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Submerged Aquatic Vegetation of the York River

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ABSTRACT

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Submerged aquatic vegetation or SAV are important components of shallow water areas of the York River estuary. The plants that comprise these communities are distributed in shallow water areas (<2m) along the estuary from polyhaline to freshwater areas according to their individual salinity tolerances. Eelgrass *(Zostera marina)* is the only true seagrass and is found only in the lower York River where salinities average above 20 psu. It is a cool water species that decreases in abundance in the summer due to high water temperatures. SAV in this region have declined precipitously from historical abundances due to excessive levels of turbidity and nutrients. Infection of a marine slime mould-like protist, *Labyrinthula zosterae*, also impacted this species in the 1930s, nearly decimating it from this area. Widgeon grass *(Ruppia maritima)* co-occurs with eelgrass but can also grow in low salinity areas. Pondweeds *(Potamogeton)* and many other SAV species grow in both low salinity and freshwater areas. Macroalgae or "seaweeds" are currently a minor component of SAV in the York River system. Several algal genera common in the area include: *Agardhiella, Ulva, Enteromorpha* and *Chara*. While there has been a great deal learned through research and monitoring relative to SAV communities in the Chesapeake Bay, in general, and the York River, in particular, more efforts are needed to advance SAV protection and restoration to achieve the SAV restoration goals. Research efforts are needed to further understand the relationships between environmental conditions and SAV response and the interactions between of various stressors on SAV. Other areas for further research focus include investigations of the relationships between natural and restored SAV growth, survival and bed persistence and biological stresses including herbivory or secondary physical disturbance through foraging, bioturbation or other activities. One important need is to quantify the short and long term relationships between SAV decline and recovery and climatic factors such as storms, droughts, and temperature extremes that may be influenced by climate change.

ADDITIONAL INDEX WORDS: *Seagrass, macrophytes, habitat conditions, water clarity.*

INTRODUCTION

Submerged aquatic vegetation or "SAV" are non-flowering or flowering macrophytes that grow completely underwater. In the Chesapeake Bay region, the term "SAV" is usually used to refer to various rooted aquatic angiosperms or "underwater grasses" found growing in shallow littoral areas ranging from high salinity regions (Figure 1) to freshwater tidal environments. Approximately 20 species are commonly found throughout the Chesapeake Bay. Individual species are distributed based on their tolerances to environmental conditions including: salinity, light, temperature, nutrient levels, sediment type, and physical setting. Moore *et al.* (2000) found that the SAV communities in the bay can be grouped into four associations based largely on their salinity tolerances (Table 1).

Beds of SAV are important habitats in the Chesapeake Bay region as both marine and freshwater SAV communities have been found to provide habitat, protection, nursery areas, and other functions for economically valuable fishery species (Lubbers *et al*., 1990; Duffy and Baltz, 1998; Richardson *et al*., 1998); are primary sources of food for waterfowl (Korschgen and Green, 1988; Perry and Uhler, 1988; Perry and Deller, 1996); serve as indicators of local water quality conditions (Fonseca *et al.*, 1982; Korschgen and Green, 1988; Dennison *et al.*, 1993, Moore *et al.*, 1996); affect key biogeochemical and sedimentological processes (Kemp *et al.,* 1984; Caffrey and Kemp, 1990, Ward *et al.* 1984, Moore, 2004); and decrease the potential for shoreline erosion by dampening nearshore waves and water flow (Fonseca, *et al.*, 1982; Fonseca and Cahalan, 1992, Koch and Gust, 1999).

SAV have declined precipitously from historical abundances (Orth and Moore, 1983; Brush and Hilgartner, 2000). In the York River this decline was greatest in the 1970s with some recovery since then (Figure 2). In the region of the Catlett Island reserve site the SAV have disappeared completely. In the lower estuary, while some SAV remain, they have been found growing down to much shallower depths than their former occurrence and the abundance and bed configuration of the SAV can vary significantly from year to year (Orth *et al*., 2005).

Figure 1. Lower York River seagrass bed.

