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Restoration of Submerged Aquatic Vegetation (SAV) in the Tidal Freshwater James River: 1999 Pilot Study

Kenneth A. Moore  
Virginia Institute of Marine Science

Robert Orth  
Virginia Institute of Marine Science

James Fishman  
Virginia Institute of Marine Science

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RESTORATION OF SUBMERGED AQUATIC VEGETATION (SAV)
IN THE TIDAL FRESHWATER JAMES RIVER:
1999 PILOT STUDY

Dr. Kenneth A. Moore, Dr. Robert Orth,
Mr. James Fishman

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The Virginia Institute of Marine Science
School of Marine Science, College of William and Mary
Gloucester Point, Virginia 23062

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EXECUTIVE SUMMARY

Native species of submerged aquatic vegetation (SAV) including wild celery (*Vallisneria americana*), which were supplied by the Chesapeake Bay Foundation (CBF), and sago pondweed (*Potamogeton pectinatus*), which were harvested from native stocks, were transplanted in May, 1999, to four, shallow water (0.3 m MLW) sites in the Hopewell estuary region of the James River by the Virginia Institute of Marine Science (VIMS). The SAV transplants were sampled for survivorship and growth at bi-weekly intervals and, concurrently, water quality sampling was conducted at bi-weekly intervals by the Hopewell Regional Wastewater Treatment Facility for nutrients, chlorophyll a, suspended solids, water transparency and other chemical and physical constituents. Objectives of the study were to: develop and evaluate effective techniques for transplantation in this region; determine the success of the transplantation effort; and evaluate the response of the transplants relative to habitat conditions at the sites as well as various model predictions of habitat suitability.

Results demonstrated that wild celery could be successfully transplanted into this region at these shallow water depths by a simple technique using unanchored, bare-rooted planting units consisting of single shoots with attached roots and rhizomes. This marks the first time SAV has been successfully transplanted into this region since declines were observed in the 1940’s. At three of the four sites the SAV grew throughout the 1999 growing season and at two sites the SAV re-sprouted in the spring of 2000. One site had to be removed due to dredge spoil placement in the cove and one site demonstrated no re-growth in 2000 due to physical disruption. The sago pondweed transplants grew and produced new shoot material, but the all shoots were eventually
broken off by wave and current action by the end of the summer. There was significant initial herbivory of the SAV transplants by fish, turtles or other animals, which was effectively stopped by encirclement of the plots by 1-inch, wire mesh fencing.

Habitat conditions were characterized by high levels of suspended sediments (>50 mg/L) during the spring at most sites and phytoplankton levels (>50 µg/L) during the summer, which typically exceeded 25% of the suspended particle loads during that time. Transparency, measured as secchi depth, was lowest during the summer when levels were typically at 0.3 m. Chesapeake Bay Program habitat model predictions confirmed that conditions in the region are poor for SAV growth to depths of one meter or greater due principally to high turbidity, however, growth at depths of less than 0.5 m are projected. Model estimates of periphyton loading on the SAV overestimate the actual loadings that were measured using artificial substrates by ten-fold. The use of seasonal medians in the models' analyses typically underestimated seasonal extremes in water quality constituents such as chlorophyll by several-fold. These high levels may be seasonally important.

SAV transplanting in this region should be repeated under multiple years of varying climatic circumstances. Future studies should investigate the effects of substrate type, herbivory as well as studies of habitat effects on other SAV species. Lack of current SAV re-colonization in the very shallow water areas of this region may be related to physical and biological factors not directly related to the water quality constraints of deeper water sites.
1.0 INTRODUCTION

Analyses of historical aerial photographs and ground survey reports for submerged aquatic vegetation (SAV) in the James River have revealed evidence that some areas of the James River near the City of Hopewell may have supported SAV growth until the mid-1940’s (Moore et al. 1999). Currently, SAV is found only in some tributary creeks in the vicinity of the Chickahominy River. The current lack of growth of SAV in many shallow areas of the tidal, freshwater James River may be related to a number of factors including: poor habitat quality due to high turbidity caused by suspended sediments and phytoplankton, fouling of SAV leaf surfaces, poor sediment characteristics (high organic content), or physical limitation due to biological or physical disturbance. Although many freshwater SAV species can be transported by a variety of mechanisms such as seed dispersal by water fowl or rafting of shoots by tidal currents, limited propagule supply or survival may be contributing to the lack of regrowth in this region. One way to assess these various hypotheses is to use experimental SAV transplants to test the current suitability of the areas for SAV growth and then evaluate the various factors that may impact their survival. Using SAV plants directly can provide an integrated measure of habitat suitability that cannot be determined solely by discreet monitoring of physical and chemical habitat conditions.

