EUTROPHICATION AND NUTRIENT LOADING IN BARNEGAT BAY: N OR P LIMITATION OF PRIMARY PRODUCTION

Contract No. P33415

FINAL REPORT
Report No. 93-2F

Reference: Research Agenda Item VII. 1. Ecological Risks. 2. Pollutant Sources, Sinks and Transport in Barnegat Bay

DSR Contact Person:
Mary Downes Gastrich, Ph.D.

Principal Investigator:
Sybil P. Seitzinger, Ph.D.

Co-Investigators:
Isabel E. Pilling
Robert DeKorsey

Submitted:

23 March 1993

THE ACADEMY OF NATURAL SCIENCES

Division of Environmental Research

1900 Benjamin Franklin Parkway Philadelphia, PA 19103

EXECUTIVE SUMMARY (1988-1992 Studies)

Eutrophication[1] is a potential threat to the ecological health of Barnegat Bay and other shallow bays behind barrier islands (back bays or coastal lagoons) that line the New Jersey coast. Nutrient inputs to these valuable commercial and recreational resources are expected to increase in the future due to continued population growth along the coast. The studies conducted here were part of NJDEPE DSR's Coastal Research Program on Eutrophication and Effects of Development Pressure on the Ecology of Barnegat Bay. Before our studies began there was little information on historic or current conditions in the Bay that could be used to assess water quality conditions in the Bay or to predict the effects of increased development on eutrophication. In addition, predicting these effects depends on a clear understanding of nutrient dynamics and factors controlling nutrient availability in Barnegat Bay or similar shallow, highly productive bays. Previous studies of eutrophication and nutrient dynamics in estuaries have focussed on relatively deep estuaries such as Delaware Bay, Narragansett Bay and Chesapeake Bay. The extent to which results from studies of deeper estuaries can be used to predict the effects of nutrient inputs to shallow bays such as Barnegat Bay was unknown.

With funds and collaborative effort from the NJDEPE DSR, studies in Barnegat Bay were conducted during 1988 to 1992 (Seitzinger and Pilling 1990; 1992; 1993; Seitzinger et al. 1993, this report). The objectives of those studies were to: (1) assess the current state of eutrophication in the Bay, and (2) investigate factors controlling nutrient availability in the Bay, and thus, factors which determine the relative degree of eutrophication of the Bay at the present nutrient loading rate. Based on research in other estuaries, it was hypothesized that the sediments were a major site for nutrient recycling and/or nutrient removal, either of which could markedly

1 Results from high rates of nutrient (N and P) inputs to aquatic systems and can lead to a variety of conditions including algal blooms, increased water column turbidity, changes in species composition, and eventually to a depletion of oxygen in the water.

affect the amount of nutrients available for phytoplankton production. Sediment-water nutrient (nitrogen, N and phosphorus, P) exchanges, therefore, were a major focus of the study. To determine whether increased external inputs of N or P to Barnegat Bay are most limiting to phytoplankton production, and therefore most important in controlling eutrophication, studies were conducted using microcosms which contained both water column and benthic components. Two nutrient enrichment experiments (summer and fall) were conducted to assess N and/or P limitation of phytoplankton production. In addition, water column nutrient and chlorophyll concentrations and phytoplankton production rates were measured at four locations in Barnegat Bay from April 1989 through April 1992. Nutrient concentrations in four rivers/streams entering the Bay were measured from June 1990 through April 1992. Results from the above studies considerably advanced our understanding of the conditions in Barnegat Bay and factors controlling nutrient availability in the Bay and other shallow coastal lagoons (Seitzinger and Pilling 1990; 1992; 1993; Seitzinger et al. 1993, this report). These studies have also demonstrated important differences in factors controlling N and P availability in shallow coastal lagoons relative to deeper estuaries. The major conclusions of these studies are summarized below. The reader is referred to the four yearly reports (Seitzinger and Pilling 1990; 1992; 1993; Seitzinger et al. 1993, this report) for further details and discussion.

Biological and chemical data indicate that Barnegat Bay is moderately eutrophic. Phytoplankton production rates are considerably higher than rates in many other East Coast estuaries that receive substantial amounts of nutrient loading from pollutant sources. For example, phytoplankton production rates are greater in Barnegat Bay than in Narragansett Bay, Delaware Bay, Charleston Pond (a Rhode Island coastal lagoon), and Great South Bay, LI (a eutrophic coastal lagoon). Chlorophyll *a* concentrations are also high in Barnegat Bay compared to many estuaries including Upper Chesapeake Bay, Narragansett Bay and coastal lagoons in North Carolina, and are similar to chlorophyll concentrations in Great South Bay, LI.

Nutrient enrichment experiments demonstrated that N and P inputs are important in controlling phytoplankton biomass and production in Barnegat Bay. Inputs of N are more important than P in controlling phytoplankton, however the greatest increases in phytoplankton biomass and production during both summer and fall experiments occurred when N and P were added together. Addition of P alone did not increase phytoplankton biomass or production above control rates in either the summer or fall experiments.

Light attenuation coefficients, and thus water column turbidities, are higher in Barnegat Bay than in many other coastal lagoons. Two factors that contribute to water column turbidity are phytoplankton biomass and suspended sediment. Both are likely important in Barnegat Bay. The high phytoplankton production rates and high chlorophyll concentrations indi-

cate high phytoplankton biomass in the water column which absorbs light and decreases light penetration. In addition, because of the shallow water column, winds and probably heavy boating activity result in considerable resuspension of bottom sediments into the water. While currently there is sufficient light for the phytoplankton to be able to use essentially all of the nutrients available in the water column during the spring, summer and early fall, the high water column turbidity has important implications for the continued occurrence of seagrasses and benthic algae in the Bay.

There is considerable benthic algal production (microscopic benthic algae such as benthic diatoms and macroalgae such as *Ulva*) in Barnegat Bay in addition to seagrass production. This contrasts with larger, deeper estuaries such as Narragansett Bay, Delaware Bay and the deeper portions of Chesapeake Bay where the light levels at the sediment surface are not sufficient to support benthic algal production. The benthic algae in Barnegat Bay are important in reducing the amount of N and P available for phytoplankton in the water column.

The sediments in Barnegat Bay are an efficient trap for nutrients which are produced during decomposition of organic matter in the sediments. Thus the sediments are an important factor regulating the degree of eutrophication in the Bay by reducing the amount of N and P available for phytoplankton production. None of the P, and only a portion of the N, are recycled to the water column from the sediments by diffusive flux. This contrasts with deeper estuaries where almost all of the phosphate and approximately half of the ammonia produced in the sediments, diffuse into the overlying water and are taken up again by phytoplankton. In deeper estuaries the release (recycling) of nutrients from the sediments often supplies 25% to 50% or more of the N and P requirements of phytoplankton.

The major mechanism reducing the release of N from the sediments in Barnegat Bay is uptake of N by microscopic benthic algae. Measurements in Barnegat Bay of sediment-water nutrient fluxes and benthic primary production rates, as a function of light intensity, demonstrated that benthic algae on the sediment surface are controlling the release of N from the sediments by assimilating ammonia as it diffuses across the sediment-water interface. In early summer and fall, when water column turbidity is lower and light levels at the sediment surface are relatively high, rates of benthic photosynthesis are substantial and no ammonia is released from the sediments. However, in mid-summer (July-August), when light levels are low at the sediment surface due to high water column turbidity, benthic photosynthesis is negligible and there is a substantial release of ammonia from the sediments. (Seagrasses do not appear to be a major factor controlling sediment-water nutrient fluxes as patterns of N and P release were similar regardless of the presence or absence of seagrasses.) A comparison of data from Barnegat Bay with data from three other shallow coastal systems, the Delaware Inland Bays, a Rhode Island coastal lagoon and a shallow estuary

in North Carolina, indicate that nutrient removal by benthic algae is important in other systems similar to Barnegat Bay.

While benthic algae are important in controlling sediment-water ammonia fluxes, factors in addition to benthic algae control P fluxes. In areas of the Bay with finer grained sediments, burial of inorganic P sorbed to particles may account for a considerable amount of P retention. However, in sandy areas, the major mechanism(s) responsible for the lack of P release from the sediments has(have) not yet been identified.

Resuspended bottom sediments remove P directly from the water in Barnegat Bay. Thus, sediments resuspended by winds and by heavy boating activity may remove additional P from the water and from phytoplankton uptake. However, this may not directly affect phytoplankton production in the Bay, since N appears to be more important than P in controlling phytoplankton production.

Concentrations of N in rivers entering the Bay are generally 10 to 100 times higher than concentrations in the Bay. Phosphorus concentrations in the rivers are similar to or slightly greater than Bay concentrations. The N:P ratio of nutrients delivered to the Bay by the rivers is generally 100 to 800:1 or greater, compared to a ratio of 16:1 required by the algae.

Studies of factors controlling eutrophication in Barnegat Bay focussed on the effect of inorganic N (ammonia) and P (phosphate). However, approximately 50% of N and 65% of P entering the Bay from rivers is in the form of dissolved organic N and dissolved organic P. The biological availability of this N and P is not known for Barnegat Bay or for any other estuary; thus their contribution to eutrophication is not known. In order to develop cost-effective nutrient management plans for the Bay, studies are required to assess the need to control dissolved organic N and P inputs to the Bay.

The results of our ecological research on nutrient cycling in Barnegat Bay, combined with information from other studies in shallow coastal lagoons and deeper estuaries, have implications for a nutrient management plan for Barnegat Bay:

(1) Nutrient concentrations are relatively low in Barnegat Bay during spring through fall because there is sufficient light for the phytoplankton to assimilate the current rate of nutrient inputs. Our nutrient enrichment experiments indicate that an increase in nutrient inputs to Barnegat Bay would further increase phytoplankton production, and thus increase eutrophication.

(2) Phytoplankton production rates and chlorophyll concentrations in Barnegat Bay are already considerably higher than in many eutrophic estuaries. Water quality management plans should consider ways to

control N and P inputs from both external sources (runoff, river inputs, etc.) or from the sediments.

(3) To minimize nutrient release from benthic sediments, water column turbidity must be controlled. Ideally, turbidity in mid-summer should be decreased to allow more light to reach the sediment surface, thus increasing benthic algal production. At a minimum, turbidity should not be allowed to increase above current levels. Controlling water column turbidity is also important for the seagrass beds in the Bay which are important habitats for finfish and shellfish.

(4) Further studies should be conducted to identify the relative importance of the forms (organic vs inorganic) of N and P contributing to eutrophication.

(5) Further studies quantifying sources, other than river (e.g., groundwater, atmospheric deposition, etc.), of N and P to the Bay are also warranted.

ABSTRACT

The current study was designed to provide information that would be useful in developing the most effective nutrient control strategies for the Bay to reduce future eutrophication. The major question addressed was:

Are increased inputs of N or of P more important in controlling algal production, and thus eutrophication, in Barnegat Bay?

Eutrophication is a potential threat to Barnegat Bay, a valuable commercial and recreational resource in New Jersey. The Bay receives considerable inputs of nutrients, both nitrogen (N) and phosphorus (P), which are expected to increase in the future due to continued population growth in the surrounding area. With funding and cooperative research efforts with the NJDEPE DSR, we began studies in 1989 to (1) assess the state of eutrophication and (2) investigate factors controlling nutrient availability within the Bay. These studies have considerably advanced our understanding of conditions in Barnegat Bay (Seitzinger and Pilling 1990; 1992; 1993).

In order to minimize continued degradation of water quality in the Bay, effective nutrient control strategies must be developed for the Bay watershed. To decrease current eutrophication levels and to minimize future nutrient loading to the Bay from increased development, we need to know which nutrient(s), N, P or both is (are) limiting phytoplankton production. Knowing which nutrient(s) to target to control eutrophication in the Bay will lead to the development of cost-effective management strategies.

Two nutrient limitation experiments were conducted: one during summer when the N:P ratios in the Bay are very low (generally <16:1) and another during fall when N:P ratios in the Bay are higher (generally >16:1). Microcosms with coupled benthic and pelagic components were used and the effect of increased inputs of N alone, P alone, and N plus P, on algal production in Barnegat Bay were measured.

These experiments demonstrated that nutrients are an important factor controlling phytoplankton biomass and rates of phytoplankton production in Barnegat Bay. External inputs of N appear to be more important than

P in controlling phytoplankton, however the greatest increases in phytoplankton biomass and production during both experiments occurred when N and P were added together. During the summer, additions of N alone increased phytoplankton biomass and production above control rates; however, increases were not as large as in the treatment receiving both N and P. Addition of P alone did not increase phytoplankton biomass or production above control rates in either the summer or fall experiment.

These results are consistent with results of nutrient enrichment experiments in other coastal marine ecosystems which generally indicate that inputs of N (or N and P together) are most important in controlling phytoplankton production (Ryther and Dunstan 1971; Maestrini et al. 1984; Smayda 1974; Thomas et al. 1974).

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF FIGURES (cont'd)

Page

LIST OF TABLES

Page

INTRODUCTION

Barnegat Bay is a valuable commercial and recreational resource in New Jersey which is threatened by eutrophication, due to excess nutrient inputs. Currently, the Bay receives considerable inputs of nutrients, both nitrogen (N) and phosphorus (P), which are expected to increase in the future due to continued population growth in the surrounding area. With funding and cooperative research efforts with the NJDEPE DSR, we began studies in 1989 to (1) assess the state of eutrophication in the Bay, and (2) investigate factors controlling nutrient availability within the Bay.

These studies have considerably advanced our understanding of conditions in Barnegat Bay (Seitzinger and Pilling 1990; 1992; 1993). The major conclusions of these studies are summarized as follows.

Barnegat Bay is currently relatively eutrophic as evidenced by the high rates of planktonic algal production, high concentrations of chlorophyll, and high water column turbidity compared to other estuaries (Figs. 1-3).

The sediments in Barnegat Bay are an important site for both N and P removal, and therefore are important in controlling the degree of eutrophication in the Bay. Assimilation of ammonia by benthic algae greatly reduces recycling of N from the benthic sediments to the water. Factors in addition to benthic algae reduce the release of P from the sediments. Resuspended bottom sediments remove P directly from the water. Thus, sediments resuspended during storms and by heavy boating activity may remove additional P from the water and from phytoplankton uptake.

Concentrations of N in rivers entering the Bay (Figs. 4a-c) are generally 10 to 100 times higher than concentrations in the Bay (Figs. 5a-c). Phosphorus concentrations in the rivers are similar to or slightly greater than Bay concentrations. The N:P ratio of nutrients delivered to the Bay by the rivers is generally 100 to 800:1 or greater (Fig. 6), compared to a ratio of 16:1 required by the algae.

Approximately 50% of N and 65% of P entering the Bay from rivers is in the form of dissolved organic N and dissolved organic P. The biological avail-

ability of this N and P is not known, and thus its contribution to eutrophication is not known.

The N:P ratio of inorganic nutrients in the Bay during summer is often low, <16:1; during fall, winter and spring the N:P ratio is generally >16:1, and often greater than 40:1, particularly during the winter (Fig. 7). The N:P ratio required by algae is approximately 16:1. These data suggest that algae in the Bay are N limited during summer, and that increased N inputs, not P inputs, would increase eutrophication in the Bay during summer. However, during late summer through winter, P, or both N and P, may control eutrophication in the Bay.

In order to minimize continued degradation of water quality in the Bay, effective nutrient control strategies must be developed for the Bay watershed. To decrease current eutrophication levels and to minimize future nutrient loading to the Bay from increased development, we need to know which nutrient(s), N, P or both is (are) limiting phytoplankton production. Knowing which nutrient(s) to target to control eutrophication in the Bay will lead to the development of cost-effective management strategies.

The following studies were designed to provide information that would be useful in developing the most effective nutrient control strategies for the Bay to reduce future eutrophication. The major question addressed was:

Are increased inputs of N or of P more important in controlling algal production, and thus eutrophication, in Barnegat Bay?

Traditionally, two experimental approaches have been used to infer which nutrient, N or P, is more limiting to algal production in estuaries. These are: 1) nutrient enrichment experiments in which changes in primary production are measured following additions of N or P to plankton samples in bottles (Ryther and Dunstan 1971; Durand 1979) or to large cultures of algae (D'Elia et al. 1986), and 2) comparing the N:P ratio of inorganic nutrients in the water to the N:P ratio required by algae for growth (16:1 by atoms) (Boynton et al. 1982). However, neither of these two approaches was considered to be appropriate for Barnegat Bay.

