NBP-88-13

Environmental Conditions & Plankton Dynamics in Narragansett Bay During An Annual Cycle Characterized By Brown-Tide 148 pp

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Narragansett Bay Estuary Program

ENVIRONMENTAL CONDITIONS AND PLANKTON DYNAMICS IN NARRAGANSETT BAY DURING AN ANNUAL CYCLE CHARACTERIZED BY A BROWN-TIDE

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NARRAGANSETT BAY PROJECT
REPORT # NBP-88-13
August 1988

FOREWORD

The United States Congress created the National Estuary Program in 1984, citing its concern for the "health and ecological integrity" of the nation's estuaries and estuarine resources. Narragansett Bay was selected for inclusion in the National Estuary Program in 1984 and designated an "estuary of national significance" in 1988. The Narragansett Bay Project (NBP) was established in 1985. Under the joint sponsorship of the U.S. Environmental Protection Agency and the Rhode Island Department of Environmental Management, the NBP's mandate is to direct a five-year program of research and planning focussed on managing Narragansett Bay and its resources for future generations. The NBP will develop a comprehensive management plan by December, 1990, which will recommend actions to improve and protect the Bay and its natural resources.

The NBP has established the following seven priority issues for Narragansett Bay:

- management of fisheries
- nutrients and potential for eutrophication
- impacts of toxic contaminants
- health and abundance of living resources
- health risk to consumers of contaminated seafood
- land-based impacts on water quality
- recreational uses

The NBP is taking an ecosystem approach to address these problems and has funded research that will help to improve our understanding of various aspects of these priority problems. The Project is also working to expand and coordinate existing programs among state agencies, governmental institutions, and academic researchers in order to apply research findings to the practical needs of managing the Bay and improving the environmental quality of its watershed.

This report represents the technical results of an investigation performed for the Narragansett Bay Project. The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement #CX812768 to the Rhode Island Department of Environmental Management. It has been subject to the Agency's and the Narragansett Bay Project's peer and administrative review and has been accepted for publication by the Management Committee of the Narragansett Bay Project. The results and conclusions contained herein are those of the author(s), and do not necessarily represent the views or recommendations of the NBP. Final recommendations for management actions will be based upon the results of this and other investigations.

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SUMMARY

Water samples were collected from three depths at seven stations along a transect extending from the Providence River to Fox Island during 34 transects from 25 July 1985 - 18 June 1986. The following variables were measured: temperature, salinity, Secchi Disc depth, NH_4, NO_3, SiO_2, PO_4, chlorophyll, ATP, phytoplankton numerical abundance and species composition, primary production, zooplankton numerical abundance, biomass and species composition, ctenophore abundance and benthic larvae abundance.

The occurrence of a brown-tide outbreak of *Aureococcus anophagefferens* beginning in May 1985 triggered the present study. This nuisance algal bloom persisted through September, 1985, with up to 1.5 billion cells L^{-1} recorded. This species was not previously recorded from Narragansett Bay, and was described as a new genus and species by Sieburth and co-workers. Its bloom was extraordinary in terms of its abundance, duration and deleterious effects on the food web. The bloom maximum of 1.5 billion cells L^{-1} exceeded by 12-fold previously recorded maximal summer phytoplankton abundance in Narragansett Bay. Whereas previous blooms persisted for several weeks, the brown-tide persisted for five months, from May - September. The brown-tide was accompanied by extensive mussel (*Mytilus edulis*) mortality and decreased total zooplankton biomass and abundance of the dominant summer copepod *Acartia tonsa*. The cladoceran component of the zooplankton failed to develope. Benthic larval abundance generally decreased with increased brown-tide cell abundance. However, there is no convincing evidence that benthic recruitment was impaired by the brown-tide event.

The 1985 brown-tide event was part of a mesoscale, regional event

which included embayments along southern Long Island. This suggests regional climatological and/or hydrographic events triggered this bloom. Within Narragansett Bay, elevated nutrient loading appeared to suppress growth rather than to be stimulatory. Growth conditions in Greenwich Bay appeared to be particularly favorable; those in the Providence River least favorable. The field studies do not support the theory of a eutrophication trigger. The environmental conditions triggering the brown-tide bloom within Narragansett Bay and regionally are unknown.

Extensive blooms of diatoms, dinoflagellates, diverse microflagellates co-occurred with the brown-tide bloom. Unusual, anomalous blooms persisted through mid-December, including highly unusual euglenid blooms, of Fibrocapsa japonica (?), and autumn blooms of the dinoflagellates Massartia rotundatum and Prorocentrum redfieldii. The winter-spring bloom beginning in December and subsequent plankton-nutrient dynamics followed normal patterns previously described for Narragansett Bay. The exception to this was the brief recurrence of the brown-tide species in mid-May 1986, but which failed to develope into a brown-tide event. Field observations suggest that grazing of Aureococcus anophagefferens by microzooplankton thwarted development of its potential bloom.

The seven station transect was aligned along a well-defined salinity and chemical gradient, with nutrient concentrations generally increasing and salinity decreasing inwards within Narragansett Bay. Nonetheless, the seasonal nutrient and plankton dynamics were generally similar at all stations. Using mean surface values, strong inverse correlations occurred between mean nutrient concentrations and salinity, and between the mean atomic ratios of N:Si and N:P and salinity. The average surface chlorophyll levels in upper Narragansett

Bay were about 2-fold greater than those in lower Narragansett Bay. Mean levels progressively increased along the salinity gradient within upper Narragansett Bay, but sequentially decreased downbay. Strong, positive correlations occurred between mean phytoplankton biomass levels and nutrients. However, while mean phytoplankton biomass increased upbay with increased nutrient levels the progressively higher nutrient loadings, including sewage effluent, in the region between Conimicut Pt. and Fields Pt. appeared to repress biomass levels.

The annual surface primary production rates ranged from about 77 to 261 mg C m^{-3} yr^{-1}. Primary production was inversely related to salinity ($r = -0.95$). Strong correlations also occurred with nutrient concentrations, with somewhat different trends characterizing the relationships with PO_4, NH_4+NO_3 and SiO_2, respectively. Carbon production in lower Narragansett Bay is much more dependent on *in situ* nutrient recycling than on upper Narragansett Bay where nutrient influx is dominated by accreted inputs.

Zooplankton biomass was strongly correlated with both phytoplankton carbon standing stock ($r = 0.86$) and carbon production ($r = 0.86$). A strong, inverse correlation occurred between mean zooplankton numerical abundance and ctenophore (*Mnemiopsis leidyi*). Phytoplankton standing stock and ctenophore abundance were positively correlated.

The general conclusion is that nutrient levels and plankton processes within Narragansett Bay are highly ordinated along a salinity gradient and show marked regional variations.

Models under development should incorporate such patterns; not place excessive reliance on "wet" and "dry" season events, nor use proxy parameters of plankton processes.

INTRODUCTION

This report presents the results of a one-year study of plankton dynamics along a gradient in Narragansett Bay. Its initiation was triggered by the extraordinary, inimical brown-tide outbreak during the summer of 1985, and which evoked considerable media, public and state government attention. A significant effort during this study was directed towards communicating the results to these groups. Numerous radio, television and newspaper interviews were held at their request. including with all major television channels in Rhode Island, the New York Times, Boston Globe, USA Today, and most local and weekly R.I. newspapers and radio stations. Weekly briefings to DEM and other appropriate agencies were also given during the brown-tide epidemic. These time-consuming efforts are not reflected in the enclosed report, nor the stressful situation during the height of the brown-tide in 1985 and during its recurrence in May 1986. The generally held fear that a rampant pollution of Narragansett Bay was occurring, threatening dysfunction of this ecosystem and interfering with its economic and recreational use. created an emergency atmosphere. The continuous public and media pressures to specify or to speculate that pollution was the root cause of this event was resisted; the incoming data did not support this notion. The present report embracing the total data base reinforces that conclusion: the anomalous brown-tide event during the 1985 summer and unusual phytoplankton dynamics through December 1985 were not demonstrably indicative of pollution. Although plankton dynamics subsequent to this bloom during 1986 were normal, the phytoplankter responsible for the brown-tide event has now established itself within Narragansett Bay. Future recurrences of its major 1985 bloom and the lesser bloom in 1986 must be expected, with continuing potential for deleterious effects on food web dynamics and loss of revenue from shellfishing such as observed in 1985. This report quantifies plankton dynamics and associated environmental conditions during and subsequent to the 1985 brown-tide bloom over an annual cycle.

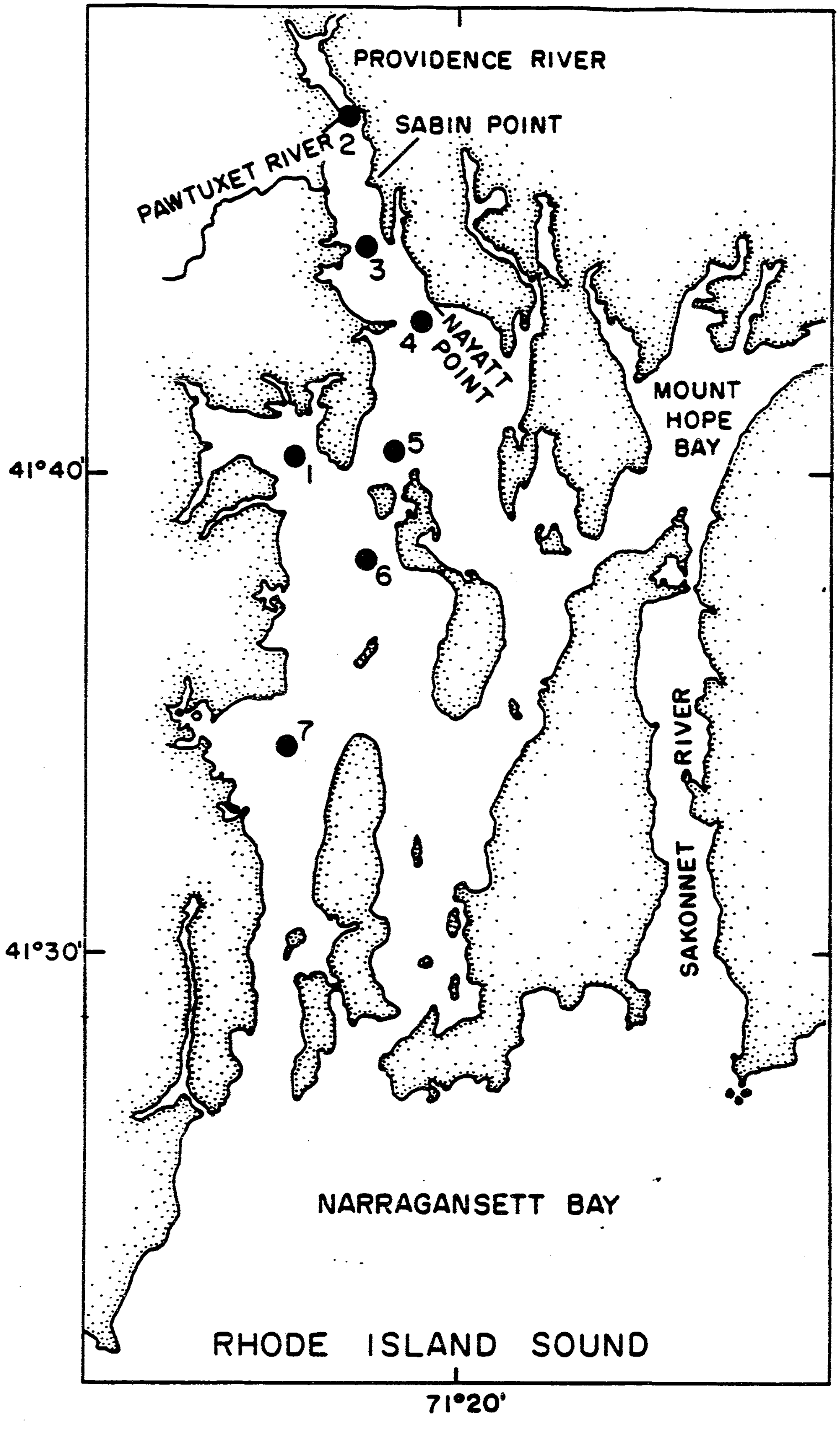
METHODS

Seven stations were established (Figure 1) along a salinity-nutrient gradient from lower Narragansett Bay (Station 7) to the entrance into the Providence River (Station 2). Stations 5 and 6 were in the region of the Narragansett Bay Sanctuary waters. Station 1 was located in Greenwich Bay, which supports a major quahog (*Mercenaria mercenaria*) shellfishery. The station grid was chosen to evaluate the environmental conditions in representative segments of Narragansett Bay and the effects of this regional environmental mosaic on plankton dynamics.

The sampling period extended from 25 July 1985 - 18 June 1986, during which period 34 transects were made. Primary production measurements were initiated during the sixth transect (28 August). At each station samples were collected from the surface, mid and bottom depths independent of tidal phase. The average total depth (m) for the sampling period at the seven stations was:

STATION:	1	2	3	4	5	6	7
	8.1 m	12.2	13.4	13.5	10.8	6.8	7.0

Figure 1


PROVIDENCE RIVER
SABIN POINT
PAWTUXET RIVER
2
3
4
NAYATT POINT
MOUNT HOPE BAY
5
1
41°40'
6
7
RIVER
SAKONNET
41°30'
NARRAGANSETT BAY
RHODE ISLAND SOUND
71°20'

At each station, measurements of light transmission (Secchi Disc depth) and temperature were made upon arrival. Otherwise, the samples were returned to the laboratory for determination of salinity (by refractometer), nutrients, chlorophyll, ATP, phytoplankton and zooplankton.

Surface water samples were collected with a clean plastic bucket or by holding a clean plastic bottle just below the surface. Subsurface samples were collected with PVC Niskin® bottles or vacuum pump. Raw seawater samples were stored and transported to the laboratory in clean polyethylene bottles. (Bottles were cleaned between uses by repeated rinse with tap water and deionized water.) Upon return to the laboratory, subsamples were immediately filtered through precombusted (500°C - 1 hr) glass fiber filters (Gelman A/E). (After a suitable rinse with sample, these filters showed negligible leaching of the measured nutrients, including silicate. Filtered samples were stored in 2 oz. polyethylene bottles with polyethylene lined caps. When at all possible, nutrient analyses are run on freshly filtered samples. When samples were not immediately analyzed, they were deep frozen (-10°C) for periods of less than one month.

The concentrations of PO_4, NH_4, NO_3 and SiO_3 were measured using standardized methods for micronutrients in seawater (Strickland and Parsons, 1972), and carried out on a Technicon Autoanalyzer® using slight modifications of these methods. The analytical manifolds and reagents for ammonia. nitrate + nitrite and silicate analysis were as given by Friederich and Whitledge (1972), and the phosphate manifold and reagents as given by Grasshof (1966). Nutrient analyses were run in duplicate, and in triplicate on occasion.

Chlorophyll a and phaeophytin are measured using the fluorescent technique introduced by Yentsch and Menzel (1963) incorporating the modifications recommended by Lorenzen (1966) and ancillary procedures and steps recommended by an international committee (Joint Group of Experts on Determination of Photosynthetic Pigments (UNESCO, 1966).

Two types of counting chambers were used to enumerate the phytoplankton (live counts were made): Haemocytometer and Sedgwick Rafter Chamber. An Improved Neubauer Haemocytometer was used (Guillard, 1978) to assess nannophytoplankton (< 10 µm diameter) abundance when present in high abundance. The minimal number of cells detectable by this counting procedure is 1,000 cells ml^{-1}. The Sedgwick Rafter Chamber was used to enumerate the larger cells following the procedures of McAlice (1971). The Haemocytometer counts were pooled with the Sedgwick-Rafter counts to yield total phytoplankton numerical abundance.

Productivity measurements were made by the ^{14}C method (Steemann Nielsen, 1952) on a pooled sample containing equal proportions of the top, mid and bottom-depth samples. The productivity samples were incubated in 50 ml glass bottles (initially cleaned with hot Ultrex 0.1N HCl and rinsed with 18 megohm deionized H_2O) inoculated with 2µCi $H^{14}CO_3$. The samples were incubated under ambient temperature and light in an outdoor flow-through incubator through which Narragansett Bay water flowed. The flushing time of the incubator was 30 mins. The productivity samples, in duplicate, were exposed to 100%, 60%, 25%, 10% and 3% natural irradiance for 24 hrs. After 24 hours incubation, the material was filtered onto GF/F filters, rinsed with 20 ml of filtered seawater, placed in glass scintillation vials and treated with 0.1 ml of 0.1 N HCl to minimize isotope adsorption onto the filters (Lean and Burnison, 1979). Activity was measured with a Beckman LS-150 scintillation counter to a minimum of 4000 cpm for each sample. Light intensity was monitored continuously during the incubation with Epply pyrheliometer located near the incubation platform.

The following procedures were used to assess the zooplankton community. Ctenophores and large medusae were sampled using a 1 m2 square net with 1 mm mesh. The net was lowered to within 1 m of the bottom and hauled vertically, with the ship at rest. Replicate tows were made. The ctenophores, removed from the net with a spoon, were sorted and counted by size classes (> 1 cm, 1-2 cm, 2-4 cm, < 4 cm) using a gridded dish.

Two nets were used to sample the non-gelatinous zooplankton: a 153 um mesh net filtered with a TSK flowmeter and a 64 µm mesh net fitted with a General Oceanics flowmeter. At station 7, a 20 µm phytoplankton net is towed in place of the 64 um mesh net. All of these nets have a 0.305 m mouth diameter. A double oblique tow was made, during which the net was slowly lowered to within 1 m of the bottom and raised at a towing speed of 1-2 knots. Each tow filtered 1 to 4 m^3 of water.

The 153 µm net samples were split in the laboratory using a sediment splitter. Half of the sample was sieved, rinsed with deionized water, dried for four weeks at 60°C in aluminum weighing pans, and the dry weights determined using a Mettler H-16 balance. The other half of the sample was preserved in 5% formalin for counting. The 64 um net samples were preserved without splitting.

The most common planktonic forms, copepods, cladocerans, and more abundant benthic invertebrate larvae were identified to species; other forms to closest possible taxon. The 153 µm preserved sample was examined for macrozooplankton (chaetognaths, medusae, fish and decapod larvae), and also used to estimate the numbers of copepodite and adult stages of copepods and other organisms over 20 mm in width. The 64 µm net sample was used to estimate numbers of copepod nauplii and smaller forms of meroplankton.

RESULTS

Physical Oceanography

The temperature, salinity and density (σ_t) characteristics at the seven stations for the 34 transects surveyed between 25 July 1985 and 18 June 1986 are given in Appendix Tables 1, 2, 3.

A crisp surface salinity gradient characterizes Narragansett Bay. The mean surface values progressively decreased upbay from 30.3 o/oo (Station 7) to 20.7 o/oo (Station 2) in the Providence R. off Fields Pt. The mean surface and bottom temperature and salinity levels were:

Table 1

STATION:	1	2	3	4	5	6	7
Surface °C	12.4	12.8	13.0	12.2	12.7	12.2	12.0
Bottom °C	11.8	11.9	12.1	11.6	12.7	11.9	11.7
Surface S o/oo	28.5	20.7	23.7	26.6	28.6	29.8	30.3
Bottom S o/oo	29.5	29.9	30.2	30.5	29.7	30.2	30.7

Mean bottom water salinities are higher, but similar; a feature consistent with a two-layer estuarine circulation pattern. These mean salinity values and their vertical and horizontal gradients indicate the persistence of the well-developed salinity gradient in Narragansett Bay. The strength of this gradient varied with the volume of freshwater input. This is reflected in the considerable range in surface salinity found at Stations 1 - 4, and to a lesser extent at lower Narragansett Bay Stations 5 - 7 (Table 2).

Table 2

STATION	Minimum	Maximum	Δ o/oo
1	17.1	31.7	15.6
2	10.9	28.6	17.7
3	11.8	28.6	16.8
4	16.5	30.7	14.2
5	24.4	30.7	6.3
6	27.5	31.7	4.2
7	28.6	31.7	3.1

Surface salinity at Station 2 exhibited a 17.7 o/oo range, with the maximum recorded value (28.6 o/oo) equivalent to the minimum salinity found at Station 7 near the entrance to Narragansett Bay. This considerable distance downbay from riverine inputs is reflected in the narrow annual surface salinity range of 3.1 o/oo. Considerable week-to-week and seasonal variations in the salinity gradient accompany the rainfall patterns. This oscillating gradient was particularly intense during the 3 surveys carried out between 3 - 16 April 1986 (Appendix Tables 2, 3).

The horizontal salinity gradient is accompanied by a well-defined vertical salinity gradient, also evident in the vertical density (σ_t) profiles (Appendix Tables 2, 3). This vertical gradient obviously influences water column mixing and the degree of vertical stratification. The σ_t Profiles (Appendix Table 3) indicate that Stations 1, 5, 6 and 7 are vertically mixed to the bottom throughout the year. In contrast. upper bay Stations 2, 3 and 4 are usually stratified year-round, with a distinct halocline present. The transitional area between the vertically mixed and stratified regions of the bay lies between Stations 4 and 5. During particularly voluminous freshwater inputs, facilitated further by wind conditions, the entire bay may become stratified for a brief period, such as found during the 2 April 1986 transect (Appendix Table 3). This condition, however, appears to be infrequent, just as vertical mixing to the bottom is at Stations 2, 3, 4.

The vertical temperature. salinity and σ_t patterns at Station 4 strongly point to an influx of bottom water different from that at Station 5. Stations 1, 5, 6 and 7 clearly reflect the influence of bottom water entering into West Passage and flowing upbay as a counter-current to the offshore flow of the less saline, near-surface waters. The bottom water at Station 4, in contrast. is often clearly distinguishable from that at Station 5. Using mean values (Table 1), the mean bottom water salinity (30.5 o/oo) at Station 4 is 0.8 o/oo more saline than that (29.7 o/oo) at Station 5, and the mean bottom temperature 1.1°C lower. Thus, the average bottom water at Station 4 is more saline and colder than at Station 5, characteristics inconsistent with an incursion of bottom water from the latter station. Differences in the mean surface temperature between Stations 3, 4 and 5 are also conspicuous. The mean surface temperature (12.2°C) at Station 4 is 0.5 to 0.8°C colder than at Stations 5 and 3 (Table 1). Examination of the individual transect surveys (Appendix Tables 1, 2, 3) indicates that Station 4 was frequently characterized by an influx of colder, more saline bottom, with an indication of periodic "upwelling" of this watermass to the surface (see 15 August 1985, for example). Moreover, the bottom water characteristics at Station 3 suggest an incursion of this watermass periodically extends to that location.

It seems likely, then, that Station 4 is frequently influenced by incursions of bottom water from East Passage (Figure 1) in addition to inputs from West Passage. This region of Narragansett Bay may therefore be a particularly unique segment hydrographically along the gradient sampled by the transect stations. It appears to be both a buffer zone and transitional region between the upper and lower bay stations with regard to freshwater input, water quality and mixing characteristics, as well as exhibit a circulation pattern beyond a simple two-layer estuarine flow. Both upwelling of bottom water and gyre flow may be occurring as a consequence of an influx of East Passage bottom water together with an inflow of West Passage bottom water moving up the bay. These physical features would be expected to influence plankton dynamics at Station 4 in several key ways, including enhanced productivity. This will be examined elsewhere in this report.

Light Penetration

The Secchi Disc measurements of light transmission are given in Appendix Table 4. Absorbance by suspended particles, chlorophyll and dissolved organic matter within the water column affect the in situ transmission of incident light. The relative contribution of these parameters to light transmission can not be determined from the available data. Since riverine input of particulate matter accompanies runoff, the general relationship between salinity and light transmission will be evaluated. The mean Secchi Disc measurements are given in Table 3.

Table 3

STATION:	1	2	3	4	5	6	7
Secchi Depth (m)	1.90	1.71	1.80	1.88	2.12	2.20	2.42
k (m^{-1})	0.76	0.84	0.80	0.77	0.68	0.65	0.60
1% Isolume Depth (m)	6.1	5.5	5.8	6.0	6.8	7.1	7.7

The seven stations segregate into two distinct optical watermass types, both characterized by very strong positive correlations (the slopes of the regression lines are significantly different). The upper Narragansett Bay and Greenwich Bay stations (1, 2, 3, 4) comprised one optical group; the lower bay stations the other group. Their correlation coefficients were $r = 0.99$ and $r = 0.96$, respectively. The conclusion suggested by these correlations that increased turbidity accompanies decreasing salinity was further evaluated by regressing the mean extinction coefficients, k (Table 3), against mean salinity. Extinction coefficients per m^{-1} (k) were calculated from (Holmes, 1970):

$$k = 1.44/D$$

where D is Secchi Disc depth in m. A strong inverse correlation ($r = -0.89$) occurred between salinity and the extinction coefficient, with all stations grouping along the regression line. Thus, the observed salinity gradient was accompanied by a gradient in the light transmission properties, with the light extinction coefficient progressively increasing upbay.

The 1% isolume depth is commonly believed to define the depth of the euphotic zone. This has been calculated based on the equation for the penetration of light in sea water:

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

where I_z is the irradiance at a given isolume depth (z), I_o is the incident irradiance and k is the extinction coefficient.

The 1% isolume depth varied from 5.5 to 7.7 m (Table 3). Relative to the station water column depths at Stations 6 and 7, photosynthetic carbon production (i.e., the euphotic zone) extended to the bottom sediments. At Stations 5 and 1, the euphotic zone ranged from 60 to 75% of the water column and at the upper bay stations (2, 3, 4) roughly the upper half of the water column.

The salinity gradient therefore influences light transmission and the depth of the euphotic zone. The proportion of the total water column depth to which photosynthesis could occur decreased with salinity.

Nutrients

The concentrations of PO_4, NH_4, NO_3 and SiO_3 are given in Appendix Tables 5, 6, 7, 8. Text Table 4 summarizes the mean concentrations and maximal and minimal nutrient levels at the surface.