Previous studies, beginning in 1996, conducted for the Hopewell Regional Wastewater Treatment Facility (HRWTF) as part of the Hopewell Estuary Region Monitoring Assessment (HERMA) project consisted of an initial screening assessment of existing water quality and biological monitoring data as well as modeling results for the Hopewell estuary region. This was followed in 1998 by an ambient water quality
monitoring study at a series of stations in this region. This study was designed to gain a greater understanding of the status and controls on water quality in both the region directly impacted by the combined Gravelly Run discharge, and in the James River region near Hopewell outside of the mixing zone (Malcolm Pirnie, Inc. 1999). Results indicated that light conditions in the Hopewell estuary region are generally poor for SAV growth and do not meet habitat criteria for restoration of SAV growth to a depth of one meter. Water column light attenuation by suspended sediments and phytoplankton was also found to be higher in near-shore stations than in mid-channel stations, possibly due to tidal and wind re-suspension of sediments. However, target concentrations for attainment of SAV habitat criteria to depths of 0.5 m or less were met, suggesting that SAV growth at these depths may be possible. A SAV restoration study would be necessary to determine if SAV could actually grow in this area.

1.1 Objectives

The objectives of this first year SAV restoration study, funded by the Hopewell Regional Wastewater Treatment Facility (HRWTF) and assisted by the Chesapeake Bay Foundation (CBF), were to:

1) Develop and evaluate techniques for effective transplantation of native SAV species to this region of the estuary.

2) Determine, if under current conditions, SAV transplants could survive in selected sites in the Hopewell Region of the James River estuary.

3) Evaluate the response of transplants relative to specific water quality conditions at the sites (monitored by HRWTF), site characteristics, or physical disturbance, as well as various model predictions of habitat suitability.
2.0 METHODS

2.1 Study Sites

Four sites were selected for test transplanting in the Hopewell region of the James River estuary. Site selection was based upon review of a number of factors including: water depth (<0.5m), site orientation and location (low erosion shoreline), sediment type (<5% organic content), photographic evidence of historical SAV occurrence, and background review of general water quality conditions in the area. Based upon this review and a field survey of the area four sites were selected along the littoral zone of the river for the transplanting efforts (Fig. 2-1).

- Turkey Island - Lat. 37.3826 N - Long. 77.2527 W
- Shirley Cove - Lat. 37.3326 N - Long. 77.2631 W
- Tar Bay Island - Lat. 37.3075 N - Long. 77.1902 W
- Powell’s Creek - Lat. 37.2979 N - Long. 77.1622 W

2.2 Preliminary Transplantings

On May 1, 1999, an initial pilot transplanting was undertaken at the Shirley Cove site. Whole plants of *Vallisneria americana* (wild celery; Fig. 2-2) were supplied by the Chesapeake Bay Foundation (CBF). With the help of CBF personnel and citizen volunteers, approximately 600 plants, ranging from 5 to 10 cm in height were cleaned of sediments, then planted by a Virginia Institute of Marine Science (VIMS) scientific diver in 6 replicate (2m x 2m) arrays of 100 planting units spaced at 0.12 m intervals. Planting units consisted of single, bare-rooted shoots that were placed directly in the sediment to a depth of approximately 5 cm using no anchoring device (cf. Orth et al. 1999). Water
depths varied between approximately 0.1 and 1.0 m below MLW. Each replicate plot was delineated with white PVC poles.

On May 17, 1999, the transplanted arrays were checked for survival. Plot survival ranged from 0-25% with survivors showing evidence of shoot cropping by unknown herbivores such as fish, turtles, or waterfowl. Surviving shoots were only 3-5 cm in length with jagged, cut off leaf tips. In addition, most of the PVC poles which extended above water had been moved and replaced further channelward by unknown individuals. There was also evidence that the bottom within the plots had been disturbed, possibly by burrowing or browsing activities.

2.3 Multi-site Transplantings: Plant Establishment and Site Monitoring

2.3.1 SAV Transplant Establishment

On June 1-2, 1999, replicate 2m x 2m plots of *V. americana* and *Potamogeton pectinatus* (sago pondweed; Fig. 2-2) planting units were planted on 0.25 m intervals at each of the four transplant sites by VIMS with assistance from CBF and HRWTF personnel. Water depths at the planting sites were estimated to be between 25-50 cm below MLW. The wild celery plants were supplied by CBF, while the sago pondweed plants were obtained by VIMS personnel from native populations in the Poropotank River, VA. Each set of transplant plots was protected from disturbance by use of exclosures consisting of staked, wire fencing of 1-inch mesh, which extended from the sediment surface to above high water. Each site was sampled by divers for SAV planting unit survival, SAV relative abundance and plant vigor monitored at semi-monthly to monthly intervals throughout the 1999 growing season and again in the spring of 2000. In July the transplants at the Shirley Cove site had to be removed and replanted at the
Turkey Island site due to dredge spoil deposition at the site by the US Army Corps of Engineers.

