intake structures at Phase II existing facilities. Federal Register. April 9: 17,121-17,225.

EPA (U.S. Environmental Protection Agency). 2002c. National water quality inventory: 2000 report to Congress. U.S. Environmental Protection Agency, Washington, DC.

Epperly, S. P. 1984. Fishes of the Pamlico-Albemarle peninsula, N.C., area utilization and potential impacts. North Carolina Division of Marine Fisheries, Morehead City, NC, Special Scientific Report 42 , 129p.

Epperly, S. P. 1985. Nekton of the Pamlico-Albemarle peninsula: area utilization. Estuaries 8(2B): 8a.

Epperly, S. P. and S. W. Ross. 1986. Characterization of the North Carolina Pamlico-Albemarle estuarine complex. National Marine Fisheries Service - Southeast Fisheries Center, Beaufort, NC, NMFS-SEFC-175 , 55p.

Ernst, C. H. and R.W. Barbour. 1972. Turtles of the United States. University of Kentucky, Lexington, KY.

Esty, A. 2007. Banking on mitigation. American Scientist 95(2): 122-123.

Etherington, L. L. and D.B. Eggleston. 2000. Large-scale blue crab recruitment: linking postlarval transport, post-settlement planktonic dispersal, and multiple nursery habitats. Marine Ecology Progress Series 204: 179-198.

Evans, D. R., R. DiGuilio, and E. Ryan. 1984. Mercury in peat and its drainage waters in eastern North Carolina. Rep. No. 218. WRRI , Raleigh, NC, 66.p.

Evans, R. O., K.L. Bass, M.R. Burchelt, R.D. Hinson, R. Johnson, and M. Doxey. 2007. Management alternatives to enhance water quality and ecological functions of channelized streams and drainage canals. Journal of Soil and Water Conservation 62(4): 308-320.

Eversole, A. G. 1987. Species profile: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic)--hard clam. US Fish and Wildlife Service, Biological

Report 82(11.75) , 33p.

Evison, L. M. 1988. Comparative studies on the survival of indicator organisms and pathogens in fresh and sea water. Water Science and Technology 20: 309-315.

Ewart, J. W. and S.E. Ford. 1993. History and Impact of MSX and Dermo Diseases on Oyster Stocks In the Northeast Region. Northeastern Regional Aquaculture Center, North Dartmouth, MA, NRAC Fact Sheet No. 200 , 8p.

Eyre, B. and A. J. Ferguson. 2002. Comparison of carbon production and decomposition, benthic nutrient fluxes and denitrification in seagrass, phytoplankton, benthic microalgae- and macroalgae-dominated warm-temperate Australian lagoons. Marine Ecology Progress Series 229: 43-59.

Fay, C. W., R.J. Neves, and G.B. Pardue. 1983a. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic) -- Atlantic silversides. US Fish and Wildlife Service, Division of Biological Services, FWS/OBS-82/11.10 , 15p.

Fay, C. W., R.J. Neves, and G.B. Pardue. 1983b. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic) -- alewife/blueback herring. US Fish and Wildlife Service, Division of Biological Services, FWS/OBS-82/11.9 , 15p.

Fay, C. W., R.J. Neves, and G.B. Pardue. 1983c. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic) -- bay scallop. US Fish and Wildlife Service, Division of Biological Services, FWS/OBS-82/11.12 , 17p.

Fay, C. W., R.J. Neves, and G.B. Pardue. 1983d. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic) -- striped bass. US Fish and Wildlife Service, Biological Report FWS/OBS-82/11.8 , 36p.

Fear, J. M., H.W. Paerl, and J.S. Braddy. 2007. Importance of submarine groundwater discharge as a source of nutrients for the Neuse River Estuary, North Carolina. Estuaries and Coasts 30(6): 1027-1033.

Fear, J. M., S.P. Thompson, T.E. Gallo, and H.W. Paerl. 2005. Denitrification Rates Measured Along a Salinity Gradient in the Eutrophic Neuse River Estuary, North Carolina, USA. Estuaries 28(4): 608-619.

Federal Register. 2000. Executive Order 13158, Marine Protected Areas. Presidential Documents 65(105): 34909-34911.

Feely, R. A., C.L. Sabine, K. Lee, W. Berelson, J. Kleypas, V.J. Fabry, and F.J. Millero. 2004. Impact of anthropogenic CO2 on the CaCO3 system in the oceans. Science 305(5682): 362-366.

Feierabend, S. J. and J.M. Zelazny. 1987. Status report on our nation's wetlands. National Wildlife Federation, Washington, D.C., 50p.

Fell, P. E., S.P. Weissbach, D.A. Jones, M.A. Fallon, J.A. Zeppieri, E.K. Faison, K.A. Lennon, K.J. Newberry, and L.K. Reddington. 1998. Does invasion of oligohaline tidal marshes by reed grass, *Phragmites australis* (Cav.) Trin. ex Steud., affect the availability of prey resources for the mummichog, *Fundulus heteroclitus* L.? Journal of Experimental Marine Biology and

Ecology 222(1-2): 59-77.

Ferguson, R. L., J.A. Rivera, and L.L. Wood. 1989. Submerged aquatic vegetation in the Albemarle-Pamlico estuarine system. Cooperative agreement between the US EPA, through the State of North Carolina, Albermarle-Pamlico Estuarine Study and the National Marine Fisheries Service Project No. 88-10: 65.

Ferguson, R. L. and L.L. Wood. 1994. Rooted vascular aquatic beds in the Albemarle-Pamlico estuarine system. NMFS, NOAA, Beaufort, NC, Project No. 94-02 , 103 p.

Fischer, C. A., G.W. Judy, J.H. Hawkins, S.E. Winslow, H.B. Johnson, and B.F. Holland Jr. 1979. North Carolina anadromous fisheries management program. North Carolina Department of Natural Resources and Community Development, Progress Report AFCS-16-1 , p.

Fitzgerald, D. M., D.K. Hubbard, and D. Nummendal. 1978. Shoreline changes associated with tidal inlets along the South Carolina coast. Coastal Zone '78, Sixth Symposium of the Waterway, Port, Coastal and Ocean Div. 1973-1984.

Fitzgerald, D. M., M.S. Fenster, B.A. Argow, and I.V. Buynevich. 2008. Coastal impacts due to sea-level rise. Annual Review of Earth and Planetary Sciences 36: 601-647.

Flemer, D. A. and W. S. Woolcott. 1966. Food habits and distribution of teh fishes of Tuckahoe Creek, Virginia, with special emphasis on the bluegill, *Lepomis m. macrochirus* Rafinesque. Chesapeake Science 7(2): 75-89.

Florida DEP (Department of Environmental Protection). 1995. Protocols for determining major seawater ion toxicity in membrane-treatment technology water-treatment concentrate. Florida Department of Environmental Protection, Bureau of Laboratories, Tallahassee, Fl.

Fong, P. P. and N. Molnar. 2008. Norfluoxetine induces spawning and parturition in estuarine and freshwater bivalves. Bulletin of Environmental Contamination & Toxicology 81: 535-538.

Fonseca, M. S. 1996a. The role of seagrasses in nearshore sedimentary processes: a review. p. 261-286 *in* C. Roman and K. Nordstrom (eds). Estuarine Shores: Hydrological, Geomorphological and Ecological Interactions. Blackwell, Boston, MA.

Fonseca, M. S. 1996b. Scale dependence in the study of seagrass systems: a review. p. 95-104 *in* J. Kuo, R. C. Phillips D. L. Walker and H. Kirkman eds. Seagrass Biology: Proceedings of an International Workshop. Rottnest Island, Western Australia.

Fonseca, M. S., G.W. Thayer, A.J. Chester, and C. Foltz. 1984. Impact of scallop harvesting on eelgrass (*Zostera marina*) meadows: implications for management. North American Fisheries Management 4: 286-293.

Fonseca, M. S., W. J. Kenworthy, and G. W. Thayer. 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. NOAA Coastal Ocean Office, Silver Springs, Md., NOAA Coastal Ocean Program Decision Analysis Series No. 12 , 222p.

Fonseca, M. S. and S.S. Bell. 1998. Influence of physical setting on seagrass landscape near Beaufort, North Carolina, USA. Marine Ecology Progress Series 171: 109-121.

Ford, A. T., T.F. Fernandes, S.A. Rider, P.A. Read, C.D. Robinson, and I.M. Davies. 2004. Endocrine disruption in a marine amphipod? Field observations of intersexuality and de-masculinisation. Marine Environmental Research 58: 169-173.

Ford, S. E. and A. J. Figueras. 1988. Effects of sublethal infection by the parasite *Haplosporidium nelsoni* (MSX) on gametogenesis, spawning, and sex ratios of oysters in Delaware Bay, USA. Diseases of Aquatic Organisms 4(2): 121-133.

Ford, S. E. and M.M. Chintala. 2006. Northward expansion of a marine parasite: testing the role of temperature adaptation. Journal of Experimental Marine Biology and Ecology 339(2): 226-235.

Ford, S. E. and M.R. Tripp. 1996. Diseases and defense mechanisms. p. 581-660 *in* Kennedy, V. S., Newell, R. I. E., and Eble (eds.), A. F. The eastern oyster *Crassostrea virginica*. Maryland Sea Grant, College Park, MD.

Francesconi, J. J. 1994. Effect of stop nets on pier and beach angler catch rates and general fish movement along Bogue Banks, NC. N.C. Department of Environment and Natural Resources, Division of Marine Fisheries, Morehead City, NC, 17p.

Frankenberg, D. 1995. Report of the North Carolina Blue Ribbon Advisory Council on Oysters . NC DEHNR, Raleigh, NC.

Frankensteen, E. D. 1976 . Genus *Alosa* in a channelized and unchannelized creek of the Tar River Basin, North Carolina. M.S. thesis, ECU, Greenville, NC, 123 p.

Fraser, S. B. and G.R. Sedberry. 2008. Reef morphology and invertebrate distribution at continental shelf edge reefs in the South Atlantic Bight. Southeastern Naturalist 7(2): 191-206.

Freese, J. L. 2001. Trawl-induced damage to sponges observed from a research submersible. Marine Fisheries Review 63(3): 7-13.

French, G. T. and K.A. Moore. 2003. Interactive effects of light and salinity stress on the growth, reproduction, and photosynthetic capabilities of *Vallisneria americana* (Wild Celery). Estuaries 26(5): 1255-1268.

Frick, E. A. and S.D. Zaugg. 2003. Organic wastewater contaminants inthe upper Chattahoochee River basin, Georgia, 1999-2002. *in* Hatcher, K. J. ed. Proceedings of the 2003 Georgia Water Resources Conference, April 23-24, 2003. Institute of Ecology, University of Georgia, Athens.

Fries, J. S., G.W. Characklis, and R.T. Noble. 2008. Sediment-water exchange of *Vibrio* sp. and fecal indicator bacteria: implications for persistence and transport in the Neuse River Estuary, North Carolina, USA. Water Research 42(4-5): 941-950.

Fries, J. S., R.T. Noble, H.W. Paerl, and G.W. Characklis. 2007. Particle suspensions and their regions of effect in the Neuse River Estuary: implications for water quality monitoring. Estuaries and Coasts 30(2): 359-364.

Frysinger, G. S., R.B. Gaines, L. Xu, and C.M. Reddy. 2003. Resolving the unresolved complex mixture in petroleum-contaminated sediments. *Environmental Science and Technology* 37.

Fulford, R. S., D.L. Breitburg, R.I.E. Newell, W.M. Kemp, and M. Luckenbach. 2007. Effects of oyster population restoration stratagies on phytoplankton biomass in Chesapeake Bay: a flexible modeling approach. Marine Ecology Progress Series 336: 43-61.

Funderburk, S. L., J.A. Mihursky, S.J. Jordan, and D. Riley. 1991. Habitat requirements for Chesapeake Bay living resources. Habitat Objectives Workgroup, Living Resources Subcommittee and Chesapeake Research Consortium with assistance from Maryland Department of Natural Resources, Solomons, MD.

Gagne, F., C.Blaise, J. Pellerin, and C. Andre. 2007. Neuroendocrine disruption in *Mya arenaria* clams during gametogenesis at sites under pollution stress. Marine Environmental Research 64: 87-107.

Gagne, F., C.Blaise, J. Pellerin, and S. Gauthier-Clerc . 2002. Alteration of the biochemcial properties of female gonads and vitellins in the clam Mya arenaria at contaminated sites in the Saguenay Fjord. Marine Environmental Research 53: 295-310.

Gallagher, R. P. 1979. Local distribution of ichthyoplankton in the lower Mississippi River, Louisiana. Ph.D. Dissertation, Louisiana State University, Baton Rouge, LA, 52 p.

Gallegos, C. L. 1994. Refining habitat requirements of submerged aquatic vegetation: role of optical models. Estuaries 17(18): 187-199.

Gallegos, C. L. 2001. Calculating optical water quality targets to restore and protect submerged aquatic vegetation: overcoming problems in partitioning the diffuse attenuation coefficient for photosynthetically active radiation. Estuaries 24(3): 381-397.

Gallegos, C. L. and W.J. Kenworthy. 1996. Seagrass depth-limits in the Indian River Lagoon (Florida, USA): application of an optical water quality model. Estuarine and Coastal Shelf Science 42: 267-288.

Galvan, K., J.W. Fleeger, and B. Fry. 2008. Stable Isotope Addition Reveals Dietary Importance of Phytoplankton and Microphytobenthos to Saltmarsh Infauna. Marine Ecology Progress Series 359: 37-49.

Gambi, M., A. Nowell, and P.A. Jumars. 1990. Flume observations on flow dynamics in *Zostera marina* (eelgrass) beds. Marine Ecology Progress Series 61: 159-169.

Garbisch, E. W., P.B. Woller, W.J. Bostian, and R.J. McCallum. 1973. Biotic techniques for shore stabilization. p. 405-407 *in* L.E. Cronin (ed.). Estuarine Research. Academic Press Inc., New York, NY, II .

Gardner, M. B. 1981. Effects of turbidity on feeding rates and selectivity in bluegills. Transactions of the American Fisheries Society 110: 446-450.

Gazeau, F., C. Quiblier, J.M. Jansen, J.P Gattuso, J.J. Middelburg, and C.H.R. Heip. 2007. Impact of elevated CO_2 on shellfish calcification. Geophysical Research Letters 34(7).

Geffard O., A. Geffard, E. Hisc, and H. Budzinskia . 2003. Assessment of the bioavailability and toxicity of sediment-associated polycyclic aromatic hydrocarbons and heavy metals applied to Crassostrea gigas embryos and larvae. Marine Pollution Bulletin 46(April): 481-490.

Geis, S. and B. Bendell. 2008. Charting the estuarine environment: methodology spatially delineating a contiguous, estuarine shoreline of North Carolina. North Carolina Division of Coastal Management, Raleigh, NC, July , 31p.

Gentile, G. 1992. Ultimate wreck diving guide. Gary Gentile Productions, Philadelphia, PA, 152p.

Gerritsen, J., J.M. Dietz, and Jr. H.T. Wilson. 1996. Episodic acidification of coastal plain streams: an estimation of risk to fish. Ecological Applications 6(2): 438-448.

Giese, G. L., H.B. Wilder, and G.G. Parker Jr. 1979. Hydrology of major estuaries and sounds of North Carolina. US Geological Survey , Water Resource Investigations 79-46 , 175p.

Giese, G. L., J.L. Eimers, and R.W. Coble. 1997. Simulation of ground-water flow in the Coastal Plain aquifer system of North Carolina. U.S. Geological Survey, U.S. Geological Survey Professional Paper 1404-M , 142p.

Giles, R. C., L.R. Brown, and C.D. Minchew. 1978. Bacteriological aspects of fin erosion in mullet exposed to crude oil. Journal of Fish Biology 13: 113-117.

Gilkenson, K., M. Paulin, S. Hurley, and P. Schwinghamer. 1998. Impacts of trawl door scouring on infaunal bivalvs: results of a physical trawl door model: dense sand interaction. Journal of Experimental Marine Biology and Ecology 224: 291-312.

Gilliam, J. W., D.L. Osmond, and R.O. Evans. 1994. Riparian wetlands and water quality. Journal of Environmental Quality 23: 896-900.

Gilliam, J. W., R.L. Huffman, R.B. Daniels, E.E. Buffington, A.E. Morey, and S.R. Leclerc. 1996. Contamination of surficial aquifers with nitrogen applied to agricultural land. UNC Water Resources Research Institute, Raleigh, NC, Rep. 306.

Gilmore, G. and Trent X. 1974. Abundance of benthic macroinvertebrates in natural and altered estuarine areas. NMFS, NOAA Technical Report NMFS SSRF - 677 .

Gilmore, R. G. 1995. Environmental and biogeographic factors influencing ichthyofaunal diversity: Indian River Lagoon. Bulletin of Marine Science 57: 153-170.

Giorgino, M. J., R.B. Rasmussen, and C.A. Pfeifle. 2007. Occurrence of organic wastewater compounds in selected surface-water supplies, triangle area of North Carolina, 2002-2005. US Geological Survey, Raleigh, NC, Scientific Investigations Report 2007-5054 .

Giorgino, M. J., R.B. Rasmussen, and C.M. Pfeifle. 2007. Occurrence of organic wastewater compounds in selected surface-water supplies, Triangle Area of North Carolina, 2002-2005. U.S. Geological Survey, Reston, VA, USGS Scientific Report 2007-5054 , 28p.

Glasgow, H. B. Jr. and J.M. Burkholder. 2000. Water quality trends and management implications from a five-year study of a eutrophic estuary. Ecological Applications 10(4): 1024-1046.

Glasgow, H. B. Jr., J.M. Burkholder, M.A. Mallin , N.J. Deamer-Melia, and R.R. Reed. 2001. Field ecology of toxic *Pfiesteria* complex species and a conservative analysis of their role in estuarine fish kills. Environmental Health Perspectives 109: 715-730.

Glibert, P. M., J.M. Burkholder, M.W. Parrow, A.J. Lewitus, and D.E. Gustafson . 2006. Direct uptake of nitrogen by *Pfiesteria piscicida* and *Pfiesteria shumwayae*, and nitrogen nutritional preferences. Harmful Algae 5: 380-394 .

Godcharles, M. F. and M.D. Murphy. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Florida) -- king mackerel and Spanish mackerel. U.S. Fish Wildlife Service / U.S. Army Corps of Engineers, Biol. Rep. 82(11.58) / TR EL-82-4 , 18p.

Goldman, S. F. and G.R. Sedberry. 2006. Feeding habits of several deep water reef fish on the continental slope off the southeastern United States: preliminary analysis. Eos Trans. AGU 87(36): Ocean Sci. Meet. Suppl., Abstract OS23A-04.

Goldsborough, W. J. and W.M. Kemp. 1988. Light responses of submersed macrophytes: implication for survival in turbid waters. Ecology 69: 1775-1786.

Goodfellow, W. L., L.W. Ausley, D.T. Burton, D.L. Denton, P.B. Dorn, D.R. Grothe, M.A. Heber, T.J. Norberg-King, and J.H. Rodgers Jr. 2000. Major ion toxicity in effluents: a review with permitting recommendations. Environmental Toxicology and Chemistry 19(1): 175-182.

Gorzelany, J. F. and W.G. Nelson. 1987. The effects of beach replenishment of the benthos of a subtropical Florida beach. Marine Environmental Research 21: 75-94.

Gould, E., P.E. Clark, and F.P. Thurberg. 1994. Pollutant effects on demersal fishes. p. 30-40 *in* R.W. Langton, J. B. Pearce and J. A. Gibson eds. Selected living resources, habitat conditions, and human perturbations of the Gulf of Maine. National Oceanographic and atmospheric Administration, Woods Hole, Mass, NMFS-NE-106 .

Govoni, J. J. and H.L. Spach. 1999. Exchange and flux of larval fishes across the western Gulf Stream front south of Cape Hatteras, USA, in winter. Fisheries Oceanography. 8(2): 77-92.

Grabowski, J. H., A.R. Hughes, D.L. Kimbro, and M.A. Dolan. 2005. How habitat setting influences restored oyster reef communities. Ecology 86(7): 1926-1935.

Grabowski, J. H. and D.L. Kimbro. 2005. Predator-avoidance behavior extends trophic cascades to refuge habitats. Ecology 86(5): 1312-1319.

Grabowski, J. H., D. Pettipas, M.A. Dolan, A.R. Hughes, and D.L. Kimbro. 2000. The economic and biological value of restored oyster reef habitat to the nursery function of the estuary. NC Sea Grant, Morehead City, NC, FRG # 97-EP-6 , 29p.

Grabowski, J. H. and S.P. Powers. 2004. Habitat complexity mitigates trophic transfer on oyster reefs. Marine Ecology Progress Series 277: 291-295.

Graff, L. and J. Middleton. 2000. Wetlands and fish: catch the link. NOAA, National Marine Fisheries Service, Office of Habitat Conservation, Silver Springs, Maryland, 48p.

Gray, J. S., R. S. Wu, and Y.Y. Or. 2002. Effects of hypoxia and organic enrichment on the coastal marine environment. Marine Ecology Progress Series 238: 249-279.

Greene, K. 2002. ASMFC Habitat Management Series #7 Beach nourishment: a review of the biological and physical impacts. ASMFC, Washington DC, 174p.

Greene, K. E., J.L. Zimmerman, R.W. Laney, and J.C. Thomas-Blate. 2009 . Atlantic Coast Diadromous Fish Habitat: A Review of Utilization, Threats, Recommendations For Conservation, and Research Needs. Atlantic States Marine Fisheries Commission, Washington, D.C., Habitat Management Series No. 9 .

Greenwood, N. and A. Earnshaw. 1984. Chemistry of the Elements. Pergamon Press, Oxford, England.

Gregg, K. L. 1995. Comparisons of Three Manufactured Artificial Reef Units in Onslow Bay, North Carolina. North American Journal of Fisheries Management 15: 316-324.

Gregory, J., R. Skaggs, R. Broadhead, R. Culbreath, J. Bailey, and T. Foutz. 1984. Hydrology and water quality impacts of peat mining in North Carolina. Report 214. Water Resources Research Institute, Raleigh, NC, 215 p.

Gregory, R. S. and T.G. Northcote. 1993. Surface, planktonic, and benthic foraging by juvenile chinook salmon (*Oncorhynchus tshawytscha*) in turbid laboratory conditions. Canadian Journal of Fisheries and Aquatic Science 50: 233-240.

Grimes, B. H., M.T. Huish, J.H. Kerby, and D. Moran. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic)--summer and winter flounder. USFWS, Biological Rep. 82(11.112) , 13p.

Grizzle, R. E., E.E. Hofmann, J.M. Klinck, E.N. Powell, J.N. Kraeuter, V.M. Bricelj, and S.C. Buckner. 2003. A simulation model of the growth of hard clams (*Mercenaria mercenaria*), IV. Effects of climate change. Journal of Shellfish Research 22(1): 333.

Grizzle, R. E., J.R. Adams, and L.J. Walters. 2002. Historical changes in intertidal oyster (*Crassostrea virginica*) reefs in a Florida lagoon potentially related to boating activities. Journal of Shellfish Research 21(2): 749-756.

Groen , C. L. and J.C. Schmulbach. 1978. The sport fishery of the unchannelized and channelized middle Missouri River. Transaction of the American Fishery Society 107: 412-418.

Groffman, P. M., A.J. Gold, T.P. Husband, R.C. Simmons, and W.R. Eddleman. 1991. An investigation into multiple uses of vegetated buffer strips. Providence, RI, NBP-91-63 .

Grossman, G. D., G.P. Jones, and W.J. Seaman Jr. 1997. Do artificial reefs increase regional fish production? A review of existing data. Fisheries 22(4): 17-23.

Grossman, P. M., J.S. Baron, T. Blett, A.J. Gold, I. Goodman, L.H. Gunderson, B.M. Levinson, M.A. Palmer, H.W. Paerl, G.D. Peterson, N.L. Poff, D.W. Rejeski, J.F. Reynolds, M.G. Turner, and K.C. Weathers. 2006. Ecoogical thresholds: the key to successful environmental management or an important concept with no practical application? Ecosystems 9: 1-13.

Guarini, J.-M., G.F. Blanchard, P. Gros, D. Gouleau, and C. Bacher. 2000. Dynamic model of the short-term variability of microphytobenthic biomass on temperate intertidal mudflats. Marine Ecology Progress Series 195: 291-303.

Guidetti, P., A. A. Terlizzi, S. Fraschetti, and F. Boero. 2003. Changes in Mediterranean rocky-reef fish assemblages exposed to sewage pollution. Marine Ecology Progress Series 253: 269-278.

Guinotte, J. M. and V.J. Fabry. 2008. Ocean Acidification and Its Potential Effects on Marine Ecosystems. p. 320-342 *in* Annals of the New York Academy of Sciences. Year in Ecology and Conservation Biology 2008. New York Academy of Sciences, New York, NY, 1134 , Abstract p.

Gunter, G. 1955. Mortality of oysters and abundance of certain associates as related to salinity. Ecology 36: 601-605.

Guthrie, J. F. and C. W. Lewis. 1982. The clam-kicking fishery of North Carolina. Marine Fisheries Review 44(1): 16-21.

Gutierrez, J. L., C.G. Jones, D.L. Strayer, and O.O. Iribarne. 2003. Mollusks as ecosystem engineers: the role of shell production in aquatic habitats. Oikos 101(1): 79-90.

Hackney, C. T., G.B. Avery, L.A. Leonard, M. Posey, and T. Alphin. 2007. Chapter 8 - Biological, chemical, and physical characteristics of tidal freshwater swamp forests of the lower Cape Fear River/estuary, North Carolina. p. 183-222 *in* W.H. Conner, T. W. Doyle and K. W Krauss. Ecology of tidal freshwater forested wetlands of the Southeastern United States. Springer, 505 p.

Hackney, C. T. and G.F. Yelverton. 1990. Effects of human activities and sea level rise on wetland ecosystems in the Cape Fear River estuary, North Carolina, USA. p. 55-61 *in* D.F. Whigham (ed.). Wetlands Ecology and Management: Case Studies. Kluwer Academic Publishers, Netherlands.

Hackney, C. T., J. Grimley, M. Posey, T. Alphin, and J. Hyland. 1998. Sediment contamination in North Carolina's estuaries. Center for Marine Science Research, UNC-W, Wilmington, NC, Publication #198 , 59p.

Hackney, C. T., L.B. Cahoon, C. Preziosi, and A. Norris. 2000. Silicon is the link between tidal marshes and estuarine fisheries: a new paradigm. p. 543-552 *in* Weinstein, M. P. and D. A. Kreeger eds. Concepts and controversies in tidal marsh ecology. Kluwer Academic Publishers, The Netherlands, 875 p.

Hackney, C. T., M.H. Posey, S.W. Ross, and A.R. Norris. 1996. A review and synthesis of data on surf zone fishes and invertebrates in the South Atlantic Bight and the potential impacts from beach renourishment. Prepared for Wilmington District, US Army Corps of Engineers. UNC-Wilmington, Wilmington, NC, 111 p.

Haines, A. C. 2004. Oyster restoration and management in coastal North Carolina. M.S. Thesis, Duke University, Nicholas School of Environment and Earth Sciences, Beaufort, NC, 75 p.

Hall, N. S., R.W. Litaker, E. Fensin, J.E. Adolf, H.A. Bowers, A.R. Place, and H.W. Paerl. 2008. Environmental factors contributing to the development and demise of a toxic dinoflagellate (*Karlodinium veneficum*) bloom in a shallow, eutrophic, lagoonal estuary. Estuaries and Coasts 31: 402-418.

Hallegraef, G. M. 1998. Transport of toxic dinoflagellates via ships' ballast water: bioeconomic risk assessment and efficacy of possible ballast water management strategies. Marine Ecology Progress Series 168: 297-308.

Halpern, B. 2003. The impact of marine reserves: do reserves work and does reserve size matter? Ecological Applications 13(1): S117-S137.

Hamilton, A. N. 2000. Gear impacts on Essential Fish Habitat in the southeastern region. NMFS, Pascagoula, Ms, Unpub. rep. 41p.

Hamner, R. M., D.W. Freshwater, and P.E. Whitfield. 2007. Mitochondrial cytochrome *b* analysis reveals two invasive lionfish species with strong founder effects in the western Atlantic. Journal of Fish Biology 71(sb): 214-222.

Harding, J. M. and R. Mann. 1999. Fish species in relation to restored oyster reefs, Piankatank River, Virginia. Bulletin of Marine Science 65(1): 289-300.

Hardy, J. D. Jr. 1978a. Development of the fishes of the Mid-Atlantic Bight, an atlas of egg, larval, and juvenile stages, Vol. II. Anguillidae through Sygnathidae. US Fish and Wildlife Service, FWS/OBS-78/12 .

Hardy, J. D. Jr. 1978b. Development of the fishes of the Mid-Atlantic Bight, an atlas of egg, larval, and juvenile stages, Vol. III. Aphredoderidae through Rachycentridae. US Fish and Wildlife Service, FWS/OBS-78/12 .

Hare, J. O., J.A. Quinlan, F.E. Werner, B.O. Blanton, J.J. Govini, R.B. Forward, L.R. Settle, and D.E. Hoss. 1999. Larval transport during winter in the SABRE study area: results of a coupled vertical larval behavior-three-dimensional circulation model. Fisheries Oceanography. 8(2): 57-76.

Hargis, W. J. Jr. and D.S. Haven. 1988. Rehabilitation of the troubled oyster industry of the lower Chesapeake Bay. Journal of Shellfish Research. 7(2): 271-279.

Harley, C. D. G., A.R. Hughes, K.M. Hultgren, B.G. Miner, C.J.B. Sorte, C.S. Thornber, L.F. Rodriguez, L. Tomanek, and S.L. Williams. 2006. The impacts of climate change in coastal marine systems. Ecology Letters 9(2): 228-241.

Hartwell, S. I., R.W. Alden, D.A. Wright, S. Ailstock, and R. Kerhin. 2000. Correlation of measures of ambient toxicity and fish community diversity in a Chesapeake Bay tributary, Maryland, USA: a biological, chemical, and geological assessment. Environmental Toxicology and Chemistry 19: 1753-1763.

Haskin, H. H., L.A. Stauber, and G. Mackin. 1966. *Minchinia nelsoni* n. sp. (Haplosporida, Haplosporidiidae): causative agent of the Delaware Bay oyster epizootic. Science 153: 1414-1416.

Hassler, W. W., N.L. Hill, and J.T. Brown. 1981. The status and abundance of striped bass, *Morone saxatilis*, in the Roanoke River and Albemarle Sound, North Carolina, 1956-1980. NC Division of Marine Fisheries, Morehead City, NC, Special Scientific Report No. 38 , 156p.

Hauxwell, J., J. Cebrian, C. Furlong, and I. Valiela. 2000. Macroalgal canopies contribute to eelgrass

(*Zostera marina*) decline in temperate estuarine ecosystems. Ecology 82: 1007-1022.

Havens, K. E. 2003. Submerged aquatic vegetation correlations with depth and light attenuating materials in a shallow subtropical lake. Hydrobiologia 493: 173-186.

Hawkins, J. H. 1980. Investigations of anadromous fishes of the Neuse River, North Carolina. DMF, Morehead City, NC, Special Science Report No. 34 , 111p.

