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Phytoplankton, nutrients, macroalgae and submerged aquatic vegetation in Delaware's inland bays, 1985-1986

Benedict Estuarine Research Laboratory.

Delaware Department of Natural Resources and Environmental Control

PHYTOPLANKTON, NUTRIENTS, MACROALGAE AND SUBMERGED AQUATIC VEGETATION IN DELAWARE'S INLAND BAYS 1985-1986

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The Academy of Natural Sciences
Benedict Estuarine Research Laboratory
Benedict, MD 20612

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EXECUTIVE SUMMARY

Kevin G. Sellner
Benedict Estuarine Research Laboratory
The Academy of Natural Sciences
Benedict, MD 20612

PHYTOPLANKTON AND NUTRIENTS

Biological and chemical data collected in Delaware's Inland Bays in 1985-1986 indicate that eutrophic conditions typify the region. Nutrient concentrations in the three Bays were very high for estuarine waters. Maximum values of 228 uM (3.2 mg/L) dissolved inorganic nitrogen, 1.22 uM (0.04 mg/L) dissolved ortho-phosphate phosphorus and 145 uM (4.1 mg/L) silicate-silicon were observed in stations in Indian River and Pepper Creek, concentrations >100, >10 and >10 times concentrations noted in other reported nutrient-rich estuarine systems. Lowest mean inorganic nitrogen and phosphorus concentrations in the productive summer months sampled exceeded 5 uM (0.07 mg/L) in all Bays and 0.3 uM (<0.01 mg/L) in Indian River Bay and Rehoboth Bay, respectively. These levels of dissolved inorganic nitrogen would not have limited phytoplankton in the region while inorganic phosphorus concentrations and associated N:P ratios suggest that phosphorus could have limited phytoplankton biomass in the Inland Bays. That is, nutrient requirements, i.e. demand, by the phytoplankton present in the Bays had reduced ambient phosphorus levels to concentrations that might limit further phytoplankton growth. Shallow euphotic zones in the Inland Bays could also restrict phytoplankton growth for much of the year. However, identification of specific limiting factors in the system requires rigorous experimentation, possibly using large flow-through mesocosms where nutrient concentrations and ratios as well as light can be controlled over several weeks in the highly productive spring-fall periods.

Not surprisingly, the high nutrient concentrations supported high phytoplankton biomass (as chlorophyll and cell numbers) in the productive spring-summer months sampled in 1986. Ambient mean chlorophyll levels in the three Inland Bays exceeded 10 ug/L with concentrations >25 ug/L in Indian River Bay throughout the summer period. Total cell densities and numbers of eucaryotes approximated 30-40 x 10^6 and 5 x 10^6 cells/L^{-1} for the same period, higher than densities typical of other eutrophic estuarine systems. Bloom forming blue-green algae were common in the Indian River stations, principally Microcystis aeruginosa; however, these halophobic populations were not observed in the lower Bays.

Discharge of creeks and tributaries of the Inland Bays apparently controlled nutrient concentrations in the region. Highest concentrations of dissolved inorganic nitrogen and phosphorus were observed during periods of highest discharge, i.e. fall, 1985. However, chlorophyll concentrations were low relative to lower flow periods in late 1986 presumably due to higher flushing rates and shorter residence times in the Inland Bays in 1985, prohibiting phytoplankton growth and accumulation. Phytoplankton biomass observed in 1986 probably arose from a larger portion of the nutrients delivered from the nutrient-rich groundwater, aperiodic storm and runoff events and nutrients associated with high summer tourism in the region.

MACROALGAE

Macroalgae in Delaware's Inland Bays were dominated by representatives from the chlorophyta (green algae) and rhodophyta (red algae). In contrast to earlier observations in the region where 59 macroalga taxa were observed, only five taxa (5) were found in the Inland Bays in 1985-1986. Highest biomass was observed in the spring (April, 1986), primarily due to a filamentous green alga. Macroalgal biomass at this time reached 1.7 g dry wt/m^2. Another chlorophyte, sea lettuce Ulva lactuca, was also noted but at much lower levels ($\leq$0.18 g dry wt/m^2). Two red algae, Gracilaria sp. and Agardhiella tenera, were also noted, generally in December-January and May and June. However, maximum biomass for Gracilaria sp. was always $<$0.07 g dry wt/m^2; Agardhiella was only noted at levels $<$0.03 g dry wt/m^2.

Macroalgal biomass in Delaware's Inland Bays was very low relative to the algal biomass noted in nutrient-replete conditions in Rhode Island. The low algal biomass and numbers of macroalgal species might be attributable to light-limited conditions, as suggested for SAV in the Inland Bays (see Orth and Moore section). Shallow euphotic depths resulting from high suspended solids and chlorophyll concentrations could restrict macroalgae growth to very shallow areas near the shores, regions where growth would also be limited by highest wave activities and resuspension of bottom sediments.

SUBMERGED AQUATIC VEGETATION

Submerged aquatic vegetation (SAV) was last seen in the 1950's in the Delaware Inland Bays system indicating that SAV had survived the catastrophic mortality that afflicted SAV populations in North America and Europe in 1930-1931. However, no SAV have been seen in the Inland Bays since the early 1970's indicating that recovery has not been possible with water quality conditions since that time. VIMS researchers (Orth and Moore) have concluded that two factors probably limit SAV growth in the Inland Bays, high light attenuation from high suspended sediment and chlorophyll concentrations and high nitrogen concentrations that could favor growth of epiphytes on the leaves of any SAV, eventually resulting in shading of the SAV blades and no plant growth.

Orth and Moore do conclude, however, that SAV recolonization should be possible in areas previously colonized by SAV. They recommend that DNREC initiate a pilot transplanting and monitoring study to determine the potential for SAV growth in the region.

RECOMMENDATIONS

Data collected in each of the three program elements, Phytoplankton and Nutrients, Macroalgae and Submerged Aquatic Vegetation, indicate that Delaware's Inland Bays are highly eutrophic systems. Nutrient concentrations and turbidity must be reduced in the system, as outlined in previous reports on the Inland Bays. Both of these parameters are a function of poor land use practices in the region.

A number of investigators have outlined the excessive nutrient loading characteristics of the Inland Bays watershed. The combination of very porous soils

and man's activities in the region have guaranteed an excessively large supply of nitrate in groundwater of the area. Agricultural activites, including the excessive application of fertilizers and poultry manure, and the high number of septic systems used in the area (>75% of the permanent residents employing septic systems for sewage disposal) have resulted in rapid percolation of inorganic nitrogen as nitrate into the groundwater. Regardless of any rigid point source nutrient controls implemented in the future, contamination of groundwaters and ultimately the Bays with nitrate from these activities is likely to continue unless Best Management Practices for agricultural lands and development are initiated and enforced. Application of fertilizers on croplands and disposal of chicken manure from the broiler industry should be significantly reduced and regulated by county, state and federal agricultural and soil conservation agents. Any new development in the region should be accompanied by construction of new sewage treatment facilities or use of current facilities that are not used to capacity. All current septic systems and package wastewater treatment plants should be inspected and if non-functioning, upgraded to, at a minimum, functional systems and, at best, destroyed with all sewage diverted to regional sewage treatment facilities.

Best Management Practices also reduce loss of topsoils from agricultural lands and if applied to development, theoretically, these practices could reduce erosion and sheet runoff in suburbanized-urbanized areas. Reductions of soil erosion will ultimately reduce turbidity in the Inland Bays as well as lower the quantity of inorganic phosphorus entering the system adsorbed to the surface of the sediments. Should turbidity be reduced through reduction in inorganic suspended materials and lower phytoplankton biomass from lower nutrient loading rates, macroalgae and SAV might return providing habitat for commercially and recreationally important fish and shellfish.

The citizens surrounding the Inland Bays must decide for themselves what is most important in their region. If the top societal priority is a healthy and clear water column, bountiful fish and shellfish and infrequent fish kills in the Inland Bays, current agricultural and development practices must be modified; the porous soils of the region insure rapid movement of dissolved inorganic nutrients, particularly nitrate, derived from fertilizers, manure and septic systems, into groundwaters and therefore the Bays. Severe reductions in nutrient loadings must occur in the watershed, through reduced fertilizer and manure application and construction of pumping stations and new sewage treatment facilities. Septic system construction should be severely curtailed and therefore, development limited to regions serviced by centralized treatment facilities. However, these practices imply drastic alterations in current agricultural activities in the watershed, large expenditures of funds for construction of pumping stations and sewage treatment facilities, development restricted to those tracts and developers with funding sufficient for construction of pumping station or sewage treatment facilities rather than septic systems and inspection of existing septic systems with required use of centralized sewage treatment facilities or installation of new septic systems for those systems that have failed.

The recovery of the Inland Bays requires a public commitment to these drastic changes in land use and reallocation of revenues. Recovery ultimately reduces to what is most important to the people in the region.

Specific recommendations are also appropriate for DNREC. If the mandate of the department is environmental control and assessment, field and laboratory techniques must be adopted for routine use in determining water quality in Atlantic

techniques must be employed for determining ambient nutrient concentrations, as for example ammonium. This inorganic nitrogen substrate is the preferred nitrogen source for estuarine and shelf phytoplankton assemblages and the primary excreted product from invertebrate populations in the sediments and water column. Current DNREC detection limits are useful for sewage effluents but not sufficiently sensitive for routine use in estuarine systems. DNREC staff should consult Strickland and Parsons (1972), Parsons et al. (1984) and Technicon literature for appropriate procedures. There also appear to be major discrepancies between total suspended solids concentrations measured for the Inland Bays by DNREC staff (present study) and by the University of Delaware (Gibbs, 1987). These two groups should discuss techniques and agree on one protocol for all future measurements.

Secondly, environmental conditions and variables of interest should determine timing of field collections for teams dedicated to sampling the Inland Bays. In the present study, sampling schedules were fixed at one day per month with an option of another day in the following week if weather prevented collections. Scheduling must be sufficiently flexible to permit sample collections at several dates within a month and preferably, more frequently in the highly productive summer months (June through September). In the present study, DNREC staff collected no samples in November, 1985 nor in February or August, 1986, the latter omission a critical short-coming of the study since lowest nutrient concentrations and dissolved oxygen levels and highest phytoplankton productivity typify this month. In addition, continued DNREC concerns on the extent of oxygen-deficient waters in the Bays cannot be addressed by collections undertaken in mid-day. Lowest dissolved oxygen concentrations in eutrophic waters would be found near dawn; therefore, frequent sampling must be undertaken near sunrise in the summer in order to discover whether low dissolved oxygen concentrations typify eutrophic, late summer Bay waters. Oxygen production and demand in the water column and sediments should be made in late summer in several 24 h studies in order to document diel oxygen production and demand and apportion the dominant source and sink terms (benthos vs. water column) for oxygen flux in the system.

Finally, our data suggest that phosphorus and light probably limit phytoplankton (and possibly macroalgae and SAV) biomass accumulation in Delaware's Inland Bays. Prior to initiation of control strategies that require excessive expenditures for controlling anthropogenic waste disposal, DNREC should consider undertaking an experimental program to determine whether inorganic nutrients and/or light control planktonic productivity in the Bays. Experiments could be conducted to identify the importance of phosphorus, nitrogen and light in phytoplankton production using either large volume batch experiments or preferably long-term flow-through mesocosm experiments where ambient plankton assemblages and nutrient concentrations are replaced at rates simulating flushing rates in the system. These types of experiments have indicated that nutrient limitation shifts seasonally in Chesapeake Bay's tributaries and that current point source nutrient removal strategies in the Chesapeake Bay watershed are not effective in controlling phytoplankton biomass in estuarine waters downstream. In addition, an SAV transplanting experiment combined with a routine monitoring program of the site should be undertaken by DNREC.

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PHYTOPLANKTON AND NUTRIENTS IN DELAWARE'S INLAND BAYS

Richard V. Lacouture and Kevin G. Sellner
Benedict Estuarine Research Laboratory
The Academy of Natural Sciences
Benedict, MD 20612

INTRODUCTION

During the past five years, considerable attention has been aimed at potential water quality problems in the Delaware Inland Bays. Decisions for Delaware (Scotto et al., 1983) and the 1984 Governor's Task Force on the Inland Bays pinpointed numerous immediate and potential problems affecting Indian River, Rehoboth and Little Assawoman Bays. Several major problems identified in these bays include: 1) nutrient enrichment leading to eutrophication; 2) land use effects on water quality; and 3) point source loading of toxic material.

There are two primary sources of nutrients for the Inland Bays, sewage from permanent and temporary residents and fertilizers employed in agricultural community. Currently, 75% of the residents employ septic systems for sewage disposal (Munda, 1985); by 2000, there will by 300,000 residences in the area. With many septic systems failing permitting direct runoff of sewage and septic effluent and porous soils permitting rapid percolation into local groundwaters, nutrient loading is increasing. Summer tourism also results in a four-fold increase in sewage production in the region; by 1995, permanent residents and tourists in the Rehoboth Bay region will increase 14% and 24%, respectively (Ratledge et al., 1977), leading to even greater sewage production for the system. Agricultural activities are also major contributors to nutrient loading in the region (Ritter and Chirnside, 1982; Beasley, 1987 and references therein). Nitrate contamination of the groundwater is primarily derived from excessive nitrate leaching from fertilizers applied to increasing agricultural acreage around the Inland Bays (170,111 acres in 1935, 255,537 acres in 1982), both as commercial fertilizers and manure derived from the large broiler industry in the region (15,700,000 broilers in 1982). Agricultural activities and development also favor sediment erosion and increasing turbidities in receiving waters; decreasing euphotic zone depths from sediment runoff can also lead to demise of submerged aquatic plants and large reductions in the fauna using these beds for protection and refuge.

The effects of nutrient enrichment are initially seen as a significant increase in the biomass of primary producers. This increase in phytoplankton standing stock can ultimately lead to higher heterotrophic metabolism in the system and the depletion of dissolved oxygen concentrations in the lower part of the water column; high oxygen consumption, in turn, reduces aerobic habitats for fish and shellfish (Coutant, 1985; Price et al., 1985) and the demise of benthic macrofauna and blue-crab populations (Carpenter and Cargo, 1957; Seliger et al., 1985). The problem of eutrophication has been documented in lakes in a number of cases (Vollenweider, 1968) and more recently the problem has been identified in numerous urbanized estuaries such as Chesapeake Bay (EPA, 1983).

The objectives of the study undertaken by the Academy of Natural Sciences were to assess current conditions of several parameters which are viable indicators of water quality. Concentrations of nutrients, chlorophyll a, total suspended solids, dissolved oxygen as well as phytoplankton species composition and densities, SAV distributions and macroalgae distribution and density were measured in order to identify possible relationships between chemical, physical, and biological indicators of water quality in the Delaware Inland Bays. Relationships between nutrient input and suspended solids and phytoplankton species and biomass (as chlorophyll a), heterotrophic demand, SAV and macroalgae distributions are formulated from the data collected during a study from September, 1985 through September, 1986 in Delaware's Inland Bays.

METHODS

Field collections were undertaken by DNREC staff. Eleven stations were sampled on twelve occasions between September, 1985 and September, 1986 in Delaware's Inland Bays (Fig. 1). Surface, mid-depth and bottom temperatures and salinities were measured at each station along with surface and bottom dissolved oxygen concentrations and Secchi disk depths. Composite water samples were collected by pooling equal volumes of water from 1 meter above the bottom and at the surface. Surface samples were collected with a bucket while samples from the near-bottom were collected with a Kemmerer closing bottle. For Station 5, the only station with a water column greater than 3 m, an intermediate depth was also included. This sampling technique provides water which is characteristic of the whole water column rather than of one specific depth. Since horizontal and vertical patchiness of plankton populations is common to all aquatic systems, the compositing technique normalizes natural variability over the entire water column (Rohde, 1976; Elder et al., 1980).

From the mixed sample, a 0.5 liter aliquot was decanted into a polyethylene bottle followed by the addition of approximately 1 ml of modified Lugols solution (I_2-KI) for fixation. Upon returning to the lab, each sample was preserved with 10 ml of 37% buffered formalin. This combination of fixative-preservative allows for the adequate preservation of the fragile flagellated forms of phytoplankton and increases the overall shelf life of the entire sample. Phytoplankton were concentrated by settling a 1-10 ml aliquot in a settling chamber. Following a 48 h sedimentation period, the settled phytoplankton were examined at 400x and 250x on a Leitz Diavert inverted microscope. Cells were identified and enumerated at 400x in a minimum of 20 random fields; at least 200 individual cells were enumerated. Rarer forms were made in a subsequent scan of 20 random fields at 250x. This counting procedure yields 95% confidence interval of the estimate within $\pm$ 14% of the mean (see Venrick, 1978).

Aliquots from the composite sample were decanted into polyethylene bottles for subsequent nutrient analyses. Within 3 h of collection, the water was filtered through pre-rinsed Millipore filters (0.45 um) and ammonium, nitrate plus nitrite, soluble reactive phosphate and silica were measured. Ammonium was analyzed immediately by DNREC using the phenol-hypochlorite method of Solorzano (1969). The remaining samples were frozen and later analyzed at the Academy of Natural Sciences, Philadelphia for: nitrate-nitrite using diazotization with sulfanilamide (Strickland and Parsons, 1972), soluble reactive phosphorus with the phospho-molybdate blue method (Murphy and Riley, 1962) and silica with the silico-molybdate blue method (Fanning and Pilson, 1973).

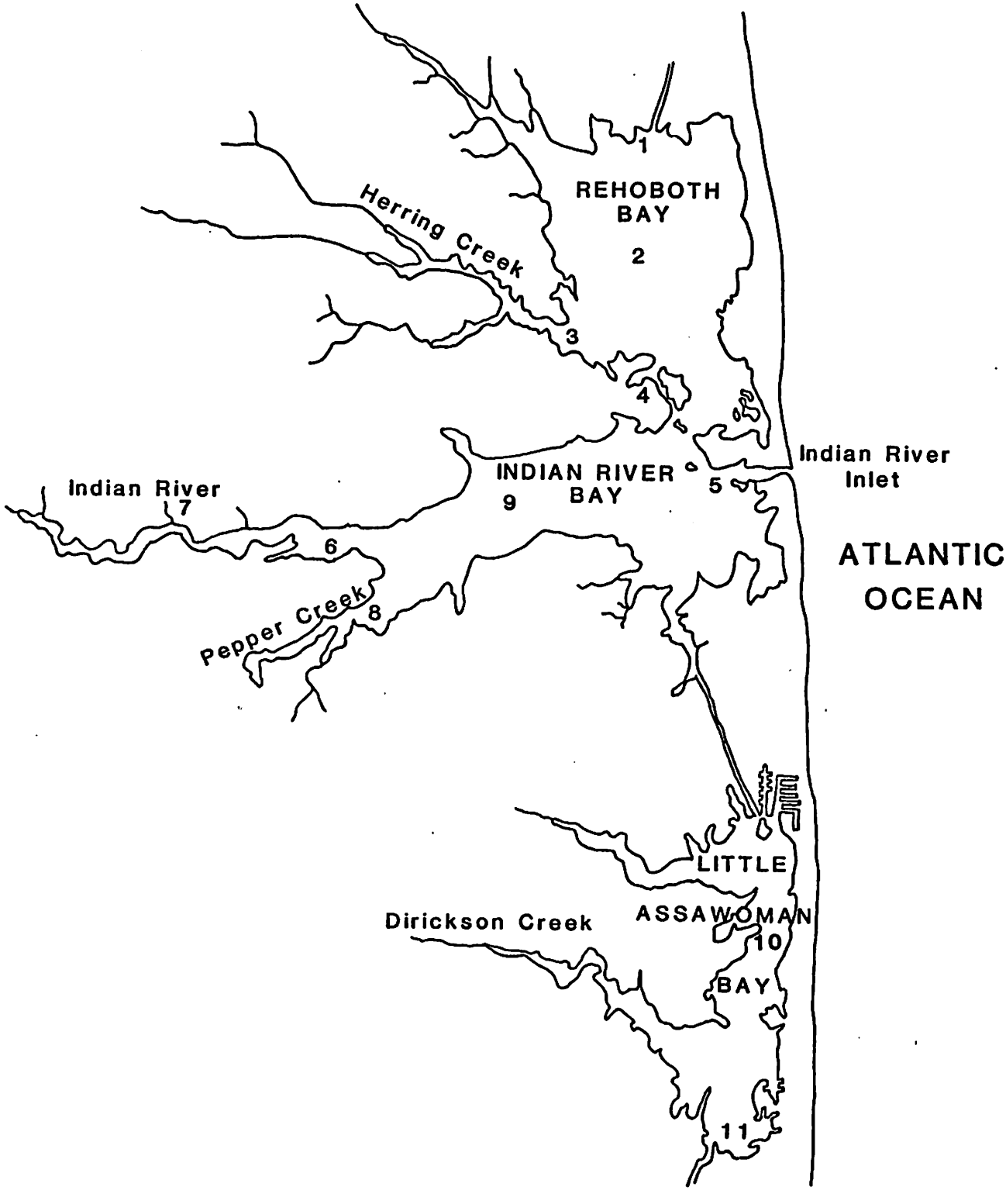


Figure 1. Location of sampling stations in Delaware's Insland Bays for the 1985-1986 plankton study conducted by the Academy of Natural Sciences.

In the field, aliquots from composite samples were filtered through a 47 mm Whatman GF/F glass fiber filter and frozen immediately; frozen samples were transferred to the Benedict Estuarine Research Laboratory of the Academy for subsequent estimation of chlorophyll a concentration. Chlorophyll a was extracted in 90% acetone and measured spectrophotometrically using the technique described by Strickland and Parsons (1972).

Total suspended solids were estimated by filtering a known volume of water through a pre-weighed Whatman GF/F glass fiber filter, drying at 60°C and measuring the dry weight of the filter and contents.

Analysis of variance techniques were used to compare water column parameters over time and space as well as compare data collected in 1985-1986 with data collected in several earlier studies in the Inland Bays.

Nutrient concentrations were also compared to expected nutrient demand by phytoplankton in Delaware's Inland Bays. Half-saturation constants for nutrient uptake (K_s) in phytoplankton were gathered from the literature, specifically for nitrate, phosphate and silicate. Half-saturation constants represent the ability of a phytoplankton species to take up nutrients from the surrounding medium; the constant is the concentration of nutrient where uptake is equal to one-half its maximum rate and therefore may be cautiously interpreted as the nutrient concentration that limits algal growth. If ambient nutrient levels in the Inland Bays were lower than the half-saturation constant, nutrient limitation was implied and phytoplankton growth was assumed to be limited. If ambient nutrient levels exceeded half-saturation constants, phytoplankton growth was not limited and therefore assumed to be maximum. For managers and environmental engineers, eutrophication can be slowed in any system by reducing ambient nutrient concentrations to levels below nutrient demand (half-saturation constant) by the algae in the receiving water body.

RESULTS

Physical Data: Temperature, Salinity and Dissolved Oxygen

Water temperatures in Delaware's Inland Bays followed expected seasonal patterns for temperate zone estuaries in the northern hemisphere (Fig. 2). Lowest mean monthly temperatures were observed in January while highest temeperatures were recorded in July. Annual minimum and maximum temperatures were probably not observed, however, since field collections were not conducted in February nor August, respectively (see Appendix 1 for detailed data listing).

Rehoboth Bay was characterized by a north-south longitudinal gradient in temperature. From September to January, a period typified by decreasing water temperatures, temperatures increased from north to south. The two main sources of freshwater entering Rehoboth Bay are the Lewes-Rehoboth Canal and the numerous creeks (Love Creek, White Oak Creek, Arnell Creek and Herring Creek) on the northern and western shores of the Bay; saltier oceanic waters enter Rehoboth Bay from the southern passages connecting Rehoboth and Indian River Bays. During the 'cooling' months (September-February), oceanic waters are typified by a slower heat loss than the shallower waters found in the creeks and Rehoboth Bay. As a result, temperatures increased from north to south, as explained by simple

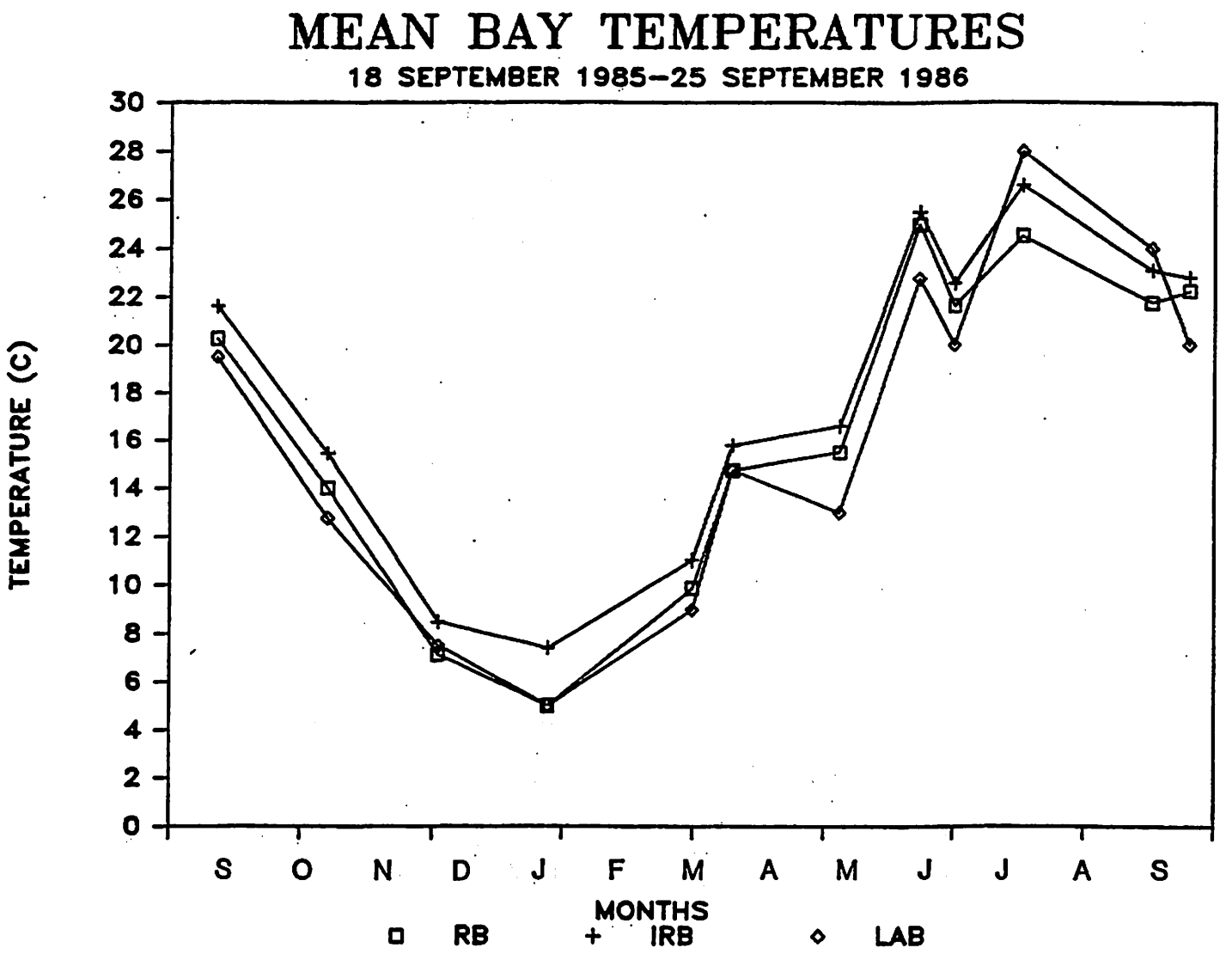


Figure 2. Mean monthly temperatures in Delaware's Inland Bays for the period September, 1985 - September, 1986. Symbols represent RB (Rehoboth Bay), IRB (Indian River Bay), LAB (Little Assawoman Bay) and INLET (Indian River Bay Inlet).

physics (Fig. 3). During the warming months (March-August), the reverse holds true. Water gains heat quicker in the shallower bays and creeks and the temperature gradient changes in Rehoboth Bay, with temperatures increasing in a south to north direction (Fig. 4). The mean maximum temperatures recorded in the sampling program in Rehoboth Bay were on 12 June 1986 (25.0°C) and 11 July 1986 (24.5°C), while the mean minimum temperature (5.0°C) was noted on 22 January 1986 (Table 1). It should be noted that these temperature measurements do not necessarily represent the actual extreme temperatures since measurements were obtained only once per month and, as noted above, no measurements were made in February or August. Rehoboth Bay showed a mean vertical temperature gradient of 0.2°C/m, with Station 2, located in the central Bay, showing the largest mean vertical gradient (Table 2).

An east-west longitudinal gradient in temperature was seen in Indian River Bay. The same general relationship noted for Rehoboth Bay was also found for Indian River Bay in that during the 'cooling' period, temperatures increased from west-east (Fig. 3), while in the warming months, temperatures increased from east-west (Fig. 4). The temperature gradient in Indian River Bay was not as large as noted in Rehoboth Bay possibly due to the larger volume of freshwater introduced into the system by the Indian River and the artificial effects of the thermal discharge produced by the Indian River Power Plant (Jensen, 1974; Ecological Analysts, 1977). This difference between the two Bays is obvious from a comparison of temperature during the 'cooling' period: from September-January when water temperature was decreasing (with the exception of the December sampling), the mean water temperature in Indian River Bay was significantly greater than the mean values for Rehoboth Bay ($F = 11.57$, September; 12.57, October; 6.3, January; $p = 0.05$). The maximum mean temperature recorded for the Indian River Bay was observed during the 22 July cruise (26.6°C), while the minimum mean temperature (7.4°C) was recorded during January (Table 1). Indian River Bay had a mean vertical temperature gradient of 0.2°C/m and Station 5, located in Indian River Inlet, showed the largest mean vertical temperature gradient (Table 2).

Since only two stations were monitored in Little Assawoman Bay, it is impossible to report longitudinal trends in temperature. Seasonally, Little Assawoman Bay was characterized by a maximum mean temperature during July (28.0°C) and a minimum mean temperature (5.0°C) during January (Table 1).

Salinities encountered in Delaware's Inland Bays were quite different in 1985 versus 1986 (Fig. 5). In the period from September-December, 1985, mean salinites for the three Bays ranged from 13-19 ‰. In contrast, salinities for the Bays for the remainder of the study never dropped below 21 ‰ and reached 29.5 ‰ in June, 1986. The low salinities in 1985 reflect high runoff and discharge in the drainage basin, associated with storms, in the late summer and fall. In 1986, high salinities typical of shelf waters immediately adjacent to the barrier island bays, dominated due to lower discharge in the water basin. For example, mean monthly discharge for the period August through December, 1985 ranged between 4.72-7.22 cfs at Stockley, DE; from June-September, 1986, mean monthly discharge ranged from 0.86-2.22 cfs at the same station (USGS, 1986, 1987).

A weak north-south longitudinal gradient in salinity noted in Rehoboth Bay in 1977 (Karpas, 1978) was not well defined in the present study (Fig. 6). Salinity measurements indicated that the Lewes-Rehoboth Canal and Herring Creek supplied appreciable amounts of freshwater to Rehoboth Bay, especially during the late-winter and spring (Table 3) with lowest salinities (13.4-18.6 ‰) during

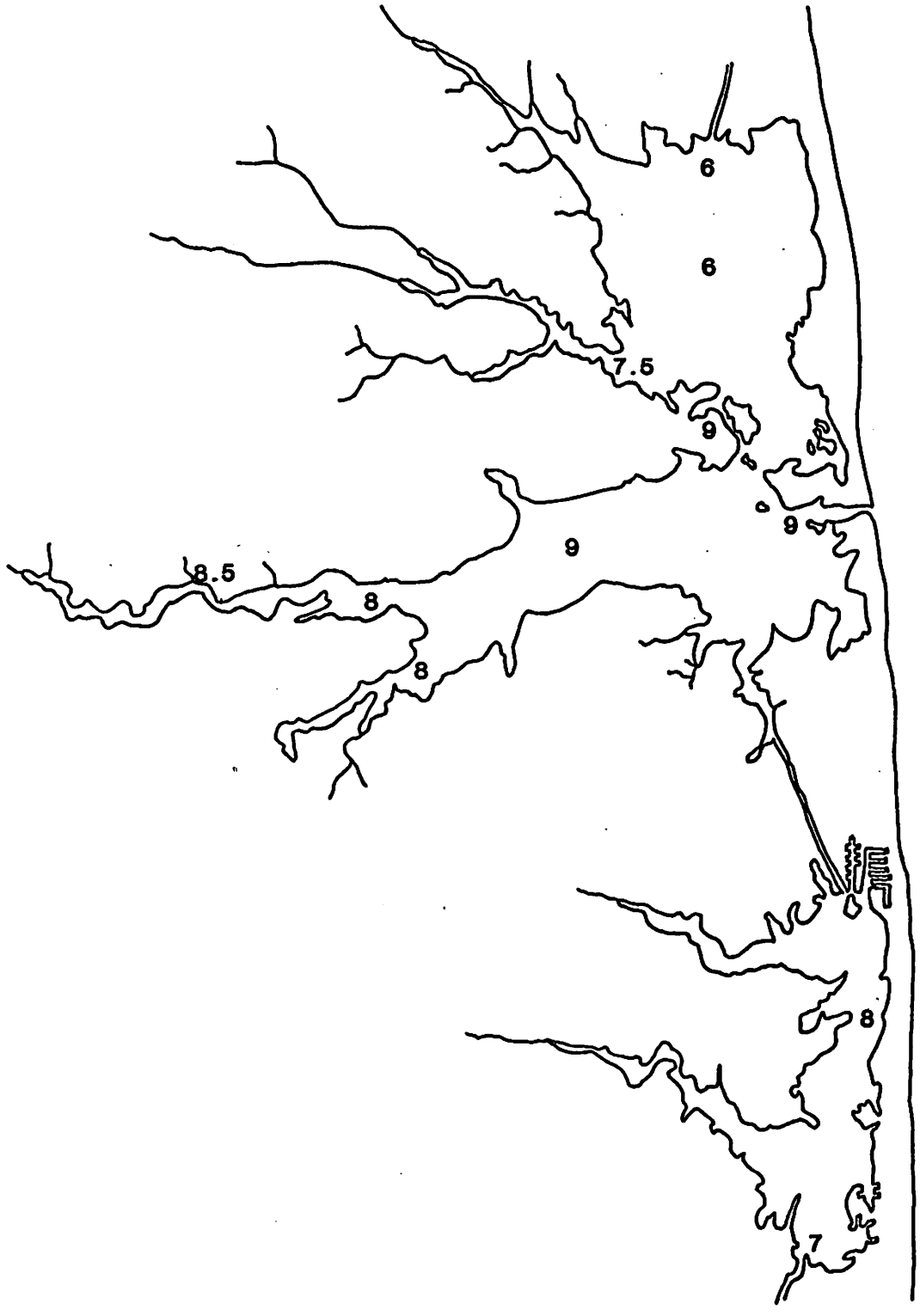


Figure 3. Surface water temperature (°C) in Delaware's Inland Bays, 11 December 1985.

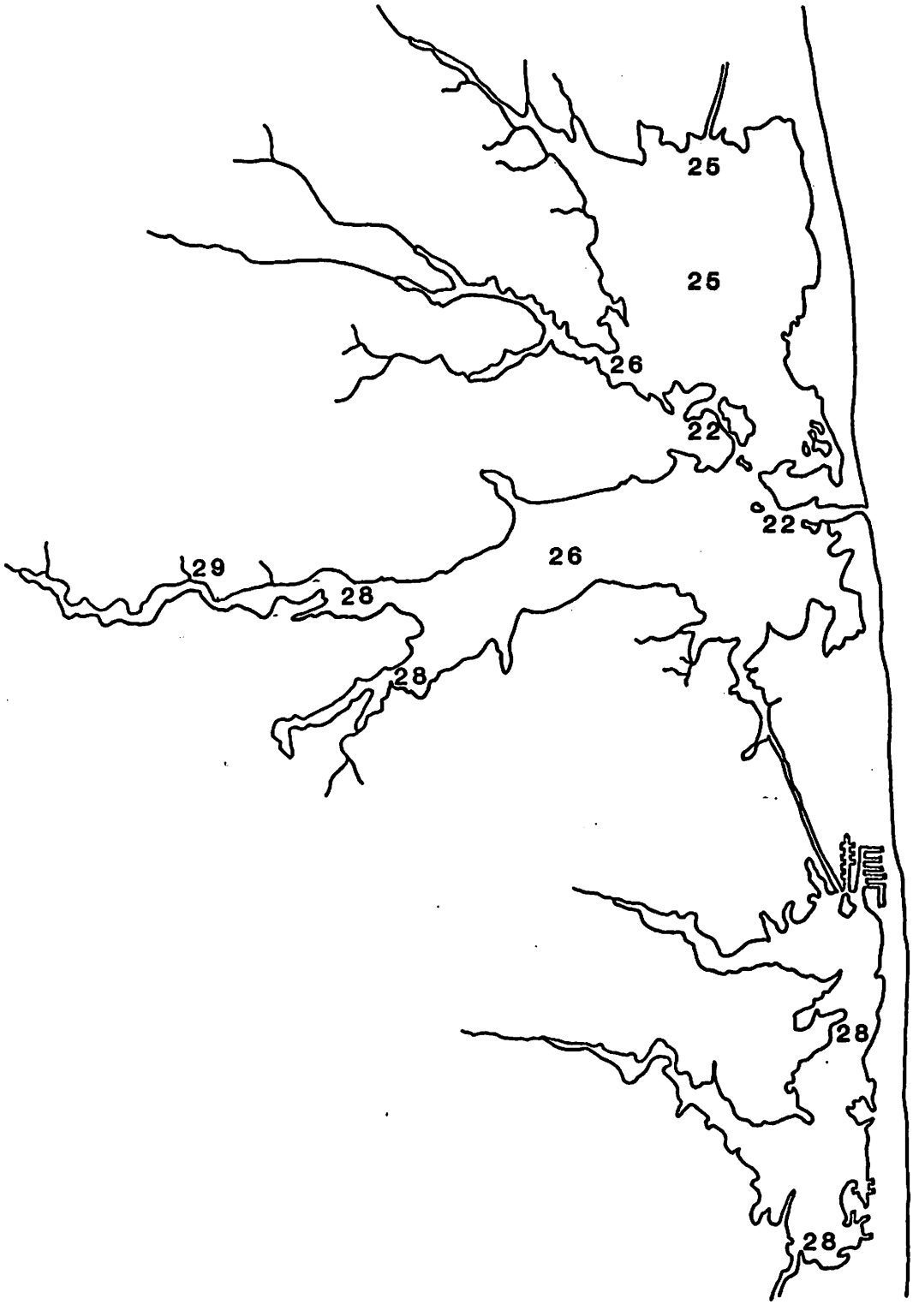


Figure 4. Surface water temperatures (°C) in Delaware's Inland Bays, 27 July 1986.

Table 1. Mean temperatures (standard error, S.E.)for Delaware Inland Bays, 18 September 1985 - 25 September 1986. Rehoboth Bay (4 stations), Indian River Bay (5 stations) and Little Assawoman Bay (2 stations). Dates in parentheses represent Little Assawoman Bay sampling dates.

DATE	REHOBOTH BAY	INDIAN RIVER BAY	LITTLE ASSAWOMAN BAY
9-18-85	20.2 (0.25)	21.6 (0.3)	19.5 (0.5)
10-30-85	14.0 (0.9)	15.5 (0.6)	12.8 (0.75)
12-11-85	7.1 (0.7)	8.5 (0.2)	7.5 (0.5)
1-22-86	5.0 (0.5)	7.4 (0.7)	5.0 (0.0)
3-18-86	9.9 (0.5)	11.1 (0.9)	9.0 (0.0)
4-02-86	14.8 (0.25)	15.8 (1.0)	14.8 (0.25)
5-13-86 (5-05-86)	15.5 (1.0)	16.6 (1.0)	13.0 (1.0)
6-12-86 (6-11-86)	25.0 (0.7)	25.5 (1.9)	22.8 (0.25)
6-26-86 (6-25-86)	21.6 (0.2)	22.6 (0.8)	*20.0
7-22-86 (7-21-86)	24.5 (0.9)	26.6 (1.2)	28.0 (0.0)
9-10-86 (8-26-86)	21.8 (0.25)	23.1 (0.2)	24.0 (0.5)
9-25-86 (9-22-86)	22.2 (0.25)	22.8 (0.5)	20.0 (0.0)

*n=1

Table 2. Vertical temperature gradients as temperature difference (°C) between surface and bottom in Delaware Inland Bays, 18 September 1985 - 25 September 1986. N.D. = no data.

	REHOBOTH BAY				INDIAN RIVER BAY				
STATION	1	2	3	4	5	6	7	8	9
MEAN DEPTH (m)	1.7	2.0	1.3	2.6	4.8	2.2	2.0	1.7	2.2
DATE									
9-18-85	0	0	0	1.0	1.0	0.5	1.0	1.0	0.5
10-30-85	0	0.5	0	1.0	0	0	0.5	0	0
12-11-85	1.0	1.0	1.0	0	1.0	0	1.0	0	0
1-22-86	1.0	1.0	2.0	1.0	0	0.5	N.D.	0.5	0
3-18-86	0.5	1.0	0	0.5	0.5	2.0	0	0	2.0
4-02-86	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
5-13-86	0	1.0	0	0	1.0	1.0	0	1.0	0.5
6-12-86	0	0	0	1.0	1.0	0	0	0.5	1.0
6-26-86	1.0	0.5	N.D.	0	1.5	0	0	1.0	0
7-22-86	0	1.0	0	0.5	0.5	0.5	0.5	1.0	1.0
9-10-86	0	0.5	0	1.0	0	0	0	0	0
9-25-86	0	0	0	0	0	0	0	0	0
Number of Observations with a gradient	4	8	2	7	7	5	4	6	5
Station Mean	0.3	0.6	0.3	0.5	0.6	0.4	0.3	0.45	0.45
Bay Mean			0.4				0.4		

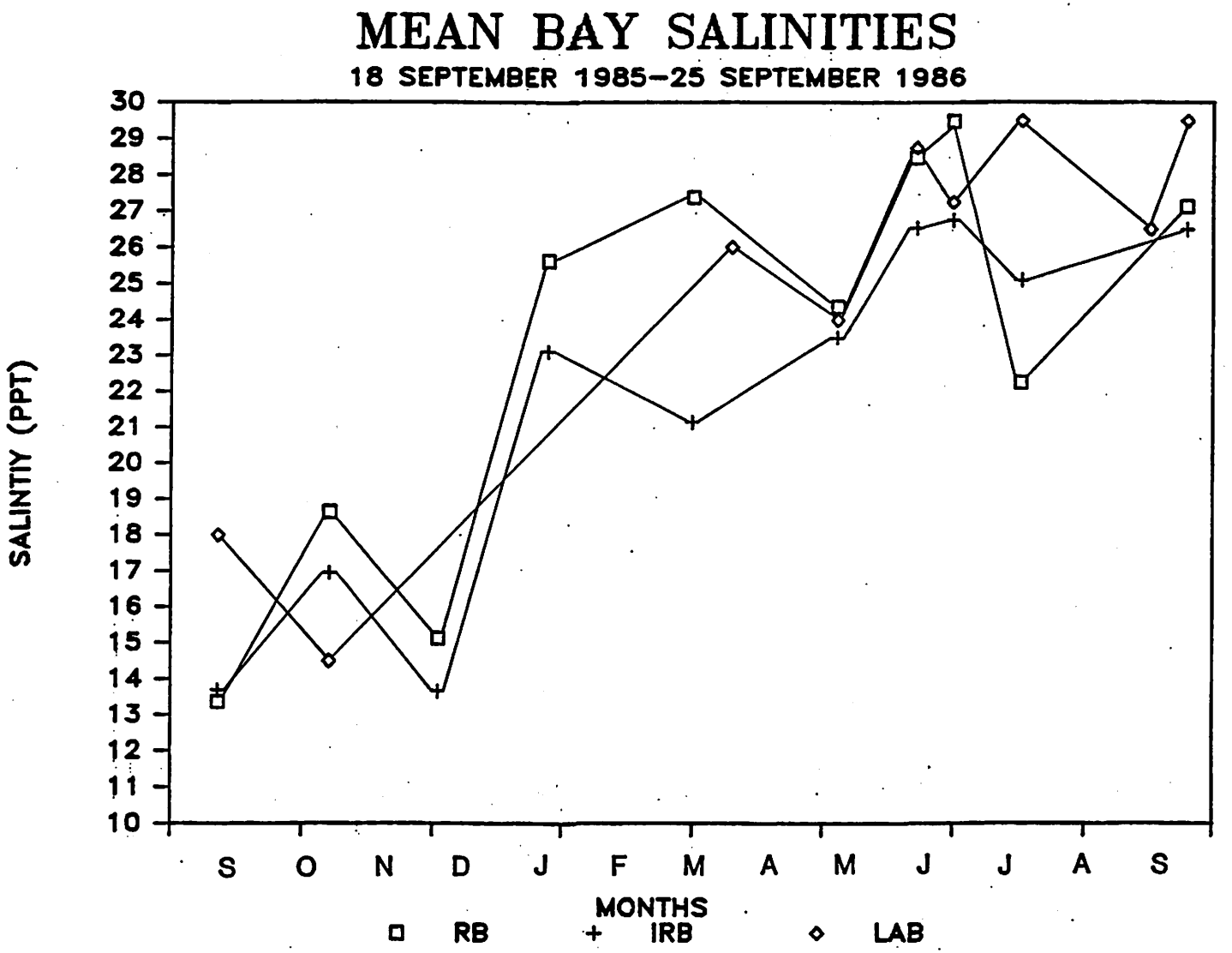


Figure 5. Mean monthly salinities (‰) in Delaware's Inland Bays for the period September, 1985 - September, 1986 (symbols as in Figure 2).

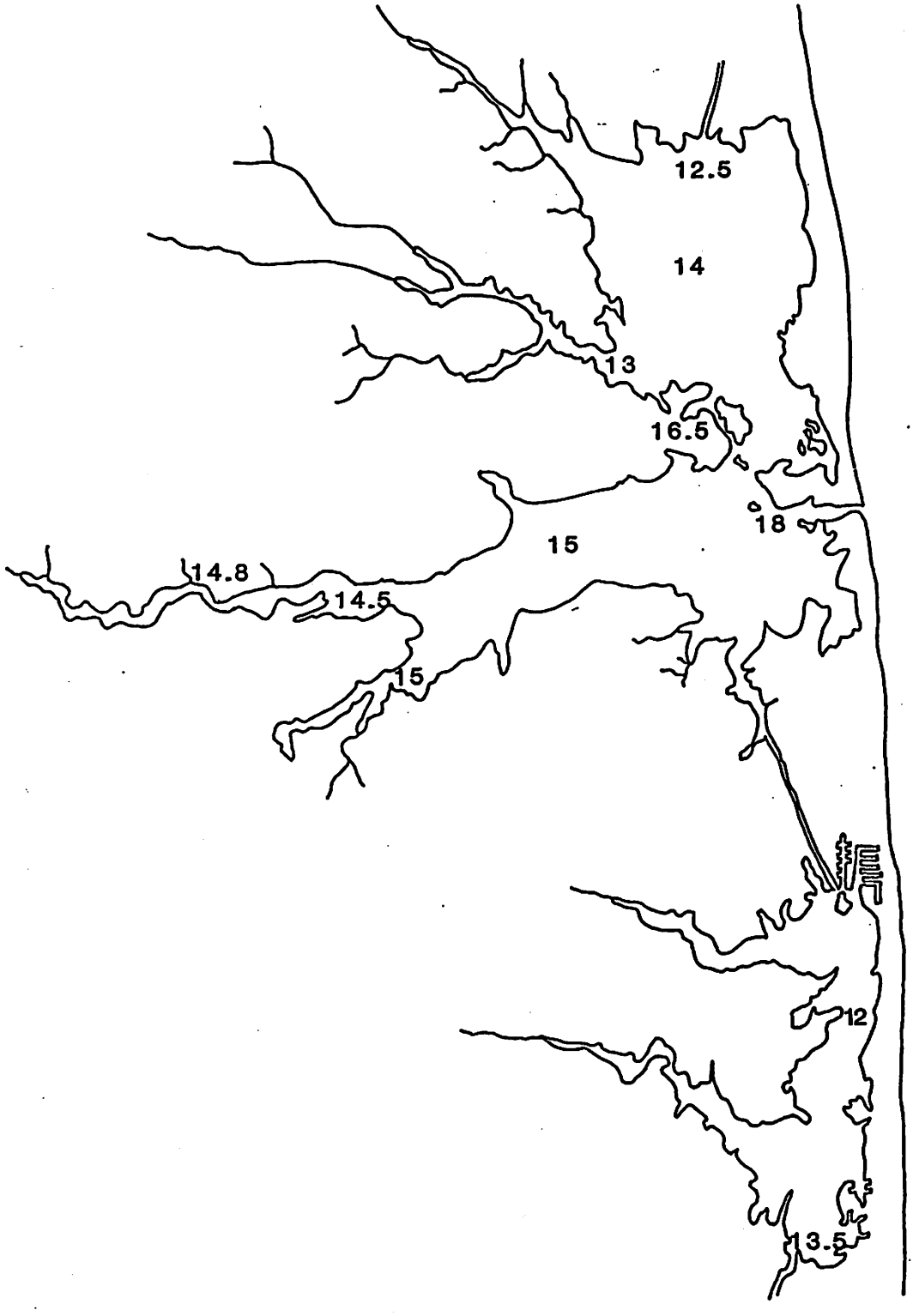


Figure 6. Surface salinities (‰) in Delaware's Inland Bays, 30 October 1985.

Table 3. Mean salinity (‰) and standard error for Delaware Inland Bays, 18 September 1985 - 25 September 1986. Rehoboth Bay (4 stations), Indian River Bay (5 stations) and Little Assawoman Bay (2 stations). N.D. = no data. Dates in parentheses represent sampling dates in Little Assawoman Bay.

DATE	REHOBOTH BAY	INDIAN RIVER BAY	LITTLE ASSAWOMAN BAY
9-18-85	13.4 (0.7)	13.7 (0.7)	*18.0
10-30-85	18.6 (0.9)	17.0 (1.4)	*14.5
12-11-85	15.1 (0.5)	13.7 (1.2)	N.D.
1-22-86	25.6 (2.2)	23.1 (2.7)	N.D.
3-18-86	27.4 (0.4)	21.1 (3.2)	N.D.
4-02-86	N.D.	N.D.	26.0 (1.0)
5-13-86 (5-05-86)	24.4 (1.1)	23.5 (0.7)	24.0 (1.5)
6-12-86 (6-11-86)	27.7 (1.3)	26.5 (1.2)	28.7 (0.2)
6-26-86 (6-25-86)	29.5 (0.6)	26.7 (1.4)	27.2 (0.2)
7-22-86 (7-21-86)	22.2 (0.9)	25.1 (1.1)	29.5 (0.0
9-10-86 (8-26-86)	N.D.	N.D.	26.5 (0.5)
9-25-86 (9-22-86)	27.1 (0.9)	26.5 (1.6)	29.5 (0.5)

* n=1

September-December 1985. Highest mean salinities (22.2-29.5 ‰) occurred during the low-flow summer months, June-September 1986. A vertical salinity gradient was most pronounced at Stations 1 and 3 located near the mouths of the Lewes-Rehoboth Canal and Herring Creek (Table 4). The overall mean vertical salinity gradient for the four sampling sites within Rehoboth Bay was 0.3 ‰/m, slightly higher than previously reported (Karpas, 1978) and defines Rehoboth Bay as a slightly stratified system.

A well defined east-west longitudinal gradient in salinity was noted in Indian River Bay. Salinity increased from west to east with high salinity, oceanic water entering the system on the east and freshwater entering the system from Millsboro Pond and Indian River. Based on the station locations used in this study and the salinity gradients measured within the water column at each station, Indian River and Pepper Creek supplied the majority of freshwater to Indian River Bay (Table 3), as noted by Karpas (1978). Seasonally, as was the case in Rehoboth Bay, lowest salinities occurred from September-December 1985 (13.7-17.0 ‰) and the highest values (25.1-26.7 ‰) occurred in summer 1986. A vertical salinity gradient was regularly and fairly sharply defined at Stations 7 and 8, located midway up Indian River and at the mouth of Pepper Creek, respectively. Overall, Indian River Bay was characterized by a mean vertical salinity gradient of 0.4 ‰/m, slightly less than previously reported (Karpas, 1978).

The surface salinity data recorded in Little Assawoman Bay showed the same seasonal pattern as previously noted for Rehoboth and Indian River Bays, lowest salinities in September and October 1985 (14.5-18.0 ‰) and highest salinities (26.5-29.5 ‰) from June-September 1986 (Table 3).

The mean dissolved oxygen concentrations for the Delaware Inland Bays are summarized in Table 5. Of the 205 measurements made during the study, only one is below the State minimum water quality standard of 5.0 mg/L (see Appendix 1 for detailed data listing). These data should be interpreted with the following reservations: 1) no data were collected in August, usually the month characterized by annual dissolved oxygen minimum (see Biggs, 1984); and 2) samples in the present study were generally collected between 0900 and 1200 h, a time of day when considerable photosynthetic activity is taking place in the water column and dissolved oxygen concentrations would be considerably greater than concentrations measured during peak algal respiratory activity, i.e., dusk to dawn. For instance, Biggs (1984) measured dissolved oxygen concentrations ranging from 1.9-3.0 mg/L from 2400-0700 h on 26-27 August 1983 at a station located at the mouth of Pepper Creek; from 0900-1200 h dissolved oxygen concentrations ranged from 5.3-6.3 mg/L.

