2015 North Carolina

Coastal Habitat Protection Plan

Source Document

Final Draft

By

North Carolina Department of Environmental Quality

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PART 1: INTRODUCTION AND HABITATS

CHAPTER 1. BACKGROUND

1.1. Habitat and water quality concerns

North Carolina contains the largest estuarine system of any single Atlantic coast state, with numerous estuarine rivers, creeks, sounds, inlets, and ocean bays creating a diverse system of over 2.3 million acres in size. Located at the convergence of the mid-Atlantic and south Atlantic biogeographical provinces, North Carolina supports a mix of northern and southern fish species. This combination of species richness, extensive estuarine and marine waters, and the diversity and abundance of habitats makes North Carolina's coastal fisheries among the most productive in the United States.

In the late 1980's, pressures from development, loss of habitat, and water quality degradation took a toll on North Carolina's estuaries. Several major fish kills associated with low oxygen events and diseases, such as *Pfeisteria*, occurred. Oysters (*Crassostrea virginica*) were dying from diseases (Dermo and MSX). Sea turtle and marine mammal disease mortalities were increasing, as were fishing gear interactions. Several commercially and recreationally important fisheries were classified as overfished, including summer flounder (*Paralichthys dentalus*), weakfish (*Cynoscion regalis*), striped bass (*Morone saxatilis*) and river herring (*Alosa pseudoharengus* and *A. aestivalis*). In response to these concerns, the public and fishermen expressed the desire for actions to improve fish habitat.

As a result, the State of North Carolina, through the Executive and Legislative branches, convened several panels to examine coastal environmental and fishery management issues. Each made policy recommendations concerning improvements to management of fish habitat and water quality.

- The Governor's Blue Ribbon Panel on Environmental Indicators published a report and recommendations in December 1990. This report, compiled by the Department of Environment, Health, and Natural Resources (now Department of Environment and Natural Resources, or 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) (Waite et al. 1994) recommended water quality, fishery management, and land use reforms in its Comprehensive Conservation and Management Plan, including: to retain, restore, and enhance water quality; conserve, 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 enactment of the Coastal Area Management Act (CAMA) in 1974. Recommendations of the report included restoration and protection of important fisheries habitats and impaired waters, addressing nonpoint source pollution, and protection of freshwater wetlands similar to existing protection of coastal wetlands (North Carolina Coastal Futures Committee 1994a).
- The Blue Ribbon Advisory Council on Oysters recommended major increases in oyster cultch planting to help restore oyster resources and changes in management of oyster culture practices (Frankenberg 1995).
- In 1994, Fisheries Moratorium Act established a steering committee to oversee study of fishery resources.

The majority of the above 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. The legislation's foremost goal was to ensure healthy fish stocks, the recovery of depleted stocks, and the wise use of fisheries resources. The FRA (G.S. 143B-279.8) requires preparation of Fishery Management Plans (FMPs) by the Division of Marine Fisheries (DMF) and Coastal Habitat Protection Plans (CHPPs) by DENR. The goal of all FMPs is to ensure the long-term viability of the state's commercially and recreationally significant species and fisheries. The FRA mandates that each plan include pertinent fishery information as well as habitat and water quality considerations consistent with the CHPP. 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)] (1996). The SFA requires regional fishery management councils and the National Marine Fisheries Service (NMFS) to amend federal fishery management plans to include provisions for the protection of "Essential Fish Habitat" (EFH)[1] from federally funded activities.

The legislative goal of the CHPP is ***"…the long-term enhancement of coastal fisheries associated with coastal habitats."*** The law specifies 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), the Environmental Management (EMC), and the Marine Fisheries (MFC) commissions, to ensure consistency among commissions, as well as their supporting DENR agencies. The FRA clearly required that recommendations of the management plans be implemented. Passage of the FRA and the initiation of the CHPP implementation process 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 will 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. 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 [North Carolina Supreme Court (*Gwathmey v. State of North Carolina*, 342 N.C. 287, 464 S. E. 2d. 674, 1995)].

State authority generally applies within the boundaries of North Carolina, extending from internal creeks, rivers, and lakes downstream through coastal sounds, into the Atlantic Ocean for three nautical (nm) or 3.45 statute miles from the state's Atlantic Ocean shoreline. Federal jurisdiction applies out to 200 nm (230.16 statute miles) from shore, an area called the Exclusive Economic Zone (EEZ).

While the MFC manages fishing practices in coastal waters through rules implemented by the DMF,

[1] **Essential Fish Habitat (EFH)**, defined by Congress in the 1996 amendments to the Magnuson-Stevens Fishery Conservation and Management Act, or Magnuson-Stevens Act, as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity."

several agencies manage activities affecting coastal fisheries and fish habitats. The EMC has authority over activities affecting water quality, such as point and nonpoint discharges, wastewater, alteration of wetlands, and stormwater. The EMC's rules are implemented by different DENR agencies, including the Division of Water Resources (DWR), the Division of Air Quality (DAQ), and the Division of Energy, Mineral, and Land Resources (DEMLR). The DEMLR administers rules adopted by multiple regulatory commissions, including the EMC, Sedimentation Control Commission (SCC), and the Mining and Energy Commission. The CRC enacts rules to manage development within and adjacent to public trust and estuarine waters, coastal marshes, and the ocean hazard area. The Division of Coastal Management (DCM) implements rules adopted by the CRC. The Wildlife Resources Commission (WRC), while not a principle participant in the CHPP process, has a direct role in the management of fisheries and habitat through the designation of Primary Nursery Areas (PNAs) and Anadromous Fish Spawning Areas (AFSAs) in Inland Waters, the review of development permits, monitoring and management of habitat, and the regulation of fishing in inland waters. There are myriad other state, federal, and interstate programs that directly or indirectly influence coastal fisheries habitat in North Carolina.

1.4. CHPP process

The CHPP Development Team developed and drafted the first Coastal Habitat Protection Plan in 2004 (Street et al. 2005). The original CHPP team included scientists and planners from DMF, DCM, DWQ (now DWR), WRC, and the Shellfish Sanitation Program in the Division of Environmental Health. An Intercommission Review Committee (IRC), consisting of two members from each of the three commissions, provided policy oversight, reviewed the plan, and developed the management recommendations. After the IRC and DENR reviewed the draft plan, the commissions separately approved 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 reorganized to reflect their new charge – meeting quarterly to discuss implementation progress, cross-cutting issues and facilitating CHPP implementation actions, as well as reviewing future CHPP updates. The group was renamed the CHPP Steering Committee (CSC) and the WRC was asked to join in 2009. In addition, DENR staff from other Divisions were invited to participate in CSC meetings.

1.5. Purpose and organization of document

1.5.1. Fish habitat

Fish habitat 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. Also included are land areas adjacent to, and periodically flooded by, riverine and coastal waters. Fish occupy specific areas where 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, soft bottom, 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). The integrity of the entire system depends upon the health of areas and individual habitat types within the system.

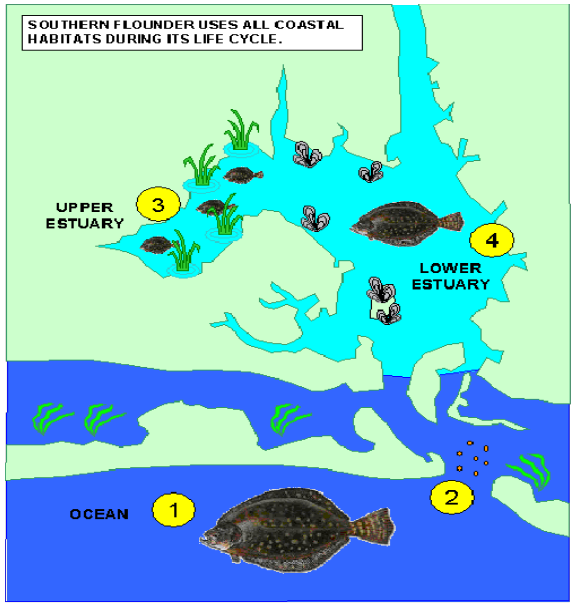


FIGURE 1.1. Life cycle of estuarine dependent southern flounder (*Paralichthys lethostigma*). 1 - Adults spawn in ocean waters in winter; 2 - Larvae drift inshore on currents, pass through inlets; 3 - Juveniles settle in upper, low-salinity estuaries containing wetlands and shallow soft bottom habitat; 4 – Subadult fish move to deeper channels and the lower estuary as they grow.

1.5.2. Purpose and Organization

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 2015 CHPP includes four overarching goals for protection of coastal fish habitat. These are the same as previous years, although there was minor wording change to Goal 2. Recommendations under these goals were reviewed and modified by the CHPP Steering Committee.

1) Improve effectiveness of existing rules and programs protecting coastal fish habitats
2) Identify and delineate strategic habitat areas
3) Enhance habitat and protect it from physical impacts
4) Enhance and protect water quality

The CHPP is organized into three parts:

Part 1 (Habitats) provides background on the habitats: water column, shell bottom, submerged aquatic vegetation (SAV), wetlands, soft bottom, and hard bottom. Within each chapter, there is the habitat's description, distribution, ecological role, and functions for finfish and shellfish species, and the habitat's status and trends. Several important fisheries in North Carolina, such as wahoo, tunas, sharks, and dolphin, are not discussed in detail in the CHPP because they occur primarily outside of state waters.

Part 2 (Threats) discusses existing and potential threats to habitats, focusing on priority issues. Threats are categorized by the mechanism of alteration – physical disturbance, hydrological alteration, water quality degradation, or other stressor. Priority issues are selected by the CSC based on concerns of their commissions and public input.

Part 3 (Management) discusses the concept of ecosystem management, including ongoing strategic habitat area assessments. This section summarizes existing habitat protection, restoration and enhancement efforts, and concludes with recommendations developed collaboratively with the CSC and

CHPP team.

In 2015, the NC General Assembly passed multiple pieces of legislation that could directly or indirectly affect habitat and water quality conditions in coastal North Carolina. Among the habitat management topics included in the legislation are stormwater rules, wetland mitigation requirements, riparian buffers, oil and gas exploration, ocean erosion control structures, environmental monitoring, shellfish leasing, and oyster restoration. Due to time limitations between the passage of the legislation and finalization of the draft, these changes are not reflected in the text, but are provided in Appendix C.

1.5.3. Public Input

Prior to initiating the CHPP update, a survey was sent to the public and interested parties through online sources. The purpose was to gauge the public's specific concerns so the plan could be appropriately focused. Public meetings were held for the purpose of getting input on potential recommendations. There were also opportunities to provide comments during public comment periods at MFC, CRC, and EMC meetings, as well as at CSC meetings.

The habitat survey results included responses from 817 respondents from 55 counties. The survey results indicate that the public feels there is more work needed to protect and restore fish habitat. Below are highlights.

- 84% agreed that aquatic habitat loss/degradation has negatively affected fish populations.
- 82% agreed that land based activities have negatively impacted aquatic habitat.
- 70% agreed that water based activities have negatively impacted aquatic habitat.
- Habitats with most degradation/loss - shell bottom, wetlands, water column.
- Activities having most negative influence on habitat - ditched/drained land, trawling/dredging, stream obstructions.
- Activities having the most negative impact on water quality - runoff from development, agriculture and forestry, wastewater treatment plant discharges and/or spills.
- Most problematic pollutant for fish - nutrients and toxins tied, and sediment.
- Highest priority issues for CHPP to address - non-compliance with existing rules protecting habitat and water quality, algal blooms/fish kills, mobile bottom disturbing fishing gear, and sedimentation.

1.6. Accomplishments

Each of the commissions and the department use information provided in the CHPP and the final recommendations to develop and update coordinated coastal habitat implementation plans. These implementation plans are the specific actions that a division commits to in order to address a CHPP recommendation partially or completely.

Since 2005, the CHPP has been a significant part of the decision making process of DENR's divisions and commissions. All three commissions and their DENR agencies use the CHPP and its recommendations as guidance. The CHPP has been successful in implementing a number of recommendations, with the majority being non-regulatory. Accomplishments include:

- Increased outreach and education
- Improved communication between agencies
- New mapping and research
- Oyster and fish passage restoration
- Compliance with existing regulations

A common thread to these accomplishments has been support from the department and the General Assembly to implement actions. Positions and funding to undertake CHPP recommendations were obtained through appropriations and grants. The most notable accomplishment of the CHPP process has been the improved interagency and intercommission communication and coordination, improving effectiveness and efficiency of processes within DENR.

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 within DENR, the IRC was reorganized into the CSC, and quarterly CHPP permit coordination meetings were established. Three DWR, four DCM, three DEH-SS, and three NCFS 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 to report possible environmental violations. These actions were directed at improving the effectiveness of existing rules and programs protecting coastal fish habitat (**Goal 1**). **Goal 2** called for identification, 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. The 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 rock, and the MFC closed additional areas to mechanical shellfish harvesting. The DCM began to formulate sediment compatibility rules through the CRC, and NC Sea Grant formed a multi-slip docking facility advisory committee. To enhance and protect water quality (**Goal 4**), DWR conducted a study of engineered stormwater structures and surveyed stormwater outfalls draining into SA and ocean waters. After hearing concerns of the CSC and MFC Habitat and Water Quality Committee, DWR began discussing new coastal stormwater rules.

In the second fiscal year (2006-2007), coordination meetings continued, and the appropriated positions were filled. To further improve effectiveness of existing rules (**Goal 1**), the CRC increased civil penalties to discourage violations. The National Estuarine Research Reserve hosted workshops and outreach events on habitat and water quality protection topics. Toward identifying SHAs, (**Goal 2**), an interagency SAV mapping workgroup was formed, with APNEP serving as lead. Progress continued on shell bottom mapping and the SHA methodology process was completed and approved. For **Goal 3**, sediment compatibility rules were approved, funding for the Beach and Inlet Management Plan (BIMP) was received, and the CRC Estuarine Shoreline Stabilization scientific work group completed a report with recommendations regarding the placement and suitability of hardened shoreline structures, and the subcommittee reviewed for possible rule implications. The DCM received funding to map the shoreline and structures. Toward protection and enhancement of water quality (**Goal 4**), Phase II stormwater rules became effective, and DWR draft coastal stormwater rules went through the public hearing process.

In the third fiscal year (2007-2008), coordination and educational outreach continued (**Goal 1).** Under **Goal 2**, the Interagency SAV Mapping Partnership pooled funding to acquire aerial imagery of SAV. The analysis of SHA Region 1 was underway. The benefits of additional resources for DMF's Resource Enhancement Section were being seen (**Goal 3**), with 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. The DMF began spawning and stream obstruction surveys, critical for prioritizing habitat restoration. The DCM began drafting the BIMP 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 was the adoption of coastal stormwater rules (effective October 2008) (**Goal 4**). The only program to address stormwater retrofitting from existing development was formed - the Community Conservation Assistance Program with the Soil and Water Conservation Districts. Other efforts included expansion of 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 NCFS to enhance forestry BMPs.

In 2008-2009, budget shortfalls constrained implementation. Funding for two DCM positions (compliance education coordinator and Clean Marina Program) was rescinded, and CHPP quarterly interagency meetings were cancelled due to travel restrictions. Funding approved by legislature in the previous year for oyster reef restoration was partially rescinded. Shell bottom and SAV mapping were slower than expected due to vacancies and the inability to fill positions, however, progress was made.

The DMF received approval for two grant funded positions dedicated to DCM permit review (**Goal 1**), and the MFC approved a revised definition of SAV habitat to improve effectiveness in identifying and protecting this habitat. Agencies worked to ensure consistency with this definition. The DWR held workshops regarding new stormwater rules and hosted a Water Quality Monitoring Forum aimed at coordinating monitoring efforts. Analysis for SHAs in Region 1 was completed (**Goal 2),** areas were approved by the MFC, and were incorporated into DENR's Conservation Planning Tool. The DMF completed spawning and obstruction surveys on the majority of the Chowan River system. Regarding **Goal 3**, DWR worked with DOT on an SAV and oyster habitat restoration and mitigation project in Currituck Sound. The DWR established a compensatory mitigation database. The DMF incorporated results of EEP and university research on compensatory mitigation to develop an MFC policy on compensatory mitigation to encourage methods to restore coastal watershed functions. The DCM made progress on drafting the BIMP and delineating the coastal estuarine shoreline. The CRC approved rules to better protect marshes from mowing, and to reduce impacts from docks and piers.

The DWR began review of several rules, such as ocean stormwater discharges and marinas, for water quality protection (**Goal 4**). They conducted a smart sponge pilot study to examine ways to clean stormwater, constructed four Low Impact Development (LID) projects, and began developing a mitigation policy for intermittent stream impacts. Additional resources were appropriated to the Soil and Water Conservation District for the Lagoon Conversion Program.

From 2010 to 2015, success has been a little slower and a bit more difficult as the economy has affected North Carolina. Even with these challenges, there have been significant accomplishments. Strategic Habitat Areas were identified in two more regions and were adopted by the MFC. Mapping of SAV continued, and the habitat was photographed in the northeastern part of the state. The DCM completed estuarine shoreline mapping, resulting in a digital representation by type and modifications, culminating in an inventory of water based structures. Low Impact Development has been promoted as environmentally sound, and a new computer model, Storm EZ, has been introduced to help design and secure permits for such projects. This was done as a partnership with the Coastal Federation, DENR agencies, and private industry.

The DCM drafted a Living Shoreline Strategy, with input from other DENR division representatives, which identifies six short-term and four long-term actions for department consideration. The document summarizes stabilization research in the state, identifies information gaps, highlights the need for continued staff engagement and public awareness, and investigates potential grant programs or cost reductions. The document recognizes the need to promote living shoreline strategies, to develop training programs/certification for marine contractors, and to partner with groups such as the military to increase demonstration sites. This will continue to be an ongoing educational effort in years to come.

In summary, relative to past efforts to protect North Carolina's coastal environment, the CHPP has been successful in implementing recommendations, with the greatest accomplishments being non-regulatory.

1.7. Area description

North Carolina's coast is framed by a chain of low-lying barrier islands extending from Virginia to the Cape

Fear. The barrier islands create large and productive sounds and estuaries. Southwest of the Cape Fear River, dredging of the Atlantic Intracoastal Waterway (AIWW) 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 (Hatteras, Lookout, and Fear) has a major influence on ocean circulation.

Weather conditions, especially temperature, precipitation, wind, and storms, exert major influences on the coastal area and fishery resources of. North Carolina’s coastal ocean lies at the convergence of the warm, north-flowing Gulf Stream and the cool, south-flowing Virginia Labrador Current. The Gulf Stream moves within 10 – 12 mi (16.1 – 19.3 km) of the coast at Cape Hatteras before turning northeast, bringing southern species such as brown (*Farfantepenaeus aztecus*), white (*Litopenaeus setiferus*), and pink (*F. duorarum*) shrimp; king (*Scomberomorus cavalla*) and Spanish (*S. maculatus*) mackerel; snappers and groupers; and calico scallops (*Argopecten gibbus*) to North Carolina’s waters. The Labrador Current ends at the Gulf Stream, supplying northern oceanic species [such as Atlantic mackerel (*Scomber scombrus*), Atlantic herring (*Clupea harengus*), and Atlantic cod (*Gadus morhua*)] to North Carolina.

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 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 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 (Maps 1.1a and 1.1b). Table 1.1 indicates the CHPP area is approximately 20% water (2,813,620 acres). For the purposes of this plan, the coastal area is divided into four management regions (Map 1.2). The regions are generally referred to as: Albemarle (Region 1), Pamlico (Region 2), Core-Bogue (Region 3), and Cape Fear (Region 4). Oregon and Ocracoke inlets are shown separately since their flow influences more than one CHPP region. These four regions are used for analyses that assess regional habitat conditions to identify a network of high quality Strategic Habitat Areas. 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 due to the migratory nature of most estuarine species and the resulting need for corridors of healthy habitats.

TABLE 1.1. Water area within CHPP regions (USGS hydrologic unit boundaries and 1:24,000 shorelines).

CHPP regions (#)*	Major water bodies included	Total area (acres)	Water area (acres)	% water area
Albemarle (1)	Albemarle, Currituck, and Roanoke sounds	3,719,898	751,018	20
Oregon Inlet (1/2)	Oregon Inlet	54,777	46,689	85
Pamlico (2)	Pamlico Sound; Neuse, Tar-Pamlico rivers	5,850,996	1,360,480	23
Ocracoke Inlet (2/3)	Ocracoke Inlet	37,166	35,329	95
Core-Bogue (3)	Core, Bogue, Stump sounds; New and White Oak rivers	1,138,271	398,325	35
Cape Fear (4)	Cape Fear River, tidal creeks and sounds in Pender, New Hanover, Brunswick counties	3,495,688	221,780	6
Total		**14,296,794**	**2,813,620**	**20**

1.7.1. Land use and human population

Population size, density, and change by county from 1990 to 2015 are shown in Table 1.2 and Map 1.3. In the twenty coastal counties, New Hanover County, followed by Onslow County, continue to have the largest populations and densities in 2015. Pasquotank County has a modest population but is third in density. Tyrrell and Hyde counties have consistently had the lowest populations and densities in eastern North Carolina (about 10 persons/mi^2). This is about 100 times less dense than in New Hanover County and about 20 times less than Onslow and Pasquotank counties. While population density is increasing along the coast, growth has been increasing at similar or greater rates in interior counties (Map 1.3).

The coastal counties that have undergone the greatest population change in the past 15 years are Brunswick, Pender, Camden, New Hanover, and Currituck counties (Table 1.2). Growth during this time has increased from 76-139% in those counties, primarily the result of urban sprawl, as all are within commuting distance of municipalities such as Wilmington, Jacksonville, and Norfolk, VA.

Since about 2005, there has been a shift to new residential development in non-oceanfront rather than oceanfront areas of coastal counties, marketed as the "Inner Banks." In 2008, sharply falling real estate prices and the recession lead to a major slowdown in new development. In 2014, signs of an improving economy were evident in some areas. Despite the low rate, population continues to increase in the coastal area, and in some areas has approximately doubled in size since 1990.

TABLE 1.2. Human population size, density (persons/mi^2), and growth in the 20 coastal counties, 1990–2015, by population change (Source: NC Office of State Budget and Management, unpublished data).

	1990		2000		2010		2015 (projected)		1990-2015
County	Size	Density	Size	Density	Size	Density	Size	Density	Population change (%)
Brunswick	50,985	82	73,143	118	108,064	128	121,744	144	139
Pender	28,855	33	41,082	47	52,384	60	57,689	66	100
New Hanover	120,284	603	160,307	803	203,299	1,061	221,590	1,157	84
Currituck	13,736	53	18,190	70	23,647	90	25,171	96	83
Camden	5,904	25	6,885	29	9,983	41	10,380	43	76
Dare	22,746	59	29,967	78	34,006	89	36,059	94	59
Carteret	52,407	101	59,383	115	66,711	132	70,911	140	35
Perquimans	10,447	42	11,368	46	13,482	55	14,013	57	34
Onslow	149,838	195	150,355	196	186,869	245	200,922	263	34
Craven	81,812	115	91,436	129	104,138	147	104,521	147	28
Pasquotank	31,298	138	34,897	154	40,644	179	38,919	172	24
Gates	9,305	27	10,516	31	12,168	36	11,470	34	23
Pamlico	11,368	33	12,934	38	13,095	39	13,067	39	15
Beaufort	42,283	51	44,958	54	47,764	58	47,782	58	13
Chowan	13,506	78	14,526	84	14,757	86	14,884	86	10
Hertford	22,317	63	22,601	64	24,733	70	24,560	70	10
Hyde	5,411	9	5,826	9	5,788	9	5,895	10	9
Tyrrell	3,856	10	4,149	11	4,397	11	4,084	10	6
Bertie	20,388	29	19,773	28	21,200	30	20,611	29	1
Washington	13,997	40	13,723	40	13,173	38	12,691	36	-9
Total	**710,743**		**826,019**		**1,000,302**		**1,056,963**		**48.7**

1.7.2. Fisheries and protected species

Throughout this plan, the term "fish" will include all finfish, shellfish, and crustaceans [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, etc.).
- Protected species are listed according to state law (G. S. 113-331) or the federal Endangered Species Act by the relevant state or federal agency or are protected under the federal Marine Mammal Protection Act. Protected species are important in the CHPP process because they can be indicators of ecological stress (Ricklefs 1993). Additionally, their habitat provides support for designating strategic habitat in locations where the distribution of fishery and protected species overlap, and in upstream areas important for maintaining estuarine water quality.

1.7.2.1. Fisheries

Authority to protect and conserve marine, estuarine, and public trust resources resides in the Secretary of DENR (GS 143B-10) who has delegated 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 …" [G.S.113-129 (2)].

North Carolina is one of the nation's leading coastal fishing states, with landings by commercial and recreational fishermen ranking among the top Atlantic coast states every year (Tables 1.3 and 1.4). 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 (http://portal.ncdenr.org/web/mf/marine-fisheries-catch), that depend on our coastal sounds and rivers to complete their life cycles. The state's history of productive fisheries is due not only to its large and diverse 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.

In 2013, the top five commercial species were blue crab (*Callinectes sapidus*), white shrimp (*Litopenaeus setiferus*), brown shrimp (*Farfantepenaeus aztecus*), southern flounder (*Paralichthys lethostigma*), and eastern oyster (*Crassostrea virginica*). The top five recreational species (inshore/nearshore waters) were flounders (*Paralichthys* spp.), bluefish (*Pomatomus saltatrix*), red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*), and kingfishes (*Menticirrhus* spp.)(NCDMF 2014a). Among the CHPP regions, the primary fisheries vary according to the range of salinity. Typical fishery species in low salinity estuaries (Albemarle system) include striped bass (*Morone saxatillis*), white perch (*Morone americanus*), American shad (*A. sapidissima*) blue crab, southern flounder, and catfishes (*Ictalurus* spp.). In moderate salinities (Pamlico system), typical species are diverse and variable, including, blue crab, striped mullet (*Mugil cephalus*), southern flounder, spotted seatrout, oysters, shrimp, and spot (*Leiostomus xanthurus*). In higher salinity estuaries (e.g., Core/Bogue sounds) and the near shore ocean, typical fisheries include flounders, hard clams (*Mercenaria mercenaria*), shrimp, sharks, kingfishes, and Atlantic croaker (*Micropogias undulatus*). Detailed statistics are summarized in DMF's License and Statistics Annual Report, which is available on the DMF website.

In 2014, there were 8212 such licenses issued with selling privileges, 3071 individual commercial fishermen, and 761 licensed fish dealers in the coastal area; approximately 42% of were used. Despite reduced levels of landings and participation compared to some previous years, the 2013 economic impact from commercial fishing is estimated at $305 million.

The majority of licensed commercial fishermen in North Carolina participate in several fisheries annually to have sufficient income (Johnson and Orbach 1996). Most own a variety of fishing gears, and many own several vessels rigged for different fisheries. The nature of the target species (growth, seasonal migrations, etc.), along with weather variations, rule changes, restrictions, and other variables require that commercial fishermen exhibit great adaptability. There are multiple fishermen that rely on commercial fishing as their sole income, but many also hold non-fishing jobs as part of their annual work cycle. Some have also transitioned away from selling their catch, but fish with Recreational Commercial Gear Licenses (RCGL) for personal pleasure. In FY 2014, there were 3,972 RCGL licenses sold.

TABLE 1.3. Annual Atlantic coast commercial fisheries landings by state, 2004-2013 (thousands of pounds, sorted by percent of total east coast harvest).*

State	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	%
Virginia	481,555	441,493	426,217	481,738	415,719	417,449	495,075	493,353	461,932	381,714	802,842	31
Massachusetts	336,948	337,214	383,466	303,006	326,064	356,021	282,601	255,799	297,561	264,585	479,869	18
Maine	208,405	214,820	234,275	176,006	174,478	183,366	198,183	269,960	262,581	265,067	373,510	14
New Jersey	185,615	156,961	175,759	153,965	162,463	161,593	161,832	175,516	180,502	120,014	284,843	11
North Carolina	136,444	79,154	68,641	62,900	71,331	68,804	72,019	67,512	56,676	50,186	188,891	7
Rhode Island	97,412	97,147	112,605	75,635	71,707	84,497	77,469	77,236	83,290	90,012	170,432	7
Maryland	49,507	67,460	51,216	50,102	61,372	55,884	97,672	78,197	73,284	43,932	104,011	4
New York	33,712	38,123	32,819	36,275	33,865	34,069	27,535	27,104	30,030	32,954	65,631	3
Florida (east)	41,824	23,113	26,342	24,483	26,103	27,302	29,258	30,865	28,703	20,578	51,648	2
New Hampshire	21,958	21,281	10,295	8,395	10,951	13,885	11,814	12,320	12,138	8,264	25,001	1
Connecticut	21,150	13,628	11,746	10,263	7,073	7,832	6,015	7,078	8,673	7,957	22,739	1
South Carolina	12,439	10,459	11,112	9,985	9,948	9,438	10,478	13,559	12,452	10,130	22,069	1
Georgia	6,341	9,697	7,747	7,180	8,639	7,363	7,351	12,646	10,182	10,620	16,496	1
Delaware	4,286	4,854	4,380	5,089	4,598	4,370	4,718	4,921	5,239	4,048	9,650	0
Total	**1,637,596**	**1,515,404**	**1,556,620**	**1,405,022**	**1,384,311**	**1,431,873**	**1,482,020**	**1,526,066**	**1,523,243**	**1,310,061**	**2,617,631**	

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

TABLE 1.4. Annual Atlantic coast marine recreational fisheries harvest by state, 2004-2013 (thousands of pounds, sorted by percent of total east coast harvest).*

State	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	%
Florida (east)	22,379	20,925	25,381	21,678	22,688	21,644	12,790	19,536	15,512	18,580	20,111	16
North Carolina	25,352	23,933	24,878	23,349	15,896	13,567	13,589	13,236	12,060	11,969	17,783	15
New Jersey	17,879	19,033	20,596	16,654	18,524	13,401	15,942	13,382	13,695	16,382	16,549	14
Virginia	12,325	13,155	14,097	17,665	17,748	13,683	17,241	16,127	13,923	15,596	15,156	12
New York	14,995	14,351	15,728	13,428	16,580	11,530	15,950	11,924	13,153	12,189	13,983	11
Massachusetts	14,800	15,737	17,131	15,529	11,035	10,227	7,502	7,254	7,544	6,793	11,355	9
Maryland	5,293	8,608	8,306	9,302	6,098	8,473	6,919	5,282	4,004	6,026	6,831	6
Rhode Island	4,339	4,837	5,629	6,139	6,845	3,774	5,859	4,028	5,789	9,480	5,672	5
South Carolina	4,409	4,072	3,721	4,596	3,956	2,249	3,252	3,194	3,073	7,254	3,978	3
Connecticut	4,402	3,120	4,132	4,234	4,377	3,987	4,479	2,731	3,950	2,284	3,770	3
Delaware	1,931	1,641	1,747	2,096	3,082	1,794	1,874	1,863	1,393	1,215	1,864	2
Georgia	869	1,726	1,714	1,512	1,837	2,610	1,420	3,084	1,524	1,735	1,803	1
Maine	1,801	2,213	2,569	1,823	1,664	1,708	1,079	987	1,050	1,110	1,600	1
New Hampshire	1,274	1,377	1,077	1,653	1,702	2,064	1,190	1,719	970	1,461	1,449	1
Total	**132,048**	**134,728**	**146,706**	**139,658**	**132,032**	**110,711**	**109,086**	**104,347**	**97,640**	**112,074**	**121,903**	

*Source: National Marine Fisheries Service. Fisheries of the United States, annual reports. Data includes type A+B1s

Recreational fishing is important economically and culturally in coastal North Carolina. There are records of surf fishing from the early colonial period; surf fishing along the Outer Banks for red drum and bluefish was the subject of articles in sporting magazines in the 1930s (Godwin et al. 1971). While commercial fishing has declined in recent years, recreational fishing has increased as North Carolina's coastal resident and visitor population has grown. Tens of thousands of recreational boaters fish the coastal waters, while thousands more fish with hired captains, as well as from the shore, piers, and other structures. In 2013, it was estimated that about 1.4 million anglers went fishing in coastal North Carolina (DMF 2008a). This included trips taken by resident and non-resident anglers from land, private boats, charter boats, and headboats. In January, 2007, GS 113-174 required establishment of a coastal recreational fishing license (CRFL) to better estimate the fishing effort. In 2013, approximately 480,000 CRFLs were issued, of which approximately one third were out-of-state visitors. Wake, Onslow, New Hanover, Carteret, and Brunswick counties, in descending order, accounted for the greatest number of licenses. The total estimated economic impact of North Carolina's recreational fishing industry in 2013 was $1.7 billion (NCDMF 2014a).

1.7.2.2. 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 both state and federal levels. The Atlantic sturgeon (*Acipenser oxyrinchus*) is listed as special concern at the state level and is a candidate at the federal level. Title 15A NCAC 03M .0508, prohibits possession of any sturgeon in North Carolina's coastal waters. Shortnose and Atlantic sturgeon occur in riverine, estuarine, and marine systems within the CHPP management area. American eel (*Anguilla rostrata*) is under consideration for listing under the Endangered Species Act.

High biodiversity increases resiliency of aquatic systems by maintaining trophic levels, species interactions, and ecosystem services. To minimize interactions between fishing gear and listed species, the division has an observer program to document interactions and modify restrictions as necessary.

1.7.3. Status of fisheries

The status of North Carolina's coastal fishery stocks are evaluated annually 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 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. Information from a single year does not indicate stock status; stock status assigned for each coastal fishery stock is based on the available time-series of data.

Stock status terms were modified by DMF in 2007 to better address the assignment of status to stocks that have unapproved or no assessment, or whose assessments are too unreliable to determine a status. 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 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)[2]
- ***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 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,

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

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 cannot 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.

In 2015, of the 25 fish stocks listed in Table 1.5, nine were listed as ***Viable*** (36%), two were classified as ***Recovering*** (8%), eleven were ***Concern*** (44%), and three were ***Depleted*** (12%) in the DMF Stock Status Report (DMF 2014). ***Depleted*** stocks include river herring (Albemarle stock), weakfish and American eel. Five stocks showed improvement from the 2014 – menhaden, black drum, gag, southern flounder, and spotted seatrout. The classification of black sea bass north of Hatteras moved from recovering to concern due to the lack of an approved stock assessment and low landings. Compared to 2010, the percent of species in 2015 classified as Viable increased while the percent classified as Depleted went down – positive trends. However the percent of species classified as Concern increased, although many of those are due to lack of sufficient information.

Habitat loss and degradation can make stocks susceptible to overfishing, as indicated by the lack of recovery after pressure is reduced. River herring stocks have not recovered despite reduced fishing effort and moratoria. While the role of environmental factors in the decline is uncertain, river herring abundance, particularly where formerly most concentrated (Chowan and Roanoke rivers) has suffered since the 70's from water quality problems, and is affected by stream obstructions and flow alterations.

1.8. Economic value of habitat protection

Given the dollar value of North Carolina's commercial and recreational fisheries described above, there are clear economic benefits to protecting and restoring habitat on which those species rely. For example, Peterson et al. (2003a) calculated that for every 10 m^2 of restored oyster reef in the southeast United States, an estimated 2.6 kg/yr of additional fish and invertebrate production would be generated for the functional lifetime of the reef. Similarly, studies have shown that the presence of SAV compared to unvegetated bottom results in significantly greater growth and survival rates of fish and supporting a higher abundance and diversity of fish. In turn, these enhanced fish populations have direct economic benefits to the commercial and recreational fishing industries, valued at over $2 billion in 2013.

In addition to enhancing fish production, coastal habitats provide many other ecosystem services that have economic value. Services such as waste treatment (pollutant removal), nutrient cycling, shoreline stabilization, and removal of carbon dioxide from the atmosphere have economic value at a local, state, national, and global level (Costanza et al. 1997). As an example, coastal wetlands were estimated to provide as much as $23.2 billion/year ($25.63 billion/year in 2014 dollars) in storm protection services (Costanza et al. 2008b). Oyster reefs in North Carolina were estimated to provide average annual ecosystem service values of $5,500 to $99,400/ha/yr ($2,200 to $40,200/ac/yr) for restored or protected reefs (Grabowski et al. 2012).

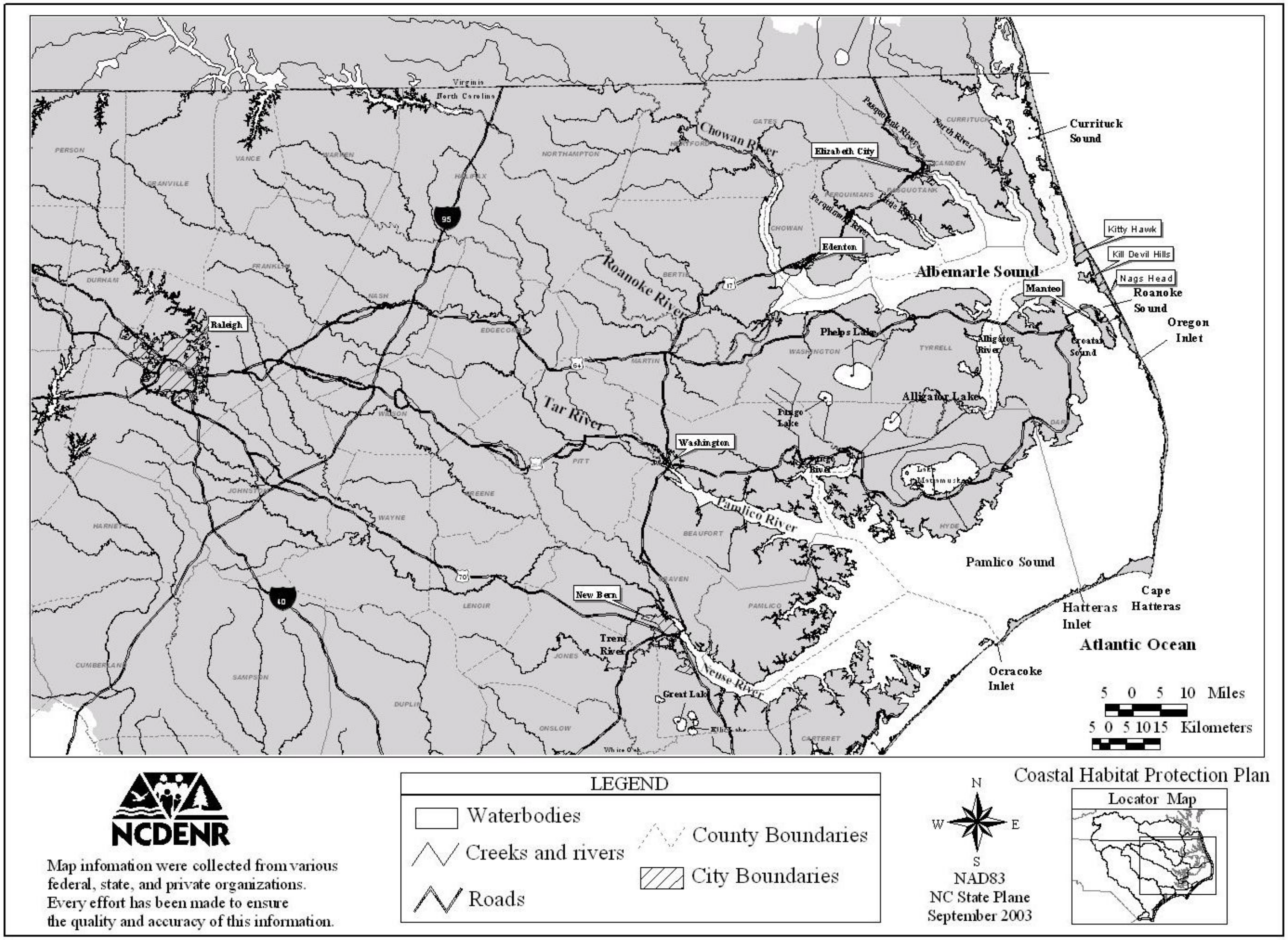
A healthy ecosystem directly benefits tourism and outdoor recreation businesses, and improves property values. The latter was documented by a study comparing waterfront properties adjacent to polluted and unpolluted waters (i.e., open shellfish harvest areas). The study found that fecal coliform levels had a significant effect on property values and that improving water quality through bacteria reductions resulted in a gain in property values of at least two percent (Leggett and Bockstael 2000).

Habitat restoration can bring revenue into coastal counties, particularly in rural communities with less business opportunities. A socio-economic analysis of coastal restoration projects in North Carolina concluded that for every $1 million spent on restoration, $1.73 million in revenue to coastal county businesses was generated, 15 jobs were created, and an additional $512,500 in coastal household earnings was produced (Lawrence et al. 2015). More details on the economic value of coastal habitats are provided throughout the following habitat chapters.

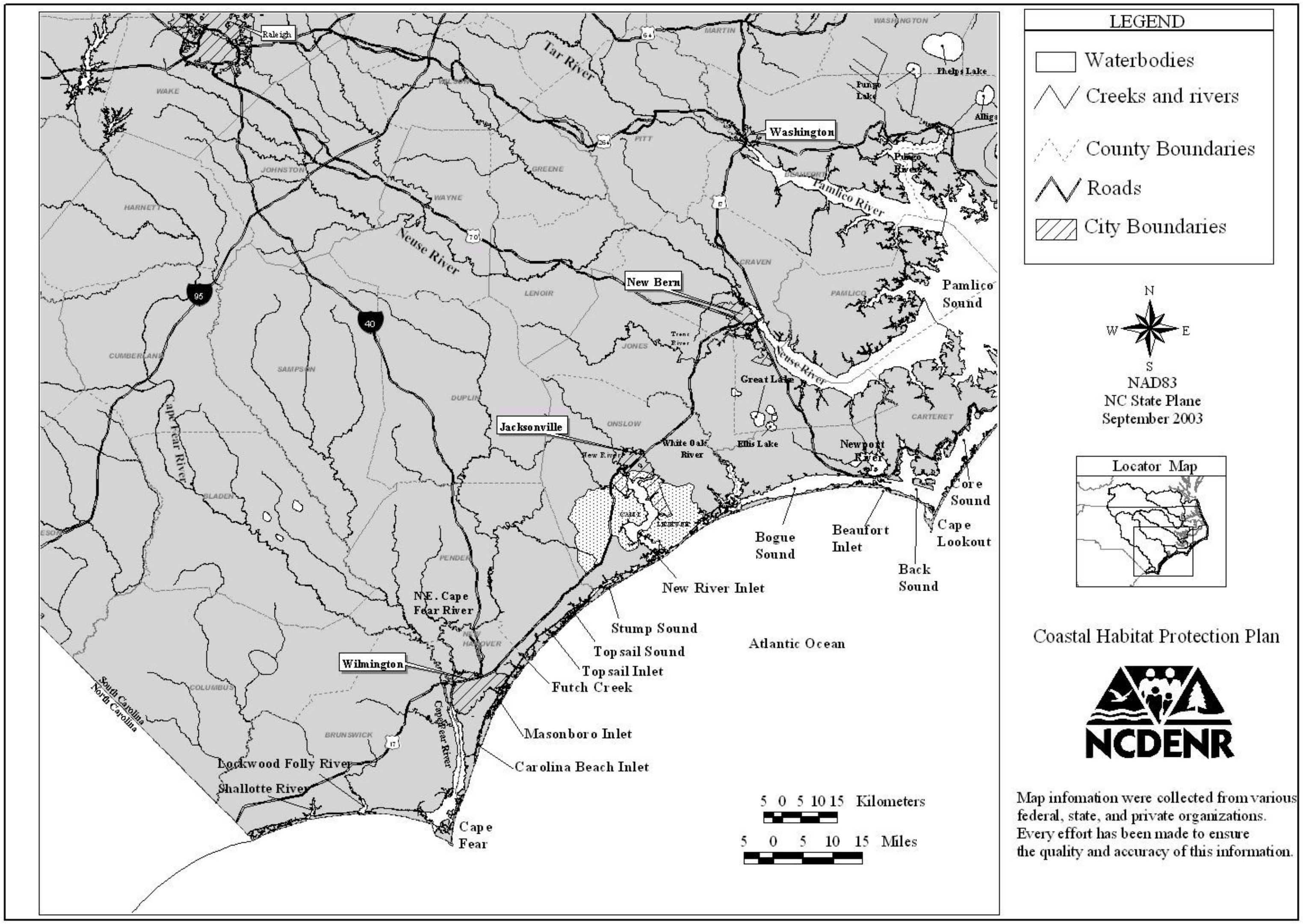
TABLE 1.5. Stock status of important fishery species and stocks over the past ten years (2005–2015).

Species/stocks	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
American shad	concern	concern	concern	concern	concern	concern	concern	concern	concern	concern	concern
Atlantic croaker	viable	viable	viable	viable	concern	concern	concern	concern	concern	concern	concern
American eel	?	?	?	?	?	?	?	depleted	depleted	depleted	depleted
Atlantic menhaden	viable	viable	viable	viable	viable	viable	concern	concern	concern	concern	viable
Bay scallops	concern	concern	depleted	depleted	recovering	recovering	concern	concern	concern	concern	concern
Black drum	n/a						?	?	?	?	viable
Black sea bass (N. of Hatteras)	viable	viable	concern	concern	concern	concern	concern	recovering	recovering	recovering	concern
Black sea bass (S. of Hatteras)	depleted	depleted	depleted	depleted	depleted	depleted	depleted	recovering	viable	viable	viable
Blue crab	concern	concern	concern	concern	concern	concern	concern	concern	concern	concern	concern
Bluefish	recovering	recovering	viable	viable	viable	viable	viable	viable	viable	viable	viable
Gag	viable	viable	concern	concern	concern	concern	concern	concern	concern	concern	recovering
Oysters	recovering	recovering	recovering	recovering	recovering	recovering	concern	concern	concern	concern	concern
Red drum	recovering	recovering	recovering	recovering	recovering	recovering	recovering	recovering	recovering	recovering	recovering
Reef fish	concern	concern	concern	concern	concern	concern	concern	concern	concern	concern	concern
River herring (Albemarle)	depleted	depleted	depleted	depleted	depleted	depleted	depleted	depleted	depleted	depleted	depleted
Shrimp	viable	viable	viable	viable	viable	viable	viable	viable	viable	viable	viable
Southern flounder	depleted	depleted	depleted	depleted	depleted	depleted	depleted	depleted	depleted	depleted	concern
Spot	viable	viable	concern	concern	concern	concern	concern	concern	concern	concern	concern
Spotted seatrout	viable	viable	viable	viable	concern	depleted	depleted	depleted	depleted	depleted	viable
Striped bass (Albemarle)	viable	viable	viable	viable	viable	viable	viable	viable	viable	concern	concern
Striped bass (Central/southern)	depleted	depleted	depleted	depleted	depleted	depleted	concern	concern	concern	concern	concern
Striped bass (Ocean)	viable	viable	viable	viable	viable	viable	viable	viable	viable	viable	viable
Striped mullet	recovering	viable	viable	viable	viable	viable	viable	viable	viable	viable	viable
Summer flounder	concern	concern	concern	concern	recovering	recovering	viable	viable	viable	viable	viable
Weakfish	depleted	concern	depleted	depleted	depleted	depleted	depleted	depleted	depleted	depleted	depleted

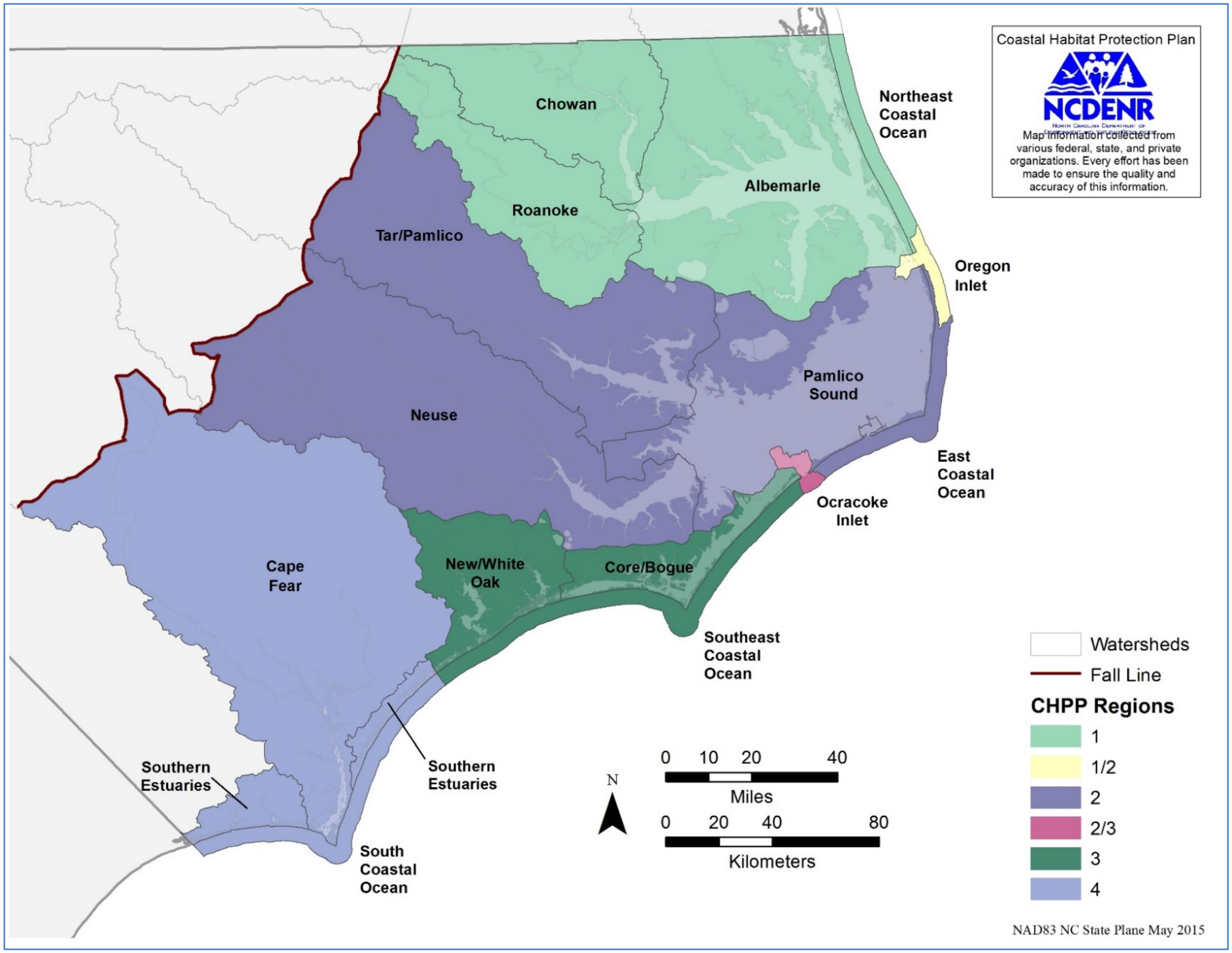
* Stock status category: concern; depleted; recovering; viable; ? unknown



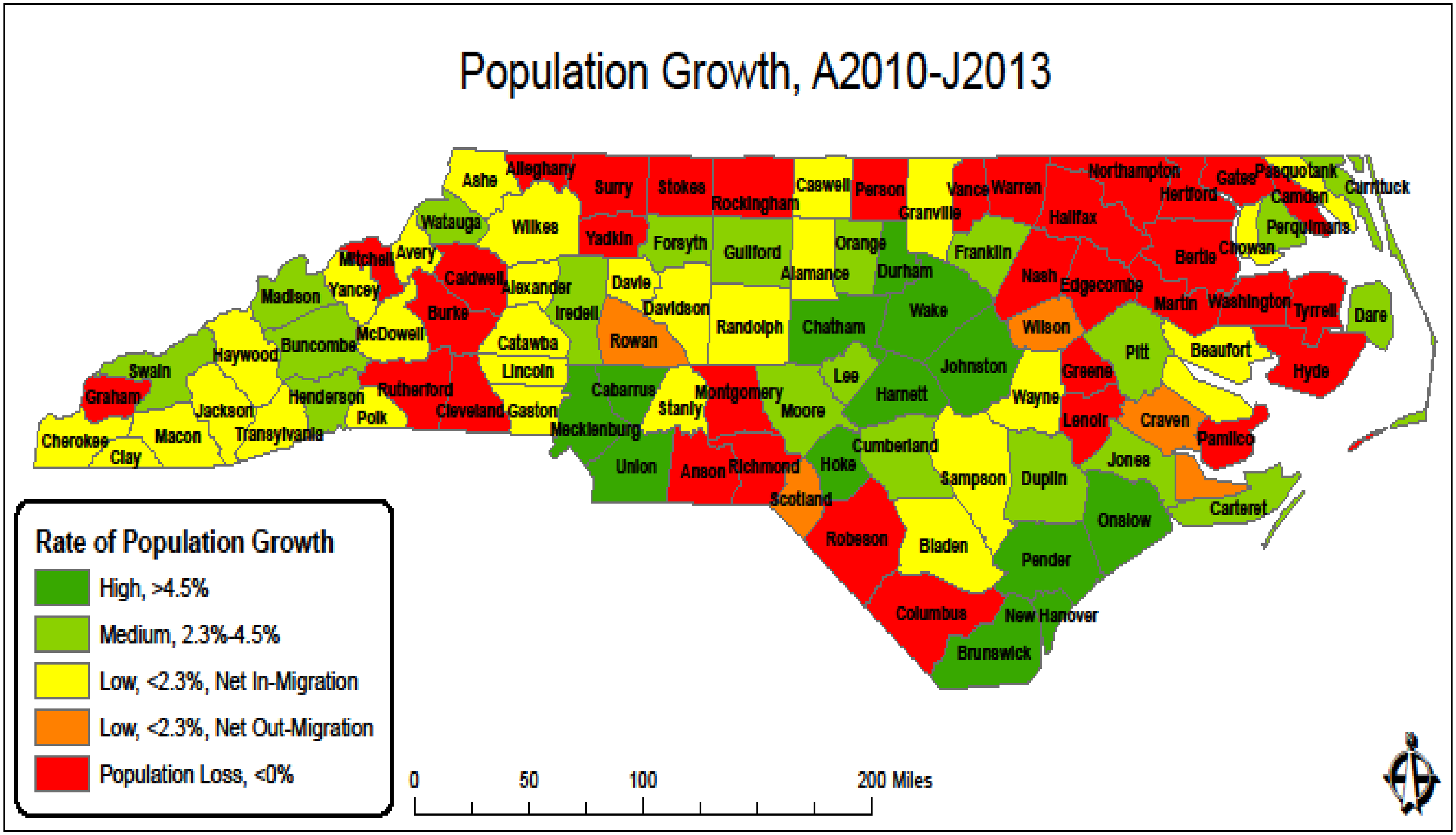
MAP 1.1A. Hydrographic features in northern coastal North Carolina. (Data from 1:100,000 scale USGS topographic maps).



MAP 1.1B. Hydrographic features in southern 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.



MAP 1.3. Rate of population growth from 2010 to 2013 by county (Source: NC Office of State Budget and Management, unpublished data).

CHAPTER 2. WATER COLUMN

The water column habitat is defined as "water covering a submerged surface and its physical, chemical, and biological characteristics." The chemical and physical properties of the water affect the biological components of the water column - including fish distribution (Street et al. 2005). The water column is the medium through which all aquatic habitats are connected.

The North Carolina coastal fishery is affected by a range of water column factors linking fish, habitat, and people, such as temperature, salinity, dissolved oxygen (DO), total suspended solids (TSS), nutrients (nitrogen, phosphorus), chlorophyll *a*, pollutants, pH, velocity, depth, movement, and clarity. To determine the best course for enhancing the water column, detailed knowledge of fishery species' needs throughout their life cycles, and the status, trends, and threats is required.

2.1. Description and distribution

The water column extends from the surface to the substrate, including physical, chemical, and biological characteristics. Deepwater habitats are permanently flooded, waterward of the wetland boundary, in which water is the principal life-sustaining medium. The coastal aquatic ecosystem includes the river basins draining into the estuarine and marine systems. Within a river basin, attributes change from the headwaters to the ocean. The results determine spatial and temporal differences in fish assemblage.

2.1.1. Riverine System

Five major riverine systems flow into North Carolina's coastal waters: Chowan, Roanoke, Tar-Pamlico, Neuse, and Cape Fear (Map 1.1a and b). The input from these systems define the estuarine systems.

River basin characteristics depend on climate, geology, topography, land cover, and land uses. They exhibit seasonal variations in flow, suspended particle concentration, and temperature. Average monthly discharge in coastal river basins peaks in March, declines through summer and fall, and increases starting around November. This pattern corresponds to changes in salinity, sediment load, and turbidity. Water temperatures are generally highest from June to September (25-27º C) and lowest during December -

January (5-9º C).

2.1.2. Lacustrine and Palustrine Systems

The Lacustrine and Palustrine Systems include isolated shallow water where wetlands extend to -6.6' Mean Low Water (MLW), and open waters greater than -6.6' MLW. Waters may be tidal or non-tidal, with salinity less than 0.5 ppt., and include lakes, reservoirs, and ponds. The Palustrine System includes non-tidal wetlands and tidal wetlands where salinity is below 0.5 ppt, with some intermittent channels. There are 16 natural lakes in North Carolina's coastal plain (Menhinick 1991), with only Alligator, Great, Ellis, and Pungo lakes having unobstructed passage to coastal waters (Map 1.1). Lake Phelps has a sporadic connection via canals, as does the largest natural lake, Lake Mattamuskeet (41,084 acres).

2.1.3. Estuarine System

Mixing salt and freshwater, lunar and wind tides, estuaries have partly obstructed access to the ocean. Including salt marshes and tidal flats, upstream limits occur where salt drops to 0.5 ppt during periods of average annual low flow (Cowardin et al. 1979). A NOAA classification is below (Map 2.1a-b, Figure 2.1):

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

Salinity zones change due to flow, weather, and tide. Coarse sediments, saline water, and migrating organisms come with flood tides to the mixing zone; fine sediments, freshwater, nutrients, and organic matter come by ebb tides (SAFMC 1998b). Freshwater is affected by the barrier island inlets. Salinity is generally lowest from December to spring, highest from late spring to early fall (Orlando et al. 1994).

Strong winds are a major component of water movement in irregularly flooded estuaries. In the Albemarle-Pamlico Sound, lunar tides are measured in inches, whereas wind tides are much greater (Reed et al. 2008). Wind tides, flooding the windward shore, expose substrate along the leeward shore, resulting in colder, nutrient-rich, or hypoxic bottom water (Borsuk et al. 2001; Luettich et al. 1999).

Salinities and circulation are reflected in the variable flushing rates of the estuarine systems. The Albemarle-Pamlico system has a flushing period of about 272 days (Table 2.1). Since the trunk estuaries

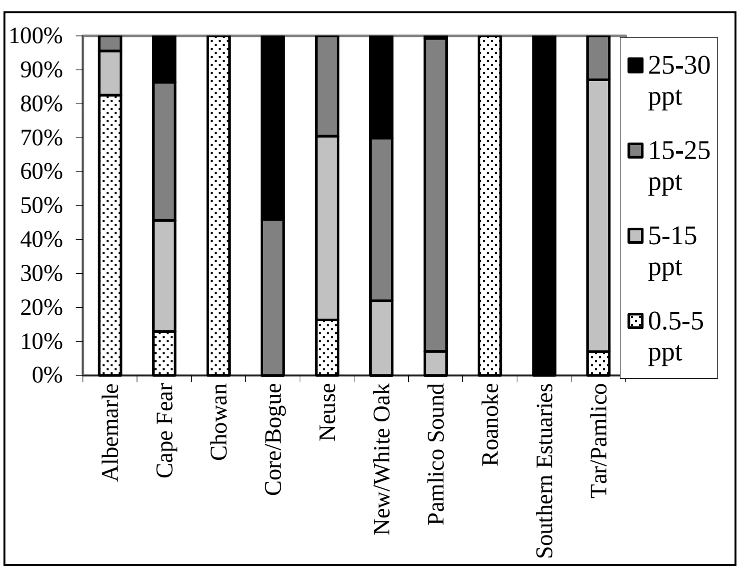


FIGURE 2.1. Estuarine salinity zones within CHPP subregions [Source: NOAA's 1:100,000 scale salinity maping (Coastal Ocean Resource Assessment Program).]

flowing into Pamlico Sound flush more rapidly than the 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 (Orlando et al. 1994), thus flushing rates are faster. In the Pamlico-Pungo, Neuse, and New Rivers, freshwater inflow is the dominant influence (Orlando et al. 1994). The shortest flushing rate of 14 days is the Cape Fear estuary, with ocean discharge and a low cross-sectional area.

TABLE 2.1. Hydrologics/hydrodynamics of major NC estuaries: (Basta et al. 1990; Burkholder et al. 2004)

Estuary	Drainage (mi^2)	Surface (mi^2)	Avg. (ft)	Volume (billion ft^3)	Avg. daily freshwater (100 cfs)	Flushing (days)
Albemarle-Pamlico and Core	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	700	102	5	13	13	116
New River	500	32	6	5	8	72
Cape Fear River	9,100	38	11	12	101	14

2.1.4. Marine System

Marine habitats overly the continental shelf, are exposed to waves and ocean currents, and the water regimes are determined primarily by the ebb and flow of oceanic tides. Salinity, temperature, and circulation patterns are affected by freshwater input, proximity to inlets, prevailing winds, currents, and shoals. Temperatures and salinities are largely vertically uniform on the inner shelf during fall and winter (Menzel 1993), and often stratified during summer.

The effects of freshwater are most apparent near inlets and river mouths. Low-salinity waters enter the ocean through inlets and from the southerly Chesapeake Bay flow. The Cape Fear River is a major source of direct ocean flow. Salinities and temperatures are lowest during periods of maximum freshwater runoff in March. Mixing is amplified by twice-daily tides. Tidal amplitude along North Carolina's ocean shoreline is greatest in the south, where the continental shelf is widest. The average tidal flux near Cape Hatteras is 2 ft (0.6 m) and near the Cape Fear River is 4.3 ft (1.3 m).

The warm, north-flowing Gulf Stream and cool, south-flowing Labrador Current meet near Cape Hatteras, delineating mid and south Atlantic waters. Gulf Stream waters elevate salinities and temperatures, transporting larvae into North Carolina nearshore waters (Menzel 1993). The Labrador Current runs along the northern shore of the Outer Banks, lowering temperatures and salinities (Pietrafesa 1989). These currents interact with near-perpendicular shoals near North Carolina's capes and inlets, creating upwellings of nutrient-rich bottom water.

2.1.5. Fish assemblages by system

Salinity and proximity to inlets are key factors in estuarine fish distribution (Noble and Monroe 1991a; Ross and Epperly 1985; Szedlmayer and Able 1996). Some species tolerate large variations in salinity (blue crab), while others cannot (black sea bass). Inlet proximity affects delivery of organisms from offshore spawning areas to estuarine nursery areas (Table 2.2). In low-salinity areas, the 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 others, migrate from the ocean and lower estuary to spawn upstream in freshwater. The adults then migrate back to the lower estuary or ocean, while the juveniles begin their seaward migration in late fall (Fischer et al. 1979; Hawkins 1980; Marshall 1976; Sholar 1975; Sholar 1977). Residents of the low-salinity zone include bay anchovy, and freshwater species such as white perch, yellow perch, catfishes, sunfishes, minnows (Copeland et al. 1983; Epperly 1984; Keefe and Harriss 1981; Keefe and Jr. 1981), and the catadromous American eel. During spring and summer, juvenile and adult estuarine species that were spawned in high-salinity estuarine waters (e.g., blue crab, red drum, weakfish), or the nearshore ocean (e.g., Atlantic menhaden, Atlantic croaker, spot, southern flounder), occupy the low-salinity zone (Table 2.2).

The moderate-to-high salinity zone has few and generally small residents (e.g., gobies, anchovies, pipefish, grass shrimp, hogchokers)(Epperly and Ross 1986), with exceptions such as sheepshead. Eastern oysters, bay scallops, and hard clams are the only fishery species residing year-round in this zone. During the growing season, these areas are dominated by young estuarine and marine spawning fishery species, e.g., 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 to spawn in the Sargasso Sea. Anadromous fish migrate through these areas during their fall-to-early-winter trek back to the ocean. Higher salinity regions of the estuary are used by marine species including black sea bass, bluefish, juvenile gag grouper, gulf flounder, summer flounder, pinfish, sheepshead, kingfish, and Spanish mackerel (Table 2.2). Common inhabitants of the nearshore zone during the growing season include bottom fish such as kingfishes, Florida pompano, and dogfish sharks, along with pelagic species like silversides, striped mullet, king mackerel, cobia, and silversides. During late fall and winter, the nearshore marine zone is flooded with post-juveniles of species reared in the estuary (southern flounder, Atlantic croaker, spot, shrimp, striped mullet, Atlantic menhaden, red drum, and seatrout) (Francesconi 1994; Hackney et al. 1996b).

2.1.6. Fish habitat requirements

Within salinity zones, the physical and chemical parameters creating suitable habitat include: flow and movement, pH, temperature, dissolved oxygen, clarity, and others.

2.1.6.1. Water flow and movement

Topographic features, tide, and wind create large-scale spatial and temporal variation in water flow (Inoue and Wiseman 2000; Xie and Eggleston 1999). Smaller scale topographic changes and bottom structures (e.g., SAV, reefs, pilings, stumps) alter velocity (Komatsu and Murakami 1994; Lenihan 1998). Aquatic organisms rely on flow and movement to: (1) distribute sediment and affect structural habitat, such as shell, soft bottom, and SAV (DMF 2003b); (2) cue spawning activity; and (3) transport and distribute eggs, larvae, and juveniles to nursery areas. Larvae and juveniles prefer low velocities; as such, juvenile, estuarine-dependent fish are highly abundant in shallow, side-channel habitats (Noble and Monroe 1991a; Ross and Epperly 1985). Powers and Kittinger (2002) found that blue crab predation on juvenile hard clams and bay scallops decreased with increased velocity, as did whelk predation on bay scallops. Palmer (1988) showed that high current velocities eroding the sediment surface released small animals (meiofauna), resulting in increased predation by spot (a more non-visual feeder).

2.1.6.2. pH

The pH of the water affects egg development, reproduction, and the ability of fish to absorb DO (Wilbur and Pentony 1999). Changes in pH can be caused by atmospheric deposition, among other things. As pH varies, many aquatic organisms have adapted. Most fish require pH >5.0 (Wilbur and Pentony 1999), above or below which diversity and reproduction can be reduced. Low pH can release toxic elements, making them available for uptake by aquatic plants and animals.

The pH of seawater is the most stable among systems and varies between 7.5 and 8.5 (Nybakken 1993). Estuarine pH depends on the mix of seawater and freshwater, freshwater having the most variable pH, depending on organic matter content and buffering capacity. The pH standard for surface freshwaters in North Carolina is 6.0 to 9.0, depending on classification. In areas of dense vegetation, pH and DO can fluctuate dramatically between day and night. Atmospheric carbon dioxide can impact shell formation by lowering pH, altering the saturation point of calcium carbonate and aragonite.

The optimum pH for egg development and larval growth of oysters is between 8.25 and 8.5 (Calabrese 1972; Calabrese and Davis 1966). The optimum pH for spawning is 7.8 and for successful recruitment is >6.75. Likewise, hard clam eggs and larvae require pH levels of 7.0-8.75 and 7.5-8.5, respectively. Anadromous fish can generally tolerate water with lower pH levels; alewife eggs and larvae require pH between 5.0-8.5, and blueback herring eggs and larvae between 5.7-8.5 (Funderburk et al. 1991).

2.1.6.3. Temperature

Temperature patterns in coastal waters affect fish distribution and functions. Being located at the southern end of the cool Mid-Atlantic Bight and the northern end of the warm South Atlantic Bight, Cape Hatteras marks the transition. 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, temperature increases from headwaters to estuaries determined by elevation, air temperature, shading, and velocity, and is one of the primary cues for anadromous fish spawning. The greatest temperature variation within North Carolina's estuaries occurs seasonally due to spring flows (Figure 2.1). The average monthly temperature ranges from 41ºF (5ºC) in January to 81ºF (27ºC) in July and August in the Pamlico River (Copeland and Riggs 1984). Estuarine water temperature also responds to tides (Peterson and Peterson 1979). In winter, water temperatures near ocean inlets rise with the incoming tide, whereas during summer, the incoming tide is cooler (Peterson and Peterson 1979).

Estuarine organisms can tolerate a wide range of temperatures if given adequate time to acclimate (Nybakken 1993). Early life stages of many species (e.g., clams, oysters, spot, croaker, flounder, menhaden) have lower tolerances than adults (Kennedy et al. 1974). If water temperature falls too low or too rapidly, sensitive species like red drum and seatrout may die. Cold shock is a key factor in spotted seatrout decline (http://www.ncdmf.net/stocks/spottedseatrout.htm).

Temperature varies least in the marine system (Peterson and Peterson 1979) and marine species tend to be less tolerant of temperature extremes. Tropical species occur off the North Carolina coast where bottom water temperatures range from 52-81ºF (11–27ºC) (SAFMC 1998b). 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 (DO)

Fish and invertebrates require DO to survive, grow, and reproduce. Oxygen level necessity varies by organism. Fish are generally more sensitive to hypoxia than other aquatic organisms, needing ≥ 2 mg/l, and to the associated sulfide production. However, being highly mobile, most can avoid areas of low DO. Growth of actively swimming fish is reduced at DO concentrations <6 mg/l, and metabolism is reduced at 4.5 mg/l (Gray et al. 2002). The majority of species requiring high DO are pelagic species, although some prominent forage species can tolerate hypoxic conditions.

Benthic invertebrates can be tolerant of low oxygen (Diaz and Rosenberg 1995), but if stationary, are defenseless. Among invertebrates, mortality often follows exposure to 0.5-1.0 mg/l for five days (90% mortality of blue crabs after three days)(Sagasti et al. 2001). Sulfide production can be associated with low DO, and combined, the two can be lethal to benthic organisms (Tenore 1972).

TABLE 2.2. Spawning location/strategy and vertical orientation of some prominent coastal fishery species.

Species	Vertical orientation[1]		Fishery [3]	Stock Status [4]
	Demersal[2]	Pelagic		2014
ANADROMOUS FISH				
River herring (alewife and blueback herring)	E	A, J, L	X	D-Albemarle Sound, U-central/southern
American shad	E	A, J, L	X	Concern
Sturgeon (Atlantic and shortnose)	A, J, E		X[5]	Depleted
Hickory shad	E	A, J, L	X	Unknown
Striped bass	A, J	E, L	X	C-Albem/Roanoke, V-Atl. migr.
CATADROMOUS FISH				
American eel	A, J	E, L	X	Depleted
ESTUARINE AND INLET SPAWNING AND NURSERY				
Bay anchovy		A, J, E, L		
Bay scallop	A, J, E	L		Concern
Grass shrimps	A, J, E	L		
Hard clam	A J	E, L	X	Unknown
Mummichog	A, J, E	L		
Oyster	A, J	E, L	X	Concern
Silversides	E	A, J, L		
Black drum	A, J	E, L	X	Unknown
Blue crab	A, J, E	L	X	Concern
Cobia		A, J, E, L	X	
Red drum	A, J	E, L	X	Recovering
Spotted seatrout	A, J	E, L	X	Depleted
Weakfish	A, J	E, L	X	Depleted
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY				
Atlantic croaker	A, J	E, L	X	Concern
Atlantic menhaden		A, J, E, L	X	Concern[6]
Shrimp	A, J, E	L	X	Viable
Southern flounder	A, J	E, L	X	Depleted
Spot	A, J	E, L	X	Concern
Striped mullet	A	J, E, L	X	Viable
MARINE SPAWNING, HIGH SALINITY NURSERY				
Black sea bass	A, J	E, L	X	V-south of Hatteras, R-north of Hatteras
Bluefish		A, J, E, L	X	Viable
Florida pompano	A, J	E, L	X	
Gag grouper	A, J	E, L	X	Concern
Gulf flounder	A, J	E, L	X	
King mackerel		A, J, E, L	X	Unknown
Kingfish ("sea mullet")	A, J	E, L	X	Unknown
Pinfish	A, J	E, L	X	
Sheepshead	A, J	E, L	X	Unknown
Spanish mackerel		A, J, E, L	X	Viable
Summer flounder	A, J	E, L	X	Viable

[1]Epperly and Ross (1986), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998b), NOAA (National Oceanic and Atmospheric Administration) (2001), USFWS, DMF.

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

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

[4] V=viable, R=recovering, C=concern, D=depleted, O=overfished, U=unknown (DMF 2014)

[5] Former fishery, but fishing moratorium since 1991.

[6] Although the 2014 ASFMC stock status is of *Concern*, this will likely be updated to *Viable* in the 2015 assessment.

Low DO during the growing season can be fueled by nutrients and oxygen-consuming wastes. Abundant algal production creates biomass that is consumed by microbial decomposition, increasing the biochemical oxygen demand (BOD). Chlorophyll *a* concentrations and BOD have been strongly correlated in coastal creeks, estuaries, lakes and rivers (Mallin et al. 2006). Warm water, calm winds, and reduced freshwater in summer limit mixing and aeration of the water column, stratifying the bottom layer, and depleting it of oxygen. Shallow water estuaries with less flushing often develop persistent stratification and bottom-water hypoxia (Tenore 1972).

2.1.6.5. Light and clarity

Clarity and light are important for aquatic plant growth, and are determined by levels of dissolved and suspended particles. While algae have low light requirements, submerged aquatic vegetation (SAV) has a greater need. Extreme turbidity reduces light availability and visibility of food for pelagic organisms (Bruton 1985), reducing reactive distance for visual feeders (Barrett et al. 1992; Gregory and Northcote 1993), volume of water searched, and feeding efficiency (Benfield and Minello 1996; Lindquist and Manning 2001). However, moderate turbidity can be beneficial to small fish by affording protection from predators, and to photophobic species by increasing overall survival rates (Bruton 1985).

2.2. Ecological role and functions

As the medium through which all aquatic habitats are connected, the water column provides basic ecological roles and functions for organisms within, 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, through integrated events and processes such as resuspension, settlement, and absorption (Warwick 1993).

2.2.1. Productivity

Primary productivity in the water column comes from phytoplankton, floating plants, macroalgae, benthic microalgae, and detritus. The potential productivity of a habitat can indicate its relative value in supporting fish populations. The net productivity in a given system depends on water column conditions affecting the relative proportion of wetlands, shallow soft bottom, SAV, shell bottom, and deep water.

Studies of phytoplankton production in several North and South Carolina estuaries have reported relatively high productivity (Peterson and Peterson 1979; Thayer 1971; Williams and Murdoch 1966). Mallin et al. (2000a) found the highest phytoplankton production in riverine estuaries where flushing was limited by extensive barrier islands, whereas areas that are well flushed (Cape Fear River) support lower phytoplankton biomass and productivity.

Phytoplankton productivity is generally considered secondary to detritus production in salt marshes (Dame et al. 2000; Peterson and Peterson 1979). Compared to open water areas, narrow tidal creeks and associated marshes contribute more detritus than phytoplankton. However, research suggests that much of the detrital production remains in the marsh, making juvenile fish production the major export.

Phytoplankton production in shallow estuaries can be secondary to phytobenthic production. Based on relative rates of primary production and nutrient cycling, Webster et al. (2002) found phytobenthos to be the dominant primary producer in a shallow estuary where light was not limiting. Both turbid and non-turbid estuaries were found to have high primary productivity from benthic, epiphytic, and edaphic algae (Cloern 1987; MacIntyre et al. 1996a; Mallin et al. 1992).

Sampling tributaries of the Lower Mississippi River basin between 2006 and 2009, Ochs et al. (2013) found phytoplankton production to be significantly greater in the summer months, and light limited. While there was significant gross primary production in the main channel in summer, the net primary production was negative, posing the hypothesis that the main flow of the channels are subsidized by hydrologically connected tributaries and slackwater areas where the light regime is greater; hence, the importance of protecting primary nursery areas for phytoplankton production.

In nearshore ocean waters, Menzel (1993) reported significant primary production rate decreases from the inner to the outer shelf of the South Atlantic Bight. Cahoon et al. (1990) found that on the inner shelf in Onslow Bay, 80% of chlorophyll *a* was associated with sediment. Benthic microalgal biomass always exceeded phytoplankton biomass (Cahoon and Cooke 1992). Mallin et al. (1992) estimated microalgal production to be at least 66% of the total annual primary production in coastal areas, mostly contributed by benthic microalgae. Hackney et al. (1996b) reported that, because of circulation patterns, inorganic nutrients could be resuspended and retained sufficiently to allow localized phytoplankton blooms in the surf zone. Production levels in nearshore waters may increase by a factor of three to ten with the warm core intrusions from the Gulf Stream (Signorini and McClain 2007).

2.2.2. Fish utilization

U.S. commercial and recreational saltwater fishing generated more than $199 billion in sales in 2012, according to the Fisheries Economics of the United States 2012. In North Carolina, the recreational and commercial fishery generated $1.87 billion in 2011, http://www.st.nmfs.noaa.gov/Assets/economics/documents/feus/2011/REC_2011_revise.pdf. This section will focus primarily on species associated with the open water habitat.

Pelagic species are most commonly found near the surface, examples being alewife, American and hickory shad, blueback herring, bay anchovy, silversides, Atlantic menhaden, striped mullet, bluefish, cobia, king and Spanish mackerel. The eggs and larvae of most fish depend on water for transport and food. Demersal species (living on or near the ocean bottom) utilize the water column on limited bases depending on life stage (e.g., egg laying or larval), and for opportunistic behaviors. Such fish include, but are not limited to, grouper, black sea bass, trigger, and sheepshead (G. Bodnar, DMF, pers. com. 2014).

2.2.2.1. Corridor and connectivity

The corridor is important to all fish, but particularly to species whose life spans more than one system (anadromous, catadromous, and marine-spawning, estuarine-dependent)(Table 2.2). Meroplankton (spend part of their life as plankton) rely on the corridor for transport from spawning areas to nursery areas. The spatial and temporal interplay of factors triggering migration, and the water conditions needed for successful migration, determine the degree of corridor function. The major conduits used by meroplankton and migrating fish are ocean inlets and channels from riverine headwaters to estuaries.

2.2.2.2. Spawning

During late winter and early spring, increasing light, flow, and temperature in freshwater systems provide spawning habitat for resident freshwater and anadromous fish (Orth and White 1993) (Table 2.3). The reverse is true for marine-spawning, estuarine-dependent species as declining light, flow, and temperature in low salinity nurseries trigger spawning in the ocean during late fall and early winter. Species completing their life cycles in the inlet estuary (e.g., red drum, seatrout, blue crab, eastern oyster) spawn during summer and fall. As conditions are met for spawning, many fish species broadcast planktonic or semi-demersal eggs. Survival of planktonic larvae (meroplankton) to free-swimming juveniles is determined by water quality, flow, and circulation patterns, in route to nursery areas.

Anadromous fish spawning

Anadromous fish species such as alewife, blueback herring, striped bass, and hickory and American shad, use the riverine water column during spring to broadcast eggs which develop as they float downstream.

Current velocity, and increasing light and temperature are important cues for spawning (Klauda et al. 1991; Orth and White 1993)(Table 2.4). Sufficient rainfall from mid-February to mid-June is needed to provide suitable velocities for spawning. Strong currents are required by striped bass and blueback herring, whereas slower velocities are needed for American shad and alewife (Funderburk et al. 1991). Successful spawning of striped bass coincides with water velocities between 3.3 and 6.6 ft/s (100-200 cm/s), while adult American shad prefer slower waters (Fay et al. 1983c; Hill et al. 1989; MacKenzie et al. 1985). Alewife spawn in lakes, slow-moving oxbows and small streams where it co-occurs with blueback herring. Blueback herring prefer deeper waters than alewife, and will use lentic (standing) water or lotic (moving) water, while alewife will only use lentic (Walsh et al. 2005). Lake Mattamuskeet is a lentic system that has historically supported significant alewife spawning runs (Epperly 1985; Winslow et al. 1983). Species differ in whether they prefer main stem rivers or tributary creeks for spawning. Main stem 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 (Funderburk et al. 1991; Pate 1972). During their spawning migration, anadromous fish actively avoid waters with low DO and extremely high turbidity (Steel 1991).

Estuarine spawning

Estuarine spawners are mostly resident forage finfish, spawning in shallow water during the warmer months (Table 2.3). This group includes important shellfish species (oysters, hard clams, bay scallops, blue crabs) and sport fish (red drum, weakfish, spotted seatrout, cobia) that spawn in deeper, flowing waters (Luczkovich et al. 1999; Powers and Gaskill 2004). Red Drum will spawn in high salinity nearshore waters in late summer (Johnson and Funicelli 1991; Murphy and Taylor 1990; Nicholson and Jordan 1994), allowing eggs and larvae transport to nursery grounds (Johnson 1978; Ross and Stevens 1992). Spawning season for blue crabs, oysters, clams, and scallops is triggered primarily by increasing spring water temperatures and/or decreasing fall water temperatures (Burrell 1986; DMF 2004; Eversole 1987; Fay et al. 1983b). Winds and currents carry larvae to nursery habitats in the estuary and nearshore ocean. Understanding water movement is essential to understanding larval transport. Successful movement of larvae through inlets is very important to North Carolina fisheries. Spawning and egg requirements are shown in Table 2.5.

Marine spawning

Marine spawners generally spawn where prevailing currents will carry their eggs and larvae to nurseries within estuaries and nearshore ocean waters. There are two groups of marine spawners: 1) low-high salinity, and 2) high salinity (Table 2.3). The first group spawns offshore from fall to late winter, and includes spot, Atlantic croaker, southern flounder, Atlantic menhaden, shrimp, and striped mullet (Anderson 1958; Epperly and Ross 1986), among others. Larvae are transported into estuaries where they settle in nursery areas of low to high salinity. The second group includes pinfish, black sea bass, gag grouper, and kingfish, and reproduces at various times in limited to higher salinity areas. Evidence suggests that gag grouper will spawn offshore and larvae will spend 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 grouper larvae to estuaries near Masonboro Inlet (C. Collier, DMF, pers. com. 2014). Between March 12 and June 20, 2012, 15 estuarine sites were sampled to monitor ingress of juveniles of winter spawning commercially and recreationally important fish species, in particular, gag grouper. The sites extend from Swansboro, NC to Brunswick, GA. During this time period (2012), gag grouper dropped to 34th most abundant taxa, from 10th and 15th in 2010 and 2009, respectively (Rester et al. 2013). The results are being used as part of a coastwide study to calculate a juvenile abundance index for gag grouper in the South Atlantic (C. Collier, DMF, pers. com. 2014). Contracts are in place to maintain sampling sites through 2016; however no additional sites are currently funded.

TABLE 2.3. Spawning seasons for coastal fish and invertebrates in NC that broadcast semidemersal or planktonic eggs. [USFWS (lit. cited: reference titles beginning Species Life Histories and Environmental Requirements), DMF FMPs, Funderburk et al. (1991) Pattilo et al. (1997), Luczkovich et al. (1999), NOAA (2001), DMF (2003a)]. Black squares indicate peak spawning. Cross-hatched squares indicate spawning period.

	Winter			Spring			Summer			Fall		
	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 grouper		■	■									
Gulf flounder	▨	▨									▨	▨
King mackerel						▨	▨	▨	▨			
Pinfish	▨	▨	▨							▨	▨	▨
Pink shrimp				▨	▨	▨	▨					
Sheepshead			▨	▨	▨							
Spanish mackerel					▨	▨	▨	▨	▨			
Southern kingfish				▨	▨	▨	▨	▨	▨			
Summer flounder	■	▨	▨								▨	■

TABLE 2.4. Spawning and egg requirements for resident freshwater and anadromous fishes inhabiting coastal NC. [Sources: Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998b), USFWS (lit. cited: reference titles beginning 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] >4	[S] >4	[O] slow current	SS <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	SS <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			SS <1000 mg/l
White perch	[S] 5-18	[S] 0-2	[S] 10-30	[S] 12-20	[S] >5			SS <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, [O] = optimum

Research projects conducted under the South Atlantic Bight Recruitment Experiment (SABRE) studied transport of winter-spawned fish larvae into 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, larvae passed through the inlets, but with the best wind and tide conditions only about 10% were successfully drawn into the inlet (Blanton et al. 1999). Larvae passing downwind and outside the withdrawal zone pass seaward of the inlet shoals, and given the right conditions, will be transported into the next downstream inlet. Churchill et al. (1999) noted that transport dynamics in the immediate vicinity of inlets are complex, and larvae may move in and out repeatedly before immigrating. 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 injected through the inlet (Hare et al. 1999). The larvae of estuarine inlet spawners, e.g., red drum, seatrout and blue crab, are also affected by hydrodynamic conditions of inlets.

Beaufort, Ocracoke, and Oregon inlets support significant larval fish passage. Oregon Inlet is especially important, providing the only opening into Pamlico Sound north of Cape Hatteras for Mid-Atlantic Bight spawned larvae. Diversity of larval fish passing through inlets is very high, as 61 larval species have been found in Oregon Inlet, with Atlantic croaker and summer flounder particularly abundant (Hettler and Barker 1993). Larval species also found in Oregon Inlet include bluefish, black sea bass, gray snapper, flounders, pigfish, pinfish, spotted seatrout, weakfish, spot, kingfish, red drum, mullet, and butterfish. Utilization and 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, (29 species) were identified, although menhaden, spot, Atlantic croaker, and pinfish dominated. 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 2.5. Requirements for spawning in the estuarine waters of coastal NC. [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 (1998b), Wannamaker and Rice (2000), NOAA (2001)]

	Salinity (ppt)		Temperature (C)		DO (mg/l)		Suspended sediment (mg/l)	
Species	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] 0->30	[S] 0.5- >30	[S] 11-30	[S] 13-30	[S] >3			
Bay scallop	[S] >14	[S] 18-30	[S] 15-30	[O] 15-20				[S] SS <500
Black drum	[S] 5->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->30	[S] >30	[S] 21->30	[S] 21 ->30				
Hard clam	[S] 10- >30, [O] 24-28	[S] 18- >30	[S] 16-30	[S] 16-30	[S] >5	[S] >0.2	[S] SS <44	[S] SS <750
Inland silversides		[S] 0-31.5	[S] 15-30	[S] 13-34, [O] 20-25	[S]>1.7			
Oyster	[S] 2 - >30, [O] 14-30	[S] 7.5-34, [O] 10-22	[S] 21-30	[S] 19-32	[S] >1			[S] SS <250
Red drum	[S] 0 - >30, [O] 20-30	[S] 10-40, [O] 29-32	[S] 21-30	[S] 21-30	[S] >5			
Spotted seatrout	[S] 2 - >30, [O] 20-25	[S] 15-28, [O] ~28.1	[S] 16-30	[S] 16 - >30, [O] ~28				
Weakfish	[S] 1 ->30	[S] 12- >30	[S] 10-30	[S] 18-24				

Larval fish are an important component of zooplankton in the ocean water column, Powell and Robbins (1998) having documented 110 families in Onslow Bay. During late fall and winter, estuarine-dependent species (e.g., Atlantic menhaden, spot, Atlantic croaker) are present. Spring and early summer, estuarine spawning species (e.g., pigfish, silver perch, weakfish) are found, with reef fish larvae most abundant in spring, summer, and early fall. The frequent occurrence of larvae from deepwater oceanic species is indicative of Gulf Stream transport, being the transport mechanism for many larval fish species, nutrients, and phytoplankton into North Carolina’s shelf waters (Govoni 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 between spawning locations, physical processes, salinity, temperature, chemical cues, and habitat preferences are critical in determining larval settlement in estuaries (Brown 2002; Luckenbach 1985; Peterson et al. 2000c).

The MFC designated PNAs initially in 1977 (the WRC in 1990) as settlement areas for post-larvae of offshore winter spawners. The designations were a result of DMF trawling and seine surveys and rigorous sampling showing areas continually supportive of juvenile shrimp, crab, and finfish populations. Primary Nursery Areas are defined in MFC rule T15A NCAC 03I .0101(4)(f). Once designated, a PNA has special protections under the rules of the MFC, CRC, and EMC (MFC rule T15A NCAC 03N .0104, CRC rules T15A NCAC 07H .0208, and EMC rules T15A NCAC 02B .0301).

Primary Nursery Areas total 76, 927 acres of coastal water column and tidal wetlands, or ±4% of the estuarine fishing waters in North Carolina. Designated Secondary or Special Secondary Nursery Area total 82,000 acres. Data from DMF Estuarine Trawl Surveys (NCDMF 2009a) indicate that the number of juvenile species in PNAs is greater in waters north of Cape Lookout than to the south. 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, while an average of 55 species was collected south of Cape Lookout.

Anadromous fish nurseries

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

Juvenile alewife and blueback herring in the Potomac River exhibited upstream movement over four months before emigration to nursery areas (Fay et al. 1983a). Both species were most abundant in surface waters through September, though blueback herring remained in the upper portion of the water column during their stay, while 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 upper areas of the Tar River later in maturity than blueback (Jones 2009). The results for blueback suggest greater benefit from early arrival to higher salinity zones. Jones (2009) documented higher CPUE of larval river herring in “backwater” tributaries of the Tar River than in the main stem. Peak abundances for both species in meroplankton occurred in April - May. Recruitment of larval river herring in tributaries of the Chowan River is related to flow conditions (O'Rear 1983). Walsh et al. (2005) observed an increase in the number of alewife larvae in 1997 when a large amount of wetlands was flooded. Juvenile river herring migrate offshore from fresh and estuarine nursery areas by November of their first year (O'Neill 1980; Richkus 1975). Sharp declines in water temperature, and heavy rainfall and water flow are shown to influence migration from nursery areas (Cooper 1961; Kissil 1974; Richkus 1975).

Larval striped bass drift downstream from spawning locations in the upper river during late spring and early summer (Funderburk et al. 1991). Larval transformation into juveniles occurs in the downstream portions of rivers or in the sounds (Funderburk et al. 1991). During late fall and winter, young striped bass begin to move seward (Fay et al. 1983c; Hill et al. 1989). Adequate flow conditions are essential for the egg, larvae, and juvenille 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).

Juvenile American shad use similar nursery areas to river herring, but young shad prefer deeper pools further from shore, occasionally moving into shallow riffles (Funderburk et al. 1991). In summer, juvenile shad and blueback herring migrate to the surface at night (Loesch and Kriete 1984). As temperatures decrease during fall with river flow slightly increasing, downstream movement of American shad seems to be triggered (Funderburk et al. 1991). Nursery area surveys conducted by DMF noted decreases in juvenile shad in October on the Cape Fear and Neuse rivers, and Albemarle Sound (Winslow 1990).

TABLE 2.6. Fish spawning requirements for marine waters of coastal NC [USFWS (lit. cited: reference titles beginning Species Life Histories and Environmental Requirements), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998b), 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]	
Shrimp, brown	[S] 0.8-45, [O]	[S] >24	[S] 4-36, [O]	[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]	[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 grouper	[S] high salinity		[S] >10.6			
Gulf flounder	[S] 6 to >30,	[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]	[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		

TABLE 2.7. Peak larval abundance of seven important fish species near Beaufort Inlet (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	■	■	■	■	■	■	■

TABLE 2.8. Larval and juvenile water quality requirements for anadromous fish species inhabiting coastal NC. [USFWS (lit. cited: reference titles beginning Species Life Histories and Environmental Requirements), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998b), 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	[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	[S] >3.6
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

Low and high salinity nurseries

The larval nursery habitat for offshore spawners extends from the inlet water column, across primarily inshore-flowing channels, to the upper reaches of estuaries. Survival depends on the nursery areas providing the biological, physical, and chemical characteristics needed for growth (Table 2.9). In Pamlico Sound, salinity and circulation are the key physical conditions affecting species composition in juvenile nursery habitat (Epperly and Ross 1986; Noble and Monroe 1991a). Low salinity nurseries include the upper Pamlico Estuary, Pungo River, upper Neuse Estuary, eastern Albemarle Sound (including Croatan and Roanoke sounds), and 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), the latter two generally being year round residents. Post-larval striped mullet enter low salinity nurseries primarily in winter (Nelson et al. 1991); menhaden post-larvae arrive February to June (Purvis 1976). By late fall, many nonresident estuarine fish migrate to the ocean or deeper regions of the estuary (Epperly and Ross 1986).

Moderate salinity areas include the waters of Pamlico Sound. In addition to juveniles present in lower salinity areas, spotted seatrout, weakfish, silver perch, and red drum are abundant in moderate salinity estuaries (Noble and Monroe 1991a). Young weakfish and silver perch occupy deeper waters of moderate and high salinity zones; young blue crabs and other demersals prefer shallow areas (Epperly and Ross 1986). Nursery habitats for juvenile weakfish are deeper portions of coastal rivers, sounds, bays, and estuaries (Mercer 1989, DMF unpublished data). Growing, juvenile weakfish are often found in shallow bays or channels of moderate depths, higher salinities, and sandy substrates (ASMFC 1996).

High salinity nurseries

High salinity nurseries (>18 ppt) include the eastern side of Pamlico Sound, Core and Bogue sounds, the mouth of the Cape Fear River, and the southern coastal estuaries, with the dominant juvenile species being mostly demersal. The juveniles of pelagic species (e.g., Spanish mackerel, bluefish, cobia) prefer deeper, open waters (NOAA 2014). The water quality requirements of these species are listed in Table 2.10. The timing of juvenile arrival in high salinity nurseries depends on the preceding spawning conditions. Bluefish begin spawning in March and their young become abundant in Bogue Sound (high-salinity) around mid-May (Nelson et al. 1991). Juvenile Spanish mackerel appear (although rarely) in Bogue Sound in mid-May (Barber et al. 1991).

Some pelagic species (e.g., anchovies, king mackerel), rely on nearshore ocean water masses as nursery habitats (SAFMC 1998a). Other species include butterfish, striped anchovy, striped mullet, and Atlantic thread herring (SEAMAP-SA 2000). Juveniles of Spanish mackerel, bluefish, and black sea bass use the surf zone and nearshore waters seasonally, while migrating between estuarine and ocean waters (DMF 2000; Godcharles and Murphy 1986; Hackney et al. 1996a). Juvenile bluefish tend to stay in one area and use the surf zone for an extended time (>25 days during the summer)(Ross and Lancaster 1996). The major recruitment period for juvenile fish to surf zone nurseries is late spring and early summer.

2.2.2.4. Foraging

The primary food sources in open waters are zooplankton, phytoplankton, and detritus, consumed by most fish at some point in their life cycles. Of over 30 species listed in Table 2.2, nearly all larval stages eat plankton. Resuspended benthic microalgae are an important food source. The diet of adult, pelagic filter-feeders (e.g., river herring, shads, Atlantic menhaden, striped mullet) includes largely zooplankton, and then detritus and phytoplankton. 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. Young-of-year (YOY) bluefish feed predominately on fish throughout the water column. In 1992 and 1993, Buckel and Conover (1997) found clupeids, moronids, and bay anchovy (*Anchoa mitchilli*) in a majority of YOY stomachs. Studies by 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 they use different habitats within the water column.

TABLE 2.9. Water quality requirements for selected larval and juvenile estuarine fish species inhabiting estuarine nurseries in coastal NC. [USFWS (Lit. cited: ref.titles Species Life Histories and Environmental Requirements), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998b), Wannamaker and Rice (2000), NOAA (2001)]

Species	Salinity (ppt)		Temperature (C)		Dissolved oxygen (mg/l)	
	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

TABLE 2.10. Water quality requirements of selected larval and juvenile coastal estuarine fish species inhabiting high salinity nurseries in coastal NC. [USFWS (see lit. cited: reference Species Life Histories and Environmental Requirements), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998b), 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

In freshwater streams, larval and juvenile American shad and blueback herring feed on zooplankton (Crecco and Blake 1983; Jenkins and Burkhead 1993). In years with a shortage of prey items, the diets of larval American shad and river herrings overlap (Jenkins and Burkhead 1993). Zooplankton abundance for river herring in the Chowan River and tributaries was studied under a Fisheries Resource Grant (S. Ensign, UNC-IMS, pers. com. 2010). The study revealed similar species composition to that observed in the early 1980's. Monitoring results from April 2008 through May 2009 showed that crustacean zooplankton, being the choice of juvenile and adult river herring, had overall densities of 2-140 times greater than in the early 1980's (Leech et al. 2008). Temperature and chlorophyll *a* were positively correlated with crustacean abundance, while discharge was positively correlated only in the main stem of the river, and otherwise negatively correlated. Rotifers were abundant for larval and juvenile river herring, while potentially of lower nutritional value. Leach et al. (2010) found that small-bodied rotifers dominated all stations, followed by copepods and cladocerans. This research and subsequent modeling that while blueback herring and alewife were the dominant planktivores in the past, they may now be surpassed by hickory, gizzard, and American shad, affecting the zooplankton community.

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

In estuaries, menhaden, anchovy, silversides, striped mullet, and other pelagics use suspended organic matter exported from adjacent marshes, SAV, and oyster reefs, without occupying these habitats (SAFMC 1998b). The relative contributions of detritus and phytoplankton between the estuarine and nearshore ocean ecosystem are seen in the foraging behavior of Atlantic menhaden. Lewis and Peters (1994) found the dominant food sources for menhaden were detritus in estuarine systems and phytoplankton in coastal waters. Adult striped mullet in North Carolina are opportunistic “interface feeders,” feeding at the water surface, water bottom, or the surface of objects. While feeding at these interfaces striped mullets will consume epiphytic microalgae and dissolved organic matter (DMF2006).

A large number of adult fish inhabit the marine water column. The September, 2013 results of the DMF Pamlico Sound Survey culminated in 70 species of finfish and invertebrates, while the June survey had 67 species. In 2012, 85 species of finfish and invertebrates were caught in September with 84 in June, compared to 73 and 57 in 2011, respectively (NCDMF 2012).

Coastal pelagic species, highly migratory species, and anadromous fishes depend on the water column for foraging. The boundaries of water masses (coastal fronts) in the nearshore ocean are favorite foraging areas for mackerel and dolphin (SAFMC 1998b). King and Spanish mackerels feed on baitfish seasonally congregating on shoals and reefs. The National Marine Fisheries Service (NMFS) has designated the cape shoals of North Carolina as Habitat Areas of Particular Concern (HAPCs) for both mackerels. Anadromous species such as shad, river herring, and striped bass utilize the cape shoals as staging areas for migration along the coast. Large aggregations of striped bass have been documented in the northern nearshore coastal area during winter months, feeding and resting prior to 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, being important to the entire Atlantic coast population (Benton 1992). During winter, the waters off of the Outer Banks support anchovies and menhaden, weakfish and other sciaenids, on which striped bass feed. Laney et al. (1999) considered the existence of areas with such abundant food sources 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.

2.2.2.5. Refuge

The refuge function of the water column varies according to the area of open water, depth, water quality, and floating plants. Expanses of open water can provide protection for forage species by reducing encounters with predators; juveniles use shallow areas for refuge. Turbidity and DO can provide refuge for pelagic forage species. Silversides create dense schools reducing DO concentrations so low as to repel predators (Fay et al. 1983a). Copepods and zooplankton tolerate low DO, impacting the food web for small invertebrate refuge (Breitburg et al. 1997; Keister et al. 2000). Turbidity can provide refuge for prey species from visual predation (Blaber and Blaber 1980; Boehlert and Morgan 1985; Miller et al. 1985). The value of floating plants in marine systems can be seen in *Sargassum,* supporting a diverse assemblage of organisms, including ≥145 invertebrates, ≥100 fishes, four marine turtles, and numerous marine birds (SAFMC 1998b). The greatest concentrations of *Sargassum* patches are in the Sargasso Sea and the outer continental shelf of the South Atlantic. Large pelagic adults (e.g., dolphin and sailfish), predate around *Sargassum*, driving sport fishermen to *Sargassum* patches. Casazza and Ross (2008) reported a higher diversity of species around *Sargassum* than in unvegetated waters of the Gulf Stream off North Carolina. In fact, 18,799 fishes, representing 80 species from 28 families, were collected in 162 *Sargassum* patches, while 2706 fishes, representing 60 species from 23 families were collected from 80 open water samples without *Sargassum*.

2.3. Status and trends

The condition of waters is described in physical and chemical context (nutrients, suspended sediment, toxins), pollution indicators (chlorophyll *a*, fecal coliform, fish kills), and status of pelagic fisheries (bluefish, Atlantic menhaden). Fish species and assemblages exhibit threshold tolerances. Conditions of the water column that are outside the threshold tolerance are considered impaired, polluted, or otherwise not supporting fishery species.

Basic parameters of water impairment as they relate to fish include: flow, movement, pH, temperature, DO, and clarity. The parameters synthesize, affecting water quality. Added chemicals can interact with biological processes, causing unintended consequences. Excessive sediment from land-based activities can exacerbate eutrophication and toxic contamination. Water flow and movement play a vital role in distributing the drivers of eutrophication and chemical pollution.

2.3.1. Physical and chemical environment

The biennial Integrated Report (IR) to Congress regarding the quality of our nation's waters is a compilation of reports of Sections 303d, 305b, and 314 of the Clean Water Act for the 50 states, 5 inhabited territories, and the District of Columbia. Together, these reports assess the conditions of the waterbodies within state and territorial jurisdictions. In 2012, the report showed results as follows:

Rivers and Streams – 29.5% assessed, 7% threatened, 53.7% impaired
Lakes, Reservoirs, and Ponds – 43.1% assessed, 8% threatened, 68% impaired
Bays and Estuaries – 38% assessed, 0% threatened, 78.1% impaired
Ocean and Near Coastal – 3.1% assessed, 0% threatened, 63.2% impaired

The 2014, North Carolina 303(d) list included: 101,997 freshwater acres, 2,936 freshwater miles, and 622,338 saltwater acres, which represents 1,113 assessment units. Surface waters of the state are assigned a classification reflecting the best-intended use of that waterbody (e.g., drinking water, shellfish harvest, primary recreation, aquatic life). To determine how well waterbodies are meeting their best-intended uses, chemical, physical, and biological parameters are regularly assessed by DWR. These data are used to develop use support ratings every two years and reported to the EPA; impaired waters are reported on the 303(d) list (DWQ 2012), and do not meet one or more standard(s) or criterion. The waterbody is not rated if data are inconclusive or unavailable.

Stations monitoring water quality are concentrated in riverine and upper estuarine waters (Map 2.3). Only shellfish sanitation surveys and university research programs provide significant monitoring coverage in lower estuarine and nearshore ocean waters. Water monitoring in offshore waters is conducted by various federal authorities and organizations. Data collected from monitoring stations within the CHPP area include those from approximately 1,020 shellfish growing area stations and 240 recreational water quality stations (S. Jenkins, DMF, pers. com. 2014); DWR monitoring stations within the overall CHPP management unit include ±256 ambient stations, 76 fish community sample sites, and 245 benthic macroinvertebrate sample sites.

Water quality data (e.g., chlorophyll *a*, nutrients, pH, DO, and turbidity) from a representative 18 DWR ambient stations throughout the CHPP region are summarized graphically by year in Figures 2.4a-f. Map 2.1 shows the locations of these ambient stations. The graphs are not statistical trends or meant to show standard exceedance, but are generated to show general trends over approximately 15 years.

The five selected stations in region 1 include:
N8550000- Roanoke River near Williamston
D8950000- Chowan River near Colerain
D999500C- Albemarle Sound near Edenton
M390000C- Albemarle Sound near Frog Island
M2750000- Pasquotank River near Elizabeth City

The graphs show that TP levels are higher in the rivers versus Albemarle Sound, while TN is increasing in all the stations, the Pasquotank River showed higher concentrations during the wetter years. Turbidity data shows peaks during wetter years and higher concentrations in the Roanoke River. High and low DO levels may indicate the growth and crash of algal production within these waterbodies. Median pH levels fluctuate at each station with the levels not indicating any extended periods of standard exceedance.

The four selected stations in region 2 include:
O787000C- Pamlico River mid-channel near
O982500C- Pamlico River mid-channel between mouths of Pungo River and Goose Creek
J8902500- Neuse River near Thurman
J9810000- Neuse River near Oriental

Data from the two upper and lower estuary stations show similar patterns over the years. The graphs clearly show higher nutrient levels in the upper estuary, whereas dilution and utilization occurs and lower concentrations of TP and TN are present at the lower estuary stations.

The five selected stations in region 3 include:
P8975000- North River near Bettie
P7300000- Newport River near Newport
P6400000- White Oak River near Stella
P1200000- New River near Jacksonville
P4600000- New River upstream of French Creek

Nutrient data was only collected at the New River stations; this data shows much higher concentrations near Jacksonville than downstream in the New River estuary. Turbidity data shows much higher concentrations in North River than in other coastal rivers, while DO and pH levels are much lower at the Newport River station than other coastal stations.

The four selected stations in region 4 include:
B8350000- Cape Fear River near Kelly
B9820000- Cape Fear River near Wilmington
I9440000- Lockwood Folly near Varnum
I9820000- Shallotte River near Shallotte

Nutrient data was only collected at the Cape Fear River stations with the higher concentration data indicated in the upstream station. The upstream Cape Fear River B8350000 station also shows larger range of turbidity concentrations and lower pH conditions that may be attributed to swamp influence.

Because of changes in methodologies and EPA requirements, current use support ratings do not directly compare to previous assessments, therefore trends cannot be readily identified. Assessments give snapshots of recent water quality conditions and help determine further studies or management strategies. Table 2.11 provides a summary of impairments for 16 coastal subbasins (8-HUC).

Toxic chemical contamination is not evaluated by DWR in estuarine and nearshore ocean waters. The current standards do not completely eliminate risk from toxins because: (1) values are not established for many toxic chemicals; (2) mixtures and breakdown products are not considered; (3) effects of seasonal exposure to high concentrations have not been evaluated; and (4) some potential effects, such as endocrine disruption and unique responses of sensitive species, have not yet been assessed.

TABLE 2.11. Impairment totals based on 2008, 2010, 2012, 2014 Integrated Reports (IR) for coastal subbasins: Lower Roanoke 03010107, Chowan 03010203, Meherrin 03010204, Albemarle 03010205, Lower Tar 03020103, Pamlico 03020104, Pamlico Sound 03020105, Middle Neuse 03020202, Lower Neuse 03020204 White Oak River 03020301, New River 03020302, Lower Cape Fear 03030005, Black 03030006, Northeast Cape Fear 03030007, Waccamaw 03040206, Coastal Carolina 03040208.

Impaired Parameter	2008 IR*		2010 IR*		2012 IR*		2014 IR*		Impairment Type
	# of AUs	Miles/ Acres	# of AUs	Miles/ Acres	# of AUs	Miles/ Acres	# of AUs	Miles/ Acres	
Arsenic	3	1,776.9a	3	9,341.2a	3	9,341.2a	3	9341.2a	Aquatic Life
Cadmium	1	24.4m	1	24.4m	1	24.4m	1	24.4m	Aquatic Life
Chloride	1	3.4m	2	4.4m	2	4.4m	2	4.4m	Aquatic Life
Copper	1 34	9.5m 404,245a	1 37	9.5m 446,957a	1 31	9.5m 446,975a	1 35m	9.5m 446,188a	Aquatic Life
Chlorophyll *a*	2 29	6.1m 78,560.2a	2 33	10m 130,949a	2 32	10m 132,978a	2 24	12.5m 30,273a	Aquatic Life
Low Dissolved Oxygen	3 11	26.1m 6,566.9a	3 10	33.6m 6,496.5a	3 5	31.4m 6,737.4a	4 8	27.0m 5,002a	Aquatic Life
Low pH	7	6,342.1a	4 6	62.1m 5,598.4a	3 1	16.3m 5,616.7a	5 6	25.6m 11,488a	Aquatic Life
High pH	5	24,667.8m	6	25,242.2a	3	14,359.2a	-	-	Aquatic Life
High Water Temperature	-	-	3	280.1a	1	139.9a	-	-	Aquatic Life
Nickel	1 11	6.2m 15,312a	4	9,421.2a	4	9,421.2a	4	9,421.2a	Aquatic Life
Turbidity	2 15	21.8m 50,520.3a	1 10	8.4m 11,776.6a	1 5	8.4m 10,001a	4	6,290a	Aquatic Life
Biological Integrity Macroinvertebrate	30 2	280.7m 64.3a	24 2	210.4m 64.3a	22 1	199.6m 15.8a	25 1	227m 15.8a	Aquatic Life
Water Column Mercury[1]	-	-	9	69.4m	9	69.4m	-	-	Aquatic Life
Dioxin	4 3	45.9m 70,851.1a	3	38.1m	3	38.1m	3	38.1m	Fish Consumption
Shellfish Growing Area closure	654	77,030a	632	70,022.7a	638	67,818.4a	644	70,805a	Shellfish Harvesting
Fecal Coliform	-	-	16	2,921.1a	17	2,956.4a	32	4,940.7a	Shellfish Harvesting
Fecal Coliform	1 3	14.1m 399.7a	3	399.7a	1	140.2a	-	-	Recreation
Enterrococcus	9 25	11.2m 2,611.7a	4 17	5.9m 6,155.5a	2	4,720.6a	14	71,547.6a	Recreation
Recreation Advisory	6 8	6.9m 340.2a	7	213.4a	10	813.5a	11	70,114.7a	Recreation

a= acres, m= miles
*Note: There is not a direct comparison between the IR assessment periods. There could be methodology assessment changes (based on EPA guidance), splits in an assessment units (AU's) due to changes in watershed or extent of identified problem or corrections made.
[1] All 13,123 and unnamed tributaries of the state are Impaired for Fish Consumption because of Statewide Mercury Advice: http://portal.ncdenr.org/web/wq/ps/mtu/tmdl/tmdls/mercury.

Other water quality monitoring in the CHPP region includes: 22 APNEP Citizen's Monitoring Stations, USGS special study investigations, and DMF fish sampling programs. The DMF modified fisheries-independent monitoring programs in 2009 to collect depth, water level, temperature, salinity, DO, sediment size, bottom composition, alteration state, and allowed fishing activities. Additional information includes Secchi depth, shoreline type and structure, land use, percent development, and SAV identification and density. The DMF has deployed nine continuous monitoring devices in the Pasquotank, Roanoke, Perquimans, Scuppernong, Chowan, and Alligator Rivers for river herring research (S. Winslow, DMF, pers. com. 2014). Data collected every two hours include temperature, DO, salinity, pH, and conductivity. The DMF samples 54 random stations in the Pamlico Sound every September and June for environmental factors, and fish abundance and distribution (NCDMF 2012), collecting temperature (°C), salinity (ppt), DO, Secchi depth, wind speed, wind direction, bottom composition, and water depth. A report is generated summarizing species composition, abundance, and size distributions.

Currently there are no water quality standards for nutrients, except 10mg/L nitrate for drinking water; nutrient enrichment is presently measured by chlorophyll *a* response in the water column, in which samples are only taken in large lakes and estuaries. Four basins carry the supplemental classification of nutrient sensitive water (NSW), including all waterbodies in the Tar-Pamlico, Neuse, and Chowan River basins, and the New River in the White Oak Basin (i.e., Onslow Bay Basin). Nutrient Sensitive Waters are subject to wastewater discharge limitations (T15A NCAC 2B .0223), and different nutrient management strategies are in place to help reduce the nutrient loads in these waterbodies.

Chowan NSW Strategy

Algal blooms and subsequent fish kills in the Chowan River led to its NSW classification in 1979, with a nutrient control plan in 1982 calling for basinwide reduction of 35% TP and 20% TN. Implementation to reduce nutrient loads by point sources included limits of 1mg/l TP and 3mg/l TN and the conversion of many municipal point source discharges to land application non-discharge systems resulted in improved water quality. The basin was a priority for implementation of agriculture BMPs, reducing nutrient runoff. Data through 2012 does not indicate chlorophyll *a* levels exceeding standards in the Chowan River.

New River NSW Strategy

The New River was classified NSW in 1991. The strategy to reduce point source nutrients to the upper estuary include: TP and TN limits on existing discharges, and monitoring for TN and TP for facilities without limits. It is recommended that no new discharges be permitted and expansions of existing facilities only be allowed if there is no increase in loading of oxygen-consuming waste. Data through 2012 indicate nutrient enrichment is still a problem in the upper estuary, and waters remain Impaired.

Tar-Pamlico NSW Strategy

The Tar-Pamlico Basin was classified as NSW in 1989. The basin has a Total Maximum Daily Load (TMDL) goal to help meet chlorophyll *a* standards in the Pamlico estuary. Water quality data is assessed at Grimesland (AMS O65600000) along the Tar River to determine whether nutrient reductions in the Tar-Pam Basin are meeting their reductions of 30% TN, and not increasing TP from the 1991 baseline data. Trend analysis of the nutrient parameters data from 1991-2013 at Grimesland indicate an increase in total Kjeldahl nitrogen (TKN) and TN concentrations and a decrease in ammonia (NH_3-N) and nitrate-nitrite (NOx-N) concentrations, while there is no trend in TP concentrations.

Neuse NSW Strategy

The Neuse River Basin was classified as NSW in 1988. Data for the Neuse River TMDL requiring a 30% decrease in TN load from the 1991-1995 baseline is assessed at Ft. Barnwell. Data from 1991-2011 indicate decreasing trends in TN, TP, NH_3 and NOx concentrations, and an increase in concentrations of TKN. Portions of the Neuse Estuary remain impaired due to nutrient enrichment.

Nutrient loading is flow dependent, with levels falling below baseline only during extreme low flows. Both basins indicate a rise in TKN, specifically organic nitrogen. The USGS LOAD ESTimator (LOADEST) tool was used to estimate TN and TP annual load time series at the compliance point in the Tar-Pamlico basin and for TN at the Neuse River compliance point. Load assessments are impacted by precipitation as seen in 1996 (Hurricane Fran), 1999 (Hurricane Floyd) and 2003 (unusually wet year). The annual load time series at Grimesland/Tar-Pamlico shows that the load fell below the targeted TMDL goal of 3,000,491 lbs/yr (green line) in 2007, 2008, 2011 (Figure 2.2a below). The LOADEST TP annual load time series at the same station fell below the targeted TP load of not-to-exceed 396,832 lbs/yr (green line) in 2007, 2008, 2010 and 2011 (Figure 2.2b below). These were drought years as seen by the low flow at the USGS gage station (black line). The annual load time series for Fort Barnwell/ Neuse River indicates that only during the low flow years of 2001, 2002, 2005, 2007, 2008, 2011 and 2012 does the TN load at the compliance point fall below the TMDL target of <6,750,000 lbs/yr of TN (green line; Figure 2.2c below).

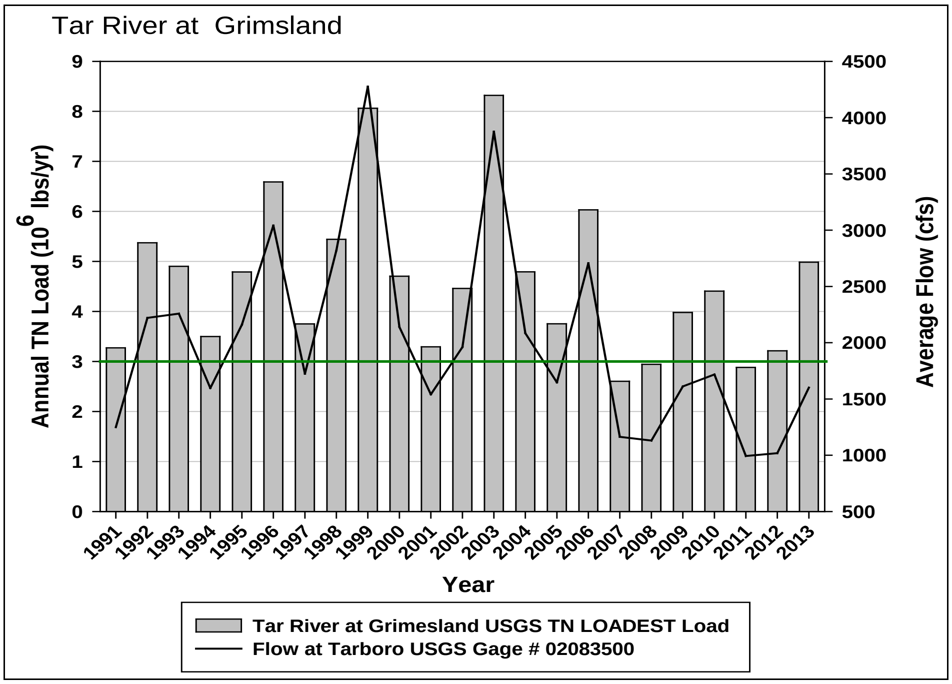


FIGURE 2.2A. Tar-Pamlico Basin USGS LOADEST nutrient time series TN annual load estimations (green line represents the TMDL loading goal).

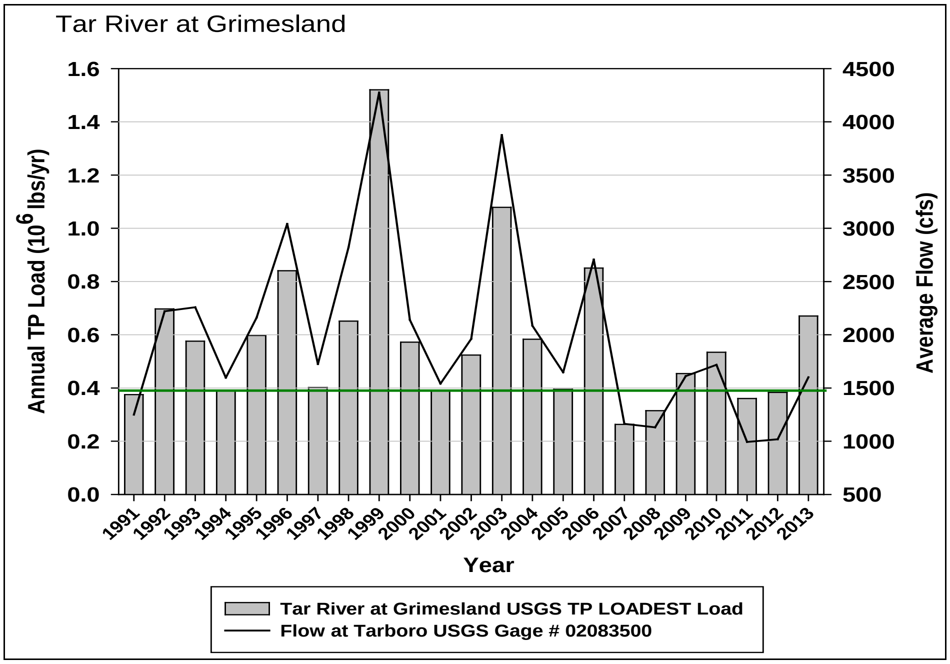


FIGURE 2.2B. Tar-Pamlico River USGS LOADEST nutrient time series TP annual load estimations (green line represents the TMDL loading goal).

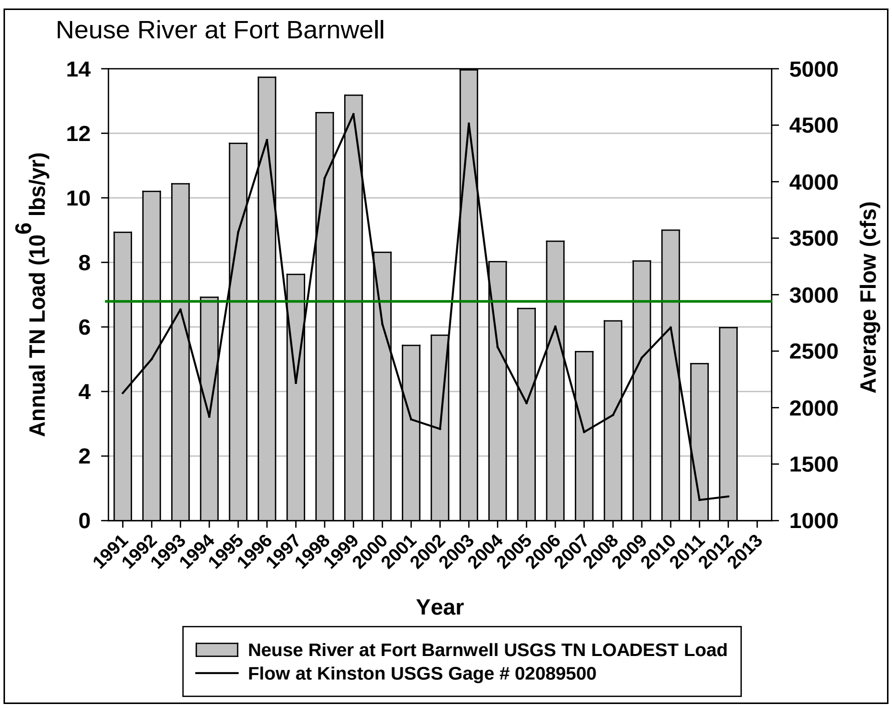


FIGURE 2.2C. Neuse River Basin USGS LOADEST nutrient time series TN annual load estimations (green line represents the TMDL loading goal).

2.3.2. Fish kills

In NOAA's 2013 2nd National Habitat Assessment Workshop, it was stated that habitat compression due to low DO may be associated with a 10-50% worldwide decline of pelagic predator diversity (Rester et al. 2013). In North Carolina in 2008, low DO was the reported cause of 28 of 61 fish kills statewide, resulting in mortality of 6,951,349 individuals, while toxic algal/phytoplankton blooms accounted for 6 kill events (DWR 2008b). Other reported causes included by-catch mortality, toxic spills, or other/unknown causes[3] (DWR 2008b), for a total in 2008 of 7,380,580 individuals. Species most frequently reported included Atlantic menhaden, spot, flounder, and croaker. The sharp increase in mortality is attributed to the 2007 drought, meteorological factors, and extended calm weather conditions (DWR 2008b).

In 2012, NOAA determined that ulcerative mycosis caused by water mold, *Aphanomyces invadans*, was the cause of an extensive menhaden kill in the Neuse River. There were 16 fish kill events statewide in 2012, totaling 306,250 dead fish, considered to be an underestimate. Water mold and/or low DO were suspected of contributing to most of the deaths. Most North Carolina fish kill events have been in the Neuse, Cape fear, and Tar-Pamlico rivers (http://portal.ncdenr.org/web/wq/ess/fishkillsmain).

According to the DWR Annual Report of Fish Kill Events, there were 13 events in 2013, with a mortality of 20,608,452, the majority occurring within the Neuse and Tar-Pamlico estuaries beginning in late September. The lower Neuse and Pamlico estuaries have historically experienced adverse environmental conditions for fish populations, such as low DO, high water temperatures, and fluctuating salinities (http://portal.ncdenr.org/web/wq/ess/fishkillsmain).

According to 2014 DWR reports, statewide fish mortality was in excess of 2,659,000, with a majority of kills in estuarine and coastal inlet waters. Estuarine events involved >650,000 fish, with a single inlet event involving >2,000,000 fish. Atlantic menhaden were the principle species of kill events in 2014, and are the principal species involved in coastal North Carolina fish kills, being particularly sensitive to environmental stress. Coastal events in 2014 followed a familiar September-early-October pattern of relatively large Atlantic menhaden kills from the Neuse and Tar-Pamlico estuaries and tributaries. These events were responsible for all reported estuarine fish mortality during the year and exhibited familiar symptoms of stress, lesions, and water mold (*Aphanomyces invadans)*. The fall season marks the beginning of young menhadens' migration to the sea. Fish that have not migrated by late September and October may be less hardy and more susceptible to changes in water temperature and oxygen levels, invasive pathogens and other stress factors.

The largest fish kill of 2014 occurred in an inlet on December 21. A kill of Atlantic menhaden (2,000,000+) was reported on in Mason Inlet, New Hanover Co., involving schools of ocean fish. The kill was attributed to DO depletion after menhaden entered the inlet and became trapped in a falling tide.

2.3.3. Fisheries associated with pelagic habitat

The water column habitat is used by all species falling under DMF management for some portion of the life cycle (Table 2.2). Larvae are transported from spawning grounds to nursery areas; adults use the water column for spawning, feeding and migration. Anadromous species spawn in fresh water and move offshore, returning as adults to spawn. American eel spawn in saltwater and migrate through coastal habitats, making their way to spawning grounds in the Sargasso Sea. Many commercially important species spawn in the ocean or nearshore areas, with the larvae and early juvenile stages transported by currents back into bays and estuaries. Table 2.2 also includes species that, although not directly managed by DMF, are important components of the ecosystem, particularly as forage species. Water quality or other habitat issues affecting the water column would also presumably affect those species.

[3] 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.

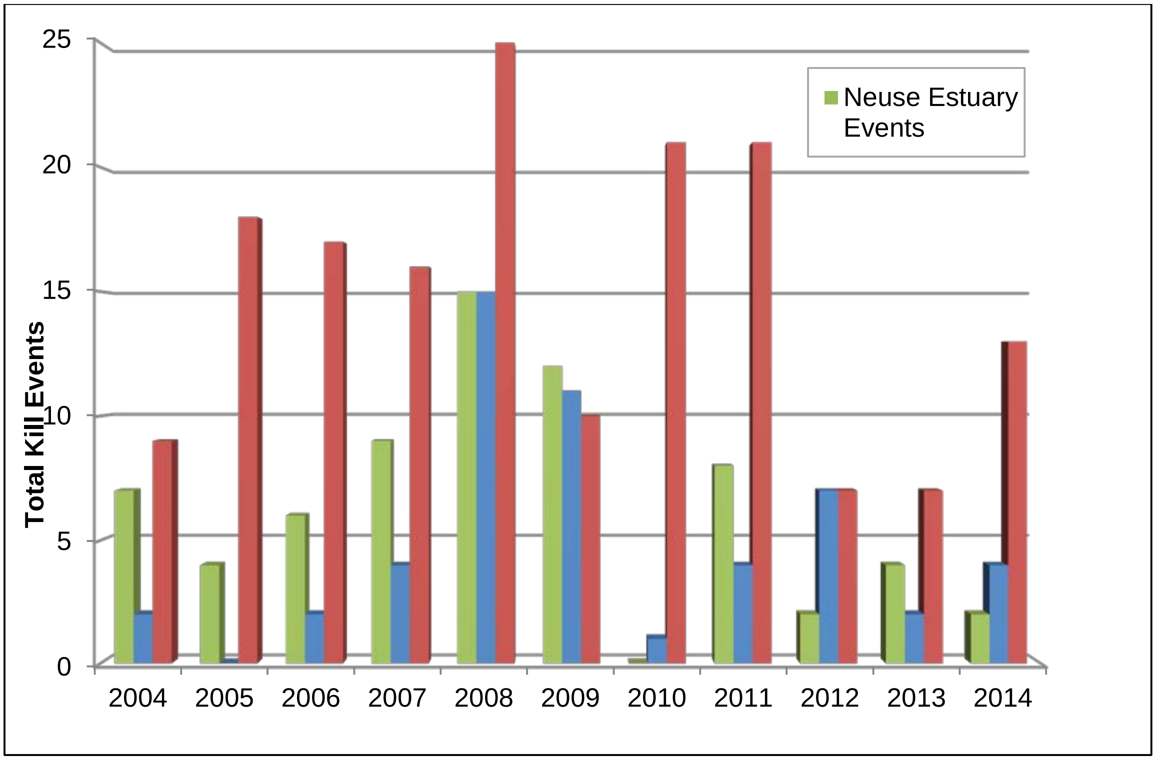


FIGURE 2.3A. Annual fish kill events (DWR 2004-2014).

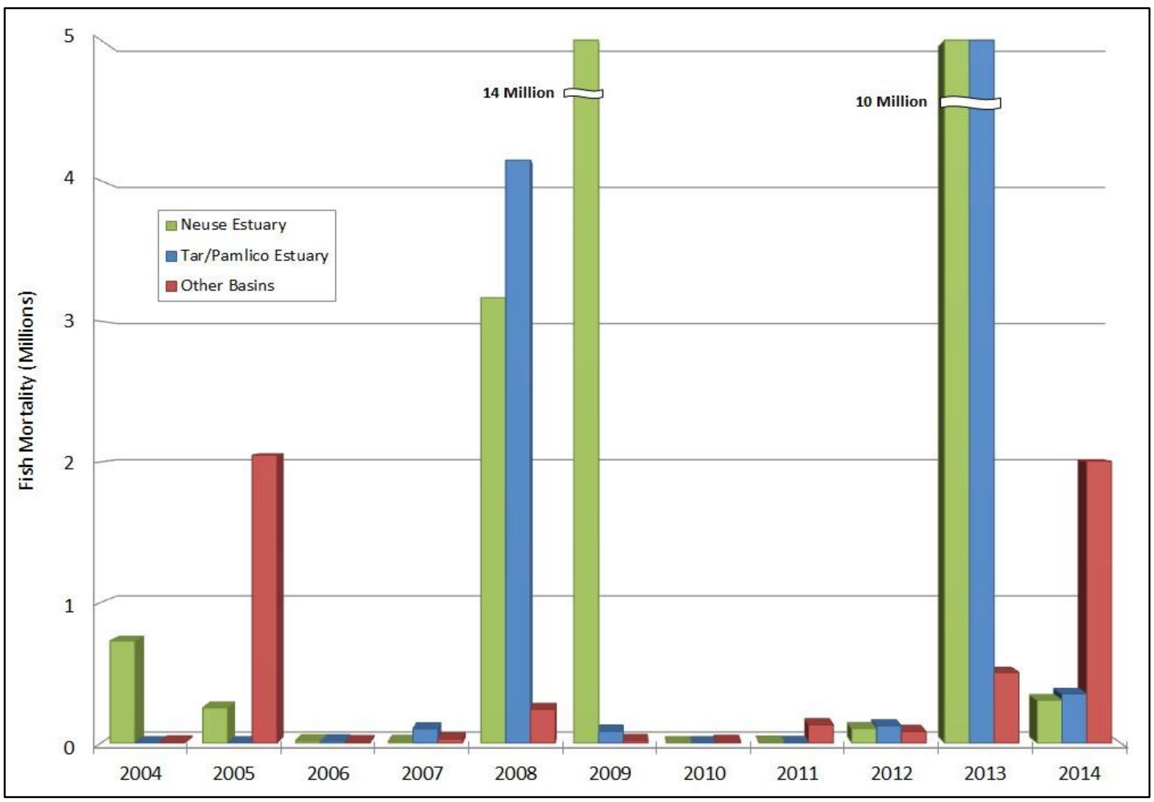


FIGURE 2.3B. Annual fish mortality (DWR 2004-2014).

Estimated fishing mortality and juvenile abundance indices are used by DMF to determine the status of fishery stocks. In 2014, DMF evaluated the stock status of 36 species or complexes (Table 2.2)(DMF 2014). Stock status is based on data collected on a species and is designed to provide a snapshot of the health of a fisheries resource. Stocks are assessed and given one of five possible categories (*Viable*, *Recovering*, *Concern*, *Depleted* and *Unknown*). A stock assessment is a complex process that involves gathering all data collected on a population, including age structure, size structure, fishing mortality, and other measures to evaluate population size and the amount of harvest that should be allowed. This is a long process completed every few years, but is used to help evaluate stock status.

Viable stocks are neither overfished nor undergoing overfishing and include bluefish, scup (north of Cape Hatteras), spiny dogfish, striped bass (Atlantic migratory stock), striped mullet, summer flounder, dolphin, Spanish mackerel, shrimp, and black sea bass (south of Cape Hatteras). *Recovering* stocks are those which have shown marked improvement and include red drum, monkfish, and black sea bass (N. of Cape Hatteras). For some species (hickory shad, river herring other than Albemarle Sound stocks, sheepshead, kingfishes, black drum, and hard clam) there is no directed sampling effort or insufficient information to determine the stock status, so the status is listed as *Unknown*. Species and stocks of *Concern* are those which exhibit negative trends in several measures or where it is not possible to determine if overfishing is occurring. These species and stocks include American shad, the Albemarle/Roanoke stock of striped bass, the Central/Southern stock of striped bass, Atlantic menhaden, Atlantic croaker, spot, sharks, blue crab, eastern oyster, six species of reef fishes, and king mackerel. A coastwide stock assessment of American shad determined that stocks were stable, but well below historical levels (ASMFC 2007b). The Albemarle/Roanoke striped bass stock is not overfished, but landings have declined steadily since 2004. This stock also experienced lower recruitment from 2002-2013 when compared with previous time periods (NCDMF 2013a). The Central/Southern stock of striped bass is of *Concern* due to lack of adequate data, but also because of population attributes indicative of problems in the fishery (truncated age distribution, low overall abundance, fewer older fish on spawning grounds). Although the 2014 stock status for menhaden is of *Concern*, this will likely be updated to *Viable* in 2015 based on the new assessment. The status of Atlantic croaker is listed as *Concern* because the estimate of spawning stock biomass is uncertain, but other measures indicate the stock is likely not in trouble. Landings for spot had generally been decreasing until 2013; adaptive management measures have been adopted. The status of sharks is listed as *Concern* because several species within that complex are overfished (sandbar, dusky, blacknose and porbeagle). Blue crabs are listed as *Concern* largely because of reduced landings in recent years. Eastern oysters face a long-term decline from excessive harvest and habitat disturbances. The reef fish complex has 60 species in it, several of which are currently overfished, including red porgy, red snapper and red grouper (SEDAR 2009). The SEDAR (2014) stock assessment states that king mackerel are not overfished, nor is overfishing occurring, but low recruitment over the previous five years, despite declining fishing mortality, is a *Concern*.

Depleted stocks exhibit low abundance and include American eel, weakfish, river herring (Albemarle Sound), southern flounder, Atlantic sturgeon, and spotted seatrout (DMF 2014). American eel were determined to be *Depleted* based on a 2012 assessment, but the stock status is not well understood, due to variations in sampling protocols across its range (ASMFC 2012a). A coastwide stock assessment in 2012 declared river herring to be *Depleted* to historically low levels (ASMFC 2012b). Stocks are still considered overfished, although fishing is no longer occurring in North Carolina due to a coastwide moratorium (NCDMF 2014c). Weakfish are considered *Depleted* because total mortality continues to increase, despite a lack of evidence for overfishing. A 2009 stock assessment for spotted seatrout indicated that overfishing was occurring and the species had been overfished for the previous 18 years (NCDMF 2009b). Atlantic sturgeon was placed on the Endangered Species list in 2012 (NOAA 2015a). Southern flounder are overfished and overfishing is occurring (NCDMF 2013b). For information on species abundance, consult the Fisheries Management Plan (http://www.ncdmf.net/fmps/index.html).

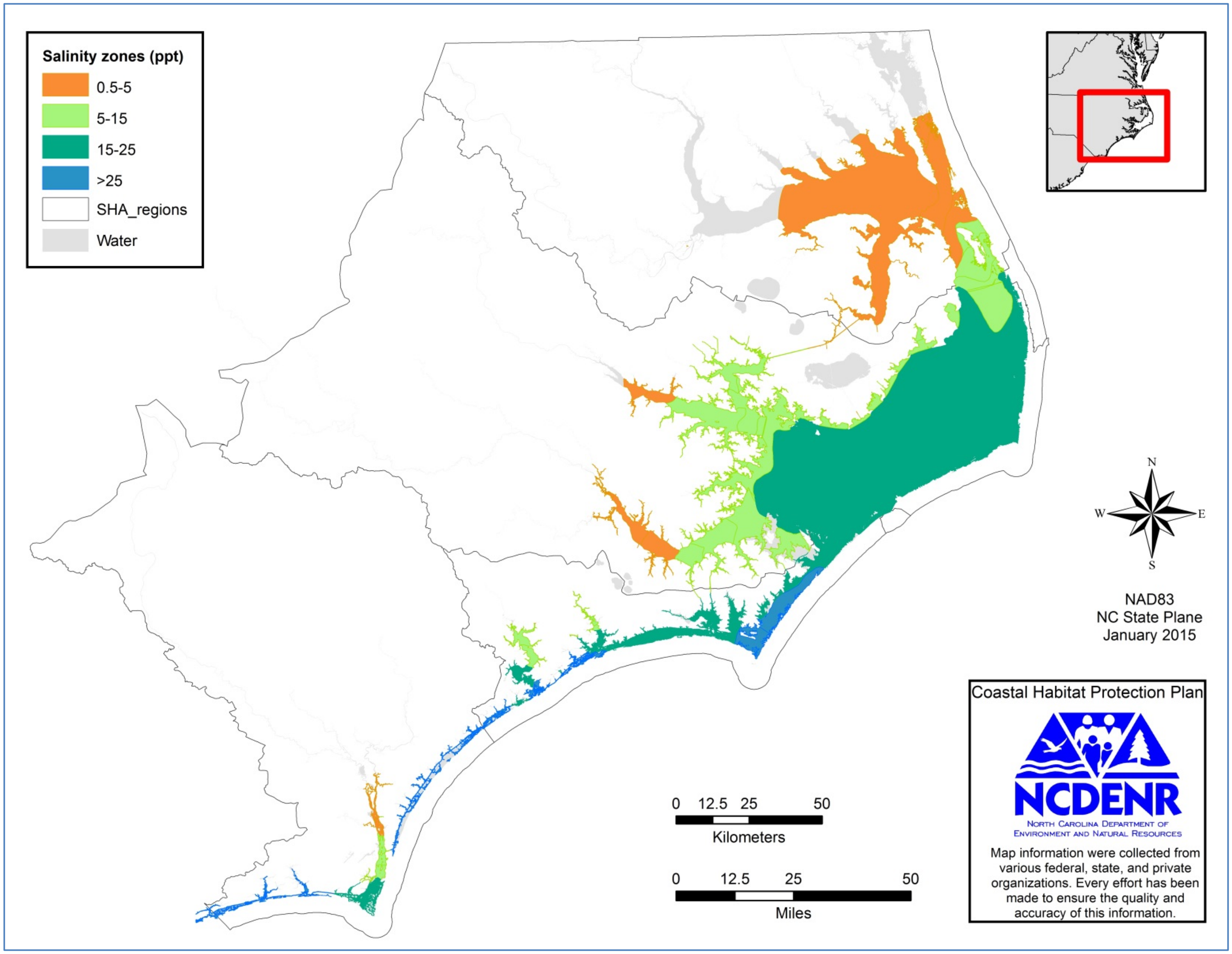
2.4. Water column summary

The global annual oceanic primary production can be estimated to be 55 gigatonnes (Carr et al. 2006), thus the global carbon storage service is equal to at least $0.66 to $13.475 trillion per year (Walser et al. 2008).

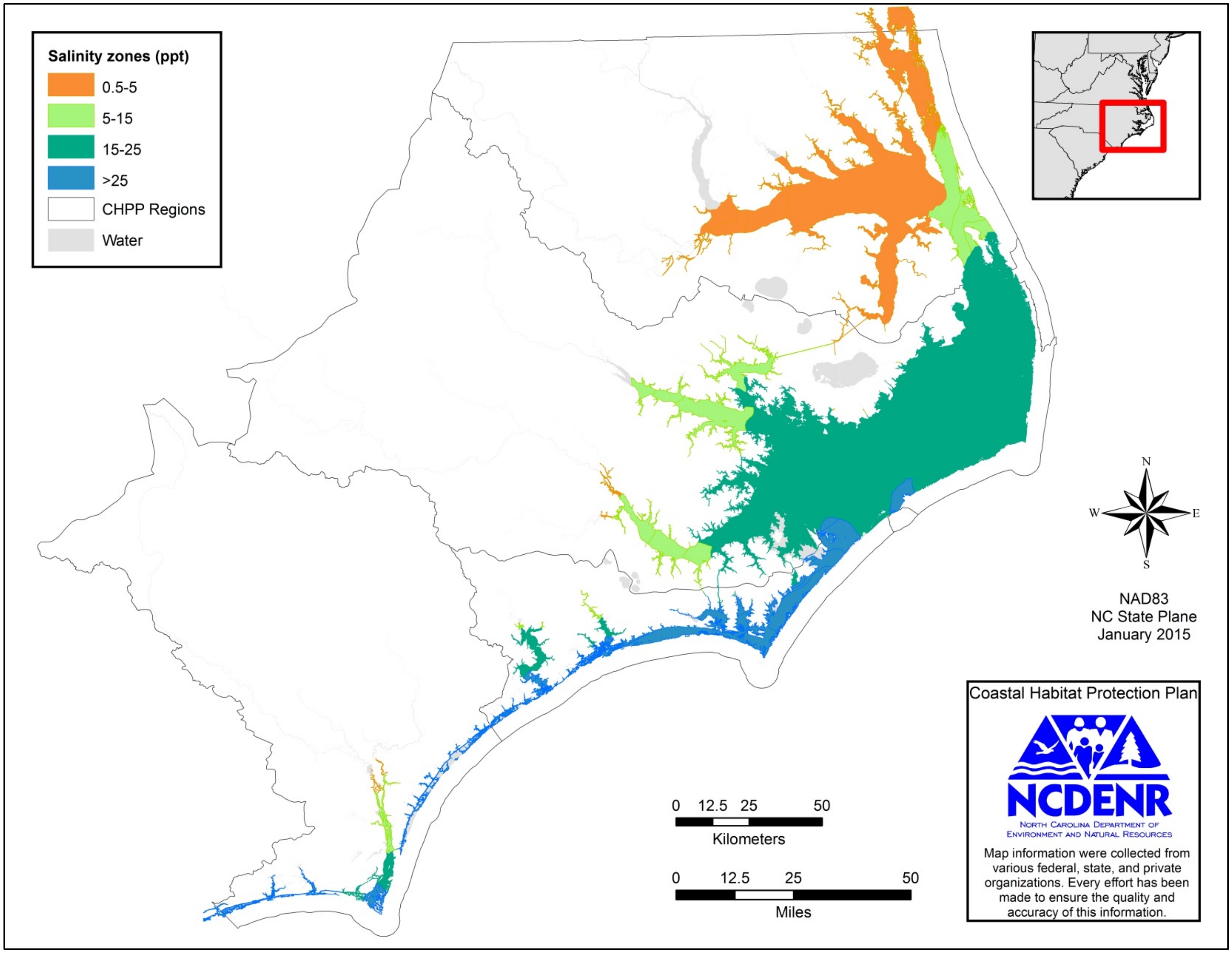
The water column connects all fish habitats, emphasizing the need for ecosystem management in aquatic systems. Environmental conditions of the water column, including salinity, temperature, flow, pH, nutrients, and DO, are the primary factors determining the distribution and abundance of coastal fish species and communities. Seasonal and annual variations in these factors are affected by both climatic cycles and anthropogenic stressors.