Hay, M. E. and J.P. Sutherland. 1988. The ecology of rubble structures of the South Atlantic Bight: a community profile. USFWS, Biological Rep. 85(7.20) , 67 p.

Heath, R. C. 1975. Hydrology of the Albemarle-Pamlico region, North Carolina: a preliminary report on the impact of agricultural developments. US Geological Survey Water Resources Investigations 80(44): 1-85.

Heck, K. L., K.W. Able, M.P. Fahay, and C.T. Roman. 1989. Fishes and decapod crustaceans of Cape Cod eelgrass meadows: species composition, seasonal abundance patterns and comparison with unvegetated substrates. Estuaries 12(2): 59-65.

Heck, K. L., T.J Carruthers, C.M. Duarte, A. R. Hughes, G. Kendrick, R.J. Orth, and S.W. Williams. 2008. Trophic transfers from seagrass meadows subsidize diverse marine and terrestrial consumers. Ecosystems 11: 1198-1210.

Heck, K. L. Jr. and R. J. Orth. 1980. Structural components of eelgrass (*Zostera marina*) meadows in the lower Chesapeake Bay - decapod crustacea. Estuaries 4: 289-295.

Hefner, J. M. and J.D. Brown. 1985. Wetland trends in the southeastern United States. Wetlands 4: 1-11.

Hemminga, M. A. and C.M. Duarte. 2000. Seagrass ecology. Cambridge Univ Press, NY.

Henderson, J. and J. O'Neal. 2003. Economic values associated with construction of oyster reefs by the Corps of Engineers. U.S. Army Engineer Research and Development Center, Vicksburg, MS, EMRRP Technical Notes Collection (ERDC TN-EMRRP-ER-01) , 10p.

Henman, J. and B. Poulter. 2008. Inundation of freshwater peatlands by sea level rise: uncertainty and potential carbon cycle feedbacks. Journal of Geophysical Research-Biogeosciences 113(G1).

Henson, M. 1995. Forest practice guidelines and best management practices - implementation and effectiveness survey on timber operations in North Carolina. NC DEHNR, Raleigh, NC, Unpub. rep. 19p.

Hermelin, J. G., C. Bouchon, and J.S. Hong. 1981. Pollution impact on the distribution of echinoderm populations of hard bottoms in Provence (North Western Mediterranean Sea). Tethys 10(1): 13-36.

Hernández Arana H.A., R.M. Warwick, M.J. Attrill, A.A. rowden, and G. Gold-Bouchot. 2005. Assessing the impact of oil-related activites on benthic macrofauna assemblages of the Campeche Shelf, southern Gulf of Mexico. Marine Ecology Progress Series 28: 89-107.

Hettler, W. F. J. and D.L. Barker. 1993. Distribution and abundance of larval fish at two North

Carolina inlets. Estuarine, Coastal, and Shelf Sciences 37: 161-179.

Hightower, J. E. and J.R. Jackson. 2000. Distribution and natural mortality of stocked striped bass in Lake Gaston, North Carolina. North Carolina Wildlife Resources Commission , Research Reports Study Number 5 .

Hildebrand, S. F. and W.C. Schroeder. 1972. Fishes of the Chesapeake Bay. Smithsonian Institution Press, Washington, DC, 388p.

Hill, J., J.W. Evans, and M.J. Van Den Avyle. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic)--striped bass. Fish Wildl. Serv. / U.S. Army Corps of Engineers, Biol. Rep. 82(11.118) / TR EL-82-4 , 35p.

Hinck, J. E., V.S. Blazer, C.J. Schmitt, D.M. Papoulias, and D.E. Tillitt. 2009. Widespread occurrence of intersex in black basses (*Micropterus* spp. from US rivers, 1995- 2004. Aquatic Toxicology 95(1): 60-70.

Hingston, J. A., R.J. Murphy, and J.N. Lester. 2006. Monitoring losses of copper based wood preservatives in the Thames Estuary. Environmental Pollution 143(2): 367-375.

Hinz, H., J.G. Hiddink, J. Forde, and M.J. Kaiser. 2008. Large-scale response of nematode communities to chronic otter-trawl disturbance. Canadian Journal of Fisheries and Aquatic Sciences 65: 723-732.

Hirst, J. A. and M.J. Attrill. 2008. Small is beautiful: an inverted view of habitat fragmentation in seagrass beds. Estuarine, Coastal, and Shelf Science 78: 811-818.

Hobbs, C. H., C.B. Landry, and J.E. Perry. 2008. Assessing anthropogenic and natural impacts on ghost crabs (*Ocypode quadrata*) at Cape Hatteras National Seashore, North Carolina. Journal of Coastal Research 24(6): 1450-1458.

Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, P. Greenfield, E. Gomez, C.D. Harvell, P.F. Sale, A.J. Edwards, K. Caldeira, N. Knowlton, C.M. Eakin, R. Iglesias-Prieto, N. Muthiga, R.H. Bradbury, A. Dubi, and M.E. Hatziolos. 2007. Coral reefs under rapid climate change and ocean acidification. Science 318(5857): 1737-1742.

Hofmann, E. E., J.M. Klinck, S.E. Ford, and E.N. Powell. 1999. Disease dynamics: modeling the effect of climate change on oyster disease. Journal of Shellfish Research 18(1): 329.

Hofmann, E. E. and T.M. Powell. 1998. Environmental variability effects on marine fisheries: four case histories. Ecological Applications 8(1): S23-S32.

Holder, D. R., L. McSwain, W.D. Hill Jr., W. King, and C. Sweet. 1970. Population studies of streams. Game and Fish Commission, Department of Natural Resources, Atlanta, GA, Annual Progress Report F-21-2, Study XVI .

Holdway, D. A. 2002. The acute and chronic effects of wastes associated with offshore oil and gas production on temperate and tropical marine ecological processes. Marine Pollution Bulletin 44(3): 185-203.

Holland, A., R. Zingmark, and J. Dean. 1974. Quantitative evidence concerning the stabilization of sediments by marine benthic diatoms. Marine Biology 27: 191-196.

Holland, A. F., D.M. Sanger, C.P. Gawle, S.B. Lerberg, M.S. Santiago, G.H.M. Riekerk, L.E. Zimmerman, and G.I. Scott. 2004. Linkages between tidal creek ecosystems and the landscape and demographic attributes of their watersheds. Journal of Experimental Marine Biology and Ecology 298: 151-178.

Holland, B. F. J. and G.F. Yelverton. 1973. Distribution and biological studies of anadromous fishes offshore North Carolina . NC Department of Natural and Economic Resources, Division of Commercial and Sport Fisheries, Morehead City, NC, Special Sci. Rep. No. 24, AFS-5-3 , 132p.

Hong, J.-S. 1983. Impact of the pollution on the benthic community. Environmental impact of the pollution on the benthic coralligenous community in the Gulf of Fos, northwestern Mediterranean. Bulletin of the Korean Fisheries Society 16(3): 273-290.

Hopple, J. A. and G.D. Foster. 1996. Hydrophobic organochlorine compounds sequestered in submerged aquatic macrophytes (*Hydrilla verticillata* (L.F.) Royle) from the tidal Potomac River (USA). Environmental Pollution 94(1): 39-46.

Hough, P. and M. Robertson. 2009. Mitigation under section 404 of the Clean Water Act: where it comes from, what it means. Wetlands Ecology and Management (17): 15-33.

Hovel, K. A. 2003. Habitat fragmentation in marine landscapes: relative effects of habitat cover and configuration on juvenile crab survival in California and North Carolina seagrass beds. Biological Conservation 110: 401-412.

Hovel, K. A., M.S. Fonseca, D.L. Myer, W.J. Kenworthy, and P.E.Whitfield. 2002. Effect of seagrass landscape structure, structural complexity and hydrodynamic regime on macrofaunal densities in North Carolina seagrass beds. Marine Ecology Progress Series 243: 11-24.

Hoyer, M. V. and D.E. Canfield. 1993. Aquatic macrophytes and their relation to fish populations of Florida lakes. Abstracts, Thirty-third Annual Meeting, The Aquatic Plant Management Society, Inc. South Carolina Aquatic Plant Management Society, Inc., Charleston, South Carolina.

Hoyer, M. V. and D.E. Canfield Jr. 1996. Lake size, aquatic macrophytes, and largemouth bass abundance in Florida Lakes: A reply. Journal of Aquatic Plant Management 34: 48-50.

Huanxin, W., Z. Lejun, and B.J. Presley. 2000. Bioaccumulation of heavy metals in oyster (Crassostrea virginica) tissue and shell. Environmental Geology 39(11): 1216-1226.

Huffman, R. L. 1999. Evaluating the impacts of older swine lagoons on shallow groundwater. p. 92-98 *In*: Proceedings of the 1999 amimal waste management symposium, January 27-28, 1999, Embassy Suites Hotel and Conference Center. Cary, NC.

Hughes, A. R. and J.H. Grabowski. 2006. Habitat context influences predator interference interactions and the strength of resource partitioning. Oecologia 149: 256-264.

Hulathduwa, Y. D. and K.M. Brown. 2006. Relative importance of hydrocarbon pollutants, salinity and tidal height in colonization of oyster reefs. Marine Environmental Research 62: 301-314.

Hulson, P.-J. F., S.E. Miller, T.J. Quinn II, G.D. Marty, S.D. Moffitt, and F. Funk . 2008. Data conflicts in fishery models: incorporating hydroacoustic data into the Prince William Sound Pacific herring assessment model. ICES Journal of Marine Science 65: 2543.

Huntsman, G. R. 1979. The biological bases of reef fishery production. Proceedings of the Gulf and Caribbean Fisheries Institute, Miami Beach, Fl : 167-174.

Huntsman, G. R. and C.S. Manooch III. 1978. Coastal Pelagic and Reef Fishes in the South Atlantic Bight. Marine Recreational Fisheries : 97-106.

Hurley, L. M. 1990. Field Guide to the Submerged Aquatic Vegetation of Chesapeake Bay. USFWS, Chesapeake Bay Estuary Program, Annapolis, Md, 48p.

Hwang, H. and G.D. Foster. 2006. Characterization of polycyclic aromatic hydrocarbons in urban stormwater runoff flowing into the tidal Anacostia River, Washington, D.C., USA. Environmental Pollution 140(3): 416-426.

Hyland, J., C. Cooksey, W.L. Balthis, M. Fulton, D. Bearden, G. McFall, and M. Kendall. 2006. The soft-bottom macrobenthos of Gray's Reef National Marine Sanctuary and nearby shelf waters off the coast of Georgia, USA. Journal of Experimental Marine Biology and Ecology 330: 307-326.

Hyland, J., D. Hardin, M. Steinhauer, D. Coats, R. Green, and J. Neff. 1994. Environmental impact of offshore oil development on the outer continental shelf and slope off Point Arguello, California. Marine Environmental Research. London 37(2): 195-229.

Hyland, J. L., W.L. Balthis, C.T. Hackney, and M.Posey. 2000. Sediment quality of North Carolina Estuaries: An integrative assessment of sediment contamination, toxicity, and condition of benthic fauna. Journal of Aquatic Ecosystem Stress and Recovery 8(1): 107-124.

Hyland, J. L., W.L. Balthis, M. Posey, and C.T. Hackney. 2004. The soft-bottom macrobenthos of North Carolina estuaries. Estuaries 27(3): 501-514.

Iannuzzi, T. J., M.P. Weinstein, K.G. Sellner, and J.C. Barrett. 1996. Habitat disturbance and marina development: An assessment of ecological effects. I. Changes in primary production due to dredging and marina construction. Estuaries 19(2A): 257-271.

Ibison, N. A., J.C. Baumer, C.L. Hill, N.H. Burger, and J.E. Frye. 1992. Eroding bank nutrient verification study for the Lower Chesapeake Bay. Department of Conservation and Recreation, Division of Soil and Water Conservation, Shoreline Programs Bureau, Gloucester Point, Va, 79 p.

Ibison, N. A., J.C. Buaumer, C.L. Hil, N.H. Burger, and J.E. Frye. 1992. Eroding Bank Nutrient Verification Study for the Lower Chesapeake Bay. Department of Conservation and Recreation. Division if Soil and Water Conservation.
Shoreline Programs Bureau. Gloucester Point, Virginia., Gloucester Point, Virginia.

Imberger, R. 1983. The influence of water motion on the distribution and transport of materials in a salt marsh estuary. Limnology and Oceanography 28: 201-214.

Incardona, J. P., M.G. Carls, H.L. Day, C.A. Sloan, J.L. Bolton, K. C. T, and N.L. Scholz. 2009.

ardiac arrhythmia is the primary response of embryonic Pacific herring (*Clupea pallasi*) exposed to crude oil during weathering. Environmental Science and Technology C: 201-207.

Inman, D. and R. Dolan. 1989. The Outer Banks of North Carolina: budget of sediment and inlet dynamics along a migrating barrier system. Journal of Coastal Research 5(2): 192-237.

Inoue, M. and W.J. Wiseman. 2000. Transport, mixing and stirring processes in a Louisiana estuary: a model study. Estuarine and Coastal Shelf Science 50: 449-466.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: Synthesis Report. 73p.

Irlandi, E. A. 1994. Large- and small-scale effects of habitat structure on rates of predation: How percent coverage of seagrass affects rates of predation and siphon nipping on an infaunal bivalve. Oecologia 98(2): 176-183 .

Irlandi, E. A. 1997. Seagrass patch size and survivorship of an infaunal bivalve. Oikos 78(3): 511-518.

Irlandi, E. A. and M.K. Crawford. 1997. Habitat linkages: the effect of intertidal saltmarshes and adjacent subtidal habitats on abundance, movement, and growth of an estuarine fish. Oecologia 110(2): 222-230.

Ivanina, A. V., E. Habinck, and I.M. Sokolova. 2008. Differential sensitivity to cadmium of key mitochondrial enzymes in the eastern oyster, *Crassostrea virginica* Gmelin (Bivalvia: Ostreidae). Comparative Biochemistry and Physiology C-Toxicology & Pharmacology 148(1): 72-79.

Iwanowicz, L. R., V.S. Blazer, C.P. Guy, A.E. Pinkney, J.E. Mullican, and D.A. Alvarez. 2009. Reproductive health of bass in the Potomac, USA draiage: part 1. Exploring the effects of proximity to wastewater treatment plant discharge. Environmental Toxicology and Chemistry 28(5): 1072-1083.

Jaap, W. C. 1984. The ecology of the South Florida coral reefs: a community profile. US Fish and Wildlife Service, FWS/OBS 82/08 , 138p.

Jackivicz, T. P. Jr. and L.N. Kuzminski. 1973. A review of outboard motors effects on the aquatic environment. Journal of the Water Pollution Control Federation 48(8): 1759-1770.

Jackson, J. B. C., M. Kirby, W.H. Berger, K.A. Bjorndal, L.W. Botsford, B.J. Bourque, R.H. Bradbury, R. Cooke, J. Erlandson, J.A. Estes, T.P. Hughes, S. Kidwell, C.B. Lange, H.S. Lenihan, J.M. Pandolfi, C.H. Peterson, R.S. Steneck, M.J. Tegner, and R.R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293: 629-638.

Jackson, T. J., T.L. Wade, T.J. McDonald, D.L. Wilkinson, and J.M. Brooks. 1994. Polynuclear aromatic hydrocarbon contaminants in oysters from the Gulf of Mexico (1986-1990). Environmental Pollution 83: 291-298.

Jacobs, J. M., M.R. Rhodes, A. Baya, R. Reimschuessel, H. Townsend, and R.M. Harrell. 2009. Influence of nutritional state on the progression of and severity, of mycobacteriosis in striped bass *Morone saxatilis*. Diseases of Aquatic Organisms 87: 183-197.

Jacobs, R. P. W. M. 1980 . Effects of the 'Amoco Cadiz' oil spill on the seagrass community at Roscoff with special reference to the benthic infauna. Marine Ecology Progress Series 2: 207-212.

Jartun, M., R.T. Ottesen, E. Steinnes, and T. Volden. 2008. Runoff of particle bound pollutants from urban impervious surfaces studied by analysis of sediments from stormwater traps. Science of the Total Environment 396(2-3): 147-163.

Jenkins, J. B., A. Morrison, and C.L. MacKenzie Jr. 1997. The molluscan fisheries of the Canadian Maritimes. p. 15-44 *in* MacKenzie Jr., C. L., Burrell Jr., V. G., Rosenfield, A., and Hobart (eds.), W. L. The History, Present Condition, and Future of the Molluscan Fisheries of North and Central America and Europe, Vol. 1. Atlantic and Gulf Coasts. U.S. Department of Commerce, NOAA, NMFS, Silver Spring, MD, NOAA Tech. Rept. NMFS 127 .

Jenkins, R. E. and N.M. Burkhead. 1993. Freshwater fishes of Virginia. American Fisheries Society, Bethesda, Maryland, 1079p.

Jewett, S. C., T.A. Dean, R.O. Smith, and A. Blanchard. 1999. 'Exxon Valdez' oil spill: impacts and recovery in the soft-bottom benthic community in and adjacent to eelgrass beds. Marine Ecology Progress Series 185: 1999.

Johnson, D. R. and N.A. Funicelli. 1991. Spawning of the red drum in Mosquito Lagoon, east-central Florida. Estuaries 14(1): 74-79.

Johnson, G. D. 1978. Development of fishes of the Mid-Atlantic Bight, an atlas of egg, larval, and juvenile stages, Vol. IV. Carangidae through Ephippidae. US Fish and Wildlife Service Biological Service Program, FWS/OBS-72/12 .

Johnson, H. B., B. F. Jr. Holland, and S. G. Keefe. 1977. Anadromous Fisheries Research Program, Northern Coastal Area. p. *in* North Carolina Division of Marine Fisheries. NC Division of Marine Fisheries Complete Report. NC Division of Marine Fisheries, AFCS-11 , p.

Johnson, L. L., T.K. Collier, and J.E. Stein. 2002. An analysis in support of sediment quality thresholds for polycyclic aromatic hydrocarbons (PAHs) to protect estuarine fish . Aquatic Conservation: Marine and Freshwater Ecosystems 12(5): 517-538.

Jokiel, P. L. 1978. Effects of water motion on coral reefs. Journal of Experimental Marine Biology and Ecology 35: 87-97.

Jone, N. A. and A.S. Overton. 2009. Habitat specific and cohort specific growth and mortality of larval river herring in the Tar-Pamlico River, North Carolina. East Carolina University, Greenville, NC, slide presentation , 21p.

Jones, N. A. 2009. Habitat-specific and cohort-specific growth and mortality of larval river harring in the Tar-Pamlico River, North Carolina. Overton, A.S., ECU Department of Biology, Greenville

Jones, R. A. and T.M. Sholar. 1981. The effects of freshwater discharge on estuarine nursery areas of Pamlico Sound. NC Division of Marine Fisheries, Morehead City, NC, Project CEIP 79-11 , 60p.

Jordan, L. K. B., D.S. Gilliam, and R.E. Spieler. 2005. Reef fish assemblage structure affected by small-scale spacing and size variations of artificial patch reefs. Journal of Experimental Marine Biology and Ecology 326(2): 170-186.

Jordan, S., C. Stenger, R. B. M. Olson, and K. Mountford. 1992. Chesapeake Bay dissolved oxygen goal for restoration of living resources. United States Environmental Protection Agency, Annapolis, MD.

Jung, J. H., U.H. Yim, G.M. Han, and W.J. Shim. 2009. Biochemical changes in rockfish, *Sebastes schlegeli*, exposed to dispersed crude oil. Comparative Biochemistry and Physiology Part C(150): 218-223.

Junk, W. J., P.B. Bayley, and R.E. Sparks. 1989. The floodplain pulse concept in river-floodplain systems. p. 110-127 *in* D.P. Dodge (ed.). Proceedings of the International Large River Symposium . Canadian Special Publications Aquatic Sciences 106 .

Jutte, P. C., R.F. Van Dolah, G.Y. Ojeda, and P.T. Gayes. 2001a. Final report. An environmental monitoring study of the Myrtle Beach renourishment project: physical and biological assessment of offshore sand borrow sites. Phase II - Cane South Borrow Area. SC DNR and Coastal Carolina University, Charleston, SC, 70p.

Jutte, P. C., R.F.Van Dolah, and M.V.Levison . 1999. An environmental monitoring study of the Myrtle Beach renourishing project: intertidal benthic community assessment. Phase II- Myrtle Beach. Final Report, prepared by Marine Resources Division; submitted to US Army Corps of Engineers. SC Department of Natural Resources, Charleston, SC, 34p.

Kao, C. M., J.Y. Wang, and M.J. Wu. 2001. Evaluation of atrazine removal processes in a wetland. Water Science and Technology 44(11-12): 539-544.

Kao, C. M. and M.J. Wu. 2001. Control of non-point source pollution by a natural wetland. Water Science and Technology 43(5): 169-174.

Kapolnai, A., R.E. Werner, and J.O. Blanton. 1996. Circulation, mixing, and exchange processes in the vicinity of tidal inlets. Journal of Geophysical Research 101(14): 253-268.

Kaumeyer, K. R. and E.M. Setzlter-Hamilton. 1982. Effects of pollutants and water quality on selected estuarine fish and invertebrates: a review of the literature. US Environmental Protection Agency, Chesapeake Bay Program, Annapolis, MD, UMCEED Ref. no. 82-13-CBL , 171p.

Keefe, S. B. and R.C. Harriss Jr. 1981. Preliminary assessment of non-anadromous fishes of the Albemarle Sound. NC Division of Marine Fisheries, Morehead City, NC, Project 2-324-R , 46p.

Keener, P., G.D. Johnson, B.W. Stender, E.B. Brothers, and H.R. Beatty. 1988. Ingress of postlarval gag, *Mycteroperca microlepis* (pisces, serranidae), through a South Carolina barrier island inlet. Bulletin of marine science 42(3): 376-396.

Keister, J. E., E.D. Houde, and D.L. Breitburg. 2000. Effects of bottom-layer hypoxia on abundances and depth distributions of organisms in Patuxent River, Chesapeake Bay. Marine Ecology Progress Series 205: 43-59.

Keller, A. E. 1996. Contaminant impacts on native freshwater mussels - lethal and sublethal responses relative to water quality criteria. Journal of Shellfish Research 15(2): 484-485.

Kelty, R. and S. Bliven. 2003. Environmental and aesthetic impacts of small docks and piers. NOAA Coastal Ocean Program, Silver Springs, MD, Workshop report: developing a science-based decision support tool for small dock management, phase 1: status of the science , 62p.

Kemp, W. M., R. Batiuk, R. Bartleson, P. Bergstrom, V. Carter, C.L. Gallegos, W. hunley, L. Karrh, E.W. Koch, J.M. Landwehr, K.A. Moore, L. Murray, M. Naylor, N.B. Rybicki, J.C. Stevenson, and D.J. Wilcox . 2004. Habitat requirements for submerged aquatic vegetation in Chesapeake Bay: water quality, light regime, and physical-chemical factors. Estuaries 27(3): 363-377.

Kemp, W. M., W.R. Boynton, J.E. Adolf, D.F. Boesch, W.C. Boicourt, G. Brush, J.C. Cornwell, T.R. Fisher, P.M. Glibert, J.D. Hagy, LW. Harding, E.D. Houde, D.G. Kimmel, W.D. Miller, R.I.E. Newell, M.R. Roman, E.M. Smith, and J.C. Stevenson. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. Marine Ecology Progress Series 303: 1-29.

Kemp, W. M., W.R. Boynton, R.R. Twilley, and J.C. Means. 1983. The decline of submerged vascular plants in upper Chesapeake Bay: Summary of results concerning possible causes. Marine Technology Society Journal 17: 78-89.

Kendall, M. S., L.J. Bauer, and C.F.G. Jeffrey. 2008. Influence of benthic features and fishing pressure on size and distribution of three exploited reef fishes from the southeastern United States. Transactions of the American Fisheries Society 137(4): 1134-1146.

Kennedy, V. S. 1996. The ecological role of eastern oyster, *Crassostrea virginica*, with remarks on disease. Journal of Shellfish Research 15: 177-183.

Kennedy, V. S., R.I.E. Newell, and A.F. Ebele. 1996. The Eastern Oyster, *Crassostrea virginica*. Maryland Sea Grant College, College Park, MD.

Kennedy, V. S., W.H. Roosenburg, M. Castagna, and J.A. Mihursky. 1974. *Mercenaria mercenaria* (Mollusca: Bivalvia): temperature-time relationship for survival of embryos and larvae. Fisheries Bulletin 72(4): 1160-1166.

Kennicutt, M. C., R.H. Green, P. Montagna, and P.F. Roscigno. 1996. Gulf of Mexico offshore operations monitoring experiment (GOOMEX), phase I: sublethal responses to contaminant exposure-introduction and overview. Canadian Journal of Fisheries and Aquatic Sciences 53: 2540-2553.

Kenworthy, W. J. and D.E. Haunert. 1991. The light requirements of seagrasses: proceedings of a workshop to examine the capability of water quality criteria, standards and monitoring progress to protect seagrasses. National Oceanic and Atmospheric Administration, Beaufort, NC, Tech. Memo. NMFS-SEFC-287 , 181p.

Kenworthy, W. J. and G.W. Thayer. 1984. Production and decomposition of the roots and rhizomes of seagrasses, *Zostera marina* and *Thalassia testudinum*, in temperate and subtropical marine ecosystems. Bulletin of Marine Science 5: 365-379.

Kenworthy, W. J., M.S. Fonseca, P.E. Whitfield, K. Hammerstrom, and A.C. Schwarzschild. 2000. A comparison of two methods for enhancing the recovery of seagrasses into propeller scars: Mechanical injection of a nutrient and growth hormone solution vs. defecation by roosting seabirds. Center for Coastal Fisheries and Habitat Research, NOAA, Beaufort, NC, Final report , 40 p.

Keppler, C. J., J. Hoguet, K. Smith, A.H. Ringwood, and A.J. Lewitus. 2005. Sublethal effects of the toxic alga *Heterosigma akashiwo* on the southeastern oyster (*Crassostrea virginica*). Harmful Algae 4(2): 275-285.

Kerhin, R. T. and J. Halka. 1981. Beach changes associated with bulldozing of the lower foreshore. Maryland Geological Survey, Open File Report 7: 28 pp.

Key, P. B., M.H. Fulton, G.I. Scott, S.L. Layman, and E.F. Wirth. 1998. Lethal and sublethal effects of malathion on three life stages of the grass shrimp, *Palaemonetes pugio*. Aquatic Toxicology 40: 311-322.

Kidd, K. A., P.J. Blanchfield, K.H. Mills, V.P. Palace, R.E.Evans, J.M. Lazochak, and R.W. Flick. 2007. Collapse of a fish population after exposure to a synthetic estrogen. PNAS 104(21): 8897-8901.

Killgore, K. J., R.P. Morgan II, and N.B. Rybicki. 1989. Distribution and abundance of fishes associated with submerged aquatic plants in the Potomac River. N. Amer. J. Fish. Management 9: 101-111.

Kimbrough, K. L., W.E. Johnson, G.G. Lauenstein, J.D. Christensen, and D.A. Apeti. 2008. An assessment of two decades of contaminant monitoring in the nation's coastal zone. NOAA, Silver Spring, MD, NOS NCCOS 47 , 105p.

Kimmel, D. G. and R.I.E. Newell. 2007. The influence of climate variation on eastern oyster (*Crassostrea virginica*) juvenile abundance in Chesapeake Bay. Limnology and Oceanography 52(3): 959-965.

King, G. M., C. Giray, and I. Kornfield. 1995. Biogeographical, biochemical and genetic differentatiation among North American saccoglossids (Hemichordata; Enteropneusta; Harrimaniidae). Marine Biology 123: 369-377.

Kingston, P. F. 1992. Impact of offshore oil production installations on the benthos of the North Sea. ICES Journal of Marine Science 49(1): 45-53.

Kirby, J., W. Maher, and F. Krikowa. 2001. Selenium, cadmium, copper, and zinc concentrations in sediments and mullet (*Mugil cephalus*) from the southern basin of Lake Macquarie, NSW Australia. Archives of environmental contamination and toxicology 40(2): 246-256.

Kirby, M. X. and H.M. Miller. 2005. Response of a benthic suspension feeder (*Crassostrea virginica* Gmelin) to three centuries of anthropogenic eutrophication in Chesapeake Bay. Estuarine, Coastal and Shelf Science 62(4): 679-689.

Kirby-Smith, W. W. 1989. The community of small macroinvertebrates associated with rock outcrops on the continental shelf of North Carolina. NOAA-National Undersea Research Program Report. 89(2): 279-304.

Kirby-Smith, W. W. and N.M. White. 2006. Bacterial contamination associated with estuarine shoreline development. Journal of Applied Microbiology 100: 648-657.

Kissil, G. W. 1974. Spawning of the anadromous alewife in Bride Lake, Connecticut. Transactions of the American Fisheries Society 103: 312-317.

Klauda, R. J., S.A. Fischer Jr., L.W. Hall, and J.A. Sullivan. 1991. Alewife and blueback herring: *Alosa pseudoharengus* and *Alosa aestivalis*. Habitat Requirements for Chesapeake Bay Living Resources, 10-1 - 10-29p.

Kleypas, J. A., R.A. Feely, V.J. Fabry, C. Langdon, C.L. Sabine, and L.L. Robbins. 2006. Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research. report of a workshop held 18–20 April 2005, St. Petersburg, FL, sponsored by NSF, NOAA, and the U.S. Geological Survey , 88p.

Kneib, R. T. 1997. The role of tidal marshes in the ecology of estuarine nekton. p. 163-220 *in* R.T. Kneib (ed.). Oceanography and Marine biology: an Annual Review. UCL Press, London, 35 .

Kneib, R. T. and S.L. Wagner. 1994. Nekton use of vegetated marsh habitats at different stages of tidal inundation. Marine Ecology Progress Series 106: 227-238.

Knutson, P. L. 1977. Planting guidelines for marsh development and bank stabilization. US Army Corps of Engineering Research Center, Fort Belvoir, Va.

Knutson, P. L. W. N. S. and M.R. Inskeep. 1982. Wave damping in *Spartina alterniflora* marshes. Wetlands 2: 85-105.

Koch, E. W. 2001. Beyond light: Physical, geological, and geochemical parameters as possible submersed aquatic vegetation habitat requirements. Estuaries 24(1): 1-17.

Kolpin, D. W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B.Barber, and H. T. Buxton. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: a national reconnaissance. Environmental Science and Technology 36: 1202-1211.

Komatsu, T. and S.I. Murakami. 1994. Influence of a *Sargassum* forest on the spatial distribution of water flow. Fisheries Oceanography 3: 256-266.

Krantz, G. E. and J.F. Chamberlin. 1978. Blue crab predation of cultchless oyster spat. Proceedings of the National Shellfisheries Association 68: 38-41.

Krimsky, L. S. and C.E. Epifanio. 2008. Multiple cues from multiple habitats: effect on metamorphosis of the Florida stone crab Menippe mercenaria. Journal of Experimental Marine Biology and Ecology 358(2): 178-184.

Kuiper, R. V., R.F. Canton, P.E. G. Leonards, B.M. Jenssen, M. Dubbeldam, P.W. Wester, M. van den Berg, J.G. Vos, and A.D. Vethaak. 2007. Long-term exposure of European flounder (*Platichthys flesus*) to the flame-retardants tetrabromobisphenol A (TBBPA) and bexabromocyclododecane (HBCD). Eoctoxicology and Environmental Safety 67: 349-360.

