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Abstract: In order to help assess the cause of the recent decline in submersed macrophytes, light attenuation was measured at selected stations in Back Bay, Virginia, in July 1987 and April 1988, using an underwater spectroradiometer. Secchi depth and concentrations of total suspended solids and chlorophyll-*a* were measured simultaneously. In July 1987, extinction coefficients ranged from 2.7 to 5.7 m^{-1} and Secchi depths ranged from 0.26 to 0.44 m. Total suspended solids ranged from 27 to 64 mg/L—37 to 80% of the suspended material was organic matter. Chlorophyll-*a* concentrations ranged from 43 to 71 μ g/L, indicating the presence of large numbers of algae. Water clarity was least in North Bay and greatest at the North Carolina border. In April 1988, during a period of strong wind, total suspended solids were extremely high, ranging from 78 to 214 mg/L, whereas the organic fraction ranged from 20 to 30%. Chlorophyll-*a* concentration ranged from 34.5 to 88 μ g/L. Secchi depth ranged from 0.16 to 0.33 m and K ranged from 3.7 m^{-1}at the North Carolina line to 19.9 m^{-1} in a canal near Pellitory Point. Comparison of the conditions in Back Bay in 1986-88 with those in the tidal Potomac River and Estuary indicate that the decline in submersed macrophytes in Back Bay is related to high light attenuation.

Introduction

The distribution and abundance of submersed aquatic macrophytes in tidal waters such as Back Bay are controlled by numerous factors, including the availability of light (Carter et al. 1985; Carter and Rybicki, 1990; Kemp et al. 1983; Batiuk et al. 1991). Light attenuation in the water column increases as total suspended solids (TSS) and chlorophyll-a concentrations increase; increases in chlorophyll-a are often the result of nutrient enrichment that encourages algal growth (Phillips et al. 1978; Moss 1983; Kemp et al. 1983; Carter et al. 1983, 1985; Haramis and Carter 1983). Submersed macrophyte populations in Back Bay have fluctuated dramatically during the 1900s (Sincock 1965; Mitchell Norman, Virginia Department of Game and Inland Fisheries, personal communication, 1990). Recently, there has been a serious decline in those populations (Mitchell Norman, Virginia Department of Game and Inland Fisheries, personal communication, 1990) and several theories, including changing salinity, decreases in water clarity, and increasing nutrients, have been advanced to explain this decline.

In 1987, the Virginia Department of Game and Inland Fisheries asked the U.S. Geological Survey (USGS) to ascertain the cause of the recent decline in submersed macrophytes in Back Bay. The USGS measured light attenuation at selected stations in July 1987 and in April 1988. Secchi depth and TSS and chlorophyll-a concentrations were measured simultaneously. This paper summarizes the results of the study.

Methods

Measurements were made at seven stations in North Bay and Back Bay in July 1987 and at five stations in Back Bay in April 1988 (fig. 1). Light attenuation was measured with a portable Licor[1] submersible scanning spectroradiometer equipped with a hemispherical silicon detector, a holographic grating monochrometer and filter wheel to select narrow bandwidths, and an internal computer that handles all data collection and storage. Light energy, in watts per square meter Wm^{-2}, was measured at 5-mm intervals from 400 to 800 nm; each measurement represents the average of either 5 or ten complete scans. Measurements were made about 1 m from the boat on the side facing the sun. Secchi depth measurements were also made at each site.

Extinction coefficients were calculated from;

$$I_z = I_o e^{-kz}$$

where I_z = average irradiance at depth z, in Wm^{-2};
I_o = average irradiance just below the water surface;
K = extinction coefficient (m^{-1}).

Depth-integrated water samples were collected at all sites. Phytoplankton were filtered onto glass-fiber filters, chlorophyll-*a* was extracted with 95% acetone, and chlorophyll-*a* and phaeophyton were determined fluorometrically (Blanchard et al. 1982). TSS samples were vacuum-filtered through tared glass-fiber filters, freeze dried for 3 h, and reweighed to obtain total suspended solids. Ash-free dry weights and organic matter content of the suspended solids were determined after combustion at 500°C in a muffle oven for 2 to 3 hrs.

Regressions of K with TSS and chlorophyll-*a* concentration were run with Minitab (Minitab 1986).

