# CHAPTER 2. WATER COLUMN

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

The water column is the medium through which all other aquatic habitats are connected

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

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

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

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

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

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

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

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

## 2.1. DESCRIPTION AND DISTRIBUTION

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

### *Freshwater systems*

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

#### Rivers and creeks

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

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

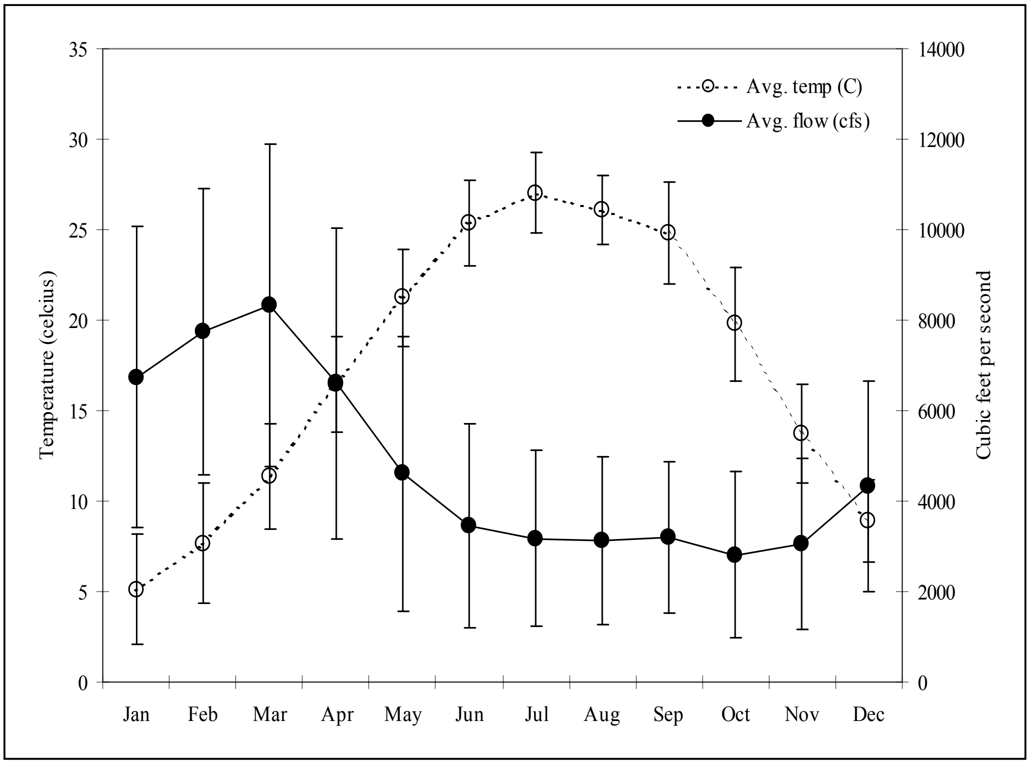

Figure 2.1. Average and standard deviation of monthly discharge (time period: 1969-1999, n = 1,464) and water temperature (time period: 1953-2001, data points per month = 52-123). [Source: USGS hydrologic monitoring stations on the lower Roanoke, Tar, Neuse, and Cape Fear rivers, North Carolina. (Station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

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

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

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

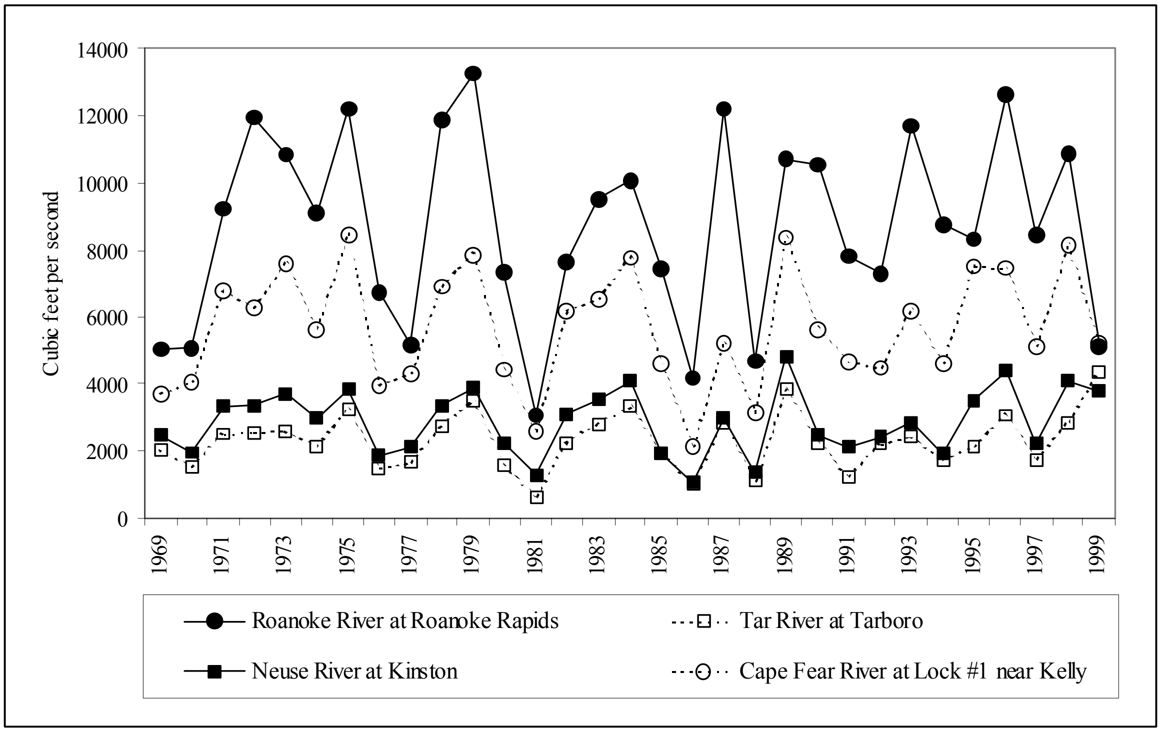

Figure 2.2. Average annual discharge in the Roanoke, Tar, Neuse, and Cape Fear rivers during 1969-2001 based on data from the USGS hydrologic monitoring stations. (Station locations are marked on Map 2.6)

Lakes and impoundments

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

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

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

### *Estuarine systems*

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

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

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

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

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

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

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

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

### Large back barrier sounds and trunk estuaries

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

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

### Small back barrier sounds and trunk estuaries

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

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

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

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

Cape Fear River estuary

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

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

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

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

* Includes Core Sound

### *Marine systems*

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

The effects of tides and bottom friction are most evident near inlets and along the shoreline. Tidal amplitude along North Carolina's ocean shoreline is greatest in the southern coastal area where the continental shelf is widest. The average tidal height in North Carolina is approximately 2 ft (0.6 m) near Cape Hatteras and 4.3 ft (1.3 m) near Cape Fear. A considerable amount of mixing is provided by the turbulence of twice-daily tides.

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

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

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

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

### *Habitat requirements for aquatic life*

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

Salinity

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

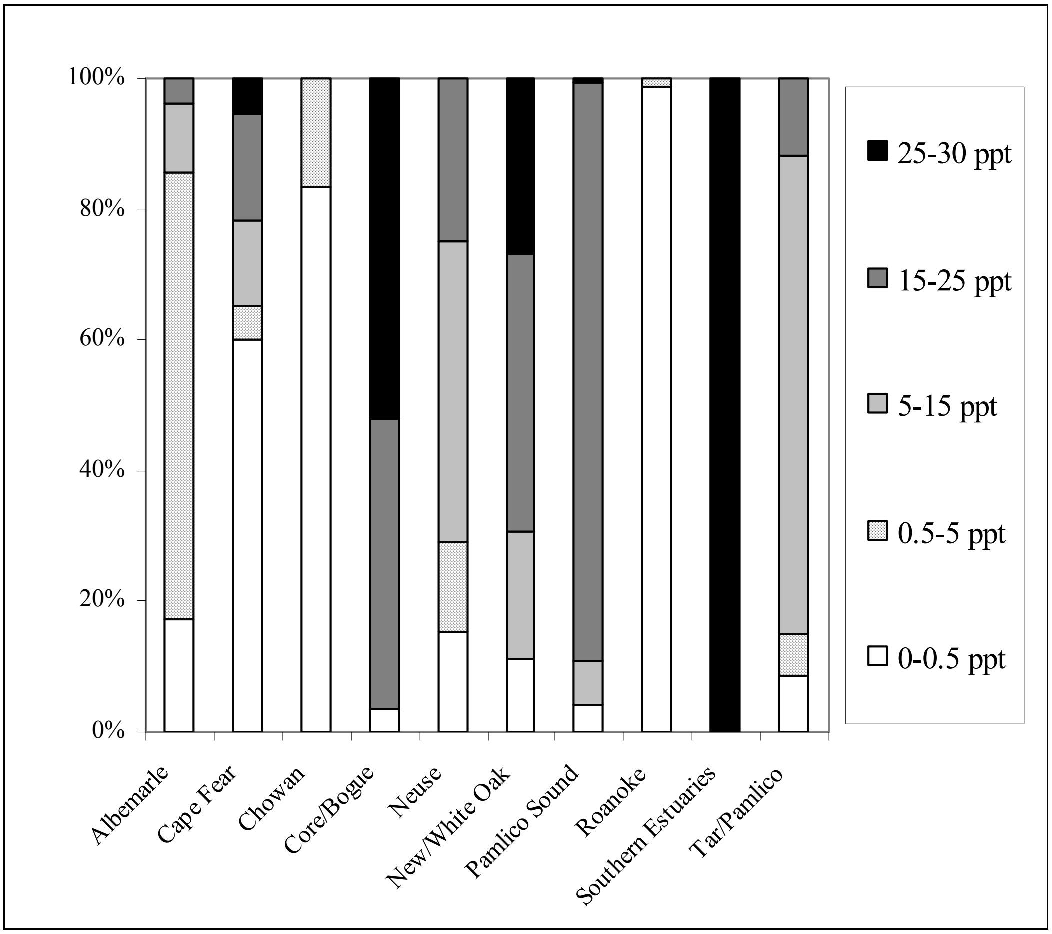

Figure 2.3. The relative proportion of average salinity zones within CHPP management units (excluding the coastal ocean). [Source: NOAA's 1:100,000 scale salinity mapping (Coastal Ocean Resource Assessment Program). The area for 0-0.5 ppt includes only mainstem rivers and lakes in the management unit.]

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

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

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

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

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

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

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

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

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

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

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

* Scientific names for species are listed in Appendix I.

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

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

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

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

[5] Former fishery, but fishing moratorium since 1991

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

### Temperature

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

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

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

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

Temperature varies least in the marine system (Peterson and Peterson 1979; Nybakken 1993) and marine species tend to be less tolerant of temperature extremes and rapid changes in temperature. Water temperature is one of the most important factors in determining use of coastal ocean habitat by warm temperate and tropical species (SAFMC 1998a). Tropical species occur off the North Carolina coast where offshore bottom water temperatures range from approximately 52-81ºF (11–27ºC) (SAFMC 1998a). Temperatures less than 54ºF (12ºC) may result in the death of some tropical fish and invertebrates (Wenner et al. 1984; SAFMC 1998a). Estuarine-dependent species in the nearshore ocean, such as black sea bass and southern flounder, have a broader temperature tolerance (Reagan and Wingo 1985; Steimle et al. 1999). Research in North Carolina marine waters has found that fish species composition at hard bottom shifted over a 15 year period, with an increase in tropical species and decrease in temperate species (Parker and Dixon 1998). The change in species composition was associated with global warming trends.

### Dissolved oxygen

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

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

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

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

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

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

Light and water clarity

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

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

### Flow and water movement

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

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

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

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

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

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

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

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

pH

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

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

## 2.2. ECOLOGICAL ROLE AND FUNCTIONS

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

### *Productivity*

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

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

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

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

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

### *Fish utilization*

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

#### Corridor and connectivity

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

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

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

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

North Carolina through Georgia (Tagatz and Dudley 1961).

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

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

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

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

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

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

Research projects conducted under the South Atlantic Bight Recruitment Experiment (SABRE) studied transport of winter-spawned fish larvae into the estuaries. Larvae concentrate on the shelf in a narrow "withdrawal zone" upwind of an inlet within the 23-foot (7m) deep isobath. Upon the appropriate conditions of ocean currents, the larvae pass through the inlets. Even during best wind and tidal conditions, only about 10% of the available larvae are successfully drawn into the inlet (Blanton et al. 1999). Larvae passing downwind and outside the narrow withdrawal zone pass seaward of the inlet shoals and, given the right conditions, will be transported into the next available inlet downstream. Churchill et al. (1999) noted that transport dynamics in the immediate vicinity of inlets are complex, and that larvae may also remain near an inlet or move in and out repeatedly before actually immigrating. However, since the along-shore flow component of the coast is four to five times greater than the cross-shelf component, larvae are highly dependent on being transported along the shore in a narrow zone and then injected through the inlet (Hare et al. 1999). Offshore-spawning, estuarine-dependent species include many of North Carolina's most important commercial and recreational fish species, such as menhaden, spot, Atlantic croaker, pinfish, flounders, shrimp, black sea bass, and gag. Red drum and blue crabs, which spawn in and near the inlets, also require transport of larvae through inlet systems. Consequently, successful movement of larvae through the inlets is of great importance to North Carolina fisheries, particularly where inlets are limited, such as along the Outer Banks.

### Spawning

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

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

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

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

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

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

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

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

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

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

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

[S] = suitable, [O] = optimum

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

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

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

[S] = suitable, [O] = optimum

Nursery

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

### *Anadromous fish nurseries*

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

Juvenile alewife and blueback herring emigrate from freshwater/estuarine nursery areas by November of their first year of life (Burbidge 1974; Kissil 1974; Richkus 1975; O'Neill 1980). Heavy rainfall, high water flow, and sharp declines in water temperature have been found to influence the initiation of migration from nursery areas (Cooper 1961; Kissil 1974; Richkus 1975). The water quality requirements for anadromous fish larvae and juveniles inhabiting pelagic waters are listed in Table 2.10.

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

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

[S] = suitable, [O] = optimum

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

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

### *Low-high salinity nurseries*

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

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

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

| **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<br>[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<br>[O] 2-36 | | [S] 16 to >30 | | |
| Hard clam | **[S] 20-33 [O] 27-28** | [S] 12-33<br>[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<br>[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<br>[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<br>[O] 10-20 | **[S] 21 to >30** | [S] 0 to >30 | | |
| Southern flounder | **[S] 10-30** | [S] 2-60<br>[O] 2-37 | **[S] 0-30** | [S] 0 to >30 | | [S] >3.7 |
| Spot | **[S] 6-35 [O] 30-35** | [S] 0-36.2<br>[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<br>[O] <10 | **[S] 11-30** | [S] 5 to >30 | | |

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

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

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

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

### *High-salinity nurseries*

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

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

| **Species** | **Salinity (ppt)** | | **Temperature (C)** | | **Dissolved oxygen (mg/l)** | |
|---|---|---|---|---|---|---|
| | Larvae | Juvenile | Larvae | Juveniles | Larvae | Juvenile |
| Black sea bass | **[S] 30-35** | [S] 8-38<br>[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,<br>[O] >20 | | [S] 11 to >30 | | |
| Gulf flounder | **[S] >21** | [S] 6-35<br>[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<br>[O] >20 | **[S] 21-30** | [S] 0 to >30 | | |
| Sheepshead | **[S] 5-24.9** | [S] 0.3-43.8 | **[S] 21-30** | [S] 21-30 | | |
| Spanish mackerel | **[S] 28-37.4** | **[S] 0.2-37 [O] >10** | **[S] 16-30** | **[S] 11 to >30** | | |
| Summer flounder | **[S] 1/2 to >30** | [S] 0 to >30 | **[S] 0 to >30** | [S] 0 to >30 | | |
| Southern kingfish | **[S] 5 to >30** | [S] 1/2 to >30 | **[S] 11 to >30** | [S] 11 to >30 | | |

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

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

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

### Foraging

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

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

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

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

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

Refuge

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

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

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

## 2.3. STATUS AND TRENDS

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

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

### *Physical and chemical environment*

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

#### Statewide and regional water quality monitoring

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

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

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

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

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

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

### *Freshwater and estuarine water quality*

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

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

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

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

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

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

[1] = See Appendix H for acronyms

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

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

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

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

Based on use-support ratings, the water quality of estuaries in North Carolina was considered in overall good condition in 1999 (DWQ 2000a). According to the DWQ 305(b) Report (DWQ 2000a), 96% of North Carolina estuaries were rated as fully supporting, with only 4% rated as partially supporting (Table 2.15). However, several changes in the use support assessment methodology will result in a substantial number of SA waters being downgraded to impaired for shellfish harvesting use support. The only ratings now used are fully supporting or impaired. Conditionally approved waters that in the past were rated as "fully supporting but threatened" or "partially supporting" are now rated as impaired. As an example, from 1995-1999, 10% of the rated waters in the White Oak River basin were classified as partially supporting and 0% were classified as not supporting for overall use support; whereas in 2001, 24% were rated as impaired for shellfish harvest use support. The increase is primarily attributed to the change in methodology, rather than to additional shellfish closures.

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

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

### *Ocean water quality*

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

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

### *Fisheries associated with pelagic habitat*

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

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

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

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

#### DMF Fishery-independent surveys

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

Figure 2.4 shows a sharp and consistent decline in blueback herring and a concurrent decline in the commercial catch of river herring beginning around 1986. River herring stocks in the Albemarle Sound Management Area are now considered Overfished and represent a collapsed fishery. The DMF River Herring FMP addressed habitat and water quality issues associated with these species (alewife and blueback herring). Striped bass (Figure 2.5), in contrast to the river herring, indicate a stock that was Overfished during the early 1970s, but is now rapidly recovering as a result of improved management. As a result, both the juvenile abundance index and the commercial catch are increasing. It is important to note that quotas and other fishery management restrictions are limiting the annual commercial landings for both fisheries.

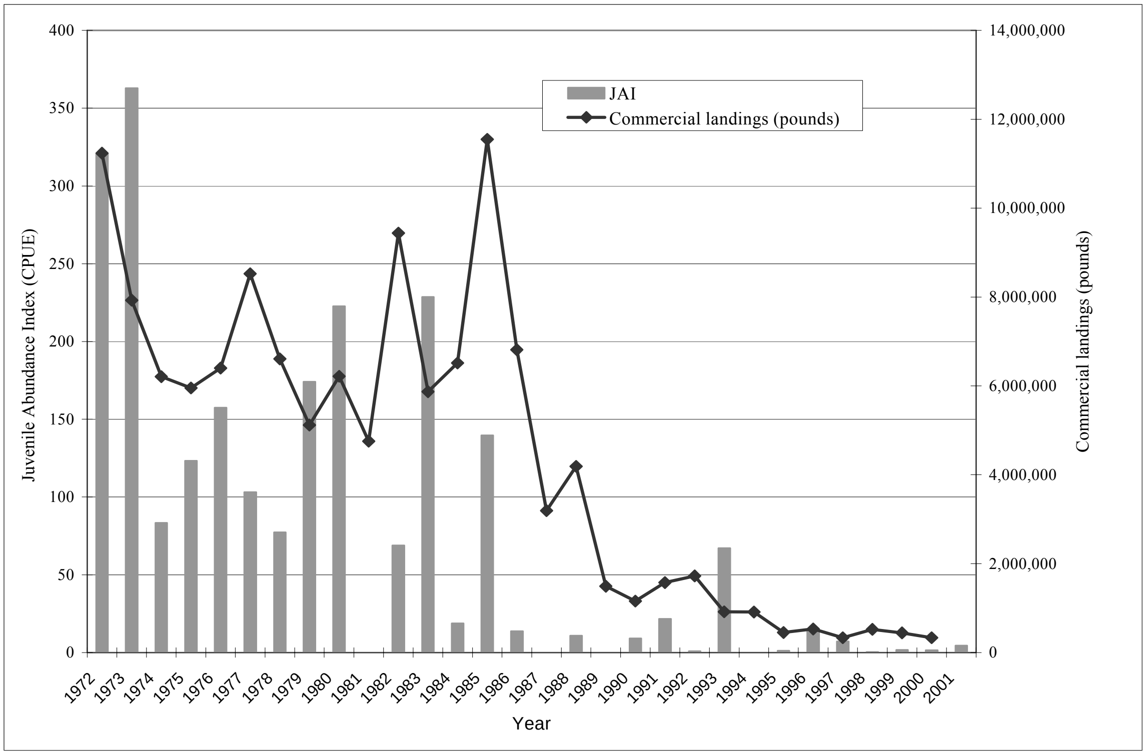

Figure 2.4. Annual North Carolina Division of Marine Fisheries juvenile abundance indices (seine survey) for blueback herring in the Albemarle Sound Management Area and total commercial landings of river herring (alewife and blueback herring), 1972-2001.