Kurihara, H. 2008. Effects of CO_2-driven ocean acidification on the early developmental stages of invertebrates. Marine Ecology Progress Series 373: 275-284.

Kurihara, H., S. Kato, and A. Ishimatsu. 2007. Effects of increased seawater PCO_2 on early development of the oyster *Crassostrea gigas*. Aquatic Biology 1(1): 91-98.

La Peyre, M., S. Casas, and J. La Peyre. 2006. Salinity effects on viability, metabolic activity and proliferation of three *Perkinsus* Species. Diseases of Aquatic Organisms 71(1): 59-74 .

La Peyre, M. K., A.D. Nickens, A.K. Volety, G.S. Tolley, and J.F. La Peyre. 2003. Environmental significance of freshets in reducing *Perkinsus marinus* infection in eastern oysters *Crassostrea virginica*: potential management applications. Marine Ecology Progress Series 248: 165-176.

La Peyre, M. K., B. Gossman, and B.P. Piazza. 2009. Short- and Long-Term Response of Deteriorating Brackish Marshes and Open-Water Ponds to Sediment Enhancement by Thin-Layer Dredge Disposal. Estuaries and Coasts 32(2): 390-402 .

Lacorte, S., S.B. Lartiges, P. Garrigues, and D. Barcelo. 1995. Degradation of organophosphorus pesticides and their transformation products in estuarine waters. Environmental Science and Technology 29(2): 431-438.

Laist, D. W. 1997. Impacts of marine debris: entanglement of marine life in marine debris, including a comprehensive list of species with entanglement and ingestion records. *in* J.M. Coe and D.B. Rogers (eds.). Marine debris: Sources, impacts and solutions. Springer-Verlag, 1997.

Lalancette, L.-M. 1984. The effects of dredging on sediments, plankton, and fish in the Vauvert Area of Lake St. Jean, Quebec. Archive fur Hydrobiologie 99(4): 463-477.

Lamers, L. P. M., G.E.T. Dolle, S.T.G. Van Den Berg, S.P.J. Van Delft, and J.G.M. Roelofs. 2001. Differential responses of freshwater wetland soils to sulphate pollution. Biogeochemistry 55: 87-102.

Lamers, L. P. M., S.-J. Falla, E.M. Samborska, I A.R. van Dulken, G. van Hengstum, and J.G.M. Roelofs. 2002. Factors controlling the extent of eutrophication and toxicity in sulfate-polluted freshwater wetlands. Limnology and Oceanography 47(2): 585-593.

Laney, R. W., D.J. Newcomb, and C.S. Manooch III. 1999. Impact assessment of proposed Corps of Engineers dredging associated with the Dare County beaches project upon fisheries resources. Appendix B. Draft Report. Northern Dare County Storm Damage Reduction Project, Dare County, North Carolina. Draft USFWS Coordination Report. 83 pp.

Langley, J. A., K.L. McKee, D.R. Cahoon, J.A. Cherry, and J.P. Megonigal. 2009. Elevated CO_2 stimulates marsh elevation gain, counteracting sea-level rise. Proceedings of the National Academy of Science 106(15): 6182-6186.

Lannig, G., J.F. Flores, and I.M. Sokolova. 2006. Temperature-dependent stress response in oysters, *Crassostrea virginica*: pollution reduces temperature tolerance in oysters. Aquatic Toxicology 79(3): 278-287.

Larkum, A. W., C.W. Duarte, and R. Orth. 2006. Seagrass conservation biology: an interdisciplinary science for protection of the seagrass biome. Springer, Netherlands.

Lauenstein, G. G., A.Y. Cantillo, and T.P. O'Connor. 2002. The status and trends of trace elements and organic contaminants n oysters, *Crassostrea virginica*, in the waters of the Carolinas, USA. The Science of the Total Environment 285: 79-87.

Lauritsen, D. and S. Moxley. 1983. Freshwater Asian clam *Corbicula fluminea* as a factor affecting nutrient cycling in the Chowan River, NC. Water Resources Research Institute of North Carolina , Raleigh, NC, Report No. 192 , 60p.

Lawrence, A. J. and J.M. Soame. 2004. The effects of climate change on the reproduction of coastal invertebrates. Ibis 146: 29-39.

Laws, E. A., J. Hiraoka, M. Mura, B. Punu, T. Rust, S. Vink, and C. Yamamura. 1994. Impact of land runoff on water quality in a Hawaiian estuary. Marine Environmental Research 38: 225-241.

Lee, D. L., T.A. Dillaha, and J.H. Sherrard. 1989. Modeling phosphorus in grass buffer strips. Journal of Environmental Engineering 115: 409-427.

LeGrand, H. E., S.E. McRae, S.P. Hall, and J. Finnegan . 2008. 2008 Natural Heritage Program list of the rare animals of North Carolina. North Carolina Natural Heritage Program, Raleigh, NC, 119 pp.p.

Lehnert, R. L. and D.M. Allen. 2002. Nekton use of subtidal oyster shell habitat in a southeastern U.S. estuary. Estuaries 25(5): 1015-1024.

Lenihan, H. S. 1998. Physical-biological coupling on oyster reefs: how habitat structures individual performance. Ecological Monographs 79: 251-275.

Lenihan, H. S. 1999. Physical-biological coupling on oyster reefs: how habitat structure influences individual performance. Ecological Monographs 69(3): 251-275.

Lenihan, H. S. and C.H. Peterson. 1998. How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. Ecological Applications 8(1): 128-140.

Lenihan, H. S., C.H. Peterson, J.E. Byers, J.H. Grabowski, and G.W. Thayer. 2001. Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. Ecological Applications 11(3): 764-782.

Lenihan, H. S. and F. Micheli. 2000. Biological effects of shellfish harvesting on oyster reefs: resolving a fishery conflict by ecological experimentation. Fishery Bulletin 98: 86-95.

Lenihan, H. S., F. Micheli, S.W. Shelton, and C.H. Peterson. 1999. The influence of multiple environmental stressors on susceptibility to parasites: an experimental determination with oysters. Limnology and Oceanography 44: 910-924.

Lenihan, H. S., J.H. Grabowski, and G.W. Thayer. 1998. Recruitment to and utilization of oyster reef habitat by commercially valuable crabs and fishes: an experiment with economic analysis. National Marine Fisheries Service, Beaufort, NC, National Research Council Final Report Number 1-97 .

Leonard, L. A. and A.L. Croft. 2006. The effect of standing biomass on flow velocity and turbulence in *Spartina alterniflora* canopies. Estuarine Coastal and Shelf Science 69(3-4): 325-336.

Lerberg, S. B. and A.F. Holland. 2000. Responses of tidal creek macrobenthic communities to the effects of watershed development. Estuaries 23: 838-853.

Levin, P. S. and G.W. Stunz. 2005. Habitat triage for exploited fishes: can we identify essential "Essential Fish Habitat?". Estuarine, Coastal and Shelf Science 64: 70-78.

Levin, P. S. and M.E. Hay. 2003. Selection of estuarine habitats by juvenile gags in experimental mesocosms. Transactions of the American Fisheries Society 132(1): 76-83.

Levinton, J. S. 1982. Marine ecology. Prentice Hall, Englewood Cliffs, NJ, 526p.

Lewis, V. P. and D.S. Peters. 1994. Diet of juvenile and adult Atlantic menhaden in estuarine and coastal habitats. Transactions of the American Fisheries Society 123: 803-810.

Lewitus, A. J., B.M. Willis, K.C. Hayes, J.M. Burkholder, H.B. Glasgow, P.M. Glibert, and M.K. Burke . 1999. Mixotrophy and nitrogen uptake by *Pfiesteria piscicida* (Dinophyceae). Journal of Phycology 35: 1430-1437.

Limburg, K. E. and J.R. Waldman. 2009. Dramatic declines in north Atlantic diadromous fishes. BioScience 59(11): 955-965.

Lin, J., L. Xie, L.J. Pietrafesa, H. Xu, W. Woods, M.A. Mallin, and M.J. Durako. 2008. Water quality responses to simulated flow and nutrient reductions in the Cape Fear River estuary and adjacent coastal region, North Carolina. Ecological Modeling 212: 200-217.

Lin, J., L. Xie, L.J. Pietrafesa, J.S. Ramus, and H.W. Paerl. 2007. Water quality gradients across Albemarle-Pamlico estuarine system: seasonal variations and model applications. Journal of Coastal Research 23(1): 213-229.

Lin, J., L. Xie, L.J. Pietrafesa, J. Shen, M.A. Mallin, and M.J. Durako. 2006. Dissolved oxygen stratification in two micro-tidal partially-mixed estuaries. Estuarine Coastal and Shelf Science 70(3): 423-437.

Lin, Q. and I.A. Mendelssohn. 1998. The combined effects of phytoremediation and biostimulation in enhancing habitat restoration and oil degradation of petroleum contaminated wetlands. *Ecological Engineering* 10: 263274.

Lin, Q. and I.A. Mendelssohn. 2008. Evaluation of tolerance limits for restoration and phytoremediation with *Spartina alterniflora* in crude oil-contaminated coastal salt marshes. International Oil Spill Conference, Savanah, GA .

Lindberg, W. J. 1997. Can science resolve the attraction-production issue? Fisheries 22(4): 10-13.

Lindberg, W. J., T.K. Frazer, K.M. Portier, F. Vose, J. Loftin, D.J. Muries, D.M. Mason, B. Nagy , and M.K. Hart. 2006. Density-depenndent habitat selection and performance by a large mobile reef fish. Ecological Applications 16(2): 731-746.

Lindeman, K. C. 1997. Development of grunts and snappers of Southeast Florida: Cross-shelf distributions and effects of beach management alternatives. Ph.D. Dissertation, Univ. of Miami, Miami, Fl, 419 p.

Lindeman, K. C. and D.B. Snyder. 1999. Nearshore hardbottom fishes of southeast Florida and effects of habitat burial caused by dredging. Fisheries Bulletin 97: 508-525.

Lindquist, D. G., I. E. Clavijo, L. B. Cahoon, S. K. Bolden, and S. W. Burk. 1989. Quantitative diver visual surveys of innershelf natural and artificial reefs in Onslow Bay, N.C.: preliminary results for 1988 and 1989. p. 219-227 *in* Lang, M. A. and W. C. Jaap (eds.). Diving for Science...1989. American Academy for Underwater Sciences, Costa Mesa, California.

Lindquist, D. G., L.B. Cahoon, I.E. Clavijo, M.H. Posey, S.K. Bolden, L.A. Pike, S.W. Burk, and P.A.Cardullo. 1994. Reef fish stomach contents and prey abundance on reef and sand substrata associated with adjacent artificial and natural reefs in Onslow Bay, North Carolina. Bulletin of Marine Science 55(2-3): 308-318.

Lindquist, D. G., M.V. Ogburn, W.B. Stanley, H.L. Troutman, and S.M. Pereira. 1985. Fish utilization patterns on rubble-mound jetties in North Carolina. Bulletin of Marine Science 37: 244-251.

Lindquist, N. and L. Manning. 2001. Impacts of beach nourishment and beach scraping on critical habitat and productivity of surf fishes. NC Division of Marine Fisheries, Fisheries Resource Grant 98-EP-05: 41 .

Line, D. E. and N.M. White. 2007. Effects of Development on Runoff and Pollutant Export. Water Environment Research 79(2): 185-190.

Lipcius, R. N., D.B. Eggleston, S.J. Schreiber, R.D. Seitz, J. Shien, M. Sisson, W.T. Stockhausen, and H.V. Wang. 2008. Importance of metapopulation connectivity to restocking and restoration of marine species. Reviews in Fisheries Sciences 16(1-3): 101-110.

Lippson, A. J. and R. Moran. 1974. Manual for identification of early development stages of fishes of the Potomac River estuary. Martin Marietta Corp., PPSP-MP-13 , 282p.

Lipton, I., L. Perillo, R. Dixon, P. Pellerite, and T.E. Lankford. Fish nursery function of ocean surf-zone habitat: response to a human disturbance gradient. UNC Wilmington

Lissner, A. L., G.L. Taghon, D.R. Diener, S.C. Schroeter, and J.D. Dixon. 1991. Recolonization of deep-water hard-substrate communities: potential impacts from oil and gas development. Ecological Applications 1(3): 258-267.

Litaker, W., C.S. Duke, B.E. Kenney, and J. Ramus. 1987. Short-term environmental variability and phytoplankton abundance in a shallow tidal estuary. I. Winter and summer. Marine Biology 96(1): 115-121.

Litaker, W., C.S. Duke, B.E. Kenney, and J. Ramus. 1993. Short term environmental variability and phytoplankton abundance in a shallow tidal estuary. II. Spring and fall. Marine Ecology Progress Series 94(2): 141-154.

Litvin, S. Y. and M.P. Weinstein. 2003. Life history strategies of estuarine nekton: the role of marsh macrophytes, benthic microalgae, and phytoplankton in the trophic spectrum. Estuaries 26(2B): 552-562.

Livingston, R. J. 1975. Impact of Kraft pulp-mill effluent on estuarine and coastal fishes in Apalachee

Bay, Florida, U.S.A. Marine Biology 32(1): 19-48.

Livingstone, D. R. 2001. Contaminant-stimulated reactive oxygen species production and oxidative damage in aquatic organisms. Marine Pollution Bulletin 42(8): 656-666.

Loesch, J. G. 1987. Overview of the life history aspects of anadromous alewife and blueback herring in freshwater habitats. American Fisheries Society Symposium 1: 89-103.

Loesch, J. G. and W.H. Kriete Jr. 1984. Anadromous fisheries research program, 1980-83. Virginia Institute of Marine Science, Gloucester Point, VA.

Loesch, J. G., Jr. W.H. Kriete, and E.J. Foell. 1982a. Effects of light intensity on the catchability of juvenile anadramous *Alosa* species. Trans. Amer. Fish. Soc. 111: 41-44.

Loflin, R. K. 1995. The effects of docks on seagrass beds in the Charlotte Harbor estuary. Florida Scientist 58(2): 198-205.

Lombardero, N., C.T. Smit, J.T. McCullough, L.S. Floyd, J. Craft, A. Hannes, and K. Wilson. 2008. Surf City/North Topsail Beach, N.C. shoreline protection project, hardbottom resource confirmation and characterization study. ANAMAR Environmental Consulting, Inc. and Coastal Planning and Engineering, Inc., 44p.

Loosanoff, V. L. 1953. Behavior of oysters in water of low salinity. Proceedings of the National Shellfish Association 1952: 135-151.

Loosanoff, V. L. 1965. The American or Eastern oyster. U.S. Fish and Wildlife Service, Circular 205 .

Lott, J. P., D.W. Willis, and D.O. Lucchesi. 1996. Relationship of Food Habits to Yellow Perch Growth and Population Structure in South Dakota Lakes. Journal of Freshwater Ecology 11(1): 27-37.

Lowe, A. J., D.R.G. Farrow, A.S. Pait, S.J. Arenstam, and E.F. Lavan. 1991. Fish kills in coastal waters. National Oceanic and Atmospheric Administration, Rockville, MD, 190-1989p.

Lowery, J. and K.T. Paynter. 2002. The importance of molluscan shell substrate. National Marine Fisheries Service, Unpub. rep. 17p.

Lowrance, R. R. 1997. Water quality functions of riparian forest buffer systems in the Chesapeake Bay watershed. Environmental Management 21(5): 687-712.

Luckenbach, M. W. 1985. Biotic and hydrodynamic processes affecting the recruitment of a marine infaunal invertebrate. Dissertation Abstracts Int. Pt. B.- Science and Engineering 46(6): 119.

Luczkovich, J. J., H.J. Daniel III, and M.W. Sprague . 1999. Characterization of critical spawning habitats of weakfish, spotted seatrout and red drum in Pamlico Sounds using hydrophone surveys. East Carolina University, Institute for Coastal and Marine Resources, Greenville, NC, Final Report and Annual Performance Report , 127p.

Luczkovich, J. J., M.W. Sprague, S.E. Johnson, and R.C. Pullinger. 1999b. Delimiting spawning areas of weakfish *Cynoscion regalis* (Family Scianenidae) in Pamlico Sound, North Carolina using passive hydroacoustics surveys. Bioacoustics, The International Journal of Animal Sound and its Recording 10: 143-160.

Luczkovich, J. J., R.C. Pullinger, S.E. Johnson, and M.W. Sprague . 2008. Identifying sciaenid critical spawning habitats by the use of passive acoustics. Transactions of the American Fisheries Society 137: 576-605.

Luettich, R. A., J.E. McNinch, J.L. Pinckney, M.J. Alperin, C.S. Martens, H.W. Paerl, C.H. Peterson, and J.T. Wells. 1999. Neuse River estuary modeling and monitoring project, final report: Monitoring phase. Water Resources Research Institute, Raleigh, NC, 190p.

Luettich, R. A., J.E. McNinch, J.L. Pinckney, M.J. Alperin, C.S. Martens, H.W. Paerl, C.H. Peterson, and J.T. Wells. 2000. Neuse River estuary modeling and monitoring project, final report: Monitoring phase. Water Resources Research Institute, Raleigh, NC, 190p.

Løkkenborg, S. 2005. Impacts of trawling and scallop dredging on benthic habitats and communities. FAO, Rome, Italy, FAO Fisheries Technical Paper No. 472 , 58p.

MacIntyre, H. L. and J.J. Cullen. 1996. Primary production by suspended and benthic microalgae in a turbid estuary: Time-scales of variability in San Antonio Bay, Texas. Marine Ecology Progress Series 145: 245-268.

MacIntyre, H. L., R.J. Geider, and D.C. Miller. 1996. Microphytobenthos: the ecological role of the "secret garden" of unvegetated, shallow-water marine habitats. I. Distribution, abundance, and primary production . Estuaries 19(2A): 186-201.

MacIntyre, I. G. 2003. A classic marginal coral environment: tropical coral patches off North Carolina, USA. Coral Reefs 22: 474.

MacIntyre, I. G. and O.H. Pilkey. 1969. Tropical reef corals: tolerance of low temperatures on the North Carolina continental shelf. Science 166: 374-375.

MacKenzie, C., L.S. Weiss-Glanz, and J.R. Moring. 1985. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates. US Fish and Wildlife Service, Biological Report 82(11) .

MacKenzie, C. L. Jr. 1977. Development of an aquacultural program for rehabilitation of damaged oyster reefs in Mississippi. Marine Fisheries Review 39: 1-3.

Mackenzie, C. L. Jr. 1983. To increase oyster production in the northeastern United States. Marine Fisheries Review 45: 1-22.

MacKenzie Jr., C. L. 1997. The U.S molluscan fisheries from Massachusetts Bay through Raritan Bay to Delaware Bay. p. 87-117 *in* MacKenzie Jr., C. L., Burrell Jr., V. G., Rosenfield, A., and Hobart (eds.), W. L. The History, Present Condition, and Future of the Molluscan Fisheries of North and Central America and Europe, Vol. 1. Atlantic and Gulf Coasts. U.S. Department of Commerce, NOAA, NMFS, Silver Spring, MD, NOAA Tech. Rept. NMFS 127 .

Mackin, J. G. 1951. Incidence of infection of oysters by *Dermocystidium marinum* in the Barataria Bay area of Louisiana. Proceedings of the National Shellfish Association 1951: 22-35 .

Macpherson, T. A., L.B. Cahoon, and M.A. Mallin. 2007. Water column oxygen demand and sediment oxygen flux: patterns of oxygen depletion in tidal creeks. Hydrobiologia 586: 235-248.

MAFMC (Mid-Atlantic Fishery Management Council). 1998. Amendment 12 to the summer flounder, scup, and black sea bass fishery management plan. Mid-Atlantic Fishery Management Council and the Atlantic States Marine Fisheries Commission, in cooperation with the National Marine Fisheries Service, the New England Fishery Management Council, and the South Atlantic Fishery Management Council, 398p.

Maiolo, J. R. and P. Tschetter. 1981. Relating population growth to shellfish bed closures: a case study from North Carolina. Coastal Zone Management Journal 9(1): 1-18.

Maljkovic, A. and T.E. Van Leeuwen. 2008. Predation on the invasive red lionfish, Pterois volitans (Pisces: Scorpaenidae), by native groupers in the Bahamas. Coral Reefs 27: 501.

Mallin, M. A. 2000. Impacts of industrial animal production on rivers and estuaries. American Scientist 88: 2-13.

Mallin, M. A. 2009. Chapter 4: Effect of human land development on water quality. p. 64-94 *in* S. Ahuja (ed.). Handbook of Water Quality and Purity. Elsevier.

Mallin, M. A. and C.C. Corbett. 2006. How hurricane atttributes determine the extent of environmental effects: Multiple hurricanes and different coastal systems. Estuaries and Coasts 29(6a): 1046-1061.

Mallin, M. A., D.C. Parsons, V.L. Johnson, M.R. McIver, and H.A. CoVan. 2004. Nutrient limitation and algal blooms in urbanizing tidal creeks. Journal of Experimental Marine Biology and Ecology 298: 211-231.

Mallin, M. A., H.W. Paerl, J. Rudek, and P.W. Bates. 1993. Regulation of estuarine primary production by rainfall and river flow. *Marine Ecology-Progress Series* 93: 199-203.

Mallin, M. A., J.M. Bukholder, and M.J. Sullivan. 1992. Contributions of benthic microalgae to coastal fishery yield. *Transactions of the American Fisheries Society* 121: 691-695.

Mallin, M. A., J.M. Burkholder, L.B. Cahoon, and M.H. Posey. 2000a. North and South Carolina coasts. Marine Pollution Bulletin 41(1-6): 56-75.

Mallin, M. A., J.M. Burkholder, M.R. McIver, G.C. Shank, H.B. Glasgow, B.W. Touchette, and J. Springer. 1997. Comparative effects of poultry and swine waste lagoon spills on the quality of receiving streamwaters. Journal of Environmental Quality 26: 1622-1631.

Mallin, M. A., K.E. Williams, E.C. Esham, and R.P. Lowe. 2000b. Effect of human development on bacteriological water quality in coastal watersheds. Ecological Applications 10(4): 1047-1056.

Mallin, M. A., L.B. Cahoon, B.R. Toothman, D.C. Parson, M.R. McIver' M.L. Ortwine, and R.N. Harrington. 2007. Impacts of a raw sewage spill on water and sediment quality in an urbanized estuary. Marine Pollution Bulletin 54: 81-88.

Mallin, M. A., L.B. Cahoon, D.C. Parsons, and S.H. Ensign. 2001a. Effect of nitrogen and phosphorus loading on plankton in coastal plain blackwater rivers. Journal of Freshwater Ecology 16(3): 455-466.

Mallin, M. A., L.B. Cahoon, J.J. Manock, J.F. Merritt, M.H. Posey, R.K. Sizemore, W.D. Webster, and T.D. Alphin. 1998. A four year environmental analysis of New Hanover County tidal creeks 1993-1997. Center for Marine Science Research, Wilmington, NC, 98-01 , 115p.

Mallin, M. A., L.B. Cahoon, J.J. Manock, J.F. Merritt, M.H. Posey, T.D. Alphin, R.K. Sizemore, and K. Williams. 1996. Water quality in New Hanover County tidal creeks, 1995-1996. University of North Carolina Wilmington, Wilmington, NC.

Mallin, M. A., L.B. Cahoon, M.H. Posey, L.A. Leonard, D.C. Parsons, V.L. Johnson, E.J. Wambach, T.D. Alphin, K.A. Nelson, and J.F. Merritt. 2002a. Environmental quality of Wilmington and New Hanover County watersheds, 2000-2001. Center for Marine Science, UNC-W, Wilmington, 102p.

Mallin, M. A., M.H. Posey, G.C. Shank, M.R. McIver, S.H. Ensign, and T.D. Alphin. 1999b. Hurricane effects on water quality and benthos in the Cape Fear watershed: natural and anthropogenic impacts. Ecological Applications 9(1): 350-362.

Mallin, M. A., M.H. Posey, M.R. McIver, D.C. Parsons, S.H. Ensign, and T.D. Alphin. 2002b. Impacts and recovery from multiple hurricanes in a Piedmont-Coastal Plain river system. Bioscience 52: 999-1010.

Mallin, M. A., M.H. Posey, T.E. Lankford, M.R. McIver, S.H. Ensign, T.D. Alphin, M.S. Williams, M.L. Moser, and J.F. Merritt. 2001c. Environmental assessment of the lower Cape Fear River system, 2000-2001. Center for Marine Science Research, UNC-W, Wilmington, NC, CMS Report No. 01-01 , 139p.

Mallin, M. A., M.I. Haltom, and B. Song. 2009. Assessing Fecal Bacteria Sources in the Wrightsville Beach, N.C. Area: Final Report. Center for Marine Science, University of North Carolina at Wilmington, Wilmington, N.C., CMS Report 09-04 .

Mallin, M. A., M.R. mcIver, H.A. Wells, D.C. Parsons, and V.L. Johnson. 2005. Reversal of eutrophication following treatment upgrades in the New River estuary, North Carolina. Estuaries 28(5): 750-760.

Mallin, M. A., M.R. McIver, M.I.H. Spivey, M.E. Tavares, T. D. Alphin, and M.H. Posey. 2008. Environmental quality of Wilmington and New Hanover County watersheds 2006-2007. CMS Report 08-01 , 201p.

Mallin, M. A., S.H. Ensign, M.R. McIvor, G.C. Shank, and P.K. Fowler. 2001b. Demographic, landscape, and meteorological factors controlling the microbial pollution of coastal water. Hydrobiologia 460(185-193): MHC CHPP planner reports/journal articles file #2.

Mallin, M. A. and T.L. Wheeler. 2000. Nutrient and fecal coliform discharge from coastal North Carolina golf courses. Journal of Environmental Quality 29: 979-986.

Mallin, M. A., V.L. Johnson, and S.H. Ensign. 2009. Comparative impacts of stormwater runoff on water quality of an urban, a suburban, and a rural stream. Environmental Monitoring and

Assessment 159: 475-491.

Mallin, M. A., V.L. Johnson, S.H. Ensign, and T.A. MacPherson . 2006. Factors contributing to hypoxia in rivers, lakes and streams. Limnology and Oceanography 51: 690-701.

Mallin, M., E. Esham, K. Williams, and J. Nearhoof. 1999a. Tidal stage variability of fecal coliform and chlorophyll a concentrations in coastal creeks. Marine Pollution Bulletin 38(5): 414-422.

Mallison, D. J., S.J. Culver, S.R. Riggs, J.P. Walsh, D. Ames, and C.W. Smith. 2008. Past, present and future inlets of the Outer Banks barrier islands, North Carolina. ECU, Greenville, NC, 22p.

Malone, T. C., L.H. Crocker, S.E. Pike, and B.W. Wendler. 1988. Influences of river flow on the dynamics of phytoplankton production in a partially stratified estuary. Marine Ecology Progress Series 48: 235-249.

Mann, R. and J. Harding. 1997. Trophic studies on constructed "restored" oyster reefs. Annual research report to the U.S. Environmental Protection Agency Chesapeake Bay Program. Living Resources Committee, Virginia Institute of Marine Science, Gloucester Point, VA.

Manooch, C. S. and D.L. Mason. 1983. Comparative food studies of yellowfin in tuna, *Thunnus albacores*, and blackfin tuna, *Thunnus atlanticus*, (Pisces: Scobridae) from the southeastern and Gulf Coast of the United States. Acta Ichthyologica et Piscatoria 8: 25-46.

Manooch, C. S., D.L. Mason, and R.S. Nelson. 1984. Food and gastrointestinal parasites of dolphin *Coryphaena hippurus* collected along the southeastern and gulf coasts of the United States. Bulletin of the Japanese Society of Scientific Fisheries 50: 1511-1525.

Manooch, C. S. I. and R.A. Rulifson. 1989. Roanoke River water flow committee report: A recommended water flow regime for the Roanoke River, North Carolina, to benefit anadromous striped bass and other below-dam resources and users. NMFS, Beaufort, NC, NOAA Tech. Mem. NMFS-SEFC-216 .

Manooch III, C. S. 1984. Fisherman's guide - fishes of the southeastern United States. North Carolina State Museum of Natural History, Raleigh, NC, 362p.

Manooch III, C. S. and W.T. Hoggarth. 1983. Stomach contents and giant trematodes of the wahoo (*Acanthocybium solanderi*) , collected along the South Atlantic and Gulf coasts of the United States. Bulletin of Marine Science 33: 227-238.

Marburger, J. E., W.E. Johnson, T.S. Gross, D.R. Douglas, and J. Di. 2002. Residual organochlorine pesticides in soils and fish from wetland restoration areas in central Florida. Wetlands 22(4): 705-711.

Marcus, J. M. and T.P. Stokes. 1985. Polynuclear aromatic hydrocarbons in oyster tissue around three coastal marinas. Bulletin of Environmental Contamination and Toxicology 35: 835-844.

Marsh, G. A. and D.B. Turbeville. 1981. The environmental impact of beach nourishment: Two studies in southeastern Florida. Shore and Beach July: 40-44.

Marshall, L. P. 1976. A biological and fisheries profile of spotted seatrout, *Cynoscion nebulosus*. NC Division of Marine Fisheries, Morehead City, NC, Completion report for project AFCS-10 , 90p.

Marshall, M. D. 1995. North Carolina oyster restoration and fishery management plan. North Carolina Division of Marine Fisheries and the North Carolina Blue Ribbon Advisory Council on Oysters, Morehead City, NC, 116p.

Marshall, M. D., J.E. French, and S.W. Shelton. 1999. A history of oyster reef restoration in North Carolina. p. 107-116 *in* Luckenbach M.W., R. Mann, and J.A. Wesson (ed.). Oyster Reef Restoration: A Synopsis and Synthesis of Approaches. Virginia Institute of Marine Science Press, Gloucester Point, VA.

Marshall, N. 1954. Changes in the physiography of oyster bars in the James River, Virginia. Proceedings of the National Shellfisheries Association 44: 113-122.

Martin, P., N. Taft, and C. Sullivan. 1994. Reducing Entrainment of Juvenile American Shad Using a Strobe Light Diversion System. p. 57-63 *in* Cooper, J. E., R. T. Eades, R. J. Klauda, and J.G. Loesch (editors). Anadromous *Alosa* Symposium. Tidewater Chapter, American Fisheries Society, Bethesda, Maryland.

Matheson, R. E. Jr., D.K. Camp, S.M. Sogard, and K.A. Bjorgo. 1999. Changes in seagrass-associated fish and crustacean communities on Florida Bay mud banks: the effects of recent ecosystem changes? Estuaries 22(2B): 534-551.

Matilla, J., K.L. Heck Jr., M. Erika, M. Emily, G. Camilla, S. Williams, and D. Byron. 2008. Increased habitat structure does not always provide increased refuge from predation. Marine Ecology Progress Series 361(June 9): 15-20.

Matoura, R. F. C. and E.M.C. Woodward. 1983. Conservative behavior of riverine dissolved organic carbon in the Severn estuary: chemical and geochemical implications. Geochimica Cosmochimica Acta 47: 1293-1309.

Matozzo, V. and M.G. Marin. 2005. Can 4-nonylphenol induce vitellogenin-like proteins in the clam *Tapes philippinarum?* Environmental Research 97: 43-49.

