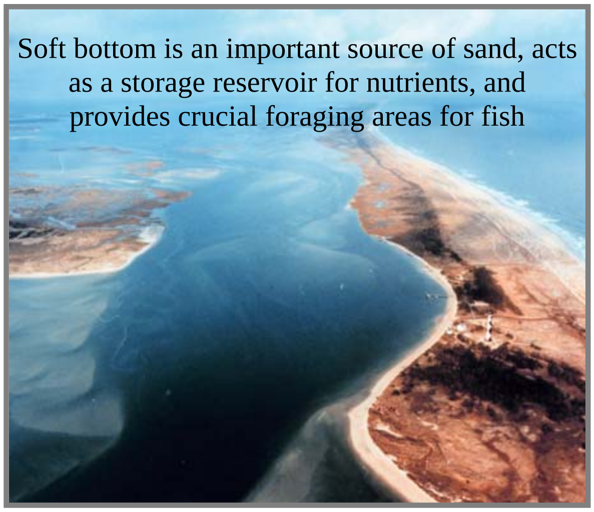
CHAPTER 6. SOFT BOTTOM

6.1 DESCRIPTION AND DISTRIBUTION

Definition

Soft bottom habitat is unconsolidated, unvegetated sediment that occurs in freshwater, estuarine, and marine systems. The MFC, CRC, or EMC do not specifically define soft bottom or unvegetated bottom in their regulations. The SAFMC defines one type of soft bottom, tidal flats, as "dynamic features of coastal landscapes whose distribution and character may change with shifting patterns of sediment erosion and deposition." This definition could in fact apply to all soft bottom. However, the CHPP definition of soft bottom includes deeper subtidal bottom as well as shallow bottom areas. Although soft bottom as a habitat type is not specifically designated or protected by any of North Carolina's regulatory commissions, it is an important component of MFC designated Primary Nursery Areas (PNAs), Anadromous Fish Spawning Areas, and Anadromous Nursery Areas.



Habitat requirements

Soft bottom has only one habitat requirement – sediment supply. Environmental characteristics, such as sediment grain size and distribution, salinity, dissolved oxygen, and flow conditions, will affect the condition of the soft bottom habitat and the type of organisms that utilize it. Nevertheless, the habitat itself will persist regardless of its condition unless it becomes starved for sediment or is colonized by other organisms, transforming it into another habitat such as SAV or shell bottom. Refer to the threats section for more information on alterations to soft bottom habitat.

Description and distribution

Although soft bottom habitat is defined as "unvegetated" and lacks visible structural habitat, the surface sediments support an abundance of microscopic plants; numerous burrowing animals are hidden below the surface (Peterson and Peterson 1979). The characteristic common to all soft bottom types is the mobility of unconsolidated, uncemented soft sediment (Peterson and Peterson 1979). Soft bottom habitat can be characterized by geomorphology (the shape and size of the system), sediment type, water depth, hydrography (riverine, intertidal, or subtidal), and/or salinity regime (DENR 2000a). Soft bottom habitat types in North Carolina's coastal waters can be categorized as the following:

Freshwater
- unvegetated shoreline
- river, creek, and lake bottom

Estuarine
- intertidal flats and unvegetated shoreline
- subtidal bottom in rivers, creeks, and sounds

Marine
- intertidal beach
- subtidal bottom

It is important to understand the physical and chemical properties of soft bottom habitat since these affect the benthic organisms that inhabit these areas and, in turn, their value as fish habitat. The physical and chemical character of all soft bottom is determined by the underlying geology, basin morphology, and associated physical processes (Riggs 1996). Geologically, North Carolina's coast can be divided into distinct northern and southern provinces that are approximately separated by Cape Lookout (Riggs 1996; Pilkey et al. 1998). In the northern province, sediment formations generally consist of a thick layer of unconsolidated muds, muddy sands, sands, and peat sediments. A gently sloping depositional basin formed north of Cape Lookout. The low slopes of the northern province are characterized by an extensive system of drowned river estuaries (i.e., Albemarle Sound, Neuse River), long barrier islands, and few inlets (Map 6.1 a-e). In contrast, the southern coastal province has only a thin and variable layer of surface sands and muds, with many areas of exposed rock outcrops in marine waters. The southern province also has a steeper sloping shoreline, resulting in narrow estuaries (e.g., Topsail Sound, Batts Mill Creek), short barrier islands, and numerous inlets (Map 6.1 a-e). These geomorphic features, in turn, affect sediment deposition and the character of soft bottom habitat.

<u>Freshwater bottom</u>

Freshwater bottom includes the bottom sediments of freshwater rivers, creeks, and lakes. These areas were described in the Water Column chapter and are shown in Map 2.5a-b. Properties of the soft bottoms within a river system depend primarily on the origin of sediment inputs but also on elevation gradient, flow conditions, riparian cover, local geology, and water column characteristics. Upstream sources of sediment inputs into riverine systems include erosion of sediment bank shorelines, flushing of swamp forests and other wetlands, and transport of suspended sediment from upstream riverine flood waters (Riggs 1996). Bottom composition generally ranges from more consolidated material upstream (bedrock, boulders) to less consolidated material downstream (gravel, sand). Because freshwater rivers and creeks are eroding through older sediment banks, there tends to be a deep main channel dominated by medium-to-coarse grained sand with varying amounts of detritus. Shallow flats may exist on one or both sides of the channel. Sediment on these flats tends to consist of a layer of fine sandy mud on top of older sediments (Riggs 1996). Where the channel bed is relatively deep or wide, pools form and water velocity slows, allowing finer particles to settle (sand, silt). Where the channel bed is relatively narrow or shallow, riffles and runs occur and water velocity increases, leaving only the heaviest particles on the bottom (boulder, cobble). Dissolved oxygen in flowing waters is generally high, leading to aerobic surface sediments.

In freshwater lakes, like Lake Mattamuskeet, the shallow bottom around the shoreline is often unvegetated due to shoreline erosion, high wind exposure, or low water clarity (from turbidity or organic staining). In sheltered areas, however, the bottom may be covered by submerged aquatic vegetation. In deeper areas of lakes, the bottom is unvegetated because of low light availability. These deeper waters may become stratified during summer, causing anoxia or hypoxia on the bottom (Mitsch and Gosselink 1993).

Estuaries and sounds - intertidal flats, unvegetated shoreline and subtidal bottom

Sediment composition of soft bottoms in estuaries and sounds varies with geomorphology and position within the estuary. The basin morphology of most northern estuaries in North Carolina is similar to a shallow, flat-bottomed dish with a small lip around the perimeter (Pilkey et al. 1998). The estuarine shoreline is a cut bank with a narrow and shallow perimeter platform (the lip) that slopes gradually away from the shoreline to approximately 3-7 ft (1.5-2 m) deep, and then more abruptly to the floor of the central basin. The central basins deepen gradually from the inner estuary to the outer estuary from about 12 – 23 ft deep (4 to 7 m). The central basins become shallow near the mouths of the estuaries due to formation of sandy bars, and behind the barrier islands due to storm overwash and transport of sand from the inlets. Coarse sands are concentrated on the shallow perimeter platforms, shoals, and inlet mouths, while fine sediments such as organic rich mud (ORM) are concentrated in the deeper central basins and downstream channels (Wells 1989; Riggs 1996; Pilkey et al. 1998) (Map 6.2). General bottom topography of estuarine water bodies is shown in Map 4.1. The relationship between sediment composition and water depth is evident when comparing Map 4.1 and Map 6.2. The width and thickness of ORM increase as the estuary widens and deepens in the downstream direction, since the fine sediments are easily suspended and transported away from high energy waters (Riggs 1996).

Soft bottoms in the northern geologic province, including the Albemarle-Pamlico Estuarine System, consist of four general types of sediment: sand, peat, inorganic mud, and ORM (Wells 1989; Riggs 1996). Sands are derived from erosion of the sediment bank shorelines and shallow perimeter platform throughout the estuaries. Sand is also transported into the lower portion of the estuaries from barrier island overwash and transport through the inlets. Peats (sediments with more than 40% organic matter) are derived from flushing of organic matter from wetlands and erosion of wetland shorelines. Inorganic muds consist of several clay minerals, primarily derived from suspended sediment transported from riverine flood waters to the estuarine system. Organic rich mud is the most extensive sediment type in North Carolina's estuaries. It is composed of 5 to 40% organic matter (most commonly about 10%), mixed with inorganic clay (approximately 76%) and quartz sand (approximately 13%). Organic rich mud comprises approximately 70% of the sediment in North Carolina's estuarine system and is primarily concentrated in the central basins of the sounds.

Soft bottom in the southern estuarine system is dominated by sloped mudflats on the perimeter and interior of the smaller estuaries (i.e., White Oak River, Pages Creek) (Pilkey et al. 1998). The mudflats are riddled with tidal channels and support extensive salt marshes. In the lower estuary, sand is transported into the estuaries from the numerous inlets and barrier island overwash. In the upper estuary, small blackwater streams carry relatively low sediment loads into these estuaries, but the water contains large quantities of dissolved organic matter that give it a brown tea color. The Cape Fear River, unlike the other smaller river systems in the Southern Province, transports large sediment loads from eroding clay sediments of the Piedmont to the lower estuary.

Unvegetated shorelines occur where wave energy prevents colonization by plants and there is a gently sloping area for sand to build upon (Riggs 2001). The shoreline provides an area to absorb the physical energy from waves, tides, and currents, protecting upland areas. Although unvegetated nontidal shorelines are ordinarily exposed from water, and therefore not used by fish, the dynamic processes of erosion and sediment deposition affect the composition and supply of sediment in adjacent shallow water habitats. This in turn affects the type and productivity of the benthic invertebrate community. For example, unvegetated sediment bank shorelines are generally eroding and sandy, providing a source of sand to adjacent waters (Riggs 2001). Sand deposits from inlet flood tide deltas and overwash events on back barrier islands form shallow sand flats behind the islands. In contrast, marsh or swamp forest shorelines are generally not eroding and have a high organic content, thus providing fine organic sediments to adjacent waters. Several shoreline erosion studies have been conducted along North Carolina's coast that provide information on the character and condition of intertidal, shoreline, and shallow subtidal soft bottom and were compiled and summarized in Riggs (2001).

Intertidal flats are the unvegetated bottoms of estuaries and sounds that lie between the high and low tide lines. These flats occur along mainland or barrier island shorelines or can emerge in areas unconnected to dry land. Intertidal flats are most extensive where tidal range is greatest, such as near inlets and in the southern portion of the coast. Because the influence of lunar tides is minimal in the large sounds (e.g., Pamlico, Albemarle, and Currituck), true intertidal flats are not extensive, except for the area immediately adjacent to inlets (Peterson and Peterson 1979). Sediment composition on intertidal shorelines tends to shift from coarser, sandy sediment on higher portions of the shoreline, with greater wave energy, to finer, muddier sediments in the lower portion of the shoreline, with relatively less wave energy (Peterson and Peterson 1979). Conditions on intertidal flats are physically stressful for associated marine organisms. Drastic fluctuations in salinity, water and air temperature (in addition to air and wind exposure) occur during each tidal cycle. Due to physiological restraints and limited water depth, some mobile organisms are restricted to deeper waters or adjacent habitats to avoid the stressful extremes associated with low tide. However, the sediment provides a buffer from changes in temperature and salinity in the water column for benthic infauna (Peterson and Peterson 1979).

The inlets separating North Carolina’s barrier islands are part of a sand-sharing system among the islands, estuaries, and nearshore ocean. Intertidal flats or deltas form on the ebb and flood sides of inlets as sediments shift with tides and waves. Sediments in the vicinity of inlets are typically composed of coarse sands and shell fragments (Peterson and Peterson 1979). Ebb-tidal and flood-tidal deltas (i.e., the seaward and estuarine shoals of an inlet, respectively) are formed by waves and currents, and may contain large volumes of sand. Intense wave and current energy cause the flats to continually change, erode, and reform. The high instability of the ebb and flood tide deltas makes colonization by benthic invertebrates difficult (Peterson and Peterson 1979). Inlets are classified as stable, migrating, or ebb-tidal delta breaching (Fitzgerald et al. 1978). Unstable inlets may form extensive spits, tidal deltas, and sand bars, creating bathymetric complexity (or differences in water depth) in nearshore waters that attract certain fish species. The process of channel realignment and abandonment provides a mechanism for large sandbar complexes to move onto the adjacent barrier islands, supporting productive intertidal beach communities (Cleary and Marden 1999).

There are currently 20 inlets in North Carolina that connect estuarine waters to the sea (Map 6.3 a-c). Ten of these inlets originated as a result of storm breaches across barrier spits or islands and remain spatially unstable, including Oregon and Mason inlets (Cleary and Marden 1999). Mason Inlet, which has been migrating south rapidly, was artificially relocated in the winter of 2002. Mad and New (Corncake) inlets closed following the hurricanes of the last few years, and Old Drum Inlet reopened. A new inlet breached between Hatteras and Frisco during Hurricane Isabel in 2003, but was refilled by the United States Army Corps of Engineers (COE). There are nine larger inlet systems, including Ocracoke, Bogue, and the Cape Fear River inlets, which occupy ancient river channels. Two other inlets were artificially created: Drum and Carolina Beach inlets. Although originating as a storm-related breach, Tubbs Inlet was artificially relocated in 1970.

<u>Ocean intertidal beaches and subtidal bottom</u>

The locations of major marine intertidal and subtidal topographic features, such as beaches, inlets, inlet-associated ebb-tidal deltas, and shoals, are indicated in Map 6.1 a-e. The seafloor off the North Carolina coast is part of the Atlantic continental shelf, which slopes gradually from the coastline before dropping off steeply at approximately the 160–250 ft (50–75 m) isobath where the continental slope begins. In North Carolina, the continental shelf is relatively narrow, approximately 16 mi (30 km) off Cape Hatteras, 32 mi (60 km) off Cape Lookout, and about 49 mi (90 km) off Cape Fear. Water depth at the seaward limit of state territorial waters ranges from 50–70 ft (15–21 m) (Map 6.1 a-e). Because North Carolina is located at a transition between two major physiographic and zoogeographic zones, the marine subtidal bottom supports a high diversity of invertebrates.

North of Cape Hatteras, the shoreline and adjacent shoals tend to be linear, the shelf is relatively steep, and the bottom consists of a regional depositional basin known as the Albemarle Embayment, resulting in few exposed rock outcrops. Several prominent shoals, such as Wimble, Kinnekeet, and Platt shoals, also occur in this region, as well as a series of prominent ridges and swales that are spaced about 1,300–2,000 ft (400–600 m) apart, with mean relief of 3–23 ft (1–7 m), averaging 6–10 ft (2–3 m) in height (Inman and Dolan 1989; Rice et al. 1998). Shoals closest to shore, such as Wimble and Kinnekeet shoals, tend to be oriented at a 20–30° angle from the coastline, while those farther offshore run more parallel to the coast (MMS 1993).

The coastline south of Cape Hatteras consists of a series of arcs, dominated by three major capes (Hatteras, Lookout, and Fear) and three associated bays (Raleigh, Onslow, and Long) (Map 6.1 a-e). Long Bay continues into South Carolina to Cape Romain. Large shoals extend across the shelf from each cape (Diamond, Lookout, and Frying Pan shoals) for more than 11 mi (20 km). South of Cape Hatteras, the continental shelf has a greater amount of exposed rock outcroppings and is intersected with younger sediments originating from filled ancient river valleys (Riggs et al. 1995). The rock outcroppings are discussed in the hard bottom chapter of this plan.

The continental shelf off North Carolina has a relatively low supply of incoming sand, due to low direct river input, entrapment of most river-borne sediment in the upper estuaries and sounds, and minimal sediment exchange between adjacent shelf embayments (Riggs et al. 1998). The shoreface is the generally concave, upward surface extending from the surf zone to the point where the slope matches that of the continental shelf (Thieler et al. 1995). The base of the shoreface off North Carolina occurs at approximately 33–40 ft (10–12 m) water depth. The shoreface represents the area of active beach sand movement. Six classes of shoreface systems were recognized by Riggs et al. (1995) based on differences in the underlying geology. The nature of these shorefaces affects the geologic composition of the surface and underlying substrate of the subtidal bottom and shoreline and partially explains the patterns of localized erosion or deposition.

The intertidal zone of oceanfront barrier island beaches is the area periodically exposed and submerged by waves, varying with frequency and with lunar tide cycles. In this high energy area, waves continually rework and sort sediment by grain size. The uprush of water carries sediment onto the beach, with larger sediments deposited first and finer-grained sediment carried farther landward. The backwash carries some sediment back into the water. Because of this regular high wave energy, as well as occasional storm events associated with extreme wave action, the intertidal beach and surf zone typically have rapid scour and fill events. The sediments are generally much coarser, more highly sorted, and contain less organic matter than in protected estuarine intertidal flats (Donoghue 1999).

The surf zone is the shallow subtidal area of breaking waves seaward of the intertidal beach. Within the surf zone, longshore sandbars frequently develop and shift seasonally in response to wave energy. Seaward of the surf zone, the subtidal bottom consists of a series of minor ridges and swales. Ripple scour depressions, ranging from 130–330 ft (40–100 m) in width and up to 3 ft (1 m) in depth, occur along the southern portion of the coast and are perpendicularly oriented to the beach, extending to the base of the shoreface (Thieler et al. 1995; Reed and Wells 2000). These features are located adjacent to areas experiencing chronic severe beach erosion, and may be indicative of rapid offshore transport of sand during storms (Thieler et al. 1995).

Three major shoals extend perpendicular to Cape Hatteras, Cape Lookout, and Cape Fear: Diamond Shoals, Cape Lookout Shoals, and Frying Pan Shoals, respectively. Water depth on the shoals ranges from 2–18 ft (0.6–5.5 m), in contrast to adjacent waters that are 20–40 ft (6–12 m) deep. Due to an interest in beach nourishment projects for Dare County, Boss and Hoffman (2000) collected detailed information on the sand resources of North Carolina's Outer Banks, including specific data about Diamond Shoals. Diamond Shoals extend approximately 11 nautical miles (nm) (20 km) and are about

5.5 nm (11 km) wide. The estimated total volume of sand on the shoal was at least 1.66 billion cu yd, with approximately 256 million cu yd within state waters (Boss and Hoffman 2000). As such, cape shoals are major sand resources for coastal processes. Detailed mapping of the bottom has been done in other areas of the coast to varying extent with different techniques. *The results of these studies need to be compiled in a comprehensive and comparable manner to evaluate changes and trends in substrate character, as well as the feasibility of beach nourishment projects.*

6.2 ECOLOGICAL ROLE AND FUNCTIONS

Community structure

Freshwater

The freshwater benthic community varies greatly from extreme headwaters to mainstem rivers and may be more similar to that found in inland lake bottoms than in estuaries. Green algae and diatoms are more common than dinoflagellates (Rulifson et al. 1986). In headwater streams, algal production is negligible where there is complete tree canopy cover and the benthic community consists largely of organisms that break down and collect detritus. As the canopy opens up downstream, algae grazers and detritivores increase in abundance (Vannote et al. 1980). Mussels are an important component of the invertebrate community in freshwater soft bottom. There are over 60 species of freshwater mussels in North Carolina. The distribution and diversity of native freshwater mussels have been in a state of decline in North Carolina as well as in other southeastern states. The freshwater Asiatic clam (*Corbicula fluminea*), introduced about 50 years ago, has become a prominent component of many rivers (Lauritsen and Moxley 1983). Ecological problems associated with this non-native species include alteration of the benthic substrate, and competition with native mussels and other mollusks (Devick 1991). Zebra mussels (*Dreissena polymorpha*) have not been reported in North Carolina, but have been found in Virginia and 20 other states. Due the rapid rate that this non-native species has spread in the United States since first found in 1986, researchers feel that zebra mussels are likely to infest all southeastern states eventually, with negative impacts to the native mollusks (Neves et al. 1997). Freshwater benthic sampling, conducted by DWQ in all of North Carolina's river basins, provides detailed information on the abundance and diversity of benthic species present in the freshwater portion of North Carolina's coastal rivers.

Estuarine

Benthic microalgae are a key part of the food chain in estuarine soft bottom habitat. Benthic microalgae are microscopic photosynthetic algae that live in the top few millimeters of the surface of soft bottom (Miller et al. 1996). Because the unvegetated bottom appears barren, but is actually rich in photosynthetic algae, MacIntyre et al. (1996) referred to benthic microalgae as "The Secret Garden." Benthic microalgae on sand, mud flats, and subtidal bottom are composed primarily of benthic diatoms and blue green algae, with benthic dinoflagellates and filamentous green algae also present (Peterson and Peterson 1979). Dense mats of blue green algae sometimes form in protected higher portions of intertidal flats, giving the sediment surface a dark brown or blue-green appearance, which can form a crusty mat when dry at low tides (Peterson and Peterson 1979). Diatom mats are more abundant in the lower intertidal zone (Peterson and Peterson 1979). Benthic microalgae can either be attached to sediment particles or be mobile, migrating vertically through the sediment. Productivity depends on photosynthesis by these microalgae, which can only occur in sediments having adequate light penetration (MacIntyre et al. 1996). Photosynthetically active light generally penetrates only about 2-3 mm into the sediment, but can reach 5-20 mm in sandy, high energy environments.

Most benthic invertebrates inhabiting soft bottom live in the sediment (infauna), as opposed to the bottom's surface (epifauna), because of the high mobility of sediments (Peterson and Peterson 1979). These animals are classified by size and feeding mode. Microfauna are the very small protozoans (< 0.06 mm). Meiofauna are about 0.06 – 0.40 mm in size (the size of a sand grain), and include nematodes and copepods. Both microfauna and meiofauna are important grazers on benthic microalgae and bacteria. Macrofauna (>0.5 mm) contribute the most to infaunal biomass and include organisms such as amphipods, polychaetes, mollusks, echinoderms, and crustaceans (Peterson and Peterson 1979). These macrofauna may be deposit feeders or suspension feeders (Peterson and Peterson 1979; Miller et al. 1996). Deposit feeders ingest sediment and detrital deposits and assimilate bacteria, fungi, and microalgae from them. Compared to detritus and larger plants, microalgae may be a nutritionally richer food source for benthic invertebrates (Miller et al. 1996). Deposit feeders include mud snails, many polychaete worms, and certain bivalve clams and crustaceans.

Suspension feeders capture particles suspended in the water column. Common suspension feeders are bivalves such as the hard clam (*Mercenaria mercenaria*) and razor clam (*Tagelus plebeius*), and some polychaete worms (Miller et al. 1996). When sediment is resuspended, the benthic microalgae become available to the suspension feeders (Miller et al. 1996). A large proportion of intertidal bivalves' diet has been shown to consist of suspended benthic microalgae, particularly when chlorophyll concentrations in the water column are low (Page and Lastra 2003). While resuspended benthic microalgae can be beneficial to the invertebrate community as an additional food source, excessive suspended sediment and associated algae have been found to reduce growth rates and survival of macrofauna, such as hard clams (Bock and Miller 1995). Although the abundance of food sources affects invertebrate populations, benthic predators (such as spot and pinfish) were found to have a larger influence on soft bottom community composition and biomass relative to that of nutrient availability (Posey et al. 1995).

Larger, mobile invertebrates live on the surface of soft bottom. Fiddler crabs (*Uca* spp.) congregate on intertidal flats foraging for microalgae and detritus, and amphipods and insects also graze on the flats. On submerged flats and shallow bottom, blue crab (*Callinectes sapidus*) is an important predator. Other mobile invertebrates include horseshoe crab (*Limulus polyphemus*), whelks (*Busycon* spp.), tulip snails (*Fasciolaria* spp.), moon snails (*Polinices duplicatus*), penaeid shrimp (*Penaeus* spp.), hermit crabs (*Pagurus* spp., *Petrochirus* spp., and *Clibanarius vittatus*), sand dollars (*Mellita quinquiesperforata*), and spider crabs (*Libinia* spp.). Overall, estuarine soft bottom supports a high diversity of benthic invertebrates, with over 300 species documented in the southern portion of North Carolina (Hackney et al. 1996).

<u>Marine</u>

On oceanfront beaches, most benthic animals in the intertidal zone consist of infaunal burrowing forms. A diverse assemblage of meiofauna (0.06 – 0.4 mm in size) occurs in the lower beach community and acts as an important food source for many juvenile fish (Levinton 1982; Hackney et al. 1996). A relatively low diversity of macrofauna (>0.5 mm in size) (~ 20 – 50 species) exists in the intertidal beach compared to estuarine intertidal flats (~ 300 – 400 species) (Hackney et al. 1996). The dominant macrofauna by biomass in North Carolina's oceanfront intertidal beaches are mole crabs (*Emerita talpoida*) and coquina clams (*Donax variablis, D. parvula*) (Hackney et al. 1996; Donoghue 1999). Several species of amphipods and the spionid polychaete (*Scolelepis squamata*) have been reported as highly abundant on some beaches as well (Lindquist and Manning 2001).

Polychaete worms, isopods, mollusks, echinoderms, amphipods, and other crustaceans occur in sediments in the oceanfront intertidal beaches, cape and ebb tide shoals, surf zone and other subtidal bottom (Jutte 1999; Peterson et al. 1999). Three general groups of polychaetes occur in intertidal beaches (Hackney et al. 1996): a) burrowing deposit feeders, including thread worms (*Lumbrineris* sp., *Scolelepsis* sp.), and red-lined worms (*Nepthys* sp.); b) suspension feeders; and c) tube building burrow dwellers, such as plumed worms (*Diopatra* sp.) and lugworms (*Arenicola* sp.). Offshore sand bottom communities along the North Carolina coast are relatively diverse habitats containing over a hundred polychaete taxa (Lindquist et al. 1994; Posey and Ambrose 1994). Tube dwellers and permanent burrow dwellers are important benthic prey for fish and epibenthic invertebrates. These species are also most susceptible to sediment deposition, turbidity, erosion, or changes in sediment structure associated with sand mining activities, compared to other more mobile polychaetes (Hackney et al. 1996). In South Carolina, 243 species of benthic invertebrates were documented in the nearshore subtidal bottom (Van Dolah et al. 1994). Polychaetes and amphipods were the most abundant, although oligochaetes, bivalves, and crabs were also highly represented (Van Dolah et al. 1994). On ebb tide deltas, polychaetes, crustaceans (primarily amphipods), and mollusks (primarily bivalves) were the most abundant infauna, while decapod crustaceans and echinoderms (sand dollars) dominated the epifauna. Because periodic storms can affect benthic communities along the Atlantic coast to a depth of about 115 ft (35 m), the soft bottom community tends to be dominated by opportunistic taxa that are adapted to recover relatively quickly from disturbance (Posey and Alphin 2001). Many faunal species documented on the ebb tide delta are important food sources for demersal predatory fishes and mobile crustaceans, including spot, croaker, weakfish, red drum, and penaeid shrimp. These fish species congregate in and around inlets during various times of the year (Peterson and Peterson 1979), presumably to enhance successful prey acquisition and reproduction.

Four species of sea turtles (loggerhead, green, leatherback, and Kemp's ridley) currently nest on the beaches of North Carolina, although the loggerhead accounts for the majority of nesting activity. Kemp's ridley and leatherback nesting events are quite rare. Generally between 400 and 1000 marine turtle nests are documented per year in North Carolina (WRC, unpub. data). Successful nesting requires sufficient area of supratidal dry beach, adequate softness of sand to facilitate digging, ability of turtle to reach the nesting site without obstructions such as seawalls or fencing, and the ability of the site to avoid inundation throughout the nesting season. Sea turtles prefer to nest on wide sloping beaches or near the base of the dunes. The composition, color, and grain size of the beach sand affect the incubation time, sex, and hatching success of turtle hatchlings (Crain et al. 1995).

Over 147 species of birds have been documented roosting, feeding, or nesting on the beach and dune systems of North Carolina (<http://plover.fws.gov>, 2001). These systems are especially important for migratory shorebirds and colonial water birds. These birds forage and nest on the beach and overwash areas. Overwash events usually occur during storm events or in low areas during spring high tide conditions when seawater flows through the primary dune line, spreading out sand from the beach and dunes. Recently created overwash fans are generally unvegetated and function similar to the beach community. The sandflats, mudflats, and flattened dunes created by these overwashes are essential for several species of wildlife endemic to our coastal systems, including shorebirds and colonial water birds. In particular, the Wilson's plover and the federally threatened piping plover are both dependent on hurricanes and storms to provide the washovers they need as nesting habitat (D. Allen, WRC, pers. com., 2002). The least tern, common tern, and black skimmer are listed by the State as species of special concern, while the gull-billed tern is designated by the State as threatened.

