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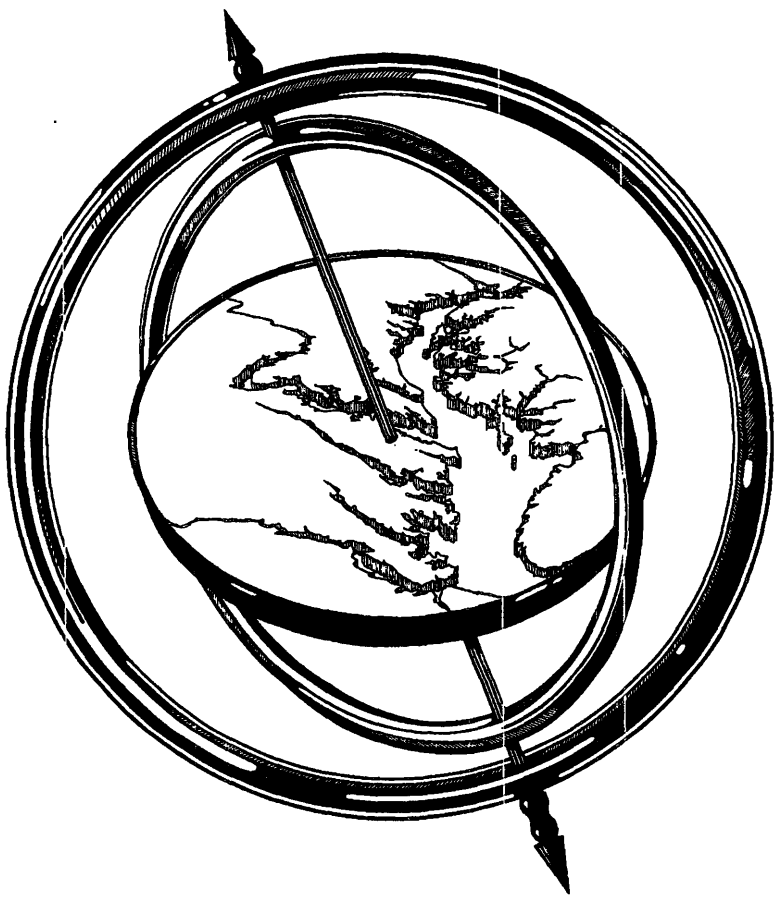

## Toward a Sustainable Coastal Watershed: The Chesapeake Experiment

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# Effects of a Polyhaline SAV Bed on Spatial and Temporal Variability in Water Quality

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***Abstract:*** Beds of submersed aquatic vegetation (SAV) may moderate or enhance the standing stocks of dissolved oxygen, nutrients, suspended particulates, and chlorophyll in water masses that are exchanged with adjacent channel areas of the Bay or its tributaries. This study investigated the short-term variability in commonly measured water column parameters at four stations located along a 1 km transect across a polyhaline SAV bed in the lower Bay. Data were collected for 10-day periods during June, August, and October 1993 at 15 min to 3 hr intervals using automated water samplers, arrays of spherical PAR quantum sensors, and Hydrolab datasondes. A similar companion study was conducted at the head of the Bay during these same periods.

Dissolved inorganic oxygen (DIN) and Dissolved inorganic phosphorus (DIP) levels were generally quite low in this polyhaline region of the Bay during most periods (< 10μM and <1 μM, respectively), however concentrations varied from 1-fold to 10-fold for DIN and 1-fold to 2-fold for DIP at intervals of hours to days. Similar short-term pulses of suspended particles and chlorophyll were also observed. Effects of the SAV meadow on the water column varied with season and the associated meadow development. During June, at maximum SAV biomass, the bed acted to moderate pulses of suspended particles and nutrients, although dissolved oxygen levels varied considerably on a diel basis as a result of the high macrophyte productivity. During August, when bed development was reduced and large amounts of detrital macrophyte production were present, the vegetated shoal appeared to be a source of DIN (especially $NH_4$), and elevated levels of total suspended solids and Chlorophyll and community respiration were evident compared to channelward stations. During October, when secondary regrowth of SAV was observed and detritus was largely gone, SAV and channel areas were most similar.