Dissolved oxygen concentrations in bottom waters of Rehoboth Bay generally exhibited a longitudinal gradient: generally, concentrations increased in a north-south direction (Fig. 7). Likewise, concentrations increased from east to west in Indian River Bay except during June when at Station 7, bottom dissolved oxygen concentrations were lower (5.0 mg/L) than at the other Indian River Bay sampling stations (6.8-7.7 mg/L). This decrease in dissolved oxygen concentration most likely resulted because of rapid increases in water temperature favoring high oxygen demand associated with respiration and decomposition of the largest phytoplankton standing stocks in the system.

Lower dissolved oxygen concentrations in bottom waters occur throughout Rehoboth and Indian River Bay during June coincident with initial development of high summer phytoplankton densities and chlorophyll concentrations and is one of

Table 4. Change in salinity (‰) from surface to bottom within the water column of the Delaware Inland Bays, 18 September 1985 - 25 September 1986. N.D. = no data.

		REHOBOTH BAY				INDIAN RIVER BAY				
	STATION	1	2	3	4	5	6	7	8	9
DATE	MEAN DEPTH (m)	1.7	2.0	1.3	2.6	4.8	2.2	2.0	1.7	2.2
9-18-85		1.0	0	0.5	1.0	0	0.5	1.0	0.5	0.5
10-30-85		0	0.5	1.0	0	0	0.5	1.5	1.0	1.0
12-11-85		1.0	0	0	0	0.5	0	0.5	1.0	1.0
1-22-86		2.0	0.5	0	0	0	0	N.D.	2.0	0
3-18-86		1.0	0	6.5	0	0	5.0	5.0	6.5	5.0
4-02-86		N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
5-13-86		0	0.5	1.0	0	2.0	0	0	1.0	1.0
6-12-86		0	1.0	0	0	1.0	0.5	3.0	1.5	0.5
6-26-86		1.0	0	N.D.	0	0	0	1.5	1.0	0
7-22-86		0	0	2.0	0	0	0	0.5	0	0.5
9-10-86		N.D.								
9-25-86		1.0	1.0	2.0	0	0	0	0.5	2.0	1.0
Number of Observations with a gradient		6	5	6	1	3	4	8	9	8
Station Mean		0.7	0.35	1.4	0.1	0.35	0.65	1.5	1.75	1.1
Bay Mean				0.64				1.07		

Table 5. Mean (S.E.) dissolved oxygen concentration (mg/L) in Delaware Inland Bays, 18 September 1985 - 25 September 1986. S = surface, B = bottom. Rehoboth Bay (4 stations), Indian River Bay (5 stations) and Little Assawoman Bay (2 stations). Measurements were made only in surface waters in Little Assawoman Bay. N.D. = no data.

DATE	DEPTH	Rehoboth Bay	Indian River Bay	Little Assawoman Bay
9-18-85	S	*8.1	9.2 (0.3)	7.0 (1.0)
	B	*8.0	8.2 (0.0)	
10-30-85	S	8.6 (0.3)	9.5 (0.4)	9.0 (0.7)
	B	8.5 (0.3)	9.1 (0.4)	
12-11-85	S	10.3 (0.5)	11.4 (0.7)	8.9 (0.3)
	B	10.7 (0.4)	11.0 (0.5)	
1-22-86	S	9.0 (0.7)	8.6 (1.4)	N.D.
	B	6.9 (0.3)	7.4 (0.5)	
3-18-86	S	10.1 (0.3)	10.5 (0.6)	6.9 (0.1)
	B	10.6 (0.2)	11.0 (0.9)	
4-02-86	S	6.0 (0.3)	7.1 (0.3)	9.2 (0.3)
	B	7.3 (0.9)	7.8 (0.3)	
5-13-86 (5-05-86)	S	8.1 (0.2)	8.2 (0.2)	8.9 (0.2)
	B	8.0 (0.2)	8.1 (0.1)	
6-12-86 (6-11-86)	S	6.0 (0.7)	8.0 (0.3)	6.1 (0.7)
	B	6.3 (0.4)	6.8 (0.5)	
6-26-86 (6-25-86)	S	7.3 (0.6)	7.2 (0.4)	6.6 (0.1)
	B	6.4 (0.6)	7.0 (0.3)	
7-22-86 (7-21-86)	S	7.3 (0.6)	7.9 (0.4)	5.9 (0.4)
	B	6.4 (0.6)	7.6 (0.2)	
9-10-86 (8-26-86)	S	7.0 (0.3)	7.9 (0.3)	6.1 (0.4)
	B	7.0 (0.2)	7.7 (0.2)	
9-25-86 (9-22-86)	S	6.4 (0.4)	*7.6	5.4 (0.4)
	B	6.3 (0.4)	*7.4	

*n = 1

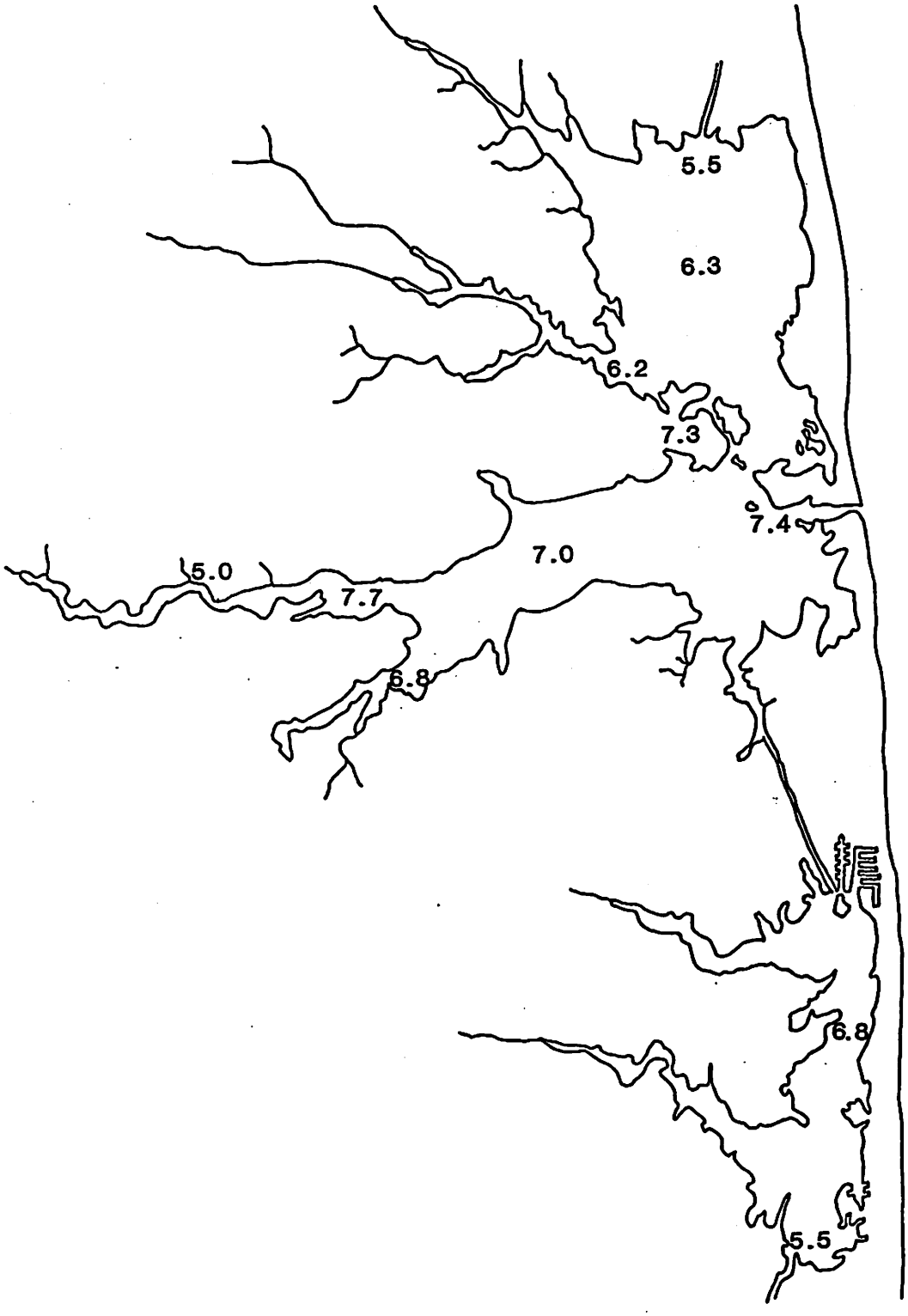


Figure 7. Concentration of dissolved oxygen (mg/L) in bottom waters of Delaware's Inland Bays, 12 June 1986.

the most striking features of the seasonal dissolved oxygen concentration data (Table 5). Other notable features of the seasonal dissolved oxygen cycle are lower concentrations in bottom waters during January and throughout the water column in April. The January decrease in dissolved oxygen concentrations might be related to respiration and/or decomposition of a large diatom assemblage in the more saline portions of the estuary (Stations 5 and 9, see Figs. 34 and 38) and a dinoflagellate bloom at Stations 6-8 (Figs. 35-37). The April decline in dissolved oxygen concentrations probably resulted from warming of the water column, decreasing oxygen solubility, respiration of high macroalgal standing crops (see Macroalgae Section) and increasing bacterial activity accompanying degradation of organic matter which has accumulated in the sediments over the winter.

In an attempt to assess the relative change in dissolved oxygen concentrations over time in Delaware's Inland Bays, a comparison was made between data from this study and a 1974-1975 study on the ecology of the Indian River estuary (Ecological Analysts, 1977). Stations and dates were matched between the two studies and in cases of a discrepancy in sampling dates, a mean value was used between the bi-weekly dissolved oxygen values measured in the earlier study. Over the 10 year period, there was no significant difference between the overall mean dissolved oxygen concentrations between the five pairs of stations, Stations 2, 5, 6, 7 and 9 and the E.A. counterparts (Table 6).

Nutrients

Dissolved Inorganic Nitrogen

Concentrations of oxidized inorganic nitrogen (nitrate + nitrite nitrogen) were high for Delaware's Inland Bays throughout most of the year (Fig. 8). Lowest concentrations were generally observed at Station 5 in the inlet to Indian River Bay, reflecting low ambient concentrations of nitrogen characteristic of shelf waters. In the three Bays, mean monthly concentrations of (nitrate + nitrite)-nitrogen exceeded 10 uM (0.14 mg/L) except for April levels, high concentrations for temperate estuarine waters. Mean concentrations in excess of 110 uM (1.54 mg/L) were observed in March, 1986 in Indian River Bay, due primarily to Station 7 concentrations >200 uM (>2.8 mg/L). Mean monthly concentrations in summer, 1986 exceeded 15 uM (0.21 mg/L) for the three Bays, coincident with high average chlorophyll levels ranging from 10-43 ug/L (see Appendix 2 for detailed data listing).

Dissolved inorganic nitrate plus nitrite nitrogen concentrations for the three Inland Bays are depicted in Figures 9-12. Concentrations of dissolved nitrogen were similar in all Rehoboth Bay stations within date, with values ranging from as low as 2 uM (0.03 mg/L) in April to maximum values of approximately 60 uM (0.84 mg/L) in September (Fig. 9). Station 3, located at the mouth of Herring Creek, was typified by highest concentrations of dissolved inorganic nitrogen in seven of twelve sampling periods, suggesting that Herring Creek may be a major source of dissolved inorganic nitrogen for Rehoboth Bay.

In striking contrast to Rehoboth Bay, large temporal variations in dissolved inorganic nitrogen concentrations were noted in Indian River Bay (Fig. 10). This was especially true for Station 7, located midway up Indian River and Station 8, at the mouth of Pepper Creek. Steadily increasing concentrations of dissolved inorganic nitrogen were seen throughout the fall and winter in Indian River Bay, peaking in March (204 uM, 2.86 mg/L). Thereafter, concentrations rapidly declined to low

Table 6. Comparison of bottom dissolved oxygen concentrations (mg/L) between ANS study, 1985-86 and EA study, 1974-75, Delaware Inland Bays. N.D. = no data.

	ANS - EA									
DATE	1-7RB		5-9		6-31		7-x42-53		9-24	
9-18-85	8.0	7.0	N.D.	7.5	N.D.	8.5	N.D.	6.0	8.2	8.0
10-33-85	7.9	9.0	8.0	9.0	9.4	8.5	10.2	9.0	9.0	9.0
12-11-85	11.4	11.0	9.9	10.0	11.2	11.0	12.8	12.8	10.6	11.0
1-22-86	6.8	12.0	6.7	13.0	7.6	12.0	N.D.		6.2	14.0
3-18-86	10.6	12.0	11.0	11.0	10.5	10.0	8.5	10.5	10.9	11.0
4-02-86	6.6	10.0	7.3	10.0	7.6	9.0	8.8	10.0	7.3	9.5
5-13-86	8.1	8.0	8.3	7.5	8.0	4.0	8.4	3.3	7.8	6.5
6-12-86	6.3	8.0	7.4	8.0	7.7	7.0	5.0	6.0	7.0	8.0
6-26-86	7.5	N.D.	7.5	6.0	6.7	4.5	6.3	4.0	6.7	4.5
7-22-86	7.6	5.0	7.2	7.0	8.0	4.0	8.1	4.0	7.0	6.0
9-10-86	7.0	6.0	7.3	7.0	7.3	7.0	8.0	6.5	7.5	6.0
9-26-86	6.9	8.0	7.4	8.0	N.D.	10.0	8.3	6.0	8.2	8.0
Mean	7.9	8.7	8.0	8.7	8.4	8.0	8.4	7.1	8.0	8.5
	F = 0.9		F = 1.15		F = 0.49		F = 1.1		F = 0.27	
	$F_{.95}$ = 4.32		$F_{.95}$ = 4.32		$F_{.95}$ = 4.38		$F_{.95}$ = 4.38		$F_{.95}$ = 4.28	

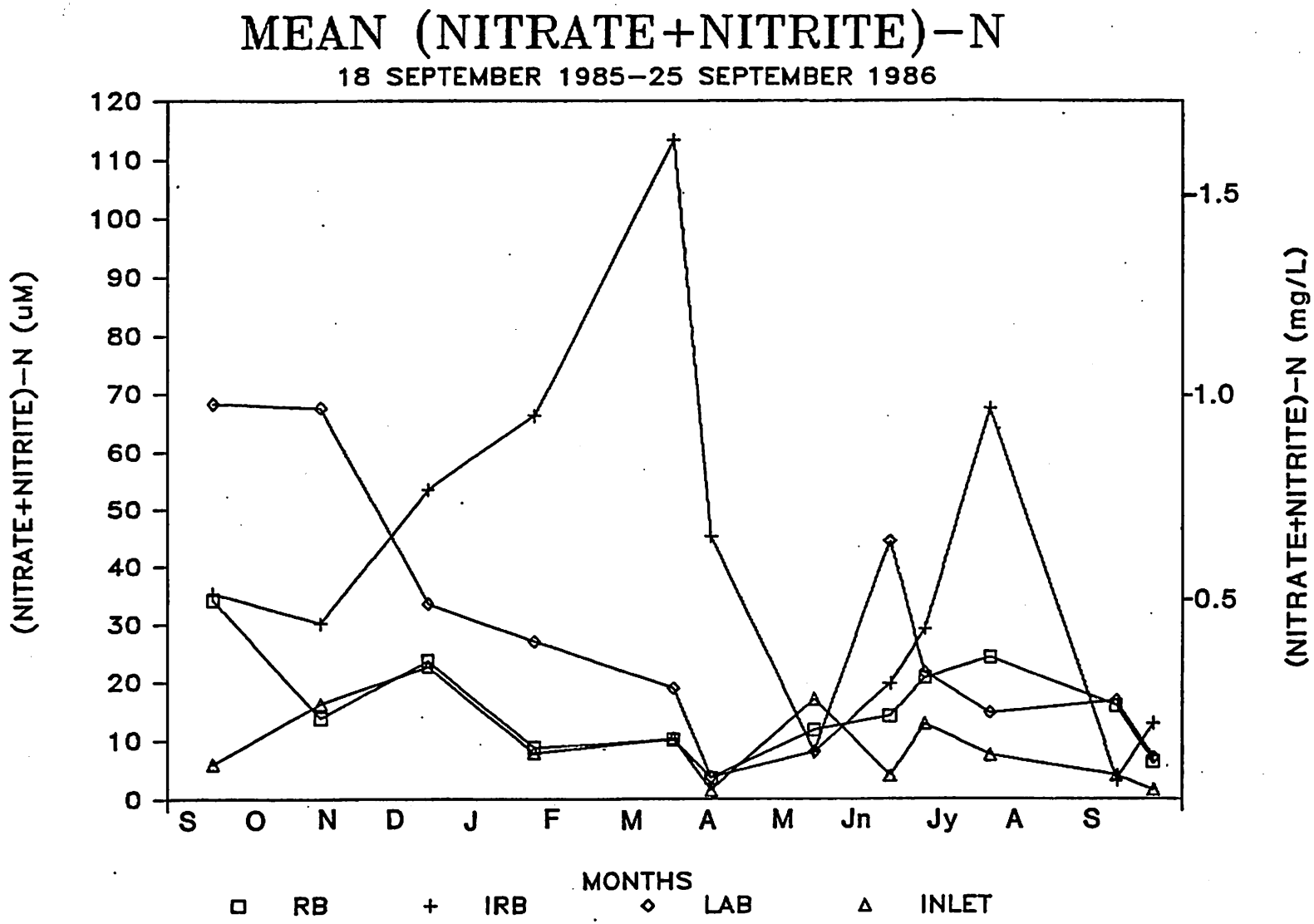


Figure 8. Mean monthly concentrations of (nitrate + nitrite) - N in Delaware's Inland Bays for the period September, 1985 - September, 1986 (symbols as in Figure 2).

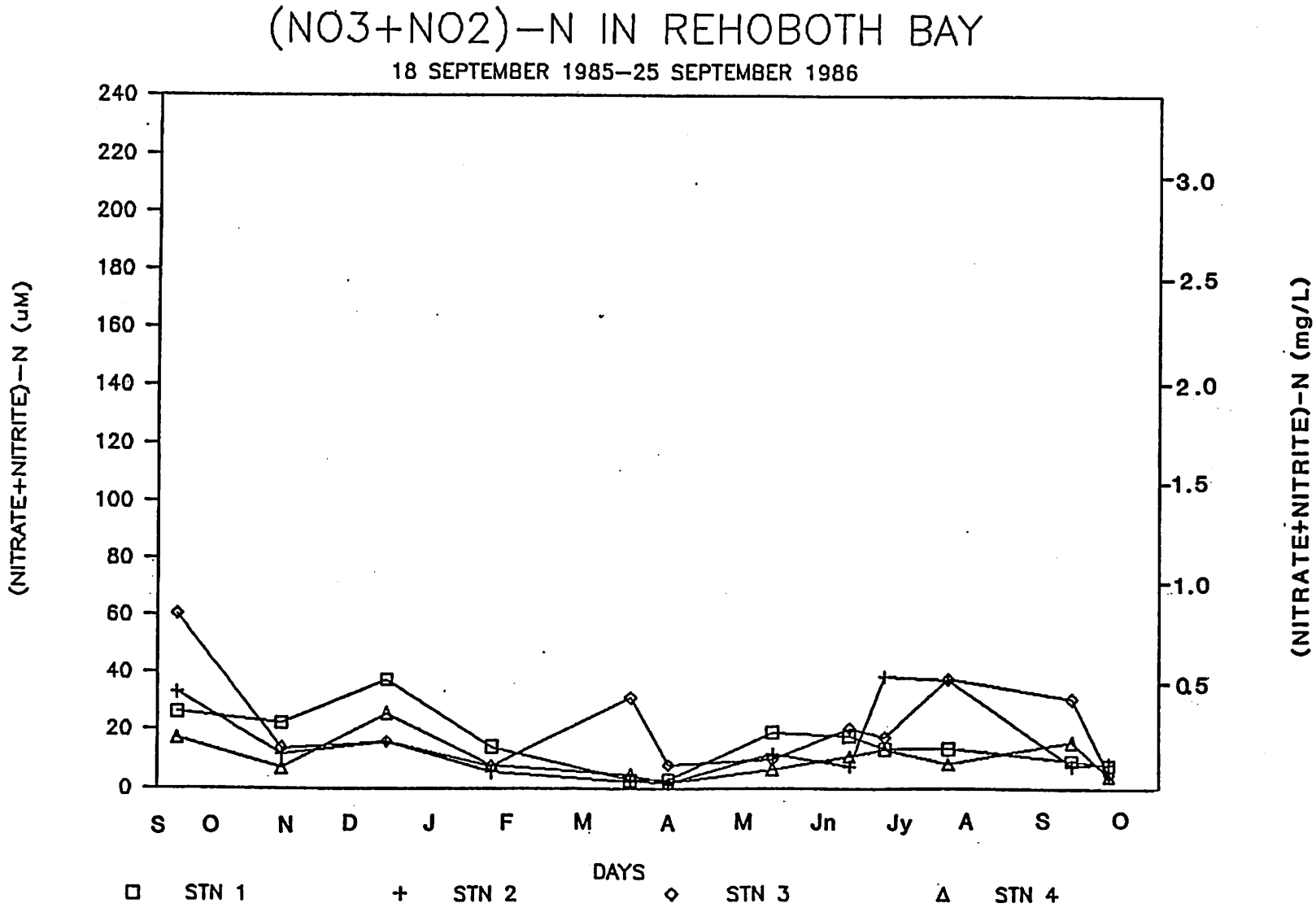


Figure 9. Concentrations of (nitrate + nitrite) - N in Rehoboth Bay for the period from September, 1985 - September, 1986.

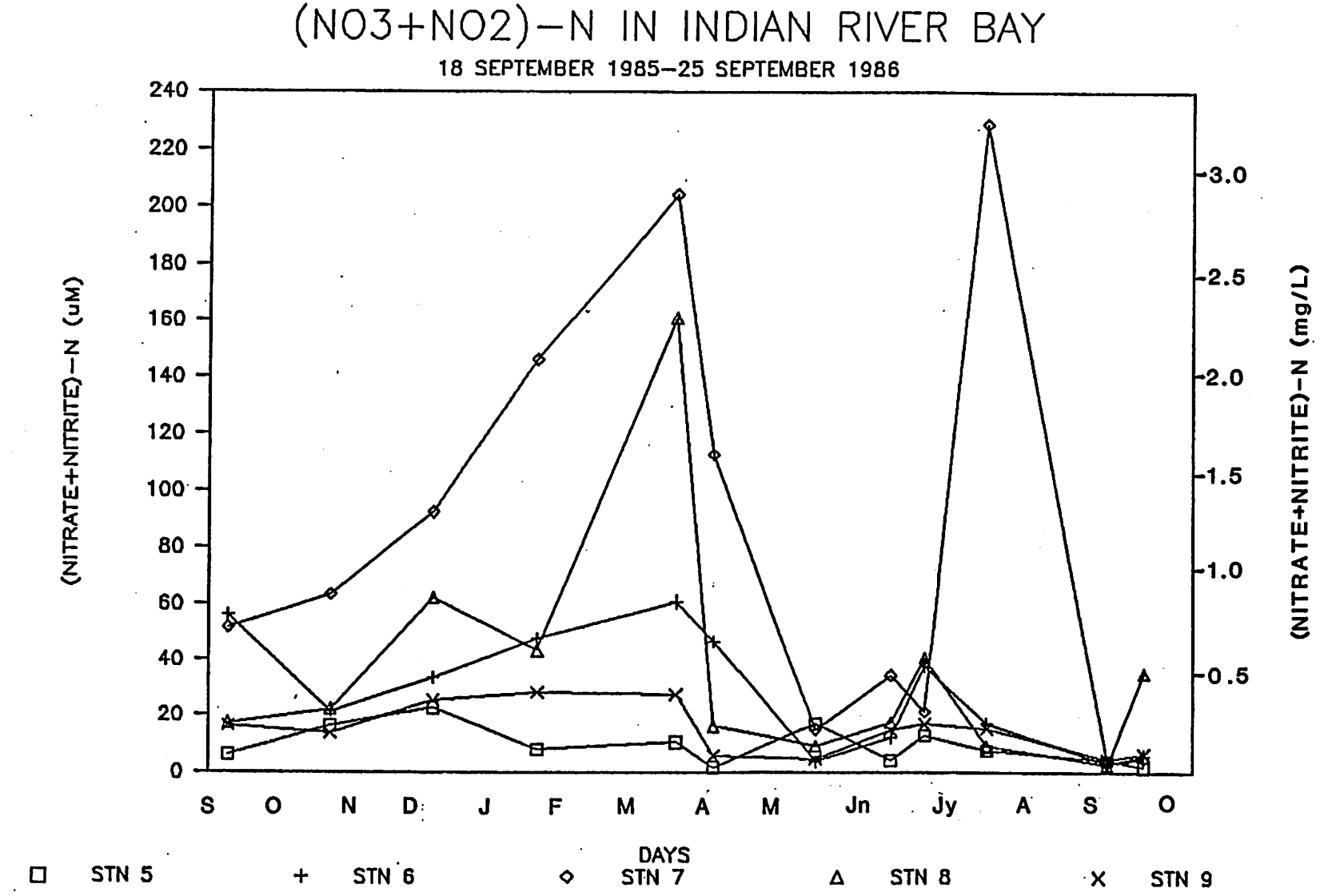


Figure 10. Concentrations of (nitrate + nitrite) - N in Indian River Bay for the period from September, 1985 - September, 1986.

levels in May (3.45-15 uM, 0.04-0.21 mg/L). Concentrations increased again in June only to decline to lowest levels (monthly mean of 8.5 uM, 0.12 mg/L) in September.

Nitrate plus nitrite nitrogen concentrations in Indian River Bay were positively correlated with freshwater input. The highest concentrations of inorganic nitrogen at Stations 6, 7, and 8 (the stations experiencing the largest amount of freshwater input) occurred during the high flow period between December and April (Fig. 11). Similar results have been recorded by Casey and Clarke (1979) in an eleven year study of the River Frome in England, EPA (1982) and Fisher et al. (submitted, 1986) in studies of Chesapeake Bay and D'Elia et al. (1986) in the Patuxent River. Conversely, the lowest concentrations of dissolved inorganic nitrogen were recorded in the low-flow period of late summer, from July-September, except at Station 7 where an unusually high concentration (229 uM, 3.21 mg/L) was observed and cannot be explained. However, possible sources for this high concentration are: a localized outfall from a point source, efflux from the sediment or a measurement artifact. Since Station 7 is typified by high chlorophyll concentrations, a reservoir of oxidizable organic matter likely accumulates in the sediments. When temperatures rise and bacterial activity increases, nitrogen in this organic reservoir is returned to the water column via bacterial decomposition of the settled material. Efflux of nutrients from the sediments has been documented in many systems including Chesapeake Bay (Boynton et al., 1986), the Potomac River (Callendar and Hammond, 1982) and Narragansett Bay (Nixon et al., 1975).

The seasonal distribution of nitrate plus nitrite nitrogen in Little Assawoman Bay was also positively correlated to freshwater input. During September and October, 1985 when salinities at the sampling stations were lowest, nitrate plus nitrite nitrogen concentrations were at their yearly maximum (37-507 uM, 0.52-7.10 mg/L) for the two stations (Fig. 12). The extremely high concentration at Station 10 in October is analytically correct but otherwise unexplainable. A secondary peak occurred in early June (31-58 uM, 0.43-0.81 mg/L) possibly attributable to rain on 9 June (NOAA, 1986).

In an attempt to assess possible changes in nitrate and therefore water quality over time in Indian River and Rehoboth Bays, analysis of variance tests were used to compare present data with data collected in 1979-80 by DNREC. Concentrations at Stations 1 and 2 in Rehoboth Bay and Stations 6, 7 and 9 in Indian River Bay were compared to levels in stations sampled as part of a routine DNREC water quality monitoring effort. The DNREC detection limit for nitrate determinations was 0.11 mg/L, so for those measurements less than 0.11 mg/L, a value of 0.05 mg/L was assumed. The results from the ANOVA showed no significant differences between the means of the present nitrate data and data collected and measured in 1979-80 (Table 7).

Half-saturation constants for nitrate uptake in neritic phytoplankton populations are 1-2 uM (0.01-0.03 mg/L; Eppley et al., 1969; MacIsaac and Dugdale, 1969; Murphy, 1980). Therefore, nitrogen limitation would be indicated at nitrate concentrations less than 2 uM (0.03 mg/L). Only four nitrate measurements (3% of the total) were below 2 uM, three found in April, suggesting that nitrogen is rarely limiting phytoplankton in Delaware's Inland Bays.

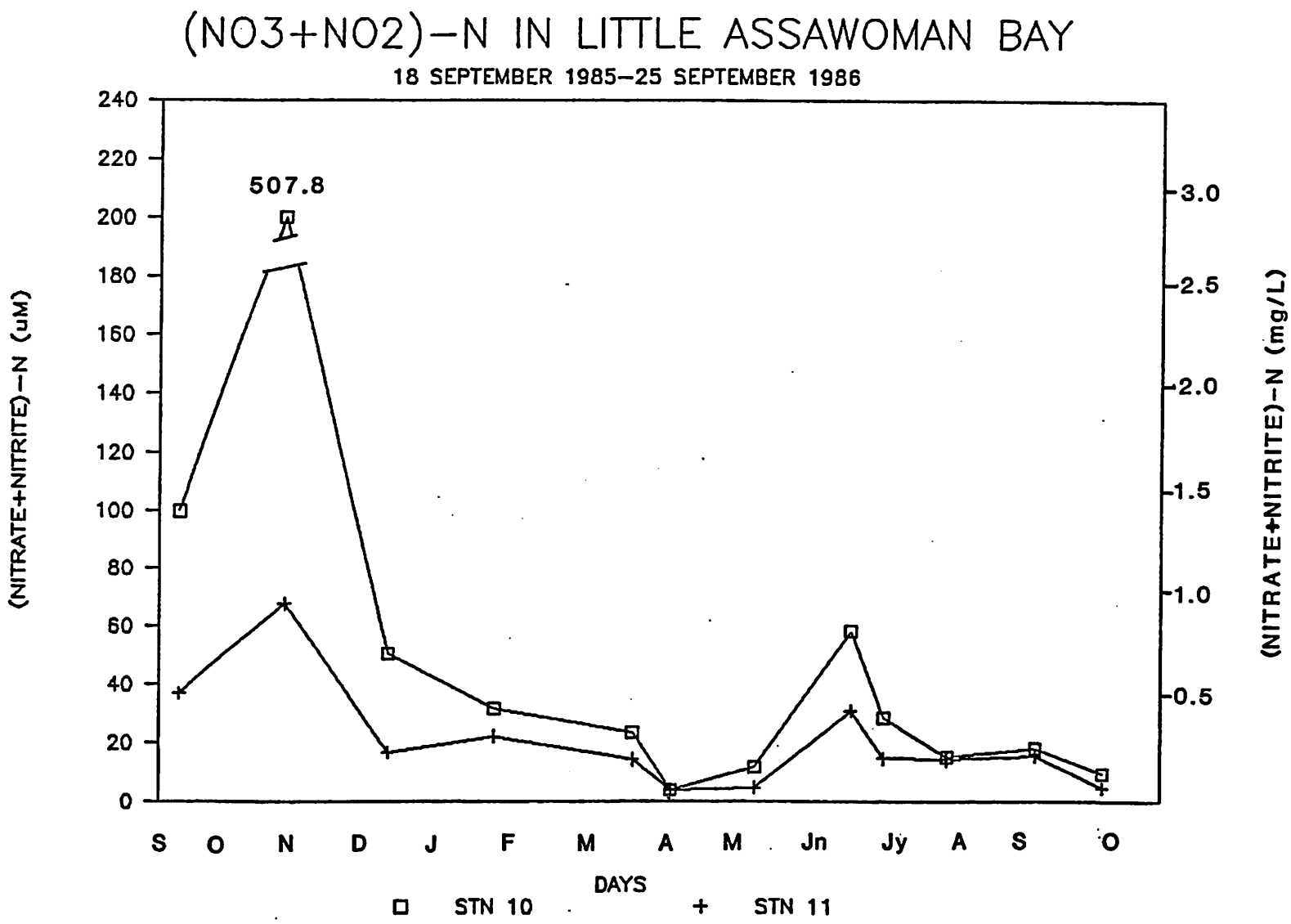


Figure 11. Concentrations of (nitrate + nitrite) - N in Little Assawoman Bay for the period from September, 1985 - September, 1986.

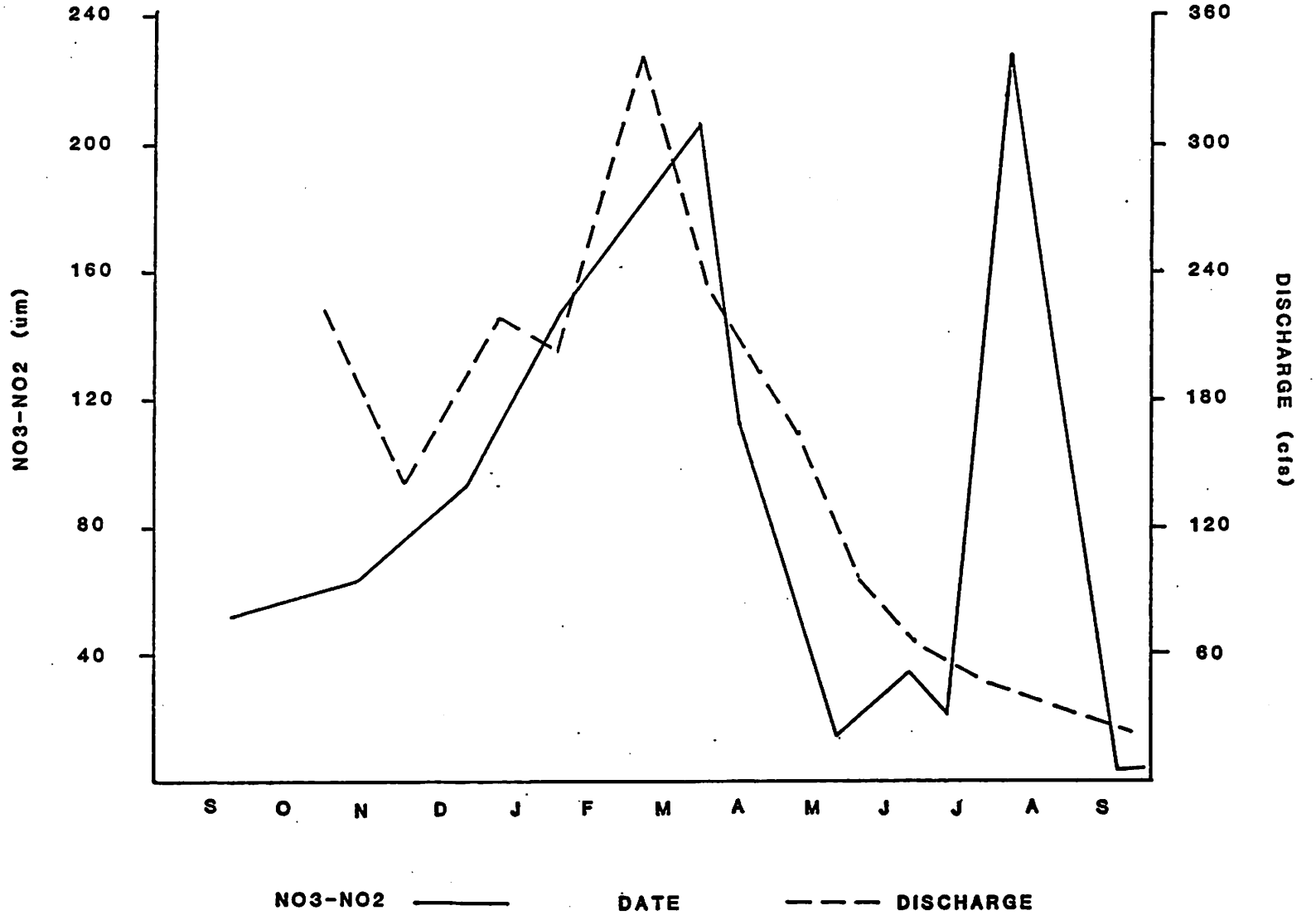


Figure 12. Concentration of (nitrate + nitrite) - N and freshwater discharge (cfs) in Indian River for the period September, 1985 - September, 1986.

Table 7. Comparison of (nitrate + nitrite) concentrations (mg/L) between ANS study from 1985-86 and DDNREC study from 1979-80 in Delaware Inland Bays. N.D. = no data.

ANS - DDNREC

Station	1	Buoy #1	2	Buoy #7	6	Buoy #30	7	Buoy #49	9	Buoy #26
Date										
March	0.04	0.20	0.03	0.24	0.85	0.53	2.86	1.92	0.38	0.29
April	0.04	<0.11*	0.02	<0.11	0.65	0.58	1.58	1.51	0.08	0.33
May	0.27	0.11	0.16	<0.11	0.05	<0.11	0.21	<0.11	0.06	<0.11
June	0.25	N.D.	0.10	N.D.	0.17	0.65	0.48	1.40	0.21	0.45
July	0.19	<0.11	0.53	<0.11	0.24	0.23	3.20	0.88	0.21	<0.10
September	0.13	<0.11	0.11	0.33	0.04	<0.11	0.04	0.26	0.06	<0.11
October	0.32	0.14	0.17	0.28	0.30	0.63	0.89	1.70	0.19	0.28
December	0.52	<0.11	0.22	<0.11	0.47	0.98	1.30	2.90	0.36	0.63
Total	1.76	0.65	1.34	1.05	2.77	03.7	10.56	10.62	1.55	2.13
Mean	0.22	0.09	0.17	0.15	0.35	0.46	1.32	1.33	0.19	0.27
	F = 3.95		F = 0.05		F = 0.57		F = 0.002		F = 0.70	
	$F_{0.95}$ = 4.67		$F_{0.95}$ = 4.67		$F_{0.95}$ = 4.60		$F_{0.95}$ = 4.60		$F_{0.95}$ = 4.60	

* data <0.11 mg/l were arbitrarily assigned a value of 0.05 mg/L

Ammonium

Only ten percent (13) of the ammonium concentration measurements were greater than the detection limit (0.05 mg/L). Even assuming that the values below the detection limit were equal to 0.025 mg/L, ammonium would comprise only 12% of the total nitrogen in the Delaware Inland Bays. Low concentrations would be expected, however, since ammonium-N is the preferred nitrogenous substrate for phytoplankton (Dugdale and Goering, 1967; McCarthy et al., 1977). Seasonally, highest ammonium concentrations were found in September, 1985 and July, 1986. These elevated levels may be related to increased sewage outfall that accompanies high summer tourism in the area as well as highest nutrient efflux from bottom sediments (see Boynton et al., 1986). Spatially, Station 7 in the upper Indian River Bay, and Station 10, located near the mouth of Dirickson Creek in Little Assawoman Bay, were typified by the greatest number of detectable ammonium concentrations.

Soluble Reactive Phosphate

Phosphate-phosphorus concentrations for the Delaware Inland Bays are depicted in Figures 13-16 and presented in Appendix 2. The general seasonal trend for mean concentrations in all three bodies of water is depicted in Figure 13. High mean monthly concentrations of phosphate were noted in September-December, 1985 followed by minimum concentrations from January-May. Concentrations again increased in the summer of 1986; however, 1986 summer concentrations in Rehoboth Bay, Indian River Bay and the inlet were much lower than noted in 1985, again reflecting a positive relationship between river flow and nutrient levels (see nitrogen discussion above).

Phosphate-P concentrations in Rehoboth Bay ranged from below the detection limit of 0.05 uM to 1.63 uM (<0-0.05 mg/L; Fig. 14). The yearly mean concentrations for Stations 1, 2, 3, and 4 were 0.51, 0.42, 0.22 and 0.43 uM, respectively (0.02, 0.01, 0.01 and 0.01 mg/L). There was no significant difference between the four mean concentrations ($F = 1.28$, $p = 0.05$).

The seasonal pattern and actual concentrations of phosphate-P in Indian River Bay (Fig. 15) were very similar to those recorded for Rehoboth Bay. The range of phosphate-P concentrations for all of the stations in Indian River Bay was from below the detection limit of 0.05 uM to 1.37 uM (<0.01-0.04 mg/L). The mean concentrations over the entire sampling period for Stations 5-9 were 0.55, 0.39, 0.52, 0.31 and 0.38 uM, respectively (0.02, 0.01, 0.02, 0.01 and 0.01 mg/L). Once again, there was no significant difference between the yearly mean concentrations for these five stations ($F = 0.97$, $p = 0.05$).

In Little Assawoman Bay, distributions of phosphate-P over the study period was slightly different than distributions in the other two bays in that concentrations were not as variable. The primary winter peak and the secondary summer peak obvious in the other two bays were only subtle features in Little Assawoman Bay (Fig. 16). The yearly means for phosphate-P concentrations for Stations 10 and 11 were 0.22 and 0.16 uM, respectively (<0.01 mg/L). There was no significant difference between the yearly mean concentrations between the two stations ($F = 0.94$, $p = 0.05$).

In an attempt to compare the present phosphorus concentrations to past values, analysis of variance tests were conducted on the ANS data and data collected by

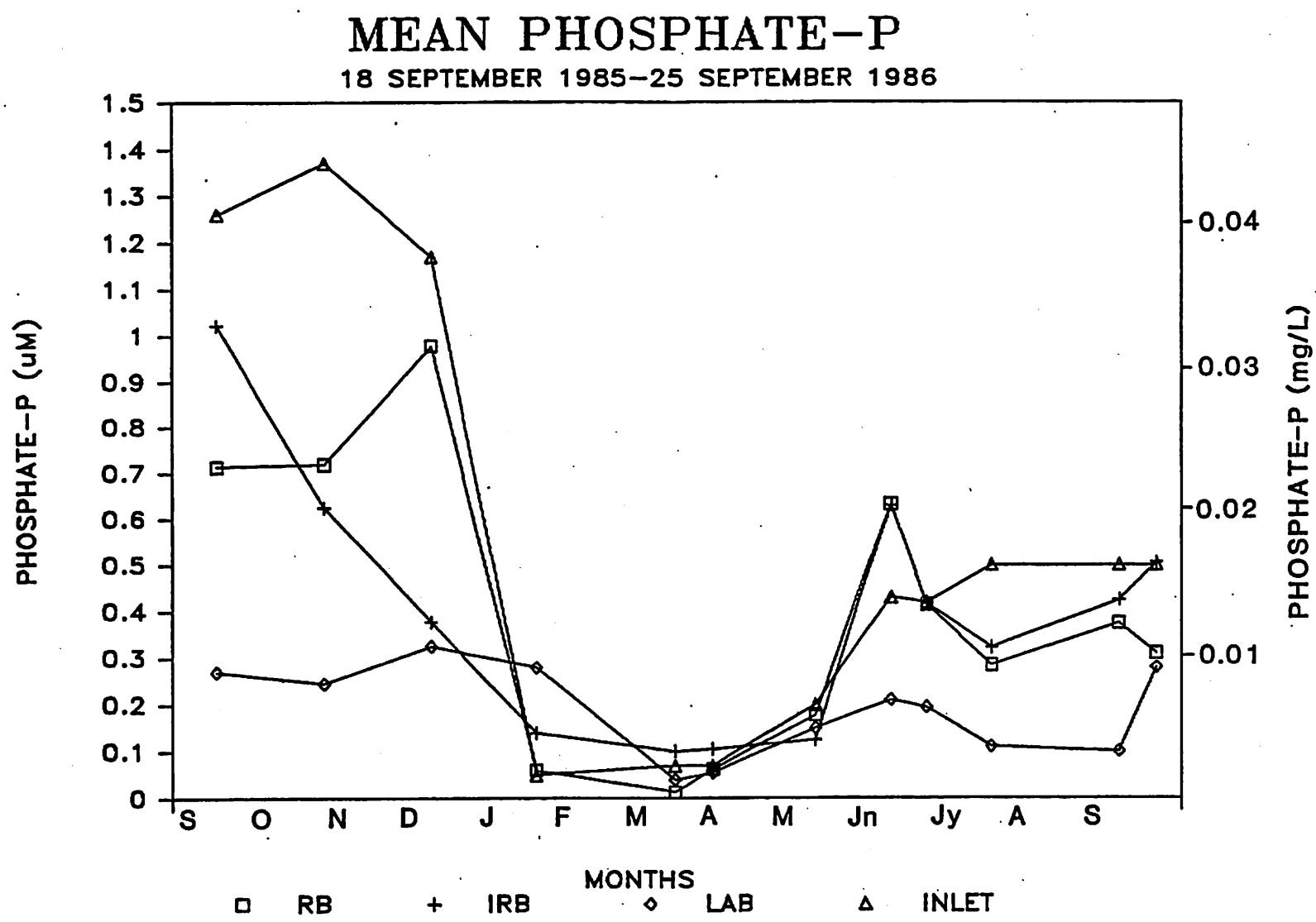


Figure 13. Mean monthly concentrations of orthophosphate-P in Delaware's Inland Bays for the period September, 1985 - September, 1986 (symbols as in Figure 2).

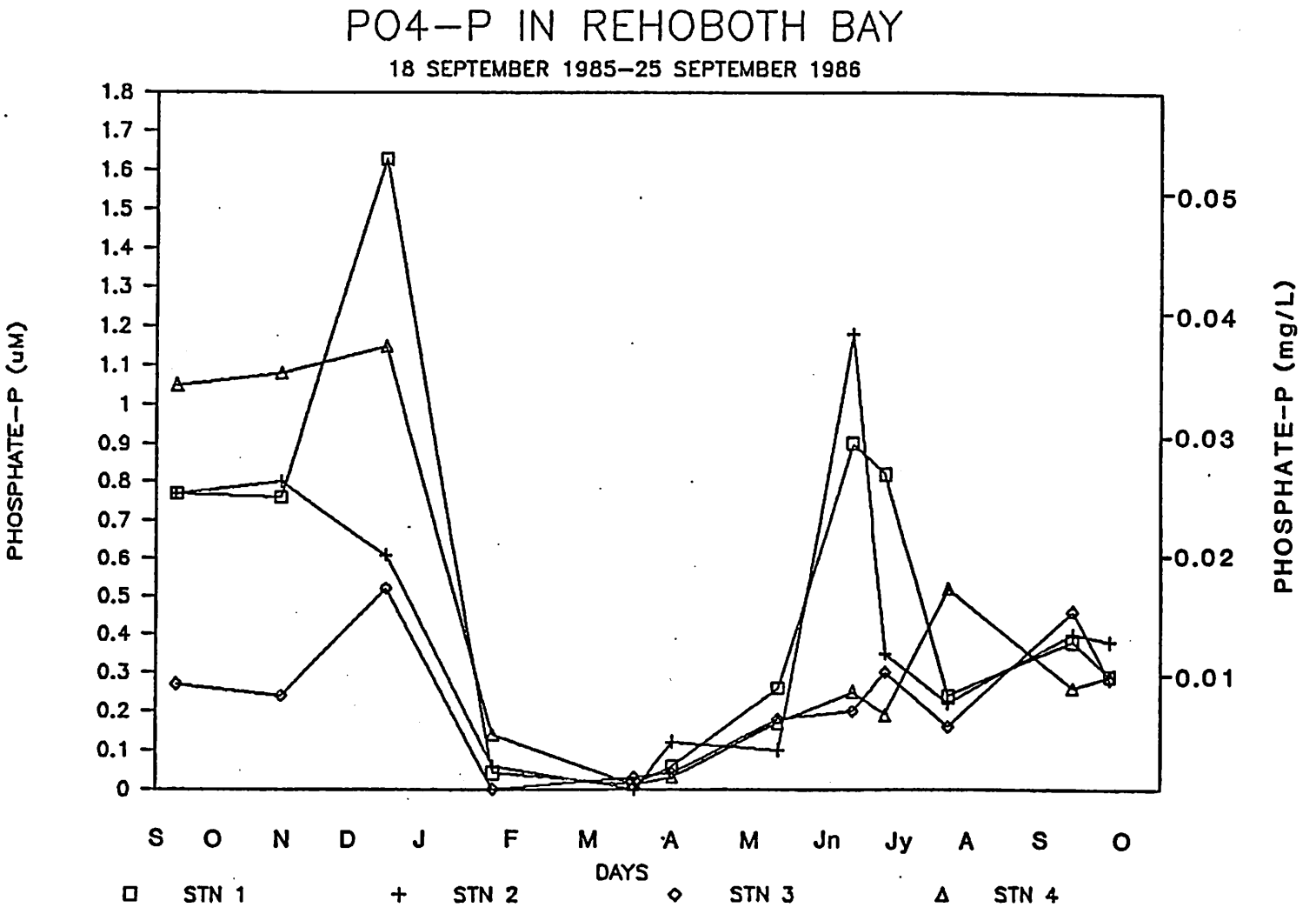


Figure 14. Concentrations of orthophosphate-P in Rehoboth Bay for the period September, 1985 - September, 1986.

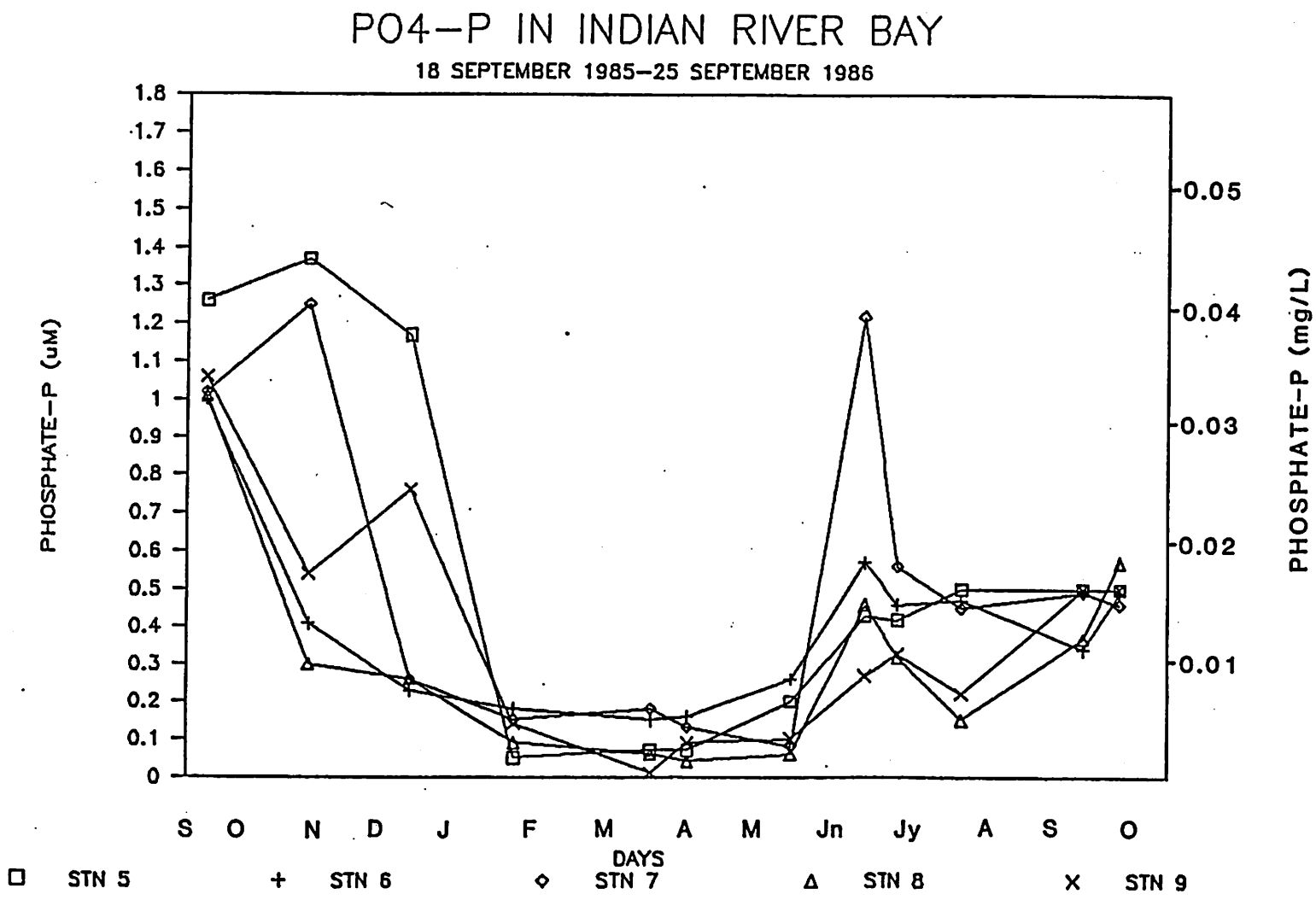


Figure 15. Concentrations of orthophosphate-P in Indian River Bay for the period September, 1985 - September, 1986.

