You are Viewing an Archived Copy from the New Jersey State Library

EUTROPHICATION AND NUTRIENT LOADING IN BARNEGAT BAY: SEDIMENT-WATER PHOSPHORUS DYNAMICS, YEAR III, FINAL REPORT

contract no. P32104 1 March 1993

DSR contact, Mary Downes Gastrich

DEP

DEP
QH
91.8
.E87
S45
1993

You are Viewing an Archived Copy from the New Jersey State Library

F490
P32104
4810-100-180000-36
PROPERTY OF NEW JERSEY
D.E.P. INFORMATION
RESOURCE CENTER
DEP
QH
91.8
.E87
S45
1993

EUTROPHICATION AND NUTRIENT LOADING IN BARNEGAT BAY: SEDIMENT-WATER PHOSPHORUS DYNAMICS

YEAR III
(Contract No. P32104)

FINAL REPORT
Report No. 92-33F

Reference:
Research Agenda Item III. Coastal Research, A. Eutrophication, and C. Effects of Development Pressure on the Ecology of Barnegat Bay.

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

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

Co-Investigator:
Isabel E. Pilling

Submitted:

1 March 1993

THE ACADEMY OF NATURAL SCIENCES

Division of Environmental Research
1900 Benjamin Franklin Parkway, Philadelphia, PA 19103

NEW JERSEY STATE LIBRARY
3 3009 00587 1043

You are Viewing an Archived Copy from the New Jersey State Library

Property of NJDEP
Information Resource Center

EXECUTIVE SUMMARY

The bottom sediments in Barnegat Bay remove considerable amounts of nutrients (both nitrogen, N, and phosphorus, P) from the Bay, and thus are an important factor reducing the amount of N and P available for phytoplankton production. Our previous studies demonstrated that benthic algae on the sediment surface control the release of N from the sediments by assimilating ammonia as it diffuses across the sediment-water interface. The objective of the current study was to provide additional insight into the mechanisms responsible for the efficient removal of P in the Bay sediments. Experiments were conducted to investigate possible mechanisms which might account for the lack of P release from Barnegat Bay sediments during decomposition of organic matter, including more extensive experiments with benthic algae, permanent burial of P in the sediments, release of P to the water column following resuspension of bottom sediments, and transport of P out of the Bay on suspended sediments.

At the silt-clay study site, permanent burial of P in the sediments was estimated to account for approximately 70% of the P removal in the sediments, and export of P out of the Bay due to suspended sediment transport was estimated to account for and additional 20% or less. At the sandy study site, burial or export on suspended sediments were estimated to account for less than 10% each.

Eutrophication 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 Barnegat Bay are expected to increase in the future due to continued population growth in the Bay watershed. However, predicting the effects of increased development depends on a clear understanding of nutrient dynamics (including the relationship between nutrient inputs and eutrophication) 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 from the NJDEPE DSR, studies in Barnegat Bay were initiated in the summer of 1988 (Seitzinger and Pilling 1990, 1992). The objectives of those studies were to begin 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

06/12/06 OCLC # 3902 5693 Horizon # 85144

You are Viewing an Archived Copy from the New Jersey State Library

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 affect the amount of nutrients available for algal (phytoplankton) production. Sediment-water nutrient [nitrogen (N) and phosphorus (P)] exchanges, therefore, were a major focus of the study. In addition, measurements were made of water column nutrient concentrations, phytoplankton production rates, benthic algal plus seagrass primary production rates, organic matter deposition rates and sediment metabolism. Results from those studies considerably advanced our understanding of the current conditions in Barnegat Bay.

A major conclusion of those studies was that Barnegat Bay is currently in a relatively eutrophic state (Seitzinger and Pilling 1992). For example, phytoplankton production rates, chlorophyll concentrations (indicative of algal biomass) and water column turbidity are high in Barnegat Bay relative to many East Coast estuaries that are themselves receiving large inputs of anthropogenic nutrients (both N and P) and are considered to be relatively eutrophic.

A second conclusion of those studies was that there is considerable benthic algal production (benthic microalgae such as benthic diatoms) 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.

A third conclusion of those studies was that the bottom sediments are removing considerable amounts of nutrients (both N and P) from the Bay, and thus 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 some of the N released during the decomposition of organic matter in the Bay sediments is recycled to the water column by diffusive flux. This contrasts with nutrient processing in deeper estuaries where 25% to 50% or more of the N and P requirements of phytoplankton often are supplied by benthic recycling processes. Our studies in Barnegat Bay demonstrated that uptake of N (ammonia) by benthic algae is a major factor reducing the release of N from the sediments to the water column (Seitzinger and Pilling 1992). 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 benthic algae are important in other systems similar to Barnegat Bay.

Mechanisms reducing P release from the sediments were not obvious from our previous studies. The current experiments were undertaken to provide additional insight into the mechanisms responsible for the efficient removal of P in the Bay sediments.

While benthic algal production, in general, can account for the low rates of sediment-water ammonia fluxes in Barnegat Bay, the data indicate that phosphate fluxes are controlled primarily by a mechanism other than benthic algae. In the current studies

You are Viewing an Archived Copy from the New Jersey State Library

we conducted more extensive experiments with benthic algae and further confirmed that P fluxes from the Bay sediments are not controlled solely by benthic algal production. Phosphate fluxes remained undetectable even after sediments were pre-incubated in the dark for 6-9 days which depletes the ability of algae to take up nutrients in the dark.

Other mechanisms to account for the lack of P release from Barnegat Bay sediments were investigated in the current studies, including permanent burial of P in the sediments, release of P to the water column following resuspension of bottom sediments, transport of P out of the Bay on suspended sediments, and a reconsideration of the expected release of P from the sediments based on the P content of the organic matter decomposed in the sediments.

Permanent burial of phosphate sorbed to metal oxides in the sediments is an important mechanism of phosphate retention in freshwater systems. However, P burial in the sediments is not a major P removal mechanism in Barnegat Bay. The calculated rate of net P burial at the silt-clay site was estimated to be approximately 16 to 21 mmol P m^{-2} yr^{-1} or 50-70 μmol m^{-2} d^{-1}, which is small compared to the "missing" P of 195 μmol m^{-2} d^{-1}. The rate of P burial in the sandy sediments was estimated to be even less than at the silt-clay site.

Phosphate sorbed to metal oxides in the sediment is in chemical equilibrium with phosphate dissolved in the pore waters. We hypothesized that when sediments are resuspended into the water column by waves or heavy boating activity, some sorbed P may be released to the overlying water as it equilibrates with the low P Bay water. However, experiments of P exchange from resuspended bottom sediments showed that release of P from resuspended bottom sediments is not a significant mechanism for P transfer to the water. There was no measurable release of P to the water when sediments were resuspended at low, medium or high rates. In fact, our experiments indicate that resuspension of bottom sediments may decrease water column P concentrations when there is a pulse input of P to the Bay such as during a storm event.

A third fate of P sorbed to surface sediments could be transport out of the Bay with suspended sediments. Estimated export of P from the Bay due to suspended sediment transport was calculated to be 22 μmol P m^{-2} d^{-1}, and small relative to the "missing" P from benthic fluxes.

While essentially all of the P removal mechanisms that are generally considered to occur in estuarine sediments were examined in this study, none of those mechanisms alone was found to be sufficient to explain the lack of P release from Barnegat Bay sediments. Low rates of P release from shallow estuarine sediments have been reported in the few other studies in systems similar to Barnegat Bay. The data from Barnegat Bay and other shallow coastal sediments contrast with data from deeper estuaries such as Narragansett Bay where the release of P from the sediments can be predicted based on the rate of organic matter decomposition.

You are Viewing an Archived Copy from the New Jersey State Library

The studies conducted here, in combination with our previous studies in Barnegat Bay (Seitzinger and Pilling 1989 and 1992), demonstrate that nutrient processes in Barnegat Bay differ quite markedly from nutrient processing in deeper estuaries. Considerable amounts of ammonia and phosphate are recycled from sediments (diffuse out of the sediments following decomposition of organic matter) in most deeper estuaries, often supplying 25% to 50% of phytoplankton N and P requirements. However, in Barnegat Bay the release of N and P from the sediments is much reduced. No P is released from the sediments and the N release (and in part P) is greatly reduced due to assimilation by benthic algae. In addition, P is removed more efficiently than N which also contrasts with patterns in deeper estuaries where N is generally removed more efficiently (via denitrification) than P.

The decreased release of both N and P from the sediments decreases nutrients available for phytoplankton growth in the water column and thus, in effect, decreases the magnitude of eutrophication in the Bay for a given rate of external nutrient input, as a portion of those external inputs are being removed by the sediments. These findings have important implications for management decisions regarding future control of nutrient inputs to Barnegat Bay as models of nutrient control based on the relationship between nutrient inputs and eutrophication developed for deeper estuaries are not applicable, in a number of ways, to Barnegat Bay and likely to other shallow back bay estuaries. We currently are working with the US Army Corp of Engineers, Waterways Experiment Station, to modify the 3-D Coupled hydrodynamic water quality model developed for Chesapeake Bay so that it is applicable to the Delaware Inland Bays and other shallow coastal lagoons where sediment-water nutrient interactions differ markedly from those in deeper estuaries.

Based on the data presented in this and previous reports, it appears that water quality management plans developed for Barnegat Bay should consider ways to control water column turbidity so as to minimize nutrient release from benthic sediments. Ideally, turbidity in mid-summer should be decreased to allow more light to reach the sediment surface. At a minimum, turbidity should not be allowed to increase above current levels.

You are Viewing an Archived Copy from the New Jersey State Library

TABLE OF CONTENTS

Property of NJDEP
Information Resource Center

You are Viewing an Archived Copy from the New Jersey State Library

LIST OF FIGURES

Page

You are Viewing an Archived Copy from the New Jersey State Library

LIST OF TABLES

Page

 Digitized by Archived Copy from the New Jersey State Library

ABSTRACT

With funds from the NJDEPE DSR, studies in Barnegat Bay were initiated in the summer of 1988 to (1) assess the current state of eutrophication in the Bay, and (2) investigate factors controlling nutrient availability in the Bay, and thus, eutrophication. Sediment-water nutrient [nitrogen (N) and phosphorus (P)] exchanges, were the primary focus. The major conclusions were: (1) Barnegat Bay is relatively eutrophic; (2) in contrast to larger, deeper estuaries, there is considerable benthic algal production in Barnegat Bay in addition to seagrass production; (3) unlike deeper estuaries, where the release of N and P due to benthic decomposition of organic matter is an important source of nutrients for phytoplankton, the bottom sediments in Barnegat Bay retain considerable amounts of N and P produced in the sediments, making them an important factor regulating the degree of eutrophication by reducing the amount of N and P available for phytoplankton production.

These studies demonstrated that while benthic algal production generally can account for the low rates of release of ammonia from Barnegat Bay sediments, factors in addition to benthic algae are controlling P fluxes. Experiments were conducted in the current study to investigate possible mechanisms which might account for the lack of P release from Barnegat Bay sediments during decomposition of organic matter, including more extensive experiments with benthic algae, permanent burial of P in the sediments, release of P to the water column following resuspension of bottom sediments, and transport of P out of the Bay on suspended sediments.

Burial of mineral P does not appear to be an important process in sandy sediments in Barnegat Bay; however, it may account for as much as 70% of the "missing" P at the silt-clay site. The calculated rate of net P burial at the silt-clay site was estimated to be approximately 16 to 21 mmol P m^{-2} yr^{-1} or 50-70 mol m^{-2} d^{-1}, which is approximately 70% of the "missing" P at that site (98 mol m^{-2} d^{-1}). The rate of P burial in the sandy sediments, however, is likely less than half that at the silt-clay site because the total P content of the sandy site sediment (approx. 0.15 mg P/gds, Seitzinger and Pilling 1992) is half that at the silt-clay site and net sediment accumulation rates in sandy sediments are generally considerably less than in finer grained sediments.