## INTRODUCTION

The decline of submersed aquatic vegetation (SAV) in tributaries of the Chesapeake Bay has been associated with light limitation resulting from changes in water quality and suspended sediment concentrations (Kemp et al. 1983, Orth and Moore 1983). Eutrophication severely limits the potential for the growth of submersed aquatic macrophytes, not only by promoting planktonic algal blooms, but also by promoting excessive epiphytic algal overgrowth. Evidence for the negative impacts of eutrophication on submersed macrophytes spans northern and southern hemispheres in marine as well as freshwater environments (Stevenson 1988). For example, nutrient loading of coastal salt ponds in New England has been shown to enhance marine macroalgae at the expense of seagrass species (Lee and Olsen 1985, Valiela and Costa 1988), and appears to be associated with a significant decline of seagrasses in Cockburn Sound, Australia (Shepherd et al. 1989).

Because of these and other relationships observed between water quality and declines in living resources in the Bay, the 1987 Chesapeake Bay Agreement called for the development and adoption of guidelines for the protection of habitat conditions necessary to support Bay living resources. In response to this request, habitat requirements for Chesapeake Bay SAV were developed using empirical models of seasonal medians in water quality, and corresponding

growth and survival of natural and transplanted SAV at various regions throughout the Bay (Orth and Moore 1988, Batuik et al. 1992, Dennison et al. 1993, Stevenson et al. 1993).

Although general relationships between water quality and SAV response have been defined, a number of questions still remain. Of particular importance in Bay management is the need for a better understanding of the temporal variability of water quality relative to SAV habitat criteria. SAV habitat requirements have been defined based upon seasonal medians using biweekly or monthly sampling of the water column. Only a few studies have investigated short-term variability of certain water quality parameters in shallow SAV sites (Ward et al. 1984). Is there short-term variability in measured parameters at shallow water vegetated, or potentially vegetated, sites that are important considerations for both monitoring programs or ecosystem model simulations? Currently, the sites that are monitored are visited at biweekly to monthly intervals, and most sampling is conducted in mid-channel areas. Although this may provide a relative measure of comparison among areas sampled at similar time scales, the variable exposure levels that are likely influencing plant response in the littoral zone may not be adequately measured. Episodic events such as storms of moderate, regular nature are important forcing functions of the system, but their influence on shallow water conditions has not been well documented. Effects of other regular, physical forcing factors such as tidal influences are not easily interpreted by such data (Hutchinson and Sklar 1993). High-frequency field sampling is necessary not only to define these conditions, but also to validate current ecosystem models that simulate certain parameters using stochastic or other functions.

Spatial variability in water quality relative to SAV habitats is another factor that is an important consideration in the continued development of SAV habitat requirements and restoration targets. Small-scale differences in certain parameters have been documented, such as decreases in the concentration of suspended solids (Ward et al. 1984), that are associated with the baffling effect of the SAV community (Kemp et al. 1984). However, variability of many other factors such as nutrients, or light availability, are not as well-known. SAV beds have the ability to modify their environment, and this may provide one key to their survival. Because of this capacity, it is possible that conditions that permit the continued existence of SAV beds may not be suitable for recovery of denuded sites; or, that conditions that originally caused the declines of SAV beds in the Bay are not the same as those inhibiting recovery.

In this project, we investigated the patterns of variability in water quality, and the resultant effects of SAV, over short spatial and temporal scales. The study site, Goodwin Island, is located near the mouth of the York River in the high-salinity region of Chesapeake Bay (37°12' N 76°23' W). It is vegetated with salt-tolerant SAV species (e.g., *Zostera marina* and *Ruppia maritima)*, which declined to low levels in the 1970's (Orth and Moore 1983), but have been increasing in abundance in recent years (Orth et al. 1992). It is an National Estuarine Research Reserve System (NERRS) site and the location of other ongoing field studies.

## METHODS

At the Goodwin Island site, four stations were established along a transect running approximately NW/SE, beginning in the shallow subtidal flat adjacent to the eastern shoreline of Goodwin Island, and extending approximately 1 km channelward. Stations 1 and 2 were located in the SAV bed; station 3 was located at the outer edge of the bed in an area sparsely vegetated with *Z. marina*; and station 4 was located outside the bed in an area of bare sand bottom. At each station a permanent pole, which supported a box that housed the remote sampling equipment, was placed in the bottom.