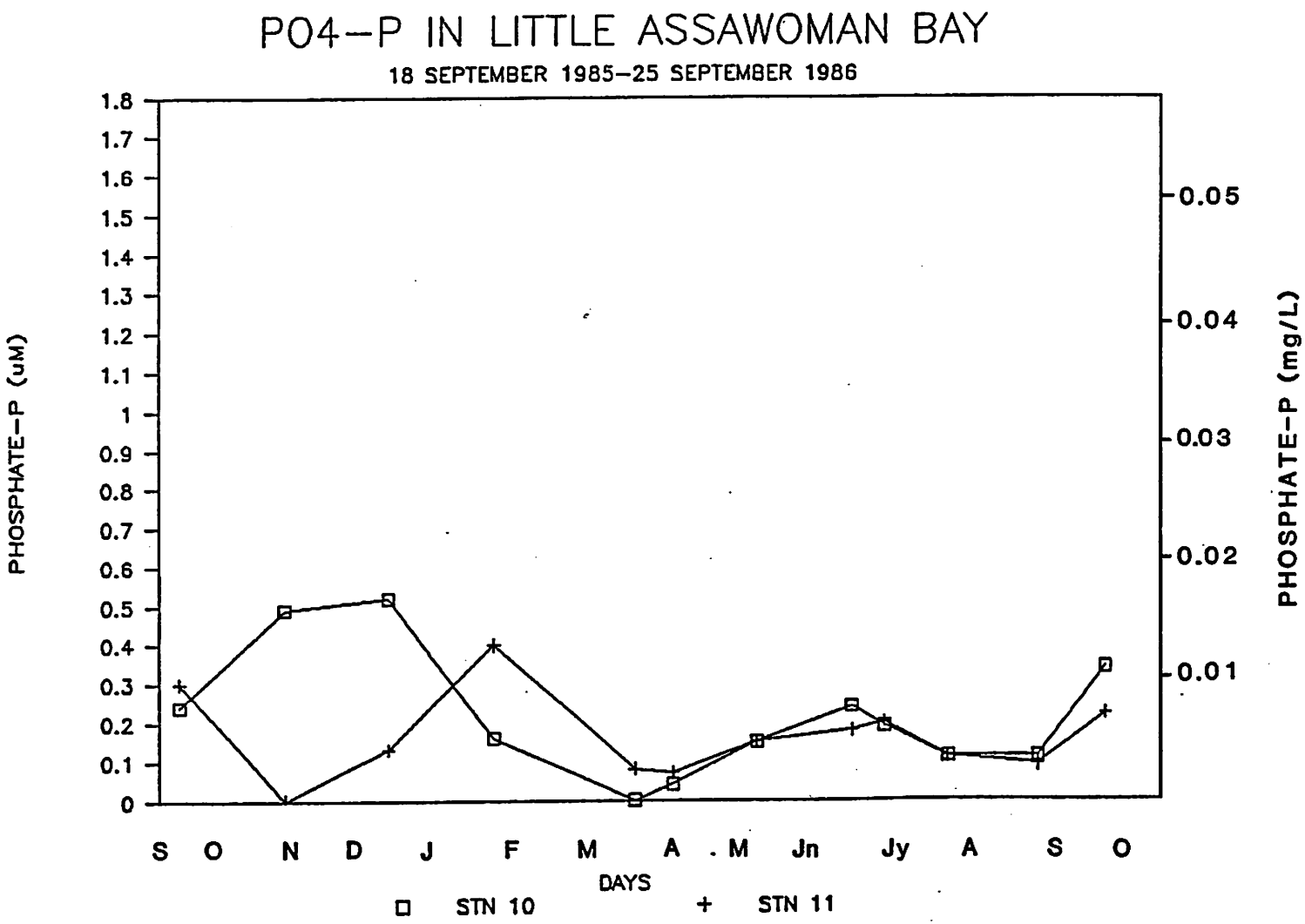


Figure 16. Concentrations of orthophosphate-P in Little Assawoman Bay for the period September, 1985 - September, 1986.

DNREC during 1979-80. For all DNREC data <0.11 mg/L, a value of 0.05 mg/L was assumed. Mean ANS phosphorus concentrations were higher than levels measured by DNREC for similar stations and dates but, none were significantly different (Table 8).

In assessing possible phosphorus limitation of phytoplankton in the Delaware Inland Bays, half-saturation constants were also compared to ambient PO_4-P concentrations. Commonly reported half-saturation constants for algal uptake of phosphate-P in eutrophic environments range from 0.1-1.7 uM (<0.01-0.05 mg/L; Harvey, 1963; Fuhs et al., 1972; Taft et al., 1977; Nalewajko and Lean, 1980). Therefore, phosphate concentrations less than 1.7 uM (0.05 mg/L) could conceivably result in phosphorus limitation of phytoplankton assemblages. All concentrations recorded in this study (132) were less than 1.7 uM, implying that phytoplankton populations in Delaware's Inland Bays could be limited by low dissolved inorganic phosphorus concentrations present in the system.

Ratios of nitrogen to phosphorus in Delaware's Inland Bays offer another means of assessing whether nutrients might limit phytoplankton. An N:P ratio below 10:1 indicates nitrogen limitation while a ratio greater than 20:1 implies phosphorus limitation (D'Elia, 1982). In calculating N:P ratios in the current study, a value of 0.05 uM was assumed for all phosphate concentrations which were below the detection limit. The mean monthly N:P ratio for each bay is presented in Table 9. The mean N:P ratios ranged from 20:1 to 202:1 for Rehoboth Bay, 7:1 to 983:1 for Indian River Bay and 24:1 to 1194:1 for Little Assawoman Bay. Seasonally, lower N:P ratios were measured in Rehoboth Bay and Indian River Bay from September-October (27:1-179:1) followed by high values from December-April (26:1-983:1); ratios decreased again for the remainder of the study (8:1-96:1) with the exception of late July. Little Assawoman Bay displayed a slightly different seasonal pattern in which mean N:P ratios were higher from September-March (113:1-1195:1), considerably lower in April-May (54:1-64:1), relatively high from June-August (112:1-207:1) and declining again in September, 1986 (24:1). The large number of these ratios that exceeded 20 supports phosphorus limitation in the system.

Silicate

Mean monthly concentrations of silicate-Si (Fig. 17) followed a similar pattern to the seasonal distribution of phosphorus. Minimum concentrations for the system were observed from January-May, 1986; mean concentrations in all areas except Indian River Bay were <15 uM (<0.42 mg/L) for this period. Concentrations in Indian River inlet were generally lower than noted in the Bays, reflecting lower silicate concentrations typical of higher salinity waters of the shelf (see Appendix 2 for detailed data listing).

Silicate-silicon concentrations in the Delaware Inland Bays varied from less than 1 uM to greater than 233 uM (<0.03-6.52mg/L). The seasonal trends varied greatly between the three bays, with the exception of a distinct summer peak (Figs. 18-20). Spatially, the station located in the area of maximum freshwater input, Station 7, was typified by the highest overall concentration of silicate while the station located in the area of maximum saltwater input, Station 5, was characterized by the overall lowest concentrations.

Silicate-silicon concentrations for stations in Rehoboth Bay showed a fairly regular seasonal pattern in which concentrations were relatively high in September-

Table 8: Comparison of phosphate concentrations (mg/L) between ANS data from 1985-86 and DDNREC data from 1979-80 in Delaware Inland Bays. N.D. = no data.

ANS - DDNREC

Station	1	Buoy #1	2	Buoy #7	6	Buoy #30	7	Buoy #49	9	Buoy #26
Date										
March	0.01	0.10	0.00	0.15	0.15	0.10	0.18	0.15	0.10	0.20
April	0.06	0.10	0.12	0.10	0.16	0.10	0.13	0.10	0.09	0.10
May	0.26	<0.10*	0.10	<0.10*	0.26	<0.10	0.08	0.20	0.10	<0.10*
June	0.90	N.D.	1.18	N.D.	0.57	0.25	1.22	0.30	0.27	0.25
July	0.24	0.25	0.22	0.30	0.47	0.30	0.45	0.20	0.20	0.30
September	0.38	0.20	0.40	0.25	0.34	0.20	0.49	0.25	0.50	0.20
October	0.76	0.25	0.80	0.85	0.41	0.50	1.25	0.35	0.54	0.35
December	1.63	0.20	0.61	0.25	0.23	0.25	0.26	0.25	0.76	0.25
Total	4.24	1.40	3.43	1.95	2.59	1.75	4.06	1.80	2.48	1.70
Mean	0.53	0.18	0.43	0.28	0.32	0.22	0.51	0.23	0.31	0.21
	F = 3.34		F = 0.69		F = 2.03		F = 2.79		F = 0.98	
	$F_{0.95}$ = 4.67		$F_{0.95}$ = 4.67		$F_{0.95}$ = 4.60		$F_{0.95}$ = 4.60		$F_{0.95}$ = 4.60	

* data <0.10 mg/l were arbitrarily assigned a value of 0.05 mg/L

Table 9: Mean atomic N:P ratios (S.E.) for Delaware Inland Bays, 18 September 1985 - 25 September 1986. Rehoboth Bay (4 stations), Indian River Bay (5 stations) and Little Assawoman Bay (2 stations). Dates in parentheses indicate Little Assawoman Bay sampling dates.

Date	Rehoboth Bay	Indian River Bay	Little Assawoman Bay
9-18-85	79.2 (48.6)	28.8 (10.3)	269.5 (146.5)
10-30-85	27.1 (11.1)	42.8 (10.9)	1194.5 (157.5)
12-11-85	25.5 (2.0)	160.1 (64.1)	113.0 (16.0)
1-22-86	145.5 (49.8)	415.0 (150.6)	127.0 (71.0)
3-18-86	202.2 (141.0)	983.4 (453.9)	325.5 (146.5)
4-02-86	64.2 (32.4)	312.6 (150.9)	64.0 (9.0)
5-13-86 (5-5-86)	71.2 (17.2)	96.0 (32.3)	54.0 (24.0)
6-12-86 (6-11-86)	43.0 (21.2)	30.2 (7.8)	207.0 (35.0)
6-26-86 (6-25-86)	63.5 (19.3)	65.7 (17.8)	111.5 (38.5)
7-22-86 (7-21-86)	119.2 (50.5)	137.4 (93.1)	133.0 (4.0)
9-10-86 (8-26-86)	42.8 (12.1)	7.8 (0.6)	169.0 (3.0)
9-25-86 (9-22-86)	20.2 (2.8)	19.4 (10.8)	24.0 (4.0)

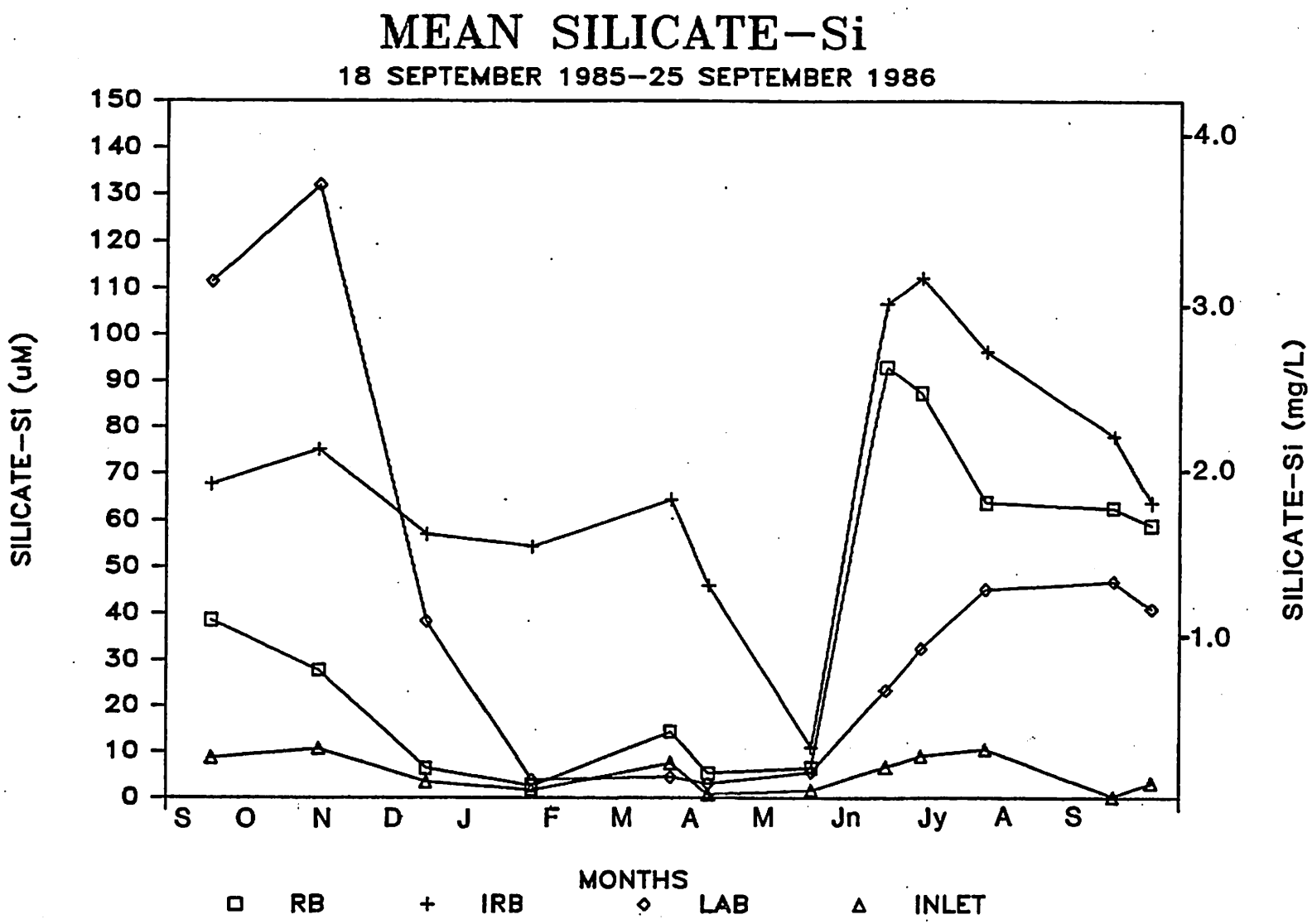


Figure 17. Mean monthly concentrations of silicate-Si in Delaware's Inland Bays for the period September, 1985 - September, 1986 (symbols as in Figure 2).

October (mean = 33.2 uM, 0.93 mg/L), steadily declined to low concentrations in March-April (mean = 9.8 uM, 0.27 mg/L) and slowly rose again to the highest yearly concentrations (mean = 73.2 uM, 2.05 mg/L) during June-September (Fig. 18). The only exception to this general pattern was a substantial increase in silicate-silicon at Station 3 on March 18, possibly a response to >1 in of precipitation between March 13-16 (NOAA, 1986).

Silicate-silicon concentrations for the stations in Indian River Bay were characterized by relatively high values from September-March (mean = 52.3 uM, 1.46 mg/L), decreasing in April to a low in May (mean = 9.1 uM, 0.25 mg/L) and again increasing to a yearly maximum in June-July (mean = 85.7 uM, 2.40 mg/L) and remaining relatively high through September (Fig. 19). The major differences between Indian River Bay and Rehoboth Bay were generally higher silicate concentrations and the absence of extremely low concentrations during the winter in Indian River Bay (compare Figs. 18 and 19).

Very similar seasonal trends were noted in stations located in Little Assawoman Bay with the exception of very high concentrations at Station 10 during September-October, 1985 (Fig. 20). The peak in September-October coincides with similar maxima in N and P for regions draining agricultural lands. Relatively high silicate concentrations were measured from September-December (25-233 uM, 0.70-6.52 mg/L), with low concentrations in January-May (0-11 uM, 0-0.31 mg/L) followed by higher levels from June-September, 1986 (19-56 uM; 0.53-1.57 mg/L).

Half-saturation constants for silicate uptake by diatoms range from 1-5 uM (0.03-0.14 mg/L; Davis, 1973; Goering et al., 1973; Guillard et al., 1973; Harrison, 1973; Paasche, 1973). Silicate concentrations were frequently below the half-saturation constant (5 uM, 0.14 mg/L) suggesting silicon limitiation. For example, concentrations less than 5 uM were noted during March-April at Station 1, January-May at Station 2, January at Station 3 and December-April at Station 4 in Rehoboth Bay. In Indian River Bay, Station 5, located at the inlet, had concentrations less than 5 uM during December-January, April-May, and during September, 1986. In Little Assawoman Bay, Station 10 exhibited silicate concentrations below 5 uM in January and April, while Station 11 was typified by low concentrations from January-May.

Phytoplankton and Related Parameters

Chlorophyll a

Mean monthly concentrations of chlorophyll a for Delaware's Inland Bays are shown in Figure 21 and Appendix 1. The distributions of chlorophyll in the system in 1985 versus 1986 are apparently inversely related to discharge in the system. As noted in the salinity data, higher discharges in 1985 would lead to shorter residence times for phytoplankton in the Bays and lower standing stocks, in general, in 1985 versus 1986. In September, 1985, mean chlorophyll levels were approximately 4, 10 and 13 ug/L for Rehoboth Bay, Indian River Bay and Little Assawoman Bay, respectively. In September, 1986, concentrations were approximately 22, 33 and 19 ug/L for these regions, reflecting lower flushing rates, possibly permitting greater chlorophyll accumulations from active phytoplankton growth in the Bays. Chlorophyll a concentrations were always lowest in Indian River inlet (Station 5), again reflecting concentrations typical of more oligotrophic shelf waters immediately offshore.

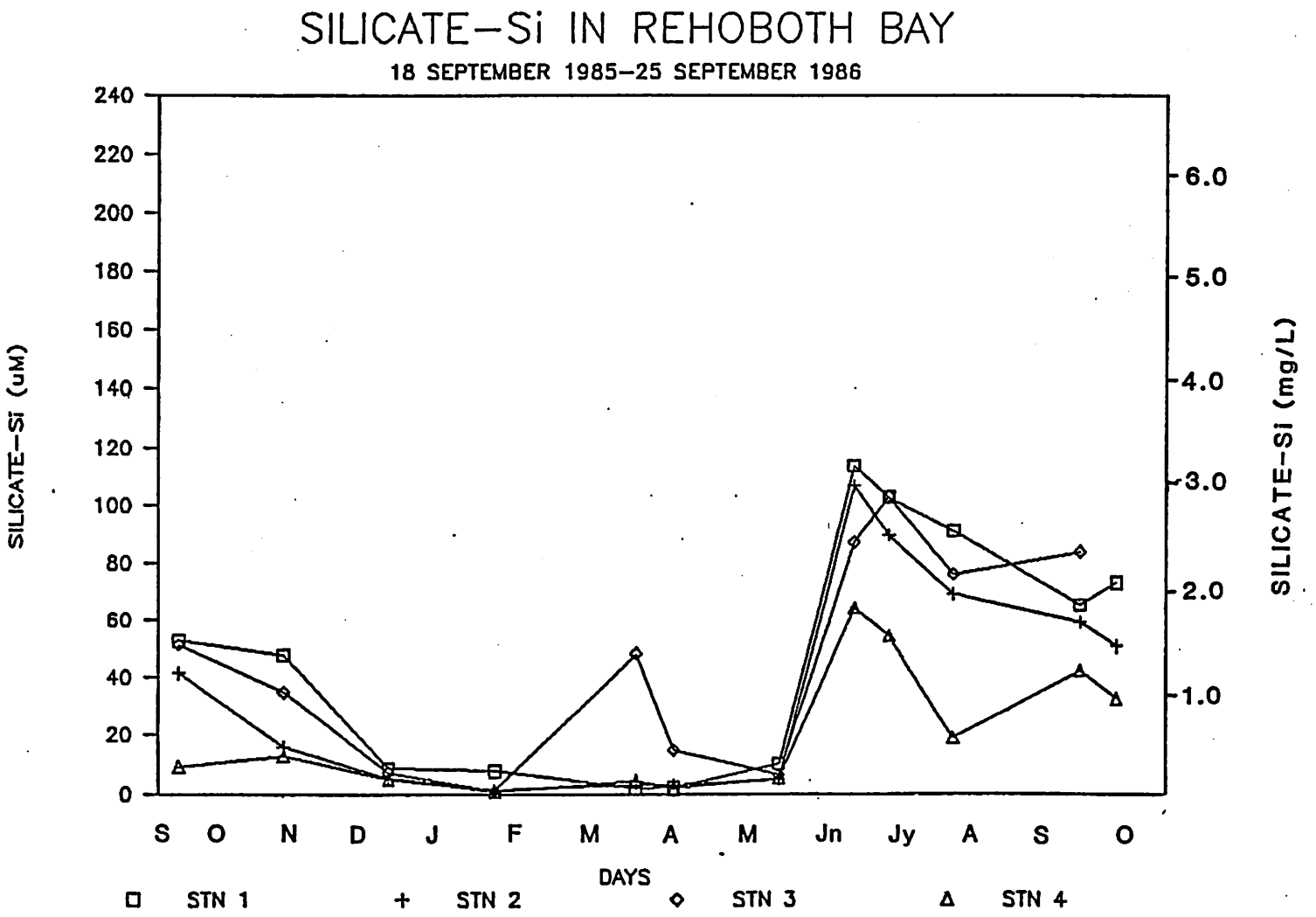


Figure 18. Concentrations of silicate-Si in Rehoboth Bay for the period September, 1985 - September, 1986.

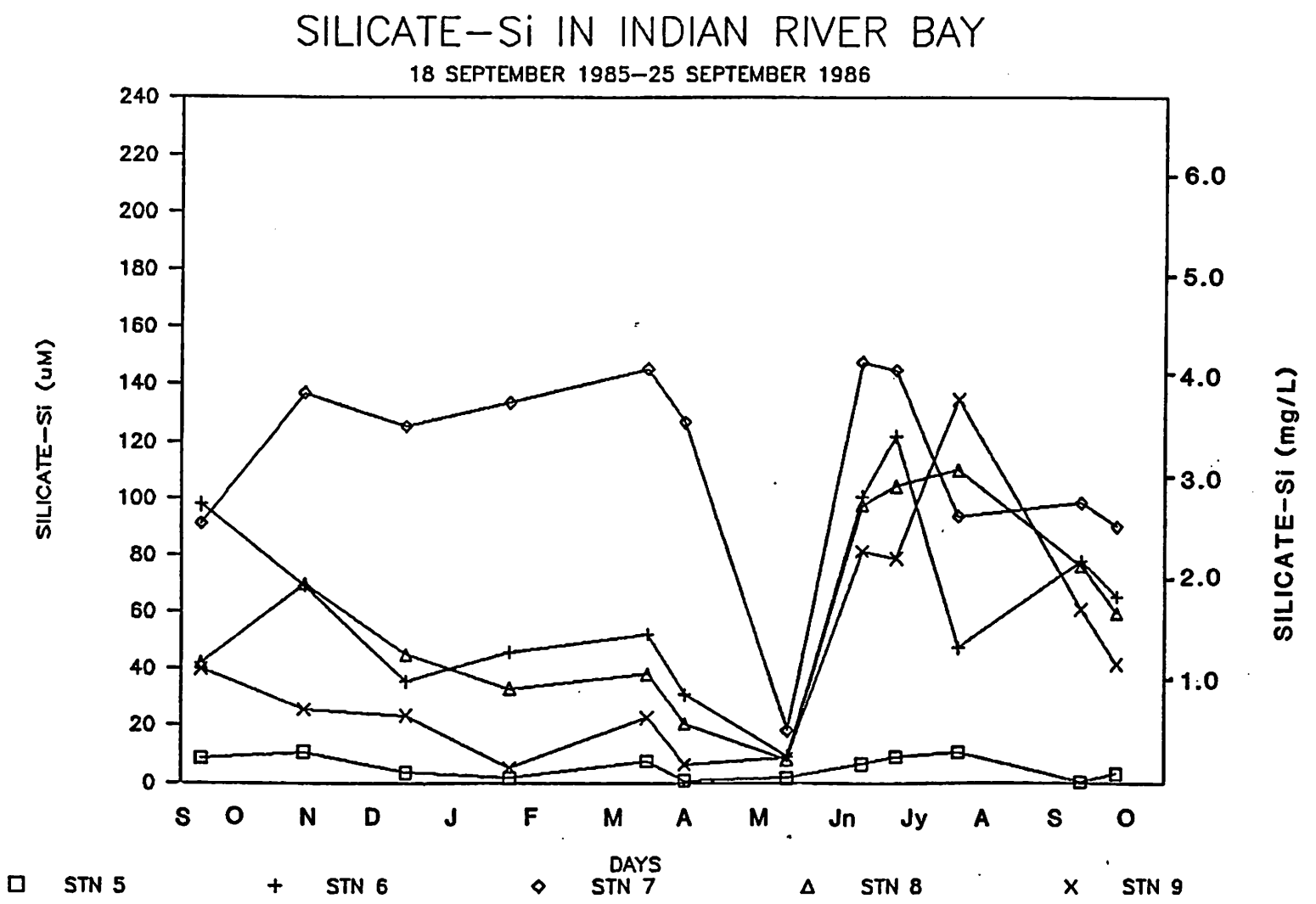


Figure 19. Concentrations of silicate-Si in Indian River Bay for the period September, 1985 - September, 1986.

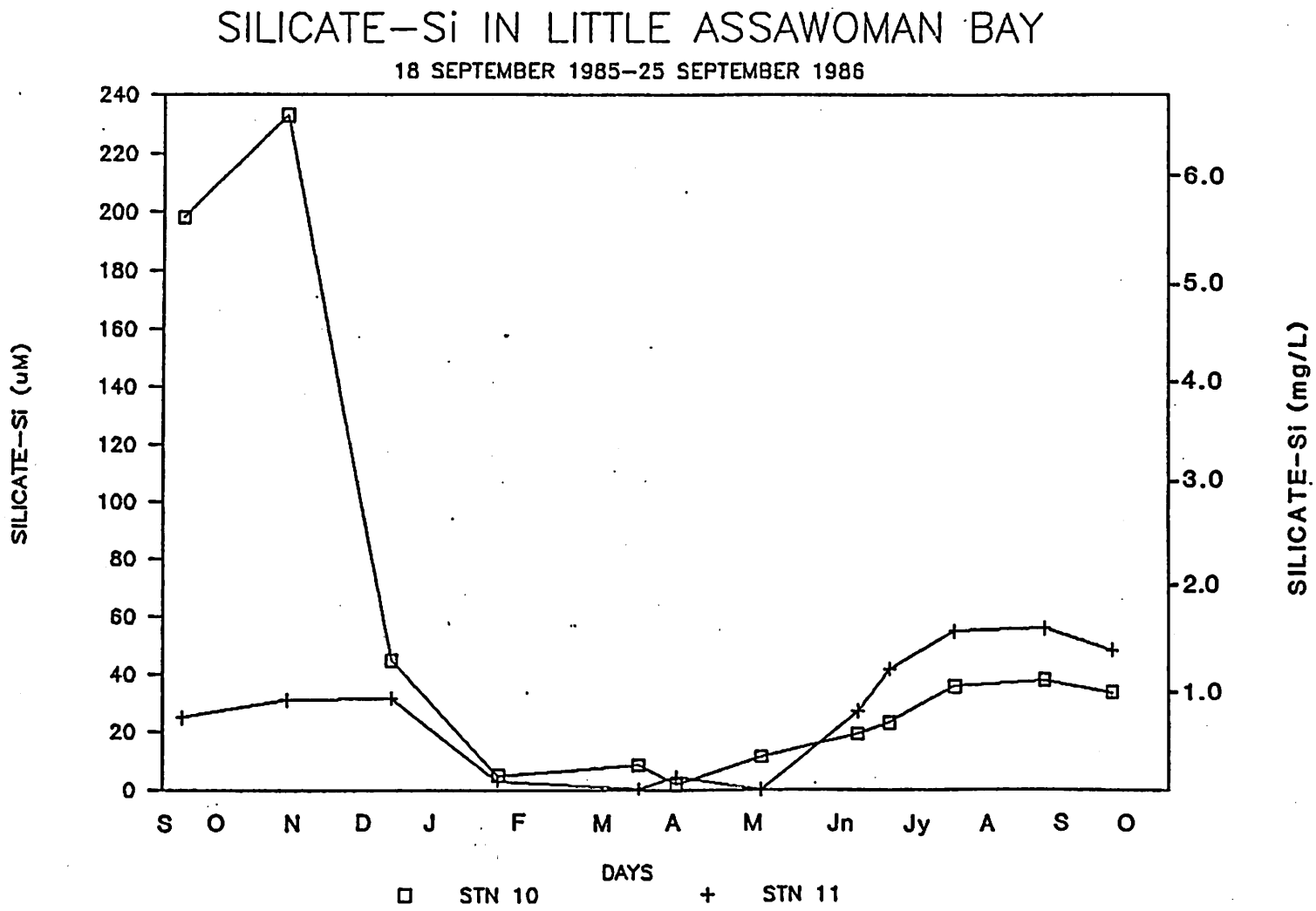


Figure 20 Concentrations of silicate-Si in Little Assawoman Bay for the period September, 1985 - September, 1986.

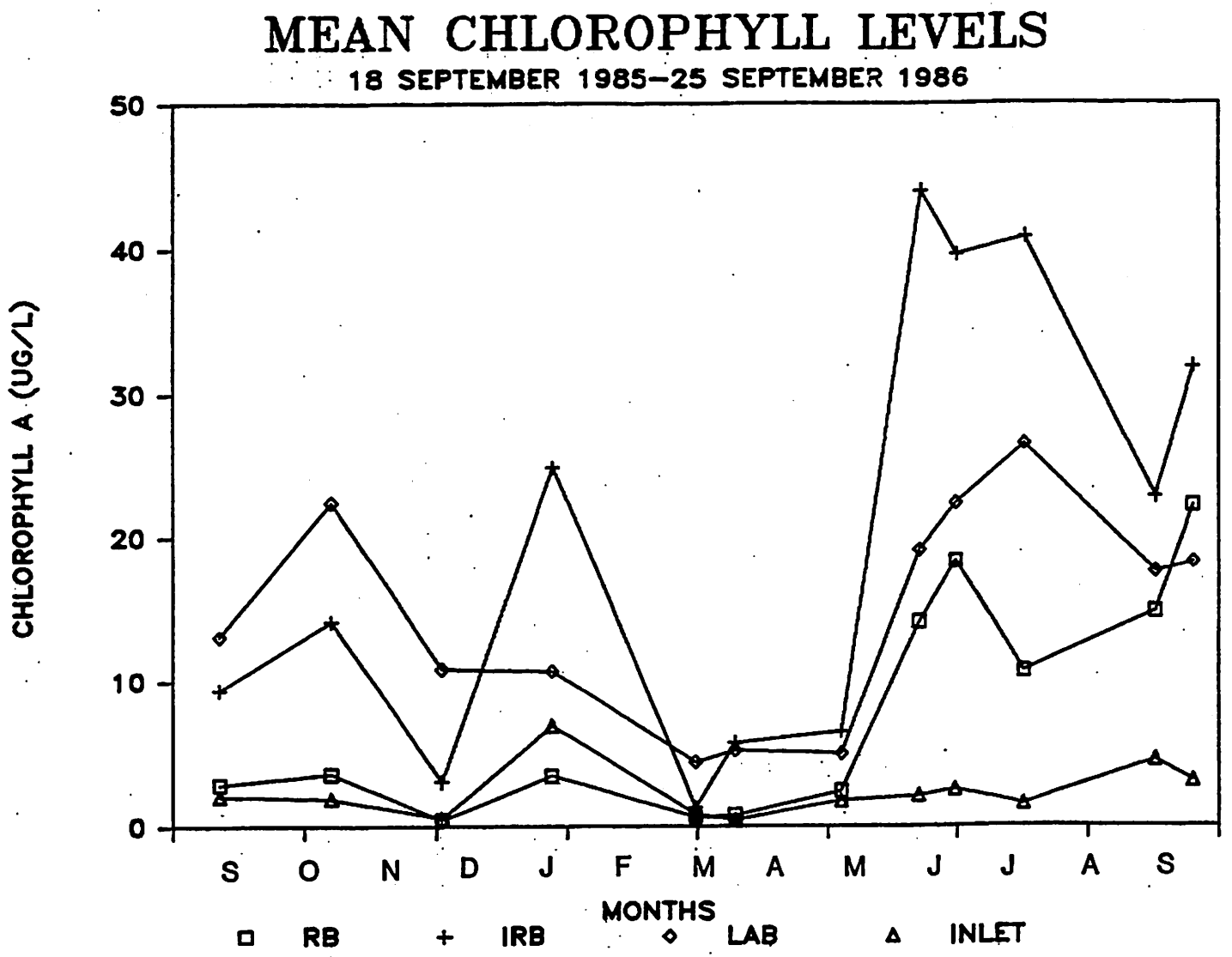


Figure 21. Mean monthly chlorophyll concentrations in Delaware's Inland Bays for the period September, 1985 - September, 1986 (symbols as in Figure 2).

Chlorophyll a concentrations at individual stations and sampling periods ranged from 0.07 to 57.0 ug/L in the Delaware Inland Bays. The major chlorophyll maximum occurred during June-July in all three bodies of water (Figs. 22-24). Generally, lower, more stable chlorophyll concentrations were measured in Rehoboth and Little Assawoman Bays than in Indian River Bay, similar to the seasonal pattern of dissolved inorganic nitrate plus nitrite nitrogen and silicate-silicon concentrations in the bays. Station 7, subject to the greatest freshwater input during the high-flow period (December-March) and to long residence time during the low-flow period (June-September), exhibited the highest seasonal chlorophyll concentrations (Fig. 23).

In Rehoboth Bay, the seasonal distribution of chlorophyll was typified by concentrations of 1.0-6.3 ug/L during September-October and even lower levels (0.4-0.5 ug/L) in December; following a minor peak in January (<8.9 ug/L), concentrations declined in March-April (0.2-1.6 ug/L) and finally attained a yearly maximum in June-July (≤28.5 ug/L) and remained relatively high throughout September (8.3-27.4 ug/L, Fig. 22). This seasonal pattern lacks the late-winter, early-spring chlorophyll maximum which is characteristic of many temperate estuaries (Smayda, 1983; Mountford, 1984; Marshall and Lacouture, 1986).

This winter-early spring chlorophyll peak common in other estuaries is present in Indian River Bay (Fig. 23) where chlorophyll a concentrations reached 32.5 ug/L in January (Station 6). In this bay, the dominant feature was a prominent summer peak in chlorophyll. In addition, stations located in the lower salinity portion of Indian River Bay show consistently higher chlorophyll concentrations than the two stations located in the more saline portion of the bay during the entire sampling period.

Chlorophyll concentrations of the two stations located in Little Assawoman Bay (Fig. 24) showed very similar seasonal trends with one exception: relatively high concentrations were noted at Station 10 in September and October (20 and 32 ug/L) which may reflect high nutrient concentrations measured at this location during this period (see above). Otherwise, the two sampling stations had relatively constant chlorophyll concentrations (2.7-13.2 ug/L) between December-May, followed by a summer peak (15.6-29.4 ug/L) in phytoplankton biomass.

Analysis of variance tests were conducted to compare the chlorophyll concentrations of the current study with those measured in 1974-75 (Ecological Analysts, 1977). Results of the statistical tests indicated that the two outermost stations in Indian River Bay and the central station in Rehoboth Bay (Stations 2, 5, and 9) displayed mean chlorophyll concentrations which were significantly lower than the corresponding stations in the earlier study (Stations 7RB, 9, and 24, Table 10). These few data suggest that chlorophyll concentrations may have significantly declined over the last decade in mesohaline and polyhaline waters of Rehoboth and Indian River Bays with no apparent change in phytoplankton biomass in the eutrophic Indian River. However, due to spatial and temporal heterogeneity in phytoplankton distributions, particularly in response to the two different discharges for 1985 and 1986, much more frequent sampling must be undertaken before this trend is substantiated.

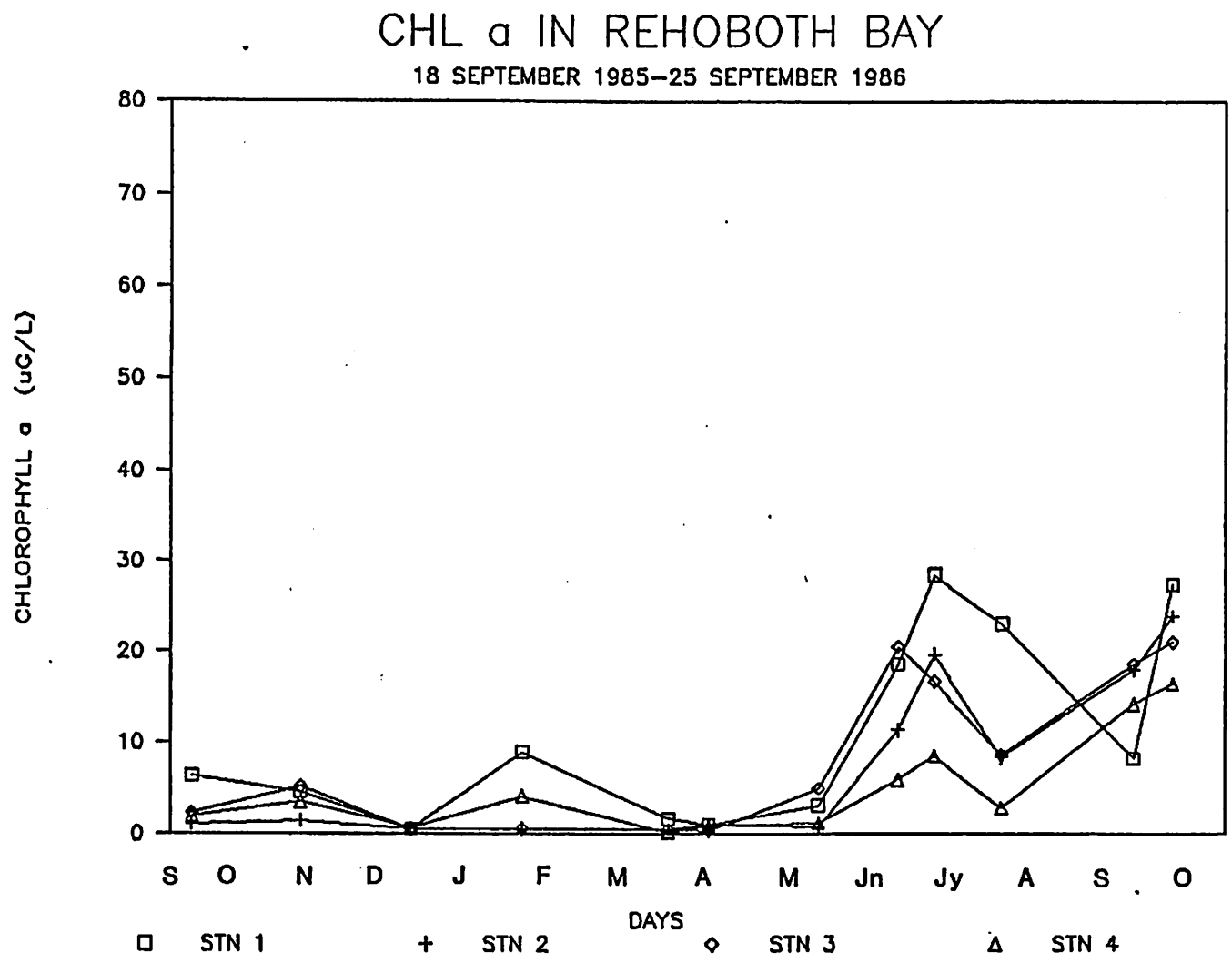


Figure 22. Concentrations of chlorophyll a in Rehoboth Bay for the period September, 1985 - September, 1986.

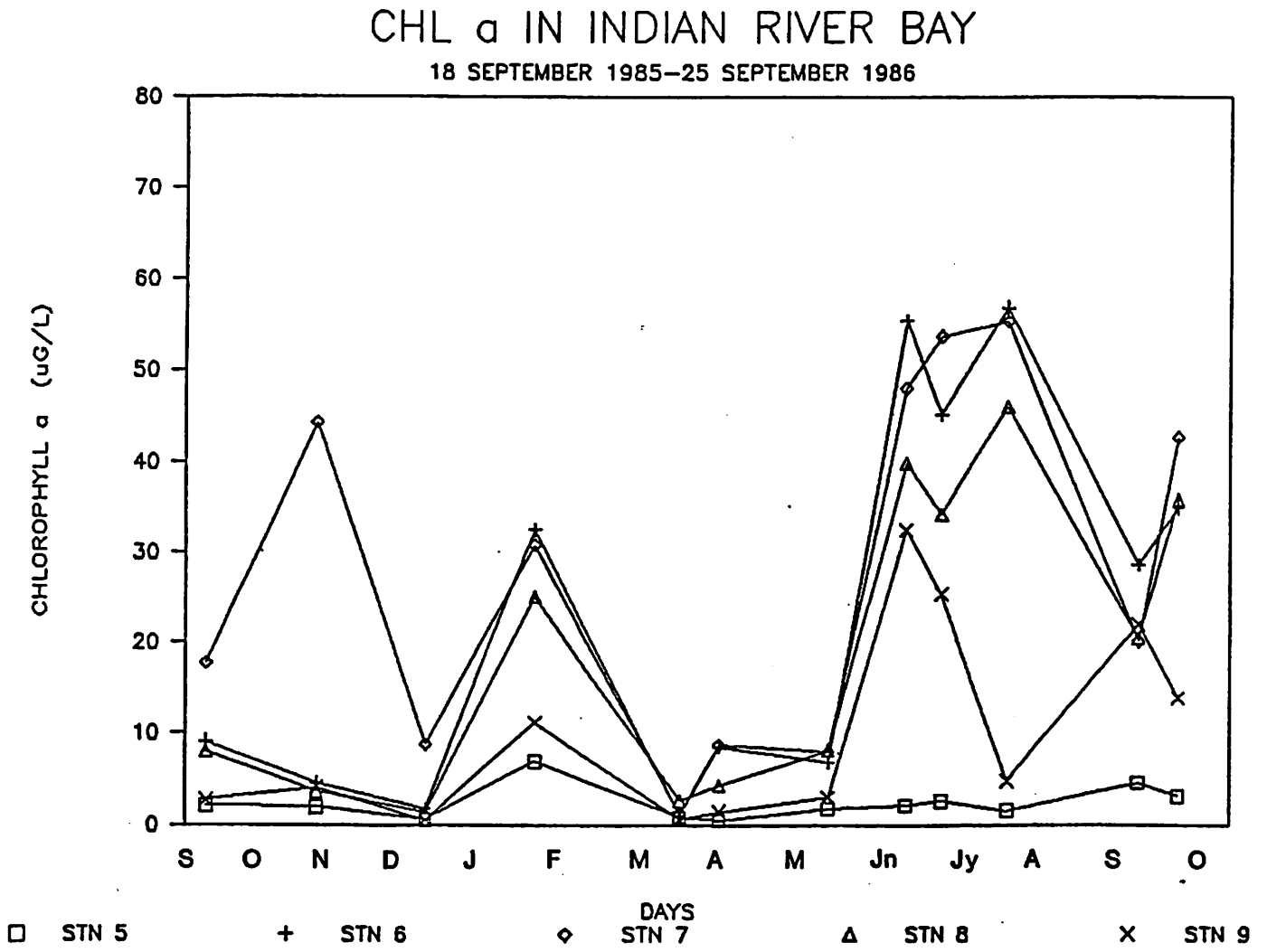


Figure 23. Concentrations of chlorophyll a in Indian River for the period September, 1985 - September, 1986.

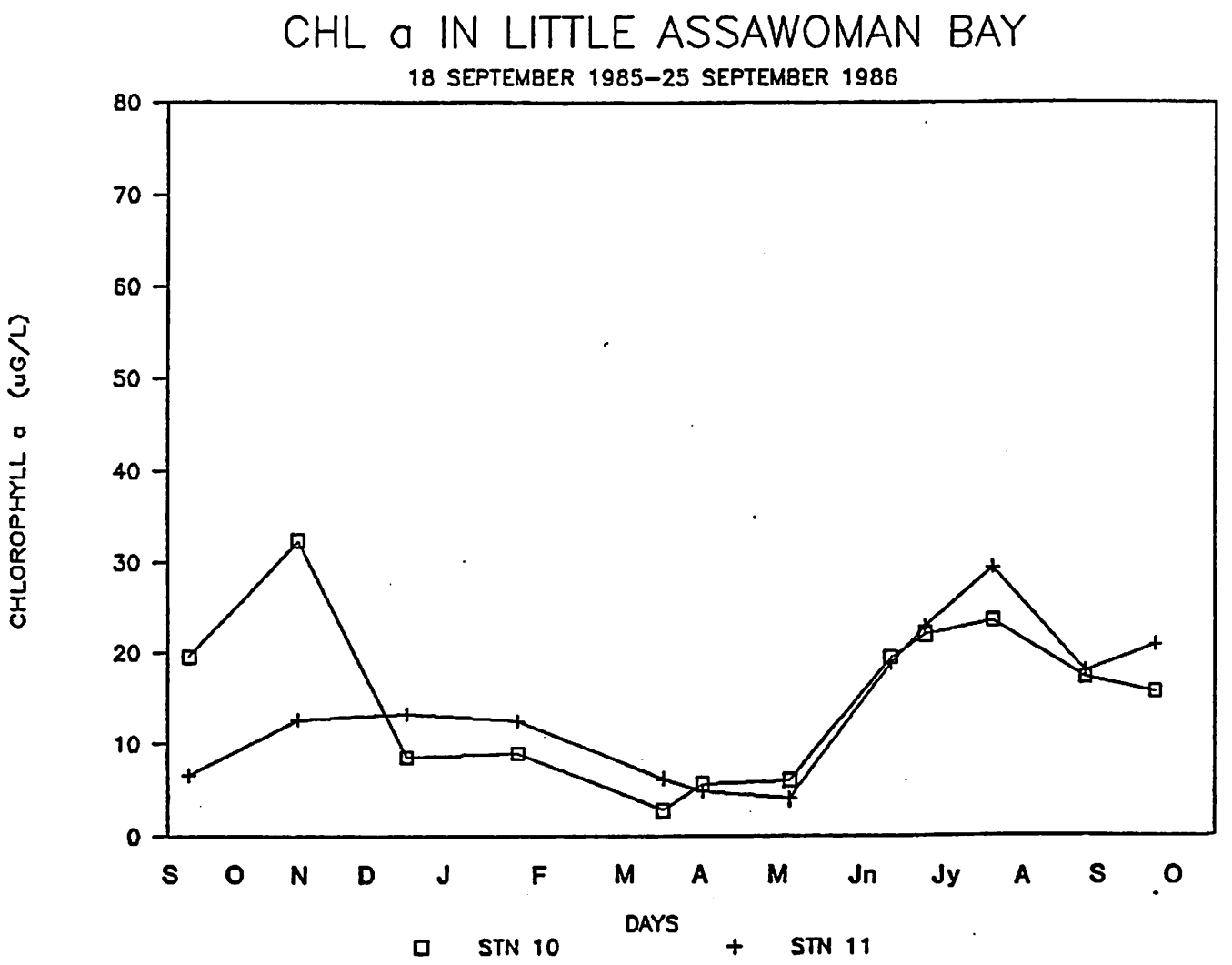


Figure 24. Concentrations of chlorophyll a in Little Assawoman Bay for the period September, 1985 - September, 1986.

Table 10: Comparison of chlorophyll data (µg/L) between 1985-86 ANS study and 1974-75 Ecological Analysts, Inc. study. N.D. = no data.

	ANS - EA									
Station	2-7RB		5-9		6-31		7-42-53		9-24	
Date										
September	1.0	20.0	2.1	24.4	9.1	59.1	17.7	152.7	2.7	57.9
October *	1.3	2.9	1.9	4.1	4.5	11.1	44.3	50.5	4.1	5.4
December	0.4	14.0	0.6	10.1	1.8	64.0	8.75	93.5	0.5	41.4
January	0.4	8.4	6.9	21.4	32.5	31.0	30.8	28.8	11.2	28.8
March	0.4	6.15	0.8	22.9	0.9	36.2	1.1	33.0	0.6	45.8
April	1.0	13.3	0.4	22.2	8.5	17.0	8.7	8.75	1.4	12.3
May	0.7	3.1	1.8	10.6	6.9	9.1	8.0	7.0	3.0	9.3
June 1	11.4	7.4	2.1	16.2	55.5	20.7	48.1	35.2	32.5	13.8
July	N.D.		1.5	12.6	57.0	58.4	55.4	190.3	4.8	48.0
Total	16.6	75.25	18.05	144.5	176.7	306.6	222.85	599.75	60.8	262.7
Station Mean	2.1	9.4	2.0	16.1	19.6	34.1	24.8	66.6	6.8	29.2
	$F =$	6.74	$F =$	32.8	$F =$	1.9	$F =$	3.37	$F =$	9.25
	$F_{0.95} =$	4.54			$F_{0.95} =$	4.49	$F_{0.95} =$	4.49		
	$F_{0.99} =$	8.86	$F_{0.99} =$	8.53					$F_{0.99} =$	8.53

* Nov. 7 data used for E.A. study.

Total Suspended Solids and Water Transparency

Light is a major factor limiting primary production in the aquatic environment (e.g., Riley, 1967). Light attenuation in the water column is measured directly by photometers or, as in this study, a secchi disk. The secchi disk depth can be used to estimate euphotic zone depth (the depth to which 1% of surface light penetrates). Another indirect implied measure of light attenuation is the quantity of light scattering and absorbing particles present in the water, total suspended solids (TSS).

The seasonal patterns of light attenuation in Rehoboth Bay and Indian River Bay are very similar in that during the relatively high freshwater input and low chlorophyll period (October-April), water transparency and secchi disk depths are highest (Table 11). During January, when a chlorophyll maximum occurred at Station 1 in Rehoboth Bay and at all the stations in Indian River Bay, the mean secchi disk depths for each bay were correspondingly lower. Water transparency was greatly reduced between May and September when phytoplankton biomass reached its yearly maximum in the two bays. During the low chlorophyll-high secchi disk depth period (October-December, March-April), the euphotic zone extended to a mean depth of 1.6 m in Rehoboth Bay (77% of the total water column depth) and 1.4 m in Indian River Bay (52% of the total water column depth). Conversely, during the phytoplankton biomass peaks in January and May-September, the mean secchi disk depth in Rehoboth Bay was 0.6 m or 35% of the total water column and 0.6 m or 24% of the total water column in Indian River Bay.

Figures 25-28 and Appendix 1 show the total suspended solid concentrations for Delaware Inland Bays. Mean monthly concentrations fluctuate dramatically for the system (Fig. 25) with highest concentrations (>100 mg/L) noted in Rehoboth Bay and Indian River inlet in January, 1986. After a marked decline to minimum values noted during the study (3-40 mg/L, March-April), concentrations increased again to levels ranging from >45-118 mg/L in July. Mean concentrations approximated 58-70 mg/L by September, 1986.

Striking fluctuations in concentrations of solids were observed in Rehoboth Bay (Fig. 26) and Indian River Bay (Fig. 27) while relatively consistent concentrations of suspended particulate matter were noted in Little Assawoman Bay (Fig. 28). The overall seasonal patterns of suspended solid concentrations reflect the major features of the seasonal chlorophyll trends (Figs. 21-24) for the three bays. There are some additional peaks in Rehoboth and Indian River Bays during the high freshwater flow period of October-March which may be attributed to increased runoff and transport of fine-grain sediments into the system or to resuspension processes caused by periods of high wind.

In trying to assess possible changes in TSS concentrations over time in the Delaware Inland Bays, analysis of variance tests were used to compare data from the current study with data collected in 1974-75 (Ecological Analysts, Inc., 1977). The concentrations in Stations 2, 5, 6, 7, and 9 of the current study were compared to concentrations at five comparably located stations in the earlier study. A mean value of surface and bottom TSS concentrations was used for the E.A. study. The results from ANOVA showed no significant differences between the mean TSS concentrations during 1985-86 and 1974-75 (Table 12).

Table 11: Mean (S.E.) secchi disk depth (m) the in Delaware Inland Bays, 18 September 1985 - 25 September 1986. Rehoboth Bay (4 stations), Indian River Bay (5 stations) and Little Assawoman Bay (2 stations). N.D. = no data. Dates in parentheses indicate Little Assawoman Bay sampling dates.

Date		Rehoboth Bay		Indian River Bay		Little Assawoman Bay	
		Total Depth	Secchi Depth	Total Depth	Secchi Depth	Total Depth	Secchi Depth
9-18-85		N. D.	N. D.	N. D.	N. D.	N. D.	0.5 (0.2)
10-30-85		2.0 (0.4)	1.2 (0.2)	2.5 (0.6)	1.3 (0.1)	N. D.	N. D.
12-11-85		2.3 (0.3)	1.9 (0.2)	2/9 (0.8)	1.4 (0.1)	N. D.	N. D.
1-22-86		1.8 (0.2)	1.4 (0.1)	1.6 (0.5)	1.0 (0.2)	N. D.	0.7
3-18-86		1.7 (0.2)	1.7 (0.2)	2.8 (0.7)	1.5 (0.3)	N. D.	0.9 (0.0)
4-02-86		2.5 (0.3)	1.8 (0.2)	N. D.	1.5 (0.2)	N. D.	N. D.
5-13-86	(5-05-86)	2.0 (0.3)	0.2 (0.1)	3.1 (0.6)	0.7 (0.0)	N. D.	N. D.
6-12-86	(6-11-86)	1.7 (0.3)	0.4 (0.1)	2.2 (0.5)	0.5 (0.1)	N. D.	N. D.
6-26-86	(6-25-86)	1.7 (0.3)	0.5 (0.0)	2.3 (0.6)	0.5 (0.2)	N. D.	N. D.
7-22-86	(7-21-86)	1.8 (0.3)	0.7 (0.1)	2.7 (0.4)	0.6 (0.2)	N. D.	N. D.
9-10-86	(8-26-86)	2.0 (0.2)	0.3 (0.0)	2.2 (0.5)	0.4 (0.1)	N. D.	<0.3
9-25-86	(9-22-86)	1.7 (0.2)	0.4 (0.0)	3.0 (0.9)	0.5 (0.2)	N. D.	N. D.

