

## CHAPTER 4. SUBMERGED AQUATIC VEGETATION

### 4.1. DESCRIPTION AND DISTRIBUTION

#### 4.1.1. 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) define SAV habitat as submerged lands that:

- “(i) are vegetated with one or more species of submerged aquatic vegetation including bushy pondweed or southern naiad (*Najas guadalupensis*), coontail (*Ceratophyllum demersum*), eelgrass (*Zostera marina*), horned pondweed (*Zannichellia palustris*), naiads (*Najas* spp.), redhead grass (*Potamogeton perfoliatus*), sago pondweed (*Stuckenia pectinata*, formerly *Potamogeton pectinatus*), shoalgrass (*Halodule wrightii*), slender pondweed (*Potamogeton pusillus*), water stargrass (*Heteranthera dubia*), water starwort (*Callitriche heterophylla*), waterweeds (*Elodea* spp.), widgeongrass (*Ruppia maritima*) and wild celery (*Vallisneria americana*). These areas may be identified by the presence of above-ground leaves, below-ground rhizomes, or reproductive structures associated with one or more SAV species and include the sediment within these areas; or
- (ii) have been vegetated by one or more of the species identified in Sub-item (4)(i)(i) of this Rule within the past 10 annual growing seasons and that meet the average physical requirements of water depth (six feet or less), average light availability (secchi depth of one foot or more), and limited wave exposure that characterize the environment suitable for growth of SAV. The past presence of SAV may be demonstrated by aerial photography, SAV survey, map, or other documentation. An extension of the past 10 annual growing seasons criteria may be considered when average environmental conditions are altered by drought, rainfall, or storm force winds.” [2009 MFC rule 15A NCAC 03I .0101 (4)(i)].



Submerged aquatic vegetation is included as fish habitat areas under MFC rules [2009 MFC rule 15A NCAC 03I .0101 (4)]. The MFC definition was modified as above since the 2005 CHPP as part of CHPP implementation to include low salinity species and address difficulties in identification of SAV habitat. The definition went into effect in April 2009. The former definition required the presence of leaves,

shoots, or rhizomes. However, because the presence of SAV vegetation varies seasonally and inter-annually, a one-time inspection could result in improper habitat determination. The modified definition allows SAV habitat to include either areas where SAV vegetation is present during the active growing season, or there is past documentation or professional knowledge of SAV in the area within the past ten years. A concern with the new definition arises for SAV habitat that has not been mapped or otherwise documented within the last 10 years. Although documentation of past occurrence may be limited, it can be taken into account where available and should improve over time. Regular mapping and monitoring of SAV habitat is consequently imperative for proper identification of SAV habitat. In areas appearing suitable for SAV, surveys are required during the active growing season. To ensure consistency in identifying SAV habitat among agencies (an action in the 2007-09 CHPP Implementation Plan) CRC rules were modified to reference the MFC definition.

### 4.1.2. Description

Submerged aquatic vegetation habitat includes marine, estuarine and riverine vascular plants that are rooted in sediment. Although SAV occurs intertidally in high salinity regions, the plants are generally submerged and cannot survive if removed from the water for an extended length of time (Hurley 1990). Leaves and stems have specialized thin-walled cells (aerenchyma) with large intercellular air spaces to provide buoyancy and support in an aquatic environment. Leaves and stems are generally thin and lack the waxy cuticle found in terrestrial plants. The lack of a waxy cuticle increases the exchange of water, nutrients, and gases between the plant and the water (Hurley 1990). The extensive root and rhizome system anchors the plants, and also absorbs nutrients (Thayer et al. 1984). Because the plants are rooted in anaerobic sediments, they need to produce a large amount of oxygen to aerate the roots, and therefore have the highest light requirements of all aquatic plants (including phytoplankton, macroalgae, floating leaf plants, etc.). Reproduction occurs both sexually and asexually (i.e., vegetatively).

There are three basic types of SAV communities in North Carolina, all of which are important to coastal fisheries – (1) high salinity or saltwater (18-30 ppt), (2) moderate salinity or brackish (5-18 ppt), and (3) freshwater - low salinity (0-5 ppt). High salinity estuarine species that occur in North Carolina include eelgrass (*Z. marina*) and shoalgrass (*H. wrightii*). Eelgrass is a temperate species at the southern limit of its Atlantic coast range in North Carolina. In contrast, shoalgrass is a tropical species that reaches its northernmost extent in the state. Widgeon grass (*R. maritime*) grows best in moderate salinity but has a wide salinity range and grows from low to high salinity environments. The co-occurrence of these three SAV species is unique to North Carolina, resulting in high coverage, both spatially and temporally, of shallow bottoms in North Carolina's estuaries (Ferguson and Wood 1994). Freshwater – low salinity SAV species in North Carolina are diverse and include native wild celery (*V. americana*), non-native Eurasian milfoil (*Myriophyllum spicatum*), bushy pondweed (*Najas guadalupensis*), redhead grass (*P. perfoliatus*), and sago pondweed (*P. pectinatus*) (Ferguson and Wood 1994). Submerged aquatic vegetation covers areas that vary in size from small isolated patches of plants less than a meter (<3 ft) in diameter to continuous meadows covering many acres.

Habitat for SAV 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.

The three-dimensional shape of SAV habitat can be quite variable, ranging from highly mounded, patchy beds several meters wide, to more contiguous, low-relief beds (Fonseca et al. 1998). Leaf canopies formed by the SAV 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). Despite the difficulty of defining the boundaries of SAV beds, unvegetated bottom between nearby adjacent patches is included as a component of patchy SAV habitat since rhizomes and/or seedlings may be present and the beds “move” around with patterns of sediment erosion and deposition (Fonseca et al. 1998).

### **4.1.3. Habitat requirements**

Beds of SAV occur in North Carolina in subtidal, and occasionally intertidal, areas of sheltered estuarine and riverine waters where there is unconsolidated substrate (loose sediment), adequate light reaching the bottom, and moderate to negligible current velocities or turbulence (Thayer et al. 1984; Ferguson and Wood 1994). While this is generally true for all SAV species, individual species vary in their occurrence along gradients of salinity, depth, and water clarity (Table 4.1). Field sampling of SAV beds in the Albemarle-Pamlico estuarine system between 1988 and 1991 found that occurrence of SAV was related to water depth, water clarity as measured by secchi depth, and salinity. In the area sampled, average depth of SAV occurrence ranged from 2.63–3.94 ft (0.8–1.2 m), depending on the species. The maximum depth of observed presence, regardless of species, was 7.87 ft (2.4 m) (Ferguson and Wood 1994). Data indicated that freshwater SAV had a somewhat greater tolerance to turbidity than salt and brackish SAV, since they were found in areas of similar water depths to high salinity grasses, but secchi depths were lower (Ferguson and Wood 1994). This conclusion supports other research (Funderburk et al. 1991) showing that salt/brackish SAV requires slightly greater water clarity (secchi depth >1.0 m, or 3.28 ft) than freshwater SAV (secchi depth >0.8 m or 2.63 ft).

The primary factors controlling distribution of SAV are water depth, sediment composition, currents/wave energy, and the penetration of photosynthetically active radiation (PAR) through the water column (Goldsborough and Kemp 1988; Duarte 1991; Kenworthy and Haurert 1991; Dennison et al. 1993; Stevenson et al. 1993; Gallegos 1994; Moore et al. 1996; Virnstein and Morris 1996; Moore et al. 1997; Koch 2001; French and Moore 2003; Havens 2003; Kemp 2004; Cho and Poirrier 2005; Duarte et al. 2007; Biber et al. 2008). At a minimum, high salinity SAV leaves require 15-25% of incident light (Dennison and Alberte 1986; Kenworthy and Haurert 1991; Bulthuis 1994; Fonseca et al. 1998). Low salinity species have generally lower light requirements (9-13%) than high salinity grasses (Funderburk et al. 1991; Fonseca et al. 1998; EPA 2000a; Kemp et al. 2004). For comparison, phytoplankton in the water column requires only 1% of light available at the surface (Fonseca et al. 1998). The light requirements of SAV species can be expressed as percent of surface light, light attenuation coefficient ( $K_d m^{-1}$ ), or secchi depth (m). Table 4.2 summarizes what is known about the growing season and light requirements of North Carolina SAV species. The amount of light penetrating through the water column is partitioned into two categories: light required through the water column, and light required at leaf. The “light required at leaf” refers to the amount of water column light that can penetrate epibiota to the leaf

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surface. If less light is available, photosynthesis is limited, reproduction may be inhibited, and growth and survival of the submerged vegetation cannot be sustained.

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

SAV species	Environmental parameter					
	Salinity (ppt)		Secchi depth m (ft)		Water depth m (ft)	
	Range	Average	Range	Average	Range	Average
<i>HIGH SALINITY (18-30 ppt)</i>						
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)
<i>MODERATE SALINITY (5-18 ppt)</i>						
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)
<i>FRESHWATER -LOW SALINITY (0-5 ppt)</i>						
Redhead Grass	0-20	1	0.4 - 1.4 (1.3 - 4.6)	0.9 (3.0)	0.4 - 2.4 (1.3 - 7.9)	0.9 (3.0)
Wild Celery	0-10	2	0.2 - 2.0 (0.7 - 6.6)	0.6 (2.0)	0.2 - 2.3 (0.7 - 7.6)	1.0 (3.3)
Eurasian Watermilfoil	0-10	2	0.2 - 1.4 (0.7 - 4.6)	0.6 (2.0)	0.5 - 2.4 (1.6 - 7.9)	1.1 (3.6)
Bushy Pondweed	0-10	1	0.2 - 2.0 (0.7 - 6.6)	0.7 (2.3)	0.5 - 1.7 (1.6 - 5.6)	1.0 (3.3)
Sago Pondweed	0-9	2	0.2 - 0.4 (0.7 - 1.3)	0.3 (1.0)	0.6 - 0.9 (2.0 - 3.0)	0.8 (2.6)

Table 4.2. Light requirements for SAV species found in coastal North Carolina. (Funderburk et al. 1991; EPA 2000a; Kemp et al. 2004)

SAV salinity categories	Light required at leaf (%)	Light required through water (%)
Moderate - high salinity (5-30 ppt)	>15	>22
Freshwater-low salinity (0-5ppt)	>9	>13

Light penetration is affected by epibiotic growth and natural substances in the water column, such as dissolved organic matter (e.g., humics), suspended particulate matter (e.g., sediment and minerals), detritus, and algae (Kemp et al. 2004; Biber et al. 2008). Dissolved organic matter affects light penetration by coloring the water. For example, dissolved organic matter such as tannic acid (produced

naturally in swamp waters via breakdown of detritus) and lignins (produced naturally as well as artificially, such as through wood pulp mill processing) strongly absorbs blue light.

Suitable or potential SAV habitat can be determined by modeling habitat requirements. This could be done by simply selecting shallow bottom with appropriate substrate or could be further refined through modeling of additional bio-optical parameters and wave exposure. Turbidity, total suspended solids (TSS), Chlorophyll *a*, and dissolved organic matter are the optically active constituents (OACs) typically measured to determine light available in the water column above the substrate (Biber et al. 2008). In the mid-Atlantic, 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 $\mu$ g/l (Kemp et al. 2004). However, another study indicated that high salinity SAV requires chlorophyll *a* < 10  $\mu$ g/l and turbidity < 1 ntu (Gallegos 1994). Bio-optical models predicting light attenuation under various environmental conditions have been calibrated for the Chesapeake Bay (Gallegos 2001), Indian River Lagoon in Florida (Gallegos and Kenworthy 1996), and North River in North Carolina (Biber et al. 2008). In North Carolina, the North River was chosen because it exhibited a broad range of depths and salinities representing the Albemarle-Pamlico estuarine system. In the North River, the bio-optical model predicted a deeper depth distribution (1.7 m MSL) for SAV than was observed (0.87 m MSL). The reason SAV was not found as deep as predicted may be due to confining hydrographic features, currents, epiphytic growth, substrate composition, or overestimation of colonization depth (Duarte 1991; Kemp et al. 2004; Bradley and Stolt 2006; Biber et al. 2008).

Kemp et al. (2004) developed a relationship to estimate epiphytic material and its associated light attenuation. The estimation required input data on light attenuation in the water column, TSS, dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphorus (DIP). In the Chesapeake Bay, epiphytic growth contributed 20-60% additional light attenuation in low salinity areas and 10-50% in moderate to high salinity areas (Kemp et al. 2004). From that, the amount of needed DIN and DIP was determined (~0.15 mg/l DIN; 0.01-0.02 mg/l DIP) (Sand-Jensen 1977; Funderburk et al. 1991; Kemp et al. 2004). However, the majority of nitrate used by SAV is derived from the sediment, rather than the water column (Thayer et al. 1984), suggesting the importance of substrate fertility in SAV distribution. Once light attenuation at both leaf and water column is determined, a maximum depth of SAV can be estimated. The actual distribution of potential habitat for SAV also depends on the distribution of substrate compositions, current velocities, and wave exposure during the growing season.

Contiguous beds of eelgrass or other species of SAV rarely occur in high energy areas or where currents are strong (>20-40 cm/s) (Thayer et al. 1984; Fonseca et al. 1998). Work conducted in Core Sound by Fonseca and Bell (1998) found that percent cover of SAV, bed perimeter to area ratio, sediment organic content, and percent silt/clay declined with increased wave exposure and currents. *A simple model to predict potential SAV habitat in North Carolina would be helpful for identification and protection of this important habitat where it has not been mapped or otherwise documented recently (within the past 10 years).* To make the most accurate prediction of SAV habitat, the bio-optical model (calibrated for North Carolina) should include adjustments for epiphytic growth, substrate composition, currents and wave energies at a location. However, the data needs for such an analysis are not satisfied by either current spatial data on bathymetry or available spatial/temporal data on physicochemical conditions. Refer to the soft bottom and water column chapters for information on bathymetric data and physicochemical monitoring stations, respectively.

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 two submerged grasses common to high salinity estuarine waters (Hurley 1990; Bergstrom et al. 2006).

4.1.3.1. High salinity SAV/sea grasses (18-30ppt)

- Eelgrass (*Zostera marina*): Grows in fine mud, silt, and loose sand in high salinity waters and can tolerate high energy waters (Thayer et al. 1984). Reproduces vegetatively throughout the growing season and sexually from December to April. Present primarily as a seed bank from July to November (P. Biber/NMFS, pers. com., 2003). Rhizomes rarely deeper than 5 cm (1.97 inches). Can spatially coexist in beds with *Halodule* and *Ruppia* 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).
- 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). May co-occur with *Zostera* and *Ruppia* and dominates mid-summer through fall in North Carolina, after which *Zostera* becomes relatively more predominant (Thayer et al. 1984).

4.1.3.2. Moderate salinity/brackish SAV (5-18ppt)

- Widgeon grass (*Ruppia maritima*): Tolerates a wide range of salinity regimes, from slightly brackish to high salinity, but grows best in moderate salinity. Found growing with eelgrass and shoalgrass, as well as low salinity species like redhead grass. Spreads vegetatively from creeping rhizome during April - October. Rare occurrence reported in fresh water. While more common on sandy substrates, is also found on soft, muddy sediments. High wave action damaging to slender stems and leaves. It reproduces sexually in summer and disperses by seed.

4.1.3.3. Freshwater-low salinity SAV (0-5ppt)

The following species typically grow best in fresh to low salinity waters, but also grow occasionally in moderately brackish waters up to about 15 ppt.

- 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 than the more narrow leaved species. Securely anchored in the substrate by its extensive root and rhizome system.
- Wild celery (*Vallisneria americana*): Primarily a freshwater species occasionally found in moderately brackish waters. Coarse silt to slightly sandy soil. Tolerant of murky waters and high nutrient loading. Can tolerate some wave action and currents compared to more delicately leaved and rooted species. Similar in appearance to eelgrass.
- 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. *Myriophyllum spicatum* is a non-native, invasive species, estimated to cover over 4000 acres in Currituck and Albermarle sounds during the 1990s (DWR 1996) and is classified by the North Carolina Board of Agriculture as a Class B noxious weed [02 NCAC 48A .1702].
- Bushy Pondweed or Southern Naiad (*Najas quadalupensis*): Present in small freshwater streams. Also tolerates slightly brackish waters. Sand substrates are preferred, but the species can grow in muddy soils. *Najas* spp. requires less light than other SAV species.
- Sago pondweed (*Potamogeton pectinatus*): Fresh to moderately brackish. 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.

#### **4.1.4. Distribution**

The dynamic nature of SAV beds has important implications for mapping and monitoring work. The distribution, abundance, and density of SAV varies seasonally and among years (Thayer et al. 1984; Dawes et al. 1995; 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). 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).

SAV habitat occurs 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. Along the Atlantic coast, North Carolina supports more SAV than any other state, except for Florida (Funderburk et al. 1991; Sargent et al. 1995). The 2005 CHPP reported that, based on interpretation and field verification 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). Other mapping efforts included Carroway and Priddy (1983) in Core and Bogue Sounds and DWQ (1998) in the Neuse River system. In addition to mapped SAV, Davis and Brinson (1989) surveyed and described the distribution of SAV in Currituck Sound and the Western Albemarle-Pamlico Estuarine System.

Since 2005, some additional mapping efforts have added over 20,000 acres of mapped vegetated areas, suggesting SAV habitat covers over 150,000 acres in coastal North Carolina (Map 4.1). The additional mapping efforts include the following:

- DMF (North Carolina Division of Marine Fisheries) Bottom Mapping Program – <http://www.ncdmf.net/habitat/shellmap.htm>, November 2010 \*Maps based on interpolated transect data.
- ECSU (Elizabeth City State University) Mapping Program – <http://www.ecsu.edu/academics/mathsciencetechnology/chemgeophys/sav/index.cfm>, December 2010 \*Maps based on aerial photography.
- NCSU (North Carolina State University) – Dr. Eggleston (<http://www4.ncsu.edu/~dbeggles/>, November 2010) \*Maps based on aerial photography.
- DWQ Rapid Response Teams - <http://portal.ncdenr.org/web/wq/ess/savmapping>, December 2010 \*Maps based on interpolated transect data.