Water quality at the site was sampled using both intensive (seasonal) and periodic (biweekly) sampling schedules. Intensive sampling was undertaken during four 10-day periods in June, August, and October of 1993, and April, 1994. During each intensive sampling period, water samples were obtained at 3 hr intervals at each station using automated samplers (ISCO, Inc.) (table 1). Biweekly sampling was conducted as part of the regularly scheduled Virginia Near-shore Submerged Aquatic Vegetation Habitat Monitoring Program.

Water samples from the intensive sampling were obtained at fixed depths of 30 cm above the bottom, stored on ice for no more than 24 hours, filtered through .45 µm filters, and then analyzed in duplicate for dissolved inorganic nutrients and suspended particles. Ammonium was determined spectrophotometrically after Parsons et al. (1984). Nitrite, nitrate, and orthophosphate were measured using an Alpkem autoanalyzer, equipped

**Table 1. Summary of parameters and sampling intervals for SAV and water quality measurements at the Goodwin Island, Virginia study area.**

| Parameter | Interval |
|---|---|
| SAV | |
| Community transect (% cover) (June, August, October, April) | Periodic |
| Biomass | |
| Above/below ground, density , canopy height, attached epiphytes | Monthly |
| Water quality | |
| Routine sampling (TSS, $K_d$, Chla, $NO_2$,$NO_3$,$NH_4$, DIN, $PO_4$, temperature, salinity) | Biweekly |
| Intensive sampling | Periodic |
| TSS (FIM, FOM) | Every 3 hours for 10 days |
| Chla | " |
| $NO_2$ | " |
| $NO_3$ | " |
| $NH_4$ | " |
| DIN | " |
| $PO_4$ | " |
| $K_d$ | Every 15 min for 10 days |
| Temperture | " |
| Salinity | " |
| DO | " |
| pH | " |
| Tidal depth | " |
| Wind direction/speed | " |

with a model 510 spectrophotometer. Total suspended solids (TSS) were determined by filtration, rinsed with fresh water, and dried at 60°C. Filterable inorganic matter (FIM) and filterable organic matter (FOM) were obtained by ashing the material at 550°C. *Chlorophyll a* was extracted using DMSO/acetone (after Shoaf and Lium 1976) and analyzed by fluorometry.

Dissolved oxygen, pH, salinity, temperature and water depth were measured at 15 min intervals using Hydrolab Datasonde instrument systems placed adjacent to the ISCO sampler intakes, and individually calibrated before each field deployment. In situ PAR light attenuation was measured continuously and integrated over 15 min periods using fixed arrays of underwater, scalar, 4 quantum sensors (LI-193SA, [LI-COR, Inc.]). The sensors were calibrated by the manufacturer prior to use, and when deployed in the field were cleaned daily to remove any accumulated epiphytes. Atmospheric, downwelling irradiance (2 quantum, LI-190SA, [LI-COR, Inc)], and 6 min, vector-averaged wind speed and direction were recorded continuously at the Gloucester Point, Virginia, meteorological station (height +45 m mean sea level).

Biweekly water samples were obtained in triplicate, at a depth of 0.25 m at station 2, and placed on ice until returned to the laboratory for analysis of dissolved nitrite, nitrate, ammonium, orthophosphate, Chla, TSS, FIM, and FOM. Triplicate analyses were made in situ for DO, pH, water temperature, salinity, and integrated water column Kd (2 quantum, LI- 92SA, [LI-COR, Inc.]).

Monthly, from May, 1993, through April, 1994, measurements of macrophyte biomass were determined at each of the vegetated stations.

Friedman's ANOVA (Zar 1984), a nonparametric procedure for testing repeated measures, was used to compare evaluate dissolved nutrients, total suspended solids (TSS), Chl*a*, and physical param-

eters for significance differences among stations within each sampling period. Analyses were accomplished using Statistica /Mac( StatSoft Inc., Tulsa, Oklahoma). If differences among stations were determined significant ($P \leq .01$), multiple, pairwise comparison analysis (Zar 1984) was used to test individual means.

## RESULTS AND DISCUSSION

The macrophyte community structure in the SAV bed was characterized by increasing biomass April dominated by *Z. marina*, highest biomass of *Z. marina* in June ( 250 gdm $m^{-2}$), a dieback in *Z. marina* and increased biomass of *R. maritima* in August, and a dieback of *R. maritima* and a slight regrowth of *Z. marina* in October. Epiphyte abundance were consistently greater on *R. maritima* than *Z. marina* throughout the year. Epiphyte loads were lowest in April and June, and greatest in August and November.