All nutrients exhibited a conspicuous range in concentration, even at Station 2 (Providence R.) where accretion accompanying both riverine and sewage effluent inputs was pronounced. Station 2 is within, or adjoins, the zone of initial dilution of the Narragansett Bay Commission sewage treatment plant (STP) at Fields Point in the Providence River (Figure 1). Stations 3 and 4 lie within the region directly subjected to STP inputs during downstream flow of the enrichment plume. The maximal surface concentrations of PO_4, NH_4, NO_3 and SiO_3 at Station 2 were 30.0, 78.5, 43.5 and 34.8 mg-at m^{-3}, respectively, and 3.0, 8.4, 12.1 and 10.7 mg-at m^{-3}, respectively, in lower Narragansett Bay at Station 7. Maximal PO_4 and NH_4 surface concentrations in the Providence River were about 10-fold greater; NO_3 and SiO_3 concentrations about 4-fold greater. The minimal concentrations at Station 2, which reflect reduced input and/or phytoplankton utilization, were significantly lower than the maximal concentrations, and even below maximal levels recorded at Station 7. The data collectively indicate a distinct nutrient gradient occurs.

The seasonal cycles and dynamics for each nutrient were generally similar at all stations. (The surface concentrations will be used to illustrate this.) PO_4 (Appendix Table 5) exhibited a summer maximum in lower Narragansett Bay at Stations 1, 5, 6, 7, i.e. during the brown-tide bloom. At upper bay Stations 2, 3, 4, a significant surge in concentrations to maximal levels occurred in mid-September, with very high values persisting through mid-October.

The NH_4 maximum (Appendix Table 6) was more variable. A December maximum occurred at Stations 1, 6, 7, whereas sporadic surges in concentration particularly characterized Stations 2, 3, 4. NH_4 levels were continuously high throughout the annual cycle at Stations 2 and 3, and from July through December at Stations 4 and 5.

The NO_3 maximum (Appendix Table 7) occurred in August at the lower bay Stations 1, 5, 6, 7; levels were continuously high at the upper bay stations throughout the summer, and at Stations 2 and 3 throughout the year.

The SiO_3 maximum (Appendix Table 8) occurred in August at the lower bay Stations 1, 5, 6, 7; levels were continuously high at the upper bay stations throughout the summer, and at Stations 2 and 3 throughout the year. The particularly high summer silicon levels at all stations is notable.

All nutrients decreased significantly to minimal levels sometime during the winter-spring phytoplankton bloom, which began in early January. Precipitous decreases then characterized all nutrients at lower bay Stations 1, 5, 6,7. At the upper bay Stations 2, 3, 4 less pronounced decreases occurred later during the bloom.

Table 4

STATION:	1	2	3	4	5	6	7
PO_4							
Mean	1.4	5.4	4.1	3.6	1.5	1.6	1.0
Min	0.1	1.5	0.3	0.2	0.1	0.2	0.2
Max	9.9	30.0	19.2	19.4	4.5	4.8	3.0

NH_4							
Mean	2.7	33.3	24.2	11.1	4.3	2.7	1.9
Min	0.4	2.5	1.6	0.6	0.6	0.0	0.5
Max	11.0	78.5	71.7	45.0	14.6	10.4	8.4
NO_3							
Mean	1.6	20.7	13.7	7.8	3.7	1.9	1.3
Min	0.1	5.4	0.1	0.1	0.2	0.1	0.1
Max	11.9	43.5	27.8	19.7	13.9	13.5	12.1
NH_4+NO_3							
Mean	4.3	54.0	37.9	18.9	8.0	4.6	3.2
SiO_3							
Mean	16.5	34.8	28.4	17.6	13.1	12.2	10.7
Min	0.0	11.0	2.4	0.0	0.0	0.0	0.0
Max	83.1	74.0	70.1	44.7	40.8	42.2	42.2

Despite high initial nutrient concentrations, phytoplankton growth frequently reduced levels to < 1 mg-at m^{-3} (excluding Station 2). Diatom growth reduced silicate levels to non-detectable concentrations at five of the seven transect stations.

The highest nutrient concentrations occurred in upper Narragansett Bay. The region between Stations 4 and 5 is transitional to the lower nutrient environment of lower Narragansett Bay. These regional nutrient distributions were strongly coupled to the salinity gradient.

Nearly perfect inverse correlations occurred between the mean nutrient concentrations and salinity at the surface (Figures 2, 3; Table 5). This reflects both the significant accretion of nutrients into upper Narragansett Bay accompanying runoff and sewage discharge and progressive dilution and utilization of these nutrients along the downbay axis. These distributions indicate that two significantly different nutrient input mechanisms occur along the nutrient-salinity gradient. In the upper bay, riverine, STP and urban inputs represent a nutrient pump. At the entrance into lower Narragansett Bay, the introduction of "new" nutrient results from the advection of nutrients accompanying inflow of bottom water. In addition to these mechanisms, recycling of nutrients accompanying food web dynamics occurs along the entire gradient. Thus, along the salinity gradient the relative importance of these mecnanisms changes. _In situ_ recycling and offshore nutrient inputs progressively become more important downbay. The persistence of extremely high nutrient concentrations at Stations 2 and 3, and low concentrations at Station 7, with intermediate characteristics at Stations 1, 4, 5, 6, is a manifestation of these differing mechanisms.

Nutrient ratios also varied along the salinity gradient reflecting differing inputs, and were highly correlated with mean salinity (Table 5). The mean ratios of N:Si and N:P, by atoms, were strongly and inversely correlated with mean salinity ($r = -0.95$). The mean N:Si ratio (using both NH_4+NO_3) progressively decreased from 1.6:1 at Station 2 to 0.3:1 at Station 7. The mean N:P ratio progressively decreased from 10:1 at Station 2 to 3.2:1 at Station 7. The relationship between the Si:P ratio and mean salinity, in contrast,

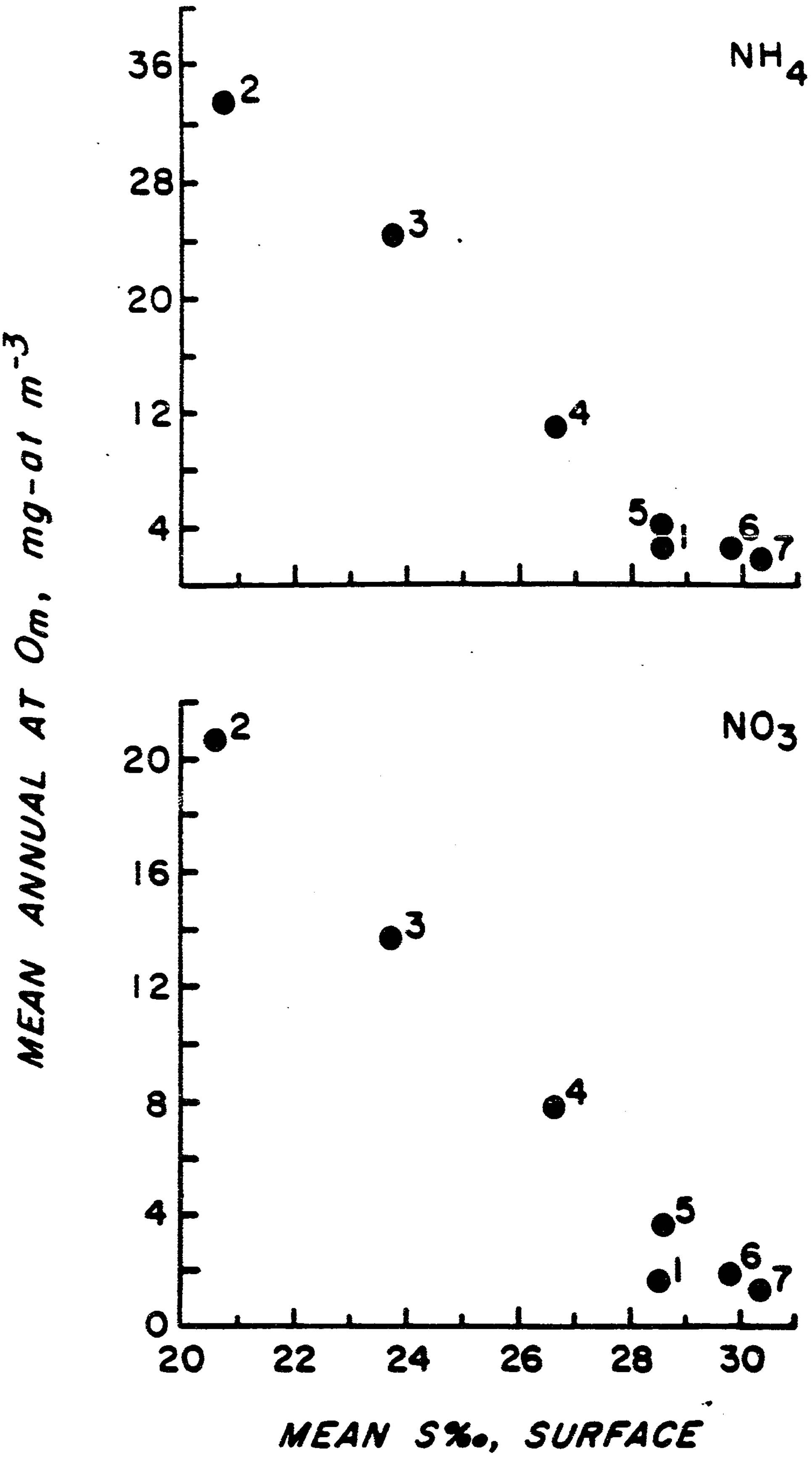


Figure 2. Mean annual NH_4 and NO_3 concentrations versus mean annual salinity at sampling stations.

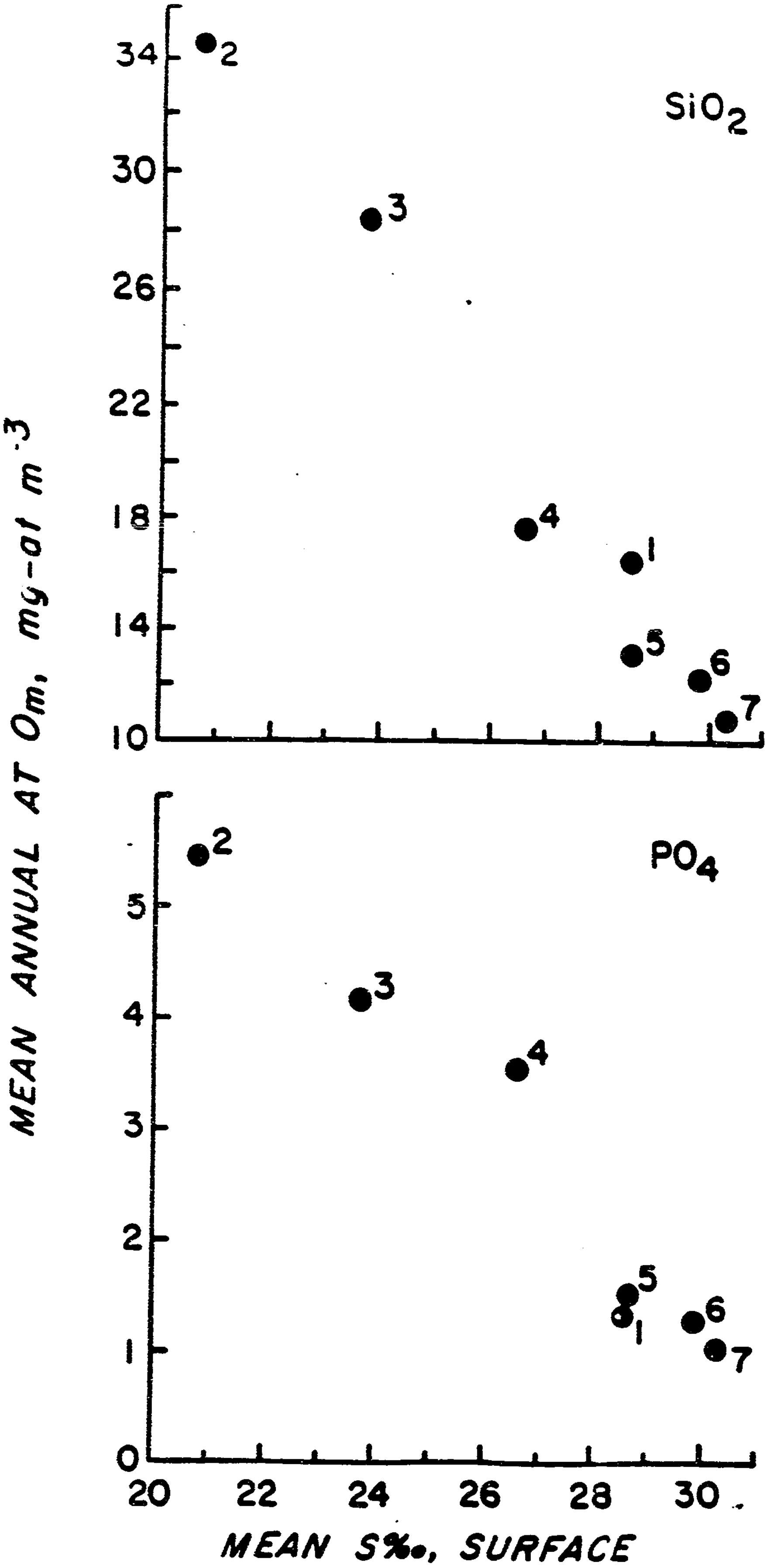


Figure 3. Mean annual SiO$_2$ and PO$_4$ concentrations versus mean annual salinity at sampling stations.

differed from the above ratios. The stations were now clustered into two subgroups, Stations 1, 2, 3 and Stations 4, 5, 6, 7. The mean ratios for each group were strongly correlated with mean salinity, but directly rather than inversely. The correlations were 0.95 and 0.89, respectively, which decreased to 0.58 when all stations are pooled. Therefore unlike the N:Si and N:P ratios, the Si:P ratios increased downbay with mean salinity. The natural inclusion of the Greenwich Bay station (1) into the Station 1, 2, 3 grouping is noteworthy. The Si:P ratio increased with salinity from 6.4:1 to 12:1 between Stations 2 and 1, and from about 5:1 to 10.5:1 along the gradient from Station 4 to 7.

These observations clearly indicate that the significant salinity gradient in Narragansett Bay also influences the absolute nutrient concentrations and their ratios. Both nutrient aspects influence phytoplankton growth.

Table 5

PO_4 vs. S o/oo	r = -0.97	N:Si vs S o/oo	r = -0.95
NH_4 "	r = -0.99	N:P "	r = -0.95
NO_3 "	r = -0.99	Si:P vs S o/oo:	
NH_4+NO_3 "	r = -0.99	All Stations	r = +0.58
Si "	r = 0.99	Stns 1, 2, 3	r = +0.95
		Stns 4, 5, 6, 7	r = +0.89

Brown-tide Event

The singular phytoplankton event during this year's investigation was the "brown-tide" development which discolored surface waters throughout Narragansett Bay. Reports that a similar bloom event was occurring off southern Long Island prompted three aerial reconnaisance surveys to verify this occurrence and to establish the extent to which the "brown-tide" event in Narragansett Bay was part of a regional phenomenon. Aerial flights using an aircraft provided by Governor DiPrete's office were made on 23 July, 1 and 23 August 1985. On 23 July, the surface waters of Narragansett Bay were discolored red-brown, as was Pt. Judith Pond and the Harbor of Refuge. The coastal salt ponds extending along the south shore of Rhode Island from Potter Pond to Napatree Pt., including Little Narragansett Bay, were not discolored. The brown-tide was not evident eastward of Sakonnet Pt., including the waters surrounding Cuttyhunk Island and at the entrance to Buzzards Bay. In contrast, plumes of brown water extended into Rhode Island from East Passage and West Passage of Narragansett Bay. The plume from East Passage was very distinctive, that from West Passage more diffuse. The eastern plume extended to Block Island and appeared to end near Southeast Light, partially curling parallel to the shoreline, but separated from the Block Island landmass by a zone of clear water. Great Salt Pond on Block Island was not discolored. Near Montauck Pt. off Long Island, large olive-colored windrows and cloud-like lenses of algal blooms were evident; windrows of yellow streaks occurred at the entrance to Long Island Sound.

A reduction in the intensity of the brown water discoloration in Narragansett Bay was evident during the aerial reconnaisance on 1 August. Discoloration was least intense, as on 23 July, in the Sakonnet River; most intense in West Passage, and persistent in Pt. Judith Pond and Harbor of Refuge. There was no evidence that the "brown tide" extended into Buzzards Bay; into the waters east of Sakonnet Pt.; into the southern coastal salt ponds of Rhode Island, nor intensified near Block Island or off Montauck, where the patterns were similar to those encountered on 23 July.

The aerial reconnaisance on 21 August was conducted on an overcast morning with scattered showers. This muted the sea surface color patterns and compromised direct comparisons with the previous flights. The extent and intensity of surface-water discoloration in Narragansett Bay were similar to conditions on 1 August in the upper bay, with color intensity lessened in the lower bay; the plumes previously found to extend from the East and West Passages were reduced. The large olive-brown plumes previously observed between Block Island and Montauck Pt. persisted.

During this period of aerial reconnaisance, additional information from a variety of sources indicated a "brown-tide" event was also rampant in the coastal embayments of southern Long Island. Thus, the "brown-tide" event in Narragansett Bay was a manifestation of a mesoscale phenomenon, at least in part. It occurred contemporaneously in Narragansett Bay, the waters surrounding Block Island, off Montauck Pt. and along the southern shore of Long Island. This regional development suggests that a regional climatological and/or associated hydrographic condition triggered the brown-tide event. Its magnitude and subsequent dynamics, however, would be expected to be modified and regulated by local environmental conditions.

The specific patterns and dynamics of the brown-tide event within Narragansett Bay were evaluated beginning on 25 July based on the 7-station sampling grid (Figure 1). The brown-tide event persisted from 25 July - 2 October. Appendix Tables 9 and 10 present data specific to that period; Appendix Tables 11-21 present data from that period together with subsequent data sets collected through 18 June 1986.

Brown-tide Dynamics

Appendix Table 9 summarizes the abundance and vertical distribution of the brown-tide cells along the 7-station transect. Maximal abundance at all stations occurred during the first survey (25 July), except for a renewed outburst at Station 1 (Greenwich Bay) on 22 August. Maximal recorded abundance ranged from 0.8 (Station 4) to 1.5 billion cells L-1 (Station 1). Abundance of the brown-tide cells more or less progressively decreased at all stations (excluding Station 1 on 22 August) between 25 July and 2 October, and were not recorded during the 9 October transect.

Brown-tide cells generally were more abundant in the upper half of the water column. At the vertically well-mixed Stations 6 and 7, abundance tended to be uniform throughout the water column. During the 2 August transect, abundance tended to be greatest near bottom at all stations. Thus, several patterns of vertical distribution characterized the brown-tide cells which, given the light extinction characteristics (Appendix Table 10), indicate their ability to grow over a wide irradiance range rather than a heliophilic preference.

Abundance of the brown-tide species varied regionally within Narragansett Bay. The mean seasonal abundance and that during the different surveys showed that maximal abundance generally occurred in Greenwich Bay (Station 1). This was part of a conspicuous plume of significant abundance in West Passage at Stations 6 and 7. Abundance in upper Narragansett Bay (Stations 2, 3, 4 and 5), i.e., north of Patience/Prudence Islands, was lower. Mean surface population abundance in Greenwich Bay (0.7 billion L^{-1}) was twice those in West Passage, and 3 to 3.5-fold greater than those in upper Narragansett Bay (Figure 4).

The environmental conditions and associated phytoplankton and zooplankton responses accompanying the brown-tide event summarized as means for the 25 July - 2 October surveys are given in Appendix Table 10. The regional variations in brown-tide abundance and watermass temperature were not correlated. Mean abundance was invariant with mean salinity at Stations 2, 3 and 4, i.e. between 24 o/oo and 27.6 o/oo, but increased from 0.2 to 0.7 billion cells L^{-1} along the salinity gradient (27.6 o/oo to 30.5 o/oo) from Station 4 to Station 7, including Station 1, in a statistically significant fashion ($r^2 = 0.96$) (Figure 4). The individual surveys, however, indicate a very broad tolerance to salinity. This suggests that salinity, <u>per se</u>, was not the causative factor of the observed regional variations in mean abundance, but that the correlations merely reflected a factor(s) running in parallel with salinity.

Mean cell abundance at the surface was inversely and curvilinearly related to NO_3+NH_4 and PO_4 levels (Figure 5). Mean surface abundance progressively decreased with increasing inorganic nitrogen and inorganic phosphorus levels along the gradient from Stations 1, 7, 6, 5 and 4, with mean abundance more or less invariant between Stations 4, 3 and 2. That is, mean brown-tide cellular abundance <u>decreased</u> with increasing concentrations of NO_3+NH_4 and PO_4. This strongly suggests

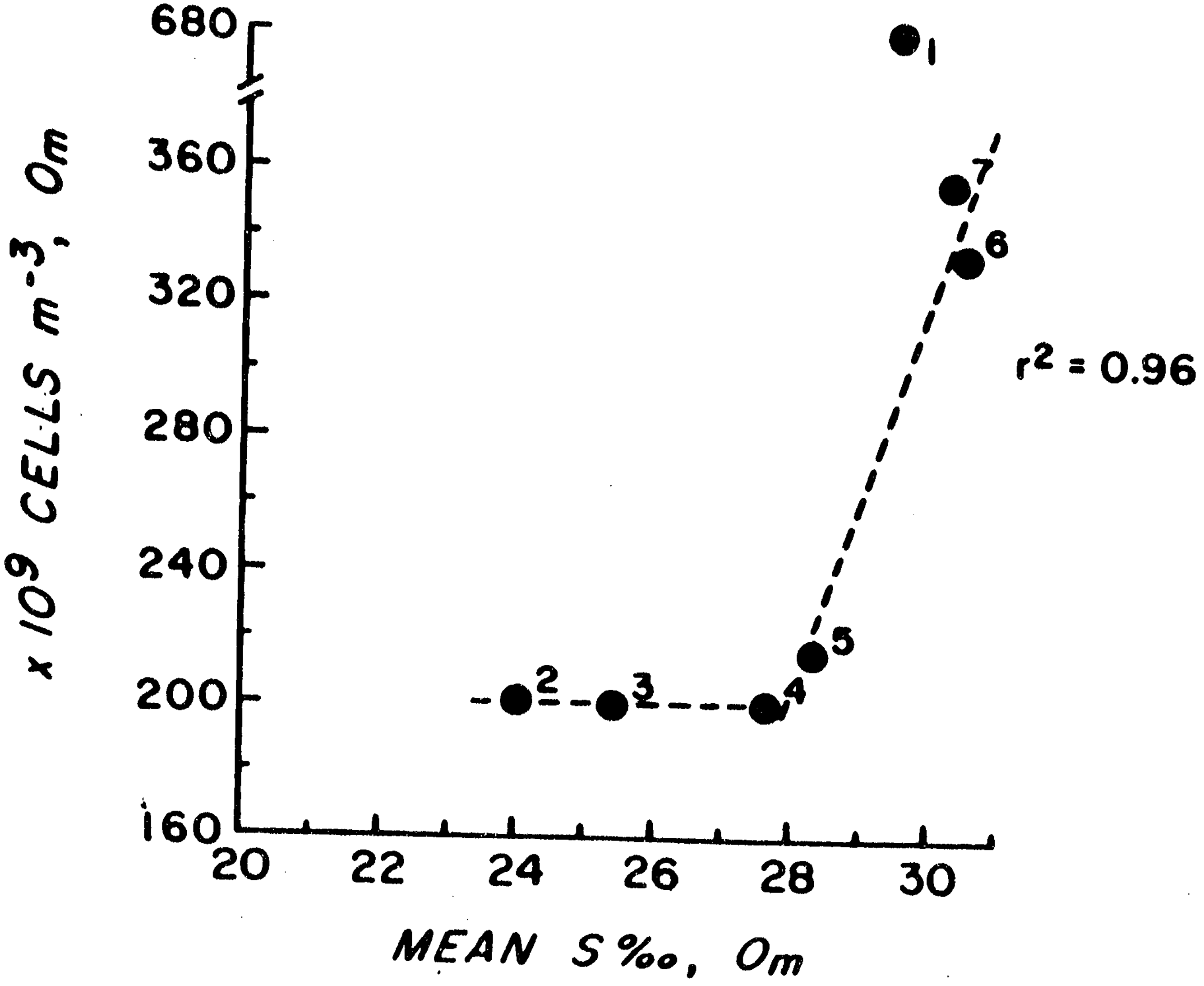


Figure 4. Mean number of brown-tide cells versus mean salinity at sampling stations.

