CHAPTER 6. SOFT BOTTOM

6.1. DESCRIPTION AND DISTRIBUTION

6.1.1. Definition

Soft bottom habitat is defined by Street et al. (2005) as “unconsolidated, unvegetated sediment that occurs in freshwater, estuarine, and marine systems.” This definition includes both deeper subtidal bottom as well as shallow intertidal flats.

6.1.2. Habitat requirements

The only requirement for the presence and persistence of soft bottom is sediment supply. Environmental characteristics, such as sediment grain size and distribution, salinity, dissolved oxygen, and flow conditions, will affect the condition of the soft bottom habitat and the type of organisms that use it. However, the habitat itself will persist regardless of its condition unless it becomes sediment starved or is colonized by organisms, such as oysters or SAV, which can transform soft bottom into another habitat.

6.1.3. Description and distribution

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

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

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

Marine
- intertidal beach
- subtidal bottom

Soft bottom covers approximately 1.9 million acres, or 85% of the total bottom area, in North Carolina’s coastal waters, excluding the coastal ocean. An estimate for its area in North Carolina’s marine waters is...
not feasible due to the uncertainty of the extent of hard bottom. As part of NC Strategic Habitat Area (SHA) assessments, soft bottom area has been described for Region 1 (Albemarle Sound to Northeastern coastal ocean) and Region 2 (Pamlico Sound to ocean). Refer to, “Ecosystem Management and Strategic Habitat Areas” chapter for more information regarding SHAs. In region 1, there is an estimated 852,346 acres of soft bottom within a total habitat area (water and adjoining wetlands) of 2,162,142.77 acres (soft bottom = approximately 39 percent). Shallow (<6ft) bottom habitat (mostly soft bottom) covers 17-37% of the total bottom area in CHPP regions (Table 6.1). Shallow bottoms occupy the largest proportion of bottom area in Regions 1 and 3. In all regions, there is a much larger area of deeper bottom below the sunlit portion of the water column. However, measuring the distribution of depth zones and bottom features is hampered by the lack of current bathymetry maps. For example, the data used to map bathymetry in Pamlico Sound ranged from 1913-1980 http://estuarinebathymetry.noaa.gov/southatlantic.html, February 2010). There have been water body-specific efforts to construct updated bathymetry in New River (J. McNinch/USACE, pers. com., April 2010) and Currituck Sound (E. Brinker/ECSU, pers. com., April 2010), but no comprehensive mapping of estuarine waters. There should be a cooperative effort to update existing NC estuarine bathymetric maps.

Table 6.1. Estimated acreage of shallow and deep bottom habitat within CHPP regions of North Carolina (bathymetry derived from NOAA navigation charts).

<table>
<thead>
<tr>
<th>CHPP regions</th>
<th>Major water bodies</th>
<th>Shallow (&lt;6 ft) acres</th>
<th>%</th>
<th>Deep (&gt;6 ft) acres</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Albemarle/Currituck sounds, Chowan River</td>
<td>240,471</td>
<td>31</td>
<td>526,531</td>
<td>69</td>
</tr>
<tr>
<td>2</td>
<td>Pamlico Sound, Neuse/Tar-Pamlico rivers</td>
<td>251,477</td>
<td>18</td>
<td>1,111,318</td>
<td>82</td>
</tr>
<tr>
<td>3</td>
<td>Core/Bogue sounds, New/White Oak rivers</td>
<td>154,492</td>
<td>37</td>
<td>268,625</td>
<td>63</td>
</tr>
<tr>
<td>4</td>
<td>Cape Fear River, southern estuaries</td>
<td>37,800</td>
<td>17</td>
<td>188,549</td>
<td>83</td>
</tr>
</tbody>
</table>

The physical and chemical character of all soft bottom habitats is determined by the underlying geology, basin morphology, and associated physical processes (Riggs 1996; Riggs and Ames 2003). Geologically, North Carolina’s coast can be divided into distinct northern and southern provinces that are separated (approximately) by Cape Lookout (Riggs 1996; Pilkey et al. 1998; Riggs and Ames 2003). In the northern province, sediment formations generally consist of a thick layer of slightly consolidated to unconsolidated muds, muddy sands, sands, and peat sediments. The low slopes of the northern province are characterized by an extensive system of drowned river estuaries (i.e., Albemarle Sound, Neuse River), long barrier islands, and few inlets (Map 6.1 a-e). In contrast, the southern coastal province has only a thin and variable layer of surficial sands and mud, with underlying rock platforms. The southern province also has a steeper sloping shoreline, resulting in narrow estuaries (e.g., Topsail Sound, Stump Sound), short barrier islands, and numerous inlets (Map 6.1 a-e). The geologic differences result in dissimilar sediment supplies and physical oceanographic conditions, thus affecting the characteristics of each province’s soft bottom habitat.
6.1.3.1. Freshwater soft bottom

Properties of freshwater soft bottom not only depend on the origin of sediment inputs, but also on the prevailing elevation gradient, flow conditions, riparian cover, local geology, and water column characteristics. Upstream sources of sediment inputs into riverine systems include erosion of sediment bank shorelines, flushing of swamp forests and other wetlands, and transport of suspended sediment from flood waters (Riggs 1996; Riggs and Ames 2003). Bottom composition generally ranges from more consolidated material (bedrock, boulders) upstream to less consolidated material (gravel, sand) downstream. Because freshwater rivers and creeks are eroding through older sediment banks, there tends to be a deep main channel dominated by medium-grained to coarse-grained sand with varying amounts of organic detritus. Shallow flats may exist on one or both sides of the channel, consisting of a layer of fine sandy mud on top of older sediments (Riggs 1996). Where the channel bed is relatively deep or wide, pools form and water velocity slows, allowing finer particles (sand, silt) to settle. Where the channel bed is relatively narrow or shallow, riffles and runs occur and water velocity increases, leaving only the heaviest particles (boulder, cobble) on the bottom.

In freshwater lakes, like Lake Mattamuskeet, the shallow bottom around the shoreline is often unvegetated due to shoreline erosion, high wind exposure, or low water clarity (from turbidity or organic staining). In sheltered areas, however, shallow bottom may become covered by submerged aquatic vegetation, assuming appropriate water clarity conditions exist (see “Submerged aquatic vegetation” chapter for more information).

6.1.3.2. Estuarine soft bottom

Sediment composition in estuaries and sounds varies greatly with geomorphology and estuarine position. The basin-scale formation of most estuaries in the northern geologic province of North Carolina is similar to a flat-bottomed dish with a narrow and shallow perimeter lip or platform, providing ample space for sediment deposition (Pilkey et al. 1998; Riggs and Ames 2003). Soft bottoms in this region, including the Albemarle-Pamlico Estuarine System, consist of three general sediment types: sand, organic rich mud (ORM), and peat (Wells 1989; Riggs 1996). Coarse sands, derived from erosion of sediment bank shorelines and transport from barrier island overwash or through inlets, are concentrated on the shallow perimeter platforms, shoals, and at inlet mouths (Wells 1989; Riggs 1996; Pilkey et al. 1998) (Map 6.2a-b). Organic rich mud, the most pervasive sediment that comprises approximately 70% of the sediment in North Carolina’s estuarine system, generally fills the deeper central basins and downstream channels of sounds and rivers (Wells 1989; Riggs 1996; Pilkey et al. 1998; Riggs and Ames 2003) (Map 6.2a-b). Since fine sediments are easily suspended and transported away from high energy waters, the width and thickness of ORM increase as the estuary widens and deepens in the downstream direction (Riggs 1996; Riggs and Ames 2003). Peats, sediments with more than 50% organic matter, form either in the swamp forests of riverine floodplains or in coastal marshes (Riggs and Ames 2003).

Soft bottoms in the estuarine systems of the southern geologic province are dominated by sloped mudflats on the perimeter and interior of small estuaries (i.e., White Oak River, Pages Creek) (Pilkey et al. 1998). Coarse sands are concentrated in the lower portion of these estuaries and are transported into the systems via inlets and barrier island overwash. Small blackwater streams carry relatively low sediment loads into the upper portion of the southern estuaries where ORM dominates, but the water does contain large quantities of dissolved organic matter that give it a brown tea color (Riggs and Ames 2003). In contrast, the Cape Fear River, the only major trunk estuary in North Carolina that discharges directly into the Atlantic Ocean, transports large sediment loads from erosion of clay Piedmont soils to the lower portion of the river basin (Riggs and Ames 2003).

Unvegetated estuarine shorelines occur where wave energy prevents colonization by plants and there is a gently sloping area for sediment to build upon (Riggs 2001). These sediment bank shorelines are
generally eroding and sandy, providing a source of sand to adjacent waters. In contrast, marsh or swamp forest shorelines are eroding to a lesser degree and have a high organic content, thus providing fine organic sediments to adjacent waters. Several shoreline erosion studies have been conducted along North Carolina’s coast and were compiled and summarized in Riggs (2001). Due to wave energy, sediments can have long-shore or cross-shore transport. Sediments undergoing long-shore transport move parallel to the shoreline where sediments can be deposited on adjacent beaches. Cross-shore transport will move sediments onshore or offshore creating an equilibrium beach profile.

Estuarine intertidal flats are unvegetated bottoms that occur along shorelines or unconnected, emergent sediment banks between the high and low tide lines. Intertidal flats are most extensive where tidal range is greatest, such as near inlets and along the southern portion of the coast. Because the influence of lunar tides is minimal in the large sounds (e.g., Pamlico, Albemarle, and Currituck), true intertidal flats are not extensive, except for areas immediately adjacent to an inlet (Peterson and Peterson 1979). Sediment composition on intertidal flats tends to shift from coarser, sandy sediment on the landward fringe, to finer, muddier sediments on the waterward fringe (Peterson and Peterson 1979).

Tidal deltas form as sediments shift with tides and waves on the ebb and flood sides of the inlets separating North Carolina’s barrier islands. Sediments in the vicinity of inlets are typically composed of coarse sands and shell fragments (Peterson and Peterson 1979). Intense wave and current energy cause the flats to continually change, erode, and reform. Inlets are classified as stable, migrating, or ebb-tidal delta breaching (Fitzgerald et al. 1978). The process of channel realignment and abandonment provides a mechanism for large sandbar complexes to move onto the adjacent barrier islands, supporting productive intertidal beach communities (Cleary and Marden 1999).

There are currently 21 inlets in North Carolina that connect estuarine waters to the ocean (Map 6.3 a-c). Eleven of these inlets originated as a result of storm breaches and remain spatially unstable, including Oregon and Mason inlets (Cleary and Marden 1999; Mallinson et al. 2008). Ophelia Inlet breached southwest of Drum Inlet during Hurricane Ophelia in 2005, and has since been expanding, nearly merging with Drum Inlet (Mallinson et al. 2008). There are nine larger inlet systems, including Ocracoke, Bogue, and the Cape Fear River inlets, which occupy ancient river channels. Several others have been artificially created (e.g. Carolina Beach Inlet) or artificially relocated (e.g. Tubbs Inlet).

6.1.3.3. Ocean soft bottom

North Carolina’s marine soft bottom is part of the Atlantic continental shelf, which slopes gradually away from oceanfront beaches before dropping off steeply at the 160–250 ft isobath, where the continental slope begins (Map 6.1 a-e). The intertidal zone of oceanfront beaches is the area periodically exposed and submerged by waves and tides. In this high energy area, waves continually rework and sort sediment by grain size, with larger sediments deposited first and finer-grained sediment carried farther landward. Sediments are generally much coarser, more highly sorted, and contain less organic matter than that found on protected estuarine intertidal flats (Donoghue 1999).

Seaward of the intertidal beach in the shallow subtidal area of breaking waves lies the surf zone. Within this zone, longshore sandbars frequently develop and shift seasonally in response to wave action. Ripple scour depressions, ranging from 130–330 ft in width and up to 3 ft in depth, occur along the southern portion of the coast and are perpendicularly oriented to the beach (Thieler et al. 1995; Reed and Wells 2000). These features are located adjacent to areas experiencing chronic beach erosion, and may be indicative of rapid offshore transport of sand during storms (Thieler et al. 1995).

Extending from the surf zone to the point where the slope matches that of the continental shelf is the generally concave, upward surface called the shoreface (Thieler et al. 1995). The base of the shoreface
off North Carolina occurs at approximately 33–40 ft water depth and represents the area of active beach sand movement. Six classes of shoreface systems were recognized by Riggs et al. (1995) based on differences in the underlying geology. The nature of these shorefaces affects the composition of the surface and underlying substrate and partially explains the patterns of localized erosion or deposition.

The continental shelf off North Carolina is relatively narrow, approximately 16 mi off Cape Hatteras, 32 mi off Cape Lookout, and about 49 mi off Cape Fear. North of Cape Hatteras, the shelf is relatively steep, the coastline tends to be linear, and the bottom consists of a regional depositional basin known as the Albemarle Embayment. Several prominent shoals, including Wimble, Kinnekeet, and Platt shoals, occur in this region, as well as a series of ridges and swales that are spaced about 1,300–2,000 ft apart (Inman and Dolan 1989; Rice et al. 1998). Shoals closest to shore, such as Wimble and Kinnekeet shoals, tend to be oriented at a 20–30° angle from the coastline, while those farther offshore run more parallel to the coast (MMS 1993). In contrast to that found to the north, the continental shelf south of Cape Hatteras is less steep and the coastline consists of a series of arcs, dominated by three major capes (Hatteras, Lookout, and Fear) and three associated bays (Raleigh, Onslow, and Long) (Map 6.1 a-e). Large shoals also occur in this region and extend across the shelf from each cape (Diamond, Lookout, and Frying Pan shoals) for more than 11 mi. Water depth on the shoals ranges from 2–18 ft, while adjacent waters are 20–40 ft deep. This region is generally sediment starved due to low direct river input and minimal sediment exchange between adjacent shelf embayments (Riggs et al. 1998).

6.2. ECOLOGICAL ROLE AND FUNCTIONS

6.2.1. Ecosystem enhancement

Soft bottom plays an important role as a storage reservoir of chemicals and microbes in coastal ecosystems. Intense biogeochemical processing and recycling allow for deposition and resuspension of natural and human-induced nutrients and toxic substances (Fear et al. 2005; Smith and Benner 2005; Sutula et al. 2006). These materials may pass through an estuary (Matoura and Woodward 1983), become trapped in the organic rich oligohaline zone (Sigels et al. 1982; Imberger 1983), or migrate within the estuary over seasonal cycles (Uncles et al. 1988). The fate of the materials depends upon freshwater discharges, density stratification, and formation of salt wedges (Matson and Brinson 1985; Matson and Brinson 1990; Paerl et al. 1998). Density stratification hampers mixing and oxygen exchange of sediments with overlying oxygenated waters, often leading to benthic hypoxia (Malone et al. 1988; Buzzelli et al. 2002; Lin et al. 2006).

In slow-moving, expansive estuaries, such as the Albemarle-Pamlico Estuarine System, nutrients and organic matter from watershed runoff and phytoplankton production are stored in the soft bottoms. Depending upon freshwater discharge and density stratification, these materials are recycled within the sediments via microbial activities and resuspended into the overlying waters (Fear et al. 2005). In organic enriched oligohaline zones (e.g., Pamlico and Neuse River estuaries), weather-induced recycling results in higher microbial activity and associated oxygen depletion (Buzzelli et al. 2002; MacPherson et al. 2007). Colonization of soft bottom by benthic microalgae reduces the extent to which sediment is resuspended at low water flow velocities, stabilizing the bottom and reducing turbidity in the water column (Holland et al. 1974; Underwood and Paterson 1993; Yallop et al. 1994; Miller et al. 1996). However, microalgae cannot stabilize sediments under intense or prolonged disturbance conditions, such as during large storm events or in the surf zone (Miller 1989). Because of the absence of large, extensive structure, soft bottom provides relatively less stabilization benefits than other estuarine habitats.

Intertidal shorelines, flats, tidal deltas, and sand bars along the ocean shoreline buffer and modify wave energy, reducing shoreline erosion. Flood-tidal deltas are an important source of sand, which allows
barrier island migration to respond to sea level rise (Cleary and Marden 1999). Alterations to these deltas can result in significant changes in the adjacent barrier island shorelines.

6.2.2. Productivity

6.2.2.1. Freshwater and estuarine

Although soft bottom habitat is defined as “unvegetated,” the surface sediments support an abundance of benthic microalgae that are an important source of primary production (Peterson and Peterson 1979; Cahoon and Cooke 1992; Pinckney and Zingmark 1993; Curran et al. 1995; MacIntyre et al. 1996; Cahoon et al. 1999; and Litvin and Weinstein 2003). Benthic microalgae including diatoms, dinoflagellates, and blue green algae, that live in the top few millimeters of the surface of soft bottom (Peterson and Peterson 1979; Miller et al. 1996). Benthic microalgae often support the base of the soft bottom food-web (Mallin et al. 2005) and are the major food source for deposit feeders such as mud snails, bivalve clams, and polychaete worms (MacIntyre et al. 1996). Values for benthic chlorophyll \( a \) biomass (an indicator of overall productivity) in North Carolina estuaries have been reported to range from 10-90 mg m\(^{-2}\) (Posey et al. 1995) and are similar to those found in other Atlantic coast states (Table 6.2). Little information is available on benthic productivity in coastal freshwater creeks and rivers. In general, primary production in these areas is greatest in shallow, well-illuminated benthic substrates.

Table 6.2. Benthic productivity estimates as measured by chlorophyll \( a \) biomass in Virginia (Chesapeake Bay), North Carolina (Masonboro Sound), and South Carolina (North Inlet Estuary).

<table>
<thead>
<tr>
<th>Region</th>
<th>Chl. ( a ) biomass (mg m(^{-2}))</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virginia</td>
<td>5 – 65</td>
<td>Rizzo and Wetzel (1985)</td>
</tr>
<tr>
<td>North Carolina</td>
<td>10 – 90</td>
<td>Posey et al. (1995)</td>
</tr>
<tr>
<td>South Carolina</td>
<td>20 – 110</td>
<td>Pinckney and Zingmark (1993)</td>
</tr>
</tbody>
</table>

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

Organic matter on soft bottom habitat arrives in the form of detritus originating from marsh grass, submerged aquatic vegetation, and macroalgae (Curran et al. 1995; Wainright et al. 2000; Litvin and Weinstein 2003). The relative contribution of different primary producers to overall secondary production varies by the diet of individual fish or invertebrate species, their position within the estuary, and seasonal or episodic weather conditions (Tester et al. 1995; Wainright et al. 2000; Page and Lastra 2003; Galvan et al. 2008).
6.2.2.2. Marine

Benthic microalgae are also an important source of primary production on marine soft bottom. Viable chlorophyll $a$ occurs in sediments across the continental shelf of North Carolina (Cahoon et al. 1990). Studies in Onslow Bay have found that roughly 80% of chlorophyll $a$ was associated with microphytobenthos and its biomass (36.4 mg m$^{-2}$) generally exceeded that of phytoplankton (8.2 mg m$^{-2}$) (Cahoon and Cooke 1992). Recently, McGee et al. (2008) discovered obligate benthic diatoms living on the upper continental slope offshore from North Carolina, in waters as deep as 191 m. This discovery increases the estimated total benthic primary production in that area of the continental margin by about 14%.

In the surf zone, wave action is generally too great to allow for the development of productive benthic microalgae communities. However, this wave action continually re-suspends inorganic nutrients in sufficient amounts to create localized phytoplankton blooms composed primarily of diatoms (McLachlan et al. 1981; Hackney et al. 1996). This self-sustaining nutrient input and associated phytoplankton production supports intertidal filter feeders and, consequently, high concentrations of fish migrating through the shallow waters of the surf zone.

6.2.3. Benthic community structure

6.2.3.1. Freshwater

The freshwater benthic community varies greatly from extreme headwaters to mainstem rivers and may be more similar to that found in inland lake bottoms than in estuaries. In headwater streams, the benthic community consists largely of organisms that break down and collect detritus associated with the dense tree canopy cover. As the canopy opens up downstream, algae grazers and detritivores increase in abundance (Vannote et al. 1980). Freshwater benthic sampling conducted by DWQ in all of North Carolina’s river basins provides more detailed information on the abundance and diversity of benthic species present in the freshwater portion of North Carolina’s coastal rivers. Common coastal freshwater invertebrates include mayfly and caddisfly larvae, leeches, chironomids, beetles, dragonfly larvae, and crayfish. Hyland et al. (2004) found that oligochaetes, insect larvae, gammaridean amphipods, and larval Coelotanypus spp. dominate the tidal freshwaters of the Chowan River.

Mussels are also an important component of the coastal freshwater invertebrate community on soft bottom (Hyland et al. 2004), with over 60 species of freshwater mussels in North Carolina. However, the distribution and diversity of native freshwater mussels have been in a state of decline as of late. The freshwater Asiatic clam (Corbicula fluminea), introduced about 50 years ago, has become a prominent component of many coastal rivers (Lauritsen and Moxley 1983; Hyland et al. 2004), resulting in alteration of the benthic substrate and competition with native mollusks (Devick 1991).

6.2.3.2. Estuarine

Estuarine soft bottom supports a high diversity of benthic invertebrates, with over 400 species documented in North Carolina waters (Hackney et al. 1996; Hyland et al. 2004). Most benthic invertebrates inhabiting soft bottom live in the sediment (infauna), as opposed to the sediment surface (epifauna), because of the high mobility of this habitat (Peterson and Peterson 1979). On intertidal flats, the sediment provides a buffer from drastic fluctuations in salinity, water temperature, and air temperature (in addition to air and wind exposure) during each tidal cycle, allowing infauna to flourish under these normally stressful conditions (Peterson and Peterson 1979). Infauna can be separated into three distinct size classes: microfauna, meiofauna, and macrofauna. Microfauna are comprised of very small protozoans (< 0.06 mm) and include foraminifera and ciliates. Meiofauna, such as nematodes and copepods, are about 0.06 – 0.50 mm in size (the size of a sand grain) and generally live within the interstitial spaces of sands or within the top centimeter of muds. Both microfauna and meiofauna are
important grazers on estuarine microphytobenthos and bacteria. Macrofauna (> 0.5 mm) contribute the most to infaunal biomass and include organisms such as amphipods, polychaetes, mollusks, echinoderms, and crustaceans (Peterson and Peterson 1979).

Benthic infauna may also be classified by feeding mode, specifically as deposit feeders or suspension feeders (Peterson and Peterson 1979; Miller et al. 1996). Deposit feeders include mud snails, polychaete worms, and certain bivalve clams and crustaceans that ingest sediment and detrital particles, and assimilate the associated bacteria, fungi, and microalgae. Suspension feeders capture particles suspended in the water column and include bivalves such as the hard clam (Mercenaria mercenaria) and razor clam (Tagelus plebeius), and some polychaete worms (Miller et al. 1996). A large proportion of suspension feeders’ diet may consist of resuspended benthic microalgae, particularly when chlorophyll a concentrations in the water column are low (Miller et al. 1996; Page and Lasta 2003).