Experiments of P exchange from resuspended bottom sediments showed that this is not a significant mechanism for P transfer to the water. In fact, resuspension of bottom

You are Viewing an Archived Copy from the New Jersey State Library

sediments may decrease water column P concentrations when there is a pulse input of P to the Bay.

Estimated export of P from the Bay due to suspended sediment transport was calculated to be 22 mol P m^{-2} d^{-1}, which is estimated to account for approximately 20% of the "missing" P from benthic fluxes at the silt-clay site and less than 10% at the sandy site.

The studies conducted here, combined with previous studies, demonstrate that nutrient processes in Barnegat Bay differ markedly from those in deeper estuaries. These findings have important implications for management decisions regarding future control of nutrient inputs to Barnegat Bay since current models of estuarine nutrient control are based on the relationship between nutrient inputs and eutrophication developed for deeper estuaries, and are not applicable, in a number of ways, to shallow estuaries such as Barnegat Bay. We currently are working with the US Army Corp of Engineers, Waterways Experiment Station, to modify the 3-D Coupled hydrodynamic water quality model developed for Chesapeake Bay so that it is applicable to the Delaware Inland Bays and other shallow coastal lagoons where sediment-water nutrient interactions differ markedly from those in deeper estuaries.

Based on the data presented in this and previous reports, it appears that water quality management plans developed for Barnegat Bay should consider ways to control water column turbidity so as to minimize nutrient release from benthic sediments. Ideally, turbidity in mid-summer should be decreased to allow more light to reach the sediment surface. At a minimum, turbidity should not be allowed to increase above current levels.

You are Viewing an Archived Copy from the New Jersey State Library

INTRODUCTION

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. Nutrients (nitrogen, N and phosphorus, P) contributing to eutrophication enter these shallow bays from a variety of non-point and point sources (e.g., rivers, storm drains, runoff, atmospheric deposition, broken sewer pipes, groundwater, septic systems and direct discharge). Nutrient inputs to Barnegat Bay are expected to increase in the future due to continued population growth in the Bay watershed, as well as increased recreational day-use of the Bay.

Gauging the effects of increased development on eutrophication in Barnegat Bay is difficult, however, because little is known about nutrient dynamics (including the relationship between nutrient inputs and eutrophication) in Barnegat Bay or any of these 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 (D'Elia et al. 1986; Boynton et al. 1982; Nixon 1981). 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 is unknown.

Until recently there was essentially no information on the present state of eutrophication in Barnegat Bay. With funds from the NJDEPE DSR, studies in Barnegat Bay were initiated in the summer of 1988 (Seitzinger and Pilling 1990, 1992). The objectives of those studies were to begin 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 affect the amount of nutrients available for algal (phytoplankton) production. Sediment-water nutrient (N and P) exchanges, therefore,

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

You are Viewing an Archived Copy from the New Jersey State Library

were a major focus of the study. In addition, measurements were made of water column nutrient concentrations, phytoplankton production rates, benthic algal plus seagrass primary production rates, organic matter deposition rates and sediment metabolism. Results from those studies considerably advanced our understanding of the current conditions in Barnegat Bay.

A major conclusion of those studies was that Barnegat Bay is currently in a relatively eutrophic state (Seitzinger and Pilling 1992). For example, phytoplankton production rates in Barnegat Bay exceed those in many East Coast estuaries that are themselves receiving large inputs of anthropogenic nutrients (both N and P) and are considered to be relatively eutrophic. Chlorophyll concentrations (indicative of algal biomass) are high compared to those in relatively eutrophic estuaries. Water column turbidity is high, resulting in low light levels at the sediment surface, particularly in mid- to late summer.

A second conclusion of those studies was that there is considerable benthic algal production (benthic microalgae such as benthic diatoms) 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.

A third conclusion of those studies was that the bottom sediments are removing considerable amounts of nutrients (both N and P) from the Bay, and thus 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 some of the N released during the decomposition of organic matter in the Bay sediments is recycled to the water column by diffusive flux (Table 1). This suggests that nutrient processing in Barnegat Bay differs quite dramatically from nutrient processing in deeper estuaries where 25% to 50% or more of the N and P requirements of phytoplankton are often supplied by benthic recycling processes (Nixon 1981; Kemp et al. 1982; Boynton and Kemp 1985). Our studies in Barnegat Bay indicate that very little N and no P is released from the sediments to the water column by diffusive flux and thus the contribution of nutrients to the phytoplankton from the sediments is much reduced. Some insight into the mechanisms responsible for this efficient nutrient trap for N and P in the Bay sediments was obtained from the 1988-1989 studies. In particular, there was a relatively good relationship between benthic algal photosynthesis and ammonia release from the sediments: when benthic algal production was high, no ammonia was released; when benthic algal production was low or negligible, ammonia release rates were high. Thus, it was concluded that uptake of N (ammonia) by benthic algae is important in reducing the release of N back to the water column (Seitzinger and Pilling 1992). Denitrification may also be important in decreasing the recycling of N from the sediments to the water; however, no measurements of denitrification were made. Mechanisms reducing P release from the sediments were not obvious. Uptake of P by benthic algae did not appear to be entirely responsible as there was no measurable release of phosphate from the sediments at either the sandy or silt-clay site regardless of whether benthic algal production rates were high or low (Table 1; Seitzinger and Pilling 1992).

You are Viewing an Archived Copy from the New Jersey State Library

The current studies were undertaken to provide additional insight into the mechanisms responsible for the efficient removal of P in the Bay sediments. Mechanisms that were investigated included:

a) assimilation of P by benthic algae not detected in the previous year's experiments

b) release of P to the water following resuspension of bottom sediments from wave action or boating activity

c) transport of P out of the Bay sorbed to suspended sediment

d) burial of P sorbed to metal oxides in the sediments

e) decomposition of organic matter in the sediments depleted in P relative to N and C

The above mechanisms were considered to be most likely to account for the apparent efficient sink/trap for P in the sediments. The removal of P in the sediments is reducing the amount of P for phytoplankton production and thus reducing the degree of eutrophication in the Bay. Information from the above studies is necessary to predict if the P removal mechanisms are likely to continue to operate if external nutrient inputs to the Bay increase.

General Discussion of Nutrient Cycling in Estuaries

Nutrients enter estuaries from a variety of external sources including river inputs, direct discharges, storm drains, runoff, atmospheric deposition, broken sewer pipes, marinas and boating activity, groundwater and septic systems. Once in the estuary the N and P are used by the algae for growth; however, the external inputs of nutrients to estuaries generally are not sufficient to supply the needs of algae. Recycling of nutrients within the water column and between the benthic sediments and water is a major source of N and P supporting algal production in estuaries (Boynton et al. 1982; Nixon 1981).

Recycling is the release of inorganic nutrients (ammonia, nitrate and phosphate) following the decomposition (i.e. metabolism, respiration) of organic matter. The organic matter is decomposed (metabolized) by microbes, zooplankton, fish, benthic invertebrates, etc., in the water column and sediments. The nutrients are released directly to the water if the organic matter is consumed in the water, or through diffusive flux from the sediments if the organic matter is consumed by benthic organisms. The nutrients are used again by phytoplankton (algae) and seagrasses. It is during the decomposition of organic matter in the sediments that N and P can be removed temporarily or permanently from the estuary, thus decreasing the supply of nutrients for phytoplankton production and affecting the degree of eutrophication resulting from a given rate of external nutrient input to the estuary.

You are Viewing an Archived Copy from the New Jersey State Library

Basic Theory of Sediment-Water Flux Measurements

In estuaries and other shallow marine systems, a considerable amount of the organic matter produced by phytoplankton or by benthic photosynthesis is decomposed (consumed, oxidized) in the bottom sediments by benthic organisms and bacteria. During the oxidation of organic matter in the presence of free oxygen, oxygen is consumed and carbon dioxide, ammonia or nitrate, and phosphate are released. According to Richards (1965), the decomposition of typical organic matter (carbohydrate) can be described stoichiometrically by the following equation:

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 106O_2 = 106CO_2 + 16NH_3 + H_3PO_4 + 106H_2O \quad \text{(Eq. 1)}$$

According to this equation, 106 moles (212 atoms) of oxygen are consumed and 16 moles of nitrogen and 1 mole of phosphate are released for every mole of organic matter consumed. This ratio of C:O:N:P of 106:212:16:1 is referred to as the Redfield ratio for the decomposition of organic matter (Redfield 1934, 1958). The rate of oxygen consumption by benthic sediments (measured as the net flux of oxygen into benthic sediments from the overlying water) can be used to estimate organic carbon decomposition, as well as the expected rate of release of ammonia and phosphate to the water column from the sediments due to organic matter decomposition using Eq. 1 (Nixon 1981; Boynton and Kemp 1985; Hopkinson and Wetzel 1982).

The equation for photosynthesis is essentially the reverse of the one for decomposition:

$$106CO_2 + 16NH_3 + H_3PO_4 + 106H_2O = (CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 106O_2 \quad \text{(Eq. 2)}$$

Thus, for every 106 moles of carbon dioxide that phytoplankton or benthic algae and seagrasses fix into organic matter during photosynthesis, 16 moles of ammonia and 1 mole of phosphate are consumed and 106 moles (212 atoms) of oxygen are produced. This equation can be used to estimate the amount of ammonia and phosphate required to support measured rates of photosynthesis (rates of oxygen production).

Decomposition of organic matter by benthic organisms and bacteria (Eq. 1) and photosynthesis by benthic algae and seagrasses (Eq. 2) occur simultaneously during the day. This results in either a net production of oxygen (flux out of the sediments) if photosynthesis is greater than decomposition, or a net consumption of oxygen (flux into the sediments) if decomposition exceeds photosynthesis. In the dark (e.g., at night or at locations in the Bay where light levels are not high enough for photosynthesis to occur) only decomposition occurs. Rates of organic matter decomposition and benthic photosynthesis can be estimated based on the rates of O_2 flux in dark and light incubated cores as follows.

Gross (Total) Organic Matter Decomposition Rate = dark O_2 consumption rate

You are Viewing an Archived Copy from the New Jersey State Library

Gross Decomposition Rate + Gross (Total) Benthic Photosynthesis = light O_2 production or consumption rate

Gross Benthic Photosynthesis = light O_2 flux + dark O_2 consumption rate

Net Benthic Photosynthesis = light O_2 production rate

You are Viewing an Archived Copy from the New Jersey State Library

METHODS

Study Areas

Studies to examine factors responsible for the apparent efficient phosphate trap/sink in Barnegat Bay sediments were conducted during the summer and early fall of 1990 using sediments from two locations in the northern end of Barnegat Bay, which is currently the most highly developed region of the Bay (Rogers et al. 1990): one fine grained silt-clay sediment area (~2 m water depth) and one sandy sediment area (with benthic algae, ~1.2 m water depth) (Fig. 1). Both of these sites were included in the previous years' studies (Seitzinger and Pilling 1990, 1992).

Sediment cores (17 cm diameter; approx. 15 cm deep) for this study were collected by SCUBA-equipped divers using plastic coring tubes. Care was taken during coring to avoid disturbance of the sediment surface. At the time of sediment collection, water was collected from each location in carboys. The cores were maintained at ambient bay water temperature during transport to the laboratory. The oxygen in the water over the cores was maintained at near saturated concentrations with the use of portable aerators. Once in the laboratory, the sediment cores were maintained at ambient bay water temperature in a temperature-controlled environmental room. The water over all cores was changed regularly with water from the site of sediment collection and was aerated continuously and mixed by a gentle stream of air.