The status and trends of the water column are described in terms of physical and chemical conditions, indicators of pollution, and status of pelagic fisheries. These parameters can change quickly at a given location, making monitoring of status and trends very challenging. The status and trends in water column condition are evaluated by government and university programs. Monitoring for microbial contamination of shellfish harvesting waters remains the most abundant measure of estuarine water quality, but is limited in parameters monitored.

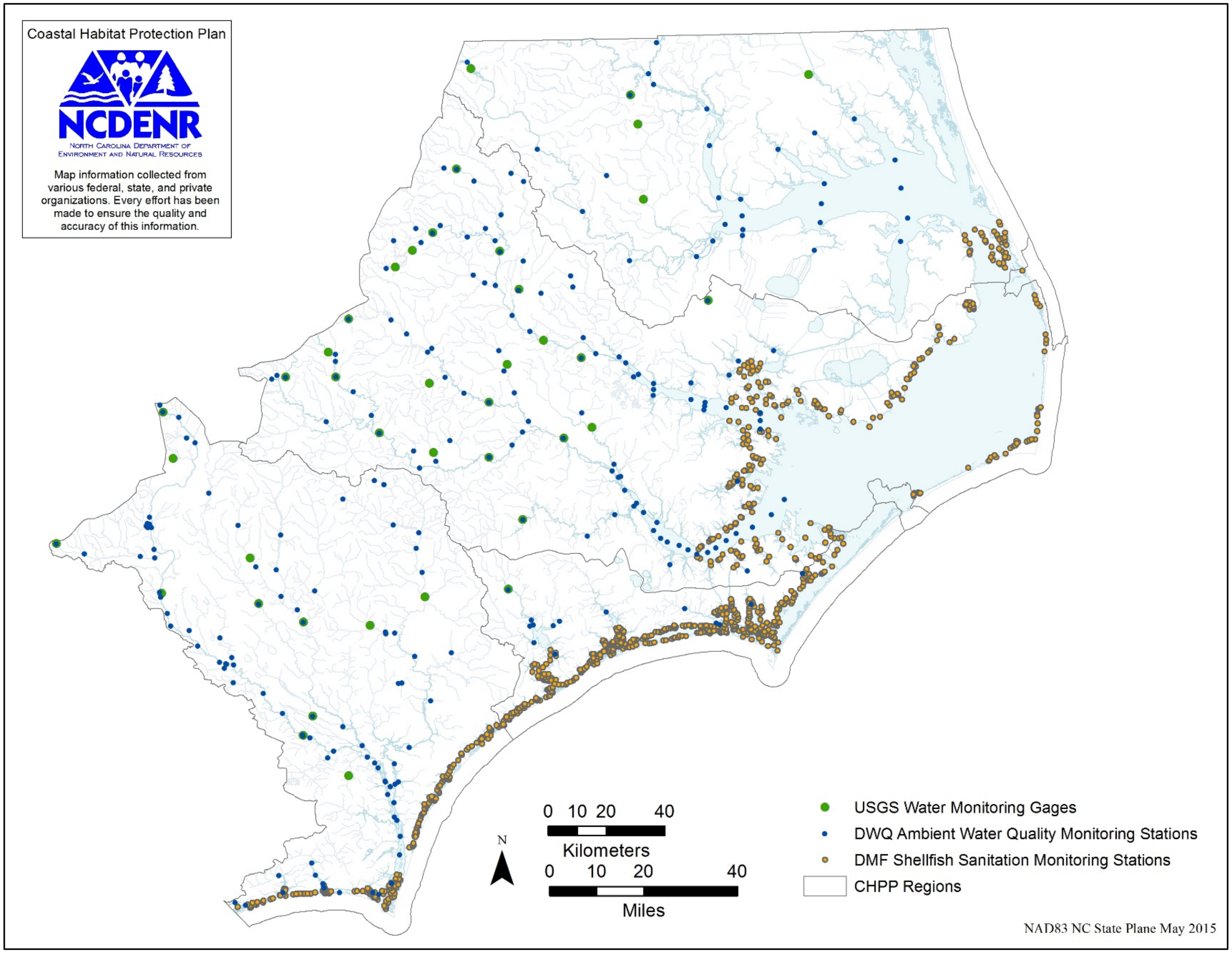
The depleted status of river herring continues to provide a target for restoration and enhancement efforts. The DMF has expanded sampling to evaluate, protect, and enhance potential spawning and nursery areas, and assess blockages of historical spawning habitat throughout the Albemarle Sound and its tributaries. Spawning area surveys were conducted in the Chowan River during the 2008-2013 spawning seasons, as well as the Yeopim River (2007), Meherrin River (2008), Scuppernong River (2009), Mackey's Creek (2009), Perquimans River (2010), Little River (2010), Alligator River (2011), the Roanoke River (2012) and the Pasquotank River (2013).



MAP 2.1A. Winter and spring salinity zones in eastern North Carolina, derived from (Orlando et al. 1994).



MAP 2.1B. Summer and fall salinity zones in eastern North Carolina, derived from (Orlando et al. 1994).



MAP 2.2. Current water quality monitoring stations and 2006 impaired waters in coastal draining river basins of North Carolina.

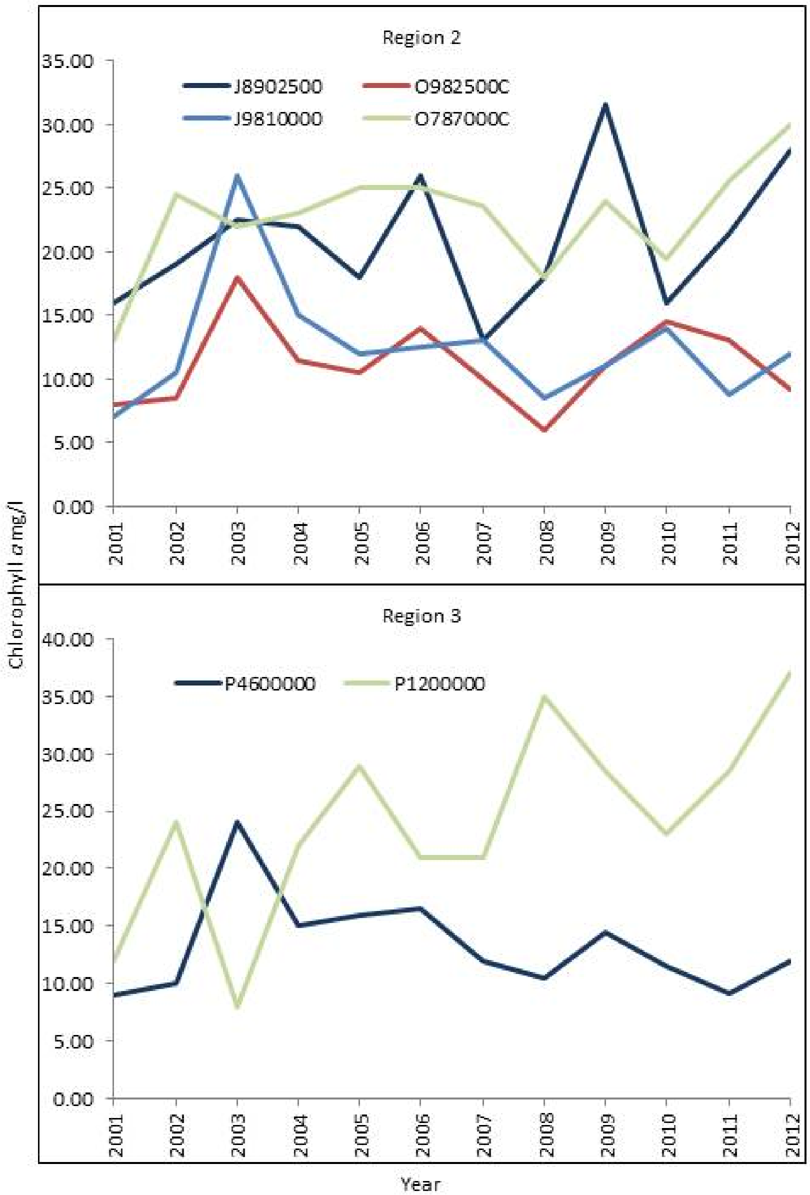


FIGURE 2.4A. Median values of Chlorophyll *a* mg/l from 18 representative DWR ambient stations throughout the CHPP management area. Map 2.1 shows the locations of these representative ambient stations. These graphs are not statistical trends or meant to show standard exceedance, but are generated to show *general* trends over the last ~15 years.

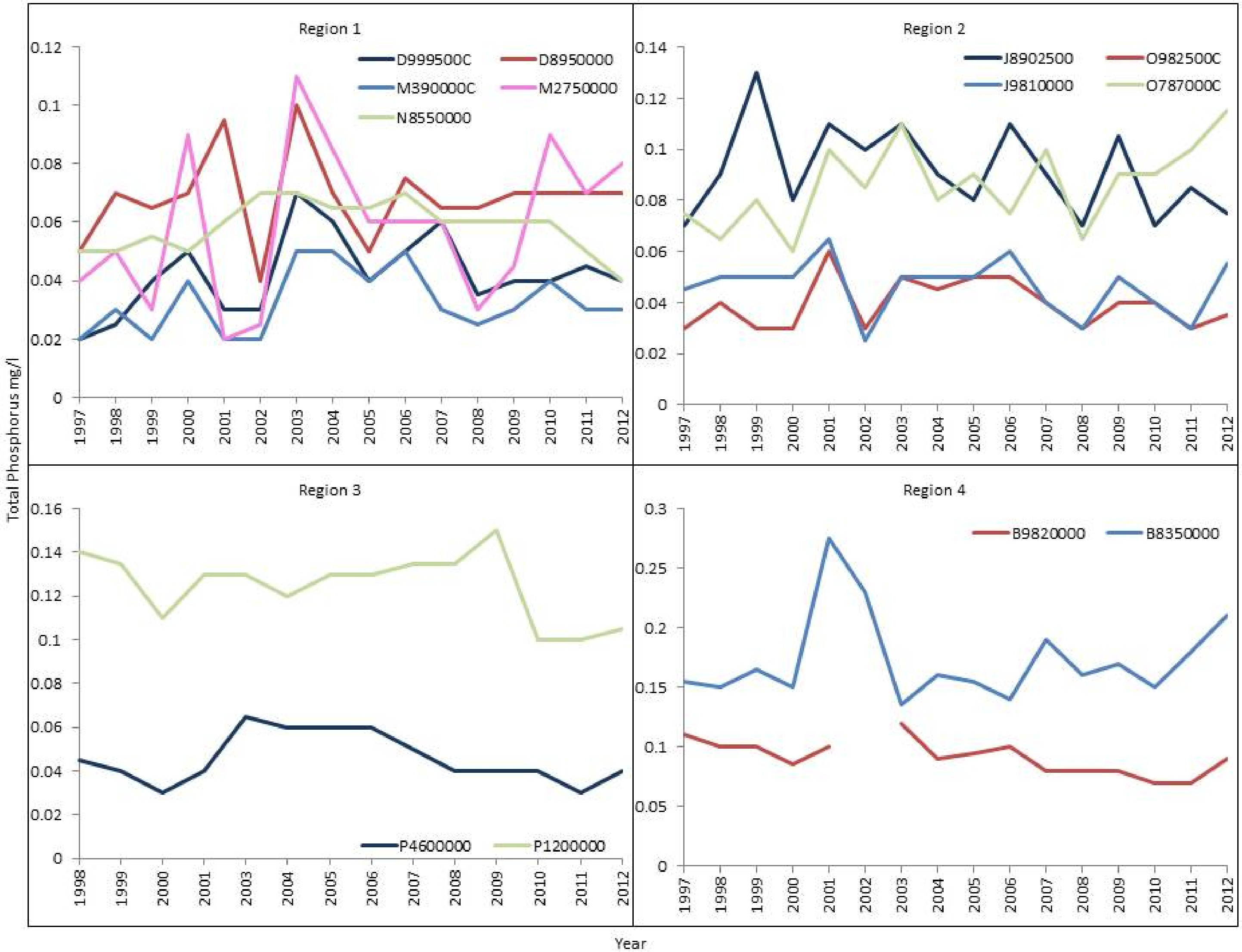


FIGURE 2.4B. Median values of Total Phosphorus mg/l from 18 representative DWR ambient stations throughout the CHPP management area. Map 2.1 shows the locations of these representative ambient stations. These graphs are not statistical trends or meant to show standard exceedance, but are generated to show *general* trends over the last ~15 years.

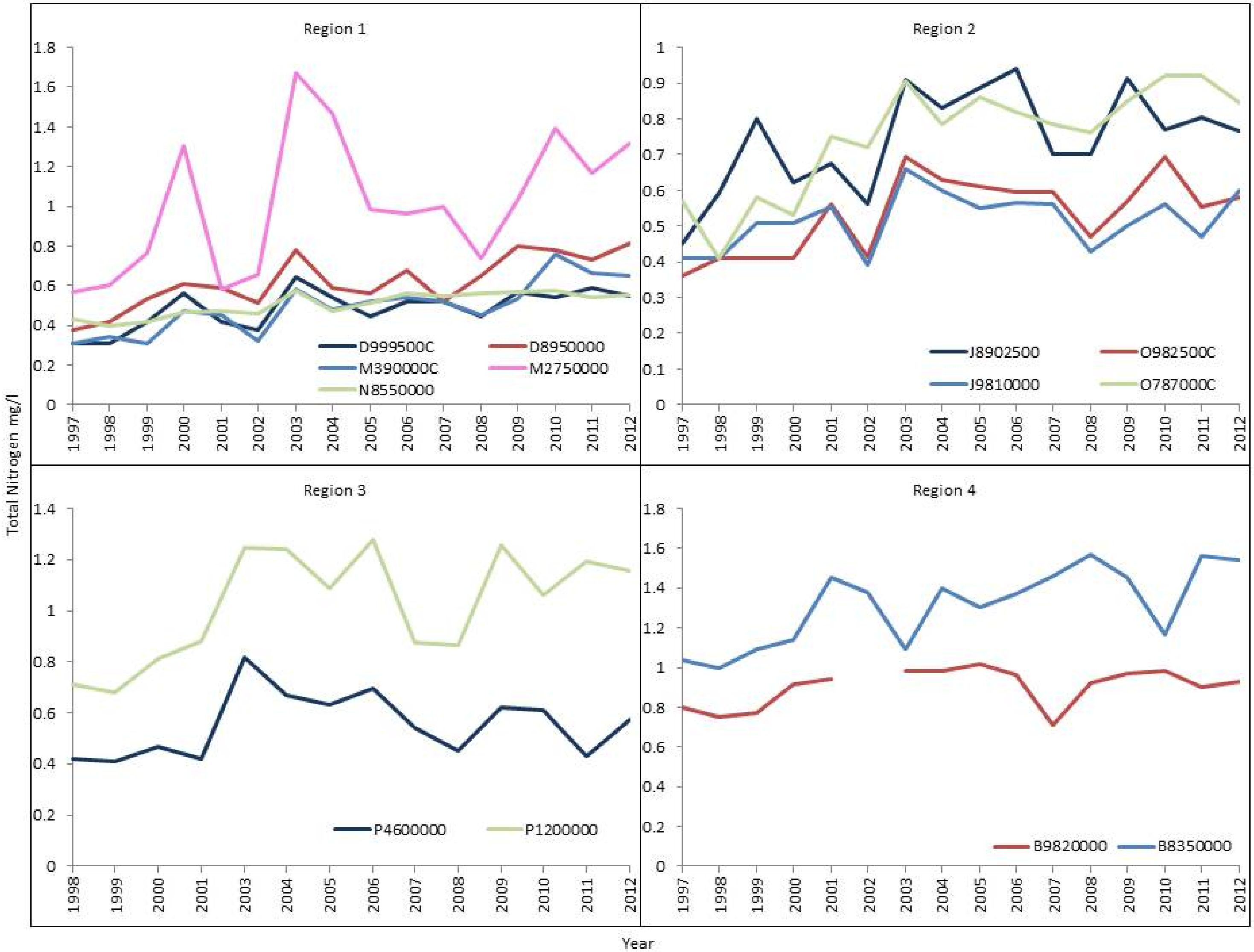


FIGURE 2.4C. Median values of Total Nitrogen mg/l from 18 representative DWR ambient stations throughout the CHPP management area. Map 2.1 shows the locations of these representative ambient stations. These graphs are not statistical trends or meant to show standard exceedance, but are generated to show *general* trends over the last ~15 years.

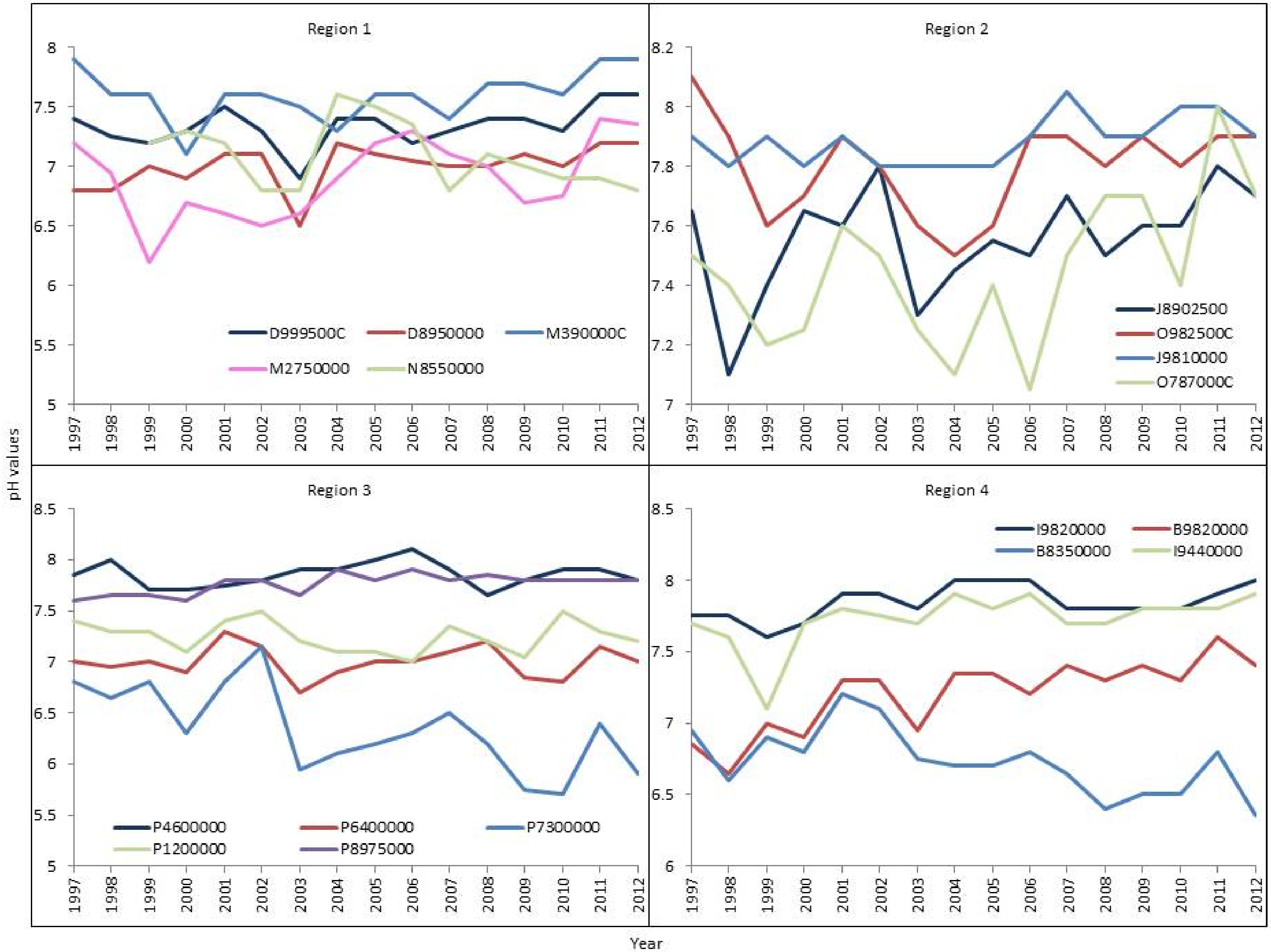


FIGURE 2.4D. Median pH values from 18 representative DWR ambient stations throughout the CHPP management area. Map 2.1 shows the locations of these representative ambient stations. These graphs are not statistical trends or meant to show standard exceedance, but are generated to show *general* trends over the last ~15 years.

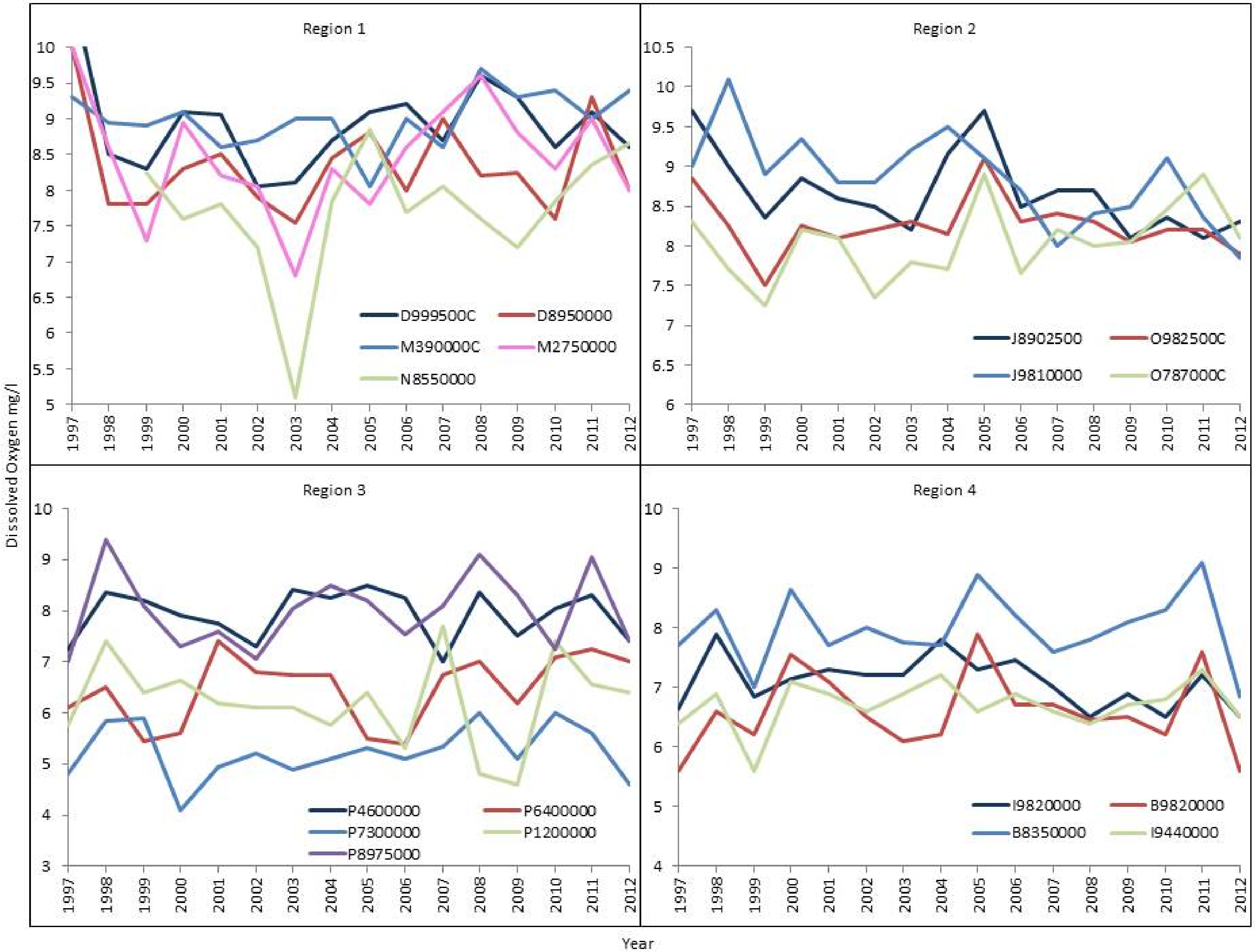


FIGURE 2.4E. Median values of Dissolved Oxygen mg/l from 18 representative DWR ambient stations throughout the CHPP management area. Map 2.1 shows the locations of these representative ambient stations. These graphs are not statistical trends or meant to show standard exceedance, but are generated to show *general* trends over the last ~15 years.

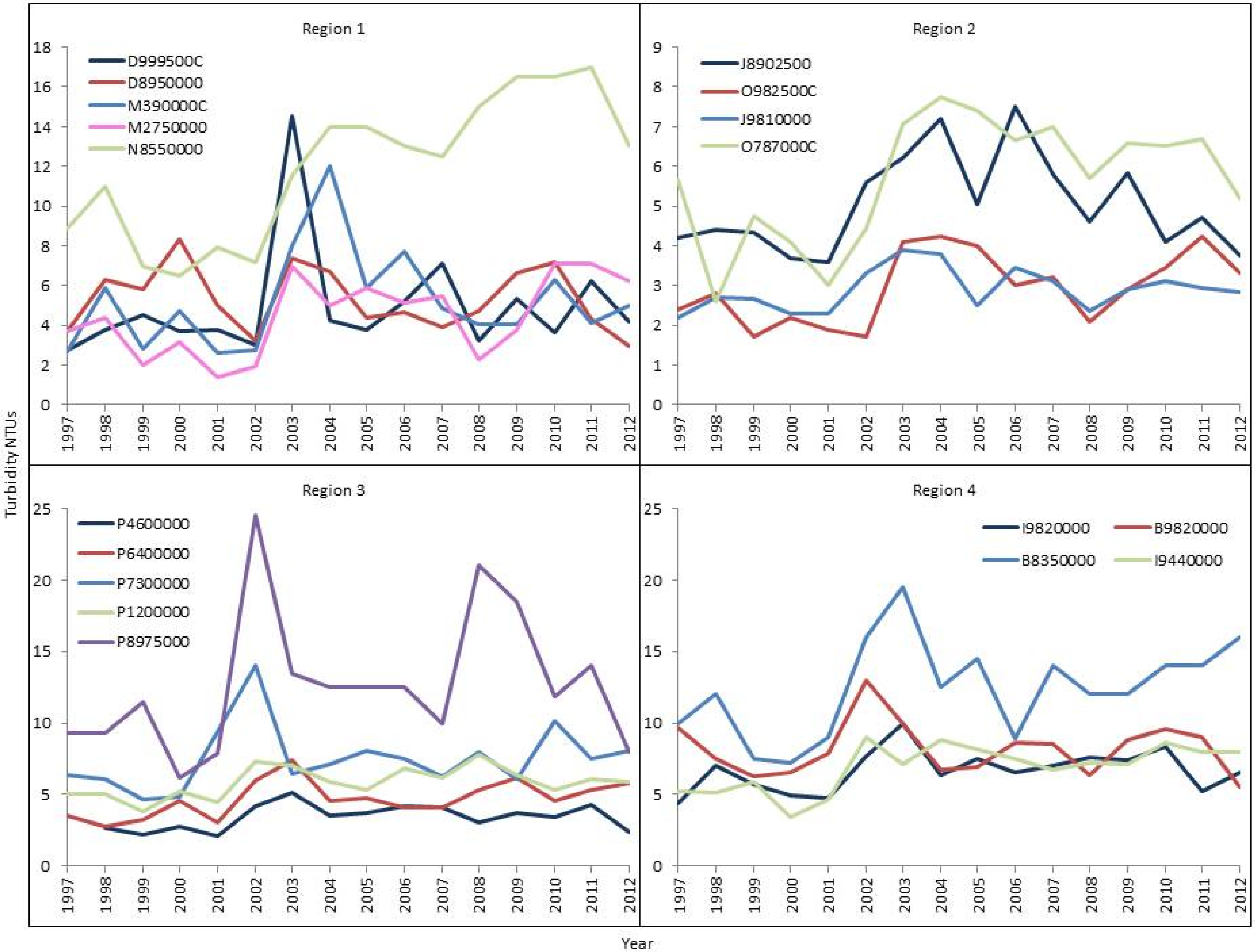


FIGURE 2.4F. Median values of Turbidity NTUs from 18 representative DWR ambient stations throughout the CHPP management area. Map 2.1 shows the locations of these representative ambient stations. These graphs are not statistical trends or meant to show standard exceedance, but are generated to show general trends over the last ~15 years.

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." The definition in this plan is limited to estuarine waters. Although molluscan shellfish are present in freshwater and the nearshore ocean, they occur primarily within the substrate, rather than on the sediment surface, and therefore do not serve as fish habitat.

Shell bottom is especially important for providing hard structure for shellfish attachment, fish refuge and nursery areas, as well as enhancing water quality and protecting nearby shorelines and seagrass from erosion.

Shell bottom habitats are commonly referred to as "oyster beds, rocks, reefs, bars, and shell hash." While most of these terms describe concentrations of living and dead oysters, shell hash refers to an accumulation of unconsolidated shell (oyster, clam, bay scallop and/or other shellfish). Shell bottom is both intertidal and subtidal, and can consist of fringing or patch oyster reefs, surface aggregations of living shellfish, and shell accumulations (ASMFC 2007; Coen et al. 1999). 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 be several meters tall (Lenihan and Peterson 1998). The horizontal extent of shell bottom habitat ranges from a few square meters of scattered shell to acres of living and dead oysters. The habitat can consist of many square miles of shell hash more than a meter deep.

Cultch is the term used for hard material, such as shell hash, oyster rocks, marl, or other materials, that provides oysters and other shellfish with important substratum for settlement, attachment, refuge, and accumulation. Although cultch exists naturally, the Division of Marine Fisheries (DMF) Shellfish Rehabilitation Program uses cultch planting to enhance and restore shell bottom for the purpose of increasing oyster spat and hard clam settlement and survival. Shellfish also use exposed roots at the margin of salt marsh, pilings, seawalls, and rip-rap as attachment sites (DMF 2008a).

Although molluscan shellfish contribute surface shell material to the estuarine environment, oysters dominate shell bottom habitat in North Carolina's estuaries. Oyster beds and rocks are critical habitat for oyster populations, as they provide the most abundant and preferred substrate for larval settlement (DMF 2008a; Kennedy 1996; Marshall 1995). While oysters colonize a widely within the estuary, their distribution and abundance is generally limited by ambient physicochemical conditions. Optimal growth conditions for adult oysters and 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 DO levels above 1-2 mg O_2/l (Funderburk et al. 1991). Studies have found that the combination of low salinities and high temperatures increase oyster mortality (Funderburk et al. 1991; Loosanoff 1953), while predation rates are highest in near seawater conditions (Bahr and Lanier 1981; Gunter 1955). The combination of these two factors effectively concentrates subtidal oysters in moderate salinity areas. Intertidal oyster growth and distribution is less influenced by predation and more by exposure, tidal flows and food availability.

Concentration of DO is critical for oyster survival, influencing viable reef distribution. While oysters can survive for up to five days in waters with < 1 mg O_2/l (Sparks et al. 1958), hypoxic (<2mg/l) and anoxic conditions result in sublethal stress and mass mortality (Lenihan and Peterson 1998; Seliger et al. 1985).

Turbidity and circulation patterns affect oyster survival, viability and species abundance (Thomsen et al. 2007a). Oyster eggs experience significant mortality at suspended sediment concentration levels of approximately 188 mg/l, while significant larvae mortality starts at 750 mg/l (Davis and Hidu 1969). Good water circulation is critical for larval dispersal and successful spat settlement (Burrell 1986). Adult oysters require adequate circulation to deliver food and oxygen and remove wastes and sediment. For subtidal oyster reefs, the vertical height of the rock maximizes circulation by elevating oysters off the bottom, avoiding anoxic water (Lenihan and Peterson 1998) and sedimentation (Coen et al. 1999).

3.1.2. 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 the West Indies (Bahr and Lanier 1981; Carlton and Mann 1996; Jenkins et al. 1997). To the degree commercial fishery landings indicate abundance, the highest documented oyster abundance along the Atlantic coast is in the Chesapeake Bay (DMF 2001c). Historically, Maryland's landings of 15 million bushels dwarfs North Carolina's highest landing of 1.8 million bushels in 1902 (DMF 2001c).

Oysters are found throughout the North Carolina coast, from southeast Albemarle Sound to South Carolina (DMF 2001c). Reefs occur at varying distances upstream depending on salinity, substrate, and flow regimes. In wind-driven Pamlico Sound, north of Cape Lookout, oyster reefs consist largely of subtidal beds. South of the cape, subtidal rocks occur in the New, Newport, and White Oak Rivers (DMF2001c). Extensive intertidal beds occur in the southern estuaries, with ample lunar tides. Plentiful shell hash exists in New River, eastern Bogue Sound, and stream and channel edges. In the Albemarle-Pamlico estuary, oysters are concentrated in the lower portion of Pamlico Sound tributaries, along the western shore of Pamlico Sound, and behind the Outer Banks (Epperly and Ross 1986)(Map 3.1).

The DMF Shellfish Habitat and Abundance Mapping Program began collecting data for the creation of detailed bottom type maps of the estuarine system in 1988. Standardized survey methods are used to compile maps from the South Carolina border through Core Sound, along the perimeter of Pamlico Sound, Lower Neuse River, Lower Pamlico River, Pungo River, and Croatan/Roanoke Sounds, in up to 12 ft of water (Map 3.2). Military restricted areas, lease areas, and major navigation channels are excluded. The program delineates all bottom habitats with surveys, and samples the density of oysters, clams, and bay scallops. The program has differentiated 24 bottom types based on combinations of depth, bottom firmness, vegetation density, and density of shells (surface or subsurface). Shell present strata is defined as significant cover (>30%) of living or dead, on the surface or in the substrate. Other habitats mapped by the program include salt marsh (fringe shellfish habitat) SAV, and soft bottom. A stratified random sampling design is used to provide statistically valid shellfish density estimates by area and habitat.

In 2005, DENR, seeking to implement the CHPP recommendation to accelerate and complete shellfish mapping, was able to secure four new shellfish mapping technician positions and a GIS analyst. Budget cuts since 2011 have reduced mapping staff and resources. The program continues to map habitat, although not at the rate it did from 2005-2011. The DMF plans mapping of Pamlico Sound subtidal beds with depths >12 feet, using acoustic sonar technology, when funding and manpower become available.

As of July 2014, 94% (590,730.15 acres of the 619, 641.85 acres within the area intended for mapping) were completed. A total of 8,154 acres remain to be mapped in Hyde County around West Bluff Bay and Wysocking Bay. In Brunswick County, from Dutchman Creek into the Cape Fear, and New Hanover County, 12, 680 acres remain to be mapped. It is currently estimated that approximately 1,433 acres within the Cape Fear will not be mapped due to depth and other restrictions within the main channel.

Of the area mapped, approximately 21,221 acres (3.6%) of benthic habitat was classified as shell bottom (Table 3.1 and Maps 3.3a-c). The Cape Fear subregion had the greatest relative area of shell bottom (9.9% - mostly intertidal) and subtidal shell bottom (6.8%) among the areas mapped to date. The largest acreage of subtidal shell bottom was in Core/Bogue (9,230 ac), followed by the Pamlico systems (3,877 ac), and Cape Fear (2,428 ac). The majority of intertidal shell bottom was mapped in the Cape Fear (3,539 ac) and Core/Bogue (1,455 ac) subregions. Estimated densities of living shellfish on shell bottom are shown on Maps 3.3a-c. The shellfish densities sampled in shell present strata/area combinations were applied to the entire strata within an area.

TABLE 3.1. Shell bottom habitat (DMF Shellfish Habitat and Abundance Mapping Program, CHPP subregions 10/14).

				Mapped Shell Bottom (subtidal)		Mapped Shell Bottom (intertidal)		Total Shell Bottom
CHPP Subregions**	Acres Intended for Mapping	Acres Mapped*	% Mapped	Acres	% of Mapped	Acres	% of Mapped	Acres
Albemarle (1)	63,111	63,110	100%	571	0.90%	44	0.07%	615
Pamlico (2)	290,404	281,945	97%	3,877	1.38%	77	0.03%	3,955
Core/Bogue (3)	217,478	209,869	97%	9,230	4.40%	1,455	0.69%	10,685
Cape Fear (4)	48,648	35,807	74%	2,428	6.78%	3,539	9.88%	5,967
Total	619,642	590,730	95%	16,106	2.73%	5,115	0.87%	21,221

*Excludes areas that cannot be mapped due to military prohibitions, leases, bridge restrictions, depths, hazards.
** Oregon Inlet acres included in Albemarle Region; Ocracoke Inlet acres included in Core/Bogue Region.

3.2. Ecological role and functions

3.2.1. Productivity

Primary production (plants that produce their own food source) on shell bottom comes from macroalgae, microphytobenthos, and organic biofilms, providing food for resident secondary consumers. The low primary productivity on oyster reefs reflects the importance of exogenous sources of primary production, like phytoplankton. Analyses of estuarine habitat productivity ratios indicate secondary production (organisms that consume primary producers) on oyster reefs is an order of magnitude greater than in *Spartina* marshes, soft bottom, SAV, and mangrove forests (English 2009), attributable to the high biomass of oysters and other macroinvertebrates inhabiting the reefs. Also, tertiary production of nektonic organisms is found to be > twice higher on oyster reefs than in *Spartina* marshes, soft bottom, and SAV, indicating the importance of this habitat for higher order consumers.

3.2.2. Fish utilization

Shell bottom is widely recognized as essential fish habitat (EFH) for oysters and other reef-forming mollusks (ASMFC 2007; Coen et al. 1999). The functional value for oysters includes aggregation of spawning stock, chemical cues for successful spat settlement, and refuge from predators (Coen et al. 1999). In addition to its role as EFH for oysters, shell bottom provides critical fisheries habitat for ecologically and economically important finfish, mollusks, and crustaceans. The net dollar benefit to recreational fishing derived from oyster reef restoration in the Chesapeake Bay in 2004 was valued at $640,000/year by (Hicks et al. 2004). In North Carolina, 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 (ASMFC 2007; Coen et al. 1999; Grabowski et al. 2005; Lenihan et al. 2001; Peterson et al. 2003b). The list includes 12 ASMFC-managed and seven SAFMC-managed species, suggesting the importance of this habitat for recreational and commercial fisheries. The most abundant species on oyster reefs are generally small forage fishes and crustaceans, such as pinfish, gobies, grass shrimp, and mud crabs (ASMFC 2007; Minello 1999; Plunket and La Peyre 2005; Posey et al. 1999), which are important prey for larger recreationally and commercially important fishes. Studies have shown that shell bottom supports a greater abundance and/or diversity of finfish and crustaceans than unstructured soft bottom (Grabowski and Peterson 2007; Nevins et al. 2013).

Fish that utilize shell bottom can be classified into three categories: resident, facultative resident, and transient (ASMFC 2007; Coen et al. 1999; Lowery and Paynter 2002). Resident species use shell bottom as their primary habitat for breeding, feeding, and refuge. Facultative resident species are generally associated with structured habitats such as shell bottom, and depend on it for food. Transient species are wide-ranging, using shell bottom for refuge and foraging, but do not depend upon the habitat. While reef residents often dominate in abundance, transients are frequently the most diverse. Peterson (2003a) estimated fish production that shell bottom and adjacent soft bottom provide. Using results from many studies, they compared density of fish at different life stages on oyster reefs and adjacent soft bottom. The results grouped species by category: recruitment enhanced, growth enhanced, and not enhanced (relative to soft bottom). The results are discussed in the nursery and foraging sections. Table 3.2 provides a partial list of finfish and macroinvertebrates documented from shell bottom collections. Species using shell bottom as spawning, nursery, foraging, or refuge are identified.

3.2.3. Ecosystem enhancement

Oysters are considered an ecosystem engineer, building shell bottom habitat that provides multiple ecological services. Grabowski et al. (2012) estimated the economic value of these ecosystem services, excluding the value of oyster harvest, to range from $5,500 to $99,400/ha/yr ($2,200 to $40,200/ac/yr).

3.2.3.1. Water quality enhancement

Shell bottom provides direct and indirect ecosystem services through water filtration, benthic-pelagic coupling, and sediment stabilization (ASMFC 2007; Coen et al. 2007; Coen et al. 1999; Newell 2004). The filtering activities of oysters and other suspension feeding bivalves remove particulate matter, phytoplankton, and microbes from the water column (Coen et al. 2007; Coen et al. 1999; Nelson et al. 2004; Wall et al. 2008; Wetz et al. 2002). Organisms attached to shell bottom, such as tunicates, sponges, and barnacles, are often suspension feeders, contributing to the water filtration capacity (ASMFC 2007). A North Carolina study documented that small-scale additions of oysters to tidal creeks can reduce total suspended solids (TSS) and chlorophyll *a* concentrations downstream of transplanted reefs (Nelson et al. 2004). Laboratory research supports this, finding that in mesocosms, environmentally realistic densities of oysters, hard clams, and blue mussels (*Mytilus edulis*) increase light penetration and lower chlorophyll *a* concentrations, facilitating the growth of SAV (Wall et al. 2008).

Modeling the effects of oyster filtration on water quality in the Chesapeake Bay suggest that oysters play an important role in determining clarity, phytoplankton biomass, and DO dynamics (Cerco and Noel 2007; Newell and Koch 2004). These studies determined 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) concluded similarly that modestly increasing oyster biomass in Chesapeake Bay would reduce suspended sediment by an order of magnitude, and increase the predicted depth for SAV growth. They found that the influence of hard clams on reducing turbidity was much less, due to a lower weight-specific filtration rate. The water quality models and *in situ* measurements of filtration capacities has led some researchers to conclude that oysters exert top-down grazer control of phytoplankton blooms (Cerco and Noel 2007; Coen et al. 2007; Newell and Koch 2004), while others question the validity of this conclusion (Fulford et al. 2007; Pomeroy et al. 2006). Still, filtration by oysters is demonstrated to improve water quality and clarity in both laboratory and field settings (Coen et al. 1999; Newell 2004; Wall et al. 2008; Wetz et al. 2002).

Shell bottom enhances water quality through the process of benthic/pelagic coupling (ASMFC 2007; DMF 2008a; Newell et al. 2005; Piehler and Smyth 2011; Porter et al. 2004). Suspension feeding bivalves consume particles excreted as biodeposits, and later suspended in the water column (Newell 2004; Newell et al. 2005; Porter et al. 2004). Nitrogen (N) and phosphorous (P) in biodeposits can become buried or lost via bacterially mediated nitrification-denitrification (Newell et al. 2002; Newell et al. 2005; Porter et al. 2004). The net ecosystem loss of N and P results in bottom-up control of phytoplankton production through alterations in nutrient regeneration processes (Newell 2004; Newell et al. 2005). Bivalve biodeposits can be released into the water by erosion, sediment reworking, or resuspension with possible uptake by SAV and phytoplankton (Newell 2004; Peterson and Peterson 1979).

Removal of nitrogen from the water column is a key ecosystem service provided by shellfish (Kellogg 2013; Piehler and Smyth 2011). On Virginia's Eastern Shore Kellogg (2013) found that oysters could denitrify 543 pounds of N/yr, converting it to harmless gas. This was the highest rate ever found in a natural system, and one of the highest in any marine environment. This research was unique in not being limiting to the sediment and oyster wastes therein, but being inclusive of the entire reef community. The conclusion was that the reef system processed 30 to 40 times more in terms of nutrients than the sediments alone. In North Carolina, Piehler and Smyth (2011) compared the ability of estuarine habitats to denitrify the water column. Their results showed that nitrogen removal was greatest in structured habitats, such as oyster reefs. Rates of denitrification by oyster reefs were similar to that of SAV and marsh, and highest in the summer and fall when oyster filtration is greatest. The dollar benefit of the nitrogen removal service provided by oyster reefs was estimated to be $2,969/ac/yr (2011 dollars, with a conversion factor to 2014 dollars of $3,167/ac/yr).

3.2.3.2. Habitat Enhancement

The structural relief of shell bottom is important to the estuarine system. As a reef matures, a complex habitat with more height and interstitial space for recruitment is created. Numerous authors describe oysters as ecosystem engineers, recognizing the importance of the biogenic reef to estuarine biodiversity, fish production, water quality, and hydrodynamic processes (Brumbaugh et al. 2006; Dame 2005; Gutierrez et al. 2003; Lenihan and Peterson 1998). High relief shell structures alter current and water flows, and physically trap and stabilize large quantities of suspended solids, reducing turbidity (Coen et al. 1999; Dame et al. 1989; Grabowski et al. 2000; Lenihan 1999). Intertidal shell bottom, protects shoreline from waves and currents, aiding in creek bank stabilization and reduction of marsh erosion (ASMFC 2007; Breitburg et al. 2000; Dame and Patten 1981; Henderson and O'Neal 2003; Marshall 1995; Piazza et al. 2005), often promoting marsh accretion (ASMFC 2007; Meyer and Townsend 2000; Piazza et al. 2005). 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 shorelines without cultch eroded. Other studies in the Gulf of Mexico and along the Atlantic coast have suggested the value of shell bottom for shoreline protection and erosion control (ASMFC 2007; Piazza et al. 2005). Grabowski et al. (2012) valued the erosion control/soil retention of oyster reefs at $87,800/ha/yr.

3.2.4. Specific biological functions

3.2.4.1. Refuge

The complex three-dimensional structure of shell bottom provides valuable refuge for larval, juvenile, and adult finfish and macroinvertebrates (Arve 1960; Breitburg 1998; Coen et al. 1999; Grabowski and Kimbro 2005; Posey et al. 2004), often being the only structural refuge in submerged estuaries (Grabowski et al. 2000). Oyster reefs represent the dominant structural habitat in the mid-intertidal to shallow subtidal zone of estuarine waters where SAV is absent (Eggleston et al. 1998; Posey et al. 1999). The interstitial spaces between and within the shell matrix are critical to the survival of recruiting oysters and small, slow-moving macrofauna, such as polychaete worms, crabs, hard clams, and amphipods (Bartol and Mann 1999; Grabowski and Kimbro 2005; Hughes and Grabowski 2006; SAFMC 1998b; Soniat et al. 2004; Zimmerman et al. 1989). Mud crabs, a dominant component of the oyster reef macrofaunal assemblage, take refuge from oyster toadfish, blue crabs, and wading birds (Grabowski and Kimbro 2005; Meyer 1994), and are important intermediate predators foraging on juvenile hard clams within 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 the reefs for juvenile hard clams and highlighting the complexity of interactions and the significance of shell bottom as refuge (Grabowski and Kimbro 2005). Previous research has documented the importance of shell bottom for predation protection of adult and juvenile hard clams, citing increased survival in shell bottom habitats compared to open soft bottom (Peterson et al. 1995).

Taking advantage of the hard clam-oyster shell relationship, DMF manages intertidal cultch planting sites in the southern area for harvesting both. Once oysters are harvested, the areas are opened for clam harvest by hand gears. Fishermen dig under and around the edge of the cultch material for hard clams that have recruited under the planted shell. In some areas, additional cultch planting creates adjacent habitat areas, and the two-year cycle begins again (DMF 2008a; Marshall et al. 1999).

3.2.4.2. Spawning

Shell bottom resident species, such as oyster toadfish, gobies, grass shrimp, and hard clams, have been documented using oyster reefs for reproduction (Coen et al. 1999; Hardy 1978a; Hardy 1978b; NOAA 2001; Tolley and Volety 2005). Many of these residents use the interstitial spaces as nesting sites and attach their eggs to the shell surface (Coen et al. 1999). Recent research suggests that estuary-spawning transient species use shell bottom for spawning. In the Neuse River estuary, spawning aggregations of red drum and spotted seatrout were found frequently over subtidal oyster beds, while a distinct preference for the habitat over soft bottom was not found (Barrios-Beckwith et al. 2006; Barrios 2004).

3.2.4.3. Nursery

Shell bottom serves as valuable nursery habitat for numerous juvenile finfish and macroinvertebrates (ASMFC 2007; Daniel III 1988; Grabowski et al. 2000; Minello 1999). Species considered "recruitment-enhanced" by shell bottom include stone crabs, sheepshead, blennies, gobies, skilletfish, gray snapper, gag, toadfish, and tautog (Peterson et al. 2003b); both juvenile oysters and hard clams settle on shell bottom (DMF 2008a; MacKenzie 1977; DMF 2008; Nestlerode et al. 2007; Peterson 1982; Wells 1957). Survival of juvenile oysters post-settlement is often higher on oyster shell than 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

(Lowery and Paynter 2002; Minello 1999). Pre-settlement stone crabs key in on the chemical signals and associated biofilms of the oysters as cues for settlement (Krimsky and Epifanio 2008). The nursery 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.

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

3.2.4.4. Foraging

Numerous aquatic organisms use shell bottom for foraging during their life stages (ASMFC 2007; Eggleston 1990; Grabowski et al. 2000; Loosanoff 1965; Mann and Harding 1997). 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. 2003b). 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 (Coen et al. 1999; Eggleston 1990; Krantz and Chamberlin 1978; Menzel and Hopkins 1955; Posey et al. 2004). 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, NC, 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 2001b; 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 (ASMFC2007).

3.2.4.5. Corridor and Connectivity

Shell bottom has been shown to serve as a corridor to other habitats, such as salt marsh and SAV, for finfish and macroinvertebrates (Coen et al. 1999; Grabowski et al. 2000; Micheli and Peterson 1999). 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 (Grabowski et al. 2000; Micheli and Peterson 1999).

In 2005, McCormick-Ray (2005) looked at the connections associated with historical oyster reefs in the Chesapeake Bay. In his research, he found that fishes display varying degrees of fidelity to oyster reefs, broadly categorized as residents, facultative residents, and transients (Coen et al. 1999). Resident oyster toadfish attach eggs to oyster shells and may show fidelity to a particular bed. Facultative residents, on the other hand, appear to remain on beds for several months. Highly motile transients, adults, and juveniles of a variety of species, move among beds with uncertain fidelity, as in the case of striped bass and bluefish (Harding and Mann 2001a). The naked goby is an example of a resident species. The spot is an example of a transient species that forages on the reef (McCormick-Ray 2005).

Oyster beds of diverse shape and size, positioned in the path of tidal flows, attract biological activity that couple primary production from other organisms into food webs. From their studies, Lenihan et al. (2001) have suggested an oyster bed-based food web for fishes and invertebrates, where oysters, mussels, crabs and shrimp are at the base. Oysters filter small diatoms, bacteria, and detritus from the water column, as do associated filter feeders, e.g., barnacles, tunicates, hydroides, bryozoans, and sponges, transferring pelagic production to the benthos. Species of decapods and fish occur more abundantly over oyster beds than adjacent sandflats (Posey et al. 1999).

The abundance of xanthid crabs (mud crabs) (*Panopeus herbstii* and *Eurypanopeus depressus*) that inhabit the intertidal North Carolina oyster reefs seek refuge in oyster shells, the former exploiting the sub-surface stratum and the latter exploiting the surface shell clusters (Meyer 1994). In the Gulf of Mexico, decapod assemblages associated with oyster beds form distinct populations from those in seagrass and marsh edge habitat (Glancy et al. 2003). Thus, oyster beds couple seasonal primary production and primary consumers to numerous estuarine feeders including various fishes, potentially influencing energy transfer efficiencies and community metabolism (McCormick-Ray 2005).

Learning about the role played by the matrix of oyster beds can help in restoration planning of reef size, shape and arrangement, and number of corridors, to optimize recruitment, retention, and dispersion of larvae, as well as adult oyster survival and growth. Understanding how reef characteristics influence detrital delivery, water clarity, anoxia, and fish use can aid in managing the overall habitat, as well as enhancing adjacent habitats. Given the importance of the information and the role played by reef habitat, there is a paucity of information documenting the corridor function of shell bottom habitat.

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, change in recruitment indices (spatfall), and water quality trends where shell bottom occurs.

During the colonial period in the Mid-Atlantic, oyster reefs occurred so extensively that they were a hazard to navigation (Newell 1988). Street et al. (2005) and DMF (2008a; 2001c) 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 differ today, 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.” While Winslow estimated 553 acres of oyster beds in the North River, the DMF Shellfish Mapping Program delineated 443 acres of shell habitat in the intertidal and subtidal zones of North River areas in the early 2000s (B. Conrad, DMF, pers. com. 2014).

In Pamlico Sound, changes in the abundance of oyster rocks since the 1880s were documented by Ballance (2004). Using new technologies to locate subtidal reefs reported by Winslow (1889), Ballance found many once-productive high profile reefs consisted of low profile shell rubble, low density reefs, or buried reefs. Ballance (2004) also found that the larger solid reefs had less live oysters, attributed to the ease of locating by fishermen. Division work and anecdotal information have noted that sediment has buried oysters in some locations that were once abundant, including the northeast side of the Neuse River, and Newport and North rivers (N. Lindquist, UNC- IMS, pers. com. 2014).

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

Species	Shell bottom functions [1]					Fishery [2]	Stock Status 2014 [3]
	Refuge	Spawning	Nursery	Foraging	Corridor		
ANADROMOUS & CATADROMOUS FISH							
American eel*	X		X	X	X	X	D
Striped bass*			X	X		X	C – Albemarle/Roanoke, V – Atlantic Migratory
ESTUARINE AND INLET SPAWNING AND NURSERY							
Anchovies (striped, bay)*		X	X	X			
Blennies*	X	X	X	X			
Black drum*				X		X	U
Blue crab*	X	X	X	X	X	X	C
Oyster*	X	X	X	X		X	C
Gobies*	X	X	X	X			
Grass shrimp*	X	X	X	X			
Hard clam*	X	X	X	X		X	U
Mummichog	X	X			X		
Oyster toadfish*	X	X	X	X		X	
Red drum*	X		X	X	X	X	R
Sheepshead minnow*		X		X			
Silversides*				X			
Skilletfish*	X		X	X			
Spotted seatrout*				X		X	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							
Atlantic spadefish						X	C [4]
Black sea bass*	X		X	X	X	X	R - north of Hatteras, V - south of Hatteras
Gag*	X		X	X	X	X	C
Gulf flounder						X	
Pigfish*				X		X	
Pinfish*	X		X	X	X	X	
Pink shrimp*	X		X	X	X	X	V
Sheephead*	X		X	X	X	X	U
Spanish mackerel						X	V
Summer flounder	X			X	X	X	V

* Species whose relative abundances have been reported in 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 lack of information. Scientific names listed in Appendix D.

[1] Sources: (Pattilo et al. 1997); (SAFMC 1998b); (Lenihan and Grabowski 1998); (Coen et al. 1999); (Grabowski et al. 2000); (Peterson et al. 2003a); (Barrios 2004); (ASMFC 2007a); A. Barrios, unpublished 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 (DMF 2014).

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

Fishery-dependent harvest data has been an indicator of overall change in oyster abundance. Based on this, North Carolina oyster stocks were in a state of decline for most of the 20th century (DMF 2001c). High landings around 1890 associated with introduction of the oyster dredge were followed by sharp declines around 1918 due to restrictions in dredging and size limits. Data on landings by gear type indicate that between 1887 and 1960, most harvest was done by dredge rather than hand (Chestnut 1955b; DMF 2001c). 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 2001c; Jackson et al. 2001).

After 1991, oyster stocks and harvests from Pamlico Sound began to collapse from disease mortalities and low spawning stock biomass (DMF 2001c). However, harvest of oysters began to rise again around 2002, and the trend has continued (Figure 3.1). Oyster dredges are still used in some central areas, but are not permitted in the southern portion of the state.

Between 1994 and 2013, oyster dredge landings accounted for 1% to 70% of the annual catch. Landings data indicate that since 1997, oyster harvest has fluctuated from approximately 50 to 70 pounds of meat per dredging trip on average (Figure 3.1). While generally increasing, the number of trips taken annually has fluctuated between 1 and 10,663 (there were no landings by mechanical harvest gear for the '95-'96 or '96-'97 seasons due to dermo and major hurricanes (DMF 2008a). Between 2000 and 2013, oyster dredging trips have risen substantially with increasing harvest, as has the number of hand harvest trips. Statistics cannot infer that oyster populations are increasing from harvest data alone.

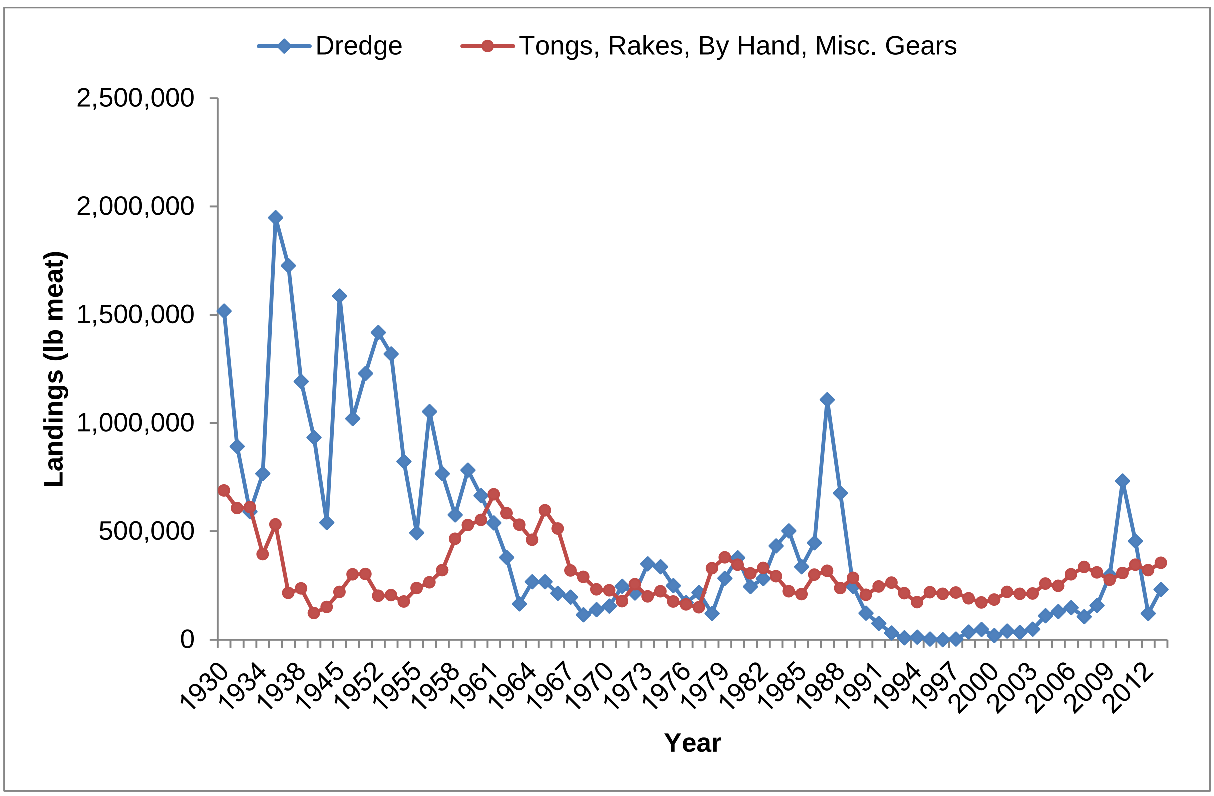


FIGURE 3.1. Commerical oyster landings (in pounds of meat) by gear type from 1930 to 2012, DMF.

During the 1990s, average oyster spat per shell (spatfall) in Pamlico Sound declined considerably, representing less than half the number of spat per shell recorded during the 80s (NCDMF et al. 2008)(Figure 3.2). Since 1999, spatfall has shown a pronounced increase, surpassing 1980s spat densities

(Figure 3.2). Annual spatfall from the Newport River southward was relatively stable from 1987–2000, and has increased similar to the northern area since. There has been no reported decline in spatfall in the southern coastal region, but more information is needed to determine trends in this area over time (R. Carpenter, DMF, pers. com. 2014). The trend of stable or increasing spatfall coastwide is indicative of increasing larval availability, connectivity, and recruitment potential to restored and existing reefs.

Research suggests that continued overall oyster population decline may be explained in part by high incidence of stress from infectious diseases or parasitic organisms, among other contributors (Choi et al. 1994; Dittman 1993; Ringwood et al. 2004). Dermo (*Perkinsus marinus*) and MSX (*Haplosporidium nelsoni*) infection may be responsible for some degree of oyster mortality, typically among the larger, more fecund individuals. High disease incidence and subsequent oyster mortality occurred in Pamlico Sound during the early 1990s, dropping considerably in the following years (NCDMF et al. 2008). These diseases are most prevalent in warm, high salinity waters; some evidence suggests oysters in smaller estuaries have a higher tolerance to infection.

Recent consideration has been given to the marine boring sponge, *Cliona spp.*, in response to increased abundance in Pamlico Sound (J. Peters and M. Jordan, DMF, pers. com. 2015; N. Lindquist, UNC-CH, pers. com. 2015). Erosion of oyster shells from boring sponge parasitism does not cause mortality, though it may induce high levels of stress, which decreases gamete viability and increases susceptibility to disease (Ringwood et al. 2004). Furthermore, bioerosion may compromise structural integrity on individual and reef scales, while also utilizing shell surface area and limiting suitable settlement substrate for recruiting oysters (Barnes et al. 2010; Ruetzler 1975).

The Shellfish Rehabilitation Program, which began in 1947, has contributed to the restoration of depleted oyster grounds through the planting of cultch material and seed oysters (Chestnut 1955b; Munden 1975; Munden 1981). State-sponsored cultch plantings began in 1915. From 1915-1994, about 15 million bushels of oysters were planted in North Carolina waters (Street et al. 2005). The primary purpose of the DMF cultch planting program has been oyster fishery enhancement, which provides temporary habitat value as well as fishery benefits. Recent research showing the important ecological and economic value of oyster reefs prompted DMF to broaden their focus to ecosystem enhancement[4] in the late 1990s.

As of January 2015, there were 13 artificial reef sanctuaries in North Carolina, with 2 more proposed. Ten of these are spread through Pamlico Sound in locations near Hatteras Island, Roanoke Island, Croatan Sound, Pea Island, Swan Quarter, Engelhard, Pamlico Point, Ocracoke, and Point of Marsh. The other three are in Deep Bay near Swan Quarter, Neuse River near Turnagain Bay, and West Bay near Cedar Island. Oyster rocks, as discussed in the Oyster FMP, are protected from mechanical methods of clam harvesting and from the use of bull rakes by MFC Rules T15A NCAC 03K .0304 and 03K .0102.

Since inception of the oyster sanctuary network, one major study has been conducted comparing population demographics among the sanctuaries. At the time of publication, eight of the existing ten sanctuaries expressed nearly 400% increase in population density (Puckett and Eggleston 2012). Density at each sanctuary is variable, ranging from 418.7 ± 82.1 to 6,585.3 ± 204.8 oysters/ m^2, though mean density among sanctuaries was 3,781.7 oyster/m^2 (Puckett and Eggleston 2012). Growth and survival at sanctuaries follows a gradient consistent with, and likely driven by, a persistent salinity gradient present in Pamlico Sound waters (Kennedy et al. 1996b; Lin et al. 2007; Puckett and Eggleston 2012; Wells 1961). Lower salinity (10-18 psu) western Pamlico Sound sanctuaries exhibit higher survival though slower growth rates, whereas eastern Pamlico Sound sanctuaries experience higher salinity (18-26 psu) and

[4]Peterson et al. (2003) estimated fish production that shell bottom adds to soft bottom habitat. Using results from numerous studies, they compared the density of fish adjacent to and on oyster reefs. Analysis revealed an additional yield of 2.6 kg of fish/year for every 10m^2 of constructed oyster reef in the SE US over the lifetime of the reef.

subsequently maintain faster growth rates and lower survival rates (Puckett and Eggleston 2012) (Peters et al. in review). In further analysis of North Carolina sanctuary efficacy, larval connectivity among sanctuaries has been validated, however modeled intrinsic growth rate is unsustainable, suggesting sanctuary network sustainability is dependent on subsidies from non-protected reefs (D. Eggleston and B. Puckett, NCSU-CMAST, pers. com. 2015) (Haase et al. 2012; Peters 2014; Puckett and Eggleston 2012).

Relative to non-protected oyster reefs, North Carolina oyster sanctuaries have demonstrated the capacity to maintain higher population density and greater abundance of large, fecund oysters. There is a striking decrease in densities ranging from no-take to unprotected oyster reefs, with mean oyster density ~72 and 8 times higher in reserves than in natural and cultch-planted reefs, respectively (Peters 2014; Puckett and Eggleston 2012)(Peters et al. in review). Unprotected reefs, in general, exhibit truncated size structure and few oysters of legally harvestable size (75 mm, 3 inches). In combination of size structure, population density, and per-capita fecundity at length, the average reproductive potential per square meter of oyster sanctuaries is up to 30 times greater than unprotected reefs (Peters 2014) (Peters et al. in review). For perspective, an estimated 5,929 ha of unprotected oyster reef exists in Pamlico Sound and at the time of study, 57.18 ha of sanctuary area existed (Peters 2014). Integrating total reef area and reproductive potential per square meter, oyster sanctuaries potentially provide 26.2% of all larvae to the system while accounting for 1% of reef area (Mroch et al. 2012; Peters 2014; Puckett and Eggleston 2012)(Peters et al. in review).

Oyster recruitment (spatfall) on newly deployed shell can be an indicator of potential larval availability and recruitment potential. Average oyster spatfall in the Pamlico Sound area for the 1989–1999 period was less than half the value of the 1979–1988 period (DMF 2008a) (Figure 3.2); data since 1999 show an increase (Figure 3.2). The DMF spatfall data (NCDMF 2014b) for cultch planting sites over the past 31 years indicate a decline in maximum spatfall relative to similar surveys reported by Chestnut (1955b). Some researchers suspect that oysters are becoming spawner-limited, while others attribute the decline to stress and mortality from infectious diseases affecting primarily larger, more fecund adults (Choi et al. 1994; DMF 2008a; Lenihan 1999), or to physical damage from dredging (Marshall et al. 1999).

3.3.2. Status of associated fishery stocks

With the link between fishery species and shell bottom established in Section 3.2, limited inferences can be made using the status and trends of fishery species that are highly dependent on shell bottom habitat (Table 3.2). Unfortunately, the majority of shell bottom loss is thought to have occurred before detailed 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, although there is no monitoring on a regular basis.

In 2014, 36 fishery species and complexes were evaluated for status (DMF 2014). Of the species with a preference for shell bottom habitat and whose status were known, six were designated *Depleted*, 16 were *Concern*, three were *Recovering*, nine were *Viable*. Specifically, American eel, southern flounder, river herring (Albemarle Sound Area), spotted seatrout, Atlantic sturgeon, and weakfish are listed as *Depleted*. *Recovering* species were monkfish, red drum, and black sea bass (North of Hatteras). Listed as species of *Concern* were Atlantic croaker, blue crab, eastern oyster, several sharks, spot, striped bass (Albemarle/Roanoke stock), gag, reef fishes (six species) bay scallop, Atlantic menhaden, and American shad. *Viable* species were bluefish, scup (north of Hatteras), spiny dogfish, striped bass (Atlantic migratory), striped mullet, summer flounder, dolphin, Spanish mackerel, black sea bass (south of Hatteras) and shrimp. Status of the other 6 species, black drum, hickory shad, sheepshead, kingfishes, king mackerel, and hard clam, was *Unknown*.

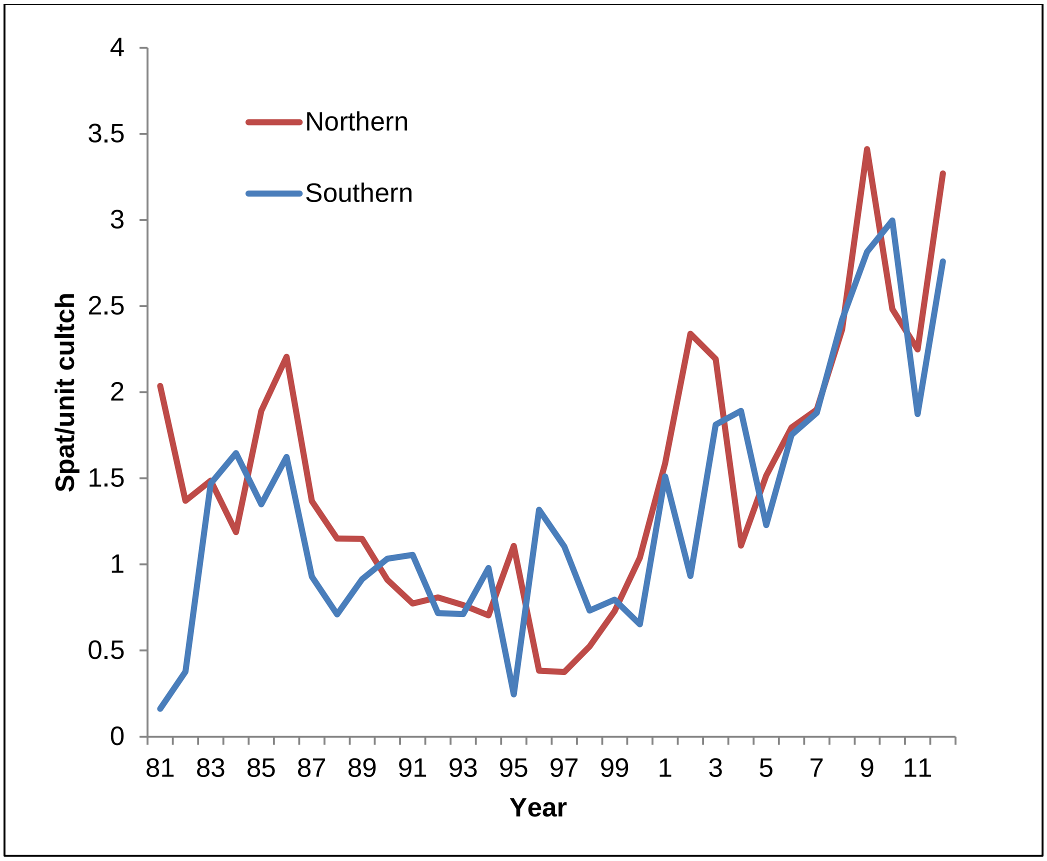
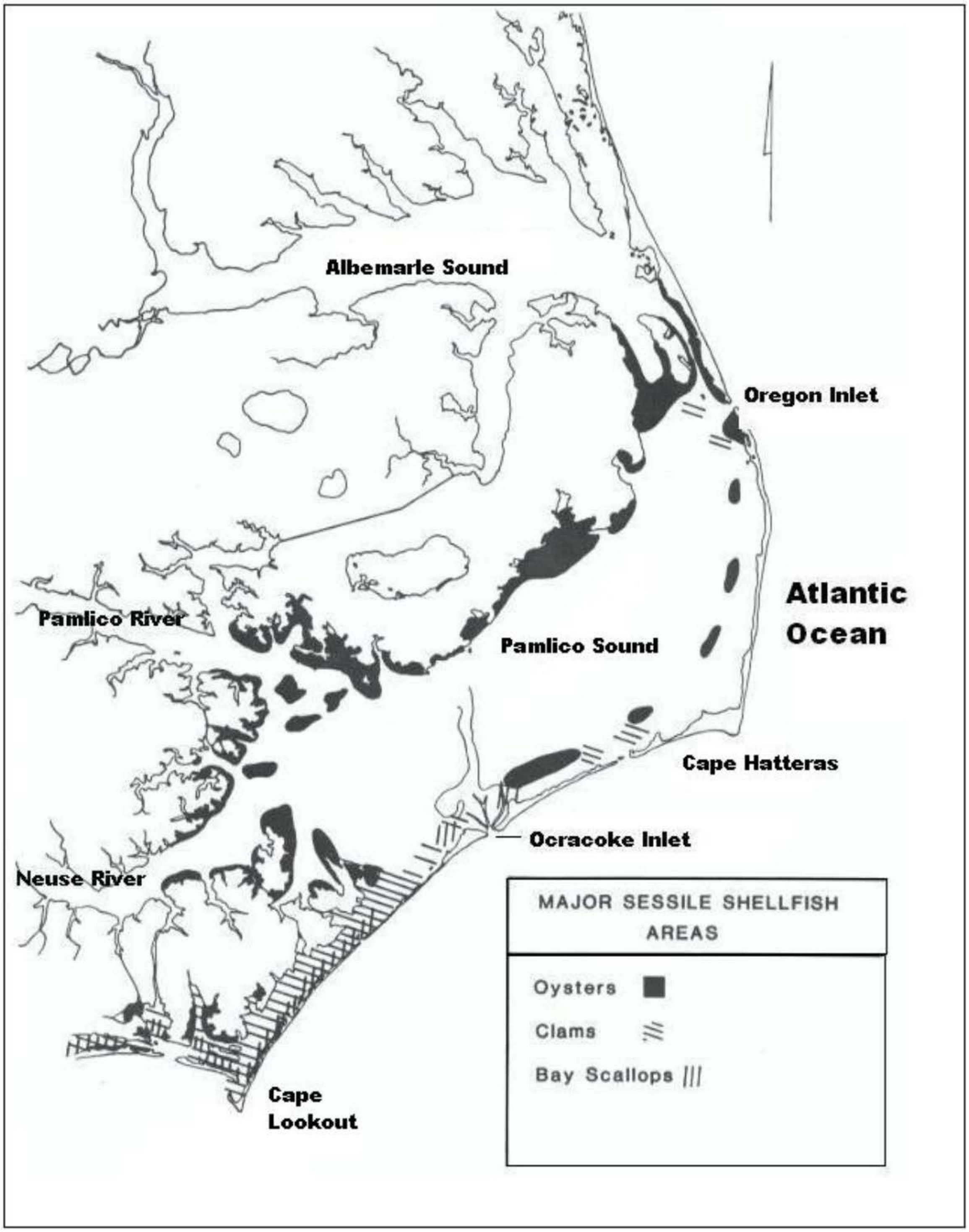


FIGURE 3.2. Average number of attached juvenile oysters (spatfall) per unit cultch (shell), in northern and southern coastal waters (southern district includes from Newport River to South Carolina), 1981-2012.

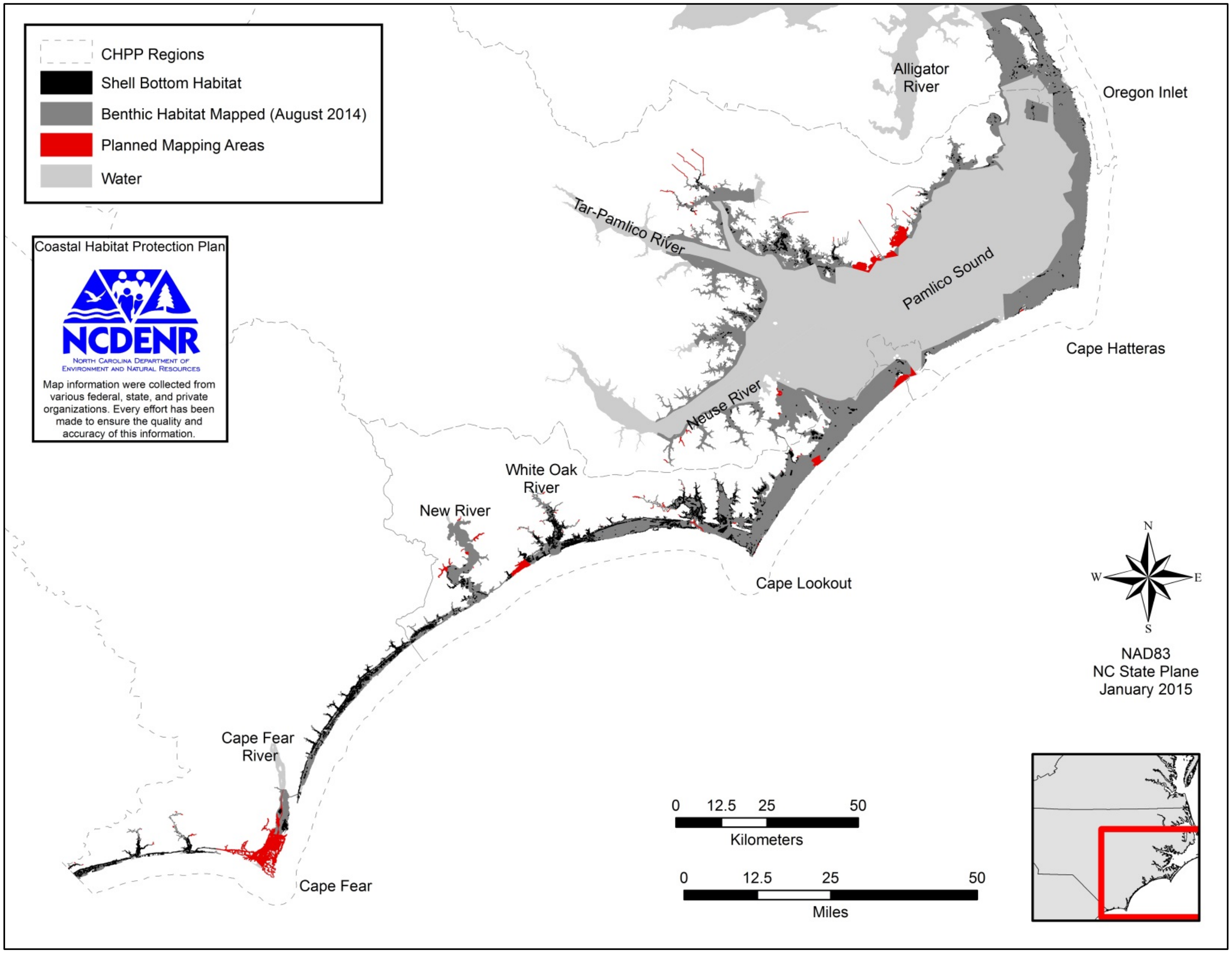
3.4. Shell bottom summary

Shell bottom habitat is unique as it is the only coastal fish habitat that is also a fishery species. Its ecological value has only recently been recognized to be as or more significant than the fishery itself, providing numerous habitat and water quality functions vital for fishery and non-fishery species. Oysters also provide buffering benefits helping establish habitats such as wetlands and SAV.

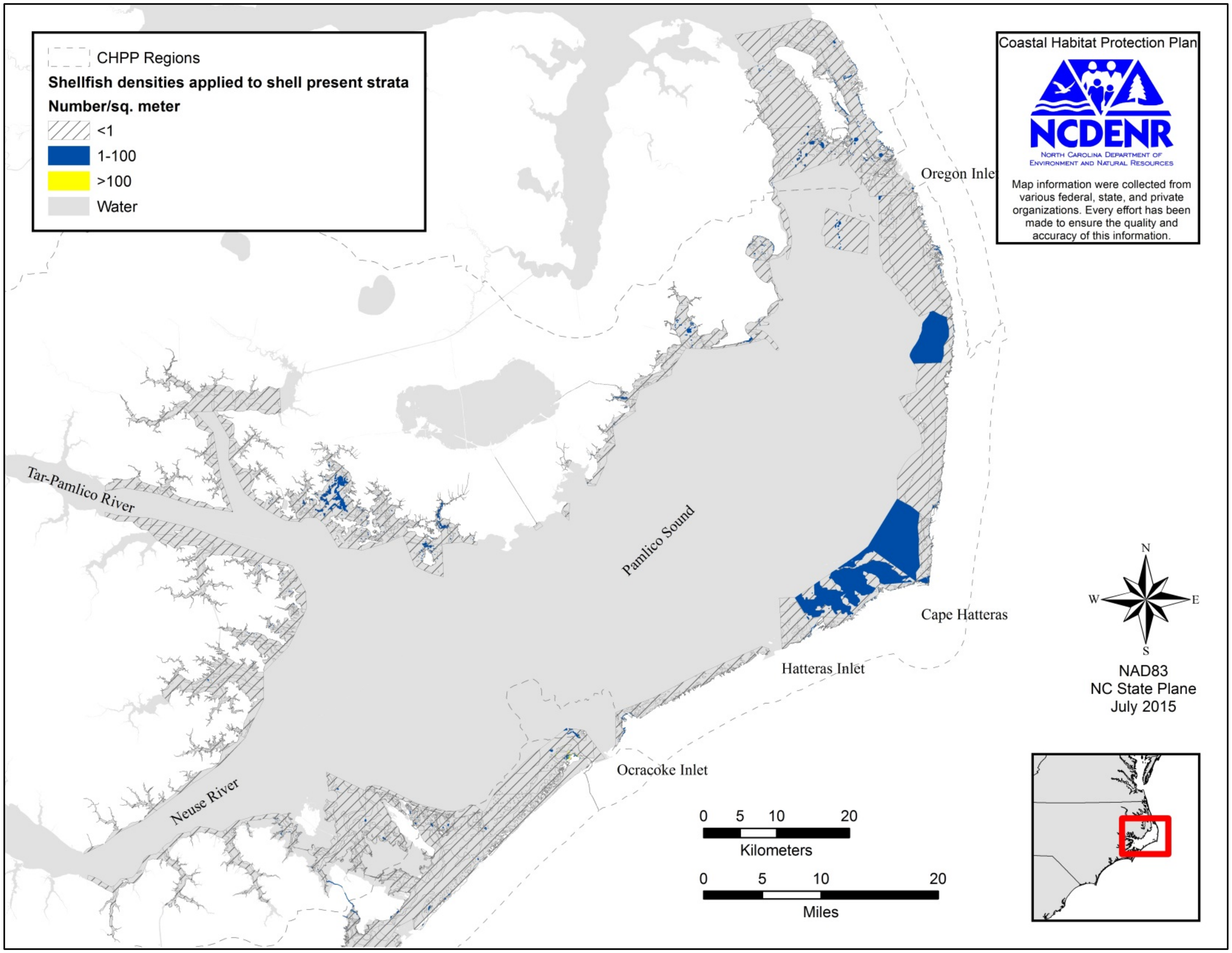
The protection and restoration of living oyster beds is critical to the restoration of numerous fishery species, as well as to the proper functioning and protection of surrounding coastal fish habitats. Efforts to restore oysters began in 1947. Through CHPP implementation, additional funds were allocated to enhance sanctuary development and monitoring. Historically, restoration was managed for oyster fishery enhancement. Current efforts mix fishery and ecosystem enhancement with sanctuary development.



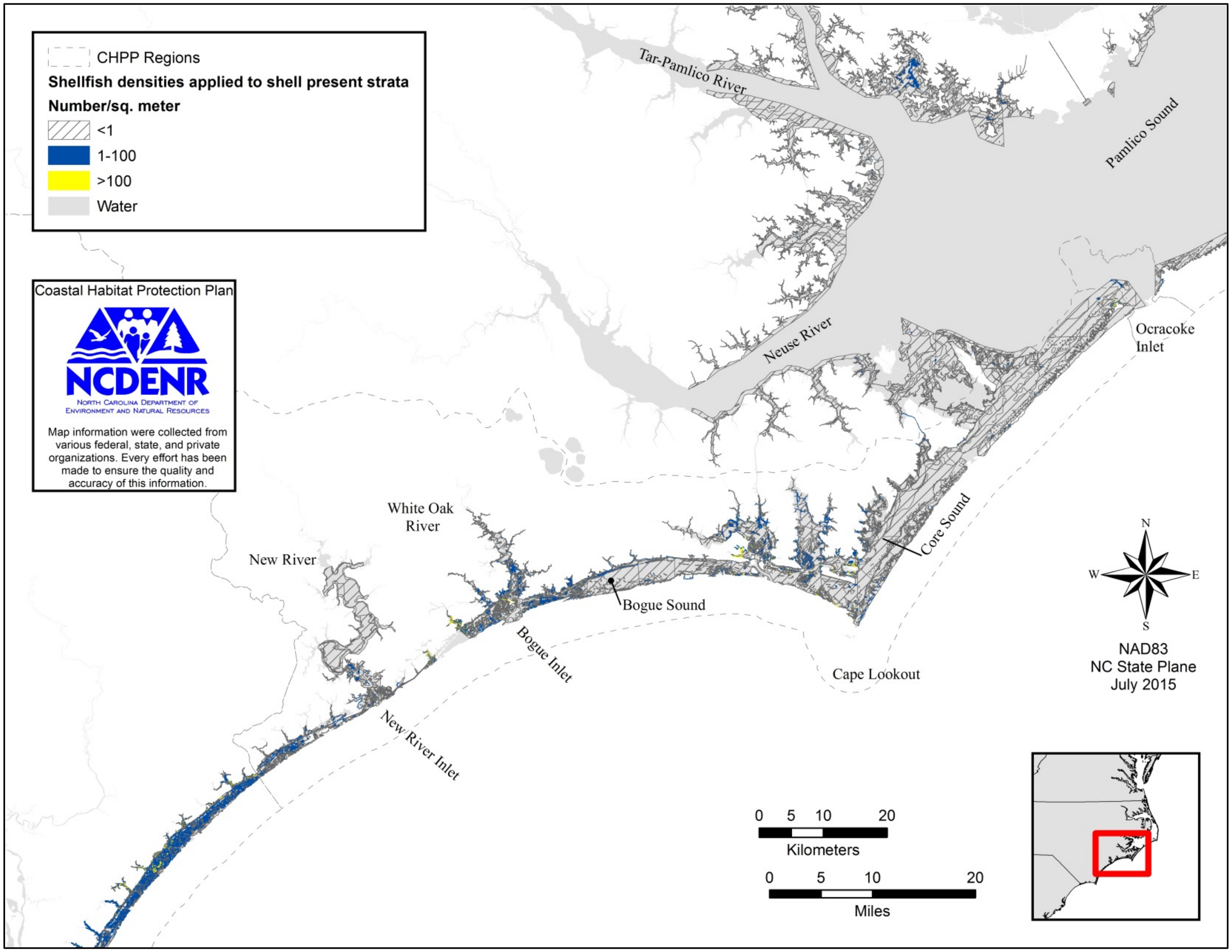
MAP 3.1. General distribution of eastern oysters, hard clams, and bay scallops in the Albemarle-Pamlico estuarine system (Epperly and Ross 1986).



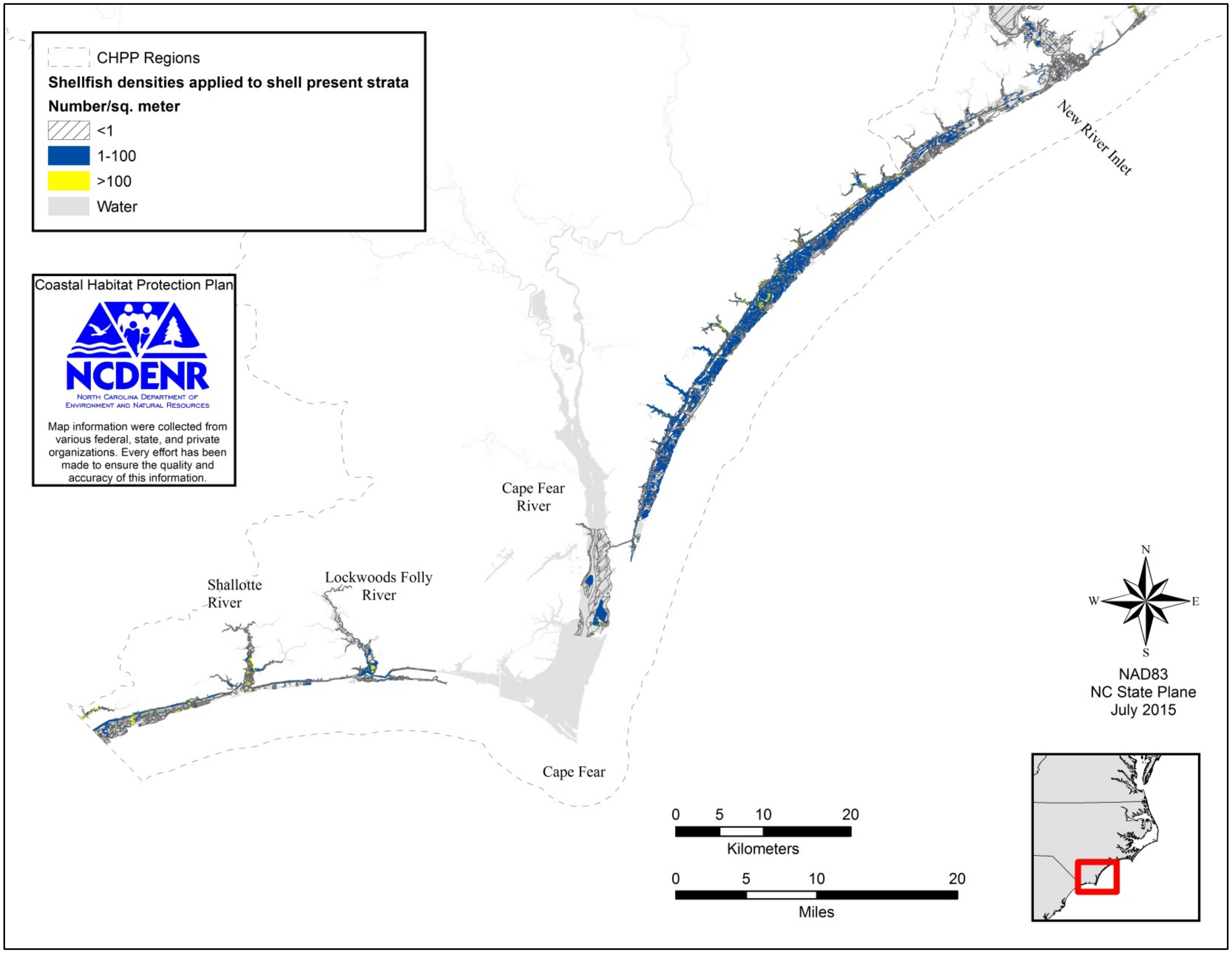
MAP 3.2. Areas for which the bottom type has been mapped or is planned for mapping by the DMF's bottom mapping program (2014).



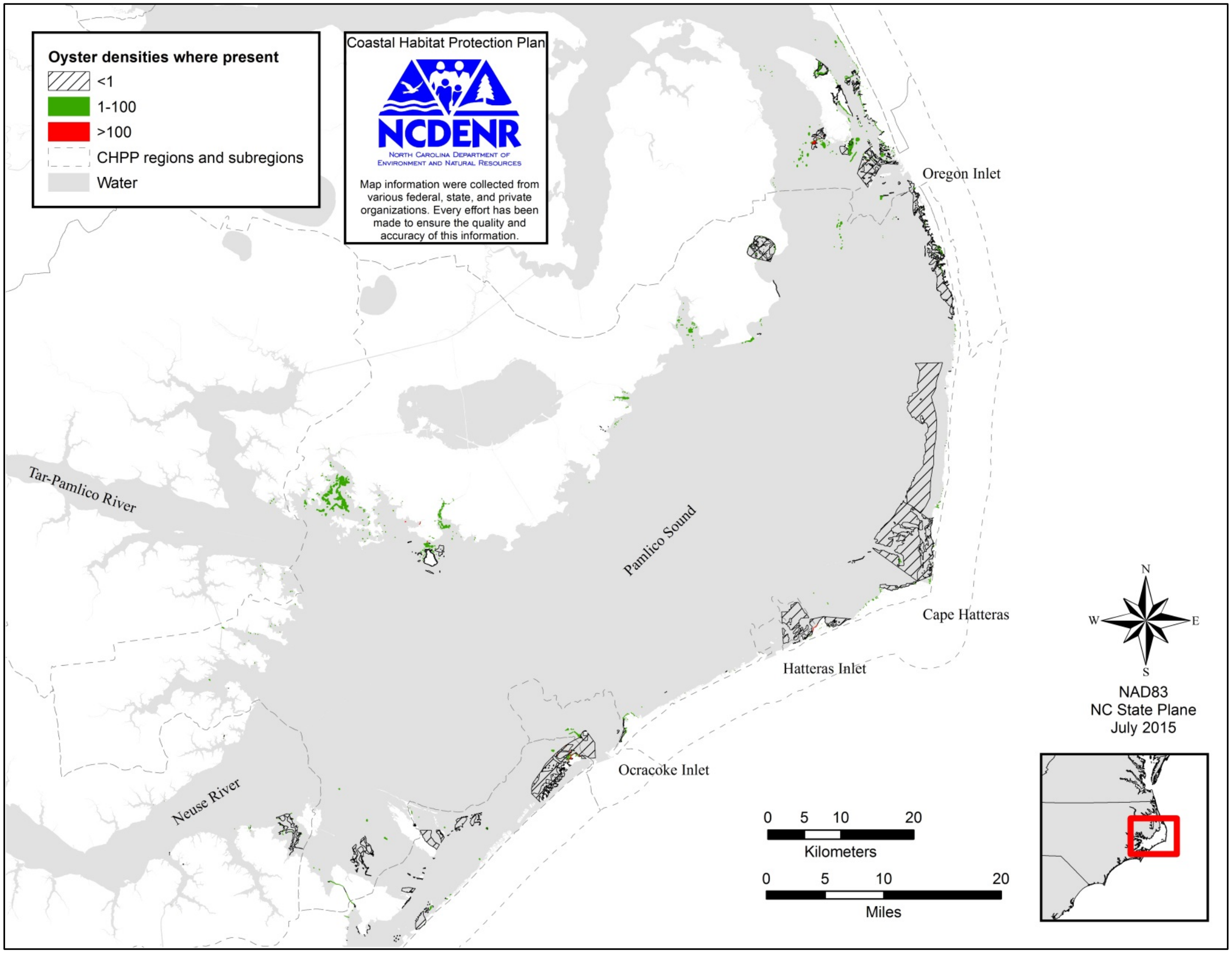
MAP 3.3A - Estimated density of living oysters, clams, scallops in completed portions of the bottom mapping area from Roanoke Island to northern Core Sound (2014). Note: Absence of mapped shell bottom is not evidence of shell absence.



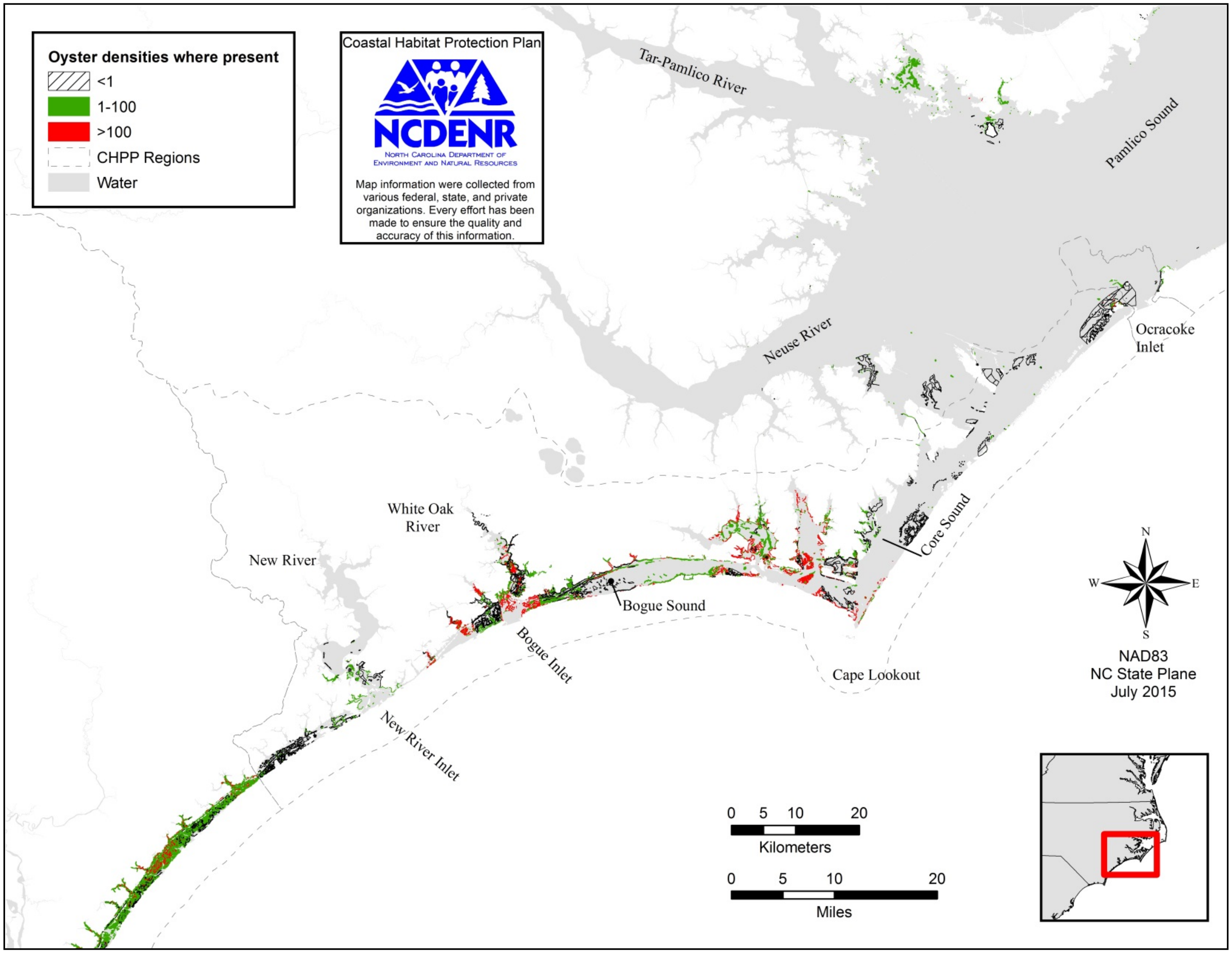
MAP 3.3B - Estimated density of living oysters, clams, scallops in completed portions of the bottom mapping area from Roanoke Island to northern Core Sound (2014). Note: Absence of mapped shell bottom is not evidence of shell absence.



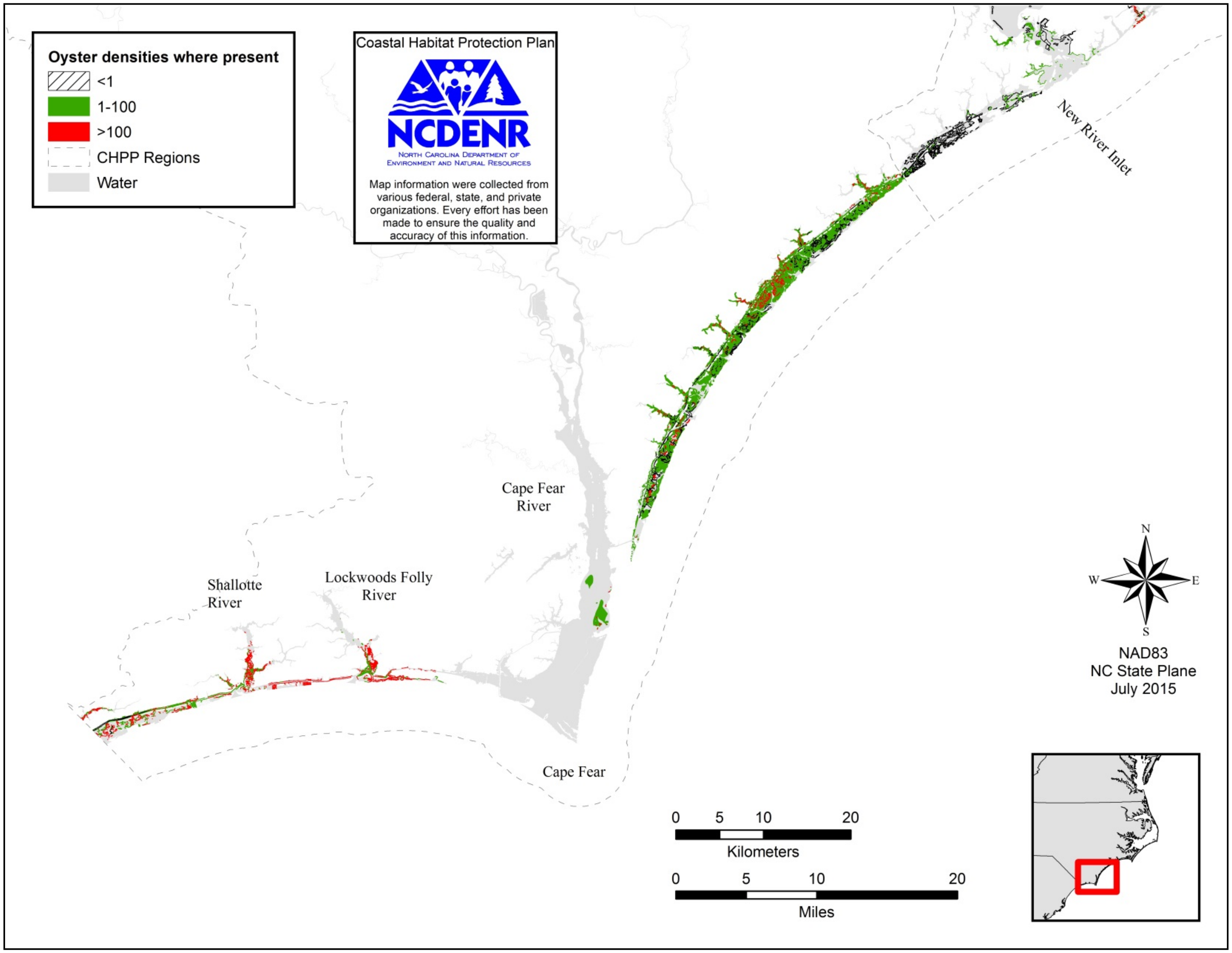
MAP 3.3C - Estimated density of living oysters, clams, scallops in completed portions of the bottom mapping area from Roanoke Island to northern Core Sound (2014). Note: Absence of mapped shell bottom is not evidence of shell absence.



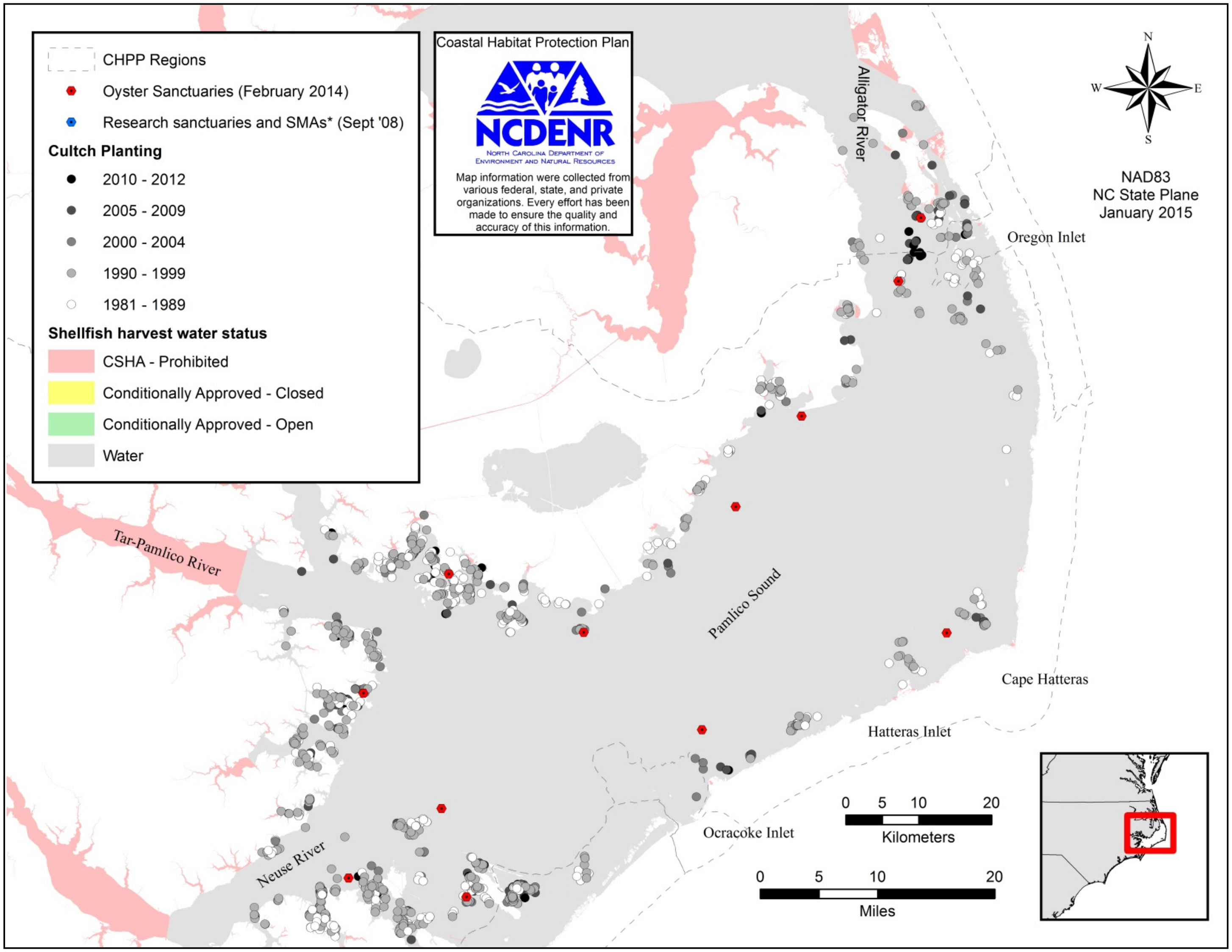
MAP 3.3D - Estimated density of oysters in completed portions of the bottom mapping area from Roanoke Island to northern Core Sound (2014). Note: Absence of mapped shell bottom is not evidence of shell absence.



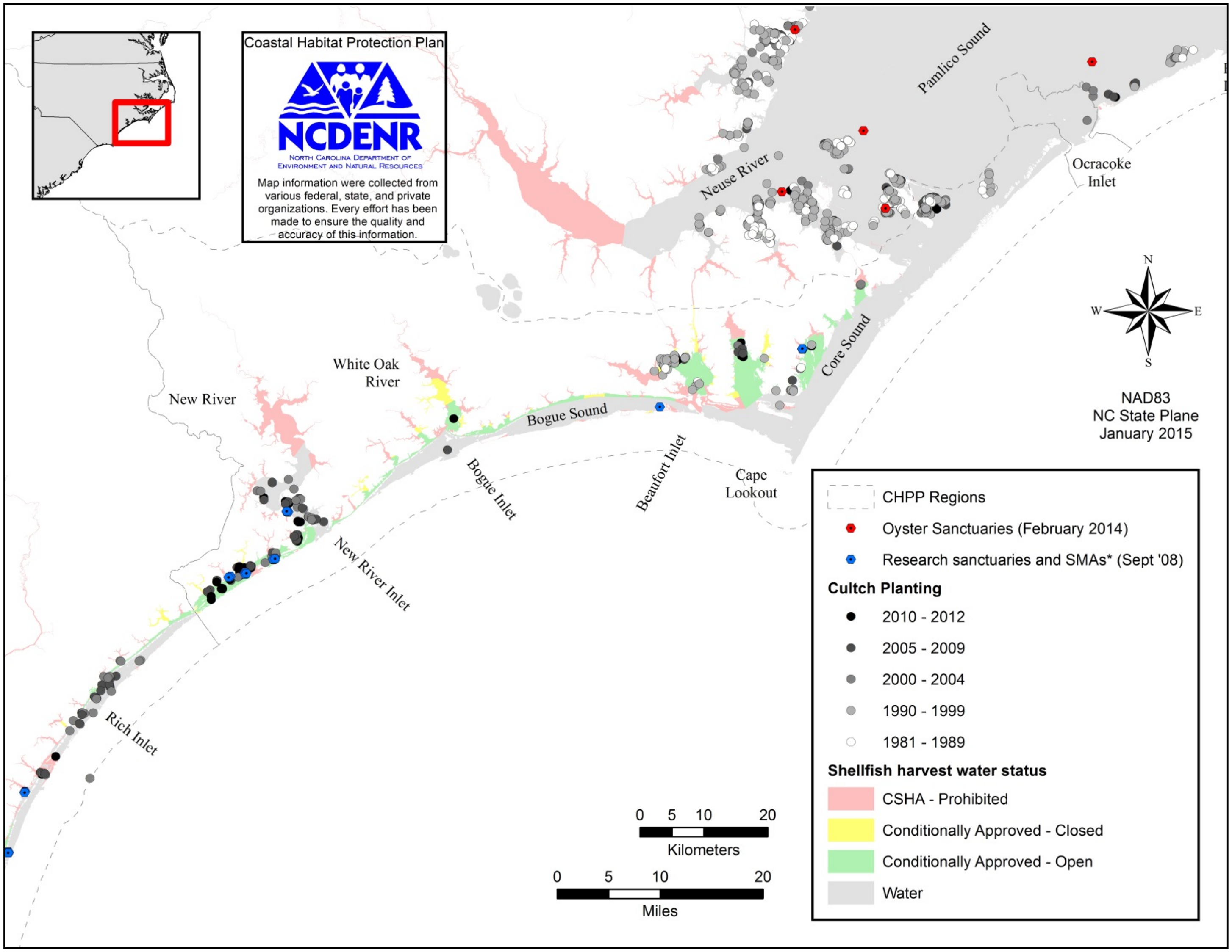
MAP 3.3E. Estimated density of oysters in completed portions of the bottom mapping area from southern Core Sound to Surf City (August 2009). Note: Absence of mapped shell bottom is not evidence of absence.



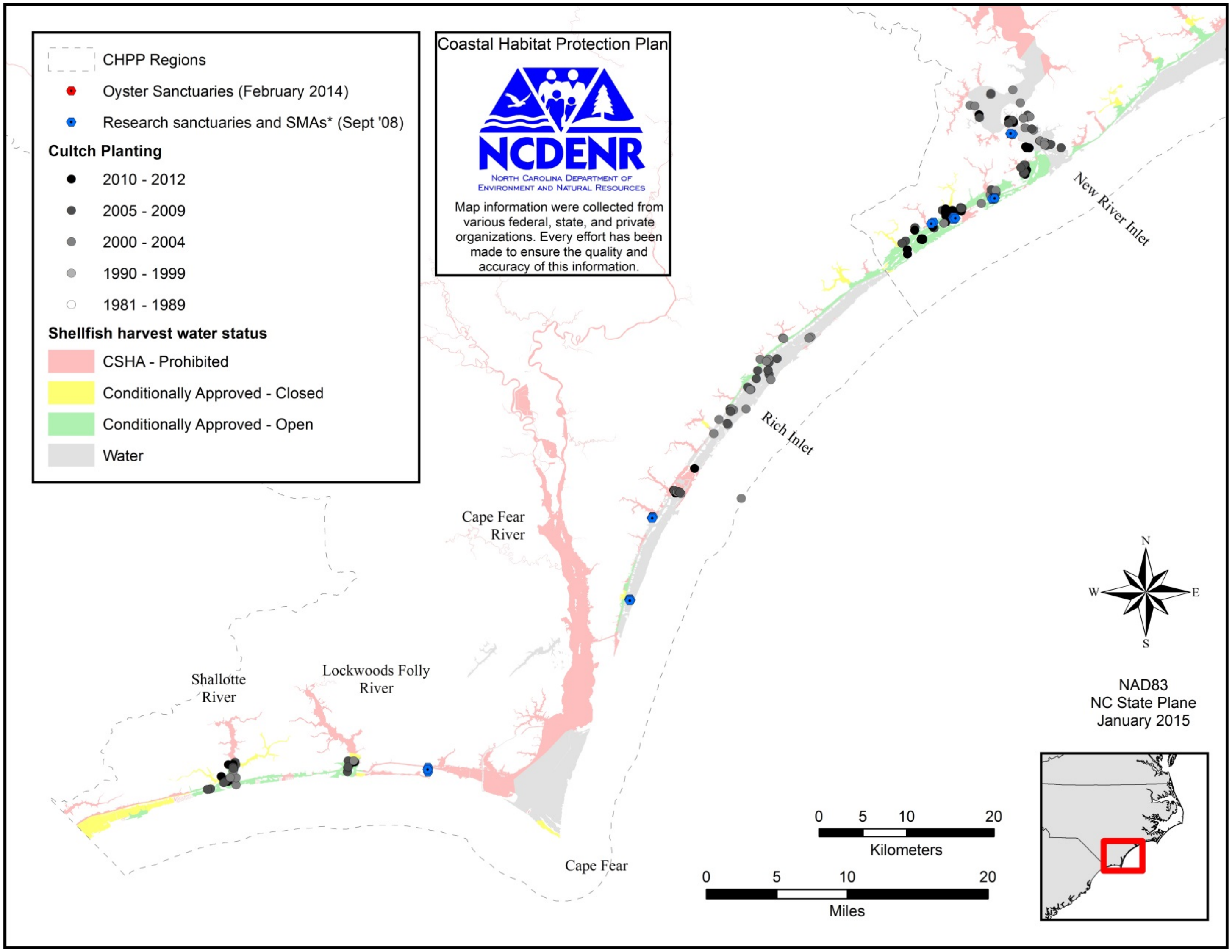
MAP 3.3F. Estimated density of oysters in completed portions of the bottom mapping area from Surf City to Shallotte River (August 2009). Note: Absence of mapped shell bottom is not evidence of absence.



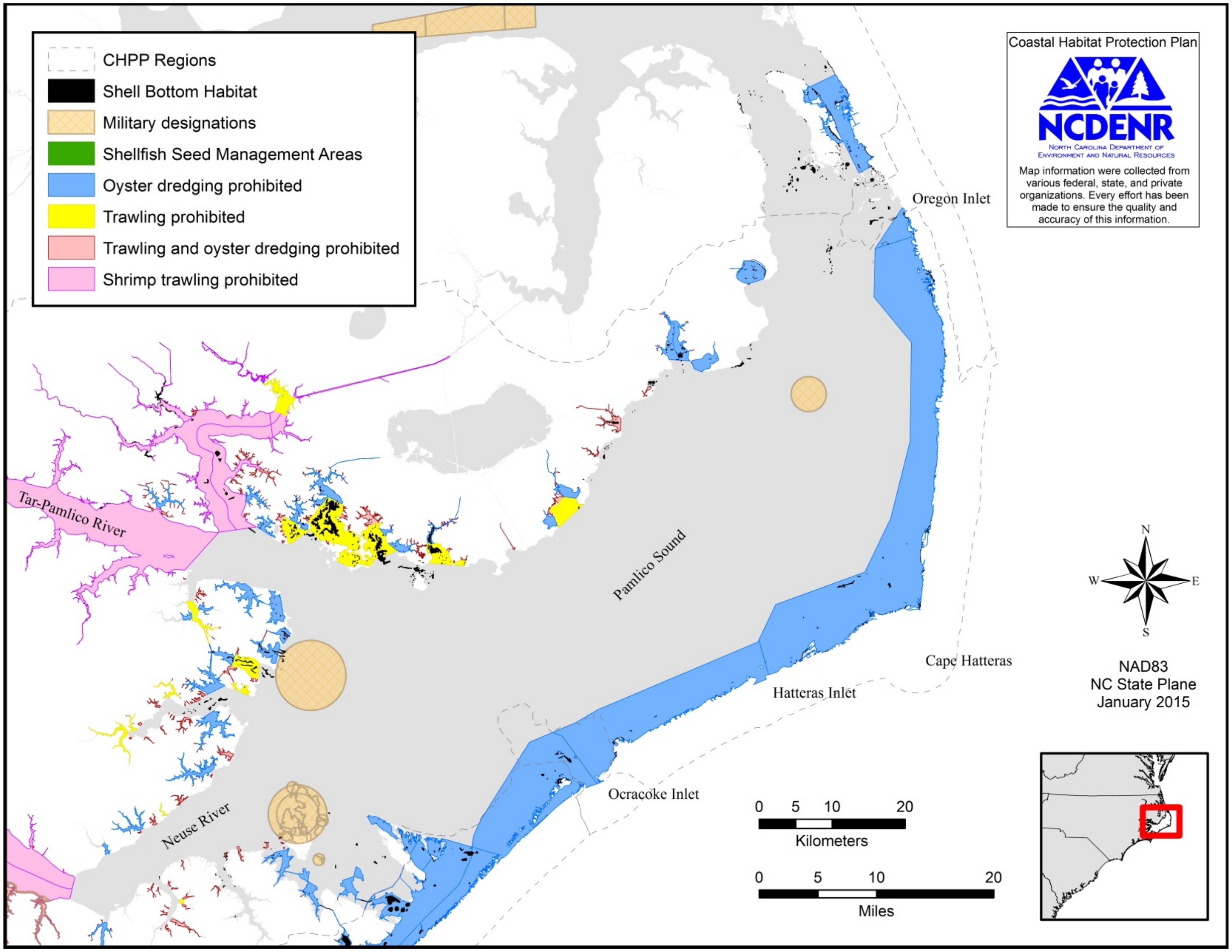
MAP 3.4A. Location of cultch planting sites (1998-2012), shellfish management areas and research sanctuaries (2008), and oyster sanctuaries (2014), from Roanoke Island to northern Core Sound.



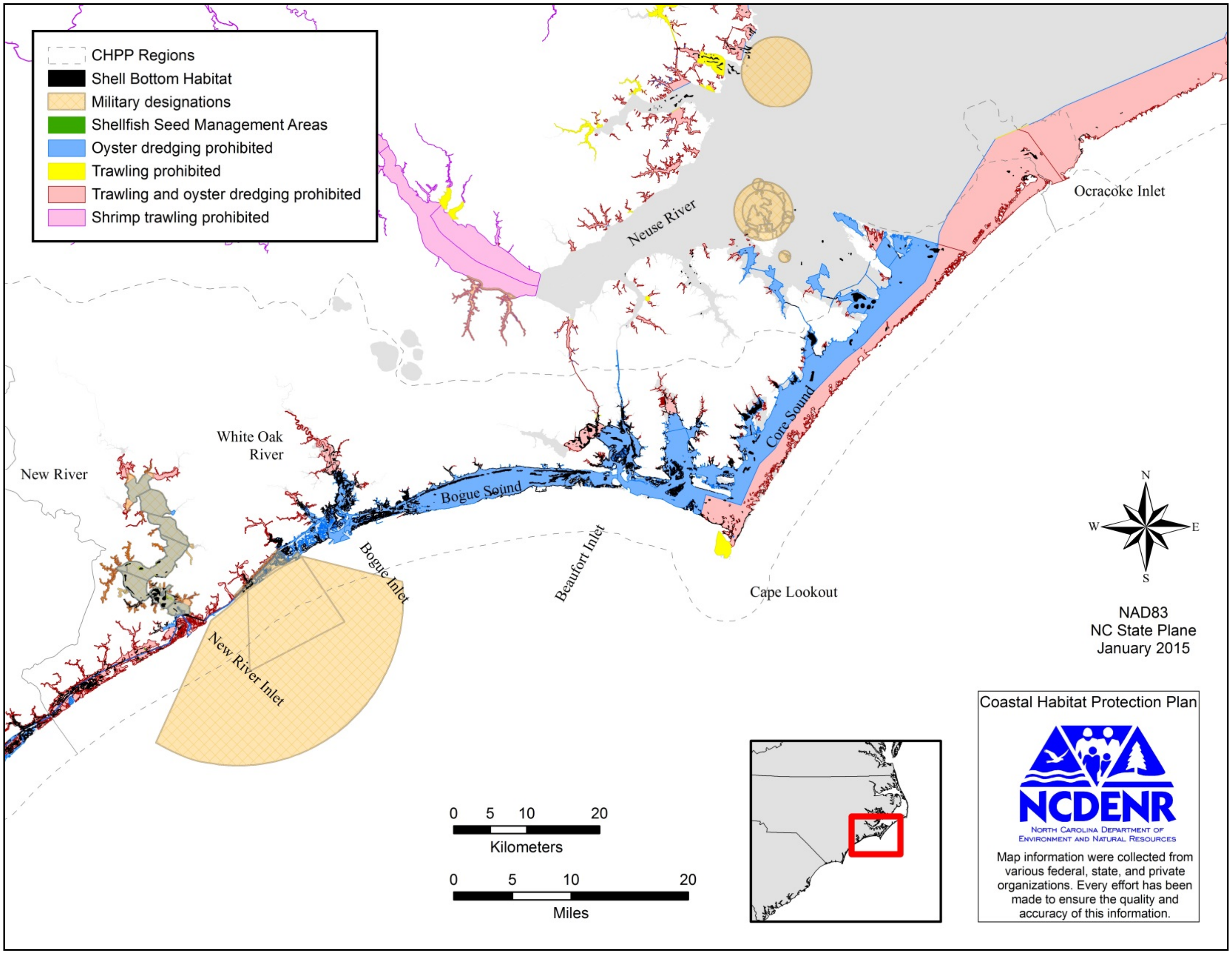
MAP 3.4B. Location of cultch planting sites (2012), shellfish management areas and research sanctuaries (2008), and oyster sanctuaries (2014) from southern Core Sound to Surf City.



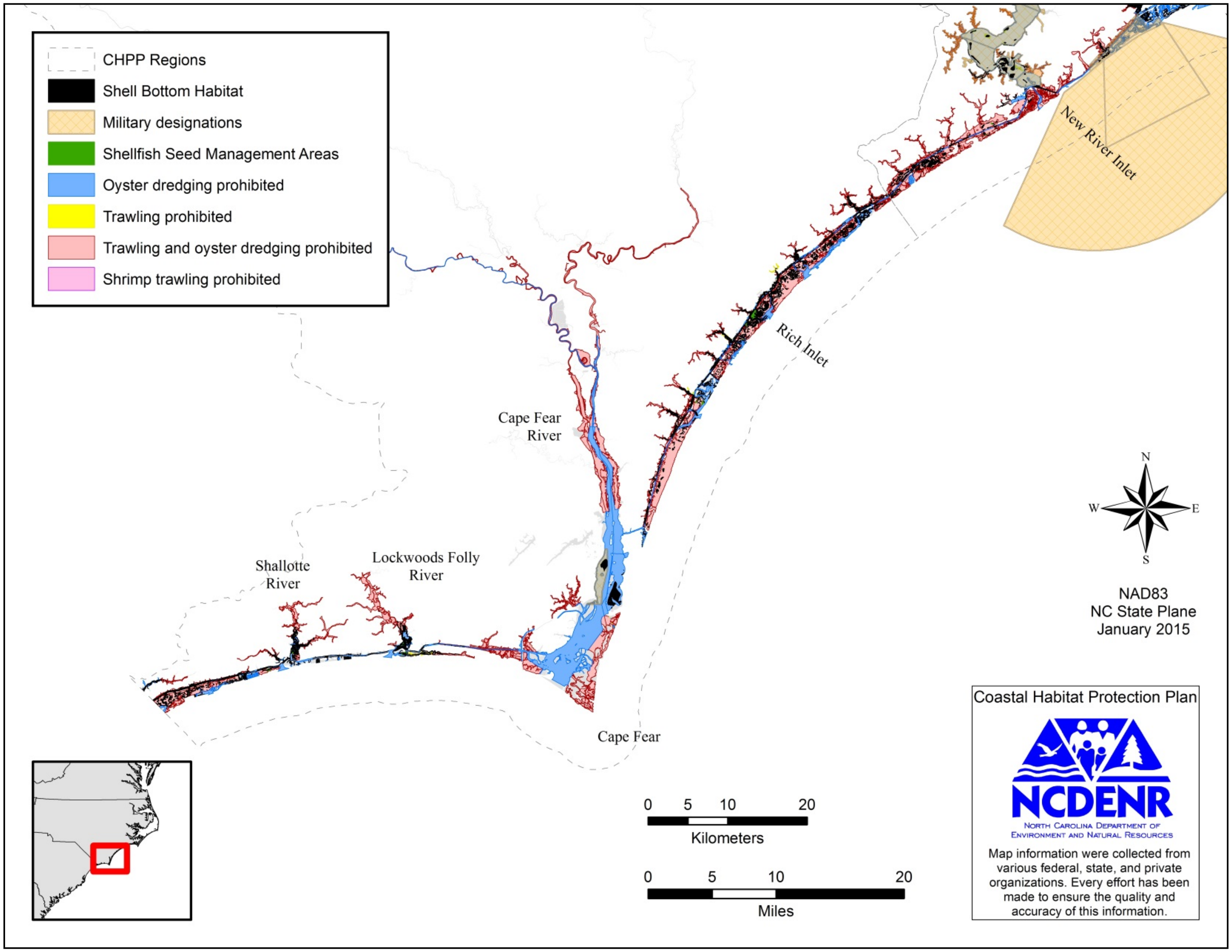
MAP 3.4C. Location of cultch planting sites (2012), shellfish management areas and research sanctuaries (2008), and oyster sanctuaries (2014) from Surf City to Shallotte River.



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 fish habitat dominated by one or more species of underwater vascular plants. The North Carolina Marine Fisheries Commission (MFC) defines SAV habitat as submerged lands that: [MFC rule T15A NCAC 03I .0101 (4)(i)]

(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 season's criteria may be considered when average environmental conditions are altered by drought, rainfall, or storm force winds.

SAV is an underwater forest for juvenile fish and small invertebrates, and is a barometer of water quality.

Submerged aquatic vegetation is included as fish habitat under MFC rules defined above, modified to include low salinity species and to address difficulties in identification of SAV habitat in 2009. The previous definition required the presence of leaves, shoots, or rhizomes. However, because the presence of SAV varies seasonally and inter-annually, a single inspection could result in improper habitat determination. The modified rule defines habitat to include areas where SAV is present, or areas where there is documentation or professional knowledge of its presence within the past ten growing seasons. Regular mapping and monitoring of SAV habitat is, consequently, imperative for proper identification. To ensure consistency among agencies, 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. Although SAV occurs within the intertidal zone 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 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, floating leaf plants, macroalgae, etc.). Reproduction occurs both sexually and asexually.

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 range in North Carolina. In contrast, shoalgrass is a tropical species that reaches its northernmost extent in the state. Widgeon grass (*R. maritima)* grows best in moderate salinity but has a wide salinity range. The co-occurrence of these three SAV species is unique to North Carolina, resulting in high coverage of shallow bottom area in North Carolina's estuaries, both spatially and temporally (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*), hydrilla (*Hydrilla verticillata)*, bushy pondweed (*Najas guadalupensis*), redhead grass (*P. perfoliatus*), and sago pondweed (*P. pectinatus*) (Ferguson and Wood 1994). Submerged aquatic vegetation covers areas from small isolated patches less than a meter in diameter, to continuous meadows covering many acres.

Habitat for SAV supports aquatic plants other than solely submerged grasses. Macroalgae (benthic, drift, and floating) often co-occur with SAV and provide similar ecological services, but the plant taxa have distinctly different growth forms and contrasting life requirements (SAFMC 1998b). Macroalgae grow faster than SAV and do not require loose sediment for anchoring of root systems. Therefore, they do not provide as much sediment stabilization as rooted vascular plants. Their leaves are less rigid than those of submerged rooted vascular plants, reducing their use for attachment and friction for sediment deposition. Macroalgal genera include salt/brackish (*Ulva, Codium, Gracilaria, Enteromorpha*) and freshwater (*Chara, 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 important components of SAV habitat, being organisms that attach or grow on the surface of living plants, and may or may not derive nutrition from the plants themselves. Micro- and macroalgae (e.g., seaweed) can grow on the leaves of SAV. Invertebrates that attach to the SAV leaves include crabs, protozoans, nematodes, polychaetes, hydroids, bryozoans, sponges, mollusks, barnacles, and shrimps.

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 grass beds range in size from a few inches to more than three feet (0.91 m) in height. The structural complexity of an SAV bed also varies because of the growth form of the species present (SAFMC 1998b). While leaf density tends to be higher in contiguous beds than in patchy habitat, below-ground root mass is often denser in patchy beds (Fonseca et al. 1998). Despite the difficulty of defining the boundaries of SAV beds, unvegetated bottom between nearby patches is included as a component of patchy SAV habitat because rhizomes and/or seedlings may be present and the beds migrate 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 sediment, adequate light reaching the bottom, and moderate to negligible current velocities or turbulence (Ferguson and Wood 1994; Thayer et al. 1984). 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 the Albemarle-Pamlico estuarine system between 1988 and 1991 found that occurrence of SAV was related to water depth, water clarity, 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 for turbidity than salt and brackish SAV (Ferguson and Wood 1994). This supports other research (Funderburk et al. 1991) in concluding that salt/brackish SAV requires slightly greater water clarity (Secchi depth >1.0 m, or 3.28 ft) than freshwater (Secchi depth >0.8 m or 2.63 ft).

The primary factors controlling distribution of SAV are water depth, sediment composition, energy, and the penetration of photosynthetically active radiation (PAR) through the water column (Biber et al. 2008; Cho and Poirrier 2005; Dennison et al. 1993; Duarte et al. 2007; French and Moore 2003; Gallegos 1994; Goldsborough and Kemp 1988; Havens 2003; Kemp et al. 2004; Kenworthy and Haunert 1991; Koch 2001; Moore et al. 1996; Moore et al. 1997). At a minimum, high salinity leaves require 15-25% of incident light (Bulthius 1994; Dennison and Alberte 1986; Fonseca et al. 1998; Kenworthy and Haunert 1991). Low salinity species have lower light requirements (9-13%) (EPA 2000a; Fonseca et al. 1998; 1991; 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 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 vegetation cannot be sustained.

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 (Biber et al. 2008; Kemp et al. 2004). 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 and artificially, such as through wood pulp mill processing) strongly absorb 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 further be 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, one study showed environmental conditions allowing adequate light penetration for SAV survival to be TSS <15 mg/l and chlorophyll *a* <15 μg/l (Kemp et al. 2004). 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). The North River in the northeast Albemarle Sound area was chosen because it exhibits a broad range of depths and salinities representative of the Albemarle-Pamlico estuarine system. The bio-optical model predicted a deeper depth distribution (1.7 m MSL) for SAV than was observed (0.87 m MSL). While SAV was not found as deep as predicted, the cause may have been confining hydrographic features, currents, epiphytic growth, substrate composition, or overestimation of colonization depth (Biber et al. 2008; Bradley and Stolt 2006; Kemp et al. 2004).

TABLE 4.1. Average environmental conditions at locations where submerged aquatic vegetation occurred in coastal North Carolina, 1988-1991 (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 (EPA 2000a; Funderburk et al. 1991; 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

Kemp et al. (2004) developed a relationship to estimate epiphytic material and its associated light attenuation. In the Chesapeake Bay, epiphytic growth reduced the intensity of light by 20-60% in low salinity areas and 10-50% in moderate to high salinity areas (Kemp et al. 2004). From that, the amount of needed dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) was determined (~ 0.15 mg/l DIN; 0.01-0.02 mg/l DIP)(Funderburk et al. 1991; Kemp et al. 2004; Sand-Jensen 1977). 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.

Below is a brief description of the habitat and plant characteristics of eight submerged grasses common to North Carolina's waters (Bergstrom et al. 2006; Hurley 1990):

4.1.3.1. High salinity SAV (18-30ppt)

- Eelgrass (*Zostera marina*): Grows in fine mud, silt, and loose sand in high salinity waters, tolerant of high energy waters (Thayer et al. 1984). Reproduces vegetatively throughout the growing season and sexually from December to April. Present primarily as a seed bank from July to November (P. Biber, NMFS, pers. com.). Rhizomes rarely deeper than 5 cm (1.97 inches). Spatially coexists with *Halodule* and *Ruppia* in North Carolina, but dominates from winter to summer, with lower densities during summer relative to *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 reproduction from April through October and sexual (although rare) in spring and summer (J. Kenworthy and P. Biber, NMFS, pers. com.). 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 disperses by seed.

4.1.3.3. Freshwater-low salinity SAV (0-5ppt, occasionally to 15ppt)

- Redhead grass (*Potamogeton perfoliatus*): Found in fresh to moderately brackish and alkaline waters. Grows best on firm muddy soils in quiet waters with slow-moving currents. Because of its wide leaves it is more susceptible to being covered with epibiotic growth than 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 delicate species. Similar in appearance to eelgrass.
- Eurasian watermilfoil (*Myriophyllum spicatum*): Inhabits fresh to moderately brackish waters. Affinity for high alkalinity and moderate nutrient loading. Grows on soft mud to sandy mud in slow moving or protected waters. Not tolerant of strong 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 NC Board of Agriculture as a Class B noxious weed [T02 NCAC 48A .1702].
- Bushy Pondweed or Southern Niad (*Najas guadalupensis*): Present in small freshwater streams. 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, tolerant of high alkalinity. Associated with silt-mud sediments. Long rhizomes and runners provide strong anchorage to substrate. Capable of enduring stronger currents and wave action than most SAV.

4.1.4. Distribution

The dynamic nature of SAV beds makes mapping and monitoring difficult. The distribution, abundance, and density of SAV varies seasonally and annually (Dawes et al. 1995; Fonseca et al. 1998; SAFMC 1998c; Thayer et al. 1984). Therefore, one needs consider historical as well as current occurrence to determine locations of viable seagrass habitat (SAFMC 1998c). 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 where water temperatures are lower (e.g., deeper areas and tidal flats with continuous water flow (SAFMC 1998c)).

Along the Atlantic coast, North Carolina supports more SAV than any other state but Florida (Funderburk et al. 1991; Sargent et al. 1995). Mapping efforts suggest SAV habitat covers over 150,000 acres in coastal North Carolina (Map 4.1). Some recent mapping efforts include:

- DMF (North Carolina Division of Marine Fisheries) Bottom Mapping Program – http://portal.ncdenr.org/web/mf/shellfish-habitat-mapping.
- ECSU (Elizabeth City State University) Mapping Program – http://www.ecsu.edu/academics/department/natural-sciences/chemistry/sav/ecsu.cfm.
- NCSU (North Carolina State University) – Dr. Eggleston (http://marinesci.ncsu.edu/research/.
- DWR Rapid Response Teams - http://portal.ncdenr.org/web/wq/ess/savmapping.
- APNEP http://portal.ncdenr.org/web/apnep/sav-monitoring, Fall 2007 north of Oregon Inlet to Back Bay Virginia, Spring 2008 south of Oregon inlet. Map based on aerial photography.
- APNEP http://www.apnep.org/web/apnep/sav-monitoring, Fall 2013 north of Oregon Inlet, Spring 2013 south of Oregon Inlet. Imagery not completed at the time of CHPP completion.

A partial inventory of SAV mapping is located at http://portal.ncdenr.org/web/mf/58. When considering only mapping data, the area of SAV habitat in North Carolina covers ~29% of the shallow (<6 foot) littoral zone[5], and ~8% of the total water area. The spatial distribution of coverage varies within and among regions, relative to the area of shallow estuarine waters (Table 4.3). A general distribution of high and low salinity submerged grass beds in North Carolina is shown in Figure 4.1 below.

Most habitat for SAV in coastal North Carolina occurs along the Outer Banks estuarine shoreline (Pamlico and Core/Bogue sounds), with sparse cover along the mainland shores (Ferguson et al. 1989). As the systems become riverine, freshwater SAV is abundant in larger blackwater systems, but rare in small blackwater streams (Smock and Gilinsky 1992), due to irregular flows and shading from forested wetlands. Freshwater SAV can be extensive in low-salinity back bays and lagoons (Moore 1992), such as Currituck Sound, and in coastal lakes like Lake Mattamuskeet (not included in SAV coverage estimates). Estuarine SAV occurs sporadically south of Bogue Inlet to the South Carolina border, but these areas were not well photographed in the early 1990's (Ferguson and Wood 1994). Small areas of habitat have been observed in New River by DMF biologists, and in Alligator and Chadwick bays, Topsail Sound, and inside Rich Inlet (Staff, DMF, pers. com. 2010). More recent imagery and site visits have verified the presence of patchy SAV beds south of Bogue Sound (S. Chappell and A. Deaton, DMF, pers. obs. 2010).

[5] Based on digitizing contours from the depth points drawn on NOAA nautical charts.

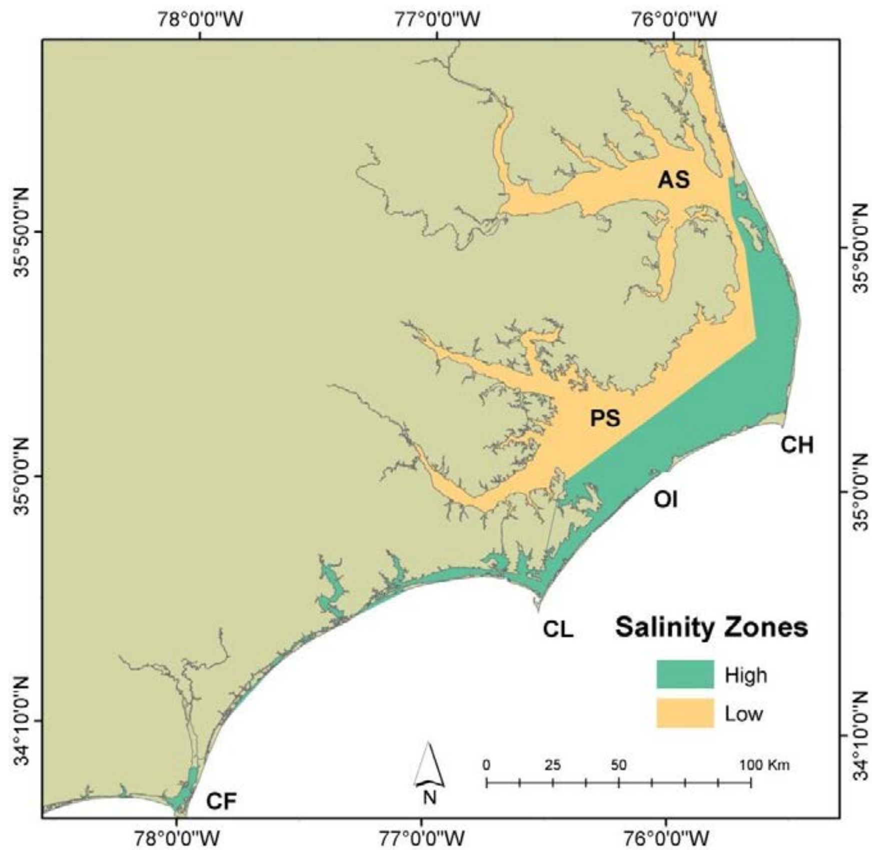


FIGURE 4.1. Submerged Aquatic Vegetation salinity zones in North Carolina. Abbreviations: AS, Albemarle Sound; PS, Pamlico Sound; CH, Cape Hatteras; OI, Ocracoke Inlet; CL, Cape Lookout; CF, Cape Fear. Source: Development of a Performance-Based Submerged Aquatic Vegetation Monitoring and Outreach Program for North Carolina, Dean E. Carpenter, Joseph J. Luczkovich, W. Judson Kenworthy, David B. Eggleston and Gayle R. Plaia, 2012.

TABLE 4.3. Estimated acreage of mapped SAV habitat within CHPP regions. The area estimates are from a mosaic of mapping efforts spanning a time period from 1981-2011.

CHPP regions	Major water bodies	SAV area (acre)	<6 foot area (% SAV)	Total water area (% SAV)
1	Albemarle/Currituck sounds, Chowan River	36,880	212,099 (17%)	670,258 (6%)
1/2	Oregon Inlet	3,490	10,043 (35%)	11,924 (29%)
2	Pamlico Sound, Neuse/Tar-Pamlico rivers	102,791	251,478 (41%)	1,329,415 (8%)
2/3	Ocracoke Inlet	3,993	14,459 (28%)	24,247 (16%)
3	Core/Bogue sounds, New/White Oak rivers	48,108	154,493 (31%)	228,241 (21%)
4	Cape Fear River/southern estuaries	579	37,800 (2%)	89,304 (1%)
Totals	CHPP Management Unit	195,841	680,372 (29%)	2,353,388 (8%)

4.2. Ecological role and functions

Submerged aquatic vegetation is recognized as 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 is reportedly very large. Costanza et al. (1997), using published international literature, estimated the total value of ecosystem services of seagrass and algal beds to be $19,000/ha/yr ($7,700/ac/yr). Their estimate took into account services such as climate regulation, erosion control, waste treatment, food production, recreation, among others. The monetary estimate of SAV services did not account for the lesser value of alternative habitats, such as subtidal soft bottom. In Bogue Sound, North Carolina, SAV denitrification had an estimated value of $3,000/acre/year compared to approximately $400/acre/year for subtidal soft bottom (Piehler and Smyth 2011). Sediments in the vicinity of submerged grassbeds also provide more annual denitrification than marsh sediments (Smyth et al. 2013). Ecosystem services of subtidal soft bottom are less than SAV (Eyre and Ferguson 2002; Piehler and Smyth 2011), although there is much more of it; proportionately, SAV habitat provides more ecosystem services than subtidal soft bottom.

4.2.1. Productivity

Seagrass habitat is dominated by dense stands of vascular plants associated with epiphyte communities and 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 (Hemminga and Duarte 2000; Larkum et al. 2006; Peterson et al. 2007; Thayer et al. 1984). 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), with the majority contained in the roots (45-285 g m^{-2}). Based on published research (Peterson et al. 2007), the annual primary production estimates for eelgrass surpassed intertidal marsh grass (*Spartina alterniflora)*, intertidal and 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 and 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, developing greater standing crops and storing biomass in extensive root and rhizome systems. Stevenson (1988) reported high salinity SAV production at >10 g carbon m^{-2} d^{-1} and low salinity SAV production at <5 g carbon 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, later stages can impede SAV growth and density by competing for light, nutrients, and carbon (Koch 2001; Thayer et al. 1984). Dillon (1971) and Penhale (1977) estimated that epiphytes (macroalgae) constitute 10-25% of the total SAV biomass in a North Carolina estuary, with seasonal variability in macroalgal abundance corresponding to fluctuations in eelgrass biomass (Penhale 1977; Thayer et al. 1975).

Because of their high rates of primary production and particle deposition, SAV beds are important sources and sinks for nutrients (SAFMC 1998b). 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 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 of greater importance as food for fish than are living SAV leaves (Kenworthy and Thayer 1984; Thayer et al. 1984).