2.3.2 Periphyton Monitoring

Rates of periphyton accumulation (ie. combined algae growth and sediment loading on the plants) were monitored by use of artificial substrates (Neckles 1990). Although the use of artificial substrates precludes any potential biological or chemical influences of the SAV on periphyton composition or mass, the benefits of standardization and replication have made this technique valuable for relative site comparisons of fouling (Robinson 1983). Artificial plants consisted of two 50 cm long strips of 5 mm wide polypropylene ribbon attached to a 0.25 m² square made of iron bars criss-crossed with lines at 10 cm intervals to form a base. Replicate squares of the artificial substrates were placed within each exclosure at each site. Two sets of artificial leaves were sampled from each square at semi-monthly to monthly intervals by clipping the strips at their base, and placing the entire strip in a zip-lock bag. The bags with the artificial leaves were transported to the lab where they were frozen. At a later date the samples were thawed, the fouling community gently scraped off the substrate into freshwater using the edge of a glass slide, collected by filtration, dried at 50 °C and weighed.

2.3.3 Sediment Characterization

Sediments at each transplant site was characterized by use of replicate cores taken at each of two locations (shallow side and deepest side) within each exclosure. The six-inch deep cores were mixed to provide a homogeneous sample, dried at 50 °C to a constant weight, weighed for dry weight, ashed for 5 hours at 550 °C and weighed again. Organic content was determined by weight difference.
2.3.4 Water Quality Monitoring

Water quality sampling was conducted at bi-weekly intervals by personnel of HRWTF. Water samples were typically collected at depths of 0.5 to 1.0 m in the shallow littoral area immediately adjacent to the transplant locations. Parameters measured included air and water temperatures, secchi depth, pH, dissolved oxygen (DO), conductance, total Kjeldahl nitrogen (TKN), nitrate + nitrite (NO₃⁻), ammonium, orthophosphate (DIP), total phosphorus (TP), total suspended solids (TSS), total organic carbon (TOC), and chlorophyll a (Chl a).

3.0 RESULTS

3.1 Transplant Survival

3.1.1 Wild Celery Survival

Survival of the wild celery transplants is summarized in Figure 3-1. Survival of the planting units at each of the planting sites was first determined on June 18, 1999. In contrast to the loss of plants observed in the unprotected preliminary plantings at the Shirley Cove site in May, initial survival at three of the four protected sites ranged from 50% to 100%. The Powell's Creek site had the lowest initial survival with survival rates averaging 60%. The other three sites demonstrated 100% survival for over one month. Qualitative observations indicated that within several weeks there was new vegetative growth, suggesting that the plants were beginning to become established at this time. By six weeks (July 16) the leaves had grown to a length of approximately one meter and new shoot clusters were observed. The successful results of the protected transplants, in comparison to the apparent herbivorous cropping and lack of survival of the earlier unprotected transplants suggests that, at least initially, wild celery transplant survival in this region may be limited by grazing or disturbance activities of fish, turtles, or other
animals. These confounding sources of impact have also been observed during transplanting efforts in other freshwater tidal regions of the Chesapeake Bay system, including the Potomac River and upper bay in Maryland (Carter and Rybicki 1985).

Although, in general, the wild celery plants were observed to be growing throughout the summer there was an apparent loss of planting units at the Turkey Island and Tar Bay sites. However, because of poor water clarity and nature of the soft sediment, which was easily stirred up by walking, it was possible that the survival rates at these sites were underestimated. Transplants at the Shirley Cove site were removed and replanted at the Turkey Island site in mid-July, just prior to the deposition of dredge spoil in the cove. The planting units at the Shirley Cove site which were removed and replanted at Turkey Island on July 16 were found to quite healthy, with many having produced three or more new leaf clusters. By August all three of the remaining sites demonstrated 60% to 80% survival rates. Declines in the survivorship at all of the sites between August and the end of September were likely related to the normal end-of-season die-back of shoot material and the resultant storage of the plant resources as below-ground tubers and over-wintering buds.