Diurnal patterns of dissolved oxygen demonstrated greater range within the beds compared to outside, illustrating higher metabolic activity per volume of water in the shallows. Daily mean and maximum DO levels were higher in the beds than in adjacent channel areas during periods of maximum SAV growth and biomass. In August, DO minimums each night were accompanied by increased water column levels of $PO_4$, presumably due to release of $PO_4$ from the sediment. These increases were reduced to background levels during the day.

**Table 2a. Means of inorganic nutrients and suspended particles by station for June 1993 and August 1993 study periods at Goodwin Island.** Units of measure: mg l-1, for basic parameters; µM for parameters in parentheses; I.µg11 for *chla*. Identical superscript letters denote no significant differences ($P > 0.05$) among stations within each study period.

| | | June 1993<br>Station 2 | Station 3 | Station 4 |
|---|---|---|---|---|
| $NO_2$ | 0.0008 $^{a}$ | 0.0008 $^{a}$ | 0.0002 $^{a}$ | 0.0009 $^{a}$ |
| | (0.059) | (0.058) | (0.084) | (0.063) |
| $NO_3$ | 0.0042 $^{a}$ | 0.0033 $^{a}$ | 0.0054 $^{a}$ | 0.0066 $^{a}$ |
| | (0.298) | (0.235) | (0.383) | (0.473) |
| $NH_4$ | 0.0186 $^{a}$ | 0.0202 $^{a}$ | 0.0196 $^{a}$ | 0.0335 $^{a}$ |
| | (1.33) | (1.45) | (1.40) | (2.39) |
| DIN | 0.0239 $^{a}$ | 0.0247 $^{a}$ | 0.0263 $^{a,b}$ | 0.0414 $^{b}$ |
| | (1.71) | (1.76) | (1.88) | (2.96) |
| $PO_4$ | 0.015 $^{a}$ | 0.015 $^{a}$ | 0.015 $^{a}$ | 0.015 $^{a}$ |
| | (0.46) | (0.48) | (0.48) | (0.47) |
| TSS | 4.21 $^{a}$ | 4.64 $^{a}$ | 8.48 $^{b}$ | 7.67 $^{b}$ |
| *Chla* | 8.67 $^{a}$ | 14.90 $^{b}$ | 23.78 $^{c}$ | 24.49 $^{c}$ |
| | | August 1993 | | |
| $NO_2$ | 0.0019 $^{a}$ | 0.0010 $^{b}$ | 0.0007 $^{b}$ | 0.0006 $^{b}$ |
| | (0.137) | (0.071) | (0.047) | (0.044) |
| $NO_3$ | 0.0044 $^{a}$ | 0.0036 $^{a}$ | 0.0042 $^{a}$ | 0.0042 $^{a}$ |
| | (0.316) | (0.259) | (0.301) | (0.303) |
| $NH_4$ | 0.028 $^{a}$ | 0.022 $^{b}$ | 0.015 $^{b}$ | 0.017 $^{b}$ |
| | (2.03) | (1.60) | (1.09) | (1.18) |
| DIN | 0.035 $^{a}$ | 0.026 $^{b}$ | 0.020 $^{b}$ | 0.022 $^{b}$ |
| | (2.47) | (1.89) | (1.43) | (1.54) |
| $PO_4$ | 0.011 $^{a}$ | 0.0096 $^{a}$ | 0.014 $^{a}$ | 0.010 $^{a}$ |
| | (0.368) | (0.310) | (0.453) | (0.319) |
| TSS | 4.91 $^{a}$ | 7.79 $^{b}$ | 4.42 $^{a}$ | 4.71 $^{a}$ |
| *Chla* | 10.82 $^{a}$ | 12.64 $^{b}$ | 9.77 $^{a}$ | 10.94 $^{b}$ |

**Table 2b. Means of inorganic nutrients and suspended particles by station for October 1993 and April 1994 study periods at Goodwin Island.** Units of measure: mg l-1, for basic parameters; µM for parameters in parentheses; .µg11 for *chla*. Identical superscripts denote no significant differences (P>0.05) among stations within each study period.