Experimental Measurements

The importance of a) assimilation of phosphate by benthic algae, b) uptake or release of phosphate during sediment resuspension, and c) biotic vs. abiotic controls on sediment-water phosphate exchanges were examined as follows:

Assimilation of Phosphate by Benthic Algae

Cores were collected in July, August and September 1990. The importance of benthic algae was examined by measuring sediment-water phosphate fluxes after holding cores in the dark 6-9 days to decrease any assimilation of phosphate by benthic algae. Benthic algal biomass was not measured, however, benthic photosynthesis at both sites was measurable during the summer and fall in the previous two years of study. The water

You are Viewing an Archived Copy from the New Jersey State Library

over all cores was changed regularly during the 6-9 day dark pre-incubation period with water from the site of sediment collection. The water over the cores was aerated continuously and mixed by a gentle stream of air.

After 6-9 days pre-incubation in the dark, the sediment-water exchange of phosphate, and at times oxygen, was measured on replicate cores as previously described (Seitzinger and Pilling 1992). Beginning approximately 1, 3, 6 and occasionally 24 h after the water over each core was changed with water from the site of sediment collection, samples of the water overlying the sediment cores were collected for P analysis (modified from Murphy and Riley 1962). In the September experiment, phosphate fluxes were measured after spiking the overlying water to 5 μM PO_4.

Oxygen concentrations in the overlying water were measured using a YSI oxygen probe. The probe and meter were calibrated prior to the first series of samples and the calibration was verified with each sample interval. Oxygen levels were monitored frequently, and when necessary, the water was reaerated to prevent oxygen levels in the overlying water from dropping below 4 mg O_2 L^{-1}.

In addition to sediment core incubations, beakers were filled with bay water from the site of sediment collection and used as controls for assessing changes in phosphate and oxygen concentrations in the water over the sediments due to water column processes. These controls were sampled at the same time intervals, using the same methods, as those used for sampling the water overlying the sediments.

Sediment-water phosphate and oxygen fluxes were calculated based on the time rate of change in the concentration of phosphate or oxygen in water overlying the sediment cores after correcting for concentration changes in control bottles, the volume of water overlying the sediment cores, and the surface area of sediment as follows:

$$\text{Flux } (\mu\text{mol m}^{-2}\text{ h}^{-1}) = ((C\text{-}c) * V)/A \qquad \text{(Eq. 3)}$$

where C and c are the time rates of change in concentration in the water overlying the sediments (C) or control (c) bottles calculated from linear regression analysis of the data in units of μmol/L/h, V equals water volume over sediments in liters, A equals cross-sectional area of sediment cores in m^2.

Sediment Resuspension and Sediment-Water Phosphate Exchanges

The effect of sediment resuspension on sediment-water phosphate exchanges was examined in experiments conducted in July, August and September 1990. Surface sediments were resuspended into the overlying water from selected cores by the continuous horizontal movement of stir paddles in the overlying water. The amount of resuspension was controlled by the rate of paddle movement, as well as the vertical position of the paddles in the water. The paddles were attached to an adjustable rate shaker table suspended over the cores. In the July experiment, eight sediment cores

You are Viewing an Archived Copy from the New Jersey State Library

from the sandy site were used: two were incubated without resuspending bottom sediments, two had ~0.1 mg (dry wt.) sediment resuspended per ml of overlying water, two had ~1.7 mg sediment per ml of water, and two had ~1.7 mg sediment per ml of water which was spiked to 5 µM PO_4. Control water (both spiked and unspiked) was incubated in bottles without any sediment contact. Time series samples for analysis of dissolved phosphate were collected from the water overlying the cores and from the control water prior to resuspension, approximately 15 min, 30 min, 60 min, 90 min and 5 h after resuspension began. Samples were filtered and the water analyzed immediately for PO_4 concentration; samples were also collected to determine the dry weight of resuspended sediment in the overlying water. In August and September 1990 additional experiments were conducted with cores from both the sandy and silt-clay sites. The dissolved phosphate concentration in the overlying water was measured in time series samples collected up to 24 h in cores without resuspended sediments, with resuspended sediments, and with and without resuspended sediments in which the overlying water was spiked to 5 µM PO_4.

The amount of sediment resuspended in our experiments ranged from 100 to 1700 mg dry sediment per liter or 8.2 to 140 g/m^2 of sediment. These rates were chosen as they are intermediate between the concentration of total suspended solids in the Bay (generally 20-40 mg dry sediment/L and as high as 160 mg/L; F. Moser, pers. comm.), and the total amount of suspended sediment in the water column overlying a m^2 of sediment in the Bay (28-224 g/m^2 based on range of measured concentrations and assuming average water depth of 1.4 m). While the higher concentrations of suspended sediments in our experiments (1700 mg/L) are not likely realistic for Barnegat Bay, the lower concentrations (100 mg/L) were likely similar to suspended sediment concentrations near the bottom where suspended sediments first contact the overlying water.

Biological and/or Chemical Control of Sediment-Water Phosphate Exchange

This topic was investigated in September 1990. Surface sediments were resuspended into the water overlying cores from the sandy (120 mg dry sediment per liter) and silt-clay (340 mg dry sediment per liter) sites. Approximately 500 ml of the overlying water (with resuspended sediments) was removed and incubated in bottles with Barnegat Bay water spiked to 5 µM PO_4, with and without addition of buffered formalin (final concentration 2%). The bottles were shaken continuously to keep the sediments in suspension. Time series samples were collected during the next 24 h, filtered, and analyzed for dissolved PO_4 concentration. The suspended sediment concentration was measured at the end of the experiment by filtering a known volume of water through pre-weighed Millipore membrane filters, and then weighing the filter after drying at 60°C for at least 48 h.

You are Viewing an Archived Copy from the New Jersey State Library

RESULTS

The net release of phosphate out of sediment cores to the overlying water or net flux of phosphate into the sediments from the overlying water was calculated based on the time rate of change of the concentration of dissolved phosphate in the water overlying the sediments as described in the Methods section (Eq. 3).

There was no measurable phosphate release from sediment cores incubated in the dark for 6-9 days (Table 2, Fig. 2). There was a net flux of phosphate into the sediments when the water was spiked to 5 μM PO_4 in both silt-clay and sandy sediments (Table 2, Fig. 3); the flux into the sediments was considerably greater with sandy sediments relative to the silt-clay sediments (Table 2).

There was no net release of PO_4 at the sandy site when sediments were resuspended at low, moderate and high rates, 0.1, 0.36 and 1.7 mg dry sediment per ml of water, respectively (Table 2, Fig. 4). In two out of eight cores there was a small increase in overlying water dissolved PO_4 concentration (~0.2 μM PO_4) which decreased to background concentrations within approximately 15 to 30 min. When the overlying water was spiked to 5 μM PO_4 there was a rapid decrease in dissolved PO_4 concentration (Table 2, Fig. 5).

Sediments suspended in Barnegat Bay water had greatly reduced phosphate uptake when treated with 2% formalin compared to phosphate uptake without formalin (Table 2).

You are Viewing an Archived Copy from the New Jersey State Library

DISCUSSION

The flux of inorganic nutrients from sediments following the decomposition of organic matter is an important source of recycled nutrients for phytoplankton production in many estuaries. Benthic mineralization processes often supply between 25% and 50% or more of the nitrogen and phosphorus requirements of phytoplankton (Nixon 1981; Kemp et al. 1982; Boynton and Kemp 1985). However, measurements of benthic nutrient fluxes primarily have been in estuaries that have little light penetration to the sediment surface due to water column turbidity and/or water depth. Few measurements of benthic nutrient fluxes have been made in shallow coastal lagoons where there is sufficient light penetration for substantial benthic algal production (Nowicki and Nixon 1985a; Rizzo et al. 1992). In such systems, all or some of the nutrients mineralized in the sediments may be assimilated at the sediment surface by benthic algae.

In Barnegat Bay sediments there are substantial rates of benthic algal and seagrass production[1] during early summer and fall when the water column is less turbid and thus there is sufficient light at the sediment surface for benthic photosynthesis (Table 1). Benthic algal production is a major factor decreasing the release of ammonia from the sediments in the Bay (Seitzinger and Pilling 1992)[2]. There was no measurable flux of ammonia out of the sediments in the Bay when benthic (gross) photosynthesis rates were approximately 900 μmol O m^{-2} h^{-1} or greater; when benthic photosynthesis rates were low (approximately 450 μmol O m^{-2} h^{-1} or less), the flux of ammonia out of the sediments was similar to that predicted from Redfield stoichiometry (Fig. 6, Table 1). A comparison of data from Barnegat Bay with data from three other shallow coastal systems, the Delaware Inland Bays (Rehoboth and Indian River bays, Seitzinger unpubl. data), Potter Pond (a RI coastal lagoon; Nowicki and Nixon 1985a,b), and the Neuse River estuary (NC; Rizzo et al. 1992) shows a pattern similar to that for Barnegat Bay (Fig. 7).

1 The methods used to measure benthic photosynthesis did not differentiate between seagrass production and algal production.

2 Seagrasses do not appear to be the major factor controlling sediment-water ammonia and phosphate fluxes at the two study sites, as patterns of N and P release were similar regardless of the presence for absence of seagrasses (Seitzinger and Pilling 1992).

Digitized by the Barnegat Bay Watershed Association Archived Copy from the New Jersey State Library

While benthic algal production, in general, can account for the low rates of sediment-water ammonia fluxes in Barnegat Bay, the data do not indicate that phosphate fluxes are controlled solely by benthic algae. Obviously, benthic algae are assimilating P along with N which can explain the lack of P release when benthic photosynthesis rates were high (and no ammonia was released). However, even when there was no benthic photosynthesis there was no measurable release of P from the sediments at either the sandy or silt-clay site (Seitzinger and Pilling 1990, 1992; Table 1). The inability of benthic algal production to explain the lack of release of P from Barnegat Bay sediments was further confirmed in the current study by four additional experiments. Phosphate fluxes remained undetectable even after sediments were pre-incubated in the dark for 6-9 days which would deplete the ability of algae to take up nutrients in the dark (Syrett 1981) (Table 2). Another demonstration that benthic algae were not solely responsible for P retention in the sediments was demonstrated by the rapid uptake of P by sediments pre-incubated in the dark when the overlying water was spiked to 5 μM PO_4 (Table 2).

Other mechanisms to account for the lack of P release from Barnegat Bay sediments were investigated, including permanent burial of P in the sediments, release of P to the water column following resuspension of bottom sediments, transport of P out of the Bay on suspended sediments, and a reconsideration of the expected release of P from the sediments based on the P content of the organic matter decomposed in the sediments. To interpret the results of those experiments, the average daily P flux that was unaccounted for (the "missing" P) was calculated from the June through October 1989 data (Table 1) as follows: the predicted release of P over a 24-h period was calculated from the oxygen flux in the light and dark incubated cores, stoichiometry for P release or assimilation associated with the measured oxygen flux according to Eqs. 1 and 2 and the measured N:P ratio of organic matter in the surface sediments at the two study sites, and assuming a 12-h light/12-h dark period. Since there was no measurable P release from either the silt-clay or sandy site during any sampling period, the "missing" P was set equal to the predicted P release rate.