The nutrient enrichment experiments in bottles exclude the effect that processes in the sediments have on controlling the relative availability of N or P to the algae in the water. As our studies in Barnegat Bay have demonstrated, the sediments are a critical component controlling N and P in the water (Seitzinger and Pilling 1990; 1992; 1993), thus their effect must be included in nutrient enrichment studies. The N:P ratio of inorganic nutrients in the water also may not be a good indicator of which nutrient is most limiting to primary production in Barnegat Bay because it is a combination of the relative rates of N and P recycling in the water and at the sediment-water interface, plus the relative rates of N and P inputs from

external sources that determines which nutrient is in least supply (Wangersky 1977; Nixon 1981). The importance of recycling of N and P in supplying nutrients for the algae is exemplified in Barnegat Bay by the low concentrations of inorganic nutrients in the water and high rates of primary production (Seitzinger and Pilling 1990); in order to sustain the high primary production rates N and P have to be recycled rapidly through the system. Therefore, to determine whether increased external inputs of N or P to Barnegat Bay are most limiting to algal production, and therefore most important in controlling eutrophication, studies were conducted using microcosms which contained both benthic sediment and water column components.

METHODS

Experimental Design

Two nutrient limitation experiments were conducted: one during summer when the N:P ratios in the Bay are often very low (<<16:1) and another during fall when N:P ratios in the Bay are higher (generally 16:1 to 20:1). Microcosms with coupled benthic and pelagic components were used and the effect of increased inputs of N alone, P alone, and N plus P, on phytoplankton production in Barnegat Bay were measured.

Study Site and Microcosm Design

The experiments of N or P limitation of phytoplankton primary production were performed at the sandy-vegetated site used in previous years of this study for sediment-water nutrient and oxygen fluxes (Seitzinger and Pilling 1990; 1992; 1993). This area is in the highly developed northern end of the Bay (Fig. 8).

The microcosms consist of 1.3-m high, 25-cm diameter transparent acrylic cylinders which are sealed off at the bottom and open at the top (Fig. 9). Separate sediment trays of slightly smaller diameter were designed to contain, transport and set up the benthic portion of the microcosms without disturbing the sediments.

Bay water, containing the natural assemblages of phytoplankton, zooplankton and microbial communities, was collected 14 October 1991 and 6 July 1992. The water was transported to the laboratory in plastic lined 55-gal drums and maintained at ambient Bay water temperatures. The day after Bay water was collected, sediment cores (7-cm diameter, 10-cm deep) were collected by SCUBA-equipped divers from an area without seagrasses at the site described above. Eight cores of sediment were carefully transferred into each microcosm sediment tray on site in the boat. The sediment trays were transported to Philadelphia and maintained with aerated overlying water at ambient Bay water temperature.

The benthic and pelagic components of the microcosms were combined the following day. The sediment trays were lowered into the bottom of the microcosms and Bay water was slowly introduced so that the sediments were not disturbed. Water in all microcosms was bubbled with a stream of air to maintain turbulence levels and dissolved oxygen levels near those in the Bay. The microcosms were maintained in a temperature and light controlled environmental room at near ambient Bay water temperatures and light intensities (Table 1). Metal halide and sodium vapor lights were used to obtain a spectral distribution similar to sunlight.

Nutrient additions were made daily to the microcosms. The experiment consisted of four treatments: N additions (377 µmols/day/microcosm of NH_4Cl), P additions (32 µmols/day/microcosm of KH_2PO_4), N + P additions (377 µmols NH_4Cl and 32 µmols KH_2PO_4 /day/microcosm), and no nutrient additions (controls). Three replicate microcosms of each treatment were used in the October experiment and two replicates of each treatment were used in the July experiment.

Phytoplankton production rates, chlorophyll *a* concentrations, and water column nutrient concentrations were measured at 3- to 4-day intervals in each microcosm for approximately two weeks. The phytoplankton species composition was measured in each microcosm at the conclusion of the experiments. Primary production rates were measured using light/dark bottle oxygen changes (Carritt and Carpenter 1966) over 4-6 hours. Water samples for nutrient analyses (NH_4, NO_3, PO_4) (Solorzano 1969, Technicon Industrial Systems 1977, Murphy and Riley 1962) and chlorophyll *a* analysis (Strickland and Parsons 1972) were filtered through glass microfibre filters and frozen for later analysis. Algal species composition samples were preserved with Lugol's solution. The volume of water in each microcosm (~51 L) was kept constant throughout the experiment by replacing the water removed with an equal volume of Bay water after each sampling period.

RESULTS

Phytoplankton production and chlorophyll data over the time course of both nutrient enrichment experiments (October and July) were analyzed statistically using ANOVA (analysis of variance) for repeated measures tests (BMDP 1990; Sokal and Rohlf 1969). The statistical results (Table 2) are consistent with interpretation of the data based on the graphical presentations.

October Nutrient Enrichment Experiment

During the October experiment, there were no significant differences ($\rho>0.05$) between the Control and N-enriched or Control and P-enriched microcosms with respect to mean primary production rates, mean chlorophyll concentrations, or primary production rates over time (Table 2 and Figs. 10 and 11). There were highly significant differences between the Control and N+P enriched microcosms with respect to mean primary production rates, mean chlorophyll concentrations, primary production rates over time, and chlorophyll concentrations over time. There were large increases in both primary production and chlorophyll concentrations in all three microcosms enriched with N+P relative to the Control microcosms (Figs. 10 and 11 and Table 2).

Changes in nutrient concentrations in the microcosms are consistent with the chlorophyll and phytoplankton production data. Ammonia increased steadily in the three ammonia (N-enriched) microcosms (Fig. 12), which is consistent with the lack of any large increases in phytoplankton biomass (chlorophyll) in the N-enriched microcosms (i.e., an increase in biomass would result from assimilation of NH_4 into particulate [algal] N). Ammonia increased between 17-21 October in the N + P-enriched microcosms and then decreased throughout the remainder of the experiment, which is consistent with the large increase in phytoplankton biomass in that treatment. The NH_4 concentration remained low in all control and P-enriched microcosms. Nitrate concentrations remained below 3 µM in all but the NH_4 treatment microcosms where there was sufficient ammonia for nitrification

(Fig. 13). In those microcosms nitrate concentrations increased in the latter part of the experiment to approximately 3-6 μM.

The pattern of P concentration with treatment was analogous to the NH_4 concentration pattern, although not quite as clear; the variability was due, in part, to analytical (instrumentation) problems the day the P samples were analyzed. Phosphate concentrations remained low in the control and N-enriched treatments (Fig. 14). Phosphate concentrations generally increased in the P-enriched microcosms, which is consistent with the lack of any large increases in chlorophyll biomass in the P-enriched microcosms. Phosphate concentrations in the N + P-enriched microcosms tended to be higher than in the control or N-enriched microcosms from 17-21 October, and then decreased throughout the remainder of the experiment; this decrease is consistent with the large increase in phytoplankton biomass (chlorophyll) in that treatment.

The phytoplankton species composition at the end of the October experiment was similar in all treatments (Table 3). Total abundance of phytoplankton was similar in the controls and N-enriched treatments and somewhat higher in the N + P and P-enriched treatments.

July Nutrient Enrichment Experiment

During the July experiment, there were no significant differences ($\rho>0.05$) between the Control and P-enriched microcosms with respect to mean primary production rates, mean chlorophyll concentrations, primary production rates over time, or chlorophyll concentrations over time (Table 2 and Figs. 15 and 16). However, in both the Control and P enriched microcosms chlorophyll and primary production rates decreased linearly over the two-week experiment. There were significant differences between the Control and N enriched microcosms with respect to primary production rates over time and chlorophyll concentrations over time. Primary production rates and chlorophyll concentrations were higher in the N enriched microcosms relative to the Control microcosms. There were significant differences between the Control and N+P enriched microcosms with respect to mean primary production rates, mean chlorophyll concentrations, and primary production rates over time. Both primary production rates and chlorophyll concentrations were greatly enhanced in the N+P enriched microcosms over that in the Control microcosms, and greater than in the N enriched microcosms as well.

Ammonia concentrations remained low throughout the experiment in all control and P treatment microcosms (Fig. 17). In the N + P treatment microcosms NH_4 concentrations also remained low throughout the experiment even though phytoplankton biomass (chlorophyll) remained constant and production decreased after the initial increase in the N + P treatment

(July 11); this indicates that some factor in addition to phytoplankton was assimilating NH_4. This could be due to assimilation of ammonia by benthic algae (Seitzinger and Pilling 1992). In the N treatment microcosms ammonia concentrations initially increased to approximately 15 μM and then remained at near that concentration throughout the remainder of the experiment. Nitrate plus nitrite concentrations were low (< 1 μM) in all microcosms throughout the experiment (Fig. 18). Phosphate concentrations remained low throughout the experiment in all control and N-enriched microcosms (Fig. 19). Phosphate concentrations similarly remained low in the N + P treatments, even though phytoplankton biomass (chlorophyll) remained constant and production decreased after the initial increase in the N + P-enriched; as with ammonia, this indicates that factors in addition to phytoplankton were removing phosphate. As with ammonia, benthic sediments are likely responsible for the P removal. In the P-enriched microcosms P concentrations started to increase by 15 July and then steadily increased throughout the remainder of the experiment which was consistent with the lack of increase in phytoplankton biomass.

The phytoplankton species composition at the end of the July experiment was similar in all treatments (Table 4), although blue-green algal abundances were higher in the P-enriched microcosms, relative to other treatments. Total abundance of phytoplankton in the N, P or N + P treatments were similar and somewhat higher than in the controls. One of the N treatments (N1) had higher overall phytoplankton abundances.

DISCUSSION

Fall and summer nutrient enrichment experiments using microcosms of Barnegat Bay demonstrated, as expected, that nutrients are an important factor controlling phytoplankton biomass and rates of phytoplankton production in Barnegat Bay. External inputs of N appear to be more important than P in controlling phytoplankton, however the greatest increases in phytoplankton biomass and production during both experiments occurred when N and P were added together. During the summer, additions of N alone increased phytoplankton biomass and production above control rates; however, increases were not as large as in the treatment receiving both N and P. Addition of P alone did not increase phytoplankton biomass or production above control rates in either the summer or fall experiment.

During the fall, when N:P ratios of inorganic nutrients in the water are generally between 16 and 20:1 (atoms) (Fig. 7), which is similar to the ratio required by phytoplankton (16:1), additions of both N and P were required to increase phytoplankton biomass and production above rates in the control microcosms. Internal recycling of N and P in the control microcosms was sufficient to maintain phytoplankton production rates during the fall experiment. During the summer experiment, additions of N were required to maintain primary production rates at initial rates; rates in control and P-enriched microcosms decreased over the two-week experiment suggesting that the algae were N deficient and that internal recycling of N was not sufficient to maintain constant rates. Additions of N and P during the summer experiment resulted in an initial rapid increase in biomass and production during the first three days. Biomass then remained relatively constant throughout the remainder of the experiment and production decreased somewhat, but still remained above the initial rates. This suggests that during the summer experiment some factor(s) in addition to N and P became limiting to further increases in biomass and production. This contrasts with the fall experiment in which there was a linear increase throughout the experiment in phytoplankton biomass and production in the N + P addition treatment.

The results of the Barnegat Bay experiments are consistent with results of nutrient enrichment experiments in other coastal marine ecosystems which

generally indicate that inputs of N (or N and P together) are most important in controlling phytoplankton production (Ryther and Dunstan 1971; Maestrini et al. 1984; Smayda 1974; Thomas et al. 1974). The most analogous nutrient addition experiments were conducted at the coastal lagoon mesocosm facility at the University of Rhode Island (URI) during 1991 Nixon and Taylor unpubl. data). Long-term nutrient addition experiments began in spring and continued through the fall using 4.55-m^3 coastal lagoon mesocosms. These mesocosms are approximately 1-m deep, 4.1 m^2 in surface area and have coupled benthic and pelagic components. Replicate mesocosms received daily additions of N alone, P alone, N + P and no additions (controls). Rates of nutrient addition were similar to the rates used in our Barnegat Bay experiments. The results of the URI coastal lagoon mesocosm experiment demonstrated that inputs of N alone were generally not sufficient to increase phytoplankton production or biomass when water column nutrient concentrations are initially low. However, additions of both N + P resulted in increased phytoplankton production.

Durand (1979) conducted small volume (300 ml), high frequency (4 to 5 times weekly), short term (24 h) nutrient enrichment experiments during the summer of 1963 in Great Bay, NJ. Great Bay water was incubated *in situ* with N (nitrate or ammonia) additions, nitrogen plus phosphorus plus trace metal additions, or no additions (controls). Enrichment of samples with nitrogen often resulted in increased algal production rates over those in control bottles, often doubling the rate. Enrichment of N + P (plus trace metals) did not further stimulate algal production. The greatest response to nutrient addition was observed in late July through early August. Our experiments were conducted in early July, when Durand observed a smaller response to N additions relative to late July/early August. Durand's data suggest that N is most important in controlling algal production. The lack of further stimulation of algal production with N + P over N alone in the Great Bay experiments contrasts with our experiments in Barnegat Bay in which the greatest increases in algal production and biomass were measured in microcosms receiving both N and P. This may be due to a number of factors including the possibility of greater P availability in the water in Great Bay (no P concentration data were reported for Great Bay) or the lack of a benthic sediment component in the Great Bay experiments. Our previous work in Barnegat Bay, as well as in coastal lagoons in Delaware, has shown that the sediments are an important removal site for P (Seitzinger and Pilling 1992; 1993; Seitzinger unpubl. data).

In a subestuary of Chesapeake Bay, the Patuxent River estuary, D'Elia et al. (1986) conducted repeated (10 times) nutrient enrichment experiments between June 1983 and October 1984 using 0.5-m^3 batch cultures of phytoplankton. Each experiment lasted approximately two weeks. Replicate experimental microcosms received continuous additions of N alone, P alone, or no additions (controls). N appeared to be the nutrient most limiting to phytoplankton production during the summer and fall. The response to N

additions during early to mid-summer was weak to moderate, during late summer (August to early September) there was a strong response to N additions, and during fall the response decreased. The response to P only additions was weak or negligible during the summer and fall period. No treatments were run with N + P addition.

The results of the Barnegat Bay microcosm nutrient enrichment experiments indicate that inputs of nutrients, particularly nitrogen, are important in controlling eutrophication in the Bay. During the summer, a decrease in the present rate of N loading to the Bay would be expected to result in decreases in the present summer biomass and production of phytoplankton in the Bay. Increases in external inputs of N alone may not increase phytoplankton biomass or production over current levels during either the summer or fall, however increased inputs of N and P together would be expected to increase biomass and production during both the summer and fall. (No experiments were conducted during other seasons.) If N and P inputs to the Bay increase during summer, factors in addition to N and P which have not yet been identified may also increase production.

The studies conducted here focussed on the effect of increased inorganic N (NH_4) and P (PO_4). However, approximately 50% of N and 65% of P entering the Bay from rivers is in the form of dissolved organic N and dissolved organic P. The biological availability of this N and P is not known, and thus its contribution to eutrophication is not known. Further studies are required to assess the need to control dissolved organic N and P inputs to the Bay.

LITERATURE CITED

BMDP Statistical Software, Inc. 1990. BMDP PC-90 User's Guide. 1990. BMDP Statistical Software, Inc. 1400 Sepulveda Boulevard. Los Angeles.

Boynton, W.R., W.M. Kemp and C.W. Keefe. 1982. A comparative analysis of nutrients and other factors influencing estuarine phytoplankton production. Pages 69-90 *in* V.S. Kennedy, ed. Estuarine Comparisons. Academic Press, NY. 709 pp.

Carritt, D.E. and J.H. Carpenter. 1966. Comparison and evaluation of currently employed modifications of the Winkler Method for determining dissolved oxygen in seawater; a NASCO report. J. Mar. Res. 24(3):286-318.

Culberson, C. M., J.R. Pennock, B.W. Lee, R.B. Biggs, T.M. Church and J.H. Sharp. 1987. Data from the YABLED Cruises, September 1981-July 1984. U. Delaware Oceanographic Data Rept. No. 4. Delaware Sea Grant Coll. Prog., U. Delaware. 170 pp.

D'Elia, C.F., J.G. Sanders and W.R. Boynton. 1986. Nutrient enrichment studies in a coastal plain estuary: Phytoplankton growth in large-scale, continuous cultures. Can. J. Fish. Aquat. Sci. 43:397-406.

Durand, J.B. 1979. Nutrient and hydrological effects of the Pine Barrens on neighboring estuaries. Pages 196-206 *in* R.T.T. Forman, ed. Pine Barrens: Ecosystem and Landscape. Academic Press, N.Y.

Harding, L.W., Jr., B.W. Meeson and T.R. Fisher, Jr. 1986. Phytoplankton production in two East Coast estuaries: Photosynthesis—light functions and patterns of carbon assimilation in Chesapeake and Delaware bays. Estuarine, Coastal and Shelf Sci. 23:773-806.

Lively, J.S., Z. Kaufman and E.J. Carpenter. 1986. Phytoplankton ecology of a barrier island estuary: Great South Bay, New York. Estuarine, Coastal & Shelf Sci. 16:51-68.

Maestrini, S.Y., D.J. Bonin and M.R. Droop. 1984. Phytoplankton as indicators of sea water quality: Bioassay approach and protocols. Pages 71-132 *in* L.E. Shubert, ed. Algae As Ecological Indicators. Academic Press, N.Y.