| | | October 1993 Station 2 | Station 3 | Station 4 |
|---|---|---|---|---|
| $NO_2$ | 0.0015 [a] | 0.0024 [a] | 0.0010 [b] | 0.0007 [b] |
| | (0.105) | (0.174) | (0.073) | (0.043) |
| $NO_3$ | 0.0072 [a] | 0.0085 [a] | 0.0121 [b] | 0.0114 [b] |
| | (0.518) | (0.610) | (0.864) | (0.815) |
| $NH_4$ | 0.033 [a] | 0.028 [a] | 0.026 [a] | 0.038 [a] |
| | (2.35) | (1.99) | (1.88) | (2.70) |
| DIN | 0.042 [a] | 0.039 [a] | 0.039 [a] | 0.050 [a] |
| | (2.96) | (2.77) | (2.82) | (3.56) |
| $PO_4$ | 0.0087 [a] | 0.010 [a] | 0.0194 [a] | 0.0090 [a] |
| | (0.280) | (0.325) | (0.627) | (0.290) |
| TSS | 5.65 [a] | 6.06 [a,b] | 5.82 [a,b] | 6.72 [b] |
| *Chla* | 6.34 [a] | 10.11 [b] | 15.96 [c] | 15.04 [c] |
| | | April 1994 | | |
| $NO_2$ | 0.003 [a] | 0.006 [b] | 0.007 [c] | 0.006 [b] |
| | (0.224) | (0.417) | (0.500) | (0.453) |
| $NO_3$ | 0.020 [a] | 0.084 [b] | 0.125 [b] | 0.127 [b] |
| | (1.45) | (6.03) | (8.90) | (9.08) |
| $NH_4$ | 0.019 [a] | 0.017 [a] | 0.018 [a] | 0.015 [a] |
| | (1.37) | (1.22) | (1.31) | (1.09) |
| DIN | 0.047 [a] | 0.108 [b] | 0.153 [c] | 0.152 [c] |
| | (3.33) | (7.70) | (10.91) | (10.84) |
| $PO_4$ | 0.0095 [a] | 0.0089 [a] | 0.0101 [a] | 0.0074 [a] |
| | (0.297) | (0.278) | (0.315) | (0.230) |
| TSS | 2.85 [a] | 2.64 [a] | 3.12 [a] | 4.68 [b] |
| Chl*a* | 19.12 [a] | 25.50 [b] | 28.35 [b] | 27.72 [b] |

Table 2a and 2b present the means of inorganic nutrients and suspended particles by station for the June, August, October, and April study periods.

The principal nitrogen species during all study periods, except for April, was $NH_4$. This is sometimes referred to as "old", or regenerated, nitrogen as compared to $NO_3$ or "new", nitrogen whose primary source is the watershed. Considering that this site is near the mouth of the Bay, and farthest removed from river inputs, the dominance of $NH_4$ observed is not surprising and has been well documented. Only during April, when riverine inputs were the highest of all the study periods was $NO_3$ the dominant species.

Uptake of dissolved inorganic nitrogen (DIN) was observed during periods when macrophyte abundance was high in April and June. During periods of highest water temperatures and therefore increased microbial activity, regeneration of $NH_4$ was observed inside the SAV bed. Net uptake of $NO_3$ in the spring was replaced by net regeneration of $NH_4$ in the summer. Rapid uptake of DIN by the macrophyte community reduces the pool of nutrients available for phytoplankton growth. This may be especially important in the lower Bay, where nitrogen levels are lower. In areas of transitional water quality, the existence of large established beds of SAV may improve local

conditions for their continued survival during years of high runoff. Small isolated patches may be overwhelmed. In the upper Bay site, DIN is in excess abundance and is apparently not limiting to epiphyte or phytoplankton growth.

Table 3 presents a summary comparison of median levels of five key water quality parameters that have been used to define habitat requirements for SAV growing in polyhaline regions of Chesapeake Bay (Batiuk et al. 1992). Polyhaline SAV habitat requirements have been defined as median levels of these particular water quality constituents measured at regular intervals during the growing season, which correspond to areas where SAV beds have remained persistent in the highest salinity regions of the bay (Moore 1992). Results of biweekly monitoring of water quality at station 2 on Goodwin Island in 1993 demonstrate that this SAV bed would have met all criteria except that for Chl *a* during this year. These results support the habitat criteria concept, where similar comparisons have demonstrated that all or all but one of the habitat requirements will be met in areas where SAV are persistent.

