Ecosystem Effects of Submersed Aquatic Vegetation
In the Tidal Freshwater Hudson River

by

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ABSTRACT

Measurements of dissolved oxygen, suspended matter, particulate organic matter, dissolved organic carbon, chlorophyll and dissolved inorganic nutrients were made at five sites containing macrophyte beds in the tidal freshwater Hudson River from June through August of 1993, to assess the ecosystem-level effects of submersed aquatic vegetation. The effects of macrophyte beds varied through the mid-Hudson River, expressing both spatial and temporal heterogeneity. In the majority of samples, SAV was not found to increase rates of sediment deposition, nor were they found to mitigate resuspension of benthic materials. Wind velocity was found to have a positive effect upon turbidity and resuspension in shallow sites, even where SAV biomass was high. Macrophyte beds had no clear effects upon either particulate organic matter or dissolved organic carbon on a seasonal scale. However, as a percent of total suspended matter, particulate organic matter was found to decrease across macrophyte beds, manifesting a possible resource gradient of available carbon to lower trophic level consumers. Dissolved nutrient concentrations were found to be as much as 30% lower in some macrophyte beds, possibly due to uptake by SAV. The variability encountered in this study suggests important and subtle differences in the effect of SAV beds upon the Hudson River.

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INTRODUCTION

Submersed aquatic vegetation (SAV) plays a critical role in many aquatic systems, contributing to primary productivity, biogeochemical cycling and sediment dynamics, as well as providing important habitat for fishes and invertebrates. Aquatic macrophyte communities are some of the most productive natural ecosystems (McRoy and McMillan, 1977), and have been found to support very productive and diverse wildlife populations (Dennison et al., 1993; Kemp et al., 1984). In the Hudson River, SAV occupies shallows and shoals where the water depth is less than 3 m deep (Moran and Limburg, 1986; Muenscher, 1937), and although their distribution is limited, they can form dense conspicuous beds of up to 100 g/m^2, dry weight (Menzie, 1979), and achieve rates of net ecosystem production as high as 5.0 g O_2/day /m ^{2} (Garritt and Howarth, 1988), dominating the autotrophic metabolism of these communities. It has been demonstrated that macrophyte beds in the Hudson provide a rich habitat for invertebrate populations (Kelly and Perrotte, 1989; Menzie, 1980), but while it seems there is an important trophic link between fish populations and macrophyte communities, it is still unclear to what extent fish populations maintain residence within main channel beds (Anderson and Schmidt, 1988; Bohne and Schmidt, 1988; Sidari and Schmidt, 1990; Hankin and Schmidt 1991).

As the largest sessile organisms in these communities, macrophytes can have quite an impact upon their physical environment. One of their most important effects is the reduction of water velocity through a bed (Carpenter and Lodge, 1986; Harlin et al., 1982) resulting in increased rates of sedimentation and decreased resuspension of fine grain sediments (Kenworthy et al., 1982; Kemp et al., 1984). Riverine beds of aquatic vegetation have been shown to act as a sieve, retaining suspended particulates and hastening the decomposition of trapped allochthonous organic matter (Kenworthy et al., 1982; Fisher and Carpenter, 1986). Sediment dynamics are of particular interest in a turbid system, such as the Hudson, where light limitation is often the restricting element in plant

and algal distribution (Howells and Weaver, 1969; Malone 1977; Moran and Limburg, 1985; Cole et al., 1992; Harley and Findlay, 1994).

Also of important consideration are the effects SAV can have upon its chemical environment. The most prominent effect is upon dissolved O_2 concentrations. Dense stands of submersed macrophytes oxygenate the water more effectively than floating leaf vegetation (Kemp et al., 1984; Carpenter and Lodge, 1986) supporting highly aerobic conditions throughout a bed during photosynthetically active periods. SAV can have very dramatic effects on organic matter processing and resource availability in dense stands where particulate carbon concentrations are often accentuated (Dawson, 1980) through the filtering capability of macrophyte beds, as well as their tendency to leak dissolved organic carbon (Wetzel, 1969; Mickle and Wetzel, 1978b; Penhale and Smith, 1977).

The question of macrophyte effects on nutrient cycling is largely one of time scale. It is generally accepted that aquatic vegetation acts as a seasonal sink of dissolved nitrogen and phosphorus, through uptake and storage in plant tissue during periods of active growth, and ultimately as a source of inorganic nutrients back to the water column during senescence and decay (Westlake, 1975; Mickle and Wetzel, 1978a; Twilley, et al., 1985; Carpenter and Lodge, 1986). However, the immediate effects of SAV upon nutrient concentrations are less well understood. Mickle and Wetzel (1978a), Kemp et al.(1984), and Howard-Williams (1981) reported rapid uptake of nitrate by SAV, while Kenworthy et al. (1984) noted that decomposition of trapped particulate organic matter acts as a source to the available nitrogen pool. SAV has been found to be a net source of dissolved phosphate where phosphorus uptake from the sediment is released to the water column by the leaves and utilized by epiphytic algae (McRoy and Barsdate, 1970; McRoy and Goering, 1974). However, Denny (1980) reported that phosphorus is not released by living macrophytes at ecologically significant rates. Howard-Williams (1981) discussed the ability of

Potamogeton pectinatus to absorb pulses of phosphorus, as well as nitrogen, on a small time scale, indicating that in addition to being seasonal sinks of dissolved nutrients, macrophytes can have immediate effects upon nutrient concentrations. In the Hudson Valley, where increased development has contributed to eutrophication in the estuary (Parsons and Lovett, 1992), rapid nutrient uptake and assimilation by SAV could have important implications for water quality and nutrient budgets.

Very little is known about the effects of submersed aquatic vegetation in large rivers and estuarine systems. Most of the ecological investigations concerning macrophytes have emphasized the consequences of various environmental factors upon growth, rather than the effects of plants on their environment. Additionally, much of the literature describing submersed vegetation is based upon lake systems. Considering the physical and chemical differences between lakes and estuarine systems, it is likely that many of the assumptions that underlie lake investigations are not valid in an estuarine system. In the Hudson River estuary there is little understanding of the roles that SAV plays in ecosystem level functions. More information is necessary in order to more fully understand the nature of these communities and their importance to the whole river, so that prudent management strategies can be drafted.

The objectives of this study were to assess the effects of submersed aquatic vegetation communities upon biogeochemical processes in selected macrophyte beds at various sites along the freshwater portions of the mid-Hudson River estuary. Specifically, I looked at suspended sediment concentrations, investigating the possible mitigating effects that SAV might have on turbidity, and the paths of particulate organic matter and dissolved carbon entering a bed and the roles that macrophytes might play in the cycling of inorganic nutrients.

METHODS

Study Site

This study focused on beds of submersed aquatic vegetation in the tidal freshwater Hudson River. Samples were collected throughout the summer months of 1993. I sampled macrophyte beds adjacent to the Tivoli Bays of the Hudson River National Estuarine Research Reserve (river km 156). Samples were collected on six dates, June 24 through August 5. Biomass data were collected monthly from both North and South Bay. The Tivoli Bays consist of two embayments located on the east bank of the river and partially separated from the main channel of the river by a railroad dike (Fig. 1). Macrophyte beds at North and South Tivoli Bay were chosen as field replicates based upon proximity, and similar bathymetry and species composition of submersed vegetation. The study was conducted on the main channel side of the dike where water flowed unimpeded over the macrophyte beds. The sites are characterized by shallow depths of less than 3 m with soft bottom sediments. Dominant vascular plant species consisted of three rooted submersed macrophytes; *Vallisneria americana, Myriophyllum spicatum, Potamogeton perfoliatus* and the floating, rooted macrophyte, *Trapa natans* . In both the North and South Bays, *V. americana* was visibly dominant along the channel, giving way to thick mats of *T. natans* along the banks and sheltered waters behind Cruger Island and Magdalen Island. Four other sites were sampled in addition to Tivoli Bays to assess spatial variability in the functioning of SAV throughout the mid-Hudson. Sites for the macrophyte survey were chosen at Catskill (rk 180), Cementon (rk 168), the Saddle Bags (rk 157) and Esopus Meadows (rk 150), based upon data from Dr. David Strayer's summer 1991 Ponar grab study, and from Garritt and Howarth, (1988). Samples from this component of the study were collected on August 13, 1993.

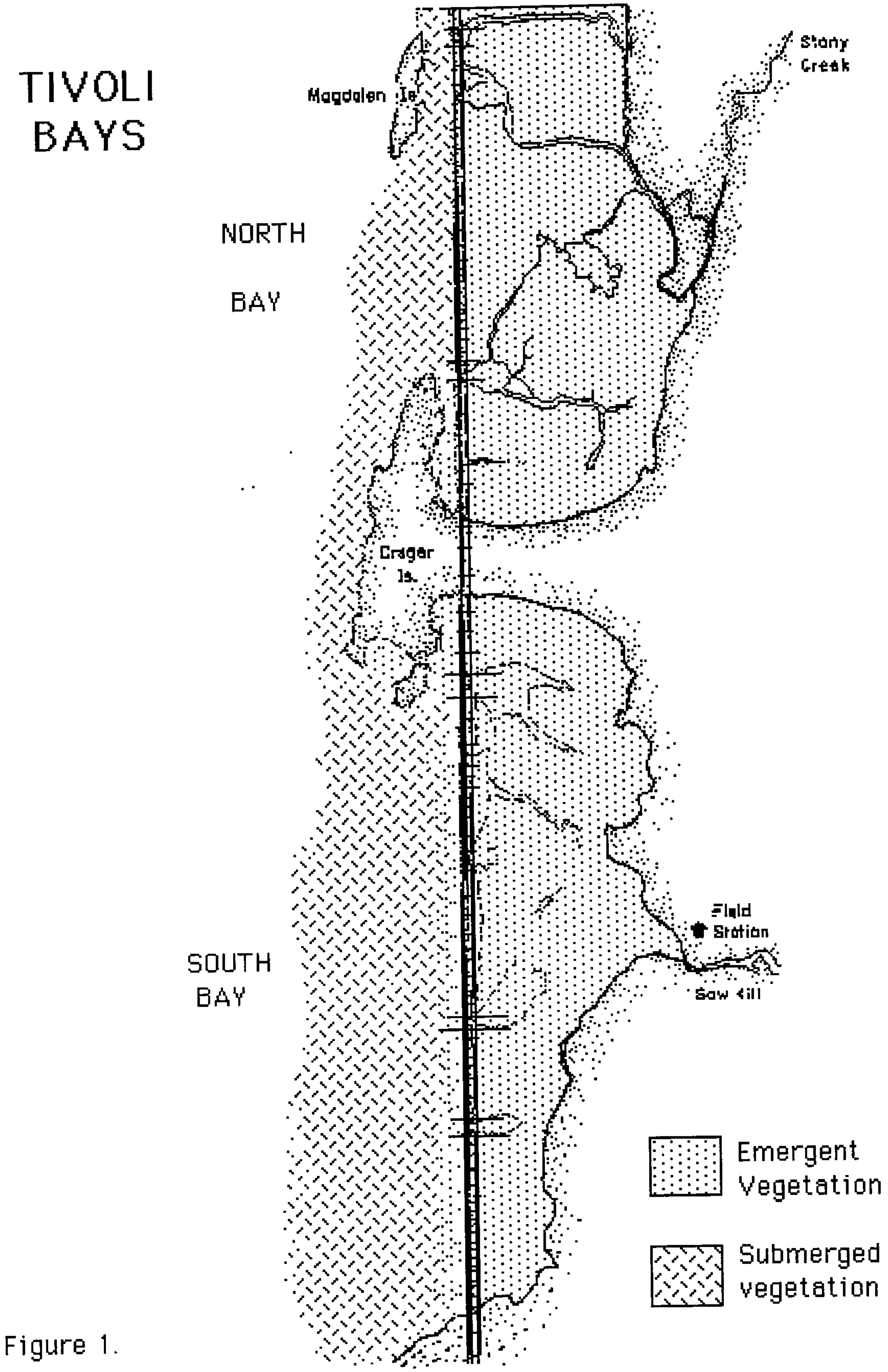

Figure 1.

Sample collection

Biomass data were collected at monthly intervals over depth transects across macrophyte beds at the North and South Tivoli Bays. Effort was made to minimize disturbance of the site. Sampling with a 0.05 m^2 Ponar grab was begun at depths of 5 m and continued in an easterly direction over the bed to depths of 1 m. Buoys were placed along these transects marking 5, 3, 2, and 1 m depths to ensure that the same relative area was being sampled on repeated visits. Vegetation samples were collected in triplicate at four sites along these transects.