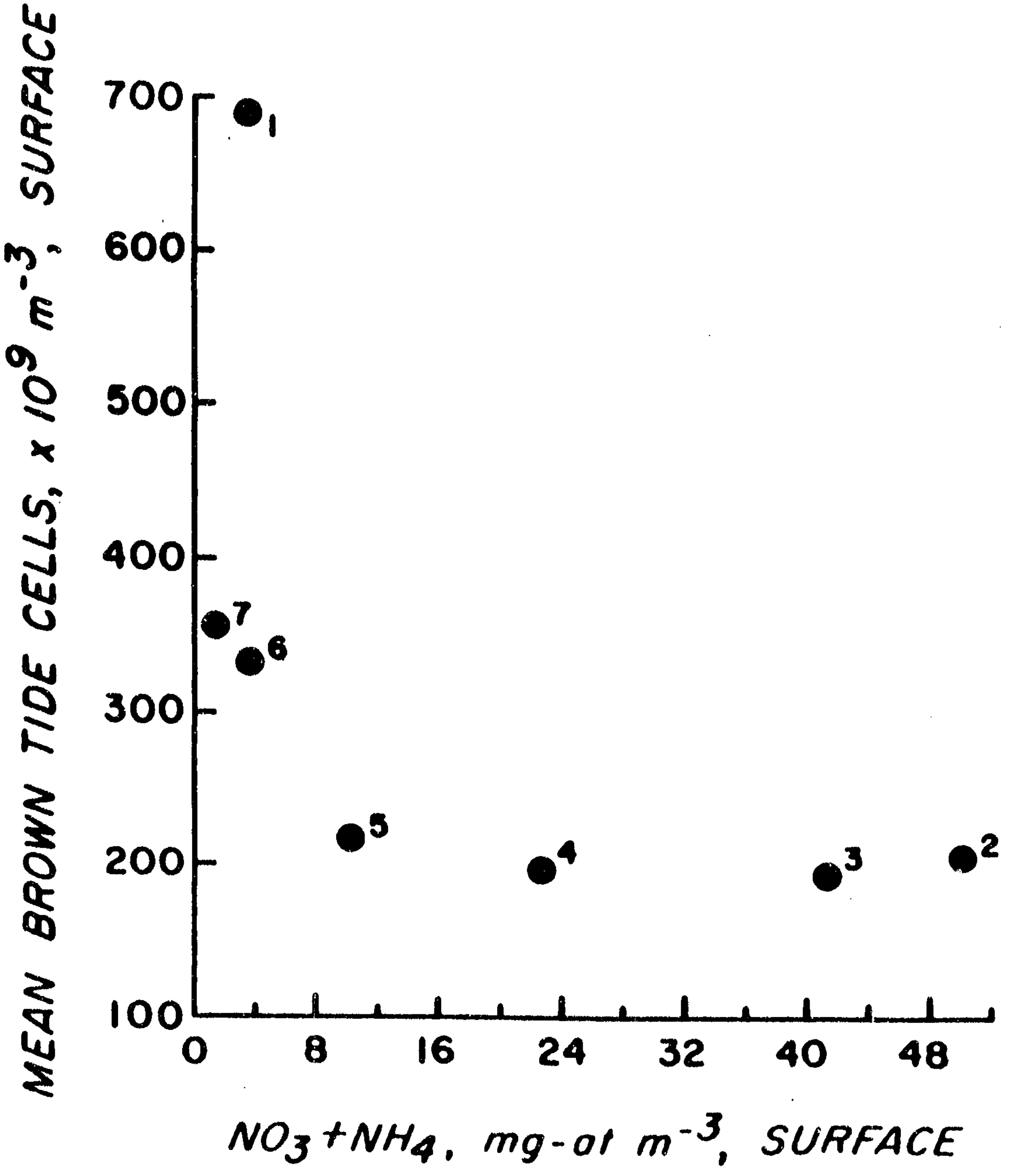
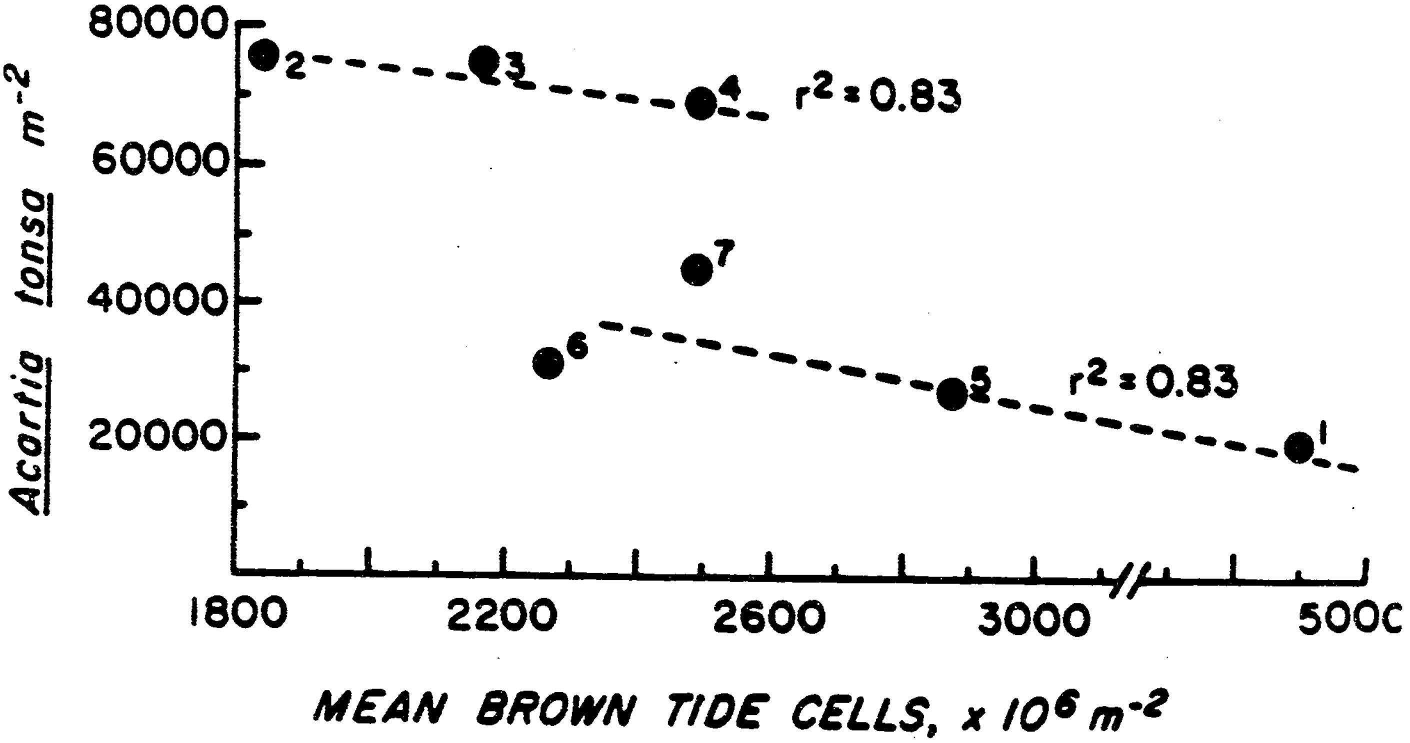


Figure 5. Relationship between mean number of brown-tide cells and NO_3+NH_4 concentrations at surface.

that the brown-tide development in Narragansett Bay was not fundamentally a response to nutrient enrichment. In fact, high nutrient loadings were accompanied by reduced abundance.

Acartia tonsa was the dominant copepod in Narragansett Bay during the brown-tide bloom (Appendix Table 17). Durbin and Durbin (personal communication) reported that its fecundity, growth rate and grazing rate decreased when fed brown-tide cells relative to diatoms. This prompted comparison of mean *Acartia tonsa* abundance (as animals m-2) and brown-tide cells (m-2). An *inverse* correlation occurred (Figure 6): increasing brown-tide cell abundance was accompanied by decreased *Acartia tonsa* abundance with two distinct regional groupings evident: Stations 2, 3, 4 and Stations 1, 5, 6, 7. r2 was -0.83 for both clusters. However, *Acartia tonsa* abundance at upper bay Stations 2, 3 and 4 was about 2-fold greater per unit of brown-tide cellular abundance than at the lower bay stations.

Regression of the total zooplankton community biomass (as mg dry wt m^{-2}) against surface abundance of brown-tide cells at all stations revealed an inverse power function, with r2 = -0.85. When total zooplankton biomass (mg m-2) was regressed against total number of brown-tide cells within the water column (m-2), the inverse correlation remained, though it was now linear with a weaker correlation coefficient (r2 = 0.31). For Stations 2 through 5, r = -0.09, and -0.95 for Stations 1, 6 and 7. Within this tendency for zooplankton biomass to decrease with increased brown-tide abundance, zooplankton levels were considerably lower (< 220 mg dry wt m-2) at Stations 1, 6 and 7, where mean surface brown-tide abundance exceeded 300 billion cells m^{-3}, than at the upper bay stations. There, where brown-tide



Rigure 6. Relationship between mean numerical abundance of Acartia tonsa and mean abundance of brown-tide cells.

abundance was less than 220 billion cells m^{-3}, zooplankton dry weight was considerably greater (> 340 mg m^{-2}).

These general trends suggest, therefore, a reduction in *Acartia tonsa* numbers accompanied increased brown-tide abundance in Narragansett Bay, with the negative effect most pronounced in the lower bay region where the brown-tide was most intense. These field observations are consistent with the Durbins' experiments. The negative correlation between zooplankton biomass levels and brown-tide cells suggests an overall effect on zooplankton development. However, augmentation ot certain minor components of the zooplankton community in response to the brown-tide bloom can not be excluded. The responses of components other than *Acartia*, cladocerans and benthic larval stages were not evaluated. Nonetheless, the reduced augmentation of the total zooplankton community biomass at all stations, and particularly where the bloom was most intense (Stations 1, 6, 7), suggests general repression of zooplankton trophic dynamics during the *Aureococcus* bloom.

Reports of spawning failure in the edible mussel *Mytilus edulis* and inimical effects on scallop during the brown-tide prompted assessment of the correlation between benthic larvae abundance and brown-tide intensity (Figure 7). A 10-fold range in benthic larvae numbers occurred, from 15603 m^{-2} at the Providence R. (Station 2) to 1456 m^{-2} in Greenwich Bay (Station 1). Benthic larvae abundance, which accounted for 7 to 19% of the total zooplankton numerical abundance (Appendix Table 10), indeed generally decreased with increased mean abundance or brown-tide cells. The correlation coefficient r was -0.58 for all stations (-0.68 if Station 6 omitted), reflecting considerable

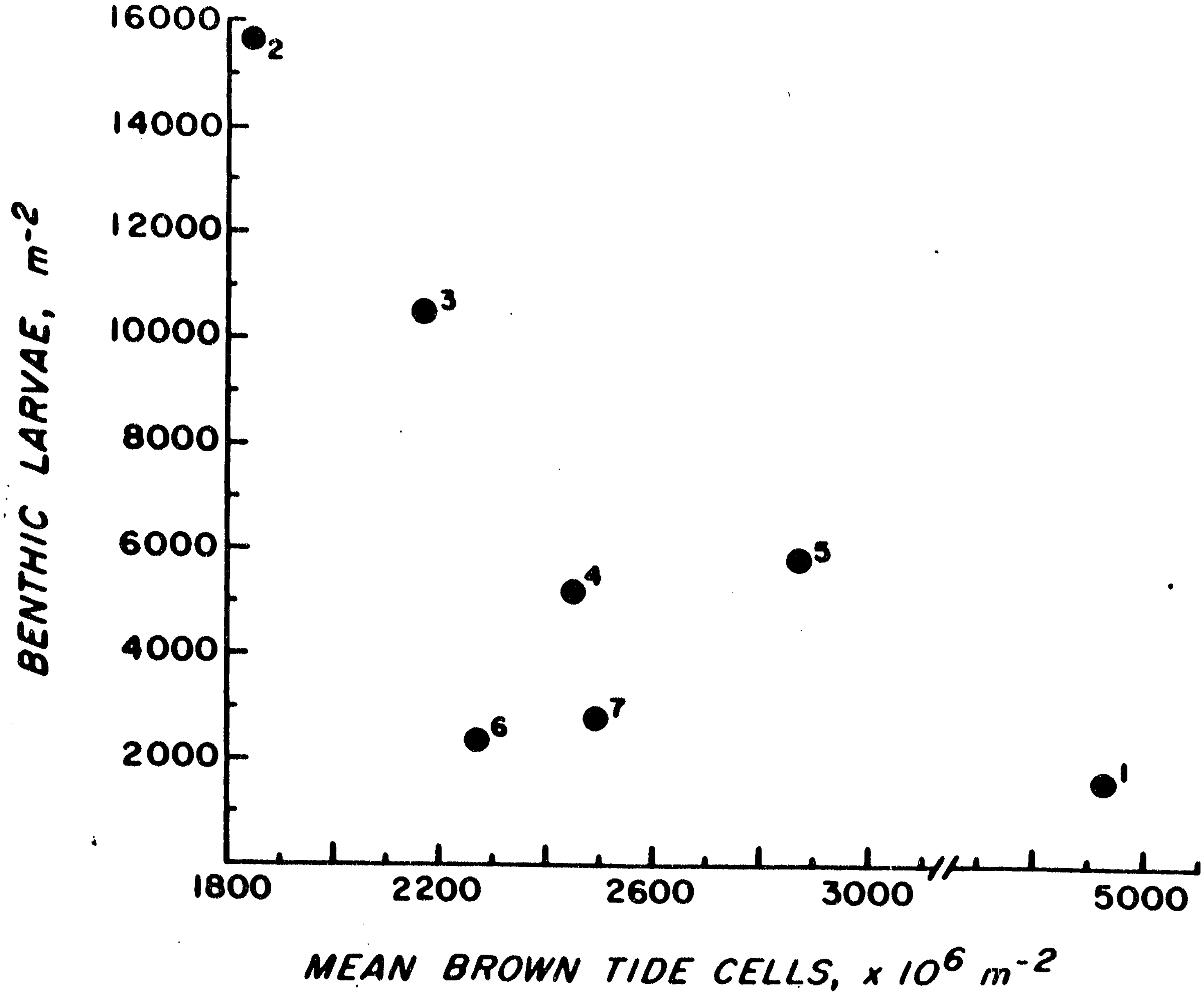


Figure 7. Mean number of benthic larvae versus mean number of brown-tide cells

variability at Stations 1, 5, 6 and 7. In contrast, along the upper bay gradient from Stations 2 - 4, r was -1.0. Although the correlations are provocative, there is no convincing statistical evidence based on larval abundance that benthic recruitment was impaired by the brown-tide event. The available data are inadequate to evaluate this with regard to edible bivalve recruitment.

The ctenophore Mnemiopsis leidyi, predatory on zooplankton, showed a distinct gradient in mean abundance ranging from 88 animals m-2 in the Providence R. to 33 m-2 in lower Narragansett Bay (Station 7). There was no correlation between ctenophore abundance and distribution and brown-tide cell abundance. In contrast, a strong inverse correlation ($r = -0.84$) occurred between ctenophore numbers and salinity. The correlation between ctenophore numbers and zooplankton dry weight was 0.70 for all stations, increasing to 0.84 excluding the Greenwich Bay station.

Brown-Tide: General Conclusions

The foregoing analysis provides no information regarding the environmental conditions triggering the brown-tide bloom. Relative to previous blooms in Narragansett Bay based on weekly assessments of phytoplankton growth in lower Narragansett Bay beginning in 1959 at the transect Station 7 (Smayda and Villareal, 1988; Smayda and Fofonoff 1988; Smayda, unpublished), the following characterizations can be made:

1. The brown-tide bloom species was not previously recorded in bloom abundance and, if present, was not significant.

2. The bloom was extraordinary in its abundance: the

maximum recorded abundance of 1.5 billion cells L-1 exceeded by 12-fold the previously observed maximal summer phytoplankton abundance.

3. The bloom was extraordinary in its duration: previous blooms persisted several weeks; the 1985 summer bloom persisted from May through September.

4. The 1985 bloom was accompanied by mussel mortality and may have suppressed *Acartia tonsa* growth. Previous brown-tide events were not shown to be noxious, excluding periodic blooms of *Olisthodiscus luteus* which appeared to be deleterious to zooplankton.

5. The 1985 summer brown-tide bloom was part ot a mesoscale, regional event which included embayments along the southern Long Island shoreline, and possibly Barnegat Bay, New Jersey. This implicates regional climatological and/or hydrographic triggering factors.

6. Within Narragansett Bay, elevated nutrient loading appeared to suppress growth rather than to be stimulatory. The field studies do not support the theory of a eutrophication trigger.

7. Growth conditions in Greenwich Bay appeared to be particularly favorable; those in the Providence R. least favorable.

8. The taxonomic status of the causative species is enigmatic. While the brown-tide development reflected the growth of several < 5 µm diameter phytoplankters, Sieburth et al. (in press) attribute this primarily to a single species new to science. They have identified it as a new genus and species *Aureococcus anophagefferens*. Their identification and conclusions are based on several samples collected late in the bloom in lower Narragansett Bay.

9. Extensive blooms of diatoms, dinoflagellates, diverse microflagellates and Euglenids co-occurred with the brown-tide bloom.

The brown-tide bloom terminated by 2 October; cells were not found during the 10 October transect (Figure 8). The causes of the bloom termination are unknown. They were not related to hurricane GLORIA which occurred on 27 September. In fact, the bloom progressively declined following the maximal abundances recorded during the first survey carried out on 25 July. Both the decline and disappearance patterns were similar throughout the bay.

The environmental/plankton changes were found on 9 October relative to the 2 October transect are presented in Table 6.

Table 6

STATION	1	2	3	4	5	6	7
°C	-3.0	-3.2	-2.4	-2.6	-2.4	-2.2	-1.4
S o/oo	-1.0	-4.1	+3.1	+1.1	0	-1.1	0
NO_3 (mg-at m^{-3})	+0.5	+22.0	-10.1	-4.5	-0.9	-0.6	+0.5
NH_4	+0.7	-8.6	-21.7	-2.0	-6.4	-1.4	-0.1
PO_4	+0.4	-4.4	-2.1	-0.6	-0.4	-0.4	-0.3
SiO_2	-14.3	-5.0	+1.3	-3.1	+2.1	-4.9	-1.2
ATP-carbon (mg m-3)	-2005	-12	+1645	?	0	-1865	-225
Zooplankton (m-3):							
Biomass (mg)	-8	-405	+19	+212	+45	-66	-25
Σ Copepod Nos.	+776	+775	-328	+6097	+1882	+417	+73
Acartia							
hudsonica	+6	+6	0	+29	+24	+6	+84
tonsa	+503	+553	-396	+4686	+1706	+316	+140
Benthic larvae	-2	-7	-45	-191	+378	+705	+600
Ctenophore nos.	+21.1	0	+28	-4.2	+1	+10	+4.1

These data suggest that a significant environmental change occurred in the one week interval between the 2 and 9 October transects. Temperature decreased significantly, by 1.7°C in the lower bay and 3.2°C in the Providence R. where a significant decrease in salinity (-4.1 o/oo) also occurred. However, changes in surface salinity varied considerably among the stations, probably symptomatic of different watermasses. For example, salinity increased

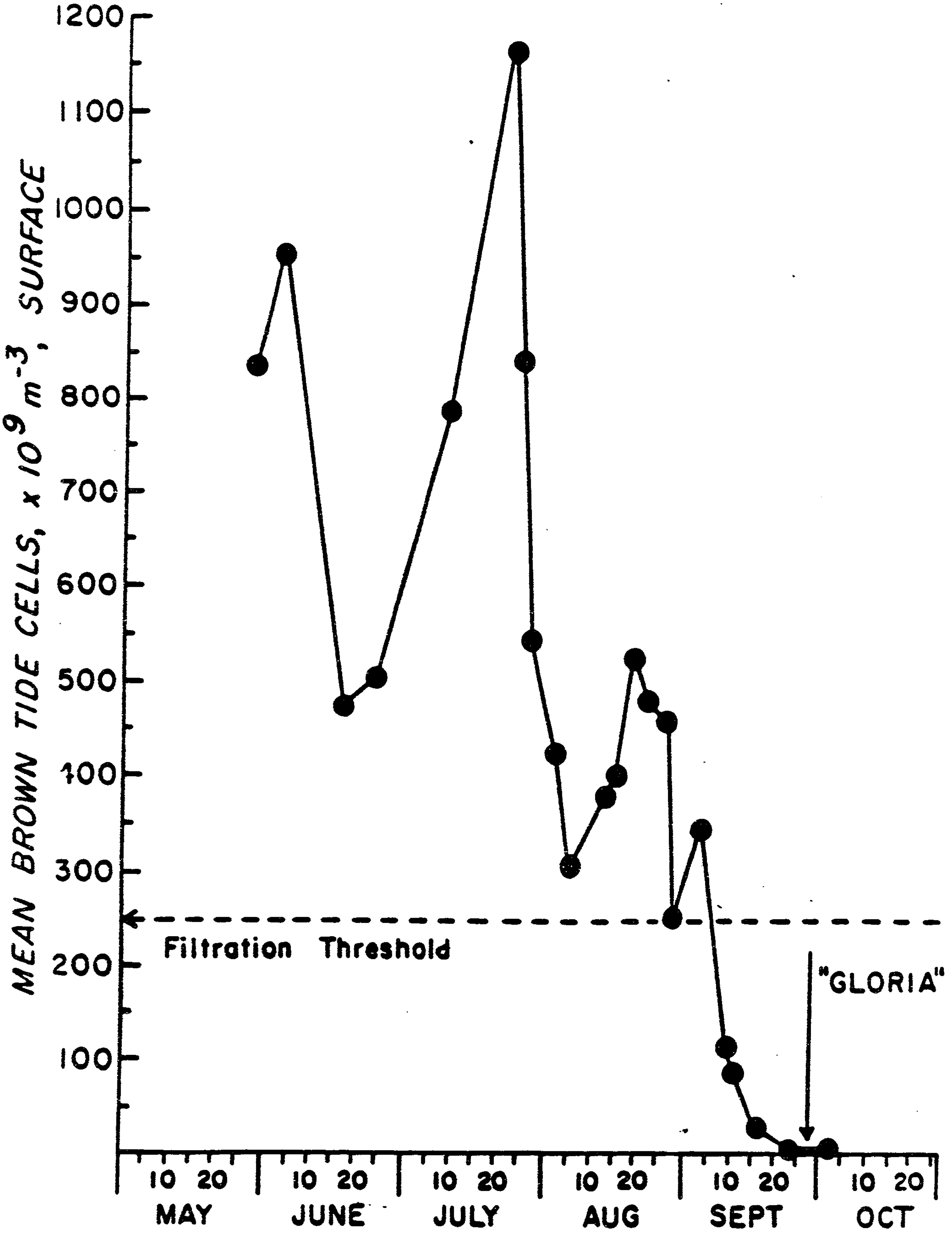


Figure 8. Brown-tide cell abundance cycle at Station 7. Filtration threshold refers to concentration above which filtration of the mussel *Mytilus edulis* ceased. "GLORIA" refers to hurricane event

significantly (+3.1 o/oo) at Station 3. Nutrient concentrations generally decreased, excluding Greenwich Bay (Station 1). Decreases in NO_3 and NH_4 were very pronounced at Station 3, accompanied by a slight increase in silicate and significant increase in phytoplankton abundance (+1645 ATP-carbon). Phytoplankton, in contrast, decreased at all other stations.

Although zooplankton biomass (= dry weight) generally decreased (excluding Stations 3, 4), a big increase in zooplankton numbers, notably *Acartia tonsa*, occurred during the week following the termination of the brown-tide. The winter-spring dominant copepod, *Acartia hudsonica*, suddenly appeared, being most prominent at the lower bay stations. A significant increase in benthic larvae abundance (+378 to +705) occurred at Stations 5, 6 and 7, unlike at the other stations where abundance decreased. Ctenophore abundance also increased at Stations 1, 3, 6 and 7. These observations suggest a general surge in zooplankton, benthic larvae (down bay) and ctenophore abundance occurred the week following termination of the brown-tide bloom. Collectively, the observations also indicate that the waters were then colder and nutrient-poorer, and the phytoplankton less abundant.

Dynamics of Other Phytoplankton Species During Brown-Tide Bloom:

1. Diatoms

Significant growth and blooms of other phytoplankton species occurred during the brown-tide bloom. During the 2 August transect, the diatom *Skeletonema costatum* ranged in abundance from about 13 to 27 million cells L^{-1} at Stations 1 - 5; < 5 million cells L^{-1} occurred at Stations 6 and 7. A small *Thalassiosira* species also occurred throughout Narragansett Bay; maximal levels were 9 million cells L-1. During the three transects carried out between 15 - 28 August, Skeletonema and the Thalassiosira sp. progressively increased following their decline in abundance between 2 and 15 August (Table 7). Maximal abundances for both species (14 to 16 million cells L-1) occurred on 28 August (Stations 3, 4, 5), with significantly decreased abundances in the Providence R. and in lower Narragansett Bay. Thereafter, both species decreased significantly through 9 October, with maximal concentrations persisting at Stations 3 and 4.

During their significant proliferation beginning on 22 August, the brown-tide species abundance ranged from 37 to 1521 million cells L-1. A strong inverse correlation (r = -0.95) then occurred between Skeletonema and brown-tide cell abundance at Stations 3 - 7. This is not considered to be indicative of an antagonistic effect of the brown-tide cells on Skeletonema. The absence of Skeletonema in Greenwich Bay where the highest brown-tide cell abundance was encountered (1.5 billion cells L-1) is provocative, however. The reduction in Skeletonema abundance in the Providence R. station (Station 2) is a persistent feature, and in addition to the potential antagonistic effects of the presumed brown-tide species (Aureococcus anophagefferens) on Skeletonema. (There was no correlation with Thalassiosira.) The surface abundance of Skeletonema and Thalassiosira (as cells ml-1) from 2 August - 9 October is given in Table 7.

Table 7

Skeletonema:

STATION:	1	2	3	4	5	6	7
2 Aug	8900	0	13300	18000	19000	0	3300
15	23	71	0	68	0	0	0
22	0	206	4163	3206	1451	218	49
28	116	2970	13400	15775	11981	150	79
11 Sept	0	143	1193	349	15	0	0
2 Oct	94	199	540	484	0	8	11
9	173	15	425	384	114	188	152

Thalassiosira:

STATION:	1	2	3	4	5	6	7
2 Aug	7800	4400	0	8900	8900	4400	1100
15	0	30	41	0	0	0	0
22	195	108	945	1878	2633	563	45
28	1676	1530	2746	5715	14000	2081	1395
11 Sept	19	26	585	810	98	15	8
2 Oct	501	105	799	1080	304	4	11
9	158	15	17	45	39	54	56

2. Bloom of *Minutocellus*

Significant blooming of the small diatom *Minutocellus* sp. also occurred during August. On 6 August a surface sample collected off the

East Greenwich Yacht Club dock located within an inner arm of Greenwich Bay revealed 140 million cells L-1. The surface abundance of *Minutocellus* (x 106 L-1) during the 9, 15, 22 and 28 August transects is given in Table 8.