Table 1. Chesapeake Bay SAV Species Associations. * indicates dominant species. (From Moore *et al*., 2000)

ZOSTERA Community	*Zostera marina**
	Ruppia maritima
RUPPIA Community	*Ruppia maritima**
	Potamogeton perfoliatus
	Potamogeton pectinatus
	Zannichellia palustris
POTAMOGETON Community	*Potamogeton perfoliatus**
	*Potamogeton pectinatus**
	Potamogeton crispus
	Elodea canadensis
FRESHWATER MIXED Community	*Vallisneria americana**
	*Hydrilla verticillata**
	*Myriophyllum spicatum**
	Ceratophyllum demersum
	Heteranthera dubia
	Elodea canadensis
	Najas guadalupensis
	Najas gracilllima
	Najas minor
	Najas sp.
	Potamogeton crispus
	Potamogeton pusillus

Over the past 5 years there has been a continual decline of SAV beds from the region that includes the areas surrounding the Goodwin Islands reserve site (Figure 3). In addition, many areas that were formerly dominated by eelgrass are now vegetated with widgeon grass (Orth *pers. comm*.). This species tends to form beds that are less persistent and more variable that the eelgrass beds they replace. In contrast to the recent losses in the lower estuary, there has been a significant growth of SAV (Figure 3) in the upper tidal freshwater regions of the Pamunkey and Mattaponi Rivers due largely to recruitment of the non-native SAV, *Hydrilla verticillata*.

There are a number of factors that can affect the local distributional changes in SAV abundance. The most important factor is water quality, especially as it affects the light available to the SAV leaf surface for photosynthesis (Moore *et al*., 1997; Batiuk *et al*., 2000, Kemp *et al*., 2004). Light attenuation can occur both through the water column as well as through the epiphyte layer that forms on the photosynthetic surfaces. The latter can be 30% or more of total light attenuation for SAV in the Chesapeake Bay (Kemp *et al*., 2004). Suspended particles, both living and nonliving, and dissolved materials in the water column attenuate light in general proportion to their concentrations (Kirk, 1994). Light attenuating material attached to photosynthetic surfaces of the plants themselves includes living plants and animals, detrital material, and sediments (Neckles *et al*., 1993). The rate of accumulation of this material on the plants is generally related to the concentration of suspended particles, the availability of light and nutrients in the water column (Moore and Wetzel, 2000; Kemp *et al*., 2004), and the rate of grazing or loss of material through physical factors (Neckles *et al.*, 1993; Duffy *et al.*, 2003). Other factors such as episodic storm events (Pulich and White, 1991), physical disturbance (Quammen and Onuf, 1993), and herbicide toxicity (Kemp *et al.,* 1985) can have local effects. Fishing, aquaculture and recreational boating practices can also affect SAV beds both directly through the use of the gear and placement of aquaculture structures, as well as indirectly through factors such as habitat deterioration (ie organic matter deposition and algae growth) and propeller scars from vessels attempting to traverse shallow areas. Given water quality

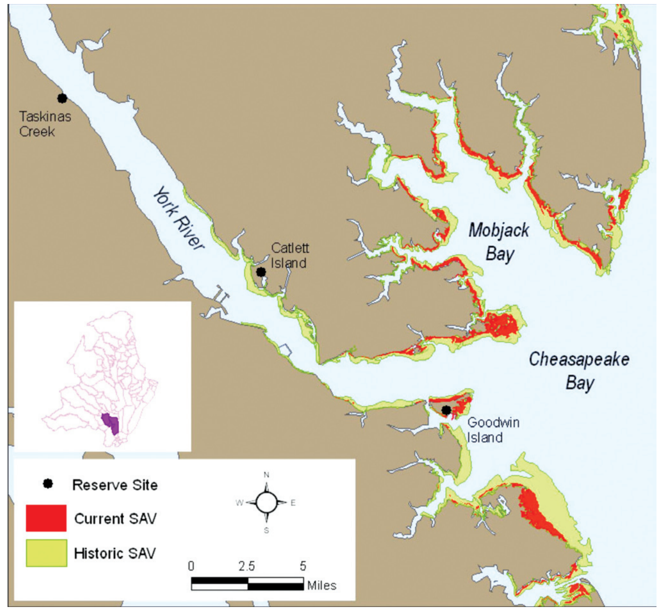

Figure 2. Current (2006) and historical (1950s) SAV distribution in the lower York River.