Murphy, J. and P. Riley. 1962. A modified single solution method of determination of phosphate in natural waters. Anal. Chim. Acta. 27:31-35.

Nixon, S.W. 1981. Remineralization and nutrient cycling in coastal marine ecosystems. *In* B.J. Neilson and L.E. Cronin, eds. Estuaries and Nutrients. Humana Press, Clifton, NJ.

_____. 1983. Estuarine ecology—A comparative and experimental analysis using 14 estuaries and the MERL microcosms. Final Rept. to the USEPA, Chesapeake Bay Program. 59 pp.

_____. 1986. Nutrient dynamics and the productivity of marine coastal waters. Pages 97-115 *in* R. Halwagy, ed. Proceedings of the First Arabian Gulf Conference on Environment and Pollution. The Alden Press, Ltd., Oxford, England.

_____ and V. Lee. 1981. The flux of carbon, nitrogen and phosphorus between coastal lagoons and offshore waters. Pages 325-348 *in* Coastal Lagoon Research, Present and Future. Div. of Marine Sciences, UNESCO, Paris.

Nowicki, B.L. and S.W. Nixon. 1985. Benthic community metabolism in a coastal lagoon ecosystem. Mar. Ecol. Prog. Ser. 22:21-30.

Pennock, J.R. and J.H. Sharp. 1986. Phytoplankton production in the Delaware Estuary: Temporal and spatial variability. Mar. Ecol. Prog. Ser. 34:143-155.

Ryther, J.H. and W.M. Dunstan. 1971. Nitrogen, phosphorus and eutrophication in the coastal marine environment. Sci. 171:1008-1013.

Seitzinger, S.P. and I.E. Pilling. 1990. Eutrophication and nutrient loading in Barnegat Bay: Initial studies of the importance of sediment-water nutrient interactions. Report No. 90-14. Acad. Nat. Sci. Phila. 50 pp.

_____ and I.E. Pilling. 1992. Eutrophication and nutrient loading in Barnegat Bay: Importance of sediment-water nutrient interactions, Year II. Report No. 92-24F. Acad. Nat. Sci. Phila. 68 pp.

_____ and I.E. Pilling. 1993. Eutrophication and nutrient loading in Barnegat Bay: Sediment-water phosphorus dynamics, Year III. Report No. 92-33F. Acad. Nat. Sci. Phila.

Sellner, K.G., R.V. Lacouture, K.L. Heck, Jr., R.J. Orth and K.A. Moore. 1988. Phytoplankton, nutrients, macroalgae and submerged aquatic vegetation in Delaware's Inland Bays, 1985-1986. Rept. for Delaware Dept. Natural Res. and Environ. Control. Acad. Natural Sci. Phila. 140 pp.

Smayda, T.J. 1974. Bioassay of the growth potential of the surface water of lower Narragansett Bay over an annual cycle using the diatom *Thalassiosira pseudonana* (oceanic clone, 13-1). Limnol. Oceanogr. 19:889-901.

Sokal, R.R and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Co. San Francisco. 749 pp.

Solorzano, L. 1969. Determination of ammonia in natural waters by the phenyl-hypochlorite method. Limnol. Oceanogr. 14:799-801.

Strickland, J.D.H. and T.R. Parsons. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Bd. Can. 167:311.

Technicon Industrial Systems. 1977. Nitrate and nitrite in water and seawater. Industrial Method No. 158-71W/A. Technicon Industrial Systems, Tarrytown, NY 4 pp.

Thayer, G.W. 1971. Phytoplankton production and the distribution of nutrients in a shallow unstratified estuarine system near Beaufort, N.C. Ches. Sci. 12:240-253.

Thomas, W.H., D.L.R. Seibert and A.N. Dodson. 1974. Phytoplankton enrichment experiments and bioassays in natural coastal seawater and in sewage outfall receiving waters off southern california. Est. Coast. Mar. Sci. 2:191-206.

Wangersky, P.J. 1977. The role of particulate matter in the productivity of surface waters. Helgol. Wiss. Meeresunters 30:546-564.

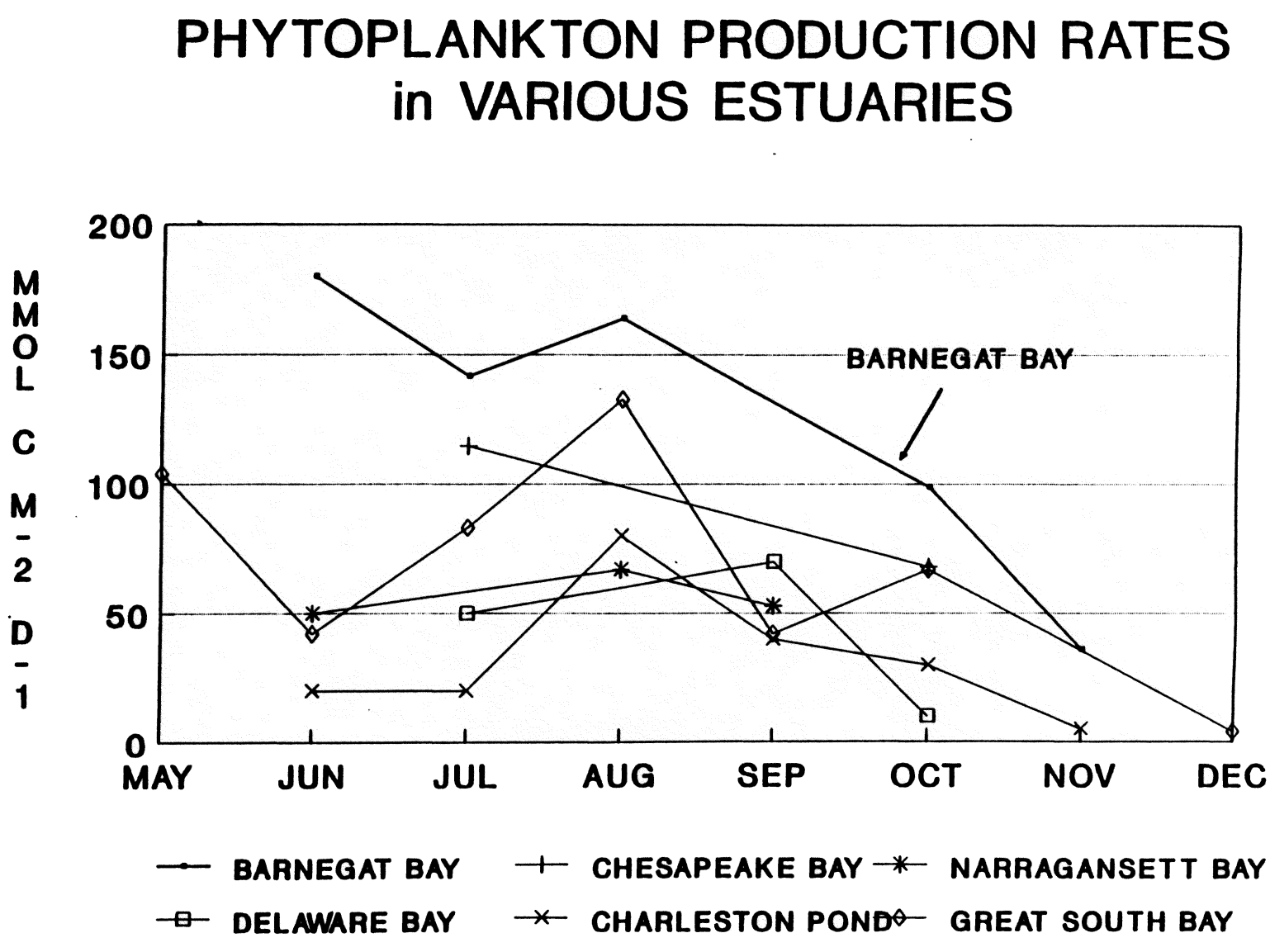

Figure 1. Phytoplankton production rates (mmol C m^{-2} d^{-1}) in various estuaries during summer. Data for Chesapeake Bay from Harding et al. (1986), Narragansett Bay from MERL (unpubl. data), Delaware Bay from Pennock and Sharp (1986), Charleston Pond, a RI coastal lagoon from Nixon and Lee (1981), and Great South Bay, LI, from Lively et al. (1986), and from Barnegat Bay (Seitzinger and Pilling 1992a) calculated from NJDEPE (unpubl. data).

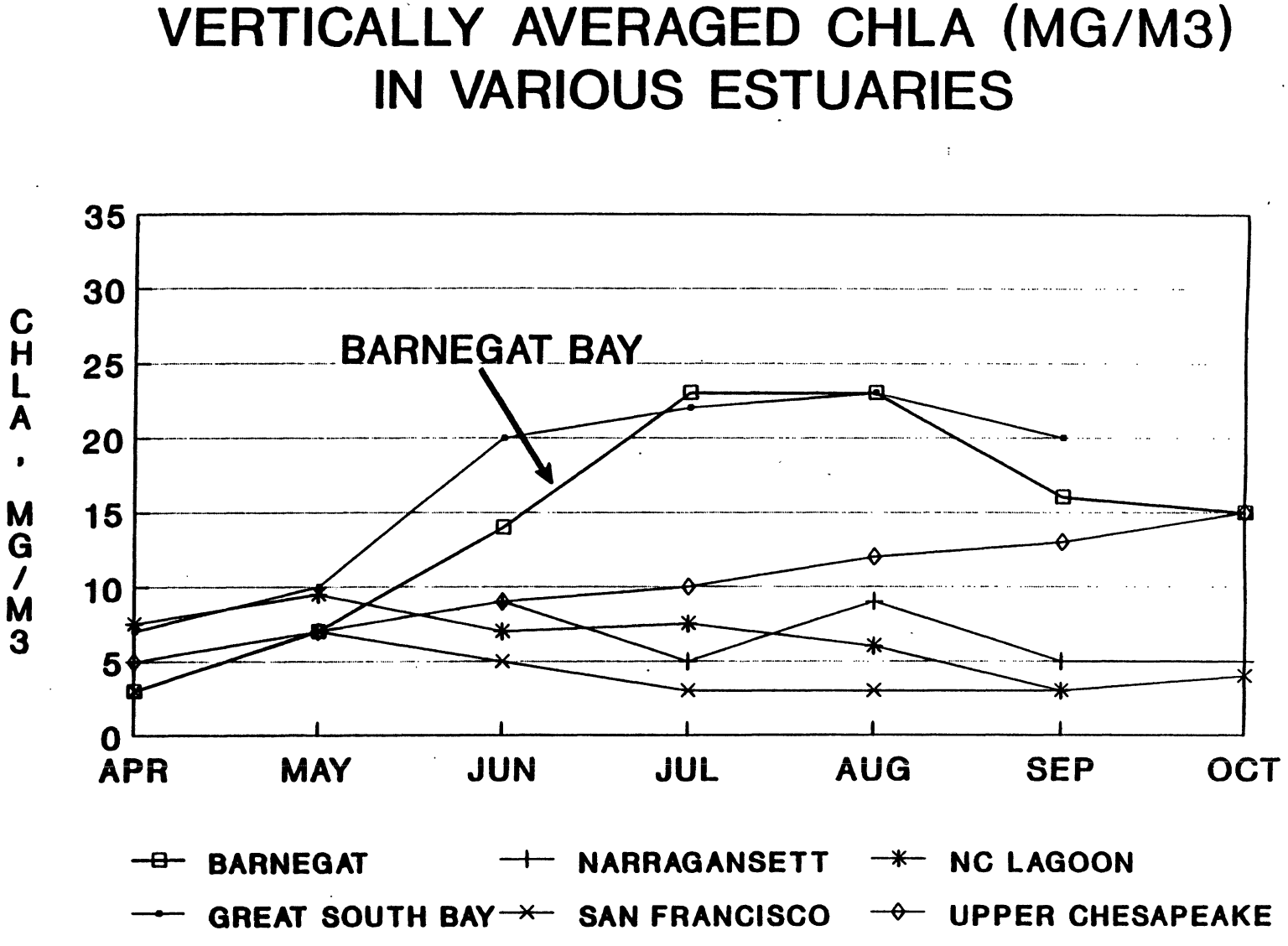

Figure 2. Comparison of vertically averaged chlorophyll *a* concentrations (mg/m^3) in various estuaries. Data for Narragansett Bay and San Francisco Bay from Nixon (1983), a North Carolina coastal lagoon from Thayer (1971), Great South Bay, LI, from Lively et al. (1986), Barnegat Bay from Seitzinger and Pilling (1992a) calculated from NJDEPE (unpubl. data), and Upper Chesapeake Bay from Harding et al. (1986).

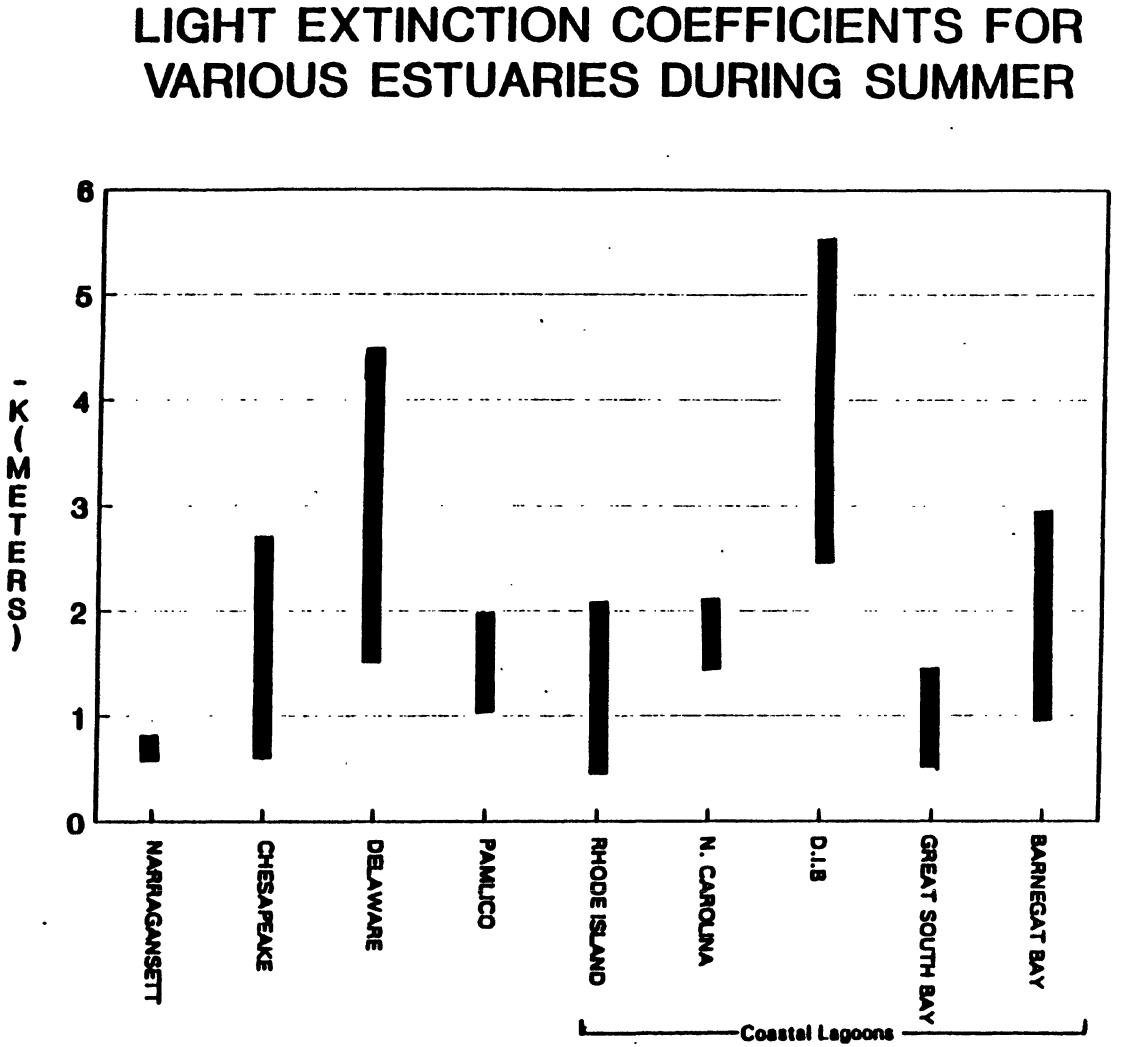

Figure 3. Light extinction coefficients ($-K_m$) in various estuaries during summer. Data for Narragansett Bay and Pamlico Sound from Nixon (1986), Chesapeake Bay from Harding et al. (1986), Delaware Bay (Culberson et al. 1987), a Rhode Island coastal lagoon, Potter Pond (annual range), from Nowicki and Nixon (1985), open water areas of a North Carolina coastal lagoon from Thayer (1971), the Delaware Inland Bays from Sellner et al. (1988), Great South Bay, LI, from Lively et al. (1986), and Barnegat Bay (Seitzinger and Pilling 1992a) calculated from NJDEPE (unpubl. data).