At the Tivoli Bays sites, changes in dissolved oxygen concentrations were measured and water samples were collected over beds of SAV following the rising tide in an adaptation of the upstream-downstream method for measuring diel oxygen curves (Odum, 1956). Tidal action of the river moves water upstream during the flood tide. All measurements and samples were taken while drifting with a water mass during flood tide. Dissolved oxygen and water chemistry were measured first in unvegetated water and then at a series of locations as the water mass moved over a SAV bed. Sampling was begun at depths of greater than 3 m to minimize the effects of vegetation upon water chemistry on initial samples. Four oranges were released into the river as drogues and allowed to float freely in an effort to follow the same water mass throughout collection. Samples were collected at approximately ten minute intervals over the bed. In instances where the oranges floated out into the main channel, the process was begun again until a water mass could be successfully followed over a macrophyte bed. Throughout the sampling run the boat was maneuvered with oars to minimize agitation of the water column.

Field sampling methods for the macrophyte survey on August 13 differed from the Tivoli Bays sites, because of time limitations. Intensive collection from each location was sacrificed for the opportunity to sample a variety of sites. At each location, one set of samples dissloved for oxygen, suspended matter, dissolved organic carbon, chlorophyll, and nutrients was collected in triplicate from a vegetated site and unvegetated site in close proximity. Plant material at each point was collected for biomass estimates.

Dissolved oxygen and river temperature were measured *in situ* using a Yellow Springs Instruments (YSI) model 57 analog oxygen meter with a membrane covered, polarographic oxygen probe. Calibrations of the oxygen probe were performed using water saturated air at the ambient temperature of the river. Calibration was checked at the beginning of each sampling run. Dissolved oxygen measurements were made using the Winkler method in addition to *in situ* probe readings, on the following sampling dates: July, 23; August 3; August 5 and August 13. No effort was made to correct dissolved oxygen readings for diffusion across the water surface. Although diffusion of O_2 can be quite important to diurnal O_2 budgets in the Hudson (Howarth et al., 1993), these corrections were not necessary for our study since the measurements served only as a quantitative indication of macrophyte presence based upon photosynthesis. Three replicate water samples were collected from just below surface depth, at each sampling point, using a peristaltic pump. Specimens were stored on ice in 500 ml polypropylene bottles until they were analyzed at the Institute of Ecosystem Studies Analytical Laboratory (IES). Weather data for each sampling date were averaged over one hour intervals, including estimates of Photosynthetic Active Radiation (PAR), wind speeds, and maximum wind speeds. These data were obtained from the IES meteorological station in Millbrook, NY.

Sample analysis

Each 500 ml water sample was subject to laboratory analysis for total suspended matter (seston), particulate organic matter, dissolved organic matter, chlorophyll *a*, phaeopigments and dissolved nitrogen and phosphorous. Three hundred to four hundred ml of river water were filtered through preweighed, precombusted glass fiber filters

(Whatman 934AH, nominal pore size 1.5 µm). Filters were dried overnight and weighed to estimate total suspended matter and then combusted at 450 °C for 4 hours and weighed once again. Organic content was estimated from the weight loss following combustion. Dissolved organic carbon was determined from filtered samples of river water with an Astro 2001 TOC Analyzer, using persulfate and UV oxidation at 70 °C. For the chlorophyll analysis, 150 ml river water was filtered through Gelman AE glass fiber filters. The filters were ground and extracted in methanol. Chlorophyll *a* concentrations were measured on a flourometer and corrected for phaeopigments and calibrated against chlorophyll *a* from Sigma Chemical Co. Analysis for nitrate, phosphate and ammonium were performed with automated colorimetric analysis on an Alpkem model 3590.

RESULTS

Tivoli Bays

Biomass data showed that SAV was limited to depths of less than 3 m and indicated that macrophytes were not present to any significant extent until early July . These data were corroborated by visual observation and past studies (see Garritt and Howarth, 1988; Menzie, 1979; Muenscher, 1937). Sample dates June 24 and June 25 were considered to be pre-macrophyte samples, where no appreciable amount of submersed vegetation was present. Ponar grab samples were consistently low in volume, in the range of 0 to 8.2 g /m^2 dry weight. For the remainder of the sample dates submersed aquatic vegetation was assumed to be at, or near, maximum standing crop. Mean biomass estimates for July 21 were 167.2 g /m^2 dry weight.

For sites at the Tivoli Bays, where samples were collected while drifting from deep water over a macrophyte bed, data were analyzed by regressing constituents (O_2, seston, nutrients, organic matter, chlorophyll) against time. Positive slopes indicate increases in concentrations within the water mass. Negative slopes indicate decreases. During the pre-macrophyte sample dates of June 24-25, macrophyte sites had no significant effect upon dissolved oxygen concentration. Regression analysis of dissolved oxygen, expressed as percent of saturation, against time (distance over bed) yielded negative slopes, -0.041 and -9.92, respectively, and were not statistically significant, $p < 0.1400$ and $p < 0.42$ (Table 1, Fig. 2 and 3). Seston concentrations were found to increase over these sites (Table 2). In the North Bay bed, on June 25, mean suspended matter increased from 11.40 to 31.83 mg DW/L over the bed yielding a strong positive slope (Fig. 4). Organic matter (AFDW) expressed as the organic fraction of total suspended matter was inversely related to seston, exhibiting negative slopes over distance for both June 24 and 25 (Table 3), especially in the North Bay, where the decline in percent particulate organic matter was highly significant, $p < 0.001$ (Fig. 5). The North Bay yielded a positive slope for chlorophyll *a* on June 25, exhibiting a step-wise increase as water moved from deep (>3m) to shallow (<3m) Fig. 6. In the South Bay bed, chlorophyll *a* did not increase significantly (Table 4) on this date, nor through the remainder of the season.

Dissolved oxygen concentrations showed a significant increase ($p<0.033$) over the North Bay macrophyte bed on July 8 (Fig. 7), indicating metabolic activity of submersed vegetation. There was an immediate increase in percent saturation of 14% as water moved from the main channel to the shallow vegetated bed. Suspended matter again showed increases over the bed (Fig. 8), despite the presence of vegetation. The percent organic fraction was again found to be weakly coupled with seston concentrations, decreasing over the macrophyte bed (Fig.9) as seston concentrations increased (Fig. 8). The macrophyte bed a small, but significant effect upon chlorophyll concentrations, $r^2= 0.46$ (Table 4).

Submersed vegetation had little effect upon dissolved oxygen concentrations in the North Bay bed on July 23 (Fig. 10), showing no significant linear relationship (Table 1).

Table 1. Regression analysis of percent oxygen saturation against time (distance over SAV bed), at the Tivoli Bays.

Site	Date	Slope	Standard Error	T Value	Probability Level	Correlation Coefficient	r^2
South Bay	6/24/93	-0.041	0.024	-1.70	0.14	-0.57	0.33
North Bay	6/25/93	-9.92	0.012	-0.87	0.42	-0.36	0.13
South Bay	7/07/93	0.013	0.035	0.37	0.72	0.12	0.015
North Bay	7/08/93	0.16	0.0604	2.57	0.033	0.67	0.45
North Bay	7/23/93	0.056	0.033	1.71	0.15	0.607	0.37
South Bay	8/03/93	0.202	0.11	1.80	0.13	0.63	0.39
North Bay	8/05/93	0.056	0.029	1.97	0.10	0.63	0.39

Table 2. Regression analysis of total suspended matter against time (distance over SAV bed), at the Tivoli Bays.

Site	Date	Slope	Standard Error	T Value	Probability Level	Correlation Coefficient	r^2
South Bay	6/24/93	0.050	0.019	2.64	0.015	0.49	0.24
North Bay	6/25/93	0.29	0.023	12.24	0.000	0.93	0.86
South Bay	7/07/93	-2.28	6.12	-0.37	0.71	-0.067	0.0045
North Bay	7/08/93	0.13	0.023	5.51	0.000	0.72	0.52
North Bay	7/23/93	-0.072	0.16	-0.46	0.65	-0.105	0.01
South Bay	8/03/93	9.58	4.75	0.202	0.84	0.043	0.0018
North Bay	8/05/93	0.019	0.015	1.25	0.22	0.28	0.076

Table 3. Regression analysis of organic fraction of total suspended matter against time (distance over SAV bed), at the Tivoli Bays.

Site	Date	Slope	Standard Error	T Value	Probability Level	Correlation Coefficient	r^2
South Bay	6/24/93	-0.21	0.070	-3.050	0.0059	-0.55	0.29
North Bay	6/25/93	-0.20	0.031	-6.55	0.00	-0.80	0.64
South Bay	7/07/93	-0.069	0.089	-0.78	0.44	-0.14	0.096
North Bay	7/08/93	-0.12	0.042	-2.78	0.0097	-0.46	0.22
North Bay	7/23/93	0.12	0.087	1.39	0.18	0.304	0.092
South Bay	8/03/93	-0.61	0.079	-0.77	0.45	-0.16	0.0307
North Bay	8/05/93	-0.095	0.14	-0.67	0.51	-0.15	0.023

Table 4. Regression analysis of chlorophyll *a* against time (distance over SAV bed), at the Tivoli Bays.

Site	Date	Slope	Standard Error	T Value	Probability Level	Correlation Coefficient	r^2
South Bay	6/24/93	-0.016	0.022	-0.702	0.49	-0.15	0.022
North Bay	6/25/93	0.11	0.0205	5.42	0.00001	0.73	0.54
South Bay	7/07/93	-5.94	0.0033	-1.78	0.085	-0.304	0.092
North Bay	7/08/93	0.015	0.0030	4.89	0.00004	0.68	0.46
North Bay	7/23/93	0.018	0.017	1.088	0.29	0.24	0.059
South Bay	8/03/93	-0.0035	0.00403	-0.87	0.39	-0.18	0.034
North Bay	8/05/93	-0.0090	0.0099	-0.91	0.37	-0.205	0.042

Suspended sediment, however, exhibited a substantial decrease of suspended matter over the bed, following an immediate peak of seston as the water mass passed into shallow water (Fig. 11). Chlorophyll *a* measurements revealed a similar, although not as pronounced effect (Fig. 12), showing an immediate increase in concentration, followed by a gradual decrease over the bed. Macrophyte beds were not found to have any effect upon dissolved organic carbon concentrations throughout the study. Nutrient analyses revealed no changes in NO_3 and PO_4 concentrations across macrophyte beds at the Tivoli Bays during any of the sample dates, demonstrating no immediate affect of SAV upon nutrient concentrations at this site.

Macrophyte Survey

Data from the macrophyte survey conducted on August 13 demonstrated great variation among and within sites. Dissolved oxygen expressed as percent saturation is recorded in Fig. 13. Two-way analysis of variance (ANOVA) showed the differences in percent saturation of oxygen between unvegetated and vegetated sites to be highly significant ($p< 0.0002$) and also demonstrated significant differences among the sites ($p< 0.001$). SAV has an important effect upon oxygen concentrations in all but the Catskill site. However, the Catskill site had the lowest rooted biomass (Table 5) of the four sites, and the macrophyte bed appeared in poor condition with many damaged leaves and silt cover on plants, possibly accounting for its depressed oxygen concentrations. Analysis of variance revealed significant differences between vegetated and unvegetated concentrations of seston ($p< 0.045$), but also demonstrated variation in suspended matter among sites that is even more pronounced, $p< 0.0001$ (Fig. 14). Particulate organic matter expressed as the organic fraction of suspended matter showed no significant differences, but was generally found to be higher in vegetated sites than in unvegetated sites (Fig. 15). Chlorophyll *a* was found to be significantly higher (ANOVA; $p < 0.006$) within macrophyte beds (Fig. 16).

However, the differences among sites were again found to be an equally important source of variation ($p< 0.012$). Vegetation samples from the survey consisted uniformly of *V. americana.*. Biomass estimates are summarized in Table 5.

Nutrient analyses revealed significantly lower concentrations of nitrate and phosphate, from samples taken within macrophyte beds than in unvegetated water adjacent to SAV (Figure 17). Nitrate was reduced by 16% in two out of the four beds (two-way ANOVA; $p < 0.00001$). Phosphorous was reduced by 31% in three out of four beds (two-way ANOVA; $p < 0.0018$). The largest reductions of nutrient concentrations occurred in macrophyte beds at Cementon and Esopus Meadows, where the greatest levels of oxygen saturation and highest biomass were also observed. Ammonium concentrations were in the range of 0.02 to 0.09 mg/L, but were not found to be affected by the presence of macrophyte beds.