Matson, E. A. and M.M. Brinson. 1985. Sulfate enrichments in estuarine waters of North Carolina. Estuaries 8: 279-289.

Matson, E. A. and M.M. Brinson. 1990. Stable carbon isotopes and the C:N ratio in the estuaries of the Pamlico and Neuse rivers, North Carolina. Limnology and Oceanography 35: 1290-1300.

Maxted, J. R., S. B. Weisberg, J. C. Chaillou, R. A. Eskin, and F. W. Kutz. 1997. The ecological condition of dead-end canals of the Delaware and Maryland coastal bays. Estuaries 20: 319-327.

McAllister, T. L., M.F. Overton, and Jr. E.D. Brill. 1996. Cumulative impact of marinas on estuarine water quality. Environmental Management. 20(3): 385-396.

McComas, S. 2003. Lake and pond management guidebook. CRC Press, Boca Raton, FL, 304 pp.p.

McDougal, W. G., M.A. Sturtevant, and P.D. Komar. 1987. Laboratory and field investigations of the impact of shoreline stabilization structures on adjacent properties. *in* Krause, N. C. ed. Coastal Sediments '87. American Society of Civil Engineering , New York, NY.

Mcgee, D., R.A. Laws, and L.B. Cahoon. 2008. Live benthic diatoms from the upper continental slope: extending the limits of marine primary production. Marine Ecology Progress Series 356: 103-112.

McGlathery, J. K. 2001. Macroagal blooms contribute to the decline of seagrass in nutrient-enriched coastal waters. Journal of Phycology (37): 453-456.

McIntosh, A. D., C.F. Moffat, G. Packer, and L. Webster. 2004. Polycyclic aromatic hydrocarbon (PAH) concentration and composition determined in farmed blue mussels (*Mytilus edulis*) in a sea loch pre- and post-closure of an aluminium smelter. J. Environ. Monit. 6: 209-218.

McIntosh, S., T. King, D. Wu, and P.V. Hodson. 2010. Toxicity of dispersed weathered crude oil to early life stages of Atlantic herring (*Clupea harengus*). Environmental Toxicology and Chemistry 29(5): 1160-1167.

McIvor, C. C. and W.E. Odum. 1987. Marsh fish community structure: roles of geomorphology and salinity. Ph.D. dissertation, University of Virginia, Charlottesville, VA, 132 p.

McKenney, C. L. Jr. 2005 . The influence of insect juvenile hormone agonists on metamorphosis and reproduction in estuarine crustaceans. Integrative and Comparative Biology 45(1): 97-105.

McLachlan, A., T. Erasmus, A.H. Dye, T. Wooldridge, G. Van der Horst, G. Rossouw, T.A. Lasiak, and L. McGwynne. 1981. Sand beach energetics: an ecosystem approach towards a high energy interface. Estuarine, Coastal, and Shelf Science 13: 11-25.

McLachlan, A. 1996. Physical factors in benthic ecology: effects of changing sand particle size on beach fauna. Marine Ecology Progress Series 131: 205-217.

McLaughlin, S. M. and S.J. Jordan. 2003. A potential ecoforecast for protozoal infections of the eastern oyster (*Crassostrea virginica*) in the upper Chesapeake Bay. p. 73-79 *in* Vallette-Silver, N. J. and Scavia (eds.), D. Ecological Forecasting: New Tools for Coastal and Ecosystem Management. NOAA, Silver Spring, MD, NOAA Technical Memeorandum NOS NCCOS 1 .

McNinch, J. E. and J.T. Wells. 1992. Effectiveness of beach scraping as a method of erosion control. Shore and Beach 1: 13-20.

McNinch, J. E. and R.A. Luettich Jr. 2000. Physical porcesses around a cuspate foreland: implications to the evolution and long-term maintenance of a cape-associated shoal. Continental Shelf Research 20: 2367-2389.

McNinch, J. E. and R.A. Luettich Jr. 2000. Physical processes around a cuspate foreland: implications to the evolution and long-term maintenance of a cape-associated shoal. Continental Shelf Research 20: 2367-2389.

Meister, H. S., D.M. Wyanski, J.K. Loefer, S.W. Ross, A.M. Quattrini, and K.J. Sulak. 2005. Further evidence for the invasion and establishment of *Pterois volitans* (Teleostei: Scorpaenidae) along the Atlantic coast of the United States. Southeastern Naturalist 4(2): 193-206.

Menhinick, E. F. 1991. The freshwater fishes of North Carolina. The Delmar Company, Charlotte, NC, 227p.

Menzel, D. W. 1993. Ocean processes: U.S. Southeast continental shelf. Office of Scientific and Technical Information, U.S. Department of Energy.

Menzel, R. W. and S.H. Hopkins. 1955. Crabs as predators of oysters in Louisiana. Proceedings of the National Shellfisheries Association 45: 177-184.

Mercer, L. P. 1984. A biological and fisheries profile of red drum, *Sciaenops ocellatus*. North Carolina Division of Marine Fisheries, Morehead City, NC, Special Scientific Report 41 .

Mercer, L. P. 1989a. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic)--weakfish. U.S. Fish and Wildlife Service, 82(11.109) , 17p.

Meyer, C. E. 1982. Zooplankton communities in Chesapeake Bay seagrass systems. M.A. Thesis, College of William and Mary, Williamsburg, VA, 96 p.

Meyer, D. L. 1994. Habitat partitioning between the Xanthid crabs *Panopeus herbstii* and *Eurypanopeus depressus* on intertidal oyster reefs (*Crassostrea virginica*) in southeastern North Carolina. Estuaries 17(3): 6674-679.

Meyer, D. L. and E.C. Townsend. 2000. Faunal utilization of created intertidal eastern oyster (*Crassostrea virginica*) reefs in the southeastern United States. Estuaries 23(1): 34-45.

Meyer, D. L., E.C. Townsend, and G.W. Thayer. 1997. Stabilization and erosion control value of oyster cultch for intertidal marsh. Restoration Ecology 5(1): 93-99.

Meyer, D. L., E.C. Townsend, and P.L. Murphey. 1996. Final report for the project evaluation of restored wetlands and enhancement methods for existing restorations. National Oceanic and Atmospheric Administration, Office of Habitat Conservation Restoration Center, Silver Springs, MD.

Meyer, D. L., J. M. Johnson, and J. W. Gill. 2001. Comparison of nekton use of *Phragmites australis* and *Spartina alterniflora* marshes in the Chesapeake Bay, USA. Marine Ecology-Progress Series 209(209): 71-84.

Meyer, J. L., L.A. Kaplan, D. Newbold, D.L. Strayer, C.J. Woltemade, J.B. Zedler, R. Beilfuss, Q. Carpenter, R. Semlitsch, M.C. Watzin, and P. Zedler. 2007. Where rivers are born: the scientific imperative for defending small streams and wetlands. American Rivers, Sierra Club, and Turner Foundation, http://amr.convio.net/site/DocServer/WhereRiversAreBorn1.pdf?docID=182, 23 pp.p.

Micheli, F., M.J. Bishop, C.H. Peterson, and J. Rivera. 2008. Alteration of seagrass species composition and function over two decades. Ecological Monographs 78(2): 225-244.

Micheli, F. M. and C. H. Peterson. 1999. Estuarine vegetated habitats as corridors for predator movement. Conservation Biology 13(4): 869-881.

Milam, C. D., J.L. Farris, and J.D. Wilhide. 2000. Evaluating mosquito control pesticides for effect on target and nontarget organisms. Archives of Environmental Contamination and Toxicology. 39(.): 324-328.

Miles, J. R., P.E. Russell, and D.A. Huntley. 2001. Field measurements of sediment dynamics in front of a seawall. Journal of Coastal Research 17: 195-206.

Miller, D. C. 1989. Abrasion effects on microbes in sandy sediments. Marine Ecology Progress Series 55: 73-82.

Miller, D. C., R.J. Geider, and H.L. MacIntyre. 1996. Microphytobenthos: the ecological role of the "secret garden" of unvegetated, shallow-water marine habitats. II. Role in sediment stability and shallow-water food webs. Estuaries 19(2A): 202-212.

Miller, G. C. and W.J. Richards. 1980. Reef fish habitat, faunal assemblages, and factors determining distributions in the South Atlantic Bight. Proceedings of the U.N.F. and Caribbean Fisheries Institute, Miami Beach, Fl 32: 114-130.

Miller, J. M. 1992. Larval fish migration at Oregon Inlet, North Carolina. Supplemental Reports to the Department of the Interior Consultant's Report. US Dept. of the Interior. USFWS 8: 27.

Miller, J. M., L.B. Crowder, and M.L. Moser. 1985. Migration and utilization of estuarine nurseries by juvenile fishes: an evolutionary perspective. p. 338-352 *in* M.A. Rankin (ed.). Migration: mechanisms and adaptive significance. Contributions to Marine Science (Supplement). 27 .

Miller, M. W. and M.E. Hay. 1996. Coral-seaweed-grazer-nutrient interactions on temperate reefs. Ecological Monographs 66(3): 323-344.

Minello, T. J. 1999. Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of Essential Fish Habitat. p. 43-75 *in* Benaka, L. R. ed. Fish Habitat: Essential Fish Habitat and Rehabilitation. American Fisheries Society, Bethesda, Maryland, 459 p.

Mitchell, W., T. Pratt, and C. Taylor. 2007. Feasibility of using mobile hydroacoustic surveys for estimating spawning stock size of blueback herring in western Albemarle Sound, North Carolina. North Carolina Sea Grant, Morehead City, NC.

Mitsch, W. J. and J.G. Gosselink. 1993. Wetlands - 2nd edition. John Wiley & Sons, Inc., U.S.A., . 722p.

Mock, C. R. 1966. Natural and altered estuarine habitats of penaeid shrimp. Proceedings Gulf Caribbean Fish Institute 19th Annual Session : 86-98.

Moeller, P. D. R., K.R. Beauchesne, K.M. Huncik, W.C. Davis, S.J. Christophoer, P. Riggs-Gelasco, and A.K. Gelasco. 2007. Metal complexes and free radical toxins produced by *Pfiesteria piscicida*. Environmental Science and Technology 41(4): 1166-1172.

Moffat and Nichol, I. 2010. Terminal groin study. for NC Coastal Resources Commission, Raleigh.

Moore, J. W. 1991. Inorganic contaminants of surface water, research and monitoring priorities.

Springer-Verlag, New York, NY, Springer series on environmental management. 334p.

Moore, J. W. and J.A. Moore. 1976. The basis of food selection in flounders, *Platichthys flesus* (L.) in Severn estuary. Journal of Fish Biology 9: 139-156.

Moore, K. A. 2004. Influence of seagrasses on water quality in shallow regions fo the lower Chesapeake Bay. Journal of Coastal Research 45: 162-178.

Moore, K. A., H.A. Neckles, and R.J. Orth. 1996. Zostera marina (eelgrass) growth and survival along a gradient of nutrients and turbidity in the lower Chesapeake Bay. Marine Ecology Progress Series. 142(.): 247-259.

Moore, K. A., R.L. Wetzel, and R.J. Orth. 1997. Seasonal pulses of turbidity and their relations to eelgrass (Zostera marina L.) survival in an estuary. Journal of Experimental Marine Biology and Ecology. 215(.): 115-134.

Moore, R. H. 1992. Low-salinity backbays and lagoons. p. 541-614 *in* C.T. Hackney, S. M. Adams and W. H. Martin eds. Biodiversity of the southeastern United States: aquatic communities. John Wiley and Sons, Inc., NY, 779 p.

Morgan, P. A., D.M. Burdick, and F.T. Short. 2009. The functions and values of fringing salt marshes in northern New England, USA. Estuaries and Coasts 32: 483-495.

Moser, M. L., A.M. Darazsdi, and J. R. Hall. 2000. Improving passage efficiency of adult American shad at low-elevation dams with navigation locks. North American Journal of Fisheries Management 20: 376-385.

Moser, M. L. and M.E. Terra. 1999. Low light as a possible impediment to river herring migration. Center for Marine Science Research, University of North Carolina at Wilmington, Wilmington, NC, 137p.

Moser, M. L. and S. W. Ross. 1995. Habitat use and movements of shortnose and Atlantic sturgeons in the lower Cape Fear River, North Carolina. Transactions of the American Fisheries Society 124(2): 225-234.

Moser, M. L. and B. L. Taylor. 1995. Hard bottom habitat in North Carolina state waters: a survey of available data. Final report to NC Division of Coastal Management. Unpub. doc., 20p.

Moss, J. A., E.M. Burreson, and K.S. Reece. 2006. Advanced *Perkinsus marinus* Infections in *Crassostrea ariakensis* maintained under laboratory conditions. Journal of Shellfish Research 25(1): 65-72.

MSC (Moratorium Steering Committee). 1996. Final report of the Moratorium Steering Committee to the Joint Legislative Commission on Seafood and Aquaculture of the North Carolina General Assembly. N.C. Sea Grant College Program, Raleigh, NC, NC-SG-96-11 , 155p.

Mu-Chan, K., C. Sang-Man, and J. Woo-Geon. 2007. Short-term physiological response of the Pacific oyster, *Crassostrea gigas*, on exposure to varying levels of polycyclic aromatic hydrocarbon. Aquaculture Research 38(15): 1612-1681.

Mudre, J. M., J.J. Ney, and R.J. Neves. 1985. An analysis of the impediments to spawning migrations of anadromous fish in Virginia rivers. Final report. Virginia Highway Research Council, V.A. Department of Highways and Transportation, Charlottesville, Va.

Mulholland, P. J. 1979. Organic carbon in a swamp-stream ecosystem and export by streams in eastern North Carolina. Ph.D. Dissertation, University of North Carolina, Chapel Hill, NC

Mulholland, P. J. and E.J. Kuenzler. 1979. Organic carbon export from upland and forested wetland watersheds. Limnology and Oceanography 24: 960-966.

Munger, A. and M. Shore. 2005. Understanding Global Warming for North Carolina: Sound Science For Making Informed Decisions. Environmental Defense, Raleigh, NC, 24p.

Murphey, P. L. and M. S. Fonseca. 1995. Role of high and low energy seagrass beds as nursery areas for *Penaeus duorarum* in North Carolina. Marine Ecology Progress Series 121: 91-98.

Murphy, M. D. and R.G. Taylor. 1990. Reproduction, growth, and mortality of red drum *Sciaenops ocellatus* in Florida waters. Fishery Bulletin 88: 531-542.

Myers, R. A., J.K. Baum, T.D. Shepherd, S.P. Powers, and C.H. Peterson. 2007. Cascading effects of the loss of Apex predatory sharks from a coastal ocean. Science 315(March): 1846-1850.

Najjar, R. G., H.A. Walker, P.J. Anderson, E.J. Barron, R.J. Bord, J.R. Gibson, V.S. Kennedy, C.G. Knight, J.P. Megonigal, R.E. O'connor, C.D. Polsky, N.P. Psuty, B.A. Richards, L.G. Sorenson, E.M. Steele, and R.S. Swanson. 2000. The potential impacts of climate change on the Mid-Atlantic coastal region. Climate Research 14(3): 219-233.

NC Sea Grant. 1997. Coastal water quality. NC State University, Raleigh, NC, UNC-SG-97-04 , 72 p.

NC Sea Grant. 2000. Aquatic nuisance species report: An update on Sea Grant research and outreach projects. Sea Grant, Raleigh, NC, 4p.

NC Sea Grant. 2009. Developing a management strategy for North Carolina's coastal ocean. UNC-SG-09-02 , 101p.

NCREDC (North Carolina Rural Economic Development Center). 2005. Water 2030 Initiative. Conclusions and Recommendations.

Neckles, H. A., R.L. Wetzel, and R.J. Orth. 1993. Relative effects of nutrient enrichment and grazing on epipyte-macrophyte (*Zostera marina* L.) dynamics. Oecologia (93): 285-295.

Nelson, D. M., M.E. Monaco, E.A. Irlandi, L.R. Settle, and L. Coston-Clements. 1991. Distribution and abundance of fishes and invertebrates in southeast estuaries. NOAA/NOS Strategic Environmental Assessment Division, Silver Spring, MD, 167p.

Nelson, K. A., L.A. Leonard, M.H. Posey, T.D. Alphin, and M.A. Mallin. 2004. Journal of Experimental Marine Biology and Ecology. Using transplanted oyster (*Crassostrea virginica*) beds to improve water quality in small tidal creeks: a pilot study 298(2): 347-368.

Nelson, R. W. and C.H. Walburg. 1977. Population dynamics of yellow perch (*Perca flavescens*), sauger (*Stizostedion canadense*) and walleye (*S. vitreum vitreum*) in four main stem Missouri

River reservoirs. Journal of the Fisheries Research Board of Canada 34: 1748-1763.

Nelson, T. C. 1938. The feeding mechanism of the oyster. I. On the pallium and branchial chambers of *Ostrea virginica*, *O. edulis*, and *O. angulata*, with comparisons with other species of the genus. Journal of Morphology 63: 1-61.

Nelson, T. C. 1960. The feeding mechanism of the oyster. II. On the gills and palps of *Ostrea virginica*, *O. edulis*, and *O. angulata*, with comparisons with other species of the genus. Journal of Morphology 107: 163-203.

Nero, L. 2001. Fiber optic cables: issues for marine habitat and fisheries. Habitat Hotline Atlantic 8(1): 1-2.

Nestlerode, J. A., M.W. Luckenbach, and F.X. O'Beirn. 2007. Settlement and survival of the oyster *Crassostrea virginica* on created oyster reef habitats in Chesapeake Bay. Restoration Ecology 15(2): 273-283.

Neves, F. M. and C.E. Bemvenuti. 2006. The ghost crab *Ocypode quadrata* (Fabruicus, 1787) as potential indicator of antropic impact along the Rio Grande do Sul coast, Brazil. Biological Conservation 133: 431-435.

Neves, R. J., A.E. Bogan, J.D. Williams, S.A. Ahlstedt, and P.W. Hartfield. 1997. Status of aquatic mollusks in the southeastern United States: a downward spiral of diversity. p. 43-85 *in* G.W. Benz, D. E. Collins eds. Aquatic fauna in peril: the southeastern perspective. Southeast Aquatic Research Institute, Decatur, GA, Special Publication 1 , 554 p.

Newcombe, C. P. and D.D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11: 72-82.

Newell, R. I. E. 1988. Ecological changes in the Chesapeake Bay: are they the result of overharvesting the Amercian oyster? p. 536-546 *in* M.P. Lynch and E.C. Krome (eds.). Understanding the estuary: advances in Chesapeake Bay research. Chesapeake Bay Research Consortium, Baltimore, MD, Publication 129 .

Newell, R. I. E. 2004. Ecosystem influence of natural and cultivated populations of suspension-feeding bivalve molluscs: a review. Journal of Shellfish Research 23(1): 51-61.

Newell, R. I. E. and E.W. Koch. 2004. Modelling seagrass density and distribution in response to changes in turbidity stemming from bivalve filtration and seagrass sediment stabilization. Estuaries 27(5): 793-806.

Newell, R. I. E., J.C. Cornwell, and M.S. Owens. 2002. Influence of simulated bivalve biodeposition and microphytobenthos on sediment nitrogen dynamics: a laboratory study. Limnology and Oceanography 47(5): 1367-1379.

Newell, R. I. E., T.R. Fisher, R.R. Holyoke, and J.C. Cornwell. 2005. Influence of eastern oysters on nitrgen and phosphorus regeneration in Chesapeake Bay, USA. p. 93-120 *in* R. Dame and S. Olenin (eds.). The comparative roles of suspension feeders in ecosystems. Springer, The Netherlands, 47 .

Nicholson, N. and S.R. Jordan. 1994. Biotelemetry study of red drum in Georgia. Georgia Department of Natural Resources, Brunswick, GA, 64p.

Nixon, S. W. 1995. Coastal marine eutrophication: a definition, social causes, and future concerns. Ophelia 41: 199-219.

Nixon, S. W. 2009. Eutrophication and the macroscope. Hydrobiologia 629: 5-19.

Nixon, S. W., C.A. Oviatt, and S.L. Northby. 1973. Ecology of small boat marinas. University of Rhode Island, Kingston, RI, Mar. Tech. Rep. Ser. No. 5 , 20p.

NMFS (National Marine Fisheries Service). 2002. Annual Report to Congress on the Status of U.S. Fisheries - 2001. NOAA, Silver Spring, MD, 142p.

NMFS (National Marine Fisheries Service). 2008. Annual Report to Congress on the Status of U.S. Fisheries - 2007. NOAA, Silver Spring, MD, 23p.

NOAA (National Oceanic and Atmospheric Administration). 1996. NOAA's estuarine eutrophication survey. Volume 1: South Atlantic Region. Office of Ocean Resources Conservation Assessment, Silver Spring, Md, 50p.

NOAA (National Oceanic and Atmospheric Administration). 2001. Unpublished data - ELMR distribution and abundance and life history tables for estuarine fish and invertebrate species. NOAA/NOS Biogeography Program, Silver Springs, MD.

NOAA (National Oceanographic and Atmospheric Administration). 2001. Seagrasses: an overview for coastal managers. NOAA, Charleston, SC, 19p.

Noble, E. 1996. Report to the oyster, clam, and scallop committee on Ward Creek field investigation by resource enhancement staff . DENR, DMF, Unpub. rep. 8p.

Noble, E. B. and K.A. Mohr. 2008. Currituck Sound Restoration Project, submerged aquatic vegetation transect field surveys, Currituck Sound NC and Back Bay VA, Summer 2006. Elizabeth City State University, Elizabeth City, NC , 21 pp.p.

Noble, E. B. and K.M. Hall. 2005. Submerged aquatic vegetation cooperative habitat mapping project: a partnership to map submerged aquatic vegetation in the estuarine and coastal riverine systems of North Carolina and Southeastern Virginia. Elizabeth City State University, Elizabeth City, NC, February , 15 pp.p.

Noble, E. B. and R.J. Monroe. 1991. Classification of Pamlico Sound Nursery Areas: Recommendations for Critical Habitat Criteria. North Carolina Department of Environment, Health, and Natural Resources, Morehead City, NC, A/P Project No. 89-09 , 70 p.

Noga, E. J. 2000. Skin ulcers in fish: Pfiesteria and other Etiologies. Toxicologic pathology 28(6): 807-823.

Noga, E. J., L. Khoo, J.B. Stevens, Z. Fan, and J.M. Burkholder . 1996. Novel toxic dinoflagellate causes epidemic disease in estuarine fish. Marine Pollution Bulletin 32: 219-224 .

North Carolina Coastal Futures Committee. 1994. Charting a Course for Our Coast. North Carolina Coastal Futures Committee, 101p.

North Carolina Ocean Resources Task Force. 1995. Management and stewardship of North Carolina's coastal ocean: Recommendations of the NC Ocean Resources Task Force. DCM, Unpub. rep. 25p.

NRC (National Research Council). 1995. Beach nourishment and protection. National Academy Press, Washington, D.C., 334p.

NRC (National Research Council). 2000. Clean coastal waters: Understanding and reducing the effects of nutrient pollution. Committee on the causes and management of eutrophication, ocean studies board, Water Science and Technology Board. National Academy Press, Washington, DC.

NRC (National Research Council). 2001. Marine Protected Areas: tools for sustaining ocean ecosystems. National Academy Press, Washington, DC.

NRC (National Research Council). 2002. Effects of trawling and dredging on seafloor habitat. National Academy Press, Washington, D.C., 125p.

NRC (National Research Council). 2003. Non-native oysters in the Chesapeake Bay. The National Academic Press, Washington, DC.

NRC (National Research Council). 2007. Mitigating shore erosion on sheltered coasts. National Academy Press, Washington, DC.

NRCS (Natural Resources Conservation Service). 2002. Restoring America's Wetlands, Wetland Reserve Program. U.S. Department of Agriculture, Natural Resources Conservation Service, ., . 8p.

Null, K., J. Burkholder, D. DeMaster, R. Corbett, C. Thomas, and R. Reed. 2009. Ammonium fluxes from channel deposits in the Neuse River Estuary, North Carolina, USA: Implications for ammonium increase in estuarine waters. In: *Proceedings of the 2009 Winter Meeting of the American Society of Limnology and Oceanography*, Nice, France (abstract; Ph.D. thesis available in April 2010) .

Nunes, M., J.P. Coelho, P.G. Cardos, M.E. Pereira, A.C. Duarte, and M.A. Pardal. 2008. The macrobenthic community along a mercury contamination in a temperate estuarine system. Science of the Total Environment 405: 186-194.

NWF (National Wildlife Federation). 2008. More variable and uncertain water supply: global warming's wake-up call for the southeastern United States. National Wildlife Federation, 8p.

Nybakken, J. W. 1993. Marine Biology, an Ecological Approach. Harper Collins College Publishers, New York, NY, Third edition , 462p.

Nye, J. A., J.S. Link, J.A. Hare, and W.J. Overholtz. 2009. Changing spatial distribution of fish stocks in relation to climate and population size on the northeast United States continental shelf. Marine Ecology Progress Series 393: 111-129.

O'Connor, T. P. and G .G. Lauenstein. 2005. Status and trends of copper concentrations in mussels and oysters in the USA. Marine Chemistry 97(1-2): 49-59.

Öham, M. C., P.Sigray, and H. Westerberg. 2007. Offshore windmills and the effects of electromagnetic fields on fish. Ambio 36(8): 630-633.

O'Neill, J. T. 1980. Aspects of the life histories of anadromous alewife and the blueback herring, Margaree River and Lake Ainsle, Nova Scotia, 1978-1979. M.S. Thesis, Acadia University, Wolfville, Nova Scotia, Canada, 306 p.

O'Rear, C. W. 1983. A study of river herring spawning and water quality in Chowan River. NC Department of Natural Resources and Community Development, DMF, Raleigh, NC, Complete Report, Project AFC-17 , 31p.

Odum, E. P. 1959. Fundamentals of ecology. 2nd Edition. W. B. Saunders Co., Philadelphia, Pa, 546p.

Odum, W. E., T.J. Smith III, J.K. Hoover, C.C. McIvor, and E.C. Pendleton. 1984. The ecology of tidal freshwater marshes of the United States East Coast: a community profile. U.S. Fish and Wildlife Service, Washington, D.C., FWS/OBS-83/17 , 177p.

Ogden J.C. 1980. Faunal relationships in Caribbean seagrass beds. p. 173–198 *in* Phillips R.C., McRoy C. P. eds. Handbook of seagrass biology. Garland Publishing, New York.

Ojeda, G. Y., P.T.Gayes, A.L. Sapp, P.C. Jutte, and R.F. Van Dolah. 2001. Habitat mapping and sea bottom change detection on the shoreface and inner shelf adjacent to the Grand Strand beach nourishment project. Coastal Carolina University and SC DNR, Charleston, SC, 48p.

Olsen, S., M.E.Q. Pilson, and J.N. Gearing. 1982. Ecological consequences of low sustained concentrations of petroleum hydrocarbons in temperate estuaries. Graduate School of Oceanography, University of Rhode Island, Narragansett, RI.

Olsgard, F. and J. Gray. 1995. A comprehensive analysis of the effects of offshore oil and gas expoloration and production on the benthic communities of the Norwegian continental shelf. Marine Ecology Progress Series 122: 277-306.

Orlando, S. P. Jr., C. J. K. P.H. Wendt, M.E. Pattillo, K.C. Dennis, and G.H. Ward . 1994. Salinity characteristics of South Atlantic estuaries. National Oceanic and Atmospheric Administration, Office of Ocean Conservation and Assessment, Silver Springs, MD, 117p.

Orr, J. C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G.K. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarmiento, R. D. S. R. Schlitzer, I.J. Totterdell, M.F. Weirig, Y. Yamanaka, and A. Yool. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437(7059): 681-686.

Ortega, S. and J.P. Sutherland. 1992. Recruitment and growth of the eastern oyster, *Crassostrea virginica*, in North Carolina. Estuaries 15(2): 158-170.

Orth, D. J. and R.J. White. 1993. Stream habitat management . p. 205-228 *in* C.C. Kohler and W.A. Hubert (eds.). Inland Fisheries Management in North America. American Fisheries Society, Bethesda, MD, 594 p.

Orth, R. J. 1975. Destruction of eelgrass, *Zostera marina*, by the cownose ray, *Rhinoptera bonasus*, in the Chesapeake Bay. Chesapeake Science 16(3): 205-208.

Orth, R. J. 1992. A perspective on plant-animal interactions in seagrasses: physical and biological determinants influencing plant and animal abundance. p. 147-164 *in* D. M. John, S. J. Hawkins and J. H. Price eds. Plant-Animal Interactions in the Marine Benthos. Clarendon Press, Oxford, Systematic Special Volume No. 46 , 570 p.

Orth, R. J., J. Simons, J. Capelli, V. Carter, L. Hindman, S. Hodges, K. Moore, and N. Rybicki. 1986. Distribution of submerged aquatic vegetation in the Chesapeake Bay and tributaries - 1985. US EPA, Washington, DC, Final report .

Orth, R. J., M. Luckenbach, and K.A. Moore. 1994. Seed dispersal in a marine macrophyte: implications for colonization and restoration. Ecology 75(7): 1927-1939.

Orth, R. J., R.A. Batiuk, P.W. Bergstrom, and K.A. Moore. 2002. A perspective on two decades of policies and regulations influencing the protection and restoration of submerged aquatic vegetation in Chesapeake Bay, USA. Bulletin of Marine Science 71(3): 1391-1403.

Orth, R. J., T.J.B. Carruthers, W.C. Dennison, C.M. Duarte, J.W. Fourqurean, K.L. Heck Jr., A.R. Hughes, G.A. Kendrick, J.D. Kenworthy, S. Olyarnik, F.T. Short, M. Waycott, and S.L. Williams. 2006. A global crisis for seagrass ecosystems. Bioscience 56(12): 987-997.

Overstreet, R. M. 1983. Aspects of the biology of the red drum, *Sciaenops ocellatus*. Gulf Research Report Supplement 1: 45-68.

Oviatt, C. A. 2004. The changing ecology of temperate coastal waters during a warming trend. Estuaries 27(6): 895-904.

Paerl, H. W. 1982. Environmental factors promoting and regulating N_2 fixing blue-green algal blooms in the Chowan River. N. C. University of North Carolina, Water Resources Research Institute, Raleigh, NC, Report No. 176 , 65p.

Paerl, H. W. and D.R. Whitall. 1999. Anthropogenically derived atmospheric nitrogen deposition, marine eutrophication and harmful algal bloom expansion: Is there a link? Ambio 28(4): 307-311.

Paerl, H. W., J.D. Bales, L.W. Ausley, C.P. Buzzelli, L.B. Crowder, L.A. Eby, J.M. Fear, M. Go, B.L. Peierls, T.L. Richardson, and J.S. Ramus. 2001. Ecosystem impacts of three sequential hurricanes (Dennis, Floyd, and Irene) on the United States' largest lagoonal estuary, Pamlico Sound, NC. Proceedings of the National Academy of Sciences, USA 98(10): 5655-5660.

Paerl, H. W., J. Pinckney, J. Fear, and B. Peierls. 1998. Ecosystem response to internal watershed organic matter loading: Consequences for hypoxia in the eutrophying Neuse River Estuary, North Carolina. Marine Ecological Progress Series 166: 17-25.