(A)

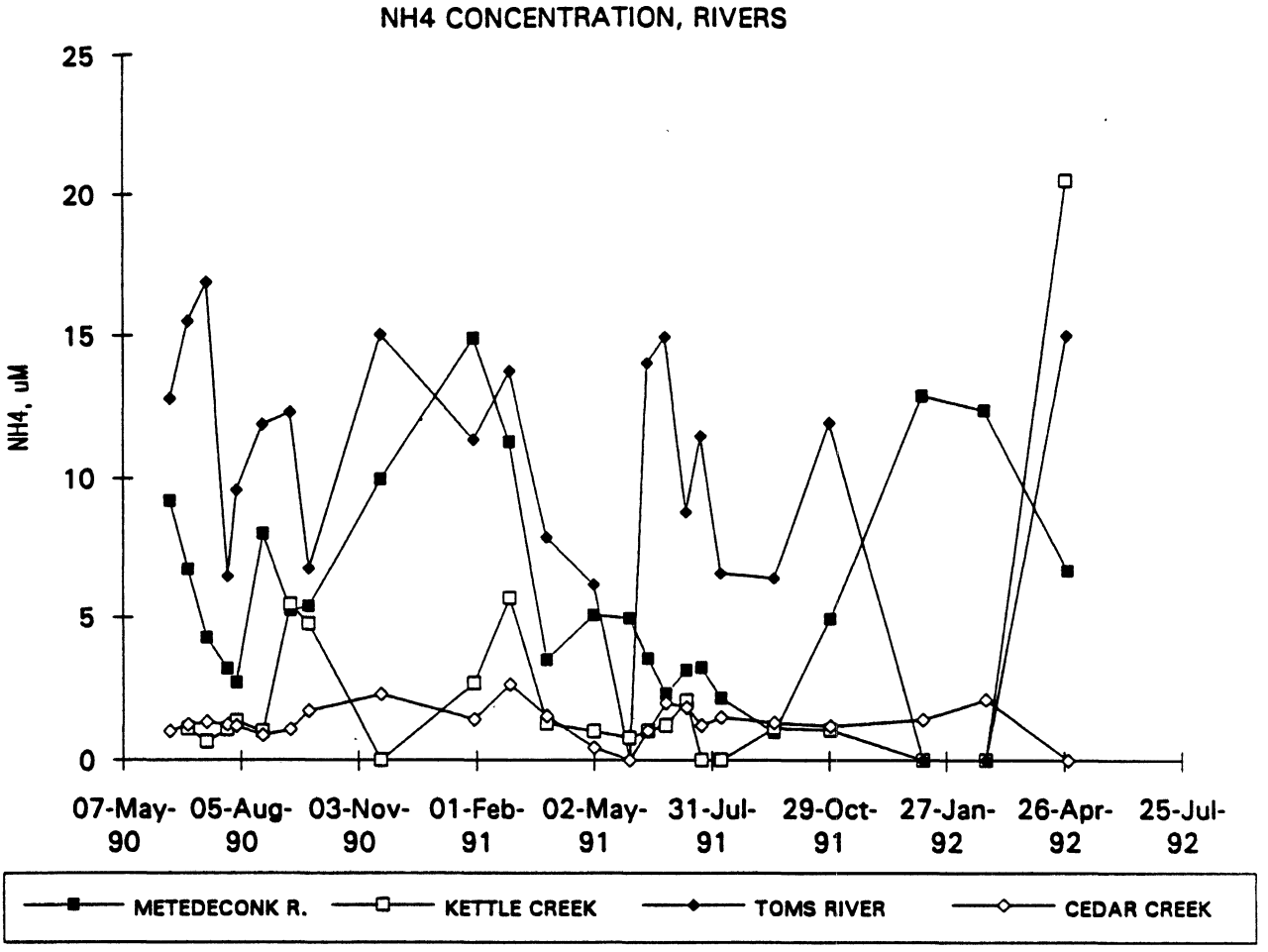

Figure 4. Concentrations (μM) of: (A) ammonia, (B) nitrate plus nitrite, and (C) phosphate in four rivers/streams entering Barnegat Bay (NJDEPE DSR unpubl. data). **NOTE:** Points are connected to make it easier to distinguish overall differences among stations. Note that there are often considerable time lapses between sample dates; the lines are not meant to imply trends between sampling dates. See Figure 8 for station locations.

(B)

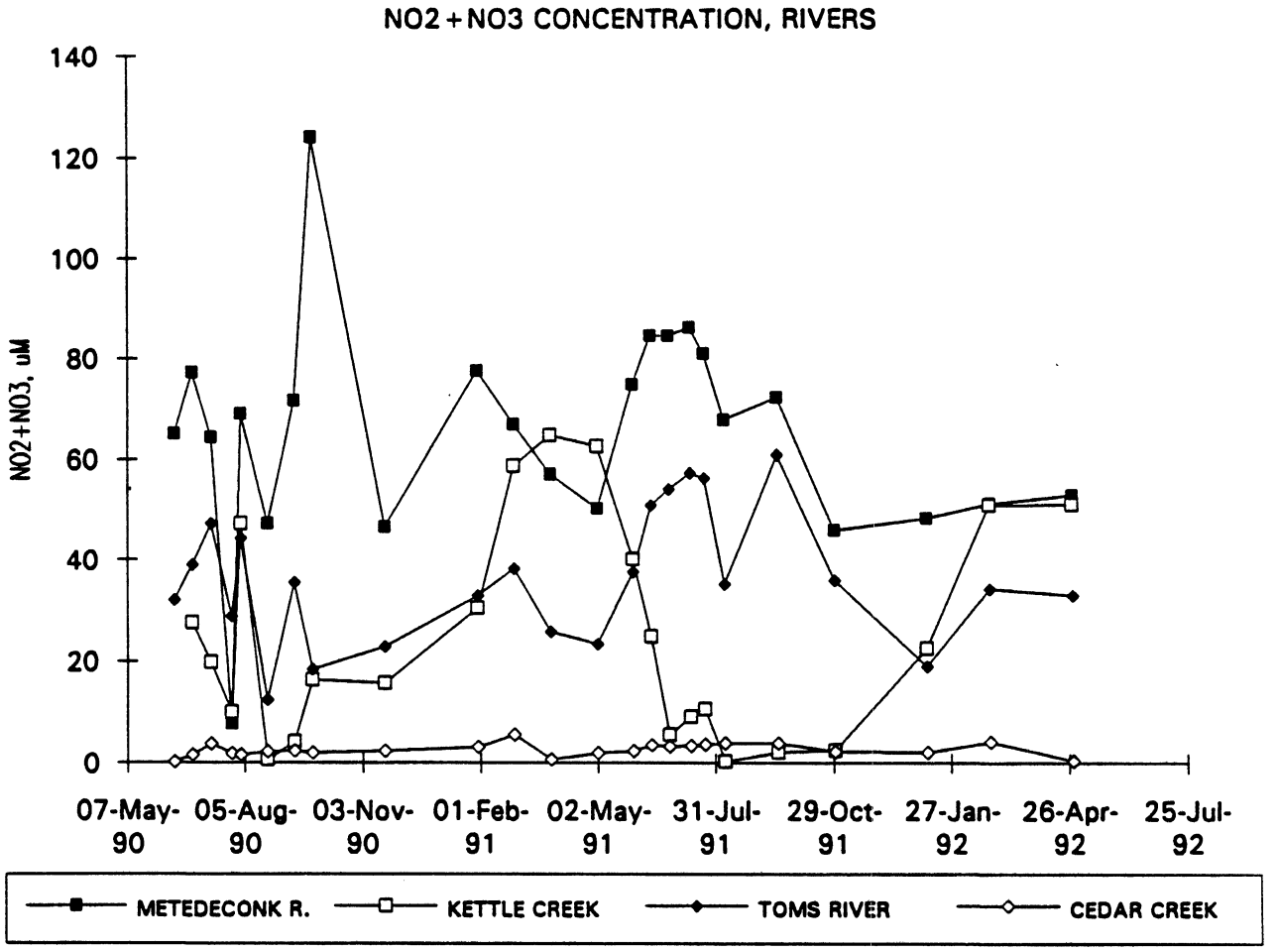

Figure 4(continued). Concentrations (μM) of: (A) ammonia, (B) nitrate plus nitrite, and (C) phosphate in four rivers/streams entering Barnegat Bay (NJDEPE DSR unpubl. data). **NOTE:** Points are connected to make it easier to distinguish overall differences among stations. Note that there are often considerable time lapses between sample dates; the lines are not meant to imply trends between sampling dates. See Figure 8 for station locations.

(C)

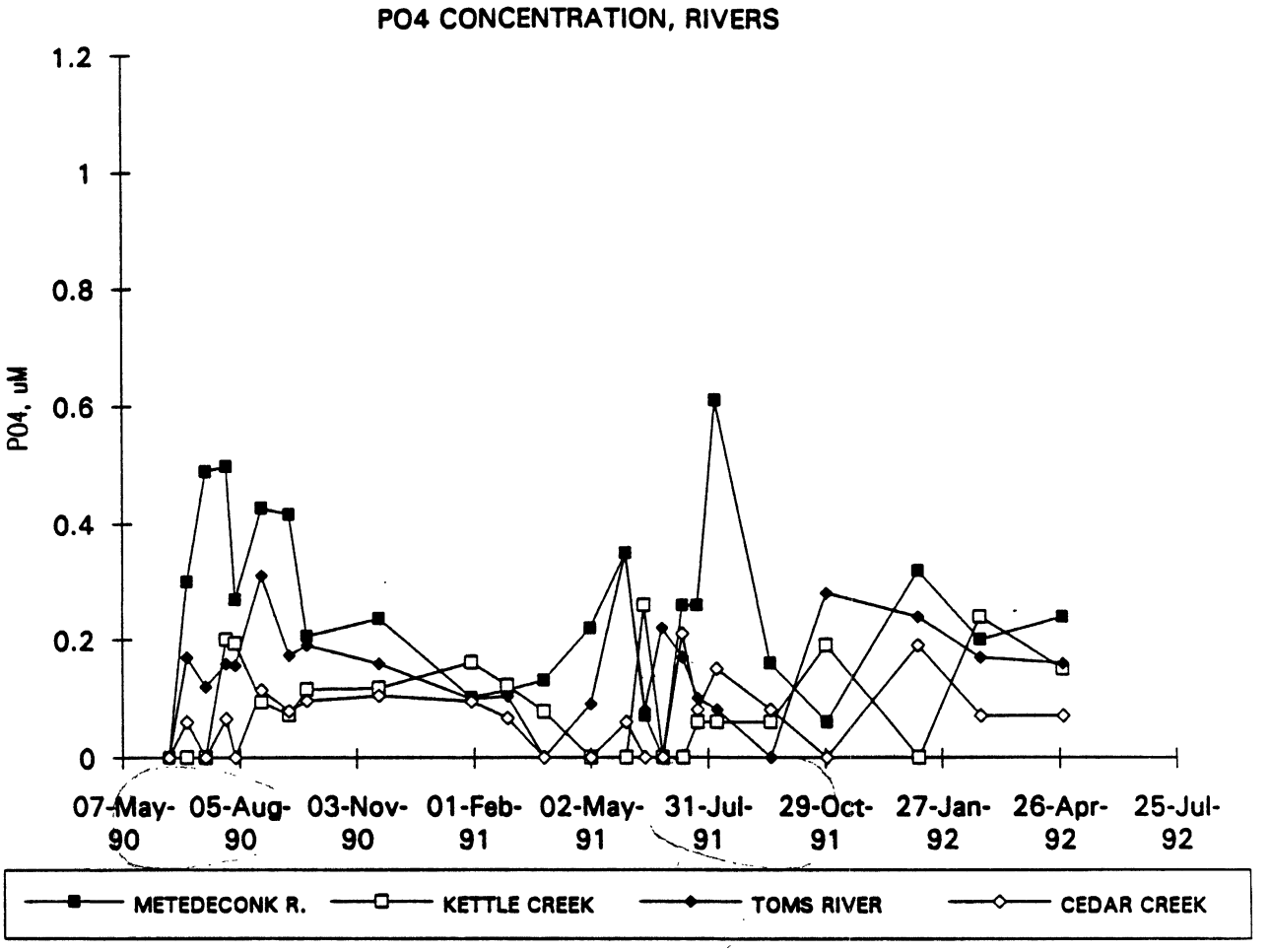

Figure 4(continued). Concentrations (μM) of: (A) ammonia, (B) nitrate plus nitrite, and (C) phosphate in four rivers/streams entering Barnegat Bay (NJDEPE DSR unpubl. data). **NOTE:** Points are connected to make it easier to distinguish overall differences among stations. Note that there are often considerable time lapses between sample dates; the lines are not meant to imply trends between sampling dates. See Figure 8 for station locations.

(A)

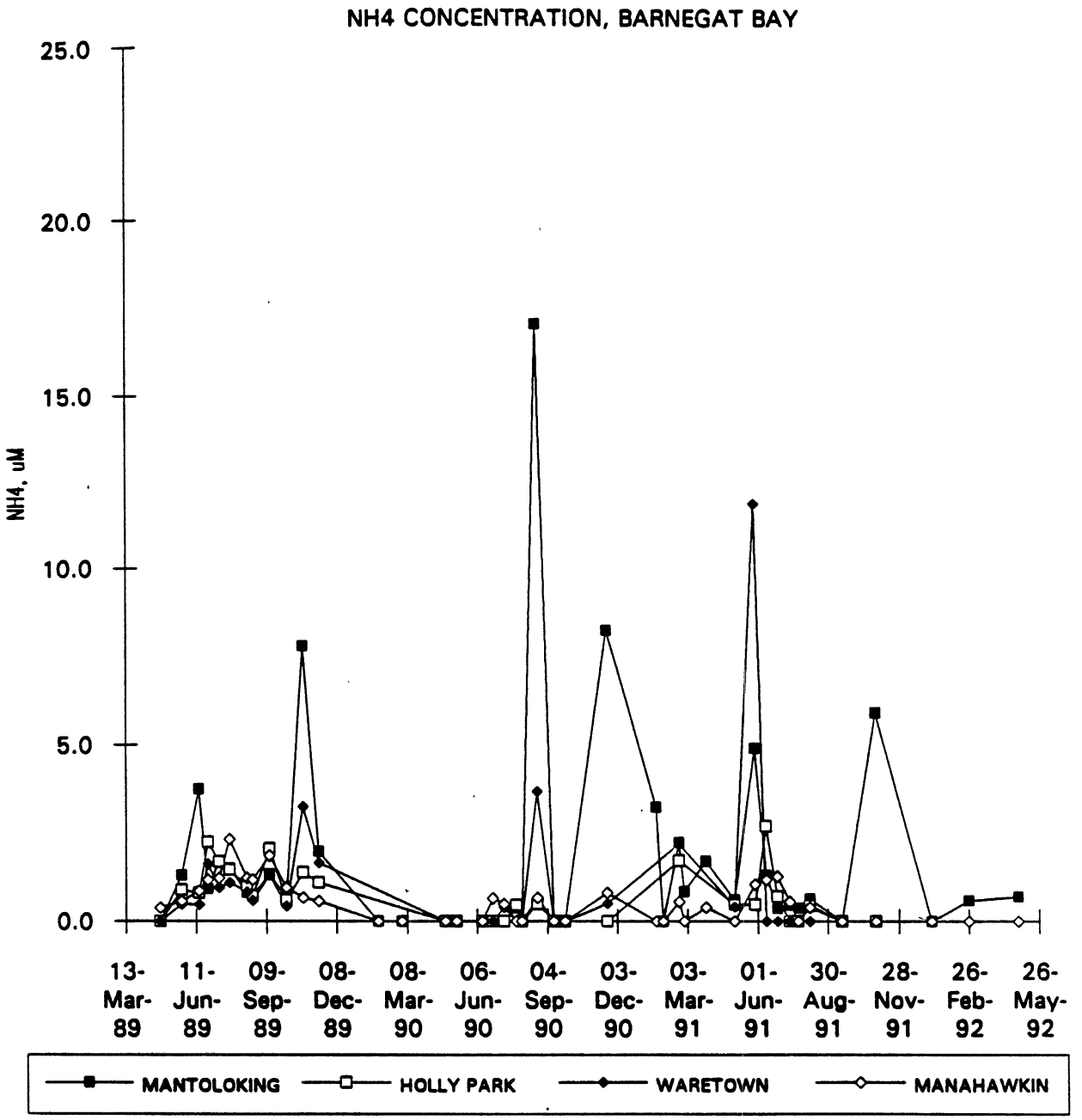

Figure 5. Concentrations (µM) of: (A) ammonia, (B) nitrate plus nitrite, and (C) phosphate at four locations in Barnegat Bay (NJDEPE DSR unpubl. data). **NOTE:** Points are connected to make it easier to distinguish overall differences among stations. Note that there are often considerable time lapses between sample dates; the lines are not meant to imply trends between sampling dates. See Figure 8 for station locations.