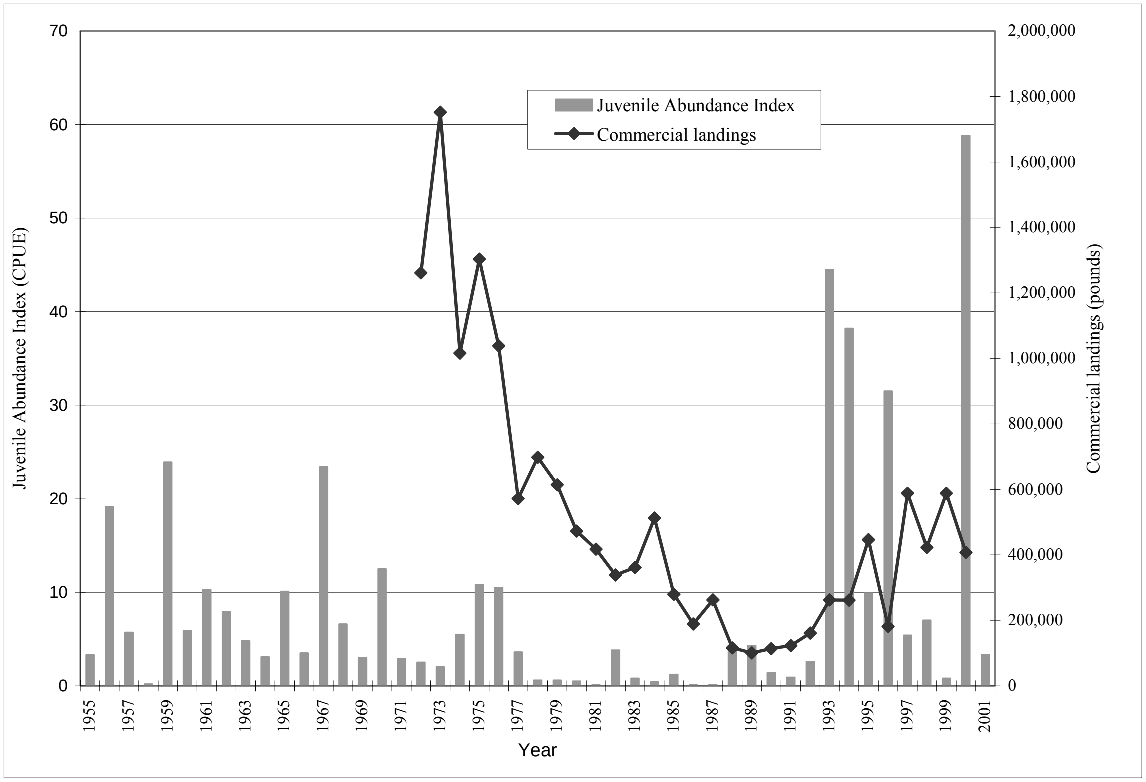

Figure 2.5. Annual DMF juvenile abundance indices of striped bass in the Albemarle Sound Management Area (1972-2001) and total commercial landings of striped bass (1972-2000).

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

## 2.4. THREATS AND MANAGEMENT NEEDS

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

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

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

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

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

### *Hydrological modifications*

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

#### Flow regulation

##### *Dams/impoundments*

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

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

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

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

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

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

In the Cape Fear River, locking procedures were modified and a fishway was installed in 1997 to improve passage of anadromous fish (Appendix K). The U.S. Army Corps of Engineers (COE) has proposed constructing an artificial bypass channel around the lowermost dam (Lock and Dam # 1). The bypass will allow about 10% of the river flow to travel around the dam in a meandering channel that approximates a natural stream (COE 2002). It is not recommended that the dam itself be removed because saltwater intrusion would likely result, impacting the City of Wilmington’s water supply. This stream restoration project should greatly benefit habitat conditions for Atlantic and shortnose sturgeon, American shad, striped bass, American eel, blueback herring, and hickory shad stocks (COE 2002). Following the construction of the bypass channel, it is hoped that Lock and Dam #2 and 3 can be removed. *Restoration efforts through removal or modification of dam structures that impede migration of anadromous fish should remain a high priority to continue in North Carolina, focusing on the lowermost structures in rivers or streams, and advancing upstream. In particular, the Cape Fear system (i.e., Lock and Dam #1) should be a high priority, since striped bass, shortnose sturgeon, and Atlantic sturgeon have not recovered.*[8]

### *Water withdrawals*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

### *Impingement and entrainment*

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

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

### *Status and trends in flow regulation*

Of the North Carolina coastal river basins, flows are regulated through a combination of dams, reservoirs, and water withdrawals within the Chowan, Roanoke, Tar-Pamlico, Neuse, and Cape Fear river systems. Flows in the Pasquotank, New, White Oak, and Northeast Cape Fear are generally unregulated. All of these rivers historically supported striped bass and other anadromous fish populations (DMF 2003b). Alteration of natural flow patterns by operation of reservoirs and dams can negatively impact fish species. Water releases in the Roanoke River adversely affect flow conditions needed for some anadromous fish species and lower dissolved oxygen levels (Fay et al. 1983b,d; USFWS, unpub. letter 2001). Among other factors, low oxygen levels have been implicated in the decline of the Albemarle/Roanoke River stock of striped bass as well as in fish kill events (USFWS 1992). Water flow regimes that minimize impacts to striped bass and other species were recommended in Manooch and Rulifson (1989). Status and trends in flow regulation (DMF 2003b) are detailed in Appendix K.

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

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

### Road fill and culverts

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

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

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

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

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

### Channelization and ditching

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

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

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

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

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

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

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

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

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

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

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

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

### Dredging (navigation channels and boat basins)

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

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

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

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

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

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

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

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

### Mining

In coastal North Carolina, there are surface, open pit mines for sand/gravel, crushed stone, and phosphate. Sand/gravel and crushed stone mines occur generally in upland areas, although some may be located in or adjacent to wetlands (M. Street, DMF, pers. com., 2004). Sand/gravel mines are the most common mine in coastal North Carolina (<http://www.geology.enr.state.nc.us/ Permitted%20Mines%201999-2000/permitte.htm>, June 2004). In CAMA counties during 2001, there were 249 permits for sand/gravel mining, seven permits for crushed stone mining, and two permits for phosphate mining. The two phosphate mining permits, totaling 15,952 acres, were for PCS Phosphate in Beaufort County. In the past, whole creeks were lost to PCS Phosphate's mining activities. The open pits created by coastal mines fill with groundwater that is often pumped into ditches and rivers (G. Cooper, DWR, pers. com., 2004). The discharge can contain sediment, nutrients, and heavy metals. However, the discharge of pollutants from mines is undoubtedly small compared to stormwater runoff from farms and urban/developing areas. Among coastal mining operations, PCS Phosphate is the largest discharger. Before 1992, PCS Phosphate was discharging 50-60 million gallons/day of phosphate-rich water into Pamlico Sound (Steel 1991). This nutrient-rich effluent was contributing to eutrophication of the Pamlico River. Today, PCS Phosphate uses a water recycling process that has greatly reduced discharge of nutrients.

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

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

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

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

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

### Jetties

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

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

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

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

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

### Shoreline stabilization

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

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

### *Water quality degradation*

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

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

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

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

#### Land cover and water quality

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

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

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

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

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

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

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

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

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

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

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

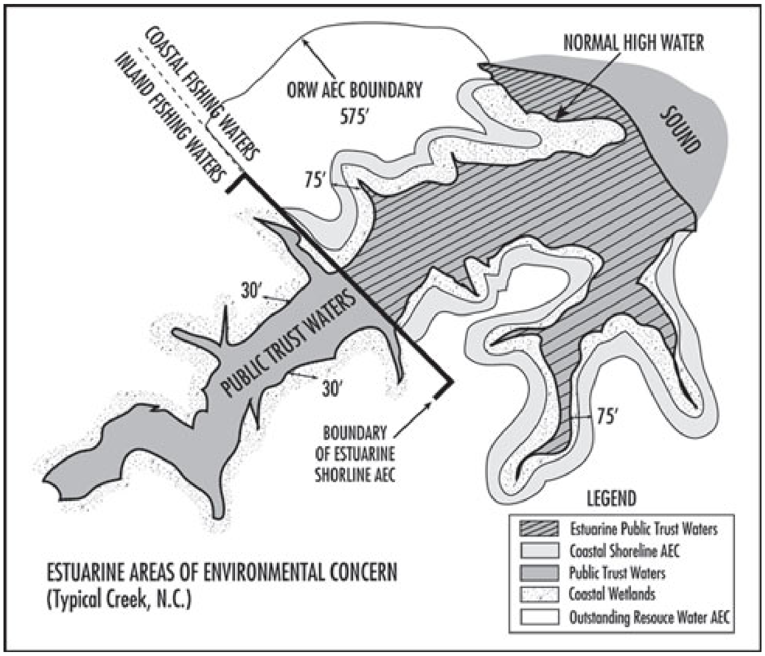

Figure 2.6. The location of Areas of Environmental Concern (AECs) along a typical creek in coastal North Carolina. (Source: <http://dcm2.enr.state.nc.us/Handbook/section2.htm>, 2003)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Nutrients

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

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

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

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

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

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

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

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

### *Sources of nutrient enrichment*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Mallin and Wheeler (2000) studied the effect of golf courses in New Hanover and Brunswick counties on water quality in adjacent water bodies. This study found that ammonium and orthophosphate appeared to be fairly tightly bound to the soils and remained on site during normal base flow conditions. However, nitrate levels in streams leaving golf courses were greater than streams entering the courses. Nitrate levels at some sites were high enough to cause significant increases in phytoplankton biomass and algal blooms in the spring and summer. Nitrate levels varied widely and appeared to be related to stormwater management practices. Waters adjacent to golf courses having vegetated buffer zones, wet detention ponds, and wooded wetland areas had considerably lower nutrient levels than sites without these landscape features and management tools (Mallin and Wheeler 2000). *BMPs, including vegetated buffers, detention ponds, and wetland areas, should be required on all new and existing golf courses draining to coastal waters to help reduce nutrient concentrations.*

### *Status and trends in nutrient enrichment*

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

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

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

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

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

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

[1] DO = Dissolved oxygen

* PS = partially supporting, NS = not supporting

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

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

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

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

The Neuse River MODMON research has found that riverine discharge, nutrient loading, and circulation (flushing and stratification) are strongly related and primarily determined by weather patterns. Irregular weather patterns and lack of long-term data complicate trend analysis. In addition, because of the shallow depth of the estuary, the bottom sediments store and release nutrients and carbon that can fuel algal blooms or low-oxygen events, independent of new sources, making it difficult to evaluate the effectiveness of nutrient reductions and management actions (Luettich et al. 1999). Some important findings of the research pertinent to fish habitat include:

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

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

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

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

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

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

Oxygen depletion and fish kills

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

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

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

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

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

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

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

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

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

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

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

### *Status and trends of fish kills and dissolved oxygen*

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

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

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

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

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

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

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

### Sediments

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

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

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

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

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

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

### *Sources of turbidity and sedimentation*

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

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

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

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

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

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

### *Status and trends in turbidity/sedimentation*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

### Fecal coliform bacteria

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

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

#### *Sources of bacterial contamination in estuarine waters*

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

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

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

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

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

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

A number of watershed studies have been conducted to identify specific sources of bacterial contamination in a watershed. The primary causes for bacterial contamination from studies in N.C. coastal waters are listed in Table 2.28. The cause of impairment varies and is often due to a combination of factors. When hydrological alterations (i.e., ditching and draining) occur, many wetland and stream functions are removed, increasing the delivery rate of nonpoint source runoff, and decreasing the time available for bacteria to be filtered out (DEM 1994; White et al. 2000). The forestry and agricultural BMPs that were in place during these studies did not prevent fecal coliform standards from being exceeded (DEM 1994; Mallin et al. 1997).

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

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

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

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

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

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

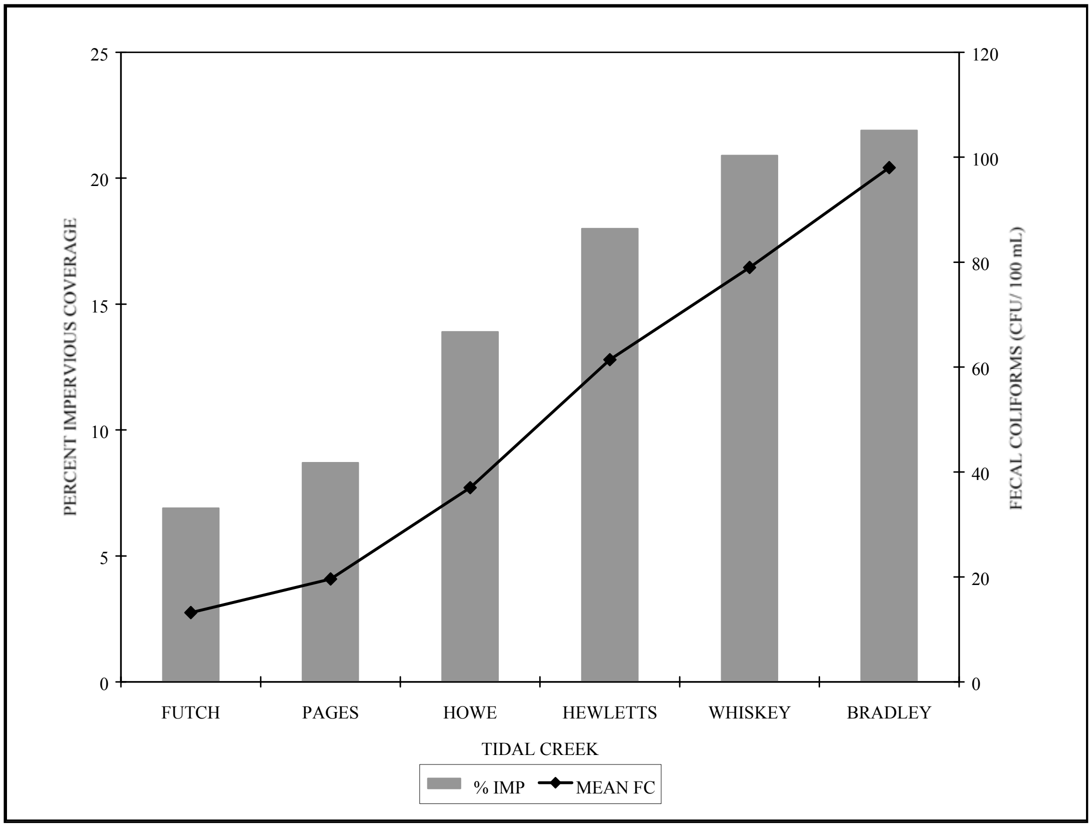

Figure 2.7. Percent watershed impervious surface coverage versus geometric mean fecal coliform bacteria counts for six New Hanover County tidal creeks. (Source: modified from Mallin et al. 2001b)

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

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

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

### *Status and trends in fecal contamination in estuarine waters*

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

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

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

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

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

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

Approximately 1,157 ac of ORW waters have been closed to shellfish since 1990. These closures have been in tributaries of Middle Sound, Stump Sound, and Topsail Sound in the Southern Estuaries MU; western Bogue, Core, and Back sounds in the Core-Bogue MU; and Swan Quarter and Juniper bays in the Pamlico Sound MU. As development activities continue, so will the number of shellfish area closures, unless changes are made to the manner in which land is developed and stormwater runoff is managed. *New or expanded stormwater outfalls to coastal shellfishing waters should be prohibited by the EMC and existing outfalls should be phased out.* Reclamation of closed areas will also become more difficult as population pressures increase. *Coordination and enhancement of rule enforcement and compliance review capabilities within DENR agencies is needed to fully enforce existing statutes and rules and minimize further water quality degradation.*

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

### *Fecal coliform contamination in ocean waters*

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

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

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

Stormwater runoff is currently the largest concern regarding bacterial contamination in ocean waters. The stormwater inputs are primarily a health concern due to bacterial contamination, but can also increase loading of nutrients and toxins into the surf zone. There are approximately 13 identified stormwater outfalls that discharge directly onto the beach near or lower than the mean high tide line; there are several others that discharge behind the primary dune (Maps 2.9a-c). Samples from the catch basins have found extremely high bacteria levels in the stormwater (J. Potts, DEH, pers. com., 2003). Hanby Beach, Carolina Beach, Emerald Isle, Atlantic Beach, and Kill Devil Hills have had precautionary advisories posted due to discharge of stormwater. Hanby Beach has a permanent point source precautionary advisory because the opening of the pipe is in the water, making it impossible to see when the pipe is discharging. All of these communities, with the exception of Emerald Isle, are served by municipal or privately operated wastewater treatment systems. Centralized sewage systems have had secondary impacts to water quality and habitat by indirectly permitting denser development than would be allowed if using individual septic systems. Dense development results in increased impervious surface area and stormwater runoff.

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

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

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

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

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

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

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

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

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

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

Toxic chemicals

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

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

### *Effects of toxic chemicals on fish*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

### *Sources of toxic chemical pollution*

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

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

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

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

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

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

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

### *Marinas and multi-slip docking facilities*

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

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

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

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

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

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

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

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

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[26] Refer to Nursery function section.

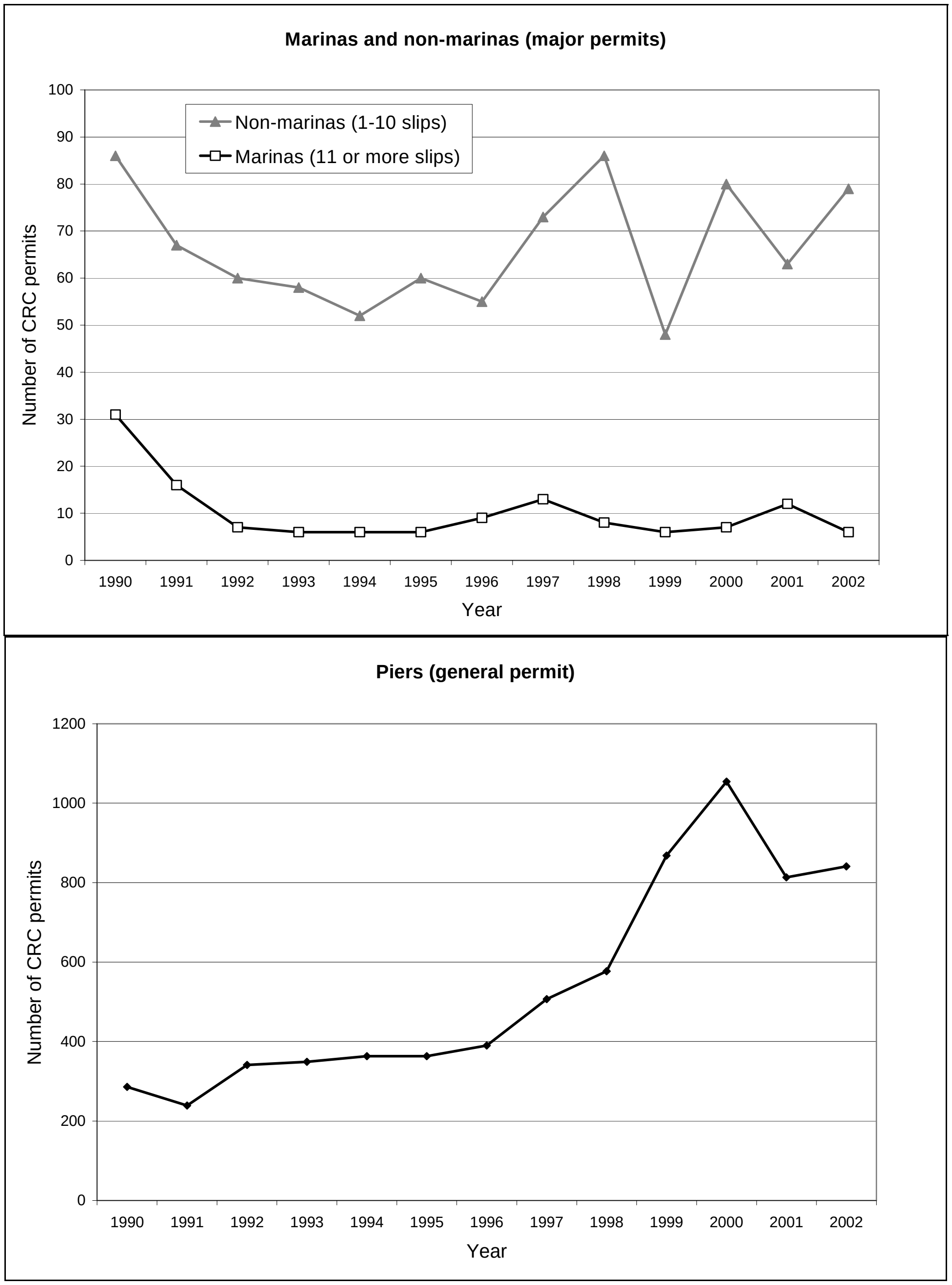

Figure 2.9. Annual number of CAMA permits issued by CRC for piers, non-marinas, and new or expanded marinas.

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

### *Pesticide spraying*

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

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

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

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

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

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

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

### *Status and trends in toxic chemical pollution*

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

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

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[27] Refer to Soft bottom chapter.