Table 8

STATION:	1	2	3	4	5	6	7
9 Aug	81.1	25.6	-	-	0	-	-
15	10.0	14.4	253.3	112.2	99.0	32.2	13.3
22	35.6	2.2	5.6	3.3	16.7	15.6	4.4
28	2.2	1.1	0	0	0	0	1.1

A prodigious bloom centered at Stations 3, 4 and 5 was found on 15 August. Its ephemeral occurrence is indicated by its significant collapse the following week and virtual disappearance by 28 August. The vertical distribution patterns of *Minutocellus* indicated maximal concentrations at the surface; mid-depth levels during the 15 August transect ranged from 9 (Station 7) to 136.7 x 106 L-1 (Station 3) and bottom depth levels from 11.1 (Station 7) to 37.8 x 106 L-1 (Station 3).

3. Dinoflagellate Blooms

A significant dinoflagellate bloom consisting of *Prorocentrum redfieldii*, *scutellum* and *triangulatum* co-occurred with the brown-tide bloom on 15 August, notably at Stations 3, 4 and 5. *Prorocentrum triangulatum* dominated (1 to 2 million cells L-1. This community decreased significantly by 22 August, persisted thereafter in modest abundance, followed by renewed blooming of *Prorocentrum redfieldii* (maximum of about 0.5 million cells L-1) in October after the brown-tide cells disappeared. *P. redfieldii* predominated in the latter half of October, its bloom preceded by the sudden appearance and blooming of *Scrippsiella trochoidea* coincident with the disappearance of the brown-tide cells. Maximal concentrations occurred at Stations 4, 5 and 6, with a surface maximum of 0.64 million cells L-1 found at Station 4. The small dinoflagellate *Massartia rotundatum* suddenly appeared in bloom proportions at Stations 4 and 5 (0.3 million cells L-1) on 23 October, declined and bloomed again on 20 November. The surface abundance (cells ml-1) of these five species is given in Table 9.

Table 9

Prorocentrum triangulatum:

STATION:	1	2	3	4	5	6	7
15 Aug	15	45	1024	1721	1823	113	64
22	8	4	0	4	0	4	0
28	0	0	0	15	8	8	8
11 Sept	338	0	4	34	49	45	79
2 Oct	2	109	62	64	2	0	0
9	4	0	47	19	24	8	4
18	2	0	0	31	2	4	0
23	0	0	0	2	8	0	0
30	0	2	0	2	4	0	0
13 Nov	2	0	0	2	0	0	0
20	0	0	0	0	0	0	0

Prorocentrum redfieldii:

STATION:	1	2	3	4	5	6	7
15 Aug	15	120	788	585	720	19	19
22	0	0	10	0	0	0	0
28	0	0	4	0	4	0	0
11 Sept	94	0	0	4	4	4	8
2 Oct	11	64	30	150	4	15	4
9	75	13	7	86	36	53	17
18	90	6	17	118	36	103	11
23	84	15	13	90	489	23	11
30	118	30	214	236	461	259	51
13 Nov	60	0	11	56	51	24	54
20	17	2	0	19	13	21	19
4 Dec	0	0	0	0	0	0	2

Prorocentrum scutellum:

STATION:	1	2	3	4	5	6	7
15 Aug	49	0	45	45	45	34	11
22	8	8	4	60	49	26	0
28	53	0	0	79	154	38	4
11 Sept	0	0	0	4	0	11	0
2 Oct	0	0	2	9	9	6	0
9	2	0	7	4	8	8	2
18	6	0	0	8	6	6	2
23	0	0	0	4	8	4	4
30	4	2	11	26	15	11	0
13 Nov	8	0	0	6	17	11	6
20	0	0	0	2	6	6	15
4 Dec	0	0	0	0	0	0	0

Scrippsiella trochoidea:

STATION:	1	2	3	4	5	6	7
28 Aug	4	0	4	0	0	0	0
11 Sept	4	0	0	0	0	0	8
2 Oct	0	11	19	641	11	158	4
9	135	7	28	131	180	146	124
18	36	0	2	110	105	41	8

23	4	4	0	38	197	4	9
30	8	4	34	13	23	8	0
13 Nov	2	0	2	6	6	2	0
20	0	0	0	0	0	0	0

Massartia rotundatum

STATION:	1	2	3	4	5	6	7
2 Oct	0	0	0	0	0	4	0
9	0	0	0	0	4	0	2
18	101		2	2	0	9	0
23	56	0	4	276	270	79	23
30	0	0	0	0	0	0	0
13 Nov	0	0	0	2	0	2	0
20	326	0	90	22	461	79	0
4 Dec	56	15	0	19	23	135	8
18	43	0	0	38	12	2	9

Heterotrophic dinoflagellates (Gymnodiniaceans) appeared in greater abundance in mid-September, and persisted thereafter. Their abundance generally was greater at Stations 1, 4, 5 and 6, with occasional blooms of > 0.1 million cells L-1. Their surface abundance (cells m L-1) is given in Table 10.

Table 10

Gymnodiniaceans:

STATION:	1	2	3	4	5	6	7
11 Sept	113	0	4	4	8	11	30
2 Oct	34	4	0	203	62	101	4
9	15	0	7	9	11	8	2
18	28	0	0	79	11	146	9
23	8	2	4	15	11	2	0
30	8	9	9	13	34	8	2
13 Nov	6	0	17	21	17	6	9
20	4	0	0	4	4	11	32

4 Dec	2	0	2	0	2	0	0
18	0	0	0	2	0	0	0

The significant observation is that dinoflagellate blooms co-occurred with the brown-tide bloom. The October blooms of *Prorocentrum redfieldii*, *Scrippsiella trochoidea* and *Massartia rotundata* following the disappearance of the brown-tide bloom in early October are notable. Dinoflagellate blooms so late in the annual cycle are unusual based on the long-term phytoplankton data set (Smayda, unpublished). *Heterocapsa triquetra* and *Dinophysis* spp. were frequently encountered in low numbers.

4. Euglenid Blooms

A remarkable Euglenid bloom developed during the brown-tide, and persisted until late November following the early October collapse of the latter. Euglenids suddenly appeared at all stations on 15 August; by August 28 maximal populations reached 1.9 million cells L-1 at Station 2 and between 0.23 and 0.34 million cells L-1 at Stations 3 and 4, respectively. The bloom was then centered in this region of upper Narragansett Bay, decreasing precipitously at Station 5 (15,000 L-1) and at the lower Narragansett Bay stations (< 5,000 L-1). On 2 October, the population pulsed in the latter region, attaining 0.5 and 0.12 million cells L-1 in the surface waters at Stations 6 and 7. The population remained fairly high at these stations; elsewhere it continued to proliferate. By mid-October, "green water" was reported from Bristol Harbor and Davisville (Hunt, personal communication) and observed at Stations 3 and 4 during the 30 October transect. The euglenid population in the surface water at these stations reached 2.7

million cells L-1; 1.5 million L-1 at Station 5; 0.9 million L-1 and 0.65 million L-1 at Stations 1 and 6, respectively. The previous week (23 October) 1.3 million cells L-1 were recorded at Station 7, where 1.2 million cells L-1 were recorded on 13 November. The Euglenid population at Stations 1, 5 and 6 was then about 0.5 million L-1; 0.3 million L-1 at Station 4, and considerably lower at Stations 2 and 3. Thus, maximal bloom occurrence shifted from upper Narragansett Bay during the brown-tide outbreak to lower Narragansett Bay in November. The population collapsed precipitously by the time of the 4 December transect.

The Euglenid bloom is remarkable for its baywide occurrence, magnitude and persistence. This community, which consisted of several species, was previously detected sporadically and in much lower numbers, rarely in bloom concentrations, at Station 7 (Smayda, unpublished). It is commonly considered to be an indicator of nutrient-enriched waters. Given this, its baywide occurrence, abundance and persistence are remarkable and unique. and equally interesting and as enigmatic as the brown-tide event. Table 11 gives the surface abundance (cells ml-1) of the Euglenids.

Table 11

Euglenids

STATION:	1	2	3	4	5	6	7
15 Aug	41	90	484	270	131	26	8
22	4	19	131	34	23	0	0
28	0	1856	225	338	15	4	1
11 Sept	4	0	0	4	8	0	8
2 Oct	26	9	8	13	26	520	125
9	182	10	10	4	17	118	37

18	169	0	0	0	116	585	39
23	36	15	0	819	900	30	1328
30	641	928	2666	2767	1564	653	186
13 Nov	568	6	54	298	574	450	1159
20	113	0	12	62	113	281	338
4 Dec	2	0	0	0	0	0	0
18	4	0	0	0	2	0	0

5. Blooms of *Olisthodiscus luteus* and other flagellates:

Bloom dynamics of several autotrophic flagellates during and subsequent to the brown-tide event provide further evidence that an unusual environmental-phytoplankton response condition occurred within Narragansett Bay during the 1985 summer and carried over into the autumn.

Olisthodiscus luteus frequently causes red tides during the summer in Narragansett Bay (Pratt, 1966), accompanied by a brief resurgence in October (Tomas, 1980). Although it was not observed during the 1985 summer transect series, it suddenly appeared on 9 October in bloom abundance at Stations 3, 4 and 5; was unimportant elsewhere, and abruptly disappeared during the following transect. Its surface occurrence (cells ml-1) is given in Table 12.

Table 12

Olisthodiscus luteus

STATION:	1	2	3	4	5	6	7
9 Oct	4	0	3724	424	810	11	2
18	0	0	0	0	6	0	15
23	0	0	4	0	0	0	0

This brief autumnal efflorescence, unusual for its occurrence without an accompanying summer abundance, is noteworthy for its occurrence subsequent to the disappearance of the brown-tide bloom. Its summer niche seems to have been filled by *Aureococcus*.

During the previous transect (2 October), a modest bloom (43,000 cells L-1) of *Oltmannsiella* sp. occurred at Stations 3 and 4. A population of *Pyramimonas* spp. appeared in late August, culminating in significant blooms on 18 October at Stations 1 and 4; surface populations reached 0.14 and 0.3 million cells L-1, respectively. In late August, maximal abundance (30,000 to 56,000 cells L-1) occurred at Stations 6 and 7. The surface population distributions (cells ml-1) of *Pyramimonas* spp. during the transects are given in Table 13.

Table 13

Pyramimonas spp.:

STATION:	1	2	3	4	5	6	7
22 Aug	0	0	0	0	0	0	4
28	0	0	0	11	4	56	30
11 Sept	15	0	0	0	0	8	4
2 Oct	0	0	0	0	0	0	0
9	6	2	0	2	4	8	13
18	135	8	0	304	0	0	0
23	0	0	0	2	6	2	2
30	2	0	0	0	0	0	0
13 Nov	0	0	0	2	0	2	0
20	2	0	0	0	0	0	0

Another remarkably persistent and unusual bloom was that exhibited by a flagellate tentatively identified as *Fibrocapsa japonica* (?). This flagellate was previously recorded only sporadically, and in relatively low abundance. It suddenly appeared during the 22 August transect at Stations 4, 5, 6 and 7 where it proliferated through 2 October, reaching maximal populations of about 0.3 million cells L-1.

By then, it occurred at all transect stations. Thereafter, it persisted below 15,000 cells L-1 through mid-November. This occurrence of *Fibrocapsa* is notable, since a related species occurring in Japanese coastal waters appears to produce an ichthyotoxin. The surface distribution characteristics (cells ml-1) of *Fibrocapsa japonica* (?) are given in Table 13 (values in ( ) indicate abundance at greater depth; absent at surface).

Table 14

Fibrocapsa japonica (?):

STATION:	1	2	3	4	5	6	7
22 Aug	0	0	0	41	79	86	53
28	8	0	0	116	375	300	323
11 Sept	0	0	0	0	0	15	8
2 Oct	8	11	79	203	58	338	23
9	0	2	4	6	6	4	2
18	8	0	2	13	6	7	13
23	(4)	0	0	0	0	(4)	2
30	2	6	8	2	4	4	2
13 Nov	0	0	0	0	2	(2)	2

Cryptomonas amphioxeiae, an autotrophic flagellate, was more ubiquitous. Its abundance prior to October is somewhat problematic because of the enumerative procedures used. However, through mid-October it appeared to be concentrated at Stations 4, 5, 6 and 7, thereafter exhibiting sporadic blooms at nearly all stations during the 23 October and 20 November transects. Maximal abundance was about 0.3 million cells L^{-1} at Station 2. The time-series distribution (cells ml-1) of *Cryptomonas amphioxeiae* is given in Table 15.

Table 15

Cryptomonas amphioxeiae:

STATION:	1	2	3	4	5	6	7
2 Oct	0	15	6	23	9	113	6
9	2	0	0	34	2	2	4
18	68	0	2	6	4	0	0
23	(45)	293	8	225	34	68	23
30	2	0	39	4	2	2	6
13 Nov	0	2	0	0	0	0	0
20	146	0	4	39	180	34	34
4 Dec	0	0	23	0	8	4	11
18	32	8	26	15	24	15	36

6. Summary of Flagellate Successional Trends

Clearly, the brown-tide bloom of *Aureococcus anophagefferens* was accompanied by co-occurring blooms of several autotrophic species of dinoflagellates and other flagellates. Moreover, unusual blooms of flagellates relative to previous studies in lower Narragansett Bay (Pratt, 1959; Smayda. 1957; 1973; unpublished) occurred following the collapse of the brown-tide bloom. The general successional trend of these various flagellates is presented in Table 16 (stations indicated in ( )).

Table 16

Transect Date	Bloom Flagellate
15 Aug	*Prorocentrum triangulatum*, *P. redfieldii*, Euglenids (3, 4, 5)
28 Aug	*Prorocentrum acutellum*; Euglenids (2), *Fibrocapsa japonica* (?)

11 Sept	*P. triangulatum* (1)
2, 9 Oct	*Scrippsiella trochoidea*, *P. triangulatum* (2); *Olisthodiscus luteus*, *F. japonica* (4, 6); *Cryptomonas amphioxeiae* (6); *Oltsmannsiella* sp. (3, 4)
18 Oct	*Pyramimonas* spp. (1, 4)
23, 30 Oct	*P. redfieldii*, *Massartia rotundata* (4, 5); Euglenids, *Cryptomonas amphioxeiae* (2, 4)
13, 20 Nov	*C. amphioxeiae* (1, 5); *M. rotundata* (1, 3, 5)

Autumn Phytoplankton Bloom Following Brown-tide:

Narragansett Bay characteristically has a late summer - autumn phytoplankton bloom, followed by a population nadir in November (Pratt, 1959; Smayda, 1957; 1973; unpublished). Phytoplankton dynamics during this period following the unusual summer brown-tide bloom are therefore of special interest. The previous sections indicated the occurrence of anomalous flagellate blooms, notably of Euglenids and *Fibrocapsa japonica* (?), during this period, including a unique flagellate successional pattern (Table 16). Since diatoms ordinarily dominate the late summer - autumn pulse, their dynamics will be scrutinized here.

An abundant Skeletonema costatum population (12 to 16 million cells L-1) occurred at Stations 3, 4 and 5 during the 28 August transect; a precipitous decrease was detected during the 11 September transect. A similar dynamics characterized a small Thalassiosira sp. which co-dominated. It was very abundant (14 million L-1) at Station 5 in August (its center of abundance was then at Stations 4 and 5) and became the dominant diatom in September. The surface distributions (cells ml-1) are shown in Table 17.

Table 17

STATION:	1	2	3	4	5	6	7
Skeletonema costatum:							
28 Aug	116	2970	13398	15773	11981	150	79
11 Sept	-	143	1193	349	15	-	-
Thalassiosira sp.:							
28 Aug	1676	1530	2756	5715	14000	2081	1395
11 Sept	19	26	585	810	98	15	8

Diatoms were otherwise depauperate during these transects. Thalassiosira rotula occurred throughout the bay on 28 Aug (34 to 153 cells ml-1), whereas Rhizosolenia fragilissima (30 to 128 cells ml-1) was significant at Stations 5, 6, 7, but scarce elsewhere. During this transect, Euglenids were very abundant (225 to 1856 cells ml-1) at Stations 2, 3 and 4. Thus a region (2, 3, 4) of very high Euglenid abundance in upper Narragansett Bay overlapped with a region of intense Skeletonema and Thalassiosira sp. growth (3, 4, 5), both populations becoming less abundant in lower Narragansett Bay (6, 7) where *Thalassiosira* sp. and *Rhizosolenia fragilissima* characterized the community.

A precipitous decline in diatom abundance during mid-September generally characterized the phytoplankton community. The regional distributional patterns observed during August were less distinct, although the *Skeletonema*, *Thalassiosira* sp. and *Thalassiosira rotula* abundance locus persisted at Stations 3 and 4.

Thus, at the time of the brown-tide collapse in early October, overall phytoplankton abundance was decreasing; species representation was low, and the diatom community was dominated by *Skeletonema costatum* and a small *Thalassiosira* sp. During the 2 October transect, the markedly decreased brown-tide population (it disappeared the following week) was accompanied by a significant diatom flowering consisting of numerous species (Table 18).

Table 18

STATION:	1	2	3	4	5	6	7
Thalassiosira sp.	501	105	799	1080	304	4	11
Skeletonema costatum	94	199	540	484	0	8	11
Lithodesmium undulatum	568	21	84	180	225	506	456
Cerataulina pelagica	394	13	139	263	99	388	302
Thalassiosira rotula	191	13	15	81	23	45	73
Thalassiosira gravida	478	23	88	81	60	75	146
Leptocylindrus minimus	199	15	26	13	13	77	120

Thalassionema nitzschioides	47	8	23	26	32	28	8
Nitzschia seriata	173	11	0	38	0	8	19
Chaetoceros didymus	17	0	51	47	19	15	11
Chaetoceros curvisetum	107	0	0	0	0	113	129
Rhizosolenia delicatula	23	0	0	8	13	73	75
Chaetoceros subtilis	19	6	0	11	35	0	13
Ditylum brightwelli	15	0	6	11	8	13	2
Scrippsiella trochoidea	0	11	19	641	11	158	4
Euglenids	26	9	8	13	26	520	125
Fibrocapsa japonica (?)	8	11	79	203	58	338	23

The appearance and predominance (about 500 cells ml-1) of *Lithodesmium undulatum* in lower Narragansett Bay (Stations 1, 6 and 7) is one of the most remarkable features of this bloom. This species is not normally significant in Narragansett Bay, exhibiting sporadic, unpredictable bloom occurrences, based on the long-term data set (1959-1986) available for Station 7 (Smayda, unpublished). The significant abundance of *Cerataulina pelagica* is also unusual. It ordinarily predominates at the end of the winter-spring bloom in May or June. The other important diatom species represented in the community are normal components of the autumn pulse.

Two other remarkable features of this bloom were the significant blooms of Euglenids and *Fibrocapsa japonica* (?), particularly in lower Narragansett Bay. These elements have previously been insignificant in the annual cycle in this region, and never found to be key species in the autumn bloom. This contrasts with the bloom of the dinoflagellate *Scrippsiella trochoidea* at Stations 4 and 6. It is a frequent bloom species in Narragansett Bay.

Three distinct regional patterns are evident. The locus of abundance for *Skeletonema* and the small *Thalassiosira* sp., as during August and September, remained in upper Narragansett Bay at Stations 3 and 4. Species generally important throughout the bay included: *Cerataulina pelagica*, *Thalassiosira rotula*, *T. gravida* and *Thalassionema nitzschioides*. Those attaining their maxima in lower Narragansett Bay (6 and 7) and Greenwich Bay (Station 1) included *Lithodesmium undulatum*, *Leptocylindrus minimus*, *Chaetoceros curvisetum* and *Rhizosolenia delicatula*. This autumnal diatom growth accompanying the disappearance of *Aureococcus anophagefferens* was therefore a bay-wide event, within which regionally distinctive diatom occurrence - abundance patterns developed. The relative insignificance of *Skeletonema costatum* in lower Narragansett Bay then is noteworthy.

Despite this diatom flowering, the failure of any species to dominate the community overwhelmingly was notable. In contrast, several species predominated in relatively modest numerical abundance. This situation differs somewhat from previous autumnal diatom blooms during which *Skeletonema costatum* usually dominates (Smayda, unpublished).

The 9 October transect revealed that *Aureococcus* disappeared; that the taxonomically diverse diatom community persisted, but overall abundance decreased; that a red-tide outbreak of *Olisthodiscus luteus* occurred at Station 3, with high abundances also at Stations 4 and 5; that the Euglenid and *Fibrocapsa japonica* (?) populations were decimated; and that the dinoflagellate *Scrippsiella trochoidea* increased its bay-wide significance. The surface abundance (cells ml-1) of the predominant species is shown in Table 19.

Table 19

STATION:	1	2	3	4	5	6	7
Olisthodiscus luteus	4	0	3724	428	810	11	2
Thalassiosira sp.	158	15	17	45	39	54	56
Skeletonema costatum	173	15	425	384	114	188	152
Lithodesmium undulatum	109	13	176	158	152	300	28
Cerataulina pelagica	23	0	41	30	26	17	41
Thalassiosira rotula	38	2	0	24	4	11	34
Thalassiosira gravida	6	4	4	6	26	30	7
Leptocylindrus minimus	30	0	49	53	41	56	115
Thalassionema nitzschioides	15	2	32	54	23	86	53
Nitzschia seriata	0	2	4	4	0	0	0
Chaetoceros didymus	13	15	131	53	26	111	329
Chaetoceros curvisetum	30	0	0	0	19	53	267
Rhizosolenia delicatula	0	0	0	0	0	0	13
Chaetoceros subtilis	30	0	6	6	19	68	15
Ditylum brightwelli	0	2	2	32	6	21	34
Scrippsiella trochoidea	135	7	28	131	180	146	124
Euglenids	182	10	10	4	17	118	37
Fibrocapsa japonica (?)	0	2	4	6	6	4	2

The transects of 2, 9 and 18 October collectively indicate an additional unusual feature of the 1985 autumn bloom. It was very brief and diatom abundance was low relative to previous years (Smayda, unpublished). This appears to be primarily due to the notable failure of *Skeletonema costatum* to bloom to a high level of abundance.

The ephemeral nature of the 1985 autumnal bloom is evident from the 18 October transect. *Chaetoceros debilis* appeared at Stations 1 and 7, attaining surface populations of 116 and 501 cells ml-1, respectively. It numerically dominated the diatom community despite its restricted distribution. The other diatom species either disappeared, or were considerably reduced in abundance relative to the 2 and 9 October transects. The phytoplankton community was now characterized primarily by the unusual Euglenid occurrence and the dinoflagellates *Scrippsiella trochoidea* and *Prorocentrum redfieldii*. The surface abundance (cells ml-1) of the prominent species is shown in Table 20.

Table 20

STATION:	1	2	3	4	5	6	7
Thalassiosira sp.	0	0	2	2	4	2	11
Skeletonema costatum	34	6	0	45	15	49	23
Lithodesmium undulatum	2	4	0	0	2	4	0
Leptocylindrus minimus	26	0	0	39	13	58	101
Thalassionema nitzschioides	15	4	6	34	13	45	41
Chaetoceros debilis	116	0	0	45	0	0	501
Chaetoceros didymus	11	0	19	0	30	36	64
Chaetoceros lorenzianum	0	0	6	4	15	11	41
Ditylum brightwelli	24	2	4	17	6	24	21
Scrippsiella trochoidea	36	0	2	110	105	41	8
Prorocentrum redfieldii	90	6	17	118	36	103	11
Euglenids	169	0	0	17	116	585	39

The anomalous autumnal bloom dynamics persisted during the 23 October transect. While the diatom community was similar to that five days earlier, the euglenid population proliferated, as did *Prorocentrum redfieldii* at Stations 5 and 7. In addition, the small dinoflagellate *Massartia rotundata* began to bloom, notably at Stations 4 and 5. Table 21 summarizes the principal surface population (cells ml-1) dynamics:

Table 21

STATION:	1	2	3	4	5	6	7
Skeletonema costatum	11	0	0	0	6	23	15
Leptocylindrus minimus	0	0	0	49	92	79	165
Thalassionema nitzschioides	17	2	4	15	6	30	9
Chaetoceros debilis	0	0	0	0	38	107	634
Chaetoceros didymus	0	0	21	0	0	23	13
Ditylum brightwelli	30	2	4	8	11	15	9
Scrippsiella trochoidea	4	4	0	38	197	4	9
Prorocentrum redfieldii	84	15	13	90	489	23	180
Euglenids	36	15	0	819	900	30	1348
Massartia rotundata	56	0	4	276	270	79	23

Euglenids and *Prorocentrum redfieldii* continued their growth through October, as revealed by the 30 October transect, whereas the diatom community, excluding *Leptocylindrus minimus*, continued to decline. This diatom response is consistent with that historically observed following their autumn bloom. In contrast, the enormous proliferation of euglenids causing green-water discoloration in upper Narragansett Bay and very active growth of the red-tide dinoflagellate *Prorocentrum redfieldii* in lower Narragansett Bay are extraordinary responses, and atypical of previous years. This anomalous phytoplankton behavior continued during the 13 and 20 November transects, marked by persistent euglenid abundance. Bloom dynamics of the euglenids, a group commonly believed to prefer nutrient-enriched waters, was occurring in late October/November, i.e., a period when phytoplankton abundance historically is at its annual nadir in the seasonal cycle (Smayda, unpublished). The dinoflagellate *Massartia rotundata* was in active growth during the 20 November transect. The predominant phytoplankton features at the surface (cells ml-1) are shown in Table 22.