(B)

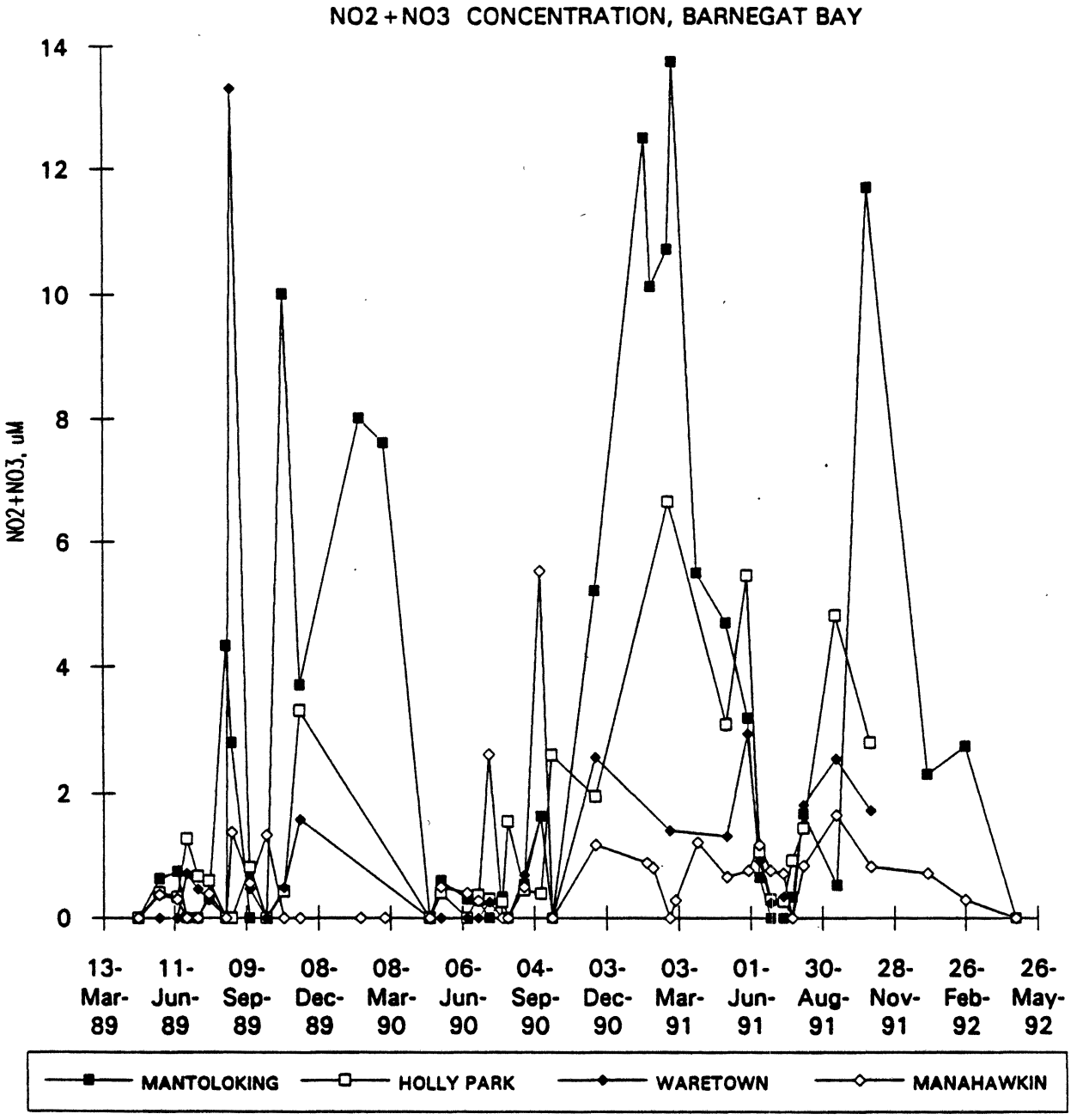

Figure 5 (continued). Concentrations (μM) of: (A) ammonia, (B) nitrate plus nitrite, and (C) phosphate at four locations in Barnegat Bay (NJDEPE DSR unpubl. data). **NOTE:** Points are connected to make it easier to distinguish overall differences among stations. Note that there are often considerable time lapses between sample dates; the lines are not meant to imply trends between sampling dates. See Figure 8 for station locations.

(C)

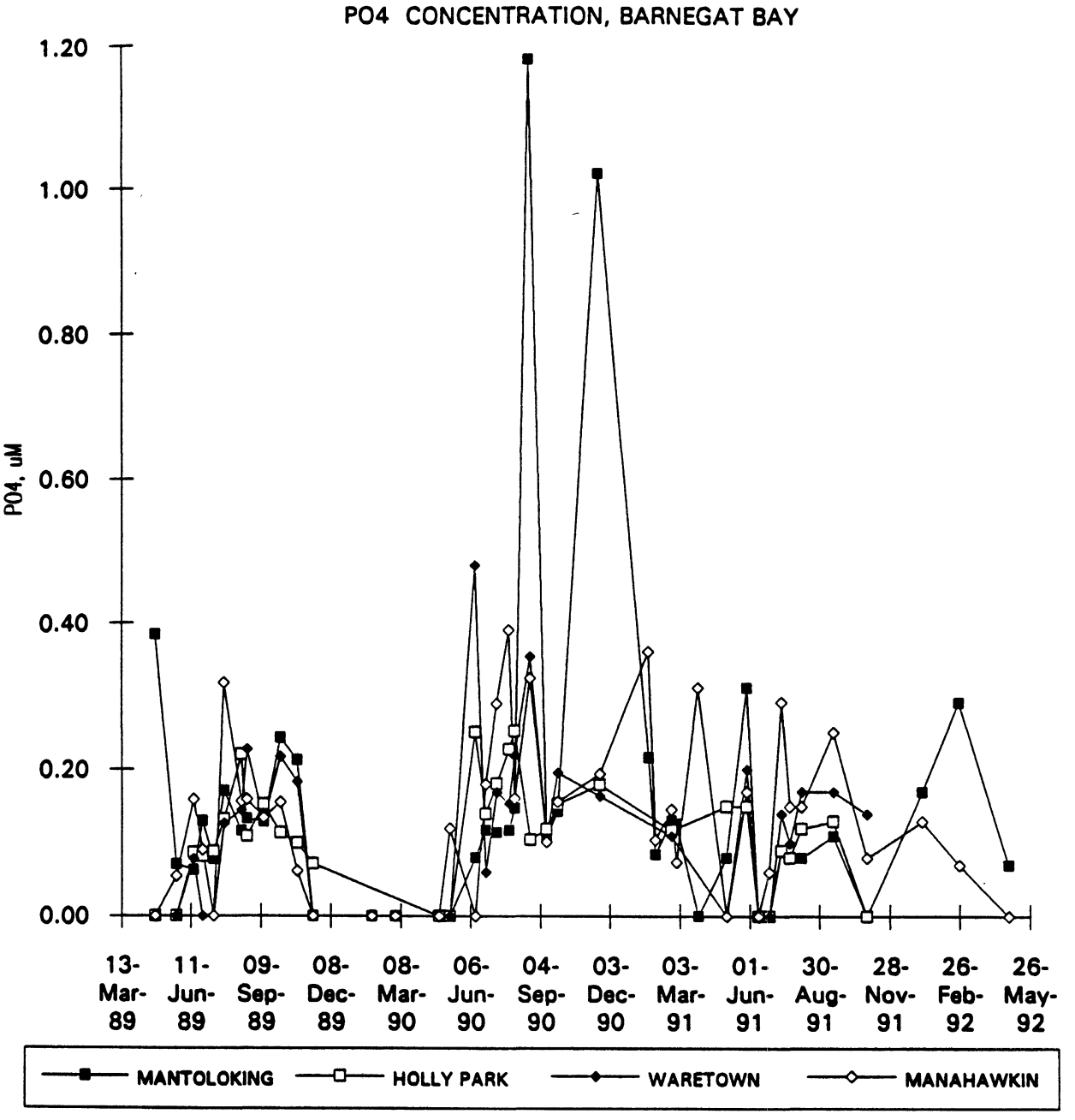

Figure 5(continued). Concentrations (µM) of: (A) ammonia, (B) nitrate plus nitrite, and (C) phosphate at four locations in Barnegat Bay (NJDEPE DSR unpubl. data). **NOTE:** Points are connected to make it easier to distinguish overall differences among stations. Note that there are often considerable time lapses between sample dates; the lines are not meant to imply trends between sampling dates. See Figure 8 for station locations.

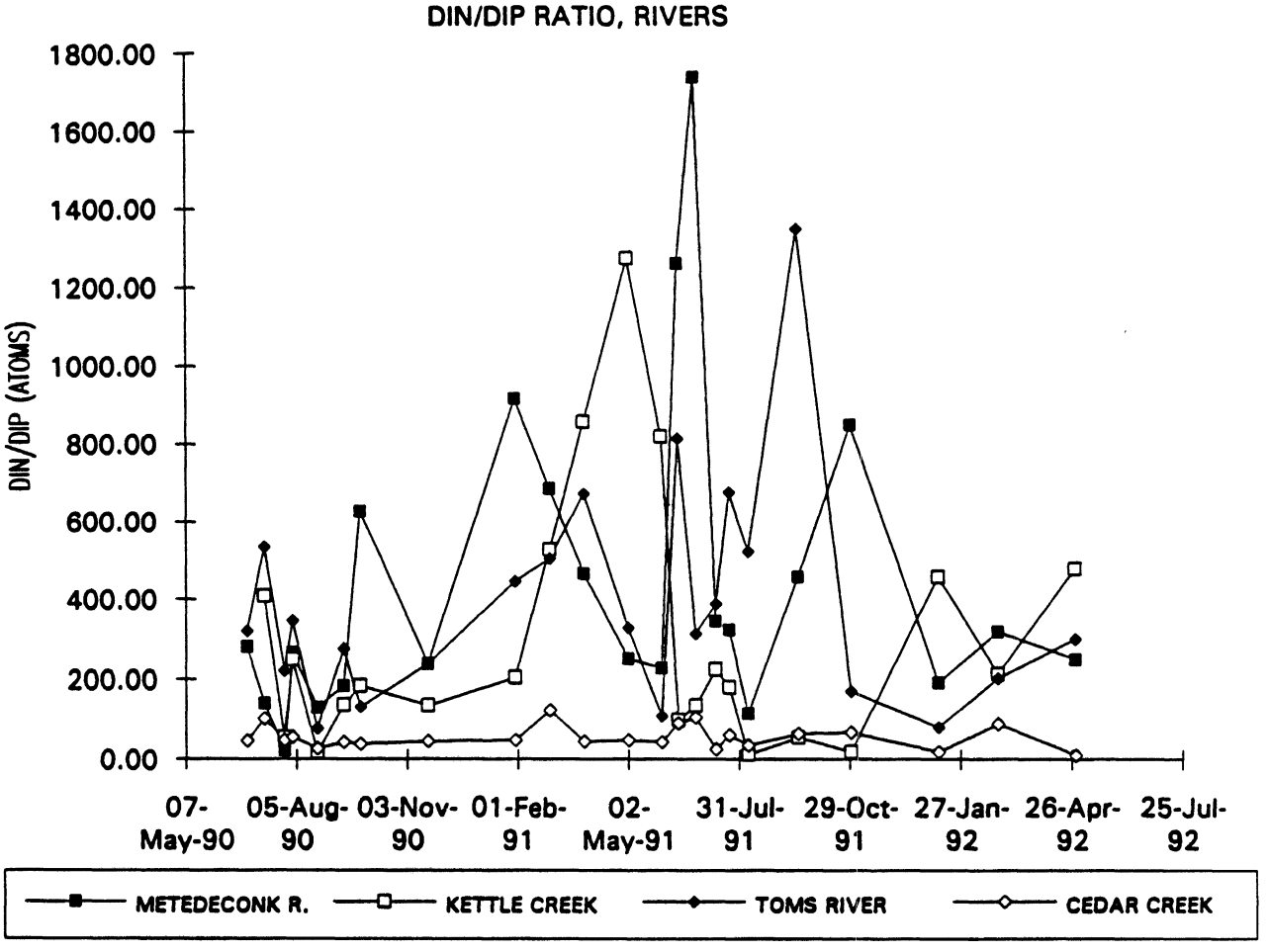

Figure 6. N:P ratio of inorganic nutrients (NH_4+ + NO_3- +NO_2-/PO_4) in four rivers/streams entering Barnegat Bay. **NOTE:** Points are connected to make it easier to distinguish overall differences among stations. Note that there are often considerable time lapses between sample dates; the lines are not meant to imply trends between sampling dates. Calculated from data in Figure 4.

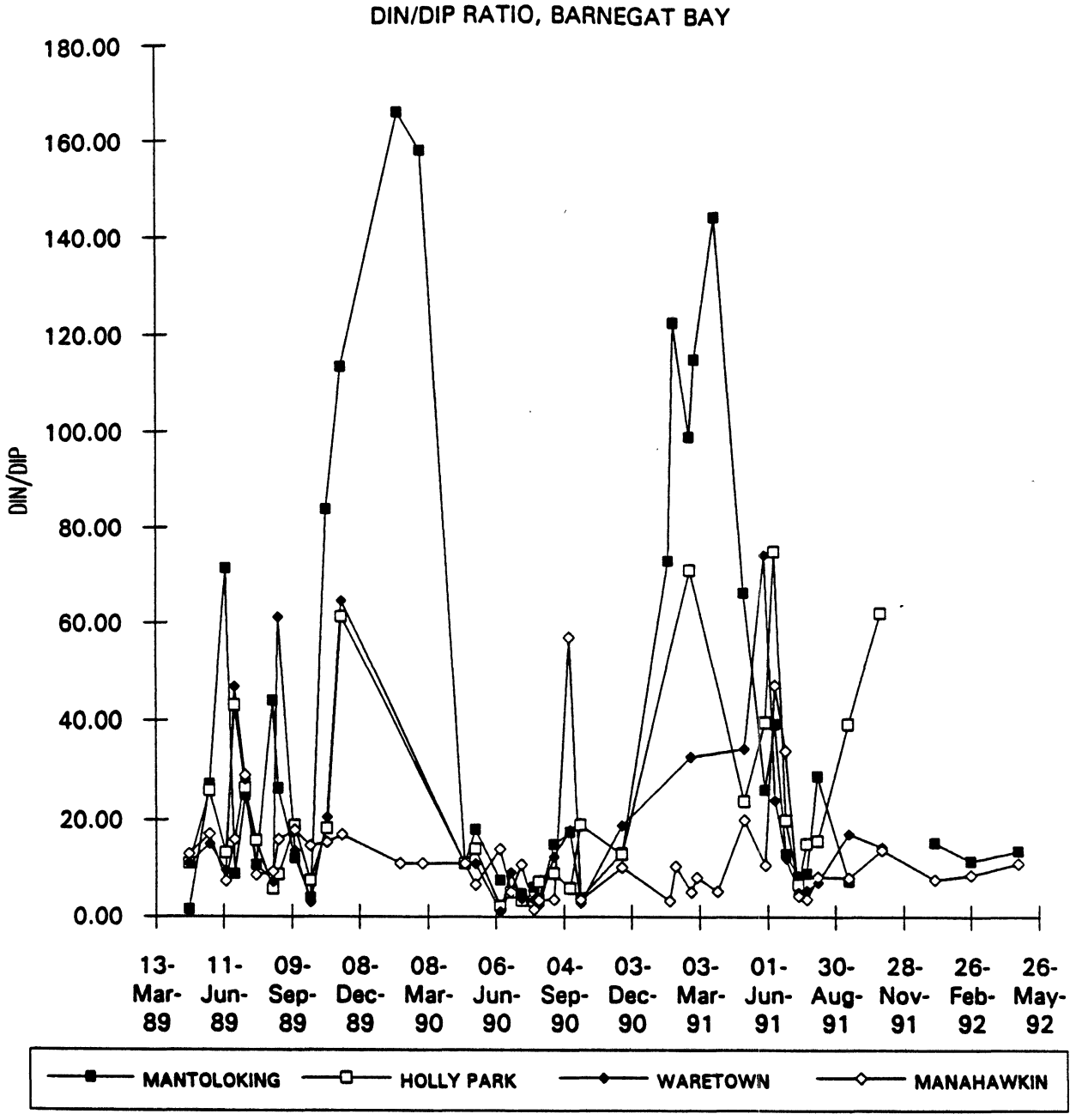

Figure 7. N:P ratio of inorganic nutrients (NH_4+ + NO_3- +NO_2-/PO_4) in Barnegat Bay. **NOTE:** Points are connected to make it easier to distinguish overall differences among stations. Note that there are often considerable time lapses between sample dates; the lines are not meant to imply trends between sampling dates. Calculated from data in Figure 5.