Initially the predicted rate of P flux from the sediments at both study sites (Seitzinger and Pilling 1992) (Table 1) was calculated assuming that the organic matter decomposed in the sediments had a C:N:P ratio of 106:16:1 (atoms) (Redfield 1964), which is similar to the ratio in organic matter in many, but not all, marine ecosystems. While the organic C content of the sediments was not measured, we did measure the organic N and organic P content (Seitzinger and Pilling 1992). The organic N:P ratio in the surface sediments at the sandy site (16.5:1) was very close to the theoretical (Redfield) ratio (16:1); at the silt-clay site the ratio was 29:1 which indicates that the organic matter is depleted in P by a factor of 2 relative to the theoretical ratio. The flux of ammonia out of the sediments (at both sandy and silt-clay sites) when benthic algal production was negligible was similar to the predicted rate of ammonia flux based on the oxygen consumption rates, indicating that the C:N ratio was not markedly different from the Redfield ratio. Based on the above, the predicted average daily P release rate for June through October at the sandy site was 195 μmol m^{-2} d^{-1}; the predicted P release rate at the silt-clay site was 98 μmol m^{-2} d^{-1}(Table 3).

You are Viewing an Archived Copy from the New Jersey State Library

The following discussion addresses the magnitude of P release from Barnegat Bay sediments attributable to these mechanisms. Phosphate released during the decomposition of organic matter can be sorbed to metal oxides (e.g., iron and aluminum oxides) and not released by diffusive flux to the overlying water. The sorbed phosphate can then be buried permanently in the sediments, released to the water following resuspension of bottom sediments, or transported out of the Bay sorbed to the resuspended sediments.

Phosphate sorption to metal oxides is an important mechanism of phosphate retention in freshwater sediments (Wetzel 1985). While burial of mineral phosphate does not appear to be an important process in sandy sediments in Barnegat Bay, it may account for as much as 70% of the "missing" P at the silt-clay site. The calculated rate of net P burial at the silt-clay site was estimated to be approximately 16 to 21 mmol P m^{-2} yr^{-1} or 50-70 µmol m^{-2} d^{-1} (Table 3), which is spproximately 70% of the "missing" P at that site (98 µmol m^{-2} d^{-1} using an N:P ratio of 29:1). The burial rate was calculated based on a total P content of the sediment below 1 cm of 0.3 to 0.4 mg P/g dry sediment (gds), a measured sediment density of 1.5 gds/cm^3, and a net sediment accumulation rate of 0.11 cm/yr at the silt-clay site (R. Bopp, pers. comm.) (Seitzinger and Pilling 1992). Net sediment burial rates were not measured at the sandy site because the isotope signal is too low in sandy sediments to obtain reliable data for dating (R. Bopp, pers. comm.). The rate of P burial in the sandy sediments, however, is likely less than half that at the silt-clay site because the total P content of the sandy site sediment (approx. 0.15 mg P/gds, Seitzinger and Pilling 1992) is half that at the silt-clay site and net sediment accumulation rates in sandy sediments are generally considerably less than in finer grained sediments.

Phosphate sorbed to metal oxides in the sediment is in chemical equilibrium with phosphate dissolved in the pore waters (Stumm and Morgan 1981). When sediments are resuspended into the water column by waves or heavy boating activity, some sorbed P may be released to the overlying water as it equilibrates with the low P Bay water (<0.5 µM PO_4, Seitzinger and Pilling 1992). However, experiments of P exchange from resuspended bottom sediments showed that release of phosphate from resuspended bottom sediments is not a significant mechanism for phosphate transfer to the water (Table 2). There was no measurable release of phosphate to the water when sediments were resuspended at low, medium or even very high rates of resuspension (Table 2). In fact, resuspension of bottom sediments may decrease water column P concentrations when there is a pulse input of P to the Bay such as during a storm event. This was indicated in the resuspended surface sediment experiments in which a rapid decrease in the P concentration occurred after the overlying water was spiked to 5 µM PO_4. In sandy sediments, the rate of PO_4 decrease was approximately proportional to the suspended sediment concentration (Table 2). Phosphate uptake by sandy sediments was more rapid than by silt-clay sediments, indicating that simple chemical sorption is not the main mechanism of phosphate retention, as silt-clay sediments would be expected to sorb more phosphate than sandy sediments (Stumm and Morgan 1981). The rate of PO_4 decrease was approximately ten times greater with resuspended sandy sediments relative to silt-clay sediments (September experiment) even though the

You are Viewing an Archived Copy from the New Jersey State Library

suspended sediment concentration was higher in the silt-clay sediment cores. Rates of phosphate uptake from silt-clay sediment cores that were not resuspended were also lower by a factor of three or more compared to sandy sediments (Table 2).

Addition of formalin to resuspended sediments also indicates that P retention/uptake is not due to simple sorption. The uptake of P by the sediments appears to be due, in part, to biological processes. Phosphate uptake in resuspended sediments treated with formalin was lower relative to sediments without formalin (Table 2).

Phosphate sorbed to surface sediments could be transported out of the Bay on suspended sediments. Estimated export of P from the Bay due to suspended sediment transport was calculated to be 22 μmol P m^{-2} d^{-1}, which is only 10% of the "missing" P at the sandy site and approximately 20% of the "missing" P at the silt-clay site (Table 3). This calculation was based on complete exchange of the Bay water every 96 tidal cycles (Chizmadia et al. 1984), a 12.7 h tidal cycle, a Bay volume of 238 X 10^6 m^3 (Chizmadia et al. 1984), a P concentration of resuspended sediment based on the total P concentration in the top 1.5 cm of sediment at the silt-clay site of 0.013 mmol P/gds (Seitzinger and Pilling 1992; sandy sediments had a lower total P concentration of 0.006 mmol/gds), and a relatively high total suspended sediment concentration of 60 mg/L (F. Moser, pers. comm.; range generally 20-60 mg/L).

While essentially all of the P removal mechanisms that are generally considered to occur in estuarine sediments were examined in this study, none of those mechanisms alone was found to be sufficient to explain the lack of P release from Barnegat Bay sediments. At the silt-clay site, burial of P in the sediments combined with removal of P through resuspension of bottom sediments which are transported out of the Bay may account for most of the mineralized P (if the organic matter mineralized in the sediments is depleted in P relative to N). However, at the sandy site, less P is estimated to be buried in the sediments or transported out of the Bay with resuspended sediments and the P budget is still very unbalanced. Low rates of P release from shallow estuarine sediments have been reported in the few other studies in systems similar to Barnegat Bay (Nowicki and Nixon 1985a; Ullman and Sandstrom 1987). However, the mechanisms responsible for the low P release rates were not identified in those studies. The data from Barnegat Bay and other shallow coastal sediments contrast with data from deeper estuaries such as Narragansett Bay where the release of P from the sediments can be predicted based on rate of organic matter decomposition (Nixon et al. 1980).

The studies conducted here, in combination with our previous studies in Barnegat Bay (Seitzinger and Pilling 1990, 1992), demonstrate that nutrient processes in Barnegat Bay differ quite markedly from nutrient processing in deeper estuaries. Sources of nutrients supporting phytoplankton production and thus eutrophication in estuaries include external inputs (e.g., rivers, runoff, groundwater) and internal recycling. Internal recycling of nutrients in the water column and in benthic sediments is a major source of nutrients for phytoplankton production. Considerable amounts of ammonia and phosphate are recycled from sediments in most deeper estuaries, often supplying 25% to 50% of phytoplankton N and P requirements (Nixon 1981; Kemp et al. 1982;

You are Viewing an Archived Copy from the New Jersey State Library

Boynton and Kemp 1985). However, in Barnegat Bay the release of N and P from the sediments is much reduced. No P is released from the sediments and the N release (and in part P) is reduced greatly due to assimilation by benthic algae. In addition, P is removed more efficiently than N which also contrasts with patterns in deeper estuaries where N generally is removed more efficiently (via denitrification) than P (Nixon 1981, 1983, Seitzinger 1988). Evidence is beginning to accumulate from other shallow estuaries suggesting that sediments in coastal lagoons are efficient nutrient traps relative to sediments in deeper estuaries. The decreased release of both N and P from the sediments decreases nutrients available for phytoplankton growth in the water column, and thus in effect, decreases the magnitude of eutrophication in the Bay for a given rate of external nutrient input, as a portion of those external inputs are being removed by the sediments. These findings have important implications for management decisions regarding future control of nutrient inputs to Barnegat Bay as models of nutrient control based on the relationship between nutrient inputs and eutrophication developed for deeper estuaries are not applicable, in a number of ways, to Barnegat Bay and likely toother shallow back bay estuaries. We currently are working with the US Army Corp of Engineers, Waterways Experiment Station, to modify the 3-D Coupled hydrodynamic water quality model developed for Chesapeake Bay so that it is applicable to the Delaware Inland Bays and other shallow coastal lagoons where sediment-water nutrient interactions differ markedly from those in deeper estuaries.

What change in conditions in the Bay would lead to a decrease in the rate of N and P removal and thus an increase in N and P input to the water column which could increase phytoplankton production and the rate of eutrophication? While we do not know all of the mechanisms that are controlling N and P release from the sediments in the Bay, it is clear that benthic algae are controlling much of the N release. Increases in water column turbidity, such as already occur in mid-summer in the Bay result in large increases in the rate of ammonia release from the sediments because benthic algal production is reduced due to the low light levels at the sediment surface. This ammonia is available for increased phytoplankton production in the water. Nutrient enrichment experiments conducted during Year IV of this program were conduced using microcosms of Barnegat Bay. Those data indicate that increases in ammonia inputs can increase phytoplankton biomass and production in the Bay. Results of those experiments will be reported in the Year IV Final Report.

Based on the data presented in this and previous reports (Seitzinger and Pilling 1990 and 1992), it appears that water quality management plans developed for Barnegat Bay should consider ways to control water column turbidity so as to minimize nutrient release from benthic sediments. Ideally, turbidity in mid-summer should be decreased to allow more light to reach the sediment surface. At a minimum, turbidity should not be allowed to increase above current levels.

You are Viewing an Archived Copy from the New Jersey State Library

LITERATURE CITED

Boynton, W.R. and W.M. Kemp. 1985. Nutrient regeneration and oxygen consumption by sediments along an estuarine salinity gradient. Mar. Ecol. Prog. Ser. 23:45-55.

_____, 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.

Chizmadia, P.A., M.J. Kennish and V.L. Ohori. 1984. Physical description of Barnegat Bay. Pages 1-28 *in* M.J. Kennish and R.A. Lutz, eds. Ecology of Barnegat Bay, New Jersey. Lecture Notes on Coastal and Estuarine Studies No. 6. Springer-Verlag, NY. 396 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.

Hopkinson, C.S. and R.L. Wetzel. 1982. *In situ* measurements of nutrient and oxygen fluxes in a coastal marine benthic community. Mar. Ecol. Prog. Ser. 10:29-35.

Kemp, W.M., R.L. Wetzel, W.R. Boynton, C.F. D'Elia and J.C. Stevenson. 1982. Nitrogen cycling and estuarine interfaces: Some current concepts and research directions. Pages 209-230 *in* V.S. Kennedy, ed. Estuarine Comparisons. Academic Press, NY. 709 pp.

Murphy, J. and J.P. Riley. 1962. A modified single solution method for determination of phosphate in natural waters. Anal. Chim. Acta 27:31-36.

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.

You are Viewing an Archived Copy from the New Jersey State Library

_____, J.R. Kelly, B.N. Furnas, C.A. Oviatt and S.S. Hale. 1980. Phosphorus regeneration and the metabolism of coastal marine bottom communities. Pages 219-242 *in* K.R. Tenore and B.C. Coull, eds. Marine Benthic Dynamics. Belle W. Baruch Library in Marine Sciences, No. 11.