Medians of each intensive monitoring study at station 2 are presented for comparative purposes. For the five parameters, the habitat requirement criteria were exceeded only twice: during October, 1993 for $K_d$, and during April 1994 for Chl*a*. $K_d$ medians in October are influenced by high $K_d$ values during the morning and afternoon. During the April study period, high levels of dissolved inorganic nitrogen (DIN) (mostly $NO_3$) are supportive of the highest levels of phytoplankton observed. Quantitative comparison with the biweekly sampling results is difficult, because both sets of medians reflect different intensities and duration of sampling. Obviously, the biweekly sampled growing season medians do not reflect the short term or seasonal variability associated with this site. In areas of marginal water quality this variability could be important in determining long-term success of the SAV. The biweekly growing season medians however, do, appear to accurately characterize the water quality classification of this area in regard to SAV requirements. They provide an overall measure of water quality that is similar to that presented by the short-term, hourly sampling.

Growing season medians were also determined using surface data from adjacent, mainstem monitoring stations. These medians when compared to similar, biweekly data for station 2, inside the bed, are identical for $K_d$, higher for TSS and DIN, and lower for Chl*a* and DIP (table 3). Habitat requirement levels were not exceeded for any of the parameters. Of the five parameters investigated, only TSS and DIP seem to be somewhat out of line with values from the shallow water site. These differences may also reflect differences in methodologies. At a deeper water, mainstem station, TSS might be expected to consist in large part of Chl*a*. However, Chl*a* levels are lower here than at station 2. DIP, which were generally consistent at the Goodwin Island stations, were much lower at the mainstem monitoring station. When the mainstem data are compared to seasonal medians from the channelmost, intensive monitoring station 4, similar results are obtained. Both TSS are higher and DIP are lower at the mainstem station than any of the seasonal medians at station 4. Although there are some differences with data from the intensive studies, overall, the mainstem monitoring data do support the conclusion that water quality in this area meets the SAV habitat criteria, and therefore SAV should be successful in this region.

Seasonal, study period medians from both inside the SAV bed, at station 2 and outside SAV bed at station 4 are very similar (table 3). During June 1993, median levels of Chl*a* exceeded the habitat limits at station 4 and not at station 2, while during April 1994, DIN was also exceeded at station 4 and not at station 2. These differences, potentially, reflect the ability of SAV beds to baffle suspended particles and take up nutrients, especially during periods when SAV growth and bed development is high. These results suggest that during certain seasonal periods, established SAV can improve water quality sufficiently within the bed to achieve the habitat criteria limits when the adjacent water mass is above the criteria. Obviously, these habitat criteria are only yardsticks that provide a general measure of SAV/water quality relationships, however, these results suggest that during seasonal pulses in reduced water quality, the existence of beds provides a positive feedback that may enhance their continued growth and survival.

Although biweekly sampling does not capture the diel, tidal, and other pulses or variability in water column constituents that we observed in these studies, they do provide a reasonable characterization of water quality levels in these areas. Daily variability may exceed seasonal variability for most parameters measured, but the median levels of these constituents are near the lower levels observed, and the high pulses are short lived. Thus only infrequently will the pulses be measured in the biweekly sampling. Many times these pulses will occur at

Table 3. Summary comparison of polyhaline SAV habitat requirements for five key water quality parameters. Median levels are calculated using (1) 1993 growing season biweekly monitoring at station 2; (2) station 2 seasonal, intensive study data; (3) 1993 growing season, biweekly monitoring data at two nearest Bay mainstem monitoring stations (WE4.2/4.3); and (4) station 4 seasonal, intensive study data.