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

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

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

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

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

Other sources of water quality degradation

Desalination plants and marine debris are two other threats to the water column. Removal of brackish water for desalination and use as a municipal water supply is a more recent activity that has potential impacts to water quantity or quality (Copeland 1967). In rapidly developing coastal counties where wells are drawing deeper into saltier groundwater, desalination of surface waters provides another source of drinking water. There are several existing desalination facilities and some proposed facilities. The first desalination plants in North Carolina discharge wastewater into the Atlantic Ocean and sounds where the receiving area had equal or higher salinity than the effluent. Newer facilities are moving more inland to less saline waters. For example, the DWQ recently issued an NPDES permit for a proposed facility in Camden County that would discharge 430,000 gallons of salt water (~13 ppt) into the Pasquotank River, where salinities range from 2-5 ppt. As of 2001, there were at least three proposed desalination plants for North Carolina, in addition to 11 existing plants in the coastal area (L. Henry, DMF, pers. com., 2003). Two of these existing plants are located in freshwater areas (L. Henry, DMF, pers. com., 2003).

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

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

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

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

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

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

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

### *Non-native or nuisance species*

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

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

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

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

### *Existing management measures*

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

#### Stormwater Management Program

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

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

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

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

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

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

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

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

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

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

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

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

Neuse and Tar-Pamlico Nutrient Reduction Strategies

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

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

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

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

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

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

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

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

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

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

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

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

### Coast-wide Buffer Rule

The CRC adopted a 30 ft buffer as part of the Coastal Shoreline AEC in August 2000 for all new development in the 20 coastal counties governed by CAMA. This buffer begins at the water's edge, and allows clearing of vegetation as long as no soil disturbance occurs. Although this buffer will certainly have positive environmental benefits throughout the coast, the science suggests that it will be inadequate in significantly reducing pollutant loading from nonpoint runoff (Lee et al. 1989; Zirschky et al. 1989; Groffman et al. 1991; Desbonnet et al. 1994; Gilliam et al. 1994; Lowrance 1997).

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

Local initiatives

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

Needed management measures

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

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

## 2.5. SUMMARY OF WATER COLUMN CHAPTER

The water column habitat surrounds and supports all aquatic organisms and connects all coastal fish habitats. Consequently, clean and healthy waters are critical to the overall viability of coastal fish habitats and aquatic organisms. The general distribution of fish within the water column is determined by the physical and chemical properties of each unique water body (e.g., salinity, temperature), while the abundance, diversity, and health of coastal fish and invertebrates are strongly influenced by water quality conditions (e.g., oxygen, turbidity, nutrients). The water column provides the necessary medium for spawning and transport of eggs and larvae to habitats favorable for survival and growth. In addition, coastal waters are an important source of primary production, providing food for the survival of early life stages of aquatic organisms. Another critical function of the water column is to support other important food sources for pelagic species, such as river herring, bluefish, and Spanish mackerel, and to serve as a critical corridor for migration. Particularly important areas of the water column include inlets, shallow estuarine nursery areas, anadromous fish spawning and nursery areas, and the nearshore surf zone.

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

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

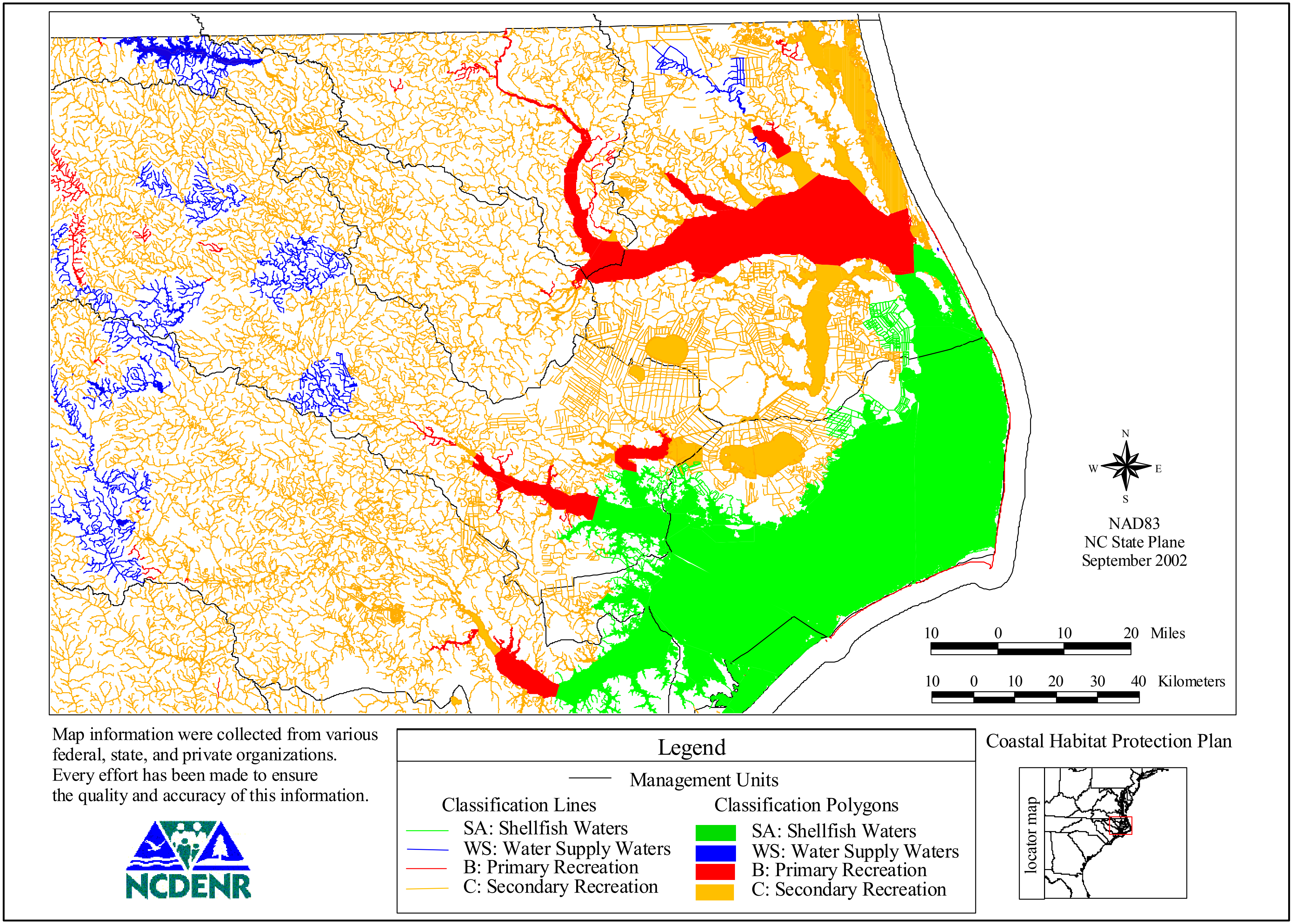
Water quality degradation affects aquatic organisms in many ways. Excessive sediment loading increases turbidity and sedimentation, which can result in a decrease in biological productivity, clogging of fish gills, reduced recruitment of invertebrates, increased mortality, and filling in of rivers and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

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

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

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

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



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

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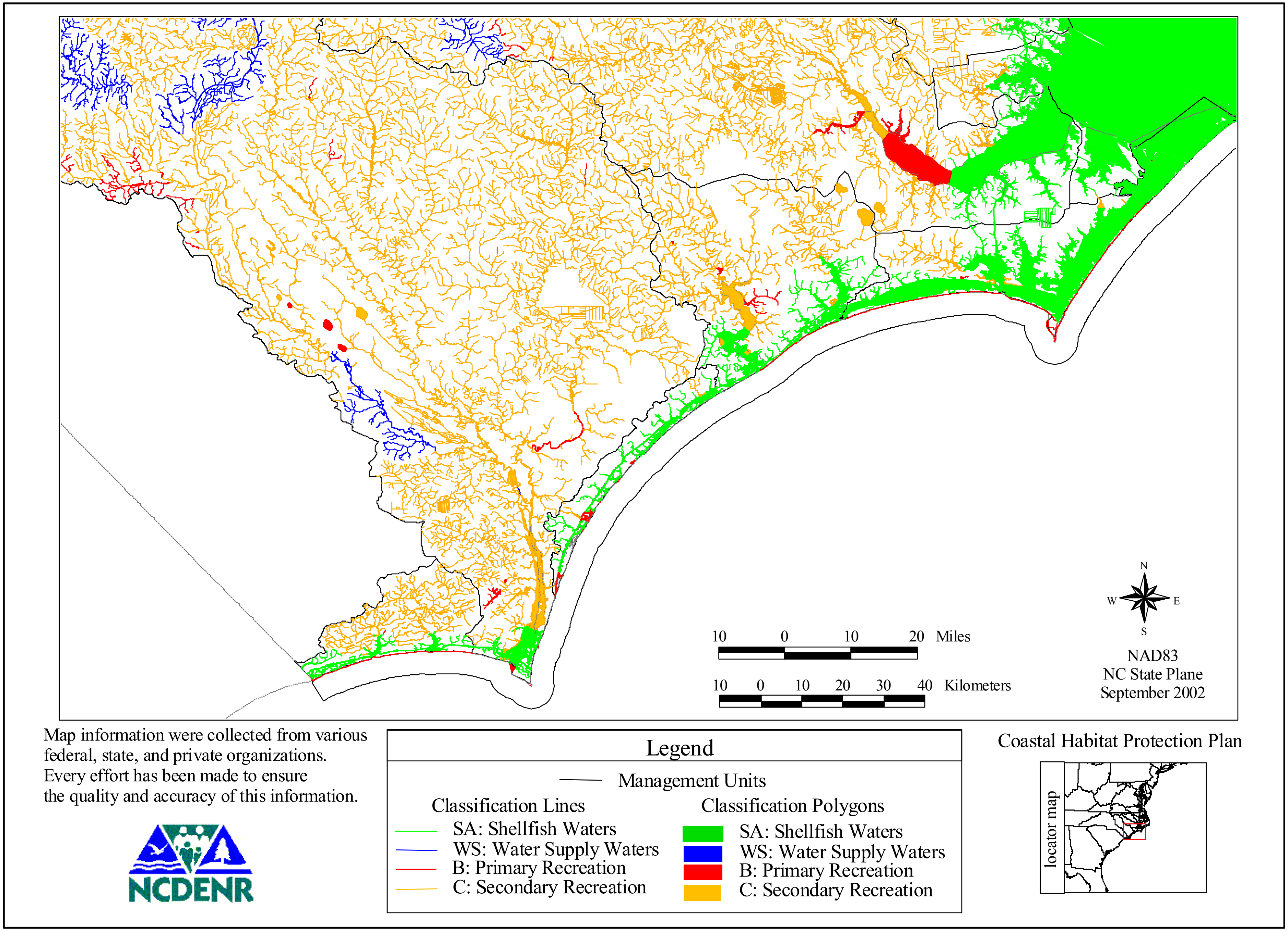

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Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

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

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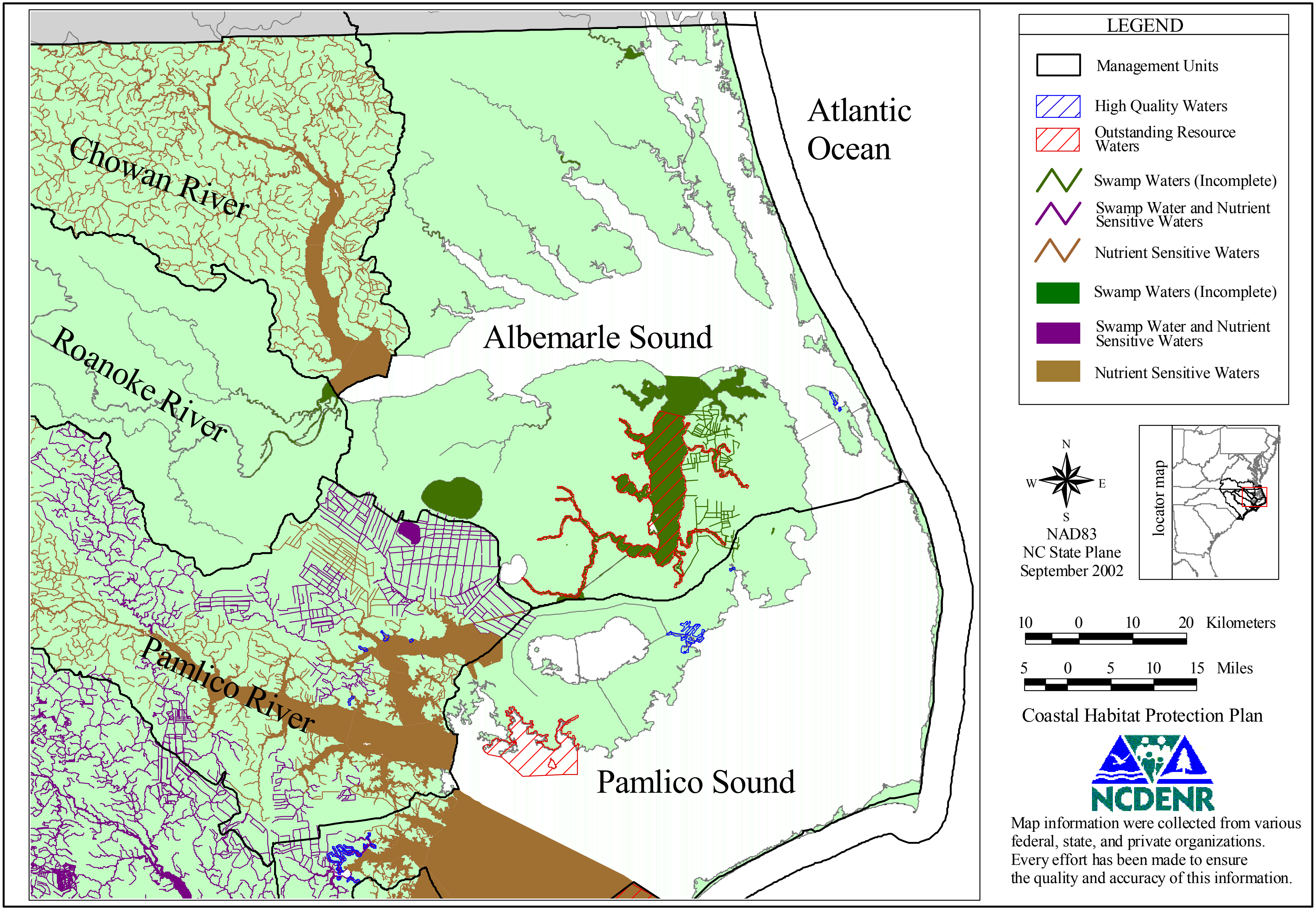

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Map 2.2a. Supplemental surface water classifications of the NC Environmental Management Commission in eastern North Carolina (1997 classification)

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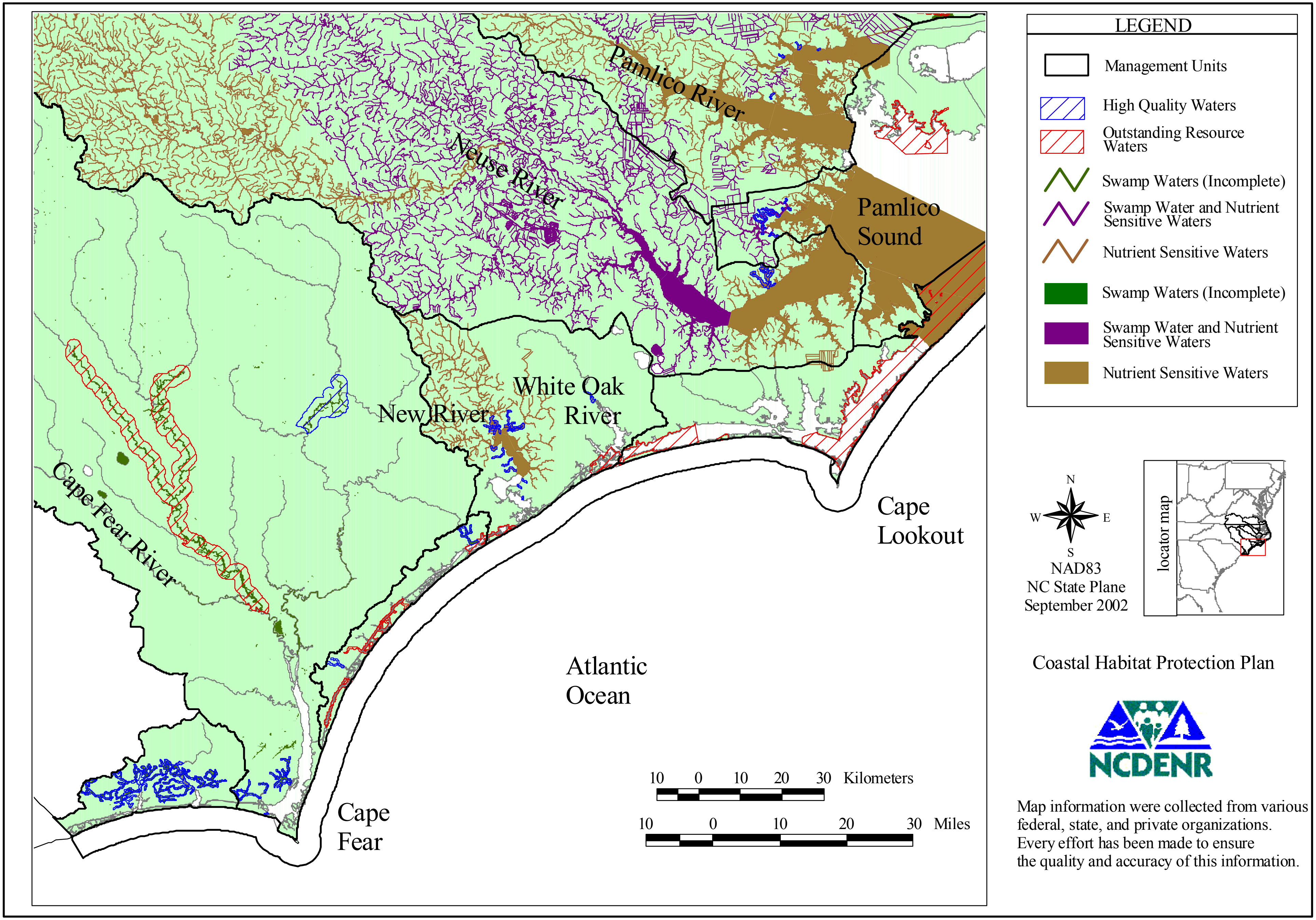

Map 2.2b. Supplemental surface water classifications of the NC Environmental Management Commission in eastern North Carolina (1997)

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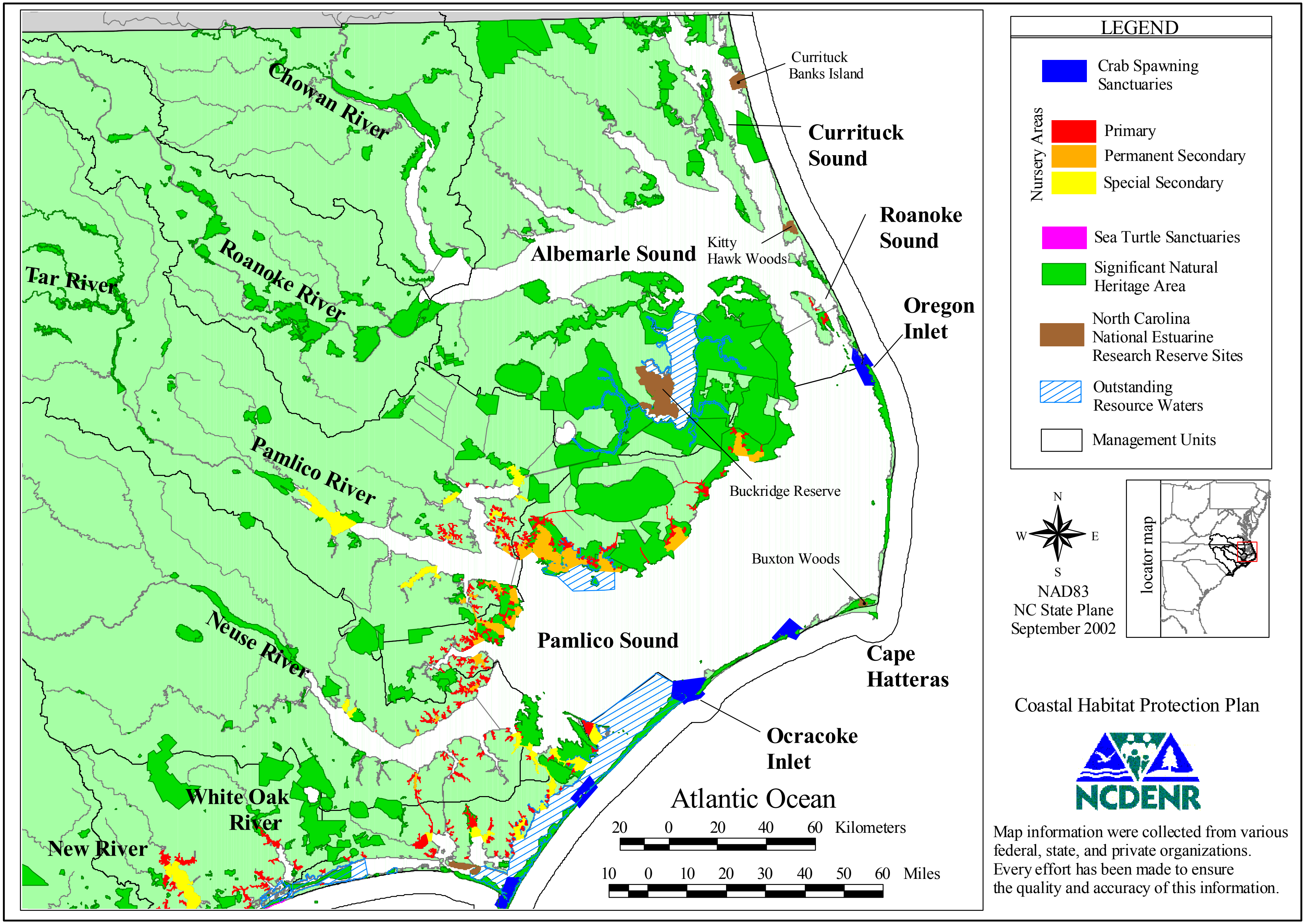

