CHAPTER 4. SUBMERGED AQUATIC VEGETATION

4.1. DESCRIPTION AND DISTRIBUTION

Definition

Submerged aquatic vegetation (SAV) is a fish habitat dominated by one or more species of underwater vascular plants. The North Carolina Marine Fisheries Commission (MFC) and Coastal Resources Commission (CRC) define SAV as:

"…those habitats in public trust and estuarine waters vegetated with one or more species of submerged vegetation such as eelgrass (*Zostera marina*), shoalgrass (*Halodule wrightii*), and widgeon grass (*Ruppia maritima*). These vegetation beds occur in both subtidal and intertidal zones and may occur in isolated patches or cover extensive areas. In either case, the bed is defined by the presence of above-ground leaves or the below-ground rhizomes and propagules together with the sediment on which the plants grow. In defining beds of submerged aquatic vegetation, the Marine Fisheries Commission recognizes the Aquatic Weed Control Act of 1991 (G.S. 113A-220 et. seq.) and does not intend the submerged aquatic vegetation definition and its implementing rules to apply to or conflict with the non-development control activities authorized by that Act" [MFC rule 15A NCAC 03I .0101 (20)(A) and CRC rule 15A NCAC 07H .0208 (6)].

Although not specifically listed in the definitions, SAV beds may also be vegetated with freshwater species such as native wild celery (*Vallisneria americana*) and sago pondweed (*Potamogeton pectinatus*). Submerged aquatic vegetation is included as a Critical Habitat Area under MFC rules [MFC rule 15A NCAC 03I .0100 (b)(20)]. The SAFMC classifies SAV as Essential Fish Habitat for peneaid shrimp, red drum, and snapper/grouper species. Although the MFC and CRC definitions may include areas with only SAV roots or propagules, SAV habitat could also occur on bottom temporarily lacking any SAV structures between patchy SAV beds or where conditions are currently unfavorable for growth, but have historically supported SAV. Therefore, for purposes of this plan, SAV habitat is defined as "bottom recurrently vegetated by living structures of submerged, rooted vascular plants, (i.e., roots, rhizomes, leaves, stems, propagules), as well as temporarily unvegetated areas between vegetated patches."

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

Description

Submerged aquatic vegetation habitat includes marine, estuarine and riverine vascular plants that are rooted in sediment. Although SAV sometimes occurs intertidally or extends to the water's surface, these plants are generally submerged and cannot survive if removed from the water for any length of time (Hurley 1990). Leaves and stems have specialized thin-walled cells (aerenchyma) with large intercellular air spaces to provide buoyancy and support in an aquatic environment. Leaves and stems are generally thin and lack the waxy cuticle found in terrestrial plants. The lack of a waxy cuticle increases the exchange of water, nutrients, and gases between the plant and the water (Hurley 1990). The extensive root and rhizome system anchors the plants, and also absorbs nutrients (Thayer et al. 1984). Reproduction occurs both sexually and asexually (i.e., vegetatively).

Habitat for SAV in North Carolina consists of two types of SAV communities, both of which are important to coastal fisheries – one in higher salinity estuarine waters and another in lower salinity to freshwater systems (Table 4.1). Estuarine species that occur in North Carolina include eelgrass (*Z. marina*), shoalgrass (*H. wrightii*), and widgeon grass (*R. maritima*). Eelgrass is a temperate species at the southern limit of its Atlantic coast range in North Carolina. In contrast, shoalgrass is a tropical species that reaches its northernmost extent in the state. Widgeon grass has a wide salinity range and grows in both fresh water and high salinity environments, although it occurs most commonly in moderate salinities (about 15 ppt). The co-occurrence of these three SAV species is unique to North Carolina, resulting in high coverage of shallow bottoms in North Carolina's estuaries (Ferguson and Wood 1994). These three species form biological and physical assemblages referred to as seagrass meadows (SAFMC 1998a). Seagrass meadows are often defined by a visible boundary marking unvegetated and vegetated bottom varying in size from small isolated patches of plants less than a meter (<3 ft) in diameter to continuous meadows covering many acres. Low salinity species that occur in North Carolina include native wild celery (*V. americana*), non-native Eurasian milfoil (*Myriophyllum spicatum*), bushy pondweed (*Najas guadalupensis*), redhead grass (*P. perfoliatus*), and sago pondweed (*P. pectinatus*) (Ferguson and Wood 1994). There is slightly greater SAV species diversity in coastal riverine systems than marine systems in North Carolina (Odum et al. 1984).

Seagrass habitat supports other types of aquatic plants in addition to submerged grasses. Macroalgae (benthic, drift, and floating forms) often co-occur with SAV and provide similar ecological services, but the plant taxa have distinctly different growth forms and contrasting life requirements (SAFMC 1998a). Macroalgae grow faster than SAV and do not require unconsolidated substrate for anchoring extensive root systems. Because of this growth pattern, macroalgae do not provide as much sediment stabilization as submerged rooted vascular plants. Their leaves are also less rigid than those of submerged rooted vascular plants, thus reducing their function as substrate for attachment and as a source of friction for sediment deposition. Macroalgal genera include salt/brackish (*Ulva, Codium, Gracilaria, Enteromorpha*) and freshwater (*Chara* and *Nitella*) species. Macroalgae common to the rivers of the Albemarle Sound system include the charophytes (*Chara* spp.). In addition, the macroalgae *Ectocarpus* and *Cladomorpha* grow on salt marsh flats (Mallin et al. 2000a) and in association with SAV beds (Thayer et al. 1984).

Epibiota are another important component of SAV habitat. Epibiota are organisms that attach or grow on the surface of a living plant and may or may not derive nutrition from the plant itself. Micro- and macroalgae (i.e., seaweed) can grow on the leaves of SAV. Invertebrates attached to the SAV leaves include protozoans, nematodes, polychaetes, hydroids, bryozoans, sponges, mollusks, barnacles, shrimps and crabs.

Table 4.1. Average environmental conditions at locations where submerged aquatic vegetation occurred in coastal North Carolina, 1988-1991. [Source: Ferguson and Wood 1994]

	Environmental parameter					
	Salinity (ppt)		**Secchi depth m (ft)**		**Water depth m (ft)**	
SAV species	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**
HIGH SALINITY SEAGRASS						
Eel Grass	10 - >36	26	0.3 - 2.0 (1.0 - 6.6)	1.0 (3.3)	0.4 - 1.7 (1.3 - 5.6)	1.2 (3.9)
Shoal Grass	8 - >36	25	0.4 - 2.0 (1.3 - 6.6)	1.0 (3.3)	0.1 - 2.1 (0.3 - 6.9)	0.8 (2.6)
Widgeon Grass	0-36	15	0.2 - 1.8 (0.7 - 5.9)	0.7 (2.3)	0.1 - 2.5 (0.3 - 8.2)	0.8 (2.6)
LOW SALINITY SEAGRASS						
Redhead Grass	0-20	1	0.4 - 1.4 (1.3 - 4.6)	0.9 (3.0)	0.4 - 2.4 (1.3 - 7.9)	0.9 (3.0)
Wild Celery	0-10	2	0.2 - 2.0 (0.7 - 6.6)	0.6 (2.0)	0.2 - 2.3 (0.7 - 7.6)	1.0 (3.3)
Eurasian Watermilfoil	0-10	2	0.2 - 1.4 (0.7 - 4.6)	0.6 (2.0)	0.5 - 2.4 (1.6 - 7.9)	1.1 (3.6)
Bushy Pondweed	0-10	1	0.2 - 2.0 (0.7 - 6.6)	0.7 (2.3)	0.5 - 1.7 (1.6 - 5.6)	1.0 (3.3)
Sago Pondweed	0-9	2	0.2 - 0.4 (0.7 - 1.3)	0.3 (1.0)	0.6 - 0.9 (2.0 - 3.0)	0.8 (2.6)

The three-dimensional shape of SAV habitat can be quite variable, ranging from highly mounded, patchy beds several yards wide, to more contiguous, low-relief beds (Fonseca et al. 1998). Leaf canopies formed by the seagrasses range in size from a few inches to more than three feet (0.91 m) tall. The structural complexity of an SAV bed also varies somewhat because of the growth form of the species present (SAFMC 1998a). While leaf density tends to be higher in contiguous beds than in patchy SAV habitat, below-ground root mass is often higher in patchy beds (Fonseca et al. 1998). Patchiness in seagrass bed distribution can result from new beds sprouting from seed or from existing beds that are fragmented by high wave energy or currents (Thayer et al. 1984). The rate that an area of unvegetated bottom can become vegetated may vary on the scale of days or decades, depending on the species and the physical conditions (Fonseca et al. 1998). Consequently, to maintain patchy seagrass beds, an area of shallow soft bottom must be maintained that is at least two times greater than the area of actual SAV coverage (Fonseca et al. 1998). Despite the difficulty of defining the boundaries of seagrass beds, unvegetated bottom between nearby adjacent patches is included as a component of patchy SAV habitat since rhizomes may be present and the beds “move” around with patterns of sediment erosion and deposition (Fonseca et al. 1998). Patchy habitats provide many ecological functions similar to continuous beds (Murphey and Fonseca 1995; Fonseca 1996b).

The dynamic nature of seagrass beds has important implications for fisheries habitat. Seagrass habitat can change at a scale of hours to decades (Fonseca et al. 1998; SAFMC 1998a). Therefore, one should consider historical as well as current SAV occurrence to determine locations of viable seagrass habitat (SAFMC 1998a). Seagrass abundance and biomass fluctuate seasonally (Dawes et al. 1995). In North Carolina, annual meadows of eelgrass are common in shallow, protected estuarine waters in the winter and spring when water temperatures are cooler. However, in the summer when water temperatures are above 25 – 30°C (77 – 86°F), shoalgrass is more abundant, and eelgrass thrives only where water temperatures are lower (i.e., deeper areas and tidal flats with continuous water flow (SAFMC 1998a).

Habitat requirements

Beds of SAV occur in North Carolina in subtidal, and occasionally intertidal, areas of sheltered estuarine and riverine waters where there is unconsolidated substrate (loose sediment), adequate light exposure on the bottom, and moderate to negligible current velocities or turbulence (Thayer et al. 1984; Ferguson and Wood 1994). The factors generally considered to limit the success of SAV are light, salinity, wave energy, and nutrients. Specific habitat requirements for individual species are presented in Table 4.1.

The primary factor controlling distribution of SAV is the penetration of light through the water column (Goldsborough and Kemp 1988; Duarte 1991; Kenworthy and Haunert 1991; Dennison et al. 1993; Stevenson et al. 1993; Virnstein and Morris 1996). Availability of light to SAV is determined by water clarity, also known as "transparency." Water clarity can be quantified indirectly by measuring turbidity (nephelometric turbidity units or NTU) or secchi depth (maximum depth where a standard object can be seen by the human eye), or directly by measuring the amount of sunlight that penetrates through the water and reaches the leaves of underwater grasses. At a minimum, seagrasses require 15-25% of the light that is available on the water's surface to reach them (Dennison and Alberte 1986; Kenworthy and Haunert 1991; Bulthius 1994; Fonseca et al. 1998). If less light is available, photosynthesis is limited, reproduction may be inhibited, and growth and survival of the submerged vegetation can not be sustained.

Water clarity can be reduced by natural substances in the water column, such as dissolved organic matter (e.g., humics), suspended particulate matter (e.g., sediment and minerals), detritus, and algae. As the water column becomes more turbid and less transparent, light attenuation (absorption and scattering of light by particles in the water column) increases. Water color also affects light penetration. For example, dissolved organic matter such as tannic acid (produced naturally in swamp waters via breakdown of detritus) and lignins (produced naturally as well as artificially, such as through wood pulp mill processing) strongly absorbs blue light. Seagrasses generally cannot survive below a certain depth because of light limitations. Therefore, as water clarity declines, SAV beds in deeper waters are lost first. In coastal North Carolina, SAV can grow in water up to 2.5 m (8.20 ft) deep and secchi depths averaging approximately one meter (3.28 ft) (Ferguson and Wood 1994) (Map 4.1).

Light and water quality requirements for SAV in Chesapeake Bay were reevaluated and revised in 2000 by the Chesapeake Bay Program in a technical synthesis (EPA 2000). These requirements are listed in Table 4.2 by salinity regime. The primary limiting factor is light; sufficient light must reach the SAV so that photosynthesis can occur. The EPA partitions available light into two categories. The "water column light requirement" refers to the amount of light penetrating through the water column. The "light at leaf requirement" refers to the amount of light that can penetrate the leaf surface due to epibiotic coverage. Environmental conditions that allow adequate light penetration for SAV survival are total suspended solids (TSS) less than 15 mg/l and chlorophyll *a* less than 15*u*g/l. No secchi depth or turbidity values were recommended. In contrast, preliminary bio-optical modeling suggests that the water conditions required for seagrass survival may be less stringent in North Carolina's North River relative to conditions in the Chesapeake Bay (P. Biber, NMFS, pers. com., 2003). Specifically, the maximum values of TSS and chlorophyll *a* that can occur at any given depth and still allow SAV survival may be somewhat higher than that needed in Chesapeake Bay. Greater tidal current magnitude (causing the prolonged suspension of relatively larger particles) and decreased absorption/scattering capacity of phytoplankton species and sediment types specific to North Carolina may be responsible for the observed regional differences (P. Biber, NMFS, pers. com., 2003). Given certain combinations of turbidity and nutrients, North Carolina's current standards may not be adequate to sustain SAV (P. Biber, NMFS, pers. com., 2003). *Additional estuaries should be modeled to determine environmental requirements for SAV over a broader scale and to determine if changes in EMC water quality standards are needed.*

Table 4.2. Recommended primary and secondary submerged aquatic vegetation habitat requirements for the Chesapeake Bay and its tidal tributaries classified by salinity regimes. [Source: Funderburk et al. 1991; EPA 2000]

		Primary Requirements		**Secondary Requirements[2]**			
Salinity regime (ppt)	**SAV growing season**	**"Light at leaf" requirement[1]**	**Water column light requirement[1]**	**Total suspended solids (mg/l)**	**Chlorophyll *a* (ug/l)**	**Dissolved inorganic phosphorus (mg/l)**	**Dissolved inorganic nitrogen (mg/l)**
Tidal fresh	April-October	>9%	>13%	<15	<15	<0.02	none
0.5 - 5.0	April-October	>9%	>13%	<15	<15	<0.02	none
5.0 - 18.0	April-October	>15%	>22%	<15	<15	<0.01	<0.15
18.0 - 30+	March-May, Sept.-Nov.	>15%	>22%	<15	<15	<0.02	<0.15

[1] Assessed with percent light at the leaf and percent light through the water parameters. All habitat requirements are independent of restoration depth.

[2] Secondary requirements are used to determine possible reason for non-attainment of primary requirement.

Field sampling of SAV beds in North Carolina between 1988 and 1991 found that occurrence of SAV in the study area was related to water depth, water clarity as measured by secchi depth, and salinity. This study did not measure light attenuation or percent light availability (Ferguson and Wood 1994). Environmental conditions where SAV species occurred are listed in Table 4.1. In the area sampled, average depth of SAV occurrence ranged from 2.63–3.94 ft (0.8–1.2 m), depending on the species. The maximum depth of observed presence, regardless of species, was 7.87 ft (2.4 m) (Ferguson and Wood 1994). Data indicated that freshwater SAV had a somewhat greater tolerance to turbidity than salt and brackish seagrasses, since they were found in areas of similar water depths to high salinity grasses, but secchi depths were less (Ferguson and Wood 1994). This feature supports other research (Funderburk et al. 1991) showing that salt/brackish seagrasses require slightly greater water clarity (secchi depth >1.0 m, or 3.28 ft) than freshwater SAV (secchi depth >2.63 ft or 0.8 m).

Other physical and chemical factors that impact SAV include salinity, nutrients, and wave exposure. The average salinity for freshwater SAV is between 1 and 2 ppt, while the average salinity for salt/brackish SAV ranges from 15 to 26 ppt (Ferguson and Wood 1994) (Table 4.1). Widgeon grass occurs in both high and low salinity waters, with an average salinity of 15 ppt. Salt/brackish SAV requires less than 0.15 mg/l of dissolved inorganic nitrogen and less than 0.01 mg/l of dissolved inorganic phosphorus (Funderburk et al. 1991). The majority of nitrate used by SAV is derived from the sediment, rather than the water column (Thayer et al. 1984). Contiguous beds of eelgrass or other species of SAV rarely occur in windswept areas or where currents are strong (>20-40 cm/s) (Thayer et al. 1984; Fonseca et al. 1998). Work was done in Core Sound by Fonseca et al. (1998) to analyze the effect of wave exposure and currents on SAV coverage. They found significant relationships, with percent cover of SAV decreasing with increasing relative wave exposure indices or current speed. *This information could be used to determine habitat suitability for SAV restoration in Core Sound. A similar process could be conducted in other areas, particularly low salinity areas, where large losses of SAV have historically occurred. Alternative measures of restoration site suitability could be investigated in areas where the Fonseca wave exposure model has yet to be tested (P. Biber, NMFS, pers. com., 2003; <http://www.marine.unc.edu/Paerllab/research/seagrass/field_experiments.htm>, 2003).*

Below is a brief description of the habitat and plant characteristics of the five submerged grasses common to North Carolina's brackish to freshwater systems and the three submerged grasses common to high salinity estuarine waters (Hurley 1990). Widgeon grass is included with high salinity grasses, but it can tolerate low salinity as well.

High salinity grasses

- Eelgrass (*Zostera marina*): Grows in fine muds, silts, and loose sand in high salinity waters and can tolerate high energy waters (Thayer et al. 1984). Reproduces vegetatively from October to June, and sexually from December to April. Present primarily as a seed-bank from July to November (P. Biber, NMFS, pers. com., 2003). Rhizomes rarely deeper than 5 cm (1.97 inches). Can spatially coexist in beds with *Halodule* in North Carolina, but is dominant from winter to summer, with lower densities during summer months relative to that of *Halodule* (Thayer et al. 1984).
- Widgeon grass (*Ruppia maritima*): Tolerates a wide range of salinity regimes. Slightly brackish to moderately brackish and high salinity. Found growing with eelgrass. Widgeon grass is more common in shallow areas, with eelgrass in deeper waters. Spreads vegetatively from creeping rhizome during April - October. Rare occurrence reported in fresh water. While more common on sandy substrates, is also found on soft, muddy sediments. High wave action damaging to slender stems and leaves.
- Shoalgrass (*Halodule wrightii*): Forms dense beds and can occur in very shallow water. Known for its relative tolerance to desiccation (drying out) once rooted. Rhizomes situated fairly shallow in sediment and may extend into the water column with attached shoots. Almost exclusively vegetative (asexual) reproduction from April through October and sexually on a very rare basis in spring and summer (J. Kenworthy and P. Biber, NMFS, pers. com., 2003). Due to its clonal reproductive strategy, genetic diversity may be quite limited and, as such, populations may be at particular risk to changing estuarine conditions (P. Biber, NMFS, pers. com., 2003). May co-occur with *Zostera* and dominates mid-summer through fall in North Carolina, after which *Zostera* becomes relatively more predominant (Thayer et al. 1984).

Low salinity grasses

- Bushy Pondweed or Southern Niad (*Najas quadalupensis*): Present in small freshwater streams. Also tolerates slightly brackish waters. Sand substrates preferred. Can grow in muddy soils. *Najas* spp. requires less light than other SAV species.
- Wild celery (*Vallisneria americana*): Primarily a freshwater species occasionally found in moderately brackish waters. Coarse silt to slightly sandy soil. Tolerant of murky waters and high nutrient loading. Can tolerate some wave action and currents compared to more delicately leaved and rooted species. Similar in appearance to eelgrass.
- Sago pondweed (*Potamogeton pectinatus*): Fresh to moderately brackish. Tolerates waters with high alkalinity. Associated with silt-mud sediments. Long rhizomes and runners provide strong anchorage to the substrate. Capable of enduring stronger currents and greater wave action than most other SAV.
- Redhead grass (*Potamogeton perfoliatus*): Found in fresh to moderately brackish and alkaline waters. Grows best on firm muddy soils and in quiet waters with slow-moving currents. Because of its wide leaves more susceptible to being covered with epibiotic growth then the more narrow leaved species. Securely anchored in the substrate by its extensive root and rhizome system.
- Eurasian watermilfoil (*Myriophyllum spicatum*): This species inhabits fresh to moderately brackish waters. Affinity for water with high alkalinity and moderate nutrient loading. Grows on soft mud to sandy mud substrates in slow moving stream or protected waters. Not tolerant of strong tidal currents and wave action. Over-wintering lower stems provide early spring cover for fish fry before other SAV species become established. *M. spicatum* is a non-native, invasive species, estimated to cover over 4000 acres in Currituck and Albermarle sounds during the 1990s

(DWR 1996), and is classified by the North Carolina Board of Agriculture as a Class B noxious weed [02 NCAC 48A .1702].

Distribution

Seagrasses occur along the entire east coast of the United States, with the exception of South Carolina and Georgia, where high freshwater input, high turbidity, and large tidal amplitude (vertical tide range) inhibit their occurrence. The published estimate for estuarine SAV in North Carolina is approximately 200,000 acres (80,937 hectares (ha)) (Field et al. 1988 and Orth et al. 1990; cited in Ferguson and Wood 1994), or about 7% of the estuarine bottom in North Carolina. Based on interpretation and ground-truthing by NOAA of remotely-sensed imagery taken during 1985-1990, the total area of visible SAV was approximately 134,000 acres (Ferguson and Wood 1994). Since these surveys were conducted at least 14 years prior to 2004, the current spatial distribution and acreage of SAV in the area sampled are likely to vary. In general, along the Atlantic coast, North Carolina supports more SAV than any other state, except for Florida (Table 4.3). Based on Ferguson and Wood (1994), areas of visible SAV were mapped as follows:

SAV Distribution in North Carolina

Eastern Pamlico Sound	90,000 acres (36,421.71 ha)
Core Sound	19,938 acres (8,068.62 ha)
Albemarle Sound	4,439 acres (1,796.39 ha)
Croatan-Roanoke sounds	926 acres (374.74 ha)
Neuse River estuary	91 acres (36.83 ha)
Pamlico River estuary	378 acres (152.97 ha)
Western Pamlico Sound	83 acres (33.58 ha)

Table 4.3. Estimated spatial coverage of submerged aquatic vegetation in coastal waters of mid- and south Atlantic states.