Paerl, H. W., L.M. Valdes, A.R. Joyner, B.L. Peierls, M.F. Piehler, S.R. Riggs, R.R. Christian, L.A. Eby, L.B. Crowder, J.S. Ramus, E.J. Clesceri, C.P. Buzzelli, and R.A. Luettich Jr. 2006. Ecological response to hurricane evens in the Pamlico Sounds system, North Carolina, and implications for assessment and management in a regime of increased frequence. Estuaries and Coasts 29(6a): 1033-1045.

Paerl, H. W., L.M. Valdes, A.R. Joyner, and M.F. Piehler. 2004. Solving problems resulting from solutions: evolution of a dual nutrient management strategy for the eutrophying Neuse River estuary, North Carolina. Environmental Science and Technology 38: 3068-3073.

Paerl, H. W., L.M. Valdes-Weaver, A.R. Joyner, and V. Winklemann. 2007 . Phytoplankton indicators of ecological change in the eutrophying Pamlico Sound system, North Carolina. Ecological Applications 17(5): S88-S101.

Paerl, H. W., M.M. Mallin, C.A. Donahue, M. Go, and B.L. Peierls. 1995. Nitrogen loading sources and eutrophication of the Neuse River, North Carolina: direct and indirect roles of atmospheric deposition. UNC - Chapel Hill, Water Resources Research Institute, Chapel Hill, NC, Publication 291 .

Page, C. A., J.S. Bonner, T.J. McDonald, and R.L. Autenrieth. 2002. Behavior of a chemically dispersed oil in a wetland environment. Water Research 36: 3821-3833.

Page, H. M. and M. Lastra. 2003. Diet of intertidal bivalves in the Ria de Arosa (NW Spain): evidence from stable C and N isotope analysis. Marine Biology 143: 519-532.

Page, L. M. and B.M. Burr. 1991. A field guide to freshwater fishes of North America north of Mexico. Houghton Mifflin Company, Boston, USA, 432p.

Palacios, S. L. and R.C. Zimmerman. 2007. Response of eelgrass Zostera marina to CO^2 enrichment: possible impacts of cimate change and potential for remediation of coastal habitats. Marine Ecology Progress Series 344: 1-13.

Paller, M. H. 1987. Distribution of larval fish between macrophyte beds and open channels in a southeastern floodplain swamp. Journal of Freshwater Ecology 4(2): 191-200.

Palmer, M. A. 1988. Epibenthic predators and marine meiofauna: separating predation, disturbance, and hydrodynamic effects. Ecology 69: 1251-1259.

Palumbi, S. R. and B.D. Kessing. 1991. Population biology of the trans-Arctic exchange: MtDNA sequence similarity between Pacific and Atlantic sea urchins. Evolution 45: 1790-1805.

Pantell, S. E. 1993. Potential environmental impacts/Coastal Act issues. *In:* Seawater Desalination in California. California Coastal Commission, San Francisco, Ca.

Parker Jr., R. O. and R.L. Dixon. 1998. Changes in a North Carolina reef fish community after 15 years of intense fishing - global warming implications. Transactions of the American Fisheries Society 127: 908-920.

Parker, R. O., D.R. Colby, and T.D. Willis. 1983. Estimated amount of reef habitat on a portion of the US South Atlantic and Gulf of Mexico continental shelf. Bulletin of Marine Science 33(4): 935-940.

Parrow, M. W., J.M. Burkholder, N.J. Deamer, and J.S. Ramsdell. 2005. Contaminant-free cultivation of *Pfiesteria shumwayae* (Dinophyceae) on a fish cell line. Aquatic Microbial Ecology 39: 97-105.

Partyka, M. L. and M.S. Peterson. 2008. Habitat quality and salt-marsh species assemblages along an anthropogenic estuarine landscape. Journal of Coastal Research 24(6): 1570-1581.

Partyka, M. L., S. W. S.W. Ross, A.M. Quattrini, G.R. Sedberry, T.W. Birdsong, J. Potter, and S. Gottfried. 2007. Southeastern United States Deep-Sea Corals (SEADESC) Initiative: A Collaborative Effort to Characterize Areas of Habitat-Forming Deep-Sea Corals. NOAA, Silver Spring, MD, NOAA Tech. Mem. OAR OER 1 , 176p.

Pate, P. P. Jr. 1972. Life History Aspects of the Hickory Shad, Alosa mediocris (Mitchill), in the Neuse River, North Carolina. M.S. Thesis, North Carolina State University, Raleigh, NC, 67 p.

Pate, P. P. Jr. and R. Jones. 1981. Effects of upland drainage on estuarine nursery areas of Pamlico Sound, North Carolina. UNC Sea Grant , Raleigh, NC, Pub. No. UNC-SG-WP-10 , 24p.

Patrick, W. S. and M.L. Moser. 2001. Potential competition between hybrid striped bass (*Morone saxatilis* x *M. americana*) and striped bass (*M. saxatilis*) in the Cape Fear River Estuary, North Carolina. Estuaries 24(3): 425-429.

Patriquin, D. G. 1975. Migration of blowouts in seagrass beds at Barbados and Carriacou West Indies and its ecological and geological applications. Aquatic Botany 1: 163-189.

Pattilo, M. E., T.E. Czapla, D.M. Nelson, and M.E. Monaco. 1997. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries. Volume II: Species life history summaries. NOAA/NOS Strategic Environmental Assessment Division, Silver Springs, MD, ELMR Rep. No. 11. 377p.

Paynter, K. T. and E.M. Burreson. 1991. Effects of *Perkinsus marinus* infection in the eastern oyster, *Crassostrea virginica*: 2. Disease development and impact on growth rate at different salinities. Journal of Shellfish Research 10: 425-431.

Paynter, K. T., J.D. Goodwin, M.E. Chen, N.J. Ward, M.W. Sherman, D.W. Meritt, and S.K. Allen. 2008. *Crassostrea ariakensis* in Chesapeake Bay: growth, disease and mortality in shallow subtidal environments. Journal of Shellfish Research 27(3): 509-515.

PCS (Potash Corporation of Saskatchewan Phosphate Division). 2006. Draft environmental impact statement for the PCS Phosphate Mine continuation, Aurora , NC.

Peacock, E. E. 2007. Long-term petroleum hydrocarbon contamination of New England salt marshes: Persistence, degradation, and sediment erosion. MA Thesis, Boston University, Boston MA

Peacock, E. E., R.K. Nelson, A.R. Solow, J.D. Warren, J.L. Baker, and C.M. Reddy. 2005. The West Falmouth oil spill: ~100 kg oil found to persist decades later. *Environmental Forensics* 6: 273281.

Pearsall, S. H., B.J. McCrodden, and P.A. Townsend. 2005. Adaptive management of flows in the lower Roanoke River, North Carolina, USA. Environmental Management 35(4): 353-367.

Peckol, P. and R.B. Searles. 1984. Temporal and spatial patterns of growth and survival of invertebrates and algal populations of a North Carolina continental shelf community. Estuarine, Coastal and Shelf Science 18: 133-143.

Penhale, P. 1977. Macrophyte-epiphyte biomass and productivity in an eelgrass (*Zostera marina L.*) community. Journal of Experimental Marine Biology and Ecology 26: 211-224.

Perillo, G. M. E., E. Wolanski, D.R. Cahoon, and M. M. Brinson. 2009. Coastal Wetlands. Elsevier, 941p.

Perillo, L. and T.E. Lankford. Long-term effects of beach nourishment on the diets of juvenile *Trachinotus carolinus* (Florida pompano) and *Menticirrhus littoralis* (Gulf kingfish)., UNC Wilmington

Peters, D. S. and L.R. Settle. 1994. Larval fish abundance in vicinity of Beaufort Inlet prior to berm construction. NMFS data summary report of project funded by the US Army Corps of Engineers. NMFS, Beaufort, NC, 38 p.

Peters, D. S., L.R. Settle, and J.D. Fuss. 1995. Larval fish abundance in the vicinity of Beaufort Inlet prior to berm construction. NMFS, Beaufort, NC, NMFS Progress Report , 20 p.

Peterson, B. J. and R.W. Howarth. 1987. Sulfur, carbon, and nitrogen isotopes used to trace organic matter flow in the salt-marsh estuaries of Sapelo Island, Georgia. Limnology and Oceanography 32(6): 1195-1213.

Peterson, C. H. 1982. Clam predation by whelks (*Busycon* spp.): experimental tests on the importance of prey size, prey density, and seagrass cover. Marine Biology 66(159-170).

Peterson, C. H. 2001. A synthesis of direct and indirector chronic delayed effects of the Exxon Valdex oil spill. Advances in Marine Biology 29: 1-103.

Peterson, C. H. 2002. Recruitment overfishing in a vivalve mollusc fishery: Hard clams (*Mercenaria mercenaria*) in North Carolina. Canadian Journal of Fisheries and Aquatic Sciences 59(1): 96-104.

Peterson, C. H. 2005. Developing the capacity for fisheries use of the non-native oyster, *Crassostrea ariakensis*. NC Department of Environment and Natural Resources, Division of Marine Fisheries, Morehead City, NC, Final Report to NC Department of Environment and Natural Resources, Division of Marine Fisheries , 29p.

Peterson, C. H., D.H.M. Hickerson, and G.G. Johnson. 2000b. Short-term consequences of nourishment and bulldozing on the dominant large invertebrates of a sandy beach. Journal of Coastal Research 16(2): 368-378.

Peterson, C. H., H.C. Summerson, E.Thompson, H.S. Lenihan, J. Grabowski, L. Manning, F. Micheli, and G. Johnson. 2000a. Synthesis of linkages between benthic and fish communities as a key to protecting essential fish habitat . Bulletin of Marine Science 66(3): 759-774.

Peterson, C. H., H.C. Summerson, H.S. Lenihan, J. Grabowski, S.P. Powers, and G.W. Sarfit Jr. 1999. Beaufort Inlet benthic resources survey . UNC-CH, Morehead City, NC, Final Report to the US Army Corps of Engineers. 18p.

Peterson, C. H., H.C. Summerson, and J. Huber. 1995. Replenishment of hard clam stocks using hatchery seed: combined importance of bottom type, seed size, planting season, and density. Journal of Shellfish Research 14(2): 93-300.

Peterson, C. H., H.C. Summerson, and S.R. Fegley. 1987. Ecological consequences of mechanical harvesting of clams. Fisheries Bulletin 85(2): 281-298.

Peterson, C. H., J.H. Grabowski, and S.P. Powers. 2003a. Quantitative enhancement of fish production by oyster reef habitat: restoration valuation. Marine Ecology Progress Series 264: 249-264.

Peterson, C. H. and L. Manning. 2001. How beach nourishment affects the habitat value of intertidal beach prey for surf fish and shorebirds and why uncertainty still exists. Proceedings of the Coastal Ecosystems and Federal activities Technical Training Symp.

Peterson, C. H., I. M.C. Kennicutt, R.H. Green, P. Montagna, E.N. Powell, and P. Rosigno. 1996. Ecolgical consequences of environmental perturbations associated with offshore hydrocabon production: a perspective from study of long-term exposures in the Gulf of Mexico. Canadian Journal of Fisheris and Aquatic Sciences 53: 2637-2654.

Peterson, C. H. and M.J. Bishop. 2005. Assessing the environmental impacts of beach nourishment. BioScience 55(10): 887-896.

Peterson, C. H., M.J. Bishop, G.A. Johnson, L.M. D'Anna, and L.M. Manning. 2006. Expoliting beach filling as an unaffordable experiment: Benthic intertidal impacts propagating upwards to shorebirds. Journal of Experimental Marine Biology and Ecology 338: 205-221.

Peterson, C. H., M. Wong, M.F. Piehler, J.H. Grabowski, R.R. Twilley, and M.S. Fonseca. 2007. Estuarine habitat productivity ratios at multiple trophic levels. UNC Institute of Marine Science, Morehead City, NC, manuscript .

Peterson, C. H. and N.M. Peterson. 1979. The ecology of intertidal flats of North Carolina: A community profile. U.S. Fish and Wildlife Service, OBS-79/39 , 73 p.

Peterson, C. H., S.D. Rice, J.W. Short, D. Esler, and J.L. Bodkin. 2003b. Long-term ecosystem response to the Exxon Valdez oil spill. Science 302(5653): 2082-2086.

Peterson, C. H., W. Laney, and T. Rice. 2001. Biological impacts of beach nourishment. *In*: Workshop on the Science of Beach Renourishment, May 7-8, 2001. Pine Knoll Shores, NC.

Peterson, M. S., B.H. Comyns, J.R. Hendon, P.J. Bond, and G.A. Duff. 2000c. Habitat use by early life-stages of fishes and crustaceans along a changing estuarine landscape: difference between natural and altered shoreline sites. Wetland, Ecology, and Management 8(2-3): 209-219.

Piazza, B. P., P.D. Banks, and M.K. La Peyre. 2005. The potential for created oyster shell reefs as a sustainable shoreline protection strategy in Louisiana. Restoration Ecology 13(3): 499-506.

Pickering, H. and D. Whitmarsh. 1996. Artificial reefs and fisheries exploitation: a review of the 'attraction versus production' debate, the influence of design, and its significance for policy. University of Portsmouth, United Kingdom, Centre for the Economics and Management of Aquatic Resources (CEMARE) Research Paper 107 , 27p.

Pidgeon, E. 2009. Carbon sequestration by coastal marine habitats: important missing sinks. p. 47 *in* La.. oley, D. d A. & Grimsditch G. eds. The managment of natural coastal carbon sinks. IUCN, Gland, Switzerland, 53 p.

Piehler M.F. and A.R. Smyth. 2010. Differences in habitat-specific estuarine denitrification affect both ecosystem function and services. In press .

Pietrafesa, L. J. 1989. The Gulf Stream and wind events on the Carolina Capes shelf. NOAA-National Undersea Research Program Report 2: 89-128.

Pihl, L. S., P. Baden, and R.J. Diaz. 1991. Effects of periodic hypoxia on distribution of demersal fish and crustaceans. Marine Biology 108: 349-360.

Pilkey, O. H. and H.L. Wright. 1989. Seawalls versus beaches. p. 41-67 *in* Krauss, N. C. and Pilkey, O. H. eds. The effects of seawalls on beaches. SI (4) .

Pilkey, O. H., W.J. Neal, S.R. Riggs, C.A. Webb, D.M. Bush, D.F. Pilkey, J. Bullock, and B.A. Cowan. 1998. The North Carolina shore and its barrier islands: restless ribbons of sand. Duke University Press, Durham and London, 318p.

Pinckney, J. and R.G. Zingmark. 1993. Modelling the annual production of intertidal benthic microalgae in estuarine ecosystems. Journal of Phycology 29(4): 396-407.

Ploskey, G. R. 1986. Effects of water-level changes on reservoir ecosystems with implications for fisheries management . p. 86-97 *in* Hall and Van Den Avyle (eds.). Reservoir fisheries management: strategies for the 80's. American Fisheries Society, Bethesda, Maryland.

Plunket, J. and M.K. La Peyre. 2005. Oyster beds as fish and macroinvertebrate habitat in Barataria Bay, Louisiana. Bulletin of Marine Science 77(1): 155-164.

Pomeroy, L. R., C.F. D'Elia, and L.C. Schaffner. 2006. Limits to top-down control of phytoplankton by oysters in Chesapeake Bay. Marine Ecology Progress Series 325: 301-309.

Porter, E. T., J.C. Cornwell, and L.P. Sanford. 2004. Effect of oysters *Crassostrea virginica* and bottom shear velocity on benthic-pelagic coupling and estuarine water quality. Marine Ecology Progress Series 271: 61-75.

Posey, M. and T. Alphin. 2002. Resilience and stability in an offshore benthic community: Responses to sediment borrow activities and hurricane disturbance. Journal of Coastal Research 18(4): 685-697.

Posey, M. H., C. Powell, L. Cahoon, and D. Lindquist. 1995. Top down vs. bottom up control of benthic community composition on an intertidal tideflat. Journal of Experimental Marine Biology and Ecology 185(1): 19-31.

Posey, M. H. and T.D. Alphin. 2001. Monitoring of benthic faunal responses to sediment removal associated with the Carolina Beach and vicinity - area south project. UNC-Wilmington, Wilmington, NC, Final Report to the US Army Corps of Engineers , 18 p.

Posey, M. H. and T.D. Alphin. 2002. Resilience and stability in an offshore benthic community: responses to sediment borrow activities and hurricane disturbance. Journal of Coastal Research 18(4): 685-697.

Posey, M. H., T.D. Alphin, C.M. Powell, and E. Townsend. 1999. Use of oyster reefs as habitat for epibenthic fish and decapods. p. 229-238 *in* M.W. Luckenbach, R. Mann and J. A. Wesson eds. Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. Virginia Institute of Marine Science Press, Gloucester Point, VA.

Posey, M. H., T.D. Alphin, D.L. Meyer, and J.M. Johnson. 2003. Benthic communities of common reed Phragmites australis and marsh cordgrass Spartina alterniflora marshes in Chesapeake Bay. Marine Ecology-Progress Series 261: 51-61.

Posey, M. H., T.D. Alphin, H.D. Harwell, and T. Molesky. 2004. Effects of reef complexity on habitat function for intertidal oysters. Journal of Shellfish Research 23(1): 307-308.

Posey, M. H. and W.G. Ambrose Jr. 1994. Effects of proximity to an offshore hard-bottom reef on infaunal abundances. Marine Biology 118: 745-753.

Potts, T. A. and A.W. Hulbert. 1994. Structural influences of artificial and natural habitats on fish aggregations in Onlsow Bay, North Carolina. Bulletin of Marine Science 55(2-3): 609-622.

Poulter, B., R.L. Feldman, M.M. Brinson, B.P. Horton, M.K. Orbach, S.H. Pearsall, E. Reyes, S.R. Riggs, and J.C. Whitehead. 2009. Sea-level rise research and dialogue in North Carolina: Creating windows for policy change. Ocean & Coastal Management 52: 147-153.

Powell, A. B. and R.E. Robbins. 1998. Ichthyoplankton adjacent to live-bottom habitats in Onslow Bay, North Carolina. NOAA , Seattle, Washington, Tech. Rep. NMFS 133 , 32p.

Powell, E. N., E.E. Hofmann, J.M. Klinck, and S.M. Ray. 1992. Modeling oyster populations. I. a commentary on filtration rate. Is faster always better? Journal of Shellfish Research 11: 387-398.

Powell, E. N., J.N. Kraeuter, and K.A. Ashton-Alcox. 2006. How long does oyster shell last on an oyster reef? Estuarine, Coastal and Shelf Science 69(3-4): 531-542.

Powell, E. N., K.A. Ashton-Alcox, S.E. Banta, and A.J. Bonner . 2001. Impact of repeated dredging on a Delaware Bay oyster reef. Journal of Shellfish Research 20(3): 961-975.

Power, M. E., A. Sun, G.Parker, W.E. Dietrich, and J.T. Wootton. 1995. Hydraulic food-chain model. Bioscience 45(3): 159-167.

Powers, E. R., R.A. Crowson, S.R. Riggs, S.W. Snyder, S.W. Snyder, and A.C. Hine. 1990. Chemical characteristics and reevaluation of the phosphate resource potential in Onslow Bay, North Carolina Continental Shelf. Marine Mining 9: 1-41.

Powers, M. J. and D. Gaskill. 2004. Recruitment, growth, and habitat utilization of red drum *Sciaenops ocellatus*, in North Carolina estuaries. North Carolina Sea Grant Extension Program, FRG project #00-EP-04 , 40p.

Powers, S. P., J.H. Grabowski, C.H. Peterson, and W.J. Lindberg. 2003. Estimating enhancement of fish production by offshore artificial reefs: uncertainty exhibited by divergent scenarios. Marine Ecology Progress Series 264: 265-277.

Powers, S. P. and J.N. Kittinger. 2002. Hydrodynamic mediation of predator-prey interactions: differential patterns of prey susceptibility and predator success explained by variation in water flow. Journal of Experimental Marine Biology and Ecology 273: 171-187.

Pratolongo, P. D., J.R. Kirby, A. Plater, and M.M. Brinson. 2009. Temperate coastal wetlands: morphology, sediment processes, and plant communities. *in* Perillo, G. M. E., E. Wolanski, D. R. Cahoon, and M. M. Brinson (eds.). Coastal Wetlands. Elsevier, 941 p.

Prescott, R. C. 1990. Sources of predatory mortality in the bay scallop *Argopecten irradians* (Lamarck): interactions with seagrass and epibiotic coverage. Journal of Experimental Marine Biology and Ecology. 144(1): 63-83.

Pruell, R. J., J.L. Lake, W.R. Davis, and J.G. Quinn. 1986. Uptake and depuration of organic contaminants by blue mussels (*Mytilus edulis*) exposed to environmentally contaminated sediment. Marine Biology 91: 497-507.

Pulich, W. M. Jr. and W.A. White. 1991. Decline of submerged vegetation in the Galveston Bay system: Chronology and relationships to physical processes. Journal of Coastal Research 7: 1125-1138.

Purvis, C. 1976. Nursery area survey of northern Pamlico Sound and tributaries. NC Division of Marine Fisheries, Morehead City, NC, Completion report for Project 2-239-R .

Purvis, C. E. and E.G. McCoy . 1972. Overwintering pink shrimp *Penaeus duorarum* in Core and Pamlico Sounds. NC Dept Natural Economic Resources , NC, Spec Sci Rep 22 .

Quast, W. D., M.A. Johns, D.E. Pitts Jr., G.C. Matlock, and J.E. Clark. 1988. Texas oyster fishery management plan. Texas Parks and Wildlife Department, Coastal Fisheries Branch, Austin, Texas, Fishery Management Plan Series Number 1 , 178p.

Quattrini, A. M. and S.W. Ross. 2006. Fishes associated with North Carolina shelf-edge hardbottoms and initial assessment of a proposed Marine Protected Area. Bulletin of Marine Science 79(1): 137-163.

Quattrini, A. M., S.W. Ross, K.J. Sulak, A.M. Necaise, T.L. Casazza, and G.D. Dennis. 2004. Marine fishes new to continental United States waters, North Carolibna, and the Gulf of Mexico. Southeastern Naturalist 3(1): 155-172.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. Science 315: 368-370.

Rakocinski, C., S.E. LeCroy, J.A. McLelland, and R.W. Heard. 1993. Responses by macroinvertebrate communities to beach renourishment at Perdido Key, Florida: benthic recovery. US Dept. of the Interior, National Park Service.

Rakocinski, C. F., R.W. Heard, S.E. LeCroy, J.A. McLelland, and T. Simons. 1996. Responses by macrobenthic assemblages to extensive beach restoration at Perdido Key, Florida, USA. Journal of Coastal Research 12(1): 326-353.

Randall, R. G., C.K. Minns, V.W. Cairns, and J.E. Moore. 1996. The relationships between an index of fish production and submerged macrophytes and other habitat features at three littoral areas in the Great Lakes. Can. J. Aquat. Sci. 53(Supplement 1): 35-44.

Raven, J., K. Caldeira, H. Elderfield, O. Hoegh-Guldberg, P. Liss, U. Riebesell, J. Shepherd, C. Turley, and A. Watson. 2005. Ocean acidification due to increasing atmospheric carbon dioxide. The Royal Society, London, UK, 68p.

Ray, S. M. 1954. Biological studies of *Dermocystidium marinum* , a fungus parasite of oysters. Rice Institute Pamplet Special Issue November.

Ray, S. M. and A.C. Chandler. 1955. Parasitological reviews: *Dermocystidium marinum*, a parasite of oysters. Experimental Parasitology 4: 172-200.

Reagan, R. E. Jr. 1985. Species Profiles: life histories and environmental requirments of coastal fishes and invertebrates (Gulf of Mexico) - red drum. US Fish and Wildlife Service, Washington, DC, Biological Report 82 (11.36) , 16p.

Reagan, R. E. Jr. and W.M. Wingo. 1985. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico)--southern flounder. US Fish and Wildlife Service, 82 (11.30) , 9p.

Rebach, S. 2005. North Carolina Under Dock Oyster Culture Program. North Carolina Sea Grant, Raleigh, NC, 21p.

Reddy, C. M., T.I. Eglinton, A. Hounshell, H.K. White, L. Xu, R.B. Gaines, and Frysinger. 2002. The West Falmouth oil spill: the persistence of petroleum hydrocarbons in marsh sediments. *Environmental Science and Technology* 36: 47544760.

Reed, A. J. and J.T. Wells. 2000. Sediment distribution patterns offshore of a renourished beach: Atlantic Beach and Fort Macon, North Carolina. Journal of Coastal Research. 16(1): 88-98.

Reed, J. K., C.C. Koenig, and A.N. Shepard. 2007. Impacts of bottom trawling on a deep-water *Oculina* coral ecosystem off Florida. Bulletin of Marine Science 81(3): 481-496.

Reed, J. P., J.M. Miller, D.F. Pence, and B. Schaich. 1983. The effects of low level turbidity on fish and their habitat. Department of Zoology, North Carolina State University, Raleigh, NC, Report No. 190 .

Reed, R. E., D.A. Dickey, J.M. Burkholder, C.A. Kinder, and C. Brownie. 2008. Water level variations in the Neuse and Pamlico Estuaries, North Carolina, due to local and non-local forcing. Estuarine and Coastal Shelf Science 76: 431-446.

Reilly, F. J. Jr. and B.J. Bellis. 1983. The ecological impact of beach nourishment with dredged materials on the intertidal zone at Bogue Banks, North Carolina. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA.

Reilly, J. D. and W.W. Kirby-Smith. 1999. Development of the technical basis and a management strategy for reopening a closed shellfishing area. Water Resources Research Institute, University of North Carolina , Chapel Hill, NC, UNC-WRRI-99-321 , 46 p.

Reise, K. and J.E.E. van Beusekom. 2008. Interactive effects of global and regional change on a coastal ecosystem. Helgoland Marine Research 62(1-2): 85-91.

Renaud, P. E., S.R. Riggs, W.G. Ambrose Jr., K. Schmid, and S.W. Snyder. 1997. Biological-geological interactions: storm effects on macroalgal communities mediated by sediment characteristics and distribution. Continental Shelf Research 17(1): 37-56.

Rheinhardt, R. D. and M.M. Brinson. 2002. An evaluation of North Carolina Department of Transportation wetland mitigation sites: selected case studies. U.S. Department of Transportation, Research and Special Programs Administration, Washington, DC, Report No. FHWA/NC/2002-009 , 99p.

Rice, T. M., R.L. Beavers, and S.W. Snyder. 1998. Preliminary geologic framework of the inner continental shelf offshore Duck, North Carolina. Journal of Coastal Research 26: 219-225.

Richards, W. R. and P.C. Ticco. 2002. The Suminoe oyster, *Crassostrea ariakensis*. Virginia Sea Grant/University of Virginia - Charlottesville, Charlottesville, VA, VSG-02-23 , 6p.

Richardson, B. J., E.S. Tse, S.B. De Luca-Abbott , M. Martin, and P.K. Lam. 2005. Uptake and depuration of PAHs and chlorinated pesticides by semi-permeable membrane devices (SPMDs) and green-lipped mussels (*Perna viridis*). Marine Pollution Bulletin 51: 975-993.

Richardson, C. J. 2003. Pocosins: Hydrologically isolated or integrated wetlands on the landscape? Wetlands 23(3): 563-576.

Richkus, W. A. 1975. Migratory behavior and growth of juvenile anadromous alewives in a Rhode Island drainage. Transactions of the American Fisheries Society 104: 483-493.

Riggs, S. R. 1996. Sediment evolution and habitat function of organic-rich muds within the Albemarle estuarine system, North Carolina. Estuaries 19(2A): 169-185.

Riggs, S. R. 2000. Were human impacts upon the riverine systems of coastal North Carolina significant factors in the flood of September 1999? Abstracts from the Annual North Carolina Water Resources research Conference: The Year of the Hurricanes : 22.

Riggs, S. R. 2001. Shoreline Erosion in North Carolina estuaries. North Carolina Sea Grant, Raleigh, NC, UNC-SG-01-11 , 68p.

Riggs, S. R. and D.V. Ames. 2003. Drowning the North Carolina coast: sea level rise and estuarine dynamics. North Carolina Sea Grant, Raleigh, NC, 152p.

Riggs, S. R., D.V. Ames, S.J. Culver, D.J. Mallinson, D.R. Corbett, and J.P. Walsh. 2009. Eye of a human hurricane: Pea Island, Oregon Inlet, and Bodie Island, northern Outer Banks, North Carolina. p. 43-72 *in* J.T. Kelley, O. H. Plkey and J. A. G. Cooper eds. America's Most Vulnerable Coastal Communities: Geological Society of America special Paper 460.

Riggs, S. R., E.R. Powers, J. T. Bray, P.M. Stout, C. Hamilton, D. Ames, R. Moore, J. Watson , S. Lucas, and M. Williamson. 1989. Heavy metal pollutants in organic rich muds of the Pamlico River estuarine system: their concentration, distribution, and effects upon benthic environments and water quality: Albemarle-Pamlico Estuarine Study. Project No. 89-06. US EPA and NC DNRCD, Raleigh, NC, 108p.

Riggs, S. R. and F.T. Manheim. 1988. Mineral resources of the US Atlantic continental margin. p. 501-520 *in* Sheridan, R. E. and J.A. Grow (eds.). The Geology of North America, Vol. I-2, The Atlantic Continental Margin: US. Geological Society of America.

Riggs, S. R., J.T. Bray, E.R. Powers, C. Hamilton, D. Ames, D. Yeates, K. Owens, S. Lucas, J. Watson, and M. Williamson. 1991. Heavy metal pollutants in organic-rich muds of the Neuse

River Estuary: their concentration and distribution. Albemarle-Pamlico Estuarine Study Report. Project no. 90-07. DENR, Raleigh, 168p.

Riggs, S. R., S.W. Snyder, A.C. Hine, and D.L. Mearns. 1996. Hardbottom morphology and relationship to the geologic framework: Mid-Atlantic continental shelf. Journal of Sedimentary Research 66(4): 830-846.

Riggs, S. R., W.G. Ambrose, J.W. Cook, S.W. Snyder, and S.W. Snyder. 1998. Sediment production on sediment-starved continental margins: the interrelationship between hardbottoms, sedimentological and benthic community processes, and storm dynamics. Journal of Sedimentary Research 68(1): 155-168.

Riggs, S. R., W.G. Ambrose Jr., J.W. Cook, S.W. Snyder, and S. Snyder. 1998. Sediment production on sediment-starved continental margins: the inter-relationships between hardbottoms, sedimentological and benthic community processes, and storm dynamics. Journal of Sedimentary Research. 68(1): 155-168.

Riggs, S. R., W.J. Cleary, and S.W. Snyder. 1995. Influence of inherited geologic framework on barrier shoreface morphology and dynamics. Marine Geology 126: 213-234.

Rilov, G. and Y. Benayahu. 2000. Fish assemblage on natural versus artificial reefs: the rehabilitation perspective. Marine Biology 136: 931-942.

Ritchie, J. C. 1972. Sediment, fish, and fish habitat. Journal of Soil Water Conservation 27: 124-125.

Rivers, D. O. and F.T. Short. 2007. Effect of grazing by Canada geese *Branta canadensis* on an intertidal eelgrass *Zostera marina* meadow. Marine Ecology Progress Series 333: 271-279.