Table 22

STATION:	1	2	3	4	5	6	7
Skeletonema costatum							
30 Oct	17	0	6	9	15	0	0
13 Nov	0	0	0	6	6	0	0
20	0	0	0	2	23	0	0
Leptocylindrus minimus							
30 Oct	68	13	49	99	244	139	159
13 Nov	0	0	2	4	0	0	0
20	0	0	0	0	4	0	0
Thalassionema nitzschioides							
30 Oct	19	19	8	2	11	9	2
13 Nov	4	0	0	2	4	0	2
20	6	0	0	0	2	0	2
Ditylum brightwelli							
30 Oct	4	11	2	8	23	8	0
13 Nov	0	0	0	2	0	0	0
20	0	0	0	0	0	0	2
Chaetoceros debilis							
30 Oct	23	0	0	38	30	0	51
13 Nov	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0
Euglenids							
30 Oct	641	928	2666	2767	1564	653	186
13 Nov	568	6	54	298	574	450	1159
20	113	0	12	62	113	281	338
Scrippsiella trochoidea							
30 Oct	8	4	34	13	23	8	0
13 Nov	2	0	2	6	6	2	0
20	0	0	0	0	0	0	0
Prorocentrum redfieldii							
30 Oct	118	30	214	236	461	259	51

13 Nov	60	0	11	56	51	24	54
20	17	2	0	19	13	21	19
Massartia rotundata							
30 Oct	0	0	0	0	0	0	0
13 Nov	0	0	0	2	0	2	0
20	326	0	90	22	461	79	0
4 Dec	56	15	15	19	23	135	8
Cryptomonas amphioxeiae							
30 Oct	2	0	39	4	2	2	6
13 Nov	0	2	0	0	0	0	0
20	146	0	4	39	180	34	34

The phytoplankton community during the 4 December transect was devoid of euglenids and diatoms. Its characteristic feature was the persistence of *Massartia rotundata* (Table 22). The autumnal phytoplankton nadir was finally reached. Between 20 November and 4 December, surface temperatures decreased by 4.0 to 6.5°C (Appendix Table 1).

The Winter-Spring Phytoplankton Bloom:

The transect on 18 December revealed that surface temperatures declined 1° to 2°C since 4 December. They then ranged from 3°C (Station 1) to 5.3°C (Station 1 in Greenwich Bay). Surface nutrient levels were high (Appendix Tables 5, 6, 7, 8). Nutrient levels in upper Narragansett Bay (Stations 2, 3, 4) were considerably higher than in lower Narragansett Bay (5, 6, 7) and Greenwich Bay (1). This pattern was superimposed on the pronounced gradient of decreasing nutrient levels downbay. The surface concentrations of PO_4 along the gradient on 18 December ranged from 1.7 to 3.6 µM; that for NH_4 from 6.8 to 34.4 µM; NO_3 from 10.0 to 27.5 µM and SiO_3 from 21.5 to 69.4 µM. The surface nutrient levels are given in Table 23.

Table 23

STATION:		1	2	3	4	5	6	7
PO_4	18 Dec	2.1	3.6	2.2	2.9	1.9	1.8	1.7
	8 Jan	0.3	4.9	2.8	5.0	1.7	1.0	0.5
	12 Feb	0.4	1.8	1.8	0.5	0.5	0.4	0.3
NH_4	18 Dec	9.0	34.4	22.5	21.0	9.6	8.2	6.8
	8 Jan	1.3	10.5	>6.0	27.9	6.7	1.9	0.8
	12 Feb	0.7	35.2	29.7	21.6	6.1	1.1	0.8
NO_3	18 Dec	10.0	27.5	20.2	19.7	13.9	13.5	12.1
	8 Jan	3.6	10.5	2.9	15.9	11.4	7.9	0.5
	12 Feb	0.1	12.5	12.6	4.0	1.7	0.3	0.3
SiO_2	18 Dec	32.0	33.4	69.4	36.9	27.1	24.5	21.5
	8 Jan	2.0	19.7	28.1	6.2	17.4	4.7	0.6
	12 Feb	0.2	22.5	21.2	4.8	1.3	?	0

The phytoplankton community remained depauperate, dominated by Skeletonema costatum which increased in abundance throughout the bay (maximum 105 cells ml-1) at Station 7 since the previous transect. Three weeks later (8 January) a pronounced winter-spring diatom bloom was in progress, dominated by Skeletonema costatum, with Detonula confervacea and Thalassiosira nordenskioeldii significant co-dominants. These three diatoms species are normal components of the winter-spring bloom in Narragansett Bay (Pratt, 1959; Smayda, 1957; 1973). This normal bloom development and its subsequent dynamics contrast markedly to the anomalous phytoplankton successional and growth patterns during the 1985 summer brown-tide and thereafter into the autumn - early winter. The progress of these winter-spring bloom species through 12 February is shown in Table 24 (values in ( ) give bottom depth abundance).

Table 24

STATION:	1	2	3	4	5	6	7
Skeletonema costatum							
4 Dec	0	0	0	0	0	0	0
18	73	11	0	43	34	49	105
8 Jan	14636	1800	3279	4905	9878	15480	13680
15	14288	22218	15409	33775	80676	53980	40117
22	15993	15085	43185	40227	23663	14238	9998
	(21161)	(15677)	(25586)	(18782)	(51171)	(22956)	(9998)
29	21971	24854	7915	19676	48671	8279	4439
	(12758)	(27516)	(18048)	(18048)	(37872)	(9559)	(5639)
12 Feb	5067	2511	592	4510	7837	6312	?
Detonula confervacea							
8 Jan	264	19	15	0	103	241	16
15	540	216	349	516	304	118	223
22	418	218	44	1429	1581	765	471
	(431)	(519)	(435)	(446)	(776)	(647)	(208)
29	859	161	118	324	1024	679	509
	(720)	(818)	(431)	(255)	(1024)	(759)	(306)
12 Feb	34	0	0	0	0	0	?

Thalassiosira nordenskioeldii

8 Jan	165	0	4	30	43	56	131
15	311	86	60	334	302	156	81
22	368	30	289	658	583	439	377
	(341)	51	(206)	(107)	(293)	(167)	214
29	398	133	30	210	516	178	109
	(152)	(661)	(154)	(143)	(313)	(240)	(169)
12 Feb	2059	1035	1643	1204	1954	673	?

The bloom, at least for *Detonula* and *Thalassiosira*, appeared to start in lower Narragansett Bay (Stations 6, 7) and Greenwich Bay (Station 1). While *Skeletonema* significantly increased throughout the bay, its abundance (13.7 to 15.5 million cells L-1) was considerably greater at Stations 1, 6 and 7. This abundance was 60- and 90-fold greater than the maximal concentrations of *Detonula* and *Thalassiosira*, respectively. The inception of this bloom between the 18 December and 8 January transects was accompanied by a further decrease in surface temperature, which ranged from 0.5 to 3.5°C (Appendix Table 1). The precipitous, substantial decreases in nutrients accompanying inception of this bloom are evident in Table 23. Although this decrease at the upper bay stations partly reflected the incursion of a different watermass (see salinity in Appendix Table 2), the observed decreases fundamentally reflect utilization by the developing bloom. Zooplankton biomass at Stations 1, 6(?) and 7 appears to have decreased between the transects, but almost doubled at the other stations. The role of zooplankton predation pressure in regulating inception of this will be considered in a later section. Benthic larval abundance (Appendix

Table 19) increased by 10- to 100-fold during this period, transitional between the successional emergence of Acartia hudsonica over Acartia tonsa, the dominant summer-autumn copepod (Appendix Tables 16, 17).

During the seven days between the 8 and 15 January transects, Skeletonema increased in abundance about 3- to 10-fold throughout the bay (excluding Greenwich Bay); its surface abundance ranged from 15.5 to 80.6 million cells L-1. Abundance was greatest in the region of Stations 4, 5 and 6. Detonula and Thalassiosira also proliferated; maximal concentrations (1.4 to 1.6 million cells L-1) of Detonula occurred at Stations 4 and 5. Thereafter, in January, Skeletonema and Detonula remained abundant, following the development of peak populations earlier in January at Stations 2 - 7. Both species exhibited their maximal abundance in Greenwich Bay during the 29 January transect. The early winter-spring flowering of Skeletonema and Detonula collapsed between the 29 January and 12 February transects. Detonula (34 cells ml-1) was then recorded only at Station 1, whereas Skeletonema abundance ranged from 0.6 to 7.8 million cells L-1. In contrast, Thalassiosira nordenskioeldii continued to proliferate reaching its maximal abundance on 12 February. Maximal concentrations (about 2 million cells L-1) occurred at Stations 1 and 5; elsewhere the maximum ranged from 0.7 to 1.6 million cells L-1.

During the 6-week period of the winter-spring bloom, minor populations of the small Thalassiosira sp., Thalassiosira rotula/gravida, Rhizosolenia delicatula, Thalassionema nitzschioides and Asterionella glacialis also occurred. Of the diatoms, the Thalassiosira sp. reached maximal populations ≥ 0.1 million L-1 through mid-January, then progressively decreased in abundance. Among the other species, Asterionella glacialis reached a maximal population of 0.1 million cells L-1; fewer than 50,000 cells L-1 usually characterized the other minor species. Among other phylogenetic groups, the ubiquitous, eurythermal flagellate Cryptomonas amphioexeiae (cells ml-1) was commonplace (Table 25).

Table 25

Cryptomonas amphioexeiae:

STATION:	1	2	3	4	5	6	7
8 Jan	8	0	13	-	180	56	4
15	23	0	96	96	45	101	28
22	129	0	62	30	78	285	68
	(38)	(0)	(4)	(9)	(6)	(9)	(15)
29	24	0	4	0	0	45	23
	(23)	(11)	(9)	(17)	(51)	(17)	(45)
12 Feb	191	0	23	39	146	90	?

It tended to be more abundant in lower Narragansett Bay and less frequent at Station 2 (Providence R.).

Two dinoflagellates. Massartia rotundata and Heterocapsa triquetra, also normal components of the winter-spring flora, exhibited active growth during the 12 February transect, with maximal surface populations occurring in Greenwich Bay (Table 26).

Table 26

STATION:	1	2	3	4	5	6	7
Heterocapsa triquetra	79	45	34	21	15	4	?
Massartia rotundata	56	0	26	2	23	2	?

The winter-spring flowering of *Skeletonema* and *Detonula* collapsed on 12 February, the date on which *Thalassiosira nordenskioeldii* reached its maximum. Surface temperatures were then similar to those at bloom inception in early January, and well within the tolerance of these species (Smayda, 1973). Nutrient conditions were quite variable (Table 23), with the surface concentrations of PO_4, NH_4, NO_3 and SiO_2 at Stations 2 and 3 remaining quite high: about 2.0, 30, 12.5 and 20 μM, respectively. These levels would be expected to allow continued growth. NH_4 levels at Station 4 remained high (21.6 μM); NO_3 and SiO_3 concentrations were each about 4 μM. Clearly, silicate levels relative to nitrogen availability were low at Station 4; both absolute SiO_3 and NH4+NO_3 concentrations at Station 5 were somewhat lower. All nutrients were considerably lower at Stations 1, 6 and 7 and most likely approached limiting concentrations: < 0.5 μM (PO_4, NO_3, SiO_3) and $\leq$ 1.0 μM (NH_4). ≤ 0.5 μM PO_4 also occurred at Stations 4, and 5.

Obviously, nutrient flux (= turnover) rather than residual standing stock concentrations determines nutrient regulation (limitation) of phytoplankton growth. Given the high residual concentrations of nitrogen at Stations 2 and 3, the apparent suppression of phytoplankton growth suggests constraining environmental factors other than essential nutrients. The low residual baywide concentrations of PO_4 at the other stations on 12 February and of SiO_2 in lower Narragansett Bay suggest their potential limitation of continued winter-spring phytoplankton growth, in addition to nitrogen limitation. However, experimental evidence for nutrient limitation, either generally or specifically, is not available.

Protozoan grazing may have contributed to the decline in *Skeletonema* and *Detonula*. On 29 January, the ebridean *Ebria tripartita* and diverse ciliates became abundant, particularly in the bottom samples. *Ebria tripartita* was previously found to predate on *Skeletonema* and *Thalassiosira* in Narragansett Bay (Smayda, 1973). Many "reddened" ciliates. probably a stage in the complicated life cycle of *Ebria tripartita*, were found packed with small *Thalassiosira* cells during the 29 January transect. These are designated as "red ebriids" in Table 27 (cells ml^{-1}).

Table 27

STATION:	1	2	3	4	5	6	7
Ebria tripartita							
T	17	8	2	4	9	15	11
B	38	34	30	101	9	18	17
"red ebriids"							
T	-	11	19	26	53	60	56
B	51	83	51	56	79	129	28
ciliates							
T	-	-	-	2	6	62	21

B	11	32	30	38	23	18	17
TOTAL							
T	17	19	21	32	68	137	88
B	100	149	111	195	104	165	62

Maximal populations during the previous transect (22 January) were 11,000 L-1 at Station 7, considerably below 28 January levels. This protozoan community was significantly decreased during the 12 February transect, and "red ebriids" were not found (Table 28).

Table 28

STATION:	1	2	3	4	5	6	7
Ebria tripartita							
T	15	4	6	2	2	4	?
Ciliates							
T	79	4	11	2	8	11	?

The role of zooplankton in contributing to the collapse of the winter-spring bloom is ambiguous. Based on dry weight (Appendix Table 14), total zooplankton biomass was not significantly different from levels present during inception of the bloom. The total copepod numerical abundance was also relatively similar through 29 January. A 2- to 3-fold increase (excluding Station 5) then occurred between the 29 January and 12 February transects (Appendix Table 15). This reflected a substantial increase in the dominant winter copepod _Acartia hudsonica_ (Appendix 16) which actively grazes on _Skeletonema costatum_ and other winter-spring diatom bloom species (Martin, 1970; Deason, 1980). Although zooplankton grazing effects on bloom dynamics can be quantified only approximately, the decline in *Skeletonema* undoubtedly reflects this. The cellular appearance of *Detonula confervacea* during the 29 January transect suggested rampant viral or other parasitic infection. The granular, somewhat chlorotic cellular contents contrasted with their robust appearance during previous transects. Thus, a combination of zooplankton grazing and microbial infection may have contributed to *Detonula*'s demise.

Recurrence of the "brown-tide" in 1986:

The species responsible for the brown-tide outbreak during the 1985 summer was detected in great numbers at the transect stations on 14 May. Surface populations (T) ranged from 53 to 180 million cells L-1, and bottom populations from 106 to 254 million cells L-1. The bottom populations (B) were from 18% to 236% greater than surface populations, excluding Station 7 where a homogeneous vertical distribution occurred. The phytoplankton community was otherwise depauperate and dominated by *Skeletonema costatum* (< 0.5 million cells L-1) and, secondarily, by *Chaetoceros socialis*. The principal features (as cells ml-1) of this community are shown in Table 29.

Table 29

STATION:	1	2	3	4	5	6	7
Brown-tide species							
T	101101	79992	53328	94435	107767	79992	104434
B	118877	124432	149985	105545	154419	123321	105545

Skeletonema costatum							
T	152	92	357	492	487	261	85
B	251	129	199	83	131	105	39
Chaetoceros socialis							
T	-	8	-	25	173	294	287
B	302	83	-	122	-	231	69
Thalassiosira rotula/gravida							
T	2	8	2	4	6	34	11
B	4	6	6	-	2	-	6
Heterocapsa triquetra							
T	39	6	13	21	-	2	2
B	28	-	2	2	2	8	47
Euglenid							
T	-	101	461	9	-	-	-
B	2	-	2	-	-	-	-
Cryptomonas amphioxeiae							
T	23	-	2	9	-	11	3
B	45	-	-	2	2	-	4
Thalassiosira sp. (wee)							
T	2	4	338	161	30	21	3
B	2	-	2	8	15	2	4
Leptocylindrus danicus							
T	-	-	-	-	-	4	20
B	-	-	-	-	-	38	49

Maximal abundance of the brown-tide cells occurred at Station 5. The environmental conditions accompanying this bloom do not suggest any unusual event(s) which may have triggered the bloom. Table 30 summarizes the surface conditions during the 4 weeks between the 16 April and 14 May transects. A 2° to 3°C increase occurred, and ranged from 10.5° to 13°C on 14 May. Surface salinity at Stations 2 and 3 increased significantly between 16 April and 8 May, and ranged from 26.5 to 30.7 o/oo. The density (σ_t) profiles indicate that the water column was well-mixed at Stations 1, 5, 6, 7 and stratified at Stations 2, 3 and 4 (Appendix Table 2). In contrast, stratification was pronounced at Stations 1-6 during the 2 and 9 April transects. Thus, development of the brown-tide bloom seemed independent of fresh-water inputs, but developed after general breakdown or weakening of stratification.

PO_4 concentrations increased 3- to 10-fold at Stations 3 - 7; even greater increases in SiO_3 occurred. NH_4-N concentrations remained high at Stations 2 and 3, and increased 2- to 6-fold elsewhere; a similar response characterized NO_3. Thus, nutrient levels generally increased in the period prior to and during the bloom, remaining persistently high in the Providence River (Station 2) and nearby Station 3. Since the brown-tide species is non-siliceous, its dynamics are expected to be independent of this nutrient. The general increases in N and P availability also altered the atomic ratios of these nutrients. N and P generally are assimilated in stoichiometric proportions in accordance with the Redfield Ratio:

$$O:C:N:P: = 212:106:16:1 \quad \text{(by atoms)}$$

Very high ambient ratios indicate an excess of N relative to P;

low ratios the converse. Interestingly, both high and low N:P ratios occurred during the 16 April and 8 May transects. During the brown-tide proliferation, the N:P ratio was less variable and in the intermediate range from 6:1 to 9:1 at six of the seven stations (the value at Station 4 would be about 8:1 assuming the NH_4 level at Station 3). The ratios and associated environmental conditions are given in Table 30.

Table 30

STATION:	1	2	3	4	5	6	7
Temperature (°C)							
16 Apr	10.0	11.0	11.0	10.0	9.0	9.0	8.0
8 May	12.0	11.0	11.5	11.0	11.0	11.0	11.0
14	12.0	13.0	13.0	12.0	12.0	11.5	10.5
Salinity (S o/oo)							
16 Apr	28.6	16.0	19.7	23.3	28.6	29.1	29.6
8 May	29.6	27.5	26.5	27.5	29.1	29.6	30.7
14	29.6	24.4	26.5	27.5	30.1	30.7	30.7
PO_4 (µM)							
16 Apr	0.4	3.2	1.0	0.3	0.3	0.4	0.3
8 May	1.0	1.8	3.5	3.4	1.9	1.3	0.7
14	0.6	3.0	4.3	3.4	1.2	1.2	1.0
NH_4-N (µM)							
16 Apr	1.7	>15.0	>15.0	1.3	1.5	1.4	0.5
8 May	7.2	18.1	24.3	28.3	8.3	4.3	0.9
14	3.5	33.9	16.1	?	5.5	5.2	4.2
NO_3-N (µM)							
16 Apr	0.5	>20.0	14.4	2.5	0.2	0.1	0.1
8 May	2.6	12.4	11.1	10.4	4.3	2.0	0.2
14	1.8	20.0	11.6	11.6	3.4	3.0	2.7
Σ NH_4+NO_3							
16 Apr	2.2	>35.0	>29.4	3.8	1.7	1.5	0.6
8 May	9.8	30.5	35.4	38.7	12.6	6.3	1.1
14	5.3	53.9	27.7	>11.6	8.9	8.2	6.9

$NH_4+NO_3:PO_4$ Ratio

16 Apr	5.5	>10.9	>29.4	12.7	5.7	3.8	2.0
8 May	9.8	16.9	10.1	11.4	6.6	4.9	1.6
14	8.8	18.0	6.4	> 3.4	7.4	6.8	6.9

Blooming of the brown-tide species during the 18 May transect did not discolor the surface waters then, or at any time subsequently in 1986, unlike in 1985. The transect survey on 18 June revealed its continued presence, but at substantially reduced numbers at Stations 1-5 compared to 18 May. Its abundance substantially increased at Stations 6 and 7 where maximal populations occurred. Bottom populations (excluding Station 1) were again more abundant than at the surface, by 13 to 51%. The general features of the phytoplankton community on 18 June are presented in Table 31.

The diatom community remained depauperate, with a notable abundance (3 to 4 million cells L-1) of a small *Thalassiosira* sp. at Stations 4 and 5. *Skeletonema costatum* persisted from May, but was now generally less important. The principal floristic changes were the modest bloom of the red-tide species *Olisthodiscus luteus* and more vigorous growth of the red-tide producing *Prorocentrum redfieldii*. The latter was commonly found in abundance during the brown-tide outbreak in 1985. *Prorocentrum triangulatum* and *Prorocentrum scutellum* co-occurred in lesser abundance, as in 1985. A modest Euglenid population, particularly at Station 2, also occurred, as frequently observed during the 1985 brown-tide outbreak.

The most significant difference from the 1985 outbreak was the large population (up 0.5 million cells L-1) of heterotrophic dinoflagellates (Gymnodiniaceans). These holozoic species, capable of feeding on particles in the size range of the brown-tide species, were not usually encountered during the 1985 brown-tide outbreak. Thus, by mid-June the brown-tide species. *Aureococcus anophagefferens*, co-occurred with several red-tide producing species as well as a large population of heterotrophic dinoflagellates capable of ingesting *Aureococcus*.

Table 31

STATION:	1	2	3	4	5	6	7
"Brown-tide" species							
T	93324	44440	78881	53328	59994	109989	176649
B	83325	52217	118877	65549	67771	165539	206646
GC	(31108)	(48884)	(73326)	(34441)	(21109)	(81103)	(33330)
Skeletonema costatum							
T	-	-	144	568	1333	210	13
B	49	49	43	58	60	36	8
Thalassiosira rotula/gravida							
T	14	2	28	139	78	57	32
B	34	8	11	30	17	15	37
Leptocylindrus danicus							
T	11	4	27	8	86	98	45
B	36	4	15	58	49	47	81
Rhizosolenia delicatula							
T	4	-	32	4	83	23	17
B	13	-	6	28	34	-	11
Olisthodiscus luteus							
T	-	1350	163	304	146	664	270
B	-	478	118	180	45	21	17

Euglenids							
T	-	360	23	71	13	19	2
B	8	107	-	15	2	-	
Prorocentrum redfieldii							
T	1328	9	34	1058	5703	1215	1294
B	956	8	-	62	124	128	534
Prorocentrum scutellum							
T	21	-	9	23	15	47	4
B	19	-	-	13	4	2	6
Heterocapsa triquetra							
T	4	-	2	9	11	9	2
B	2	-	-	4	-	2	6
Scrippsiella trochoidea							
T	24	-	4	17	68	23	9
B	19	4	-	4	4	-	9
Thalassiosira sp.							
T	4	13	298	3038	4466	236	-
B	2	39	15	17	39	10	-
Gymnodiniaceans							
T	417	6	163	270	?	293	135
B	203	208	11	529	68	13	11
Peridinian spp.							
T	4	-	-	17	45	11	135
B	23	-	-	6	4	11	11

Surface samples were collected at seven additional stations (GC1 - GC7) in Greenwich Bay (Fig. 1) during the 18 June transect to check for brown-tide development. The picoplankton population ranged from about 21 to 81 million cells L-1 and consisted of a diverse assemblage, among which *Aureococcus* was found:

GC1	31,108	GC3	73,326	GC5	21,109 cells ml-1
GC2	48,884	GC4	34,421	GC6	81,103
				GC7	33,330

During the latter half of June, green-tide and red-tide outbreaks were reported and relayed to this project by Dr. Christopher Deacutis of the R.I. DEM. A green-tide near Quonset Pt. was due to euglenids. A large die-off of Menhaden accompanied red-tide outbreaks in upper Narragansett Bay. Phytoplankton samples collected near the mouth of the Barrington R. revealed the dinoflagellate *Prorocentrum redfieldii* (2.7 million L-1) and, secondarily, *Olisthodiscus luteus* (0.5 million L-1) as the causative organisms. *Scrippsiella trochoidea* (68,000 L-1) was a minor dinoflagellate. Samples were collected on 30 June at three stations where the surface water was discolored reddish-brown: at the mouth of the Warren and Barrington Rivers (A); northeast of Prudence Island (B), and off Barrington Beach (C). The principal phytoplankton features (cells ml-1) are given in Table 32.

Table 32

	A	B	C
Olisthodiscus luteus	3611	4624	7031
Prorocentrum redfieldii	110	675	653
" *triangulatum*	270	169	124

Heterocapsa triquetra	-	495	551
heterophic Gymnodiniaceans	214	56	495

The red-tide outbreak was attributable primarily to *Olisthodiscus luteus* and secondarily to the dinoflagellates *Prorocentrum redfieldii*, *P. triangulatum* and *Heterocapsa triquetra*. Brown-tide cells (*Aureococcus*) were not the primary cause of water discoloration. Moreover, since none of these bloom flagellates are known producers of ichthyotoxins or of paralytic shellfish poison (PSP), the observed die-off of Menhaden must have been due to other causes.

These ancillary obsevations, based on the transect surveys, and observations made during the 1986 summer revealed an important fact. Brown and red water discoloration in Narragansett Bay following the winter-spring diatom bloom was not due to the brown-tide species (*Aureococcus*) which proliferated during the 1985 summer. Rather, surface blooms of *Olisthodiscus luteus* and various dinoflagellates were primarily responsible. While the brown-tide species appeared in May 1986, its subsequent growth was significantly reduced and/or it was rapidly grazed. These prevented its bloom development during the 1986 summer. This contrasts with its behavior in the coastal lagoons of southern Long Island (Carpenter, personal communication). There, *Aureococcus* again exhibited brown-tide blooms during the 1986 summer which adversely affected the scallop population.

Phytoplankton Biomass Levels and Dynamics

Phytoplankton biomass as chlorophyll and carbon (based on ATP) exhibited significant regional variations (Appendix Tables 11, 12).

The mean annual concentrations (mg m-3) at the seven stations are given in Table 33.

Table 33

STA	Chl	ATP-C	STA	Chl	ATP-C
4	24.6	1475	6	13.9	873
3	21.0	1218	2	13.9	575
5	20.5	1196	7	11.2	728
1	16.2	964			

Mean annual levels varied among stations by 2.6-fold for chlorophyll and 2.2-fold for carbon; with the maximum/minimum levels found at Stations 4/7 for chlorophyll and 4/2 for carbon, respectively.