Benthic epifauna consist of larger, mobile invertebrates that live on the surface of soft bottom. Fiddler crabs (Uca spp.), amphipods, and insects congregate on intertidal flats, foraging for microalgae and detritus. On submerged flats and shallow bottom, the blue crab (Callinectes sapidus) functions as an important predator and scavenger. Other mobile epifauna include horseshoe crabs (Limulus polyphemus), whelks (Busycon spp.), tulip snails (Fasciolaria spp.), moon snails (Polinices duplicatus), penaeid shrimp, hermit crabs (Pagurus spp., Petrochirus spp., and Clibanarius vittatus), sand dollars (Melitta quinquesperforata), and spider crabs (Libinia spp.).

6.2.3.3. Marine

Benthic invertebrate species composition and diversity varies greatly from oceanfront beaches to subtidal marine soft bottom. A diverse assemblage of meiofauna (0.06 – 0.5 mm) occurs in the intertidal zone of the lower beach (Levinton 1982; Hackney et al. 1996), while a relatively low diversity of macrofauna (> 0.5 mm) (~ 20 – 50 species) exists (Hackney et al. 1996). The dominant macrofauna in North Carolina’s oceanfront intertidal beaches are mole crabs (Emerita talpoida), coquina clams (Donax variabilis, D. parvula), several species of haustoriid amphipods, and the spionid polychaete Scolelepis squamata (Hackney et al. 1996; Donoghue 1999; Lindquist and Manning 2001; Peterson et al. 2006).

Because North Carolina is located at a transition between two major physiographic and zoogeographic zones, the marine subtidal bottom supports a high diversity of invertebrates. Offshore sand bottom communities along the North Carolina coast have been reported to contain over 600 species of benthic invertebrates (Posey and Alphin 2002), with over 100 polychaeta taxa (Lindquist et al. 1994; Posey and Ambrose 1994). Posey and Alphin (2002) found that polychaetes dominated the benthic invertebrate assemblage on soft bottom offshore from Kure Beach, although bivalves, crabs, and amphipods were also highly represented. On ebb tide deltas, spionid and oweniid amphipods, and the spionid polychaete Scolelepis squamata (Hackney et al. 1996; Donoghue 1999; Lindquist and Manning 2001; Peterson et al. 2006).

6.2.4. Fish utilization

Like the water column, soft bottom is used to some extent by almost all native coastal fishes in North Carolina. Estuary-dependent migratory species, including spot, Atlantic croaker, and penaeid shrimp are common components of the estuarine soft bottom during summer and fall (Weinstein 1979; Epperly 1984; Ross and Epperly 1985; Noble and Monroe 1991; Ross 2003). Spot and Atlantic croaker also frequent shallow (< 10 m) nearshore soft bottom, where they dominate the benthic fish assemblage (Wenner and Sedberry 1989). Certain species, such as flatfish, skates, and rays, are best adapted to,
characteristic of, or dependent on shallow unvegetated bottom (Peterson and Peterson 1979; Burke et al. 1991; Walsh et al. 1999; Schwartz 2003). Habitat utilization patterns by fishes on soft bottom are primarily related to season and ontogenetic stage (Walsh et al. 1999; Ross 2003). Table 6.3 summarizes important fishery and nonfishery species that are dependent on subtidal bottom for some portion of their life history and the ecological function of the soft bottom habitat.

Table 6.3. Partial list of common or important fish species occurring on soft bottom habitat in riverine, estuarine, and ocean waters, and ecological functions provided to those species.

<table>
<thead>
<tr>
<th>Species*</th>
<th>Soft bottom functions ¹</th>
<th>2010 Stock status ²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spawning</td>
<td>Nursery</td>
</tr>
<tr>
<td>ANADROMOUS SPAWNING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atlantic sturgeon</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Shortnose sturgeon</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>ESTUARINE AND INLET SPAWNING AND NURSERY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard clam</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hermit crab spp.</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Horseshoe crab</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mud crab spp.</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mummichog</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Red drum</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Sheepshead minnow</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Whelks</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>MARINE SPAWNING, LOW-HIGH SALINITY NURSERY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atlantic croaker</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hogchoker</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Penaeid shrimp</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Southern flounder</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Spot</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Striped mullet</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>MARINE SPAWNING, HIGH SALINITY NURSERY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atlantic stingray</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Coastal sharks³</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cownose ray</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Florida pompano</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Gulf flounder</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Gulf kingfish</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Smooth dogfish</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Spiny dogfish</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Striped anchovy</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Summer flounder</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

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

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

² V = Viable, R = Recovering, C = Concern, D = Depleted, U = Unknown (DMF 2009a), E = federally and state listed as endangered (http://www.ncdmf.net/stocks/2010NCDMF%20StockStatusReport.pdf)

³ Incl. Atlantic sharpnose, blacknose, blacktip, bonnethead, dusky, sandbar, scalloped hammerhead, and spinner sharks
6.2.5. Specific biological functions

6.2.5.1. Foraging

One of the most important functions of soft bottom habitat is as a foraging area. In freshwater reaches, high concentrations of organic matter and the associated secondary production (i.e. benthic invertebrates) support a diverse array of freshwater fishes. Several species of coastal freshwater fishes, including yellow perch (*Perca flavescens*), bluegill (*Lepomis macrochirus*), and channel catfish (*Ictalurus punctatus*), rely heavily on benthic food resources, such as mayfly nymphs, chironomids, corixids, and tendipedid larvae, for maintaining elevated growth rates (Bailey and Harrison 1948; Flemer and Woolcott 1966; Lott et al. 1996; Schaeffer et al. 2000). In North Carolina, largemouth bass (*Micropterus salmoides*) and white catfish (*Ameiurus catus*) have been reported to forage on both benthic-associated crustaceans and fishes in oligohaline, intertidal rivulets of the upper Cape Fear River Estuary (Rozas and Hackney 1984).

Reliance on benthic productivity for food is not unique to freshwater areas. Members of several trophic levels, including primary, secondary, and tertiary consumers, benefit directly or indirectly from detrital and benthic microalgal production, as well as the numerically abundant and diverse invertebrate fauna associated with estuarine soft bottom (Peterson and Peterson 1979). On shallow intertidal flats, planktonic and benthic feeding herbivorous fish, such as anchovies, killifish, and menhaden, consume phyto- and zooplankton in the water column, as well as resuspended benthic algae, microfauna, and meiofauna (Peterson and Peterson 1979). While numerous fish species use detritus as an alternate food source when preferred items are not available, striped and white mullet feed preferentially on detritus collected on estuarine soft bottom.

Most fish that forage on estuarine soft bottom are predators of benthic invertebrates. These fish include juvenile and adult rays, skates, flatfish, drums, pigfish, sea robins, lizardfish, gobies, and sturgeons (Peterson and Peterson 1979; Bain 1997). Larger piscivorous fishes typically move onto estuarine flats during high water to feed on schools of baitfish. These predators include sharks (sandbar, dusky, smooth dogfish, spiny dogfish, Atlantic sharpnose, and scalloped hammerhead), drum (weakfish and spotted seatrout), striped bass, and estuary-dependent reef fish (black sea bass, gag grouper, sand perch) (Peterson and Peterson 1979; Thorpe et al. 2003). Flatfish, rays, and skates are particularly adapted to forage on shallow intertidal flats due to their compressed body forms (Peterson and Peterson 1979). Small flatfish, (i.e. bay whiff, fringed flounder, hogchoker, and tonguefish), feed mostly on copepods, amphipods, mysids, polychaetes, mollusks, and small fish. Summer and Southern flounder, larger flatfish primarily consume fish, such as silversides and anchovies, as well as shrimp and crabs, small mollusks, annelids, and amphipods (Peterson and Peterson 1979; Burke 1995). These larger flatfish will ambush their prey by blending into the bottom sediments or by slowly stalking prey items (Sharf et al. 2006). Various rays excavate large pits while searching for mollusks, annelids, crustaceans, and benthic fish prey (Cross and Curran 2004). In the Chowan Creek Channel, SC Cross and Curran (2004) observed an average of 17.8% of the intertidal surface was disturbed by pit formation not including excavation piles. Due to the increasing numbers of rays in NC, the impact of ray foraging pits in NC waters should be examined.

Ocean soft bottom, particularly in the surf zone, and along shoals and inlets, serves as an important feeding ground for numerous fishes that forage on benthic invertebrates (Peterson and Peterson 1979). These predators generally have high economic value as recreational and commercial fisheries, and include Florida pompano, red drum, kingfish, spot, Atlantic croaker, weakfish, Spanish mackerel, and striped bass. Many of these species congregate in and around distinct topographic features of the subtidal bottom, such as the cape shoals, channel bottoms, sandbars, sloughs, and ebb tide deltas during various times of the year, presumably to enhance successful prey acquisition or reproduction. The natural processes that create these features need to be maintained. Additional public outreach is needed to emphasize the importance of natural barrier island and estuarine processes.
Hard bottom fishes are also supported by the food resources present in and on soft bottom. Demersal zooplankton and infauna from sand substrate have been found to be an important component of many species’ diets and an important link to reef fish production (Cahoon and Cooke 1992; Thomas and Cahoon 1993; Lindquist et al. 1994). Reef species documented foraging over sand bottom away from the reef include tomtate (Haemulon aurolineatum), whitebone porgy (Calamus leucosteus), cubbyu (Equetus umbrosus), black sea bass (Centropristis striata), and scup (Stenotomus chrysops) (Lindquist et al. 1994).

6.2.5.2. Spawning

Many demersal fish spawn over soft bottom habitat in North Carolina’s coastal waters (Table 6.2). In freshwater, largemouth bass (Micropterus salmoides) and bluegill (Lepomis macrochirus) spawn on shallow flats where they lay eggs in bowl-shaped nests. Longnose gar occasionally spawn in the depressions made by these fishes, exploiting the brood care afforded by nest-defending species. Anadromous fishes, such as Atlantic and shortnose sturgeon (Acipenser oxyrinchus oxyrinchus and A. brevirostrum, respectively), will spawn in the upper freshwater portions of coastal rivers (Moser and Ross 1995).

In estuarine reaches, resident fish and invertebrates, as well as seasonal migratory fish spawn over soft bottom, particularly in summer. Resident flatfish, including hogchokers and tonguefish, use subtidal estuarine soft bottom as spawning grounds (Hildebrand and Schroeder 1972; Manooch 1984). Estuarine invertebrates, like hard clams,whelks, and hermit crabs use the intertidal flats that they inhabit as their primary spawning habitat. Migratory estuarine spawners, including several species of drum, predominately spawn over soft bottom during the summer months. Spotted sea trout spawn on the east and west sides of Pamlico Sound during a similar time period, with peak activity observed around Rose Bay, Jones Bay, Fisherman’s Bay, and Bay River (Luczkovich et al. 1999a; Luczkovich et al. 2008). Red drum were also documented spawning in the mouth of the Bay River on the west side of Pamlico Sound, and in estuarine channels near Ocracoke Inlet (Luczkovich et al. 1999a; Luczkovich et al. 2008). The evidence for blue crabs spawning in inlet areas was enough to warrant their protection as Crab Spawning Sanctuaries (DMF 2004 – blue crab FMP).

Several species of estuary-dependent fishes use ocean soft bottom as critical spawning habitat during winter, primarily seaward of state waters. Eggs and larvae of these species are carried by currents through nearshore state waters and inlets to estuarine nursery areas. Important spawning aggregations of summer flounder occur during winter on Wimble, Platt, and Kinnekeet shoals off the Outer Banks (MAFMC 1998). Locations of summer flounder spawning aggregations are linked to environmental conditions, such as water temperature and wind direction, and are generally concentrated north of Cape Hatteras.

Nearshore ocean waters in North Carolina also serve as important pupping grounds for several species of sharks. North of Cape Hatteras, pupping of spiny dogfish over subtidal bottom has been documented in winter months (ASMFC 2002a). Subtidal bottom in the southern portion of North Carolina state waters serves as pupping grounds for the Atlantic sharpnose shark (Rhizoprionodon terraenovae), bonnethead shark (Sphyraena tiburo), blacknose shark (Carcharinhus acronotus), spinner shark (C. brevipinnia), dusky shark (C. obscurus), and, to a lesser extent, blacktip shark (C. limbatus), sandbar shark (C. plumbeus), and scalloped hammerhead shark (S. lewini). Most neonate (newborn) sharks from this area are found in June and July (Beressoff and Thorpe 1997; Thorpe et al. 2003).

6.2.5.3. Nursery

Shallow soft bottom, usually adjacent to wetlands, is utilized as a nursery for many species of juvenile fish (Table 6.2). This habitat provides an abundance of food and is relatively inaccessible to larger predators. Shallow unvegetated flats have been documented as being a particularly important nursery
habitat for summer and southern flounder, spot, Atlantic croaker, and penaeid shrimp (Weinstein 1979; Burke et al. 1991; Walsh et al. 1999; Ross 2003). Ongoing DMF juvenile fish monitoring has found that shallow unvegetated bottom supports an abundance of juvenile fish, composed of relatively few species that have similar life histories and feeding patterns (Ross and Epperly 1985).

The dominant fishes using shallow estuarine soft bottom as nursery areas are estuary-dependent species, which primarily spawn offshore in winter. For many species, the uppermost reaches of shallow creek systems correspond to the site of larval settlement, i.e. the primary nursery areas (Weinstein 1979; Ross and Epperly 1985). However, in tributaries far removed from ocean inlets, such as Neuse, Pamlico, Bay and Pungo rivers, larval settlement tends to occur in lower reaches of the system. Abundance of juvenile species in estuarine nursery areas generally peaks between April and July and is correlated with water temperatures (Ross and Epperly 1985). As they grow, fish move to deeper waters and areas farther down-estuary.

In the early 1980s, fishery independent data from shallow creeks and bays in Pamlico Sound documented 78 fish and invertebrate species over a two-year period (Ross and Epperly 1985). Eight species, including spot, bay anchovy, Atlantic croaker, Atlantic menhaden, silver perch, blue crab, brown shrimp, and southern flounder, comprised more than 97% of the total nekton abundance. Data from DMF’s ongoing juvenile fish monitoring program, which began in 1971, show that the same eight species continue to dominate North Carolina’s nekton assemblage, with pinfish and white shrimp also among the most abundant species collected. The consistency of catch characteristics during 1990-2008 is an indication that these areas continue to function as healthy nurseries. *Temporal and spatial expansion of juvenile fish sampling would provide additional information on trends in juvenile fish utilization of soft bottom and other habitats, especially summer and fall spawning species, which are generally not present at existing sampling stations during May and June.*

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

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

<table>
<thead>
<tr>
<th>Group</th>
<th>Location</th>
<th>Dominant fish species</th>
<th>Primary Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pamlico, Pungo, Neuse rivers, eastern Albemarle Sound</td>
<td>Atlantic croaker, brown shrimp, blue crab, southern flounder</td>
<td>Shallow unvegetated sediment</td>
</tr>
<tr>
<td>2</td>
<td>Western bays of Pamlico Sound</td>
<td>Species above + weakfish, spotted seatrout, silver perch</td>
<td>Shallow unvegetated sediment</td>
</tr>
<tr>
<td>3</td>
<td>Behind the Outer and Core banks</td>
<td>Pinfish, pink shrimp, black sea bass, gag, pigfish, red drum</td>
<td>SAV beds</td>
</tr>
<tr>
<td>4</td>
<td>Western shore and tributaries of Core Sound</td>
<td>Summer and southern flounder, brown shrimp</td>
<td>Shallow unvegetated sediment</td>
</tr>
</tbody>
</table>
Soft bottom in freshwater areas and the nearshore ocean also function as valuable nursery habitat for numerous fish species. Benthic anadromous fish, such as Atlantic and shortnose sturgeon, use freshwater soft bottom as a primary nursery during spring and summer. In the nearshore ocean, subtidal soft bottom is used extensively as a nursery area for coastal sharks, such as spinner (*C. brevipinna*), blacknose (*C. acronotus*), and dusky (*C. obscurus*) sharks (Beresoff and Thorpe 1997; Thorpe et al. 2003). Ocean soft bottom, particularly the surf zone, is also a nursery area for Florida pompano, and southern and gulf kingfish (Hackney et al. 1996). Juvenile Atlantic sturgeon and spiny dogfish, both demersal feeders, have been documented over nearshore subtidal bottom between Oregon Inlet and Kitty Hawk during winter months (Cooperative Striped Bass Tagging Program, unpub. data). In New Jersey, Able et al. (2009), observed recently hatched juvenile fish in the surf zone during the spring and summer months.

### 6.2.5.4. Refuge

Shallow soft bottom, such as intertidal flats, can provide refuge to small and juvenile fish and invertebrates through exclusion of large fish predators (Peterson and Peterson 1979; Ross and Epperly 1985). Consequently, juvenile fish benefit from settling in the shallowest portions of the estuary first. Many fish and invertebrates, including hard clams, flatfish, skates, rays, and other small cryptic fish, like gobies, avoid predation by burrowing partially or completely into the sediment, thus camouflageing themselves from predators (Peterson and Peterson 1979; Luettich et al. 1999). Deep water soft bottom habitat may be a treacherous environment for small fish and invertebrates, particularly for those that cannot burrow. These areas are generally the most accessible to large piscivorous fishes and because of this, many fish venture out on the open bottom only at night (Summerson and Peterson 1984).

### 6.2.5.5. Corridor and connectivity

Numerous migrating juvenile and subadult demersal fishes use soft bottom as corridors for movement from freshwater and estuarine nursery habitats to the coastal ocean. As fishes grow, they slowly move from up-estuary primary nurseries down estuary to secondary nurseries and eventually out into the coastal ocean. Because large fish are less likely to be consumed as prey, they can travel relatively safely over the less turbid sand flats and channels of the middle and lower estuary (Walsh et al. 1999). However, juvenile summer flounder were found in higher density in muddy bottoms that were adjacent to wetlands, than areas in sandy bottoms (Walsh et al. 1999). In fact, substrate type is the most important factor influencing juvenile summer flounder habitat (Burke 1991 and Burke et al. 1991). Anadromous fish, including sturgeon and striped bass, also require a corridor of soft bottom to reach upstream spawning areas.

While connectivity among structured habitat patches, such as SAV, wetlands, and shell bottom, facilitates movement of mobile predators, a few meters of unvegetated bottom can act as a barrier to movement (Micheli and Peterson 1999). Such barriers can be beneficial to small invertebrates by potentially obstructing predator dispersal and reducing predation risk. In Back Sound, North Carolina, Micheli and Peterson (1999) documented higher densities and survival rates of small crabs, gastropods, and infaunal bivalves on isolated oyster reefs (at least 10-15 m of unvegetated bottom between habitats) than on oyster beds adjacent to salt marsh or SAV. Blue crab predation on infaunal bivalves was greater along vegetated edges of salt marshes and SAV than on unvegetated intertidal flats (Micheli and Peterson 1999). Although structural habitat separations by unvegetated soft bottom may benefit the viability of infaunal populations, fish and crustacean productivity may be enhanced by connectivity of structured estuarine habitats (Micheli and Peterson 1999).
6.3.  STATUS AND TRENDS

6.3.1. Status of soft bottom habitat

Since standardized or comprehensive baseline mapping of soft bottom habitat has not been completed, and because sediments shift and move over time, it is currently not possible to quantify how the extent and condition of the habitat has changed through time. The loss of more structured habitat, such as SAV, wetlands, and shell bottom, has undoubtedly led to gains in soft bottom habitat, but the low quality of areas gained may not be considered beneficial to the ecosystem as a whole.

6.3.2. Status of associated fishery stocks

6.3.2.1. Fishery independent monitoring programs

The DMF began a juvenile fish monitoring program (Estuarine Trawl Survey) in 1971. This long-term database provides fishery independent (data gathered independent of the fishery) information on species composition and abundance to identify primary and secondary nursery areas, shallow soft bottom habitat usually surrounded by wetlands. Although the data is not discussed here, the Pamlico Sound Survey is another long-term monitoring program used to calculate juvenile abundance indices (JAI) in Pamlico Sound and the lower portion of the Pamlico and Neuse estuaries. JAI, the annual geometric mean (weighted by strata) of the number of individuals per tow for young of the year fish and invertebrates, are calculated from these sampling programs for important fish and invertebrate species. The JAI is considered an accurate indicator of recruitment and year-class strength for many recreational and commercially important species (DMF 2003c). The information is used to determine stock status of fishery species by various fishery management agencies. JAI are also used as a criterion to qualify an area as a designated Primary or Secondary Nursery Area. Designated areas are monitored regularly to provide long-term information on status and trends in recruitment of the dominant estuarine dependent species. Trends in JAI may indicate change in the habitat conditions (DMF 2003c). However, consistent and comparable JAI data are only available since 1990 and, prior to this time, considerable habitat losses and changes occurred. Habitat information has been collected by NCDMF for the Estuarine Trawl survey since the beginning, while this information has only been collected for Pamlico Sound Trawl Survey since 2009. Currently a Sea Grant project is being completed by East Carolina University researchers examining the impacts of land use change on several species of fish and invertebrates using NCDMF Estuarine Trawl Survey data (J. Luczkovich/ECU, pers. com., 2009).

Several species are closely linked to soft bottom habitat and juvenile abundance indices from the Estuarine Trawl Survey for recreationally and commercially important species (i.e. southern flounder, spot, and Atlantic croaker) are shown in Figure 6.1 and 6.2. Southern flounder JAI have varied between 1 and 8.1 with peak JAI in 1996 and 2003, whereas there were large declines in 1997, 1998, 2002 and 2004 through 2006 (Figure 6.1). Atlantic croaker and spot are benthic feeding fish that could be affected by changes in soft bottom habitat, such as reductions in benthic food sources due to toxicity or anoxic conditions in sediments. The JAI for Atlantic croaker from the Estuarine Trawl Survey has fluctuated between 8.6 and 97.1 while spot have fluctuated between 50 and 350 (Figure 6.2). An Atlantic croaker ASMFC FMP was completed in 1987 and is in the process of being updated in 2009. The stock assessment determined that Atlantic croaker is a recruitment-driven stock, where biomass and landings fluctuate in response to large year classes. Research priorities for Atlantic croaker include determining the impacts of any dredging activity (i.e. for beach re-nourishment) on all life history stages of croaker (ASMFC 2009).
Figure 6.1. Southern flounder juvenile abundance indices (geometric mean CPUE) from DMF Estuarine trawl survey, core stations sampled in May and June, 1990-2008.

Figure 6.2. Spot and Atlantic croaker juvenile abundance indices (geometric mean CPUE) from DMF estuarine trawl survey core stations sampled in May and June (1990-2008).