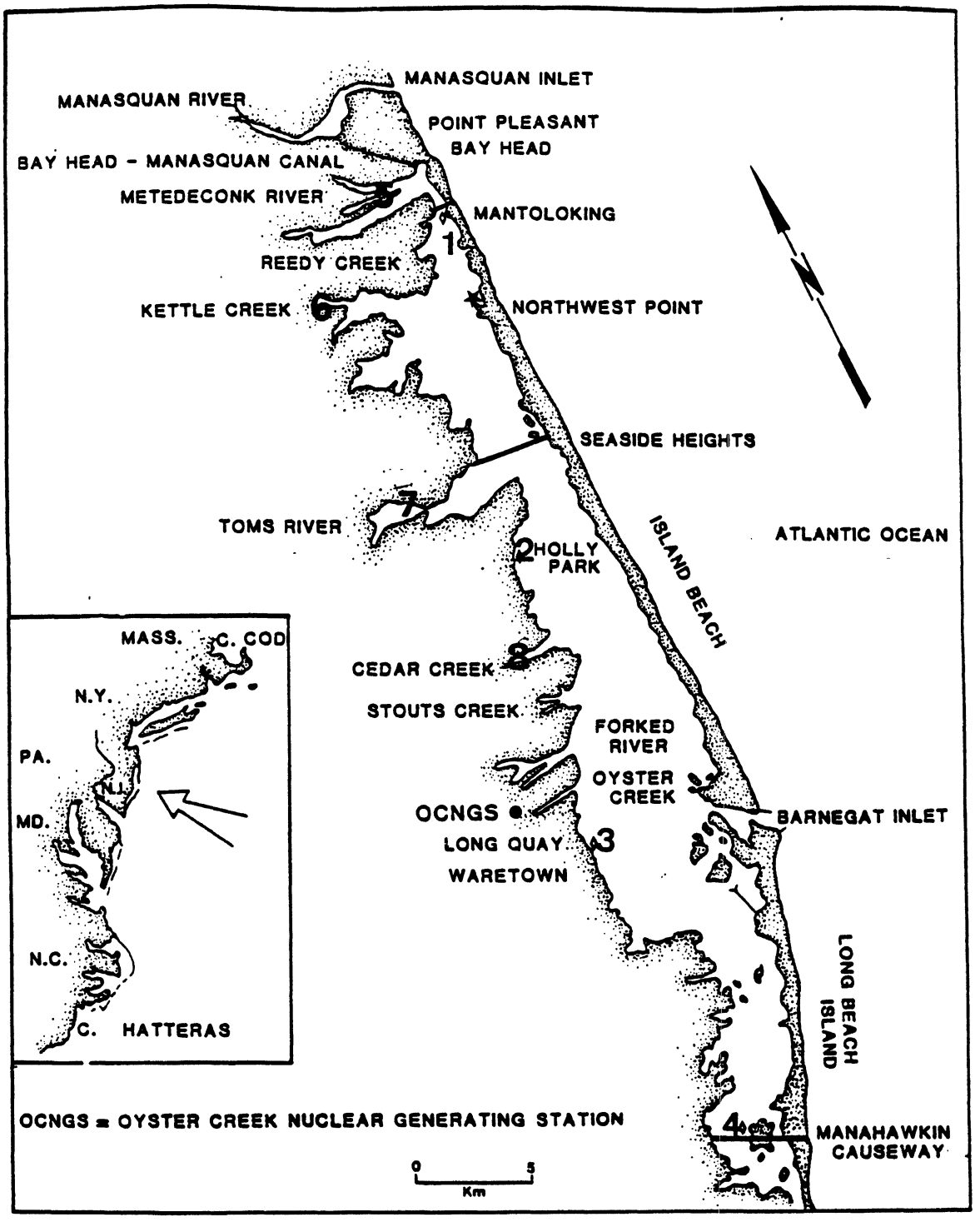

Figure 8. Map of Barnegat Bay, New Jersey, indicating NJDEPE DSR water column nutrient and primary production sampling stations (1-4); tributary nutrient sampling stations (5-8) and ANSP N or P limitation experiment station (★).

1-North Mantoloking, 2-Holly Park, 3-Waretown, 4-South-Manahawkin, 5-Metedeconk, 6-Kettle Creek, 7-Toms River and 8-Cedar Creek

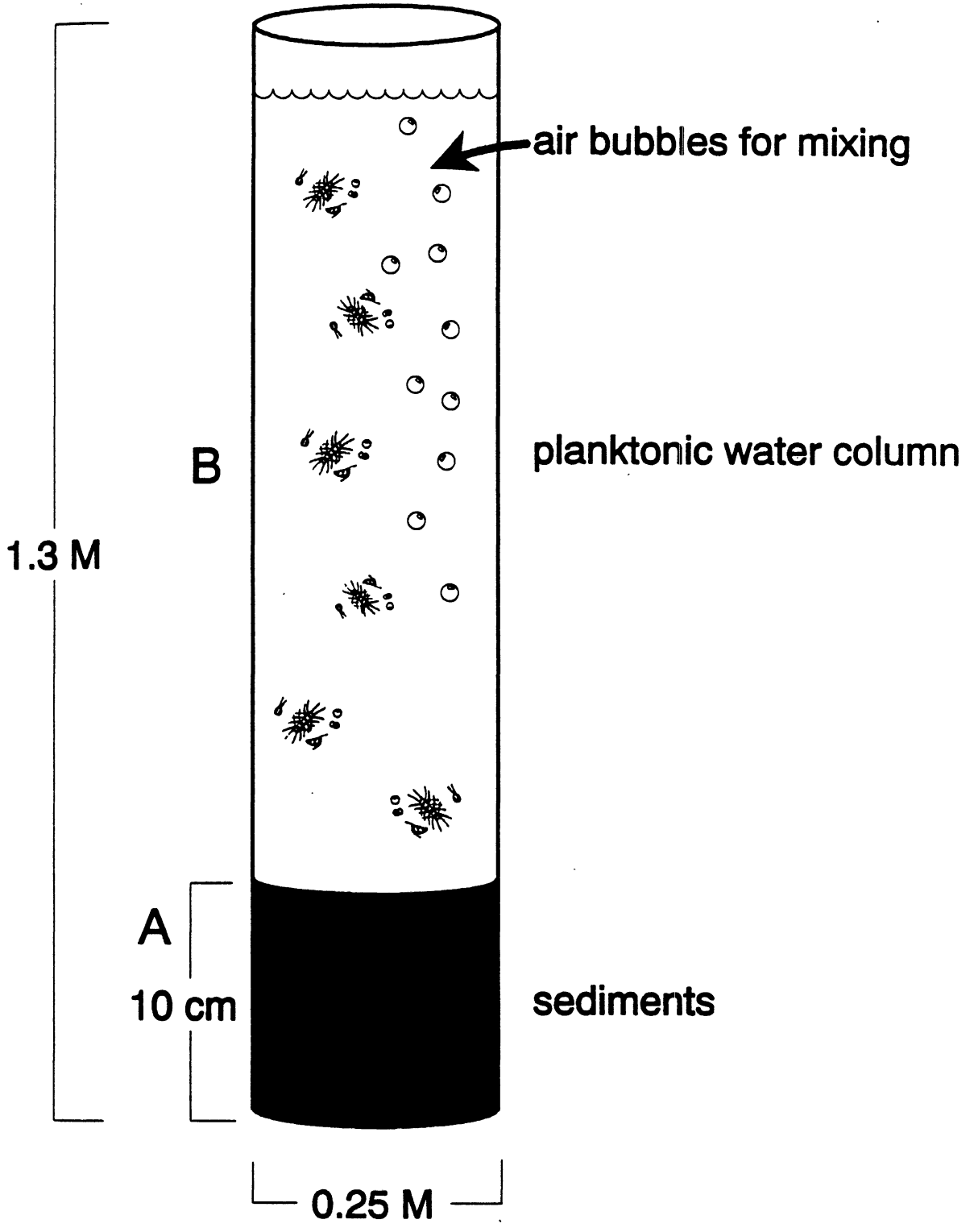

Figure 9. Schematic of Barnegat Bay microcosms with benthic sediments and planktonic water column components for studies of nutrient limitation. The microcosms are constructed of transparent plexiglass cylinders, 25 cm in diameter and 1.3-m high.

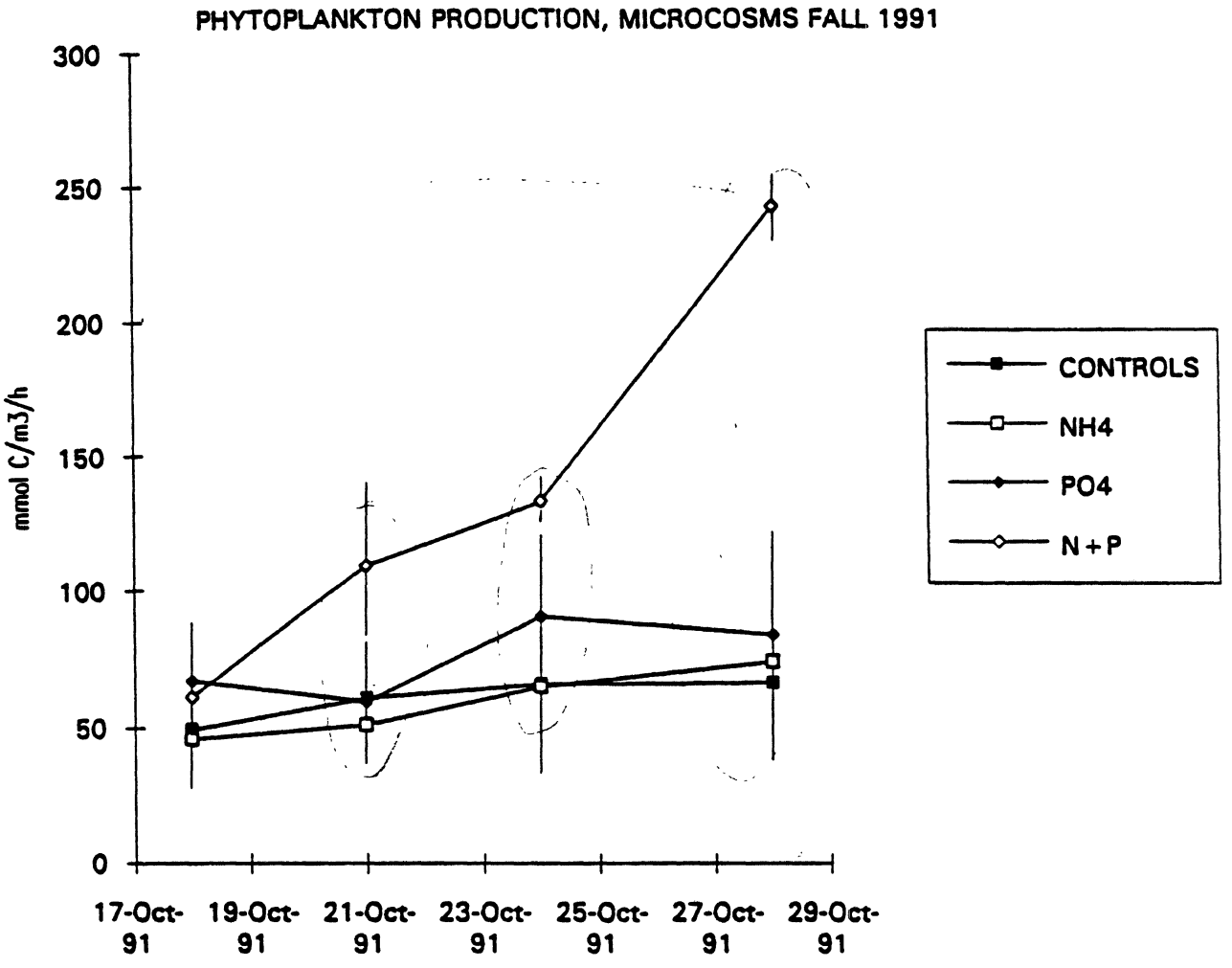

Figure 10. Phytoplankton photosynthesis rates in Barnegat Bay microcosms during the October 1991 nutrient enrichment experiment. The average ± S.D. for each treatment is shown.

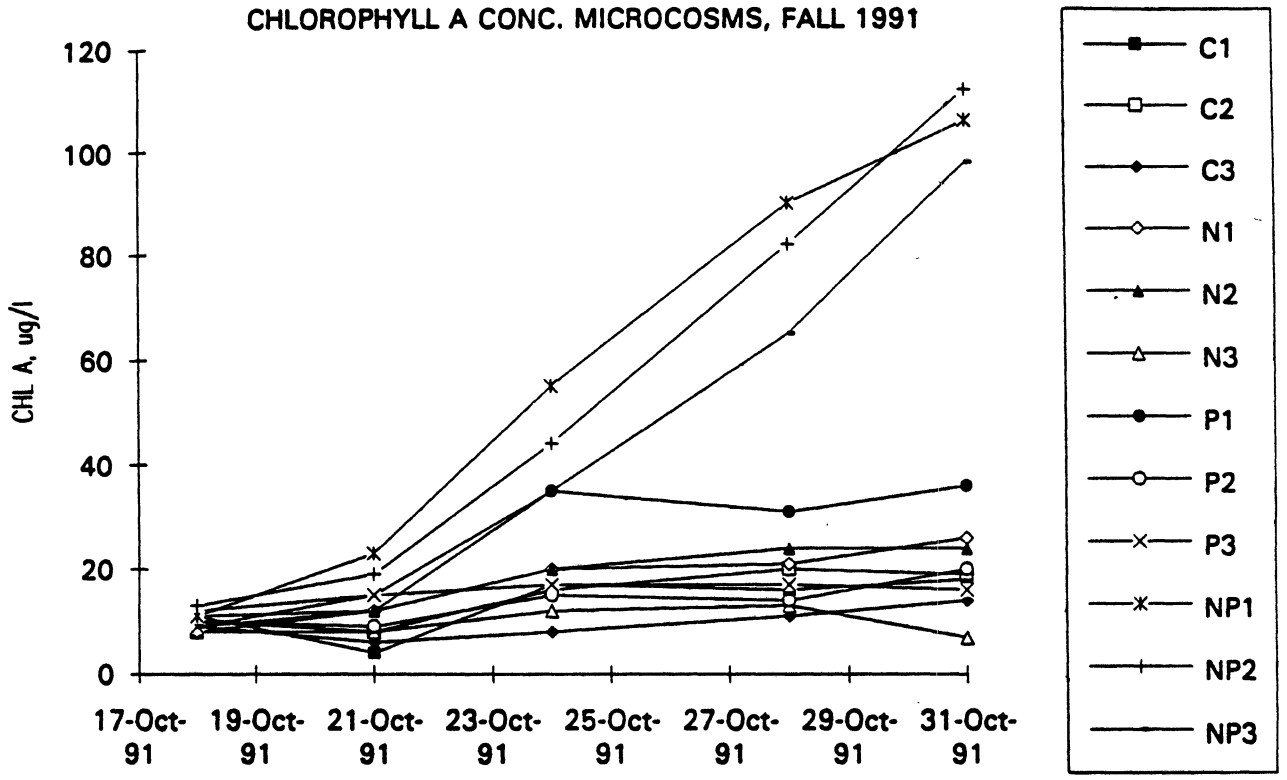

Figure 11. Chlorophyll *a* concentrations (µg/L) in Barnegat Bay microcosms during the October 1991 nutrient enrichment experiment.

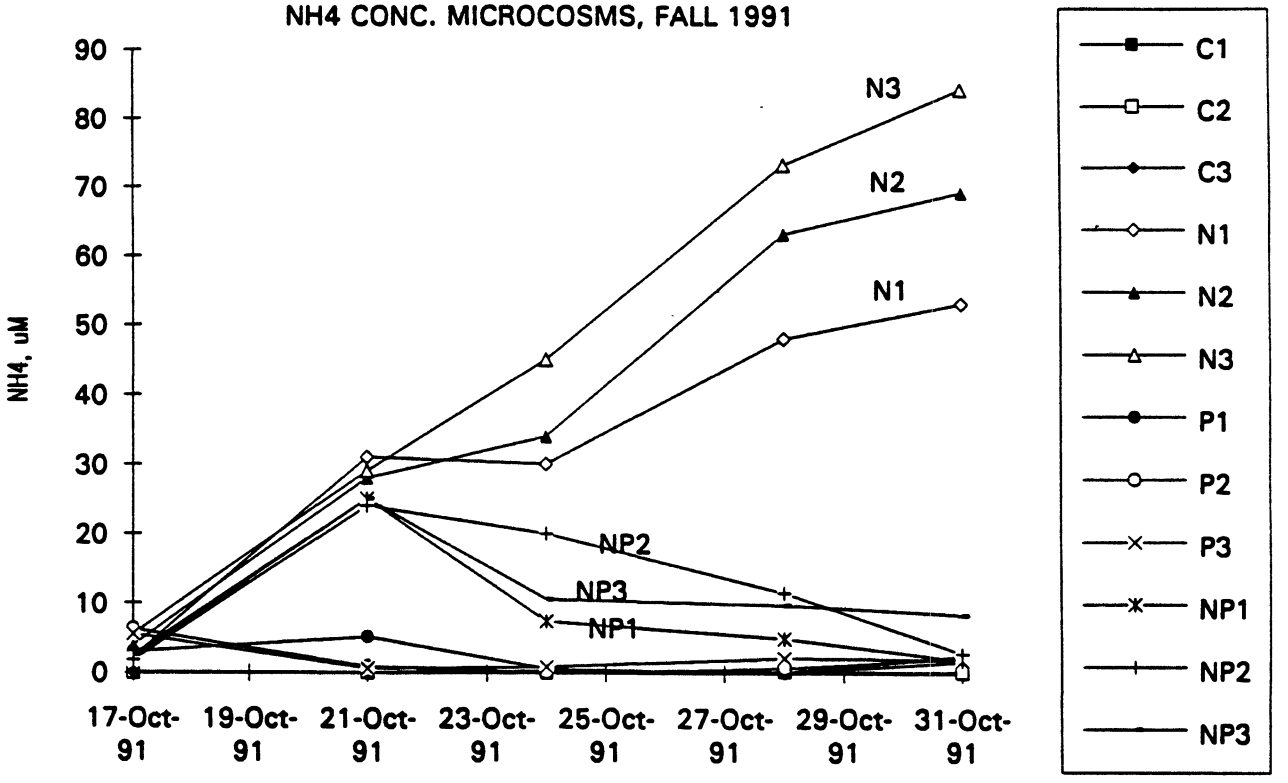

Figure 12. Ammonia concentrations (μM) in Barnegat Bay microcosms during the October 1991 nutrient enrichment experiment.