Productivity

Freshwater and estuarine

Production of organic matter in North Carolina's estuarine system is derived from several primary producers, including phytoplankton in the water column, detritus from wetlands and submerged grasses, and benthic microalgae and macroalgae on soft bottoms and other structure (Currin et al. 1995; Wainright et al. 2000). Of these, benthic microalgae have only recently been recognized as an important source of primary production in estuarine systems (Cahoon and Cooke 1992; Pinckney and Zingmark 1993; de Jong and Van Beusekom 1995; MacIntyre et al. 1996). Benthic microalgae are the major food source for deposit feeders such as mud snails, certain bivalve clams, and many polychaete worms (MacIntyre et al. 1996). Chlorophyll *a* biomass and carbon productivity rates are often used as indicators of overall productivity. In North Carolina estuaries, values for chlorophyll *a* biomass from soft bottom has varied widely but generally ranged from 10-90 mg/m^2 (Posey et al. 1995). Similar ranges were found in other Atlantic coast states (Table 6.1). Production rates in North Carolina are thought to be similar to that reported for Delaware and South Carolina (Table 6.1) (C. Currin, NMFS, pers. com., 2004). In flowing freshwater creeks and rivers, little information is available in the scientific literature on benthic productivity. In general, primary production in these freshwater areas is greatest in shallow, well-illuminated benthic substrates.

Table 6.1. Benthic productivity estimates in Virginia and Delaware (Chesapeake Bay), North Carolina (Masonboro Sound), and South Carolina (North Inlet Estuary).

Region	Chl. *a* biomass (mg/m^2)	Carbon production ($g\ C/m^2/yr$)	Reference
Virginia	5 – 65	-	Rizzo and Wetzel (1985)
Delaware	-	79 – 99	Rizzo and Wetzel (1985)
North Carolina	10 – 90	-	Posey et al. (1995)
South Carolina	20 – 110	56 – 234	Pinckney and Zingmark (1993)

The most productive estuarine bottom, in terms of benthic microalgae, tends to be protected and shallow areas with muddy/fine sand (Pinckney and Zingmark 1993; MacIntyre et al. 1996). Productivity is generally lower in exposed areas, deep areas, or on coarse sand bottom (Chester et al. 1983; Sundback et al. 1991; MacIntyre et al. 1996). In the upper reaches of the estuary, where the bottom consists of soupy mud/silt, productivity declines because of the instability of the fine sediment and greater frequency of high turbidity (M. Posey, UNC-W, pers. com., 2003). Many of the typically productive areas of soft bottom, in terms of benthic microalgae, are also productive fish nursery areas. In shallow intertidal bottom, primary production may be greater than in the water column, while in deeper subtidal bottom, benthic production may be slightly less than in the water column (MacIntyre et al. 1996). In the Newport River estuary, benthic diatoms were found to be resuspended into the water column following wind or rain events, greatly altering the composition and abundance of plankton in the water column (Tester et al. 1995). Since there is a large and ongoing exchange of sediment, algae, and nutrients between the soft bottom and water column (benthic-pelagic coupling), especially in shallow waters, it is difficult to distinguish between productivity in the water column versus soft bottom (Cahoon and Cooke 1992; MacIntyre et al. 1996).

Factors that control the magnitude and variability of benthic primary productivity on soft bottom include temperature, light availability, sediment grain size, and community biomass (amount of chlorophyll present) (Pinckney and Zingmark 1993; Barranguet et al. 1998; Cahoon et al. 1999; Guarini et al. 2000). Since the depth to which benthic microalgae photosynthesize is determined by light, most researchers consider light the major factor affecting primary production rates (MacIntyre et al. 1996). Nutrients are not thought to limit productivity in soft bottom habitat because bacteria quickly convert detritus to inorganic nutrients (remineralization), making nutrients readily available in the sediment (Peterson and Peterson 1979; Admiraal et al. 1982).

In addition to primary productivity from benthic microalgae, organic matter on soft bottom habitat is derived from detrital matter from marsh vegetation, submerged grasses, and macroalgae that settles on soft bottoms (Currin et al. 1995; Wainright et al. 2000). In a South Carolina estuary, benthic microalgae accounted for approximately 22 – 38% of the primary production, with marsh vegetation accounting for approximately 30 – 59% and phytoplankton accounting for approximately 15 – 27%. The relative contribution of different primary producers varies by the diet preference of individual fish or invertebrate species, their position within the estuary, and seasonal and episodic weather conditions (Tester et al. 1995; Wainright et al. 2000; Page and Lastra 2003). Each source of primary production contributes to the estuarine food web. This web supports large numbers of benthic invertebrates, which are the primary food base for North Carolina’s bottom feeding larval, juvenile, and adult fish and invertebrates (Peterson and Peterson 1979).

Marine

In the surf zone, inorganic nutrients are continually resuspended by wave action and retained by circulation patterns in sufficient amounts to create localized phytoplankton blooms, particularly composed of diatoms (McLachlan et al. 1981; Hackney et al. 1996). This self-sustaining nutrient input drives phytoplankton production, which supports intertidal filter feeders and, consequently, high concentrations of baitfish and estuarine dependent fish migrating through the shallow waters of the surf zone. Benthic invertebrates in the subtidal bottom of the surf zone and inlets provide an important link between primary producers and predators, such as demersal fish and crustaceans. Many of these predators have high economic value in recreational and commercial fisheries. Peterson and Peterson (1979) compiled a list of the diets of many common fish that forage in the intertidal flats. Some of the species that forage on benthic invertebrates in the surf zone and shoals include inshore lizardfish, pompano, pigfish, pinfish, spot, kingfish, red drum, Atlantic croaker, northern sea robin, and summer flounder. Additional information on fish utilization of the surf zone is discussed in the water column chapter of this plan.

Benthic microalgae on subtidal bottom in the coastal ocean are an important source of primary production. Viable chlorophyll *a* occurs in sediments across the continental shelf in Onslow Bay (Cahoon et al. 1990). Studies in Onslow Bay have found that roughly 80% of the chlorophyll *a* in the bay was associated with microalgae in or on the sediment. Benthic microalgal biomass (36.4 mg chlorophyll a/m^2) exceeded phytoplankton biomass (8.2 mg chlorophyll a/m^2). Gross benthic microalgal production averaged 24.9 mg carbon/m^2/hr, compared to 27.4 mg carbon/m^2/hr integrated water column phytoplankton production (Cahoon and Cooke 1992). Benthic microalgal production also surpassed integrated phytoplankton production primarily in the summer months, when light flux to the bottom is greater and phytoplankton biomass is generally lower. Pennate diatoms dominate the benthic microflora. These microalgae are grazed by demersal zooplankton, meiobenthos, and other macrofauna.

Ecosystem enhancement

Soft bottom plays a very important role in the ecology of estuarine ecosystems as a storage reservoir of chemicals and microbes. Intense biogeochemical processing and recycling establish a filter to trap and reprocess watershed-derived natural and human-induced nutrients and toxic substances. These materials may pass through an estuary (Matoura and Woodward 1983), become trapped in the organic rich oligohaline (low salinity) zone (Sigels et al. 1982; Imberger et al. 1983), or migrate within the estuary over seasonal cycles (Uncles et al. 1988). The fate of the materials depends upon salinity gradients, which are driven by freshwater discharges, density stratification, and formation of salt wedges (Matson and Brinson 1985, 1990; Paerl et al. 1998). Density gradients (stratification) hamper mixing and oxygen exchange of sediments and water in bottom waters with overlying oxygenated waters, leading to depletion of dissolved oxygen in bottom water (Malone et al. 1988).

In North Carolina's slow-moving, expansive estuaries, nutrients and organic matter from the watershed runoff and phytoplankton production are stored in the soft bottoms. Depending upon freshwater discharge and density stratification, these materials are recycled within the sediments via microbial activities and from the sediments into the overlying waters. Increased inflows of nutrients exacerbate the process, leading to more rapid and expanding dissolved oxygen depletion. In organic enriched oligohaline zones (e.g., Pamlico and Neuse River estuaries), nutrient-induced recycling results in higher microbial activity and oxygen depletion (B.J. Copeland, NCSU, pers. com., 2004).

Although soft bottom habitat is composed of unconsolidated shifting sediments, colonization by benthic microalgae reduces the extent to which sediment is resuspended at low velocities, stabilizing bottom sediments and reducing turbidity in the water column (Holland et al. 1974; Underwood and Paterson 1993; Yallop et al. 1994; Miller et al. 1996). In spite of this, microalgae cannot stabilize sediments under intense or prolonged disturbance conditions, such as during large storm events or in the surf zone (Miller 1989). Structure from tube dwelling invertebrates also helps to bind the sediment (Peterson and Peterson

1979), while filtering activity of dense aggregations of suspension feeders (hard clams) clears significant amounts of plankton and sediment from the water column and improves water clarity (Miller et al. 1996). Yet, because of the absence of large, extensive structure, soft bottom provides relatively less stabilization benefits than other estuarine habitats.

Intertidal shorelines, flats, tidal deltas, and sand bars along the ocean shoreline buffer and modify wave energy, reducing shoreline erosion. Alterations to the ebb and flood tide deltas can result in significant changes in the adjacent barrier island shorelines. Flood-tidal deltas are an important source of sand, which allows barrier island migration to respond to sea level rise (Cleary and Marden 1999). The soft bottom associated with inlets has a great influence on overall barrier island dynamics.

Fish utilization

Like the water column, soft bottom is used to some extent by almost all native coastal fish species in North Carolina. However, certain species are better adapted to, characteristic of, or dependent on shallow unvegetated bottom. Flatfish, rays, and skates are well suited for utilization of soft bottom. Juvenile and adult fish species that forage on the rich abundance of microalgae, detritus, and small invertebrates are highly dependent on the condition of soft bottom. Table 6.2 summarizes important fishery and nonfishery species that are dependent on subtidal bottom for some portion of their life history and the ecological function of the soft bottom habitat.

Foraging

One of the most important functions of soft bottom habitat is as a foraging area. Members of several trophic levels in the benthic community benefit directly or indirectly from a) the high concentrations of organic matter transported to and produced on soft bottom and b) the numerically abundant, diverse invertebrate fauna associated with soft bottom – including herbivores (e.g., planktonic and benthic algal feeders), detritivores, predators of benthic invertebrates and fish (secondary consumers), and predators of those predators (tertiary consumers) (Peterson and Peterson 1979).

Table 6.2. Partial list of common or important fish species occurring on soft bottom habitat in riverine, estuarine, and ocean waters, and ecological functions provided to those species. Bolded species indicate relatively higher association on soft bottom habitat.

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

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

[1] Sources: Peterson and Peterson (1979); Thorpe et al. (2003); Manooch (1984); Hildebrand and Schroeder (1972); Lippson and Moran (1974); Wang and Kernehan (1979)

[2] Existing commercial or recreational fishery. Other species important to the system as prey items.

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

[4] Former fishery, but fishing moratorium since 1991

[5] Incl. Atlantic sharpnose, blacknose, blacktip, bonnethead, dusky, sandbar, scalloped hammerhead, and spinner sharks

[6] Uses surf zone almost exclusively as nursery area

Both plankton and benthic feeding herbivorous fish are found in abundance on intertidal flats. Schools of baitfish, small pelagic fish that tend to group together, are common over subtidal soft bottom and very abundant on shallow intertidal flats. These baitfish, such as anchovies, killifish, and menhaden, feed on the abundant supply of phyto- and zooplankton in the water column, but also consume resuspended benthic algae, microfauna, and meiofauna (Peterson and Peterson 1979). Although the majority of detritivores of the soft bottom habitat are invertebrates, striped mullet, white mullet, and pinfish also feed on detritus on subtidal bottom and intertidal flats. Other fish species use detritus as an alternate food source when preferred items are not available.

Most fish that forage on soft bottom are predaceous. Predators of benthic invertebrates include juveniles and adults of the following species (Peterson and Peterson 1979; Bain 1997):

- rays and skates,
- flatfish (southern flounder, summer flounder, hogchoker, tonguefish),
- several species of drum (spot, Atlantic croaker, red drum, kingfishes, silver perch),
- Florida pompano,
- pigfish,
- sea robins,
- lizardfish,
- spadefish,
- gobies, and
- shortnose and Atlantic sturgeons.

The compressed body forms of flatfish, rays, and skates assist in prey acquisition and predator avoidance on shallow intertidal flats (Peterson and Peterson 1979). For example, flounder forage on shallow flats by laying still, by concealing themselves under a thin layer of sediment, or by changing skin color. Small flatfish, including the bay whiff, fringed flounder, hogchoker, and tonguefish, feed mostly on copepods, amphipods, mysids, polychaetes, mollusks, and small fish. By way of comparison, summer and southern flounder primarily consume fish, such as silversides and anchovies, as well as shrimp and crabs, small mollusks, annelids, and amphipods (Peterson and Peterson 1979). Various rays excavate large pits while feeding, creating slightly deeper pockets of water that other fish and invertebrates use as refuge. Mollusks, annelids, crustaceans, and fish comprise the typical diet of rays.

To avoid predation, small fish commonly feed on open, unvegetated bottom at night and hide near structure during the day (Peterson and Peterson 1979). Larger predators that feed on smaller, benthic-feeding fish and invertebrates typically move onto the flats during high water to feed on schools of fish. These predators include sharks (sandbar, dusky, smooth dogfish, spiny dogfish, Atlantic sharpnose, scalloped hammerhead), drum (weakfish, spotted seatrout), striped bass, and estuarine dependent reef fish (black sea bass, gag grouper, sand perch, sheepshead) (Peterson and Peterson 1979; Thorpe et al. 2003).

Due to their size and shape, small baitfish and flat bodied rays, skates, and flounders have a feeding advantage over other fish in that they can forage on intertidal flats for greater amounts of time than larger fish. These fish groups are considered to be most characteristic of intertidal flats and would be most affected by habitat degradation and loss of intertidal flats from dredging, filling, bulkheading, or other anthropogenic causes (Peterson and Peterson 1979).

Fish species and age composition over soft bottom vary seasonally. Baitfish are present on shallow flats throughout the year. In the spring, large schools of baitfish are joined by juvenile fish that were spawned offshore in the winter (spot, Atlantic croaker, menhaden). In the summer, these species remain abundant on shallow unvegetated bottom; flatfish and rays also appear at this time. By fall, fish species diversity is at a maximum since summer residents and fall migrants are both present. Migratory fish feeding on the soft bottom include bluefish, striped mullet, kingfish, spotted seatrout, red drum, and many others

(Peterson and Peterson 1979).

Ocean subtidal bottom serves as important foraging grounds for numerous fish species, particularly for Florida pompano, red drum, kingfish, spot, and Atlantic croaker, weakfish, and striped bass. Many commercially or recreationally important fish and invertebrate species, such as red drum, striped bass, shrimp, and summer flounder, are caught while they aggregate and feed over subtidal bottom in nearshore ocean waters. These species appear to be strongly associated with distinct topographic features of the subtidal bottom, such as the cape shoals, channel bottoms, sandbars, and sloughs. *The natural processes that create these features need to be maintained. Additional public outreach is needed to emphasize the importance of natural barrier island and estuarine processes.*

The food resources present in and on soft bottom are needed to support hard bottom fish species. Demersal zooplankton and infaunal macroinvertebrates from sand substrate have been found to be a quantitatively important component of many species' diets and an important link to reef fish production (Cahoon and Cooke 1992; Thomas and Cahoon 1993; Lindquist et al. 1994). Reef species documented foraging over sand bottom away from the reef include tomtate (*Haemulon aurolineatum*), whitebone porgy (*Calamus leucosteus*), cubbyu (*Equetus umbrosus*), black sea bass (*Centropristis striata*), and scup (*Stenotomus chrysops*) (Lindquist et al. 1994). Therefore, benthic microalgal production on the subtidal bottom of Onslow Bay, as well as other similar shelf habitats, is an important component to the continental shelf productivity and is an important link to the ecology of hard bottom habitats[77].

Spawning

Many demersal fish spawn over various areas of soft bottom habitat in North Carolina's coastal waters (Table 6.2). In fresh water, resident species such as largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*) spawn on shallow flats where they lay eggs in bowl-shaped nests. Eggs may be dependent on the small structure available on the unvegetated bottom, such as emerging worm tubes or woody debris, to hold them in position. Since all life stages of freshwater resident fish (spawning adults, eggs, larvae, juveniles) remain near the same area of soft bottom habitat, they are relatively more vulnerable to degraded soft bottom habitat conditions than migratory species. Anadromous species, such as Atlantic and shortnose sturgeon (*Acipenser oxyrinchus oxyrinchus* and *A. brevirostrum*, respectively), spawn in upper freshwater portions of coastal rivers (Moser and Ross 1995).

Estuarine spawners include resident fish and invertebrates, as well as migratory fish that are summer estuarine spawners. Estuarine resident species include common invertebrates that occupy the intertidal flats, like hard clams, whelks, snapping shrimp, and hermit crabs. Small schooling baitfish such as mummichogs and striped killifish spawn in the marsh edges near soft bottom (Hildebrand and Schroeder 1972; Manooch 1984). Species of flatfish, including the windowpane, and hogfish have been reported to spawn on estuarine soft bottom (Hildebrand and Schroeder 1972; Manooch 1984).

Summer estuarine spawners include several species of drum. Weakfish and silver perch were documented spawning in deep estuarine channels near Pamlico Sound inlets (Ocracoke and Hatteras inlets) and in deep areas of Pamlico Sound from May to September, peaking in May and June (Luczkovich et al. 1999a). Spotted sea trout spawn on the east and west sides of Pamlico Sound during a similar time period, with peak activity observed around July. Specific spawning areas for spotted sea trout identified on the west side of Pamlico Sound were Rose Bay, Jones Bay, Fisherman's Bay, and Bay River (Luczkovich et al. 1999a). Red drum were documented spawning in the mouth of the Bay River on the west side of Pamlico Sound, and in estuarine channels near Ocracoke Inlet (Luczkovich et al. 1999a). Blue crabs also spawn near inlets in summer (DMF 2000d).

Several species of sharks pup in North Carolina's nearshore ocean waters. North of Cape Hatteras,

[77] Refer to Hard bottom Chapter, Ecological role and function for additional information.

pupping of spiny dogfish over subtidal bottom has been documented in winter months (W. Laney, USFWS, pers. com., 2003). Subtidal bottom in the southern portion of North Carolina state waters serves as pupping grounds for the Atlantic sharpnose shark (*Rhizoprionodon terraenovae*), bonnethead shark (*Sphyrna tiburo*), blacknose shark (*Carcharhinus acronotus*), spinner shark (*C. brevipinna*), dusky shark (*C. obscurus*), and, to a lesser extent, blacktip shark (*C. limbatus*), sandbar shark (*C. plumbeus*), and scalloped hammerhead shark (*S. lewini*). Most neonate (newborn) sharks were found in June and July (Beresoff and Thorpe 1997; Thorpe et al. 2003).

Most ocean spawning activity by estuarine dependent species occurs beyond state waters during the winter months. However, eggs and larvae are carried in the water column by currents through nearshore state waters and inlets to estuarine nursery areas. Important spawning aggregations of summer flounder occur on Wimble, Platt, and Kinnekeet shoals off the Outer Banks, in state and federal waters from November to March, peaking near January in North Carolina (MAFMC 1998). Locations of summer flounder spawning aggregations are linked to environmental conditions, such as water temperature and wind direction, and are generally concentrated north of Cape Hatteras, but extend to Cape Lookout.

Nursery

Shallow soft bottom habitat, usually adjacent to wetlands, is utilized as a nursery for many species of juvenile fish. The shallow unvegetated bottom provides an abundance of food and is inaccessible to larger predators. Shallow unvegetated flats have been documented as being particularly important nursery habitats for juvenile summer and southern flounder (Burke et al. 1991; Walsh et al. 1999). A partial list of species that use soft bottom habitat as a nursery area is included in Table 6.2. Studies and ongoing DMF juvenile fish monitoring have found that shallow unvegetated bottom supports high abundances of juvenile fish, composed of relatively few species but which have similar life histories and feeding patterns (Ross and Epperly 1985).

The dominant juvenile species utilizing shallow soft bottom estuarine nursery areas are estuarine dependent winter spawners. Most of the species spawn offshore during the winter. The larvae are transported through inlets into estuarine waters. For many species, the uppermost area of shallow creek systems corresponds to where larval settlement of winter spawned species occurs – the primary nursery areas (Weinstein 1979; Ross and Epperly 1985). However, in tributaries on the western side of Pamlico Sound, such as Neuse, Pamlico, Bay and Pungo rivers, larval settlement tends to occur in lower portions of the creeks. Unlike larval settlement in areas south of Pamlico Sound, salinity is low in the upper reaches of the Sound's tributaries and this may deter larval settlement in those areas. Abundance of juvenile species in estuarine nursery areas peaks between April and July and is correlated with water temperatures (Ross and Epperly 1985). As fish grow, they move to deeper waters and areas lower in the estuary.

Analysis of fishery independent trawl sampling data, from shallow creeks and bays in Pamlico Sound tributaries, found 78 different fish and invertebrate species over a two-year period (Ross and Epperly 1985). Eight species comprised more than 97% of the total fish abundance. Data from DMF's ongoing juvenile fish monitoring program, which began in 1971, show that the same eight species continue to dominate North Carolina's estuaries (Ross and Epperly 1985). This long-term database provides fishery independent information on species composition and abundance to identify primary and secondary nursery areas. From 1990 to 2003, the eight species that were the most abundant in both the northern and southern sampling sites were:

- spot
- pinfish
- brown shrimp
- Atlantic croaker
- bay anchovy

- blue crab
- silver perch
- Atlantic menhaden

In addition, southern flounder and white shrimp were among the most abundant species sampled in the northern and southern areas, respectively. From 1990 to 2003, a total of 178 species was collected and identified from the juvenile fish monitoring stations throughout the coast (DMF, unpub. data). Because sampling is not conducted year-round, it is probable that this figure underestimates the true number of species present. The annual number of species has ranged from 49 to 83 species per year north of Cape Lookout, and from 45 to 60 species per year south of Cape Lookout (DMF, unpub. data). The consistent abundance of several species over time is an indication that these areas continue to function as healthy nurseries. *Temporal and spatial expansion of juvenile fish sampling would provide additional information on trends in juvenile fish utilization of soft bottom and other habitats, especially summer and fall spawning species, which are generally not present at existing sampling stations during May and June.*

Statistical analyses of DMF's juvenile fish data in the Pamlico Sound system identified specific fish groupings or associations (Ross and Epperly 1985; Noble and Monroe 1991). From the latter analysis, four geographically distinct groupings of juvenile fish species occur in the Pamlico estuarine system (Table 6.3). Menhaden and spot were omitted from the analysis because they were so abundant in all areas that they masked other species abundance trends. Group 1 occurred in the Pamlico, Pungo, and Neuse rivers, and along eastern Albemarle Sound. Group 2 occurred in the western bays of Pamlico Sound. Group 3 was located in the shallow area behind the Outer and Core banks, from Oregon Inlet south to Cape Lookout. Group 4 was located along the western shore and tributaries of Core Sound (Table 6.3). Fish groupings in Pamlico Sound appeared to be affected by Bluff Shoal, which runs across the sound in a southeast-northwest direction from around Ocracoke Inlet north to Bluff Point. Bluff Shoal effectively separates Pamlico Sound into distinct basins of differing depth and sediment composition and alters larval settlement patterns into the sound. Distinct fish species groupings are found north and south of the shoal (Ross and Epperly 1985). Salinity was the most important abiotic variable affecting species composition (Noble and Monroe 1991). Groups 1, 2, and 4 occurred where the bottom consisted primarily of shallow unvegetated sediment, while group 3 occurred in SAV beds.

Table 6.3. Dominant juvenile fish species groupings found in the Pamlico Sound system by biotic cluster analysis of juvenile fish data (Noble and Monroe 1991).

Group	Location	Dominant fish species	Primary Habitat
1	Pamlico, Pungo, Neuse rivers, eastern Albemarle Sound	Atlantic croaker, brown shrimp, blue crab, southern flounder	Shallow unvegetated sediment
2	Western bays of Pamlico Sound	Species above + weakfish, spotted seatrout, silver perch	Shallow unvegetated sediment
3	Behind the Outer and Core banks	Pinfish, pink shrimp, black sea bass, gag, pigfish, red drum	SAV beds
4	Western shore and tributaries of Core Sound	Summer and southern flounder, brown shrimp	Shallow unvegetated sediment

In the southern portion of the coast, DMF biologists have found that juvenile fish tend to be most abundant in shallow waters with unvegetated muddy sediment (J. Schoolfield, DMF, pers. com., 2003). The dominant, demersal, juvenile species in coastal waters south of the Pamlico system were also found behind Core Banks and the Outer Banks. Although black sea bass and gag are not very common, brown shrimp, white shrimp, striped mullet, spot, and menhaden are more common in the southern estuaries (R. Carpenter, DMF, pers. com., 2003).

Many areas used as nurseries by estuarine dependent fish have been designated as Primary or Secondary Nursery Areas by MFC (Maps 2.3 and 2.4 in Chapter 2). However, there are other areas of soft bottom that function as nurseries but are undesignated. Benthic anadromous fish, such as Atlantic and shortnose sturgeon, use freshwater soft bottom as a nursery. *The specific locations of anadromous fish spawning areas need to be designated by the MFC and adequately protected*. Nearshore ocean subtidal bottom is also a nursery area for summer flounder and shark species. The primary nursery grounds for coastal shark species is in the vicinity of where pupping occurs. Small coastal sharks that use this habitat for a nursery area include spinner (*C. brevipinna*), blacknose (*C. acronotus*), and dusky (*C. obscurus*) sharks (Beresoff and Thorpe 1997; Thorpe et al. 2003). Juvenile Atlantic sturgeon and spiny dogfish, both demersal feeders with Overfished fishery status, have been documented over nearshore subtidal bottom between Oregon Inlet and Kitty Hawk during winter months (Cooperative Striped Bass Tagging Program, unpub. data). Subtidal bottom, particularly the surf zone, is also a nursery area for Florida pompano, southern and gulf kingfish (Hackney et al. 1996).

<u>Refuge</u>

Soft bottom habitat can provide refuge to some organisms in some locations through predator exclusion. Shallow, intertidal flats may be inaccessible to large fish predators and therefore protect small and juvenile fish and invertebrates (Peterson and Peterson 1979; Ross and Epperly 1985). Consequently, juvenile fish recruit into the shallowest portions of the estuary first. Many invertebrates, including hard clams, can avoid predation by burrowing into the sediment (Luettich et al. 1999). Flatfish, such as flounder and rays, and other small cryptic fish, like gobies, can bury slightly into the sediment, camouflaging themselves from predators (Peterson and Peterson 1979). Nonetheless, soft bottom habitat in deep water is a vulnerable place for small fish and invertebrates that cannot burrow. For example, flounders also camouflage themselves in the sediment to ambush prey (Walsh et al. 1999). Because of this, many fish in subtidal water will venture out to feed on the open bottom only at night (Summerson and Peterson 1984).

<u>Corridor and connectivity</u>

Freshwater and estuarine soft bottom channels are the highways for migrating adult demersal fish species to and from other estuarine habitats and the ocean. Demersal feeding anadromous fish, such as sturgeon and striped bass, require a corridor of soft bottom to reach upstream spawning areas. Inlets act as conduits for exchange of sediment, water, and marine organisms between the estuaries and the ocean. Because large fish are less likely to be consumed as prey, they can travel relatively safely over less turbid sand flats and in channels of the middle and lower estuaries (Walsh et al. 1999). Smaller flatfish tend to be more abundant in the shallower uppermost portion of the estuary, where salinities are low, turbidity high, and sediments muddy with high detritus content (Walsh et al. 1999).

While connectivity among structured habitat patches, such as SAV, wetlands, and shell bottom, facilitates movement of blue crabs and other mobile predators through an estuary, a few meters of unvegetated bottom can act as a barrier to movement (Micheli and Peterson 1999). Such barriers can be beneficial to small invertebrates by potentially obstructing predator dispersal and reducing predation risk. Small crabs, gastropods, and infaunal bivalves, such as hard clams, were more abundant, denser, and had higher survival rates on isolated oyster beds (at least 10-15 m of unvegetated bottom between habitats) than on oyster beds adjacent to salt marsh or SAV (Micheli and Peterson 1999). Blue crab predation on infaunal bivalves was greater along vegetated edges of salt marshes and seagrass beds than in unvegetated intertidal flats (Micheli and Peterson 1999). Although structural habitat separations by unvegetated soft bottom may benefit the survival or viability of infaunal populations, fish and crustacean productivity may be enhanced by connectivity of structured estuarine habitats (Micheli and Peterson 1999). These habitat-mediated predator/prey interactions point out the importance of maintaining the integrity of an entire estuarine system.

6.3 STATUS AND TRENDS

Status of soft bottom habitat

Since standardized or comprehensive baseline mapping of soft bottom habitat has not been completed, and because sediments shift and move over time, it is currently not possible to quantify how the extent and condition of the habitat has changed through time. The loss of more structured habitat, such as SAV and shell bottom, has undoubtedly led to gains in soft bottom habitat, but the low quality of areas gained may not be considered beneficial to the ecosystem as a whole. The general type and condition of shorelines in the Albemarle-Pamlico region and Bogue Sound, as well as the rough location of eroding and stabilized shorelines in these areas, were summarized by Riggs (2001). The primary alterations to soft bottom habitat are associated with dredging for navigational channels and marina basins. Refer to the threats section for more information.