Several patterns in biomass dynamics are evident (the chlorophyll distributions are used to document these). The average surface chlorophyll levels (20.2 mg m-3) in upper Narragansett Bay (Stations 2, 3, 4, 5) were about 50% greater than that (13.8 mg m-3) in the lower Bay (Stations 1, 6, 7). A crisp gradient in mean station levels occurred: 4 > 5 = 3 > 1 > 2 > 6 > 7. Thus, mean chlorophyll levels progressively increased along the gradient from Station 2 (Providence R.) to Station 4, and then sequentially decreased downbay from Station 4. The phytoplankton biomass epicenter during the annual study from 25 July 1985 - 14 June 1986 was in the region between Gaspee Pt. (Station 3) and Providence Pt. (Station 5). The chlorophyll distributions during the individual transect surveys (n = 31) are consistent with this average condition (Appendix Table 11). The transect chlorophyll maximum occurred at Stations 4 and 5 during 29% and 26% of the surveys, respectively; 23% at Station 1, and less than 10% at the other stations.

The high frequency of occurrence in Greenwich Bay (Station 1) indicates the favorable growth conditions there, even though the average yield is less than that in upper Narragansett Bay.

Maximum chlorophyll concentrations were observed during the 1985 summer brown-tide event, although not concurrently with brown-tide cell abundance. The maximum occurred on 25 July at Station 2; 2 August at Station 1, 5, 6 and 7, and 15 August at Station 3 and 4 (Table 34).

Table 34

STA	Chl	STA	Chl	STA	Chl
2	67.9	1	37.6	3	137.3 mg m-3
		5	46.2	4	84.5
		6	34.8		
		7	34.4		

The enormous bloom at Stations 3 and 4 was accompanied by carbon levels of 5.4 and 4.7 g m-3, respectively (Appendix Table 12). The summer brown-tide continued until early November at Stations 4, 5, 6, at least two weeks longer than at the other stations.

Biomass levels were lowest during the 4 December transect: < 1.2 mg m-3 chlorophyll throughout the Bay. The winter-spring bloom began simultaneously at all stations soon after, in early January. Bloom intensity was initially greatest in the lower Bay, including Greenwich

Bay, and progressively moved upbay during the next two weeks. This simultaneous baywide bloom with bloom intensity progressing upbay contrasts with Pratt's (1959) conclusion (based on cell number) that the winter-spring bloom begins upbay, then moves downbay. This bloom, due principally to the growth of <u>Skeletonema</u> <u>costatum</u>, produced biomass levels at Stations 1, 5 and 6 which exceeded or equalled those during the 1985 summer brown-tide event; in Greenwich Bay surface chlorophyll levels ranged between 42 to 49 mg m^{-3} over a 3-week period. Maximal surface chlorophyll concentrations during the winter-spring bloom varied from 23.6 (Station 2) to 55.9 mg m-3 (Station 4) and occurred between 15 - 22 January. The rank order of the chlorophyll maximum was $4 > 1 = 5 > 6 > 3 > 7 > 2$; however, the bloom was most intense in Greenwich Bay (Station 1) during January (Appendix Table 11). The termination of the winter-spring bloom varied regionally. In the lower Bay (Stations 1, 6, 7) the bloom ended (< 10 mg m-3 chlorophyll) in early March, about 6 weeks earlier than the mid-April collapse at upper Bay Stations 2 - 5. Inception of the summer bloom also varied. Within two weeks of the collapse of the winter-spring diatom bloom at Stations 2, 3, 4, blooms of the brown-tide species <u>Aureococcus</u>, <u>Olisthodiscus</u> and dinoflagellates (discussed previously) were evident on 21 May. This bloom event occurred 1 and 2 weeks earlier than in Greenwich Bay and lower Bay Stations 5, 6 and 7. This downbay progression was the reverse of the winter-spring bloom progression. Chlorophyll levels during this bloom exceeded those during the winter-spring diatom bloom at Stations 2 (53.2); 3 (44.6); 5 (54.2), and were similar at Station 4 (54.2 mg m-3).

The survey results clearly show the considerable fertility of

Narragansett Bay. Significant phytoplankton growth, particularly in upper Narragansett Bay, is a persistent feature. Using a surface concentration of 10 mg m-3 (quite high) as an indicator of bloom conditions, this level was exceeded during the 31 transect surveys at the various stations 42% to 77% of the year:

STATION:	1	2	3	4	5	6	7
> 10 mg m-3	48%	55	68	77	62	47	42
> 20 mg m-3	39	23	29	61	41	33	23

Blooms exceeding 20 mg m-3 chlorophyll occurred in Greenwich Bay and nearby Station 5 40% of the year; 60% of the year near Conimicut Pt. (Station 4) and 25% to 33% elsewhere. The exceptional fertility of Greenwich Bay, Stations 4 and 5 is evident.

These results also indicate that phytoplankton blooms are nearly continuous and most prolific in upper Narragansett Bay, with a significant downbay gradient in chlorophyll and carbon levels occurs. This gradient in biomass is related to the regional variation and patterns in nutrient levels (Appendix Tables 5, 6, 7, 8). The mean annual surface concentrations of chlorophyll and nutrients are entered in Table 35.

Table 35

STATION:	1	2	3	4	5	6	7
Chl (mg m-3)	16.2	13.9	21.0	24.6	20.5	13.9	11.2
PO_4 (mg-at m^{-3})	1.4	5.4	4.1	3.6	1.5	1.6	1.0

NH_4	2.7	33.3	24.2	11.1	4.3	2.7	1.9
NO_3	1.6	20.7	13.7	7.8	3.7	1.9	1.3
Σ NH_4+NO_3	4.3	54.0	37.9	18.9	8.0	4.6	3.6
SiO_3	16.5	34.8	28.4	17.6	13.1	12.2	10.7

Two effects are evident based on statistical analysis. Regression of the mean chlorophyll level at each station against each of the concentrations of PO_4, NH_4+NO_3 and SiO_3 indicates a strong positive correlation for Stations 1, 4, 5, 6 and 7. The coefficients of correlation (r) for these station-clusters are 0.84, 0.90 and 0.79 for the above nutrients, respectively, all highly significant. That is, mean chlorophyll levels increased with mean ambient nutrients along the upbay nutrient gradient extending from Station 7 to Station 4. Along the gradient extending further upbay, from Station 4 into the Providence R. (Station 2 off Fields Pt.) and including Station 3 (off Gaspee Pt.), mean chlorophyll levels decreased with increasing ambient levels of each nutrient. The inverse correlations ranged from $r = -0.94$ (SiO_2) to -1.0 (PO_4).

These correlations, all statistically significant, indicate that mean phytoplankton biomass in Narragansett Bay increased with nutrient loading accompanying riverine inputs and in situ processes in the region extending from Fox Island (Station 7) in lower Narragansett Bay up to the region off Conimicut Pt. (Station 4). However, the progressively higher nutrient loadings accreted via the Providence R. in the region between Conimicut Pt. and Fields Pt. appeared to repress biomass levels. It should be pointed out that the mean levels of chlorophyll and nutrients represent residual values. That is, the levels of chlorophyll are those remaining above grazing, sinking and advective losses at the time of sampling, and the nutrient levels are those yet to be used. Moreover, use of mean values blurs significant day-to-day events which influence the biomass-nutrient availability relationship. Nonetheless, the strong statistical correlations suggest that these apparent beneficial and negative effects of nutrient inputs into Narragansett Bay along its gradient are major, general features.

Primary Production

Primary production rates at the surface based on ^{14}C measurements during 29 transects are given in Appendix Table 13. A distinct regional gradient characterizes the mean annual rates (g C m^{-3} $year^{-1}$) in Table 36.

Table 36

STATION:	1	2	3	4	5	6	7
	120.5	159.0	261.3	231.1	151.5	112.7	76.5

The maximal rate observed at Station 3 was about 3.5-fold greater than the minimal rate at Station 7. The most productive region encompasses the area between Gaspee Pt. (Station 3) and Conimicut Pt. (Station 4). Annual rates upbay of this region in the Providence R. (Station 2) and in the transitional area into the lower Bay (Station 5) were about 40% lower. This 3.5-fold regional variation in primary production was greater than that found for standing stock: a 2.2-fold difference occurred between the maximal/minimal mean phytoplankton biomass (as chlorophyll).

The statistical relationships between the regional variations and gradients in primary production and irradiance, salinity and nutrients were evaluated. The mean irradiance levels at 1 m were calculated based on the extinction coefficient derived from the Secchi Disc measurements (Appendix Table 4):

$$k = 1.70/_D$$

where k is the extinction coefficient (m^{-1}) and D is the Secchi Disc disappearance depth (m) (Holmes, 1970), and from:

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

where I_z is the irradiance level at 1 m (z) and I_o is the incident irradiance.

The relationship between surface primary production and mean irradiance at 1 m for the seven stations segregated into two groups: Stations 3 - 7 and Stations 1 and 2. A strong inverse correlation ($r = -0.98$) characterized Stations 3 - 7. Stations 1 and 2 were also characterized by an inverse trend (since $n = 2$, no statistics run), but the mean annual production rates were 40% lower than for Stations 3 - 7 at equivalent irradiance levels.

The mean surface salinity at Stations 1 and 3 - 7 ranged from 23.7 to 30.3 $^o/oo$. Primary production exhibited a strong inverse correlation ($r = -0.95$) with salinity, i.e, primary production increased inwards along the gradient of decreasing salinity (Figure 9). At Station 2 located in the Providence R., mean surface production (159 g C m^{-3} year^{-1}) was depressed at the low mean salinity (20.7 $^o/oo$) relative to that at the other stations. At Station 3, production (261.3 g C m^{-3} year^{-1}) increased by 74%; the mean salinity (23.7 $^o/oo$) was 3 $^o/oo$ higher than at Station 2.

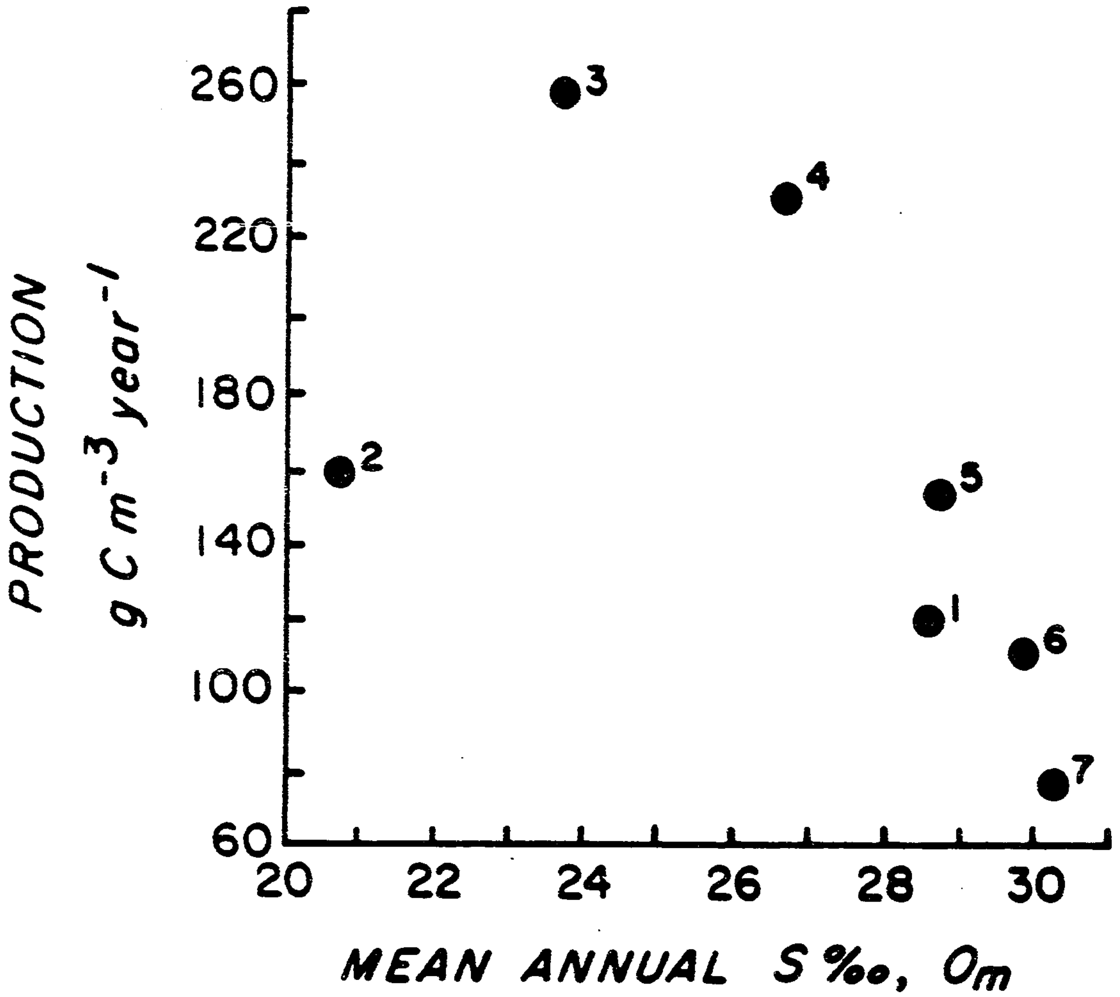


Figure 9. Relationship between mean annual primary production at the surface and mean annual surface salinity

Strong correlations also occurred between the mean annual carbon production rates and nutrient concentrations. However, three distinct patterns characterized the relationships with PO_4, NH_4+NO_3 and SiO_3. Carbon production and PO_4 availability at Stations 1, 3 - 7 were strongly correlated ($r = 0.97$) in linear fashion (Figure 10). Station 2, characterized by the highest mean PO_4 levels (5.43 mg-at m^{-3}), deviated from this relationship, as observed for the production-S o/oo and production-irradiance relationships. A similar deviation characterized the relationships with $\sum$ N and SiO_3. Production when related to $\sum$ N concentration exhibited a marked hyperbolic relationship. Annual production rates progressively increased with $\sum$ N availability at Stations 1 and 4 - 7 ($r = 0.94$); higher $\sum$ N levels were characterized by a reduced rate of increased production (Station 3) suggestive of a saturation effect (Figure 10). A similar hyperbolic relationship characterized the regressions of production against silicate availability, except that a family of two curves is evident. Stations 1 and 2 fall on a lower asymptotic curve, a pairing analogous to that characterizing the production-irradiance levels found at these two stations.

These correlations clearly indicate that primary production increases upbay along the salinity gradient, which is related to increased nutrient availability. Moreover, the relationships suggest a classical yield-dose response, with both linear (PO_4) and hyperbolic ($\sum$ N, SiO_3) patterns evident. Surprisingly, an apparent repression occurred at the highest nutrient levels (Station 2) (Figure 10).

Strong inverse correlations between mean nutrient levels and salinity (Figures 2, 3) and between production and salinity (Figure 9)

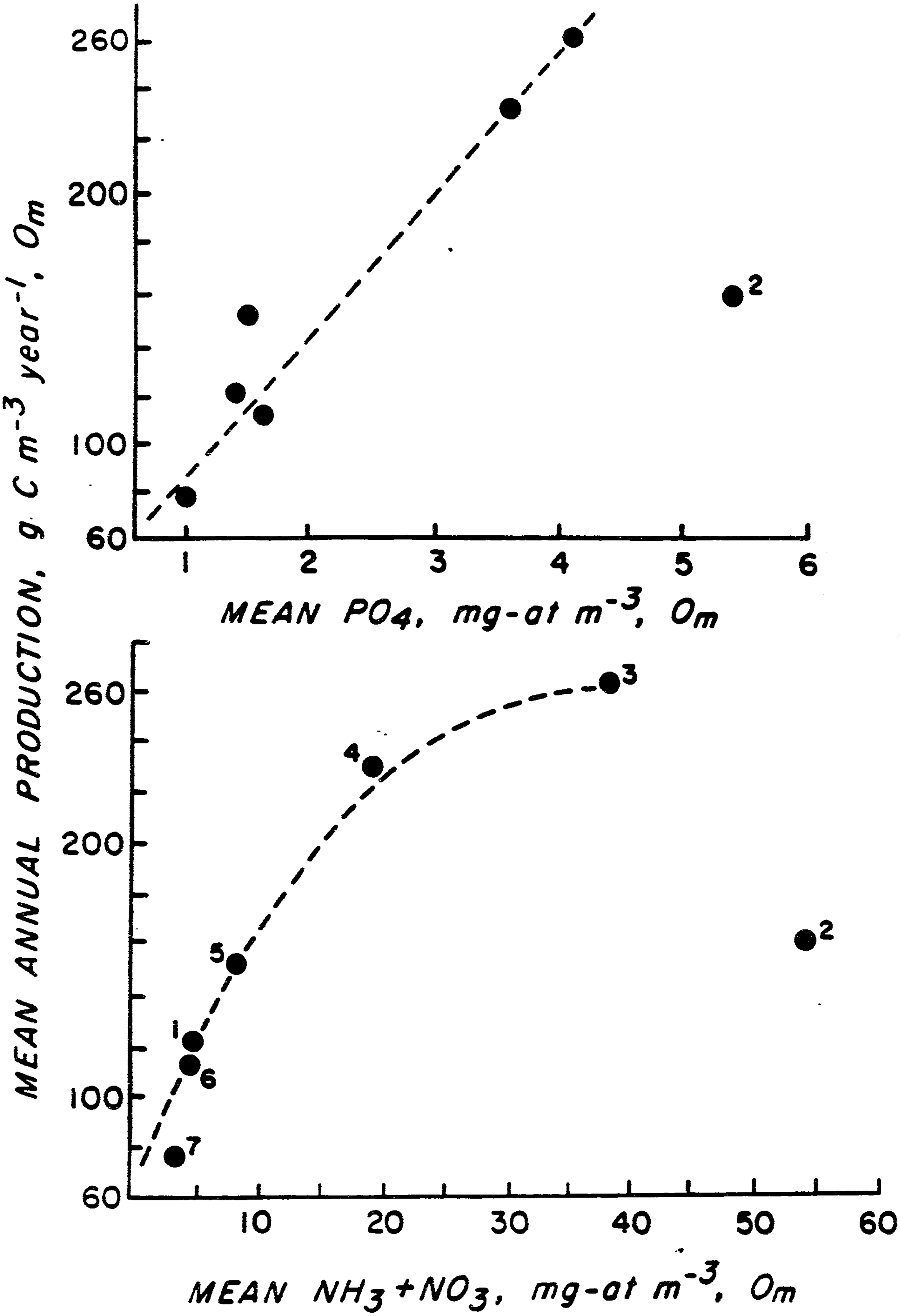


Figure 10. Relationship between mean annual surface primary production and mean annual surface concentrations of PO_4 and NH_4+NO_3

were previously demonstrated. It might therefore be argued that the increased surface production along the gradient upbay might really be regulated by salinity; that is; the apparent correlations with nutrients are merely indicative of parallel patterns. This potential importance of salinity *per se* seems highly unlikely, given the strong euryhaline nature of the phytoplankton. Nonetheless, independent comfirmation of this apparent regulation by nutrients was tested by evaluating the effect of nutrient levels on carbon turnover. Carbon turnover was simply defined as the mean carbon production per mean unit of phytoplankton standing stock as carbon. The latter was based on the ATP measurements. The regressions of carbon turnover [mg C produced·m^{-3} per mg C standing stock·m^{-3}] against PO_4, Σ N and SiO_3 revealed very strong, positive linear correlations in every instance, $r = 0.96, 0.99, 0.98$, respectively. Moreover, Station 2 was no longer deviant, nor were hyperbolic trends evident with Σ N and SiO_2 regulation. The standing stock carbon estimate is based on a C:ATP ratio of 250:1. It might therefore be argued that seasonal and regional changes in this ratio accompanying changes in the phytoplankton flora and in the degree of nutrient limitation compromise this estimate of standing stock and calculated turnover times. Therefore the mean assimilation number (= production index) was calculated for the various stations, expressed as C produced per unit chlorophyll·m^{-3}·d^{-1}, and regressed against nutrient concentrations. The correlation coefficients (r) were 0.92, 0.80 and 0.91 for PO_4, Σ N and SiO_3, respectively. This reaffirms the evidence for nutrient regulation.

Mean carbon growth rates were also calculated and related to nutrient levels. Growth rate (k) was determined from

$$k = \ln \frac{C_p + C_b}{C_b} . \left(\frac{t}{1 \ln 2} \right)$$

where C_p is the mean daily carbon production rate (mg C•m-3.d-1) and C_b is the mean daily phytoplankton carbon standing stock (mg C•m-3). The mean daily growth rates (k) were:

STATION:	1	2	3	4	5	6	7
k	0.42	0.81	0.67	0.52	0.4	0.44	0.37.

A strong direct linear correlation was obtained between growth rate and nutrients; for $\sum$ N, r was 0.99 (Figure 11). Mean daily phytoplankton growth rates increased significantly along the nutrient gradient. The average generation time (= doubling time), calculated from (1/k), decreased from 2.7 to 1.2 days between Stations 7 and 2. This further indicates that the increased productivity upbay along the salinity gradient is attributable to an increased nutrient flux. Moreover, the fastest growth rates; the most rapid carbon turnover, and the highest assimilation number were obtained for Station 2 in the Providence R. This suggests that the low phytoplankton levels (as chlorophyll and carbon) at that station, and lower than expected from the relationship between standing stock and nutrients, was not completely attributable to water quality. Washout in this rapidly flushed region and possibly grazing (secondarily) may have prevented an accumulation of phytoplankton biomass commensurate with its production.

Thus, at Station 2, two mechanisms may be operative in causing the

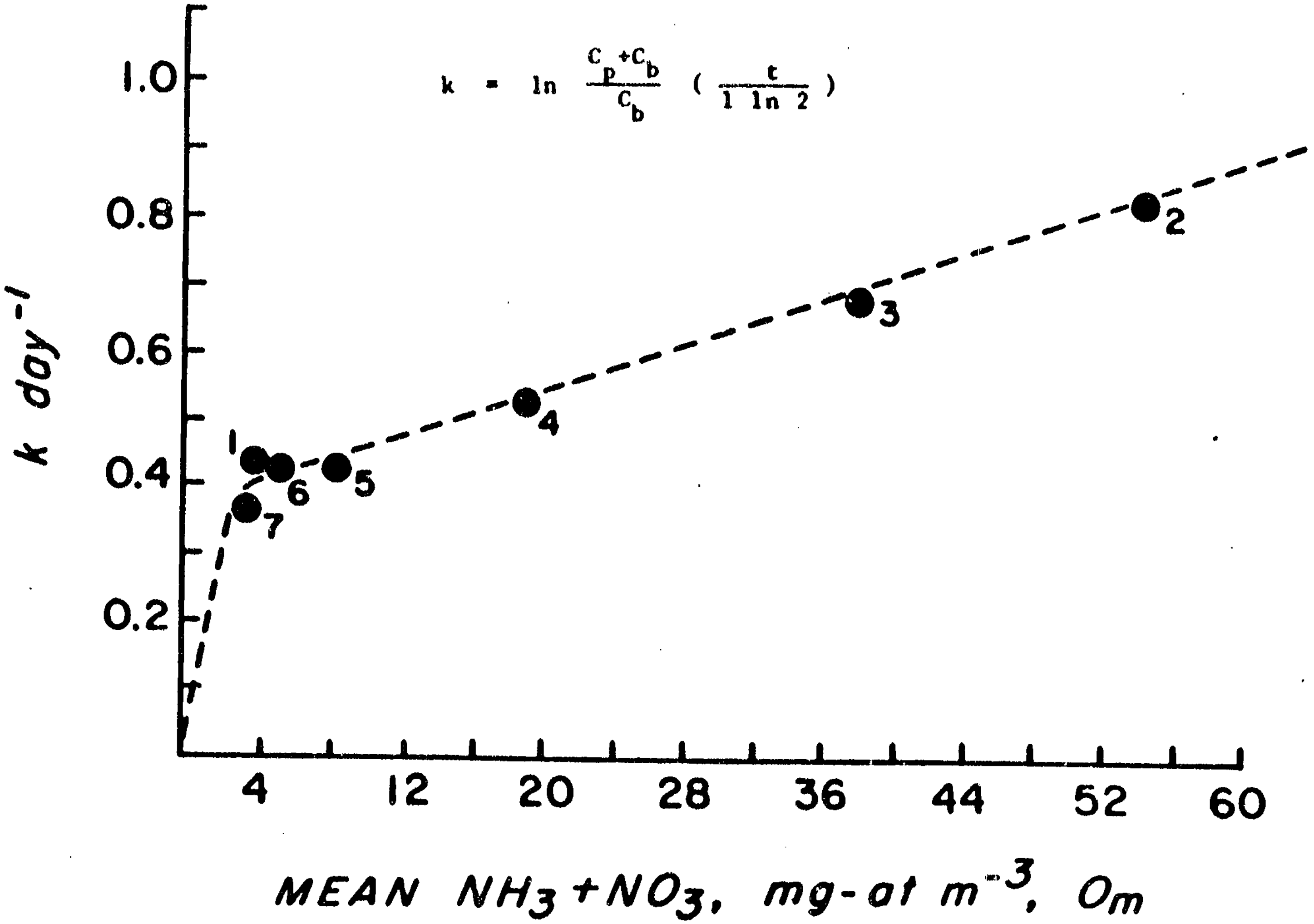


Figure 11. Relationship between mean carbon growth rate and mean NH_3+NO_3 concentrations at the surface

apparent suppression of biomass development associated with the high nutrient levels characteristic of that area: repression of phytoplankton growth due to chemical·water quality (e.g. nutrient concentrations, their ratios and toxicants) and the physical mechanism of washout. Resolution of the contribution of these and other processes to the apparent suppression of a phytoplankton biomass in upper Narragansett Bay Station 2 requires experimental evaluation.

The data indicate, therefore, that nutrients, particularly nutrients accreted into upper Narragansett Bay via the Providence R. and STP inputs strongly regulate phytoplankton growth in Narragansett Bay. Along the downstream gradient this effect would be greatest in upper Narragansett Bay. The progressive dilution and utilization by phytoplankton would progressively diminish this input downstream and increase the importance of <u>in situ</u> remineralization and offshore inputs to nutrient flux. This suggests that two primary nutrient pumps are operative in Narragansett Bay which regulate phytoplankton growth: nutrient accretion in upper Narragansett Bay and <u>in situ</u> remineralization/ advection in lower Narragansett Bay.