An inventory of all SAV mapping and monitoring efforts is provided at <http://www.ncdmf.net/habitat/chpp28.html> (June 2009). When considering only mapping data, the area of SAV habitat in North Carolina covers approximate 20% of the shallow (<6 foot) littoral zone within the area mapped<sup>20</sup>, and approximately 5% of the total water area. Of course, the spatial distribution of SAV coverage varies within and among regions, corresponding generally to the relative area of shallow estuarine waters (Table 4.3).

SAV habitat in coastal North Carolina occurs mostly along the estuarine shoreline of the Outer Banks (Pamlico and Core/Bogue sounds), with sparse cover along much of the mainland shores of the estuarine system (Ferguson et al. 1989). As the systems become more riverine (i.e., tributaries of Albemarle

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<sup>20</sup> Based on digitizing contours from the depth points drawn on NOAA nautical charts.

Sound), freshwater SAV is locally abundant in larger blackwater streams and rivers, but 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 also be extensive in some low-salinity back bays and lagoons (Moore 1992) such as Currituck Sound and in coastal lakes, such as Lake Mattamuskeet (not included in the area estimate of SAV habitat). Estuarine SAV occurs sporadically west of Bogue Inlet to the border with South Carolina, but these areas had not been suitably photographed in the early 1990's (Ferguson and Wood 1994). Small areas of SAV habitat have been observed in the past by DMF biologists in the New River, Alligator and Chadwick bays, Topsail Sound and inside Rich's Inlet (DMF southern district office staff, pers. com., 2002). More recent imagery and monitoring have verified the presence of patchy SAV beds south of Bogue Sound (S. Chappell and A. Deaton/DMF, pers. observation).

Table 4.3. Estimated acreage of mapped SAV habitat within regions of North Carolina. The area estimates are from a mosaic of mapping efforts spanning a time period from 1981-2008.

<b>CHPP regions</b>	<b>Major water bodies</b>	<b>SAV area (acre)</b>	<b>&lt;6 foot area (% SAV)</b>	<b>Total water area (% SAV)</b>
1	Albemarle/Currituck sounds, Chowan River	21,577	240,471 (9%)	767,002 (3%)
1/2	Oregon Inlet	2,124	10,043 (21%)	52,927 (4%)
2	Pamlico Sound, Neuse/Tar-Pamlico rivers	87,241	251,477 (35%)	1,362,795 (6%)
2/3	Ocracoke Inlet	3,740	14,459 (26%)	36,640 (10%)
3	Core/Bogue sounds, New/White Oak rivers	40,042	154,492 (26%)	423,117 (9%)
4	Cape Fear River, southern estuaries	0	37,800 (0%)	226,349 (0%)

**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. Submerged aquatic vegetation is recognized as an essential fish habitat because of five interrelated features – primary production, structural complexity, modification of energy regimes, sediment and shoreline stabilization, and nutrient cycling. Water quality enhancement and fish utilization are especially important ecosystem functions of SAV relevant to the enhancement of coastal fisheries.

The economic value of ecosystem services provided by SAV habitat has been reported to be very large. Costanza et al. (1997) estimated that the average global value of annual ecosystem services of seagrass and algal beds was \$3,801 trillion/yr. Their estimate took into account services such as climate regulation, erosion control, waste treatment, food production, recreation, and others. Compared to the total global gross national product of \$18 trillion per year, this is a significant amount of services that would otherwise have to be paid for. However, the monetary estimate of SAV services did not account for the lesser value of alternative habitats, such as subtidal soft bottom. While estimated ecosystem services of subtidal soft bottom are reportedly less than SAV (Eyre and Ferguson 2002; Piehler and Smyth in press), there is much more of this habitat (see “Soft bottom” chapter for more information). Despite the correction, SAV habitat provides proportionately greater ecosystem services than subtidal soft bottom.

### 4.2.1. Productivity

SAV habitat is dominated by dense stands of vascular plants, their associated epiphyte communities, as well as benthic micro- and macroalgae. These grasses produce large quantities of organic matter under optimum conditions. Estimates of daily production for eelgrass beds rank among the most productive of marine plant habitats (Thayer et al. 1984; Peterson et al. 2007; Hemminga and Duarte 2000; Larkum et al. 2006). The typical biomass of growing eelgrass beds (leaves, roots, and rhizomes) in North Carolina was reported as 57–391 g (dry weight)/m<sup>2</sup> (Thayer et al. 1984; Twilley et al. 1985). The majority of biomass was contained in the roots (45–285 g m<sup>-2</sup>). The productivity of eelgrass beds in North Carolina was reported as 1.05–1.32 g C m<sup>-2</sup> d<sup>-1</sup> (Thayer et al. 1984). Based on a compilation of published research (Peterson et al. 2007), the annual primary production estimates for eelgrass surpassed intertidal *Spartina*, intertidal soft bottom, subtidal soft bottom, and shell bottom. The relative productivity of SAV suggests its importance as a source of secondary production. The components of SAV habitat production include epiphytes, above-ground biomass, below-ground biomass, epibenthic algae, and water column phytoplankton.

Contributions of the various components of SAV productivity varies by species, salinity type, and location throughout the growing season (Stevenson 1988). In general, high salinity grasses have more annual production than freshwater SAV where they develop greater standing crops and have more capacity to store biomass in extensive root and rhizome systems. Stevenson (1988) reported high salinity SAV production at >10 g C m<sup>-2</sup> d<sup>-1</sup> and low salinity SAV production at <5 g C m<sup>-2</sup> d<sup>-1</sup>. Attached epiphytes contribute substantially to the total productivity of SAV beds (Koch 2001) and are an important food source for fish and invertebrates. While early stages of epiphytic growth increase primary productivity of the habitat, later stages can may impede SAV growth and density due to competition for light, nutrients, and carbon (Thayer et al. 1984; Koch 2001). Excessive epiphytic and macrophytic growth can result in loss of SAV (Hauxwell et al. 2000; McGlathery 2001) (see “Water quality degradation, nutrients” section). Dillon (1971) and Penhale (1977) estimated that epiphytes (macroalgae) constitute 10–25% 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). Freshwater and high salinity grasses also vary in growing season (see “Habitat description” and “Habitat requirements” sections), suggesting temporal variation in productivity.

Because of their high rates of primary production and particle deposition, SAV beds are important sources and sinks for nutrients (SAFMC 1998a). Thayer et al. (1984) concluded that SAV beds in high velocity areas are sources (exporters) of organic matter, while SAV in low current areas are sinks (importers) of organic matter. Exported matter represents a large portion of total SAV production in high salinity SAV beds in North Carolina (Thayer et al. 1984). When grasses die and decompose, the detrital material is broken down by invertebrates, zooplankton and bacteria, and energy is transferred through the estuarine detrital food web. Decomposed SAV matter and its associated bacteria are actually of greater importance as a food source for fish than the living SAV leaves (Thayer et al. 1984; Kenworthy and Thayer 1984).

### 4.2.2. Ecosystem enhancement

Because SAV are rooted in the substrate and provide semi-permanent structures in estuaries and coastal rivers, system enhancement is one of their more important ecological functions. Some of these functions include (Thayer et al. 1984; SAFMC 1998a):

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

These functions improve water quality in estuaries by removing 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 (Dennison et al. 1993; Virnstein and Morris 1996; Biber et al. 2008). Moore (2004) studied the effect of SAV beds on water quality inside compared to outside the bed in Chesapeake Bay. During spring (April – June), the rapidly growing SAV beds were a sink for nutrients, suspended solids, and phytoplankton. The beds began to die as the summer progressed, releasing sediment and nutrients to the surrounding water. The improvements in water quality were not measureable until SAV biomass exceeded 50-100 g (dry weight) m<sup>-2</sup> or 25-50% vegetative cover. The rapid uptake of nutrients by growing SAV was reflected in a 73% decline in nitrate levels inside the bed compared to outside. A threshold coverage and density of SAV is needed to ensure bed survival through high levels of spring turbidity (Moore et al. 1997; Moore 2004). Beds of SAV can also enhance grazing on phytoplankton by providing a daytime refuge for planktonic filter feeders (Scheffer 1999). Scheffer (1999) synthesized an extensive literature resource to model the effect of SAV density on planktivore abundance. The analysis suggested a threshold level of SAV density and grazing pressure where phytoplankton can be reduced to very low levels.

Aquatic grasses, by absorbing moderate wave energy (Fonseca 1996a), buffer nearshore turbulence and reducing erosion along adjacent shorelines, improves water clarity, and helps stabilize marsh edge habitat (Stephan and Bigford 1997). 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).

### **4.2.3. Fish utilization**

Many fish 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. Because of the temporal abundance patterns among SAV species, refuge and foraging habitat are provided almost year-round for estuarine-dependent species (Steel 1991). In addition to natural fluctuations in 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, Heck et al. 2008; Hovel et al. 2002).

The SAFMC considers SAV Essential Fish Habitat (EFH) for red drum; brown, white, and pink shrimp; and species in the snapper-grouper complex. 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 SAV-enhanced species and species utilizing SAV habitat in North Carolina is compiled in Table 4.4.

#### **4.2.3.1. Moderate-high salinity SAV**

In brackish and high salinity estuaries, fish and invertebrates use seagrass, to varying extents, as nursery, refuge, foraging, and spawning locations. Studies in eelgrass beds in the Newport River estuary and 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 SAV 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). Composition of long haul seine catches sampled by DMF reported at least 49 adult fish species collected over SAV 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). Spotted seatrout (*Cynoscion nebulosus*), are highly dependent on the quantity and quality of seagrass habitat (Vetter 1977), and bay scallops occur almost exclusively in seagrass beds (Thayer et al. 1984).

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

Species*	SAV Functions <sup>1</sup>					2010 Stock status <sup>2</sup>
	Refuge	Spawning	Nursery	Foraging	Corridor	
<b>ANADROMOUS &amp; CATADROMOUS FISH</b>						
River herring (blueback herring and alewife)	X		X	X	X	D-Albemarle Sound, U-Central/Southern
Striped bass				X		V- Albemarle Sound, Atlantic Ocean, D-Central /Southern
<b>Yellow perch</b>		<b>X</b>				<b>C</b>
American eel	X		X	X	X	U
<b>ESTUARINE AND INLET SPAWNING AND NURSERY</b>						
<b>Bay scallop</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>		<b>R</b>
<b>Blue crab</b>	<b>X</b>		<b>X</b>	<b>X</b>	<b>X</b>	<b>C</b>
<b>Grass shrimp</b>	<b>X</b>		<b>X</b>	<b>X</b>		
<b>Hard clam</b>	<b>X</b>		<b>X</b>	<b>X</b>		<b>U</b>
<b>Red drum</b>	<b>X</b>		<b>X</b>	<b>X</b>	<b>X</b>	<b>R</b>
<b>Spotted seatrout</b>	<b>X</b>		<b>X</b>	<b>X</b>	<b>X</b>	<b>D</b>
Weakfish	X		X	X	X	D
<b>MARINE SPAWNING, LOW-HIGH SALINITY NURSERY AREA</b>						
Atlantic croaker	X		X	X	X	C
Atlantic menhaden	X		X	X	X	V
<b>Brown shrimp</b>	<b>X</b>		<b>X</b>	<b>X</b>	<b>X</b>	<b>V</b>
Southern flounder			X	X		D
Spot	X		X	X	X	V
Striped mullet	X		X	X	X	V
White shrimp	X		X	X	X	V
<b>MARINE SPAWNING, HIGH SALINITY NURSERY</b>						
Black sea bass	X		X	X	X	D- south of Hatteras, C- north of Hatteras
Bluefish			X	X		V
Gag	X		X	X	X	C
Kingfish spp.	X		X	X	X	U
<b>Pinfish</b>	<b>X</b>		<b>X</b>	<b>X</b>	<b>X</b>	
<b>Pink shrimp</b>	<b>X</b>		<b>X</b>	<b>X</b>	<b>X</b>	<b>V</b>
<b>Smooth dogfish</b>				<b>X</b>		
Spanish mackerel			X	X		V
Summer flounder			X	X		R

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

<sup>1</sup> Sources: ASMFC (1997a), Thayer et al. (1984), NOAA (2001), Peterson and Peterson (1979), NMFS (2002), and SAFMC (1998)

<sup>2</sup> V=viable, R=recovering, C=Concern, D=Depleted, U=unknown (<http://www.ncdmf.net/stocks/stockdef.htm>, November 2010)

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 SAV beds compared to unvegetated bottom (Thayer et al. 1975; Summerson and Peterson 1984; Thayer et al. 1984; Heck et al. 1989; Ross and Stevens 1992; Irlandi 1994; ASMFC 1997a; Wyda et al. 2002; Hirst and Attrill 2008). 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). Wyda et al. (2002) found significantly higher abundance, biomass, and species richness of fish at sites with high levels of seagrass habitat (biomass  $>100$  wet g  $m^{-2}$ ; density  $> 100$  shoots  $m^{-2}$ ) than sites with low-absent eelgrass (biomass  $<100$  wet g  $m^{-2}$ ; density  $<100$  shoots  $m^{-2}$ ). The sites with low-absent SAV biomass and density also had higher proportions of pelagic species than sites with high SAV biomass and density. 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). In Back Sound, N.C., Elis et al. (1996) found that fish and shrimp were more abundant on artificial SAV beds than on shell bottom. 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 inhabiting seagrass beds (such as crustaceans and pipefish) with decreases in seagrass coverage, while larger demersal predatory fish (such as toadfish and sharks) increased. Similarly, increases in seagrass 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).

Some studies have shown a linkage between the abundance and species composition of fish and the quantity and/or quality of seagrass beds. 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 habitat complexity (biomass  $>100$  wet g/ $m^2$ ; density  $>100$  shoots/ $m^2$ ) compared to sites with reduced habitat complexity (Wyda et al. 2002). Abundance, biomass, and species diversity were also more variable at sites with reduced SAV complexity. Sites with lower habitat complexity also had a greater proportion of pelagic species than bottom, structure-oriented species. In North Carolina, comparison of pink shrimp densities in continuous and patchy SAV beds found significantly greater shrimp densities in continuous beds than in patchy grass beds (Murphey and Fonseca 1995). Although patchy beds did not support as great a density of shrimp, they still functioned as important habitat for pink shrimp (Murphey and Fonseca 1995). Hirst and Attrill (2008), in examining benthic invertebrate composition, found that the size of the SAV patch did not impact the level of increased invertebrate diversity – presence of SAV alone significantly increased diversity.

Hovel et al. (2002) examined the effect of SAV bed structure (percent cover and total linear edge), local-scale ecological attributes (shoot density, shoot biomass, percent organic matter), and elements of physical setting (water depth and wave energy regime) on fish and shellfish densities in Core and Back Sound, North Carolina. The surveys were conducted in two consecutive years in both spring and fall. Wave energy regime and SAV shoot biomass had the most influence of species densities. Other factors explained little of the variation in species densities. Processes operating at larger than local spatial scales (e.g., larval delivery by currents) were evident between sites with high and low faunal abundance (western vs. eastern Core Sound). The results support treating all moderate-high salinity SAV within different regions equally in terms of fish and shellfish use.

#### 4.2.3.2. Freshwater-low salinity SAV

Less information is available on fish use in low-salinity SAV habitat. Fish abundance and size has been shown to be greater in freshwater and low-salinity systems with submerged aquatic vegetation than in

similar systems devoid of SAV (Randall et al. 1996; <http://www.fao.org/DOCREP/006/X7580E/X7580E10.htm>, August 2007). In Currituck Sound, Borawa et al. (1979) observed an increase in fish abundance from approximately 1,000 to more than 15,000 fish hectare<sup>-1</sup> after *Myriophyllum spicatum* became established. However, the size of fish declined drastically. Another study in the Potomac River (VA) found densities of fish in SAV habitat that were 2-7 times higher than areas without SAV (Killgore et al. 1989). Floating leaf aquatic vegetation is particularly important in freshwater systems such as the Roanoke River (Cooper et al. 1994). Common species using freshwater SAV is shown below and in Table 4.4. Species that utilize freshwater SAV include not only freshwater species but certain estuarine species and anadromous fish species (Rozas and Odum 1987; SAFMC 1998a; NOAA 2001). The most commonly occurring include:

<u>Freshwater</u>	<u>Estuarine</u>	<u>Anadromous</u>
Minnnows	Juvenile menhaden	Striped bass
Juvenile American eel	Spot	Shad (American and hickory)
Pirate perch	Blue crab	River herring
Inland silversides	Grass shrimp	
Yellow perch	Bay anchovy	
Largemouth bass	Striped mullet	
Bluegill (bream)	Tidewater silverside	
White perch		

#### **4.2.4. Specific biological functions**

##### **4.2.4.1. 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). Light levels are reduced within the canopy as well, further concealing small prey (SAFMC 1998a). 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. In addition, cryptic species that have the ability to change color use camouflage to decrease their visibility within the SAV habitat. The roots and rhizomes of SAV also provide a substrate matrix for meiofauna<sup>21</sup> and macrofauna<sup>22</sup> (Kenworthy and Thayer 1984). Hard clams, for example, are significantly more abundant in SAV beds than in adjacent unvegetated bottom due to differences in food supply, predation, and sediment stability (Peterson and Peterson 1979; Peterson 1982; Irlandi 1994, 1997).

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; Rooker et al. 1998 for juvenile red drum). Estuarine-dependent spring-summer spawners (i.e., red drum, seatrout) 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).

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. Matilla et al. (2008) found that SAV beds of various densities equally increased survival of shrimp from predators compared to unvegetated bottom. In freshwater systems, excess

<sup>21</sup> Very small benthic animal, 0.1 – 0.5 mm in size, about the size of a sand grain, important food source for larval fish

<sup>22</sup> Small benthic animal larger than 0.5 mm in size; e.g., mole crabs, amphipods

vegetation can actually hamper movement and foraging efficiency of large predatory fish, resulting in a stunted fish population (Colle and Shireman 1980). Based on investigation of 60 Florida lakes, Hoyer and Canfield (1993) concluded that total harvestable fish biomass (per unit of adjusted Chlorophyll *a*) is maximal when the percent coverage of SAV ranged from 20-40%. However, large opportunistic predators such as largemouth bass can thrive at <20% SAV coverage, as long as higher nutrient levels are maintained and sufficient nursery habitat is available (Hoyer and Canfield 1996). Percent coverage of SAV in North Carolina estuaries is much lower than 20%, and cannot reach >40% given the proportion of shallow and deep waters (Table 4.3).