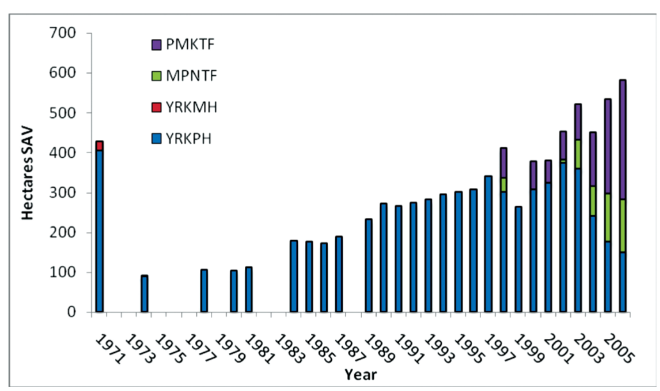

Figure 3. SAV abundance in the York River system. YRKPH-York Polyhaline. YRKMH-York Mesohaline. MPNTF-Mattaponi Tidal Fresh. PMKTF-Pamunkey Tidal Fresh.

conditions of adequate light for growth and limited nutrient concentrations, SAV beds are regulated by the physical, geological and geochemical conditions at a site (Koch, 2001).

Recruitment and growth of SAV can also occur as habitat conditions improve. In some cases the re-growth may be a result of the explosive growth of non-native species, especially in tidal freshwater and low salinity areas. This growth may result in persistent vegetation in these regions and may be accompanied by a simultaneous re-growth of more native species (Rybicki and Landwehr, 2007).

EELGRASS COMMUNITY

There are only approximately 60 species of seagrasses found world-wide (den Hartog, 1970; Green and Short, 2003). Seagrasses are thought to have evolved from flowering land plants beginning approximately 100 million years BP (Waycott *et al*., 2004). While seagrasses are a diverse group of plants they are generally characterized by a tolerance to salt water, reduced cuticle, no stomata, epidermal chloroplasts, reduced structural material in leaves, and flowers that are pollinated completely underwater. Eelgrass *(Zostera marina)* is the only true seagrass occurring in the Chesapeake Bay (Moore *et al*., 2000; Figure 4). It is the species which typically dominates in the higher salinity regions (>20 psu) of the Chesapeake Bay including the lower York River (Table 1). In this region eelgrass flower formation is initiated in the late winter (Silberhorn *et al*., 1983), seeds are released in May and germination begins in the fall as water temperatures drop below 20 °C (Moore *et al*., 1993). Germination of seeds is reduced by oxygenated conditions (Moore *et al*., 1993), therefore they must usually be incorporated into the sediment for germination to proceed. Most seeds of eelgrass do not appear to be widely distributed after release and are rapidly incorporated into the sediment (Orth *et al*., 1994). However, reproductive shoots of eelgrass can float and any seeds that remain attached can be transported many km (Harwell and Orth, 2002). There appears to be little in the way of a long term seed bank in eelgrass beds in the bay and it is hypothesized that the seeds only remain viable for a year or less. Ongoing research is attempting to evaluate this aspect of seed ecology. Eelgrass commonly reproduces through vegetative clonal growth by continually producing new leaves, rhizome internode segments and lateral shoots from a basal meristematic region. Typically, an individual eelgrass shoot consists of 3-5 strap-like leaves enclosed in a basal leaf sheath. As eelgrass grows, the base of the shoot pushes through the sediment. The rhizome acts as a storage organ and the roots function both in anchoring the plant and as the primary site for nutrient uptake (Pregnall, 1984). Although eelgrass is a perennial plant, individual shoots generally survive for one to two years and some vegetative shoots will differentiate and become flowering shoots during their second growing season (Setchell, 1929).