Currently in coastal waters of North Carolina, fishery-independent data are available from shallow water trawl surveys conducted by the Southeast Area Monitoring and Assessment Program – South Atlantic (SEAMAP-SA). SEAMAP currently provides the only region-wide standardized surveys for monitoring long-term (1983-present) status and trends of demersal fish and invertebrate populations that utilize marine soft bottoms as well as other habitats. The SEAMAP study area includes inner (4m depth contour) and outer (10m depth contour) strata stations in Long Bay, Onslow Bay, and Raleigh Bay in North Carolina.
The status of benthic macroinvertebrate populations is another measure of soft bottom conditions. Hard clams, although also present in shell bottom and SAV habitats, require soft bottom habitat for burrowing. Because clams remain fairly stationary and are filter feeders, they may be vulnerable to habitat degradation, such as sediment contamination or sedimentation. The status of the hard clam stock is currently unknown due to lack of adequate data (DMF 2009a). However, using trip ticket data, DMF (2001b) concluded that hand harvest of clams appeared to be stable, but that clam abundance, in areas where mechanical clam harvest occurred, appeared to decline from 1994 to 1999. MFC recommended that mechanical harvest limits in Core Sound be further restricted. From 1978 to 2001 *Mercenaria mercenaria* recruitment in central North Carolina decreased 65-72% while fishing pressure for hard clams has continued to increase (Peterson 2002). *Reducing the area available to mechanical clam harvesting is another means of protecting clam stocks, particularly in location within close proximity of SAV habitat.*

In 2010 the stock status of twelve of 18 soft bottom associated fishery species (bolded species in Table 6.2) were evaluated by NCDMF ([http://www.ncdmf.net/stocks/2010NCDMF%20StockStatusReport.pdf](http://www.ncdmf.net/stocks/2010NCDMF%20StockStatusReport.pdf)). Of these twelve species, two (17%) were of unknown status. Of the ten stocks whose status is known, two (20%) were classified as Viable, two (20%) were Recovering, four (40%) were of Concern, and two (20%) were Overfished (Table 6.2). Viable species included penaeid shrimp and striped mullet; red drum and summer flounder were Recovering. Depleted species included Atlantic and shortnose sturgeons and southern flounder. The species listed as Concerned include blue crab, Atlantic croaker, spot, and coastal sharks.

Atlantic sturgeon has historically supported a valuable commercial fishery; however, landings declined dramatically by the early 1900s. Shortnose sturgeon is currently a federally listed endangered species and Atlantic sturgeon is considered threatened in North Carolina (Ross et al. 1988). In 2009, the Atlantic sturgeon has been petitioned to be classified as a federally endangered species. A decision on this petition should be reached in 2010. Despite a fishing moratorium in North Carolina since 1991 both sturgeon species have not shown signs of recovery, indicating that habitat and water quality issues are also affecting recovery. Potential habitat issues could include reduction of benthic food sources in fresh water due to eutrophication or toxin contamination, or degradation of spawning and nursery habitat from channel obstructions, channelization, and sedimentation. The Cape Fear River and Albemarle Sound are the only estuaries in NC that presently show evidence of spawning for the Atlantic sturgeon. The Interstate Fishery Management Plan for Atlantic sturgeon has listed dredging as a major concern (ASMFC 1998) to essential habitat for sturgeon.

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

The Depleted status of southern flounder is due in part to overfishing but may also be related to habitat issues in the low salinity estuaries. Dredging (navigational and fishery) and inlet stabilization are listed as threats to Southern flounder habitat in the NCDMF 2005 FMP. Severe hypoxic events and anoxia can directly affect populations of southern flounder through mortality from suffocation and indirectly from reduced growth rates, loss of preferred prey (mortality of benthic community), changes in activity patterns, or disease. The Division is updating the southern flounder Fishery Management Plan in 2009.

Striped mullet are of concern primarily due to an increase in associated fishing effort. The Division developed a Fishery Management Plan for striped mullet in 2005. As a result of the 2005 FMP, one objective is to “Restore, improve, and protect critical habitats that affect growth, survival, and...
reproduction of the North Carolina striped mullet stock” (DMF 2005-Striped mullet FMP). Atlantic croaker is listed as Concern because JAs and estuarine landings have remained low.

6.3.3. Designated areas

There have been some federal actions taken to designate and protect certain portions of soft bottom habitat in coastal ocean waters. The SAFMC designated all coastal inlets as Habitat Areas of Particular Concern (HAPC) for blue crab, estuarine-dependent snapper-grouper species, penaeid shrimp, and red drum. The sandy shoals of Cape Hatteras, Cape Lookout, and Cape Fear are designated as HAPC for all coastal migratory pelagics, including king mackerel, Spanish mackerel, dolphin, and cobia. In May 2000, Presidential Executive Order 13158, Marine Protected Areas, was implemented. The order mandated strengthening of the management, protection, and conservation of existing marine protected areas and establishing or expanding additional marine protected areas. Marine protected areas (MPA) were defined as “any area of the marine environment that has been reserved by Federal, State, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein” (Federal Register 2000). Among the many agencies cited in the order, the Environmental Protection Agency (EPA), relying on existing Clean Water Act authorities, is required to identify and prioritize natural and cultural resources for additional protection, propose science-based protocols for monitoring and evaluating marine protected areas, and propose science-based regulations to ensure appropriate protection of habitat and water quality standards. These actions may provide additional protection for North Carolina’s marine soft bottom habitat, as well as hard bottom and other ocean habitats. In 2004, DCM compiled an inventory of existing marine managed areas prior to assessing the need and feasibility of establishing new MPAs in North Carolina. In 2004, there were 84 state sites, 13 de facto sites, and 7 federal sites in the Marine Managed Area (MMA) inventory that were located within North Carolina; with a proposal to include three more federal sites (Trappe 2004). Additionally, there are approximately 160 mi of federally or state owned barrier islands along the 320 mi of ocean shoreline. This includes all or portions of eight (of 23) barrier islands or peninsulas. Intertidal beaches adjacent to these areas are protected from most development associated threats.

Although soft bottom as a habitat type is not specifically designated or protected by any of North Carolina’s regulatory commissions, it is an important component of MFC designated Primary Nursery Areas (PNAs), Anadromous Fish Spawning Areas, Anadromous Nursery Areas, and crab spawning sanctuaries (See “Designation” section of Water Column chapter for more information). Most of the North Carolina PNAs have soft muddy bottoms that are surrounded by marshes and wetlands (http://www.ncfisheries.net/habitat/pna.htm, 2009).

In July 2001, the USFWS designated 1,798 miles of intertidal and supratidal (dry) beaches and dunes to the mean low water (MLW) in eight states as Critical Habitat for the wintering population of piping plover (Charadrius melodus). Critical Habitat is defined in the Endangered Species Act as a specific geographic area that is essential for the conservation of a threatened or endangered species and that may require special management and protection (http://www.fws.gov/endangered/, December 2010). This may include suitable habitat that is not currently occupied by the species but is needed for its recovery, thereby providing more habitat protection. Federal agencies are required to consult with the USFWS to ensure that any federal actions do not adversely modify Critical Habitat functions, including areas not currently occupied by a designated species. This action, by providing protection to wintering habitat, also protects intertidal benthos, which will benefit foraging habitat for piping plover as well as benthic feeding surf fish. There are 18 designated areas in North Carolina, primarily inlet systems and adjacent shoals and spits. Refer to website (http://plover.fws.gov, 2009) for maps of the designated areas.
6.4. **THREATS AND MANAGEMENT NEEDS**

Although the soft bottom habitat is always changing, there are several threats to the overall habitat stability. These threats may be direct impacts to the soft bottom or they may affect water quality thereby altering the soft bottom community. As people continue to live in coastal North Carolina, there will be continued channel dredging, dock construction, shoreline stabilization, and commercial fishing. These methods may all potentially be detrimental to the soft bottom habitat. Water quality will also continue to be affected by increased nutrient input and heavy metal contamination.

6.4.1. **Physical threats**

6.4.1.1. Water-dependent development

*Dredging (navigation channels and boat basins)*

Existing dredged navigational channels and basins are necessary to sustain current boating and fishing activities and provide access to state ports for transport of commerce. However, dredging activities do affect physical and biological features of soft bottom communities. New dredging for navigational channels or marina construction can alter topographic and hydrologic features that attract fish for feeding, refuge, or spawning, and modify sediment grain characteristics (SAFMC 1998a). Dredging removes all benthic infauna from the affected areas immediately, reducing food availability temporarily to bottom feeding fish and invertebrates, including southern and gulf kingfish, Florida pompano, spot, Atlantic croaker, flounder, and shrimp (Hackney et al. 1996; Peterson et al. 2000a). Whether the magnitude of prey reduction limits fish growth, reproduction or survival depends on the species’ diet preference, foraging range, mobility, abundance of prey elsewhere, and extent and location of other benthic disturbing activities. Inlet dredging in winter can kill or displace female blue crabs that are burrowing in the inlet sediments. Disturbance associated with inlet dredging can also deter or alter summer spawning activity of red drum, weakfish, spotted seatrout, silver perch, and blue crab (Luczkovich et al. 1999a; DMF 2000c). Spawning activity around the inlets occurs from May through October, depending on the species (Table 2.3 in Water Column chapter). Because spawning activity occurs at night, daytime dredging may have less of an effect. However, there are also possible indirect effects associated with dredging, such as reductions in benthic prey availability and alterations of the acoustic environment (J. Luczkovich/ECU, pers. com., 2009). While new dredging is prohibited in designated Primary Nursery Areas, and seasonally restricted in Anadromous Fish Spawning Areas, similar restrictions do not exist for undesignated anadromous fish nursery areas, which require shallow bottom habitat. Some anadromous species also require shallow bottom for spawning. *Permitting agencies should avoid or minimize dredging projects in Anadromous Fish Spawning Areas and important associated anadromous fish nursery areas.*

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

Map 2.8 a-b depicts the location of the major navigational channels in North Carolina’s coastal waters. Soft bottom habitat in the southern portion of the coast has been highly modified by navigational dredging and associated spoil islands. Immediate effects to soft bottom from original dredging have
recovered. The current system of navigational channels is necessary to maintain boating and fishing activities, and in some cases, may be beneficial by enhancing flushing. Many of the dredged channels were originally chosen because they were naturally deeper. While fish have adapted to these channels, creation of additional navigational channels and basins may require dredging in shallow, undesignated nursery habitats. Converting shallow bottom into deeper basins and channels is likely to reduce primary and secondary productivity of the bottom (Wendt et al. 1990). As of November 2009, the USACE had completed 5 navigational dredging maintenance projects in NC, while 17 projects were ongoing or scheduled to start in the 2009 fiscal year. Commenting and permitting agencies should continue to use their existing authorities to a) minimize new dredging of shallow soft bottom habitat, b) prevent direct impacts from dredge and fill projects, and c) limit as much as possible indirect impacts to shallow soft bottom or other habitats.

Dredge material disposal on subtidal bottom

Deposition of dredge material from navigational channel maintenance on estuarine or coastal dredge disposal sites, ebb tidal deltas, or other areas of subtidal bottom results in increased turbidity, temporary reduction and slow recovery of the abundance and diversity of benthic invertebrates (SAFMC 1998a). In estuarine waters, dredge material islands, also referred to as spoil islands, were often created adjacent to the dredged navigational channels. Subsequent maintenance dredging deposits new material onto these islands. The majority of the dredge material islands were produced when the ICW was first created in the 1930s. The creation of permanent dredge islands a) reduced the amount of available underwater habitat (including soft bottom), b) changed the natural hydrology of the surrounding water bodies, and c) had a relatively more profound effect on the smaller water bodies of the southern coast. However, the islands can provide beneficial nesting bird habitat and fringing wetland habitat along the perimeter (Parnell et al. 1986).

In ocean waters, dredge disposal occurs in both offshore, designated disposal sites and in nearshore waters and ebb tide deltas. Offshore sites are in federal waters in depths greater than 30 ft, whereas nearshore areas are in state waters in depths less than 30 ft deep. Sidecast dredging only occurs within shallow inlet systems in North Carolina with course grained sediment in order to minimize turbidity impacts and keep littoral sediment within the system. No open water sidecast dredging occurs in estuarine areas with fine grained sediments and subsequent high turbidity concerns. Hopper dredges also take dredged material from navigational channels and dispose of the sediment within designated dredged material disposal sites. All littoral material dredged with a hopper is disposed within designated nearshore disposal areas to keep the material within the littoral system in accordance with state requirements. Sediment deposited in nearshore waters and on ebb tide deltas is incorporated into the beach profile and is discussed further in the beach nourishment section. The rate of bottom recovery will depend on the volume discharged, characteristics and similarity of the dredge material, hydrography of the disposal area, time of year, and the resulting turbidity (Windom 1976; SAFMC 1998a). According to Bolam and Rees (2003) the recovery time for macrobenthos varied (greater than 1 year), but was related to how stable the environment is, the more stable prior to deposition, the longer the recovery time. All other offshore disposal is in accordance with EPA requirements for designated Offshore Dredged Material Disposal Sites (ODMDS). Currently there are three designated EPA approved ocean dredge material disposal sites off North Carolina, one off Beaufort Inlet and two off Cape Fear River Inlet (Maps 6.3a-c). All three are located just seaward of the state territorial seas (http://www.epa.gov/region4/water/oceans/sites.html#wilmington, 2010). A significant amount of sediment testing, including bioassays, is conducted on dredged material before being placed in designated ODMDS sites; therefore, contaminated sediments are not authorized for ocean disposal. Disposed dredge material that contains elevated levels of toxic contaminants may have adverse impacts on the benthic community through bioaccumulation (Winger et al. 2000).
Marinas and docks

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

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

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

In another study in South Carolina, differences in the benthic community in areas with no, low, and high densities of docks were examined. Similar to the other South Carolina study (Wendt et al. 1990), some pollution sensitive species of polychaetes were more abundant at control sites than at high dock sites (Sanger and Holland 2002). Areas in the high dock category usually had the lowest values of benthic abundance. Three species (S. benedicti, T. acutus, P. cornuta), in addition to the total number of organisms, had a significant correlation to docks, with the abundance of organisms decreasing as the number of docks increased (Sanger and Holland 2002). Total fish and crustacean abundance, including bay anchovy, silver perch, spot, and brown shrimp, were highest in the no dock category, but were not significantly correlated with dock number (Sanger and Holland 2002). This study also found that shading from docks decreased stem density of Spartina alterniflora by 70%, which was comparable to studies in Virginia and other areas of the United States. This reduction can lower the overall productivity in the vicinity of marinas and multi-docking facilities. Overall productivity in a marina can also be reduced by
effects on associated wetland and shell bottom communities. Refer to these sections for more information related to marina and dock impacts.

The presence of docks can alter the young-of-year fish population present. In the Hudson River, New York and New Jersey, Able et al. (1998) examined the impacts docks had on the YOY fish population present under docks. Although most YOY fish tend to utilize complex habitats for refuge from predators, several studies found fewer fish that feed using sight under piers than in adjacent areas (Able et al 1998 and Duffy-Anderson et al. 2003). This difference may be due to light not penetrating under the pier. YOY winter flounder (*Psuedopleuronectes americanus*), (a species similar to southern flounder) had faster growth rates and consumed more prey in caged areas at pier edges than those under piers (Duffy-Anderson and Able 1999).

Several studies indicate that marinas and concentrations of individual docks have potential to alter soft bottom habitat, particularly shallow water habitat, in ways that can reduce productivity of the system as a whole. Marina siting issues were discussed in the water column chapter, and the location of marinas in North Carolina was shown in Map 2.8 a-b. The majority of docking facility permits are for individual piers. The number of individual pier permits issued annually by the CRC, with the exception of 2001, has continually increased in the coastal counties through 2000 (Figure 2.9). Since then, the number of permits issued annually has dropped below 1999 levels to around 800 per year. The DCM estimates that approximately 10% of these piers do not have boats associated with them and are used solely for fishing, swimming, view, etc. The large increase in permit numbers from 1999 to 2000 is at least partially due to large numbers of repair or replacement requests following hurricane damage. Based on DEH-SS shoreline surveys in SA, SB, and SC waters, there is approximately one multi-slip docking facility for every 7 miles of shoreline in coastal North Carolina (see “Marinas and multi-slip docking facilities” section of Water Column chapter for more information). If properly designed and located, individual piers do not pose a large threat to soft bottom habitat. However, when docks are permitted in very shallow areas, moored boats or floating docks may actually sit on the bottom for a large portion of a tidal cycle (up to 12 hr) or cause considerable turbidity or prop dredging when attempting to motor to deeper navigable waters (SAFMC 2009). Either situation can significantly reduce primary or secondary productivity (F. Rohde/DMF, pers. com., 2009). Recent rule changes by the CRC, allow for piers and docking facility to be constructed if the following two conditions are met: (1) Water depth at the docking facility is equal to or greater that two feet of water at normal low water level or normal water level (whichever is applicable). (2) The pier and docking facility is located to minimize the area of submerged aquatic vegetation or shellfish beds under the structure” [CRC rule 15A NCAC 07H.1205(h)]. The general permit requirements also include a minimum water depth of 18 inches when a floating dock is proposed over PNA, shellfish, or SAV. Dock siting criteria should include a minimum water depth over all habitats to prevent boats or floating docks from sitting directly on shallow soft bottom.

Multi-slip docking facilities (10 slips or less according to the CRC definition) may be a greater threat to soft bottom habitat due to the number of these facilities and their concentration in shallower areas than typical marinas. However, by concentrating boat use, overall impacts may be less than what would be needed to serve the same number of boats with individual piers at individual residences. Also, because boat use is concentrated, other areas of the shoreline, including wetland and shell bottom habitats, may not be impacted by docking related activities. There are currently more marinas than multi-slip docking facilities along estuarine shorelines (see “Marinas and multi-slip docking facilities” section of Water Column chapter for more information). As waterfront property becomes increasingly developed, requests for new piers, docks, and marinas in shallower and less suitable locations will likely increase (see “Marinas and multi-slip docking facilities” section of Water Column chapter for more information).
Research is needed on the cumulative impact of docks and marinas on soft bottom and other fish habitats in North Carolina.

Shoreline stabilization

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

Estuarine and riverine shoreline stabilization

In North Carolina, estuarine and riverine shoreline stabilization has traditionally utilized hard structures such as bulkheads, rock revetments or riprap, sills, breakwaters, groins, or combinations thereof. Bulkheads are the most commonly used structure. Although excessive sediment loading is considered a water quality issue, erosion of sediments is a natural process that provides sand for maintenance of beaches, wetlands, and shallow water habitat. When this sand supply is cut off by a hard structure under rising sea level conditions, the long-term results are a net loss of beach and intertidal shoreline and the deepening of shallow water habitat, which impacts the function of intertidal shoreline and shallow water habitat as nursery, feeding, and spawning grounds to fish species in North Carolina. Multiple studies have shown that the diversity and abundance of invertebrates and juvenile fish is lower adjacent to bulkheaded areas than natural shorelines (Mock 1966; Ellifrit et al. 1972; Gilmore and Trent 1974; O’Rear 1983; Byrne 1995; Peterson et al. 2000c; Waters and Thomas 2001; Seitz et al. 2006; Bilkovic and Roggero 2008; Partyka and Peterson 2008). Deepening of waters adjacent to the bulkhead structure allows large piscivorous fish access to previously shallow nursery areas, enhancing their feeding efficiency on small and/or juvenile fishes looking for shallow water (Rozas 1987). Non-vertical structures, such as marsh sills, offer an alternative to bulkheads that may have less long-term impact on shallow soft bottom habitat, as well as wetlands and submerged aquatic vegetation. However the larger footprint of a marsh sill can result in some habitat tradeoff from soft bottom to wetlands and rock and/or oysters. In the 2003 legislative session, House Bill 1028 was approved, which allows the CRC to establish a general permit for construction of offshore parallel rock sills for estuarine shoreline protection. Despite this incentive, only 12 general permits and 22 major permits have been issued for marsh sill construction. Refer to the wetlands chapter for additional information on the impact of shoreline stabilization to that habitat, efforts agencies have taken to revise shoreline stabilization rules to minimize impacts from shoreline hardening, and remaining management needs that should be implemented.

An additional concern of wooden bulkheads is the toxicity of preserved wood to certain aquatic organisms. Chemically treated wood is also used for dock and marina construction. Estuarine and riverine bottom may be contaminated by wooden bulkheads treated with copper, chromium, and arsenic (CCA). These elements are leached from CCA-treated wood, gradually accumulate in adjacent sediments, and have the capacity to harm marine benthos (i.e. oysters, amphipods, polychaetes, fiddler crabs, mud snails, fish embryos, and sea urchin) (Weis and Weis 1994 and Weis et al. 1998). CCA-treated wood preservative has been shown to leach copper, chromium VI, and arsenic into adjacent sediments and to impact marine benthos (Weis and Weis 1994; Weis et al. 1998). Among CCA chemicals, copper appears to have the most toxic effect on marine organisms and also consistently appears to leach the greatest amount (Weis and Weis 1994). The toxicity of these metals to aquatic organisms is well recorded and all three are listed as priority pollutants by the EPA (Hingston et al. 2001).

Studies have documented significantly elevated concentrations of metals and reduced abundance and diversity of the benthic community extending approximately 30 ft (10 m) from bulkheads treated with CCA, decreasing with distance from the structure (Weis and Weis 1994; Weis et al. 1998). Benthic organisms that were lethally or sublethally impacted included macroalgae, amphipods, polychaetes,
oysters, fiddler crabs, sea urchins, mud snails, and fish embryos. Sediment contamination has been documented to be higher in a residential bulkheaded canal than adjacent to bulkheaded open water (Weis and Weis 1995). Concentrations decreased more rapidly with distance from bulkhead in the open water system. Weis et al. (1995) found that oysters living on CCA-treated wood in a residential canal had 15 times more copper (∼ 200 µg/g wet weight), two to three times more arsenic, and significantly more degeneration of digestive gland diverticula than compared to that of reference oysters. Copper is known to cause this pathology. Although bioaccumulation has been observed in shellfish and other invertebrates grazing on CCA contaminated algae or bivalves, similar biomagnification in fish has not been documented for these elements (Weis and Weis 1999). The extent of sediment contamination from CCA could be significant considering the magnitude of preserved timber used in the marine environment for bulkheads and docks (Weis and Weis 1994) (refer to wetlands chapter on DCM shoreline study to assess extent of shoreline alterations). Toxicity of wood decreases with time but CCA can continue leaching for many years. In addition, bulkheads and docks need to be replaced periodically, providing a continual source of newly treated wood in coastal waters. In 2003, the EPA required new labeling on all CCA products specifying use restrictions. The lumber industry voluntarily agreed to eliminate use of CCA for residential use, although CCA is still being used in certain marine and industrial applications. Local home stores or lumberyards now sell lumber treated with less toxic alternatives such as amine copper quat (ACQ), copper azone (CA). Alternative wood preservatives containing copper or other chemicals may have similar toxicity to marine organisms. Rock sills and revetments are non-wood shoreline stabilization alternatives that do not require any chemical preservatives. Due to the toxic sediment contamination associated with pressure treated wood, revised shoreline stabilization rules should require or encourage use of non-wood materials or wood that is not toxic to benthic organisms. Any new wood preservative products should be evaluated for toxicity to marine benthic organisms and juvenile fish.

Oceanfront shoreline hardening

Shoreline hardening, or hard stabilization, involves construction of hard immovable engineered structures, such as seawalls, rock revetments, jetties, and groins. Seawalls and rock revetments run parallel to the beach. Seawalls are vertical structures, constructed parallel to the ocean shoreline, and are primarily designed to prevent erosion and other damage due to wave action. Revetments are shoreline structures constructed parallel to the shoreline and generally sloped in such a way as to mimic the natural slope of the shoreline profile and dissipate wave energy as the wave is directed up the slope. Breakwaters are structures constructed waterward of, and usually parallel to, the shoreline. They attempt to break incoming waves before they reach the shoreline, or a facility (e.g., marina) being protected. Jetties and groins are manmade structures constructed perpendicular to the beach, with jetties usually being much longer, and are located adjacent to inlets with the purpose of maintaining navigation in the inlet by preventing sand from entering it. In contrast, terminal groins are structures built at the end of a littoral cell to trap and conserve sand along the end of the barrier island, stabilize inlet migration, and widen a portion of the updrift beach. Terminal groins are designed so that when the area behind the groin fills in with sand, additional sand will go around the structure and enter the inlet system.