	SAV		
State	**acres**	**hectares**	**Source**
Florida	2,658,290	1,075,772	Sargent et al. (1995)
North Carolina	200,000	80,937	Field et al. 1988 and Orth et al. 1990; cited in Ferguson and Wood (1994)
Chesapeake (VA and MD)	59,300	23,998	Funderburk et al. (1991)

In 1981, visible SAV in Core and Bogue sounds covered 19,458 acres (7,874.37 ha) within a total water area of 104,840 acres (42,427.24 ha) (19% SAV coverage; Carraway and Priddy 1983). However, acreage for these areas may be underestimated, particularly in low salinity riverine areas, since aerial photography at the scale utilized (1:24,000) may not be able to detect some SAV due to the relatively small patch size and high turbidity of the water.

Physical and chemical conditions of the Albemarle-Pamlico estuarine system provide suitable habitat conditions for SAV growth. The extensive barrier islands of the Outer Banks protect the east side of Pamlico Sound and other smaller sounds within the Albemarle-Pamlico estuary. Tides and currents are primarily wind-driven. The western shorelines of the sounds are less protected from the wind, but, because of the reduced currents and tidal amplitude, they also support SAV growth where water depth is shallow enough and water quality conditions allow. Aside from physical and chemical limitations, survival of SAV can be affected by excessive covering of drifting macroalgae or epiphytes, and disease outbreaks like eelgrass wasting disease (Stephan and Bigford 1997). In Florida Bay, uncommon yet large-scale grazing events by urchins (Rose et al. 1999) restricted seagrass distribution. It is unknown if similar overgrazing incidents by these or other organisms have affected seagrasses, recently or historically, in North Carolina.

SAV habitat in coastal North Carolina occurs mostly in sandy and muddy sediment and high salinity waters along the estuarine shoreline of the Outer Banks, with sparse cover along much of the mainland shores of the estuarine system (Ferguson et al. 1989). Within the Coastal Plain, freshwater SAV is locally abundant in some larger blackwater streams and rivers, but is rare in small blackwater streams (Smock and Gilinsky 1992) due to shading from forested wetlands and irregular flows typical of low order streams. Freshwater SAV can be extensive in some low-salinity back bays and lagoons (Moore 1992), and may also occur in coastal lakes such as Lake Mattamuskeet.

Limited SAV distribution and lower species diversity of SAV have been associated with areas of low salinity (5–18 ppt) (Ferguson and Wood 1994). Seagrasses in these regions may be limited by long wind fetch (the horizontal distance over which wind blows, creating waves), lack of protected shallow bottom, extreme currents, reduced light availability, and excessive nutrient enrichment. Shoalgrass or eelgrass were not observed in western Pamlico Sound or the Pamlico or Neuse estuaries despite acceptable salinity ranges. The presence of SAV in low salinity waters (<5 ppt) of Albemarle and Currituck sounds and their tributaries was relatively low (Ferguson and Wood 1994). Map 4.2 shows SAV areas mapped by Carraway and Priddy (1983) and Ferguson and Wood (1994). The area of SAV habitat within CHPP management units is presented in Table 4.4.

Table 4.4. Submerged aquatic vegetation (SAV) coverage within Coastal Habitat Protection Plan management units (MU) based on mapping work of Carraway and Priddy (1983) and Ferguson and Wood (1994).

MU	SAV		Total Water*		% SAV
	acres	hectares	acres	hectares	
Albemarle	13638	5519	604417	244599	2.26
Core/Bogue	36189	14645	167946	67966	21.55
Neuse	96	39	112817	45655	0.08
Pamlico	83403	33752	1020522	412991	8.17
Tar/Pamlico	392	159	117123	47398	0.33
Total	133718	54114	2022825	818608	6.61

* Water area includes broad, open waters detected on 1:100,000 scale USGS topographic maps

Estuarine SAV occurs sporadically west of Bogue Inlet to the border with South Carolina, but these areas have not been suitably photographed (Ferguson and Wood 1990). Small areas of SAV habitat have been observed in the past few years by DMF biologists in the New River, Alligator and Chadwick bays, Topsail Sound and inside Rich's Inlet (M. Allison, DMF, pers. com., 2002). Other studies reporting distribution of salt/brackish SAV include Davis and Brinson (1983) for Currituck Sound, Brinson and Davis (1976) for the Chowan River, and DWQ (1998) for the Neuse River. The U.S. Fish and Wildlife Service's National Wetland Inventory (NWI) Program has mapped some SAV in inland fresh waters. However, this information has not been summarized by CHPP management unit or region.

4.2. ECOLOGICAL ROLE AND FUNCTIONS

Submerged aquatic vegetation provides important structural fish habitat and other important ecosystem functions in estuarine and riverine systems in coastal North Carolina. The SAFMC (1998a) recognized SAV as an essential fish habitat because of five interrelated features of seagrass meadows – primary production, structural complexity, modification of energy regimes, sediment and shoreline stabilization, and nutrient cycling. Water quality enhancement and fish utilization are especially important functions of SAV relevant to the enhancement of coastal fisheries.

Productivity

Seagrass habitat is dominated by dense stands of primary producers – underwater grasses. These grasses produce large quantities of organic matter. Estimates of daily production for eelgrass beds rank among the most productive of marine plant habitats (Thayer et al. 1984). The typical biomass of growing SAV beds (leaves + rhizomes) in North Carolina was reported as 57–391 g (dry weight)/m^2 (Thayer et al. 1984; Twilley et al. 1985). Primary productivity is derived approximately equally from above-ground and below-ground growth.

Because of their high rates of primary production and particle deposition, SAV beds are important nutrient sources (nutrients are exported from the bed to other users) and sinks (nutrients are retained within the bed by the plant structure (leaves and roots), especially during high growth periods (SAFMC 1998a)). Thayer et al. (1984) concluded that SAV beds in high velocity areas are sources of organic matter, while SAV in low current areas are sinks of organic matter (detritus). Important sources of organic matter produced by SAV habitat include the SAV plant tissue, epibiotic organisms attached to SAV leaves, microalgae and macroalgae present on sediments among SAV plants, and dissolved organic matter released during metabolism (SAFMC 1998a). Ultimately, large amounts of nutrients, originally retained by SAV, are exported via secondary production and trophic interactions by animals as they depart nursery areas following larval and juvenile development (Thayer et al. 1984).

Attached epibiota contribute substantially to the total productivity of SAV beds (Thayer et al. 1984) and are an important food source for fish and invertebrates. Approximately 25% of the average annual above-ground biomass of an eelgrass bed in the Newport River was attributable to epiphytes (Penhale 1977). In certain instances, total biomass of epibiota can actually exceed that of the SAV leaves to which the epibiota are attached. While they may increase primary productivity of the habitat, epibiota may also significantly reduce productivity of individual plants if coverage is too extensive (Thayer et al. 1984). Dillon (1971) estimated that epiphytic macroalgae constitute 10% of the total SAV biomass in a North Carolina estuary, although seasonal variability in macroalgal abundance corresponds to seasonal fluctuations in eelgrass biomass (Thayer et al. 1975; Penhale 1977).

Exported matter represents a large portion of total SAV production in salt/brackish SAV beds in North Carolina (Thayer et al. 1984). When grasses die and decompose, the detrital material is broken down by invertebrates, zooplankton and bacteria, and energy is transferred through the estuarine detrital food web. Because SAV breaks down much slower than algae, SAV decomposition generally does not cause anoxic conditions (Hurley 1990). Decomposed SAV matter and its associated bacteria are actually of greater importance as a food source for fish than the living SAV leaves (Thayer et al. 1984).

Ecosystem enhancement

System enhancement includes any positive effect on other habitats provided by proximity to SAV. Because seagrasses are rooted in the substrate and provide long-term submerged structure in estuaries and coastal rivers, system enhancement is one of their more important ecological functions. Some of these functions include (SAFMC 1998a):

- Modification of water flow and reduction in wave turbulence,
- Accelerated deposition of sediment and organic matter,
- Physical binding of sediments beneath the canopy, and
- Nutrient cycling between the water column and sediments.

The network of leaves, stems, and roots of an SAV bed oxygenate the surrounding water, filter and trap sediments, and utilize excess nutrients (nitrogen and phosphorus) dissolved in the water (Thayer et al.

1984). These processes increase water clarity and improve conditions for further SAV growth. The absorption of excess nitrogen and phosphorus by SAV can reduce the frequency of nuisance algal blooms and resultant anoxic waters when the blooms die off and decay (Thayer et al. 1984). During active periods of growth and leaf turnover, nutrients cycle rapidly between plant tissues and the organisms that feed upon them. This retention and controlled release of nutrients improves water quality down current and also provides a stable foraging base for herbivores, detritivores, and secondary consumers (Thayer et al. 1984).

Suspended sediment is removed from the water column when the frictional drag of water flowing over the leaves and stems reduces water velocity and wave energy, allowing sediment to settle out of the water column. Roots bind and stabilize the substrate, partially inhibiting bottom sediments from being resuspended (Thayer et al. 1984; SAFMC 1998a). This deposition enhances the productivity, stability, and biodiversity of SAV. The rhizomes and roots of SAV stabilize the substrate and form large pools of organic matter and structural matrices supporting many species that live in the sediment (Kenworthy and Thayer 1984). Particle deposition and burial, as well as formation of organic matter in the sediment, facilitate temporary and permanent retention of nutrients within SAV beds by the roots and rhizomes (Thayer et al. 1984; SAFMC 1998a). These functions improve water quality down current of the bed by removing suspended solids from the water column, improving water clarity, and adding dissolved oxygen. The presence of SAV is both a maintainer and indicator of good water quality (Virnstein and Morris 1996; R. Ferguson, NMFS, pers. com., 2000). *However, the exact relationship between the extent of SAV coverage and water quality is unknown and requires research.*

Seagrasses have a stabilizing effect on substrate and nearby shorelines by absorbing wave energy (Fonseca 1996a). By buffering nearshore turbulence, SAV beds reduce erosion along adjacent shorelines, which also helps stabilize marsh edge habitat (Stephan and Bigford 1997). Where water turbulence is too great for SAV to persist, its buffering capacity over time may be limited (Thayer et al. 1984). Although oyster reefs are relatively more resilient to turbulence than SAV beds, both oyster reefs and SAV beds provide, among other ecosystem functions, shoreline protection (Day et al. 1989; Fonseca 1996a).

Fish utilization

Many species occupy SAV at some point in their life cycle (Thayer et al. 1984). However, the importance of SAV depends on its relative contribution to a particular species' refuge, spawning, nursery, foraging, and corridor needs. For instance, some species use SAV directly as a food source (consumption of living plant material) while other species rely on SAV indirectly, by hunting for prey along the edge of the beds, or finding refuge from predation while foraging within the beds.

Submerged aquatic vegetation was classified as “Essential Fish Habitat” (EFH)[42] by the SAFMC (1998a) due to its habitat heterogeneity, plant biomass, and surface area, all of which enhance animal abundances. Because of the different temporal abundance patterns in SAV species, feeding habitat and refuge for fish and shellfish are provided almost year-round for estuarine-dependent species (Steel 1991). In North Carolina, the species for which SAV is considered EFH include red drum; brown, white, and pink shrimp; and species in the snapper-grouper complex. While bay scallops are not managed by the SAFMC, the SAV habitat that bay scallops share with federally managed species is technically considered EFH (K. Abrams, NOAA, pers. com., 2003). Several important forage species also depend on SAV habitat. The two EFH categories for SAFMC-managed species are salt/brackish and freshwater SAV.

Salt/brackish grasses

In brackish and high salinity estuaries, fish and invertebrates use SAV, to varying extents, as nursery, refuge, foraging, and spawning locations. Studies in eelgrass beds in the Newport River estuary and

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[42] EFH is defined by SAFMC as those waters and substrate necessary to fish for spawning breeding, feeding, or growth to maturity.

vicinity reported between 39 and 56 fish species during regular monitoring conducted in the 1970s (Thayer et al. 1975; Adams 1976; Thayer et al. 1984). Results from DMF's juvenile fish sampling in seagrass beds in eastern Pamlico and Core sounds found over 150 species of fish and invertebrates from 1984 to 1989, of which 34 fish and six invertebrate species were important commercial species (DMF 1990). Adult fish as well as juveniles utilize grass beds. Composition of long haul seine catches sampled by DMF reported at least 49 adult fish species collected over seagrass beds in eastern Pamlico Sound (DMF 1990). In addition to fish, over 70 benthic invertebrate species have been reported from eelgrass beds along the east coast (Thayer et al. 1984). Bay scallops occur almost exclusively in SAV beds (Thayer et al. 1984), and spotted seatrout (*Cynoscion nebulosus*), an important recreational and commercial species in North Carolina, is also highly dependent on the quantity and quality of SAV habitat (Vetter 1977). Species whose relative abundances at some life stage are generally higher in SAV than in other habitats, or otherwise show some preference for SAV, are referred to as "SAV-enhanced." A partial list of species utilizing SAV habitat in North Carolina is compiled in Table 4.5.

Several studies along the coasts of the Atlantic Ocean and the Gulf of Mexico have demonstrated significantly greater species richness and numerical abundance of organisms in seagrass beds compared to unvegetated bottom (Thayer et al. 1975; Summerson and Peterson 1984; Heck et al. 1989; Ross and Stevens 1992; Irlandi 1994; ASMFC 1997a; Wyda et al. 2002). In Back Sound, N.C., a study found that fish and shrimp were more abundant on artificial SAV beds than on shell bottom (Elis et al. 1996). In the Newport River estuary (Core/Bogue MU), rough silverside (*Membras martinica*) and smooth dogfish (*Mustelus canis*) were classified as abundant in SAV beds, but were rare or absent in marsh channel and intertidal flats (Thayer et al. 1984). Blue crabs and pink shrimp were significantly more abundant in SAV beds than in adjacent shallow non-vegetated estuarine bottoms in North Carolina, Alabama, and Florida (Williams et al. 1990; Murphey and Fonseca 1995). In the Chesapeake Bay region, juvenile crabs grow faster, occur more densely, and have higher survival rates in SAV beds (Heck and Orth 1980; Chesapeake Bay Commission 1997). In addition to natural fluctuations in SAV coverage and density, the utilization of SAV by fish and invertebrates differs spatially and temporally due to species distribution ranges, time of recruitment, and life histories (Nelson et al. 1991).

Some studies have shown a linkage between the abundance and species composition of fish and the quantity and quality of SAV. Abundance, biomass, and species richness of fish assemblages in two spatially distant areas of the Mid-Atlantic Bight (Buzzards Bay and Chesapeake Bay) were significantly higher at sites with higher levels of seagrass complexity (biomass >100 wet g/m^2; density >100 shoots/m^2) compared to sites with reduced seagrass complexity (Wyda et al. 2002).

Table 4.5. Partial list of species documented to use submerged aquatic vegetation habitat.

Species*	**SAV Functions [1]**					**Fishery [2]**	**Stock status [3]**
	Refuge	**Spawning**	**Nursery**	**Foraging**	**Corridor**		
ANADROMOUS & CATADROMOUS FISH							
River herring (blueback herring and alewife)	X	X	X	X	X	X	O-Albemarle Sound, U-Central/Southern
Sturgeon spp.				X		X [4]	O
Striped bass				X		X	V- Albemarle Sound, Atlantic Ocean, O- Central / Southern
American eel	X		X	X	X	X	U
ESTUARINE AND INLET SPAWNING AND NURSERY							
Bay scallop	**X**	**X**	**X**	**X**		**X**	**C**
Blue crab	**X**		**X**	**X**	**X**	**X**	**C**
Grass shrimp	**X**	**X**	**X**	**X**			
Hard clam	**X**		**X**	**X**		**X**	**U**
Red drum	**X**		**X**	**X**	**X**	**X**	**R**
Rough silverside	**X**	**X**	**X**	**X**			
Spotted seatrout	**X**		**X**	**X**	**X**	**X**	**V**
Weakfish	**X**		**X**	**X**	**X**	**X**	**V**
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY AREA							
Atlantic croaker	**X**		**X**	**X**	**X**	**X**	**C**
Atlantic menhaden	X		X	X	X	X	V
Brown shrimp	**X**		**X**	**X**	**X**	**X**	**V**
Southern flounder			X	X		X	O
Spot	X		X	X	X	X	V
Striped mullet	**X**		**X**	**X**	**X**	**X**	**C**
White shrimp	X		X	X	X	X	V
MARINE SPAWNING , HIGH SALINITY NURSERY							
Black sea bass	X		X	X	X	X	O- south of Hatteras, V- north of Hatteras
Bluefish			X	X		X	R
Gag	**X**		**X**	**X**	**X**	**X**	**V**
Tautog	**X**		**X**	**X**	**X**	**X**	**O**
Kingfish spp.	X		X	X	X	X	U
Pinfish	**X**		**X**	**X**	**X**	**X**	
Pink shrimp	**X**		**X**	**X**	**X**	**X**	**V**
Sheepshead	X		X	X	X	X	C [5]
Smooth dogfish				**X**		**X**	**O**
Spanish mackerel			X	X		X	V
Summer flounder			**X**	**X**		**X**	**V**

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

[1] Sources: ASMFC (1997a), Thayer et al. (1984), NOAA (2001), Peterson and Peterson (1979), NMFS (2002), and SAFMC (1998)

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

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

[4] Species under harvest moratorium

[5] Status of reef fish complex as a whole. Sheepshead has not been evaluated in NC.

Abundance, biomass, and species diversity at sites with reduced seagrass complexity were more variable than at sites with high seagrass complexity. Sites with lower SAV complexity also had a greater proportion of pelagic species than bottom, structure-oriented species. In Florida Bay, changes in animal abundances were compared between the 1980s and 1990s when significant changes in SAV coverage also occurred (Matheson et al. 1999). The major change observed was a decrease in abundance of small fish and invertebrates that live within the seagrass canopy (such as crustaceans and pipefish) with decreases in SAV coverage, while larger demersal predatory fish (such as toadfish and sharks) increased. Similarly, increases in SAV density were characterized by significant increases in crustaceans. In another study in Florida Bay, greater reductions in pink shrimp abundance occurred in seagrass die-off areas relative to adjacent undamaged or recovering areas (Roblee and DiDomenico 1992). In North Carolina, comparison of pink shrimp densities in continuous and patchy seagrass beds found significantly greater shrimp densities in continuous beds than in patchy grass beds (Murphey and Fonseca 1995). Although patchy seagrass beds did not support as great a density of shrimp, they still functioned as important habitat for pink shrimp (Murphey and Fonseca 1995). The presence of SAV may be the reason pink shrimp can overwinter and survive, supporting a spring pink shrimp fishery in North Carolina (T. Murphey, DMF, pers. com., 2003). The pink shrimp fishery comprises a large portion of North Carolina's annual shrimp landings. In contrast, in South Carolina and Georgia, where no SAV is present, pink shrimp comprise an extremely small portion of the shrimp landings. Similarly, survival of blue crabs in a New Jersey estuary was attributed to the ability of the species to overwinter in SAV (Wilson et al. 1990).

Freshwater grasses

In coastal riverine systems, such as the Chowan River, finfish, shellfish, and crustaceans utilize SAV as nursery areas for refuge and protection, particularly minnows, killifish, juvenile striped bass, largemouth bass, and molting/soft shelled blue crabs (Hurley 1990). Floating leaf aquatic vegetation is particularly important in freshwater systems such as the Roanoke River (Cooper et al. 1994). Freshwater SAV is also an important habitat for estuarine species, in streams and some lakes, such as Lake Mattamuskeet. Common species using freshwater SAV is shown below and in Table 4.5. *More research is needed to improve scientific understanding of the relationship of SAV to fresh and brackish water fish species*.

COMMON FISH SPECIES THAT UTILIZE FRESHWATER SAV
(Sources: Rozas and Odum 1987; SAFMC 1998a; NOAA 2001)

Freshwater species

In freshwater streams and lakes

Minnows
White perch
Juvenile American eel
Pirate perch
Inland silversides
Yellow perch
Largemouth bass
Bluegill ("bream")

Estuarine species

In freshwater streams
Juvenile menhaden
Spot
Blue crab
Grass shrimp
Bay anchovy

In freshwater lakes
Striped mullet
Tidewater silverside
White perch

Anadromous Species
Striped bass
Shad (American and hickory)
River herring

Specific biological functions

Refuge

The physical structure of SAV conceals prey from visual detection, restricts the pursuit and capture of prey by predators and protects small organisms from adverse weather conditions (Savino and Stein 1989; SAFMC 1998a; Rooker et al. 1998). High densities of seagrass shoots and increased plant surface area inhibit predator efficiency and provide shelter to prey (Coen et al. 1981 for grass shrimp; Prescott 1990 for bay scallops; Orth 1992 for blue crabs). Moreover, the predation mortality rate of red drum in unvegetated habitat was up to four times greater than that observed in SAV habitat (Rooker et al. 1998). Light levels are reduced within the canopy as well, further concealing small prey (SAFMC 1998a). In addition, cryptic species that have the ability to change color use camouflage to decrease their visibility within the SAV habitat.

Since beds of SAV can be as tall as one meter (3.28 ft), their leaf canopies provide a three-dimensional structure containing a large volume of sheltered water. The blades of SAV can increase the available surface area for colonization by an order of magnitude when compared to adjacent unvegetated habitats (SAFMC 1998a). In the sediment, the roots and rhizomes of SAV also provide a matrix for meiofauna [43] and macrofauna [44] (Kenworthy and Thayer 1984). Organisms utilize the leaves, roots, and rhizomes, as well as the space between shoots, for refuge from predators and adverse environmental conditions (SAFMC 1998a). Hard clams are significantly more abundant in SAV beds than in adjacent unvegetated bottom due to changes in food supply, predation, and sediment stability (Peterson and Peterson 1979; Peterson 1982; Irlandi 1994, 1997).

The refuge value of SAV also depends on its corresponding value for predators. For example, benthic macroinvertebrates can be more vulnerable to crab predation in SAV because crabs use SAV for refuge from avian predators (Skilleter 1994; Micheli and Peterson 1999; Beal 2000). Summerson and Peterson (1984) hypothesized that nocturnal bottom predators living on sand flats use SAV during the day to avoid their own predators. Predator–prey interactions in SAV habitat are a function of canopy structure, shoot and blade density, and surface area (SAFMC 1998a). Moreover, the relative value of SAV as refuge is also likely to change over time, not only with seasonal patterns of SAV abundance (Prescott 1990) but also during the course of the day. As previously mentioned, mobile epibenthic[45] organisms that typically hide from predators in seagrass beds during daylight may later feed and successfully avoid visually-searching predators on unvegetated flats under the cover of darkness (Summerson and Peterson 1984).