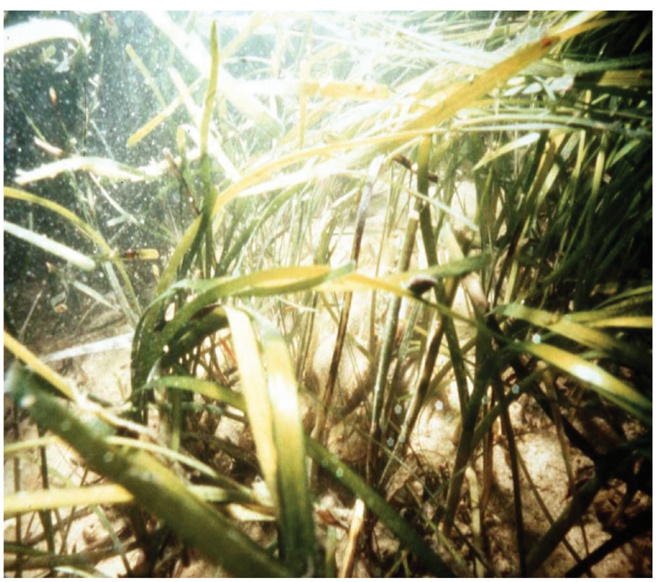

Figure 4. Eelgrass *(Zostera marina)*

Eelgrass is a polyhaline species and it does not usually survive in regions where salinities are commonly below 10 psu. In the lower York, eelgrass usually dominates in the deeper regions of beds out to water depths of 1.5m and is most abundant in this region at depths from 0.25m to 0.75m below mean low water (Orth and Moore, 1988). It is most abundant near the mouth of the York River in the vicinity of Goodwin Island. Historically, beds grew nearly continuously along the shoreline from the mouth of the estuary to several mi. upriver from the Catlett Island reserve site (Figure 2). On average eelgrass above ground biomass in this region ranges to 250 gdm m^{-2} (Moore *et al.,* 2000).

Eelgrass is a temperate species that is widely distributed along the North American coast from Newfoundland in the north to the North Carolina coastal bays in the south (Green and Short, 2003). Eelgrass populations in the Chesapeake Bay are therefore growing near their southern temperature limits. Here, beds reach maximum abundances in the late spring, dieback in the summer as water temperatures rise above 23°C, demonstrate some re-growth in the fall, and maintain low abundances throughout the winter (Orth and Moore, 1986; Moore *et al*., 1996; Batiuk *et al.,* 1992). Summertime conditions therefore appear to be particularly stressful for these populations, although the production of carbon reserves during other times of the year can influence the survival throughout the summer (Burke *et al.,* 1996).

In addition to stresses from habitat conditions eelgrass populations have been decimated by a "wasting disease" that affected many Atlantic populations, including those in the Chesapeake and Virginia coastal bays, in the 1930s (Muehlstein, 1989). Eelgrass wasting disease symptoms are caused by the infection of a marine slime mould-like protist, *Labyrinthula zosterae* Porter and Muehlstein (Short *et al*., 1987; Muehlstein *et al.,* 1988, 1991; Muehlstein, 1992) which has been reported in several species of *Zostera* (Short *et al.,* 1987, 1993). It was thought that Labyrinthula was a secondary decomposer of senescent leaves (den Hartog, 1987; den Hartog *et al.,* 1996). Ralph and Short (2002) have demonstrated that *L. zosterae* rapidly invades the healthy green tissue around black disease spots, impairing photosynthesis, and is a primary pathogen causing the wasting disease infection. Salinity plays a role in regulating disease activity (Burdick *et al.,* 1993) with higher infection levels typically found under higher salinity conditions. However, the actual conditions that initiate broad-scale die-off from the disease are not well understood. Although there have been records of eelgrass die-off infections from virulent strains of Labyrinthula in recent years (Green and Short, 2003) there is little evidence that this "wasting disease" is prevalent in Chesapeake Bay populations at the present.

WIDGEON GRASS COMMUNITY

Widgeon grass (*Ruppia maritima*; Figure 5) is the second most abundant species found in the higher salinity regions of the bay and a dominant species in the middle regions of the bay. In comparison to eelgrass, widgeon grass has a much broader salinity tolerance (Stevenson and Confer, 1978) and can be found from freshwater to high salinity areas throughout the bay (Moore *et al.,* 2000). Widgeon grass can grow at depths as shallow as mean low water (Orth and Moore, 1988) and can also be found in shallow panes in bay marshes as well as shallow road side ditches. It is usually a much less robust plant than eelgrass with average peak seasonal biomass of 100 gdm m^{-2} in this region compared to 250 gdm m^{-2} for eelgrass. Individual shoots are characterized by straight threadlike leaves 3 to 10 cm long and 0.5 mm or less wide (Figure 5). It has an extensive root system of branched, creeping rhizomes that produce vertical shoots with leaves. Widgeon grass has a higher temperature photosynthetic capacity compared to eelgrass (Evans *et al.,* 1986) and in the York River it reaches maximum abundance in mid-summer. At this time it can develop into a tall highly branched form with flowering shoots that extend to the water surface. Pollen released from the stamens floats on the water until it contacts the extended pistils. The fertilized flowers produce individual oval-shaped fruits with pointed tips enclosed in hard seed coats. The seeds may remain viable in the sediment for long periods. Like eelgrass it is a valuable food resource for water fowl (Schulthorpe, 1967; Martin and Uhler, 1951), however it can be more easily uprooted by storms and in the winter has much lower biomass. It is a rapid spreader and in recent years it has spread into many areas in the mid-bay where eelgrass has died off (Orth *et al.,* 2006). In beds mixed with eelgrass it will initially spread more rapidly than eelgrass into scars caused by boat propellers and other damaged areas. However it can eventually be replaced with eelgrass if that eelgrass is the more dominant for that bed. In the York River widgeon grass is only found mixed with eelgrass in the lower, polyhaline region of the estuary. In the Chesapeake Bay widgeon grass is usually the most abundant throughout the oligohaline and mesohaline regions of system (Moore *et al.,* 2000).