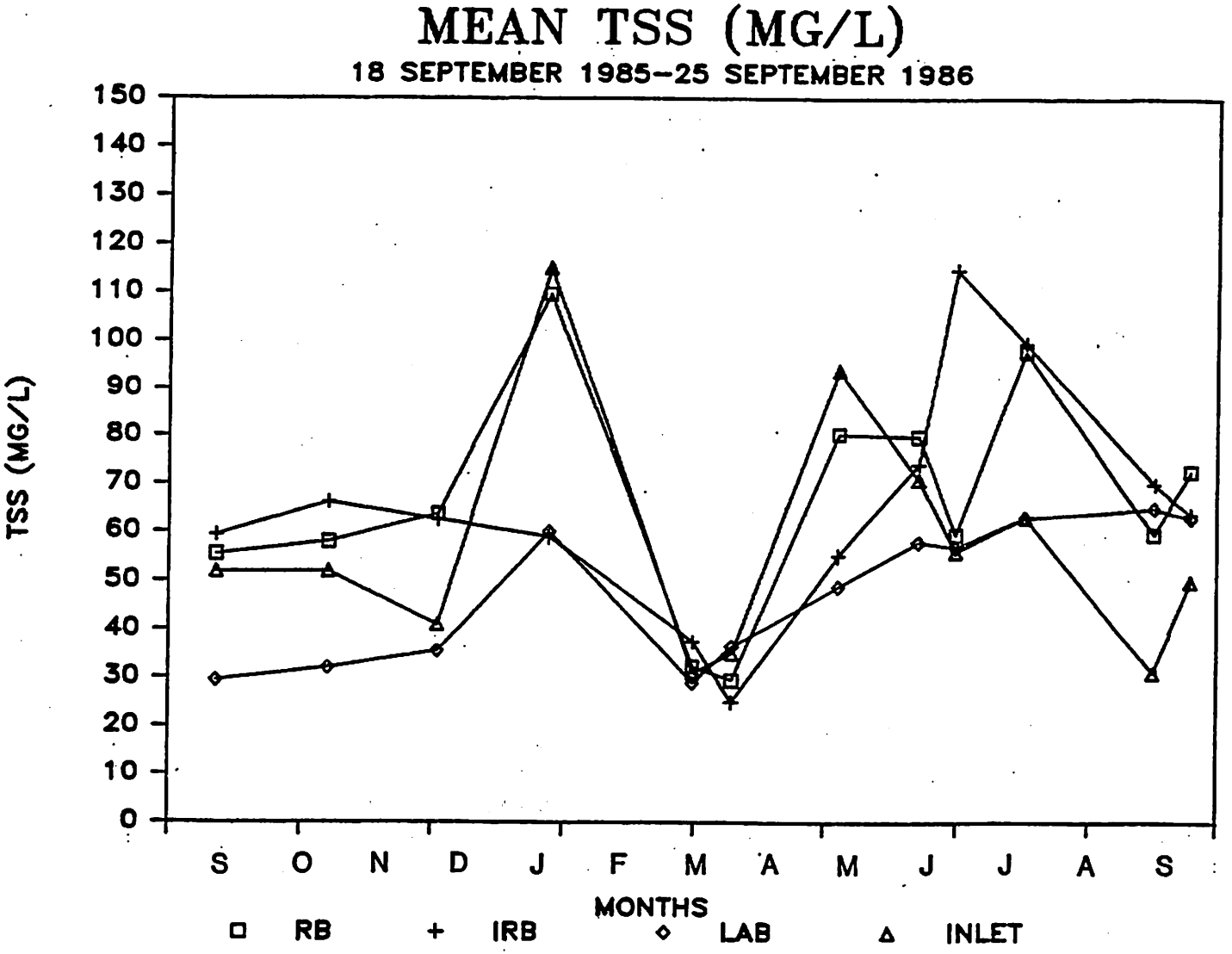


Figure 25. Mean monthly concentrations of total suspended solids (TSS) in Delaware's Inland Bays for the period September, 1985 - September, 1986 (symbols as in Figure 2).

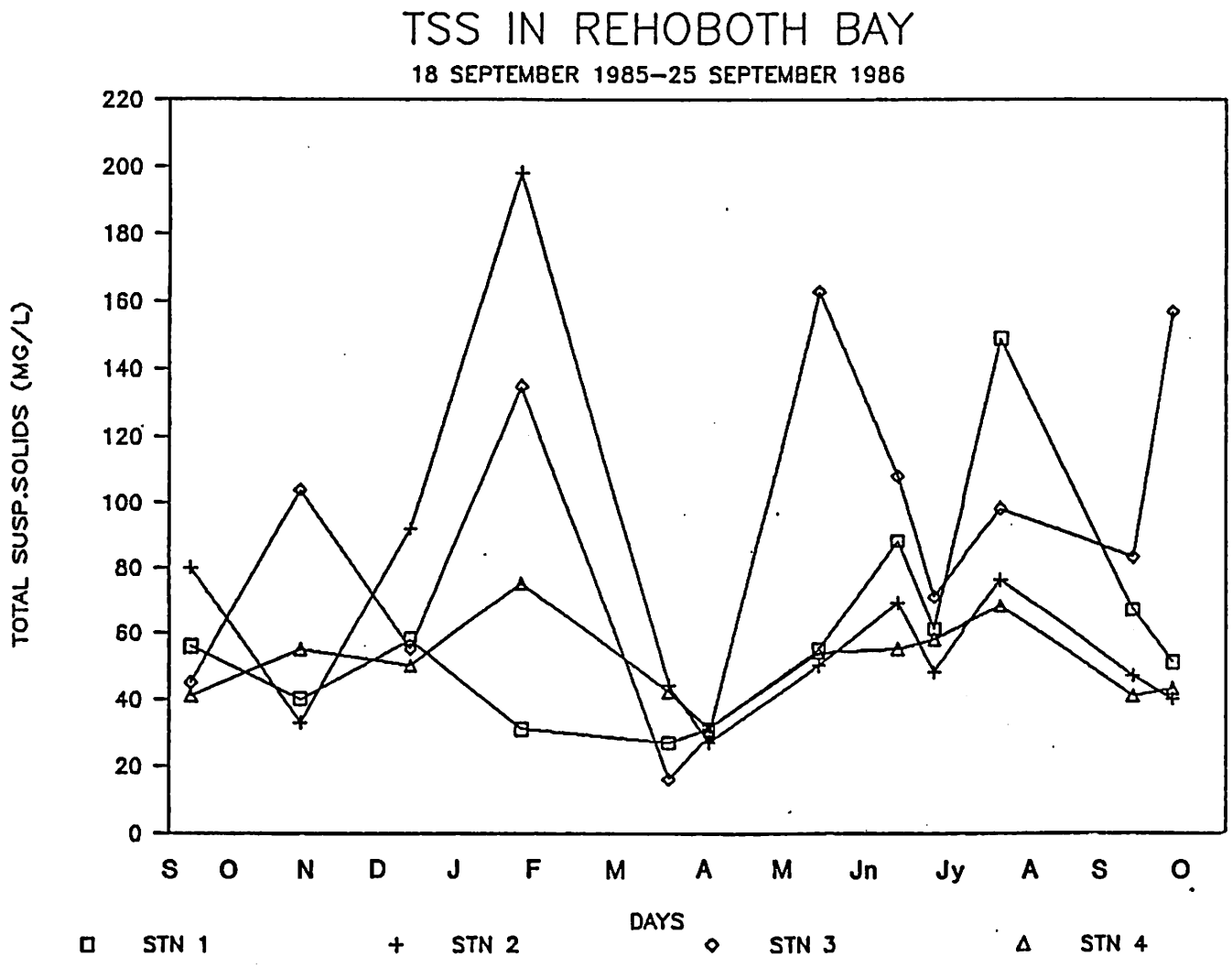


Figure 26. Concentrations of total suspended solids (TSS) in Rehoboth Bay for the period September, 1985 - September, 1986.

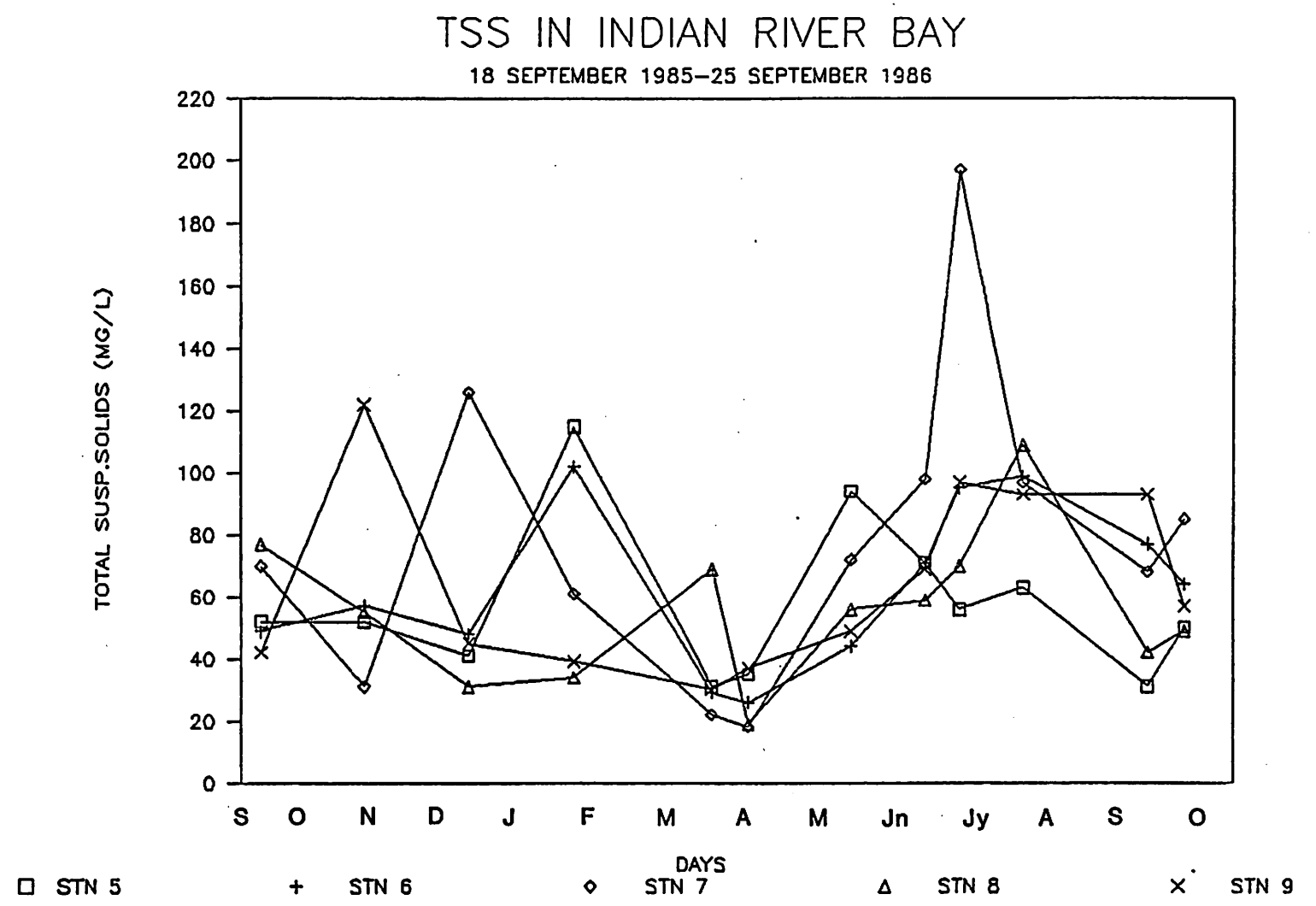


Figure 27. Concentrations of total suspended solids (TSS) in Indian River Bay for the period September, 1985 - September, 1986.

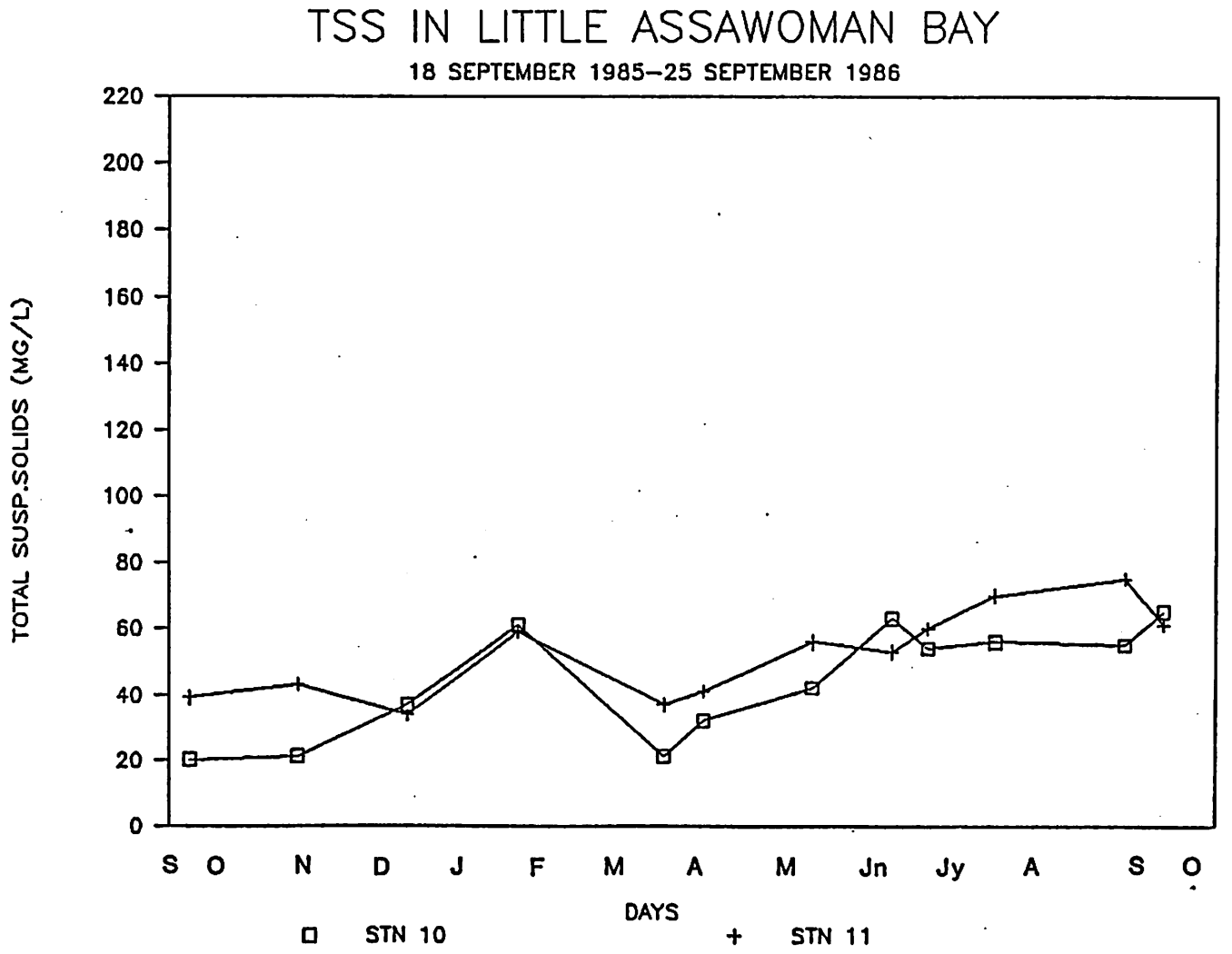


Figure 28. Concentrations of total suspended solids (TSS) in Little Assawoman Bay for the period September, 1985 - September, 1986.

Table 12: Comparison of TSS concentrations (mg/L) between ANS data from 1985-86 and 1974-75 Ecological Analysts, Inc. study.

	ANS - EA				
Station	2-7RB	5-9	6-31	7-42-53	9-24
Date					
September	80 - 35	52 - 13.5	49 - 25	70 - 40.5	42 - 94
October	33 - 42	52 - 9.5	57 - 54	31 - 37.5	122 - 225
December	92 - 45.5	41 - 39.5	48 - 93.5	126 - 41.5	45 - 98
January	198 - 34.5	115 - 34.5	102 - 32.5	61 - 23.5	39 - 37.5
March	44 - 46	31 - 88	29 - 66.5	22 - 34.5	30 - 99
April	27 - 81	35 - 41.5	26 - 54.5	18 - 62.5	37 - 46.5
May	50 - 23	94 - 29	44 - 38	72 - 49	49 - 32
June 1	69 - 34.5	71 - 51	71 - 34	98 - 32	69 - 36
Total	593 - 341.5	491 - 306.5	426 - 398	498 - 321	433 - 465.5
Mean	74.1 - 42.7	61.4 - 38.3	53.2 - 49.8	62.2 - 40.1	54.1 - 58.2
	$F = 2.39$	$F = 2.86$	$F = 0.09$	$F = 2.49$	$F = 0.07$
	$F_{0.95} = 4.60$	$F_{0.95} = 4.60$	$F_{0.95} = 4.60$	$F_{0.95} = 4.60$	$F_{0.95} = 4.60$

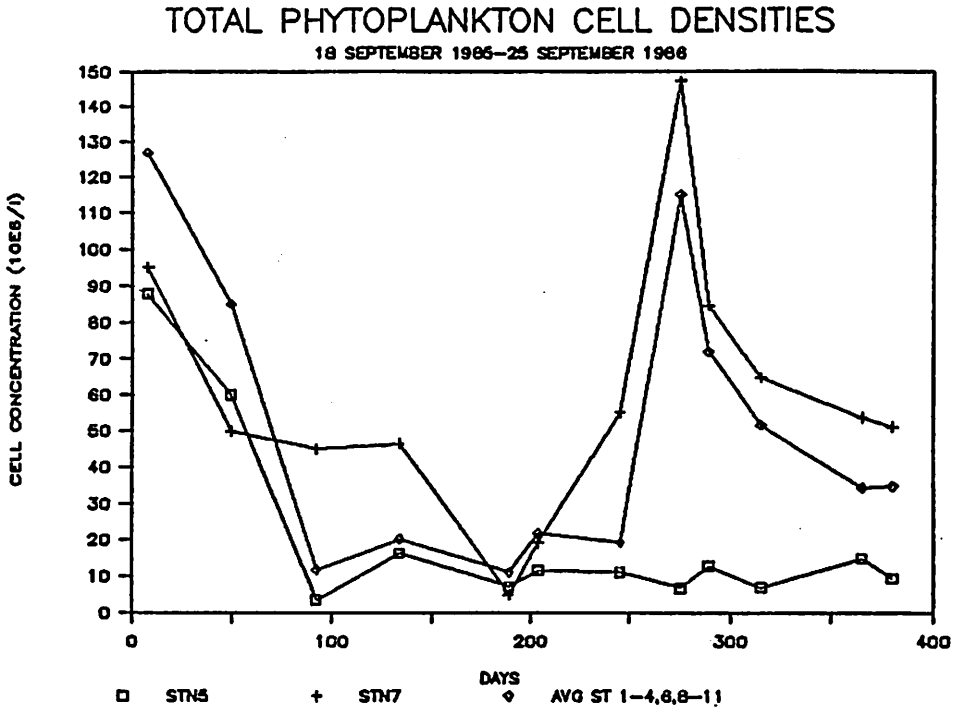
* Nov. 7 data used for E.A. study.

Species Composition

Figure 29 and Appendix 3 indicate the total phytoplankton cell densities and the eukaryotic cell densities for the current study. Seasonally, total cell densities displayed a bimodal pattern with peaks in September and June and lowest values during December-April (Fig. 29A). The eukaryotic cell densities exhibited a less pronounced bimodal pattern with peaks in January and May-early June (Fig. 29B). Spatially, Station 7 was generally characterized by higher total and eukaryotic cell densities while lowest densities were observed at Station 5. Phytoplankton assemblages collected during this study were most often numerically dominated by 1-3 um cells, representative of picoplankton (0.2-2.0 um). These cells may be coccoid cyanobacteria (Fig. 30-40), ubiquitous in marine and estuarine environments (Johnson and Sieburth, 1979; Waterbury et al., 1979; Marshall, 1982; Marshall and Lacouture, 1986; Sellner and Brownlee, 1986a,b). The picoplankton consisted of individual coccoid cells as well as colonies of 10-20 coccoid cells, identified as Microcystis sp. Eukaryotes were most often dominated by members of the Bacillariophyceae, but in several instances, large numbers of an individual species occurred representative of the Dinophyceae, Cryptophyceae, and Chlorophyceae. The dominant diatoms (Bacillariophyceae) were Skeletonema costatum, Chaetoceros sp., Asterionella glacialis, Leptocylindrus danicus, Leptocylindrus minimus, Melosira sp., Thalassiosira sp. and Chaetoceros didymus. These diatom species are either common members of the marine flora of the continental shelf area or brackish water environments of the nearshore zone (Smayda, 1958; Hulbert, 1963; Marshall, 1976; Marshall and Lacouture, 1986). The dominant dinoflagellates (Dinophyceae) were Katodinium rotundatum and Gymnodinium sp. The most abundant flagellates were several members of the genera Cryptomonas and Eutreptia. The major representative of the Chlorophyceae was a small coccoid form, possibly Nannochloris sp., containing parietal chloroplasts and larger (5 um) than the coccoid cells tentatively identified as cyanobacteria. Nannochloris sp. bloomed during September, 1986 in Rehoboth and Indian River Bays and was dominant in Barnegat Bay in 1977 (Mountford, 1984).

In September in Rehoboth Bay, the phytoplankton assemblage was dominated by picoplankton, probably cyanobacteria (an unidentified coccoid form, 1-3 um and Microcystis sp.) and relatively large numbers of flagellates (Figs. 30-33). Mean densities of each group reached 7.9×10^7 and 2.8×10^6 cells/L, respectively. A bloom of the ubiquitous marine diatom, Skeletonema costatum, occurred in October at Station 4 (1.3×10^7 cells/L). As water temperatures declined from December-April, picoplankton became less numerous; diatoms, flagellates and picoplankton were co-dominant, with mean densities of 4.7×10^6, 5.5×10^6 and 3.1×10^6 cells/L, respectively. The chlorophyll maximum, beginning in May and lasting through the summer, was composed mainly of picoplankton (mean = 3.4×10^7 cells/L) and was supplemented with relatively large numbers of flagellates (mean = 2.6×10^6 cells/L), especially Cryptomonas sp., and diatoms (mean = 4.3×10^6 cells/L). In September, 1986, the previously mentioned small coccoid chlorophyte, Nannochloris sp. (mean = 1.3×10^7 cells/L), dominated.

Phytoplankton in Indian River Bay (Figs. 34-38) were similar to those in Rehoboth Bay except that Katodinium rotundatum dominated the assemblage in January (mean density = 1.4×10^7 cells/L). As noted in Rehoboth Bay, picoplankton dominated the assemblage during the warmer months, April-September (mean = 3.0×10^7 cells/L). Picoplankton were supplemented by small chain-forming centric diatoms (mean = 5.1×10^6 cells/L; Melosira sp., Leptocylindrus minimus and Cyclotella sp.) and members of the genus Cryptomonas (mean = 25×10^6 cells/L).



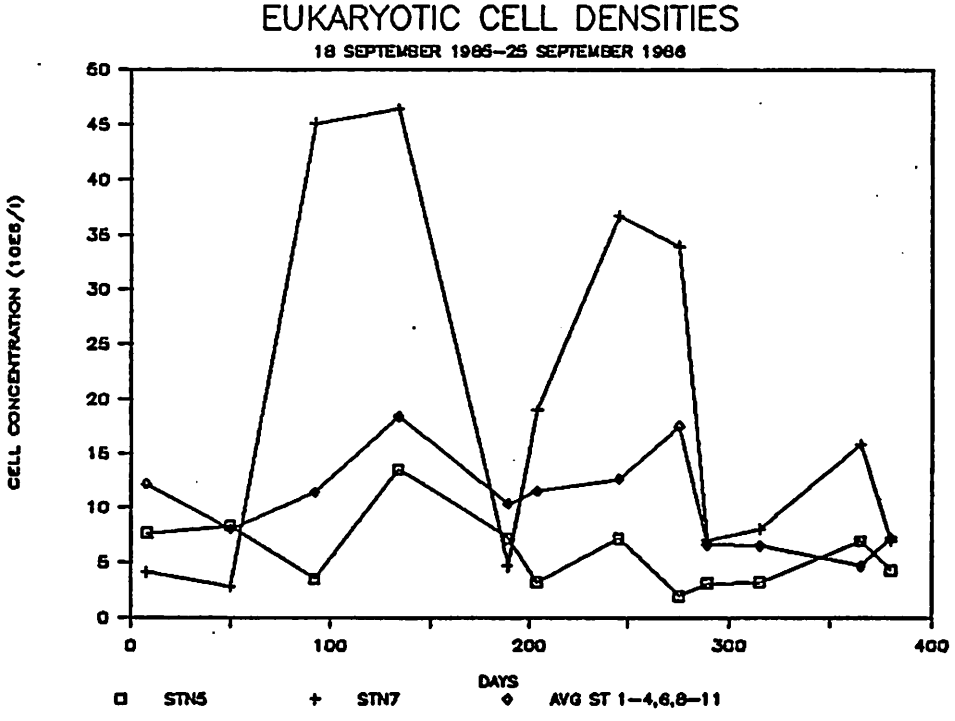


Figure 29. Total phytoplankton densities (A) and eukaryote densities (B) in Delaware's Inland Bays for the period September, 1985 - September, 1986. In both figures, data are presented for the Indian River Inlet (Station 5), upper Indian River (Station 7) and mean densities for the remaining stations. Densities represent cells $\times 10^6$/L.

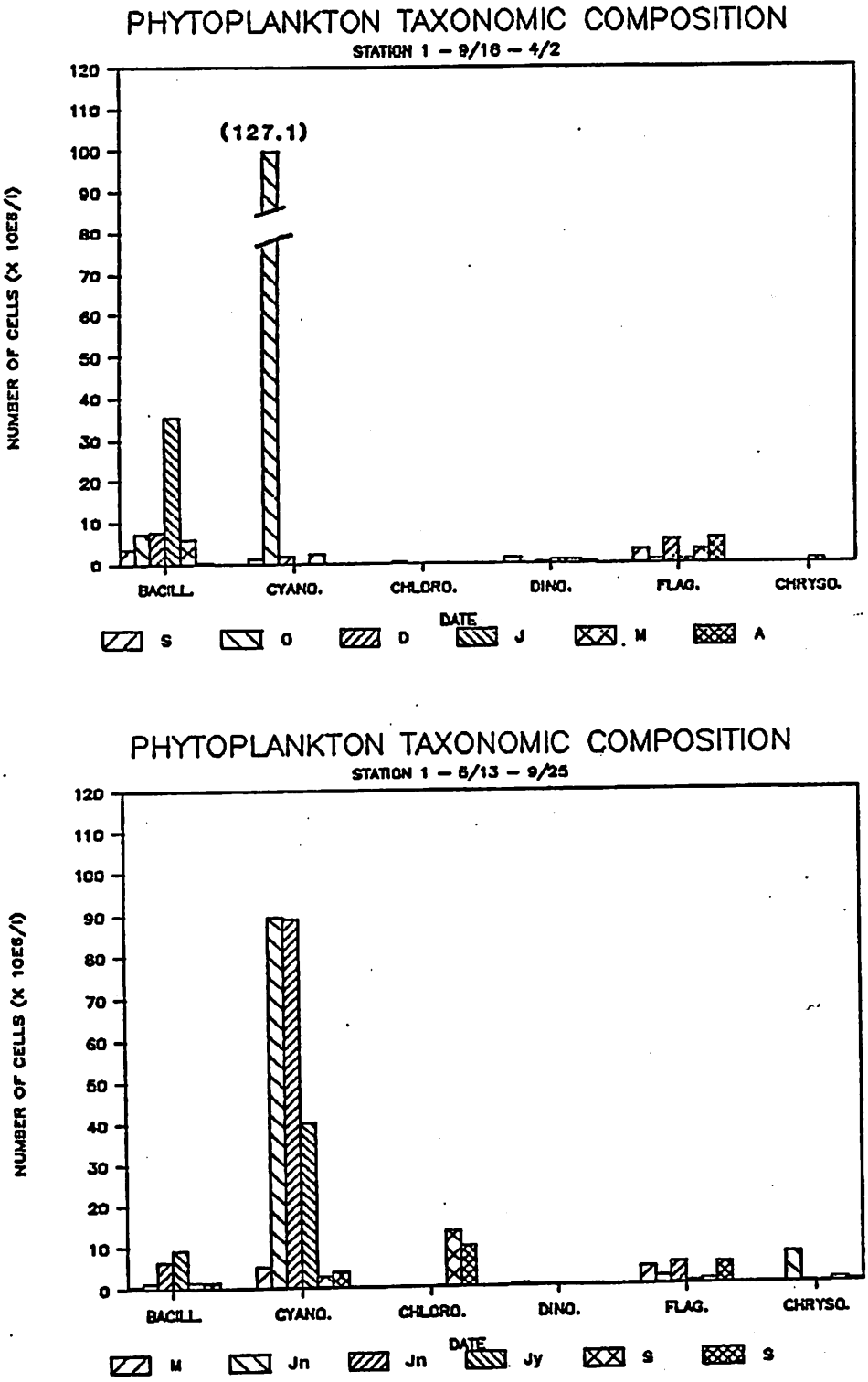
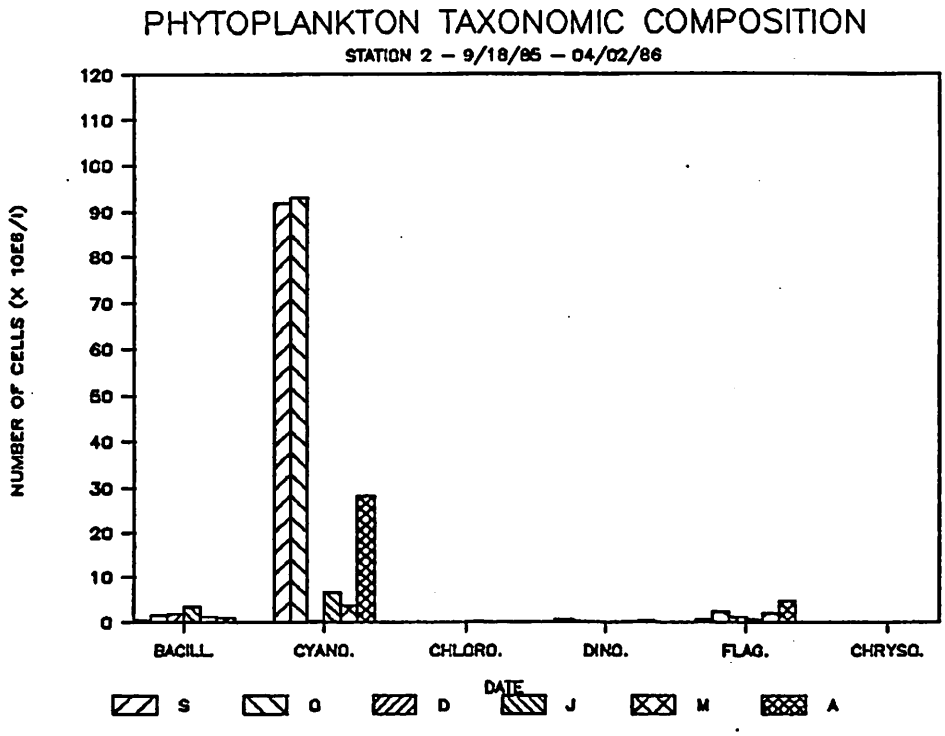


Figure 30. Phytoplankton taxonomic composition at Station 1 for (A) September, 1985 - April, 1986 and (B) May, 1986 - September, 1986. Letters adjacent to symbols represent initials of each sampling month beginning in September, 1985. Labels along the X-axis refer to : Bacill (Bacillariophyta), Cyano (presumed coccoid Cyanobacteria and picoplankton), Chloro (Chlorophyta), Dino (Pyrrhophyta), Flag (Undetermined flagellate spp.) and Chryso (Chrysophyta).



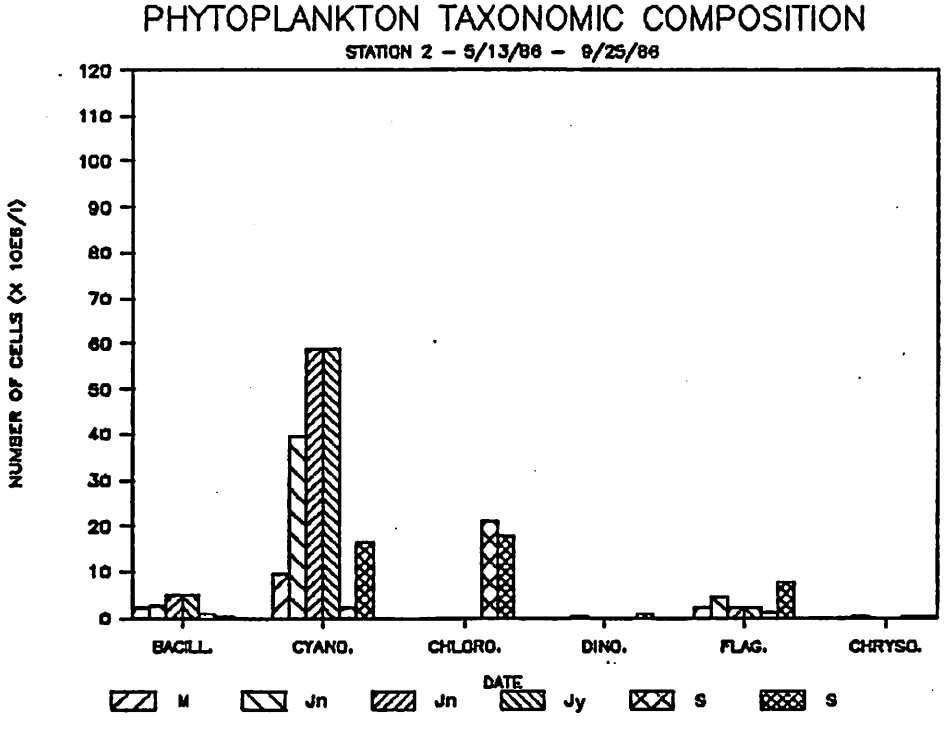


Figure 31. Phytoplankton taxonomic composition at Station 2 for (A) September, 1985 - April, 1986 and (B) May, 1986 - September, 1986. Letters adjacent to symbols represent initials of each sampling month beginning in September, 1985. X-axis labels as noted in Figure 30.

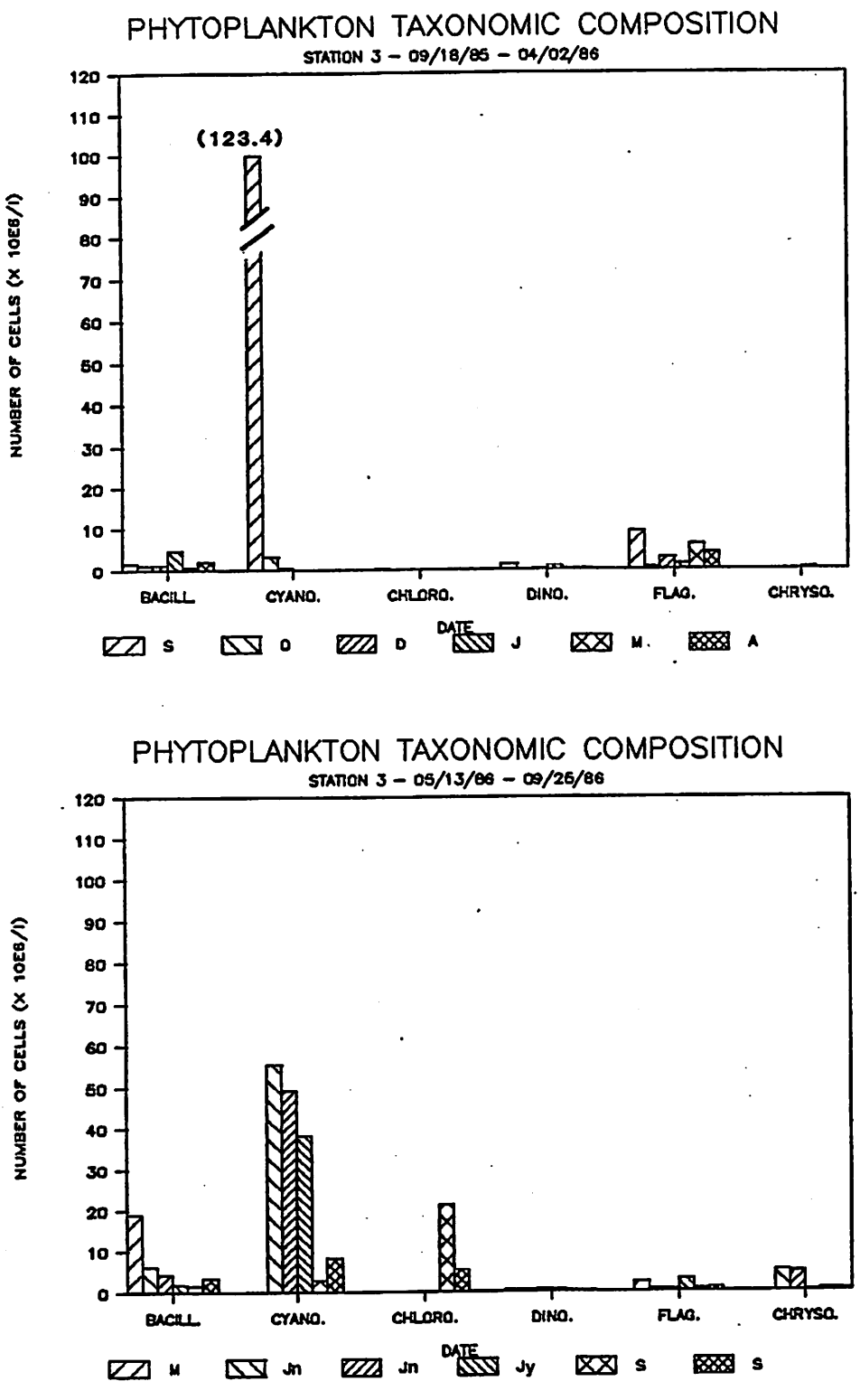


Figure 32. Phytoplankton taxonomic composition at Station 3 for (A) September, 1985 - April, 1986 and (B) May, 1986 - September, 1986. Letters adjacent to symbols represent initials of each sampling month beginning in September, 1985. X-axis labels as noted in Figure 30.

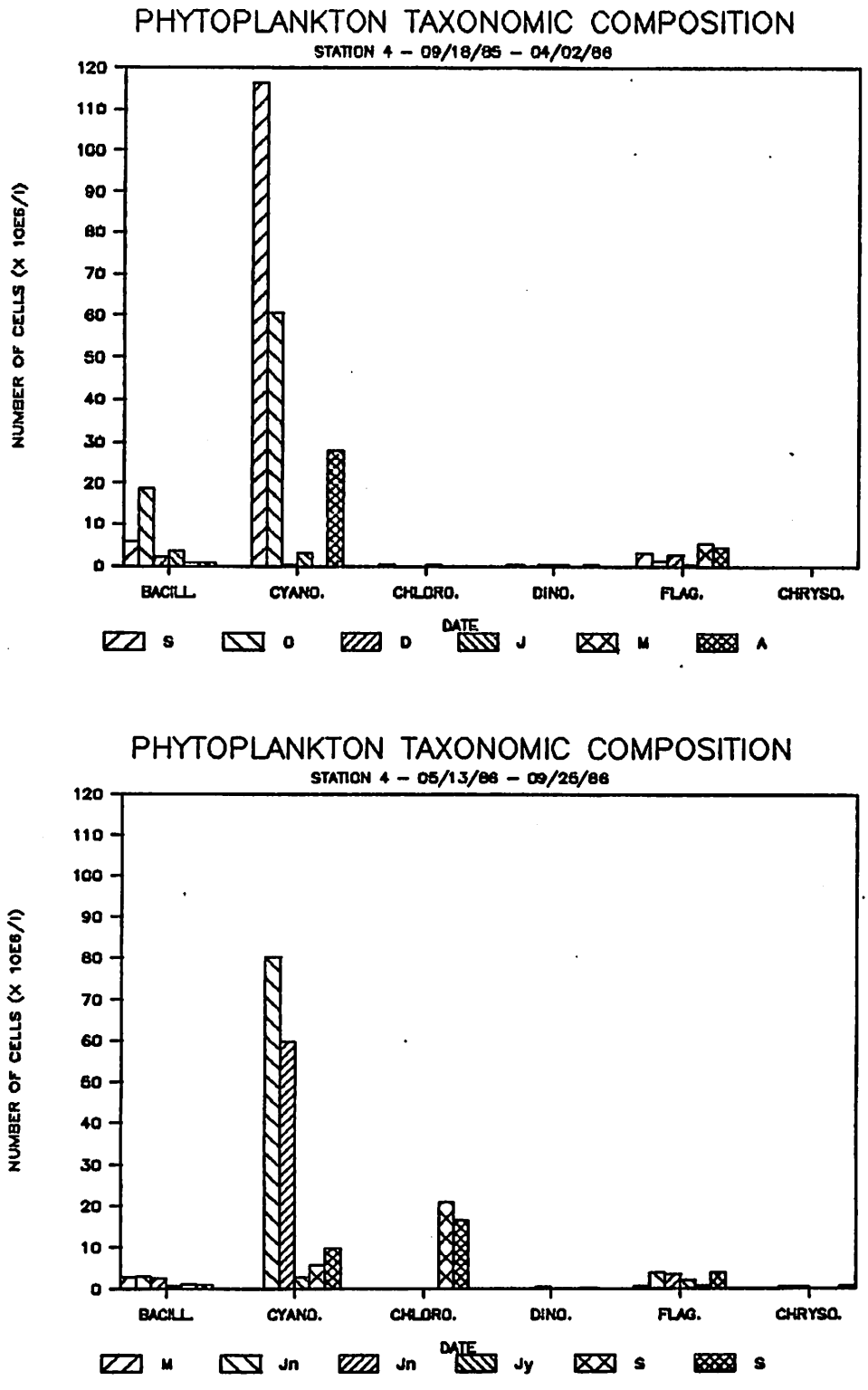


Figure 33. Phytoplankton taxonomic composition at Station 4 for (A) September, 1985 - April, 1986 and (B) May, 1986 - September, 1986. Letters adjacent to symbols represent initials of each sampling month beginning in September, 1985. X-axis labels as noted in Figure 30.

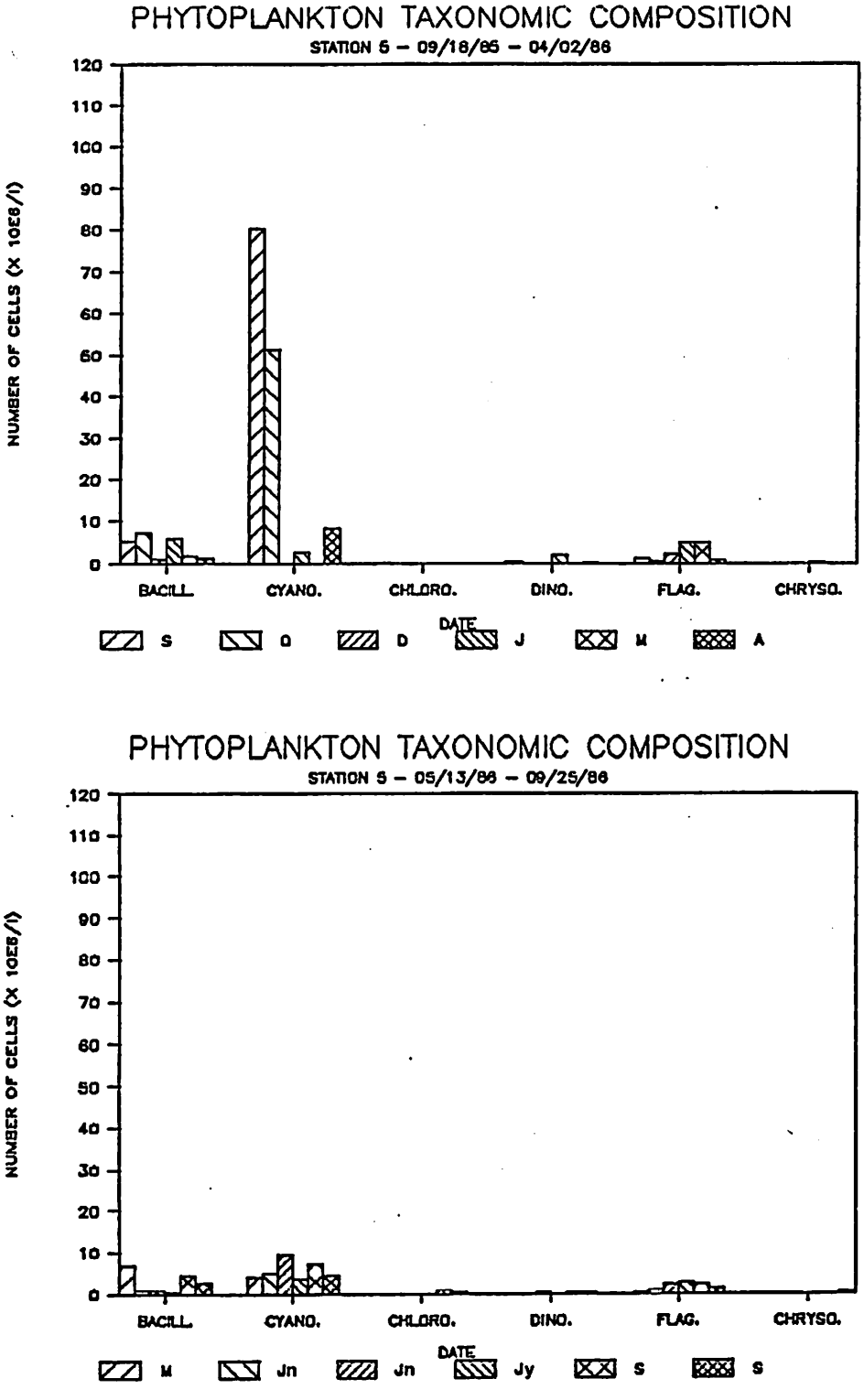
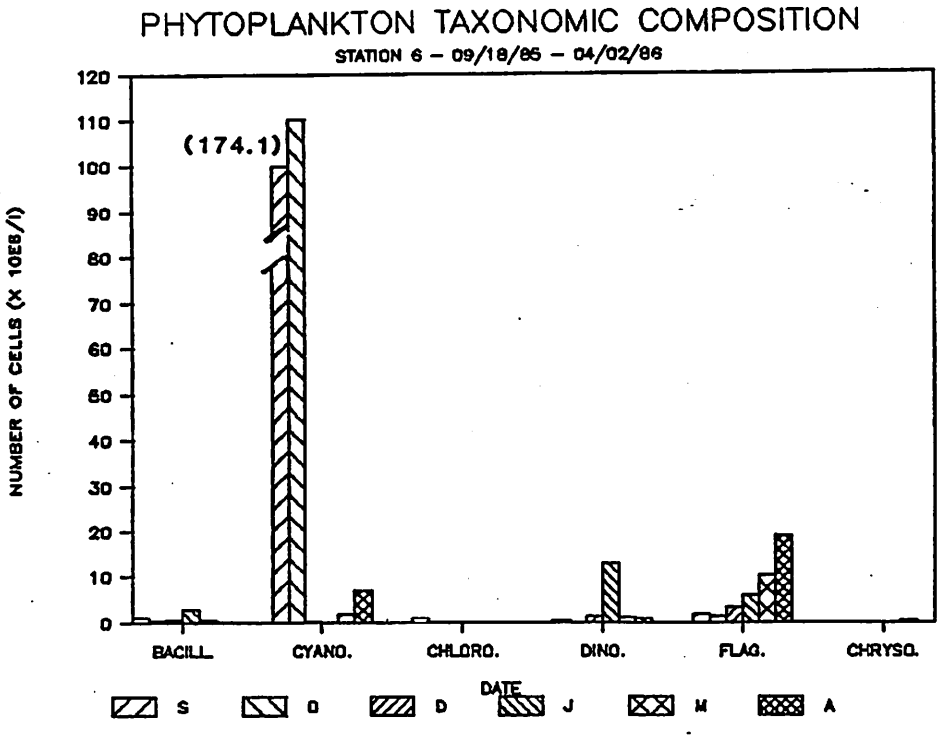


Figure 34. Phytoplankton taxonomic composition at Station 5 for (A) September, 1985 - April 1986 and (B) May, 1986 - September, 1986. Letters adjacent to symbols represent initials of each sampling month beginning in September 1985. X-axis labels as noted in Figure 30.



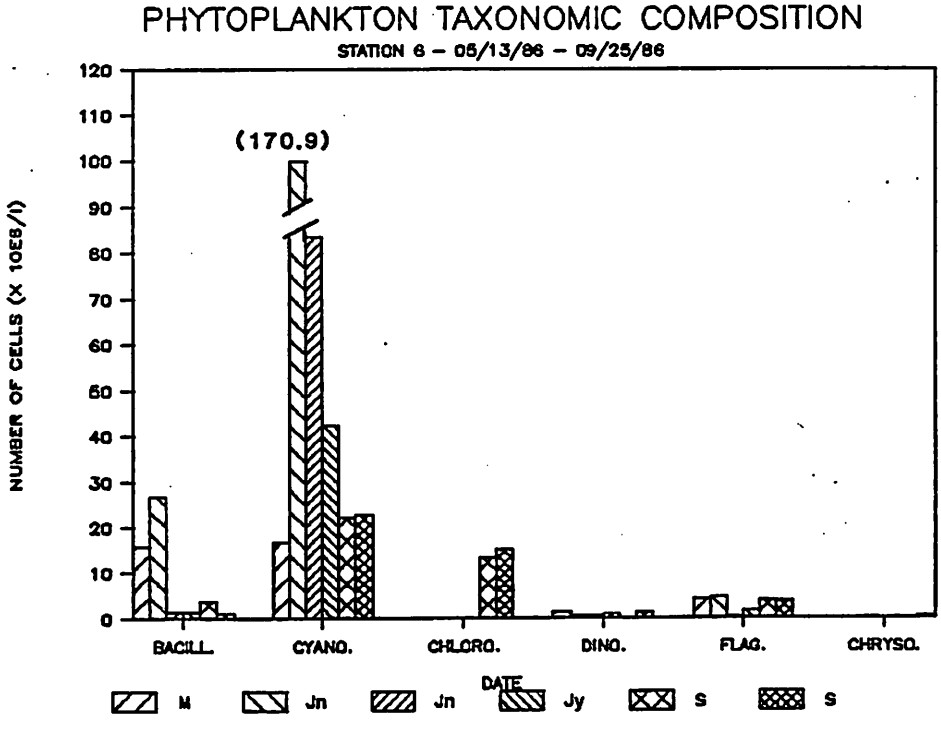


Figure 35. Phytoplankton taxonomic composition at Station 6 for (A) September, 1985 - April, 1986 and (B) May, 1986 - September, 1986. Letters adjacent to symbols represent initials of each sampling month beginning in September, 1985. X-axis labels as noted in Figure 30.