3.1.2 Sago Pondweed Survival

In contrast to the long-term growth and survival of the wild celery transplants, the sago pondweed planting units, while demonstrating general expansion and elongation of shoot material, gradually disappeared throughout the summer (Fig. 3-2). Few new shoots were produced during this time. This may have been related to the type of planting material, which consisted of transplants of shoots that were harvested from a natural stock in the Poropotank River in Virginia. A lack of apical meristems in the rootstock of
the source material may have contributed to poor new shoot production. Loss of planting units appeared more related to physical breakage or dislodgment of the shoots due to currents or wave action than dieback of the plants themselves. The canopy-type growth of this species may have contributed to this dislodgment as the individual plants consisted of a dense, canopy of leaves at the distal end of a long, thin stem which measured a meter or more in length. A number of broken shoots were observed throughout the summer as they were caught on the inside of the wire fencing.

3.2 Habitat Monitoring

3.2.1 Sediments

Sediments at the transplant sites (Fig. 3-3) were within the general range of organic content that will support SAV growth. Typically, the range of suitable sediments is between 0.5 and 5% organic content, although SAV have been observed to grow successfully in higher organic substrates (Barko and Smart 1983). Tar Bay was situated between two islands and tidal currents and wave action likely maintained the low organic conditions there. At the Turkey Island and Shirley Cove sites there were marked increases in sediment organic content with water depth. A large sand bar that was an apparent relic of previous dredge disposal operations characterized the shallowest area of the Shirley Cove transplant site. Organic content rapidly increased with water depth here. The Turkey Island site was adjacent to an eroding bank that was the likely source of sand in the shallowest depths where the organic content was lowest. The Powell’s Creek site, which was situated along a reach of sandy shoreline, demonstrated less variability in substrate type within the planting area. Just offshore of the transplant plots the sediments were qualitatively much more organic rich. All of the sites, however, were chosen so as
to minimize the organic content of the sediments compared to surrounding areas which
were primarily composed of soft muds.

3.2.2 Artificial Substrate Fouling

Periphyton mass accumulations on the artificial substrates (Fig. 3-4) remained
consistent after placement at the sites in mid-July. Accumulations were minimal until the
day of October when strips at both the Powell’s Creek and Tar Bay sites showed high
levels of periphyton mass. However, the strips at both of these sites appeared to have lost
some buoyancy by the end of October when they were found to not be floating vertically
in the water. This increased mass may have been from bottom sediments that had
become attached to the strips. In contrast, strips at the Turkey Island site that remained
buoyant showed little change throughout the growing season.

3.2.3 Water Quality

Approximately one year of water quality data are summarized in this report. In
general there are few consistently large differences between sites. Water temperatures
(Fig. 3-5) demonstrated strong seasonal patterns, with lows in mid-February of 7-8 °C
and highs in late July of 30-34 °C. Conductivity increased throughout the summer (Fig.
3-6) achieving a maximum at all sites in mid-September just prior to the passage of a
Tropical Storm Floyd. Highest values were observed in the most downstream station
(Powell’s Creek) where peak conductance levels of 900 µmhos equated to a salinity of
approximately 0.3 PSU, or less than 1% that of seawater. These salinities are well within
the range of tolerance for both transplanted SAV species. DO concentrations
demonstrated bi-modal annual patterns (Fig. 3-7) and lowest values were recorded in the
spring to early summer period as well as in the fall. Daytime values reported for the
shallow water transplant sites did not typically fall below 5 mg/l. pH levels (Fig. 3-8) were relatively consistent throughout the year, although lowest levels coincided with periods of minimum DO in June and September.

Suspended particle loads (TSS) were typically highest in the spring and decreased to lowest levels in October (Fig. 3-9). In contrast to other measured water quality parameters no apparent effect of Tropical Storm Floyd on TSS levels were observed at any of the sites. TSS levels were consistently lowest within the embayment of the Shirley Cove site, especially during the spring, with little annual variability observed at this location compared to the other transplant locations. TSS consistently exceeded the habitat requirement of 15 mg/l established by the Chesapeake Bay Program (Batiuk et al. 1992) for SAV restoration to one-meter depth at all sites (Table 3-1). Phytoplankton, measured as Chl a, demonstrated consistently high levels during the summer as well as a second smaller peak during the winter (Fig. 3-10). These peaks greatly exceeded the SAV habitat requirement of 15 µg/l for freshwater regions. However, seasonal medians for all the sites were below the habitat requirement (Table 3-1). This was due, in part, to the low phytoplankton abundance during the spring and early summer when non-phytoplankton derived suspended particles in the water column were high. There were no marked differences among the sites. Phytoplankton comprised a relatively large proportion of the total suspended particle concentrations (Fig. 3-11) during August and again during several peaks in December and February. Water transparency measured as secchi depth (Fig. 3-12) showed a seasonal decline to minimum levels of 0.3 m or less in August and September. Light transparencies reported as median seasonal light
attenuation ($K_d$) or secchi depth (Table 3-1) did not meet the habitat criteria for SAV growth to one meter at any of the sites.