| Key Water Quality Parameters | Polyhaline SAV *Habitat Requirements | 1) Goodwin Station 2 Biweekly Monitoring | 2) Goodwin Intensive Monitoring Station 2 (inside SAV) | | | | 3) Mainstem WE4.2/4.3 Biweekly Monitoring | 4) Goodwin Intensive Monitoring Station 4 (outside SAV) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | June | Aug | Oct | Apr | | June | Aug | Oct | Apr |
| $K_d$ ($m^{-1}$) | 1.5 | **1.3** | 1.2 | 1.0 | 1.7 | 1.1 | **1.3** | 1.7 | 0.9 | 1.2 | 0.88 |
| TSS ($mg\ l^{-1}$) | 15 | **7.8** | 3.7 | 6.0 | 4.9 | 2.5 | **13.0** | 6.9 | 4.6 | 6.5 | 4.9 |
| Chl*a* ($\mu g\ l^{-1}$) | 15 | **16.8** | 13.6 | 10.8 | 8.8 | 23.2 | **9.7** | 23.8 | 10.4 | 13.9 | 24.2 |
| DIN ($\mu M$) | 10 | **1.5** | 1.3 | 1.5 | 2.4 | 6.84 | **2.8** | 1.5 | 1.3 | 3.3 | 11.3 |
| ($mg\ l^{-1}$) | (0.14) | **(0.02)** | (0.02) | (0.02) | (0.03) | (0.10) | **(0.04)** | (0.02) | (0.02) | (0.05) | (0.16) |
| DIP ($\mu M$) | 0.67 | **0.50** | 0.44 | 0.30 | 0.40 | 0.33 | **0.10** | 0.47 | 0.60 | 0.30 | 0.29 |
| ($mg\ l^{-1}$) | (0.02) | **(0.02)** | (0.02) | (0.01) | (0.01) | (0.01) | **(0.004)** | (0.02) | (0.02) | (0.01) | (0.01) |

*From Batiuk et al. 1992

night or during storm events and they will not be sampled with infrequent, point sampling. However, the monitoring will likely capture the median conditions, which in turn are most important for SAV response. In both areas studied here growing season medians were below the habitat requirements thresholds set for each area. Thus, they correctly predicted that these areas should be suitable for SAV growth.

In areas of limiting or transitional water quality however, these infrequent pulses may be limiting SAV survival. Thus, certain areas that meet median water quality levels but have no SAV may be limited by irregular high levels of TSS or nutrients that are not effectively measured by biweekly sampling. In addition, slight year-to-year variations in water quality conditions during the growing season are unlikely to be effectively measured by biweekly or less-frequent sampling. Therefore establishing why SAV expanded in distribution one particular year compared to another, especially in areas of transitional water quality, may not be possible. Trends may be identified using 3 or 4 years of data records. For example, water quality in one particular region during the late 1980s may be compared effectively to that of the late 1990s. This can only be obtained by maintaining long term monitoring programs of this type.

Records of seasonal, short-term, site-specific variability such as investigated here are also highlighted. Not only do they provide a more integrative view relationships between SAV and water quality, and processes relating the two, but they provide a test of the effectiveness of the more spatially distributed, infrequent data.

Except in areas where groundwater or local upland runoff is high, mid-channel nutrient concentrations are useful to characterize the long-term inputs or stresses to the macrophyte, or potential macrophyte, areas. Where SAV occurs, concentrations inside the beds can be quite different than outside. These differences reflect the net effect of the SAV bed community on the particular water quality constituent. As the field studies demonstrate, rapid uptake and release of inorganic nutrients can occur by the SAV, algal, heterotrophic, and microbial components of the system. Therefore, nutrient concentrations outside the bed better reflect long-term system impacts on SAV areas than concentrations measured within large SAV meadows, especially where water residence time is high. In areas where SAV beds are small and scattered, or where water velocities are high and residence time is short, concentrations of nutrients within the beds better reflect channel concentrations.

Other important variables, including suspended particle load and light attenuation, can also be quite different in and out of existing beds. However, because the macrophyte communities are integrating the light available to them, not the light available outside of the bed, measurements should be made over the vegetated areas. In shallow water areas this water column attenuation may be more or less than in the channel. In sparsely vegetated areas, these differences may be more similar than in areas with extensive vegetation. Estimates of these differences are needed if models relating water quality to SAV are to be accurate. In certain areas, such as regions of marginal water quality in the lower Bay, persistence of vegetation is likely related to the capacity of the vegetation to improve water clarity. In the lower Bay, limiting conditions earlier in the year may be reducing survival during the summer. Natural year-to-year variability in SAV may also may be related not only to annual differences in water quality, but also to the normal interrelationships between SAV and bay waters. In one possible scenario, optimum growing conditions and extensive growth of an eelgrass bed during the spring lead to the effective trapping of suspended particles and algae. The decomposition of this biomass along with the large SAV biomass within the bed causes an increase in sediment oxygen demand, which reduces SAV growth during the summer, resulting in a unusually large late-summer decline.

## ACKNOWLEDGEMENTS

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