Status of associated fishery stocks

<u>Fishery independent monitoring programs</u>

The DMF began a juvenile fish monitoring program (Estuarine Trawl Survey) in 1971. This long-term database provides fishery independent (data gathered independent of the fishery) information on species composition and abundance to identify primary and secondary nursery areas, shallow soft bottom habitat usually surrounded by wetlands. The Pamlico Sound Survey is another long-term monitoring program used to calculate juvenile abundance indices in Pamlico Sound and the lower portion of the Pamlico and Neuse estuaries. Data from this survey are compared to results from the Estuarine Trawl Survey and are also used as an indicator of young of year class strength. Juvenile abundance indices (JAI) are calculated from these sampling programs for major fish and invertebrates. The JAI is the annual geometric mean (weighted by strata) of the number of individuals per tow for young of the year fish or invertebrates. The JAI is considered an accurate indicator of recruitment and year-class strength for many species, including southern flounder (DMF 2003c). The information is used to determine stock status of fishery species by various fishery management agencies. Juvenile abundance indices are also used as a criterion to qualify an area as a designated Primary or Secondary Nursery Area. Designated areas are monitored regularly to provide long-term information on status and trends in recruitment of the dominant estuarine dependent species. Both surveys are critical components to stock assessments since they are independent of commercial or recreational fisheries (DMF 2003c). Trends in juvenile abundance indices may indicate change in the habitat conditions (DMF 2003c). However, consistent and comparable JAI data are only available to about 1990 and, prior to this time, considerable habitat losses and changes occurred.

Flatfish are closely linked to soft bottom habitat and juvenile abundance indices from the Estuarine Trawl Survey for southern flounder and hogchoker are shown in Figure 6.1. Southern flounder is a commercially and recreationally important fishery species, while hogchoker is a non-fishery species found in northern and southern estuaries of the state. The JAIs for both species have followed similar temporal patterns, varying between 0.5 to 2.5. Both species had peak JAIs in 1996. JAI of southern flounder experienced large declines in 1997, 1998, and 2002; notably, a 16.7% decline was recorded between 2001 and 2002. The 2002 stock status report stated that the estimated population biomass of this species had declined by 32% over the past decade (DMF 2003a). Hogchoker JAI also declined to low levels in 1998, showed some improvement in 1999, but has remained relatively low since 2000. These results indicate that recruitment of both fishery and non-fishery flatfish species has been variable over time and strongly influences annual JAIs. However, hogchoker has exhibited greater recovery following years with low JAIs than southern flounder. Both species have exhibited relatively low JAIs since 1996.

Trends in JAI of Atlantic croaker from both the Estuarine Trawl Survey and the Pamlico Sound Survey are very similar (Figure 6.2). Atlantic croaker is a benthic feeding fish that could be affected by changes in soft bottom habitat, such as reductions in benthic food sources due to toxicity or anoxia in sediments. Annual trends in juvenile abundance of both surveys are very similar. Sizes of fish collected in the

Pamlico Sound Survey were larger, accurately reflecting that juvenile fish first settle in the primary nursery areas and later move into the sound. Both juvenile abundance indices for Atlantic croaker experienced large fluctuations and are currently near their lowest recorded levels in the past 12 years. According to the DMF 2002 stock status report, there are some signs of recovery, such as increased commercial CPUE, increased landing size, and improved age structure (multiple year classes), but JAIs remain below average and landings in estuarine waters have not returned to historical levels. An ASMFC FMP was created in 1987 and was reviewed most recently in 1998. Research needs, including a coast-wide stock assessment, have been completed and are being reviewed by ASMFC. The stock assessment determined that Atlantic croaker is a recruitment-driven stock, where biomass and landings fluctuate in response to large year classes.

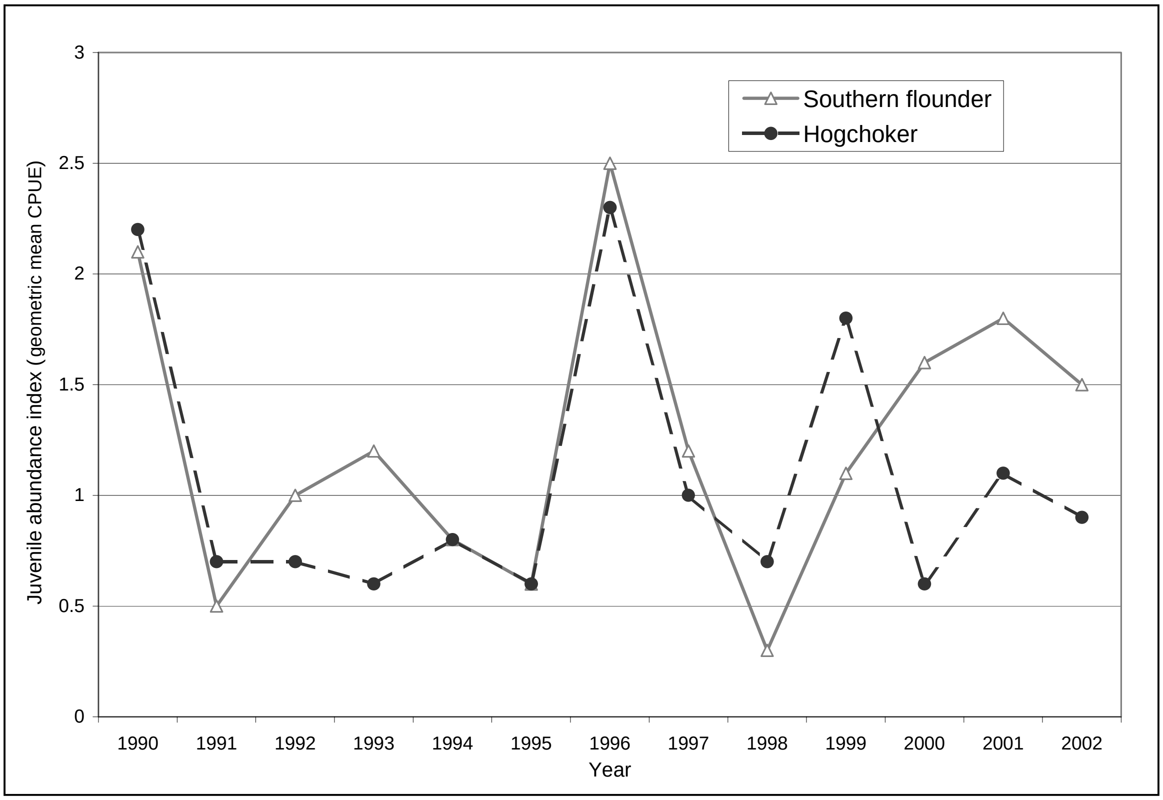


Figure 6.1. Southern flounder and hogchoker juvenile abundance indices (geometric mean CPUE) from two DMF juvenile fish sampling programs, core stations sampled in May and June for each program pooled (Estuarine Trawl Survey and the Pamlico Sound Survey), 1990-2002.

Hard clams, although also present in shell bottom and SAV habitats, require soft bottom habitat for burrowing. Because clams remain fairly stationary and are filter feeders, they may be vulnerable to habitat degradation, such as sediment contamination or sedimentation. The status of the hard clam stock is currently unknown due to lack of adequate data (DMF 2001b). However, using trip ticket data, DMF (2001b) concluded that hand harvest of clams appeared to be stable, but that clam abundance, in areas where mechanical clam harvest occurred, appeared to decline from 1994 to 1999. MFC recommended that mechanical harvest limits in Core Sound be further restricted. *Reducing the area available to mechanical clam harvesting is another means of protecting clam stocks and would also provide additional habitat protection*.

Twelve of 18 soft bottom associated fishery species (bolded species in Table 6.2) were evaluated by DMF for stock status in 2002. Of these twelve species, two (17%) were of unknown status. Of the ten stocks whose status is known, three (30%) were classified as Viable, one (10%) was Recovering, two (20%)

were of Concern, and four (40%) were Overfished (Table 6.2, Figure 6.3). Viable species included shrimp, spot, and summer flounder; red drum was a Recovering species. Overfished species included Atlantic and shortnose sturgeons, southern flounder, and coastal sharks. The species listed as Concern include striped mullet and Atlantic croaker.

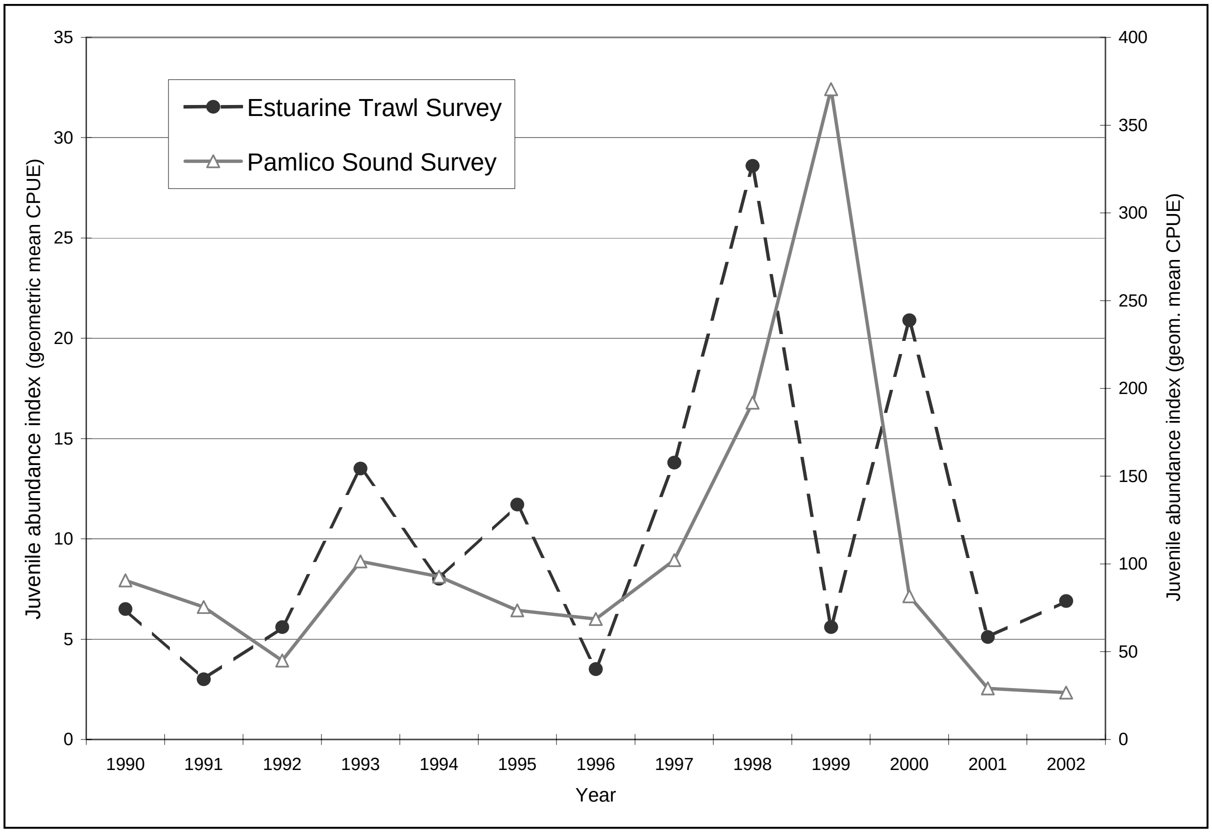


Figure 6.2. Atlantic croaker juvenile abundance indices (geometric mean CPUE) from two DMF juvenile fish sampling programs, core stations sampled in May and June for each program pooled (Estuarine Trawl Survey and the Pamlico Sound Survey), 1990-2002.

Both sturgeons historically supported a valuable commercial fishery; however, landings declined dramatically by the early 1900s. Shortnose sturgeon is currently a federally listed endangered species and Atlantic sturgeon is considered threatened in North Carolina (Ross et al. 1988). Atlantic and shortnose sturgeon have not shown signs of recovery despite a fishing moratorium in North Carolina since 1991, indicating that habitat and water quality issues are also affecting recovery. Potential habitat issues could include reduction of benthic food sources in fresh water due to eutrophication or toxin contamination, or degradation of spawning and nursery habitat from channel obstructions, channelization, and sedimentation.

Coastal shark species, such as sand bar sharks, Atlantic blacktips, Atlantic sharpnose, hammerheads, and duskys, are slow growing and mature late, making them more vulnerable to overfishing. Federal and state harvest restrictions have been in place since 1993, but there has not been evidence of recovery. Degradation of nearshore marine bottom from beach nourishment or nonpoint runoff could potentially impact pupping and nursery areas.

The Overfished status of southern flounder is due in part to overfishing but may also be related to habitat issues in the low salinity estuaries. Severe hypoxic events and anoxia can directly affect populations of southern flounder through mortality from suffocation and indirectly from reduced growth rates, loss of preferred prey (mortality of benthic community), changes in activity patterns, or disease. The Division is currently working on a Fishery Management Plan for southern flounder.

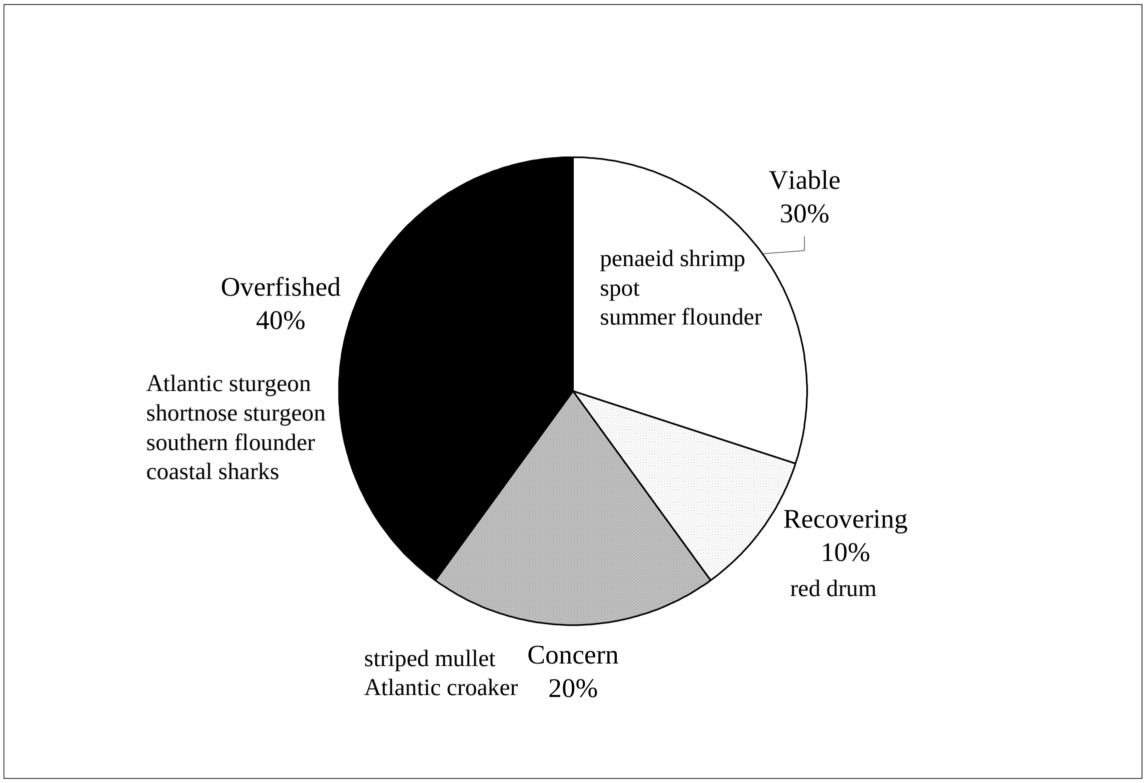


Figure 6.3. Percent of soft bottom dependent fishery species classified as Overfished, Concern, Recovering, or Viable in the DMF 2003a stock status report, N = 10 (DMF 2003a).

Striped mullet are of concern primarily due to an increase in associated fishing effort. A juvenile abundance index is currently not available for striped mullet and more biological information is needed to determine habitat threats. The Division is currently working on a Fishery Management Plan for striped mullet. Atlantic croaker is listed as Concern because JAIs and estuarine landings have remained low. *All three commissions should work together to address habitat issues that will protect or enhance southern flounder, sturgeon, and shark habitat.*

From 1968 to 1981, monthly fish surveys by DMF were conducted in coastal ocean waters but have since been discontinued. Currently in coastal waters of North Carolina, fishery-independent data are available from shallow water trawl surveys conducted by the Southeast Area Monitoring and Assessment Program – South Atlantic (SEAMAP-SA). SEAMAP is a cooperative state/federal/university program that was first implemented in the southeastern United States in 1983 and is coordinated by ASMFC. SEAMAP currently provides the only region-wide standardized surveys for monitoring long-term status and trends of demersal fish and invertebrate populations that utilize marine soft bottoms as well as other habitats. The SEAMAP study area includes inner (4m depth contour) and outer (10m depth contour) strata stations in Long Bay, Onslow Bay, and Raleigh Bay in North Carolina.

Since 1990, 141 species were found in all three bays. Many of the dominant species are also dominant in estuarine waters. In examining data from 1990 to 2000, spot and Atlantic croaker consistently comprised a large portion of the catch in all bays and years. Spot is generally most abundant in Long Bay and accounted for 20 to 50% of the catch in most years in the three bays. Other abundant species included striped anchovy, squid, pinfish, and porgies.

Since 1990, species diversity from the shallow (approximately 4m) strata sampling sites has been highest in Long Bay (124 – 147 species) and lowest in Raleigh Bay (81 – 104 species). The total number of species collected in each bay has only fluctuated slightly from year to year, and appears fairly stable over time. Densities in Long Bay ranged from 212 individuals/hectare (ind./ha) in 1993 and 2000 to 511 ind./ha in 1991. Long Bay and Onslow Bay had very similar densities of fish and fluctuations in abundance. Fluctuations in fish density among years were greatest in Raleigh Bay. These data indicate strong inter-annual variation in year class abundance but demonstrate no clear trends.

Trends in annual catch per tow, or CPUE, of demersal species from SEAMAP data are an indicator of relative abundance of late juvenile and adult species. Annual trends in catch per tow for summer and southern flounder, striped anchovy, and southern kingfish were examined since the flounders are strongly associated with estuarine and marine soft bottom and latter two species are common in the surf zone and nearshore waters. Of these four species, SEAMAP bottom trawl data indicate a decline in abundance only for southern flounder (Figure 6.4). Southern flounder CPUE has shown a general decline since its peak abundance from about eight fish/tow in 1992 to two fish/tow in 2002. Southern flounder spend more time in low salinity estuarine waters than summer flounder, and therefore may be more affected by estuarine habitat and water quality changes. The decline noted in southern flounder CPUE is consistent with DMF’s stock status for this species. While DMF’s stock status report indicates that the decline in population biomass is primarily due to overfishing (DMF 2003a), habitat degradation, such as toxin contamination of bottom sediments or bottom anoxia and benthic kills, could add additional stress to the species, delaying recovery.

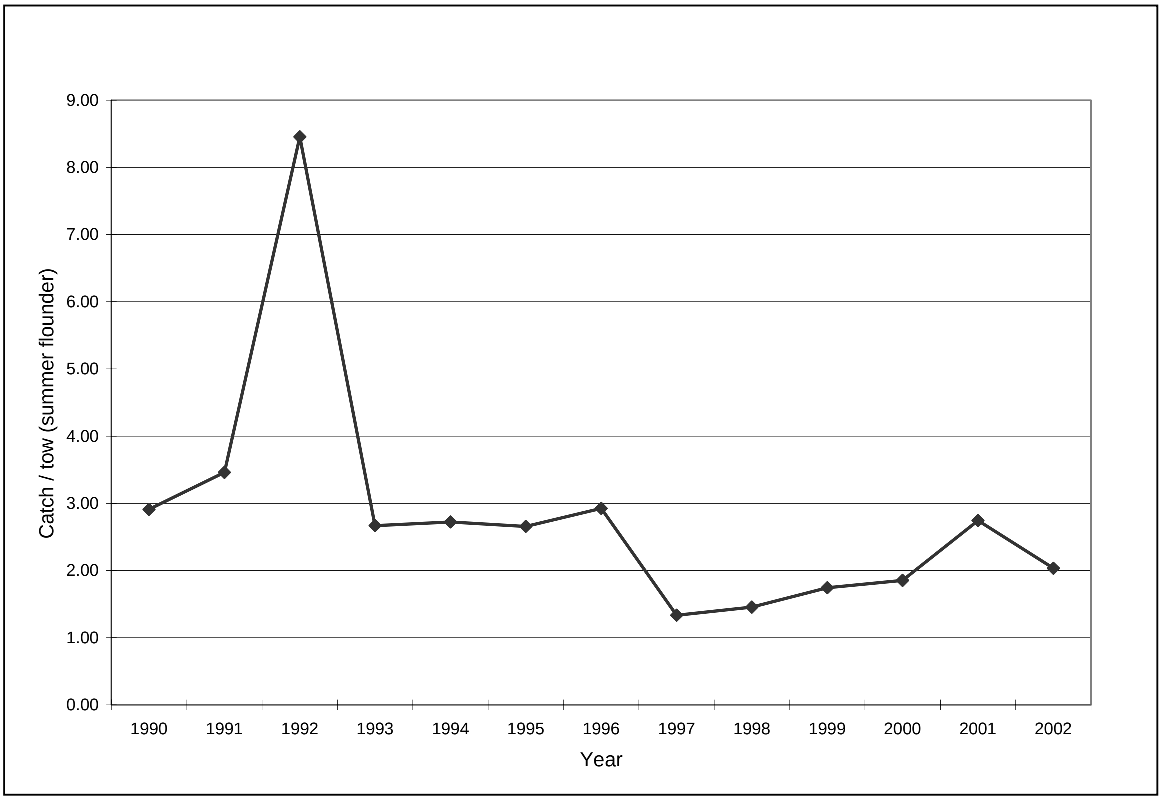


Figure 6.4. Annual CPUE of southern flounder collected in nearshore coastal ocean waters, by fishery independent SEAMAP-SA trawl surveys, 1990-2002.

Designated areas

There have been some federal actions taken to designate and protect certain portions of soft bottom habitat in coastal ocean waters. The SAFMC designated all coastal inlets as Habitat Areas of Particular Concern (HAPC) for blue crab, estuarine-dependent snapper-grouper species, penaeid shrimp, and red drum. The sandy shoals of Cape Hatteras, Cape Lookout, and Cape Fear are designated as HAPC for all coastal migratory pelagics, including king mackerel, Spanish mackerel, dolphin, and cobia. In May 2000, Presidential Executive Order 13158, Marine Protected Areas, was implemented. The order mandated strengthening of the management, protection, and conservation of existing marine protected areas and establishing or expanding additional marine protected areas. Marine protected areas (MPA) were defined as "any area of the marine environment that has been reserved by Federal, State, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein" (Federal Register 2000). Among the many agencies cited in the order, the Environmental Protection Agency (EPA), relying on existing Clean Water Act authorities, is required to identify and prioritize natural and cultural resources for additional protection, propose science-based protocols for monitoring and evaluating marine protected areas, and propose science-based regulations to ensure appropriate protection of habitat and water quality standards. These actions may provide additional protection for North Carolina's marine soft bottom habitat, as well as hard bottom and other ocean habitats. State agencies are in the process of compiling an inventory of existing marine managed areas prior to assessing the need and feasibility of establishing new MPAs in North Carolina. Also, there are approximately 160 mi of federally or state owned barrier islands along the 320 mi of ocean shoreline. This includes all or portions of eight (of 23) barrier islands or peninsulas. Intertidal beaches adjacent to these areas are protected from most development associated threats.

6.4 THREATS AND MANAGEMENT NEEDS

Physical threats

Of the coastal habitats in North Carolina, soft bottom is probably the most resilient to physical alterations because of its lack of structure and dynamic nature. However, because this habitat plays a vital role as nursery and foraging grounds for fish and invertebrate species, it is important that threats to soft bottom are identified and addressed. Human activities that can physically impact soft bottom habitat include dredge and fill activities, marinas and docks, shoreline stabilization, and use of bottom disturbing fishing gear.

<u>Dredging</u>

Existing dredged navigational channels and basins are necessary to sustain current boating and fishing activities and provide access to state ports for transport of commerce. However, dredging activities do affect physical and biological features of soft bottom communities. New dredging for navigational channels or marina construction can alter topographic and hydrologic features that attract fish for feeding, refuge, or spawning, and modify sediment grain characteristics (SAFMC 1998a). Dredging removes all benthic infauna from the affected areas immediately, reducing food availability temporarily to bottom feeding fish and invertebrates, including southern and gulf kingfish, Florida pompano, spot, Atlantic croaker, flounder, and shrimp (Hackney et al. 1996; Peterson et al. 2000a). Whether the magnitude of prey reduction limits fish growth, reproduction or survival depends on the species' diet preference, foraging range, mobility, abundance of prey elsewhere, and extent and location of other benthic disturbing activities. Inlet dredging in winter can kill or displace female blue crabs that are burrowing in the inlet sediments. Disturbance associated with inlet dredging can also deter or alter summer spawning activity of red drum, weakfish, spotted seatrout, silver perch, and blue crab (Luczkovich et al. 1999a; DMF 2000d). Spawning activity around the inlets occurs from May through October, depending on the species (refer to spawning table in the Water Column chapter). Because spawning activity occurs at night, daytime dredging may not be a problem. However, there are also possible indirect effects associated with dredging, such as reductions in benthic prey availability and alterations of the acoustic environment (J. Luczkovich, ECU, pers. com., 2003).

Impacts in the water column associated with dredging induced turbidity were discussed in the water column chapter of the plan. Turbidity, however, also affects benthic invertebrates in the soft bottom. For example, mole crabs were killed by excess turbidity generated during a beach nourishment project in Atlantic Beach (Reilly and Bellis 1983). Growth of coquina clams was significantly reduced when exposed to elevated turbidity (Lindquist and Manning 2001). The invertebrates and fish associated with inlet subtidal bottoms, tidal deltas, meandering channels, and shallow shoals have adapted to that specific environment and to its natural disturbance regimes. *More research is needed to assess direct and indirect dredging impacts on blue crabs and inlet spawning species*.

Map 2.13 a-c depicts the location of the major navigational channels in North Carolina's coastal waters. Soft bottom habitat in the southern portion of the coast has been highly modified by navigational dredging and associated spoil islands. Immediate effects to soft bottom from original dredging have recovered. The current system of navigational channels is necessary to maintain boating and fishing activities, and in some cases, may be beneficial by enhancing flushing. Many of the dredged channels were originally chosen because they were naturally deeper. While fish have adapted to these channels, creation of additional navigational channels and basins would require dredging in shallow and productive habitat areas. Converting shallow bottom into deeper basins and channels can reduce primary and secondary productivity of the bottom (Wendt et al. 1990). *Commenting and permitting agencies should continue to use their existing authorities to a) minimize new dredging of shallow soft bottom habitat, b) prevent direct impacts from dredge and fill projects, and c) limit as much as possible indirect impacts to shallow soft bottom or other habitats.*

Log salvage is another form of dredging that causes disturbance of soft bottom and water column habitat. However, the magnitude of disturbance is much less than that created by dredging of a permanent channel or basin. Refer to the water column chapter for more information on this activity.

Mining

Mining or mineral extraction is another dredging activity that has potential habitat impacts. Phosphate deposits, of sufficient quality and quantity to be potentially exploitable, have been identified within the Pungo River geological formation in Onslow Bay (Map 6.4). The formation occurs beneath the Pamlico River, extends beneath ocean soft bottom from Bogue Banks southwest to Frying Pan Shoals, is approximately 150 km long and 40 km wide, and covers approximately 6,000 km^2 (Powers et al. 1990). The largest deposit occurs at Frying Pan Shoals, seaward of state jurisdiction, and is potentially available to dredge mining. Other phosphate deposits, referred to as the Northeast Onslow Bay phosphate district, occur immediately off Bogue Banks within and seaward of state jurisdiction. Because of its proximity to shore and a deep-water port, the economic potential of mining these deposits is high. In addition, other minerals occur in offshore sediments (as phosphate mining byproducts) including trace elements, radioactive substances like uranium and phosphogypsum, heavy minerals such as titanium, zirconium, aluminosilicates, and valuable metals such as gold and silver (Riggs and Manheim 1988). Currently no mining is ongoing in North Carolina waters, although the potential for such activities exists. Continued cooperation between COE, DWQ 401 staff, CAMA, and others responsible for review of mining projects is necessary to protect and mitigate against soft bottom and other habitat impacts.