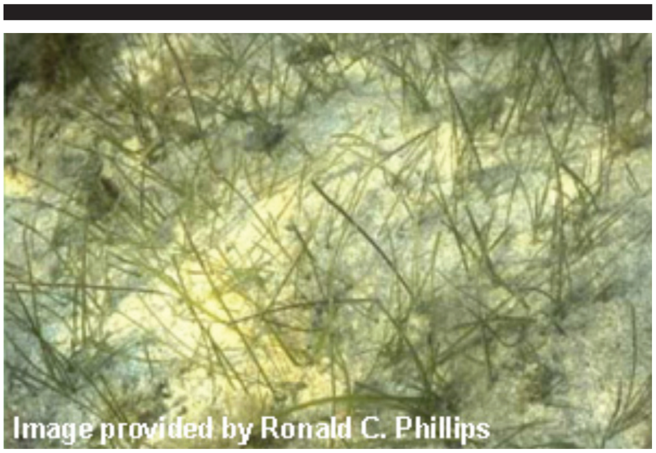

Figure 5. Widgeon Grass *(Ruppia maritima)*

PONDWEED COMMUNITY

The pondweed community is dominated by several species of the Potamogeton including: *Potamogeton pectinatus* (sago pondweed) and *Potamogton perfoliatus* (redhead grass). Both species have some tolerance for salinity and are most abundant in the Bay at salinities of less than 10 psu (Stevenson and Confer, 1978). Typically, this community reaches greatest abundance in mid-late summer and on average has been found to have a peak biomass of 100 gdm m^2, although individual beds may reach much higher levels.

Redhead grass (Figure 6) is characterized by extensive, branching shoots with alternate, ovate, leaves that curl slightly. It can exhibit extensive morphological variation. Stevenson and Confer (1978) indicate that the variation bupleuroides is the most common variant found in the Chesapeake Bay. It is found in both fresh and brackish waters of the bay but more typically is found where salinities are 5-10 psu (Bergstrom *et al.,* 2006). Reproduction is both asexual, through extensive shoot and root/rhizome growth and over-wintering buds, and sexual. Flowers extend above the water surface and pollen is carried by air. Seeds are produced in clusters at shoot tips.

Sago pondweed can form elongated stems up to several meters in length with fanlike clusters of filiform leaf blades extending to the water's surface. It reproduces both through vegetative and sexual processes. Sago pondweed grows through vegetative spread of shoots and roots. It also produces over-wintering tubers as well as specialized turions or winter buds (Sculthorpe, 1967). Pollination, fertilization and fruit development occur at the water/air interface (Yeo, 1965). Seeds form in clusters at the tips of the stems. Sago pondweed can be a prolific spreader and rapid colonizer through both extensive seed and tuber production (Stevenson and Confer, 1978). Although abundant in oligohaline regions of the Chesapeake Bay, sago pondweed has only been occasionally

Figure 6. Redhead Grass *(Potamogeton perfoliatus)*

observed in the York River where it grows in small beds at the heads of small tributaries of the York. While not recorded in Taskinas Creek, the low salinity region at the upper limits of tidal influence in that tributary would be a potential site for sago occurrence. Like most of the SAV species discussed here, sago pondweed can be an important component of the diet of waterfowl and habitat for fish and invertebrates (Stevenson and Confer, 1978).

FRESHWATER MIXED COMMUNITY

Moore *et al.* (2000) have identified 12 species that have been observed in 10% or more of the samples of freshwater mixed SAV beds throughout the bay during the period of 1986 to 1996 (Table 1). While most of these species reach greatest abundance in areas with very low or no salinity, nearly all have some amount of salinity tolerance up to and exceeding 5 psu (Stevenson and Confer, 1978; Bergstrom *et al.*, 2006). Because of the tidal and climatic variations in the Bay, many areas with the freshwater mixed SAV community experience some level of salinity over time. The individual salinity tolerances of each species may, therefore, affect their composition in a bed over periods varying seasonally to annually. The three species described below have been found to dominate freshwater SAV beds throughout the bay, although individual small systems or beds may be dominated by a number of the other species found in this community type.