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

_____. 1985b. Benthic nutrient remineralization in a coastal lagoon ecosystem. Estuaries 8:182-190.

Redfield, A.C. 1934. On the proportions of organic derivatives in sea water and their relation to the composition of plankton. Pages 176-192 *in* James Johnstone Memorial Volume. Liverpool Univ.

_____. 1958. The biological control of chemical factors in the environment. Am. Scientist 46:206-221.

Richards, F. 1965. Anoxic basins and fjords. Pages 611-645 *in* J.P. Riley and G. Skirrow, eds. Chemical Oceanography. Vol. 1, Chap. 13. Academic Press.

Rizzo, W.M., G.J. Lackey and R.R. Christian. 1992. Significance of euphotic, subtidal sediments to oxygen and nutrient cycling in a temperate estuary. Mar. Ecol. Prog. Ser. 86:51-61.

Rogers, Golden and Halpern, Inc. 1990. Profile of the Barnegat Bay. Prepared for the Barnegat Bay Study Group, in association with Expert Information Systems, Inc.

Seitzinger, S.P. 1988. Denitrification in freshwater and coastal marine ecosystems: Ecological and geochemical significance. Limnol. Oceanogr. 33:702-724.

_____ 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.

Stumm, W. and J.J. Morgan. 1981. Aquatic Chemistry. John Wiley and Sons, Inc. NY. 580 pp.

Syrett, P.J. 1981. Nitrogen metabolism of microalgae. Can. Bull. Fish. Aquat. Sci. 210:182-210.

You are Viewing an Archived Copy from the New Jersey State Library

Ullman, W.J. and M.W. Sandstrom. 1987. Dissolved nutrient fluxes from the nearshore sediments of Bowling Green Bay, Central Great Barrier Reef Lagoon (Australia). Estuarine, Coastal and Shelf Sci. 24:289-303.

Wetzel, R.G. 1983. Limnology. Second ed. W.B. Saunders.

You are Viewing an Archived Copy from the New Jersey State Library

FIGURES

You are Viewing an Archived Copy from the New Jersey State Library

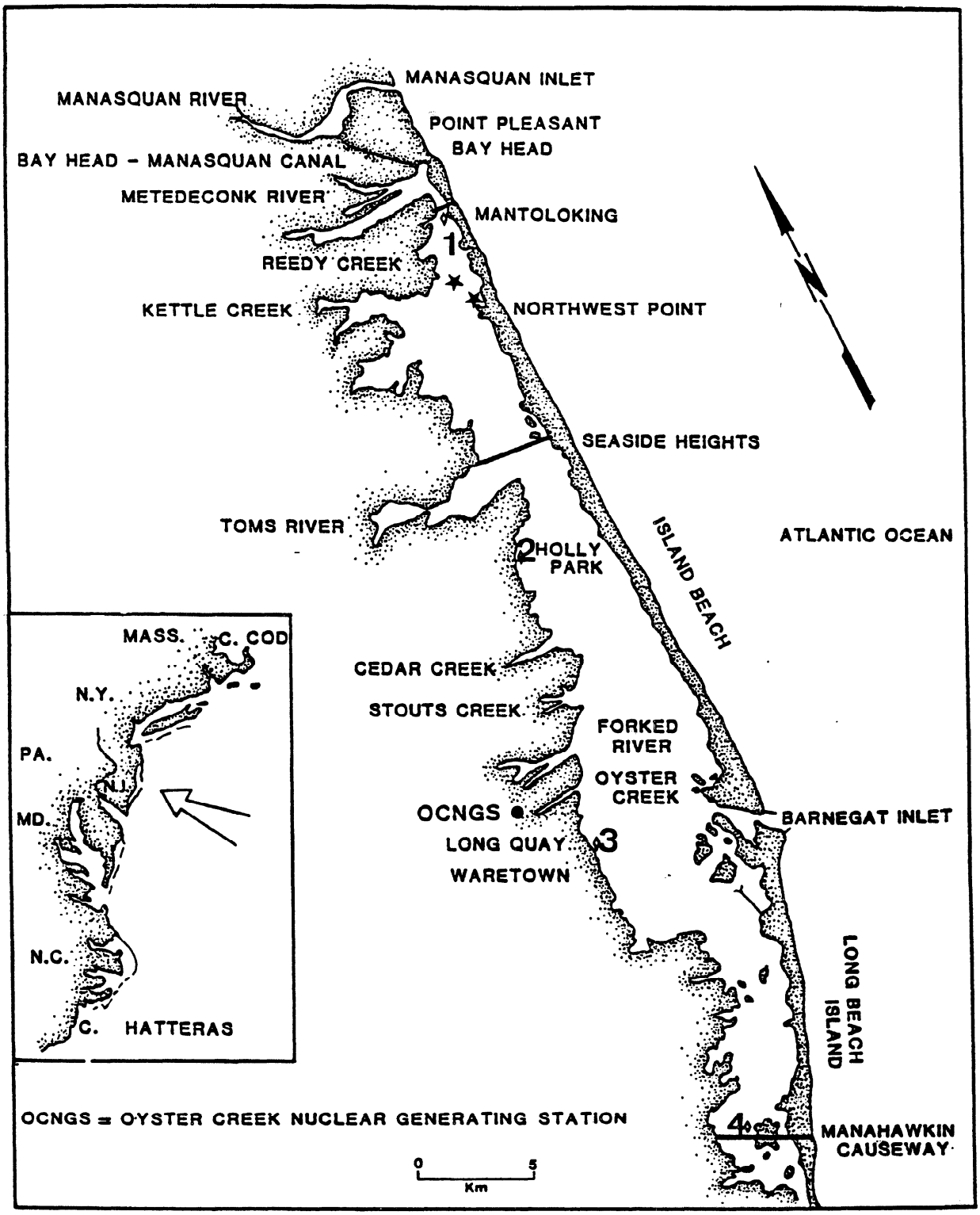

Figure 1. Map of Barnegat Bay, NJ, indicating NJDEPE DSR water column nutrient and primary production sampling stations (1-4) and ANSP sediment deposition and benthic flux stations (*). 1-Mantoloking; 2-Holly Park; 3-Waretown; 4-Manahawkin.

You are Viewing an Archived Copy from the New Jersey State Library

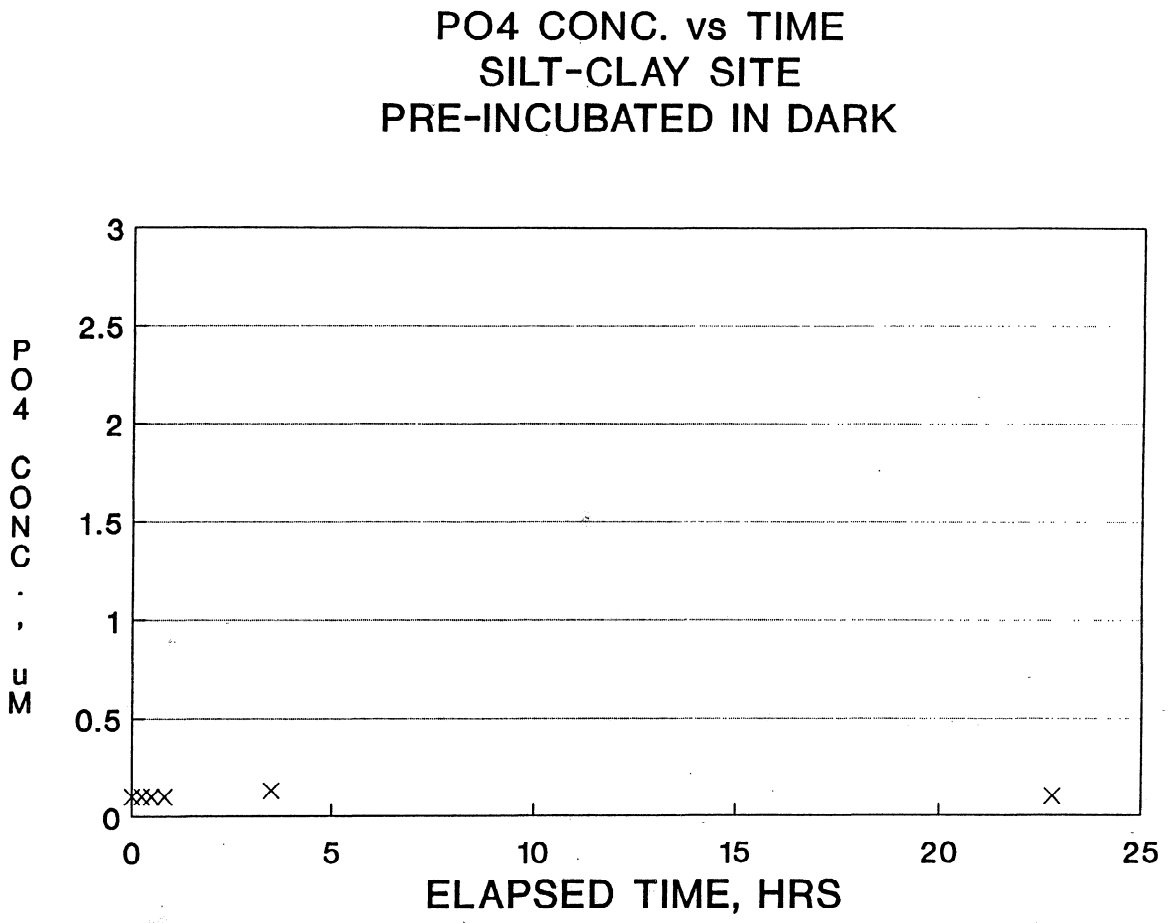

Figure 2. Phosphate concentration vs time in water overlying sediment core from silt-clay site in Barnegat Bay, August 1990. Core was incubated in the dark for 6 days prior to flux measurement to minimize benthic algal assimilation of phosphate.

You are Viewing an Archived Copy from the New Jersey State Library

(a)