Seagrass, particularly eelgrass, may also provide overwintering habitat for some estuarine species. Pink shrimp have been collected in SAV during winter months in North Carolina sounds (Williams 1964; Purvis and McCoy 1972). The presence of SAV in the winter is thought to contribute to the pink shrimp's ability to survive, supporting the spring pink shrimp fishery (Murphey and Fonseca 1995), which comprises a large portion of North Carolina's annual shrimp landings. In contrast, in South Carolina and Georgia, where 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).

#### 4.2.4.2. Spawning

It is difficult to discern species whose reproduction is more successful in SAV than in other habitats. Preference for spawning in SAV could be assumed for species found exclusively in SAV habitat. The bay scallop is one estuarine species that occurs almost exclusively in high salinity SAV beds (Thayer et al. 1984). The presence of spawning adults is therefore dependent on high salinity SAV. There are few other year-round estuarine residents found almost exclusively in moderate-high SAV. However, many species benefit from the close proximity of spawning and SAV nursery areas (see "Nursery" function section below). Seasonal patterns of reproduction and development of many temperate fishery species also coincide with seasonal abundance of seagrass (Stephan and Bigford 1997).

Freshwater fish spawning preferentially on or near SAV include common carp, crappie, yellow perch and chain pickerel (Balon 1975; Graff and Middleton 2000). The roots and stems of the submerged vegetation provide substrate for attachment of eggs. As with high salinity SAV, many species benefit from the close proximity of spawning areas and SAV nursery area (see "Nursery" function section below). *Research is needed to assess the effect of SAV proximity to spawning areas on juvenile production.*

#### 4.2.4.3. Nursery

Submerged aquatic vegetation is considered a nursery habitat for numerous species of fish and invertebrates along the Atlantic coast (Thayer et al. 1984). The roots and stems of SAV provide ideal protection and foraging habitat for developing fish and invertebrate larvae (Ambrose and Irlandi 1992; SAFMC 1998a). Important commercial and recreational species present in SAV as juveniles in the spring and early summer include gag, black sea bass, snappers, weakfish, spotted seatrout, bluefish, mullet, spot, Atlantic croaker, red drum, flounders, southern kingfish, hard clam, and herrings (Rooker et al. 1998, SAFMC 1998a). Estuarine-dependent reef fish (i.e., gag, black sea bass) use seagrass meadows as juveniles, prior to moving offshore (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). In North Carolina, where SAV is present year-round, some larval and early juvenile finfish, molluscan, and crustacean species are present in SAV habitat much of the year (SAFMC 1998a). Offshore, winter-spawning species such as spot, croaker, shrimp, and pinfish inhabit SAV habitat as early juveniles in winter and early spring (Rooker et al. 1998).

While some juveniles of a species have been documented occurring in SAV, other species show some preference for SAV habitat over other habitat types. Minello (1999) summarized information on densities of juvenile fisheries species (<100 mm TL) in shallow-water estuarine habitats (marsh edge, SAV, and soft bottom) of Texas and Louisiana, which showed highest densities of pink shrimp and red drum in SAV habitat. Submerged aquatic vegetation has been recognized as critical nursery habitat for pink shrimp in North Carolina (Murphey and Fonseca 1995). For juvenile red drum in Galveston Bay, Stunz et al. (2002) reported measuring increased growth rates in SAV enclosures compared to other habitat enclosures (shell bottom, wetland edge, and soft bottom). 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 during summer months and in grass beds that are close to spawning areas (Zieman 1982; DMF, unpub. data). Juvenile red drum were also 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 SAV behind the Outer Banks (DMF 2001c). More rigorous analysis of DMF data, including both juvenile abundance and concurrent habitat measurements, indicated a higher affinity to seagrass for both age-1 and age-2 red drum (Bachelor et al. 2009).

Other species showing some preference for SAV habitat include brown shrimp, bay scallop, hard clams, and blue crabs. Clark et al. (2004) compared the density of juvenile brown shrimp in various habitats (marsh edge, SAV, and soft bottom) using 16 years of data for Galveston Bay. The results indicated a preference of marsh and SAV over soft bottom, with SAV selected over marsh where both habitats co-occurred. 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<sup>23</sup> (Thayer et al. 1984; Stephan and Bigford 1997).

Juvenile blue crabs prefer shallow water areas with structures, including SAV, tidal marsh, shell bottom and detritus (Etherington and Eggleston 2000). In the Albemarle-Pamlico system, the majority of initial recruitment of juvenile crabs occurs in SAV 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). 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). Hovel (2003) correlated the survival of juvenile blue crabs to SAV landscape characteristics such as patch size, patch isolation, and proximity to edge in Back Sound, North Carolina. The results indicated that juvenile blue crab survival was positively correlated with patch area and was negatively correlated with seagrass shoot biomass.

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). Hoyer and Canfield 1996 determined that although adult largemouth bass can thrive with very little SAV coverage, adequate nursery habitat must be available for juveniles. Paller (1987) determined that the standing stock of larval fish in freshwater

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<sup>23</sup> Recruitment = 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.

SAV beds 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). Hirst and Attrill (2008) found that a decrease in patch size (increase in fragmentation) did not affect the invertebrate biodiversity. These findings suggest that habitat fragmentation could have a varying effect on recruitment, depending on the species.

#### 4.2.4.4. Foraging

The majority of macrofauna in SAV habitat forage on secondary production from epibiotic communities, benthic algae, organic detritus, and bacteria rather than direct consumption of SAV (Day 1967; Adams and Angelovic 1970; Carr and Adams 1973; Meyer 1982; SAFMC 1998a). Only a few fish species are known to consume submerged grasses directly. These include pinfish (*Lagodon rhomboides*), spot (*Leiostomus xanthurus*), filefish (*Monocanthus hispidus*), and toadfish (*Opsanus tau*). However, SAV comprised only 1 – 12% of their diet (Thayer et al. 1984). In contrast, there are numerous air-breathing species grazing directly on SAV that include migratory birds (e.g., black brant, *Branta bernicla*; Canada goose, *Branta canadensis*; and widgeon, *Anas penelope*), green sea turtles, and West Indian manatees (SAFMC 1998a). Green sea turtles appear to be more abundant in seagrass than in unvegetated areas in North Carolina, based on data from incidental occurrence in pound nets (SAFMC 1998a). Abundant green turtles closely crop seagrass, greatly reducing the input of organic matter and nutrients to sediments near the SAV (Ogden 1980). Dramatic declines in eelgrass abundance have also been documented following the over-winter foraging activity of Canadian geese (River and Short 2007). Due to the geese consuming plant meristems, sexual reproduction of the remaining eelgrass was minimal the following summer. 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<sup>24</sup> (Jackson et al. 2001). The balancing of SAV abundance and grazer populations is another example of ecosystem management.

Large predatory fish, such as Atlantic stingrays, flounders, bluefish, sandbar and other sharks, weakfish, red drum, spotted seatrout, and blue crabs, are attracted to SAV beds for their concentrations of juvenile fish and shellfish (Thayer et al. 1984). Though large shellfish predators represent 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). Overharvesting predators of shellfish consumers (i.e., large coastal sharks) could therefore lead to increasing damage on their foraging habitat (Myers et al. 2007).

#### 4.2.4.5. 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% compared to areas 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 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

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<sup>24</sup> See “Threats” section

additional food resources (Irlandi and Crawford 1997). 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 (i.e., juvenile red drum, seatrout) that are more susceptible to predation in open water. *Research is needed on the relationship between juvenile Sciaenid abundance and connectivity among nursery habitats and spawning area.*

### **4.3. STATUS AND TRENDS**

#### **4.3.1. Status of submerged aquatic vegetation habitat**

When SAV beds are subjected to human-induced impacts in addition to natural stressors, large-scale losses of SAV may occur (Fonseca et al. 1998). Scientific studies indicate a global and national trend of declining SAV habitat (Orth et al. 2006; Waycott et al. 2009). Orth et al. (2006) summarized status and trends information on SAV at a global scale and found reports of large-scale SAV losses in the European Mediterranean, Japan, and Australia. Reports of SAV recovery were very low by comparison. Waycott et al. (2009) showed sea grasses disappearing at rates similar to coral reefs and tropical rainforests based on more than 215 studies and 1,800 observations dating back to 1879. The compilation of studies shows a 29% decline in known SAV extent since 1879. The study also indicated an acceleration of loss since 1940 (7%/yr, up from <0.9%/yr prior). In North America, losses of seagrass beds have been as high as 50% in Tampa Bay, 43% in northern Biscayne Bay, 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 on 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.

Trend data on SAV distribution in North Carolina are either limited to qualitative information for broad areas or quantitative information for selected areas of the coast. The qualitative information includes:

- Elderly fishermen and fishermen's journal accounts from the late 1800s describe extensive beds of SAV in many coves along mainland Pamlico Sound where it was absent in the late 1990's (Mallin et al. 2000a).
- Seagrass wasting disease devastated eelgrass populations throughout the North Atlantic, including North Carolina, between 1930 and 1933, dramatically disrupting estuarine systems. Healthy eelgrass beds were generally re-established by the 1960s.
- In the upstream half of the Pamlico River estuary, tidal freshwater SAV was common until the mid-1970s (Davis and Brinson 1976; Davis and Brinson 1990). During the mid-1980's, SAV in western Albemarle Sound and Neuse River declined significantly (Davis and Brinson 1990).
- During the 1990's, Mallin et al. (2000a) reported extensive losses of eelgrass beds along the intercoastal waterway (Morehead City area) and near the Harker's Island mainland. There was also a major die-off of SAV in the Perquimans River after Hurricane Floyd in 1999 (S. Chappell/DMF, pers. observation). But there was also a resurgence of SAV during the 1990's in some locations. The resurgence was implied by complaints about abundant SAV around docks in the Neuse River and fishermen's anecdotal accounts in the Pamlico River (Mallin et al. 2000a).
- In 2002, DMF biologists noted high abundance of SAV throughout many shallow water areas of Albemarle Sound and its tributaries, especially in Perquimans River (S. Winslow/DMF, pers. com., 2002).
- In 2007 and 2008, DMF biologists reported extensive SAV growth throughout the estuarine system (attributed primarily to drought conditions and lack of major storm events).

Quantitative information on SAV status and trends comes in basically 3 forms: 1) station monitoring, 2) transect monitoring, and 3) areal coverage monitoring (i.e., mapping). The earliest data on SAV status and trends comes from a history of station and transect monitoring in Currituck Sound (Davis and Brinson 1983). Studies have documented the status of SAV in Currituck Sound since 1909, 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. Before 1962, native sago pondweed and wild celery were the dominant and subdominant SAV species. By 1973, Eurasian watermilfoil had replaced sago pondweed as the dominated aquatic plant species, followed by bushy pondweed. After a severe storm in 1978, bushy pondweed was virtually eliminated, and total macrophyte biomass was 42% less than in 1973. 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. The monitoring transects referenced in Davis and Brinson (1983) were revisited in recent years by the Marine Environmental Science Program at Elizabeth City State University (Liz Noble, unpub. data 2006) and USACE (report pending). It is apparent from the historical record that SAV coverage and biomass are greatly affected by weather events, site conditions, and human activities that affect turbidity and salinity (see "Threats and management needs" sections). This relationship is true not only for Currituck Sound, but also for other coastal water bodies containing SAV. *In order to quantify trends in SAV abundance, regular mapping efforts of all or a subset of the habitat are needed in addition to monitoring data from stations and transects. Monitoring should focus on SAV in the most vulnerable locations (close to land where water quality degradation and shoreline development impacts greatest, edge of southern and western distribution range) and in areas of current or former importance to bay scallops.*

Coast-wide aerial photography of SAV combined with on-site sampling is the standard method for mapping SAV in Chesapeake Bay and elsewhere. The relatively short history of SAV mapping in North Carolina estuaries started in 1981 with digitizing from aerial photographs of Core and Bogue sounds (Carroway and Priddy 1983). The largest mapping coverage (Albemarle-Pamlico estuarine system) over the shortest time period (1983 – 1992) was completed by NOAA and published in Ferguson and Wood (1994).<sup>25</sup> Since then, comparable repeat mapping is available for the Neuse River, Currituck Sound, and Back Bay (Virginia). The Neuse River was remapped in 1998 by DWQ, and the Currituck Sound and Back Bay were remapped by ECSU in 2003. However, basic change analysis has only been completed

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<sup>25</sup> An inventory of SAV mapping and monitoring efforts is provided at (<http://www.ncdmf.net/habitat/chpp28.html>, June 2009).

for the Neuse River (DWQ 1998). The DWQ assessment was conducted using aerial photography and field verification methods similar to those of Ferguson and Wood (1994). Results showed that SAV was present at four of five areas that had supported 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 differences in methodology, any change in coverage cannot be determined with certainty. In 2006, NOAA acquired SAV imagery of Core and Bogue Sound and completed digitizing in 2009 (D. Field/NOAA, pers. com., August 2009). The multiple years of data for Bogue and Core Sound (Carroway and Priddy 1983; Ferguson and Wood 1994) suggest the possibility of change analysis. However, conducting SAV change analysis in different areas should be undertaken with careful consideration of annual differences in growth-integrated environmental conditions. Undigitized imagery is also available for the purpose of SAV mapping and change analysis. The earliest such imagery was funded by DOT in 2004, for the Pea Island Area in northern Pamlico Sound. However, field verification data is lacking for the area and time period.

Prior to 2007, the mapping and monitoring of SAV was sporadic and piece meal, resulting in the lack of a comprehensive baseline dataset for SAV distribution. Comprehensive mapping of SAV habitat in coastal North Carolina was initiated in 2007 by a joint effort of federal and state agency and academic institutions (<http://www.apnep.org/pages/sav.html>, June 2009). The SAV Partnership began in summer 2001 when Region 5 (Virginia) staff of the U.S. Fish and Wildlife Service (FWS) needed matching non-federal funds to secure an agency grant. The outcome of their initial inquiry was the formation of a SAV Working Group, whose common goal was to pool resources from organizations with a common interest in assessing SAV habitat along the North Carolina and southeast Virginia coastal region. The first aerial surveys in support of this goal were flown during fall 2003 in the northernmost portion of the region. The Albemarle-Pamlico National Estuarine Program (APNEP) became the lead coordinator in summer 2004. During this period the Working Group began the process of creating a Memorandum of Understanding to formalize agency interactions for implementing a combined effort map and monitor SAV habitat. Beginning in winter 2006, meetings were scheduled on a regular (quarterly) basis and agenda topics expanded beyond mapping and monitoring to include assessment, restoration, policy, and outreach. The Memorandum of Understanding was signed by all signatories in fall 2006, thus creating the Partnership.

The APNEP then allocated \$160,000 toward contracting out imagery for 2007-08. The FWS, DMF, DENR, and NOAA contributed an additional \$130,000. The NOAA representative took the lead on imagery specifications and securing the contract. The DMF was responsible for verifying water clarity conditions, coordinated field survey efforts and conducting the photo-interpretation. A stratified random sampling design was used to conduct 1,250 field surveys to accompany the 1-m resolution imagery. The strata consisted of previously vegetated and nonvegetated bottom less than 6 feet deep. The DMF conducted the majority of field surveys, with the remaining stations covered by ECU, ECSU, DWQ, DOT, WRC, NERR, FWS, and DCM. Over 90% of the flight lines were covered in 2007, with the remaining area flown in 2008. Digitizing SAV polygons on the imagery is currently discontinued due to a staff position vacancy and freeze on hiring. The SAV Partnership is looking into other locations to house a GIS analysis for digitizing SAV polygons from the imagery (J. Luczkovich/ECU, pers. com., May 2009).

While a quantified change analysis is not available, preliminary review of core areas of SAV, such as behind the Outer Banks in Pamlico Sound and Core Sound do not indicate large change since previous imagery for those areas in 2004 (D. Field/NOAA, pers. com, 2010). However, there may have been a shift to increased patchiness of previously dense beds in Bogue Sound. Observations of DENR field staff have noted SAV presence in previously unvegetated areas in some of the low salinity systems and southern range of SAV, which may be related to improved water clarity associated with the coastwide drought in 2007-2008.

A comprehensive SAV monitoring program must employ methods covering the range of water quality conditions where SAV grows in North Carolina. The relatively shallow estuarine waters of North Carolina vary in optical properties from highly organic stained in the coastal rivers to clear saline behind the barrier islands. Ferguson and Wood (1994) noted the difficulty in digitizing SAV beds in turbid, low salinity waters. Aerial reconnaissance conducted during 2005 revisited some field-verified SAV beds in the upper Neuse River and found most of the beds indistinguishable from the air (S. Chappell/DMF and J. Green/DWQ, pers. observation). The low visibility in riverine areas from the air presents a challenge to periodic areal monitoring of SAV coverage in the state. Other comprehensive SAV monitoring methods are being investigated to address the issue. The APNEP was awarded a North Carolina Coastal Recreational Fishing License grant from the DMF and WRC for a 2-year project to establish a protocol for sampling submerged aquatic vegetation in the field. This field sampling will use underwater video and acoustic equipment to compare methodology and be complementary to the aerial imagery acquired in 2007-2008. The project will attempt to provide a rigorous statistical evaluation of annual changes in SAV abundance and develop a standardized method of field monitoring SAV in North Carolina. Partnering organizations for this grant include APNEP, NOAA, NCSU, and ECU. *The results of this new SAV monitoring research should be evaluated for broader application in the estuary as a whole.*

There have been several smaller mapping projects involving various techniques. DMF's Bottom Mapping Program and DWQ's Rapid Response Program map SAV by delineating bottom type strata boundaries along transect lines and interpolating. The DMF has been mapping subtidal vegetated strata in moderate to high salinity waters since 1989. Bottom mapping personnel also comprised a large portion of the field survey crew working with the 2007-2008 aerial imagery. The DWQ started mapping freshwater and low salinity SAV in western Pamlico Sound tributaries in 2005. However, there has been no repeat sampling of areas mapped using transect-based interpolation methods. The DMF also surveys for SAV presence and density in conjunction with selected fisheries monitoring programs. The NEER is also monitoring SAV on their reserves as part of 2005 CHPP implementation. *Local and regional monitoring programs should eventually be coordinated with a comprehensive SAV monitoring program.*

#### **4.3.2. Status of associated fishery stocks**

It is very difficult to attribute changes in fish abundance to changes in habitat due to the difficulty of achieving the data needs for such an analysis. The analysis needs accurate density estimates for fish species and size classes among accurately delineated habitat types over a time series to predict fish – habitat relationships. Assessments have been attempted for penaeid shrimp and red drum. The habitat relationships of fishery species and life stages were used to estimate population densities of brown shrimp by Clark et al. (2004), and priorities for habitat protection by Levin and Stunz (2005) in Galveston Bay. Clark et al. (2004) used the density of juvenile brown shrimp in different habitats to estimate an overall population size of 1.3 billion in Galveston Bay. Levin and Stunz (2005) estimated that habitat for red drum larval and juveniles should be given the highest priority for protection. Such analyses have not been conducted in North Carolina. *Research is needed to quantify habitat relationships of fisheries species and life stages in North Carolina in order to estimate population sizes and determine habitat protection priorities.*

Fish-habitat change analysis is also difficult because of the confounding effect of fishing on fish populations. In North Carolina, estimated fishing mortality and juvenile abundance indices are used by the DMF to determine the status of fishery stocks. Stock status evaluations may also suggest habitat issues for concern or depleted species. Of the species identified in Table 4.4 with a preference for SAV habitat, 8 stocks were evaluated for fishery status.<sup>26</sup> The hard clam was assigned an Unknown status. Of the remaining 7 stocks with a designated status, one was designated Depleted (spotted seatrout), two were

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<sup>26</sup> Refinement of the ecological role and function section lead to a reduction in documentation of SAV-enhanced species noted in the 2005 CHPP (Street et al. 2005).