Dredge material disposal on subtidal bottom

Deposition of dredge material from navigational channel maintenance on estuarine or coastal dredge disposal sites, ebb tidal deltas, or other areas of subtidal bottom results in increased turbidity, temporary reduction in and slow recovery of the abundance and diversity of benthic invertebrates (SAFMC 1998a). In estuarine waters, dredge material islands, also referred to as spoil islands, were often created adjacent to the dredged navigational channels. Subsequent maintenance dredging deposits new material onto these islands. The majority of the dredge material islands were produced when the ICW was first created in the 1930s. The creation of permanent dredge islands a) reduced the amount of available underwater habitat (including soft bottom), b) changed the natural hydrology of the surrounding waterbodies, and c) had a relatively more profound effect on the smaller waterbodies of the southern coast. However, the islands can provide beneficial nesting bird habitat and fringing wetland habitat along the perimeter. *A state policy on dredge material management, that a) minimizes impacts to coastal fish habitat, including soft bottom habitat, and b) is consistent with federal existing guidelines, should be developed.*

In ocean waters, dredge disposal occurs in both offshore, designated disposal sites and in nearshore waters and ebb tide deltas. Offshore sites are in federal waters in depths greater than 30 ft, whereas nearshore areas are in state waters in depths less than 30 ft deep. Sediment deposited in nearshore waters and on ebb tide deltas is incorporated into the beach profile and is discussed further in the beach nourishment section. The rate of bottom recovery will depend on the volume discharged, characteristics and similarity of the dredge material, hydrography of the disposal area, time of year, and the resulting turbidity (Windom 1976; SAFMC 1998a). Disposed dredge material that contains elevated levels of toxic contaminants may have adverse impacts on the benthic community. There are two EPA approved and designated ocean dredge material disposal sites off North Carolina, one off Beaufort Inlet and one off Cape Fear River Inlet. Both are located just seaward of the state territorial seas.

Marinas and docks

Soft bottom habitat may be affected by marina and dock facilities through alteration of the shoreline configuration, circulation patterns, and, subsequently, changes in bottom sediment characteristics (Wendt et al. 1990). Because benthic microalgae, an important component of primary production in soft bottom habitat, are light dependent, bottom sediments in dredged marinas will have reduced light availability due to the deeper water depth and shading from docking structures. There are few studies that examine the effect of marinas and boating activity on benthic productivity. A study estimating macroalgal and microalgal productivity before and after construction of a marina in Long Island Sound found that microalgal production on soft bottom would decline by 48% post construction and macroalgal production would decline by 17%, due to changes in depth, light, and hard structures (Ianuzzi et al. 1996). However, the authors concluded that some of this loss would be offset by additional microalgal production on hard structures in the marina.

Operation of a marina can also affect productivity of the soft bottom community due to introduction of heavy metals, hydrocarbons, and bacteria (Chmura and Ross 1978; Marcus and Stokes 1985; Voudrias and Smith 1986). In a South Carolina estuary, distinct differences were found in the benthic community at a marina compared to the control site (Wendt et al. 1990). The marina appeared to favor the occurrence of infaunal burrowers over infaunal tube dwellers. Overall, there was greater abundance of deposit feeders at the marina. The authors concluded that the presence of docks and pilings may have resulted in greater habitat complexity and therefore greater diversity of sessile and motile epifauna. However, the study did find a lower abundance of several pollution sensitive species at the marina, indicating some environmental degradation, which could affect the food chain. Faunal differences were attributed to the finer grained sediments occurring in the marina and proximity to hard structures.

While the higher concentration of organic matter contributed to a greater abundance of certain deposit feeders, certain species were excluded from the marina. While the additional colonization of non-mobile epifauna on dock structures within the marina may provide additional biotic diversity and a food source for some fish, high densities of fouling organisms (tunicates, barnacles, bryozoans) in marinas can reduce dissolved oxygen levels due to high respiration rates (Wendt et al. 1990). Toxic substances in fouling organisms bioaccumulate and can become concentrated in successively higher levels of the aquatic food chain (Nixon et al. 1973; Marcus and Stokes 1985). Both PAHs and heavy metals were found to be significantly higher in bottom sediments in the marina compared to the control site. Heavy metals and hydrocarbons are toxic to many soft bottom dwelling invertebrates and benthic feeding fish (Weis and Weis 1989). The effect of toxins from marinas or other sources is discussed in more detail in the toxins section. *Stringent efforts are needed to prevent toxic contamination of sediments from marinas to reduce impacts to soft bottom productivity. Toxic sources at marinas should also be addressed.*

In another study in South Carolina, differences in the benthic community in areas with no, low, and high densities of docks were examined. Similar to the other South Carolina study, some pollution sensitive species of polychaetes were more abundant at control sites than high dock sites (Sanger and Holland 2002). Areas in the high dock category usually had the lowest values of benthic abundance. Three species (*S. benedicti*, *T. acutus*, *P. cornuta*), in addition to the total number of organisms, had a significant correlation to docks, with the abundance of organisms decreasing as the number of docks increased (Sanger and Holland 2002). Total fish and crustacean abundance, including bay anchovy, silver perch, spot, and brown shrimp, were highest in the no dock category, but were not significantly correlated with dock number (Sanger and Holland 2002). This study also found that shading from docks decreased stem density of *Spartina alterniflora* by 70%, which was comparable to studies in Virginia and other areas of the United States. This reduction can lower the overall productivity in the vicinity of marinas and multi-docking facilities. Overall productivity in a marina can also be reduced by effects on associated wetland and shell bottom communities. Refer to these sections for more information related to marina and dock impacts.

Several studies indicate that marinas and concentrations of individual docks have potential to alter soft bottom habitat, particularly shallow water habitat, in ways that can reduce productivity of the system as a whole. Marina siting issues were discussed in the earlier water column chapter, and the location of marinas in North Carolina was shown in Map 2.18 a-c. The majority of docking facility permits are for individual piers. The number of individual pier permits issued annually by the CRC, with the exception of 2001, has continually increased in the coastal counties through 2000 (Figure 2.9, water column chapter). Since then, the number of permits issued annually has dropped below 1999 levels to around 800 per year. The DCM estimates that approximately 10% of these piers do not have boats associated with them and are used solely for fishing, swimming, view, etc. The large increase in permit numbers from 1999 to 2000 is at least partially due to large numbers of repair or replacement requests following hurricane damage. If properly designed and located, individual piers do not pose a large threat to soft bottom habitat. However, when docks are permitted in very shallow areas, moored boats or floating docks may actually sit on the bottom for a large portion of a tidal cycle (up to 12 hr) or cause considerable turbidity or prop dredging when attempting to motor to deeper waters (F. Rohde, DMF, pers. com., 2003). Either situation can significantly reduce primary or secondary productivity (F. Rohde, DMF, pers. com., 2003). There is currently no minimum water depth required to receive a dock permit. *Dock siting criteria should include a minimum water depth to prevent boats or floating docks from sitting directly on soft bottom or other benthic habitats*.

Multi-docking facilities (10 slips or less according to the CRC definition) may be a greater threat to soft bottom habitat due to the number of these facilities and their concentration in shallower areas than typical marinas. However, by concentrating boat use, overall impacts may be less than what would be needed to serve the same number of boats with individual piers at individual residences. Also, because boat use is concentrated, other areas of the shoreline, including wetland and shell bottom habitats, may not be impacted by docking related activities. There are about five to eight times more permits issued annually for small multi-docking facilities (non-marinas, 1-10 slips) than marinas (> 10 slips). The annual number of non-marinas has generally increased since 1996 (Figure 2.9, water column chapter). The annual number of permits issued for new or expanding marinas has remained fairly stable over the past ten years. As waterfront property becomes increasingly developed, requests for new piers and marinas in shallower and less suitable locations will increase. *A comprehensive dock and marina policy is needed to address appropriate design, siting, operation, maintenance procedures, and cumulative impacts to minimize impacts to soft bottom and other fish habitats. Research on the impacts of these parameters is needed.*

Shoreline stabilization

Different shoreline stabilization strategies are effective under different environmental conditions, with varying effects on soft bottom and other habitats. Strategies range from soft techniques such as marsh planting to engineered hard stabilization techniques. Estuarine and ocean shoreline stabilization are discussed separately below.

Estuarine and riverine shoreline stabilization

In North Carolina, estuarine and riverine shoreline stabilization has traditionally utilized hard structures such as bulkheads, rock revetments or riprap, sills, breakwaters, groins, or combinations thereof. Bulkheads are the most commonly used structure. Beach nourishment is generally not utilized. Although excessive sediment loading is considered a water quality issue, erosion of sediments is a natural process that provides sand for maintenance of beaches, wetlands, and shallow water habitat. When this sand supply is cut off by a hard structure under rising sea level conditions, the long-term results are a net loss of beach and intertidal shoreline and the deepening of shallow water habitat. High quality intertidal shoreline and shallow water habitat serve as important nursery, feeding, and spawning grounds to many economically and biologically valuable fish species in North Carolina. Multiple studies have shown that the diversity and abundance of invertebrates and juvenile fish are reduced adjacent to bulkheaded areas (Mock 1966; Ellifrit et al. 1972; Gilmore and Trent 1974; O'Rear 1983; Byrne 1995; Peterson et al. 2000c; Waters and Thomas 2001). In the 2003 legislative session, House Bill 1028 was approved, which allows the CRC to establish a general permit for construction of offshore parallel rock sills for estuarine shoreline protection. Prior to this, a major permit was required for such activity, while construction of a bulkhead required a general permit. *A comprehensive examination and revision of current CRC shoreline* *stabilization rules using best scientific information are still needed to minimize impacts from this activity to soft bottom, particularly intertidal estuarine shorelines. Research is needed to determine if and how oyster shell could be utilized as an alternative to rock or wooden stabilization structures to create "living shorelines" that are effective in stabilizing the shoreline while also providing habitat value.* Refer to the wetlands chapter for additional information of the impact of shoreline stabilization to that habitat.

An additional concern of wooden bulkheads is the toxicity of preserved wood to certain aquatic organisms. Estuarine and riverine bottom may be contaminated by wooden bulkheads treated with copper, chromium, and arsenic (CCA). These elements are leached from CCA-treated wood, gradually accumulate in adjacent sediments, and have the capacity to harm marine benthos (Weis and Weis 1994; Weis et al. 1998). The toxicity of these metals to aquatic organisms is well recorded and all three are listed as priority pollutants by the EPA (Hingston et al. 2001). Copper appears to have the most toxic effect on marine organisms and is consistently released in the largest relative amount (Weis and Weis 1994).

Studies have documented significantly elevated concentrations of metals and reduced abundance and diversity of the benthic community extending approximately 30 ft (10 m) from bulkheads treated with CCA, decreasing with distance from the structure (Weis and Weis 1994; Weis et al. 1998). Benthic organisms that were lethally or sublethally impacted included macroalgae, amphipods, polychaetes, oysters, fiddler crabs, sea urchins, mud snails, and fish embryos. Sediment contamination has been documented to be higher in a residental bulkheaded canal than adjacent to bulkheaded open water (Weis and Weis 1995). Concentrations decreased more rapidly with distance from bulkhead in the open water system. Weis et al. (1995) found that oysters living on CCA-treated wood in a residential canal had 15 times more copper (~ 200 μg/g wet weight), two to three times more arsenic, and significantly more degeneration of digestive gland diverticula than compared to that of reference oysters. Copper is known to cause this pathology. Although bioaccumulation has been observed in shellfish and other invertebrates grazing on CCA contaminated algae or bivalves, similar biomagnification in fish has not been documented for these elements (Weis and Weis 1999). The extent of sediment contamination from CCA could be significant, considering the magnitude of preserved timber used in the marine environment for bulkheads and docks (Weis and Weis 1994). Toxicity of wood decreases with time but CCA can continue leaching for many years. In addition, bulkheads need to be replaced periodically, providing a continual source of newly treated wood in coastal waters. Rock sills and revetments are non-wood alternatives that do not require any chemical preservatives. *Any new wood preservative products should be evaluated for toxicity to marine benthic organisms and juvenile fish. When formulating revisions to CRC's shoreline stabilization regulations and guidelines, CRC should take into account the impact of sediment contamination and potential toxicity of wood preserved bulkheads on marine organisms.*

Oceanfront shoreline hardening

Shoreline hardening, or hard stabilization, involves construction of hard immovable engineered structures, such as seawalls, rock revetments, jetties, and groins. Seawalls and rock revetments run parallel to the beach. Seawalls are vertical structures, constructed parallel to the ocean shoreline, and are primarily designed to prevent erosion and other damage due to wave action. Revetments are shoreline structures constructed parallel to the shoreline and generally sloped in such a way as to mimic the natural slope of the shoreline profile and dissipate wave energy as the wave is directed up the slope. Breakwaters are structures constructed waterward of, and usually parallel to, the shoreline. They attempt to break incoming waves before they reach the shoreline, or a facility (e.g., marina) being protected. Jetties and groins are manmade structures constructed perpendicular to the beach, with jetties usually being much longer and located adjacent to inlets. The primary purpose of jetties and groins is to create or widen beaches by capturing sand moving along the shoreline (littoral drift).

It is now well accepted that hard stabilization techniques along high energy ocean shorelines will accelerate erosion in some location along the shore, resulting in the eventual loss of beach and intertidal bottom as well as increased scouring and chronic turbidity in the surf zone (Walton and Sensabaugh 1979; NRC 1995; Pilkey et al. 1998; Peterson et al. 2000a). Recognizing that hardened structures destroy recreational beaches and the intertidal zone, four states have prohibited shoreline armoring: Maine, Rhode Island, South Carolina, and North Carolina (effective in North Carolina since 1985).

Only a relatively small amount of North Carolina's ocean shoreline is hardened compared to other states, having roughly 6% of the developed shoreline hardened (Pilkey et al. 1998). In contrast, South Carolina, Florida (Atlantic coast), and New Jersey have 27%, 45%, and 50% of their respective shorelines covered with some form of hard stabilization. Of all hardened structures, seawalls are the greatest threat to beach erosion and degradation of the intertidal beach (Pilkey et al. 1998). Moreover, the areal loss of beach at hardened shorelines is often managed by implementing nourishment projects, possibly having additional damage to subtidal bottom. In addition to causing erosion on downdrift beaches and accelerating the need for beach nourishment projects, jetties obstruct fish passage through adjacent inlets (Blanton et al. 1999). Jetties in some locations may therefore be the most directly detrimental shoreline stabilization structure to coastal fish habitat (for more information, refer to water column threats section). In the 2003 legislative session, House Bill 1028 was approved, putting into law the CRC prohibition on construction of permanent erosion control structure on an ocean shoreline. *Prohibition of shoreline hardening of the oceanfront should continue to be enforced for overall protection of barrier island processes, nearshore soft bottom communities, and associated fish species.*

Soft stabilization on oceanfront shorelines

Because hard stabilization is currently prohibited in North Carolina, the only beach stabilization techniques available to local communities are soft techniques, such as beach nourishment and beach bulldozing. Beach nourishment is the introduction of new sand to dry and intertidal beach and adjacent shallow waters from upland areas, navigational channels, inlet systems, or submerged mine sites to restore or enlarge a beach. There are generally two categories of COE projects that result in sand being put on beaches: disposal projects and storm damage reduction projects. Disposal projects are generally much smaller in magnitude than storm damage reduction projects, and can be expected to have a smaller impact on fish habitat. Sand bypassing is a type of disposal project where sand is moved around physical barriers, such as a jetty or deep port, that interrupt the natural littoral drift along the shoreline.

Beach bulldozing, also referred to as beach scraping, is a method of short-term erosion protection that has been used in North Carolina for approximately 40 years. Beach bulldozing is the process of mechanically redistributing beach sand from the lower portion of the intertidal beach to the upper portion of the dry beach to create or enhance the primary dune. In contrast to beach nourishment, new sediment is not added and the existing beach is not widened. Because beach bulldozing only utilizes sand on-site, the impacts of this soft technique are less, relative to those from beach nourishment (Pilkey et al. 1998). *The effectiveness and cumulative impact of this activity should be assessed and appropriate guidelines should be included in a coastal beach management plan.*

Soft stabilization offers an alternative to hard stabilization that has less severe habitat impacts to soft bottom and some positive effects. For example, wider beaches from properly constructed beach nourishment projects can enhance sea turtle nesting habitat and protect oceanfront development that is important to North Carolina's economy. However there are potential biological impacts to soft bottom habitat, depending on specific factors of the project and site, which should be considered.

Beach nourishment impacts at mining areas

Mining is defined under the Mining Act (G.S. 74-48 and G.S. 47-49) as "the breaking of surface soil in order to facilitate or accomplish extraction or removal of mineral, ores, or other solid matter." Whether the purpose is beach nourishment, channel maintenance, or mineral extraction, the consequences of mining activities have similar effects upon the habitat. Dredging of subtidal bottom initially causes mortality of benthic organisms within the dredged area and causes elevated turbidity in an extended area, which may also result in negative impacts. Physical recovery of mining sites in nearshore areas and shoals can be a slow process, but is quite variable. In South Carolina, comparison at multiple mine sites found that sediment refilling took from two to at least 12.5 years at various mine sites. Because mine sites often refill with finer-grained material than was originally present (NRC 1995; Van Dolah et al. 1998), post-dredging turbidity may remain high indefinitely (Peterson et al. 2000). Since these areas often refilled with a more fine-grained, muddy sediment, most sites became unsuitable as future sand sources and altered benthic species recruitment patterns (Van Dolah et al. 1992; Van Dolah et al. 1998; Jutte et al. 2001a). Use of ebb or flood tidal deltas and nearshore sandbars as a sand source for nourishment projects removes sand from the inlet system, alters the sediment budget, and may result in accelerated erosion from adjacent beaches (Wells and Peterson 1986). Roessler (1998) also suggested that the major cause of beach erosion on Bogue Banks was the removal of sediment from the longshore system due to the intense dredging and deepening of Beaufort Inlet for access to the state port at Morehead City. Sand from that dredging operation has at times been taken out of the inlet, hence out of the longshore system, and disposed of offshore beyond the active beach profile. Biological recovery rates of mined sites vary, but generally are longer than those reported at the intertidal beach disposal sites, and in some cases may be altered indefinitely (Table 6.4).

Table 6.4. Reported biological recovery time at mine sites

Location	Mine site recovery time	Reference
North Carolina	6 – 18 months	Posey and Alphin 2001
South Carolina	3 – 6 months	Van Dolah et al. 1992
South Carolina	2 – 12.5 years	Van Dolah et al. 1998
South Carolina	11 – 14 months	Jutte et al. 2001b
South Carolina	14 – 17 months	Jutte et al. 2001a
New Jersey	18 – 30 months	COE 2001
location undisclosed	> 12 months	NRC 1995

Van Dolah et al. (1998) observed significant changes in the species composition of the recruited benthos, shifting from a dominance by amphipods to mollusks. During the time period monitored (> 12.5 years), the original species composition within the affected area was never restored due to the change in substrate composition (Van Dolah et al. 1998). Mining activities that changed bottom sediment composition were often associated with impacts of the greatest magnitude and most prolonged recovery, typically occurring in areas with little sand movement, with deep mine pits, or that were previously mined (Saloman et al. 1982; COE 2001). Comparison of mine areas and control sites associated with a storm damage reduction project at Carolina Beach found few statistically significant differences in species abundance 0.5 and 1.5 years after sediment removal (Posey and Alphin 2001). However, after sediment removal, dominant species composition at the mine site was more dissimilar to the control site than before sediment removal. The authors concluded that year to year variability in the benthic community, in addition to multiple hurricanes during the monitoring period, made effects from the project difficult to determine, suggesting that the effect of beach nourishment is minimal compared to the natural variability of the system (Posey and Alphin 2001; Posey and Alphin 2002). Observed recovery at this site was more rapid than expected, due in part to the configuration of the mine areas. The mine area was long (3 mi), relatively wide (0.5 mi), and, most importantly, not excessively deep (5-10 ft deep) (M. Posey, UNC-W, pers. com., 2003). At mine sites monitored off New Jersey, infaunal assemblages (diversity) recovered within one year after disturbance, while biomass and taxonomic richness took 1.5 to 2.5 years to fully recover (COE 2001). Because material was removed from a topographically diverse bottom, a deep pit was not created, leading the authors to conclude that time to recovery was reduced. In addition, strong water currents and dynamic sand movement in the project area facilitated more rapid infilling.

Repeated use of a mine site for beach nourishment is generally not possible since the excavated areas tend to refill with more muddy substrate or have not completely refilled prior to the next renourishment interval (3 – 8 year cycles). Because of the slow recovery and change in sediment composition, Van Dolah et al. (1998) stated that nearshore mine areas must be viewed as a non-renewable resource and as the regions most impacted by beach nourishment projects (R. Van Dolah, SC DNR; pers. com., 2002). The benthic community appeared to recover more quickly where hopper dredges were used rather than pipeline dredges (Jutte et al. 2001a). Locating mine sites at specific soft bottom locations known to support seasonal aggregations of demersal fish, such as the critical overwintering area off the Outer Banks for juvenile Atlantic sturgeon, spiny dogfish, and striped bass, could negatively impact those species. Mine sites established on ebb and flood tide deltas may recover relatively faster due to nearby longshore sediment transport. However, these deltas serve as important feeding sites to a number of commercially and recreationally important species, including red drum, striped bass, spot, Atlantic croaker, weakfish, blue crabs, and shrimp, and serve as spawning sites for red drum, weakfish, spotted sea trout, and blue crab. Removal of a major component of their diet could negatively impact these species (Peterson et al. 1999). Factors that appeared to maximize biological recovery rates include:

- Shallow excavation of mine areas,
- Use of topographic highs, and
- Location in areas of high sand movement.

When mine areas are necessary for beach nourishment projects, guidelines should strongly encourage siting protocol that maximizes biological recovery rates and does not degrade critical fish foraging areas. Many steps are already taken to minimize environmental impacts. Environmental Impact Statements (EIS), Environmental Assessments (EA), Findings of No Significant Impact (FONSI), State Environmental Policy Act (SEPA) documents, or National Environmental Policy Act (NEPA) documents must be completed and reviewed. A memorandum of agreement between DCM and COE provides for a coordinated permit review process between state and federal agencies (Federal Consistency Program). A federal project cannot begin unless DCM finds that it is consistent with state policies. Other agencies are given an opportunity to comment on projects as well. The MFC adopted a beach nourishment policy in 2000 to guide the permitting process to more fully consider fish habitat impacts (Appendix N).

Beach nourishment impacts at intertidal beach and adjacent subtidal bottom

Biological impacts of sediment disposal to the intertidal beach community have been studied by Reilly and Bellis (1983), Van Dolah et al. (1992), Hackney et al. (1996), Donoghue (1999), Jutte et al. (1999), Peterson et al. (2000b), and others. Studies of dredge disposal and storm damage reduction projects demonstrated an almost complete initial reduction in the number of benthic invertebrates in the intertidal zone, as well as in the subtidal zone and dry beach, immediately following the disturbance. The effect on smaller meio- and microfauna is unknown. The rate of reported biological recovery on nourished intertidal beaches has varied from about one month to one year, but in some cases longer (Table 6.5).

Table 6.5. Reported biological recovery times at nourished ocean beaches.

Locaton	Biological recovery following beach nourishment	Reference
Atlantic Beach, N.C.	More than 3 months. Coquina clams in nearshore overwintering bottom killed initially by turbidity; delayed recruitment and repopulation; Haustoriid amphipods had not recovered after 3 months. Polychaete *S. squamata* recovered 15 – 30 days post nourishment.	Reilly and Bellis 1983
Atlantic Beach, N.C.	Densities of mole crabs and coquina clams were 86 – 99% lower than control sites, 5 – 10 weeks post-nourishment, during mid-summer.	Peterson et al. 2000b
North Topsail, N.C.	After 1 year, mole crab, coquina clam, and amphipod abundance remained significantly less than at control sites and body size was significantly smaller. Polychaetes increased in abundance.	Lindquist and Manning 2001
Pea Island N.W.R., N.C.	2 – 9 months for coquina clams and mole crabs.	Donoghue 1999
Hilton Head, S.C.	Density and diversity returned to levels similar to control sites in 6 months.	Van Dolah et al. 1992
Folly Beach, S.C.	2 – 5 months, depending on benthic group and site, polychaetes recruiting earlier than mollusks.	Jutte et al. 1999
Panama City, F.L.	Large reductions in abundance and diversity remained after 2 years.	Rakocinski et al. 1993
Manasquan, N.J.	Abundance, biomass, and diversity completely recovered after 6.5 months. Recovery quickest when filling completed before low point in seasonal infaunal abundance and where grain size of fill material matched natural beach.	COE 2001

Factors likely affecting the recovery time of the intertidal beach community include:

- compatibility of deposited material with native sand (sediment grain size)
- volume of sand
- depth of filled sand
- length of area covered
- time of year
- time period between renourishment events on an individual site
- alteration of the beach geomorphology
- location placed on the beach

In the studies referenced above and others, biological impacts persisted longer when supplemented sand was either coarser (Rakocinski et al. 1993; McLachlan 1996; Rakocinski et al. 1996; Peterson et al. 2000a) or finer (Gorzelany and Nelson 1987; NRC 1995) than the existing sand. Increased grain size of the beach can result in significant reduction in species richness and abundance by 1) limiting body size, 2) limiting burrowing performance and other functions in some species, and 3) changing the beach condition to a higher energy swash zone (McLachlan 1996). A decrease in grain size impacts the benthos by 1) smothering organisms, 2) clogging gills from sediment plumes, and 3) decreasing the interstitial space between sediment grains available to small burrowing invertebrates (Rakocinski et al. 1996). Current CRC rules state that sediment grain size shall be equal to or larger than that found naturally at the site. *More specific minimum and maximum grain size standards are needed to minimize biological impacts*.

The time period between renourishment events is also an important factor for successful recovery. Lindquist and Manning (2001) found that at a beach where dredge material was placed between April and June, and redeposited the following year (April – June), the abundance of the mole crabs, coquina clams, and amphipods was significantly lower than that of the control beach after one year. Also, mole crabs and coquina clams were significantly smaller in size than at control sites, indicating that repeated disturbance from beach disposal (once a year) prevented full recovery of the populations. Peterson et al. (2000b) also argued that recovery could be accelerated if projects were timed to occur before spring recruitment of benthos.

Dredge material from inlet dredging is often placed in nearshore water (< 30 ft deep) within the beach profile to enhance sand supply on the beach. Such sand placement in nearshore waters can delay the duration and reduce the magnitude of the benthos reduction on the beach, but cause additional impacts to subtidal bottom (Donoghue 1999). Monitoring of a nearshore disposal project that occurred on an ebb tide delta near Beaufort Inlet in March – April found that after eight months (December), infaunal invertebrates were only 50% as dense as that of the original benthic community, but mobile epifauna had fully recovered (Peterson et al. 1999). In the following two months (December – February), density estimates doubled, as new recruits rapidly entered the area (Peterson et al. 1999). Projects timed to occur in the winter, prior to peak infauna larval recruitment in the summer and fall, will speed up the recovery of intertidal benthic organisms within the impacted area (Donoghue 1999).

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

- Use of sand similar in grain size and composition to original beach sands (specific minimum and maximum standard needed).
- Restrict beach nourishment to winter months to minimize mortality of infauna and enhance recovery rates of intertidal benthic organisms, an important prey source for many surf fish (Donoghue 1999).
- Limit time interval between projects to allow full recovery of benthic communities (1-2 years, depending on timing of project and compatibility of sediment).
- Limit linear length of nourishment projects to provide undisturbed area as a source of invertebrate colonists for the altered beach, and a food source for fish.

The extent of biological impacts from beach nourishment activities is determined not only by these individual conditions, such as grain size, time of project, and frequency of reapplication, but also by combinations of factors. *Because of the potential impact of beach nourishment and dredge disposal on soft bottom communities, there is a need for a coast-wide Beach Management Plan that carefully reviews cumulative impacts of activities and provides ecologically based guidelines, including sediment compatibility standards, to minimize cumulative impacts. The CRC's beach nourishment rules should be evaluated and modified in a comprehensive manner as needed to minimize overall impacts from this activity. Additional research is also needed to more clearly quantify the cumulative impact of nearshore dredge disposal on fish populations.*

The largest biological impact of beach bulldozing appears to be reduction in ghost crab populations on the dry beach (Peterson et al. 2000b). Lindquist and Manning (2001) found no significant impact on dominant beach invertebrates associated with beach bulldozing. No decline in surf fish or shorebird use at or adjacent to scraped beaches was observed. Peterson et al. (2000b) found that beach bulldozing at Bogue Banks reduced the width of the intertidal beach, shifted sediment composition, and immediately reduced abundance of benthic organisms. Because of the relatively quick recovery on intertidal and shallow subtidal benthic communities and the relatively small area that occurs in subtidal waters, fish impacts from bulldozing should be less than other beach management activities. However, beach scraping has not been shown to provide any erosion control benefit, and has actually increased wind erosion of sand where created dunes were left unvegetated (Kerhin and Halka 1981; Tye 1983; McNish and Wells 1992; Peterson et al. 2000b). The CRC modified specific conditions for beach bulldozing in

2000 which should help minimize biological impacts if properly enforced, including time windows for work to be completed, maximum depth of scraping, and replanting of dunes.