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

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

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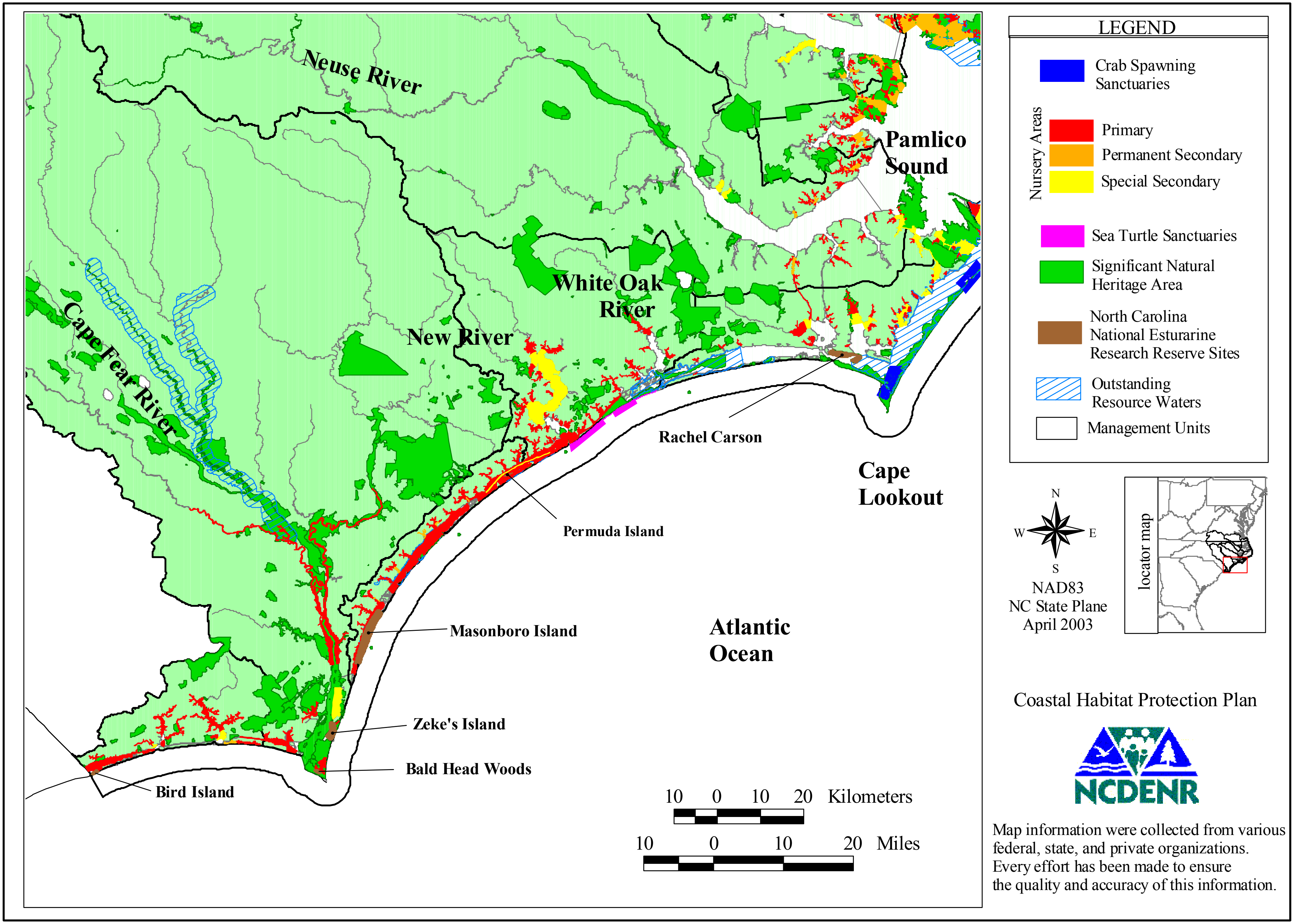

Map 2.3b. Designated protected habitat areas in eastern North Carolina south of Cape Lookout (map themes from BasinPro3 software).

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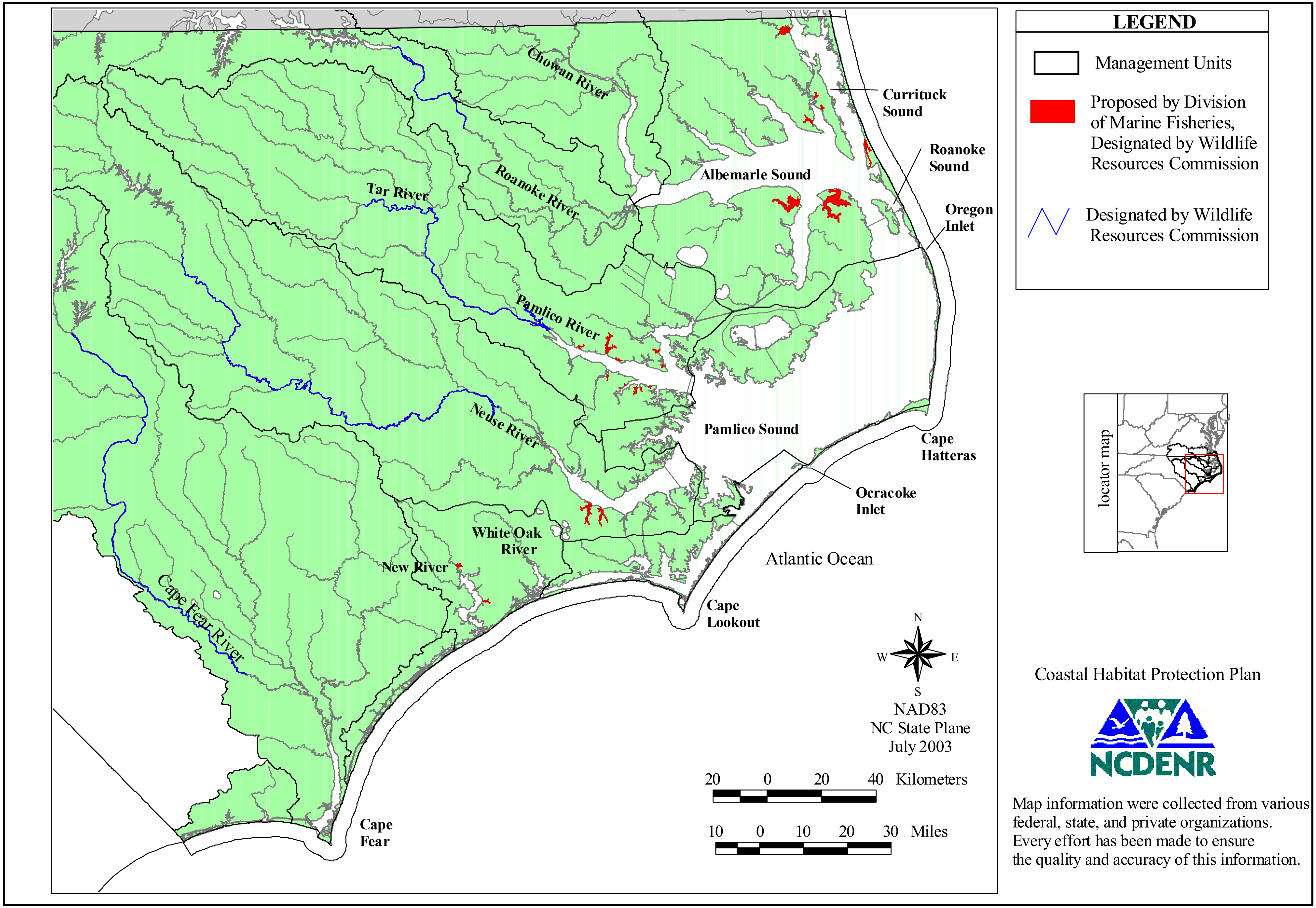

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Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

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

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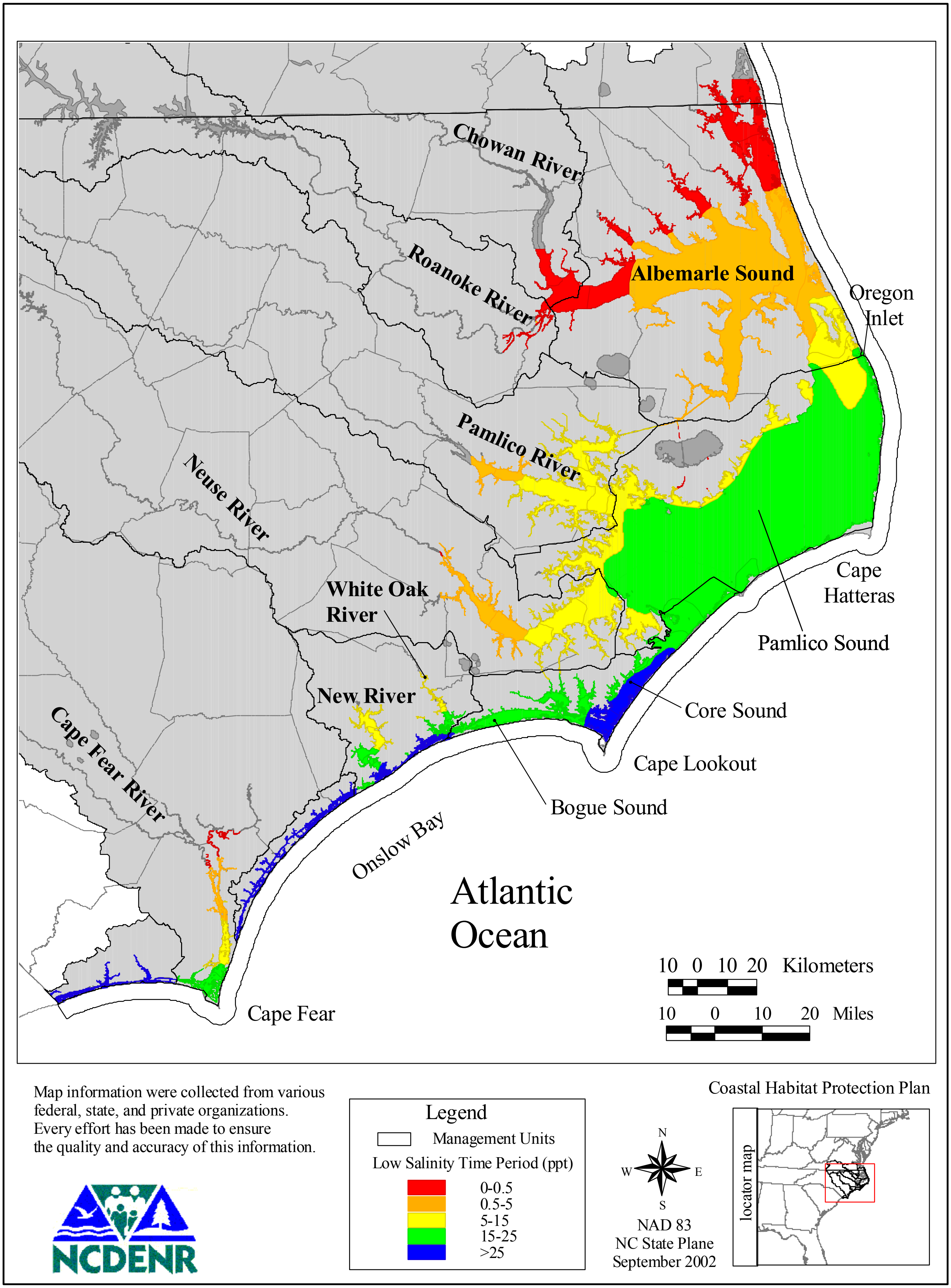

Map 2.5a. Winter and spring salinity zones in eastern North Carolina (derived from Orlando et al. 1994).

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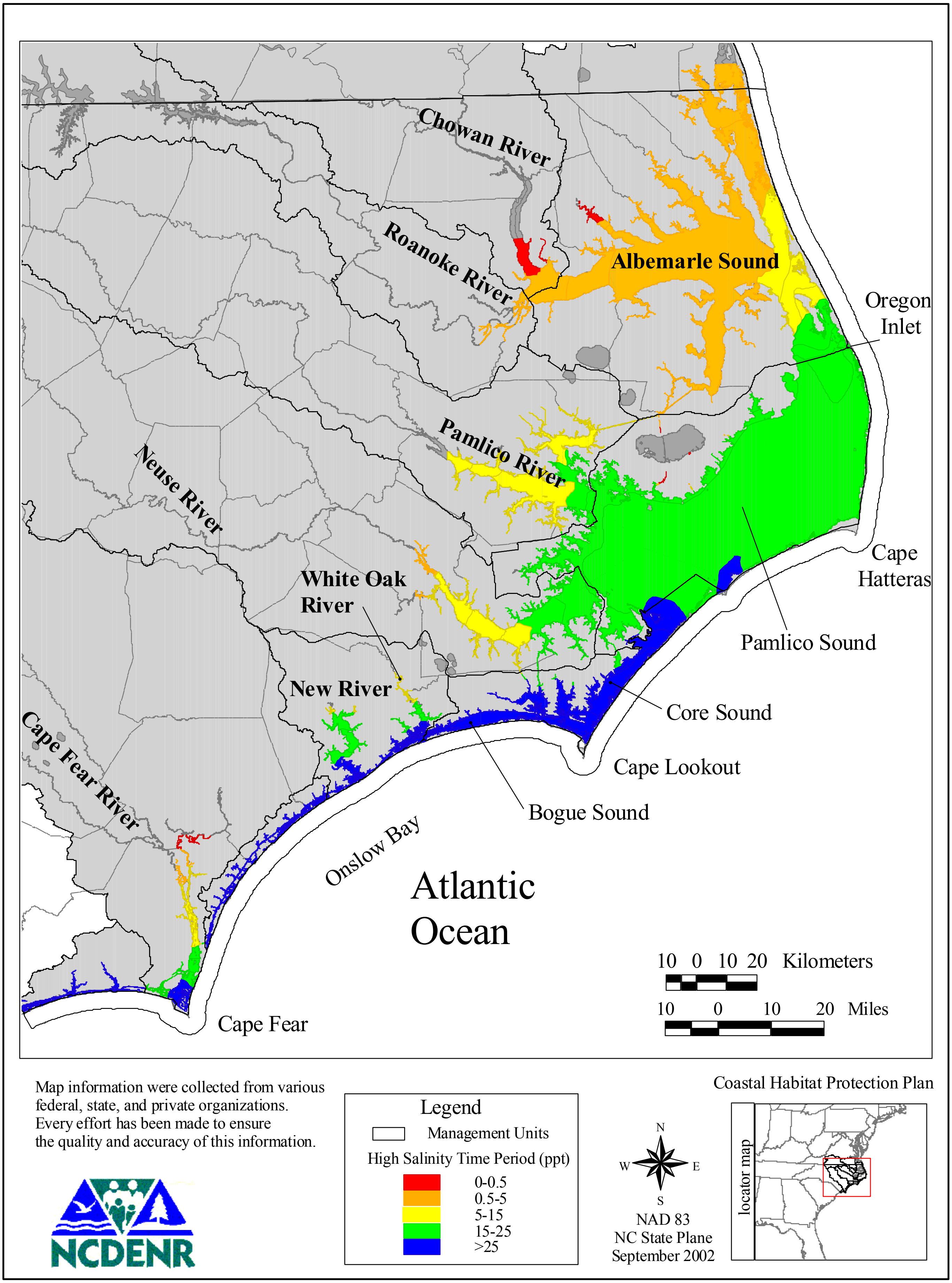

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

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

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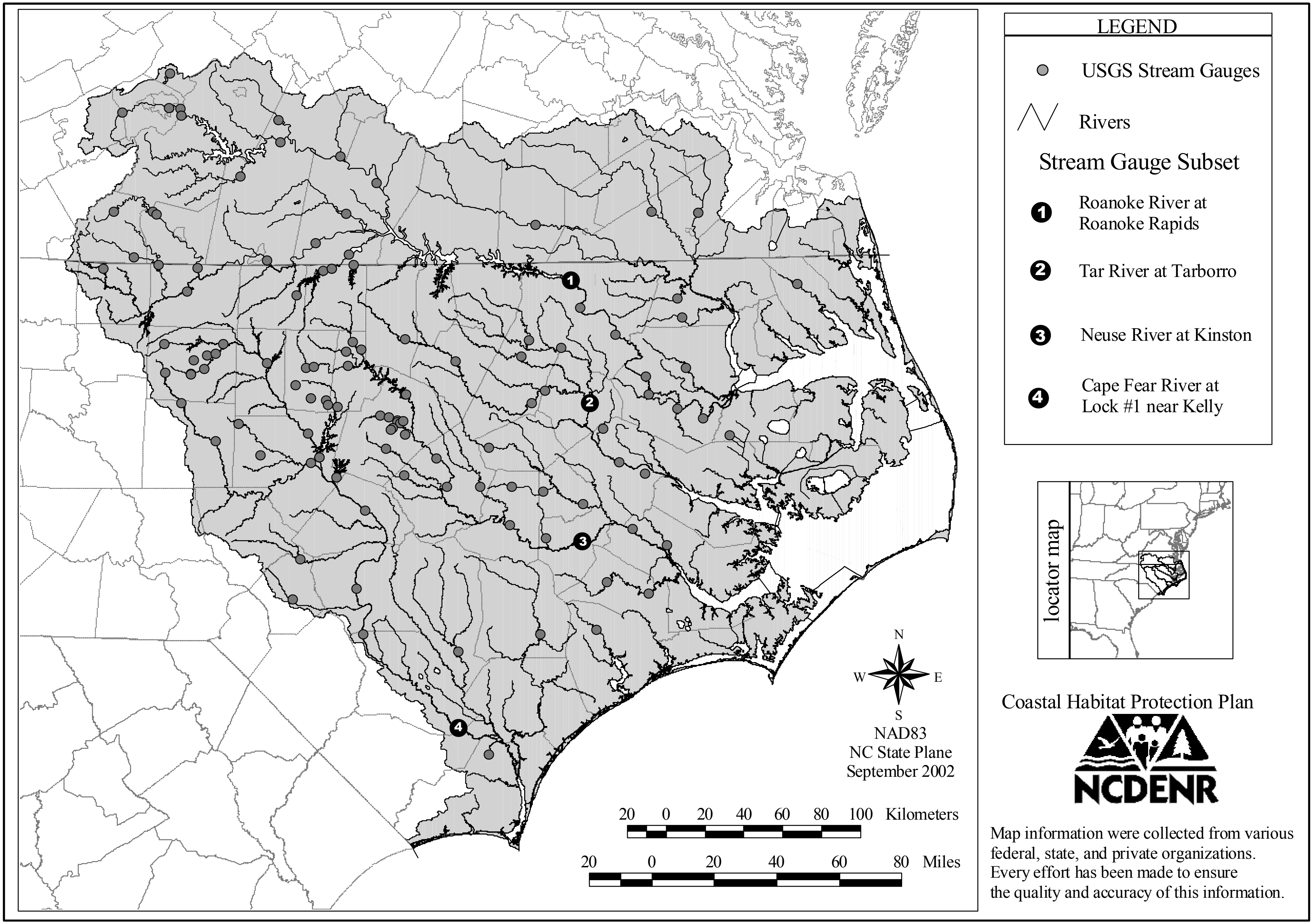

Map 2.6. Locations of US Geological Survey stream gauge stations in the area included in the NC Coastal Habitat Protection Plan (source: BasinPro3 software).