4.2.2. Ecosystem enhancement

Because SAV is rooted and provides semi-permanent structures, system enhancement is one of its more important ecological functions. Some of these include (SAFMC 1998b; Thayer et al. 1984):

- 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 TSS from the water column, improving water clarity, and adding DO. The presence of SAV is both a maintainer and indicator of good water quality (Biber et al. 2008; Dennison et al. 1993; Virnstein and Morris 1996). Moore (2004) studied the effect of SAV beds on water quality inside compared to outside of the bed in Chesapeake Bay. During spring (April – June), the rapidly growing beds were a sink for nutrients, TSS, and phytoplankton. As summer progressed, death of the vegetation caused a release of the 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 2004; Moore et al. 1997). Beds of SAV can also enhance grazing on phytoplankton by providing daytime refuge for planktonic filter feeders (Scheffer 1999). By absorbing wave energy, aquatic grasses buffer turbulence, reduce erosion, improve clarity, and help stabilize marsh edge habitat (Fonseca 1996; Stephan and Bigford 1997).

4.2.3. Fish utilization

Many fish species occupy SAV at some point in their life cycles (Thayer et al. 1984), the value of the grassbed depending on its contribution to species' refuge, spawning, nursery, foraging, and corridor needs. Because of the seasonal abundance patterns of SAV, refuge and foraging habitat are provided almost year round for estuarine-dependent species (Steel 1991). Fish and invertebrates' use of SAV differs spatially and temporally due to distribution ranges, time of recruitment, and life histories (Heck et al. 2008; Hovel et al. 2002; Nelson et al. 1991). The SAFMC considers SAV as EFH for brown, white, and pink shrimp, and species in the snapper-grouper complex. Table 4.4 is a partial list of species utilizing SAV habitat in North Carolina.

4.2.3.1. Moderate to high salinity SAV

In brackish and high salinity estuaries, fish and invertebrates use seagrass for nursery, refuge, foraging, and spawning. Studies in eelgrass beds in the Newport River estuary reported between 39 and 56 fish species found during monitoring in the 1970s (Adams 1976; Thayer et al. 1975; Thayer et al. 1984). The DMF juvenile fish sampling in SAV beds in eastern Pamlico and Core Sounds found >150 species of fish and invertebrates from 1984 to 1989, of which 34 fish and six invertebrates were important commercial species (DMF 1990). Long haul seine catches reported 49 adult fish species collected over SAV beds in eastern Pamlico Sound (DMF 1990). Over 70 benthic invertebrates have been reported in eelgrass beds along the east coast (Thayer et al. 1984). Spotted seatrout (*Cynoscion nebulosus*) are highly dependent on grass beds (Vetter 1977), and bay scallops occur almost exclusively in the beds (Thayer et al. 1984).

TABLE 4.4. Partial list of species documented to use submerged aquatic vegetation habitat.

Species*	SAV Functions [1]					2014 Stock status [2]
	Refuge	Spawning	Nursery	Foraging	Corridor	
ANADROMOUS & CATADROMOUS FISH						
River herring - blueback/alewife	X		X	X	X	D-Albemarle Sound, U-Central/Southern
Striped bass				X		C- Alb/Roa; V-Atl Migratory
Yellow perch		**X**				**C**
American eel	X		X	X	X	D
ESTUARINE AND INLET SPAWNING AND NURSERY						
Bay scallop	**X**	**X**	**X**	**X**		**C**
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	C
Brown shrimp	**X**		**X**	**X**	**X**	**V**
Southern flounder			X	X		D
Spot	X		X	X	X	C
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	V- S of Hat., R- N of Hat.
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		V

Names in bold are species with relative abundances reported in literature as higher in SAV than other habitats. Note: lack of bolding does not imply non-selective use of the habitat, but lack of information.

[1] Sources: (ASMFC 1997), (Thayer et al. 1984), (Peterson and Peterson 1979), (NMFS 2002), (SAFMC 1998b)

[2] V=viable, R=recovering, C=Concern, D=Depleted, U=unknown

Studies along the Atlantic and Gulf coasts have demonstrated significantly greater species richness and abundance in SAV beds compared to unvegetated bottom (ASMFC 1997; Heck et al. 1989; Hirst and Attrill 2008; Irlandi 1994; Ross and Stevens 1992; Summerson and Peterson 1984; Wyda et al. 2002). Blue crabs and pink shrimp were significantly more abundant in SAV beds than in shallow unvegetated estuarine bottoms in North Carolina, Alabama, and Florida (Murphey and Fonseca 1995; Williams et al. 1990). Wyda et al. (2002) found significantly higher abundance, biomass, and species richness of fish at sites with higher levels of seagrass habitat (biomass >100 wet g m^{-2}; density > 100 shoots m^{-2}) than sites with low-absent SAV (biomass <100 wet g m^{-2}; density <100 shoots m^{-2}), although the sites with low-absent

SAV biomass and density had higher proportions of pelagic species. In the Newport River estuary, 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, Elis et al. (1996) found that large macrofauna (e.g., fish, crabs, shrimp) were generally more abundant on artificial SAV beds (green plastic ribbon tied to black plastic mesh) than on shell bottom.

In Florida Bay, animal abundances were compared between the 1980s and 1990s when significant changes in SAV coverage occurred (Matheson et al. 1999). The major change was a decrease in abundance of small fish and invertebrates (e.g., crustaceans, pipefish) with decreases in SAV coverage, while larger demersal predatory fish (e.g., toadfish, sharks) increased. Increases in SAV density revealed significant increases in crustaceans. Another Florida Bay study saw reductions in pink shrimp abundance in SAV die-off areas relative to undamaged/recovering areas (Roblee and DiDomenico 1992).

In the Long Island estuaries of New York's Shinnecock Bay, Carroll et al. (2008) focused on the ability of hard clams to increase nutrient availability for eelgrass. Compared to control plots, eelgrass production in both ambient light and artificially shaded treatments was significantly higher with hard clams. Eelgrass on plots with hard clams also had higher N concentrations in their tissues. These results were nearly identical to those obtained with fertilizer stakes. The results demonstrate the positive interactions between hard clams and eelgrass, and show clams being capable of broadening the range of physical conditions within which eelgrass can survive by improving its habitat. Restoration efforts targeting SAV will benefit hard clams and vice versa.

Hovel et al. (2002) examined the effect of SAV bed structure (% 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 spring and fall. Wave energy regime and SAV shoot biomass had the most influence on species densities; other factors explained little of the variation. 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 equally regarding fish and shellfish use.

4.2.3.2. Freshwater to 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 SAV than in similar systems void of SAV (Petr 2000; Randall et al. 1996). 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 significantly. Another study in the Potomac River, VA, found densities of fish in SAV habitat 2-7 times higher than in areas without (Killgore et al. 1989). Species that inhabit freshwater SAV also include certain estuarine and anadromous fish (NOAA 2001; Rozas and Odum 1987; SAFMC 1998b). The most commonly occurring include:

Freshwater
- Minnows
- Juvenile American
- Pirate perch
- Inland silversides
- Yellow perch
- Largemouth bass
- Bluegill (bream)
- White perch

Estuarine
- Juvenile menhaden
- Spot
- Blue crab
- Grass shrimp
- Bay anchovy
- Striped mullet
- Tidewater

Anadromous
- Striped bass
- Shad (American and
- River herring

4.2.4. Specific biological functions

4.2.4.1. Refuge

The structure of SAV conceals prey from visual detection, restricts capture by predators, and protects organisms from adverse weather (Rooker et al. 1998; SAFMC 1998b; Savino and Stein 1989). Light levels are reduced within the canopy, further concealing prey (SAFMC 1998b). Since SAV can be as tall as one meter (3.28 ft), their canopies are three-dimensional, and contain large volumes of sheltered water. Additionally, cryptic species use camouflage to decrease visibility within SAV habitat. Rhizomes and roots of SAV provide a substrate matrix for meiofauna and macrofauna (Kenworthy and Thayer 1984). Hard clams are significantly more abundant in SAV beds than in unvegetated bottom due to differences in food supply, predation, and sediment stability (Irlandi 1994; Irlandi and Crawford 1997; Peterson and Peterson 1979). Estuarine-dependent spring-summer spawners (e.g., red drum, seatrout) utilize SAV habitat in the spring and summer for forage and refuge, residing prior to emigrating to the mouths of bays, rivers, inlets, or coastal ocean shelf waters to spawn (SAFMC Luczkovich et al. 1999; 1998b).

Benthic macroinvertebrates can be more vulnerable to crab predation in SAV because crabs use SAV for refuge from avian predators (Beal 2000; Micheli and Peterson 1999; Skilleter 1994). Summerson and Peterson (1984) hypothesized that nocturnal bottom predators living on sand flats use SAV diurnally to avoid predators. Matilla et al. (2008) found that SAV beds of various densities equally increased survival of shrimp from predators. In freshwater systems, excess vegetation can hamper movement and foraging efficiency of large predatory fish, resulting in stunted populations (Colle and Shireman 1980).

Seagrass, particularly eelgrass, may provide overwintering habitat for some estuarine species. Pink shrimp have been collected in SAV during winter months in North Carolina (Purvis and McCoy 1972; Williams 1964). The presence of SAV in the winter may contribute to pink shrimp's ability to survive, supporting the spring 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 there is very minimal SAV, pink shrimp comprise a very small portion of shrimp landings. Similarly, survival of blue crabs in a New Jersey estuary was attributed to the ability to overwinter in SAV (Wilson et al. 1990).

4.2.4.2. Spawning

It is difficult to know species whose reproduction success rate is higher in SAV than in other habitats. Preference for spawning in SAV could be assumed for species found almost exclusively in SAV habitat, such as the bay scallop (Thayer et al. 1984). Many other year-round estuarine residents benefit from proximity to SAV spawning and nursery areas. In the Chesapeake Bay, where bay scallops have been disappearing, researchers believe the population can be restored if spawning scallops can be protected from predators in SAV (Cordero et al. 2012). Seasonal patterns of reproduction and development of many temperate species coincide with seasonal abundance of seagrass (Stephan and Bigford 1997).

Freshwater fish spawning preferentially on or near SAV include carp, crappie, yellow perch and chain pickerel (Balon 1975; Graff and Middleton 2000). The roots and stems of the SAV provide substrate for attachment of eggs. Many species benefit from proximity to spawning and SAV nursery areas.

4.2.4.3. Nursery

Many species of fish and invertebrates along the Atlantic coast use SAV for nursery habitat (Thayer et al. 1984). The roots and stems provide protection and foraging habitat for developing fish and invertebrate larvae (Ambrose and Irlandi 1992; SAFMC 1998b). Commercial and recreational species present in SAV as juveniles in 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

(SAFMC Rooker et al. 1998; 1998b). Estuarine-dependent reef fish (e.g., gag, black sea bass) use seagrass as juveniles prior to moving offshore (Ross and Moser 1995). Juvenile sheepshead and gray snapper also utilize SAV beds (Pattilo et al. 1997). 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 1998b). 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).

In North Carolina, SAV has been recognized as critical nursery habitat for pink shrimp (Murphey and Fonseca 1995). The degree of preference by red drum is uncertain since they also utilize unvegetated estuaries. Still, red drum eggs, larvae, postlarvae, and juveniles, have been documented in SAV in North Carolina, which is particularly important for foraging young (1-2 year old) (Mercer 1984; Reagan 1985; Ross and Stevens 1992). Abundance of juvenile red drum in SAV varies seasonally and spatially, being more common during summer, in beds close to spawning areas (Zieman 1982; DMF, unpublished data). Juveniles are 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 seine surveys and tagging studies indicate high abundance of late YOY red drum in shallow high salinity SAV behind the Outer Banks (DMF 2001b). Analysis of DMF data, including juvenile abundance and concurrent habitat measurements, indicate a higher affinity to seagrass for ages 1 and 2 (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 in Galveston Bay. The results indicated a preference for marsh and SAV over soft bottom, with SAV selected over marsh where habitats co-occur. Bay scallops and hard clams attach to grass blades temporarily before settling on the bottom (SAFMC 1998b; Thayer et al. 1984). Hard clams will also utilize other substrates, such as oysters and shell hash.

Juvenile blue crabs prefer shallow water with structures, such as SAV, marsh, shell bottom and detritus (Etherington and Eggleston 2000). In the Albemarle-Pamlico system, most initial recruitment of juvenile crabs occurs in SAV beds around inlets behind the Outer Banks, excepting major storm events. In years with large storm events, crabs disperse into lower salinity habitats (Etherington and Eggleston 2000). Near Ocracoke and Hatteras inlets, juvenile blue crab density rose significantly with increasing seagrass blade length, not with biomass or shoot abundance (Etherington and Eggleston 2000). In the Chesapeake Bay area, juvenile crabs grow faster, occur more densely, and survive at higher rates in SAV beds (Chesapeake Bay Commission 1997; Heck and Orth 1980). Hovel (2003) correlated the survival of juvenile crabs to SAV landscape characteristics such as patch size, isolation, and edge proximity in Back Sound. Survival was positively correlated with patch area and negatively correlated with shoot biomass.

In coastal riverine systems, finfish, shellfish, and crustaceans, particularly minnows, killifish, striped bass, largemouth bass, and molting blue crabs, utilize SAV as nursery areas (Hurley 1990). Paller (1987) found standing stock of larval fish in freshwater SAV beds to be 160 times higher than in adjacent open waters, and larvae concentrating in the interior of aquatic beds rather than in transition zones between habitats. This suggests that large SAV beds provide better refuge for larvae than equivalent areas of patchy SAV. Several studies in estuarine SAV beds found juvenile hard clams, pink shrimp, and blue crabs to be more abundant in large or continuous SAV beds than in small or patchy beds, whereas the opposite was found for adult pink and grass shrimp (Eggleston et al. 1998; Irlandi 1997; Murphey and Fonseca 1995). Hirst and Attrill (2008) found that a decrease in patch size did not affect invertebrate biodiversity, suggesting 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 (Adams and Angelovic 1970; Carr and Adams 1973; Day 1967; Meyer 1982; SAFMC 1998b). Only a few fish species are known to consume SAV directly, including 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 turtle, and West Indian manatee (SAFMC 1998b). 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 1998b). 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 been documented following over-winter foraging activity of Canada Geese (Rivers and Short 2007). Geese' consumption of plant meristems caused sexual reproduction of the remaining eelgrass to be minimal the following summer. An absence of grazers can result in excessive growth and accumulation of slime mold, which is largely responsible for SAV wasting disease (Jackson et al. 2001). The balancing of SAV abundance and grazer populations is an example of ecosystem management.

Large predatory fish, (e.g., stingrays, flounders, bluefish, sharks, weakfish, red drum, spotted seatrout, blue crabs), are attracted to SAV beds for their concentrations of juvenile fish and shellfish (Thayer et al. 1984). Though large shellfish predators (e.g., cownose ray) represent a small proportion of the fish biomass in SAV habitat, they can be important in structuring seagrass communities, and can uproot grasses or alter the substrate (Orth 1975). Overharvesting predators of shellfish consumers (e.g., coastal sharks, skates) could therefore lead to increasing damage on their foraging habitat (Myers et al. 2007).

4.2.4.5. Corridor and connectivity

For some species, 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). Organisms associated with marsh edge habitat at high tide are provided refuge at low tide by SAV adjacent to marshes (Rozas and Odum 1987). Consequently, fish catch was higher at sites with both marsh and SAV. In a North Carolina estuary where SAV occurred adjacent to intertidal marsh, pinfish showed more movement, abundance, and weight than those in areas lacking SAV. These findings indicate that SAV provided safe passage and additional food resources (Irlandi and Crawford 1997). Another North Carolina study found adult fish abundances were greater where marsh, seagrass, and oyster reefs co-occurred, than in reefs or reefs with marsh (Grabowski et al. 2000). The corridor function of SAV may also apply to small predators susceptible to predation in open water.

4.2.4.6. Bird Utilization

Submerged aquatic vegetation is critical habitat for birds. Wading birds utilize SAV for foraging (Lantz et al. 2010). Lantz et al. (2010) experimentally showed that wading birds prefer shallow areas with dense SAV over the less dense areas, possibly as an expectation of higher density of prey.

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 may occur (Fonseca et al. 1998). Globally, SAV abundance is declining with approximately 14 % (10 species) of all seagrass species at an elevated risk for extinction and three at an endangered level (Short et al. 2011). 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 in > 215 studies and 1,800 observations dating 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, 30% in the northern portion of Indian River Lagoon, and as much as 90% in Galveston Bay, Texas, and Chesapeake Bay (Kemp et al. 1983; Pulich and White 1991; Smith 1998; Taylor and Saloman 1968). 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 sounds (North Carolina Sea Grant 1997), (J. Hawkins, pers. com., B. J. Copeland, pers. com.).

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:

- Fishermen with journal accounts from the late 1800s describe extensive beds of SAV in 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, generally re-established by the 1960s.
- In 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 loss of eelgrass beds along the AIWW (Morehead City area) and near Harkers Island. There was a die-off of SAV in the Perquimans River after Hurricane Floyd in 1999 (S. Chappell, DMF, pers. obs.). A resurgence of SAV during the 1990’s in some locations was implied by complaints about abundant grass 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 in many shallow areas of Albemarle Sound and its tributaries, especially in Perquimans River (S. Winslow, DMF, pers. com.).
- In 2007 and 2008, DMF biologists reported extensive SAV growth throughout the estuaries (attributed to drought and lack of storms). The trend continued in most areas through 2014.

Quantitative information on SAV status and trends comes in three forms: 1) station monitoring, 2) transect monitoring, and 3) areal coverage monitoring. The earliest data comes from a 70+ year 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, with a major decline in 1918 attributed mainly to turbidity (Bourn 1932; Davis and Brinson 1983). The locks of the Albemarle and Chesapeake Canal were opened during this time. This canal connects the Norfolk Harbor at the mouth of the Chesapeake Bay with Currituck Sound, via the North Landing River. From 1914 to 1918 the canal was deepened and widened, and the river was extensively dredged. In 1932, operation of the canal locks was modified and SAV began recovery. Fully recovered by 1951, SAV had the highest production in the Currituck-Back Bay system since 1918 (Davis and Brinson 1983). During 1954 and 1955, four hurricanes along North Carolina increased turbidities and resulted in widespread destruction of SAV beds (Dickson 1958). The community recovered rapidly, as growth was considered good by 1957 (Davis and Brinson 1983). After a severe nor'easter in 1962, saltwater intrusion in Currituck Sound raised the average salinity by 4.4 ppt, causing major reductions in freshwater SAV biomass (Davis and Brinson 1983).

As SAV beds recovered after 1962, Eurasian watermilfoil (non-native) began to spread across Currituck Sound from its northern extremities (Davis and Brinson 1983), possibly encouraged by improved water clarity due to dry conditions, and higher post-1962 salinities. Before this time native sago pondweed and wild celery were dominant and subdominant. By 1973, Eurasian watermilfoil had become the dominant aquatic plant species, followed by bushy pondweed. After a severe storm in 1978, bushy pondweed was virtually eliminated, and macrophyte biomass was 42% less than in 1973, again associated with extreme turbidity from severe weather during the early growing season. 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, ECSU, unpublished data) and USACE (Piatkowski 2011).

Coast-wide aerial photography of SAV combined with on-site sampling is the standard method for mapping. The history of mapping in North Carolina estuaries began in 1981 with digitizing aerial photographs of Core and Bogue sounds (Carraway and Priddy 1983). The largest mapping coverage (Albemarle-Pamlico) over the shortest time period (1983–1992) was completed by NOAA and published in Ferguson and Wood (1994). Since then, comparable repeat mapping is available for the Neuse River, Currituck Sound, and Back Bay (Virginia). The Neuse River was remapped in 1998 by DWQ, and Currituck Sound and Back Bay were remapped by ECSU in 2003. Basic change analysis was only 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 it in 1991, indicating there was not a major decline in SAV abundance over the seven-year period. More SAV was identified in 1998 than in 1991, possibly due to differences in methodology. In 2006, NOAA acquired SAV imagery of Core and Bogue sounds and completed digitizing in 2009 (D. Field, NOAA, pers. com.). The Multiple years of data for Bogue and Core sounds (Carraway and Priddy 1983; Ferguson and Wood 1994) suggest the possibility of change analysis. Non-digitized imagery is available for the purpose of SAV mapping and change analysis, the earliest funded by DOT in 2004 for Pea Island in northern Pamlico Sound, without field verification.

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. This interagency workgroup began in summer 2001, with the formation of the SAV Partnership, to pool resources with a common interest in assessing SAV habitat along the North Carolina and southeast Virginia coastal region. The Albemarle-Pamlico National Estuarine Partnership (APNEP) was the lead agency initially, but it now rotates among participating agencies. A Memorandum of Understanding formalized agency participation in a combined effort to map and monitor SAV habitat. The stated goal of the Partners is to “manage and conserve SAV habitats in the coastal areas of North Carolina and southeastern Virginia in a comprehensive manner through cooperative research, monitoring, restoration and educational activities.”

The first aerial surveys in support of this goal were flown during fall of 2003 in the northern coastal area. In 2007 and 2008, all areas known to potentially support SAV were mapped with aerial photography and field ground-truthing. This was accomplished with a collaborative effort pooling resources. The APNEP allocated $160,000 toward funding the imagery and an additional $130,000 was contributed by USFWS, DMF, DENR, and NOAA. The NOAA determined imagery specifications and secured the contract. The DMF monitored pre-flight conditions for suitability, organized field sampling, and conducted most of the ground-truthing. Staff from ECU, ECSU, DWR, DOT, WRC, NERR, FWS, and DCM also assisted. Over 90% of the flight lines were covered in 2007, with remaining areas flown in 2008.

In 2013, a subset of the SAV partnership completed a Coastal Recreational Fishing License Grant. The purpose of the grant was to investigate and recommend the best method for long-term mapping and monitoring of SAV. Partnering organizations for this grant included APNEP, NOAA, NCSU, and ECU. The study recommended that mapping be done regionally on five year cycles, breaking the coast into five regions (Figure 4.2). Aerial photography was recommended by the grant partners for mapping high salinity grass beds due to the greater visibility. For low salinity areas, they recommended using acoustic SONAR to conduct surveys, and periodic underwater video to ground-truth acoustic results. Use of this protocol can discern changes in SAV coverage from 10% to 40% at a site (Kenworthy 2012). The areas mapped since the coastwide mapping event in 2007-2008 are shown in Table 4.5.

TABLE 4.5. Areas mapped or proposed for mapping since the 2007-2008 coastwide SAV mapping effort.

Date	Area	Method
Fall 2012	Currituck Sound	Aerial
Spring 2013	East Pamlico Sound to White Oak River	Aerial
Summer-Fall 2014	Albemarle Sound	SONAR
Planned for Fall 2015	Tar/Pamlico River	SONAR
Planned for Spring 2015	South of White Oak River	Aerial

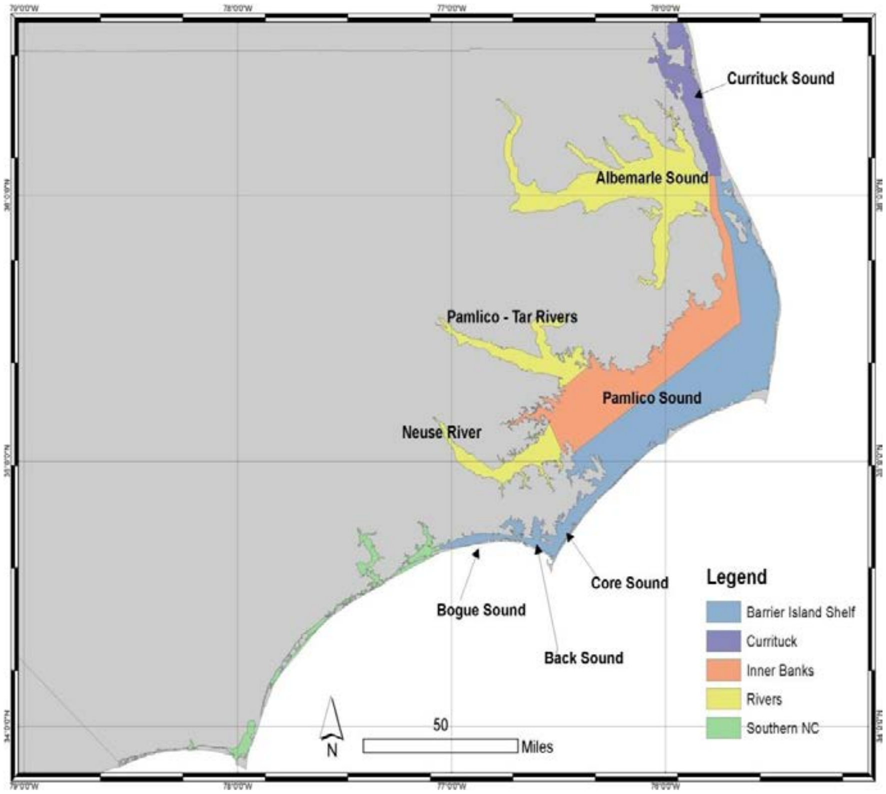


FIGURE 4.2. Recommended geographical stratification of North Carolina estuaries and river systems for SAV monitoring in a rotational sampling scheme.

The SAV mapping and monitoring protocol calls for annual sampling of sentinel sites. Trend analysis will require annual visits to various sites across coastal North Carolina. Random site selection will need to be employed for early detection of changes in areas outside of the sentinel sites (Kenworthy et al. 2012).

4.3.2. Status of associated fishery stocks

It is difficult to attribute changes in fish abundance to changes in habitat for lack of data. Assessments have been attempted for penaeid shrimp and red drum. Habitat relationships of certain life stages of fishery species 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 to estimate an overall population size of 1.3 billion in Galveston Bay. Levin and Stunz (2005) estimated that habitat for red drum larvae and juveniles should be given the highest priority for protection. Analyses have not been conducted in North Carolina.

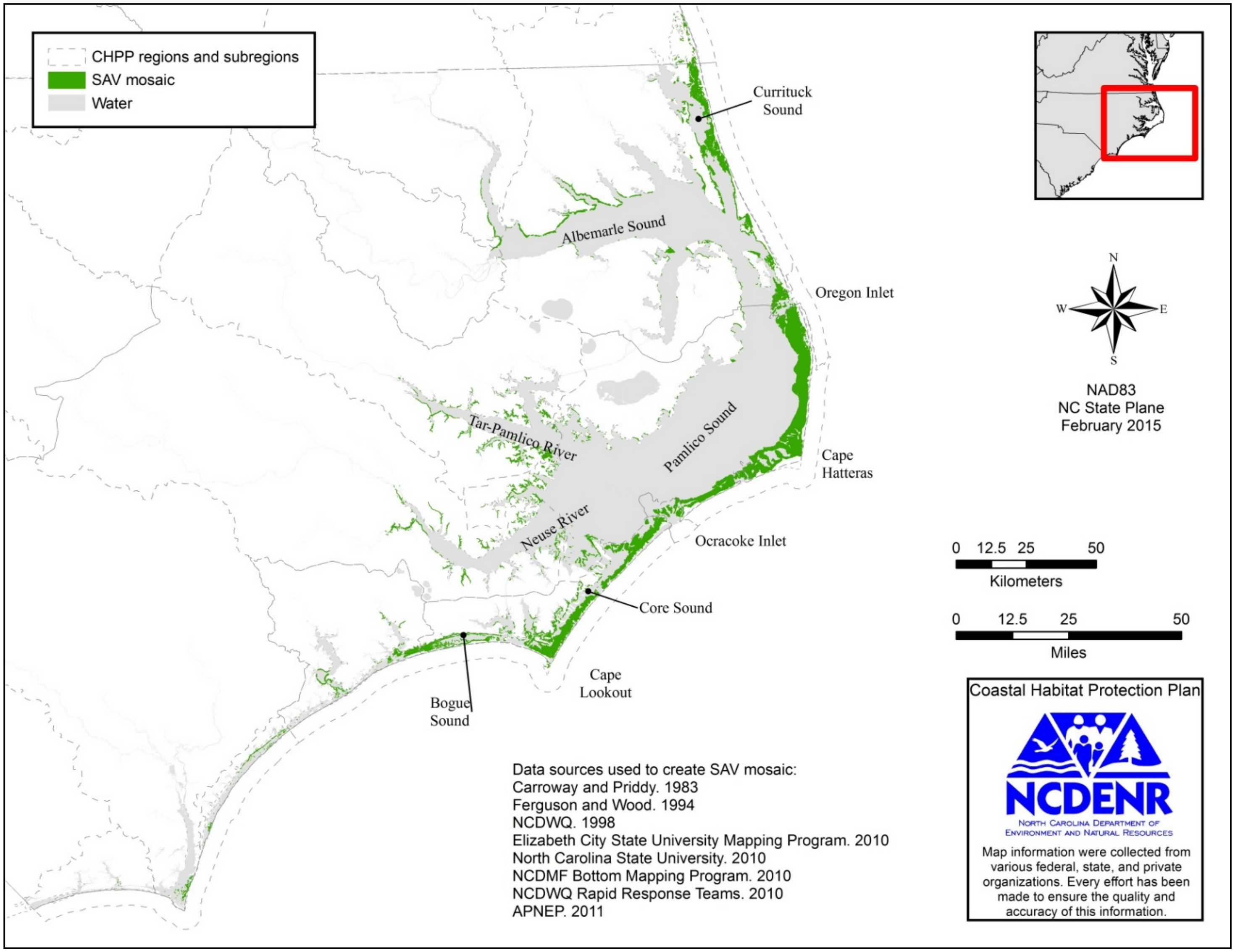
Estimated fishing mortality and juvenile abundance indices are used by DMF to determine the status of fishery stocks. Stock status evaluations may suggest habitat issues for *Concern* or *Depleted* species. Of the species identified in Table 4.4 with a preference for SAV habitat, 8 stocks were evaluated for fishery status. 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) (DMF 2014). Whereas much of the cause of declining stock status is attributed to overfishing, habitat loss and degradation can make a stock more susceptible. Protected or enhanced SAV habitat can be particularly beneficial to SAV-enhanced species classified as *Depleted* or *Concern*, by maximizing recruitment and productivity (Minello 1999; Minello et al. 2003; SAFMC 1998b; Thayer et al. 1984).

4.4. Submerged aquatic vegetation summary

The ecological importance of SAV habitat is well documented in literature; research monitoring fish use of SAV of various patchiness or density is finding that SAV presence, regardless of bed shape or density, supports a greater diversity and abundance of organisms than unvegetated bottom. Valuation studies indicate the monetary value of ecosystem services provided by SAV is significant. With North Carolina having the second largest expanse of SAV on the east coast, protection and enhancement of this resource should be a high priority for the state.

Natural events, human activities, and an ever-changing climate influence the distribution and quality of SAV habitat. Natural events include shifts in salinity due to drought and excessive rainfall, animal foraging, storm events, temperature, and disease. Submerged vegetation is vulnerable to water quality degradation, in particular, suspended sediment and pollutant runoff.

Digitizing SAV polygons on aerial imagery was completed after the 2010 CHPP, and rotational updating of this process is currently underway. Additional mapping in western Pamlico Sound, Neuse River, and Tar/Pamlico River by DMF and DWR have increased the total area of mapped SAV to over 196,000 acres (NCDMF 2015a). Mapping SAV using aerial imagery to assess status and trends is a large and difficult task that must be augmented with monitoring.



MAP 4. 1 Submerged aquatic vegetation mapped from 1981 to 2011. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not reflect current state, as data dates to 1981.

CHAPTER 5. WETLANDS

The global community recognizes the inherent value of our wetlands (168 Ramsar contracting parties). The following mission statements substantiate and validate the need for research, education, and action to protect the remaining wetlands in North Carolina.

The Ramsar International Conventions on Wetlands 1971

The Convention's mission is "the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world."

National Ocean Policy Implementation Plan 2013

The health and integrity of coastal habitats—such as coral reefs, wetlands, mangroves, salt marshes, and sea grass beds—are key to sustaining our nation's valuable coastal and ocean ecosystems and the wealth of benefits they provide to us.

NC Coastal Area Management Act 1978

It is the objective of the Coastal Resources Commission to conserve and manage coastal wetlands so as to safeguard and perpetuate their biological, social, economic and aesthetic values, and to coordinate and establish a management system capable of conserving and utilizing coastal wetlands as a natural resource essential to the functioning of the entire estuarine system.

Wetlands are essential breeding, rearing, and feeding grounds for many species of fish and wildlife. They provide critical ecosystem services that contribute to healthy ecosystems and fisheries habitat. Coastal wetlands cover 40 million acres, or 38 percent of the wetlands in the continental United States, with 81% in the southeast. From 2004 to 2009, wetlands in the U.S. coastal watersheds declined by ±360,720 acres, 31% being on the Atlantic Coast (Dahl and Stedman 2013).

5.1. Description and Distribution

5.1.1. Definition

Wetlands require the presence of water at or near the surface, and vegetation adapted to wet soils (Mitsch and Gosselink 1993). Defined by EPA [40 CFR 230.3(t)], used for regulatory purposes, wetlands are: "those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions." This definition and that of the NC Environmental Management Commission (EMC), include freshwater wetlands. The coastal wetlands definition under the Coastal Area Management Act does not: "any salt marsh or other marsh subject to regular or occasional flooding by tides, including wind tides … provided this shall not include hurricane or tropical storm tides." Division of Coastal Management regulated wetlands must contain one or more of the following: *Spartina alterniflora*, *Juncus roemerianus*, *Salicornia* spp., *Distichlis spicata*, *Limonium* spp., *Scirpus* spp., *Cladium jamaicense*, *Typha* spp., *Spartina patens, and S. cynosuroides*.

This chapter will focus on wetlands contiguous with coastal water bodies directly affecting fishery habitats while addressing fringe and non-riparian wetlands supportive of riverine and estuarine systems.

5.1.2. Description

Riparian wetlands abut water bodies, and provide numerous functions that protect water resources. They trap sediment, nutrients, and pollutants from overland runoff, and reduce the magnitude and velocity of flood waters, slowly releasing them into the waterbody. In general, wetlands protect and enhance the quality of the contiguous ecosystem.

For purposes of this chapter, riparian wetlands will be grouped into those categories most frequently utilized by fish: estuarine, and riverine, with the focus on saltwater and brackish marsh, freshwater marsh, and to a lesser degree, bottomland hardwood forest. Non-riparian headwater and pocosin wetlands will be discussed in lesser detail.

Estuarine wetlands are found along the margins of estuaries, and include salt/brackish marsh, estuarine shrub/scrub, and estuarine forests. While the salt and brackish marshes interact most directly with coastal waters, the adjacent wetlands perform myriad of ecosystem services as they transition inland for what can sometimes be miles across low-lying coastal habitat.

- Salt/brackish marshes - herbaceous plant communities subject to tides, containing species such as cordgrass, black needlerush, glasswort, salt grass, sea lavender, and salt meadow hay.
- Estuarine shrub/scrub - vegetation <20’ tall, subject to occasional tides. Usually found at the high end of coastal marshes, inclusive of species such as wax myrtle, marsh elder, and yaupon holly.
- Estuarine forested wetlands - forested communities ≥20’ tall, subject to occasional tides. Typical species include pine, cypress, black and sweet gums, and oaks.

Salt marsh occurs in salinities >15 ppt and brackish marsh occurs from 0.5-15 ppt. Within these salinity ranges, salt-tolerant plants persist in absence of excessive erosion stress. The rate of erosion depends on shoreline orientation, fetch, water depth, bank height, sediment bank composition, shoreline vegetation, and presence of offshore vegetation. Few species can survive the high salinity and frequent inundation of low marshes. Estuarine shrub scrub requires less tidal influx than marshes, and more fresh overland and pore water influence. Estuarine forested wetlands require intermittent flooding, being of short duration with periods of very low flow (Schafale and Weakley 1990).

The hydrology of riverine wetlands is determined by proximity to perennial streams with salinities <0.5 ppt. Overbank flow feeds the adjacent wetlands. Riverine wetlands include tidal and non-tidal freshwater marshes, and bottomland hardwood and riverine swamp forests.

- Freshwater marshes are herbaceous areas flooded for extended periods during the growing season. Communities include sedges, millets, rushes, and giant cane.
- Bottomland hardwood forests and riverine swamp forests are usually found in floodplains, seasonally to permanently flooded. Bottomland hardwood forests contain mostly oaks, sweet gum, green ash, willows, and river birch. Riverine swamp forests contain cypress, black gum, water tupelo, green ash and red maple.

Tidal freshwater wetlands occupy the upper limits of tidal influence where brackish water meets downstream flow (Perillo et al. 2009). They have more diverse plant communities than salt/brackish marshes due to increased soil aeration and lack of salinity stress (Odum et al. 1984; Perillo et al. 2009). Some fish (e.g., carp, sunfish, bass, catfish) spend their entire lives in tidal freshwater marshes (Mitsch and Gosselink 1993). The hydrology of non-tidal freshwater wetlands is more variable, owing to uncertain water budgets. These communities are adapted to survive in varying water levels.

Bottomland hardwood forests are irregularly to seasonally flooded, while riverine swamp forests are semi-permanently to permanently flooded. The timing and duration of flooding affects not only the type of vegetation, but the type and regularity of fish use.

Palustrine wetlands include non-tidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses/lichens, and small, shallow, ponds. Headwater wetlands are palustrine, and develop upstream in systems with intermittent or perennial tributary streams. Some contain intermittent channels with primary water sources of precipitation, overland runoff, and groundwater discharge. Headwater swamps are forested, with moist soils conducive to hardwood communities. Headwater wetlands are critical in buffering harmful effects of land use, thereby protecting downstream waters.

Pocosin wetlands, within the palustrine category, are not generally proximate to surface waters. While they are hydrologically disconnected, the hydrology of the pocosin wetland is primarily determined by groundwater and precipitation. Pocosins are non-riparian wetlands very often formed by perched water tables owing to poor soil conditions. The very word pocosin means "swamp on a hill" in Algonquian.

5.1.3. Distribution

According to the 2011 NLCD, there were ±3,759,729 acres of woody and emergent herbaceous wetlands within the CHPP regions (Jin et al. 2013). This represents a 2.7% decrease in woody wetlands and an 18.9% increase in emergent herbaceous wetlands since 2001. The US Fish and Wildlife Service (FWS) has produced the National Wetlands Inventory (NWI) of the United States since the mid 1970's. The NWI geospatial dataset classifies wetlands from aerial imagery following the Cowardin et al. (1979) classification system. Within the CHPP management area, most of the NWI data (±8,494,790 acres) is based on imagery from the 1980's. However, much of the outer coastline (±5,637,832 acres) is based on imagery flown since 2004. For this discussion, the Cowardin classification codes from the NWI data were further classified into the CHPP's targeted wetland types (salt/brackish marsh, freshwater marsh, bottomland hardwood, swamp forest, and pocosin) (Sutter 1999). In 1994, DCM led an effort to map wetlands in the 20 coastal counties using NWI maps, NRCS soil maps, satellite imagery (1988, 1994), and hydrography maps (USGS Digital Line Graphs). The results showed a total of between 3.1 and 3.9 million acres of unaltered riparian and non-riparian wetlands, respectively (piers and docks spanning marsh were not considered "altered," and therefore counted as unaltered wetlands), in the CHPP management area at that time. The 1994 DCM maps have not been updated, and therefore are not included in this discussion, although a detailed discussion can be found in the 2005 and 2010 CHPP documents.

Abundance and distribution of targeted wetland types from the NWI are defined in Table 5.1. Salt/ brackish marsh accounted for ±228,146 acres, or 7.5% of target wetland types within the CHPP management area, with the greatest acreage in CHPP Region 2. Freshwater marsh represented ±101,582 acres, accounting for 3.3% of target wetland types, with the greatest acreage also in CHPP Region 2. Bottomland Hardwood/Swamp Forest had ±1,734,102 acres, or 57% of target wetland types, the greatest acreage in Region 1. Pocosins accounted for ±976,049 acres, or 32.1% of target wetland types, with the greatest amount in Region 4.

TABLE 5.1. Total acreage of wetlands by CHPP region. [Source: NWI data (derived from imagery spanning 1977-2010). Cowardin classifications assigned by the NWI were reclassified into wetland types following (Sutter 1999).

Wetland Type	CHPP Regions						Total Acres (By Wetland Type)	% of Wetland Area
	1	1/2	2	2/3	3	4		
Salt/Brackish Marsh	45,416	576	107,697	9	47,048	27,400	228,146	7.5%
Freshwater Marsh	30,555	0	44,086	0	4,836	22,105	101,582	3.3%
Bottomland Hardwood/ Swamp Forest	705,887	0	549,919	0	53,892	424,405	1,734,102	57.0%
Pocosin	154,610	0	325,773	0	150,232	345,435	976,049	32.1%
Total Wetland Acres	936,468	576	1,027,475	9	256,007	819,345	3,039,880	100.0%
Total Region Acres	3,719,900	54,777	5,851,000	37,166	1,138,270	3,495,690	14,296,803	N/A
% Wetlands in Region	25%	1%	18%	0%	22%	23%	21	N/A

1 = Albermarle 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

5.2. Ecological roles and functions

The services provided by wetlands are vast, including improving the quality of habitats through water control and filtration; protecting upland habitats from erosion; providing abundant food and cover for finfish, shellfish, and other wildlife; and contributing to the economy. Recent research shows the critical importance of even narrow fringe wetland edges for fish utilization and erosion control (Gewant and Bollens 2012; MacRae and Cowan 2010; Minello et al. 2011; Whaley and Minello 2002).

5.2.1. Ecosystem enhancement

Flood control and water quality benefits of wetlands have been extensively studied. Some store flood waters and slowly release them to surface and groundwater systems during periods of low flow (Mitsch and Gosselink 1993). By storing, spreading, and slowing releasing waters, flooding is reduced. Wetland loss has been linked to increased hurricane flood damage. Costanza et al. (2008b) estimated that the loss of 1 acre of coastal wetlands could result in a $13,360 loss in GDP ($14,759 in 2014 dollars), and that U.S. coastal wetlands could provide as much as $23.2 billion/year (25.63 billion/year in 2014 dollars) in storm protection services.

Rooted vegetation consolidates sediment, buffers erosive forces, and improves water clarity for SAV and benthic microalgae (Mitsch and Gosselink 1993; Riggs 2001). Studies have shown that even narrow (7-25m) marsh borders reduce wave energy by 60-95% (Knutson and Inskeep 1982; Morgan et al. 2009). Buffering sediment-laden water allows deposition of suspended solids onto the marsh substrate (Mitsch and Gosselink 1993). Under favorable conditions, toxic chemicals, minerals, and nutrients are retained by adsorption to sediment particles (Mitsch and Gosselink 1993; Wolfe and Rice 1972). The sediment is subsequently deposited, buried, accumulated in peat, decomposed, or otherwise stored. These processes, including nitrogen processing, can prevent nutrient over-enrichment, resulting in oxygen stress, and can remove chemicals from the water through conversion and plant uptake. Forested riparian wetlands in agricultural drainages have been shown to remove ~80% of the phosphorus and 90% of the nitrogen from the water (EPA 2006). Constructed wetland systems can reduce excess nutrients in adjacent waterbodies. These systems remove nitrogen by transforming it into inert nitrogen gas (Song et al. 2014). Research by Song et al. (2014) of UNC Wilmington helped characterize the microbial processes that allow this transformation to occur.

Marshes are silica storing repositories, critical for benthic diatom production (Hackney et al. 2000; Struyf et al. 2005). Maintaining high concentrations of silica is important, as it supports an abundance of diatoms, critical for secondary production of commercial fish and crustaceans (Hackney et al. 2000). Recent studies have revealed the importance of freshwater and coastal marshes in storing silicon (Hackney et al. 2000; Struyf et al. 2005). 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). There is evidence that salt/brackish marshes act as nutrient sources during the growing season, and as sinks in winter and spring (Woodwell et al. 1979). Retention and controlled release of particles, toxic chemicals, and nutrients can improve water quality downstream, hence, "wetland sinks."

The most active uptake and retention of nutrients in riverine systems can be found in headwater wetlands (Meyer et al. 2007; Peterson et al. 2001; Thompson et al. 1998). These upstream wetlands influence the potential for erosion, flooding, sedimentation, algal blooms, and fish kills downstream. Though non-riparian wetlands are rarely used by fish, they can have a significant effect on riparian water quality. Pocosins cover a vast and continuous expanse of the coastal North Carolina landscape and are connected to surface waters through shallow aquifers. Thus, their effect is less obvious but undeniable.

5.2.2. Productivity

Wetland communities are among the most productive ecosystems in the world (Mitsch and Gosselink 1993; SAFMC 1998b; Teal and Teal 1969). 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 (Mitsch and Gosselink 1993; Wiegert and Freeman 1990). King and Lester (1995) estimated that an 80 m wide saltmarsh border could provide shore protection savings in the amount of $0.76 to $1.42 million/ha in capital costs, and $14,182/ha in annual maintenance costs.

5.2.2.1. Salt/brackish marsh

Salt marshes are widely recognized as being among the most productive ecosystems in the world, and contributing considerably to the production and transport of nutrients and detrital matter. Primary production in salt/brackish marshes is converted into fish production in several ways. Experiments using sulfur, carbon, and nitrogen isotopes to trace organic matter flow in the salt marshes of Sapelo Island, Georgia 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 consumers (Peterson and Howarth 1987). Benthic microalgae support herbivorous snails, whereas detritus supports sheepshead, mummichogs, and their prey. Algae can be found on marsh grass, intertidal mudflats, and shallow subtidal bottom near the marsh.

5.2.2.2. Freshwater marsh

Lacking saltwater stress, tidal freshwater marshes can be as or even more productive and diverse than saltwater marshes (Mitsch and Gosselink 1993). Frequency and duration of flooding affect productivity. Regularly flooded herbaceous sites are reported to have higher productivity than irregularly flooded (Schafale and Weakley 1990). In general, grasses are more productive than broad leaved species. Since plant material above and below ground must decay to lend productivity to the system, various factors come into play. While temperature, organic export, and energy flow all influence the rates of decay and transport, temperature is most important. Higher temperatures cause faster decay, allowing for the transport of nutrients and detritus. In general, nutrient cycling and budgets in coastal freshwater wetlands are similar to those in salt marshes (Mitsch and Gosselink 1993), however, macrophyte diversity, biomass, and nutrient retention decreases from tidal fresh to tidal salt marshes (Węski et al. 2010). Removal of nitrogen from surface water by freshwater marshes is approximately 50% and phosphorus removal is approximately 10-15% of inputs (Mitsch and Gosselink 1993).

5.2.2.3. Bottomland hardwood and riverine swamp forest

Productivity in riverine forested wetlands may be similar to salt/brackish marsh when stem growth and below ground production are taken into account. The export of detritus from riverine forested wetlands can be significant (Mitsch and Gosselink 1993), but varies with temperature and frequency of inundation. Variation in water budget is key in the productivity of wooded swamps. Floodplain forests with unaltered hydroperiods generally have aboveground net primary productivity in excess of 1000 $g/m^2/yr$ (Taylor et al. 1990). Day et al. (1977) found that high productivities of the floodplain forest are made possible by several subsidies offered by the watershed, including particulate and dissolved organic matter, water, soil (especially clay and silt), and nutrients. These inputs support an increased rate of ecosystem metabolism, reflected in litterfall and nutrient turnover rates, detrital decomposition rates, flushing of refractory organic detritus and metabolic by-products, and the operation of several microbial conversion processes. Additionally, macro- and microfauna during flood periods speed detrital decomposition and participate in floodplain food chains, nutrient cycles, and import/export pathways. Floodplain forests are among the highest in primary productivity of any ecosystem in the southeastern United States (Day et al. 1977). A forested wetland overlaying permeable soil may release up to 100,000 gallons of water per acre per day into the groundwater (Anderson and Rockel 1991).

5.2.2.4. Headwater and pocosin wetland

An estimated 70% of the United States' pocosins occur on North Carolina's coastal plains. Nutrients and other compounds removed by atmospheric deposition into pocosins via rainfall are retained for long periods, and released slowly through lateral flow. Pocosins are hydrologically connected to waters of the coastal plain by broad scale surface flow to adjacent estuaries, and their presence is essential to the continued productivity of these estuaries (Richardson 2003). Such wetlands must be managed to protect the enhanced water quality service they provide and for the function primarily responsible for their existence - that of responding to rising sea level by accretion of sediments (Brinson 1991).

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 Zelazny 1987). In the southeast, fish and shellfish depending on coastal and estuarine wetlands comprise the majority of the commercial catch (Lellis-Dibble et al. 2008)(Table 5.2). In studying the changing environment of the Mississippi River Deltaic Plain (MRDP), (Madden et al. 1988) showed that migratory patterns and food habits of fish assemblages were similar among the fresh, mesohaline, and polyhaline systems. In all three estuaries, the most abundant species were bay anchovy, Atlantic croaker, gulf menhaden, sand seatrout, and hardhead catfish.

5.2.3.1. Salt/brackish marsh

Finfish and shellfish using salt/brackish marsh are categorized based on location and time of use. Year-round residents include small forage species such as killifish, mummichogs, sheepshead minnows, gobies, grass shrimp, bay anchovies, and silversides (SAFMC 1998b). Transient species include those spawned in deeper waters and using marsh habitat for nursery or foraging, such as red drum, flounder, spot, and croaker. Some transients prefer the marsh edge, e.g., red drum and flounder, while others prefer the unvegetated area near the edge, e.g., spot and croaker. Some species are not found in the marsh, but feed on detrital export or microalgae, such as menhaden. Of fisheries in North Carolina, penaeid shrimp and red drum are considered critically linked to the marsh edge (SAFMC 1998b). Limited studies have shown positive correlations between flooding duration and regularity in marsh habitat selection for brown and white shrimp, and blue crab (Minello et al. 2011). Studies of nekton movement have shown a consistent pattern of resident species entering early in the rising tide, and transient species entering mid to late tide (Bretsch and Allen 2006). The depth of migrations among species was also consistent between creeks, days, and years. Variation occurred as summer progressed, with some species, e.g., spot, mullet, and pinfish, moving into deeper water.

Fish use of low salinity marshes in North Carolina was studied by Rozas and Hackney (1984), finding a combination of freshwater and estuarine species. Most abundant were spot, grass shrimp, bay anchovy, and Atlantic menhaden. Seasonal abundance peaks were: (1) spring of juvenile spot, Atlantic menhaden, Atlantic croaker, southern flounder (2) summer of grass shrimp (3) fall of bay anchovy, grass shrimp.

5.2.3.2. Freshwater marsh

Fish utilizing 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 the marsh is species-dependent. Striped bass and river herring are abundant along and adjacent to the marsh edge. Bluegill, black crappie, largemouth bass, and warmouth are almost exclusive to near shore structures. Mosquitofish are important forage species and “mosquito control agents,” associated with freshwater marsh (Odum et al. 1984). McIvor and Odum (1987) found that when marshes contiguous with tidal creeks become inundated, fish swim with flood tides onto the marsh surface. Because of unfavorable physicochemical conditions, such as high temperatures and low DO, and/or physical constraints of shallow water, studies show that the upper reaches of tidal creeks have a particular absence in predators (Hackney et al. 1976; Rozas and Hackney 1984; Shenker and Dean 1979).

5.2.3.3. Bottomland hardwood and riverine swamp forest

There is a strong relationship between fishery yields and forested river floodplains (Junk et al. 1989; Mitsch and Gosselink 1993; Wharton et al. 1982). Studies have shown fish production to be greater in floodplain sloughs than in the main river (Holder et al. 1970), and in wetlands that dried less often, were connected to intermittent water bodies, and had elevations close to the nearest permanent waterbody (Snodgrass et al. 1996). Fish use of riverine forested wetlands is largely restricted to periods of seasonal inundation. In North Carolina, seasonal high water in riverine systems generally occurs from winter to spring. Summer conditions (falling water levels, increasing temperatures, and low DO) exclude most fish. However, fish adapted to low DO levels, e.g., bowfin, gar, mudminnows, killifish (Wharton et al. 1982), continue to inhabit forested wetlands as long as water remains. A study on fish use of creek floodplains in North Carolina documented several common species using channels in the floodplain (Walker 1984), such as sunfishes, redfin pickerel, bowfin, brown bullheads, killifish, pumpkinseed, shiners, darters, and crayfish. Estuarine-dependent species found in river floodplains include hickory shad, blueback herring (Wharton et al. 1982), and alewife (SAFMC 1998b). At least 20 families and 53 species of fish spawn and/or feed on the floodplain (Walker 1984; Wharton et al. 1982).

5.2.3.4. Headwater and pocosin wetlands

Fish use of normally isolated wetlands (e.g., 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). Where pocosins are in close proximity to primary nursery areas, they may have a direct influence on water quality and saltwater stratification (Brinson 1991). Headwater wetlands are not normally occupied by fish, but as has been described, they have a significant impact on the quality of the waters inhabited by the fisheries themselves.

5.2.4. Specific biological functions

5.2.4.1 Nursery

Expanses of vegetated shallow water habitat in riparian wetlands provide food and cover for larval, juvenile and small organisms (Graff and Middleton 2000). Refuge from predators is provided by dense structures, shallow depth, and expanse of water (Rozas and Odum 1987). Large, deep-bodied predators avoid shallows, thereby protecting smaller fish and reducing predation in the shallow tidal creeks.

Salt/brackish marsh

Along with the shallow soft bottom and shell hash borders, salt/brackish marshes along North Carolina's coast are probably the most recognizable nursery habitat for estuarine-dependent species. Detrital export and the shelter found along marsh edges make salt marshes important as nursery areas for many commercially important fish and shellfish (Mitsch and Gosselink 1993). The majority of Primary and Secondary Nursery Areas designated by the MFC are located in these habitats.

Many of the juvenile fish species found in estuarine nurseries were spawned offshore during winter, with larvae transported through inlets and into estuarine waters where they settled in the upper (lower salinity) or lower (higher salinity) reaches of creek systems (Ross 2003). Peak 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 (Ross 2003).

The DMF's juvenile abundance survey data shows the dominant species in high salinity marshes behind Outer Banks and in Core Sound to include pinfish, blue crab, brown shrimp, pigfish, silver perch, gulf and summer flounder (NCDMF 2009a)(actively updated database, although the date would imply otherwise). Juvenile spot, brown shrimp, striped mullet, and southern flounder predominate the western shores of Pamlico and Core Sounds and their tributaries (Epperly and Ross 1986; Noble and Monroe 1991b). In the Newport River estuary, juvenile southern flounder show preference for marsh edge habitat during fall (Walsh et al. 1999). Juvenile southern flounder are most abundant in more turbid, upper regions of the estuary. In high salinity marshes of Pamlico Sound, spotted seatrout, weakfish, silver perch, and red drum are abundant (Noble and Monroe 1991b). 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 demersal species such as Atlantic croaker, brown shrimp, blue crab, red drum, and southern flounder (Noble and Monroe 1991a; Tagatz and Dudley 1961).

Salt/brackish marsh substrates differ, and some, such as peat, provide important nursery habitat. Peat blocks are generally found along eroding marsh edges serving as firm substrate for sessile invertebrate attachment, and refuge for juvenile blue crabs (D. Eggleston, NCSU, pers. com.).

Freshwater marsh

Freshwater marshes comprise a small portion of riparian wetlands in coastal North Carolina. A study in Virginia found that larval and juvenile fish represented 79% and 59% of the number of fish collected at tidal freshwater and salt marsh sites, respectively (Yozzo and Smith 1997). Anadromous fish pass through freshwater marshes as they make their way to freshwater streams to spawn. For some, tidal freshwater marshes become the nursery area for juveniles (Mitsch and Gosselink 1993). The American eel, being catadromous, spends most of its life in tidal and non tidal marshes and creeks, returning to the ocean to spawn (Lippson et al. 1981). Juveniles of several species, such as menhaden, spot, croaker, spotted trout, summer flounder, black drum, snook, tarpon, and silver perch, have extended their territories into freshwater marshes (Lippson et al. 1981).

TABLE 5.2. Partial listing of fish and their use of wetland habitat in coastal North Carolina.

	Wetland Functions [1]						
Species*	Nursery	Foraging	Refuge	Spawning	Corridor	Fishery [2]	2014 Stock Status [3]
RESIDENT FRESHWATER OR BRACKISH							
White perch	X			X		X	
Yellow perch	X	X		X		X	C
Catfish	X	X	X	X	X	X	
ANADROMOUS AND CATADROMOUS							
American eel		X	X		X	X	D
Sturgeon spp.	X	X	X		X	X [4]	D
River herring (alewife & blueback herring)	X	X	X	X	X	X	D
Striped bass	X	X	X		X	X	V-Atlantic Migratory C-Alb/Roanoke & Cen/So.
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	C
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	V-south of Hatteras R-north of Hatteras
Pinfish	X	X	X		X	X	
Summer flounder	X	X	X		X	X	V

[1] Sources: (Micheli and Peterson 1999; Minello 1999; Mitsch and Gosselink 1993; NOAA 2001; Odum et al. 1984; Wharton et al. 1982; Wiegert and Freeman 1990).
[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 (DMF 2014)
[4] Fishery species under harvest moratorium.
* Scientific names are included in Appendix D.

Freshwater inputs into estuarine systems result in high variability of salinity, turbidity, and other physiochemical gradients (Abril et al. 2002; Gonzalez-Ortegon and Drake 2012). In turn, this variability may impact the nursery function of estuarine habitats (Abril et al. 2002; Elliott and Whitfield 2011; Gonzalez-Ortegon and Drake 2012). However, comparisons between fresh, mesohaline, and polyhaline systems in the Mississippi River Deltaic Plain have shown that the increasingly fresh nursery grounds continue to function in that capacity. In particular, Atchafalaya Bay continues to function as a nursery and feeding area for migratory nekton even with a shift towards freshwater composition (Madden et al. 1988). Alternatively, nektonic communities in European estuaries have shown strong resilience associated with long-term decreases in freshwater inputs (González-Ortegón et al. 2012). Thus, while estuarine habitats experience higher levels of phisiochemical variability than other aquatic habitats, the biological structure and nursury function remain highly resilient over extended time periods (Elliott and Whitfield 2011; González-Ortegón et al. 2012).

Bottomland hardwood and riverine swamp forest

Forested wetlands are important nursery areas for anadromous and resident freshwater species (DMF 2000a; Wharton et al. 1982), and for some transient estuarine species (e.g., spot, croaker, southern flounder, blue crab) (Mallin et al. 2001c). Larval and juvenile river herring have been collected near flooded riverine forested wetlands in North Carolina (DMF 2000b). In a study of blueback herring and alewife in the Lower Roanoke River, Walsh et al. (2005), found eggs and larvae of both to be present from early April through late May, indicating that both species spawned in backwater tributaries, including flooded bottomland hardwood forests. The timing and extent of flooding are critical to fish use of bottomland hardwood and riverine swamp forests. 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; Ploskey 1986; Strange et al. 1982).

5.2.4.2 Foraging

Salt/brackish marsh

Few aquatic species feed directly on living plant tissue in salt/brackish marsh (e.g., periwinkle), and their productivity is very low compared to that of detritivores and consumers of microalgae (SAFMC 1998b; Steel 1991; Wiegert and Freeman 1990). Decomposition in salt marshes at or near the surface enhances the protein content of detritus for other estuarine organisms (Mitsch and Gosselink 1993). Almost three quarters of the detritus produced in salt marshes is broken down by bacteria and fungi (Teal 1986).

Microbial fungi and bacteria live in and on the sediment and are the primary consumers of the benthic habitat. Meiofaunal organisms forage on the primary consumers, and are then fed upon by larger invertebrates. Foraging invertebrates scour the sediment for algae, detritus and meiofauna. Filter feeders utilize the water column. Several species of reptiles, amphibians, birds, and mammals predate during low tide in remnant pools where organisms have concentrated. Thus, the production of detritus and bacteria from salt/brackish marsh exhibits some of the highest recorded values per unit area of any ecosystem in the world (Wiegert and Evans 1967).

Deegan et al. (2000) concluded that secondary production from salt marsh occurs in close proximity to the marsh. Salt marsh support of offshore fisheries is likely 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).

Freshwater marsh

Compared to salt/brackish marsh, living vegetation in freshwater marsh can be more readily consumed by insects, crayfish, muskrats, waterfowl, and carp (Mitsch and Gosselink 1993). The export of this production in the form of particulate detritus is less understood than that of salt marshes (Mitsch and Gosselink 1993; SAFMC 1998b), although it is probably similarly affected erosion and water exchange. Therefore, the rate of detrital export in slow-moving systems is lower than that of salt marshes.

The detritus remaining in the marsh provides food for meio and macrobenthic communities (Mitsch and

Gosselink 1993; Odum et al. 1984; SAFMC 1998b), as in salt marsh systems. In turn, food is provided for small fish, grass shrimp, crayfish, crabs, and waterfowl. Large fish feeding in the marsh include chain pickerel, bowfin, and gars (Odum et al. 1984). Other aquatic predators (e.g., largemouth bass, crappie) feed along the edges of freshwater marshes where there is deep water nearby (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 slowly. In spite of this, riverine forested wetlands produce abundant food for invertebrates, such as copepods, ostracods, amphipods, isopods, oligochaetes, flatworms, crayfish, and insects (Mitsch and Gosselink 1993; Wharton et al. 1982). Fish adapted to feed in riverine swamp forests include adult mosquitofish, gar, bowfin, carp and chain pickerel, and early life stages of many other species (Mitsch and Gosselink 1993; Wharton et al. 1982). Others, such as largemouth bass and catfish, are opportunistic predators within the habitat.

5.2.4.3. Refuge

Many small resident species, such as grass shrimp and killifish, find refuge from predators and adverse weather conditions among the dense vegetation of marshes (Graff and Middleton 2000; Pattilo et al. 1997; Rozas and Zimmerman 2000; SAFMC 1998b). Large, less mobile organisms also find refuge in the vegetation. Micheli and Peterson (1999) found that adult blue crabs utilize marsh edge in preference to unvegetated, open water. 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 freshwater ambush predators for vegetated habitat (Savino and Stein 1989).

5.2.4.4. Spawning

Salt/brackish marsh

The structural complexity of vegetation and intertidal submersion regime in salt/brackish marsh provide spawning habitat for forage species such as killifish, mummichogs, silversides, gobies, and grass shrimp (Anderson 1985; Pattilo et al. 1997). A large majority of the U.S. commercial fishes depend on estuaries and salt marshes for nursery or spawning grounds. Among the more familiar wetland-dependent fishes are menhaden, bluefish, fluke, seatrout, spot, mullet, croaker, striped bass, and drum (Tiner 1984).

Freshwater marsh

A diverse assortment of habitats exists where fresh and saline waters meet in the upper branches of rivers and tributaries. Most recreationally important freshwater species spawn in wetlands. Northern pike, yellow perch, carp, smallmouth bass, largemouth bass, bluegill, and bullhead, are examples of freshwater fish that spawn in wetlands. Tidal freshwater marshes can enhance spawning grounds for migratory fish like striped bass, alewife, blueback herring, hickory shad, white perch, yellow perch, and American shad. Over time, these species have selected spawning and nursery grounds in river areas contiguous to or near areas of maximum tidal freshwater marsh. Anadromous and estuarine-dependent fish make use of the entire fresh-to-salt continuum during their life cycles. All told, tidal freshwater marshes may be one of the more important parts of the estuary.

Bottomland hardwood and riverine swamp forest

The combination of egg-laying structures, abundant food, and relative scarcity of predators (Power et al. 1995) in seasonally flooded wetlands makes them ideal spawning areas. Stems and leaves of wetland vegetation provide surfaces for egg attachment. At least 20 families and up to 53 species of fish spawn and/or feed on the floodplain during inundation. Catfish, sunfish, gar, perch, and sucker are well represented (Wharton et al. 1982). River herring is an important coastal species that spawns adhesive eggs in flooded swamps, oxbows, and along stream edges (DMF 2000b; Wharton et al. 1982). Spawning of river herring in North Carolina occurs in tributaries during elevated spring flows, from March through May (DMF 2000b). Spawning hickory shad use flooded swamps and river tributaries (Funderburk et al. 1991; Pate 1972). Pate (1972) collected hickory shad larvae and eggs in flooded swamps and sloughs off of the Neuse River. River herring spawning activity was surveyed by DMF in riverine forested wetlands in the early 1970's and again in 2008-2009. The data from the original baseline survey was used to map and designate Anadromous Fish Spawning Areas in 2008.

5.2.4.5. Corridor and connectivity

Within the marsh, elevation and proximity to open water affect fish distribution. Rozas and Odum (1987) found that shallow water and greater distance from deep water typically meant lower abundance of large predator fish (Rozas and Odum 1987). Wetlands can enhance the foraging function of adjacent habitats. The movement of pinfish between intertidal marsh and subtidal grass beds could provide an important link in the transfer of secondary production between the marsh and aquatic habitats. Marsh edge is more utilized when adjacent to SAV or shell beds where small organisms can take refuge at low tide. Subtidal structures (e.g., SAV, woody debris) near freshwater wetlands may serve a similar corridor function in wind tide systems. Micheli and Peterson (1999) found that marsh edge provided a corridor function for blue crabs foraging on nearby subtidal oyster reefs, and that adult blue crabs utilized marsh edge habitat in preference to unvegetated, open waters. Fodrie et al. (2014) found that fish utilization of oyster reefs adjacent to saltmarsh or seagrass meadows was proportionally more than equally productive to oyster reefs on isolated sand flats. However, constructing the reef proximate to the marsh dissipated wave action, allowing for sediment deposition and marsh accretion, thereby overtaking the reef. While good for the fish it was not successful for oysters. Additionally, fish that normally show a preference for foraging on reefs were shown to adapt to foraging in marsh when oyster reefs were not present, albeit not to the same nutritional advantage. The study also showed that red drum demonstrated a preference for occupying the border between habitat alternatives (Fodrie et al. 2014).

5.3. Status and trends

5.3.1 History of loss of habitat

In the late 1800s to early 1900s, the greatest loss of wetlands resulted from ditching and draining for agriculture (one important exception was the construction of the Atlantic Intracoastal Waterway, North Carolina's section beginning in 1913). Several large agricultural drainage projects occurred during that period (Heath 1975), resulting in ~1 million miles of drainage ditches and canals throughout the Coastal Plains of North Carolina (Wilson 1962). Much land around the Albemarle-Pamlico estuary was drained to accommodate agriculture and forestry. Studies indicate that North Carolina had approximately 7.2 million acres of wetlands prior to European colonization, of which 95% (6,840,000 acres) was in the Coastal Plains (DWQ 2000b). Dahl (1990) estimated that by the mid-1980s, about 50% of these wetlands remained. The trend in wetland loss for North Carolina mirrors national trends (Dahl 1990).

Prior Converted (PC) wetlands have been subsequently converted to residential or other development, against the directives of the Farm Bill (http://www.ag.senate.gov/issues/farm-bill). About one-third of the loss of wetlands has occurred since 1950 (Bales and Newcomb 1996). Ditching of wetlands was common for flood and vector control until the mid-1970s. Based on national trends during the mid-1970s, the major cause of coastal wetland loss was conversion to deep-water habitat, followed by upland development (Hefner and Brown 1985). Many acres of wetlands were excavated for the Intracoastal Waterway, boat basins, and channels, before applicable laws were implemented. Wetlands are being lost to erosion and shoreline hardening intended to prevent erosion. In 1975, Riggs (2001) mapped 50% of the northeastern coastal North Carolina shoreline. A recent analysis of this same shoreline concluded, conservatively, that over 42 square miles were lost between 1975 and 2000 (Riggs 2001). Pamlico County was not mapped and has the highest rates of erosion (Riggs 2001).

The U.S. Fish and Wildlife Service (USFWS), in coordination with the National Oceanic and Atmospheric Administration (NOAA), released a report documenting wetland trends in the coastal watersheds of the Pacific, Atlantic, Gulf of Mexico and Great Lakes (Dahl and Stedman 2013). Findings indicated that there was an estimated net loss of 361,000 acres of wetlands in the coastal watersheds of the U.S. between 2004 and 2009, representing a 25% increase in loss over the previous reporting period of 1998-2004.

In what is known as the Regulatory Reform Act of 2014, Governor Pat McCrory of North Carolina signed into law Senate Bill 734 on September 18, 2014. Section 54 of the bill increases the allowable impacts for isolated wetlands west of Interstate 95 from 1/10 acre to 1/3 acre. Likewise, the threshold for allowable impacts was raised from 1/3 acre to 1 acre east of Interstate 95. The bill reduces the mitigation ratio for wetland impacts from 2:1 to 1:1 (Assembly 2014).

Losses and degradation of wetlands in coastal watersheds can be directly traced to population pressures (Figure 5.1) and conversion of wetlands to developed or agricultural uses, with resulting changes in water flow, increased pollution, and habitat fragmentation (Dahl and Stedman 2013). Dewatering of peat from groundwater withdrawal has shrunk marsh soils, as pore spaces compact with the loss of pore water, decreasing surface elevation and thus increasing flooding, sometimes drowning marshes (Kearney and Ward 1986).

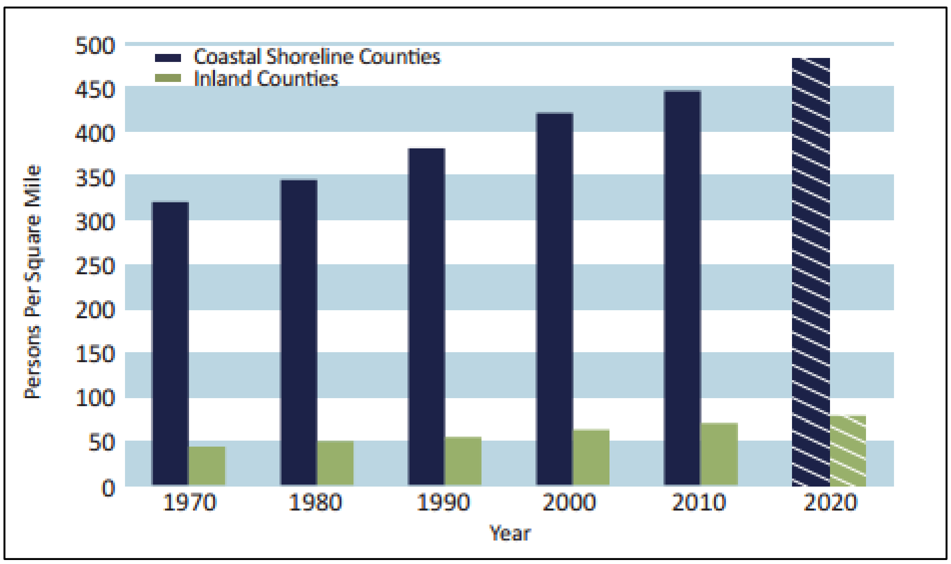


FIGURE 5.1. Changes in population density in the conterminous United States, 1970 to 2010, with predictions for 2020 (Crossett et al. 2014).

<u>5.3.1.2. Regulatory response to historic losses</u>

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 amendments); the Coastal Zone Management Act of 1972; the Food Security Act of 1985; the Emergency Wetlands Resources Act of 1986; and the Food, Agriculture, Conservation, and Trade Act of 1990. The primary state laws affecting wetlands were the NC Coastal Area Management Act (CAMA) of 1974 and the NC Dredge and Fill Law of 1969.

The 1899 River and Harbors Act gives the U.S. Army Corps of Engineers (USACE) the authority to regulate activities in navigable waters. These activities include those damaging to wetlands such as impounding, deepening, filling, excavating, and placing structures. Section 404 of the 1972 Clean Water Act (CWA) requires that the USACE regulate the discharge of dredge or fill material into "Waters of the United States" (riparian, estuarine, and headwater wetlands). Permit decisions for activities affecting waters of the United States are decided after consultation with the Environmental Protection Agency (EPA), Fish and Wildlife Service (FWS), National Marine Fishery Service (NMFS), and state agencies (Mitsch and Gosselink 1993). The EPA has the ultimate authority on wetlands and waters of the United States. The USACE acts as the permitting agency under a memorandum of understanding (MOU) with EPA. Section 401 of the CWA gives states the authority to approve, apply conditions, or deny Section 404 permits. The authority is applied in North Carolina by DWR with the 401 Water Quality Certification program.

While Section 404 permits are the most widely used federal management tools protecting wetlands, normal farming, ranching, and silviculture activities are exempt from permits (Bales and Newcomb 1996). "Swampbuster" provisions discourage (through financial disincentives) the draining, filling, or other alterations of wetlands for agricultural use.

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 under the NC Coastal Area Management Act (CAMA) of 1974. The Division of Coastal Management (DCM) was established as the operational arm of the CRC. Prior to the NC CAMA, dredging and filling of coastal waters was regulated under the 1969 NC Dredge and Fill Law.

In the late 1980's, the federal government began adopting "No Net Loss" policies for wetland protection (Wiebe and Heimlich 1995). However, a major problem of wetland protection remains that of protecting wetlands for public benefit when the majority of converted and remaining wetlands are privately owned. These factors have led to increasing reliance on land acquisition and direct incentives for protecting remaining wetlands.

<u>5.3.1.3. Recent loss of wetland habitat (1999-present)</u>

Within coastal draining river basins, 401 WQCs-permitted wetland impacts over a period of eight fiscal years (FY 1999/2000-2013/2014) indicate a potential conversion of 6,626 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, Neuse, and Pasquotank had the most impacts (Figure 5.3). It should be noted that Section 401 WQCs (state) precede Section 404 permits (federal) that may never be issued. In addition, some permitted impacts never occur. There were an additional 11,580 acres of pocosin wetlands lost after repeal of the Tulloch Rule, which had required permits for ditching resulting in incidental fallback (see "Regulatory response to recent losses"). However, most of this acreage had its hydrology restored through an intensive state and federal enforcement effort. There is an unquantified amount of wetland acres lost each year to the indirect effects of bulkheads, as well as unauthorized and/or small projects not requiring notification of DWR.[6] The DWR is working to resolve the issue of

[6] Impacts to wetlands less than1/3 acres (east of I-95) or 1/10 acre (west of I-95) and not designated as unique wetlands, or adjacent to ORW, WS-1, WS-22, or contiguous with a state or national Wild and Scenic River (http://portal.ncdenr.org/c/document_library/get_file?p_l_id=38446&folderId=285750&name=DLFE-8521.pdf, February 2015).

tracking unauthorized and cumulative, small impacts (EEP 2004).

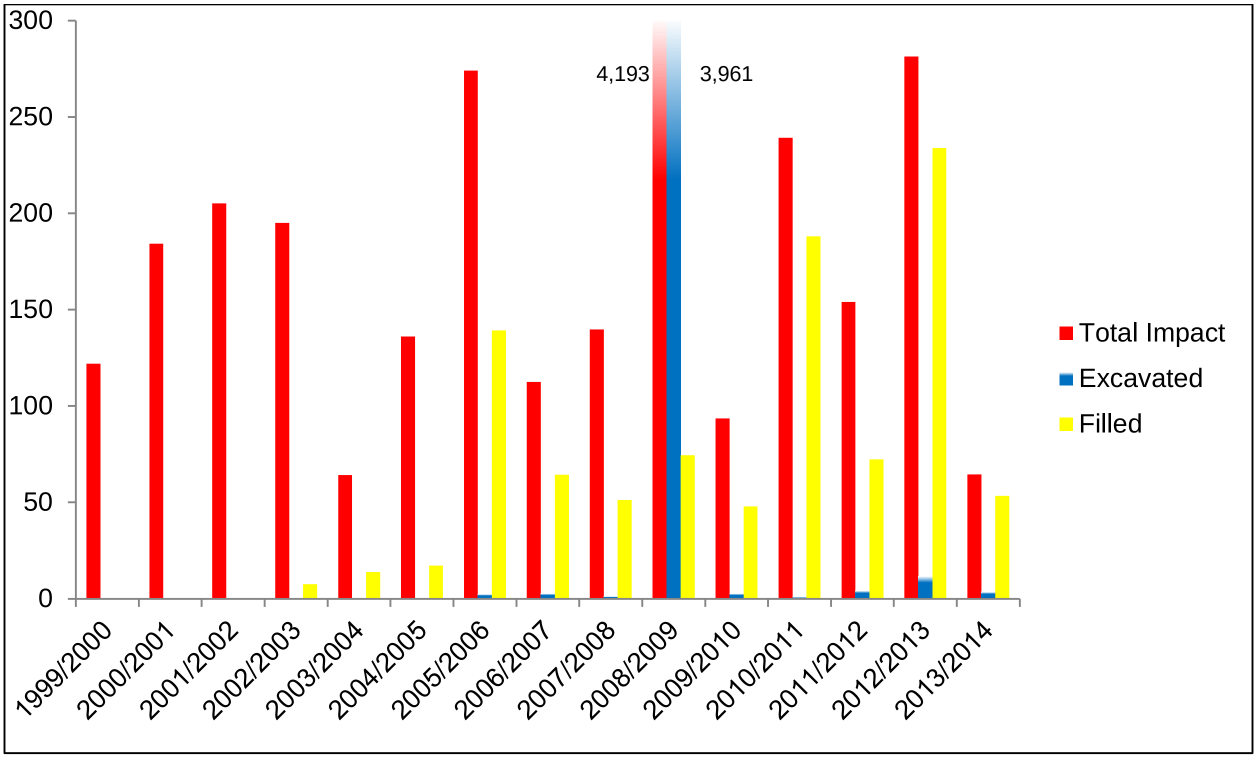


FIGURE 5.2. Total 401 Permitted Wetland Impacts (acres) during FY 1999/2000-2013/2014 in the seven coastal draining river basins (excluding the Lumber River basin) by fiscal year. Note: These data are for permanent wetland loss and do not include impacts from CAMA, Corps of Engineers Nationwide Permits 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. In addition, vast majority of impacts from FY 2008/2009 occurred during a single project when PCS Phosphate was issued a permit to impact 3,955 acres of wetlands in Beaufort County under DWQ 401 Certification 20080868 Ver. 2.

Since 2003, EEP no longer summarizes wetland losses by river basin. The EEP now tracks gross mitigation requirements and credits for restoration, enhancement, and high quality preservation. The Basinwide Information Management System (BIMS) database, which contains both 401 WQCs and CAMA Permit records, does not easily facilitate the extraction and summarization of these records, (A. Mueller/DWQ, pers. com., 2009). However, the ability to aggregate and summarize data on wetland impacts is essential for conducting cumulative assessments, as required by CRC rules. The DCM's Coastal Development Activity and Impact Tracking System (CDAITS) is an attempt to provide a central database for recording permits for this purpose. The database is available, but does not include CAMA General Permits.

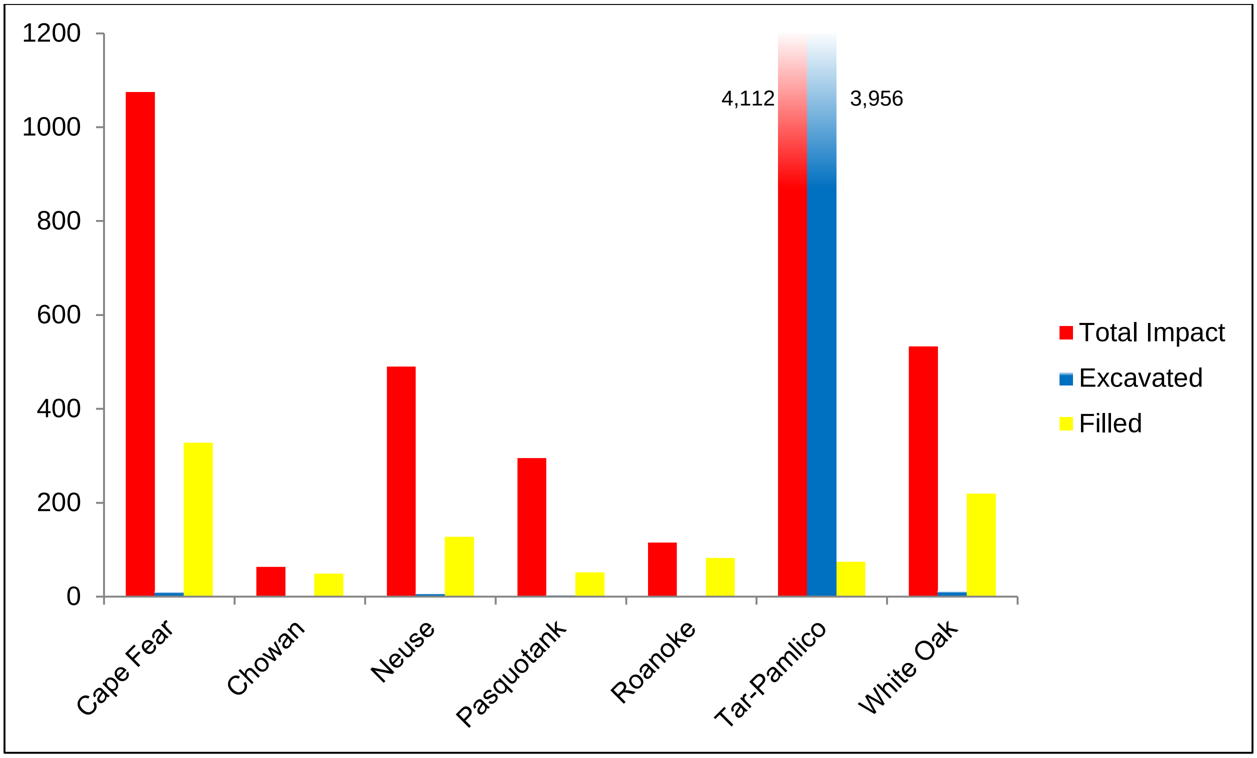


FIGURE 5.3. Total 401 permitted wetlands impacts (acres) during FY 1999/2000-2013/2014 by coastal draining river basin. Note: These data are for permanent wetland loss and do not include impacts from CAMA, Corps of Engineers Nationwide Permits 12, 27, and 33, and Corps of Engineers Regional General Permit 030 since these impacts are temporary, impacts to water (e.g., drainage), or impacts for wetland creation, restoration, or enhancement.

Between 2010 and 2014, DCM issued General Permits allowing less than 1 acre/year of coastal wetland disturbance in high and low marsh (Figure 5.4). In total, 1.61 acres of high marsh and 2.16 acres of low marsh were permitted for disturbance during these years (Figure 5.4). Major Permits issued by DCM also allowed less than 1 acre/year of coastal wetland disturbance in high and low marsh between 2010 and 2014 with the exception of 6.51 acres of low marsh in 2012 and 13.46 acres of high marsh in 2013. In total, 15.09 acres of high marsh and 8.72 acres of low marsh were permitted for disturbance during these years (Figure 5.5). The peak in 2012 was due in part to a DOT permit allowing 1.07 acres of impacts to coastal wetlands issued for the Herbert C. Bonner Bridge replacement. The permit allowed for 1.04 acres to be impacted for temporary fill, and 0.03 acres for mechanized clearing (C. Brittingham, DCM, pers. com. 2015). The peak in 2013 is related to the U.S. 17 Wilmington Bypass. The allowable impacts include approximately 12.5 acres for temporary clearing of vegetation, 0.41 acres for temporary excavation, and 0.07 acres for permanent fill in coastal wetlands (C. Brittingham, DCM, pers. com. 2015).

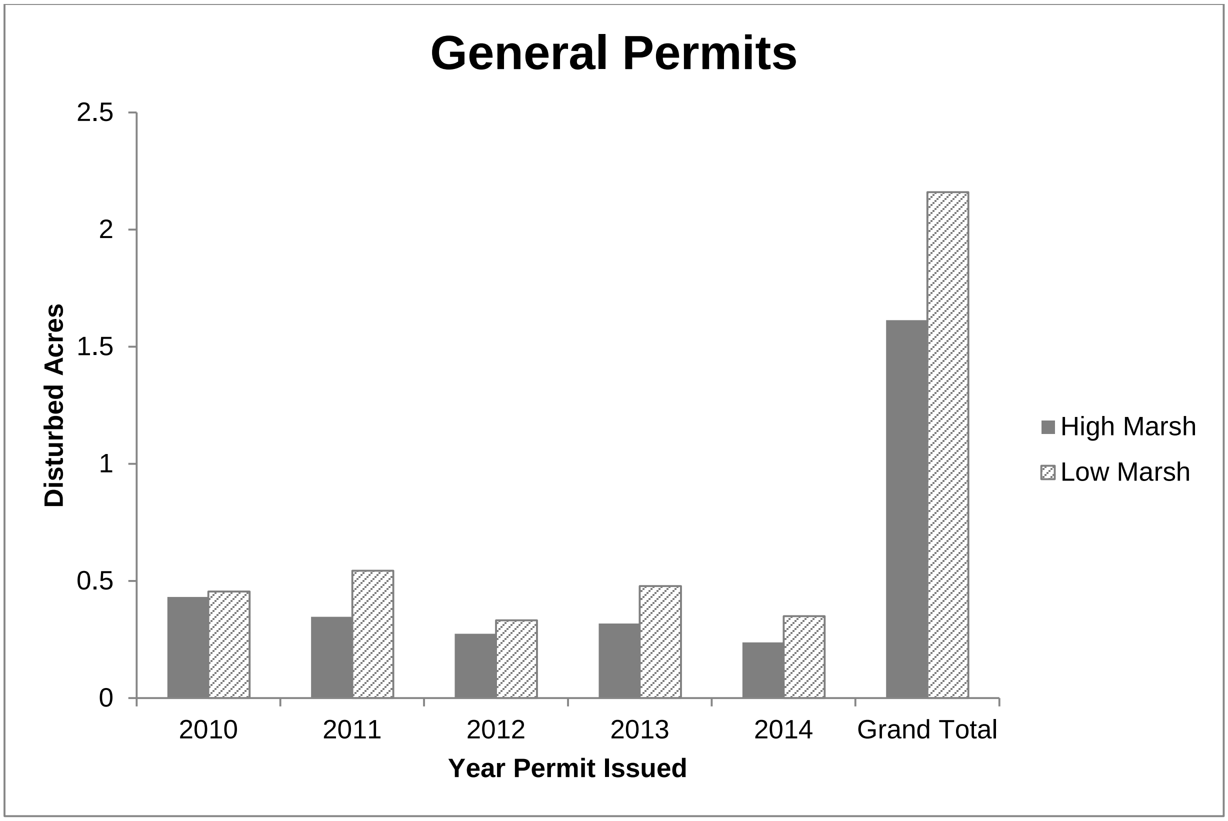


FIGURE 5.4. DCM General Permits issued between 2010 and 2014. Permitted acreage represents temporary and permanent disturbance allowed under the permit conditions. It does not represent acreage disturbed upon development completion.

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 wetlands. Because of this ruling, ditching required a Section 404 permit with a DWR 401 WQC, 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 WQC 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 determined wetlands ditching and draining activities to fall under its authority. The EMC adopted a wetland draining policy to ensure that required wetland conditions were maintained. Inspections were made of previously ditched wetlands to determine if the ditching was conducted in a manner that violated wetland standards, and where violations had occurred, property owners were required to restore natural hydrology by filling the ditches. Approximately 50% of the ditched wetlands have been restored.

In 1995, the USACE and EPA issued a joint guidance memo to specify how mechanical site preparation for forestry activities must be conducted in order to maintain a silviculture exemption under Section 404 of the CWA. This memo describes six mandatory BMPs for conducting mechanical site preparation for the establishment of pine plantations. The memo also describes nine wetland types in which a permit is required to conduct such 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

After 1995, silviculture site preparation activities for the establishment of pine plantations in any of the above nine types of wetlands required applicable permits.

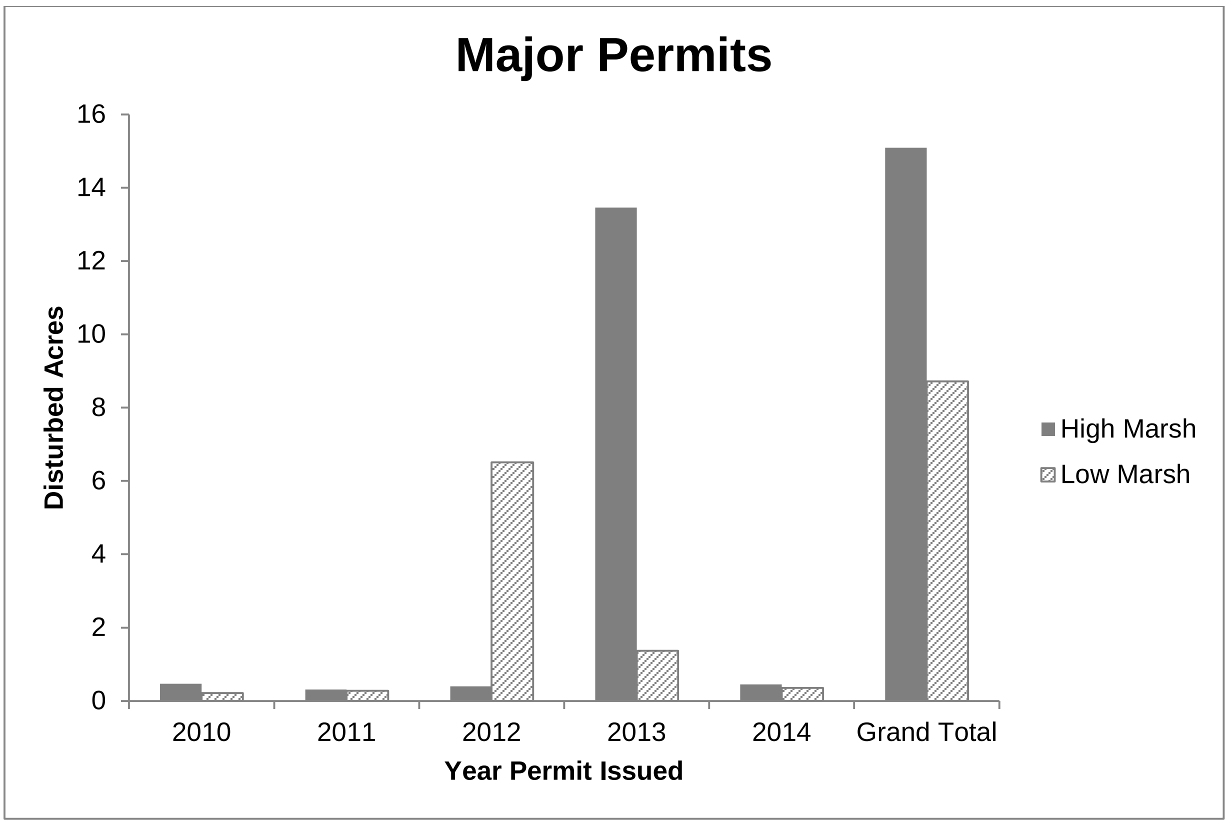


FIGURE 5.5. DCM Major Permits issued between 2010 and 2014. Permitted acreage represents temporary and permanent disturbance allowed under permit conditions. It does not represent acreage disturbed upon development completion.

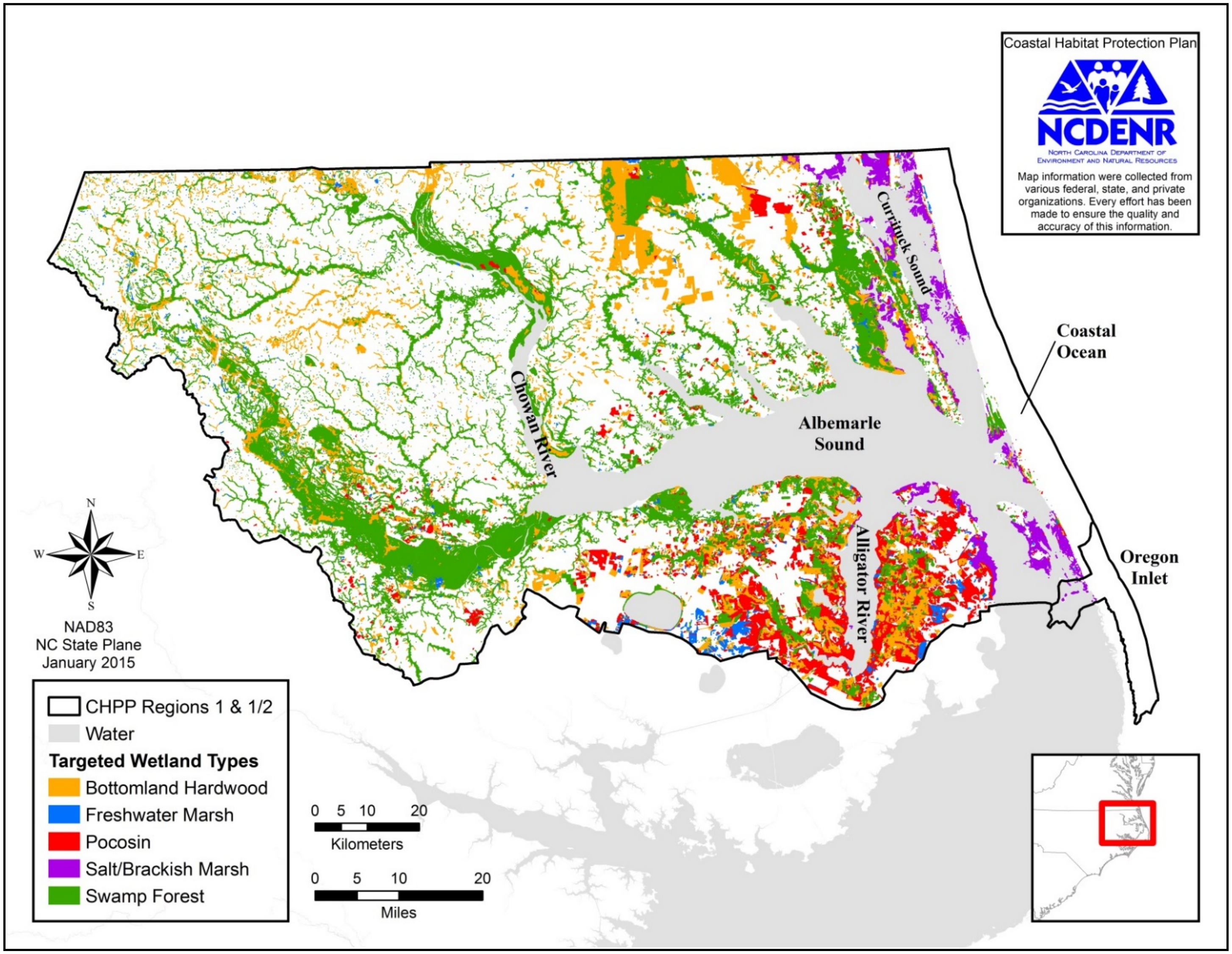
5.3.2. Status of associated fishery stocks

In North Carolina, estimated fish mortality and juvenile abundance indices are used by 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), five carry a status of *Depleted*, six of *Concern*, two of *Recovering*, and five, *Viable* (DMF 2014). There are approximately equal numbers of *Viable* and *Concern* stocks showing preference for wetland habitat. The wetland-enhanced[7] stocks listed as *Depleted* were American eel, river herring (alewife and blueback herring in Albemarle Sound), sturgeon spp., spotted seatrout and southern flounder. Wetland-enhanced species of *Concern* included the Albemarle Sound Management Area (ASMA) and the Central Southern Management Area (CSMA) striped bass, blue crab, Atlantic croaker, Atlantic menhaden, and spot. The two *Recovering* species were red drum and black sea bass (North of Hatteras). The *Viable* species were striped bass (Atlantic Ocean migratory stock), shrimp, striped mullet, and summer flounder. While most of the concern over declining fish stocks has focused on overfishing, habitat loss and degradation also prevent recovery or make stocks more susceptible to overfishing. Therefore, protection or enhancement of wetland habitat can be especially beneficial to *Depleted* or *Concern* wetland-enhanced species by maximizing recruitment and productivity.

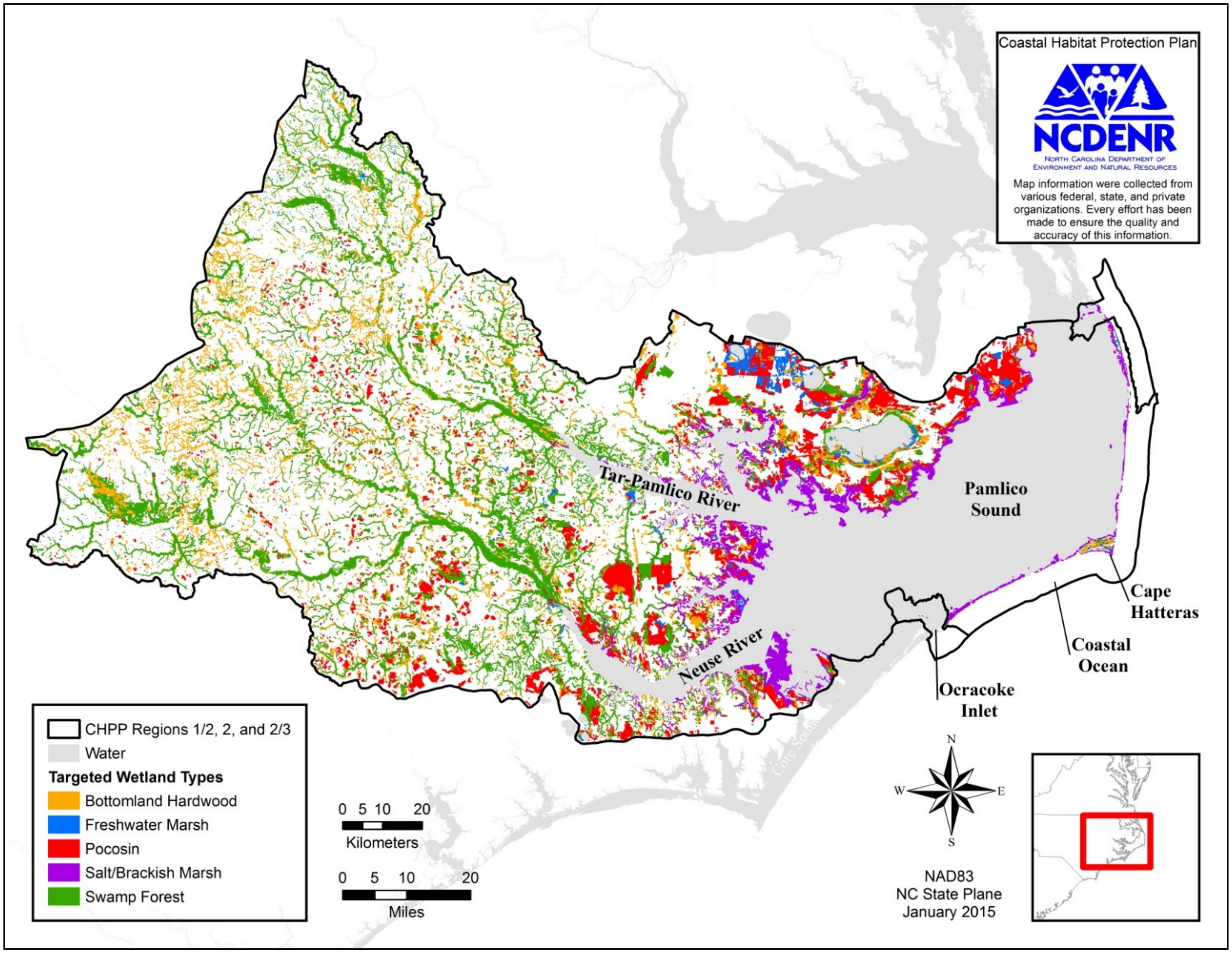
5.4. Wetlands summary

Wetlands are among the most productive ecosystems in the world. They improve the quality of adjacent upland and open-water habitats with their capacity for water storage, nutrient filtration, and protection from erosion and storm damage. Wetlands play a vital role in providing food, cover, and spawning area for finfish and shellfish. It is widely estimated that over 95% of the finfish and shellfish species commercially harvested in the United States are wetland-dependent. Mitigating for a history of wetland alterations may be possible with opportunities such as restoration on conservation lands, re-building marsh islands, and constructing living shorelines. A multi-level approach to the future health of our waters and wetlands involving research, non-profit engagement, and regulatory actions, is needed. Only then will sustainable development and activity be possible.

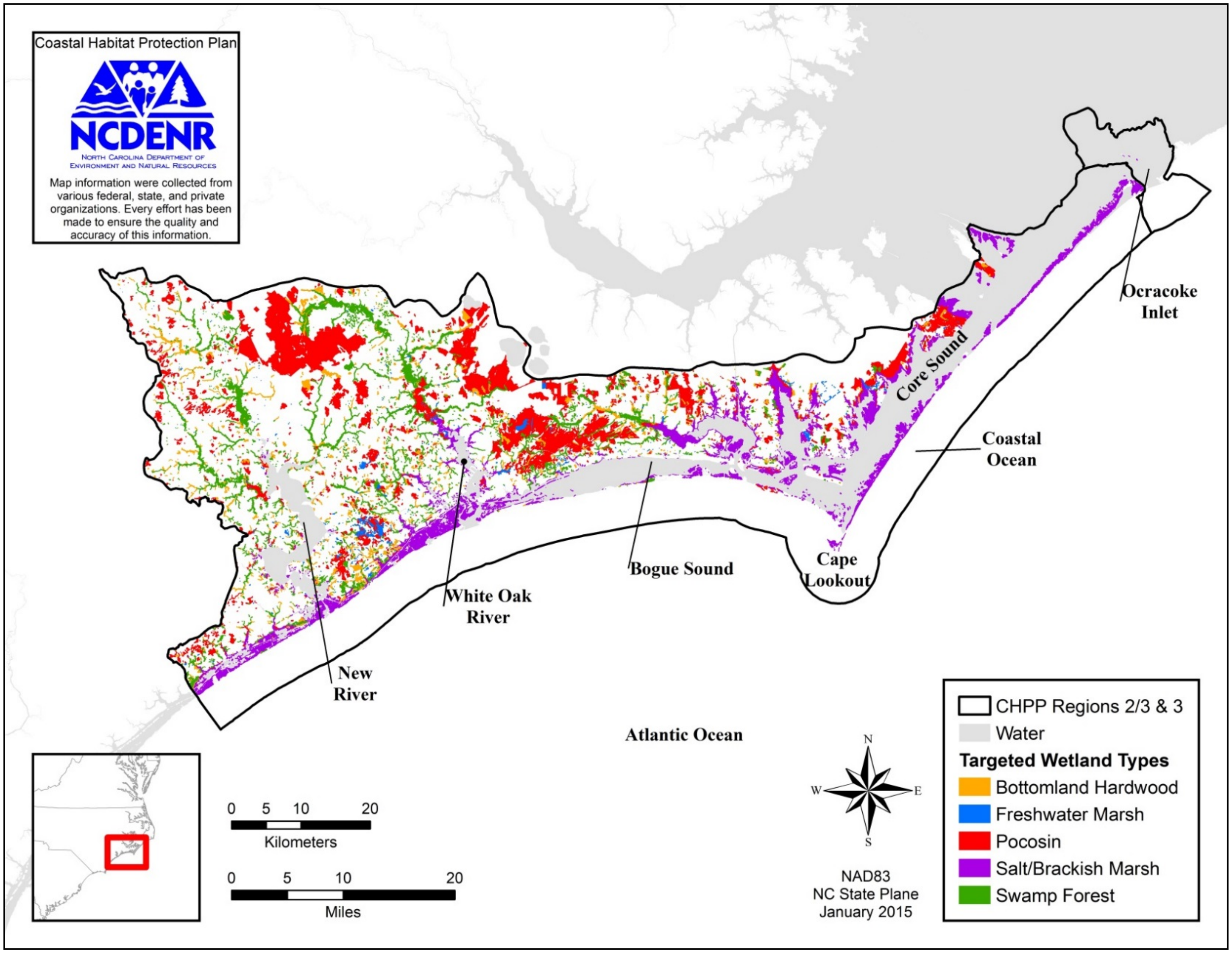
[7] Wetland-enhanced species are those showing some documented preference for wetland habitat.



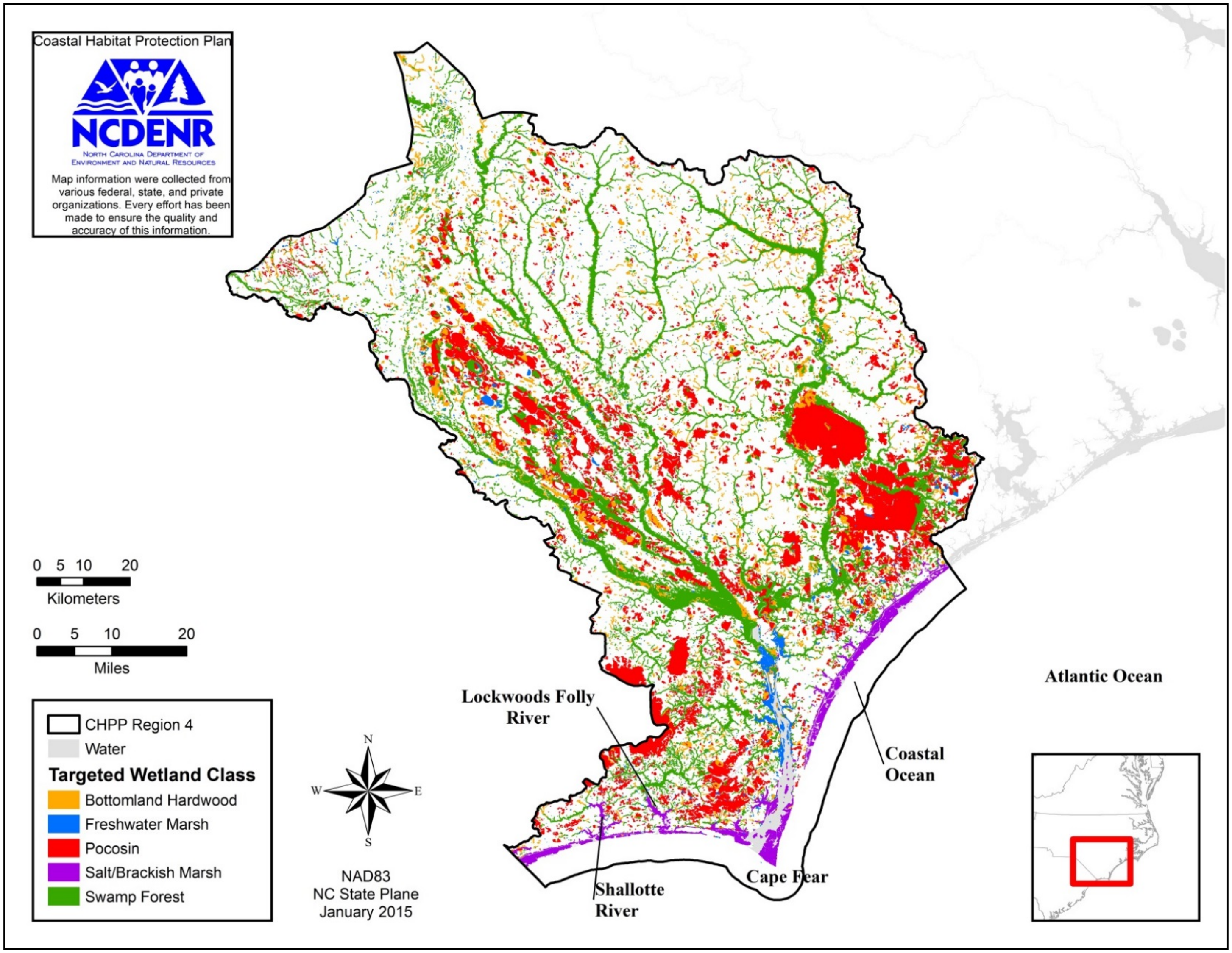
MAP 5.1A. Location of targeted wetland types derived from the NWI geospatial dataset for region 1 and 1/2 of the CHPP management area.



MAP 5.1B. Location of targeted wetland types derived from the NWI geospatial dataset for regions 1/2, 2, and 2/3 of the CHPP management area.



MAP 5.1C. Location of targeted wetland types derived from the NWI geospatial dataset for regions 2/3 and 3 of the CHPP management area.



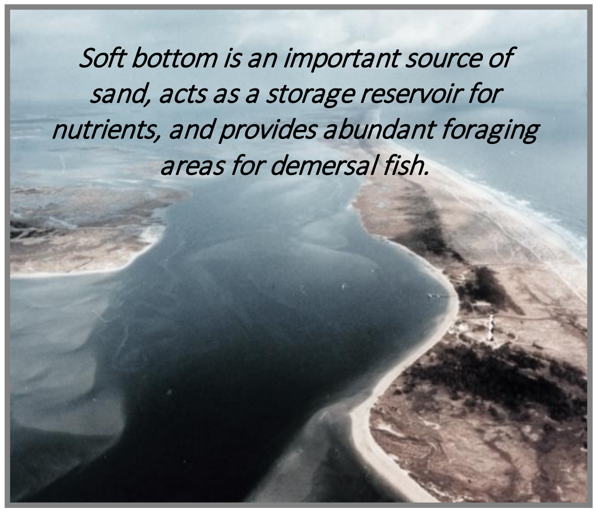
MAP 5.1D. Location of targeted wetland types derived from the NWI geospatial dataset for region 4 of the CHPP management area.

CHAPTER 6. SOFT BOTTOM

6.1. Description and distribution

6.1.1. Definition

Soft bottom habitat is defined as "unconsolidated, unvegetated sediment that occurs in freshwater, estuarine, and marine systems" Street et al. (2005); includes subtidal bottom and shallow intertidal flats.



6.1.2. Habitat requirements

Marine sediments constitute one of the largest habitat types on earth, covering roughly 80% of the ocean bottom (Lenihan and Micheli 2001). The only requirement for the persistent presence of soft bottom is sediment supply. Environmental characteristics, such as grain size, salinity, DO, and flow conditions affect the condition of the habitat and the organisms using it. But the habitat will persist regardless, unless it becomes sediment starved or is colonized by organisms, such as oysters or SAV, that transform it into another habitat.

6.1.3. Description and distribution

The characteristic common to all soft bottom is the mobility of unconsolidated sediment (Peterson and Peterson 1979). The habitat in North Carolina's coastal waters can be characterized by geomorphology, sediment type, water depth, hydrography, and salinity regime, and can be categorized accordingly:

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 90% of the 2.1 million acres of estuaries and coastal rivers in North Carolina (Riggs 2001). Soft bottom is in a constant state of flux, as other habitats expand or contract. As part of the Strategic Habitat Area (SHA) assessments, soft bottom area has been described for Region 1 (Albemarle Sound to Northeastern coastal ocean), Region 2 (Pamlico Sound to ocean), and Region 3 (White Oak River Basin, from Ocracoke Inlet through Stump Sound). In Region 1, there are estimated to be 852,346 acres of soft bottom (39%) within a total habitat area (water and adjoining wetlands) of 2,162,142 acres. Shallow (<6ft) bottom habitat covers 17-37% of the total bottom area in CHPP regions (Table 6.1), and occupies the largest proportion of bottom area in Regions 1 and 3. Determining the distribution of depth zones and bottom features is hampered by a lack of current bathymetric maps. The data used to map Pamlico Sound ranged from 1913-1980 http://estuarinebathymetry.noaa.gov/southatlantic.html. A renewed effort to map the bathymetry of Pamlico Sound began in 2008 with an expansion of DMF's Habitat and Abundance Mapping Program, but was curtailed due to budget cuts and loss of staff in 2011 (B. Conrad, DMF, pers. com. 2014). There have been waterbody-specific efforts to update bathymetry in New River and Currituck Sound, but no comprehensive mapping of estuarine waters.

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 water bodies	Shallow (<6 ft) acres	Shallow (<6 ft) %	Deep (>6 ft) acres	Deep (>6 ft) %
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 soft bottom habitats is determined by the underlying geology, basin morphology, and associated physical processes (Riggs 1996; Riggs and Ames 2003). North Carolina's coast can be divided into geologically distinct northern and southern provinces separated, approximately, by Cape Lookout (Pilkey et al. 1998; Riggs 1996; Riggs and Ames 2003). In the northern province, sediment formations consist of a thick layer of slightly to unconsolidated muds, muddy sands, sands, and peat sediments. The low slopes of this province are characterized by an extensive system of drowned river estuaries (e.g., Albemarle Sound, Neuse River), long barrier islands, and few inlets. In contrast, the southern province has a thin and variable layer of surficial sands and mud, with underlying rock platforms. It has a steeper sloping shoreline, resulting in narrow estuaries (e.g., Topsail Sound, Stump Sound), short barrier islands, and numerous inlets. The geologic differences result 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 input include erosion of shorelines, flushing of swamp forests/wetlands, and transport of suspended sediment from flood waters (Riggs 1996; Riggs and Ames 2003). Bottom composition generally ranges from consolidated material (bedrock, boulders) upstream to unconsolidated 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 to coarse-grained sand with varying amounts of organic detritus. Shallow flats may exist on the channel sides, 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 to settle. Where the channel bed is relatively narrow or shallow, riffles and runs occur and water velocity increases, leaving the heaviest particles 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.

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 is flat-bottomed with a narrow and shallow perimeter lip, providing ample space for sediment deposition (Pilkey et al. 1998; Riggs and Ames 2003). Soft bottoms in this region, including the Albemarle-Pamlico system, consist of three general sediment types: sand, organic rich mud (ORM), and peat (Riggs 1996; Wells 1989). 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 (Pilkey et al. 1998; Riggs 1996; Wells 1989) (Map 6.1a-b). Organic rich mud, the most pervasive sediment comprising approximately 70% of the sediment in North Carolina's estuarine system, largely fills the deeper central basins and downstream channels of sounds and rivers (Pilkey et al. 1998; Riggs 1996; Riggs and Ames 2003; Wells 1989) (Map 6.1a-b). Since fine sediments are easily suspended and transported, the plume 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 in the swamp forests of riverine floodplains or in coastal marshes (Riggs and Ames 2003).

Soft bottoms in estuaries of the southern geologic province are dominated by sloped mudflats of small systems (e.g., White Oak River, Pages Creek)(Pilkey et al. 1998). Coarse sands are concentrated in the lower portion of the estuaries and are transported via inlets and barrier island overwash. Small blackwater streams carry relatively low sediment loads into the upper portion of the estuaries where ORM dominates, but the water contains large quantities of dissolved organic matter giving it a dark color (Riggs and Ames 2003). In contrast, the Cape Fear River, the only major trunk estuary in North Carolina discharging 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 vegetation and there is a gently sloping area for sediment to build upon (Riggs 2001). These sediment bank shorelines provide a source of sand to adjacent waters, while marsh or swamp forest shorelines erode less, have a high organic content, and provide fine organic sediments to adjacent waters. Several shoreline erosion studies of North Carolina's coast were compiled and summarized in Riggs (2001), and updated in 2011. Depending on wave energy, sediments can have long or cross-shore transport. Sediments undergoing long-shore transport move parallel to the shoreline where they can be deposited on adjacent beaches. Cross-shore transport moves sediments onshore or offshore creating an equilibrium beach profile.

Estuarine intertidal flats are unvegetated bottom areas 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 portions of the coast. Because the influence of lunar tides is minimal in the large sounds (e.g., Pamlico, Albemarle, and Currituck), intertidal flats are not extensive in those areas, except for immediately adjacent to inlets (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 these vicinities are typically composed of coarse sands and shell fragments (Peterson and Peterson 1979). Intense wave and current energy cause the flats to regularly 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 roughly 19-21 inlets in North Carolina connecting estuarine waters to the ocean. The number depends on the stability of the Ophelia/Drum Inlet system. Eleven originated as a result of storm breaches and remain spatially unstable, including Oregon and Mason inlets (Cleary and Marden 1999; Mallinson et al. 2008). Twelve of the inlets are developed, and as such are regulated Inlet Hazard Areas (NCDCM). Ophelia Inlet breached southwest of Drum Inlet during Hurricane Ophelia in 2005, and has since expanded, nearly merging with Drum Inlet (Mallinson et al. 2008). There are nine larger inlets, (e.g., Ocracoke, Bogue, and Cape Fear River), which occupy ancient river channels. Several others have been artificially created (e.g., Carolina Beach Inlet) or relocated (e.g., Mason Inlet, 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 steeply at the 160–250 ft isobath, where the continental slope begins. In the intertidal zone of oceanfront beaches waves continually rework and sort sediment by grain size, with larger sediments deposited first and finer-grained sediment carried on slower moving waves. Beach 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 (Reed and J.T.Wells 2000; Thieler et al. 1995). 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 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 (Minerals Management Service 1993). In contrast 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). 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 is important as a storage reservoir of chemicals and microbes in coastal ecosystems. Intense biogeochemical processing and recycling allow for deposition and resuspension of 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 (Imberger et al. 1983; Sigels et al. 1982), 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 (Buzzelli et al. 2002; Lin et al. 2006; Malone et al. 1988).

In slow-moving, expansive estuaries like 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 sediment resuspension at low flow velocities, stabilizing the bottom and lessening water column turbidity (Holland et al. 1974; Miller et al. 1996; Underwood and Paterson 1993; Yallop et al. 1994). However, microalgae cannot stabilize sediments under intense or prolonged events, such as large storms or in the surf zone (Miller 1989). In the absence of large, extensive structures, soft bottom provides less stabilization 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 important sources of sand, which allow barrier island migration to respond to sea level rise (Cleary and Marden 1999). Alterations to these deltas can result in significant changes to the adjacent barrier island shorelines.

Studies are lacking regarding the economic value of soft bottom habitat for ecosystem services and fishery production. However, many studies have looked at the economic benefit of clean beaches and surf for recreational purposes. One study, averaging data from seven beaches in North Carolina, found the net economic benefits of a day at a North Carolina beach ranged from $14 to $104 for single day trips and $14 to $53 for users that stay onsite overnight (Bin et al. 2005).

6.2.2. Productivity

6.2.2.1. Freshwater and estuarine

Although soft bottom habitat is defined as “unvegetated,” surface sediments support an abundance of benthic microalgae, an important source of primary production (Cahoon et al. 1999; Currin et al. 1995; Litvin and Weinstein 2003; MacIntyre et al. 1996a; Peterson and Peterson 1979; Pinckney and Zingmark 1993b). Benthic microalgae (e.g., diatoms, dinoflagellates, blue green algae) live in the top few millimeters of the surface (Miller et al. 1996; Peterson and Peterson 1979). 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. 1996a). Values for benthic chlorophyll *a* biomass (an indicator of overall productivity) in North Carolina estuaries are reported to range from 10 to 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. Temperature and sediment supply are the two most closely linked factors to benthic bacterial productivity in both marine and freshwater systems (Sander and Kalff 1993).

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 1993b)

The most productive estuarine bottom, in terms of benthic microalgae, tends to be shallow, protected areas with muddy/fine sand (MacIntyre et al. 1996a; Pinckney and Zingmark 1993b), while productivity in exposed or deep areas, or on coarse sand bottom tends to be low (Chester et al. 1983; MacIntyre et al. 1996a; Sundback et al. 1991). In some locations, primary production on shallow intertidal bottom may be greater than that in the water column (MacIntyre et al. 1996a). Following wind or rain events, benthic diatoms can resuspend, greatly altering the composition and abundance of phytoplankton (Tester et al. 1995). Given the complex exchange of materials between soft bottom and the water column (benthic-pelagic coupling), it is often difficult to distinguish differences in productivity between the habitats (Cahoon and Cooke 1992; MacIntyre et al. 1996a). Factors that control the magnitude and extent of benthic primary production include temperature, light availability, sediment grain size, and community biomass (Barranguet et al. 1998; Cahoon et al. 1999; Guarini et al. 2000; Pinckney and Zingmark 1993b), with light availability considered by most researchers to be the major factor (MacIntyre et al. 1996a). Other factors, including nutrient availability, are not thought to be limiting (Admiraal et al. 1982; Peterson and Peterson 1979). Photosynthetically active light generally penetrates about 2-3 mm into the sediment, but can reach 5-20 mm in sandy, high energy environments.

Organic matter on soft bottom arrives in the form of detritus originating from marsh grass, SAV, and macroalgae (Currin et al. 1995; Litvin and Weinstein 2003; Wainright et al. 2000). 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 (Galvan et al. 2008; Page and Lastra 2003; Tester et al. 1995; Wainright et al. 2000).

6.2.2.2. Marine

Benthic microalgae are important sources 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). 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 the development of productive benthic microalgal communities. However, wave action continually re-suspends inorganic nutrients sufficient to create localized phytoplankton blooms composed primarily of diatoms (Hackney et al. 1996a; McLachlan et al. 1981). This self-sustaining nutrient input/phytoplankton production supports intertidal filter feeders and, consequently, high concentrations of fish migrating 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 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. As the canopy opens downstream, algae grazers and detritivores increase in abundance (Vannote et al. 1980). Common coastal freshwater invertebrates include mayfly and caddisfly larvae, leeches, chironomids, beetles, dragonfly larvae, and crayfish. Hyland et al. (2004) found that insect larvae, oligochaetes, larval *Coelotanypus* spp., and gammaridean amphipods 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 in recent decades. The freshwater Asiatic clam (*Corbicula fluminea*), introduced about 50 years ago, has become a prominent component of many coastal rivers (Hyland et al. 2004; Lauritsen and Moxley 1983), resulting in alteration of the benthic substrate and competition with native mollusks (Devick 1991).

6.2.3.2. Estuarine

Estuarine soft bottom supports a large diversity of benthic invertebrates, with over 400 species documented in North Carolina (Hackney et al. 1996a; Hyland et al. 2004). Most benthic invertebrates inhabiting soft bottom live in the sediment (infauna), as opposed to the surface (epifauna), because of the mobility of the habitat (Peterson and Peterson 1979). On intertidal flats, the sediment provides a buffer from drastic fluctuations in salinity, water and air temperature, 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 mud. 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 be classified as deposit or suspension feeders (Miller et al. 1996; Peterson and Peterson 1979). Deposit feeders include mud snails, polychaete worms, and certain bivalve clams and crustaceans that ingest sediment and detrital particles, assimilating the bacteria, fungi, and microalgae. Suspension feeders capture particles 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 their diet 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 soft bottom surface. 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 (Hackney et al. 1996a; Levinton 1982) compared to a relatively low diversity of macrofauna (> 0.5 mm) (~ 20 – 50) (Hackney et al. 1996a). 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* (Donoghue 1999; Hackney et al. 1996a; Lindquist and Manning 2001; Peterson et al. 2006).

Because North Carolina is located between two physiographic and zoogeographic zones, the marine subtidal bottom supports a high diversity of invertebrates. Offshore sand bottom communities along the coast have been reported to contain over 600 species of benthic invertebrates (Posey and Alphin 2002), with over 100 polychaete taxa (Lindquist et al. 1994a; 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 are abundant epifauna. Since 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 adapted to recover relatively quickly (Posey and Alphin 2001; Posey and Alphin 2002).

6.2.4. Fish utilization

Soft bottom is used by most coastal fishes in North Carolina. Estuary-dependent migratory species, including spot, Atlantic croaker, and penaeid shrimp are common inhabitants of the estuarine soft bottom during summer and fall (Epperly 1984; Noble and Monroe 1991a; Ross 2003; Weinstein 1979). Spot and Atlantic croaker also frequent shallow (<10 m) nearshore soft bottom, where they dominate the benthic fish assemblage (Wenner and Sedberry 1989). Flatfish, skates, and rays, are best adapted to shallow unvegetated bottom (Burke et al. 1991; Peterson and Peterson 1979; Schwartz 2003; Walsh et al. 1999). Habitat use patterns by fishes on soft bottom are primarily related to season and ontogenetic stage (Ross 2003; Walsh et al. 1999). Table 6.3 summarizes important species that are dependent on soft bottom for some portion of their life history and the ecological function of the soft bottom habitat.

6.2.4.1. Foraging

One of the most important functions of soft bottom habitat is foraging. In freshwater reaches, high concentrations of organic matter and the associated secondary production (e.g., 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; 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 primary, secondary, and tertiary trophic levels benefit directly or indirectly from detrital and benthic microalgal production, as well as from the abundant and diverse invertebrate fauna associated with estuarine soft bottom (Peterson and Peterson 1979). On shallow intertidal flats, planktonic and benthic feeding herbivorous fish, (e.g., anchovies, killifish, menhaden) consume phyto- and zooplankton in the water column, as well as suspended 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 (Bain 1997; Peterson and Peterson 1979). Larger piscivorous fishes typically move onto estuarine flats during high water to feed on baitfish. These predators include sharks (sandbar, dusky, smooth dogfish, spiny dogfish, Atlantic sharpnose, and scalloped hammerhead), red drum, weakfish, bluefish, 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 flats with their compressed body forms (Peterson and Peterson 1979). Small flatfish (e.g., bay whiff, fringed flounder, hogchoker, and tonguefish) feed mostly on copepods, amphipods, mysids, polychaetes, mollusks, and small fish. Summer and southern flounder and larger flatfish primarily consume fish such as silversides and anchovies as well as shrimp and crabs, small mollusks, annelids, and amphipods (Burke 1995; Peterson and Peterson 1979). These flatfish ambush their prey by blending into sediments or stalking them (Scharf 2006). Various rays excavate pits while searching for mollusks, annelids, crustaceans, and benthic fish (Cross and Curran 2004).

Ocean soft bottom, particularly the surf zone and along shoals and inlets, serves as an important feeding ground for numerous fishes foraging on benthic invertebrates (Peterson and Peterson 1979). These predators can have high recreational and commercial value, and include Florida pompano, red drum, kingfish, spot, Atlantic croaker, weakfish, Spanish mackerel, and striped bass. Many of these species congregate around topographic features of the subtidal bottom, such as cape shoals, channel bottoms, sandbars, sloughs, and ebb tide deltas, presumably to enhance prey acquisition or reproduction. Hard bottom fishes are supported by food resources in and on soft bottom. Demersal zooplankton and infauna from sand substrate have been found to be important components of many species' diets and an important link to reef fish production (Cahoon and Cooke 1992; Lindquist et al. 1994b; Thomas and Cahoon 1993). Reef species known to 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. 1994b).

6.2.4.2. Spawning

Many demersal fish spawn over soft bottom habitat in North Carolina's coastal waters (Table 6.3). In freshwater, largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*) spawn on shallow flats, laying eggs in bowl-shaped nests. Longnose gar occasionally spawn in these depressions, 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 they inhabit as primary spawning habitat. Migratory estuarine spawners, including several species of drum, spawn primarily over soft bottom during summer months. Spotted seatrout spawn on the east and west sides of Pamlico Sound during this time, with peak activity observed around Rose, Jones, and Fisherman's bays, and Bay River (Luczkovich et al. 1999; Luczkovich et al. 2008). Red drum have been documented spawning on the west side of Pamlico Sound at the mouth of the Bay River and in estuarine channels near Ocracoke Inlet (Luczkovich et al. 1999; Luczkovich et al. 2008). The evidence for blue crabs spawning in inlet areas warranted Crab Spawning Sanctuaries (DMF 2004 - Blue Crab FMP).

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, DMF 2014.

	Soft bottom functions [1]						Stock status
Species*	Spawning	Nursery	Foraging	Refuge	Corridor	Fishery [2]	2014[3]
ANADROMOUS SPAWNING							
Atlantic sturgeon	X	X	X		X	X[4]	D
Shortnose sturgeon	X	X	X		X	X[4]	E-moratorium
ESTUARINE AND INLET SPAWNING AND NURSERY							
Blue crab	X	X	X	X		X	C
Hard clam	X	X	X	X		X	U
Hermit crab spp.	X	X	X				
Horseshoe crab	X	X	X			X	
Mud crab spp.	X	X	X				
Mummichug	X	X	X				
Naked goby	X	X	X				
Red drum	X	X	X			X	R
Sheepshead minnow	X	X	X				
Silver perch	X	X	X			X	
Striped killifish	X	X	X				
Whelks	X	X	X			X	
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY							
Atlantic croaker		X	X			X	C
Bay whiff		X	X	X	X		
Blackcheek tonguefish	X	X	X	X	X		
Hogchoker	X	X	X	X	X		
Penaeid shrimp (brown, white, pink)		X	X	X	X	X	V
Southern flounder		X	X	X	X	X	D
Spot		X	X			X	C
Striped mullet		X	X			X	V
MARINE SPAWNING, HIGH SALINITY NURSERY							
Atlantic stingray	X	X	X	X	X	X	
Coastal sharks [5]	X	X	X			X	C
Cownose ray	X	X	X	X	X	X	
Florida pompano		X[6]	X			X	
Fringed flounder		X	X	X	X		
Gulf flounder		X	X	X	X	X	
Gulf kingfish		X[6]	X			X	U
Smooth dogfish	X	X	X			X	
Spiny dogfish		X	X			X	V
Striped anchovy		X[6]	X				
Summer flounder	X	X	X	X	X	X	V

*Scientific names listed in Appendix D. Names in bold font are species whose relative abundances have been reported in literature as being generally higher in soft bottom than in other habitats. 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 Existing commercial or recreational fishery. Other species important to the system as prey items
3 V = Viable, R = Recovering, C = Concern, D = Depleted, U = Unknown, E = Endangered (DMF 2014)
4 Former fishery, but fishing moratorium since 1991
5 Incl. Atlantic sharpnose, blacknose, blacktip, bonnethead, dusky, sandbar, scalloped hammerhead, spinner sharks
6 Uses surf zone almost exclusively as nursery area

Several species of estuary-dependent fishes use ocean soft bottom as critical spawning habitat during winter, primarily seaward of state waters. Eggs and larvae are then carried by currents through nearshore 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 serve as important pupping grounds for several species of sharks. North of Cape Hatteras, pupping of spiny dogfish over subtidal bottom has been noted in winter months (ASMFC 2002a). Subtidal bottom in the southern portion of 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 (*C. limbatus*), sandbar (*C. plumbeus*), and scalloped hammerhead sharks (*S. lewini*). Most neonate sharks in this area are seen in June and July (Beresoff and Thorpe 1997; Thorpe et al. 2003).

6.2.4.3. Nursery

Shallow soft bottom, mostly adjacent to wetlands, is used as nursery for many species of juvenile fish (Table 6.3). This habitat provides an abundance of food and is relatively inaccessible to larger predators. Shallow, unvegetated flats have been documented as important nursery habitats for spot, summer and southern flounder, Atlantic croaker, and penaeid shrimp (Burke et al. 1991; Ross 2003; Walsh et al. 1999). The DMF juvenile fish monitoring notes this habitat to support an abundance of juvenile fish, composed of species with similar life histories and feeding patterns (Ross and Epperly 1985).

The dominant fishes using shallow estuarine soft bottom as nursery area are estuary-dependent and primarily spawn offshore in winter. For many species, the uppermost reaches of shallow creek systems correspond to the site of larval settlement, i.e., PNAs (Ross and Epperly 1985; Weinstein 1979). However, in tributaries far removed from ocean inlets, such as Neuse, Pamlico, Bay, and Pungo rivers, larval settlement tends toward the lower reaches. Abundance of juvenile species in estuarine nurseries generally peaks from April to July and is correlated with water temperatures (Ross and Epperly 1985).

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 - spot, bay anchovy, Atlantic croaker, Atlantic menhaden, silver perch, blue crab, brown shrimp, and southern flounder - comprised >97% of total nekton abundance. Data from DMF's juvenile fish monitoring program show those same eight species continue to dominate nekton assemblage, with pinfish and white shrimp also among the most abundant species. The consistency of catch characteristics from 1990-2014 indicates that these areas continue to function as healthy nurseries.

Historical analyses of DMF's juvenile fish data in the Pamlico Sound system have found significant geographical differences in the assemblages (Noble and Monroe 1991a; Ross and Epperly 1985). Noble and Monroe (1991a) identified four distinct groupings of juvenile fish (Table 6.4), with salinity as the primary abiotic variable structuring composition. Fish assemblages in Pamlico Sound are also segregated by a feature called Bluff Shoal, which extends across the sound from Ocracoke Inlet to Bluff Point. Bluff Shoal effectively splits the sound into separate basins of differing depth and sediment composition, causing distinct fish assemblages north and south of the shoal (Ross and Epperly 1985).

Soft bottom in freshwater areas and the nearshore ocean function as valuable nursery habitat for numerous fish species. Benthic anadromous fish, such as Atlantic and shortnose sturgeon, use freshwater soft bottom as PNA during spring and summer. In the nearshore ocean, subtidal soft bottom is used extensively as nursery for coastal sharks, such as spinner, blacknose, and dusky sharks (Beresoff and Thorpe 1997; Thorpe et al. 2003). Ocean soft bottom, particularly the surf zone, is a nursery area for

Florida pompano, and southern and gulf kingfish (Hackney et al. 1996a). 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 (States 2007). Juvenile fish are frequently found in the surf zone alone the North Carolina coast during the spring and summer months.

TABLE 6.4. Dominant juvenile fish species groupings found in the Pamlico Sound system by biotic cluster analysis of juvenile fish data (DMF 2014; Noble and Monroe 1991a).

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

6.2.4.4. 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 into the sediment (Luettich et al. 1999; Peterson and Peterson 1979). Deepwater soft bottom may be treacherous for small fish and invertebrates, particularly those that cannot burrow. These areas are generally the most accessible to large piscivorous fishes, which leads many small fish to venture out to the open bottom only at night (Summerson and Peterson 1984).

6.2.4.5. Corridor and connectivity

Numerous migrating juvenile and sub adult 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 to the 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 are found in higher density in muddy bottoms adjacent to wetlands than in sandy bottom areas (Walsh et al. 1999). Substrate type is the most important factor influencing juvenile summer flounder habitat (Burke 1991; 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 predators, a few meters of unvegetated bottom can act as a barrier (Micheli and Peterson 1999). Such barriers can be beneficial to small invertebrates by obstructing predator dispersal and reducing predation. In Back Sound, Micheli and Peterson (1999a) 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 habitats (Micheli and Peterson 1999).

6.3. Status and trends

6.3.1. Status of soft bottom habitat

Since mapping of soft bottom habitat has not been completed, and because sediments shift over time, it is 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, leads to gains in soft bottom habitat. Gains in soft bottom habitat may not be as beneficial as mature soft bottom habitat.

The quality of soft bottom habitat can affect species abundance and diversity. Sediments in soft bottom habitat can accumulate both chemical and microbial contaminants, potentially impacting benthic organisms and the community structure. Tidal creeks are sensitive to various aspects of human activity, but sensitivity depends on the size and location of the creeks. Because tidal creeks are the nexus between estuaries and land-based activities, the potential for contamination is great. Smaller intertidal creeks closer to headwaters demonstrate greater concentrations of nonpoint source contamination than larger systems closer to the mouth (NOAA 2008).

Studies in North Carolina have shown that sites having higher concentrations of contaminants have lower indices of biotic integrity (Hyland et al. 2004). One study included the Currituck, Albemarle, and Pamlico sounds and estuarine portions of major rivers (Chowan, Roanoke, Tar-Pamlico, Neuse, New, and Cape Fear), in which 441 benthic samples were processed from 208 stations. The impaired benthic site groups were concentrated mostly in the Neuse and Pamlico Rivers, and were characterized by very low species abundance. All of these dominant members are recognized as opportunists or pollution indicators with a high resistance to organic over-enrichment (Pearson 1978), chemical contamination (Chapman et al. 1997), or low-oxygen conditions (Diaz and Rosenberg 1995).

The National Coastal Condition Report NCCR IV (EPA 2012) is a series of reports by the US EPA Office of Water and Office of Research and Development that assesses the condition of coastal resources in several key areas (water quality, sediment quality, benthic quality, coastal habitat, and fish tissue contamination). In the latest report, the southeast coast from North Carolina to Florida was rated 3.6 overall (fair), essentially unchanged from the first report, although some of the key areas have declined since that report. Sediment quality was rated 2 (fair to poor), which was lower than in previous reports. Sediment quality is based on sediment toxicity, contaminants and total organic carbon (TOC). The percentage of area determined to be in poor condition was 13%. The primary reason for the low rating was sediment toxicity (EPA 2012).

Water quality declined from previous reports, mainly due to changes in clarity. The benthic index was rated good, based on species abundance and the presence of contaminant-sensitive taxa, among other measures. The fish contaminant index was rated as good. Only 8% of sites found fish with significant contaminant loads, including mercury and PCBs.

6.3.2. Status of associated fishery stocks

The DMF began a long-term juvenile fish monitoring program (Estuarine Trawl Survey) in 1971 (NCDMF 2009a). This database provides fishery independent information on species composition and abundance to identify Primary and Secondary Nursery Areas - shallow soft bottom habitat usually surrounded by wetlands. Although 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 (NCDMF 2012). For the 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. The JAI is considered an accurate indicator of recruitment and year-class strength (DMF 2003b). The information is used to determine stock status by various fishery management agencies. Juvenile abundance indices are also used as criteria to qualify areas for nursery designation. 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 2003b). However, consistent and comparable JAI data are only available since 1990, before which considerable habitat losses and changes occurred. In 2011, a Sea Grant project was completed by East Carolina University researchers examining the impacts of land use change on several species of fish and invertebrates using Estuarine Trawl Survey data (Meyer 2011). Using this data, land use changes were found to be influential to the number of blue crab, southern flounder, and Atlantic croaker in a system, and declines were further defined with percent land cover change.

Several species are closely linked to soft bottom habitat as indicated by juvenile abundance indices from the Estuarine Trawl Survey for recreationally and commercially important species (e.g., southern flounder, spot, and Atlantic croaker), shown in Figure 6.1 and 6.2. Southern flounder JAIs have varied between 1 and 8 with peaks in 1996, 2003, and 2010, and large declines in 1997, 1998, 2002, 2004 through 2006, and 2011 (Figure 6.1). Atlantic croaker and spot are benthic feeders potentially affected by changes in soft bottom habitat, such as reductions in food sources from toxicity or anoxic conditions. The JAI for Atlantic croaker has fluctuated between 5 and 97, and for spot between 38 and 350 (Figure 6.2). An Atlantic croaker ASMFC FMP was updated in 2011, following recommendations of the stock assessment in 2010 (ASMFC 2011). This addendum updated biological reference points and the management area. The assessment concluded that Atlantic croaker was neither overfished nor experiencing overfishing (ASMFC 2010), and 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 dredging activity on all life history stages of croaker (ASMFC 2013).

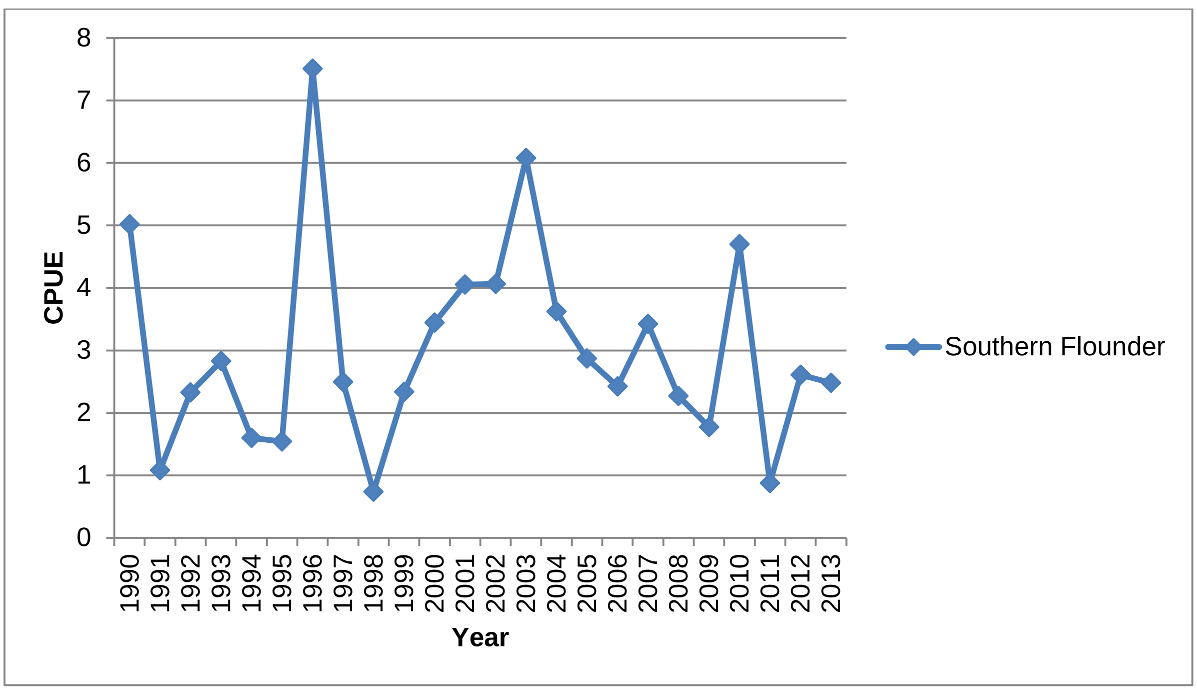


FIGURE 6.1. Southern flounder juvenile abundance indices (mean CPUE) from DMF Estuarine trawl survey, core stations sampled in May and June, 1990-2013.

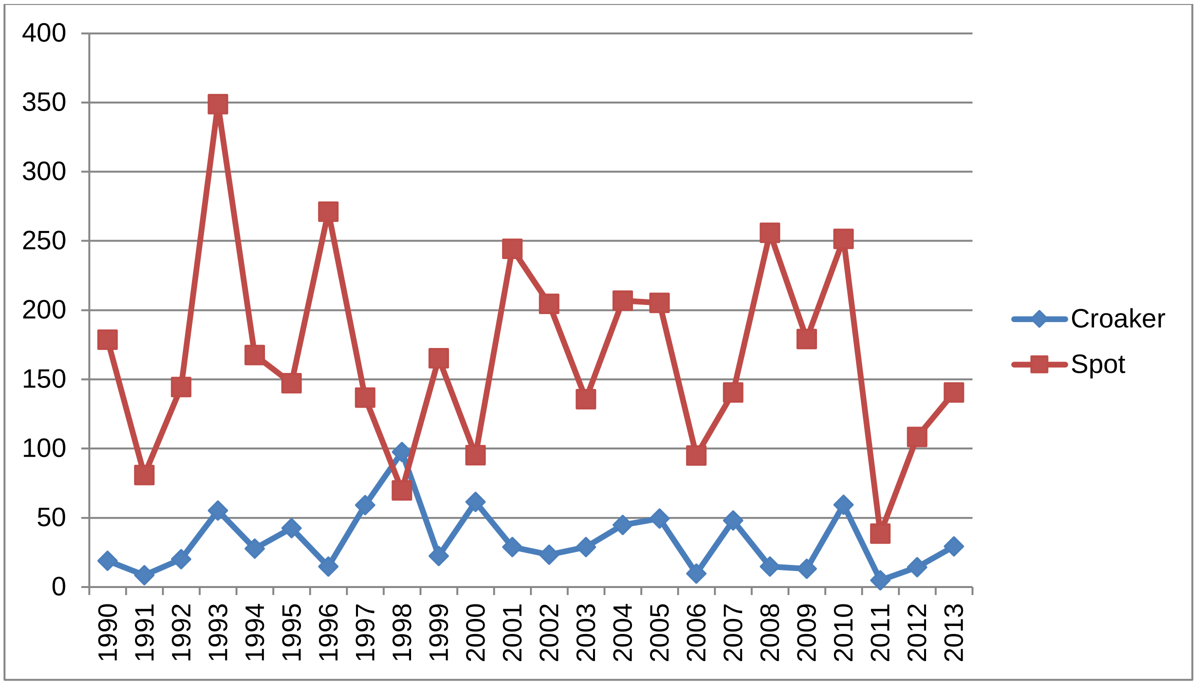


FIGURE 6.2. Spot and Atlantic croaker juvenile abundance indices (mean CPUE) from DMF estuarine trawl survey core stations sampled in May and June, 1990-2013.