Roberts, C. M., J.A. Bohnsack, F. Gell, J.P. Hawkins, and R. Goodridge. 2001. Effects of marine reserves on adjacent fisheries. Science 294: 1920-1923.

Roberts, D. A., E.L. Johnston, and A.G.B. Poore. 2008. Contamination of marine biogenic habitats and effects upon associated epifauna. Marine Pollution Bulletin 56: 1057-1065.

Roberts, J. M., A.J. Wheeler, and A. Freiwald. 2006. Reefs of the deep: the biology and geology of cold-water coral ecosystems. Science 312(5773): 543-547.

Robins, C. R. and G.C. Ray . 1986. A field guide to Atlantic coast fisheries of North America. Houghton Mifflin Company, Boston, USA, 354p.

Roblee, M. B. and W.J. DiDomenico. 1992. Seagrass die-off in Florida Bay, Everglades National Park. Park Science 11: 21-23.

Rodriquez, K., N. Grindlay, L. Abrams, T. Alphin, and S. Artabane. 2006. Implications of high-resolution geophysical techniques in oyster habitat identification: Cape Fear River, North Carolina. Journal of Shellfish Research 25(2): 769.

Roessler, T. S. 1998. Effects of offshore geology and the Morehead City Harbor Project on eastern Bogue Banks, NC. M.S. Thesis, University of North Carolina, Chapel Hill, NC

Rogers, S. and T. Skrabal. 2002. Managing erosion on estuarine shorelines. North Carolina Division of Coastal Management and North Carolina Sea Grant, ., UNC-SG-01-12 , 32p.

Romano, J. A. 2007. Acute toxicity and sub-lethal effects of non-point source pollutants on invertebrates. Ph.D. Dissertation, Duke University, Durham, NC

Rommel, S. A. and D. McCleave. 1973. Sensitivity of American eels (*Anguilla rostrata*) and Atlantic salmon (*Salmo salar*) to weak electric and magnetic fields. Journal of Fisheries Research Board of Canada 30: 657-663.

Rooker, J. R., G.J. Holt, and S.A. Holt. 1998. Vulnerability of newly settled red drum (*Sciaenops ocellatus*) to predatory fish: is early-life survival enhanced by seagrass meadows? Marine Biology 131(1): 145-151.

Rooth, J. E. and J.C. Stevenson. 2000. Sediment deposition patterns in *Phragmites australis* communities: implications for coastal areas threatened by rising sea-level. Wetlands Ecology and Management 8: 173-183.

Rosenburg, W. M. 1994. Nesting habitat requirements of the diamondback terrapin: a geographic comparison. The Wetland Journal 6(2): 8-11.

Ross, J. L. and T.M. Stevens. 1992. Life history and population dynamics of red drum (*Sciaenops ocellatus*) in North Carolina waters. NC Division of Marine Fisheries, Morehead City, NC, Marine Fisheries Research Completion Report Project F-29 , 130p.

Ross, M. R. 1991. Recreational Fisheries of Coastal New England. University of Massachusetts Press, Amherst, MA, 279p.

Ross, S. W. 2003. The relative value of different estuarine nursery areas in North Carolina for transient juvenile marine fishes. Fishery Bulletin 101: 384-404.

Ross, S. W. 2006. Review of distribution, habitats, and associated fauna of deep water coral reefs on the southeastern United States continental slope (North Carolina to Cape Canaveral, FL). South Atlantic Fishery Management Council, Charleston, SC, 36p.

Ross, S. W. and A.M. Quattrini. 2007. The fish fauna associated with deep coral banks off the southeastern United States. Deep-sea Research 54: 975-1007.

Ross, S. W., F.C. Rohde, and D.G. Lindquist. 1988. Endangered, threatened, and rare fauna of North Carolina: a re-evaluation of marine fisheries. Occasional Papers of the NC Biological Survey 1988-7(20).

Ross, S. W. and J.E. Lancaster. 1996. Movements of juvenile fishes using surf zone nursery habitats and the relationship of movements to beach nourishment along a North Carolina beach: pilot project. North Carolina National Estuarine Research Reserve, Wilmington, NC, Final report submitted to NOAA Office of Coastal Resource Management and the US Army Corps of Engineers , 31 p.

Ross, S. W. and M.L. Moser. 1995. Life history of juvenile gag, *Mycteroperca microlepis,* in North Carolina estuaries. Bulletin of Marine Science 56(1): 222-237.

Ross, S. W. and M.S. Nizinski. 2007. State of deep coral ecosystems in the U.S. southeast region:

Cape Hatteras to southeastern Florida. p. 233-270 *in* Lumsden, S. E., Hourigan, T. F., Bruckner, A. W., and Dorr (eds.), G. The State of Deep Coral Ecosystems of the United States. NOAA, Silver Spring, Maryland, NOAA Technical Memorandum CRCP-3 .

Ross, S. W. and S.P. Epperly. 1985. Chapter 10: Utilization of shallow estuarine nursery areas by fishes in Pamlico Sound and adjacent tributaries, North Carolina. p. 207-232 *in* A. Yanez-Aranciba (ed.). Fish Community Ecology in Estuaries and Coastal Lagoons: Towards and Ecosystem Integration. DR (R) UNAM Press, Mexico, 654 p.

Rothenberger M., J.M. Burkholder, and C. Brownie . 2009b. Long-term effects of changing land use practices on surface water quality in a major lagoonal estuary. *Environmental Management* 44: 505-523.

Rothenberger M., J.M. Burkholder, and T. Wentworth . 2009a. Multivariate analysis of phytoplankton and environmental factors in a eutrophic estuary. *Limnology and Oceanography* 54: 2107-2127.

Rothschild, B. J., J.S. Ault, P. Goulletquer, and M. Heral. 1994. Decline of the Chesapeake Bay oyster population: A century of habitat destruction and overfishing. Marine Ecology Progressive Series 111: 29-39.

Rowe, G. T. 2001. Seasonal hypoxia inthe bottom water off the Mississippi River delta. Journal of Environmental Qualitiy 30: 281-290.

Rozas, L. P. 1987. Submerged plant beds and tidal freshwater marshes: nekton community structure and interactions. Ph.D. dissertation, University of Virginia, Charlottesville, VA, 144 p.

Rozas, L. P. 1992. Comparison of nekton habitats associated with pipeline canals and natural channels in Louisiana salt marshes. Wetlands 12(2): 136-146.

Rozas, L. P. and C.T. Hackney. 1984. Use of oligohaline marshes by fishes and macrofaunal crustaceans in North Carolina. Estuaries. 7(.): 213-224.

Rozas, L. P. and R.J. Zimmerman. 2000. Small-scale patterns of nekton use among marsh and adjacent shallow nonvegetated areas of the Galveston bay estuary, Texas (USA). Marine Ecology Progress Series. 193(.): 217-239.

Rozas, L. P., T.J. Minello, R.J. Zimmerman, and P. Caldwell. 2007. Nekton populations, long-term wetland loss, and the effect of recent habitat restoration in Galveston Bay, Texas, USA. Marine Ecology Progress Series 344: 119-130.

Rozas, L. P. and W.E. Odum. 1987. The role of submerged aquatic vegetation in influencing the abundance of nekton on contiguous tidal freshwater marshes. Journal of Experimental Marine biology and Ecology 114(2-3): 289-300.

Rulifson, R. A. and B.L. Wall. 1998. Fish passage through water control structures at Mattamuskeet National Wildlife Refuge, North Carolina, using flap gates and fish slots. East Carolina University, Institute of Coastal and Marine Resources, Greenville, NC, 7p.

Rulifson, R. A. and C.S. Manooch III. 1990. Recruitment of juvenile striped bass in the Roanoke River, North Carolina, as related to reservoir discharge. North American Journal of Fisheries

Management 10: 397-407.

Rulifson, R. A., T.L. Woods, and K.E. Kleber . 2006a. Ecological Assessment of the Pasquotank County Reverse Osmosis Water Treatment Plant Discharge Site, Albemarle Sound, North Carolina: Final Report, November 2006. *in* Hobbs, Upchurch & Associates P. A. Support of Environmental Assessment Report for Pasquotank County. East Carolina University, Greenville, NC, ICMR Contribution Number 06-03 , 128 p.

Rulifson, R. A., T.L. Woods, and K.E. Kleber . 2006b. Ecological Assessment of the Currituck County Reverse Osmosis Water Treatment Plant Discharge Site, Albemarle Sound, North Carolina: Final Report, November 2006. *in* Hobbs, Upchurch & Associates P. A. Support of Environmental Assessment Report for Pasquotank County. East Carolina University, Greenville, NC, ICMR Contribution Number 06-03 , 128 p.

SAFMC (South Atlantic Fishery Management Council). 1982. Fishery management plan final environmental impact statement for corals and coral reefs. SAFMC, Charleston, SC, 389p.

SAFMC (South Atlantic Fishery Management Council). 1994. Amendment 2 to the fishery management plan for coral and coral reefs of the Gulf of Mexico and South Atlantic . SAFMC, Charleston, SC, 140p.

SAFMC (South Atlantic Fishery Management Council). 1998a. Final habitat plan for the South Atlantic region: Essential Fish Habitat requirements for fishery management plans of the South Atlantic Fishery Management Council. SAFMC, Charleston, SC.

SAFMC (South Atlantic Fishery Management Council). 1998b. Final Amendment 9 to the fishery management plan for the snapper grouper fishery of the South Atlantic region. SAFMC, Charleston, SC, 246 p.

SAFMC (South Atlantic Fishery Management Council). 2007a. Final Amendment 15A to the fishery management plan for the snapper grouper fishery of the South Atlantic region. SAFMC, Charleston, SC, 389p.

SAFMC (South Atlantic Fishery Management Council). 2007b. Final Amendment 14 to the fishery management plan for the snapper grouper fishery of the South Atlantic region. SAFMC, Charleston, SC, 389p.

SAFMC (South Atlantic Fishery Management Council). 2008a. Fishery Ecosystem Plan of the South Atlantic region. Volume II: South Atlantic habitats and species, public hearing draft. SAFMC, Charleston, SC, 705p.

SAFMC (South Atlantic Fishery Management Council). 2008b. Comprehensive Ecosystem Based Amendment for the South Atlantic region. SAFMC, Charleston, SC.

SAFMC (South Atlantic Fishery Management Council). 2009. Fishery Ecosystem Plan of the South Atlantic region. Volume II: South Atlantic habitats and species. SAFMC, Charleston, SC, 705p.

Sagasti, A. S., L.C. Schaffner, and J.E. Duffy. 2001. Effects of periodic hypoxia on mortality, feeding and predation in an estuarine epifaunal community. Journal of Experimental Marine Biology and Ecology 258: 257-283.

Saloman, C. H., S. Naughton, and J. Taylor. 1982. Benthic community response to dredging borrow pits, Panama City Beach, Florida. US Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va, Misc. Rep. No. 82-3 .

Sanchez, P., M. Demestre, M. Ramirez, and M.J. Kaiser. 2000. The impact of otter trawling on mud communities in the Northwestern Mediterranean. ICES Journal of Marine Science 57: 1352-1358.

Sand-jensen, K. 1977. Effects of epiphytes on eelgrass photosynthesis. Aquatic Botany 3: 55-63.

Sanders, H. L., J.F. Grassle, G.R. Hampson, L.S. Morse, S. Garner-Price, and C.C. Jones. 1980. Anatomy of an oil spill: long-term effects from the grounding of the barge Florida off West Falmouth. Massachusetts. *Journal of Marine Research* 38: 265380.

Sando, S. K., E.T. Furlong, J.L. Gray, M.T. Meyer, and R.C. Bartholomay. 2005. Occurence of organic waterwater compounds in wastewater effluent and the Big Sioux Rive inthe upper Big Sioux River basin, South Dakota: U.S. Geological Survey Scientific Investigations Report. USGS, 2005-5249 , 108p.

Sanger, D. M. and A.F. Holland. 2002. Evaluation of the impacts of dock structures on South Carolina estuarine environments. SC Department of Natural Resources, Marine Resources Research Institute, Charleston, SC, Tech. Rep. No. 99 , 82p.

Sanger, D. M., A. F. Holland, and D.L. Hernandez. 2004. Evaluation of the impacts of dock structures and land use on tidal creek ecosystems in South Carolina estuarine environments. Environmental Management 33(3): 385-400.

Sargent, F. J., T.J. Leary, D.W. Crewz, and C.R. Kruer. 1995. Scarring of Florida's seagrasses: Assessment and management options. Florida Department of Environmental Protection, St. Petersburg, Fl, FMRI Technical Report TR-1 , 46p.

SARP (Southeast Aquatic Resource Partnership). 2008. Southeast Aquatic Habitat Plan. Southeast Aquatic Resources Partnership, 55p.

Savino, J. F. and R.A. Stein. 1989. Behavior of fish predators and their prey: habitat choice between open water and dense vegetation. Environmental Biology of Fishes 24(4): 287-293.

SC DHEC (South Carolina Department of Health and Environmental Control. 1987. Heavy metals and extractable organic chemicals from the Coastal Toxics Monitoring Network 1984 - 1986. SC DHEC, Tech. Rep. No. 007-87 .

Scavia, D., J.C. Field, D.F. Boesch, R.W. Buddemeier, V. Burkett, D.R. Cayan, M. Fogarty, M.A. Harwell, C. M. R.W. Howarth, D.J. Reed, T.C. Royer, A.H. Sallenger, and J.G. Titus. 2002. Climate change impacts on US coastal and marine ecosystems. Estuaries 25(2): 149-164.

Schaaf, W. E., D.S. Peters, D.S. Vaughan, L. Costonclements, and C.W. Krouse. 1987. Fish population responses to chronic and acute pollution: the influence of life history strategies. Estuaries 10(3): 267-275.

Schaaf, W. E., D.S. Peters, L. Costonclements, D.S. Vaughan, and C.W. Krouse. 1993. A simulation model of how life history strategies mediate pollution effects on fish populations. Estuaries

16(4): 697-702.

Scheffer, M. 1999. The effect of aquatic vegetation on turbidity; how important are the filter feeders. Hydrobiologia 408-409: 307-316.

Schlacher, T. A. and L.M.C Thompson. 2008. Physical impacts caused by off-road vehicles to sandy beachs: spatial quantification of car tracks on an Australian barrier island. Journal of Coastal Research 24(2b): 234-242.

Schlacher, T. A., L.M.C. Thompson, and S.J. Walker. 2008. Mortalities caused by off-road vehicles (ORVs) to a key member of sandy beach assemblages, the surf clam *Donax deltoids*. Hydrobiologia 610: 345-350.

Schneider, C. W. 1976. Spatial and temporal distributions of benthic marine algae on the continental shelf of the Carolinas. Bulletin of Marine Science 26(2): 133-151.

Schneider, S. Z. 2009. Mecury source and cycling processes in the Cafe Fear River Estuary, North Carolina. UNC-CH, Chapel Hill, NC

Schoof, R. 1980. Environmental impact of channel modification. Water Resources Bulletin 16(4): 697-701.

Schott, E. J., J, .A. Fernandez-Robledo, M.R. Alavi, and G.R. Vasta. 2008. Susceptibility of *Crassostrea ariakensis* (Fujita 1913) to *Bonamia* and *Perkinsus* spp. infections: potential for disease transmission between oyster species. Journal of Shellfish Research 27(3): 541-549.

Schroder, A., L. Persson, and A.M. De Roos. 2005. Direct experimental evidence of alternative stable states: a review. OIKOS 110: 3-19.

Schueler, T. R. 1994. The importance of imperviousness. Watershed Protection Techniques 1(3): 100-111.

Schueler, T. R. 1997. Impact of suspended and deposited sediment. Watershed Protection Techniques 2(3): 443-444.

Schueler, T. R. 1999. Microbes and urban watersheds- implications for watershed managers. Watershed Protection Techniques 3(1): 549-620.

Schueler, T. R. 2003. Impacts of impervious cover on aquatic systems. Center for Watershed Protection, Ellicott, Md, Monograph No. 1 , 140p.

Schultz, S. L. W., E.L. Steinkoenig, and B.L. Brown. 2001. Ploidy of feral grass carp in the Chesapeake Bay watershed. North American Journal of Fisheries Management in press.

Schwartz, F. J. 2003. Sharks, skates, and rays of the Carolinas. University of North Carolina, Chapel Hill, NC, 161p.

Scudder, B. C., L.C. Chasar, D.A. Wentz, N.J. Bauch, M.E. Brigham, P.W. Moran, and D.P. Krabbenhoft. 2009. Mercury in fish, bed sediment, and water from streams acress the United States, 1998-2005. US Geological Survey, Reston, Va, USGS Scientific Investigations Report 2009-5109 , 74p.

SEAMAP-SA (Southeast Area Monitoring and Assessment Program). 2000. SEAMAP-south Atlantic 10-year trawl report, results of trawling efforts in the coastal habitat of the South Atlantic Bight, FY 1990-1999. 143p.

SEAMAP-SA (Southeast Area Monitoring and Assessment Program). 2001. South Atlantic Bight hard bottom mapping. SEAMAP South Atlantic Bottom Mapping Workgroup, Charleston, South Carolina, 166p.

SEAMAP-SA (Southeast Area Monitoring and Assessment Program). 2004. SEAMAP Deep water (200 - 2,000 meters) Bottom Mapping Protocols to Capture and transform data into standardized database. SEAMAP South Atlantic Bottom Mapping Workgroup, Charleston, South Carolina, 22p.

Searles, R. B. 1984. Seaweed biogeography of the mid-Atlantic coast of the United States. Helgolander Meeresuntersuchungen 38: 259-271.

Sedberry, G. R. and N. N. Cuellar. 1993. Planktonic and benthic feeding by the reef-associated vermilion snapper, *Rhomboplites aurorubens* (Teleostei, Lutjanidae). Fishery Bulletin 91(4): 699-709.

Seitz, R. D., L.S. Marshall Jr., A.H. Hines, and K.L. Clark. 2003. Effects of hypoxia on predator-prey dynamics of the blue crab *Callinectes sapidus* and the Baltic clam *Macoma balthica* in Chesapeake Bay. Marine Ecology Progress Series 257: 179-188.

Seitz, R. D., R.N. Lipcius, N.H. Olmstead, M.S. Seebo, and D.M. Lambert. 2006. Influence of shallow-water habitats and shoreline development on abundance, biomass, and diversity of benthic prey and predators in Chesapeake Bay. Marine Ecology Progress Series 326: 11-27.

Seliger, H. H., J.A. Boggs, and W.H. Biggley . 1985. Catastrophic anoxia in the Chesapeake Bay in 1984. Science 228: 70-73.

Sellner, K. G. and R.G. Zingmark. 1976. Interpretations of the ^{14}C method of measuring the total annual production of phytoplankton in a South Carolina estuary. Botanica Marina 19: 119-125.

Selman, M., S. Greenhalgh, R. Diaz, and Z. Sugg. 2008. Eutrophication and hypoxia in coastal areas: global assessment of the state of knowledge. WRI Policy Note Water Quality: Eutrophication and Hypoxia(1): 1-6.

Serafy, J. E., K.C. Lindeman, T.E. Hopkins, and J.S. Ault. 1997. Effects of freshwater canal discharge on fish assemblages in a subtropical bay: field and laboratory observation. Marine Ecology Progress Series 160: 161-172.

Shafer, D. J. 1999. The effects of dock shading on the seagrass *Halodule wrightii* in Perdido Bay, Alabama. Estuaries 22(4): 936-943.

Shatkin, G., S.E. Shumway, and R. Hawes. 1997. Considerations regarding the possible introduction of the Pacific oyster (Crassostrea gigas) to the Gulf of Maine: a review of global experience. Journal of Shellfish Research 16(2): 463-477.

Shea, D., C.S. Hofelt, D.R. Luellen, A. Huysman, P.R. Lazaro, R. Zarzecki, and J.R. Kelly. 2001.

Chemical contamination at National Wildlife Refuges in the lower Mississippi River ecosystem. Report by NC State University to the US Fish and Wildlife Service, Atlanta, Ga, 40p.

Sheavly, S. B. 2007. National Marine Debris Monitoring Program: Final Program Report, Data Analysis and Summary. Prepared for U.S. Environmental Protection Agency by Ocean Conservancy, Grant Number X83053401-02, 76p.

Sheehan, R. J. and J.L. Rasmussen. 1993. Large Rivers. p. 445-468 *in* C.C. Kohler and W.A. Hubert (eds.). Inland Fisheries Management in North America. American Fisheries Society, Bethesda, MD.

Shertzer, K. W. and E.H. Williams. 2008. Fish assemblages and indicator species: reef fishes off the southeastern United States. Fishery Bulletin 106(3): 257-269.

Shervette, V. R. and F. Gelwick. 2008. Seasonal and spatial variations in fish and macroinverterate communities of oyster and adjacent haitats in a Mississippi estuary. Estuaries and Coasts 31(3): 584-596.

Sholar, T. M. 1975. Anadromous fisheries survey of the New and White Oak River systems. NC DMF, Morehead City, NC, Compl. Rep. Proj. AFC-9 , 49p.

Sholar, T. M. 1977. Anadromous Fisheries Research Program, Cape Fear River System, Phase I. North Carolina Division of Marine Fisheries, Rep #AFCS-12 , p.

Short, F. T., L.K. Muehlstein, and D. Porter . 1987. Eelgrass wasting disease: cause and recurrence of a marine epidemic. Biological Bulletin 173: 557-562.

Shull III, L. N. 1999. An accuracy assessment of GIS wetland mapping in the coastal counties of North Carolina. North Carolina Department of Environment and Natural Resources, Division of Coastal Management, ., 41p.

Shumway, S. E. 1996. Natural environmental factors. p. 467-513 *in* Kennedy, V. S., Newell, R. I. E., and Eble (eds.), A. F. The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant College, University of Maryland, College Park, Maryland.

Shumway S.E., J.M. Burkholder, and J. Springer . 2006. Effects of the estuarine dinoflagellate *Pfiesteria shumwayae* (Dinophyceae) on survival and grazing activity of several shellfish species. Harmful Algae 5: 442-458.

Shumway, S. E. and R.K. Koehn. 1982. Oxygen consumption in the American oyster *Crassostrea virginica*. Marine Ecology Progress Series 9: 59-68.

Sigels, A. C., T.C. Hoering, and G.R. Helz. 1982. Composition of estuarine colloidal material: organic components. Geochimica Cosmochimica Acta 46: 1619-1626.

Signorini, S. R. and C. R. McClain. 2007. Large-scale forcing impact on biomass variability in the South Atlantic Bight. Geophysical Research Letters 34: 6.

Silliman, B. R. and M.D. Bertness. 2002. A trophic cascade regulates salt marsh primary production. Proceedings of the National Academy of Science 99(16): 10500-10505.

Simonsen, K. A. 2008. The effect of an inshore artificial reef on the community structure and feeding ecology of estuarine fishes in Barataria Bay, Louisiana. Louisiana State University, Baton Rouge, LA, 100 p.

Simpson, A. W. and L. Watling. 2006. An investigation of the cumulative impacts of shrimp trawling on community structure. ICES Journal of Marine Science 63(9): 1616-1630.

Skaggs, R. W., G.M. Chescheir, and B.D. Phillips. 2005. Methods to determine lateral effect of a drainage ditch on wetland hydrology. Transaction of the ASAE 48(2): 577-584.

Skilleter, G. A. 1994. Refuges from predation and the persistence of estuarine clam populations. Marine Ecology Progress Series 109(1): 29-42.

Slater, G. F., H.K. White, T.I. Eglinton, and C.M. Reddy. 2005. Determination of microbial carbon sources in petroleum contaminated sediments using molecular 14C analysis. *Environmental Science & Technology* 39: 25522558.

Smaoui-Damak W., T. Rebai, B. Berthet, and A. Hamza-Chaffai. 2006. Does cadmium pollution affect reproduction in the clam *Ruditapes decussates*? A one-year case study. Comparative Biochemistry and Physiology 143C: 252-261.

Smart, R. M., G.O. Dick, and R.D. Doyle. 1998. Techniques for establishing native aquatic plants. Journal of Aquatic Plant Management 36: 44-49.

Smayda, T. J. 1989. Primary production and the global epidemic of phytoplankton blooms in the sea: A linkage? In: *Novel Phytoplankton Blooms*, by E.M. Cosper, V.M. Bricelj and E.J. Carpenter (eds.). Springer-Verlag, New York, Coastal and Estuarine Studies No. 35 , 449-484p.

Smith, C. M. and C.T. Hackney. 1989. The effects of hydrocarbons on the setting of the American oyster, *Crassostrea virginica*, in intertidal habitats in southeastern North Carolina. Estuaries 12: 42-48.

Smith, K. 1998. A summary of limited vessel entry zones for managed seagrass protection in Florida. Florida Department of Environmental Protection, St. Petersburg, Fl, 30p.

Smith, S. V., W.J. Kimmerer, E.A. Laws, R.E. Brock, and T.W. Walsh. 1981. Kanehoe Bay sewage diversion experiment: perspectives on ecosystem responses to nutritional perturbation. Pacific Science 35: 278-396.

Smock, L. A. and E. Gilinsky. 1992. Coastal plain blackwater streams. p. 271-313 *in* C.T. Hackney, S. M. Adams and W. H. Martin eds. Biodiversity of the southeastern United States: aquatic communities. John Wiley and Sons, Inc., NY, 779 p.

Snodgrass, J. W., A.L. Bryan Jr., R.F. Lide, and G.M. Smith. 1996. Factors affecting the occurrence and structure of fish assemblages in isolated wetlands of the upper coastal plain, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences. 53: 443-454.

Sobsey, M. D. 1996. Pathogens and their indicators in North Carolina surface waters. p. 6-10 *in* NCSU (ed.). Solutions: Proceedings of a Technical Conference on Water Quality. 19-21 March 1996. NCSU, Raleigh.

Sobsey, M. D., R. Perdue, M. Overton, and J. Fisher. 2003. Factors influencing faecal contamination in coastal marinas. Water Science and Technology 47: 199-204.

Soniat, T. M., C.M. Finelli, and J.T. Ruiz. 2004. Vertical structure and predator refuge mediate oyster reef development and community dynamics. Journal of Experimental Marine Biology and Ecology 310(2): 163-182.

Sparks, A. K., J.L. Boswell, and J.G. Mackin . 1958. Studies on the comparative utilization of oxygen by living and dead oysters . Proceedings of the National Shellfisheries Association 48: 92-102.

Sprague, L. A. and W.A. Battaglin. 2005. Wastewater chemicals in Colorado's streams and ground water: U.S. Geological Survey Fact Sheet . 2004-3127 , 4p.

Spruill, T. B., D.A. Harned, P.M. Ruhl, J.L. Eimers, G. McMahon, K.E. Smith, D.R. Galeone, and M.D. Woodside. 1998. Water quality in the Albemarle-Pamlico Drainage Basin, North Carolina and Virginia, 1992-1995. U.S. Geological Survey Circular 1157 .

Spruill, T. B. and J.F. Bratton. 2008. Estimation of groundwater and nutrient fluxes to the Neuse River estuary, North Carolina. Estuaries and Coasts 31: 501-520.

Stachowicz, J. J., J.R. Terwin, R.B. Whitlatch, and R.W. Osman. 2002. Linking climate change and biological invasions: ocean warming facilitates nonindigenous species invasions. Proceedings of the National Academy of Science 99: 15497-15500.

Stanley, D. and S. Nixon. 1992. Stratification and bottom-water hypoxia in the Pamlico River Estuary. Estuaries 15(2): 270-281.

Stanley, E. H. and M.W. Doyle. 2003. The ecological effects of dam removal. Frontiers in Ecology and the Environment 1(1): 15-22.

Stant, J. 2010. Out of Control: Mounting Damages From Coal Ash Waste Sites . Environmental Integrity and Earthjustice, 113p.

Steel, J. 1991. Albemarle-Pamlico Estuarine System, technical analysis of status and trends. DENR, Raleigh, NC, APES Report No. 90-01 .

Steimle, F. W., C.A. Zetlin, P.L. Berrien, and S. Chang. 1999. Black sea bass, *Centropristis striata*, life history and habitat characteristics. NOAA, Northeast Fisheries Science Center, Woods Hole, Mass, NMFS-NE-143 , 42p.

Steimle, F. W. and C. Zetlin. 2000. Reef habitats in the Middle Atlantic Bight: abundance, distribution, associated biological communities, and fishery resource use. Marine Fisheries Review 62(2): 24-42.

Steiner, A. J. and S.P. Leatherman. 1981. Recreational impacts on the distribution of ghost crabs, *Ocypode quadrata* fab. Biological Conservation 20: 11-122.

Stephan, C. D. and T.E. Bigford. 1997. Atlantic coastal submerged aquatic vegetation: a review of its ecological role, anthropogenic impacts, state regulations, and value to Atlantic coastal fish stocks. Atlantic States Marine Fisheries Commission, 77p.

Stevenson, J. C. 1988. Comparative ecology of submersed grass beds in freshwater, estuarine, and marine environments. Limnology and Oceangraphy 33(4, part 2): 867-893.

Stevenson, J. C., L.W. Staver, and K.W. Staver. 1993. Water quality associated with survival of submerged aquatic vegetation along an estuarine gradient. Estuaries 16(346-361).

Stevenson, J. C. and N.M. Confer. 1978. Summary of available information on Chesapeake Bay submerged vegetation. US Fish and Wildlife Service, Office of Biological Services, FWS/OBS-78/66 , 335p.

Steward, J. S. and W.C. Green. 2007. Setting load limits for nutrients and suspended solids based upon seagrass depth-limit targets. Estuaries and Coasts 30(4): 657-670.

Stoecker, D., J. Adolf, A. Place, P. Gilbert, and D. Meritt. 2008. Effects of the dinoflagellates *Karlodinium veneficum* and *Prorocentrum minimum* on the early life history stages of the eastern oyster (*Crassostrea virginica*). Marine Biology 154(1): 81-90.

Stone, K. C., P.G. Hunt, S.W. Coffey, and T.A. Matheny. 1995. Water quality status of a USDA water quality demonstration project in the eastern Coastal Plain. Journal of Soil and Water Conservation 40: 567-571.

Stout, V. F. 1980. Organochlorine residues in fishes from the northwest Atlantic Ocean and Gulf of Mexico. Fishery Bulletin 78(1): 51-58.

Strange, R. J., W.B. Kittrell, and T.D. Broadbent. 1982. Effects of seeding reservoir fluctuation zones on young-of-the-year black bass and associated species. North American Journal of Fisheries Management 2: 307-315.

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

Street, M. W., P.P. Pate, B.F. Holland Jr., and A.B. Powell. 1975. Anadromous Fisheries Research Program, Northern Coastal Region. NC Division of Marine Fisheries, AFCS-8 , 262p.

Strelcheck, A. J., J.H. Cowan, and A. Shah. 2005. Influence of reef location on artificial-reef fish assemblages in the northcentral Gulf of Mexico. Bulletin of Marine Science 77(3): 425-440(16).

Struyf, E., S. Van Damme, B. Gribsholt, and P. Meire. 2005. freshwater marshes as dissolved silica recyclers in an estuarine environment (Schelde estuary, Belgium). Hydrobiologia 540: 69-77.

Stunz, G. W., T.J. Minello, and P.S. Levin. 2002. A comparison of early juvenile red drum densities among various habitat types in Galveston Bay, Texas. Estuaries 25(1): 76-85.