The Redfield Ratio expresses the stoichiometry between carbon production and N and P utilization: C:N:P = 106:16:1 (by atoms). It was used to convert the mean daily carbon estimates to equivalent N and P production rates (i.e. supply rates), to which the residual N and P concentrations were added. This sum represents the average daily availability of N and P before production (= utilization). The percentage of the concentration used in daily production when plotted against the residual concentration showed a strong inverse curvilinear correlation for all nutrients. For $\sum$ N, the mean daily percentages of the available nitrogen used in carbon production were:

STATION:	1	2	3	4	5	6	7
	49%	10	19	30	40	46	45

Thus, along the gradient from 10 to 50% of the surface nitrogen pool is used daily in primary production. Upper Narragansett Bay (Stations 2, 3, 4), on average, has a 3 to 10 days' supply of N to meet measured mean daily production rates; lower Narragansett Bay, a 2 to 2.5 day reserve. This indicates that carbon production in lower Narragansett Bay is much more dependent on *in situ* nutrient recycling than in upper Narragansett Bay where nutrient flux is dominated by accreted inputs. A shift in dominant nutrient flux mode, i.e., from accretion to remineralization, probably occurs in the region of the Narragansett Bay Sanctuary waters near Station 5.

Zooplankton

Appendix Tables 14-21 present the zooplankton data. The zooplankton community was dominated by copepods, specifically *Acartia hudsonica* and *Acartia tonsa*. Their combined numerical abundance as a percentage of the mean total copepod abundance at each station varied from 77% to 90%. The less abundant copepod species included *Pseudocalanus*, *Centropages*, *Oithona* and *Pseudodiaptomus*. Benthic larvae were the other major zooplankton group. Their mean numerical abundance at the 7 stations ranged from 13% to 56% of the copepod abundance (Appendix Table 20). Table 36 summarizes the mean numerical abundance (m-3) of these components and total zooplankton community biomass (mg dry weight m-2).

Table 36

STATION:	1	2	3	4	5	6	7
Copepods	7964	4494	5448	6951	7394	8859	9814
Acartia							
hudsonica	5985	1808	2968	3812	5345	6465	6774
tonsa	939	1643	1645	2035	1276	1392	1945
Benthic larvae	1669	2101	3069	2529	1581	1637	1321
Biomass	329	378	536	611	535	327	287

Acartia hudsonica dominates the zooplankton community during the winter-spring period. It is succeeded by *Acartia tonsa* during the summer, which then persists into early winter. *Acartia tonsa* usually appears during late-May to early-June. *Acartia hudsonica* usually disappears in late July to early August. Thus, the 1985 summer brown-tide event coincided with an annually significant zooplankton event during which a key copepod successional change leads to a shift in community dominance and structure. Historical data allow evaluation of potential deviations in *Acartia hudsonica* - *tonsa* behavior during the brown-tide event. For *A. tonsa*, the data (May - August; 1981-1986) indicate that its numerical abundance fell within the range for these other years. In fact, its peak and mean abundances during 1985 were exceeded only in 1981 during this 6-year period. Therefore, at least at Station 7, no unusual events or affects associated with the brown-tide are discernible for A. tonsa, based on its 1985 abundance. In contrast, data from the seven transect stations indicate that the brown-tide development influenced abundance of A. tonsa. Mean abundance m-2 regressed against the mean number of brown-tide cells (m-2) exhibits an inverse relationship. The stations cluster into two subgroups: Stations 2, 3, 4 and Stations 1, 5, 6, 7; i.e., into upper and lower Bay groupings. A strong inverse correlation ($r = -0.91$) characterizes both groupings. Stations 2, 3 and 4 are distinguished from the others only in the higher A. tonsa standing stocks m-2. The slopes of the two subgroups are not statistically different.

An adverse affect of the brown tide on A. hudsonica may also have occurred, based on the inter-annual comparison. The mean abundance of A. hudsonica during May - August 1985 was the lowest recorded during the six-year (1981-1986) period. Rigorous statistical analysis is vitiated by the high standard deviations associated with the variable week-to-week abundance characteristic of copepods. For example, the 1984 mean abundance is heavily influenced by a single event; the 1984 and 1985 means would otherwise be comparable. However, the peaks of high abundance of A. hudsonica usually found in May - June did not develop in 1985 (Appendix Table 16). The late spring - early summer abundance and dynamics of A. hudsonica may have been adversely affected by the 1985 brown-tide; A. hudsonica was absent during the 1985 summer.

Benthic larvae abundance may also have been adversely affected by the brown-tide development. Mean abundance was inversely correlated ($r = -0.58$) with brown-tide cell numbers (both m-2). Based on the six year inter-annual comparisons at Station 7, benthic invertebrate larvae were least abundant (857 m-3) in 1985, following attainment of its greatest abundant (2385 m-3) in 1984.

The most remarkable zooplankton.modification accompanying the brown-tide outbreak was failure of the cladoceran community to develop. Evadne nordmanni and Podon sp. normally exceed > 10,000 animals m-3 during June - August. They failed to appear in 1985. Based on the six-year inter-annual comparisons at Station 7, the mean 1985 May - August abundance of only 80 m-3 was 10- to 75-fold lower than the means for the comparison years.

These observations collectively suggest that zooplankton and benthic larvae occurrence were influenced by the brown-tide development, with a trend suggesting that adverse effects predominated. These include apparent reductions in abundance and/or suppression of occurrence. It should be noted, however, that no correlation was found between zooplankton dry weight (biomass) and brown-tide cell numbers, both per m-2.

With regard to zooplankton dynamics after the brown-tide bloom, A. hudsonica increased in response to the winter-spring diatom bloom, peaking to > 10,000 animals m-3 in early March at all stations except 2 and 3, where this level of abundance was not achieved until early May. Vigorous growth then occurred from early March through June, > 40,000 animals m-3 occurred at Stations 1, 7 and about 30,000 m-3 at Stations 5, 6. At upper bay Stations 2, 3 and 4, A. hudsonica was less abundant. Table 36 indicates that the mean abundance of A. hudsonica progressively decreased along the salinity gradient up the bay. There is a very strong correlation with salinity (r2 = 0.96). Not only was the mean abundance of A. hudsonica significantly reduced in the low salinity environment of upper Narragansett Bay (Stations 2, 3, 4), its numerical abundance represented only 40% to 55% of the total copepod population in contrast to 69 - 76% at the lower bay stations.

A. tonsa progressively decreased during the winter-spring diatom bloom, disappeared in mid-March, and reappeared in early June following sporadic, transient occurrences after mid-March. The average abundance of A. tonsa during this annual survey was considerably less than that for A. hudsonica, excluding Station 2, by 2- to 7-fold. The regional distribution of A. tonsa was remarkably similar, from about 900 to 2035 animals m-3. However, unlike for A. hudsonica its abundance was not correlated with salinity.

Benthic larvae made a surprisingly large contribution to the zooplankton community, both numerically and in percentage representation (Appendix Tables 19, 20). The mean abundance ranged from about 1300 to 3100 larvae m^{-3}; this corresponded to 13 to 56% of the copepod abundance. In fact, mean benthic larvae abundance generally exceeded that for A. tonsa and even A. hudsonica at Stations 2, 3. Benthic larvae abundance progressively decreased down the bay, reflecting a strong inverse correlation with salinity ($r = -0.67$; -0.97 excluding Station 2). These distributional patterns influenced zooplankton community structure in that the predominance of benthic larvae in upper Narragansett Bay increased their representation to 35% - 55% from $\leq$ 20% in the lower bay, expressed as numerical abundance.

Benthic larvae tended to be most numerous in the summer. The polychaete Mediomastus ambiseta spawned from August - October 1985. The increased abundance accompanying inception of the winter-spring diatom bloom reflected the spawning of the barnacle Semibalanus balanoides in January. This was followed by the late-March to mid-April spawning or the barnacle Balanus crenatus. The large benthic larvae surge in April - May represented polychaete spawning, mostly Polydora sp. and the May spawning of the barnacle Balanus eburneus. The polychaete Streblospio benedicti also spawned in May. The high levels in June reflected spawning of the limpet Crepidula fornicata.

The strong inverse correlations between salinity and numerical abundance of A. hudsonica and benthic larvae were noted. Zooplankton biomass is also strongly correlated with salinity, but the relationship is more complex. Mean biomass levels (dry weight m-2) regressed against mean salinity were strongly and positively correlated at Stations 2, 3, 4 (r = 0.98), but strongly, but negatively correlated at Stations 4, 5, 1, 6, 7 (r = -0.85). That is, along the salinity gradient from Fields Pt. (Providence R.) to Conimicut Pt. (Station 4) mean zooplankton biomass increased. However, mean zooplankton biomass progressively decreased with increasing mean salinity along the gradient at the lower bay stations.

This gradient effect incorporates the relationships noted previously for A. hudsonica and benthic larvae abundance, and also found between total copepod abundance and salinity (r = 0.96). However, the inverse correlation between biomass and salinity sharply contrasts with the positive correlations based on numerical abundance.

The relationship with salinity undoubtedly does not primarily reflect an osmotic effect, but a parameter running in parallel with salinity. The relationships between nutrient concentrations and salinity were previously described. However, since zooplankton do not utilize inorganic nutrient, nutrients undoubtedly are not the parallel factor responsible for the correlation. Since the sampled zooplankton are mostly herbivorous, this prompted assessment of the relationship between zooplankton biomass along the salinity gradient and phytoplankton biomass and production. Zooplankton biomass (m-2) is strongly correlated with surface values for both phytoplankton carbon standing stock (r = 0.86) and phytoplankton carbon production (r = 0.86).

Ctenophores

The abundance of the ctenophore Mnemiopsis leidyi, a voracious grazer of copepods, is given in Appendix Table 21. Mean abundance varied about 6-fold, from 15 animals m-2 (Station 7) to 95 m-2 (Station 3). Mean and maximal abundances (m-2) at the stations are given in Table 37.

Table 37

STATION:	1	2	3	4	5	6	7
Mean	50	60	95	66	67	33	15
Maximum	350	436	742	243	806	280	61

Maximal abundance occurred in October following the brown-tide disappearance, and ranged from 61 to 806 animals m-2. Thereafter, the population declined and persisted at very low levels until it disappeared in March. Mnemiopsis reappeared baywide in May and persisted in very low abundance, usually < 6 animals m-2, through June.

The mean abundance of Mnemiopsis significantly increased up the salinity gradient from Station 7 to Station 3, then decreased at Station 2 (60 m^{-2}), where its abundance was about 40% lower than that at Station 3 (95 m^{-2}). Excluding Station 2, a strong, inverse correlation occurred between mean ctenophore numbers and salinity ($r = -0.92$). Thus, a strong gradient highly correlated with salinity characterizes the nutrient, phytoplankton, zooplankton and ctenophore distributions in Narragansett Bay.

Previous studies in Narragansett Bay (Deason & Smayda, 1982) revealed that when ctenophores were very abundant, zooplankton numerical abundance decreased significantly, accompanied by a significant concurrent increase in phytoplankton abundance. This increased phytoplankton abundance during ctenophore pulses results from a relaxation or zooplankton grazing pressure accompanying their decimation by the carnivorous *Mnemiopsis*. That is, ctenophore abundance indirectly controls phytoplankton abundance through predation on zooplankton. The relationships between the standing stocks of phytoplankton, zooplankton and ctenophores at the transect stations were therefore examined.

Excluding aberrant Station 2, a near-perfect inverse correlation ($r = -0.99$) occurs between mean ctenophore abundance (m^{-2}) and mean numerical abundance of the copepods. This inverse relationship is consistent with previous field observations (Deason & Smayda, 1982) and grazing down or copepods by ctenophores. However, regression of the mean zooplankton biomass (dry weight m^{-2}) against ctenophore abundance yields a *positive* correlation ($r = 0.79$). The biomass measurements include zooplankters not grazed by ctenophores and incorporate significant mid-winter zooplankton biomass pulses (when ctenophores are absent) during the phytoplankton bloom. In contrast, ctenophores are most abundant during summer-early autumn. This may partly account for the divergent correlations between ctenophore numerical abundance and zooplankton numerical and biomass abundance.

Regression of phytoplankton standing stocks as carbon and chlorophyll against ctenophore abundance, again excluding aberrant Station 2, yields positive correlations of $r = 0.81$ and $r = 0.84$, respectively. These correlations are consistent with previously observed field observations (Deason & Smayda, 1980), and the indirect regulation of phytoplankton abundance by ctenophores through their predation on herbivorous zooplankton.

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Appendix Table 1. TEMPERATURE (°C) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986)
(T = Surface, M = Mid-depth, B = Bottom)

STATION:		1	2	3	4	5	6	7
1985								
25 July	T	22.0	23.0	24.0	23.5	23.0	23.0	22.0
	M	23.0	22.0	23.0	23.5	23.0	24.0	22.0
	B	23.0	18.0	23.0	22.0	23.0	23.0	22.5
2 Aug.	T	22.3	22.4	22.6	22.7	22.5	22.2	22.8
	M	22.3	21.7	21.9	22.0	21.8	22.1	22.1
	B	22.1	21.2	21.2	21.4	22.0	22.4	22.4
9	T	25.6	-	-	-	23.3	-	-
	M	23.6	-	-	-	23.1	-	-
	B	23.6	-	-	-	23.2	-	-
15	T	25.9	25.7	26.6	26.2	26.6	25.3	25.8
	M	24.8	24.2	22.1	21.3	24.9	24.1	24.1
	B	-	23.4	21.9	21.3	23.8	23.9	23.2
22		-	-	-	-	-	-	-
28	T	22.8	23.3	23.7	22.6	22.9	22.6	22.2
	M	22.7	22.8	23.1	22.2	22.6	22.4	21.8
	B	22.6	22.5	22.7	21.6	22.5	22.1	21.4
11 Sept.	T	19.9	19.3	19.5	19.1	20.1	19.5	20.3
	M	19.8	18.9	19.0	18.6	19.6	19.8	20.3
	B	19.5	19.1	18.7	18.5	20.1	20.1	20.1
2 Oct.	T	19.5	20.0	20.0	19.8	20.0	20.0	19.3
	M	19.5	19.8	19.8	19.6	20.0	20.0	19.5
	B	19.5	19.6	19.5	19.6	20.0	20.0	19.5
9	T	16.5	16.8	17.6	17.2	17.6	17.8	17.9
	M	16.8	18.2	18.2	17.3	17.8	17.8	18.0
	B	17.4	17.6	18.1	18.0	18.0	17.5	18.0
18	T	15.1	16.0	14.9	16.0	16.0	16.0	16.8
	M	15.0	17.0	16.5	16.3	16.0	16.2	16.2
	B	14.4	16.9	16.5	16.2	16.0	16.2	16.2
23	T	14.8	15.1	14.0	14.0	15.0	15.6	15.5
	M	15.0	15.5	15.9	15.8	15.0	15.6	15.5
	B	15.0	15.8	15.8	16.1	15.7	15.8	15.3
30	T	11.0	12.5	12.2	12.0	12.8	12.5	13.0
	M	11.0	13.0	13.0	13.0	12.8	12.5	13.0
	B	10.8	13.0	13.8	12.8	12.6	12.3	13.0
13 Nov.	T	11.5	12.0	12.0	12.0	12.0	12.0	12.0
	M	11.5	12.5	12.3	12.3	12.0	12.0	12.0
	B	11.5	13.0	12.8	12.8	12.2	12.0	12.0

Appendix Table 1. (cont.)

20	T	11.0	11.3	12.1	11.8	11.3	11.0	11.5
	M	-	11.9	11.6	11.8	11.3	11.4	11.4
	B	-	11.8	12.0	11.9	11.3	11.1	11.7
4 Dec.	T	4.5	5.7	-	6.0	6.5	7.0	7.3
	M	5.0	8.0	9.0	8.0	6.5	7.0	7.3
	B	6.0	10.0	9.0	9.0	7.0	7.3	8.0
18	T	3.0	4.5	4.5	5.0	4.5	5.0	5.3
	M	3.1	5.5	6.0	5.8	4.2	5.0	5.0
	B	3.1	5.5	6.0	6.0	5.0	5.0	5.0
1986								
8 Jan.	T	0.5	3.5	3.2	2.0	1.5	1.2	3.0
	M	-0.5	3.3	2.2	2.0	1.3	1.0	2.0
	B	-0.5	3.0	1.9	1.2	1.3	1.0	2.3
15	T	-0.5	1.0	0.5	-1.0	-0.5	-0.5	0.5
	M	-0.5	0.5	1.0	1.0	-0.5	-0.5	0.5
	B	-0.5	1.5	1.5	1.5	0.0	-0.5	0.5
22	T	2.0	3.8	4.0	3.8	3.0	3.0	3.0
	M	2.8	3.5	4.0	3.7	3.0	3.0	3.0
	B	3.5	3.2	4.0	4.5	3.5	2.5	3.0
29	T	2.0	2.2	2.0	1.5	2.5	2.5	3.0
	M	2.0	3.5	4.0	3.5	3.5	3.5	3.5
	B	2.0	3.5	4.0	3.5	3.5	3.5	3.5
12 Feb.	T	0.8	3.0	2.5	2.0	2.5	2.0	2.2
	M	1.0	3.0	3.0	2.0	3.0	2.0	2.1
	B	1.0	3.5	3.0	2.0	3.0	2.0	2.0
5 Mar.	T	3.5	5.0	5.0	4.0	3.0	3.0	2.5
	M	3.5	4.0	3.5	3.8	3.5	3.0	3.0
	B	3.5	3.0	4.0	3.8	3.5	3.0	3.0
12	T	2.0	4.0	4.5	2.5	3.5	3.0	2.0
	M	2.0	3.0	3.0	2.5	3.0	3.0	2.0
	B	2.0	3.5	3.0	3.0	3.0	2.5	2.0
26	T	5.5	7.0	7.0	5.5	5.5	5.5	4.0
	M	6.0	-	-	5.0	-	-	4.5
	B	6.0	-	-	5.0	-	-	4.1
2 Apr.	T	11.0	11.0	11.0	10.0	10.0	10.0	8.8
	M	9.0	7.0	8.0	6.5	8.5	10.0	8.5
	B	8.0	7.0	6.5	6.0	8.0	7.0	8.0
9	T	8.5	10.0	10.0	8.5	9.5	8.0	7.5
	M	8.0	7.0	7.0	8.0	7.5	7.0	7.5
	B	8.0	7.0	7.0	6.0	7.5	7.0	6.5

Appendix Table 1. (cont.)

16	T	10.0	11.0	11.0	10.0	9.0	9.0	8.0
	M	9.0	7.0	7.5	7.0	8.5	8.5	8.0
	B	9.0	7.0	6.5	6.5	8.0	8.0	8.0
8 May	T	12.0	11.0	11.5	11.0	11.0	11.0	11.0
	M	11.5	10.0	10.5	9.5	11.0	11.0	11.0
	B	11.0	10.0	9.5	9.0	11.0	11.0	11.0
14	T	12.0	13.0	13.0	12.0	12.0	11.5	10.5
	M	11.5	11.0	11.0	11.0	11.0	11.5	10.5
	B	11.5	10.0	10.0	11.0	11.0	11.5	10.5
21	T	17.0	18.0	18.0	18.0	17.0	16.0	14.5
	M	16.0	14.0	16.0	17.0	16.0	15.5	14.0
	B	16.0	12.0	13.0	15.0	16.0	15.5	13.0
28	T	18.0	19.0	18.0	17.0	18.0	18.0	16.0
	M	18.0	17.0	16.5	16.0	17.0	17.0	16.0
	B	17.0	15.5	16.0	15.0	17.0	16.0	15.0
4 June	T	18.0	17.5	17.0	17.0	17.0	17.0	16.5
	M	17.5	17.0	16.5	16.0	16.0	17.0	16.0
	B	17.5	15.5	15.0	15.0	16.0	16.5	16.0
11	T	19.0	19.0	19.0	18.0	18.0	19.0	18.0
	M	19.0	16.0	19.0	18.0	18.0	19.0	18.0
	B	19.0	16.0	16.0	16.5	18.5	19.0	18.5
18	T	19.5	19.0	19.5	19.0	19.5	18.5	18.0
	M	19.0	18.0	16.0	18.0	17.5	17.5	18.0
	B	18.5	17.0	16.0	17.5	17.5	16.0	18.0

Appendix Table 2. SALINITY LEVELS (o/oo) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986)
(T = Surface, M = Mid-depth, B = Bottom)

STATION:		1	2	3	4	5	6	7
1985								
25 July	T	30.7	28.6	28.6	29.6	29.6	29.6	30.7
	M	30.7	29.6	28.6	29.6	29.6	29.6	30.7
	B	30.7	29.6	29.6	30.7	29.6	29.6	30.7
2 Aug.		-	-	-	-	-	-	-
9	T	28.6	-	-	-	24.4	-	-
	M	29.6	-	-	-	29.6	-	-
	B	29.6	-	-	-	29.6	-	-
15	T	29.6	21.2	24.4	26.5	28.6	30.7	30.7
	M	30.1	26.5	30.1	30.7	29.6	30.7	30.7
	B	30.1	30.1	30.7	31.2	30.1	30.7	30.7
22		-	-	-	-	-	-	-
28	T	29.6	24.4	23.3	26.5	28.6	30.7	30.7
	M	29.6	29.6	29.6	29.6	29.6	30.7	30.7
	B	29.6	29.6	29.6	30.7	29.6	30.7	30.7
11 Sept.	T	29.1	24.4	26.5	27.3	28.8	30.7	28.8
	M	29.6	31.7	30.7	31.7	30.7	30.7	29.6
	B	30.7	31.7	30.7	31.7	30.7	30.7	29.6
2 Oct.	T	29.6	21.2	24.4	28.0	29.6	30.7	30.7
	M	29.6	28.6	27.5	29.6	29.6	30.7	30.7
	B	29.6	29.6	29.6	30.7	29.6	30.7	30.7
9	T	28.6	17.1	27.5	29.1	29.6	29.6	30.7
	M	29.1	21.2	30.1	28.6	30.1	29.6	30.7
	B	29.6	28.6	30.7	30.7	30.7	29.6	31.7
18	T	29.6	24.4	24.4	28.6	29.6	30.7	30.7
	M	29.6	28.6	29.6	29.6	29.6	30.7	30.7
	B	29.6	29.6	29.6	31.7	29.6	30.7	30.7
23	T	29.1	23.3	23.3	30.7	28.6	30.7	30.7
	M	29.1	28.6	29.6	30.7	29.6	30.7	30.7
	B	29.1	29.6	31.7	31.2	30.7	30.7	30.7
30	T	29.6	26.5	28.0	29.1	29.6	30.7	30.7
	M	30.1	28.6	29.6	29.6	29.6	30.7	31.7
	B	30.1	29.6	30.7	30.7	29.6	30.7	31.7
13 Nov.	T	28.0	23.0	24.4	27.5	29.6	29.6	30.7
	M	28.0	28.5	28.6	30.7	29.6	29.6	30.7
	B	28.0	29.6	30.7	29.6	29.6	29.6	30.7

Appendix Table 2. (cont.)

20	T	28.6	13.4	19.2	24.4	28.6	29.6	29.6
	M	28.6	28.0	28.6	29.6	28.6	29.6	30.7
	B	28.6	29.1	29.6	30.1	29.6	29.6	30.7
4 Dec.	T	27.5	15.0	22.3	22.3	27.5	28.6	29.6
	M	28.6	29.6	28.6	28.6	28.6	28.8	29.6
	B	28.6	30.7	29.9	29.6	28.6	29.6	30.7
18	T	28.0	17.1	24.4	25.4	28.6	29.6	30.1
	M	28.6	28.0	29.1	28.6	28.6	29.6	30.1
	B	28.6	28.6	29.6	29.6	28.6	29.6	30.1
1986								
8 Jan.	T	28.8	27.5	27.5	27.5	28.6	29.6	30.7
	M	28.8	28.8	28.6	28.6	28.6	29.6	30.7
	B	28.8	31.7	30.7	30.1	29.4	29.6	30.7
15	T	31.7	26.5	27.0	28.6	28.6	31.7	31.7
	M	31.7	27.5	29.1	29.6	29.1	31.7	31.7
	B	31.7	29.6	30.1	29.6	28.6	31.7	31.7
22	T	28.6	19.7	23.3	25.4	28.6	29.6	30.1
	M	29.1	29.6	29.6	29.6	29.6	29.6	30.1
	B	29.6	30.7	30.7	31.2	29.6	29.6	30.1
29	T	23.3	13.9	11.8	16.5	28.0	28.6	29.6
	M	27.5	28.6	26.5	24.4	28.6	28.6	30.1
	B	28.6	29.6	29.6	27.5	28.6	29.1	30.7
12 Feb.	T	28.6	22.3	25.4	28.6	27.5	29.6	29.6
	M	28.6	29.6	29.6	28.6	30.1	29.6	29.6
	B	28.6	29.6	30.7	29.1	30.7	29.6	29.6
5 Mar.	T	28.6	16.0	21.3	22.3	27.5	29.6	29.6
	M	29.1	28.6	29.1	29.6	29.6	29.6	30.7
	B	29.1	29.6	29.6	30.7	29.6	29.6	30.7
12	T	29.6	22.3	18.1	28.6	28.6	29.6	30.7
	M	29.6	28.6	28.0	28.6	28.6	30.7	31.7
	B	29.6	29.6	29.6	30.7	29.6	30.7	31.7
26	T	28.6	16.0	21.3	26.0	28.6	28.6	30.7
	M	28.6	-	-	27.5	-	-	30.7
	B	28.6	-	-	28.6	-	-	30.7
2 Apr.	T	26.0	13.9	18.6	23.3	25.4	27.5	28.6
	M	27.5	26.5	26.7	29.1	28.0	28.6	29.6
	B	28.6	29.1	30.7	31.7	28.6	30.1	30.7
9	T	17.1	16.0	19.2	24.9	24.4	28.6	29.6
	M	28.6	29.6	29.1	27.5	27.5	29.6	29.6
	B	28.6	29.6	29.6	30.7	29.6	29.6	30.1

Appendix Table 2. (cont.)