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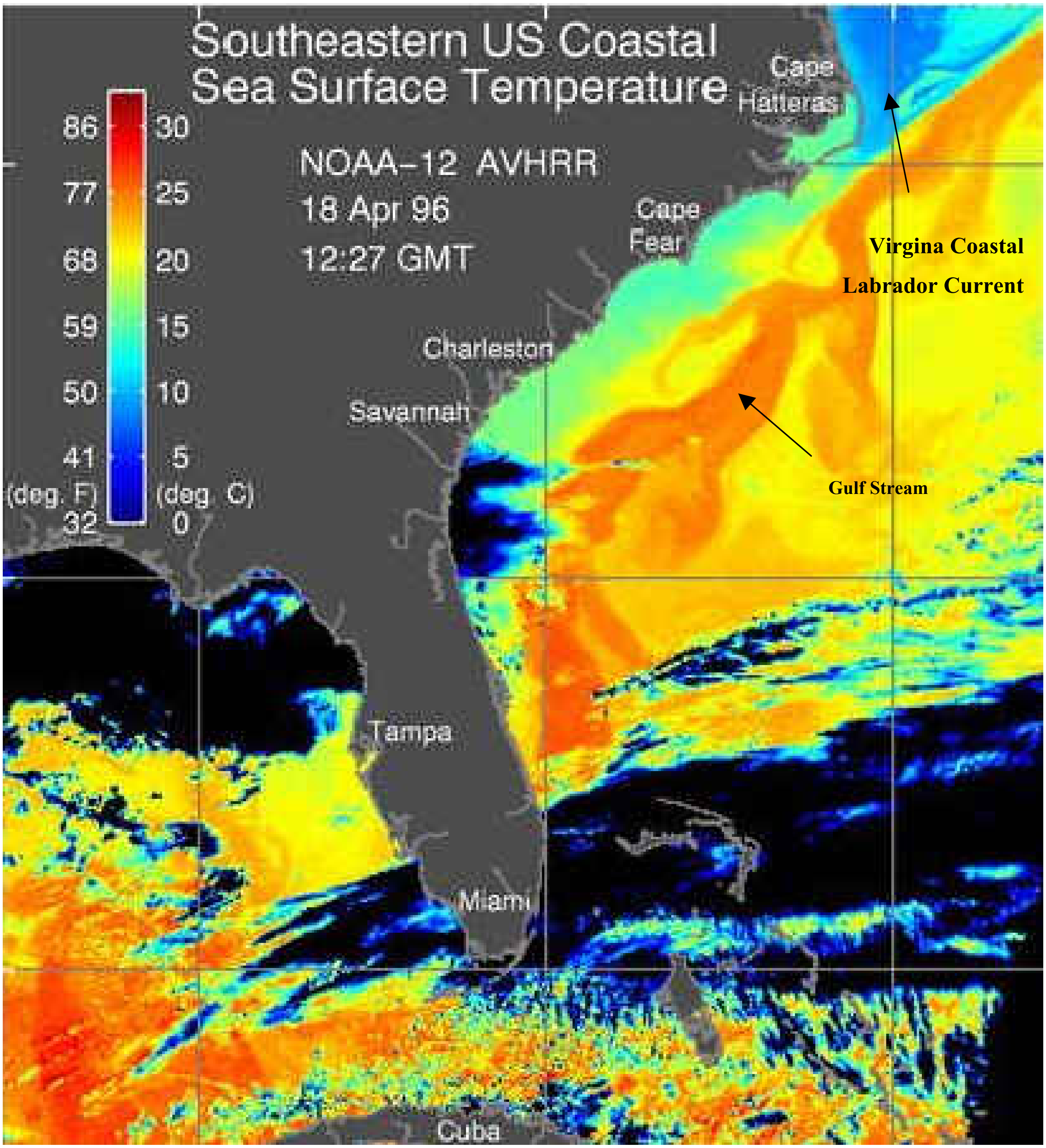

Map 2.7. Satellite imagery of sea surface temperature of North Carolina ocean waters, depicting position of the Virginia Current and Gulf Stream (Source: NOAA web site).

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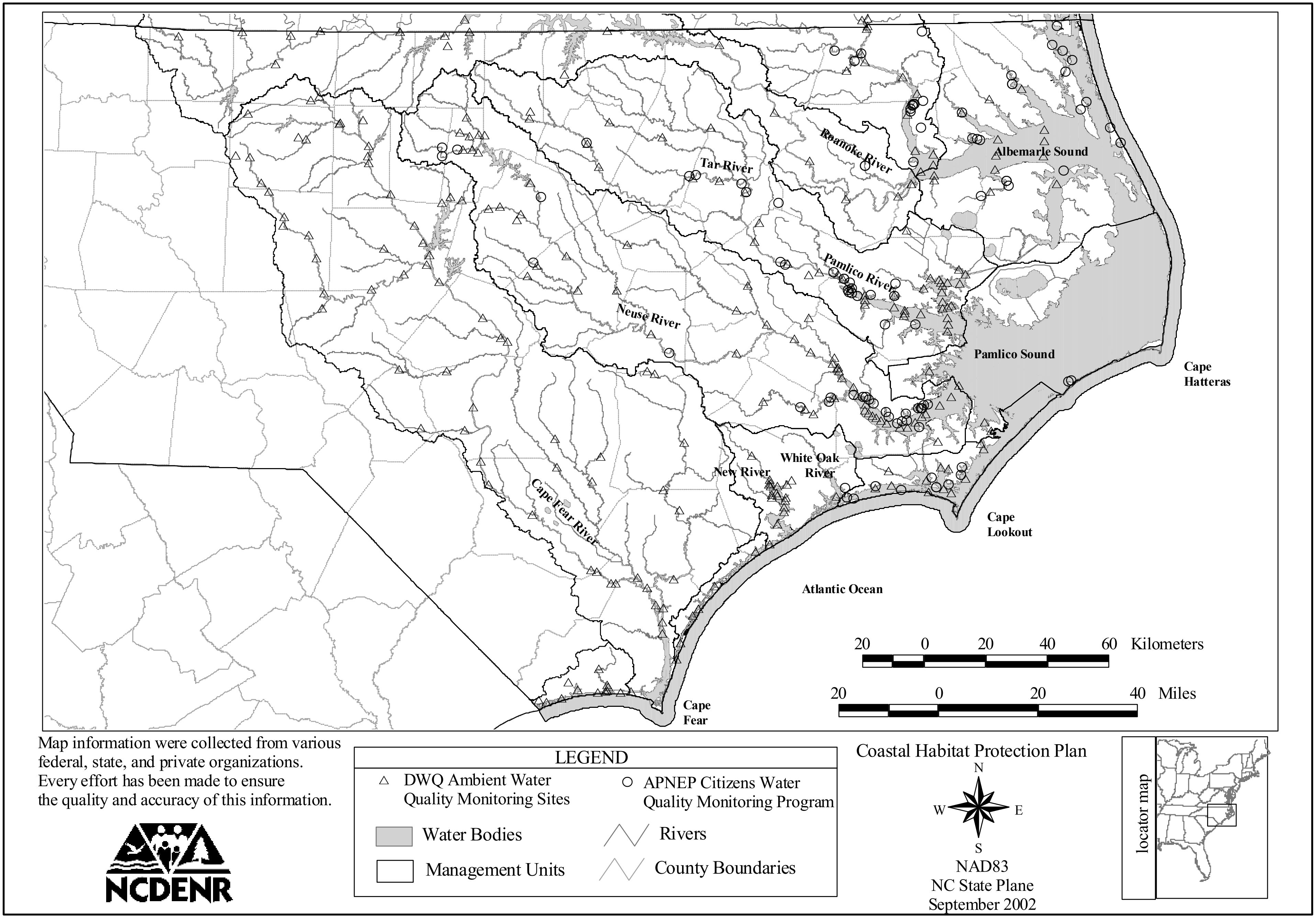

Map 2.8. Water quality monitoring stations within N.C. Coastal Habitat Protection Plan area (source: NC CGIA BasinPro3 software).

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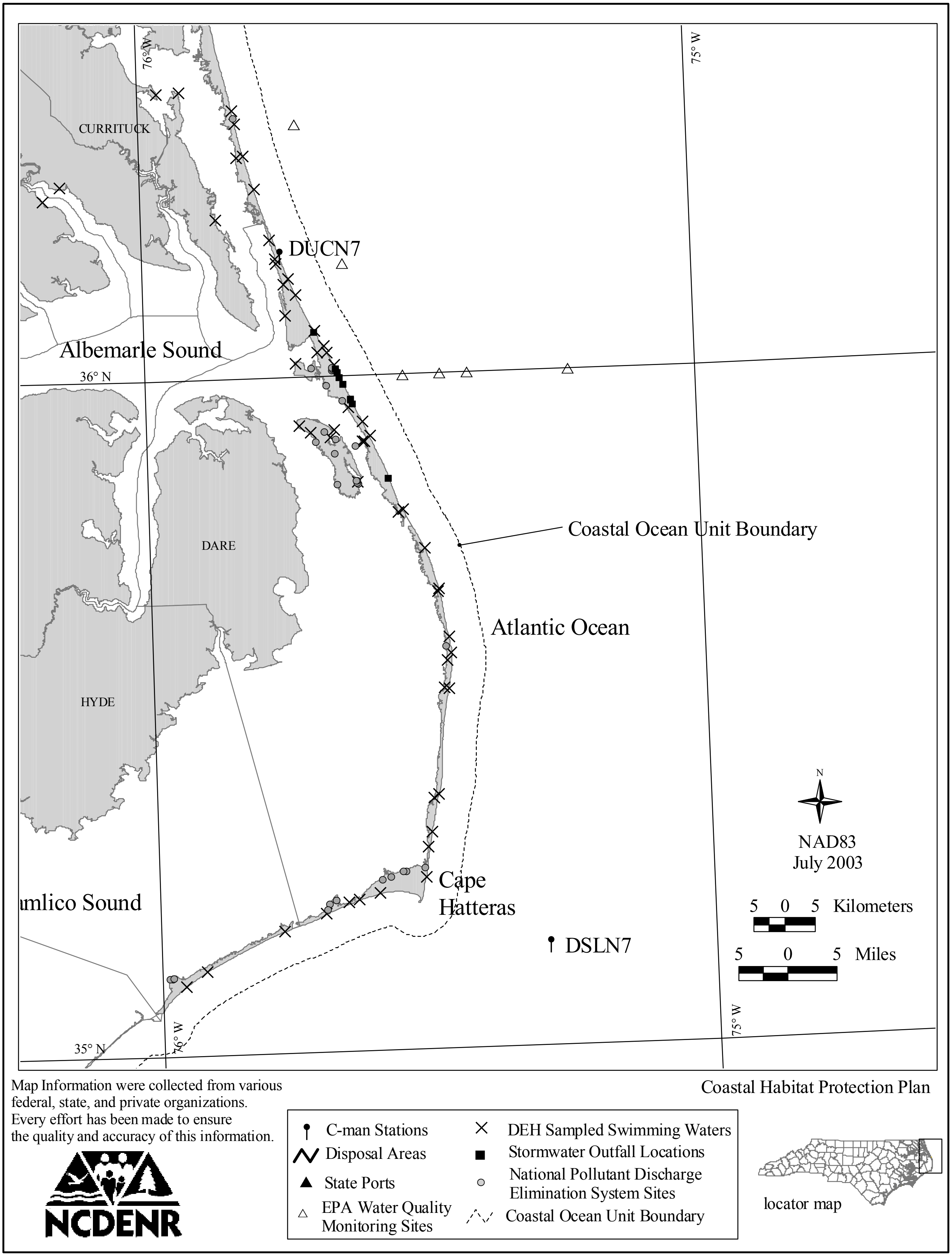

2.9a. Water quality monitoring stations and potential water quality threats in coastal North Carolina north of Ocracoke Inlet

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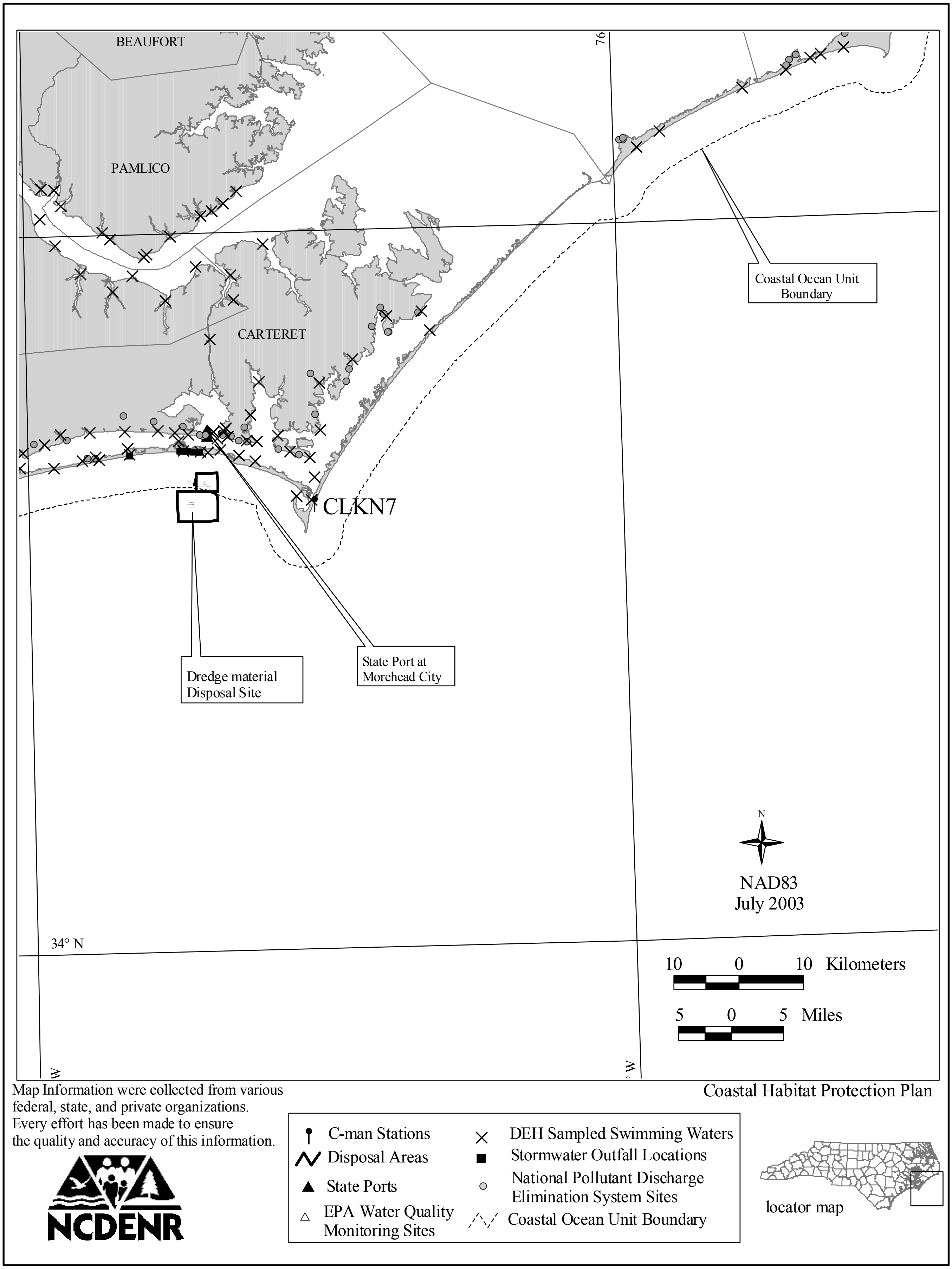

Map 2.9b. Water quality monitoring stations and potential water quality threats in coastal North Carolina from Bogue Sound to Ocraco

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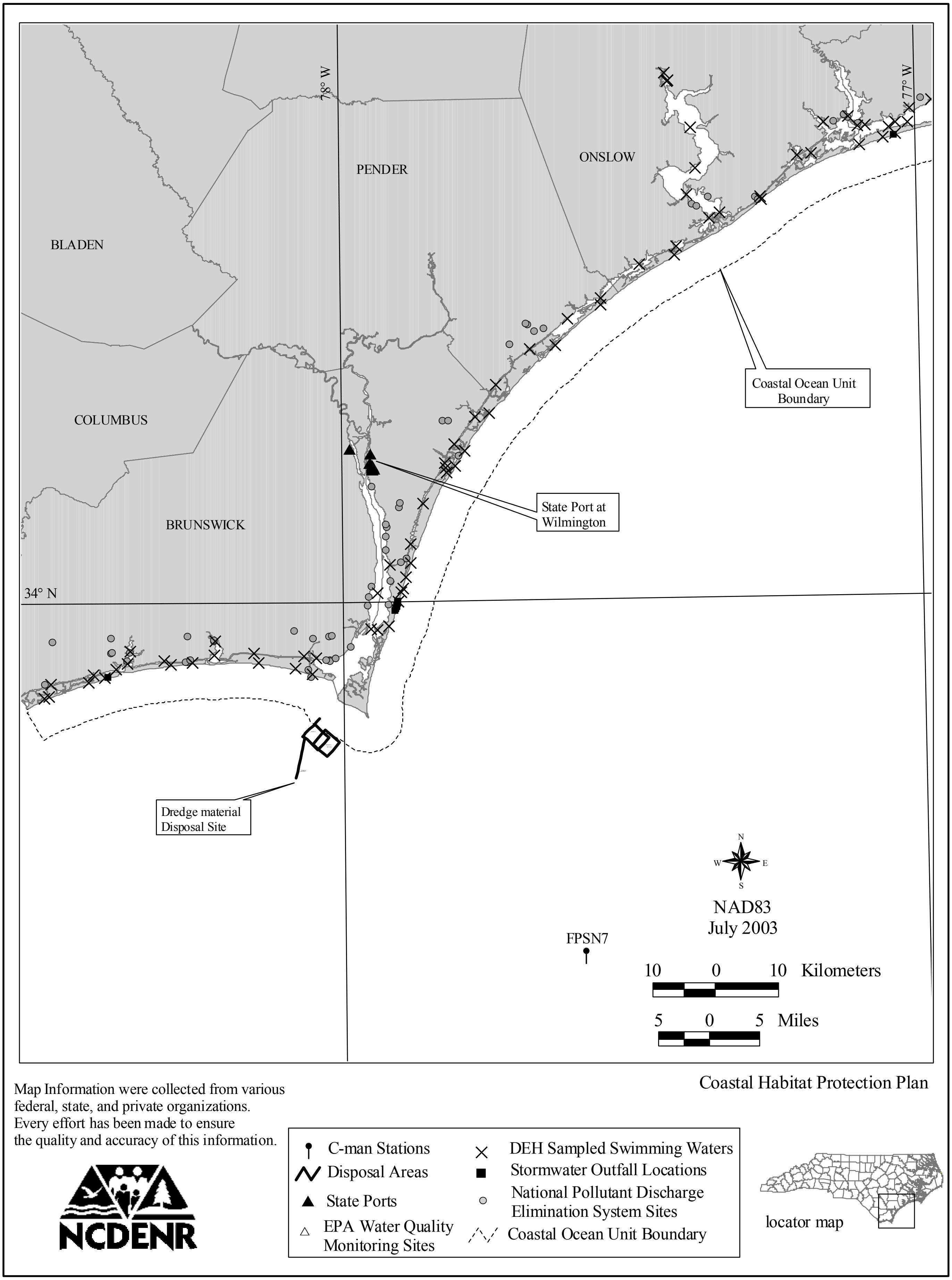

Map 2.9c. Water quality monitoring stations and potential water quality threats in coastal North Carolina south of Bogue Sound

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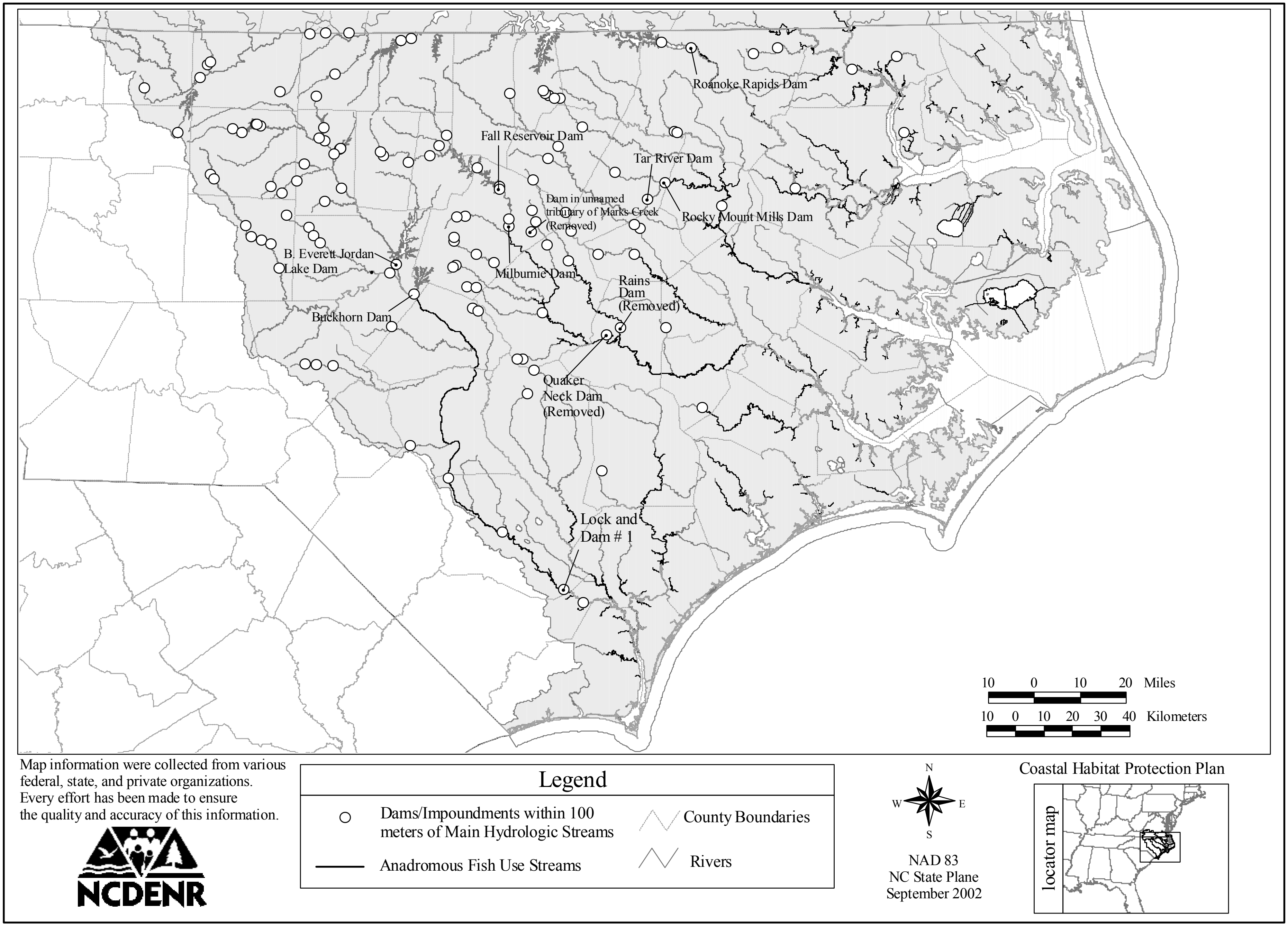