It is well accepted that hard stabilization techniques along high energy ocean shorelines will accelerate erosion in some location along the shore as a result of the longshore sediment transport being altered (Defeo et al. 2009). The hydromodifications resulting from coastal armoring modifies sediment grain size, increases turbidity in the surf zone, narrows and steepens beaches, and results in reduced intertidal habitat and diversity and abundance of macroinvertebrates (Walton and Sensabaugh 1979; NRC 1995; Dolan et al. 2004; 2006; Pilkey et al. 1998; Peterson et al. 2000a; Miles et al. 2001; Dugan et al. 2008; Walker et al. 2008; Riggs and Ames 2009). A study looking at the effect of a short groin (95m) on the benthic community found that the groin created a depositional condition on one side of the structure and erosion on the other, and macroinvertebrate diversity and abundance was significantly reduced within 30 m of the structure, as sand particle size and steepness increased (Walker et al. 2008). The change in
benthic community was attributed to the change in geomorphology of the beach. Hard structures along a sandy beach can also result in establishment of invasive epibenthic organisms (Chapman and Bulleri 2003). A secondary impact of hardened structures is that the areal loss of beach resulting from hardening of shorelines is often managed by implementing nourishment projects, possibly having additional damage to subtidal bottom (Riggs et al. 2009). Anchoring inlets also prevents shoal formation and diminishes ebb tidal deltas, which are important foraging grounds for many fish species. Recognizing that hardened structures are damaging to recreational beaches and the intertidal zone, four states have prohibited shoreline armoring: Maine, Rhode Island, South Carolina, and North Carolina (effective in North Carolina since 1985).

Perhaps the greatest impact of terminal groins and jetties results in the long-term effect on barrier islands and the effect that will have on marine and estuarine ecosystems. By stabilizing the inlet, inlet migration and overwash processes are interrupted, causing a cascade of other effects (Riggs and Ames 2009). In the case of Oregon Inlet, the terminal groin anchored the bridge to Pea Island and stopped the migration of the inlet on the south side. But the continuing migration of the north end of Bodie Island led to an increased need for inlet dredging. The combination of reduced longshore transport of sediment due to the groin and the post-storm dune construction to open and protect the highway prevented overwash processes that allow Pea Island to maintain its elevation over time. With overwash processes disrupted, the beach profile has steepened, and the island has flattened and narrowed, increasing vulnerability to storm damage (Dolan et al. 2006; Riggs and Ames 2009; Riggs et al. 2009). At Oregon Inlet and Pea Island, the accelerated need for beach replenishment is further aggravated by the need to maintain Hwy 12 on the narrowing beach. From 1983 to 2009 approximately 12.7 million cubic yards of sand have been added to the shoreline within three miles of the terminal groin (Riggs and Ames 2009). Dolan (2006) documented that the large volumes of sand replenishment in this area, required to maintain the channel, protect the road, and maintain a beach have resulted in a significant reduction in grain size and reduction in mole crab abundance. Mole crabs are considered an important indicator of beach conditions due to their importance in the food web as prey for shorebirds and surf fish. In addition to causing erosion on downdrift beaches, altering barrier island migration processes, and accelerating the need for beach nourishment projects, jetties obstruct larval fish passage through adjacent inlets (Blanton et al. 1999). Disruption of larval transport is discussed in detail in the water column threats section.

In contrast, where natural coastal barrier island processes, such as overwash and the opening, closing, and shifting of inlets have occurred without manipulation, the islands have grown in width and elevation and migrated. Core Banks and Drum Inlet are an example of one of a barrier island with inlets that opened and closed throughout time (Mallinson et al. 2008). Drum Inlet initially opened in 1899, but closed and reopened multiple times during storm events. It is possible that several other areas that have historically had inlets will again in the future (i.e. Buxton Inlet, New Inlet, and Isabel Inlet) (Mallinson et al. 2008). When inlets open, the new sediment deposition of a flood tide delta aids barrier island migration and widening. Where new inlets form, Mallison et al.(2008) recommended that allowing the inlets to remain open even if temporarily until a substantial flood tide delta forms, would allow for long-term maintenance and stability of the barrier island. Ferries could be used on a temporary basis to allow critical transportation to continue.

Only a relatively small amount of North Carolina’s ocean shoreline is hardened compared to other states, having roughly 6% of the developed shoreline hardened (Pilkey et al. 1998). In contrast, South Carolina, Florida (Atlantic coast), and New Jersey have 27%, 45%, and 50% of their respective shorelines covered with some form of hard stabilization. Existing seawalls and revetments in North Carolina were constructed prior to CAMA (e.g., Atlantic Beach) or were for the purpose of protecting historic structures (e.g., Ft. Fisher). Existing jetties in North Carolina occur at Masonboro and Barden’s inlets, terminal groins occur at Oregon and Beaufort inlets, and small groin fields were constructed at Bald Head Island and Hatteras Island.
Use of sandbags is a temporary method of erosion control that is permitted for protection to imminent threats to structures (shoreline less than 20 feet from structure) while their owners seek more permanent solutions, such as beach nourishment or relocation of the structure. While filled with sand, these bags are stacked and act like a seawall, although they can be removed more easily. Sandbag walls may remain in place for up to two years if the protected structure is 5,000 square feet or less, or for up to five years if the structure is larger than 5,000 square feet. Sandbags also may remain in place for up to five years—regardless of the protected structure’s size—if the community in which it is located is taking part in a beach nourishment project. Sandbags may remain in place indefinitely if they have become covered with sand and stable natural vegetation. However, if a storm exposes them, they must be removed if their time period has expired. However, there has been difficulty in enforcing removal of temporary sandbags. As of July 2008, there were a total of 381 total sandbag structures on record, 150 of which were still installed with an expired removal date (K. Richardson/DCM, pers. com. 2009). In 2008, the CRC instructed all property owners with exposed sandbags that had exceeded their time limit to remove the bags. However, Session Law 2009-479 intervened on this action by implemented a moratorium on the removal of sandbags.

In the 2003 legislative session, House Bill 1028 was approved, putting into law the CRC prohibition on construction of permanent erosion control structures on ocean shorelines. However, there has been lobbying efforts by special interests to weaken this law by allowing the use of terminal groins. In 2009, Session Law 2009-479 mandated that the CRC 1) shall not order the removal of sandbags if actively pursuing a beach nourishment or inlet relocation project; and 2) shall conduct a study on the feasibility and advisability of use of terminal groins as an erosion control device at the end of a littoral cell or inlet, and present a report to the Environmental Review Commission and the General Assembly by April 1, 2010.

CRC and DCM contracted the study out to Moffitt and Nichols. The goals of the study were to:

- Characterize physical and environmental impacts of terminal groin structures,
- Determine engineering techniques used to construct terminal groins including those which may help minimize impacts on adjacent shorelines,
- Determine economic impacts of shifting inlets as well as potential construction/maintenance costs of terminal groin structures, and
- Determine whether the construction of terminal groins is both feasible and advisable in North Carolina, and if so, what are the types of locations where such structures function as designed with minimal impacts.

These questions were to be answered by assessing five existing terminal groins which had available data and were located in a similar environment as North Carolina’s beach community. The study sites included Oregon Inlet and Beaufort Inlet in NC, Amelia Island/Nassau Sound in northeast Florida, and Captiva Island and St John’s Pass, on the west coast of Florida. The study documented that constructing terminal groins resulted in the need for periodic nourishment behind the structures, where it had previously been futile due to dynamic inlet processes (Moffatt and Nichol 2010). Without nourishment, erosional impacts to adjacent beach areas would occur. This means that construction of terminal groins create a condition of long-term mandatory maintenance, increasing the expensive of beach management. The study found that the groins did reduce erosion rates immediately adjacent to the structure, but there was evidence of increased erosion about two miles downdrift, and on the opposite side of the inlet. However, effects were inconclusive because of simultaneous inlet dredging and sand disposal. The CRC terminal groin subcommittee concluded that use of terminal groins may be feasible but not advisable due to environmental consequences, expense, and large uncertainty of long-term impacts. However, the CRC voted to state that the study was inconclusive and therefore could not recommend for or against their use. Because there is strong evidence available on the potential ecological impacts of hardened structures,
large uncertainty on the environmental impacts of terminal groins specifically, and no clear economic benefit from inlet stabilization, North Carolina should not reverse its position or policies on ocean shoreline hardening. The long-term consequences of hardened structures on larval transport and recruitment should also be thoroughly assessed prior to approval of such structures (refer to water column chapter for details). Overall, the scientific evidence does not support changing North Carolina’s policy on prohibition of shoreline hardening structures on the oceanfront.

Soft stabilization on oceanfront shorelines

Soft stabilization techniques available for oceanfront erosion control include beach bulldozing and beach nourishment. Beach bulldozing, also referred to as beach scraping, is a method of short-term erosion protection that has been used in North Carolina for approximately 40 years. Beach bulldozing is the process of mechanically redistributing beach sand from the lower portion of the intertidal beach to the upper portion of the dry beach to create or enhance the primary dune. In contrast to beach nourishment, new sediment is not added and the existing beach is not widened. Because beach bulldozing only utilizes sand on-site, the impacts of this soft technique are less, relative to those from beach nourishment (Pilkey et al. 1998). The largest biological impact of beach bulldozing appears to be reduction in ghost crab populations on the dry beach (Peterson et al. 2000b). Peterson et al. (2000b) found that beach bulldozing at Bogue Banks reduced the width of the intertidal beach, shifted sediment composition, and immediately reduced abundance of benthic organisms. Because of the relatively quick recovery on intertidal and shallow subtidal benthic communities and the relatively small area that occurs in subtidal waters, fish impacts from bulldozing should be less than other beach management activities. However, beach scraping has not been shown to provide any erosion control benefit, and has actually increased wind erosion of sand where created dunes were left unvegetated (Kerhin and Halka 1981; Tye 1983; McNinch and Wells 1992; Peterson et al. 2000b). The CRC modified specific conditions for beach bulldozing in 2000 which should help minimize biological impacts if properly enforced, including time windows for work to be completed, maximum depth of scraping, and replanting of dunes. There is also a federal bulldozing moratorium in NC from May 1 to November 15 to protect sea turtles.

Beach nourishment is the introduction of new sand to dry and intertidal beach and adjacent shallow waters from upland areas, navigational channels, inlet systems, or submerged mine sites to restore or enlarge a beach. There are generally two categories of USACE projects that result in sand being put on beaches: disposal projects and Coastal storm damage reduction projects. Disposal projects are placement of dredged material from maintenance dredging of navigation channels. Specifically, they do not include an engineered and constructed profile designed for protection purposes. Rather, the intent is to take dredged material from navigation dredging and place it on the recipient site. Disposal projects are generally smaller in magnitude than storm damage reduction projects, and can be expected to have a smaller impact on fish habitat. The sand source for disposal projects is inlet dredging. Sand bypassing is a type of disposal project where sand is moved around physical barriers, such as a jetty or deep port, that interrupt the natural littoral drift along the shoreline. Storm damage reduction projects have used sand from dredged channels, offshore borrow areas, ebb tide delta shoals, or inlet relocation. Erosion rates near inlets tend to be large and variable due to the natural migration processes of barrier islands. Because of that and the associated risk near inlets, CRC has designated Inlet Hazard Areas along barrier islands. Greater setbacks are required in these areas. Beach nourishment is generally not recommended immediately adjacent to the inlet because of the dynamic nature of the area and the expected low retention time of sand.

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

**Beach nourishment impacts at mining areas**

Mining is defined under the Mining Act (G.S. 74-48 and G.S. 47-49) as “the breaking of surface soil in order to facilitate or accomplish extraction or removal of mineral, ores, or other solid matter.” Whether the purpose is beach nourishment, channel maintenance, or mineral extraction, the consequences of mining activities have similar effects upon the habitat. Dredging of subtidal bottom initially causes mortality of benthic organisms within the dredged area and causes elevated turbidity in an extended area, which may also result in negative impacts. Physical recovery of mining sites in nearshore areas and shoals can be a slow process, but is quite variable. In South Carolina, comparison at multiple mine sites found that sediment refilling took from two to at least 12.5 years at various mine sites. Because mine sites often refill with finer-grained material than was originally present (NRC 1995; Van Dolah et al. 1998), post-dredging turbidity may remain high indefinitely (Peterson et al. 2000). Since these areas often refilled with a more fine-grained, muddy sediment, most sites became unsuitable as future sand sources and altered benthic species recruitment patterns (Van Dolah et al. 1992; Van Dolah et al. 1998; Jutte et al. 2001a). Use of ebb or flood tidal deltas and nearshore sandbars as a sand source for nourishment projects removes sand from the inlet system, alters the sediment budget, and may result in accelerated erosion from adjacent beaches (Wells and Peterson 1986). Roessler (1998) suggested that the major cause of beach erosion on Bogue Banks was the removal of sediment from the longshore system due to the intense dredging and deepening of Beaufort Inlet for access to the state port at Morehead City. Sand from that dredging operation has at times been taken out of the inlet, hence out of the longshore system, and disposed of offshore beyond the active beach profile. Jay Bird Shoals, an ebb tide shoal off of the Cape Fear River, will be used as a mine site for Bald Head Island beaches in 2010. This shoal and adjacent waters are known for high fish productivity and diversity. The effects of mining on this shoal or the adjacent downdrift Oak Island are unknown. It is also unknown what effect use of the cape shoals would have on fish productivity or how long recovery would take. Biological recovery rates of mined sites vary, but generally are longer than those reported at the intertidal beach disposal sites, and in some cases may be altered indefinitely (Table 6.4).

**Table 6.4. Reported biological recovery time at mine sites.**

<table>
<thead>
<tr>
<th>Location</th>
<th>Mine site recovery time</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Carolina</td>
<td>6 – 18 months</td>
<td>Posey and Alphin 2001</td>
</tr>
<tr>
<td>South Carolina</td>
<td>3 – 6 months</td>
<td>Van Dolah et al. 1992</td>
</tr>
<tr>
<td>South Carolina</td>
<td>2 – 12.5 years</td>
<td>Van Dolah et al. 1998</td>
</tr>
<tr>
<td>South Carolina</td>
<td>11 – 14 months</td>
<td>Jutte et al. 2001b</td>
</tr>
<tr>
<td>South Carolina</td>
<td>14 – 17 months</td>
<td>Jutte et al. 2001a</td>
</tr>
<tr>
<td>New Jersey</td>
<td>18 – 30 months</td>
<td>USACE 2001</td>
</tr>
<tr>
<td>location undisclosed</td>
<td>&gt; 12 months</td>
<td>NRC 1995</td>
</tr>
</tbody>
</table>

Van Dolah et al. (1998) observed significant changes in the species composition of the recruited benthos, shifting from dominance by amphipods to mollusks. During the time period monitored (> 12.5 years), the original species composition within the affected area was never restored due to the change in substrate composition (Van Dolah et al. 1998). Mining activities that changed bottom sediment composition were often associated with impacts of the greatest magnitude and most prolonged recovery, typically occurring in areas with little sand movement, with deep mine pits, or that were previously mined (Saloman et al. 1982; USACE 2001). Comparison of mine areas and control sites associated with a storm damage reduction project at Carolina Beach found few statistically significant differences in species abundance 0.5 and 1.5 years after sediment removal (Posey and Alphin 2001). However, after sediment removal, dominant species composition at the mine site was more dissimilar to the control site than before.
sediment removal. The authors concluded that year to year variability in the benthic community, in addition to multiple hurricanes during the monitoring period, made effects from the project difficult to determine, suggesting that the effect of beach nourishment is minimal compared to the natural variability of the system (Posey and Alphin 2001; Posey and Alphin 2002). Observed recovery at this site was more rapid than expected, due in part to the configuration of the mine areas. The mine area was long (3 mi), relatively wide (0.5 mi), and, most importantly, not excessively deep (5-10 ft deep) (M. Posey/UNC-W, pers. com., 2003). At mine sites monitored off New Jersey, infaunal assemblages (diversity) recovered within one year after disturbance, while biomass and taxonomic richness took 1.5 to 2.5 years to fully recover (USACE 2001). Because material was removed from a topographically diverse bottom, a deep pit was not created, leading the authors to conclude that time to recovery was reduced. In addition, strong water currents and dynamic sand movement in the project area facilitated more rapid infilling. Another potential concern of sand mining is impacts to nearby hard bottom from physical damage or elevated turbidity during the mining. Along many of the beaches in Onslow and Long Bays, low to high profile hard bottom is scattered along the coast, making mining without impacting hard bottom difficult.

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

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

Since the 2005 CHPP, there has been increased interest from barrier island municipalities in use of the cape shoals as a sediment source for beach nourishment projects. Boss and Hoffman (2000) collected detailed information on the sand resources for North Carolina’s Outer Banks, including specific data about Diamond Shoals. Diamond Shoals extend approximately 11 nautical miles (nm) (20 km) and are about 5.5 nm (11 km) wide. The estimated total volume of sand on the shoal was at least 1.66 billion cu yd, with approximately 256 million cu yd within state waters (Boss and Hoffman 2000). As such, cape shoals are major sand resources for coastal processes. Detailed mapping of the bottom has been done in other areas of the coast to varying extent with different techniques. Research on Cape Lookout Shoal found that the cape associated shoals act as a barrier to longshore transport, diverting southerly flow of water and sediment seaward in a tidal-driven headland flow, resulting in net sediment transport and deposition onto the shoal. The shoals are maintained by this sediment transport and serve as a long-term sink for littoral sediment and limits exchange between adjacent littoral cells and shelf regions (McNinch and Wells 1999; McNinch and Luettich 2000).
Due to the increased interest in long-term storm damage reduction projects, there are also several projects requesting use of borrow areas in nearshore subtidal bottom for large storm reduction projects. This includes the Bogue Banks, Nags Head, Topsail Beaches, and Brunswick Beaches projects that are at various stages of the permit process. **When mine areas are necessary for beach nourishment projects, guidelines should strongly encourage siting protocol that maximize biological recovery rates, do not degrade critical fish foraging areas, do not impact hard bottom, and minimize impacts to longshore transport processes.** Many steps are already taken to minimize environmental impacts. State or National Environmental Policy Act (SEPA or NEPA) documents, likely including Environmental Impact Statements (EIS) or Environmental Assessments (EA), must be completed and reviewed prior to these projects being permitted. A memorandum of agreement between DCM and USACE provides for a coordinated permit review process between state and federal agencies (Federal Consistency Program). A federal project cannot begin unless DCM finds that it is consistent with state policies. Other agencies are given an opportunity to comment on projects as well. The MFC adopted a beach nourishment policy in 2000 to guide the permitting process to more fully consider fish habitat impacts (Appendix I). Existing CRC rules (15A NCAC 07H.0208(b)(12)(A)(iv)) require a 500 m buffer between dredging and high relief hard bottom. High relief is defined as relief greater than or equal to 0.5 m per 5 m of horizontal distance. Research has shown that there is a halo area around hard bottom which reef fish use as a foraging area to derive a significant portion of their diet. The halo distance was estimated to extend about 500 m from exposed hard bottom of any relief (Lindquist et al. 1994). **Because of this, the 2009 Ocean Policy report (NC Sea Grant 2009) recommended that CRC rule language be modified to require a 500 m dredging buffer around all hard bottom areas, including those of low relief that are periodically buried with thin ephemeral sand layers.**

**Beach nourishment impacts at intertidal beach and adjacent subtidal bottom**

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

Factors likely affecting the recovery time of the intertidal beach community include:
- compatibility of deposited material with native sand (sediment grain size)
- seasonal timing of nourishment
- time period between renourishment events on an individual site volume, depth, and length of sand
- alteration of the beach geomorphology
- location placed on the beach
- longshore transport conditions (higher transport results in more rapid recruitment

In the studies referenced above and others, biological impacts persisted longer when supplemented sand was either coarser (Rakocinski et al. 1993; McLachlan 1996; Rakocinski et al. 1996; Peterson et al. 2000a) or finer (Gorzelany and Nelson 1987; NRC 1995) than the existing sand. Increased grain size of the beach can result in significant reduction in species richness and abundance by 1) limiting body size, 2) limiting burrowing performance and other functions in some species, and 3) changing the beach condition to a higher energy swash zone (McLachlan 1996). A decrease in grain size impacts the benthos by 1) smothering organisms, 2) clogging gills from sediment plumes, and 3) decreasing the interstitial space between sediment grains available to small burrowing invertebrates (Rakocinski et al. 1996).
### Table 6.5. Reported biological recovery times at nourished ocean beaches.

<table>
<thead>
<tr>
<th>Location</th>
<th>Biological recovery following beach nourishment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bogue Banks, NC</td>
<td>Mole crabs recovered within months, coquina clams and amphipods failed to initiate recovery after one growing season. No follow up sampling.</td>
<td>Peterson et al. 2006</td>
</tr>
<tr>
<td>Bogue Banks, NC</td>
<td>On ebb tide delta, where sediment deposited, significant coarsening of sediment, and reductions in spionid polychaetes after 8 mo.</td>
<td>Bishop et al. 2006</td>
</tr>
<tr>
<td>Bald Head Island, Caswell Beach, Oak Island, NC</td>
<td>Coquina clams, mole crabs - &gt; 1 year. Abundance declined 1 – 10 times from control. Most severe reductions and longest times of recovery due to season of project – greatest in spring and summer, except Oak Island coquina clams recovered within 1 year – timing of sand deposition allowed summer recruitment.</td>
<td>Versar 2003</td>
</tr>
<tr>
<td>Atlantic Beach, N.C.</td>
<td>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 <em>S. squamata</em> recovered 15 – 30 days post nourishment.</td>
<td>Reilly and Bellis 1983</td>
</tr>
<tr>
<td>Atlantic Beach, N.C.</td>
<td>Densities of mole crabs and coquina clams were 86 – 99% lower than control sites, 5 – 10 weeks post-nourishment, during mid-summer.</td>
<td>Peterson et al. 2000b</td>
</tr>
<tr>
<td>North Topsail, N.C.</td>
<td>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.</td>
<td>Lindquist and Manning 2001</td>
</tr>
<tr>
<td>Pea Island N.W.R., N.C.</td>
<td>2 – 9 months for coquina clams and mole crabs.</td>
<td>Donoghue 1999</td>
</tr>
<tr>
<td>Hilton Head, S.C.</td>
<td>Density and diversity returned to levels similar to control sites in 6 months.</td>
<td>Van Dolah et al. 1992</td>
</tr>
<tr>
<td>Folly Beach, S.C.</td>
<td>2 – 5 months, depending on benthic group and site, polychaetes recruiting earlier than mollusks.</td>
<td>Jutte et al. 1999</td>
</tr>
<tr>
<td>Panama City, F.L.</td>
<td>Large reductions in abundance and diversity remained after 2 years.</td>
<td>Rakocinski et al. 1993</td>
</tr>
<tr>
<td>Manasquan, N.J.</td>
<td>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.</td>
<td>USACE 2001</td>
</tr>
</tbody>
</table>

Similarity between native and introduced sediments is considered to be the most important factor determining the rate of recovery of beach invertebrate populations following nourishment (Nelson 1993; Peterson et al. 2000). Due to these problems, the 2005 CHPP had recommended that more specific minimum and maximum grain size standards were needed. Recognizing the ecological problems of sediment incompatibility, and problems resulting from projects at Pine Knoll Shores and Oak Island, the CRC, through recommendations of the CRC Coastal Hazards Science Panel, worked to modify CRC rules regarding sediment compatibility to be more specific and effective. New rules became effective in February 2007.
The season and time period between renourishment events are also important factors that affect the rate of recovery of the beach community (Dolan et al. 1992; Donoghue 1999; Versar 2003). At the Brunswick Beaches project, conducted as part of the Cape Fear harbor deepening project, sand was placed sequentially from east to west: Baldhead Island in spring 2001, Caswell Beach in summer 2001, Oak Island in fall 2001, and Holden Beach in winter 2002. Impacts were observed immediately to the intertidal beach community at all beaches, but the severity of invertebrate reductions and time to recovery was the greatest at beaches nourished in the spring and summer (Versar 2003). The time period between renourishment events is also an important factor for successful recovery. Lindquist and Manning (2001) found that at a beach where dredge material was placed between April and June, and redeposited the following year (April – June), the abundance of the mole crabs, coquina clams, and amphipods was significantly lower than that of the control beach after one year. Also, mole crabs and coquina clams were significantly smaller in size than at control sites, indicating that repeated disturbance from beach disposal (once a year) prevented full recovery of the populations. Peterson et al. (2000b) also argued that recovery could be accelerated if projects were timed to occur before spring recruitment of benthos.