Regression analysis of chlorophyll *a* and suspended matter through both parts of the study revealed weak but statistically significant coupling of these two variables, $p < 0.001$ (Fig. 18). Average wind speed and the slopes of suspended matter were found also to be weakly linearly related($p < 0.048$; Fig. 19).

Table 5. Macrophyte Survey biomass data from August 13.

LOCATION	DEPTH	AVG. BIOMASS	SD
Catskill	1.5 m	43.26 g/m^2	23.77
Cementon	1.1 m	99.70 g/m^2	25.64
Saddlebags (Cruger I.)	2.3 m	87.00 g/m^2	37.18
Esopus Meadows	1.0 m	88.92 g/m^2	51.96

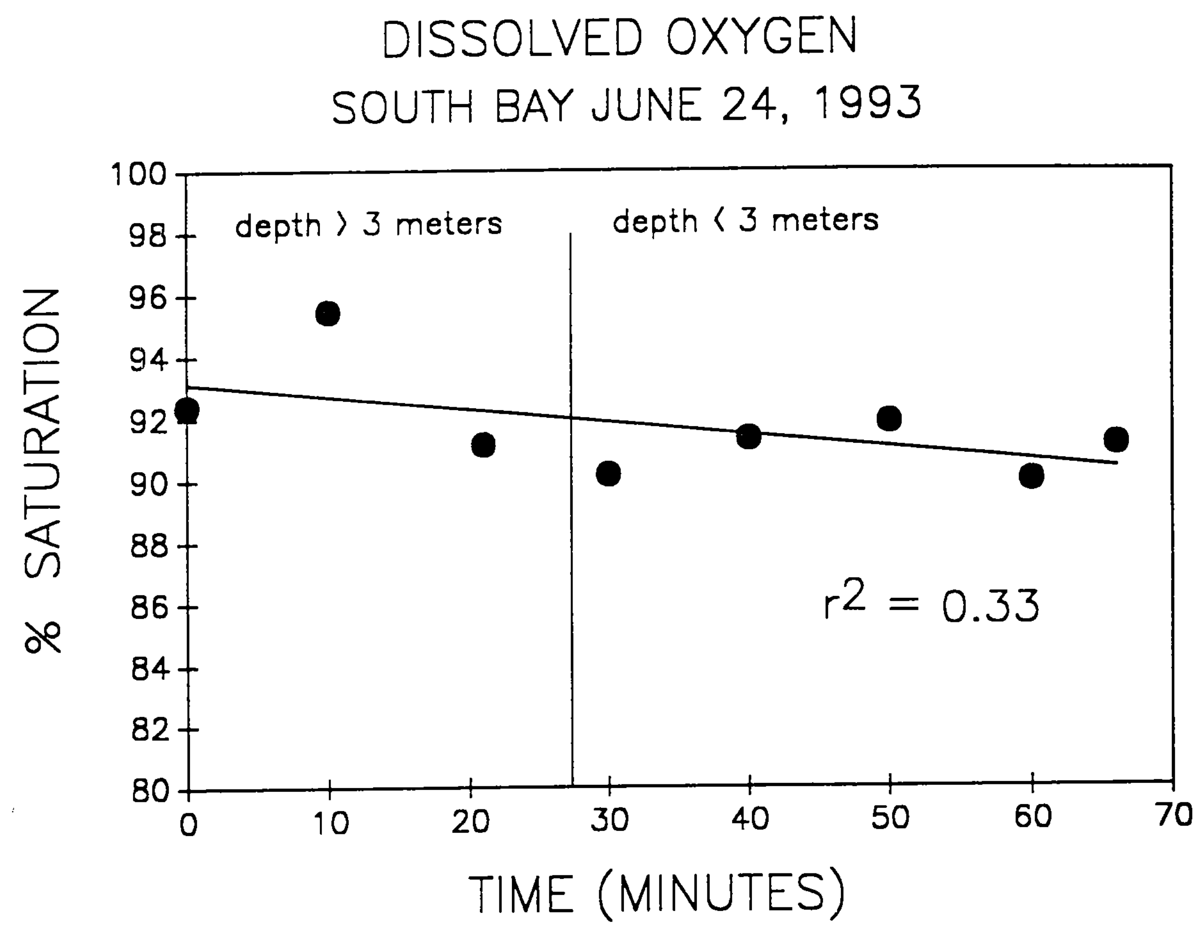

Figure 2. Time series regression of % dissolved O_2 saturation over a macrophyte bed at South Tivoli Bay, June 24, 1993. Water at 100 % O_2 saturation is in equilibrium with the atmosphere. The first three sample points were taken at depths greater than 3 meters, while the last five points were taken at depths of less than 3 meters. Macrophyte biomass was negligible on this date at the South Bay.

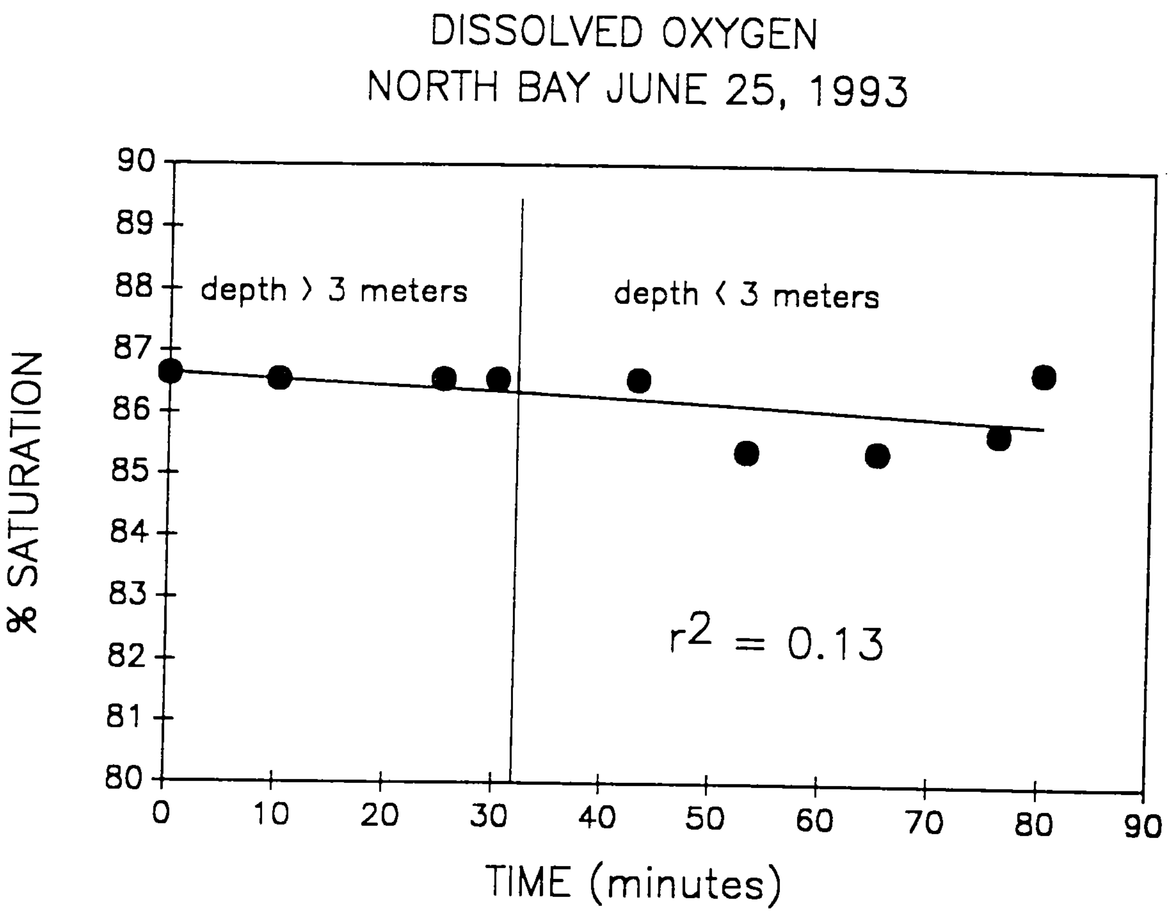

Figure 3. Time series regression of % dissolved O_2 saturation over a macrophyte bed at North Tivoli Bay, June 25, 1993. Water at 100 % O_2 saturation is in equilibrium with the atmosphere. The first four sample points were taken at depths greater than 3 meters, while the last five points were taken at depths of less than 3 meters. Macrophyte biomass was negligible on this date at the North Bay.

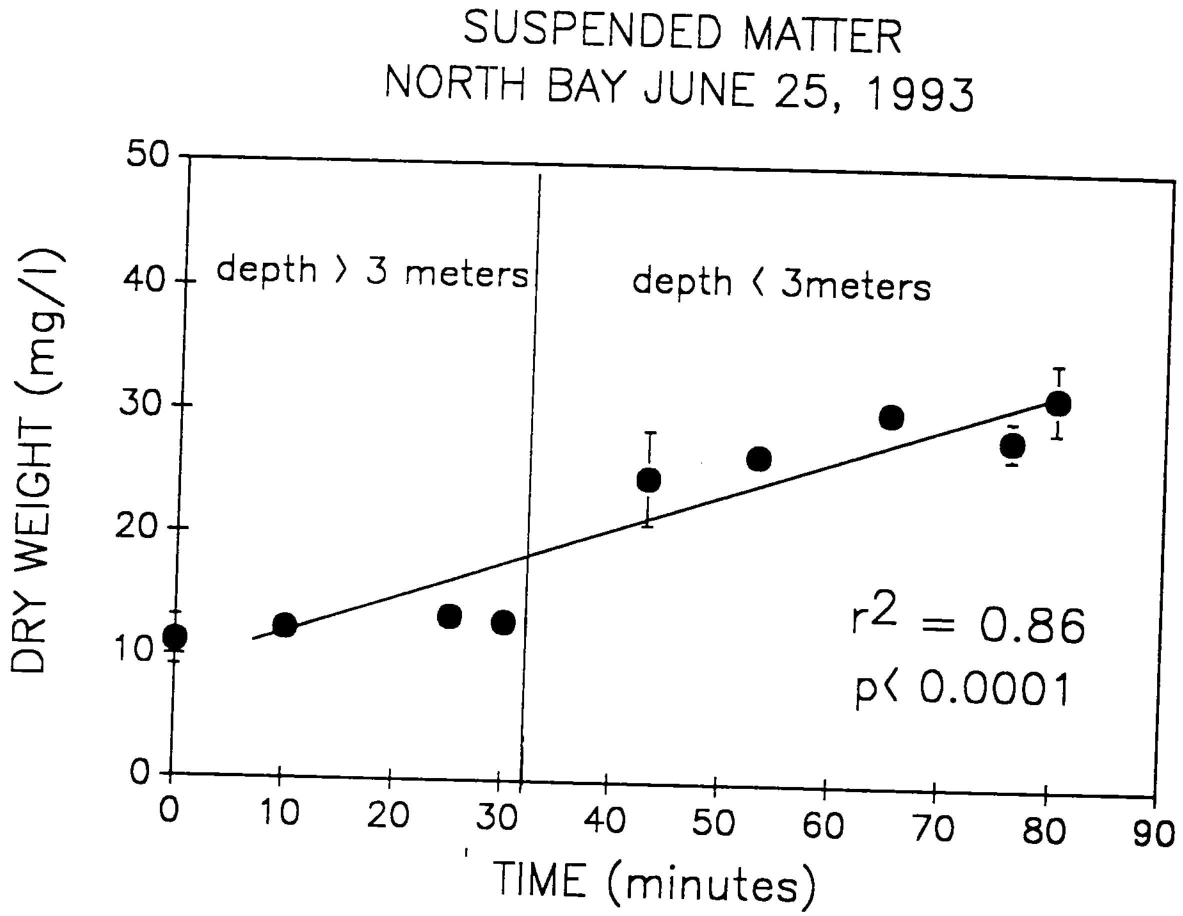

Figure 4. Time series regression of total suspended matter (mg dry weight / liter) over a macrophyte bed at the North Tivoli Bay, June 25, 1993. The first four sample points were taken at depths greater than 3 meters, while the last five points were taken at depths of less than 3 meters. Macrophyte biomass was negligible on this date at the North Bay.