Spawning

Coastal aquatic species that spawn in SAV include blueback herring, mummichog, bay scallop, grass shrimp, and rough silversides (Stephan and Bigford 1997; NOAA 2001). The roots and stems of SAV also provide substrate for attachment of eggs and invertebrates (such as barnacles, sea squirts, and bryozoans). Seasonal patterns of reproduction and development of many temperate fishery species coincide with seasonal abundance of seagrass (Stephan and Bigford 1997). Estuarine-dependent spring-summer spawners utilize SAV habitat in the spring and summer for forage and refuge, residing there prior to emigrating to the mouths of bays and rivers, inlets, or coastal ocean shelf waters to spawn (SAFMC 1998a; Luczkovich et al. 1999). Some of these species include red drum, weakfish, spotted sea trout, silver perch, and southern kingfish. *Additional research is needed on how SAV affects spawning success of these or other species.*

Nursery

Submerged aquatic vegetation is a primary nursery habitat for numerous species of fish and invertebrates

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[43] Very small benthic animal, 0.1 – 0.5 mm in size, about the size of a sand grain, important food source for larval fish
[44] Small benthic animal larger than 0.5 mm in size; e.g., mole crabs, amphipods
[45] Organism that lives at the surface of the bottom, as opposed to burrowed below bottom; e.g., starfish, flounder

along the Atlantic coast (Thayer et al. 1984). Important commercial and recreational species present in SAV as juveniles in the spring and early summer include gag, black sea bass, snappers, weakfish, bluefish, mullet, spot, Atlantic croaker, red drum, flounders, and herrings (SAFMC 1998a). The roots and stems of SAV provide ideal protection and food for developing fish and invertebrate larvae (Ambrose and Irlandi 1992; SAFMC 1998a). Larvae of spring-summer spawning fish (such as anchovies, gobies, pipefish, spotted seatrout, weakfish, hard clams and southern kingfish) use SAV habitat (SAFMC 1998a). In North Carolina, where SAV is present year-round, some larval and early juvenile finfish, molluscan, and crustacean species are also present much of the year (SAFMC 1998a). Both bay scallops and hard clams attach to seagrass blades temporarily before settling on the bottom (Thayer et al. 1984; SAFMC 1998a). While hard clams also utilize other substrates, such as oysters and shell hash, bay scallops almost exclusively utilize seagrass, and are therefore highly dependent on its existence for successful recruitment[46] (Thayer et al. 1984; Stephan and Bigford 1997). Juvenile blue crabs prefer shallow water areas with structure, including SAV, tidal marsh, shell bottom and detritus (Etherington and Eggleston 2000). In the Albemarle-Pamlico system, the majority of initial recruitment occurs in seagrass beds around inlets behind the Outer Banks, unless there is a major storm event. In years with large storm events, crabs are dispersed into additional lower salinity habitats (Etherington and Eggleston 2000). At sites near Ocracoke and Hatteras inlets, the density of juvenile blue crabs increased significantly with increasing seagrass blade length, but not with biomass or shoot abundance (Etherington and Eggleston 2000). *More research is needed on the use of SAV for larval fish and invertebrate settlement and as a nursery; by determining optimal conditions for such species, additional success criteria may be developed for seagrass restoration projects.*

Several groups of fish use SAV as nursery habitat. Spot, croaker, shrimp, and pinfish are estuarine-dependent offshore spawners that inhabit SAV habitat as early juveniles in winter and early spring. Submerged aquatic vegetation has been recognized as critical nursery habitat for pink shrimp in North Carolina (Murphey and Fonseca 1995). Silver perch, spotted seatrout, and red drum are estuarine spawners, and their juveniles are present later in the spring and in the summer. Estuarine-dependent reef fish use seagrass meadows as juveniles, prior to moving offshore. For example, juvenile gag (*Mycteroperca microlepis*) use SAV habitat for refuge and foraging on crustaceans before moving to offshore hard bottom as a secondary nursery area (Ross and Moser 1995). Juvenile sheepshead (<50 mm or <2.17 in) and juvenile gray snapper also utilize SAV beds (Pattilo et al. 1997). However, juvenile gray snapper are rare in most interior waters of North Carolina, and they are common only in Pamlico Sound from July to November (Nelson et al. 1991).

Some studies have found that juvenile red drum, as well as pink shrimp and sand seatrout (*Cynoscion arenarius*) were more abundant in SAV beds compared to marsh edge, inner marsh, shell bottom, or shallow non-vegetated bottoms (Minello 1999); other studies disagree (Stunz et al. 2002). The degree of preference by red drum for SAV is somewhat uncertain since they also utilize estuaries lacking SAV, such as in the southern portion of North Carolina and South Carolina. However, red drum eggs, larvae, postlarvae, and juveniles have been documented in SAV beds in North Carolina which is particularly important as a foraging area for young (1-2 year old) red drum (Mercer 1984; Reagan 1985; Ross and Stevens 1992). Abundance of juvenile red drum in SAV beds varies seasonally and spatially, being more common in grass beds during summer months and in grass beds that are close to spawning areas (Zieman 1982; DMF, unpub. data). Also, juvenile red drum were more abundant in edge habitat with patchy grass coverage than in homogeneously vegetated sites (Mercer 1984; Reagan 1985; Ross and Stevens 1992). Data from DMF red drum seine surveys and tagging studies indicate high abundance of late young of year red drum in shallow high salinity grass beds behind the Outer Banks (DMF 2001c). Rooker et al. (1998) also examined post-settlement patterns by several species in SAV habitat and found densities of red drum, spotted seatrout and silver perch were highest for very small individuals (4-8 mm or 0.1-0.3 in). These fish utilized SAV habitat at smaller sizes and remained in SAV longer than spot and croaker. Spot and

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[46] Successful settlement, and in some cases metamorphosis, of pelagic larvae into their juvenile habitat. Also refers to successful movement of juveniles into adult habitat or fishery.

croaker seemed to utilize SAV habitat more as temporary residents, migrating to alternate habitats shortly after their arrival (Rooker et al. 1998).

Studies have shown that recruitment of small juvenile fishes corresponded to periods of greatest SAV coverage (SAFMC 1998a). In freshwater SAV beds, Paller (1987) determined that the standing stock of larval fish was 160 times higher than in adjacent open waters, and that larvae would concentrate in the interior of aquatic beds rather than in the transition zones between habitats. This difference suggests that large SAV beds provide better refuge for larvae than an equivalent area of patchy SAV. Several studies in estuarine SAV beds also found that juvenile hard clams, pink shrimp, and blue crabs were more abundant in large or continuous SAV beds than in small or patchy SAV beds, whereas the opposite was found for adult pink shrimp and grass shrimp (Murphey and Fonseca 1995; Irlandi 1997; Eggleston et al. 1998). This finding suggests that habitat fragmentation could have a significant impact on recruitment of some species.

Noble and Monroe (1991) analyzed environmental variables associated with relative abundance and diversity of juvenile finfish and crustacean from the DMF nursery area database for the Albemarle-Pamlico estuarine area. Critical habitat criteria, based on core group characterizations, were developed to better define and protect critical fishery habitats functioning as nursery areas for economically important finfish and crustaceans. The study recommended classifying a “new type” of nursery area characterized by higher salinities, SAV presence, and a somewhat different species composition than the typical Albemarle-Pamlico Peninsula nursery areas (such as Rose Bay). *Criteria should be developed and implemented to assist with designation of SAV beds as Strategic Habitat Areas by the MFC.*

Foraging

Submerged aquatic vegetation supports numerous complex food webs and serves as a foraging area for fish and invertebrate species. Nutrient sources associated with SAV include, but are not limited to, dissolved organic matter, epibiota, plants and animals living on and in the sediment surrounding SAV rhizomes, and living SAV tissues (Adams and Angelovic 1970; Thayer et al. 1975; SAFMC 1998a). The majority of organisms in SAV habitat utilize secondary production from epibiotic communities, benthic algae, organic detritus, and bacteria rather than direct consumption of SAV (Day 1967; Adams and Angelovic 1970; SAFMC 1998a).

Benthic invertebrates (e.g., worms, snails) and fish graze on other benthic animals that live in the sediment among SAV roots and stems. These small invertebrates and fish, in turn, provide food for larger fish and shellfish adapted to feed upon them. Benthic algae are important forage items for pelagic-feeding planktivorous fishes (such as silversides) that inhabit the grass beds at night (Meyer 1982). Eelgrass and shoalgrass are highly productive (Thayer et al. 1984), and their stems and leaves provide an important substrate for attachment by small organisms that contribute to the overall productivity of the system and serve as forage for larger organisms (Carr and Adams 1973).

Only a few fish species are known to consume submerged grasses directly. These include pinfish (*Lagodon rhomboides*), spot (*Leiostomus zanthurus*), filefish (*Monocanthus hispidus*), and toadfish (*Opsanus tau*). However, SAV comprised only 1 – 12% of their diet (Thayer et al. 1984). Rather than direct grazing, most fish and invertebrates benefit from SAV indirectly by foraging on small plants and animals associated with the vegetation. In contrast, many species of birds (e.g., black brant, *Branta bernicla;* Canada goose, *Branta canadensis;* and widgeon, *Anas penelope*) graze directly on freshwater SAV. The green sea turtle and West Indian manatee consume salt/brackish SAV (SAFMC 1998a). Green turtles appear to be more abundant in seagrass than in unvegetated areas in North Carolina, based on data from incidental occurrence in pound nets (SAFMC 1998a). Abundant green turtles closely crop seagrass and greatly reduce the input of organic matter and nutrients to sediments (Jackson et al. 2001). An absence of SAV grazers can result in excessive growth and accumulation of substrate suitable for proliferation of slime mold, which is largely responsible for SAV wasting disease [47] (Jackson et al. 2001).

Fisheries production by SAV results primarily from predator consumption of the plants and animals that live on the seagrass (leaves and roots/rhizomes), benthic algae, and organic detritus (SAFMC 1998a). Large predatory fish, such as Atlantic stingrays, flounders, bluefish, sandbar and other sharks, weakfish, red drum, spotted seatrout, and blue crabs eat small fish, crustaceans and invertebrates that live in seagrass beds (Thayer et al. 1984). Although large finfish predators represent only a small proportion of the fish biomass in SAV habitat, they can be important in structuring seagrass communities and, at times, can uproot grasses or alter the substrate (e.g., cownose ray; Orth 1975).

Corridor and connectivity

For some species, such as blue crabs, SAV can function as a safe corridor between habitats, thereby reducing predation (Micheli and Peterson 1999). In marshes where adjacent SAV was removed, the abundance of grass shrimp declined 27% and was significantly higher where SAV was not removed (Rozas and Odum 1987). Submerged aquatic vegetation adjacent to marshes also provides a refuge at low tide for organisms associated with marsh edge habitat at high tide (Rozas and Odum 1987). Consequently, the catch of fish was also higher at sites with both marsh and SAV, rather than at marsh-dominated sites. In a North Carolina estuary where SAV occurred adjacent to intertidal marsh, pinfish showed more movement, were more abundant, and weighed more than those in areas where SAV was not present adjacent to the marsh edge. These findings indicate that SAV provided a safe passage and offered additional food resources (Irlandi and Crawford 1997). Similarly, another study in North Carolina found that adult fish abundances were greater where marsh, seagrass, and oyster reefs co-occurred, rather than areas with shell bottom alone or shell bottom with marsh (Grabowski et al. 2000). The corridor function of SAV may also apply to other small predators that are more susceptible to predation in open water. Although red drum have a strong association with marsh edge habitat in Gulf coast estuaries (Minello 1999; Stunz et al. 2002), information is lacking for North Carolina. *Examination of the relationship between juvenile red drum abundance in SAV and marsh edge habitat and the effect of spatial connectivity on habitat use should be conducted to support management of this important species.*

4.3. STATUS AND TRENDS

Status of submerged aquatic vegetation habitat

When SAV beds are subjected to human-induced impacts in addition to natural stressors, large-scale losses of SAV may occur (Fonseca et al. 1998). Such losses of seagrass beds have been as high as 50% in Tampa Bay, 43% in northern Biscayne Bay, and 30% in the northern portion of Indian River Lagoon (all in Florida), and as much as 90% in Galveston Bay, Texas, and Chesapeake Bay (Taylor and Saloman 1968; Kemp et al. 1983; Pulich and White 1991; Smith 1998). In North Carolina, SAV loss has not been quantified, but anecdotal reports indicate that the extent of SAV may have been reduced by as much as 50%, primarily from the mainland side of the coastal sounds (North Carolina Sea Grant 1997; J. Hawkins, DMF, pers. com., 2003; B.J. Copeland, MFC, pers. com., 2003). However, since low salinity SAV tends to exhibit large fluctuations from year to year, and because no mapping has been conducted to quantify the reported SAV changes, the extent of loss is uncertain.

In North Carolina, data on trends in SAV distribution are limited to qualitative information or only certain areas of the coast. For example, while SAV currently is concentrated along the sound side of the Outer Banks (Ferguson et al. 1989), elderly fishermen and fishermen’s journal accounts from the late 1800s describe extensive beds of SAV in many coves along the mainland where it is absent today (Mallin et al. 2000a). Seagrass wasting disease devastated eelgrass populations throughout the North Atlantic, including North Carolina, between 1930 and 1933, dramatically disrupting estuarine systems. Higher

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[47] see Threats section

water temperatures apparently stressed the seagrasses, making them more susceptible to the slime mold protist *Labryinthula* (Steel 1991). Healthy eelgrass beds were generally re-established by the 1960s. Some specific information on SAV changes in Currituck Sound and the Tar-Pamlico and Neuse rivers is given below and is depicted in Table 4.6.

Table 4.6. Timeline of major trends in abundance of submerged aquatic vegetation (SAV) in North Carolina estuaries. [Source: Davis and Brinson 1990; Steel 1991]

Year	Changes in submerged aquatic vegetation in coastal North Carolina
1918 - 1919	Major decline in Currituck Sound due to turbidity from opening Albemarle and Chesapeake Canal
1930	Major decline in eelgrass in Pamlico, Core, and Bogue sounds from seagrass wasting disease
1952	Full recovery in Currituck Sound from improved management of canal locks
1955	Four hurricanes cause major loss to SAV in Currituck Sound, but it recovers within two years
1960	Eelgrass in Pamlico, Core, and Bogue sounds mostly recovered from seagrass wasting disease
1962	Decline in native freshwater species in Currituck Sound due to saltwater intrusion and displacement by non-native Eurasian watermilfoil
1975	SAV common in upper Pamlico River estuary
1985	Significant declines in SAV in upper Pamlico River estuary (1% of pre-1970s levels), western Pamlico Sound, and Neuse River estuary due to excessive sediment loading
1990	Improved erosion control methods and/or weather patterns result in slight recovery of SAV in Neuse and Pamlico estuaries
2002	Reports of increased SAV in Albemarle Sound, possibly due to drought conditions improving water clarity

Currituck Sound has a significant historical record of observations and/or biomass of brackish water SAV (Davis and Brinson 1983). Studies have documented the status of SAV in Currituck Sound since 1909, including a major decline around 1918 attributed principally to increased turbidity (Bourn 1932; Davis and Brinson 1983). The locks of the Albemarle and Chesapeake Canal were opened during this period (Davis and Brinson 1983). This canal connects the Norfolk (Virginia) Harbor at the mouth of the Chesapeake Bay with Currituck Sound, by way of the North Landing River. From 1914 to 1918 the canal was deepened and widened, and the North Landing River was dredged extensively. In 1932, operation of the canal locks was modified, improving the situation, and the SAV began to recover. Submerged vegetation had fully recovered by 1951, with the highest production of submerged aquatic plants in the Currituck-Back Bay system since 1918 (Davis and Brinson 1983). During 1954 and 1955, the occurrence of four hurricanes along the North Carolina coast increased turbidities via sediment suspension and resulted in widespread destruction of plant beds (Dickson 1958). Submerged vegetation in other hurricane-impacted areas of North Carolina may have been similarly affected. However, the SAV community recovered rapidly, as growth was considered good in 1957 (Davis and Brinson 1983). After a severe nor'easter storm in 1962, saltwater intrusion in the sound raised the average salinity slightly (4.4 ppt) and caused major reductions in freshwater SAV biomass (Davis and Brinson 1983). Another likely factor contributing to reductions in northern Currituck Sound was the accumulation of silty, semiliquid dredge spoil in the North Landing River and the resulting turbidity (Davis and Brinson 1983).

As the native SAV beds recovered after 1962, Eurasian watermilfoil (a non-native species) began to spread across Currituck Sound from its northern extremities (Davis and Brinson 1983). The spread of the exotic plant was probably encouraged by improved water clarity caused by dry conditions and higher salinities after 1962 (Davis and Brinson 1983). Before 1962, native sago pondweed and wild celery were the dominant and subdominant SAV species (Davis and Brinson 1983). By 1973, Eurasian watermilfoil had replaced sago pondweed as the dominated aquatic plant species, followed by bushy pondweed (Davis and Brinson 1983). After a severe storm in 1978, bushy pondweed was virtually eliminated, and total macrophyte biomass was 42% less than in 1973 (Davis and Brinson 1983). Again, the reductions in SAV biomass were associated with extreme turbidity and turbulence associated with the severe weather during the early growing season in 1978. It is apparent from this historical record that SAV coverage and biomass are greatly affected by weather events, site conditions, and human activities that affect turbidity and salinity. This relationship is true not only for Currituck Sound, but also for other coastal water bodies containing SAV.

In the upstream half of the Pamlico River estuary, SAV was common until the mid-1970s (Davis and Brinson 1976; Davis and Brinson 1990). By 1985, SAV biomass had been reduced to about 1% of its pre-1970s biomass (Davis and Brinson 1990). Tidal freshwater SAV (primarily wild celery) was historically abundant in western Pamlico Sound (Copeland et al. 1984), and to a lesser extent, the Neuse River, with pondweeds (*Potamogeton* spp.) and widgeon grass also common (Steel 1991). Submerged aquatic vegetation in these areas declined significantly during the mid-1980s, under excessive sediment loading, and then experienced a resurgence as modest improvements in erosion control promoted an increase in water clarity (Mallin et al. 2000a). This information is derived mostly from many recent complaints about abundant SAV around dock areas (Neuse) and from visual observations and fishermen's anecdotal accounts (Pamlico) (Mallin et al. 2000a). *Regular mapping efforts should confirm the status of SAV in western Pamlico Sound and its tributaries. Ideally, the experimental design should allow inference regarding the cause of any observed changes.*

In 1998, presence and distribution of SAV in the Neuse River estuary were assessed by DWQ, in coordination with NMFS and EPA using aerial photography and field ground-truthing (DWQ 1998). The study area extended from the N.C. Highway 43 bridge north of New Bern downstream to Rattan Bay where the river opens to Pamlico Sound, about 48 river miles (77 km). Distribution of SAV in the Neuse River estuary is shown in Maps 4.3a and 4.3b. Eleven species of SAV were documented at the sample sites. The SAV occurred in multiple small patches along both the north and south shorelines of the Neuse River and its tributaries in water depths ranging from 0.5 to 1.4 m (1.6 – 4.6 ft). Roughly 514 acres (208 ha) of SAV were delineated. North of New Bern, *Nuphar lutea* was the prevalent species found. In the middle of the river, where most SAV occurred, coontail or hornwort (*Ceratophyllum* sp.) was the most common species, followed by wild celery. The largest patch of SAV occurred on the south shore of the river, downstream of the mouth of the Trent River. This large patch was dominated by wild celery. In the lower portion of the river, widgeon grass was most common. Results showed that SAV was present at four of five areas that had supported SAV in 1991, indicating there has not been a major decline in SAV abundance over the seven-year period on the Neuse. More SAV was identified in 1998 than in 1991. However, because of the different methodologies used, change in coverage cannot be accurately assessed.

Some recent, unquantified changes have been noted in SAV distribution and abundance in the Albemarle Sound area and Bogue Sound. Several large eelgrass beds have disappeared in the Intracoastal Waterway in the Morehead City area (Core/Bogue MU) following intensive use of herbicides to control macroalgal growth over the last ten years (Mallin et al. 2000a). During that same time period, large SAV beds near Harkers Island (Core/Bogue MU) have also disappeared following construction activity (Mallin et al. 2000a). In 1988, the shallow waters of Perquimans River were overgrown with dense stands of Eurasian watermilfoil and other species (Steel 1991) (Map 4.2). After Hurricane Floyd in 1999, those dense stands of milfoil had disappeared. Local commercial fishermen reported that the blue crabs had disappeared along with the grass. In 2002, DMF biologists noted high abundance of SAV throughout many shallow water areas of Albemarle Sound and its tributaries, especially in Perquimans River (S. Winslow, DMF, pers. com., 2002). The SAV was reportedly spreading upstream from the lower reaches of the rivers, near the main body of Albemarle Sound. *Research is needed to verify if a recovery of SAV has occurred and to determine if there is a spatial pattern of that recovery. If there is a pattern, special monitoring and protection should be afforded to those core areas from which SAV begins its recolonization.*

Coast-wide aerial photography of SAV combined with on-site sampling is the standard method for mapping SAV in coastal North Carolina and Chesapeake Bay. The method was last used in North Carolina in the late 1980s to early 1990s (Ferguson and Wood 1994). Regular aerial photography and mapping of the coastal area would provide the necessary information to determine status and trends in SAV distribution, coverage, and health over the long-term. *Coast-wide mapping should be repeated at regular intervals using similar methodology to the early 1990s mapping to determine the current location and quantity of SAV coverage and compare changes over time. In addition to maps of current SAV coverage, a comprehensive map of all potential SAV habitat should also be developed.*

A process to calculate relative wave exposure indices has been completed by NMFS for Core and Back sounds. This process allows identification of areas that have physical characteristics, such as water depth, wave exposure, and currents that are suitable for SAV colonization, which could include SAV habitat. *This process should be conducted in other areas of the coast to identify potential restoration sites for SAV.*

Status of associated fishery stocks

Inadequate data are available to assess if trends in SAV-enhanced fishery species are related to changes in SAV coverage. Of the species identified in Table 4.5 with a preference for SAV habitat, 13 stocks were evaluated for fishery status. The hard clam was assigned an Unknown status. Of the remaining 12 stocks with a designated status, two were designated Overfished (17%), four were Concern (33%), one was Recovering (8%), and five were Viable (42%) (SAFMC 2002; DMF 2003a; Figure 4.1). Specifically, smooth dogfish and tautog were listed as Overfished. The SAV-enhanced stocks given a Concern status included bay scallop, blue crab, Atlantic croaker, and striped mullet. Viable and Recovering stocks included red drum, spotted seatrout, weakfish, shrimp (brown and pink combined), gag, and summer flounder. Whereas much of the cause of declining stock status is attributed to overfishing, habitat loss and degradation can make a stock more susceptible to overfishing. Therefore, protection or enhancement of SAV habitat can be especially beneficial to SAV-enhanced species classified as Overfished or Concern, by maximizing recruitment and productivity.