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

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

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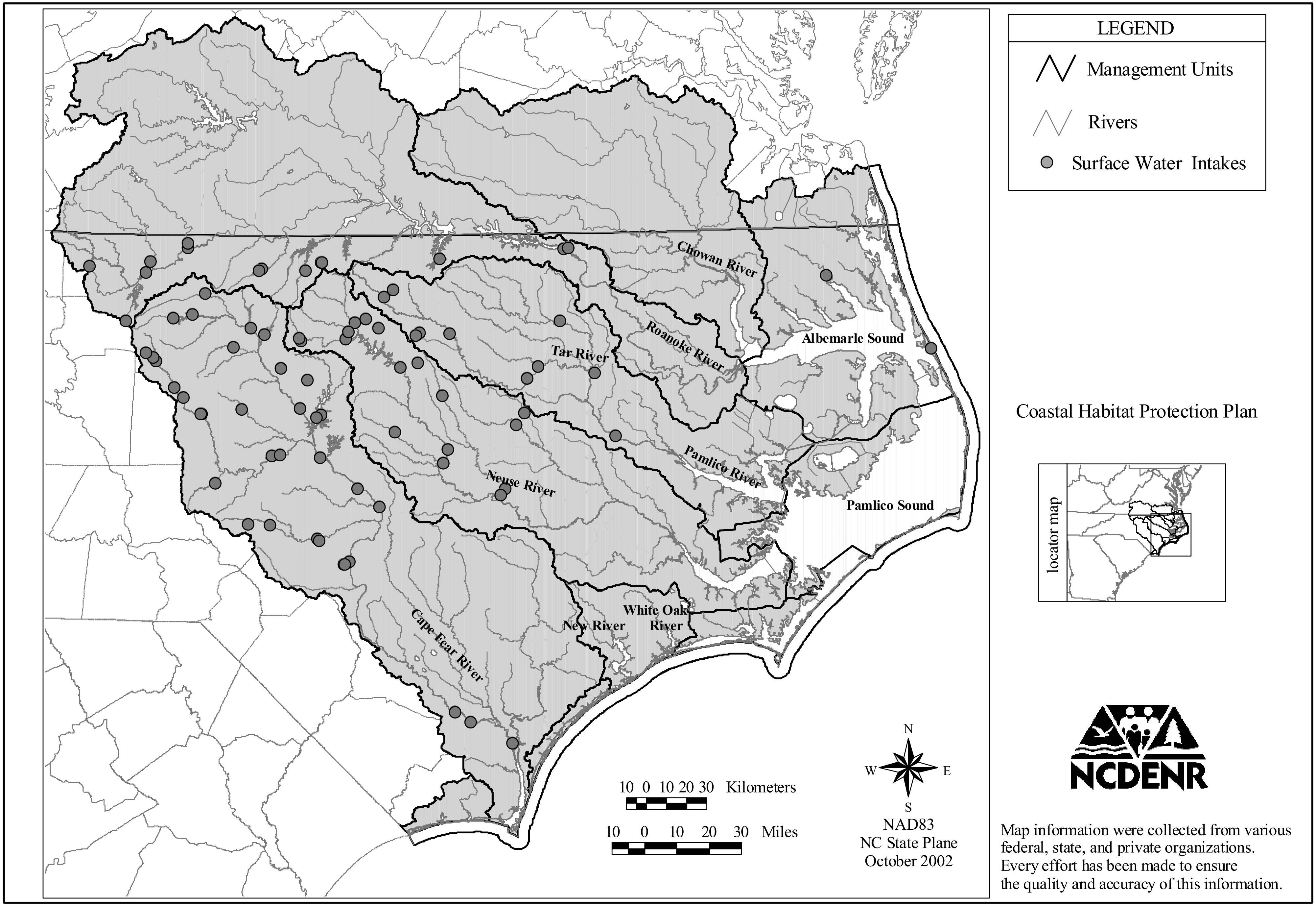

Map 2.11. Location of registered surface water intakes in North Carolina coastal river basins (from BasinPro3 software).

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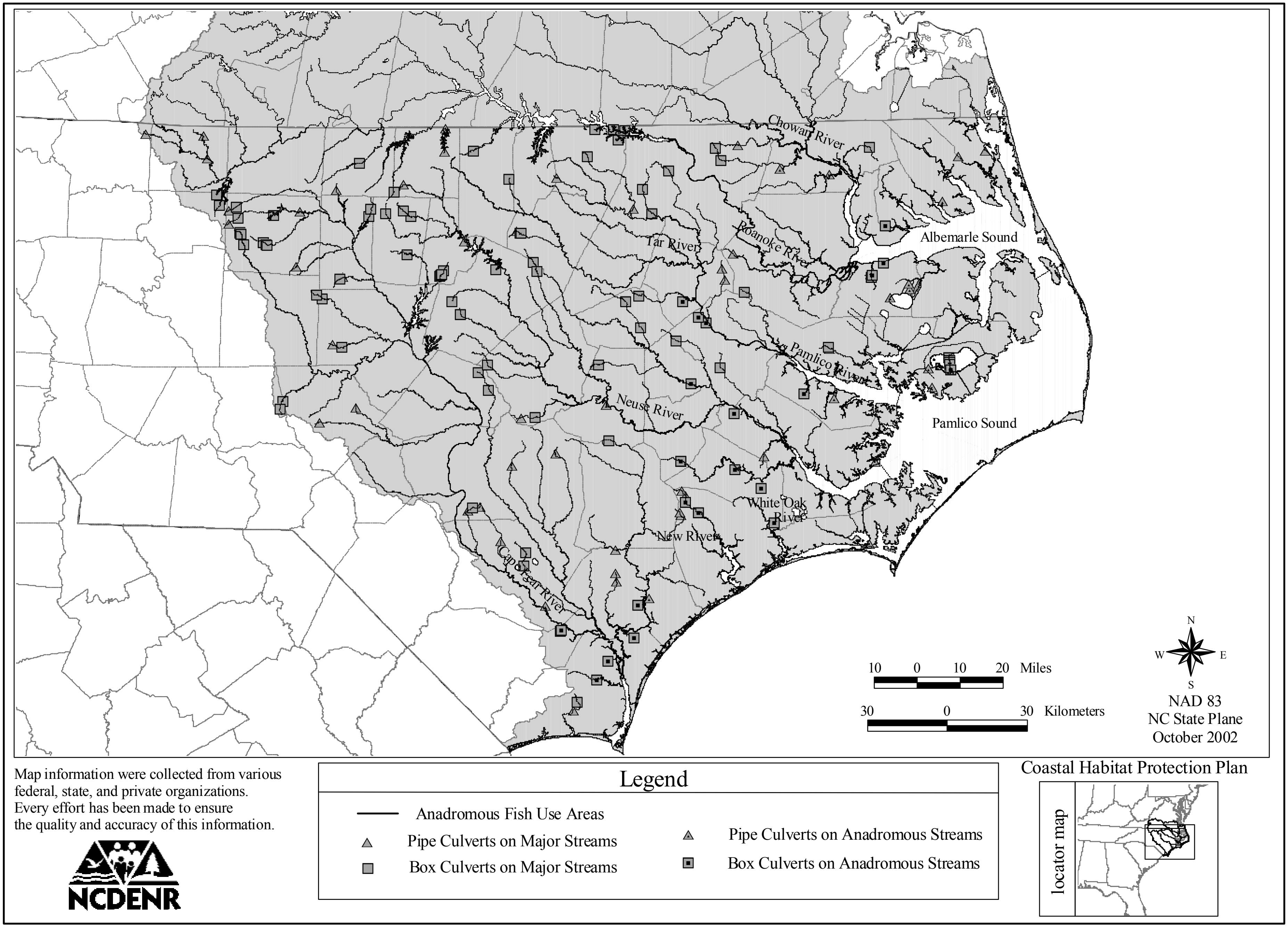

Map 2.12. Location of pipes and culverts on major streams in coastal North Carolina drainages.

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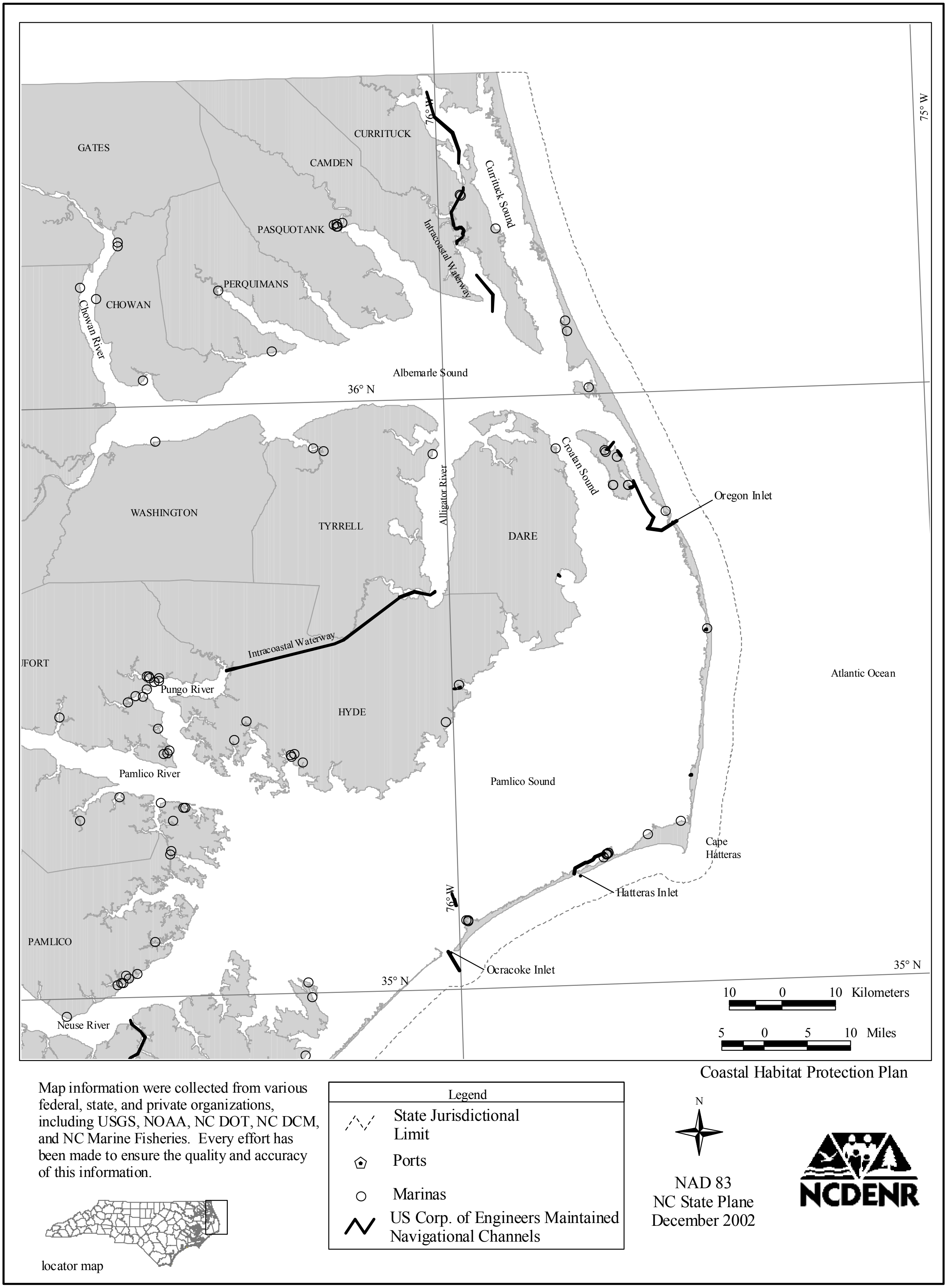

Map information were collected from various federal, state, and private organizations, including USGS, NOAA, NC DOT, NC DCM, and NC Marine Fisheries. Every effort has been made to ensure the quality and accuracy of this information.

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

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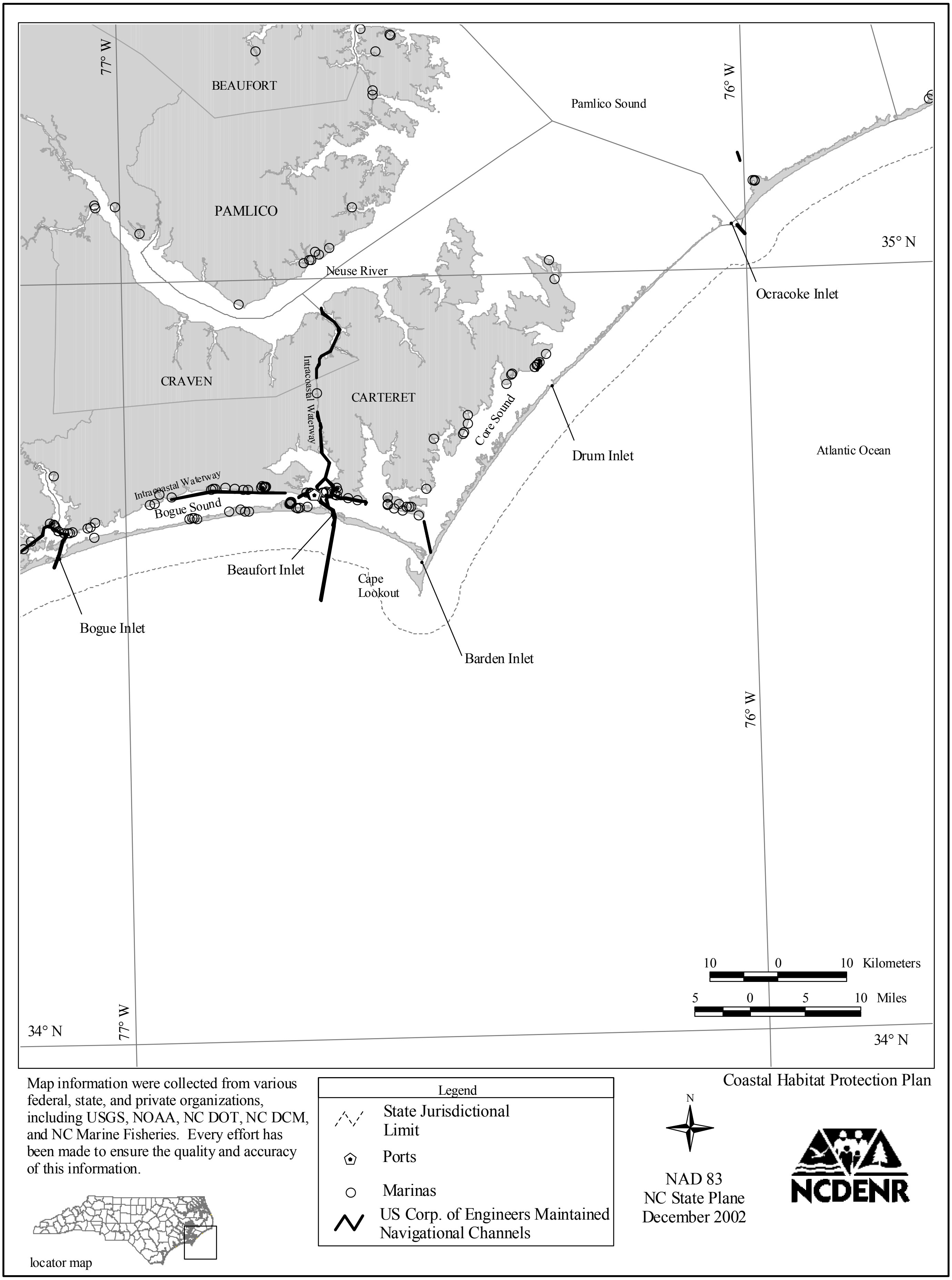

Map information were collected from various federal, state, and private organizations, including USGS, NOAA, NC DOT, NC DCM, and NC Marine Fisheries. Every effort has been made to ensure the quality and accuracy of this information.

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

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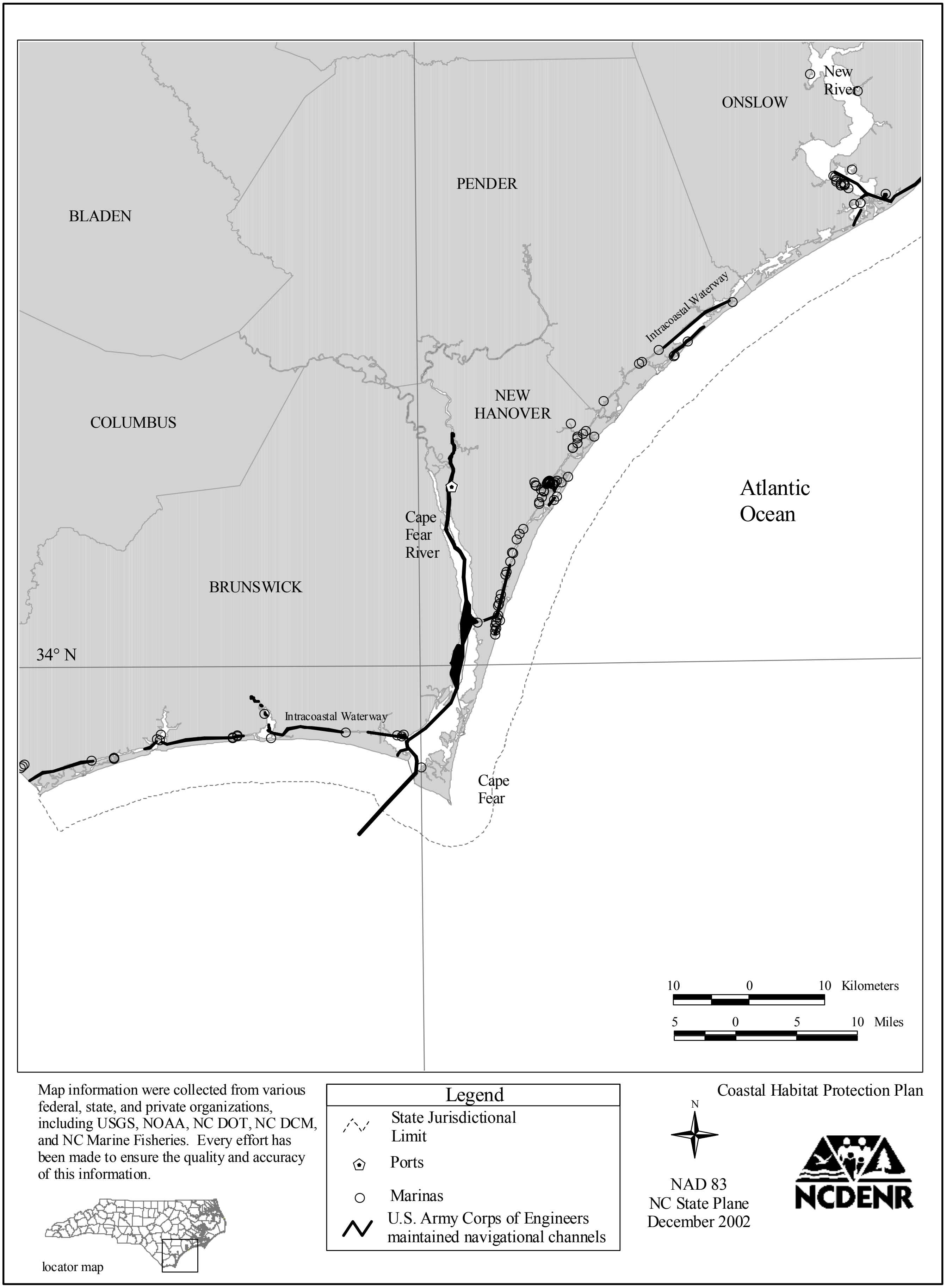

Map information were collected from various federal, state, and private organizations, including USGS, NOAA, NC DOT, NC DCM, and NC Marine Fisheries. Every effort has been made to ensure the quality and accuracy of this information.