Concern (yellow perch, blue crab), two were Recovering (red drum, bay scallop), and two were Viable (brown shrimp, pink shrimp) (<http://www.ncdmf.net/stocks/2010NCDMF%20StockStatusReport.pdf>). 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 Depleted or Concern, by maximizing recruitment and productivity. *More fishery-independent information and habitat change analysis are needed to evaluate the effect of SAV-coverage on the abundance of fish and invertebrates.*

### ***4.3.3. Submerged aquatic vegetation restoration and enhancement***

Although protection, rather than mitigation or restoration, is the more environmentally sound and a less costly management approach for long-term enhancement of SAV habitat, restoration and/or enhancement is possible in areas of recovering SAV abundance or where human impacts have physically removed the vegetation (Fonseca et al. 1998, SAFMC 1998a, Treat and Lewis 2006, Orth et al. 2006). Restoration in the latter case requires only replacing SAV where it had recently existed. Successfully restoring SAV to areas where it is not currently present depends on conditions at the site throughout the year.

As SAV grows and spreads, it creates a feedback loop of increasing resilience to perturbation and improving habitat conditions for itself, up to a point (see “Diseases and microbial stressor” section for more information). This positive feedback suggests a critical mass of SAV, above which, the vegetation is less susceptible to periodic disturbances (Moore et al. 1997; Moore 2004). Recent research examining the water treatment capacity of SAV beds (see “Ecosystem enhancement section” for more information) observed water quality benefits at bed densities of 50% or greater. The actual density, extent and location of SAV needed to establish resilience and ecological functions depends on the corresponding quality and quantity of water circulating through the system. To use an analogy, dirtier water needs a larger filter to prevent clogging. Successful restoration efforts will establish an SAV coverage during optimum conditions that is sufficient to allow recovery after natural perturbations to the system. In areas of recovering SAV abundance, restoration and enhancement techniques can be used to accelerate the recovery of SAV toward some critical density and coverage. Hard clam restoration could be one possible means of enhancing water quality for SAV growth. SAV has been observed expanding adjacent to some clam aquaculture leases in Virginia and North Carolina. This suggests that by seeding areas adjacent to SAV with hard clams, the filter feeders will reduce suspended sediment and nutrients. *Research is needed on the feasibility of hard clam augmentation for the purpose of water quality based restoration of SAV.*

In suitable habitat areas, SAV can recover quickly after a natural disturbance. In more human-altered areas, SAV may recover very slowly or not at all. Water-based restoration efforts are warranted in areas where SAV is very slow to recover. A perfect example of slow recovery may be occurring in Back Bay, Virginia, just north of Currituck Sound. Throughout most of the 20<sup>th</sup> Century, Back Bay and Currituck Sound garnered a reputation for excellent hunting and fishing along the East Coast. This began to change during the 1970s. Annual Mid-winter Waterfowl Surveys coupled with Back Bay NWR aerial waterfowl surveys revealed a decline in waterfowl populations during the early 1970s (Baker et al. 2006) in the system. The decline was linked to significant reductions in the distribution and abundance of freshwater and low salinity SAV throughout the Bay. Unfortunately, systematic water quality monitoring was not in place in Back Bay; so the cause of the decline could not be correlated with data. However, the decline corresponded to major landscape changes in the northwestern portion of Back Bay’s watershed during the 1970s and 1980s, as new housing developments and farming activities increased. A similar decline was noticed about ten years later in the Knotts Island Bay-Currituck Sound (Baker et al. 2006), immediately south of Back Bay.

The SAV in Back Bay-Currituck Sound was mapped by ECSU in 2003 and again by the APNEP SAV partnership in 2007. The 2003 imagery and field verification indicated a very low abundance of SAV in

the Back Bay portion of the system (Noble and Hall 2005). A very low abundance of SAV was also indicated from ECSU transect monitoring of Back Bay during 2006 (Noble and Mohr 2008). However, the imagery from 2007 and observations during 2008 suggest a substantial increase in SAV abundance from 2003-2008 (J. Gallegos/USFWS, pers. observation). The increase in SAV is an encouraging sign for the multiple federal and state agencies interested in restoring the SAV resources of Back Bay (i.e., USACE, USFWS, Virginia Game and Inland Fisheries (VDGIF), APNEP). The VDGIF is pursuing a pilot project to enhance SAV habitat in Back Bay with the use of strategically placed turbidity curtains (C. Boyce/VDGIF, pers. com., May 2009). The VDGIF is seeking information regarding potential habitat locations, effective planting techniques, and seed/rhizome dispersal patterns.

Given the range of environmental conditions at a site, modeling potential habitat must indicate both habitat suitability and probability of occurrence. Restoration efforts could then move out from locations of highest probability. Probabilities are indicated by the pattern of SAV recovery in a water body. The reported spread of SAV in Perquimans River after Hurricane Floyd occurred upstream from the lower reaches of the rivers, near the main body of Albemarle Sound (S. Winslow/DMF, pers. com.). A recovery pattern was also suggested in the Neuse River from small, sunlit coves and tributaries having a consistent coverage of SAV (J. Paxon/DWQ, pers. com.). The observed patterns suggest core areas of abundance from which to launch restoration efforts. Research in Chesapeake Bay observed eelgrass seeds settling rapidly with the waves and currents to disperse only a few meters from the seed sources (Orth et al. 1994). However, other SAV species may differ in their dispersion range, suggesting a pattern of succession in species composition during recovery. *Research is needed to verify where recovery of SAV is occurring and if there is a spatial (and species) 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. In the mean time, Back Bay/Currituck Sound should serve as a test case for re-establishing SAV in a recovering/recoverable ecosystem.*

Land-based restoration may also be possible in locations of historical SAV abundance where it is currently absent or severely reduced (even in the best of years). Improving the quality of water circulating through the system will mitigate the need for extensive water-based restoration of SAV. A good example of land-based restoration facilitating SAV restoration is occurring in Wilson Bay, New River. The Wilmington USACE-Jacksonville SAV Restoration project (Section 206) has done a lot of work restoring water quality, wetland, and oysters in Wilson Bay. And there are plans to establish SAV in the system (C. Wilson/USACE, pers. com., 2009) where it currently exists upstream and downstream. The restoration was made possible by removing or diverting polluted effluent entering the bay (Mallin et al. 2005). A nursery facility on Wilson Bay is producing plants for restoration, with technical assistance from the Chesapeake Bay Program (Dr. Deborah Shafer and Steve Ailstock). The project employs annual seed collections from areas of high SAV abundance for growing rooted transplants for restoration (P. Donovan-Potts, pers. com., June 2009).

The facility on Wilson Bay could also be expanded to supply SAV transplants for other project areas. Other projects with an SAV restoration component include USACE's Festival Park & Wanchese Marsh Restoration Projects on Roanoke Island, USFWS's Monkey Island Restoration in Currituck Sound (shoreline protection component could include SAV restoration as wave buffers), DWR's Silver Lake Harbor estuarine shoreline restoration project, and the town of Kitty Hawk's proposal to protect an eroding marsh shoreline where SAV is abundant offshore (need to avoid, mitigate and/or monitor SAV impacts). In 2007, Elizabeth City State University (ECSU) was granted \$59,834 to evaluate restoration opportunities in Currituck Sound and Back Bay (J. Gallegos/USFWS, pers. com., November 2009). ECSU faculty investigators Elizabeth Brinker and Dr. Maurice Crawford are tasked with: (1) producing digital polygon maps of potential SAV restoration sites in Currituck Sound and Back Bay; (2) completing some experimental SAV plantings in Currituck Sound to assess plant survival, vigor, and feasibility of SAV restoration efforts in Back Bay and Currituck Sound; (3) calibrating the Kemp et al. (2004)

algorithm and/or other light attenuation models; (4) producing a GIS data layer of the bathymetry of Currituck Sound and Back Bay, and (5) hosting a workshop at ECSU to communicate SAV restoration techniques to State, Federal, and Non-governmental agency staff. ECSU will also produce a final report on SAV restoration techniques and recommendations for re-establishment of SAV in Currituck Sound and Back Bay. As of October 2009, ECSU has completed bathymetric transects of Currituck Sound and Back Bay and has established reference and transplants sites in Coinjock Bay (Currituck Sound). Transplanting efforts in 2008 met with limited success, whereas 2009 efforts exhibited survival and growth attributed to retention of transplanted sediment (Brinker and Crawford 2009). Lessons learned and data accumulated from the Coinjock Bay restoration site will be applied to proposed expanded restoration efforts. Back Bay is targeted as the high priority for a restoration site. The results from Brinker and Crawford study could also be used in SAV restoration for mitigation in low salinity areas.

Compensatory mitigation is often required for major shoreline development projects involving direct removal of SAV. The mitigation is required by the USACE's enforcement of Clean Water Act Section 404 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. Though in practice, mitigation is only designed to replace an acreage equal to or greater than that which was lost or impacted (see "Wetland enhancement and restoration" section of "Wetlands" chapter for more information). So mitigation activities should represent very little net change in SAV coverage, if the restored habitat is functionally equivalent to what was lost. Mitigation may also be required by enforcement actions, such as the recent (2004) case of unpermitted dredging in northern Currituck Sound by DOT.

Mitigation for impacts to SAV is only allowed by CRC rules if the activity associated with the proposed project will have public benefits that outweigh the short or long range adverse impacts. Otherwise, direct impacts to SAV are not allowed by DCM policies and CRC rules. Most permitted impacts have involved transportation (bridge construction) or navigation (channel dredging). 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 documented in Carteret and two in Onslow counties between 1978 and 1991. Three projects were done as N.C. Department of Transportation (DOT) mitigation, while the others were research projects conducted by NOAA. A total of 1.95 acres (0.79 ha) of bottom was restored to SAV by these projects. The general criteria for determining success was defined 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%20type>, November 2010). Of the 14 sites, 11 were considered "successful."

Since 1991, there have been four more DOT projects involving some level of SAV impacts/mitigation: Neuse River bridge, Chowan River US 17 bridge, Wright Memorial bridge from Currituck to Dare county, (D. Huggett/DCM, pers. com., August 2009), and the illegal dredging of a channel off Corolla's Heritage Park (see "Dredging (navigation channels and boat basins)" section for more information). The impacts were estimated at 1-2 acres for each project, and the mitigation was almost always out-of-kind. Some mitigation was also required for at least two private projects. The Sandy Point Development near Edenton impacted around 3-4 acres of SAV habitat, with mitigation occurring adjacent to the site. The Joseph Thompson Project in Dare County involved moving a navigation channel away from SAV habitat. Mitigation for this project involved transplanting SAV into the old channel area. The DCM generally does not permit projects with direct SAV impacts, therefore negating the need for restoration/mitigation (D. Huggett/DCM, pers. com., August 2009).

Techniques and success criteria for SAV restoration have been developed and evaluated by the NOAA's Coastal Ocean Office (Fonseca et al. 1998) and others (Orth et al. 1994; Smart et al. 1998; Boustany 2003; Ailstock and Shafer 2006; Treat and Lewis 2006). However, a detailed description of the various restoration techniques and specific success criteria will not be discussed here. The APNEP SAV Partnership is developing an action plan for SAV restoration activities in North Carolina and southeastern Virginia, with guidance from the Chesapeake Bay experience (Orth et al. 2002). Some important action items for the plan include developing a central database of SAV restoration projects, a central repository for mapping/monitoring data, and some means of coordinating research, monitoring, and restoration activities among multiple agencies and conservation organizations. *The plan for SAV restoration should also be coordinated with other habitat restoration plans and activities.*

Any plan for SAV restoration should include target goals for measuring progress toward some end point. Setting goals based on historical abundance has been suggested (Street et al. 2005). However, setting goals based on historical abundance may not be justified given an evolving system. Setting restoration goals based on potential habitat maps and projected water quality improvements would be more justifiable (see "Habitat requirements" section for more information on modeling potential habitat). An accurate map of potential habitat could guide restoration work aimed at accelerating SAV recolonization after a period of low abundance due to unfavorable or extreme conditions. *The SAV restoration action plan should include restoration goals based on potential habitat maps and projected water quality improvements (see "Water column restoration and enhancement" section of water column chapter for more information).*

#### **4.3.4. Designated areas**

Strong regulations are in place to protect SAV, particularly from physical damage. Special designations may provide additional, indirect protection for native SAV above the regulatory protection granted wherever they occur. State designations protecting SAV in public trust waters fall into basically three categories: (1) water quality protection, (2) physical habitat protection, and (3) both water quality and physical habitat. EMC rules related to water quality designations such as Outstanding Resource Waters, High Quality Waters, Nutrient Sensitive Waters, and Water Supply Water I & II protect water quality, which in turn benefits SAV. These designations are described in the "Designations" section of the "Water Column" chapter. MFC designations such as trawling and mechanical methods prohibited areas, Crab Spawning Sanctuaries, Oyster Sanctuaries, Shellfish Management Areas, and Military Prohibited Areas provide protection from fishing gear damage. CRC rules (general use standards 7 H .0208) require activities in public trust waters, such as navigation channel dredging and marina siting, to avoid significant adverse impacts to SAV habitat, as defined by the MFC. Both physical and water quality protections are afforded to open shellfish harvesting waters and Primary Nursery Areas. At the federal level, the South Atlantic Fishery Management Council (SAFMC) classifies SAV as Essential Fish Habitat for penaeid shrimp, red drum, and snapper/grouper species. The protections are described later in reference to particular threats. The vast majority of mapped SAV occurs within one or more designations providing some degree of additional protection, based on GIS analysis comparing SAV maps and regulatory designations (DMF unpub. data, July 2009).

#### **4.4. THREATS AND MANAGEMENT NEEDS**

Natural events, human activities, and global climate change influence the distribution and quality of SAV habitat. Natural events may include regional shifts in salinity because of drought or excessive rainfall, animal foraging, storm events, cold temperatures, or disease. 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 inflict damage or mortality on SAV directly, as well as by indirectly influencing future survival, reproduction, or establishment through alteration of habitat conditions (e.g., increased turbidity via

sediment resuspension). SAV is also vulnerable to water quality degradation, and in particular to suspended sediment, due to its relatively high light requirements (see “Habitat requirements” section for more information). Human impacts to SAV habitat have been documented and summarized by the Chesapeake Bay Program (CBP 1995), Atlantic States Marine Fisheries Commission (ASMFC 1997a), South Atlantic Fisheries Management Council (SAFMC 1998a), NOAA (Thayer et al. 1984; Fonseca et al. 1998), and others (Funderburk et al. 1991; Mallin et al. 2000; Orth et al. 2006). The most recent synthesis of research describes a global crisis for seagrass ecosystems (Orth et al. 2006; Waycott et al. 2009). Climate change and sea-level rise could cause large-scale losses of SAV habitat due to rising temperatures, water levels, and a collapse of the barrier island system (see “Sea-level rise and climate change” section for more information). The situation for North Carolina SAV will be described using these sources, in addition to permitted impacts documented by regulatory agencies, and personal observations.

### **4.4.1. Physical threats**

#### **4.4.1.1. Water-dependent development**

##### *Dredging (navigation channels and boat basins)*

Dredge and fill activities are considered the primary physical threat to SAV (Orth et al. 2006). Dredging for creation or maintenance of navigational channels and inlets resulted in degradation or elimination of SAV habitat. 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). 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 more 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.<sup>27</sup> SAV habitat can also be destroyed if dredged material is placed directly on shallow soft bottom where it could grow. However, placement of dredge spoil is restricted to upland sites except on subtidal bottom where spoil islands are permitted. The current permit process should prevent spoil islands being placed on SAV habitat. However, dredge spoil could also be used in deeper water to create SAV habitat. The beneficial use of dredge material is addressed in the wetlands and soft bottom chapters.

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; Duarte et al. 2005). North Carolina’s ports in Wilmington and Morehead City are small in comparison. The Wilmington port resides in the turbid, riverine section of the Cape Fear River where suitable habitat for SAV is lacking. 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. Dredged channels connecting marinas and small docking facilities (including boat ramps) to major navigation channels are another source of SAV habitat loss and degradation. Maps 2.13a-c (Water Column chapter) shows the location of ports, navigational channels (both dredged and undredged), boat ramps, marinas, and multi-slip docking facilities in coastal North Carolina. Some artificial channels bisect uniformly shallow areas with SAV beds on both sides, indicating a possibly unmitigated loss of SAV habitat (S. Chappell/DMF, pers. observation). Restoration goals could be established for historic losses of dredged SAV habitat, by using the 2007-08 SAV imagery and GIS data for marinas, boat ramps, small boat basins, and navigation channels to calculate the amount of dredged area. This would provide a conservative starting point for

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<sup>27</sup> Refer to the “Habitat Requirements” section for the light and sediment conditions needed for SAV colonization

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SAV restoration compared to other methods for determining restoration goals (i.e., predicted changes in water quality are uncertain, as is the historic distribution of SAV).