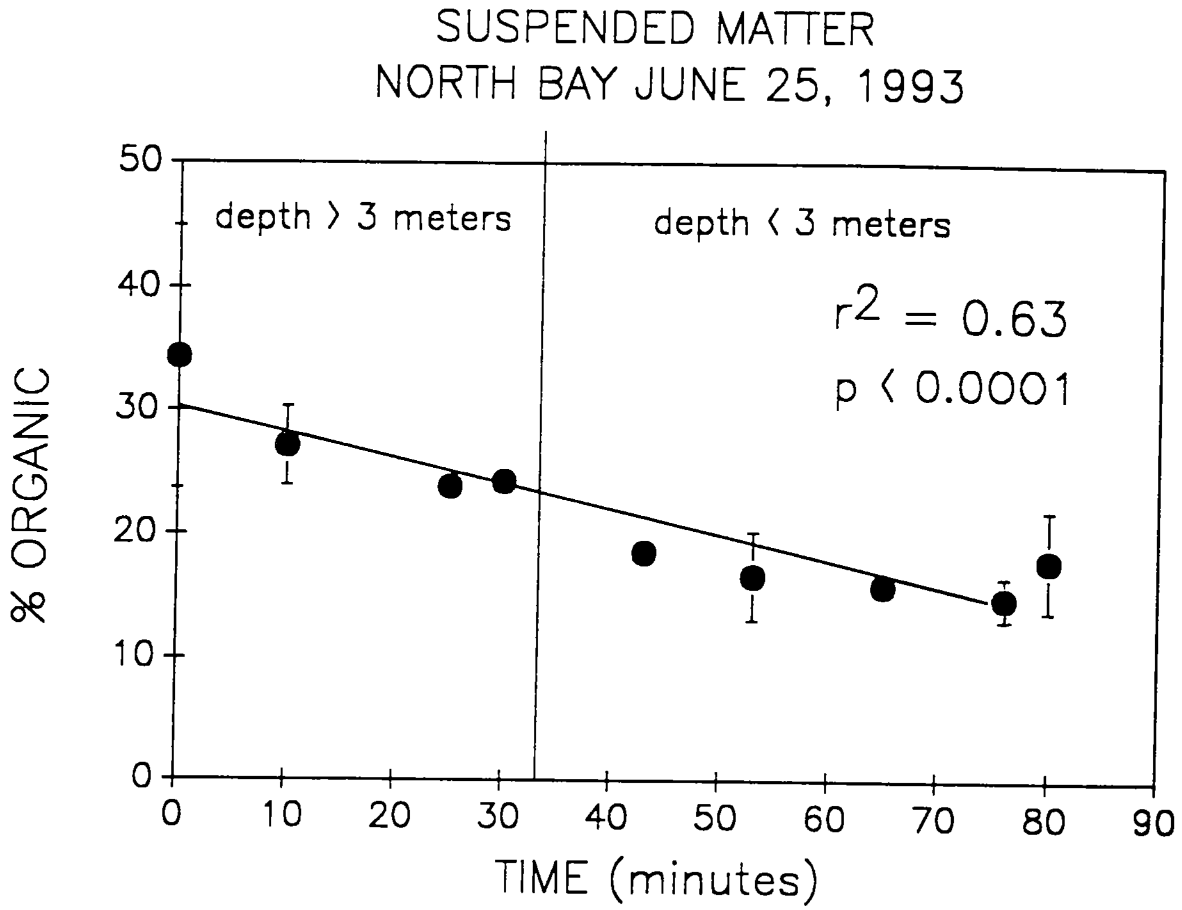

Figure 5. Time series regression of particulate organic fraction (% AFDW of total suspended matter) over a macrophyte bed at the North Bay, June 25, 1993. The first four sample points were taken at depths greater than 3 meters, while the last five points were taken at depths of less than 3 meters. Macrophyte biomass was negligible on this date at the North Bay.

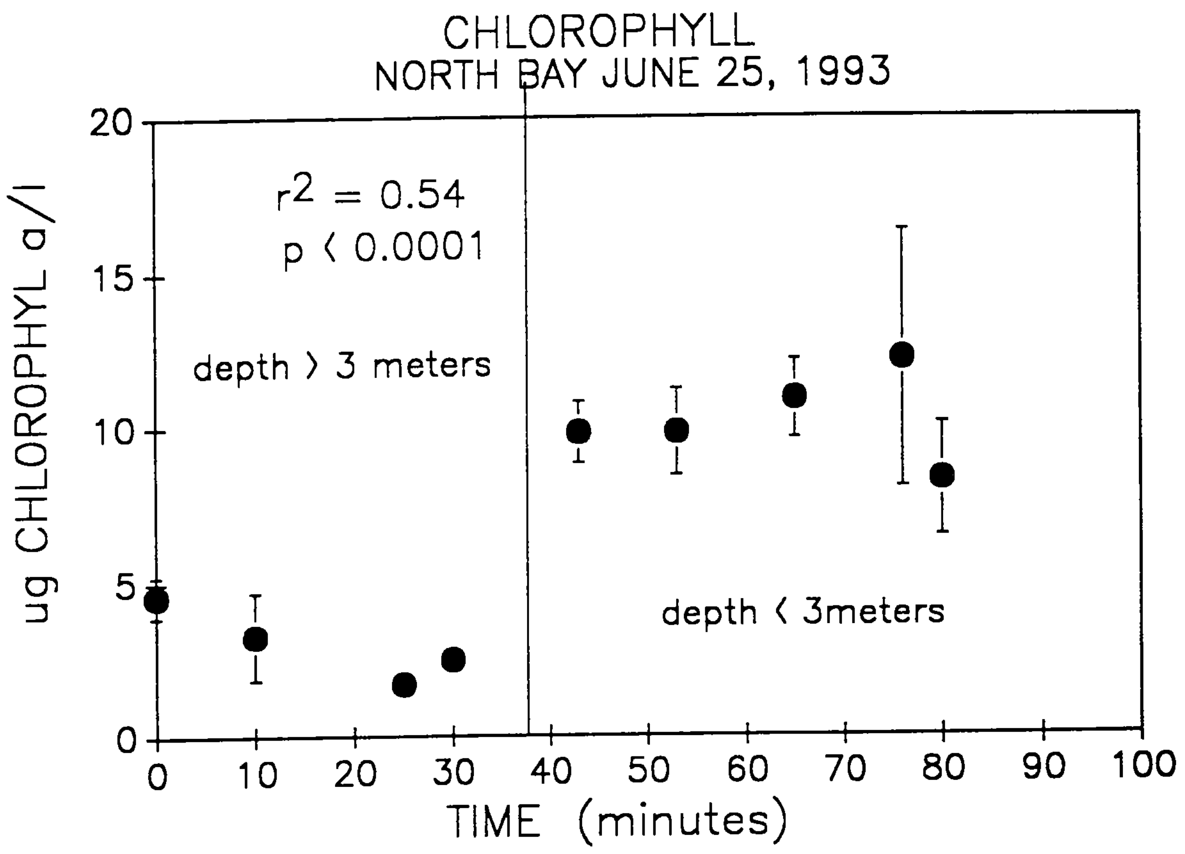

Figure 6. Time series regression of chlorophyll *a* concentrations over a macrophyte bed at North Tivoli Bay, June 25, 1993. The first four sample points were taken at depths greater than 3 meters, while the last five points were taken at depths of less than 3 meters. Macrophyte biomass was negligible on this date at the North Bay.

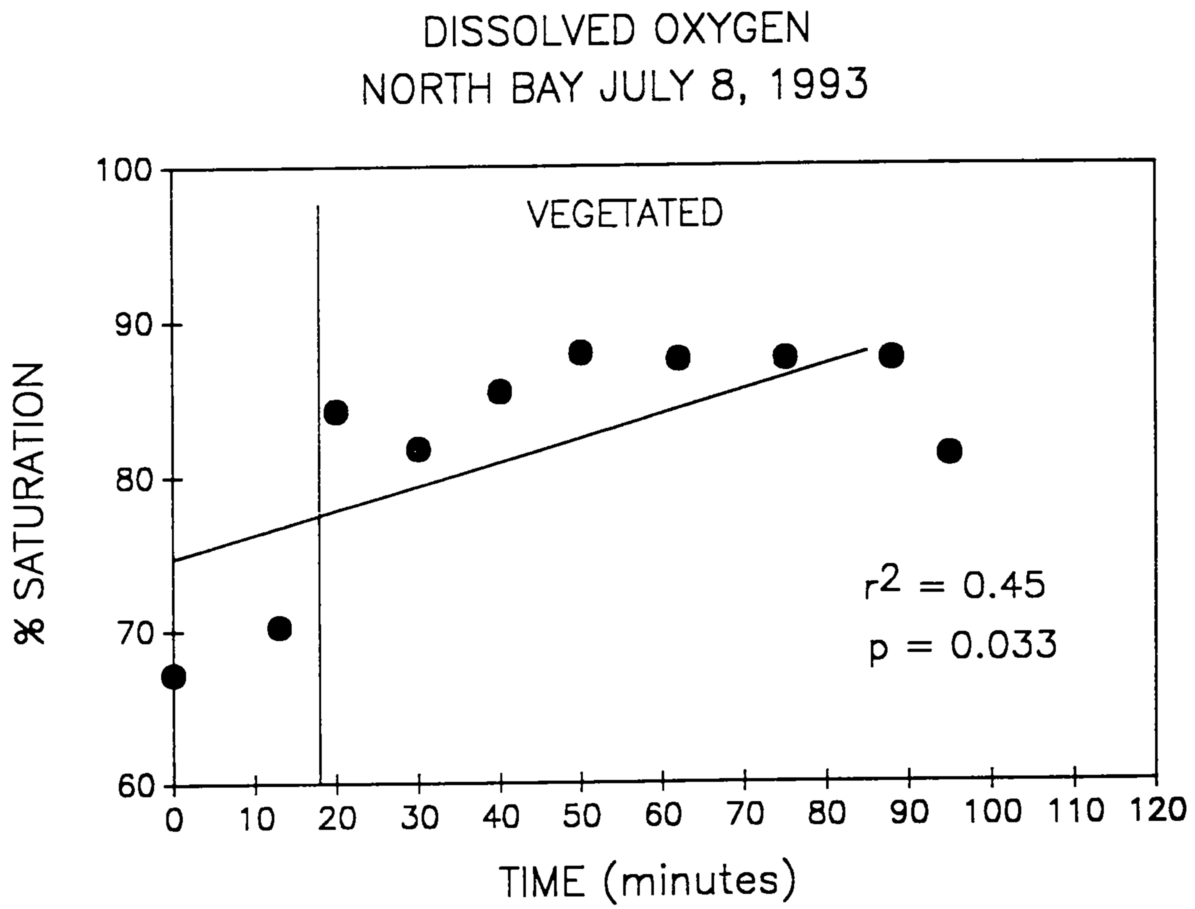

Figure 7. Time series regression of % dissolved O_2 saturation over a macrophyte bed at North Tivoli Bay, July 8, 1993. Water at 100 % O_2 saturation is in equilibrium with the atmosphere. The partition in the x-axis separates samples taken from unvegetated sites at depths of greater than 3 meters, from samples taken within a macrophyte bed at shallow depths.