Results

Water clarity was very poor in Back Bay in 1987 and no submersed macrophytes were observed. Light-extinction coefficients ranged from 2.7 m^{-1} at Pellitory Point to 5.7 m^{-1} in North Bay and Secchi depths at the stations ranged from 0.26 to 0.44 m (table 1). TSS ranged from 37 to 64 mg/L—37 to 80% of the suspended material was organic matter. Chlorophyll-*a* concentrations ranged from 42.8 to 70.9 μ g/L, indicating the presence of relatively large numbers of phytoplankton. Water clarity was least in North Bay and greatest near the Virginia-North Carolina border. Water clarity was less in April 1988 than in July 1987 because of high winds that resuspended phytoplankton and sediments. Extinction coefficients ranged from 3.7 m^{-1} at the North Carolina line to 19.9 m^{-1} in a canal near Pellitory Point and Secchi depth ranged from 0.16 to 0.33m (table 1). *Myriophyllum spicatum* was only found near the North Carolina site. TSS ranged from 78 to 214 mg/L—only 20 to 30% of the suspended material was organic matter—and chlorophyll-*a* concentration ranged from 34.5 to 88.0 μ g/L.

Figure 2A shows the extinction coefficients by wavelength between 400 and 800 nm (visible plus near infrared) for stations 20 (Pellitory Point), 14 (Drum Point) and 9 (North Bay) in July 1987. Figure 2 also shows TSS and chlorophyll-*a* concentration for these stations. In these coastal waters, blue light (400 to 500 nm) hardly penetrates into the water, and the wavelength of maximum light penetration is shifted from the blue-green found in clear near-coastal waters to the orange (570 to 590 nm) or the near-IR (>700 nm) (Carter and Rybicki 1990). Chlorophyll-*a* and TSS concentrations were highest at station 9 and lowest at Station 22 in 1987 (table 1). Extinction coefficients for three of the five stations sampled in April 1988 are shown in figure 2B. Changes in extinction coefficient from station to station were caused primarily by differences in TSS concentration.

Regression analysis showed that TSS concentration explained 72.7% of the variation in K in 1987 and 95.6% of the variation in K in 1988 (table 2). When all data were combined, TSS concentration explained 85.1% of the variability in K. Chlorophyll-*a* concentration explained 75.6 percent of the variability in K in 1987, but was overwhelmed by the effect of the TSS concentration in 1988 and did not explain a significant part of the variability in K when data were combined.

Discussion

The above results support the hypothesis that poor water clarity is a major cause of the near absence of submersed aquatic macrophytes in Back Bay. Our Secchi depth and TSS measurements (table 3) are within or slightly higher than the ranges reported by Southwick and Norman (1987). Our TSS data for April were higher than the reported range for 6 Back Bay stations in April 1986 (15 to 56 mg/L), however, our samples are probably representative of extreme wind conditions in the bay. We have seen no published data on chlorophyll-*a* concentrations for Back Bay for comparison with our data; however, chlorophyll-*a* concentrations are unusually high for an oligohaline tidal environment.

The K values measured at the Back Bay station 22, the station with the greatest water clarity in 1987, were compared with K values measured at two mainstem sites in the tidal Potomac River (fig. 3). Elodea Cove is a freshwater site with dense macrophyte beds. Wades Bay is an oligohaline site with patchy beds limited to the shallow (<1.5 m) margin along the shoreline. Extinction coefficients were generally lower in the entire visible range (400 to 700 nm) at Elodea Cove than at Wades Bay or Back Bay station 22. Wades Bay extinction coefficients in the spectral region between 400 to 550 nm (the blue to green region) are also lower than those at station 22. The chlorophyll-*a* and TSS concentrations shown with the curves demonstrate that K is a function of both TSS and chlorophyll-*a* concentrations. Other factors probably influence K as well. Mean growing-season K values of ≤ 2.2 m^{-1} have been associated with good growth of submersed macrophytes in the freshwater reach of the tidal Potomac, but in the oligohaline zone of the Potomac Estuary, however, submersed macrophytes grow along the shallow margins at mean seasonal K values of ≤ 2.7 m^{-1} (Carter and Rybicki 1990). This suggests that light conditions are marginal for submersed macrophytes at station 22 and the station at the North Carolina Line.