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

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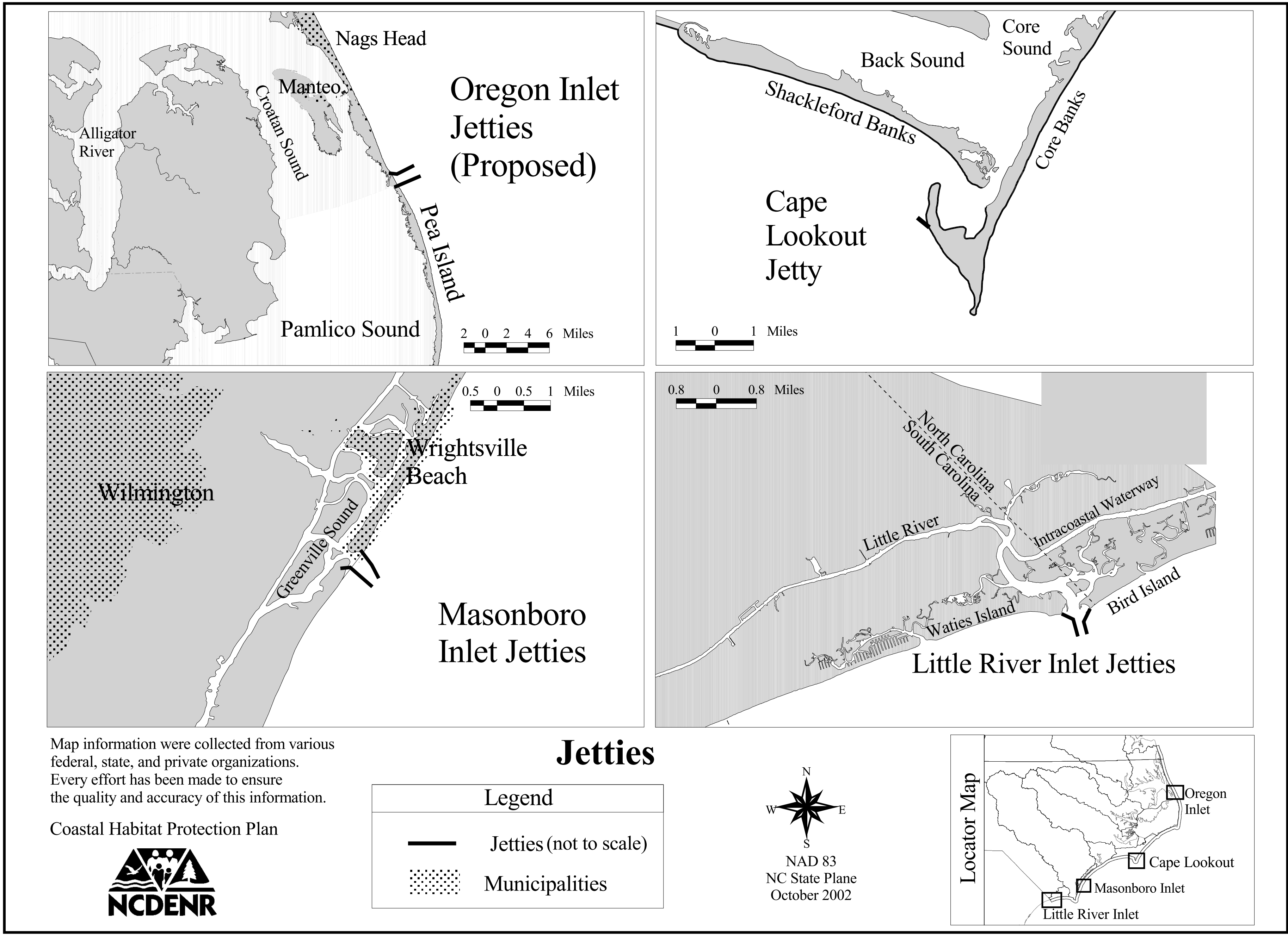

Map 2.14. Location of ocean jetties along the North Carolina coast.

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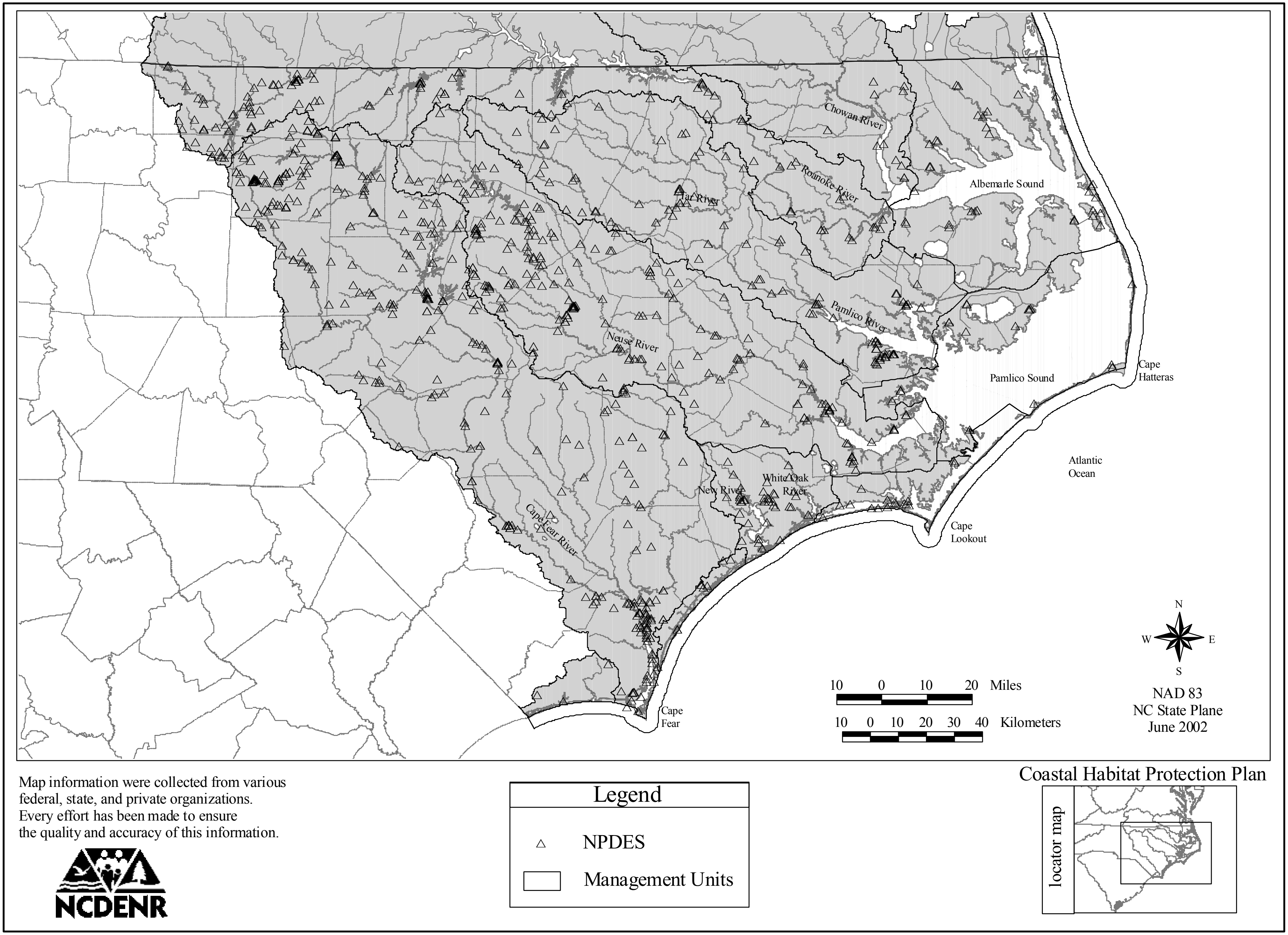

Map 2.15. Location of point source discharges permitted by the North Carolina Division of Water Quality (source: NC CGIA BasinPro3 software).

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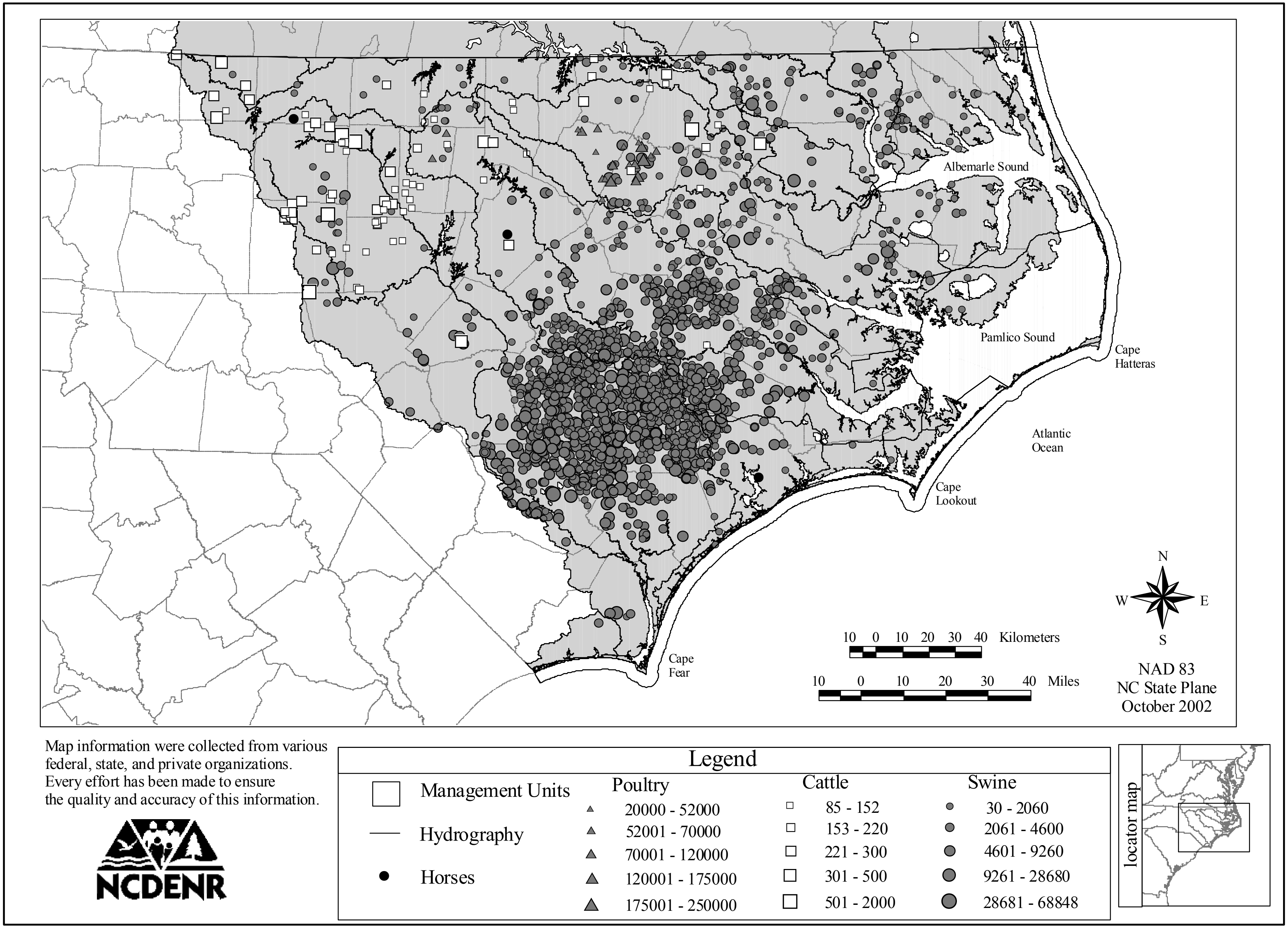

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

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

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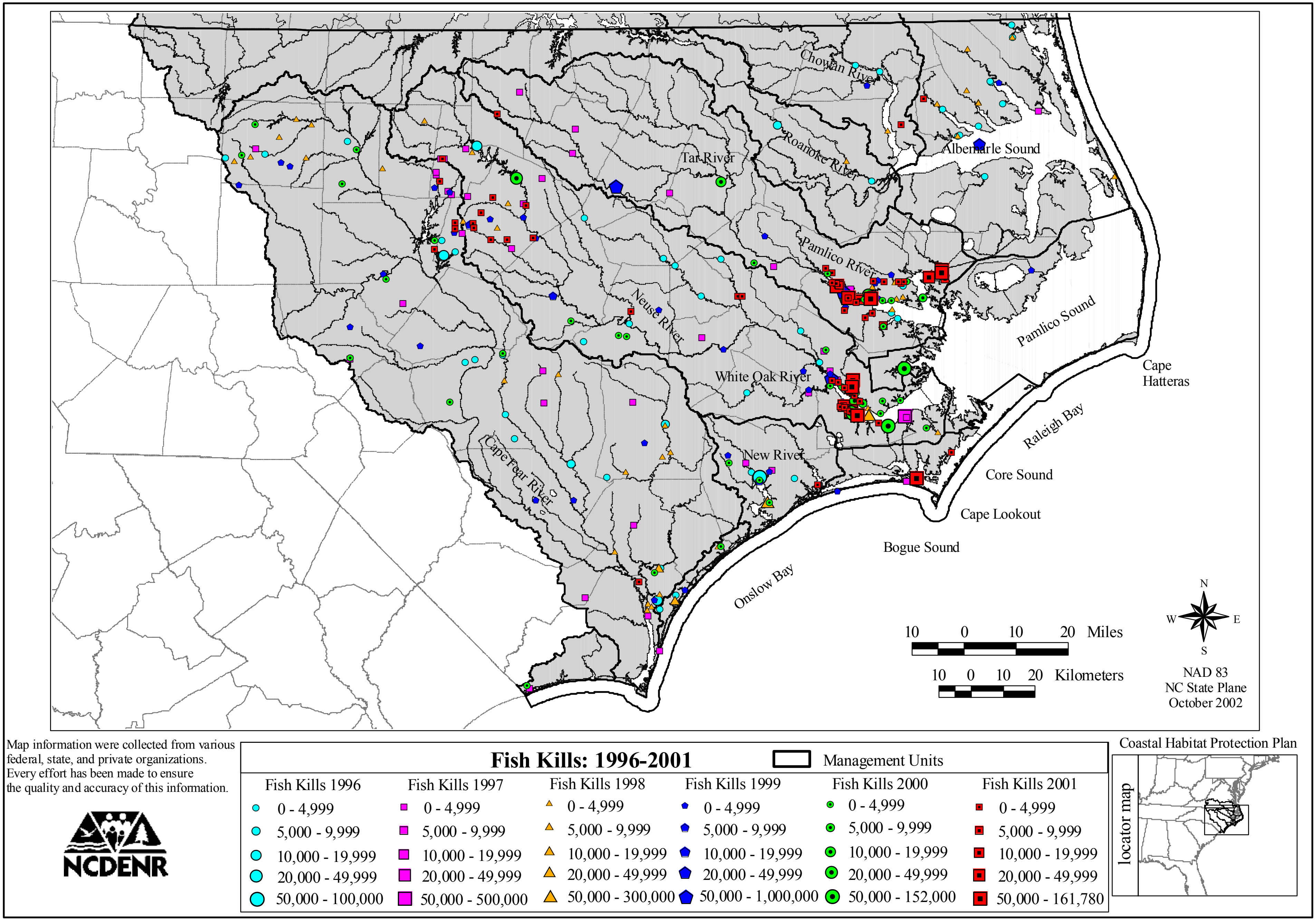

Map 2.17 Location of reported fish kills, 1996-2001 (source: DENR-DWQ Environmental Sciences Branch)

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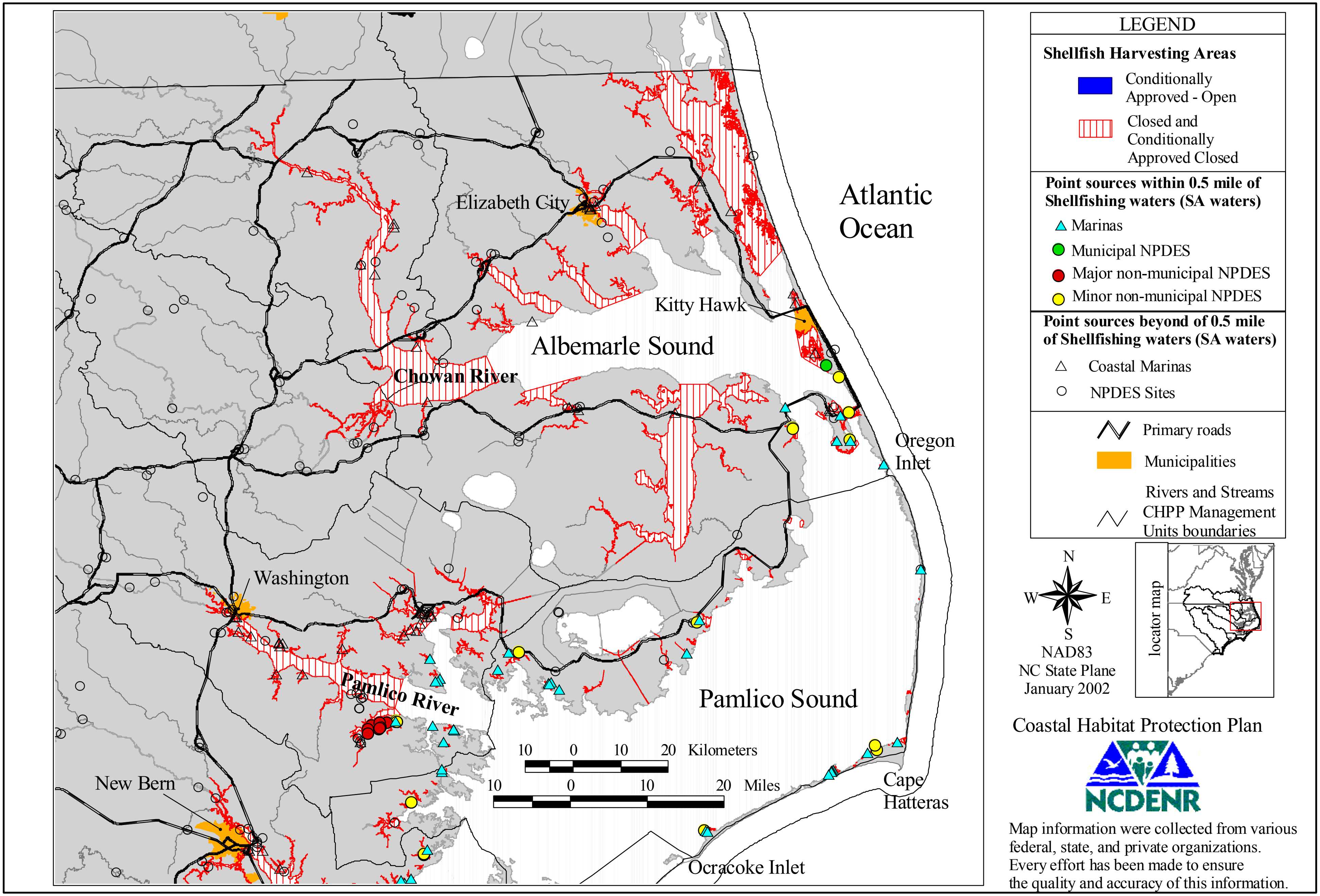

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Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

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

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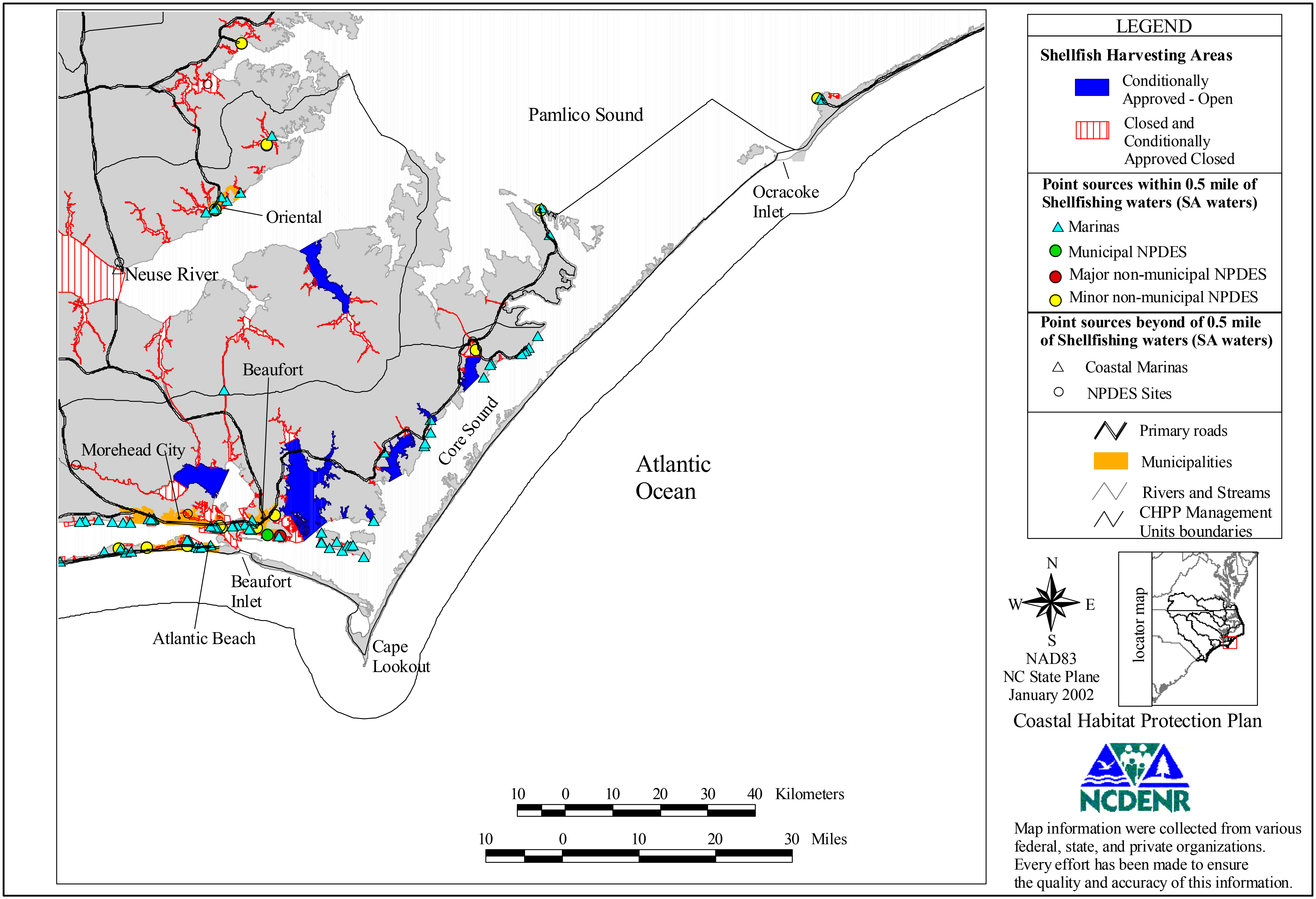