Trends in fishery data indicate a decline in catch and effort for some prominent SAV-enhanced species. Landings data for bay scallops indicate a long-term decline in catch and effort (Figure 4.2). However, landings and fishery independent sampling indicated that this annual stock showed improved recruitment in Core and Bogue sounds in 2002 (DMF, unpub. data). Blue crabs also appear to be experiencing long-term declines in catch and effort, and possibly reduced abundance in some regions. More fishery-independent information and habitat change analysis are needed to determine the effect of SAV-coverage on the abundance of fish and invertebrates. *To obtain needed information on use and trends of fish utilization in SAV habitat, DMF staff should assess where additional juvenile fish sampling stations are needed and add these to existing sampling programs. Research should be conducted to better assess the relationships of bay scallop and blue crab to SAV and to investigate if long-term declining trends in these fisheries are related to declines in or degradation of SAV.*[48]

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[48] Relationships can be generally inferred from habitat studies, which are covered in the Ecological role and function section.

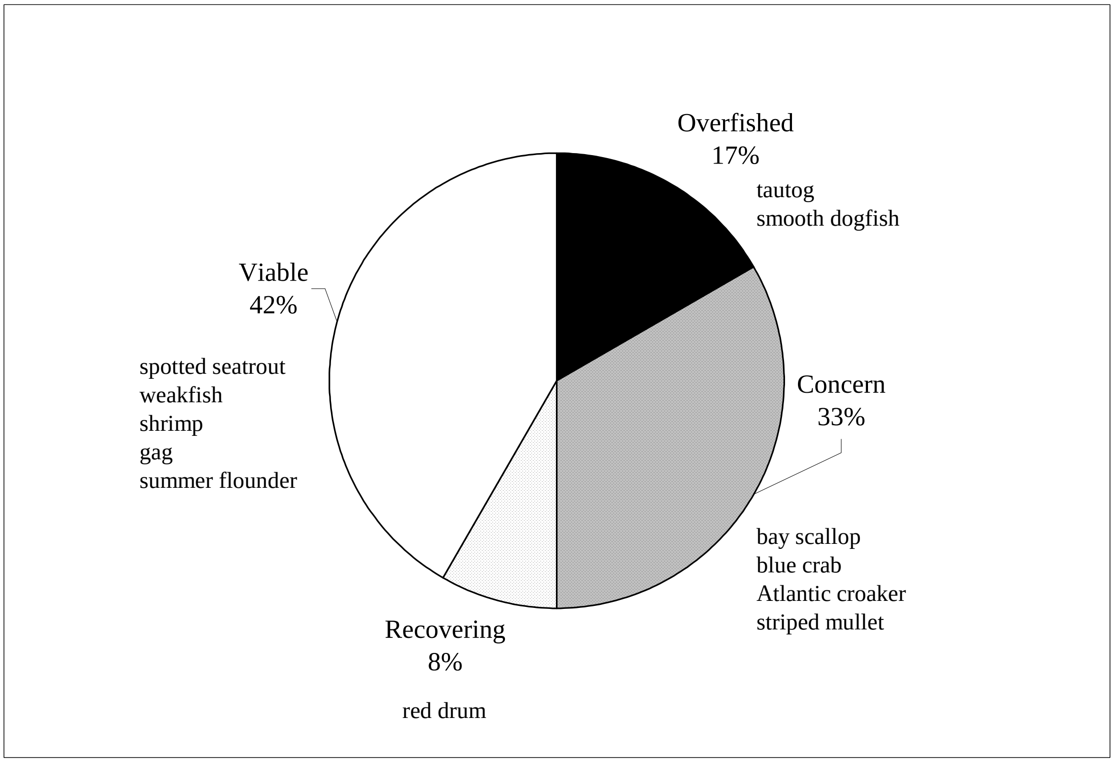

Figure 4.1. Percent of SAV-enhanced fishery stocks classified as Overfished, Concern, Viable, or Recovering in the 2003 stock status report. [Source: DMF 2003a]

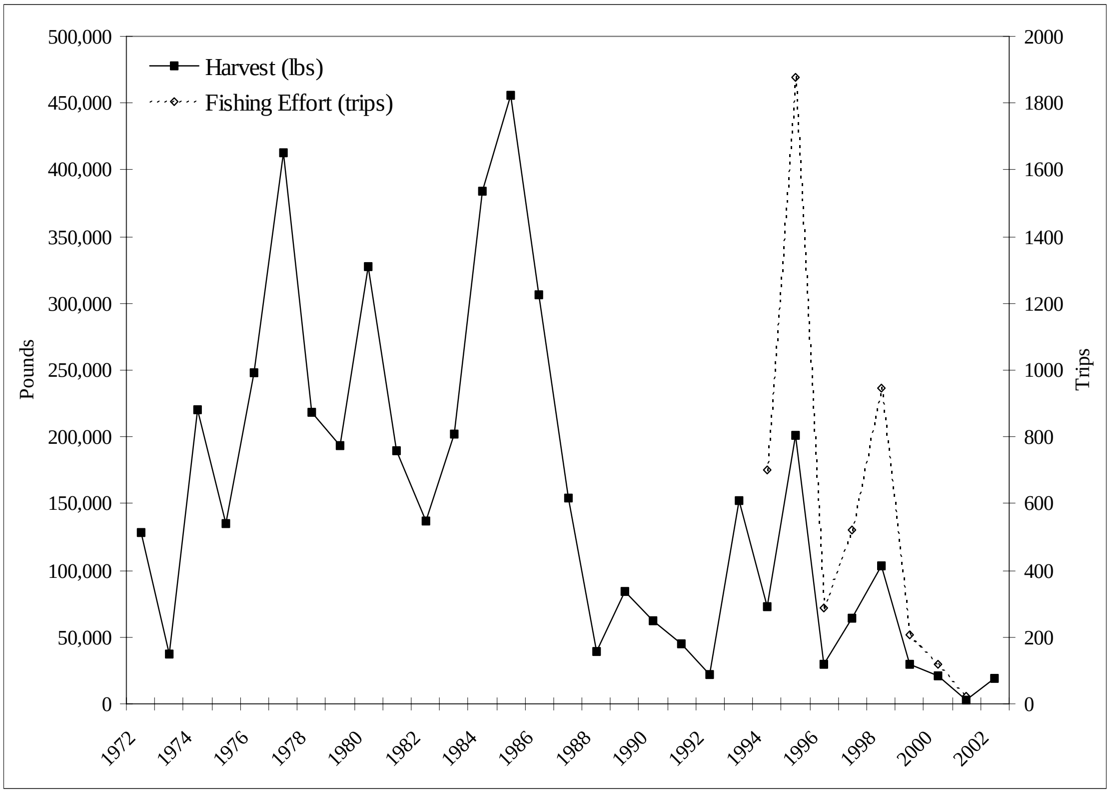

Figure 4.2. Annual commercial landings and fishing effort for bay scallops, 1972 – 2002. [Source: DMF, unpub. data]

Submerged aquatic vegetation restoration

Although protection, rather than mitigation or restoration, is the more environmentally sound and less costly management approach for long-term enhancement of SAV fisheries habitat (SAFMC 1998a), restoration of SAV beds in areas that historically supported this habitat is possible to offset past losses. Seagrass restoration techniques have been developed and evaluated by the NMFS. Depending on environmental variables, a similar faunal community can return, at the earliest, within two years (Fonseca et al. 1998). The success of replanting efforts is often gauged by an evaluation of "functional equivalency." As defined by Fonseca et al. (1998), an area has achieved functional equivalency when "a restored or mitigated system attains [ecological] functions the same as those of an unimpacted system in a similar setting." According to the authors, an impacted seagrass bed has the potential to become functionally equivalent, but not identical, to an undisturbed seagrass bed if a) it is at least equal in space to that of the original area prior to disturbance and b) the seagrass species composition is unchanged and persists after the disturbance. Based on review by Fonseca et al. (1998), the time needed to attain functional equivalency for seagrasses ranges dramatically, from less than two to more than 31 years. Seagrass shoot densities and canopy height can be used to determine when a restoration project has reached functional equivalency (Fonseca et al. 1998). Studies in Florida have found that SAV shoot densities approximately one third as dense as a natural bed supported similar animal densities (Fonseca 1996a; Fonseca 1996b). In North Carolina, beds having 30-40% SAV coverage had penaeid shrimp densities virtually indistinguishable from beds with continuous cover (Murphey and Fonseca 1995). The size of the restored SAV bed can also affect fish utilization. Some organisms, such as larval fish, juvenile blue crabs, and juvenile hard clams, were more abundant in large, contiguous beds than in smaller, patchy beds (Paller 1987; Irlandi 1997; Eggleston et al. 1998). However, even SAV habitats as small as 1-2 m^2 have significantly greater numbers of fish, shrimp, and crabs than found in adjacent sand areas (Fonseca et al. 1998).

Reference materials discussing planting techniques emerged prior to and during the 1970s, but major attention and financial support to study seagrass restoration did not develop until the early 1990s (Fonseca et al. 1998). Prior to that time, the variable track records of SAV mitigation projects, many of which were unpublished or not subject to peer review, discouraged its establishment as a management tool, even though suitable planting methods were available (Fonseca et al. 1998). There have been both failures and successes in seagrass planting (Stein 1984; Thayer et al. 1985). If SAV is not present in an area because of water quality conditions (e.g., insufficient light, excess nutrients), establishment of planted submerged grasses, without improving water quality, is likely to be unsuccessful. Furthermore, EPA (2000) stated that water quality conditions needed to restore underwater grasses are likely to be more stringent than conditions needed to support existing healthy SAV beds. Maintenance of existing beds should, therefore, be a higher priority than restoration. In order to maintain existing SAV habitat, more stringent water quality standards need to be established in those areas. [49]

Restoration of submerged aquatic vegetation is generally conducted for compensatory mitigation, mitigation banking, or research purposes. Benefits of SAV restoration include fish habitat enhancement, sediment and shoreline stabilization, and water quality enhancement. Compensatory mitigation is the replacement of a natural resource, such as a bed of SAV destroyed or severely degraded by a permitted action. Such replacement is often required by the enforcement of Section 404 of the Clean Water Act by the U.S. Army Corps of Engineers (COE) or by state regulations enforced by other regulatory agencies (DCM, DWQ). The intent is replacement of ecological functions such as water quality, habitat, and hydrology. Mitigation is usually also meant to replace an acreage equal to or greater than that which was lost or impacted (<http://dcm2.enr.state.nc.us >, May 2002). Based on data available through the Internet on SAV restoration and mitigation (<http://dcm2.enr.state.nc.us/ims/restsites/srchall.htm>, May 2002), there were 12 SAV restoration projects in Carteret and two in Onslow counties between 1978 and 1991. Of these 14 sites, 11 were considered "successful".

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[49] This approach is discussed in the water quality threats section.

Specifically, “success criteria” were identified by DCM as “those conditions which must be met for a mitigation site to be considered successful in order to receive a permit to impact those wetlands…[and the criteria] may include any combination of the following and often include all of the following: vegetation establishment, wildlife use and a hydrologic regime that is characteristic of the target wetland type” (<http://dcm2.enr.state.nc.us/Wetlands/defs.htm#habitat type>, Spring 2004). Three projects were done as N.C. Department of Transportation (DOT) mitigation, while the others were research projects conducted by NMFS. A total of 1.95 acres (0.79 ha) of bottom was restored to SAV by these projects. This area is relatively small compared to restored shell bottom areas. Seagrass restoration projects tend to be more limited due to the relatively high water quality conditions needed for survival of the plants. *Restoration goals for SAV habitat should be established, including goals for SAV acreage, abundance, and species diversity, considering historical distribution and estimates of potential habitat. However, protection of existing SAV beds should be given a high priority*.

4.4. THREATS AND MANAGEMENT NEEDS

Natural events and human-related activities may negatively impact the distribution and quality of SAV. Natural events may include regional shifts in salinity because of drought or excessive rainfall, animal foraging, storm events, cold temperatures or disease.[50] Human-related activities can be broken into two basic categories: physical and water quality. Submerged aquatic vegetation is extremely susceptible to physical disturbance because of its vulnerable location in shallow nearshore waters. Physical threats can negatively affect SAV by inflicting damage or mortality directly, as well as by indirectly influencing future survival, reproduction or establishment through alteration of preferred conditions (e.g., increased turbidity via bottom sediment resuspension). SAV is vulnerable to water quality degradation, and in particular to sedimentation, primarily because of its relatively high light requirements (Fonseca et al. 1998). Moreover, the timing of anthropogenic impacts can have important ramifications for SAV. For example, disturbances that remove eelgrass and their surrounding sediment during the summer and fall months may have the added consequences of eliminating the seed bank that will produce future season’s plants and of reducing genetic diversity (P. Biber, NMFS, pers. com., 2003). Human-related impacts to SAV habitat have been documented and summarized by the ASMFC (ASMFC 1997a), the Chesapeake Bay Program (1995), NMFS (Thayer et al. 1984; Fonseca et al. 1998), and others. Much of the information on threats is from these sources.

Physical threats

Channel dredging

Dredging and filling activities were at one time considered to have the greatest detrimental impact on SAV (Thayer et al. 1984). Dredging for creation or maintenance of navigational channels and inlets resulted in removal or destruction of existing grass beds. The change in bottom depth, bottom sediment characteristics, and water clarity that accompanies dredged channels prevents or discourages future growth or establishment of SAV (Stevenson and Confer 1978; Funderburk et al. 1991). SAV habitat can be destroyed if dredged material is placed directly on existing SAV. Potential SAV habitat can also be eliminated if unvegetated soft bottom is filled and converted to an upland spoil island, or dredged to an excessive water depth. The increased water depth in dredged channels reduces light penetration to the bottom, limiting the ability of SAV to colonize the area. In addition, dredged channels tend to refill with finer sediments (Thayer et al. 1984; Bishof and Kent 1990) that are easily resuspended by currents or boat wakes. The resulting chronic elevated turbidity and sedimentation can reduce light penetration to levels that reduce or eliminate productivity of adjacent grass beds and make colonization of unvegetated areas difficult (Thayer et al. 1984). Turbidity from dredging of fine sediments, such as mud bottom, is usually more severe and persistent than dredging of coarse sand bottom.[51]

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[50] Changes in SAV coverage due to changing salinity patterns were discussed in the Status and Trends section.

[51] Refer to the “Habitat Requirements” section for the light and sediment conditions needed for SAV colonization

Loss of SAV habitat from dredge and fill activities has been particularly severe in bays with major ports or metropolitan areas, such as Tampa Bay, Galveston Bay, and Chesapeake Bay (Taylor and Saloman 1968; Thayer et al. 1984). North Carolina's ports in Wilmington and Morehead City are small in comparison. No SAV occurs in the vicinity of the Wilmington port. In contrast, considerable SAV loss may have occurred in Morehead City when the port's turning basins and access channels were originally dredged, given that nearby, similar yet undredged areas within Bogue Sound support SAV. Maps 4.5a-b show the location of the ports, navigational channels and marinas in coastal North Carolina and their proximity to SAV. Because almost all of the eastern shoreline of Core Sound and the southern shoreline of Back Sound are undeveloped (Shackleford and Core banks), the grass beds in that area have not been highly impacted by channel dredging, marinas, or docks.

Current state and federal regulations minimize impacts to SAV from permitted dredge and fill activities, particularly those associated with private development, and have reduced the severity of this threat (SAFMC 1998a). Although dredging is currently prohibited in SAV beds, maintenance excavation "essential to maintain a traditional and established use" is approved if four criteria are met [15A NCAC 07H .0208]: "(i) the applicant demonstrates and documents that a water-dependent need exists for the excavation; (ii) there exists a previously permitted channel which was constructed or maintained under permits issued by the State or Federal government (if a natural channel was in use, or if a human-made channel was constructed before permitting was necessary, there shall be clear evidence that the channel was continuously used for a specific purpose); (iii) excavated material can be removed and placed in an approved disposal area without significantly impacting adjacent nursery areas and beds of submerged aquatic vegetation; (iv) the original depth and width of a human-made or natural channel will not be increased to allow a new or expanded use of the channel."

Although the COE maintains 6,992 acres (2,829.56 ha) of navigation channels in coastal North Carolina (COE, unpub. data), the quantity dredged in a typical year will likely amount to less than 1,000 acres, the majority of which is restricted to maintenance dredging in deep water ports and ocean inlets (J. Sutherland, DWR, pers. com., 2004). Nevertheless, some of these channels may be adjacent to or bisect SAV occurrence (Maps 4.5a-b). New public dredging projects that could potentially impact SAV continue to be proposed. For example, relocation of a ferry landing at the north end of Ocracoke Island might require dredging a new access channel through seagrass. Realignment of an existing navigational channel through Bogue Inlet as part of the Emerald Isle beach nourishment project could destroy existing SAV habitat directly and indirectly through changes in scouring patterns of inlet currents. Alternative proposals often require weighing the impact of one habitat versus another. As the coast becomes more developed, additional projects involving SAV impacts are likely to occur. *The DMF and MFC should continue to use existing permit review authorities and CRC and EMC should provide more protection to SAV within existing permitting authority to prevent or limit as much as possible direct or indirect impacts to SAV from all dredge and fill projects.*

Infrastructure

Other public works projects that can impact SAV include placement of infrastructure, such as bridge supports and fiber optic cables, on submerged lands. Bridge construction and replacement have resulted in SAV loss in several areas of Florida (Fonseca et al. 1998). In North Carolina, two bridge projects on the Outer Banks could result in SAV loss. Replacement of the Oregon Inlet bridge with a new bridge and extended causeway behind Pea Island could cause direct impacts to the grass beds west and south of the current bridge, as well as indirect impacts from changing current patterns and scouring. Also, a new bridge is proposed to cross the middle of Currituck Sound. The proposed location is in the vicinity of the largest concentration of SAV in Currituck Sound, but the project is in the early stages of development and could change substantially. Laying of fiber optic cables across submerged bottom can also damage SAV where trench excavation is used (Nero 2001).[52] Impacts to SAV can be minimized by use of directional drilling technology. This method involves drilling a small tunnel under the seafloor instead of dredging a trench from the seafloor surface. *Infrastructure projects that require SAV impacts should be avoided. Where impacts are unavoidable, SAV losses should be minimized and adequately compensated through mitigation, using methods recommended by NMFS for SAV restoration or creation. Such projects should be monitored over time to determine persistence of restored SAV beds.*

Boating activity

Direct physical impacts from propeller scarring, vessel wakes, and mooring scars have recently been identified nationally as a major and growing source of SAV loss (Sargent et al. 1995; ASMFC 1997a; Fonseca et al. 1998). Propeller scarring of SAV occurs when outboard vessels travel through water that is shallower than the draft of the boat. The propeller cuts the plants' leaves, roots, and stems, as well as creates a narrow trench through the sediment. The damaged area is referred to as a "prop scar" (Sargent et al. 1995). A "blow hole" may also be excavated where boaters attempt to rapidly power off the shallow bottom (Kenworthy et al. 2000). Mechanical disturbance to sediments damages the plant's rhizomes, which reduces plant abundance and cover for extensive periods of time, sometimes for many years. Recovery of SAV can take anywhere from two to 10 years, depending on the SAV species and local conditions, or in some cases, the habitat may never recover (Zieman 1976; ASMFC 2000). Once started, SAV damage can increase beyond the initial footprint of the prop scar due to physical scouring by tidal currents, storms, or biological disturbance such as crab and ray burrowing (Patriquin 1975; Townsend and Fonseca 1998). As long as the affected areas are unvegetated, their ecological value is reduced (Fonseca et al. 1998).

In some areas, particularly in Florida, watercraft have severely scarred seagrass beds (Sargent et al. 1995). Prop scarring was identified as an increasing problem in some areas of Chesapeake Bay as well (Funderburk et al. 1991). In both locations, increasing occurrence of prop scarring was associated with an increasing human population, as well as an increasing number of registered vessels (Hurley 1990; Sargent et al. 1995). Preliminary aerial observations of high salinity grass flats in North Carolina indicate that damage to SAV from propeller scarring is currently not a significant problem. However, as the human population along North Carolina's coast increases, so will the number of boats. From 1990 to 2000, the permanent population of Dare County, which borders most of the high salinity SAV in Pamlico Sound, increased by 31%, while the population of Carteret County, bordering Core and Bogue sounds, increased by 13% (Table 1.2). In addition, the seasonal (summer) population in barrier island municipalities jumped three to as much as 53 times more than the permanent population in 2000 (Table 1.3). Many of the seasonal visitors are also recreational boaters. The permanent population adjacent to waters with low salinity SAV has also increased at varying rates. Along the western shore of Pamlico Sound, population increased 12% in Craven County, 14% in Pamlico County, and 6% in Beaufort County. In northeastern North Carolina, the permanent population of Currituck County grew by 32%, while the counties along tributaries of Albemarle Sound increased by 7-16%. During this same time period, the number of registered boats in North Carolina increased by about 40% (Figure 4.3). As the number of boaters in North Carolina continues to increase, the potential for damage to SAV via prop scarring is likely to increase, as has happened in Florida and Virginia. *Educational outreach is needed to increase awareness by the boating public of the ecological value of SAV and the damaging effects of boat propellers to SAV habitat. The level of damage to SAV from prop scarring should be assessed periodically. In areas where boating activity is found to cause significant SAV impacts, navigational markers should be installed to clearly delineate navigational channels to be used or SAV beds to avoid.*

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[52] More information on the use of fiber optic cables in fish habitats is included in the hard bottom chapter of the CHPP

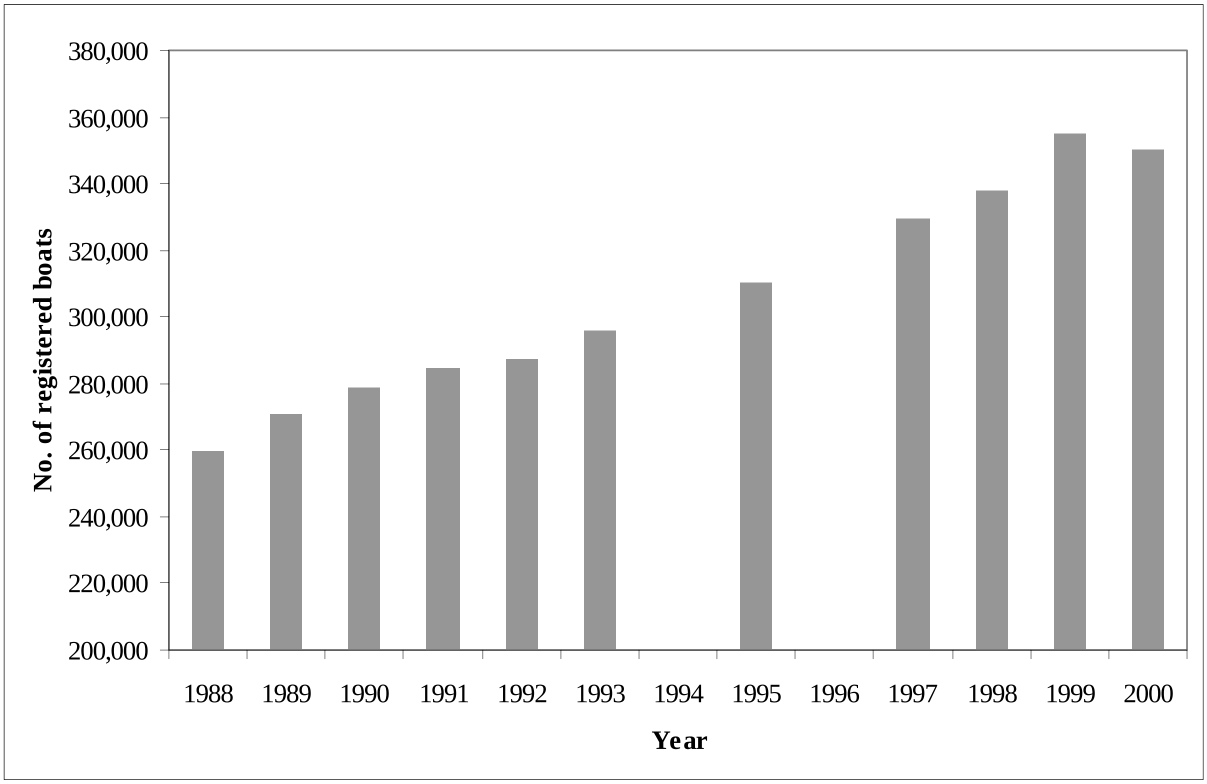

Figure 4.3. Total number of registered boats in North Carolina (no data for 1994 and 1996). [Source: C. Murphey, North Carolina WRC, 2001]

<u>Marinas and docks</u>

Marinas and docks impact SAV in several ways. During construction, placement of pilings or dredging of basins may destroy SAV. Once dredged, boat basins, like navigational channels, reduce light availability at the seafloor because of the increased depth, or change the sediment composition so that SAV cannot survive or recruit into the area (Stevenson and Confer 1978). Shoreline hardening structures associated with docking facilities (bulkheads) impact SAV by increasing wave energy and scour along the shoreline where SAV may occur, and by reducing shallow water habitat where SAV exists or could potentially colonize (Funderburk et al. 1991).