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

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

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

The extent of biological impacts from beach nourishment activities is determined not only by these individual conditions, such as grain size, time of project, and frequency of reapplication, but also by combinations of factors. Because of the potential impact of beach nourishment and dredge disposal on soft bottom communities, there is a need for a coast-wide Beach Management Plan that carefully reviews cumulative impacts of activities and provides ecologically based guidelines, including sediment compatibility standards and limits on time of year, linear length, and interval between nourishment to enhance recovery of the benthic community. The CRC’s beach nourishment rules should be evaluated and modified in a comprehensive manner as needed to minimize overall impacts from this activity. Comprehensive monitoring to assess the impact of each project should be required of the applicant to determine if and how nourishment practices should be modified. Additional research is also needed to more clearly quantify the cumulative impact of nearshore dredge disposal on fish populations.
Beach nourishment impacts on fish

Fish may be impacted by beach nourishment due to reduction in food availability, alteration of preferred topographic features, disturbance prior to or during spawning, or reduced visibility. Fish and invertebrate species that spend considerable time in the surf zone and feed on benthic invertebrates, such as Florida pompano, gulf kingfish, Atlantic croaker, spot, and shrimp, would be most vulnerable to beach nourishment activities. Some studies have found insignificant impact to fish populations (Van Dolah et al. 1994; USACE 2001) or a temporary increase (Saloman 1974). This may be 1) due to release of nutrients and infauna during dredging, 2) because resident fish are wide-foraging, or 3) because migratory fish spend only a portion of their life cycle at the mine site or target beach (Greene 2002). Other researchers suggest that fish are dependent on the amount of available habitat and that any loss represents a decrease in production (Peterson et al. 2001). Although USACE (2001) did not observe a significant change in the surf zone fish population, they stated that due to the inter-annual variability of surf zone fishes, a change would only be observed if a catastrophe occurred. Unfortunately, very little monitoring has been done at the level needed to adequately assess and detect the impacts of nourishment projects on fish distribution, feeding, growth, or survival. Although, there has been few studies examining the direct effects of beach nourishment on pelagic fish, several studies have examined the impacts on pelagic fish prey items (i.e. polychaetes, copepods, and mollusks). Peterson (2000) concluded that nourishment projects should be ceased in April or May (warm season) to reduce the effects of nourishment on Domax and Emerita populations. For further discussion on nourishment impacts on invertebrates, refer to the beach nourishment impacts on the intertidal beach section.

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

In North Carolina, the effects of a Brunswick County beach nourishment project on surf fish, benthic invertebrates, and water quality, were evaluated from March 2001 to May 2002 (USACE 2003; Versar 2003). Sand from the lower Cape Fear River dredging project was placed on Bald Head Island, Caswell Beach, Oak Island, and Holden Beach. Seining and trawling before and after the project found no significant differences in fish abundance or diversity among disturbed, undisturbed, and reference sites during any season. This was attributed to the high mobility and schooling behavior of the dominant fish species (anchovies and drum family), resulting in clustered and variable distribution. Although statistically not significant, gulf kingfish were less abundant at the disturbed sites than the undisturbed sites. The decline was thought to be at least partially due to the reduced availability of benthic invertebrates preferred by gulf kingfish (USACE 2003). The intertidal benthic community was the most directly impacted by the beach nourishment project. Analysis of the effects of this project was limited by problems with the statistical design (USACE 2003; Versar 2003). Sample size was often insufficient to calculate confidence limits, partly due to uneven sampling among treatments (disturbed, undisturbed, reference). Research is currently being conducted by UNC-Wilmington investigating the effects of beach nourishment on the nursery function of the surf zone by comparing fish and invertebrate assemblages, density and nutritional condition of juvenile Florida pompano and gulf kingfish. Initial findings indicate that fish composition and diet differed significantly at nourished beaches compared to unnourished beaches, potentially affecting diet and growth (Lipton et al. 2010; Perillo and Lankford 2010). Adequate monitoring of the effects of beach nourishment on the soft bottom community and associated surf fish populations is increasingly important as the number of beach nourishment projects increase and should
be required for all large-scale or long-term nourishment projects.

Status of beach disposal from navigational dredge disposal projects

The USACE is charged to maintain North Carolina’s navigable inlets and ocean channels through dredging as necessary. Navigational dredging in inlets by the USACE is allowed at any time of the year and is not subject to any mandatory dredging moratoria unless sea turtle take quotas are exceeded. Industry-owned hopper dredges working in the Wilmington and Morehead City port areas and Oregon Inlet are requested to refrain from using hopper dredges in the December to March time period to avoid the taking of sea turtles. These take can jeopardize the future of that and future dredging projects (J. Richter/USACE, pers. com., 2009).

Maintenance of the seven federal inlet channels is performed by a sidecast dredge or a small hopper dredge. Maintenance of the federal channels at Morehead City, Wilmington Harbor, and Oregon Inlet is conducted by hydraulic pipeline dredge or hopper dredge. Timing of all work is dependent upon the area to be maintained, the type of equipment to be used, and the anticipated environmental effects. Performing work with a hopper dredge requires consideration of possible impacts on endangered and threatened sea turtles. The USACE has no anticipated impacts from the dredging aspect of hydraulic dredge jobs, but beach disposal is conditioned to avoid/minimize impacts to all flora and fauna, specifically turtles, piping plovers and seabeach amaranth (J. Richter 2009).

Material from navigation dredging projects is put on or adjacent to ocean beaches in close proximity to the dredged site, or in an EPA designated ocean dredge material disposal site. Beaches receiving sand from dredged inlets and adjacent waterways are indicated in Table 6.6 and Map 6.3 a-c. Sand from these projects usually only covers a relatively short linear length of the beach (< one mile), generally close to the inlet where the sand originated. The amount of sand deposited and the frequency of dredging vary between sites and with each dredging event (Table 6.6). There are 51 miles of beach designated and approved for dredge disposal, but only about 16 miles of beach receive dredge material (J. Richter/USACE, pers. com., 2009). Areas receiving dredge disposal include several locations on Hatteras Island, south end of both ends of Bogue Banks, Onslow Beach, several locations on Topsail Island, Wrightsville Beach, Masonboro Island, north end of Carolina Beach, Caswell Beach, Oak Island, east end of Ocean Isle Beach, east end of Holden Beach and both ends of Bald Head Island. In addition, privately owned Figure 8 Island has received nourishment projects periodically.
Table 6.6. Ongoing USACE dredge disposal projects on North Carolina ocean beaches (Source: J. Richter/USACE, pers. com., 2009).

<table>
<thead>
<tr>
<th>Dredging Project</th>
<th>Disposal location</th>
<th>Approved disposal limits (mi)</th>
<th>Actual disposal limits (mi)</th>
<th>Estimated quantity (cu. Yd.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avon Harbor vicinity, Avon</td>
<td>Hatteras Island, south of Avon Harbor and extend north.</td>
<td>3.1</td>
<td>0.4</td>
<td>&lt;50,000 every 5-6 yr.</td>
</tr>
<tr>
<td>Rodanthe Harbor vicinity, Rodanthe</td>
<td>Extends from south end of Pea Island NWR to south of Rodanthe Harbor.</td>
<td>0.9</td>
<td>0.4</td>
<td>&lt;100,000 every 5-6 yr</td>
</tr>
<tr>
<td>Rollinson channel/ Hatteras</td>
<td>Hatteras Island south of Hatteras Harbor and extends 5.85 mi north of Frisco.</td>
<td>5.9</td>
<td>0.4</td>
<td>&lt;60,000 every 2-3 yr</td>
</tr>
<tr>
<td>Silver Lake</td>
<td>Southwest end of Ocracoke Island.</td>
<td>0.4</td>
<td>0.4</td>
<td>&lt;50,000 every 2-3 yr</td>
</tr>
<tr>
<td>Oregon Inlet</td>
<td>Pea Island south from Oregon inlet.</td>
<td>3.0</td>
<td>1.5</td>
<td>300,000 / year</td>
</tr>
<tr>
<td>Drum Inlet</td>
<td>Core Banks, extending 1 mi either side</td>
<td>2.0</td>
<td>1</td>
<td>298,000 initial, 100,000 maint.</td>
</tr>
<tr>
<td>Morehead City</td>
<td>Bogue Banks, from Beaufort Inlet west to Coral Bay Club, Pine Knoll Shores</td>
<td>7.3</td>
<td>5.2</td>
<td>3,500,000 every 8-10 yr.</td>
</tr>
<tr>
<td>AJWW, Bogue Inlet</td>
<td>Pine Knoll Shores</td>
<td>2.0</td>
<td>0.4</td>
<td>&lt;50,000 every 5-6 yr.</td>
</tr>
<tr>
<td>AJWW, Mason Inlet crossing</td>
<td>North end Wrightsville Beach 2000’ from Mason Inlet</td>
<td>1.0</td>
<td>0.4</td>
<td>&lt;100,000 / year</td>
</tr>
<tr>
<td>Masonboro sand bypassing</td>
<td>North end Masonboro Island, south from Masonboro Inlet</td>
<td>1.2</td>
<td>1</td>
<td>500,000 every 4 yr</td>
</tr>
<tr>
<td>AJWW, Carolina Beach Inlet, Snows Cut</td>
<td>South end Masonboro Island, from Carolina Beach Inlet north</td>
<td>1.3</td>
<td>0.4</td>
<td>&lt;50,000 / yr</td>
</tr>
<tr>
<td>AJWW</td>
<td>North end of unincorp. Carolina Beach, south of Carolina Beach Inlet to town limit</td>
<td>0.8</td>
<td>0.4</td>
<td>&lt;100,000 / yr</td>
</tr>
<tr>
<td>Cape Fear River, Wilmington Harbor</td>
<td>Bald Head Island</td>
<td>3.0</td>
<td></td>
<td>Approx. 1,000,000 / 2 yr. for Bald Head, Caswell, and eastern Oak Island</td>
</tr>
<tr>
<td>Cape Fear River, Wilmington Harbor</td>
<td>Caswell Beach and eastern part of Oak Island</td>
<td>4.7 mi initially, 2.8 mi/2 yr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cape Fear River, Wilmington Harbor</td>
<td>Sea Turtle Restoration Site, Oak Island (Continuing Authorities Project)</td>
<td>2.4</td>
<td></td>
<td>Only received one time from initial dredging</td>
</tr>
<tr>
<td>Cape Fear River, Wilmington Harbor</td>
<td>Oak Island, west of sea turtle project</td>
<td>4.9</td>
<td></td>
<td>Only received one time from initial dredging</td>
</tr>
<tr>
<td>Cape Fear River, Wilmington Harbor</td>
<td>Holden Beach</td>
<td>2.0</td>
<td></td>
<td>Only received one time from initial dredging</td>
</tr>
<tr>
<td>AJWW Cape Fear River to SC line</td>
<td>East end Ocean Isle Beach</td>
<td>0.6</td>
<td>0.6</td>
<td>&lt;100,000 every 1-2 yr; 250,000 if Lockwood Folly Inlet dredged (every 8-10yr)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>50.7</strong></td>
<td><strong>16.14</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Status of beach nourishment from coastal storm damage reduction projects**

Coastal storm damage reduction projects involve dredging sand specifically to increase the width and height of the beach and dunes to reduce storm damage to infrastructure and private property adjacent to the beach. To implement a federally authorized and subsidized storm damage reduction project, local governments must follow a lengthy process that can take up to 10 years to initiate. A local government
must first identify an erosion problem and request a study by the USACE to determine if and how a project could be conducted. While designing these projects avoiding and minimizing environmental impacts is a primary consideration. DMF and other agencies are given an opportunity to comment to DCM and the USACE on the potential impacts of a project to fisheries, fish habitat, and other environmental concerns. The MFC adopted a beach nourishment policy in 2000 to guide the permitting process to more fully consider fish habitat impacts (Appendix I).

The frequency and magnitude of beach nourishment on developed beaches have increased over time. From the 1960s to 2000, only nine miles of beach (3% of the ocean shoreline) had ongoing storm damage reduction projects - Wrightsville Beach, Carolina Beach, and Kure Beach (Table 6.7; Map 6.3 a-c). These projects were initially authorized and begun in the 1960s, although the first nourishment project in Wrightsville Beach occurred in 1939 (USACE 1992). With the exception of Currituck County where there have been no nourishment projects, Onslow County has had the least beach renourishment, with only one small project in the 1990s. Currently there are 14.2 mi of beach along North Carolina’s coast that have authorized and funded storm damage reduction projects ongoing. Additionally beach renourishment projects are under development for Bogue Banks, Oak Island/ Caswell/ Holden, Bodie Island, and Topsail Island (Table 6.7). All of Hatteras and Ocracoke islands are also under consideration because of the DOT NC 12 study, but it is likely that only a small part of these islands would actually be nourished (J. Sutherland/WRC, pers. com., 2004). Beach renourishment of federally authorized storm reduction projects generally occurs on three or four year intervals. Potentially 155 mi or 48% of North Carolina’s beaches could be renourished regularly if resources existed, and these beaches could be potentially impacted by such activities. This does not include approximately 16 mi of beaches with periodic disposal from channel, inlet, and port dredging. There are approximately 160 mi of federally or state owned barrier islands along the 320 mi of ocean shoreline where storm damage reduction projects would be unlikely. Along with the federally funded USACE coastal storm reduction projects, there are several beaches that have or in the process of privately funding beach nourishment projects (including but not limited to Nags Head, Surf City, North Topsail Beach, Bogue Banks, Figure 8 Island, and Bald Head Island) (Table 6.8). These privately funded projects must undergo an USACE permit review, and are considered one time projects.

Preliminary examination of commercial gill net landings data for demersal feeding surf fish in counties with differing levels of beach nourishment activity indicates some relationship may exist between beach nourishment events and low landings (DMF, unpub. data). However, more information and analysis are needed to determine if beach nourishment events negatively impact surf fish abundance, CPUE, or landings. Given the increasing numbers of existing and requested nourishment projects over time, the cumulative impacts of activities on the intertidal and subtidal communities are also expected to increase. Increasing use of beach nourishment may have a cumulative impact on fish productivity of nearshore waters through impacts on the benthic community and alteration of natural barrier island processes.

Due to the increasing interest by municipalities in beach nourishment of some kind, it was evident that a plan was needed to provide guidelines on how to manage a limiting resource in an effective and environmentally sensitive manner. DWR and DCM agreed to collaboratively develop a Beach and Inlet Management Plan (BIMP) in part, to address the CHPP recommendation to prepare a BIMP that addresses ecologically based guidelines, socio-economic concerns and fish habitat. In addition, in 2000, House Bill 1840 required DENR to develop a multiyear beach management and restoration strategy, and in 2005 the GA commissioned a study of the cost and management issues related to maintaining NC’s shallow draft navigation channels. The purpose of the BIMP was to compile data, define regional sand management regions, and develop management strategies to assist with the decisions and review process associated with beach nourishment activities. The plan will also assist DWR in developing funding priorities for beach nourishment projects, and be an educational tool for legislators.
Table 6.7. North Carolina beach communities with federally authorized or requested storm damage 
reduction projects by the USACE (does not include beach disposal from navigational dredging 
projects).  (Source:  DWR, unpub. doc., 2009.)

<table>
<thead>
<tr>
<th>Project Name</th>
<th>County</th>
<th>Local Sponsor</th>
<th>Length of Beach (miles)</th>
<th>Project Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bogue Banks</td>
<td>Carteret</td>
<td>Carteret County (Towns of Atlantic Beach, Pine Knoll Shores, Salter Path, Indian Beach, and Emerald Isle)</td>
<td>TBD</td>
<td>Study on-going, expected completion in FY2012 if Federal funding appropriated</td>
</tr>
<tr>
<td>Brunswick County Beaches GRR (Oak Island/Caswell/Holden)</td>
<td>Brunswick</td>
<td>Brunswick County (Town of Oak Island, Town of Caswell Beach, and Town of Holden Beach), N.C.</td>
<td>TBD</td>
<td>Re-evaluation study on-going, expected completion in FY2011 if Federal funding is appropriated</td>
</tr>
<tr>
<td>Dare County Beaches (Bodie Island)</td>
<td>Dare</td>
<td>Dare County (Towns of Kitty Hawk, Kill Devil Hills, and Nags Head)</td>
<td>TBD</td>
<td>Study complete, awaiting funding for engineering &amp; design</td>
</tr>
<tr>
<td>Surf City and North Topsail Beach</td>
<td>Onslow</td>
<td>Town of North Topsail Beach</td>
<td>TBD</td>
<td>Study on-going, expected completion in FY2010 if Federal funding is appropriated</td>
</tr>
<tr>
<td></td>
<td>Pender</td>
<td>Town of Surf City</td>
<td>TBD</td>
<td>Re-evaluation study on-going, expected completion in FY2010 if Federal funding is appropriated</td>
</tr>
<tr>
<td>West Onslow Beach (Topsail Island)</td>
<td>Pender</td>
<td>Town of Topsail Beach</td>
<td>TBD</td>
<td>Active 50 year project (ends 2051). Next renourishment scheduled for 1st quarter 2010</td>
</tr>
<tr>
<td>Brunswick County Beaches (Ocean Isle)</td>
<td>Brunswick</td>
<td>Town of Ocean Isle Beach</td>
<td>5.3</td>
<td>Active 50 year project (ends 2048). Next renourishment scheduled for 1st quarter 2010</td>
</tr>
<tr>
<td>Carolina Beach and Vicinity (Area South Portion)</td>
<td>New Hanover</td>
<td>Town of Kure Beach</td>
<td>3.4</td>
<td>Active 50 year project (ends 2015). Next renourishment scheduled for 1st quarter 2010</td>
</tr>
<tr>
<td>Carolina Beach and Vicinity (Carolina Beach Portion)</td>
<td>New Hanover</td>
<td>Town of Carolina Beach</td>
<td>2.7</td>
<td>Active 50 year project (ends 2036). Next renourishment scheduled for 1st quarter 2010</td>
</tr>
<tr>
<td>Wrightsville Beach</td>
<td>New Hanover</td>
<td>Town of Wrightsville Beach</td>
<td>2.8</td>
<td>Active 50 year project (ends 2021). Next renourishment scheduled for 1st quarter 2010</td>
</tr>
</tbody>
</table>
### Table 6.8. North Carolina beach communities with non-federally authorized or requested storm damage reduction projects (does not include beach disposal from navigational dredging projects). (Source: D. Piatkowski/USACE, pers. com., 2010.)

<table>
<thead>
<tr>
<th>Project Name</th>
<th>County</th>
<th>Local Sponsor</th>
<th>Length of Beach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Town of Nags Head - Beach Nourishment Project</td>
<td>Dare</td>
<td>Offshore Borrow Areas</td>
<td>10</td>
</tr>
<tr>
<td>Emerald Isle FEMA Project</td>
<td>Carteret</td>
<td>USACE ODMDS – Morehead City Port Shipping Channel</td>
<td>4</td>
</tr>
<tr>
<td>Bogue Banks FEMA Project</td>
<td>Carteret</td>
<td>USACE ODMDS – Morehead City Port Shipping Channel</td>
<td>13</td>
</tr>
<tr>
<td>Bogue Banks Restoration Project – Phase I – Pine Knoll Shores and Indian Beach Joint Restoration</td>
<td>Carteret</td>
<td>Offshore Borrow Areas</td>
<td>7</td>
</tr>
<tr>
<td>Bogue Banks Restoration Project – Phase II – Eastern Emerald Isle</td>
<td>Carteret</td>
<td>Offshore Borrow Areas</td>
<td>6</td>
</tr>
<tr>
<td>Bogue Banks Restoration Project – Phase III – Bogue Inlet Channel Realignment Project</td>
<td>Carteret</td>
<td>Offshore Borrow Areas</td>
<td>5</td>
</tr>
<tr>
<td>North Topsail Dune Restoration (Town of North Topsail Beach)</td>
<td>Onslow/Pender</td>
<td>Upland borrow source near Town of Wallace, NC</td>
<td>NA</td>
</tr>
<tr>
<td>North Topsail Beach Shoreline Protection Project</td>
<td>Pender</td>
<td>New River Inlet Realignment and Offshore Borrow Area</td>
<td>11</td>
</tr>
<tr>
<td>*Topsail Beach - Beach Nourishment Project</td>
<td>Pender</td>
<td>New Topsail Inlet Ebb Shoal and Offshore Borrow areas</td>
<td>6</td>
</tr>
<tr>
<td>*Figure Eight Island</td>
<td>New Hanover</td>
<td>Banks Channel and Nixon Channel</td>
<td>3</td>
</tr>
<tr>
<td>*Rich Inlet Management Project</td>
<td>Pender</td>
<td>Relocation of Rich Inlet</td>
<td>NA</td>
</tr>
</tbody>
</table>

With approximately 50% of North Carolina’s ocean shoreline in state or federal ownership, the remaining 50% are developed. Of those, 80 mi of shoreline in the recent past have been managed, and potentially 80 mi more may be managed in the future. The state funding required to maintain potentially 160 mi of beach would be huge. With that in mind, the BIMP may recommend establishment of a dedicated fund, and a regional commission to coordinate and facilitate projects. As of February 2010, the BIMP was drafted but not finalized.