**TABLE 3-1**

1999 JAMES RIVER TRANSPLANT SITE WATER QUALITY AND HABITAT CRITERIA FOR RESTORATION OF SAV TO A DEPTH OF ONE METER

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SAV Growing Season Medians (April-October)</th>
<th>1999 Transplant Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SAV Habitat Criteria</td>
<td>Powell's Creek</td>
</tr>
<tr>
<td>Light Attenuation ($K_d$, m$^{-1}$)</td>
<td>&lt;2</td>
<td>4.0</td>
</tr>
<tr>
<td>Secchi Depth (m)</td>
<td>&gt;0.7</td>
<td>0.30</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>&lt;15</td>
<td>38</td>
</tr>
<tr>
<td>Chl a (µg/L)</td>
<td>&lt;15</td>
<td>12.6</td>
</tr>
<tr>
<td>DIP (mg/L)</td>
<td>&lt;0.02</td>
<td>0.01</td>
</tr>
</tbody>
</table>

TOC, TKN and TP were characterized by somewhat different patterns of abundance. Nitrogen levels (Fig. 3-13) were variable among the sites and generally decreased to below detection limits (0.5 mg/l) during the fall. Total organic carbon concentrations (Fig. 3-14) increased throughout the summer and reached a peak after the passage of Tropical Storm Floyd in late September. Total phosphorus concentrations (Fig. 3-15) were relatively consistent throughout the year at all sites, although a slight downward trend throughout the year paralleled that of total TSS and TKN.

Dissolved inorganic nutrients (nitrogen and phosphorus), that are readily available for uptake by phytoplankton and epiphytic algae, demonstrated relatively high levels for nitrogen and low levels for phosphorus. DIP concentrations typically met the SAV habitat requirement threshold of 0.02 mg/l for the tidal fresh salinity regime at all sites for most of the year (Fig. 3-16; Table 3-1). Dissolved inorganic nitrogen (DIN) habitat requirements have not been established for freshwater tidal areas as with phosphorus.
Phosphorus is typically considered the limiting nutrient for algae growth in these areas, whereas nitrogen can be quite high in many areas of freshwater SAV growth. In low salinity regions, however, SAV growth to one-meter depths has been found to be associated with DIN concentrations of 0.15 mg/l or lower. In this study ammonium, which is one component of DIN (ammonium + nitrate + nitrite), was nearly always at or below the detection limit of 0.2 mg/l (data not shown). NOx concentrations (Fig. 3-17) were typically highest in the fall and winter and lowest during July and August.

3.2.4 Attainment of Conditions Suitable for SAV Growth

Using a "Diagnostic Tool" developed by Dr. Charles Gallegos of the Smithsonian Environmental Research Center for the Chesapeake Bay Program SAV Technical Synthesis II Workgroup, TSS and Chl a data collected during the SAV growing season can be evaluated to predict if SAV growth may be possible at specific target depths. This modeling tool also estimates the median TSS and Chl a concentrations that would be necessary for attainment of habitat criteria at those depths. The target concentrations correspond to the scenarios of reductions in both TSS and Chl a (by projection to origin method), reducing only Chl a, or reducing only TSS. Evaluations of the 1999 growing season water quality monitoring data for each of the transplant sites are presented in Table 3-2. Median growing season conditions at all of the transplant sites are estimated to meet the habitat criteria (ie. 13% light available through the water column) at water depths of 0.5 m or less. Combined reductions in TSS and Chl a or TSS only to the specified levels would be required for attainment of one-meter or two-meter habitat criteria. These projected reductions would have to be quite significant. For example at Powell's Creek growing season median TSS and Chl a levels of 38 mg/L and 12.6 µg/L
respectively (Table 3-1) would have to be reduced to 17.2 mg/L and 6.2 μg/L (TSS and Chlorophyll Reduction) to achieve the light conditions estimated for SAV growth to one meter. For TSS reduction alone (TSS Reduction Only) a target of 16.2 mg/L would have to be met. Reductions in Chl a alone, even to zero concentration, are predicted to be insufficient for SAV growth at one and two-meter depths due to the residual turbidity from the suspended sediments.