Fishery-independent data are available from shallow water trawl surveys conducted by the Southeast Area Monitoring and Assessment Program (SEAMAP). Currently, SEAMAP 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 and other habitats. The SEAMAP study area includes inner (4m depth contour) and outer (10m depth contour) strata stations in Long, Onslow, and Raleigh bays in North Carolina.

The status of benthic macroinvertebrate populations is a measure of soft bottom conditions. Hard clams, while also present in shell bottom and SAV habitats, require soft bottom for burrowing. Because clams remain fairly stationary and filter feed, they are vulnerable to habitat degradation, such as sediment contamination or sedimentation. The status of the hard clam stock is currently unknown due to lack of data (DMF 2014). Hard clam landings from public waters declined by nearly half between 2001 (NCDMF 2008) and 2013, while catch rates increased over time for both hand and mechanical harvesting (T. Moore, DMF, pers. com. 2014). Some of that decline in overall catch can be attributed to changes in catch limits or areas available for harvest. 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). There have been no studies of recruitment since the Peterson study, and therefore no more recent information (T. Moore, DMF, pers. com. 2014). In order to identify threats to hard clam habitat, DMF has been engaged in habitat mapping since 1988. Of the areas scheduled to be mapped, 94% of the estimated commercial shellfish harvest areas has been completed. Current threats include bottom-disturbing fishing gear, water-dependent development, and water quality degradation.

In 2014, the stock status of 14 soft bottom associated fishery species and complexes (Table 6.3) were evaluated by DMF (DMF 2014), and two (14%) were of *Unknown* status. Of the 12 stocks whose status is known, four (20%) were classified as *Viable*, one (5%) was *Recovering*, four (33%) were of *Concern*, and three (25%) were *Depleted*. *Viable* species included penaeid shrimp, striped mullet, spiny dogfish and summer flounder; red drum is listed as *Recovering*. *Depleted* species included Atlantic and shortnose sturgeons and southern flounder. *Concerned* are blue crab, Atlantic croaker, spot, and coastal sharks.

Atlantic sturgeon historically supported a valuable commercial fishery; landings declined dramatically by the early 1900s. Atlantic and shortnose sturgeon are now federally endangered species. In 2012, NOAA listed the Carolina Distinct Population Segment of Atlantic sturgeon as an endangered species under the ESA (NOAA 2012). Despite a fishing moratorium in North Carolina since 1991, neither species has shown signs of recovery. Potential habitat issues affecting recovery include reduction of freshwater benthic food sources 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 North Carolina 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) for essential sturgeon habitat.

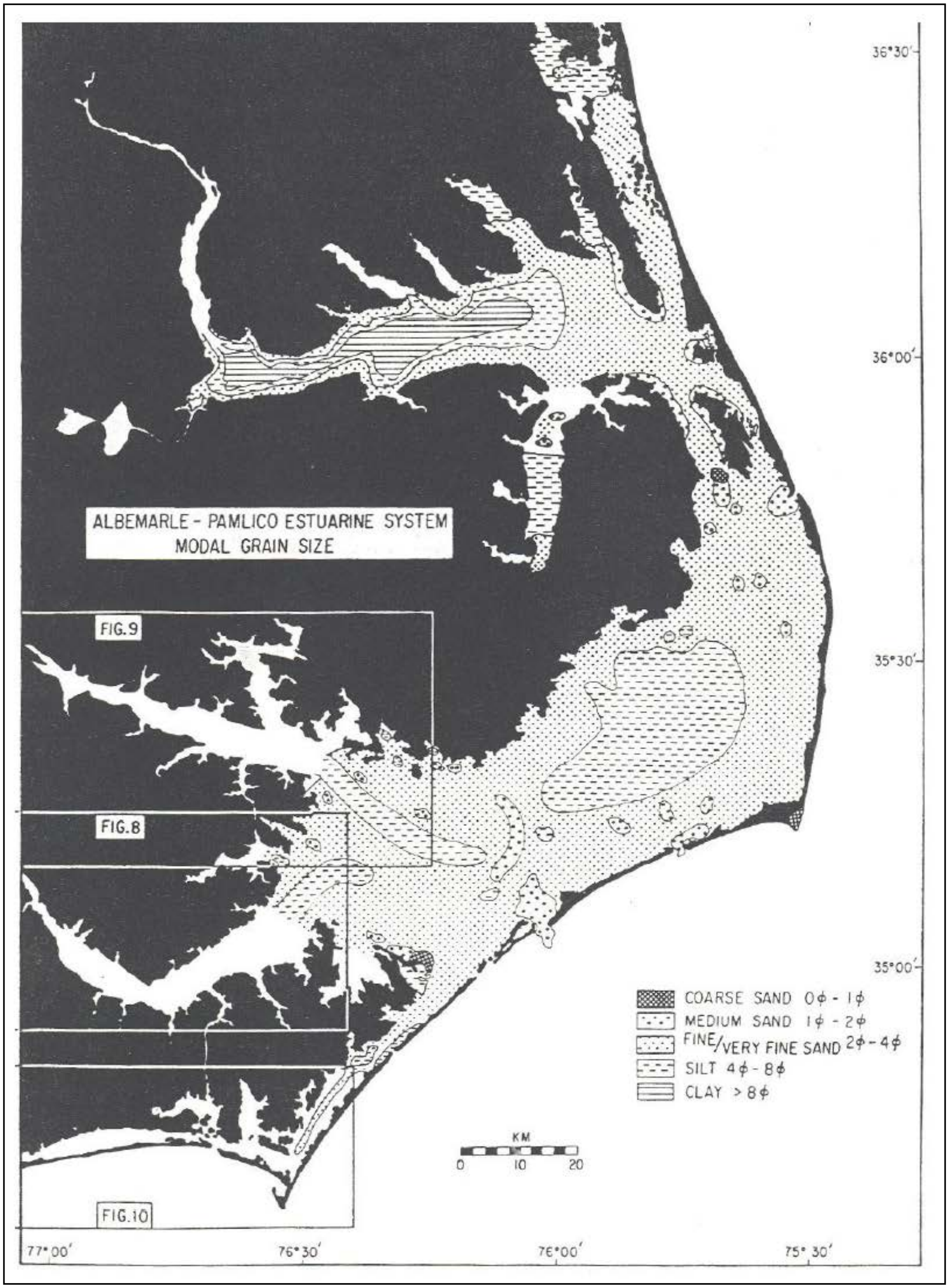
The *Depleted* status of southern flounder is due in part to overfishing, but may also be related to habitat issues in the low salinity estuaries. Dredging (navigational and fishery) and inlet stabilization are listed as threats to southern flounder habitat in the 2013 Southern Flounder FMP (NCDMF 2013b). Severe hypoxic events and anoxia can directly affect populations of southern flounder through mortality from suffocation and reduced growth rates, loss of preferred prey, changes in activity patterns, and disease.

Coastal sharks such as sandbars, Atlantic blacktips, Atlantic sharpnose, hammerheads, and duskys, are slow growing and late maturing, subjecting them to overfishing. Federal and state harvest restrictions have been in place since 1993, but there is no evidence of recovery. Degradation of nearshore marine bottom (beach nourishment, nonpoint runoff) could potentially impact pupping and nursery areas.

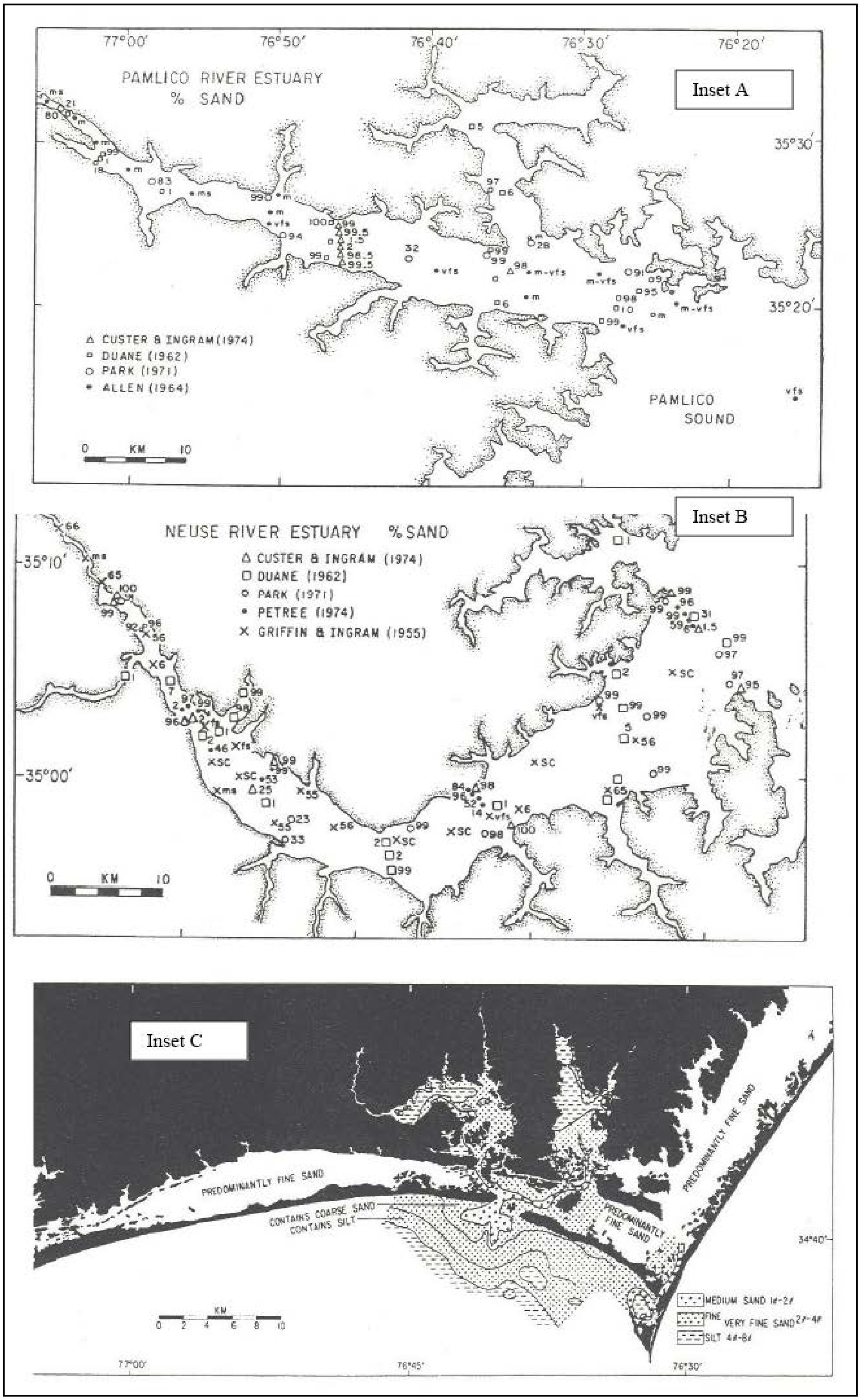
6.4. Soft bottom summary

There are a variety of soft bottom habitat types, ranging from intertidal ocean beaches to sound bottoms to mud flats. Soft bottom is an important source of primary (benthic microalgae) and secondary (infauna and epifauna) productivity, and is 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 seatrout, 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.

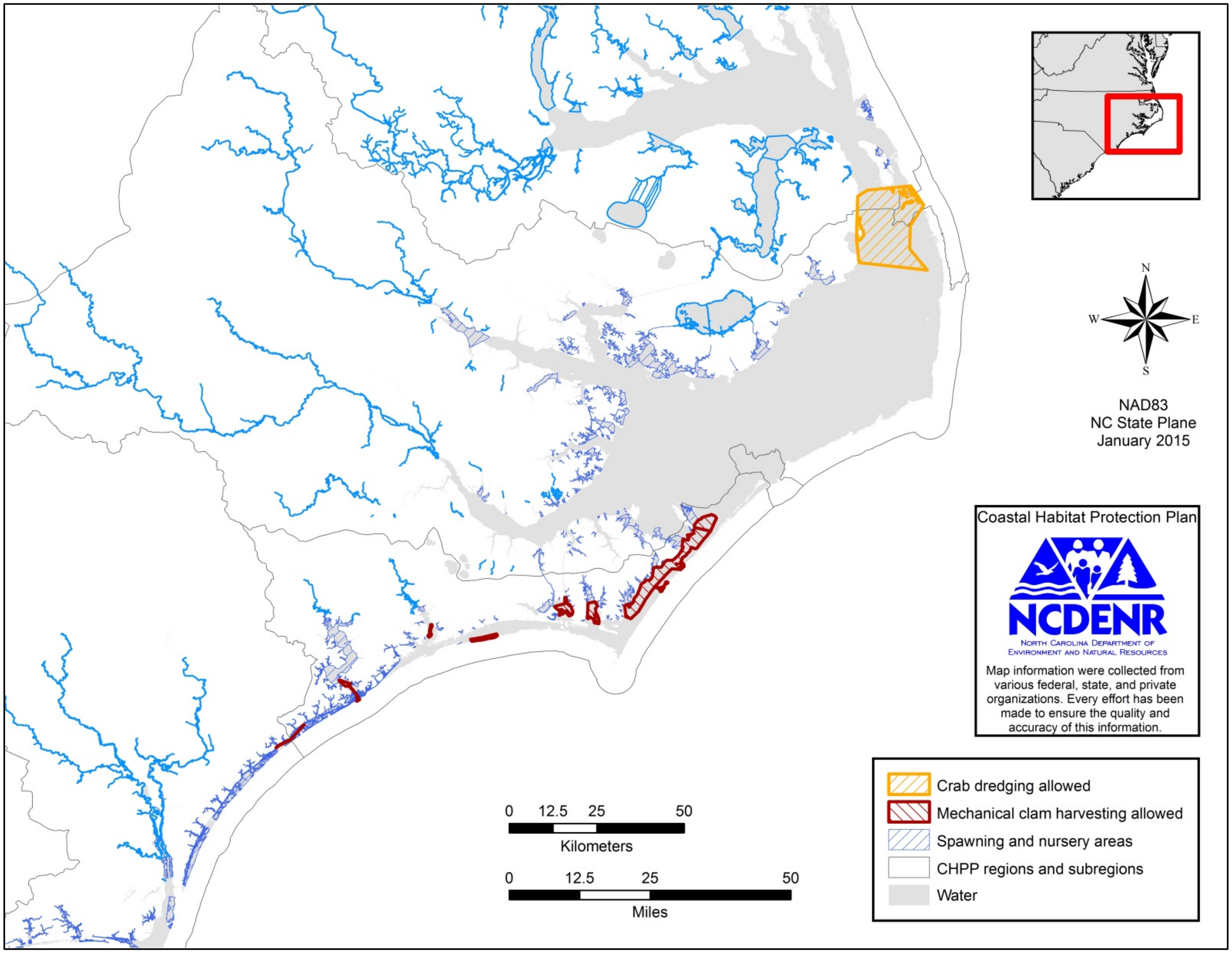
Fortunately, this habitat is relatively resistant to a changing environment. Soft bottom is the most abundant submerged coastal fish habitat, and estuarine acreage of soft bottom has undoubtedly increased over time as shell bottom, SAV, and wetland habitats have declined.



MAP 6.1A. 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 6.1B. Sediment composition in Tar-Pamlico, Neuse, and Core/Bogue estuaries (Wells 1989). Numbers = % sand, M= mud, SC=silty clay, VFS= very fine sand, MS= medium sand.



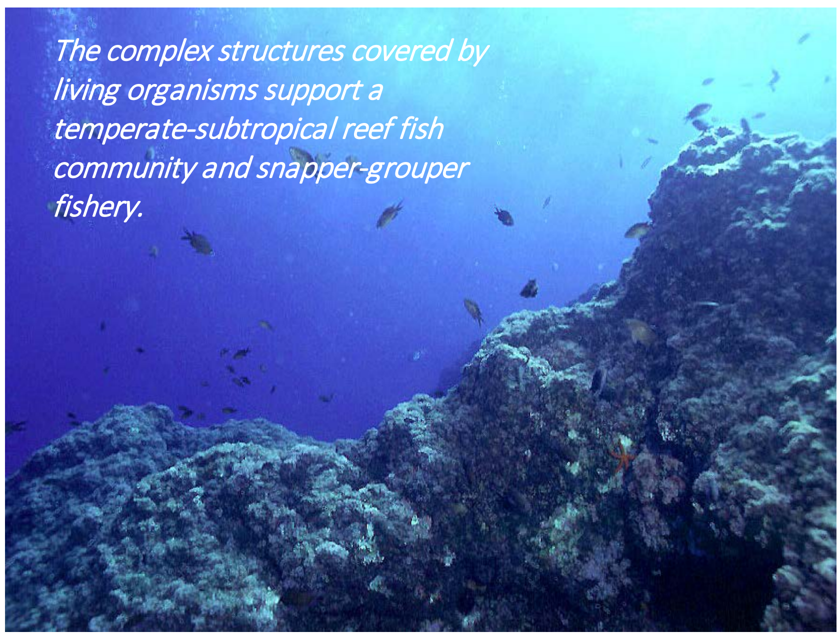
MAP 6.2. Areas where mechanical harvest for clams (clam kicking, hydraulic dredge) and crabs (crab dredging) is authorized in estuarine waters of North Carolina.

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 substrata for the development of hard bottom communities.



7.1.2. Description

Natural hard bottom, 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 1998b; SAFMC 2008b). 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 hard substrate by encrusting organisms produces large-scale morphological features, including overhangs and undercut sloped scarps (Riggs et al. 1998; Riggs et al. 1996). 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).

A study of live bottom areas from North Carolina to northern Florida (Continental Shelf Associates 1979; Wenner et al. 1984) revealed three hard bottom habitat types: 1) emergent hard bottom dominated by sponges and gorgonian corals; 2) sand bottom underlain by hard substrate dominated by anthozoans, sponges and polychaetes, with hydroids, bryozoans, and ascidians frequently observed; and 3) softer bottom areas not underlain with hard (SAFMC 2008a). The shelf edge habitat extends more or less continuously along the edge of the continental shelf at depths of 55 to 110 m (180 to 360 ft). The sediment types in this EFH zone vary from smooth mud to areas that are characterized by great relief and heavy encrustations of coral, sponge, and other predominately tropical invertebrate fauna. Some of these broken bottom areas (e.g., Onslow Bay, North Carolina) may represent the remnants of ancient reefs that existed when sea level was lowered during the last glacial period (SAFMC 2008a). The lower shelf habitat has a predominately smooth mud bottom, but is interspersed with rocky and very coarse gravel substrates where snowy and yellowedge groupers (*Epinephelus niveatus*, *E. flavolimbatum*) and tilefishes (*Malacanthidae*) are found. This habitat and its associated fishes roughly marks the transition between the fauna of the continental shelf and the fauna of the continental slope. The continental slope off North Carolina, Georgia and Northern Florida is interrupted by the relatively flat Blake Plateau, with recently identified mounds consisting primarily of dense thickets of the branching ahermatypic coral *Lophelia pertusa*, although other coral species have also been identified. In North Carolina, two mounds have been documented off Cape Lookout and one mound off Cape Fear (two recently designated Coastal Habitat Areas of Particular Concern discussed later in this chapter)(SAFMC 2008a).

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. Materials used in artificial reef construction vary greatly, and are placed into two general categories: materials of opportunity and prefabricated units. Materials of opportunity were not intended for artificial reef construction as were prefabricated units designed for reefs. These have received a measure of testing in regards to suitability and durability. In North Carolina, artificial reefs have been constructed from materials of opportunity such as: surplus vessels, steel boxcars, concrete pipe, concrete rubble, limestone rock, boat molds, tires, and surplus military aircraft. Prefabricated units include various forms of Reef Balls™, Reef Pyramids, etc. Artificial reef materials provide structurally complex habitat in areas where none existed previously, increasing available hard bottom habitat and enhancing fisheries resources. 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 Artificial Reef Master Plan (DMF 1988). Shipwrecks off the North Carolina coast also provide structure 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 boulders) 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 and other concrete structures also provide suitable substrate for hard bottom communities in high salinity estuarine waters.

7.1.3. Habitat requirements

The primary requirement for the formation and stability of hard bottom habitat is consistently exposed areas of hard substrate above the sand water interface. Ecologically and geologically, hard bottom and hard banks are diverse categories. Both habitats include corals, but typically not the carbonate structure of a patch or outer bank coral reef nor the lithified rock of lithoherms, a type of deepwater bank. Diverse biotic zonation patterns have evolved in many of these communities because of their geologic structure and geographic location. Hard bottom is common on rocky ledges, overlying relic reefs, or on a variety of sediment types. In each case, species compositions may vary dependent upon water depth and associated parameters (light, temperature, etc.)(SAFMC 1998b). 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 observed at these habitats range from approximately 11°C to 27°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. Although a number of attempts have been made, estimations of the total area of hard bottom are confounded due to the discontinuous or patchy nature of this habitat type (SAFMC 2008a). There have been many efforts made to update Parker's 1983 estimation of the eastern Atlantic hard bottom acreage, to no avail.

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, 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, side scan sonar, and video and diver observations. The amount of hard bottom habitat documented 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 Monitoring and Assessment Program) (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, Monitoring and Assessment Program) (2001) 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).[8]

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-SA2004). 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 Cape Lookout Lophelia Banks and

[8] 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.

TABLE 7.1. Hard bottom locations and possible locations in NC territorial waters by coastal bay. [Source: Point and line data identified by (SEAMAP-SA 2001b). 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)**

TABLE 7.2 Hard bottom and potential hard bottom locations in NC territorial waters according to SHA Region. Source: (Moser and Taylor 1995; SEAMAP-SA 2001a).

	SHA Region						
Hard Bottom Source	1	1/2	2	2/3	3	4	Total
Moser & Taylor Hard Bottom Points	0	0	4	0	31	88	123
Moser & Taylor Hard Bottom Polygons (hectares)	0 (0)	0 (0)	0 (0)	0 (0)	4 (1095)	1 (317)	5 (1412)
Moser & Taylor Hard Bottom Lines (kilometers)	0 (0)	0 (0)	4 (8)	0 (0)	15 (37)	19 (37)	38 (82)*
2001 SEAMAP Hard Bottom Points	1	0	1	0	6	9	17
2001 SEAMAP Potential Hard Bottom Points	1	1	2	0	7	5	16
2001 SEAMAP Hard Bottom Lines (kilometers)	0 (0)	0 (0)	0 (0)	0 (0)	23 (26)	13 (17)	35 (45)*
2001 SEAMAP Potential Hard Bottom Lines (kilomet	1 (2)	5 (17)	9 (22)	0 (0)	33 (46)	38 (61)	86 (148)*
*Some lines cross SHA region boundaries							

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-SA2004). 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 Cape Lookout Lophelia Banks and the Cape Fear Lophelia Bank Deepwater Coral CHAPCs (Partyka et al. 2007; Ross 2006; SAFMC 2008b). Cape Lookout and Cape Fear were part of Amendment 6 to the Coral, Coral Reefs, Live/Hard Bottom Habitats of the South Atlantic Region Fishery Management Plan to establish Coral Habitat Areas of Particular Concern (CHAPC)(NOAA 2010). Amendment 8 to the FMP proposes to expand the boundaries of the Cape Lookout Lophelia Bank CHAPC (NOAA 2014).

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 regard 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. 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 2003, HDR Engineering Inc. of the Carolinas in association with William J. Cleary, PhD, PG., was contracted by the USACE to use side scan sonar, multibeam, and diver ground truth data collection, to assess the potential impacts of offshore dredging as part of a Surf City/North Topsail beach renourishment project. Results of the report indicate an extremely complex exposure pattern of hard bottom throughout the study area, extending from the -9.1 m (-30 ft.) contour seaward to a distance of ~8 km (5.0 miles) offshore from Surf City through the southern end of Onslow Beach.

In 2004, Greenhorne and O'Mara, Inc., together with Ocean Surveys Inc., were able to further refine the extent of the hard bottom using "Chirp" and "boomer" profiles. This technique revealed a thin veneer of sand over relatively flat hard bottom. The habitat was further refined in following years, but only within the originally defined borrow area (Mr. Glenn McIntosh 2009). In boring for compatible sand sources for a Brunswick County beach nourishment project, the USACE identified substantial areas of low-relief hard bottom seaward of Oak Island, Holden Beach, and Ocean Isle (US Army Corps of Engineers 2000). Similarly, in 2008, several areas of hard bottom were revealed through side scan sonar while preparing for an environmental impact statement for Bogue Banks beach renourishment, detecting at least two hard bottom areas 9-22 acres in size (Mid-Atlantic Technology and Environmental Research 2008).

7.1.4.2. Distribution of man-made hard bottom

There are 50 DMF-managed artificial reefs of varying construction in North Carolina, of which 29 are located in federal ocean waters, 13 in state ocean waters (Map 7.1), and eight in estuarine waters.[9] The artificial reefs are located from one to 38 miles from shore, and are strategically positioned near every maintained inlet and one unmaintained inlet along the coast (SAFMC 2008a). The Artificial Reef Program enhances a subset of the reef sites yearly and creates new sites when needed. Data collected on the artificial reefs regarding species utilization helps to fill gaps in knowledge. This information allows the program to develop BMPs for future reef enhancement activities. 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 DMF maintains one of the most active artificial reef programs in the nation. State and Sportfish Restoration funding, and enthusiastic support from many civic and fishing clubs continues to ensure the success of North Carolina's artificial reef program (SAFMC 2008a).

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). 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 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

[9] The Shell Bottom chapter (3.0) covers estuarine reefs located in salinities suitable for oysters.

Cape Hatteras Lighthouse, and on the west side of Beaufort Inlet.

In 2011, the North Carolina state legislature lifted the state ban on oceanfront hardened structures through Senate Bill 110 (Assembly 2011), followed by NC General Statute G.S. 113A-115.1. In 2013, the statute was further relaxed by the Coastal Policy Reform Act (Assembly 2011), followed by statute, NCGS 113A-115.1. Four island communities have since sought permits for terminal groins. Bald Head Island has received a permit, with Holden Beach, Ocean Isle, and Figure Eight pending. Numerous small groins and jetty systems are in estuarine waters, 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 sand to sediment-starved sections of the North Carolina continental margin, such as Onslow and Long bays (Riggs et al. 1998; Riggs et al. 1996). Three primary groups of bioeroders, including rock boring bivalves, burrowing shrimp, and macroalgae, physically and/or chemically degrade hard bottom of varying hardness 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 rocks until chunks sever, leaving fresh surfaces for bivalve larvae to settle on and bore into. Macroalgae erode rock (primarily limestone) when storms and strong 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 enhance the structural complexity of the hard bottom outcrops, which promotes diversity of fish habitat within the reef (Riggs et al. 1998; Riggs et al. 1996).

7.2.2. Productivity

Exposed hard substrate provides stable attachment surfaces for colonization by sessile invertebrates and algae. Vertical relief and irregularity of structure affords habitat complexity, allowing more species to coexist (Fraser and Sedberry 2008; Wenner et al. 1984). Areas of exposed hard bottom may be small and isolated, considered havens of productivity surrounded by less productive unconsolidated bottom (SAFMC 1998b; SAFMC 2008b). Species diversity and extent of colonization on temperate hard bottom vary with topography, distance from shore, and environmental conditions. Much of the research on hard bottom communities in North Carolina has been focused on locations beyond the three-mile state boundary (Kirby-Smith 1989; MacIntyre and Pilkey 1969; Peckol and Searles 1984; Schneider 1976).

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 (DMF 2001a; Mallin et al. 2000a; Peckol and Searles 1984; Renaud et al. 1997; Schneider 1976). The shallow inshore flora consists largely of temperate species, while offshore areas support more tropical flora (Searles 1984). The greatest abundance of macroalgae occurs offshore due to 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 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). Research conducted in 2013-2014 on both artificial and natural structures off Onslow Bay, NC noted sessile invertebrate colonization averaged 19.5% (Peterson and Paxton 2014). Dominant sessile invertebrates included: *Occulina* spp. hard corals, soft coral *Titanideum fraunenfeldii* and *Cliona spp.* boring sponge. 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 shelf edge. Inner shelf sites, in approximately 16–27 m water depths, had 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[10] 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.[11]

Species composition of hard bottom communities in the nearshore waters of North Carolina is less tropical in nature than that farther offshore or to the south due to cooler water temperatures and greater temperature fluctuations (Fraser and Sedberry 2008; Kirby-Smith 1989). 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). Peterson and Paxton (2014) noted approximately 17% macroalgae coverage from 2013 to 2014, consisting mostly of *Dictyopteris (hoytii & membranacea), Dictyota spp., Hypnea spp., Sargassum spp., Solieria filiformis, Zonaria tournefortii,* crustose coralline algae and *Peyssonnelia spp.* 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 depths of 20 to 40 m approximately 32 km offshore (MacIntyre 2003; MacIntyre and Pilkey 1969). 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* (Hay and Sutherland 1988; Wenner et al. 1984).

Unique and productive hard bottom communities are also found on the slope off North Carolina (> 250 m water depth) (Partyka et al. 2007; Ross 2006; 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 the deepwater 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

[10] sponges (89 Porifera taxa); bryozoans (91 Bryozoa taxa); and corals and anemones (70 Cnidaria taxa)
[11] polychaetes (285 species, 72% of total individuals); mollusks (251 species, 4.3% of total individuals); and amphipods (100 species, 13% of total individuals)

invertebrate community in the deepwater reefs off North Carolina (Ross 2006).

7.2.4. Fish utilization of natural hard bottom

Fish comprise a significant proportion of faunal biomass on hard bottom and are important components of the overall trophic structure (Jaap 1984; Steimle and Zetlin 2000; Thomas and Cahoon 1993). Habitat utilization patterns by hard bottom fishes are primarily determined by water temperature and topography (SAFMC 1998b; SAFMC 2008b; Wenner et al. 1984). Temperatures less than 12˚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.

There is great diversity, with at least 325 invertebrate and algal species, and at least 192 fish species associated with nearshore hard bottom habitat ((Lindeman and Snyder 1999). Surveys conducted by Lindeman and Snyder (1999) found that over 80% of the fish occupying this habitat were from early life stages, and an estimated 34 fish species used it as a nursery area (Greene 2002). The abundance of fish on hard bottom and artificial reefs is related to the amount and type of structural complexity of the reef (Carr and Hixon 1997). Rocky structures with high complexity consistently supported a more abundant and diverse resident fish community than less complex structures. In addition, areas with small patches of hard bottom surrounded by sand bottom supported greater fish abundance and diversity than one large area of equal material, suggesting the importance of habitat edge and diversity to ecosystem productivity (Bohnsack et al. 1994; Langton and Auster 1999; SAFMC 2008a). 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 (Clavijo et al. 1989; Grimes et al. 1989; Huntsman and III 1978; Lindquist et al. 1989; Parker and Dixon 1998; Quattrini and Ross 2006; Quattrini et al. 2004; 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 (Grimes et al. 1989; Huntsman and III 1978). A list of species/stocks reported at nearshore hard bottom in North and South Carolina is provided in Table 7.3.

Invasive species have become an ever increasing issue. Shallow water census surveys on hard bottom and wreck sites in North Carolina indicate high densities (21.2 ha^{-1}) of lionfish (Whitfield et al. 2007). Attempts are underway to limit the lionfish's influence through efforts to commercially market the flesh, conduct targeted removal events, and inform the public about these predators.

Lindquist et al. (1989) reported 30 species in 14 families at a natural inner shelf (~5 miles offshore) hard bottom in Onslow Bay, North Carolina. Commonly occurring, numerically abundant species, in order of decreasing abundance were, 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 subligarius*), and sand perch (*Diplectrum formosum*). A partial list of the most important species utilizing hard bottom in North Carolina's state territorial waters and the function the habitat provides is in Table 7.4.

TABLE 7.3. Fishes occurring at nearshore hard bottom in North Carolina and South Carolina coastal waters (Sources: DMF; Grimes et al. 1989; Powell and Robbins 1998).

Family	Scientific name	Common name
Carcharhinidae	*Carcharhinus falciformis*	Silky shark
Muraenidae	*Gymnothorax nigromarginatus*	Blackedge moray
Ophichthidae	*Ophichthus ocellatus*	Palespotted eel
Engraulidae	*Anchoa* spp.	Anchovies
Synodontidae	*Synodus foetens*	Inshore lizardfish
	Trachinocephalus myops	Snakefish
Batrachoididae	*Opsanus pardus*	Leopard toadfish
Antennariidae	*Antennarius ocellatus*	Ocellated frogfish
Gadidae	*Urophycis earllii*	Carolina hake
Ophidiidae	*Ophidion marginatum*	Striped cusk-eel
Syngnathidae	*Hippocampus erectus*	Lined seahorse
	Syngnathus spp.	Pipefishes
Serranidae	*Centropristis ocyurus*	Bank sea bass
	Centropristis striata	Black sea bass
	Dermatolepis inermis	Marbled grouper
	Diplectrum formosum	Sand perch
	Epinephelus adscensionis	Rock hind
	Epinephelus drummondhayi	Speckled hind
	Epinephelus morio	Red grouper
	Cephalopholis fulva	Coney
	Epinephelus guttatus	Red hind
	Mycteroperca microlepis	Gag
	Mycteroperca phenax	Scamp
	Mycteroperca venenosa	Yellowfin grouper
	Cephalopholis cruentata	Graysby
	Serranus subligarius	Belted sandfish
Priacanthidae	*Pristigenys alta*	Short bigeye
	Heteropriacanthus cruentatus	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
	Lutjanus campechanus	Red snapper
	Lutjanus griseus	Gray snapper
Haemulidae	*Haemulon aurolineatum*	Tomtate
	Haemulon plumieri	White grunt
	Orthopristis 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	*Halichoeres 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

TABLE 7.4. 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	Spawning	Nursery	Foraging	Corridor	Fishery[2]	Stock status 2014[3]
MARINE SPAWNING, HIGH SALINITY NURSERY							
Black sea bass [4]	**X**	**X**	**X**	**X**	**X**		**V (s of Cape Hatteras) R (n of Cape Hatteras)**
Bluefish	X			X		X	V
Dmselfish (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	U
Pigfish	**X**	**X**	**X**	**X**		**X**	
Planehead filefish	**X**	**X**	**X**	**X**			
Scup [4]	**X**	**X**	**X**	**X**		**X**	**V (north of Cape Hatteras)**
Spottail pinfish	**X**	**X**	**X**	**X**		**X**	
Summer flounder	X	X		X		X	V
Tautog	**X**		**X**	**X**	**X**	**X**	
Wrasses (mult. spp.)	**X**	**X**	**X**	**X**			
MARINE REEF FISH COMPLEX							
Atlantic spadefish	**X**	**X**	**X**	**X**		**X**	
Greater amberjack	**X**			**X**		**X**	C- reef fish complex as a whole in NC. Individual species have not been evaluated in NC.
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] (Grimes et al. 1982; Powell and Robbins 1998; F. Rohde, DMF, personal communication)
[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
[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 (Ambrose and Swarbrick 1989; Bohnsack et al. 1994; Huntsman and III 1978; Lindquist et al. 1989; Miller and Richards 1980; 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 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 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 (*Rhombloplites 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, possibly reflecting the naturalization of artificial substrata over time (Jensen 2010). Additional DMF research investigated the effects of the density of material per area. Data suggested that seasonality was the largest driver of species composition, and that species may be attracted to certain metrics of complexity. This determination was based on functional responses (Bodnar 2009).
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 (Hay and Sutherland 1988; Lindquist et al. 1985). 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 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.

While providing suitable habitat for some fish, the species that utilize jetties do not require them for survival, as they are attracted to jetties from other hard bottom or oyster reefs, or use the jetties as temporary stopovers. Estuarine dependent species such as gag grouper use nearshore complex habitat like jetties, artificial reefs, and oyster reefs as the young of year migrate offshore (Moser and Ross 1995).

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 (Fraser and Sedberry 2008; Huntsman and III 1978; Kendall et al. 2008; Mallin et al. 2000a; Potts and Hulbert 1994; Quattrini and Ross 2006). Hard bottom habitats are often the only source of structural refugia in open shelf waters. Rocky faces with more complexity consistently support a greater abundance and diversity of resident reef fish than less complex habitats. Metrics that can influence abundance and diversity of the resident reef complex are: rugosity, profile, variety of refuge spaces, percent hard substratum, percent live cover and variety of growth forms (Gratwicke and Speight 2005).

The structure provided by hard bottom also concentrates prey resources and attracts predators. In general, most reef fish are carnivores (Goldman and Sedberry 2006; Jaap 1984; Lindquist et al. 1994b; Sedberry and Cuellar 1993). Benthic invertebrates are therefore very important as energy assimilators and food sources for reef fish (Jaap 1984). Lindquist et al. (1994b) 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 functions as crucial spawning area for many 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 predation. While offshore and shelf-edge reefs are documented as important spawning habitat for the snapper-grouper complex (Burgos et al. 2007; Burton et al. 2005; White and Palmer 2004; Wyanski et al. 2000), nearshore hard bottom provides spawning sites for smaller, more temperate reef species. Known to spawn on nearshore hard bottom are black sea bass and sand perch (Powell and Robbins 1998). Atlantic spadefish (*Chaetodipterus faber*), Sheepshead (*Archosargus probatocephalus*), inshore lizardfish (*Synodus foetens*), seaweed blenny (*Parablennius marmoreus*), 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).

7.2.6.3. Nursery

Nearshore and inner shelf hard bottom serves as important settlement and nursery habitat for larvae and early juveniles of many reef fishes. In a study of the abundance and distribution of ichthyoplankton adjacent to hard bottom in open shelf waters (< 55 m depth) in Onslow Bay, Powell and Robbins (1998) collected the larvae of 22 reef-associated families. Planehead filefish (*Monacanthus hispidus*), blenny *Parablennius marmoreus*, goby *Loglossus calliurus*, black sea bass, sand perch, and several species of grunts, snappers, and wrasses were commonly collected. These taxa are thought to spawn in deeper waters of Onslow Bay and recruit locally to nearshore hard bottom (Powell and Robbins 1998). Although the mechanisms of recruitment to hard bottom are generally unclear, it is apparent that successful recruitment depends on water circulation patterns transporting larvae to suitable habitat (Jaap 1984).

7.2.6.4. Corridor and connectivity

Nearshore hard bottom serves as a migratory corridor for late juveniles of estuary-dependent reef fishes (Baron et al. 2004; Lindeman and Snyder 1999). 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, unpublished data, 2014). 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 individuals at nearshore hard bottom sites (Baron et al. 2004; Lindeman and Snyder 1999). These assemblages are 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 early life stage survival, 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 territorial waters is of particular importance to the health and stability of the snapper-grouper species that utilize this habitat as "way stations" or protective stopping points as they emigrate offshore. Between 2011 and 2013, the North Carolina commercial snapper-grouper fishery harvested an annual average of 1,638,434 lbs (total 5,015,570 lbs) with an annual market value of >$4.2 million (total for 3 years - $12,567,964) (Table 7.5). During that same period, recreational fisherman (private, charter, and head boats) harvested an average of 568,146 lbs of fish in the snapper-grouper complex/year, for a total of 1,204,439 lbs (Table 7.6).

In April 2012, sheepshead was removed from the SAFMC snapper-grouper complex and is no longer federally regulated. Management now resides with individual states (Register 2011). As a result, North Carolina implemented General Statute T15A NCAC 03M .0521 giving the director proclamation authority to impose size, time, location, means, method, season, and quantity restrictions. An issue paper is being written by the Fisheries Management Section of DMF to ascertain any further measures needed.

The DMF Commercial Trip Ticket Program is legislatively mandated to collect trip level reporting on all commercial landings by licensed dealers. Table 7.5 represents trip ticket data for the snapper-grouper complex, included in the "commercial landings of select species of finfish and shellfish" from 2011-2013.

TABLE 7.5 Snapper and grouper complex extracted from commercial landings of select species of finfish and shellfish from 2011-2013, showing landings in pounds and dollar value (Source: DMF Trip Ticket Program).

	2013		2012		2011	
Species	Pounds	Value	Pounds	Value	Pounds	Value
Amberjack	90,180	$90,035	124,325	$104,212	72,797	$62,815
Porgies	70,944	$115,763	81,532	$129,798	89,612	$133,027
Scup	28,691	$13,323	3,954	$2,768	308,907	$126,875
Sea Basses	329,731	$868,920	256,007	$687,905	272,280	$627,825
Spadefish	20,369	$9,246	24,238	$9,043	21,535	$6,839
Tilefishes	217,079	$522,652	361,094	$753,966	133,824	$314,600
Triggerfish	160,861	$342,228	143,114	$278,968	220,204	$411,373
Snappers	276,533	$917,987	279,368	$899,624	326,371	$1,004,700
Groupers	311,428	$1,248,616	382,085	$1,421,867	408,507	$1,462,989

TABLE 7.6 Snapper and grouper complex from recreational landings of select species of finfish and shellfish from 2011-2013, showing landings by number and pounds (Source: DMF Marine Recreation Information Program).

		2013		2012		2011
Species	Number	Pounds	Number	Pounds	Number	Pounds
Amberjack	13,656	179,436	13,388	154,734	6,510	113,032
Porgies	8,460	16,720	15,857	26,249	6,683	11,117
Scup	630	507	1,800	1,940	607	475
Sea Basses	49,856	68,472	75,922	127,755	101,157	146,425
Spadefish	17,472	12,459	27,263	25,905	4,995	2,711
Tilefishes	6,976	33,950	8,643	43,680	4,922	27,163
Triggerfish	47,629	96,262	55,549	149,895	34,935	77,371
Snappers	9,852	14,013	27,822	60,163	13,376	25,167
Groupers	5,390	54,418	10,198	126,567	9,676	107,853

Nearshore hard bottoms were considered to be in "good general" condition overall in 1998 (SAFMC 1998b). Although information exists on the distribution of hard bottom off the North Carolina coast (SEAMAP-SA 2001; Moser and Taylor 1995; Udouj 2007), little information is available to evaluate the status and trends of hard bottom habitat in state territorial waters. The exact extent and distribution of productive live bottom habitat on the continental shelf north of Cape Canaveral is unknown. Although a number of attempts have been made, estimations of the total area of hard bottom are confounded due to the discontinuous or patchy nature of the habitat type. Henry and Giles (1980) estimated about 4.3% of the Georgia Bight to be hard bottom, considered an underestimate. Miller and Richards (1980) reported that live bottom reef comprises a larger area of the South Atlantic Bight. The method used to determine areas of live bottom involved the review of vessel station sheets from exploratory research cruises. Parker et al. (1983) suggested that rock-coral-sponge (live bottom) habitat accounts for about 14%, or 2,040 km2, of the substratum between the 27 m and 101 m isobaths from Cape Hatteras to Cape Fear. Parker et al. (1983) estimated that approximately 30%, or 7,403 km2, of the bottom from Cape Fear to Cape Canaveral was composed of live bottom (SAFMC 2008a). Anecdotal information from fishermen and residents in coastal North Carolina suggests that many nearshore hard bottom sites in the mid-twentieth century are now covered by sand, reducing the abundance of fish in these areas.

Some areas have already been lost to the effects of beach nourishment, such as hard bottom habitat off the coast of Wrightsville Beach, which was buried under two to six inches of sand through erosion from the nourished beach. These once productive fishing grounds no longer support the fish they once did, leading researchers to conclude that the conflict between beach nourishment and hard bottom productivity is very serious conflict, and will only get bigger (Greene 2002; Riggs et al. 1998).

7.3.2. Status of associated fishery stocks

Commercially and recreationally harvested reef fish are managed collectively as the reef fish complex or Snapper-Grouper management unit, which includes 59 species of snappers, sea basses and groupers, porgies, tilefishes, grunts, triggerfishes, wrasses, spadefish, wreckfish, and jacks (NMFS 2014). Management authority is shared by NMFS, SAFMC, and MFC. Of these species, only some are found on hard bottoms in North Carolina 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 (Collier 2002). Fishery-independent data are available from the Marine Resources Monitoring, Assessment, and Prediction Program (http://www.dnr.sc.gov/marine/mrri/MARMAP/index.html), 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 surveys from Cape Lookout 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, focusing seaward of state waters.

Amendment 21 to the Snapper-Grouper FMP of the South Atlantic Region by NMFS, redefined overfishing for the Snapper-Grouper management unit. The amendment was necessary due to low natural mortality rates of the 59 species in the fishery, eight of which are commercially fished. Overfished for purposes of the FMP is now defined as 75% of spawning stock biomass at maximum sustained yield (MSY), i.e., depleted to a degree such that the stock's capacity to produce MSY is jeopardized. Of the 59 managed species in the South Atlantic Snapper-Grouper management unit, four species were classified as "Overfished" in 2013 by NMFS, nine were "Not Overfished", and 46 were "Unknown".[12] Overfished species include snowy grouper, red porgy, and red snapper (NOAA 2013).

North Carolina historically led the South Atlantic States in commercial landings of gag grouper, averaging ~42% of annual landings by lb. wet weight (ww). From 2003 to 2007, North Carolina's average annual share of commercial gag grouper landings was ~36% and from 2008 through 2012, ~42%. North Carolina led in landings of blueline tilefish, averaging ~79% of annual landings by lb. ww from 2002 through 2012 and ~94% since 2008. North Carolina ranked first in commercial landings of red porgy from 2008 through 2012. Over the 5-year period from 2008 through 2012, North Carolina ranked first in landings of vermilion snapper with ~39% of landings by weight and dockside revenue (NMFS 2014).

In North Carolina, the reef fish complex as a whole was classified as *Concern* by DMF in 2014 (DMF 2014). 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,

[12] Overfished is defined as a stock with a biomass level depleted to a degree that the stock's capacity to produce MSY is jeopardized 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. 2014. Regulatory Amendment 21 to the Fishery Management Plan for the Snapper Grouper Fishery of the South Atlantic Region. Pages 176 *in* U. D. o. Commerce, editor, D.C.)

Assessment, and Review (SEDAR) stock assessments.

Of the species listed in Table 7.4 that are highly associated with nearshore hard bottom in North Carolina, seven stocks were evaluated by DMF in 2014. One stock was reported as *Concern* (gag grouper), one as *Recovering* (black sea bass north of Cape Hatteras) one as *Unknown* (king mackerel), and four as *Viable* (scup, summer flounder, bluefish, and black sea bass south of Cape Hatteras). No stocks in this group were considered *Depleted* in the 2014 DMF Stock Status Update (DMF 2014).

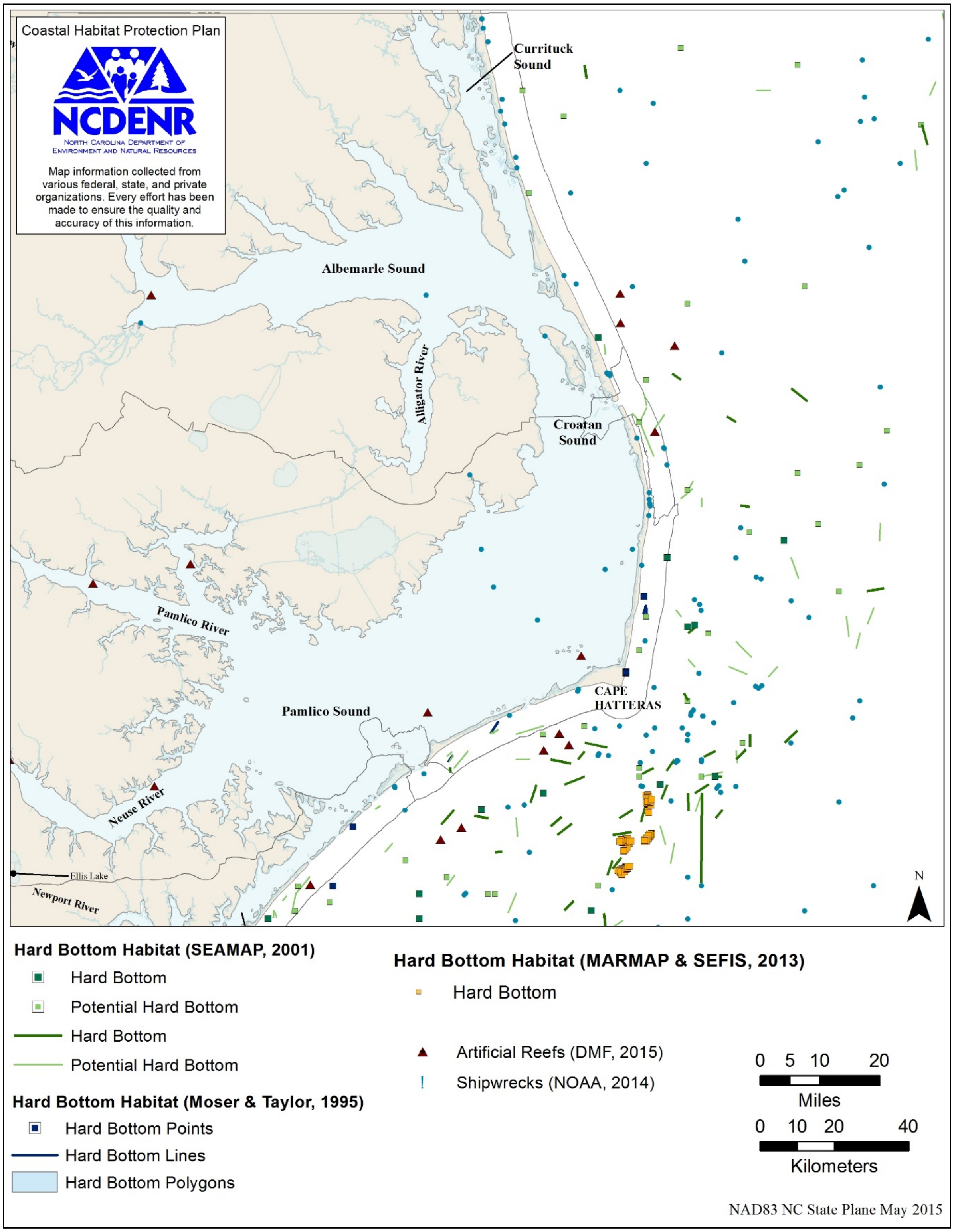
Although most exploited reef fish are caught primarily in federal waters, several, such as gag grouper and black sea bass, are highly dependent on nearshore hard bottom as primary and secondary nursery areas, and for providing migratory corridors as individuals move offshore with age. The apparent vulnerability 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 have been nominated as Strategic Habitat Areas because of their importance as secondary nursery habitats and migratory corridors for black sea bass, gag grouper, 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 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 correlation implies a relationship between habitat quantity and the size of reef fish populations.

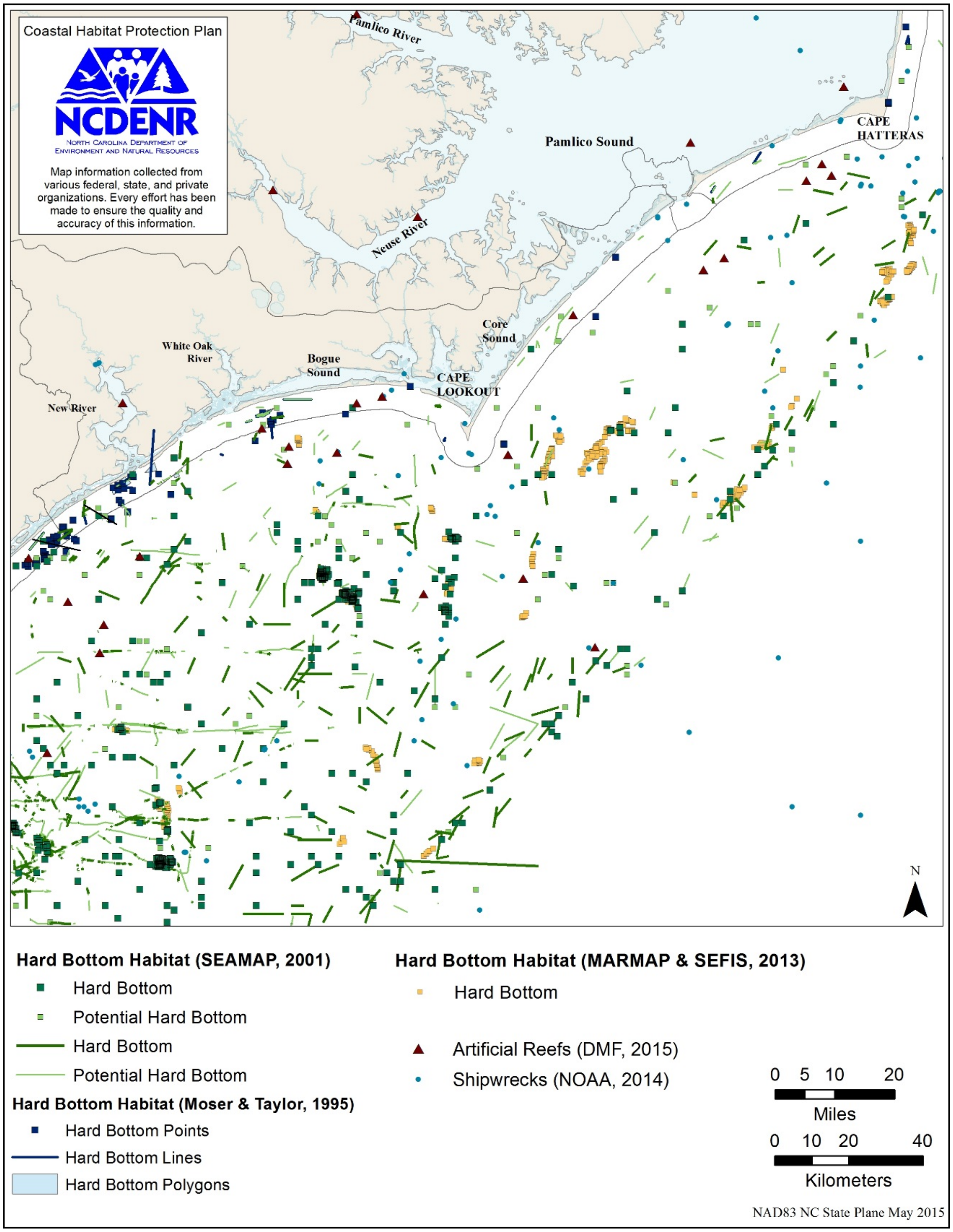
7.4. Hard bottom summary

Hard bottom provides havens 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 grouper and black sea bass, as they move between the estuary and offshore reef areas. Because of their importance for spawning, nursery, and foraging, all of the nearshore hard bottoms off North Carolina have been federally designated as Habitat Areas of Particular Concern for the snapper-grouper complex.

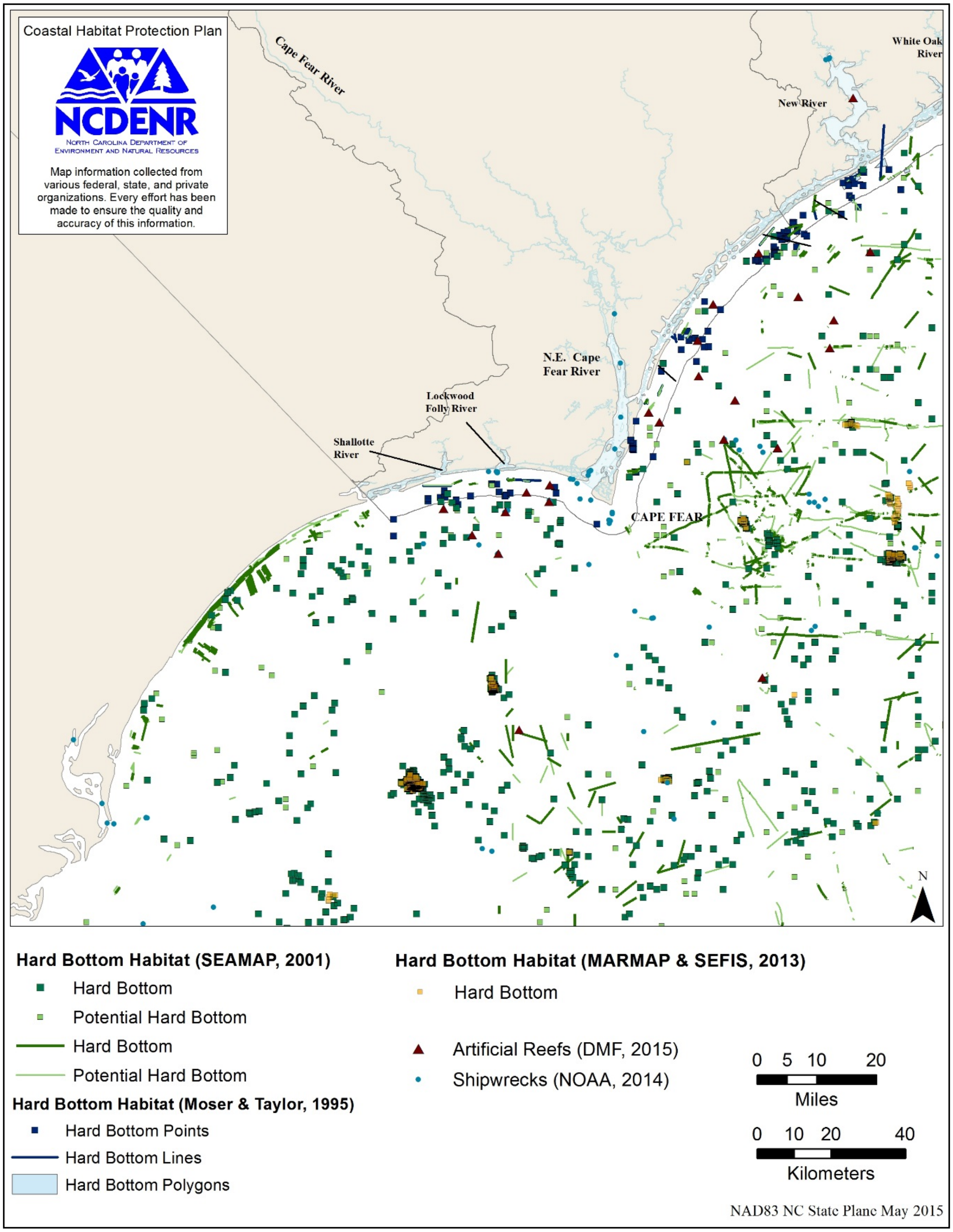
While the distribution of hard bottom off the North Carolina coast was mapped in the 1990s, little is known about the biological condition of specific hard bottom sites or how hard bottom distribution has changed over time. However, increases in beach nourishment activities, which require an environmental 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.



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. PHYSICAL DISTURBANCES

8.1. Fishing Gear Impacts

The extent of habitat damage from fishing gear varies with gear type, habitat complexity, and amount of contact. The concern has generated many studies, with Rester (2000) and Dieter et al. (2003) compiling bibliographies of the studies. The 1996 reauthorization of the Magnuson-Stevens Fishery Management and Conservation Act required that federal fishery management plans (FMPs) include adverse impacts to essential fish habitat (EFH) as a result of fishing activities (Barnette 2001). Fishing related impacts to fish habitat have been reviewed in federal FMPs for managed species by South Atlantic and Mid-Atlantic Fishery Management Councils and are addressed in DMF FMPs. Few studies have been conducted on passive or static gear effects, but it is generally assumed that these gears have less impact than mobile gears (Barnette 2001). Some studies suggest that it is the cumulative effects rather than the type of gear that is more important (Collie 1998). Effects can be short -term, such as sediment resuspension, or long-term, such as effects on biodiversity, which may be more difficult to measure (Barnette 2001).

8.1.1. Mobile Bottom-Disturbing Fishing Gear

Mobile bottom-disturbing gear is towed or run by power, including bottom trawls, dredges, clam kicking gear, patent tongs, and haul seines. Most commonly used in North Carolina is the shrimp trawl (Table 8.1), followed by oyster and clam dredges. A legislative report to the Moratorium Steering Committee (MSC 1996) compiled a list of gears used in North Carolina and probable habitat impacts. Trawls and dredges were found to have the greatest potential. Bottom trawling is mostly used on soft bottom in both estuarine and coastal ocean waters, primarily to catch shrimp, and some crabs (Table 8.2).

TABLE 8.1. Most common mobile bottom-disturbing gear types for commercial fisheries by year and number of trips, DMF 2013.

Year	Clam Dredge[1]	Clam Trawl Kicking	Crab Trawl	Flounder Trawl	Haul Seine	Beach Seine	Oyster Dredge	Shrimp Trawl
1994	407	636	3,824	508	972	862	236	18,989
1995	767	823	2,207	532	961	959	88	19,817
1996	637	1,089	4,308	415	899	870	3	14,622
1997	473	1,120	5,049	237	713	1076	31	16,575
1998	668	1,081	5,710	654	609	690	671	12,201
1999	639	1,176	3,546	517	536	527	942	15,317
2000	735	791	2,223	469	436	822	392	14,082
2001	459	838	2,539	524	429	489	822	10,717
2002	691	879	1,034	667	395	557	621	12,916
2003	431	838	1,693	459	480	125	893	9,886
2004	657	1,026	1,775	491	450	411	1,750	8,380
2005	426	538	1,117	408	431	681	2,342	4,550
2006	386	372	301	389	494	317	2,487	5,711
2007	343	211	157	419	393	242	1,732	6,737
2008	469	423	314	354	364	329	2,688	6,003
2009	355	536	484	340	315	123	4,481	5,745
2010	603	517	273	394	246	183	10,709	5,591
2011	400	286	228	346	197	102	7,434	4,373
2012	492	187	20	108	130	68	2,264	6,195
2013	344	180	85	71	195	57	3,763	5,657
TOTAL	10,382	13,547	36,887	8,302	9,645	9,490	44,349	204,064

[1]Includes hydraulic dredges.

Bottom trawls are conical nets towed behind a vessel, held open by water pressure against a pair of "otter boards" or "doors" attached to the front of the net. Three components of a trawl can dig into the sediment: the doors, the weighted line at the opening of the net, and the tickler chains (sometimes added in front of the net to improve harvest). Dredges are used in both clam and oyster fisheries. Oyster dredges have metal frames to which bags of metal rings are attached, often with teeth designed to dig into the sediment, towed behind the vessel (Barnette 2001). Oyster dredges are primarily used on shell bottoms. Crab dredges are similar to oyster dredges, with sometimes longer teeth. There was only one crab dredge trip reported in 2013 (NCDMF 2014a).

There are two types of scallop dredges in North Carolina. Bay scallop dredges are used in SAV beds, while sea scallop dredges are used in the coastal ocean off Cape Lookout. Three bay scallop trips and 19 sea scallop trips were reported in 2012-2013. Hydraulic dredges are used primarily in the clam fishery. This dredge has an escalator or conveyor on the vessel, with a sled connected to the conveyor, using water to force clams from the sediment which are then collected by the escalator (NCDMF 2008). Clam kicking is a form of trawling in which propeller is used to dislodge clams from the bottom, then collected in the trawl. Most dredging is done on shell bottoms where the resource is abundant. Clam kicking is only allowed in areas without significant SAV or oyster resources (NCDMF 2008).

Haul and beach seines are large nets used to encircle schools of fish. Beach seines are used on beaches and haul seines may be deployed from a boat. Both scrape the bottom with a lead line. The impact of these gears is unknown and likely minor. Patent tongs are not currently used in North Carolina.

Annual effort in number of trips of commonly used mobile bottom-disturbing gears is shown in Table 8.1 (NCDMF 2014a). Shrimp trawling accounts for most of the effort, followed by oyster dredging. Oyster dredging increased to over 10,000 trips in 2010 due to higher abundances and a good market, but has declined since. Most of the decline is attributed to changes in regulations regarding gear restriction areas for mechanical harvesting of clams and oysters. Most oyster dredging occurs in the Pamlico Sound region, while most clam dredging occurs in the southern region, followed by the Core/Bogue Sound region, which also experiences the majority of clam kicking trips.

Commercial shrimp trawling accounted for the majority of trawl trips 2013. About 75% of shrimp trawl trips occur in estuarine waters (Table 8.2), the remainder in ocean waters, primarily within state territorial waters off the central and southern coast. Total annual estuarine shrimp trawling effort has ranged from 2,944 trips in 2005 to 15,791 trips in 1995 (Table 8.2). The number of estuarine shrimp trawl trips has not exceeded 10,000 trips since 2002. Shrimp trawling effort fluctuates with abundance, but has gradually declined since 1994, due to a number of factors including increasing imports, fuel prices, regulation changes, and retiring fishermen (DMF 2015). In 1999, a recreational commercial gear license (RCGL) became available. With this license, shrimp can be caught recreationally with a trawl, but cannot be sold. Effort from RCGLs are not included in Table 8.2. Surveys of RCGL holders ceased in 2008, but over 2,000 shrimp trawl trips were taken in 2013 (DMF 2015).

Over 99% of crab trawling occurs in estuarine waters (Table 8.2), with the majority in the Pamlico Sound system, followed by Core/Bogue sounds and estuaries. No finfish trawling is allowed in internal waters. All directed flounder trawling occurs in ocean waters, primarily >3 miles offshore. Effort in the nearshore waters (<3 miles) has ranged from 204 trips in 1998 to zero trips in 2012 and 2013 (Table 8.2).

Impacts from mobile bottom-disturbing fishing gear range from changes in community composition from removal of species to physical disruption of the habitat (Barnette 2001). Corbett et al (2004), found an increase in total suspended sediment 1.5 – 3 times above background concentrations for less than a day, and minor impacts on nutrient and chlorophyll *a* concentrations. Wind played a greater role in mixing the water column and altering its nutrient and sediment characteristics.

Bottom trawls, dredges, and other mobile gears can cause rapid and extensive physical damage to hard bottom habitat (Auster and Langton 1999; Freese 2001; NRC 2002; Reed et al. 2007; SAFMC1998a; Wells et al. 2008). Studies have found that scallop dredges cause extensive damage to hard bottom and reduce habitat complexity on soft 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; Løkkenborg 2005). Dragged fishing gear removes or damages benthic organisms such as sponges, corals, and macroalgae, often leading to mortality. These gear types displace outcrop seafloor structures. Damage from mobile gear is extensive where the bottom is uneven and there is a concentration of epiflora and/or epifauna. The removal of structure and attached biota reduces species richness, diversity, and habitat complexity (Auster and Langton 1999; NRC 2002; Watling and Norse 1998). Indirect damages to hard bottom occur through altered trophic linkages and nutrient cycles, and increased vulnerability of organisms, and subsequent disease and predation (Auster and Langton 1999; NRC 2002). Trawling reduces mobile benthic invertebrates on hard bottom, limiting food resources available to other reef organisms.

Fishermen avoid hard bottom areas because of potential damage to nets and gear, but there is one type of trawl 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 where roller-rigged trawls had been used (Tilmant 1979; Van Dolah et al. 1987). While many sponges and corals can partially recover within one year following trawling, slower-growing species require several years to completely regenerate (Van Dolah et al. 1987). Because of the potential for hard bottom degradation, roller-rigged trawls have been prohibited by federal regulation for the harvest of snapper-grouper south of Cape Hatteras since 1989 (SAFMC 1998a).

Oyster and clam dredges are the primary gears used to harvest on shell bottoms. Oyster harvesting reduces the vertical relief of subtidal reefs, and dredging results in additional negative impacts, including scattering, which removes shell and oysters, and destabilizes the structure (Lenihan et al. 1999b; Lenihan and Peterson 1998). These effects result in reduced spawning stock biomass, reduced substrate for recruitment, reduced structural complexity for refuge and foraging, and decreased disease resistance. While many factors have contributed to the decline in the oyster fishery, dredging and tonging have most impacted the physical structure of reefs in the Chesapeake Bay (Hargis Jr. and Haven 1988; Rothschild et al. 1994). One full season of simulated oyster dredge harvesting effort reduced the mean height of high profile mounds by 30% (DeAlteris et al. 1999; Lenihan and Peterson 1998).

The use of oyster dredges has been limited by the Marine Fisheries Commission (MFC) in recent years (DMF 2008a), still, historical subtidal oyster beds have not recovered (Lenihan and Peterson 1998), and oysters are listed as a species of *Concern* in the 2014 stock status report (DMF 2014). Degraded water quality, partially due to reduced filtration by oysters from loss of resource, is thought to have impaired full recovery (Jackson et al. 2001; Lenihan and Micheli 2000). The extent of dredge damage to shell bottom depends on trip duration and frequency, and the amount of reef area worked over time (Powell et al. 2001). Some of the damage is mitigated through cultch planting at 3-4 year intervals (Map 3.4a).

Trawling for shrimp, crabs, and finfish, long haul seining, and crab dredging have similar but reduced impacts on shell bottom habitats (DMF 2001c). The weight and movement of trawl doors or chains towed across the seafloor can disrupt the oyster mound structure, removing the upper layers of shells or scattering oysters (DMF 2001c). Long haul seines dragged through shell bottom can damage oyster mound structures by entangling, uprooting, and scattering shell. Frankenberg (1995) concluded that trawling had a significant negative impact on living shell bottom habitat. South of Pamlico Sound, a significant area is closed to oyster dredging but not trawling. Where bottom disturbing gears are allowed in subtidal habitat, creation, maintenance, and re-establishment of beds may be deterred.

TABLE 8.2. Annual number of trips reported for shrimp, crab, and flounder trawls in North Carolina estuarine and ocean waters, 1994-2013 (DMF Trip Ticket Data). Trawling is not permitted in Albemarle Sound.

	Shrimp Trawls					Crab Trawls					Flounder Trawls				
	Estuarine Rivers and Sounds[1]			Ocean Waters		Estuarine Rivers and Sounds[1]			Ocean Waters		Estuarine Rivers and Sounds[1]			Ocean Waters	
Year	Core/Bogue	Pamlico	Southern	< 3 miles	> 3 miles	Core/Bogue	Pamlico	Southern	< 3 miles	> 3 miles	Core/Bogue	Pamlico	Southern	< 3 miles	> 3 miles
1994	7,176	4,870	3,066	3,639	238	238	3,531	35	15	5	0	4	1	49	454
1995	7,244	5,185	3,361	3,771	256	207	1,898	101	1	0	1	14	6	88	423
1996	6,069	2,906	2,352	2,970	325	197	4,058	51	2	0	1	5	0	112	297
1997	5,745	4,792	2,722	2,994	322	657	4,193	198	0	1	0	11	2	68	156
1998	4,679	1,864	2,053	3,212	393	542	5,104	63	1	0	0	1	0	204	449
1999	4,867	4,082	2,156	3,939	273	410	3,104	32	0	0	0	0	0	169	348
2000	3,460	5,513	1,942	3,011	156	265	1,911	47	0	0	0	0	0	106	363
2001	3,533	3,180	1,273	2,654	77	397	2,036	106	0	0	0	0	0	104	420
2002	3,763	4,883	1,619	2,598	53	85	870	79	0	0	0	0	0	141	526
2003	3,553	1,752	1,591	2,811	179	112	1,476	105	0	0	0	0	0	62	397
2004	1,806	2,728	910	2,791	145	403	1,210	162	0	0	0	0	0	26	465
2005	1,336	861	747	1,535	71	163	823	125	6	0	0	0	0	11	397
2006	884	1,819	600	2,323	85	51	245	5	0	0	0	0	0	23	366
2007	786	2,922	787	2,196	46	61	96	0	0	0	0	0	0	69	350
2008	674	2,721	832	1,691	85	41	273	0	0	0	0	0	0	24	330
2009	763	2,187	958	1,776	60	37	447	0	0	0	0	0	0	29	311
2010	561	2,053	1,363	1,582	32	88	153	32	0	0	0	0	0	21	372
2011	174	1,956	913	1,297	33	82	123	23	0	0	0	0	0	31	315
2012	942	2,245	1,282	1,689	37	2	18	0	0	0	0	0	0	0	108
2013	765	2,052	1,247	1,583	10	30	44	11	0	0	0	1	0	0	70

[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; AIWW.

Shearing or cutting of SAV leaves, flowers, or seeds, and uprooting of the plant are most often caused by dragging or snagging by gears such as long haul seines or bottom trawls (ASMFC 2000). Shearing of above ground biomass does not always result in SAV mortality, but productivity is reduced since energy is diverted to replace damaged tissue, and the nursery and refuge functions are reduced in the absence of structure. Auster and Langton (1999), ASMFC (2000), and Collie et al. (2000) discussed 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, requiring months to years to recover. Excessive sedimentation from trawling, dredging, and propeller wash can bury SAV. Qualitatively, damage to eelgrass meadows from unspecified shellfish harvest dredges was surpassed only by damage from propellers (Thayer et al. 1984). Turbidity from bottom-disturbing gear can reduce clarity, SAV growth, productivity, and survival.

Most trawling in Bogue and Core sounds occurs in or near the AIWW, with some commercial trawling during high tide in shallow regions outside the AIWW. Eleuterius (1987) noted that shallow SAV beds were not affected by trawling but during high tides when beds were accessible. Most SAV in western portions of the Albemarle-Pamlico system is protected from shrimp trawling (Table 8.3). However, crab trawling is allowed in the Pungo, Upper Neuse, and Pamlico rivers (Maps 3.5a-c).

TABLE 8.3. Mapped bottom habitat acreage of MFC designated areas within Estuarine Bottom Habitat Mapping (EBHM) mapping boundaries. EBHM areas are not inclusive of all PNAs (DMF 2014). Acreage calculated from GIS layers.

MFC designation	Area (acres) within NC Coastal Waters for GIS layer	Area (acres) within EBHM areas	% of Specific Area that falls within Mapping Area	Area (acres) within EBHM mapped	% Mapped
Crab Spawning Sanctuaries	27,497.72	16,458.36	59.85%	14,798.33	89.91%
Military Restricted Areas	104,452.14	21,718.16	20.79%	19,049.46	87.71%
Seed Management Areas	2,178.54	2,321.79	106.58%	2,321.79	100.00%
Oyster Sanctuaries	228.42	97.22	42.56%	97.22	100.00%
Special Secondary Nursery Areas	35,794.69	31,793.33	88.82%	31,247.32	98.28%
Mechanical Clam Harvest areas	43,899.93	4,0915.49	93.20%	40,089.97	97.98%
Mechanical Oyster Harvest prohibited areas	407,396.56	347,402.79	85.27%	327,801.01	94.36%
Primary nursery areas	44,973.28	48,556.80	107.97%	46,491.35	95.75%
Taking crab with dredges	86,094.68	28,031.02	32.56%	28,030.07	100.00%
Trawl net prohibited	208,591.77	158,268.09	75.87%	152,727.26	96.50%

Bay scallop dredges, in contrast to oyster and crab dredges, cause less severe damage to SAV as they are smaller [not over 50 lb (22.68 kg)] and have no teeth. They are intended to glide over the surface, taking scallops from the bed. Bay scallops depend on SAV for initial post-larval setting, and as such are strongly associated. An evaluation of impacts to eelgrass (*Zostera marina*) from bay scallop dredging in North Carolina found that scallop dredging over grass beds significantly reduced biomass, surface area, and shoot density (Fonseca et al. 1984). The impacts were more severe in soft bottom than in 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. 1983b), 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 the propeller pulling the dredge, particularly when season opening coincides with low tide (T. Murphey, DMF, pers. com. 2015). Most 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 by proclamation for a specified area when DMF biologists determine there is a sufficient population (NCDMF 2015a). Annual monitoring of populations not only provides data for fisheries management actions, but also provides information on a sensitive environmental indicator.

When hydraulic clam dredging occurs in SAV beds, a swath approximately three feet (0.91 m) wide is excavated (ASMFC 2000), which can also significantly increase local turbidity (ASMFC 2000). Because of the severe bottom impacts, the MFC restricts use of this gear to open sand and mud bottoms, including areas frequently dredged for navigation, such as the AIWW. This gear is not allowed in SAV or oyster beds, a restriction strictly enforced. Clam kicking can also severely damage SAV, reducing plant biomass in eelgrass and shoalgrass beds (Peterson and Howarth 1987). Loss of SAV biomass and time needed for recovery increased as intensity of clam kicking increased (Peterson and Howarth 1987). The probability of historic damage to SAV via kicking seems likely because: (1) kicking was 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 operate in shallow waters (Guthrie and Lewis 1982). As a part of CHPP implementation, the area allowed for clam kicking was modified by proclamation to clearly avoid all SAV and oysters beds and to establish a buffer of 50-100 feet between the gear and habitat.

Trawl doors have been shown to bring infaunal bivalves to the sediment surface. Gilkenson et al. (1998) and Sanchez et al. (2000) observed more annelids in muddy bottom post trawling in the Mediterranean Sea. Studies in areas that are consistently trawled show that otter trawls negatively affect nematode abundance, production, and genus richness in areas not susceptible to environmental stresses (e.g., wind events) (Hinz et al. 2008). Gear contact can uproot and remove invertebrates attached to the seafloor, such as sponges and worm tubes, and expose them to predators.

Changes to and reduction in the structural complexity of the seafloor, with increases in turbidity from frequent trawling, can reduce success of filter feeding invertebrates by clogging gills and augmenting predation due to increased exposure. A reduction in filter feeders on the subtidal bottom can also result in reduced water clearing capacity (Auster and Langton 1999). Increased turbidity reduces light penetration and consequently, the primary productivity of benthic microflora on the seafloor, as well as phytoplankton in the water column (Auster and Langton 1999). Decreased primary productivity affects demersal zooplankton that support higher trophic layers. The sediment composition of the bottom can also change with frequent trawling. Given 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 (Auster and Langton 1999; Thrush et al. 2006), as well as a shift in dominant species and reduction in community stability. Long-lived species, which take more time to recover from 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 have a significant negative impact on soft bottom habitat in the estuarine system.

Trawling can affect primary productivity through the connection of bottom and water column processes (DMF 1999). Nutrients released into the water can increase nitrogen and phosphorus levels, stimulating phytoplankton growth and enhancing secondary productivity of herbivorous zooplankton and larger prey (DMF 1999). The increased plant growth can reduce bottom penetrating light and extend the effects of trawling beyond 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 increase in plankton can reduce water oxygen levels, causing hypoxia and anoxia (Paerl et al. 1998; West et al. 1994). By resuspending sediments, trawling can make inorganic and organic pollutants available in the water column (DMF 1999b; Kinnish 1992). Such toxins can negatively affect productivity and accumulate in organisms through food chain interactions.

Some feel trawling may mimic natural disturbances and stimulate benthic processes, 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. To 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 (Auster and Langton 1999; Watling and Norse 1998), and varies depending on the amount of natural disturbance (weather or macrofaunal).

The impact of trawling and associated bottom changes on fish populations depends in part on each species' habitat dependence (Auster and Langton 1998). Where a demersal species' life stage is obligate on the structural component of a habitat where trawling occurs, particularly for recruitment, there is a greater potential for impact by trawling (Auster and Langton 1998). However, if individuals can move to and survive in alternative habitats, impacts may be less severe (DMF1999).

Primary nursery areas and inlets are "recruitment bottlenecks" for estuarine dependent species . Since larval flounder, shrimp, and Atlantic croaker must pass through inlets to recruit to PNAs, trawling impacts to larval fish in inlets and PNAs could be greater than in ocean or deep estuarine waters. Protection in these areas is therefore very important for estuarine dependent fish and invertebrates. Current MFC restrictions on trawling protect PNAs, however many shallow soft bottom areas are productive but not designated as primary or secondary nursery.

Many studies have been conducted around the world assessing the effects of trawling on soft bottom habitat in offshore waters. A meta-analysis of literature on fishing impacts to continental shelf benthos quantified impacts of otter trawls on subtidal bottom in eastern North America (Table 8.4)(Collie et al. 2000; DMF 1999a). Some conclusions were:

- Otter and beam trawling have fewer negative impacts on benthos than intertidal or scallop dredging or intertidal raking.
- In subtidal areas, sand habitats were least impacted and muddy sand and gravel most impacted.
- In muddy sand, polychaetes and large bivalves were most negatively impacted. Smaller bodied organisms were 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.
- Epifaunal organisms are less abundant in areas subjected to intensive bottom fishing.
- Fish and benthos in areas heavily fished 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, to examine and better quantify cumulative fishing impacts and recovery patterns.

TABLE 8.4. 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 negatively influences the benthic fauna, decreasing the abundance and diversity of epifaunal invertebrates, possibly altering the food web (Hinz et al. 2008).

Even with a low fishing effort, dredges are considered to be the most habitat destructive fishing gear (Collie et al. 2000; DeAlteris et al. 1999). Because of the gears' teeth, crab and oyster dredges can dig deep into the sediment and cause extensive sediment disturbance. In 2013, mechanical clamming, including kicking and dredging, accounted for approximately 7% of the annual hard clam landings (NCDMF 2014a). The dredging and kicking activity creates trenches and mounds of discarded material on soft bottom habitat, redistributing and resuspending sediment (Adkins et al. 1983). Water jets from the hydraulic dredge can penetrate 18 inches into sediments, uprooting living structures (Godcharles 1971). Dredge tracks can remain from days to more than a year, and vegetation recolonization can take months to begin. Recruitment of clams and other benthic invertebrates does not appear to be affected by hydraulic dredging (Godcharles 1971; Peterson et al. 1987). Because of the impacts to habitats, both hydraulic clam dredging and kicking are restricted to open sand and mud bottoms, including areas frequently dredged for navigational. There are approximately 43,900 acres that are potentially available to mechanical clam harvest statewide, with the majority of these located in Core Sound (29,954 acres). These fisheries can be opened by proclamation between December 1 and March 31.

Gillnets are passive fishing gear that can be made active by dragging weighted objects to scare fish into nets. These objects (e.g., weights, chains, cinder blocks) vary in weight, and can disturb the habitat in a manner similar to trawl doors or toothless scallop dredges. In 2007 DMF became aware of active gillnets in PNAs in the spot, mullet, flounder, and speckled trout fisheries. While there was no rule against active gillnets in PNAs, bottom disturbing gears were prohibited. According to T15A NCAC 03J .0103, the director may limit the use of gillnets and the means/methods they are fished. North Carolina Marine Patrol had observed active gillnets being used in PNAs in the central district of the state, and more prevalently in the southern district (DENR 2008). To determine the necessity for further action, an issue paper was written in 2008 by Katy West, DMF, and presented to the MFC in April of 2007. The paper detailed potential impacts from this activity, with options for actions. In August, the MFC recommended action by proclamation. Additionally, there was an NC Sea Grant Fisheries Resource Grant (Kimel et al. 2010) investigating the impacts of active gillnets on PNAs. The study concluded that the bottom impact from the dragged objects represented a low disturbance and that the impact from the boat prop during side-setting was likely more significant. They also noted that the prolonged effects would be greater in low energy environments like bays and creeks than in open high energy areas of the AIWW, rivers, and large sounds. These results, in combination with the low level of effort to this technique, indicated that the short and long term habitat impacts from side-setting and active gillnet fishing would be low. Given this outcome of the study, DMF opted not to take proclamation action.

8.1.2. Hand Harvest Gear Types

The majority of hard clams in North Carolina are harvested by hand harvest methods (NCDMF 2014a), including hand and rake in shallow water (< 1.2 m or 4 ft.) and tongs and bull rakes in deeper waters. The harvest of clams or oysters by tonging or raking on intertidal beds causes damage to living oysters and to the cohesive structure of the reef (Lenihan and Peterson 1998). This destruction is an issue where both mollusks exist, primarily around the inlets in the northern part of the state and on intertidal oyster beds in the south (DMF 2001c). 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 due to incidental shell damage and sedimentation. Conversely, oyster harvesting had little effect on clam populations.

Oyster rocks are protected from mechanical harvest of clams and bull rakes by MFC rules (T15A NCAC 03K .0304 and 03K .0102), Table 8.3. 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).

Bull rakes and large oyster tongs can uproot SAV, causing substantial damage, while hand rakes are more selective and cause less damage (Thayer et al. 1984). Some effects include removal of shoots and rhizomes and the amount of damage increases with the size of the gear (Peterson et al. 1987).

8.1.3. Passive Capture Techniques

Entanglement gear, such as gillnets, does not cause bottom disturbance and is size selective, allowing passage to smaller species. However, certain sized gillnets can unintentionally capture larger non-targeted species. The gillnets then impede the corridor function of the water column that allows migration of protected species, which, in North Carolina, includes several species of sea turtles and two of sturgeon. All five sea turtles that regularly visit North Carolina are listed as endangered or threatened under the Endangered Species Act of 1973 (ESA; 16 U.S.C. 1531-1543). The DMF has been issued two Incidental Take Permits under Section 10 of the ESA by NMFS. The permits require DMF to monitor commercial fisheries closely through the observer program and to minimize interactions between the fisheries and these species. This is accomplished through regulations affecting the fishing operations, including mesh size, area/seasonal closures, and net attendance requirements.

Bottom longlines and fish traps can physically damage the structure of hard bottom, and injure or kill associated sessile biota (SAFMC 1998a). However, these fishing gears are of minimal concern as they are not used extensively in 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 FMP in 1991 to reduce fishing mortality and habitat damage. Fish traps were also prohibited in 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 potential waste from lost pots. In North Carolina state territorial waters, fish traps cannot be used to target snapper-grouper, 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.

Pots are used extensively in the crab fishery in North Carolina, primarily in estuarine waters. Most crabs are landed between May and October. Crab pots are wire-mesh boxes measuring approximately 2 by 2 feet. Pots for hard crabs require escape rings, while peeler pots do not (DMF 2013). Pots are weighted to rest on the bottom and can have a variety of habitat impacts. They can smother SAV, damage of hard bottom (Barnette 2001), and are capable of ghost fishing if lost or abandoned. Many states, including North Carolina, have a closed season in which crab pots are required to be removed from the water.

8.1.4. Rod and reel

Although direct impacts of rod and reel gear on hard bottom habitat are considered low, recreational fishing was identified by NMFS 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 the habitat may receive concentrated use, leading to unknown cumulative impacts. Lost gear 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 fishing line, 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 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. 2005; Chiappone et al. 2004). In addition to the potential physical effects of discarded fishing gear, chemical contamination from lost lead sinkers is a concern.

8.2. Navigational Dredging

Dredging is the excavation of sediment for navigation and docking facilities, and sand for beach nourishment. Dredging for drainage purposes is addressed in the Hydrological Alterations chapter.

Early waterfront communities were developed adjacent to deepwater for boating access. With much of the deepwater now built upon, new development often occurs where dredging is needed for boating access. Dredging to create, expand, or maintain deepwater access in shallow waters can involve dredging through intertidal habitat, or creating new access from uplands to form canals, basins, or marinas. Most of North Carolina's estuarine waters are shallow, and are where structured habitats, like wetlands, SAV, and shell bottom exist. They are, consequently, most vulnerable to dredging.

Inlets are dredged at variable frequencies to maintain navigation access to the ocean or to protect oceanfront development; some inlet channels have been relocated through extensive dredging to shift erosion patterns. In North Carolina, shipping channels are dredged in ocean waters for access to state ports or to obtain sand from borrow areas for beach nourishment. Other potential reasons for dredging include development and operation of offshore energy facilities, or for installation of infrastructure such as fiber optic cables or utility lines. Maintenance dredging is necessary to preserve water depths for commercial and recreational navigation. The location of channels, (dredged and not) ports, marinas, boat ramps, and multi-slip docking facilities in coastal North Carolina are shown in Maps 8.2a-b.

8.2.1. Location and types of dredging

The U.S. Army Corps of Engineers (USACE) has authority to maintain navigation in the waters of the United States for the purpose of interstate commerce. The USACE dredging can be performed with sidecast, hopper, clamshell, or pipeline dredge, depending on the size and location of work, and material disposal methods. 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 hydraulic pipeline can be placed on nearby beaches or within confined upland diked disposal areas.

Navigational dredging in inlets is allowed year round by the USACE, but is subject to a variety of fish, mammal, sea turtle, and bird moratoria by different federal and state agencies regarding excavation, equipment presence, and spoil placement. Contractors 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 avoid the taking of sea turtles (J. Richter, USACE, pers. com. 2010).

Commercial navigational channels were dredged through coastal North Carolina by the USACE in the 1930s while creating the Atlantic Intracoastal Waterway (AIWW). The USACE is responsible for maintaining the AIWW. There are now over 1500 miles of navigable channels in the AIWW, including 300 miles in North Carolina. Most of the AIWW is targeted for a 12 ft maintained depth. The AIWW immediately inside of inlets are more vulnerable to shoaling and are dredged more frequently than other areas of the AIWW. Shallow draft inlets are authorized to be maintained at 14 ft or less. These include Bogue, New River, New Topsail, Carolina Beach, Lockwood's Folly, Barden, Oregon, and Masonboro inlets (J. Richter, pers. com. 2015). The latter two are targeted for 14 ft depth, while the others are targeted for 6-8 ft. Ocracoke Inlet is federally authorized for 18 ft. Carolina, Masonboro, and Shallotte inlets are designated borrow areas for beach nourishment.

Inlet dredging by the USACE is done by sidecast or hopper dredge. Associated disturbance can deter or alter summer spawning activity of red drum, weakfish, spotted seatrout, silver perch, and blue crab (Luczkovich et al. 2008), which occurs from May through October, depending on the species. Because spawning activity occurs at night, daytime dredging may have less effect. Possible indirect effects from dredging include reductions in benthic prey and alterations of the acoustic environment.

The USACE procedures for inlet sidecast dredging require working during outgoing tides to reduce sedimentation over marsh, oysters, and SAV, and to prevent refilling of estuarine areas. This has been a logistical challenge with some non-compliance (S. Corbett, MFC, pers. com. 2015). There are two deep draft ports in North Carolina maintained at depths of 45 and 42 ft - the Beaufort and Cape Fear ports, respectively. Maintenance of the federal channels at Morehead City, Wilmington Harbor, and Oregon Inlet is conducted by hydraulic pipeline or hopper dredge.

There are many privately maintained channels serving marinas and docking facilities. Requests for new channels continue as development increases, putting wetlands, SAV, oyster beds, and nursery areas at risk. The southern coast has been modified substantially relative to its small waterbodies, proportion of shallow waters, and amount of developed shorelines.

8.2.2. Disposal of dredge material

Prior to implementation of the Coastal Area Management Act in 1974, dredge material was often used to fill wetlands and low elevation uplands to create land suitable for development. During the initial dredging of the Intracoastal Waterway in the 1930s, numerous spoil islands were created in estuarine waters to store dredge material, converting estuarine waters and wetlands to uplands. Dredge material can be used for beach nourishment (suitable material), put on nearby land, stored on the aforementioned spoil islands, or disposed of in designated ocean dredge material disposal sites.

8.2.3. Impacts

8.2.3.1. Loss of shallow estuarine habitats

An obvious dredging impact is the physical loss of habitat, such as wetlands, SAV, or shell bottom, within the dredge footprint. Impacts extend around the dredge footprint from sloughing into the channel and when sedimentation covers nearby SAV or oysters. Dredge and fill activities have historically been recognized as the primary physical threat to SAV (Erftemeijer and Robin Lewis Iii 2006; Orth et al. 2006) and wetlands (Dahl 1990; Hefner and Brown 1985). In the United States, loss of SAV habitat from dredge and fill activities has been particularly severe in bays with major ports or metropolitan areas, such as Tampa, Galveston, and Chesapeake bays (Duarte et al. 2005; Taylor and Saloman 1968).

8.2.3.2. Hard bottom

In ocean waters, dredging can damage hard bottom by dislodging corals or colonized rock (live rock), and associated sedimentation can smother coral polyps, as well as injuring live tissue, which may lead to infection or mortality (Erftemeijer et al. 2012; SAFMC 1998a). While state and federal regulatory measures have reduced dredging impacts to these habitats (Dahl 2000), small losses are sometimes permitted, resulting in cumulative losses over time.

8.2.3.3. Soft bottom

Deepening of shallow-water soft bottom results in loss of nursery habitat for some estuarine-dependent species (Rozas 1992). When waters are deepened close to the shoreline, predator protection is abated. Productivity is affected because primary and secondary production of the benthic community is higher in shallow habitat, where microalgae thrive on the sediment surface and SAV grow. Fish also grow faster in this environment. Converting shallow habitat to deeper basins and channels reduces this productivity (Wendt et al. 1990). Dredging can similarly lower productivity in deeper waters by temporarily removing existing benthic infauna from the affected areas, reducing food availability to bottom feeding fish and invertebrates (Hackney et al. 1996a; Peterson et al. 2000b). In addition to direct habitat loss, dredging reduces shallow bottom with suitable depth, sediment characteristics, and water clarity for recolonization by wetlands, oysters, or SAV (Funderburk et al. 1991; Stevenson and Confer 1978).

8.2.3.4. Sedimentation and Turbidity

Dredging can adversely affect aquatic habitat by altering sediment characteristics and increasing turbidity and sedimentation. Dredged channels tend to refill with finer sediments and flocculants (Bishof and Kent 1990; DWQ 1990; Thayer et al. 1984). The finer redeposited sediments are more susceptible to resuspension by currents or bottom disturbance from gear or boat wakes, increasing potential for long-term elevated turbidity (Dellapenna et al. 2006b; Schoellhamer 1996b). Chemicals, metals, nutrients, and organic matter that accumulate in the sediment can be released into the water column, causing short-term increases in toxins, algae, and bacterial concentrations, which are then biologically available to organisms (Corbett et al. 2009; Lalancette 1984; Warnken et al. 2003). Redeposited sediment on SAV leaves and elevated turbidity reduce light necessary for SAV survival and retard colonization of unvegetated areas (Thayer et al. 1984; Wilber 2005). When sediment settles on oysters, SAV, and hard bottom, living organisms can be smothered, resulting in mortality or impeded growth (Wilber 2005). Even low levels of siltation affect growth of oyster beds by reducing recruitment of larvae. Spawning habitat for sensitive species such as anadromous fish and mussels, which prefer exposed rock, rubble, and coarse sediment, is degraded by increased turbidity and sedimentation (Bock and Miller 1995). Depending on the severity and extent of turbidity, reefs can be buried or decreased productivity can occur (Crowe et al. 2006; SAFMC 1998a). The biological impacts of dredging are less severe in coarse sediment and strong currents because the sediments lend themselves to shorter suspension times, and the currents can disperse the sediments (Corbett et al. 2004; Schoellhamer 1996b).

The effects on aquatic organisms of suspended and redeposited sediments associated with dredging were summarized in (Wilber and Clarke 2001) and (Wilber 2005). Suspended sediments can clog gills of fish, oysters, and other invertebrates. Turbidity reduces visibility for visually foraging predators, disrupting feeding or causing fish to relocate to less optimal areas. The suspended sediment can also cause abrasion and damage to fish eggs, reduce bivalve pumping and consequently growth rates, and cause mortality, particularly of non-mobile invertebrates (Hackney et al. 1996a; Lindquist and Manning 2001; Reilly and Bellis 1983; Wilber and Clarke 2001). Where dredging occurs near ocean hard bottom, sedimentation can cause sublethal stress to corals and other sessile invertebrates. A meta-analysis by Wilber and Clarke (2001) concluded that the combination of exposure, duration, and concentration of sediments controlled the effect on aquatic organisms. Sediment characteristics, currents, and mobility of organisms were also important. For mobile fish, exposure durations to sediment increases was estimated to range from minutes to hours, with a maximum of one day. For non-mobile organisms, such as bivalves or demersal adhesive fish eggs, maximum exposure duration was estimated to be 3.5 days. Within the one day window of excess sediment exposure for juvenile and adult salmonid and freshwater fish, the response was behavioral or sublethal. Within the 3.5 day window for salmonid and freshwater fish eggs and larvae, the response varied from less than 25% mortality to 75% mortality. The response of estuarine and non-salmonid fish eggs and larvae varied from no effect to less than 25% mortality.

8.2.3.5. Impacts to fish

Fish species using dredged, poorly flushed waterbodies, such as channelized ditches, dead-end canals, or enclosed marinas, are at greater risk to exposure from degraded water quality conditions. These waterbodies can have low DO, high contaminant loading, extreme water temperatures, and rapid salinity changes (Chaillou and Weisburg 1996). Water quality assessments by EPA in Delaware and Maryland coastal bays found that dead end canals had the lowest water quality conditions, with chemical contaminants exceeding guideline values in 91% of canals, DO concentrations exceeding standards in 57% of the canals, and that the benthic community diversity was significantly lower than in other waters (Chaillou and Weisburg 1996). However, dredged waterbodies provide fish habitat, and shallow channelized streams and canals located at the headwaters of PNAs can augment critical nursery habitat. A visual GIS evaluation of over 2,400 fish nursery areas (PNA, SNA and IPNAs) suggested that about 40 designated areas were drainage canals (DMF, unpublished data, 2010).

8.2.3.6. Flow alterations

Channel deepening and dredging can alter circulation patterns with several different outcomes (Beck 2009; van Maren et al. 2015; Wilber 2005; Yanosky et al. 1995). Dredging channels can increase tidal amplification, flood flow velocities, and estuarine circulation. Since more sediment is transported with increased velocity, sediment and saline water is transported further up estuary (van Maren et al. 2015; Yanosky et al. 1995). Dredged channels can further concentrate and increase flows within the altered conduit, and reduce flows over shoals and shallower bottom. Slower velocities over the shallow bottom results in less transport of sediment out of the estuary (Beck 2009).

8.3.3.7. Saltwater Intrusion

The dredging and deepening of inlets and waterways can increase saltwater intrusion, causing a change in wetland species composition along the boundary between salt/brackish and riverine wetlands. Saltwater intrusion in the Cape Fear River was documented by Hackney and Yelverton (1990) and Yanosky et al. (1995). The latter concluded that the cause of the saltwater intrusion was channel dredging that began in the late 1800s, the creation of Snow's Cut connecting the Intracoastal Waterway in Carolina Beach with the lower Cape Fear River, and/or a rise in sea level. The effect of saltwater intrusion on wetlands in the Cape Fear River is readily noted by the dead bald cypress. Yanosky et al. (1995) confirmed higher concentrations of salt elements (chloride, sodium, and bromide) in trees located in areas exposed to a greater extent and frequency to saline waters. In the area of higher impact, approximately 50% of the forested wetland converted to salt marsh over a period of roughly 40 years, and areas once known for rice farming (freshwater) now have salinities ranging from 5-18 ppt (brackish) (Hackney et al. 2007; Hackney and Yelverton 1990).

Data from NOAA /NOS tide gauge stations support that dredging has increased tidal inflow. Data from the Cape Fear River show that during the years of 1935-1999, the average tide range increased at a rate of 542 mm (21 in) per century (Flick et al. 2003), allowing ocean water to reach further upstream. Zervas (2004), looking at the same data for 116 stations in the US, found that four sites, including Beaufort Inlet and Cape Fear River, had statistically significant trends in mean tide range. In Beaufort, mean tidal range increased 0.1 m since the mid-1970s. In the Cape Fear River, tide range increased by about 0.3 m up to the mid-1970s, and then slowed. Both inlets were extensively dredged over the years to support ports. Beaufort Inlet was dredged to 20 ft by 1911, to 35 ft by 1961, and to 47 ft by 1994. The Cape Fear River was dredged to 16 ft by the late 1800s, to 40 ft by 1964, and is currently maintained at 44 ft. The study concluded that the increases in average tide range were most likely due to the alterations in bathymetry of the inlets and river channels (Zervas 2004).

Researchers have hypothesized that the dredging of other inlets and estuarine channels in North Carolina, as well as a rise in sea level, has led to an increasing inflow of ocean water, which has gradually increased the salinity of the estuaries (N. Lindquist, UNC-IMS, pers. com. 2015). In 2012, staff at APNEP compiled salinity data from DWQ estuarine monitoring stations to examine long-term (1980-2009) trends in salinity in the Albemarle-Pamlico system. Seven of the nine assessed sub-regions had a slight upward trend in salinity that was statistically significant. The results indicated that mean salinities and fluctuations were primarily associated with proximity to large areas of freshwater or saltwater inputs (APNEP 2012). Some areas in Pamlico Sound that traditionally supported oyster reefs no longer do so because of boring sponge (*Cliona* spp.) infestations which can survive in the current salinity range (22-25 ppt) (N. Lindquist, UNC-IMS, unpublished data, 2014). Boring sponges bioerode calcareous material, which then weakens the organism, allowing other predators such as oyster drills, to continue to weaken and kill the shellfish (Dunn et al. 2014). In fresher (<20 ppt salinity) and intertidal waters, boring sponges cannot survive. Research is underway at the UNC Institute of Marine Sciences (IMS) to compile an historical salinity database in order to assess trends in salinity, and determine the major drivers of the observed trends (e.g., dredging, sea level rise, rainfall, runoff) (B. Govoni, DMF, pers. com. 2015).

8.2.4. Benefits of dredging

While dredging can degrade aquatic habitat, it has been used in some instances for beneficial purposes. The mouths of some creeks along the AIWW have shoaled due to suspension and settlement of sediment. 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 a small amount of additional acreage was opened to shellfish harvesting. As of 2008, the creek continued to maintain better fecal coliform levels since the mouth was dredged (Mallin et al. 2002b; Mallin et al. 2008). However, when Bald Head Creek was similarly dredged to reduce bacterial contamination, the dredging was not successful at improving water quality (R. Carpenter, DMF, pers.com. 2010).

The USACE has conducted several restoration projects that involved dredging and filling. In the Cape Fear River, an upland dredge material island was excavated to create shallow meandering creeks with sloped edges supporting fringe marsh. Similarly, in Wanchese, a rock sill was constructed and fill material was removed and contoured to create a wide marsh with shallow tidal creeks. Other beneficial uses of dredge material include creation of bird nesting islands, and enhancement and restoration of wetlands due to losses from previous dredging, interruption of barrier island overwash processes, and sea level rise. The USACE, as mitigation for past channel dredging activities, is planning to establish 42 acres of subtidal oyster habitat in Pamlico Sound, which will be managed as oyster sanctuaries.

8.2.5. Status of navigational dredging

The maintenance frequency for federal channels ranges from two to 12 years, depending on funding availability and severity of shoaling. The areas authorized for dredging by the USACE and the 2015 dredge status are shown in Table 8.5. While approximately 40 miles of beach are approved for disposal, only about 15 miles of beach usually receive dredge material (J. Richter, USACE, pers. com. 2015).

Funding for federally authorized projects is mostly derived from the USACE and DWR. Non-federal channels can be maintained with state and local funding. Federal funding continues to decline for maintenance dredging projects. Subsequently, many channels are not being dredged enough to maintain adequate water depth for recreational and commercial vessels. The Coast Guard closed Oregon Inlet intermittently in the past few years when shoaling made navigation hazardous. State and local governments have looked to other sources to supplement funds. The North Carolina Beach, Inlet and

Waterway Association (NCBIWA), was formed to lobby for additional funding for navigational dredging and beach nourishment. In 2013, the General Assembly passed a law creating a fund to support dredging of shallow draft inlets (S.L. 2013-360), or the Shallow Draft Navigation Channel and Lake Dredging Fund. Revenues for the fund are specified to come from increased boater registration and title fees and a portion of the Highway Fund proceeds, and are to be managed by DWR. Approximately $7 million/year has been raised through this law. Dredging of large navigation channels through ocean bottom in North Carolina is limited to entrance channels leading to the state ports in Wilmington and Morehead City via Cape Fear and Beaufort inlets.

Seasonal timing of dredging projects is dependent upon the area, the type of equipment, and the anticipated environmental impacts. Resource agencies have established moratoria to protect species during critical life stages. These moratoria are from sampling data, known fish distribution, and known impacts to a fish or habitat from exposure to turbidity or sedimentation. For example, DMF has regional moratoria for work in designated PNAs, or anadromous fish spawning and nursery areas (Table 8.6). Similarly, WRC has moratoria related to protected species like nesting sea turtles, and NMFS has moratoria for anadromous fish. The USACE and dredging companies sometimes request extensions during the moratorium when they have not completed work or shoaling is a hazard. Requests to work during dredging moratoria have increased in recent years, and are considered on a case-by-case basis.

8.2.6. Summary

Navigational dredging has impacted wetlands, SAV, and shell bottom located in shallow nearshore waters. Sedimentation and turbidity degrades water quality during and following dredging. Dredging moratoria are designed to minimize turbidity and other impacts. Federally authorized channels are maintained, but funding shortages have limited the frequency. New federal channels are not being permitted currently, but some private channels are, as developers of shoreline communities' desire deepwater access.

TABLE 8.5. Ongoing USACE dredge disposal projects on North Carolina ocean beaches (J. Richter, USACE, pers. com. 2015).

Dredging Project	Disposal location	Length limits (mi)	Estimated quantity (cu. yd.)	Comments
Avon Harbor vicinity, Avon	Hatteras Island, south of Avon Harbor and extend north.	3.1	< 50,000 every 5-6 yr.	Beach disposal highly unlikely
Rodanthe Harbor vicinity, Rodanthe	Extends from south end of Pea Island NWR to south of Rodanthe Harbor.	0.9	<100,000 every 5-6 yr	Beach disposal highly unlikely
Rollinson/ Hatteras	Hatteras Island south of Hatteras Harbor and extends 5.85 mi north of Frisco.	5.9	<60,000 every 2-3 yr	Beach disposal highly unlikely
Silver Lake	Southwest end of Ocracoke Island.	0.4	<50,000 every 2-3 yr	Beach disposal highly unlikely
Oregon Inlet	Pea Island south from Oregon inlet.	3.0	~ 1,000,000 every 4-5 yr	
Drum Inlet	Core Banks, extending 1 mi either side	2.0	298,000 initial, 100,000 maint.	Has not occurred in 15+ yr; highly unlikely
Morehead City	Bogue Banks, from Beaufort Inlet west to Pine Knoll Shores	7.3	3,500,000 every 8-10 yr.	DMMP* underway - sand to go on Bogue Banks and offshore of Shackelford.
AIWW, Pine Knoll	Pine Knoll Shores	2.0	<50,000 every 10-12 yr.	
AIWW Bogue Inlet	Bogue Banks from Bogue Inlet east to Emerald Point Villas	1.0	<100,000 /2-3 year	
AIWW, Onslow	Camp Lejeune, from Browns Inlet west	1.6	<200,000 every 3-5 yr	
AIWW, New River Inlet	N. Topsail Beach from inlet west to Maritime Way	1.5	<200,000 / yr	
AIWW	Surf City opposite N.C. 50 bridge	1.0	<75,000 every 5-6 yr (only used in 1996)	Has not occurred since 1996; beach disposal unlikely
AIWW, Topsail Inlet and Creek	Topsail Beach, north of Topsail Inlet	1.0	<75,000 / 2-3 yr	Beach disposal possibly every 2-3 yr but otherwise sidecast
AIWW, Mason Inlet crossing	North end Wrightsville Beach 2000' from Mason Inlet	0.4	<100,000 (not scheduled)	Inlet and AIWW crossing maintained by county due to inlet relocation in 2000.
Masonboro sand bypassing	North end Masonboro Island, south from Masonboro Inlet	1.2	750,000 - 1,000,000 every 4 yr	Usually closer to 5-7 yrs
AIWW, Carolina B. Inlet, Snows Cut	North end of Carolina Beach	1.3	<50,000 / yr	
AIWW	North end of Carolina Beach, south of Carolina Beach Inlet to town limit	0.8	<100,000 / yr	
Cape Fear River, Wilm. Harbor	To Bald Head for first 2 events, then to Caswell and Oak Island for 3rd event; repeat cycle	4.7 mi 1st event, 2.8 mi after	Approx. 1,000,000 every 2 yr	Determined by DMMP, under revision.
Cape Fear River, Wilm. Harbor	Oak Island, Holden Beach	0.2	<30,000 - one time/ 8-10 yrs	Only received one time to date from initial dredging
AIWW Holden Beach	Holden Beach	2.0		5-6 times in recent years with additional local funding
AIWW Ocean Isle	East end Ocean Isle Beach	0.6	50,000-150,000 every 1-2 yr	
Total		**~40**		

TABLE 8.6. DMF regional moratoria for in-water work. *

District Office	Area	Standard fish moratorium period	Anadromous fish moratorium period
Southern	SC line north through Onslow Co	1 April – 30 September**	1 February – 30 June
Central and Pamlico	Carteret Co north through Long Shoal River, including the Neuse basin above New Bern and all of Tar-Pamlico basin	1 April – 30 September**	1 February – 30 September
Northern - Albemarle (sounds/tribs)	North of Long Shoal River and including the Roanoke River basin	1 April – 30 September	15 February – 30 September (extended to 31 October from Alligator River east)
Northern - Outer Banks (sounds/tribs)	North from Ocracoke Inlet in high energy, sandy estuaries	1 April – 30 September	N/A
Inlets	shoals/channels dynamic	April 1 - 31 July	N/A
WRC		15 Feb – 30 Sep (IPNAs)	15 February – 30 June

* All dates are approximate and dependent on site specific environmental conditions. In the Cape Fear River - use anadromous moratorium north of Snow's Cut, standard moratorium south of Snow's Cut

8.3 Shoreline stabilization

8.3.1. Estuarine shoreline stabilization

8.3.1.1. Description

Estuarine shorelines are dynamic; they accrete and erode over time due to sedimentation, tidal action, storms, boat wakes, and long-term changes in water levels. Shoreline stabilization is the modification of the natural shoreline using hardened structures or organic materials to prevent or reduce erosion. The purpose is to stabilize and protect waterfront property. As shoreline development increases, more property will be threatened by storm events and rising sea level. North Carolina’s policies and rules for estuarine shoreline stabilization allow landowners to protect their property from erosion, while attempting to minimize the impacts on natural resources. This section will discuss the effects of various estuarine shoreline stabilization methods on fish habitat and the status of this activity in North Carolina.

There are a variety of methods and structure types to stabilize shorelines (Figure 8.1). These range from natural methods, such as planting wetland vegetation or constructing oyster reefs, to engineered non-living structures. Structures can be vertical (bulkheads) or sloped (riprap revetments, groins, sills). Another option is a hybrid of non-living and natural materials (sills, breakwaters, or groins that incorporate vegetation or shell plantings). The most suitable method, when considering habitat, is the one that alters the natural shoreline function the least while providing the necessary erosion control. This varies based on shoreline type, wave energy, construction accessibility, waterbody size, presence of adjacent structures, and available footprint for the structure. Hardened structures are the traditional method of choice in North Carolina, with bulkheads being the most commonly used.

Erosion control structures impact fish habitat when they alter or degrade the shoreline and shallow submerged habitat. Shallow, sloped shorelines provide refuge and migratory corridors for small and young fish. They support wetland vegetation, SAV, and intertidal oyster reefs, filter and trap pollutants, cycle nutrients, and support higher habitat and fish biodiversity. Erosion control structures can adversely impact fisheries by directly, indirectly, or cumulatively degrading these features (Seitz et al. 2006).

8.3.1.2. Fish Habitat Impacts

The effects of estuarine shoreline stabilization on fish habitat vary by structure and habitat. Natural methods, such as planted vegetation or reef construction, are considered to have the least, or positive, impact, while vertical structures are generally considered to have the greatest impact (DCM 2006).

Bulkheads

Numerous physical, biological, and hydrological impacts have been attributed to bulkheaded shorelines. (Bilkovic and Roggero 2008; Bozek and Burdick 2005; DCM 2006; NRC 2007; Pilkey et al. 1998; Pilkey and Wright 1989; Rogers and Skrabal 2002; Walton and Sensabaugh 1979). Vertical hard structures alter the bathymetry and hydrodynamics of the adjacent bottom, with potentially adverse effects on shallow nursery and wetland habitats. Such structures can increase reflective wave energy, causing scouring at the toe of bulkheads, eroding adjacent shorelines, and deepening adjacent water, thus reducing or eliminating wetland vegetation and shallow subtidal habitat (Berman et al. 2007; Bozek and Burdick 2005; Riggs 2001). Deepening of waters adjacent to the bulkhead allows large predators access to small fish, reducing nursery and refuge functions (Rozas 1987). Marsh vegetation waterward of bulkheads has been shown to experience up to 63% mortality post-construction due to stress from increased turbulence and scour (Garbisch et al. 1973). Similarly impacted is SAV, in some cases.

The changes in water flow and depth at the base of bulkheads prevent wetland vegetation from reestablishing once lost (Berman et al. 2007; Knutson 1977). As water levels swell from storm events or rise from warming sea level, bulkheads obstruct shoreward migration of fringing wetlands (Boorman 1992; Bozek and Burdick 2005; NRC 2007; Titus 1998). Degradation and loss of wetlands affect many fishery species linked to this habitat, including penaeid shrimp, red drum, spotted seatrout, striped bass, and river herring, either directly, due to reduced habitat (SAFMC 1998b; SAFMC 2008b) or indirectly, due to reduced prey (Peterson et al. 2000c; Seitz et al. 2006).

Bulkheads prevent transport of sediment from adjacent shorelines to the intertidal and shallow subtidal zones (Currin et al. 2010; NRC 2007; Riggs 2001). Sediment transport into the estuary is necessary to support continued growth and maintenance of marshes and intertidal habitat over time, which provide critical nursery, feeding, and spawning grounds for fish species. This disconnect is also problematic for aquatic species that move between water and land during their life cycle, 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 tide line (Brennessel 2007; USFWS1972; Isdell et al. 2015; Rosenburg 1994; USFWS 2008).

There are many studies finding lower relative abundance/diversity of fishes and invertebrates adjacent to bulkheaded shorelines relative to natural shorelines with marsh, wetlands, oyster reefs, and sills:

- Gittman et al. in press: Comparing shorelines with marsh sills, bulkheads, and natural marsh, marsh sills support higher abundance and diversity of fish and bivalves than bulkheads or natural marsh.
- (Scyphers et al. 2015): In Mobile Bay, Alabama, eroded shorelines with breakwaters constructed of Reef Balls ™ or bagged oyster shell supported a greater number of species of juvenile and small resident fish than control shorelines. Both breakwaters supported low numbers oysters, more on bagged oyster shell.
- (Fodrie et al. 2014): In NC, higher fish catch rates and bivalve abundance at marsh sills than at bulkheads.
- (Lawless and Seitz 2014): Chesapeake Bay, benthic infaunal densities were lower adjacent to bulkheaded shorelines than shorelines with oyster reefs, natural marsh, or riprap.
- (Fear and Currin 2012): In North Carolina, fringe marshes in front of bulkheads had higher abundance of birds and marsh nekton species when compared to bulkheads without marsh.
- (Long et al. 2011): In the Chesapeake Bay, predation pressure on tethered juvenile blue crabs (*Callinectes sapidus*) was higher adjacent to bulkheads than in riprap or marshes.
- (Bilkovic and Roggero 2008): James River, fish community integrity and diversity reduced along bulkhead shorelines w/low and high upland development as to natural and riprap shorelines w/low development.
- (Partyka and Peterson 2008): In the Pascagoula River estuary, Mississippi, epifaunal nekton and infaunal species richness and density were greater at natural shore stabilization than hardened.
- (Bilkovic et al. 2006): Chesapeake Bay, a benthic index of biological integrity and an abundance biomass comparison of the macrobenthic community reduced significantly when developed shoreline >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.
- (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 also the least abundant along bulkhead or rubble shorelines.
- (Waters and Thomas 2001): NC, lower numbers and diversity of fish occurred along bulkheaded shorelines than forested wetland and riprap shorelines, with particularly low numbers of juvenile anadromous fish.

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 impacts increase in relation to the length of the bulkhead. Where a greater proportion of a system is hardened, cumulative impacts on the benthic community are expected, as less marsh can mitigate the reduced ecosystem functions from the altered shorelines (Lawless and Seitz 2014; Seitz and Lawless 2008).

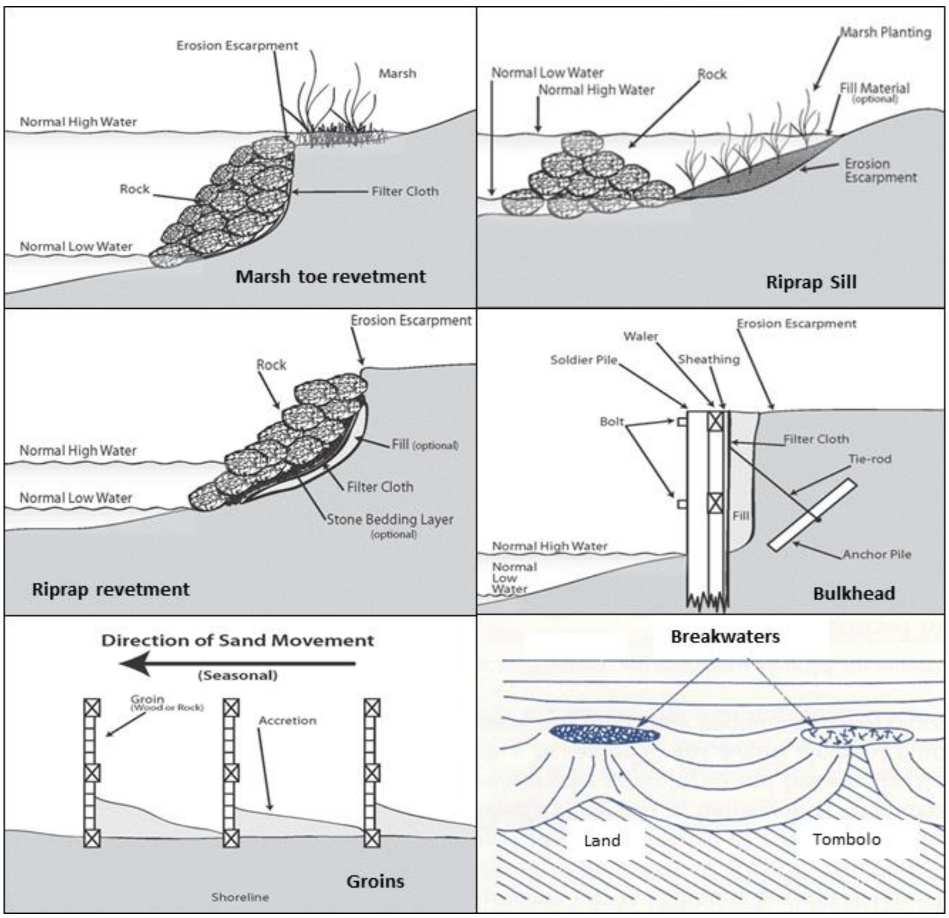


FIGURE 8.1. Vertical and non-vertical erosion control structures. Marsh toe revetments constructed of rock, bagged shell, etc. Sills of rock, bagged shell, wood, vinyl, sheetpile, etc. Groins of rock, wood, vinyl, etc. Breakwaters of rock, wood, vinyl, sheetpile. Vegetative plantings, oyster reefs are more passive techniques not shown here. Source of diagrams: DCM website.

Sloped rock structures

Sloped rock structures, such as riprap revetments, possibly breakwaters and groins, are erosion control structures that are used in medium to high energy environments, to a lesser extent than bulkheads. The sloped profiles increase wave refraction to a lesser degree than vertical structures. They dissipate wave energy, resulting in less waterward scour than that of bulkheads. The three-dimensional rock material provides habitat for recruitment of larval shellfish and other invertebrates, and interstitial space provides refuge for juvenile fish (Scyphers et al. 2015; Waters and Thomas 2001). While these structures provide more habitat than bulkheads, they directly impact more shallow bottom area, due to the larger footprint over submerged bottom (DCM 2006).

Groins are designed to build sediment on the leeward side of the structure (Berman et al. 2007). Breakwaters are built parallel to eroding shorelines, for the purpose of reducing wave energy (Price 2006). These sloped rock structures provide varying levels of erosion control while maintaining valuable wetland and shallow intertidal habitat (Currin et al. 2008; DCM 2006; Piazza et al. 2005). Breakwaters can also be vertical structures with openings to allow for the passage of water, which reduces the effect of bottom scour.

Hyporheic zone

Shoreline stabilization structures have the potential to impact the hyporheic zone of the estuarine or coastal ocean system by interrupting the connectivity between the groundwater system and surface waters. In North Carolina, shoreline stabilization is prohibited in large part on the ocean shoreline. On the oceanfront, the potential to affect the hyporheic zone would only apply to shorelines stabilized by sandbags. However, if deleterious impacts from the interruption of the hyporheic zone are determined to be a threat by bulkheads and other stabilizing structures, there are approximately 10,658 miles of estuarine shoreline in subject to stabilization under the rules of the Coastal Area Management Act.

The hyporheic zone is an active ecotone between stream and groundwater (Boulton et al. 1998). Exchanges of water, nutrients, and organic matter occur in response to variations in discharge and bed topography and porosity (Boulton et al. 1998). According to the USDA-Natural Resources Conservation Service (NRCS), the hyporheic zone is the groundwater region where bidirectional flows between the stream and groundwater are common (Triska et al. 1993). Zone 1 vegetation (adjacent to the stream channel) is very important because of potential access to water and pollutants in the hyporheic zone, and should be managed for N uptake and for formation of high organic matter surface soils. Provision of leaf litter and other organic matter to the stream channels may increase denitrification in the channel and hyporheic zone (Lowrance 1997).

The importance of the hyporheic zone to the quality of coastal waters was well recognized during the development of the Chesapeake Bay buffer rules, when Maryland, Virginia, and Pennsylvania agreed to reduce nutrient loading to the Chesapeake Bay by 40% by the year 2000 (Lowrance 1997). It was established in this process that riparian ecosystems were connected to aquatic ecosystems both by direct fluxes and, belowground, through the hyporheic zone (Lowrance 1997), and that if the buffer was to be a success, this must to be taken into account.

Fear et al. (2005) studied seepage rates and the chemical composition of groundwater discharge entering the Neuse River Estuary (NRE) over an annual cycle from July 2005 through June 2006. They found high porewater nutrient concentrations (especially NH4+) coupled with the measured seepage rates suggesting that submarine groundwater discharge (SGD) may be an important component of nutrient cycling within the system. Their equations predicted that 21.2 metric tons of N and 2.2 metric tons of P are loaded to the system via SGD annually. The SGD represents a mechanism by which nutrients, especially N, can be transported from the sediments to the water column where they are available to support phytoplankton production.

Fear et al. (2005) addresses side-to-side seiching (oscillations within a waterbody) known to occur in the system (Buzzelli et al. 2002; Reynolds-Fleming 2003), and considers that local small scale nutrient pumping by SGD may become a more important player for main stem productivity due to the cross channel flows created (Buzzelli et al. 2002; Reynolds-Fleming 2003). Localized small scale nutrient pulses added to the system likely make SGD much more important than indicated by its relative contribution to total system nutrient loads as they occur throughout the estuary, throughout the year. The interaction of available organic matter and oxygen and biogeochemical transformations will affect the extent that hyporheic processes influence stream nutrient budgets (Findlay 1995).

Since 1984, DCM has issued permits to bulkhead approximately 633 miles of shoreline, or about 6% of the estimated 10,658 miles of estuarine shoreline[13] in North Carolina (DCM, unpublished data, 2015). Whether the chemical and biological integrity of the surface waters are altered because of the impedance of groundwater is currently unknown.

The abundance of stabilizing structures may cause a break in the natural link between groundwater and the water table with regard to seal level rise, from an elementary perspective. It is possible that by breaking the link, the water table will not be able to interact with the groundwater in a natural fashion, and allow the groundwater to rise accordingly. However, without further research, it may also be speculative (Dr. A. K. Manda, Ph.D., pers. com., 2015).

Living shorelines

Living shorelines are defined as "any shoreline management system that is designed to protect or restore natural shoreline ecosystems through the use of natural elements and, if appropriate, manmade elements" (Estuaries 2015). In areas of low wave energy, erosion can be managed with nonstructural living methods, such as planting of wetland vegetation or oyster shell, or biodegradable organic materials such as natural fiber logs (Berman et al. 2007; Broome et al. 1992; CBF 2007; Rogers and Skrabal 2001; Rogers 1994). These methods can control erosion while providing beneficial ecosystem functions. Currin et al., in press, in comparing erosion rates along shorelines with and without marsh vegetation in the New River, found the greatest erosion occurred on unvegetated sediment banks, and that shorelines with even narrow fringes of marsh had significantly lower erosion rates. Several wetland planting projects have been conducted in North Carolina by conservation groups who have successfully retarded erosion along those shorelines (T. Skrabal, pers. com. 2015). Similarly, loose shell planted adjacent to eroded shorelines and in combination with marsh plantings have successfully recruited oysters, reestablished fringing marshes, and reduced shoreline wave energy in a demonstration project in Rachel Carson National Estuarine Research Reserve (Fear and Currin 2012)(NCCF, unpublished report).

Erosion control structures that include living components, also referred to as hybrid structures, include marsh sills with riprap or bagged oyster shell, marsh toe revetments using oyster shell or riprap, sills comprised of reef balls that recruit oyster spat, or groin fields constructed in low wave energy environments with wetlands (Berman et al. 2007; Broome et al. 1992; CBF 2007; Rogers and Skrabal 2001). A marsh toe revetment is a low sloped rock structure placed at the toe of existing wetland vegetation. Because it is non-vertical, small in scale, does not involve backfill, and is limited to 6 inches above marsh substrate, it protects existing wetland vegetation with minimal impacts. Only in low to moderate energy environments are these methods effective. With marsh sills, riprap or bagged shell is placed parallel to the shoreline at varying distances offshore. The area between the sill and shoreline is sometimes graded, with or without added fill material, to recreate a sloped intertidal area where wetland vegetation is then planted.

One habitat concern with marsh sills is the covering of existing habitat under the footprint of the structure, particularly that of SAV. Another concern is that the area landward of the sill could potentially increase in elevation due to sediment accumulation and therefore not sustain wetlands (Currin et al. 2008). However, a DCM survey of 30 experimental marsh sills in 2009 didn't reveal any conversion of wetlands to high marsh or uplands behind sills; additionally, since the General Permit for such structures

[13] Number dependent on scale of delineations and boundaries to separate marine, estuarine, and riverine systems.

was implemented in 1994, there have been no recognized instances of this happening.

Habitat Tradeoffs

In comparing impacts of stabilization methods, it is important to take into account habitat trade-offs. For example, bulkheads to prevent erosion on high ground can increase water depth adjacent to the structure, resulting in a loss of shallow soft bottom areas near SAV or marsh. In contrast, non-vertical structures, while not causing as much scouring or deepening, may require placement of rock farther out onto submerged lands with a wider footprint. The placement of a rock sill structure further seaward has the potential to create additional wetland or oyster habitat landward of the structure (Geis and Bendell 2008), potentially enhancing water quality, which in turn could enhance growth of SAV.

8.3.1.3. Bulkhead status

Since 1984, DCM has issued permits to bulkhead approximately 633 miles of shoreline through the Major and General Permit processes, which is about 6% of the estimated 10,658 miles of estuarine shoreline[14] in North Carolina (DCM, unpublished data, 2015). These numbers represent repairs, replacements, projects that may not have been accomplished or completed, and changes in processing[15] which could alter record keeping. While the coastwide percentage of stabilization is low, there are local concentrations of bulkheaded shorelines that are much higher than 6% (DMF, unpublished data; Corbett et al. 2008). Numbers appear to increase sharply from 1997 to 2000 and 2002 to 2006, probably due to repairs following damaging hurricanes (during 1996–1999) and to the strong economy of the mid-1990s. The highest number of bulkhead permits issued annually by General Permit occurred in 2006.

To obtain 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. In the years 2010-2014, a total of 54 miles of bulkhead were permitted in coastal counties by General Permit. In the previous five year period (2005-2009), 93 miles were permitted, and five years prior to that (2000-2004), 115 miles were permitted by General Permit (DCM, unpublished data, 2014, Figure 8.2). These numbers include new bulkheads and repairs of existing bulkheads (exceeding maintenance limits).

In the past five years (2010-2014), a total of 13.7 miles of bulkhead were permitted in coastal counties by Major Permit. In the previous five years (2005-2009) 27.7 miles were permitted, and five years prior (2000-2004), 23.4 miles were permitted by Major Permit (DCM, unpublished data, 2014, Figure 8.3).
The DCM has performed mapping to spatially delineate the estuarine shoreline, in which the location and extent structurally modified (e.g., bulkheads, riprap revetments) were identified using aerial imagery (Geis and Bendell 2008). In 2012, the coasts' entire estuarine shoreline was mapped (estimated 10,658 miles). There were 497 miles of bulkhead (n=6,391), 75.9 miles of bulkhead with marsh waterward of the structure (n=1,694), and 17.4 miles of bulkhead with a sediment bank waterward of the structure (n=471), for a total of 590.3 miles and 8,556 discrete structures (DCM 2015).

[14] Number dependent on scale of delineations and boundaries to separate marine, estuarine, and riverine systems.
[15] Prior to 2002 bulkheads landward of MHW and not affecting wetlands (7K .0203) were not entered into database.

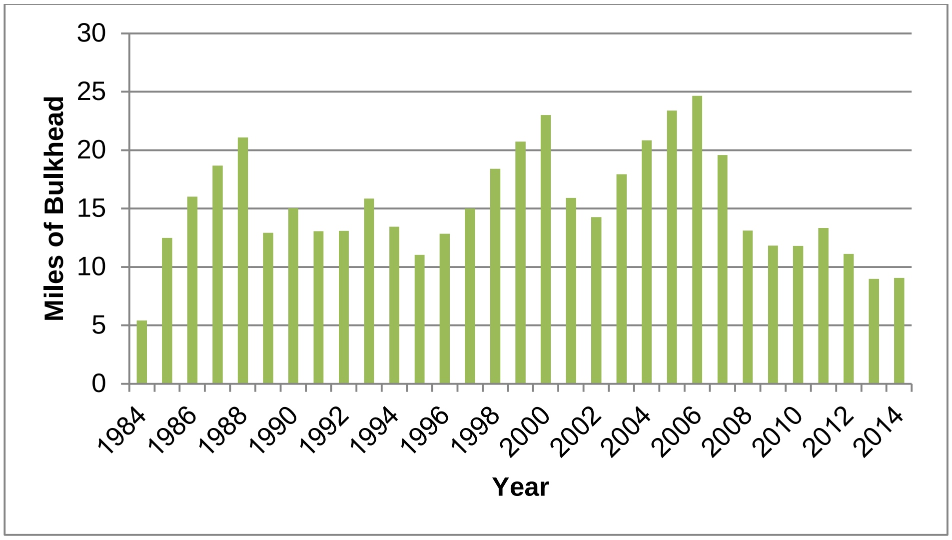


FIGURE 8.2 Linear miles of bulkhead authorized through DCM General Permit process by year, 1984-2014[2]. Includes new and replacement bulkheads (Source: DCM, unpublished data, 2015).

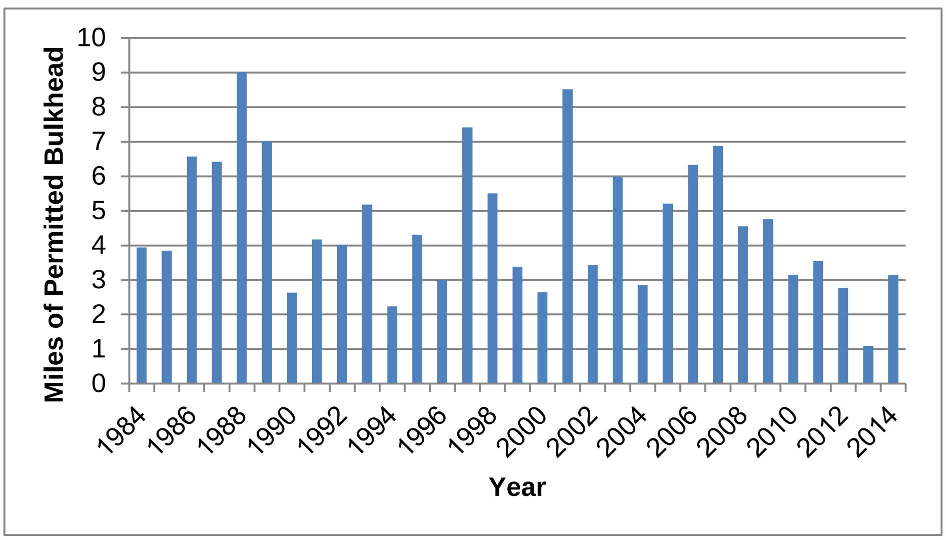


FIGURE. 8.3. Linear miles of bulkhead authorized through DCM Major Permit process by year, 1984-2014[2]. Includes new and replacement bulkheads (Source: DCM, unpublished data, 2015).

8.3.1.4. Shifting to Alternative Shoreline Stabilization Methods

Although CRC rules state that sloping riprap, gabions, or vegetation, rather than vertical seawalls/ bulkheads should be used where possible [T15A NCAC 07H .0208 (b)(7)(E)], bulkheads continue to be constructed at a rate greater than alternative shoreline protection methods. In addition, bulkheads are sometimes permitted where erosion is not evident. For example, digitization of shoreline alterations along approximately seven miles of estuarine shoreline in New Hanover County found that roughly 39% of the shoreline along protected Pages Creek with a wide marsh fringe and little obvious erosion had been hardened by 2000 (DMF 2001, unpublished report). To increase property owners' understanding of stabilization options, DCM, NOAA, and the Nicholas Institute for Environmental Policy Solutions, with funding from The Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), developed a "Weighing Your Options" brochure (DCM 2009).

Although marsh sill living shorelines were encouraged by the CRC, there are relatively few examples of marsh sills to show landowners and contractors interested in shoreline stabilization. There are a total of 59 marsh sill projects permitted, with the majority in Carteret County (DCM, unpublished data, 2015).

The CHPP Steering Committee requested that DCM conduct a survey to assess the effectiveness of existing marsh sills in controlling erosion and whether adverse impacts to adjacent habitats or properties occurred. 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 (2000-2009) that were reviewed. The Major Permit projects had 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., 2010). State and federal agencies (DMF, WRC, DWR, USACE, NMFS) conducted on-site evaluations of marsh sill projects in the fall of 2009 to further evaluate their effectiveness and impacts on adjacent habitats and property. This evaluation concluded that the sills were adequately providing erosion protection, and were not causing habitat impacts. Impacts to adjacent properties were indeterminate (John Fear 2011).

Gittman et al. (2014) evaluated performance of shorelines with unaltered marsh and shoreline stabilization structures after Hurricane Irene (Category 1; 2 m storm surge, 30 hr duration) in 2011. The visual survey found 76% of the bulkheads were damaged to varying extents, while no damage to other shoreline stabilization structures was observed. The study also compared shorelines with marsh and marsh sills, located within 25 km of the storm's landfall, before and after the hurricane. The storm did not affect marsh surface elevations at sites with or without sills, but reduced density of marsh vegetation, which recovered within one year. Their findings suggest that marshes with and without sills were more durable and could protect shorelines better than bulkheads subjected to Category 1 hurricane conditions in some situations. Currin (2011) also assessed erosion control performance after Hurricane Irene at two stabilization projects on Piver's Island. The marsh planting (with waterward oyster reef) and marsh sill sites gained 2-33 mm of sediment. There was no erosion observed in the marsh, sill, or adjacent upland, although areas adjacent to bulkheads and riprap revetment did exhibit some erosion. The findings were consistent with (Gittman et al. 2014) and demonstrated that living shorelines are capable of trapping sediment and controlling erosion in some situations.

The DENR, WRC, EEP, APNEP and NMFS have been working to promote the use of living shorelines and have developed a Living Shorelines Strategy that is discussed in the Living Shorelines Priority Section.

8.3.2. Ocean shoreline stabilization

In North Carolina, the frequency and magnitude of ocean shoreline stabilization activities have increased over time. These activities include beach nourishment, as part of storm management plans, beach disposal of material from inlet maintenance, sandbag use for temporary shoreline stabilization, and a limited number of terminal groins. These projects face limited borrow sources for beach suitable material, potential negative environmental impacts, and almost certain difficulty in dependable funding.

8.3.2.1. Soft stabilization

Beach bulldozing

Soft stabilization techniques 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 dune system. In contrast to beach nourishment, new sediment is not added and the existing beach is not widened. The smaller scale of beach bulldozing and use of on-site sand, and the relatively small area of bulldozing that occurs in subtidal waters, minimize biological impacts to the benthos and fish (Pilkey et al. 1998). However, beach scraping has not been shown to provide any erosion control benefit, and can potentially increase wind erosion of sand where created dunes are left unvegetated (Kerhin and Halka 1981; McNinch and Wells 1992; Peterson et al. 2000a; Tye 1983). The CRC modified specific conditions for beach bulldozing in 2000 to minimize biological impacts, which included time windows for work to be completed, maximum depth of scraping, and replanting of dunes (15A NCAC 07H.1805). There is a federal bulldozing moratorium in North Carolina from May 1 to November 15 for the protection of sea turtles.

Beach nourishment

Beach nourishment is the placement of additional 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 consist of the placement of dredged material from maintenance dredging of navigation channels. Specifically, they do not include engineered and constructed profiles 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 scale than storm damage reduction projects, and can be expected to have a lesser impact on fish habitat. The sand source for most disposal projects is the adjacent inlet. 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. This is done periodically at Masonboro and Oregon inlets.

Storm damage reduction projects use sand from dredged channels, offshore borrow areas, ebb tide delta shoals, or inlet relocation. Erosion rates near inlets are often the greatest due to the influence of strong inlet currents and the natural migration processes of barrier islands. Because of this and the associated risk near inlets, the CRC designated Inlet Hazard Areas along barrier islands. More regulatory restrictions apply in these areas. Beach nourishment is not allowed immediately adjacent to an inlet because of the dynamic nature of the area and the expected low retention time of sand.

Soft stabilization offers a less severe alternative than hard stabilization, with fewer 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.

Impacts at sand mining areas

When sand from channel dredging is insufficient for a nourishment project, sand can be "mined" or dredged from the ocean floor, often referred to as borrowing. The ecological impacts of borrowing from the ocean are similar to those from navigational dredging. Those include mortality of benthic organisms and elevated turbidity around the dredged area. Physical recovery of mining sites vary, and have been documented to range from two to 12 years; in some cases the sites may be altered indefinitely (Table 6.4). Because mine sites often refill with finer-grained material than was originally present (NRC 1995; Van Dolah et al. 1998), many borrow areas become unsuitable as future sand sources and benthic species recruitment patterns are altered (Jutte et al. 2001; Van Dolah et al. 1998; Van Dolah et al. 1992).

Mining sand from ebb or flood tidal deltas and nearshore sandbars for nourishment projects alters the sediment budget and may result in accelerated erosion from adjacent beaches (Wells and Peterson 1986). These sand deposits are the source of material for down current shorelines. Removing or reducing these deltas from the system can exacerbate erosion (Roessler 1998).

TABLE 8.7. Reported biological recovery time at mine sites.

Location	Recovery Time	Reference
North Carolina	6 – 18 months	Posey and Alphin 2001
North Carolina	12 – 24 months	CZR Inc and CSE, Inc 2014
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

Benthic recovery is affected by dredging methods and site conditions. In cases where benthic recovery is relatively quick, the mine area was not excessively deep (5-10 ft deep) or strong currents facilitated more rapid sand infilling (M. Posey, UNC-W, pers. com. 2010). Studies in South Carolina also indicated that the benthic community appeared to recover more quickly where hopper dredges were used rather than pipeline dredges (Jutte et al. 2001). Van Dolah et al. (1998) observed significant changes in the species composition of the recruited organisms, shifting from 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). Impacts to soft bottom benthic communities are more severe and with prolonged recovery when located in areas with little sand movement and where the mine pits are deep (Saloman et al. 1982; USACE 2001).

Siting mines at 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, or spawning areas or feeding grounds (e.g., inlet shoals used for red drum feeding and spawning) could disrupt or degrade ecological functions that these areas provide (Peterson et al. 1999). In the last decade, 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. In 2000, the estimated total volume of sand on the shoals was at least 1.66 billion cu yds, with approximately 256 million cu yds in state waters (Boss and C.W.Hoffman 2000). As such, cape shoals are major sand resources for coastal processes. 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, limiting exchange between adjacent littoral cells and shelf regions (McNinch and Jr 2000; McNinch and Wells 1999). Shoals are classified as EFH and use of the shoals as a borrow area should be studied closely before they are given consideration. A recent study released by the Bureau of Ocean Energy Management (BOEM) found higher abundances and diversity of both vertebrate and invertebrate assemblages in shoal habitats (D. Rutecki 2014).

Dredging of ocean borrow areas can directly or indirectly impact hard bottom via removal, fracturing, injuring, or silting over of hard corals, soft corals, sponges, algae, and other benthic organisms (Blair et al. 1990). Current CRC rules discourage dredging activities within a 500 m buffer of significant biological communities, such as high relief hard bottom areas [T15A NCAC 07H .0208(b)(12)(A)(iv)]. Under this rule, "high relief" is defined as greater than or equal to one-half meter per five meters of horizontal distance. Because reef fishes derive a significant portion of their nutritional requirements within a 500 m "halo" of exposed hard bottom Lindquist et al. (1994b), this dredging buffer was recommended by the DCM appointed Ocean Policy Steering Committee around hard bottom areas, including those periodically buried with thin, ephemeral sand layers (DCM 2009).

Within Onslow and Long Bays, low and high profile hard bottom is scattered, making mining difficult to perform without impacting hard bottom. Sand mining off North Topsail Beach in 2015 resulted in a large amount of hard bottom rock being pumped onto the beach, despite pre-dredging survey work. In 2014, the BOEM and East Carolina University signed a two-year cooperative agreement to evaluate sand resources off North Carolina. Under this agreement, scientists from ECU and the University of North Carolina Coastal Studies Institute (UNC CSI) will work with DCM and a contractor to evaluate and consolidate existing geological and geophysical data offshore. These data will be used to identify and locate potential areas of sand resources, as well as benthic habitat, to aid in regional planning for future beach nourishment projects and reducing impacts to hard bottom.