In 2008 an Ocean Policy Steering Committee was formed to reexamine ocean resource issues and update existing policies on ocean uses. In April 2009 DCM published an ocean policy report (NC Sea Grant 2009) which identified five emerging resource policy issue areas and provides recommendations for
changes to state policy that ensures North Carolina will be responsive with adaptive rule language as the
ocean climate continues to experience technological, social, and economic change. Sand resource
management was identified as an emerging issue. The report recommended:

- Identification of regional available sand sources
- Development of a state-level comprehensive plan to protect beaches and inlets
- Comprehensive management of inlet tidal delta sand sources
- Preventing loss to the barrier island system of sand in inlet channels
- Amendment to rules regarding dredging around hard bottom areas
- Incorporation of a sea level rise component to CAMA land use plans

All of the sand management recommendations of the Ocean Policy Report should be implemented. The
first four items should be addressed in the BIMP.

6.4.1.2. Infrastructure

Oil and gas development

As described in the water column and hard bottom section, oil and natural gas drilling can be a major
threat to the ocean environment. Specifically, oil drilling can affect the soft bottom community by
altering both the inter- and sub-tidal soft bottom habitat. Sub-tidal habitat can be directly influenced by
moving or removing soft sediments during the drill process. This removal process can potentially create
disturbances similar to those caused by soft bottom dredging impacts. As a result of offshore drilling
there is a possibility of increased levels of pollutants and changes in the bottom composition (sediment
characteristics and water movement) that can alter the nearby benthic community (Olsgard and Gray,
1995; Kennicutt et al., 1996; Barros et al., 2001). Studies have found diversity lowest adjacent to oil/gas
platforms, with increasing diversity the further you traveled from the platforms (Kingston 1992; Daan and
Mulder 1996; and Peterson et al. 1996). Although these results have been observed, other studies believe
these changes are influenced by differences in depth, sediment characteristics, distance from shore,
interannual variability, or the presence of previously unavailable hard substrate (Hernández et al. 2005
and Terlizzi et al. 2008). A common theme throughout this research is that in order to determine the
effects of drilling on soft bottom benthos, information regarding pre-drilling, during, and post drilling
conditions, as well as the use of control sites. In 2009 the General Assembly formed a Legislative
Research commission Advisory Subcommittee on Offshore Energy Exploration to examine the impacts of
offshore energy in North Carolina. For further discussion refer to the “Infrastructure” section of the Hard
Bottom chapter.

The potential for an oil spill can be detrimental to the entire ecosystem. Not only can ocean habitats be
impacted by released oil, estuarine habitats can also be affected if the spill occurs in or is transported
through the inlets to estuarine waters. In North Carolina, as a result of wind and water movement, the
first habitat point of contact for oil floating on the water’s surface in the ocean environment is the
intertidal beaches and flats. Although most of North Carolina’s coastal beaches are high energy areas, oil
spills can cause closures of beaches and fishing activities. In the areas where there is low flow, oil can
persist for decades (Peterson 2001 and Peterson et al. 2003b). The presence of oil in soft bottom
sediments can prevent fish eggs from hatching, limiting the growth rate of small fish, and prevents fish
from returning to previously utilized spawning habitat (Peterson 2001 and Peterson et al. 2003b). It is
important to note, that these impacts can be caused by other sources such as shipping vessels running
aground and leaking oil or gas.
Wind Energy

Wind farms are discussed in further detail in the hard bottom section, while this section focuses on the potential impacts on soft bottom and the associated fauna. Duke Energy Progress is proposing to construct a wind turbine field in either Pamlico Sound or off the coast of North Carolina and run underground power lines from the turbines to land. In areas where there is soft bottom, pilings may be driven deep into the bottom sediments (approximately 30 to 35 meters). This practice can act similarly to that of driving pilings into the substrate (i.e. oil/gas platforms, docks, or bridges) or like a platform itself (modifying sediment composition or water movement). Cables will then be run from the structures to a facility where the electricity will be distributed. Putting pilings and cables in soft bottom habitat will immediately crush or kill benthic invertebrates and remove soft bottom habitat that was previously available. In order to minimize these impacts cables should be below the surface using directional boring methods. Although hard bottom habitat will be created, the benthic community will change from infaunal bivalves and annelid worms to epifaunal bivalves and algae, altering the food web (see “Ecosystem management and Strategic Habitat Areas” for discussion of habitat trade-offs). The practice of driving pilings into the soft bottom can also have a negative effect on sound producing fish, mammals, and turtles causing them to leave the immediate area while pilings are being installed. In preliminary work, Wahlberg and Westerberg (2005) estimated that fish were only affected by the sound produced by wind mills up to 4 m away when winds were above 13m s$^{-1}$. Wahlberg and Westerberg (2005) go on to state that these wind turbines are masking communication sounds (i.e. mating and warning) and orientation signals. Underground energy cables are known to give off an electrical charge that can alter fishes’ migration patterns. Studies have shown different species (including the American eel, Anguilla rostrata) to be affected by these electrical charges (Rommel and McCleave 1973 and Öham et al. 2007).

While current CRC rules prohibit the placement of wind turbines in state waters as they are not considered water-dependent structures, the CRC has taken steps to amend these rules (M. Lopazanski/DCM, pers. com., January 2010). The proposal currently under consideration would declare wind energy facilities of three MW or larger to be water dependent structures. Should the State consider locating a wind facility in state or federal waters, proper placement of energy infrastructure is necessary to minimize potential impacts to SAV habitat and minimize conflicts with existing activities.

The 2009 Ocean Policy Steering Committee made several recommendations regarding ocean based alternative energy, primarily regarding review and modification of legal structure as needed to support alternative energy development. Other alternative energy industries that could develop in the future include wave energy, current energy, and tidal energy.

6.4.1.3. Off-road vehicles

The use of off-road vehicles (ORV) has been allowed in designated beach areas of North Carolina. These ORV have been shown to increase the loss of sediment from intertidal shoreline and negatively affect intertidal fauna (Schlacher and Thompson 2008). Fauna can be affected directly by being crushed by ORVs, or indirectly by altering the sediment composition and behavior (Schlacher and Thompson 2008). On the Cape Hatteras National Seashore Hobbs et al. (2008) observed a decrease in the number of ghost crabs (Ocypode quadrata) in areas that had been previously closed to ORV. This is important to note since ghost crabs have been described to be indicator species of anthropogenic influences on coastal shorelines (Steiner and Leatherman 1981; Neves and Bemvenuti 2006; and Hobbs et al. 2008). In Australia, low volumes of ORVs (5 passes through an area) were found to crush large numbers of surf clams (Donax deltoid) (Schlacher et al. 2008). As the number of trips increased more surf clams were crushed (Schlacher et al. 2008). On Fire Island, NY, ORVs were estimated to deliver large amounts of sand to the swash zone contributing to the overall erosion rate (Anders and Leatherman 1987). It is unclear of whether or not the sand is lost from the long shore sediment transport. In North Carolina, the National Park Service regulates where ORVs are permitted to drive on beach. Current regulations include
restrictions to keep ORVs above the wrack line (which protect intertidal fauna) and out of important nesting areas for birds and other fauna. *The National Park Service should continue to restrict ORV beach access to areas that will not negatively influence soft bottom fauna.*

### 6.4.2. Mining/salvage

#### 6.4.2.1. Minerals

Mining or mineral extraction is another dredging activity that has potential habitat impacts. Phosphate deposits, of sufficient quality and quantity to be potentially exploitable, have been identified within the Pungo River geological formation in Onslow Bay (Map 6.4). The formation occurs beneath the Pamlico River, extends beneath ocean soft bottom from Bogue Banks southwest to Frying Pan Shoals, is approximately 150 km long and 40 km wide, and covers approximately 6,000 km² (Powers et al. 1990). The largest deposit occurs at Frying Pan Shoals, seaward of state jurisdiction, and is potentially available to dredge mining. Other phosphate deposits, referred to as the Northeast Onslow Bay phosphate district, occur immediately off Bogue Banks within and seaward of state jurisdiction. Because of its proximity to shore and a deep-water port, the economic potential of mining these deposits is high. In addition, other minerals occur in offshore sediments (as phosphate mining byproducts) including trace elements, radioactive substances like uranium and phosphogypsum, heavy minerals such as titanium, zirconium, aluminosilicates, and valuable metals such as gold and silver (Riggs and Manheim 1988). Currently no mining is ongoing in North Carolina waters, although the potential for such activities exists.

#### 6.4.2.2. Logs/pilings

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

### 6.4.3. Fishing gear impacts

The extent of habitat damage from fishing gear varies greatly with the gear type, habitat complexity, and amount of gear contact. While MFC rules are designed to minimize commercial fishing gear impacts to fisheries habitat, these restrictions primarily focus on restricting the use of highly destructive bottom disturbing gear from most structural habitats such as oyster or SAV beds. Soft bottom habitat, because of its low structure and dynamic nature, has historically been considered the most appropriate location to use bottom disturbing gear. There are some fishery rules that restrict bottom disturbing gears in soft bottom habitat, since DMF research found that their use disturbed shallow soft bottom functions (i.e., nursery characteristics). These include prohibition of trawls, dredges, and long haul seines in PNAs [15A NCAC 3N .0104] and prohibition of trawls or mechanical shellfish gear in crab spawning sanctuaries [15A NCAC 3L .0205] in the five northern-most inlets of North Carolina during the blue crab spawning season (March-August) (Map 3.5a-c in the Shell Bottom chapter).

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

Dredging

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

There are two types of scallop dredges used in North Carolina. Bay scallop dredges are used in SAV beds. Refer to the SAV chapter for more information on this gear. Sea scallop dredges are used occasionally in the coastal ocean off Cape Lookout. Studies have found that scallop dredges cause extensive damage to hard bottom and significantly reduce habitat complexity on soft bottom and shell hash bottom (Auster et al. 1996; Currie and Parry 1996). Habitat complexity is reduced through flattening of mounds, filling of depressions, dispersing shell hash, and removing small biotic cover such as hydrozoans and sponges (Auster et al. 1996; Løkkeborg 2005). Due to a decline in bay scallops, a moratorium was in place from 2005 through 2008. Sea scallop dredging is a sporadic fishery, primarily occurring in deep coastal waters (federal) north of North Carolina. Since 1994, commercial landings of sea scallop meats have been very low, ranging from 13,815lb in 1999 to 512,624lb in 2001 (DMF, unpub. data). Because of the location of the fishery and the low level of effort, no additional restrictions appear to be needed.

Hydraulic clam dredging and clam kicking were described in detail in the SAV chapter. Mechanical clamming, including kicking and dredging, accounts for approximately 21% of the annual hard clam landings (DMF, unpub. data). The dredging and kicking activity creates trenches and mounds of discarded material in soft bottom habitat, redistributing and resuspending sediment (Adkins et al. 1983). Water jets from the hydraulic dredge can penetrate 18 inches into bottom sediments, and uproot any living structure present (Godcharles 1971). Dredge tracks can remain present from a few days to more than one year and recolonization by vegetation can take months to begin. Recruitment of clams and other benthic invertebrates does not appear to be affected by hydraulic dredging (Godcharles 1971). Because of the severe impacts to habitats, both hydraulic clam dredging and clam kicking are restricted to open sand and mud bottoms, including areas frequently dredged as navigational channels. However, a study in North Carolina found no significant effect of this fishing activity on recruitment of hard clams or abundance of other benthic invertebrates in unvegetated sandy bottom (Peterson et al. 1987). The locations where mechanical clam harvest is allowed are shown in Map 6.5. There are approximately 39,517 acres that are potentially available to mechanical clam harvest in portions of Core, Bogue, and Pamlico sounds, Newport, North, White Oak, and New rivers, and a portion of the ICW in Topsail Sound. The majority of mechanical harvest areas are located in Core Sound (29,951 acres). These fisheries may be opened by proclamation between Dec 1 and March 31. At this time, no changes are necessary to protect soft habitat because of the low frequency of the activity and dynamic nature of the habitat.

Bottom trawling

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

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

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

Trawl doors were shown to bring a high number of infaunal bivalves to the sediment surface (Gilkenson et al. 1998) and Sanchez et al. (2000) observed more annelids in a muddy bottom after trawling had occurred in the Mediterranean Sea. This is important to note since in Kaiser and Spencer (1996) observed a large number of benthic organisms that are damaged by trawls in the diets of demersal fish scavengers after a trawl has been pulled through an area. Studies in areas that are consistently trawled have shown otter trawls to have a negative effect on the nematode (a food source for fishery species) community by reducing abundance, production, and genus richness in areas that are not susceptible to environmental stresses (i.e. wind events) (Hinz et al. 2008). Gear contact can uproot and remove invertebrates attached to the seafloor, such as sponges and worm tubes and can expose them to predators.

The change and reduction in the structural complexity of the seafloor and increase in turbidity from frequent trawling can reduce feeding success of filter feeding invertebrates due to gill clogging, or increase predation due to increased exposure and reduced cover. A reduction in filter feeders on the subtidal bottom may also result in reduced water clearing capacity in the water column (Auster and Langton 1999). The increased turbidity reduces light penetration and consequently reduces primary productivity of benthic microflora on the seafloor as well as phytoplankton in the water column (Auster and Langton 1999). Decreased primary productivity will affect demersal zooplankton that, in turn, supports higher trophic layers. The sediment composition of the bottom may also change with frequent trawling. Due to the close relationship between sediment size and benthic community structure, this sediment shift will alter the benthic community (Thrush and Dayton 2002). Reduced diversity and abundance of some benthic taxa are commonly observed in areas experiencing intense fishing activities (Auster and Langton 1999; Thrush et al. 2006). A shift in dominant species and a reduction in community stability may also occur. Long-lived species, which take more time to recover from fishing disturbance, may be temporarily or indefinitely replaced by short-lived species. However, given the frequency, magnitude, and location of trawling, it is unknown whether these events are having a significant negative impact on soft bottom habitat in North Carolina’s estuarine system.

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

While some consider trawling to be physically disruptive to the bottom and potentially harmful to the benthic community due to gear damage, sedimentation, predation exposure, and reduction in benthic primary production (Auster and Langton 1998), others feel that trawling may mimic natural disturbances and stimulate benthic production, enhancing fish production. In a literature review of the effects of trawling in estuarine waters, DMF (1999) noted that multiple studies demonstrated the presence and absence of long-term effects of trawling in estuarine waters. No or minimal long-term impacts were reported in MacKenzie (1982), Van Dolah et al. (1991), and Currie and Parry (1996). Of these studies, Van Dolah et al. (1991) was located closest to North Carolina, in a South Carolina estuary. After five months of trawling, Van Dolah et al. (1991) found no significant change in abundance, diversity, or composition of soft bottom habitat. On the contrary, several studies have found trawling to have long-term habitat impacts (Bradstock and Gordon 1983, Brown 1989, Collie et al. 1997, Engel and Kvitek 1998). Benthic community recovery time greatly depends on the effort and intensity of trawls in a given area (Watling and Norse 1998, Auster and Langton, 1999). The recovery time tends to vary depending on the amount of natural disturbances in the area (weather or macrofaunal). In the Gulf of Maine, the recovery time after trawling over a mud bottom was 3 months, possibly due to the presence of burrowing megafauna that naturally disturb the bottom (Simpson and Watling 2006).

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

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

Many studies have been conducted around the world assessing the effect of trawling on soft bottom habitat in offshore waters. A thorough review of literature on fishing impacts to continental shelf benthos quantified impacts via a meta-analysis, examining data derived in part from studies of otter trawl effects on subtidal bottom in eastern North America (Table 6.9) (Collie et al. 2000). Some of their conclusions included:

- Otter and beam trawling were found to have fewer negative impacts on benthos than intertidal or scallop dredging or intertidal raking.
- In subtidal bottom, sand habitats were the least impacted, and muddy sand and gravel the most impacted.
- In muddy sand, polychaetes and large bivalves were most negatively impacted. Smaller bodied organisms are displaced by pressure waves in front of fishing gear.
- Depth and scale of fishing had insignificant effect on initial impact but significant effect on recovery. Recovery is slower where the spatial scale of impact is larger and in deeper waters where the bottom is more stable.
- Recovery was most rapid in less physically stable habitats such as sandy bottom (recovery in sand, estimated from modeling, was approximately 100 days).
- Benthos most impacted were Anthozoa (corals and anemones) and Malacostraca (crabs, amphipods), while copepods and ostracods were least impacted.
- Benthos had more negative responses to chronic disturbances than to acute disturbances.
- Epifaunal organisms are less abundant in areas subjected to intensive bottom fishing.
- Results suggested that fish and benthos in areas heavily fished would shift from communities dominated by high biomass species towards those with high abundance of small-sized organisms.
- Large-scale long-term experiments with and without fishing pressure are needed, rather than short-term small-scale studies, to examine and better quantify cumulative fishing impacts and recovery patterns.

<table>
<thead>
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</table>

These conclusions suggest that the dynamic soft bottom community found in nearshore ocean communities is less impacted by trawling and recovers much quicker than in estuarine systems. However, some long-term impacts to the benthic community may occur, especially to the epibiota, depending on the frequency of trawling and site-specific characteristics. Repeated and prolonged trawling over muddy ocean bottom will negatively influence the benthic fauna, decreasing the abundance and diversity of epifauna invertebrates, possibly altering the marine food web (Hinz et al 2008).

*Status and trends of estuarine and ocean trawling*

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

Annual effort with various commercial trawling gears in North Carolina water bodies is shown in Table 6.6 (DMF, unpub. data). Commercial shrimp trawling accounts for the majority of all trawl trips (92% in 2002). About 75-80% of shrimp trawl trips occur in estuarine waters, with the remainder in ocean waters, primarily within state territorial seas (<3 mi offshore) off the central and southern coast of North Carolina. Total annual estuarine shrimp trawling effort has ranged from 2,944 in 2005 to 15,791 in 1995. The total number of estuarine shrimp trawl trips has not exceeded 10,000 trips since 2002. Prior to 2002, the numbers of estuarine shrimp trawl trips declined to below 10,000 during two years: 1998 and 2001. Total annual shrimp trawling effort has fluctuated with shrimp abundance but appears to have gradually declined since 1994. However, the lower commercial fishing effort observed from 1999 – 2002, when compared to earlier years, is thought to be mostly due to a change in licensing procedure (R. Carpenter/DMF, pers. com., 2004). In 1999, a recreational commercial gear license became available to fishermen. Under this license, shrimp may be caught recreationally using a trawl, but cannot be sold. Some fishermen, with previously held commercial licenses, switched from standard commercial gear licenses (SCGL) to recreational commercial gear licenses (RCGL). Effort from RCGL licenses are not included in the data shown in Table 6.10. In 2002, approximately 5,000 trips for shrimp were reported (DMF, unpub. data).

Regionally, the shrimp trawling effort has generally been greatest in Core and Bogue sounds and the associated estuaries (3,400-6,783 trips/year) (Table 6.10). Estuarine rivers and sounds represent 60 to 99% of NC shrimp trawls. Pamlico Sound and associated rivers and estuaries account for the second largest number of trawl trips per year, ranging from 2,900-5,500 trips/year. However in 2000, 2002, 2006, 2007, and 2008, the Pamlico region accounted for more trips than the Core/Bogue waters. Decreased effort in Core/Bogue sounds is not attributed to changes in shrimp management or habitat condition. In ocean waters, shrimp trawling is highly concentrated in the southern portion of the state (Onslow through Brunswick counties), primarily in the summer (approximately 2,300-3,400 trips/year). In contrast, the annual effort has ranged from 137 to 457 trips per year in the central district (Carteret County) and from 2 to 34 trips per year in the northern district (Virginia state line through Hyde County). Commercial shrimp trawl effort has remained relatively stable over time in the southern district of the state.

Over 99% of crab trawling occurs in estuarine waters, while all directed flounder trawling (specially targeting flounder) occurs in ocean waters (i.e., no directed trawling for finfish is allowed in internal waters). The majority of crab trawling occurs in Pamlico Sound and adjacent estuarine rivers, followed by Core/Bogue sounds and estuaries. The number of crab trawl trips has decreased dramatically since 2004 as crab trawlers have switched to other fisheries such as scallop trawling in Virginia (S. McKenna/NCDMF, pers. com., 2009). Flounder trawling effort occurs primarily in the northern district of North Carolina’s coastal waters. Effort in the northern district has varied from 7 trips in 1997 to 134 trips in 1999 (Table 6.10). Overall, current bottom trawling effort in estuarine waters for all fishery species is greatest in Pamlico Sound and associated estuaries.
Table 6.10. Annual number of trips reported for shrimp, crab, and flounder trawls in NC estuarine and ocean waters <3 miles, 1994-2008 (DMF, unpub. data). Trawling is not permitted in Albemarle Sound.

### Shrimp Trawl

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### Crab Trawl

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Flounder Trawl

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</table>

1Pamlico Area: Pamlico, Croatan, and Roanoke sounds; Pamlico, Bay, Neuse, and Pungo rivers.
Core/Bogue Area: Core and Bogue sounds; Newport, White Oak, and North rivers.
Southern Area: Masonboro, Stump, and Topsail sounds; Cape Fear, New, Shallotte, and Lockwood Folly rivers; ICW.
Northern district ocean waters: Virginia line through Hyde County.
Central district ocean waters: North of Cape Hatteras.
Southern district ocean waters: South of Cape Hatteras.

Active Gillnet Techniques

Although gillnets are a passive fishing gear, they can be made active by dragging weighted objects to “scare” fish into gillnets. These objects (including weights, chains, and cinder blocks) may weigh anywhere between 5 and 29 pounds and may disturb the soft bottom habitat in a manner similar to a small trawl door or a toothless scallop dredge. In 2007, the NCDMF became aware of fishermen utilizing active gillnets in PNAs in the Spot, Mullet, Flounder, and Speckled trout gillnet fisheries. Although there was no specific rule against active gillnets in PNAs, all bottom disturbing gears are prohibited. According to MFC rule 15A NCAC 03J .0103, the fisheries director may limit the use of gillnets and the means/methods they are fished. While the NC Marine Patrol have observed active gillnets in PNAs in the central and southern districts of NC, they found it to be more prevalent in the Southern district (DENR 2008). Currently, there is a NC Sea Grant Fisheries Resource Grant investigating the impacts of active gillnets on PNAs. Results of this study are expected to be complete in June of 2010. The impacts of active gillnets on soft bottom should continue to be investigated.

6.4.4. Water quality degradation

The condition of soft bottom is determined by the character and quality of bottom sediments and the quality of the overlying water column. Solids and organic matter in the water column eventually settle out and become a part of the soft bottom habitat. However, soft bottom sediments can also be resuspended by disturbances (e.g., storms and human activities such as dredging). The cycling of material between the bottom and the water column was discussed previously in this chapter and in the
water column chapter. In general, bottom sediments tend to act more as a sink than a source with regards to benthic-pelagic coupling. Aquatic organisms can accumulate pollutants from the sediment or the water column. Because water quality inevitably affects soft bottom (i.e., anoxia in the water column leads to increased production of hydrogen sulfide ($\text{H}_2\text{S}$), a gas that is toxic to aquatic life, in bottom sediments), many of the same threats to the water column are threats to soft bottom. The primary pollutants of concern to soft bottom are discussed below.

6.4.4.1. Eutrophication and oxygen depletion

The primary discussion of eutrophication resides in the “Water quality degradation – causes” section of the Water Column chapter. The enrichment of bottom sediment is discussed in this section.