We compared Secchi depth and TSS and chlorophyll-*a* concentrations for Back Bay in 1986-88 with data from the Potomac River at Quantico, Virginia, where salinities are similar to those in Back Bay in dry years (table 3). These data are from several sources, including water-quality data collected by the USGS in 1980 (Blanchard et al. 1982; Coupe and Webb 1984) and data collected by the Maryland Department of the Environment from 1983-89 (Batiuk et al. 1991). Median seasonal (April-October) Secchi depth at Quantico was 0.51 m in 1980 when there were no plants at this station. Median growing seasonal Secchi depth was 0.8 m in 1987 when there were dense beds of submersed macrophytes at the station. The range of Secchi depths found in Back Bay in 1986-88 is below the 1980 value for Quantico. A recent analysis of TSS and chlorophyll-*a* data from the Potomac River and Estuary for the period 1980-89 showed that growing-season median chlorophyll-*a* concentrations $\leq$ 15 to 20 μ /L and median suspended-sediment concentrations $\leq$15 to 20 mg/L could be correlated with survival and spread of submersed aquatic macrophytes (Batiuk et al. 1991). Median growing-season TSS concentrations at six stations in Back Bay in 1986 (calculated from Southwick and Norman 1987) ranged from 38 to 53 mg/L—a concentration considerably higher than the above limit—whereas the median growing-season TSS concentration in the tidal Potomac River at Quantico, Virginia, was 11.5 mg/L (table 3). Chlorophyll-*a* concentrations in Back Bay are similar to those in the Potomac River at Quantico in 1980 when there were no plants (table 3).

Because high nutrient concentrations are commonly associated with an increase in phytoplankton and a decline in submersed aquatic macrophytes, we compared median growing-season nutrient concentrations in Back Bay in 1986 (calculated from Southwick and Norman 1987) with median concentrations in the tidal Potomac River at Quantico (table 4). The comparison showed differences between the two sites, but insufficient information is available to establish a cause and effect relation. Ammonia, total phosphorus, and orthophosphate concentrations, which are often responsible for increased numbers of phytoplankton, were similar at both locations. Nitrate plus nitrite concentrations were higher in the tidal Potomac River than in Back Bay; higher total Kjeldahl nitrogen concentrations were found in Back Bay than in the total Potomac River (table 4). The nutrient concentrations in the tidal Potomac River support algae blooms when other factors such as sunlight, water temperature, and discharge are favorable (Bennett et al. 1986). It is possible that the poor tidal flushing in Back Bay provides favorable conditions for development of large phytoplankton populations at the present nutrient concentrations.

[1] Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

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Table 1. Extinction coefficient (K), Secchi depth, mean TSS and chlorophyll-*a* concentrations in Back Bay, Virginia, July 1987 and April 1988. (Stations are listed by date in order of increasing K; n.d. is no data; n is number of samples.)

Sampling Date/Station Number Location	K (m^{-1})	Secchi depth (m)	TSS (n) (mg/L)	Chlorophyll-*a*(n) (μ g/L)
July 1987				
20-Pellitory Pt.	2.7	0.30	44(2)	49.1(2)
NC-North Carolina line	2.9	0.30	44(2)	43.9(2)
22-Half Moon Bay	2.9	0.40	43(2)	54.0(2)
3-Sand Bay	2.9	0.44	44(2)	51.2(1)
14-Drum Point	4.7	0.26	51(2)	54.7(2)
5-Bread Island	5.0	0.34	62(2)	62.2(2)
9-North Bay	5.7	0.26	61(2)	70.9(1)
April, 1988				
NC-North Carolina line	3.7	0.33	88(2)	73.5(2)
D-Long Island	6.7	0.28	99(2)	84.4(2)
B-Cedar Island	8.3	0.23	116(3)	34.5(2)
E-Canal	19.9	n.d.	214(1)	88.0(1)
20-Pellitory Pt.	n.d.	0.16	149(3)	44.0(2)

Table 2. Results of regression of K with suspended sediment and chlorophyll-*a* concentration for July 1987, April 1988, and both dates combined. (P is probability; N is number of samples)

Regression	Coefficient of determination (r^2)	P	N
July 1987	0.727	0.000	10
K vs TSS	0.756	0.721	10
K vs chlorophyll-*a*			
April 1988	0.956	0.000	8
K vs TSS	0.000	0.721	8
K vs chlorophyll-*a*			
Both Dates	0.851	0.000	18
K vs TSS	0.086	0.143	18
K vs chlorophyll-*a*			

Table 3. TSS, chlorophyll-*a* and Secchi depth in Back Bay and the Potomac River at Quantico, Virginia. Data for 1986 are the ranges of growing-season medians for 6 Back Bay stations calculated from data in Southwick and Norman (1987) and Norman and Southwick (1987). Potomac River data are growing-season medians (Batiuk et al. 1991). (TSS is mg/L; chlorophyll-*a* in μ g/L; Secchi depth in m; n.d. is no data).