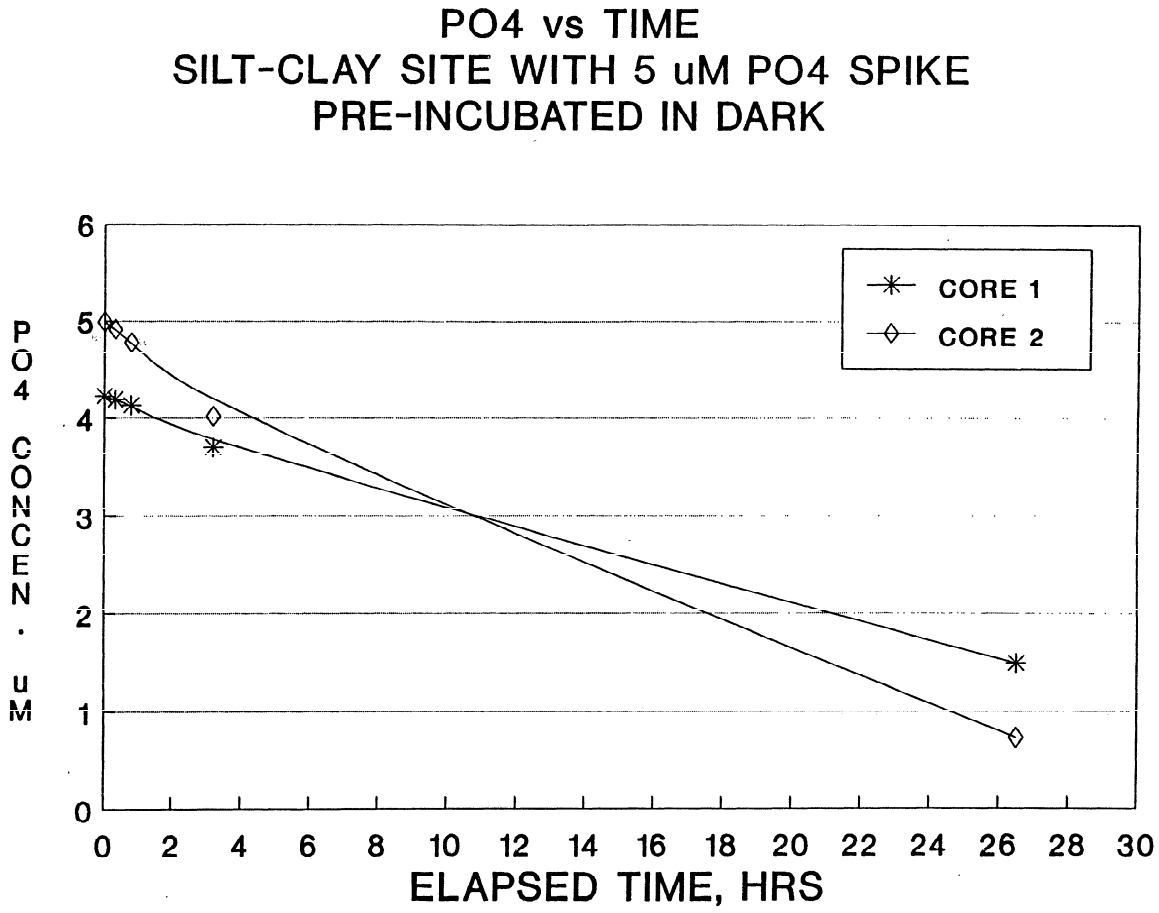

Figure 3. Phosphate concentration vs time in water overlying sediment cores collected in Barnegat Bay from (a) silt-clay site, and (b) sandy site, September 1990. Cores were incubated in the dark for 6 to 8 days prior to flux measurement to minimize benthic algal assimilation of phosphate; overlying water was spiked to approximately 5 µM PO_4 before flux measurements began.

You are Viewing an Archived Copy from the New Jersey State Library

(b)

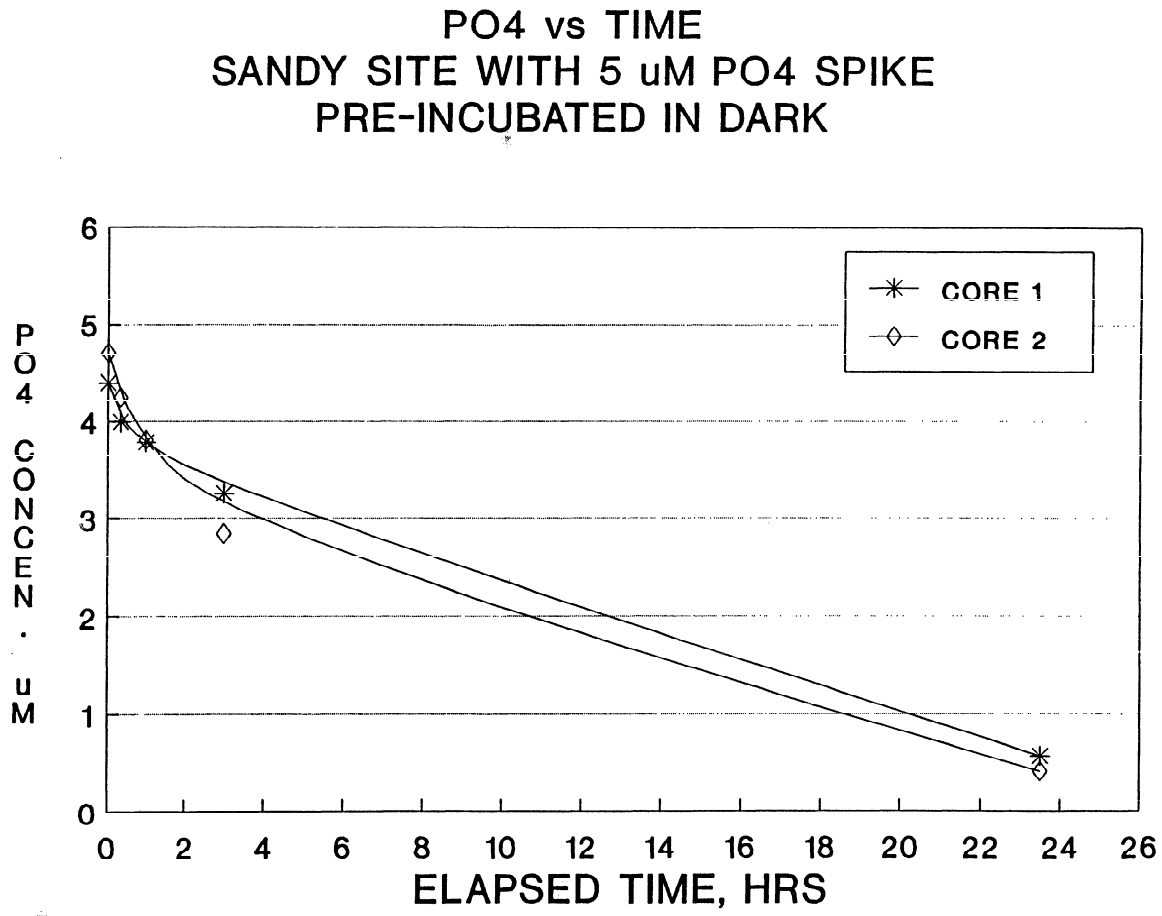

Figure 3 (continued). Phosphate concentration vs time in water overlying sediment cores collected in Barnegat Bay from (a) silt-clay site, and (b) sandy site, September 1990. Cores were incubated in the dark for 6 to 8 days prior to flux measurement to minimize benthic algal assimilation of phosphate; overlying water was spiked to approximately 5 μM PO_4 before flux measurements began.

You are Viewing an Archived Copy from the New Jersey State Library

(a)

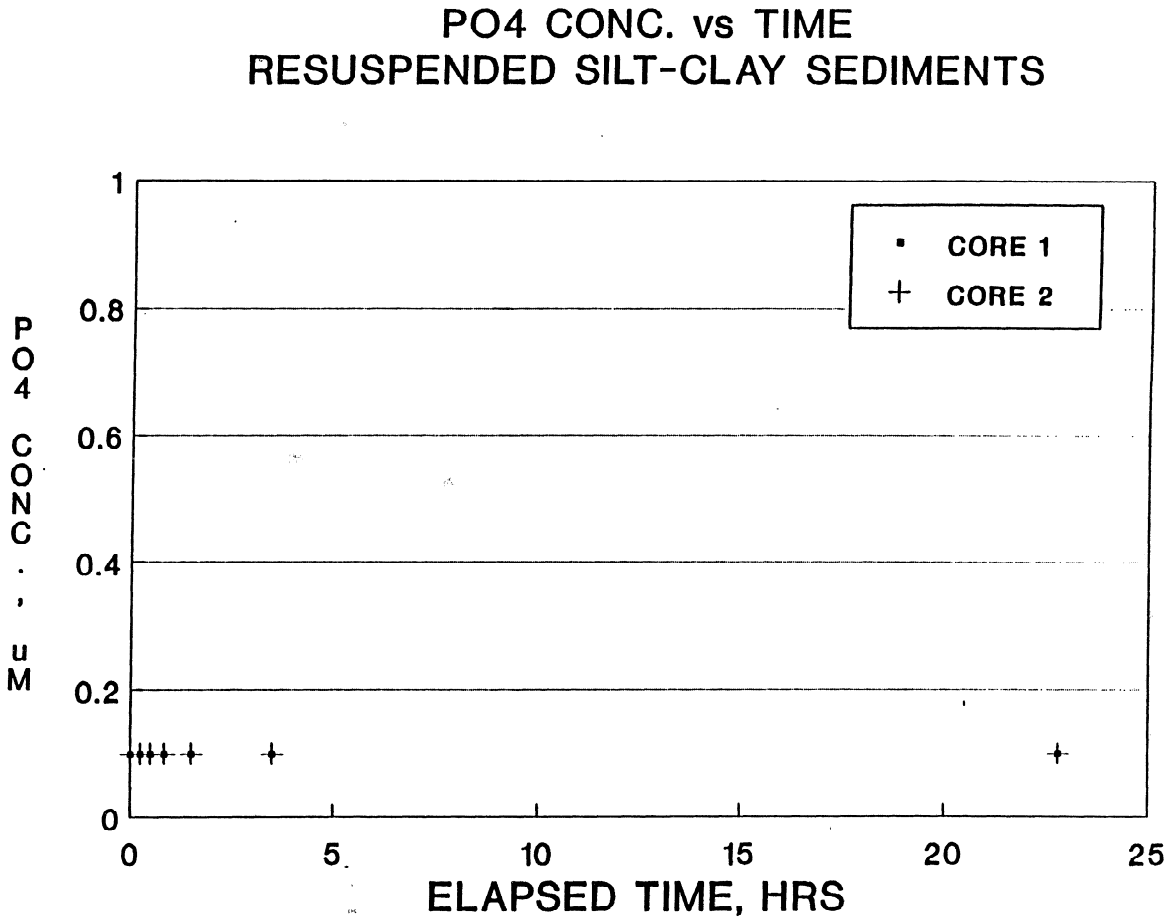

Figure 4. Phosphate concentration vs time in water overlying sediment cores collected in Barnegat Bay from (a) silt-clay site, and (b) sandy site, August 1990. Surface sediments were resuspended continuously into overlying water.

You are Viewing an Archived Copy from the New Jersey State Library

(b)

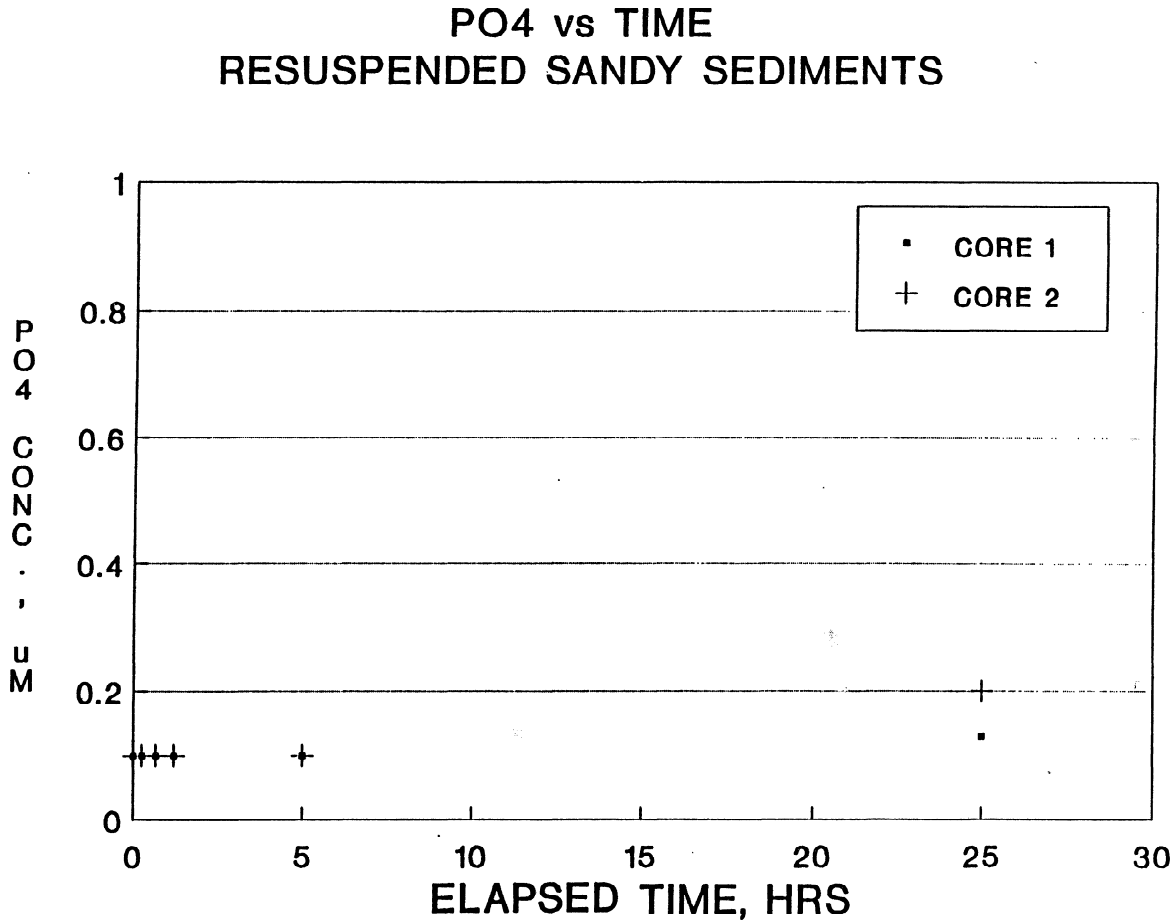

Figure 4 (continued). Phosphate concentration vs time in water overlying sediment cores collected in Barnegat Bay from (a) silt-clay site, and (b) sandy site, August 1990. Surface sediments were resuspended continuously into overlying water.