**TABLE 3-2**

PREDICTED CONCENTRATIONS NECESSARY FOR ATTAINMENT OF SAV TO TARGET DEPTHS USING SEVERAL REDUCTION STRATEGIES

<table>
<thead>
<tr>
<th>Station</th>
<th>Target Depth (m)</th>
<th>Growing Season Median Concentration</th>
<th>TSS and Chlorophyll a Reductions</th>
<th>TSS Reduction Only</th>
<th>Chlorophyll a Reduction Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Chla (µg/L)</td>
<td>TSS (mg/L)</td>
<td>Chla (µg/L)</td>
<td>TSS (mg/L)</td>
</tr>
<tr>
<td>Powell’s Creek</td>
<td>0.5</td>
<td>Met</td>
<td>Met</td>
<td>Met</td>
<td>Met</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
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<td>7.0</td>
<td>Met</td>
<td>N/A</td>
</tr>
<tr>
<td>Tar Bay</td>
<td>0.5</td>
<td>Met</td>
<td>Met</td>
<td>Met</td>
<td>Met</td>
</tr>
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<td></td>
<td>1.0</td>
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<td>7.0</td>
<td>Met</td>
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<td>Met</td>
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<td>Met</td>
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<td>6.0</td>
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</tbody>
</table>

‘Met’ indicates that no reductions are necessary for SAV growth at that depth; ‘N/A’ indicates that a 100% reduction in that parameter would still not permit sufficient water clarity for SAV at that depth.

3.2.5 Light Availability for SAV Growth

Light availability for SAV growth was also calculated using a second empirical model developed by the Chesapeake Bay Program SAV Technical Synthesis II Work Group (Batiuk et al. In press.). This model predicts the percent of incident light available
to SAV at specified depths in the water column (PLW), as well as the residual light available for SAV photosynthesis after passage through the predicted periphyton layer on leaf surfaces (PLL). The PLW determination is a function of water column light attenuation (secchi depth or $K_d$), water depth and mean tidal range. The PLL determination is a function of PLW as well as water column TSS, DIN and DIP. Seasonal median thresholds or requirements for growth of freshwater SAV are estimated as 13% for PLW and 9% for PLL. For the data presented here it was assumed that DIN was equivalent to dissolved NO$_x$, and DIP was equivalent to orthophosphate. Transplant depth was set at 0.3 m and tidal range at 0.66 m.

Table 3-3

<table>
<thead>
<tr>
<th>Site</th>
<th>PLW (% of Surface Irradiance)</th>
<th>PLL (% of Surface Irradiance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powell's Creek</td>
<td>8.1</td>
<td>5.7</td>
</tr>
<tr>
<td>Tar Bay</td>
<td>11.8</td>
<td>6.9</td>
</tr>
<tr>
<td>Shirley Cove</td>
<td>20.1</td>
<td>15.6</td>
</tr>
<tr>
<td>Turkey Island</td>
<td>10.4</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Results of the calculations of SAV growing season median PLW and PLL for each of the transplant sites are presented in Table 3-3. According to this model sufficient light (both PLW and PLL) for SAV growth during 1999 would only be predicted for the Shirley Cove site. This is in contrast to the successful transplant results observed at all locations, suggesting under-prediction of actual light conditions at the sites by the model, lower light requirements of the SAV than estimated, and/or shallower effective water column depth at the leaf surface due to SAV canopy development.
4.0 CONCLUSIONS

4.1 Evaluation of Transplanting Techniques

The transplantation of nursery-grown, bare-rooted, unanchored shoots of wild celery into shallow water areas of the Hopewell region of the tidal James River was successful and marks the first time that SAV has been successfully transplanted into this tidal freshwater region of the James River. Transplantation in late May or early June allows sufficient time for the plants to become established, flower and produce reproductive structures prior to fall die-back. These successful results indicate that SAV transplanting in the Hopewell estuary region of the James River can be successful without damaging the remaining natural bay stocks. The production of the planting stock used here was accomplished non-destructively using field collected seeds from natural beds. The seeds were then germinated and seedlings grown under various artificial conditions, including those designed by the Chesapeake Bay Foundation for use by private citizens and schools.

The transplanting of wild stock of sago pondweed met with less success than the wild celery. This may have been due to the lack of rhizome apical meristems in the source material as well as elongated canopy development that precluded survival in the wave and current conditions of this tidal James River region. This species does occur throughout many low salinity and freshwater regions of the Chesapeake Bay (Orth et al. 1999, Moore et al. 2000). Therefore, its use in further transplanting efforts should be pursued if adequate nursery grown stock can be obtained.