Shading from docks also results in loss of SAV beneath the dock structures. In a study in the Indian River Lagoon, Florida, light availability was reduced under docks that were 3 ft (0.91 m) and 5 ft (1.52 m) high to 11 and 14% of ambient light, which is less than the minimum amount needed (15-25%) for growth and survival of seagrass (Beal and Schmit 1998). Light availability increased with increasing dock elevation, and was significantly greater under the higher dock (5 ft or 1.52 m). The Florida Department of Environmental Protection (unpub. data) assessed the impact of dock shading to SAV in Palm Beach County, Florida, and found that 45% of surveyed docks had SAV around them but no SAV under them. Shading effects extended 1–3 m (3.28 - 9.84 ft) to either side of the docks. Seagrass presence was strongly correlated with dock height for docks ranging from 0–5.5 ft (1.68 m) above mean high water (MHW). Other studies in Florida found significantly less SAV under docks than in adjacent unshaded areas (Loflin 1995), and no seagrasses under docks having light levels less than 14% of surface irradiance (Shafer 1999). Offshore mooring of boats for extended periods of time in one location has also been shown to result in SAV loss in a circular area beneath the boat due to shading or damage from anchor and chain movement (Fonseca et al. 1998). These small individual losses of SAV may seem insignificant, but they can have significant cumulative impacts. The location of marinas and public boat access areas relative to SAV is depicted in Maps 4.5a-b.

In addition to direct damage from docks and marinas, indirect damage to SAV can result from boating activity associated with these structures. Shoals and other shallow bottoms supporting SAV may become scarred as boating activity to and from the docking areas increases. Boat wakes can destabilize and erode SAV beds, or resuspend sediment, reducing light penetration. As additional docks and marinas are constructed along the coast, the potential for boating-related damage increases. Based on marina records from DCM and SAV distribution maps, there are at least 104 marinas within 0.5 mi (0.81 km) of mapped SAV beds (Maps 4.5a-b). *Direct, indirect, and cumulative impacts to SAV and other habitats from marina and dock siting should be minimized. Development of a comprehensive state marina policy is needed to achieve this objective.*

Along the southeast coast of Florida, there are stringent standards for dock construction to minimize impacts to SAV. In John Pennekamp Coral Reef State Park in the Florida Keys, docks are prohibited over park bottom because of the documented impacts to SAV from construction, shading, and boating activity associated with the docks (R. Skinner, F.L. Park Service, pers. com., 2002). In other areas, the total square footage, width, or minimum height is limited. In aquatic preserves, guidelines for dock construction at one time required that access piers be five feet (1.52 m) above MHW with half inch (1.27 cm) deck spacing to allow more light to reach beneath the structure (Beal 1999). A minimum water depth of four feet (1.22 m) mean low water (MLW) at the dock end is required in most areas, and in some areas, a dock may not be permitted if deep-water access is not available (minimum of 4 ft [1.22 m] water depth MLW from dock to offshore waters).

In North Carolina, the depth of water at the dock end is not considered in CRC rules. With some exceptions, dock length is limited to no more than 25% of a water body's width, and cannot extend into navigation channels and should not extend beyond the length of other piers along the same shoreline. To minimize shading effects to wetland plants, CRC rules require a dock height of at least three feet (0.91 m) above the wetland substrate, and a pier width of no greater than six feet (1.83 m) [CRC rule 15A NCAC 07H.0208 (6)]. However, there is no requirement for height above the water surface. Total shading of the bottom by piers and docks is limited by a requirement that pier surface area associated with a given waterfront lot may not exceed a combined total area of four square feet per linear foot of adjacent shoreline. *Research is needed to determine if adequate light is available beneath North Carolina docks, given the current CRC dock siting criteria. These criteria should be evaluated to determine if existing requirements are adequate for SAV survival and growth and what changes would be needed to allow at least the minimum amount of light beneath docks. The permit requirements for docks and piers may need to be changed accordingly.*

The cumulative impacts from dock structures in rapidly developing coastal subdivisions must also be considered. The DCM has the authority to deny coastal development permits based on cumulative impacts. However, the research and modeling tools necessary to determine criteria for denial are lacking. *Any research and modeling effort conducted on dock impacts should address the cumulative impact of shading, turbidity, boater access, and other impacts on the quality and quantity of SAV beds.*

Fishing gear impacts

Several bottom disturbing fishing gears have the potential to destroy or damage SAV. The ASMFC SAV policy (ASMFC 1997b) urged development of technical guidelines and standards to objectively determine fishing gear impacts and develop standard mitigation strategies, in cooperation with NMFS and FWS. In North Carolina, the Fisheries Moratorium Steering Committee's Habitat Subcommittee identified specific habitat impacts from various commercial and recreational fishing gears used in North Carolina waters, and made recommendations to minimize such impacts (MSC 1996). The Fisheries Moratorium Steering Committee presented the summary of findings to the Joint Legislative Commission on Seafood and Aquaculture of the General Assembly. Fishing gear found to be potentially damaging to SAV is listed in

Table 4.7.

Table 4.7. Fishing gears used in North Carolina identified as potentially damaging to submerged aquatic vegetation habitat. [Source: MSC 1996]

Severe damage	Moderate damage	Low damage or unsure
Oyster dredge	Crab trawl	Long haul seine
Crab dredge	Clam Tongs	Otter trawl
Hydraulic clam dredge		Clam hand rake
Clam trawl (kicking)		Bay scallop dredge (very little)
Bull rake		

Damage from fishing gear varies in severity. Shearing or cutting of the leaves, flowers, or seeds, and uprooting of the plant without major disruption of the sediment, are most often caused by dragging or snagging of gear, such as long haul seines or bottom trawls (ASMFC 2000). Bull rakes and large oyster tongs can uproot SAV and cause substantial damage, while hand rakes are more selective and cause less damage (Thayer et al. 1984). Shearing of above ground plant biomass does not necessarily result in mortality of SAV, but productivity is reduced since energy is diverted to replace the damaged plant tissue, and the nursery and refuge functions are reduced in the absence of structure. Some fishing practices can cause severe disruption of the sediment and damage the roots of SAV. The ASMFC (2000) discussed several impacts of fishing gears on SAV. Belowground effects, such as those from toothed dredges, heavy trawls, and boat propellers, may cause total loss of SAV in the affected area, requiring months to years to recover. SAV can be buried by excessive sedimentation associated with trawling, dredging, and propeller wash. High turbidity from use of bottom-disturbing fishing gear can reduce water clarity, affecting SAV growth, productivity, and in some cases, survival.

All toothed dredges can cause severe damage when pulled through SAV. Dredges, like trawls, are dragged across the bottom and organisms are caught in a net or cage. Oyster and crab dredges are essentially the same gears, although a few fishermen may use longer teeth to take blue crabs. Both oyster and crab dredges are limited to a weight of 45.36 kg (100 lb) in North Carolina [MFC rule 15A NCAC 03J .0303 (a)]. Oyster and crab dredges have a metal frame less than 1.52 m (5 ft) wide to hold the net open and a blade at the bottom of the frame to which teeth are attached for digging the target species out of the bottom (crabs) or breaking them off from adjoining material (oysters). Qualitatively, damage to eelgrass meadows caused from unspecified dredges used to harvest shellfish was surpassed only by damage associated with propellers (Thayer et al. 1984). Because oyster and crab dredges affect bottom structure, there are strict limits on their use in North Carolina.

Use of crab dredges is restricted to an area in northern Pamlico Sound west of Oregon Inlet [MFC rule 15A NCAC 03R.0109]. In recent years, crabs have not been dredged from areas where SAV was present. However, the designated area overlaps with SAV habitat and could become a problem. Based on SAV data from the late 1980s and early 1990s (Ferguson and Wood 1994), there are 15,560 acres (6,296.91 ha) of SAV within the designated crab dredging area. Crab dredge effort is very low, with roughly 10 crab dredge trips annually in recent years. Use of oyster dredges is currently restricted to parts of Pamlico Sound and its tributaries. The majority of high salinity SAV occurs in areas where the mechanical methods for oyster harvesting are prohibited. However, brackish and freshwater SAV in western Pamlico Sound is generally unprotected from dredging, except in PNAs and SNAs.[53] However, there has been relatively little oyster dredging in the Neuse or Pamlico rivers in recent years, indicating that most potential problems are in Pamlico Sound. Submerged aquatic vegetation will not be able to recolonize areas that historically supported SAV if they continue to be dredged. *Research is needed to determine*

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[53] The cumulative number of oyster dredge trips reported in Pamlico Sound varies annually: 224 trips (1997), 1,298 trips (1998), 239 trips (1999) and 691 trips (2000) (DMF, unpub. data).

where there is suitable potential SAV habitat along the mainland shorelines of the Albemarle-Pamlico system for the purpose of establishing defined SAV restoration goals. Once determined, oyster dredging should be prohibited from areas targeted for SAV restoration.

Bay scallop dredges, in contrast to oyster and crab dredges, cause less severe damage to SAV because they are smaller (not over 50 lb (22.68 kg)) and have no teeth. They are intended to glide along the substrate surface, taking bay scallops lying on the surface within SAV beds. Bay scallops depend on SAV for initial post-larval setting, so they are strongly associated with SAV beds. An evaluation of impacts to eelgrass (*Zostera marina*) from bay scallop dredging in North Carolina found that scallop dredging over grass beds significantly reduced the biomass, surface area, and shoot density of eelgrass (Fonseca et al. 1984). The impacts were more severe in soft bottom compared to harder bottom. Full recovery was estimated to take up to two years. Because bay scallop populations in North Carolina typically spawn between August and December (Fay et al. 1983c), eelgrass leaves are most needed for attachment of juveniles (the next season's scallop crop) during the winter, which is also the time of maximum fishing effort (Fonseca et al. 1984). However, most damage observed by DMF staff has not been from the dredge, but from propeller scarring while pulling the dredge, particularly when the season opening coincides with low tide (T. Murphey, DMF, pers. com., 2002).

The area fished with bay scallop dredges in the Albemarle-Pamlico region (Cunningham et al. 1992) encompasses approximately 46,000 acres (18,615.54 ha) of mapped SAV in eastern Pamlico, Core, Back, and Bogue sounds. Bay scallop landings have been quite variable in recent years, ranging from about 201,000 lb (91,172.07 kg) in 1995 to only 19,000 lb (8,618.26 kg) in 2002. Bay scallops are an annual crop with availability dependent on the previous year's spawning success and survival. Therefore, fishing effort is also quite variable. Reported scallop dredging trips in Core and Bogue sounds have generally declined from 1994 to 2000, peaking at around 1,800 trips in 1995 and falling to fewer than 15 trips annually by 2002 (DMF, unpub. data). Bay scallop dredges accounted for 62-92% of the harvest during 1994-1998, but only 38% in 1999, and 3% in 2000. Most of the catch is now taken by various hand methods. The low dredge effort is due to very short periods of time open for dredging and reduced bay scallop stocks in recent years. To reduce SAV impacts, DMF allows hand harvest methods for bay scallops early in the season, followed by proclamations to open scallop dredging later in the season, starting on a high tide. This management practice is based on the presumption that the majority of the scallops have been hand harvested in the shallow beds prior to allowing dredging. By opening the first day of dredging on a rising or high tide, damage to SAV by propeller scarring from dredging vessels is minimized because the water depth is approaching or at its maximum (T. Murphey, DMF, pers. com., 2002). At that time, dredgers can harvest the few scallops hypothetically remaining in the shallow beds and then, during the course of the day, move out to the deeper water. *Research should be conducted to determine whether gear impacts or other factors are causing the decline observed in bay scallop landings that was discussed in the Status and Trends section. If current bay scallop harvesting methods are found to negatively impact SAV and bay scallop populations, the DMF and MFC should consider rotation of fishing areas, as recommended in Fonseca et al. (1984), or other fishery management techniques.*

Hydraulic clam dredging can cause severe impacts to SAV. This gear directs high-pressure water jets into the bottom to blow surface sediment away and expose clams. The clams are then captured by the dredge head and brought to the surface on a conveyor belt. Hydraulic dredges dig trenches in the bottom, create mounds of discarded material, and redistribute bottom material (Adkins et al. 1983). When hydraulic clam dredging occurs in SAV beds, it digs up all vegetation in a swath approximately three feet (0.91 m) wide (ASMFC 2000). Hydraulic clam dredging can also significantly increase local turbidity (ASMFC 2000). Because of the severe impacts on the bottom, the MFC and DMF restrict use of this gear to open sand and mud bottoms, including areas frequently dredged as navigation channels, such as sections of the Atlantic Intracoastal Waterway. This gear is not allowed in SAV or oyster beds and the restrictions are strictly enforced. On average, about 38 vessels make more than 600 hydraulic clam dredge trips to harvest about 72,000 lb (32,658.65 kg) of clam meats annually (DMF, unpub. data).

Another method of mechanical clamming is clam kicking. Several kicking techniques have been developed over time (e.g., anchor, bedstead, oyster drag, clam trawl); each technique uses different gear but all rely on propeller backwash to expose clams buried in the sediment to facilitate their harvest (Guthrie and Lewis 1982). The most prevalent technique currently employed in North Carolina is the clam trawl, in which a small, heavily weighted trawl is towed approximately 15 feet (4.6 meters) behind a kicking vessel (Guthrie and Lewis 1982). These vessels are modified or weighted so that the stern is low in the water, to achieve a more efficient angle and depth at which to force or deflect the propeller backwash into the bottom, thereby displacing the substrate so that the buried clams are collected in the trawl (Guthrie and Lewis 1982). Although the size of associated nets and trawl boards varies according to boat size and water depth, most kicking activities are restricted to depths below about 10 feet (3 m) (Guthrie and Lewis 1982). Some areas where this method is used (open waters of Core Sound, southeast Pamlico Sound) contain clams that otherwise might not be harvested because the areas are exposed to the wind, making it difficult for fishermen to use clam tongs. The methods and gears associated with kicking can also cause severe damage to SAV. Peterson et al. (1987) found that clam kicking reduced plant biomass in eelgrass and shoalgrass beds. Loss of SAV biomass and time needed for recovery increased as intensity of clam kicking increased (Peterson et al. 1987). The probability of historic damage to SAV via kicking seems likely to be high, given that kicking techniques were first experimented with in eastern North Carolina during the 1940s, that almost 150 kicking vessels operated in 1980 in Carteret County alone, and that kicking vessels tend to operate in shallow waters (Guthrie and Lewis 1982).

Because of the severe disturbance to the bottom, clam kicking is restricted to open sand areas in Core and Pamlico sounds, and Newport, North, New, and White Oak rivers (Maps 4.4a-b). The fishery is managed intensively, with strong enforcement to prevent clam kicking outside the designated areas. Much of the designated mechanical clamming areas have SAV in close proximity to them, so vessels that fish illegally outside the open areas may severely impact SAV. Turbidity generated by clam kicking may also affect adjacent SAV beds. Annual effort in this fishery varies.[54] During 1994 - 2000, clam kicking accounted for about 6-12% of the annual commercial hard clam harvest in North Carolina. Mechanical clamming, including kicking and dredging, accounts for about 21% of annual hard clam landings. High salinity SAV species are more likely to be impacted by mechanical clamming practices due to the location of the fishery.

The Fisheries Moratorium Steering Committee (MSC 1996) recommended that existing areas for mechanical harvest remain, but not be expanded. However, opening a new mechanical harvest area in southeast Pamlico Sound was raised as an issue during development of DMF Hard Clam FMP. The area selected contained SAV, particularly in the shallower water. The final DMF Hard Clam FMP (DMF 2001b) added this location as a new mechanical clam harvest area, but restricted harvest to deeper waters where SAV was not present. This new area in southeast Pamlico Sound will be rotated with existing mechanical harvest areas in Core Sound to allow recovery of clam populations in each area. Turbidity and non-compliance with area restrictions could potentially damage surrounding SAV. *Turbidity impacts to SAV at this new location and other existing mechanical harvest areas should be assessed through water quality monitoring.*

Hand gears can also cause varying amounts of damage, but generally to smaller areas than mechanical gears. A hand clam rake looks similar to a garden rake, usually with nine teeth or less. Clam rakes are pulled through the sediment to obtain clams; different techniques are associated with different types of rakes, which reach different depths (Peterson et al. 1983). A bull rake is a large heavy clam rake having 18 to 24 teeth and a basket attached behind the teeth to catch the harvested clams. The length and spacing of the teeth are designed to prevent harvest of undersized clams. Clam tongs, similar to oyster tongs, are a pair of rakes attached to the end of two long poles which are fastened together like a pair of scissors.

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[54] Clam kicking effort: 640 trips (1994), 824 trips (1995), 1095 trips (1996), 1116 trips (1997), 1083 trips (1998), 1162 trips (1999) and 364 trips (2000) (DMF, unpub. data).

Bull rakes and large clam tongs can uproot SAV and cause substantial damage to grass beds, while hand rakes are smaller and lighter in weight, and cause less damage. (Thayer et al. 1984). A comparison of the impact of bull rakes and hand rakes on SAV found that a bull rake removed over 80% of the shoots, roots, and rhizomes in a completely raked area, while a hand rake removed 55% of shoots and 37% of roots and rhizomes (Peterson et al. 1983).

Hand clam rakes are used to take intertidal clams during all tidal stages, but are used mostly by recreational clammers during low tide (Cunningham et al. 1992). Clamming with hand rakes occurs in areas around Ocracoke Inlet in eastern Pamlico Sound and in the higher salinity sounds, rivers, and creeks from Core Sound south through Brunswick County. Bull rakes are used by commercial clam fishermen in the same general area, primarily in deeper water (such as New, White Oak, Newport, and North rivers) or during colder months. Many of the bull rake areas are in close proximity to significant SAV beds. Clam tonging occurs primarily in limited areas where there is very little known SAV. Current MFC rules prohibit use of bull rakes and clam tongs in SAV [MFC rule 15A NCAC 03K.03049 (a) (2)]. Use of hand rakes and clamming by hand are allowed.

Long haul seines have been reported to cause little or no damage to SAV. A long haul seine is a long (more than 1,000 yd or 914.4 m) net that hangs in the water from the surface to the bottom. The top of the net is suspended at the surface with floats, and the bottom line (“leadline”) is weighted so that it will skim the estuarine bottom. Both ends are pulled slowly through the water by boats until the end of the “haul” (Guthrie et al. 1973; DeVries 1981). The extent of damage from haul seining is dependent upon seine length, weight, and the density and height of the SAV. Possible damage includes shearing of the leaves or reproductive structures.

Long haul seine fishing is used in Croatan and Roanoke sounds; northern and eastern portions of Pamlico Sound along the Outer Banks; portions of the Pamlico River estuary, including the Pungo River and adjacent areas of western Pamlico Sound; and also in portions of the Neuse River estuary, West Bay, Core and Back sounds, and North River (Cunningham et al. 1992). These areas include approximately 78,148 acres (31,625.37 ha) of mapped SAV. The Fisheries Moratorium Steering Committee (MSC 1996) recommended that research be conducted to assess bottom damage associated with long haul seines. A study conducted in Chesapeake Bay found no detectable effect from this gear on plant height, density, or species composition of brackish SAV (wild celery and *Hydrilla*) in Chesapeake Bay (Sadzinski et al. 1996), indicating no need for further restrictions to protect SAV. However, use of the gear differs between North Carolina and Chesapeake Bay, with much larger nets used in North Carolina. Peak use of long haul seines occurred during the 1970s and 1980s, with far less effort in recent years (about 50–60 crews active during the peak, down to 20–25 crews by the early 1990s (DMF 1993)). Trip ticket data indicate that the number of seine trips has fallen by more than half from the 1994–1996 period to the 2000–2002 period (DMF, unpub. data).