	Back Bay			Potomac R. at Quantico	
	1986	1987	1988	1980 (no plants)	1987 (plants)
TSS	38-53	37-64	78-214	9.5	11.5
Chlorophyll-*a*	n.d.	42.8-70.9	31.0-88	41.9	5.14
Secchi Depth	0.15-0.30	0.26-0.44	0.16-0.33	0.51	0.8

Table 4. Median growing-season (April-October) nutrient concentrations for six stations in Back Bay (1986) (Southwick and Norman 1987) and the Potomac River at Quantico, Virginia in 1987.

(Concentrations in mg/L)

	Back Bay, 1986 (no plants)	Potomac River at Quantico, 1987 (plants)
Total phosphorus as P	0.1	0.07
Orthophosphate as P	0-0.04	0.03
Total Kjeldahl nitrogen as N	2.4-3.0	0.78
Ammonia as N	0.1	0.1
Nitrate plus nitrite N	0.6-0.07	1.35

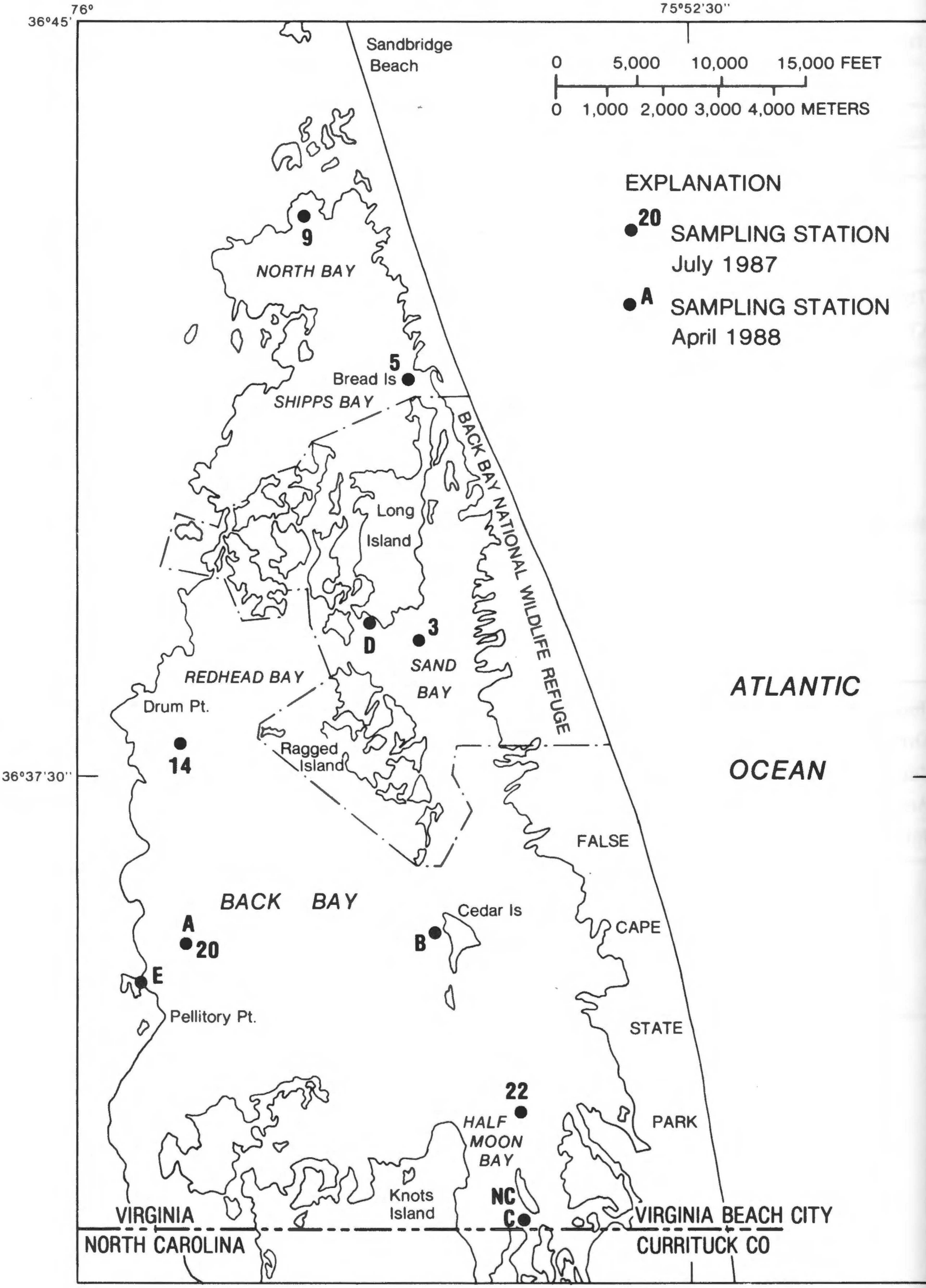
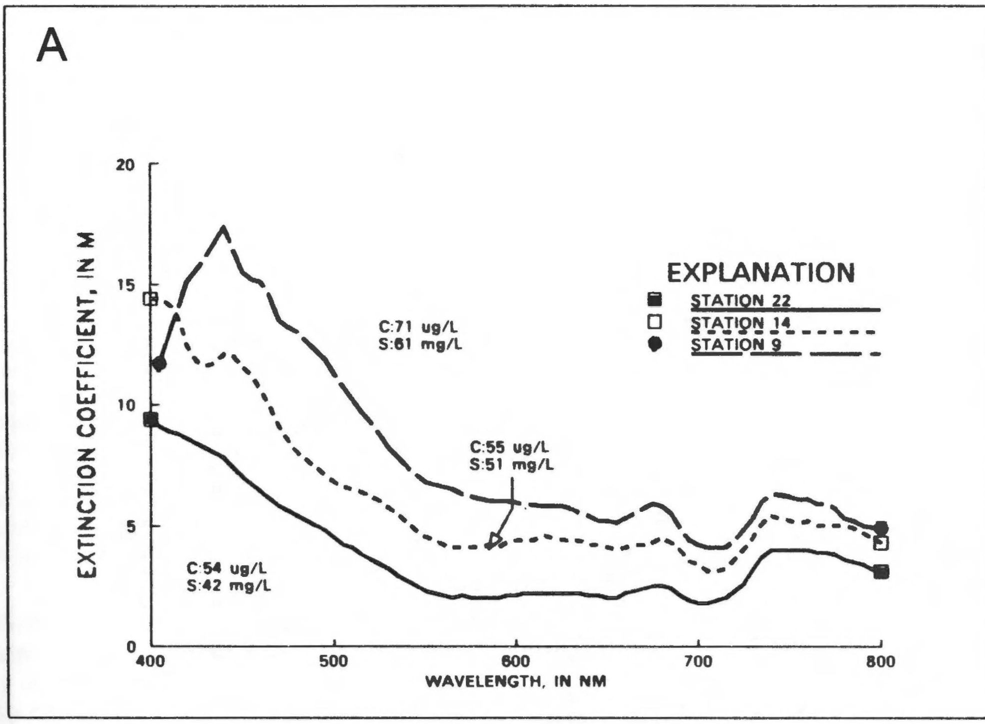


Figure 1. Map of Back Bay showing sampling stations for July 1987 (numbered stations) and April 1988 (stations with letters).