Due to increasing demand for sand, borrow areas are being increasingly utilized in areas such as Nags Head, Duck, Kill Devil Hills, Rodanthe, Bogue Banks, Topsail, and Brunswick Beaches. Some of these have been completed and others are in the permitting process.

Impacts at intertidal beach and 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. 1996a), (Donoghue 1999), (Jutte et al. 1999), (Peterson et al. 2000a), and (CZR Incorporated 1999), among others. Studies of dredge disposal and storm damage reduction projects demonstrate 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. The effect on smaller meio- and microfauna is unknown. The rate of reported biological recovery on nourished intertidal beaches varies from about one month to one year, 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 a single site, volume, depth, and length of project
- 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 (McLachlan 1996; Peterson et al. 2000b; Rakocinski et al. 1993; Rakocinski et al. 1996) 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 8.8. Reported biological recovery times at nourished ocean beaches.

Location	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 spionid polychaetes after 8 mo.	Bishop et al. 2006
Bald Head, Caswell, and Oak Islands	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, NC	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, NC	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, NC	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, NC	2 – 9 months for coquina clams and mole crabs.	Donoghue 1999
Hilton Head, SC	Density and diversity returned to levels similar to control sites in 6 months.	Van Dolah et al. 1992
Folly Beach, SC	2 – 5 months, depending on benthic group and site, polychaetes recruiting earlier than mollusks.	Jutte et al. 1999
Panama City, FL	Large reductions in abundance and diversity remained after 2 years.	Rakocinski et al. 1993
Manasquan, NJ	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 the most important factor in the rate of recovery of beach invertebrate populations post-nourishment (Peterson et al. 2000a). Recognizing the problems of sediment incompatibility, and problems resulting from projects at Pine Knoll Shores and Oak Island, the CRC Coastal Hazards Science Panel modified rules regarding sediment compatibility to be more specific and effective [15A NCAC 07H .0312(3)]. New rules became effective in February 2007.

The season and time period between renourishment events are important factors affecting the rate of recovery of a beach community (Dolan et al. ; Donoghue 1999; Versar Inc. 2003). At the Brunswick Beaches project, conducted as part of the Cape Fear harbor deepening project, sand was placed sequentially from east to west: Bald Head Island in spring 2001, Caswell Beach in summer 2001, Oak Island in fall 2001, and Holden Beach in winter 2002. Impacts were observed immediate 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 Inc. 2003). Lindquist and Manning (2001) found that at a beach where dredge material was placed between April and June, and redeposited the following April and 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 prevented full recovery of populations. Peterson et al. (2000a) argued that recovery could be accelerated if projects were timed to occur before spring recruitment of benthos.

Sand from inlet dredging can be placed in nearshore water (< 30 ft deep) within the beach profile to enhance sand supply on the beach. Such sand placement 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 placement 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, speed up the recovery of intertidal benthic organisms within the impacted area (Donoghue 1999).

The addition of sand to the shoreface can negatively affect nearshore hard bottom through burial and sediment redistribution. At a beach nourishment project site in Florida, dramatic decreases in fish species and abundance of individuals was observed following the burial of nearshore hard bottom. The number of species detected 15 months after burial decreased considerably, from 54 to eight (Lindeman and Snyder 1999). The average number of individual fish recorded per transect also declined from 38 to less than one (Lindeman and Snyder 1999). At several other beach nourishment projects in Florida, sand was documented to have redistributed offshore from the beach via cross-shelf currents, covering hard bottom habitat (Continental Shelf Associates 2002; Marsh and Turbeville 1981). Studies in Wrightsville Beach and Atlantic Beach, North Carolina documented movement of sands from the nourished beaches across the shoreface (Reed and J.T.Wells 2000; Thieler et al. 1995; Thieler et al. 1998), with the hard bottom being buried in the vicinities of the projects (R. Thieler, USGS, pers. com. 2015).

Commercial fishermen in the Wrightsville Beach area, where nourishment has been conducted regularly since the 1960s, report 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. 2015). 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). The majority of nourishment projects are located south of Cape Lookout where hard bottom is most abundant, especially in the nearshore.

In summary, the conditions that minimize biological impacts of nourishment projects to the intertidal beach community include, but are not limited to:

- Use of sand similar in grain size and composition to original beach sands.
- 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 length of nourishment projects to provide undisturbed area as a source of invertebrate colonists for the altered beach, and a food source for fish.
- Avoidance of nearshore hard bottom habitats.

Impacts to fish

Beach nourishment can impact fish by reducing food availability, altering preferred topographic features, disturbing spawning, or reducing visibility. Fish and invertebrate species that spend much 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 (USACE 2001; Van Dolah et al. 1994) or temporary impacts (Saloman 1974) to fish populations. This may be 1) due to release of nutrients and infauna during dredging, 2) because resident fish are wide-foraging, or 3) because migratory fish spend only a portion of their life cycle at the mine site or target beach (Greene 2002). Other researchers suggest that fish are dependent on the amount of available habitat and that any loss represents a decrease in production (Peterson et al. 2001).

Unfortunately, very little monitoring has been done at the level needed to adequately assess and detect the impacts of nourishment projects on fish distribution, feeding, growth, or survival. Although, there have been few studies examining the direct effects of beach nourishment on pelagic fish, several studies have examined the impacts on pelagic fish prey (e.g., polychaetes, copepods, and mollusks). Peterson et al. (2000a) concluded that nourishment projects should be ceased in April or May to reduce the effects of nourishment on *Domax* and *Emerita* populations.

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, and the density and nutritional condition of juvenile Florida pompano and gulf kingfish. Initial findings indicate that fish composition and diet differ significantly at nourished beaches compared to natural beaches, potentially affecting diet and growth (Lipton et al. 2010; Perillo 2010).

Preliminary studies of commercial gillnet landings for demersal feeding surf fish in areas with differing levels of beach nourishment activity indicates some relationship may exist between beach nourishment events and low landings (DMF, unpublished data, 2015). More data and analysis is needed to determine if nourishment negatively impacts abundance, CPUE, or landings. Given the increasing numbers of nourishment projects, cumulative impacts on the intertidal and subtidal communities, fish productivity, the benthic community, and the natural barrier island processes can be expected to increase.

Status of beach placement from navigational dredge disposal projects

Uncontaminated sand from navigational dredging projects meeting sediment grain size criteria can be placed on beaches or in a nearshore placement area. 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 covers a relatively short length of beach, generally close to the originating inlet. The amount of sand deposited and the frequency of dredging varies between sites and with the amount of sand available.

Status of beach nourishment from coastal storm damage reduction projects

Coastal storm damage reduction projects are long-term beach nourishment projects specifically designed to reduce storm damage to oceanfront property and infrastructure by increasing the width and height of the beach. To implement a federally authorized and subsidized storm damage reduction project, local governments must follow a lengthy process. 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. The MFC developed a beach nourishment policy in 2000 to provide guidance to help minimize fish habitat impacts (Appendix E). The ASMFC also provided recommendations for conducting and monitoring beach nourishment projects (ASMFC 2002).

The frequency and magnitude of beach nourishment projects 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. Currituck County, Hatteras, Ocracoke, and Sunset Beach are the only developed barrier island beaches that have not received and are not pursuing beach nourishment. Beach renourishment of federally authorized storm reduction projects generally occurs on three or four year intervals. In recent years, local communities have taken the financial burden of planning and contracting environmental assessments due to lack of federal funding. Similarly, local communities that have been unable to get federally authorized projects, or do not want to wait until federal funding is available, are raising funds to cover the expense. These privately funded projects must undergo a USACE permit review, and are considered one time projects. Oceanfront communities that have, or are in the process of planning, beach nourishment projects are listed in Table 8.9.

TABLE 8.9. Storm damage reduction (beach nourishment) projects ongoing or in the planning stage.

Beach community	Status	Fed. authorized [1]
Duck	Preparing permit application information	N
Kitty Hawk	Preparing permit application information	N
Kill Devil Hills	Preparing permit application information	N
Nags Head	Completed in 2011	N
Rodanthe	Completed one time emergency nourishment in 2014	N
Buxton	Preparing permit application information	N
Bogue Banks	Carteret County Beach Commission was formed to plan and coordinate nourishment and develop a programmatic EIS for all projects on Bogue Island. Sand sources primarily from different dredging projects and funded locally.	Y*
North Topsail Beach	Project using offshore borrow areas in 2015. Excessive amount of limestone rock was dredged onto the beach, requiring beach raking.	N
Surf City	Preparing permit application information	N
Topsail Beach	Preparing permit application information	N
Wrightsville Beach	Last done spring 2014	Y
Carolina Beach	Last done winter 2012/2013	Y
Bald Head	Receives sand regularly from Wilmington Harbor dredging	N
Caswell, Oak Islands	Receives sand regularly from Wilmington Harbor dredging	Y
Holden Beach	Last done in 2009; planning for nourishment and groin on east end	Y*
Ocean Isle	Last done in 2014; planning for nourishment and groin on east end	Y

[1] Non-federally authorized projects are locally funded. Federal funds are not always available for federally authorized projects. Locally funded federally authorized projects are denoted with *.

The value of wider beaches registers to the property owner at a very small scale. A 1995 South Carolina study showed that the addition of one foot in width of beach real estate (from 79’ to 80’) increased the value of the property by 35% (Pompe and Rinehart 1995). Subsequently, municipalities are increasingly interested in beach nourishment, and guidelines have became necessary to manage limited resources in an effective and environmentally sensitive manner. In 2000, House Billl 1840 was passed requiring DENR to develop a multiyear beach management and restoration strategy and plan. With this bill, DWR and DCM agreed to collaborative on a Beach and Inlet Management Plan (BIMP), which was finalized in April of 2011.

Close to 50% of the states’ ocean shoreline is state or federally owned, with the remainder developed. Because of uncertainties regarding future nourishment requests, sand availability, and funding, the BIMP recommends using regional planning and a dedicated state fund to support regional projects.

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 (North Carolina Sea Grant 2009) which identified five emerging resource policy issue areas, and provided recommendations for changes. This was to ensure that North Carolina have adaptive rule language. Sand resource management was identified as an emerging issue, and thus 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

8.3.2.2. Hard stabilization

Jetties and groins

In North Carolina, hard stabilization techniques on oceanfront beaches have been limited to a few jetties, groins, and seawalls. Seawalls (bulkheads) and rock revetments extend parallel to the ocean shoreline. Seawalls are vertical structures, and are primarily designed to prevent erosion and other damage due to wave action. Jetties and groins are constructed perpendicular to the beach, with jetties usually being longer. They are located adjacent to inlets with the purpose of maintaining navigation by preventing sand from entering the inlet. In contrast, terminal groins are structures built at the end of littoral cells to trap and conserve sand at the end of barrier islands, stabilize inlet migration, and widen a portion of the updrift beach. Terminal groins are designed so that when the area behind the groin fills with sand, additional sand will bypass the structure and enter the inlet system.

It is well accepted that hard stabilization techniques along high energy ocean shorelines accelerate erosion in some locations along the shore, partially as a result of the longshore sediment transport being altered (Defeo et al. 2009). The hydromodifications resulting from coastal armoring alters sediment grain size, increases turbidity in the surf zone, narrows and steepens beaches, and results in reduced intertidal habitat and diversity and macroinvertebrate abundance (Dolan et al. 2004; 2006; Dugan et al. 2008; Miles et al. 2001; NRC 1995; Pilkey et al. 1998; Riggs and Ames 2009; Walker et al. 2008; Walton and Sensabaugh 1979). A study looking at the effect of a short groin (95 m) 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 loss of beach 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 with some exceptions.

Perhaps the greatest impact of terminal groins and jetties is the long-term effects on marine and estuarine ecosystems. By stabilizing the 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 greatly reduced 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, and the post-storm dune restoration to remove sand from and open NC 12, have 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. From 1983 to 2009, approximately 12.7 million cubic yards of sand were added to the shoreline within three miles of the terminal groin (Riggs and Ames 2009).

Dolan (2006) documented that the sand replenishment in this area required to maintain the channel, protect the road, and maintain a beach, resulted in a significant reduction in grain size and mole crab abundance. Mole crabs, an important part of the food web for shorebirds and surf fish, are considered an indicator species for monitoring beach condition.

Jetties obstruct larval and early juvenile fish passage from offshore spawning grounds (Blanton et al. 1999). Successful transport into estuarine nursery areas 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, block the natural passage for larvae into inlets and reduce recruitment success (Blanton et al. 1999; Churchill et al. 1997; Kapolnai et al. 1996). 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.

Impacts from jetties and groins may be greatest in coastal areas like the Outer Banks, where there are few inlets. Miller (1992), in reviewing 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 by 60-100%. The Environmental Impact Statement (USACE 1999) for the Oregon Inlet project concluded the jetties should not be constructed because of this and other concerns. Although there is uncertainty regarding the magnitude of fisheries impacts, jetties and groins would likely reduce larval recruitment into estuarine nurseries (Blanton et al. 1999; Churchill et al. 1997; Kapolnai et al. 1996).

In contrast, where natural coastal barrier island processes, such as overwash and the opening, closing, and shifting of inlets have occurred, the islands have grown in width and elevation and have migrated. Core Banks with Drum Inlet is an example of a barrier island with inlet or inlets that opened and closed throughout time (Mallinson et al. 2008). Drum Inlet initially opened in 1899, but has closed and opened multiple times during storm events. It is possible that other areas that historically had inlets will again in the future (e.g., Buxton Inlet, New Inlet, Ophelia Inlet, Isabel Inlet) (Mallinson et al. 2008). When inlets open, sediment deposition of a flood tide delta aids barrier island migration and widening. Where new inlets form, Mallison et al.(2008) recommends allowing the inlets to remain open, even if temporarily, until a substantial flood tide delta forms, allowing long-term maintenance and stability of the island.

A relatively small amount of North Carolina's developed ocean shoreline is hardened compared to other states, at roughly 6% (Pilkey et al. 1998). In contrast, South Carolina, Florida (east coast), and New Jersey have 27%, 45%, and 50% of their respective shorelines hardened. Existing revetments and seawalls in North Carolina were constructed prior to the CAMA (e.g., Atlantic Beach) or were for the purpose of protecting historic structures (e.g., Fort Fisher). Existing jetties in North Carolina occur at Masonboro and Barden's inlets, terminal groins occur at the Cape Fear River, Oregon and Beaufort inlets, and small groin fields are constructed at Bald Head Island and Hatteras Island.

Sandbags

The use of sandbags is a temporary method of erosion control permitted for protection to imminently threatened structures (shoreline less than 20 feet from structure) while property owners seek more permanent solutions, such as beach nourishment or relocation of the structure. Filled with sand, bags are stacked and perform like seawalls. Sandbag walls may remain in place for up to two years if the protected structure is 5,000 square feet or less, or up to five years if the structure is larger than 5,000 square feet. Sandbags may remain in place for up to five years, regardless of structure size, if the community is taking part in a beach nourishment project. Sandbags may remain in place indefinitely if they are covered with sand and stable natural vegetation. If a storm exposes the bags, they must be removed if their time period has expired. Variances to the rules are available from the CRC. Presently, sandbag structures range in age from newly installed to 28 years in various locations along the coast.

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. In 2009, Session Law 2009-479 required that the CRC 1) not order the removal of sandbags if a community was actively pursuing beach nourishment or inlet relocation; 2) 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 (discussed below).

Terminal Groins

The CRC and DCM contracted the above mentioned study to Moffatt and Nichol. Five existing terminal groins were examined to draw conclusions on the effectiveness and impacts of the structures where used before. The study sites included Oregon and Beaufort inlets in North Carolina, 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 (Moffat and Nichol Inc. 2010), without which erosion to adjacent beaches would occur. The long-term maintenance increases the overall costs of terminal groins. The study found that groins reduced erosion rates immediately adjacent to the structure, but showed evidence of increased erosion about two miles downdrift, and opposite of the inlet. The effects could not be directly attributed to the structure due to simultaneous inlet dredging and sand disposal nearby. The CRC subcommittee concluded that use of terminal groins may be feasible but not advisable due to environmental consequences, expense, and uncertainty of long-term impacts, thus voted to state that the study was inconclusive and therefore could not recommend for or against.

On June 28, 2011, SB110 was passed into law amending the CAMA to allow for permitting of up to four terminal groins, to be treated as a pilot program to determine the effectiveness of such structures in North Carolina. Senate Bill 110 contains criteria to be met by the applicant prior to permit issuance. For example, SB110 requires the development of an inlet management plan, commitments to monitor and mitigate for adverse impacts to adjacent beaches, properties, or structures, etc. The bill requires the applicant provide financial assurances for impact mitigation, restoration, and/or groin removal. The first four communities to receive permits would be allowed to construct a terminal groin. The following summaries outline the status of these communities:

Village of Bald Head Island

In early 2014, the Village of Bald Head Island submitted a Draft Environmental Impact Statement (DEIS) for agency and public comment. The DCM provided comment to the USACE. The Village and USACE have incorporated these comments into a Final EIS (FEIS), which was released for agency and public review and comment in August of 2014. A permit application was submitted to DCM on July 25th, 2014. All permits for construction of the terminal groin have been approved. In spring of 2015, a multi-agency pre-construction meeting was held and construction is expected to be completed by late 2015.

Ocean Isle Beach

Following scoping meetings for the proposed project, a DEIS was released in January 2015 by the USACE.

Figure Eight Island Homeowners Association

The Figure Eight Island HOA prepared a DEIS addressing shoreline stabilization options for Rich Inlet. The preferred alternative is construction of a terminal groin with beach fill. The project would involve beach nourishment every five years following groin completion. Proposed impact monitoring would be based on comparing anticipated beach volumes with actual beach volumes along multiple transects. In July, 2012, DCM provided comments on the DEIS to the USACE. The applicant and USACE are in the process of incorporating these comments and those from public and other agencies, into a Supplemental EIS (SEIS). Further, the applicant is investigating potential design modifications that could cause revisions to the SEIS.

Holden Beach
Scoping meetings have been held to discuss a potential project. As of February 2015, the applicant is working with the USACE on the development of a DEIS for this potential project.

Carteret County
Carteret County proposes a terminal groin at Bogue Inlet as one option in response to anticipated erosion over the next 30 years. At this time, it is unclear if the county will be formally pursuing a project.

North Topsail Beach
The Town of North Topsail Beach has expressed an interest in pursuing DCM authorization for a terminal groin, but as of February 2015 it is unclear if they intend to study the option further.

8.4 Marinas, docks, and boating

Docking facilities effect the habitat in which they exist, during construction and for the lifetime of the structure. Such facilities are regulated under T15A NCAC 07H .0208(b), enforced by DCM. This section will explore the ways in which marinas, docks, and the boating activities for which they are constructed affect shallow bottom, SAV, wetlands, shell bottom, hard bottom, and the water column.

8.4.1 Facilities

8.4.1.1. Marinas

The Division of Coastal Management is responsible for permitting marinas and docking facilities under the Coastal Area Management Act (CAMA). The CAMA permitting process requires coordination with the Shellfish Sanitation and Recreational Water Quality Section of DMF (DMF-SS&RWQ), the Division of Water Resources (DWR), US Army Corps of Engineers (USACE), and other federal, state, and local authorities. Authority comes from DCM's governing body, the Coastal Resources Commission (CRC).

A marina is defined by the CRC as any publicly or privately owned dock, basin or wet boat storage facility constructed to accommodate more than 10 boats and providing any of the following services: permanent or transient docking spaces, dry storage, fueling facilities, haul out facilities and repair service [T15A NCAC 07H .0208(b)(5)]. Because of the fragile nature of the areas in which marinas are located, construction alone has the ability to negatively impact the surrounding ecosystem. Upon completion, operation and use of the waters by customers can contribute to degradation of the system.

Direct impacts from marina construction come from pile jetting/driving, shoreline stabilization, excavation, installation of docks, wave attenuation, construction of associated high ground facilities, etc. Lesser recognized impacts are indirect, and come from associated boating activities.

8.4.1.2. Multi-slip docking facilities (MSDFs)

Docking facilities provide varying degrees of impacts depending on location, size, and use. Many docking facilities are composed of several multi-slip docks, thereby avoiding the designation, "marina." Multi-slip docking facilities of 10 slips or less do not meet the definition, and may be allowed in open shellfishing waters. While the accumulation of multi-slip docking facilities has not been directly linked with increasing bacterial contamination and shellfish harvest area closures, the associated residential development has been (Kirby-Smith and White 2004; Kirby-Smith and White 2006).

Multi-slip docking facilities are common amenities in waterfront communities. Developers of coastal subdivisions frequently construct community docks to increase the value of inland lots. While serving as incentives to buyers, the slips regularly go unoccupied. Multi-slip docking facilities with 11-29 slips and vessels less than 25' in length, with no heads or cabins, are considered marinas "with shellfish harvest closure exclusions," per T15A NCAC 18A .0911. The exclusion conditions minimize the risk of bacterial contamination in open shellfish harvest waters and increase siting opportunities for marina developers.

8.4.1.3. Individual docks

The majority of docking facilities are individual docks, with the least impact to resources. An individual dock permitted under the CAMA General Permit process (GP .1200) has the allowance for two slips. This permit can be combined with GP .2200, which allows freestanding moorings, for a combined dockage of four spaces. The number of GPs steadily increased until 2000, and then fluctuated until 2004. Figure 8.4 shows a significant decrease in the number of GPs from then until 2014. While the reason is unknown, the economic decline and the doubling of GP fees in 2005 could have contributed to the downturn.

The impacts from individual docks are less than those from marinas or MSDFs, yet the number of such dock permits far exceeds those of marinas or MSDFs. If properly designed, individual piers may not pose significant threats to soft bottom, PNAs, wetlands, shellfish resources, water column, or beds of SAV.

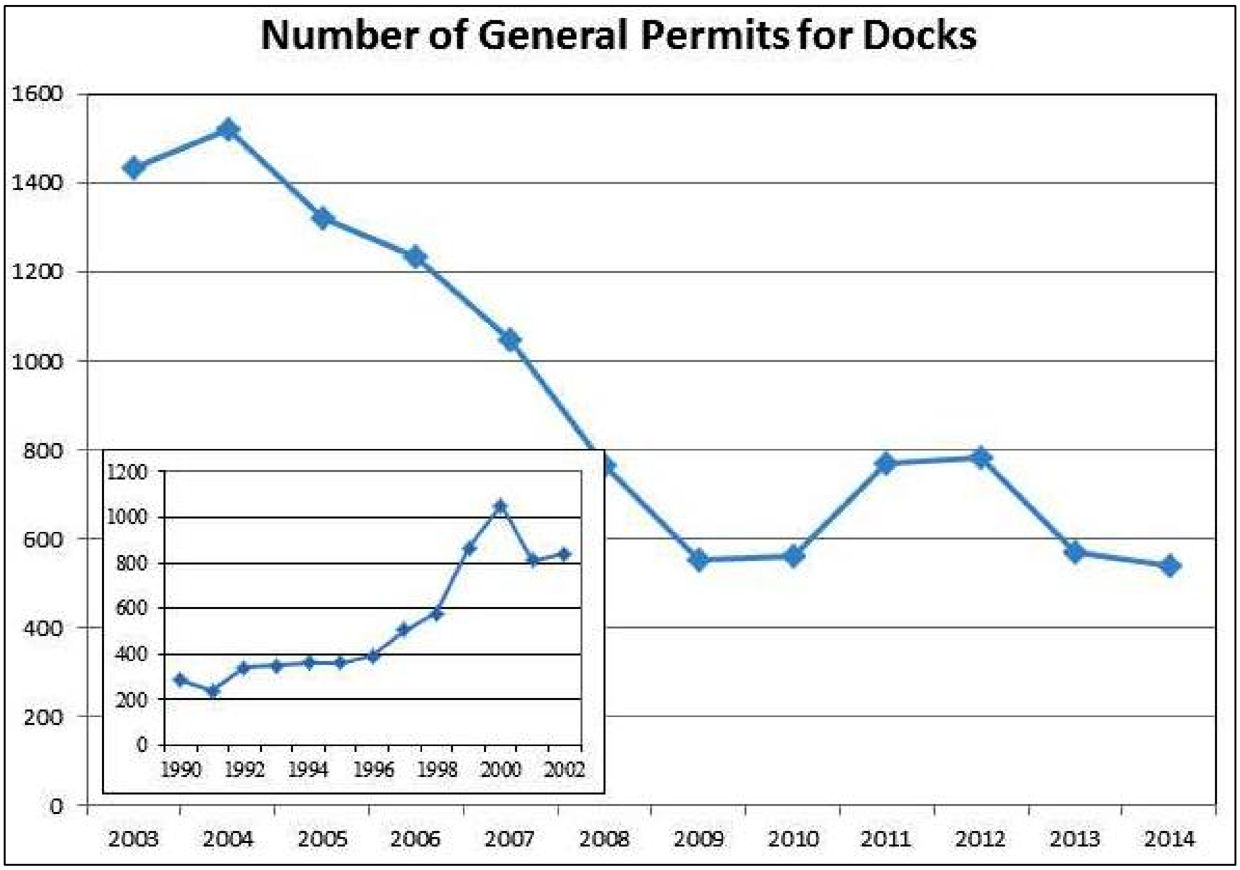


FIGURE 8.4. Annual number of CAMA general permits issued by the North Carolina Division of Coastal Management for docks, 2003-2014, with inset for 1990-2002 (DCM, unpublished data, 2015).

8.4.2 Potential Impacts

There are many potential impacts related to the construction and operation of marinas, multi-slip docking facilities, and individual docks, from materials to size, location, and use. In simple terms, these potential impacts are:

- docks shade shallow bottom habitat, SAV, and wetlands
- lumber is treated with chemicals
- a concentration of pilings can alter the hydrology of the system
- marinas and community docking systems often require shoreline stabilization
- construction of docking systems often require excavation for basins, canals, and channels

- driving of pilings and installation of docks disturbs and resuspends sediments
- floating docks sitting on substrate for a portion of tide cycle can impair benthic community
- wave attenuation systems, boat ramps, railway or launch systems create additional impacts

Depending on the type of facility, there may be fuel discharge and bottom paint leachate. In eastern North Carolina, many docking facilities are located in tidal areas where docks or vessels are on the bottom during mid to low tides, causing disturbance to substrate and benthic organisms. In other cases, the substrate is excavated during construction of the project. During ingress and egress from docking systems, there is inevitable kicking of shallower connecting creeks during borderline tides, and while inshore boating, fishing for bait or marsh species such as flounder or drum, kicking of the shallow bottom is common, and resuspension of sediments follows. Shallow habitat supporting SAV and marsh can become scarred from propellers, boat wakes destabilize and erode SAV and marsh edges, and bottom sediments can be resuspended through energy of the propeller or jet of the engine.

In 2008, the CRC modified dock and pier rules, giving property owners greater flexibility in facility construction. The new rules provide better protection for shallow water habitat by requiring minimum water depths for docks located in PNAs, SAVs, and shell bottom habitat.

Marinas are regulated by the CRC to prevent, in every case possible, excavation of shellfish, SAV, and wetlands. Marinas cannot be located in or adjacent to areas where shellfish harvesting for human consumption is a significant existing use and a closure to the resource is anticipated. In areas where shellfish waters are closed to harvest or are not a significant resource, this may inadvertently promote development, resulting in further degradation of water quality and degradation of bottom habitat.

8.4.2.1. Sedimentation

An increase in water column turbidity causes a decrease in sunlight penetration and oxygen availability; toxins can be released with sediment, shellfish smothered, and blades of SAV covered. Resuspended sediment can settle onto wetland plants, alter the composition and elevation of substrate, changing the competition between wetland species; sediment can smother benthic organisms and clog finfish gills, alter pH, salinity, temperature, and the chemical composition of the water column.

Piles for dock and pier construction can be installed in two ways. The jetting of pilings uses a water pump with a high energy nozzle to displace sediment. Fines are released into the water column, increasing turbidity for various lengths of time depending on grain size (Denton 2004; Smith 2003). Heavier material settles faster, leaving localized elevated mounds, potentially affecting local flow conditions. Pile driving is a technique consisting of mechanically hammering the piling into the substrate. This method displaces a negligible amount of material compared to jetting, with less impacts, but is more time consuming and expensive.

Dredging for boat basins, canals, or channels produces sediment plumes on a larger scale. Hydraulic pipeline excavation disturbs sediment while “vacuuming” the bottom. Material is piped directly into a containment area on high ground. Small organisms, such as larvae and shellfish can be entrained with the dredge material. The duration of suspension varies from hours to days depending on sediment type, currents, and equipment specifics. Sessile benthic invertebrates can be adversely impacted depending on the suspended sediment exposure (LaSalle et al. 1991). Clamshell bucket dredging employs buckets to remove the substrate, and in theory, close tightly by hydraulics prior to removing the material. In practice, the bucket is often lifted in the process of closing, and material is lost to the water column. Bucket-to-barge excavation employs a simple bucket to remove sediment. The material is removed with a dragline or excavator, and lifted to a barge for transporting and offloading. Material is dragged through the water as the bucket pulls to the surface, and lifted from the surface into the barge. Spillage from the barge is common. This method of material transport is also used by hydraulic clam bucket.

In shallow creeks and sounds with lunar tides, floating docks can cause a release of sediment by settling onto the bottom during low tides, pushing the water from beneath the dock. As floats rise with the tide, the force causes suction, pulling sediments into the water column. As wave action lifts and lowers the float, pumping sediment separates, with coarser materials on the bottom and fines on top.

Boating associated with marinas and docks can cause siltation of shell habitat through bottom scour and resuspension, with an effect similar to dredging on oyster beds. Boat wakes increase wave energies and shoreline erosion, and promote the development of dead margins along intertidal reefs (Grizzle et al. 2002; Wall et al. 2005; Walters et al. 2003). 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 had higher sediment loads, water motion, and juvenile oyster mortality than pristine reefs. Other studies in this system indicated reef migration away from the AIWW, and total reef destruction in response to increased boating activity since the mid twentieth century (Grizzle et al. 2002).

As suspended sediment disperses and settles, it can bury oyster larvae, adults, or shell, deterring successful recruitment from lack of exposed hard substrate (Coen et al. 1999). In some areas, historic reefs have been completely covered with fines and mud (Rodriquez et al. 2006). Oyster eggs and larvae are most sensitive to sediment loading (Davis and Hidu 1969). Excessive sediment and associated algae can reduce growth rates and survival of macrofauna, such as hard clams (Bock and Miller 1995).

Suspended sediments can impact aquatic animals by clogging gills and pores of juvenile fish and invertebrates, resulting in mortality or reduced feeding (Ross and Lancaster 1996). Auld and Schubel (1978) demonstrated reduced hatching success and larval fish survival for several fisheries species in the Chesapeake Bay. Increases in nonfood items ingested by suspension-feeding shellfish and polychaetes lower the nutrient value of their diet and their growth rates (Benfield and Minello 1996; Lindquist and Manning 2001; Reilly and Bellis 1983; SAFMC 1998b). Turbidity has also been found to disrupt spawning migrations and social hierarchies (Reed et al. 1983) and decrease biomass (Aksnes 2007).

Hard bottom in close proximity to shore is more vulnerable to pollutants than offshore, although problem levels of nutrients have generally not been found in North Carolina's coastal ocean waters. Residues of the organochlorine pesticides DDT, PCB, dieldrin, and endrin have been found in gag grouper, red and black grouper, and red snapper (Stout 1980), indicating that toxins from stormwater runoff are a potential threat to the hard bottom community.

Suspended sediment absorbs toxic chemicals, heavy metals, phosphorus, and bacteria, providing a mechanism for pollutants to be transported downstream where they may be ingested by filter feeding fish and invertebrates (Steel 1991). Sediment allows bacteria to persist longer in the water column than in clear waters (Fries et al. 2008; Jartun et al. 2008; Schueler 1999). Results from the Neuse River Estuary Modeling and Monitoring Project 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 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).

Sediment is a significant impairment to water quality in North Carolina. The 2014 DWR Integrated Report on water quality (DWR 2014), based on data collected from 18 ambient stations, shows the highest 2012 turbidity levels in the Cape Fear River near Kelly, NC. In 2014, 6,290 acres of coastal rivers and sounds were impaired due to turbidity.

8.4.2.2. Shading

Shading from docks results in loss of SAV beneath the dock structures (Beal and Schmit 1998; Connell and

Murphey 2004; Loflin 1995; Shafer 1999). In a study in the Indian River Lagoon, Florida, light availability was reduced under docks that were 3 feet and 5 feet high to 11% and 14% of ambient light, respectively, which is less than the minimum shown to be optimal (15-25%) for growth and survival of seagrass (Beal and Schmit 1998). Light availability increased with increasing dock height, and was significantly greater under the higher dock (5 feet). Other studies in Florida found significantly less SAV under docks than in adjacent unshaded areas (Loflin 1995), and no seagrass under docks having light levels less than 14% of surface irradiance (Shafer 1999). Burdick and Short (1999) identified dock height, orientation, and width as the most important factors affecting SAV survival under docks.

Shading of marsh vegetation results in loss of plant growth and vigor. A South Carolina study compared stem densities of *Spartina alterniflora* under docks with stem densities five meters away (Sanger and Holland 2002). Results indicated an average reduction in density of 71% under docks. Shading from the average dock (100m long x 1.22m wide) adversely affected ~87 m^2 of marsh. Sanger and Holland (2002) surmised that on a built-out scale, these effects could be significant.

In North Carolina, CRC rules allow property owners to waive riparian corridor setback requirements. Further, with neighbor permission, owners of narrow properties (e.g., 30 ft, 40 ft) can construct within riparian areas of others [T15A NCAC 07H .0208(b)(6)(I)]. This can, and does, permit congested docking systems. In areas where marsh is fringed along the edges of creeks or canals, a plethora of docks places a visible burden on the coastal marsh system (Figure 8.5). In this situation, a reduction of 71% in marsh stem density could place a significant burden on the remaining habitat.

In Georgia, two studies found a reduction of ~50% in stem density under docks, resulting in 21-37% reduction in biomass and carbon production per m^2, estimating that to cause a 0.5-0.9 g dry weight nekton/m^2 reduction in total annual primary nekton production (Alexander and Robinson 2004; Alexander and Robinson 2006). With the increasing proliferation of docks in Georgia, the conclusion was that the cumulative effects from dock shading on critical fish nursery areas should be further assessed.

Pagliosa et al. (2012) studied the influence of piers on functional groups of benthic primary producers and consumers in the channel of Conceicao Lagoon in southern Brazil. They determined the main impact to be light reduction, reducing micropyhytobenthos and macroalgae. Twenty six taxa of macroalgae and twenty six taxa of macrofauna were identified and grouped. The findings, while inconclusive for all groups, showed that shading caused by piers decreased phytobenthic biomass, also evidenced by the reduction of chlorophyll *a,* Pagliosa et al. (2012). “We can conclude that all algal functional groups responded negatively to the abiotic and biotic conditions provided by the piers. Regarding the macrofauna, the primary production reduction and the presence of the new habitats resulted in changes of the analyzed groups. Thus, we concluded that piers exert a negative effect over base-trophic level organisms responsible for bottom-up controls” (Pagliosa et al. 2012).

The presence of docks can alter young-of-year (YOY) fish populations. In the Hudson River, New York and New Jersey, Able et al. (1998) examined the impacts docks had on YOY fish populations 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; Duffy-Anderson et al. 2003). This difference may be due to reduced light penetration under piers. Young of year winter flounder *(Psuedopleuronectes americanus)*, a species similar to southern flounder (*Paralichthys lethostigma)*, had faster growth rates and consumed more prey in caged areas at pier edges than in those under piers (Duffy-Anderson and Able 1999).

Because of shading impacts to habitat, CRC rules include specific criteria to limit these impacts. Shading rules affecting platform space, dockage, boathouses, etc., allow eight square feet per linear foot of shoreline with a maximum of 2,000 square feet, not including the pier, with some exceptions. This restriction does not apply to marinas. The DCM regulates the width and height of structures in that piers and docking facilities over coastal wetlands shall be no wider than six feet and shall be elevated at least three feet above coastal wetland substrate [T15A NCAC 07H .0208(b)(6)(C)]. If the applicant qualifies for a General Permit, they cannot construct within a PNA, SAV, or shellfish bed, with less than 2' of water, unless pre-approved by DMF and WRC. Floating piers and docks located in PNAs, over shellfish beds, or over beds of SAV shall only be allowed if the water depth between the bottom of the structure and the substrate is at least 18 inches at normal low water or normal water level (T15A NCAC 07H .1200).

8.4.2.3. Excavation and marina design

The CRC rules include use standards related to dredging, [T15A NCAC 7H .0208(b)] to avoid or minimize impacts to PNAs, shellfish beds, SAV, and coastal wetlands.

Soft bottom habitat can be affected by alteration of shoreline configuration, circulation patterns, and changes in bottom sediment characteristics (Wendt et al. 1990). Because benthic microalgae are light dependent, bottom sediments in dredged marinas have reduced light availability due to increased water depth. The difficulty in assessing impacts to soft bottom sediments and benthic habitat is that for the facility to continue operations, excavation must be maintained. Therefore, even if the habitat recovers, impacts will recur. This same fact applies to the loss of wetlands, SAV, and shell bottom within the excavation footprint, and within the slough and adjacent energy zone.

There is a regulatory dilemma regarding the design of basins, caused by the different missions of individual agencies. While DWR is focused on protecting the quality of the water and wetlands, DCM and the USACE also look at protecting navigation and public trust access. Because of this, the DWR recommends marinas designed with open basins to enhance flushing, while DCM and the USACE recommend upland basins and connecting channels to minimize obstruction to navigation.

8.4.2.4. Boating use, propeller scar, wake turbulence

Marinas and docks of all types have one function – to allow for the safe storage, use, and service of marine vessels. There are impacts to all six CHPP habitats from the use of boats, depending on the size of the boat, the competency of the user, the tide schedule during use, the type of activity, and the system in which the activity takes place.

Boating related activities, such as anchoring or diving on hard bottom, can 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 1998a). Divers can kick or overturn corals and live rock, resulting in habitat damage. Recreational spearfishing with power heads can damage corals where diving activity is concentrated (SAFMC 1998a). 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 1998a). 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 and live rock in state waters (T15A NCAC 03I .0116). In addition, any live rock or coral incidentally harvested with gear must be returned immediately to the waters from where it was taken. Similar NMFS regulations exist for federal waters, prohibiting the collection of live rock, stony and black corals, fire coral and hydrocoral, and some species of sea fans (SAFMC 1982; SAFMC 1994). Permits may be issued by NMFS to take prohibited coral for scientific, research, and educational purposes, to use chemicals, and to harvest octocorals.

Direct physical impacts from propeller scarring, vessel wakes, and mooring scars have been identified nationally as a major and growing source of SAV loss (ASMFC 1997; Fonseca et al. 1998; Sargent et al. 1995). Propeller scarring of SAV occurs when outboard vessels travel through water that is shallower than the draft of the boat. The propeller blade cuts leaves, roots, and stems, as well as creates a narrow trench, or scar, through sediment (Sargent et al. 1995). Large holes may also be blown where boaters rapidly power off shallow bottom (Kenworthy et al. 2000). Mechanical disturbance to the sediment damages plant rhizomes, which reduces abundance and cover for extensive periods of time. Recovery of SAV can take from two to 10 years, depending on species and local conditions, or in some cases, the habitat may never recover (ASMFC 2000; Zieman 1976). Once started, SAV damage can increase beyond the initial footprint of the scar, due to scour, 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 habitat is reduced (Bell et al. 2002; Fonseca et al. 1998).

An effect of boating on wetlands is the loss of vegetation from wave action, although the impact has not been quantified (Riggs 2001; SAFMC 1998b). Erosion from boat traffic along the AIWW and elsewhere is readily observable and is likely responsible for substantial loss of fringing wetland habitat (Riggs 2001). According to the WRC, there were ~219,482 vessels registered in the coastal counties in 2015 (Table 8.10). This is an increase of 111,382 over the 2008 number of 108,100, representing a 103% increase in the number of registered recreational boat owners in the coastal counties in seven years.

Counties with the greatest number of boats are in the tidally driven southern counties of New Hanover, Carteret, Brunswick, and Onslow. Craven, Beaufort, Dare and Pender counties also have a considerable number of registered vessels. Boats less than 16 feet in length comprise almost 42% of all vessels, and boats 19 to 23.9 feet are the second most common boat size, accounting for 21% of all vessels.

There are currently 240 marinas located within 500 meters of a PNA (Table 8.11). Of these, 152 meet the shellfish exclusion necessary to prevent closure of harvest for human consumption (less than 30 vessels, no boats over 24’, no heads, no cabins). There are 33 marinas located within 500 meters of designated Anadromous Fish Spawning Areas.

As of 2014, there are at least 648 marinas within North Carolina CHPP Regions (Table 8.12). Of these, 368 meet the shellfish exclusion necessary to prevent closure of harvest for human consumption (less than 30 vessels, no boats over 24’, no heads, no cabins). The majority of marinas are clustered in high salinity waters, followed by transitional and low salinity (Map 2.1a-b). The greatest numbers of marinas (in descending order) occur in the Core/Bogue, Southern Estuaries, and Neuse subregions.

8.2.4.5. Chemicals, toxins and fecal and microbial contamination

Marinas and boatyards often provide services such as maintenance, wastewater pumpout, pressure washing, sandblasting, and painting that can lead to the introduction of toxins into adjacent waters. To assess the types of activities and potential water quality concerns, DWQ conducted a survey of 141 marinas in the 20 coastal counties in 2007 (DWQ 2008a). They found elevated levels of copper, iron, zinc, and aluminum in the wastewater, with lead, nickel, chromium, arsenic, and cadmium elevated to a lesser extent. High metal concentrations were attributed to sloughing of residual paints from boat hulls during washing, with pressure washing contributing greater loading of copper, zinc, and aluminum. Boats with anti-fowling, or bottom paint, had the highest concentrations of metals in process wastewater compared to water from boats without. The report concluded that due to concentrations of metals generated in the power washing process, and since the majority of the operations are located adjacent to coastal surface waters, the environmental effects are a significant concern. As a result, there are now regulations in place for marinas with wash down and sand blasting facilities.

Boats can be sources of fecal microbial contamination from head discharge, as in the Town of Wrightsville Beach (Mallin et al. 2009a). Because of frequent swimming advisories posted to estuarine beaches, studies were undertaken. In the study by Mallin et al. (2009a), sampling for fecal coliform bacteria and *Enterococcus* bacteria was done at nine locations from 2007-2009. Standards for Enterococcus were exceeded on four occasions at one location and three occasions at two other locations. The DNA fingerprint analysis revealed human fecal bacteria signals at all sites, most frequently at local marinas. Lacking evidence of sewer or septic leaks, discharge from boat heads was indicated.

TABLE 8.10. Registered recreational boats of different length categories in NC coastal counties (WRC, 2015).

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	13,337	3,510	3,145	2,420	7,084	2,486	736	32,718
Carteret	9,462	3,457	2,775	2,362	8,796	2,900	930	30,682
Brunswick	12,019	3,074	1,966	1,792	4,461	1,566	360	25,238
Onslow	10,261	3,091	2,548	1,912	4,235	1,118	308	23,473
Craven	8,040	1,827	1,675	1,374	3,666	1,147	443	18,172
Beaufort	6,412	1,837	1,266	1,252	3,161	1,132	377	15,437
Dare	5,479	1,577	1,105	1,151	3,688	1,587	382	14,969
Pender	5,792	1,516	1,106	802	2,089	565	123	11,993
Currituck	3,911	1,185	807	825	1,668	535	76	9,007
Pamlico	2,755	697	568	517	1,529	775	312	7,153
Pasquotank	2,447	600	479	407	1,059	295	58	5,345
Perquimans	1,924	423	310	273	777	237	37	3,981
Chowan	1,684	452	359	326	821	234	59	3,935
Bertie	1,619	506	361	247	480	105	15	3,333
Hertford	1,585	428	266	247	411	85	16	3,038
Washington	1,278	442	232	239	442	121	21	2,775
Camden	1,029	242	187	181	439	225	25	2,328
Gates	1,127	289	195	162	302	47	5	2,127
Hude	761	330	234	241	550	276	104	2,496
Tyrrell	516	215	105	99	221	102	24	1,282
TOTAL	91,438	25,698	19,689	16,829	45,879	15,538	4,411	219,482

TABLE 8.11. Marinas and multi-slip docking facilities by CHPP Region within 500 m of AFSA and PNA, between 10 and 29 slips (excluded from shellfish closure), and equal to or greater than 30 slips (DMF, unpub. data, 2014).

	AFSA			PNA		
CHPP Region	Between 10 and 29	≥30	Totals	Between 10 and 29	≥30	Totals
1	18	8	26	0	2	2
1/2	0	0	0	0	0	0
2	5	1	6	53	25	78
2/3	0	0	0	0	0	0
3	1	0	1	35	17	52
4	0	0	0	64	44	108
TOTAL	24	9	33	152	88	240

TABLE 8.12. Number of multi-slip docking facilities by CHPP Region with between 10 and 29 slips (marinas excluded from shellfish closure), and equal to or greater than 30 slips (DMF, unpublished data, 2014).

	Number of docking facilities		
CHPP Region	> 10 and < 29	≥30	Totals
1	42	37	79
1/2	0	1	1
2	110	55	165
2/3	0	0	0
3	126	100	226
4	90	87	177
TOTAL	368	280	648

Microbial contamination from fecal matter is important because it affects the opening and closing of shellfish harvest waters. Fecal coliform bacteria occur in the digestive tract of, and are excreted in solid waste from, warm-blooded animals. While these bacteria are not harmful to humans or other animals, their presence in water or in filter-feeding shellfish may indicate the presence of other bacteria that are detrimental to human health (DWQ 2000a). Shellfish harvest closures have occurred over time (DMF 2001a; DMF 2001b) leading to a reduction in available harvest areas. Over 442,106 acres of coastal waters were closed to shellfish harvesting in North Carolina as of March 05, 2014, due to high levels of fecal coliform or the potential risk of bacterial contamination (S. Jenkins, pers. com.). The most recent closures have primarily affected the central and southern areas of the coast, which coincides with the largest concentrations of marinas.

Regulated by the EPA, wood used for marine construction can be treated with chromated copper arsenate (CCA) to a minimum retention of 0.60 - 2.50 pounds of preservative per cubic foot (pcf). Marine construction is defined as (abridged): Wood used for pilings, timbers, walers, plywood and framing, stringers and cross bracing. Wood for marine construction for saltwater use (includes brackish) subject to saltwater (or brackish) splash (splash means any member of a marine structure positioned above mean high tide, but subject to frequent wetting from wave action) is treated to a minimum of 0.60 pcf (http://www.epa.gov/oppad001/reregistration/cca/awpa_table.htm).

Laboratory studies by (Weis et al. 1991; Weis et al. 1992) have shown leachate from CCA -treated wood to be toxic to estuarine species. Leaching decreases by about 50% daily once immersed in seawater. Approximately 99% of the leaching occurs within the first 90 days (Brooks 1996; Cooper 1990; Sanger and Holland 2002). Elevated concentrations of metals from CCA-treated wood can be found in organisms living on treated pilings and in areas near pilings (Weis and Weis 1996a; Wendt et al. 1996).

In areas of low water flow, elevated concentrations of chromium, copper, and arsenic were found in fine sediments adjacent to bulkheads constructed of CCA-treated wood, and in organisms living on and around treated pilings (Weis and Weis 1996b; Weis et al. 1998). Dilution appears to reduce these impacts; the bioaccumulation of dock leachates by marine biota did not impact survival of mummichogs, juvenile red drum, white shrimp, or mud snails in South Carolina estuaries characterized by higher flow rates (Wendt et al. 1990). However, tidal flushing thresholds for contaminant impacts have not been identified, and data does not exist to evaluate the dilution capacity of an area.

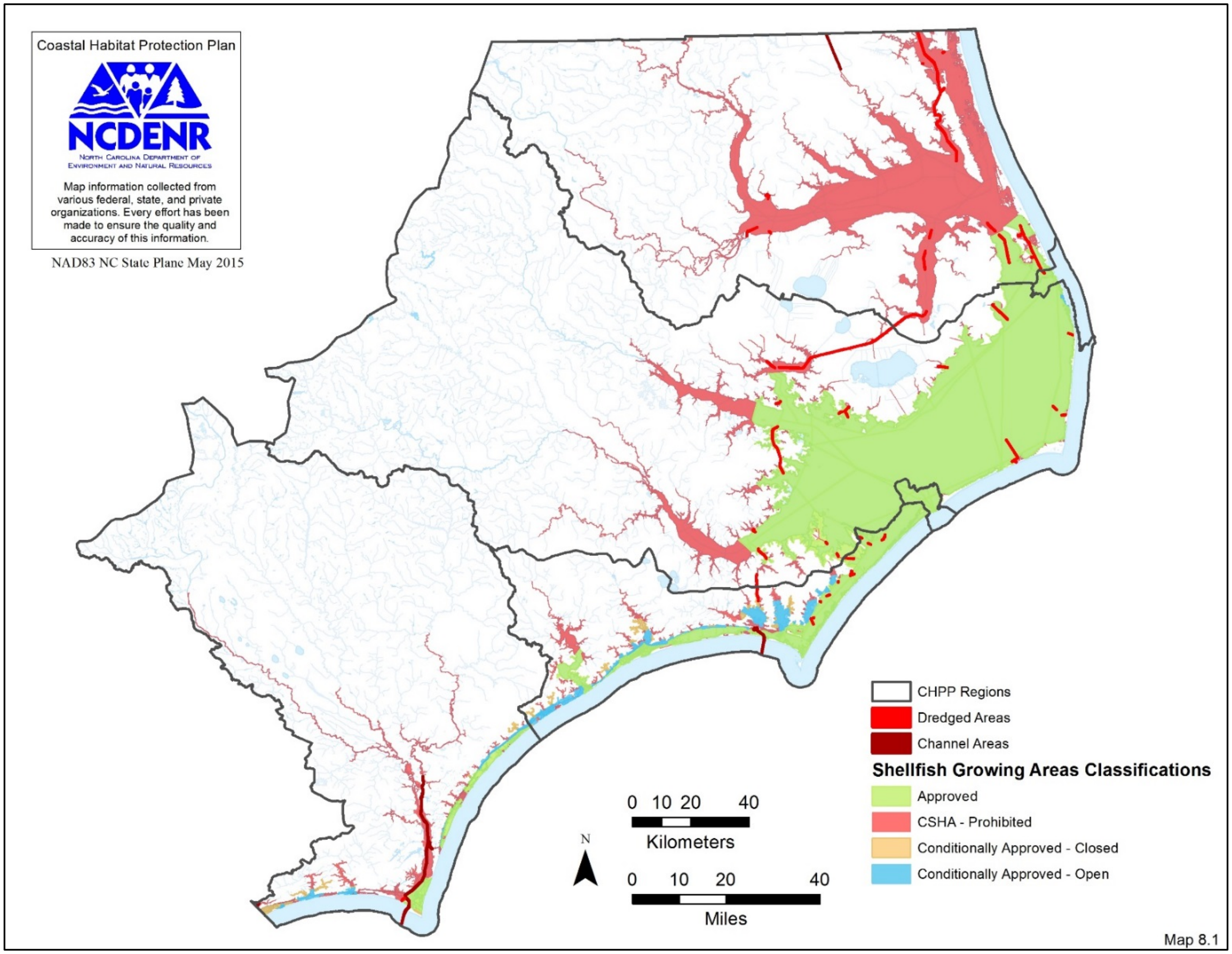
While the additional colonization of non-mobile epifauna on dock structures within a marina may provide additional biotic diversity and a food source for some fish, high densities of fouling organisms (tunicates, barnacles, bryozoans) in marinas can reduce DO levels due to high respiration rates (Wendt et al. 1990). Toxic substances in fouling organisms bioaccumulate and can become concentrated in successively higher levels of the aquatic food chain (Marcus and Stokes 1985; Nixon et al. 1973).

Metals such as mercury, cadmium, and copper are capable of adversely affecting genetic development in bivalve embryos (Roesijadi 1996). Early developmental stages of bivalve mollusks are most sensitive to metal toxicity. Exposure to organic contaminates has resulted in impairment of physiological mechanisms, histopathological disorders, and loss of reproductive potential (Capuzzo 1996). Reductions in growth and increased mortality have been observed in soft-shelled clams (*M. arenaria*) following oil spill pollution events (Appeldoorn 1981).

Outboard motors associated with boating have long been associated with contamination of waterways. Two-cycle engines release up to 20% of unburned fuel along with exhaust gases (Crawford et al. 1998). Crawford et al. (1998) compared the PAH output from a two-cycle outboard engine with that from a four-cycle engine. Discharge from the two-cycle contained five times as much PAH as that from the four-cycle. Most of this difference was due to a reduction in discharge of 2 and 3-ring compounds—those that are generally considered acutely toxic—in the four-cycle. However, the comparison found little difference between the levels of discharge of 4- and 5-ring compounds — those generally related to chronic toxicity. Albers (2002) notes that PAH concentrations in the water column are “usually several orders of magnitude below levels that are acutely toxic,” but those in sediments may be much higher. The PAHs related to boating activities can accumulate in bottom sediments (Sanger et al. 1999) to be stirred up by boat traffic (Albers 2002).

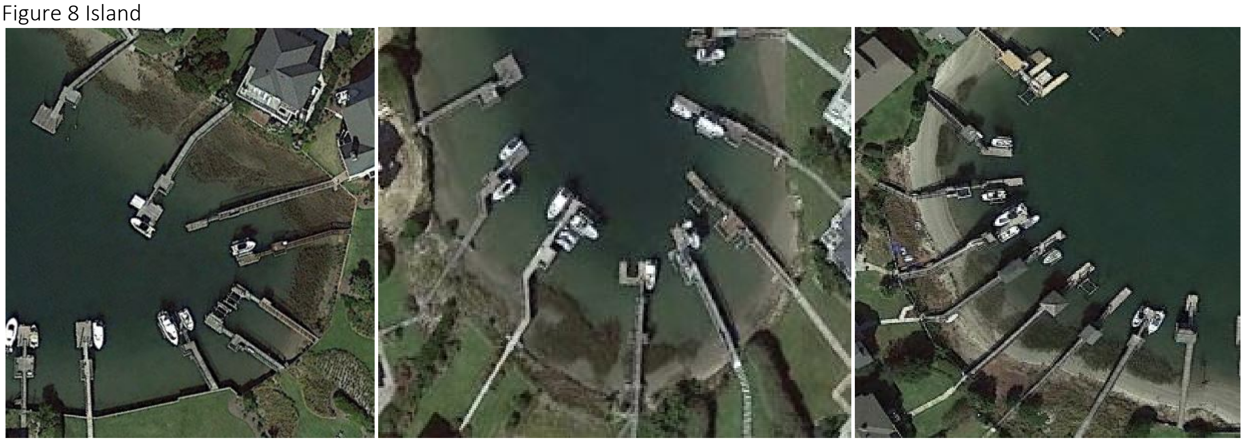
8.4.3 Marinas, docks, and boating summary

The combination of possible impacts from docks and marinas could cumulatively lead to significant degradation of coastal habitats, specifically to primary and secondary nursery area functioning. The Division of Coastal Management undertook mapping of the shoreline and docking structures based on 2012 imagery, documenting a total of 29,583 piers, floating docks, and wharfs on a total of 597.3 acres within the 20 coastal counties (DCM 2015). Commenting agencies must consider cumulative impacts of this scale of coastwide development when making permitting decisions, but the research, models, and tools to determine cumulative impacts with scientific certainty are lacking and therefore currently unaddressed by regulatory agencies.

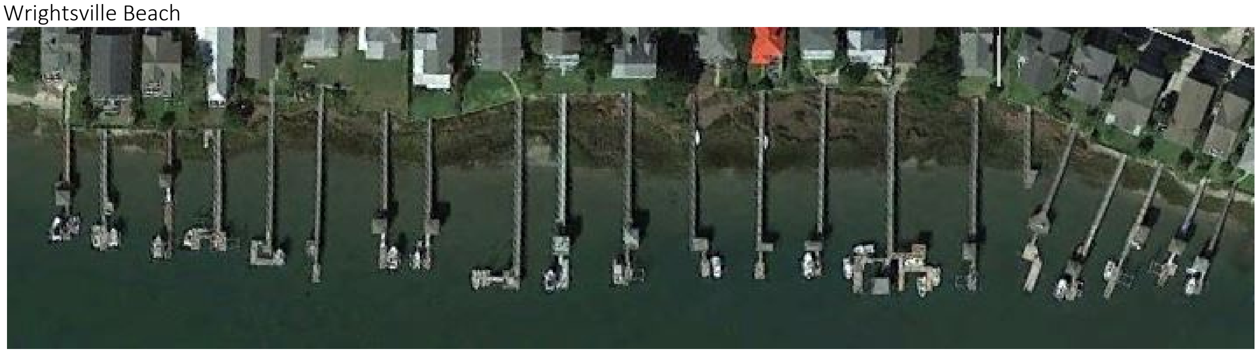


MAP 8.1. Federally dredged channels, marinas, and 10-slip docking facilities.

Figure 8 Island



Wrightsville Beach



Holden Beach

Ocean Isle Beach

FIGURE 8.5. Clusters of piers crossing *Spartina alterniflora* marsh

CHAPTER 9. HYDROLOGICAL ALTERATIONS

9.1. Hydrological Alterations

Human activities can negatively impact fish communities by altering naturally occurring flow 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.

Hydrological alterations can cause both impediments and barriers to movement. Impediments are defined as any feature that impedes or delays fish movement or causes injury (Brownell 2012). A barrier completely blocks fish movement. Whether a feature is considered an impediment or a barrier depends on the specific characteristics of both the feature itself and the species of consideration. For example, a culvert may increase flow rates beyond the swimming ability of smaller fish species, while larger species can still easily pass. Alternatively, a dam that reduces downstream flow year-round may impede or block all fishes, while a dam that releases adequate flow during the spawning season may cause little to no harm to downstream fishes. Impediments and barriers are often discussed in reference to diadromous fishes, where impediments or barriers interfere with spawning migrations. However, impediments and barriers may also reduce the effective habitat available to resident fishes (Gardner 2006).

Diadromous fishes are those whose life histories include regular migrations between freshwaters and saltwaters (McDowall 1997). There are three subcategories of diadromy: anadromy, catadromy, and amphidromy. Anadromous fishes feed and grow in oceanic waters, then migrate into freshwaters to reproduce (McDowall 1997). Catadromous fishes do the opposite, feeding and growing in freshwater, followed by a migration to the ocean to reproduce (McDowall 1997). Amphidromous fish begin life in freshwater, migrate as a larvae to the sea, and then return to freshwater as a postlarvae. Subsequent feeding, growth, and reproduction all occur in freshwater (McDowall 1997).

There are several diadromous fishes of commercial or recreational importance in North Carolina waters. Alewife *(Alosa pseudoharengus*), blueback herring (*A. aestivalis*), American shad (*A. sapidissima*), hickory shad (*A. mediocris*), striped bass (*Morone saxatilis*), Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*), and shortnosed sturgeon (*A. brevirostrum*) are anadromous species. The American eel (*Anguilla rostrata*) is a catadromous species. There are no amphidromous species in North Carolina waters. Long distance migrations are obligatory for reproduction in both anadromous and catadromous species. Thus, hydrological alterations resulting in impediments or barriers to migration can have negative impacts on the population viability of these important fish species (Brownell 2012).

9.2. Flow Obstructions

9.2.1. Dams

Dams have been constructed throughout North Carolina to provide flood control, hydropower generation, water supply, irrigation, navigation, recreation, fish and wildlife ponds, debris and sediment control, and fire protection. Dams affect habitats both upstream and downstream. Upstream habitats may become inaccessible to anadromous fish and downstream habitats receive altered surface water from upstream sources. The majority of dams in North Carolina are 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 spawning migrations of anadromous fish and the catadromous American eel (Maps 9.1a-d). 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. The Chowan sub region of Region 1 had the largest percent of dam-obstructed streams at 38%. Table 9.1 tallies the number of dams, locks, and culverts in CHPP regions and sub regions.

TABLE 9.1. Number of documented obstructions (e.g., dams, locks, culverts) in coastal plains portion of CHPP regions based on Virginia Game and Inland Fisheries (1983 data), Collier and Odum (1989), Moser and Terra (1999), NCDOT (2003 data), NCDWR (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 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 DO levels (Fay et al. 1983a; Fay et al. 1983c). 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 which historically supported striped bass and other anadromous fish populations (DMF 2004).

The Roanoke River in CHPP Region 1 has been regulated by a series of dams since the 1950's. The upstream dams cause extended flooding during the growing season of riverine forested wetlands downstream – an area identified by The Nature Conservancy (TNC), the USFWS, 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 to enable riverine forested wetlands in the lower Roanoke to regenerate and continue supporting associated biota (e.g., river herring)(Pearsall et al. 2005). Of all the connected wetlands[16] in

[16] Includes riparian wetlands and adjoining non-riparian wetlands

CHPP region 1 (including both North Carolina and Virginia), approximately 6% (72,132 acres) were obstructed by impoundments (DMF 2009). The amount of downstream wetland area affected by impoundments is more difficult to determine. The data on impoundment locations was acquired from the North Carolina Division of Water Resources (DWR), U.S. Army Corp of Engineers (USACE), Collier and Odum (1989), and the NWI "impounded" modifier.

Concern for anadromous fish spawning resulted in a cooperative agreement between the USACE (the operators of Kerr Reservoir), the Wildlife Resources Commission (WRC), and the Division of Marine Fisheries (DMF) 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., 2010). 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. Adequate flow levels below the dams are critical during the spawning season. When flows are too low, anadromous species, such as hickory shad, are not able to migrate as far upstream, thereby limiting the total available spawning habitat (Harris and Hightower 2011b). The timing of adequate flows is also critical. Smith et al. (2015) recently found that Atlantic sturgeon spawn in the Roanoke River during the fall season. Thus, complete life history data on all anadromous fishes may be essential for properly managing discharge and flow levels in North Carolina rivers.

The USACE undertook a Neuse River Basin Study for which the WRC recommended the following flow guidelines for anadromous species, based on their spring striped bass and American shad survey work. The guidelines have not been put into use (B. Wynn, WRC, pers. com., 2010). Currently, the USACE's 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 is used. Since winter flows usually exceed 184 cfs, for practical purposes the target can be considered 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 600 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 (B. Wynn, WRC, pers. com., 2010). There is no federal project on the Tar River, thus 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.

Efforts have been made to restore spawning habitat for anadromous species by removing dams that are no longer necessary. The Quaker Neck Dam at river km 225 of the Neuse River near Goldsboro was impeding passage of striped bass and American shad to high quality spawning habitat above the dam (Beasley and Hightower 2000). In 1997, the Quaker Neck was removed, reclaiming 120 km of historic spawning habitat available upstream to the Milburnie Dam near Raleigh. In 2003 and 2004, three anadromous species (American shad, hickory shad, and striped bass) were confirmed to be spawning in the newly restored habitat upstream of the removed dam (Burdick and Hightower 2006). Restoration Systems, LLC has proposed to remove the Milburnie Dam as well, thereby opening the Neuse River to diadromous species from the mouth all the way to the Falls Lake dam. However, to date, the USACE has not issued the required Section 404 Permit (USACE 2014). In the Little River, a tributary of the Neuse River, 3 dams have been removed since 1998. The Cherry Hospital Dam at river km 3.7 was removed in 1998 (Raabe and Hightower 2014b). A partially removed dam still exists just upstream of the Cherry Hospital Dam at river km 7.9 (Raabe and Hightower 2014b). The Rains Mill Dam at river km 56.2 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. The 2005 removal of Lowell Mill Dam at river km 56.2 in Johnston County provided 210 newly opened river km of the Little River and its tributaries. Raabe and Hightower (2014b) estimated that 24-31% of American shad and 45-49% of gizzard shad migrated past the former Lowell Mill dam site in 2009 and 2010. The partially removed dam just upstream of the former Cherry Hospital Dam site appeared to impede the upstream migration of American shad and gizzard shad, blocking some individuals and delaying others (Raabe and Hightower 2014b). Weight loss of American shad during spawning migrations leads to low survival rates (Raabe and Hightower 2014a). Therefore, removing migration impediments could aid in restoration efforts (Raabe and Hightower 2014a).

The farthest downstream dam in the Roanoke River is the Roanoke Rapids dam at river km 221 (Harris and Hightower 2011a). Several dams are upstream of the Roanoke Rapids dam, including the Gaston and Kerr dams, which impound the reservoirs of the same names (Harris and Hightower 2011a). While anadromous species have access to the first 221 km of the Roanoke River, there has been much interest in providing access to historic spawning habitat above the Roanoke Rapids dam. One such approach would be a trap-and-transport program, where spawning adults are captured below dams and safely transported and released above the dam. Harris and Hightower (2011a) conducted a trap-and-transport experiment with American shad in the Roanoke River, and concluded that transporting spawning adults resulted in reduced effective fecundity and post-spawning survival (Harris and Hightower 2011a). Further density-dependent, deterministic, stage-based matrix models predicted that trap-and-transport programs would not benefit American shad populations unless effective fecundity and survival rates were optimal (Harris and Hightower 2012).

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 10 miles of the Deep River (Cape Fear subregion, Piedmont physiographic region). Field surveys in the years following indicated a return to lotic conditions and increases in aquatic species richness and abundance, including the documented presence of the federally endangered Cape Fear shiner in previously impounded waters (EEP 2007).

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 migration further upstream to reclaimed habitat (Bowman and Hightower 2001; Burdick and Hightower 2006; Hightower and Jackson 2000). 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 needed 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.

9.2.2. Fish Passages

Where obstructions cannot be removed, fish passages (e.g., 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). 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 is 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.

9.2.3. Locks

In the Cape Fear River, locking procedures were modified and a fishway was installed in 1997 to improve passage of anadromous fish. Previous to this modification, Lock and Dam 1 at river km 96 was known to block the upstream migration of anadromous fishes, including the endangered shortnose sturgeon (Moser and Ross 1995). The USACE was required to enhance fish passage around the lowermost dam (Lock and Dam # 1) as mitigation for deepening the Wilmington Harbor, resulting in sturgeon impacts, finishing in 2004. Removal of the dam was discussed but the City of Wilmington was opposed because their water intake is upstream of the dam. They were concerned that dam removal would lower water levels and increase salt content, impacting their water supply. Moser et al. (2000) investigated the success of American shad using Lock #1 and fish passages on the Cape Fear River with 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. Sonic telemetry tagging in 2008 and 2009 indicated that 35% of American shad and 23% of striped bass remained below the first lock and dam, while 35% of American shad and 25% of striped bass migrated past all three lock and dams (Smith and Hightower 2012).

In November 2012, USACE completed a rock arch ramp or fish passageway at Lock #1. This structure provides for fish passage over the dam without removal of the lock and dam structure. Completion of a fish passage at Lock and Dam #1 should greatly benefit habitat conditions for Atlantic and shortnose sturgeon, American shad, striped bass, American eel, blueback herring, and hickory shad stocks (USACE 2002). State and federal natural resource agencies, along with university and non-governmental organizations, have partnered to develop a *Cape Fear Basin Action Plan for Migratory Fish* (http://www.habitat.noaa.gov/protection/capefear/pdf/CapeFearActionPlan.pdf), as well as to undertake a two year study to evaluate the success in moving anadromous fish upstream to previously known spawning grounds. Since completion of the fishway, striped bass, American shad, and Atlantic sturgeon have been tagged as part of this study. Cape Fear River Watch, a non-profit advocacy organization, has several links to videos showing the movements of these tagged fish throughout the lower Cape Fear River system (http://www.capefearriverwatch.org/advocacy/fish-restoration).

Following the construction of the fish passageway at Lock and Dam #1, 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, Lock and Dam #2 should be a high priority, since striped bass, shortnose sturgeon, and Atlantic sturgeon have not recovered. In late 2015, the NC General Assembly approved $250,000 to be used towards the engineering and design of a fish passage at lock and dam 2. The funds require a 50/50 match of non-federal monies. Fundraising for the matching funds is currently under way by the Cape Fear River Partnership.

The Southeast Aquatic Resources Partnership (SARP) has developed a GIS tool to assist in the prioritization of dam removal in North Carolina (Hoenke 2014). This tool, and other efforts, should assist in removing or modifying the lowermost dams and locks in the Cape Fear, Neuse, Tar-Pamlico, and Chowan rivers, in order to increase spawning habitat available to anadromous fish species. Additionally, new dam construction should be avoided whenever possible or designed and sited to minimize impacts to anadromous fish use and to maintain appropriate flow conditions. Flow alterations that may significantly change the temporal and spatial features of inflow and circulation that are required for successful spawning of anadromous fish should be prohibited.

9.2.4. Culverts and road fill

Culverts, if improperly designed, primarily obstruct fish passage to upstream tributaries and riparian wetlands and can alter the hydrology of upstream wetlands. Based on analysis of Department of Environment and Natural Resources (DENR) and Department of Transportation (DOT) records, it has been estimated that the state loses on average about 500 acres of wetlands per year, mostly from road construction. Road construction over rivers, streams, or wetlands often involves blockage of a portion of the original stream channel and floodplain. Bridges may cross over 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 in 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 (Clay 1995; Mudre et al. 1985; 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, National Marine Fisheries Service (NMFS), USFWS, Division of Environment Management (DEM), and the DOT developed guidelines for minimizing the impact of bridge and culvert infrastructure on anadromous species. The guidelines pertain to “blue line” streams (streams that appear as a broken or solid blue line on a USGS topographic map) 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 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 Marine Fisheries Commission (MFC) supported replacement of all temporary stream crossing structures with those 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 (EEP).

According to DOT, there are numerous aging culverts and bridges in need of replacement. Because of this, DOT formed an interagency permit group to discuss streamlining the permit process for bridge and culvert replacement to reduce permit process time and expense. Economics discourages 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. For example, as part of the proposed realignment of U.S. 70 from Radio Island to near Olga Road (SR 1429) in Beaufort, Carteret County, the culverts on Turner Street are being removed with approximately 585 ft of causeway and associated fill. While the culverts (four-barrel 95 in by 67 in corrugated metal pipe arch) are considered to be hydraulically adequate, and mitigation credit is not likely to be provided simple for removing the causeway, high quality wetlands are present adjacent to Turner Street in the vicinity of the stream crossing. The DOT will provide on-site mitigation for Coastal Wetland impacts associated with the project and to bank any additional mitigation credits for future DOT projects, with overall environmental benefits. While this relatively large project allowed for the replacement of culverts in one stream, other culverts may not qualify for mitigation credits. 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 Fund (EDF) produced a report using a GIS-based tool to identify the most valuable spawning and nursery habitats for river herring in coastal watersheds (McNaught et al. 2010). 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 (Johnson et al. 1977; Street et al. 1975; Winslow et al. 1985; Winslow and Rawls 1992; Winslow et al. 1983);
    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 was 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.

Strategic Habitat Area assessment in CHPP Region 1 (Albemarle Sound and tributaries), a larger area than the EDF 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[17] (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 increase 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 anadromous fish spawning areas (AFSAs) are shown on Maps 9.1a-d and inventoried in Table 9.1.

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., 2010). Information collected included; culvert type, material, dimensions, water depth, distance between water level and top/bottom of culvert, water level and waterbody width. The results of the EDF study and DMF field surveys should be used to determine priorities for culvert removal (L. Batt, American Rivers, pers. com.).

9.2.5. Power Plants

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 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 2002). Once entrained, organisms can be subjected to physical,

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

thermal, and toxicity stresses. Studies have shown that very large numbers of fish larvae can be entrained through a power plant and that mortality is high, but varies by species and life stage.

Entrainment survival studies found that mortality rates ranged from 2% for naked goby larvae to 97% for bay anchovy (ASMFC 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 2002). Devices including electrical screens, air bubble curtains, high-frequency sound, chemicals, and lights have been developed as a "warning" system to deter fish from intake systems (Greene et al. 2009; Martin et al. 1994). 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 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 AFSAs.

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://water.epa.gov/lawsregs/lawsguidance/cwa/316b/rules.cfm, March 2015). 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 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 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 2004).

9.3. Flow Alterations

9.3.1. 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 followed by public water supply, irrigation, industrial, and aquaculture withdrawals in the CHPP regions. The estimated surface or groundwater use by CHPP counties are listed in Table 9.2 (USGS Circular 1405, Estimated Use of Water in the United States 2010, http://pubs.usgs.gov/circ/1405/).

Some amount of water withdrawn from surface and ground water is tracked through water withdrawal registrations. The Registration of Water Withdrawals and Transfers law (G.S.143-215.22H) requires users who withdraw predetermined amounts of ground and surface water in North Carolina to register annually with the Division of Water Resources (if non-agricultural) or with the Department of Agriculture and Consumer Services (if agricultural) (Table 9.3). 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. Current compliance with water withdrawal registrations is low; the creation of water withdrawal permits may help assess and monitor the status of the State's water use.

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 9.3).

Rules also require reductions in withdrawals from the Pee Dee, 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. CCPCUA rules require a 75% reduction of the Black Creek and Upper Cape Fear aquifers by 2018.

TABLE 9.2. 2010 estimate of water use by county in millions of gallons per day (mgd) (Source: USGS Circular 1405).

County	Total groundwater withdrawals (fresh+saline) MGD	Total surface-water withdrawals (fresh+saline) MGD	Total withdrawals MGD
Beaufort County	88.87	1.01	89.88
Bertie County	15.08	5.73	20.81
Bladen County	11.26	81.89	93.15
Brunswick County	3.98	1379.97	1383.95
Camden County	1.12	5.01	6.13
Carteret County	9.84	0.81	10.65
Chowan County	1.77	5.26	7.03
Columbus County	6.65	36.41	43.06
Craven County	21.74	15.60	37.34
Cumberland County	11.95	33.73	45.68
Currituck County	4.63	1.01	5.64
Dare County	8.63	0.10	8.73
Duplin County	25.84	12.65	38.49
Edgecombe County	7.39	7.88	15.27
Gates County	2.14	0.71	2.85
Greene County	5.31	2.31	7.62
Halifax County	1.86	29.84	31.70
Harnett County	5.02	22.66	27.68
Hertford County	8.16	2.50	10.66
Hoke County	5.26	20.97	26.23
Hyde County	1.31	0.50	1.81
Johnston County	8.36	21.31	29.67
Jones County	3.09	0.59	3.68
Lenoir County	8.52	21.12	29.64
Martin County	3.38	60.19	63.57
Nash County	4.59	16.01	20.60
New Hanover County	15.86	26.51	42.37
Northampton County	5.02	16.41	21.43
Onslow County	30.35	1.92	32.27
Pamlico County	3.76	0.00	3.76
Pasquotank County	4.79	0.52	5.31
Pender County	6.83	5.76	12.59
Perquimans County	2.47	0.38	2.85
Pitt County	13.25	15.57	28.82
Robeson County	22.95	14.20	37.15
Sampson County	21.24	16.63	37.87
Tyrrell County	0.56	0.03	0.59
Washington County	4.73	1.07	5.80
Wayne County	14.11	20.20	34.31
Wilson County	4.18	21.79	25.97

TABLE 9.3. 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 9.4). Permitted withdrawals include community water systems, thermoelectric generation, agricultural operations, golf courses, quarries, and non-electric generating industrial operations. The permitted volumes 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 9.4). The Cape Fear and Roanoke basins have the largest quantities 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 9.4 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 9.5). The additional sources add 59 mgd to the total quantity of surface water withdrawn in the Cape Fear, Roanoke (North Carolina portion), Neuse, and Tar-Pamlico subregions. However, the reported withdrawals represent some degree of under-reporting.

Withdrawal of groundwater from wells can also reduce river flows by reducing subsurface flow into adjacent rivers (Bair 1995; DMF 2004). Removal of shallow groundwater can be particularly detrimental during low flow periods when subsurface flow is more critical to maintaining minimal sustained low flows (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 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 declines in groundwater levels ranged between 3 ft in Greene County and 45 ft in Onslow County. Groundwater levels declined 27 ft 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., 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.

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 forecast 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.

9.3.2. Channelization and Ditching

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 cross-section and flow capacity, reducing the frequency of overbank flow events that allow wetland filtration and fish access to the riparian wetlands (DMF 2000a). Consequently, loading and movement of sediment and other pollutants are often greater in channelized streams than in natural streams (EPA 1993; White 1996). The banks created by disposal of spoil along the shoreline further prevent fish from entering the adjacent.

The impacts of channelization primarily affects smaller species and life stages (e.g., larval river herring) using wetlands and shallow stream margins (O'Rear 1983) and 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 (DMF 2000b; Frankensteen 1976). 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 (Hawkins 1980; Schoof 1980; Tarplee et al. 1971).

Channelized streams have 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 2000a). 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 contributes to accelerating water velocity. Excessive woody debris can hamper upstream fish migration and downstream water conveyance, suggesting a need for threshold criteria.

Most streams in eastern North Carolina have been channelized to some extent (North Carolina Sea Grant 1997), with a long state history of stream channelization and drainage. However, documentation of historic drainage activities has not differentiated between channelized streams and artificial drainage channels. While no new channelization projects have occurred since the 1970’s, maintenance of existing channels in agricultural drainage districts with activities such as de-snagging and installing water control structures are common. 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 have re-naturalized and are now supporting river herring migration (S. Winslow, DMF, pers. com., 2010). So far, DMF has successfully opposed the maintenance of re-naturalized channels. Channelization regulations could be modified to discourage or prevent maintenance of previously non-navigable and re-naturalized channels in Anadromous Fish Spawning Areas and Primary Nursery Areas.

9.3.3. Mines

In coastal North Carolina, there are surface mines, 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., 2010). 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., 2010). Many mine sites are located in the vicinity of rivers and estuaries (http://www.dlr.enr.state.nc.us/pages/permittedmines.html, *April 2015*). The discharge can contain sediment, nutrients, and heavy metals. More resources are needed to assess monitoring compliance of mining activities to be able to document mining impacts to the environment.

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 for crushed stone mining, and 1 for phosphate mining. The number of mines in CAMA counties has changed very little since 2000. The phosphate mining permit, which includes 12,140 acres along and within the Pamlico River in Beaufort County, is now owned by PCS Phosphate (a subsidiary of Potash Corp.). The phosphate mine is the largest wastewater discharger among all coastal North Carolina mining operations. In addition to substantial stream and wetland impacts due to excavation before 1992, the mine was discharging 50-60 million gpd 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).

9.3.4. Dewatering

An emerging issue since the 2005 CHPP is the effect of dewatering in estuarine waters. Dewatering is often done in association with mining to temporarily lower the water table by discharging fresh water. Where the water is discharged to shellfishing (SA) waters, there is concern regarding the effect on salinity. Excessive decrease or rapid change in salinity can be detrimental to juvenile fish and shellfish.

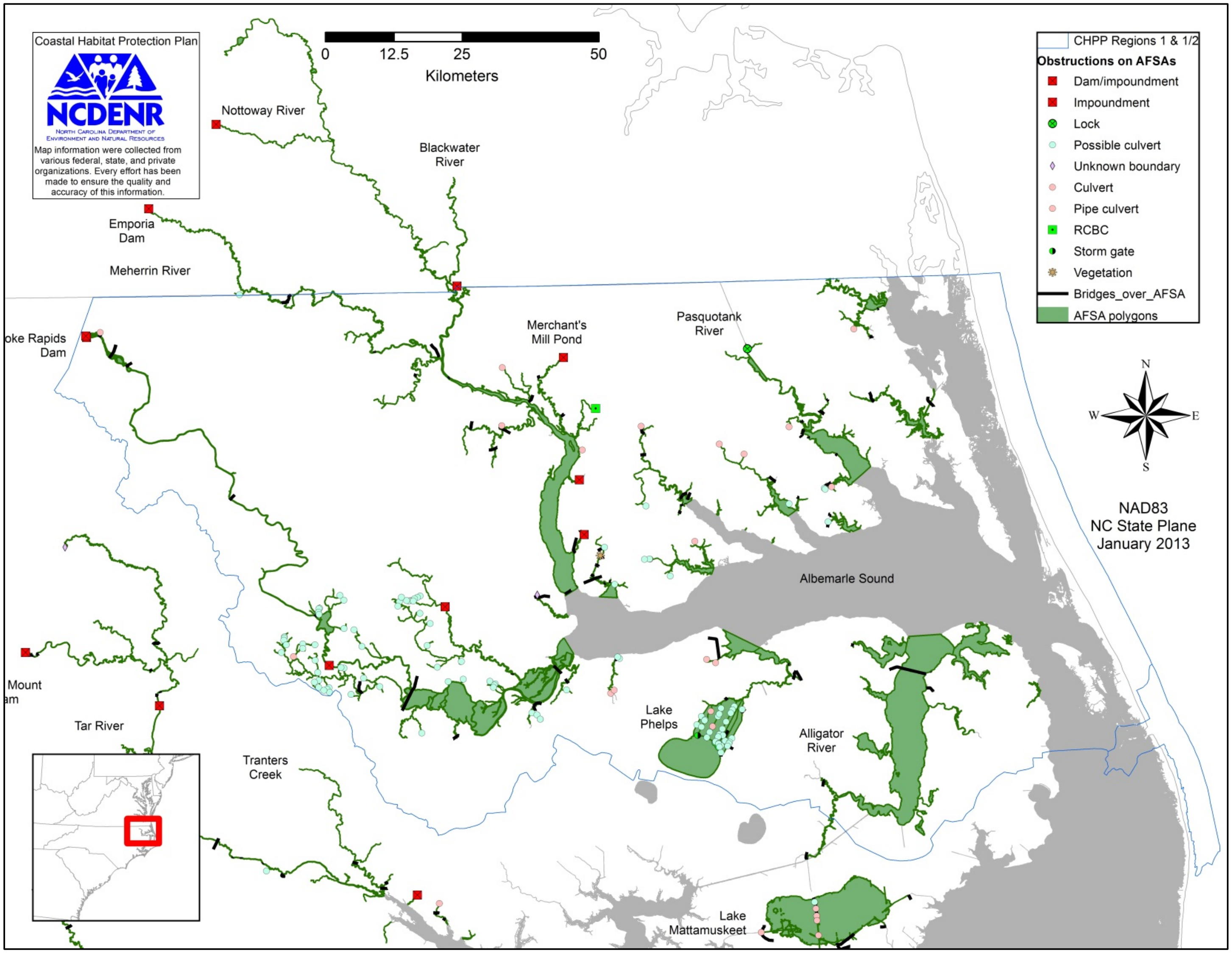
Dewatering is also required when utilizing a type of wastewater treatment system known as rapid infiltration. In this centralized wastewater treatment system, treated effluent is discharged into a storage pond. Wells are installed around the pond for dewatering, lowering water table levels to allow room for the treated effluent to filter. Not only do large amounts of freshwater discharge to adjacent streams, but over time, the groundwater can be contaminated with the effluent, and be discharged to the stream as freshwater (L. Willis, DWQ, pers. com., 2010). This technology is being increasingly used.

9.3.5. Drought

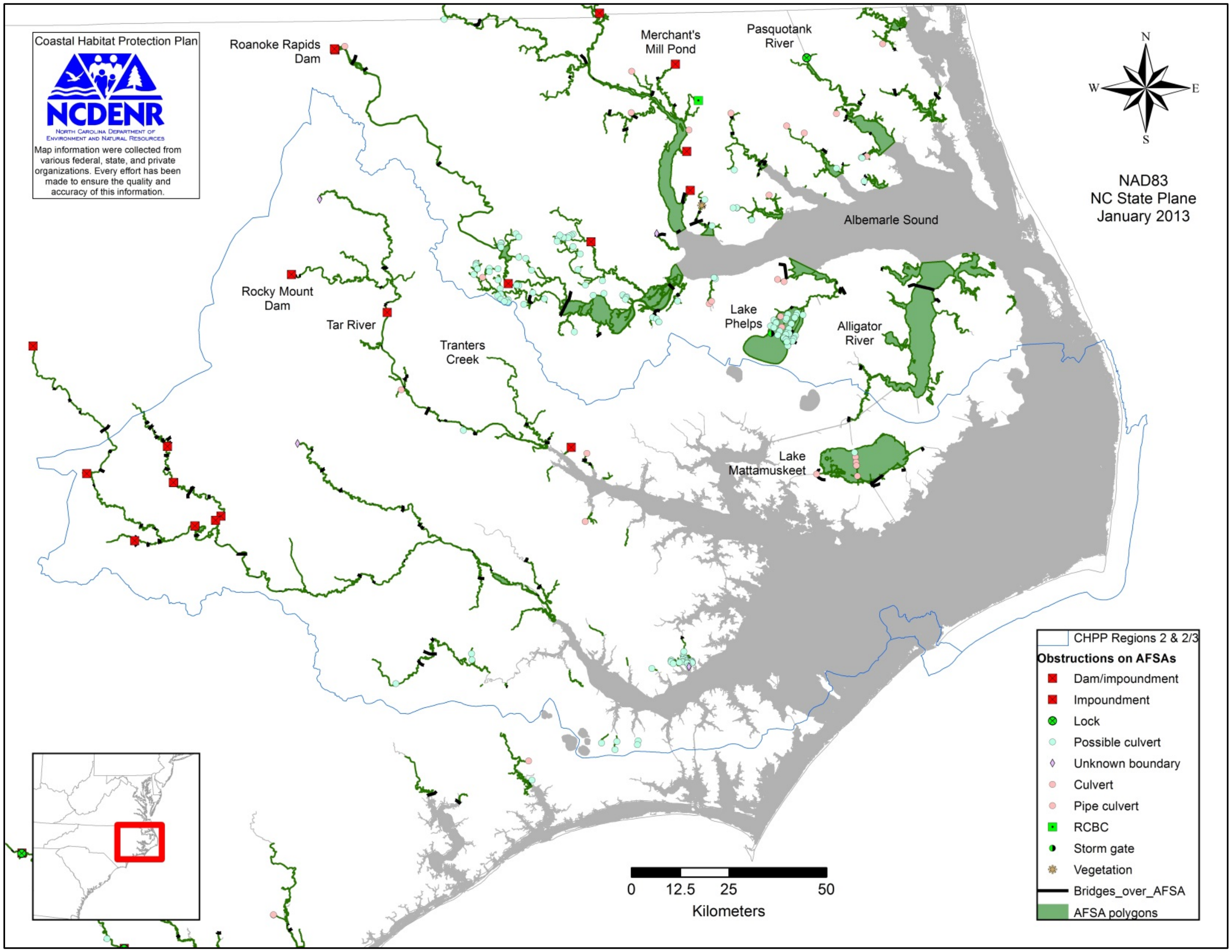
The current frequency of droughts and forecast increases with climate change could also exacerbate water supply issues (NWF2008). Major droughts occurred during 2000-2002 and 2007-2008. The drought of 2007-2008 was the worst in North Carolina since recordkeeping began on the subject in 1895. The drought 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.

9.4. Hydrologic Alterations Summary

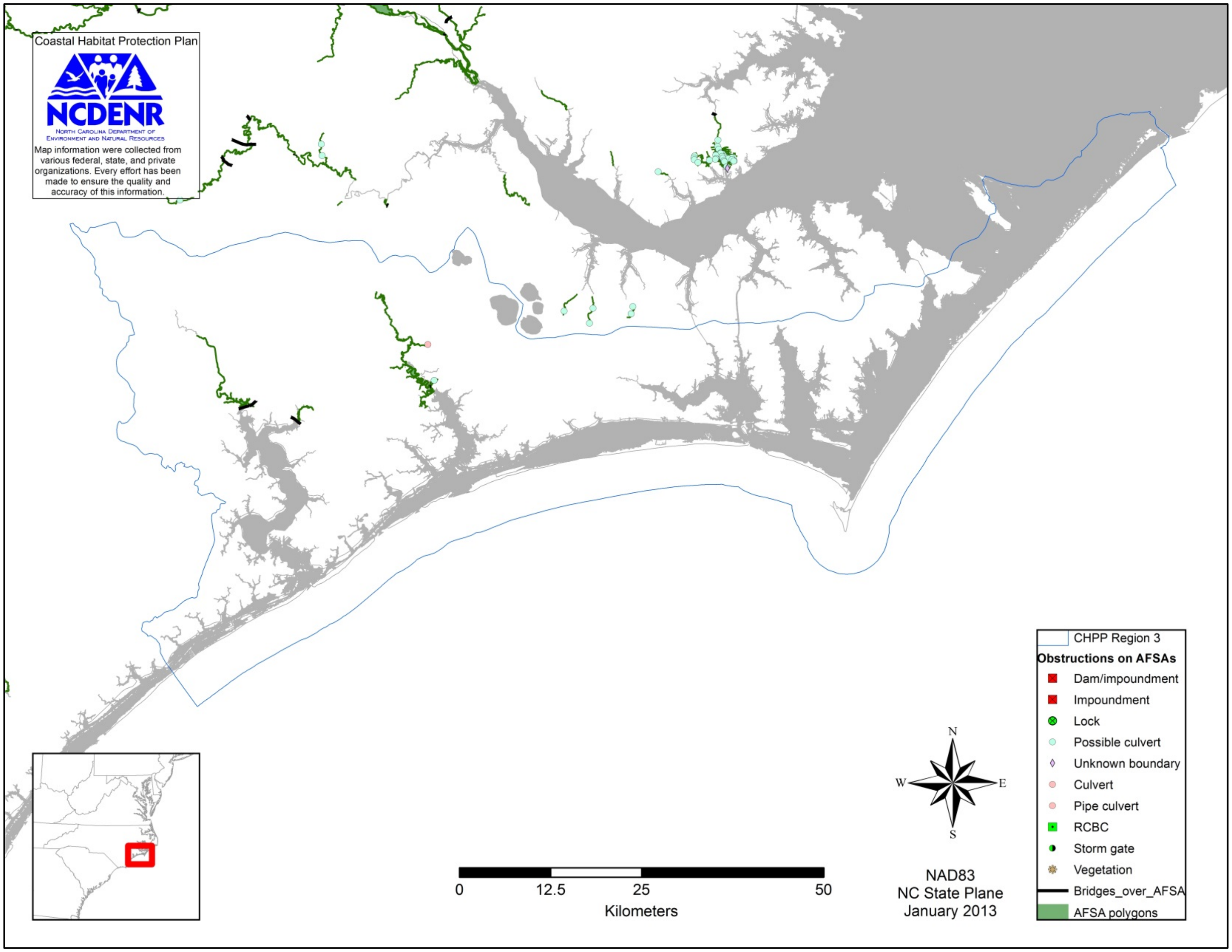
Flow alteration can negatively impact resident and diadromous species by impeding or blocking migrations, reducing the quality and availability of habitat, and by physically injuring individuals. Protecting the quality of instream habitats and reversing the trend of fragmentation will require continued efforts to understand the impacts of alterations and how to prioritize restoration. Current efforts to protect flow regimes include the removal of dams, improving fish passage in the remaining Cape Fear River lock and dams, prioritizing culvert design and replacement, and research into the biological response to altered flow regimes.



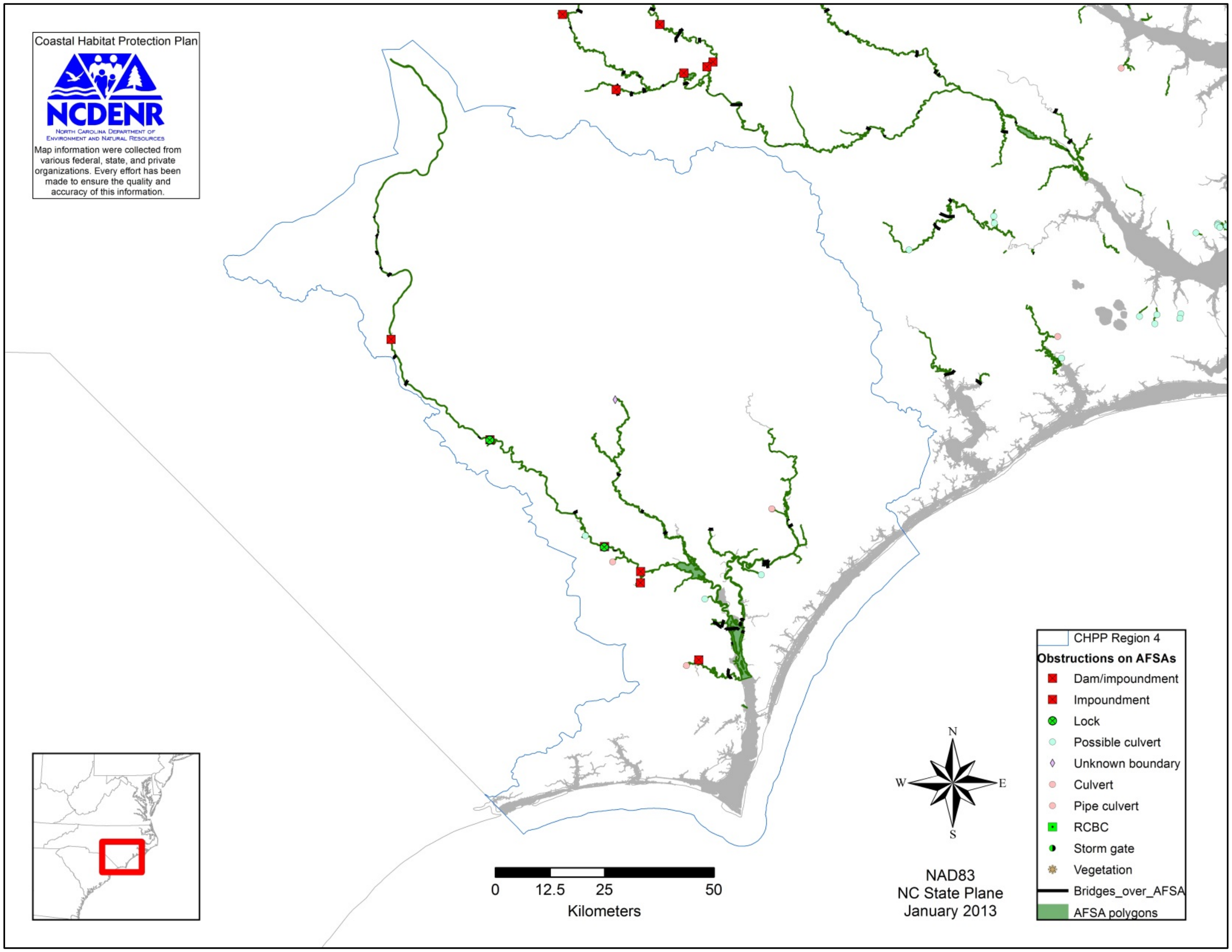
MAP 9.1A. Documented water control structures in the North Carolina coastal plains (northern regions) relative to Anadromous Fish Spawning areas (AFSAs). Data from Virginia Game and Inland Fisheries (1983 data), Colier and Odum (1989), Moser and Terra (1999), Department of Transportation (2003 data), Division of Water Resources (2003 data), and USACE obstructions inventory (2009 data).



MAP 9.1B. 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), Colier 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 9.1C. 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), Colier 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 9.1D. 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), Colier and Odum (1989), Moser and Terra (1999), Department of Transportation (2003 data), Division of Water Resources (2003 data), and USACE obstructions inventory (2009 data).

CHAPTER 10. WATER QUALITY IMPACTS

10.1. Land use cover/change

While every ecosystem is affected by changes in land use and water quality, of the six habitats in the CHPP, those most affected by water quality degradation are: Water Column, Shell Bottom, and SAV.

Water Column: Changes in chemistry causing degradation of water quality originate from defined points such as industrial or wastewater discharges (point sources) and from land-use patterns such as sheet flow or drainage features (nonpoint sources). Primary pollutants are oxygen-consuming wastes, nutrients, suspended sediment, and toxins (e.g., chlorine, ammonia, metals).

Shell Bottom: Nutrient loading from urban, agricultural, and industrial development can impair shell bottom habitat by stimulating phytoplankton blooms, causing oxygen depletion. Excessive turbidity and sedimentation can negatively affect oyster health and viability. Human population growth and impervious surfaces contribute to fecal coliform bacteria and associated pollutants in surface waters (Maiolo and Tschetter 1981; Mallin 2009; Mallin et al. 2001b), leading to closures of shellfish waters.

SAV: Most SAV loss is attributed to nutrient enrichment and sedimentation reducing light penetration to the leaf (Dennison et al. 1993; Durako 1994; Funderburk et al. 1991; Goldsborough and Kemp 1988; Kenworthy and Haunert 1991; Orth et al. 2006; Orth et al. 1986; Stevenson et al. 1993; Steward and Green 2007; Twilley and Davis. 1985), reducing water clarity, causing algal blooms, increasing epiphytic coverage, covering blades by drift algae, reducing DO concentrations, increasing concentrations of hydrogen sulfide resulting in toxicity (Dennison et al. 1993; Fonseca et al. 1998).

Changes in land use and vegetative cover can alter water quality conditions. Excessive inputs of nutrients, bacteria, sediment, toxins, or biochemical agents can lead to habitat degradation, including algal blooms, hypoxia, fish kills, and fish deformation. Low oxygen can kill shellfish; suspended sediment and nutrients impair light penetration, deterring SAV survival; and toxins in the water column can settle out and accumulate in soft bottom habitat. The impacts depend on the location of specific uses in the context of watershed hydrology, which is affected by land surface characteristics (e.g., slope, elevation, soil type) and local weather conditions (e.g., prevailing winds, precipitation, evapotranspiration).

Figures 10.1, A-F, provide an overview of land cover changes between 2001 and 2011 in the CHPP subregions. Developed areas are characterized by a high percentage (30 percent or greater) of constructed materials. Grassland, forest, and shrub land include upland habitat, whereas wetlands include periodically saturated areas with more than 20% vegetative cover.

Development intensity within the CHPP area decreases northward, with the highest percentage near the southern estuaries. Region 1 had the largest change in high intensity development from 2001-2011. Pollutants from nonpoint sources are delivered to surface waters via atmospheric deposition (including air-borne particles, gases, and precipitation), surface drainage, and groundwater seepage. Sources of atmospheric pollutants include vehicle exhaust, industrial emissions, and animal operations (USGS 2003; Walker et al. 2000). A significant portion of nutrient pollution is attributable to atmospheric sources.

Septic systems discharging near the water are sources of nonpoint pollution (Cahoon et al. 2003) when failing during heavy rain events, due to improper siting or construction, or improper maintenance (North Carolina Ocean Resources Task Force 1995). The Shellfish Sanitation & Recreational Water Quality Section of DMF documents failing septic systems in estuarine waters. Malfunctioning wastewater systems as defined in T15A NCAC 18A .1961(a) are identified and referred to local health departments for corrective action. Historically, the percentage of onsite wastewater issues average 1% to 4% of inspections made (S. Jenkins, DMF, pers. com. 2014).

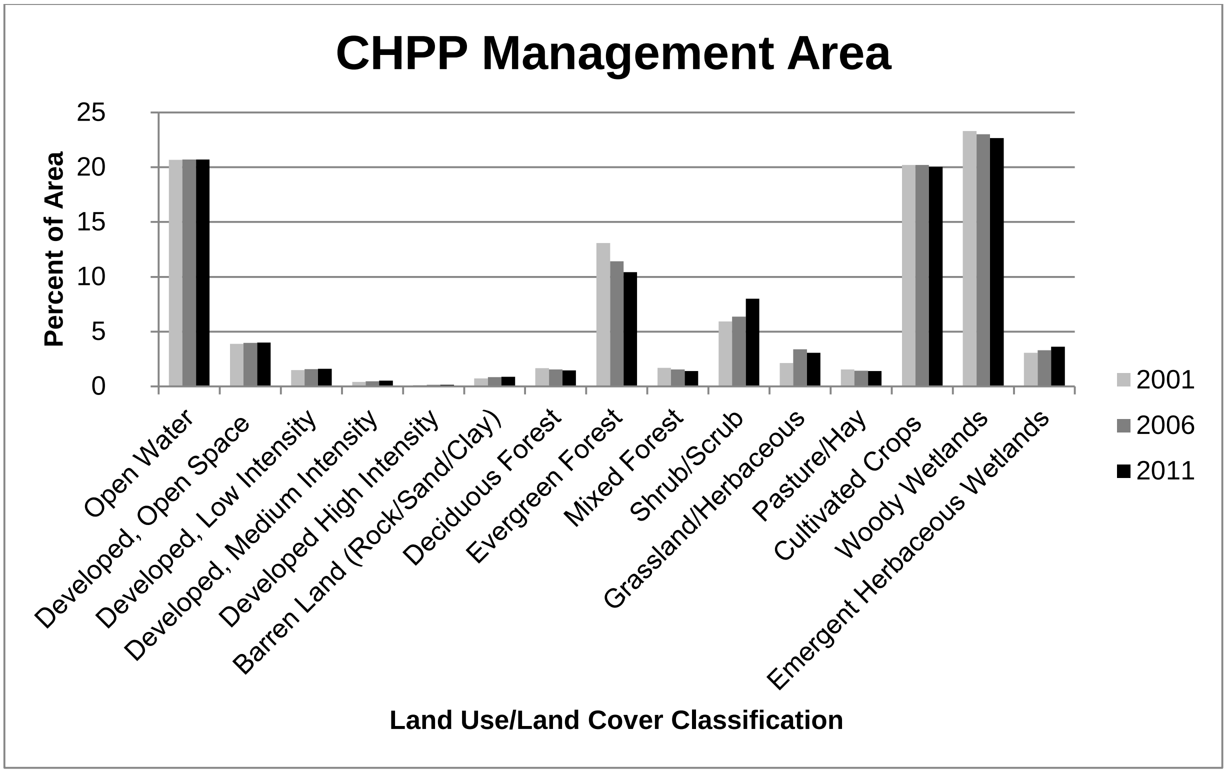


FIGURE 10.1A. Percent land use/land cover classifications within CHPP Management Area based on 2001, 2006, and 2011 National Land Cover Database (NLCD).

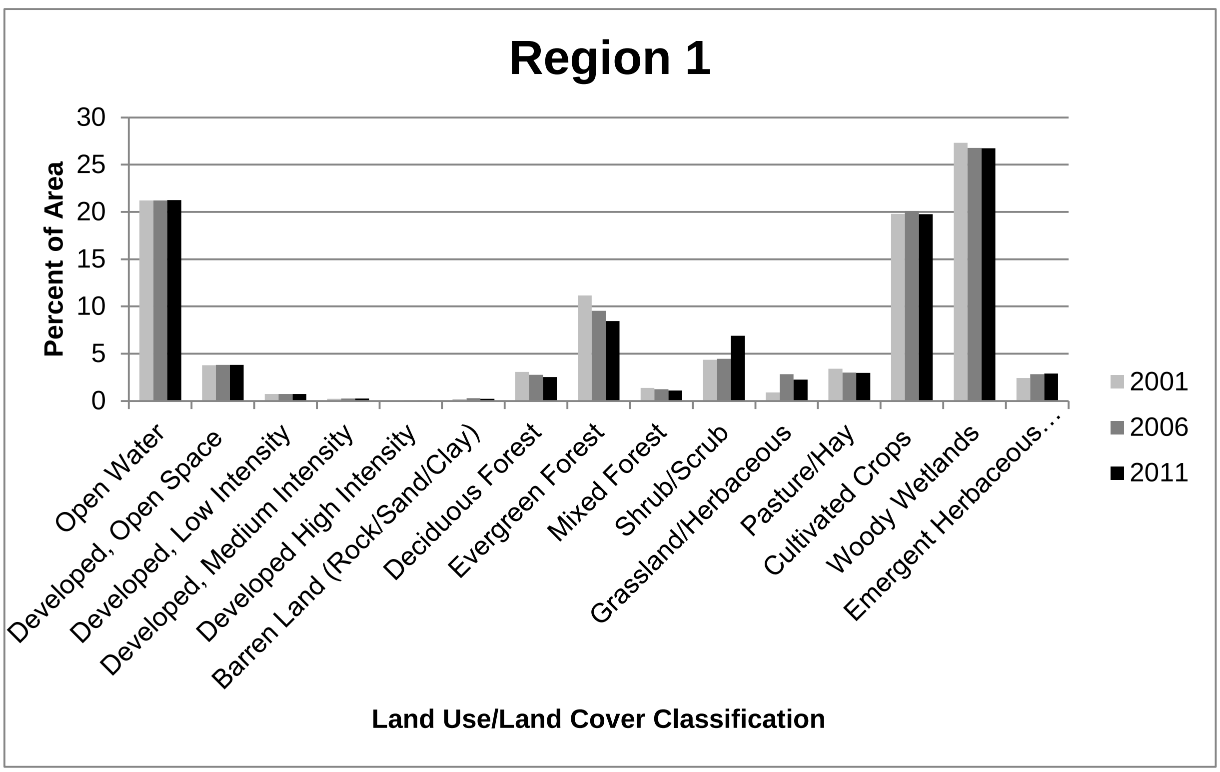


FIGURE 10.1B. Percent land use/land cover classifications within CHPP Region 1 based on 2001, 2006, and 2011 NLCD.

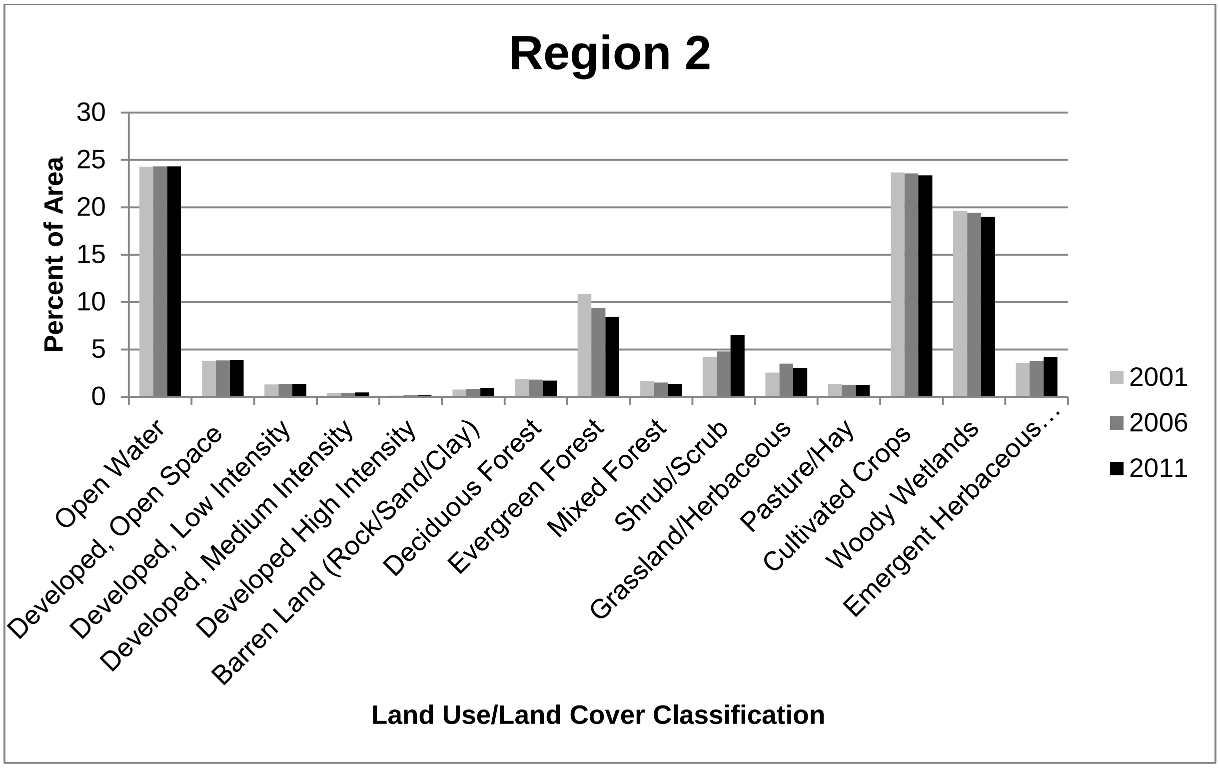


FIGURE 10.1C. Percent land use/land cover classifications within CHPP Region 2 based on 2001, 2006, and 2011 NLCD.

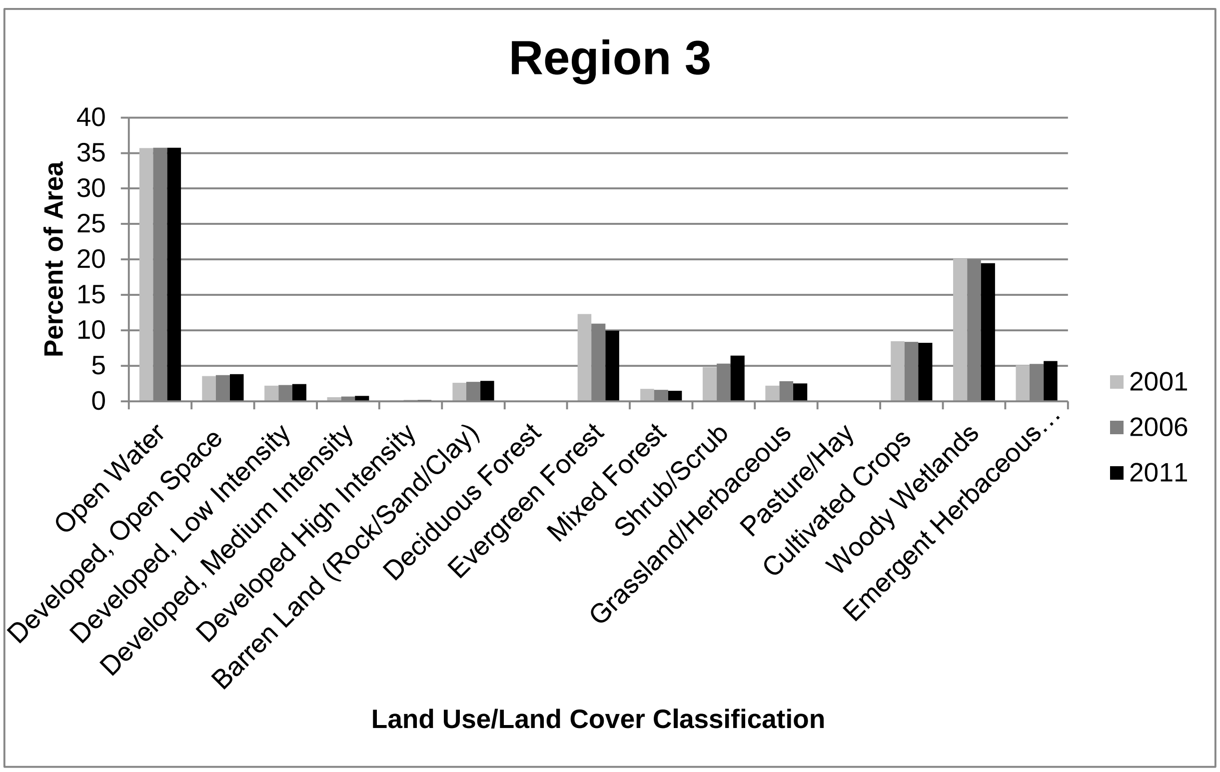


FIGURE 10.1D. Percent land use/land cover classifications within CHPP Region 3 based on 2001, 2006, and 2011 NLCD.

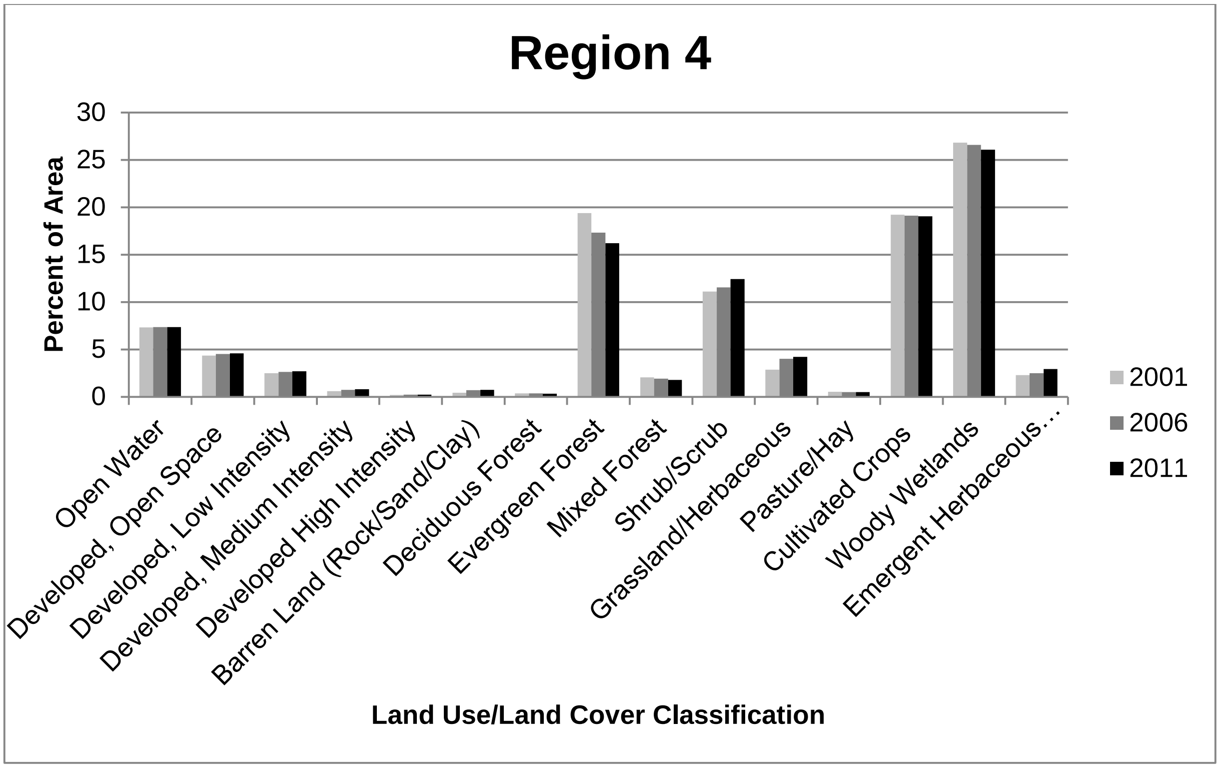


FIGURE 10.1E Percent land use/land cover classifications within CHPP Region 4 based on 2001, 2006, and 2011 NLCD.

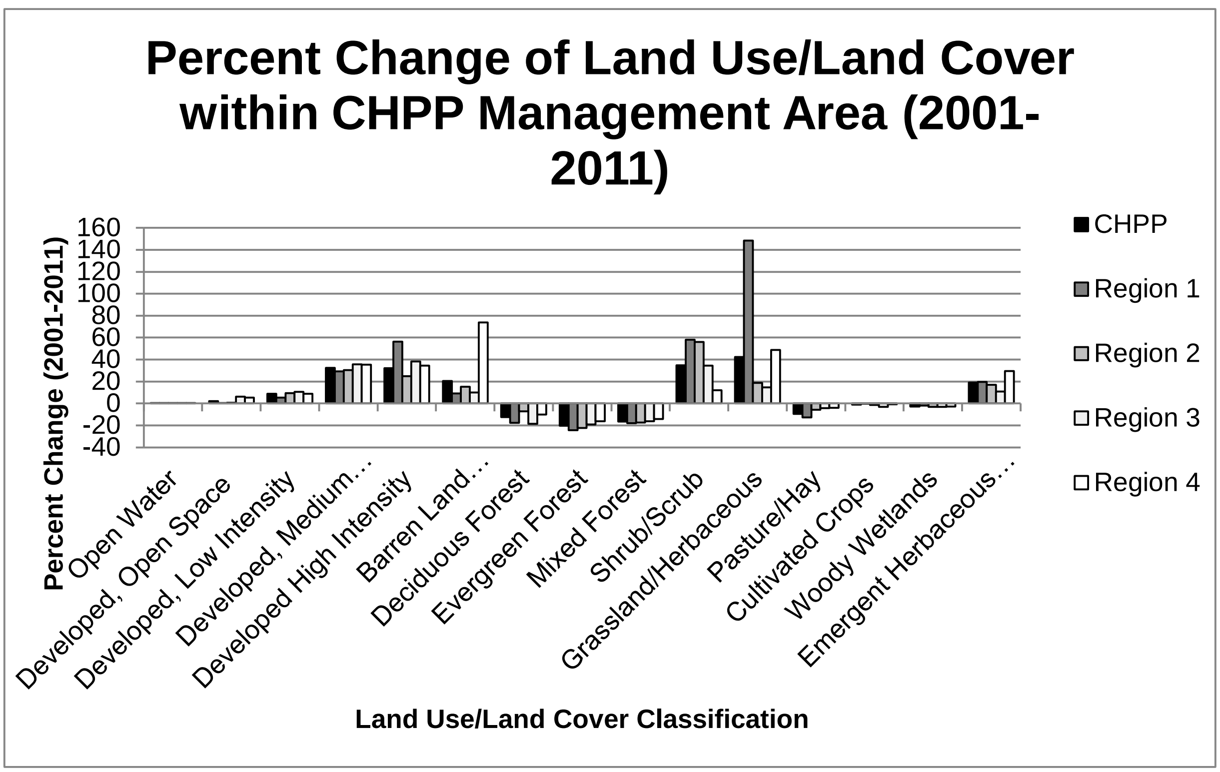


FIGURE 10.1F. Percent land use/cover classification change within CHPP MGT Area based on 2001, 2006, and 2011 NLCD.

Ditches and vegetated swales constructed for surface drainage (Map 2.7) can degrade water quality and alter flow conditions by increasing stormwater movement and causing pulses of low salinity stormwater, sediment, nutrients, chemicals, and/or bacteria (Cahoon et al. 2006; Heath 1975; Jones and Sholar 1981; Maxted et al. 1997; Serafy et al. 1997; White et al. 2000). On the Pamlico-Albemarle peninsula, ditch networks through peatlands have replaced intermittent streams that were historically important to spawning river herring (M. Wicker, USFWS, pers. com. 2010). Ditches and canals around Lake Phelps have replaced seasonal overflow channels that once concentrated river herring passage into the lake. Restoring hydrology to drained peatlands can prevent carbon, nitrogen, mercury and other pollution sources from entering coastal waters or the atmosphere.

10.1.1. Land use trends

Much of the land around the Albemarle-Pamlico Estuarine System has been drained to accommodate existing agriculture and silviculture. It is estimated that over two million acres have been drained and developed for agriculture and silviculture along the North Carolina coast. Within each square mile of agricultural land in coastal North Carolina, there are estimated to be more than 20 miles of ditches and canals (Daniel 1978; Heath 1975) (Map 2.7). However, North Carolina agriculture and silviculture lands are currently being replaced with developed uses (ENCRPC 2007). Agricultural lands include cropland, pastureland, animal operations, and land-based aquaculture. According to the USDA census, farmland in North Carolina declined from ~9.0 to ~8.4 million acres from 2002-2012. Swine numbers in swine operations dropped from ~10 to ~8 million from 2002-2012; poultry production increased steadily.

Ditching and drainage is associated with residential development and infrastructure. Many roads on the Albemarle-Pamlico Peninsula were constructed atop spoil piles between canals to prevent flooding. In urban coastal areas, ditches are constructed along subdivision streets, draining to coastal waters. These drainage features often connect to headwaters, altering the natural hydrology of downstream systems. Unlike agriculture and silviculture, developed land uses have been steadily increasing. Table 10.1 shows the percent of urban/built-upon and transportation classifications in 12-digit USGS hydrologic units (HUs) in 1997 and 2012. Over the past 15 years, the percent increase in urban built-up/transportation classifications have ranged from 28.2–137.7%.

10.1.2. Stormwater Runoff

A means of assessing changes in developed land use is through the distribution of stormwater permits issued from 2001-2013 (Table 10.2). A permit is required for all developments disturbing more than one acre of land, or requiring a CAMA Major Permit. The number of stormwater permits issued in CAMA counties increased from >500/year from 2001 through 2004, to ~800/year from 2005 through 2007. From that point, issuance of new permits began to decline, a trend that has continued through 2013.

Ocean outfalls discharge stormwater or cooling water. There are 19 ocean outfalls along the coast; eight stormwater outfalls are in Dare County, six are in Kure Beach, five are in Emerald Isle, (J.D. Potts, DMF, pers. com. 2015). One cooling water discharge is in Brunswick County (Duke Energy). Rules of the EMC prohibit discharge of wastes to open waters of the ocean unless permitted by a rule of the EMC.

10.1.3. Studies comparing land use and water quality

Studies indicate that degradation of water quality and aquatic habitat occurs when impervious cover (e.g., roads, roofs, parking lots) within a watershed reaches 10-20% (Arnolds and Gibbons 1996; Barnes et al. 2001; Beach 2002; Mallin et al. 2000b; Schueler 1994). Significant water quality and habitat degradation occurs when impervious surface exceeds 20%. As vegetated areas are replaced with built upon areas, the ability of the land to absorb and filter runoff is reduced; flooding, bank erosion, and runoff subsequently increase. More impervious surface increases peak runoff in streams and reduces groundwater input for stream base-flow. A study by (Mallin 2009) compared water quality in three oligohaline tidal creeks of varying impervious coverage designated as urban, suburban, and agricultural. 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.

TABLE 10.1 Percentage urban/built-upon and transportation classifications in 12-digit USGS HUs in 1997 and 2012.

USGS hydrologic unit	% change 1982-1997	% Urban/built-up and rural transportation[1] 1997 (measured)	2012 (predicted)	% change (1997-2012)
Upper Neuse	91.8	24.8	47.6	91.9
Haw	50.21	23.8	35.7	50.0
Carolina Coastal-Sampit	131.58	20.5	47.5	131.7
Upper Cape Fear	78.71	15.1	27.0	78.8
Deep	47.14	13.2	19.4	47.0
Upper Dan	87.04	12.7	23.7	86.6
New	33.23	11.9	15.8	32.8
Lower Tar	60.82	11.8	19.0	61.0
Upper Tar	81.03	10.7	19.3	80.4
Roanoke Rapids	77.55	10.3	18.2	76.7
Contentnea	51.27	9.5	14.4	51.6
Lower Cape Fear	66.5	9.4	15.7	67.0
Middle Neuse	43.03	8.9	12.7	42.7
Bogue-Core Sounds	89.58	6.8	13.0	91.2
Northeast Cape Fear	54.38	6.6	10.2	54.5
Middle Roanoke	139.22	6.2	14.7	137.1
Lower Dan	92.36	5.8	11.2	93.1
Lower Roanoke	41.02	5.8	8.1	39.7
Black	62.57	5.6	9.2	64.3
Lower Neuse	36.31	5.6	7.6	35.7
Pamlico	30.58	5.3	6.9	30.2
Meherrin	32.77	4.7	6.3	34.0
Albemarle	62.4	4.1	6.6	61.0
Chowan	33.33	3.9	5.2	33.3
Fishing	28.00	3.9	5.0	28.2
Pamlico Sound	83.72	1.3	2.4	84.6

By developing a statistical model that integrates land use/land cover and water quality data in the Neuse River, Rothenberger et al. (2009a) found that areas with high concentrations of wastewater treatment plants (WWTPs) or confined swine feed operations (CSFOs) significantly affected nutrient levels in the watershed. Nutrient type and concentration varied by season and land use; total phosphorus concentrations were significantly higher during summer in subbasins with high densities of WWTPs and CSFOs; nitrate was significantly higher during the winter season in subbasins with high numbers of WWTPs; and organic nitrogen concentrations were higher in subbasins 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 phosphorus to the Neuse.

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). Mallin (1998); Mallin et al. (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. With human and domestic animal populations supplying sources for fecal bacteria, the impervious surface and associated runoff provide the conveyance of microbes into coastal waters. This and similar studies concluded that fecal bacteria contamination is an important polluting factor once impervious surface coverage reaches > 10% of the watershed (Holland et al. 2004; Mallin et al. 2001b).

TABLE 10.2. Stormwater permits by CAMA county and CHPP region (Bradley Bennett, DWR November, 2014). Includes newly issued permits, renewals, modifications, 2001-2013.

CHPP Region	New Permits	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1	Bertie	4	2	4	7	18	8	10	5	9	5	8	7	5
1	Camden	11	6	6	10	6	7	6	4	10	5	4	1	3
1	Chowan	6	4	4	7	9	8	10	12	9	3	3	6	4
1	Currituck	25	19	25	34	34	32	34	19	18	13	15	13	24
1	Gates	1	1	2	0	1	2	2	3	2	0	3	3	1
1	Hertford	4	4	1	7	9	7	7	5	6	4	12	8	2
1	Pasquotank	17	18	24	18	38	27	25	15	22	14	15	7	5
1	Perquimans	7	7	4	11	19	9	15	3	6	5	8	5	14
1	Tyrrell	5	3	3	4	2	3	3	3	7	7	3	2	2
1	Washington	6	8	3	4	4	0	7	5	2	8	3	2	2
1.2	Dare	53	52	55	49	43	29	42	26	26	16	28	16	19
2	Beaufort	30	26	28	16	37	28	49	26	39	29	27	34	25
2	Craven	48	47	34	29	72	74	63	57	36	26	21	27	25
2	Hyde	6	9	5	3	11	9	8	6	8	5	6	6	7
2	Pamlico	10	6	14	7	19	21	31	22	12	13	10	6	9
3	Carteret	50	50	50	68	51	61	63	70	53	36	39	29	19
3	Onslow	70	75	91	83	85	131	124	126	86	100	115	97	79
4	Brunswick	78	73	91	100	116	155	166	95	60	60	48	34	45
4	New Hanover	109	107	111	123	115	153	153	110	78	53	53	53	67
4	Pender	25	35	35	35	55	44	40	28	27	21	24	23	28
Totals	New Permits	565	552	590	615	744	808	858	640	516	423	445	379	385
	Renewals	0	0	3	0	2	38	48	102	203	47	66	44	49
	Modifications	81	75	93	88	112	168	209	318	229	293	294	358	320
	Total Actions	**646**	**627**	**686**	**703**	**858**	**1014**	**1115**	**1060**	**948**	**763**	**805**	**781**	**754**

Sanitary surveys conducted by DMF implicate nonpoint stormwater runoff as the primary cause of microbial contamination in the large majority of shellfishing areas sampled (S. Jenkins, DMF, pers. com. 2015). Fecal coliform concentration tends to be highest upstream and in shallow creeks and water bodies, which are also areas with high concentrations of shell bottom habitat. From 1994 to 2006, waters permanently closed to shellfish harvest ranged from 365,162 to 442,106 acres. After 2006, the program began classifying shellfish closures differently to allow for some flexibility in shellfish harvest openings. Approved waters were those open to shellfish harvest. Conditionally approved open areas were normally open, but could close on a temporary basis if rainfall thresholds were exceeded. Conditionally approved closed areas were normally closed but could be open by proclamation when dry weather resulted in sufficient water quality. There has been a steady rise in fecal coliform contamination with increasing human population along the North Carolina coast (Maiolo and Tschetter 1981; Mallin et al. 2001b). In 2002, 263 SA waterbodies were on the 303(d) list of impaired waters because of fecal coliform contamination (DWQ 2002). In 2012, there were 583 SA waterbodies closed to the taking of shellfish in the state for the same reason. As of March 05, 2014, over 442,106 acres of shellfish harvesting waters were closed in North Carolina due to high levels of fecal coliform or the potential risk of bacterial contamination (S. Jenkins and A. Haines, DMF, pers. com. 2014). Figure 10.2 below reflects the status of shellfishing waters since the inception of testing, monitoring, and regulating the waters for health and safety of harvest for consumption.

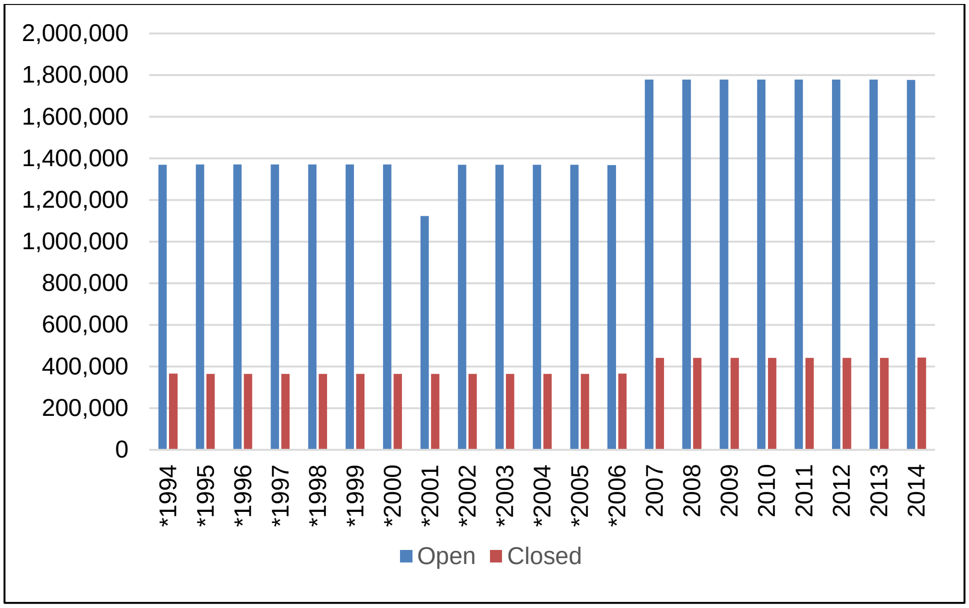


FIGURE 10.2 Status of shellfishing waters since inception of testing, 1994-2014, DMF Shellfish Sanitation & Recreational Water Quality (Note: In 2007 the Division of Environmental Health – Shellfish Sanitation Section began calculating acreage from GIS; prior figures were hand-tallied by planimeter on NOAA Charts. Thus, 2007 data will be slightly higher than previous data).

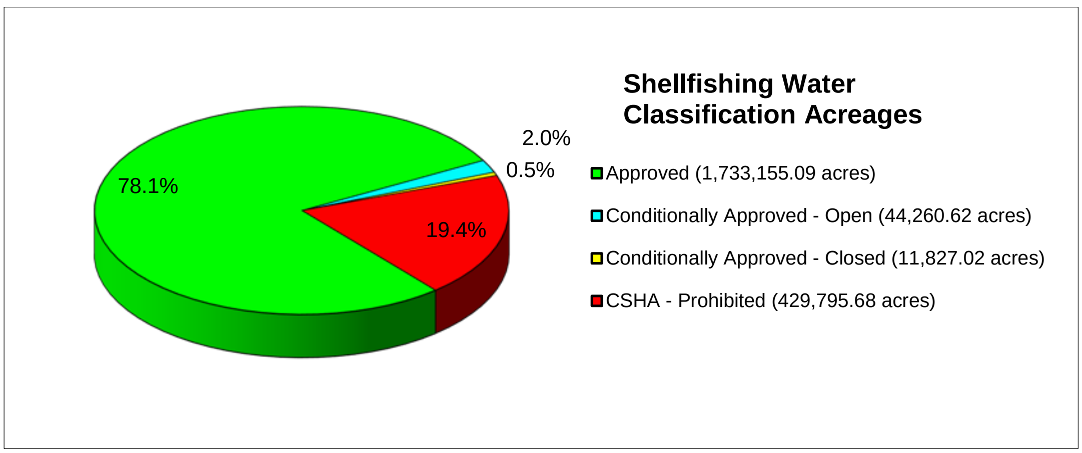


FIGURE 10.3. Shellfishing water classification acreages for year 2014.

10.2. Pollution sources

Tracking sources of pollutants is more difficult than measuring pollutant levels. Changes in chemistry can originate from point or nonpoint sources. Primary pollutants are oxygen-consuming wastes, nutrients, suspended sediment, and toxins (including chlorine, ammonia, and metals). Most point sources are regulated, and include treated municipal or industrial wastewater discharges. Those not regulated can include straight pipes, grey water pipes, drainage of some aquaculture ponds, ballast waters, etc. The concentration of point source pollutants in streams increases under low flow or drought conditions. Nonpoint source pollution enters waters through diffuse sources with no defined point of entry. Nonpoint pollutants are carried by rainfall, runoff, groundwater seepage, or atmospheric deposition. Unlike point sources, nonpoint loading varies with weather patterns and land disturbance.

10.2.1. Land Disturbing Activities

Any activity involving clearing of vegetation, grading, or ditching can increase erosion and sediment runoff into surface waters. Such land disturbing activities include building and road construction, grading, crop agriculture, timber harvesting, animal operations, mining, and removal of vegetated buffers. Of sediment loading sources, that from agriculture is cited as one of the largest contributors to water pollution in the southeast (SAFMC 1998b). The EPA concluded that siltation and nutrients impair more miles of rivers and streams than other pollutants, affecting 45% and 37% of impaired rivers and streams, respectively. In naturally forested systems of the southeast, there is little surface runoff during and after rainfall events, as rainwater flows slowly over vegetation, infiltrating the soil (Beach 2002). Increased impervious areas associated with development result in higher volumes and rates of flow into receiving streams, which can increase stream bank erosion (Beach 2002). Sediment inputs are high where erosion rates are high, thus shorelines are unstable. While shoreline stabilization with vertical structures helps retain sediments, erosion is often intensified waterward of structures (Crowell 1998; Pilkey et al. 1998).

Estuaries in the southeast are lined with tributaries and marshes that widen as they join the trunk estuary. These areas act as temporary storage of sediment, delivering sediment to the estuary only during high flows or storm events. In some cases, these tributaries accumulate large amounts of sediment that can store contaminants, nutrients, and organic matter (Corbett et al. 2009).

In addition to sediment being introduced into surface waters from runoff, sediment can also be resuspended by water dependent activities. Dredging for channels and boat basins, beach nourishment, boating activities, and bottom disturbing fishing activities, e.g., trawling, clam kicking, and hydraulic clam dredging, can resuspend sediment, increasing turbidity in the water column, releasing buried contaminants and nutrients, and potentially silting over benthic habitats, such as submerged aquatic vegetation or shell bottom.

10.2.2. Point Source Discharges

Point source discharges in North Carolina must obtain a National Pollutant Discharge Elimination System (NPDES) permit, and comply with applicable Nutrient Management Strategies and stormwater rules. Discharge permits are issued under the NPDES program, delegated to the DWR by the EPA. These permits are reviewed and potentially renewed every 5 years. There are ~289 major and minor discharge facilities in the CHPP region (Map 10.1).

10.2.3. Wastewater Treatment Plants and Infrastructure

The DMF requires closures around all NPDES wastewater discharges located within shellfish waters due to the possibility that mechanical failure could allow the flow of inadequately treated sewage. Current EMC rules discourage creation of new direct discharges into shellfish waters (T15A NCAC 02B .0224]. The DWR requires new and expanding NPDES permit applicants to consider non-discharge alternatives such as spray irrigation, rapid infiltration basins, and drip irrigation systems.

There are Notices of Violation (NOVs), Notices of Deficiency (NODs) and Civil Penalty Assessments (CPAs) issued according to effluent measurements at permitted wastewater discharges (Tables 10.5a and 10.5b). The violations are for a variety of EMC standards exceedances, such as Biological Oxygen Demand (BOD), chlorine, fecal coliform, and DO. On occasion, informal protocol may eliminate the necessity for use of the formal Notice process, thus the numbers do not represent a complete picture. North Carolina currently requires Best Practicable Technology for wastewater treatment. Advanced treatment methods, especially biological nutrient removal (BNR), exist that lower effluent limits and can remove pollutants that currently aren't treated (e.g., pharmaceuticals).

10.2.4. Saline discharge from reverse osmosis plants

Withdrawal of brackish water for desalination and use in municipal water supply has potential impacts to water quantity or quality (Copeland 1967). 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 species diversity, the majority of which occupy lower tropic levels (Buzzelli et al. 2002; Stanley and Nixon 1992). The reduction in species diversity and isolation from the surrounding aquatic community could constitute a loss of habitat. Even under natural circumstances, vertical salinity stratification in the estuarine water column creates unfavorable low DO conditions, which serves to degrade bottom habitat, cause stress or mortality in benthic species, and force mobile species movement (Buzzelli et al. 2002; Stanley and Nixon 1992).

Currently, DWR general permits restrict flow in HQWs and PNAs to no more than 50% of the 7Q10 (lowest 7-day average flow that occurs once every 10 years), but there is no 7Q10 calculated for tidal creeks, resulting in no flow restrictions in these areas. In some waters, unrestricted effluent from a desalination plant could greatly affect water salinity, as well as ammonia, pH and temperature. A recent concern regarding the desalination process is the withdrawal of nitrogen rich groundwater, and thus high levels of nitrogen being discharged with the effluent. Presently, in coastal North Carolina, there are 18 reverse osmosis desalination facilities and two nanofiltration facilities discharging to the following: Albemarle Sound, Atlantic Ocean, Bald Head Island Marina, Blackmar Gut, Cedar Island Bay, Far Creek, AIWW (Fig. 8 Island Bridge), Lake Mattamuskeet, Neuse River, New River, North River, Pamlico Sound, Pantego Creek, Pasquotank River, Pungo Lake Canal, Stumpy Point Bay.

TABLE 10.3. Sewage spills (gallons) reaching surface waters in coastal counties from 2010-2014 (DWR, unpublished data, 2015).

CHPP Region	County	2010	2011	2012	2013	2014
1	Bertie	204,300	107,190	2,950	1,300	
1	Camden					
1	Chowan	111,365	40,035	1,060		
1	Currituck			8,000		
1	Hertford	72,000	180,800	40,005		
1	Pasquotank	652,501	900	1,450		
1	Perquimans		1,600	80,100		
1	Tyrrell		800			
1	Washington	29,830	28,810			
1,2	Martin	80,600	14,600	6,500		
1,2	Dare		8,350			
2,3	Carteret	136,000	600	200,000	13,000	32,000
2	Beaufort	43,855	3,650	73,000	650	
2	Craven	918,828	68,542	12,738	420	7,600
2	Hyde			999		
2	Jones	51,500				
2	Lenoir	300	8,600		1,000	
2	Pamlico	800	580	4,600	1,050	800
2	Pitt	13,074	29,383	111,980	16,610	
2	Wayne	447,970	1,795	76,125	10	
3	Onslow	263,500	36,750	41,100	24,755	52,500
4	Brunswick	4,564,100	100	207,000	2,455,000	1,800
4	Duplin	252,000	144,000	824,000	112,175	200,000
4	New Hanover	1,570,070	113,971	2,903,473	519,855	50,150
4	Pender	10,100				407,000
1-4	Total	9,422,693	791,056	4,595,080	3,145,825	751,850

TABLE 10.4. NPDES Wastewater Dischargers (Individual Permits), NCDWR-IT, 2015.

CHPP Region	Class	County	NPDES Wastewater Dischargers (Individual Permits)						
			100% Domestic WW, < 1MGD	Groundwater Remediation	Municipal WW, Large	Municipal WW, < 1MGD	Industrial Process & Commercial WW	Water Plants & Water Conditioning	Total Permits
1	Major	Bertie	0	0	1	0	0	0	1
		Hertford	0	0	1	0	0	0	1
		Pasquotank	0	0	1	0	0	0	1
		Major Total	0	0	3	0	0	0	3
	Minor	Bertie	0	0	0	1	1	0	2
		Camden	0	0	0	0	0	2	2
		Chowan	0	0	0	0	0	3	3
		Currituck	0	0	0	0	0	2	2
		Gates	3	0	0	0	0	0	3
		Pasquotank	0	0	0	0	0	3	3
		Perquimans	0	0	0	1	0	2	3
		Washington	0	0	0	3	0	3	6
		Minor Total	3	0	0	5	1	15	24
1-2	Major	Dare	0	0	1	0	0	0	1
		Major Total	0	0	1	0	0	0	1
	Minor	Dare	0	0	0	1	3	5	9
		Minor Total	0	0	0	1	3	5	9
2	Major	Beaufort	0	0	2	0	1	0	3
		Craven	0	0	2	0	3	0	5
		Major Total	0	0	4	0	4	0	8
	Minor	Beaufort	1	0	0	2	3	6	12
		Craven	2	0	0	3	1	5	11
		Hyde	0	0	0	0	2	4	6
		Pamlico	0	0	0	0	4	5	9
		Minor Total	3	0	0	5	10	20	38
3	Major	Carteret	0	0	2	0	0	0	2
		Onslow	0	0	0	0	1	0	1
		Major Total	0	0	2	0	1	0	3
	Minor	Carteret	1	0	0	1	1	8	11
		Onslow	16	3	0	3	1	3	26
		Minor Total	17	3	0	4	2	11	37
4	Major	Brunswick	0	0	1	0	3	0	4
		New Hanover	0	0	3	0	4	0	7
		Major Total	0	0	4	0	7	0	11
	Minor	Brunswick	2	0	0	2	3	3	10
		New Hanover	5	3	1	3	8	2	22
		Pender	2	0	0	0	0	2	4
		Minor Total	9	3	1	5	11	7	36
	Major Subtotal		0	0	14	0	12	0	26
	Minor Subtotal		32	6	1	20	27	58	144
Grand Total			**32**	**6**	**15**	**20**	**39**	**58**	**170**

Residuals and biosolids, or treated sludge, are by-products of the wastewater treatment process. After pathogen reduction, vector attraction reductions, and metal limits are met, residuals are disposed in a manner protecting public health and the environment. Disposal sites include landfills, residual disposal sites, agricultural land for crops not-for-human-consumption, and distribution to the public for home use. There are ~89 permits for residual land applications in the CHPP region.

TABLE 10.5A NPDES Wastewater Dischargers Notices of Deficiency and Notices of Violation – 2006 through May, 2015. Notices of Deficiencies were not used prior to 2011 (DWR-IT 2015). Note: On occasion, informal protocol may eliminate the necessity for use of the formal Notice process, thus the numbers do not represent a complete picture.