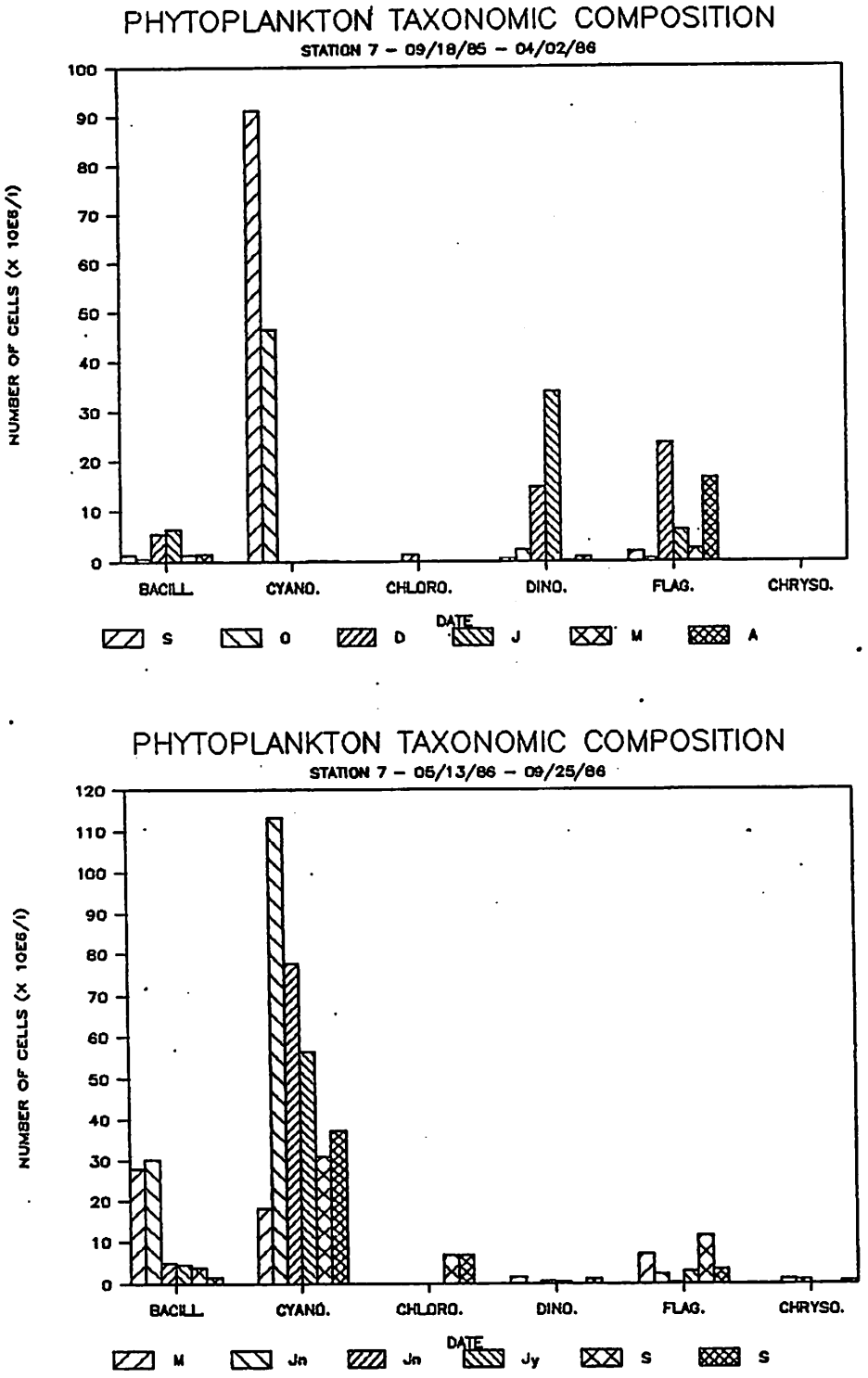
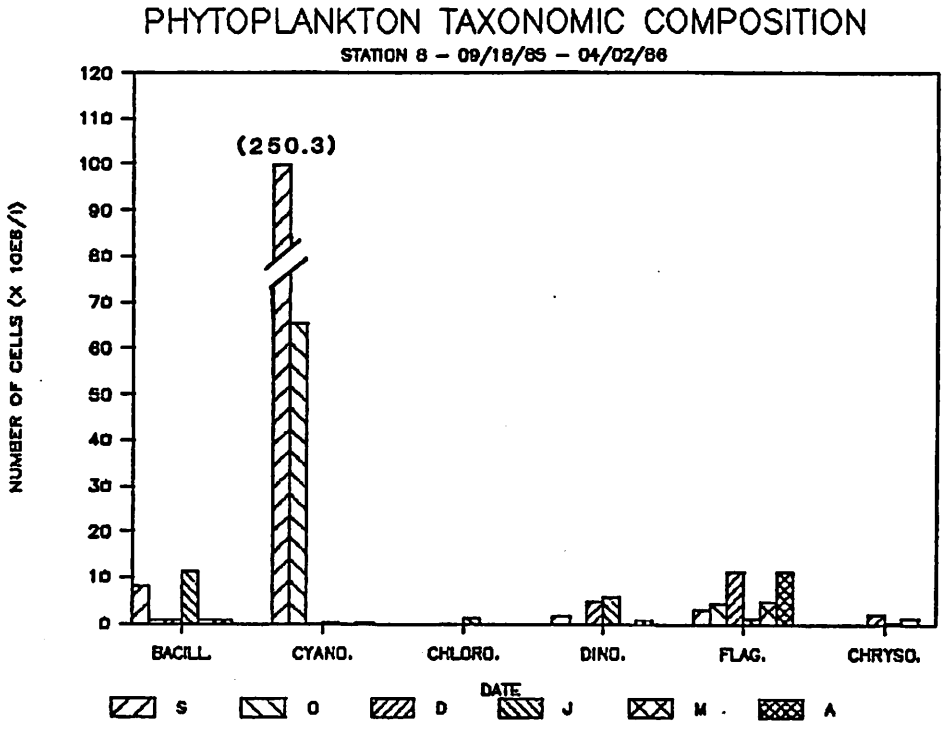


Figure 36. Phytoplankton taxonomic composition at Station 7 for (A) September, 1985 - April, 1986 and (B) May, 1986 - September, 1986. Letters adjacent to symbols represent initials of each sampling month beginning in September, 1985. X-axis labels as noted in Figure 30.



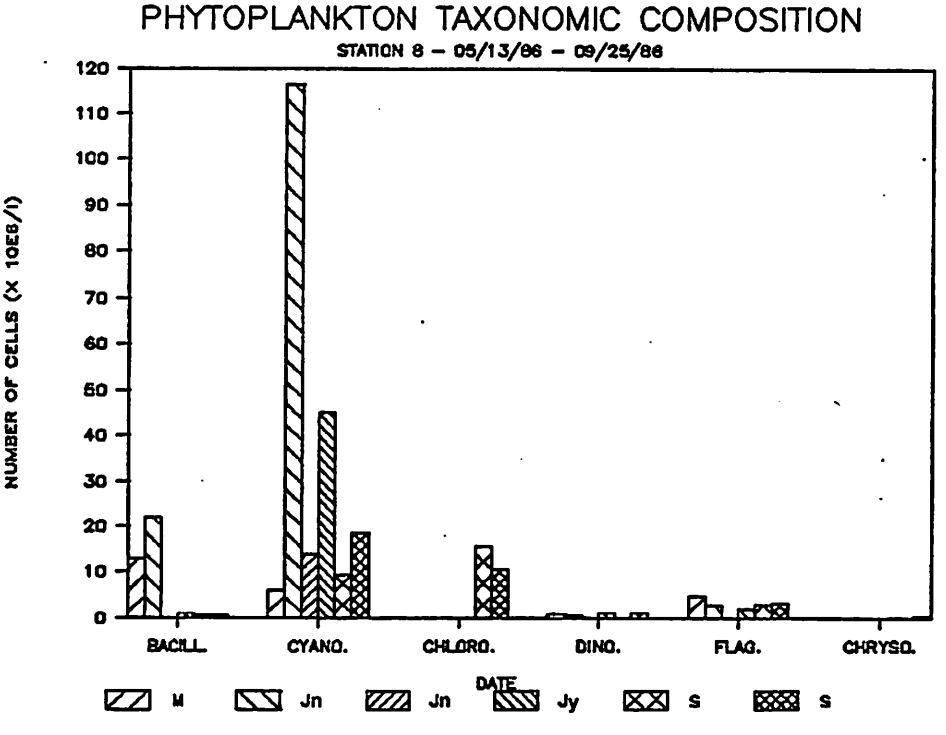


Figure 37. Phytoplankton taxonomic composition at Station 8 for (A) September, 1985 - April, 1986 and (B) May, 1986 - September, 1986. Letters adjacent to symbols represent initials of each sampling month beginning in September, 1985. X-axis labels as noted in Figure 30.

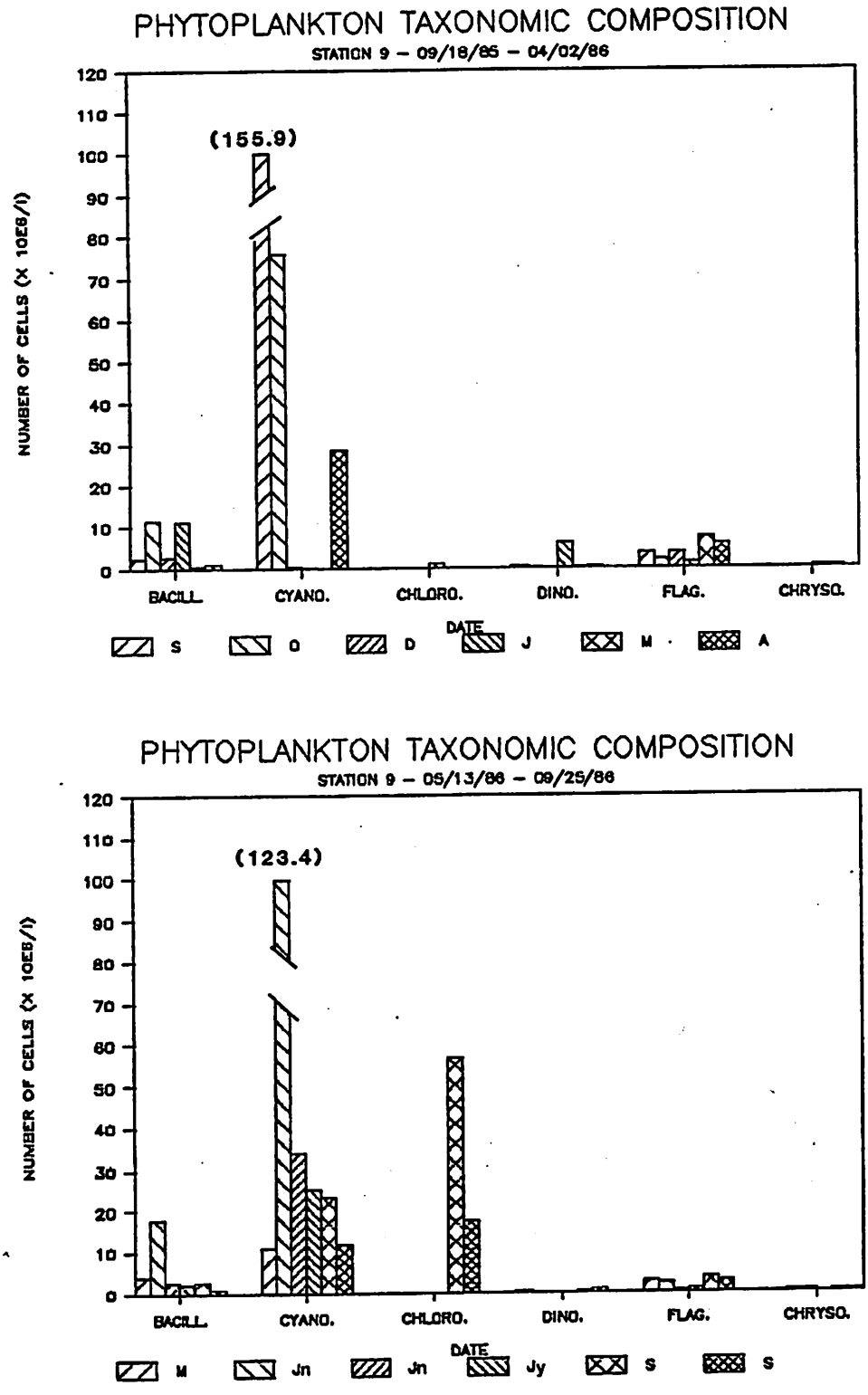


Figure 38. Phytoplankton taxonomic composition at Station 9 for (A) September, 1985 - April, 1986 and (B) May, 1986 - September, 1986. Letters adjacent to symbols represent initials of each sampling month beginning in September, 1985. X-axis labels as noted in Figure 30.

During the colder period when Katodinium rotundatum was not the dominant taxon, flagellates such as Eutreptia sp. and Cryptomonas sp. (mean flagellate number = 1.5×10^6 cells/L) and diatoms (mean = 4.0×10^6 cells/L), such as Skeletonema costatum (mean = 1.9×10^6 cells/L), were found in relatively high concentrations.

Little Assawoman Bay displayed a flora which was dominated by picoplankton (mean = 6.7×10^7 cells/L) during the warmer months (June-October), by centric diatoms (mean = 1.6×10^7 cells/L, mainly Cyclotella sp. and Chaetoceros didymus), during December and January and by flagellates (mean = 1.2×10^7 cells/L) in March-April (Figs. 39,40). A member of the Chrysophyceae, Calycomonas ovalis, became subdominant in late September, reaching mean densities of 7.7×10^6 cells/L.

One way of identifying the importance of Delaware's Inland Bays in supporting phytoplankton production is to examine phytoplankton standing stocks relative to the contribution from oceanic waters. Phytoplankton densities and taxa encountered in Indian River inlet (Station 5) are most representative of assemblages from waters overlying the continental shelf. In Figure 41, average densities of three phytoplankton groups (total cells, eucaryotes and picoplankton) have been calculated for the Inland Bays by initially subtracting densities noted at Station 5 from densities noted at each of the other stations in the Inland Bays and subsequently determining the mean monthly density of each group for the Bays. Several points are obvious for the system. First, in September, 1985 and in the summer of 1986, mean total cell densities are high relative to contributions from the continental shelf principally due to large contributions of phytoplankton taxa in the picoplanktonic size fraction. These small cells comprised over 90% of total cell densities in these periods in the Bays suggesting relatively high growth potential in the system or influx of the small autotrophs from freshwaters into the Bays. Secondly, picoplankton, primarily the small coccoid cells (possibly Synechococcus, the ubiquitous cyanobacterial cell) and Microcystis, the colonial cyanobacteria that forms nuisance blooms in many lakes and rivers world-wide, predominated in warmer months (September, 1985 and summer, 1986). Fortunately, salinities typical of Delaware's Inland Bays inhibit growth of most representatives of this bloom-forming genus (Reed and Walsby, 1985; Sellner et al., 1988) preventing bloom development and possibly favoring death of the cells. More desirable eucaryote taxa, as dinoflagellates and diatoms, were higher in the system relative to the oceanic assemblages, in the cooler months (December-May). Mean eucaryote densities of 10^7/L are high for environments with salinities comparable to the Inland Bays, also suggesting the Inland Bays provide a fertile habitat for phytoplankton growth. The fate of this labile organic material cannot be resolved but could support production in other trophic levels (heterotrophic metabolism) in the Bays or be exported to shelf waters.

There are several striking differences evident in Delaware Inland Bays over the last 20 years. In earlier studies (Bishop, 1966; Brooks, 1972; Ecological Analysts, 1977) picoplankton (cyanobacteria) were not reported, yet this fraction was a numerical dominant in the present study. Identification of large numbers of picoplankton is possibly attributable to better resolution in microscopes employed in the present study. Brooks (1972) did note large concentrations of what he termed nanoplankton during August, October and April but did not elaborate on the composition of this fraction. The second major difference was the lack of flagellated forms such as Cryptomonas or Eutreptia in the previous work perhaps due to loss of these fragile forms during preservation or sample storage in the previous studies. The final major discrepancy between data in current and past

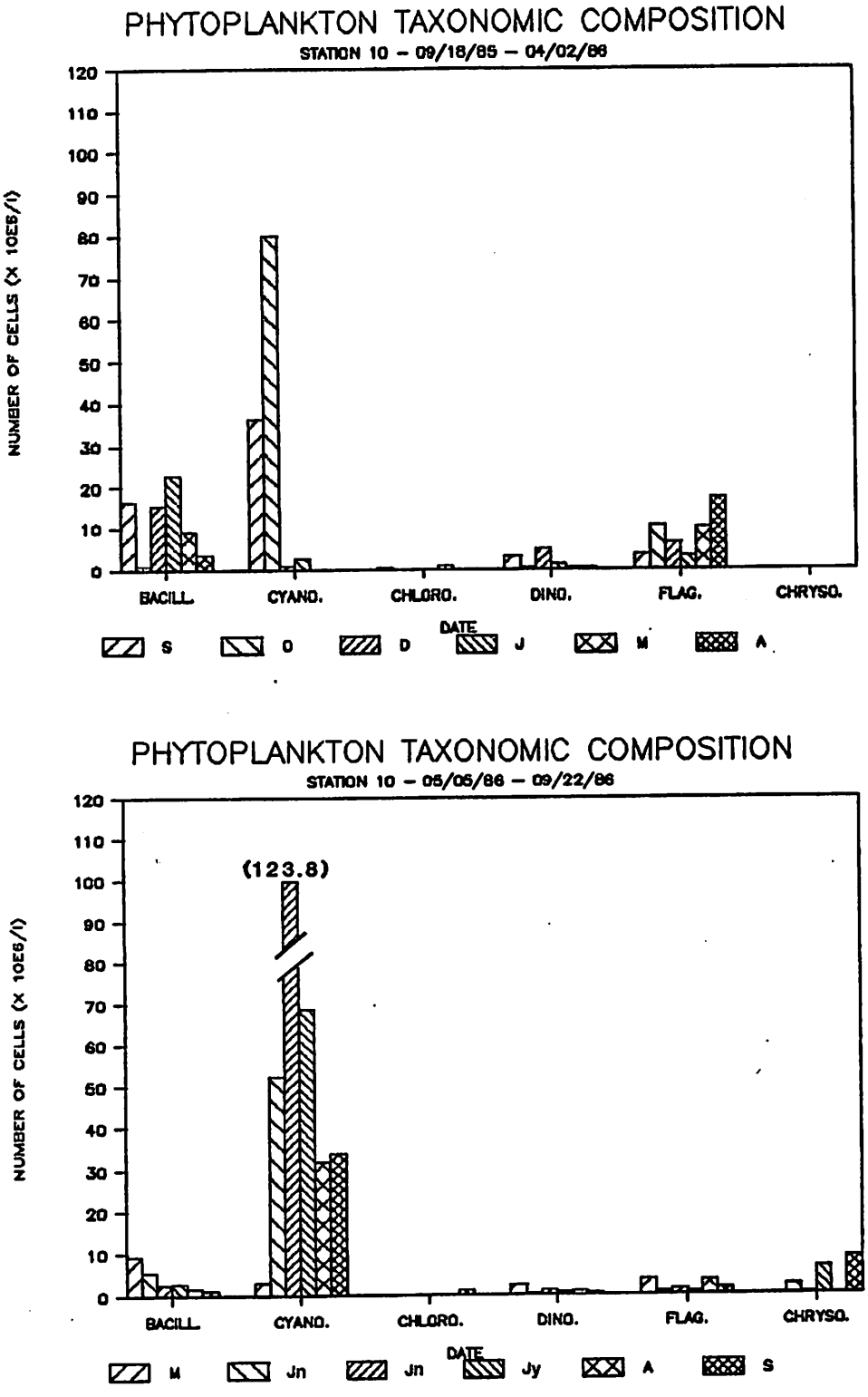
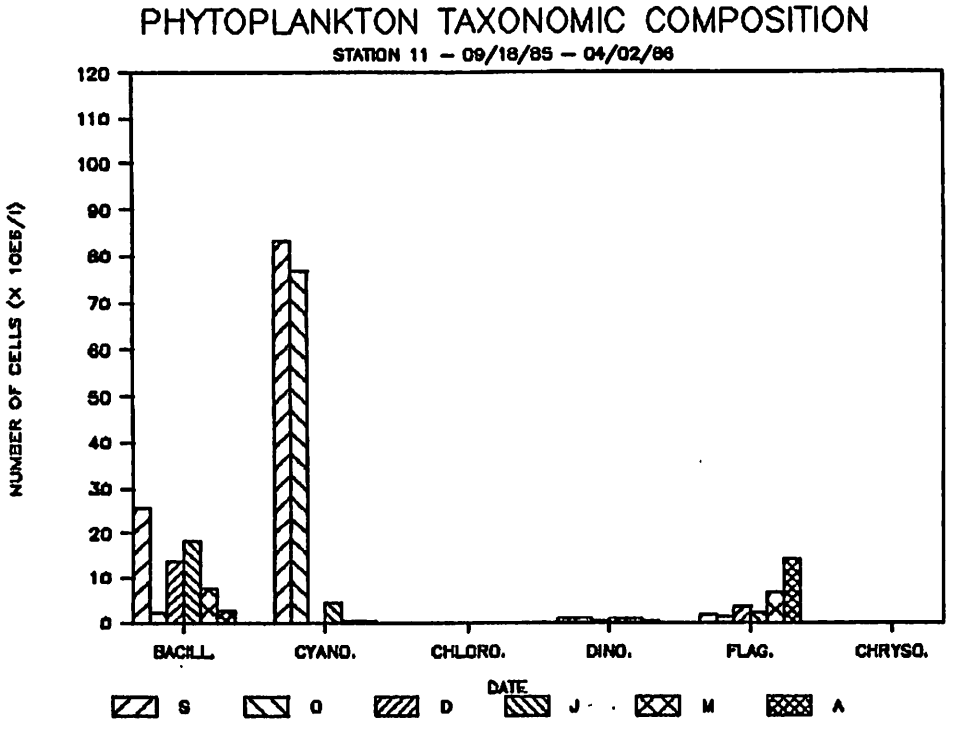


Figure 39. Phytoplankton taxonomic composition at Station 10 for (A) September, 1985 - April, 1986 and (B) May, 1986 - September, 1986. Letters adjacent to symbols represent initials of each sampling month beginning in September, 1985. X-axis labels as noted in Figure 30.



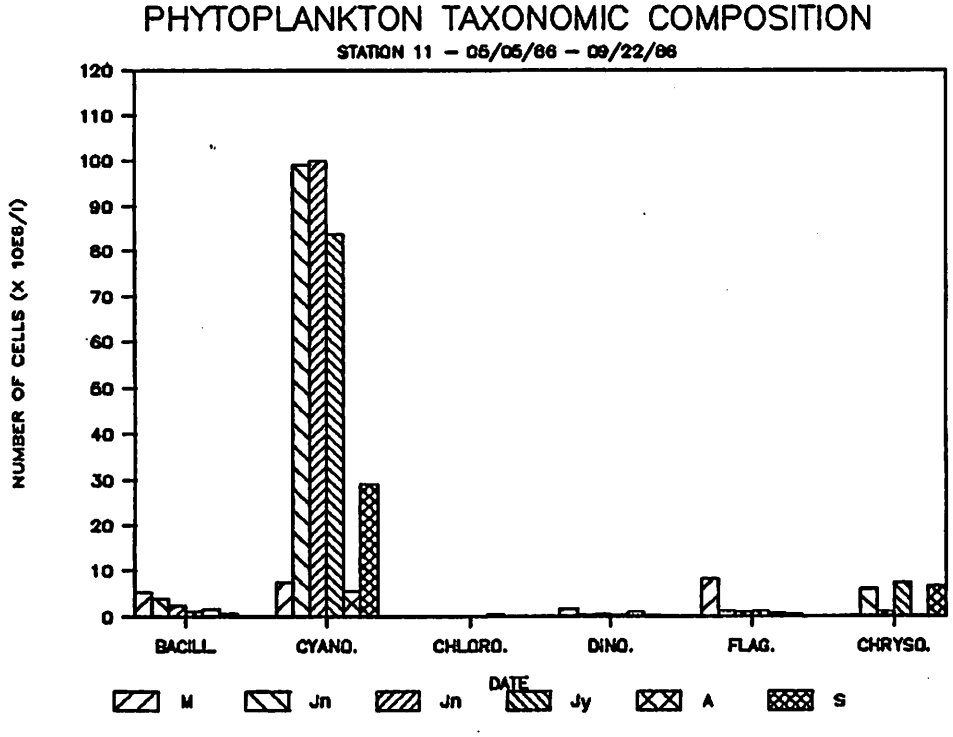


Figure 40. Phytoplankton taxonomic composition at Station 11 for (A) September, 1985 - April, 1986 and (B) May, 1986 - September, 1986. Letters adjacent to symbols represent initials of each sampling month beginning in September, 1985. X-axis labels as noted in Figure 30.

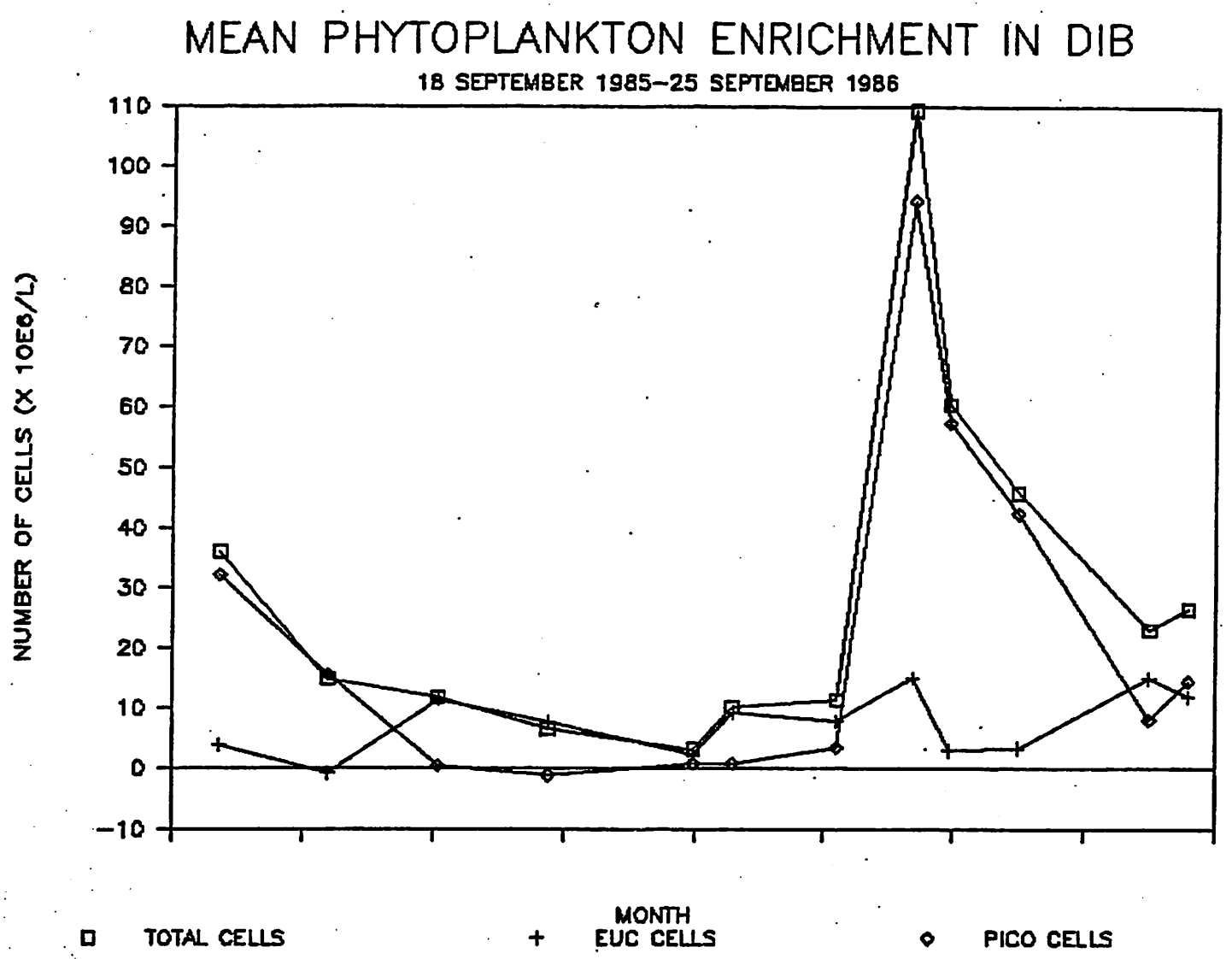


Figure 41. Phytoplankton enrichment in Delaware's Inland Bays (DIB) for the period September, 1985 - Sepember, 1986. Mean densities (x 10^6/L) of total cells, eucaryotes and picoplankton relative to densities at Indian River Inlet (Station 5).

studies is the absence of Katodinium rotundatum, the dominant member of the winter assemblage in Indian River Bay in the current study (December-January), from species lists in the earlier studies. However, year-to-year differences in species composition are not too surprising; slightly different environmental conditions in the present study versus the previous studies could select for growth of this winter bloom-forming dinoflagellate. In addition, different sample collection techniques (net vs. whole water) could also lead to species and size differences between years and studies.

DISCUSSION

The Delaware Inland Bays complex is a lagoon-type barrier island estuary typical of the east coast of the U.S., with an inlet (Indian River Inlet) through the barrier island permitting exchange of water between the bays and the Atlantic Ocean. The Inland Bays exhibit features common to other east coast lagoonal estuaries: shallow water depths, freshwater input via surface runoff, groundwater seepage, river and creek discharge along the western shore, a circulation pattern largely influenced by wind, a small exchange ratio (the proportion of bay water flowing into the ocean during each tidal cycle), extensive wetlands surrounding the Bays and a slightly stratified water column.

The effects of residential development, sewage treatment discharge, light industrial discharge, agricultural practices, poultry production, dredging, and increased sedimentation on this lagoonal-estuarine ecosystem are major concerns for managers and land-use planners in the region (Scotto et al., 1983). By monitoring physical parameters, nutrient concentrations, primary producer biomass and species composition and dissolved oxygen concentrations, conclusions regarding the current status of Delaware's Inland Bays can be drawn and future recommendations for development can be formulated.

Nutrient concentrations in Delaware's Inland Bays were very high for the 1985-1986 study period. Lowest concentrations of dissolved inorganic nitrogen and phosphorus were noted in summer and spring, respectively, a pattern identified in other east coast estuaries (EPA, 1982). The primary sources of nutrients appeared to be the major tributaries for each Bay, i.e. Dirickson Creek for Little Assawoman Bay, Herring Creek for Rehoboth Bay and, as noted in the 1986 DNREC Water Quality Report, Indian River and its associated tributary creeks, i.e., Swan, Pepper, Blackwater, Vines and White Creeks. Groundwater contributions of dissolved nutrients, particularly nitrate, must also be substantial considering the excessively high nitrate levels recorded in wells in the region. Indian River dissolved inorganic nitrogen and phosphorus concentrations were very high, with maximum concentrations exceeding 200 uM and 1.3 uM (2.8 and 0.04 mg/L), respectively. Dissolved inorganic nitrogen fluctuated about 15.5 uM ($\pm$ 2.3, std. error; 0.22 $\pm$ 0.03 mg/L) in the three Bays in the productive summer months of 1986, an appreciable nitrogen reservoir for the Bays' phytoplankton assemblages. Although there were few ammonium-nitrogen data supplied by DNREC that were above the detection limit of 0.5 uM (0.01 mg/L), those that were $>$0.5 uM were also found in the productive summer months. Ammonium concentrations exceeding 0.5 uM are high for polyhaline waters and as the preferred nitrogen substrate for phytoplankton, nitrogen supply from ammonium and nitrate plus nitrite was more than sufficient for phytoplankton in Delaware's Inland Bays throughout the productive summer months. This observation is supported by the few instances of possible nitrogen limitation seen either as ambient nitrogen levels that were less than half-saturation

constants for uptake and only one instance out of 36 where mean N:P ratios were <10.

Phosphorus concentrations could limit phytoplankton in Delaware's Inland Bays, as observed in the spring in Delaware Bay (Pennock, 1985b). Phosphorus concentrations were low in Indian River Bay, Rehoboth Bay and Little Assawoman Bay in the productive summer months (mean $\pm$ std error = 0.36 ± 0.05 uM; 0.01 ± 0.002 mg/L). These concentrations could all be limiting to phytoplankton since half saturation constants for eutrophic phytoplankton taxa range from 0.2-1.7 uM (<0.01-0.05 mg/L). N:P ratios generally exceeded 20 throughout the year also supporting P-limited conditions. However, care should be taken in acting solely on these data. Caution is suggested because the relationship between nutrient concentration and algal response is subject to tremendous temporal and spatial variability. Phytoplankton may also be light-limited in the Bays due to rapid attenuation of light and shallow euphotic depths noted in the Bays (see Table 11). In nutrient-rich Delaware Bay, suspended sediment concentrations >50 mg/l are associated with minima in chlorophyll and carbon fixation in the upper estuary; phytoplankton standing stocks in the lower estuary are also intermittently limited by turbidity in the water column (Pennock, 1985a; Pennock and Sharp, 1986). Since suspended solids concentrations ≥ 50 mg/l were common in Rehoboth and Indian River Bays (Figs. 27 and 28) in the most productive months, light as well as nutrients could limit phytoplankton in the system.

In order to definitively identify phosphorus and/or light limitation of phytoplankton in Delaware's Inland Bays, a study comparable to a recent investigation conducted in the Patuxent River, Maryland, should be initiated. Large-scale (0.5 m^3) naturally-occurring phytoplankton cultures could be enriched with N and P at different times of the year in an effort to measure algal response and assess nutrient limitation (D'Elia et al., 1986; Sanders et al., 1987). Patuxent River phytoplankton responded to enrichment with nitrogen during the late summer (a period when N:P ratios were below 5:1) and to enrichment with phosphorus in the late winter (a period when N:P ratios were above 90:1). The timing of these responses coincided with periods when the river had the lowest yearly concentration of each nutrient. As noted above, N:P ratios in Indian River Bay were >20 supporting phosphorus limitation year-round. If P limits phytoplankton production and biomass accumulation, phosphorus enrichment should result in higher algal standing crops throughout the year. If these types of studies in Delaware's Inland Bays indicate P-limitation, it is important that nutrient management strategies be designed, implemented and enforced to limit phosphorus additions to Delaware's Inland Bays. It should be remembered, however, that excess nitrogen exported from the system will enhance phytoplankton growth in N-limited waters of the coastal Atlantic Ocean, transporting potential problems to other locales. Total nutrient input into the Bays should always be kept to a minimum.

Bay concentrations of dissolved nitrogen and phosphorus coupled with 1) continuous point and nonpoint source additions of these nutrient species and 2) natural regeneration processes in the water column and sediments in the system provide adequate substrates for relatively high phytoplankton standing stocks as chlorophyll and cell numbers. For example, chlorophyll concentrations ranged from approximately 2 to 57 ug/L for all stations except eutrophic Station 7 during the summer of 1986, with an average of 20.7 (± 7) ug/L. Total cell densities and total eucaryote densities (eucaryotes include all taxa except cyanobacteria) for the summer period ranged from 34.3-115.1 x 10^6 and 4.7-17.5 x 10^6 cells/L, respectively.

For comparison, chlorophyll concentrations in waters of similar salinities and nutrient concentrations in Delaware Bay (receiving point source nutrient enrichment, e.g. >200 uM-N or >2.8 mg/L, from Philadelphia) were always <12 ug/L for the period 1978-1980 (Sharp et al., 1982). In another similar system in southern New Jersey, the Mullica River-Great Bay complex, but with no nutrient enrichment at the headwaters of the major tributary, chlorophyll concentrations approximated 10 ug/L in surface waters of the inner bay for the summer of 1975 (Durand, 1984). These data and comparisons suggest that the Delaware Inland Bays have higher nutrient levels and greater phytoplankton standing stocks than observed in systems in the region with similar salinity regimes.

The fate of the higher chlorophyll concentrations is not known. If phytoplankton production remains in the Bays supporting secondary producers such as planktonic copepods or fish larvae or sinks to the bottom to support immobile benthic macrofauna, the Inland Bays complex will remain a viable ecosystem. If, on the other hand, the material remains uneaten by these biota and settles to the bottom where microheterotrophic processes consume the material (e.g., bacterial decomposition), high oxygen demand could result in low oxygen concentrations in bottom waters, potentially limiting habitat for aerobic fish and shellfish communities. However, in the present study, oxygen concentrations collected in mid-day exceeded the State minimum standard of 5 mg/L on all occasions except one suggesting that high organic loading from high discharge of BOD (DNREC, 1986) and high summer chlorophyll concentrations (>20 ug/L, present study) did not result in oxygen demand sufficiently high to cause potential problems for aerobic fauna in the system. These data contrast results obtained by Biggs (1984) and DNREC (1986) where concentrations <2 mg/L were noted in Indian River and the Lewes-Rehoboth Canal. Beasley (1987) also reports eutrophication and anoxia are identifiable in the system since the turn of the century. However, caution must be advised for speculating on the extent of anoxia over all Inland Bay regions from Beasley's data. Low oxygen tolerant diatoms were observed in one of two cores, not both, and the core where these taxa were observed was collected from wetland-marsh sediments which more frequently experience low oxygen tensions than open-water systems. In the present study, oxygen concentrations were not measured by the DNREC field teams in August, the month typified by minimum DO levels in the two previous studies, supporting the observation that at least for 11 months of the year, mid-day oxygen concentrations in the system should not restrict distributions of aerobic fauna. In the future, summer oxygen concentrations should be routinely determined over 24 h and, at a minimum, just prior to sunrise, following maximum oxygen consumption in the water column during the night. Nocturnal oxygen consumption could be sufficiently large to reduce levels to hypoxic concentrations (<2 mg/L) perhaps resulting in a temporary loss of habitat for fish and shellfish in the region. Even a short exposure to low oxygen concentrations could effectively prevent maximum use of Delaware's Inland Bays by typical estuarine biota.

Although summer dinoflagellate blooms were not encountered during the monthly collections in the present study, "red tides" are not uncommon to Delaware's Inland Bays and may be associated with low dissolved oxygen concentrations and fish kills in the region (M. Blosser, pers. communication). Gymnodinium sp., a frequent summer red tide organism in Chesapeake Bay, was noted at 6.9×10^6 cells/L at Station 11 in Little Assawoman Bay on 26 August 1986; however, dinoflagellate densities in summer "red tides" may reach 10^7-10^8 cells/L (Sellner and Olson, 1985). Aperiodic summer blooms of dinoflagellates in the Inland Bays should be observed due to the high salinities of the Bays, high water temperatures, high nutrient concentrations and variable flow conditions in the

summer months. For example, low river flow and calm conditions in a drought could favor dinoflagellate blooms. As motile cells, dinoflagellates can maintain themselves in the surface lighted zone favoring growth while non-motile forms such as diatoms might sink to bottom sediments. Blooms are also observed when local winds resuspend surficial bottom sediments containing dinoflagellate cysts (resting stages) into lighted surface waters. Once in the euphotic zone, cysts rupture releasing cells for resumption of photosynthesis and growth and if calm conditions follow, a bloom may result. Finally, dinoflagellates may also respond to localized water column stratification resulting from thermal or salinity differences in the water column. For example, dinoflagellate blooms have been observed in the Rhode River estuary, a sub-estuary of Chesapeake Bay, following a rain event (Loftus et al., 1972) as well as high river runoff in Florida coastal waters (Rounsefell and Nelson, 1966). All of the conditions described above are characteristic of the Inland Bays, suggesting summer dinoflagellate blooms should not be unexpected in the system. Summer dinoflagellate blooms are a natural response to stratification in saline waters.

Should blooms occur, deleterious conditions may be observed in the Bays. One effect of a bloom would be large diel changes in dissolved oxygen concentrations with diurnal photosynthetic production of oxygen yielding supersaturated oxygen concentrations in the day and nocturnal respiration leading to local hypoxic or anoxic conditions. at night. This nocturnal decline in oxygen in the water column can lead to suffocation of the aerobic fauna in the area if the fauna cannot escape to aerobic waters; fish kills and crab jubilees result. Fish kills could also accompany growth of toxic dinoflagellate species. Dinoflagellates that produce toxins are common to waters off New England and Florida but to our knowledge and as in Chesapeake Bay, toxic forms have not been recorded in Delaware's waters. Should toxic species occur in the Inland Bays during the summer months, problems associated with dissolved oxygen described above will also occur as well as low dissolved oxygen problems associated with decomposition of dead fish and predators of fish and shellfish killed by the toxin-rich dinoflagellate species.

One final note concerning phytoplankton species observed in Delaware's Inland Bays in 1985-1986. High picoplankton densities, containing cyanobacteria, were noted in the Delaware Inland Bays primarily during the warmer months of the sampling period. In September, 1985 and June, 1986, this picoplankton group was most abundant with densities reaching 3.2×10^8 cells/L (September, Station 9). This same phytoplankton group was found in the lower Chesapeake Bay at densities reaching 5×10^7 cells/L (Marshall and Lacouture, 1986) and in the York River, Virginia at concentrations as high as 7.2×10^8 cells/L (Ray, 1986). The dominant taxa in the Bays was a small colonial form containing 10-20 3 um cells, possibly the colonial blue-green algae Microcystis that dominated the upper Potomac River in 1985 (Sellner et al., 1988). However, in fresh waters of the upper Potomac and other freshwater environments, thousands of cells may be observed in colonies. In lower estuarine portions of the same system, these colonies disappear perhaps due to salinity-induced loss of cell viability (Sellner et al., 1988). The small colonies noted in Delaware's Inland Bays could conceivably represent remnants of blue-green algae blooms, obvious as surface scums (e.g., Red Mill Pond, Broadkill River watershed; p. 17, Coastal Sussex Cooperative River Basin Study, 1986), formed from salinity-induced disintegration of larger colonies. Higher salinities of Delaware's Inland Bays therefore serve as effective osmoregulatory barriers to continued photosynthesis and growth of freshwater blue-green algae and therefore prevent nuisance algae blooms in the Inland Bays.

A common trend for many temperate estuaries including the Inland Bays (Ecological Analysts, 1977) is the occurrence of a diatom bloom during the late winter-early spring period (Pratt, 1965; Smayda, 1983; Marshall and Lacouture, 1986; Sellner and Brownlee, 1986a,b). A winter diatom bloom was not observed in the Delaware Inland Bays (with the exception of a minor increase in Skeletonema costatum at Stations 1 and 9) during the December-March period. Possible explanations for the absence of the bloom include development and subsidence of a bloom between sampling periods, grazing and high suspended solids concentrations limiting diatom growth. Another possibility is silicate-limitation in the January-May period as occasionally noted for phytoplankton in mesohaline Chesapeake Bay (Sellner and Kachur, 1987). In Indian River Bay where silicate concentrations were high, chlorophyll concentrations reached 32.5 ug/L in January principally due to taxa not requiring silicon, namely a dinoflagellate Katodinium rotundatum and a flagellate, Cryptomonas sp.

Rates of exchange of water between the Inland Bays and the ocean will have a dramatic effect on water quality in the system. Presently, residence time has been estimated at three months (Karpas, 1978), sufficiently long to permit chlorophyll accumulation in the system from 1) slow transport of freshwater taxa entering the Bays through the estuary to the ocean and 2) growth and development of euryhalinic phytoplankton populations. Differences in residence time and subsequent effects on phytoplankton seemed to be obvious from a comparison of salinities (Fig. 5) and chlorophyll (Fig. 21) for 1985 and 1986. Should residence times in Delaware's Inland Bays increase due to reduced freshwater flow into the lower estuary, even higher chlorophyll levels might be expected in the estuary potentially supporting even greater dissolved oxygen demand and the problems associated with hypoxia or anoxia in estuarine environments.

Data collected in the present study suggest that the visible signs of eutrophication identified in earlier studies have not been removed; conditions may have been exacerbated. Delaware has two choices ultimately dependent on what conditions are deemed most important to its citizens. With projected development in the watershed dependent on septic systems for waste disposal, increasing tourism and continuation of the present agricultural and broiler industries, continued deterioration of the Inland Bays is almost guaranteed. If the vitality of the economy in the area is dependent on relatively healthy Inland Bays in the future, remedial practices must be implemented in the watershed, including the Indian River drainage basin. Maintenance of current conditions in the Bays is unlikely without a change in land use practices in the watershed. In order to reduce nutrient input into the Inland Bays, thereby reducing nutrient supplies for maintaining high phytoplankton standing stocks and high turbidities, rigorous land use planning must be developed and enacted. For example, zoning in the region should consider that high soil percolation is deleterious to the system in that nutrients present in fertilizers and soluble wastes simply leach into the groundwater and directly into the Bays. Therefore, septic systems may not be a preferred mode of waste disposal in the area. Centralized facilities and the expense of waste transport and tertiary treatment might be mandatory for future residential construction in the area. In addition, fertilizer application and poultry waste disposal should be rigidly controlled in the agricultural community since these materials have already been implicated as major contributors to nitrate contamination of the groundwater. Best management practices for application of these nutrient-rich materials on to porous soils of the watershed should be designed, implemented and enforced with applications cued to ambient rainfall and not to overloading the soils with nutrients far in excess of crop assimilatory abilities, ultimately resulting in most of the

fertilizer enriching the Bays. Undertaking these activities can slow the processes, not stop them. As long as permanent and tourist populations increase in the region and agriculture continues, nutrient additions to the Bays will increase. The goal should be to reduce the input to the lowest level possible. Implementation of these strategies could reduce phytoplankton levels, increase water clarity and result in recolonization of the Bays by submerged aquatic vegetation and macroalgae providing habitat for high production of fish and shellfish in Delaware's Inland Bays.

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MACROALGAE IN DELAWARE'S INLAND BAYS

K.L. Heck, Jr.[1] and K.G. Sellner[2]

[1]Marine Environmental Sciences Consortium
Dauphin Island Sea Lab
Dauphin Island, AL 36528

and

[2]Benedict Estuarine Research Laboratory
The Academy of Natural Sciences
Benedict, MD 20612

INTRODUCTION

Submerged aquatic vegetation, along with associated macroalgae, provides major nursery habitat in bays and estuaries along the Atlantic and Gulf coasts (Gore et al., 1981; Orth, Heck and Van Montfrans, 1984; Thayer et al., 1984). In Delaware's Inland Bays, unattached macroalgae, also known as drift algae, are commonly observed. For example, Orris and Taylor (1973) describe 59 taxa of macroalgae from Rehoboth Bay and conclude that there are three distinct algal associations: a Gracilaria assemblage, an Agardhiella assemblage and an Ulva assemblage. Such assemblages of drift algae have been observed in Florida (Hooks et al., 1976; Thorhaug and Roessler, 1977; Gore et al., 1981), Texas (Conover, 1964), Massachusetts (Conover, 1958) and New Jersey (Moeller, 1964; Loveland et al., 1984) where they often support exceedingly large numbers of animals.

However, great abundances of macroalgae, especially chlorophytes such as Ulva and Cladophora, are often associated with eutrophic conditions (den Hartog and Polderman, 1975; Harlin and Thorne-Miller, 1981; Thorne-Miller et al., 1983). Consequently, information on the composition and abundance of macroalgae should be useful in drawing some conclusions regarding the degree to which eutrophication may exist in a given area versus less polluted conditions where drift algae are present in greater diversity but less abundance.

The study described below was designed to provide qualitative information on the composition, relative abundance and seasonality of macroalgae in Rehoboth and Indian River Bays. This information will be discussed as it pertains to possible eutrophication of the Inland Bays and in terms of the potential nursery role of macroalgae in the region.

METHODS

Qualitative samples of benthic macroalgae were taken by DNREC staff at approximately monthly intervals from September, 1985 to September 1986. The sampling gear was a 4.9 m otter trawl with 19 mm mesh wings and 6.3 mm mesh cod end. Each sample consisted of the catch contained in the trawl after being towed for 100 m at each of the four stations identified in Figure 1. Two trawls were taken

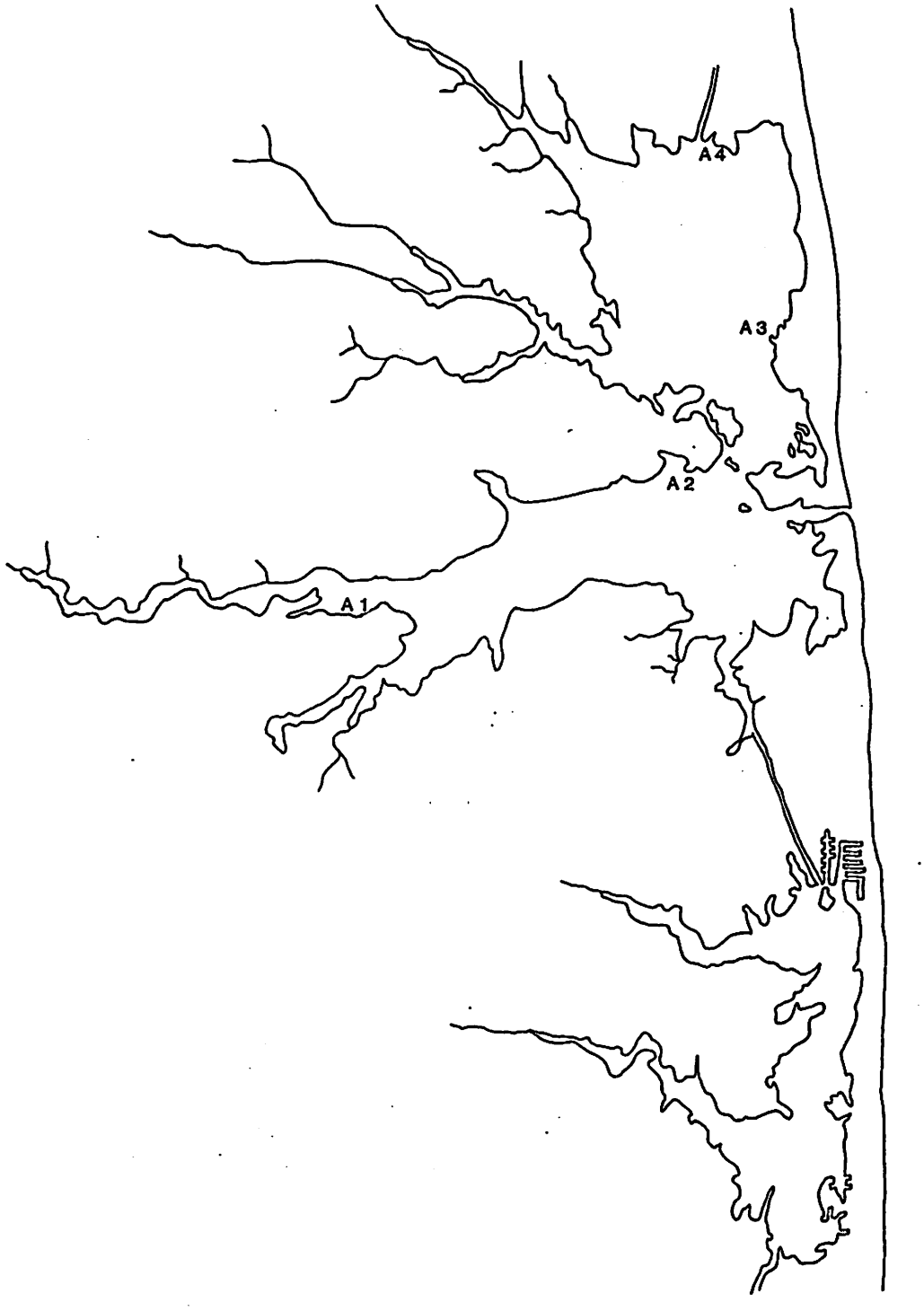

Figure 1. Location of sampling stations in Delaware's Inland Bays for the 1985-1986 macroalgae study conducted by the Academy of Natural Sciences.

at each station (except for one occasion at Site 3 in September, 1985), combined in the field and the biomass of algae from both samples later determined by drying to constant weight in a drying oven at 100°C after animals and other material had been removed. Dry weights were also determined for bryozoan colonies when it was discovered on the first sampling trip that bryozoans were present in great abundance in some of the samples. All dry weights for algal species and bryozoans were then divided by 980 m^2, the product of the width of the trawl and the distance travelled in one tow, to give biomass collected per m^2. Algae were only identified to species in the case of the taxa of major abundance and no species level identifications were made for epiphytic species or filamentous green algae.

Depth at the macroalgae sampling sites ranged from approximately 0.5 to 4.0 m. Salinity and other physico-chemical variables were determined by the DNREC staff in conjunction with the Phytoplankton and Nutrient component (see Phytoplankton and Nutrients section).

RESULTS

Net hauls in the study area from September, 1985 through September, 1986 resulted in the collection of a drift algal community dominanted by green and red algae and a colonial bryozoan. Macroalgal biomass at the four study sites was highest in spring (Fig. 2), predominantly due to dense accumulations of filamentous chlorophytes reaching 1.7 g dry wt/m^2 at Site 2. Macroalgal biomass was always <0.3 g dry wt/m^2 at all other times of the study period, (see Appendices 4 and 5).

For the period, January-early June, 1986, bryozoan dry weight generally exceeded the weight of all macroalgae identified in the samples (Fig. 3). Biomass of this colonial animal exceeded 1 g/m^2 in all four sites in April or June, 1986. Site 1 was typified by bryozoan biomass ranging from 1.2-1.7 g dry wt/m^2 for January-April, 1986. At Sites 2-4, biomass of this animal reached 1.6, 1.0 and 1.4 g dry wt/m^2 in April, April and May, respectively.

Dry weights for each of the algal taxa collected are expressed as weight per m^2 in Figures 4-7. The major macroalgae collected in the study were Gracilaria sp., Agardhiella tenera, Ulva lactuca and unidentified filamentous green algae.

As noted above, filamentous green algae were very abundant at Site 2 in April, 1986, reaching 1.7 g dry wt/m^2 (Fig. 4). Biomass of the filamentous algae at Sites 1, 3 and 4 was 0.05, 0.07 and 0 g dry wt/m^2, respectively. These chlorophytes never accounted for more than 0.02 g dry wt/m^2 at any other time of the sampling period.