While a certain level of these nutrients is needed to support aquatic life, an overabundance of nutrients, or eutrophication, due to human activities can lead to increased primary production resulting in algal blooms and hypoxic bottom water (Nixon 1995). The effects of nutrient enrichment on soft bottom habitat are also complicated by additional stressors, such as toxins or hydrological modifications, and by benthic-pelagic coupling (Riedel et al. 2003). High concentrations of organic material in bottom sediments serve as continual sources of additional nutrients to the water column, which can fuel algal blooms. Soft bottoms in North Carolina’s estuaries tend to store nutrients for several reasons (Peterson and Peterson 1979). Small clay sized sediment particles that are abundant in ORM adsorb nutrients readily. In addition, suspension feeding invertebrates remove nutrients and particles from the water column which later are transformed and deposited on the bottom as feces (a process known as biodeposition). The ebb and flood of tides increases the residence time of particles in estuarine waters, further retaining nutrients in the system (Peterson and Peterson 1979). Extensive monitoring in the Neuse River revealed that large quantities of nutrients were stored in the sediment. Refer to the “water column chapter” for detailed discussion of the sources and status of nutrient enrichment in the water column.

In the shallow Neuse River estuary, high but variable rates of exchange of nutrients between the water column and soft bottom were noted, with soft bottom efficiently storing and providing nutrients that can fuel algal blooms and cause hypoxia (Luetich 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 (Luetich et al. 1999), making management strategies difficult to evaluate in the short term (see “Non-point source management” section of Water Column chapter for related information). In an effort to reduce the amount of run-off from farming and animal feed operations, the EMC approved a rule [15A NCAC 02T .1310-.1311] in 2008 designed to increase monitoring of the Nitrogen, Ammonia, fecal coliform, and chlorine. Long-term monitoring is required, in combination with management actions that reduce discharge concentrations, to determine effectiveness and future management needs. Adequate supply of dissolved oxygen is critical to survival of sessile benthic invertebrates and fish living on or in soft bottom habitat. In freshwater systems, low oxygen levels resulting from eutrophication has been suggested as an important source of mortality in mussels (Neves et al. 1997). In mesohaline estuaries, low oxygen events occur when the water column becomes stratified for a long period, particularly during summer in areas of deeper water (Tenore 1972). If stratification persists, hypoxic events in the water column can cause changes in the physical and chemical conditions at the sediment-water interface, lead to stress or mortality of benthic organisms, and reduce species richness (Tenore 1972). In the benthic community, polychaetes tend to be most tolerant to low oxygen, followed by bivalves and then crustaceans (Diaz and Rosenberg 1995). Severe oxygen depletion in the sediment also results in release of toxic levels of sulfide into bottom waters (Luetich 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; Luetich 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 km² area (Buzelli et al. 2002). The areas of high benthic mortality coincided with the area estimated to have been the most severely oxygen depleted. Powers et al. (2005) linked the decrease of *Macoma balthica* to a diet switch in Atlantic croaker. As a result of less *M. balthica*, croaker tended to consume more polychaetes and plants, providing evidence of a change in the food web.

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

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

While hypoxia and anoxia can occur naturally, they can also be attributed, in part, to anthropogenic changes in the system, including excess nutrient and organic loading from waste discharges, nonpoint runoff, streambank erosion, and sedimentation (Schueler 1997). In the Neuse River system, MODMON studies found that the sediment oxygen demand is much greater than the biological oxygen demand in the water column. Oxygen depletion in the water column was positively correlated with accumulation of organic material in the sediments (Luettich et al. 1999). Site-specific information on sediment condition is generally lacking in other areas of North Carolina. Several studies have indicated that the frequency, duration, and spatial extent of low oxygen events have increased over the years due to increasing eutrophication of coastal waters from human and animal waste discharges, greater fertilizer use, loss of wetlands, and increased atmospheric nitrogen deposition (Cooper and Brush 1991; Dyer and Orth 1994;
Paerl et al. 1995; Buzelli et al. 2002). Research is ongoing at NCSU looking at the effect of hypoxic events in the Neuse River on fish displacement, foraging, growth, and survival (B.J. Copeland/MFC, pers. com. April 2010). The research results suggest that the energy utilized by fish to avoid hypoxia and find adequate food impacts fish growth and productivity. More information is needed to understand the consequences on the estuarine food web and to what extent anoxia is impacting the soft bottom community. Refer to Water Column chapter for more information on eutrophication and oxygen depletion.

6.4.4.2. Sedimentation and turbidity

While resuspended benthic microalgae can be beneficial to the invertebrate community as an additional food source, excessive suspended sediment and associated algae have been found to reduce growth rates and survival of macrofauna, such as hard clams (Bock and Miller 1995). These species are also most susceptible to sediment deposition, turbidity, erosion, or changes in sediment structure associated with sand mining activities, compared to other more mobile polychaetes (Hackney et al. 1996).

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

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

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

Excess sedimentation can reduce or eliminate aquatic insect larvae from stream bottoms (AFS 2003). These larvae are the basic fish food source in freshwater streams, and impacts to them can affect the productivity of associated fish species (AFS 2003). High levels of suspended sediment in an estuarine or marine habitat can greatly reduce successful settlement of larval clams and oysters, and can smother other benthic invertebrates (AFS 2003). In some areas, historic oyster bars have been completely covered with fine sediment and mud (Rodriguez et al. 2006). Refer to the water column chapter for information on habitat degradation from sedimentation and options for addressing sedimentation.

Excessive sedimentation has been cited as the major cause of freshwater mussel decline in the United States since the late 1800s (Neves et al. 1997; Box and Mossa 1999). Poor land use practices, including construction and road building activities, agriculture, forestry, dams, reservoirs, and channelization are among the causes cited for sedimentation (Neves et al. 1997; Box and Mossa 1999). Because freshwater mussels are dependent on specific host fish to complete their reproductive cycle, changes in resident fish populations, due to dams, channelization, or other habitat alterations, jeopardize survival of mussels (Neves et al. 1997). The decline in mussel populations in North Carolina is considered severe (Neves et
al. 1997). Over 50% of approximately 60 native freshwater mussels are designated as Endangered, Threatened, or of Special Concern within the state and approximately 22 of these occur within coastal draining river basins (Neves et al. 1997; http://www.ncwildlife.org, April 2009). The Tar River spiny mussel (*Elliptio steinostansana*) and dwarf wedgemussel (*Alasmidonta heterodon*) are federally and state endangered species that occur in the upper Tar and Neuse rivers, respectively (http://www.ncwildlife.org, April 2009). Since these species are highly sensitive to water quality and habitat degradation, freshwater mussels are often considered an excellent early biological indicator of freshwater stream condition.

6.4.4.3. Toxic chemicals

The primary discussion of toxic chemicals resides in the Water Column chapter. This section focuses on the storage and release of chemicals stored in soft bottom habitat.

While toxins can fluctuate between the sediment and water column, concentrations of toxic chemicals tend to accumulate in sediments to several orders of greater magnitude than overlying waters (Kwon and Lee 2001). Multiple studies have examined the toxic chemical contamination in North Carolina’s estuaries. One study of bottom sediments throughout coastal North Carolina waters found PAHs, nickel, arsenic, DDT, chromium, PCBs, and mercury to be the most abundant chemicals between 1994 and 1997 (in order of descending concentration) (Hackney et al. 1998). The study also found concentrations of other heavy metals such as antimony, copper, lead, cadmium, silver, and zinc. According to the survey, sediment in 13.4% of estuarine sites sampled was nearly devoid of life during harsh summer conditions. The bioavailability and transport of a chemical depend on the form of the chemical incorporated into the sediments, the feeding habits and condition of aquatic organisms, and the physical and chemical conditions of the environment. Toxins can also be active in surface waters, when dry sediment is hydrated from rainfall or runoff, toxic chemicals in the soils become oxidized, and heavy metals are released and transported downstream by heavy rains or water movements. Toxic chemicals that tend to accumulate in bottom sediments include:

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

Large spills of toxic chemicals, such as pesticides or petroleum products, can result in fish kill events. In North Carolina, spills of pesticide, chlorinated water, and sewage waste were responsible for 8% of fish kill events in 2001 (DWQ 2001b). Contaminated sediments affect benthic feeding fish and invertebrates in several ways. Some toxins can inhibit or alter reproduction and development of marine and aquatic organisms, or cause mortality in some situations (Weis and Weis 1989; Gould et al. 1994). Lethal and sublethal levels of toxicity are known for some benthic aquatic species. Mollusks are known to be very sensitive to petroleum products, pesticides, and TBT, with relatively low levels of exposure affecting reproduction, tissue development, growth, and survival (Funderburk et al. 1991) (refer to shell bottom chapter for toxicity levels). Because macrobenthic invertebrate diversity significantly declines with increasing sediment contamination (Weis et al. 1998; Brown et al. 2000; Dauer et al. 2000), food resources for benthic feeders may be limited in areas having significant contamination. See Appendix F for more information on toxicity thresholds for early life stages of fish. However, most information comes from acute toxicity tests conducted in laboratory settings on standard test species. Data are lacking on chronic or sublethal toxicity levels for many important fishery species and interactions of contaminants in the field. Following oil spills, sub-lethal levels of contamination can delay population recovery due to

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

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indirect effects, and may lead to increased fish mortality where predation risk is size-dependent (Peterson et al. 2003b). *More information is needed on the in situ effects of various contaminant levels, in combination with other contaminants and existing environmental stressors, on survival, growth, and reproduction of many important fish species in North Carolina.*

While some aquatic organisms experience mortality from exposure to toxins, chemicals may bioaccumulate to toxic levels within surviving organisms and pass through the food chain. Multiple studies have shown clear connections between concentrations of toxins in sediments and those in benthic feeding fish and invertebrates (Kirby et al. 2001; Marburger et al. 2002). Heavy metal contamination of sediments has been documented to result in elevated trace metal concentrations in striped mullet, shrimp, oysters, and flounder (Kirby et al. 2001; Livingstone 2001). Largemouth bass and catfish, stocked in a restored and flooded freshwater wetland, had high concentrations of organochlorine (chlor dane, DDT, dieldrin) corresponding to contaminant levels in the sediment (Marburger et al. 2002). Toxic contaminants are also considered one of the most serious threats to native freshwater mussels, which are the most imperiled fauna in North America (Keller 1996). In high concentrations copper and ammonia, by-products of water treatment outfalls, can be fatal to freshwater bivalves (Ward et al. 2007). For further discussion on toxicity in fishes, refer to “Toxic chemical section” of the Water Column chapter.

*Fossil fuels*

Anthropogenic sources of hydrocarbons include burning of fossil fuels, the marine industry (boat maintenance/activity), urban/suburban sprawl, dock and marina development and operation, automotive transportation, and industrial emissions (Wilbur and Pentony 1999). Potential sources of heavy metals from these activities include anti-fouling paint, zinc plates on boats, fuel, runoff from parking lots or other road surfaces, and wood preservatives leached from dock structures (EPA 1985; Marcus and Stokes 1985; Sanger and Holland 2002).

Hydrocarbons are derived from fuel emissions, runoff from roads, spills from boats and fuel facilities. Runoff from impervious surfaces such as roads and parking lots appears to be one of the major sources of heavy metals and hydrocarbons in estuaries and nearshore ocean waters. It was estimated that in the United States, 11 million gallons of oil enters surface waters through runoff every eight months, equivalent to the Exxon Valdez-size oil spill (PEW Ocean Commission report; http://www.pewtrusts.org/our_work_report_detail.aspx?id=30009&category=130). The major source of this oil appears to be from cumulative oil drips on roadways and dumping of waste crankcase oil (Latimer et al. 1990). In Maryland, a study of suburban watersheds with little industrial activity found that metals from lawns, roads, and automobiles accumulated in sediments at levels toxic to aquatic life in streams (Hartwell et al. 2000). In the Charleston, S.C. area, Lerberg and Holland (2000) found a strong correlation between increasing impervious surface coverage in tidal creek watersheds and the cumulative level of contaminants in tidal creek sediments.

*Heavy metals*

Anthropogenic sources of metals include industrial ore processing, chemical production, agriculture, the marine industry (boat maintenance/activity), urban/suburban sprawl, dock and marina development and operation, dredge spoil disposal, automotive transportation, atmospheric deposition, and industrial emissions (Wilbur and Pentony 1999). Of the heavy metals, arsenic, copper, cadmium, chromium, nickel, lead, zinc, tin, and mercury are among the greatest concerns. A study in the lower San Francisco Bay found that half of the cadmium and zinc in the bay came from tire wear (Beach 2002). Lead originated primarily from diesel-fueled vehicles and half the copper in the bay was derived from brake pad wear. An additional 25% of the copper came from atmospheric emissions. Also, several studies have shown that mercury and other metals are released from peat soils subjected to intensive drainage (Evans et al. 1984; Gregory et al. 1984). Nunes et al (2008) showed that in areas with a high concentration of heavy metals
studies surface deposit feeders and herbivores decreased in abundance, while subsurface deposit feeders have increased in areas of high concentration of heavy metals (Nunes et al. 2008). Because low concentrations of heavy metals in the water column can be easily incorporated into organic rich mud (ORM), chemicals can accumulate in the sediment to toxic levels and be resuspended into the water column (Riggs et al. 1991, Steel 1991).

Fine-grained sediments are common in sheltered creeks and small trunk estuaries, or in the deeper regions of larger estuaries. The highest contamination levels were found in low-salinity areas with limited flushing and high river discharge (e.g., upper estuaries) (Riggs et al. 1989, Riggs et al. 1991, Hackney et al. 1998). Some heavy metals and pesticides can cause hormone alterations that affect reproduction (Wilbur and Pentony 1999). Heavy metals in these areas are of particular concern because they cover the majority of designated anadromous and low-salinity nursery areas, where young fish gravitate in spring and summer. Determining the distribution and concentration of heavy metals and other toxins in bottom sediments throughout the coast is needed to comprehensively assess potential threat to the water column.

Heavy metal concentrations have been measured in Durham Creek, Porter Creek, South Creek, Pamlico River, Jacks Creek, Huddles Cut, and Tooley Creek by PCS as part of their permit compliance. Arsenic, cadmium, molybdenum, selenium, and zinc were all found to be higher in concentration than continental crust concentrations (CZR 1999). The presence of these heavy metals has been directly linked to shell disease in blue crabs (Callinectes sapidus) found in the Pamlico River (Weinstein et al. 1992).

Steps have been made to reduce heavy metal input into the aquatic system. Mercury and arsenic are no longer used in antifouling paints due to their toxicity (Bellinger and Benham 1978). Tributyltin (TBT), another toxic metal compound used in antifouling paints, was restricted on non-military vessels by the Organotin Antifouling Paint Control Act of 1988 (Milliken and Lee 1990). The use of TBT-containing paints for coating the hulls of military vessels has been either officially discontinued or is currently in the process of being phased out.46

**PAHs, PCBs, and pesticides**

Polycyclic aromatic hydrocarbons (PAHs) are a group of over 100 different chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances like tobacco or charbroiled meat. Compounds in the PAH group are found in coal tar, crude oil, creosote, and roofing tar, but a few are used in medicines or to make dyes, plastics, and pesticides. Polychlorinated biphenyls (PCBs) are organic chemicals containing chlorine that have properties that make them useful for many industrial and commercial applications like electrical, heat transfer, and hydraulic equipment; in paints, plastics and rubber products; in pigments, dyes and carbonless copy paper and many other areas. PCBs are used in plasticizers and flame retardants.

Certain PAHs have been shown to cause mutations or cancer in fish (White and Triplett 2002). Documented effects of PAHs to flatfish include DNA damage, liver lesions, and impacts on growth and reproduction (Johnson et al. 2002). Several pesticides also have been detected in sediments of the Albemarle-Pamlico estuary (Hyland et al 2000). The concentration of many herbicides was greatest in spring and summer, during and immediately following application periods. The seasonal pattern of concentration was less evident for the insecticides prometon, diazinon, and chlorpyrifos (Woodside and

46 Currently, most Navy, MSC [Military Sealift Command], USCG [United States Coast Guard], and Army ships have steel hulls with copper-based antifouling paints. Paints containing tributyltin (TBT) are still found on some aluminum-hulled small craft because some copper-based paints are incompatible with aluminum hulls. Currently, TBT-based antifouling paints are found on approximately 10-20% of small boats and craft with aluminum hulls. The numbers of vessels from the respective Armed Forces branches estimated to have TBT coatings are: Navy-56, USCG-50, MSC-0, Air Force-50, Army-11 (U.S. Navy and EPA 1999). It is unknown how many of these vessels have operated or presently operate in North Carolina waters, or if the policy regarding TBT use has changed since the date of the reference’s publication.
As a result of offshore transport and atmospheric deposition, pesticides, PAH, and PCBs have been found 32 km off of the coast of Georgia in the Grey’s Reef Marine Sanctuary (Hyland et al. 2006). Refer to the water column chapter for more detailed information on the sources of toxic chemicals.

Status of sediment contamination

The extent of sediment contamination in North Carolina coastal waters is not well known. Sediment sampling is not conducted by the DWQ since there are no sediment standards in the state. Although the NCDWQ does not sample sediments for heavy metals in NC coastal waters, they require that dredging applicants sample for heavy metals under certain circumstances (i.e. historically commercial ports). The NCDWQ requires heavy metal sampling so that if dredging does occur in an area with contaminated sediments proper dredging and disposal methods can be utilized. A complete list of DWQ pollutant standards can be found in the DWQ surface water and wetlands standard “redbook”, but the pollutants that are sampled include but are not limited to Mercury, Selenium, and Cadmium (http://portal.ncdenr.org/c/document_library/get_file?folderId=285750&name=DLFE-8513.pdf, August 2010).

Studies examining sediment contamination at sites in North Carolina soft bottom have found various levels of contamination. The EPA Environmental Monitoring and Assessment Program surveyed 165 sites within North Carolina’s sounds and rivers during 1994-1997 to evaluate condition of bottom sediments (Hackney et al. 1998). The sediment in 13.4% of estuarine sites sampled was nearly devoid of life during harsh summer conditions, according to the survey. Highest contamination levels occurred in low salinity areas with low flushing and high river discharge. Benthic communities were dominated by tolerant opportunistic species and low species richness. Laboratory bioassays showed that sediments from many sites were toxic to biological organisms. Hyland et al. (2000) sampled 174 station from 1994-1997, from these stations Hyland estimated less than 10 percent of North Carolina estuaries are contaminated by toxins. However, because of the low sample size, frequency of sampling, and the confounding effects of hypoxia in areas sampled, results from this study may not accurately assess the condition of North Carolina sediments (C. Currin/NOAA, pers. com., 2003). Concentrations of heavy metals in the Neuse and Pamlico estuaries have been assessed (Riggs et al. 1989; Riggs et al. 1991). In the Neuse River, surface sediments were found to contain elevated levels of several heavy metals, including zinc, copper, lead, and arsenic. Furthermore, 17 areas between New Bern and the mouth of the river were identified as “contaminated areas of concern”. The contaminated sites were primarily attributed to permitted municipal and industrial treatment plant discharges. Marinas were also found to contribute substantial amounts of copper and variable amounts of zinc and lead. In the Pamlico River, heavy metal enrichment was generally less severe than in the Neuse River. In the Pamlico and Neuse rivers, individual waste treatment plants, marinas, industrial plating facilities, and military facilities were identified as probable sources of heavy metal enrichment (Steel 1991).

Nonpoint sources were more difficult to evaluate. In the Pamlico River, heavy metal contamination was less severe, although arsenic, cobalt, and titanium exceeded the levels found in the Neuse River. These studies suggest that sediment contamination in some estuarine areas, especially those where both organic rich mud and waste water discharges are present, may be significant and could affect fish populations and the base of their food chain. Corbett et al. (2009) investigated the presence of heavy metals in Slocum Creek, Hancock Creek, and the adjacent Neuse River Estuary, finding higher concentrations of the heavy metals in the portions of the creeks with low sedimentation rates. Additionally, Corbett et al (2009) observed little to no macrofauna in sediment cores where the heavy metal concentrations were high. Heavy metal and toxin concentrations have been monitored yearly by NOAA’s mussel watch monitoring program since 1986 (Kimbrough et al. 2008). In NC, there are 10 sites (Roanoke Sound, Pamlico Sound, Cape Fear River, and Beaufort Inlet areas) that the heavy metal levels found in the eastern oyster...
Crassostrea virginica are monitored (Lauenstein et al. 2002). For more information regarding toxins see water column and oyster sections. To better determine if contaminated sediment is a significant threat to coastal fish habitat, the distribution and concentration of heavy metals and other toxic contaminants in freshwater and estuarine sediments need to be adequately assessed and areas of greatest concern need to be identified. Continued minimization of point and nonpoint sources of toxic contaminants is vital for protecting not only soft bottom but also the other fisheries habitat.

**Resident time**

Chemical contamination may reside in soft bottom sediments for any period of time. The residence time depends on the specific chemical. The portion of oil that reaches the bottom may persist for several years (Olsen et al. 1982). Lead compounds from gasoline additives have a tendency to sink to the bottom (Chmura and Ross 1978). The degradation (half-life) of pesticides such as malathion, parathion, endosulfan, fenvalerate, chlorpyrifos-methyl, methanidathion, and diazinon in seawater ranges from 2.2-17 days (Walker 1977; Cotham and Bidleman 1989; Lacorte et al. 1995). However, the toxicity and longevity of degradation products must also be considered in evaluating water quality. Toxic chemical pollution has been affected by severe weather striking the North Carolina coast. For example, after flooding accompanying Hurricane Floyd in 1999, pesticide concentrations in upper Pamlico River estuary declined by a factor of ten, while concentrations in the lower estuaries had increased slightly (D. Shae/NCSU, pers. com., 2002). One year following Floyd, however, the overall concentration of current-use pesticides was comparable to pre-hurricane levels (D. Shae/NCSU, pers. com., 2002). Toxins can accumulate and persist over time, chemicals that have been banned since 1977 (e.g. DDT, Tetrachlorvinphos, and TBT) continue to be found in sediments (Hackney et al. 1998; Marburger et al. 2002).

**6.4.4.4. Sewage spill**

Sewage spills and overflows can cause an influence in nutrient and fecal coliform bacteria concentrations in the water column and soft bottom habitats. These higher than normal concentrations can contribute to anoxic conditions (refer to eutrophication section) that can cause fish kills to bottom feeding fish and soft bottom invertebrates. Both the nutrients and bacteria can settle out of the water column into the sediments and remain for several weeks where they will be subject to resuspension (Mallin et al. 2007). These elevated levels of fecal coliform can create shellfish closure areas as mandated by the Shellfish Sanitation and Recreational water quality section of NCDENR, due to the potential human health issues. For further discussion refer to the Shell bottom and Water Column Chapter.

**6.4.5. Non-native, invasive, and nuisance species**

The presence of non-native species poses a threat to soft bottom habitat by out-competing native species for food and habitat. An introduced species that has an influence on soft bottom habitats found in coastal North Carolina is red algae (Gracilaria vermiculophylla).