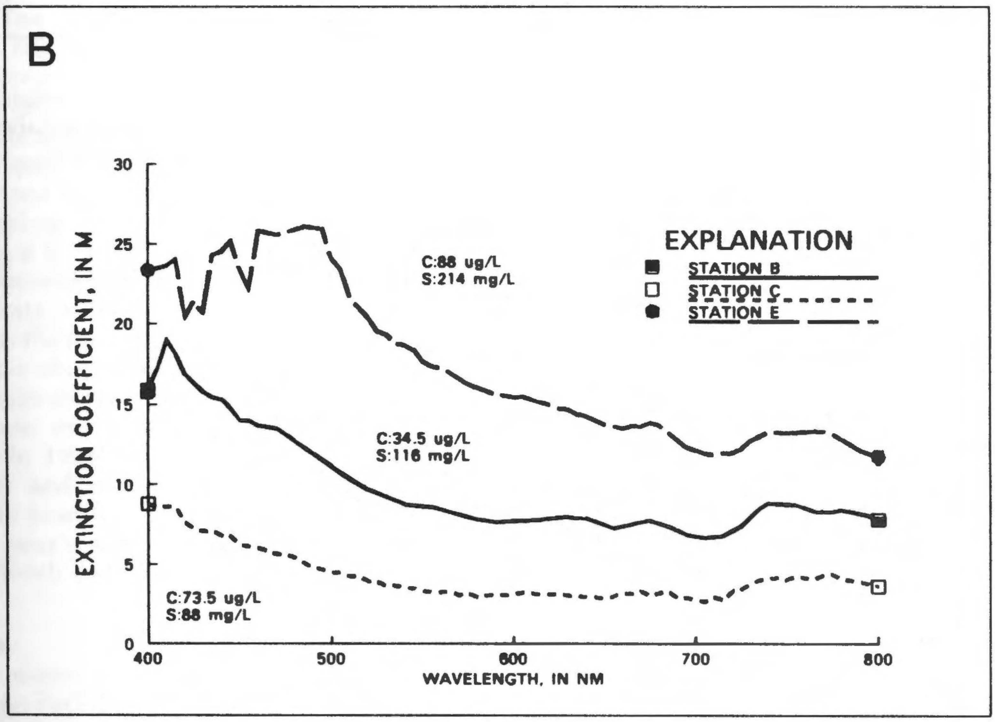


Figure 2. Extinction coefficients, in m^{-1}, at three Back Bay stations in July 1987 (A) and April 1988 (B). (C is chlorophyll-*a* concentration; S is TSS; NM is nanometers).

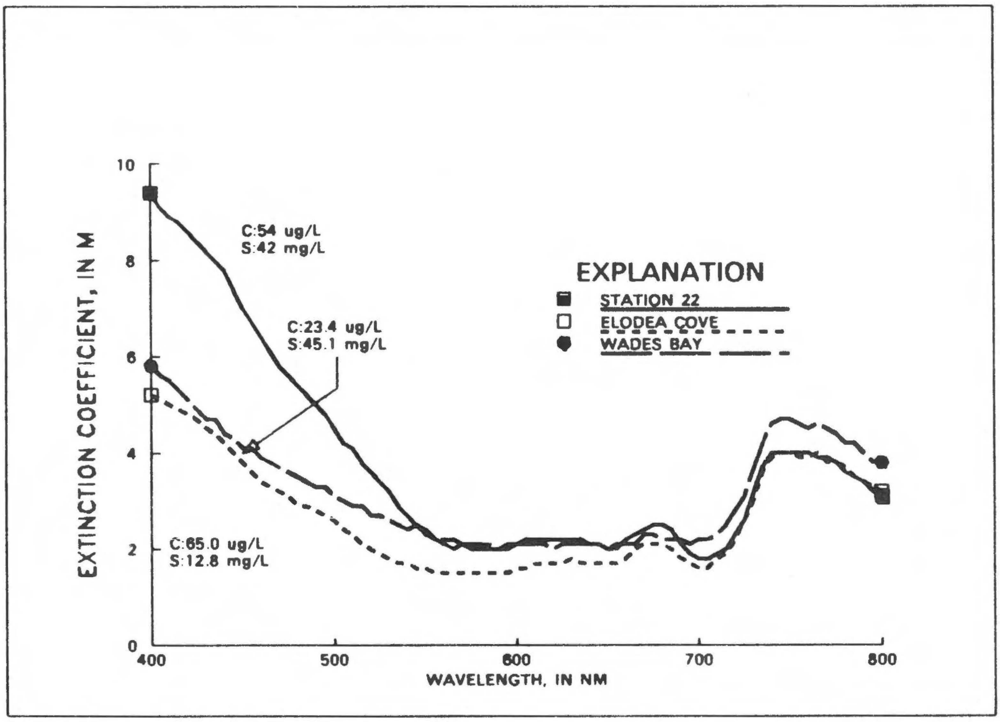


Figure 3. Comparison of extinction coefficients at Back Bay station 22 with extinction coefficients at Elodea Cove, in the tidal freshwater Potomac River, and Wades Bay, in the oligohaline Potomac Estuary. (C is chlorophyll-*a* concentration; S is TSS; NM is nanometers).