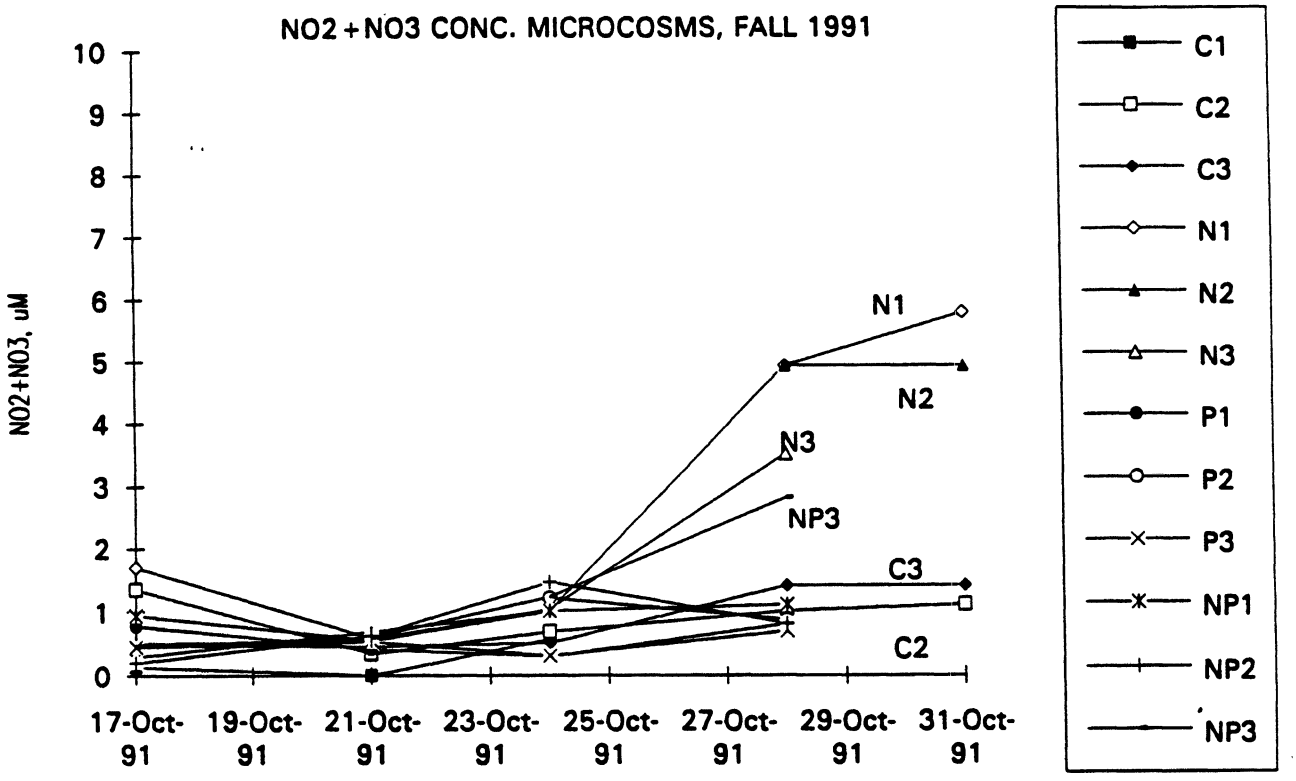

Figure 13. Nitrate plus nitrite concentrations (μM) in Barnegat Bay microcosms during the October 1991 nutrient enrichment experiment.

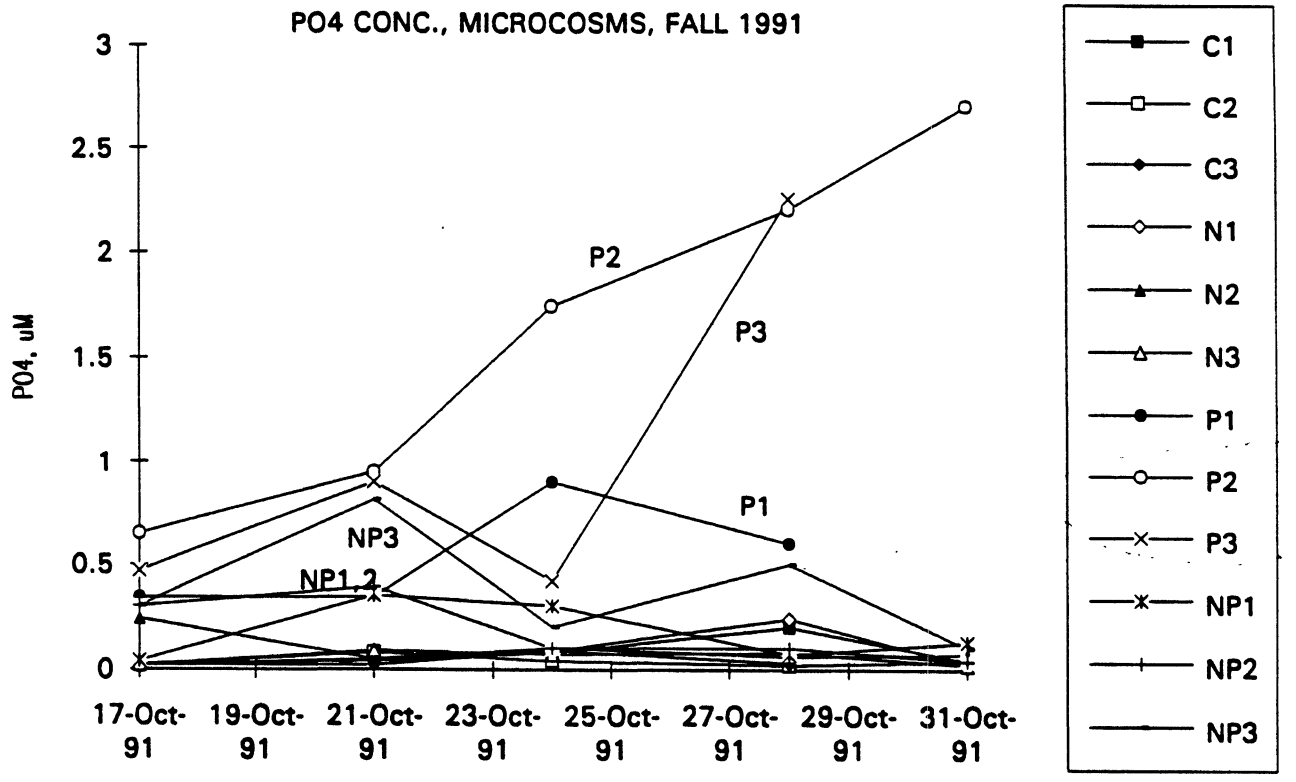

Figure 14. Phosphate concentrations (μM) in Barnegat Bay microcosms during the October 1991 nutrient enrichment experiment.

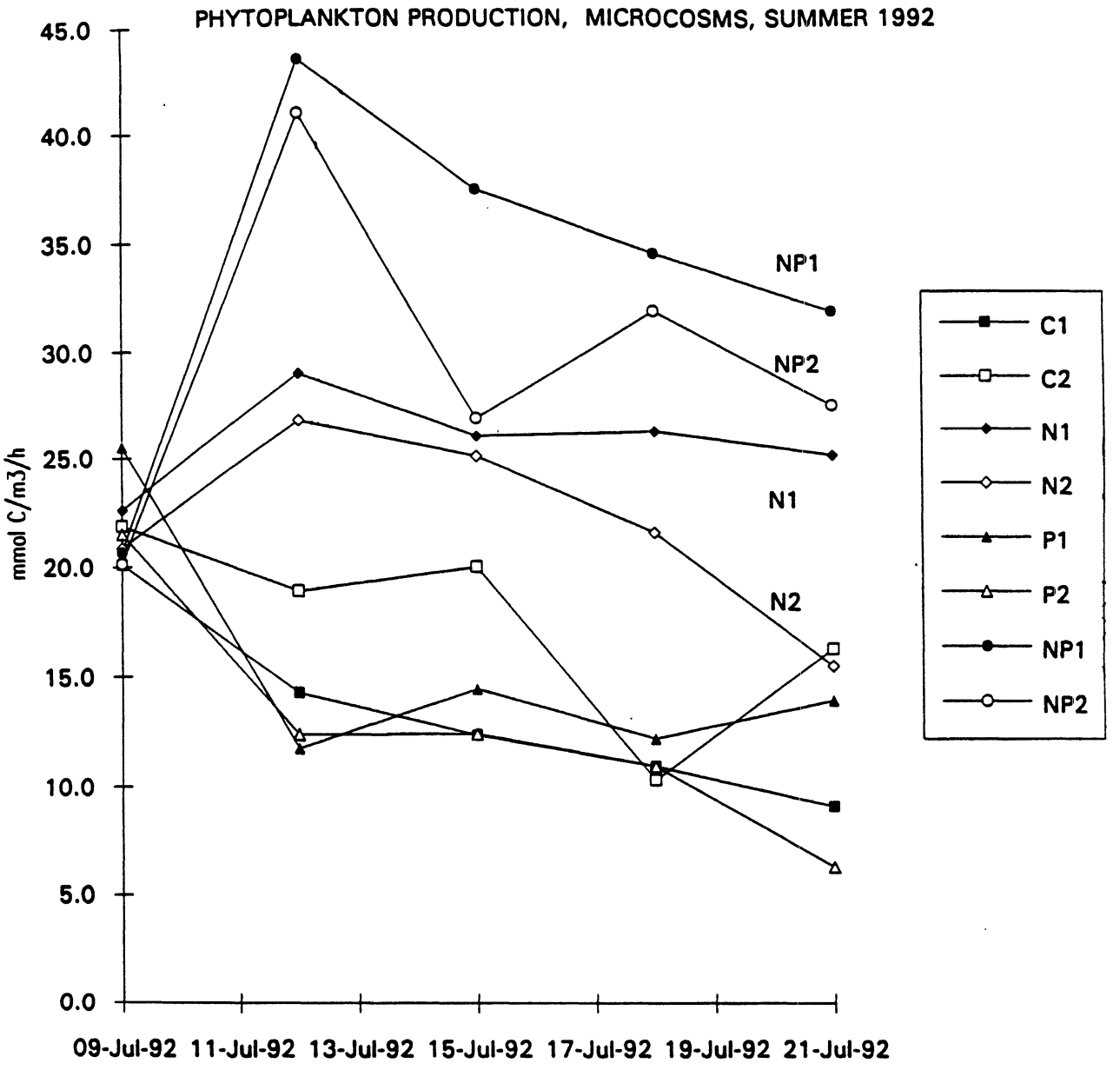

Figure 15. Phytoplankton photosynthesis rates in Barnegat Bay microcosms during the July 1992 nutrient enrichment experiment.

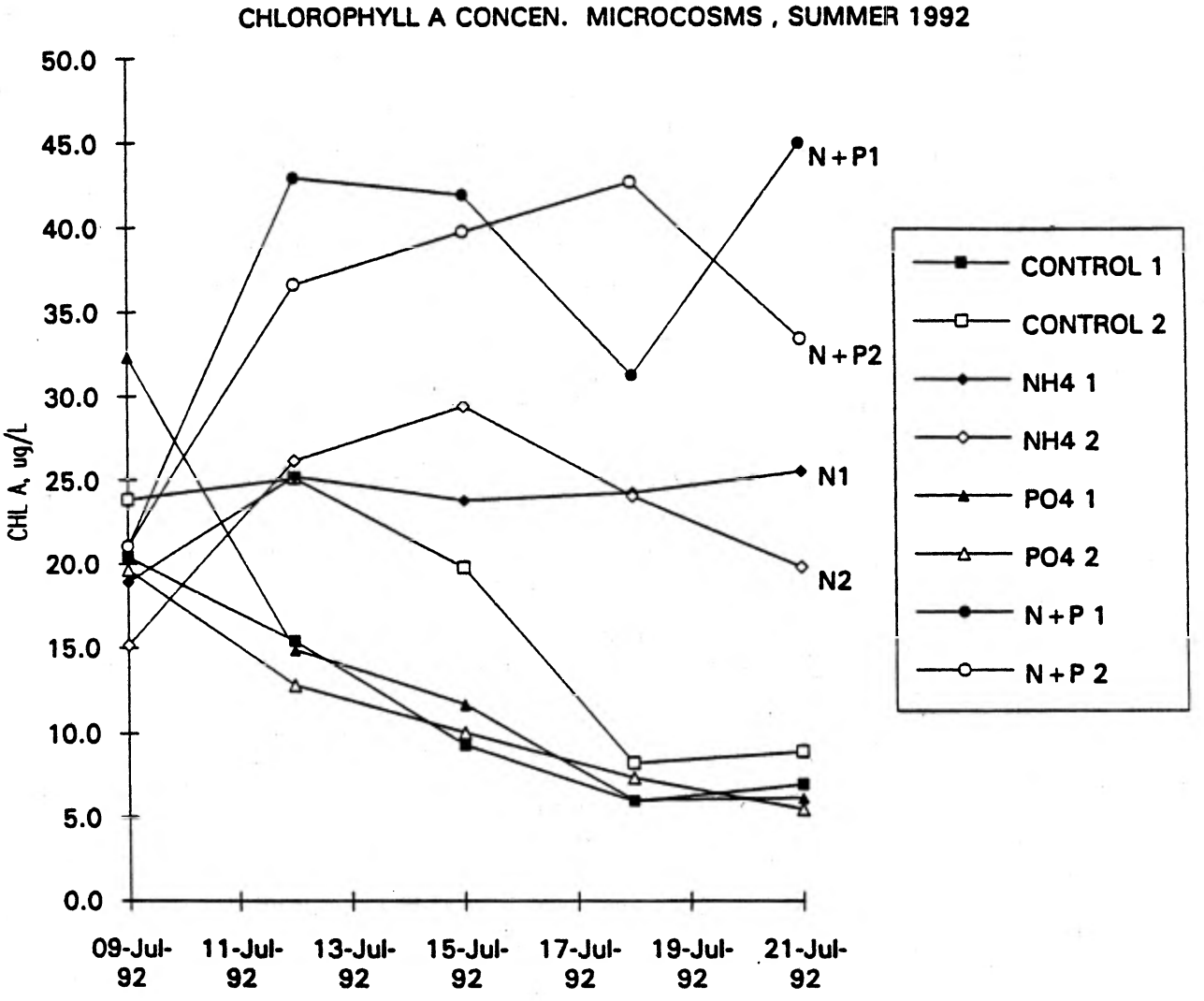

Figure 16. Chlorophyll *a* concentrations (μg/L) in Barnegat Bay microcosms during the July 1992 nutrient enrichment experiment.