Coastal Management rules and policies require aligning dredge channels to avoid submerged aquatic vegetation, as defined by the MFC [CRC rule 15A NCAC 7H .0208(b)(1)]. In the past, to satisfy these criteria, the permit process would work with the applicant to locate the proposed area for dredging between visible patches of SAV. As part of CHPP implementation the MFC modified the definition of SAV habitat to take into account growing seasons and inter-annual variability. CRC modified their rules to refer to the MFC definition. With this modified definition effective in 2009, regulatory and review agencies, now assess past and current occurrence of documented SAV coverage within the past 10 years (see “Definition” section for more information) when siting coastal development projects to avoid areas of SAV habitat. However, some areas of historic SAV occurrence can still be dredged if they are “essential to maintain a traditional and established use” based on meeting four criteria [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 that 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 a disposal area in accordance with Part (b)(1)(B) of this rule without impacting adjacent nursery areas and submerged aquatic vegetation as defined by the MFC; (iv) the original depth and width of a human-made or natural channel shall not be increased to allow a new or expanded use of the channel.”

Although the USACE maintains 6,992 acres (2,829.56 ha) of navigation channels in coastal North Carolina (USACE, unpub. data, 2003), 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). Some of these channels are adjacent to or bisect SAV occurrence (Maps 4.3a-b), suggesting the potential for historic and/or indirect impacts. New dredging projects that could potentially impact SAV continue to be proposed. Some of the major projects (proposed, permitted, or discussed) with SAV considerations included:

- Relocation of ferry landing on north end of Ocracoke Island -
- Realignment of existing navigation channel through Bogue Inlet -
- Town of Southern Shores (Dare County) -
- Sandy Point Development (Chowan County) -
- Sunset Village (Dare County) - Mitigation/restoration
- Kitty Hawk Landing HOA(Dare county) – currently proposed
- Craven Board of Education – boat ramp with SAV

Alternative proposals often require weighing the impact on one habitat versus another (see “Ecosystem management and Strategic Habitat Areas” chapter for discussion of habitat trade-offs). As the coast becomes more developed, additional projects involving SAV impacts will likely be proposed. *The DMF and MFC should continue to use existing permit review to prevent or limit as much as possible direct or indirect impacts to SAV from all dredge and fill projects.*

There is also some degree of illegal propeller dredging (i.e., “kicking”) where large boats are docked in very shallow water. One notable case of illegal dredging occurred in 2004 when a DOT work boat kicked 2 feet of sediment to create a 5 foot deep channel through shallow water and SAV in Currituck Sound (S. Mitchell/DOT, pers. com., 2009). The intent was to deepen an existing channel in order to accommodate a pedestrian ferry to Currituck’s Heritage Park in Corolla. Permits for the project had previously been denied by DCM to protect shallow nursery habitat in the area. The CRC’s current rules and regulations adequately addressed the situation and DCM staff handled a complicated enforcement case appropriately,

ensuring all impacted SAV habitat was restored (M. Lopazanski/DCM, pers. com., January 2010). The DOT efforts to restore SAV in the affected area have been successful (S. Mitchell/DOT, pers. com., July 2009).

### *Shoreline stabilization*

The primary discussion of shoreline stabilization occurs in the Wetlands chapter and includes information on SAV impacts. Hardened vertical structures in moderate-energy environments can potentially degrade shallow SAV habitat by increasing wave energy, turbidity, and water depth. Scouring, deepened water, and reduced water clarity due to suspended sediments degrade optimal conditions for SAV growth. One specific observation was noted by ECU researchers conducting a video and acoustic assessment of SAV near Sandy Point on Albemarle Sound. A graduate student working with Dr. Joe Luczkovich noticed a conspicuous contraction and degradation of SAV habitat along hardened portions of the shoreline relative to natural shoreline. Dr. Luczkovich has considered investigating the observation further. *The relationship between SAV habitat characteristics and associated shoreline types should be investigated further.*

In comparing impacts of vertical versus non-vertical structures, there are habitat trade-offs that can make one alternative more ecologically beneficial than another. For example, bulkheads placed to prevent upland erosion typically increase the depth of shallow nearshore soft bottom, resulting in a loss of shallow soft bottom areas near SAV. In contrast, non-vertical structures, while not causing as much scouring and deepening, may require placement of rock structure further out onto submerged lands, resulting in loss of SAV habitat under the subtidal footprint of the sill. However, the gain of marsh habitat and increased stormwater runoff control landward of the sill may enhance water quality for SAV (see “Ecosystem enhancement” section of “Wetland” chapter for more information). The issue of habitat trade-offs is explored further in the “Ecosystem management and Strategic Habitat Areas” chapter.

### *Marinas and docks*

The CRC requires marinas to be sited in non-wetland areas in deep waters that don't require dredging and shall not disturb SAV as defined by the MFC. The CRC's preference is for upland basins, where SAV may become established. However, upland 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). Vertical shoreline stabilization and docking facilities associated with marinas may also impact SAV. Recent rule changes by the CRC state that, “Piers and docking facilities located over shellfish beds or submerged aquatic vegetation (as defined by the Marine Fisheries Commission) may be constructed without prior approval from the Division of Marine Fisheries or the Wildlife Resources Commission (whichever is applicable) if the following two conditions are met: (1) Water depth at the docking facility is equal to or greater than two feet of water at normal low water level or normal water level (whichever is applicable). (2) The pier and docking facility is located to minimize the area of submerged aquatic vegetation or shellfish beds under the structure” [CRC rule 15A NCAC 07H.1205(h)]. The location of marinas, boat basins, and public boat access areas relative to SAV is depicted in Maps 2.13a-b of the Water Column chapter.

Shading from docks also results in loss of SAV beneath the dock structures (Loflin 1995; Beal and Schmit 1998; Shafer 1999; Connell and Murphey 2004). 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

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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 sea grasses under docks having light levels less than 14% of surface irradiance (Shafer 1999). These small individual losses of SAV may seem insignificant, but they can have significant cumulative impacts. *The overall significance of dock shading on SAV should be assessed by comparing concurrent maps of shoreline structures and SAV habitat.*

A study by NCDMF in 2002-2003 (Connell and Murphey 2004) found reduced shoot density and coverage of SAV under docks compared to pre-construction conditions, indicating shading impacts. 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. Burdick and Short (1999) identified dock height, orientation, and width as the most important factors affecting SAV survival under a dock. Plank spacing was of some but less importance. Their assessment in Massachusetts recommended that docks be built less than 2 m wide, oriented within 10 degrees of north-south, be at least 3 m above the bottom, and add 0.4 m in dock height for every additional m in width. The impact of dock structures on SAV habitat in North Carolina could be minimized given sufficient height of dock structures above the water surface. CRC dock rules were modified in 2009 providing some additional protection for SAV by requiring applications for docking facilities over SAV in less than 2 ft of water (MLW) to be reviewed by the state resource agencies. *Where SAV habitat is evident, additional permit conditions regarding dock design should be considered on a case by case basis to maximize light penetration below docks.* Minimum height requirements are not without precedent in the Atlantic region. State regulations in Maryland, Virginia, Florida and Rhode Island as well as federal regulations have stringent restrictions on constructing piers over SAV, often requiring the applicant to pier out past the SAV, specifying width and height standards, and prohibiting or limiting new dredging in SAV habitat (Orth et al. 2002; DMF unpub. report 2008- tech guidance doc for SAV). In Florida aquatic preserves, guidelines for dock construction require 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).

In addition to direct damage from docks and marinas, indirect damage to MFC-defined SAV habitat 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. The potential for boating-related damage increases as additional docks and marinas are constructed along the coast.

As part of 2005-07 CHPP implementation, a workgroup was established to examine the issue of marinas and multi-slip docking facilities in North Carolina. The Sea Grant Marina Advisory Group completed its report on Multi-slip docking Facilities (MSDFs) and provided recommendations to the CRC in 2007. The report resulted in a revised application form for MSDFs (DCM-MP-4) designed to capture information that can be used to judge the impacts of projects. The CRC has also proposed changes to the rules regarding the general permit conditions for dock and piers which give property owners flexibility in docking facilities (8 sq. ft/linear ft shoreline) and provides better protection of shallow water habitat by requiring minimum water depth for docks permitted under a general permit (2 ft) and minimum water depth for floating docking facilities under the general permit if located in a PNA, in SAV, or in Shell bottom (18 in between bottom of floating dock and substrate). Where these conditions aren't met, the applicant may apply for a permit through the major permit process. Pre-existing rules limited dock lengths to no more than 25% of a water body's width (with some exceptions), and not extending into navigation channels or beyond the length of other piers along the same shoreline.

The cumulative impacts from dock structures in rapidly developing coastal areas must also be considered. The DCM has the authority to deny coastal development permits based on the comments of other DENR review agencies relative to cumulative impacts. However, the research and modeling tools necessary for review agencies 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.* Subdivisions choosing community docks over individual docks could minimize the cumulative impact of dock structures on SAV and other aquatic habitats (see “Water-dependent development” section of “Water column” chapter for more information).

### Infrastructure

Infrastructure is generally defined as a conduit spanning the length between supply and demand locations (i.e., bridges, power lines, fiber optic cables, pipelines). Infrastructure can be an SAV issue where the structures overshadow or replace SAV habitat with hard substrate (see “Ecosystem management and Strategic Habitat Areas” chapter for further discussion of habitat trade-offs) or require dredging to lay cables or pipes. *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 (Street et al. 2005).*

In North Carolina, proposed and completed bridge projects can and have resulted in loss and degradation of SAV habitat. The Highway 17 By-pass Bridge over the Neuse River at New Bern resulted in a loss of SAV habitat and subsequent mitigation (referenced in “Submerged aquatic vegetation restoration and enhancement” section). The bridge constructed over Croatan Sound in 2002 managed to avoid all mapped SAV habitat in the area. The pending replacement of Bonner bridge over Oregon Inlet could cause direct impacts to the grass beds in the area, as well as indirect impacts from changing current patterns and scouring. The current status of the Oregon Inlet bridge replacement remains in the plan development phase (A. Deaton/DMF, pers. com., July 2009). A new bridge was also proposed to cross the middle of Currituck Sound (Street et al. 2005). The proposed location is just north of the largest concentration of SAV in Currituck Sound. As of July, 2009, the Mid-Currituck Bridge is still proposed by the NC Turnpike Authority and will be funded “privately” (S. Winslow/DMF, pers. com., July 2009). The EIS is being finalized and will be out for review soon.

Infrastructure can also be an SAV issue where development of alternative energy sources is considered water-dependent (i.e., requires location in public trust waters). The conduit for transferring the energy produced in the estuary may intersect SAV habitat. There is an increasing interest in the development of wind farms in Albemarle and Pamlico sounds, as well as off the coast of Cape Hatteras and Cape Lookout, as these areas have some of the most abundant wind resources in the state (<http://www.ncsc.ncsu.edu/>, 2009). Although wind farms are generally considered a source of “green” energy, the construction of towers and infrastructure can impact immediate and adjacent marine or estuarine habitats (Byrne Ó Cléirigh et al. 2000). While current CRC rules prohibit the placement of wind turbines in state waters as they are not considered water-dependent structures, the CRC has taken steps to amend these rules (M. Lopazanski/DCM, pers. com., January 2010). The proposal currently under consideration would declare wind energy facilities of three MW or larger to be water dependent structures. *Should the State consider locating a wind facility in state or federal waters, proper placement of energy infrastructure is necessary to minimize potential impacts to SAV habitat and minimize conflicts with existing activities.*

#### 4.4.1.2. Boating activity

Direct physical impacts from propeller scarring, vessel wakes, and mooring scars have 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). Large holes 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). Where prop scarring is extensive and SAV beds destabilized, the ecological value of the SAV habitat is reduced (Fonseca et al. 1998). A study in Florida found that fish abundance was not significantly different between scarred and unscarred seagrass beds, but that severe scarring leading to complete bed removal could affect nekton (Bell et al. 2002).

In Florida, boats 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; Moore et al. 1997). 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 (see "Introduction" chapter on population trends), so will the number of boats. 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. *Clearly marked navigation channels, boater training, and SAV education materials would help boaters avoid SAV beds.* Educational material targeting boaters include an excerpt in the coastal boating guides describing the value of SAV habitat for fishery species and the threats posed by careless boating activity ([http://www.ncwildlife.org/fs\\_index\\_05\\_boating.htm](http://www.ncwildlife.org/fs_index_05_boating.htm), May 2009). Broader educational outreach for CHPP implementation was undertaken by the NC-NERR and the DMF. There is also an outreach subcommittee of the SAV partners workgroup chaired by NC-NERR staff. The DCM has a *Boater's Guide to Protecting Coastal Resources* that briefly mentions boating impacts to SAV (<http://www.nccoastalmanagement.net/Marinas/BoaterGuide2004.pdf>). This document could be enhanced to provide better education to NC's recreational boaters.

#### 4.4.1.3. 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 4.5.

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Table 4.5. 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
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. Auster and Langton 1999, ASMFC 2000, and Collie et al. (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. 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). High turbidity from frequent use of bottom-disturbing fishing gear can reduce water clarity, affecting SAV growth, productivity, and in some cases, survival.

Regulatory designations protecting SAV from fishing gear include crab spawning sanctuaries, mechanical methods prohibited areas, military protected areas, Shellfish Management Areas, Oyster Sanctuaries, Primary Nursery Areas (PNA), Secondary Nursery Areas (SNA), Special Secondary Nursery Areas (SSNA), and trawl net prohibited areas protect SAV in those areas from potential physical disturbance associated with bottom fishing gear (Maps 3.5a-c of the “Shell bottom” chapter). Crab spawning areas protect an area from crab dredging, crab trawling, and other methods disturbing the substrate. Oyster dredging is restricted in Mechanical Methods Prohibited areas, Oyster Sanctuaries and PNAs. Fishing activities in military protected areas are by permission only. Trawling of all kinds is prohibited in Shellfish Management Areas, Oyster Sanctuaries, PNAs, SNAs, and periodically in SSNAs. Trawl net prohibited areas apply to trawling of all kinds, whereas some areas are closed to shrimp trawling only (Maps 3.5a-c of the “Shell bottom” chapter). Areas open to clam trawling (“kicking”) were delineated to avoid SAV impacts. The efficiency of most mechanical fishing gears is reduced when pulled through dense SAV beds, therefore discouraging the practice. Only scallop dredging is both conducted and allowed in SAV habitat. Hand assisted methods (rakes <12 inches wide and <6 pounds, tongs) are prohibited in established SAV beds [MFC rule 15A NCAC 03K .0102 and 15A NCAC 03K .0304].

Areas closed to both oyster dredging and trawling protect 70% of mapped SAV in coastal North Carolina (Table 4.6). An additional 10% of SAV is protected from oyster dredging only. The area of SAV protected from only trawling or shrimp trawling was <1%. Crab Spawning Areas protected 5% of mapped SAV followed by Special Secondary Nursery Areas at 2%. Military designations and planted Shellfish Management Areas and Oyster Sanctuaries protect <1% of SAV. Areas open to hand harvest (approved, conditionally approved-open, and conditionally approved-closed) include 134,812 acres (90%) of mapped SAV. However, high densities of shell bottom and SAV do not generally overlap.

Though a large portion of SAV is protected from dredging and trawling, the spatial distribution of protection leaves some areas relatively unprotected. The great majority of SAV beds along the eastern perimeter of the Albemarle-Pamlico system are protected within these areas. However, trawling is technically allowed over much of the SAV present in western Core Sound, southern Bogue Sound, both sides of Roanoke Sound, and along the shoreline of West Bay in the southern Pamlico Sound area (Maps 3.5a-c of the “Shell bottom” chapter). Exceptions occur within PNAs, along the northern shoreline of Bogue Sound and one small area in western Bogue Sound (DMF 2007 - Bay Scallop FMP). However, the majority of trawling in Bogue and Core sounds occurs in or near the Atlantic Intracoastal Waterway, with some commercial trawling during the high tide in shallow regions outside the ICW. Eleuterius (1987) noted that shallow SAV beds were not affected by trawling except during high tides when beds were more accessible. Most of the SAV occurring in western portions of the Albemarle-Pamlico system is protected from shrimp trawling. However, crab trawling is allowed in the Pungo River, upper Neuse and Pamlico rivers (Maps 3.5a-c of the “Shell bottom” chapter). The number of participants and trips for crab trawling has been declining in recent years; 1,780 trips in 2004 to only 157 trips in 2007 (DMF 2008c). Cunningham et al. (1992) reported that peeler crab trawls (16-20 feet in head rope length) are pulled in shallow areas such as creeks and grass beds. However, only a small portion of peeler crabs landings are from trawls (DMF 2004a).

Table 4.6. Amount of mapped SAV within areas receiving specific North Carolina Marine Fisheries Commission designations that restrict fishing activities (as of September 2008).

<b>Bottom disturbing fishing gear prohibited</b>	<b>Acres of SAV covered</b>	<b>Percent of mapped SAV</b>
Only oyster dredging <sup>1</sup>	15,556	10%
Only trawling <sup>2</sup>	552	<1%
Only shrimp trawling	1,142	<1%
Both trawling and oyster dredging <sup>3</sup>	105,601	70%
<b>Other MFC designations</b>		
Crab Spawning Sanctuaries	7,684	5%
Military designations	80	<1%
Planted Shellfish Management Areas and Oyster Sanctuaries	19	<1%
Special Secondary Nursery Areas	2,683	2%

<sup>1</sup> Designations include Primary Nursery Areas and Mechanical Methods Prohibited

<sup>2</sup> Designations include Permanent Secondary Nursery Areas and Trawl Net Prohibited

<sup>3</sup> PNAs + overlap of SNAs or No Trawling Areas with Mechanical Methods Prohibited areas

As part of 2005 CHPP implementation, the DMF prepared maps identifying areas where allowed use of bottom disturbing fishing gear does or could overlap with sensitive estuarine habitat (CHPP IP database 2009 – Action #223). The largest spatial gap in SAV protection from fishing gear impacts was in northern Pamlico Sound where dredging for crabs is allowed [MFC rule 15A NCAC 03R.0109]. This area included SAV beds in the sound immediately west of Pea Island National Wildlife Refuge. 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. In 2004, the MFC removed the portion of crab dredge area that overlapped with the no trawl area in northeastern Pamlico Sound. This was one of the earliest accomplishments of the 2005 CHPP. The shrimp (3/06), bay scallop (11/07), and oyster

FMP (6/08) also identified and resolved some of the conflicts. No trawl areas were expanded along the banks side of northern Core Sound, and no shrimp trawl areas were established in the Pamlico, Neuse, and Pungo rivers (DMF 2006a) (Maps 3.5a-c of the “Shell bottom” chapter). The MFC supported modifying no trawl areas as needed to protected SAV habitat (DMF 2007a) and expanded Mechanical Methods Prohibited areas in Pamlico Sound (DMF 2008a).