You are Viewing an Archived Copy from the New Jersey State Library

(a)

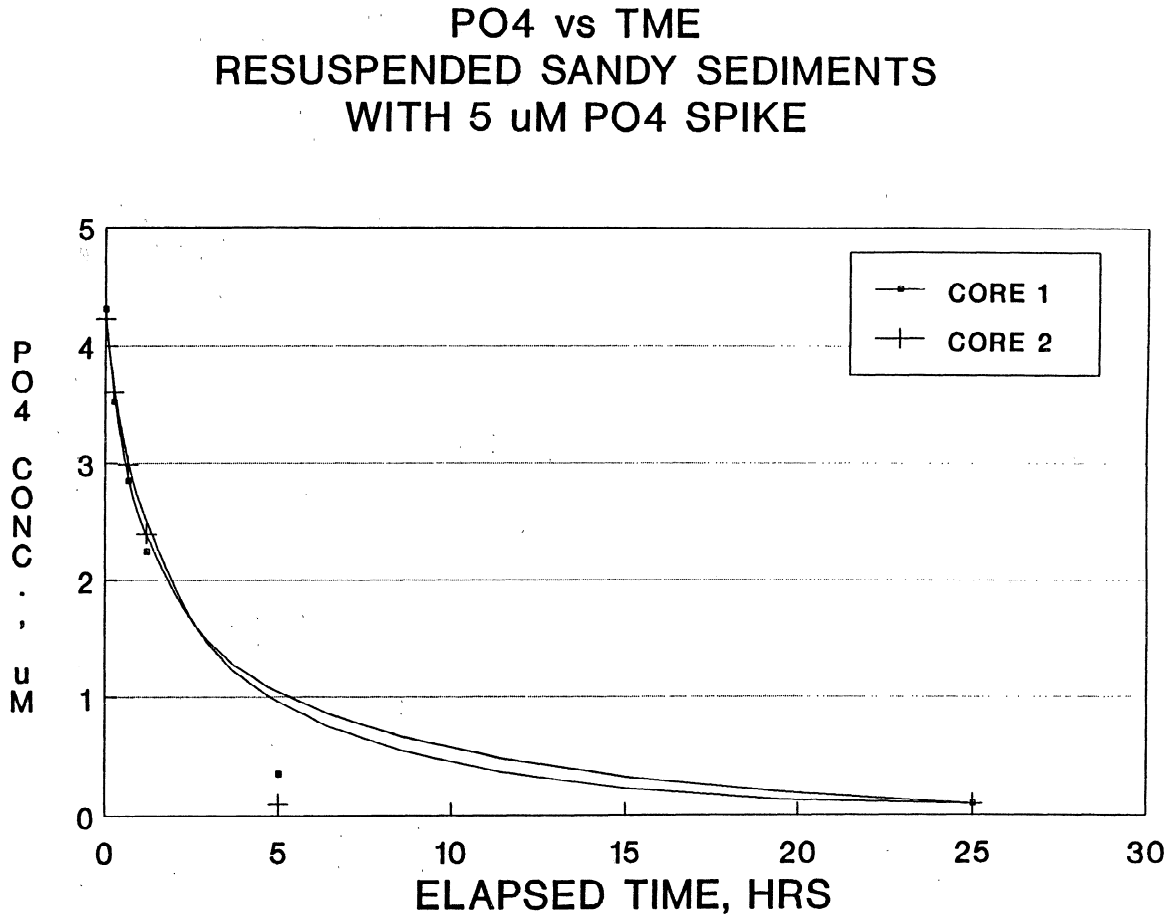

Figure 5. Phosphate concentration vs time in water overlying sediment cores collected from silt-clay site in (a) August 1990, and (b) September 1990 from Barnegat Bay. The overlying water was spiked to approximately 5 µM PO_4 before flux measurements began. Surface sediments were resuspended continuously into overlying water.

You are Viewing an Archived Copy from the New Jersey State Library

(b)

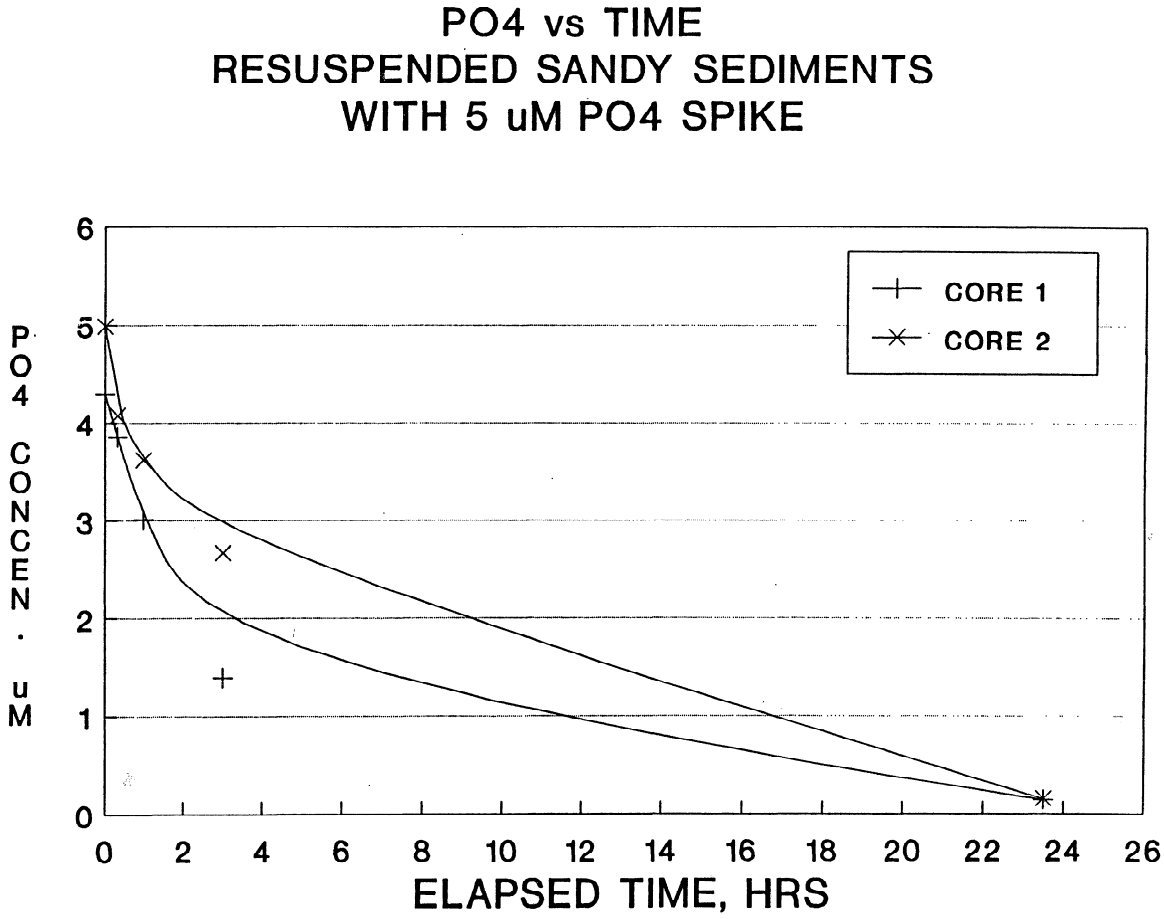

Figure 5 (continued). Phosphate concentration vs time in water overlying sediment cores collected from silt-clay site in (a) August 1990, and (b) September 1990 from Barnegat Bay. The overlying water was spiked to approximately 5 µM PO_4 before flux measurements began. Surface sediments were resuspended continuously into overlying water.

You are Viewing an Archived Copy from the New Jersey State Library

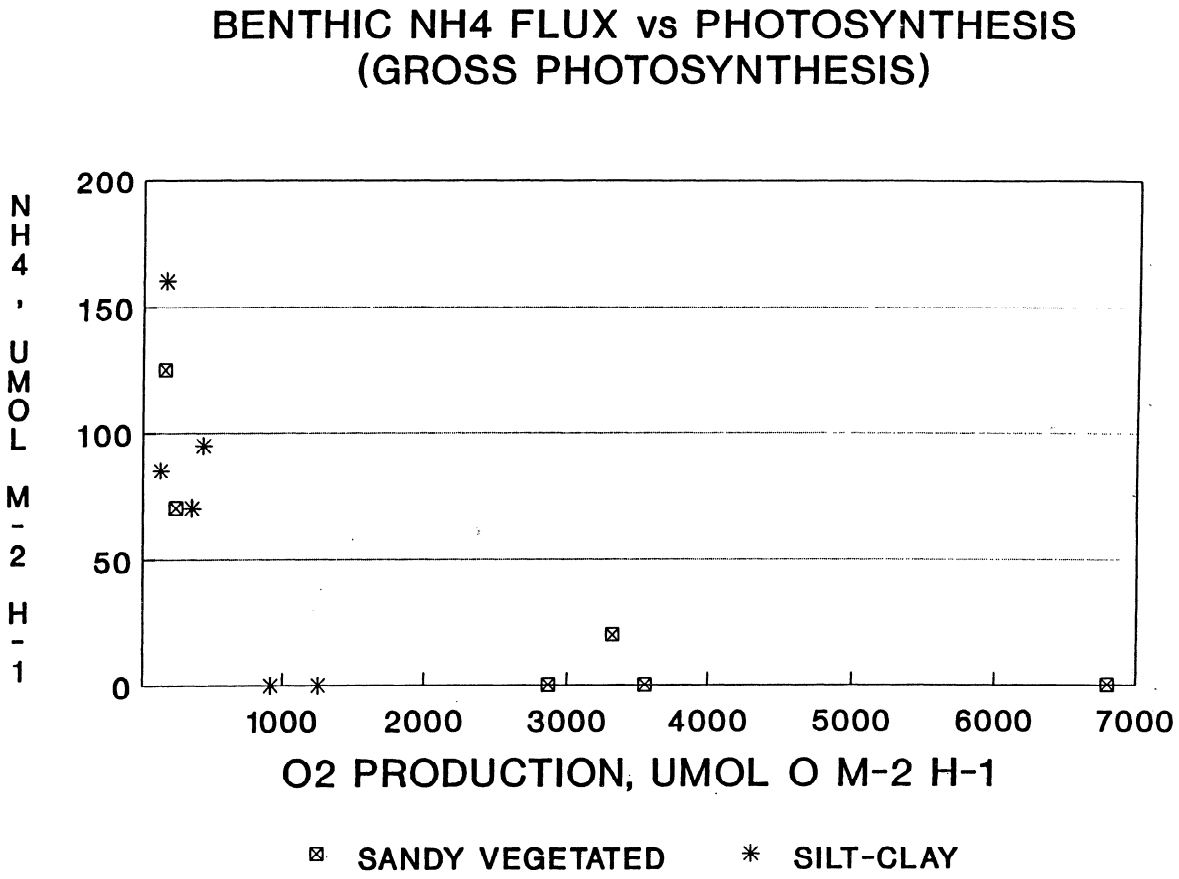

Figure 6. Sediment-water flux of ammonia vs. gross benthic photosynthesis at two locations in Barnegat Bay.