Beach nourishment impacts on fish

Fish may be impacted by beach nourishment due to reduction in food availability, alteration of preferred topographic features, disturbance prior to or during spawning, or reduced visibility. Fish and invertebrate species that spend considerable time in the surf zone and feed on benthic invertebrates, such as Florida pompano, gulf kingfish, Atlantic croaker, spot, and shrimp, would be most vulnerable to beach nourishment activities. Some studies have found insignificant impact to fish populations (Van Dolah et al. 1994; COE 2001) or a temporary increase (Saloman 1974). This may be 1) due to release of nutrients and infauna during dredging, 2) because resident fish are wide-foraging, or 3) because migratory fish spend only a portion of their life cycle at the mine site or target beach (Greene 2002). Other researchers suggest that fish are dependent on the amount of available habitat and that any loss represents a decrease in production (Peterson et al. 2001). Unfortunately, very little monitoring has been done at the level needed to adequately assess and detect the impacts of nourishment projects on fish distribution, feeding, growth, or survival.

A New Jersey study examined surf zone fish distribution, abundance, and diet in response to ongoing nourishment projects (COE 2001). In the immediate vicinity, abundance of bluefish, a visual feeder, decreased and northern kingfish, a benthic feeder, appeared to increase. However, no long-term trends were detected in distribution or abundance. Stomach content analyses of kingfish and silversides did not suggest differences in prey availability between control and project sites. This study concluded that "because inter-annual variation of surf zone fish community dynamics is considerable, it is unlikely that anything other than catastrophic environmental impacts on surf zone fish populations would be evident (COE 2001)."

In North Carolina, the effects of a Brunswick County beach nourishment project on surf fish, benthic invertebrates, and water quality, were evaluated from March 2001 to May 2002 (COE 2003). Sand from the lower Cape Fear River dredging project was placed on Bald Head Island, Caswell Beach, Oak Island, and Holden Beach. Seining and trawling before and after the project found no significant differences in fish abundance or diversity among disturbed, undisturbed, and reference sites during any season. This was attributed to the high mobility and schooling behavior of the dominant fish species (anchovies and drum family), resulting in clustered and variable distribution. Although statistically not significant, gulf kingfish were less abundant at the disturbed sites than the undisturbed sites. The decline was thought to be at least partially due to the reduced availability of benthic invertebrates preferred by gulf kingfish (COE 2003). The intertidal benthic community was the most directly impacted by the beach nourishment project. Analysis of the effects of this project was limited by problems with the statistical design (COE 2003). Sample size was often insufficient to calculate confidence limits, partly due to uneven sampling among treatments (disturbed, undisturbed, reference). *Adequate monitoring of the effects of beach nourishment on the soft bottom community and associated surf fish populations is increasingly important as the number of beach nourishment projects increase and should be required for all large-scale or long-term nourishment projects*.

Status of beach nourishment from navigational dredge disposal projects

The COE is charged to maintain North Carolina's navigable inlets and ocean channels through dredging as necessary. Navigational dredging in inlets by the COE is allowed at any time of the year and is not subject to any mandatory dredging moratoria unless sea turtle take quotas are exceeded. Industry-owned hopper dredges working in the Wilmington and Morehead City port areas and Oregon Inlet have a voluntary dredge window of January 1 – May 31, to minimize taking of turtles (T. Wilder, COE, pers. com., 2003).

Maintenance of the seven federal inlet channels is performed by a sidecast dredge or a small hopper dredge. Maintenance of the federal channels at Morehead City, Wilmington Harbor, and Oregon Inlet is conducted by hydraulic pipeline dredge or hopper dredge. Timing of all work is dependent upon the area to be maintained, the type of equipment to be used, and the anticipated environmental effects. Performing work with a hopper dredge requires consideration of possible impacts on endangered and threatened sea turtles.

Material from dredge disposal projects is put on or adjacent to ocean beaches in close proximity to the dredged site, or in an EPA designated ocean dredge material disposal site. Beaches receiving sand from dredged inlets and adjacent waterways are indicated in Table 6.6 and Map 6.3 a-c. Sand from these projects usually only covers a relatively short linear length of the beach (< one mile), generally close to the inlet where the sand originated. The amount of sand deposited and the frequency of dredging vary between sites and with each dredging event (Table 6.6). There are 51 miles of beach designated and approved for dredge disposal, but only about 16 miles of beach receive dredge material (T. Wilder, COE, pers. com., 2003). Areas receiving dredge disposal include several locations on Hatteras Island, south end of Ocracoke Island, Core Banks, both ends of Bogue Banks, Onslow Beach, several locations on Topsail Island, Wrightsville Beach, Masonboro Island, north end of Carolina Beach, Caswell Beach, Oak Island, east end of Ocean Isle Beach, and both ends of Bald Head Island. In addition, privately owned Figure 8 Island has received nourishment projects periodically, most recently in 2002 from the Mason Inlet relocation project.

Table 6.6. Ongoing COE dredge disposal projects on North Carolina ocean beaches (Source: T. Wilder, COE, pers. com., 2003).

Dredging Project	Disposal location	Approved disposal limits (mi)	Actual disposal limits (mi)	Estimated quantity (cu. Yd.)
Avon Harbor vicinity, Avon	Hatteras Island, south of Avon Harbor and extend north.	3.1	0.4	< 50,000 every 5-6 yr.
Rodanthe Harbor vicinity, Rodanthe	Extends from south end of Pea Island NWR to south of Rodanthe Harbor.	0.9	0.4	<100,000 every 5-6 yr
Rollinson channel/ Hatteras	Hatteras Island south of Hatteras Harbor and extends 5.85 mi north of Frisco.	5.9	0.4	<60,000 every 2-3 yr
Silver Lake	Southwest end of Ocracoke Island.	0.4	0.4	<50,000 every 2-3 yr
Oregon Inlet	Pea Island south from Oregon inlet.	3.0	1.5	300,000 / year
Drum Inlet	Core Banks, extending 1 mi either side	2.0	1	298,000 initial, 100,000 maint.
Morehead City	Bogue Banks, from Beaufort Inlet west to Coral Bay Club, Pine Knoll Shores	7.3	5.2	3,500,000 every 8-10 yr.
AIWW	Pine Knoll Shores	2.0	0.4	<50,000 every 5-6 yr.
AIWW Bogue Inlet	Bogue Banks from Bogue Inlet east to Emerald Point Villas	1.0	0.4	<100,000 / year
AIWW	Camp Lejeune, from Browns Inlet west	1.6	1	<200,000 every 2-3 yr
AIWW, New River Inlet	N. Topsail Beach from inlet west to Maritime Way	1.5	0.8	<200,000 / yr
AIWW	Surf City opposite N.C. 50 bridge	1.0	0.04	<75,000 every 5-6 yr (only used in 1996)
AIWW	Topsail Island, Queen's Grant	0.6	0.6	<50,000 every 5-6 yr
AIWW, Topsail Inlet and Topsail Creek	Topsail Beach, north of Topsail Inlet	1.0	0.4	<75,000 / yr
AIWW, Mason Inlet crossing	North end Wrightsville Beach 2000' from Mason Inlet	0.4	0.4	<100,000 (not scheduled)
Masonboro sand bypassing	North end Masonboro Island, south from Masonboro Inlet	1.2	1	500,000 every 4 yr
AIWW, Carolina Beach Inlet, Snows Cut	South end Masonboro Island, from Carolina Beach Inlet north	1.3	0.4	<50,000 / yr
AIWW	North end of unincorp. Carolina Beach, south of Carolina Beach Inlet to town limit	0.8	0.4	<100,000 / yr
Cape Fear River, Wilmington Harbor	Bald Head Island	3.0		Approx. 1,000,000 / 2 yr.- total for Bald Head, Caswell, and eastern Oak Island
Cape Fear River, Wilmington Harbor	Caswell Beach and eastern part of Oak Island	4.7 mi initially, 2.8 mi./2 yr		
Cape Fear River, Wilmington Harbor	Sea Turtle Restoration Site, Oak Island (Continuing Authorities Project)	2.4		Only received one time from initial dredging
Cape Fear River, Wilmington Harbor	Oak Island, west of sea turtle project	4.9		Only received one time from initial dredging
Cape Fear River, Wilmington Harbor	Holden Beach	2.0		Only received one time from initial dredging
AIWW Cape Fear River to SC line	East end Ocean Isle Beach	0.6	0.6	<100,000 every 1-2 yr; 250,000 if Lockwood Folly Inlet dredged (every 8-10yr)
Total		**50.7**	**16.14**	

Status of beach nourishment from storm damage reduction projects

Storm damage reduction projects involve dredging sand specifically to increase the width and height of the beach and dunes to reduce storm damage to infrastructure and private property adjacent to the beach. To implement a federally authorized and subsidized storm damage reduction project, local governments must follow a lengthy process that can take up to 10 years to initiate. A local government must first identify an erosion problem and request a study by the COE to determine if and how a project could be conducted. Numerous regulations and policies guide permit review and authorization, although protection of fish habitat is not the primary consideration. DMF and other agencies are given an opportunity to comment to DCM and the COE on the potential impacts of a project to fisheries, fish habitat, and other environmental concerns. The MFC adopted a beach nourishment policy in 2000 to guide the permitting process to more fully consider fish habitat impacts (Appendix N).

The frequency and magnitude of beach nourishment on developed beaches have increased over time. From the 1960s to 2000, only nine miles of beach (3% of the ocean shoreline) had ongoing storm damage reduction projects - Wrightsville Beach, Carolina Beach, and Kure Beach (Table 6.7; Map 6.3 a-c). These projects were initially authorized and begun in the 1960s, although the first nourishment project in Wrightsville Beach occurred in 1939 (COE 1992). With the exception of Currituck County where there have been no nourishment projects, Onslow County has had the least beach renourishment, with only one small project in the 1990s. Currently there are 16 mi (5%) of beach along North Carolina’s coast that have authorized and funded storm damage reduction projects ongoing. An additional 35 mi (11%) of beaches have authorization to conduct projects, and 104 mi of additional beaches (33%) are at some stage of requesting long-term beach nourishment (storm damage reduction projects). This includes all of Hatteras and Ocracoke islands because of the DOT NC 12 study, but it is likely that only a small part of these islands would actually be nourished (J. Sutherland, WRC, pers. com., 2004). Beach renourishment of federally authorized storm reduction projects generally occurs on three or four year intervals. Potentially 155 mi or 48% of North Carolina’s beaches could be renourished regularly if resources existed, and these beaches could be potentially impacted by such activities. This does not include approximately 16 mi of beach renourished periodically by disposal from channel, inlet, and port dredging. There are approximately 160 mi of federally or state owned barrier islands along the 320 mi of ocean shoreline where storm damage reduction projects would be unlikely.

Table 6.7. North Carolina beach communities with federally authorized or requested storm damage reduction projects (does not include beach disposal from navigational dredging projects). [Source: COE, unpub. doc., 2003.]

Beach	**Project length (miles)**		
	Existing	**Authorized**	**Requested/Under study**
S. Kitty Hawk & N. Kill Devil Hills		4.5	2.2
Nags Head		10.5	
Hatteras Island			53 (NC 12 project)
Ocracoke Island			17 (NC 12 project)
Bogue Banks, excluding Atlantic B.			17
Onslow Beach		1.0	
North Topsail Beach			4
Surf City			5.5
Topsail Beach		3	5.5
Figure 8 Island	2		
Wrightsville Beach	3 (every 4 yrs)		
Carolina and Kure Beach	6 (every 3 yrs)		
Caswell Beach, southern part of Oak Island		7.3	
Holden Beach		5.7	
Ocean Isle	5.3		
Sunset Beach		2.7 (needs re-evaluation)	
Total	**16.3**	**34.7**	**104.2**

Preliminary examination of commercial gill net landings data for demersal feeding surf fish in counties with differing levels of beach nourishment activity indicates some relationship may exist between beach nourishment events and low landings (DMF, unpub. data). However, more information and analysis are needed to determine if beach nourishment events negatively impact surf fish abundance, CPUE, or landings. Given the increasing numbers of existing and requested nourishment projects over time, the cumulative impacts of activities on the intertidal and subtidal communities are also expected to increase. *To adequately and correctly assess the direct and cumulative impacts of beach nourishment activities on fish, their habitat, and biological recovery rates, thorough monitoring must be conducted*. Increasing use of beach nourishment may have a cumulative impact on fish productivity of nearshore waters through impacts on the benthic community and alteration of natural barrier island processes. *Because the demand for beach nourishment has increased in recent years, due in part to the state's prohibition of shoreline hardening, there is a need to complete a comprehensive beach management plan to provide guidelines to minimize long-term impacts. In addition, multi-agency efforts should be made to educate local government officials and the general public (since these groups initiate and drive the demand for beach nourishment) on natural hazards and other factors associated with dynamic coastal systems.*

<u>Fishing gear impacts</u>

The extent of habitat damage from fishing gear varies greatly with the gear type, habitat complexity, and amount of gear contact. While MFC rules are designed to minimize commercial fishing gear impacts to fisheries habitat, these restrictions primarily focus on restricting the use of highly destructive bottom disturbing gear from most structural habitats such as oyster or SAV beds. Soft bottom habitat, because of its low structure and dynamic nature, has historically been considered the most appropriate location to use bottom disturbing gear. There are some fishery rules that restrict bottom disturbing gears in soft bottom habitat, since DMF research found that their use disturbed soft bottom substrate. These include prohibition of trawls, dredges, and long haul seines in PNAs [15A NCAC 3N .0104] and prohibition of trawls or mechanical shellfish gear in crab spawning sanctuaries [15A NCAC 3L .0205] in the five northern-most inlets of North Carolina during the blue crab spawning season (March-August).

Fishing related impacts to fish habitat have been reviewed and compiled in federal fishery management plans for managed species and have been summarized in fishery management plans by SAFMC and MAFMC, as well as by MSC (1996), Auster and Langton (1999), DMF (1999), and Collie et al. (2000). A legislative report to the Moratorium Steering Committee (MSC 1996) compiled a list of the gears used in North Carolina waters and their probable impacts (Appendix O). The gears with the greatest potential for damage to soft bottom or other habitats include dredges and trawls. The impacts of these gears and where they are used are discussed below.

Dredging

Of gears used in North Carolina, dredges are considered to be the most habitat destructive (DeAlteris et al. 1999; Collie et al. 2000). Oyster and crab dredging are conducted in limited areas in northern Pamlico Sound and its tributaries. Oyster dredging is conducted over shell bottom and was discussed in detail in the shell bottom chapter. Crab dredging is allowed in one area in northern Pamlico Sound (approximately 100,653 acres), primarily on soft bottom (Map 6.5), and is opened by proclamation from January 1 to March 1. Crab dredges are similar to oyster dredges, although the dredge teeth are sometimes longer on the crab dredge. Because of the gears' teeth, crab and oyster dredges can dig deep into the sediment and cause extensive sediment disturbance. Crab dredges are limited to a weight of 100 lbs and can only be used in January and February [15A NCAC 3L .0203]. Mechanical methods, as well as trawls and pots, for the taking of crabs are prohibited in designated Crab Spawning Sanctuaries from March through August. In recent years, fishing effort has been very low, with fewer than 10 crab dredge trips reported per year. Although the amount of fishing effort is low, this gear is documented to cause significant damage (DeAlteris et al. 1999; Collie et al. 2000). *Because less habitat damaging methods are available for harvesting crabs, MFC should prohibit crab dredging.*

There are two types of scallop dredges used in North Carolina. Bay scallop dredges are used in SAV beds. Refer to the SAV chapter for more information on this gear. Sea scallop dredges are used occasionally in the coastal ocean off Cape Lookout. Studies have found that scallop dredges cause extensive damage to hard bottom and significantly reduce habitat complexity on soft bottom and shell hash bottom (Auster et al. 1996; Currie and Parry 1996). Habitat complexity is reduced through flattening of mounds, filling of depressions, dispersing shell hash, and removing small biotic cover such as hydrozoans and sponges (Auster et al. 1996). Sea scallop dredging primarily occurs in deep coastal waters north of North Carolina. Dredging for sea scallops off North Carolina has been a sporadic fishery, primarily located in federal waters. Since 1994, commercial landings of sea scallop meats have been very low, ranging from 13,815 lb in 1999 to 206,790 lb in 1995 (DMF 2001c). Because of the location of the fishery and the low level of effort, no additional restrictions appear to be needed.

Hydraulic clam dredging and clam kicking were described in detail in the SAV chapter. Mechanical clamming, including kicking and dredging, accounts for approximately 21% of the annual hard clam landings (DMF, unpub. data). The dredging and kicking activity creates trenches and mounds of discarded material in soft bottom habitat, redistributing and resuspending sediment (Adkins et al. 1983). Water jets from the hydraulic dredge can penetrate 18 inches into bottom sediments, and uproot any living structure present (Godcharles 1971). Dredge tracks can remain present from a few days to more than one year and recolonization by vegetation can take months to begin. Recruitment of clams and other benthic invertebrates does not appear to be affected by hydraulic dredging (Godcharles 1971). Because of the severe impacts to habitats, both hydraulic clam dredging and clam kicking are restricted to open sand and mud bottoms, including areas frequently dredged as navigational channels. The locations where mechanical clam harvest is allowed are shown in Map 6.5. There are approximately 39,517 acres that are potentially available to mechanical clam harvest in portions of Core, Bogue, and Pamlico sounds, Newport, North, White Oak, and New rivers, and a portion of the ICW in Topsail Sound. The majority of mechanical harvest areas are located in Core Sound (29,951 acres). These fisheries may be opened by proclamation between Dec 1 and March 31. At this time, no changes are necessary to protect soft habitat because of the low frequency of the activity and dynamic nature of the habitat. However, some changes are needed to better protect SAV and are discussed in that chapter.

Bottom trawling in estuarine waters

Bottom trawling is used more extensively than dredges on soft bottom habitat in both estuarine and coastal ocean waters. Bottom trawling in estuarine waters is used primarily to catch shrimp, although some crab trawling is also conducted. Flounder trawling is restricted to ocean waters. Bottom trawls are conical nets that are towed behind a fishing vessel, held open by water pressure against a pair of "otter boards" or "doors" that are attached to the front of the net. Three components of a bottom trawl can dig into the sediment: the doors, the weighted line at the opening of the net, and the tickler chains (which are sometimes added in front of the net to improve the harvest).

Impacts of shrimp and crab trawling in estuarine waters were reviewed and compiled by DMF (1999), at the request of the MFC and were reported to the General Assembly's Joint Legislative Commission on Seafood and Aquaculture. This report found that trawling can impact fish habitat by altering the physical structure or biological components of soft bottom. Pulling trawl nets across soft bottom reduces habitat complexity by (Auster and Langton 1999):

- directly removing or damaging epifauna
- removing benthic invertebrates which produce structure like burrows and pits
- smoothing sediment features of the seafloor, such as sediment ridges and contours

Gear contact can uproot and remove plants and invertebrates attached to the seafloor, such as algae, sponges, worm tubes, and SAV, and can expose them to predators. This structure, although small relative to other benthic habitats, is important to certain species, such as *Sabellaria* worms, for recruitment (Wilson 1968). Gear effects on bottom were described in the SAV chapter and in ASMFC (2000). Trawl doors penetrate more than the rest of the gear and will penetrate deeper in muddy substrates. The change and reduction in the structural complexity of the seafloor and increase in turbidity from trawling can reduce feeding success of filter feeding invertebrates due to gill clogging, or increase predation due to increased exposure and reduced cover. Clam trawling (clam kicking) causes severe disturbance to bottom sediments. However, a study in North Carolina found no significant effect of this fishing activity on recruitment of hard clams or abundance of other benthic invertebrates in unvegetated sandy bottom (Peterson et al. 1987).

Reduced diversity and abundance of some benthic taxa are commonly observed in areas experiencing intense fishing activities (Auster and Langton 1999). A shift in dominant species and a reduction in community stability may also occur. Long-lived species, which take more time to recover from fishing disturbance, may be temporarily or indefinitely replaced by short-lived species. Sediment resuspension by trawling can significantly increase the suspended sediment load (turbidity) over soft bottom on the outer shelf. Increased turbidity reduces light penetration and consequently reduces primary productivity of benthic microflora on the seafloor as well as phytoplankton in the water column (Auster and Langton 1999). Decreased primary productivity will affect demersal zooplankton that, in turn, support higher trophic layers. A reduction in filter feeders on the subtidal bottom can result in reduced water clearing capacity in the water column (Auster and Langton 1999). However, given the frequency, magnitude, and location of trawling, it is unknown whether these events are having a significant negative impact on soft bottom habitat in North Carolina's estuarine system. Trawling can affect primary productivity of both soft bottom and water column by (DMF 1999):

- stimulating chemical exchange between resuspended sediment and the water column

- increasing turbidity and reducing light availability at the surface of soft bottom
- reducing primary production of benthic microalgae

Increased chemical exchange between bottom sediments and the water column (benthic-pelagic coupling) can have positive and negative effects on estuarine systems. Nutrients released into the water column can greatly increase nitrogen and phosphorus levels, stimulating phytoplankton growth, as well as enhancing secondary productivity of herbivorous zooplankton and larger prey (DMF 1999). Eventually, the remains of plankton and other organisms will settle, adding to the food available to benthic deposit feeders. However, if large amounts of organic matter are resuspended, the subsequent increase in plankton can reduce water oxygen levels, causing hypoxia and anoxia (West et al. 1994; Paerl et al. 1998). By resuspending sediments, trawling can make inorganic and organic pollutants (e.g., heavy metals and pesticides, respectively) available in the water column (Kinnish 1992; DMF 1999). Such toxins can negatively affect productivity and may also accumulate in organisms through food chain interactions.

While some consider trawling to be physically disruptive to the bottom and potentially harmful to the benthic community due to gear damage, sedimentation, predation exposure, and reduction in benthic primary production (Auster and Langton 1998), others feel that trawling may mimic natural disturbances and stimulate benthic production, enhancing fish production. In a literature review of the effects of trawling in estuarine waters, DMF (1999) noted that multiple studies demonstrated the presence and absence of long-term effects of trawling in estuarine waters. No or minimal long-term impacts were reported in MacKenzie (1982), Van Dolah et al. (1991), and Currie and Parry (1996). Of these studies, Van Dolah et al. (1991) was located closest to North Carolina, in a South Carolina estuary. After five months of trawling, Van Dolah et al. (1991) found no significant change in abundance, diversity, or composition of soft bottom habitat. Studies which have found long-term habitat impacts include Bradstock and Gordon (1983), Brown (1989), Collie et al. (1997), and Engel and Kvitek (1998).

The DMF trawl report recommended that additional studies be done in North Carolina estuarine waters to better assess the impact of trawling on the estuarine environment. *Further analysis is needed to identify the location, duration, and initiation of trawling over soft bottom habitat as well as over structured habitats, such as shell bottom and SAV. It is also important to quantify the effects of trawling on the habitat*. Specific research needed to evaluate the habitat impacts of trawling include (DMF 1999):

- *Determine the intensity, duration, and spatial scale of trawling effort in different regions of North Carolina.*
- *Determine turbidity levels generated by different gear configurations and the subsequent rates of redeposition.*
- *Determine the physical effect of natural forms of disturbance to compare significance of trawling effects.*
- *Sample areas normally subjected to trawling to describe the local benthic community, identifying seasonal cycles of species abundance and recruitment, to determine the times of year that benthos would be most sensitive to trawling disturbance.*
- *Measure in situ rates of growth, mortality, and recruitment of selected benthic organisms that are exposed to trawling.*
- *Evaluate the effect of trawling on benthic algal growth and primary productivity overall.*
- *Determine the impact of trawling on secondary productivity*.

Attempting to answer questions in the DMF trawl report, Cahoon et al. (2002) studied changes in benthic microalgae, demersal zooplankton, and benthic macroalgae (important food sources for recreationally and commercially important species) in the Pamlico River estuary in 1999-2000. Demersal zooplankton include small crustaceans, nematodes, and other animals that are important grazers of benthic microalgae and prey for larger fish and invertebrates. Experimental trawling was conducted to document natural seasonal changes in the benthic community, examine changes before and after experimental trawling, and compare regularly trawled and untrawled areas. No significant differences were recorded in benthic algal biomass prior to and after experimental trawling. In comparing commercially trawled and untrawled areas, benthic microalgae were more abundant in the untrawled sites. This could be because benthic algae in trawled areas are resuspended into the water column. Nematodes, an important food source for shrimp, were the most abundant demersal organism found. The authors concluded that, because the soft bottom community in shallow systems is frequently subjected to disturbance (such as exposure to waves and currents), trawling was not detrimental (Cahoon et al. 2002). However, since the experimental treatment consisted of one trawling pass, observed changes do not accurately reflect those consistent with chronic trawling. A key issue in determining if trawling is having a negative impact to soft bottom communities is the frequency and intensity of disturbance. *Further analysis is needed to spatially quantify where, how often, and when trawling occurs in specific areas of soft bottom habitat.*

The impact of trawling and associated bottom changes on fish populations also depends in part on each species' habitat dependence (Auster and Langton 1998). Where a life stage of a demersal species is highly dependent (obligate) on the structural components of a habitat where trawling occurs, particularly for recruitment, there is a greater potential for that species to be impacted by trawling (Auster and Langton 1998). However, if individuals can move to and survive in alternative habitats, impacts may be less severe (i.e., adult flounder foraging over ocean bottom can occupy other habitats) (DMF 1999). Primary nursery areas and inlets are described as "recruitment bottlenecks" for estuarine dependent species in DMF (1999). Since larval flounder, shrimp, and Atlantic croaker must pass through inlets and recruit to shallow PNAs, trawling impacts in inlets and PNAs could be greater than trawling in ocean waters. *Protection of these "recruitment bottlenecks" from trawling or other impacts is therefore very important for estuarine dependent fish and invertebrates.* The current MFC restrictions on trawling protect PNAs. However, there are productive shallow water areas of soft bottom that are not designated as primary or secondary nursery areas but still serve as important habitat to many juvenile fish and invertebrates. *Shallow areas where trawling is currently allowed should be re-examined to determine if additional restrictions are necessary*. There are also other non-habitat related concerns regarding trawling in estuarine waters, including bycatch or socio-economic reasons which may warrant additional restrictions on trawling in estuarine waters. *However, further studies are needed to more accurately assess if trawling is having a negative effect on soft bottom habitat and justify if additional closures are necessary for habitat concerns.*

Bottom trawling in ocean waters

Many studies have been conducted around the world assessing the effect of trawling on soft bottom habitat in offshore waters. A thorough review of literature on fishing impacts to continental shelf benthos quantified impacts via a meta-analysis, examining data derived in part from studies of otter trawl effects on subtidal bottom in eastern North America (Table 6.8) (Collie et al. 2000). Some of their conclusions included:

- Otter and beam trawling were found to have fewer negative impacts on benthos than intertidal or scallop dredging or intertidal raking.
- In subtidal bottom, sand habitats were the least impacted, and muddy sand and gravel the most impacted.
- In muddy sand, polychaetes and large bivalves were most negatively impacted. Smaller bodied organisms are displaced by pressure waves in front of fishing gear.
- Depth and scale of fishing had insignificant effect on initial impact but significant effect on recovery. Recovery is slower where the spatial scale of impact is larger and in deeper waters where the bottom is more stable.
- Recovery was most rapid in less physically stable habitats such as sandy bottom (recovery in sand, estimated from modeling, was approximately 100 days).
- Benthos most impacted were Anthozoa (corals and anemones) and Malacostraca (crabs, amphipods), while copepods and ostracods were least impacted.
- Benthos had more negative responses to chronic disturbances than to acute disturbances.

- Epifaunal organisms are less abundant in areas subjected to intensive bottom fishing.
- Results suggested that fish and benthos in areas heavily fished would shift from communities dominated by high biomass species towards those with high abundance of small-sized organisms.
- *Large- scale long-term experiments with and without fishing pressure are needed, rather than short-term small-scale studies, to examine and better quantify cumulative fishing impacts and recovery patterns*.

Table 6.8. Trawl impact studies on the continental shelf of eastern North America.

Reference	Habitat	Depth (m)	Recovery Period (days)
Van Dolah et al. (1991)	Hard bottom	20	365
Kaiser and Spencer (1996)	Gravel	94	n/a
Van Dolah et al. (1991)	Sand	20	180
Van Dolah et al. (1991)	Sand	8	180
Auster et al. (1996)	Sand	30	3,650

These conclusions suggest that the dynamic soft bottom community found in nearshore ocean communities is less impacted by trawling and recovers much quicker than in estuarine systems. However, some long-term impacts to the benthic community may occur, especially to the epibiota, depending on the frequency of trawling and site-specific characteristics.