Ulva lactuca (sea lettuce), the other dominant chlorophyte in the study area, was also restricted to the period from January-June, 1986 (Fig. 5). Over this six month high biomass period, U. lactuca biomass was higher at Site 2 than at any of the other sampling locations. This large alga reached 0.18 and 0.06 g dry wt/m^2 at Sites 2 and 3, respectively, in January. Highest biomass of this alga at the other two sites was 0.01 g dry wt/m^2 at Site 1 in March and 0.17 g dry wt/m^2 at Site 4 in May.

Biomass of the two red macroalgae, Gracilaria sp. and Agardhiella tenera, was always low relative to the contributions from the chlorophytes. Biomass of Gracilaria sp., either G. verrucosa or G. folifera, was always <0.07 g dry wt/m^2 for the study period (Fig. 6). Over the winter-early summer period, this alga appeared to be distributed in a bimodal pattern, with a peak in late winter, a decline and

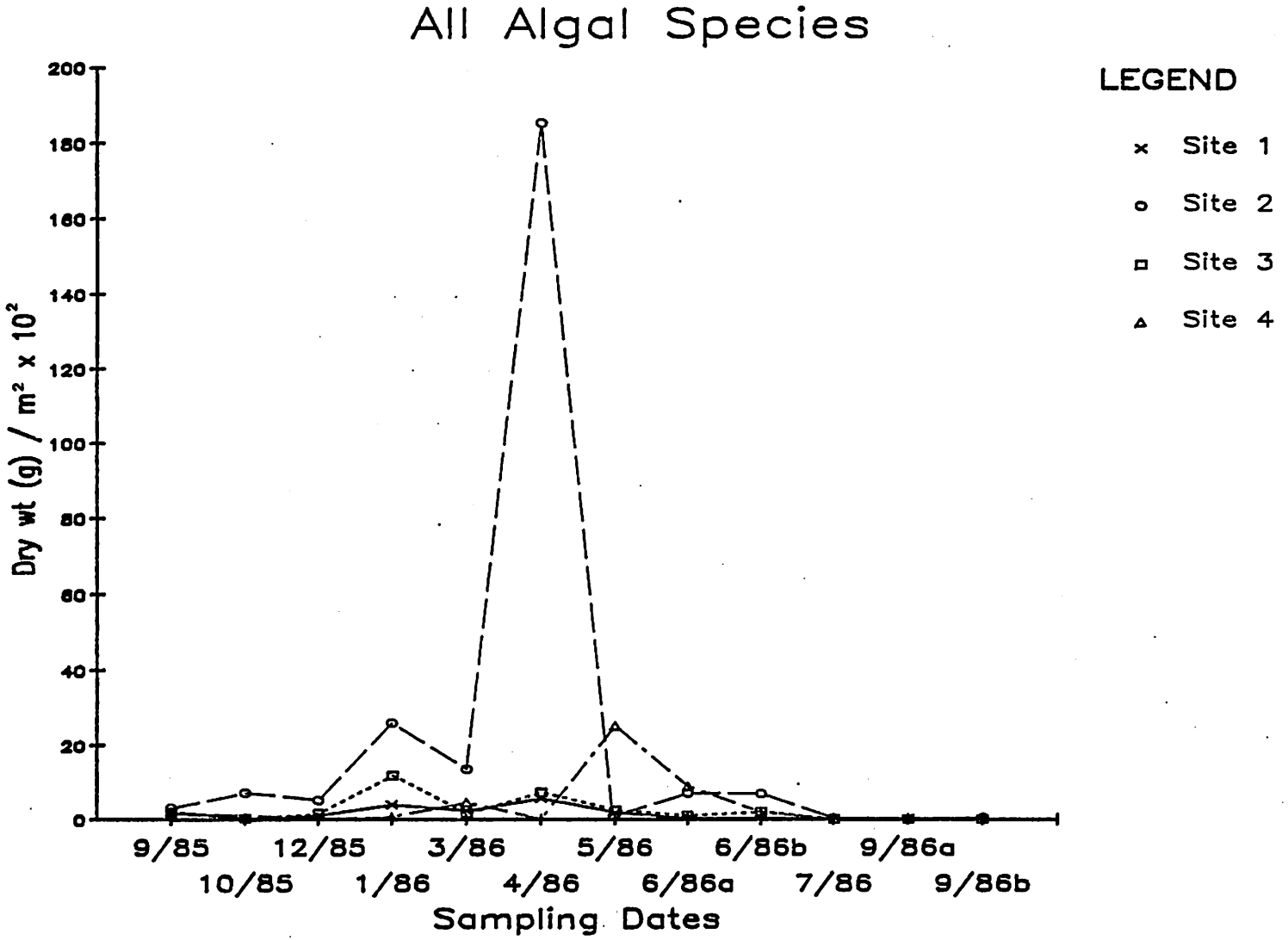

Figure 2. Total macroalgal biomass (g dry wt/m2) in Delaware's Inland Bays for the period September, 1985 - September, 1986.

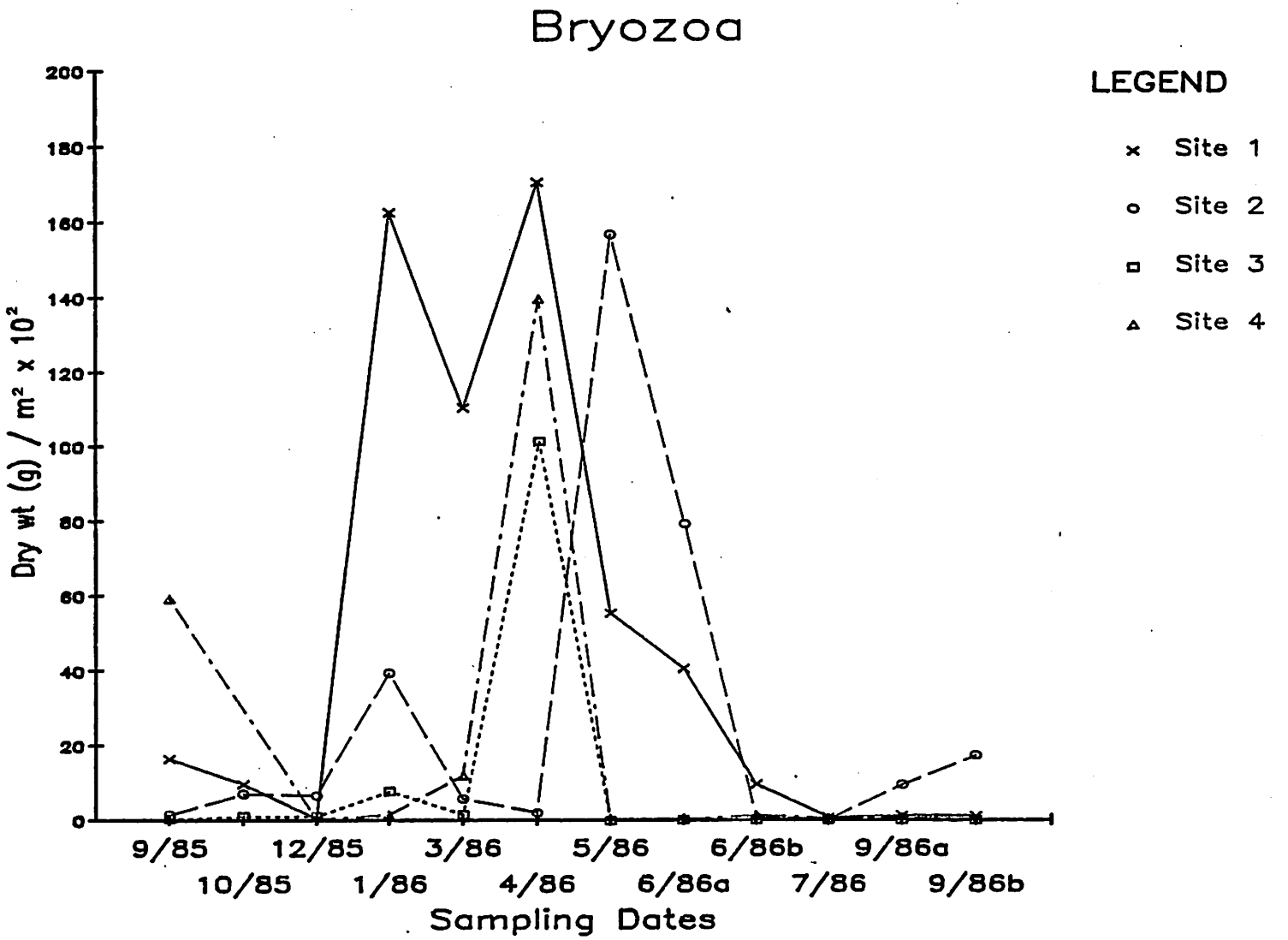

Figure 3. Bryozoan biomass (g dry wt/m2) in Delaware's Inland Bays for the period September, 1985 - September, 1986.

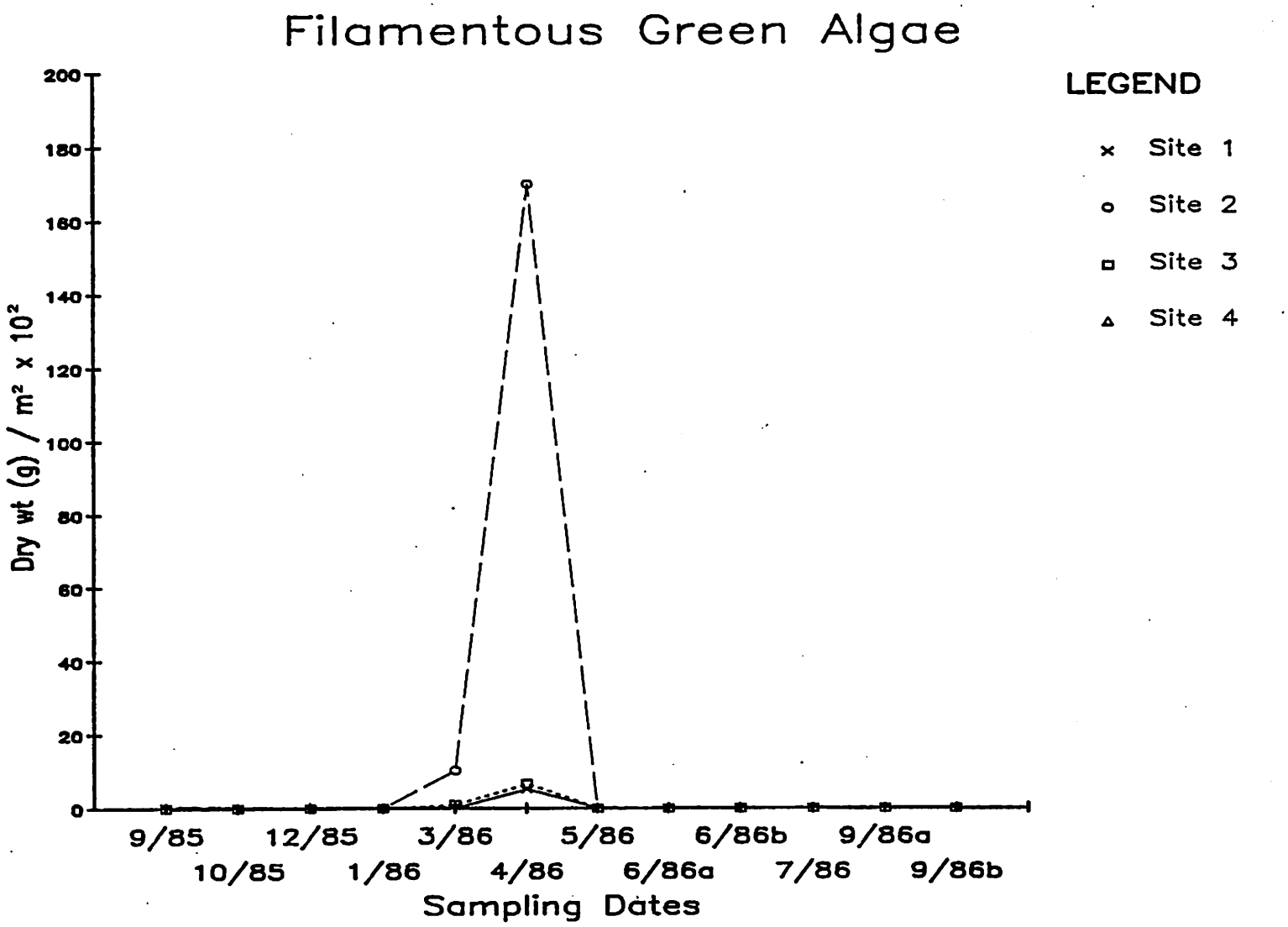

Figure 4. Biomass of filamentous green algae (Chlorophyta, g dry wt/m2) in Delaware' Inland Bays for the period September, 1985 - September, 1986.

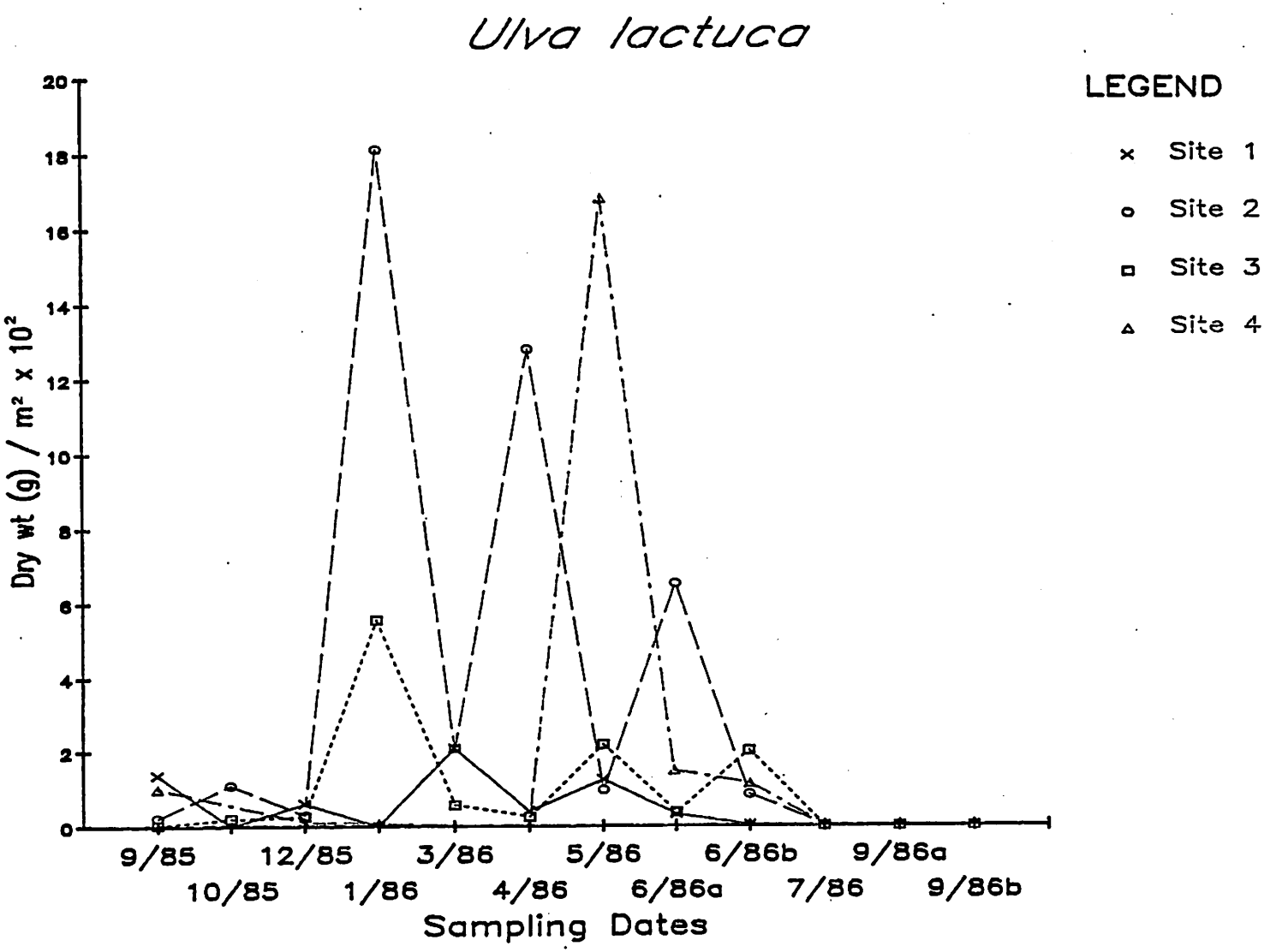

Figure 5. Biomass of Ulva lactuca (Chlorophyta, g dry wt/m2) in Delaware's Inland Bays for the period September, 1985 - September, 1986.

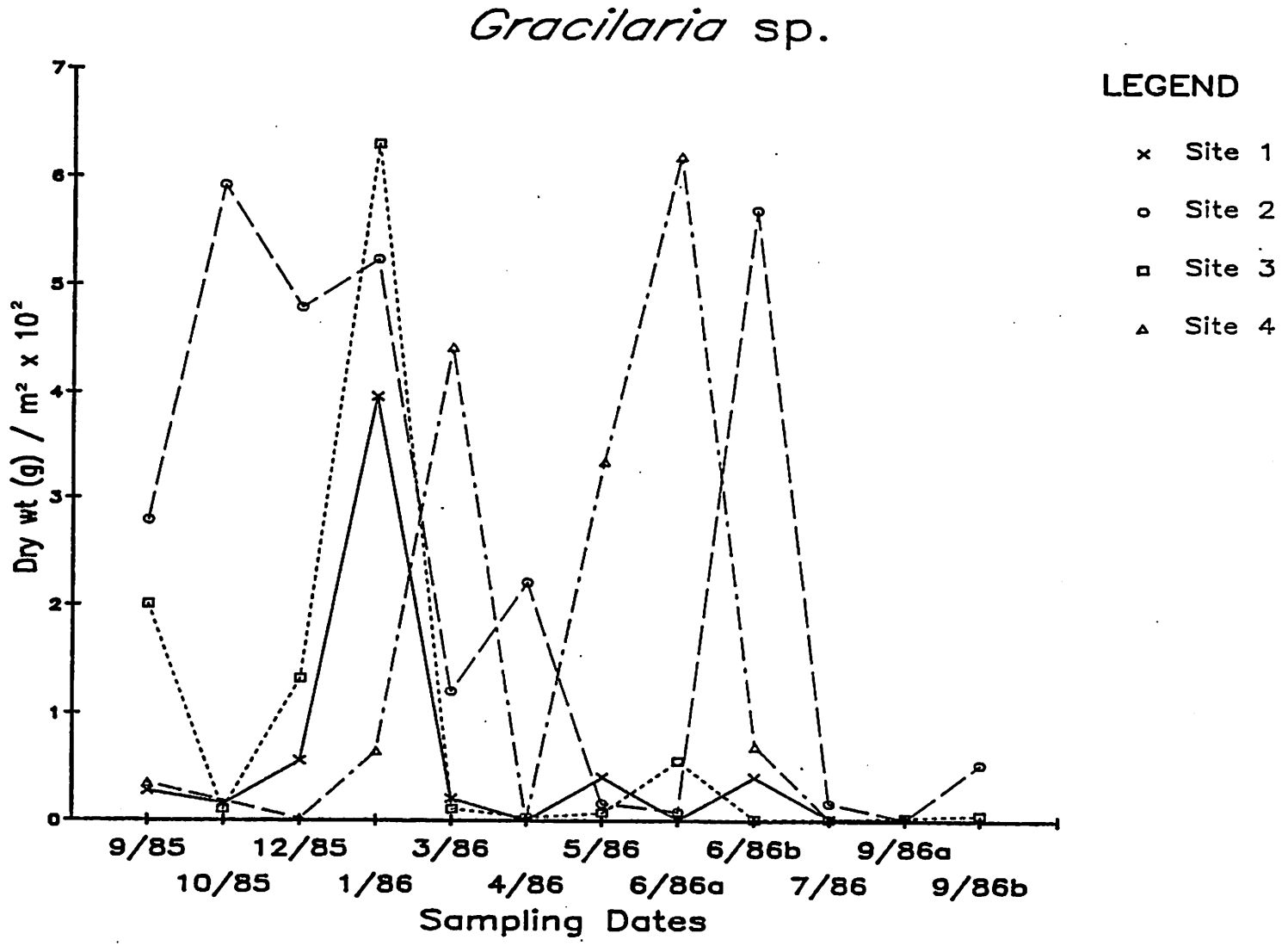

Figure 6. Biomass of Gracilaria sp. (Rhodophyta, g dry wt/m2) in Delaware's Inland Bays for the period September, 1985 - September, 1986.

another maximum in May or June. Biomass of this rhodophyte ranged from 0.05-0.06 g dry wt/m^2 at Site 2 in October, 1985-January, 1986, then declined to levels <0.01 g dry wt/m^2 by May, 1986; Gracilaria increased again in late June to reach 0.06 g dry wt/m^2 only to decline to <0.01 g dry wt/m^2 in July. In contrast, highest biomass of this alga for the other sites was noted in January, 1986 at Site 1 (0.04 g dry wt/m^2) and Site 3 (0.06 g dry wt/m^2) and at Site 4 in March (0.04 g dry wt/m^2) and early June, 1986 (0.06 g dry wt/m^2).

Agardhiella tenera biomass was the lowest of the major macroalgae taxa noted in the study area (Fig. 7). Two minor peaks were seen, at Site 2 in January (0.02-0.03 g dry wt/m^2) and Site 4 in May-early June (0.01-0.05 g dry wt/m^2). Biomass for this alga was $<<0.01$ g dry wt/m^2 during all other times of the year.

DISCUSSION

The dominant algal taxa identified in the Delaware Inland Bays study in 1985-1986 correspond to the Gracilaria, Agardiella, and Ulva assemblages reported by Orris and Taylor (1973), indicating no major shifts in the dominant algae in the 15 years separating their study from the present. However, in contrast to the 59 macroalgal taxa noted by Orris and Taylor, only 5 taxa were noted in the Inland Bays for the 1985-1986 study period.

Chlorophytes and rhodophytes were most abundant during the late winter and spring (Figs. 4-7), a pattern previously observed in Rehoboth Bay by Orris and Taylor (1973). The overall biomass of algae taken by the trawl samples is relatively low expressed on an areal basis, with values rarely exceeding 1.7 g/m^2. This contrasts with values reported from nutrient-enriched sites in Rhode Island where macroalgal biomass exceeded 80 g/m^2, with approximately half of this biomass consisting of Ulva lactuca (Thorne-Miller et al., 1983). However, the trawl is an extremely inefficient collecting device for macroalgae and there is no doubt that the abundance of algal biomass is underestimated in our samples. Yet the underestimates would have to be on the order of two orders of magnitude to approximate the biomasses reported from the eutrophic Rhode Island waters. Thus, even though drift algae can be abundant in the Inland Bays, data collected in 1985-1986 do not suggest that exceedingly high inorganic nutrient concentrations in the Inland Bays region (see Phytoplankton Section) resulted in elevated macroalgal biomass at the four sampling stations during the period of study.

Highest macroalgal biomass in March and April was coincident with deep secchi disc depths and lowest inorganic phosphorus concentrations at Sites 1-4. Average secchi depth was 1.7 m corresponding to euphotic zone depth of 4.7 m, permitting macroalgae growth over a large portion of the shallow Inland Bays. The deep euphotic zone at this time could be attributed to low concentrations of chlorophyll and total suspended solids in the water column. In March and April, the mean planktonic chlorophyll concentration was 1.80 ug/L for the four sites. Total suspended solids in March and April were also at the lowest levels for the year with an average concentration of 32 mg/L.

The absence of significant macroalgal biomass in the summer and fall could be partially attributed to much shallower secchi depths arising from elevated concentrations of chlorophyll and total suspended solids in the water column. From June-September, mean secchi depth was 0.4 m yielding a euphotic zone depth of 1.2 m for the four sites. Macroalgal growth, therefore, would be limited to very

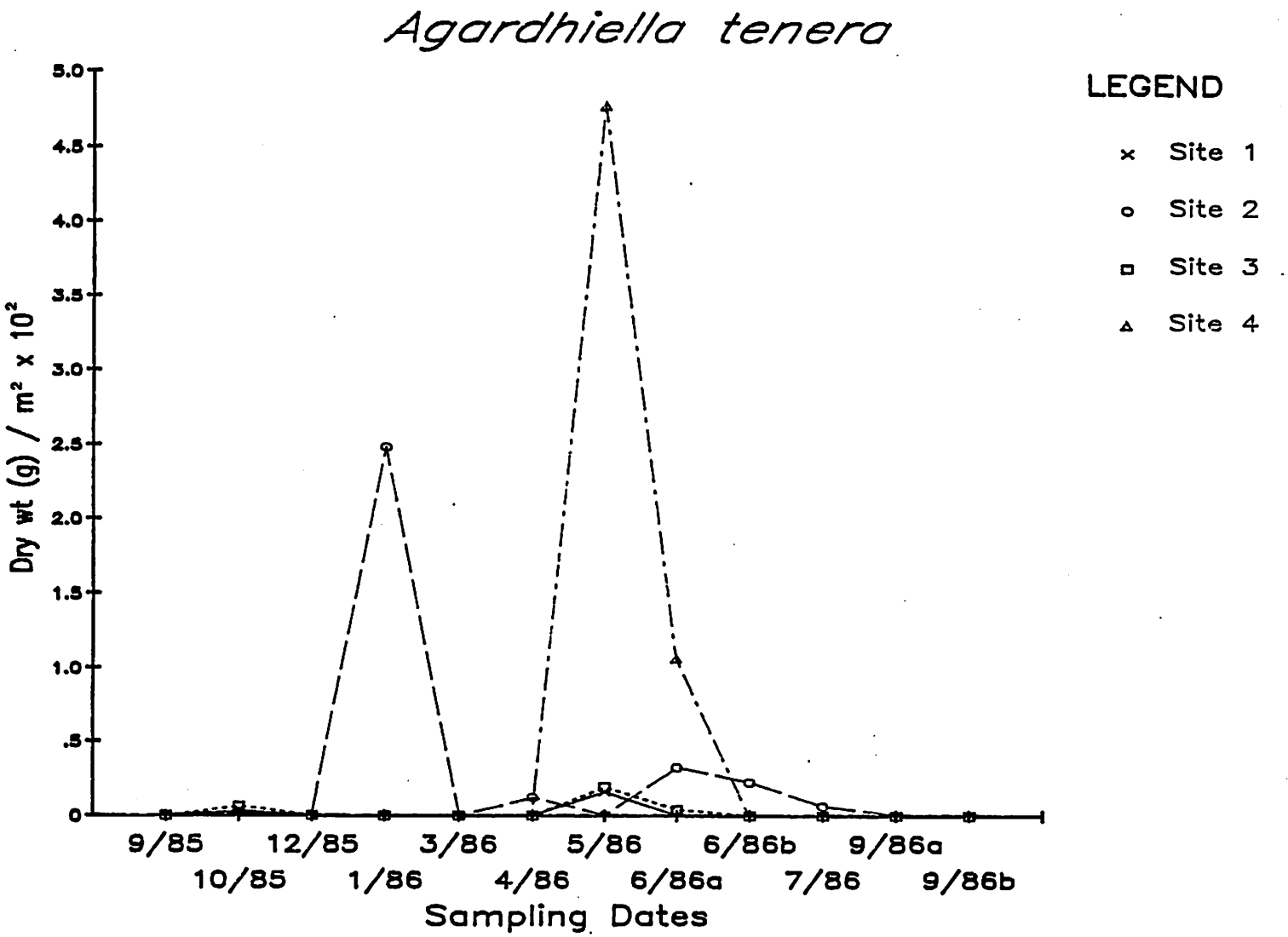

Figure 7. Biomass of Agardhiella tenera (Rhodophyta, g dry wt/m2) in Delaware's Inland Bays for the period September, 1985 - September, 1986.

shallow depths fringing the shores of the Inland Bay region. In addition, the absence of firm substrates in the region could limit attachment and growth of these macroalgae in the Inland Bays.

The coincidence of highest macroalgal biomass and minimal concentrations of planktonic chlorophyll with lowest concentrations of inorganic phosphorus suggest that macroalgae in the system might conceivably be responsible for a large portion of the phosphorus removal at this time of year. Dissolved phosphorus concentrations were 0.07 uM (<0.01 mg/L) at the four sites in March and April with macroalgal biomass at maximum levels of 1.8 g dry wt/m2. However, the overall role of macroalgae in phosphorus utilization in the Inland Bays cannot be assessed from the limited data collected on the distributions of macroalgae in the present study.

The abundance of bryozoans was usually greater than macroalgae at the study sites and is certainly a common inhabitant at the study areas. Whether the abundance has changed over the recent past is uncertain as Orris and Taylor (1973) do not discuss any fauna in their paper.

Although no attempt was made to identify the animals associated with the drift algae collected, our observations indicate that a rich animal community is associated with the algae. This was expected based on observations reported elsewhere (e.g. Hooks et al., 1976; Gore et al., 1981) but the drift algal habitat may have special significance in the Inland Bays because submerged vegetation has been lacking in the Bays over the last 25 years (see SAV Section). Thus, it is likely that the drift algae serve as important nursery habitats for juvenile blue crabs and finfish such as sea bass (Centropristis striabta), summer flounder (Paralichthys dentatus) and tautog (Tautoga onitis) that were observed in the algae. There is less indication from our observations that the bryozoan colonies serve as nursery habitats, although their abundance and arborescent growth form make it possible that they could function in this capacity.

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SUBMERGED AQUATIC VEGETATION IN DELAWARE'S INLAND BAYS

Robert J. Orth and Kenneth A. Moore
Virginia Institute of Marine Science
School of Marine Science
College of William and Mary
Gloucester Point, Virginia 23062

INTRODUCTION

Submerged aquatic vegetation (SAV) is an important living resource in many coastal areas throughout the world. These plant communities have been cited as some of the most biologically important in the world (McRoy and Helfferich, 1977; Stevenson and Confer, 1978; Phillips and McRoy, 1980) for the following reasons:

1. They provide habitat for numerous species of vertebrates and invertebrates that occur in or over the plant canopy, on the blades of vegetation or in the sediment surrounding the vegetation. Densities of animals in vegetated areas can be orders of magnitude greater than in nearby, unvegetated areas. Many of these smaller organisms serve as a source of food for larger invertebrates, fishes or waterfowl.

2. The plants themselves can serve as food for waterfowl.

3. The plants bind sediments and reduce current velocities, thus stabilizing the bottom, and in areas with very dense beds, reduce shoreline erosion.

4. SAV, with their attached micro- and macroalgae, have extremely high rates of primary production that rival many cultivated crops.

5. Most of this primary production is eventually exported from the bed and enters the detrital food pathway, thus serving a biological community far removed from the existing bed.

6. SAV can remove nutrients from the water column, thus reducing ambient levels, and can pump nutrients from the sediment to the leaves, releasing nutrients to the surrounding water, increasing ambient concentrations.

There are numerous species of SAV with a generally higher diversity found in freshwater as compared to marine areas. Worldwide there are only 50-60 species of SAV that tolerate saline conditions (>15 ‰) (den Hartog, 1970). Along the mid-Atlantic coast of the United States, only two species, eelgrass (Zostera marina) and widgeongrass (Ruppia maritima), are dominant in saline areas compared to six species found in the warmer Florida and Gulf of Mexico areas (Zieman, 1982; Thayer et al., 1984). These two species can be found in both mono-specific as well as mixed stands. In the Chesapeake Bay, eelgrass has been found to be dominant generally in water depths of greater than one meter below mean low water (MLW) while widgeongrass has been found dominant in water depths less than 0.25 m below MLW. Both species are found in mixed beds at intermediate depths (Orth et al., 1979).

SAV most commonly occur in the shallowest areas of coastal estuaries, lagoons or bays. Available light penetrating the water column is one important, and usually limiting, factor regulating the depth distribution of any SAV species. In the water column, light is attenuated with depth by adsorption and scattering due to the water itself as well as dissolved and particulate matter in the water. The dissolved and particulate matter are, in turn, influenced by a number of factors such as runoff of silts and clays from the upland, resuspension of bottom sediments by wave action, bioturbation and biodeposition and phytoplankton levels regulated to some degree by nutrient levels and nutrient regeneration rates (Kemp et al., 1983). Light can also be attenuated on the leaves of the plants themselves through the growth of epiphytic plant and animal communities (Sand-Jensen and Borum, 1984) which are regulated, in turn, by the supply of nutrients, as well as the rate at which these attached communities are grazed by larger organisms (Orth and van Montfrans, 1984; van Montfrans et al., 1984). At high densities, epiphytes can also act as a boundary layer limiting the exchange of dissolved gases necessary for photosynthesis (Sand-Jensen, 1977). Thus, depth distribution of some species of SAV in very clear tropical waters or oligotrophic lakes can be 50 meters or more. In normally turbid, estuarine or lagoonal environments, light penetration is substantially reduced and so are the depths to which SAV are found. In the Chesapeake Bay, SAV are not found in water depths greater than two meters below MLW and are most common in water depths of one meter or less below MLW (Orth and Moore, 1981, 1984).

Because SAV grow in shallow water environments, they are very susceptible to disturbances, biological (e.g. uprooting by cownose rays), climatological (e.g. hurricanes), or man-induced, either directly (e.g. damage by boat propellers, dredging or filling) or indirectly (e.g. increased nutrient or sediment inputs from improper sewage treatment facilities or land use practices).

Dramatic, natural shifts in SAV abundance have been characteristic of SAV populations along the east coast. Episodic explosions of water chestnut (Trapa natans), Eurasian watermilfoil (Myriophyllum spicatum) and hydrilla (Hydrilla verticillata) in the Chesapeake Bay have been well documented in the past 80 years (Orth and Moore, 1981, 1983a, 1984). The most documented natural alteration of any species of SAV occurred with the worldwide decline of eelgrass in the early 1930's. Eelgrass populations along its entire range on the east coast of the U. S. from North Carolina to Canada and the west coast of Europe were dramatically altered in the span of several years (Cottam and Munro, 1954; Rasmussen, 1977). Initially, a pathogen, Labyrinthula spp., was suspected as the causal agent. Later, an hypothesis relating climatic changes to this decline became more acceptable. Populations in most areas subsequently returned at various rates of recovery where levels of abundance by the 1950's and 1960's were similar to populations present prior to the decline. Some areas along the east coast never recovered, however, including many of the bays behind the barrier islands along the Delmarva peninsula (Cottam and Munro, 1954; Orth and Moore, 1984).

Associated with the large decline of eelgrass in the 1930's were major changes in the animal communities that were closely tied to the presence of this vegetation (Stauffer, 1937; Rasmussen, 1977). For example, scallop and waterfowl populations, which are heavily dependent upon eelgrass as a settling substrate or for food, respectively, were markedly reduced (Orth, 1978; Perry et al., 1981).

Eutrophication or increased nutrient enrichment of coastal waters has been often cited as a primary factor responsible for the declining populations of seagrasses as well as freshwater submerged vascular plants in Europe, Asia, North America and Australia (den Hartog and Polderman, 1975; Peres and Picard, 1975; Kemp et al., 1983; Orth and Moore, 1983a; Cambridge and McComb, 1984; Lewis et al., 1985). Increased water column nutrients result in the rapid growth of two very distinct groups of smaller plants, phytoplankton and epiphytes, that can both shade or foul the seagrass leaf surface (Bulthius and Woelkerling, 1983; Borum, 1985; Twilley et al., 1985). However, the negative effects attributed to either phytoplankton or epiphytes may be highly variable. Much of the published literature to date indicates that epiphytes stimulated by increased nutrients either from a point or non-point source, rather than phytoplankton, are, in many marine areas, a major factor in the decline of submerged macrophytes (Phillips et al., 1978).

Decline of seagrasses can be rapid, occurring in one to two years, or may take many years. Where declines have been shown to take many years, losses of seagrasses first occurred in the deeper sections of the bed. This would be expected since light reaching the plant surface under optimal conditions decreases with increased depth of the bed. The deeper, outer limits of seagrass beds are, in most cases, light limited and any reduction in light caused by sediment, phytoplankton or epiphytes would affect those plants already light-limited. Orth et al. (1979) showed that declines of the seagrass Zostera marina in one section of the Chesapeake Bay first occurred in the deeper, offshore sections of the bed during a ten year time span. Sand-Jensen and Borum (1984) found the depth limitation of Lobelia dortmanna, a fresh water SAV species, to be 1.0 m, but without epiphyte attenuation, the daily light compensation depth in the spring was 3.5 m. They suggested that epiphyte attenuation is important in the seasonal growth and depth penetration of macrophytes. Not only does this phenomena occur with seagrasses, but Kautsky et al. (1986) showed that the macroalga Fucus vesiculosus changed its depth distribution in the Baltic Sea over a period of 40 years in response to increased eutrophication. The lower limit of growth decreased from 11.5 m to 8.5 m while the zone of maximum development decreased from 5-6 m to 3-4 m during this time period.

Although much emphasis has been placed on the declines of submerged aquatic vegetation because of eutrophication, two studies document the return of vegetation following improvements in water quality. These two studies have particular relevance in that they indicate that submerged vegetation can rapidly recover in some situations when water quality improved. Nienhuis and De Bree (1977) and Nienhuis (1983) followed the distribution patterns of Zostera marina in the Grevelingen estuary in the Netherlands following the closure of the estuary by a dam. Because tidal circulation was stopped, the estuary became primarily influenced by wind-driven currents and water transparency substantially improved. Suspended sediment fluctuated between 0 and 100 mg/L before closure to 0-30 mg/L after closure. Transparency of the water measured by secchi readings changed from 1-2 m before closure to 4 m after closure. Nitrogen concentrations decreased dramatically after the closure while phosphorus increased mainly due to the mobilization from the sediments. After closure, the intertidal populations of Zostera marina extended to 5 m below the surfacel; the lower limit was 7.5 m.

The second example is from the Potomac River, Maryland. Prior to 1981, there were no recorded populations of SAV in the tidal freshwater portion of the river since the 1920's. In 1982 and subsequent years, substantial populations of vegetation have been found in this section in increasing abundance each year (Orth

et al., 1985, 1986). The cause for the increase may be related to nutrient changes in this part of the river. There has been a dramatic decrease in phosphorus loading from the Blue Plains sewage treatment plant (the largest treatment plant in this region, handling all the raw sewage from the metropolitan Washington, D. C. area) since the late 1970's. In 1983, Blue Plains began nitrification, changing the predominant nitrogen species in the river from ammonia to nitrate. At the same time, Blue Plains reduced the suspended solids output from the plant from 4.2-9.8 mg/L in 1982 to 1.0-1.3 mg/L in 1983. Secchi depths in the upper tidal river were significantly higher in 1983 (approx. 86 cm) than in the 1978-1981 period (approx. 52 cm). Plant populations continue to increase and reached even higher levels of abundance in 1985 (Orth et al., 1986).

In addition to nutrients, light penetration can also be affected by suspended sediment. Sediment sources can be direct, from dredge or fill operations, or indirect, from improper land use practices. Both sources increase water column turbidity which has a similar affect on seagrass productivity as nutrients described above. Control of the direct sources may be less difficult than indirect sources. The latter may require long term, expensive land use management practices which, in some cases, may necessitate legal regulation of land based activities and firm enforcement of existing sediment and erosion control laws.

PRESENT AND HISTORICAL DISTRIBUTION OF SAV IN REHOBOTH BAY, INDIAN RIVER BAY AND INDIAN RIVER

SAV distribution can be determined by ground or aerial surveys. In aerial photography, SAV may show up as distinct, dark areas adjacent to land or shallow, lighter toned, unvegetated areas. This allows SAV to be photographed and mapped, resulting in a quantitative delineation of their distribution in a given area. Aerial photographs require ground truth information because submerged features such as macroalgal stands or rocks exhibit similar signatures as SAV. Aerial photography of SAV beds has distinct limitations and, if flown at inappropriate times of the day or season, can result in an underestimate of abundance. Guidelines for acquiring accurate imagery of SAV should incorporate conditions for sun angle, tidal height, cloud cover, wind, time of day and season (usually coinciding with periods of maximum SAV standing crop). Under the appropriate conditions, aerial photography, in conjunction with some level of ground information, can be a very effective mechanism for assessing distribution of SAV in most areas (Orth and Moore, 1983b).

SAV presence or absence in the Indian River, Indian River Bay and Rehoboth Bay (as well as Little Assawoman Bay) was initially determined on July 13, 1985, by field checking numerous shallow water sites that potentially could have supported SAV. This survey resulted in no rooted SAV being found. A few plants, widgeongrass, were found floating in Little Assawoman Bay but these may have resulted from irregularly flooded ponds where widgeongrass commonly occurs. Because of these findings, it was concluded that an aerial photographic mission was not necessary. A second intensive survey was conducted on August 7, 1986, at sites visited in 1985, as well as several additional areas, especially around Indian River Inlet, where anecdotal information and historical photography indicated that SAV formerly had occurred. As in 1985, no SAV was found at any sites in Rehoboth Bay, Indian River and Indian River Bay. A small but dense bed of widgeongrass was found growing in a small, non-tidal pond on what appeared to be a dredge spoil island on the

western shore of Rehoboth Bay. The results of these two recent surveys indicate that SAV is not present in the Rehoboth Bay and Indian River systems today.

Although SAV reports both in the literature and from local residents suggest SAV may have previously occurred, none of these reports indicated precise distributional limits. Historical photography is one technique for examining more precisely the past limits of SAV at any specific location. However, limitations occur in the actual use of these photographs for two reasons:

1. Most aerial photography was obtained in flights undertaken for a different purpose and flights were not subject to guidelines necessary for accurate delineation of SAV beds, e.g. mid-day sun glint on the water obscures SAV, seasons when SAV standing crop are very low (early spring or late fall) or on clear, but windy days where the wind stirs the bottom creating very turbid water conditions obscuring SAV from the air.

2. There is usually no ground truth information associated with the photography to confirm whether many of the dark images were actually SAV. Delineation of permanent SAV beds compared with seasonally, and usually spatially, variable macroalgal beds, sometimes can best be determined through annual, aerial photographic surveys conducted around the same time each year, under similar environmental conditions with accurate ground truth surveys.

Given the above limitation, although an area may have adequate and regular aerial coverage, much of it may be unusable. However, careful inspection and use of only appropriate photographs for SAV mapping can provide documentation on historical changes in SAV distribution. Indeed, historical photography provided detailed data on changes in SAV populations in the Chesapeake Bay (Orth et al., 1979; Orth and Moore, 1981, 1983a, 1984).

References to SAV presence, specifically in Rehoboth Bay, Indian River and Indian River Bay, in the early 1900's were not found. One publication indicated the abundance of eelgrass in Isle of Wight and Assawoman Bays in the 1920's (Cottam, 1935), two bays just south of Delaware's Inland Bays, both being very similar in depth and morphology. Cottam and Munro (1954) reported no known stands of eelgrass in Delaware in the 1950's especially in the Indian River where it had formerly occurred. These references indicate that eelgrass was probably very abundant throughout Indian River, Indian River Bay and Rehoboth Bay in the 1920's. Anecdotal information from old-time residents indicated that dense beds of vegetation were indeed present in these bays in the 1920's.

SAV in the Delaware Inland Bays subsequently declined in the 1930's (specifically in 1931 and 1932). This decline was related to the major eelgrass decline that occurred along the east coast at this time (see above). Whether any eelgrass remained immediately after this period cannot be determined from currently available information but it is likely that small, remnant beds may have remained in some areas and were overlooked in subsequent surveys. Photography available of this area in 1937 (taken by the U.S. Department of Agriculture) revealed no apparent SAV beds although very small patches (<2 m) sometimes are not readily seen in these photographs. Similar photography taken during 1937-1938 of the Chesapeake Bay did show SAV throughout the lower bay area in different densities, indicating that some eelgrass survived the 1930's decline. Photography available from 1942 (Defense Intelligence Agency) revealed what appeared to be SAV near

the Indian River Inlet. Ground truth data are not available for this period. However, the photography taken in July and August, 1954, revealed distinct areas at the Inlet (Figs. 1 and 2). These were most probably eelgrass, or eelgrass and widgeongrass, and corroborate comments by a local resident of the abundance of eelgrass in this exact area in the 1950's. This information contradicts Cottam and Munro's report (1954) of no eelgrass in Indian River.

Attempts were apparently made to transplant eelgrass into the Indian River area (Cottam and Munro, 1954) but there are no data as to the location and date of the plantings, where plants came from, how they were planted and their eventual success or failure. It is possible that some of the eelgrass planted may have survived and grew into larger areas evidenced on the photographs. It is also possible that the eelgrass present here in the 1950's was the result of growth of small beds that survived the 1930's decline.

Aerial photographs available for 1960 showed no apparent SAV in these areas. Subsequent photography in the 1970's and 1980's revealed the continued absence of any SAV. Some of the photography from the 1970's and 1980's revealed dark patches along some of the shoreline in Indian River Bay and Rehoboth Bay. These are areas that did not show evidence of SAV in the 1954 photography so it is more probable that they are large stands of macroalgae. Their high density images are quite different compared to the mottled images many SAV beds exhibit on aerial photographs. Consultation with Dr. V. Klemas of the University of Delaware's Center for Remote Sensing, and one who has also reviewed aerial photographs from the 1960's and 1970's, indicates that the dark images present on the photographs probably reflect the presence of macroalgae rather than seagrass.

The changes observed in the photography from the 1950's to 1960's parallel the anecdotal information from one long time local resident who now owns and operates Murray's Bait and Tackle shop on White Creek. A personal interview with him in August, 1986, provided an enlightening insight into the changes that occurred in the SAV population but also with the associated animal community, particularly the blue crab. He recalls eelgrass being very abundant in the 1950's in areas observed in the 1954 photography. He recalled a large storm in 1960 after which much of the eelgrass was lost (possibly being covered by sand).

The most vivid comments from the local resident pertained to the crabbing he did around the SAV beds. He distinctly remembered catching a bushel of hard crabs in a few hours and many soft crabs. When the SAV was lost (and continuing through today), crab catches were never as high (when he gets out). These observations tend to confirm much of the on-going research on blue crabs in Chesapeake Bay eelgrass beds, indicating the importance of eelgrass to juvenile and soft shell crabs.

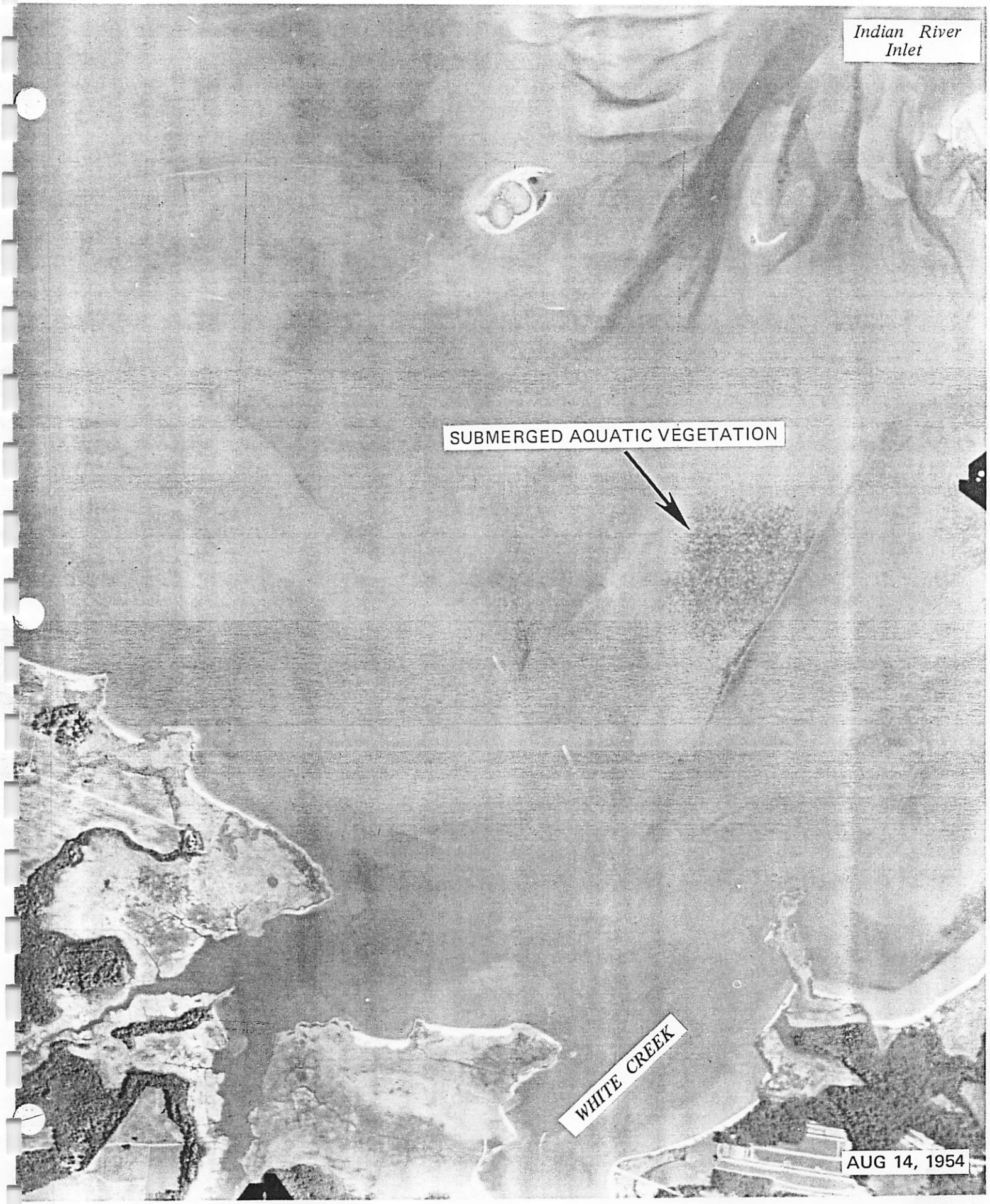
Additional anecdotal information for SAV presence comes from a University of Delaware geology professor (Dr. John Kraft) who conducted class field trips in the Delaware Inland Bays beginning in the late 1960's. His recollections are of abundant SAV growth in the eastern and southeastern portions of the bays, the areas closest to the inlet where water quality would be more optimal for SAV growth.

In summary, SAV beds were probably quite common throughout Indian River, Indian River Bay and Rehoboth Bay prior to the early 1930's. Much of the vegetation was lost during the pandemic eelgrass demise of 1931-1933. Some recovery occurred in the next 20 years. SAV was abundant in some sections by the

Figure 1. Aerial photograph taken on July 20, 1954, showing stands of aquatic vegetation along the western shore of Indian River Bay between Indian River Inlet and Pasture Point.


SUBMERGED AQUATIC VEGETATION
Pasture Point
Beach Cove
JULY 20, 1954

Figure 2. Aerial photograph taken on August 14, 1954, showing a large patch of submerged aquatic vegetation just south of the Indian River Inlet in Indian River Bay. This is the same large patch seen in the photograph taken on July 20 in Figure 1.


Indian River Inlet
SUBMERGED AQUATIC VEGETATION
WHITE CREEK
AUG 14, 1954

mid- to late 1950's and 1960's. Most, if not all SAV, was lost in the 1960's and completely gone by the early 1970's. No eelgrass or any other SAV species has been observed in the Delaware Inland Bay area in the last 15-20 years.

ENVIRONMENTAL FACTORS CONTROLLING GROWTH OF SAV: A COMPARISON OF DELAWARE'S INLAND BAYS AND CHESAPEAKE BAY

Evidence presented in the previous section indicated the presence of SAV in the 1950's, likely from recovery from the pandemic decline of the 1930's, or from the transplanting efforts of Cottam and Munro (1954). These populations declined from 1960-1970 and have never recovered. The question arises as to whether the present lack of vegetation is currently due to unsuitable environmental conditions.

Current data suggests that light and temperature are the primary determinants of SAV growth in the lower Chesapeake Bay (Wetzel and Penhale, 1983) and it is likely that these two factors may also limit SAV growth in the Delaware region, provided sites meet the appropriate limits of salinity, depths, sediment type, wave energies, etc. Temperature acts as a physiological control on enzymatically regulated processes, like photosynthesis and respiration, and, as such, regulates the geographic distribution of a species. Eelgrass, for example, reaches the southern limit of its range in North Carolina and is stressed by the high summertime water temperatures (>25°C) common in the mid-Atlantic region (den Hartog, 1970). Submarine irradiance is a primary determinant of the photosynthetic rate at levels below light saturation (Dennison, 1987).

The Virginia Institute of Marine Science (VIMS) has been involved in SAV research in the Chesapeake Bay since 1978. This program evolved because of the large scale, unprecedented, baywide decline of all species of SAV (Orth and Moore, 1981, 1983a, 1984). In recognition of the magnitude of this decline and its importance to the bay ecosystem, a baywide effort to study SAV biology and ecology was initiated (EPA, 1982).

A major, ongoing program for the last three years at VIMS has been comparing water quality parameters in the York River estuary at sites that currently support SAV and never experienced a major decline in the 1970's, to sites that formerly, but no longer, support vegetation. We have chosen this system as a model for comparison with Delaware's Inland Bays. We believed this would provide a "model" for determining whether levels of various parameters important for SAV (principally eelgrass) growth and survival in the Delaware system are within the range of values presently found for SAV beds in the York River.