### Scallop dredging

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 opening of the scallop dredging season now corresponds to high tide, and is often limited to hand harvest.

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, ranging from about 201,000 lb (91,172.07 kg) in 1995 to only 19,000 lb (8,618.26 kg) in 2002. There have been no trips documented for scallop dredging in North Carolina since 2003 (DMF 2008c) due to a harvest moratorium. Most of the catch is now taken by hand when the season is opened by proclamation. The projected impact of intense scallop dredging on juvenile scallops prompted Bishop et al. (2005) to recommend only hand harvesting methods for bay scallops. The season is opened for a specified area when DMF biologists determine there is a sufficient population (see DMF 2007a for more information). Annual monitoring of bay scallop populations not only provides data for fisheries management actions, but also provides information on a sensitive environmental indicator.

### Mechanical clam harvesting

Mechanical clam harvesting methods include clam dredging and clam trawling (kicking). Clam dredging can cause severe impacts to SAV. There are basically two types of clam dredges: basic and hydraulic. The impacts of and restrictions on basic clam dredging is similar that of oyster dredging. Hydraulic dredges direct 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. The reported number of participants, vessels, and trips for clam dredging include both basic and hydraulic dredging (DMF 2008c). There were 768 clam dredge trips in 1995 and only 344 in 2007. The number of trips declined markedly after 2004. However mechanical clam harvesting in close proximity to SAV could cause turbidity impacts.

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 behind a vessel. The vessel's propeller backwash is directed into the bottom and displacing the substrate so that the buried clams are collected in the trawl (Guthrie and Lewis 1982). Most kicking activities are restricted to depths less than 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 for three reasons: (1) kicking techniques were first experimented with in eastern North Carolina during the 1940s, (2) almost 150 kicking vessels operated in 1980 in Carteret County alone, and (3) kicking vessels 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, Newport, North, New, and White Oak rivers, and southeastern Pamlico Sound. 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 has been declining from around 1,000 trips (1996-1999) to 214 trips in 2007 (DMF 2008c). High salinity SAV species are more likely to be impacted by mechanical clamming practices due to the location of the fishery. As a part of CHPP implementation, the clam kicking area was modified by proclamation to clearly avoid all SAV and oysters beds and establish a buffer of 50-100 feet between the gear and habitat. *If this buffer appears inadequate, DMF should modify it to an effective and scientifically based distance (CHPP IP database 2009 – Action #71).*

### **4.4.2. Water quality degradation**

Degradation of the water column affects all living habitat features of the coastal aquatic ecosystem. Submerged aquatic vegetation, in particular, is highly dependent on water quality conditions. Whereas the primary discussion of water quality degradation resides in the “Water Column” chapter, the major water quality issues for SAV are summarized in this section.

#### **4.4.2.1. 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 attributed to large-scale nutrient enrichment and sedimentation, which reduces light penetration to the leaf (Twilley et al. 1985; Orth et al. 1986; Goldsborough and Kemp 1988; Kenworthy and Haunert 1991; Funderburk et al. 1991; Dennison et al. 1993; Stevenson et al. 1993; Durako 1994; Orth et al. 2006; Steward and Green 2007). Nutrient enrichment and/or increased sediment loads impact light at leaf for SAV by:

- Reducing water clarity with suspended sediment or phytoplankton associated with algal blooms that absorb light rays prior to reaching SAV blades,
- Increasing epiphytic coverage, sedimentation, or covering by drift algae on the SAV blades (Virnstein and Morris 1996), and

- Diminishing dissolved oxygen concentrations as photosynthesis from SAV beds decrease, coupled with increasing concentrations of hydrogen sulfide resulting in toxicity (Dennison et al. 1993; Fonseca et al. 1998).

In addition to epiphytic growth, eutrophication of shallow estuaries can lead to the proliferation of extensive thick unattached mats of ephemeral macroalgae over and around SAV, often filamentous or sheet-like bloom forming green and brown algae (*Ulva*, *Cladophora*, *Chaetomorpha*, *Gracilaria*, *Ectocarpus*) (McGlathery 2001). Some of these macroalgal species are also epiphytes (Neckles et al. 1993). Studies have found that macroalgal biomass was directly related to increased nutrient levels (Neckles et al. 1993; Valiela et al. 1997) and that SAV loss (density and productivity) increased with increasing macroalgae, particularly the macroalgal canopy height (Hauxwell et al. 2000). Where eelgrass loss occurred due to macroalgal cover, nitrogen loading rates were 30 kg/ha/yr in the urbanized watershed compared to 5 kg/ha/yr in the forested watershed. Once heavy macroalgal blooms die off, they decompose rapidly, increasing nutrient levels in the water column, which stimulates phytoplankton production and further light reductions. Low grazing pressure has also been shown to lead to increased epiphytic biomass on SAV, and may have a greater effect than nutrient enrichment (Neckles et al. 1993). Monitoring of the epiphytic and macrophytic algal community has been used as an indicator of SAV condition and anthropogenic impacts in some areas (Dunn et al. 2008). *Epiphytic and macroalgal cover should be considered as a monitoring parameter for SAV in North Carolina.*

Nutrient concentrations could indicate eutrophic conditions favoring faster-growing epiphytic algae over SAV. In freshwater lakes, algae begin to dominate SAV at phosphorus concentrations greater than 50 mg/l (McComas 2003). Nutrients also adsorb to sediment particles, which contribute to turbidity and reduced water clarity. 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 of algal biomass (e.g. phytoplankton), by measuring the green pigments contained in plants in the water column. Higher abundances of Chlorophyll *a* indicate an increasing dominance of algae and phytoplankton around SAV in the water column.

Research has shown that elevated nitrogen concentrations not only affect SAV through light reduction from phytoplankton and epiphyte biomass, 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  $\mu\text{M}$  water column  $\text{NO}_3^- - \text{Nd}^{-1}$  (Burkholder et al. 1992b). In another experiment with eelgrass, nitrogen enrichment (10  $\mu\text{M}$  water column  $\text{NO}_3^- - \text{Nd}^{-1}$  for 14 wk) significantly lowered shoot production compared to control plants without nitrogen enrichment (<2  $\mu\text{M}$  water column  $\text{NO}_3^- - \text{Nd}^{-1}$ ) (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 indicate that of the three species studied, eelgrass would be most impacted by eutrophication.

Nutrient concentrations (mainly phosphorus and nitrogen) and dissolved or suspended matter (organic or inorganic) can also affect the distribution and condition of SAV beds (see “Habitat requirements” section for more information). Even before nutrient and sediment enrichments from human activities, SAV distribution and abundance expands and contracts naturally with climatic conditions (i.e., storms, droughts) since these weather patterns alter timing and magnitude of nutrient, sediment and freshwater inputs. The specific effects of human-caused eutrophication on SAV 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). Early season pulses of turbidity

can also affect SAV survival along the river continuum where conditions are suitable later in the growing season (Moore et al. 1997). Therefore, optimal criteria for preventing eutrophication and sedimentation vary by salinity, species, time of year, and specific location of SAV beds.

Threshold nutrient and sediment concentrations for SAV growth have been provided in the literature (Funderburk et al. 1991; Fonseca et al. 1998; McComas 2003; Kemp et al. 2004). The threshold values vary among freshwater, moderate and high salinity SAV, with freshwater-low salinity SAV having slightly higher tolerance for nutrient concentrations. Table 4.7 provides those threshold values for dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), total suspended solids (TSS), and Chlorophyll *a* (proxy for nutrient concentrations). Table 4.8 provides the North Carolina water quality classifications and standards that most closely match these parameters. There is no official standard for light attenuation in North Carolina. However, several water quality standards can be used as indicators of light conditions, including turbidity, total suspended solids, and chlorophyll *a* levels (EPA 2000a). Other standards affecting SAV growth include dissolved oxygen and nitrate. However, the standards are sometimes different among DWQ water body classifications (Table 4.8). The water quality parameters are measured periodically by DWQ at fixed stations concentrated in riverine systems of the coast (Street et al. 2005). There are relatively few water quality stations in the estuarine system (see “Water column” chapter for more information). Regulations on wastewater discharge, development density, buffer requirements, erosion and sediment controls, best management practices, and landfill restrictions may also affect light conditions in receiving waters with SAV (see “Water column” chapter for more information). However, the effect of regulations on water clarity can only be measured in terms of a water quality standard.

Table 4.7. Threshold nutrient and sediment concentrations for SAV. (Funderburk et al. 1991; Fonseca et al. 1998; EPA 2000a; Kemp et al. 2004)

SAV salinity categories	Growing season	Total suspended solids (mg/l)	Dissolved inorganic Nitrogen (mg/l)	Dissolved inorganic Phosphorus (mg/l)	Chlorophyll a (mg/l)
High salinity (18-30 ppt)	March-May, September-November	<15	<0.15	<0.01	<15
Moderate salinity (5-18 ppt)	April-October	<15	<0.15	<0.01	<15
Freshwater-low salinity (0-5ppt)	April-October	<15	-	<0.02	<15

In comparing current North Carolina water quality standards to SAV habitat requirements, the standard for chlorophyll *a* is higher (40 mg/l vs. <15 mg/l). The standard for TSS is also higher, but to a lesser degree and applies only to discharges (20 mg/l vs. <15 mg/l) (Table 4.8). Given the current standards for water quality in North Carolina, the system is not being managed to support SAV requirements even with continuous monitoring of parameters. There are basically two alternatives for supporting SAV habitat via standards monitoring: (1) lowering existing standards pertaining to light attenuation, or (2) including a light attenuation standard. *A study is needed to evaluate the feasibility of implementing adequate water quality standards for supporting SAV habitat.* The study would include selecting representative locations for monitoring the standards, when and how often to measure the standard, what constitutes a 303(d) listing, and additional cost estimates. Another important question affecting feasibility would be where to apply the enhanced standards (e.g., Outstanding Resource Waters, NSWs, High Quality Water, Strategic Habitat Areas). Areas not meeting the standard could then be targeted by DWQ for Total Maximum

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Daily Load (TMDL) development (for nutrient and sediment standards). With or without an official standard, the need for restoration requires an attribution of cause regarding a degraded parameter. Because degraded light attenuation in a system can be due to variable precipitation and/or storm events as well as nutrient and sediment additions by humans, the use of water quality standards is complicated.

Table 4.8. North Carolina Environmental Management Commission classifications and standards (mg/l) related to SAV presence and condition (May 2007).

Standards/ regulations	Supplemental Classifications			Salt water		Fresh water
	ORW	HQW (salt or freshwater)	NSW	SA	SB, SC	Aquatic life (B, C)
Dissolved oxygen (mg/l)	*	6	*	6	5	5
Nitrate (mg/l)	*	-	*	-	-	-
Turbidity (NTU)	*	25	*	25	25	50
Total suspended solids (mg/l)**	*	20	*	20	-	(narrative)
Chlorophyll <i>a</i> (mg/l)	*	40	*	40	40	40

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

\*\* Applies to discharges only

Another factor complicating the use of water quality standards is the natural cycle of SAV expansion and contraction in aquatic systems. Establishment of new SAV in an area requires more stringent water quality conditions than maintaining or expanding existing SAV due to water quality enhancement provided by the existing SAV (see “Ecosystem enhancement” section for more information). Loss or contraction of SAV habitat, whether from physical impacts or water quality degradation, leads to a cascade 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). Future SAV restoration may also be confounded by the loss of existing beds, which increases sediment resuspension and turbidity (P. Biber/NMFS, pers. com., 2003). Therefore higher water quality conditions may be needed for survival of newly restored SAV than for survival of existing vegetation due to the synergistic effect on water quality. Therefore, management efforts should focus on protecting and enhancing existing SAV habitat and preventing any additional direct or indirect losses.

The presence of SAV can, in itself, be valuable as a sensitive indicator of water quality (Dennison et al. 1993). 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 rates have been determined 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.

Further research in Indian River lagoon has addressed setting load limits for nutrients and suspended solids based on seagrass depth-limit targets (Steward and Green 2007). Total Maximum Daily Loads were calculated based on regressing total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) loading [ $\log(\text{kg ha}^{-1} \text{ yr}^{-1})$ ] against seagrass depth limits (percent of depth limit targets). Calculating TMDLs for SAV in North Carolina would require coordinated multi-year monitoring of: (1) SAV depth and distribution, and (2) nutrient and sediment loading. However, TMDLs should only be developed for areas where light attenuation is strongly affected by watershed pollutant loading (i.e., NSWs). A multi-year protocol for detecting annual changes in SAV distribution in North Carolina is being developed jointly by APNEP, NOAA, ECU, and NCSU (see “Status and trends” section for more information). The primary discussion of nutrient and sediment monitoring is in the “Water column” chapter.

In Chesapeake Bay, cooperative efforts by scientists, managers, and politicians have worked for over two decades to protect and restore SAV (Orth et al. 2002). Chesapeake Bay Agreements in 1983, 1987, and 2000 as well as other related ongoing efforts have established policies and regulations to protect and restore SAV through adaptive management. Research and modeling was conducted to determine light and water quality standards needed to sustain SAV and evaluate point and nonpoint pollutant loading reductions needed to achieve these conditions. Despite the enormous efforts, success in terms of water quality improvements and SAV habitat increases has been limited.

*Knowing that water quality degradation is the largest contributor to declines in SAV, and that North Carolina’s growing coast will likely lead to additional water quality degradation, North Carolina needs to investigate the best method to protect SAV habitat from water quality degradation.*

#### 4.4.2.2. Toxic chemicals

##### Herbicides

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). Some SAV species may even be viable candidates for monitoring hydrophobic organochlorines (cis- and trans-chlordane, dieldrin, and polychlorinated biphenyls). Along the tidal Potomac River, Hopple and Foster (1996) found toxic concentrations in *Hydrilla* beds similar to surrounding riverine sediment. 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. The following section (“Introduced and nuisance species”) includes more information on toxic chemicals effects on SAV.

##### Fossil fuels

Oil spills can have negative impacts on SAV in several ways. SAV can be smothered and die by high concentrations of oil. In lesser concentrations oil may leave a “burnt” look on SAV blades, but this is a temporary effect since new leaf production continues once oil concentrations subside (Jacobs 1980). In lower concentrations of oil SAV can have a reduced photosynthetic rate as a result of oil toxicity. Oil may also have sublethal effects by accumulating PAH in sea grasses reducing its tolerance to other stress factors (as described in above sections) potentially leading to death of the SAV (Zieman et al. 1984).

Although in most field studies of oil effects on SAV and the associated fauna there is seldom pre-event data, many studies compare oil affected sites versus non affected sites or observe trends over a period of time. After the 'Exxon Valdez' spill Jewett et al. (1999) observed lower abundance of amphipods at oil affected sites than those not affected as well a higher numbers of certain polychaetes species. The reduced number of amphipods may be caused by the acute toxicity of oil, while the increased number of polychaetes may be from the increased amount of detritus from the dead/decaying SAV. This shift in the benthic invertebrates may cause a shift in the food web. These results have been observed in other studies such after other spills such as the 'Amico Cadiz' (Dauvin 1982). Dispersants may be useful in the cleanup of oil, but they may be detrimental to SAV. Edwards et al. (2003) showed dispersants encourage the breakdown of SAV's waxy cuticle, allowing greater penetration of oil into SAV blades.

#### 4.4.3. *Non-native, invasive, or nuisance species*

There is a general perception by some of the public that all SAV is a nuisance. Grass blades may get in boat propellers, water intakes, or entangle or weigh down fishing gear. Aesthetically, swimmers may prefer a sand bottom to a grass bottom. 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](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). Native species may also be more resilient to long-term patterns in temperature, salinity and energy regime.

The Division of Water Resources, under the Aquatic Weed Control Act of 1991 [General Statute 113A-220 ff; DENR rules 15A NCAC 02G .0600], manages the North Carolina Aquatic Weed Control Program (AWCP)<sup>28</sup>, 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 program's focus is determined by public notices, which are primary directed at vegetation problems in impoundments (mostly hydrilla in Lake Gaston) (R. Emens/DWR, pers. com., May 2009). Program staff ("the Weed Team") work with local governments to provide technical and financial assistance (50:50 cost share). The Weed Team conducts a site assessment using the DENR list of noxious aquatic weeds (includes Hydrilla, Elodea, water hyacinth, Eurasian watermilfoil, alligator weed, purple loosestrife, brittle naiad, and Phragmites) to identify projects for assistance. The species most pertinent for DMF in 2010 included *Alternanthera philoxeroides* (alligator weed), *Myriophyllum spicatum* (Eurasian milfoil), and *Phragmites australis*. Hydrilla was reported for the first time in the Chowan River. Aquatic herbicides may be used to kill the nuisance vegetation. Herbicides used include copper-based compounds (cheap but results in water use restrictions), 2-4-Dichlorophenoxyacetic acid (2-4-D), and/or SONAR (expensive but can be used with no water use restrictions). The Weed Control Program also posts signs at boat ramps warning of the danger in spreading noxious weeds to other systems. *Signs could also be posted to educate the public on the value of native aquatic plants.*

The most troublesome species in low salinity, estuarine waters is Eurasian watermilfoil. Weed control activities in coastal waters are primarily focused on this species. Control activities target areas where native species are not the dominant species based on site assessments (R. Emens/DWR, pers. com., May 2009). The AWCP may consult with DENR resource management agencies in assessing coastal sites

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<sup>28</sup> [http://www.ncwater.org/Education\\_and\\_Technical\\_Assistance/Aquatic\\_Weed\\_Control](http://www.ncwater.org/Education_and_Technical_Assistance/Aquatic_Weed_Control)

concerning any impacts on native SAV. A recent consultation involved the area of Kitty Hawk Bay where treatments of dense Eurasian milfoil stands resulted in a significant reduction of milfoil coverage (R. Emens/DWR, pers. com., August 2009). *The Weed Team also observed native species resilience to 2-4-D treatments of milfoil and would like to test the observation further (R. Emens/DWR., pers. observation, May 2009).* The AWCP, in cooperation with the Town of Kill Devil Hills intends to continue monitoring the milfoil infestation and conduct spot treatments on an as needed basis. *Long-term management and restoration of SAV habitat should include replacement of Eurasian watermilfoil with native species throughout the estuary.* However, because milfoil is providing habitat for important fishery species, treatment of milfoil should only be conducted where milfoil occurs as a dense monoculture and native species are minimally or not present. The AWCP staff agreed to consult with regional DMF staff prior to chemical applications in public trust waters to ensure that fish habitat impacts are minimized, and should continue to do so.