Protection of the transplanted SAV material from herbivory for at least the first growing season appears necessary for adequate survival. Qualitative observations from
transplanting efforts with wild celery in the Potomac River as well as other areas in the upper Chesapeake Bay in Maryland suggest that eventually, as the stands of SAV become established and more numerous in an area, the herbivory will decrease. However, flocks of waterfowl or other animals can also cause a significant damage to even established beds.

The use of chicken wire screening to protect the beds met with mixed success. Although it proved successful in protecting the transplants, corrosion reduced its effectiveness after approximately two months. This may have affected the survival rates of the transplants at the Tar Bay and Turkey Island sites where the wire fencing became less effective over time. During the year 2000 growing season plastic mesh screening will be used. Field trials in early 2000 suggest that it will be superior to the wire and it has been used for other purposes in aquatic situations for two years or more.

4.2 Response of SAV to Habitat Conditions

Current habitat conditions at the transplant sites appear adequate for the successful growth of both wild celery and sago pondweed transplants at the depths planted. Although sago pondweed is more commonly found throughout the bay in areas of low salinity rather than freshwater it also survived, and the shoots elongated and grew until the stems broke. The wild celery was much more successful and demonstrated vigorous growth during the first growing season and there was significant regrowth during the spring of 2000 at both the Powell's Creek and Turkey Island sites. Physical and biological factors appeared important in limiting SAV survival at the shallow water transplant sites. Rapid elongation of shoots to over one-meter in length is one possible mechanism by which these plants may reduce the negative effect of light limitation from
the turbid waters. Suspended sediments are the major component of light attenuation in these shallow water sites, although phytoplankton is an important component of light attenuation during the summer. Algae, sediments, and other fouling components on the shoots of the SAV here appeared minor and there was little accumulation throughout the growing season.

Results of the evaluation of the water quality conditions in the Hopewell estuary during this study in 1999 are very similar to those of the HERMA study in 1998 (Malcom Pirnie, Inc. 1999) which concluded that there should be sufficient light for SAV growth at depths < 0.5m. That work also suggested that there was significantly greater turbidity in the shallows compared to channel, due in part to resuspension of sediments by tidal currents as well as wave action which may affect this survival. We did not evaluate this here, although given these successful results the SAV appear to be receiving sufficient light for growth at depths of less than 0.5 m. Development of established bed canopies could help to reduce this turbidity by baffling wave action and reducing resuspension.

These transplant sites were chosen to provide the best sediment substrate possible (ie. low organic content) for SAV growth. However, sediments in much of the surrounding shallow water areas are comprised of very soft mud. The survival of SAV in this substrate type is unknown. In any event, transplanting SAV by the methods used here would be very difficult in soft sediments that are easily stirred up and offer no support. There are other SAV species (*Ceratophyllum demersum, Myriophyllum demersum*) that can grow in muddy substrates, but *C. demersum*, in particular, because of its lack of root material does not withstand strong currents or wave action. During the year 2000 transplant locations will include areas with more organic-rich substrates.
4.3 Evaluation of SAV Habitat Quality Models

The concurrent measurements of water quality and SAV growth and survival at these transplant sites provided the opportunity to evaluate several different SAV habitat quality models for their effectiveness in predicting SAV growth in the Hopewell estuary region. Results of the first model (Table 3-1), which was developed as part of the CBP SAV Technical Synthesis (Batiuk et al. 1992), suggest that total suspended solids and light attenuation should be insufficient for SAV growth to one meter depth but that Chl a levels should be sufficient. While we could not evaluate that here directly, we did show that persistent growth at shallower depths even to 20 cm or less is possible and that the shallowness of growth may only be limited by exposure during extreme low tides. The use of growing season medians (<15 µg/L) greatly under-represented the high Chl a levels (>50 µg/L) observed during the summer. Since SAV have been demonstrated to respond negatively to extreme conditions over time scales of less than a single growing season, the use of median values may be an underestimate of the true environmental stress at water depths greater than those planted here.

The Gallegos' model which predicts growth at depths other than one meter using TSS and Chl a data (Table 3-2) was successful in predicting SAV transplant survival at all sites at a target depth of 0.5 m or less. Nearly a 50% reduction in seasonal median TSS levels, however, is predicted to be required for SAV growth to one meter. Given the ambient TSS levels, even complete removal of Chl a is predicted to be insufficient for SAV growth to one meter or greater. As with the previous SAV Habitat Requirements' model, the use of seasonal medians underestimates the potential impacts of the high Chl a observed here during the summer. Reductions of Chl a during this period would result in
much greater increases in available light than predicted for the growing season as a whole.