Sudduth, E. B., J.L. Meyer, and E.S. Bernhardt. 2007. Stream restoration practces in the southeastern United States. Restoration Ecology 15(3): 573-583.

Summerson, H. C. and C.H. Peterson. 1984. Role of predation in organizing benthic communities of a temperate-zone seagrass bed. Marine Ecology Progress Series 15: 63-77.

Summerson, H. C. and C.H. Peterson. 1990. Recruitment failure of the bay scallop, *Argopecten irradians-concentricus*, during the 1st red tide, *Ptychodiscus brevis*, outbreak recorded in North Carolina. Estuaries 13(3): 322-331.

Sutter, L. 1999. DCM wetland mapping in coastal North Carolina. Division of Coastal Management, Raleigh, NC, 33p.

Sutula, M., K. Kramer, J. Cable, H. Collis, W. Berelson, and J. Mendez. 2006. Sediments as an internal source of nutrients to upper Newport Bay, California. Southern California Coastal Water Research Project No. 482, Technical Report , 167p.

Sved, D. W., P.A. Vanveld, and M.H. Roberts. 1992. Hepatic erod activity in spot, *Leiostomus xanthurus*, exposed to creosote-contaminated sediments. Marine Environmental Research 34(1-4): 189-193.

Szedlmayer, S. T. and K.W. Able. 1996. Patterns of seasonal availability and habitat use by fishes and decapod crustaceans in a southern New Jersey estuary. Estuaries 19(3): 697-709.

Tagatz, M. E. and D.L. Dudley. 1961. Seasonal occurrence of marine fishes in four shore habitats near Beaufort, NC, 1957-1960. U.S. Fish and Wildlife Service, Special Scientific Report No. 390 .

Tamburri, M. N., C.M. Finelli, D.S. Wethey, and R.K. Zimmer-Faust. 1996. Chemical induction of larval settlement behavior in flow. Biological Bulletin 191(3): 367-373.

Tarnowski, M. 2003. Maryland oyster population status report: 2002 Fall survey. Maryland Department of Natural Resources, Annapolis, MD, 32p.

Tarnowski, M. 2005. Maryland oyster population status report: 2003 and 2004 Fall survey. Maryland Department of Natural Resources, Annapolis, MD, 33p.

Tarplee, W. H. Jr., D.E. Louder, and A.J. Weber . 1971. Evaluation of the effects of channelization on fish populations in North Carolina's coastal plain streams. North Carolina Wildlife Resources Commission, Raleigh, NC.

Taylor, D. L. and D.B. Eggleston. 2000. Effects of hypoxia on an estuarine predator-prey interaction: foraging behavior and mutual interference in the blue crab *Callinectes sapidus* and the infaunal clam prey *Mya arenaria*. Marine Ecology Progress Series 196: 221-237.

Taylor, J. C. and J.M. Miller. 2001. Physiological performance of juvenile southern flounder, *Paralichthys lethostigma* (Jordan and Gilbert 1984), in chronic and episodic hypoxia. Journal of Experimental Marine Biology and Ecology 258(2): 195-214.

Taylor, J. C. and P.S. Rand. 2003. Spatial overlap and distribution of anchovies (*Anchoa* spp.) and copepods in a shallow stratified estuary. Aquatic Living Resources 16(3): 191-196.

Taylor, J. E. 1999. Making salmon: An environmental history of the Northwest fisheries crisis. University of Washington Press, Seattle, WA.

Taylor, J. L. and C.H. Saloman. 1968. Some effects of hydraulic dredging and coastal development in Boca Ciega Bay, Florida. Fisheries Bulletin 67: 213-241.

Teal, J. 1962. Energy flow in salt marsh macrophyte production: a review. Ecology 43: 614-624.

Teal, J. and M. Teal. 1969. Life and death of the salt marsh. Audubon/Ballentine Books, New York, NY, 274p.

Teal, J. M., J.W. Farrington, K.A. Burns, J.J. Stegeman, B.W. Tripp, B. Woodin, and C. Phinney. 1992. The West Falmouth oil spill after 20 years: fate of fuel oil compounds and effects on animal. *Marine Pollution Bulletin* 24: 607614.

Teal, J. M., K. Burns, and J. Farrington. 1978. Analyses of aromatic hydrocarbons in intertidal sediments resulting from two oil spills of no. 2 fuel oil in Buzzards Bay. *Massachusetts Journal of the Fisheries Research Board of Canada* 35: 510520.

Tenore, K. R. 1972. Macrobenthos of the Pamlico River estuary, North Carolina. Ecological Monographs 42: 51-69.

Terlizzi, A., S. Fraschetti, P. Guidetti, and F. Boero. 2002. The effects of sewage discharge on shallow hard substrate sessile assemblages. Marine Pollution Bulletin 44(6): 544-550.

Tester, P. A., M.E. Geesey, C. Guo, H.W. Paerl, and D.F. Millie. 1995. Evaluating phytoplankton dynamics in the Newport River estuary (North Carolina, USA) by HPLC-derived pigment profiles. Marine Ecology Progress Series 124: 237-245.

Tester, P. A. and P.K. Fowler . 1990. Brevetoxin contamination of *Mercenaria mercenaria* and *Crassostrea virginica*: a management issue. p. 499-503 *in* E. Graneli et al. (eds). Toxic Marine Phytoplankton. Elsevier Science Publishing Co., Inc..

Thayer, G. W. 1971. Phytoplankton production and distribution of nutrients in a shallow unstratified estuarine system near Beaufort, NC. Chesapeake Science 12: 240-253.

Thayer, G. W., S.M. Adams, and M.W. La Croix. 1975. Structural and functional aspects of a recently established *Zostera marina* community. p. 518-540 *in* L.E. Cronin (ed.). Estuarine Research. Academic Press, New York, NY, .

Thayer, G. W., W.J. Kenworthy, and M.S. Fonseca. 1984. The ecology of eelgrass meadows of the Atlantic coast: a community profile. U.S. Fish and Wildlife Service, FWS/OBS-84/02 , 147p.

Thieler, E. R., A.L. Brill, W.J. Cleary, C.H. Hobbs III, and R.A. Gammisch. 1995. Geology of the Wrightsville Beach, North Carolina shoreface: implications for the concept of shoreface profile of equilibrium. Marine Geology 126: 271-287.

Thieler, E. R., W.C. Schwab, M.A. Allison, J.F. Denny, and W.W. Danforth. 1998. Sidescan-sonar imagery of the shoreface and inner continental shelf, Wrightsville Beach, North Carolina . USGS Open-file Report 98-596 , 16p.

Thomas, C. J. and L.B. Cahoon. 1993. Stable isotope analyses differentiate between different trophic pathways supporting rocky reef fishes . Marine Ecology Progress Series 95: 19-24.

Thompson, T. 2000. Intake modifications to reduce entrainment and impingement at Carolina Power and Light Company's Brunswick Steam Electric Plant, Southport, North Carolina. Environmental Science and Policy 3(1): 417-424.

Thomsen, M. S., P. Staehr, C.D. Nyberg, S. Schwaerter, D. Krause-Jensen, and B.R. Silliman. 2007. *Gracilaria vermiculophyll* (Ohmi) Papenfuss, 1967 (Rhodophyta, Gracilariaeae) in northern Europe, with emphasis on Danish conditions, and what to expect in the future. Aquatic Invasions 2(2): 83-94.

Thorne, R. E. and G.L. Thomas. 2008. Herring and the "Exxon Valdez" oil spill: an investigation into historical data conflicts. ICES Journal of Marine Science 65: 44-50.

Thorpe, T., C.F. Jensen, and M.L. Moser. 2003. Relative abundance and reproductive characteristics of sharks in southeastern North Carolina coastal waters. Bulletin of Marine Science (in press).

Thrush, S. F., J.S. Gray, J.E. Hewitt, and K.I. Ugland. 2006. Predicting the effects of habitat homogenization on marine biodiversity. Ecological Applications 16(5): 1636-1642.

Thrush, S. F. and P.K. Dayton. 2002. Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. Annual Review of Ecology and Systematics 33: 449-743.

Tilmant, J. T. 1979. Observations on the impacts of shrimp roller frame trawls operated over hard bottom communities, Biscayne Bay, Florida. National Park Service, Miami, Fl, Report Series No. P-553 , 23p.

Titus, J. G. 1998. Rising seas, coastal erosion, and the takings clause: How to save wetlands and beaches without hurting property owners. Maryland Law Review 57: 1279-1399.

Toft, J., C. Simenstad, J. Cordell, and L. Stamatiou. 2004. Fish distribution, abundance, and behavior at nearshore habitats along City of Seattle marine shorelines, with an emphasis on juvenile salmonids. University of Washington, Seattle, WA, SAFS-UW-0401 , 51p.

Toft, J. D., J.R. Cordell, C.A. Simenstad, and L.A. Stamatiou. 2007. Fish distribution, abundance, and behavior along city shoreline types in Puget Sound. North American Journal of Fisheries Management 27(2): 465-480.

Tolley, S. G. and A.K. Volety. 2005. The role of oysters in habitat use of oyster reefs by resident fishes and decapod crustaceans. Journal of Shellfish Research 24(4): 1007-1012.

Townsend, E. and M. S. Fonseca. 1998. Bioturbation as a potential mechanism influencing spatial heterogeneity of North Carolina seagrass beds. Marine Ecology Progressive Series 169: 123-132.

Townsend, P. A. 2001b. Relationships between vegetation patterns and hydroperiod on the Roanoke River floodplain, North Carolina. Plant Ecology 156(1): 43-58.

Trappe, C. 2004. Marine protected areas in North Carolina. Master's Thesis, Duke University, Beaufort, NC

Treat, S. F. and R.R. Lewis. 2006. Seagrass restoration: success, failure, and the costs of both. Lewis Environmental Services, Inc., Valrico, FL, June , 175 pp.p.

Trent, L. and W.W. Hassler. 1968. Gill net selection, migration, size and age composition, sex ratio, harvest efficiency, and management of striped bass in the Roanoke River, North Carolina.

Chesapeake Science 9(4): 217-232.

Turberty, S. R. and C.L.Jr. McKenney . 2005. Ecdysteroid responses of estuarine crustaceans exposed through complete larval development to juvenile hormone agonist insecticides. Integratvie and Comparitive Biology 45(1): 106-117.

Turner, R. E. 1977. Intertidal vegetation and commercial yields of Penaeid shrimp. Transactions of the American Fisheries Society 106(5): 411-416.

Twilley, R. R., W.M. Kemp, K.W. Staver, J.C. Stevenson, and W.R. Boynton. 1985. Nutrient enrichment of estuarine submersed vascular plant communities. 1. Algal growth and effects on production of plants and associated communities. Marine Ecology Progress Series 23: 179-191.

Tye, R. 1983. Impact of Hurricane David and mechanical dune restoration on Folly Beach, SC. Shore and Beach 51: 3-9.

Tyler, M. 1989. Potential for long-term persistence of the red tide dinoflagellate *Ptychodiscus brevis* in North Carolina coastal waters. Final Report prepared to N.C. Department of Natural Resources and Community Development, Albemarle-Pamlico Estuarine Study 88-09: 14 .

Tyrrell, M., M. Dionne, and J. Edgerly. 2008. Physical factors mediate effects of grazing by a non-indigenous snail species on saltmarsh cordgrass (*Spartina alterniflora*) in New England marshes. ICES Journal of Marine Science 65(5): 746-752.

Udouj, T. 2007. Final Report Deepwater Habitat Mapping Project Phase III: Partnership with the FWC Florida Fish and Wildlife Research Institute in the Recovery, Interpretation, Integration and Distribution of Bottom Habitat Information for the South Atlantic Bight (200 – 2,000 m). SAFMC, Charleston, South Carolina, 16p.

Ulanowicz, R. E. and J.J. Tuttle. 1992. The trophic consequences of oyster stock rehabilitation in the Chesapeake Bay. Estuaries 15(3): 298-306.

Uncles, R. J., J.A. Stephens, and T.Y. Woodrow. 1988. Seasonal cycling of estuarine sediment and contaminant transport. Estuaries 11: 108-116.

UNCW (University of North Carolina at Wilmington). 2008. The potential impacts of climate change on coastal North Carolina. A report by the faculty of the University of North Carolina Wilmington. University of North Carolina at Wilmington, Wilmington, NC, 124p.

Underwood, G. J. C. and D. Paterson. 1993. Seasonal changes in diatom biomass, sediment stability and biogenic stabilization in the Severn Estuary. Journal of the Marine Biological Association of the United Kingdom. Plymouth 73: 881-887.

UNEP (United Nations Environment Programme). 2010. Blue carbon - the role of healthy oceans in binding carbon. www.unep.org.

UNEP (United Nations Environmental Program). 2009. Marine litter: a global challenge. United Nations Environmental Program, Nairobi, 232p.

USACE (US Army Corps of Engineers). 1992. Draft environmental impact statement: beach erosion control and hurricane wave protection, Carolina Beach and vicinity area, south project New Hanover County, NC . U.S. Army Corps of Engineers, Wilmington District, Wilmington, NC, 54p.

USACE (US Army Corps of Engineers). 2001. The New York District's biological monitoring program for the Atlantic coast of New Jersey, Asbury Park to Manasquan section beach erosion control project. USACOE, Vicksburg, MS, Final report , 103p.

USACE (US Army Corps of Engineers). 2002. Environmental assessment, fish bypass at Lock and Dam #1. US Army Corps of Engineers, Wilmington District, Wilmington, NC, 28p.

USACE (US Army Corps of Engineers). 2003. Effects of dredged material beach disposal on surf zone and nearshore fish and benthic resources on Bald Head Island, Caswell Beach, Oak Island, and Holden Beach, North Carolina: Interim study findings. Versar, Inc., Columbia, Md.

USACE (US Army Corps of Engineers). 2008. Draft Programmatic Environmental Impact Statement for Oyster Restoration in Chesapeake Bay Including the Use of Native and/or Nonnative Oyster. U.S. Army Corps of Engineers, Norflok District, Norfolk, VA, 20p.

USACE (US Army Corps of Engineers) and EPA (US Environmental Protection Agency). 1996. Site management and monitoring plan for the Wilmington ocean dredged material disposal site. U.S. Army Corps of Engineers, Wilmington District, Wilmington, NC, 30p.

USACE (US Army Corps of Engineers) and EPA (US Environmental Protection Agency). 1997. Site management and monitoring plan for the Morehead City ocean dredged material disposal site. U.S. Army Corps of Engineers, Wilmington District, Wilmington, NC, 29p.

USACE (US Army Corps of Engineers) and EPA (US Environmental Protection Agency). 2002. Site management and monitoring plan for the New Wilmington ocean dredged material disposal site. U.S. Army Corps of Engineers, Wilmington District, Wilmington, NC, 13p.

USCG (United State Coast Guard). 2009a. Standards for living organisms in ships' ballast water discharged in U.S. waters. Federal Register, Proposed Rules 74(166): 44632-44672.

USCG (United States Coast Guard). 12/2009b. USCG Ballast water discharge standard - Overview of notice of proposed rulemaking. http://www.uscg.mil/hq/cg5/cg522/cg5224/docsNPRM%20Public%20Meeting%202009%20FINAL-CA-NY.pdf.

USFWS (U.S. Fish and Wildlife Service). 1992. Albemarle Sound and Roanoke River Basin. US Dept Interior, Washington, DC, p.

USFWS (U.S. Fish and Wildlife Service). 2008. American Alligator *Alligator mississippiensis*. US Fish and Wildlife Service, Arlington, VA.

USGS (US Geological Survey). 2001. Federal standards for delineation of hydrologic boundaries. 49p.

USGS (US Geological Survey). 2003. National Water Quality Assessment - Nutrients in surface waters. http://nc.water.usgs.gov/albe/findings.html, 2/14/2003.

Utne-Palm, A. C. 2002. Visual feeding of fish in a turbid environment: Physical and behavioural aspects. Marine and Freshwater Behavioral Physiology 135: 111-128.

Valiela, I., J. Costa, K. Foreman, J.M. Teal, B.L. Howes, and D. Aubrey. 1990. Transport of ground-borne nutrients from watersheds and their effects on coastal waters. Biogeochemistry 10: 177-197.

Valiela, I., J. H. J. McClelland, P.J. Behr, D. Hersh, and K. Foreman. 1997. Macroagal blooms in shallow estuaries: Controls and ecophysiological and ecosystem consequences. Limnology and Oceanography 45(5): 110-1118.

Van Dolah, R. F., B.J. Digre, P.T. Gayes, P. Donovan-Ealy, and M.W. Dowd. 1998. An evaluation of physical recovery rates in sand borrow sites used for beach nourishment projects in South Carolina. Final Report prepared for the South Carolina Task Force on Offshore Resources and Minerals Management Service. SC Department of Natural Resources, Charleston, SC, 77 p.

Van Dolah, R. F., P.H. Wendt, and N. Nicholson. 1987. Effects of a research trawl on a hard-bottom assemblage of sponges and corals. Fisheries Research 5: 39-54.

Van Dolah, R. F., P.H. Wendt, R.M. Martore, M.V. Levison, and W.A. Roumillat. 1992. A physical and biological monitoring study of the Hilton Head beach nourishment project. Final Report prepared for the Town of Hilton Head Island and South Carolina Coastal Council. SC DNR, Charleston, SC, 159p.

Van Dolah, R. F., R.M. Martore, A.E. Lynch, M.V. Levison, P.H. Wendt, D.J. Whitaker, and W.D. Anderson. 1994. Environmental evaluation of the Folly Beach nourishment project. SC Department of Natural Resources, Charleston, SC, Final Report prepared by US Army Corps of Engineers and Marine Resources Division of the South Carolina Dept of Natural Resources. 100p.

Vandermeulen, J. H. and D. Mossman. 1996. Sources of variability in seasonal hepatic microsomal oxygenase activity in winter flounder (*Pleuronectes americanus*) from a coal tar contaminated estuary. Canadian Journal of Fisheries and Aquatic Sciences 53: 1741-1753.

Vandersea, M. W., R.W. Litaker, B. Yonnish, E. Sosa, J.H. Landsberg, C. Pullinger, P. Moon-Butzin, J. Green, J.A. Morris, H. Kator, E.J. Noga, and P.A. Tester. 2006. Molecular assays for detecting *Aphanomyces invadans* in ulcerative mycotic fish lesions. Applied and Environmental Microbiology 72(2): 1551-1557.

Vannote, R. L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130-137.

Vergeer, L. H. T., T.L. Aarts, and J.D. de Groot. 1995. The 'wasting disease' and the effect of abiotic factors (light intensity, temperature, salinity) and infection with *Labyrinthula zosterae* on the phenolic content of *Zostera marina* shoots. Aquatic Botany 52: 35-44.

Versar Inc. 2003. Year 2 recovery from impacts of beach nourishment on surf zone and nearshore fish and benthic resources on Bald Head Island, Caswell Beach, Oak Island, and Holden Beach, North Carolina. Final Study Findings. Columbia, Maryland, 126 p.

Vetter, R. D. 1977. Respiratory metabolism of and niche separation between, two co-occurring congeneric species, *Cynoscion nebulosus* and *Cynoscion arenarius*, in a South Texas estuary. M.S. Thesis, University of Texas, Austin, TX, 114 p.

Vigil, D. L. 1998. North Carolina/Minerals Management Service Technical Workshop on Manteo Unit Exploration: February 4-5, 1998. U.S . Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA, OCS Study MMS 98-0024 , 168p.

VIMS (Virginia Institute of Marine Science). 2002. Oyster Diseases of the Chesapeake Bay: Dermo and MSX Fact Sheet. 4p.

VIMS (Virginia Institute of Marine Sciences). 2007. Status of research on the Asian oyster. NOAA Chesapeake Bay Office, Annapolis, MD, NOAA Ariakensis Team 1/17/07 Update , 2p.

Vingard, G. L. and W.J. O'Brien. 1976. Effects of light and turbidity on the reactive distance of bluegill (*Lepomis macrochirus*). Journal of the Fisheries Research Board of Canada 33(2845-2849).

Virnstein, R. W. and L.J. Morris. 1996. Seagrass preservation and restoration: a diagnostic plan for the Indian River Lagoon . St. Johns River Water Management District, Palatka, Fl, Tech. Mem. #14 , 43p.

Virnstein, R. W., P.S. Mikkelsen, K.D. Cairns, and M.A. Capone. 1983. Seagrass beds versus sand bottoms: the trophic importance of their associated benthic invertebrates. Florida Scientist 46: 363-381.

Voudrias, E. A. and C.L. Smith. 1986. Hydrocarbon pollution from marinas in estuarine sediments. Estuarine Coastal Shelf Sciences 22: 271-284.

Waddy, S. L., L.E. Burridge, M.N. Hamilton, S.M. Mercer, D.E. Aiken, and K. Haya. 2002. Emamectin benzoate induces molting in American lobster, *Homarus americanus*. Canadian Journal of Fisheries and Aquatic Sciences 59(7): 1096-1099.

Wahlberg, M. and H. Westerberg. 2005. Hearing in fish and their reactions to sounds from offshore wind farms. Marine Ecology Progress Series 288: 295-309.

Wainright, S., M.P.Weinstein, K.W. Able, and C.A. Currin. 2000. Relative importance of benthic microalgae, phytoplankton and the detritus of smooth cordgrass *Spartina alterniflora* and the common reed *Phragmites australis* to brackish-marsh food webs. Marine Ecology Progress Series 200: 77-91.

Waite, R., J. Giordano, M. Scully, K. Rowles, J. Steel, M. Rumley, T. Stroud, G. Stefanski, A. Coburn, L. Everett, L. Webb-Margeson , J. Chazal, L. Peck, and N. Petrovich. 1994. Comprehensive Conservation and Management Plan (Technical Document), Albemarle-Pamlico Estuarine Study. U.S. Environmental Protection Agency, Washington, DC, .

Walker, J. T., V.P. Aneja, and D.A. Dickey. 2000. Atmospheric transport and wet deposition of ammonium in North Carolina. Atmospheric Environment 34: 3407-3418.

Walker, M. D. 1984. Fish utilization of an inundated swamp-stream floodplain. M.S. Thesis , East Carolina University, Greenville, NC, 72 p.

Walker, S. J., T.A. Schlacher, and L.M.C. Thompson. 2008. Habitat modification in a dynamic environment: The influence of a small articial groyne on macrofaunal assemblages of a sandy beach. Estuarine, Coastal, Shelf Science 79: 24-34.

Walker, W. W. 1977. Pesticides and their residues in the Mississippi coastal zone. Journal of the Mississippi Academy of Science 21: 148-154.

Wall, C. C., B.J. Peterson, and C.J. Gobler. 2008. Facilitation of seagrass *Zostera marina* productivity by suspension-feeding bivalves. Marine Ecology Progress Series 357: 165-174.

Wall, L. M., L.J. Walters, R.E. Grizzle, and P.E. Sacks. 2005. Recreational boating activity and its impacts on the recruitment and survival of the oyster *Crassostrea virginica* on intertidal reefs in Mosquito Lagoon, Florida. Journal of Shellfish Research 24(4): 965-973.

Walsh, H. J., D.S. Peters, and D.P. Cyrus. 1999. Habitat utilization by small flatfishes in a North Carolina estuary. Estuaries 22(3B): 803-813.

Walsh, H. J., L.R. Settle, and D.S. Peters. 2005. Early life history of blueback herring and alewife in the lower Roanoke River, North Carolina. Transactions of the American Fisheries Society 134: 910-926.

Walters, L., P. Sacks, L. Wall, J. Grevert, D. LeJeune, S. Fischer, and A. Simpson. 2003. Declining intertidal oyster reefs in Florida: direct and indirect impacts of boat wakes. Journal of Shellfish Research 22(1): 359-360.

Walton, T. L. and W.M. Sensabaugh. 1979. Seawall design on the open coast. Florida Sea Grant Report 29: 24 p.

Wang, C. and R.P. Croll. 2006. Effects of sex steroids on spawning in the sea scallop, *Placopecten magellanicus*. Aquaculture 256: 423-432.

Wang, J. C. S. and R.J. Kernehan. 1979. Fishes of the Delaware estuaries. Ecological Analysts, Inc., Towson, Md, 410p.

Wang, Y. and T.R. Allen. 2008. Estuarine shoreline change detection using Japanese ALOS PALSAR HH and JERS-1 L-HH SAR data in the Albemarle-Pamlico sounds, North Carolina, USA. International Journal of Remote Sensing 29(15): 4429-4442.

Wannamaker, C. M. and J.A. Rice . 2000. Effects of hypoxia on movements and behavior of selected estuarine organisms from the southeastern United States. Journal of Experimental Marine Biology and Ecology 249: 145-163.

Ward, S., T. Augspurger, F.J. Dwyer, C. Kane, and C.G. Ingersoll. 2007. Risk assessment of water quality in three North Carolina, USA, streams supporting federally endangered freshwater mussels (Unionidae). Environmental Toxicology and Chemistry 26(10): 2075-2085.

Warinner, J. E., J.P. Miller, and J. Davis. 1969. Distribution of juvenile river herring in the Potomac River. Proceedings of the Annual Conference of the Southeast Association of Game and Fish Commissions 23: 384-388.

Warwick, R. 1993. Environmental impact studies in marine communities: pragmatical considerations.

Australian Journal of Ecology 18: 63-80.

Waters, C. T. and C.D. Thomas. 2001. Shoreline hardening effects on associated fish assemblages in five North Carolina coastal rivers. North Carolina Wildlife Resources Commission, Raleigh, NC, 20p.

Watling, L. and E. Norse. 1998. Disturbance of the seabed by mobile fishing gear: a comparison to forest clearcutting. Conservation Biology 12(6): 1180-1197.

Watts, J. G. 1987. Physical and biological impacts of bulkheads on North Carolina's estuarine shoreline. Duke University, Durham, NC, Report to North Carolina Division of Coastal Management , 39 p.

Waycott, M., C.M. Duarte, T.J.B. Carruthers, R.J. Orth, W.C. Dennison, S. Olyarnik, A. Calladine, J.W. Fourqurean, K.L. Heck Jr., A.R. Hughes, G.A. Kendrick, W.Judson Kenworthy, F.T. Short, and S.L. Williams. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the National Academy of Science 106(30): 12377-12381.

Webster, I. T., P.W. Ford, and B. Hodgson. 2002. Microphytobenthos contribution to nutrient-phytoplankton dynamics in a shallow coastal lagoon. Estuaries 25(4A): 540-551.

Weinstein, M. P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, NC. Fisheries Bulletin 2: 339-357 .

Weinstein, M. P. and J.H. Balletto. 1999. Does the common reed, *Phragmites autralis,* affect Essential Fish Habitat? Estuaries Annual Marine and Estuarine Shallow Water Science and Management Conference: The Interrelationship among habitats and their management(No. 3B): 793-802.

Weis, J. S. and P. Weis. 1989. Effects of environmental pollutants on early fish development. Aquatic Sciences 1(1): 45-55.

Weis, J. S. and P. Weis. 1994. Effects of contaminants from chromated copper arsenate-treated lumber on benthos. Archives of Environmental Contamination and Toxicology 26: 103-109.

Weis, J. S. and P. Weis. 1995. Effects of bulkheads made of pressure-treated wood and other materials on shallow water benthos in estuaries. Second Annual Marine and Estuarine Shallow Water Science and Management Conference : 14 .

Weis, J. S. and P. Weis. 2003. Is the invasion of the common reed, Phragmites australis, into tidal marshes of the eastern US an ecological disaster? Marine Pollution Bulletin 46(7): 816-820.

Weis, J. S., P. Weis, and T. Proctor . 1998. The extent of benthic impacts of CCA-treated wood structures in Atlantic coast estuaries. Archives of Environmental Contamination and Toxicology 34(4): 313-322.

Weis, P. and J.S. Weis. 1999. Accumulation of metals in consumers associated with chromated copper arsenate-treated wood panels. Marine Environmental Research 48: 73-81.

Weis, P., J.S. Weis, A. Greenberg, and J.T. Nosker. 1992. Toxicity of construction materials in the marine environment: a comparison of chromated copper arsenate-treated wood and recycled plastic. Archives of Environmental Contamination and Toxicology 22: 99-106.

Weis, P., J.S. Weis, and J. Couch. 1993. Histopathology and bioaccumulation in oysters *Crassostrea virginica* living on wood preserved with chromated copper arsenate. Diseases of Aquatic Organisms 17(1): 41-46.

Weis, P., J.S. Weis, J. Couchl C. Daniels, and T. Chen. 1995. Pathological and genotoxicological observations in oysters (*Crassostrea virginica*) living on chromated copper arsenate (CCA)-treated wood. Marine Environmental Research 39(1-4): 275-278.

Wells, H. W. 1957. Abundance of the hard clam *Mercenaria mercenaria* in relation to environmental factors. Ecology 38: 123-128.

Wells, H. W. 1961. The fauna of oyster beds, with special reference to the salinity factor. Ecological Monographs 31: 239-266.

Wells, J. T. 1989. A scoping study of the distribution, composition, and dynamics of water-column and bottom sediments: Albemarle-Pamlico estuarine system. Institute of Marine Sciences, UNC-Chapel Hill, Morehead City, NC, 89-05 , 39p.

Wells, J. T. and C.H. Peterson. 1986. Restless ribbons of sand: Atlantic and Gulf coastal barriers . USFWS, National Wetlands Research Center. 24 p.

Wells, R. J. D., J.H. Cowan Jr., and W.F. Patterson III. 2008. Habitat use and the effect of shrimp trawling on fish and invertebrate communities over the northern Gulf of Mexico continental shelf. ICES Journal of Marine Science 65(9): 1610-1619.

Wendt, P. H., R.F. Van Dolah, M.Y. Bobo, and J.J. Manzi. 1990. Effects of marina proximity on certain aspects of the biology of oysters and other benthic macrofauna in a South Carolina estuary. South Carolina Wildlife and Marine Resources Department, Charleston, SC, South Carolina Marine Resources Center Tech. Rep. No. 74 , 49p.

Wendt, P. H., R.F. Vandolah, M.Y. Bobo, T.D. Mathews, and M.V. Levisen. 1996. Wood preservative leachates from docks in an estuarine environment. Archives of Environmental Contamination and Toxicology 31(1): 24-37.

Wenner, C. A. and G.R. Sedberry. 1989. Species composition, distribution,and relative abundance of fishesin the coastal habitat off the southeastern United States. NOAA/NMFS, Silver Spring, MD, NOAA Technical Report NMFS 79 , 47p.

Wenner, E. L., D.M. Knott, R.F. Van Dolah, and V.G. Burrell. 1983. Invertebrate communities associated with hard bottom habitats in the South Atlantic Bight. Estuarine Coastal Shelf Science 17: 143-158.

Wenner, E. L., P.Hinde, D.M. Knott, and R.F. Van Dolah. 1984. A temporal and spatial study of invertebrate communities associated with hard-bottom habitats in the South Atlantic Bight. NOAA, Technical Report NMFS 18. 104 p.

Wessel, S. Rousseau, X. Caisey, R. Quiniou, and R. Akcha. 2007. Investigating the relationshop between embryotoxic and genotoxic effects of benzo(a)pyrene, 17a-ethinylestradiol and endosulfan on *Crassostrea gigas* embryos. Aquatic Toxicology 85: 133-142.