Three sites located along an upstream gradient in the York River estuary in Virginia (Fig. 3) have been chosen for comparison with four sites monitored in the Delaware Inland Bays program (Fig. 4) for the period from September,1985 to September,1986. Sampling was undertaken approximately biweekly in the York River and monthly in the Delaware Inland Bays. Parameters compared were analysed using similar analytical techniques. In the York River, the first station, Guinea Marsh, is located at the mouth of the river in an area where SAV beds consisting of eelgrass and widgeongrass have been abundant and relatively stable over the past 50 years. The second site, Gloucester Point, is located approximately 15 km upriver from Guinea Marsh in an area that marks the current upriver limits of existing vegetation. Transplanting of eelgrass at this site, as part of a major SAV revegetation program funded by the Commonwealth and being conducted in

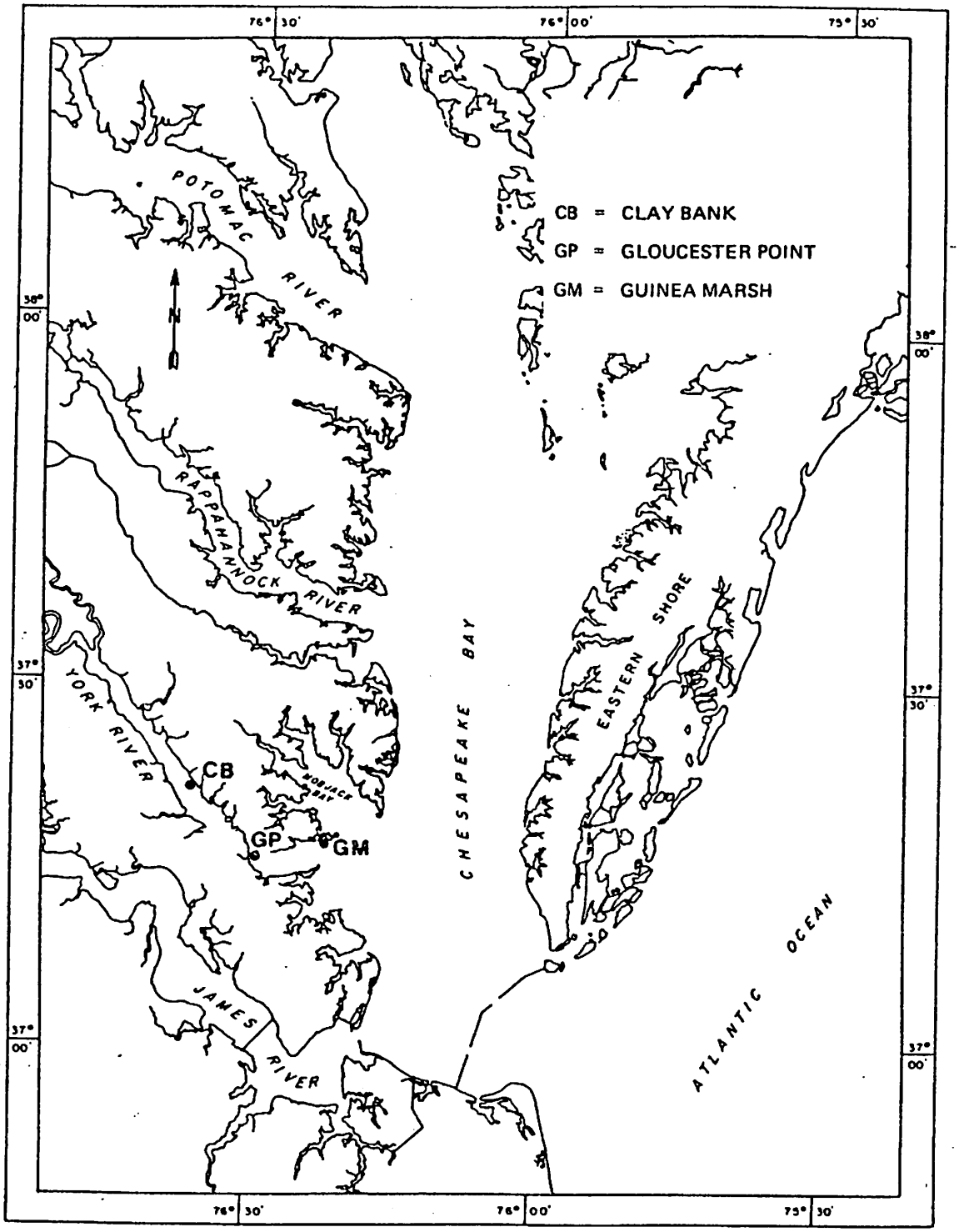


Figure 3. Map of the York River, Virginia, showing the Guinea Marsh, Gloucester Point and Clay Bank locations where environmental data were taken to compare with the Indian River stations. Eelgrass transplanting has been conducted at the Gloucester Point and Clay Bank stations.

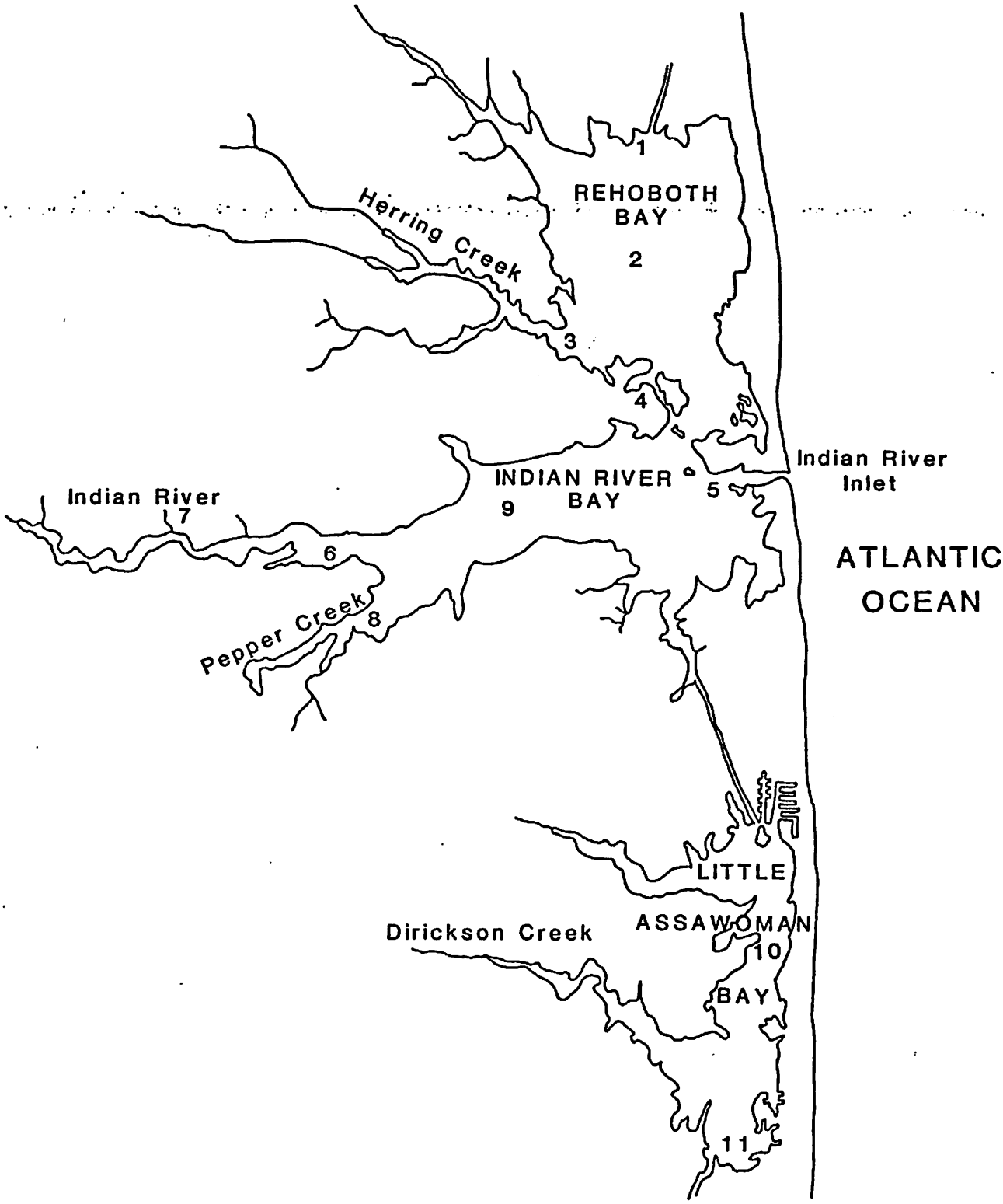


Figure 4. Map of the Indian River and Indian River Bay showing station locations that were used to compare environmental data with the York River stations.

concert with the VIMS environmental monitoring program (Orth and Moore, unpublished data), has been very successful. Both transplanted material and naturally recruited material are surviving and growing very well at this site. The third site, Clay Bank, is located approximately 15 km upriver from Gloucester Point (Fig. 3) in an unvegetated shoal area that formerly (prior to 1973) marked the upstream limits of eelgrass-dominated beds. Transplanting of eelgrass at this site since 1982 has never been successful over a full year. Vegetation planted in the fall does well until late spring but has never survived through the summer. In the Delaware Inland Bays region, water quality parameters in the Rehoboth Bay region were consistent with values obtained along the Indian River and the absence of any historical evidence for SAV in the Rehoboth region permitted us to focus on the Indian River system. Data, as seasonal means, for both the York and the Indian River systems were graphically compared with "Winter" representing December to February, "Spring"-March to May, "Summer"-June to August and "Fall"-September to November.

Comparison of temperature (Fig. 5A and B) and salinity (Fig. 6A and B) illustrate basic similarities in the physical environments of both systems. Thus, there is no reason to conclude that the Indian River system is beyond the salinity or temperature tolerances of eelgrass or widgeongrass. In fact, during this study period for all but the most upstream station, salinities were generally higher at the Indian River stations, a factor that generally favors these marine tolerant species.

Dissolved nutrients do reflect some marked differences in the systems. Dissolved phosphate in the York River (Fig. 7A) demonstrated increasing concentrations upriver during all seasons with mean values in the range of 0.4 to 1.4 ug-at/L (0.01-0.04 mg/L) while the Indian River data (Fig. 7B) displayed varied trends with a distinct spring minimum and an overall range of approximately 0.1 to 1.0 ug-at/L (<0.01-0.03 mg/L). Differences in nitrogen are quite large, however, with levels in the York River (Fig. 8A) being low in comparison to the Indian River stations (Fig. 8B). Only the inlet and lower Indian River Bay stations have inorganic nitrogen ($NH_4 + NO_3 + NO_2$) values comparable to the York River study area. The most upstream Indian River station is very heavily enriched, with over 10 times the ambient levels found in the York River during the winter, spring and summer periods.

Levels of total chlorophyll in the water column demonstrated marked differences between the York and Indian River systems. Mean seasonal levels in the York River (Fig. 9A) are quite low, with levels generally below 10 ug/L, by comparison to the Indian River system (Fig. 9b). Extensive blooms are evident in the Indian River with highest levels observed during the summer. Generally, levels increase with distance upstream and it is only in the immediate vicinity of the Indian River inlet that levels approach those observed in the York River.

Total suspended sediments also demonstrate wide differences between the two systems. In the York River (Fig. 10A), concentrations of suspended matter increase with distance upstream, with highest levels averaging below 20 mg/L. Data from the Indian River system (Fig. 10B) document exceptionally high levels of suspended matter in the water throughout much of the year, with maximum concentrations greater than 130 mg/L. Some of this is due to the high phytoplankton levels, particularly during the summer, while the remainder is likely due to sediments entering from upland drainage as well as the resuspension of bottom sediments already in the system.

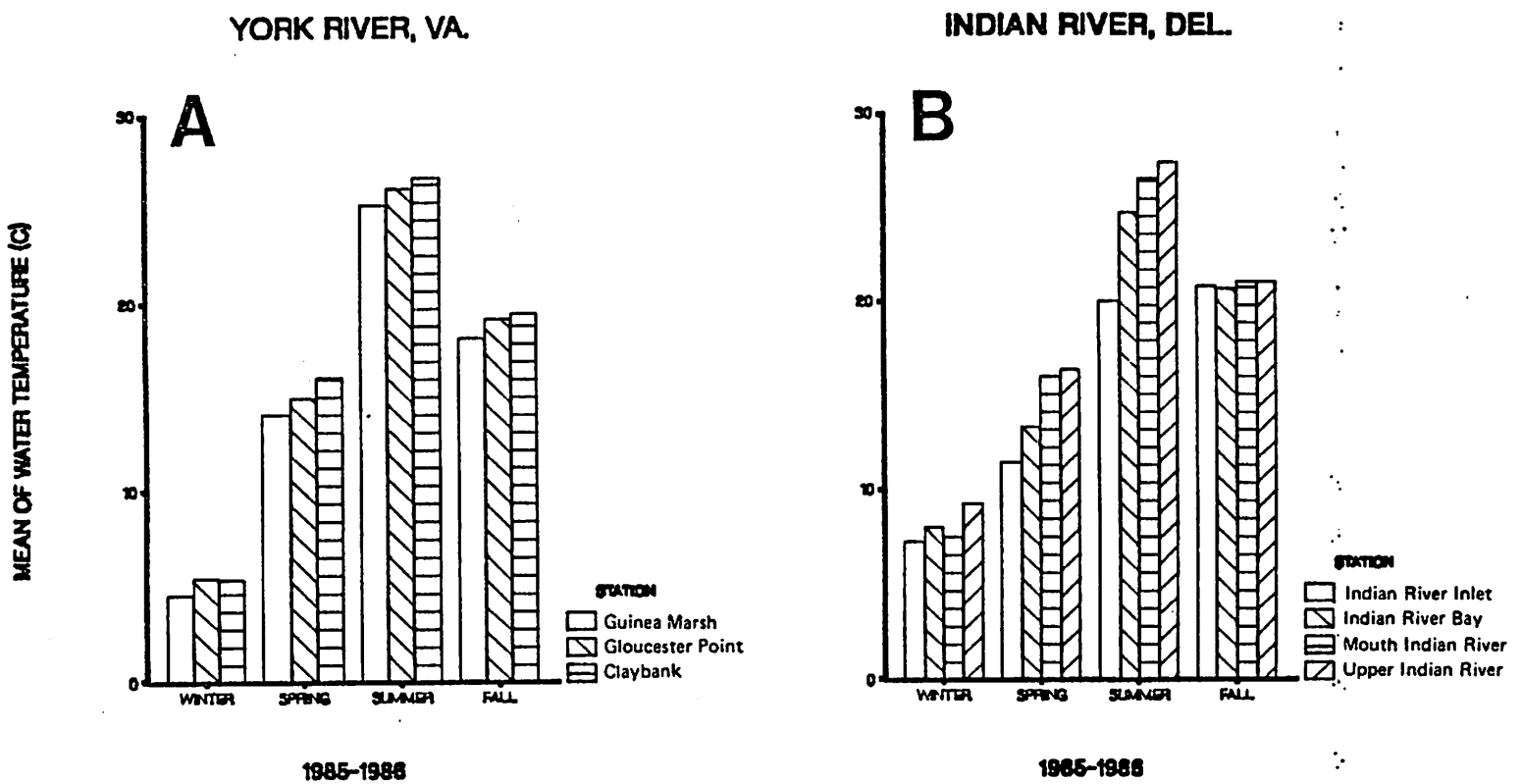


Figure 5. Seasonal means of temperature for stations in (A) York River, Virginia,and (B) Indian River, Delaware.

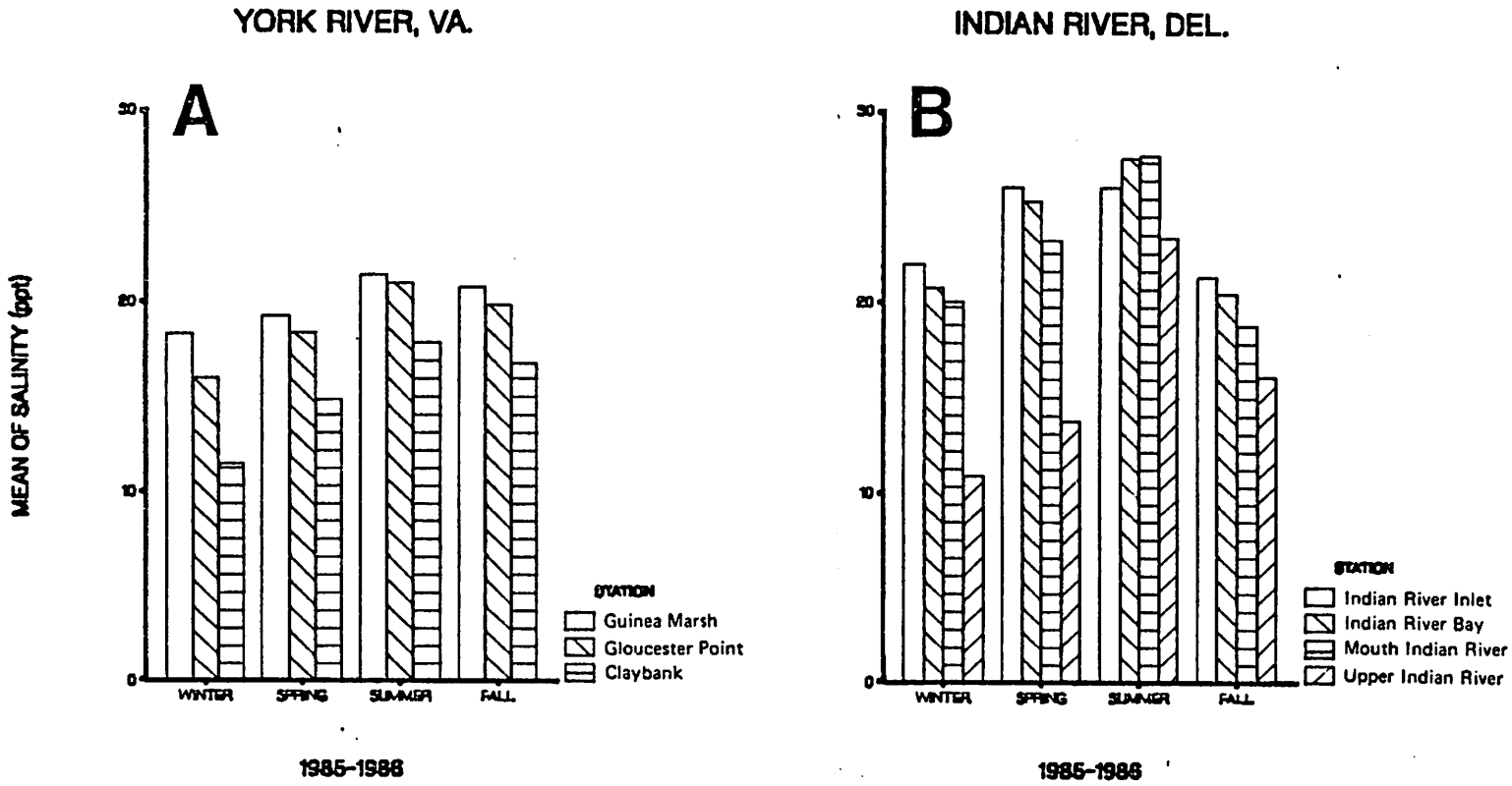


Figure 6. Seasonal means of salinity for stations in (A) York River, Virginia and (B) Indian River, Delaware.

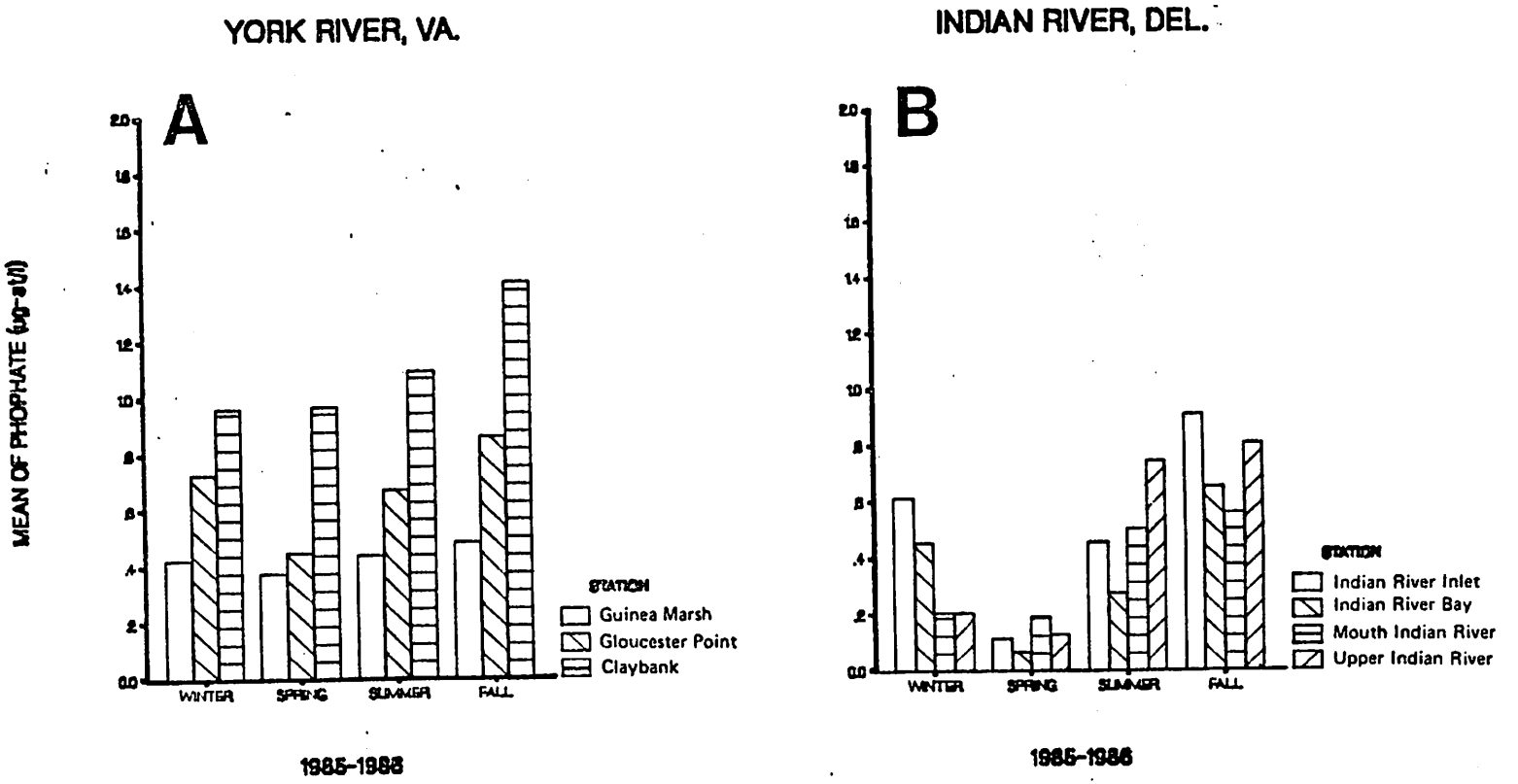


Figure 7. Seasonal means of dissolved inorganic phosphate for stations in (A) York River, Virginia and (B) Indian River, Delaware.

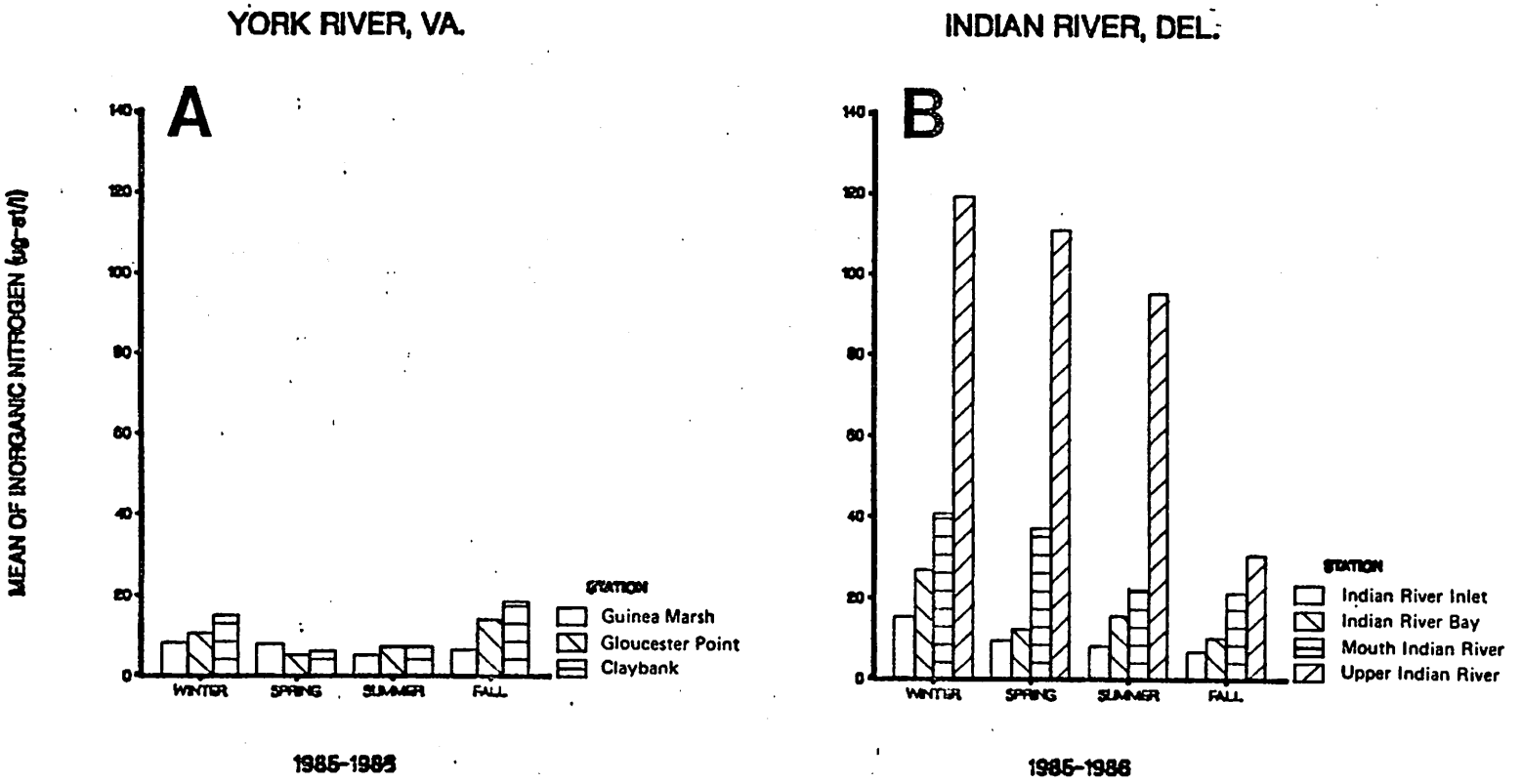


Figure 8. Seasonal means of dissolved inorganic nitrogen for stations in (A) York River, Virginia and (B) Indian River, Delaware.

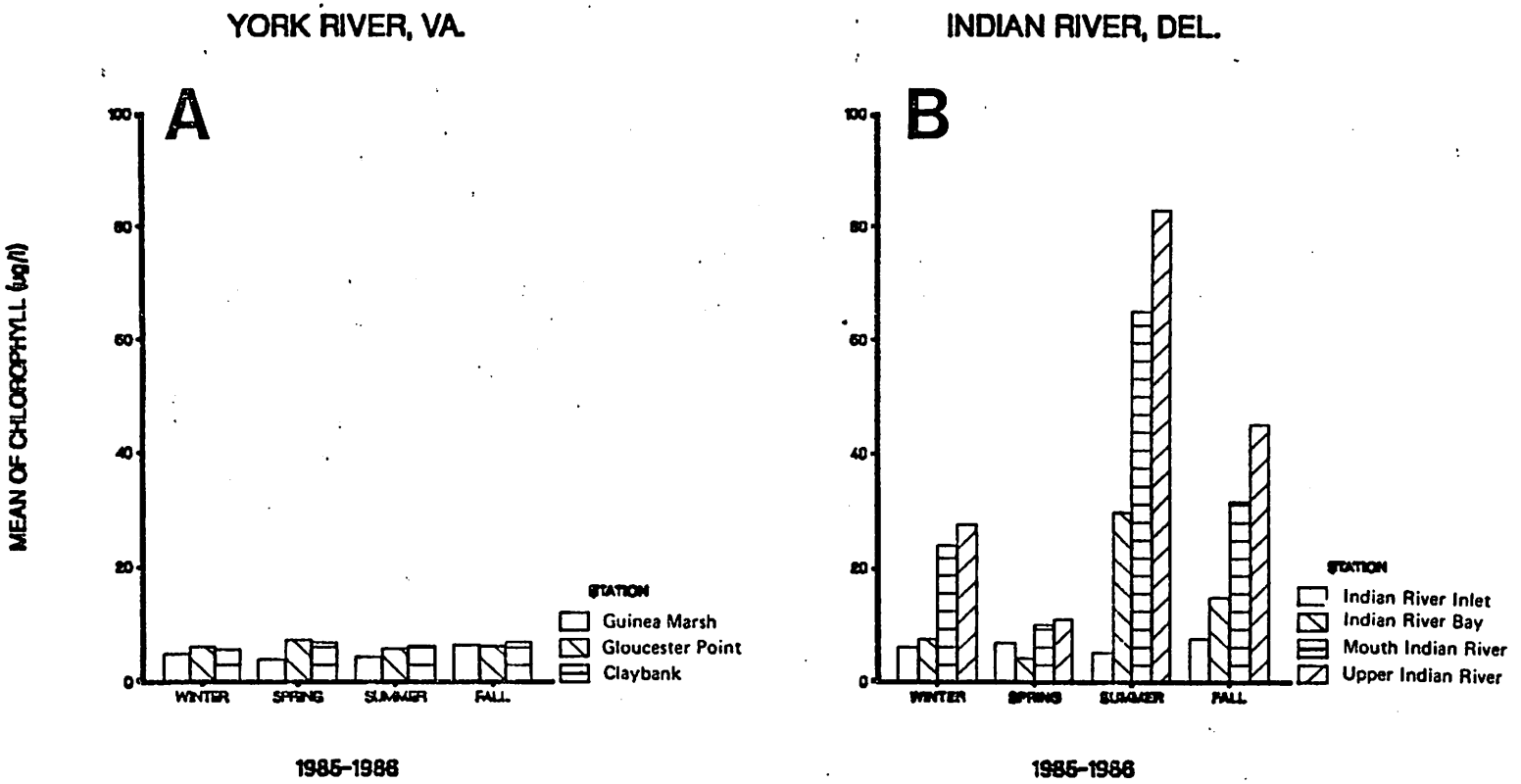


Figure 9. Seasonal means of chlorophyll for stations in (A) York River, Virginia and (B) Indian River, Delaware.

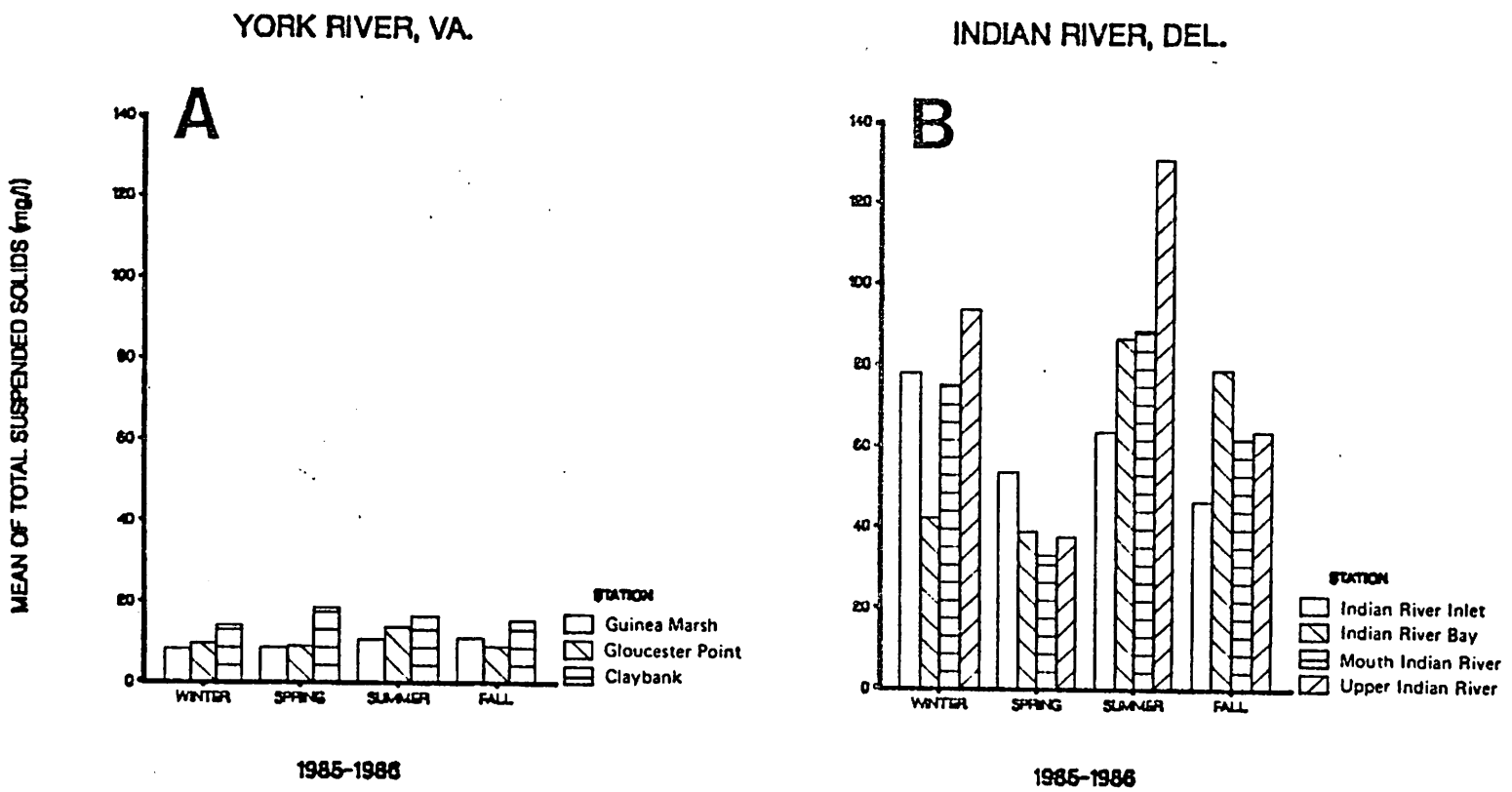


Figure 10. Seasonal means of total suspended solids for stations in (A) York River, Virginia and (B) Indian River, Delaware.

Secchi disk readings obtained during the Delaware Bays study were converted to attenuation coefficient (k) (Idso and Gilbert, 1974) for comparison with the York River data that were obtained by use of an underwater quantum sensor (LICOR 192B, Quantum Sensor). Levels in the York River demonstrated increasing attenuation (decreasing light) with distance upriver during all seasons (Fig. 11A). Highest levels were found at the Clay Bank site in the spring. This is the period of maximum runoff which brings in significant quantities of silts and clays. In the Indian River system (Fig. 11B), the only station which approximated the York River for water clarity was the station located in the inlet. While light attenuation was observed to be low at most stations during the winter, attenuation at all but the inlet station were exceptionally high during the summer and fall.

WATER QUALITY IMPLICATIONS ON POTENTIAL SAV POPULATIONS IN THE INLAND BAYS

Levels of certain water quality parameters in the inland bays, e.g. dissolved nitrogen, chlorophyll, light attenuation, total suspended solids, were much higher than the levels measured in eelgrass beds in the York River. More significantly, levels at all sites in the Indian River and Indian River Bay, except the inlet area, were greater than those recorded at the Clay Bank site in the York River. Clay Bank was the most upriver limit of eelgrass growth prior to the recent major decline documented in the 1970's and transplant experiments have determined that the area is currently unsuitable for eelgrass survival. It is also the site along the gradient of York River stations where levels of nutrients are highest and available light the lowest. Thus, we hypothesize that water quality in this area is poorer than that necessary to support eelgrass growth in the region. Model studies (Wetzel and Neckles, 1986) support this hypothesis. Therefore, considering the water quality observed in the inland bays, it is likely that, in most areas, conditions are limiting for SAV growth. Research to define the precise levels of water quality necessary for eelgrass growth is on-going in Virginia. However, exact limits remain to be determined.

In the York River, eelgrass no longer grows naturally or survives if transplanted in areas such as the Clay Bank site if the attenuation coefficient, or k, is 2.00 or greater. At this level, less than 5% of the incident solar irradiance reaches the bottom in water where the mean depth is 1.5 m. For much of the day, therefore, plants at such a depth would be at or below their compensation depth. This does not include any additional attenuation of light due to epiphytic growth. In the Indian River system, only the inlet stations have k values less than 2.0. In the summer and fall, k values in most area are approximately 4.0, a level at which only 0.2% of incident light would reach the bottom. The attenuation is due to the high levels of total suspended matter in the water column throughout much of the year. This suspended matter includes phytoplankton, inorganic and organic particles. Not only can such high levels have devastating effect on submerged vegetation by attenuating light through the water column but this material can settle and bind to the epiphytes on the leaves, compounding the fouling effects.

The high levels of nutrients, in particular nitrogen, found in the Indian River could pose additional problems for SAV, notably increased epiphyte growth. Twilley et al. (1985) examined plant responses to three levels of nutrient enrichment in experimental ponds in the Chesapeake Bay. They found that biomass of submerged macrophytes decreased significantly under high and medium treatments, compared

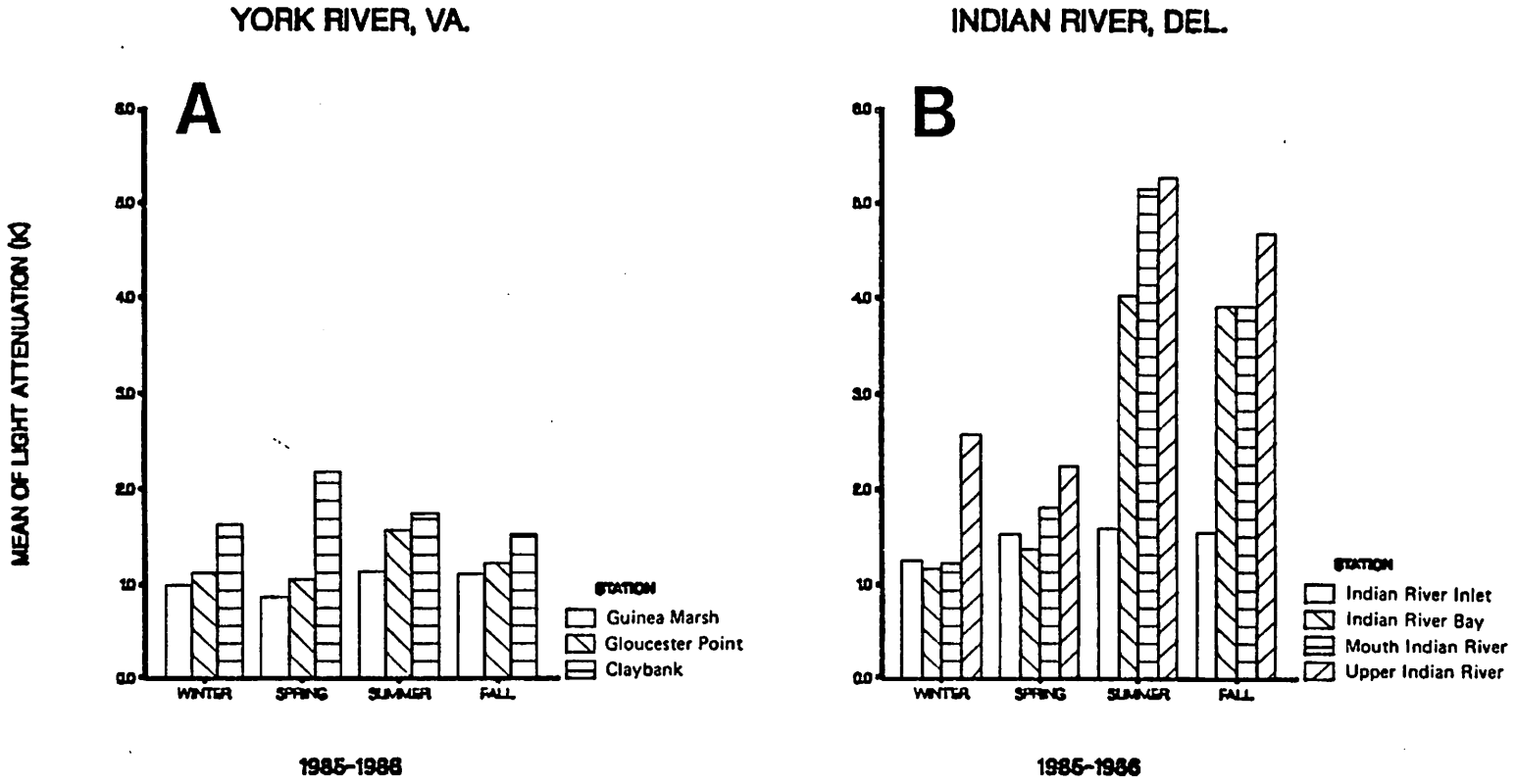


Figure 11. Seasonal means of light attenuation (k) for stations in (A) York River, Virginia and (B) Indian River, Delaware.

to control and low treatments. All fertilized treatments (high, medium and low) had elevated levels of epiphytic material compared to controls, whereas phytoplankton had elevated levels only under the most extreme nutrient addition. Bulthuis and Woelkerling (1983) also found highest rates of biomass accumulation of epiphytes on an Australian seagrass, Heterozostera tasmanica, where nutrient concentrations were highest. They found that growth of epiphyte biomass could occur rapidly enough to shade H. tasmanica leaves and significantly reduce the time (to less than one half of the leaf life span) in which positive net photosynthesis of the leaf blade is possible.

The high levels of suspended chlorophyll, turbidity and dissolved nutrients observed in Delaware's Inland Bays, compared to levels recorded in vegetated areas in the York River, suggest that it is unlikely that SAV species tolerant to the levels of salinity and temperature found here (principally eelgrass and widgeongrass) would be able to survive in the bay system. The only potentially suitable area would be in the immediate vicinity of the inlet where marine influence is greatest.

Transplanting of eelgrass along the east coast has proven successful in North Carolina, Virginia and New York. Presently, Virginia is using transplants as a tool to understand those factors controlling the growth of eelgrass as well as attempting to revegetate denuded areas (Orth and Moore, unpublished data). The mechanics of transplanting have been well established (season for transplanting and planting methods) for the Chesapeake Bay area and should be applicable to the Delaware system. In general, planting is most successful when conducted in the fall months (September to early November) and when bundles of sediment-free shoots are planted in the sediment with a slow release fertilizer. Any proposal to initiate a transplant project should consider the site and depth of water at the site. Criteria should, at a minimum, include the fact that SAV must have previously grown at the site. Any plantings should be frequently monitored as should environmental parameters in the water column. Transplanting in conjunction with a detailed monitoring program at the site could identify factors that would affect the growth of the plants. This could provide managers with needed information as to the important parameters necessary to improve water quality so that SAV populations could recover.

We recommend that Delaware initiate a small scale eelgrass transplant project to determine if the Delaware Inland Bay system can support eelgrass. This project should be conducted as close to the Inlet as possible where eelgrass used to grow and where present environmental conditions, except for possibly suspended solids, appear most suitable, based on a comparison with our data from the Chesapeake Bay. Plantings should occur in the fall (September being optimum) using whole plants obtained from the Chincoteague Bay area. Eelgrass is currently thriving in Chincoteague Bay, principally in areas along the east side behind Assateague Island (Orth et al., 1987). Plants should be fertilized with a small amount of slow-release fertilizer (Osmocate) placed in the sediment adjacent to the roots. Plants should be monitored monthly except for semi-monthly from May to August, the period when we have observed the most rapid changes in Chesapeake Bay transplant efforts. Water quality parameters, especially light intensity, should also be monitored regularly in the area where the plants are located. We expect that results from these efforts should provide data on the potential for SAV growth in the region.

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GLOSSARY

Angiosperm: A flowering plant; vascular plant.

Autotroph: Organisms that can produce their own food from inorganic materials and light, e.g. angiosperms, macroalgae, phytoplankton and submerged aquatic vegetation.

Compensation depth: The depth where photosynthetic production is balanced by cellular respiration.

Cyanobacteria: A procaryotic member of the phytoplankton often forming dense blooms in some eutrophic freshwater systems. This group is also known as the blue-green algae.

Eucaryote (also eukaryote): A cell with membrane-bound intracellular organelles associated with specific metabolic functions. In the Inland Bays text, this term specifically includes all of the following phytoplankton groups: diatoms, dinoflagellates, chlorophytes, microflagellates, cryptophytes, chrysophytes, prasinophytes and euglenophytes. Blue-green algae or cyanobacteria are procaryotes (see below).

Euphotic zone: The lighted portion of the water column generally accepted as the depth to which 1% of light reaching the surface penetrates.

Euryhaline: The ability of an organism to withstand large variations in salinity.

Heterotroph: Organisms that cannot produce their own food and must secure food through the ingestion and assimilation of previously synthesized organic matter.

Halophobic: Taxa that are restricted to waters with little or no salt.

Mesohaline: The part of an estuary with a salinity ranging from 5-18 ‰.

Oligohaline: The part of an estuary with a salinity range from 0.5-5 ‰.

Picoplankton: That group of plankton ranging in size from 0.5-2 um. In the present study, numbers of cells in this size category could be estimated with our light microscope techniques; however, taxonomic resolution was impossible since identification of morphological characteristics within the cells was not possible with a resolution limit of 1 um at 400 fold magnification.

Polyhaline: The part of an estuary with a salinity range of 18 to 30 ‰

Procaryote (also prokaryote): A cell containing no defined intracelluar organelles. This group, in the Inland Bays text, includes only the autotrophic blue-green algae (or cyanobacteria).

uM: Equivalent to 1 ug-at/L or a micromole per liter.