		NPDES Wastewater Dischargers (Individual Permits)									
		Notice Of Deficiency (NOD) Counts									
CHPP Region	**County**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
1	Bertie	0	0	0	0	0	0	2	2	0	0
	Camden	0	0	0	0	0	0	0	0	0	0
	Chowan	0	0	0	0	0	0	2	1	0	0
	Currituck	0	0	0	0	0	0	0	1	0	0
	Gates	0	0	0	0	0	1	1	1	0	0
	Hertford	0	0	0	0	0	0	0	0	0	0
	Pasquotank	0	0	0	0	0	1	1	2	0	0
	Perquimans	0	0	0	0	0	0	0	1	0	0
	Washington	0	0	0	0	0	2	9	8	0	0
1-2	Dare	0	0	0	0	0	0	0	0	0	1
2	Beaufort	0	0	0	0	0	1	1	1	0	0
	Craven	0	0	0	0	0	0	1	2	0	1
	Hyde	0	0	0	0	0	0	0	0	0	0
	Pamlico	0	0	0	0	0	2	6	3	0	1
3	Carteret	0	0	0	0	0	0	5	2	1	1
	Onslow	0	0	0	0	0	0	6	7	10	0
4	Brunswick	0	0	0	0	0	0	5	2	1	1
	New Hanover	0	0	0	0	0	1	2	0	2	0
	Pender	0	0	0	0	0	0	2	0	0	0
Total		**0**	**0**	**0**	**0**	**0**	**8**	**43**	**33**	**14**	**5**

		NPDES Wastewater Dischargers (Individual Permits)									
		Notice Of Violation (NOV) Counts									
CHPP Region	**County**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
1	Bertie	3	9	2	3	6	11	1	2	2	0
	Camden	2	4	1	1	0	0	0	0	0	0
	Chowan	0	1	2	6	0	0	4	1	3	0
	Currituck	2	1	0	0	0	0	0	0	0	0
	Gates	0	0	2	4	8	4	5	2	0	0
	Hertford	1	0	0	0	0	0	1	0	0	0
	Pasquotank	2	2	1	2	1	1	1	1	1	0
	Perquimans	0	3	4	0	3	0	0	1	1	0
	Washington	8	7	4	7	11	13	7	6	3	1
1-2	Dare	5	2	0	0	6	2	6	2	0	0
2	Beaufort	11	5	2	2	2	10	3	1	2	0
	Craven	3	10	8	10	9	16	10	11	10	3
	Hyde	1	1	0	2	2	2	2	0	3	0
	Pamlico	0	4	3	6	3	4	6	6	3	0
3	Carteret	12	3	7	11	5	9	5	3	7	2
	Onslow	54	13	51	40	35	38	37	41	29	8
4	Brunswick	16	11	6	3	8	13	15	13	3	2
	New Hanover	22	11	9	7	6	25	46	39	16	7
	Pender	4	2	0	1	7	5	6	2	2	1
Grand Total		**146**	**89**	**102**	**105**	**112**	**153**	**155**	**131**	**85**	**24**

TABLE 10.5B NPDES Wastewater Civil Penalty Assessments and Totals of NODs, NOV, and CPAs for 2006 through May 2015 (DWR-IT 2015). Note: On occasion, informal protocol may eliminate the necessity for use of the formal Notice process, thus the numbers do not represent a complete picture.

		NPDES Wastewater Dischargers (Individual Permits) Civil Penalty Assessment (CPA) Counts									
CHPP Region	County	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	Bertie	1	0	1	0	1	2	0	0	0	0
	Camden	0	2	1	0	0	0	0	0	0	0
	Chowan	4	0	3	0	0	0	0	0	0	0
	Currituck	0	0	0	0	0	0	0	0	0	0
	Gates	0	0	8	4	4	2	3	0	0	0
	Hertford	0	0	0	0	0	0	0	0	0	0
	Pasquotar	2	0	2	1	2	0	0	0	0	0
	Perquima	1	0	0	2	4	0	0	0	0	0
	Washingt	4	4	7	15	10	7	1	0	0	0
1-2	Dare	10	6	1	0	0	0	3	0	0	0
2	Beaufort	1	1	1	2	6	4	1	0	0	0
	Craven	2	5	8	7	7	1	2	0	2	0
	Hyde	0	0	0	1	0	0	0	0	0	0
	Pamlico	1	0	2	7	4	1	0	0	0	0
3	Carteret	2	8	8	15	7	3	2	1	1	1
	Onslow	41	32	33	23	26	10	14	19	14	3
4	Brunswick	11	6	9	5	9	10	11	8	0	0
	New Hand	6	7	3	6	11	22	32	21	2	0
	Pender	2	0	0	1	0	4	2	2	0	0
Grand Total		**88**	**71**	**87**	**89**	**91**	**66**	**71**	**51**	**19**	**4**

		NPDES Wastewater Dischargers (Individual Permits) Total Count of NOD/NOV/CPA									
CHPP Region	County	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	Bertie	4	9	3	3	7	13	3	4	2	0
	Camden	2	6	2	1	0	0	0	0	0	0
	Chowan	4	1	5	6	0	0	6	2	3	0
	Currituck	2	1	0	0	0	0	0	1	0	0
	Gates	0	0	10	8	12	7	9	3	0	0
	Hertford	1	0	0	0	0	0	1	0	0	0
	Pasquotar	4	2	3	3	3	2	2	3	1	0
	Perquima	1	3	4	2	7	0	0	2	1	0
	Washingt	12	11	11	22	21	22	17	14	3	1
1-2	Dare	15	8	1	0	6	2	9	2	0	1
2	Beaufort	12	6	3	4	8	15	5	2	2	0
	Craven	5	15	16	17	16	17	13	13	12	4
	Hyde	1	1	0	3	2	2	2	0	3	0
	Pamlico	1	4	5	13	7	7	12	9	3	1
3	Carteret	14	11	15	26	12	12	12	6	9	4
	Onslow	95	45	84	63	61	48	57	67	53	11
4	Brunswick	27	17	15	8	17	23	31	23	4	3
	New Hand	28	18	12	13	17	48	80	60	20	7
	Pender	6	2	0	2	7	9	10	4	2	1
Grand Total		**234**	**160**	**189**	**194**	**203**	**227**	**269**	**215**	**118**	**33**

10.2.5. Septage

Septage is regulated by DENR, Division of Waste Management (DWM) and is covered under T15A NCAC 13B .0830. Typically, septage refers to the fluid mixture of untreated and partially treated sewage solids, liquids, and sludge of domestic origin which is removed from an on-site wastewater system (septic system). Septage also includes other waste streams such as grease trap and portable toilet waste. In order to function properly, residential and other septic systems must be pumped regularly by someone certified in the removal and proper treatment of septage.

Once pumped, septage can be disposed of at permitted DWR WWTPs, septage detention or treatment facilities (SDTF), or septage land application sites (SLAS) (Map 10.2). The SDTF and SLAS are permitted through DWM. Approximately 74% of pumped septage is disposed of at WWTPs. The majority of SDTF are for temporary storage until the septage can be taken to a WWTP or SLAS. There are some SDTF that are septage treatment facilities where septage is treated prior to disposal at a WWTP or SLAS. At a permitted SLAS, septage is applied to crops for non-human consumption. The septage is lime stabilized to a pH of 12 prior to application. The application rate for a SLAS is based upon nitrogen requirement rates of the crop, with the typical application rate for SLAS being 50,000 gal/ac/yr. Annual soil samples are taken to monitor the accumulation of heavy metals.

10.2.6. Non-Discharge Systems

Non-discharge systems are the preferred alternative to surface water discharge for NSW waterbodies, and DWR requires new and expanding NPDES permit applicants to consider alternatives to surface water discharge. Non-discharge wastewater options include spray irrigation, rapid infiltration basins, and drip irrigation systems. The DWR permit ensures that treated wastewater is applied to land at a rate that is protective of groundwater and surface water. There are ~8 groundwater remediation, ~25 closed-loop recycle, ~69 high rate infiltration, ~55 reclaimed water, ~13 single family wastewater irrigation, ~104 wastewater irrigation, and ~16 other types of non-discharge permits in the CHPP region (Map 10.2).

High-rate infiltration systems are a growing variation of land application in the coastal plain. These systems are proposed to address the needs of new developments where receiving waters cannot accommodate direct discharge of treated wastewater and no publicly owned treatment is available. The nutrient load from these systems is not captured by point source rules or other strategy accounting mechanism. Nutrient contributions of these systems to surface waters are not quantified.

As point sources transition to non-discharge permits, and as population grows, the number of land application permits is expected to increase. As new land application facilities are permitted or existing facilities expand, potential water quality impacts will increase. Annual application rates for individual fields in 2010 ranged from 0.02” to 3,903” with a median of 13.63” and a mean of 56.8”. Large applications in small watersheds could significantly impact surface and groundwater (NCDENR 2013).

Figure 10.4 highlights the location of land applied treated wastewater, showing the highest volume being applied in the coast, based on data through 2010. The concentration of constituents can vary greatly from permit to permit; site specific conditions, such as soil type, can vary; and improper management can impact the effectiveness of the site to attenuate nutrients. Some sites have underground tile drains or groundwater lowering ditches that by-pass the necessary in-ground treatment of applied wastewater, circumventing groundwater monitoring wells. Some sites utilize groundwater lowering wells to allow greater rates of infiltration leading to inadequate residence times. Nutrient data from these groundwater lowering wells require close monitoring (NCDENR 2013).

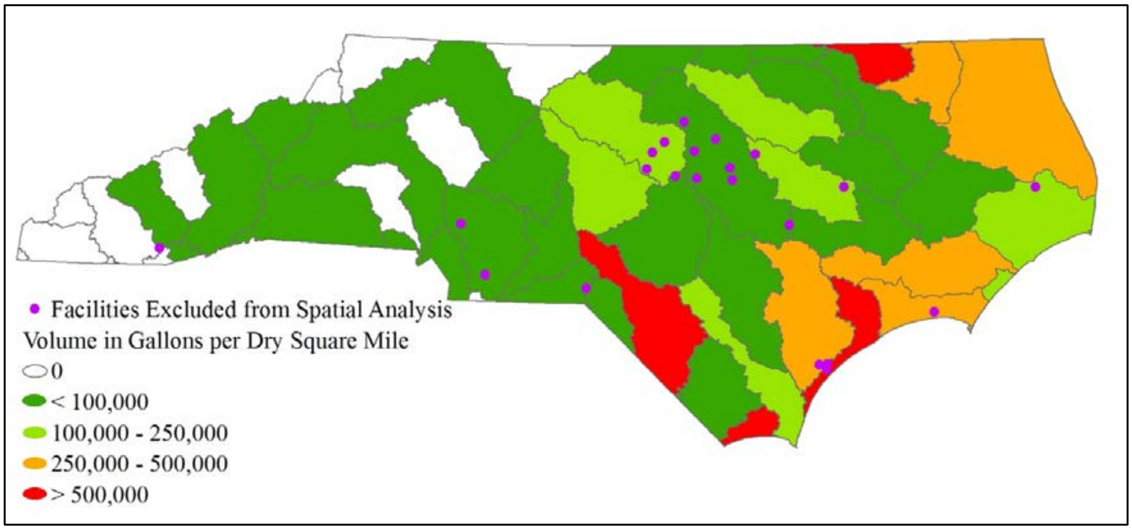


FIGURE 10.4. Volume of Treated Wastewater Applied to the land in 2010 by subbasin

10.2.7. Marinas and multi-slip docking facilities

Marinas and boatyards often provide services such as boat maintenance, wastewater pumpout, pressure washing, sandblasting, and painting that can lead to the introduction of toxins into adjacent waters. To assess potential water quality concerns, DWQ conducted a survey of 141 marinas in the 20 coastal counties in 2007 (DWQ 2008a). They found elevated levels of copper, iron, zinc, and aluminum in the wastewater, with lead, nickel, chromium, arsenic, and cadmium elevated to a lesser extent. High metal concentrations were attributed to sloughing of residual paints from boat hulls during washing, with pressure washing contributing greater loading of copper, zinc, and aluminum. Boats with anti-fowling paint had the highest concentrations of metals in process wastewater than those without. The conclusion was that high concentrations of metals generated in the power washing process, and the location of these operations adjacent to coastal surface waters, posed significant environmental concerns. As a result, DWR now has regulations for marinas with wash down and sand blasting facilities.

Boats head discharge can be sources of fecal microbial contamination, as in the Town of Wrightsville Beach (Mallin et al. 2009a). Because of frequent swimming advisories posted to estuarine beaches, studies were undertaken to determine the cause. In a study by Mallin et al. (2009a), sampling for fecal coliform and *Enterococcus* bacteria was done at nine locations from 2007-2009. Standards for *Enterococcus* were exceeded on four occasions at one location and three occasions at two other locations during the study. The DNA fingerprint analysis revealed human fecal bacteria signals at all sites. Lacking sewer or septic leaks in the area, boat head discharge was indicated.

Multi-slip docking facilities with 11-29 slips, vessels less than 25' in length, with no heads or cabins, are defined as marinas "with shellfish harvest closure exclusions." The exclusion minimizes the risk of bacterial contamination into shellfish waters. Marinas cannot be located in or adjacent to areas where shellfish harvesting for human consumption is a significant existing use and closure to the resource is anticipated. The DMF closes waters where a high potential for bacterial contamination exists.

Both the construction and operation of a marina can cause the release or resuspension of sediment, from pile jetting, to dredging, to the boating activity itself (see Marina Section). Toxic substances in fouling organisms bioaccumulate in the aquatic food chain (Marcus and Stokes 1985; Nixon et al. 1973). Both PAHs (polycyclic aromatic hydrocarbons) and heavy metals are found to be significantly higher in bottom sediments in a marina than the control site.

Regulated by the EPA, wood used for marine construction can be treated with chromated copper arsenate (CCA) to a minimum retention of 0.60 - 2.50 pounds of preservative per cubic foot (pcf). Laboratory studies by (Weis et al. 1991; Weis et al. 1992) show that leachate from CCA treated wood can be toxic to estuarine species. Leaching decreases by about 50% daily once immersed in seawater. Although approximately 99% of the leaching occurs within the first 90 days (Brooks 1996; Cooper 1990; Sanger and Holland 2002), pilings and bulkheads are periodically replaced, providing a continual source of toxins. Elevated concentrations of metals from CCA treated wood can be found in organisms living on or near treated pilings (Weis and Weis 1996a; Wendt et al. 1996).

Elevated concentrations of chromium, copper, and arsenic were found in fine sediments adjacent to CCA treated bulkheads, and in organisms living on and around treated pilings (Weis and Weis 1996b; Weis et al. 1998). Dilution can reduce the impacts; bioaccumulation of dock leachates by marine biota did not impact survival of mummichogs, juvenile red drum, white shrimp, or mud snails in South Carolina estuaries characterized by higher flow rates (Wendt et al. 1990). However, tidal flushing thresholds for contaminants have not been identified, nor does data exist to evaluate the dilution capacity of an area.

Metals such as mercury, cadmium, and copper are capable of adversely affecting genetic development in bivalve embryos (Roesijadi 1996), especially during early developmental stages. Exposure to organic contaminates has resulted in impairment of physiological mechanisms, histopathological disorders, and loss of reproductive potential (Capuzzo 1996). Reductions in growth and increased mortality have been observed in soft-shelled clams (*M. arenaria*) following oil spill events (Appeldoorn 1981).

Two-cycle marine engines release up to 20% of unburned fuel along with exhaust gases (Crawford et al. 1998). Crawford et al. (1998) compared PAH output from a two-cycle outboard engine with that from a four-cycle engine, finding that discharge from the two-cycle contained five times as much PAH as that from the four-cycle. Albers (2002) notes that PAH concentrations in the water column are "usually several orders of magnitude below levels that are acutely toxic," but in sediments may be much higher. The PAHs can accumulate in sediments (Sanger et al. 1999) to be stirred up by boat traffic (Albers 2002).

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).

10.2.8. Marine Litter and Debris

Marine debris includes trash and other waste carried from land or vessels into coastal waters. It is a threat to fishery resources due to potential entanglement and ingestion, which can strangle or injure organisms, or impair mobility. Ingestion of plastic resin pellets, 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). According to the United Nations Environmental Programme (UNEP et al. 2005):

> "about 6.4 million tons of marine litter are disposed in the oceans and seas each year. According to other estimates and calculations, some 8 million items of marine litter are dumped in oceans and seas every day, approximately 5 million of which (solid waste) are thrown overboard or lost from ships. Furthermore, it has been estimated that over 13,000 pieces of plastic litter are floating on every square kilometre of ocean today" (UNEP et al. 2005).

In 2010, plastics were estimated to comprise 4.8 to 12.7 million metric tons of litter entering the ocean from 192 coastal countries (Jambeck et al. 2015). Land based sources, including storm drains, sewer outfalls, and litter from pedestrians, motorists, and beach visitors, contribute 80% of the debris in the oceans. Water based sources include cruise ships, recreational and commercial boating, offshore oil drilling, and military vessel operations (Commission 2015).

Programs and organizations such as NOAA's Marine Debris Program and The Ocean Conservancy (TOC) are involved in monitoring and clean-up efforts. On September 17, 2015, NOAA awarded nearly $1.4 million in grants to groups in 13 communities for the express purpose of marine debris removal and coastal cleanup. This years' grants include monies for removal of derelict vessels, abandoned fishing gear, and harmful marine debris (NOAA 2015c).

Until April, 2015, North Carolina Big Sweep was a state-wide organization whose mission was a litter-free environment. The Big Sweep conducted educational events to prevent litter, and coordinated annual events, the state component of the International Coastal Cleanup, in which volunteers clean land and waterways. During the 2014 International Coastal Cleanup, 209,698 volunteers picked up 4,144,109 lbs of debris along 8,517 miles of shoreline, comprised of 4,924,820 items of trash. In North Carolina, 15,136 Big Sweep volunteers collected 102,850 pieces of debris along 1,327.3 miles of shoreline, totaling ~301,550 lbs (Conservancy 2015).

In another 2014 effort, fishermen worked alongside Marine Patrol officers during two days when crab pots are required to be removed from the water (NC General Statute 113-268) to remove derelict pots and marine debris. During this period, volunteers removed 201 crab pots, while Marine Patrol removed 163; associated shoreline volunteers removed 620 pounds of solid waste and 380 pounds of derelict fishing gear from the north end of Roanoke Island. A recent study by Uhrin and Schellinger (2011), regarding the impacts to coastal marsh from derelict crab pots, anthropogenic construction debris, vehicle tires, and similar debris common to North Carolina waters, shows that crab pots and vehicle tires resting on top of marsh grass for extended periods cause stems and blades to become broken or abraded, which may disrupt normal function. Injuries sustained by *S. alterniflora* varied considerably between the two types of debris, with the plants in the footprint of the tires and heavier debris being crushed, suffering breakage, suffocation, and eventual death. Plants within the footprint of the lightweight and open structures, such as crab pots, suffered inhibited stem growth, but were able to rebound after structure removal. Belowground impacts were not studied (Uhrin and Schellinger 2011).

Since 2009, volunteers have removed tons of trash from Masonboro Island during the annual 4th of July Celebration. In 2014, more than 75 volunteers helped clean 2.87 tons ‐ or 5,740 pounds and four dumpsters full ‐ of trash and recyclables from the island just south of Wrightsville Beach.

10.2.9. Agriculture

10.2.9.1. Crop agriculture

Fertilizer, pesticides and herbicide runoff from crop agriculture all impact water quality. Protecting the waters from impacts of agriculture is promoted through voluntary natural resource management with assistance from the Department of Agriculture and Consumer Services' Division of Soil & Water Conservation (NCDA&CS S&WC). The division is active in education and implementation efforts to reduce nutrient loading in river basins. Strategies include BMPs, nutrient management, and riparian buffer protection. As of the 2014 Annual Report, implementation of the strategies promoted by the program had resulted in a 43% reduction in nitrogen loss compared to the baseline data collected in 1991 (NCDA&CS 2014). Gilliam et al. (1997) of NC State University, studied the nitrogen reduction values of shrub buffers in the Neuse River Basin. This effort helped increase the number of BMPs available to farmers in the region. The impacts of herbicides, pesticides, crop spraying, runoff, ground disturbance sedimentation, etc., on water quality, are addressed in various sections of this chapter.

10.2.9.2. Animal operations

Nonpoint pollution from agricultural operations is a significant source of stream degradation. North

Carolina has addressed this problem by combining regulatory and voluntary assistance programs. Currently, DEQ has regulatory authority over waste management of swine and cattle feedlots that use dry systems and applications of a wastewater or liquid manure; these permitted facilities are inspected by DWR on an annual basis. Hog and cattle CAFO's discharging waste have NPDES permits, but there is no associated water quality monitoring requirements. Most poultry operations produce dry litter waste, programs which typically fall under the deemed-permitted category and are inspected on a complaint driven basis. The locations of dry litter poultry operations and disposal of such waste is not known to regulators, making nonpoint sources contributions difficult to locate within a watershed.

The DWR Animal Feeding Operations Unit is responsible for permitting and compliance activities of CAFOs across the state. There are ~1,980 permitted animal facilities, the majority of them being swine operations, located in the lower Cape Fear and Neuse River basins (Map 10.3). There is one large poultry farm near the Pungo River in Hyde County.

Animal waste is often stored in lagoons before it is applied to fields. Numerous environmental hazards exist from the lagoons including: ammonia emissions, overflows into surface waters, and groundwater contamination. In a recent study, Rothenberger et al. (2009a) examined land-use data and nutrient concentrations in 26 subbasins throughout the Neuse River basin and modeled specific land-use characteristics that influenced surface-water quality among the study sites. Contributions of N and P to streams in the Upper Neuse basin were found to be highly influenced by wastewater dischargers in urban subbasins, whereas in the Lower Neuse basin, agricultural subbasins with intensive swine production were the most important contributors of N and P to receiving streams.

10.2.10. Forestry

The headwaters of most of the state's rivers and streams are in forests, therefore protection of waters from the impacts of forestry is an important responsibility, as coordinated by the NC Forest Service. The primary state-enacted water quality regulations affecting silviculture practices are:

- Forest Practices Guidelines (FPGs) Related to Water Quality (02 NCAC 60C .0100-.0209).
- General Statutes prohibiting blockage of flow in streams or ditches (NCGS 77-13 and 77-14).
- Aerial application of pesticides is governed under NPDES #NCG560000, if thresholds met (Table 10.6).
- Silviculture is statutorily exempt from the NC Coastal Area Management Act and NC Dredge and Fill Law.

Harden (2013) with the USGS undertook an Investigative Report (#2013-5007) to determine the impacts of several forestry characteristics on nutrient and streamflow, to aid in modeling estimates of nitrogen, nitrates, and phosphorous loads. Forty eight sites were chosen from the Roanoke, Chowan, Tar-Pamlico, Neuse, Cape Fear, and Lumber River basins. Regression tree analyses were performed to learn whether a particular watershed's attributes may be indicators of its potential for exporting nutrients.

TABLE 10.6 NC DWR Pesticides General Permit – NCG560000

Annual Treatment Area Thresholds	
Pesticide Use	Annual Threshold
Mosquitoes and other flying insect pests	15,000 acres of treatment area (adulticide applications)[1]
Aquatic weed and algae control:	
- in water	1000 acres of treatment area
- at water's edge	200 linear miles of treatment area
Aquatic nuisance animal control:	
- in water	200 acres of treatment area
- at water's edge	200 linear miles of treatment area
Forest canopy pest control	10,000 acres
Intrusive vegetation control	500 linear miles

[1]Multiple applications to the same area are added together only for mosquito and other flying pest control

The analyses indicated that variables examined were useful for predicting observed yields of nitrate, total N, and total P. Model 1 identified annual point-source flow yields as the primary watershed environmental variable influencing the stream yields for nitrate. Models 2, 3, and 4 could not identify any watershed environmental variables to adequately explain observed variables. Models 2, 3, and 4 all indicated that watersheds with higher percentages of forested land (> 41 to 46%) have lower median annual total N and total P yields compared to watersheds with lower percentages of forested land (< 41 to 46 %), which have higher median annual total N and P yields. Watersheds with lower proportions of forested lands also have proportionately higher amounts of agricultural and/or developed urban lands in the watersheds, which contributes to higher total N and P yields. The nutrient and pesticide effects from silviculture and sedimentation from clearcutting are addressed in the applicable sections of this chapter.

TABLE 10.7 The NC Forest Service evaluates sites across the state to monitor compliance with water quality regulations, summarized here for the time period of 2011-2014.*

Inspections	Northeastern Coastal Plain (NCFS District 7)	Albemarle-Pamlico Peninsula (NCFS District 13)	Central Coastal Plain (NCFS District 4)	Southeastern Coastal Plain (NCFS District 8)	Total NCFS Coastal Region
Timber Harvest Site Inspections					
Number of Inspections	1,148	357	1,272	1,033	3,810
Estimated Acres	51,620	22,315	60,022	51,348	185,305
Occurrences of Non-Compliance	20	2	40	28	90
Other Forestry Site Inspections					
Number of Inspections	143	38	102	111	394
Estimated Acres	7,815	4,537	3,696	4,229	20,277
Occurrences of Non-Compliance	1	0	4	2	7

* District 7: Bertie, Camden, Chowan, Currituck, Gates, Hertford, Martin, Pasquotank, Perquimans.
District 13: Dare, Hyde, Tyrrell, Washington.
District 4: Beaufort, Carteret, Craven, Jones, Lenoir, Onslow, Pamlico, Pitt.
District 8: Bladen, Brunswick, Columbus, Duplin, New Hanover, Pender.

10.2.11. Ocean Acidification

A result of industrial and other anthropogenic emissions is the reduction in pH levels of the ocean waters. The increase in acidity in the water column can lead to severe consequences for marine calcifying organisms. This process is referred to as ocean acidification.

Carbon is constantly in flux between land, ocean, and the atmosphere. Anthropogenic activities, such as burning fossil fuels and developing lands, have introduced a new source of carbon into the cycle, in the form of gaseous carbon dioxide (CO_2). Through biological and chemical processes, a majority of CO_2 is integrated into the ocean water column, while approximately 45% is absorbed into the atmosphere, and a small remaining portion is stored in terrestrial plants and animals (Raven and Falkowski 1999). The ocean stores carbon mostly as particulate or dissolved inorganic compounds such as CO_2 or carbonates.

The ocean's pH, is regulated by its ability to buffer carbonates. Specifically, when carbon dioxide dissolves in water, it forms a carbonic acid, then bicarbonate ion, then carbonate ion, and ultimately increases the concentration of free hydrogen ions in seawater, as depicted in the below formula:

H_2CO_3

$HCO_3^- + H^+$

$CO_3^{2-} + 2H^+$

In effect, a higher concentration of hydrogen ions in the water equates to a lower pH. This is a two way reaction, so as the concentration of hydrogen ions increases, the buffer system shifts to favor bicarbonates and subsequently increase pH, meaning less acidic ocean water. The proportion of chemicals is also dependent on ocean temperature, among other factors. Anthropogenic delivery of CO_2

to the atmosphere has increased substantially since the industrial revolution of the late 1800s (Sabine et al. 2004). As a result, carbon uptake in the oceans has increased. In general, ocean acidity has increased over time as the ocean's buffering capacity becomes more limited (Hall-Spencer et al. 2008; Sabine et al. 2004). If atmospheric CO_2 continues to increase at the current rate, the average pH of the world oceans is expected to decline by 0.3-0.5 units by 2100 (Caldeira and Wickett 2005; Orr et al. 2005).

10.3. Pollution effects

The previous section covered the major sources and management of pollution causing impairment based on existing water quality standards. The next section will cover ecological impacts and causes of nutrient enrichment, turbidity, toxic chemicals, desalinization, and marine litter in coastal waters.

10.3.1. Eutrophication, oxygen depletion, and algal blooms

Nutrients are chemical compounds or elements needed for the growth of living organisms and are beneficial in appropriate amounts. Nitrogen and phosphorus are the major plant nutrients responsible for regulating growth of algae and other freshwater and marine plants (DeAngelis et al. 1989). While a certain level of these nutrients is needed to support aquatic life, an overabundance often leads to increased primary production resulting in algal blooms, or eutrophication (Nixon 1995). Nixon (1995) defines eutrophication as ''an increase in the rate of supply of organic matter to an ecosystem." Andersen et al. (2006) defines eutrophication as "the enrichment of water by nutrients, especially nitrogen and/or phosphorus and organic matter, causing an 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) emphasizes that nutrient enrichment is not the only cause of eutrophication. It is important to separate the process of eutrophication from its causes and consequences.

Several North Carolina estuarine environments are characterized by slowly moving, poorly flushed waters with high levels of nutrients, offering ideal conditions for algae, fungi, and bacteria to thrive. These organisms promote low DO that can lead to fish kills, and some of these microbes can attack fish and shellfish directly (Shumway et al. 2006; Vandersea et al. 2006), compounding the impacts.

Algal blooms produce large amounts of oxygen during photosynthesis and raise the pH by increasing hydroxide. When the water column becomes supersaturated with DO and has a high pH, this may mean a bloom is in progress. The DWR records algal blooms by measuring DO and pH, assuming a bloom is in progress when DO > 110% saturation or > 9.0 mg/ L, and/or pH > 8.0 s.u.

10.3.1.1. Algal Blooms

Algal Blooms in Region 1

The majority of blooms in Region 1 are usually blue-green algae in estuarine areas. There were nine blooms in the Albemarle Sound during 2010-2014— six blooms of *Pseudanabaena, Cylindrospermopsis*, and *Chroococcus* and three blooms of *Pseudanabaena* near Edenton. Two blooms of *Pseudanabaena* and *Cylindrospermopsis* occurred in the Pasquotank River during 2010-2014. Three blooms of the filamentous blue-green *Anabaena* were investigated in the Chowan River during 2013. There were two blooms of the raphidophyte algae *Heterosigma* and *Chattonella* in the Perquimans and Roanoke rivers during July 2011. One report in 2010 of green paint in Roanoke Sound ditches turned out to be *Euglena,* and a 2010 report of green water in the Little River was found to be *Cylindrospermopsis* and *Anabaena*.

A large growth of an aquatic fungus was investigated in Ivy Creek below a wood processing facility beginning in 2011. The growth was documented on three occasions from 2010-2014, but it is unclear how long it had been present. It shifted between forms of fungi; one form found was *Saprocheate* *saccharophila*, an indicator of decaying vegetation associated with stormwater runoff from mulch piles.

Algal Blooms in Region 2

The majority of algal blooms recorded during 2010-2014 in Region 2 were in the Neuse (Craven, Pamlico counties) and Pamlico (Beaufort County) rivers. These rivers are regularly monitored in response to frequent fish kills during the 1990s. The 32 Neuse River and 76 Pamlico River blooms were often a mix of different algae. The algal assemblage in the Neuse River is usually dominated by small diatoms and the dinoflagellate *Gyrodinium instriatum*. The diatom *Chaetoceros* and dinoflagellates (*Heterocapsa*, *Katodinium, Prorocentrum)* are usually dominant during winter-spring. The algal assemblage in the Pamlico River is similar but with occasional blooms of filamentous blue-green algae (*Pseudanabaena, Aphanizomenon, Cylindrospermopsis*), raphidophytes (*Heterosigma*), or green algae (*Nephroselmis*).

There were four investigations in the Northeast Cape Fear River (Wayne County) during 2010-2014 documenting bottom dwelling diatoms and *Cylindrospermopsis*. Three investigations in the Trent River (Craven County) found small diatoms and *Heterosigma*. Other investigations during 2010-2014 in Region 2 included a report of white filamentous growth in a Pamlico County ditch (sulfur bacteria), reports of green surface film in private ponds (filamentous algae or duckweed), and a lakewide bloom of the mat-forming blue-green alga *Lyngbya wollei* at Wiggins Mill in Wilson County.

Algal Blooms in Region 3

The majority of algal blooms documented during 2010-2014 in Region 3 were in New River (Onslow County) and Calico Creek (Carteret County). These waterbodies are regularly monitored by the DWR Wilmington Regional Office in response to wastewater treatment plant reconfigurations in the late 1990s. The 33 blooms investigated in Calico Creek were mostly comprised of bottom-dwelling diatoms, and the 88 blooms investigated in the New River were often a mix of different types of algae—especially small diatoms, chain-forming diatoms (*Cylindrotheca* and *Skeletonema*), dinoflagellates (*Prorocentrum, Heterocapsa, Karlodinium*, and *Gyrodinium instriatum*), and raphidophytes (*Heterosigma, Chattonella*).

The most unusual bloom occurred during early August 2014, caused by the red tide dinoflagellate *Cochlodinium* at Sea View and Surf City piers. This is the first time *Cochlodinium* has been observed by DWR personnel. Only low cell concentrations were observed; the bloom ended after two days.

Algal Blooms in Region 4

Algal blooms documented in Region 4 during 2010-2014 were mostly freshwater. Nineteen blooms of the blue-green alga *Microcystis* were investigated—particularly in the Cape Fear River. *Microcystis* in the Cape Fear River was first reported in 2009. The bright green surface blooms were sporadic and concentrated around Lock and Dam 1 near Kelly, NC. *Microcystis* returned in 2011, reported from June through August. The peak of the bloom covered ~70 miles from above Lock and Dam 3 (Cumberland County) down to Sutton Lake (Brunswick County). Sporadic blooms of *Microcystis* recurred between Lock and Dam 3 and Lock and Dam 1 from June to July 2012. A bloom was reported at Lock and Dam 1 in 2014, but no bloom was found upon investigation. *Microcystis* blooms were reported in other waters in Region 4, such as Beaverdam Creek (Duplin County) during October 2010 and May 2011. Laurel Lea Lake, a small residential lake in New Hanover County, had a recurring bloom throughout 2013.

Eight other algal blooms were investigated in the Cape Fear (Bladen County) and Northeast Cape Fear (Duplin, Pender counties) Rivers during 2011 and 2013, mainly consisting of diatoms and the blue-greens *Anabaena* and *Pseudanabaena*. Other bloom investigations during 2010-2014 were conducted in lakes, creeks, and ponds, and the algae were often bottom-dwelling diatoms and filamentous greens (*Tetraedron, Vaucheria*) and blue-greens (*Ocsillatoria*).

Algal blooms usually occur when water flow is slow and mixing reduced due to salinity or temperature gradient. In freshwater, blue-green algae, with lower nutritional value than others, are usually associated with blooms. In estuarine and marine waters, dinoflagellates and other flagellated algae are usually responsible for blooms (Mallin et al. 2000a; North Carolina Sea Grant 1997; Smayda 1989). 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 P-limited for phytoplankton growth, whereas phytoplankton growth in the Tar-Pamlico and Neuse estuaries is generally nitrogen limited (Lin et al. 2007), or, in the Neuse, co-limited by N and P (Mallin and Rudek 1991).

Elevated levels of phytoplankton in the water column reduce clarity, diminishing successful feeding by visually feeding fish (Peterson et al. 2000b). Nutrient enrichment affects biomass, community structure, invertebrate growth and reproduction rates, organic carbon inputs, and biogeochemistry of the sediments (Cloern 2001). Some dinoflagellates release toxic chemicals into the water column, harming fish and shellfish by affecting their nervous and respiratory systems (Tyler 1989). Many fish kills have been attributed to toxic algal blooms and associated ulcerative mycosis.

10.3.1.2. Sources of nutrient enrichment

Most nutrient pollution in the Albemarle-Pamlico system has been linked to agriculture operations (Cahoon and Ensign 2004; Gilliam et al. 1996; Mallin et al. 2000a; Mallin et al. 2001c; Paerl and Whitall 1999; Rothenberger et al. 2009a; Stone et al. 1995). Research shows that use of spray fields by concentrated animal feeding operations (CAFOs) significantly and chronically impacts surface and groundwater through runoff, subsurface flow, and atmospheric deposition (Burkholder et al. 2007a; Costanza et al. 2008a; Gilliam et al. 1996; Stone et al. 1995). The presence of CAFOs on river floodplains is of particular 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, and pathogenic microbes (Burkholder et al. 1997; Mallin et al. 2000a; Mallin et al. 1997; Sobsey 1996). Wastes are discharged into lagoons to undergo anaerobic digestion, then sprayed onto fields. Pollutants can transport to surface or groundwater with ruptures, leaks, overflows, or if the field is saturated (Mallin et al. 2000a; Mallin et al. 2001c). Pollutants can enter groundwater below spray fields, moving laterally (Mallin et al. 2000a). Of concern is the release of pharmaceuticals, antibiotics and veterinary drugs from CAFOs (Bartelt-Hunt et al. 2011; Burkholder et al. 2007a; Nicole 2013).

An NCSU study found that 38% of older unlined lagoons leak nitrogen into groundwater at strong or very strong levels (Huffman 1999). Swine facilities are responsible for an estimated 20% of North Carolina's total atmospheric nitrogen compounds, 53% of which are contributed by eastern North Carolina (Paerl and Whitall 1999). Empirically-verified modeling results from Costanza et al. (2008a) indicate that a small portion of CAFOs contribute disproportionately to atmospheric deposition of nitrogen in the Albemarle-Pamlico Sound, with an estimated 14-37% of the state receiving 50% of the deposition.

Coastal aquaculture facilities are nutrient sources. Many in eastern North Carolina range from small catfish farms to large hybrid striped bass facilities discharging over 30 times a year. Discharges from three hybrid striped bass farms resulted in violation of water quality standards for DO and Chlorophyll *a* in the tributaries receiving pond drainage (DWQ 2007), which led to requirements for NPDES permits. Farms can continue to discharge with low flow drains and BMPs to reduce food and fecal waste.

Other sources of nutrient pollution include golf courses, ocean acidifying compounds, and in some cases, even shoreline erosion processes. Mallin and Wheeler (2000) studied the effect of golf courses on water quality of adjacent waterbodies in New Hanover and Brunswick counties. The study found that ammonium and orthophosphate was tightly bound to the soils, but that nitrate levels increased as the streams flowed, and in some places caused increases in phytoplankton biomass and algal blooms. The conclusion was that golf courses with vegetated buffers, wet detention ponds, and wooded wetlands exported considerably less nutrients than those without (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. 2002b).

10.3.1.3. Status and trends in nutrient enrichment

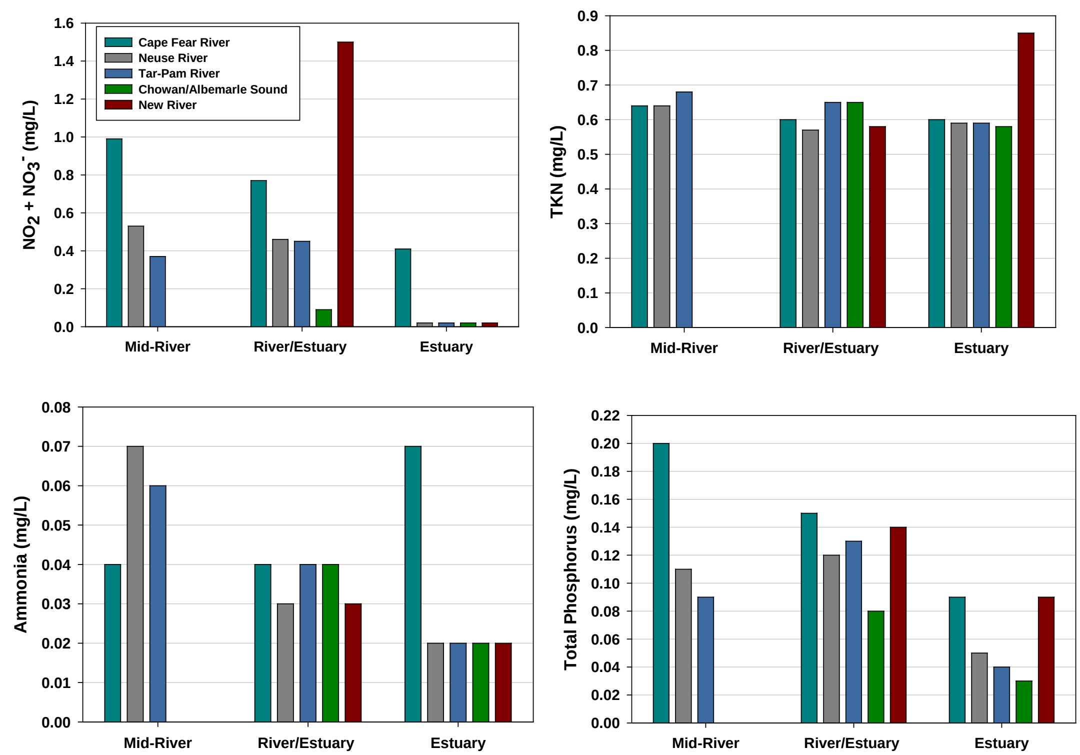
According to the 2014 DWR integrated 305(b) and 303(d) report, there are approximately 445.3 freshwater acres, 12.5 freshwater miles, and 29,827.7 saltwater acres impaired by excessive chlorophyll *a* levels (DWR 2014). Nutrient enrichment in North Carolina's estuarine systems, and the subsequent effects on phytoplankton populations and water quality parameters, has been observed by many researchers since the 1970s. Since phytoplankton blooms seen in North Carolina estuaries result from nutrient enrichment, chlorophyll *a* (a photosynthetic pigment found in all algae and most cyanobacteria) is the natural response measure to indicate elevated algal biomass, primary production, and eutrophication. Paerl (2004); Paerl et al. (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.

In the lower Cape Fear River, Mallin et al. (2001c) reported high nutrient levels in the channels, but algal blooms rarely occurred. This was attributed to high flushing and reduced clarity from turbidity and color, limiting photosynthesis. A study of tidal creeks in New Hanover County found that chlorophyll *a* concentrations were greatest at mid to low tide (Mallin et al. 1999). This was primarily attributed to the transport of nutrients from adjacent marsh and headwater areas, headwaters often having the highest chlorophyll *a* concentrations within a tidal creek (Laws et al. 1994; Mallin et al. 1996; Mallin et al. 2004). In continental-draining tidal creeks, phytoplankton growth in the lower reaches is nitrogen-limited, while in the upper reaches, phosphorus-limited, often due to elevated nitrate inputs, or by light through self-shading of algae (Mallin et al. 2004). Other studies have found falling tides to transport algae from upstream to downstream sources (Litaker et al. 1987; Litaker et al. 1993).

Data collected in the mid-1990s from the Albemarle-Pamlico system found that the Neuse Basin had the highest N and P concentrations due to intensive agriculture and urban runoff, while the lowest concentrations occurred in the forested Chowan Basin (Spruill et al. 1998). Although concentrations had shown a general decline since 1980 in all four basins, they were still such as to cause algal blooms in the Pamlico and Neuse estuaries. The authors estimated that a 50% reduction of N and P concentrations in the Neuse River, and a 30% reduction in the Tar River, during summer months, was needed to reach levels to reduce the nuisance algal blooms and fish kills (Spruill et al. 1998).

DWR data collected from 2008 through 2012 indicate that the Cape Fear and New rivers and their associated estuaries have the highest median inorganic (nitrate + nitrite) nitrogen and total phosphorus concentrations of the coastal plain basins (Figure 10.5). Organic nitrogen (TKN) and ammonia concentrations are fairly similar between all coastal basins, with the exception of higher organic nitrogen (TKN) concentrations in the New River Estuary and higher ammonia concentrations in the Cape Fear River Estuary (Figure 10.5).

Geologic sources can also contribute to high P levels, such as in the Neuse and Tar-Pamlico rivers. 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 N and P 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 groundwater. 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 concluded that groundwater is an important mechanism forcing nutrients from porewaters to the water column in this shallow lagoonal estuary.



Station Identification:

Waterbody	Mid-River		River/Estuary		Estuary	
	Station #	Location	Station #	Location	Station #	Location
Cape Fear River	B8320000	CFR @ Elizabethtown	B8360000	CFR @ East Arcadia	B9800000	CRF Estuary @ Wilmington
Neuse River	J6150000	NR @ Kinston	J7930000	NR @ Streets Ferry	J9530000	NR Estuary - Minnesott Beach
Tar-Pamlico River	O6240000	Tar R. @ Greenville	O6500000	Tar-R. @ Grimesland	O865000N	Pamlico R. @ Gum Point N. shore
Chowan/Albemarle Sound	na		D0010000	Chowan River @ Riddicksville	M390000C	Albemarle Sound near Frog Island
New River	na		P0600000	New River @ Gum Branch	P2113000	New River @ Wilson Bay

FIGURE 10.5. Median Nutrient Concentration Comparison within the Riverine, Estuarine Headwaters (River/Estuary) and Estuarine Systems in the Coastal Plain. Data from 2014 IR Stations Summaries (data years 2008-2012). No Mid-River data available for New River (White Oak River basin) and Chowan River basins.

For 22 years ongoing, NCSU Center for Applied Aquatic Ecology's (CAAE) Neuse River Monitoring and Research Program has tracked riverine discharge, DO 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 (Burkholder et al. 2004; Burkholder et al. 2006). Important findings contributed by this effort pertinent to fish health and 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 in the middle and lower watershed (Rothenberger et al. 2009b).
- Total N loading declined over the period from 1994 to 2009, while ammonium increased. Ammonium is an important form of N preferred by many phytoplankton species.
- Radon-222 (222Rn) and ammonium ($NH4^+$) were measured in interstitial water of the Neuse River Estuary (NRE) to determine the advective flux of $NH4^+$ from sediments to the overlying water column (Null et al. 2011). $NH4^+$ concentrations in sandy environments of the NRE were 10-fold higher than concentrations in the water column. Shallow porewaters exhibited seasonal variations in $NH4^+$ concentrations, resulting in temporal changes in $NH4^+$ flux from the sediment.
- Submarine groundwater discharge (SGD) was measured indirectly using 222Rn as a tracer and directly via seepage meters (Null et al. 2011). Seasonal trends in groundwater seepage rates and $NH4^+$ concentration suggest groundwater to be an important mechanism advecting nutrients from porewaters to surface waters, which is comparable to riverine $NH4^+$ discharge. SGD N:P ratios ($NH4^+$as N) were >16:1, indicating that SGD is an important contributor of inorganic N for phytoplankton growth and may influence the NRE toward a less N-limited system.
- Algal biomass (as chlorophyll *a*) has significantly increased in the oligohaline and mesohaline estuaries from 1993 to 2009, despite management efforts to control algal biomass by reducing the total N load. The significant trend upward in biomass appears related to nonpoint source pollution (Burkholder et al. 2006).
- Bottom-water DO 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, degradation of habitat.
- Co-management of both N and P, and major reductions in inputs from nonpoint as well as point sources, are needed to reverse water quality degradation in this estuary (Glasgow and Burkholder 2000).

The ongoing (1997 to the present) Neuse River Modeling and Monitoring Project (ModMon) research has found that riverine discharge, nutrient loading, and circulation are strongly related and primarily determined by weather patterns. Irregular weather patterns, especially the occurrence of tropical storms (Xu et al. 2010), complicate trend analysis. The Albemarle-Pamlico estuaries have limited and weak tidal flushing, and are freshwater, wind-driven systems not draining directly into ocean waters. Consequently, nutrients and detrital matter are stored in sediments and help maintain eutrophic conditions through regeneration (Buzzelli et al. 2002; Luettich et al. 2000; Paerl et al. 2006). 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, making it difficult to evaluate the short-term effectiveness of nutrient reductions and management actions ((Luettich et al. 2000; Paerl et al. 2006). Some important findings pertinent to fish habitat are:

- Inorganic nitrogen (DIN) loading has declined since 1999 and blooms in the upper Neuse River Estuary (NRE) north of New Bern have declined. This is largely attributed to upstream WWTP improvements. However, total N reduction goals (TMDL) have not been met because of increases in total Kjeldahl N loading, probably driven by increased organic N inputs (Lebo et al. 2012). Downstream of New Bern, estuarine algal blooms and chlorophyll *a* exceedances (of the TMDL 10/40 criterion) have not abated, most likely because overall, total N reductions have not been met (Lebo et al. 2012; Paerl et al. 2006).
- The mesohaline portion of the estuary has persistent salinity stratification and regular phytoplankton blooms due to nutrient enrichment. One was toxin-forming dinoflagellate (*Karlodinium veneficum*) in response to high nutrient availability and intense vertical stratification following runoff from a tropical storm. The decline of the bloom coincided with multiple fish kills in mesohaline NRE (Hall et al. 2008).
- The NRE has been impacted by several major hurricanes; as such effects on water column habitat depended on the track and rainfall associated with each storm (Paerl et al. 2010). Droughts improved habitat through a

reduction in hypoxia, but caused lower primary productivity that cascaded to lower mesozooplankton abundances, a key food item for estuarine fish (Wetz et al. 2011).
- Primary production is largely influenced by freshwater flushing the estuary. Large amounts of discharge move algal biomass downstream; droughts result in biomass upstream (Ma et al. 2014).
- Diel vertical migration of flagellated phytoplankton groups enhances primary productivity and potentially affects trophic transfer through changes in encounter rates with predators (Hall and Paerl 2011).
- Benthic and pelagic respiration is capable of depleting the oxygen pool in stratified bottom water in <5 days during summer. Oxygen depletion is positively correlated with accumulation of organic material in sediment from water column production (algal bloom) or external organic matter loading and appropriate environmental conditions, including warm temperatures and density stratification (Buzzelli et al. 2002).
- Low-oxygen conditions occur more often and for longer in deeper portions of the water column, causing lethal and sublethal stress of benthic infauna (Buzzelli et al. 2002; Luettich et al. 2000).

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, low flow throughout 2008 being the likely explanation for annual mean turbidity levels being lower than the long-term average (Mallin et al. 2008). Dissolved oxygen levels were similar to the annual average in the river channel but lower in blackwater creeks. These blackwater systems often have low to moderate phytoplankton production, but given a source of human-generated nutrients and an open canopy, they can support dense phytoplankton blooms (Ensign and Mallin 2001; Mallin et al. 2001a).

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 significantly increasing trend 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. 2007). 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 increases, 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 North Carolina estuaries (Christian et al. 1991; Paerl and Wetz 2009).

Historically, the lower Cape Fear River has had little of nuisance algal blooms. Generally, phytoplankton productivity would be low in years of elevated river discharge and increase during dry years, especially in summer. However, in recent years new threats to migratory and other fish species have arisen in the lower Cape Fear River system. The first is posed by algal blooms. Whereas in previous years the abundance of cyanobacteria (blue-green algae) has been very low in the lower Cape Fear (Dubbs and Whalen 2008), in recent years (2009-2012), the river has been host to unprecedented cyanobacterial blooms consisting primarily, but not exclusively, of *Microcystis aeruginosa*, at one point impacting 75 miles of the river. This species has long been known as a toxin-producing organism (Anderson et al. 2002). The blooms have occurred in the summer months; sometimes in early fall, and have centered from just above Lock and Dam #1 downstream to the Black River (NCDENR 2011). Additional blooms of other species have occurred as far upstream as the upper Haw River above Buckhorn Dam during this period (NCDENR 2011). In 2011 additional cyanobacterial blooms (*Anabaena planktonica* and *Microcystis*) occurred in the Northeast Cape Fear River, leading to strong hypoxia with DO levels falling to 0.7 mg/L (S.

Petter-Garrett, DWQ, pers. com. 2011). At least two issues directly related to fish and human health can result from these new blooms: river hypoxia and toxin production.

The lower Cape Fear River and estuary are on the 2014 North Carolina 303(d) list for impaired water due to low DO or hypoxia. The same segment of the lower Cape Fear River is being considered for a possible reclassification to "Swamp Waters," which allows for lower DO levels if caused by naturally occurring conditions. One cause of hypoxia can be algal blooms. Long-term chlorophyll *a* and BOD data collected by researchers from UNC-W have demonstrated that at Station NC11, just downstream of Lock and Dam #1, chlorophyll *a,* and BOD are strongly correlated, $r = 0.53$, $p = 0.0001$ (Mallin et al. 2006). These data were collected prior to the new set of blooms; follow-up statistical studies in summer 2012 have confirmed that the blue-green algal blooms are directly correlated with BOD, with samples from three different depths positively correlated with BOD5 ($r = 0.54$), and surface samples, where the blooms are concentrated, showing an even stronger r value of 0.66. Thus it is likely that this new algal bloom threat will create stronger summer BOD, and further lower DO in the river.

Some of the blooms in the main stem of the Cape Fear have produced toxins. The North Carolina Division of Public Health had a 2009 bloom sample from Lock and Dam #1 tested and it came out positive for 73 ppb (μg/L) of microcystin (Dr. Mina Shehee, NC Division of Public Health, memo September 25, 2011), resulting in an advisory to keep children and dogs from swimming in the waters. For comparison, the World Health Organization has a guideline of < 1.0 μg/L of microcystin-LR for drinking water. Additionally, a UNC-W Marine Science group directed by chemist Dr. Jeff Wright isolated two hepatotoxins, microcystin LR and microcystin RR, from Cape Fear *Microcystis aeruginosa* blooms in 2010 (Isaacs et al. 2014). In a related issue, the metabolites produced by cyanobacterial blooms in 2009 forced Brunswick County, which draws drinking water from the impacted area, to increase levels of treatment to control the taste and odor problems from the cyanobacteria blooms.

Dubbs and Whalen (2008) found that a 45% dilution of instream nutrients did not elicit a decline in phytoplankton growth response, indicating that nutrients present in the Cape Fear River were well in excess of phytoplankton growth requirements. The Cape Fear River is not classified as "nutrient-sensitive waters" by the state, and as a result, few wastewater dischargers have effluent limits for total N and P. Between 1995 and 2006 parts of the lower Cape Fear system experienced statistically significant increasing trends in ammonium concentrations ranging from 100% in the main stem to 300% in the Northeast Cape Fear River (Burkholder et al. 2006). Inputs of N have been experimentally shown to cause algal biomass increases in blackwater streams and rivers that are present in the Cape Fear system (Mallin et al. 2004). Thus, periods of low flow, coupled with already-elevated nutrients present in the river, are likely to lead to more nuisance and toxic blooms unless efforts are undertaken to reduce nutrient loading in this system.

In 2015, DWR began developing instream nutrient criteria for the central portion of the Cape Fear River and for Albemarle Sound, estimating completion by 2021. In September, 2015, NOAA announced awards totaling $2.1 million for 12 new research grants for organizations to research harmful algal blooms and hypoxia. The intent is to advance the understanding and ability to predict the outbreak of harmful blooms and hypoxia, which have become concerns along the coasts nationwide (NOAA 2015b).

10.3.1.4. Nutrients and eutrophication

Studies have indicated a fundamental change in fish 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 species/trophic level and adding excessive nutrients and sediments, greatly alters relative community composition, allowing 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 impacts to benthic structure, may be a precondition to disease, eutrophication, and microbial outbreaks. They reason that large scale oyster reef restoration for increased water filtration may be required, in addition to nutrient input reduction, for significant reduction in eutrophication (Boesch et al. 2001; Jackson et al. 2001; Peterson 2001). In a review of eutrophication in Chesapeake Bay, Kemp et al. (2005) note that declines in eastern oyster stocks may have exacerbated eutrophication. 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).

Research indicates that the magnitude of eutrophication in coastal waters has increased globally over the past century (CENR 2003; NRC 2000; Paerl et al. 1995; 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 BOD (CENR 2003; Diaz and Rosenberg 2008; Lenihan and Peterson 1998; Selman et al. 2008). 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; Luettich et al. 2000). When nutrient loading is reduced, a decline in nutrient levels may not be observed in the waterbody until the supply in the sediment is depleted (Luettich et al. 1999), making management strategies difficult to evaluate in the short term.

Adequate supply of DO is critical to the survival of sessile benthic invertebrates and fish living on or in soft bottom. In freshwater systems, low oxygen levels from eutrophication has been suggested as a 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 deeper areas (Tenore 1972). If stratification persists, hypoxic events 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 crustaceans (Diaz and Rosenberg 1995). Severe oxygen depletion in the sediment results in release of toxic levels of sulfide into bottom waters (Luettich et al. 1999).

Mass mortality of benthic infauna such as clams and worms due to anoxia and toxic sulfide levels has been documented in the deeper portions of the Neuse River estuary, in association with summer stratification of the water column (Lenihan and Peterson 1998; Luettich et al. 1999). Epifauna like oysters and mud crabs and some benthic fish, like blennies, also died, lacking adequate tall refuge (oyster reefs) with oxygenated water (Lenihan and Peterson 1998). Mobile benthos, such as blue crabs, left their burrows when oxygen was unavailable. 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 (Buzzelli 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 *M. balthica* to a diet switch in Atlantic croaker. As a result of less *M. balthica*, croaker consumed more polychaetes and plants, evidence of a change in the food web.

During severe anoxic events, mortality of benthic microalgae can occur due to anaerobic sediments and higher turbidity that often accompanies the stratification of the water column (MacIntyre et al. 1996a) (M. Posey, UNC-W, pers. com. 2010). Predation on members of the benthic community by species such as flounder, spot, blue crab, and croaker generally increases in the short-term as burrowing organisms move into the shallowest sediment layers to avoid sulfide release and lack of oxygen in deeper sediments (Luettich et al. 1999). Results from statistical modeling indicates 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. 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).

The majority of SAV loss is attributed to large-scale nutrient enrichment and sedimentation, which reduces light penetration to the leaf (Dennison et al. 1993; Durako 1994; Goldsborough and Kemp 1988; Kenworthy and Haunert 1991; Orth et al. 2006; Stevenson et al. 1993; Steward and Green 2007; Twilley et al. 1985). 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;
- Increasing epiphytic coverage, sedimentation, drift algae coverage (Virnstein and Morris 1996);
- Diminishing DO 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).

Eutrophication of shallow estuaries can lead to proliferation of ephemeral macroalgae surrounding SAV, and filamentous 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 is directly related to increased nutrient levels (Neckles et al. 1993; Valiela et al. 1997) and that SAV loss is greater with increased macroalgae (Hauxwell et al. 2000). Where eelgrass loss occurs due to macroalgal cover, N loading rates were 30 kg/ha/yr in urbanized watersheds compared to 5 kg/ha/yr in forested. Once macroalgal blooms die, they decompose rapidly, increasing nutrient levels in the water column, stimulating phytoplankton production, further reducing light.

10.3.2. Sedimentation and turbidity impacts to aquatic life

Excessive suspended sediments directly impact aquatic animals by clogging gills and pores of juvenile fish and invertebrates, resulting in mortality or reduced feeding (Ross and Lancaster 1996). Increases in nonfood particles ingested by suspension-feeding shellfish and polychaetes lower the nutrient value of their diet and slow their growth rates (Benfield and Minello 1996; Lindquist and Manning 2001; Reilly and Bellis 1983; SAFMC 1998b). Turbidity has been found to disrupt spawning migrations and social hierarchies (Reed et al. 1983), resulting in decreased combined fish biomass (Aksnes 2007).

Excess sedimentation can reduce or eliminate aquatic insect larvae from stream bottoms (AFS 2003), affecting 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 smother other benthic invertebrates (AFS 2003). Excessive sedimentation can profoundly affect oyster health and viability when settling, as it can bury oyster larvae, adults, or shell, deterring successful recruitment of larvae by reducing exposed hard substrate (Coen et al. 1999). Excessive sedimentation increases survival time of pathogenic bacteria (SAFMC 1998b). Oyster eggs and larvae are most sensitive to suspended sediment loading (Davis and Hidu 1969).

Sediment in excessive amounts transports pathogenic microorganisms and toxic chemicals in stormwater, allowing bacteria to persist longer in the water column than it would in clear waters (Fries et al. 2008; Jartun et al. 2008; Schueler 1999). Suspended sediment absorbs toxic chemicals, heavy metals, phosphorus, and bacteria, providing a mechanism for pollutants to be transported downstream, to be ingested by filter feeding fish and invertebrates (Steel 1991). In North Carolina oligohaline tidal creeks Mallin et al. (2009b) 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 estimated that the amount of N and organic carbon stored in the upper 2 cm of bottom sediments is ten times more than the amount of total N 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 sedimentation has been cited as the major cause of freshwater mussel decline in the United States since the late 1800s (Box and Mossa 1999; Neves et al. 1997). This decline in North Carolina is considered severe (Neves et al. 1997). Freshwater mussels are highly sensitive to water quality and habitat degradation, and are often considered excellent early biological indicators of stream condition.

The EPA Environmental Monitoring and Assessment Program surveyed 165 sites within North Carolina's sounds and rivers during 1994-1997 to evaluate the condition of bottom sediments (Hackney et al. 1998). The sediment in 13.4% of estuarine sites sampled was nearly devoid of life during summer conditions. Concentrations of heavy metals in the Neuse and Pamlico estuaries have been assessed. In the Neuse River, elevated levels of several heavy metals, including zinc, copper, lead, and arsenic were found in surface sediments. 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. In its most recent report, the National Coastal Condition Report NCCR IV (EPA 2012) gave the southeast coast a rating of 2 (based on 1-5) in the category of "sediment," a downgrade from previous ratings, based on toxicity.

Nonpoint sources are more difficult to evaluate. In the Pamlico River, arsenic, cobalt, and titanium exceeded the levels found in the Neuse River. This suggests sediment contamination in some estuarine areas, especially those where both organic rich mud and wastewater discharges are present. Corbett et al. (2009) investigated the presence of heavy metals in Slocum and Hancock creeks, and the Neuse River Estuary, finding higher concentrations of heavy metals in the portions of the creeks with low sedimentation rates. Corbett et al (2009) observed little to no macrofauna in sediment cores with high heavy metal concentrations. Heavy metal and toxin concentrations have been monitored yearly by NOAA's mussel watch monitoring program since 1986 (Kimbrough et al. 2008). In North Carolina, there are 10 sites at Roanoke Sound, Pamlico Sound, Cape Fear River, and Beaufort Inlet where heavy metal levels found in the eastern oyster *Crassostrea virginica* are monitored (Lauenstein et al. 2002).

10.3.3. Toxic chemical impacts on aquatic life

A toxic substance is defined in the North Carolina Administrative Code [T15A NCAC 02B. 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 in the water column include:

- Heavy metals - Metals with a density of at least five times that of water. These include mercury, nickel, lead, arsenic, cadmium, aluminum, iron, platinum and copper.
- Pesticides - Chemical compounds typically composed of chlorinated hydrocarbons and 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 process, chemical bleaching of pulp in paper production (DWQ 1997); present as trace impurities in some commercial products.
- Petroleum hydrocarbons - Compounds in fuel-type products - gas, oil, grease. There are >100 in gas. Lubricant oil contains elements such as zinc, sulfur, phosphorus (Jackivicz and Kuzminski 1973).
- Polycyclic aromatic hydrocarbons (PAHs) - Group of over 100 chemicals formed during the incomplete burning of coal, oil, gas, garbage, or other organic substances like tobacco or charbroiled meat. Found in coal tar, crude oil, creosote, roofing tar; few used in medicines, and to make dyes, plastics, and pesticides.
- Biocides- chlorine, others used to disinfect waste, pool water, clean clothes, wash boats, etc.
- Polychlorinated biphenyls (PCBs) - Organic chemicals containing chlorine that have properties 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. Used in plasticizers and flame retardants.

- Plasticizers and flame retardants - Plasticizers (containing bisphenol A) used to soften PVC, in storage containers, flame retardants, building materials, insulation, electric cable insulation, electronics, motor vehicles, household furnishings, plastics, and polyurethane foams. Found increasingly in surface waters (Kimbrough et al. 2008; Kuiper et al. 2007), bioaccumulate in organisms, and disrupt endocrine processes.
- Ammonia - Form of nitrogen from CAFOs, cleaning products, and point source dischargers.
- Pharmaceuticals and personal care products - Broad collection of products for personal health or cosmetic reasons, such as over-the-counter drugs like ibuprofen, prescription drugs, antibiotics, antidepressants and oral contraceptives, caffeine, nicotine, disinfectants, and fragrances in shampoo and detergents, etc.

Many factors affect a chemical's toxicity to marine organisms. Eggs and larvae are generally more sensitive to toxics than adult and juvenile life stages as they have more permeable membranes and less developed detoxifying systems (Funderburk et al. 1991; Gould et al. 1994; Weis and Weis 1989). For example, larval striped bass are less tolerant of copper sulfate ($CuSOB_{4B}$) 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. Chemicals can damage aquatic organisms directly by causing mortality, or indirectly by altering endocrine related growth and reproductive processes.

Some pesticides and metals (e.g., toxaphene, TBT, mercury) cause acute mortality in fish or shellfish at very low concentrations (1 ppb or less), whereas others (e.g., chromium, atrazine) cause toxic effects only at much higher concentrations (>10,000 ppb) (Funderburk et al. 1991). The effect on organisms varies with the properties of the water column; higher salinity water can neutralize more dissolved chemicals than fresh water, making these toxics less biologically available for uptake. Other physiochemical conditions can either increase or decrease toxicity of a given chemical.

While some toxins remain in aqueous form in the water column, others, especially heavy metals, are readily adsorbed on sediment particles and eventually removed from the water column (Butler 1971; Vandermeulen and Mossman 1996; Wolfe and Rice 1972). This adsorption allows some toxic chemicals to accumulate and contaminate sediments until they degrade into less harmful substances. However, when the chemicals are re-suspended, they become biologically available to pelagic species 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).

10.3.3.1. Toxicity and bioaccumulation

Chemicals can cause acute or chronic toxicity to aquatic organisms, varying in severity based on the extent of exposure, organism, and life stage at exposure. In addition to the direct impact, there is also the ability to bioaccumulate, which can cause health problems in human consumers (Wilbur and Pentony 1999). The EPA has guidance documents regarding the assessment of chemical contamination for use in fish advisories (EPA 2000a; EPA 2000b). The effects of environmental pollutants on early life stages of fish are listed in table 10.8, according to DWQ 2009 (current) and (Funderburk et al. 1991).

Scudder et al. (2009) found that blackwater coastal plain streams draining forested wetlands yielded the highest concentrations of mercury in fish tissue. Studies have documented that the Cape Fear River system is favorable for conversion to, and retention of, methylmercury (Schneider 2009). There is a statewide mercury advisory, and site specific advisories for PCBs, dioxin, and coal ash. Both inorganic and organic mercury have been reported to be lethal to fish and invertebrates in low concentrations and to cause various physiological, reproductive, and biochemical abnormalities at sublethal concentrations (Boening 2000) (Table 10.9). Temperature, pH, salinity, and DO affect toxicity values.

An emerging source of toxic contamination is coal ash containment facilities in North Carolina and elsewhere (Stant 2010). Facilities located in coastal draining river basins include the Cape Fear Steam Plant in Chatham County, Lee Steam Plant in Wayne County, Weatherspoon Steam Plant in Robeson Co., and Sutton Steam Plant in New Hanover County. Two of the facilities – Lee and Sutton – have converted to natural gas. Cape Fear and Weatherspoon have closed. In February 2014, approximately 39,000 tons of coal ash were released into the Dan River from a Duke Energy impoundment pond in Eden. This led to extensive clean-up and remediation, resulting in civil penalties to Duke Energy. It is estimated that 94% of the ash settled to the bottom of the river, which raises concerns about the future safety for wildlife and fish (Connors 2015). Coal ash can bury benthic organisms and their food; it can cause toxicological issues for aquatic animals due to high levels of metals (FWS 2014). The North Carolina legislature enacted the Coal Ash Management Act in September 2014 (NCGA 2104).

TABLE 10.8. Water quality standards and literature values (micrometers/liter) for measured toxicity of selected chemicals on selected pelagic species (Sources: 2009 DWQ standards (current in 2015) 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 in [2B .0211 & .0220]; N = 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

TABLE 10.9. 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 (g/l)[1]		Hard clam (g/l)[1]		NC surface saltwater standards
	Acute	Chronic	Acute	Chronic	(ug/L)
Aldrin (insecticide)	15	0.1	-	202.5	0.003
Arsenic (metaloid)	500	-	-	-	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	-	-	0.002
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 numerical standard, but use "no toxics in toxic amounts" T15A NCAC 2B .0208 to control substances not listed in rules.

10.3.3.2. Endocrine disruptors impacts on aquatic life

Many compounds used in products to improve our lifestyles, such as antibiotics, cleaning supplies, hand sanitizer, flea control, lawn pesticides and herbicides, can enter the environment with significant environmental and human health effects. 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 (DeFur and Foersom 2000; Weis and Weis 1989; Wilbur and Pentony 1999). Endocrine disrupting chemicals include some industrial chemicals, pesticides, metals, flame retardants, plasticizers, disinfectants, prescription medications, pharmaceuticals, and personal care products. These contaminants have been found in wastewater, surface water, and groundwater in the United States and other countries (Giorgino et al. 2007; Kolpin et al. 2002; Shea et al. 2001).

Some effects documented from exposure to these contaminants include: decreases in reproduction, altered sexual development or "gender bending," antibiotic resistance, and changes in population structure, or localized extinction of species. These chemicals are human generated, persistent in the environment, and can be active at very low levels (P. McClellan-Green, NCSU, pers. com. 2010).

Kidd et al. (2007) found exposure of fathead minnows to estrogens and mimics downstream of wastewater outfalls to cause feminization of males and reproductive alterations leading to near population extinction, suggesting that EDC can affect the sustainability of fish populations. Estrogenic and estrogen-like compounds can potentially affect molting, growth, mating, reproduction, and development of crustaceans (B. Roer, UNCW, pers. com. 2010). Decreased reproduction, increased vitellogenesis, and sperm abnormalities have been documented in oysters, clams, and scallops exposed to human hormones or hormone-like substances (Canesi et al. 2008; Gagne et al. 2002; Matozzo et al. 2008; Wang and Croll 2006). In studies looking at mixed contaminants in marina harbor pollutants and sewage, altered sex ratios, impaired immune function, delayed growth and development, and decreased reproduction were observed in mussels (Gagne et al. 2007; Gagne et al. 2002).

In North Carolina, the USGS conducted limited monitoring for endocrine disrupting chemicals in freshwater reaches of the Tar, Neuse, and Cape Fear river basins (Giorgino et al. 2007); estuaries were not targeted. Prescription and non-prescription drugs, flame retardants, plasticizers, fragrances, pesticides, detergent metabolites, antimicrobial agents, and other suspected endocrine disruptors were detected. 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. Typical municipal wastewater treatment processes are not capable of removing hormones, antibiotics, and other EDCs, making sewage effluent a major source (Giorgino et al. 2007).

10.3.3.3. Pesticide impacts on aquatic life

Pesticides and herbicides can be toxic to aquatic organisms or act as endocrine disruptors. The most commonly applied pesticides in agricultural areas of the North Carolina Coastal Plain include atrazine and metolachlor (McCarthy 2003; McCarthy et al. 2007). These pesticides are among the most frequently detected in streams of the Tar-Pamlico River Basin (Woodside and Ruhl 2001). Atrazine was detected in 38 – 92% of samples annually in the Tar-Pamlico basin during 1992 – 2001, and metolachlor was detected in 73 – 100% of the samples each year during the same period (McCarthy 2003; McCarthy et al. 2007; Woodside and Ruhl 2001). 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. 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 (Harned et al. 1995).

Studies in Texas have shown atrazine to affect the larval stages of red drum. Red drum spawn in coastal waters and their larvae utilize estuarine areas along the coast of North Carolina that can be affected by runoff of atrazine. Exposure to atrazine, even at a sublethal level, can lead to significantly reduced growth rates causing the duration of the larval period to be longer, potentially leading to an increase in cohort mortality (del Carmen Alvarez and Fuiman 2005). Exposed larvae swim faster and are more hyperactive leading to more lethal encounters with predators; higher metabolic rates could potentially lead to starvation (del Carmen Alvarez and Fuiman 2005; McCarthy and Fuiman 2008). A study in the Albemarle-Pamlico region indicated that the presence of any pesticide had a detrimental effect on larval (megalopae) and juvenile blue crabs (*Callinectes sapidus*); juvenile crabs had an increased frequency of mortality within 6 hours of molting compared to the control group (Osterberg et al. 2012).

The Department of Agriculture and Consumer Services administers the NC Pesticide Law of 1971 and North Carolina Pesticide Board-adopted regulations, including crop spraying practices. Policies on drift from aerial applications affect the potential for toxin contamination in coastal waters and associated chronic and acute effects on fish populations. Rules prohibit aerial application of pesticides under conditions that will potentially result in drift and adverse effects to non-target areas. Deposition of pesticides labeled toxic or harmful to aquatic life is not permitted in or near waterbodies.

Insecticides can have a negative impact on macroarthropods, which are important to the ecology of wetland systems (freshwater and estuarine). The effect of an individual insecticide on a particular group of arthropods is based on the phylogeny of the species and the class of chemicals used (Halstead et al. 2015). In Halstead et al. (2015) freshwater macroarthropods were comparatively less affected by organophosphates, such as malathion. The same chemicals, especially malathion, have sublethal effects on arthropods in the estuary (e.g., *P.pugio*) for all stages (Lund et al. 2000).

10.3.3.4. Fossil fuels impacts on aquatic life

Water quality begins to degrade under the presence of oil, making fauna more susceptible to other stress factors such as disease (Giles et al. 1978). Fish can uptake oil products through their gills following a spill (Jung et al. 2009); oil can prevent eggs from hatching, limit the growth rate of small fish, and prevent fish from returning to previously utilized spawning habitat (Peterson 2001; Peterson et al. 2003c). Tar balls, partially degraded patches of oil, 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).

Exposure to hydrocarbons can be toxic to or alter development of oyster embryos and larvae (Geffard et al. 2003). Oyster spat development on shell covered in petroleum has been shown to decline, although barnacles tended to flourish with reduced competition (Roberts et al. 2008; Smith and Hackney 1989). In general, oysters recover from small-scale spills, but with larger spills during a period of highest settlement, recovery is hindered by the presence of oil (Hulathduwa and Brown 2006).

Shellfish are good indicators of contaminants due to their abilities to accumulate chemicals, including PAHs, in their soft tissues (Jackson et al. 1994). Blue mussels, *Mytilus edilus,* have shown slowed growth rates when exposed to oil due to reduced feeding rates and food absorption efficiency (Widdows et al. 1987) (Mu-Chan et al. 2007). While oil can have negative impacts on shellfish, laboratory experiments have shown that they have the ability to eliminate PAHs once removed from contaminated water and placed in clean water (Enwere 2009). These results are consistent with other studies showing shellfish reducing PAH levels in varying time periods (2-120 days) depending on the type of oil and the length of exposure (Boehm et al. 1998; McIntosh et al. 2004; Pruell et al. 1986; Richardson et al. 2005).

Wetland plants can be smothered by oil reaching the shoreline, leading to increased shoreline erosion (Culbertson et al. 2008; Peacock 2007). In low energy anaerobic areas, oil can persist. In Wild Harbor, Massachusetts, residual oil and the effects of the *Florida* barge spill were evident 40 years after the spill (Frysinger et al. 2003; Peacock et al. 2005; Reddy et al. 2002; Sanders et al. 1980; Slater et al. 2005; Teal et al. 1978; Teal et al. 1992). Elevated levels of crude oil have been shown to decrease stem density, reduce photosynthesis rates and shoot height (Lin and Mendelssohn 2008).

With the exception of oil and gas development,[18] the primary threats to water quality at hard bottom sites are ocean dumping and pollution from the discharge of sewage, stormwater runoff, herbicides, and pesticides (SAFMC1998a). North Carolina (EMC) regulations 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. Hard bottom in close proximity to shore is more vulnerable to pollutants than offshore hard bottom. 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.

10.3.3.5. Other toxins impacts on aquatic life

Polymers are organic compounds such as polyacrylamides (PAM) and the Smart Sponge being used as soil erosion control. These substances are synthetic and designed to increase the soil's available pore volume, flocculate suspended sediments, increase retention of sediment, oil and gas products, and in some cases, bacteria. The compound can be used in fiber check dams, filter bags, or applied directly to a side bank or ditch. They can be used as BMPs for disturbed soils that discharge to a sediment trap or basin. In its anionic state, PAM is not considered toxic to aquatic, soil, or crop species when used as directed (http://water.epa.gov/polwaste/nps/agriculture/upload/2003_09_24_NPS_agmm_chap4f.pdf). The toxicity is related to a monomer associated with PAM known as acrylamide (AMD); AMD is present in PAM as a contaminant of the manufacturing process. Acrylamide can be toxic to aquatic organisms; however, LC50 values are 4-5 times higher than what is indicated for application (Barvenik et al. 1996). Effects on aquatic biota are buffered if the water contains sediments, humic acids, or other impurities (Barvenik et al. 1996). Improper application or degradation over time could result in toxic products entering surface waters and impacting the nervous system of aquatic organisms.

[18] Refer to the Energy Development section for more information on the effects of oil and gas development.

10.3.3.6. Resident time

The residence time of chemicals in soft bottom sediment is chemical dependent. Oil reaching the bottom may persist for years (Olsen et al. 1982). Lead compounds from gas additives commonly sink to the bottom (Chmura and Ross 1978). The half-life of pesticides like malathion, parathion, endosulfan, fenvalerate, chlorpyrifos-methyl, methanidathion, and diazinon in seawater ranges from 2.2-17 days (Cotham Jr. and Bidleman 1989; Lacorte et al. 1995; Walker 1977). This must be considered in areas affected by severe weather. After Hurricane Floyd in 1999, pesticide concentrations in the upper Pamlico River estuary declined by a factor of ten, while concentrations in the lower estuaries increased slightly (D. Shae, NCSU, pers. com. 2005). A year following Floyd, however, the overall concentration of current-use pesticides was comparable to pre-hurricane levels (D. Shae, NCSU, pers. com. 2005).

10.3.4 Microbial contamination

10.3.4.1 Bacterial contamination

Bacterial contamination of the water column, sediments, and surrounding ecosystems refers to the presence of fecal bacteria derived from warm-blooded animal waste. The main concern with bacterial contamination is not ecological but the potential human health hazard that fecal bacteria presents. While the majority of the fecal bacteria are not dangerous, they are associated with pathogenic bacteria, viruses, and protozoans such that exposure can potentially lead to a higher risk of contracting an illness (Curriero et al. 2001; EPA 2006; Gaffield et al. 2003). Exposure to fecal bacteria through direct contact with water or consumption of shellfish are correlated with gastrointestinal illnesses (Feng P. 2013; Haile et al. 1999; NOAA 2008).

Enteric pathogens are monitored indirectly using indicator organisms from the suite of coliform bacteria, specifically fecal coliform bacteria (FCB). Coliform bacteria is a group of Gram-negative, facultative anaerobic bacillus bacteria that ferments lactose producing acid and gas within 48 hours at 35°C; FCB are a subset that ferment lactose at elevated temperatures between 44-45°C (Feng P. 2013; USEPA 2006). Fecal coliform bacteria are composed of species from genera such as *Enterococcus, Escherichia*, *Klebsiella*, *Citrobacter*, and *Enterobacter* (Vymazal 2005). These species are used as proxies for the pathogens as they originate from the same source and tend to be more numerous therefore making them safer and cheaper to enumerate (USEPA 2006). Common indicator organisms monitored in estuarine and saltwaters are *E. coli* and *Enterococcus* (USEPA 2006).

Non-human fecal sources can include, cows, hogs, deer, chickens, waterfowl (especially geese), dogs, cats, rats, gulls, beaver, raccoons, and pigeons (Byappanahalli et al. 2012; NRCD 1993). Human health risks associated with bacterial contamination vary depending on the source, but generally bacterial contamination from animals poses less risk than human waste (Calderon et al. 1991; Soller et al. 2010). Mostly undeveloped creek systems can show high levels of fecal contamination from wildlife (Bohn and Buckhouse 1985; Niemelä and Niemi 1989; Niemi and Niemi 1991; Walter and Bottman 1967). Pettiford Creek in Croatan National Forest (Line et al. 2008) and several primarily undeveloped tidal creek systems in the New River estuary (Stumpf et al. 2010) have been shown to contribute large amounts of bacteria to their respective systems.

In urban areas, wildlife can also contribute to microbial contamination. Retention ponds in the coastal Carolinas can harbor large amounts of fecal bacteria from wildlife, potentially affecting adjacent waters (Siewicki et al. 2007). In these areas, tidal creeks and surrounding marshes act as refuges for wildlife due to human activity within watersheds resulting in higher FCB (Siewicki et al. 2007; Whitaker 2004). The largest contributor of domesticated animal waste affecting bacterial contamination in urban areas is dogs (Ervin et al. 2014; Wright et al. 2009).

In the more agricultural areas of a watershed, domesticated animal fecal contamination comes largely from grazing livestock and the spread of manure on fields as fertilizer. Much of the livestock in North Carolina are in CAFOs, with the majority concentrated in the Cape Fear and Neuse River watersheds (Mallin 2000). Hog farms are abundant and are probably the biggest concern to watersheds (Heaney et al. 2015; Wing et al. 2000); poultry CAFOs are also abundant (Mallin 2000; Mallin and Cahoon 2003). Cattle CAFOs are less of a concern for North Carolina, although also a source of fecal contamination (Mallin and Cahoon 2003). Animal wastes from these operations are either dried and spread on fields as fertilizer (poultry) or pumped into holding ponds and the liquid sprayed onto fields (swine) (Mallin and Cahoon 2003). Higher fecal bacteria counts are found downstream of these farming operations than upstream (Heaney et al. 2015; Mallin et al. 2000b).

Pollution associated with CAFOs is often caused by spills or ruptures to the waste lagoons. Due to weather or mismanagement, there have been several such cases in North Carolina (Mallin et al. 2000b). Burkholder et al. (1997) showed that fecal contamination from a 25 million gallon, 23 mile long hog waste spill into the New River lasted in the sediment for months. On the Cape Fear River the same year, (1995) poultry (Duplin County) and hog (Brunswick County) waste spills led to elevated FCB counts in the water column for several days (Mallin et al. 1997). Following hurricanes in 1998 and 1999, there were several spills from lagoons caused by overflow that elevated FCB counts (Mallin 2000; Wing et al. 2002).

Human sources of fecal contamination include septic tank leaching/failing drain fields, wastewater treatment plants, and discharge from boats (Cahoon et al. 2006; Conn et al. 2012; Habteselassie et al. 2011; Kirby-Smith and White 2006; Mallin 2010; Mallin et al. 2007; Mallin et al. 2009a; Mallin and McIver 2012; Sobsey et al. 2003). In more developed counties, sewage systems can become stressed during peak times. In 2005, approximately 3 million gallons of raw sewage was spilled into Hewletts Creek in New Hanover County, causing increased FCB counts in the water column and sediments for months (Mallin et al. 2007). Less developed counties, such as Brunswick and those in the Outer Banks, are more affected by septic failures (Cahoon et al. 2006; Mallin 2010; Mallin and McIver 2012). High water tables, ditching, and sandy, porous soils can lead to contamination of adjacent waters (Cahoon et al. 2006; Mallin and McIver 2012). This contamination can be exacerbated by the density of the systems (Duda and Klimek. 1982). Occasionally, discharge from boat heads at marinas or in open waters can contribute to increases of FCB (Kirby-Smith and White 2006; Mallin et al. 2009a; Sobsey et al. 2003).

The amount of FCB in the water column correlates strongly with weather conditions. Increases in impervious surfaces means less infiltration and filtering of runoff, and during wet periods the amount of FCB found for a given area can be an order of magnitude greater than under normal dry conditions (Coulliette and Noble 2008; Mallin et al. 2001b; Mallin et al. 2009b; Noble et al. 2003; Parker et al. 2010; Patni et al. 1985; Stumpf et al. 2010). In New Hanover County, Mallin et al. (2001b) found a significant positive correlation between rainfall and higher FCB counts, observed in both urban and rural creeks (Line et al. 2008; Mallin et al. 2009b). During dry periods, FCB tend to be much lower due to lack of runoff (Coulliette et al. 2009; Mallin et al. 2001b; Mallin et al. 2000b; Noble et al. 2003).

Once FCB have entered the waterway, the survival is dependent on a number of factors and they can potentially persist for extended periods (Mallin et al. 2007; Toothman et al. 2009). In many cases the water column will return to normal limits within a few days to weeks. The decrease in FCB numbers can be due to a number of reasons, including predation by protozoans, breakdown by UV radiation, dilution by tidal cycles, temperature, salinity, and sedimentation. The decrease of FCB due to sedimentation is a concern. Fecal bacteria have been shown to attach to particles in the water column thereby increasing their rate of deposition into the bottom (Fries et al. 2006; Fries et al. 2008). Their fate and transport is affected by the settling and resuspension of the associated particles (Fries et al. 2006; Russo et al. 2011). Since FCB are protected from UV radiation once in the sediments, and have a number of essential nutrients for survival, bacterial contamination due to sedimentation can persist for months (Chudoba et al. 2013; Mallin et al. 1997; Mallin et al. 2007). Submerged aquatic vegetation also acts as a refuge for FCB, in much the same way as sediments; FCB are protected from UV radiation by the SAV and there are likely increased nutrients available (Badgley et al. 2010). When compared to sediments and water column, SAV had significantly higher densities of Enterococcus sp. (Badgley et al. 2010). Major storms, such as hurricanes, (Burkholder et al. 2004; Mallin et al. 2002a; Mallin and Corbett 2006), wind events, trawling, and boat wakes can resuspend sediments and associated bacteria. Resuspension of sediment impaired by bacterial contamination (closed to shellfish harvest) could potentially result in the transport of high concentrations of bacteria to open shellfish waters.

10.3.4.2. Effect on coastal habitats

Bacterial contamination alone is not a detriment to coastal habitats. However, increased sediment loading and turbidity, and nutrient input, algal blooms, and BOD have all shown strong relationships with elevated FCB numbers (Mallin et al. 2001b; Mallin et al. 2009a; Mallin et al. 2000b). With an increase in nutrients and FCB in the water column and soft bottom habitats from sewage spills, CAFOs, septic leaching, etc., anoxic and eutrophic conditions can occur. In 1995, a hog waste lagoon spill in the New River resulted in extremely low DO and a fish kill extending for over 20 miles (Burkholder et al. 1997). That same year a poultry waste lagoon spill resulted in a fish kill in one of the creeks that drain into the Northeast Cape Fear River (Mallin et al. 1997). There are studies that show poor water quality due to increased nutrient loads and sedimentation can affect nearshore and offshore hard bottom fish habitats (SAFMC 1998a). However, there is little consensus on what the effects of fecal loading are, and in many cases, runoff signatures (e.g., FCB) are only found at sites closest to inlets Futch et al. (2011). There is less known about the effects of fecal contamination on offshore hard bottom habitat.

In North Carolina, the major concern with fecal contamination is the potential human health hazard present, especially as concerns shellfish waters. Many tidal creeks and estuaries in North Carolina are classified as “impaired” under the CWA 303(d) listing due to elevated FCB levels and are closed to the harvest of shellfish. Monitoring of FCB levels are determined by multi-tube fermentation (APHA methods). The state standard for FCB in shellfish waters is 14 CFU/100mL (geomean), and growing areas are evaluated tri-annually to determine if they are exceeding this standard. It should be noted that significant portions of closed shellfish waters are located in areas not suitable for shellfish propagation and maintenance due to salinity or other conditions. There are also some closed areas that have robust oyster populations (C. Peterson, UNC, pers. com. 2015). Some closed shellfish harvesting waters may have significant value as shell bottom habitat. Research is currently underway to address the question of oyster condition in closed areas and to evaluate the potential function of these areas as sanctuaries in the southern region (T. Alphin, UNCW, pers. com. 2015). Similar work is needed in the central and northern regions. Some NGOs have sponsored research sanctuaries in closed areas. The location of high quality oyster beds in shellfish growing areas was assessed and summarized in Haines (2004).

For areas that are conditionally approved, each growing area is under a management plan and is closed based on rainfall totals determined from historical sampling data. These areas are in the southern and central regions, corresponding with the most productive shellfish waters (lower Pamlico Sound through the South Carolina border), as well as the part of the state undergoing the most rapid urbanization (North Carolina Coastal Futures Committee 1994b). No part of the northern region is under a management plan. Runoff from large rain events can lead to the temporary closure of shellfish waters due to elevated fecal loads. Depending on the rain event, close to 40,000 acres of shellfishing waters may be closed (from Cedar Island to the South Carolina line). Closures can last days to months based on the amount of rainfall and area sampled. Occasionally, single samples that indicate exceptionally high levels of *E.coli* result in the closure of shellfish waters until levels return to acceptable limits.

Fecal contamination, in general, is decreased by groundwater infiltration and the presence of natural or constructed wetlands. A recent study of constructed wetlands has shown a marked decrease (53-59%) in fecal loading to a tidal creek in New Hanover County (Mallin and McIver 2012; Shirazi 2011). An improvement was also shown to the runoff entering Hewletts Creek after it had passed through a constructed wetland; fecal loading was reduced from 38% to up to 99% depending on the rain event sampled. Greater reductions were seen in warmer months and attributed to the presence of more vegetation. Golf courses have also been shown to reduce fecal loading into the headwaters of some tidal creeks under normal flow conditions (Mallin and Wheeler 2000).

10.3.5. Ocean Acidification

Increasing global concentrations of atmospheric CO_2 directly influence ocean acidity, which may have ecological consequences on a variety of ecosystems, notably nearshore benthic environments (Wootton et al. 2008). Estuaries are susceptible to acidification because they are less buffered than oceans and influenced by multiple carbon sources. Researchers have identified a variety of acidification impacts on SAV, shell bottom, and water column. Present research has not elucidated direct effects of ocean acidification on hard bottom, wetland, or soft bottom habitats, rather indirect impacts on transient species (e.g., calcifying organisms, trophic cascades, etc.).

10.3.5.1. Submerged Aquatic Vegetation (SAV)

Submerged aquatic vegetation may have conflicting responses to increased carbon. High CO_2 and subsequent low pH are known to increase primary productivity of photosynthetic organisms, including seagrasses (Alcoverro et al. 1999; Beer and Koch 1996; Beer and Rehnberg 1997; Björk et al. 1997; Invers et al. 2001; Jiang et al. 2010). However, these same conditions may reduce presence of calcareous epiphytes, therefore making seagrass more susceptible to predation (Hall-Spencer et al. 2008). Compounding predator defense limitations is a noted decrease in phenolic substances associated with lower pH (Arnold et al. 2012). In marine plants, phenolics offer structural and chemical defenses against predation, therefore acidic conditions may increase the value of seagrass as forage (Arnold et al. 2012).

10.3.5.2. Hard Bottom

The ocean acidification process can have severe consequences for marine calcifying organisms that inhabit hard bottom, such as hard corals, gorgonians, calcareous algae, mollusks, sponges, echinoderms, and calcitic plankton, such as such as foraminifera and coccolithophorids (Feely et al. 2004; Hoegh-Guldberg et al. 2007; Kleypas et al. 2006; Orr et al. 2005). Effects include reduced rates of calcification (shell and reef formation), diminished growth rates, hindered larval development and settlement, and thinner shell formation (Feely et al. 2004; Gazeau et al. 2007; Hoegh-Guldberg et al. 2007; Kleypas et al. 2006; Kurihara 2008; Kurihara et al. 2007; Roberts et al. 2006). In addition, calcifying organisms may be unable to maintain exoskeletal structures in waters that are under-saturated with respect to carbonates, ultimately resulting in dissolution of their calcium carbonate skeletons (Orr et al. 2005). Thus, the density and diversity of calcifying organisms on hard bottom are likely to decline with acidification of coastal waters (Hoegh-Guldberg et al. 2007; Orr et al. 2005).

10.3.5.3. Shell Bottom

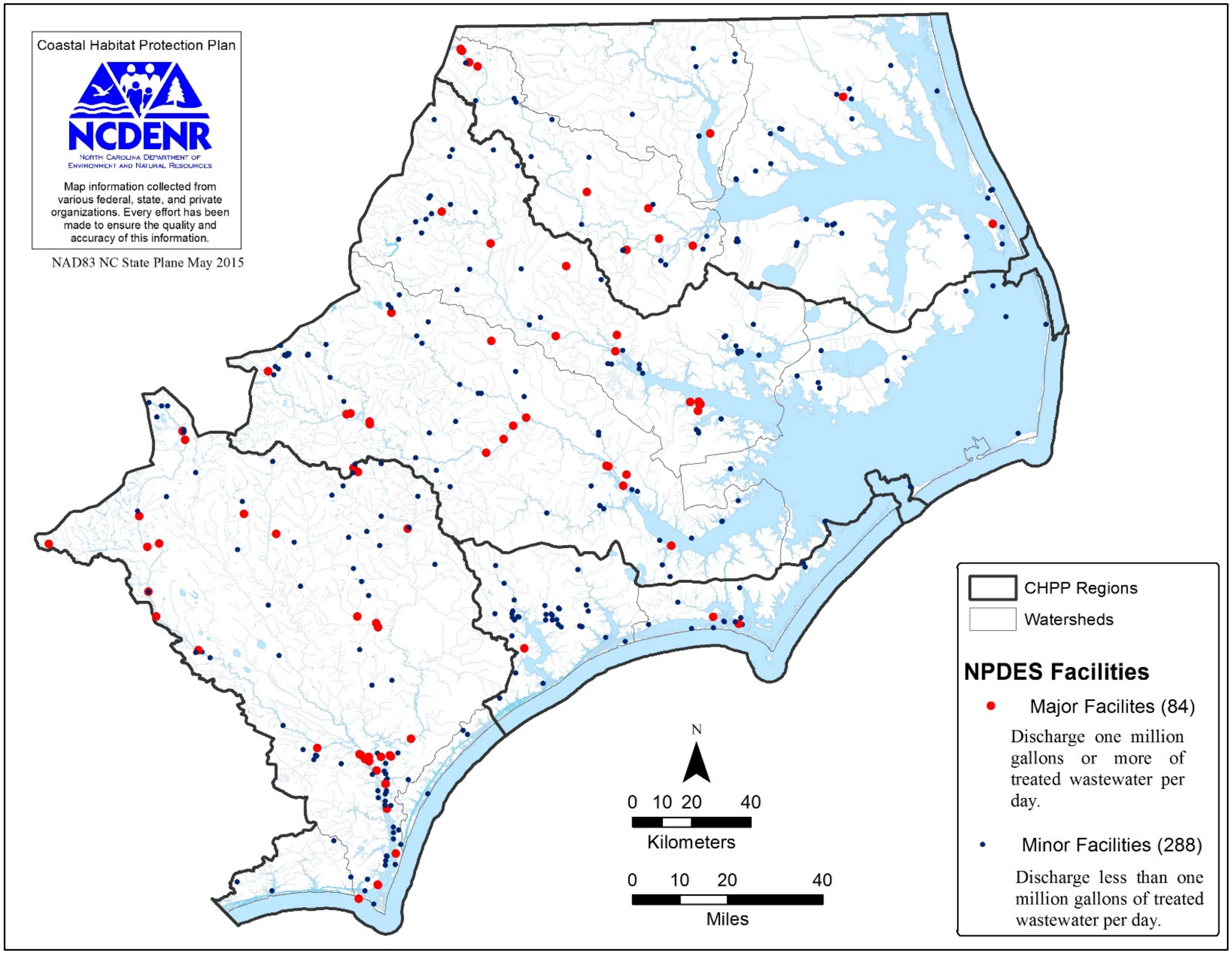
Many marine organisms that produce calcium carbonate shells or skeletons are negatively impacted by increasing CO_2 levels and decreasing pH in seawater. For example, oysters exposed to prolonged elevated CO_2 levels (hypercapnia) have been found to have reduced shell mass, tissue mass, and shell hardness (Beniash et al. 2010). Further, juvenile mollusks under hypercapnic conditions have high mortality and reduced somatic growth rates (Beesley et al. 2008; Ellis et al. 2009; Gazeau et al. 2007). Weaker and small shells over time increases juvenile mollusk susceptibility to predation and other mortality factors

(Kennedy et al. 1996a; Newell et al. 2000; Newell et al. 2007). Negatively impacted recruitment, growth, and survival rates may implicate intrinsic reef development and shell budget over time.

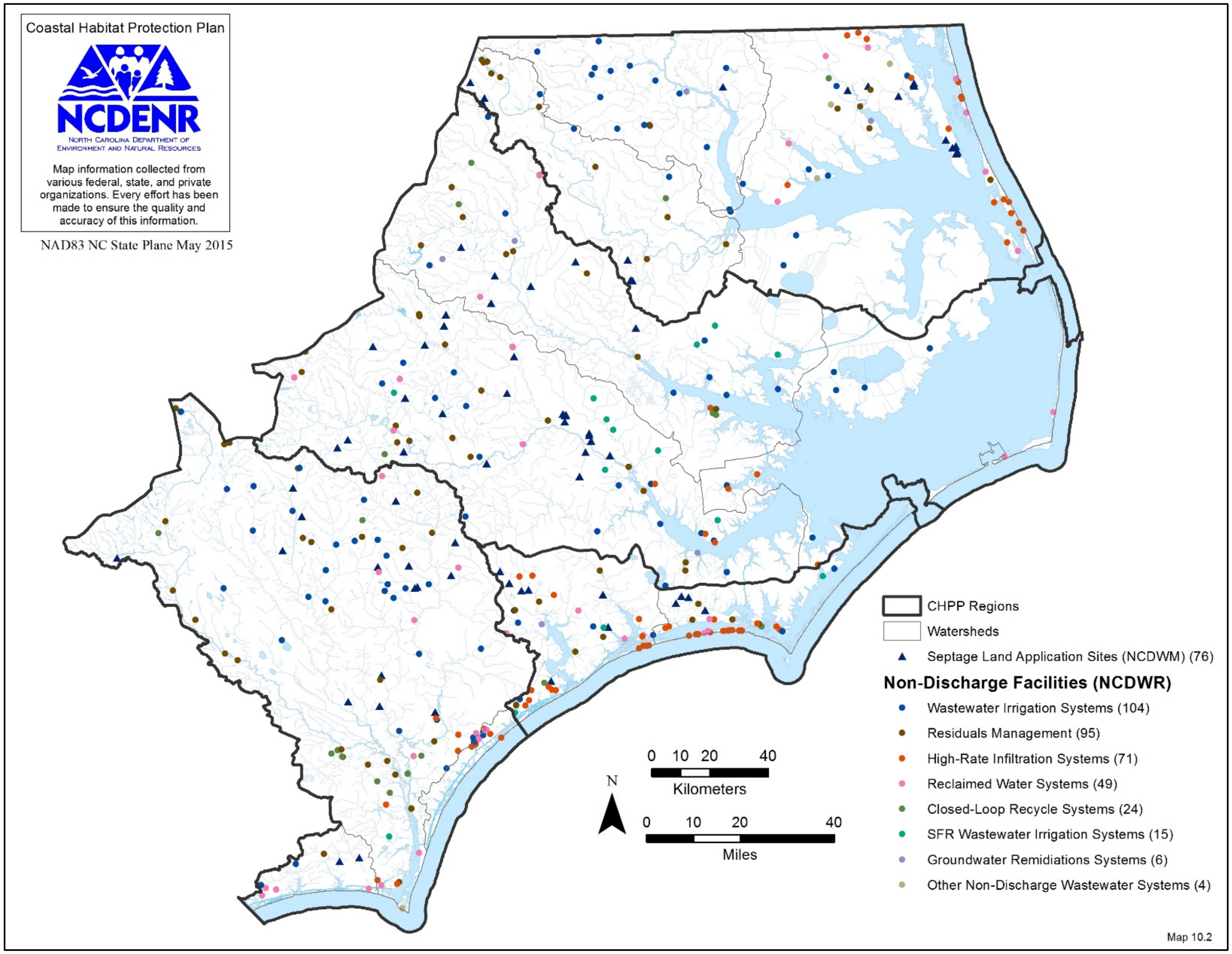
10.3.5.4. Water Column

Dissolved CO_2 influences the water column. Chemical changes associated with pH shifts can limit the bioavailability of iron (Fe) to phytoplankton (Shi et al. 2010). This may have a cascading effect on trophic interactions, as phytoplankton are primary producers in marine food webs. Conversely, eutrophication may lead to water column acidification as a product of respiratory CO_2 (Gypens 2010). These antagonistic processes may counter each other, though the interaction has not been studied. The impacts of environmentally relevant concentrations of CO_2 on zooplankton are also unclear.

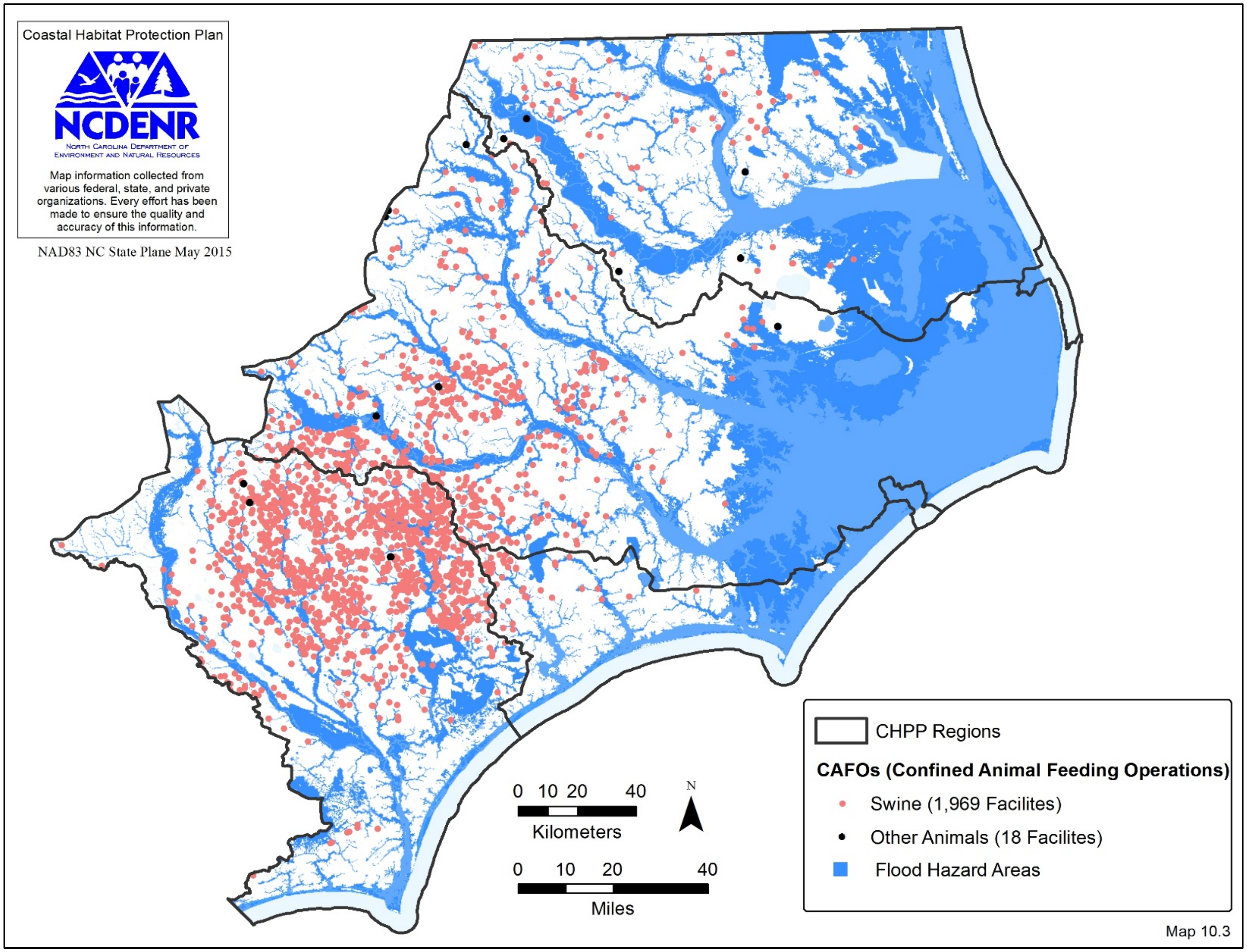
In June 2002, the North Carolina General Assembly acted toward reducing emissions from power plants through the Clean Smokestacks Act. Under the act, power plants were required to reduce nitrogen oxide emissions 77% by 2009, and sulfur dioxide emissions 73% by 2013. The 2014 final report on the Clean Smokestacks Act prepared by DENR states that Duke and Progress Energy met the emissions limitations set out and were in accordance and compliance with the act at that time (Commission 2014).



MAP 10.1. NPDES facilities within the CHPP regions.



MAP 10.2. Non-discharge facilities and septage land application sites within the CHPP regions.



MAP 10.3. Confined animal feeding operations within the CHPP regions.

CHAPTER 11. ADDITIONAL STRESSORS

11.1. Non-native, invasive, or nuisance species

In 2014, a multi-agency committee was formed and charged with developing a plan for management of aquatic nuisance species (ANS) (NCDENR 2015). The committee's purpose was to improve the state's ability to address issues associated with aquatic invasive and nuisance species in a way that would have measurable and meaningful results. The plan was drafted in accordance with the National Invasive Species Act of 1996 (Congress 1996), which encouraged individual states to create their own plans and established a federal-level Aquatic Nuisance Species Task Force to review and approve state plans. The North Carolina Aquatic Nuisance Species Management Plan (NCANSMP) of 2015 provides an overview of current ANS policies and agency responsibilities, details the known attributes and scope of the impacts of ANS, provides a classification of actual and potential ANS, and identifies issues that are hampering more effective action to reduce the incidence and spread of ANS (NCDENR 2015).

> The committee's findings include the following: there is a general lack of both spatial and biological information about existing ANS and their impacts, there is no systematic reporting mechanism or monitoring procedure in place, little research has been conducted on the economic implications of ANS introduction and proliferation and control efforts are underway on various fronts – though they are seldom done in coordination with other efforts. For these reasons, the committee has recommended that a standing Aquatic Nuisance Species Task Force (ANSTF) be established to coordinate reporting, control and monitoring of existing and new ANS occurrences (NCDENR 2015).

Invasive species are plants, animals and other organisms (pathogens, fungi, etc.) that are not native to an ecosystem and may cause economic or environmental harm. Non-native species introductions are a growing and imminent threat to living aquatic resources throughout the United States. The introduction of such species puts the health and viability of North Carolina habitats at risk. There is widespread documentation that some non-native species can out-compete native species, altering the established ecosystem (Burkholder et al. 2007b; Mallin et al. 2001c). Non-native species enter North Carolina waters through release from aquaria and mariculture facilities, boat movement, discharge of ballast water, attachment to fishing gear, and through association with other non-native species (Carlton 2001; Sea Grant 2000). In particular, fish species are often introduced deliberately, for sport-fishing purposes (catfish) or for aquatic weed control (grass carp). These introductions can have unintended negative consequences.

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 to introduce native species when such species originates outside of the state's boundaries, are subject to T15A NCAC 03I .0104. An application must be submitted to the DMF Director for the Director to "determine the level of risk to any native marine resource or the environment." The WRC also has authority, based on G.S. 113-274 and G.S. 113-292, to regulate and permit the transportation, purchase, possession, sale, or stocking of species within its jurisdiction. It is illegal to stock fish into public waters, or to transport live freshwater nongame fishes, or live game fishes in excess of the possession limit, or fish eggs, without a permit (T15A NCAC 10C .0209). The WRC also prohibits possession of certain exotic species (T15A NCAC 10C .0211).

In 2004, the Coast Guard published regulations establishing a mandatory ballast water management (BWM) program for ships headed to the U.S. These regulations require vessels to maintain a ballast water management plan specific to that vessel. The regulations increased the number of vessels subject to these provisions by expanding the reporting and recordkeeping requirements on ships, which increased the Coast Guard's ability to determine the patterns of ballast water movement as required by the

National Invasive Species Act of 1996. This rule changed the voluntary BWM program to a mandatory one, requiring vessels to conduct mid-ocean ballast water exchanges (BWE), to retain their ballast water onboard, or alternatively, to use a Coast Guard approved, environmentally sound, BWM method (USCG 2009). After it was determined that 60% of U.S. ships do not travel 200 nautical miles offshore, as required in the former rules, and BWE was not always effective in removing non-native organisms (USCG 2012), the regulations were again updated. In 2012, new discharge standards were developed and a new approval process put in place to set allowable concentrations of living organisms in ballast water.

Foreign organisms in ballast water discharged 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 (human illness from consumption of shellfish contaminated with certain red tide toxins) with increased translocation of non-native dinoflagellates via ships' ballast and the import/export of shellfish. In Australia, the sudden appearance of dinoflagellate cysts was tied to the exportation of woodchips (Hallegraeff 1998), an industry active in North Carolina.

The Australian spotted jellyfish, *Phyllorhiza punctata*, was found in Bogue Sound and Sunset Beach in 2006 (T. Moore, DMF, pers. com.). In October of 2012, another was spotted, also in Bogue Sound, west of Peletier Creek (T. Moore, DMF, pers. com.). This jellyfish has an average diameter of around 50 cm (1.64 ft), can consume large amounts of plankton, eggs, and larvae, and is known to foul fishing gear. The Australian spotted jellyfish is thought to have arrived in the U.S. attached to ships or in ship ballast water in the Gulf of Mexico (Botton and Graham 2004).

Another species thought to have arrived in the United States via ship ballast water is the Asian shore crab (*Hemigrapsus sanguineus*). This crab is indigenous to the western Pacific and has been reported in most Northeastern states, including North Carolina. This species occupies the same habitat as native mud crabs and may compete with them for food or living space (USGS 2014).

The 2010 Ocean Policy Report, produced by the Coastal Resources Commission's Ocean Policy Steering Committee, Sea Grant, and the Division of Coastal Management (DCM) identified marine aquaculture as an emerging issue in which the primary concern was the escapement of farmed fish. The report recommended that the state conduct a technical assessment of marine aquaculture in its coastal ocean waters, and further, that if the federal government passes a national offshore aquaculture act, for DCM policies to be developed accordingly. Species farmed in aquaculture facilities that often escape include blue and Nile tilapia (*Oreochromis aureus, O. niloticus*). There are reports of tilapia being captured in the Neuse and Cape Fear River drainages, although none in the coastal area (USGS 2014).

Aphanomyces invadans, a water mold thought to be the major cause of the characteristic lesions that commonly afflict Atlantic menhaden in North Carolina estuaries, is an invasive species from the western Pacific. This fungal pathogen infects schooling species in low-salinity and freshwater. Held responsible for ulcerative fish diseases worldwide, it includes red spot disease (RSD) in Australia, epizootic ulcerative syndrome (EUS) in Asia, and mycotic granulomatosis (MG) in Japan. It is suspected that *A. invadans* was introduced to the U.S. via the northern snakehead fish (*Channa argus*) from China, because the genetic make-up of the two strains of water mold are identical (Blazer et al. 2002).

11.1.2. Invasive Plants

A major non-native species issue in wetlands is the spread of *Phragmites australis* (*P. australis,* common reed) into salt/brackish marshes (Weinstein and Balletto 1999). Since the early 1900s, *P. australis* has been replacing other salt/brackish marsh vegetation along the Atlantic coast at a rate of about 1% to 6% per year (Weinstein and Balletto 1999). Although *P. australis* is a native and ubiquitous species, it is thought that its rapid spread is due to introduced strains (Saltonstall 2002). *P. australis* forms dense, monotypic stands of vegetation, possibly altering fish use of the marsh. Research in the northeast and mid-Atlantic found no clear observed effect on shrimp, mummichogs and large fish when the non-native vegetation initially invaded a native *Spartina alterniflora (S. alterniflora,* smooth cordgrass) marsh (Able and Hagan 2000; Fell et al. 1998; Meyer et al. 2001). However, as the vegetation became more established, the substrate became elevated and flattened, with fewer depressions for holding water (Able et al. 2003; Rooth and Stevenson 2000). Higher elevations and dense vegetation associated with *P. australis* marshes have 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).

A study in the Chesapeake Bay (Posey et al. 2003) compared benthic communities associated with *P. australis* and *S. alterniflora* ecosystem (high marsh, low marsh, rivulets, and hummocks). In the microhabitat studied, the benthic infaunal communities were not greatly affected. Weis and Weis (2003) observed a similar result for the nekton community observed, but a reduced larval mummichog abundance in *P. australis* compared to *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 Maryland's 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 litter accumulation and below-ground accumulation from root biomass of *P. australis* were responsible for rapid and substantial increase in substrate elevation. The elevation increase appeared to modify the habitat in a way that made it less accessible to estuarine species over a short period of time.

11.1.3. Invasive Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) can get in boat propellers and water intakes, entangle fishing gear, and inconvenience swimmers. Despite this, it is critically important for fish and other aquatic organisms, and provides ecosystem services such as protection from erosion and storm surge. Many economically important fish and shellfish in North Carolina are highly dependent on SAV for food and shelter. However, there are non-native invasive submerged grasses that can cause detriment to the ecosystem. Many of these can be transported from one system to another on boats, trailers and other equipment. Invasive non-native species form dense beds, making swimming, fishing, and boating difficult; clog water intake systems for municipalities and industries; and impede water flow in drainage canals. Moreover, dense beds of Eurasian watermilfoil (*Myriophyllum spicatum)*, a submerged rooted grass, can cause the water column to become anoxic at night, stressing fish or causing them to leave the area. Although these nuisance species provide some benefits to fish, such as refuge and sediment stabilization, they can negatively impact natural habitat by shading or out-competing other native SAV species, which may have greater value to fish (DWR 1996).

The Department of Environment and Natural Resources is charged with the regulation of noxious weeds in the Aquatic Weed Control Act of 1991 (Article 15 113A-220). By virtue of the regulations created following the act (T15A NCAC 02G .0600), DWR implements the Aquatic Weed Control Program (AWCP), which focuses primarily on non-native invasive species in freshwater lakes, ponds, and rivers.

The AWCP responds to requests for assistance from local governments, public utilities and other agencies, providing technical and financial assistance (50:50 cost share). Aquatic plants listed as noxious vary by year, and can be found on the above web page. The species most pertinent for DMF in 2013 included Hydrilla (*Hydrilla verticillata*), alligator weed (*Alternanthera philoxeroides*), Eurasian milfoil, and common reed (*Phragmites australis*). Hydrilla has been documented in many of the North Carolina coastal rivers and the Albemarle Sound.

Once invasive plants are introduced into a system it typically requires years of management to eliminate them. Hydrilla management in Lake Gaston cost ~$800K to control and Lake Waccamaw approximately

350K. The Lake Waccamaw hydrilla project is estimated to cost ~$2.5M to complete.

Historically, weed control activities in coastal waters were primarily focused on Eurasian watermilfoil. Control activities target areas where native species are not the dominant species based on site assessments. 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, NCDOA, pers. com.). General Statute 113-300.1 states that WRC has authority to regulate, prohibit or restrict use of poisons or pesticides severely affecting wildlife resources (including SAV). Further, an Attorney General review in 1995 found that MFC had authority under 143B-289.3(b) to regulate use of pesticides on SAV. The DWR has developed an NPDES permitting requirement to regulate the use of pesticides based on the area and amount of pesticides that will be used each calendar year (NCG560000). Permit conditions include minimizing discharges to state waters by applying pesticides at or below the highest rate allowed by the label, performing regular maintenance to reduce leaks or spills, and reporting requirements if federal threatened or endangered species or critical habitats are adversely impacted.

Gracilaria vermiculophylla is an exotic and invasive rhodophyte (red algae) believed to have arrived in North Carolina around 2000. It is native to the northwest Pacific coast and thought to have arrived to the Atlantic coast by way of imported shellfish. It is considered nuisance algae which fouls fishing gear, boat motors, water intakes, and negatively impacts native habitat. This algae is now found in many North Carolina estuaries inhabiting shallow, low energy sounds and lagoons, tidal creeks, and marsh edges, but also inhabits harbors and inlets (Nyberg et al. 2009; Thomsen et al. 2007b). *G. vermiculophylla* is sometimes confused with native *G. tikvahiae* as the two are morphologically very similar. The two may be distinguished by examining their shape of the thalli; *G. tikvahiae* thalli are flattened while *G. vermiculophylla* are round (Freshwater et al. 2006; Thomsen and McGlathery 2005).

G. vermiculophylla is well adapted to North Carolina estuaries. It is tolerant to a wide range of salinities, temperatures, and light regimes suggesting that it is likely to persist wherever it becomes established (Freshwater et al. 2006; Nyberg and Wallentinus 2009; Thomsen et al. 2006; Thomsen et al. 2009; Weinberger et al. 2008). It has been observed to proliferate in multiple habitats including mudflats, oyster reefs (Thomsen et al. 2007a; Thomsen et al. 2009), and SAV meadows (Cacabelos et al. 2012; Holmer et al. 2011; Martínez-Lüscher and Holmer 2010; Thomsen et al. 2013). The algae spread quickly through sexual reproduction and fragmentation, with spores settling and growing from attachments on hard objects such as shells and rocks. The algal thalli fragment easily from hydrodynamic shearing forces and may be transported passively by currents, growing from locations where they become entangled or partially buried. Humans can be responsible for translocation when transporting fragments by fishing gear, ballast tanks, and recreational activity (Freshwater et al. 2006; Nyberg and Wallentinus 2009).

G. vermiculophylla adds structure and rugosity to mudflats which may provide improved habitat for some species. Small invertebrates, grazers, and larval species take advantage of the cover and edge habitat provided by anchored tufts of the algae (Aikins and Kikuchi 2002; Falls 2008; Lipcius and Stockhausen 2002; Nyberg et al. 2009; Thomsen 2010). This positive effect may be nullified in habitats where *G. vermiculophylla* causes increased hypoxia (Bell and Eggleston 2005; McGlathery 2001; Thomsen et al. 2013). A polychaete tube worm frequently found in estuarine mud flats, *Diopatra cuprea*, incorporates fragments of the drifting algae into its tube casing. Thomsen and McGlathery (2005) demonstrated a mutualism between *Diopatra* and *G. vermiculophylla*. Diopatra facilitates the spread of *G. vermiculophylla* and provides an anchorage for drifting algae where it continues to grow. The growing alga provides cover which attracts small prey for the carnivorous tube worm. In that study, 70% of the algae found on the mudflat were growing from *Diopatra* tube caps.

Seagrass may be particularly vulnerable to *G. vermiculophylla* invasion. Increases in turbidity, sulfide, hypoxia, and shading have negative and synergistic impacts on seagrasses (Holmer et al. 2011; Martínez-

Lüscher and Holmer 2010; McGlathery 2001; Thomsen et al. 2013). Thomsen and McGlathery (2005) speculated that this association could lead to a transition from mudflat or SAV meadow to stabilized *G. vermiculophylla* meadows. This novel habitat type may provide some of the habitat functionality of seagrass beds (Falls 2008; Lipcius and Stockhausen 2002; Thomsen 2010), however, mats of entangled algae have been documented smothering seagrasses (Holmer et al. 2011) and damaging salt marsh as they wash ashore.

Nuisance species are not always introduced. Examples of native nuisance species include macroalgae and "animal grass" (*Zoobotryon verticillatum)*, a bryozoan, that sometimes overwhelms SAV in high salinity waters (T. Murphy, DMF, pers. com.). In 2007, animal grass was abundant in some high salinity waters. The overabundance of animal grass appears to occur in drought years in high salinity areas. Though animal grass 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. Excessive macroalgae growth (drift algae or epiphytic), has also been shown to negatively impact productivity of SAV (Kemp et al. 2004).

The additional benefits sometimes derived from non-native species can diminish if the species becomes too prolific. In Texas, researchers compared the refuge benefits of Eurasian milfoil and Widgeon grass (*Rupia maritima*) for grass shrimp (*Palaemonetes* spp.) when juvenile blue crabs (*Callinectes sapidus*) were present. When blue crabs were present, the grass shrimp were more likely to choose the Eurasian milfoil due to its denser canopy providing greater cover (Valinoti et al. 2011).

Invasive plants are often introduced by activities like "hitchhiking" on boats, trailers, or other equipment being moved from one location to another. Many aquatic plants can regenerate from a fragment, as well as being released intentionally (R. Emens, DENR, pers. com.). Increasing public awareness of aquatic weeds, and aquatic invasive species in general, is paramount to a more proactive and preventative management approach. The DWR, in cooperation with WRC, has posted signs at over one hundred public boating access areas, intending to educate boaters and encourage them to clean and dry their equipment prior to going to other locations.

11.1.4. Invasive Fish

Non-native fish can be introduced deliberately or accidentally. Blue catfish (*Ictalurus furcatus*) and flathead catfish (*Pylodictus olivaris*) have been introduced to North Carolina to attract anglers. Flathead catfish are native to some rivers in North Carolina, but were introduced into others, most notably the Cape Fear in 1966, to enhance sport-fishing. By 1976, they had established a sustainable population (Guier 1981). While blue catfish were introduced into Virginia rivers, it is unknown how they arrived in Albemarle Sound. Although this introduction has economic benefits, it can also have negative environmental consequences, mainly involving changes to biodiversity and the food web. In North Carolina, flathead catfish do not target native species, but they are opportunistic feeders (Pine et al. 2005). Both species are apex predators, primarily consuming other fish, including potentially large quantities of river herring (*Alosa* spp.), most of which are severely depleted (Schloesser et al. 2011).

The blue catfish population is expanding in the Albemarle Sound and its tributaries. The number of adult and sub-adult blue catfish caught in the Albemarle Sound Independent Gill Net Survey has risen from 86 in 2008 to over 2,000 in 2013 (NCDMF 2015b). Flathead catfish do not appear to be an issue in the Albemarle Sound region, but they have been collected by DMF throughout coastal waters (NCDMF 2015b). The negative impact of flathead catfish on native fish populations has been estimated for the Cape Fear River at 5-50%, varying by trophic (Pine III et al. 2007). Although both catfish species are popular sportfish, neither DMF nor WRC have regulations for the taking of invasive catfish commercially in North Carolina, but market demand is low. In addition, there are a number of public health advisories recommending against the consumption of larger catfish, due to the presence of contaminants such as dioxin, mercury and PCBs. As apex predators, these fish accumulate contaminants in their tissues. The effect these species are having on North Carolina fishes is unclear, but the DMF River Herring FMP recommends that the impacts be studied further.

The successful invasion of Indo-Pacific lionfish (*Pterois volitans* and *P. miles* complex) in the South Atlantic Bight is a threat to the hard bottom ecosystem health and biodiversity (Hamner et al. 2007; Meister et al. 2005; Whitfield et al. 2007). These species grow and mature quickly; reproduce often; produce an egg mass in a protective secretion; and are exceptional predators, all characteristics that accelerate invasion success (Diller et al. 2014). Lionfish were first documented in marine waters off North Carolina in 2000; by 2001, they 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). Current research in North Carolina locates the highest densities of lionfish from 38 to 46m with year round residency limited to temperatures greater than 15.3°C and depth greater than 27 meters of seawater (Whitfield et al. 2014). Laboratory experiments conducted by Kimball et al. (2004) concluded that lionfish feeding halted at 15.3°C, lethargic and stationary behavior occurred at 13°C, and perish at 10°C. Whitfield et al. (2014) noted no presence of lionfish in waters below the 15.3°C threshold. These tolerances restrict lionfish in North Carolina to deeper and warmer waters, suggesting water temperature is responsible for distribution in North Carolina (Kimball et al. 2004).

P. volitans and *P. miles* are nearly identical in morphology, with *P. volitans* accounting for 93% of collections in the Atlantic and North Carolina (Hamner et al. 2007). Lionfish have a general or opportunistic carnivorous diet that changes due to prey availability (Muñoz et al. 2011). As individual size increases, prey size increases, with the smallest individuals feeding on a greater volume of crustaceans and smaller benthic finfish such as gobies and blennies (Muñoz et al. 2011). 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%. Further, Albins (2015) observed negative effects on density, biomass and localized species richness on small fishes along larger, continuous patch reefs in the Bahamas. This small size class includes juveniles of larger and prey species for larger bodied piscivores. These findings suggest that an increasing lionfish population on North Carolina hard bottoms has the potential to decrease the abundance of juvenile and smaller bodied reef dwelling species, as well as increase 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) and there are growing instances of moray eels attacking and consuming injured lionfish (Pimiento et al. 2012), (Jud et al. 2011). Diller et al. (2014) conducted predation experiments by tethering lionfish in various habitats, with predation responses elicited from nurse sharks and Nassau grouper. These reports, along with numerous anecdotal reports, indicate that the invasive predators may be susceptible to predation. However, large piscivores are systematically targeted by commercial and recreational fisheries. Staff at the NOAA Center for Coastal Fisheries and Habitat Research has been conducting studies on lionfish to better understand distribution, density, life history, temperature tolerances, and genetics. Reporting of lionfish captured by rod and reel, as well as sightings by divers is encouraged by NOAA.

As temperate-tropical transition zones, such as North Carolina, experience increasing ocean temperatures, there is potential for lionfish to invade near shore and estuarine habitats, at least seasonally. Lionfish have been able to inhabit a wide variety of systems, from ocean depths of 300m to shallow brackish waters (Jud et al. 2015). This could drastically alter the estuarine and juvenile community structure. Many species important to commercial and recreational fisheries spend some portion of their life in the estuaries. Species that utilize the estuaries as nursery habitat could be severely impacted if lionfish, even seasonally, occupy the estuaries. Species such as *Mycteroperca microlepis* (gag grouper), *Archosargus probatocephalus (*sheepshead), *Cynoscion nebulosus* (spotted seatrout), *Orthopristis chrysoptera* (pigfish), *Leiostomus xanthurus* (spot), *Micropogonias undulatus* (Atlantic croaker), *Sciaenops ocellatus* (red drum), *Lagodon rhomboides* (inshore pinfish) and *Paralichthys (*flounders) utilize the estuary at some point in their life history. Lionfish have been observed in tropical estuarine habitats such as mangroves (Barbour et al. 2010) and seagrass beds Claydon et al. (2011), and Jud et al. (2011) documented the invasion of lionfish into the Loxahatchee River estuary near Jupiter, Florida. Continuing research into the alteration of invaded systems and the potential for expansion into estuaries and other nursery areas is of growing interest.

Grass carp (*Ctenopharyngodon idella*) are often introduced into reservoirs in order to control other invasive species, often hydrilla and other alien plant species. They have been successfully used for hydrilla control in many southeastern reservoirs, resulting in the reduction and elimination of hydrilla and the return of native vegetation (Manuel et al. 2013). However, these carp have also escaped from stocked ponds and reservoirs into some river systems in North Carolina, which can significantly impact native freshwater SAV. Stocking grass carp (even triploid, non-reproductive individuals) is controversial because they can cause long-term depletions in vegetation (Cassani et al. 2008). North Carolina requires that only sterile triploid grass carp be used for stocking because of their potential damage to submerged vegetation. However, a study in the Chesapeake Bay found that although stocking of only sterile grass carp has been allowed for over 20 years, 18% of the non-native grass carp were not sterile (Schultz et al. 2001). In North Carolina the WRC issues permits for the stocking of triploid grass carp that have gone through a USFWS inspection. This inspection includes the testing of 120 randomly selected fish in the presence of a USFWS inspector. If one carp is not triploid, the lot fails and another test must be completed. The DMF reviews stocking permits in areas that have potential for escapement. In areas where there is a high risk of escapement the DMF does not support the stocking of grass carp or they may request that a barrier be constructed to reduce the risk of escapement. According to DMF unpublished data, there have been 73 grass carp collected during DMF sampling from 1995 to 2012. Currently, the WRC and DMF have been working to update grass carp stocking guidelines.

11.1.5. Shellfish

Bioinvasions of zebra mussels (*Dreissena polymorpha*) had not been reported in North Carolina as of 2008, but they had been in Virginia and Tennessee, as well as 23 other states (Benson and Raikow 2008). Zebra mussels are notorious for their biofouling capabilities, frequently clogging water intake pipes and smothering native mussels and large crustaceans (e.g., 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 2008b). 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 2008b). 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.

Several candidates for non-native oyster introduction have been considered, such as the Suminoe oyster (*Crassostrea ariakensis*) (DMF 2008b; USACE 2008). Laboratory and field trials have shown rapid growth and survival in the Middle and South Atlantic Bights (Bishop and Peterson 2005; NRC 2003; Richards and Ticco 2002; VIMS 2007), and overboard tests in Newport River 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 (Peterson 2005). Also, *C. ariakensis* was documented to have a significant level of tolerance to the parasite-induced diseases Dermo and MSX during initial studies in the Chesapeake Bay (Paynter et al. 2008; Richards and Ticco 2002; USACE 2008). However, in other studies, the Suminoe oyster was shown to be vulnerable to Dermo infections (Moss et al. 2006; Schott et al. 2008), *Bonamia* spp. (Audemard et al. 2008a; Audemard et al. 2008b; Carnegie et al. 2008), predation by blue crabs (Bishop and Peterson 2006), *Polydora* spp. infestations (Bishop and Peterson 2005), and the ichthyotoxic dinoflagellate *Karlodinium veneficum* (Brownlee et al. 2006; Brownlee et al. 2008). Because of these susceptibilities, the ANSMP placed the Suminoe oyster in the 2015 category of species considered as "high risks" of becoming nuisances should they arrive in the state (NCDENR 2015).

A draft Programmatic Environmental Impact Statement (PEIS) was completed by the USACE concerning the use of non-native oysters for fishery and ecosystem restoration in the Chesapeake Bay (USACE 2008). The PEIS highlighted three alternatives to investigate more thoroughly. Concerns over non-native oyster introduction included 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 (DMF 2008b; USACE 2008). In November 2008, the MFC wrote a letter commenting on the PEIS, expressing concern that the project in the Chesapeake Bay would likely result in an unwanted introduction of the Suminoe oyster into North Carolina waters. In 2009, officials from Virginia and Maryland concluded that the potential benefits associated with Asian oysters outweighed the ecological risks.

In 2012, the USACE issued the Record of Decision (ROD) on the proposal to introduce the nonnative Suminoe oyster, and continue efforts to restore the native Eastern oyster (USACE 2012). After considering all available information and the input of stakeholders, the lead agencies concluded that Alternative 8a was the preferred approach for restoring the Chesapeake Bay oyster population. This alternative used a combination of alternatives involving only the native Eastern oyster *(Crassostrea virginica).* The Preferred Alternative was identified as the alternative that would cause the least damage to the biological and physical environment, and best protect, preserve, and enhance historic, cultural, and natural resources. The Preferred Alternative 8a consists of the following elements:

> *Alternative 2 (Enhanced Native Oyster Restoration)* - Expand, improve, and accelerate Maryland's oyster restoration and repletion programs, and Virginia's oyster restoration program in collaboration with Federal and private partners. *Alternative 3 (Harvest Moratorium)* - Implement a temporary harvest moratorium on native oysters and an oyster industry compensation (buy-out) program in Maryland and Virginia or a program under which displaced oystermen are offered on-water work in a restoration program. *Alternative 4 (Expansion of Native Oyster Aquaculture)* - Establish and/or expand State-assisted, managed or regulated aquaculture operations in Maryland and Virginia using the native oyster species (USACE 2012).

Tiger shrimp *(Penaeus monodon),* a non-native shrimp species, have been observed in NC waters since 1988 (T. Murphy, DMF, pers. com.) when they were believed to have been released accidentally from an aquaculture facility in Bluffton, SC (Kingsley-Smith and DNR 2013). Tiger shrimp have been observed from North Carolina to Texas. Although impacts are not definitive at this time, tiger shrimp may pose a disease threat to native shrimps. The DMF has been recording reported observations of tiger shrimp in North Carolina waters since 2008. Public encounters are reported to DMF and confirmed if possible (Table 11.1). The majority of the shrimp reported occurred in southern catches after Hurricane Irene in August of 2011, which may be a result of local news stories after Hurricane Irene, or a potential offshore spawning community. The USGS is investigating a potential community by collecting and genetically testing individuals to determine their relationship (P. Fuller, USGS, pers. com.).

TABLE 11.1. Reported observations of tiger shrimp in NC since 2008.

	Confirmed[1]		
Year	Yes	No	Total Number of reported tiger shrimp
2008	12	4	16
2009	10	10	20
2010	1	4	5
2011	54	203	257
2012	26	8	34
2013	26	9	35
2014	12	9	21

Reported tiger shrimp not confirmed may still be tiger shrimp.
[1]Confirmed by DMF and NC Coastal Federation staff.

11.2. Diseases and microbial stressors

11.2.1. Diseases and microbial stressors not associated with specific habitats

North Carolina's coastal habitats are occasionally susceptible to varying diseases and microbial stressors. Causative agents of these diseases include algae, dinoflagellates, protists, protozoa, and other toxins. The primary habitats impacted by diseases and microbial stressors are shell bottom and SAV, although some toxins can be present in all habitats.

11.2.1.1. Domoic Acid Toxicity (DAT)

Domoic acid toxicity (DAT) is the result of ingesting naturally occurring alga and diatoms commonly associated with members of the genus *Pseudo-nitzschia*. These organisms create the neurotoxin, domoic acid. Algal toxins accumulate in planktivorous organisms which subsequently cascade up the food web to collect into harmful concentrations in apex predators. Domoic acid intoxication has been linked as the likely causative agent involving large mortalities of marine mammals in North Carolina (Lefebvre and Robertson 2010).

Domoic acid also has the potential to affect human populations through ingestion of fish and shellfish containing the toxin. "In North America, domoic acid has been responsible for several deaths and both permanent and transitory illness in more than 100 people" (http://wdfw.wa.gov/).

11.2.1.2. Ciguatera Fish Poisoning

Various species of dinoflagellates create the neurotoxins associated with ciguatera poisoning. Predatory reef fish such as snappers, groupers, and barracudas are some of the most toxic fishes consumed by humans. Animals in higher trophic levels tend to have higher concentrations of the toxin due to the fact that toxin producing dinoflagellates are consumed by herbivorous fish and the toxin concentrations are biomagnified up the food web (Friedman et al. 2008). The condition normally manifests with a plethora of gastrointestinal problems but can also be associated with other neurologic and cardiovascular presentations. Most cases of these poisonings in North America are in the Caribbean. With the higher frequency of documented subtropical species in North Carolina (Tester et al. 2013) (Munoz, R., NOAA, pers. com.), and possibility of warming waters, cases of ciguatera poisoning could become more frequent over time.

11.2.1.3. Neurotoxic Shellfish Poisoning (NSP)

Neurotoxic Shellfish Poisoning (NSP) is a disease caused by consumption of molluscan shellfish contaminated with brevetoxins primarily produced by the dinoflagellate, *Karenia brevis*. Brevetoxins are a group of more than ten natural neurotoxins produced by the marine dinoflagellate, *K. brevis* (Duagbjerg 2001). Blooms of *K. brevis*, called Florida red tide, occur frequently along the Gulf of Mexico (Watkins et al. 2008).

K. brevis is naturally occurring in the Gulf of Mexico, Caribbean Sea and along the New Zealand coast; it regularly produces blooms along the coasts of Florida and Texas. This environmental phenomenon is a harmful algal bloom (HAB) known as “Florida red tide” (Kusek 1998; Steidinger 1975). Blooms of red tide can appear red, brown, or simply darkened due to the dense aggregation of cells which often includes several species of unicellular algae. Although *K. brevis* has a lower thermal tolerance and is more frequent in late summer and early fall, Florida red tide has been documented to occur in almost every month of the year (Heil and Steidinger 2009). In 2006, a bloom off the coast of Sarasota (Florida) lasted over 12 months. On a global scale, HABs, including *K. brevis*, may be increasing in frequency, duration and geographic range in all aquatic environments (Stumpf et al. 2008; Van Dolah 2000; Vrieling et al. 1995).

The first recorded blooms of red tide from the Gulf of Mexico were in the 1840’s (Magana et al. 2003; Moore 1881). The largest reported outbreak of NSP in the US occurred in North Carolina after *K. brevis* was carried into that region (Fowler and Tester 1989; Morris et al. 1991; Sobel and Painter 2005). It began in October 1987 when a *K. brevis* bloom became entrained in the Gulf Stream off eastern Florida and was transported up the eastern seaboard (Fowler and Tester 1989). This was the first recorded red tide (*K. brevis*) in North Carolina, and caused 358,993 acres (145,280 hectares) of shellfish growing waters to be closed between November 2, 1987 and January 21, 1988. These closures affected 98% of the clam harvesting areas. The economic loss to the coast was estimated at $25 million and had its greatest impact on the clam fishermen. Clam landings were less than half of the previous year and caused a $2 million reduction in dockside value (Tester and Fowler 1990). There were 48 people with confirmed neurotoxic shellfish poisoning (NSP), most of the cases (35) occurring before the first shellfish closure on November 2 (Tester et al. 1988).

K. brevis cells are motile and attracted to light; therefore they concentrate on the surface of the water during the day where their distribution can be affected by cloud cover, wind, and tide (Tester and Fowler 1990). The FDA recommends shellfish closures when cell counts are higher than 5,000 per liter (Tester and Fowler 1990). *K. brevis* produces a neurotoxin that accumulates in filter feeding shellfish such as clams, oysters, whelks, mussels, conch, coquinas, and other filter-feeding molluscs. Mild to severe nausea, vomiting, diarrhea, chills, dizziness, numbness, and tingling of the face and extremities can occur within three to four hours (mean onset time) after consumption of contaminated shellfish (Tester et al. 1988).

North Carolina shellfish relay efforts intensified From December 1987 through March 1988 when North Carolina had its first occurrence of red tide in inside waters. The governor of North Carolina and director of the Division of Marine Fisheries (DMF) initiated an assistance program to aid full-time commercial shellfishermen who had become unemployed as a result of the red tide disaster. Fishermen were paid $1 per bushel, at a maximum of $100 per day and $500 per week, for gathering oysters and clams from areas designated as polluted by the DMF, and transporting them to locations open for harvest. Relay permits were issued to 146 qualified commercial shellfishermen. Throughout the harvest season, the central region of the state had an average 25 to 30 participants working daily under these permits (J. French and T. Piner, NCDMF, pers. com.).

Former DMF Director, Bill Hogarth considered the relay a "valuable program," as it not only provided immediate economic help for the affected community, but also provided additional resources for harvest once the shellfish went through the depuration process. Between the dates of December 15th and 23rd, 1987, 16,725 bushels were relayed, which paid shellfishermen $16,725 by December 24th. Relaying operations continued through the harvest season (S. Murphy and J. Holland, DMF, pers. com.). The director of DMF stated, through a news release, that relay operations closed on March 18, 1988 due to the decreased number of participants and quantity of readily available polluted oysters.

The DMF has a contingency plan in place as required by the FDA, including a monitoring program and management plan. The DMF also has a contingency plan for aerial surveillance of offshore waters, collecting samples, and closing and patrolling areas closed to harvest due to red tide (P. Fowler, NCDEH-SS, pers. com.). The following language is from the National Shellfish Sanitation Program Model Ordinance, regulating the closure and reopening of shellfish growing waters following red tide events:

> A shellfish growing area or portion thereof shall be placed in the closed status for the taking of shellstock when the number of toxin-forming organisms in the growing waters and/or the level of biotoxin present in shellfish meats are sufficient to cause a health risk. For neurotoxic shellfish poisoning (NSP), the harvesting of shellstock shall not be allowed when:
>
> (1) The concentration of NSP equals or exceeds 20 mouse units per 100 grams of edible portion of raw shellfish; or
>
> (2) The cell counts for *Karenia brevis* organisms in the water column exceed 5,000 per liter.

The closed status shall remain in effect until the authority has data to show that the toxin content of the shellfish in the growing area is below the level established for closing the area. The determination to return a growing area to the open status shall consider whether toxin levels in the shellfish from adjacent areas are declining. The analysis upon which a decision to return a growing area to the open status is based shall be adequately documented (P. Fowler, NCDEH-SS, pers. com.).

11.2.2. Shell bottom habitat diseases and microbial stressors

11.2.2.1. Dermo disease

The protozoan pathogen *Perkinsus marinus* (henceforth, "Dermo"), has been responsible for major oyster mortalities in North Carolina in the past. Dermo, a protist similar to dinoflagellates, causes degradation of oyster tissue. Once infected, oysters suffer reduced growth, diminished reproductive capacity, and ultimately mortality resulting from tissue lysis and occlusion of hemolymph vessels (Ford and Figueras 1988; Ford and Tripp 1996; Haskin et al. 1966; Ray and Chandler 1955). Dermo infects a disproportionate amount of larger, more fecund individuals (Andrews and Hewatt 1957; Mackin 1951; Ray 1954). While Dermo primarily infects the eastern oyster, *Crassostrea virginica*, it has also been reported in the mangrove oyster *C. rhizophorae*, the pleasure oyster *C. corteziensis*, and the Pacific oyster, *C. gigas*.

Infected oysters can range from Maine to Florida along the east coast of the Atlantic, into the Gulf coast of the United States and continuing into Mexico and Venezuela. Parasites thought to be *P. marinus* have been found in oysters from Jamaica, Puerto Rico, Cuba, Brazil, and Hawaii, although only significant mortalities have been reported in Hawaii.

Prevalence of Dermo has a pronounced seasonal cycle in the eastern oyster. Infection rates generally increase with water temperature and salinity (Ewart and Ford 1993; Paynter and Burreson 1991). Salinities below 10 parts per thousand (ppt) are energetically stressful to Dermo. Dermo disease has caused significant oyster mortality throughout the species' geographic range (Andrews 1988; Hargis Jr. and Haven 1988; Kennedy 1996; Lenihan et al. 1999b). 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 had been rare or absent (Burreson and Ragone Calvo 1996; Tarnowski 2003). Environmental stressors, such as low dissolved oxygen, sediment loading, and anthropogenic pollution, increase the susceptibility of oysters to parasitism and disease (Barber 1987; Kennedy et al. 1996a; Lenihan et al. 1999b). Changes to environmental conditions as a result of anthropogenic activities can also affect disease-related oyster mortality. Activities such as inlet dredging artificially increase salinities (SAFMC 1998b), creating conditions more favorable to oyster pathogens.

In 1989 DMF began operating a small laboratory to diagnose Dermo infections. All diagnoses were made using the rectal thioglycolate method described by (Ray 1952). New categories of infection intensity were applied to all existing Dermo samples in this analysis based on recommendations from oyster disease experts at the Virginia Institute of Marine Sciences (VIMS) (E.M. Burreson, VIMS, personal communication, 2007). Intensity of Dermo is rated by counting number cells per field under the microscope; 10's-light, 100’s-moderate, 1000's-heavy. A weighted incidence (W.I.) is then determined and is used for comparison of intensity levels of other sites. Weighted incidence is determined by multiplying the number of lightly infected individuals by 1, the number of moderate by 3, and the number of heavy by 5. Those numbers are then added together and divided by the number of individuals in the sample (NCDMF 1989). Categories of infection intensity are established using weighted incidence values based on (Mackin 1962), except only three breakdowns are used: uninfected = no infected oysters in sample; 0.1-1.5 = low; 1.51-2.5 = moderate; and >2.5 = high. Low, moderate, and high refer to the expected mortality rates at the respective infection intensities. Weighted incidence values range from 0 to 5. Samples with moderate and high categories of infection intensity are expected to have mortality rates that significantly affect harvest if optimum conditions for parasitic growth and dispersal persist.