Wild celery *(Vallisneria americana)* is a valuable and important species that, unlike many of the canopy forming species characteristic of freshwater SAV in the Bay, grows long, strap-like leaves up to 2m in length, from basal clusters (Figure 7). Vegetative propagation of leaf clusters occurs through growth of stolons, while in the spring regrowth is from over-wintering buds. Sexual reproduction occurs as pistillate flowers are fertilized at the water surface with pollen from free-floating staminate flowers that break away from the plant base at anthesis (Sculthorpe, 1967). Wild celery is most abundant in the upper Chesapeake Bay, including the Susquehanna Flats, and its major tributaries such as the Potomac River (Orth *et al.*, 2006). In the York, beds have been observed in the Mattaponi River, but it may occur elsewhere in small beds, especially in freshwater regions of many small tributaries of the York.

Figure 7. Freshwater mixed SAV bed with wild celery and water milfoil.

Hydrilla verticillata (Figure 8) was first introduced into the US in the 1960s and since then has been found growing across the southeastern states to California (Bergstrom *et al.*, 2006). It was first found in the Potomac River in 1982 and since then has been observed throughout the upper Chesapeake Bay. Currently, in the York River system, it is abundant in oligohaline and freshwater areas in the Pamunkey and Mattaponi Rivers (Orth *et al.*, 2006). Hydrilla is a rapid colonizer, especially in shallow and protected water. It can reproduce through a variety of mechanisms including sexual reproduction where pollination occurs at the water surface. Asexual reproduction occurs from vegetative growth and fragmentation as well as the production of rootstock, tubers and turions (Bergstrom *et al.*, 2006).

Eurasian watermilfoil (*Myriophyllum spicatum*; Figure 7) has been a dominant species in the bay since the 1950s having been first introduced to the US from Europe in the late 1800s (Stennis *et al.*, 1962). It has undergone periods of explosive growth followed by declines, both in the Chesapeake Bay and elsewhere (Stevenson and Confer, 1978). Today it is a persistent component of many freshwater SAV beds, especially in the Potomac River and upper bay where it grows in protected waters (Moore *et al.*, 2000). It has not been observed in the York River system as yet. It can reproduce through flowering and seed formation, fragmentation, rhizome growth and bud formation (Patten, 1955, 1956). Biomass can be high, especially in regions of nutrient enrichment. Although an introduced species that has been subject to extensive weed control actions, especially in ponds and reservoirs, it is an important component of the diet of many species of waterfowl (Stevenson and Confer, 1978).

MACROALGAE

Macroalgae or "seaweeds" are currently a minor component of SAV in the York River system. Macroalgae are non-vascular plants lacking the more highly developed structures

Figure 8. *Hydrilla verticillata*.

including flowers, roots, and transport systems found in aquatic angiosperms. Their initial evolution and development is thought to have preceded the aquatic angiosperms and seagrasses by hundreds of millions of years (Waycott *et al.*, 2004; Simpson, 2006). In many coastal systems undergoing anthropogenic eutrophication macroalgae may outcompete and displace seagrasses (Valiela *et al.*, 1997). There are several species that can be locally abundant, and given the declines of seagrasses in the higher salinity regions of the system, they may be providing some local habitat value for organisms such as the blue crab (R. Lipcius, VIMS, per. comm.).

There are few quantitative studies of seaweeds in the Chesapeake Bay (Ott, 1972; Orris, 1980). Humm (1979) provides the most comprehensive published review of macroalgae in Virginia waters. His summary indicates that many of the algae found in the bay include species of cold-water affinity that range from Cape Cod to North Carolina, and warm-water species that range from the Caribbean Seas northward to Cape Cod. Most species found here are of the cold-water affinity group, with many warm water species carried up into the bay from southern areas by ocean currents during the summer (Humm, 1979).