To spray submerged or emergent vegetation in public trust waters, one must be licensed for herbicide spraying and have a special certification for public water spraying (B. Bruss/Dept of Agriculture, pers. com. 2009). The spraying must be done according to the label and overspray to unintentional areas would be a violation of the label. Only state agencies or local government are allowed to have the public water certification. Possible violations are investigated by the Dept. of Agriculture on request. In 2008 property owners in a private subdivision treated a large area of public trust waters independently, without having proper certification or consulting with DWR or DMF staff. As a result, a large area of native and non-native SAV species was obliterated. G.S. 113-300.1 states that WRC has authority to regulate, prohibit or restrict use of poisons or pesticides severely affecting wildlife resources (includes SAV as resource), as long as the rules do not conflict with the Pesticide Law of 1971 or Structural Pest Control Act of 1955. Furthermore, an Attorney General review in 1995 found that MFC had authority under 143B-289.3(b) to regulate use of pesticides on SAV. EPA is in the process of requiring a NPDES permit for any spraying of aquatic pesticides and herbicides over or near public trust waters. NC DWQ is in the process of developing the permit. However, the exemption thresholds will be fairly high and the permit will not address the spraying of native vegetation. *Legislation is needed to prohibit chemical treatment of native vegetation in estuarine waters, due to its high value as fish habitat.*

Another introduced species affecting SAV is the grass carp, which is often stocked in ponds and impoundments for nuisance weed control. Grass carp have escaped from stocked ponds and reservoirs into some river systems in North Carolina. The escaped carp can have a significant impact on native freshwater SAV in receiving waters. 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. Nuisance species, from the perspective of SAV habitat, may or may not be introduced. Examples include macroalgae and the “animal grass” (a bryozoan) that sometimes overwhelms SAV in high salinity waters (T. Murphy/DMF, pers. com., 2007). Excessive macroalgae growth (drift algae or epiphytic), has been shown to negatively impact productivity of SAV (Kemp et al. 2004). The animal grass infestations observed in 2007 were identified as the Sauerkraut bryozoan, *Zoobotryon verticillatum* (B. Burns/DMF, pers. com., October 2007). The overabundance of animal grass appears to occur in drought years in high salinity areas. Though *Z. verticillatum* competes with SAV for space and interferes with certain fisheries activities, it also filters large quantities of water to provide a function similar to living oyster reefs. *Research is needed to determine the ecological role and effects of animal grass on SAV beds and related fish communities in North Carolina.*

#### **4.4.4. Diseases and microbial stressors**

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 sea grasses, making them more susceptible to *Labryinthula*. Vergeer et al. (1995) later confirmed a decline in the microbial defenses of seagrass with increasing temperature. The primary factor enhancing microbial defenses was increasing light intensity, which is related to both water quality and self-shading. Jackson et al. (2001) suggested that declining grazer abundance has caused, among other things, a self-shading stressor for dense seagrass beds. Healthy eelgrass beds were generally reestablished by the 1960s. More recently, similar large-scale die-offs of eelgrass from Nova Scotia to Connecticut, and turtle grass in Florida Bay have been attributed to *Labryinthula* (Short et al. 1987). Eelgrass infected with *Labryinthula* was also found near Beaufort, North Carolina in the 1980s (Short et al. 1987). Submerged aquatic vegetation is less susceptible to infection by the pathogen in low salinity waters (Short et al. 1987). Potential impacts in North Carolina include reductions in bay scallops and other fisheries resources, and large reductions in migratory waterfowl populations and loss of ecosystem services. Although the current infections have not caused catastrophic declines in eelgrass populations such as those which occurred in the 1930s, the disease is a potential threat to coastal fisheries should large-scale mortalities occur. *Submerged grasses need to be monitored on a periodic basis to assess the status of wasting disease and its association with human-induced stresses.*

Another microbial stressor on SAV could be the gall-like growths on widgeon grass observed in low salinities areas such as Blounts Bay on the Tar River (C. Wilson/USACE, pers. com., April 2008). The effects of the gall-like growths on widgeon grass in Blounts Bay are unknown. However, the 2009 disappearance of widgeon grass in Blounts Bay may suggest a causal link (J. Paxon/DWQ, pers. com., 2009). *Research is needed to determine effects of gall infections on SAV beds and related fish communities in North Carolina.*

#### **4.4.5. Sea level rise and climate change**

The “Wetlands” chapter contains the primary discussion of sea level rise and its effect on coastal habitats. Changing temperature and salinity patterns with climate change are discussed primarily in the “Water column” chapter. Specific issues and effects of sea level rise and climate change on SAV habitat in North Carolina are discussed in this section. The effects/issues include:

1. The significant impact of increasing CO<sub>2</sub> concentrations on growth of CO<sub>2</sub>-limited seagrass species (Palacios and Zimmerman 2007);
2. Shifting relative abundance and distribution of eelgrass and shoal grass with increasing temperature (Micheli et al. 2008).
3. The importance of seagrass genetic diversity in providing resilience to heat waves and other extreme climate conditions (Ehlers et al. 2008);
4. Loss of marsh and barrier island windbreaks and subsequent loss of sheltered SAV habitat (D. Piatkowski /USACE, pers. observation, 2009).
5. Deepening of waters adjacent to hardened shoreline (see “Shoreline stabilization” section of Wetlands chapter) exacerbated by predicted increases in the severity and frequency of large storm events (IPCC 2007).

Palacios and Zimmerman (2007) compared the growth of eelgrass with various levels of CO<sub>2</sub> enrichment. The results indicated significantly higher reproductive output, below-ground biomass and vegetative production of new shoots at 33% surface irradiance at leaf. The results suggest an increasing CO<sub>2</sub> content

in the atmosphere and ocean surface will increase the area-specific productivity of seagrass meadows. This also suggests the value of seagrass beds in sequestering carbon. However, warming trends pose a threat to eelgrass growing near its southern limits in North Carolina. There is some evidence of declining summer densities and biomass of eelgrass in Bogue Sound at sites that were monitored between 1985 and 2004 (Micheli et al. 2008). The study also found that an increase in shoal grass compensated for the eelgrass decline, but invertebrate diversity and abundance declined. In a study looking at the role of eelgrass genetic diversity on their resilience to temperature extremes, the results suggested a reduction in seagrass resilience to climate change with alterations that tend to reduce genetic diversity (Ehlers et al. 2008). *Site monitoring of SAV should include species composition and genetic diversity to track the potential impacts of climate change.* North Carolina is uniquely situated to conduct such research.

The reduction in extent of marsh islands described in the wetlands chapter was observed by USACE managers working in Currituck Sound and associated with loss of SAV (D. Piatkowski /USACE, pers. observation, 2009). Marsh islands provide shelter from the wind and waves during the growing season for SAV. The shrinking of marsh islands is caused by sea level rise, erosion, and the interruption of barrier island over-wash by oceanfront development (see “Soft bottom” chapter for more information). *The relationship between marsh island extent and quality of surrounding SAV beds should be investigated further.*

Seagrass habitat, as one of the most productive systems in the world, is considered an important carbon dioxide sink relative to other terrestrial and aquatic habitats. Because the plants have a slow turnover rate, the leaves degrade slowly, and a large part of the carbon production is put into the below-ground rhizome system, sea grasses have a large capacity for accumulation and storage of carbon. It is estimated that seagrass habitat is responsible for about 15% of the total carbon storage in the ocean while occupying a lesser portion of the seafloor (Pidgeon 2009; UNEP 2009). *To sustain the carbon sink service provided by submerged grasses, the habitat must be preserved, with management efforts focused on maintaining environmental conditions (nutrient and sediment concentrations) needed for SAV growth (Bjork et al. 2008).*

#### **4.4.6. Management needs and accomplishments**

The global and nationwide trend of declining SAV habitat (Orth et al. 2006; Waycott et al. 2009), coupled with recognition of its ecological importance, has led several regional and state resource management agencies to develop protective management policies for SAV habitat, including Atlantic States Marine Fisheries Commission, South Atlantic Fishery Management Council, Chesapeake Bay Program, and Rhode Island Coastal Resources Management Program. Virginia and Maryland, through the Chesapeake Bay program, developed a guidance document for SAV (EPA 1995) and Rhode Island Coastal Resources Management Program has definitions, findings, policies, and standards regarding activities that can impact SAV ([http://www.edc.uri.edu/Eelgrass/300\\_18.pdf](http://www.edc.uri.edu/Eelgrass/300_18.pdf), November 2010). Both documents address identification and protection of both existing and historically occurring SAV habitat, recommend SAV mapping, require surveys of the SAV habitat during appropriate growing seasons, require buffers around identified grass beds, and restrict certain specific activities from occurring in or over SAV habitat. Chesapeake Bay implements a tiered approach in SAV habitat protection, based on the documented bottom information available. 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 (Appendix G). The policy includes the following guidelines:

- *In order to delineate and assess the distribution and health of SAV habitat, SAV beds need to be mapped and monitored. The saltwater end of coastal waters supports 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*

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- adequate water quality as defined by water-column clarity in standard measurement units.*
- *All SAV needs to be protected from all bottom-disturbing fishing and recreational gear. Sufficient buffer zones surrounding SAV beds should also be protected from disturbance to prevent impacts of sediments on growing SAV.*
- *Provide adequate safeguards to prevent direct (or indirect) impacts from development projects adjacent to or connected to SAV.*
- *Assess cumulative impacts of land use and development changes in the watershed affecting SAV to identify the potential impact. Require identification of cumulative impacts as a condition of development of permit applications.*
- *Require compensatory mitigation where impacts are unavoidable. Initiate restoration programs to recoup and/or enhance lost SAV habitat.*
- *Educate landowners adjacent to SAV, boaters, and other potential interested parties about the value of SAV as a habitat for many coastal fishes and invertebrates.*

Commission actions (MFC, CRC, and EMC) have been fairly consistent with this policy. Substantial progress has been made on the majority of these guidelines, but there are others that have not yet been addressed.

The management needs noted by italics in the 2005 CHPP were addressed to some degree during 2005-2010. Some needs are considered accomplished, whereas others are considered ongoing with or without progress. Emerging management needs are new or significantly modified from their 2005 versions and may or may not be refined and adopted as actions in the 2009-2011 CHPP implementation plans. Discontinued needs includes those recommendations from Street et al. (2005) that were omitted from the chapter update for various reasons (i.e., included in another chapter as part of primary discussion, need discontinued, considered minor, redundant, or too general). The subheadings reflect these distinctions.

### 4.4.6.1. Research needs and progress (2005-2010)

#### *Accomplished research needs*

1. *Model a wide range of estuaries to determine environmental requirements for SAV over a broader spatial and temporal scale to determine if changes in EMC water quality standards are needed. **The relationship between water quality and SAV has been examined sufficiently in North Carolina, the Chesapeake Bay, and Florida (see Section 4.1.3. "[Habitat requirements](#)" and Section 4.4.2. "[Water quality degradation](#)" for more information and context).***
2. *Examine the relationship between juvenile red drum abundance in SAV and marsh edge habitat and the effect of spatial connectivity on habitat use to support management of this important species. **Conclusive research has been conducted (see Section 4.2.4.3. "[Nursery](#)" for more information and context).***

#### *Research needs with progress*

1. *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. 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 (Street et al. 2005). **The DMF Habitat Section assembled an inventory of water quality monitoring stations to help determine if conditions could be modeled throughout the estuary – part of mapping potential habitat for SAV. The results show that water quality data are few and far between, especially in estuarine waters (see Section 4.1.3. "[Habitat requirements](#)"). Relating land-use characteristics to downstream water quality in a hydrodynamic model could be the most cost effective means of locating potential SAV habitat – existing WQ monitoring stations could be used to calibrate the model.***

2. *Determine the relationship between changing SAV coverage and water quality conditions (Street et al. 2005). There has been some research in North Carolina, Virginia and Florida relating SAV habitat characteristics to water quality measurements (see Section 4.1.3. "[Habitat requirements](#)" and Section 4.2.2. "[Ecosystem enhancement](#)").*
3. *DENR should work with NMFS to determine what levels of TSS, chlorophyll a and other parameters are needed to achieve desired water clarity (Street et al. 2005). The latest research is presented in Section 4.4.2.1. "[Nutrients and sediment](#)".*
4. *Determine if adequate light is available beneath North Carolina docks, given the CRC's current siting criteria. The criteria should be evaluated to determine if changes would be needed to allow the minimum amount of light for SAV growth (Street et al. 2005). A study by NCDMF in 2002-2003 (Connell and Murphey 2004) found reduced shoot density and coverage of SAV under docks compared to pre-construction conditions (see "[Marinas and docks](#)" subsection of Section 4.4.1.1. "Water-dependent development").*
5. *Develop criteria to designate SAV beds as a component of Strategic Habitat Areas (Street et al. 2005). The DMF has also developed criteria for designating Strategic Habitat Areas that capture the vast majority of low and high salinity SAV and assesses potential alteration from fishing gear, among other factors (see chapter 8. "[Ecosystem management and Strategic Habitat Areas](#)" for more information).*

Research needs without progress

1. *Verify if a recovery of SAV has occurred and determine if there is a spatial pattern of that recovery. If there is a pattern, special monitoring and protection should be afforded those core areas from which SAV begins its recolonization (Street et al. 2005). In the mean time, Back Bay/Currituck Sound should serve as a test case for re-establishing SAV in a recovering/recoverable ecosystem. No specific progress. See Section 4.3.3. "[Submerged aquatic vegetation restoration and enhancement](#)" for more information.*
2. *Assess the cumulative impacts of dock placement (i.e., shading, boating activity, associated development) on SAV habitat in selected water bodies (Street et al. 2005). No progress, but anticipated completion of shoreline mapping and structures inventory will help DCM and other permit review authorities evaluate cumulative impacts (see "[Marinas and docks](#)" subsection of Section 4.4.1.1. "Water-dependent development" for more information).*
3. *Conduct research to determine the relative fishery value of Eurasian watermilfoil compared to native vegetation (Street et al. 2005). No specific progress. See Section 4.4.3. "[Non-native, invasive, or nuisance species](#)" for more information.*

Emerging research needs

1. *A simple model to predict potential SAV habitat in North Carolina would be helpful for identification and protection of this important habitat where it has not been mapped or otherwise documented recently (within the past 10 years). See Section 4.1.3. "[Habitat requirements](#)" for more information.*
2. *Research is needed on how much SAV proximity affects juvenile production from spawning areas. See Section 4.2.4.2. "[Spawning](#)" for more information.*

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3. *Research is needed on the relationship between juvenile Sciaenid abundance and connectivity among nursery habitats and spawning areas. See Section 4.2.4.5. “[Corridor and connectivity](#)” for more information.*
4. *Research is needed to determine the habitat preferences of other fisheries species and life stages in North Carolina in order to estimate population sizes and determine habitat protection priorities. See Section 4.3.2. “[Status of associated fishery stocks](#)” for more information.*
5. *More fishery-independent information and habitat change analysis are needed to evaluate the effect of SAV-coverage on the abundance of fish and invertebrates. See Section 4.3.2. “[Status of associated fishery stocks](#)” for more information.*
6. *The relationship between SAV habitat characteristics and associated shoreline types should be investigated further. See “[Shoreline stabilization](#)” subsection of Section 4.4.1.1. “[Water-dependent development](#)” for more information.*
7. *Research is needed to estimate the loss of SAV habitat from apparent dredging using the 2007-08 SAV imagery and GIS data for marinas, boat ramps, small boat basins, and navigation channels. The results of such research could be used to set restoration goals addressing historic losses of SAV habitat to dredging. See “[Dredging \(navigation channels and boat basins\)](#)” subsection of Section 4.4.1.1. “[Water-dependent development](#)” for more information.*
8. *The overall significance of dock shading on SAV should be assessed by comparing concurrent maps of shoreline structures and SAV habitat. See “[Marinas and docks](#)” subsection of Section 4.4.1.1. “[Water-dependent development](#)” for more information.*
9. *The Weed Team observed native species resilience to 2-4-D treatments of milfoil and would like to test the observation further (Rob Emens/DWR., pers. observation, May 2009). See Section 4.4.3. “[Non-native, invasive, or nuisance species](#)” for more information.*
10. *Research is needed to determine the ecological role and effects of animal grass on SAV beds and related fish communities in North Carolina. See Section 4.4.3. “[Non-native, invasive, or nuisance species](#)” for more information.*
11. *Research is needed to determine effects of gall infections on SAV beds and related fish communities in North Carolina. See Section 4.4.4. “[Diseases and microbial stressors](#)” for more information.*
12. *The relationship between marsh island extent and quality of surrounding SAV beds should be investigated further. See Section 4.4.5. “[Sea level rise and climate change](#)” for more information.*
13. *Epiphytic and macroalgal cover should be considered as a monitoring parameter for SAV condition in North Carolina. See Section 4.4.2.1. “[Nutrients and sediment](#)” for more information.*
14. *Research is needed on the feasibility of hard clam augmentation for the purpose of water quality based restoration of SAV. See Section 4.3.3. “[Submerged aquatic vegetation restoration and enhancement](#)” for more information.*

### 4.4.6.2. Management needs and progress (2005-2010)

#### Accomplished management needs

1. *Ensure consistency in habitat definitions among agencies and commissions (CHPP IP database 2009 – Action #152). MFC approved revised definition of SAV habitat in 2009. CRC references definition in*

revised General and Specific Use Standards for Development. See Section 4.1.1. "[Definition](#)" for more information.