Status and trends of estuarine and ocean trawling

Trawling is primarily allowed in relatively deeper soft bottom areas. Map 3.5a-c (from shell bottom chapter) shows the areas where trawling is currently not allowed in estuarine waters. Use of trawl nets is not allowed in Albemarle Sound and is not allowed for taking of finfish in internal (estuarine) waters [15A NCAC 3L .0205, 15A NCAC 3J .0104(a&b)]. Shrimp trawling is not allowed in primary or secondary nursery areas [15A NCAC 3N .0105], or in No Trawl Areas [15A NCAC 3R .0106]. In North Carolina, bottom trawling in ocean waters is prohibited over hard bottom but is allowed over most soft bottom communities. Trawling is prohibited in military prohibited areas [15A NCAC 3I .0110 and 3R .0102], a designated sea turtle sanctuary seaward of Onslow Beach from June 1 to August 31 [15A NCAC 3I .0107 and 3R .0101], within 0.5mi of the beach from Virginia to Oregon Inlet [15A NCAC 3J .0202], and in designated crab spawning sanctuaries from March 1 to August 1 [15A NCAC 3L .0205]. Map 6.6 a-c shows areas where trawling and some other gears are restricted over soft bottom in ocean waters. The purpose of these regulations is to protect spawning areas and reduce bycatch or user conflicts.

Annual effort with various commercial trawling gears in North Carolina waterbodies is shown in Table 6.9 (DMF, unpub. data). Commercial shrimp trawling accounts for the majority of trawl trips (92% in 2002) (Table 6.9). About 75-80% of shrimp trawl trips occur in estuarine waters, with the remainder in ocean waters, primarily within state territorial seas (<3 mi offshore) off the central and southern coast of North Carolina. Total annual shrimp trawling effort has decreased since 1995 by about 5,500 trips. Total annual shrimp trawling effort has fluctuated with shrimp abundance but appears to have gradually declined since 1994. However, the lower commercial fishing effort observed from 1999 – 2002, when compared to earlier years, is thought to be mostly due to a change in licensing procedure (R. Carpenter, DMF, pers. com., 2004). In 1999, a recreational commercial gear license became available to fishermen. Under this license, shrimp may be caught recreationally using a trawl, but cannot be sold. Some fishermen, with previously held commercial licenses , switched from standard commercial gear licenses (SCGL) to recreational commercial gear licenses (RCGL). Effort from RCGL licenses are not included in the data shown in Table 6.9. In 2002, approximately 5000 trips for shrimp were reported (DMF, unpub. data).

Regionally, shrimp trawling effort has generally been greatest in Core and Bogue sounds and associated estuaries (3,400-7,200 trips/year) (Table 6.9). Pamlico Sound and associated rivers and estuaries account for the second largest number of trawl trips per year, ranging from 2,900-5,500 trips/year. In 2000 and 2002, however, the Pamlico region accounted for slightly more trips than the Core/Bogue waters. Decreased effort in Core/Bogue sounds is not attributed to changes in shrimp management or habitat condition. In ocean waters, shrimp trawling is highly concentrated in the southern portion of the state (Onslow through Brunswick counties), primarily in the summer (approximately 2,300-3,400 trips/year). In contrast, the annual effort has ranged from 137 to 457 trips per year in the central district (Carteret County) and from 2 to 69 trips per year in the northern district (Virginia state line through Hyde County). Commercial shrimp trawl effort has remained relatively stable over time in the southern portion of the state.

Over 99% of crab trawling occurs in estuarine waters, while all directed flounder trawling (specially targeting flounder) occurs in ocean waters (i.e., no directed trawling for finfish is allowed in internal waters). The majority of crab trawling occurs in Pamlico Sound and adjacent estuarine rivers, followed by Core/Bogue sounds and estuaries. Flounder trawling effort occurs primarily in the northern and central portions of North Carolina’s coastal waters. Effort in the northern district has varied from 14 trips in 1994 to 123 trips in 2002. In the central district, trips seem to be declining over time, with a peak of 95 trips in 1996 and 19 trips in 2002 (Table 6.9). Overall, current bottom trawling effort in estuarine waters for all fishery species is greatest in Pamlico Sound and associated estuaries.

Table 6.9. Annual number of trips reported for shrimp, crab, and flounder trawls in estuarine and ocean waters [1], 1994-2002 (DMF, unpub. data).

Shrimp trawl								
	Estuarine rivers and sounds				State ocean waters (< 3 mi.)			
Year	Albemarle estuaries	Core/Bogue estuaries	Pamlico estuaries	Southern estuaries	Northern district	Central district	Southern district	Total
1994	2	7,186	4,869	3,066	3	223	3,409	18,758
1995	0	7,252	5,185	3,361	41	316	3,414	19,569
1996	32	6,070	2,903	2,352	13	327	2,630	14,327
1997	1	5,745	4,790	2,722	23	229	2,742	16,252
1998	0	4,679	1,864	2,053	2	376	2,834	11,808
1999	1	4,868	4,105	2,178	18	457	3,468	15,095
2000	1	3,462	5,556	1,946	69	311	2,657	14,002
2001	0	3,534	3,211	1,273	6	137	2,528	10,689
2002	3	3,763	4,917	1,622	2	210	2,384	12,901

Crab trawl								
	Estuarine rivers and sounds				State ocean waters (< 3 mi.)			
Year	Albemarle	Core/Bogue	Pamlico	Southern	Northern district	Central district	Southern district	Total
1994	12	238	3,523	36	2	13	0	3824
1995	0	207	1,895	102	0	1	0	2205
1996	9	197	4,058	51	0	2	0	4317
1997	0	657	4,193	198	0	0	0	5048
1998	1	542	5,103	63	1	0	0	5710
1999	0	410	3,127	32	0	0	0	3569
2000	1	265	1,985	50	0	0	0	2301
2001	1	397	2,093	107	0	0	0	2598
2002	7	87	811	79	0	0	0	984

Flounder trawl								
	Estuarine rivers and sounds				State ocean waters (< 3 mi.)			
Year	Albemarle	Core/Bogue	Pamlico	Southern	Northern district	Central district	Southern district	Total
1994	0	0	4	1	14	35	0	54
1995	0	1	13	6	43	45	0	108
1996	0	1	5	0	17	95	0	118
1997	0	0	11	2	22	46	0	81
1998	0	0	1	0	115	87	0	203
1999	0	0	0	0	99	70	0	169
2000	0	0	0	0	84	22	0	106
2001	0	0	0	0	74	30	0	104
2002	0	0	0	0	123	19	0	142

[1] Albemarle Area: Albemarle Sound, Currituck Sound, and all tributaries of Albemarle Sound.
Pamlico Area: Pamlico, Croatan, and Roanoke sounds; Pamlico, Bay, Neuse, and Pungo rivers.
Core/Bogue Area: Core and Bogue sounds; Newport, White Oak, and North rivers.
Southern Area: Masonboro, Stump, and Topsail sounds; Cape Fear, New, Shallotte, and Lockwood Folly rivers; ICW.
Northern district ocean waters: Virginia line through Hyde County.
Central district ocean waters: Carteret County.
Southern district ocean waters: Onslow County to the South Carolina line.

Water quality degradation

The condition of soft bottom is determined by the character and quality of bottom sediments and the quality of the overlying water column. Solids and organic matter in the water column eventually settle out and become a part of the soft bottom habitat. However, soft bottom sediments can also be resuspended by disturbances (e.g., storms and human activities such as dredging). The cycling of material between the bottom and the water column was discussed previously in this chapter and in the water column chapter. In general, bottom sediments tend to act more as a sink than a source with regards to benthic-pelagic coupling. Aquatic organisms can accumulate pollutants from the sediment or the water column. Because water quality inevitably affects soft bottom (i.e., anoxia in the water column leads to increased production of hydrogen sulfide (H_2S), a gas that is toxic to aquatic life, in bottom sediments), many of the same threats to the water column are threats to soft bottom. The primary pollutants of concern to soft bottom are discussed below.

<u>Toxic chemicals</u>

Toxic chemicals that tend to accumulate in bottom sediments include:

- heavy metals
- polycyclic aromatic hydrocarbons (PAHs)
- petroleum hydrocarbons
- pesticides
- polychlorinated biphenyls (PCBs)
- ammonia

Of the heavy metals, arsenic, copper, cadmium, chromium, nickel, lead, zinc, tin, and mercury are among the greatest concerns. While toxins can fluctuate between the sediment and water column, concentrations of toxic chemicals tend to accumulate in sediments to several orders of greater magnitude than overlying waters (Kwon and Lee 2001). The bioavailability and transport of a chemical depend on the form of the chemical incorporated into the sediments, the feeding habits and condition of aquatic organisms, and the physical and chemical conditions of the environment. Because toxins can accumulate and persist over time, chemicals that have been banned since 1977, such as DDT, Diedrin, and TBT, continue to be found in sediments (Marburger et al. 2002). Toxic chemicals can become active in soft bottom sediment or overlying waters through several mechanisms, including resuspension from natural weather events or human activities. Toxins can also be active in surface waters, when dry sediment is hydrated from rainfall or runoff, toxic chemicals in the soils become oxidized, and heavy metals are released and transported downstream by heavy rains or water movements. Also, several studies have shown that mercury and other metals are released from peat soils subjected to intensive drainage (Evans et al. 1984; Gregory et al. 1984).

Because low concentrations of heavy metals in the water column can be easily incorporated into fine-grained sediment, chemicals can accumulate in the sediment to toxic levels and be resuspended into the water column (Riggs et al. 1991). Studies have shown that fine-grained sediments are the primary reservoir for heavy metals, particularly organic rich muds (ORM) (Riggs et al. 1991). Since organic rich muds are the most extensive sediment type in North Carolina’s estuaries and since many primary nursery areas are composed of ORM, resuspension of contaminated ORM sediments in PNAs is of particular concern.

Contaminated sediments affect benthic feeding fish and invertebrates in several ways. Some toxins can inhibit or alter reproduction and development of marine and aquatic organisms, or cause mortality in some situations (Weis and Weis 1989; Gould et al. 1994). Large spills of toxic chemicals, such as pesticides or petroleum products, can result in fish kill events. In North Carolina, spills of pesticide, chlorinated water, and sewage waste were responsible for 8% of fish kill events in 2001 (DWQ 2001b)[78]. Some heavy metals and pesticides cause hormone alterations that affect reproduction (Wilbur and Pentony 1999). Certain PAHs have been shown to cause mutations or cancer in fish (White and Triplett 2002). Documented effects of PAHs to flatfish include DNA damage, liver lesions, and impacts on

[78] Other suspected causes reported: unknown (46%), dissolved oxygen (34%), blooms (4%), other (9%), and bycatch (1%).

growth and reproduction (Johnson et al. 2002).

Early life stages (embryos and larvae) of fish are most susceptible to toxins (Funderburk et al. 1991; Gould et al. 1994; Rice et al. 2001). Visible indications of heavy contamination are development of lesions, deformities, and tumors on fish or high mortality rates of larvae. Anadromous fish larvae are particularly sensitive to many toxins (Funderburk et al. 1991). In Alaskan waters, salmon eggs and larvae were killed or exhibited damage for up to four years following long-term exposure to low concentrations of weathered crude oil, and migrating salmon fry had reduced growth rates and population reductions (Rice et al. 2001). See Appendix L for more information on toxicity thresholds for early life stages of fish. Mollusks are known to be very sensitive to petroleum products, pesticides, and TBT, with relatively low levels of exposure affecting reproduction, tissue development, growth, and survival (Funderburk et al. 1991) (refer to shell bottom chapter for toxicity levels). Because macrobenthic invertebrate diversity significantly declines with increasing sediment contamination (Weis et al. 1998; Brown et al. 2000; Dauer et al. 2000), food resources for benthic feeders may be limited in areas having significant contamination.

Lethal and sublethal levels of toxicity are known for some benthic aquatic species. However, most information comes from acute toxicity tests conducted in laboratory settings on standard test species. Data are lacking on chronic or sublethal toxicity levels for many important fishery species and interactions of contaminants in the field. Following oil spills, sub-lethal levels of contamination can delay population recovery due to indirect effects, and may lead to increased fish mortality where predation risk is size-dependent (Peterson et al. 2003b). *More information is needed on the in situ effects of various contaminant levels, in combination with other contaminants and existing environmental stressors, to many important fish species in North Carolina.*

While some aquatic organisms experience mortality from exposure to toxins, chemicals may bioaccumulate to toxic levels within surviving organisms and pass through the food chain. Multiple studies have shown clear connections between concentrations of toxins in sediments and those in benthic feeding fish and invertebrates (Kirby et al. 2001; Marburger et al. 2002). Heavy metal contamination of sediments has been documented to result in elevated trace metal concentrations in benthic feeding striped mullet, shrimp, oysters, and flounder (Kirby et al. 2001; Livingstone 2001). Largemouth bass and catfish, stocked in a restored and flooded freshwater wetland, had high concentrations of organochlorine (chlordane, DDT, dieldrin) and internal contaminants were significantly correlated to contaminant levels in the sediment (Marburger et al. 2002). Toxic contaminants are also considered one of the most serious threats to native freshwater mussels, which are the most imperiled fauna in North America (Keller 1996).

The bioaccumulation of toxins in fish may pose a risk to human health. High levels of mercury have been found in four saltwater fish species (sharks, swordfish, tilefish, and king mackerel) and three freshwater species (bowfin, largemouth bass, and chain pickerel). Fish consumption advisories have been posted for all of these species (<http://www.epi.state.nc.us/epi/fish/current.html>, 2003). The saltwater fish consumption advisory for sharks, swordfish, tilefish, and king mackerel covers the entire state of North Carolina and much of the lower East Coast. The fish advisory for bowfin, largemouth bass, and chain pickerel extends south and east from Interstate 85. In addition, several site-specific advisories exist (<http://www.epi.state.nc.us/epi/fish/current.html>). Limits on consumption of catfish and carp due to dioxin contamination exist for Albemarle Sound, the lower portion of Roanoke River from Williamston to the mouth of Albemarle Sound, all of Welch Creek, a tributary of Roanoke River, and Walters Lake, a reservoir.

Toxic chemicals come from localized point sources as well as diffuse nonpoint sources. Point sources include industrial and municipal waste discharges. Nonpoint sources of toxins include urban runoff containing household and yard chemicals, roadways, marinas and docks, boating activity, runoff from agriculture and forestry, industrial emissions, spills from industrial shipping, and dredge spoil disposal (Wilbur and Pentony 1999). Refer to the water column chapter for more detailed information on the sources of toxic chemicals.

The extent of sediment contamination in North Carolina coastal waters is not well known. Sediment sampling is not conducted by the DWQ since there are no sediment standards in the state. Studies examining sediment contamination at sites in North Carolina soft bottom have found various levels of contamination. The EPA Environmental Monitoring and Assessment Program surveyed 165 sites within North Carolina's sounds and rivers during 1994-1997 to evaluate condition of bottom sediments (Hackney et al. 1998). Highest contamination levels occurred in low salinity areas with low flushing and high river discharge. Benthic communities were dominated by tolerant opportunistic species and low species richness. Laboratory bioassays showed that sediments from many sites were toxic to biological organisms. However, because of the low sample size, frequency of sampling, and the confounding effects of hypoxia in areas sampled, results from this study may not accurately assess the condition of North Carolina sediments (C. Currin, NOAA, pers. com., 2003).

Concentrations of heavy metals in the Neuse and Pamlico estuaries have been assessed (Riggs et al. 1989; Riggs et al. 1991). In the Neuse River, surface sediments were found to contain elevated levels of several heavy metals, including zinc, copper, lead, and arsenic. Furthermore, 17 areas between New Bern and the mouth of the river were identified as "contaminated areas of concern". The contaminated sites were primarily attributed to permitted municipal and industrial treatment plant discharges. Marinas were also found to contribute substantial amounts of copper and variable amounts of zinc and lead. Nonpoint sources were more difficult to evaluate. In the Pamlico River, heavy metal contamination was less severe, although arsenic, cobalt, and titanium exceeded the levels found in the Neuse River. These studies suggest that sediment contamination in some estuarine areas, especially those where both organic rich mud and waste water discharges are present, may be significant and could affect fish populations and the base of their food chain. *To better determine if contaminated sediment is a significant threat to coastal fish habitat, the distribution and concentration of heavy metals and other toxic contaminants in freshwater and estuarine sediments need to be adequately assessed and areas of greatest concern need to be identified. Continued minimization of point and nonpoint sources of toxic contaminants is vital for protecting not only soft bottom but also the other fisheries habitat.*

<u>Nutrients</u>

Increased nutrient loading and accumulation in bottom sediments are other concerns to this habitat. The effects of nutrient enrichment are complicated by additional stressors, such as toxins or hydrological modifications, and by benthic-pelagic coupling (Riedel et al. 2003). High concentrations of organic material in bottom sediments serve as continual sources of additional nutrients to the water column, which can fuel algal blooms. In the shallow Neuse River estuary, high but variable rates of exchange of nutrients between the water column and soft bottom were noted, with soft bottom efficiently storing and providing nutrients that can fuel algal blooms that may lead to hypoxia (Luettich et al. 1999). When nutrient loading reductions occur, a decline in nutrient levels may not be observed in a water body until the nutrient supply in the sediment is depleted (Luettich et al. 1999), making management strategies difficult to evaluate in the short term. Work is currently underway to determine the contribution of resuspended nutrients from bottom sediments to phytoplankton production (<http://www.marine.unc.edu/Paerllab/research/mudboy>, 2003). *Long-term monitoring is required, in combination with management actions that reduce discharge concentrations, to determine effectiveness and future management needs.*

Soft bottoms in North Carolina's estuaries tend to store nutrients for several reasons (Peterson and Peterson 1979). Small clay sized sediment particles that are abundant in ORM adsorb nutrients readily. In addition, suspension feeding invertebrates remove nutrients and particles from the water column which later are transformed and deposited on the bottom as feces (a process known as biodeposition). These nutrients can become stored in the sediment, but later can be resuspended into the water column, maintaining nutrient concentrations at high levels in estuarine waters. The ebb and flood circulation increases the residence time of particles in estuarine waters, further retaining nutrients in the system (Peterson and Peterson 1979). Extensive monitoring in the Neuse River revealed that large quantities of nutrients were stored in the sediment. Refer to the water column chapter for detailed discussion of the sources and status of nutrient enrichment in the water column.

Oxygen-depleted sediment

Adequate supply of dissolved oxygen is critical to survival of sessile benthic invertebrates and fish living on or in soft bottom habitat. In freshwater systems, low oxygen levels resulting from eutrophication has been suggested as an important source of mortality in mussels (Neves et al. 1997). In mesohaline estuaries, low oxygen events occur when the water column becomes stratified for a long period, particularly during summer in areas of deeper water (Tenore 1972). If stratification persists, hypoxic events in the water column can cause changes in the physical and chemical conditions at the sediment-water interface, lead to stress or mortality of benthic organisms, and reduce species richness (Tenore 1972). In the benthic community, polychaetes tend to be most tolerant to low oxygen, followed by bivalves and then crustaceans (Diaz and Rosenberg 1995). Severe oxygen depletion in the sediment also results in release of toxic levels of sulfide into bottom waters (Luettich et al. 1999).

Mass mortality of benthic infauna due to anoxia and toxic sulfide levels has been documented in the deeper portions of the Neuse River estuary, in association with stratification of the water column in the summer (Lenihan and Peterson 1998; Luettich et al. 1999). During these events, oxygen depletion caused mass mortality of infauna such as clams and worms. Epifauna like oysters and mud crabs and some benthic fish, like blennies, also died when adequate tall refuge (oyster reefs) with oxygenated water was not available (Lenihan and Peterson 1998). More mobile benthos, such as blue crabs, left their burrows when oxygen was not available and moved to shallower or higher areas. In 1997 during a large hypoxic event in the Neuse River estuary, the abundance and biomass of *Macoma balthica* and *M. mitchelli*, the dominant benthic invertebrates and critical food sources for demersal fishes such as spot and croaker, declined by 90 - 100% over a 100 km^2 area (Buzelli et al. 2002). The areas of high benthic mortality coincided with the area estimated to have been the most severely oxygen depleted.

Low oxygen in bottom sediments can also affect the primary productivity of soft bottom and predation on the benthic community. Benthic microalgae are limited to oxygenated sediments (MacIntyre et al. 1996). During a severe anoxic event, mortality of benthic microalgae can occur, due to anaerobic sediments and the higher turbidity that often accompanies the stratification of the water column (M. Posey, UNC-W, pers. com., 2003). Predation on members of the benthic community by species such as flounder, spot, blue crab, and croaker generally increases in the short-term since burrowing organisms tend to move into the shallowest sediment layers to avoid sulfide release and lack of oxygen in deeper sediments (Luettich et al. 1999). However, the overall reduction in prey could decrease long-term fish production (P. Peterson, UNC-CH, pers. com., 2004). Results from statistical modeling, utilizing field data from the Neuse River, indicated that benthic invertebrate mortality, resulting from intensified hypoxia events, reduced total biomass of heterotrophs (demersal predatory fish and crabs) during the summer by 51% in 1997 and 17% in 1998 (Baird et al. 2004). The decrease in available energy (fewer benthic invertebrates) greatly reduced the ecosystem’s ability to transfer energy to higher trophic levels at the time of year most needed by juvenile fish (Baird et al. 2004).

When the benthic community is depleted by a low oxygen event, the pattern of recolonization of the soft bottom will affect higher trophic levels differently over time (Luettich et al. 1999). Opportunistic, fast-growing species of polychaetes and copepods will begin to recolonize the bottom first. Juvenile clams and larger polychaetes will recruit afterwards. The various successional stages may affect or benefit different benthic feeders to differing extents. For example, early successional communities composed of very small, shallow-burrowing opportunists (capitellid worms) and meiofauna may favor small species, such as penaeid shrimp and larval and juvenile croaker and red drum, but not provide food for large adult fish species. Partially recovered benthic communities consisting of polychaetes and small juvenile clams could benefit demersal species like spot, croaker, and blue crab. A fully recovered community with deep burrowing polychaetes and large clams might benefit adult spot and hogchoker but not benefit shrimp (Luettich et al. 1999).

While hypoxia and anoxia can occur naturally, they can also be attributed, in part, to anthropogenic changes in the system, including excess nutrient and organic loading from waste discharges, nonpoint runoff, streambank erosion, and sedimentation (Schueler 1997). In the Neuse River system, MODMON studies found that the sediment oxygen demand is much greater than the biological oxygen demand in the water column. Oxygen depletion in the water column was positively correlated with accumulation of organic material in the sediments (Luettich et al. 1999). Site-specific information on sediment condition is generally lacking in other areas of North Carolina. Several studies have indicated that the frequency, duration, and spatial extent of low oxygen events have increased over the years due to increasing eutrophication of coastal waters from human and animal waste discharges, greater fertilizer use, loss of wetlands, and increased atmospheric nitrogen deposition (Cooper and Brush 1991; Dyer and Orth 1994; Paerl et al. 1995; Buzelli et al. 2002). *More information is needed to understand the consequences on the estuarine food web and to what extent anoxia is impacting the soft bottom community.* As hypoxia and anoxia of bottom sediments become more frequent, the quality of soft bottom habitat will deteriorate. *Efforts are needed to reduce anthropogenic nutrient loading, particularly in systems that have a history of hypoxia and anoxia.* Fish kill events that have been attributed to low oxygen can be used as an indication of these hot spot areas.

Turbidity and sedimentation

Organisms in soft bottom habitat are adapted to shifting and changing sediments. Shoreline erosion and stormwater runoff transport sediment into coastal waters, which helps maintain shallow water habitat. However, when sedimentation is excessive, there can be negative impacts. Impacts of sedimentation include (Schueler 1997):

- Physical smothering of benthic invertebrates
- Reduced survival of fish eggs
- Destruction of fish spawning areas in freshwater streams
- Elimination of sensitive species such as anadromous fish or darters
- Increase in sediment oxygen demand and depletion of oxygen
- Decline in freshwater mussels
- Reduced channel capacity, and subsequent acceleration of downstream bank erosion and flooding

The primary areas that are adversely affected by sedimentation are freshwater systems and upstream estuarine systems. The effects of sedimentation can be very gradual. Excessive deposition of sediments in a stream over time causes the depth and velocity to decrease and the width to increase. Consequently, the number and depth of riffle pools, and the temperature gradients within them, decrease. These riffle pools are important habitat for some fish species, such as minnows and darters (AFS 2003). The deposition of silt and fine sediment in gravel bottom rivers and streams fills the interstices of the gravel, and can decrease dissolved oxygen content if the organic content is high. Most North Carolina coastal rivers and streams do not consist of gravel substrate, however.

Excess sedimentation can reduce or eliminate aquatic insect larvae from stream bottoms (AFS 2003). These larvae are the basic fish food source in freshwater streams, and impacts to them can affect the productivity of associated fish species (AFS 2003). High levels of suspended sediment in an estuarine or marine habitat can greatly reduce successful settlement of larval clams and oysters, and can smother other benthic invertebrates (AFS 2003). In some areas, historic oyster bars have been completely covered with fine sediment and mud (P. Peterson, UNC-CH, pers. com., 2004). Refer to the water column chapter for information on habitat degradation from sedimentation and options for addressing sedimentation.

Excessive sedimentation has been cited as the major cause of freshwater mussel decline in the United States since the late 1800s (Neves et al. 1997; Box and Mossa 1999). Poor land use practices, including construction and road building activities, agriculture, forestry, dams, reservoirs, and channelization are among the causes cited for sedimentation (Neves et al. 1997; Box and Mossa 1999). Because freshwater mussels are dependent on specific host fish to complete their reproductive cycle, changes in resident fish populations, due to dams, channelization, or other habitat alterations, jeopardize survival of mussels (Neves et al. 1997). The decline in mussel populations in North Carolina is considered severe (Neves et al. 1997). Over 50% of approximately 60 native freshwater mussels are designated as Endangered, Threatened, or of Special Concern within the state and approximately 22 of these occur within coastal draining river basins (Neves et al. 1997; <http://www.ncwildlife.org>, April 2004). The Tar River spiny mussel (*Elliptio steinstansana*) and dwarf wedgemussel (*Alasmidonta heterodon*) are federally and state endangered species that occur in the upper Tar and Neuse rivers, respectively (<http://www.ncwildlife.org>, April 2004). Since these species are highly sensitive to water quality and habitat degradation, freshwater mussels are often considered an excellent early biological indicator of freshwater stream condition.

Existing management measures

The majority of the management measures discussed in the water column and other habitat chapters would also benefit soft bottom by reducing loading of point and nonpoint pollutants. Recently, several actions have been taken regarding beach nourishment and management of intertidal and subtidal ocean soft bottom habitat. The North Carolina General Assembly enacted House Bill 1840 in the 2000 Session, which required DENR to prepare a Beach Management Plan (DENR 2000b) and make recommendations on several related policy issues. This plan was to be completed by April 2001, although no funding was allocated for this task. *Completion of a beach management plan using the best scientifically based information could be helpful in directing beach nourishment activities in a manner that minimizes impacts to the soft bottom community.*

In addition, the Legislative Research Commission studied the cost, need, and feasibility of beach nourishment, and submitted a report to the 2001 Session of the General Assembly on Coastal Beach Movement, Beach Renourishment, and Storm Mitigation as mandated by the 1999 General Assembly (Legislative Research Commission 2001). The focus of this report was on economics more than environmental impacts, however. As impacts from beach nourishment are increasingly documented and the magnitude of this activity increases, the scientific community has expressed concern regarding the long-term consequences to fish habitat. An environmental forum on beach nourishment was held in April 2001 by the North Carolina Coastal Federation to compile information and knowledge of scientists on beach nourishment and associated impacts to the marine and estuarine environment. In 2000, the MFC adopted a beach nourishment policy that provides specific suggestions and guidance to agencies concerning the effects of beach nourishment on fisheries stocks and the habitats on which they depend. Policies call for avoidance, minimization, and mitigation for impacts that do occur, monitoring to document pre- and post- conditions, and assessments that take cumulative impacts into account (Appendix K).

In July 2001, the USFWS designated 1,798 miles of intertidal and supratidal (dry) beaches and dunes to the mean low water (MLW) in eight states as Critical Habitat for the wintering population of piping plover (*Charadrius melodus*). Critical Habitat is defined in the Endangered Species Act as a specific geographic area that is essential for the conservation of a threatened or endangered species and that may require special management and protection (<http://endangered.fws.gov/listing/critical_habitat.pdf>, 2004). This may include suitable habitat that is not currently occupied by the species but is needed for its recovery, thereby providing more habitat protection. Federal agencies are required to consult with the USFWS to ensure that any federal actions do not adversely modify Critical Habitat functions, including areas not currently occupied by a designated species. This action, by providing protection to wintering habitat, also protects intertidal benthos, which will benefit foraging habitat for piping plover as well as benthic feeding surf fish. There are 18 designated areas in North Carolina, primarily inlet systems and adjacent shoals and spits. Refer to website (<http://plover.fws.gov>, 2003) for maps of the designated areas.