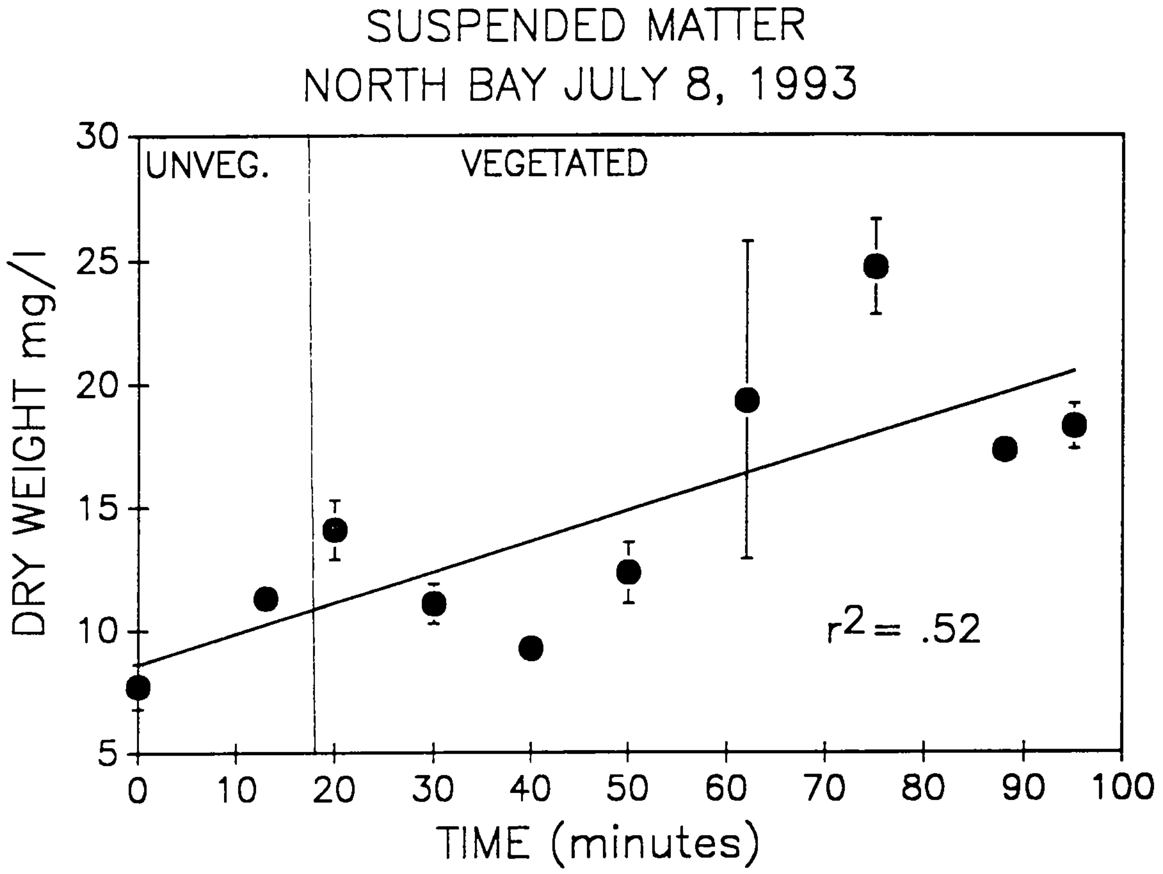

Figure 8. Time series regression of total suspended matter (mg dry weight / liter) over a macrophyte bed at the North Tivoli Bay, July 8, 1993. The partition in the x-axis separates samples taken from unvegetated sites at depths of greater than 3 meters, from samples taken within a macrophyte bed at shallow depths.

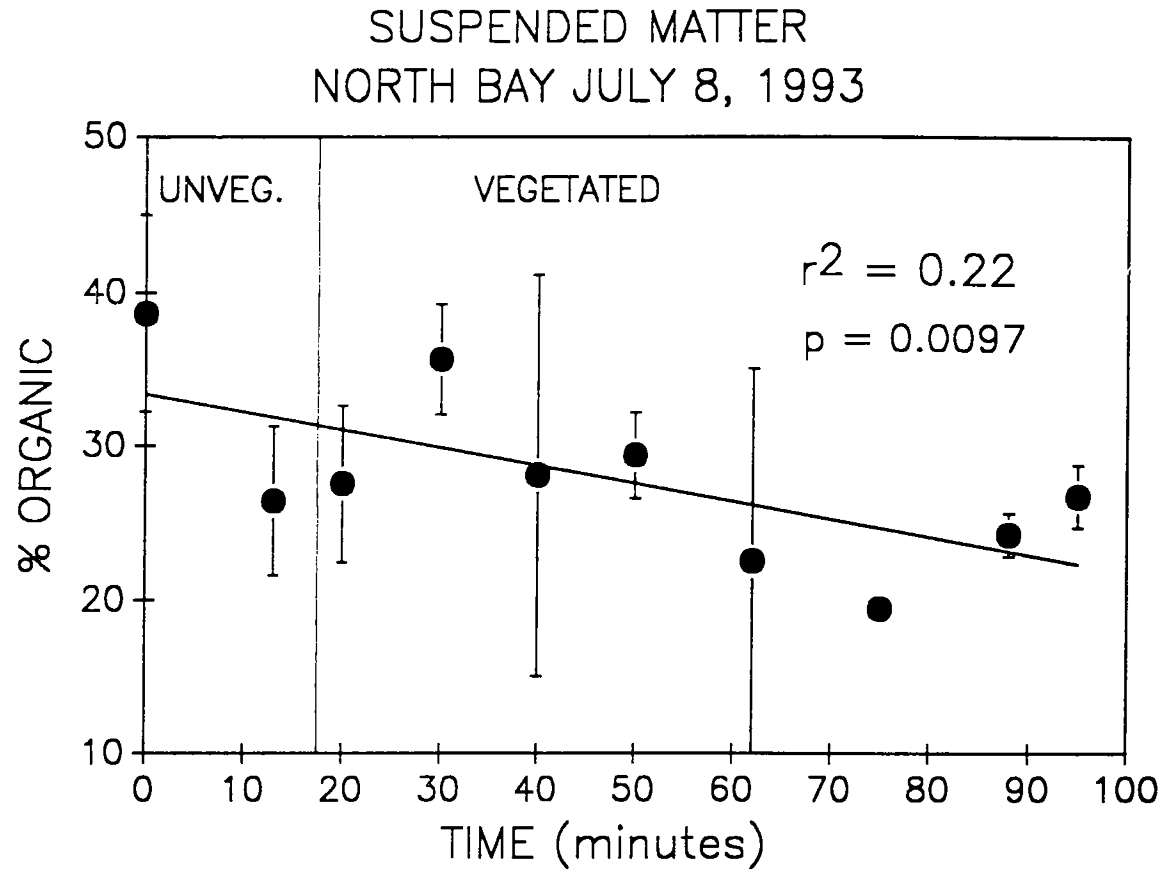

Figure 9. Time series regression of particulate organic fraction (% AFDW of total suspended matter) over a macrophyte bed at the North Tivoli Bay, July 8, 1993. The partition in the x-axis separates samples taken from unvegetated sites at depths of greater than 3 meters, from samples taken within a macrophyte bed at shallow depths.

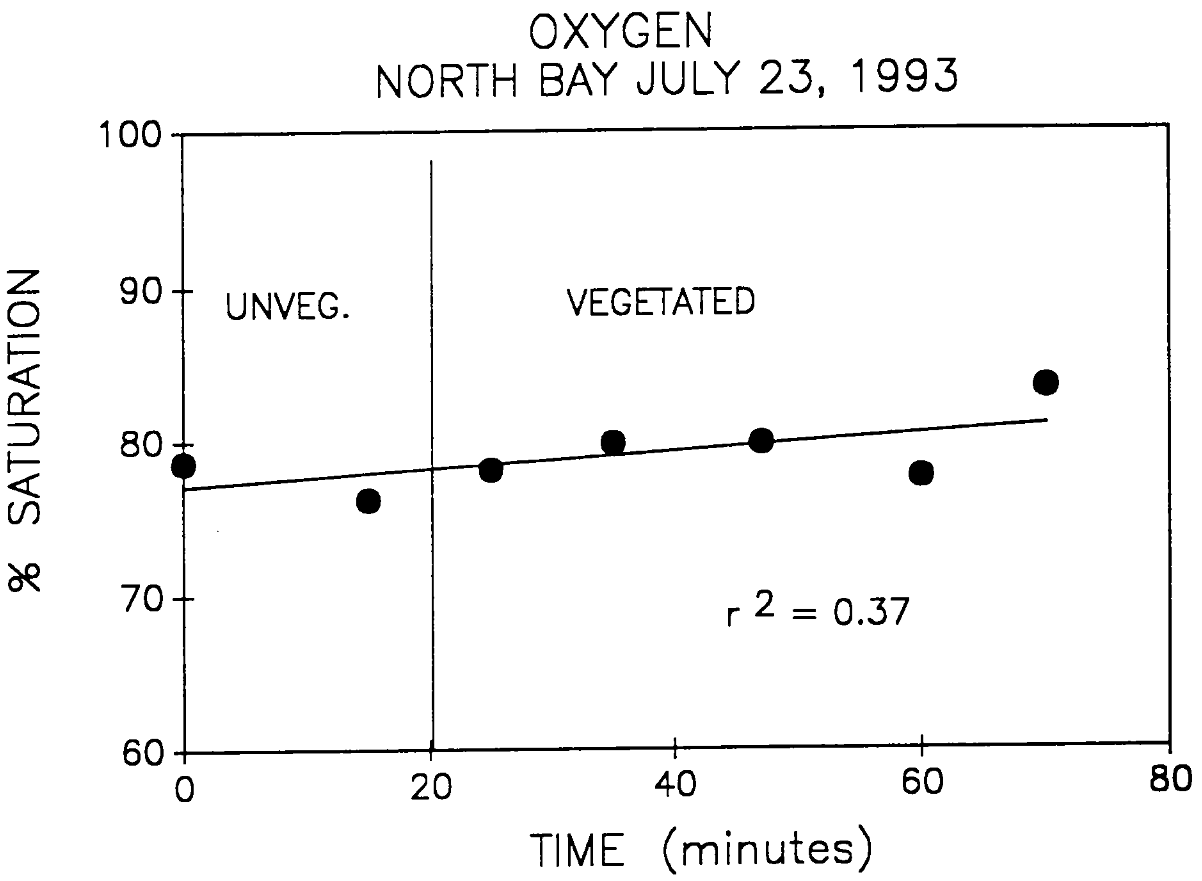

Figure 10. Time series regression of % dissolved O_2 saturation over a macrophyte bed at North Tivoli Bay, July 23, 1993. Water at 100 % O_2 saturation is in equilibrium with the atmosphere. The partition in the x-axis separates samples taken from unvegetated sites at depths of greater than 3 meters, from samples taken within a macrophyte bed at shallow depths.

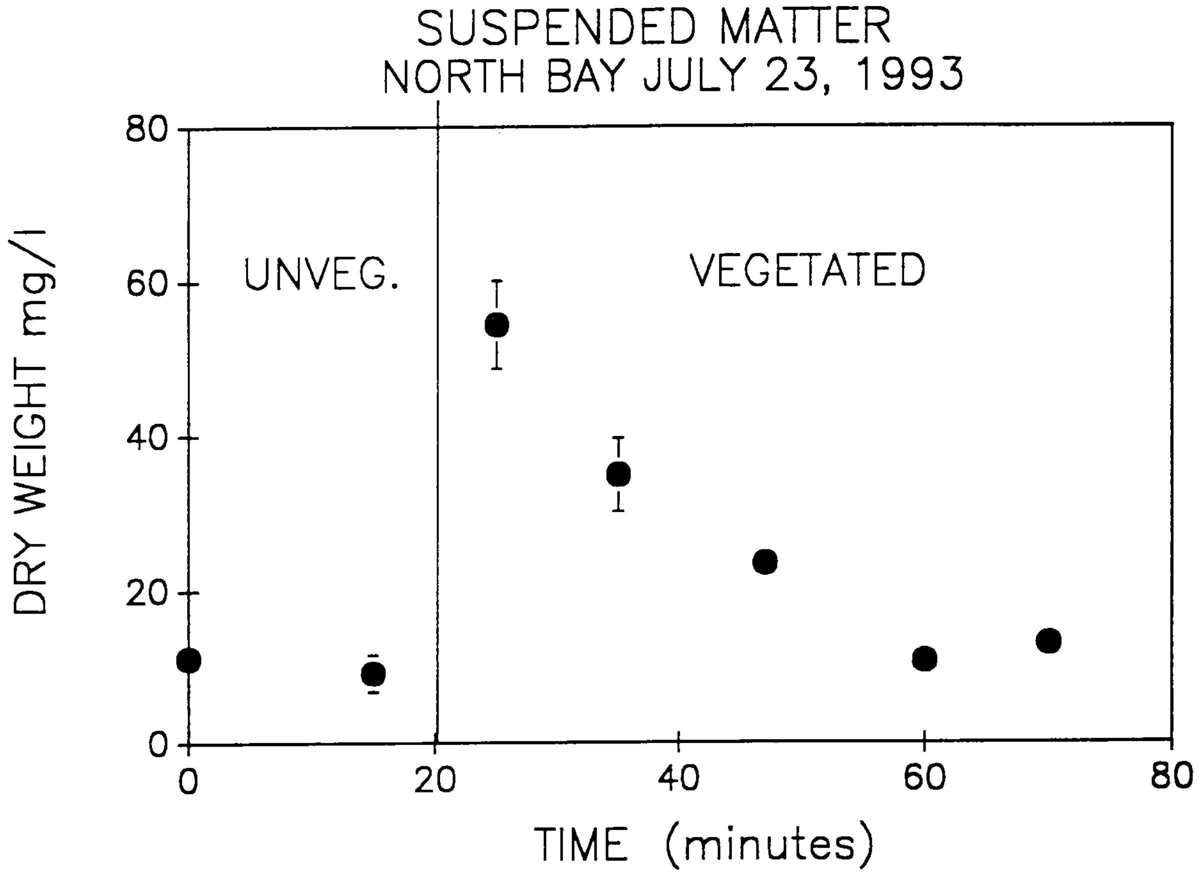

Figure 11. Time series regression of total suspended matter (mg dry weight / liter) over a macrophyte bed at the North Tivoli Bay, July 23, 1993. The partition in the x-axis separates samples taken from unvegetated sites at depths of greater than 3 meters, from samples taken within a macrophyte bed at shallow depths.