You are Viewing an Archived Copy from the New Jersey State Library

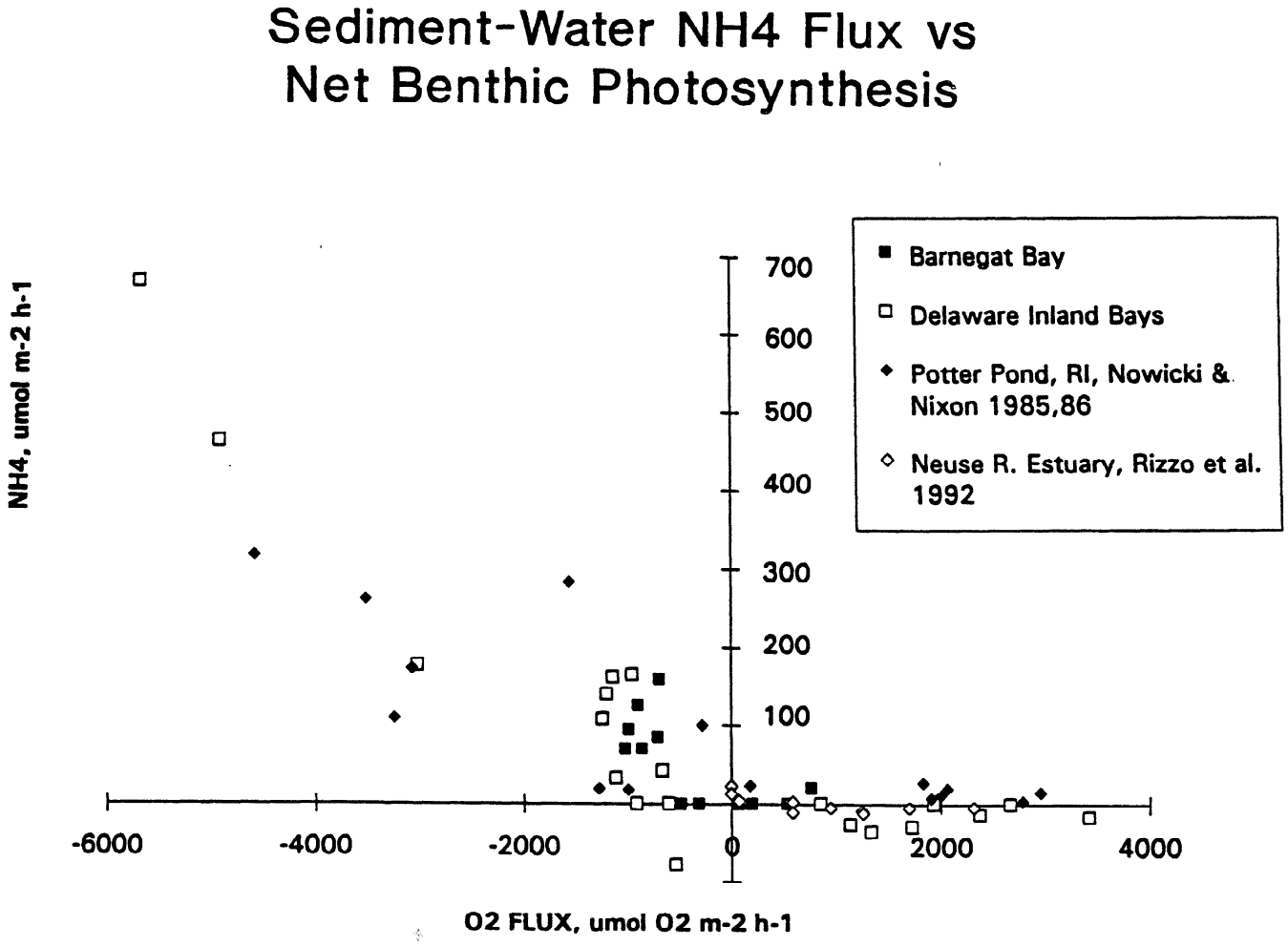

Figure 7. Sediment-water flux of ammonia vs net benthic photosynthesis in Barnegat Bay (Seitzinger and Pilling 1992), Delaware Inland Bays (Seitzinger unpubl. data), Potter Pond, RI (Nowicki and Nixon 1985a,b), and the Neuse River Estuary, NC (Rizzo et al. 1992).

You are Viewing an Archived Copy from the New Jersey State Library

TABLES

You are Viewing an Archived Copy from the New Jersey State Library

Table 1. Sediment-water fluxes (μmol $m^{-2}h^{-1}$) of oxygen, ammonia, nitrite + nitrate and phosphate measured at a sandy vegetated site and a silt-clay site in Barnegat Bay, NJ, as a function of light intensity (μE m^{-2} s^{-1}) and mid-day (gross) benthic primary production (μmol O m^{-2} h^{-1}). Predicted NH_4 and PO_4 fluxes are based on O_2 flux and Redfield stoichiometry (Eqs. 1 and 2). (n.s. = flux not significantly greater than 0 at $\rho = 0.05$; L = 100% and M = 50% of ambient bottom light intensity, and D = dark; for complete details of methods and interpretation of results see Seitzinger and Pilling 1992.)

Date	Core	Temp. (°C)	Salinity (‰)	Light Intensity	Measured O_2-O	Measured NH_4	Measured NO_2+NO_3	Measured PO_4	Mid-day Gross Benthic Primary Production	Predicted NH_4	Predicted PO_4
Sandy Vegetated Site											
6/21/89		25	11						6675		
	L1			150	380	n.s.	-7	n.s.		-29	-2
	L2			150	130	n.s.	n.s.	n.s.		-10	-1
	M1			75	-2350	n.s.	-9	n.s.		177	11
	M2			75	-1940	10	n.s.	n.s.		146	9
	D1			0	-6380	n.s.	n.s.	n.s.		482	30
	D2			0	-6460	n.s.	n.s.	n.s.		488	30
8/22/89		25	10						0		
	L1			15	-1810	125	n.s.	n.s.		137	9
	L2			15	-1730	70	n.s.	n.s.		131	8
	M1			7	-2300	75	n.s.	n.s.		174	11
	M2			7	-2420	140	n.s.	n.s.		183	11
	D1			0	-1850	115	n.s.	n.s.		140	9
	D2			0	-2090	150	n.s.	n.s.		158	10
10/4/89		18.5	12						3090		
	L1			60	1060	n.s.	n.s.	n.s.		-80	-5
	L2			60	1510	20	n.s.	n.s.		-114	-7
	D1			0	-1460	n.s.	n.s.	n.s.		110	7
	D2			0	-2150	n.s.	n.s.	n.s.		162	10
Silt-clay Site											
6/28/89		25	11						395		
	L1			20	-1980	95	n.s.	n.s.		149	9
	L2			20	-2060	70	n.s.	n.s.		155	10
	M1			10	-1820	85	n.s.	n.s.		137	9
	M2			10	-1350	40	n.s.	n.s.		102	6
	D1			0	-2240	175	n.s.	n.s.		169	11
	D2			0	-2590	140	n.s.	n.s.		195	12
8/15/89		25	8						150		
	L1			20	-1420	85	-5	n.s.		107	7
	L2			20	-1380	160	n.s.	n.s.		104	7
	M1			10	-1420	80	n.s.	n.s.		107	7
	M2			10	-1690	165	2	n.s.		128	8
	D1			0	-1630	150	n.s.	n.s.		123	8
	D2			0	-1470	120	n.s.	n.s.		111	7
10/4/89		18.5	12						1085		
	L1			15	-970	n.s.	n.s.	n.s.		73	5
	L2			15	-630	n.s.	n.s.	n.s.		48	3
	D1			0	-1830	n.s.	n.s.	n.s.		138	9
	D2			0	-1940	n.s.	n.s.	n.s.		146	9

 You are Viewing an Archived Copy from the New Jersey State Library

Table 2. Sediment-water phosphate fluxes from Barnegat Bay sediment cores (A) pre-incubated for 6-9 days in the dark to minimize benthic algal uptake, (B) with resuspended sediments, and (C) resuspendeded sediments with and without formalin added to inhibit biological activity. Positive numbers represent a net flux of P from sediments to the water; negative numbers are a net flux from the water to the sediments. All cores incubated in the dark during flux measurements. Units: μmol P m^{-2} h^{-1}.

Date	Site	PO_4 Flux	Overlying Water Treatment	Suspended Sediment Concentration (mg/L)
(A) CORES PREINCUBATED (6-9 DAYS) IN THE DARK				
7/25/90	sandy	0 0		
8/6/90	silt-clay	0		
9/17/90	sandy	-30 -40	5 μM PO_4 5 μM PO_4	
9/19/90	silt-clay	-5 -10	5 μM PO_4 5 μM PO_4	
(B) SEDIMENTS RESUSPENDED ABOVE CORES				
7/25/90	sandy	0 0		100 100
8/2/90	sandy	0 0		360
7/26/90	sandy	0 0		1700
8/26/90	silt-clay	0		410
7/26/90	sandy	-300 -280	5 μM PO_4 5 μM PO_4	1700
8/2/90	sandy	-50 -60	5 μM PO_4 5 μM PO_4	360
9/17/90	sandy	-70 -50	5 μM PO_4 5 μM PO_4	290
9/19/90	silt-clay	-5 -10	5 μM PO_4 5 μM PO_4	450
(C) SEDIMENTS SUSPENDED IN 5 μM PO_4 WATER WITH AND WITHOUT FORMALIN		**(μmol P/L/h)**		
9/11/90	sandy	-1.01	without formalin	120
		-0.11 -0.27	with formalin with formalin	120
9/13/90	silt-clay	-1.4 -1.5	without formalin without formalin	340
		0 -0.84	with formalin with formalin	340

You are Viewing an Archived Copy from the New Jersey State Library

Table 3. Summary of the phosphorus budget for Barnegat Bay sediments, based on available data at the silt-clay and sandy study sites. See text for explanation of each term.

Mechanism	Silt-clay μmol P m^{-2} d^{-1}	Sandy μmol P m^{-2} d^{-1}
SOURCES		
Rate of PO_4 production (net organic mineralization)*	98	195
REMOVAL MECHANISMS		
Burial in sediments	50-70	<25
Loss from resuspended sediments	0 or uptake	0 or uptake
Transport out of Bay with resuspended sediments	22	<22
Sum of P removal	72-92	<47
Estimated diffusive flux of PO_4 out of sediments	7-26	>148
Measured diffusive flux	0	0
PO_4 unaccounted for	7-26	>148

* after accounting for benthic algal assimilation during photosynthesis and using measured N:P ratio of organic matter in surface sediments at each site.

Property of NJDEP
Information Resource Center