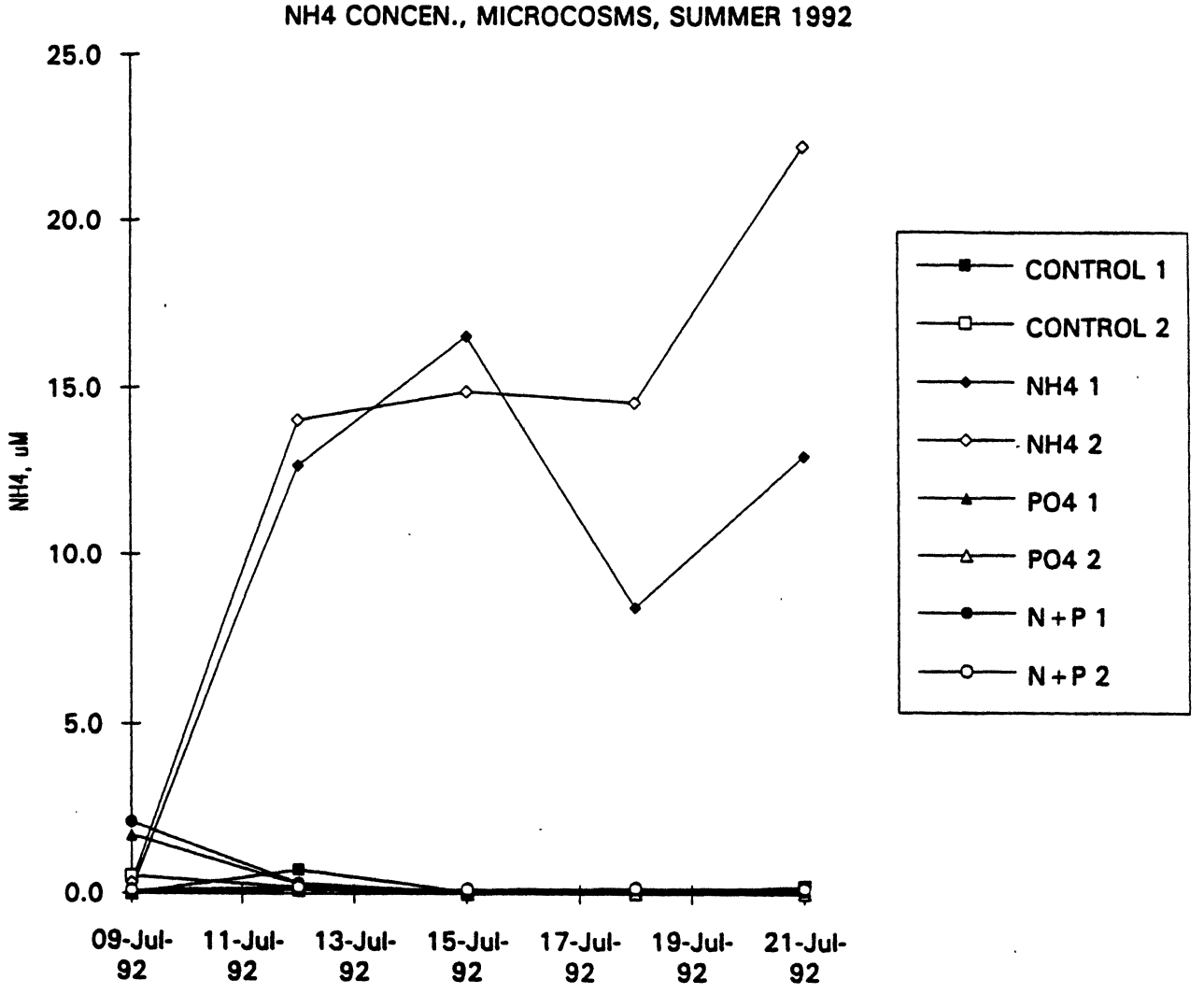

Figure 17. Ammonia concentrations (μM) in Barnegat Bay microcosms during the July 1992 nutrient enrichment experiment.

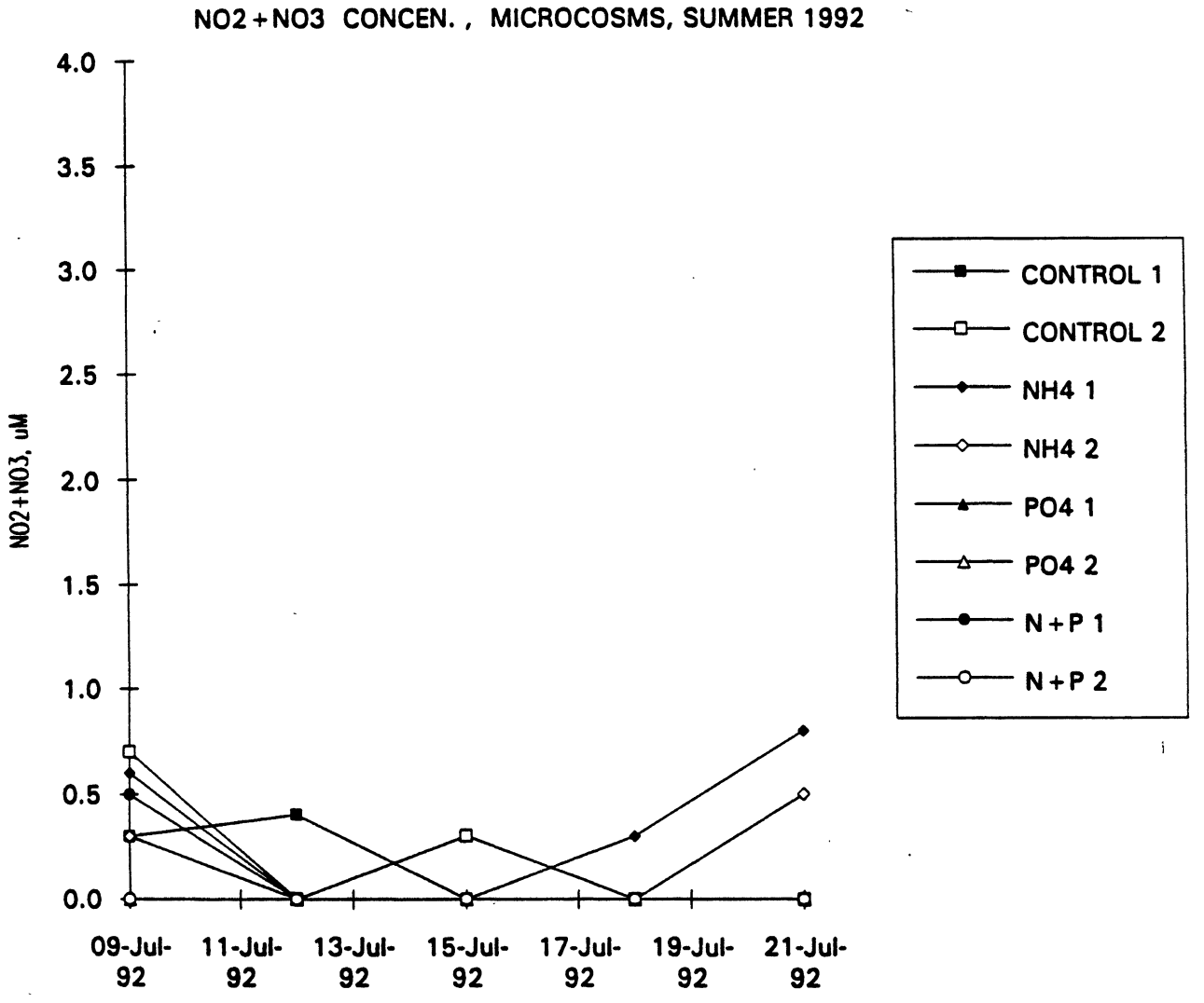

Figure 18. Nitrate plus nitrite concentrations (μM) in Barnegat Bay microcosms during the July 1992 nutrient enrichment experiment.

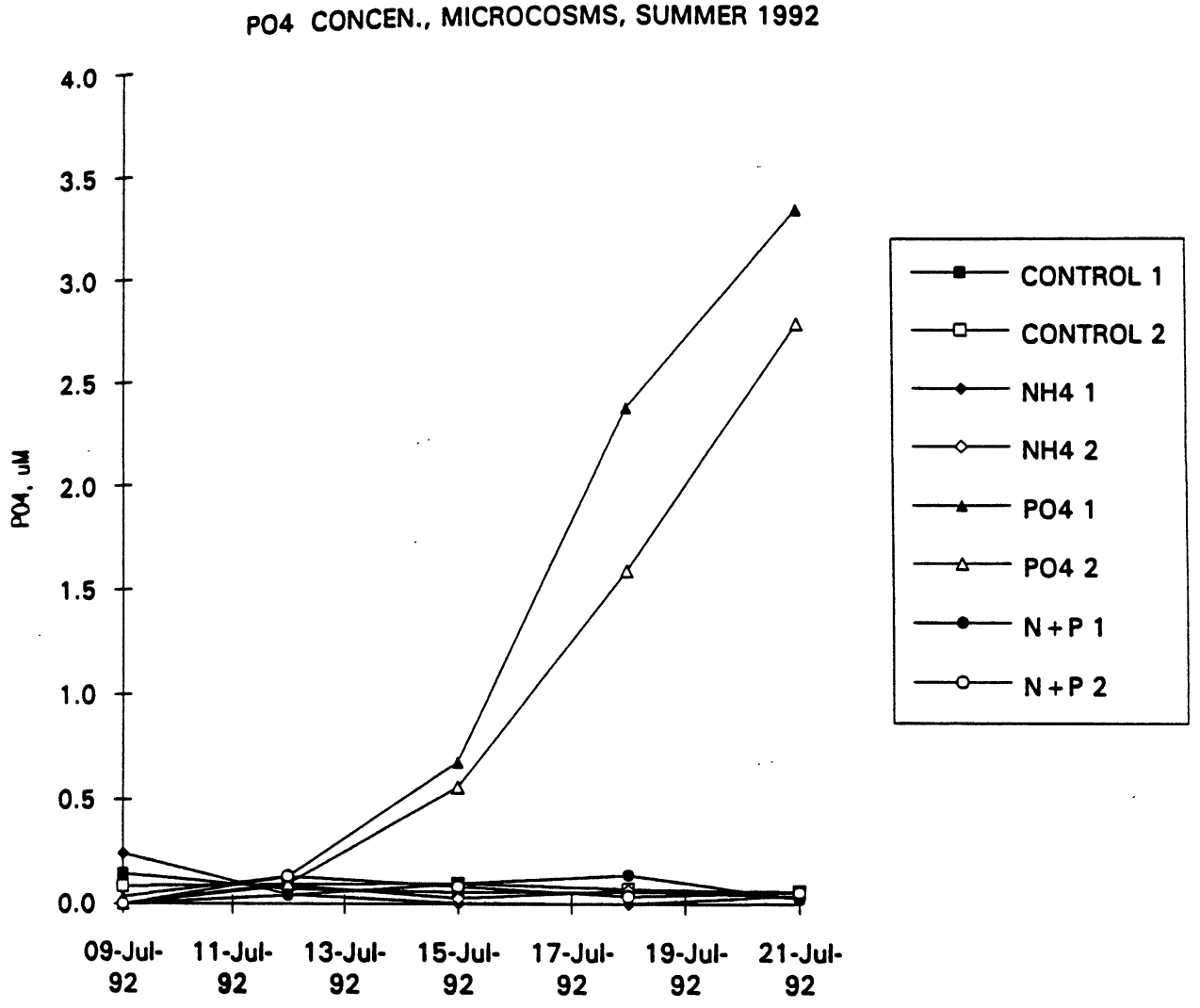

Figure 19. Phosphate concentrations (μM) in Barnegat Bay microcosms during the July 1992 nutrient enrichment experiment.

Table 1. Physical parameters during Barnegat Bay microcosm nutrient limitation experiments.

Parameter	October 1991	July 1992
Water Depth	~100 cm	~100 cm
Water Volume	~51 L	~51 L
Sediment Depth	~10 cm	~10 cm
Temperature	18°C	21°C
Salinity	18 ppt	21 ppt
Light Cycle	6 h on:18 h off	8 h on:16 h off
Light Intensity ($\mu Em^{-2}s^{-1}$) (mid-depth: 50 cm)	250-300	250-300

Table 2. Results of statistical analyses of chlorophyll and primary production data from summer and fall microcosm nutrient enrichment studies. ρ values from analysis of variance (ANOVA) with repeated measures test are shown: (A) grouping factor indicates differences between mean values of chlorophyll or primary production for the treatments indicated; pooled orthogonal polynomial results for (B) within factor and (C) the interaction between time and chlorophyll or primary production.

	Prim			Chlorophyll		
Treatment	**A**	**B**	**C**	**A**	**B**	**C**
			Summer			
C+N	0.0948	0.0392	0.0546	0.0881	0.0398	0.0092
C+P	0.6565	0.0010	0.2858	0.6399	0.0005	0.3593
C+N+P	0.0313	0.0081	0.0008	0.0185	0.1349	0.0073
			Fall			
C+N	0.8611	0.3117	0.9208	0.3877	0.0003	0.8320
C+P	0.3116	0.2145	0.6990	0.2370	0.0004	0.5509
C+N+P	0.0003	0.0000	0.0000	0.0008	0.0000	0.0000

Table 3. Phytoplankton species composition and abundance (#/ml) from Barnegat Bay microcosms sampled 31 October 1991.

	Initial	C1	C2	C3	N1	N2	N3	P1	P2	P3	NP1	NP2	NP3
Total Phytoplankters	2084	4410	2847	3847	4110	2897	2576	5559	2144	2402	3804	2890	4109
Total Microflagellates	1706	2889	1796	3568	2679	2635	2247	3923	2012	2218	2710	1797	3970
sm. (1-5 μm) undet. flagellates	1081	2053	816	1776	1816	1304	1194	2017	959	2077	1586	817	3017
Calycomonas sp.	185	257	778	1586	770	778	1015	1282	1015	56	1007	778	921
Cryptomonas acuta	222	401	60	148	32	104	14	153	24	19	72	60	16
C. ovata	49	20	104	0	13	60	0	131	9	14	13	38	8
Cryptomonas sp.	169	158	38	58	48	389	24	340	5	52	32	104	8
Total Diatoms	33	1336	1046	254	1078	235	286	778	113	160	1053	1046	114
Nitzschia closterium	0	1198	937	197	921	148	197	515	89	103	941	937	90
undetermined pennate diatoms	21	112	104	41	125	60	70	252	19	52	92	104	16
undetermined centric diatoms	12	26	5	16	32	27	19	11	5	5	20	5	8
Total Dinoflagellates	345	185	5	25	34	27	43	658	19	24	27	37	25
Amphidinium crassum	29	13	0	0	0	0	0	0	0	0	0	0	0
Gymnodinium sp.	25	7	0	0	7	11	24	11	5	5	13	5	0
Gyrodinium sp.	70	145	0	25	20	16	14	647	9	19	7	27	25
Heterocapsa triquetra	45	0	0	0	0	0	0	0	0	0	0	0	0
Katodinium rotundatum	0	7	0	0	0	0	0	0	0	0	0	0	0
Peridinium brevipes	0	0	0	0	7	0	5	0	5	0	7	0	0
Polykrikos hartmanii	12	0	0	0	0	0	0	0	0	0	0	0	0
Prorocentrum dentatum	152	13	0	0	0	0	0	0	0	0	0	0	0
P. minima	12	0	5	0	0	0	0	0	0	0	0	5	0
Total Euglenoids	0	0	0	0	0	0	0	0	0	0	7	5	0
Trachelomonas sp.	0	0	0	0	0	0	0	0	0	0	0	5	0
undetermined euglenoid	0	0	0	0	0	0	0	0	0	0	7	0	0

Table 4. Phytoplankton species composition and abundance (#/ml) from Barnegat Bay microcosms sampled 22 July 1992.

	Initial	C1	C2	N1	N2	P1	P3	NP2	NP3
Total Phytoplankters	2487	2163	3397	11542	4359	4404	4351	4257	4217
Total non-blue-green	2343	1999	3323	11408	4233	4009	4009	4123	4116
Total Microflagellates	902	638	1307	1176	873	1412	1605	1041	1512
Cryptomonas acuta	154	71	302	235	176	269	412	92	286
Pyramimonas sp.	24	8	47	17	0	25	17	0	0
undet. microflagellates (5-10 μm)	494	173	395	353	319	454	412	344	521
undet. microflagellates (<5 μm)	230	386	563	571	378	664	764	605	705
Total Diatoms	1210	1298	1856	10080	3302	2538	2436	3066	2495
Nitzschia closterium	0	0	7	0	0	34	17	8	0
Thalassiosira (?)	0	0	0	0	118	59	33	0	0
undetermined pennate diatoms	1210	1248	1749	9895	2999	2218	2184	2873	2352
undetermined centric diatoms	0	50	100	185	185	227	202	185	143
Total Dinoflagellates	202	55	147	152	50	51	58	8	109
Gymnodinium splendens	0	0	0	17	0	0	0	0	0
Gymnodinium sp.	39	13	80	34	8	34	42	0	0
Peridinium sp.	48	17	27	17	17	0	8	0	0
Peridinium (?) sp.	115	4	13	34	17	0	0	8	17
Prorocentrum minima	0	21	27	50	8	17	8	0	92
Total Euglenoids	29	8	13	0	8	8	0	8	0
Euglena sp.	24	0	13	0	8	8	0	8	0
Trachelomonas sp.	5	8	0	0	0	0	0	0	0
Total Blue-Greens	144	164	74	134	126	395	252	134	101
Schizothrix calcicola	144	164	74	134	126	395	252	134	101