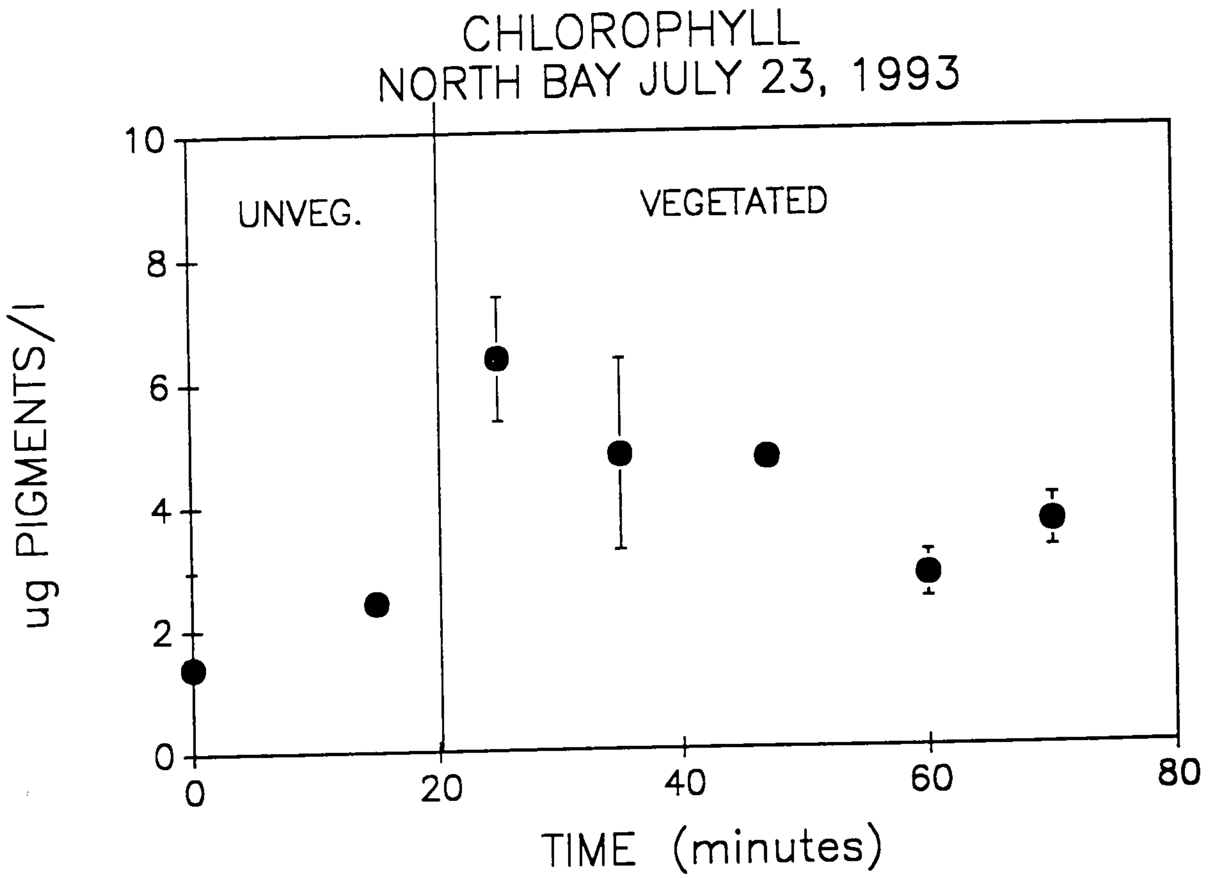

Figure 12. Time series regression of chlorophyll *a* over a macrophyte bed at the North Tivoli Bay, July 23, 1993. The partition in the x-axis separates samples taken from unvegetated sites at depths of greater than 3 meters, from samples taken within a macrophyte bed at shallow depths.

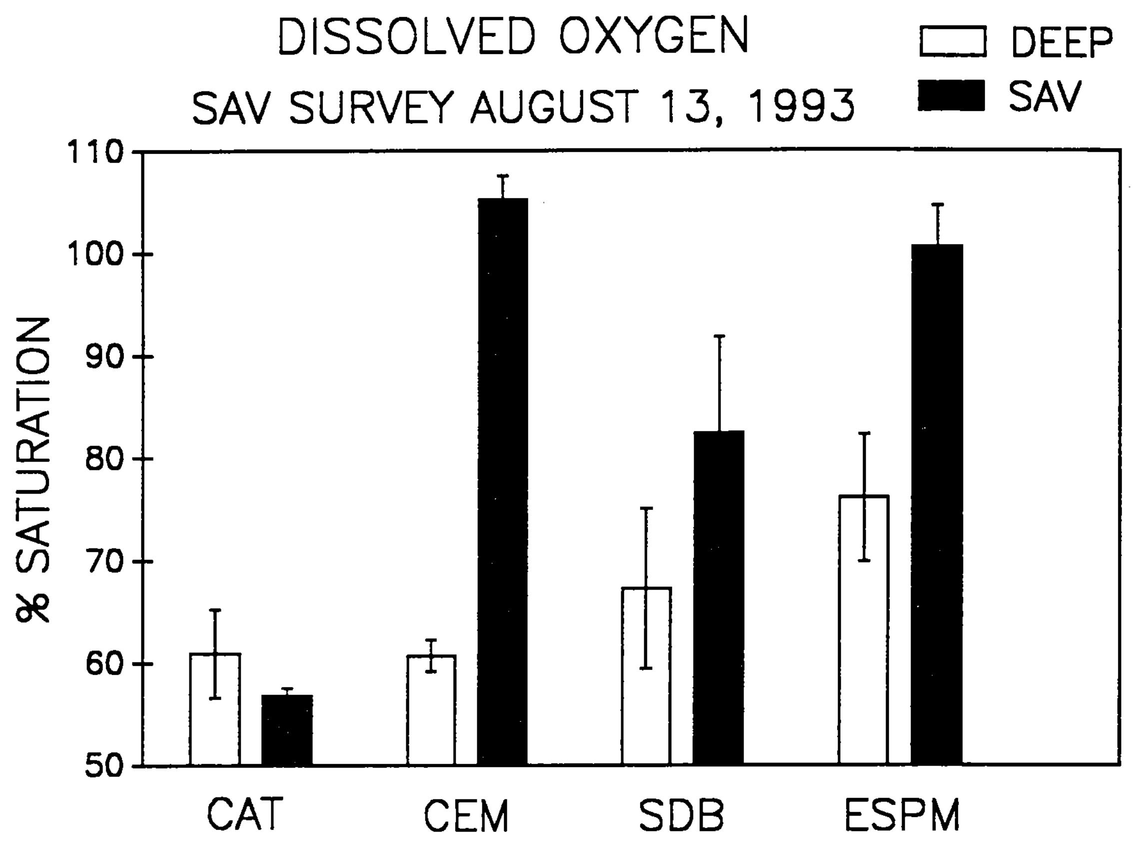

Figure 13. Comparison of % O_2 saturation between deep sites (unvegetated sites at depths greater than 3 meters) and SAV sites (macrophyte beds at shallow depths). Water at 100 % O_2 saturation is in equilibrium with the atmosphere. CAT = Cattskill, river km 182; CEM = Cementon, river km 170; SDB = Saddle Bags, river km 160: and ESPM = Esopus Meadows, river km 150.

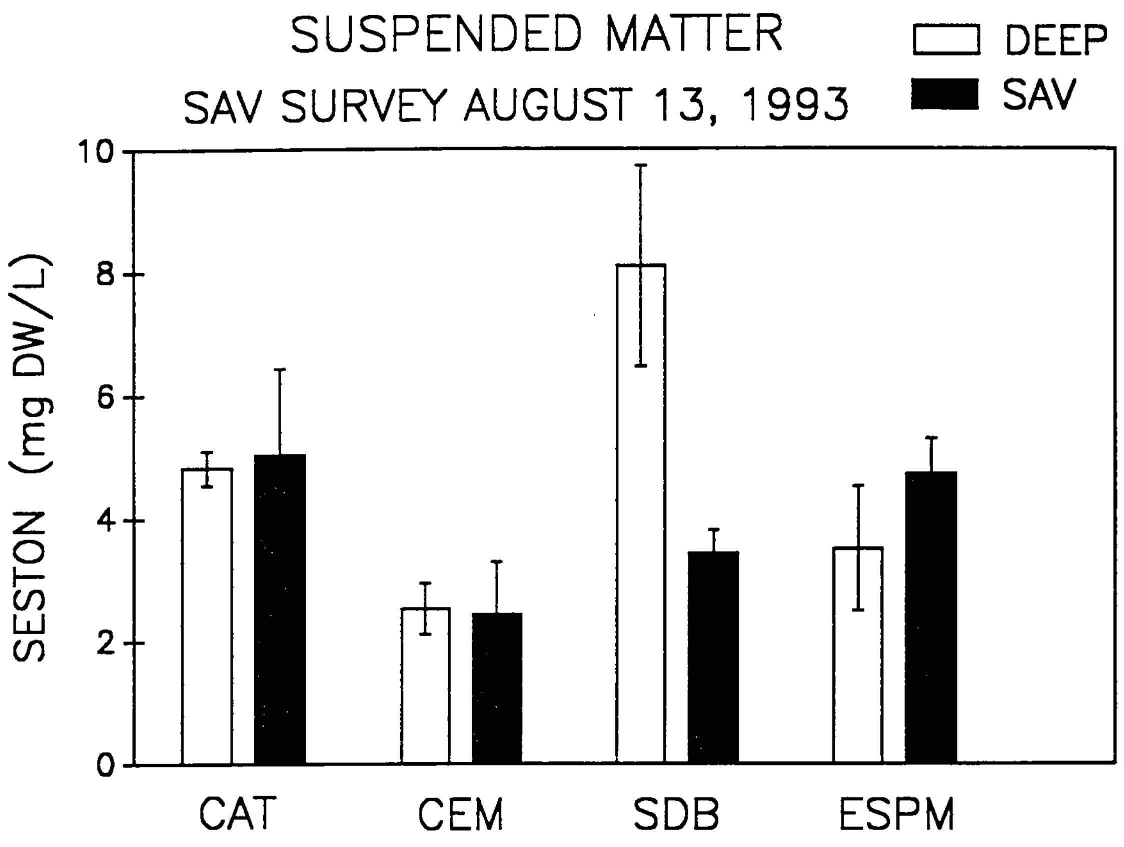

Figure 14. Comparison of total suspended matter concentrations in mg dry weight / liter, between deep sites (unvegetated sites at depths greater than 3 meters) and SAV sites (macrophyte beds at shallow depths).