2. *Evaluate the boundaries of No Trawl Areas and adjusting, if necessary, to adequately protect all high salinity SAV beds from both direct and indirect impacts, such as turbidity. Additional law enforcement may be needed to enforce buffers necessary to protect SAV from gear-induced turbidity (Street et al. 2005). The DMF prepared maps identifying areas where allowed use of bottom disturbing fishing gear does or could overlap areas with sensitive estuarine habitat. The Shrimp FMP (2007), Bay scallop FMP (2007) and oyster FMP (2008) identified and resolved gear/habitat conflicts (i.e., crab dredging in Oregon Inlet overlapping SAV). See Section 4.4.1.3. "[Fishing gear impacts](#)" for more information.*
3. *Modify clam kicking and hydraulic dredging areas by proclamation to clearly avoid all SAV and oyster beds and allow a buffer of 50-100 ft between mechanical shellfish gear and SAV and shell bottom. The size of the buffer may be modified if supported by scientific studies. Done for Core Sound in 2006. The MFC also closed >30,000 acres in Pamlico Sound tributaries to mechanical shellfish harvest in 2005. See Section 4.4.1.3. "[Fishing gear impacts](#)" for more information.*
4. *Provide 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 (Street et al. 2005). Broader educational outreach for CHPP implementation was undertaken by the DCM NERR and the DMF. There is also an outreach subcommittee of the SAV partners workgroup chaired by NC-NERR staff. See Section 4.4.1.2. "[Boating activity](#)" for more information.*
5. *Conduct educational outreach to increase awareness by the boating public of the ecological value of SAV and the damaging effects of boat propellers on SAV habitat (Street et al. 2005). Educational material targeting boaters includes an excerpt in the coastal boating guides describing the value of SAV habitat for fishery species and the threats posed by careless boating activity ([http://www.ncwildlife.org/fs\\_index\\_05\\_boating.htm](http://www.ncwildlife.org/fs_index_05_boating.htm) and <http://www.nccoastalmanagement.net/Marinas/BoaterGuide2004.pdf>, May 2009).*
6. *Conduct a review of current chlorophyll, TSS, and turbidity standards to determine if they are appropriate for the protection of SAV in North Carolina waters. A review is provided in Section 4.4.2.1. "[Nutrients and sediment](#)".*
7. *Ensure that chemical removal of European watermilfoil and other non-native vegetation does not also eradicate native species in the process (Street et al. 2005). The DWR Weed Team is consulting with DENR resource management agencies as part of their site assessments. See Section 4.4.3. "[Non-native, invasive, or nuisance species](#)" for more information.*

#### Management needs with progress

1. *To quantify trends in SAV abundance, regular mapping efforts of all or a subset of the habitat is needed in addition to monitoring data from stations and transects (Street et al. 2005). The mapping was coordinated through the Albemarle-Pamlico National Estuary Program (APNEP), in partnership with multiple agencies. A multi-agency MOU was signed in 2006; state and federal funds were allocated for SAV aerial photography in 2007; sampling protocols were developed in 2006-2007, and image acquisition was completed in 2007-2008. However, the imagery has not been classified due to loss of staff position. See Section 4.1.4. "[Distribution](#)" for more information.*
2. *Require compensatory mitigation where impacts to SAV are unavoidable. Initiate restoration programs to recoup and/or enhance lost SAV habitat (Street et al. 2005). DWQ worked with DOT on a SAV and oyster habitat restoration and mitigation project in the Currituck Sound. Restoration work*

has been completed and monitoring continues to assess the success of the project. EEP has initiated internal research to determine the functional value of SAV restoration. EEP will review the DCM permitting requirements involving impacts to SAV. EEP will incorporate SAV restoration recommendations into the non-traditional mitigation strategy to be proposed to the PACG in the following year. See Section 4.3.3. "[Submerged aquatic vegetation restoration and enhancement](#)" for more information.

3. *Use existing permit review and issuing authorities to provide more protection of SAV by addressing both direct and indirect impacts from dredge and fill projects (Street et al. 2005). Change in SAV definition and dock rules has helped improve protection, but is an ongoing battle with progress difficult to quantify. See Section 4.3.3. "[Dredging \(navigation channels and boat basins\)](#)" for more information.*
4. *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 (Street et al. 2005). Ongoing need with the placement and replacement of bridges in coastal North Carolina. See the "[Infrastructure](#)" subsection of Section 4.4.1.1. "Water-dependent development" for more information.*

*Management needs without progress*

1. *Conduct regular monitoring of SAV beds to assess their changing distribution and condition (Street et al. 2005). The DMF and NERR will initiate SAV monitoring of sentinel sites. Initial concepts have been discussed at the APNEP SAV Partners meetings. Monitoring activities are dependent on identification of funding; a multi-agency team of SAV researchers (NOAA, ECU, and NCSU) submitted a CRFL proposal for testing long term field monitoring of SAV in August 2008, but no SAV monitoring plan has been established. NC-NERR sites may be included in monitoring sites if the project is selected for funding. See Section 4.3. "[Status and trends](#)" for more information.*
2. *Conduct additional juvenile fish sampling stations in SAV habitat (Street et al. 2005). No specific progress. However, the DMF Resource Enhancement Section is planning a sampling program to track juvenile fish abundance in and around oyster sanctuaries (G. Bodnar/DMF, pers. com., February 2009). The sampling will be conducted in SAV, shell bottom, and soft bottom habitats.*
3. *Periodically assess the level of prop scar damage on SAV habitats. 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 persistent SAV beds to avoid (Street et al. 2005). No specific progress. See Section 4.4.1.2. "[Boating activity](#)" for more information.*
4. *Focus management efforts on protecting (and enhancing) existing SAV habitat and preventing any additional direct or indirect losses (Street et al. 2005). Direct losses of habitat areas meeting the definition of SAV are strongly discouraged by permitting authorities. If losses are unavoidable, publicly funded projects are required to mitigate for the losses whereas privately funded project may be asked to include a mitigation plan. Indirect losses due to changes in water quality are more difficult to project. See Section 4.4.2.1. "[Nutrients and sediment](#)" for more information.*
5. *The need and feasibility for a water quality standard for light attenuation should be further investigated to provide a pro-active target or standard for protection and restoration of SAV (Street et al. 2005). The need for a water quality standard is demonstrated in Section 4.4.2. "[Water quality degradation](#)". See Section 4.4.2.1. "[Nutrients and sediment](#)" for more information.*
6. *Knowing that water quality degradation is the largest contributor to declines in SAV, and that North Carolina's growing coast will likely lead to additional water quality degradation, North Carolina*

*needs to investigate the best method to protect SAV habitat from water quality degradation (See Section 4.4.2.1. [“Nutrients and sediment”](#) for more information).*

7. *Include replacement of Eurasian watermilfoil with native species as an objective in SAV management and restoration plans. No specific progress. The need is predicated on research demonstrating the value of milfoil as fish habitat. See Section 4.4.3. [“Non-native, invasive, or nuisance species”](#) for more information.*
8. *Conduct regular monitoring of submerged grasses for wasting disease and its association with human-induced stresses (Street et al. 2005). No specific progress. See Section 4.4.4. [“Diseases and microbial stressors”](#) for more information.*

Emerging management needs

1. *Local and regional monitoring programs should eventually be coordinated with a comprehensive SAV monitoring program. See Section 4.3. [“Status and trends”](#) for more information.*
2. *The results of this new SAV monitoring research should be evaluated for broader application in the estuary as a whole. See Section 4.3. [“Status and trends”](#) for more information.*
3. *Monitoring should focus on SAV in the most vulnerable locations (close to land where water quality degradation and shoreline development impacts greatest, edge of southern and western distribution range) and in areas of current or former importance to bay scallops. See Section 4.3.1. [“Status of submerged aquatic vegetation habitat”](#) for more information.*
4. *The APNEP SAV Partnership is developing an action plan for SAV restoration activities in North Carolina and southeastern Virginia, with guidance from the Chesapeake Bay experience (Orth et al. 2002). The plan for SAV restoration should also be coordinated with other habitat restoration plans and activities. See Section 4.3.3. [“Submerged aquatic vegetation restoration and enhancement”](#) for more information.*
5. *The SAV restoration action plan should include restoration goals based on potential habitat maps and projected water quality improvements. See Section 4.3.3. [“Submerged aquatic vegetation restoration and enhancement”](#) for more information.*
6. *Where SAV habitat is evident, additional permit conditions regarding dock design should be considered on a case by case basis to maximize light penetration below docks. See [“Marinas and docks”](#) subsection of Section 4.4.1.1. [“Water-dependent development”](#) for more information.*
7. *Should the State consider locating a wind facility in state or federal waters, proper placement of energy infrastructure is necessary to minimize potential impacts to SAV habitat and minimize conflicts with existing activities. See the [“Infrastructure”](#) subsection of Section 4.4.1.1. [“Water-dependent development”](#) for more information.*
8. *Clearly marked navigation channels, boater training/licensing, and SAV education materials would help boaters avoid SAV beds. See Section 4.4.1.2. [“Boating activity”](#) for more information.*
9. *If this buffer appears inadequate, DMF should modify it to an effective and scientifically based distance. See Section 4.4.1.3. [“Fishing gear impacts”](#) for more information.*
10. *Site monitoring of SAV should include species composition and genetic diversity to track the potential impacts of climate change. See Section 4.4.5. [“Sea level rise and climate change”](#) for more information.*

11. The Weed Control Program also posts signs at boat ramps warning of the danger in spreading noxious weeds to other systems. *Signs could also be posted to educate the public on the value of native aquatic plants.* See Section 4.4.3. [“Non-native, invasive, or nuisance species”](#) for more information.
12. *Legislation is needed to prohibit chemical treatment of native vegetation in estuarine waters, due to its high value as fish habitat.* See Section 4.4.3. [“Non-native, invasive, or nuisance species”](#) for more information.
13. *To sustain the carbon sink service provided by submerged grasses, the habitat must be preserved, with management efforts focused on maintaining environmental conditions (nutrient and sediment concentrations) needed for SAV growth (Bjork et al. 2008).* See Section 4.4.5. [“Sea level rise and climate change”](#) for more information.

#### **4.5. SUMMARY OF SUBMERGED AQUATIC VEGETATION CHAPTER**

The ecological importance of SAV habitat is well documented in the literature. Some additional research since the 2005 CHPP has looked at fish use of SAV of various patchiness or density and found that SAV presence, regardless of the bed shape or density, supports a greater diversity and abundance of organisms than unvegetated bottom, although some species favor certain SAV habitat characteristics over others. Valuation studies indicate that the monetary value of the ecosystem services provided by SAV is very significant. With North Carolina having the second largest amount of SAV on the east coast, protection and enhancement of this resource should be a high priority for the state. The major threats to SAV habitat remain channel dredging and water quality degradation from excessive nutrient and sediment loading. An emerging issue that could have large consequences on SAV is the effect of sea level rise associated with global climate change.

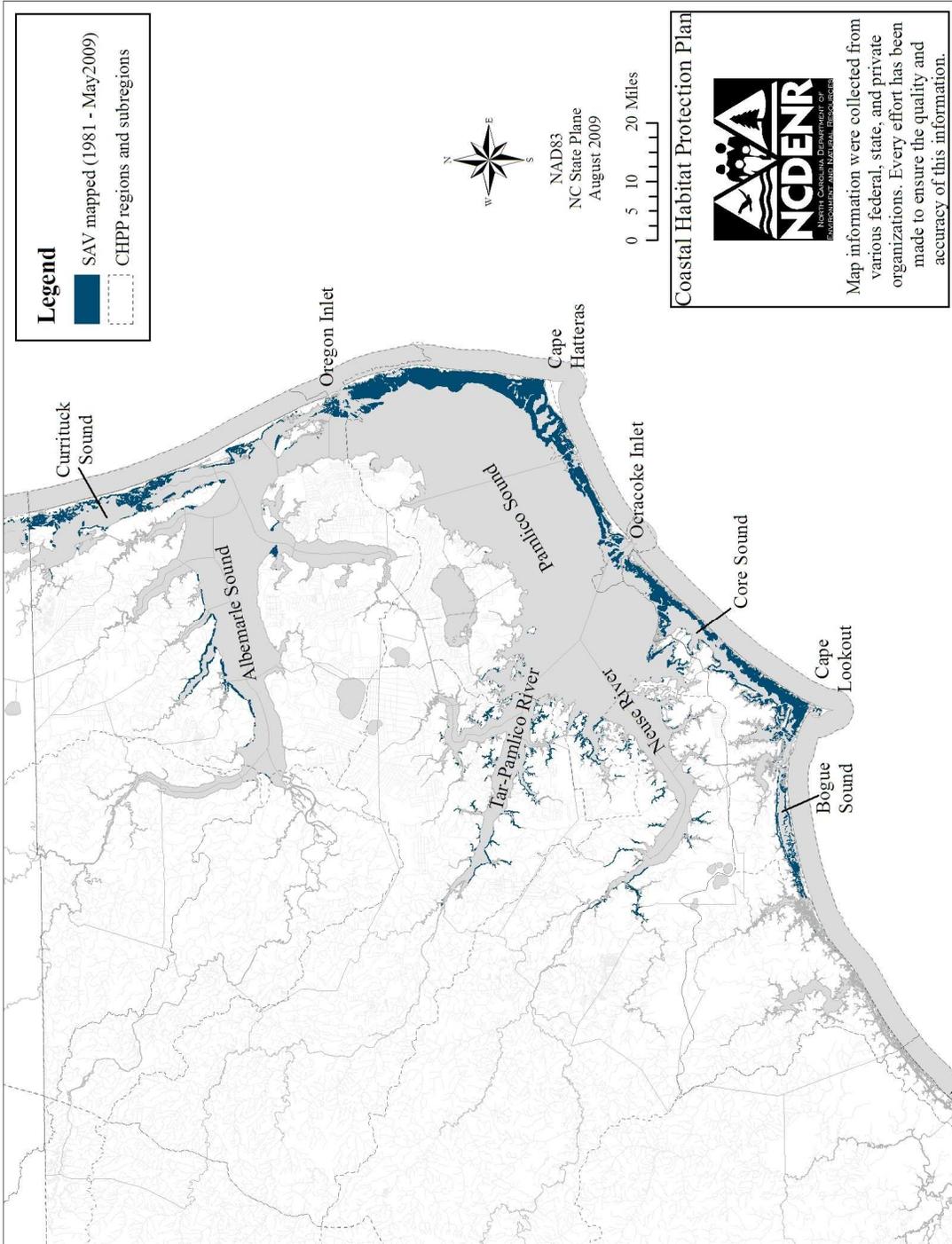
The 2010 CHPP provides additional information on habitat requirements and distribution of SAV. The light requirements of SAV groups (based on salinity) are now well established and documented in this chapter. Since the 2005 CHPP, coastwide imagery of SAV was obtained in 2007-2008, with delineation delayed due to staff vacancies (a state/federal cooperative mapping effort). Digitizing SAV polygons on the imagery is in progress. Additional mapping in western Pamlico Sound, Neuse River, and Tar/Pamlico River by the DMF and DWQ have increased the total area of mapped SAV to over 150,000 acres. While a quantified change analysis is not available, there appeared to be an increase of SAV in some of the low salinity systems and southern range of SAV, which may be related to improved water clarity associated with the coastwide drought in 2007-2008. Preliminary review of core areas of SAV, such as behind the Outer Banks in Pamlico Sound and Core Sound do not indicate large change. However, there may have been a shift to increased patchiness of previously dense beds in Bogue Sound. Mapping SAV using aerial imagery to assess status and trends is a large and difficult task that must be augmented with monitoring.

Some annual monitoring of SAV presence and species composition is being done, but is not being applied to a coastwide analysis of annual change in distribution and abundance. A cooperative agency/academic research project (funded by Coastal Recreational Fishing License dollars) is underway and investigating methods to employ for SAV change analysis. Less rigorous analysis of change has been conducted for the Currituck Sound and Back Bay system, where restoration plans are being developed by the USACE in consultation with other resource management agencies and University researchers. The SAV in these systems is currently recovering naturally, but could benefit from restoration/enhancement work to build more resilience during less favorable conditions in the future. With better information available on light and other habitat requirements of SAV, it may be possible to manage water quality for protection of SAV. The 2010 CHPP provides information on techniques to identify potential SAV habitat so that these areas can be targeted for protection and restoration. However, the bathymetric data and existing network of water quality monitoring stations remain inadequate for coastwide modeling SAV habitat suitability. The

state of North Carolina would have to commit substantial resources to adequately manage SAV habitat through regular monitoring, mapping, and development of SAV specific water quality standards such as has been done in the Chesapeake Bay and regions of Florida.

Over half of the research and management needs identified in the 2005 CHPP have advanced to some degree. Nine were accomplished, nine others had significant progress, and eleven had no action. Of the research needs, the most significant advancement is information regarding the bio-optical habitat requirements of SAV. Numerous management needs were accomplished while some are ongoing and require continued effort and funding. The most significant management accomplishment was obtaining aerial imagery to map all SAV along the coast. However progress to get the SAV imagery delineated has been delayed due to staffing shortages and budget issues. There are also 13 and 12 emerging or modified research and management needs, respectively.

Progress since the 2005 CHPP included an updated, regulatory definition of SAV habitat that should further reduce piecemeal loss and degradation of SAV habitat from water-dependent development. There are also more areas of SAV habitat closed to bottom disturbing fishing gear, and fishing gear buffer boundaries were re-evaluated and are being enforced. Direct dredge and fill impacts to existing and historic SAV are being avoided to a greater extent, due to improved education and commitment of the permitting agencies, revisions to the MFC definition of SAV habitat and revisions of the CRC dock rules. So the management of SAV habitat loss to individual, direct impacts has improved, while management of cumulative impacts continues to be an issue. Steps have been taken to reduce nutrient and sediment loading from nonpoint sources through implementation of coastal stormwater rules. Though water quality degradation affects large areas of SAV habitat, monitoring of water quality standards continues to only marginally reflect support of SAV habitat requirements. There remains a need for improved water quality standards and monitoring for SAV habitat. Some research is underway looking at various monitoring methods however. Educational awareness of the value of SAV habitat remains a great need.



Map 4.1.1. Location of mapped submerged aquatic vegetation (SAV) habitat in coastal North Carolina (1981-2009). See “Distribution” section for mapping efforts included. Note: Absence of SAV beds in a given area does not suggest actual presence/absence of SAV because surveys have not been conducted in all areas.