Wetz, M. S., A.J. Lewitus, E.T. Koepfler, and K.C. Hayes. 2002. Impact of the Eastern oyster *Crassostrea virginica* on microbial community structure in a salt marsh estuary. Aquatic Microbial Ecology 28: 87-97.

Wetzel, R. G. 2001. Limnology: Lake and River Ecosystems. Academic Press, San Diego, CA, 3rd Edition .

Wharton, C. H., W.M. Kitchens, E.C. Pendleton, and T.W. Sipe. 1982. The ecology of bottomland hardwood swamps of the southeast: a community profile. U.S. Fish and Wildlife Service, Biological Services Program, Washington, D.C., . 133p.

Whitall, D., S. Bricker, J. Ferreira, A. M. Nobre, T. Simas, and M. Silva. 2007. Assessment of eutrophication in estuaries: pressure-state-response and nitrogen source. Environmental Management 40(4): 678-690.

White, D. B. and S.M. Palmer. 2004. Age, growth, and reproduction of the red snapper, *Lutjanus campechanus*, from the Atlantic waters of the southeastern US. Bulletin of Marine Science 75(3): 335-360.

White, J. C. and T. Triplett. 2002. Polycyclic Aromatic Hydrocarbons (PAHs) in the sediments and fish of the Mill River, New Haven, Connecticut. Bulletin of Environmental Contamination and Toxicology 68(1): 104-110.

White, K. 1996. Restoration of channelized streams to enhance fish habitat. http://www.ies.wisc.edu/research/ies900/kimchannelization.htm, Dec. 2003.

White, N. M., D.E. Line, J.D. Potts, W. Kirby-Smith, B. Doll, and W.F. Hunt. 2000. Jumping Run Creek shellfish restoration project. Journal of Shellfish Research 19(1): 473-476.

Whitehead, P. J. P. 1985. FAO Species catalogue. Clupeoid fishes of the world. An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf-herrings. Part 1 Chirocentridae, Clupeidae and Pristigasteridae. 7 , 303p.

Whitfield, P. E., J.A. Hare, A.W. David, S.L. Harter, R.C. Munoz, and C.M. Addison. 2007. Abundance estimates of the Indo-Pacific lionfish *Pterois volitans/miles* complex in the western North Atlantic. Biological Invasions 9(1): 53-64.

Whitfield, P. E., T. Gardner, S.P. Vives, M.R. Gilligan, W.R. Courtenay, G.C. Ray, and J.A. Hare. 2002. Biological invasion of the Indo-Pacific lionfish *Pterois volitans* along the Atlantic Coast of North America. Marine Ecology Progress Series 235: 289-297.

WHO (World Health Organization). 2002. Global assessment of the state-of-the-science of endocrine disruptors. International Programme On Chemical Safety.

Widdows, J., P. Donkin, and S.V. Evans. 1987. Physiological responses of *Mytilus edulis* during chronic oil exposure and recovery. Marine Environmental Research 23: 15-32.

Widdows, J., R.I.E. Newell, and R. Mann. 1989. Effects of hypoxia and anoxia on survival, energy metabolism, and feeding of oyster larvae (*Crassostrea virginica*, Gmelin). Biological Bulletin 177(1): 154-166.

Wiebe, K. and R. Heimlich. 1995. Evolution of federal wetland policy. Choices 10(1): 8-14.

Wiegert, R. G. and F.C. Evans. 1967. Investigations of secondary production in grasslands. p. 499-518 *in* Petrusewicz, K. Secondary productivity in terrestrial ecosystems. Polish Academy of Science, Krakow, Poland.

Wiegert, R. G. and B. J. Freeman. 1990. Tidal salt marshes of the southeast Atlantic coast: a community profile. U.S. Fish and Wildlife Service Biological Reports 85(7.29): 71.

Wiegert, R. G., L.R. Pomeroy, and W.J. Wiebe. 1981. Ecology of salt marshes: an introduction. p. 2-19 *in* Pomeroy, L. R. and R. G. Wiegert. Ecology of a salt marsh. Springer-Verlag New York, Inc., New York, USA.

Wilber, D. H. and D.G. Clarke. 2001. Biological effects of suspended sediments: A review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries. North American Journal of Fisheries Management 21(4): 855-875.

Wilber, D. H., D.G. Clarke, and M.H. Burlas. 2006. Suspended sediment concentrrations associated with a beach nourishment project on the northern coast of New Jersey. Journal of Coastal Research 25(5): 1035-1042.

Wilbur, A. R. and M.W. Pentony. 1999. Human-induced nonfishing threats to essential fish habitat in the New England region. p. 299-321 *in* L.R. Benaka (ed.). Fish Habitat: Essential Fish Habitat and Rehabilitation. American Fishery Society , Silver Springs, MD, Symposium 22 , 459 p.

Wilhelmsson, D. and T. Malm. 2008. Fouling assemblages on offshore wind power plants and adjacent substrata. Estuarine, Coastal and Shelf Science 79(3): 459-466.

Williams, A. B. 1964. A postlarval shrimp survey in North Carolina. NC Dept Development, Spec Sci Rep 3 .

Williams, A. H., L.D. Coen, and M.S. Stoelting. 1990. Seasonal abundance, distribution, and habitat selection of juvenile *Callinectes sapidus* (Rathbun) in the northern Gulf of Mexico. Journal of Experimental Marine Biology and Ecology 137: 165-183.

Williams, R. B. and M.B. Murdoch. 1966. Phytoplankton production and chlorophyll concentration in the Beaufort channel, North Carolina. Limnology and Oceanography 11: 73-82.

Williamson, R. B. and D.J. Morrisey. 2000. Stormwater contamination of urban estuaries. 1. Predicting the build-up of heavy metals in sediments. Estuaries 23(1): 56-66.

Wilson, K. A. 1962. North Carolina wetlands--Their distribution and management. North Carolina Wildlife Resources Commission, Raleigh, NC, Project W-6-R , 169p.

Wilson, K. A., K.W. Able, and K.L. Heck Jr. 1990. Habitat use by juvenile blue crabs: a comparison among habitats in southern New Jersey. Bulletin of Marine Science 46: 105-114.

Windom, H. L. 1976. Environmental aspects of dredging in the coastal zone. CRC Critical Review Environmental Control 7: 91-109.

Winger, P. V., P.J. Lasier, D.H. White, and J.T. Seginak. 2000. Effects of contaminants in drege material from the lower Savannah River. Archives of Environmental Contamination and Toxicology 38(1): 128-136.

Winner, M. D. and C.E. Simmons. 1977. Hydrology of the Creeping Swamp watershed, North Carolina with reference to potential effects of stream channelization. U.S. Geological Survey, Water Resources Investigation 77-26 , 54p.

Winslow, F. 1889. Sounds and estuaries of North Carolina with reference to oyster culture, US Coast and Geodetic Survey. Bull. No. 10 , 137p.

Winslow, S. E. 1990. Status of the American shad, *Alosa sapidissima* (Wilson), in North Carolina. NC Division of Marine Fisheries, Morehead City, NC, Special Scientific Report No. 52 , 77 pp. p.

Winslow, S. E. and K.B.Rawls. 1992. North Carolina Alosid Management Program. Compl. Rep. Proj. AFC-36, Seg. 1-3. North Carolina Dept. Environ, Health, Nat. Resour, Div Mar. Fish . 77.

Winslow, S. E., N.S. Sanderlin, G.W. Judy, J.H. Hawkins, B.F. Holland Jr., C.A. Fischer, and R.A. Rulifson. 1983. North Carolina anadromous fisheries management program. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Completion report for project AFCS-16 , 402p.

Winslow, S. E., S.C.Mozley, and R.A.Rulifson. 1985. North Carolina Anadromous Fisheries Management Program. Compl. Rep. Proj. AFCS-22, North Carolina Dept. and Community Develop, Div. Mar. Fish. . 207.

Wintermeyer, M. L. and K.R.Cooper. 2007. The development of an aquatic bivalve model: Evaluating the toxic effects on gametogenesis following 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD) exposure in the eastern oyster (*Crassostrea virginica*). Aquatic Toxicology 81(1): 10-26.

Wintermyer, M. L. and K.R. Cooper. 2007. The development of an aquatic bivalve model: evaluating the toxic effects on gametogenesis following 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8 TCDD) exposure in the eastern oyster (*Crassostrea virginica*). Aquatic Toxicology 81(1): 10-26.

Witherington, B. E. 2002 . Ecology of neonate loggerhead turtles inhabitating lines of downwelling near a Gulf Stream front. Marine Biology 140: 843-853.

Wolfe, D. A. and T.R. Rice. 1972. Cycling of elements in estuaries. Fisheries Bulletin 70: 959-972.

Wood, R. J., D.F. Boesch, and V. S. V.S. Kennedy. 2002. Future consequences of climate change for the Chesapeake Bay ecosystem and its fisheries. p. 171-184 *in* Rose (ed.), G. A. Fisheries in a Changing Climate . American Fisheries Society, Bethesda, Maryland, Symposium 32 .

Wood, R. J. and H.M. Austin. 2009. Synchronous multidecadal fish recruitment patterns in Chesapeake Bay, USA. Canadian Journal of Fisheries and Aquatic Science 66: 496-508.

Woodling, J. D., E.M. Lopez, T.A. Maldonado, D.O. Norris, and A.M. Vajda. 2006. Intersex and other reproductive disruption of fish in wastewater effluent dominated Colorado streams. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology 144(1): 10-15.

Woodside, M. D. and K.E. Ruhl. 2001. Pesticides in streams in the Tar-Pamlico drainage basin, North Carolina, 1992-94. US Geological Survey.

Woodwell, G. M., C.A.S. Hall, D.E. Whitney, and R.A. Houghton. 1979. The Flax Pond ecosystem study: exchanges of inorganic nitrogen between an estuarine marsh and Long Island Sound. Ecology 60: 695-702.

WRP (Wetland Restoration Program). 2001. NC Wetlands Restoration Program, 2000-2001 Annual Report. N.C. Department of Environment and Natural Resources, Wetlands Restoration Program, Raleigh, NC, .

WRP (Wetland Restoration Program). 2002. NC Wetlands Restoration Program, 2001-2002 Annual Report. N.C. Department of Environment and Natural Resources, Wetlands Restoration Program, Raleigh, NC, . 111p.

WRP (Wetland Restoration Program). 2003. NC Wetlands Restoration Program, 2002-2003 Annual Report. N.C. Department of Environment and Natural Resources, Wetlands Restoration Program, Raleigh, NC, . 84p.

Wyanski, D. M., D.B. White, and C.A. Barans. 2000. Growth, population age structure, and aspects of the reproductive biology of snowy grouper, *Epinephelus niveatus*, off North Carolina and South Carolina. Fishery Bulletin 98(1): 199-218.

Wyda, J. C., L.A. Deegan, J.E. Hughes, and M.J. Weaver. 2002. The response of fishes to submerged aquatic vegetation complexity in two ecoregions of the Mid-Atlantic Bight: Buzzards Bay and Chesapeake Bay. Estuaries 25(1): 86-100.

Xie, L. and D.B. Eggleston. 1999. Computer simulations of wind-induced estuarine circulation patterns and estuary-shelf exchange processes: the potential role of wind forcing on larval transport. Estuarine, Coastal, and Shelf Science 49(2): 221-234.

Xie, L. and L.J. Pietrafesa. 1999. Systemwide modeling of wind and density driven circulation in Croatan-Albemarle-Pamlico estuary system part I: model configuration and testing. Journal of Coastal Research 15(4): 1163-1177.

Yallop, M. L., B. de Winder, D.M. Paterson, and L.J. Stal . 1994. Comparative structure, primary production and biogenic stabilization of cohesive and non-cohesive marine sediments inhabited by microphytobenthos. Estuarine Coastal Shelf Science 39: 565-582.

Yozzo, D. J. and D.E. Smith. 1997. Composition and abundance of resident marsh-surface nekton: comparison between tidal freshwater and salt marshes in Virginia, USA. Hydrobiologia 362(1-3): 9-19.

Zheng, L., R.J. Stevenson, and C. Craft. 2004. Changes in benthic algal attributes during salt marsh restoration. Wetlands 24(2): 309-323.

Zieman, J. C. 1976. The ecological effects of physical damage from motor boats on turtle grass beds in southern Florida. Aquatic Botany 2: 127-139.

Zieman, J. C. 1982. The ecology of seagrasses of south Florida: a community profile. US Fish and Wildlife Service, Washington, DC, FWS/OBS-82/25 , 123p.

Zieman, J. C., R. Orth, R.C. Phillips, G. Thayer, and A. Thorhaug. 1984. The effects of oil on seagrass ecosystems. p. 37-64 *in* Cairns, J. and Buikema A. L. Eds. Resoration of Habitats Impacted by Oil Spills. Butterworth, Boston.

Zimmerman, R. T., T. Minello, and M. Gastiglione. 1989. Oyster reef as habitat for estuarine macrofauna. National Oceanic and Atmospheric Administration, Springfield, VA, NOAA Technical Memorandum NMFS-SEFC-249 .

Zirschky, J. D., D. Crawford, L. Norton, and D. Deemer. 1989. Metals removal in overland flow. Journal of the Water Pollution Control Federation 16: 470-475.

Zou, E. and M. Fingerman. 1999. Effects of exposure to diethyl phthalate, 4-(tert)-octyophenol, and 2,4,5-trichlorobiphenyl on activity of chitobiase in the epidermis and hepatopancreas of the fiddler crab, *Uca pugilator*. Comparative Biochemistry and Physiology Part C(122): 115-120.

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 B. CHPP STEERING COMMITTEE AND PLAN DEVELOPMENT TEAM (2005-2010)

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APPENDIX C. 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
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
COBRA	Coastal Barrier Resources Act
COMP	Coastal Ocean Monitoring Program
CORMP	Coastal Ocean Research and Monitoring Program
CPH	Commission for Public Health (formerly Commission for Health Services)
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

Acronym	Meaning
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
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

Acronym	**Meaning**
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

Acronym	Meaning
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
USACE	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)

Acronym	Meaning
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 C. 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.
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

Term	Description
	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.
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.
Evapo-transpiration	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

Term	Description
	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

Term	Description
	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 D: 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*
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 E: 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

[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
	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		
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

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
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

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
	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
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

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
		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
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	

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
		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
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	

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
		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
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

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
		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
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

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

APPENDIX F: EFFECTS OF ENVIRONMENTAL POLLUTANTS ON FISH EARLY LIFE STAGES

[modified from Weis and Weis (1989), Key et al. (2000); "exp" = "exposure"]

	Effect on fish			Water quality standards (ug/l) for aquatic life	
Chemicals	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		
Aroclor 1254	Sheepshead minnow	>0.1 ug/l exp.	Reduced fry survival		

Chemicals	Effect on fish			Water quality standards (ug/l) for aquatic life	
	Test organism	Test	Results	Salt-water	Fresh-water
		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		
Kepone	Sheepshead minnow	1.9 ug/l exp.	16% arrested development of embryos		

Chemicals	Effect on fish			Water quality standards (ug/l) for aquatic life	
	Test organism	Test	Results	Salt-water	Fresh-water
	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		
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					

Chemicals	Effect on fish			Water quality standards (ug/l) for aquatic life	
	Test organism	Test	Results	Salt-water	Fresh-water
Pentachlorophenol	Fathead minnow	128 ug/l exp.	Reduced larval survival		
		>73 ug/l exp.	Reduced growth of larvae		

APPENDIX G. POLICY STATEMENT FOR PROTECTION OF SAV HABITAT

North Carolina Marine Fisheries Commission
(Adopted May 12, 2004)

Submerged aquatic vegetation (SAV) serves as the basis for premium habitat for many coastal fish and invertebrates. The SAV habitat is so important that special efforts are required to protect and enhance water quality and physical conditions for its propagation and distribution.

The purpose of this statement is to provide guidance for management needs to protect SAV habitat in the development of fisheries management plans and habitat protection plans. The following is a summary of the special quality of SAV as habitat and the attendant water quality/physical conditions necessary for its maintenance. Details and additional information can be found in the SAV chapter in the Coastal Habitat Protection Plan (CHPP) and background scientific references.

The role of SAV as habitat

- Submerged aquatic vegetation, which consists of plants having growing roots (rhizomes) in the sediment, serves as physical hiding places for important fish and shellfish species, as well as a food base for essential food chains. Aquatic productivity in waters with SAV beds is significantly higher than in coastal waters without SAV.
- SAV supports a vast array of epiphytes and attached invertebrates that serve as a source of food for many important fish and shellfish.
- The major criterion limiting distribution and propagation of SAV is the amount of light reaching the bottom. Suspended solids and proliferation of algae in the water column are significant causes of reduced light penetration in coastal waters. Water-column clarity, therefore, should be a significant water-quality criterion. SAV, in turn, can also improve water quality through its baffling effects on currents and through its filtering of water by attached epiphytes and invertebrates.
- SAV serves as important habitat for species such as scallops, shrimp, blue crabs and some species of fish.

Management guidelines

- 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, widgeongrass 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.

APPENDIX H. POLICIES FOR THE PROTECTION AND RESTORATION OF MARINE AND ESTUATINE RESOURCES AND ENVIRONMENTAL PERMIT REVIEW AND COMMENTING

North Carolina Marine Fisheries Commission
(Adopted September 24, 2009)

Issue

This document establishes the policies of the NC Marine Fisheries Commission (Commission) regarding overall protection and restoration of the state's marine and estuarine resources, and for environmental permit review for proposed projects with the potential to adversely impact those resources.

Background

The "marine and estuarine resources" of North Carolina are defined broadly as "[a]11 fish, except inland game fish, found in the Atlantic Ocean and in coastal fishing waters; all fisheries based upon such fish; all uncultivated or undomesticated plant and animal life, other than wildlife resources, inhabiting or dependent upon coastal fishing waters; and the entire ecology supporting such fish, fisheries, and plant and animal life." N.C.G.S. 113-129(11). The Commission is charged with the duty to "(m)anage, restore, develop, cultivate, conserve, protect, and regulate the marine and estuarine resources within its jurisdiction." N.C.G.S. 143B-289.51(b)(1).

Two powers of the Commission constitute its primary authorities to effectuate that charge, and thereby to protect and restore North Carolina marine and estuarine resources. First, the Commission is specifically empowered "[t]o comment on and otherwise participate in the determination of permit applications received by state agencies that may have an effect on the marine and estuarine resources of the state." N.C.G.S. 143b-289.52(2)(9). Second, the Commission has to power and duty to participate in the development, approval and implementation of Coastal Habitat Protection Plans (CHPPs) for all "critical fisheries habitats." N.C.G.S. 143B-279.8; 143B-289.52(a)(11). The goal of such CHPPs is "the net long-term enhancement of coastal fisheries associated with each coastal habitat identified." N.C.G.S. 142B-279.8. The Commission by unanimous vote has delegated its permit commenting authority to its Habitat and Water Quality Standing Advisory Committee (Committee) for the sake of efficiency and effectiveness. Likewise, the Commission has designated the Committee as its participating body in the development of CHPPs ~~Habitat Plans~~, which will then be approved and implemented by the full Commission. However, since the formal preparation of will not begin until at least 1 July 1999, it will be some time before final CHPPs can be developed and implemented in order to help protect against the impacts of coastal development and other human activities that adversely affect North Carolina's marine and estuarine resources. Consequently, the Commission's environmental permit review authority currently constitutes the primary vehicle by which the Commission can effectuate its duty to protect and enhance the state's marine and estuarine resources.

Discussion

There are two equally serious challenges to the Commission's successfully maintaining and enhancing North Carolina's marine and estuarine resources: (1) the lack of necessary information on the current nature and status of many of those resources; and (2) the lack of obvious mechanisms to account for and ameliorate the ever accumulating changes that impair the functioning of critical fisheries habitats and otherwise adversely affect fisheries stocks. The Commission cannot hope to comply with its statutory duties to protect and enhance marine and estuarine resources without the abilities to identify and monitor changes in those resources, to compensate for losses to critical fisheries habitats, and to enhance the overall functioning of the altered coastal ecosystem.

Cumulative adverse resource impacts from both large and small scale human activities constitute the principal impediment to the Commission's ability to achieve its statutory mandate of conserving, protecting and restoring North Carolina's marine and estuarine resources. Many of the activities that contribute to coastal resource destruction or impairment require no environmental permits. As a consequence, their impacts are not accounted for, to the long-term detriment of marine and estuarine resources. Even for permitted activities, the adverse impacts on marine and estuarine resources may be individually minor, causing them to fall below the thresholds that require compensatory mitigation under existing state policy.

However, where specific projects requiring environmental permits pose a threat to resources under the Commission's jurisdiction, it is reasonable to expect the permittee to contribute to resolving both the informational and resource protection dilemmas faced by the Commission to ensure that unacceptable impacts to marine and estuarine resources do not occur. A direct precedent to such action by a state agency is found in the N.C. Division of Water Quality's current requirement that NPDES permittees conduct upstream and downstream monitoring as a condition of their permits, to ensure that state water quality standards are not violated. In addition, that agency has worked with dischargers in certain river basins to establish industry - funded, integrated monitoring networks to track water quality trends in those waters.

Specific action by the Commission is required if it is to meet its charge of protecting and restoring the state's marine and estuarine resources. To the greatest extent possible, activities that potentially threaten those resources must be prevented from contributing to overall resource degradation. Instead, adequate measures must be implemented to ensure a long-term, net improvement in the quantity and quality of fisheries stocks and critical fisheries habitats under the Commission's jurisdiction. To achieve that end, two goals must be attained:

- adequate compensatory and resource enhancement measures must be incorporated into existing environmental permitting processes
- resource restoration and enhancement programs must be developed to offset losses from activities not requiring permits

No net loss policies for permitted activities, while having many benefits, have at times limited the ability of state agencies to implement compensatory mitigation in a manner that effectively offsets losses to the impacted watershed. By requiring in-kind mitigation, primarily for wetland impacts, mitigation, in some instances, targets wetlands in a different landscape position or watershed, which serves different ecological functions, and consequently does not replace the ecological services lost by the permitted activity in the affected watershed. In addition, mitigation is not required for permitted aquatic resource impacts associated with private water dependent activities, such as loss of submerged aquatic vegetation habitat from channel dredging or degradation of a primary nursery area from shoreline hardening.

The Marine Fisheries Commission authorized DMF staff to begin to incorporate mitigation policy into bylaws at their Business Meeting in Atlantic Beach, NC, on December 2-3, 2004. MFC endorsed the concept of holding workshops to address technical and policy issues related compensatory mitigation. These workshops have now been completed, and provided guidance for a study conducted by East Carolina University, Environmental Defense Fund, and NC Ecosystem Enhancement Program. From this work utilizing two expert panels – one on wetland science and the other on wetland policy, two documents have been completed to provide guidance on alternatives to traditional mitigation. The first report, A Science-based Framework for Compensatory Mitigation of Coastal Habitat in North Carolina (ECU 2006) presented a scientific framework for an alternative approach to compensatory mitigation to better assure functional replacement. The framework involves evaluating watershed condition, encouraging the use of varied complementary techniques for functional recovery, and designing restoration projects in response to system-wide watershed scale challenges. The goal was to integrate compensatory mitigation requirements into watershed protection strategies that are consistent with the goals and objectives of the CHPP. In the second phase of the project, in a report entitled, An Approach to Coordinate Compensatory Mitigation Requirements to Meet Goals of the Coastal Habitat Protection Plan (ECU and Environmental Defense, 2006), the group developed an alternative assessment procedure for North Carolina's watersheds. The results of the study were presented during a day-long meeting (October 15, 2008) to a group represented by state and federal regulatory agencies and academic researchers, most of who were involved in the original workshops. The next phase of the project involves demonstrating application of the approach in two subwatersheds of the White Oak River basin.

A summary of the first two phases of this project were presented to the MFC on November 6, 2008. The MFC endorsed developing a compensatory mitigation process as part of the policy statement. On January 16, 2009 the Habitat and Water Quality Committee unanimously voted to recommend the following policy for consideration by the MFC. This compensatory mitigation policy would be implemented as a final component of the existing Resource Protection and Environmental Permit Review and Commenting Policies.

The first two policies below were established in 1999 primarily to achieve the first goal of incorporating adequate compensatory and resource enhancement measures into existing environmental permitting processes. The third policy was established in 2009 to provide more direction in how to accomplish that, given our evolving understanding of ecosystem functions, threats, and techniques for successful mitigation and restoration. Progress on the second goal (developing restoration/enhancement programs to offset losses not directly associated with permitted activities) has primarily occurred in North Carolina through enhancement of DMF's oyster sanctuary program, Clean Water Management Trust Fund projects, and numerous wetland and oyster restoration projects conducted by non-profit environmental organizations.

Proposed Resource Protection and Environmental Permit Review and Commenting Policies

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 Habitat and Water Quality Standing Advisory Committee 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; and

3) incorporate the following array of options when planning compensatory mitigation to allow focus on restoration of equivalent ecosystem functions within a watershed, based on our evolving understanding of the needs of compensatory mitigation to protect and enhance coastal water quality and watersheds:

i. Establish goals for coastal watersheds by the MFC based on desired outcomes - protection/restoration of shellfishing waters, PNAs, SAV beds, etc.;
ii. Identify watersheds/areas where these goals can be realistically achieved. The Strategic Habitat Areas approach that emerged from CHPP can be used to identify locations where protection/restoration is most likely to be successful;
iii. Utilize the Rapid Watershed Assessment Procedure (or other assessment methods) to assess watershed condition and identify problems/solutions;
iv. Evaluate and authorize compensatory mitigation projects based on their ability to contribute to goals established for coastal watersheds. Projects that provide functional replacement, e.g., increased water retention/storage through the use of BMPs, may be approved if documentation is provided that the projects are the most effective mechanism to achieve the goals established for a watershed;
v. Implement monitoring to support data acquisition necessary to support the SHA process and the effectiveness of projects that have been implemented;
vi. Solicit funding from all available sources (compensatory mitigation, CWMTF, 319, etc.) to fully implement protection/restoration strategies in coastal watersheds.

APPENDIX I: MFC BEACH NOURISHMENT POLICY

North Carolina Marine Fisheries Commission
(Adopted 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.

APPENDIX J: CHPP IMPLEMENTATION PLAN (2009-2011)

The listing below was drawn from the CHPP 2008-2009 Annual Report approved by the Joint Legislative Commissio on Seafood and Aquaculture in September 2009. The full implementation plans can be queried from a database housed on the Division of Marine Fisheries, Habitat Protection server. Implementation Plans also contain specific actions from previous plans that are "carried forward" due to an incomplete status. These action may also be considered "on-going" until the CHPP Steering Committee decides to discontinue them.

September 2009 – August 2010 Planned Action and Needs

- Delineate SHAs in Region 3 (Approximately White Oak River Basin).(DMF/MFC, WRC, EEP/DENR).
- Conduct SHA evaluation and designation process for Region 2 (Pamlico Sound and tributaries).(DMF, WRC)
- Continue to review "Inner Banks" development issues and address environmental issues.(CRC/DCM, DWQ/EMC)
- Begin to address the challenges associated with Sea Level Rise and climate change more broadly in a context consistent with the reports of the Legislative Committee on Climate Change to NC.(DENR)
- Continue to increase public awareness on the value of and threats to coastal fish habitats and the role of the CHPP process to protect and enhance these resources.(DMF, DCM, EEP/DENR)
- Continue to study the feasibility and benefits of dam and barrier removal in general and for mitigation.(DMF/DCM, EEP/DWR/DENR, WRC)
- Examine the feasibility and preferred siting of wind turbines in North Carolina without significantly impacting fish habitat.(DENR)
- Pursue funding for the Community Conservation Assistance Program (CCAP) in the Division of Soil and Water Conservation.(DSWC/DENR)
- Seek dedicated funding to staff DCM's Clean Marina Program and effectively implement Best Management Practices as a non-regulatory way to improve water quality in and around marinas and docks.(DCM, DENR)
- Continue development and refinement of shoreline stabilization rules that preserve ecosystem function and consider rising sea levels and a changing land/water interface.(DCM/CRC, EEP/DENR)
- Take steps to encourage more restoration of degraded waters and work towards removal from the Federal 303-d listing.(APNEP, DWQ)
- Continue to identify problems regarding infrastructure for Waste Water Treatment Plants and system maintenance. Work with the local governments to develop and implement plans to correct deficiencies.(DWQ)
- Continue to develop a non-traditional mitigation strategy with the White Oak basin as a pilot project. The consultants developing the Local Watershed Plan (East Carolina University and Environmental Defense Fund) are working through EEP's Non-Traditional Mitigation Steering Committee and two ad hoc advisory committees to seek consensus goals and a viable mitigation strategy.(EEP/DENR)
- Work with the Division of Water Resources to minimize conflicts between Aquatic Weed Control practices and protection of SAV habitat.(DMF/MFC, WRC)
- Consider development of a conservation lease for the purpose of oyster and other habitat restoration.(DMF/MFC)
- Seek funding to initiate research on impacts of endocrine-disrupting chemicals to blue crabs and oysters.(DENR)

- Work with the Department of Agriculture and Consumer Services to develop and implement a drug disposal program for pharmaceuticals.(DMF/MFC)
- Complete photo-interpretation of SAV imagery of coast.(DMF, APNEP)
- Continue to study the feasibility and benefits of developing an SAV Restoration Program.(DMF, APNEP, EEP/DENR)
- Seek dedicated funding for the state SAV mapping program.(DMF, APNEP)
- Complete river herring spawning surveys in Albemarle system and prioritize obstruction removals.(DMF)
- Continue expanding the oyster sanctuary program, seeding sanctuaries with live oysters, and construct a shellfish hatchery.(DMF)
- Continue to work toward more funding for the Community Conservation Assistance Program. (DSWC)
- Workshops currently planned for next year include topics such as water reuse (i.e. rain water harvesting, gray water use), stormwater workshops for realtors, an invasive red fox symposium, a microbial pollution workshop, and a grant writing workshop depending upon budget constraints.(DCM/NERR)
- In the coming year, APNEP will work with the NC Division of Water Quality to implement several projects: 1) to host Coastal Stormwater and Riparian Buffer Rules Workshop for Development Professionals. 2) Develop information for display and distribution about Riparian Buffers and 401 Water Quality Certifications. Information will focus on the riparian buffer rules in the Neuse and Tar-Pamlico River Basins and the 401 Water Quality Certification Program which is in effect throughout the entire state. 3) A project will provide information to focus on students in K-12 understanding the biodiversity the lakes, streams and estuaries.(APNEP, DWQ)
- APNEP will continue to build upon the data inventory survey conducted in 2006 in partnership with the Virginia Institute for Marine Sciences. Data referenced in the survey for the Virginia portion of the Pasquotank and Chowan Rivers. Data will include monitoring data on water quality and living resources as well as land use, population trends and other potential ecosystem stressors. Analyses will be conducted for indications of change over the period of record. The goal is to develop a preliminary State of the River Basin report for the Pasquotank and Chowan Rivers. The approach will be holistic in that changes in monitored variables will be tracked throughout river basins and river systems. These stations are monitored by the Virginia Department of Environmental Quality. These data can be further analyzed to look for trends in seasons as well as trends in other monitored parameters. An attempt will be made to trace changes in water quality and living resources back to changes in the basin.(APNEP)
- DEH – SS will continue meeting with the Shoreline Survey Task Force finalizing proposed inspection program and put the plan in the form of a report for presentation to CHPP Steering Committee.(DEH-SS/DENR)