Appendix 1. General physical and chemical characteristics of Delaware's Inland Bays for the period 18 September 1985 through 25 September 1986. All data except chlorophyll a concentrations were obtained by DNREC staff; chlorophyll concentrations were estimated by ANS staff from frozen samples filtered in the field by DNREC staff. ND = not determined; ED = erroneous datum, datum not reported

Column designations are as follows:

STATION	Stations 1-11 in Rehoboth Bay, Indian River and Bay and Little Assawoman Bay
DATE	Sample collection date (month/day/year)
SUR TEMP MID TEMP BOT TEMP	Water temperatures (°C) recorded in surface, middle and bottom depths of each station
SUR SAL MID SAL BOT SAL	Salinities (parts per thousand, ppt) noted for samples obtained from the surface, middle and bottom depths of each station
SUR D.O. BOT D.O.	Concentration of dissolved oxygen (mg/L) in surface and bottom samples collected at each station
SECCHI	Secchi disc depth (m) for each station
TSS	Concentration of total suspended solids (mg/L) recorded at each station
CHL a	Concentration of active chlorophyll a (ug/L) measured for samples collected at each station

STATION	DATE	SUR TEMP (C)	MID TEMP (C)	BOT TEMP (C)	SUR SAL (ppt)	MID SAL (ppt)	BOT SAL (ppt)	SUR D.O. (mg/L)	BOT D.O. (mg/L)	SECCHI (m)	TSS (mg/L)	CHL a (ug/L)
1	09/18/85	20.0	20.0	20.0	14.0	14.0	13.0	ND	ND	ND	56	6.3
1	10/30/85	12.5	ND	12.5	17.0	ND	17.0	8.7	8.9	0.8	40	4.5
1	12/11/85	6.0	6.0	7.0	13.0	14.0	14.0	10.9	11.0	1.8	58	0.4
1	01/22/86	5.0	4.0	4.0	26.0	28.0	28.0	7.9	6.5	1.2	31	8.9
1	03/18/86	10.5	ND	10.0	27.0	ND	28.0	9.8	10.2	>1.7	27	1.6
1	04/02/86	15.0	ND	15.0	12.0	ND	12.0	5.8	9.9	2.1	31	1.0
1	05/13/86	15.0	15.0	15.0	25.0	25.0	25.0	8.2	8.0	1.0	55	3.0
1	06/12/86	26.0	26.0	26.0	30.0	30.0	30.0	4.0	5.5	0.5	88	18.6
1	06/26/86	22.0	22.0	23.0	29.5	29.0	28.5	8.0	7.0	0.5	61	28.5
1	07/22/86	25.0	25.0	25.0	24.0	24.0	24.0	7.8	5.2	0.6	149	23.0
1	09/10/86	22.0	22.0	22.0	ED	ED	ED	7.2	7.0	0.3	67	8.3
1	09/25/86	22.0	22.0	22.0	25.0	ND	24.0	6.5	4.1	0.4	51	27.4
2	09/18/85	20.0	20.0	20.0	13.5	13.5	13.5	8.1	8.0	ND	80	1.0
2	10/30/85	14.0	14.0	14.5	19.0	19.0	19.5	8.0	7.9	1.8	33	1.3
2	12/11/85	6.0	6.0	7.0	15.0	15.0	15.0	9.2	11.4	2.3	92	0.4
2	01/22/86	4.5	4.5	3.5	27.0	28.0	27.5	7.7	6.8	1.5	198	0.4
2	03/18/86	9.0	ND	8.0	28.0	ND	28.0	9.6	10.6	>1.8	44	0.4
2	04/02/86	15.0	15.0	ND	12.0	12.0	ND	5.9	6.6	2.1	27	1.0
2	05/13/86	14.0	13.0	13.0	26.0	23.5	25.5	8.3	8.1	1.2	50	0.7
2	06/12/86	25.0	25.0	25.0	30.0	30.0	29.0	6.5	6.3	ND	69	11.4
2	06/26/86	22.0	22.0	21.5	31.0	31.0	31.0	8.7	7.5	0.5	48	19.7
2	07/22/86	26.0	25.0	25.0	23.0	23.0	23.0	8.6	7.6	0.7	76	8.3
2	09/10/86	21.5	21.0	21.0	ED	ED	ED	6.8	7.0	0.3	47	18.0
2	09/25/86	22.0	ND	22.0	29.0	ND	28.0	7.0	7.1	0.3	40	23.8
3	09/18/85	20.0	20.0	20.0	11.5	12.0	11.5	ND	ND	ND	45	2.2
3	10/30/85	13.0	ND	13.0	17.0	ND	18.0	9.4	9.0	0.8	104	5.1
3	12/11/85	7.0	ND	8.0	15.0	ND	15.0	11.2	11.0	ND	55	0.5
3	01/22/86	6.0	ND	4.0	19.0	ND	19.0	9.5	7.9	1.2	135	0.5
3	03/18/86	11.0	ND	11.0	20.0	ND	26.5	10.2	10.5	>1.2	16	0.4
3	04/02/86	15.0	15.0	ND	12.0	12.0	ND	5.3	5.5	1.4	29	0.2
3	05/13/86	16.0	ND	16.0	26.0	ND	25.0	7.7	7.5	1.1	163	4.9
3	06/12/86	26.0	ND	26.0	25.0	ND	25.0	6.3	6.2	0.3	108	20.5
3	06/26/86	21.0	ND	ND	28.0	ND	ND	7.4	7.1	0.5	71	16.7
3	07/22/86	26.0	26.0	26.0	21.0	20.0	19.0	6.0	5.7	0.5	98	8.6
3	09/10/86	22.0	22.0	22.0	ED	ED	ED	6.3	6.5	0.3	83	18.6
3	09/25/86	23.0	ND	23.0	26.0	ND	28.0	6.5	1.9	0.4	157	21.0
4	09/18/85	21.0	21.0	22.0	14.0	14.5	15.0	ND	ND	ND	41	1.9
4	10/30/85	17.0	16.0	16.5	21.0	20.0	21.0	8.3	8.3	1.3	55	3.4
4	12/11/85	9.0	9.0	9.0	16.5	16.5	16.5	10.0	9.5	1.5	50	0.5
4	01/22/86	6.0	6.5	7.0	28.0	28.0	28.0	10.7	6.4	1.5	75	4.1
4	03/18/86	9.5	ND	10.0	27.0	ND	27.0	10.8	11.2	2.1	42	0.1
4	04/02/86	14.0	ND	14.0	12.0	ND	12.0	6.9	7.1	1.6	31	0.9
4	05/13/86	13.0	13.0	13.0	26.0	26.0	26.0	8.4	8.4	1.3	54	1.1
4	06/12/86	23.0	23.0	24.0	29.0	29.0	29.0	7.1	7.3	0.5	55	5.9
4	06/26/86	21.5	21.5	21.5	30.0	30.0	30.0	7.8	7.6	0.5	58	8.5
4	07/22/86	22.0	22.0	22.5	22.0	22.0	22.0	6.8	7.0	0.9	68	2.7
4	09/10/86	22.0	22.0	21.0	ED	ED	ED	7.7	7.7	0.4	41	14.2

STATION	DATE	SUR TEMP (C)	MID TEMP (C)	BOT TEMP (C)	SUR SAL (ppt)	MID SAL (ppt)	BOT SAL (ppt)	SUR D.O. (mg/L)	BOT D.O. (mg/L)	SECCHI (m)	TSS (mg/L)	CHL a (ug/L)
4	09/25/86	22.0	ND	22.0	28.5	ND	28.5	7.0	7.3	0.5	43	16.4
5	09/18/85	21.0	21.0	22.0	15.0	15.0	15.0	ND	ND	ND	52	2.1
5	10/30/85	18.0	18.0	ND	21.0	21.0	ND	8.0	8.0	1.5	52	1.9
5	12/11/85	9.0	9.0	10.0	17.0	16.5	16.5	9.6	9.9	1.5	41	0.6
5	01/22/86	5.5	5.5	5.5	27.5	27.5	27.5	6.3	6.7	1.2	115	6.9
5	03/18/86	8.5	ND	8.0	28.0	ND	28.0	11.7	11.0	2.4	31	0.8
5	04/02/86	13.0	13.0	ND	12.0	12.0	ND	6.6	7.3	2.2	35	0.4
5	05/13/86	14.0	13.0	13.0	23.0	25.0	25.0	8.2	8.3	0.6	94	1.8
5	06/12/86	18.0	18.0	19.0	27.0	27.0	26.0	7.2	7.4	0.8	71	2.1
5	06/26/86	20.5	20.0	19.0	29.0	29.0	29.0	7.7	7.5	1.1	56	2.5
5	07/22/86	22.0	22.0	22.5	22.0	22.0	22.0	7.0	7.2	1.5	63	1.5
5	09/10/86	23.0	23.0	23.0	ED	ED	ED	7.0	7.3	0.9	31	4.5
5	09/25/86	21.0	ND	21.0	28.0	ND	28.0	7.6	7.4	1.0	50	3.1
6	09/18/85	22.5	22.5	23.0	13.0	13.0	12.5	ND	ND	ND	49	9.1
6	10/30/85	14.5	14.5	14.5	16.5	16.5	17.0	9.3	9.4	1.4	57	4.5
6	12/11/85	8.0	8.0	8.0	14.0	14.0	14.0	12.4	11.2	1.5	48	1.8
6	01/22/86	10.0	ND	9.5	22.0	ND	22.0	6.1	7.6	0.8	102	32.5
6	03/18/86	13.0	ND	11.0	20.0	ND	25.0	11.4	10.5	1.2	29	0.9
6	04/02/86	18.0	18.0	ND	12.0	12.0	ND	7.3	7.6	1.4	26	8.5
6	05/13/86	18.0	18.0	17.0	24.0	24.0	24.0	8.1	8.0	0.6	44	6.9
6	06/12/86	27.5	27.5	27.5	28.0	27.5	27.5	8.8	7.7	0.4	71	55.5
6	06/26/86	24.0	24.0	24.0	27.5	27.5	27.5	7.0	7.0	0.3	95	45.2
6	07/22/86	28.0	28.0	27.5	28.0	28.0	28.0	8.8	8.0	0.3	99	57.0
6	09/10/86	24.0	24.0	24.0	ED	ED	ED	7.5	7.3	0.3	77	28.6
6	09/25/86	23.0	ND	23.0	27.0	ND	27.0	6.8	6.9	0.4	64	34.9
7	09/18/85	22.0	22.0	23.0	11.5	12.0	11.0	9.8	8.3	ND	70	17.7
7	10/30/85	15.0	ND	14.5	12.0	ND	13.5	10.6	10.2	1.1	31	44.3
7	12/11/85	8.0	ND	9.0	9.0	ND	9.5	13.2	12.8	0.9	126	8.8
7	01/22/86	10.0	ND	ND	12.5	ND	ND	12.5	ND	0.5	61	30.8
7	03/18/86	13.0	ND	13.0	7.0	ND	12.0	8.5	8.5	0.9	22	1.1
7	04/02/86	18.0	18.0	ND	11.0	11.0	ND	8.1	8.8	0.8	18	8.7
7	05/13/86	18.0	18.0	18.0	21.0	21.0	21.0	8.1	8.4	0.6	72	8.0
7	06/12/86	29.0	29.0	29.0	23.5	22.5	20.5	7.8	5.0	0.3	98	48.1
7	06/26/86	24.0	24.0	24.0	22.0	21.5	20.5	6.3	6.3	0.4	197	53.8
7	07/22/86	29.0	29.0	28.5	27.0	27.0	27.5	8.5	8.1	0.3	97	55.4
7	09/10/86	23.0	23.0	23.0	ED	ED	ED	8.5	8.0	0.3	68	20.1
7	09/25/86	24.0	ND	24.0	24.5	ND	24.0	6.4	6.5	0.3	85	42.7
8	09/18/85	21.0	21.0	22.0	13.5	14.0	14.0	ND	ND	ND	77	8.0
8	10/30/85	15.0	ND	15.0	15.0	ND	16.0	10.2	9.0	1.4	55	3.6
8	12/11/85	8.0	8.0	8.0	13.0	13.0	14.0	11.9	10.7	1.2	31	1.3
8	01/22/86	7.5	7.5	8.0	22.5	23.5	24.5	11.3	9.0	0.8	34	25.0
8	03/18/86	12.0	ND	12.0	17.5	ND	24.0	10.0	14.1	1.2	69	2.6
8	04/02/86	16.0	16.0	ND	12.0	12.0	ND	7.0	7.8	1.0	19	4.3
8	05/13/86	18.0	18.0	17.0	23.0	23.5	24.0	8.5	7.9	0.8	56	8.2
8	06/12/86	27.0	27.0	26.5	28.0	27.5	26.5	8.6	6.8	0.4	59	39.8
8	06/26/86	24.0	23.0	23.0	27.0	27.0	26.0	8.7	7.6	0.4	70	34.2

STATION	DATE	SUR TEMP (C)	MID TEMP (C)	BOT TEMP (C)	SUR SAL (ppt)	MID SAL (ppt)	BOT SAL (ppt)	SUR D.O. (mg/L)	BOT D.O. (mg/L)	SECCHI (m)	TSS (mg/L)	CHL a (ug/L)
8	07/22/86	28.0	28.0	27.0	24.0	24.0	24.0	8.1	7.6	0.3	109	46.1
8	09/10/86	22.5	22.5	22.5	ED	ED	ED	8.7	8.3	0.3	42	20.4
8	09/25/86	23.0	ND	23.0	27.0	ND	25.0	5.4	5.3	0.4	49	35.8
9	09/18/85	21.5	21.5	21.0	14.5	15.0	15.0	8.7	8.2	ND	42	2.7
9	10/30/85	15.0	15.0	15.0	18.0	19.0	19.0	9.5	9.0	1.4	122	4.1
9	12/11/85	9.0	9.0	9.0	15.0	15.5	16.0	10.0	10.6	1.7	45	0.5
9	01/22/86	7.0	7.0	7.0	26.0	26.0	26.0	6.8	6.2	1.3	39	11.2
9	03/18/86	11.0	ND	9.0	23.0	ND	28.0	11.0	10.9	1.8	30	0.6
9	04/02/86	14.0	14.0	ND	12.0	12.0	ND	6.7	7.3	1.9	37	1.4
9	05/13/86	16.5	16.0	16.0	25.0	25.0	26.0	7.9	7.8	0.8	49	3.0
9	06/12/86	26.0	26.0	25.0	29.0	29.0	28.5	7.4	7.0	0.5	69	32.5
9	06/26/86	22.0	22.0	22.0	29.0	29.0	29.0	6.6	6.7	0.4	97	25.3
9	07/22/86	26.0	26.0	25.0	24.5	24.5	24.0	6.9	7.0	0.5	93	4.8
9	09/10/86	23.0	23.0	23.0	ED	ED	ED	7.7	7.5	0.3	93	22.0
9	09/25/86	23.0	ND	23.0	27.0	ND	28.0	7.2	6.6	0.4	57	13.9
10	09/18/85	20.0	ND	ND	ND	ND	ND	8.0	ND	0.3	20	19.6
10	10/30/85	12.0	ND	ND	ND	ND	ND	9.7	ND	ND	21	32.3
10	12/11/85	8.0	ND	ND	ND	ND	ND	8.7	ND	ND	37	8.5
10	01/22/86	5.0	ND	ND	ND	ND	ND	ND	ND	>0.6	61	8.9
10	03/18/86	9.0	ND	ND	ND	ND	ND	7.0	ND	0.9	21	2.7
10	04/02/86	15.0	ND	ND	27.0	ND	ND	9.5	ND	ND	32	5.6
10	05/05/86	12.0	ND	ND	22.5	ND	ND	9.1	ND	ND	42	6.0
10	06/11/86	22.5	ND	ND	28.5	ND	ND	6.8	ND	ND	63	19.4
10	06/25/86	ND	ND	ND	27.0	ND	ND	6.7	ND	ND	54	21.9
10	07/21/86	28.0	ND	ND	29.5	ND	ND	6.3	ND	ND	56	23.5
10	08/26/86	23.5	ND	ND	26.0	ND	ND	5.7	ND	ND	55	17.2
10	09/22/86	20.0	ND	ND	30.0	ND	ND	5.8	ND	ND	65	15.6
11	09/18/85	19.0	ND	ND	18.0	ND	ND	6.0	ND	0.7	39	6.6
11	10/30/85	13.5	ND	ND	14.5	ND	ND	8.3	ND	ND	43	12.6
11	12/11/85	7.0	ND	ND	ND	ND	ND	9.2	ND	ND	34	13.2
11	01/22/86	5.0	ND	ND	ND	ND	ND	ND	ND	>0.8	59	12.5
11	03/18/86	ND	ND	9.0	ND	ND	ND	6.8	ND	0.9	37	6.1
11	04/02/86	14.5	ND	ND	25.0	ND	ND	8.9	ND	ND	41	4.8
11	05/05/86	14.0	ND	ND	25.5	ND	ND	8.8	ND	ND	56	4.0
11	06/12/86	23.0	ND	ND	29.0	ND	ND	5.5	ND	ND	53	18.8
11	06/25/86	20.0	ND	ND	27.5	ND	ND	6.5	ND	ND	60	22.8
11	07/21/86	28.0	ND	ND	28.0	ND	ND	5.5	ND	ND	70	29.4
11	08/26/86	24.5	ND	ND	27.0	ND	ND	6.5	ND	ND	75	17.9
11	09/22/86	20.0	ND	ND	29.0	ND	ND	5.0	ND	ND	61	20.8

Appendix 2. Concentrations of dissolved inorganic nutrients in Delaware's Inland Bays for the period 18 September 1985 through 25 September 1986. All samples were collected and filtered in the field by DNREC staff; analyses were conducted in Dr. S. Seitzinger's laboratory, ANS.

Column designations are as follows:

STATION	Stations 1-11 in Rehoboth Bay, Indian River and Bay and Little Assawoman Bay
DATE	Sample collection date (month/day/year)
ORTHO-P	Concentrations of orthophosphate-phosphorus in micromoles per liter (umoles P/L) and milligrams per liter (mgP/L)
(NO3 + NO2)-N	Concentrations of nitrate plus nitrite nitrogen in micromoles per liter (umoles N/L) and milligrams per liter (mgN/L)
SILICATE-Si	Concentrations of silicate-silicon in micromoles per liter (umoles Si/L) and milligrams per liter (mgSi/L)

STATION	DATE	ORTHO-P umoles P/L	ugP/L	(NO3+NO2)-N umoles N/L	ugN/L	SILICATE-Si umoles Si/L	ugSi/L
1	09/18/85	0.77	0.02	26.14	0.37	52.55	1.48
1	10/30/85	0.76	0.02	22.53	0.32	47.73	1.34
1	12/11/85	1.63	0.05	37.32	0.52	8.48	0.24
1	01/22/86	0.04	0.00	14.17	0.20	7.65	0.21
1	03/18/86	0.01	0.00	2.66	0.04	1.83	0.05
1	04/02/86	0.06	0.00	2.88	0.04	2.00	0.06
1	05/13/86	0.26	0.01	19.14	0.27	10.14	0.28
1	06/12/86	0.90	0.03	17.84	0.25	113.75	3.19
1	06/26/86	0.82	0.03	13.49	0.19	102.77	2.89
1	07/22/86	0.24	0.01	13.51	0.19	91.13	2.56
1	09/10/86	0.38	0.01	9.43	0.13	65.36	1.84
1	09/25/86	0.29	0.01	7.89	0.11	73.34	2.06
2	09/18/85	0.77	0.02	32.98	0.46	41.57	1.17
2	10/30/85	0.80	0.02	11.82	0.17	15.80	0.44
2	12/11/85	0.61	0.02	15.97	0.22	5.16	0.14
2	01/22/86	0.06	0.00	5.48	0.08	1.33	0.04
2	03/18/86	0.00	0.00	2.02	0.03	2.83	0.08
2	04/02/86	0.12	0.00	1.67	0.02	2.83	0.08
2	05/13/86	0.10	0.00	11.76	0.16	4.66	0.13
2	06/12/86	1.18	0.04	7.44	0.10	106.76	3.00
2	06/26/86	0.35	0.01	38.52	0.54	89.47	2.51
2	07/22/86	0.22	0.01	37.50	0.53	69.18	1.94
2	09/10/86	0.40	0.01	7.74	0.11	59.20	1.66
2	09/25/86	0.38	0.01	8.42	0.12	50.72	1.42
3	09/18/85	0.27	0.01	60.36	0.85	51.22	1.44
3	10/30/85	0.24	0.01	13.80	0.19	34.92	0.98
3	12/11/85	0.52	0.02	15.97	0.22	7.32	0.21
3	01/22/86	0.00	0.00	7.57	0.11	0.83	0.02
3	03/18/86	0.03	0.00	31.20	0.44	48.23	1.35
3	04/02/86	0.04	0.00	7.94	0.11	14.63	0.41
3	05/13/86	0.18	0.01	9.94	0.14	6.32	0.18
3	06/12/86	0.20	0.01	20.46	0.29	87.14	2.45
3	06/26/86	0.30	0.01	17.55	0.25	103.11	2.90
3	07/22/86	0.16	0.00	37.68	0.53	76.16	2.14
3	09/10/86	0.46	0.01	30.70	0.43	83.98	2.36
3	09/25/86	0.28	0.01	4.92	0.07	79.32	2.23
4	09/18/85	1.05	0.03	17.19	0.24	9.15	0.26
4	10/30/85	1.08	0.03	7.07	0.10	12.80	0.36
4	12/11/85	1.15	0.04	25.56	0.36	4.82	0.14
4	01/22/86	0.14	0.00	7.80	0.11	0.67	0.02
4	03/18/86	0.01	0.00	4.60	0.06	4.49	0.13
4	04/02/86	0.03	0.00	1.81	0.03	1.66	0.05
4	05/13/86	0.17	0.01	6.43	0.09	5.32	0.15
4	06/12/86	0.25	0.01	10.90	0.15	64.19	1.80
4	06/26/86	0.19	0.01	13.26	0.19	54.38	1.53
4	07/22/86	0.52	0.02	8.28	0.12	18.96	0.53
4	09/10/86	0.26	0.01	15.73	0.22	42.41	1.19

STATION	DATE	ORTHO-P umoles P/L	ugP/L	(NO3+NO2)-N umoles N/L	ugN/L	SILICATE-Si umoles Si/L	ugSi/L
4	09/25/86	0.29	0.01	4.04	0.06	32.59	0.92
5	09/18/85	1.26	0.04	5.94	0.08	8.65	0.24
5	10/30/85	1.37	0.04	16.22	0.23	10.64	0.30
5	12/11/85	1.17	0.04	22.70	0.32	3.49	0.10
5	01/22/86	0.05	0.00	7.83	0.11	1.66	0.05
5	03/18/86	0.07	0.00	10.33	0.14	7.48	0.21
5	04/02/86	0.07	0.00	1.49	0.02	0.67	0.02
5	05/13/86	0.20	0.01	17.03	0.24	1.66	0.05
5	06/12/86	0.43	0.01	4.07	0.06	6.65	0.19
5	06/26/86	0.42	0.01	12.82	0.18	8.98	0.25
5	07/22/86	0.50	0.02	7.48	0.10	10.48	0.29
5	09/10/86	0.50	0.02	4.05	0.06	0.17	0.00
5	09/25/86	0.50	0.02	1.56	0.02	3.16	0.09
6	09/18/85	1.00	0.03	56.19	0.79	97.95	2.75
6	10/30/85	0.41	0.01	21.49	0.30	68.85	1.93
6	12/11/85	0.23	0.01	33.63	0.47	35.26	0.99
6	01/22/86	0.18	0.01	47.68	0.67	45.90	1.29
6	03/18/86	0.15	0.00	61.00	0.85	51.89	1.46
6	04/02/86	0.16	0.00	46.60	0.65	30.77	0.86
6	05/13/86	0.26	0.01	3.45	0.05	9.15	0.26
6	06/12/86	0.57	0.02	12.20	0.17	100.44	2.82
6	06/26/86	0.46	0.01	37.56	0.53	121.56	3.41
6	07/22/86	0.47	0.01	17.07	0.24	47.23	1.33
6	09/10/86	0.34	0.01	2.99	0.04	77.50	2.18
6	09/25/86	0.49	0.02	5.64	0.08	65.02	1.83
7	09/18/85	1.02	0.03	51.73	0.72	91.13	2.56
7	10/30/85	1.25	0.04	63.53	0.89	136.86	3.84
7	12/11/85	0.26	0.01	92.51	1.30	125.22	3.52
7	01/22/86	0.15	0.00	146.14	2.05	133.54	3.75
7	03/18/86	0.18	0.01	204.20	2.86	145.35	4.08
7	04/02/86	0.13	0.00	112.60	1.58	126.55	3.55
7	05/13/86	0.08	0.00	14.95	0.21	18.13	0.51
7	06/12/86	1.22	0.04	34.48	0.48	147.67	4.15
7	06/26/86	0.56	0.02	21.36	0.30	144.85	4.07
7	07/22/86	0.45	0.01	228.80	3.20	93.63	2.63
7	09/10/86	0.49	0.02	2.99	0.04	98.28	2.76
7	09/25/86	0.46	0.01	4.64	0.06	89.80	2.52
8	09/18/85	1.01	0.03	17.27	0.24	41.91	1.18
8	10/30/85	0.30	0.01	22.30	0.31	69.51	1.95
8	12/11/85	0.26	0.01	62.24	0.87	44.90	1.26
8	01/22/86	0.09	0.00	43.44	0.61	32.93	0.92
8	03/18/86	0.06	0.00	160.80	2.25	38.08	1.07
8	04/02/86	0.04	0.00	16.22	0.23	20.45	0.57
8	05/13/86	0.06	0.00	8.99	0.13	7.98	0.22
8	06/12/86	0.46	0.01	17.48	0.24	97.28	2.73
8	06/26/86	0.32	0.01	40.80	0.57	103.94	2.92

STATION	DATE	ORTHO-P umoles P/L	ugP/L	(NO3+NO2)-N umoles N/L	ugN/L	SILICATE-Si umoles Si/L	ugSi/L
8	07/22/86	0.15	0.00	8.91	0.12	109.76	3.08
8	09/10/86	0.37	0.01	2.48	0.03	75.83	2.13
8	09/25/86	0.57	0.02	35.12	0.49	59.20	1.66
9	09/18/85	1.06	0.03	16.38	0.23	39.91	1.12
9	10/30/85	0.54	0.02	13.60	0.19	25.44	0.71
9	12/11/85	0.76	0.02	25.36	0.36	23.28	0.65
9	01/22/86	0.14	0.00	28.22	0.40	5.32	0.15
9	03/18/86	0.01	0.00	27.40	0.38	22.62	0.64
9	04/02/86	0.09	0.00	5.53	0.08	6.32	0.18
9	05/13/86	0.10	0.00	4.49	0.06	8.65	0.24
9	06/12/86	0.27	0.01	14.74	0.21	81.15	2.28
9	06/26/86	0.33	0.01	16.93	0.24	78.66	2.21
9	07/22/86	0.22	0.01	15.13	0.21	134.70	3.78
9	09/10/86	0.50	0.02	4.42	0.06	60.53	1.70
9	09/25/86	0.50	0.02	6.21	0.09	41.41	1.16
10	09/18/85	0.24	0.01	99.84	1.40	198.06	5.56
10	10/30/85	0.49	0.02	507.18	7.10	232.82	6.54
10	12/11/85	0.52	0.02	50.47	0.71	44.90	1.26
10	01/22/86	0.16	0.00	31.70	0.44	4.99	0.14
10	03/18/86	0.00	0.00	23.60	0.33	8.65	0.24
10	04/02/86	0.04	0.00	3.64	0.05	1.66	0.05
10	05/05/86	0.15	0.00	11.68	0.16	11.31	0.32
10	06/11/86	0.24	0.01	58.12	0.81	19.46	0.55
10	06/25/86	0.19	0.01	28.56	0.40	23.12	0.65
10	07/21/86	0.11	0.00	15.11	0.21	35.75	1.00
10	08/26/86	0.11	0.00	18.26	0.26	37.92	1.06
10	09/22/86	0.34	0.01	9.47	0.13	33.76	0.95
11	09/18/85	0.30	0.01	36.88	0.52	24.94	0.70
11	10/30/85	0.00	0.00	67.60	0.95	31.10	0.87
11	12/11/85	0.13	0.00	16.73	0.23	31.76	0.89
11	01/22/86	0.40	0.01	22.31	0.31	2.83	0.08
11	03/18/86	0.08	0.00	14.33	0.20	0.33	0.01
11	04/02/86	0.07	0.00	3.82	0.05	4.49	0.13
11	05/05/86	0.15	0.00	4.55	0.06	0.00	0.00
11	06/11/86	0.18	0.01	30.88	0.43	27.27	0.77
11	06/25/86	0.20	0.01	14.66	0.21	41.74	1.17
11	07/21/86	0.11	0.00	14.23	0.20	54.55	1.53
11	08/26/86	0.09	0.00	15.49	0.22	55.71	1.56
11	09/22/86	0.22	0.01	4.50	0.06	48.23	1.35

Appendix 3. Phytoplankton densities (x 10^6/L) for various groups in Delaware's Inland Bays for the period 18 September 1985 through 25 September 1986.

Column designations are as follows:

STATION	Stations 1-11 in Rehoboth Bay, Indian River and Bay and Little Assawoman Bay
DATE	Sample collection date (month/day/year)
PICO	Picoplankton, including small unidentified coccoid cells and cyanobacteria (blue-green algae)
BACILL	Bacillariophytes or diatoms
CHLORO	Chlorophytes or green algae
DINO	Pyrrophytes or dinoflagellates
FLAGEL	Microflagellates, including cryptophytes, prasinophytes and unidentifiable flagellated cells
TOT CELLS	Total cell densities

STATION	DATE	PICO	BACILL	CHLORO	DINO	FLAGEL	CHRYSO	TOT CELLS
1	09/18/85	1.3	3.4	0.0	1.5	3.3	0.0	9.6
1	10/30/85	127.1	7.4	0.3	0.1	0.8	0.0	135.8
1	12/11/85	1.8	7.6	0.0	0.3	5.4	0.0	15.1
1	01/22/86	0.0	35.1	0.0	0.7	0.9	0.7	37.4
1	03/18/86	2.2	6.0	0.0	1.0	3.0	0.0	12.3
1	04/02/86	0.0	0.5	0.0	0.3	5.7	0.0	6.5
1	05/13/86	5.3	0.6	0.0	0.6	4.4	0.0	10.9
1	06/12/86	89.6	1.4	0.0	0.2	2.1	7.4	100.5
1	06/26/86	89.0	6.5	0.0	0.3	5.3	0.2	101.1
1	07/22/86	40.3	9.2	0.0	0.2	0.7	0.0	50.4
1	09/10/86	2.7	1.6	13.4	0.0	1.2	1.0	20.1
1	09/25/86	3.9	1.7	9.9	0.3	5.2	0.4	21.2
2	09/18/85	91.9	0.4	0.1	0.6	0.8	0.0	93.9
2	10/30/85	92.9	1.7	0.1	0.2	2.4	0.0	97.4
2	12/11/85	0.2	1.8	0.0	0.0	1.1	0.0	3.1
2	01/22/86	6.8	3.5	0.2	0.1	0.6	0.1	11.3
2	03/18/86	3.8	1.3	0.0	0.2	2.1	0.0	7.3
2	04/02/86	28.1	1.0	0.0	0.4	4.8	0.0	34.3
2	05/13/86	5.3	0.6	0.0	0.6	4.4	0.0	14.2
2	06/12/86	90.4	1.4	0.0	0.1	3.3	2.9	98.2
2	06/26/86	39.7	2.5	0.0	0.2	4.7	0.3	47.3
2	07/22/86	58.9	5.1	0.0	0.1	2.3	0.0	66.4
2	09/10/86	2.0	0.8	20.9	0.1	1.4	0.5	25.8
2	09/25/86	16.3	0.4	18.1	0.6	7.6	0.2	43.6
3	09/18/85	123.4	1.7	0.2	1.5	9.6	0.0	136.4
3	10/30/85	3.3	1.1	0.0	0.1	0.8	0.0	5.3
3	12/11/85	0.5	1.2	0.0	0.2	3.1	0.0	5.1
3	01/22/86	0.0	4.9	0.0	1.0	1.5	0.4	8.0
3	03/18/86	0.0	0.6	0.0	0.2	6.3	0.0	7.2
3	04/02/86	0.0	2.0	0.0	0.2	4.1	0.0	6.2
3	05/13/86	0.0	19.1	0.0	0.5	2.2	0.0	21.8
3	06/12/86	55.4	6.2	0.0	0.5	0.6	5.0	67.8
3	06/26/86	49.3	4.3	0.0	0.7	0.5	4.8	59.6
3	07/22/86	38.2	1.9	0.0	0.5	3.0	0.2	43.9
3	09/10/86	2.9	1.6	21.2	0.3	0.7	0.6	27.3
3	09/25/86	8.3	3.4	5.4	0.3	0.9	0.5	18.7
4	09/18/85	116.4	5.9	0.4	0.3	3.2	0.0	126.3
4	10/30/85	60.6	18.6	0.1	0.1	1.1	0.0	80.5
4	12/11/85	0.5	2.0	0.0	0.3	2.6	0.0	5.4
4	01/22/86	3.1	3.5	0.4	0.4	0.3	0.1	7.8
4	03/18/86	0.0	0.6	0.0	0.1	5.3	0.0	6.0
4	04/02/86	27.8	0.6	0.0	0.2	4.4	0.0	33.0
4	05/13/86	0.0	2.7	0.0	0.0	0.6	0.0	3.4
4	06/12/86	80.3	3.0	0.0	0.1	3.9	0.5	87.8
4	06/26/86	59.8	2.5	0.0	0.4	3.5	0.4	66.3
4	07/22/86	2.7	0.7	0.0	0.1	2.0	0.1	5.7
4	09/10/86	5.8	1.2	21.0	0.1	0.7	0.1	29.0
4	09/25/86	9.9	1.0	16.6	0.2	3.9	0.7	31.7

STATION	DATE	PICO	BACILL	CHLORO	DINO	FLAGEL	CHRYSO	TOT CELLS
5	09/18/85	80.3	5.3	0.2	0.4	1.5	0.0	87.9
5	10/30/85	51.4	7.5	0.0	0.1	0.7	0.0	59.7
5	12/11/85	0.0	1.1	0.0	0.0	2.3	0.0	3.5
5	01/22/86	2.9	6.1	0.0	2.0	5.0	0.4	16.4
5	03/18/86	0.0	1.9	0.1	0.0	5.1	0.1	7.2
5	04/02/86	8.4	1.5	0.1	0.3	1.0	0.0	11.6
5	05/13/86	3.9	7.0	0.0	0.0	0.2	0.0	11.1
5	06/12/86	4.8	1.0	0.0	0.1	0.9	0.1	6.8
5	06/26/86	9.7	0.6	0.0	0.2	2.2	0.0	12.8
5	07/22/86	3.8	0.4	0.0	0.1	2.7	0.0	7.0
5	09/10/86	7.3	4.4	0.8	0.2	2.2	0.0	15.0
5	09/25/86	4.7	2.7	0.5	0.2	1.3	0.5	9.5
6	09/18/85	174.1	1.2	0.9	0.5	1.9	0.0	178.6
6	10/30/85	110.3	0.4	0.0	0.0	1.5	0.0	112.2
6	12/11/85	0.3	0.7	0.0	1.4	3.6	0.0	6.7
6	01/22/86	0.0	3.0	0.0	12.9	5.9	0.0	21.5
6	03/18/86	1.9	0.6	0.0	1.3	10.4	0.4	15.1
6	04/02/86	7.2	0.2	0.0	1.0	19.2	0.1	27.7
6	05/13/86	16.8	16.0	0.0	1.4	4.1	0.0	38.4
6	06/12/86	170.9	26.8	0.0	0.6	4.5	0.1	202.9
6	06/26/86	83.5	1.5	0.0	0.6	0.3	0.1	86.3
6	07/22/86	42.4	1.4	0.0	0.9	1.7	0.1	46.4
6	09/10/86	22.2	3.8	13.4	0.1	3.9	0.1	43.6
6	09/25/86	22.8	1.2	15.2	1.5	3.8	0.5	45.1
7	09/18/85	91.0	1.4	0.1	0.7	2.0	0.0	95.1
7	10/30/85	46.4	0.5	0.0	2.3	0.7	0.0	49.9
7	12/11/85	0.0	5.4	1.3	14.8	23.6	0.0	45.1
7	01/22/86	0.0	6.3	0.0	33.9	6.1	0.1	46.4
7	03/18/86	0.3	1.4	0.0	0.3	2.5	0.0	5.0
7	04/02/86	0.2	1.6	0.0	0.9	16.5	0.0	19.2
7	05/13/86	18.2	27.9	0.0	1.7	7.1	0.0	54.9
7	06/12/86	113.3	30.3	0.0	0.1	2.3	1.3	147.3
7	06/26/86	77.7	5.2	0.0	0.7	0.3	0.9	84.7
7	07/22/86	56.5	4.7	0.0	0.4	3.0	0.0	64.5
7	09/10/86	30.9	4.0	6.9	0.1	11.6	0.1	53.6
7	09/25/86	37.3	1.6	6.9	1.1	3.5	0.6	51.1
8	09/18/85	250.3	8.0	0.0	1.7	3.2	0.0	263.3
8	10/30/85	65.3	0.6	0.1	0.0	4.5	0.0	70.5
8	12/11/85	0.0	0.6	0.0	4.8	11.3	2.4	19.0
8	01/22/86	0.2	11.4	1.3	6.1	1.3	0.4	20.2
8	03/18/86	0.0	1.0	0.0	0.1	5.0	1.4	8.6
8	04/02/86	0.5	0.7	0.0	1.0	11.2	0.0	13.4
8	05/13/86	6.1	12.8	0.0	1.0	4.9	0.0	24.9
8	06/12/86	116.4	22.0	0.0	0.7	2.7	0.1	142.0
8	06/26/86	14.0	0.1	0.0	0.0	0.0	0.0	14.1
8	07/22/86	45.2	1.0	0.0	1.2	2.0	0.1	49.4
8	09/10/86	9.6	0.7	15.7	0.1	3.0	0.1	29.2

STATION	DATE	PICO	BACILL	CHLORO	DINO	FLAGEL	CHRYSO	TOT CELLS
8	09/25/86	18.7	0.6	10.5	1.1	3.3	0.4	34.6
9	09/18/85	155.9	2.5	0.1	0.4	3.8	0.0	162.7
9	10/30/85	75.8	11.5	0.0	0.2	3.0	0.0	90.4
9	12/11/85	0.4	2.9	0.1	0.1	3.8	0.0	7.1
9	01/22/86	0.2	11.4	1.3	6.1	1.5	0.4	20.8
9	03/18/86	0.0	0.8	0.0	0.2	7.3	0.4	8.6
9	04/02/86	28.5	1.2	0.0	0.4	5.7	0.1	35.8
9	05/13/86	11.0	4.2	0.0	0.2	2.6	0.0	17.9
9	06/12/86	123.4	17.9	0.0	0.1	2.4	0.3	144.0
9	06/26/86	34.1	2.7	0.0	0.0	0.5	0.4	37.6
9	07/22/86	25.3	2.0	0.0	0.1	0.8	0.0	28.2
9	09/10/86	23.2	2.6	56.7	0.2	3.6	0.5	86.8
9	09/25/86	11.9	0.8	17.3	0.7	2.5	0.2	33.4
10	09/18/85	36.5	16.4	0.2	3.2	3.6	0.0	59.8
10	10/30/85	80.0	0.9	0.0	0.5	10.5	0.0	91.4
10	12/11/85	0.7	15.7	0.0	5.2	6.4	0.1	28.0
10	01/22/86	2.7	22.7	0.0	1.2	3.0	0.1	29.8
10	03/18/86	0.0	9.0	0.7	0.2	10.1	0.1	20.1
10	04/02/86	0.1	3.8	0.0	0.3	17.2	0.0	21.5
10	05/05/86	3.1	9.4	0.0	2.4	3.7	0.0	18.7
10	06/11/86	52.2	5.5	0.0	0.2	0.8	2.4	81.8
10	06/25/86	123.8	2.5	0.0	1.3	1.5	0.2	129.2
10	07/21/86	68.6	2.7	0.0	0.7	0.7	6.6	79.5
10	08/26/86	31.7	1.7	0.0	1.0	3.5	0.1	38.0
10	09/22/86	33.9	1.1	1.2	0.4	1.6	9.0	47.3
11	09/18/85	83.2	25.9	0.1	0.6	1.6	0.1	111.1
11	10/30/85	76.7	2.3	0.0	0.8	1.2	0.0	80.9
11	12/11/85	0.0	13.6	0.0	0.5	3.4	0.1	17.7
11	01/22/86	4.5	18.4	0.1	0.8	2.4	0.0	26.3
11	03/18/86	0.4	7.7	0.1	0.6	7.0	0.1	15.8
11	04/02/86	0.2	2.9	0.0	0.4	14.2	0.0	17.6
11	05/05/86	7.7	5.4	0.0	1.7	8.3	0.0	23.2
11	06/11/86	99.1	3.9	0.0	0.3	1.3	6.0	110.6
11	06/25/86	100.2	2.4	0.0	0.4	1.0	1.0	104.9
11	07/21/86	83.8	1.2	0.0	0.3	1.3	7.3	94.0
11	08/26/86	5.5	1.6	0.4	1.0	0.7	0.0	9.3
11	09/22/86	29.1	0.8	0.0	0.2	0.5	6.6	37.1

Appendix 4. Dry weight (g/m^2) of flora and fauna collected at the four stations (A1-A4) in the Macroalgae portion of the Delaware Inlands Bays, 18 September 1985 through 25 September 1986. A (-) in REP 1 WT or REP 2 WT columns indicates that the macrobiota from each replicate haul were combined in the field by DNREC staff to yield a POOLED WT. A (-) in the POOLED WT column indicates dry weights for each replicate were obtained. NC indicates that no collections were made.

Column designations are as follows:

STATION	Stations A1-A4 in Rehoboth Bay and Indian River Bay
DATE	Sample collection date (month/day/year)
TAXON	BRYOZOA FIL CHLORO = Filamentous chlorophyte, either Ulva or Enteromorpha ULVA = Ulva lactuca L. GRACILARIA = Gracilaria sp., either G. verrucosa (Hud.) Papenfuss or G. folifera (forssk.) AGARDHIELLA = Agardhiella tenera (J. Agardh)Schmitz UD PHAEO = Undetermined Phaeophyta spp.
REP 1 WT REP 2 WT REP 3 WT	Dry weight (g/m^2) of the macrobiota collected in replicate otter net hauls
POOLED WT	Dry weight (g/m^2) of macrobiota in composited samples derived from pooling two replicate samples

STATION	DATE	TAXON	REP 1 WT (G DRY WT/M2)	REP 2 WT (G DRY WT/M2)	REP 3 WT (G DRY WT/M2)	POOLED WT (G DRY WT/M2)
A1	09/18/85	BRYOZOA	1.663	0.122	NC	-
A1	10/30/85	BRYOZOA	0.000	0.000	NC	4.784
A1	12/11/85	BRYOZOA	0.147	0.000	NC	-
A1	01/22/86	BRYOZOA	-	-	NC	81.148
A1	03/18/86	BRYOZOA	28.608	135.418	NC	1.618
A1	04/02/86	BRYOZOA	-	-	NC	85.153
A1	05/13/86	BRYOZOA	-	-	NC	27.550
A1	06/12/86	BRYOZOA	-	-	NC	20.215
A1	06/26/86	BRYOZOA	-	-	NC	4.752
A1	07/22/86	BRYOZOA	-	-	NC	0.344
A1	09/10/86	BRYOZOA	-	-	NC	0.619
A1	09/25/86	BRYOZOA	-	-	NC	0.553
A1	09/18/85	FIL CHLORO	0.144	0.000	NC	-
A1	10/30/85	FIL CHLORO	-	-	NC	0.000
A1	12/11/85	FIL CHLORO	0.000	-	NC	-
A1	01/22/86	FIL CHLORO	-	-	NC	0.000
A1	03/18/86	FIL CHLORO	0.000	0.001	NC	0.000
A1	04/02/86	FIL CHLORO	-	-	NC	2.610
A1	05/13/86	FIL CHLORO	-	-	NC	0.000
A1	06/12/86	FIL CHLORO	-	-	NC	0.000
A1	06/26/86	FIL CHLORO	-	-	NC	0.000
A1	07/22/86	FIL CHLORO	-	-	NC	0.006
A1	09/10/86	FIL CHLORO	-	-	NC	0.000
A1	09/25/86	FIL CHLORO	-	-	NC	0.000
A1	09/18/85	ULVA	0.128	1.247	NC	-
A1	10/30/85	ULVA	-	-	NC	0.000
A1	12/11/85	ULVA	0.302	-	NC	-
A1	01/22/86	ULVA	-	-	NC	0.000
A1	03/18/86	ULVA	1.460	1.292	NC	0.372
A1	04/02/86	ULVA	-	-	NC	0.201
A1	05/13/86	ULVA	-	-	NC	0.619
A1	06/12/86	ULVA	-	-	NC	0.153
A1	06/26/86	ULVA	-	-	NC	0.015
A1	07/22/86	ULVA	-	-	NC	0.000
A1	09/10/86	ULVA	-	-	NC	0.000
A1	09/25/86	ULVA	-	-	NC	0.000
A1	09/18/85	GRACILARIA	0.050	0.233	NC	-
A1	10/30/85	GRACILARIA	-	-	NC	0.082
A1	12/11/85	GRACILARIA	0.281	-	NC	-
A1	01/22/86	GRACILARIA	-	-	NC	1.980
A1	03/18/86	GRACILARIA	0.102	0.027	NC	0.183
A1	04/02/86	GRACILARIA	-	-	NC	0.000
A1	05/13/86	GRACILARIA	-	-	NC	0.205
A1	06/12/86	GRACILARIA	-	-	NC	0.004
A1	06/26/86	GRACILARIA	-	-	NC	0.206
A1	07/22/86	GRACILARIA	-	-	NC	0.009
A1	09/10/86	GRACILARIA	-	-	NC	0.007
A1	09/25/86	GRACILARIA	0.000	-	NC	0.000
A1	09/18/85	AGARDHIELLA	0.000	0.000	NC	-
A1	10/30/85	AGARDHIELLA	-	-	NC	0.017

STATION	DATE	TAXON	REP 1 WT (G DRY WT/M2)	REP 2 WT (G DRY WT/M2)	REP 3 WT (G DRY WT/M2)	POOLED WT (G DRY WT/M2)
A1	12/11/85	AGARDHIELLA	0.000	-	NC	-
A1	01/22/86	AGARDHIELLA	-	-	NC	0.000
A1	03/18/86	AGARDHIELLA	0.000	0.000	NC	0.000
A1	04/02/86	AGARDHIELLA	-	-	NC	0.000
A1	05/13/86	AGARDHIELLA	-	-	NC	0.078
A1	06/12/86	AGARDHIELLA	-	-	NC	0.000
A1	06/26/86	AGARDHIELLA	-	-	NC	0.000
A1	07/22/86	AGARDHIELLA	-	-	NC	0.001
A1	09/10/86	AGARDHIELLA	-	-	NC	0.000
A1	09/25/86	AGARDHIELLA	-	-	NC	0.000
A1	05/13/86	UD PHAEO	-	-	NC	0.027
A2	09/18/85	BRYOZOA	0.007	1.447	NC	-
A2	10/30/85	BRYOZOA	2.903	4.017	NC	-
A2	12/11/85	BRYOZOA	5.105	1.302	NC	-
A2	01/22/86	BRYOZOA	-	-	NC	19.602
A2	03/18/86	BRYOZOA	-	-	NC	2.779
A2	04/02/86	BRYOZOA	-	-	NC	0.877
A2	05/13/86	BRYOZOA	-	-	NC	78.367
A2	06/12/86	BRYOZOA	-	-	NC	39.508
A2	06/26/86	BRYOZOA	-	-	NC	0.286
A2	07/22/86	BRYOZOA	-	-	NC	0.108
A2	09/10/86	BRYOZOA	-	-	NC	4.654
A2	09/25/86	BRYOZOA	-	-	NC	8.564
A2	09/18/85	FIL CHLORO	0.000	0.000	NC	-
A2	10/30/85	FIL CHLORO	0.000	0.000	NC	-
A2	12/11/85	FIL CHLORO	0.000	0.000	NC	-
A2	01/22/86	FIL CHLORO	-	-	NC	0.000
A2	03/18/86	FIL CHLORO	-	-	NC	5.087
A2	04/02/86	FIL CHLORO	-	-	NC	84.849
A2	05/13/86	FIL CHLORO	-	-	NC	0.000
A2	06/12/86	FIL CHLORO	-	-	NC	0.033
A2	06/26/86	FIL CHLORO	-	-	NC	0.012
A2	07/22/86	FIL CHLORO	-	-	NC	0.001
A2	09/10/86	FIL CHLORO	-	-	NC	0.000
A2	09/25/86	FIL CHLORO	-	-	NC	0.004
A2	09/18/85	ULVA	0.011	0.206	NC	-
A2	10/30/85	ULVA	0.000	1.073	NC	-
A2	12/11/85	ULVA	0.268	0.011	NC	-
A2	01/22/86	ULVA	-	-	NC	9.051
A2	03/18/86	ULVA	-	-	NC	1.015
A2	04/02/86	ULVA	-	-	NC	6.379
A2	05/13/86	ULVA	-	-	NC	0.472
A2	06/12/86	ULVA	-	-	NC	3.246
A2	06/26/86	ULVA	-	-	NC	0.409
A2	07/22/86	ULVA	-	-	NC	0.000
A2	09/10/86	ULVA	-	-	NC	0.000
A2	09/25/86	ULVA	-	-	NC	0.000
A2	09/18/85	GRACILARIA	0.841	1.946	NC	-
A2	10/30/85	GRACILARIA	2.628	3.294	NC	-

STATION	DATE	TAXON	REP 1 WT (G DRY WT/M2)	REP 2 WT (G DRY WT/M2)	REP 3 WT (G DRY WT/M2)	POOLED WT (G DRY WT/M2)
A2	12/11/85	GRACILARIA	2.377	2.403	NC	-
A2	01/22/86	GRACILARIA	-	-	NC	2.617
A2	03/18/86	GRACILARIA	-	-	NC	0.602
A2	04/02/86	GRACILARIA	-	-	NC	1.104
A2	05/13/86	GRACILARIA	-	-	NC	0.081
A2	06/12/86	GRACILARIA	-	-	NC	0.040
A2	06/26/86	GRACILARIA	-	-	NC	2.852
A2	07/22/86	GRACILARIA	-	-	NC	0.082
A2	09/10/86	GRACILARIA	-	-	NC	0.003
A2	03/25/86	GRACILARIA	-	-	NC	0.264
A2	09/18/85	AGARDHIELLA	0.000	0.000	NC	-
A2	10/30/85	AGARDHIELLA	0.000	0.020	NC	-
A2	12/11/85	AGARDHIELLA	0.000	0.000	NC	-
A2	01/22/86	AGARDHIELLA	-	-	NC	1.240
A2	03/18/86	AGARDHIELLA	-	-	NC	0.000
A2	04/02/86	AGARDHIELLA	-	-	NC	0.062
A2	05/13/86	AGARDHIELLA	-	-	NC	0.000
A2	06/12/86	AGARDHIELLA	-	-	NC	0.161
A2	06/26/86	AGARDHIELLA	-	-	NC	0.112
A2	07/22/86	AGARDHIELLA	-	-	NC	0.030
A2	09/10/86	AGARDHIELLA	-	-	NC	0.000
A2	09/25/86	AGARDHIELLA	-	-	NC	0.000
A2	04/02/86	UD PHAEO	-	-	NC	0.074
A3	09/18/85	BRYOZOA	0.000	0.522	0.040	-
A3	10/30/85	BRYOZOA	0.000	0.890	NC	-
A3	12/11/85	BRYOZOA	0.140	0.759	NC	-
A3	01/22/86	BRYOZOA	-	-	NC	3.791
A3	03/18/86	BRYOZOA	-	-	NC	0.618
A3	04/02/86	BRYOZOA	-	-	NC	50.480
A3	05/13/86	BRYOZOA	-	-	NC	0.015
A3	06/12/86	BRYOZOA	-	-	NC	0.000
A3	06/26/86	BRYOZOA	-	-	NC	0.007
A3	07/22/86	BRYOZOA	-	-	NC	0.026
A3	09/10/86	BRYOZOA	-	-	NC	0.009
A3	09/25/86	BRYOZOA	-	-	NC	0.000
A3	09/18/85	FIL CHLORO	0.000	0.000	0.000	-
A3	10/30/85	FIL CHLORO	0.000	0.000	NC	-
A3	12/11/85	FIL CHLORO	0.000	0.000	NC	-
A3	01/22/86	FIL CHLORO	-	-	NC	0.000
A3	03/18/86	FIL CHLORO	-	-	NC	0.466
A3	04/02/86	FIL CHLORO	-	-	NC	3.393
A3	05/13/86	FIL CHLORO	-	-	NC	0.000
A3	06/12/86	FIL CHLORO	-	-	NC	0.004
A3	06/26/86	FIL CHLORO	-	-	NC	0.000
A3	07/22/86	FIL CHLORO	-	-	NC	0.000
A3	09/10/86	FIL CHLORO	-	-	NC	0.000
A3	09/25/86	FIL CHLORO	-	-	NC	0.000
A3	09/18/85	ULVA	0.027	0.000	0.000	-
A3	10/30/85	ULVA	0.190	0.012	NC	-

STATION	DATE	TAXON	REP 1 WT (G DRY WT/M2)	REP 2 WT (G DRY WT/M2)	REP 3 WT (G DRY WT/M2)	POOLED WT (G DRY WT/M2)
A3	12/11/85	ULVA	0.202	0.068	NC	-
A3	01/22/86	ULVA	-	-	NC	2.786
A3	03/18/86	ULVA	-	-	NC	0.264
A3	04/02/86	ULVA	-	-	NC	0.127
A3	05/13/86	ULVA	-	-	NC	1.084
A3	06/12/86	ULVA	-	-	NC	0.193
A3	06/26/86	ULVA	-	-	NC	1.005
A3	07/22/86	ULVA	-	-	NC	0.000
A3	09/10/86	ULVA	-	-	NC	0.000
A3	09/25/86	ULVA	-	-	NC	0.000
A3	09/18/85	GRACILARIA	0.001	0.096	2.919	-
A3	10/30/85	GRACILARIA	0.029	0.057	NC	-
A3	12/11/85	GRACILARIA	1.213	0.112	NC	-
A3	01/22/86	GRACILARIA	-	-	NC	3.133
A3	03/18/86	GRACILARIA	-	-	NC	0.069
A3	04/02/86	GRACILARIA	-	-	NC	0.016
A3	05/13/86	GRACILARIA	-	-	NC	0.041
A3	06/12/86	GRACILARIA	-	-	NC	0.278
A3	06/26/86	GRACILARIA	-	-	NC	0.006
A3	07/22/86	GRACILARIA	-	-	NC	0.003
A3	09/10/86	GRACILARIA	-	-	NC	0.016
A3	09/25/86	GRACILARIA	-	-	NC	0.032
A3	09/18/85	AGARDHIELLA	0.000	0.000	0.000	-
A3	10/30/85	AGARDHIELLA	0.000	0.056	NC	-
A3	12/11/85	AGARDHIELLA	0.000	0.000	NC	-
A3	01/22/86	AGARDHIELLA	-	-	NC	0.000
A3	03/18/86	AGARDHIELLA	-	-	NC	0.000
A3	04/02/86	AGARDHIELLA	-	-	NC	0.000
A3	05/13/86	AGARDHIELLA	-	-	NC	0.096
A3	06/12/86	AGARDHIELLA	-	-	NC	0.019
A3	06/26/86	AGARDHIELLA	-	-	NC	0.000
A3	07/22/86	AGARDHIELLA	-	-	NC	0.000
A3	09/10/86	AGARDHIELLA	-	-	NC	0.000
A3	09/25/86	AGARDHIELLA	-	-	NC	0.000
A4	09/18/85	BRYOZOA	0.000	59.143	NC	-
A4	10/30/85	BRYOZOA	NC	NC	NC	NC
A4	12/11/85	BRYOZOA	-	-	NC	0.037
A4	01/22/86	BRYOZOA	-	-	NC	0.699
A4	03/18/86	BRYOZOA	-	-	NC	5.946
A4	04/02/86	BRYOZOA	-	-	NC	69.765
A4	05/13/86	BRYOZOA	-	-	NC	0.000
A4	06/12/86	BRYOZOA	-	-	NC	0.086
A4	06/26/86	BRYOZOA	-	-	NC	0.602
A4	07/22/86	BRYOZOA	-	-	NC	0.261
A4	09/10/86	BRYOZOA	-	-	NC	0.241
A4	09/25/86	BRYOZOA	-	-	NC	0.031
A4	09/18/85	FIL CHLORO	0.431	0.000	NC	-
A4	10/30/85	FIL CHLORO	NC	NC	NC	NC
A4	12/11/85	FIL CHLORO	-	-	NC	0.009

STATION	DATE	TAXON	REP 1 WT (G DRY WT/M2)	REP 2 WT (G DRY WT/M2)	REP 3 WT (G DRY WT/M2)	POOLED WT (G DRY WT/M2)
A4	01/22/86	FIL CHLORO	-	-	NC	0.000
A4	03/18/86	FIL CHLORO	-	-	NC	0.000
A4	04/02/86	FIL CHLORO	-	-	NC	0.000
A4	05/13/86	FIL CHLORO	-	-	NC	0.075
A4	06/12/86	FIL CHLORO	-	-	NC	0.005
A4	06/26/86	FIL CHLORO	-	-	NC	0.000
A4	07/22/86	FIL CHLORO	-	-	NC	0.000
A4	09/10/86	FIL CHLORO	-	-	NC	0.000
A4	09/25/86	FIL CHLORO	-	-	NC	0.000
A4	09/18/85	ULVA	0.000	0.995	NC	-
A4	10/30/85	ULVA	NC	NC	NC	NC
A4	12/11/85	ULVA	-	-	NC	0.054
A4	01/22/86	ULVA	-	-	NC	0.041
A4	03/18/86	ULVA	-	-	NC	0.000
A4	04/02/86	ULVA	-	-	NC	0.000
A4	05/13/86	ULVA	-	-	NC	8.385
A4	06/12/86	ULVA	-	-	NC	0.744
A4	06/26/86	ULVA	-	-	NC	0.562
A4	07/22/86	ULVA	-	-	NC	0.000
A4	09/10/86	ULVA	-	-	NC	0.000
A4	09/25/86	ULVA	-	-	NC	0.000
A4	09/18/85	GRACILARIA	0.350	0.000	NC	-
A4	10/30/85	GRACILARIA	NC	NC	NC	NC
A4	12/11/85	GRACILARIA	-	-	NC	0.005
A4	01/22/86	GRACILARIA	-	-	NC	0.327
A4	03/18/86	GRACILARIA	-	-	NC	2.211
A4	04/02/86	GRACILARIA	-	-	NC	0.000
A4	05/13/86	GRACILARIA	-	-	NC	1.672
A4	06/12/86	GRACILARIA	-	-	NC	3.094
A4	06/26/86	GRACILARIA	-	-	NC	0.348
A4	07/22/86	GRACILARIA	-	-	NC	0.003
A4	09/10/86	GRACILARIA	-	-	NC	0.000
A4	09/25/86	GRACILARIA	-	-	NC	0.000
A4	09/18/85	AGARDHIELLA	0.000	0.000	NC	-
A4	10/30/85	AGARDHIELLA	NC	NC	NC	NC
A4	12/11/85	AGARDHIELLA	-	-	NC	0.000
A4	01/22/86	AGARDHIELLA	-	-	NC	0.000
A4	03/18/86	AGARDHIELLA	-	-	NC	0.000
A4	04/02/86	AGARDHIELLA	-	-	NC	0.000
A4	05/13/86	AGARDHIELLA	-	-	NC	2.379
A4	06/12/86	AGARDHIELLA	-	-	NC	0.535
A4	06/26/86	AGARDHIELLA	-	-	NC	0.000
A4	07/22/86	AGARDHIELLA	-	-	NC	0.000
A4	09/10/86	AGARDHIELLA	-	-	NC	0.000
A4	09/25/86	AGARDHIELLA	-	-	NC	0.000