Although both Dermo and MSX (to be discussed later) have been documented in North Carolina’s estuaries, Dermo has been responsible for the majority of adult oyster mortality in recent years (DMF 2008b). 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 2008b). Conversely, Dermo prevalence has remained near 100% coast wide during that same time period (Figure 11.1), although disease-related mortality has been relatively low (DMF 2008b). 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, unpublished data, 2010).

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 2008b), indicating possible pathogen regulation of spawning stock and recruitment potential. Some research results suggests that North Carolina oysters are developing an increased tolerance to Dermo infections (Brown et al. 2005).

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 driver of higher survival of oysters in the southern estuaries at Dermo infection intensities similar to Pamlico Sound stocks (DMF 2008b).

Research on experimental subtidal oyster reefs in the Neuse River estuary (Lenihan et al. 1999b) 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.

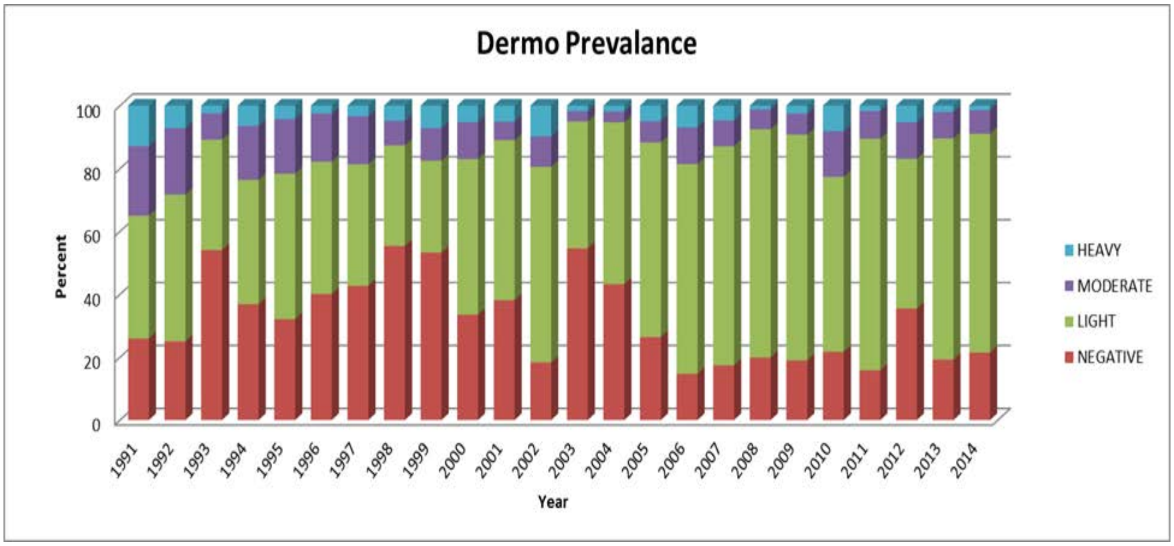


FIGURE 11.1. Infection categories and proportion of individuals infected by Perkinsus marinus in North Carolina 1991-2014 (DMF unpublished data).

Monitoring of Dermo disease by DMF shows a declining trend in heavy prevalence, with an increasing trend in overall infection. These trends, when compared to discrete samples such as those taken in 1992 which have similar percentages of negative infections, could substantiate the possibility that perhaps native oyster populations are able to cope with minor presences of Dermo without suffering negative impacts; however, there is no scientific proof at this time. 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 tolerant" 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. The seeding of sanctuaries and restoration sites with disease tolerant oysters could enhance oyster survivability and provide disease tolerant broodstock for repopulating highly impacted areas.

11.2.2.2. Multinucleated Sphere Unknown (MSX) disease

Multinucleated Sphere Unknown, or MSX, is the name of the disease associated with the single-celled Protozoan parasite, *Haplosporidium nelsoni*. Plasmodia are the most common life stage of *H. nelsoni* found in oysters (ICES 2010). *H. nelsoni* spores are rarely found in adult oysters and are more common in juveniles with advanced infections (ICES 2010). The pathogen MSX originally caused oyster populations to experience high mortality rates in the 1950s in Delaware Bay and Chesapeake Bay, and is still prevalent today. It is believed to have been introduced by experimental transfers of the Pacific oyster, which is resistant to this disease. Further, MSX can infect all ages of oysters (Andrews 1966; Barber et al. 1991). Infected oysters have truncated reproductive potential, caused by carbohydrate deficiency from reduced feeding rates. This, in turn, inhibits normal gametogenesis in the spring, causing reduced fecundity. Succptible species include the Eastern Oyster (*C. virginica*), rarely the Pacific oyster (*C. gigas*).

MSX has been document along the East Coast of North America from Nova Scotia, Canada to Florida, USA. Infected oysters are present along the west coast of the US in the Pacific oyster, *C. gigas*, where it is rare and has not caused noticeable mortality (ICES 2010).

The parasite is highly sensitive to salinity. Salinities below 10 ppt are lethal to MSX when persisting for two weeks or more (DMF 2008b; La Peyre et al. 2006; VIMS 2002). The parasite is expelled from oysters during high runoff periods when salinities drop precipitously. There is an observable seasonal cycle in which the infection is most often acquired, from May through October. The parasites multiply most rapidly in the summer months and result in host mortalities in the late summer and autumn (ICES 2010).

In North Carolina, MSX was originally found in Crab Slough and Wysocking Bay of Pamlico Sound in 1988. The two sites, Crab Slough in Dare County and Wysocking Bay in Hyde County, had high infection levels during 1988 but showed little or no infection in 1989. A total of 11 of the 36 sites sampled in 1989 were positive for MSX. Only two sites, Middle Ground and Great Island, showed infections at levels causing mortality. Sampling conducted by the North Carolina State University (NCSU) College of Veterinary Medicine during 1990-1992 indicated no high intensity MSX infections (unpublished data). Analyses from 1989 to 1992 were conducted using hemolymph analysis (Burreson et al. 1988). Occasional sampling during 1993-1995 did not indicate any infections and since 1996, heavy rainfall from intense hurricane activity has reduced Pamlico Sound salinities to the point that sampling has been deemed unnecessary.

Though DMF has stopped monitoring MSX, a recent was study done by (Wilbur et al. 2012), using quantitative polymerase chain reaction (PCR) to determine the prevalence and intensity of MSX at seven sites in North Carolina. These sites were Buxton, Crab Hole, Legged Lump, West Bluff, White Oak, New River, and Hewletts Creek. All seven locations revealed evidence of the parasite, with some locations having high intensities (Wilbur et al. 2012). This research noted that the trigger and prevalence related to the disease emergence are still unknown.

11.2.2.3. Bonamia spp.

One of the most recent subjects of study is the emergence of a novel oyster parasite, the protistan parasite *Bonamia exitosa*. The official notice that *Bonamia* infects *C. virginica* wasn't announced until September 11, 2013, from William and Mary's Virginia Institute of Marine Science and Rutgers New Jersey Agricultural Experiment Station (Carnegie 2013). Due to the pathogen's damage to some hosts, it has been placed on the World Organization for Animal Health (OIE) list of notifiable pathogens (Carnegie 2013).

B. exitosa is a protistan parasite which infects oyster tissue. The specific method of infection is through the oyster's hemocytes, or blood cells. Once transmission occurs, infection can cause inflammation of tissues which compromises structure and function (Carnegie 2013). *B. exitosa* was originally described from New Zealand in association with the oyster *Ostrea chilensis* (Hine et al. 2001). Associated mortality in *Crossastrea ariakensis* can exceed 90%, however, in *C. virginica* the disease has only been detected in small seed less than 20 mm. South of Cape Hatteras, the crested oyster, *Ostrea stentina* is a host. The European flat oyster, *Ostrea edulis,* in New England, had been documented as a host in some European systems (Carnegie 2013). Many different species worldwide have been infected with *Bonamia spp.* in countries and regions such as New Zealand, Australia, Europe, South America, and the Eastern and Western coasts of North America.

From what limited studies have been done on these unrelated instances, it seems that the parasite is limited by salinities under 20 ppt. Due to the fact that this parasite has been documented in cooler temperate systems, as well as sub-tropical systems, it is clear that this parasite can tolerate a wide range of temperatures (Carnegie 2013).

While only small oysters of *C. virginica* are infected, North Carolina had a case where 93.8% were infected, albeit lightly with no associated mortality (Carnegie 2013). A study by (Carnegie et al. 2008) included two North Carolina areas, Bogue Sound and Masonboro Sound to examine the seasonal trends of the infection. The study looked at triploid Asian oysters and found that there was a strong seasonal pattern to the parasitism. The overall trend in both locations was that in summer months corresponding to higher water temperatures there were higher rates of infection and mortality compared to colder winter months (Carnegie et al. 2008).

11.2.2.4. Green gill

The term "green gill" is a colloquialism which describes a benign condition that can affect both clams and oysters. This condition is a result of the single-celled alga called *Haslea ostrearia.* This is a blue-green diatom found in the coastal waters of North Carolina. The diatom produces a blue pigment called marennine. This pigment is released into the water turning it a bluish color. Filter feeding bivalves pick up this blue pigment while filtering water, which combines with the gill's natural yellow color, turning the tissues green in appearance. The greened gilled clams, usually found in the cooler months, are harmless and safe to consume. The French consider the green gilled shellfish a delicacy and culture the alga to produce a somewhat nuttier tasting shellfish. However, in the US, shellfish markets have a hard time selling them because the American consumer considers them unsightly and inedible.

11.2.2.5. Boring sponge

Sponges belonging to the genus *Cliona* are found among shell bottom habitats excavating and occupying the calcareous shells of bivalves. These boring sponges create a canal system inside calcareous substrata by chemically etching out a space to occupy (López-Victoria and Zea 2005). *Cliona* boring sponge is a bioreoder of calcareous materials and is linked to reduced oyster gamete viability and possibly increased oyster mortality rates (Chaves-Fonnegra et al. 2005). While these sponges are not obtaining any nutrients from their host, they compromise the integrity of shells and have the capability of encrusting and smothering the host. Members of the family *Clionaidae* have been found in fossil records as early as the Lower Cambrian (Ward and Risk 1977).

Recent consideration has been given to the marine boring sponge, *Cliona spp.*, in response to an observed increased abundance in Pamlico Sound (C. Weychert, J. Peters and M. Jordan, DMF, pers. obs. 2015; N. Lindquist, UNC-CH, pers. com.). Erosion of oyster shells from boring sponge parasitism does not cause mortality directly, though it may induce high levels of stress, which decreases gamete viability and increases susceptibility to disease (Ringwood et al. 2004). Further, bioerosion may compromise structural integrity on individual and reef scales, while also utilizing shell surface area and limiting suitable settlement substrate as a resource for recruiting oysters (Barnes et al. 2010; Ruetzler 1975).

Certain environmental stressors have emerged as impediments to subtidal reef restoration in North Carolina. Despite a steep increase in population density overall, two sanctuaries in high salinity areas experienced dramatic population decline following the Puckett and Eggleston (2012) study (D. Eggleston and B. Puckett, NCSU-CMAST, pers. com.). Coincident with this decline was an increased percent cover of marine boring sponge on limestone marl reef material (D. Eggleston, NCSU-CMAST and N. Lindquist, UNC-CH, pers. com.). This sponge is endemic to North Carolina, though recently more pervasive, especially on limestone marl rocks (Peters 2014; Wells 1959). To improve reef design in high salinity waters and throughout North Carolina estuaries, DMF is conducting research on alternative settlement substrates for oyster restoration. The objective is to identify construction materials which maximize oyster recruitment, growth, and survival, while offering high resistance to environmental stressors, such as *Cliona* boring sponge.

11.2.3. SAV habitat diseases and microbial stressors

The endophytic protist *Labyrinthula zosterae* has been identified as the causative agent of wasting disease in eelgrass; however, there isn't a full understanding of what triggers these pathogenic outbreaks (Bockelmann et al. 2013). Bockelmann et al. (2013) have found that traces of *L. zosterae* endophytes are omnipresent in contemporary grassbeds*. L. zosterae* are detectable as black lesions on grass blades, a result of necrosis, but may also be present on apparently green healthy tissue. 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 protists, *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 sea grasses, 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. Future research should focus on obtaining quantitative data on the prevalence and abundance of the wasting disease pathogen *Labyrinthula zosterae* in *Zostera marina* populations.

Seagrass wasting disease is a natural event that has affected SAV not only in North Carolina, but simultaneously affected areas along the western and north Atlantic. During one of the most extended epidemics concerning SAV, ~90% of East and Western Atlantic eelgrass (*Zostera marina*) beds died-off between 1932-1934.

Submerged grasses need to be monitored on a periodic basis to assess the status of wasting disease and its association with human-induced stresses. Because the highest abundance of seagrass wasting disease occur in the summer months (Bockelmann et al. 2013; Vergeer et al. 1995), the possibility of global climate change, sea level rise, and increasing rates of marine diseases, baseline data could prove necessary in order to detect trends spatially and temporally.

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.). 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 (J. Paxon, DWQ, pers. com.).

Outbreaks of diseases and microbial stressors are largely out of the control of coastal managers. However, North Carolina is proactive in its approach to dealing with disease. Through extensive monitoring of current conditions and long-term trends, surveys, and contingency plans, North Carolina is well prepared to deal with outbreaks of disease and microbial stressors, while ensuring the health and safety of citizens and fisheries.

11.3. Offshore Energy

North Carolina has more than 64 million acres of federal Outer Continental Shelf (OCS) acreage – the most of any state on the east coast. The waters hold energy potential for oil and gas as well as renewable energy development. Safe, responsible OCS development could create thousands of jobs in onshore, offshore, infrastructure and support industries. However, North Carolina's coastline is unique and its waters are filled with a particularly diverse and important mix of fish and other organisms at various stages of the life cycle, including a variety of endangered and threatened sea turtles, pelagic seabirds, and marine mammals. In accordance with the North Carolina Coastal Area Management Act (CAMA), DENR is working with the Bureau of Ocean Energy Management (BOEM) to bring offshore energy to North Carolina in a manner that preserves the coastal economy and the public's opportunity to enjoy the physical, esthetic, cultural, and recreational qualities of the natural shorelines of the state to the greatest extent feasible.

11.3.1. Geological and geophysical (G&G) activities

Various geological and geophysical (G&G) surveys will be required for offshore energy development to take place. Activities include seismic, electromagnetic, gravity, and high-resolution geophysical surveys. Surveys are necessary to determine the location and extent of oil and gas reserves, to site structures, and to identify geologic hazards and hard bottom habitats that should be avoided. They are also used to identify sand resources for beach nourishment projects and to advance scientific knowledge, as was the case of the recent seismic survey performed by the National Science Foundation (NSF).

Seismic imaging involves directing an acoustic wave into the rock formation below the sea floor and measuring the amount of time it takes for the wave to return to the surface, as well as other characteristics about the sound wave. The high energy sound wave is produced by a compressed air source (airgun) and picked up by hydrophones connected to parallel streamers towed behind the survey vessel. Prolonged noise from the compressed air sources can cause temporary behavioral changes in nearby marine mammals, fish and other aquatic organisms and may displace marine mammals or finfish, mask sounds, and cause temporary hearing loss (Popper and Hastings 2009). Both temporary threshold shift (TTS) and permanent threshold shift (PTS) may result from exposures to intense sound levels. Permanent threshold shift is the result of permanent damage to the hearing mechanism of the ear (Finneran et al. 2000; Schlundt et al. 2000). According to the US Department of Energy, Energy Information Administration, data suggest that anthropogenic acoustical signals may lead to a variety of adverse effects in marine mammals, possibly including hearing loss, physiological damage, alterations in feeding and breeding behavior, and changes in cetacean migration patterns (NOAA 2000). Several clupeid species, including the American shad (*Alosa sapidissima*), blueback herring (*Alosa aestivalis*) and alewife (*Alosa pseudoharengus*), are able to detect sounds at frequencies greater than 120kHz. Disruption of normal migration patterns can potentially affect fish populations and commercial or recreational fishing activity (Weilgart 2007). Some studies have shown that high frequency sounds (124.6 and 130.9 kHz) have caused river herring to avoid certain areas for up to an hour (Nestler et al. 1992), and that frequencies between 110 and 140 kHz elicited a consistently strong avoidance response from blueback herring in the Savannah River (Nestler et al. 1992). Fish have shown permanent and temporary hearing loss, reduced catch rates, stress, and behavioral reactions to noise (Weilgart 2007).

The BOEM spent four years preparing the Atlantic Geological and Geophysical (G&G) Activities Programmatic Environmental Impact Statement (G&G PEIS) as a requirement of the NEPA process. The PEIS refers to the following as impact-producing factors or IPFs: active acoustic sound sources (airguns and electromechanical sources); vessel and equipment noise; vessel traffic; aircraft traffic and noise; vessel exclusion zones; trash and debris; seafloor disturbance; drilling discharges; onshore support activities; and accidental fuel spills. The following is the assessment of the proposed geological and geophysical activities as disclosed in the PEIS:

> The Area of Impact (AOI) focuses on ~600 demersal and pelagic fishes, including ichthyoplankton and essential fish habitat (EFH). Potential impacts of acoustic sounds (e.g., airguns) on fishes include behavioral responses, masking, hearing loss, and

physiological effects. Exposure to an airgun array could lead to temporary hearing loss, vacating of the area, masking of relevant sounds, or no unaffect. Mortality is unlikely. Several studies show that high-frequency sounds would likely affect the behavior of fishes capable of hearing in the range of 25-135 kHz, such as herrings, menhaden, and anchovies. Behavioral changes, particularly in pre-spawning fish assembling to move, could affect reproductive potential or feeding activity. Temporary displacement of prey species could affect feeding routines of predatory fishes and marine mammals.

Many federally managed species would be at risk in a fuel spill. Drifting in windrows or mats, Sargassum supports numerous fishes and invertebrates including young greater amberjack, almaco jack, gray triggerfish, blue runner, dolphin, and wahoo. The AOI includes endangered smalltooth sawfish and Atlantic sturgeon. The shortnose sturgeon is an endangered anadromous species inhabiting rivers but rarely coastal marine waters. NMFS has been petitioned to list the scalloped hammerhead shark as threatened or endangered. Impacts could include behavioral responses, masking, temporary hearing loss, and physiological effects.

In 2012, total commercial landings within the AOI were 294,094 metric tons valued at ~$432.2 million. The benthic environment includes the Mid-Atlantic and South Atlantic bights. Several G&G survey activities could disturb the seafloor resulting in localized burial, crushing, or smothering of benthic organisms. A small fuel spill would unlikely reach the seafloor or contaminate bottom sediments.

The Marine Protected Areas (MPAs) within the AOI include 2 national marine sanctuaries, 6 SAFMC designated MPAs, and numerous federal fishery management areas. Adjacent MPAs include 5 national seashores, 1 National Estuarine Research Reserve, 10 national wildlife refuges, and numerous state-designated MPAs.

A report prepared for NOAA by the Conservation and Development Problem Solving Team Graduate Program in Sustainable Development and Conservation Biology, University of Maryland, to evaluate the impacts of anthropogenic noise on the marine environment finds the following (NOAA 2000):

"oil tankers, auxiliary vessels, seismic exploration, and decommissioning of existing drilling platforms may prove greater acoustic threats than the day to day operations of offshore drilling structures. Marine seismic exploration is the greatest potential acoustic threat associated with offshore oil and gas. Air gun arrays used in exploring operations emit very high-level pulses. Most pulses occur at less than 100 Hz, lasting less than a second with 10 to 15 second intervals (Richardson et al. 1995a). Beyond a few kilometers these pulses attenuate to between 100 and 250 Hz. Peak noise levels from air gun arrays are in the range of 240 to 250 dB re 1 microPa. These levels far exceed the standard safety level of 180 dB established by the High Energy Seismic Survey (HESS) team in February 1999 (Fahy, pers. com. 2000; MMS 2000; Richardson pers. com.). In fact, pulses can be detected at levels above 160 dB at distances over 100 km from the air gun blast. Received levels vary with depth, becoming several decibels stronger in deeper water (NOAA 2000)."

Specific to the types of issues addressed in the PEIS above, NOAA (2000) states (citations are within originally cited document):

Fishes use sound for courtship, aggressive interactions, spawning, schooling, escaping predators, searching prey, and potentially to navigate (Mann 1997; Croll et al. 1999; Myrberg 1978a). Fishes with swim bladders respond to wider bandwidths, particularly at higher frequencies (Popper and Fay 1993). Many members of the family Clupeidae and Atherinidae (the silversides) form large schools. Sounds may play a key role in keeping schools together (Croll et al. 1999). The ultrasound detection capabilities of American shad may allow them to detect high-frequency echolocation pulses of cetaceans preying upon them (Mann et al. 1997). The Sciaenidae (the drums) produce loud sounds using swim bladders during spawning bouts (Moyle and Cech 1988). Myrberg and Riggio (1985) discuss the ability of male bicolor damselfish to recognize individual vocalizations of other males. They hypothesize that this may help males maintain territories in their coral reef habitats (NOAA 2000). The literature suggests that frequencies of 50 to 2,000 Hz at levels exceeding 180 dB may cause physical harm to many fish species. In various studies, exposure to sound has induced startle responses, damage to hair cells, balance effects, and reduced catch (NOAA 2000).

Several reports examine the impacts of seismic operations on fishes. Pearson et al. (1987) looked at changes in behavior and in catch-per-unit-effort resulting from exposure to firing a single air gun among several species of rockfish in which the catch-per-unit-effort declined by 52.4%, resulting in a 49.8% drop in the cash value of the rockfish caught (Pearson et al. 1987). Dalen and Knutsen (1987) used sonar to check the distribution of fishes from air gun noise. Certain demersal species tended to go to the bottom post-firing. Eggs, larvae, and fry of cod were exposed to two different air guns and a water gun. Larvae and younger fry showed no effects to the smaller air gun (222 dB//1 microPa re 1m and 640 cm chamber volume), while older fry experienced temporary balance problems. Older fry (the only group exposed) experienced temporary balance problems from the larger air gun (231 dB//1 microPa re 1 m and 8610 cm chamber volume). When fired at a distance of 2 m, the water gun (229 dB//1 microPa re 1 m and 8610 cm chamber volume) caused 90% mortality among older fry (the only group exposed). Non-hearing physiological effects of intense sound on marine fishes may include: swim bladder injuries, eye hemorrhages at peak pressure levels of 220 dB, and lower egg viability and growth rates (Gisiner et al. 1998). Banner and Hyatt (1973) showed sheepshead minnow (Cyprinodon vairegatus) eggs and larvae with decreased viability after exposure to noise levels of 20 dB/mb (NOAA 2000).

Myrberg (1978b) reports that the attractiveness of sound to sharks increases at lower frequencies (40 Hz or below) and that irregular pulses are more attractive than regular ones. One study indicated sharks to be attracted to struggling fish sounds; another examined their responsiveness to low frequency sounds. Vessel traffic may mask the ability to feed (NOAA 2000). Spiny dogfish, porbeagle, great white, basking, makos, and blue may be affected (NOAA 2000).

Forcing a marine mammal to modify its vocal behavior could reduce its ability to find food, navigate, or contact conspecifics (Fletcher and Busnel 1978; Richardson et al. 1995a; Lesage et al. 1999). There are indications that gray whales and bottlenose dolphins shift primary frequencies of communication to avoid background noise (Würsig and Richardson 2000). Reductions in call detection rates have been reported for sperm whales exposed to seismic pulses and sonar (Watkins et al. 1985; 1993), and vocalizing discontinuance found in response to weak seismic pulses (Bowles et al. 1994). Call detection rate reductions have also been found for harp seals exposed to shipping (Terhune et al. 1979). Studies by Rankin and Evans (1998) show seismic exploration to have negative impacts on communication and orientation in sperm whales, but not on other odontocetes (NOAA 2000).

Typical short-term responses of cetaceans to anthropogenic noise are sudden dives, orientation away from source, changes in vocal behavior, longer dives, shorter surface intervals with increased blow rates, attempts to shield young, increased swimming speed, and departure. Cetaceans appear more sensitive to novel sound and increasing intensity level. Noise-induced disruption of feeding, breeding, migration, and care of young may result in less food intake, lower breeding success, or reduced offspring survival rate. Detrimental impacts are likely most severe where cetaceans are temporarily or permanently displaced from areas that are important for feeding or breeding (NOAA 2000).

Studies of leatherback and loggerhead turtles indicate that they hear sounds between 250-750 Hz (Eckert pers. com. 2000; Bartol et al. 1999), with green turtles hearing best between 200-700 Hz (Ridgway et al. 1969). Turtles may use low frequency hearing for predator avoidance (Eckert pers. com. 2000). Hearing may be damaged by high-energy sources, though the levels, if any, are unknown. Hearing damage is more likely than tissue damage (Eckert pers. com. 2000) and may recover over time (Eckert pers. com. 2000; Musick pers. com. 2000). Some research shows that noise causes turtles to move from the source (O'Hara and Wilcox 1990). In one study of air gun effects, turtles showed alarm responses at 2 km and avoidance responses at 1 km from the source (McCauley et al. 2000). Increased turtle strandings have been observed following explosion of offshore petroleum platforms (NOAA 2000).

Captive bait shrimp exposed to the sound of a seismic exploration device did not show behavioral changes or increased mortality. A similar study using air guns showed no ill effects (Linton 1995). In contrast, a French study of brown shrimp showed decreased growth and increased mortality with constant exposure to sound (Lagardere 1982) (NOAA 2000).

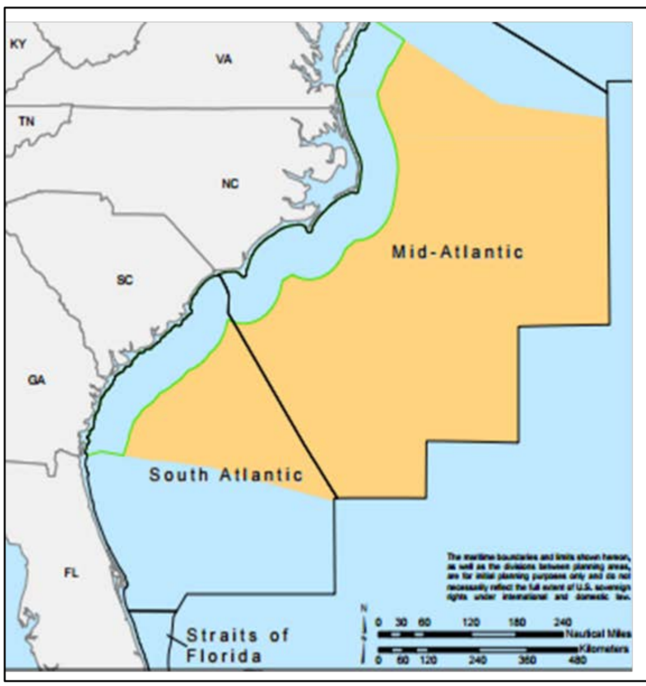
The G&G PEIS identifies mitigation and monitoring measures to avoid, reduce or minimize impacts that could occur from seismic and other G&G activities performed in the Atlantic OCS to the maximum extent practical and serves as the framework for the G&G permits. The NSF adhered to the G&G PEIS protocol when they conducted a high energy, 2D seismic survey in the Atlantic Ocean off the coast of Cape Hatteras in September and October 2014. At this point, the North Carolina Divisions of Coastal Management (DCM) and Marine Fisheries (DMF) are unaware of adverse impacts from the NSF testing.

Seismic surveys were performed offshore North Carolina in the 1970s and 1980s and identified several geological formations that are likely to contain hydrocarbons. Advanced seismic technologies and computer modeling are needed to provide a clearer assessment of the various geological formations beneath the ocean floor. This information will provide oil and gas developers with a better understanding of the location and quantity of potential hydrocarbon resources and guide them to determine the best locations to drill, potentially reducing the number of wells required.

Several companies applied in 2014 for G&G permits to conduct surveys offshore North Carolina. The first permits are expected to be approved in 2015 or early 2016 and all activities must be completed within twelve months of BOEM permit issuance. Under the federal consistency provisions of CAMA, the North Carolina Division of Coastal Management (DCM) has the authority to review federal permit applications for seismic activities. The intent of this review is to ensure that the proposed activities are consistent, to the maximum extent practicable, with the Coastal Area Management Act. The DCM has determined that the applications reviewed thus far are consistent with the CAMA contingent on a pre-survey meeting. The DCM and DMF will meet with each G&G company in advance of the survey to review precise survey transects and timing and to discuss ways to avoid, minimize and mitigate possible impacts to or conflicts with commercial and recreational fishing and habitat. In addition, DCM has recommended, where practical, that survey transects avoid designated Habitat Areas of Particular Concern and foraging, spawning and refuge areas and that surveys be timed to minimize conflicts.

11.3.2. Oil and gas development

The BOEM is in the process of developing the next Five-Year Program that will consist of a schedule of oil and gas lease sales indicating the size, timing and location of proposed leasing activity. A Record of Decision for the Five-Year Program is expected by January 2017. In its Draft Proposed Program (DPP), the BOEM proposed one lease sale in 2021 in federal waters off North Carolina, Virginia, South Carolina and Georgia and established a 50 mile coastal buffer zone within which no lease will be offered.



Area	Year
Gulf of Mexico Region	2017
Gulf of Mexico Region	2018
Gulf of Mexico Region	2018
Gulf of Mexico Region	2019
Gulf of Mexico Region	2019
Gulf of Mexico Region	2020
Beaufort Sea	2020
Gulf of Mexico Region	2020
Gulf of Mexico Region	2021
Cook Inlet	2021
Gulf of Mexico Region	2021
Mid- and South Atlantic	2021
Gulf of Mexico Region	2022
Chukchi Sea	2022

Planning Area Boundary
Program Area
50-Mile Buffer
BOEM

FIGURE 11.2. BOEM gas lease program area with 50-mile coastal buffer zone.

If the proposed sale remains in the final program, it will be the first lease sale to occur offshore North Carolina since the 1980s. All previous leases were relinquished by 2000 before the first exploratory well was drilled. Since that time, there have been technological advancements and new regulatory oversights put into place following the 2010 gulf oil spill.

Concurrent to the Five-Year Program, the BOEM is preparing a Programmatic Environmental Impact Statement (PEIS). They will analyze environmental impacts, multiple use conflicts, and reasonable alternatives to the proposed lease sale schedule in the DPP and will identify ways to avoid, reduce or mitigate negative effects. Mitigation measures and buffer areas are needed for offshore energy development to maintain our natural viewsheds, protect sensitive coastal habitats and resources, and minimize conflicts with ongoing and future marine activities. The draft PEIS is targeted to be released for public comment in 2016. Public input is a critical component of the safe and responsible exploration and development of offshore energy resources and will continue to engage the public and solicit input.

The final 2017-2022 Oil and Gas Leasing Program PEIS will identify stresses to coastal habitats and require mitigation to minimize the impact of oil and gas development to the marine environment and aquatic life, and will serve as a framework for exploration and development plans. The DCM will have the opportunity to review plans for consistency with the Coastal Area Management Act, as shown in BOEM's exploration and development phase timelines below:

Exploration Phase

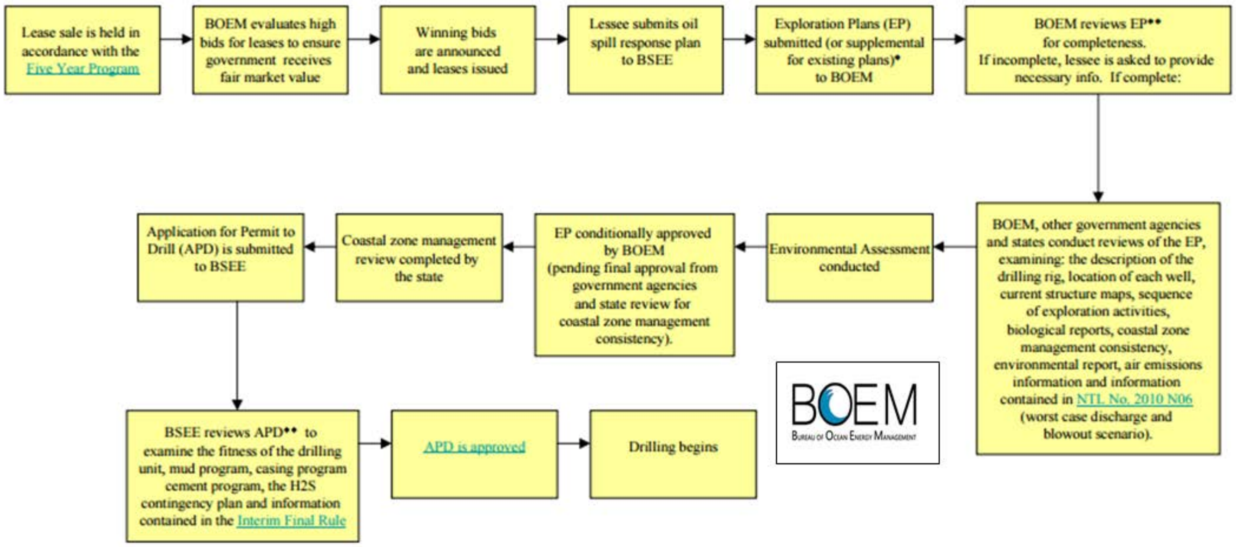


FIGURE 11.3. BOEM exploration phase flow chart.

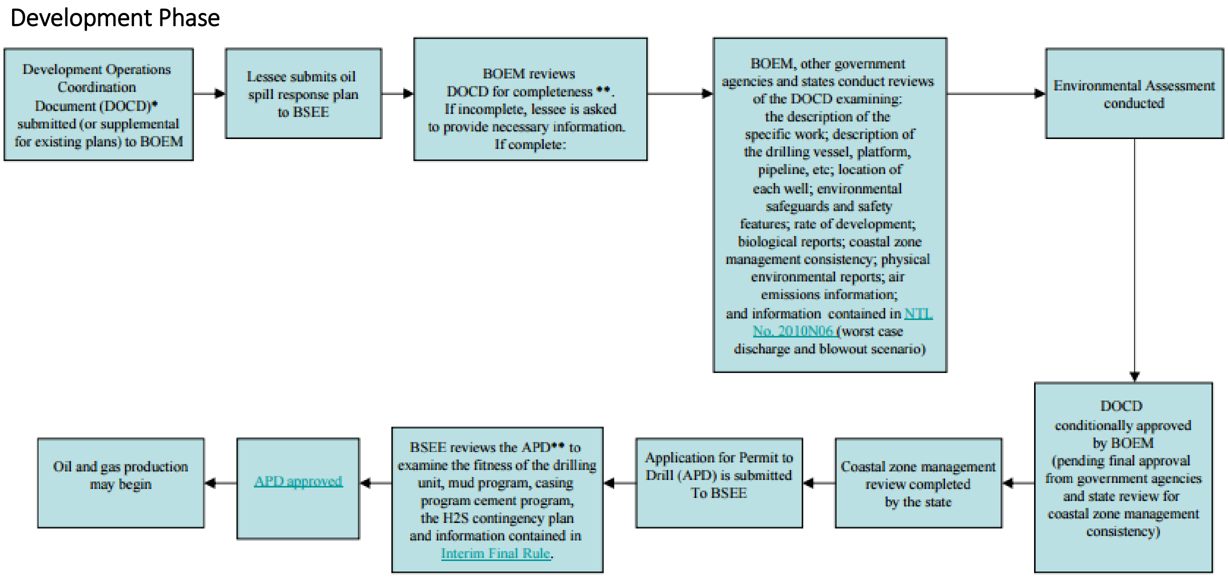


FIGURE 11.4. BOEM development phase flow chart.

Provided the proposed schedule is not revised, 2022 is the earliest any exploratory wells are expected to be drilled. During the next update planned for 2020 or prior to lease sales, whichever comes first, DENR will revise the Coastal Habitat Protection Plan to address the potential impacts to the coastal habitats from oil and gas exploration and development in federal waters offshore North Carolina.

11.3.3. Wind energy development

There are excellent opportunities for wind energy development off North Carolina's coast, which must be consistent with other offshore activities. Sustaining natural viewsheds, protecting sensitive habitats and resources, while minimizing conflicts with marine activities requires mitigation measures. North Carolina is following the Virginia Offshore Wind Technology Advancement Project (VOWTAP). The VOWTAP demonstration project will help establish appropriate design standards for wind turbines located in the hurricane-prone Mid-Atlantic Ocean and evaluate technological innovations that may contribute to establishing wind as a cost-effective renewable energy solution for North Carolina.

In 2011 and 2012, the Coastal Resource Commission (CRC) amended its rules to enable wind energy turbines to be permitted in state waters. The amended rules are the CRC's Coastal Energy Policies at T15A NCAC 7M .0400, and Specific Use Standards for Wind Energy Facilities at 7H .0208(b)(13). The rules seek to protect resources and uses in state waters through direct permitting and in federal waters through the federal consistency process.

In August 2014, the BOEM announced three Wind Energy Areas (WEAs) offshore North Carolina to be considered for leasing (Figure 11.5). These include the Kitty Hawk WEA, beginning 24 nautical miles (nm) from shore; the Wilmington West WEA, beginning 10 nm from shore; and the Wilmington East WEA, beginning 15 nm from Bald Head Island (Figure 11.5). In January 2015, the Environmental Assessment for Commercial Wind Lease Issuance and Site Assessment Activities on the Atlantic Outer Continental Shelf Offshore North Carolina was made available for public review and comments. As a result of comments received, the BOEM will publish a Finding of No Significant Impact (FONSI), revise the EA, or issue a notice of intent to prepare an Environmental Impact Statement (EIS). When a FONSI or final EIS is published, the next step by BOEM will be to offer lease sales to wind energy companies, if it determines that competitive interest exists, following the outline in the chart below.

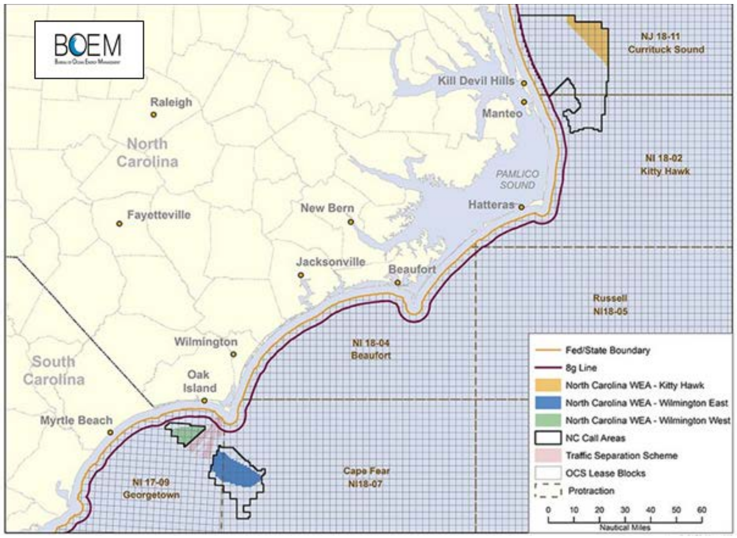


FIGURE 11.5. BOEM Wind Energy Areas (WEAs) being considered for leasing.

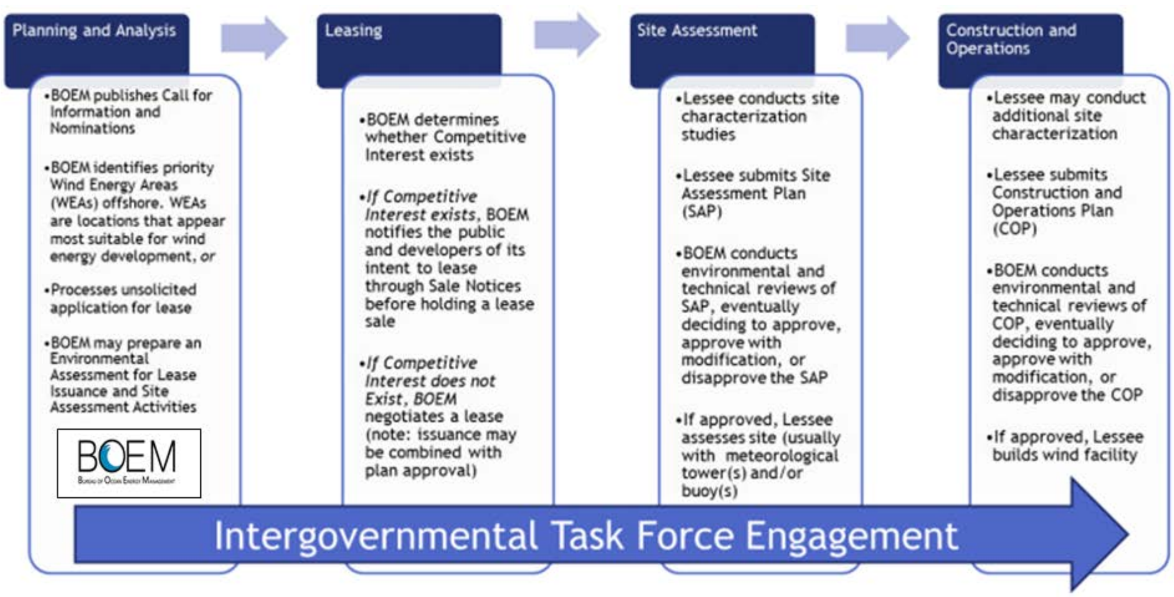


FIGURE 11.6. BOEM Intergovernmental Task Force Engagement flow chart.

The BOEM will engage environmental agencies throughout the leasing and plan approval process (Figure 11.6). The DCM will have an opportunity to conduct a consistency determination for the facility construction and operation plan related to the electricity transmission lines. Should it find that the transmission route would have a significant adverse impact, North Carolina has the option to request mitigation measures or plan modifications. The state could also delay or stop the project if it is found to be inconsistent with the enforceable policies of the Coastal Area Management Act.

11.3.4. Advisory Subcommittee on Offshore Energy Exploration

In 2009 the North Carolina General Assembly formed a Legislative Research Commission Advisory Subcommittee on Offshore Energy Exploration, which has since disbanded. The Advisory Subcommittee made three recommendations in its May 2009 Interim Report, all of which remain relevant today. As recommended in the report, North Carolina will continue to:

1. Engage federal agencies overseeing offshore energy exploration.
2. Work with its congressional delegation to explore options for revenue sharing with the federal government.
3. Identify the probable exploration, development and production scenarios based on potential offshore resources, clarify what types offshore and onshore infrastructure are needed; assess social and economic implications; and determine DENR's authority in the leasing process.

11.4 Changing Weather Conditions

Basic weather conditions, such as air temperature and precipitation, influence the occurrence and distribution of habitat and fish in coastal North Carolina waters by affecting physical and chemical properties of water, such as water temperature, salinity, and oxygen. For example, a large amount of precipitation lowers salinity. High sustained air temperatures increase water temperature, which in combination with low winds, can lead to stratification of the water column and hypoxic waters. As described in the water column chapter, physical and chemical properties of water are key to biota distribution and influence growth and survival of all habitats. Predominant winds, currents, and rainfall at a certain time of year highly affect annual recruitment success of larval fish into nursery habitat.

Extreme weather events such as droughts, floods, nor'easters, and hurricanes affect water quality and habitat conditions in positive and negative ways. Droughts can result in small streams and wetlands being inaccessible to river herring for spawning, while improving water clarity and enhancing conditions favorable for SAV. In addition, reduced runoff during droughts can decrease pollutant inputs and increase salinity within estuarine waters, the latter affecting shellfish and shellfish predator distribution. Floods can have almost the opposite effect. Hurricanes can cause flooding; flush pollutants from the upper estuarine bottom; cause sedimentation over oyster reefs; erode wetland shorelines; and damage coastal property and economy. While these extreme weather events have always occurred, there is evidence that the frequency and severity of minor (non-storm event) nuisance flooding and hurricanes on the east and Gulf coasts are increasing (IPPC 2014; Melillo et al. 2014; Sweet et al. 2014).

From 1851 to 2014, North Carolina had more direct hurricane landfalls (48 hurricanes) than any other state on the east coast, except for Florida (141 hurricanes)(NC Climate Office). The maximum classifications of the North Carolina hurricanes were as follows; 17 were Category 1, 8 were Category 2, 15 were Category 3, 6 were a Category 4, and 2 were a Category 5. Hurricanes can be beneficial by flushing accumulated sediment and pollutants from some portions of the estuaries, but can also cause tremendous and rapid loading of pollutants from runoff, as observed with Hurricane Floyd in 1999, where nutrient loading from breached hog lagoons and flooded uplands resulted in temporary algal blooms and hypoxic zones (Mallin et al. 2002a; Paerl et al. 2001). Significantly lower statewide blue crab landings in 2000 compared to landings in the late 1990's were attributed to prolonged water quality degradation in the Pamlico estuarine system following the 1999 hurricanes (Burgess et al. 2007). Tropical storms, fueled by warm water temperatures and favorable atmospheric conditions, may increase in frequency and intensity with a warming climate (Melillo et al. 2014).

A warming trend in air temperature is the primary driver of changing weather patterns that can alter the distribution and health of fish and their habitat. Warming air temperatures can lead to increases in water temperature, ocean water volume, and changes in atmospheric conditions and patterns. The latter influences ocean currents, precipitation patterns, and tropical storm development. Some indicators of warming conditions include higher average air and sea temperatures, change in precipitation patterns, decline in sea ice, and increasing sea level. The 2014 National Climate Assessment summarizes observed and expected climate change and impacts regionally and overall in the U.S.(Melillo et al. 2014).

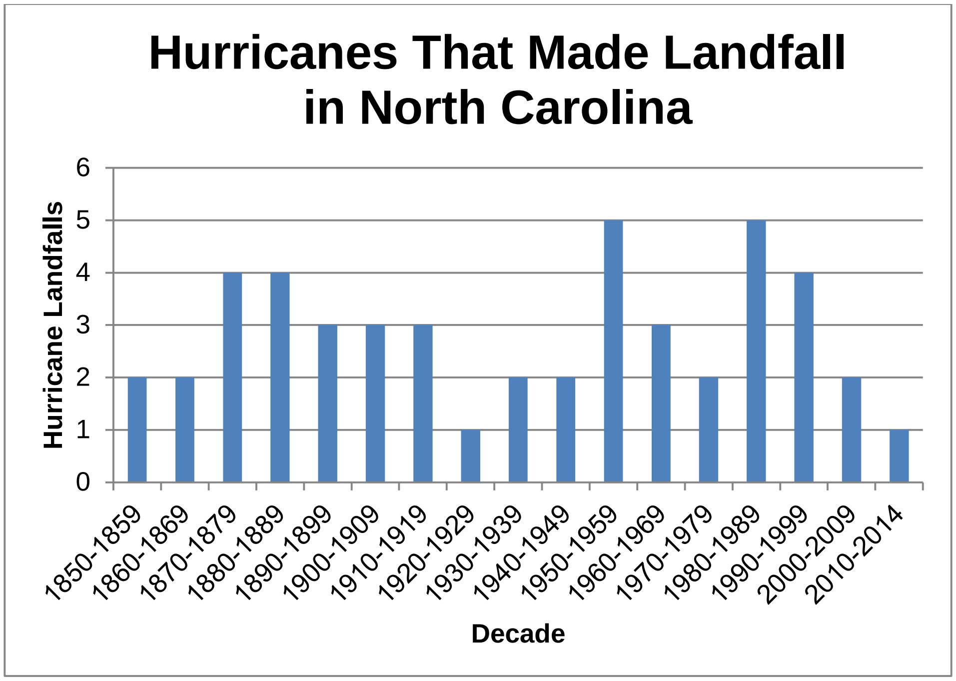


FIGURE 11.7. Category 1-5 hurricanes that made landfall in North Carolina by decade. Source: NC State Climate (Panel 2015)Office, http://www.nc-climate.ncsu.edu/climate/hurricane.php.

Of the potential changing oceanographic conditions under warming temperatures, rising sea level has large implications to North Carolina's coastal habitats, waters, and fish populations. Sea level is affected not only by global temperature patterns, but by regional subsidence due to vertical movement of the earth, ocean-atmospheric oscillations like El Nino and the Atlantic Multidecadal Oscillation, and tides (Church et al. 2013). The CRC Science Panel updated the NC Sea Level Rise Assessment Report in 2014. The report, which is still draft, summarizes past long term sea level change trends based on data from the four NOAA tide gauges in North Carolina. The study estimated relative sea level rise over the next 30 years using rates determined by published NOAA gauge data from the past to 2013 (2008 for Southport gauge), and by using rates presented in Church et al. (2013) representing the low and high greenhouse gas scenarios and modifying those to account for regional North Carolina variations in sea level rise (NC CRC Science Panel 2015). Using observed tide gauge rates, relative sea level rise in 30 years (2015-2045) was projected to range from 2.4 inches in Southport to 5.4 inches in Duck. The low and high greenhouse gas scenarios were higher (NC CRC Science Panel 2015). Projected sea level rise is greater north of Cape Lookout due to greater subsidence. Regardless of the rate or the cause, the earth is in a geological period of rising sea level, and due to the low elevations of coastal North Carolina and the expected increase in extreme weather and other factors, North Carolina's coast is considered at moderate to very high vulnerability to sea level rise (Melillo et al. 2014) (Figure 11.8).

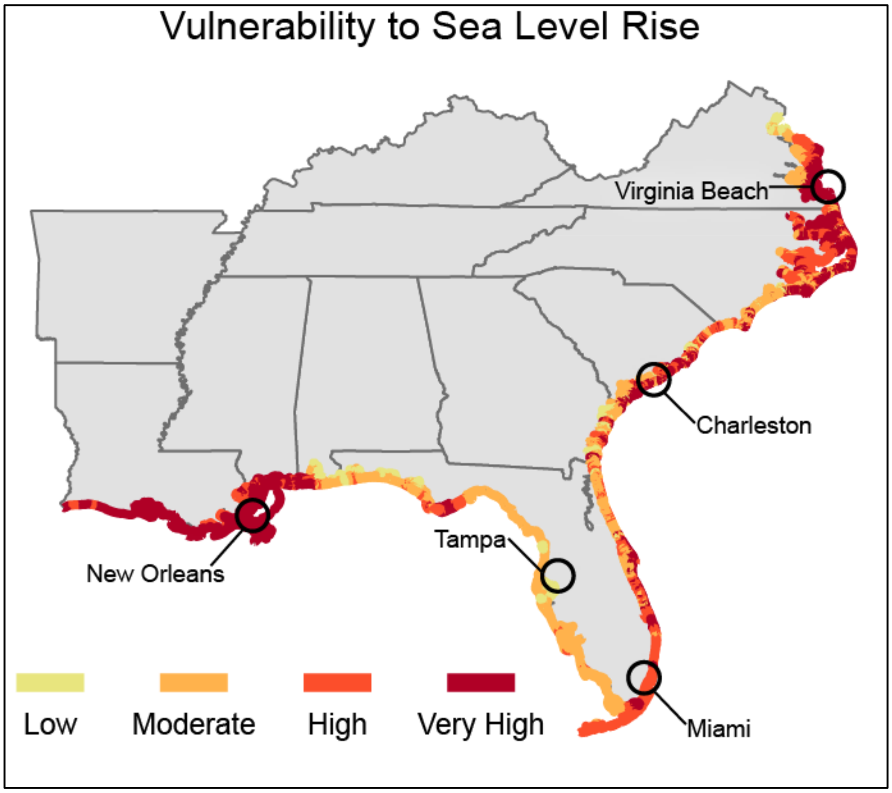


FIGURE 11.8. Vulnerability to Sea Level Rise in the Southeast US. The USGS Coastal Vulnerability Index was based on tidal range, wave height, coastal slope, shoreline change, landform and processes, and historical rate of relative sea level rise. Source: (Melillo et al. 2014); data from Hammar-Klose and Thieler 2001)

11.4.1. Coastal waters

Storms, floods, droughts, and changes in sea level can cause modification of the geomorphology of North Carolina's estuaries, the location and health of coastal habitats, and the distribution of fish are expected, the extent of which will depend on the rate and magnitude of change. Higher water levels adjacent to low elevation barrier islands and increased frequency of storms are expected to lead to increasing frequency of inlet breaches along the barrier islands and could significantly increase salinities in Pamlico Sound and tributaries (Riggs and Ames 2003). Even without the formation of new inlets, there may be increasing flow through existing inlets and elevated water levels. Pearsall and Poulter (2005) projected the area of land in the northern coast that will be submerged under different increases in sea level. Taking into account local subsidence, they estimated that 1870 km^2 of land would be inundated under a 0.3 m scenario, and 4670 km^2 would be inundated under a 1.1 m scenario. The Albemarle-Pamlico peninsula would be the greatest impacted. Depth, flow, temperature, and salinity are basic parameters that determine both species and habitat distribution. Changing precipitation patterns influence freshwater inflow, nutrient delivery, and salinity regimes (Najjar et al. 2000; Scavia et al. 2002). Increased precipitation can cause an upsurge in freshwater input and a subsequent decline in estuarine salinity. Increased freshwater runoff can also cause water column stratification and nutrient enrichment (Najjar et al. 2000; Scavia et al. 2002; Wood et al. 2002), which in turn are conducive to development of hypoxia or anoxia. Decreased precipitation, on the other hand, would reduce freshwater inflows, increasing estuarine salinity.

11.4.2. Fish Distribution

The distribution of various life stages of species will change as temperature, salinity, water depth, flow and habitat occurrence change. Nye et al. (2009) evaluated changes in fish species distribution from 1968 to 2007 with concurrent increases in water 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.

In ocean waters, 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.

11.4.3. Wetlands

Wetland habitat, particularly along developed mainland shorelines and in the northern portion of the coast, is highly vulnerable to an increasing rate of sea level rise because coastal wetland accretion and migration may not keep pace (Voss et al. 2013). Large areas of the Pamlico-Albemarle peninsula may erode, become inundated, and exposed to more saline water (Henman and Poulter 2008). Salt-intrusion into freshwater peats accelerates collapse of peat soils (Hackney and Yelverton 1990). Conversely, back-barrier marshes may potentially expand as sediment from the ocean side of barrier islands and new inlets is redistributed. Coastal marshes may keep pace with sea level rise depending on the rate of vertical 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 decreases and erosion of barrier islands increases (Fitzgerald et al. 2008). As wetland habitat is lost and storms increase, erosion of intertidal soft bottom will increase.

During periods of rising sea level, shorelines are generally receding over the long-term, although there may be areas of accretion in the short-term (Riggs 2001). Rate of shoreline erosion varies based on shoreline orientation, fetch, water depth, bank height, sediment composition, shoreline vegetation, presence of offshore vegetation, and boat wakes. While most of the Albemarle-Pamlico estuarine shoreline is receding, 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 Atlantic Intracoastal Waterway (AIWW) and navigational channels (Riggs 2001). Wetland shorelines are expanding in some small sheltered tributaries where sediment inputs from runoff and bank erosion allow marsh expansion. In more exposed areas lower in the system, marshes have been documented to be losing acreage (Cunningham 2013b). In the New River system (Onslow County), wetlands east of the AIWW were keeping up with sea level rise due to receiving sediment from barrier island overwash events. West of the AIWW, marshes were sediment starved, as the AIWW acts as a sediment sink, trapping barrier island overwash material. The AIWW was shown to have increased in width over the years, and as it expanded, marshes were lost. Boat wakes were a significant source of wave energy. Estuarine 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 (e.g., marsh, beach, bluff) was eroding to some degree. 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 (e.g., bulkheads, riprap, sills, and groins) and found that 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.

Loss of wetlands can have severe negative consequences on water quality, due to its pollutant filtering ability, productivity due to its role as a primary producer of food for organisms and habitat for juvenile fish and invertebrates, and will exacerbate shoreline erosion and property loss, turbidity and subsequent decline in SAV and shellfish, and loss of other important ecosystem services.

11.4.4. SAV

Changing weather conditions could have both positive and negative impacts on SAV. A positive effect of increasing carbon dioxide concentrations is that growth and productivity of carbon dioxide-limited SAV species could increase (Palacios and Zimmerman 2007). The referenced study found significantly higher reproductive output, below-ground biomass and vegetative production of new shoots at 33% surface irradiance at leaf. By absorbing carbon dioxide, SAV can remove (sequester) carbon dioxide from the atmosphere, reducing greenhouse gas effects. Seagrass habitat is considered an important carbon dioxide sink relative to other terrestrial and aquatic habitats. It is estimated that SAV 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).

While growth rates could increase, a loss of marsh and barrier island windbreaks is likely to result in loss of sheltered areas where SAV can survive. This was observed by USACE managers working in Currituck Sound (D. Piatkowski, USACE, pers. com.). Distribution of SAV will also be affected due to increasing water depth associated with sea level rise. Light availability in deeper waters is reduced. SAV will need to migrate to shallower water to survive, which will be problematic adjacent to hardened shorelines (J. Kenworthy, NOAA, pers. com.)

A shift to warmer water temperatures could result in a shift in species distribution. Eelgrass, which is at its southern limit, could decline due to temperature stress, while shoal grass, which is at its northern limit, could increase. 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). That study also found that an increase in shoal grass compensated for the eelgrass decline, but invertebrate diversity and abundance declined. An expected decline in overall seagrass resiliency has also been reported (Ehlers et al. 2008).

11.4.5. Shell Bottom

Long-term changes in temperature regimes, precipitation/streamflow patterns, and sea level can alter shellfish distributions, growth, reproduction, and survival (Dekshenieks et al. 2000; Harley et al. 2006; Hofmann and Powell 1998; Kimmel and Newell 2007; Lawrence and Soame 2004; Najjar et al. 2000; Oviatt 2004; Scavia et al. 2002; Wood et al. 2002). Temperature increases may initially benefit oysters and other shellfish, allowing for increased growth rates (Grizzle et al. 2003; Powell et al. 1992) and a longer spawning season. However, sustained higher temperatures amplify the susceptibility of oysters to environmental stressors such as toxins and disease, increasing the likelihood of mortality (Ford and Chintala 2006; Hofmann et al. 1999; Lannig et al. 2006; McLaughlin and Jordan 2003; Najjar et al. 2000). Deepening water depth in the intertidal zone could potentially lead to oyster reef loss since the intertidal zone provides refuge from predation and disease. However, (Rodriguez et al. 2014), in measuring vertical accretion of selected oyster reefs, found that the intertidal reefs should be able to keep pace with an increased rate of sea level rise.

Increasing precipitation and flooding could lower salinity regimes in the upper estuary while storms and higher sea level could raise salinity in the lower estuary. Salinities <5 ppt can result in mass oyster mortalities, especially when combined with higher temperatures, and salinities < 10 ppt, can cause sublethal stress (Burrell 1986; Hofmann and Powell 1998). Salinities above 15 ppt increase the susceptibility of oysters to pathogens (Lenihan et al. 1999b; McLaughlin and Jordan 2003; Paynter and Burreson 1991; Wood et al. 2002) and predators (Bahr and Lanier 1981; Gunter 1955). Thus, these salinity changes could result in a distribution squeeze, shifting shellfish occurrence away from the upper and lower portions of the estuary.

11.4.7. Economic Impacts

More frequent and severe flooding, storm events, and rising water levels can affect the coastal economy in several ways. Tourism and real estate are at risk to flooding and storms. (Bin et al. 2007) estimated that more than $2.8 billion in property loss could occur in Dare, Carteret, New Hanover, and Bertie counties combined with an 18” increase in sea level by 2080. Under the same scenario, tourism could be impacted by as much as $10.6 billion due to the combination of sea level rise and hurricane events. Agriculture is also at risk from these weather patterns. From 1996 to 2006, 14 tropical cyclones caused agriculture damages totaling $2.4 billion (Bin et al. 2007). Droughts and heat stress have been documented to impact livestock growth. Hurricanes damage timber, with forestry impacts from one hurricane (Fran, Category 3, 1996) totaling $1.7 billion.

11.4.8. Minimizing Impacts from Extreme and Changing Weather

While climate changes over time, the rate of change affects the ecosystem’s ability to adapt and shift with changing conditions. 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 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 (includes North Carolina) provides suggestions on how governments and coastal communities can plan for and adapt to rising sea levels, and is available online at http://downloads.globalchange.gov/sap/sap4-1/sap4-1-final-report-all.pdf. Some key findings:

- In the short time frame of a few decades, negative consequences may be avoided or minimized by enhanced efforts in managing traditional stressors of estuarine ecosystems through existing best management practices (BMPs).

- 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.
- Establishing baselines and monitoring ecosystem state and key processes related to weather conditions and environmental stressors is an essential part of any adaptive approach to management.

There are numerous ongoing research projects and initiatives associated with understanding ecosystem response to changing weather conditions and gathering information needed to mitigate impacts. A few of these include:

- 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 are examining the response of coastal wetlands to sea level rise, and investigating a model to predict the role of wind waves and boat wakes on estuarine shoreline erosion (Cunningham 2013b) or https://dcerp.rti.org/). The results of these projects will provide valuable information for devising management strategies to face climate change.
- The EPA "Climate Ready Estuaries" program works with the National Estuary Programs and other coastal managers to: 1) assess climate change vulnerabilities, 2) develop and implement adaptation strategies, and 3) engage and educate stakeholders (http://www.epa.gov/cre, 2015).
- NC FEMA, Floodplain Mapping Program remapped flood elevations and zones and maps are available online (http://fris.nc.gov/fris/Home.aspx?ST=NC).

While we cannot control the weather, researchers can continue to better understand drivers of weather changes and expected ecosystem effects, and coastal communities can take steps to plan for future expected changes and mitigate human activities contributing to accelerated change in weather.

CHAPTER 12. PRIORITY HABITAT ISSUES

12.1. OYSTER REEF HABITAT RESTORATION

I. ISSUE

Worldwide oyster populations have been depleted (Beck et al. 2011) and in the United States oyster spatial extent has decreased by 64% and biomass has decreased by 88% (Zu Ermgassen et al. 2012).

II. ORIGINATION

This issue was selected by North Carolina Division of Marine Fisheries (NCDMF) staff, the North Carolina Coastal Resources Commission (NCCRC), and through Coastal Habitat Protection Plan (CHPP) concerns to be addressed in the 2015 CHPP update.

III. BACKGROUND

As a consequence of historical overfishing, habitat destruction, disease, and pollution, worldwide oyster populations have suffered extensive population decline (Cooper et al. 2004; Lenihan and Peterson 1998; Paerl et al. 1998). Globally, an estimated 85 percent of historic oyster reefs have been lost (Beck et al. 2011). Similarly in the United States, present oyster populations have 64% less spatial extent and 88% less total biomass, relative to historical surveys (Zu Ermgassen et al. 2012). More locally, population decline has been observed, especially on sub-tidal reefs along the US East Coast (Hargis and Haven 1988; NCDMF 2001; Rothschild et al. 1994). In 2007, a National Oceanic and Atmospheric Administration biological review team found that current east coast oyster harvest is 2 percent of peak historical volume and suggested that oyster restoration and enhancement efforts are “necessary to sustain populations” (EOBRT 2007). Oyster harvest in North Carolina has shown a similar trend of decline (Deaton et al. 2010; Street et al. 2005). For example, in the Neuse River Estuary, oyster habitat loss is particularly apparent where viable oyster beds have been “displaced downstream roughly 10-15 miles” since the late 1940s (Jones and Sholar 1981; Steel 1991). Natural expansion of healthy oyster reefs is not expected in this area because adjacent bottom lacks attachment substrate, and any shell that is sloughed from an existing reef might be subject to deepwater hypoxia and sediment burial, where reef establishment is unlikely (Lenihan 1999; Lenihan and Peterson 1998).

Recognized as an ecosystem engineer, oysters play an important ecological role, delivering a variety of ecosystem services, such as improving water quality through water filtration, bottom consolidation, benthic-pelagic coupling, shoreline stabilization, and essential fish habitat (Coen et al. 2007; Harding and Mann 2001b; Mackenzie 2007; Peterson et al. 2003a; Pierson and Eggleston 2014; Posey et al. 1999; Soniat et al. 2004). Fully developed coastal oyster reefs can support high oyster population density, mature size structure, and subsequently high reproductive output (Peters 2014; Puckett and Eggleston 2012)(Peters et al. in review). In order to improve ecosystem function, oyster restoration is essential. In recognition of this need, DMF coordinates restoration activities to improve statewide oyster populations and subsequently enhance the ecosystem services they provide.

<u>State Oyster Restoration Measures: Cultch Planting</u>

Program History

The State of North Carolina has been interested in increasing oyster production in the estuarine waters suitable for shellfish cultivation since the 1880’s. The State’s early efforts promoted private oyster culture and resulted in the granting of approximately 50,000 acres of oyster franchises. The franchises were minimally successful and state efforts were shifted to enhancing public bottom for oyster production. Relatively small amounts of shell were planted (10,000 – 12,000 bushels per year) between 1915 and 1920 with excellent results. The Fisheries Commission Board requested and received $10,000 in funding for oyster enhancement for the next two years. Approximately 100,000 bushels of shells and seed oysters were planted in 1921 and 1922 (Thorson 1982). Oyster enhancement efforts (planting of seed oysters and shells) in the early 1920's and in 1934 were credited with significant increases in oyster production. The only significant reference to oyster enhancement activities in the period between 1926 and 1946 occurred during 1934. The 1934 project was the largest annual oyster enhancement project in North Carolina and resulted in 825,000 bushels of seed oysters and 78,567 bushels of shells being planted. These planted areas were closed until 1936. Oyster landings more than doubled from 271,192 bushels in 1934 to 651,050 bushels in 1936 (*adapted from* (Chestnut 1951)). In this case, the 1934 restoration efforts likely provided for substantially increased harvest landings.

Governor Cherry created a special oyster commission in 1946. The legislation resulting from the oyster commission's recommendations contained landmark changes in oyster management in North Carolina (Chestnut 1955a). The renewed enhancement effort was known as the Oyster Rehabilitation Program. Provisions were made for an ongoing, large-scale shell and seed oyster planting program on natural oyster rocks, an oyster tax to support the program, a requirement that 50% of the shell from shucking operations be contributed to the program, a 50 cent-per-bushel tax on shell stock shipped out-of-state, and a $100,000 appropriation to initiate the program. Plantings during the first ten years of the program totaled 838,000 bushels of shell and 350,734 bushels of seed oysters (Chestnut 1955a). By the mid 1950's appropriations were exhausted, landings and oyster tax collection had not increased, and a request for an $80,000 annual appropriation was presented to the 1956 legislature with plans to increase oyster enhancement efforts to 500,000 bushels per year. This request was approved, as were additional increases in annual appropriations in 1972, 1977, and 1979. The Oyster Rehabilitation Program was revised by the legislature in 1997 to the Shellfish Rehabilitation Program with an annual budget of approximately $268,650 and the additional responsibility of enhancing hard clam production.

Program Implementation

Oyster rehabilitation efforts have utilized various methods in seed oyster and cultch material (shells: oyster, bay scallop, calico scallop, sea scallop, and surf clam; and marl) deployment. Methods include hiring fishermen to gather and transplant seed oysters; contracting private tugs, barges and labor; and using DMF enhancement vessels and personnel. Oyster enhancement activities before 1954 were conducted with contracted fishermen. In 1954 the program acquired a 40-foot wooden barge which was towed with larger enforcement vessels. Shells were deployed by washing overboard with high-pressure water pumps. Due to the scarcity of shell cultch, available experimental plantings were begun using marl as an alternative cultch material in 1968. The plantings were successful and a tug and barge was contracted to continue marl deployment in 1970. The contracted tug and barge utilized a bulldozer to push the marl overboard in piles. These piles create mounds of various heights on the bottom depending on the movement of the vessel.

In 1972 increased appropriations and a one-time grant provided funds for the purchase of a Hatteras class ferry (110 foot converted landing craft) and a bulldozer. This vessel replaced the contracted tug and barge but the planting techniques were retained. Also purchased with these funds was a 50-foot self-propelled shallow draft barge to be used in the enhancement activities in the southern part of the state. Operations in this area involve the enhancement of intertidal oyster habitat requiring a shallow draft vessel. These vessels have been replaced by four vessels designed for the specific areas in which they work. Two small (32 and 36 foot) shallow draft self-propelled barges equipped with inboard/outboard power are assigned to the southern area of the state. Three medium size (40- 65 foot) flat bottomed self-propelled barges conduct activities primarily in the bays and rivers adjacent to Pamlico and Core sounds. A 135-foot ex-military landing craft works the deeper areas of the sounds and adjacent waters. The five smaller vessels utilize high-pressure water pumps to wash the shell overboard. A front-end loader is used for cultch deployment on the landing craft.

Cultch planting activities are typically conducted between the first of May and the end of August to correlate with the period of oyster spawning and spat settlement. Planting sites are selected based on criteria including bottom type, salinity, currents, historical production, input from local fishermen, and effects of fishing operations in the area. The planting sites are monitored for three years for oyster recruitment and survival. Recent planting efforts have incorporated mound construction techniques and increased planting site size to increase recruitment and reduce the effects of anoxic events, siltation, and subsidence. Efforts to increase the size of planting sites have reduced the total number of sites planted per year, but the integrity and effectiveness of the sites seem to have improved. The increased relief and size is intended to extend effective life of the sites.

A continued refining of vessels, equipment, and techniques has produced a rehabilitation program capable of deploying in excess of half a million bushels of cultch and relaying 20,000+ bushels of oysters per season.

Recycled Shell

The N.C. Oyster Shell Recycling Program was established in the fall of 2003 in an effort to supplement purchased material for cultch planting. The purpose of the program was to recover post-consumer oyster shells that were being lost to driveways, landscaping, construction, and landfills and utilize them to create and enhance oyster habitat in cultch planting, hatcheries, and sanctuaries. The recycling program also accepted other calcium-based shells for rebuilding oyster habitat such as clam, scallop, mussel, and whelk shells. On July 1, 2013, funding for the Oyster Shell Recycling Program was discontinued and the program ended. However, some recycling responsibilities have been absorbed by other programs within NCDMF's Habitat & Enhancement and Fisheries Management staff. Historically high-yield recycling sites have been maintained, while low-yield collections sites have been closed. Convenient drop-off locations, with containers and bins at recycling centers, are provided for individuals who may have 20 bushels or less from small oyster roasts. Collections of oyster shells from larger oyster roasts (e.g., church, community, civic organizations, and festivals) require use of trailers or dump trucks. Staff coordinates pickup and delivery of shells to stockpile sites, enlisting help from solid waste disposal facilities and private waste companies (Table 12.1.1.).

Since 2003, NCDMF restoration efforts have benefitted from 211,255 bushels of donated oyster shells. However, recycled shell volume has decreased substantially since the termination of the program (Table 12.1.2.).

TABLE 12.1.1. List of active shell recycling locations.

Site Name	Address	City	County
Washington DOT Yard	258 Clarks Neck Rd.	Washington	Beaufort
Beaufort County Landfill	1342 Hawkins Beach Rd.	Washington	Beaufort
Magnolia School Rd., GDS	1057 Magnolia School Rd.	Washington	Beaufort
Washington Crab & Oyster Co.	321 N. Pierce St.	Washington	Beaufort
Abbottsburg - County Trash Site	13887 Twisted Hickory Rd.	Bladenboro	Bladen
Bladenboro - County Trash Site	46 Webb Faulk Rd.	Bladenboro	Bladen
Sandy Grove - County Trash Site	3206 Horse Shoe Rd.	Bladenboro	Bladen
Council - County Trash Site	120 Carvers Creek Rd.	Council	Bladen
Dublin - County Trash Site	6771 Hwy 41 W	Dublin	Bladen
East Arcadia - County Trash Site	77 Kennedy Store Rd.	East Arcadia	Bladen
Bladen County Transfer Station	1522 Mercer Mill Rd.	Elizabethtown	Bladen
Wards - County Trash Site	370 NC Hwy 53 W	Elizabethtown	Bladen
Kelly - County Trash Site	19867 N.C. Hwy 53 E	Kelly	Bladen
Libson - County Trash Site	2373 White Plains Church Rd.	Lisbon	Bladen
Tar Heel - County Trash Site	423 Tar Heel Ferry Rd.	Tar Heel	Bladen
White Oak - County Trash Site	13763 NC Hwy 53 W	White Oak	Bladen
Tobemory - County Trash Site	1852 Tobemory Rd.	St. Pauls	Bladen
Ammon - County Trash Site	119 Ammon Com. Center Rd.	Garland	Bladen
Garland - County Trash Site	80 Hwy 210 W	Garland	Bladen
Bay Tree - County Trash Site	10431 NC 41 Hwy E	Harrells	Bladen
Rowan - County Trash Site	16956 Hwy 210 E	Ivanhoe	Bladen
Brunswick Community College	50 College Rd.	Bolivia	Brunswick
Brunswick County Landfill	170 Landfill Rd.	Bolivia	Brunswick
Calabash -County Trash Site	736 Seaside Rd.	Seaside	Brunswick
Southport - County Trash Site	8392 River Rd.	Southport	Brunswick
Supply - County Trash Site	1709 Oxpen Rd.	Supply	Brunswick
Cabarrus County Landfill	4441 Irish Potato Rd.	Can	Carbarrus
Town of Beaufort Public Works	512 Hedrick St.	Beaufort	Carteret
Hwy 58, GDS	Fire Tower Rd. Hwy 58	Cape Carteret	Carteret
DMF Office - Morehead City	3441 Arendell St.	Morehead City	Carteret
Hibbs Rd., GDS	365 Hibbs Rd.	Newport	Carteret
Otway, GDS	501 Harker's Island Rd.	Otway	Carteret
South River Stockpile Site	229 Tosto Rd.	Beaufort	Carteret
Jordan's Restaurant	8106 Emerald Dr.	Emerald Isle	Carteret
Morehead City State Port	111 arendell st	Morehead City	Carteret
Cedar Island Stockpile	2660 Cedar Island Rd	Cedar Island	Carteret
Edenton Fish Hatchery	1102 W. Queen St	Edenton	Chowan
Columbus County Landfill	354 Landfill Rd.	Whiteville	Columbus
Hwy 55, County Trash Site	681 Highway 55	Bridgeton	Craven
Old Cherry Point Rd., County Trash Site	4001 Old Cherry Point Road	New Bern	Craven
Cumberland County Landfill	698 Ann St.	Fayetteville	Cumberland
Moyock Recycling Center	101 Panther Landing Road	Moyock	Currituck
Barco Recycling Center	183 Shortcut Rd	Barco	Currituck
Grandy Recycling Center	6815 Caratoke Hwy	Grandy	Currituck
Dare County Trash Site - Buxton	47015 Buxton Back Rd.	Buxton	Dare
Kill Devil Hills Recycling Ctr.	701 Bermuda Bay Blvd.	Kill Devil Hills	Dare
Kitty Hawk Recycling Center	4190 Bob Perry Rd.	Kitty Hawk	Dare
Dare County Public Works	1018 Driftwood Dr.	Manteo	Dare
Rodanthe/Waves/Salvo Recycling Center	23176 Myrna Peters Rd.	Rodanthe	Dare
DMF stockpile site - Wanchese	604 Harbor Rd.	Wanchese	Dare
Leggett - County Trash Site	1500 Spivey Rd.	Leggett	Edgecombe
33 Grill & Oyster Bar	3309 NC Hwy 33N	Tarboro	Edgecombe
Edgecombe County Landfill	1601 Colonial Rd.	Tarboro	Edgecombe
Rocky Mount - County Trash Site	1136 Baie Rd.	Rocky Mount	Edgecombe
Swan Quarter Ferry Teminal	748 Oyster Creek Rd	Swan Quarter	Hyde
Johnston County Landfill	680 County Home Rd.	Smithfield	Johnston
Seaview Crab Company	6458 Carolina Beach Rd.	Wilmington	New Hanover
Trails End Park	613 Trails End Rd.	Wilmington	New Hanover
Carolina Beach - State Park	1010 State Park Rd.	Carolina Beach	New Hanover
Airlie Gardens	300 Airlie Rd.	Wilmington	New Hanover
New Hanover County Landfill	5210 Hwy 421 N.	Wilmington	New Hanover
Wrightsville Beach DMF Lab	Causeway Dr.	Wrightsville Beach	New Hanover
Onslow County Landfill	415 Meadowview Rd.	Jacksonville	Onslow
Morris Landing Preserve	898 Morris Landing Rd.	Holly Ridge	Onslow
Sturgeon City Education Ctr.	4 Court St.	Jacksonville	Onslow
T&W Oyster Bar	2383 NC Hwy 58	Swansboro	Onslow
Mile Hammock Bay - TLZ Bluebird	NC 172	Jacksonville	Onslow
Orange County Landfill	1514 Eubanks Rd.	Chapel Hill	Orange
Pamlico County Transfer Station	Hwy 306 N.	Grantsboro	Pamlico
Hobucken	NC 33	Hobucken	Pamlico
Vandemere	NC 307	Vandemere	Pamlico
DMF Office - Elizabeth City	1367 Hwy 17	Elizabeth City	Pasquotank
Bells Fork Collection Site	4554 County Home Rd.	Greenville	Pitt
Pitt County Landfill	3025 Landfill Rd.	Greenville	Pitt
Port Terminal Rd. Collection Site	970 Port Terminal Rd.	Greenville	Pitt
Sampson County Landfill	7434 Roseboro Hwy.	Roseboro	Sampson
Sampson County Trash Site	285 Potato House Rd	Keener	Sampson
New manteo Dump Trailer #1	TBD	TBD	TBD
New Wilmington Dump Trailer	TBD	TBD	TBD
Bennetts Stockpile	TBD	TBD	TBD
Wake County Trash Site	10505 Old Stage Rd.	Raleigh	Wake
Wake County Trash Site	3401 Holleman Rd.	New Hill	Wake
Wake County Landfill	6025 Old Smithfield Rd	Apex	Wake
Wake County Trash Site	3600 Yates Mill Rd.	Raleigh	Wake
Wake County Trash Site	8401 Battle Bridge Rd.	Raleigh	Wake
Wake County Trash Site	5216 Knightdale-Eagle Rock Rd.	Knightdale	Wake
Wake County Trash Site	5051 Wendell Blvd	Wendell	Wake
Wake County Trash Site	266 Aviation Pkwy	Morrisville	Wake
Wake County Trash Site	9008 Deponie Dr.	Raleigh	Wake
Wake County Trash Site	3931 Lillie Liles Rd	Wake Forest	Wake
Wake County Trash Site	2001 Durham Rd	Wake Forest	Wake
Washington County Landfill	718 Landfill Rd.	Roper	Washington
Wilson County Landfill	4536 Landfill Rd.	Wilson	Wilson

TABLE 12.1.2. Bushels of donated shell collected by the Oyster Shell Recycling Program 2003/04 to 2013/14. Year is from July through June.

Year	Total Bushels
2003-04	817.64
2004-05	2,139.29
2005-06	22,096.72
2006-07	23,713.52
2007-08	25,814.54
2008-09	26,931.08
2009-10	20,663.46
2010-11	24,931.52
2011-12	27,384.06
2012-13	27,345.00
2013-14	9,419.00
Total	211,255.41

Current Status

2015 marks 100 years of cultch planting in North Carolina for restoration purposes. From 1915 through 2005, about 19 million bushels of cultch material were planted in North Carolina waters (Street et al. 2005). More recently, from 1981 to 2014 the state has constructed 1,637 cultch planting sites, totaling 8,585,840 bushels of cultch material, throughout coastal counties (Table 12.1.3.). Cultch sites range in size from 0.1-10 acres, with less than 100 acres of cumulative impacts per year. These sites are made publically available as harvestable bottom. Most cultch planting sites maintain or exceed the threshold of 10 oysters per meter squared, and mean population density for cultch-planted sites is 247 oysters per square meter (Peters 2014; Powers et al. 2009)(Peters et al. in review). Some sites are exceptions, presumably due to low spat fall, catastrophic events, or depletion (Powers et al. 2009).

TABLE 12.1.3. Bushels of cultch material deployed by county and time period from 1980 to present.

	Time Period				
County	1981 - 1989	1990 - 1999	2000 - 2009	2010-2014	Total
Beaufort			3,320		3,320
Brunswick	31,700		39,662	29,766	101,128
Carteret	829,625	846,168	585,114	220,350	2,481,257
Dare	464,400	843,420	451,203	223,426	1,982,449
Hyde	730,600	799,830	471,538	293,668	2,295,636
New Hanover	14,450		34,927	11,614	60,991
Onslow	68,200		211,680	157,556	437,436
Pamlico	285,500	368,323	262,135	112,860	1,028,818
Pender	1,600		20,655		22,255
Unknown	114,000	58,550			172,550
Total	**2,540,075**	**2,916,291**	**2,080,234**	**1,049,240**	**8,585,840**

Cultch planting efforts are highly variable as the limiting factors are funding and cultch material availability. In recent years, the amount of cultch planting has decreased due to limited budgets, increased cost, and a shortage of cultch material. Eastern oyster shells are the preferred cultch material for planting operations; however, in recent years it has become increasingly difficult to secure them. This has been exacerbated by restoration efforts in Virginia, Maryland, and South Carolina as they spend considerably more for restoration than North Carolina. Virginia and Maryland are reportedly paying as much as $4.00 per bushel for oyster shells, including transportation, and $2.20 per bushel without transportation (G. Wright, DMF, pers. com.). In comparison, North Carolina pays approximately $1.00 per bushel and cannot financially compete with neighboring states for available shell. As a supplemental measure for reduced oyster shell volume, North Carolina uses 2-4" limestone marl, scallop shells, and any other suitable material; however, this is also limited due to funding. Another alternative material, processed recycled concrete, is being considered as it is somewhat less expensive than oyster shell, more widely available, and highly suited for oyster recruitment and survival. Identification of alternative materials for oyster restoration are of paramount importance to cultch planting efforts in order to reduce costs and alleviate reliance on limited shell resources, while providing similar or improved ecosystem services.

Evaluation of success is a key factor in any restoration effort. Each year, cultch planting sites are monitored by DMF with only sites from the last three planting seasons sampled. A sample consists of a minimum of 30 pieces of cultch collected from each site. The number and size of each spat on each piece of cultch is recorded. Data is summarized by the number of spat per piece of cultch. Spat recruitment onto cultch planting sites is variable among years, areas, and salinities with no clear trends. Recommendations have been made by resource managers to emphasize long term monitoring in an effort to supplement oyster stock status data for future decision making. However, long-term monitoring of cultch planting sites has not been conducted due to funding and staffing limitations.

State Oyster Restoration Measures: Hatchery Oyster Seed Production

Program History

The Oyster Rehabilitation Program was initiated in 1947. However, according to the Oyster Fishery Management Plan (NCDMF 2001) "It is doubtful that the existing level of rehabilitation effort is sufficient to overcome the sources of depletion of the resource." A productive oyster culture industry in the state, hatchery produced seed, and other mariculture efforts are the keys to maintaining and restoring oyster populations. According to the Fishery Management Plan (NCDMF 2001), "the health of North Carolina's oyster populations is a good indicator of the overall health of our estuaries, and all prudent measures should be taken to ensure a viable oyster resource." Recognizing the Eastern Oyster's role as a keystone species in the estuarine environment, in 2005 the Governor and legislature supported several key initiatives to protect and restore the native oyster and the water it inhabits in North Carolina. In response to legislation co-sponsored by Senators Julia Boseman and Scott Thomas, and budget appropriations in FYs 05-06 (R) and FYs 06-07 (R), the North Carolina Aquariums created the North Carolina Oyster Hatchery Program (NCOHP) and Interagency Advisory Team.

NCOHP's overarching goal is to restore the oyster population in North Carolina's coastal waters by facilitating the availability of in-state oyster seed. Among general restoration objectives, the hatchery program exists to educate and train growers for hatchery management, develop an education program to promote and link existing educational efforts by multiple agencies, and support research initiatives.

Current Status

In order to meet regional needs for restoration, the Advisory Team recommended the construction of three regional hatchery facilities for the production of oyster larvae, education/extension and research. The primary production facility would be located at Morris Landing (Onslow County), with secondary facilities located at the North Carolina Aquarium on Roanoke Island (Dare County) and University of North Carolina Wilmington Center for Marine Science (New Hanover County). These facilities would produce eyed larvae, which can be set on shell for existing DMF restoration and sanctuary efforts, or raised as "singles" by growers. Remote setting locations would be established at South River (Carteret County) and at Swan Quarter (Hyde County) to provide spat on shell for DMF restoration and sanctuary efforts focused in Pamlico Sound. Additionally, exhibits were planned at each of the three North Carolina Aquariums to educate stakeholders on the value of oysters and oyster habitat and to inspire action to protect this vital economic and ecological resource.

Presently, funding for NCOHP is sparse and prevents to program expansion. Hatchery development in NC will rely on additional funding to 1) support expansion of the existing research hatchery at UNC-Wilmington to provide seed for shellfish lease operations, or 2) serve as an incentive for a private entity to start a production hatchery, or 3) develop a private-public partnership production hatchery, potentially using the Division of Marine Fisheries property in Cedar Island. Costs for a production hatchery were reviewed and summarized in the NC Oyster Hatchery Plan and would provide a starting point for developing costs under different scenarios.

State Oyster Restoration Measures: Oyster Sanctuaries

Program History

In 1995, the Blue Ribbon Advisory Council on Oysters recommended the development of oyster sanctuaries in North Carolina waters. The objective of this program is to establish a self-sustaining network of protected oyster broodstock sanctuaries. These sanctuaries are intended to provide larval subsidies to other reefs throughout Pamlico Sound, including the Neuse River, through larval transport and connectivity. Construction began in 1996 and was initially administered by the Artificial Reef and Oyster Rehabilitation programs. Five oyster/artificial reef sanctuaries were constructed in North Carolina prior to the 2001 Oyster FMP adoption (NCDMF 2001). These sanctuaries were developed in Bogue Sound, West Bay (Cedar Island), Deep Bay (Swan Quarter), Croatan Sound, and Clam Shoal behind Hatteras Village. The site in Bogue Sound has become covered with sand by natural processes while all other sites still have bottom relief. As of 2015, the Oyster Sanctuary program has expanded to consist of 15 permitted sites, including 13 completed or under development, and two in design (Table 12.1.4.). Current sanctuaries are spread throughout Pamlico Sound in locations near Pea Island, Hatteras Island, Ocracoke, West Bay, Point of Marsh, Turnagain Bay, Pamlico Point, Deep Bay, Bluff Point, Engelhard, Long Shoal River, Stumpy Point, and Roanoke Island. New sanctuaries are planned for the Neuse and Cape Fear rivers (Figure 12.1.1.; DMF Program 601, unpublished data; C. Weychert and M. Jordan, DMF, pers. com. 2015).

TABLE 12.1.4. Summary of oyster sanctuaries in North Carolina. (*) permitted but not established, (**) split amongst four new sanctuaries in Pamlico Sound, (***) verbally agreed upon with USACE.

	Sanctuary name	Latitude	Longitude	Permitted area (acres)	Developed area (acres)	Intentional void (acres)	Available area (acres)	Material type	Total Tons of Material
1	Croatan Sound	35.804737	-75.638933	7.7	5.4	1.6	0.7	Limestone Marl Riprap Reef Balls	2,093
2	Crab Hole	35.381877	-76.369353	30.5	30.5	0	0.0	Limestone Marl Riprap	36,489
3	Gibbs Shoal	34.980862	-76.356053	30	30	0	0.0	Limestone Marl Riprap Reef Ball Reef Cube	22,447
4	Deep Bay	35.291333	-75.619667	17.2	5.69	6.9	4.6	Limestone Marl Riprap Reef Balls	1,749
5	West Bluff	35.728055	-75.675138	19.9	9.1	3.8	7.0	Limestone Marl Riprap Reef Balls	10,162
6	Clam Shoal	35.180250	-75.993867	58.2	31.4	0	26.8	Limestone Marl Riprap	38,359
7	Middle Bay	35.235967	-76.502967	4.6	0.4	0	4.2	Limestone Marl Riprap	900
8	Ocracoke	35.007903	-76.532583	28	25.44	0	50.6	Limestone Marl Riprap	15,183
9	Neuse River	35.305000	-76.168150	5.7	5.3	0	0.4	Limestone Marl Riprap	7,357
10	West Bay	35.455928	-75.930723	6.7	2.23	3.9	0.6	Limestone Marl Riprap Reef Balls	2,329
11	Long Shoal	35.563450	-75.830600	10	6.6	2.3	1.1	Reef Balls	2,173
12	Raccoon Island	35.090366	-76.391233	10	7	3	0.0	Reef Balls Precast Concrete Processed Recycled Concrete	1,824
13	Little Creek	35.043600	-76.514820	20.7*	9.8 (proposed and funded)	10.9	0.0	Limestone Marl Reef Balls Precast Concrete Processed Recycled Concrete Concrete Blocks Reef Pyramids Granite Riprap Basalt Riprap	5,880
14	Pea Island	35.666000	-75.615670	32	18.6 (completed fall 2015)	13.4	0.0	Reef Balls Precast Concrete Processed Recycled Concrete	3,420
15	Cape Fear River	TBD	TBD	Proposed	TBD	TBD	TBD	TBD	TBD
16-19	USACE Mitigation**	TBD	TBD	160***	20 proposed	TBD	TBD	TBD	TBD
	Total			**281.2**	**177.7**		**95.9**		**150,365**

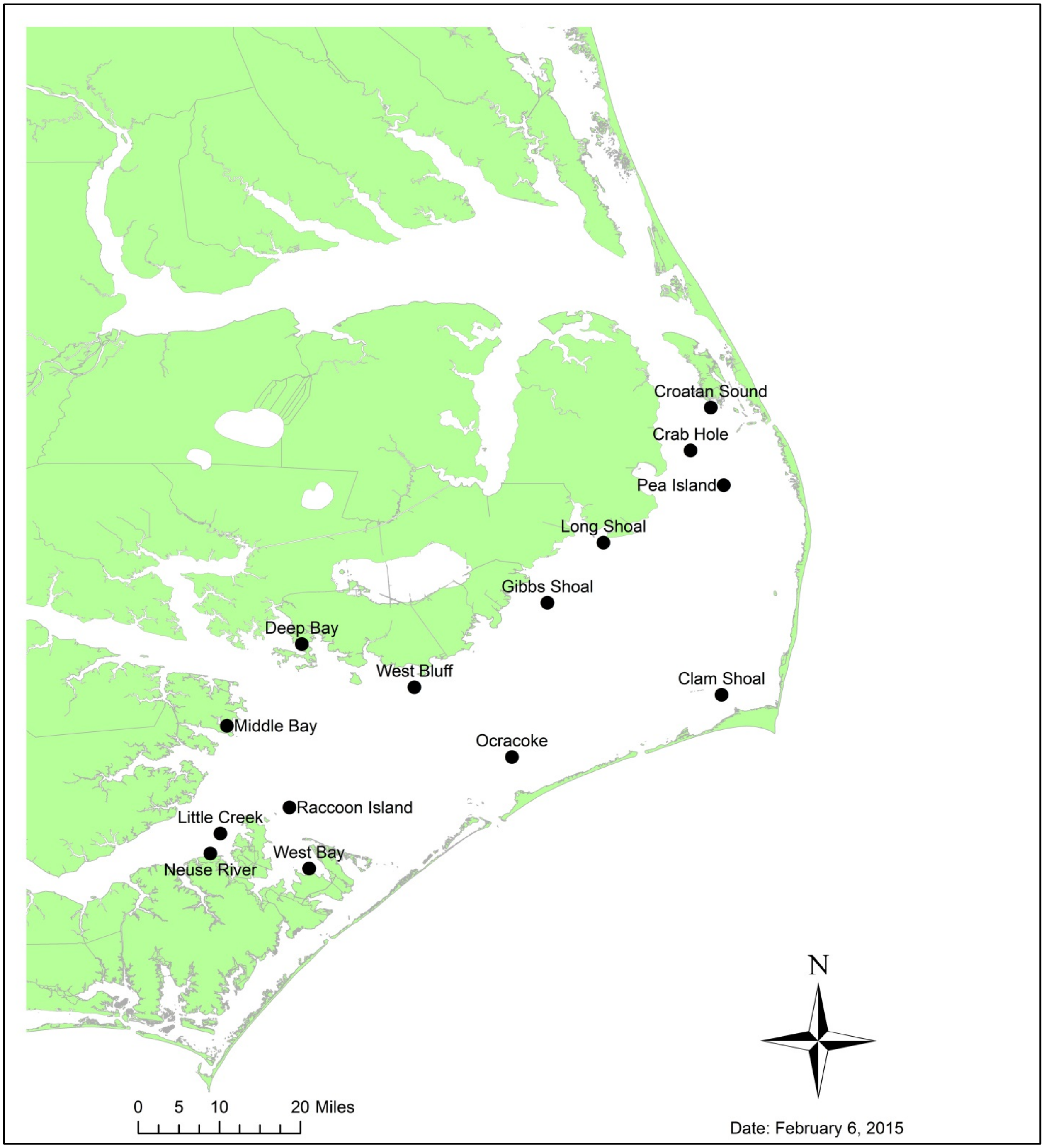


FIGURE 12.1.1. North Carolina permitted sanctuary locations, April 2015.

To supplement DMF planned and implemented sanctuaries, the United States Corps of Engineers (USACE) will be constructing approximately 20 acres of 42 required acres additional sanctuary bottom as environmental mitigation. Post-construction, DMF will monitor reef biology.

As a strategic plan to withstand catastrophic events (e.g., hurricane or anoxic event), a network of small oyster sanctuaries was established in lieu of a few larger ones. This strategy may prevent a catastrophic event from damaging or causing mass mortalities throughout the oyster sanctuary network. Additionally, a network of oyster reefs is necessary to ensure reef connectivity through larval supply. In oyster populations, as with many other marine metapopulations, larval connectivity is essential to restoration of marine species (Lipcius et al. 2008). Site locations are selected based on physical and biological environmental conditions, individual project goals, regulatory stipulations, preservation of active fishing grounds, existing resources (e.g., sea grass or oyster beds), and cultural value.

North Carolina oyster sanctuaries were traditionally constructed of multiple, high profile mounds using mostly Class B Riprap (fossil stone). Recent sanctuary designs emphasize high material diversity, providing better opportunities to recruiting fish and better settlement habitat for recruiting oysters. Contemporary sanctuaries utilize recycled concrete products, such as reinforced concrete pipe and other prefabricated structures. Limestone is no longer used as a dominant material type, as it is prone to supporting marine boring sponges, which are detrimental to healthy oyster populations. Within permitted boundaries, material is typically arranged in mound or grid patterns with void, interstitial space between grids and around the perimeter. While reef height (vertical relief) is an important design consideration, sanctuaries adhere to minimum vertical clearance requirements of the US Coast Guard. Existing sanctuaries range from 4.6 to 40 acres in size (Table 12.1.4.), and sanctuary area incorporates approximately 281.2 acres. Roughly 180 additional acres of permitted but undeveloped sanctuary area are planned among four USACE projects and two DMF projects.

Oyster sanctuaries are protected under Marine Fisheries Rule T15A NCAC 03K .0209 and delineated in 15A NCAC 03R .0117, which prohibits harvest of oysters and use of trawls, long haul seines, and swipe nets, therefore promoting growth and enhancing survivability of large oysters within the sanctuaries. Oyster sanctuaries under construction but not yet incorporated into T15A NCAC 03R.0117 can be protected under Rule 15A NCAC 03H .0103 and 03K. 103 through proclamation authority.

Sanctuary Efficacy

The effective size of an oyster sanctuary for metapopulation restoration is largely unknown and subjective as limited data exists to this point, and goals are not clearly defined (Geraldi et al. 2013). However, with respect to sanctuaries as broodstock habitat and larval sources, consideration must be paid to environmental conditions such as system hydrodynamics and water quality (Garrison 1999; Paynter and Dimichele 1990; Puckett et al. 2014; Shumway 1996; Wells 1961), which influence population dynamics. In a hypothetical hierarchy of requirements for sanctuary efficacy in the capacity of a larval source, connectivity is first necessary to supply a sanctuary with recruiting larvae. Connectivity is largely attributed to reef location, larval supply, and system hydrodynamics. System hydrodynamics play an important role in larval dispersal through transport. Each oyster reef and oyster sanctuary relies on currents or tides to disperse larvae throughout coastal waters. In the absence of these currents oyster larvae would not be transferred from reef to reef for settlement. In many instances, natural oyster reefs provide larvae to oyster sanctuaries, especially for initial spat sets. In turn, the oyster sanctuaries provide an unfished biomass of oysters which provide larvae to both natural reefs and other sanctuaries. Second in the hierarchy of requirements, suitable settlement substrate for planktonic larvae must be available and settlement cues for those larvae must be present. Once settled, water quality must be adequate for survival and growth to broodstock size. At this point, the combination of high recruitment, growth, and survival (optimal population demographics), will support high population density and size structure with multiple size-based cohorts (including large broodstock oysters). Maintenance of these characteristics is also dependent on no harvest pressure or subsequent size selection. Larval production of a whole sanctuary is then determined by the size of the sanctuary. Among sanctuaries with equal population density and size structure, the assumption is that the larger sanctuary will have higher larval production. The final hierarchical requirement for sanctuary efficacy might be, again, connectivity through hydrodynamics. Fertilized larvae from a sanctuary must be distributed to other reefs in order to support the goal of providing larval subsidies to the rest of the system. Without connectivity, high production sanctuaries have little value to system-wide restoration.

Since inception of the oyster sanctuary network, one major study has been conducted comparing population demographics among the sanctuaries. At the time of publication, eight of the existing ten sanctuaries expressed a nearly 400% increase in population density over two years (Puckett and Eggleston 2012). Population density at each sanctuary is variable, ranging from 418.7 ± 82.1 to 6,585.3 ± 204.8 oysters per square meter, though mean density among sanctuaries was 3,781.7 oysters per square meter (Puckett and Eggleston 2012). Growth and survival at sanctuaries follows a gradient consistent with, and likely driven by, a persistent salinity gradient present in Pamlico Sound waters (Lin et al. 2007; Puckett and Eggleston 2012; Wells 1961; White and Wilson 1996). Lower salinity (10-18 psu) in western Pamlico Sound sanctuaries exhibit higher survival though slower growth rates, whereas eastern Pamlico Sound sanctuaries experience higher salinity (18-26 psu) and subsequently maintain faster growth rates and lower survival rates (Puckett and Eggleston 2012). In further analysis of North Carolina sanctuary efficacy, larval connectivity among sanctuaries has been validated, however modeled intrinsic growth rate is unsustainable, suggesting sanctuary network sustainability is dependent on subsidies from non-protected reefs (D. Eggleston and B. Puckett, NCSU-CMAST, pers. com.)(Haase et al. 2012; Peters 2014; Puckett and Eggleston 2012).

Research in Pamlico Sound has indicated that the existing network of sanctuaries is not self-sustaining, though oyster densities within sanctuaries overall are increasing over time (Puckett and Eggleston 2012). This suggests sanctuary sustenance is reliant on larval subsidies from non-protected reefs in the system, including natural and enhanced (cultch-planted) reefs. In Pamlico Sound, population density is considerably lower at non-protected reefs versus sanctuaries; however the expansive total area of non-protected reefs far surpasses that of sanctuaries. Oyster size is directly related to gamete and larval production, with larger individuals producing a higher number of gametes (Mroch et al. 2012). Relative to non-protected reefs, sanctuaries exhibit ~72-times greater oyster densities and a size structure favoring larger oysters. Therefore, reproductive potential of reserves is estimated to be ~30-times greater than non-protected reefs (Peters 2014). Peters et al. (in review) noted that due to areal coverage of natural reefs compared to oyster sanctuaries the potential larval output was similar. This is attributed to about two orders of magnitude difference in natural reefs areal coverage compared to oyster sanctuaries.

Relative to non-protected (cultch-planted and natural) oyster reefs, North Carolina oyster sanctuaries have demonstrated the capacity to maintain higher population density and greater abundance of large, fecund oysters. There is a striking decrease in oyster densities going from no-take to non-protected oyster reefs, with mean total oyster density ~72- and 8-times higher in sanctuaries than natural and cultch-planted reefs, respectively (Peters 2014; Puckett and Eggleston 2012). Non-protected reefs, in general, exhibit truncated size structure and few oysters of legally harvestable size (75 mm, 3 inches). In combination of size structure, population density, and per-capita fecundity at length, the average reproductive potential per square meter of oyster sanctuaries is up to 30-times greater than non-protected reefs (Peters 2014)(Peters et al. in review). For perspective, an estimated 14,650 acres of non-protected oyster reef exists in Pamlico Sound and at the time of study, 141 acres of sanctuary area existed (Peters 2014). Integrating total reef area in the estuary and reproductive potential per square meter, oyster sanctuaries potentially provide 26.2% of all larvae to the system while only accounting for 1% of all reef area (Mroch et al. 2012; Peters 2014; Puckett and Eggleston 2012). This a testament not only to the stand-alone value of sanctuaries in this case, but also to the degraded state of natural and cultch-planted reefs, which serves to boost the importance of protected reefs as a mitigation measure.

While research has highlighted the restoration potentential of protected reefs , it should be noted that recent trends indicate that Pamlico Sound Oyster Sanctuaries have experienced moderate decline in population density since the publication of Puckett and Eggleston (2012). These trends are likely attributed to aging reefs and subsequent ecological succession. These successional trends suggest that initially, oyster densitities may be very high then decline somewhat over time, due to increased competition for settlement space with other fouling organisms and predation, which limit successful recruitment (Luckenbach et al. 2005; Osman et al. 1989; White and Wilson 1996). Present sanctuary oyster population abundance may reflect a truncated difference in reproductive potential between harvested and protected reefs, though sanctuaries likely supply more oyster larvae per square meter than nearby non-protected reefs.

Current Status

The total required sanctuary area for restoration is a major consideration in North Carolina. While it is unknown how much protected acreage is needed, North Carolina has included sanctuaries as a major component of its restoration effort. In Virginia and Maryland, sanctuaries are also emphasized as important to restoration. In 2000, an agreement was reached among scientists, managers, watermen, and environmentalists on an appropriate acreage for oyster sanctuary designation in the Chesapeake Bay. The agreement, known as the Chesapeake Bay 2000 Agreement, called for setting aside at least ten percent of traditional oyster reef acreage as sanctuaries (in Keiner 2009). In North Carolina, 16,106 acres of subtidal shell bottom area has been mapped statewide, to date (B. Conrad, DMF unpub. data). Using the Chesapeake Bay's model, an estimated 1,600 acres of sanctuary area should be designated. By recommendation of the North Carolina Coastal Federation, a goal was established to create 500 acres of sanctuary area by 2020, though there is no formal agreement to this effect (NCCF 2014). To accomplish this goal, sanctuary network design has moved toward creating a network, whereby many small reefs are built, rather than a few large areas. Environmental considerations have also become increasingly important to accomplishing this goal with effective results (e.g., high oyster production).

Certain environmental stressors have emerged as impediments to subtidal reef restoration in North Carolina. Despite a steep increase in population density overall, two sanctuaries in high salinity areas experienced dramatic population decline following the Puckett and Eggleston (2012) study (D. Eggleston and B. Puckett NCSU-CMAST, pers. com.). Coincident with this decline was an increased percent cover of marine boring sponge on limestone marl reef material (*Cliona* spp.; M. Jordan, P. Holmlund, C. Hardy, NCDMF; N. Lindquist, UNC-CH, pers. com.). *Cliona* boring sponge is a bioeroder of calcareous materials and linked to reduced oyster gamete viability and possibly increased oyster mortality rates (Ringwood et al. 2004). This sponge is endemic to North Carolina, though recently more pervasive, especially on limestone marl rocks (NCDMF; N. Lindquist, UNC-CH, pers. com.)(Wells 1959). To improve reef design in high salinity waters and throughout North Carolina estuaries, DMF is conducting research on alternative settlement substrates for oyster restoration. The objective is to identify construction materials which maximize oyster recruitment, growth, and survival, while offering high resistance to environmental stressors, such as *Cliona* boring sponge. In addition, marl riprap and concrete precast structures (reef balls, reef cubes, recycled pipe, boxes, manholes, etc.), granite riprap, basalt riprap, and reef pyramids will be used as experimental construction materials. These materials will also be assessed for their quality as fish habitat. Monitoring protocol is currently under revision to address challenges associated with new material types.

Under current protocol, recently utilized materials (concrete pipe, reef balls, etc.) cannot be sampled due to their size. Therefore, the Oyster Sanctuary program is exploring options for in-situ monitoring protocol. Current proposals include (1) photo/video sampling coupled with image analysis and (2) using scaled modular sampling units.

Observations by DMF staff, both biological and enforcement, as well as reports by working watermen, have indicated an increase in poaching activity within sanctuaries. Poaching by means of dredging is most commonly observed in these locations. Bottom disturbing gear is destructive of costly state property and extremely detrimental to the function of sanctuaries. Conservatively, restored and protected oyster reefs provide up to $40,234 per acre per year in ecosystem benefits (Grabowski et al. 2012). Sanctuary planners should include considerations for deterring poaching within boundaries.

Learning from other inter- and intra-state agency restoration efforts will provide crucial guidance on development and monitoring innovation.

IV. PROPOSED MANAGEMENT OPTIONS

Cultch Planting

1. Increase spending limit per bushel of shell to compete with other states
2. Develop a cooperative public/private, self-sustaining shell recycling program by providing financial incentives in exchange for recycled shell
3. Work with the shellfish industry to institute an "oyster use fee" to help support the cultch planting program.
4. Identify alternative substrates for larval settlement in intertidal and subtidal reefs, including a cost-benefit analysis
5. Establish long term monitoring program to support future decision making
6. Utilize new siting tools and monitoring protocols to maximize reef success

Hatchery Oyster Seed Production

1. Explore options for increasing funds to support UNCW oyster hatchery
2. Identify regional genetic variability within NC
3. Improve availability of seed oysters genetically suited to respective regions

Oyster Sanctuaries

1. Identify alternative substrates for larval settlement in intertidal and subtidal reefs, including a cost-benefit analysis
2. Identify the size and number of sanctuaries needed
3. Develop reefs that are resistant to poaching
4. Utilize new siting tools to maximize reef success
5. Explore options for in-situ sampling protocol to incorporate alternative construction materials
6. Expand oyster sanctuary network to include intertidal reefs in euhaline waters

12.2. Living Shorelines

I. ISSUE

The shoreline edge and intertidal zone serves as the transition between uplands and estuarine waters. This shoreline zone is critical to both estuarine species and property owners. For fish and invertebrate species, the shoreline edge provides an abundance of food, structural cover and shallow water that protects small fish from predators, and provides a corridor for fish to migrate from one area of the system to another. For waterfront property owners, wetland vegetation and oyster reefs along the shoreline can deter erosion of their property and filter pollutants from the water, keeping it safe for swimming and shellfish harvest. Yet natural biotic shorelines (wetlands and oysters) are declining along developed shorelines due to stabilizing shorelines with bulkheads, as well as erosion from storm events and rising water levels.

Property owners' have long used vertical structures, such as bulkheads, to protect their property from erosion. These structures have been documented to cause impacts to fisheries' habitats (e.g. wetlands, submerged aquatic vegetation, and shallow soft bottom). More recently an alternative stabilization method using non-vertical structures, referred to as living shorelines, has been developed to protect properties while enhancing fisheries' habitats. However, bulkheads are still the structure type that is the most utilized shoreline stabilization method.

II. ORIGINATION

Encouraging non-vertical shoreline stabilization methods to maintain shallow habitat has been a CHPP recommendation since 2005. The Coastal Habitat Protection Plan (CHPP) Steering Committee (CSC) has decided to make living shorelines a priority for the 2015 CHPP.

III. DEFINITION

"Living Shorelines" are a designed erosion control technique that can include a suite of options that incorporate living structures, such as marsh plants, often in combination with a rock or oyster sill structure. This method is used to control erosion while maintaining existing connections between upland, intertidal, estuarine, and aquatic areas, which are necessary for maintaining good water quality, ecosystem services, and habitat values. Unlike vertical stabilization measures such as bulkheads, living shoreline techniques typically use native materials such as marsh plants and oyster shells and sometimes, minimal amounts of structural materials (e.g. stone), to stabilize estuarine shorelines, minimize erosion, and enhance habitats. Non-vertical approaches to estuarine shoreline control have been supported by the N.C. Coastal Resources Commission (CRC) and have also been included as a recommendation of the N.C. Coastal Habitat Protection Plan (Deaton et al. 2010).

IV. BACKGROUND

There are a variety of methods and structure types that can be used to stabilize shorelines (Figure 8.1). These range from natural methods, such as planting of wetland vegetation where no fill is required or construction of an oyster reef close to shore, to hardened non-living structures. Hardened structures can be vertical (bulkheads) or sloped (riprap revetments, groins, sills, breakwaters). Another option is a hybrid structure of non-living and native materials (sills, breakwaters, or groins that incorporate vegetation or shell plantings). The most commonly used structure types are non-living, with bulkheads being the dominant type. The most suitable method, when considering habitat, is the one that alters the natural shoreline function the least while providing the necessary erosion control. This will vary based on the specific conditions of the site including shoreline type, wave energy exposure, construction accessibility, waterbody size, water depths, presence of other structures on adjacent properties, and available footprint for the structure. More detailed descriptions of erosion control options are described in Division of Coastal Management (DCM) (2006), DCM (2009), and on DCM's website: (http://nccoastalmanagement.net/web/cm/estuarine-shoreline-stabilization).

The impacts associated with vertical structures (i.e. bulkheads) are discussed in detail in the threats section (Chapter 8). Vertical structures in moderate-energy environments can potentially degrade shallow soft bottom, SAV and wetland habitats by increasing wave energy, turbidity, and water depth. These impacts may have adverse impacts to fisheries either through direct or cumulative effects of multiple shorelines being hardened (Lawless and Seitz 2014). While living shorelines can benefit the coastal environment, there may also be trade-offs in habitat types associated with their construction. Living shorelines can provide additional hard substrate for oysters and barnacles, foraging area for fish and blue crabs, maintaining and enhancing biotic productivity, and trapping sand for wetland plants. However, utilization of living shoreline techniques may result in the conversion of shallow bottom habitats (soft bottom, submerged aquatic vegetation, or shellfish) to hard bottom or wetlands, loss of benthic animals and the potential for upland development.

TABLE 12.1.5. Benefits and Trade-Offs associated with living shorelines.

Benefits	Trade-Offs
Creates forage area for fish and blue crabs.	Fill placed landward of structure kills benthic animals.
Maintains and enhances biotic productivity.	Placement of stone sill covers soft bottom habitat.
Where rock or oyster is used, provides three dimensional hard surface area for attachment of oysters and barnacles.	Habitat tradeoff from shallow water habitat (submerged aquatic vegetation, shell bottom, or mud flats) to wetlands.
Traps sand for establishment of wetland plants.	Sediment trapped may result in conversion of wetlands to upland habitats.
Maintains shallow sloped intertidal zone.	
Traps sediment and filters pollutants from runoff.	

Permitting of Living Shorelines

There are various living shoreline designs that can be used to protect the shoreline, with varying permitting requirements. For instance, planting wetland plants without grading the shoreline will not require a permit, while marsh sills will require a CAMA permit (CAMA, § 113A-100). Depending on the design, location and potential impacts to coastal resources there are two permit options, a CAMA General Permit (15ANCAC07H.2700 for Riprap Sills for Wetland Enhancement in Estuarine And Public Trust Waters) or a CAMA Major Permit. If a marsh sill design is less than 500 ft long, 30 ft waterward of NWL, six inches above NWL, and no fill is associated the project can be permitted with a General Permit from DCM. Although the state has the ability to permit these structures with a general permit, the USACE does not have the legal framework for rapid issuance of a USACE general permit. The USACE states that living shorelines are a site specific project and require complete review. Even if a permit meets the requirements for a CAMA General Permit, it can be faster if an applicant is to apply for a CAMA Major Permit so that the project can be reviewed concurrently by the state and federal agencies where the USACE has the ability to use their Section 291 Programmatic General Permit allowing permit issuance time averaging 75 days or even as short as 30-45 days. If a project design exceeds the CAMA General Permit requirements, a project can go through the Major CAMA review process.

DCM completed an effort to map the state's entire estuarine shoreline after developing a methodology that utilizes the most recent county-level orthophotographs at a viewing scale of approximately 1:500 to digitize the shoreline and related structures in ArcGIS®. DCM completed the Estuarine Shoreline Mapping Project in June of 2012 after mapping more than 10,000 miles of North Carolina's estuarine shoreline in the state's 20 coastal counties (McVerry 2012). The estuarine shoreline data can be viewed or downloaded from DCM's website. The final product is a geospatial representation of the complete estuarine shoreline and structures including docks, piers, bulkheads and riprap revetments.

There are an estimated 10,658 miles of estuarine shoreline in North Carolina with 93 of those miles being stabilized with a bulkhead (DCM 2015). From 2000 to 2015, 35 and 24 living shorelines have been permitted by CAMA Major and General Permits, respectively. In contrast, 67.7 miles of bulkheads were permitted (CAMA Major and General Permits combined) from 2010 to 2014.

In 2005, CHPP implementation actions encouraged 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. The Subcommittee updated a set of principles and concepts, originally developed in 2000, to guide further development of shoreline stabilization rule changes. DCM assembled an Estuarine Biological and Physical Processes Workgroup to advise the sub-committee on the science of the estuarine systems and to develop recommendations on appropriate shoreline stabilization methods for the different North Carolina shoreline types. The Workgroup 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]. The changes include increasing the permit fee to $400.00 for the construction of any bulkhead, and positioning bulkheads at approximate NHW.

The DCM coordinated an interagency meeting in November of 2012 to discuss recent research and mapping projects, the offshore riprap sill General Permit, staff outreach and public awareness efforts, research needs, and short- and long-term actions for the Department to consider. Meeting participants included representatives from DCM, Division of Marine Fisheries (DMF), Albemarle Pamlico National Estuary Partnership (APNEP), Division of Water Resources (DWR), Wildlife Resources Commission (WRC), Ecosystem Enhancement Program (EEP), Community Conservation Assistance Program (CCAP), and the National Oceanographic and Atmospheric Administration (NOAA). The resulting discussions with agencies and partners led to the development of the Living Shorelines Strategy, a joint DCM-DMF initiative (2015).

IV. AUTHORITY

North Carolina General Statutes

§ 113-229	NC Dredge and Fill Law. Permits to dredge or fill in or about estuarine waters or State Owned lakes.
§ 113A-100	Coastal Area Management Act (CAMA)

15A NCAC 7H.0200	The Estuarine and Ocean System Area of Environmental Concern
15A NCAC 7H.1100	General Permit for Construction of Bulkheads and the Placement of Riprap for Shoreline Protection in Estuarine and Public Trust Waters
15A NCAC 7H.2700	General Permit for the Construction of Riprap Sills for Wetland Enhancement in Estuarine and Public Trust Waters

Federal Regulations

33 U.S.C. 403	Rivers and Harbors Act of March 3, 1899
33 U.S.C 1344	Section 404 of the Clean Water Act
Regional General Permit 198000291	Authorizes construction activities in the 20 coastal counties receiving prior CAMA permit and/or a state dredge and fill permit, and if required a water quality certification.
Regional General Permit 197800080	To maintain, repair, construct and backfill bulkheads and riprap structures along eroding high ground shorelines and construct riprap structures to protect eroding wetland shorelines in navigable waters and waters of the United States in the State of North Carolina.
Section 7 of the Endangered Species Act	The Endangered Species Act (ESA) directs all Federal agencies to work to conserve endangered and threatened species and to use their authorities to further the purposes of the Act. Section 7 of the Act, called "Interagency Cooperation," is the mechanism by which Federal agencies ensure the actions they take, including those they fund or authorize, do not jeopardize the existence of any listed species.

V. DISCUSSION

The current Living Shoreline Strategy consists of a series of short-term and long-term goals that are currently in various stages of implementation (Table 12.1.6). The short-term action items include efforts to reduce the permit processing timelines and reduce the number of specific conditions on the state General Permit (15A NCAC 7H.2700), have DCM field representatives continue to educate the public regarding living shorelines, reprint the “Weighing Your Options” booklet, conduct workshops regarding living shorelines, post informational signage at living shorelines sites, and leverage grant resources.

The DCM has been making progress in taking actions that have been described in the Living Shoreline Strategy. The DCM has been working to remove conditions from the living shoreline General Permit and to date DCM, DMF, and DWR have agreed that coordination from DMF and DWR is no longer required. Also, an increased effort by DCM field representatives to distribute information about living shorelines to property owners, marine contractors, or consultants during site visits as an option if site conditions are suitable. A reprinting of “Weighing Your Options” handbook was completed and the booklets distributed to the DCM field offices for further distribution to waterfront property owners. This booklet describes different shoreline stabilization methods and the site specific conditions that are required for them to work effectively in protecting the shoreline while keeping surface waters and uplands connected. The North Carolina National Estuarine Research Reserve Coastal Training Program (NCNERR CTP), a program within DCM, will continue to conduct Estuarine Shoreline Stabilization workshops as a way to engage marine contractors, landscaping companies, landscape architects and realtors on the topic of living shorelines. NCNERR CTP hosted workshops in Beaufort and Wilmington, NC in May and June 2015 with workshops scheduled for the northern coast in fall 2015. These training sessions focus on existing living shoreline examples and discuss the specific costs, materials used, equipment access issues, the permitting process, and demonstrated performance of these methods. Another method of outreach will be the placement of informational signage at new living shoreline demonstration sites such as those constructed at Wildlife Resource Commission boat ramps. Signs are being designed for posting at living shoreline sites that are in visible locations to educate the public of living shorelines and their benefits. A final short-term action is the leveraging of grant resources by DCM and partners for living shoreline research proposals for funding from the CRFL Grant Program as well as guidance from DCM to property owners about potential living shoreline funding assistance available through CCAP, APNEP, SARP or other sources.

The long-term action items include data collection, GIS analysis, and ultimately product development to be utilized by the public in the installation of living shorelines. DCM will continue to analyze the existing shoreline inventory while considering adding other data attributes such as bank height, nearshore depth, fetch, locations of buildings, and other data that may factor into the suitability of living shoreline construction. The DCM is working on creating a GIS data layer to map all of the currently constructed living shorelines and the design attributes. This data layer will be beneficial for researchers to continue to study living shorelines in North Carolina. DCM and NCNERR staff will pursue research projects and funding to evaluate the performance of living shorelines during storm events, the effects of living shorelines on adjacent properties, the feasibility of using oyster shell or alternative materials that support oyster growth, as a construction material for marsh sills, the short- and long-term cost of living shorelines as compared to other methods, and the effectiveness of existing sheet pile sills. DCM will also work to develop living shoreline workshops that meet certain standards that could provide engineering Continuing Education credits to eligible participants, as well as a certification or other official acknowledgement for attendees. DCM NCNERR CTP has formed a Living Shoreline Workshop Advisory Committee consisting of marine contractors, staff from DCM, DMF, Sea Grant, Coastal Federation and NOAA. This advisory panel met in April 2015 for the purpose of developing a workshop agenda and living shoreline certification process. The advisory panel informs the aforementioned workshops for realtors and marine contractors and coastal consultants and planners to educate them on alternatives to vertical structures and the ecological benefits of living shorelines. The contractors' workshop will include best management practices for construction and design of living shorelines.

TABLE 12.1.6 Strategies included in the DCM/DMF Living Shoreline Strategy.

Short-Term Strategies	Long-Term Strategies
General Permit	Data Collection and GIS Products
Site Visits and Outreach	Marsh Sills Research
"Weighing Your Options"	Certification Program for Marine Contractors
Training	Partner with the Military
Informational Signage	
Leverage Grant Resources	

VI. PROPOSED MANAGEMENT OPTIONS

These options support and build upon the DCM and DMF Living Shoreline Strategy.

1. Continuing to **educate** the public and waterfront property owners regarding the benefits of living shorelines.
    a. Seek funding and partnerships to increase the number of highly visible

demonstration projects.

   b. Develop case studies that property owners can relate to that discuss site conditions, initial and ongoing costs, and performance of the structure.
   c. Actively engage with contractors, realtors, and home owners associations in the design and benefits of living shorelines.
   d. Enhance communications, marketing, and education initiatives to increase awareness of and build demand for living shorelines among property owners.
2. Promoting additional **research** and monitoring of living shorelines
   a. Examine the effectiveness of natural and other structural materials for erosion control and ecosystem enhancement.
   b. Examine the long-term stability of living shorelines and vertical structures, particularly after storm events.
   c. Map areas where living shorelines would be suitable for erosion control.
   d. Investigate use of living shorelines as a BMP or mitigation option.
3. Continuing to simplify the federal and state **permitting** process for living shorelines.
   a. Pursue further discussions with the US Army Corps of Engineers to modify the Corps permit process in coordination with the CRC riprap sill general permit (15A NCAC 7H .2700).
4. Promote the appropriate use of oyster shells to facilitate habitat enhancement and availability for incorporation into living shorelines.

12.3. SEDIMENTATION IN ESTUARINE CREEKS

I. ISSUE

Fishermen, scientists, the public, and members of the North Carolina Marine Fisheries Commission (MFC) and the CHPP Steering Committee have expressed concern that some tidal creeks appear to be filling in from sedimentation. The MFC were particularly concerned with the waters designated as Primary Nursery Areas (PNA) or Secondary Nursery Areas (SNA), since these were considered the most productive for juvenile fish. This is a cross-cutting management issue since activities contributing to sedimentation fall under the authority of several DENR agencies including DEMLR, DWR, DCM, and DMF, as well as the Department of Agriculture.

II. ORIGINATION

The CHPP Steering Committee selected this as a priority issue to investigate at their January 6, 2015 meeting. The MFC also requested that DMF look into this in 2013. Monitoring habitat condition and reducing nonpoint source pollution through a variety of means have been CHPP recommendations since 2005.

III. BACKGROUND

<u>Ecological value of upper estuarine creeks</u>

Estuarine creeks and tributaries, due to their morphology and landscape position within coastal river basins, are generally sediment traps. In unaltered systems the natural sedimentation processes are in balance with sediment transport so that estuaries are maintained over the long term, despite short term increases or decreases in sedimentation. The shallowing effect of natural sediment inputs is offset over time by conditions of rising sea level.

Shallow upper reaches of estuarine creeks provide critical nursery area for juvenile fish and invertebrates. Productive nursery areas have a combination of optimum physical and chemical parameters (eg. salinity, temperature), predator protection from wetland and oyster reef structural complexity and shallow waters, and high productivity. Productivity in an estuarine system can refer to primary (plant production-phytoplankton, benthic algae, SAV, marsh) or secondary (grazers of the plants, predators of the grazers) production. The surface sediments support an abundance of microscopic benthic algae (microalgae) that are an important source of primary production (Cahoon et al. 1999; Currin et al. 1995; Litvin and Weinstein 2003; MacIntyre et al. 1996a; Pinckney and Zingmark 1993a). Benthic microalgae are a significant food source for a variety of small invertebrates and post-settled juvenile finfish, including meiofauna (tiny benthic invertebrates < 0.5 mm) such as nematodes and copepods, and macrofauna (slightly larger benthic invertebrates > 0.5 mm) such as amphipods, polychaetes, mollusks, and crustaceans (MacIntyre et al. 1996b). The most productive estuarine bottom, in terms of benthic microalgae, tends to occur in shallow, protected areas with muddy/fine sand (MacIntyre et al. 1996b; Pinckney and Zingmark 1993a). Productivity in exposed or deep areas, or on coarse sand bottom tends to be low (Chester et al. 1983; MacIntyre et al. 1996b; Sundback et al. 1991). The magnitude of benthic primary production is affected by light availability, temperature, sediment grain size, and community biomass, with light being the most significant factor (Barranguet et al. 1998; Cahoon et al. 1999; Guarini et al. 2000; Pinckney and Zingmark 1993a). Meiofauna and macrofauna are critical food sources for small mobile invertebrates such as shrimp and juvenile finfish. Reduction in primary production in and over soft bottom can reduce food availability for small benthic invertebrates and juvenile fish, lowering secondary production.

In 1977, the MFC, based on DMF sampling data, designated highly productive creeks and bay tributaries as PNAs. Rules were implemented to prohibit trawling in these areas to protect the nursery habitat conditions and allow fish and shrimp to grow undisturbed during this sensitive stage of their life. The CRC subsequently implemented rules to prohibit new navigational dredging in designated PNAs, and the EMC designated all PNAs as High Quality Waters. Collectively, these rules have aided in protecting the nursery areas of the dominant commercial and recreational fishery species in North Carolina.

<u>Effects of sedimentation</u>

Sedimentation is essential to maintaining productive estuaries. Sediment deposited along shorelines deters erosion of waterfront property and maintains shallow water habitat to support wetland expansion, submerged aquatic vegetation, intertidal oyster reefs and nursery habitat. Deposited sediments can bind contaminants and remove excess nutrients from the water column, making them biologically unavailable to aquatic organisms. While sedimentation is a natural and beneficial process in estuaries, elevated sedimentation rates due to land use activities or other causes can negatively impact estuarine habitats. An example of this is Cross Rock, an oyster reef running perpendicular to shore in the upper Newport River (Morehead City area) which has been observed to be silting over. However, it is important to keep in mind that while conditions may be changing adversely for an oyster reef in one position within the estuary, they could be changing positively in another area. For example, in Newport River, the south side of the shoreline and wetland vegetation tends to be expanding (beneficial for juvenile fish habitat), but the north side is eroding (losing wetland vegetation and juvenile fish habitat) (Gunnell et al. 2013).

Negative effects of excessive sedimentation in estuaries were discussed in detail in the Water Quality Degradation chapter. Effects include silting and smothering of benthic invertebrates and plants, reduced survival of fish eggs, increase in sediment oxygen demand and depletion of oxygen, reduced channel capacity and subsequent acceleration of bank erosion and flooding (Schueler 1997; Wilber 2005). Microalgae and the benthic community in North Carolina's nursery areas are highly productive because, among other reasons, they are located in shallow water. However in some locations, shoaling of these waters has resulted in portions going dry at low tides, therefore reducing habitat availability (J. Fodrie, personal communication). In addition, alteration of the sediment composition could lead to a less diverse and abundant benthos, reducing the quality or quantity of food available for juvenile fish. Sediment covering oyster reefs reduces interstitial spaces, the habitat niche for mud crabs and other small resident invertebrates, resulting in potentially lower secondary productivity (Wilber et al. 2012). A shift in sediment composition will affect the types of organisms that occur in the bottom, since sandy mud bottom generally supports a greater abundance of invertebrates and are considered the most productive for juvenile fish (Thrush and Dayton 2002).

Sedimentation can greatly reduce successful settlement and survival of larval shellfish and can reduce survival of adult shellfish (Coen et al. 1999; Thomsen and McGlathery 2006). Additional impacts in freshwater include degradation of fish spawning areas and elimination of sensitive species such as anadromous fish and mussels (Box and Mossa 1999). Resuspension of the accumulated sediments increases turbidity, reducing primary production of benthic microalgae and growth rates and survival of macrofauna such as hard clams (Bock and Miller 1995).

Another negative effect of sedimentation is accumulation of pollutants and toxins in bottom sediment with lethal or sublethal impacts to the benthos. In the sediment, toxins can be taken up by benthic organisms, but eventually become buried and biologically inactive. Resuspension of sediment containing contaminants, such as heavy metals, pesticides, bacteria, or endocrine disrupting chemicals, releases harmful pollutants into the water column. When resuspended in the water column, they become biologically active and available to organisms and can be incorporated into fish tissue through absorption or diet. Studies have shown that a significant portion of the microbes in surface waters attach to sediment particles. Their fate and transport is affected by the settling and resuspension of the associated particles (Fries et al. 2006; Russo et al. 2011). Bacteria bound to sediment are also likely to survive longer. Consequently resuspension of sediment in waters impaired by bacterial contamination (closed to shellfish harvest) could result in the transport of high concentrations of bacteria to open shellfish harvest waters, depending on the type of sediment, direction of currents, and dilution of effect.

Similarly, toxic chemicals which tend to attach to sediment particles and settle to the bottom could be released into the water column, becoming biologically available, and potentially contaminating fishery species or their prey (1999a; Kinnish 1992). Toxic chemicals that tend to accumulate in bottom sediments include heavy metals, polycyclic aromatic hydrocarbons (PAHs), petroleum hydrocarbons, pesticides, and polychlorinated biphenyls (PCBs). These toxins can affect benthic invertebrates by inhibiting or altering reproduction or growth, or causing mortality in some situations (Weis and Weis 1989). Early life stages are most vulnerable to toxins (Funderburk et al. 1991). Because macroinvertebrate diversity significantly declines with increasing sediment contamination, food resources for benthic feeders, may be limited in highly contaminated areas (Brown et al. 2000; D.M. et al. 2000; Weis et al. 1998). While the survival of some aquatic organisms is affected by toxins, other organisms survive and bioaccumulate the chemicals to toxic levels, passing them along in 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 shrimp, striped mullet, oysters, and flounder (Kirby et al. 2001; Livingstone 2001). Fine-grained sediments are the primary sediment type that binds heavy metals, and since that is the most common sediment type in nursery areas, the sediments in nursery areas are at risk to metal contamination.

<u>Sedimentation sources and rates</u>

Sediment entering the upper estuary can originate from land clearing and associated stormwater runoff, and shoreline erosion. Land clearing can be associated with agriculture (Rothschild et al. 1994), forestry (Gunnell et al. 2013), construction of buildings or roads (Beck 2009), or golf course construction and maintenance (Mallin et al. 2000b). Agriculture has been cited as a major source of sediment in estuaries (Yuan et al. 2009); http://water.epa.gov/polwaste/nps/agriculture.cfm). The amount of sediment transported into the estuary is affected by past and present land use activities occurring in the watershed, drainage basin size, slope of shoreline, and rainfall patterns. Riparian vegetation and wetlands buffer waterbodies and slow the transport of sediment into estuaries. However, ditching or concentrated flow through a vegetated buffer decreases the effectiveness of sediment trapping (Dillaha et al. 1989); http://www.soil.ncsu.edu/publications/BMPs/buffers.html). The rate of sediment deposition once in the estuary is dependent on many variables, such as sediment type, the receiving waterbody's orientation to dominant winds and currents, magnitude and fetch of winds, tides, proximity to inlets, as well as the amount of sediment introduced into the estuary. Hydrologic alterations from ditching and dredged channels can also influence how suspended sediments are transported through shoreline vegetation and the receiving waters (Peterson 1984; van Maren et al. 2015).

Sources of sedimentation in the lower estuary include shoreline erosion, overwash events (Cunningham 2013a), tidal inflow (van Maren et al. 2015), boat wakes (Grizzle et al. 2002; Wall et al. 2005), channel dredging (Wilber 2005), oyster dredging (Friedrichs and Battisto 2001), and shrimp trawling (Dellapenna et al. 2006a). Dredged channels increase tidal amplification and flood flow velocities, resulting in more sediment being transported further up the estuary than out (van Maren et al. 2015; Yanosky et al. 1995). Dredged channels also tend to increase flow within the channel and reduce flow over the adjacent shallow bottom, causing sediment to settle out (Beck 2009). Another source of sedimentation in the lower estuary is boat wakes. Resuspension and transport of bottom sediment from the waterway to the mouth of tidal creeks can result in shoal forming, restricting flow. Smith and Osterman (2014), in examining sedimentation in Mobile Bay, Alabama, found that sediment accumulation rates were 60-80% greater at the head and mouth of the waterbody than in the central portion.

In North Carolina's estuaries, rates and sources of sedimentation have been studied in Newport River (Gunnell et al. 2013; Mattheus et al. 2010) and in Slocum and Hancock Creeks (tributaries of the Neuse River near Cherry Point Marine Corps Air Station) (Corbett et al. 2009). In these studies, timing and rate of sediment accumulation was determined using radionuclide analysis of sediment cores. These results were compared to land use changes to evaluate the relationship between the two.

In the study of the Neuse River tributaries (Corbett et al. 2009), moderate to high rates of sedimentation (0.29-0.36 cm/yr) indicated that the sediment was being retained in the low energy creeks. Both creeks are designated as Inland Primary Nursery Areas by North Carolina Wildlife Resources Commission. Slocum Creek was bordered by Havelock subdivisions on one shoreline, and Cherry Point Marine Corps Air Station (MCAS) on the other, and received treated effluent from multiple wastewater discharges. Sediment grain size and contaminant analyses indicated that a sharp increase in deposition of fine sediments and heavy metals coincided with the construction of the military base around 1940 and installation of wastewater outfalls. There was evidence of continuing contamination from the 1950s to 1980s primarily due to metal plating at the base. Sediments were retained in the upper portions of the creek, and due to the rate of deposition, contaminants were buried from surface bioactivity in 10-20 years. Hancock Creek was also bordered by Cherry Point MCAS but had no wastewater discharges and was bordered by Croatan National Forest. In this creek, gradual increases in fine sediments indicated a nonpoint source of sediment, but changes began around 1940, again corresponding to the military base construction. In contrast, cores from the higher energy environment of the Neuse River mainstem, indicated lower sedimentation rates and contamination in the sediment was associated with broad nonpoint pollutants from continued residential and industrial development in the river basin.

Sedimentation rates in the upper Newport River were studied in an area visibly observed to be accreting using core analyses to date sediment deposition. Results indicated that a sharp increase in the rate of sediment accumulation (0.58 cm/yr to 0.97 cm/yr) occurred on the Newport delta (upper Newport estuary where the river widens, just upstream of Cross Rocks, MFC designated Primary Nursery Area) around 1964, and the rate remained high (Gunnell et al. 2013; Mattheus et al. 2010). The source of the increased sedimentation was correlated to extensive land clearing from a forestry operation which began in 1964, and ended around 1983. The relatively rapid transport of sediment to the estuary indicated a high connectivity between upstream and downstream sources. Although the upper Newport River has extensive forest and wetlands, ditching and large rain events likely accelerated the movement downstream (Mattheus et al. 2010). Marsh expanded on the southern side of the river as the sediment inputs formed mud flats, which then reduce wave energy, promoting additional sediment deposition, followed by marsh colonization. In contrast, the northern marsh shoreline is more exposed to prevailing winds, and resulting erosion has deterred bottom shoaling and marsh expansion (Gunnell et al. 2013). These two studies indicate that sedimentation rates increase following land use changes that clear vegetation and increase connectivity between runoff and the estuary via ditching, navigational dredging, or loss of vegetated buffers.

In 2015, DWR conducted a field investigation in Hawkins Creek due to complaints about a stormwater pond release (DWR 2015). The watershed of Hawkins Creek, a small creek that receives runoff from a large portion of the town and the nearby Hwy 24, is 76% developed with 22% impervious cover. Sand was observed upstream and downstream of the stormwater discharge for a distance of over 600 yards. Upstream areas of Hawkins Creek had characteristics of an urbanized stream; rutted banks and a large amount of sand sediment in the stream bed. There was lower biotic diversity and more pollutant resistant taxa in Hawkins Creek compared to the nearby and less developed Dennis Creek. Staff concluded, based on the pattern and volume of sand in the stream bed that sedimentation in the creek was from multiple sources, most likely related to stormwater drainage over a period of time.

IV. AUTHORITY

North Carolina General Statutes

G.S. 143B-279.8

V. DISCUSSION

Sedimentation is a natural process in estuaries with positive and negative effects, depending on the magnitude. For example, sedimentation is a mechanism to bury contaminants, making them biologically unavailable to organisms. Sedimentation is also needed to maintain shallow water habitat, which is the most productive soft bottom habitat for juvenile fish. In excess, however, there are negative impacts to benthic habitat and organisms. In past North Carolina studies, sedimentation rates were relatively high and found to be associated with land clearing and ditching. Deposition of suspended sediment in coastal waters, whether introduced through upstream stormwater runoff, shoreline erosion, or resuspension from bottom disturbing fishing gear or storm events will vary greatly based on energy regime, tide, wind direction and magnitude, and especially runoff from land use activities. Studies that examined the effectiveness of trawling to flush out excess sediment from the upper estuary did not indicate that trawling would be a viable tool to flush out excess sediment in the upper portion of tidal creeks (Corbett et al. 2004; Schoellhamer 1996a).

Concerns over increasing sedimentation in shallow estuarine creeks have been raised several times over the years, as far back as 1985. In addition to Newport River, concerns have been raised about Futch Creek, White Oak River, Lockwood Folly River and possibly others. Studies in Newport River, and Slocum and Hancock creeks detected increased sedimentation rates dating back decades that correlated to distinct land use activities – forestry and ditching in the Newport River, and development of a large military base and stormwater runoff in Slocum and Hancock creeks. Another potential cause of change in sedimentation patterns in estuaries is due to dredging of the Intracoastal Waterway (AIWW) and deepening of creek channels. Shoals at the mouth of some tributaries, thought to have formed as a result of AIWW dredging or boat wakes, can partially block flow out of estuarine creeks. Also, dredged creek channels can funnel and accelerate flow, slowing flow along the shallower sides, potentially increasing sedimentation.

Effect of sedimentation on productivity

There is little data available to assess the effect of sedimentation on estuarine productivity. NCDMF designated a subset of tidal creeks as Primary, Secondary, and Special Secondary Nursery Areas beginning in 1977. The areas were selected based on abundance of estuarine dependent juvenile fish and habitat conditions. PNAs are monitored regularly through the juvenile trawl survey (Program 120) to develop juvenile abundance indices for fishery species. Trends in juvenile abundance are highly dependent on environmental conditions and overall coastwide stock abundance but can provide an indicator of whether waterbodies are still productive nursery areas. Preliminary analysis by NCDMF of juvenile abundance data from 1985 to 2013 was conducted using a general linearized model to assess trends by species (DMF, unpublished data, 2015). Standardized abundance indices indicated declining abundance of blue crab, spot, Atlantic croaker, and southern flounder, and increasing abundance of brown shrimp. Of the environmental factors assessed, water temperature was significant. Water depth effect was not included in the model because of partially incomplete or inaccurate data. A community analysis was done in a subset of waterbodies along the coast using a Bray Curtis similarity index and multi-dimensional scaling plots. Results indicated significant differences occurring over time in species composition in the selected waterbodies. Years of similar species composition were not consistent across water bodies or over time. However samples that were further apart in years tended to be less similar in species composition (DMF, unpublished data, 2015). The results of these analyses could indicate a change in 1) overall juvenile fish abundance, 2) some type of primary or secondary productivity change that is driving that juvenile fish change, or 3) just a change in a few species that is primarily responsible for the apparent overall differences in juvenile fish abundance or composition in nursery areas over time. More detailed analyses need to be conducted to determine if these changes are based on population abundance, water quality, or habitat changes that affect nursery area function.

Meyer (2011) used data from the same NCDMF program (Program 120, estuarine trawl survey) to analyze long-term trends in abundance of juvenile species in PNAs and the relationship between species abundance and land use change. The study compared five year averages in abundance of seven species from 1980 to 1984, and from 2000 to 2004. Results found overall species abundance was stable in both time periods, very few stations showed decline in abundance, and there was no significant decrease or increase in productivity for any of the species. However, further analysis comparing change in species abundance with changing land use using a classification and regression tree (CART) analysis detected a negative correlation between abundance of juvenile blue crabs and conversion of undeveloped forest and wetlands to agriculture or development where the change was greater than or equal to 12%. Southern flounder and Atlantic croaker also declined with increasing land use change, but at higher values. Stations in counties exhibiting greater increase in development (New Hanover, Onslow, and Carteret) showed declines, while less developed counties (Hyde, Beaufort, and Pamlico) showed increases. In the declining areas, southern flounder and Atlantic croaker were most negatively affected by the shift to increasing development. Water depth influenced juvenile abundance of brown shrimp and southern flounder, with greater abundance at shallower stations. These results indicated that productivity remained stable in most areas, although declines were observed in more developed counties. In addition, brown shrimp and southern flounder, two important commercial species, prefer shallower nursery areas.

Other studies examining juvenile fish abundance and distribution in North Carolina found that numerous environmental factors including but not limited to salinity, water temperature, wind direction, speed, tidal currents, habitat type, geographic region, and proximity to inlet greatly influenced the distribution and abundance of juvenile fish (Pietrafesa et al. 1986; Ross and Epperly 1985; Taylor et al. 2009; Xie and Eggleston 1999). The large number of environmental factors that can affect juvenile fish abundance make it difficult to assess temporal changes in nursery productivity.

VI. SUMMARY OF FINDINGS

Estuarine creek assessments in NC are needed to determine whether sediment accumulation has adversely impacted productivity. Rates and sources of sedimentation have been studied in only a few waterbodies in North Carolina. Those results indicated that rates are relatively high and are primarily associated with runoff from development and ditching and draining for forestry or agriculture. More assessment of sedimentation across a broad spectrum of estuarine river and creek characteristics is needed to draw coastwide conclusions.

The effect of high sedimentation rates on the function of nursery areas is uncertain. Data analysis by NCDMF and Meyer (2011) saw some indication of decline in abundance of some juvenile species in Primary Nursery Areas, but results were inconclusive overall. Areas exhibiting some decline in nursery productivity were in counties that experienced larger percentage of land use change from undeveloped forest or wetlands to developed land (Meyer 2011). More data are needed to comprehensively determine if overall productivity (primary and secondary) in nursery areas has declined due to sedimentation prior to considering any type of stream restoration.

To effectively reduce sedimentation impacts, managers must first address reducing sediment inputs into estuarine waters. Once more information is obtained on the rate of sedimentation in tidal creeks and the effect on ecological function, several solutions could be pursued, depending on the major sources of the sediment inputs. These range from reducing stormwater runoff through increased use of voluntary stormwater BMPs including vegetated buffers, enhanced non-voluntary stormwater controls, outreach to property owners on the sediment and erosion control requirements and techniques and the importance of compliance, and modification of ditches to divert flow from directly entering into estuarine creeks.

VII. PROPOSED MANAGEMENT OPTIONS

1. Determine magnitude and change in sedimentation rates and sources over time at sufficiently representative waterbodies and regions.
2. Determine the effect of sedimentation in the upper estuaries on primary and secondary productivity and juvenile nursery function.
3. Encourage research for innovative and effective sediment control methods in coastal areas.
4. Encourage expanded use of voluntary stormwater BMPS and low impact development (LID) to reduce sediment loading into estuarine creeks.
5. Improve effectiveness of sediment and erosion control programs by:
    a. Encouraging development of effective local erosion control programs to maintain compliance and reduce sediment from reaching surface waters.
    b. Enhancing monitoring capabilities for local and state sediment control programs (eg. purchase turbidity meters for testing turbidity coming off site and train staff to use).
    c. Continue to educate the public, developers, contractors, and farmers on the need for sediment erosion control measures and techniques for effective sediment control.
    d. Providing education and financial/technical support for local and state programs to better manage sediment control measures from all land disturbing activities
    e. Partner with NCDOT to retrofit road ditches that drain to estuarine waters.