An otter trawl is another gear that may impact SAV. A trawl consists of a conical net towed behind a fishing vessel at various locations in the water column. Most types of trawls used in North Carolina are held open by water pressure against a pair of “otter boards” or “doors” attached to the front of the net. Bottom trawls used to catch shrimp, crabs, and finfish are towed along the bottom, and both the bottom weighted line (“leadline”) at the opening of the net and part of the doors dig into the bottom. Many shrimp trawl fishermen attach a “tickler” chain in front of the leadline to cause shrimp to jump off the bottom in front of the net. The tickler chain also digs into the bottom to some degree.

Many studies have shown that trawling can have severe impacts to sensitive bottom habitats (Auster and Langton 1999, Collie et al. 2000). Because almost all shrimp and crab trawling occurs on sand/mud bottoms, the least complex bottom types, habitat impacts may be relatively low (Auster and Langton 1999). Where trawling does occur over SAV, impacts may occur from the dragging of the net across the seafloor and the digging of the trawl doors into the sediment (ASMFC 2000). It is estimated that the maximum cutting depth for otter trawl doors ranges between about an inch and a foot (2.54–30.48 cm) when used in depths over about 100 ft (30.48 m) (ASMFC 2000), although such deep water does not occur in North Carolina's estuaries. The variation is due to differences in gear weight, bottom hardness, and towing warp to depth ratio (a measure of the force of the gear). Trawl doors were found to penetrate the bottom more than the rest of the gear (ASMFC 2000). Crab trawling impacts to SAV are expected to be more severe than shrimp trawling because of the heavy chain used on the bottom line. However, far fewer crab trawl trips (about 2,000) occur annually than estuarine shrimp trawl trips (about 10,000).

The greatest use of trawls in North Carolina is in the shrimp fishery, with about 13,000 trips annually during 2000–2002. About 75% of the trips occur in estuarine waters, and the rest are mainly within the U.S. Territorial Sea (0-12 nautical miles or 22.22 km). Shrimp trawls are used primarily in Croatan, Roanoke, and Pamlico sounds; the Pamlico, Pungo, Bay and Neuse rivers; and in Core, Back, and Bogue sounds, including the New, White Oak, Newport, and North rivers (Cunningham et al. 1992). The areas open to trawling cover approximately 20,035 acres (8,107.88 ha) of mapped SAV. Trawling is not allowed in designated Primary or Secondary Nursery Areas (PNA, SNA) or No Trawl Areas (NTA) (Maps 3.5a-c). Low-salinity SAV beds occurring along the western shoreline of Pamlico Sound and its tributaries are protected from trawling primarily by the PNA and SNA regulations. The No Trawl Areas primarily protect high salinity SAV located along the eastern edge of Pamlico Sound, and a few areas along the western shoreline of Pamlico Sound, as well. Trawling is also prohibited in Currituck and Albemarle sounds. Core Sound and a large portion of Bogue Sound, which both contain significant amounts of SAV, are open to trawling. The average annual harvest of shrimp in Core and Bogue sounds is about 893,000 and 338,000 pounds (405,057.99 and 153,314.22 kg), respectively. The harvest indicates a substantial trawl fishery in these areas.

Fishery restrictions already exist for most of the gears used in North Carolina that are potentially damaging to SAV. Based solely on numbers of trips and SAV acres covered, trawling in Core and Bogue sounds has the greatest potential for significant fishing gear impacts on SAV. However, without knowing the specific areas affected per fishing trip, it is difficult to evaluate the impact of these fishing gears on SAV habitat. *Field studies are needed to assess the effect of shrimp and crab trawling on SAV in North Carolina, particularly in Core and Bogue sounds. In addition, the boundaries of No Trawl Areas should be evaluated and adjusted, if necessary, to adequately protect all high salinity SAV beds and provide a buffer of unvegetated area to reduce turbidity impacts. Additional law enforcement may be needed to enforce buffers around SAV.*

In identifying potentially damaging fishing gear, the ASMFC recognized that varying physiological and habitat requirements of the different species of marine, fresh, and brackish water SAV affects their susceptibility to damage and their ability to recover (ASMFC 2000). Characteristics of concern include light requirements, location of asexual and sexual reproductive structures, dependence on sexual or asexual reproduction for maintenance and growth of beds, and ability to recover from plant damage. Species having higher light requirements (i.e., eelgrass) or whose growth and vegetative reproduction are primarily above ground or just below the sediment surface (i.e., pondweed) are more vulnerable to above-ground disturbance (ASMFC 2000). Seagrass beds composed of species that rely primarily on vegetative spreading (asexual reproduction) recover more slowly (many years) than those with species that rely more heavily on seed set and sexual reproduction (1–2 growing seasons) (Fonseca et al. 1998).

Many factors affect recovery, including the magnitude of the injury, the amount of stored energy reserves in the plant, seed or tuber set before disturbance, and local environmental conditions. Taking as many factors as possible into account, the SAV workgroup of the ASMFC estimated the relative ability of different SAV species to recover from physical impacts. The overall recovery potential of species occurring in North Carolina are listed in Table 4.8. Species having moderate potential for recovery are more sensitive to disturbance than those with high potential for recovery. No species occurring in North Carolina were listed as having a low potential for recovery.

Table 4.8. Estimated recovery potential of selected species of submerged aquatic vegetation occurring in North Carolina. [Source: ASMFC 2000]

Moderate Recovery Potential	High Recovery Potential
Eelgrass	Shoalgrass
Wild celery	Widgeon grass
Redhead grass	Horned pondweed
Sago pondweed	Common elodea

Water quality degradation

Nutrients and sediment

While physical damage to SAV beds generally occurs in a discrete area and within discrete time periods, water quality degradation can cause SAV loss over less defined and much larger areas and time periods. The majority of SAV loss is now considered to result from large-scale nutrient enrichment (causing enhanced epiphytic and phytoplanktonic growth) and sedimentation, which result in reductions in water transparency and light penetration (Goldsborough and Kemp 1988; Kenworthy and Haunert 1991; Funderburk et al. 1991; Dennison et al. 1993; Stevenson et al. 1993). Catastrophic losses of seagrass beds have been correlated with these water quality problems in Virginia and Florida waters (Twilley et al. 1985; Orth et al. 1986; Durako 1994). Nutrient enrichment and/or increased sediment loads impact SAV growth, survival, and productivity by:

- Increasing chronic turbidity in the water column from suspended sediment or phytoplankton associated with algal blooms,
- Increasing epiphytic loads, sedimentation, or covering by drift algae on the SAV blades, and
- Diminishing dissolved oxygen concentrations as photosynthesis decreases, coupled with increasing concentrations of hydrogen sulfide resulting in toxicity (Dennison et al. 1993; SAFMC 1998a; Fonseca et al. 1998).

The effects of human-related eutrophication on seagrass survival are dependent on the growth periods and environmental requirements of the dominant species, and the timing and duration of the water quality problem (Burkholder et al. 1994). Eutrophication effects are generally most severe in sheltered habitats with reduced tidal flushing where nutrient loadings are concentrated and frequent, and where temperature fluctuations may be greater (Burkholder et al. 1994). Therefore, optimal criteria for preventing eutrophication vary by salinity, species, time of year, and specific location of SAV beds.

Decreased water clarity due to dissolved organic matter, suspended particulate matter, detritus, or algae that is suspended in the water column has a major effect on SAV distribution[55]. In addition to light attenuation in the water column, sedimentation and algal growth on the surface of grass blades (epiphytes) also reduce light reaching the surface of SAV (Virnstein and Morris 1996). Because algal growth is directly related to dissolved nutrient concentrations, epiphyte loads are considered to be caused by excessive nutrients in the water column.

Loss of SAV habitat, whether from physical impacts or water quality degradation, leads to a “snowball effect” of additional habitat and water quality degradation (Durako 1994; Fonseca et al. 1998). In the absence of SAV, the ability of the rooted grasses to bind sediment and baffle wave action is reduced, which results in sediment destabilization and increased turbidity. The destabilized bottom can result in accelerated shoreline erosion, putting more sediment into the water, decreasing water clarity further. These effects, in turn, can lead to additional SAV loss above and beyond the initial impact area or reduce the rate of recolonization (Durako 1994; Fonseca 1996b). Large-scale losses of SAV are particularly problematic because the rate of recovery (measured in the scale of years) often cannot keep up with the

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[55] see Habitat requirements section.

rapid rate of losses (occurring within weeks or months) (Fonseca et al. 1998). Furthermore, future seagrass restoration may be confounded by the loss of existing seagrass beds, which increases sediment resuspension and turbidity (P. Biber, NMFS, pers. com., 2003). *Therefore, management efforts should focus on protecting existing SAV habitat and preventing any additional direct or indirect losses.*

Several water quality variables can be used as indicators of light conditions, including turbidity, total suspended solids, chlorophyll levels, and color (EPA 2000). Turbidity is a measure of the reduced transparency of water due to suspended or dissolved substances, while total suspended solids is a measure of the density of suspended solids in the water column. Chlorophyll *a* is a measure of the abundance and variety of phytoplankton in the water column. Chlorophyll levels may have the greatest impact on SAV in spring and summer (EPA 2000). Color is an indication of the amount of dissolved organic matter in the water.

In North Carolina, there is no official standard for light attenuation or light availability. There are EMC standards for other light associated parameters including turbidity, total suspended solids, and chlorophyll *a*. The standards for water clarity parameters are listed in Table 4.9 for the different water quality classifications. Waters classified as Nutrient Sensitive Waters (NSW) in the CHPPs area include the Neuse, Tar-Pamlico, and Chowan river basins, and the New River watershed within the White Oak River basin. In general, no increase in background nutrient levels is allowed within NSW waters unless preventing the increase would result in serious economic hardship, would not endanger human health and safety, or is due to natural variations. In both the Tar-Pamlico and Neuse basins, nitrogen limits were placed on point source discharges, and BMPs were established with the goal of reducing annual nitrogen loading by 30% of the amount occurring during a selected past year (DWQ 2000b). In the Chowan River basin, the updated 1990 NSW strategies called for reducing nitrogen inputs from all sources by 20%, as well as targeting BMP implementation. In the New River, nitrogen limits were placed on point source discharges, no new discharges were permitted, and expansions of existing facilities were allowed only if there was no increase in permitted loading of oxygen-consuming waste.

High Quality Waters include all waters designated SA for harvesting of shellfish, as well as Primary Nursery Areas designated by the MFC. Standards for those waters are shown in Table 4.8. For Outstanding Resource Waters, standards are based on the primary classification of those waters or if the standards are found to be insufficient to protect the ORW resource(s), then site-specific standards may be developed as part of the management strategy and rule-making process.

In the Chesapeake Bay, a multi-state and federal effort is underway to restore Chesapeake Bay water quality and SAV, in part by defining specific water quality criteria for water clarity, chlorophyll *a*, and dissolved oxygen as part of the process of maintaining and restoring SAV and other habitat. These parameters were considered the best and most direct measure of the effects of excessive nutrient and sediment pollution on SAV and other resources (<http://www.chesapeakebay.net/>, 2002).

In comparing current North Carolina water quality standards to those proposed for the Chesapeake Bay, North Carolina's chlorophyll *a* standard is higher (40 µg/l vs. <15 µg/l), while the TSS standard is very similar (10-20 mg/l vs. <15 mg/l) (Tables 4.2 and 4.9). The EPA did not list a standard for turbidity for the Chesapeake Bay (EPA 2000). Historically, water clarity standards have been based on phytoplankton requirements, which are much lower than that required for submerged grasses–only approximately one percent of incident light, compared to 15–25% (Kenworthy and Haunert 1991). Research is currently being conducted at NMFS in Beaufort to determine specific light requirements for SAV in North Carolina's estuaries and the relationship between light attenuation and other water quality parameters (P. Biber, NMFS, pers. com., 2004). Preliminary results indicate that, given certain combinations of turbidity and nutrients, North Carolina's current standards may not be adequate to sustain SAV (P. Biber, NMFS, pers. com., 2004). *Modifications may be needed to regulations and monitoring programs to improve their effectiveness for SAV protection. A review of current chlorophyll, TSS, and turbidity standards* *should be conducted to determine if they are appropriate for the protection of SAV in North Carolina waters. DENR should work with NMFS to determine what levels of TSS, chlorophyll a and other parameters are needed to achieve desired water clarity. The need and feasibility (scientific defensibility and "implementability") for a water quality standard for light attenuation should be investigated to provide a pro-active target or standard for protection and restoration of SAV.*

Minimal water quality monitoring is conducted in Pamlico and Core sounds by DWQ, where the vast majority of SAV coverage occurs. The North Carolina light-associated water quality standards adopted by the EMC that apply directly to SAV are shown in Table 4.9. *Once the appropriate water quality conditions for protection of SAV are determined, DWQ should evaluate whether current sampling locations and methods are sufficient in estuarine waters to monitor the suitability of water quality conditions for SAV survival and growth. Monitoring should be conducted in waters with SAV habitat to ensure that the standards and conditions are being met. If additional monitoring is needed, establishment of continuous monitoring stations should be considered. In either case, priority should be given to those areas already classified NSW.*

Table 4.9. North Carolina Environmental Management Commission standards for light-associated parameters by North Carolina surface water quality classifications.

Parameter	Supplemental Classifications			Salt water			Fresh water
	ORW	HQW (salt or freshwater)	NSW	SA	SB	SC	Aquatic life
Turbidity (NTU)	**	25	**	25	25	25	50
Total dissolved solids (mg/l)*	**	10 – in PNAs; 20 – other	**	10 – in PNAs; 20 – other	30	30	20
Chlorophyll *a*	**	40	**	40	40	40	40

* Applies to discharges only

** Determined by primary classifications (SA – SC and C) or site-specific management strategies developed by EMC through rule-making.

In North Carolina, between 1995 and 1999, chlorophyll *a* concentrations at or above the state surface water quality standard of 40 µg/L were identified as one of the major causes of impairment in the freshwater portions of the Neuse and White Oak river basins (Table 4.10) and in the saltwater portions of the Neuse, Tar-Pamlico, and White Oak river basins. During calendar year 2000, 183 algal bloom samples were received from the basins included in the CHPPs area.[56] The Neuse (Maps 4.3a-b), Tar-Pamlico and White Oak river basins support SAV habitat, and at one time supported larger grass bed areas. Since some SAV is present in the shallow portions of the Neuse and portions of the White Oak river basins, and water quality data indicate some level of eutrophication exists, nutrient levels may be limiting survival or expansion of SAV in these areas. *These areas should be a high priority for monitoring of SAV and water clarity.*

Research has shown that elevated nitrogen concentrations not only affect SAV through light reduction, but may actually be toxic to eelgrass. In laboratory experiments, long-term exposure of eelgrass to enriched nitrate concentrations was lethal at enrichment levels ranging from 3.5 – 35 µM water column NO_3^- - Nd^{-1} (Burkholder et al. 1992b). In another experiment with eelgrass, nitrogen enrichment (10 µM water column NO_3^- - Nd^{-1} for 14 wk) significantly lowered shoot production compared to control plants without nitrogen enrichment (<2 µM water column NO_3^- - Nd^{-1}) (Burkholder et al. 1994). In contrast, growth in shoalgrass and widgeon grass was stimulated by similar nutrient enrichment conditions (Burkholder et al. 1994). Widgeon grass shoot production actually increased by 300%. These results

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[56] 50 samples from the Tar-Pamlico River Basin, 79 from the Neuse River Basin.

indicate that of the three species studied, eelgrass would be most impacted by eutrophication. The results also suggest that shoalgrass or widgeon grass might be successfully established by transplanting efforts in areas where eelgrass beds have been lost (Burkholder et al. 1994). More research is needed on the effect of nutrient enrichment on other brackish and freshwater species of SAV.

Table 4.10. Major causes of use support impairment in freshwater streams by coastal draining river basin, 1995-1999[1] [Source: DWQ 2000a]

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

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

Over the past several decades, there have been some nutrient reductions in waters supporting SAV due to improvements in wastewater treatment systems (Glasgow and Burkholder 2000), the 1988 ban on phosphorus-detergents (<http://pubs.er.usgs.gov/pubs/cir/cir1157>, June 2002) and more stringent water quality and management strategies in NSW areas (DWQ 1997b). Despite efforts to reduce nutrient loading, nutrient concentrations will continue to fluctuate as bottom sediments containing nutrients are resuspended into the water column and stormwater runoff introduces additional nutrients, varying with rainfall and runoff patterns. In addition, increasing population along the coast potentially increases nutrient loading into wastewater systems and nonpoint runoff. Nutrient and sediment levels may be preventing recovery of SAV in areas that historically supported SAV. The edges of existing SAV beds mark the general transitional area where water quality conditions become adequate to support SAV (Virnstein and Morris 1996). *To restore SAV habitat in fresh and estuarine systems where it historically occurred, management strategies should focus on water quality improvements at the edges and upstream of SAV occurrence.*

Suspended sediment, suspended solids, and dissolved solids concentrations have decreased throughout the Albemarle-Pamlico watershed from 1980 to 1995 (<http://water.usgs.gov/pubs/circ/circ1157

/nawqa91.9.html>, June 2002). Decreasing concentrations of suspended solids in the sounds and estuaries may not adequately improve water clarity for SAV growth if nutrient levels remain high. As a result, reduction of nutrients will be even more important in controlling water clarity conditions for SAV.

Increased sediment and nutrient loading in the water column can enter coastal waters from point source discharges, nonpoint stormwater runoff, or resuspension of bottom sediments. Specific sources that contribute to increased sediment loading include construction activities, unpaved roads, road construction, golf courses, uncontrolled urban runoff, mining, silviculture, row crop agriculture, and livestock operations (DWQ 2000b). Urbanization can increase the flow and velocity of stormwater runoff, which in turn leads to increased stream bank erosion. Stream bank erosion is a significant source of sediment loading (DWQ 2000b). Specific sources that contribute to increased nutrient loading include agricultural and urban runoff, wastewater treatment plants, forestry activities, and atmospheric deposition. Nutrients in point source discharges are from human waste, food residues, cleaning agents, and industrial processes. The primary contributors of nutrients from nonpoint sources are fertilizer and animal wastes (DWQ 2000b).

Addressing wetland and riparian restoration and management can reduce the effects of nonpoint pollution on water quality. Reductions in sediment or nutrient loading, particularly in river basins draining to the northern two-thirds of the coast (Albemarle Sound south through Topsail Sound), would help maintain or improve water clarity and light conditions needed for SAV growth and survival. *Nonpoint source loading of nutrients and sediment could be reduced through multiple strategies, including preservation and restoration of upland and wetland riparian habitats, modifications in land use regulations and agricultural BMPs. Conservation priorities should be set for land acquisition programs which will aid in protecting Strategic Habitat Areas.*[57] *Nutrient and sediment reduction goals should be established by the EMC to achieve the minimum of 15-25% light availability at depth requirement for SAV growth. An increase in staffing to fully implement and enforce existing stormwater and other nonpoint source-related regulations is needed to achieve this goal.*

Implementation of NSW rules for the Neuse, Tar-Pamlico, Chowan, and New rivers by the EMC are positive steps needed for nutrient and sediment reductions from both point and nonpoint sources. Goals and strategies vary, but in general aim to obtain nutrient reductions ranging from 20 to 40% of a targeted previous year, depending on the river basin. In addition, implementation of the CRC's coast-wide 30 ft (9.14 m) buffer rule [CRC rule 15A NCAC 07H .0209 (d)(10)], and EMC's 50 ft (15.24 m) buffer [58] in the Neuse and Tar-Pamlico river basins [EMC rule 15A NCAC 02B.0232 and 2B.0229] should aid in reducing nonpoint pollution. *The New River nutrient management strategy [EMC rule 15A NCAC 02B.0223] was heavily focused on point sources and should be revisited to determine what additional controls, such as buffers, might be necessary to achieve continued water quality improvements*.

The presence of SAV can, in itself, be valuable as a sensitive indicator of water quality (Smith et al. 1981; Valiela et al. 1990). In the Indian River Lagoon, Florida, where stormwater runoff has caused large SAV losses, SAV is used as a barometer of overall water quality conditions because of its sensitivity to water quality, the ecological value and functions it provides, and its importance as a keystone species for numerous other species (Virnstein and Morris 1996). To manage the lagoon, light attenuation models have been developed that link water quality to seagrass health. From the information obtained, pollution load reduction goals were developed to maintain and extend SAV coverage to historically occurring depths. Seagrass acreage and density were used as the measures of success. The conceptual model was based on the following relationship, which is supported in the scientific literature (Virnstein et al. 1983; Thayer et al. 1984; Gilmore 1995):

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[57] Because nonpoint source pollution also affects other habitats as well, including oyster reefs, soft bottom, tidal marsh, and the water column, this topic is discussed in more detail in the Water Column habitat section of this plan.

[58] First 30 ft (9.14 m) from water must remain forested and undisturbed and the next 20 ft (6.10 m) must have at least grass vegetation.

Proper watershed management → Adequate water quality → Healthy SAV coverage → High biological productivity and diversity → Healthy fish populations

The SAFMC SAV policy (1998a) encourages long-term trend analyses to monitor distribution and abundance of SAV. *An approach similar to that used in Indian River Lagoon and the Chesapeake Bay, where the condition of water quality, SAV, and fish populations are linked in monitoring and management, would be useful for protection of SAV habitat in North Carolina*.

Toxic chemicals

Herbicides are the primary toxic chemical known to have negative impacts to SAV (Funderburk et al. 1991). Herbicides enter riverine and estuarine waters from agricultural runoff and other sources. The most common agricultural herbicides used in Chesapeake Bay were atrazine, simazine, diquat, paraquat, and linuron. Research in Chesapeake Bay found that concentrations of the toxins in the water column were seldom high enough to damage SAV beds. In addition, SAV recovery was rapid following exposure to low concentrations of herbicides (Funderburk et al. 1991). However, impacts to SAV from sporadic or localized pulses of higher concentrations are not known, and could potentially cause problems.

While most agricultural herbicides come in contact with SAV indirectly through runoff, there are other chemicals specifically developed for aquatic weed control in freshwater and brackish systems. These chemicals are designed to be short-lived and should not persist in the water for long periods of time. Aquatic herbicides are at times used to intentionally kill SAV that is considered a nuisance. The Division of Water Resources, under the Aquatic Weed Control Act of 1991, manages the North Carolina Aquatic Weed Control Program, under direction from the Aquatic Weed Control Council. This program primarily focuses on non-native invasive species in freshwater lakes, ponds, and rivers. Some of the annual control activities occur in fresh and low salinity waters used by anadromous fishes and blue crabs, including the Albemarle Sound system.