The red algae Gracilaria vermiculophylla, originally described from East Asia, is believed to occur in NC’s southeastern estuaries (Freshwater et al. 2006). It was observed fouling nets and water intakes and growing on mudflats in Masonboro Sound in 2000. If confirmed it will be the seventh red algae reported in NC. It is associated with human-related mechanisms of dispersal, likely in fouled fishing gear or boats (Freshwater et al. 2006). It has also been reported as abundant along saltmarsh borders and mudflats in Virginia (Thomsen et al. 2009). It is expected that the primary mode of dispersal is through oyster transplants because it is not generally found in ships ballast and is abundant on Virginia oyster reefs (Thomsen et al. 2007).
6.4.6. Climate change and sea level rise

Anticipated climate change is expected to affect soft bottom environmental conditions, thus altering the biological community. These changes include a rise in sea surface temperatures, intensification of tropical storms, larger and more extreme waves and storm surges, and altered nutrient run-off (IPCC 2007).

The expected changes from climate change will facilitate an increase erosion rate of the intertidal soft bottom. Using diatoms to model former sea levels, Horton et al. (2006) observed a rise of 0.7m over approximately the past 150 years. As sea level rises (SLR) erosion will continue to occur at intertidal shorelines. Research has stated that if all conditions remain the same as sea level rises, the intertidal beach will move landward and upland (Brunn Rule) (Zhang et al. 2004). Using data from the mid nineteenth century to 2004, Zhang et al. (2004) observed approximately 24% of the NC coast that is not influenced by coastal engineering projects or inlets to be eroding by at a rate of 0.32 m/y. Development has increased in coastal communities not allowing the intertidal zones to move landward. In an attempt to reduce the effects of this landward movement, developers have been utilizing varying shoreline stabilization methods. In NC, the coastal hazards science panel has been issued the task of presenting the NC CRC with scientific data and recommendations regarding the hazards of SLR on the coastal community. The science panel has estimated a sea level rise of approximately 1 meter by 2100. Currently, the international best practice is using setbacks, not allowing development landward from the first line of stable, natural vegetation (DeLeo et al. 2009). In NC, the CRC determines setbacks for single family homes by multiplying the average annual erosion rate by 30, or the set back must be at least 60 ft.

Schlacher et al. (2008) summarized the 2006 Sandy Beach Ecology Symposium (Vigo Spain) workshops, describing the loss of habitat and associated biota as the most severe and immediate effect of climate change. As a result, Schlacher (2004) states that there is a need to expand the understanding of how climate change will influence sandy beaches. These research needs include:

- long-term studies on communities and populations that quantify ecological responses to changes in beach morphology and variability
- key ecological traits of individual species (i.e. dispersal abilities, reproductive strategies, thermal tolerance, etc.)
- ability of species to adapt or acclimatize
- metapopulation studies
- realized and predicted geographic range shifts of biota
- habitat requirements of iconic and threatened species (birds, turtles, fish)
- identification of indicator species and their efficacy in monitoring the effects of climate change on sandy beaches
- linkages across ecosystems – ecotonal coupling (e.g. dunes, estuaries, reefs)
- ecological consequences of alternative societal responses to erosion and shoreline retreat (e.g. do nothing, retreat/setback, nourish, armor)
- scale-dependency and cumulative effects of societal responses to beach erosion
- effects of management interventions to sea-level rise and beach erosion on critical linkages of sandy beaches with adjacent systems (dunes, nearshore, estuaries)
- efficacy of mitigation, rehabilitation and restoration measures
- impacts on economically important fisheries species on beaches

Increasing water temperatures and sea level rise are thought to influence aquatic community structure. Although the biological changes that might occur from sea level rise are difficult to predict, researchers expect the settlement of non-native species to increase, shift in prey availability, and changes to the nutrient flux originating from upland areas to occur (Stachowicz 2002, Diederich 2005, Büttger et al.)
2008). As sea level rises, certain species of mollusks found in the intertidal zone may become unavailable to certain bird species. As this shift occurs the mollusks will become more readily available to predatory fish in subtidal zones (Reise and van Beusekom 2008). Many experts expect tropic and sub-tropic species (Smith et al. 2000) to move north to the sub-arctic as a result of this warming trend. In southeastern NC, researchers have observed an increase in the number of benthic invertebrates (e.g. Caribbean crabs, bivalves, snails, and polychaetes) from waters further south (UNCW 2008). This trend has already been observed in geologic records from the Pleistocene Epoch (Palumbi and Kessing 1991, Dayton et al. 1994, King et al. 1995).

Currently, researchers are working on five independent projects that have been examining the impacts of sea level rise in NC as part of North Carolina Sea Level Rise project. Refer to the Wetlands chapter for a comprehensive list of sea-level rise and climate change projects/initiatives occurring in North Carolina. Of these projects, researchers at UNC-CH are modeling estuarine habitat (including intertidal and subtidal soft bottom) response to sea level rise (http://www.cop.noaa.gov/stressors/climatechange/current/slr/abstracts.aspx, December 2010). This project is scheduled to be completed by FY2010. Research needs to continue to investigate the impacts of climate change on the soft bottom habitat and the associated fauna. This should include effects on productivity.

As the climate changes, more severe and frequent storms are predicted to occur. Sediment erosion and run-off is expected to increase with the climate changes. After hurricane activity occurs in the Neuse River Estuary (NRE), phytoplankton dynamics are altered through nutrient. These high levels of nutrients can create soft bottom hypoxic conditions (Paerl et al. 2006). Hurricanes may alter the benthic community, by changing the community structure as a result of salinity changes and hypoxic conditions (Malin and Corbett 2006). The increase hurricane events can cause inlets to open and close, affecting NC’s estuaries (refer to Water Column chapter for more information).

6.4.7. Management needs and accomplishments

Some of the management needs from the 2005 CHPP were refined and adopted as actions in the multi-agency CHPP implementation plans (IPs). The status of 2005 research and management needs is listed below, along with new emerging needs. Emerging needs includes new issues and previously existing actions that were extensively reworded in the 2010 draft, and therefore considered “new”. Research and management needs are classified as accomplished, with progress, without progress, emerging, or discontinued because they were found to be redundant or too general or minor.

6.4.7.1. Research needs and progress (2005-2010)

Accomplished research needs

None

Research needs with progress

1. Further analysis is needed to spatially quantify where, how often, and when trawling occurs in specific areas of soft bottom habitat. It is also important to quantify the episodic and chronic effects of trawling on nursery functions in different estuarine settings. Some new research presented in the “Bottom trawling” subsection of section 6.4.3.1. “Mobile bottom disturbing gear”.

2. More information is needed to understand the consequences on the estuarine food web and to what extent hypoxia is impacting the soft bottom community. Some research has been done by NCSU, Jim Rice on effect of hypoxia on fish displacement and growth. See “Eutrophication and oxygen depletion” section for context.
Research needs without progress

1. Research that quantifies the cumulative impact of dock and marina policies on soft bottom and other fish habitats. Research conducted regarding the cumulative impact of microbial contamination from multiple docks in an area (see the “Marinas and docks” subsection of section 6.4.1. “Water-dependent development” for context). See section 2.4.2. “Marinas and multi-slip docking facilities” in the “Water column” chapter for more information.

Emerging research needs

The following needs are quoted or paraphrased from the text.

1. There should be a cooperative effort to update existing NC estuarine bathymetric maps. See Section 6.1.3. “Description and distribution” for more information.

2. The long-term consequences of hardened structures on larval transport and recruitment should also be thoroughly assessed prior to approval of such structures (groins or jetties). See the “Oceanfront shoreline hardening” subsection of section 6.4.1.1. “Water-dependent development” for context.

3. The impacts of active gillnets on soft bottom should continue to be investigated. NC Sea Grant has funded a Fisheries Resource Grant to investigate the impacts of active gillnets on PNAs, report pending (see section 6.4.3.1. “Mobile bottom disturbing gear” for context).

4. Research needs to be conducted to investigate the impacts of climate change on the soft bottom habitat and fauna. This should include effect on productivity. NC researchers are investigating the impacts of sea level rise as part of the North Carolina Sea Level Rise Project. The DCM coastal hazards science panel has been discussing the issues of sea level rise on NC coastal areas. Refer to section 6.4.6. “Climate change and sea level rise” for context.

5. Due to the increasing numbers of rays in NC, the impact of ray foraging pits in NC waters should be examined. See section 6.2.5.1. “Foraging”.

6.4.7.2. Management needs and progress (2005-2010)

Accomplished management needs

1. Designating the specific locations of anadromous fish spawning and nursery areas by the MFC and ensuring they are adequately protected. Anadromous Fish Spawning Areas have been designated by the MFC and WRC (see section 2.3.5. “Designations” in the “Water column” chapter for more information).

2. More specific minimum and maximum grain size standards for beach nourishment that minimize biological impacts. CRC has implemented effective sediment criteria rules (see the “Beach nourishment impacts on intertidal beach and adjacent subtidal bottom” subsection in section 6.4.1.1. “Water-dependent development” for more information).

Management needs with progress

1. Reducing the area available to mechanical clam harvesting is another means to protect clam stocks and provide additional habitat protection. Ongoing DMF effort to adjust boundaries with expansion of SAV (see section 6.3.2. “Status of associated fishery stocks” for more context.

2. Commenting and permitting agencies should continue using their existing authorities to a) minimize new dredging of shallow soft bottom habitat, b) prevent direct impacts from dredge and fill projects,
and c) limit as much as possible indirect impacts to shallow soft bottom or other habitats. Ongoing (see the “Dredging (navigation channels and boat basins)” subsection in section 6.4.1.1. “Water-dependent development” for more information).

3. Completing a coast-wide beach management plan that carefully reviews cumulative impacts of activities and provides ecologically based guidelines, including sediment compatibility standards, to minimize cumulative impacts. The CRC’s beach nourishment rules should be evaluated and modified in a comprehensive manner as needed to minimize overall impacts from this activity. Conditions should include sediment compatibility, restricting time of nourishment, interval between nourishment events, and linear length of projects to enhance recovery of the benthic community. The coastwide Beach and Inlet Management Plan has been drafted and pending review and finalization (see “Status of beach nourishment from coastal storm damage reduction projects” section for more information).

4. Encourage sand mining guidelines for beach nourishment that maximize biological recovery rates and do not degrade fish habitat functions. Increased need due to storm damage projects using offshore borrow areas. See the “Beach nourishment impacts at mining areas” subsection in section 6.4.1.1. Water-dependent development” for context. May be addressed in BIMP.

5. Re-examining shallow areas where trawling is currently allowed to determine if additional restrictions are necessary. Some areas were re-examined for the 2004 shrimp FMP http://www.ncdmf.net/download/shrimpfnmp2004finial.pdf. See section 6.4.3.1. “Mobile bottom disturbing gear” for context.

6. Additional public outreach to emphasize the importance of natural barrier island and estuarine processes. ECU has produced several publications on barrier island migration and shoreline stabilization of estuarine and ocean shorelines. See section 6.2.5.1. “Foraging” for context.

7. Including minimum water depth criteria for siting docks in shallow nursery habitats. Minimum water depth included for structured habitat and PNAs (see the “Marinas and docks” subsection of section 6.4.1.1. “Water-dependent development” for context).

Management needs without progress

1. Expanding temporal and spatial sampling of juvenile fish to provide additional information on trends in juvenile fish utilization of soft bottom and other habitats, especially summer and fall spawning species, which are generally not present at existing sampling stations during May and June. See section 6.2.5.3. “Nursery” for context.

2. More research to assess direct and indirect dredging impacts on blue crabs and other inlet spawning species. See the “Dredging (navigation channels and boat basins)” subsection in section 6.4.1.1. “Water-dependent development” for context.

3. Developing a state policy on dredge material management, that a) minimizes impacts to coastal fish habitat, including soft bottom habitat, and b) is consistent with federal existing guidelines. See the “Dredge material disposal on subtidal bottom” subsection in section 6.4.1.1. “Water-dependent development” for context.

4. Due to the toxic sediment contamination associated with pressure treated wood, revised shoreline stabilization rules should require or encourage use of non-wood materials or wood that is not toxic to benthic organisms. Any new wood preservative products should be evaluated for toxicity to marine benthic organisms and juvenile fish. See the “Estuarine and riverine shoreline stabilization” subsection in section 6.4.1.1. “Water-dependent development” for context.
5. Adequate monitoring of the effects of beach nourishment projects on the soft bottom community and associated surf fish populations. The monitoring should assess the direct and cumulative impact of beach nourishment activities on fish, their habitat, and biological recovery rates. See the “Beach nourishment impacts at intertidal beach and adjacent subtidal bottom” subsection in section 6.4.1.1. “Water-dependent development” for context.

6. Because less habitat damaging methods are available for harvesting crabs, MFC should consider if prohibition of crab dredging is advisable. See section 6.4.1.1. “Mobile bottom disturbing gear” for context.

7. Protection of “recruitment bottlenecks” from trawling or other impacts is very important for estuarine dependent fish and invertebrates. See the “Bottom trawling” subsection of section 6.4.3.1. “Mobile bottom disturbing gear” for context.

8. More information on the in situ effects of various contaminant levels, in combination with other contaminants and existing environmental stressors, on survival, growth, and reproduction of many important fish species in North Carolina. See section 6.4.4.3. “Toxic chemicals” for context.

9. To better determine if contaminated sediment is a significant threat to coastal fish habitat, the distribution and concentration of heavy metals and other toxic contaminants in freshwater and estuarine sediments need to be adequately assessed and areas of greatest concern need to be identified. Continued minimization of point and nonpoint sources of toxic contaminants is vital for protecting not only soft bottom but also the other fisheries habitat. See section 6.4.4.3. “Toxic chemicals” for context.

**Emerging management needs**

1. Where new inlets form, recommend allowing inlets to remain open even if temporarily until a substantial flood tide delta forms. This will allow for long-term maintenance and stability of the barrier island. See the “Oceanfront shoreline hardening” subsection of section 6.4.3.1. “Mobile bottom disturbing gear” for context.

2. The natural processes that create these features (shoals, sand bars, sloughs, and tidal deltas that surf fish utilize) need to be maintained. See section 6.2.5.1. “Foraging” for context.

3. Because there is strong evidence available on the potential ecological impacts of hardened structures, large uncertainty on the environmental impacts of terminal groins specifically, and no clear economic benefit from inlet stabilization, North Carolina should not reverse its position or policies on ocean shoreline hardening. Overall, the scientific evidence does not support changing North Carolina’s policy on prohibition of shoreline hardening structures on the oceanfront. See the “Oceanfront shoreline hardening” subsection of section 6.4.3.1. “Mobile bottom disturbing gear” for context.

4. In an effort to reduce the amount of run-off from farming and animal feed operations, the EMC approved a rule [15A NCAC 02T .1310-.1311] in 2008 designed to increase monitoring of the Nitrogen, Ammonia, fecal coli form, and chlorine. Long-term monitoring is required, in combination with management actions that reduce discharge concentrations, to determine effectiveness and future management needs. See “Eutrophication and oxygen depletion” section for context.

5. Efforts should be taken by state agencies to assist with creating Ecosystem Sensitivity Index (ESI) maps of NC. NCDMF is currently cooperating with NOAA to create maps showing the presence of fauna collected by NCDMF sampling surveys (see section 6.4.4.1. “Toxic chemicals” for context).
6. The National Park Service should continue to restrict ORV beach access to areas that will not negatively influence soft bottom fauna. See section 6.4.1.3. “Off-road vehicles” for context.

7. Should the State consider locating a wind facility in state or federal waters, proper placement of energy infrastructure is necessary to minimize potential impacts to SAV habitat and minimize conflicts with existing activities. See the “Wind energy” subsection of section 6.4.1.2. “Infrastructure” for context.

8. Permitting agencies should avoid or minimize dredging projects in Anadromous Fish Spawning Areas and undesignated but important associated anadromous fish nursery areas. See the “Dredging (navigation channels and boat basins)” subsection of section 6.4.1.1. “Water-dependent development” for context.

9. Dock siting criteria should include a minimum water depth over all habitats to prevent boats or floating docks from sitting directly on shallow soft bottom. See the “Marinas and docks” subsection of section 6.4.1.1. “Water-dependent development” for context.

10. All of the sand management recommendations of the Ocean Policy Report should be implemented. The first four items should be addressed in the BIMP. See the “Shoreline stabilization” subsection of section 6.4.1.1. “Water-dependent development” for context.

11. Because of this, the 2009 Ocean Policy report (NC Sea Grant 2009) recommended that CRC rule language be modified to require a 500 m dredging buffer around all hard bottom areas, including those of low relief that are periodically buried with thin ephemeral sand layers. See the “Shoreline stabilization” subsection of section 6.4.1.1. “Water-dependent development” for context.

6.5 SUMMARY OF SOFT BOTTOM CHAPTER

There are a variety of soft bottom habitat types, ranging from intertidal ocean beaches, to sound bottoms and mud flats. Soft bottom is an important source of primary (benthic microalgae) and secondary (infauna and epifauna) productivity, and therefore the primary foraging habitat for many species. Soft bottom also plays an important role in the ecosystem by storing and releasing nutrients and chemicals into the water column. Shallow soft bottom serves as important nursery areas for many species, especially spot, croaker, flounder, penaeid shrimp, and blue crabs. Shallow riverine waters function as spawning areas for some anadromous fish species and inlet channels are often spawning areas for species like blue crab, speckled sea trout and red drum. Other species highly associated with soft bottom include shortnose sturgeon in riverine waters, hard clams, and coastal sharks, kingfish, and Florida pompano in marine waters. It is estimated that roughly 17-37% of soft bottom is less than six feet deep, although bathymetric maps need updating.

Inadequate data are available to clearly indicate the current condition of soft bottom habitat. Fortunately this habitat is relatively resistant to a changing environment. This is the most abundant submerged coastal fish habitat, and estuarine acreage of soft bottom has undoubtedly increased over time as shell bottom, SAV, and wetland habitats have declined. With the increased effort to map SAV, hard, and shell bottom habitats in North Carolina, a better understanding of the extent of soft bottom habitat is available. This increased effort to map North Carolina habitats has included updating both Nursery and Anadromous Fish Spawning Areas designations. Species that are highly dependent on soft bottom with depleted stock status in 2009 include Atlantic sturgeon and southern flounder. Those with concern stock status are croaker, spot, and coastal sharks. Shortnose sturgeon is not classified since they are federally listed as endangered and there is a fishing moratorium on the species.
In estuarine and fresh waters, a significant threat to shallow soft bottom habitat is channel dredging, as the need for boat access continues to grow. Toxin contamination of bottom sediments, particularly where sediments are fine and flushing is low, can have a negative impact on the benthic community and entire food chain in fresh and estuarine waters particularly. Although many toxic chemicals and metals that are harmful to aquatic fauna have been banned from being used in the aquatic environment, they have remained in soft bottom sediments. In order to fully understand the extent of this issue, chemical analyses need to be performed on North Carolina estuarine and marine sediments to determine the heavy metal and toxin distribution and their effect on aquatic organisms. Potential oil and gas development and infrastructure in North Carolina waters could introduce another source of toxin contamination. There needs to be a complete understanding of the impacts on the soft bottom habitat and the associated organisms, as well as other habitats. Eutrophication can also be problematic by exasperating hypoxia and mortality of the benthic community.

On the oceanfront, shoreline stabilization is a large and growing threat. Since the last CHPP, there have been increased requests by beach communities along the coast for large-scale storm damage reduction projects and inlet relocation projects, including Dare and Brunswick counties, Bogue Banks and Topsail Island. These projects are requesting use of offshore borrow areas for a sand source. There has also been a shift to more communities requesting privately funded nourishment projects, due to unavailability of federal funds in a short time frame. Private projects have been done or are in planning stages for approximately 65 mi of beach. There has also been increased interest in using ebb tidal deltas and the cape shoals as a sand source for nourishment projects. An emerging issue for this habitat since the 2005 CHPP is the consideration by the legislature to reverse the State’s long standing policy against ocean shoreline hardening due to severe erosion on portions of some developed islands and private interests to protect the affected homes and infrastructure.

As a result of the 2005 CHPP, approximately one third (11) of the 35 research and management needs (excluding new emerging items) have had some progress in being addressed. Three management needs were accomplished, but six management needs and two research needs are ongoing and require continued effort and funding. There were 10 management and research needs that were not addressed, and 14 were discontinued due to duplication, vagueness, or lack of supporting information. Since the 2005 CHPP, 14 additional emerging research and management needs were identified. These needs include understanding the long-term effects of climate change, sea level rise, and construction of wind energy facilities. Climate change and sea level rise are directly linked to the soft bottom habitat threat of shoreline stabilization. With the threat of sea level rise, there will continue to be a desire to utilize varying methods to stabilize the shoreline. As these structures continue to be built we must fully understand both the positive and negative effects they have on the ecosystem as a whole.

Accomplishments related to soft bottom include designation of anadromous fish spawning areas by the MFC and WRC, new CRC rules regarding sediment criteria for beach nourishment and additional conditions on siting of docking facilities over designated Primary Nursery Areas. Other progress underway includes additional MFC restrictions on bottom disturbing gear over shallow soft bottom, preparation of a draft Beach and Inlet Management Plan, research on the effect of hypoxia on fish productivity, and some additional public outreach on the importance of natural barrier island and estuarine processes by ECU. Initial progress has been made regarding improvements to estuarine shoreline stabilization rules, primarily through development of outreach products, discussions of the issue with scientists and managers, research on effects of various shoreline stabilization structures on habitat and associated fauna. Even though several needs have been addressed since 2005, there is more to be done.

Emerging needs for this habitat include preventing hardened structures along ocean shorelines and inlets, modifying post-storm practices to allow newly formed inlets to temporarily remain open to form flood channels.
tide deltas, restricting dredging or implementing other needed management actions to protect designated Anadromous Fish Spawning Areas, and implementing the sand management strategies of the 2009 Ocean Policy Report, including rule changes regarding dredging near hard bottom. In order to continue to preserve the soft bottom habitat and associated fauna there needs to be a continued effort to address the research and management needs outlined in this document. Informed decisions can be made as we expand on the available information regarding the soft bottom habitat and its response to its threats.
Map 6.1a. Location of marine topographic features, northeastern coast of North Carolina.
Map 6.1b. Location of marine topographic features, central coast of North Carolina.
Map 2.1c. Location of marine topographic features, southcentral coast of North Carolina.
Map 6.1d. Location of marine topographic features, southeast coast of North Carolina.
Map 6.1e. Location of marine topographic features, south coast of North Carolina.
Map 6.2b. Sediment composition in the Tar-Pamlico, Neuse, and Core/Bogue estuaries (Wells 1989). Numbers = % sand, M= mud, SC=silty clay, VFS= very fine sand, MS= medium sand.
Map 6.3a. Location of Storm Damage Reduction projects (active, awaiting funding, or pending study), dredge disposal sites (approved areas), jetties, groins, and designated CBRA zones, northern coastal area of North Carolina.
Map 6.3b. Location of Storm Damage Reduction projects (active, awaiting funding, or pending study), dredge disposal sites (approved areas), jetties, groins, and designated CBRA zones, central coastal area of North Carolina.
Map 6.3c. Location of Storm Damage Reduction projects (active, awaiting funding, or pending study), dredge disposal sites (approved areas), jetties, groins, and designated CBRA zones, southern coastal area of North Carolina.
Map 6.4. Location of phosphate districts (known concentrations of phosphate deposits) on the continental shelf off North Carolina (from Riggs and Manheim 1988).
Map 6.5. Areas where mechanical harvest for clams (clam kicking, hydraulic dredge) and crabs (crab dredging) is authorized in estuarine waters of North Carolina.