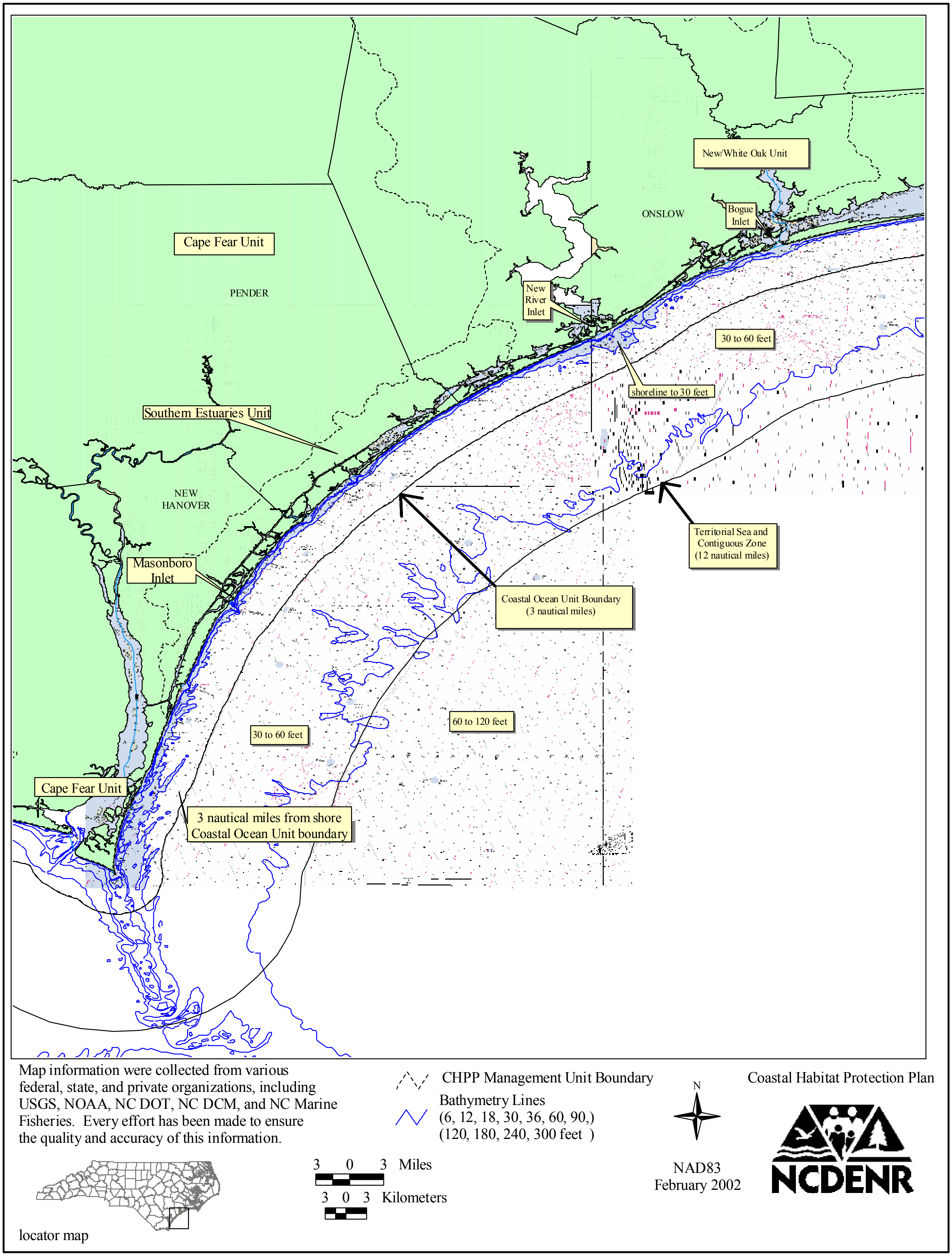
Another federal initiative that provides resource protection to ocean soft bottom habitat is the Coastal Barrier Resources Act (COBRA). Initiated in 1982, COBRA (16 U.S.C. '' 3501-3510) generally restricts federal spending for establishment or expansion of infrastructure (roads, wastewater systems) and disaster relief funds in high-risk coastal areas. It also prohibits federally guaranteed low-cost flood insurance from designated areas that might contribute to development on designated undeveloped barrier islands. The restrictions are intended to discourage unwise development in ecologically sensitive areas. In North Carolina, some of the areas requesting storm damage reduction projects (portions of Cape Hatteras and North Topsail Beach) are located within federally designated COBRA sites (Map 6.3 a-c). This act demonstrates an innovative strategy to protect undeveloped natural resources through economic disincentives, while imposing no new regulations on how an individual may develop their land. *Funding for beach nourishment in designated COBRA areas should not be supported by state or local funds*.

6.5 SUMMARY OF SOFT BOTTOM CHAPTER

Soft bottom habitat is the unvegetated bottom sediment in all coastal systems, and includes features such as inlets, shoals, channel bottoms, intertidal ocean beaches, and cape shoals. Soft bottom plays a key role in primary productivity in shallow estuarine and marine systems. This habitat strongly influences the water column through dynamic cycling processes, storing and releasing nutrients and chemicals over time. Other ecosystem functions of soft bottom include the reduction of physically destructive storm effects on oceanfront beaches, and providing sand sources for barrier island and inlet migration. Soft bottom habitat is particularly important as a foraging area for all size ranges of bottom feeding fish and invertebrates, such as blue crabs, shrimp, flounders, striped mullet, spot, croaker, and kingfish. Burrowing mollusks (e.g., hard clams, coquina clams), flatfishes (e.g., southern flounder, hogchoker) and baitfish (e.g., striped mullet) are highly associated with shallow soft bottom, while larger benthic feeding predators (e.g., weakfish, coastal sharks, sturgeons) typically utilize deeper soft bottom areas. Valued fishery species that depend on healthy soft bottom habitat include hard clams, shrimp, blue crabs, southern flounder, Atlantic croaker, striped mullet, kingfish, and spot. Of these, the DMF stock status of Atlantic and shortnose sturgeons, southern flounder, and coastal sharks was Overfished. Striped mullet and Atlantic croaker were listed as Concern. The Atlantic sturgeon, which is classified as Overfished, has been under a fishing moratorium since 1991 but has not shown signs of recovery. Coastal inlets have been federally designated as Habitat Areas of Particular Concern for blue crab, estuarine-dependent snapper and grouper, penaeid shrimp, and red drum.

Inadequate data are available to clearly indicate the current condition of soft bottom habitat. Fortunately this habitat is relatively resistant to a changing environment. This is the most abundant submerged coastal fish habitat, and estuarine acreage of soft bottom has undoubtedly increased over time as shell bottom, SAV, and wetland habitats have declined.

Threats of greatest concern include large-scale alterations such as dredging of productive shallow bottom areas, construction of marinas and docks, bottom dredge and trawl fisheries in estuarine waters, and large-scale beach nourishment. Depletion of oxygen and toxic contamination of bottom sediments are the major water quality concerns since those conditions can cause mortality or poor recruitment of benthic invertebrates, which in turn can affect food availability for numerous benthic feeding invertebrates and fish. Therefore, minimizing dredging of productive shallow bottom, properly managing beach nourishment to maintain healthy benthic communities in the surf zone, and reductions in nutrient and toxin loading in all coastal waters are the primary management needs for soft bottom.



Map 6.1a. Location of marine topographic features, southern coastal area of North Carolina.

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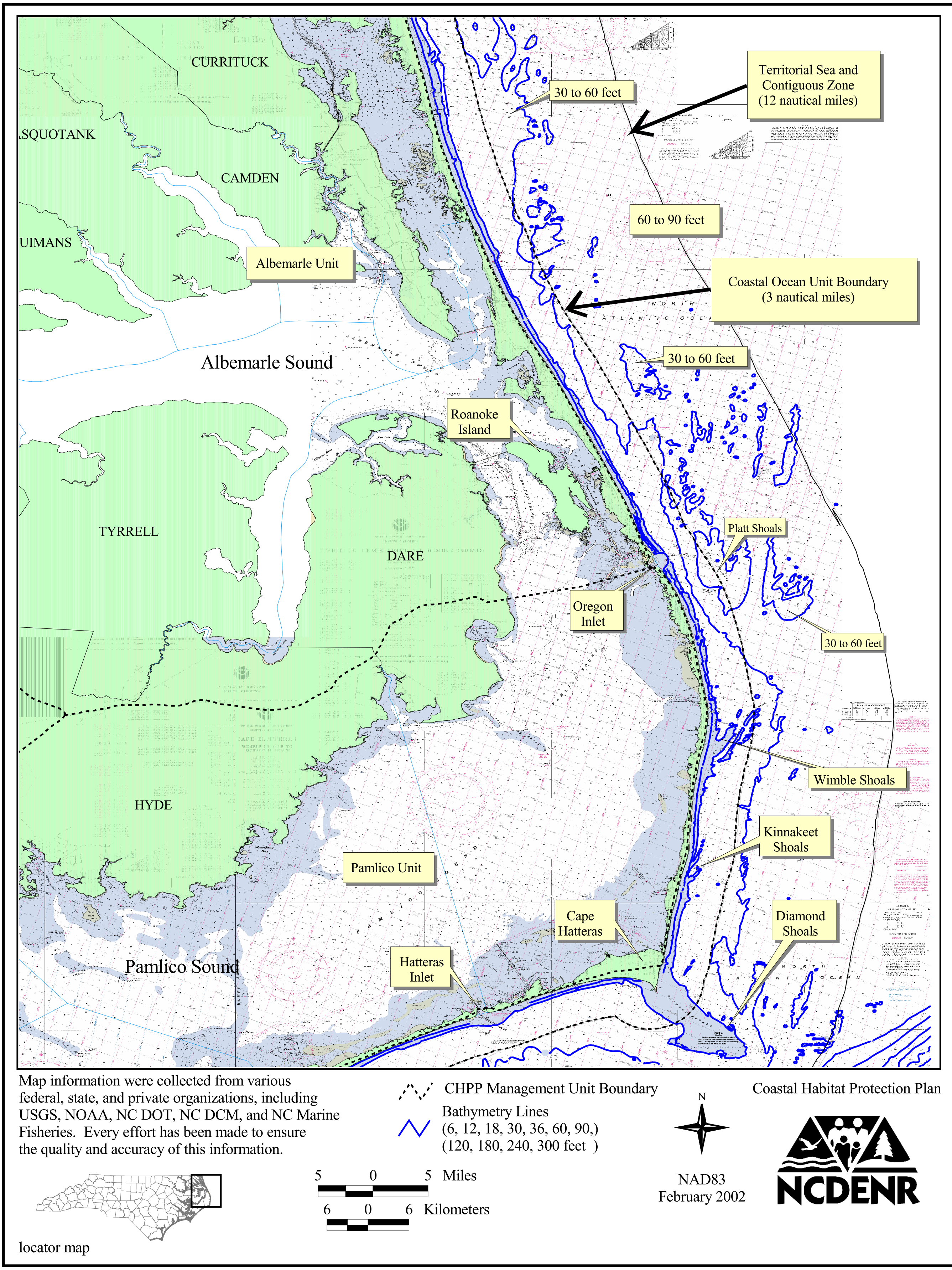

Map 6.1b. Location of marine topographic features, northern coastal area of North Carolina.

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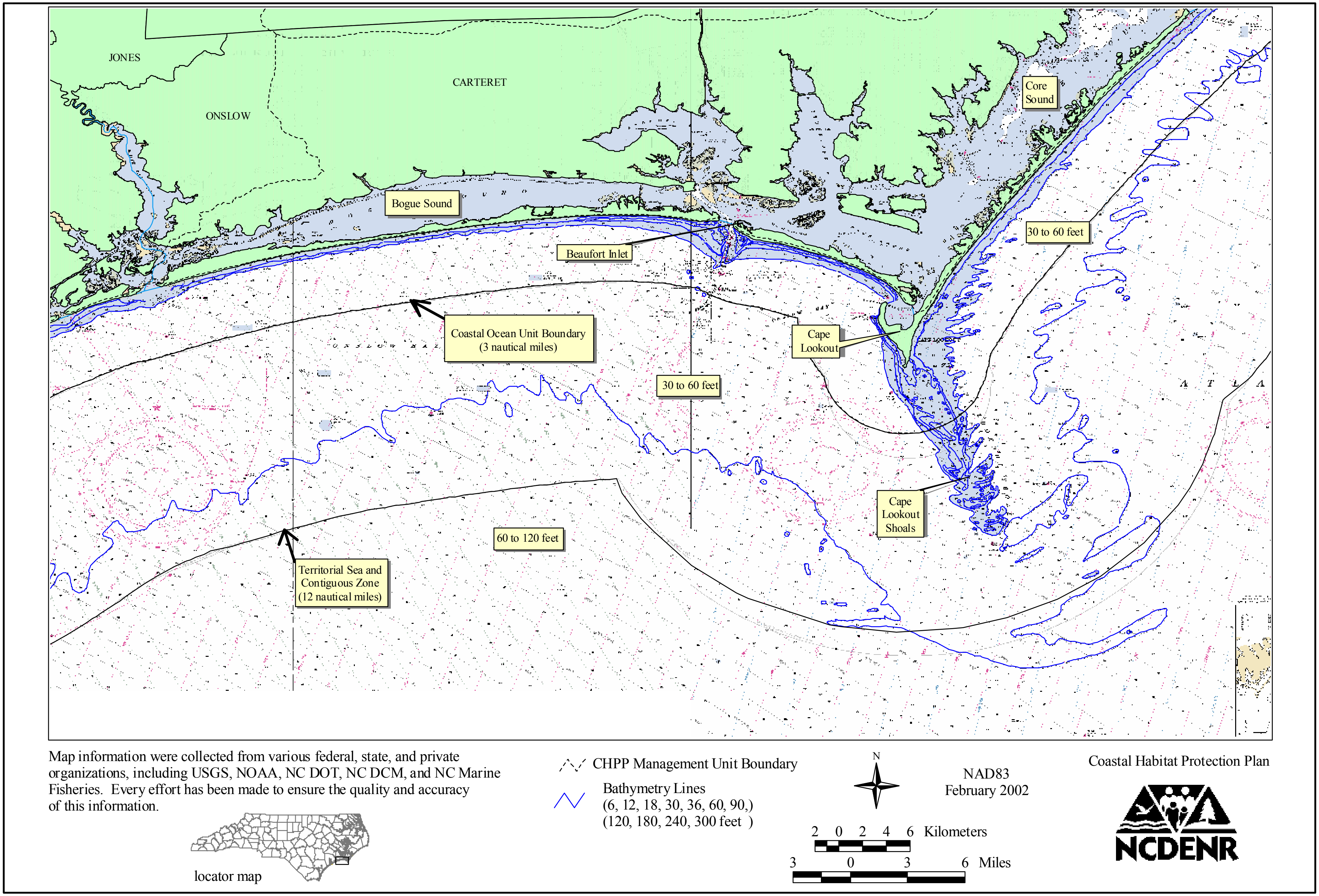

Map 6.1c. Location of marine topographic features in the Cape Lookout area of North Carolina.

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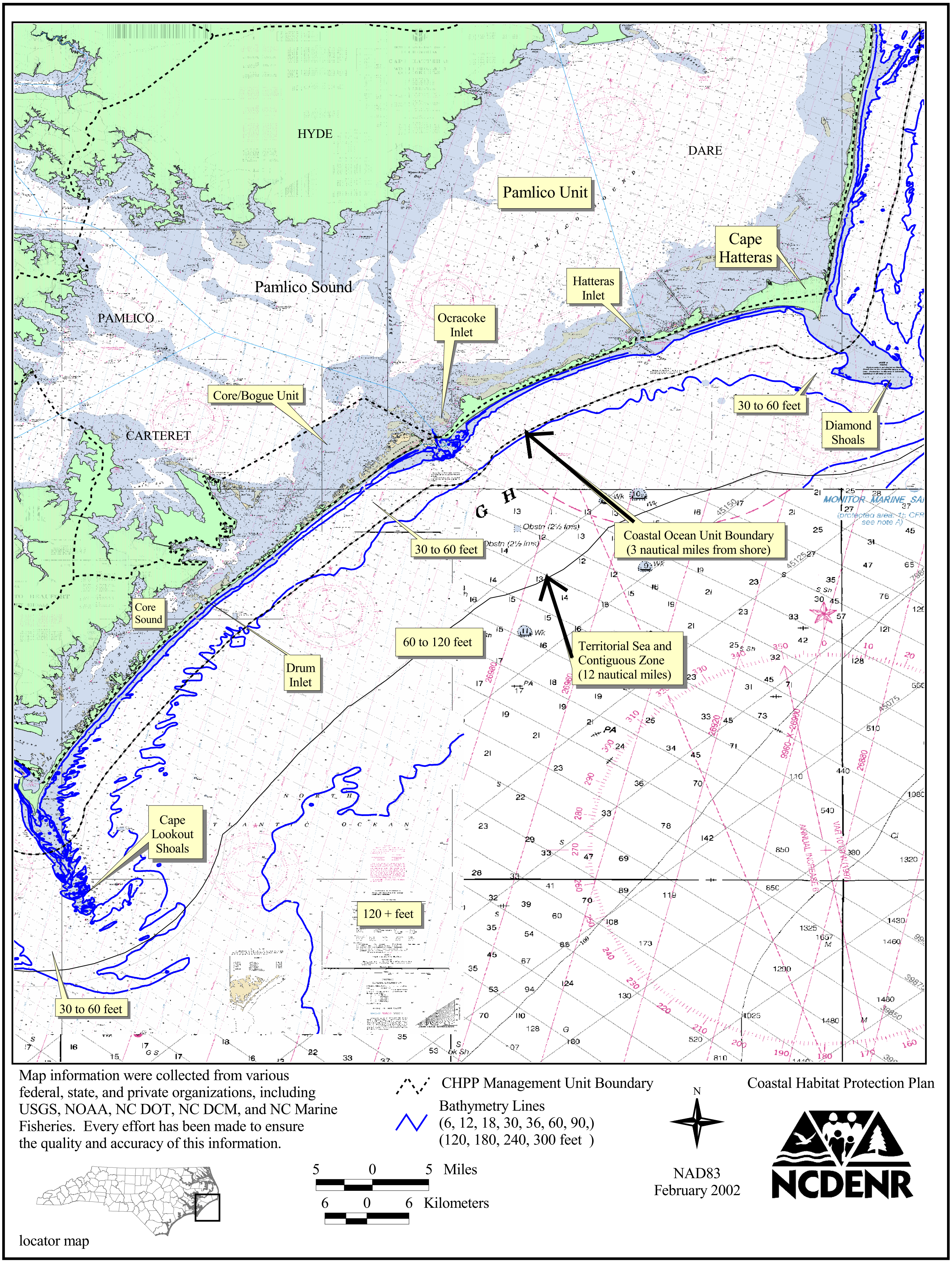

Map 6.1d. Location of marine topographic features between Cape Lookout and Cape Hatteras, North Carolina.

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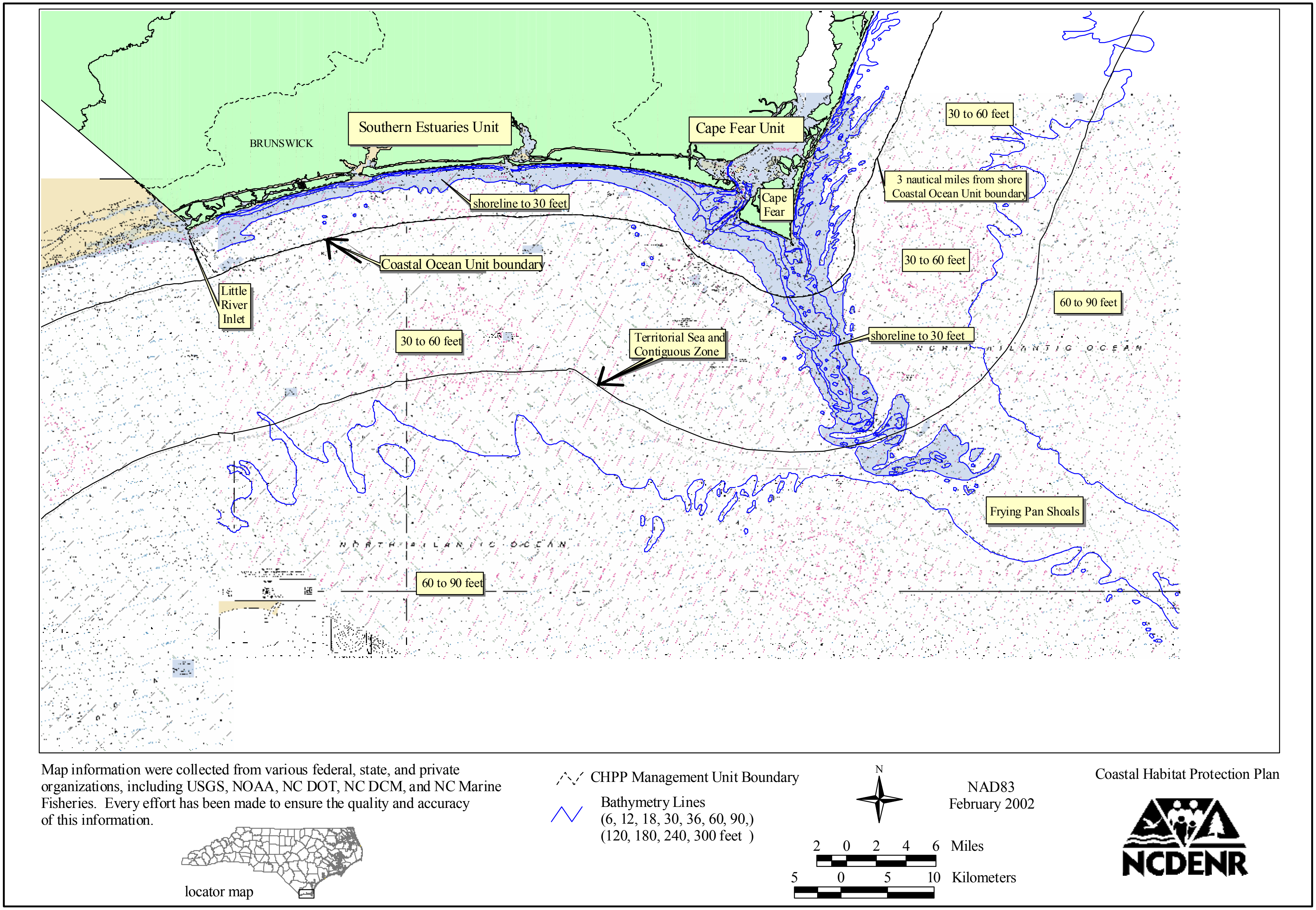

Map 6.1e. Location of marine topographic features in the Cape Fear Area, North Carolina.

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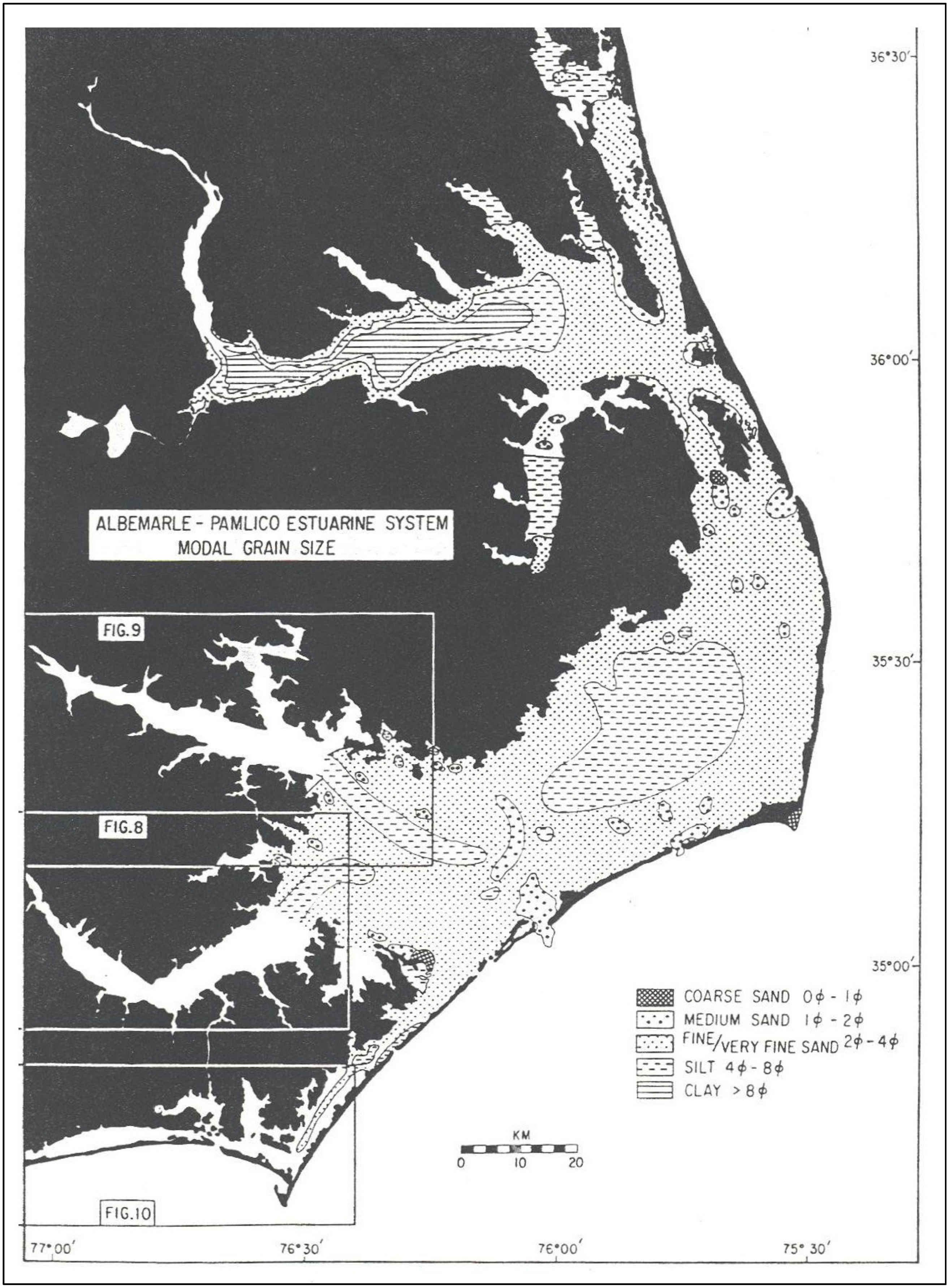

Map 6.2a. Sediment composition in the Albemarle-Pamlico estuarine system.
Inset A = Tar-Pamlico, Inset B = Neuse, Inset C= Bogue (Wells 1989)

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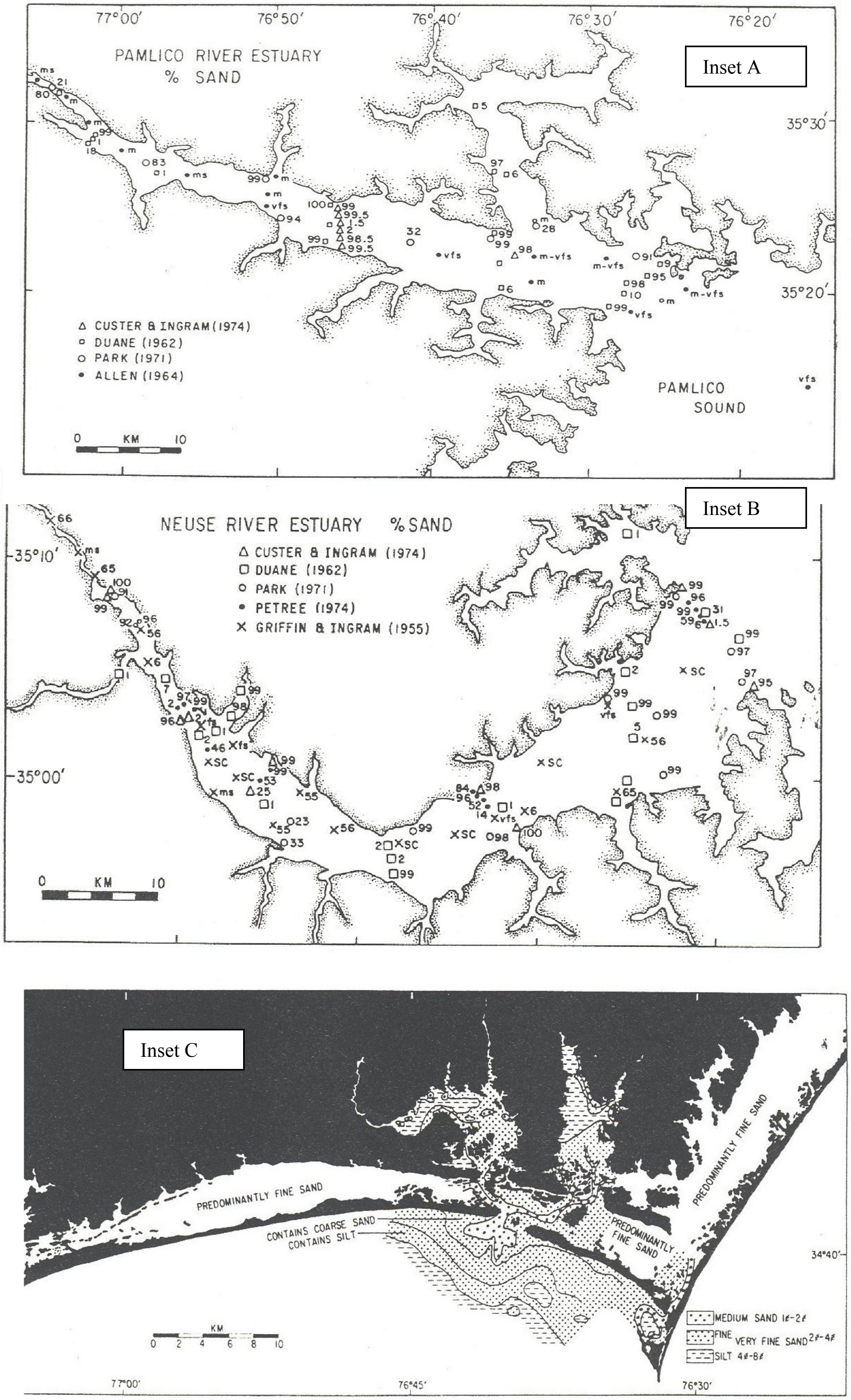

Map 6.2b. Insets. Sediment composition in the Tar-Pamlico, Neuse, and Core/Bogue estuaries (Wells 1989). Numbers = % sand, M= mud, SC=silty clay, VFS= very fine sand, MS= medium sand.