The non-native European watermilfoil is the most troublesome SAV species in low salinity waters. It sometimes forms dense beds that can interfere with boating in local areas. Native submerged grasses may be impacted indirectly where occurring near treated areas or directly when herbicides are used by the general public. There is a general perception by some of the public that SAV is a nuisance. Grass blades may get in boat propellers, or entangle or weigh down fishing gear. Aesthetically, swimmers may prefer a sand bottom to a grass bottom. *Permitting for chemical removal of European watermilfoil and other non-native vegetation should be carefully restricted where native species co-occur to prevent non-target impacts. More education on the value of SAV to the health of North Carolina's estuaries and fisheries is needed to modify attitudes toward this habitat and improve individual and community stewardship of SAV.*

Introduced and nuisance species

The North Carolina Aquatic Weed Control Program is mandated by the North Carolina Aquatic Weed Control Act of 1991 [General Statute 113A-220 ff; DENR rules 15A NCAC 02G .0600] to assist local governments with aquatic weed problems affecting public waters. (<http://www.ncwater.org/Education_and_Technical_Assistance/Aquatic_Weed_Control/>, May 2002). Primary species targeted for control under the Program include:

- Giant salvinia (*Salvinia molesta*)
- Hydrilla (*Hydrilla verticellata*)
- Alligator weed (*Alternantherea philoxeroides*)
- Eurasian watermilfoil (*Myriophyllum spicatum*)

The above mentioned species, in addition to Elodea (*Lagarosiphon* spp.) and Water hyacinth (*Eichhornia azurea*), are classified as Noxious Aquatic Weeds under section .0602 of the Act. These highly invasive non-native species form dense beds in the water, which can make swimming, fishing, and boating difficult; clog water intake systems for municipalities and industries; and impede water flow in drainage canals (<http://www.ncwater.org/Education_and_Technical_Assistance/ Aquatic_Weed_Control/>, May 2002). Moreover, dense beds of Eurasian watermilfoil, a submerged rooted grass, can cause the water column to become anoxic at night, which can stress fish or cause fish to leave the area (T. West, ECU, pers. com., 2003). Although these nuisance species do provide some beneficial fish functions, such as refuge and sediment stabilization, they can also negatively impact SAV habitat by shading or out-competing other native species, which may have greater value to fish as a food source or refuge area (DWR 1996). *Long-term management and restoration of SAV habitat should include replacement of Eurasian watermilfoil with native species. The DENR should coordinate with the Division of Water Resources to ensure that native species are not targeted for removal. Research is also needed to determine the relative fishery value of Eurasian watermilfoil compared to native vegetation.*

While most introductions of non-native fish have little noticeable effect on habitat, grass carp can have a significant impact on submerged grass beds. Grass carp is a non-native species that has escaped from stocked ponds and reservoirs into some river systems. North Carolina requires that only sterile triploid grass carp be used for stocking because of their potential damage to submerged vegetation. However, a recent study in the Chesapeake Bay found that although stocking of sterile grass carp has been required for over 20 years, 18% of the non-native grass carp were not sterile (Schultz et al. 2001). Non-native species may also be introduced through unintentional releases from aquaculture and live bait facilities. *Policies should be developed by state agencies overseeing aquaculture and bait facilities to prevent such releases into coastal waters*.

Other threats

Seagrass wasting disease is a natural event that has affected SAV in North Carolina and may occur when SAV is stressed. Historic population losses of large vertebrate grazers may have, among other consequences, increased seagrass vulnerability to infection by pathogens (Jackson et al. 2001). It was suspected, but never proven, that the slime mold protist, *Labryinthula,* was the cause of the wasting disease event that devastated eelgrass populations throughout the North Atlantic between 1930 and 1933, dramatically disrupting estuarine systems (Steel 1991). Higher water temperatures apparently stressed the seagrasses, making them more susceptible to *Labryinthula*. Healthy eelgrass beds were generally reestablished by the 1960s. More recently, similar large-scale die-offs of eelgrass from Nova Scotia to Connecticut, and turtle grass in Florida Bay have been attributed to *Labryinthula* (Short et al. 1987). Eelgrass infected with *Labryinthula* was also found near Beaufort, North Carolina in the 1980s (Short et al. 1987). Recent studies indicate that characteristics of wasting disease are appearing in some eelgrass beds in southern Core Sound, Back Sound and Bogue Sound (SAFMC 1998a). Submerged aquatic vegetation is less susceptible to infection by the pathogen in low salinity waters (Short et al. 1987). Potential impacts in North Carolina include reductions in bay scallops and other fisheries resources, and large reductions in migratory waterfowl populations. Although the current infections have not caused catastrophic declines in eelgrass populations such as those which occurred in the 1930s, the disease is a potential threat to coastal fisheries should large-scale mortalities occur. *Submerged grasses need to be monitored on a regular basis to assess the status of wasting disease and its association with human-induced stresses.*

Existing management measures

Regulatory designations of coastal waters can either protect or potentially allow degradation of SAV habitat. The MFC-designated crab spawning sanctuaries, mechanical oyster harvest prohibited areas, military restricted areas, fish nursery areas, and trawl net prohibited areas protect SAV in those areas from potential physical disturbance associated with bottom fishing gear (Maps 3.5a-c). The great majority of SAV beds along the eastern perimeter of the Albemarle-Pamlico system are protected within these areas. However, SAV occurring in the western portion of the Albemarle-Pamlico system is generally not within these gear-restricted areas. Moreover, the likelihood of sedimentation and eutrophication is relatively greater on the sounds' western perimeter due to the closer proximity of river discharge. Although SAV functions as a nursery for many economically important species, SAV is predominantly absent from designated fish nursery areas. In particular, most of the high salinity SAV beds are not designated Primary Nursery Areas. *The DMF should develop criteria for designating Strategic Habitat Areas and designate SAV areas that meet those criteria.*

The largest spatial gap in SAV protection from fishing gear impacts is in northern Pamlico Sound where dredging for crabs is allowed. This area includes SAV beds in the sound immediately west of Pea Island National Wildlife Refuge. There are smaller areas of unprotected SAV along both the eastern and western sides of Roanoke Sound and along the shoreline of West Bay in the southern Pamlico Sound area. The extensive SAV beds of Core and Bogue sounds are protected from mechanical oyster methods, but not from trawling or from bay scallop dredging. Area designations that could result in SAV impacts include mechanical clam harvest areas and areas where trawling and bay scallop dredging occur. Most of the designated mechanical clam harvest areas are not located where SAV is found (Maps 4.4a-b). Areas open to trawling generally do not support SAV, since SAV is limited in occurrence to shallow water. However, SAV does occur in Core and Bogue sounds where trawling and bay scallop dredging are allowed. *The DMF should assess the effect of trawling and dredging activities in Core and Bogue sounds on SAV. The DMF should also assess where additional protective distances are needed between SAV and bottom disturbing fishing methods, including clam trawling (kicking), oyster dredging, crab dredging, bay scallop dredging, and bottom trawling.*

There are several regulations and designations that provide some direct and indirect protection of SAV beds. Area designations that provide water quality protection for SAV include Primary Nursery Areas (PNAs), High Quality Waters (HQWs), and Outstanding Resource Waters (ORWs). The CRC prohibits new dredge and fill activities in areas with SAV, but maintenance dredging of existing permitted navigation channels is allowed. Rules of the CRC do not allow authorization of projects that can violate water quality standards of estuarine resources, including SAV and PNAs [CRC rule 15A NCAC 07H .0207]. CRC rules state that activities directly impacting SAV, such as dredging or construction of docking facilities, should be avoided [CRC rule 15A NCAC 07H .0209(d)(4)]. Waters designated as PNAs by the MFC, or that have a special water quality classification by the EMC, such as ORW, are given additional consideration for impacts by DCM prior to issuing development permits. Despite these additional considerations, permits that result in cumulative impacts to SAV, particularly from dock construction, continue to be authorized (T. Murphey, DMF, pers. com., 2002).

Several Outstanding Resource Waters (classified by the EMC) have significant SAV coverage. The ORW designation carries with it more site-specific management strategies based on the resources to be protected, as well as some minimum requirements for discharges and development. For example, new development adjacent to ORW waters must comply with specified stormwater provisions [EMC rule 15A NCAC 2H .1007] and non-discharge permits are required to meet reduced loading rates and increased buffer zones. Outstanding Resource Waters and their more stringent water quality standards, as adopted by the EMC, cover approximately 25% of the mapped SAV habitat in coastal North Carolina. Submerged aquatic vegetation habitat within ORWs is located in Core Sound, western Bogue Sound, and the lower White Oak River (Maps 2.3a-b). *The remaining 75% of mapped SAV should be evaluated for designation as Outstanding Resource Waters or Strategic Habitat Areas to invoke adequate protective measures.*

Because development and associated impacts occur in areas adjacent to existing ORWs, such as in the Bogue Sound area, the designation of waters alone will not effectively protect habitats unless the rules associated with those designations are adequate and enforced. *The effectiveness of ORW and HQW rules* *in protecting SAV and other habitats should be examined and strengthened as necessary. The EMC, CRC, and MFC should develop appropriate management strategies that maintain water quality at a level that adequately protects SAV.*

In 2003 the MFC adopted a policy statement for protection of SAV habitat. The document summarizes the habitat value of SAV and provides management guidelines for protection of SAV, to aid in development of habitat protection and fishery management plans. These management needs are listed below.

- *In order to delineate and assess the distribution and health of SAV habitat, SAV beds need to be mapped and monitored. The saltwater end of coastal waters supports eelgrass, widgeon grass and shoalgrass, and the freshwater end supports several species of freshwater SAV.*
- *Minimize nutrient and sediment loading to coastal waters that support existing SAV to protect adequate water quality as defined by water-column clarity in standard measurement units.*
- *All SAV needs to be protected from all bottom-disturbing fishing and recreational gear. Sufficient buffer zones surrounding SAV beds should also be protected from disturbance to prevent impacts of sediments on growing SAV.*
- *Provide adequate safeguards to prevent direct (or indirect) impacts from development projects adjacent to or connected to SAV.*
- *Assess cumulative impacts of land use and development changes in the watershed affecting SAV to identify the potential impact. Require identification of cumulative impacts as a condition of development of permit applications.*
- *Require compensatory mitigation where impacts are unavoidable. Initiate restoration programs to recoup an/or enhance lost SAV habitat.*
- *Educate landowners adjacent to SAV, boaters, and other potential interested parties about the value of SAV as a habitat for many coastal fishes and invertebrates.*

Commission actions (MFC, CRC, and EMC) should be consistent with this policy.

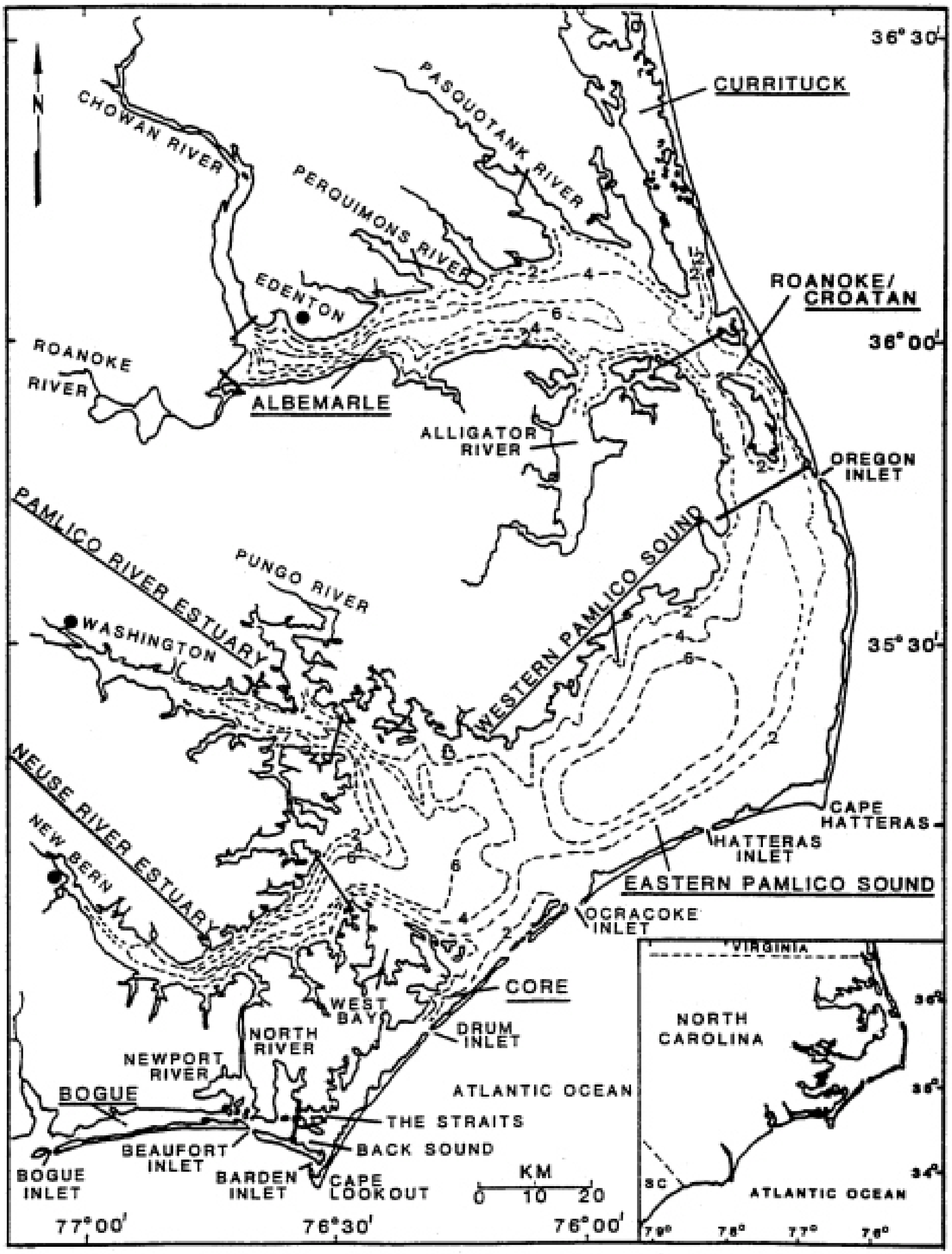
4.5 SUMMARY OF SUBMERGED AQUATIC VEGETATION CHAPTER

Submerged aquatic vegetation is an extremely valuable fish habitat that occurs in North Carolina’s coastal estuarine and freshwater systems. Because light is the primary limiting factor affecting its distribution, SAV is restricted to relatively shallow waters. Submerged aquatic vegetation provides ecosystem functions similar to shell bottom, such as enhancing water quality through stabilizing and trapping sediment, reducing wave energy, cycling nutrients within the system, and providing structure for invertebrate attachment and refuge from predators. Seagrasses also produce large quantities of organic matter, which supports a complex food base for coastal fishes and other organisms. This habitat is especially valuable as a nursery and refuge from larger predators for the young of many important commercial and recreational fishery species. Bay scallops, pink shrimp, hard clams, gag, black sea bass, summer flounder, and others are typically associated with high salinity SAV. Juvenile striped bass, striped mullet, brown and white shrimp, Atlantic croaker, and others frequently use low salinity grasses. Red drum and blue crabs are among several species that rely upon both low and high salinity grasses at different stages of their life cycles. The high fisheries value of this habitat has been well established by the scientific community, and SAV is federally designated as a Habitat Area of Particular Concern for penaeid shrimp, blue crab, and red drum.

Historical accounts indicate that there have been large-scale losses of SAV in North Carolina’s low salinity tributaries on the mainland side of Pamlico Sound and along much of the shoreline of western Albemarle Sound, while the high salinity grass beds to the east appear relatively stable. Loss of low salinity SAV habitat could negatively affect stocks of striped mullet, Atlantic croaker, and blue crab, which were classified as Concern by DMF in 2003. Impacts to high salinity SAV beds could be especially detrimental to bay scallops and black sea bass (south of Hatteras), which are currently listed as

Overfished. Protection, enhancement, and restoration of this habitat are high priorities for recovery of those species and for sustained health of many others.

The major threat to SAV is large-scale nutrient enrichment and sediment loading, which increases turbidity, reduces light penetration, and subsequently impacts SAV growth, survival, and productivity. In North Carolina, most of the low salinity areas that have experienced large reductions in SAV coverage are also designated Nutrient Sensitive Waters. Major contributors of nutrients and sediments include point source discharges, nonpoint runoff (from crop agriculture, animal operations, urban and road construction, and impervious surfaces) and resuspended sediments (from bottom disturbing fishing gear and channel dredging). There are also activities that threaten the physical structure of SAV. Dredging for navigational channels, marinas, or infrastructure such as bridges or cables can result in large, direct losses of SAV. Docks constructed over SAV can cause immediate loss during construction or gradual loss due to shading effects. Boating activity in shallow vegetated waters can damage SAV from propeller damage to SAV. Bottom disturbing fishing gears used within or near SAV habitat, such as oyster and crab dredges, hydraulic clam dredges, clam trawls, and bull rakes, may cause significant damage to SAV habitat. As human population, boating activity, fishing pressure, and shoreline development increase, losses of SAV are likely to continue if steps are not actively taken to protect SAV and maintain suitable water quality conditions. State and local managers need to ensure that 1) SAV habitat is not physically impacted by water-dependent activities and 2) water quality (especially clarity) is enhanced to allow persistence of existing SAV and re-colonization of former habitat.



Map 4.1. Depth contours (meters) of the Albemarle-Pamlico Sound system, North Carolina (from Ferguson and Wood 1994).

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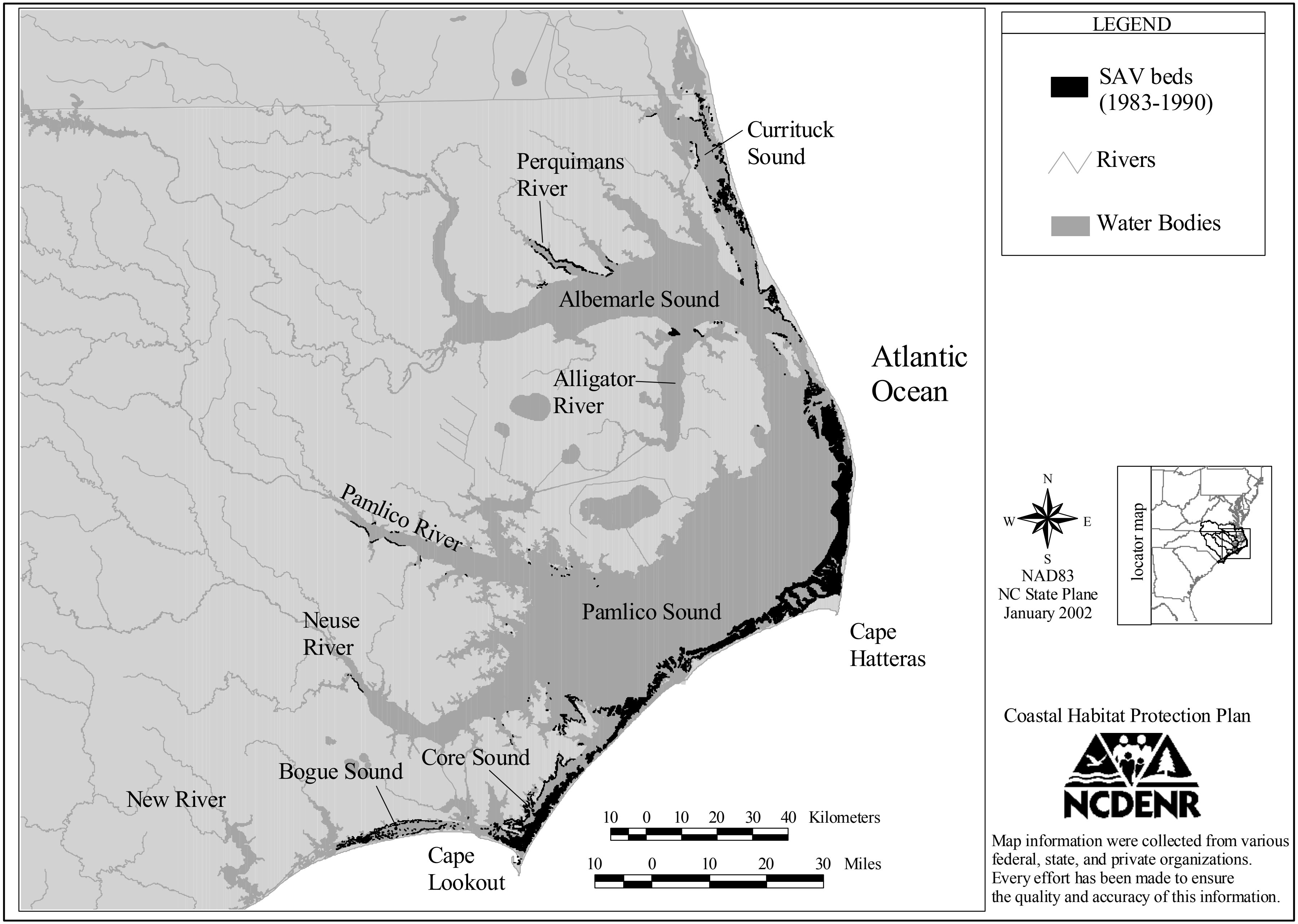

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

Map 4.2. Location of known of submerged aquatic vegetation (SAV) habitat in coastal North Carolina (from Ferguson and Wood 1994; Carraway and Priddy 1983). Note: absence of SAV beds in a given areas does not suggest actual presence/absence of SAV because surveys have not been conducted in all areas.