12.4. GENERATING METRICS ON MANAGEMENT SUCCESS AND HABITAT TRENDS

I. ISSUE

Members of the Coastal Habitat Protection Plan (CHPP) Steering Committee (CSC) have expressed concern over the lack of quantified trends in habitat condition and success of management actions. A request was made to the CHPP team to study the generation of indicator metrics on habitat trends and specific and measurable performance criteria on management decisions.

II. ORIGINATION

The Coastal Habitat Protection Plan (CHPP) Steering Committee (CSC) has voted to make generating metrics on management success and habitat trends a priority for the 2015 CHPP.

III. BACKGROUND

In recent years, there has been an increasing awareness of the need to incorporate ecosystem-based management (EBM) into coastal and aquatic resource conservation strategies (Beck et al. 2001; Levin et al. 2009; Wasson et al. 2015). Here, EBM is defined as "management driven by explicit goals executed by policies, protocols and practices, and made adaptable by monitoring and research based on our best understanding of the ecological interactions and processes necessary to sustain ecosystem structure and function "(Christensen et al. 1996). Implementation of EBM includes the identification of management goals, risk analysis, and stakeholder input to establish management strategies (Levin et al. 2009). In an EBM, the monitoring of ecosystem indicators tests the effectiveness of management strategies (Levin et al. 2009; Samhouri et al. 2014). The concept of EBM represents a paradigm shift away from the management of individual species or isolated locales, and towards entire ecosystems at multiple scales. Four critical components that EBM emphasizes are 1) connectivity between and among habitats, 2) consequences of human actions and management strategies, 3) protection and restoration of ecosystems and ecosystem function, and 4) the cooperation of multiple stakeholders, including scientists, managers, and socioeconomic interests (Clarke and Jupiter 2010).

Although EBM has become widely accepted as a concept, actual implementation remains difficult to accomplish (Levin et al. 2009). Recognizing this difficulty, NOAA's Science Advisory Board commissioned an external review of NOAA's ecosystem research, resulting in a recommendation that NOAA prioritize the production of a framework for making EBM decisions (Fluharty et al. 2006; Samhouri et al. 2014). Levin et al. (2009) describe an "integrated ecosystem assessment" (IEA) framework that organizes resource science in order to make decisions in an EBM context. The IEA is comprised of a five-step process outlined below [from Levin et al. (2009)]:

1. Scoping: identify goals of EBM and threats to achieving goals
2. Indicator Development: identify and validate indicators of ecosystem status or attributes of interest.
3. Risk Analysis: evaluate the risk to the indicators posed by human activities and natural processes.
4. Management Strategy Evaluation: evaluate the potential for different management strategies to influence the status of natural and human system indicators.
5. Monitoring and Evaluation: continued monitoring and assessment of ecosystem indicators.

Although each step of the five-step IEA process is equally important, the last step (Monitoring and Evaluation) is what helps to make an EBM truly adaptive. This step is not intended to just monitor ecosystem status, but rather ecosystem response to management strategies.

The Albemarle-Pamlico National Estuary Partnership (APNEP) has taken an important step toward the implementation of an EBM in coastal North Carolina by producing the Albemarle-Pamlico Ecosystem Assessment (APNEP Albemarle-Pamlico National Estuarine Program 2012). This program defined and evaluated indicators for a comprehensive ecosystem assessment of the Albemarle-Pamlico region (APNEP Albemarle-Pamlico National Estuarine Program 2012). This assessment presents a wide array of ecosystem indicators across a large scale (APNEP Albemarle-Pamlico National Estuarine Program 2012). The assessment addresses two important stakeholder questions: 1) what is the status of the Albemarle-Pamlico Estuarine System? and 2) what are the greatest challenges facing the Albemarle-Pamlico Estuarine System? (APNEP Albemarle-Pamlico National Estuarine Program 2012). The APNEP assessment is intended to play a critical role in the prioritization of APNEP planning actions (Figure 12.4.1.), and is a required step in developing true EBM in coastal North Carolina (APNEP Albemarle-Pamlico National Estuarine Program 2012).

The 1997 Fisheries Reform Act (FRA) (G.S. 143B-279.8) requires the preparation of Coastal Habitat Protection Plans (CHPPs) to be produced by the North Carolina Department of Environment and Natural Resources (DENR). The FRA specifies that the CHPP identify threats and recommends management actions to protect and restore habitats critical to North Carolina's coastal fishery resources. The plan must be approved and adopted by the Coastal Resources (CRC), Environmental Management (EMC), and Marine Fisheries (MFC) commissions. Representatives from these three commissions, along with the CHPP development team (consisting of scientists and planners from DENR) develop management recommendations for coastal habitats at public meetings (Street et al. 2005). This process is intended, in part, to insure that the interests of multiple stakeholders (commercial and recreational fisherman, developers, managers, public, etc.) are taken into account when developing management recommendations.

One of the management recommendations of the 2005 CHPP (Goal #2) was to "identify, designate, and protect strategic habitat areas" (Street et al. 2005). Population growth in coastal areas of North Carolina is expected to further stress the habitats and resources critical to estuarine and oceanic ecosystems through the degradation of water quantity and quality, conversion of productive habitat types, and incidental damage from boating and fishing activities. Conservation of "Strategic Habitat Areas" (SHA) that represent priority habitat areas for protection due to their exceptional condition or imminent threat to their ecological functions supporting commercially and recreationally important fish and shellfish species has been an implementation goal of the Coastal Habitat Protection Plan since 2005 (Deaton et al. 2006).

Protection of SHAs is critical to preserving viable populations of commercially and recreationally important fish and shellfish species. Currently, SHA nominations have been identified in three of the four CHPP regions (Albemarle Sound, Pamlico Sound, and White Oak River Basin). Identification of Region 4 (Cape Fear River Basin) nominations began in 2015. The identification of SHAs is a two-step process: 1) using GIS-based habitat and alteration data in a computerized site-selection analysis, and 2) verifying and modifying information based on input from a scientific advisory committee (Deaton et al. 2006). The SHA nominations are intended to be incorporated into conservation and restoration planning efforts.

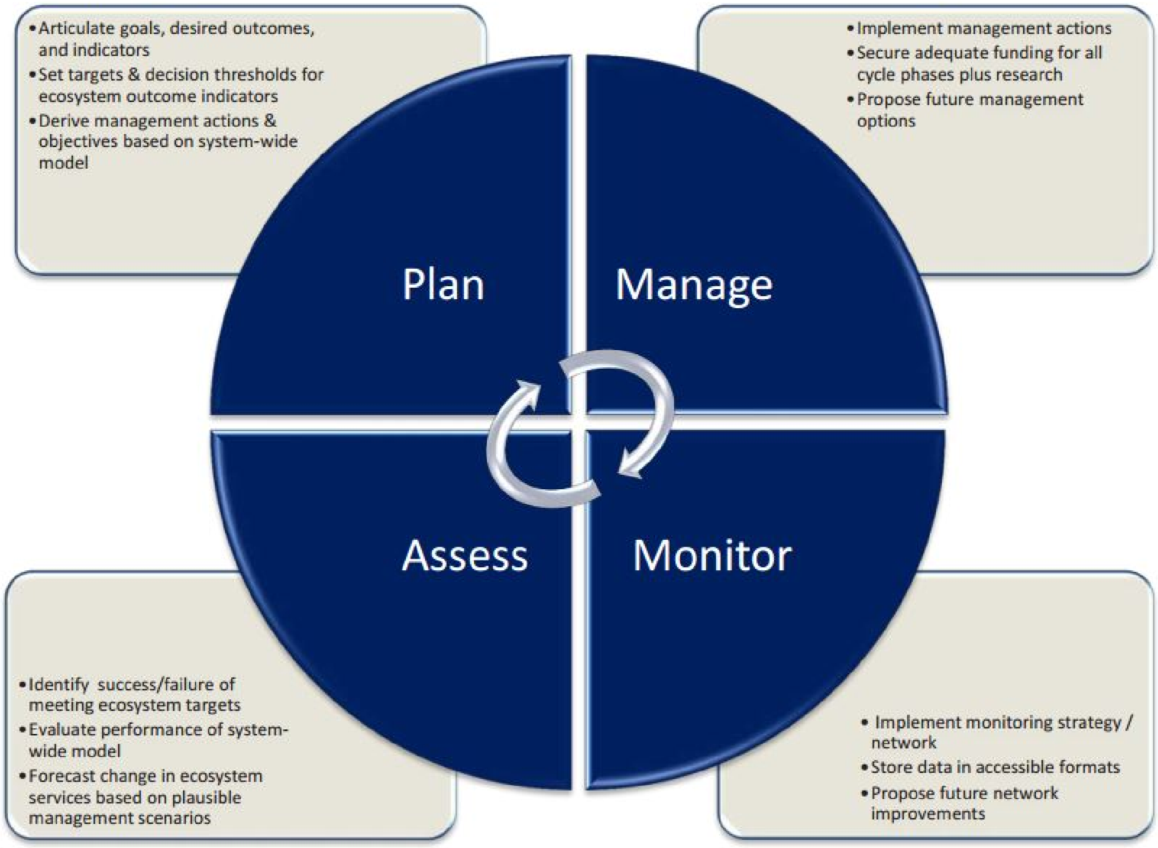


FIGURE 12.1.2. The role of assessment in APNEP's adaptive management cycle (Carpenter and Dubbs 2012). The adaptive nature of this cycle, and emphasis of desired goals and monitoring of management strategies closely align with EBM.

The SHAs, like the EBM concept, represent a movement away from single species management and toward the conservation and enhancement of varied and connected fisheries habitat. However, although SHAs were selected based on ecologically relevant criteria, it is not yet know whether fish production truly is higher within SHAs than in similar habitats outside of SHAs. In order for the SHAs to maximally influence management strategies, it is important to develop indicators that verify the enhanced ecosystem function of SHA areas.

Great effort has been taken to describe the status, trends, and threats to habitats in the CHPP (Deaton et al. 2010), however there is no formal process in place for continuously monitoring these habitats coast-wide, or the establishment of thresholds to initiate management options. Certain threshold values have been in use as a tool in fisheries management for some time, however the development of limit reference points (LRPs) introduced the concept of identifying potentially dangerous situations and automatically initiating a response (Caddy and Mahon 1995). Caddy (2002) describes the three components comprising LRP as:

1. "an appropriate value for the control variable is defined, such that irreversible damage to the resource has not already taken place when this situation is reached,
2. an agreement has been pre-negotiated between the managing body and the fishing industry [or other stakeholders] as to what to do when such a situation occurs,
3. immediate management action is taken to reduce the level of fishing"

Implicit in the LRP concept, is that if management actions are automatically implemented when certain thresholds are met, there must be another recovery threshold where management actions are ended or revised. Presumably, these two thresholds are not equal; otherwise the species being managed could become stuck at potentially threatening levels (Caddy 2002). This two-threshold concept can be graphically represented as a traffic light, where the red light represents an ecosystem threshold that initiates a management response, and a green light represents a recovery threshold that ends or revises the management response (Caddy 2002). The traffic light approach is a simple and convenient tool for communicating management decisions to the public, and has been incorporated into many fisheries management plans, including here in North Carolina. However, similar programs for habitats or ecosystems have not yet been developed in North Carolina.

Between the APNEP ecosystem assessment, CHPP, and SHAs, all of the pieces of an EBM implementation are in place. However, a formalized EBM framework is not yet in place for the coastal areas of North Carolina. Such a framework should address the need for specific and measurable performance criteria for management decisions made in coastal areas. While it is relatively clear to see how current efforts fit into the EBM concept (e.g. planning and assessment), the aspect that is not as clearly in place is the evaluation of management outcomes. The CSC has requested the implementation of this type of evaluation in future management decisions.

IV. AUTHORITY

143B-279.8. Coastal Habitat Protection Plans

(a) (4) Recommend actions to protect and restore the habitats.

V. DISCUSSION

The cyclical, adaptive nature of EBM and IEA concepts provide clear benefits to the management of complex marine ecosystems. Despite these benefits and the wide acceptance of these concepts, successful implementation has been slow. Recognizing the inherent difficulty in shifting from more ad hoc ecosystem management to a full EBM, Samhouri et al. (2014) proposed eight Key tenets to the successful implementation of IEA in US coastal zones:

1. Engage with stakeholders early and often
2. Conduct rigorous human dimensions research
3. Recognize the importance of transparency in selecting indicators
4. Set ecosystem targets to create a system of EBM accountability
5. Set ecosystem targets to create a system of accountability
6. Establish a formal mechanism for the scientific review
7. Serve current management needs, but not at the expense of integrative coastal management
8. Provide avenue for decision-making that takes full advantage of EBM products
9. Embrace realistic expectations about EBM process and implications

An additional advantage of an EBM or IEA approach is the generation of products that are relevant to stakeholders. These products, being peer-reviewed, based on sound science, and communicated to stakeholders serve as an important tool to educate all stakeholders on the condition of the ecosystem, the theory driving management decisions, and the management outcomes (Levin et al. 2009). Specific products include:

- Identification of key management or policy questions and specification of ecosystem goals and objectives
- Assessments of status and trends of the ecosystem
- Assessments of environmental, social, and economic causes and consequences of these trends

- Forecasts of likely status of key ecosystem components under a range of policy and/or management actions
- Identification of crucial gaps in the knowledge of the ecosystem that will guide future research and data acquisition efforts

In addition to the management performance criteria, a critically needed IEA product for North Carolina is the development of metrics to measure habitat status and trends for each of the primary habitats identified in the CHPP (water column, shell bottom, submerged aquatic vegetation, wetlands, soft bottom, and hard bottom). Habitat is essential for maintaining fisheries stocks and ecosystem functions, however, the lack of information on the quality and quantity of habitats compromises our ability to manage at the ecosystem level (NMFS 2015). A first step toward establishing a comprehensive EBM in North Carolina is developing a plan for monitoring the quality, quantity, and extent of each CHPP habitat type at regular intervals. For some habitats (e.g. SAV), this may be possible to do on a state-wide scale by utilizing airborne platforms (i.e. air photos or satellite imagery). But other habitats may require the use of statistical sampling or sentinel monitoring sites.

Another step toward establishing EBM in North Carolina is the identification of indicators of habitat condition. Indicators can serve two functions; 1) communicating the condition of habitats to stakeholders in a simple and easily understandable way, and 2) initiating pre-negotiated management implementations. An example of the former is the Index of Biotic Integrity, employed as a measure of stream fish assemblages throughout the country (Karr and Dudley 1981). These systems rate the condition of fish assemblages using a numeric score as well as a qualitative ranking (e.g. poor, fair, good, or excellent)(Karr and Dudley 1981). Researchers have developed fish-based indicators that measure fish assemblage responses to habitat degradation in coastal systems. For instance, (Deegan and Garritt 1997) produced an “Estuarine Biotic Integrity Index” for two bays in southern Massachusetts. This approach could also be applied directly to habitats. Development of these types of indicators allows mangers to monitor the status and trends of jurisdictional habitats using simple, proven, and repeatable methods. The second function of indicators is exemplified by the LRP, or traffic light, approach. The distinction is that LRP thresholds initiate a pre-negotiated management response, whereas IBI’s are used primarily to educate stakeholders. However, there can be overlap between the uses of each system. The development of indicators or LRP thresholds should be accomplished in concert with the development of monitoring strategies, to ensure the accuracy and precision of indicator reporting.

In addition to monitoring the status and trends of the habitats themselves, it is also essential to monitor the fish utilization of habitats, especially SHAs. The development of specific and measurable indicators of fish utilization could be used to validate the SHA nomination process, modify individual SHA nominations, and monitor the status and trends of fish utilization of habitats. Validated or modified SHAs will assist in the management decisions made by the DMF and MFC, prioritization of land stewardship and conservation in coastal North Carolina, and development of predictive relationships between important fish species and measurable habitat variables.

A final step in establishing EBM is the development of management performance criteria. An EBM recognizes that managers have to balance multiple and often conflicting stakeholder objectives (NMFS 2015)(NMFS 2015). As such, an EBM must be flexible enough to change or refine management strategies if they are not achieving stated goals. Incorporation of management performance criteria completes the circular nature of EBM. If assessments indicate that performance criteria are not being met, management strategies can be refined in attempt to meet the stated, planned goals of EBM.

VI. PROPOSED MANAGEMENT OPTIONS

1. Develop indicator metrics for monitoring the status and trends of each of the six habitat types

within North Carolina's coastal ecosystem (water column, shell bottom, SAV, wetlands, soft bottom, hard bottom).

2. Establish thresholds of habitat quality, quantity, or extent, similar to LRP or traffic lights, which would initiate pre-determined management actions.
3. Develop indicators for assessing fish utilization of SHAs.
4. Develop performance criteria for measuring success of management decisions.
5. Include specific performance criteria in CHPP management actions where possible.

CHAPTER 13. 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, habitats, and threats 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; 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; SAFMC 2009). To address habitat biodiversity within the South Atlantic, the South Atlantic Fishery Management Council (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 (SAFMC 2009). Other regional initiatives, such as the Southeast Aquatic Resource Partnership (SARP) developed a Southeast Aquatic Habitat Plan (SAHP) that provides regional watershed conservation and restoration targets (SARP 2008). 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.

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 Albemarle-Pamlico National Estuary Partnership (APNEP) has developed indicator metrics for the Albemarle-Pamlico region (APNEP Albemarle-Pamlico National Estuarine Program 2012). 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).

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 (e.g., soft bottom) (Airoldi et al. 2008). The changes have been linked to coastal development, overfishing, and eutrophication as described in the "Other Stressors" chapter of the CHPP. Maintaining structurally complex habitat is undoubtedly a positive influence on biodiversity.

13.1 Threats and cumulative impacts

Threats and stressors often affect multiple habitats, with a corresponding impact on biodiversity and ecosystem function. Threats and stressors affecting a single habitat have indirect impacts on other habitats depending on their proximity and ecological interactions. 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. 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 (DMS) and Total Maximum Daily Loads (DWR), 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). In the 2005 and 2010 CHPPs, threats were discussed in the individual habitat chapters. In these chapters, it was evident that most threats affected more than one habitat and all habitats were affected by multiple threats. To reduce redundancies, the 2015 CHPP implemented a new section (Part 2-Existing and Potential Threats) to discuss each threat as a new chapter. Table 13.1 depicts which habitats have documented impacts from a threat category. A qualitative rating of the relative severity of a threat to each habitat is shown. Ratings were determined, utilizing input from agency staff and university scientists, and took into account the type and severity of damage that a threat could have on a habitat and the extent that a habitat is likely to be affected by that threat. From the table it is clear that some alteration sources have potential impact across multiple habitats in a system. The most "cross-cutting" threats include weather events, 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.

13.2. 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 selection 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.[19] 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.

Deaton et al. (2006) describe the process for identifying SHAs in North Carolina's coastal waters. Using this process and several refinements, three of the four regional assessments have been completed and presented to the Marine Fisheries Commission. Through the analysis, maps of habitats and relative alteration levels were produced, and a network of exceptional areas was selected as SHAs (Maps 13.1 - 13.3). Currently, SHAs and supporting data from Regions 1 (Albemarle Sound), 2 (Pamlico Sound), and 3 (White Oak River Basin) are being used in conservation planning (at the DENR level) and as information for the CHPP update. Additionally, a Sea Grant research fellowship supported the analysis of DMF sampling data and proximity to altered habitats. The results indicated some correlations between juvenile

[19] In the SHA region 1 (Albemarle Sound and tributaries), there were 42 habitat types and 18 alteration factors.

fish data and cumulative alteration within a 0.5 kilometer radius, with low fish abundance where alteration levels were greater (Ellis 2009). Currently, SHA nominations for regions 1, 2, and 3 have been completed. The SHA assessment for Region 4 (Cape Fear River Basin) will begin this calendar year (2015) should be complete by late 2016. Additional research is needed to verify the relative impact and distribution of cumulative alterations affecting the selection of areas.

TABLE 13.1. Threat sources, impact severities (both measured and potential), and documented interactions with habitats. Shading = relative severity of impact, based on qualitative information; 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	Bottom disturbing fishing gear				-	-	
	Dredging (navigation channels, boat basins)						
	Estuarine shoreline stabilization						-
	Ocean shoreline stabilization	-	-	-	-		
	Jetties and groins		-	-	-		-
	Mining		-	-			-
Hydrological alterations	Obstructions (dams, culverts, locks)		-	-		-	-
	Water withdrawals		-	-		-	-
	Channelization		-	-		-	-
Water quality degradation	Nonpoint - Development (buildings, roads,non-discharge sewage systems)						-
	Nonpoint - Agriculture (crop and animal)						
	Nonpoint- Forestry					-	-
	Water-dependent development (marinas, docks, boating)				-		-
	Point source discharges				-		-
	Marine debris		-	-	-	-	-
	Microbial contamination			-	-	-	-
	Nutrients and eutrophication						
	Suspended sediment and turbidity				-		-
	Toxic chemicals						
	Ocean acidification			-	-	-	
Other	Disease and microbial stressors	-			-	-	-
	Non-native, invasive or nuisance species						
	Weather events					-	-

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 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. Additionally, the SHA approach could provide input regarding the maintenance of habitat diversity in DMS restoration crediting systems. A basic need of SHA assessment continues to be the development of accurate and contemporary distribution maps for habitats and threats, as well as assessing fish utilization within SHA areas.

The SHAs are intended to help prioritize conservation, enhancement, and restoration projects that benefit fish and fisheries in coastal North Carolina. Additionally, SHAs can serve as sentinel sites for monitoring fish-habitat relationships and can be used in outreach efforts to educate the public on the importance of habitat in supporting coastal biodiversity. A tremendous effort has already identified SHAs in three of the four CHPP regions. The final region (Cape Fear River Basin) will be completed soon. A remaining need is the development of ecosystem indicator metrics for SHAs, which would not only assist in prioritizing conservation efforts, but would also allow DMF staff to quantitatively monitor the condition, status, and trends of fisheries habitat in jurisdictional waters.

13.3 Other habitat designations and protection programs

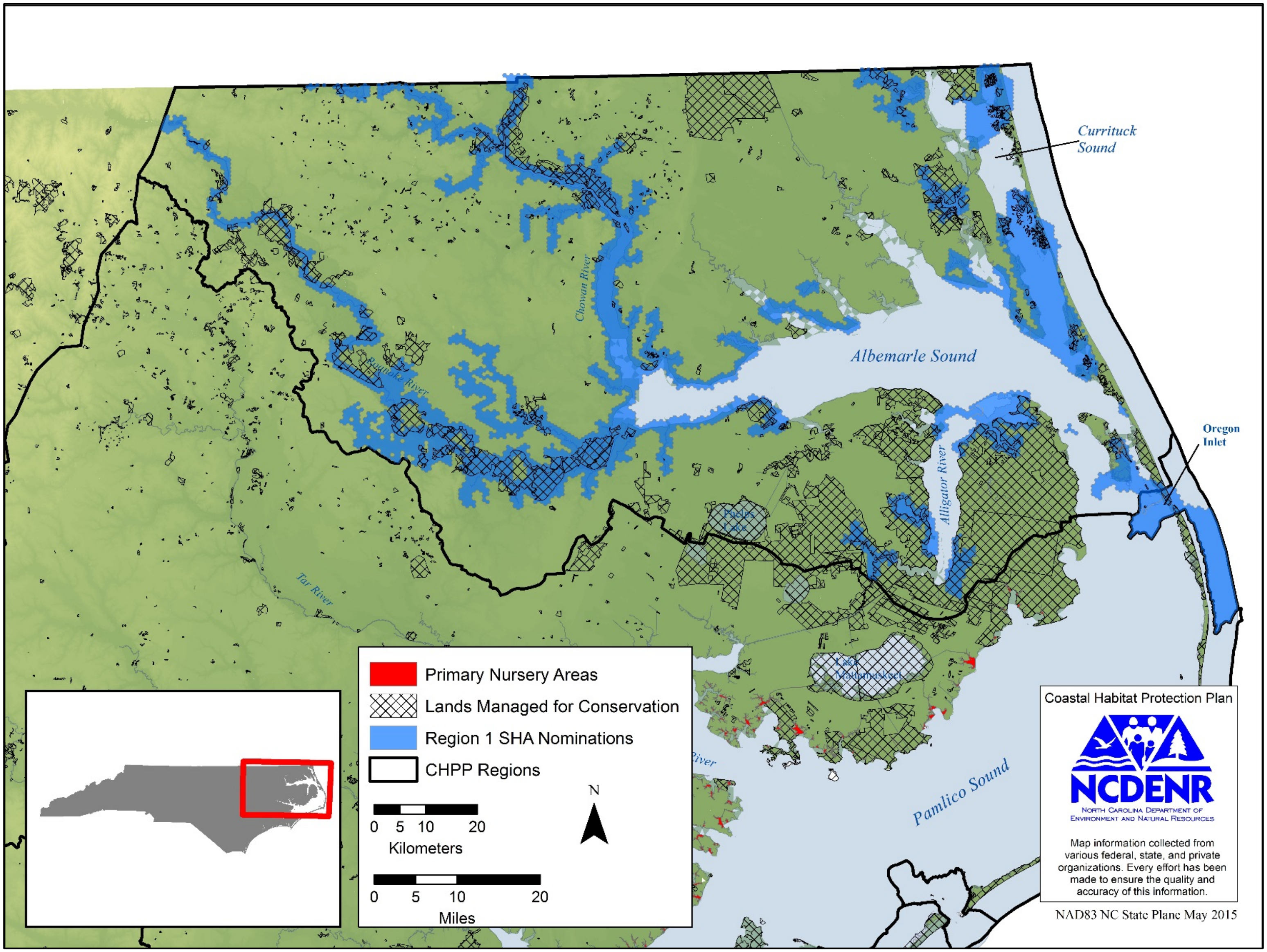
There are several different existing designations used in North Carolina that identify, delineate, and designate functionally important habitat areas. At the federal level, the Magnuson-Stevens Fishery Conservation and Management Act Reauthorization of 1996 [the Sustainable Fisheries Act (SFA)] requires 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 1998b).

North Carolina Primary Nursery Areas, first designated by the MFC in 1977, are similar in concept to HAPCs. The MFC/DMF and WRC have designated tens of thousands of acres as nursery areas since 1977 and 1990, respectively, in North Carolina. 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 several hundred additional stream miles in the four main rivers draining North Carolina’s coast (Roanoke, Tar-Pamlico, Neuse, and Cape Fear). The state designations are well accepted by the various state and federal regulatory and permitting agencies, as well as by the public.

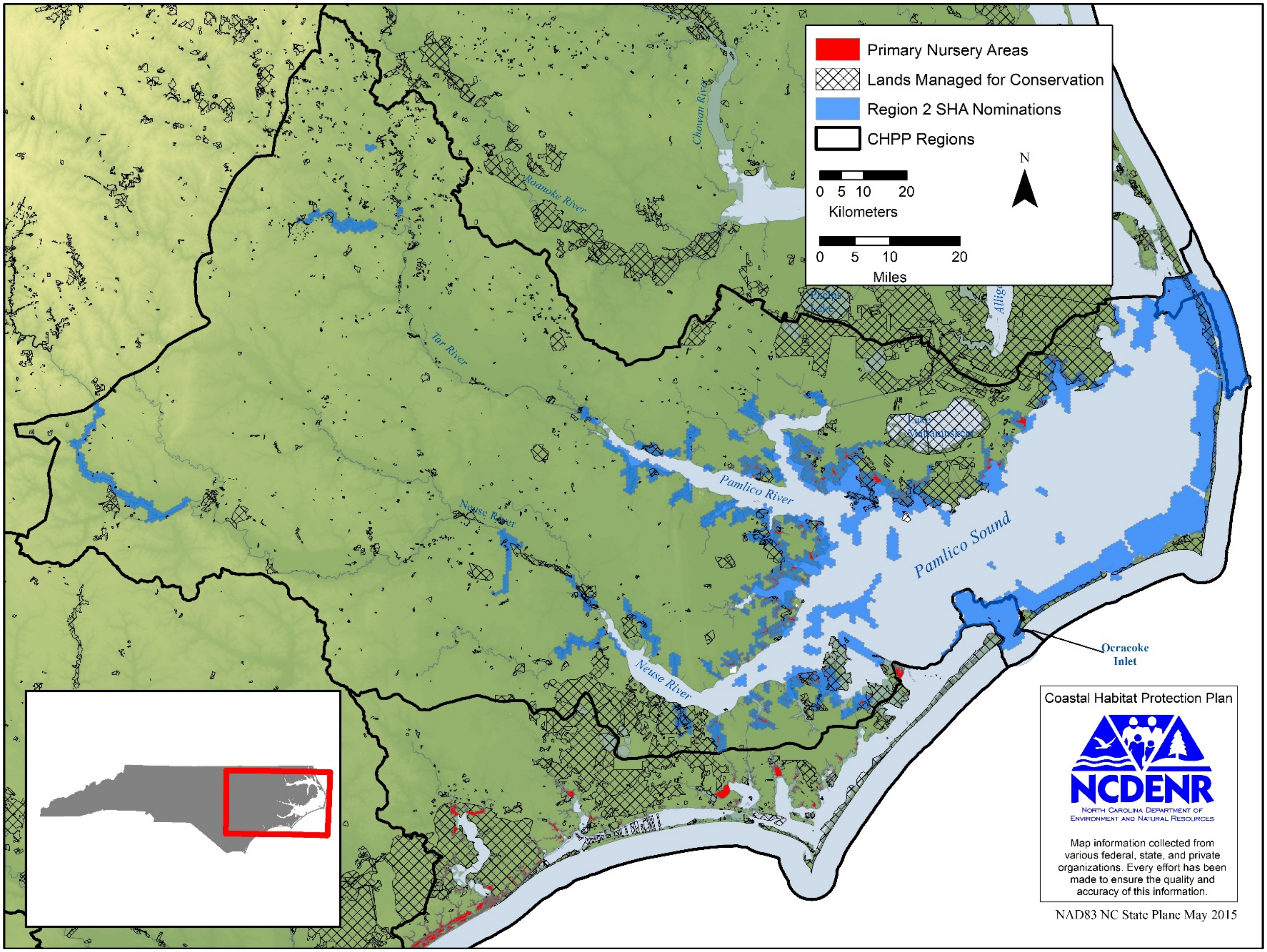
There are specific protections for designated nursery areas included in the rules of all three commissions. For example, an MFC rule [15A NCAC 03N .0104] prohibits use of any trawl net, long haul seine, swipe net, dredge, or mechanical shellfishing gears in Primary Nursery Areas (PNAs). Once an area 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)].

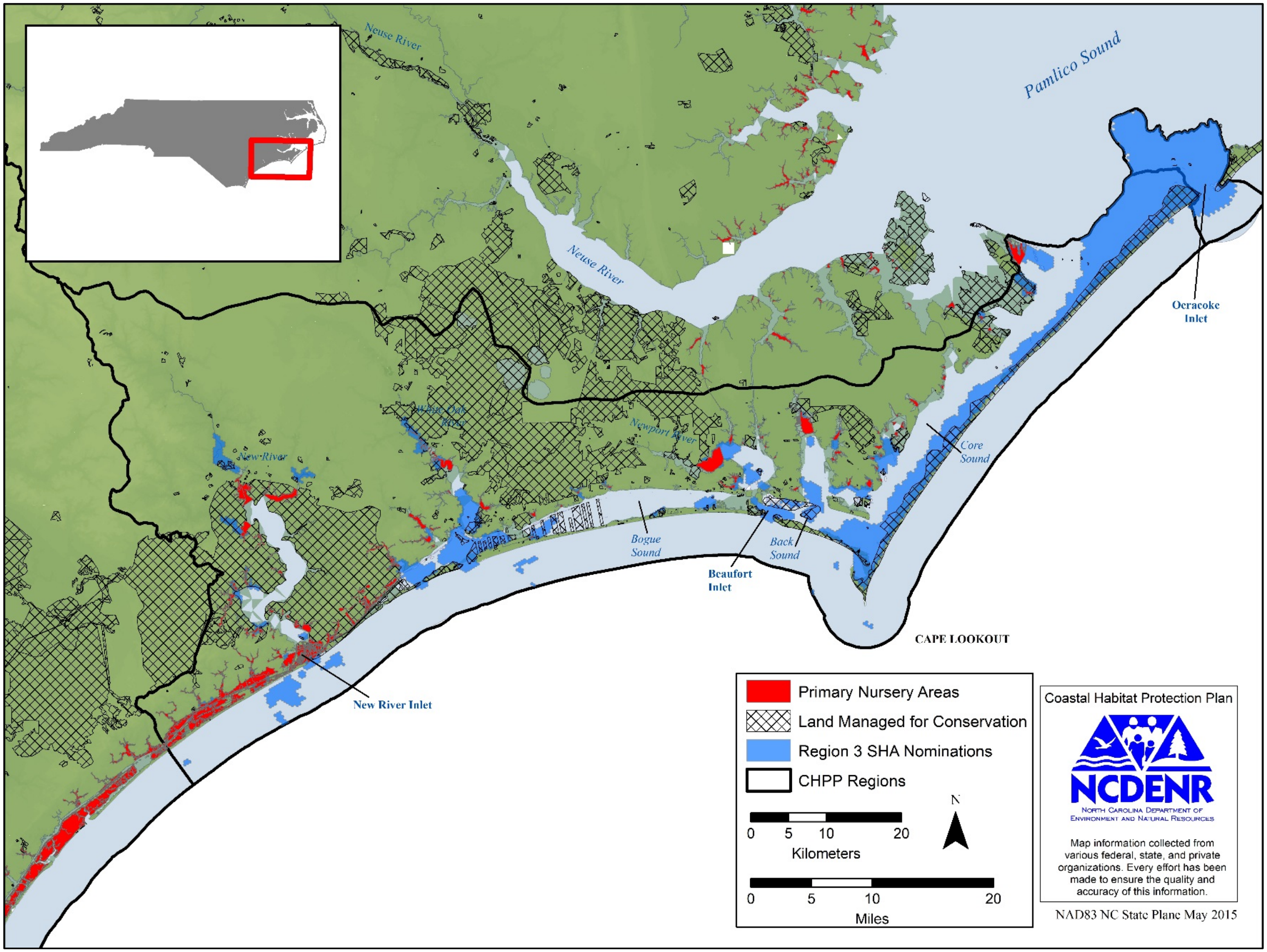
Identification and protection of strategic habitat areas was meant to improve on the piecemeal protection of individual habitats and functional areas. While Regions 1, 2, and 3 SHAs have been identified and approved under the CHPP, they have not been placed in agency rule due to the need to develop site specific management plans for each SHA that will determine if regulatory actions or restrictions are needed.



MAP 13.1. Region 1 strategic habitat area nominations presented and approved by the Marine Fisheries Commission in January 2009.



MAP 13.2. Region 2 strategic habitat area nominations presented and approved by the Marine Fisheries Commission in November 2011.



MAP 13.3. Region 3 strategic habitat area nominations presented and approved by the Marine Fisheries Commission in November 2014.

CH 14. EXISTING PROTECTION, RESTORATION, AND ENHANCEMENT EFFORTS

14.1. Existing Protection Efforts

Preventing loss or degradation of habitat and water quality through management and planning proves to be much cheaper than restoring resources. North Carolina's state agencies rely on a variety of approaches to protect habitat and water quality. Habitat can be protected through regulatory measures, encouragement of Best Management Practices (BMPs), technical assistance, land conservation, outreach and planning. Regulatory designations are used to identify and prioritize areas for protection. State, federal, and interstate agencies have developed policies to provide guidance on managing fish habitat. The MFC has habitat related policies on submerged aquatic vegetation, beach nourishment, and environmental permit review (Appendix E).

14.1.1. Fishing Gear

Habitat protection from fishing gear impacts is accomplished by the MFC primarily through spatial and temporal fishing gear restrictions, particularly in habitat areas designated for their ecological importance. Habitat designations that have gear restrictions include Primary and Secondary Nursery Areas, Oyster Sanctuaries, Crab Spawning Sanctuaries, and No Trawl Areas. Trawling restrictions are found in several rules. For example, trawling is not allowed in Primary or Secondary Nursery Areas, in designated Shellfish Management Areas, Oyster Sanctuaries, and No Trawl Areas (SAV habitat in eastern Pamlico and Core Sounds, as well as portions of some western tributaries of Pamlico Sound). Trawling is prohibited in designated Crab Spawning Sanctuaries from March 1-August 31. Like trawling, dredging is restricted from certain areas by several rules. Prohibited areas include PNAs, Shellfish Management Areas, and Mechanical Methods Prohibited Areas. Mechanical gear included in the latter category includes oyster dredges and hydraulic clam dredges. Where oyster dredging is permitted was further restricted in the western bays of Pamlico Sound by the MFC based on FMP recommendations (DMF 2008a). Oyster dredging is not permitted in Onslow, Pender, New Hanover, and Brunswick counties. Maps 14.1a-b depict where trawling and dredging is restricted. Anadromous Fish Spawning Areas (AFSAs) were designated in MFC rule, but do not have any fishery rules associated with them. The WRC designated Inland Primary Nursery Areas (IPNAs) in inland waters that serve as nursery areas for freshwater and coastal migratory species. While the majority of PNAs occur in the southern portion of the coast (CHPP regions 3 and 4), most AFSAs occur in the northern portion of the coast (Table 14.1).

TABLE 14.1. MFC and WRC fish habitat designations in CHPP management regions. Note: Area of PNA, Permanent SNA, and IPNA are not inclusive of tidal areas between mean high water or normal water level and the apparent shoreline (i.e., wetland edge). Miles of AFSA includes streams and shorelines; IPNA and AFSA have some overlap.

CHPP Region	PNA (acres)	SNA (acres)	IPNA (acres)	AFSA (miles)	AFSA (acres)
1	167	168	16,285	2,201	152,968
2	12,370	46,687	8,992	1,450	49,999
3	23,864	0	703	108	830
4	40,525	608	4,404	821	13,518
Total	**76,927**	**47,463**	**30,384**	**4,579**	**217,314**

Federal agencies are also engaged in fish habitat protection in North Carolina waters through designation of Essential Fish Habitat (EFH) and establishment of Marine Protected Areas (MPAs). The Sustainable Fisheries Act of 1996 (SFA) states that habitat loss and degradation contributed to fishery decline, and therefore required through the amended Magnuson-Stevens Act a program be created to protect EFH, defined as “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity” (SAFMC 2009). Subsets of EFH, referred to as Habitat Areas of Particular Concern (HAPC), were to be geographically identified and designated. For activities with potential adverse effects on EFH, consultation with National Marine Fisheries Service is required so that an assessment can be done and recommendations made to avoid, minimize, or mitigate impacts. Fisheries in North Carolina with designated EFH include penaeid shrimp, estuarine dependent species in the snapper-grouper complex, coastal pelagic species (cobia, Spanish and king mackerel), spiny lobster, and dolphin/wahoo, (Table 14.2). Portions of each CHPP habitats are defined as EFH for at least one of these species.

14.1.2. Coastal Development

Coastal development activities impacting wetlands and other fish habitat are regulated by federal and state agencies. The River and Harbors Act of 1899, the Clean Water Act of 1972, and the Coastal Zone Management Act of 1972 are the most significant federal laws directing the EMC and CRC on avoidance and minimization of development impacts to fish habitat.

States were given the authority to approve, apply conditions, or deny 404 permits by Section 401 of the Clean Water Act (CWA). The authority is applied in North Carolina by DWR with the 401 Water Quality Certification program. While issuance or denial of Section 404 Permits are the most widely used federal management tool protecting wetlands, most farming, ranching, and silviculture activities are exempt from such permits (Bales and Newcomb 1996). The “Swampbuster” provision of the Food Security Act of 1985 (Farm Bill) discourages (through financial disincentives) the draining, filling, or other alterations of wetlands for agricultural use. The majority of wetlands lost to agriculture occurred before 1985.

The Coastal Area Management Act (CAMA), passed in 1974, encourages wetland protection, coastal planning, and rule implementation, to minimize impacts from development activities. The CRC and DCM were established in 1974 and 1978, respectively, to implement the CAMA, stating that coastal resources are to be managed to balance competing uses of and impacts to coastal resources so that the natural ecological conditions and productivity of the beaches, estuaries and coastal system are sustained. Rules focus on activities such as excavation of channels, canals, and boat basins, construction of marinas, estuarine and ocean shoreline stabilization, and development setbacks. The CRC rules state that activities must avoid adverse impacts to PNAs, highly productive shellfish beds, SAV beds, and marshes.

Setbacks and vegetated buffers are utilized by the EMC and CRC to protect wetlands and water quality. Required setback distance varies based on the regulatory designation of the shoreline or waterbody. For example CRC setbacks are greater for property adjacent to the Estuarine Shoreline Area of Environmental Concern (AEC), than for the Public Trust AEC. The EMC requires vegetated riparian buffers adjacent to waters classified as Nutrient Sensitive Waters. Setbacks and buffers are low-cost strategies to reduce and filter nonpoint runoff.

Since the 2010 CHPP, there have been several changes to ocean shoreline stabilization. In 2011, the N.C. General Assembly passed legislation allowing up to four terminal groins in the state’s inlets, despite CRC rules prohibiting ocean hardening. Also, more coastal communities are seeking beach nourishment, using non-federal funding, and requesting to conduct work during previously restricted times of year.

The DCM administers the North Carolina Clean Marina program as a voluntary initiative to recognize marina operators for their efforts toward environmental stewardship by implementing Clean Marina BMPs. There are currently 38 certified Clean Marinas in the program.

TABLE 14.2. Habitats designated Essential Fish Habitat (EFH) or EFH-Habitat Areas of Particular Concern by the South Atlantic Fishery Management Council. Note: This table only includes habitats and fisheries occurring off NC (SAFMC 2009).

	NC fisheries associated with the habitat designation	
Essential Fish Habitat	Fisheries/Species	Habitat Areas of Particular Concern
Wetlands		
Estuarine and marine emergent wetlands	Shrimp, Snapper-grouper	Shrimp: State designated areas
Tidal palustrine forested wetlands	Shrimp	
Submerged Aquatic Vegetation		
Estuarine and marine submerged aquatic vegetation	Shrimp, Snapper-grouper, Spiny lobster	Snapper-grouper
Shell bottom		
Oyster reefs and shell banks	Snapper-grouper	Snapper-grouper
Hard bottom		
Coral reefs, live/hardbottom, medium to high rock outcroppings from shore to at least 600 ft where the annual water temperature range is sufficient.	Snapper-grouper, Spiny lobster, coral	Snapper-grouper, migratory pelagics, coral: The Point, Ten Fathom Ledge, Big Rock
Artificial reefs	Snapper-grouper	
Soft bottom		
Subtidal, intertidal non-vegetated flats	Shrimp	
Offshore marine habitats used for spawning and growth to maturity	Shrimp	
Sandy shoals of capes and offshore bars	Coastal Migratory Pelagics	Sandy shoals; Capes Lookout, Fear, Hatteras
Water column		
Ocean-side waters, from the surf to the shelf break zone, including Sargassum	Coastal Migratory Pelagics	
All coastal inlets	Coastal Migratory Pelagics	Shrimp, Snapper-grouper
All state-designated nursery habitats of particular importance (e.g., PNA, SNA)	Coastal Migratory Pelagics	Shrimp, Snapper-grouper
High salinity bays, estuaries	Cobia in Coastal Migratory Pelagics	Spanish mackerel: Bogue Sound, New River
Pelagic Sargassum	Dolphin in Coastal Migratory Pelagics	
Gulf Stream	Shrimp, Snapper-grouper, Coastal Migratory Pelagics, Spiny lobster, Dolphin-wahoo	
Spawning area in the water column above the adult habitat and the additional pelagic environment	Snapper-grouper	

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 CRC, for which the division of provides technical assistance. These plans are a collection of policies and maps to serve as each community's blueprint for growth and are important pro-active elements of coastal management in North Carolina.

14.1.3. Water Quality Management

14.1.3.1. Surface Water Classifications

The EMC protects water quality by classifying surface waters according to the best use of the water (e.g., water supply, aquatic life, shellfish harvest, swimming, and fish consumption) and adopting water quality standards intended to protect the designated uses. Supplemental surface water quality classifications, such as Outstanding Resource Waters and Nutrient Sensitive Waters, are applied to unique high quality waters or degraded waters needing additional water quality protection. Table 14.3 and 14.4 describe the different water quality classifications.

TABLE 14.3. EMC definitions & overview of requirements for primary surface water classifications (15A NCAC 2B .0101).

Primary Classification	Definition **	Overview of Requirements and Restrictions**
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.	Basic water quality standards and standard erosion and sediment controls.
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).	Adds bacterial standards for Enterococcus in SC waters and allows for restriction of discharges from within the swimming areas.
SA*	Commercial shellfishing waters and all Class SC and SB uses.	More stringent fecal coliform bacteria standard to protect human consumption. No direct discharges.
WS (Water Supply)	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).	Adds point source restrictions, development activity requirements including setbacks, and BMP requirements for agriculture, forestry, and transportation depending on the WS classification. For WS-I, II and III, more stringent erosion and sediment controls and transportation BMPs are mandated. Site-specific management strategies may also be adopted into rule.
WL or SWL* (Fresh and Salt Water Wetlands)	Wetlands are “waters” as defined by G.S. 143-212(6) and are areas that are inundated or saturated by an accumulation of surface or ground water 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. Wetlands generally include swamps, marshes, bogs and similar areas. Wetlands classified as water of the state are restricted to waters of the United States as defined by 33 CFR 328.3 and 40 CFR 230.3 .	No discharges that would cause adverse impact to existing wetland uses are allowed.

TABLE 14.4. EMC definitions & overview of requirements for supplemental surface water classifications (15A NCAC 2B .0101).

Supplemental Classification	Definition	Overview of Requirements and Restrictions**
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.	No new or expanding discharges. Development density requirements, agriculture, forestry and transportation BMPs mandated, more stringent erosion and sediment controls required, and no new discharging landfills allowed. Site-specific management strategies may be developed and adopted into rule.
HQW (High Quality Waters)	Waters rated as excellent by DWR; 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 DWR has received reclassification to WS-I or WS-II.	Stricter treatment standards for new or expanding dischargers Development density requirements, agriculture, forestry and transportation BMPs mandated, more stringent erosion and sediment controls required, and possible restrictions on new discharging landfills.
NSW (Nutrient Sensitive Waters)	Waters needing additional nutrient management due to their being subject to excessive growth of microscopic or macroscopic vegetation.	Watershed specific nutrient removal requirements for point sources, agriculture, forestry and transportation, as well as, watershed specific development density and setback requirements. A nutrient management strategy is developed and adopted when the waters are classified.
SW (Swamp Waters)	Waters with low velocities and other characteristics different from adjacent water bodies (generally low pH, DO, high organic content).	Lower pH and DO allowed due to natural background conditions. Otherwise same as Classes C and SC.
UWL (Unique Wetlands)	Wetlands of exceptional state or national ecological significance which require special protection to maintain existing uses. 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.	Site specific requirements developed as waters are designated.

Point source discharges, i.e., those entering surface waters from a discrete point, are managed by EMC and DWR through effluent standards specified in NPDES permits. In contrast, nonpoint source runoff is managed through a variety of strategies, depending on the source, water classification, and location. There are different stormwater programs throughout the state, but coastal stormwater rules implemented in 2008 apply to new construction in the 20 coastal counties. These rules were implemented since the previous stormwater rules were found to be lacking in the prevention of water quality degradation, particularly in shellfish harvest waters.

In 2013, DWR's Stormwater Permitting Unit administering construction, industrial, municipal and post construction stormwater programs, was transferred to DEMLR to simplify the permitting process. The DEMLR has been working on a Stormwater Fast Track Permitting program to be implemented in 2016. The Stormwater Permitting Unit has also worked with public and private partners to develop a new StormEZ application which introduces the concept of runoff volume matching—pre and post development hydrology, to calculate whether a proposed project meets stormwater requirements. Table 14.5 explains is shorthand the stormwater permitting requirements pre and post 2008.

Retrofitting existing development with appropriate 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 Department of Agriculture and Consumer Service's Division of Soil & Water Conservation (NCDACS, SWC). Funding allocated to this program is very limited.

TABLE 14.5. Development Requirements before and after October 1, 2008 within the 20 coastal counties (NC DEMLR-Stormwater Program).

All Areas Within the 20 Coastal Counties		
	Requirements Prior to 2008	Requirements as of Oct. 01, 2008
Threshold for Permit Coverage for Any and All Development	Activities that require a CAMA Major Permit or an Erosion and Sedimentation Control Plan (disturbance of one acre or greater)	Activities that require a CAMA Major Permit or an Erosion and Sedimentation Control Plan (disturbance of one acre or greater)
Threshold for Permit Coverage for Non-Residential Development	Same as above	In addition to the coverage requirements above, activities that add more than 10,000 sf of built-upon area
Vegetative Setback Requirement - Redevelopment	30 feet from surface waters (for low density projects only)	30 feet from surface waters for redevelopment projects (for low and high density projects
Vegetative Setback Requirement - New Development	30 feet from surface waters (for low density projects only)	50 feet from surface waters for new development projects (for low and high density projects
Wetlands and Impervious Calculations	Portions of wetlands may be included in the calculations to determine the built-upon area percentage per DWQ Policy (Oct. 05, 2006)	No CAMA jurisdictional wetland areas may be included in the calculations to determine the built-upon area percentage. All other wetlands can be included in the calculations.
Within the 20 Coastal Counties & Within 1/2 Mi. of Shellfishing Waters (SA) & within 575' of ORW Waters		
Low Density Threshold*	Built-upon area of 25% or less	Built-upon area of 12% or less (maximum built-upon area of 25% for ORW)
Stormwater Control Requirement for High Density Projects	Control and treat the runoff from the first 1.5 " of rainfall	Control and treat runoff generated by 1.5" of rainfall - or - the difference from the pre and post development conditions for the a-year, 24-hour storm, whichever is greater*
Discharge Requirements	No discharge for the first 1.5" 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
Within the 20 Coastal Counties & Not Within 1/2 Mi. of Shellfishing Waters (non-SA)		
Low Density Threshold	Built-upon area of 30% or less	Built-upon area of 24% or less
Stormwater Control Requirement for High Density Projects	Control the runoff generated by 1.0" of rainfall	Store, control and treat runoff generated by 1.5" of rainfall

4.1.3.2. Reduction Strategies

The EMC designated a number of coastal river basins as Nutrient Sensitive Waters (NSW). In the CHPP region, this includes the Chowan, Neuse, Tar-Pamlico, and New rivers. Nutrient reduction strategies are required for such waters. The Chowan River was designated NSW in 1979. Nutrient reduction strategies, which have been in place for over 20 years have had some success. Strategies recommended to reduce point and nonpoint phosphorus and nitrogen inputs were (DWQ 2002):

- Convert point source discharges to land application systems.
- Require point source effluent limit of 1 mg/l for P and 3 mg/l for N in the North Carolina portion of basins.
- Target funds from Agriculture Cost Share Program to implement BMPs for agricultural nonpoint sources.

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 2002). Despite the reduced nutrient levels, measured chlorophyll *a* and DO concentrations exceeded North Carolina water quality standards on occasion in the mainstem Chowan River, and more than 60% of the time in the upper portion of some tributaries.

The Neuse and Tar-Pamlico river basins were designated as NSW in 1988 and 1989, respectively, as a response to a large number of fish kills and other concerns over deteriorating water quality. To meet the required 30% reduction in total nitrogen requirement, five "Nutrient Reduction Strategies" were developed and implemented.

Agriculture and silviculture are affected by agriculture rule (T15A NCAC 2B .0238) and the nutrient management rule (T15A 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 (T15A NCAC 2B .0234) and stormwater rule (T15A 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 basins and divides that amount among different discharger groups. The stormwater rule requires that local governments 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 Lowrance (1997) zonation scheme. Zone 1 must be a 30 ft wide forested area, beginning at mean high water (MHW). Landward of this, Zone 2 must be 20 ft wide and have plant cover where no fertilizer use. The rule applies to all perennial and intermittent streams, lakes, ponds, and estuaries. Man-made ditches are exempt from this rule [T15A NCAC 02B .0233 (6)].

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 2009; H. Patt, DWQ, pers. com.). 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.

14.1.3.3. Managing Nonpoint Pollution from Silviculture, Agriculture, and Construction

The N.C. Dredge and Fill Law (GS 113-229) requires permitting for construction of roads or ditches within estuarine waters, tidelands, marshlands or state-owned lakes. Silviculture and agriculture (crop and animal) is statutorily exempt from the Coastal Area Management Act under GS 113A-103(5)(b)(4). Federal exemption under Section 404 of the Clean Water Act applies if several conditions are met, such as adhering to BMPs. Each industry has specific BMPs related to their activities. For development, stormwater BMPs are non-mandatory, structural or non-structural means of treating or limiting pollutants and other damaging effects of stormwater runoff to meet required water quality standards.

Silviculture

The purpose of forestry BMPs or guidelines is to avoid long-term conversion of wetlands to uplands, and to minimize water quality impacts to adjacent waters. The regulatory framework under which silviculture operates in wetlands, and associated BMPs, are described in detail within BMP Manual (NC Forest Service 2006). Specific conditions must be achieved for silviculture activities to take place, as defined either by USEPA and USACE guidance documents, or federal rule code:

- Nationwide mandatory 15 BMPs for road construction (33 CFR Part 323.4).
- Nationwide mandatory 6 BMPs for mechanical site preparation for the establishment of pine plantations (Joint Memo to the Field, 1995).
- Guidance from USACE Wilmington District developed in 2004 for the construction or maintenance of forest roads in wetlands of North Carolina.

In North Carolina, silviculture related site-disturbing activities must comply with the performance standards described in the state water quality regulations (TO2 NCAC 60C .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 North Carolina Sedimentation Pollution Control Act, (GS 113A-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 water bodies. 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.

Forestry activities must also comply with riparian buffer protection and maintenance rules described by the nutrient sensitive water strategies within NSW-classified watersheds and laws that prohibit stream obstruction. The NCFS inspects forestry sites across the state for compliance with the aforementioned rules and laws. Of the over 3,800 sites inspected from 2011-2014, compliance with forestry rules and laws increases yearly (Table 10.6, Chapter 10).

In addition to following guidelines of the Forestry BMP manual, wetland and water quality impacts are offset through forest regeneration. During the period between 2010 and 2014 the North Carolina Forest Service (NCFS) recorded 83,949 acres of forest regeneration across the 27 counties that comprise the NCFS coastal operating districts (Table 14.6). Most of the acres reported are for the planting of trees after timber harvests, while some acres were newly established forests upon former pasture or croplands, or were regenerated by in-place seed or stump sprouts.

TABLE 14.6. Forest regeneration in the coastal plain, 2010-2014.

Forest Service District	Reforested Area (acres)
7 (Northeastern Coastal Plain)	27,983
13 (Albemarle-Pamlico Peninsula)	4,812
4 (Central Coastal Plain)	28,589
8 (Southeastern Coastal Plain)	22,565

The Forest Service provides training and education, as well as participating in outreach events across the state on a range of topics including BMPs for erosion & sediment control, and overall water resources protection. Examples include logger training through the ProLogger Program, instruction for college students, water resource conference presentations, and one-on-one assistance. Each year, the Forest Service summarizes its water quality and nonpoint source program accomplishments in an annual "Year in Review," available from its website: http://ncforestservice.gov/water_quality/year_in_review.htm.

Agriculture

Protecting water quality from the impacts of agriculture is promoted through voluntary natural resource management with assistance from NCDA&CS, S&WC. The division utilizes financial incentives, technical assistance, and outreach to reduce nutrient loading in river basins. Strategies include BMPs, nutrient management, and riparian buffer protection. Financial incentives are provided through an Agriculture Cost Share Program was authorized in 1983 as a pilot program to address nonpoint source problems in the NSWs but has been extended to all Soil and Water Conservation Districts. As of the 2014 Annual Report, implementation of the strategies promoted by the program had resulted in a 43% reduction in nitrogen loss compared to the baseline data collected in 1991 (NCDA&CS 2014).

To reduce water quality impacts from CAFOs, permitting, training, facility inspections, and odor control standards are in place. The 2007 Swine Farm Act prohibited new lagoon and sprayfield systems and established a swine farm methane capture pilot program.

Construction

The sedimentation of streams, lakes and other waters of the state constitutes a major pollution problem. Sedimentation occurs from the erosion or deposition of soil into the water from ground disturbing activities such as construction and road maintenance.

The Division of Energy, Mineral, and Land Resources (DEMLR), Land Quality Section, administers the Sedimentation Pollution Control Act (SPCA, GS 113A-50). The Sedimentation Control Commission delegates administration of the SPCA to 53 county or municipal governments, while maintaining control at the state level in other areas. Construction site BMPs (e.g., groundcover on slopes, skimmer basins, etc.) are implemented by DEMLR with approved Erosion and Sediment Control Plans (ESCPs) required for projects impacting one acre or more, or requiring a CAMA Permit within a coastal county. Some Local ESCPs require “approved” plans for site impacts starting at 5,500 square feet (one-eighth acre).

The EPA implements federal permitting requirements for stormwater discharges from active construction sites, but also has the authority to delegate permitting responsibilities to states. North Carolina has delegated authority that allows DENR to issue federal construction stormwater permits. The state Sedimentation Program plays a critical role in meeting federal construction stormwater permitting requirements under the Clean Water Act. The NPDES Construction Stormwater Permit (NCG 010000) is issued automatically for a construction site upon receiving approval of an Erosion and Sediment Control Plan. Effective August 1, 2013, the Stormwater Permitting Unit of DWR, including 29 appropriated and receipt based positions administering the construction, industrial, municipal and post construction stormwater programs, was transferred to DEMLR, Land Quality Section. The Land Quality Section has incorporated cross-training of central and regional personnel and consolidation of forms between the Erosion and Sedimentation Control Program and the Construction Stormwater Program so that one point of contact for meeting both programs' permitting, inspection, and reporting requirements are used to communicate compliance with both program's state and federal provisions.

Mining

The Mining Act of 1971 was enacted by the General Assembly in 1971 to require that no mining be "carried on in the State unless plans for such mining include reasonable provisions for protection of the surrounding environment and for reclamation of the area of land affected by mining." The Act includes broad authority in granting and denying applications for mining permits in order to protect the environment and public safety. The DENR has broad flexibility in reviewing applications for site-specific mining operations, and may deny a permit if criteria (G.S. 74-51) cannot be met. The Land Quality Section of DENR requires submittal of pertinent environmental and public safety information, circulates applications to other agencies for review, and invites public input.

14.1.4 Land Conservation

Land conservation is an effective non-regulatory means of protecting wetlands and water quality. 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. Protected lands cover 127,275 acres (34%) of riparian wetlands in coastal NC (Table 14.7). A greater proportion of estuarine and flat/depressional wetlands are within wetlands than headwater and riverine wetlands.

An estimated 16% of the CHPP region watershed is managed for land conservation by a federal, state, local, or private entity (Table 14.7), including uplands and wetlands. The Natural Heritage Program maintains GIS data on most of the conservation lands within North Carolina. These "Managed Areas" are a diverse collection of properties and easements that are managed to some degree for conservation of biodiversity and ecosystem function. Also included are a number of properties and easements that are not managed for conservation, but are of conservation interest. It should be noted that the analysis for Table 14.7 is focused on wetlands, but land conservation of all terrestrial areas contributes to watershed protection (Table 14.8). Conservation lands often have multiple benefits to the public beyond water quality protection, including recreation, wildlife habitat, scientific research and education opportunities, and aesthetic value. Protection of water quality through land acquisition and deed obligations is a passive and less controversial approach to water pollution management than regulatory measures.

TABLE 14.7. Amount and percentage of hydrogeomorphic wetland class in eastern North Carolina located within lands where conservation is a management goal (http://www.ncnhp.org/web/nhp/managed-areas, June 2015).

Hydrogeomorphic wetland category	Alteration type	Wetlands in conservation lands (acres)	Total wetland acres	Wetlands in conservation lands (%)
Estuarine	Unaltered	100,654.39	228,388.51	44.1%
	Cleared	175.24	339.98	51.5%
	Cutover	228.24	570.88	40.0%
	Drained	4,869.93	31,437.43	15.5%
Flat/depressional	Unaltered	616,600.01	1,482,991.59	41.6%
	Cleared	2,259.53	15,512.60	14.6%
	Cutover	3,161.47	32,187.25	9.8%
	Drained	91,358.11	263,984.94	34.6%
	Impacted	47,533.65	680,832.70	7.0%
Headwater	Unaltered	2,307.58	22,199.08	10.4%
	Cleared	11.14	470.12	2.4%
	Cutover	364.43	2,342.37	15.6%
	Drained	335.40	1,590.52	21.1%
Riverine	Unaltered	17,830.72	76,648.63	23.3%
	Cleared	21.09	1,373.70	1.5%
	Cutover	357.98	3,471.48	10.3%
	Drained	119.84	5,069.09	2.4%
Total Riparian		127,275.98	373901.8	34.0
Total Non-riparian		760912.74	2475509.08	30.7
Total		888,188.74	2,849,410.89	31.2

TABLE 14.8. Percent of watershed managed for land conservation by a federal, state, local, or private entity.

CHPP Watershed	Federal	Local	Private	State	Total
Albemarle	20.95	0.13	1.61	11.73	34.41
Cape Fear	2.39	0.19	1.48	9.52	13.57
Chowan	0.06	0.00	0.13	7.97	8.15
Core/Bogue	32.82	0.37	2.28	3.78	39.24
East coastal ocean	5.57	0.00	0.00	0.03	5.61
Neuse	4.65	0.03	0.54	1.83	7.05
New/White Oak	36.10	0.37	0.26	3.35	40.09
Northeast coastal ocean	0.21	0.00	0.02	0.05	0.27
Ocracoke Inlet	1.94	0.00	4.90	0.00	6.85
Oregon Inlet	2.44	0.00	0.00	0.31	2.75
Pamlico Sound	19.98	0.00	0.08	3.44	23.49
Roanoke	2.88	0.00	4.62	8.33	15.83
South coastal ocean	0.00	0.00	0.01	0.89	0.91
Southeast coastal ocean	3.29	0.00	0.00	0.67	3.96
Southern estuaries	0.00	0.40	6.00	7.77	14.16
Tar/Pamlico	2.38	0.07	0.36	2.37	5.18
Total	**8.98**	**0.10**	**1.14**	**5.92**	**16.14**

The DENR recognizes the need to coordinate statewide conservation efforts and thus developed the NC Conservation Planning Tool (CPT) to streamline the process of identifying and prioritizing terrestrial and aquatic natural areas for conservation. The CPT approach is based on the "Green Infrastructure" principle, which emphasizes the importance of maintaining an interconnected network of natural areas for ecosystem stability. The geospatial data layers supporting the tool are separated into four assessments considered equally valuable: biodiversity/wildlife habitat, open space/conservation, farmland, and forestry lands.

The state currently has three Conservation Trust Funds including the Parks and Recreation Trust Fund (established 1994), Clean Water Management Trust Fund (established 1996), the Agricultural Development and Farmland Preservation Trust Fund (established 1986). The Natural Heritage Trust Fund (established 1987), was repealed in 2013 and the balance was put into the Clean Water Management Trust Fund. In addition to the state trusts, there are numerous local land trusts. Statewide, a total of 643,319 acres have been acquired through the trust funds. Together, these funds have significantly contributed to protecting coastal habitat and water quality in a manner that the public greatly supports.

Conservation makes economic sense. For every $1 invested in land conservation in NC, there is estimated to be a $4 return in economic value from natural resource goods and services alone (Land 2011) without considering numerous other economic benefits. Land conservation benefits the economy by enhancing tourism and outdoor recreation. In 2006, anglers, hunters, and wildlife viewers spent $2.62 billion, creating $1.26 billion in salaries and wages, supporting 45,200 jobs. Land acquisition benefits the military by acquiring buffers around bases, which aids military training. In 2007, the military contributed 7% to the state's domestic product and supported 416,000 jobs. Farmland preservation helped agriculture add $32 billion and 120,000 jobs to the state's economy in 2009.

The Clean Water Management Trust Fund (CWMTF) has contributed greatly to habitat protection. The purpose of the fund is to provide grant assistance for projects that enhance or restore degraded water quality, protect unpolluted waters, establish a network of riparian buffers for environmental, educational, and recreational benefits, provide buffers around military bases, or acquire land to preserve ecological diversity or historic properties. Since established in 1996, CWMTF was provided with $100 million in annually recurring appropriated funds. Funding could go toward land acquisition for conservation easement, riparian buffers, green corridors, or military buffers; habitat and water quality restoration; implementation of innovative stormwater management, or water quality remediation. In 2009, the legislature reallocated the $100 million and changed future funding to be non-recurring. In 2013, funding for wastewater improvement or conventional stormwater projects became ineligible, although an alternative funding source was established. Since the inception of the trust fund in 1996, approximately $100 million was appropriated for water quality and habitat improvements. Since 2008, the funding allocated to the CWMTF has been reduced to ~10% of its original amount (Figure 14.1).

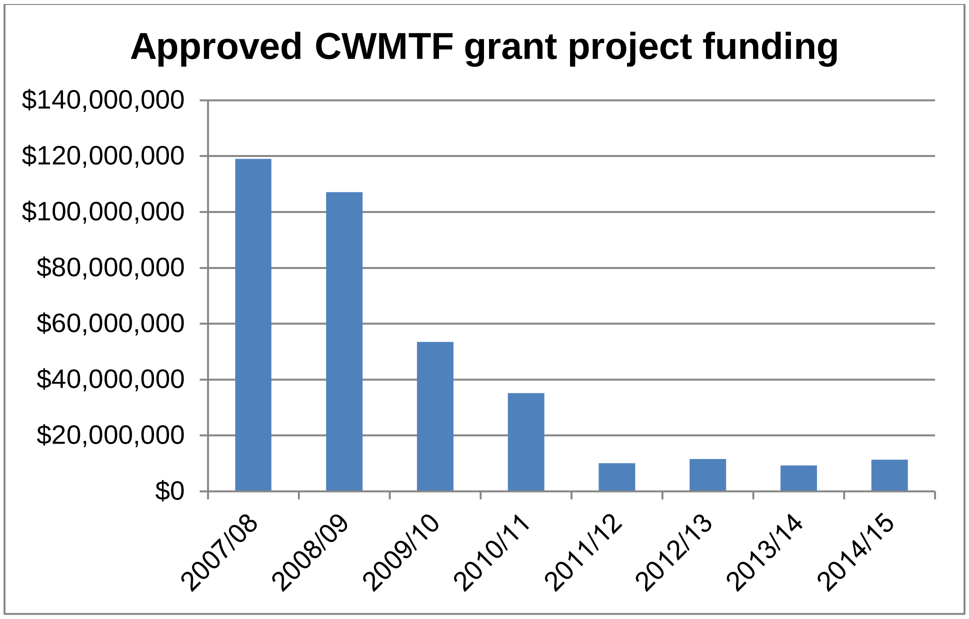


FIGURE 14.1.1. Annual expenditures ($) for approved CWMTF projects, all types (Source: Data from Office of Land & Water Stewardship – CWMTF).

14.2. Existing Restoration and Enhancement Efforts

Restoration and enhancement work is done by state and federal agencies and non-governmental organizations. In coastal North Carolina, habitat restoration efforts have focused primarily on shell bottom and wetland habitat.

14.2.1. Shell Bottom

The DMF has a long history of oyster restoration. The earliest state restoration efforts were directed at fishery enhancement, but shifted to increasing effort in oyster habitat restoration through development of no-take sanctuaries. Cultch planting provides hard substrate for oyster larvae to attach. Shell and other hard substrate is a limiting factor for oyster population growth. Harvest on areas planted with shell or marl is controlled by minimum size limit. Once new oysters reach legal size (2-3 yr), harvest of shellfish is permitted. Despite being open to harvest, cultch planting sites enhance shell habitat because 1) shell is put on bottom that did not have existing shell bottom habitat, 2) structure remains after harvest since only legal oysters can be removed, and 3) adult oysters spawn before harvest, contributing to population. Oyster sanctuaries provide protected areas of habitat for over 40 species of finfish and invertebrates. Adult oysters serve as a concentrated sources of brood stock that can release larvae, seeding shell material throughout the system. They provide several ecosystem services including water filtration, sediment stabilization, and nutrient cycling. Oyster Sanctuaries are designated and delineated under T15A NCAC 03R .0117 and are protected from damaging harvest practices under rule T15A NCAC 03K .0209. Strategic siting of sanctuaries and cultch plant sites can optimize benefits to both the ecosystem and shellfish harvest. Shellfish aquaculture also provides temporary habitat and water quality enhancement in areas that did not have a naturally occurring shellfish resource.

With an estimated 90% decline in historic oyster populations in North Carolina and the US (Beck et al. 2011; DMF 2008a; Zu Ermgassen et al. 2012), there is a continued need for oyster habitat restoration. Chapter 12, Priority Habitat Issues, describes in detail ongoing enhancement and restoration efforts of DMF, bottlenecks in expansion, and options to further advance.

Oyster restoration (sanctuaries) and enhancement (cultch planting) work is limited by funding and available cultch material. General Statute 136-123(b) states that 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 DENR, DMF, for use in any oyster bed revitalization programs or any other program that may use the shells.

In 2014-15, the General Assembly passed the Senator Jean Preston Shellfish Sanctuary (SL 2014-120). The purpose of the law was to designate an oyster sanctuary complex in Pamlico Sound that included areas of restored no-take reefs and areas designated for shellfish leasing to facilitate habitat and water quality enhancements, as well as economic growth of the shellfish aquaculture industry. The 2015-16 budget bill includes language that would modify SL 2014-120 to be more effective. The Habitat and Enhancement Section of DMF is in the planning stages of implementing this legislation.

As mentioned in Chapter 3, Shell Bottom Habitat, research documenting the important ecological and economic value of oyster reefs (Breitburg 1998; Coen et al. 1999; Grabowski et al. 2000; Harding and Mann 1999; Lenihan et al. 1998; Lenihan et al. 2001; Peterson et al. 2003b) supports the concept that economic benefits gained from shellfish harvest and ecosystem services of oyster habitat outweigh the costs of oyster restoration and cultch planting. As of 2015, DMF has established 13 Oyster Sanctuaries totaling 177.7 acres, with two others under development (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 shell and seeded shell as part of the research needs. The Nature Conservancy (TNC), the North Carolina Coastal Federation (NCCF), the NMFS Hurricane grant 2001-2006, state appropriations through DMF, and other mitigation sources have provided funding.

Non-governmental organizations (NGOs) and universities are also involved in oyster restoration, with a greater focus on research techniques and community outreach. These sites were designated as Research Sanctuaries (T15A NCAC 03I .0109) or Shellfish Management Areas (T15A NCAC 03K .0103) under proclamation authority of the DMF Director. The NCCF has sponsored sites located in Williston Creek, Everett Bay, Hewlett's Creek, New River near Sneads Ferry, Dicks Bay in Myrtle Grove Sound, Alligator Bay, and the lower Cape Fear shoreline (Map 3.4a-b). The sites are generally monitored for oyster density and abundance, epifaunal coverage, bed height and rugosity, and selected water quality measurements. Other groups involved with oyster restoration include The Nature Conservancy, UNC-Wilmington, Pender Watch, and the Town of St. James.

Oyster restoration as mitigation has also contributed to enhancing shell bottom habitat. The USACE, US Navy, and DOT are the government agencies associated with those projects. The Division of Mitigative Services does not include oyster restoration as a suitable mitigation option.

There are numerous organizations that play a role in the development and monitoring of shell bottom enhancement and restoration. To coordinate various organizations' interests with DMF restoration work, an inter-organizational steering committee was established by the NCCF to draft an oyster restoration plan for North Carolina. In 2014, NCCF organized a workshop to summarize oyster restoration and enhancement progress and to develop guidelines for future restoration. In 2015, based on results of the workshop, the Oyster Restoration and Protection Plan for NC: A Blueprint for Action, 2015-2020 was completed. The plan was presented at the 2015 Oyster Summit to researchers, agencies, NGOs, policy makers, and legislators.

In 2011, The Nature Conservancy, Florida Atlantic University, and the NOAA Restoration Center convened a workshop, and from that beginning stemmed a committee, a handbook, and many workshops on standardizing monitoring techniques and performance criteria to allow for consistent post-restoration assessment of both the eastern and Olympia oysters. This handbook is available for restoration practitioners online at http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf.

14.2.2. Hard bottom/Artificial reefs

Artificial reefs serve as structured habitat for fish and colonizing organisms. Studies suggest that the additional habitat in an area that was once soft bottom enhances fish production by providing foraging, spawning, and refuge habitat, and increasing an area's carrying capacity (Bohnsack 1989; Brickhill et al. 2005; Grossman et al. 1997; Lindberg 1997). In addition to providing habitat, artificial reefs are used for recreational fishing, and consequently contribute significantly to the coastal economy.

Artificial reefs must be properly designed, sited, and managed to successfully increase production of benthic organisms and fish populations (Brickhill et al. 2005; DMF 1988; Gregg 1995; Strelcheck et al. 2005). The DMF Artificial Reef Master Plan provides siting guidelines and construction standards for artificial reefs in North Carolina (DMF 1988). Some of the habitat-related guidelines are:

- Use non-toxic, stable, and durable materials
- Use materials that provide the degree of habitat complexity and profile appropriate for the targeted reef species, but that will not create a navigation hazard.
- Design for structures with large surface area, interstitial space, and structural complexity.
- Do not site in areas with natural hard bottom, high energy, traditional commercial fishing activities.
- Design to provide proven biologically productive habitat.

The DMF Artificial Reef Program includes 41 ocean reefs, eight estuarine reefs, and 14 estuarine oyster sanctuary fishing reefs. The materials on ocean reefs are ships, box cars, concrete pipe, etc. Estuarine reefs consist of concrete reef balls, concrete pipe, recycled processed concrete, or other materials. In 2009, the Artificial Reef Program shifted its focus toward development of estuarine artificial reefs. Staff monitors artificial reefs periodically for durability and fish use. An interactive map and artificial reef guide are available at http://portal.ncdenr.org/group/mf/habitat/enhancement/artificial-reefs.

14.2.3. Wetlands and Streams

14.2.3.1. Restoring stream connectivity

There have been several projects involving restoring connectivity and flow in rivers to improve diadromous species' access to historic spawning grounds. On the Roanoke River, Dominion Generation, as part of the Federal Energy Regulatory Commission (FERC) relicensing, built two eelways at the Roanoke Rapids Hydroelectric Dam, the most downstream dam on the Roanoke River. The eelways were operational in 2010 through 2014, and have successfully passed over 1.8 million American eels (F. Rohde, NOAA, pers. com. 2015). On the Cape Fear River at the most downstream dam (Lock and Dam #1), the USACE built a natural looking fishway (called a rock-arch ramp) around Lock and Dam #1. The ramp was built as mitigation for dredging operations in the lower Cape Fear River at Wilmington and is designed to pass American shad, blueback herring, striped bass, and potentially Atlantic sturgeon to historic spawning areas near Smiley Falls located on the fall line. Both American shad and striped bass have been documented using the fishway. Spawning substrate for these two species has also been placed downstream of Lock and Dam No. 2 (F. Rohde, NOAA, pers. com. 2015).

14.2.3.2. Wetland and stream mitigation

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 between the EPA and USACE develop requirements to compensate for wetlands lost to dredge and/or fill activities. In addition to wetland and stream compensatory mitigation, conservation organizations also conduct restoration on a smaller scale.

The 2008 USACE/EPA federal rule specifies the following order of preference: (1) mitigation bank credits, (2) in-lieu fee (ILF) credits, (3) permittee responsible under a watershed approach, (4) permittee responsible in-kind and on-site, and (5) permittee responsible off-site and/or out of kind. The rule also states a preference for mitigation completed in advance of impacts over any particular provider type. The USACE and DWR use the mitigation types in Table 14.10 for determining in-kind. Off-site mitigation is typically allowed within the same 8-digit USGS hydrologic unit (HU). Wetland mitigation may include restoration, enhancement, creation, or preservation of wetlands.

- Restoration is the re-establishment or rehabilitation of wetlands or stream hydrology into an area where wetland conditions (or stable stream bank and stream channel conditions) have been lost or degraded.
- 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 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 (USACE 2008):

- 1 acre of restoration is equal to 1 credit
- 2 acres of enhancement is equal to 1 credit
- 3 acres of creation is equal to 1 credit
- 5 acres of preservation is equal to 1 credit
- On most permits, enhancement or preservation credits can only be employed after applying planning at least one acre of credit of restoration or creation.

Federal and state agencies have minimum thresholds specifying when mitigation is required for wetland impacts. For DWR, the minimum threshold for mitigation due to 401 permitted impacts is 1.0 acre. The DCM does not have a minimum threshold since rules strongly discourage coastal wetland impacts unless for public projects that could not otherwise occur (15A NCAC 07M .0700). The USACE minimum threshold for mitigation begins at 0.1 acre.

The Division of Mitigation Services currently operates four In-Lieu Fee Mitigation Programs:

1. Statewide Stream and Wetland In-Lieu Fee Program
2. NCDOT Stream and Wetland In-Lieu Fee Program
3. Riparian Buffer In-Lieu Fee Program
4. Nutrient Offset In-Lieu Fee Program

The Statewide Stream and Wetland In-Lieu Fee Program began in 1996 with the establishment of the Wetland Restoration Program (WRP), later expanded to form the Ecosystem Enhancement Program (EEP) in 2003, which is now the Division of Mitigation Services (DMS). The purpose of this program is to provide cost-effective mitigation alternatives to improve the state's water resources. The DMS restoration activities are primarily undertaken as mitigation for present and anticipated losses of stream and wetland acreage. The program was initiated to provide effective, science based, mitigation that would be more successful than independent projects, and would utilize a watershed planning approach.

The DOT Stream and Wetland In-Lieu Fee Program was added through a Memorandum of Agreement (MOA) in 2003 (updated in 2008) between DENR, DOT, and the USACE. The DOT Stream and Wetland ILF Program provides mitigation to offset unavoidable environmental impacts from transportation-infrastructure improvements. The USACE joined as a sponsor in the MOA. The DOT Stream and Wetland ILF program develops mitigation in advance of impacts.

Both stream and wetland ILFs utilize watershed planning to identify and focus the implementation of restoration, enhancement and preservation projects. The DMS uses river basin watershed plans to identify targeted watersheds where mitigation projects will be concentrated. The DMS also uses regional and Local Watershed Plans (LWPs) to focus restoration work where most needed, guided by local interest and support for developing a plan, information on water quality degradation (restoration potential), ILF mitigation needs due to development (where mitigation banks are unable to provide credit) and compensatory mitigation needs of DOT.

The LWPs prioritize restoration/enhancement projects, preservation sites, and BMPs that provide water quality and hydrologic improvement, habitat protection and other environmental benefits to the local watershed. The strategies include stormwater management projects, water supply protection strategies, land use planning guidelines, and BMPs for reducing sediment pollution and soil erosion. The DMS is committed to funding restoration projects identified in the LWPs through payments made to the Wetlands Trust Fund to satisfy compensatory mitigation requirements.

The Riparian Buffer ILF Program operates in the Neuse, Tar-Pamlico, and portions of the Cape Fear, Yadkin, and Catawba River basins. The program provides compensatory mitigation for riparian buffer impacts in those areas. The Nutrient Offset ILF Program offers nutrient buy-down options for developers in the Neuse, Tar-Pamlico, Jordan Lake, and Falls Lake regulated areas.

Since 2004, DMS records annual mitigation by gross assets divided among 12 categories of wetlands. Projects are listed as assets when land has been secured and the design initiated. 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. The DMS summarizes mitigation assets in terms of gross and remaining assets (after mitigation is applied). Mitigation for streams includes restoration, enhancement, and high quality preservation. The remaining assets represent progress that DMS has achieved to produce mitigation in advance of permits.

In coastal drainage river basins, the total mitigation assets (planned and constructed) in FY 2013-14 were 10,730 acres (Gross Mitigation Credit) (Table 14.9). The total amount of annual mitigation assets has increased over time. As comparison, DMS had 8,311 acres (gross) of credits in 2004/05. Additionally, mitigation assets from private mitigation banks cover an estimated 20% of total assets not accounted for by DMS. In FYs 2013-2015, the DMS reported a 99.56% compliance rate for mitigating permitted stream impacts (Jim Stanfill, DMS, 2015). Mitigation compliance reported for nutrients offset was 99.99% and riparian buffer varied from 58% to 100%. The 58% compliance was in the Randleman Watershed.

Statewide, the total wetland area in North Carolina has declined from 7,175,000 acres in the 1950's to 5,132,634 acres in 2001, for a total loss of over 2 million acres (DWQ 2000b). Mitigating for part of this loss may be possible with progress made through the advanced compensatory mitigation work, as well as restoration on conservation lands, re-building marsh islands, reclaiming wetlands by purchasing agricultural properties and closing ditches, and constructing living shorelines. It should be noted, however, that restored and created wetlands may not function as do their natural counterparts, and require much staff time in monitoring and maintaining for success.

TABLE 14.9. Gross mitigation credits (planned and constructed) from EEP in coastal draining river basins from FY 2010/2011 to 2013/2014. Note: The Lumber is not included in NC coastal river basins. Credits are calculated using the equation: [Preservation/5] + [Creation/3] + [Enhancement/2] + [Restoration/1].

	Gross Mitigation Assets (Credits)				
Mitigation Type	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014
Riparian	4,188.47	4,523.88	4,518.32	4,525.77	4,537.72
Non-Riparian	6,649.85	6,290.78	6,250.07	6,083.57	6,057.14
Coastal Marsh	138.57	137.49	137.49	137.49	135.21
Total	**10,976.90**	**10,952.20**	**10,905.90**	**10,746.80**	**10,730.10**

While DMS has successfully completed advanced mitigation (EEP 2008; EEP 2009; Program 2010-11), much of the current mitigation is focused in particular HUs, whereas wetland and stream impacts 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.

The need for a USACE Section 404 permit authorizing the fill or alteration of wetlands or streams triggers the 401 Water Quality Certification process by DWR. However, projects impacting less than 150 linear feet of stream are not required to notify DWR and represent an unknown loss of stream segments. The loss of streams refers to altered hydrologic conditions affecting water quality (e.g., 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 nonpoint sources of pollution. Point source pollution is addressed by NPDES permit requirements and Total Maximum Daily Load (TMDL) allocations (see Chapter 10, Water Quality Impacts). Impoundment effects on water quality have only recently been included as a potential violation of the Clean Water Act.

The State of North Carolina did not require mitigation for impacts to intermittent streams prior to 2009, but impacts to these streams were reported. As of 2009, the DWR requires mitigation for impacting a cumulative total of greater than 150 linear feet of intermittent and/or perennial streams (J. Dorney, DWR, pers. com., 2010). However, the permitting is applied to streams as they are mapped on USGS topographic quadrangles. The DWR is currently re-mapping stream channels through the Headwater Stream Spatial Dataset program. The DWR mapping sample watersheds that are then used to develop GIS models by EPA level IV ecoregion. These models are used to predict the location of intermittent and perennial headwater streams (M. Tutwiler, DWR, pers. com. 2015).

The DMS is required to document statewide wetland losses from permitting and gains from mitigation and restoration. The permitted alteration of streams and buffers through 401 certifications and buffer authorizations is tracked by the Wetlands Unit of DWR and sent to DMS. Table 14.10 summarizes the statewide gains and losses of wetlands, streams, and buffers by DWR and compensatory mitigation by DMS from FY 2012/13 to 2014/15. With the exception of a small net gain in wetlands in FY 2014-15, there was a net loss of streams, wetlands, and riparian buffers in the past three years.

TABLE 14.10. Permitting and gains from compensatory mitigation during FY 2012/13, 2013-14, and 2014-15. Data provided by DWR and DMS and reflect permitting by DENR and compensatory mitigation by DMS.

Wetland/Stream Type	Permitted gains and losses		
Linear feet of streams	FY 2012-13	FY 2013-14	FY 2014-15
Losses	81,473.0	117,694.0	59,498.9
Gains	48,712.0	78,024.0	22,620.0
Net change	-32,761.0	-39,670.0	-36,878.9
Acres of wetlands			
Losses	203.6	98.9	102.1
Gains	197.8	59.9	104.5
Net change	-5.8	-39.0	2.4
Acres of riparian buffers			
Losses	75.6	48.0	56.1
Gains	37.9	21.2	18.2
Net change	-37.8	-26.9	-37.9

14.2.3.3. Other initiatives

Government and private organizations and individuals conduct initiatives independent of DMS local watershed plans. The DMS encourages these wetland restoration organizations and individuals to join 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 USDA to purchase easements from landowners who agree to protect or restore wetlands. By 2008, the total program enrollment in North Carolina had exceeded 34,148 acres.

Other programs restoring streams and riparian buffers include the Conservation Reserve Enhancement Program (CREP) and Agriculture Cost-share Program (ACSP) administered by the Department of Agriculture, 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.

To guide regulatory and non-regulatory wetland conservation and restoration efforts, DENR has developed a conservation planning tool incorporating GIS information supporting prioritization of areas based on myriad of program objectives. Refer to the CPT Report for information on conservation at http://portal.ncdenr.org/web/cpt/cpt-usage.

The rate of wetland losses and gains documented by permit records and DMS reports does not account for functional equivalency, which is the replacement of full ecological functions specific to a wetland type. Criteria for successful mitigation should reflect the ecological functions that need replacing. The North Carolina Wetlands Assessment Method (NCWAM) provides the current guidance for evaluating functional replacement. The monitoring associated with DMS mitigation projects continues for at least 5 years, or until success criteria are achieved (EEP 2005).

In 2009, the MFC approved a compensatory mitigation policy that was incorporated into the “Policies for Protection and Restoration of Marine and Estuarine Resources and Environmental Permit Review and Commenting.” Based on 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 allow 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.

14.2.4. Submerged aquatic vegetation

Although protection, rather than mitigation or restoration, is the more environmentally sound and 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; Orth et al. 2006; SAFMC 1998b; Treat and Lewis 2006). Restoration 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 year round. Light penetration, energy exposure, sediment type, and water quality are critical parameters to successful SAV restoration.

In areas of recovering SAV abundance, restoration and enhancement techniques can be used to accelerate the recovery of SAV toward critical density and coverage. Shellfish restoration and aquaculture could enhance water quality conditions, which in turn could enhance SAV growth. This has been observed in clam aquaculture leases in Virginia and North Carolina.

Water-based restoration efforts are warranted in locations where SAV has historically occurred but has declined in spatial extent or density, and is not recovering naturally. An example of this is in Back Bay, Virginia, north of Currituck Sound. Seagrass was abundant in these waters until the 1970s. 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 area immediately south of Back Bay. Aerial imagery of SAV from 2007 and observations during 2008 suggest an increase in SAV abundance from 2003-2008 (J. Gallegos, USFWS, pers. obs. 2010).

Breaking wave energy with subsequent improvements in water clarity are being considered in Pamlico Sound as mitigation for SAV impacts from bridge construction. Restoration of SAV through land-based water quality improvements is possible in locations of historical SAV abundance where it is currently absent or reduced. Without adequate water quality conditions, planted SAV will not survive. An example of land-based improvements facilitating SAV restoration is in Wilson Bay, New River. The Jacksonville SAV restoration project improved water quality, wetlands, and oysters in Wilson Bay. Once water quality improved (Mallin et al. 2005), the USACE and the City of Jacksonville conducted the pilot restoration project using several techniques developed and successfully used in the Chesapeake Bay. Plants with seed heads were collected and some were planted in the bay. The seeds of other plants were extracted, germinated and grown in runways, later transplanted into the bay. The plants directly anchored in the bay survived better than the seedlings (P. Donovan-Potts, pers. com. 2010).

Mitigation for impacts to SAV is only allowed by CRC rules if the activity associated with the proposed project has an overriding public benefit. Otherwise, direct impacts to SAV or wetlands are not allowed by DCM policies or CRC rules. Most permitted impacts have involved transportation (bridge construction) or navigation (channel dredging).

Techniques and success criteria for SAV restoration have been developed and evaluated by NOAA's

Coastal Ocean Office (Fonseca et al. 1998) and others (Ailstock and Shafer 2006; Boustany 2003; Orth et al. 1994; Smart et al. 1998; Treat and Lewis 2006). However, more research is needed to develop viable SAV restoration techniques in North Carolina.

14.3. Outreach and Volunteerism

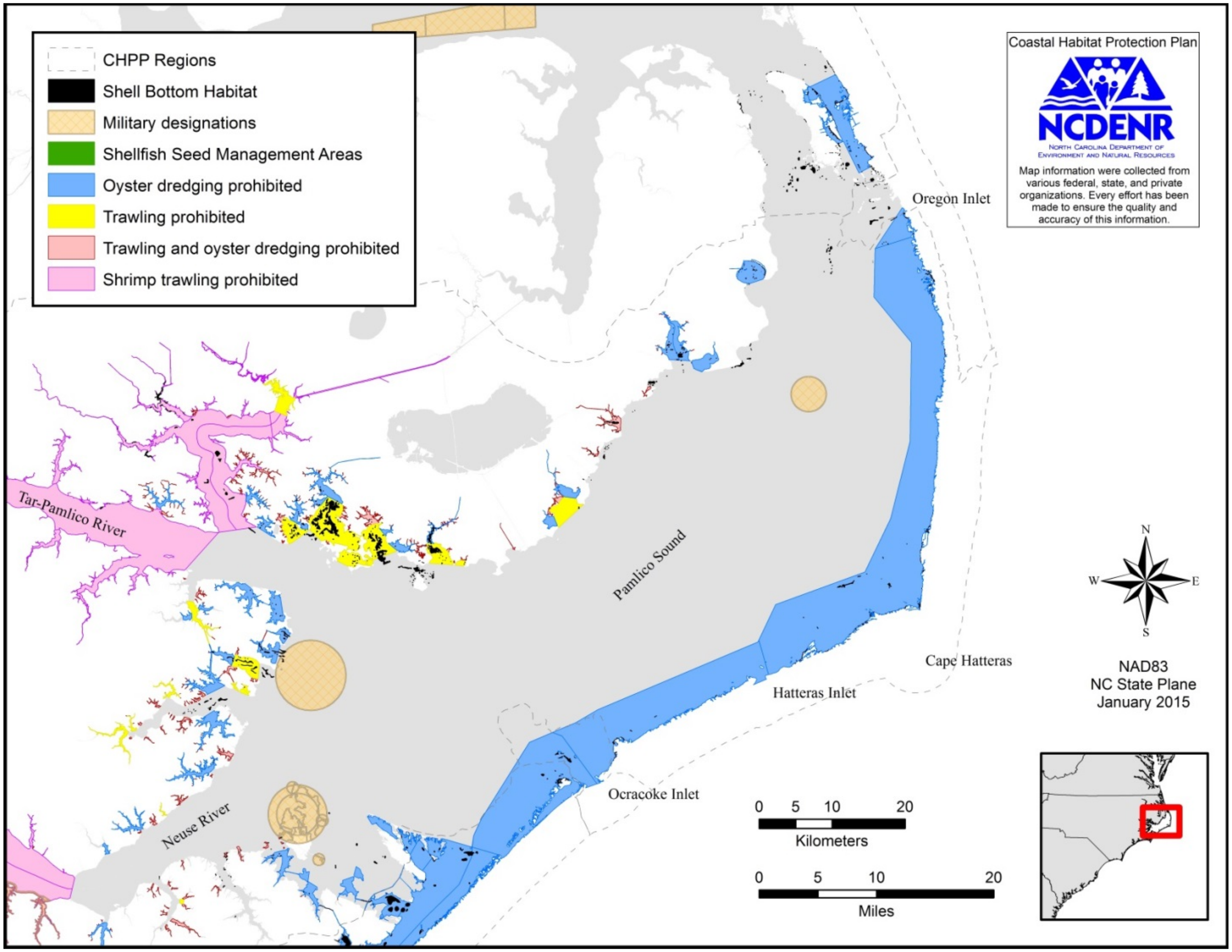
14.3.1. Litter and Marine Debris

Agency programs and organizations such as NOAA's Marine Debris Program and The Ocean Conservancy (TOC) are involved in monitoring and clean-up efforts. Until April of 2015, North Carolina Big Sweep was a state-wide nonprofit organization whose mission was a litter-free environment. The Big Sweep conducted education events to prevent litter and coordinated an annual Big Sweep event, the state component of the International Coastal Cleanup in which volunteers clean land and waterways. During the 2014 event, North Carolina Big Sweep volunteers collected 102,850 pieces of debris along 1,327 miles of shoreline, totaling some 301,550 lbs. In another 2014 effort, fishermen worked alongside Marine Patrol officers when crab pots are required to be removed from the water by NC General Statute 113-268, to remove derelict pots and marine debris from the water. During this two day period volunteers removed 201 crab pots, while Marine Patrol removed 163; associated shoreline volunteers removed 620 pounds of solid waste and 380 pounds of derelict fishing gear from Roanoke Island. Since 2009, hundreds of volunteers have removed tons of trash from Masonboro Island during annual 4th of July Celebrations. In 2014, more than 75 volunteers helped clean 2.87 tons of trash and recyclables from this island just south of Wrightsville Beach.

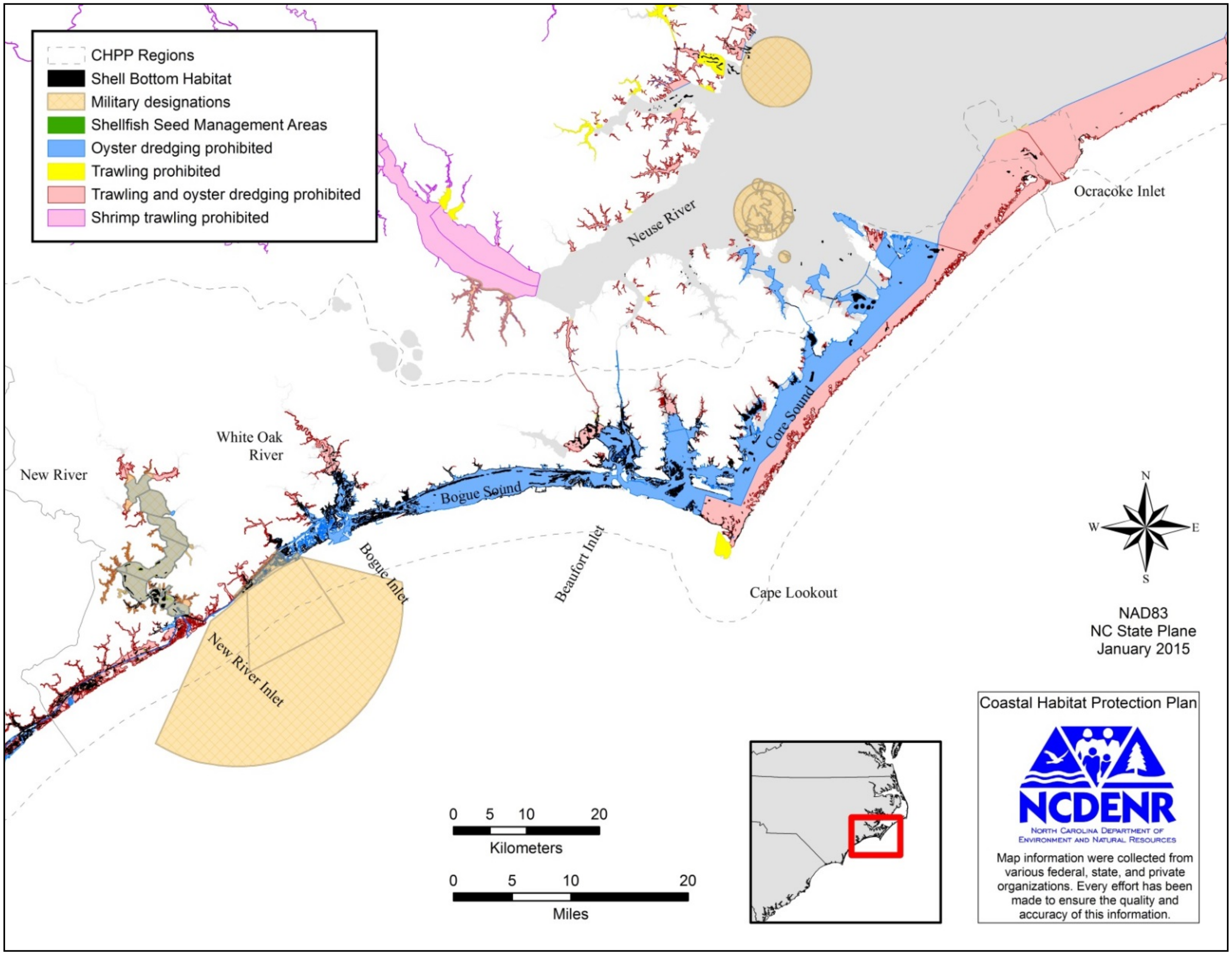
14.3.2. NC Coastal Reserve and National Estuarine Research Reserve

The six Coastal Reserve and four National Estuarine Research Reserve sites protect over 42,000 acres of estuarine habitat in N.C. The Reserve is a partnership between the National Oceanic Atmospheric Administration and the N.C. Division of Coastal Management and its purpose is to "promote informed management and stewardship of North Carolina's estuarine and coastal habitats through research, education, and example." The reserve sites are living laboratories and outdoor classrooms and support compatible traditional uses, such as fishing and recreation. Reserve sites are monitored to understand visitor use and the condition of natural resources, including protected and invasive species.

The reserve staff provides numerous workshops for decision makers on issues such as sustainable development, water quality and habitat protection, and coastal resilience. On-site field trips focused on estuarine ecology target K-12 teachers and students and the public. The Reserve's System-Wide Monitoring Program (SWMP) provides long-term data on water quality, weather, biological communities, habitat, and land-use and land-cover characteristics.



MAP 14.1A. Location of cultch planting sites (2012), shellfish management areas and research sanctuaries (2008), and oyster sanctuaries (2014) in Pamlico Sound.



MAP 14.1B. Location of cultch planting sites (2012), shellfish management areas and research sanctuaries (2008), and oyster sanctuaries (2014) from Core Sound to Surf City.

CHAPTER 15. MANAGEMENT RECOMMENDATIONS

The scientific information in the preceding chapters demonstrate the importance and vulnerability of coastal fish habitats, and the need for 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."* The CHPP Steering Committee, after reviewing the updated information and discussing habitat and water quality issues, made modifications to the CHPP recommendations. These recommendations include management, monitoring, outreach, and research items. Identified research needs were compiled in a separate document. The CHPP Steering Committee selected four priority issues to focus implementation on over the next five years. The recommendations table notes which items address a priority habitat issue.

15.2. Public input

The draft plan was presented at four Marine Fisheries Commission Advisory Committee meetings in December 2015. Public comments were accepted at those meetings and could be submitted in writing during the month of December. All four advisory committees (Northern, Southern, Shellfish/Crustacean, and Habitat and Water Quality) passed motions to recommend to the Marine Fisheries Commission to support the Coastal Habitat Protection Plan and Source Document. In addition, the Habitat and Water Quality AC recommended further strengthening of the plan's role in protecting and enhancing habitats that support healthy fisheries (Table 15.1).

TABLE 15.1. Summary of public comments on the December 2015 draft CHPP.

Source	Comments
Shellfish/ Crustacean Advisory Committee	Rec. 3.1.a.- modify recommendation to include restoration of intertidal oyster reefs as well as subtidal; on p 24 of CHPP; add some information on the economic value of habitat restoration (RTI study done recently for NCCF could be used).
Northern Advisory Committee	Would like to see more on the effects of agriculture (pesticides, fertilizer, poultry farms) and recommendations to address it; the plan has less teeth than the previous plan and would like to see more; suggested partnering with NCSU Agriculture program; too many exceptions/waivers to rules – no benefit if rules aren't enforced; much erosion of wetlands near Core Point, Pamlico River (near PCS) – there is a need for living shorelines and he is willing to help.
Habitat and Water Quality Advisory Committee	Pratt supported CHPP but wanted the plan to have stronger recommendations that are implemented; concern that water quality wasn't included in the priority issues; concern that compliance monitoring has declined, buffer and stormwater rules are weaker, and these are all proven to be effective at protecting water quality.
Lauren Morris/NC Fisheries Assoc.	Supports the Coastal Habitat Protection Plan; its been neutered to ineffectiveness; consider that water quality also has impacts on the oyster stocks, that you need better water quality to improve the population, and is important to protect.
David Knight/NC Wildlife Federation	Document needs to be beyond politics - can't stop because politics change; CHPP is important for the future of our coast; would prefer if it didn't focus on just certain "priority" issues; sedimentation is a huge problem due to urban development and agriculture; supports different avenues of oyster restoration; need to integrate climate change into the plan; NC Wildlife Federation would like to partner on CHPP implementation.

Heather Deck/Sound Rivers	As the Tar-Pam Riverkeeper, she stressed the importance of protecting and enhancing water quality; she supports the recommendations and proposed sedimentation implementation actions that address assistance to the local sedimentation control programs- better capability of addressing problems in the field; neither river reached its nutrient reduction loading goals and data indicate an increasing negative influence on water quality from poultry farms, which currently don't require permitting.
Terry Pratt	Information compiled is good but DEQ should not go backward on habitat and water quality protection and improvements; Chowan River experiencing algal blooms due to increase in poultry operations; can't endorse the CHPP if it is less protective than previous plans – recommends we (not sure who we is) go to the legislature and ask for more teeth in the plan. A specific example of information needed to be more effective was a recommendation for funding to treat endocrine disrupting chemicals.
James Fletcher	Talked about the negative impacts of endocrine disrupting chemicals and water withdrawals from Lake Gaston; would like to see a recommendation that all treated wastewater be land disposal application and suggested using highway medians for that; would like to see more concrete solutions going to the legislature.
Keith Larick/NC Farm Bureau	Supportive of the intent of the plan. No comments on the recommendations, but provided multiple technical comments regarding agriculture to the Source Document.

Public comments were summarized and presented to the CHPP Steering Committee in January, and based on those as well as additional input from some of the steering committee members, some technical changes were made within the Source Document, miscellaneous edits were made to the CHPP, Recommendation 3.1a was modified, Recommendation 3.1d was deleted, and Recommendation 4.5 was modified. The final recommendations are shown in Table 15.2. By approving the CHPP recommendations, the Marine Fisheries, Coastal Management, and Environmental Management commissions commit to working on these recommendations through development of implementation plans. The CHPP Team and Steering Committee will compile a CHPP Implementation Plan for 2016-2018 following finalization of the plan. The focus of actions will be on recommendations that address a priority issue, as indicated in the recommendations table. A separate report of priority research needs will be compiled by the CHPP Team, based on information in the Source Document.

TABLE 15.2. Recommendations, related priority issue, and responsible commission or agency for the long-term enhancement of coastal fisheries associated with coastal habitats.

No.	Recommended Actions	Related Priority Issue(s)	Responsible Commission or Agency [Lead group(s) in bold]
GOAL 1. IMPROVE EFFECTIVENESS OF EXISTING RULES AND PROGRAMS PROTECTING COASTAL FISH HABITATS			
1.1	Continue to ensure compliance with Coastal Resources Commission (CRC), Environmental Management Commission (EMC), and Marine Fisheries Commission (MFC) rules and permits.	sedimentation, oyster restoration, establishing metrics	**CRC/DCM**, **EMC/DWR**,**DEMLR/SCC MFC/DMF**
1.2	Coordinate and enhance: a) monitoring of water quality, habitat, and fisheries resources (including data management) from headwaters to the nearshore ocean. b) assessment and monitoring of effectiveness of rules established to protect coastal habitats.	establishing metrics	**DENR**, DMF, DWR, DCM, DEMLR, WRC, NCFS
1.3	Enhance and expand educational outreach on the value of fish habitat, threats from land use and other activities, and explanations of management measures and challenges.	living shorelines, sedimentation	**DENR**, WRC, NCFS
1.4	Continue to coordinate among commissions and agencies on coastal habitat management issues.		EMC, CRC, MFC, SCC, DENR, WRC, SWCC, and cooperating agencies
1.5	Enhance management of invasive species with existing programs. Monitor and track status in affected waterbodies.		DENR, APNEP, WRC, DACS
GOAL 2. IDENTIFY AND DELINEATE STRATEGIC COASTAL HABITATS			
2.1	Support assessments to classify habitat value and condition by: a) coordinating, completing, and maintaining baseline habitat mapping (including seagrass, shell bottom, shoreline, and other bottom types) using the most appropriate technology b) selectively monitoring the condition and status of those habitats. c) assessing fish-habitat linkages and effects of land use and other activities on those habitats.	establishing metrics	**DMF**, DCM, DWR, DENR, WRC
2.2	Continue to identify and field groundtruth strategic coastal habitats.	establishing metrics	**DENR**, MFC/DMF

No.	Recommended Actions	Related Priority Issue(s)	Responsible Commission or Agency [Lead group(s) in bold]
GOAL 3. ENHANCE AND PROTECT HABITATS FROM ADVERSE PHYSICAL IMPACTS			
3.1	Expand habitat restoration in accordance with restoration plan goals, including: a) increasing subtidal and intertidal oyster habitat through restoration. b) re-establishing of riparian wetlands and stream hydrology. c) restoring SAV habitat and shallow soft bottom nurseries.	oyster restoration, living shorelines, sedimentation	**DMF**, DMS, **DWR**/EMC
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/DWR, MFC/DMF, DWR, WRC, DENR
3.3	Protect habitat from adverse fishing gear effects through improved compliance.	oyster restoration	**MFC/DMF**
3.4	Improve management of estuarine and public trust shorelines and shallow water habitats by revising shoreline stabilization rules to include consideration of site specific conditions and advocate for alternatives to vertical shoreline stabilization structures.	living shorelines	**CRC/DCM, DWR/EMC**
3.5	Protect and restore habitat for migratory fishes by: a) incorporating the water quality and quantity needs of fish in water use planning and management. b) restoring fish passage through elimination or modification of stream obstructions, such as dams and culverts.		**DENR**, EMC, DWR, DEMLR, WRC, DMF
3.6	Ensure that energy development and infrastructure is designed and sited to minimize negative impacts to fish habitat, avoid new obstructions to fish passage, and where possible provide positive impacts.		CRC/DCM, EMC/DWR, DEMLR
3.7	Protect and restore important fish habitat functions from damage associated with activities such as dredging and filling.	oyster restoration, living shorelines	CRC/DCM, EMC/DWR
3.8	Develop coordinated policies including management adaptations and guidelines to increase resiliency of fish habitat to ecosystem changes.	living shorelines, sedimentation	DENR, WRC
GOAL 4. ENHANCE AND PROTECT WATER QUALITY			

No.	Recommended Actions	Related Priority Issue(s)	Responsible Commission or Agency [Lead group(s) in bold]
4.1	Reduce point source pollution discharges by: a) increasing inspections of wastewater discharges, treatment facilities, collection infrastructure, and disposal sites b) providing incentives and increased funding for upgrading all types of discharge treatment systems and infrastructure c) developing standards and treatment methods that minimize the threat of endocrine disrupting chemicals on aquatic life	establishing metrics	**EMC/**DWR
4.2	Address proper reuse of treated wastewater effluent and promote the use of best available technology in wastewater treatment plants (including reverse osmosis and nanofiltration effluent), to reduce wastewater pollutant loads to rivers, estuaries, and the ocean.		**EMC**
4.3	Prevent additional shellfish closures and swimming advisories by: a) conducting targeted water quality restoration activities b) prohibiting 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 Resource's Stormwater Flooding Relief Discharge Policy) when public safety and health are threatened c) continuing to phase-out existing outfalls by implementing alternative stormwater management strategies	sedimentation	**EMC/**DWR, CRC/DCM, DEMLR
4.4	Enhance coordination with, and provide financial/technical support for, local government/private actions to effectively manage stormwater, stormwater runoff, and wastewater.	sedimentation	**DENR**, DWR/EMC, DCM, DEMLR, SCC,
4.5	Continue to improve strategies throughout the river basins to reduce nonpoint 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) encouraging and providing incentives for implementation of Low Impact Development practices. d) increased inspections of onsite wastewater treatment facilities . e) increased use of reclaimed water and recycling. f) increased voluntary use of riparian vegetated buffers for forestry, agriculture, and development.	sedimentation	**DENR**, DWR/EMC, DCM/CRC, , , SCC, DEMLR, DSWC, DACS, NCFS

No.	Recommended Actions	Related Priority Issue(s)	Responsible Commission or Agency [Lead group(s) in bold]
	g) increased funding for strategic land acquisition and conservation.		
4.6	Maintain effective regulatory strategies throughout the river basins to reduce nonpoint pollution and minimize cumulative losses of fish habitat, including use of vegetated buffers and established stormwater controls.	sedimentation	**EMC,** CRC
4.7	Maintain adequate water quality conducive to the support of present and future mariculture in public trust waters.	oyster restoration	**DENR**
4.8	Reduce nonpoint source pollution from large-scale animal operations by: a) Ensuring proper oversight and management of animal waste management systems. b) Ensuring certified operator compliance with permit and operator requirements and management plan for animal waste management systems.		**DWR,** DSWC, DACS

Acronym List

APNEP - Albemarle-Pamlico National Estuary Partnership
CRC - Coastal Resource Commission
DACS - Department of Agriculture and Consumer Services
DCM - Division of Coastal Management
DEMLR - Division of Energy, Mineral, and Land Resources
DENR - Department of Environment and Natural Resources
DMF - Division of Marine Fisheries
DMS - Division of Mitigation Services
DSWC - Division of Soil and Water Conservation
DWR - Division of Water Resources
EMC - Environmental Management Commission
MFC - Marine Fisheries Commission
NCFS - NC Forest Service
SCC - Sedimentation Control Commission
SWCC - Soil and Water Conservation Commission
WRC - Wildlife Resources Commission

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APPENDIX A. LIST OF ACRONYMS

Acronym	Meaning
A	One of the three primary surface water classifications established by the EMC
ACSP	Agriculture Cost-Share Program
AEC	Area of Environmental Concern
AFS	American Fisheries Society
AFSA	Anadromous Fish Spawning Areas
AIWW	Atlantic Intracoastal Waterway (see "ICW" below)
ANS	Aquatic Nuisance Species
AOI	Area of Impact
APNEP	Albemarle-Pamlico National Estuary Partnership
ASMFC	Atlantic States Marine Fisheries Commission
AWCP	Aquatic Weed Control Program
B	One of the three primary surface water classifications established by the EMC
BEACH	Beaches Environmental Assessment and Coastal Health Act of 2000
BIMP	Beach and Inlet Management Plan
BMPs	Best Management Practices
BOEM	Bureau of Ocean Energy Management
BOD	Biochemical Oxygen Demand
BOD	Biological Oxygen Demand
BRACO	Blue Ribbon Advisory Council on Oysters
BWE	Ballast Water Exchange
BWM	Ballast Water Management
C	One of the three primary surface water classifications established by the EMC
CAAE	Center for Applied Aquatic Ecology at North Carolina State University
CAFO	Concentrated Animal Feeding Operation
CAMA	Coastal Area Management Act
CBF	Chesapeake Bay Foundation
CCA	Copper, Chromium, and Arsenic
CCAP	Community Conservation Assistance Program
CCPCUA	Central Coastal Plain Capacity Use Area
CFRE	Cape Fear River Estuary
cfs	Cubic feet per second
CFU	Colony Forming Unit
CHAPC	Coral Habitat Area of Particular Concern
CHPP	Coastal Habitat Protection Plan
CICEET	Cooperative Institute for Coastal and Estuarine Environmental Technology
CO_2	Carbon Dioxide
COBRA	Coastal Barrier Resources Act
CPA	Civil Penalty Assessment
CPT	Conservation Planning Tool
CPUE	Catch Per Unit Effort
CRAC	Coastal Resources Advisory Council
CRC	Coastal Resources Commission
CREP	Conservation Reserve Enhancement Program

Acronym	Meaning
CREWS	Coastal Region Evaluation of Wetland Significance
CRFL	Coastal Recreational Fishing License
CSC	CHPP Steering Committee
CSHA	Closed Shellfish Harvesting Area
CWMTF	Clean Water Management Trust Fund
DAQ	Division of Air Quality
DAT	Domoic Acid Toxicity
DCM	Division of Coastal Management
DDT	Dichlorodiphenyltrichloroethane
DEH	Division of Environmental Health
DEH - SS	Division of Environmental Health - Shellfish Sanitation
DEHNR	Department of Environment, Health and Natural Resources
DEIS	Draft Environmental Impact Statement
DEM	Division of Environmental Management
DEMLR	Division of Energy, Mineral, and Land Resources (previously DLR)
DENR	Department of Environment and Natural Resources (now DEQ)
DEQ	Department of Environmental Quality (previously DENR)
DLR	Division of Land Resources (now DEMLR)
DMF	Division of Marine Fisheries
DMS	Division of Mitigation Services (previously EEP)
DNA	Deoxyribonucleic acid
DO	Dissolved Oxygen
DOT	Department of Transportation
DPP	Draft Proposed Program
DSWC	Division of Soil and Water Conservation
DWQ	Division of Water Quality (now DWR)
DWR	Department of Water Resources (previously DWQ)
EA	Environmental Assessment
EBM	Ecosystem Based Management
ECU	East Carolina University
EDC	Endocrine Disrupting Chemicals
EDF	Environmental Defense Fund
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
EPA	United States Environmental Protection Agency (see "USEPA" below)
ESA	Endangered Species Act
ESCP	Erosion and Sediment Control Plans
FCB	Fecal Coliform Bacterial
FDA	Food and Drug Administration
FEIS	Final Environmental Impact Statement
FEMA	Federal Emergency Management Agency

Acronym	Meaning
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)
FY	Fiscal year
G&G	Geological and Geophysical
GIS	Geographic Information System
gpd	Gallons per day
GS	General Statute
HAB	Harmful Algal Bloom
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)
IEA	Integrated Ecosystem Assessment
ILF	In-lieu Fee
IMS	Institute of Marine Sciences
IPNA	Inland Primary Nursery Area
IRC	Intercommission Review Committee
JAI	Juvenile Abundance Index
LC50	Lethal Concentration 50%
LID	Low Impact Development
LRP	Limited Reference Points
LWP	Local Watershed Plans
MAFMC	Mid-Atlantic Fishery Management Council
MARMAP	Marine Resources Monitoring, Assessment, and Prediction Program
MCAS	Marine Corps Air Station
MFC	Marine Fisheries Commission
mgd	Million gallons per day
MHW	Mean High Water
MLW	Mean Low Water
MMS	Minerals Management Service
MODMON	Neuse River Estuary Modeling and Monitoring project
MPA	Marine Protected Area
MSC	Moratorium Steering Committee
MSDF	Multi-Slip Docking Facilities
MSX	*Haplosporidium nelsoni*
MSY	Maximum Sustained Yield
MU	Management Unit
NCAC	North Carolina Administrative Code
NCCF	North Carolina Coastal Federation
NCDA&CS	North Carolina Department of Agriculture and Consumer Services
NCDEHNR	North Carolina Department of Environment, Health and Natural Resources

Acronym	Meaning
NCDENR	North Carolina Department of Environment and Natural Resources
NCDOT	North Carolina Department of Transportation
NCGS	North Carolina General Statute
NCOHP	North Carolina Oyster Hatchery Program
NCSU	North Carolina State University
NCSU-CMAST	North Carolina State University Center for Marine Sciences and Technology
NCWRP	North Carolina Wetlands Restoration Program
NERR	National Estuarine Research Reserve
NGO	Non-Governmental Organizations
$NH4^+$	Ammonium
NHP	Natural Heritage Program
NHW	Normal High Water
NLCD	National Land Cover Database
NLW	Normal Low Water
NM	Nautical Mile
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOD	Notice of Deficiency
NOV	Notice of Violation
NOS	National Ocean Service
NPDES	National Pollution Discharge Elimination System
NRC	National Research Council
NRE	Neuse River Estuary
NRCS	Natural Resources Conservation Service
NRI	National Resource Inventory
NSF	National Science Foundation
NSP	Neurotoxic Shellfish Poisoning
NSW	Nutrient Sensitive Waters (EMC supplemental water quality classification)
NTU	Nephelometric Turbidity Unit
NWI	National Wetland Inventory
NWL	Normal Water Level
NWR	National Wildlife Refuge
OCS	Outer Continental Shelf
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
PAM	Polyacrylamides
PCBs	Polychlorinated Biphenyls
PEIS	Programmatic Environmental Impact Statement
PNA	Primary Nursery Area
ppb	Parts per billion
ppm	Parts per million
ppt	Parts per thousand

Acronym	Meaning
PWS	Public Water Supply
RCGL	Recreational Commercial Gear License
RO	Reverse Osmosis
ROD	Record of Decision
SA	A primary surface water classifications for coastal waters established by the EMC
SAB	South Atlantic Bight
SABRE	South Atlantic Bight Recruitment Experiment
SAFMC	South Atlantic Fishery Management Council
SARP	Southeast Aquatic Resources Partnership
SAV	Submerged Aquatic Vegetation
SB	A primary surface water classifications for coastal waters established by the EMC
SB	Senate Bill
SC	A 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
SDTF	Septage Detention or Treatment Facility
SEAMAP	Southeast Area Monitoring and Assessment Program
SEAMAP-SA	Southeast Area Monitoring and Assessment Program - South Atlantic
SECC	Sedimentation and Erosion Control Commission
SEDAR	Southeast Data, Assessment, and Review
SEPA	State Environmental Policy Act
SFA	Sustainable Fisheries Act
SGD	Submarine Groundwater Discharge
SHA	Strategic Habitat Area
SL	Session Law
SLAS	Septage Land Application Site
SMZ	Streamside Management Zone
SNA	Secondary Nursery Area
SNHA	Significant Natural Heritage Area
SOD	Sediment Oxygen Demand
SSMAs	Shellfish Seed Management Areas
SW	Swamp Waters (EMC supplemental water quality classification)
SWCC	Soil and Water Conservation Commission
TBT	Tributyltin
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TNC	The Nature Conservancy
TOC	The Ocean Conservancy
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total suspended solids
UNC	University of North Carolina
UNC-CH	University of North Carolina – Chapel Hill

Acronym	Meaning
UNC-IMS	University of North Carolina - Institute of Marine Science
UNC-W	University of North Carolina - Wilmington
UNEP	United Nations Environmental Programme
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)
USFWS	United States Fish & Wildlife Service
USGS	United States Geological Survey
UV	Ultraviolet Light
VIMS	Virginia Institute of Marine Science
VOWTAP	Virginia Offshore Wind Technology Advancement Project
WEA	Wind Energy Area
WQC	Water Quality Certification
WRC	Wildlife Resources Commission
WRP	Wetland Restoration Program
WS	Water Supply (EMC supplemental water quality classification)
WWTP	Wastewater Treatment Plants
YOY	Young of Year

APPENDIX B. TECHNICAL DEFINITIONS

Term	Definition
Accretion	Natural process by which marshes build in elevation with rising water level.
Adsorption	Chemical attachment to a particle.
Anadromous	Fish species that migrate from the ocean to fresh water streams, lakes, and wetlands to spawn.
Anoxia	Absence of oxygen.
Anthropogenic	Human-like or caused by humans.
Benthic	Associated with the bottom under a water body.
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.
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).
Detritus	Fragments of plant material occurring in the water during the process of decomposition by bacteria and fungi.
Epibenthic	Living on the surface of the bottom.
Estuary	A dynamic coastal water body in which fresh water from rivers and creeks mixes with ocean waters.
Eutrophication	Process of enrichment of a water body with excessive nutrients to the extent that abnormal algae blooms occur and community structure changes.
Hydrodynamic conditions	How the water is moving or circulating through a body of water.
Hydrogeomorphic	Characterized by the interaction and linkage of hydrologic processes with landforms or earth materials and the interaction of geomorphic processes with surface and subsurface water in temporal and spatial dimensions.
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.
Isobath	Lines on a map or graph connecting points with the same water depth.
Light attenuation	The reduction of radiant energy (light) with depth, by both scattering and absorption mechanisms.
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.
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).
Pelagic	Fish species that live primarily up in the water column.
Phytobenthic	Refers to microscopic plants that live on the bottom.

Term	Definition
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.
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.
Sinks	Habitats where certain organisms have a higher mortality rates and production rate (i.e., areas that are heavily fished or otherwise dangerous).
Subsidence	Natural degradation of marsh wetlands to open waters.
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	Of or involving the feeding habits or relationships of differentorganisms in a food chain or food web
Trunk estuaries	Coast-perpendicular, drowned river estuaries.
Turbidity	Reduced water clarity caused by sediment or other particulates suspended in the water column.
Water clarity	A measure of the depth to which light penetrates the water column.

APPENDIX C. HABITAT RELATED LEGISLATIVE CHANGES ADOPTED IN 2015

The following legislation was adopted or formalized after the CHPP was drafted, thus was not reflected in the document. Some may indirectly affect CHPP areas, while others directly affect the way development is regulated (e.g., stormwater rules, mitigation requirements, riparian buffer standards). Note: This is exceedingly abridged for space and is only meant to brief you on the changes. In some cases, legislative subsections that are not habitat related, are omitted. Please refer to statute references for further information.

§ 113-415.1 Local ordinances regulating oil and gas exploration, development, and production activities invalid; petition to preempt local ordinance …
Notwithstanding any authority granted to counties, municipalities, or other local authorities to adopt local ordinances … all provisions … that regulate or have the effect of regulating oil and gas exploration, development, and production activities: within the jurisdiction of a local government are invalidated and unenforceable, to the extent necessary to effectuate the purposes of this Part, that do the following: …

§ 130A-309.205 Local ordinances regulating management of coal combustion residuals and coal combustion products invalid; petition to preempt local ordinance …
Notwithstanding any authority granted to counties, municipalities, or other local authorities to adopt local ordinances … all provisions … that regulate or have the effect of regulating the management of coal combustion residuals and coal combustion products, including regulation of carbon burn-out plants, within the jurisdiction of a local government are invalidated and unenforceable …

Subchapter 2H Chapter 2 Title 15A Discharges to Isolated Wetlands and Isolated Waters
The isolated wetlands provisions of Section .1300 shall apply only to a basin wetland or bog … The isolated wetlands provisions of Section .1300 shall not apply to an isolated man-made ditch or pond constructed for stormwater management purposes, any other man-made isolated pond, or any other type of isolated wetland, and the DEQ shall not regulate such water bodies under Section .1300.

Section 54 (b) Notwithstanding 02H .1305 all of the following shall apply …
(2) Mitigation requirements for impacts to isolated wetlands shall only apply to the amount of impact that exceeds the threshold set out in subdivision (1) ... The mitigation ratio for impacts exceeding the threshold for the entire project … shall be 1:1 and may be located on the same parcel.
(4) Impacts to isolated wetlands shall not be combined with the project impacts to 404 jurisdictional wetlands or streams for the purpose of determining when impact thresholds that trigger a mitigation requirement are met.

§ 143-214.7 Stormwater runoff rules and programs
For State stormwater programs and local stormwater programs approved pursuant to subsection (d) of this section, all of the following shall apply:
(1) The volume, velocity, and discharge rates of water associated with the one-year, 24-hour storm and the difference in stormwater runoff from the predevelopment and post development conditions for the one-year, 24-hour storm shall be calculated using any acceptable engineering hydrologic and hydraulic methods.
(2) Development may occur within the area that would otherwise be required to be placed within a vegetative buffer required … to protect classified shellfish waters, outstanding resource waters, and high-quality waters …
(3) The requirements that apply to development activities within one-half mile of and draining to Class SA waters or within one-half mile of Class SA waters and draining to unnamed freshwater tributaries shall not apply to development activities and associated stormwater discharges that do not occur within one-

half mile of and draining to Class SA waters or are not within one-half mile of Class SA waters and draining to unnamed freshwater tributaries.

<u>143-214.23A Limitations on local government riparian buffer requirements</u>
b) Except as provided in this section, a local government may not enact, implement, or enforce a local government ordinance that establishes (or) exceeds riparian buffer requirements necessary to comply with or implement federal or State law …
(e) Cities and counties shall not treat the land within a riparian buffer area as if the land is the property of the State or any of its subdivisions...
(f) … When riparian buffer requirements are placed outside of lots in portions of a subdivision that are designated as common areas or open space and neither the state nor its subdivisions holds any property interest … the local government shall attribute to each lot … a proportionate share … for development-related regulatory requirements …

<u>Section 13.3(b) 02B .0233 and 02B .0259 Neuse River Basin and Tar-Pamlico River Basin: Nutrient Sensitive Waters Management Strategy: Protection and Maintenance of Existing Riparian Buffers</u>: … Zone 1 of a protective riparian buffer for coastal wetlands shall begin at the most landward limit of the normal high water level or the normal water level as appropriate.

<u>Exempt certain wetland mitigation activities under the Sedimentation Pollution Control Act § 113A-52.01</u>. This Article shall not apply to the following land-disturbing activities:
(5) Activities undertaken to restore the wetland functions of converted wetlands to provide compensatory mitigation to offset impacts permitted under Section 404 of the Clean Water Act.
(6) Activities undertaken pursuant to Natural Resources Conservation Service standards to restore the wetlands functions of converted wetlands as defined in Title 7 Code of Federal Regulations § 12.2 …

<u>153A-346 and 160A-390 Conflict with other laws</u>
(b) … a county (city) may not use a definition of dwelling unit, bedroom, or sleeping unit that is more expansive than any definition of the same in another statute or in a rule adopted by a State agency.

<u>130A-335 Wastewater collection, treatment and disposal</u>; rules
(a1) Any proposed site … may be evaluated … by a licensed soil scientist …
(b) All wastewater systems shall either (i) be regulated by the Department … or (ii) conform with the engineered option permit criteria set forth in G.S. 130A-336.1 …
(c1) The rules … approved under the private option permit criteria pursuant to GS 130A-336.1 shall be, at a minimum, as stringent as the rules for wastewater systems established by the commission …

<u>§ 130A-336.1 Alternative process for wastewater system approvals.</u>
(a) Engineered Option Permit Authorized – A professional engineer licensed under Chapter 89C of the General Statutes may … prepare drawings, specifications, plans, and reports for the design, construction, operation, and maintenance of the wastewater system …
(e)(2) Notwithstanding G.S. 130A-335(a1), the owner of the proposed wastewater system shall employ either a licensed soil scientist or a geologist … to evaluate soil conditions and site features.

<u>8-58.53 Environmental audit report</u>; privilege
(a) An environmental audit report or any part is privileged, immune from discovery, not admissible as evidence in civil or administrative proceedings, except as (in) GS 8-58.54 and GS 8-58.56 …
8-58.61 Voluntary Disclosure; limited immunity …
(a) An owner or operator of a facility is immune from imposition of civil and administrative penalties and fines for a violation of environmental laws voluntarily disclosed …
(b) If a person or entity makes a voluntary disclosure of a violation …

8-58.63 Preemption of local laws:
No local law, rule, ordinance, or permit condition may circumvent or limit the privilege …

SL 2015-241 Section 4.4(a) Temporary erosion control structures to provide for all of the following:
(1) Allow the placement of temporary erosion control structures on property experiencing coastal erosion even (without) imminently threatened structures … if the property is adjacent to a property where temporary erosion control structures have been placed.
(2) Allow placement of contiguous temporary erosion control structures from one shoreline boundary of a property to the other shoreline boundary, regardless of proximity to imminently threatened structure.
(3) The termination date of all permits for contiguous temporary erosion control structures on the same property shall be the same and shall be the latest termination date for any pf the permits.
Section 14.6 (r) G.S. 113A-115.1(g) reads as rewritten:
(g) The Commission may issue no more than six permits for terminal groin(s) … provided that two may be issued … on the sides of New River Inlet in Onslow County and Bogue Inlet …

Limits environmental review under SEPA (State Environmental Policy Act)
(7a) "Significant expenditure of public moneys" means expenditures of public funds greater than ten million dollars ($10,000,000) for a single project or action or related group of projects or actions …
(11) "Use of public land" means land-disturbing activity of greater than 10 acres that results in substantial, permanent changes in the natural cover or topography of those lands that includes …
§ 113A-12 Environmental document not required in certain cases
Notwithstanding any other provision in this Article, no environmental document shall be required in connection with …

Amend Risk-Based Remediation Provisions Section 4.7(a) Part 8 of Article 9 §130A-310.65 Definitions:
(3a) "Contaminated off-site property" or "off-site property" means property under separate ownership from the contaminated site, contaminated as a result of a release or migration of contaminants at the contaminated site. Includes publicly owned property, rights-of-way for public streets, roads, sidewalks.
§ 130A-310.67 Applicability
(a) This Part applies to contaminated sites subject to remediation pursuant to any of the following:
(6) Oil Pollution and Hazardous Substances Control Act of 1978 … except with respect to those sites identified in subdivision (1a) of subsection (b)
(b) This Part shall not apply to contaminated sites subject to remediation pursuant to any of the following programs or requirements:
(1a) Leaking petroleum aboveground storage tanks and other sources of petroleum releases …
(4) The Coal Ash Management Act of 2014 under Part 2I of Article 9 of Chapter 130A of …
(5) Animal waste management systems permitted under Part 1 or Part 1A of …

§ 130A-310.73A Remediation of sites with off-site migration of contaminants
(a) Contaminated sites at which contamination has migrated to off-site properties may be remediated pursuant to this Part … if either of the following occur …
Section 4.7 (b) Article 21A of Chapter 143 Part 7 Risk-Based Remediation …
§ 143-215.104AA. Standards for petroleum releases from aboveground storage tanks and other sources
a. Risk-based corrective action gives the State flexibility in requiring different levels of cleanup based on scientific analysis of different site characteristics and allowing no action or no further action at sites that pose little risk to human health or the environment.
(2) The General Assembly intends the following:
a. To direct the Commission to adopt rules that will provide for risk-based assessment and cleanup of discharges and releases of petroleum from aboveground storage tanks and other sources ...

Prohibit the Requirement of Mitigation for Impacts to Intermittent Streams

Section 4.31(a) Article 21 § 143-214.7C
Except as required by federal law, the DEQ shall not require mitigation for impacts to an intermittent stream … "intermittent stream" means a well-defined channel (with) the following characteristics:
(1) It contains water for only part of the year, typically during winter and spring when the aquatic bed is below the water table.
(2) The flow of water in the intermittent stream may be heavily supplemented by stormwater runoff.
(3) It often lacks the biological and hydrological characteristics commonly associated with the conveyance of water.

Use of Oyster Shells Prohibited in Commercial Landscaping Section 14.7(a) Article 20 § 113-270
(a) No landscape contractor shall use oyster shells as a ground cover.
(b) Enforcement of the prohibition … shall be under the jurisdiction of the Marine Fisheries Commission.
(c) For purposes of this section, landscape contractor shall have the definition set forth in G.S. 89D-11."

Core Sound Oyster Leasing Section 14.8
The DMF shall create a proposal to open to shellfish cultivation leasing certain areas of Core Sound that are currently subject to a moratorium.

Amend Senator Jean Preston Marine Shellfish Sanctuary Legislation Section 14.9. Revises Section 44 of S.L. 2014-120:
Senator Jean Preston Marine Oyster Sanctuary Program Section 44(a) … to enhance shellfish habitats within the Albemarle and Pamlico Sounds and their tributaries to benefit fisheries, water quality, and the economy. … through the establishment of a network of oyster sanctuaries, harvestable enhancement sites, and coordinated support for the development of shellfish aquaculture. The network of oyster sanctuaries to be named … the "Senator Jean Preston Oyster Sanctuary Network.
Section 44(b) The DMF and DEQ shall develop a plan to construct and manage additional oyster habitats. … The plan shall include:
(1) The location and delineation of oyster sanctuaries and proposed enhancement sites … shall take into account connectivity to existing oyster sanctuaries … shall be designed to provide hook-and-line fishing while allowing the development of complex fish habitats and brood-stock ... outline a 10-year development project ...
(3) Enhancement of oyster habitat restoration: The General Assembly finds the lack of a reliable State-based supply of oyster seed and inadequate funding for cultch planting are limitations to the expansion of oyster harvesting and the restoration of wild oyster habitat in NC. The plan should include:
a. Provisions and recommendations to facilitate the availability of oyster seed produced in North Carolina for wild oyster habitat restoration projects as well as oyster aquaculture and to reduce potential negative impacts from importation of non-native oyster seed …
(6) Monitoring – include a monitoring plan to (i) determine the success of oyster reef construction and (ii) evaluate the cost benefit…
(7) Funding – include a request for appropriations … to expand oyster … activities for 10 years.
(8)Recommendations – needed to expedite the expansion of shellfish restoration and harvesting…

Simplify oyster restoration project permitting. Section 14.10 A (a):
DMF and DCM, shall, in consultation with representatives of nongovernmental conservation organizations …create a new permitting process

Water Column Leasing Clarification Section 14.10C (b) GS 113-202 amended by adding new subsection:
(r) A lease under this section shall include the right to place devices or equipment related to the cultivation or harvesting of marine resources on or within 18 inches of the leased bottom ...

Section 14.10C(c) GS 113-202.1 reads are rewritten: Water column leases for aquaculture …
(c) The Secretary shall not amend shellfish cultivation leases to authorize uses of the water column involving devices or equipment not resting on the bottom or that extend more than 18 inches above the bottom unless: …

Ambient Air Monitoring
Section 4.25.(a) The DEQ shall review its ambient air monitoring network and, in the next annual … plan submitted to the US EPA, shall request the removal of any ambient air monitors that are not required by applicable federal laws and regulations and that the Department has determined are not necessary to protect public health, safety, and welfare; the environment; and natural resources …

§ 143B-135.234. Clean Water Management Trust Fund
(c) Fund Purposes – … Revenue in the Fund may be used for any of the following purposes: …

Prohibit Cities and Counties from Requiring Compliance with Voluntary Regulations and Rules Adopted by State Departments or Agencies:
Section 2(a) Article 6 Chapter 153A and Section 2(b) Article 8 Chapter 160A of the General Statutes are amended by adding a new section to read as follows:
(a) If a State department or agency declares a regulation or rule to be voluntary … a county shall not (§ 160A-205.1- "city shall not") require or enforce compliance with the applicable regulation or rule …
(b) This section shall apply to the following regulations and rules: …
(c) This section shall not apply to any water usage restrictions during either extreme or exceptional drought conditions as determined by the Drought Management Advisory Council …

Deep Draft Navigation Channel Dredging and Maintenance Section 14.6(c) Article 21 § 143-215.73G Cape Fear Estuarine Resource Restoration Section 14.6(h)
The General Assembly finds that the New Inlet Dam or "The Rocks" was constructed by the USACE … of two components, a Northern Component that extends from Federal Point to Zeke's Island and a Southern Component that extends southwestward from Zeke's Island and separates the New Inlet from the main channel of the Cape Fear River. … Further finds that the Southern Component … impedes the natural flow of water between the Cape Fear River and the Atlantic Ocean that occurred prior to emplacement of the dam. … Further finds that it is necessary to consider removal of the Southern Component of the New Inlet Dam in order to reestablish the natural hydrodynamic flow between the Cape Fear River and the Atlantic Ocean. To this end, the DEQ shall do all of the following: …

§ 143-214.18 Exemption to riparian buffer requirements for certain private properties
(a) Definition. – For purposes of this section, "applicable buffer rule" refers to any of the following rules:
(1) Neuse River Basin – 15A NCAC 02B .0233, effective August 1, 2000.
(2) Tar-Pamlico River Basin – 15A NCAC 02B .0259, effective August 1, 2000.
(3) Randleman Lake Water Supply Watershed – 15A NCAC 02B .0250, effective June 1, 2010.
(4) Catawba River Basin – 15A NCAC 02B .0243, effective August 1, 2004.
(5) Jordan Water Supply Nutrient Strategy – 15A NCAC 02B .0268, effective September 1, 2011.
(6) Goose Creek Watershed of the Yadkin Pee-Dee River Basin – 15A NCAC 02B .0605 and 02B .0607.
(b) Exemption – Absent a requirement of federal law or an imminent threat to public health or safety, an applicable buffer rule shall not apply to any tract of land that meets all of the following criteria: …

§ 143-214.19 Delineation of riparian buffers for coastal wetlands: Neuse and Tar-Pamlico River Basins
(b) If State law requires a protective riparian buffer for coastal wetlands in the Neuse River Basin or the Tar-Pamlico River Basin, the coastal wetlands shall not be treated as surface waters but shall be included in the measurement of the riparian buffer. The riparian buffer … shall be delineated as follows:
(1) If the coastal wetlands or marshlands extend less than 50 feet from the high normal water or normal

water level, as appropriate, and therefore would not encompass a 50-foot area beyond the appropriate water level, then the protective riparian buffer shall include all of the coastal wetlands …
(2) If the coastal wetlands or marshlands extend 50 feet or more from the normal high water or normal water level, as appropriate, then the protective riparian buffer shall be the full width of the marshlands or coastal wetlands up to the landward limit of the marshlands or coastal wetlands but shall not extend beyond the landward limit of the marshlands or coastal wetlands.

§ 143-214.27 Riparian Buffer Conditions in Environmental Permits
(a) Except as set forth in subsection (b) of this section, the Department may not impose as a condition of any permit … riparian buffer requirements that exceed established standards for the river basin within which the activity or facility receiving the permit is located …

APPENDIX D. SCIENTIFIC AND COMMON NAMES OF FISH

Common name	Scientific name
Alewife	*Alosa pseudoharengus*
American eel	*Anguilla rostrata*
American shad	*Alosa sapidissima*
Atlantic croaker	*Micropogonias undulatus*
Atlantic menhaden	*Brevoortia tyrannus*
Atlantic spadefish	*Chaetodipterus faber*
Atlantic stingray	*Dasyatis sabina*
Atlantic sturgeon	*Acipenser oxyrhynchus*
Banded killifish	*Fundulus diaphanus*
Bay anchovy	*Anchoa mitchilli*
Bay scallop	*Argopecten irradians*
Bay whiff	*Citharichthys spilopterus*
Black drum	*Pogonias cromis*
Black sea bass	*Centropristis striata*
Blackcheek tonguefish	*Symphurus plagiusa*
Blennies	*Blenniidae family*
Blue crab	*Callinectes sapidus*
Blueback herring	*Alosa aestivalis*
Bluefish	*Pomatomus saltatrix*
Brown shrimp	*Penaeus aztecus*
Channel catfish	*Ictalurus punctatus*
Cobia	*Rachycentron canadum*
Cownose ray	*Rhinoptera bonasus*
Florida pompano	*Trachinotus carolinus*
Gag	*Mycteroperca microlepis*
Grass shrimp	*Palaemonetes* spp.
Greater amberjack	*Seriola dumerili*
Gulf flounder	*Paralichthys albigutta*
Hard clam	*Mercenaria* spp.
Hermit crab	*Pagurus bernhardus*
Hickory shad	*Alosa mediocris*
Horseshoe crab	*Limulus polyphemus*
Inland silverside	*Menidia beryllina*
Inshore lizardfish	*Synodus foetens*
King mackerel	*Scomberomorus cavalla*
Kingfish	*Menticirrhus* spp.
Mantis shrimp	*Squilla empusa*
Moon snail	*Polinices duplicatus*

Common name	Scientific name
Mummichog	*Fundulus heteroclitus*
Naked goby	*Gobiosoma bosc*
Oyster	*Crassostrea virginica*
Oyster toadfish	*Opsanus tau*
Pigfish	*Orthospristis chrysotera*
Pinfish	*Lagodon rhomboides*
Pink shrimp	*Penaeus duorarum*
Planehead filefish	*Stephanolepis hispidus*
Red drum	*Sciaenops ocellatus*
Rough silverside	*Membras martinica*
Round scad	*Decapterus macarellus*
Scup	*Stenotomus chrysops*
Sheepshead	*Archosargus probatocephalus*
Sheepshead minnow	*Cyprinodon variegatus*
Stone crab	*Menippe mercenaria*
Shortnose sturgeon	*Acipenser brevirostrum*
Silver perch	*Bairdiella chrysoura*
Skilletfish	*Gobiesox strumosus*
Smooth dogfish	*Mustelus canis*
Southern flounder	*Paralichthys lethostigma*
Southern kingfish	*Menticirrhus americanus*
Spanish mackerel	*Scomberomorus maculatus*
Spiny dogfish	*Squalus acanthias*
Spot	*Leiostomus xanthurus*
Spottail pinfish	*Diplodus holbrooki*
Spotted seatrout	*Cynoscion nebulosus*
Striped anchovy	*Anchoa hepsetus*
Striped bass	*Morone saxatilis*
Striped mullet	*Mugil cephalus*
Summer flounder	*Paralichthys dentatus*
Tautog	*Tautoga onitis*
Tomtate	*Haemulon aurolineatum*
Weakfish	*Cynoscion regalis*
Whelks	*Busycon* spp.
White grunt	*Haemulon plumieri*
White perch	*Morone americana*
White shrimp	*Penaeus setiferus*
Yellow Perch	*Perca flavescens*

APPENDIX E. MARINE FISHERIES COMMISSION HABITAT POLICIES

POLICY STATEMENT FOR THE 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 eel grass, widgeon grass and shoal grass, 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.

POLICIES FOR THE PROTECTION AND RESTORATION OF MARINE AND ESTUARINE RESOURCES FROM BEACH DREDGING AND FILLING AND LARGE-SCALE COASTAL ENGINEERING

North Carolina Marine Fisheries Commission
(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.

POLICIES FOR THE PROTECTION AND RESTORATION OF MARINE AND ESTUARINE RESOURCES AND ENVIRONMENTAL PERMIT REVIEW AND COMMENTING

North Carolina Marine Fisheries Commission
(adopted April 13, 1999; modified to incorporate MFC approved Compensatory Mitigation component September 4, 2009; MFC adopted final version 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 the CHPP, 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 the CHPP 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.

<u>Proposed Resource Protection and Environmental Permit Review and Commenting Policies</u>
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. 1 -289.B2(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.