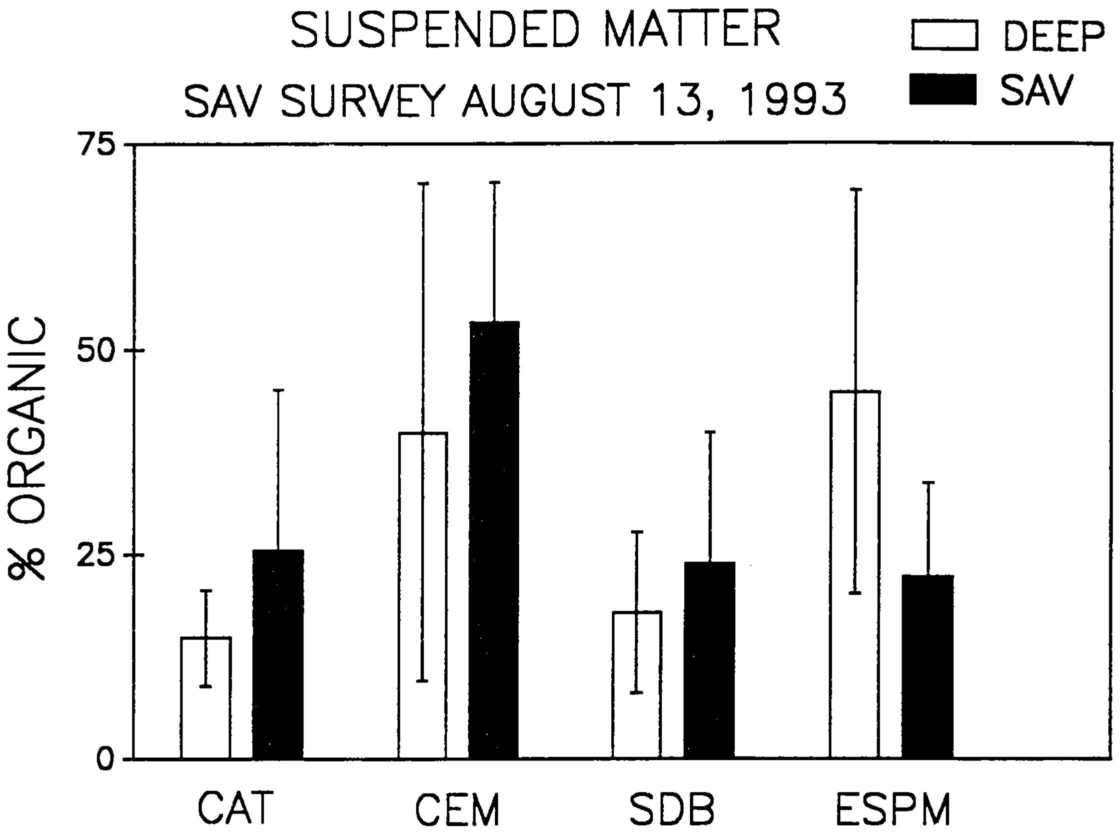

Figure 15. Comparison of particulate organic fraction (% AFDW of total suspended matter) between deep sites (unvegetated sites at depths greater than 3 meters) and SAV sites (macrophyte beds at shallow depths).

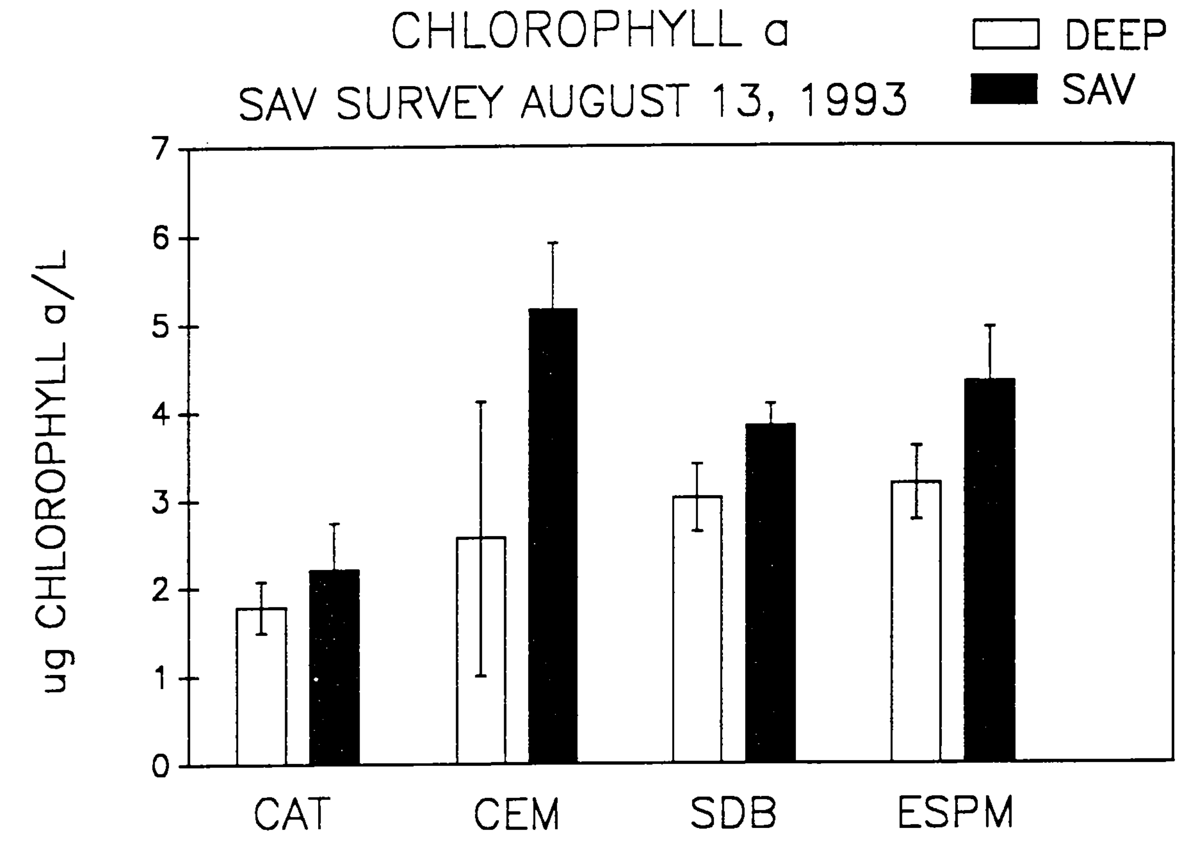

Figure 16. Comparison of chlorophyll *a* concentrations (µg / liter) between deep sites (unvegetated sites at depths greater than 3 meters) and SAV sites (macrophyte beds at shallow depths).

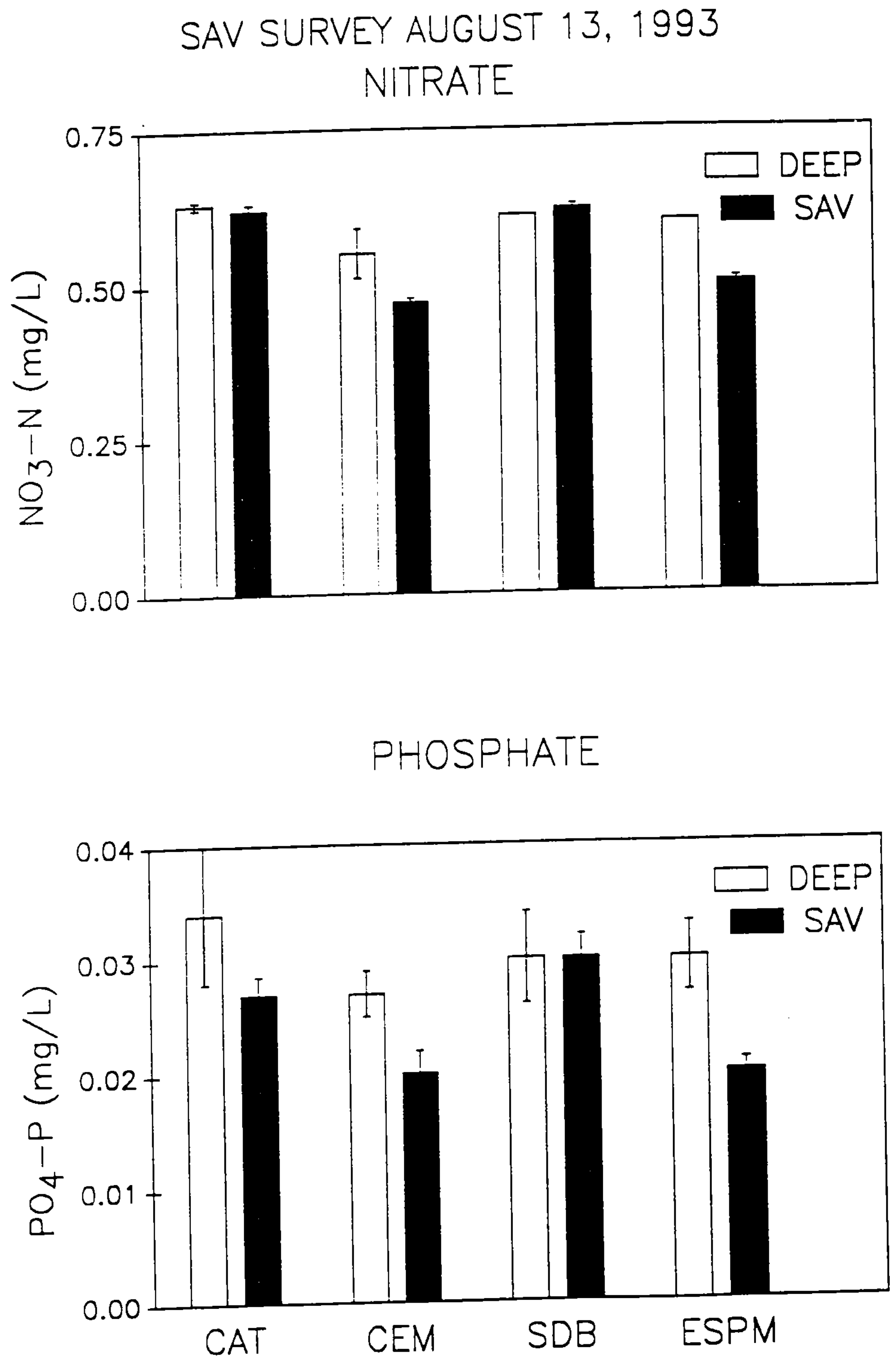

Figure 17. Comparison of NO_3 and PO_4 concentrations (mg / liter) between deep sites (unvegetated sites at depths greater than 3 meters) and SAV sites (macrophyte beds at shallow depths).

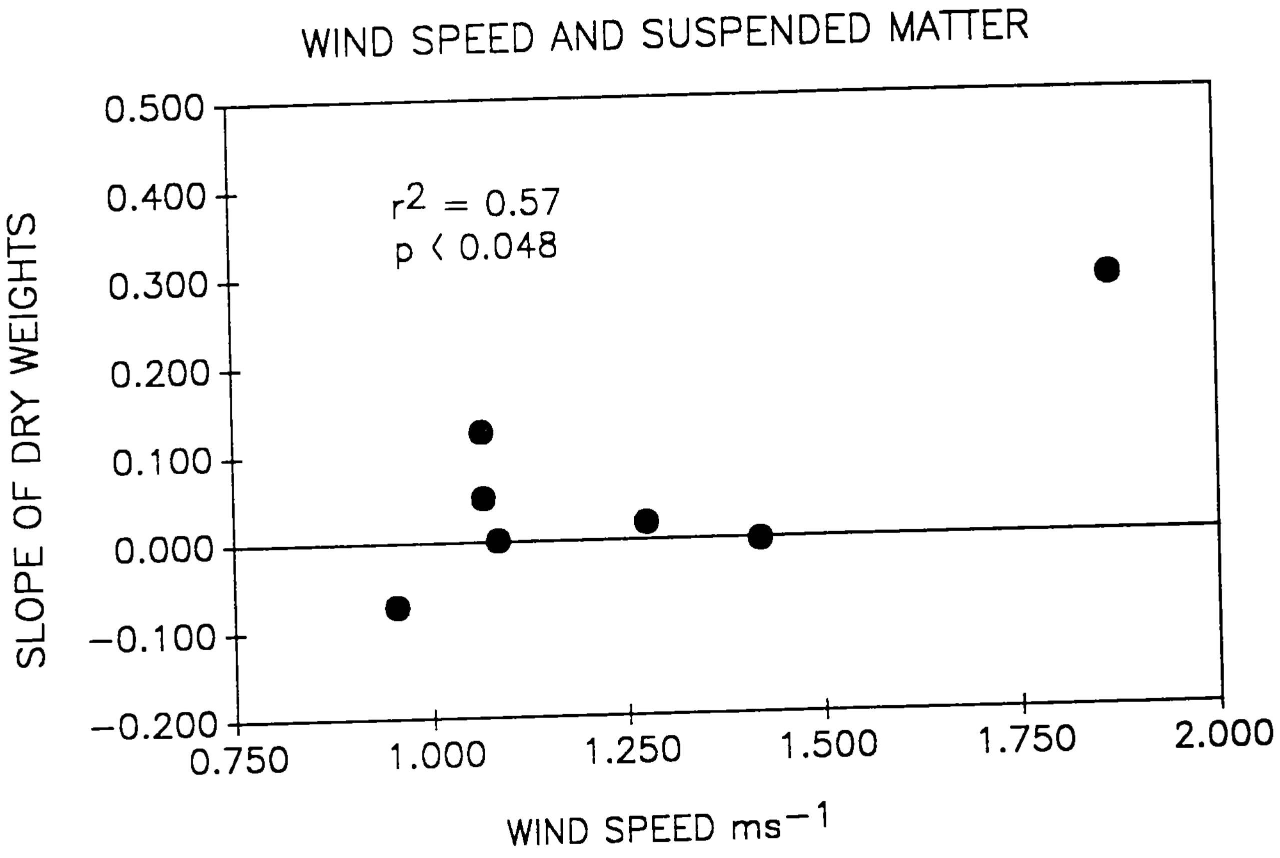

Figure 18. Regression of slopes from time series observation of suspended matter over SAV beds against mean hourly wind speeds (meters / second). Positive slopes (y -axis) indicate increasing concentrations of seston over a bed, negative slopes show a decrease in the concentrations of seston over a SAV bed.