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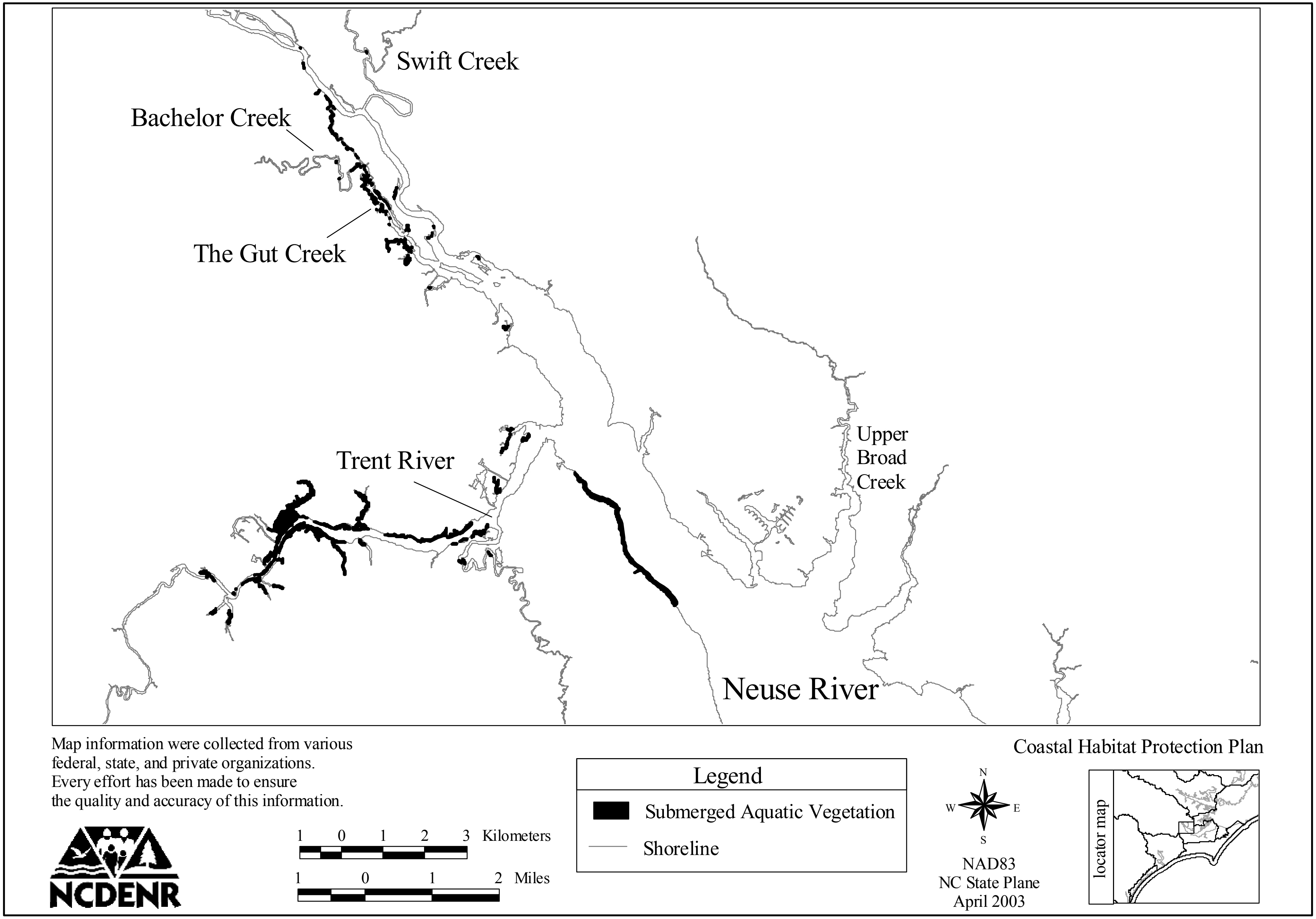

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

Map 4.3a. Distribution of submerged aquatic vegetation in the Neuse River estuary in 1998 (From DWQ 1998).

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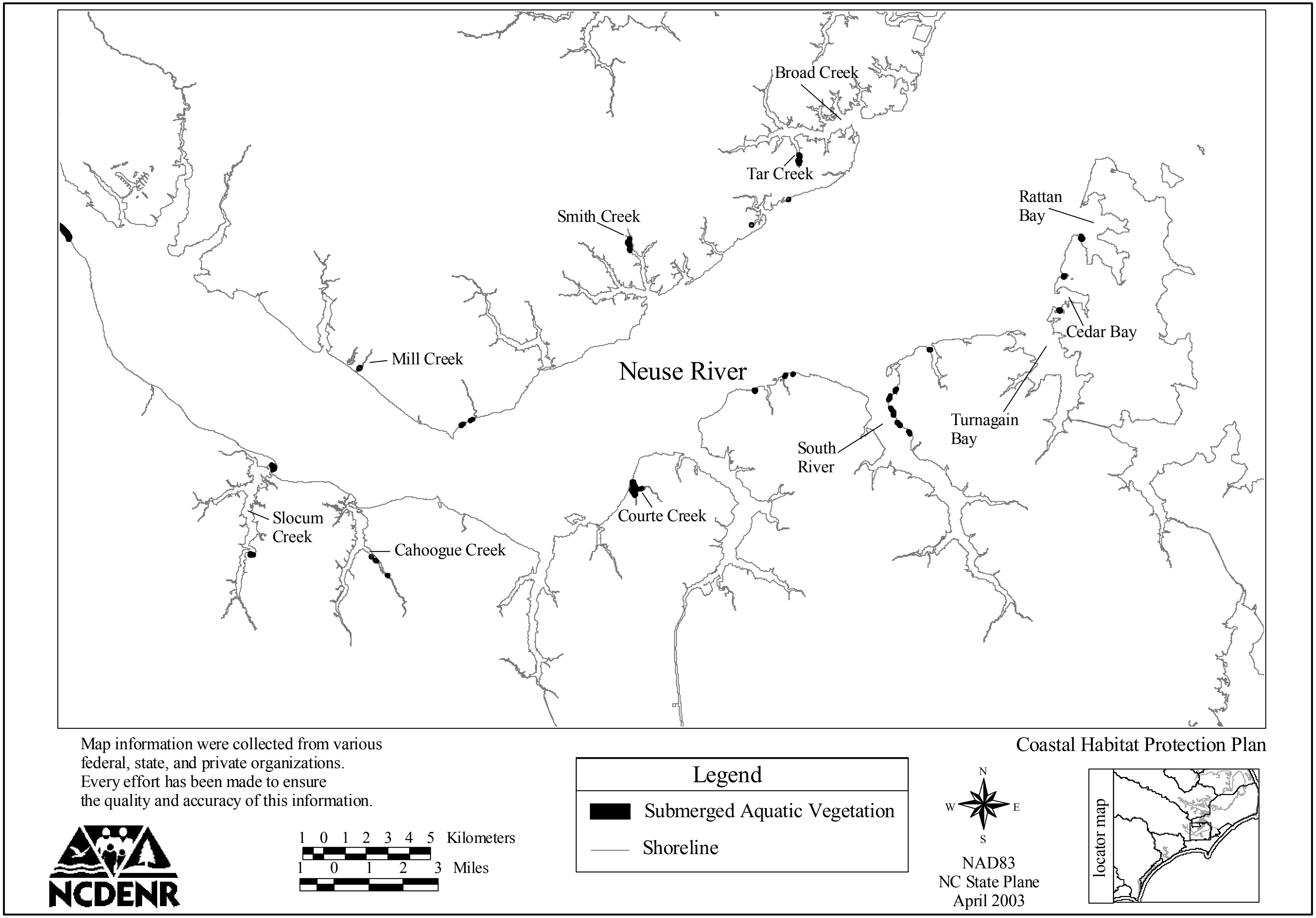

Map information were collected from various
federal, state, and private organizations.
Every effort has been made to ensure
the quality and accuracy of this information.

Coastal Habitat Protection Plan

NAD83
NC State Plane
April 2003

Map 4.3b. Distribution of submerged aquatic vegetation in the Neuse River estuary in 1998 (From DWQ 1998).

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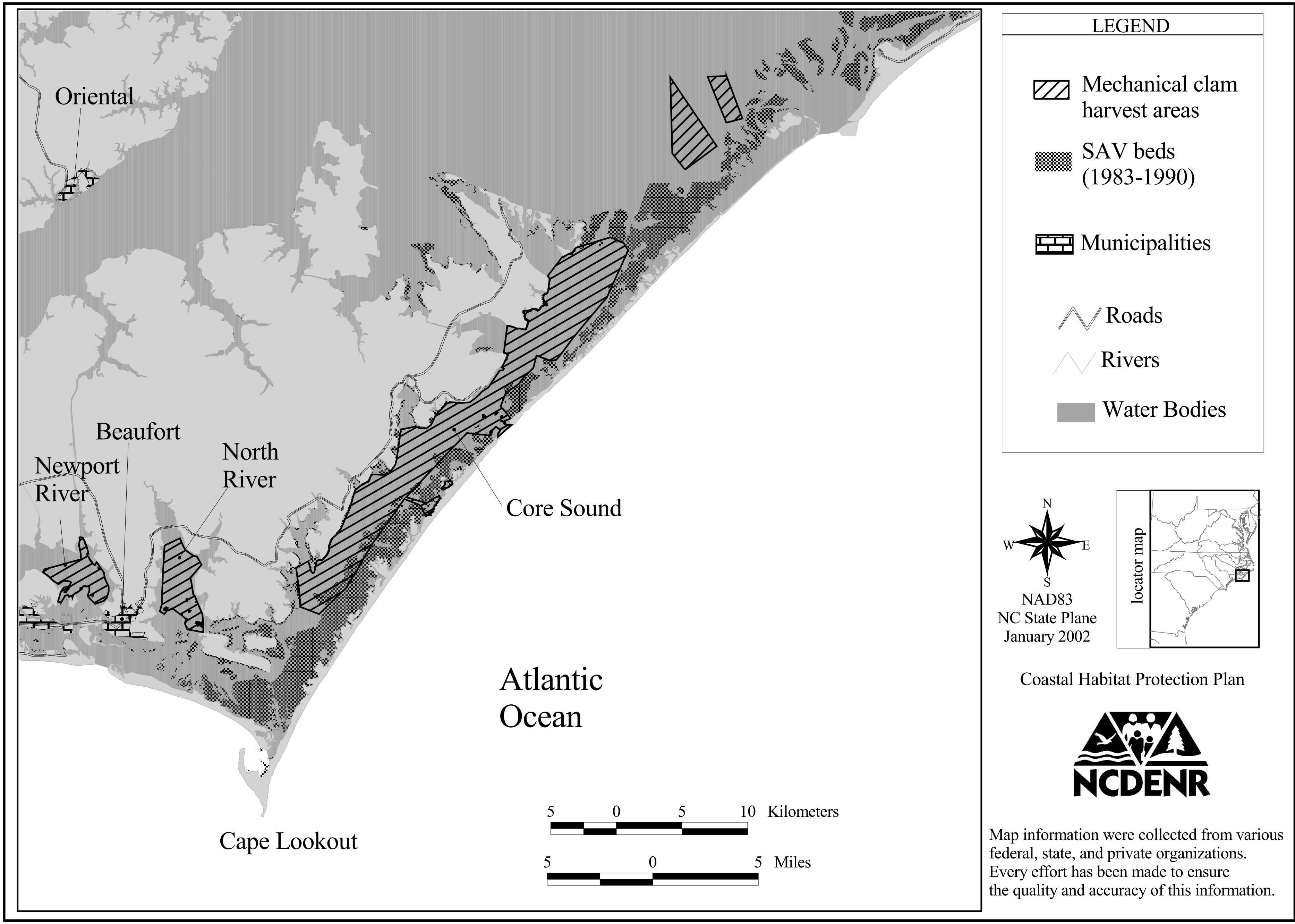

Map 4.4a. Location of mechanical clam harvesting areas relative to submerged aquatic vegetation habitat in the Core Sound area of North Carolina.

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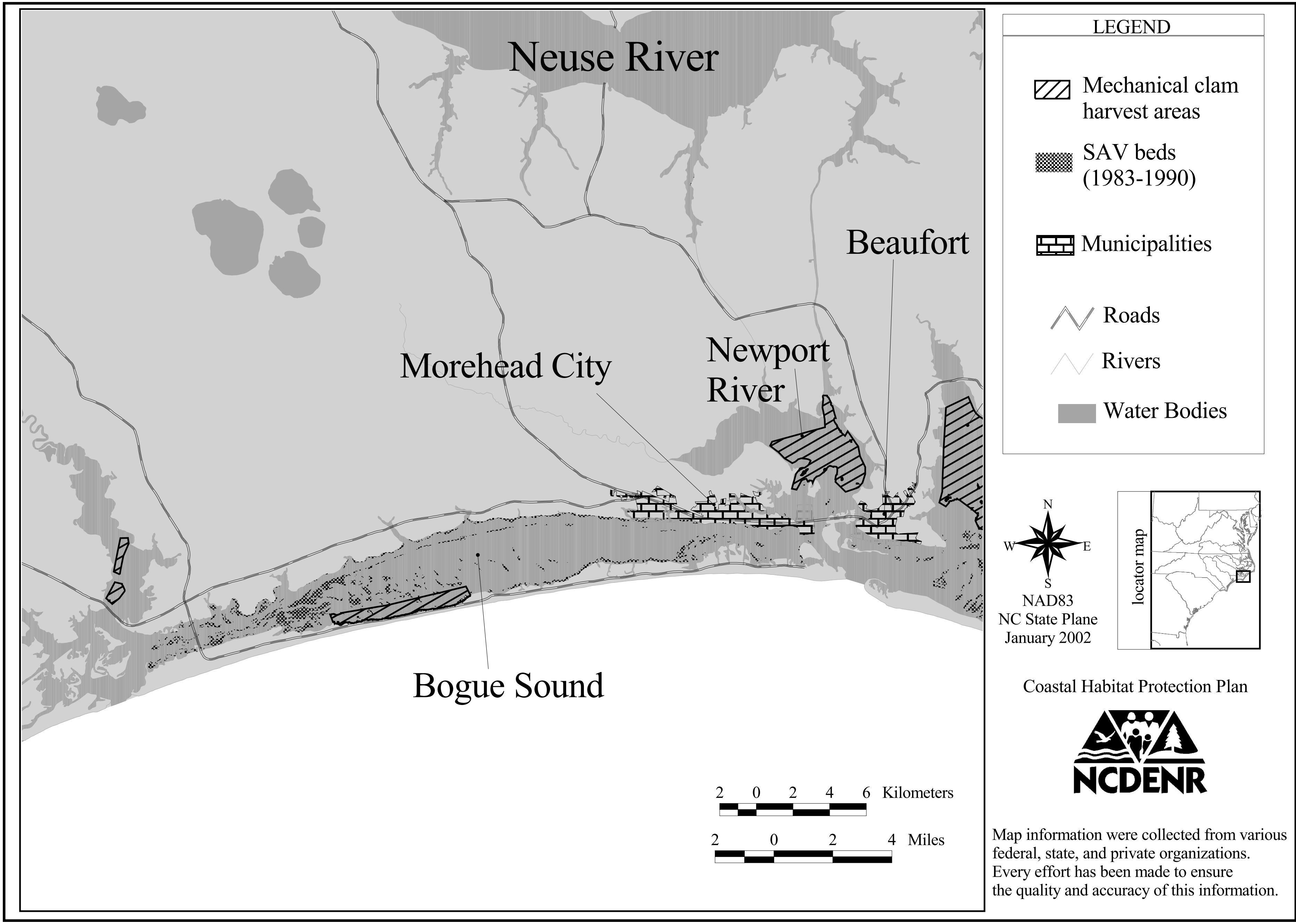

Map 4.4b. Location of mechanical clam harvesting areas relative to submerged aquatic vegetation habitat in the Bogue Sound area of North Carolina.

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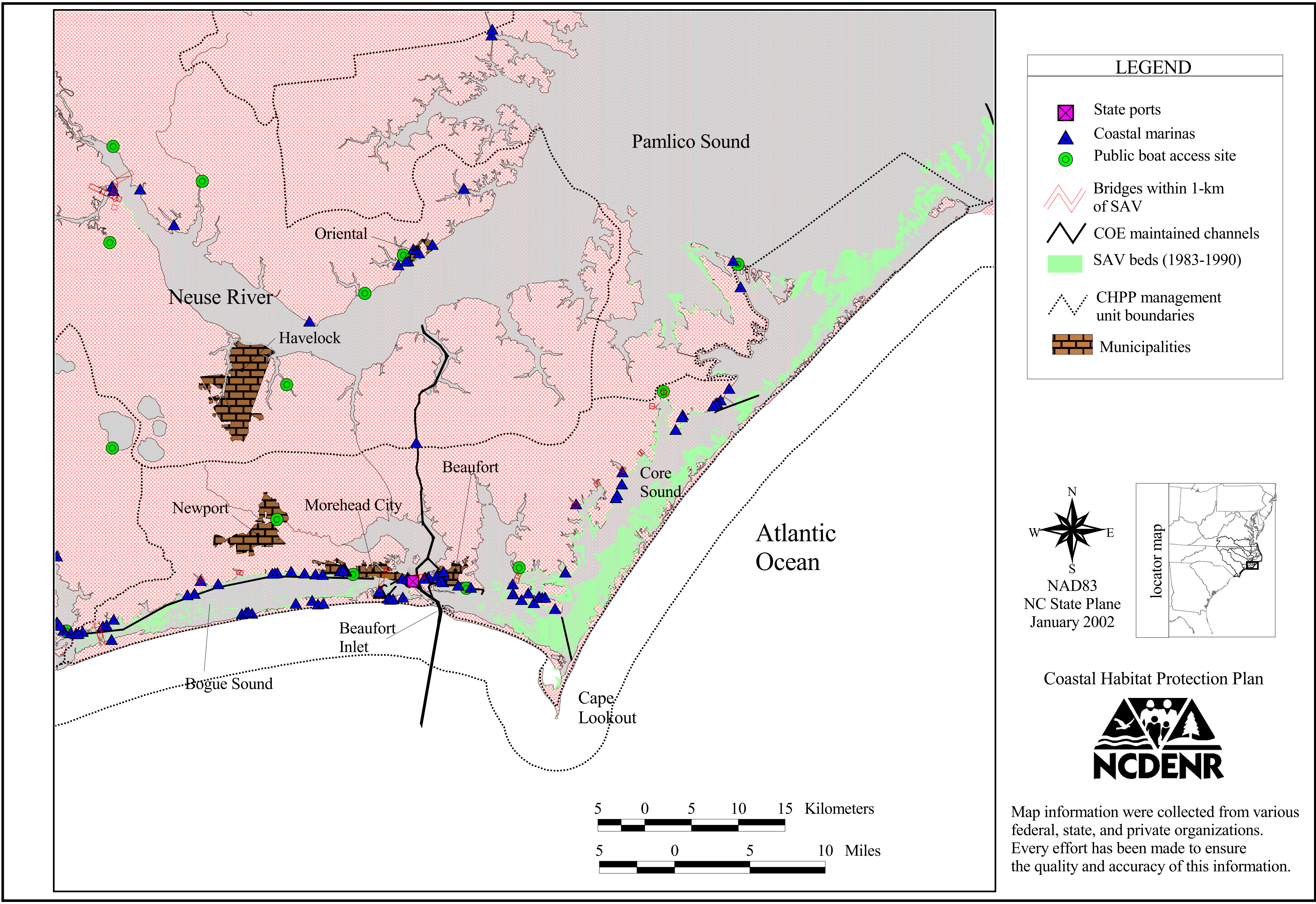

Map information were collected from various federal, state, and private organizations. Every effort has been made to ensure the quality and accuracy of this information.

Map 4.5a. Locations of marinas, boating access sites and other man-made facilities relative to beds of submerged aquatic vegetation in the Core-Bogue sounds and lower Neuse River areas of North Carolina

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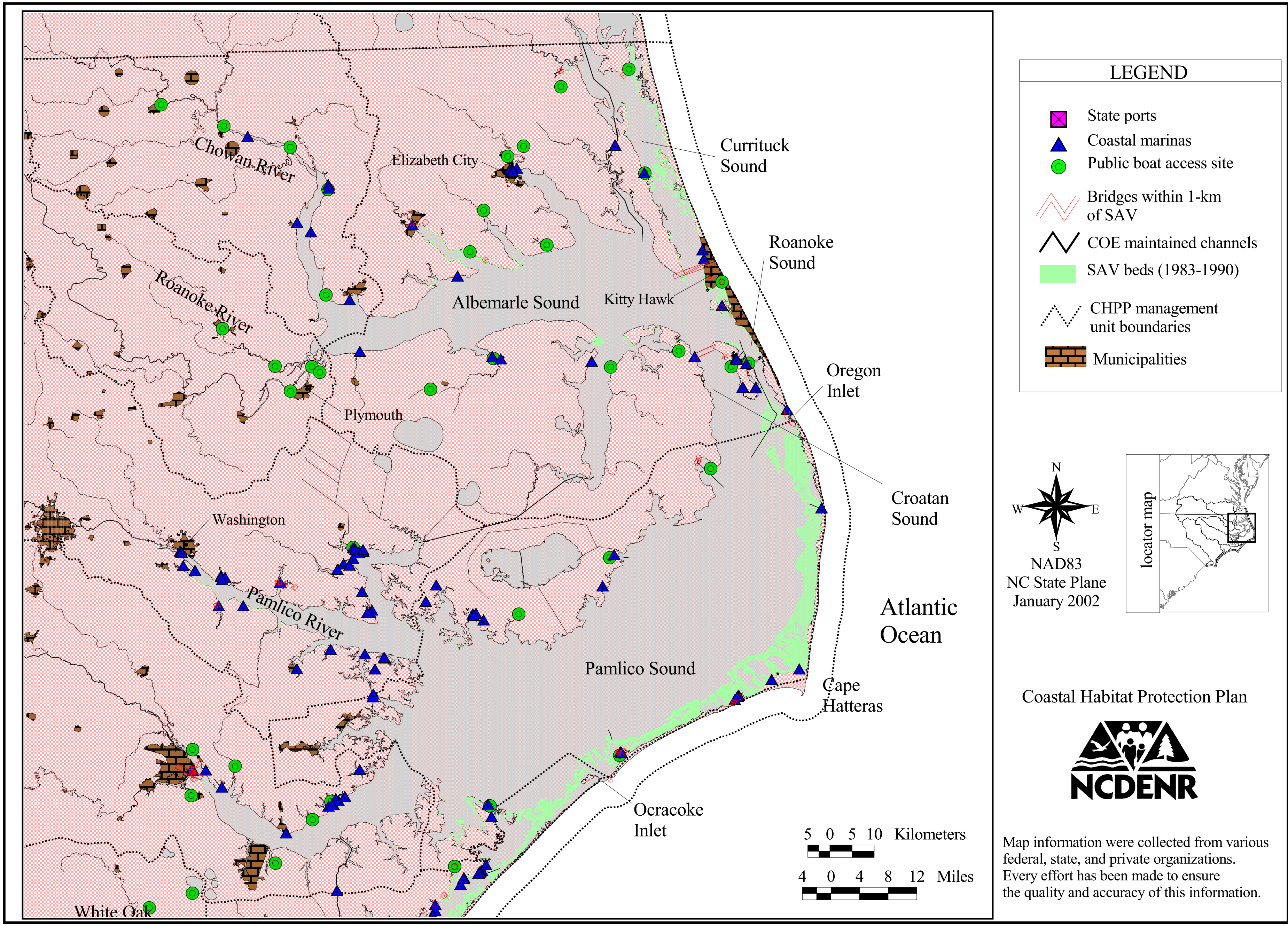

Map 4.5b. Locations of marinas, boating access sites and other man-made facilities relative to beds of submerged aquatic vegetation in the Albemarle-Pamlico sound systems of North Carolina

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