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

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

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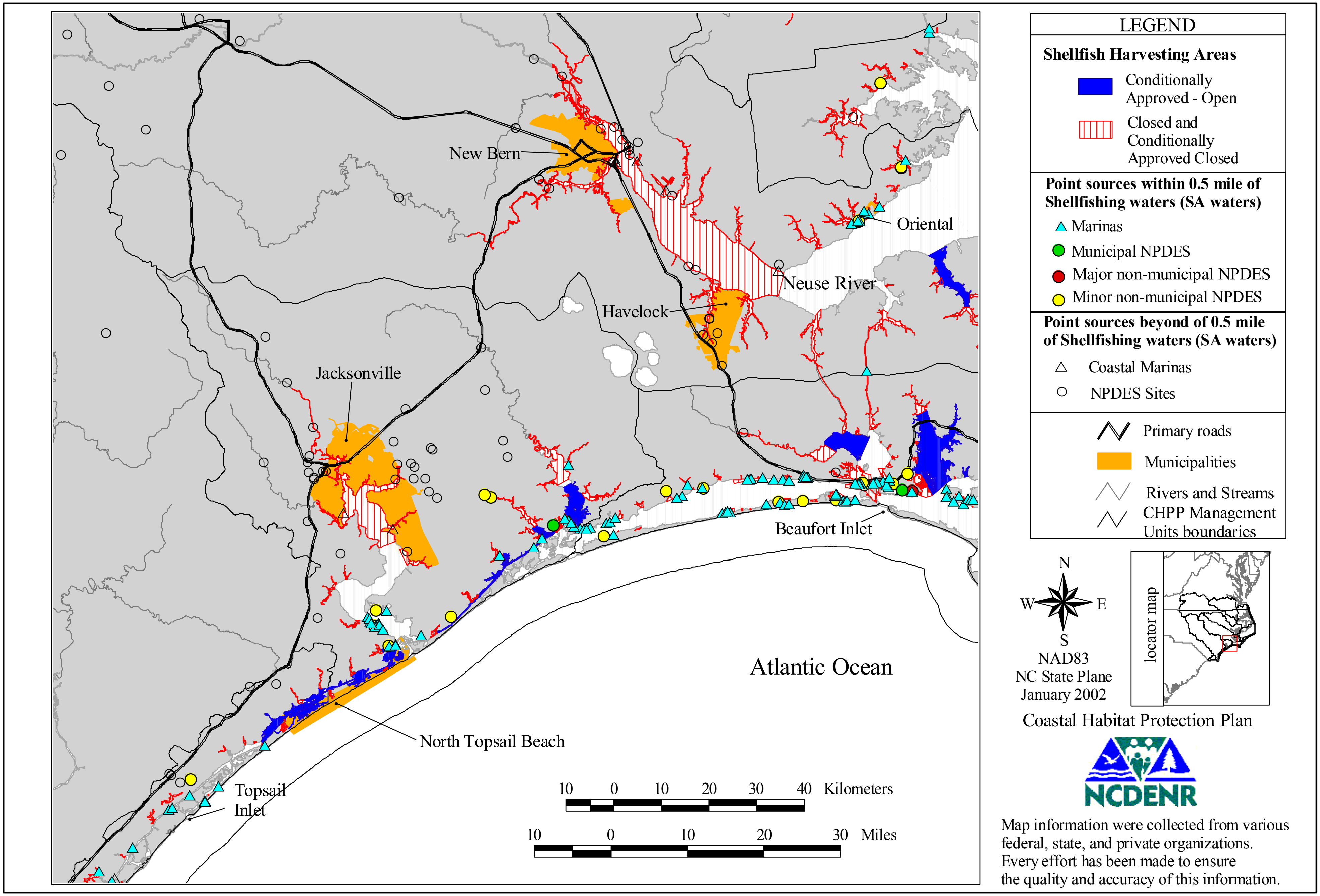

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

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

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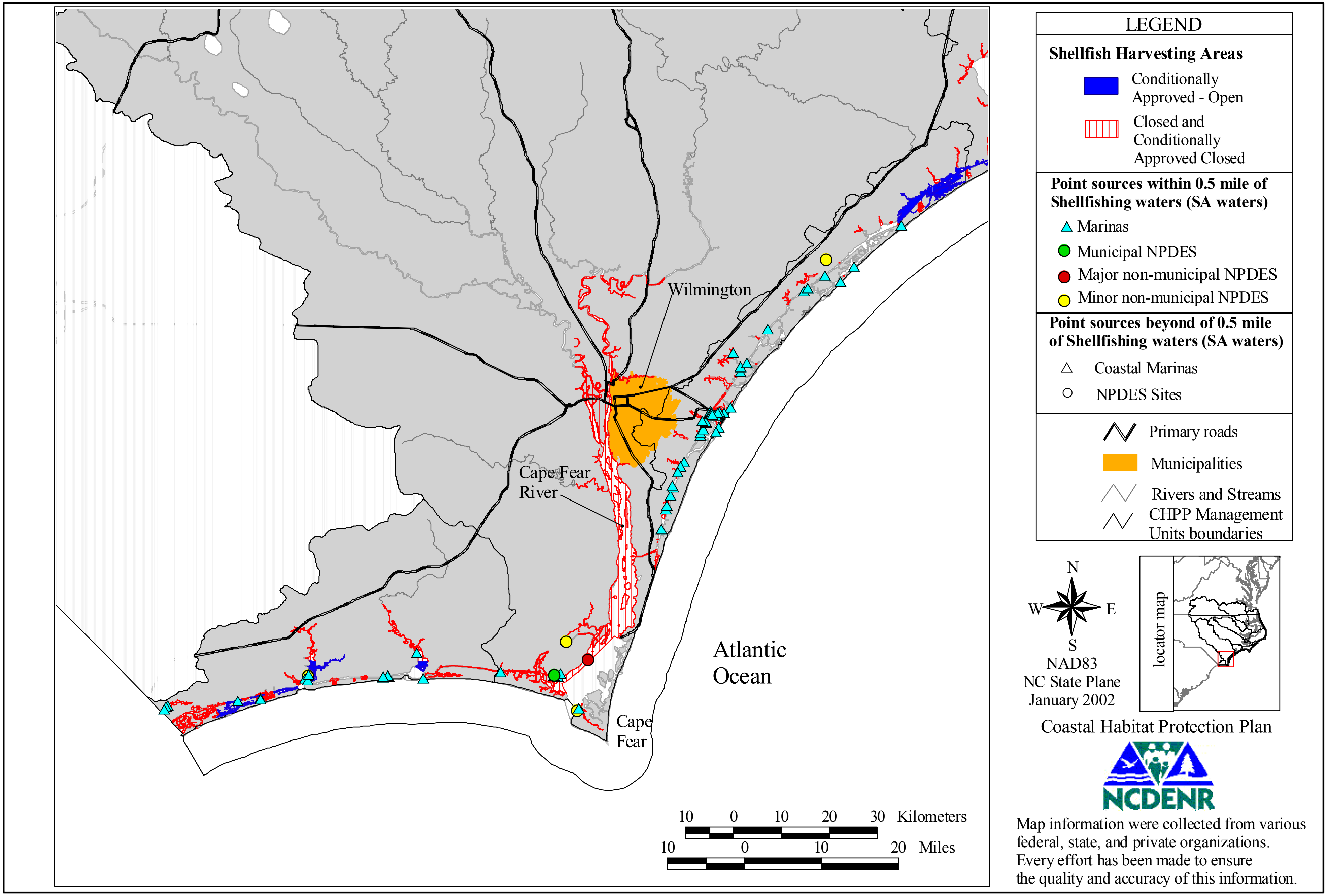

Map 2.18d --Location of National Pollution Discharge Elimination System marinas and discharges in relation to North Carolina Division of Environmental Health shellfish harvesting areas - Topsail Inlet to South Carolina state line

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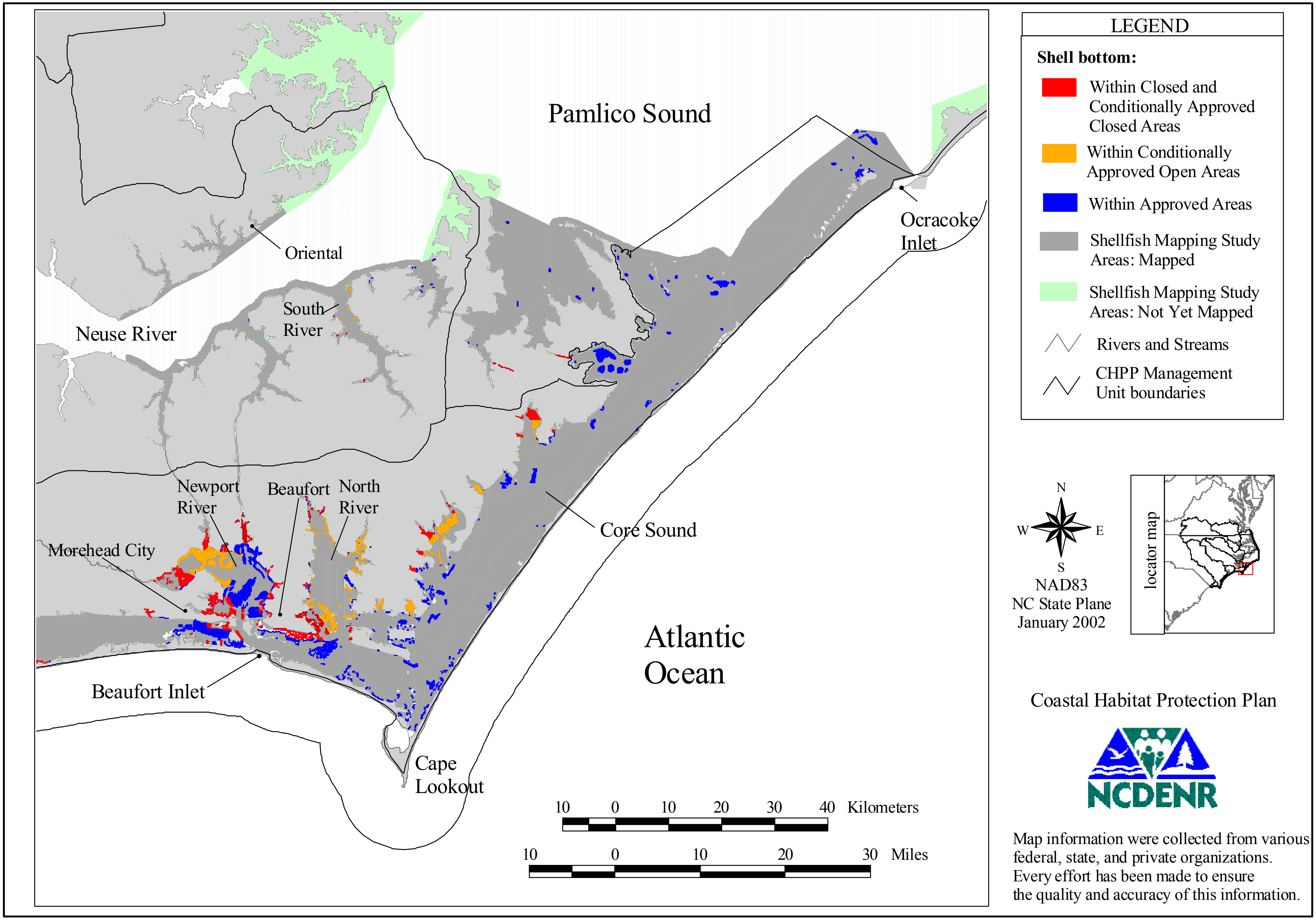

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

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

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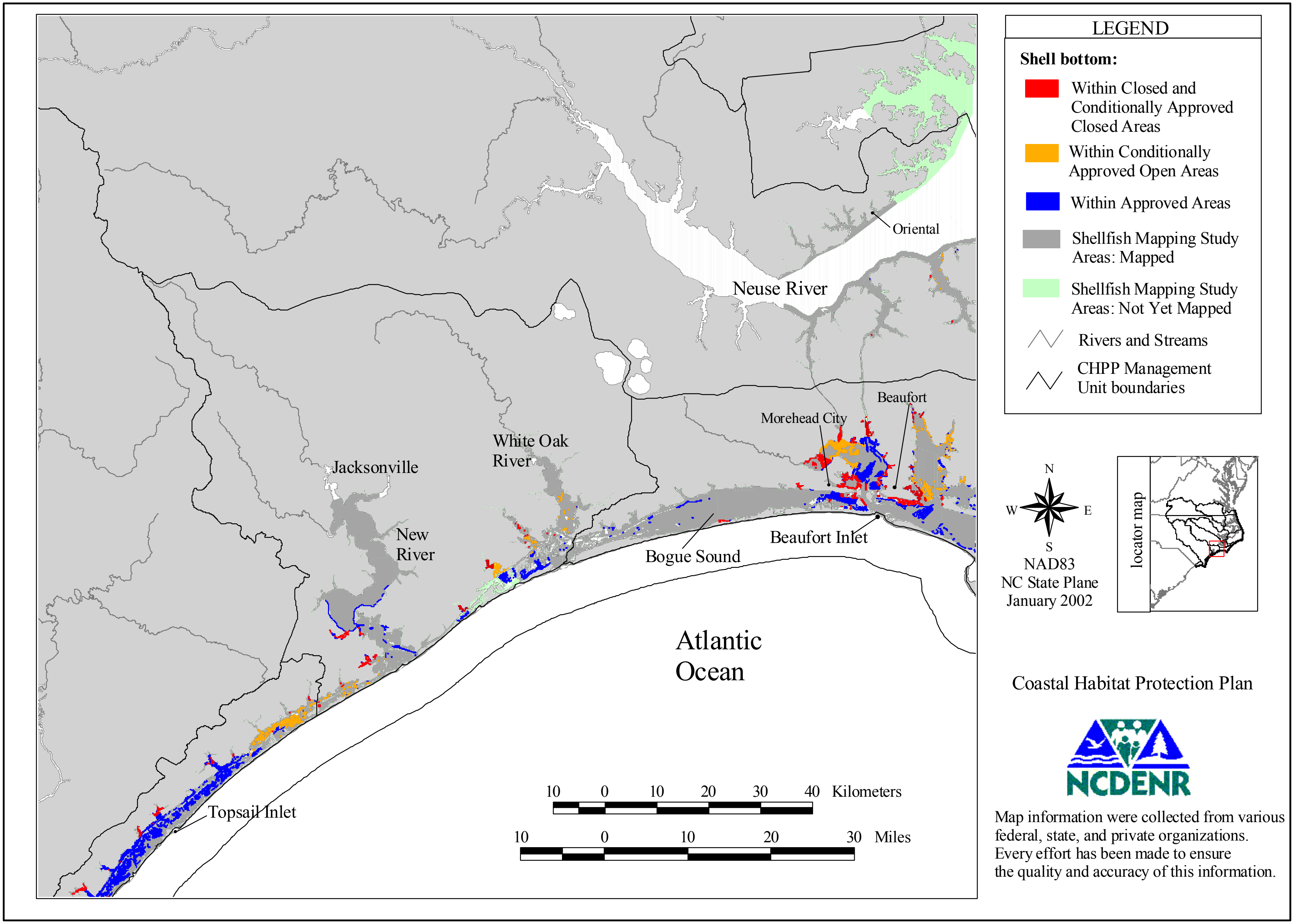

Map 2.19b--- Extent of shell bottom within North Carolina Division of Environmental Health Shellfish Area designations - Beaufort Inlet to Topsail Inlet

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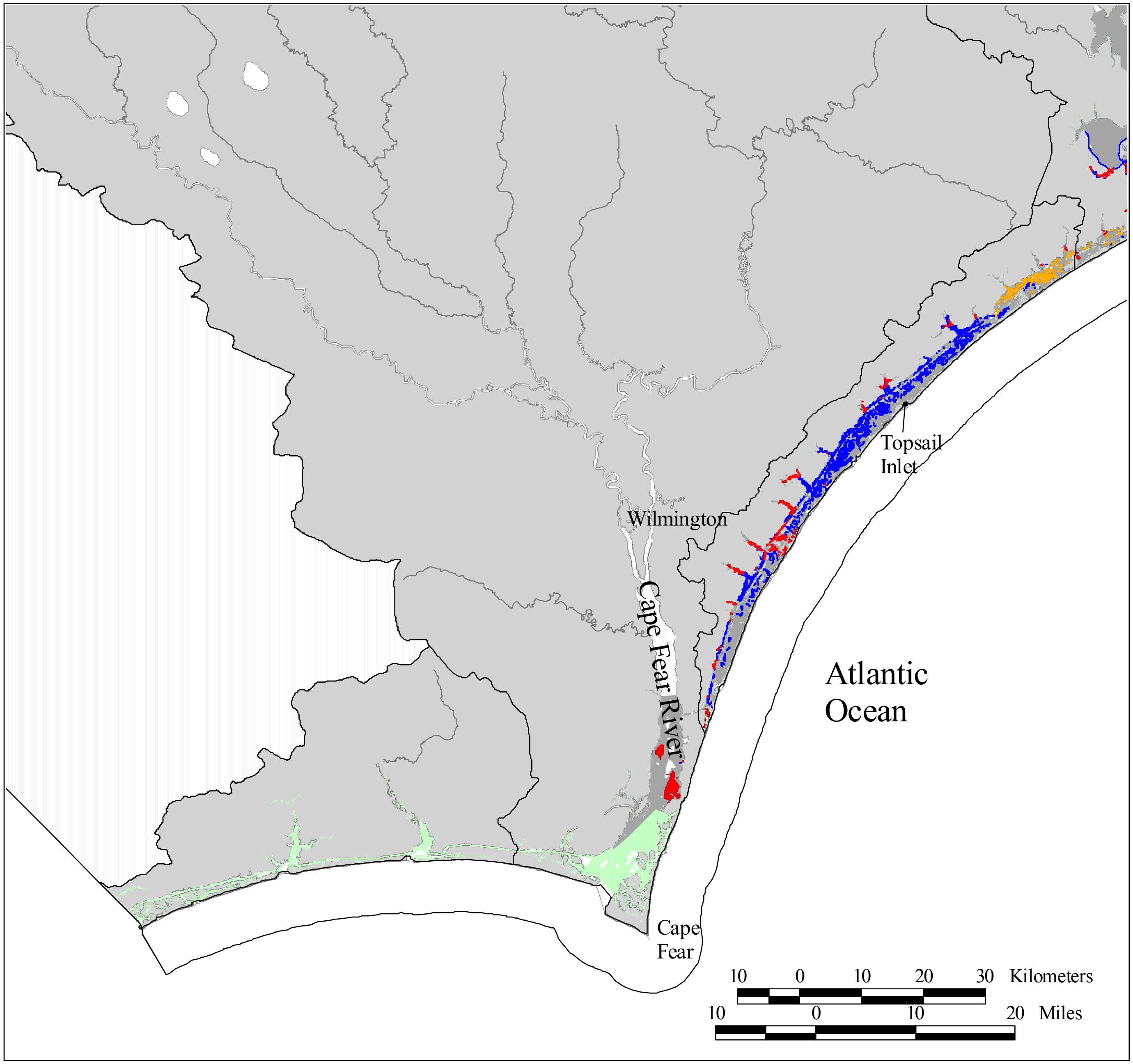

LEGEND

**Shell bottom:**

- 🟥 Within Closed and Conditionally Approved Closed Areas
- 🟧 Within Conditionally Approved Open Areas
- 🟦 Within Approved Areas
- ▨ Shellfish Mapping Study Areas: Mapped
- 🟩 Shellfish Mapping Study Areas: Not Yet Mapped
- ╱╲ Rivers and Streams
- ╱╲ CHPP Management Unit boundaries

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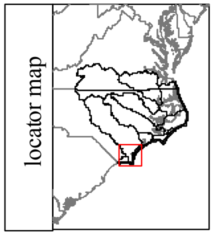
NAD83
NC State Plane
January 2002



Coastal Habitat Protection Plan

NCDENR

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

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

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