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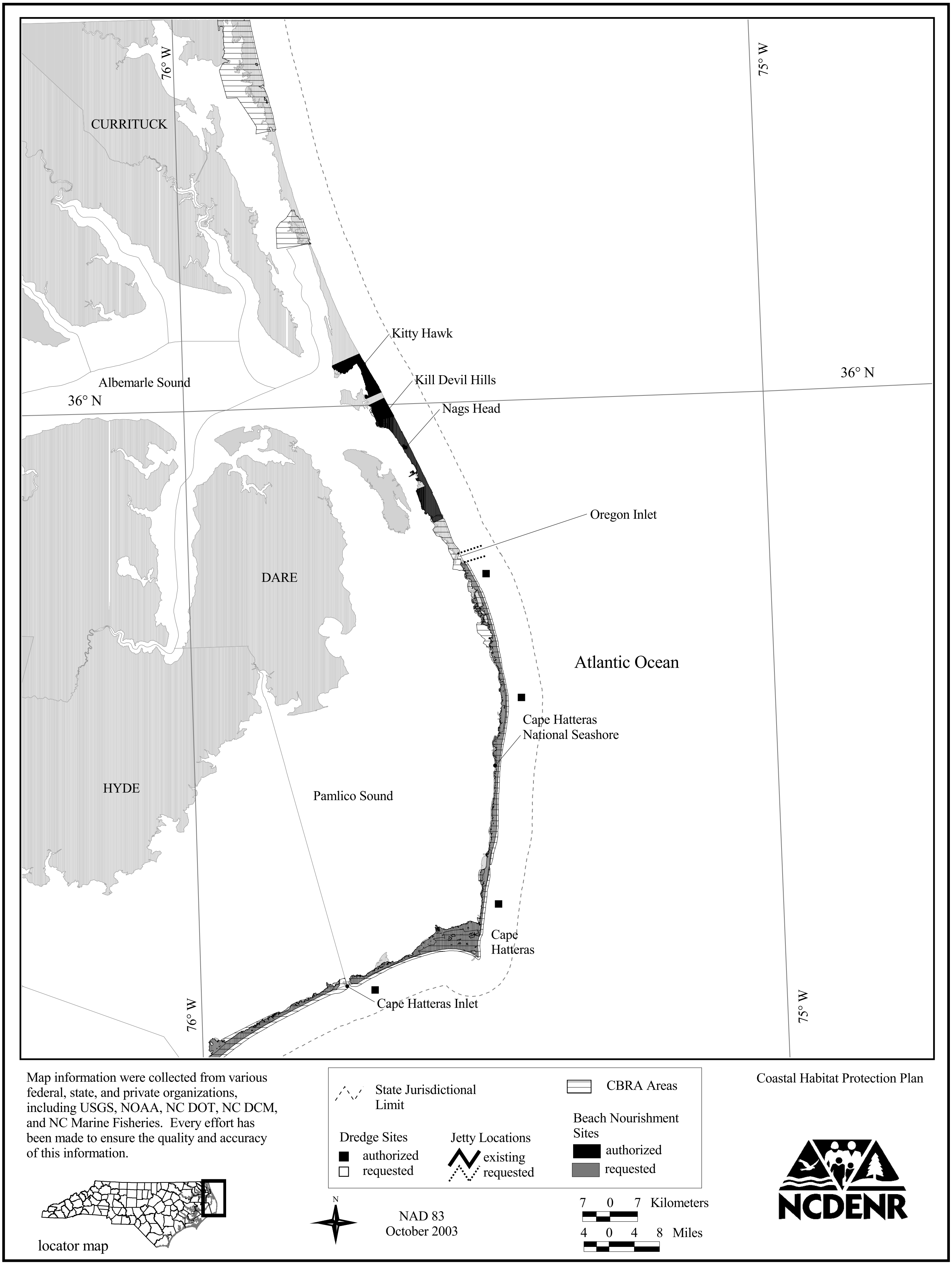

Map 6.3a. Location of authorized and requested beach nourishment projects, dredge disposal sites, jetties,inlets, and designated CBRA sites, northern coastal area of North Carolina.

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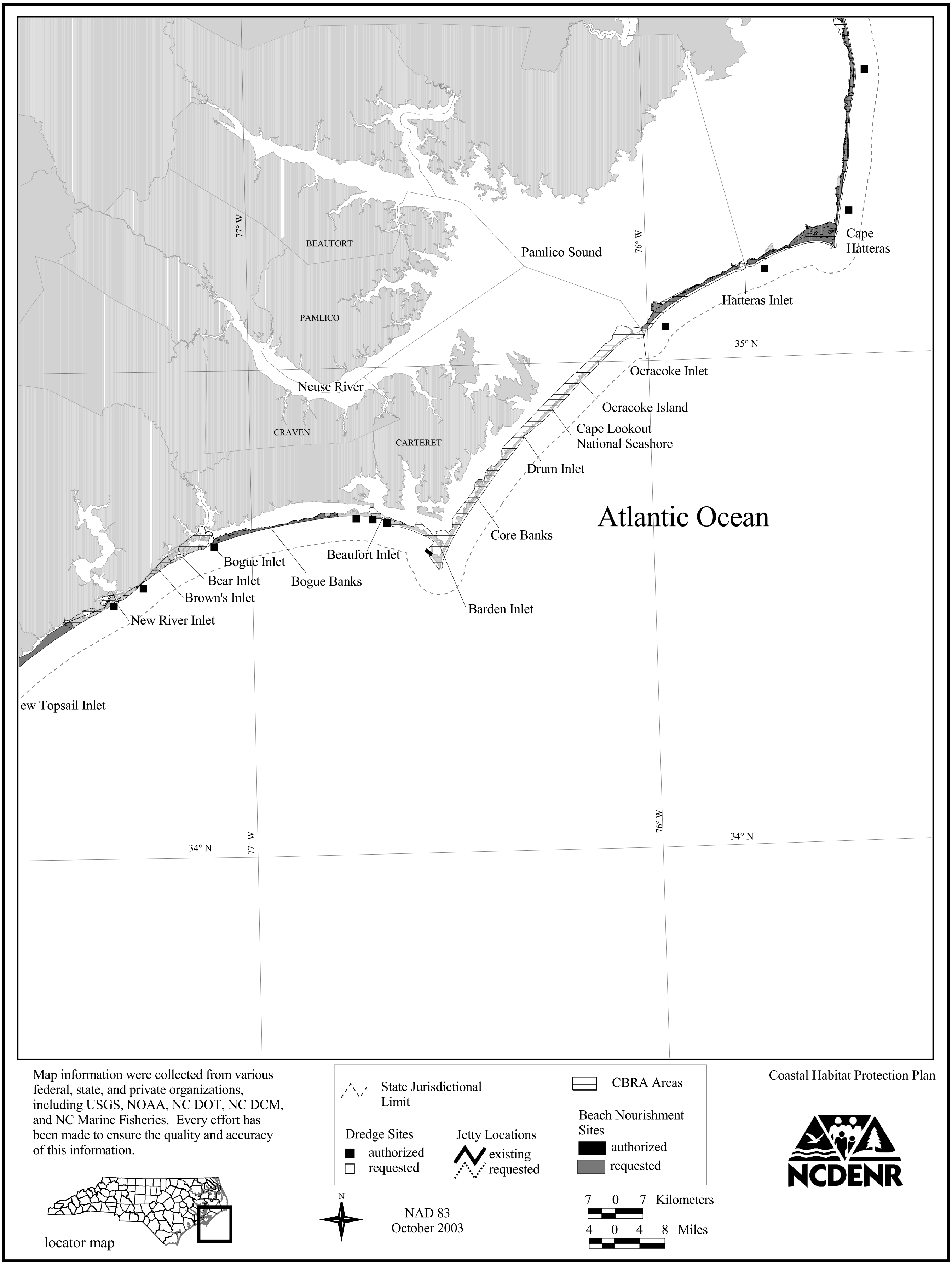

Map 6.3b. Location of authorized and requested beach nourishment projects, dredge material disposal sites, jetties, inlets, and designated CBRA sites, central coastal area of North Carolina.

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Map 6.3c. Location of authorized and requested beach nourishment projects, dredge material disposal sites, jetties, inlets, and designated CBRA sites, southern coastal area of North Carolina.

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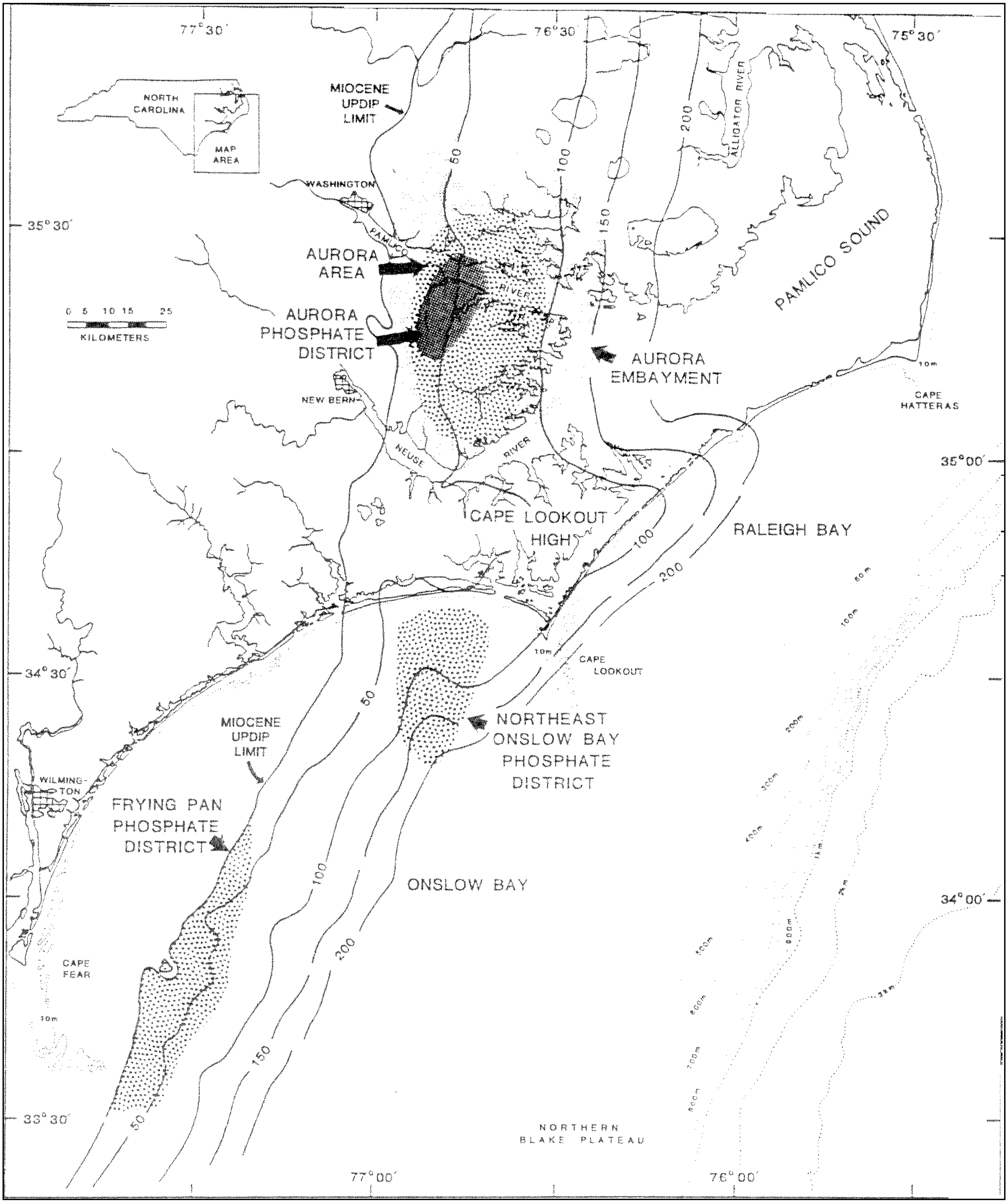

Map 6.4. Location of phosphate districts (known concentrations of phosphate deposits) on the continental shelf off North Carolina. (from Riggs and Manheim - 1988).

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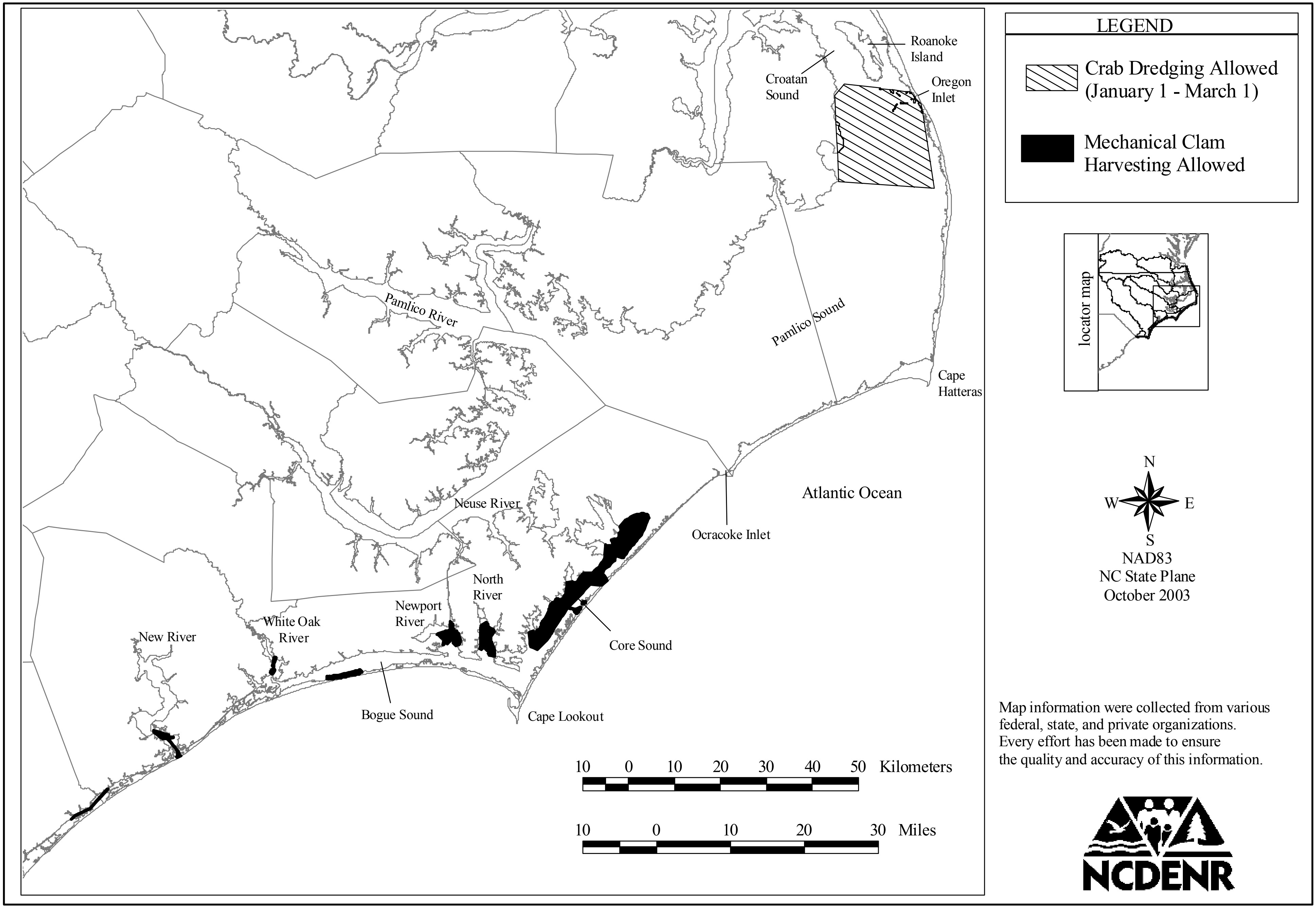

Map 6.5. Areas where mechanical harvest for clams (clam kicking, hydraulic dredge) and crabs (crab dredge) is authorized in estuarine waters of North Carolina.

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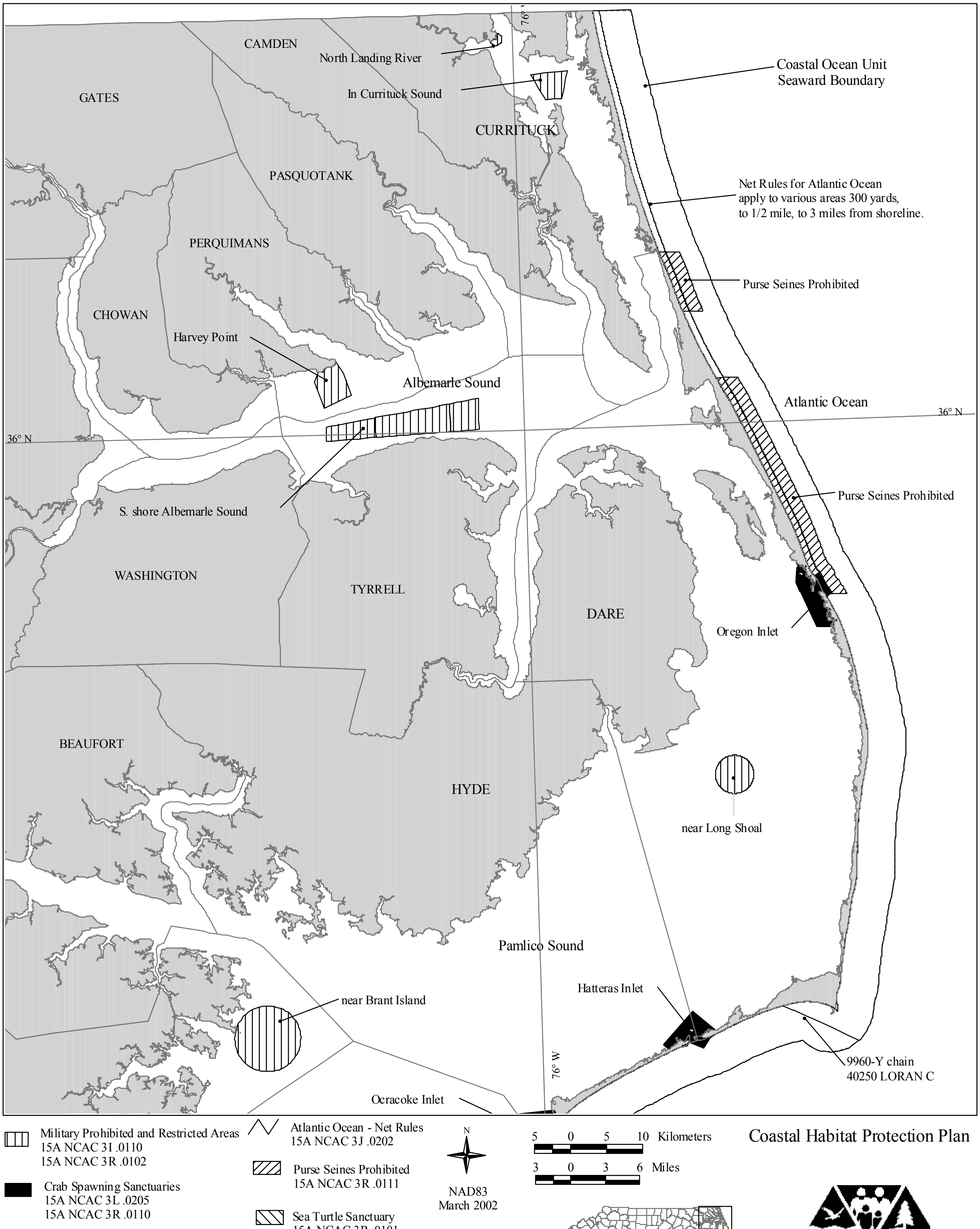

Map information were collected from various federal, state, and private organizations, including USGS, NOAA, NC DOT, NC DCM, and NC Marine Fisheries. Every effort has been made to ensure the quality and accuracy of this information.

Map 6.6a. North Carolina Marine Fisheries Commission fishing gear restrictions in coastal waters, northern coastal area.

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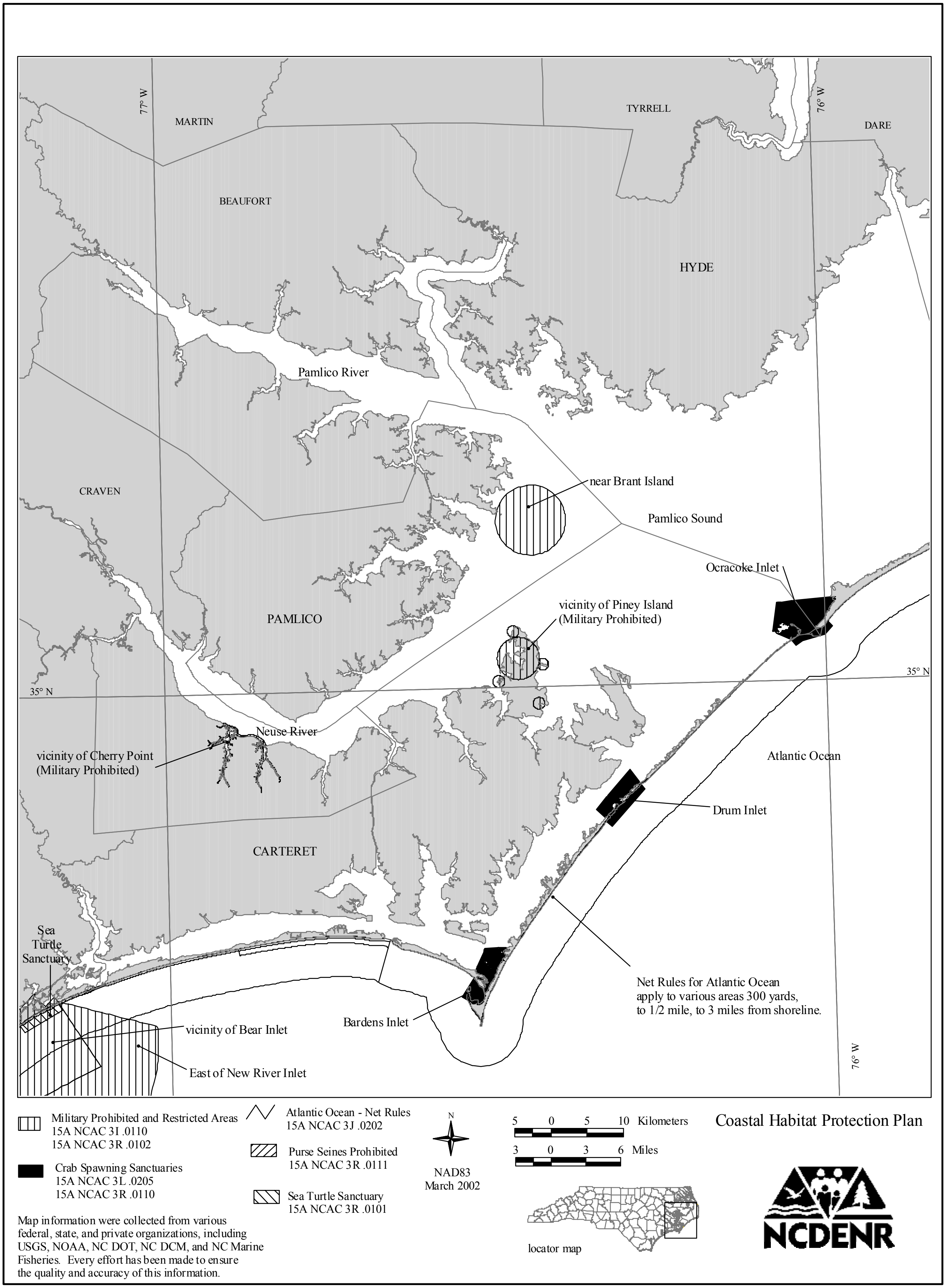

Map 6.6b. North Carolina Marine Fisheries Commission fishing gear restrictions in coastal waters, central coastal area.

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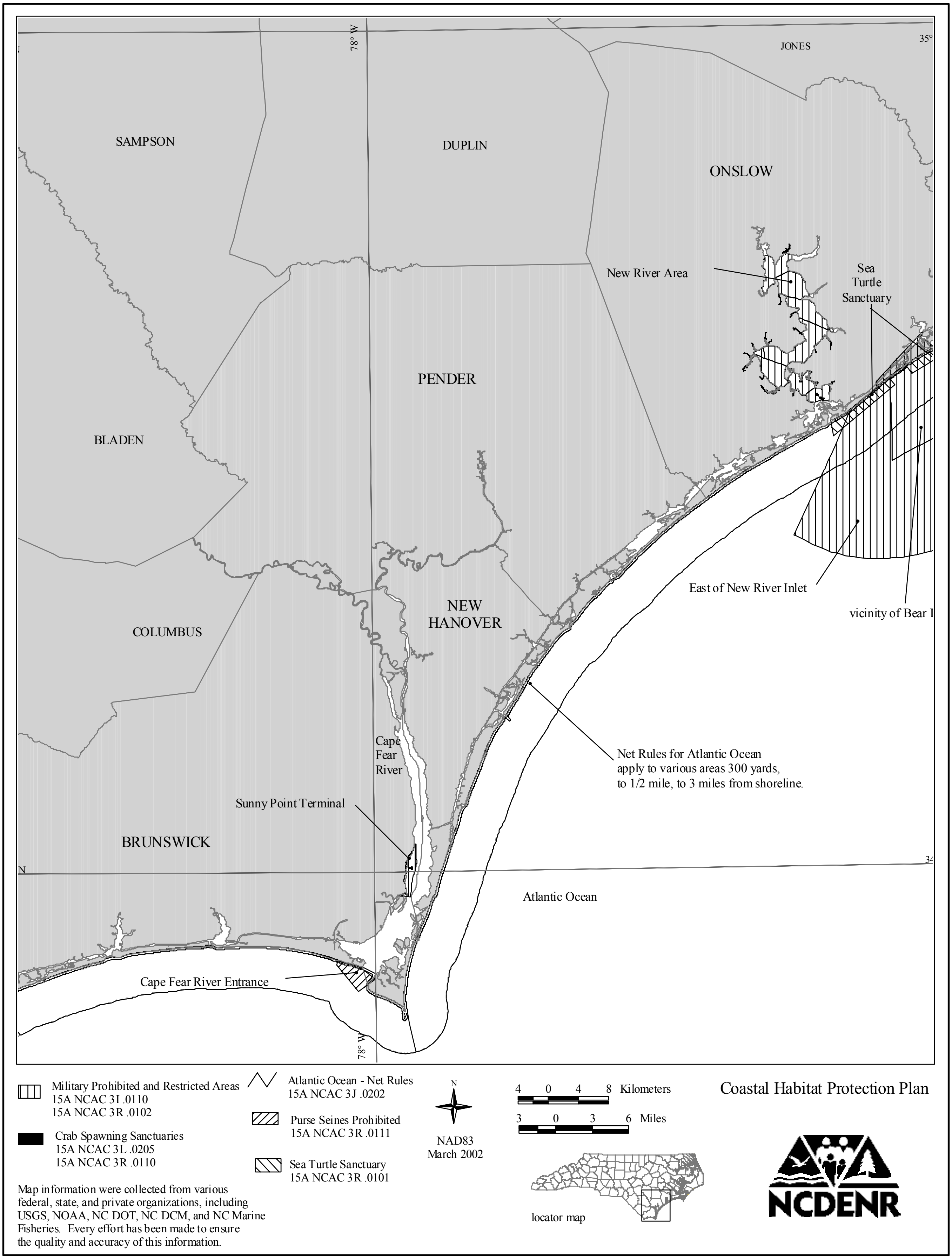

Map 6.6c. North Carolina Marine Fisheries Commissions fishing gear restrictions in coastal waters, southern coastal area.

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