Several groups of seaweeds that are common in the bay include the red algae *Agardhiella* spp. (Agardh's Red Weed; Family Champiaceae) and Gracilaria spp. (False Agardhiella; Family: Solieriaceae). Both groups are very similar in appearance with a highly branched structure. *Agardhiella*; (Figure 9) is usually distinguished from *Gracilaria* by the lack of tapering branch bases. Both occur here as freely floating forms in large clumps and may accumulate in large abundances in sheltered, shallow water areas. They can be found in varying abundances within eelgrass and widgeon grass beds either freely floating or attached to shell throughout the beds. There are also numerous other red algae found in the lower bay and lower York River during the summer (Humm, 1979) many are epiphytic on eelgrass and widgeon grass plants.

Several green algae which are abundant in the York River include *Ulva* spp. (Sea Lettuce; Family: Ulvaceae; Figure 10) and *Enteromorpha* spp. (Family: Ulvaceae; Figure 11). *Ulva* forms flat sheets resembling wilted lettuce that grows both free-floating and attached to shell, pilings and other structures. It can be found in salinities as low as 5 psu and can be especially abundant in areas of high nutrient enrichment. It has been found to accumulate in large abundances in eelgrass beds where it can both greatly reduce the light necessary for photosynthesis and smother the eelgrass (Brush and Nixon, 2003). *Enteromorpha* typically has thin, tubular fronds that are usually found throughout mesohaline and polyhaline areas attached to many structures including pilings, shells, invertebrate tubes, and even other SAV. Humm (1979) reports 11 species of *Enteromorpha* in Virginia waters with some forms resembling *Ulva*. Like *Ulva* it can reach dense abundances under conditions of high light and high nutrient availability, and has been observed to impact eelgrass in some areas of the world (den Hartog, 1994).

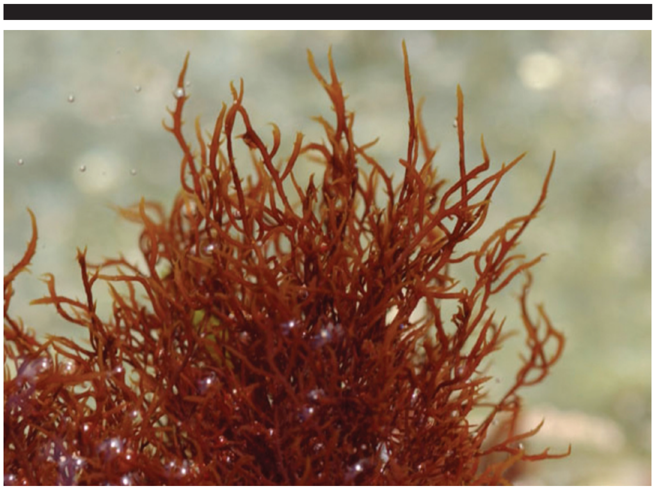

Figure 9. *Agardhiella* spp.

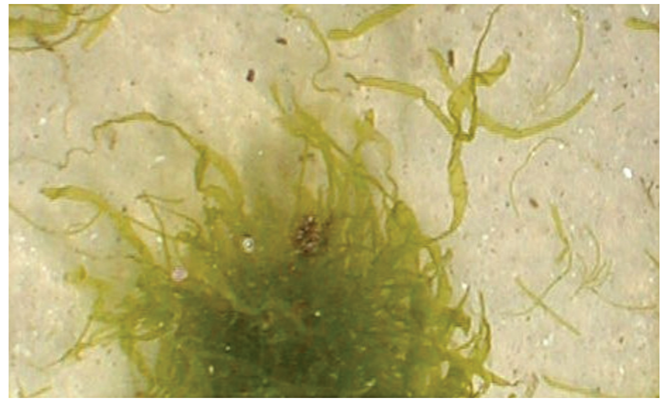

Figure 10. *Ulva* spp.

In freshwater tidal regions of the York system, numerous filamentous green macroalgae occur. Under conditions of nutrient enrichment there is the potential for many to reach nuisance levels. Two common genera include *Spirogyra* and *Cladophora*.

Two common freshwater algae that resemble rooted SAV are *Chara* spp. (Muskgrass; Family Characeae; Figure 12) and *Nitella* spp. (Brittle Grass; Family Characeae). Both types are composed of whorls of leaf-like branches surround-

Figure 11. *Enteromorpha* spp.

Figure 12. *Chara* spp.

ing a central stem-like axis. They anchor to the sediment by root-like organs and can form large dense canopies extending to the water surface. Both can propagate through spores or fragmentation. They can be important food for ducks and their canopies can provide structure for fish similar to other SAV. Like many algae they can become prolific growers under high nutrient loads and can outcompete rooted SAV for shallow water habitat. Unlike other freshwater SAV they do not form significant overwintering structures and therefore are less valuable for migrating waterfowl in the winter in this region.