Finally, the calculations of PLW and PLL by the third model did not predict the successful growth of SAV at any of the transplant sites, except Shirley Cove, at the transplant water depth of 0.3 m MLW. As previously mentioned this may have been due to the rapid SAV canopy development and shoot elongation that diminished the effective water column over the plant leaves. Once having grown to one meter in length the leaves were very close to the water surface during low tides. It may be that adequate light can be obtained during these periods to sustain growth. The plants may also require less than the predicted 9% of incident light at the leaf surface for growth. Experimental studies of wild celery suggest that this may be so. PLL predicted by the model for the three sites ranged from 5.7 to 7.4 %, which may be adequate levels for these SAV species. Finally, the model may underestimate the actual light available to SAV at the leaf surface by overestimating light attenuation, especially through the periphyton layer. The fouling estimates made in this study indicate that in this freshwater region substrate fouling is quite low. For example periphyton typically accumulated to levels of 0.02 mgdw cm² or less throughout the growing season. In contrast model predictions of epiphyte loads using growing season medians are 1.29, 1.80, 0.90, and 1.18 mgdw cm² for the Powell’s Creek, Tar Bay, Shirley Cove and Turkey Island transplant sites, respectively.

These comparisons suggest that habitat requirement models of SAV growth are only some of the tools that should be used for general guidance, not absolute predictors, in the evaluation of suitable habitat conditions for SAV growth, especially in very shallow water conditions. In addition to water quality measures, biological and physical as well
as sediment substrate factors should also be considered. In most cases, overall habitat conditions in a region such as this may only be effectively evaluated through actual transplantation studies that are repeated under multiple years of varying climatic circumstances.

The results of this study are a promising start for continued investigations of SAV restoration in the Hopewell estuary region. Future investigations on the effects of substrate type, herbivory, as well as studies of habitat effects on other SAV species will enhance the probability of success of larger scale transplant efforts. Such information will be useful in management of the region for the enhancement of SAV re-colonization.
5.0 LITERATURE CITED


APPENDIX OF FIGURES
Figure 2-1: Location of SAV Transplant Sites
Figure 2-2

Wild Celery (*Vallisneria americana*)

Sago Pondweed (*Potamogeton pectinatus*)
Figure: 3-1: Wild Celery \textit{(Vallisneria americana)} Survival

- Turkey Island
- Shirley Cove
- Tar Bay
- Powell's Creek

Wild Celery \% Survival

- Jun 2, 99
- Jun 18, 99
- Jul 2, 99
- Jul 16, 99
- Aug 2, 99
- Aug 16, 99
- Sep 27, 99
Figure: 3-2: Sago Pondweed (*Potamogeton pectinatus*) Survival

- Turkey Island
- Shirley Cove
- Tar Bay
- Powell's Creek
Figure 3-3: Sediment Organic Content
Figure 3-4: Periphyton Dry Weight Accumulation on Artificial Substrates

Legend:
- Yellow: Powell's Creek
- Blue: Tar Bay
- Red: Turkey Island

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Aug</td>
<td>Powell's Creek</td>
</tr>
<tr>
<td>16-Aug</td>
<td>Tar Bay</td>
</tr>
<tr>
<td>27-Sep</td>
<td>Turkey Island</td>
</tr>
<tr>
<td>28-Oct</td>
<td>Powell's Creek</td>
</tr>
</tbody>
</table>
Figure 3.6: Surface Conductivity
Figure 3.7: Surface Dissolved Oxygen
Figure 3-8: Water Column pH
Figure 3-10: Phytoplankton as Chlorophyll a
Figure 3.11: Phytoplankton Component of TSS
Figure 3.13: Total Kjeldahl Nitrogen (TKN)
Figure 3.15: Total Phosphorus (TP)
Figure 3-16: Dissolved Inorganic Phosphate (DIP)
Figure 3.17: Dissolved Nitrate + Nitrite

Nitrate + Nitrite (mg/l)

- Turkey Island
- Tar Bay
- Shirley Cove
- Powell's Creek

Apr 20, 99
May 4, 99
May 18, 99
Jun 3, 99
Jun 16, 99
Jun 30, 99
Jul 20, 99
Aug 3, 99
Aug 10, 99
Sep 8, 99
Sep 23, 99
Oct 6, 99
Oct 19, 99
Nov 16, 99
Dec 15, 99
Jan 4, 2000
Feb 16, 2000
Mar 7, 2000
Mar 29, 2000