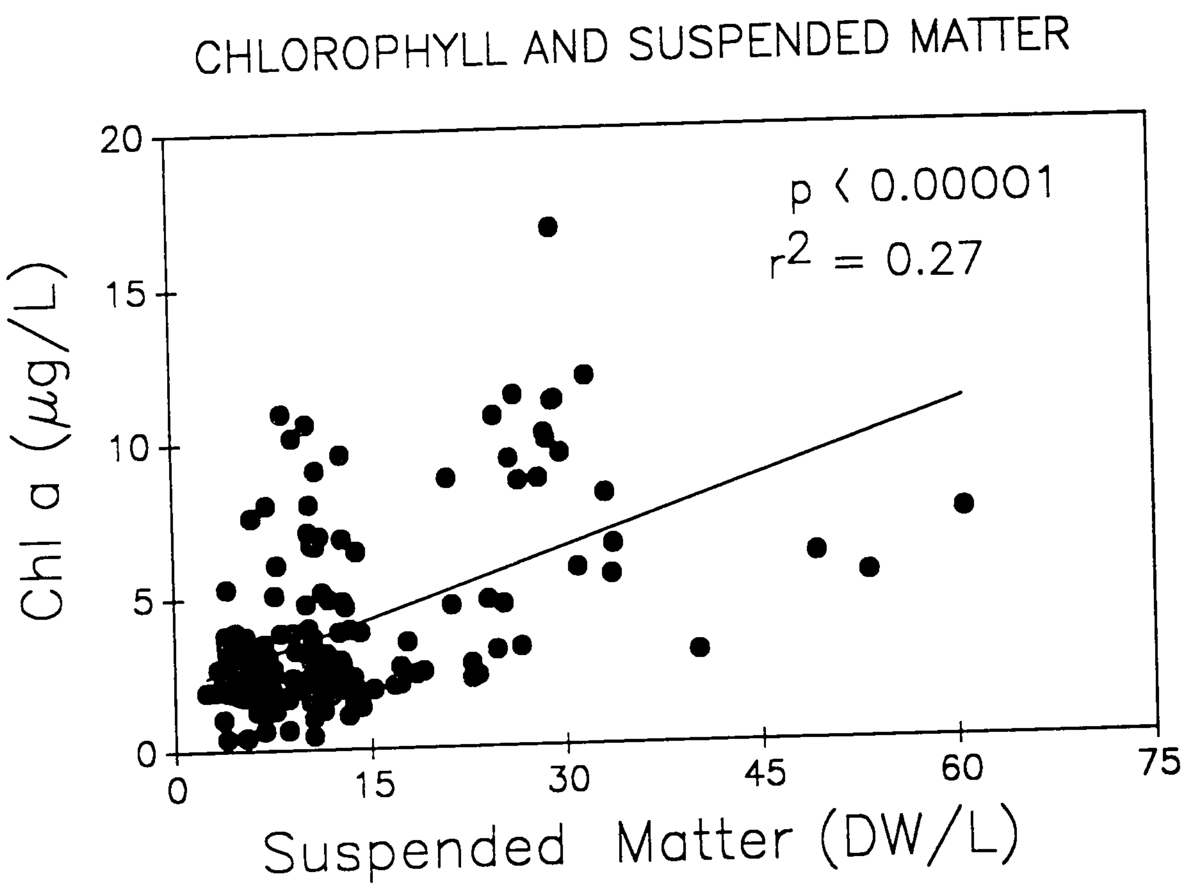

Figure 19. Regression of chlorophyll *a* (µg / l) concentrations against suspended matter (mg/l dry weight), including all sample points from the Tivoli Bays, Cattskill, Cementon, the Saddle Bags, and Esopus Meadows.

DISCUSSION

This study has demonstrated a significant amount of variability among different macrophyte beds in their ability to manipulate their physical and chemical environments. We saw that the effects of SAV on biogeochemical processes vary on a spatial as well as a temporal scale. The ability of these plants to enrich oxygen concentrations above main channel concentrations was noted and served as an indication of macrophyte presence. Macrophyte effects upon sedimentation and organic matter dynamics, however, were not as clear and were often contrary to the findings of previous investigations.

Suspended sediment

The reported ability of macrophytes to act as a sieve for fine grained suspended matter was not evident in this study. On all but two dates at the Tivoli Bays, seston concentrations increased across the macrophyte beds. I found a positive correlation between average wind speed and the slopes of suspended matter over the bays, indicating that these increased seston concentrations are at least partially due to wind driven resuspension of benthic sediments. The increased seston concentrations on June 24 and 25, while macrophyte biomass was still negligible, can be attributed to greater resuspension at shallower depths across the bay without the mitigating effects of SAV. However, with the exception of July 7 and August 23, similar increases were expressed throughout the Tivoli Bays to different degrees of magnitude and at various levels of significance. July 8, for instance yielded a positive slope that was highly significant despite the presence of abundant macrophytes, due possibly to a combination of wind driven resuspension and shallow depths. Although the data observed on July 7 and 23 are not statistically significant, July 23 does show an interesting trend. On this date an immediate peak in suspended matter was observed as the water mass moved into shallow water and then a subsequent decline as the water mass moved further over the bed until seston concentrations were again at ambient river levels. There is an identical trend expressed for chlorophyll on the same date . Considering the correlation between seston and wind speeds one can interpret this trend as an initial increase in seston concentrations due to wind driven resuspension before a gradual deposition of sediment and a mitigation of resuspension, as macrophyte biomass retards water flow and filters out suspended matter. Other dates showed few effects at all upon suspended sediments. Although, both August 3 and 5 exhibited positive slopes, they were insignificant, as was the negative slope of July 7, showing no statistically significant change in suspended matter over the length of the macrophyte bed . It is likely that on these dates the filtering effects of submersed vegetation were balanced by wind driven resuspension.

Kemp et al. (1984) discussed the ability of submersed vegetation to dampen the effects of wind driven resuspension and erosion in the Chesapeake Bay where reported macrophyte biomass are generally much denser than the Hudson, achieving above ground standing stocks as high as 500 g dw/m^2. In the Hudson, where SAV densities are generally less than 200 g dw/m^2 (Harley and Findlay, 1994) these wind dampening effects would be less pronounced, allowing resuspension due to wind to overcome the filtering capacity of macrophyte beds. Additionally, the Chesapeake Bay experiences higher main channel concentrations of suspended matter. Kemp et al. (1984) reported mean September seston concentrations of over 80 mg dw/l in an unvegetated plot, with 3-20 times lower concentrations in an adjacent bed of *Potamogeton.*. Dennison et al., (1993) found suspended matter concentrations within SAV beds to be generally less than 15 mg dw/l in the Chesapeake Bay. In the Hudson, the annual average is 16.9 mg dw/l (Findlay et al., 1991), while this study found a mean of 12.64 mg dw/l in vegetated beds of the Tivoli Bays over the 1993 growing season.

Seston concentrations measured in our survey from four sites, showed significant decreases in vegetated beds at only one site (Fig. 14). At the Saddle Bags (SDB) there was more than a two-fold decrease in suspended matter within the macrophyte bed. In the other sites, the difference between habitats was negligible, while the overall variation among the sites was highly significant. There are differences in both absolute quantities of suspended matter and in functioning of SAV among the various locations. The heterogeneity among sites represent important implications upon river sediment dynamics. Findlay et al. (1991) reported that there was little variation in seston concentrations through a 150 km stretch of the mid-Hudson River over a three year period. This variation among macrophyte beds represents complex interactions on a physical and biological scale.

In the Hudson, where light is the limiting factor to primary production (Malone, 1977; 1984; Cole et al., 1992) and turbidity may influence species composition within vascular plant communities (Harley and Findlay, 1994), sedimentation dynamics play an important role in river management. Because macrophyte communities seem to have such a variable impact on suspended matter, and do not correlate well with models from other systems, it is apparent that SAV acts differently under different circumstances. Differences in plant density and species composition could account for variation within the Hudson, as well as among systems. It is likely that wind and tidal action have important effects on whole river sedimentation processes.

Organic Matter Processing

Wetzel (1969) states that submersed plants can exude up to 10 percent of their total photosynthate as dissolved organic carbon (DOC) to the water column, Penhale and Smith (1977), Mickle and Wetzel (1978b), and Wetzel and Penhale (1979), all report that submersed vegetation is an important source of DOC, contributing directly to the heterotrophic metabolism of macrophyte communities. In the Hudson, DOC represents half the organic carbon available in the water column and varies little through the mid-Hudson River (Findlay et al., 1991). We found no effect of macrophyte communities upon DOC concentrations in either the Tivoli Bays study or the macrophyte survey. It is possible that exudates are less than 10 % or that labile plant exudates are quickly metabolized by epiphytic microorganisms and invertebrates. This rapid turnover would underestimate the importance of macrophyte derived DOC in these communities.

The organic fraction of suspended matter (% AFDW) was found to be inversely related to seston, and in all but one sample date declined across SAV beds at the Tivoli Bays. On July 23 at North Bay, particulate organic matter increased across the bay as both a percentage of suspended matter and absolute weight, but not significantly (Table 3). With two exceptions, organic matter by weight, did not change significantly across the bays . On June 25 and July 7, where rather large concentrations of sediment were also observed, chlorophyll *a* increased significantly across the macrophyte bed. Considering the positive correlation between chlorophyll *a* and seston, and the significant increases in chlorophyll concentrations observed on these dates in particular, it follows that at least a portion of this organic fraction consists of resuspended benthic algae or fairly fresh plant material. Kemp et al. (1984) reported a rapid degradation of chlorophyll *a*, so it is unlikely that these concentrations are a result of senesced macrophyte tissue. Findlay et al. (1991) found that particulate organic carbon (POC) varied considerably through the river and over a period of several years, stating that both autochthonous primary production and resuspension of detrital organic matter are contributing to POC standing stocks. Fringing wetlands and SAV may be an important source of POC to the Hudson River on an annual scale. On a seasonal scale, however, this study did not demonstrate that macrophyte beds are acting as a trap for organic matter. Resuspended sediment was shown to decrease in organic content across the macrophyte beds. This cline in organic content has very important implications to invertebrate and microfaunal populations, especially those organisms that do not graze selectively. Filter feeders must work harder to obtain more organic matter as the inorganic fraction rises relative to the organic, across a macrophyte bed.

Nutrient Dynamics

Previous work on macrophyte effects upon nutrient cycling in lakes, rivers and estuaries has shown both consumption and release of nitrogen and phosphorous (Carpenter and Lodge, 1986). The relations between SAV and nutrient content has been found to vary even among identical plants within the same site (Hutchinson, 1975; Kimball and Baker, 1982; 1983). In this study, SAV demonstrated no immediate effect upon nutrients at the Tivoli Bays. However, we found evidence for consumption of both nitrate and phosphate (Fig 17 and 18) at macrophyte survey sites with high biomass (Table 5) and greatest concentrations of dissolved oxygen (Fig. 13). Active oxygen production implies high metabolism, which requires concurrent nutrient assimilation. Macrophyte beds accumulating biomass may well act as short-term sinks for nitrate and phosphate in the Hudson.

The extent of knowledge concerning macrophytes in the Hudson River Estuary is limited. Considering the worldwide decline in SAV biomass (Dennison et al. (1993), and the changes likely to occur in the Hudson, because of exotic species introduction, increased population pressures and changes in land use patterns, it is important to obtain baseline data on macrophyte distribution and abundance as well as potential ecosystem level effects. This study revealed that the effects of submersed aquatic vegetation in the mid-Hudson River are heterogeneous on both a spatial and temporal scale. Sedimentation and organic matter dynamics often did not follow the predictions of past studies in other systems. It cannot be taken for granted that models from lakes and small rivers or streams can effectively describe biogeochemical processes in the Hudson. Management agencies must recognize this variability and plan strategies accordingly. It is evident that decisions concerning SAV must be made on a site by site basis. More intensive monitoring efforts are necessary before we can more fully understand the role that these communities play on whole river ecosystem processes.

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