RESTORATION OF SAV

Because of the importance of SAV to the bay ecosystem and the widespread and extensive declines that been observed since the 1970s, restoration of SAV has been an important component of Chesapeake Bay management for nearly 30 years (Batiuk *et al.*, 1992). And, due to the direct links between SAV and water quality there has been a focus on restoring water quality to levels (Table 2) below which SAV are present (Kemp *et al.*, 2004) to enhance natural restoration.

To assist in this recovery, replanting efforts using both vegetative material and seeds have been undertaken. Eelgrass restoration has been studied using a variety of techniques in both Maryland and Virginia for a number of years (Orth *et al.*, 2006). Currently efforts are focusing on the use of seeds, harvested from wild beds, to develop founder beds in areas where water quality may be suitable for SAV regrowth. Seeds are harvested in the late spring, held throughout the summer under ambient temperature and salinity conditions in shaded tanks, and dispersed in the fall just prior to natural seed germination. Restoration of freshwater SAV species has utilized a variety of techniques including tissue culture, shoot transplanting, and seed broadcasting (Moore and Jarvis, 2007; Ailstock and Shafer, 2006 a, b). In both Maryland and Virginia there are currently a number of programs where freshwater SAV are grown from seeds in classrooms (Figure 13) and then transplanted into the natural environment. Restoration results have demonstrated that SAV can be transplanted successfully in many areas; however, in some currently unvegetated areas herbivory of seedlings have limited restoration success (Moore and Jarvis, 2007).

RESEARCH PRIORITIES AND MONITORING NEEDS

While there has been a great deal learned through research and monitoring relative to SAV communities in the Chesapeake Bay, in general, and the York River, in particular, more efforts are needed to advance SAV protection and restoration to achieve the SAV restoration goal. As diversity has long been recognized as important to a healthy ecosystem, more research is necessary to quantify the role of plant community diversity in restored and natural SAV bed persistence. Some unanswered questions include: What is the role, value and utility of colonizer species in natural and restored SAV bed succession? What is the role of non-native species in native SAV restoration, recovery, or decline? How are SAV community stability, succession and change related to environmental conditions? In addition, more information is needed to quantify relationships among patterns of abundance at the landscape-scale (bed size, etc.) and SAV growth, survival, and persistence. We are now just beginning to be able to investigate the relationships between environmental conditions and SAV response on high frequency temporal and spatial scales. One important need is to quantify the short and long term relationships between SAV decline and recovery and climatic factors such as storms (including physical stresses), droughts, temperature extremes, etc. We also must quantify the role of flowering success, seeds, seed banks and other propagules on SAV bed persistence, natural recovery and restoration if we are to fully understand

Table 2. Chesapeake Bay water clarity habitat thresholds for SAV occurrence in different salinity zones. K_d-Light Attenuation, TSS-Total Suspended Solids, Chl-Plankton Chlorophyll a, DIN-Dissolved Inorganic Nitrogen, Dissolved Inorganic Phosphorus, PLW-Percent Light Through the Water to the SAV Plant, PLL-Percent Light to the SAV Leaf

Salinity Zone	K_d (m^{-1})	TSS (mg l^{-1})	Chl (μg l^{-1})	DIN (mg l^{-1})	DIP (mg l^{-1})	PLW (%)	PLL (%)
Tidal Fresh (<0.5 psu)	<2	<15	<15	--	<0.02	>13	>9
Oligohaline (0.5-5 psu)	<2	<15	<15	--	<0.02	>13	>9
Mesohaline (5-18 psu)	<2	<15	<15	<0.15	<0.02	>22	>15
Polyhaline (>18 psu)	<2	<15	<15	<0.15	<0.02	>22	>15

the potential for natural recovery of areas that have improved habitat quality. Other areas for research focus include investigations of the relationships between natural and restored SAV growth, survival and bed persistence and biological stresses including herbivory or secondary physical disturbance through foraging, bioturbation or other activities. And finally given the complex nature of the estuarine system we must investigate the interactive effects of various stresses on SAV habitat requirements (eg. light availability and salinity).


Figure 13. Wild celery seedlings being grown by students in a classroom. (Photo courtesy Chesapeake Bay Foundation)

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