16	T	28.6	16.0	19.7	23.3	28.6	29.1	29.6
	M	28.6	29.6	28.6	29.6	28.6	29.1	29.6
	B	28.6	29.6	30.7	30.7	29.1	29.6	29.6
8 May	T	29.6	27.5	26.5	27.5	29.1	29.6	30.7
	M	29.6	29.6	29.6	30.7	29.6	29.6	30.7
	B	29.6	30.7	30.7	31.7	30.7	30.7	30.7
14	T	29.6	24.4	26.5	27.5	30.1	30.7	30.7
	M	30.7	30.7	30.7	30.7	30.7	30.7	30.7
	B	30.7	30.7	31.2	31.2	30.7	31.7	30.7
21	T	30.1	21.2	26.5	27.5	30.7	30.7	30.7
	M	30.7	29.6	29.6	29.6	30.7	30.7	31.2
	B	30.7	30.7	30.7	30.7	30.7	30.7	31.2
28	T	29.6	17.1	24.4	28.6	29.6	30.7	31.7
	M	29.6	28.6	29.1	29.6	30.1	30.7	31.7
	B	30.7	29.6	29.6	30.7	30.1	30.7	31.7
4 June	T	29.6	25.4	27.5	28.6	29.6	30.1	30.1
	M	29.6	27.5	29.1	29.6	29.6	30.1	31.2
	B	30.7	30.1	30.7	31.2	30.7	30.1	31.2
11	T	29.1	10.9	22.8	27.5	29.6	29.6	30.7
	M	29.6	29.6	26.5	28.6	29.6	29.6	30.7
	B	29.6	30.7	29.6	30.7	29.6	29.6	30.7
18	T	28.6	17.1	27.5	22.3	24.9	28.6	29.6
	M	28.6	27.5	30.7	29.6	29.6	29.6	29.6
	B	29.6	27.5	30.7	29.6	29.6	30.7	29.9
$\overline{x}$	T	28.5	20.3	23.7	26.4	28.5	29.8	30.3
	M							
	B	29.5	29.8	30.2	30.5	29.7	30.2	30.7
$\overline{x}$	T&B	29.0	25.0	27.0	28.6	29.2	30.0	30.5

Appendix Table 3. DENSITY (σ_t) DISTRIBUTION AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986) (T = surface; M = mid-depth; B = bottom)

STATION:		1	2	3	4	5	6	7
1985								
25 July	T	21.0	19.1	18.8	19.7	19.9	19.9	21.0
	M	20.7	20.2	21.3	19.7	19.9	19.6	21.0
	B	20.7	21.2	21.3	21.0	19.9	19.9	20.8
2 Aug.		-	-	-	-	-	-	-
9	T	18.3	-	-	-	15.8	-	-
	M	19.7	-	-	-	19.8	-	-
	B	19.7	-	-	-	19.8	-	-
15	T	19.0	12.8	14.9	16.6	16.6	20.0	19.9
	M	19.0	17.2	20.5	21.2	19.3	20.4	20.4
	B	-	20.1	21.0	21.6	20.7	20.5	20.7
22		-	-	-	-	-	-	-
28	T	19.9	15.8	14.9	17.6	19.1	20.8	20.9
	M	19.9	19.9	19.8	20.1	20.0	20.8	21.0
	B	20.0	20.0	19.9	21.1	20.0	20.9	21.1
11 Sept.	T	20.3	16.9	18.4	19.2	20.1	21.6	20.0
	M	20.7	22.6	21.8	22.6	21.6	21.6	20.6
	B	21.6	22.5	21.8	22.7	21.5	21.5	20.7
2 Oct.	T	20.8	14.3	16.8	19.5	20.7	21.5	21.7
	M	20.8	20.0	19.1	20.8	20.7	21.5	21.6
	B	20.8	20.8	20.8	21.6	20.7	21.5	21.6
9	T	20.8	11.9	19.7	21.0	21.3	21.2	22.0
	M	21.1	14.9	21.5	20.6	21.6	21.2	22.0
	B	21.3	20.4	22.0	22.0	22.0	21.3	22.8
18	T	21.8	17.7	17.9	20.9	21.6	22.5	22.3
	M	21.9	20.6	21.5	21.6	21.6	22.4	22.4
	B	22.0	21.4	21.5	23.2	21.6	22.4	22.4
23	T	21.5	17.0	17.2	22.9	21.1	22.6	22.6
	M	21.5	21.0	21.7	22.5	21.9	22.6	22.6
	B	21.5	21.7	23.3	22.8	22.5	22.5	22.6
30	T	22.6	20.0	21.2	22.0	22.3	23.2	23.1
	M	23.0	21.5	22.3	22.3	22.3	23.2	23.9
	B	23.0	22.3	22.9	23.1	22.3	23.2	23.9
13 Nov.	T	21.3	17.3	18.4	20.8	22.4	22.4	23.3
	M	21.3	21.5	21.6	21.6	22.4	22.4	23.3
	B	21.3	22.3	23.1	22.3	22.4	22.4	23.3

Appendix Table 3. (cont.)

20	T	21.8	10.0	14.4	18.5	21.8	22.6	22.5
	M	-	21.2	21.7	22.5	21.8	22.6	23.4
	B	-	22.1	22.4	22.8	22.6	22.6	23.3
4 Dec.	T	21.8	11.9	-	17.6	21.6	22.4	23.2
	M	22.7	23.1	22.2	22.3	22.5	22.6	23.2
	B	22.5	23.6	23.2	22.9	22.4	23.2	23.9
18	T	22.3	13.6	19.4	20.1	22.7	23.4	23.8
	M	22.8	22.1	22.9	22.6	22.7	23.4	23.8
	B	22.8	22.6	23.3	23.3	22.7	23.4	23.8
1986								
8 Jan.	T	23.1	21.9	21.9	22.0	22.9	23.7	24.5
	M	23.2	23.0	22.9	22.9	22.9	23.7	24.6
	B	23.2	25.3	24.6	24.1	23.6	23.7	24.5
15	T	25.5	21.3	21.7	23.0	23.0	25.5	25.5
	M	25.5	22.1	23.3	23.7	23.4	25.5	25.5
	B	25.5	23.7	24.1	23.7	23.0	25.5	25.5
22	T	22.9	15.7	18.6	20.2	22.8	23.6	23.9
	M	23.2	23.6	23.5	23.6	23.6	23.6	23.9
	B	23.6	24.5	24.4	24.7	23.6	23.7	23.9
29	T	18.7	10.9	9.5	13.3	22.4	22.9	23.6
	M	22.0	22.3	21.1	19.5	22.8	22.8	24.0
	B	22.9	23.6	23.5	21.9	22.8	23.2	24.5
12 Feb.	T	23.0	17.8	20.3	22.9	22.0	23.7	23.7
	M	22.9	23.6	23.6	22.9	24.0	23.7	23.7
	B	22.9	23.6	24.5	23.3	24.5	23.7	23.7
5 Mar.	T	22.8	12.7	16.9	17.7	21.9	23.6	23.6
	M	23.2	22.7	23.2	23.5	23.6	23.6	24.5
	B	23.2	23.6	23.5	24.4	23.6	23.6	24.5
12	T	23.7	17.7	14.4	22.9	22.8	23.6	24.6
	M	23.7	23.8	22.3	22.9	22.8	24.5	25.4
	B	23.7	23.6	23.6	24.5	23.6	24.5	25.4
26	T	22.6	12.6	16.7	20.6	22.6	22.6	24.4
	M	22.5	-	-	22.7	-	-	24.4
	B	22.5	-	-	22.7	-	-	24.4
2 Apr.	T	19.8	10.5	14.1	17.9	19.5	21.1	22.2
	M	21.3	20.8	20.8	22.9	21.7	22.0	23.0
	B	22.3	22.8	24.1	25.0	22.3	23.6	23.9
9	T	13.2	12.2	14.7	19.2	18.8	22.3	23.1
	M	22.3	23.2	22.8	21.4	21.5	23.2	23.1
	B	22.3	23.2	23.2	24.2	23.1	23.2	23.7

Appendix Table 3. (cont.)

16	T	22.0	12.1	15.0	17.9	22.2	22.5	23.1
	M	22.2	23.2	22.4	23.2	22.2	22.6	23.1
	B	22.2	23.2	24.1	24.1	22.7	23.1	23.1
8 May	T	22.4	21.0	20.1	21.0	22.2	22.6	23.5
	M	22.5	22.8	22.7	23.7	22.6	22.6	23.5
	B	22.6	23.6	23.7	24.6	23.5	23.5	23.5
14	T	22.4	18.3	19.9	20.8	22.8	23.4	23.6
	M	23.4	23.5	23.5	23.5	23.5	23.4	23.6
	B	23.4	23.6	24.0	23.8	23.5	24.0	23.6
21	T	21.8	14.8	18.8	19.6	22.3	22.5	22.8
	M	22.5	22.1	21.6	21.4	22.5	22.6	23.3
	B	22.5	23.3	23.1	22.7	22.5	22.6	23.5
28	T	21.2	11.5	17.2	20.6	21.2	22.0	23.3
	M	21.2	20.6	21.1	21.6	21.8	22.2	23.3
	B	22.3	21.7	21.6	22.7	21.8	22.5	23.5
4 June	T	21.2	18.1	19.7	20.5	21.3	21.8	21.9
	M	21.3	19.7	21.1	21.6	21.6	21.8	22.9
	B	22.1	22.1	22.7	23.1	22.5	21.9	22.9
11	T	20.5	6.8	15.8	19.6	21.2	20.9	22.1
	M	20.9	21.4	18.6	20.4	21.2	20.9	22.1
	B	20.9	22.5	21.4	22.4	21.1	20.9	21.9
18	T	20.1	11.5	19.2	15.4	17.3	20.3	21.2
	M	20.2	19.6	22.5	21.2	21.3	21.3	21.2
	B	21.1	19.8	22.5	21.3	21.3	22.5	21.4

Appendix Table 4. SECCHI DISC MEASUREMENTS (m) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986)

STATION:	1	2	3	4	5	6	7
1985							
25 July	0.5	0.75	0.5	0.75	0.75	0.75	1.0
2 Aug.	1.0	1.75	2.0	1.5	1.75	1.5	1.0
9	0.75	-	-	-	1.25	-	-
15	1.0	1.0	0.75	1.0	1.0	1.0	1.25
22	-	-	-	-	-	-	-
28	1.25	1.5	1.5	1.25	1.5	1.25	1.75
11 Sept.	1.5	2.25	2.25	2.25	2.25	2.5	2.0
2 Oct.	1.25	1.75	1.5	1.5	2.75	1.5	2.0
9	1.75	2.0	1.5	2.25	2.25	2.0	1.75
18	1.75	3.0	3.75	2.75	3.25	2.25	2.25
23	-	2.25	2.25	2.75	2.25	3.0	1.75
30	2.0	2.0	1.75	1.75	1.5	2.0	2.5
13 Nov.	2.25	1.75	2.25	2.25	2.25	2.5	2.25
20	2.25	2.0	2.0	2.5	3.0	3.0	2.5
4 Dec.	2.25	2.0	2.0	2.5	2.5	2.75	3.0
18	3.25	2.0	2.5	2.5	3.0	2.25	2.0
1986							
8 Jan.	2.25	2.25	2.25	1.75	2.0	2.0	1.75
15	2.5	1.5	1.5	1.5	1.5	1.5	1.5
22	1.25	1.5	1.5	1.25	1.25	1.75	1.5
29	1.25	1.0	0.75	1.0	1.25	2.25	3.25
12 Feb.	2.0	1.75	2.25	2.5	2.25	2.25	3.5
5 Mar.	2.75	1.5	2.0	2.0	2.25	3.0	3.75
12	2.5	1.75	2.0	2.0	2.25	2.25	3.75
26	2.5	1.5	1.5	1.75	2.25	-	3.25
2 Apr.	1.25	1.25	0.75	1.25	1.5	2.25	3.25
9	2.5	1.5	1.5	1.5	1.5	2.5	4.25
16	3.25	1.25	1.25	1.25	3.75	4.25	4.25
8 May	3.25	2.5	3.0	2.75	3.25	3.0	3.0
14	2.5	2.5	3.0	3.0	3.25	3.5	3.0
21	1.75	1.25	1.0	1.75	2.25	2.25	2.5
28	1.25	1.5	2.0	1.5	2.0	2.0	2.5
4 June	1.75	2.0	1.75	2.0	2.25	2.25	2.75
11	2.0	1.25	1.25	1.5	1.5	1.75	1.75
18	2.0	1.0	1.25	1.75	1.0	1.25	2.25

Appendix Table 5. PO_4 CONCENTRATION (mg-at m^{-3}) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986) (T = Surface, M = Mid-depth, B = Bottom)

STATION:		1	2	3	4	5	6	7
1985								
25 July	T	9.9	9.5	8.4	5.3	4.5	4.8	-
	M	3.0	5.3	4.8	4.5	5.1	5.0	3.5
	B	6.1	5.4	3.9	3.5	5.7	6.6	3.9
2 Aug.	T	1.5	2.4	1.6	1.6	1.5	1.1	1.0
	M	1.6	2.9	2.0	1.8	1.6	1.2	1.0
	B	1.6	3.8	2.4	1.5	1.7	1.2	1.1
9	T	0.9	-	-	-	3.1	-	-
	M	1.3	-	-	-	2.3	-	-
	B	1.6	-	-	-	2.5	-	-
15	T	3.2	3.5	3.8	3.3	4.1	3.3	2.6
	M	4.0	9.1	6.0	4.7	3.7	3.9	2.8
	B	3.2	8.4	5.8	4.6	3.8	5.3	2.9
22		-	-	-	-	-	-	-
28 Aug.	T	4.1	8.9	4.5	5.2	-	3.5	3.0
	M	3.8	5.6	4.6	4.7	3.2	3.8	3.1
	B	3.7	5.6	4.9	4.6	10.7	3.5	3.2
11 Sept.	T	3.7	30.0	19.2	19.4	3.8	3.1	2.3
	M	3.4	17.9	18.7	15.8	4.5	3.1	2.5
	B	4.8	17.0	16.1	-	4.1	2.9	2.4
2 Oct.	T	0.8	21.7	16.4	14.3	2.3	1.4	1.4
	M	0.9	15.6	14.7	13.9	2.4	1.3	1.3
	B	0.9	15.1	15.3	14.3	2.3	1.5	1.4
9	T	1.2	17.3	14.3	13.7	1.9	1.0	1.1
	M	1.2	14.7	3.1	9.9	1.6	2.0	1.1
	B	1.8	16.8	14.2	14.2	2.1	1.1	1.8
18	T	0.9	3.9	4.2	2.3	1.4	1.1	1.6
	M	0.8	2.0	1.5	1.7	1.4	1.0	1.0
	B	1.0	1.0	1.1	-	1.5	1.1	1.2
23	T	1.1	4.2	6.3	4.1	2.4	1.6	1.1
	M	0.8	3.0	2.8	2.1	2.1	1.3	1.0
	B	0.9	3.1	2.9	2.0	2.2	1.4	0.8
30	T	0.9	4.6	2.3	2.5	1.6	1.1	1.3
	M	1.0	2.6	1.1	2.1	1.2	2.5	1.3
	B	0.9	2.3	1.6	0.9	1.3	1.1	1.3
13 Nov.	T	1.4	2.7	2.0	2.3	1.6	1.4	1.4
	M	1.5	1.4	1.2	1.6	1.5	1.4	1.5
	B	1.4	1.2	1.6	1.4	1.3	1.3	1.5

Appendix Table 5. PO_4 CONCENTRATION (mg-at m^{-3}) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986) (T = Surface, M = Mid-depth, B = Bottom)

STATION:		1	2	3	4	5	6	7
1985								
25 July	T	9.9	9.5	8.4	5.3	4.5	4.8	-
	M	3.0	5.3	4.8	4.5	5.1	5.0	3.5
	B	6.1	5.4	3.9	3.5	5.7	6.6	3.9
2 Aug.	T	1.5	2.4	1.6	1.6	1.5	1.1	1.0
	M	1.6	2.9	2.0	1.8	1.6	1.2	1.0
	B	1.6	3.8	2.4	1.5	1.7	1.2	1.1
9	T	0.9	-	-	-	3.1	-	-
	M	1.3	-	-	-	2.3	-	-
	B	1.6	-	-	-	2.5	-	-
15	T	3.2	8.5	3.8	3.3	4.1	3.3	2.6
	M	4.0	9.1	6.0	4.7	3.7	3.9	2.8
	B	3.2	8.4	5.8	4.6	3.8	5.3	2.9
22		-	-	-	-	-	-	-
28 Aug.	T	4.1	8.9	4.5	5.2	-	3.5	3.0
	M	3.8	5.6	4.6	4.7	3.2	3.8	3.1
	B	3.7	5.6	4.9	4.6	10.7	3.5	3.2
11 Sept.	T	3.7	30.0	19.2	19.4	3.8	3.1	2.3
	M	3.4	17.9	18.7	15.8	4.5	3.1	2.5
	B	4.8	17.0	16.1	-	4.1	2.9	2.4
2 Oct.	T	0.8	21.7	16.4	14.3	2.3	1.4	1.4
	M	0.9	15.6	14.7	13.9	2.4	1.3	1.3
	B	0.9	15.1	15.3	14.3	2.3	1.5	1.4
9	T	1.2	17.3	14.3	13.7	1.9	1.0	1.1
	M	1.2	14.7	-	9.9	1.6	2.0	1.1
	B	1.8	16.8	14.2	14.2	2.1	1.1	1.8
18	T	0.9	3.9	4.2	2.3	1.4	1.1	1.6
	M	0.8	2.0	1.5	1.7	1.4	1.0	1.0
	B	1.0	1.0	1.1	-	1.5	1.1	1.2
23	T	1.1	4.2	6.3	4.1	2.4	1.6	1.1
	M	0.8	3.0	2.8	2.1	2.1	1.3	1.0
	B	0.9	3.1	2.9	2.0	2.2	1.4	0.8
30	T	0.9	4.6	2.3	2.5	1.6	1.1	1.3
	M	1.0	2.6	1.1	2.1	1.2	2.5	1.3
	B	0.9	2.3	1.6	0.9	1.3	1.1	1.3
13 Nov.	T	1.4	2.7	2.0	2.3	1.6	1.4	1.4
	M	1.5	1.4	1.2	1.6	1.5	1.4	1.5
	B	1.4	1.2	1.6	1.4	1.3	1.3	1.5

Appendix Table 5. (cont.)

20	T	1.3	2.6	1.5	1.9	1.5	2.2	0.9
	M	-	1.2	1.0	2.9	1.4	1.4	0.9
	B	1.5	0.9	0.8	1.5	1.6	1.7	1.9
4 Dec.	T	1.8	3.3	1.8	2.7	2.0	1.9	2.4
	M	1.8	2.5	1.3	2.0	2.0	1.7	1.9
	B	1.8	2.6	1.0	1.8	1.9	2.0	1.9
18	T	2.1	3.6	2.2	2.9	1.9	1.8	1.7
	M	1.4	2.7	1.4	2.1	2.2	2.0	1.9
	B	1.5	2.5	1.3	2.1	2.1	2.0	2.1
1986								
8 Jan.	T	0.3	4.7	2.8	5.0	1.7	1.0	0.5
	M	0.3	4.7	2.1	2.6	1.7	0.8	0.6
	B	0.4	4.0	1.5	2.5	1.4	0.7	0.5
15	T	0.3	2.0	2.1	1.8	0.6	0.3	0.4
	M	0.6	1.2	1.3	0.9	0.4	0.3	0.4
	B	0.3	0.6	-	1.2	0.0	0.3	0.4
22	T	0.2	2.8	1.9	1.3	0.3	0.3	-
	M	0.2	0.7	0.2	0.9	0.2	0.3	-
	B	0.3	0.6	0.2	1.2	0.3	0.2	-
29	T	0.1	2.4	2.9	1.2	0.7	0.4	0.3
	M	0.1	1.8	1.0	0.5	0.4	0.4	0.3
	B	0.1	1.4	0.7	0.4	0.4	0.5	0.3
12 Feb.	T	0.4	1.8	1.8	0.5	0.5	0.4	0.3
	M	0.2	0.9	0.8	0.6	0.5	0.4	0.3
	B	0.2	0.7	1.6	0.6	0.6	0.4	0.2
5 Mar.	T	0.4	2.9	2.5	4.1	0.4	0.3	0.2
	M	0.3	0.4	0.5	0.3	0.4	0.4	0.4
	B	0.6	0.7	0.6	0.3	0.4	0.4	0.7
12	T	-	1.5	4.4	0.3	0.4	0.4	0.4
	M	-	0.2	0.7	0.3	0.4	0.5	0.4
	B	-	0.4	0.5	0.5	0.4	0.6	1.2
26	T	0.3	3.3	1.4	0.5	0.1	0.3	0.5
	M	0.3	-	-	0.4	-	-	0.4
	B	0.3	-	-	0.4	-	-	0.5
2 Apr.	T	0.2	1.7	0.3	0.2	0.4	0.2	0.3
	M	0.7	0.7	0.5	0.3	0.3	0.2	0.3
	B	0.3	0.3	0.7	0.3	0.2	0.4	0.3
9	T	0.3	2.1	1.4	0.2	0.3	0.5	0.4
	M	0.4	1.1	0.5	0.3	0.1	0.4	0.4
	B	0.6	1.6	0.7	0.2	0.5	0.6	0.5

Appendix Table 5. (cont.)

16	T	0.4	3.2	1.0	0.3	0.3	0.4	0.3
	M	0.7	1.9	0.9	0.6	0.4	0.4	0.4
	B	0.8	0.9	0.9	0.7	0.5	0.5	0.3
8 May	T	1.0	1.8	3.5	3.4	1.9	1.3	0.7
	M	1.0	0.8	1.4	1.2	1.6	1.3	0.8
	B	1.0	0.7	1.0	1.1	1.1	1.5	0.8
14	T	0.6	3.0	4.3	3.4	1.2	1.2	1.0
	M	1.0	1.4	1.2	1.1	1.1	1.1	1.0
	B	1.3	3.0	1.2	1.0	1.2	1.0	1.0
21	T	0.3	1.9	1.1	1.2	0.3	0.4	0.3
	M	0.4	1.6	0.9	0.8	0.3	0.4	0.3
	B	0.4	4.0	3.1	0.9	0.5	0.4	0.4
28	T	0.4	3.8	3.6	1.5	0.6	0.5	0.5
	M	0.4	2.2	1.3	1.1	0.6	0.5	0.5
	B	0.6	2.0	1.1	1.3	0.6	0.5	0.8
4 June	T	1.5	3.0	2.4	1.8	1.8	1.5	1.1
	M	1.4	3.3	4.2	2.4	1.8	1.5	1.1
	B	1.8	2.9	1.9	2.1	2.1	1.5	1.1
11	T	0.7	3.2	4.4	0.7	0.6	0.5	0.7
	M	0.7	2.1	2.0	1.1	0.7	0.7	0.7
	B	0.8	2.9	2.0	1.8	0.7	0.5	0.6
18	T	1.3	4.4	2.4	2.8	0.9	1.5	0.9
	M	1.3	2.8	2.9	1.3	1.2	1.4	0.9
	B	1.6	2.6	3.3	1.3	1.4	1.2	1.1

Appendix Table 6. NH_4-N CONCENTRATIONS (mg-at m^{-3}) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986) (T = surface, M = Mid-depth, B = Bottom)

STATION:		1	2	3	4	5	6	7
1985								
25 July	T	8.7	54.5	62.8	13.3	3.1	4.5	-
	M	0.9	20.6	11.2	11.1	8.8	6.2	0.5
	B	0.8	17.5	7.9	6.2	8.9	6.3	-
2 Aug.	T	4.5	2.5	1.6	4.2	1.4	1.1	3.1
	M	2.1	13.3	3.2	1.2	2.0	3.9	1.0
	B	0.8	21.0	9.1	10.8	2.2	1.2	1.3
9	T	0.8	-	-	-	14.6	-	-
	M	1.6	-	-	-	2.9	-	-
	B	2.9	-	-	-	8.1	-	-
15	T	0.6	40.8	7.4	0.7	1.1	1.0	1.8
	M	2.8	49.8	51.4	19.6	5.5	3.5	0.6
	B	9.8	34.5	18.4	13.6	6.5	7.2	1.2
22	T	0.6	49.1	28.3	16.0	1.4	3.6	0.5
	M	0.5	51.2	46.6	12.3	6.9	3.8	3.4
	B	4.1	21.0	12.5	7.9	6.4	11.9	3.9
28	T	0.4	45.5	47.5	45.0	-	0.4	1.0
	M	-	11.9	10.0	6.5	0.5	0.4	1.0
	B	0.6	14.2	12.7	8.6	1.6	0.7	4.8
11 Sept.	T	4.7	31.9	36.2	29.8	12.8	7.5	1.4
	M	5.4	19.0	2.0	17.5	17.5	8.5	3.7
	B	21.0	20.7	1.5	-	7.2	6.4	2.8
2 Oct.	T	1.4	45.2	29.8	4.4	9.0	1.4	1.3
	M	0.8	19.8	12.1	13.5	7.5	4.9	0.0
	B	0.8	19.1	36.5	13.9	14.9	6.2	0.0
9	T	2.1	36.6	8.1	2.4	2.6	0.0	0.8
	M	2.1	13.2	11.4	3.7	3.2	0.0	0.8
	B	7.8	34.2	10.6	9.6	9.6	0.1	3.8
18	T	1.6	35.7	43.9	12.4	3.9	1.7	3.6
	M	2.8	15.9	12.3	10.0	4.3	1.5	2.3
	B	-	7.6	11.6	-	5.8	1.6	2.3
23	T	1.3	25.1	71.7	26.5	4.1	1.9	1.3
	M	0.7	11.2	10.1	5.5	4.0	1.2	1.9
	B	0.7	10.9	8.7	5.2	5.6	4.5	1.8
30	T	1.3	42.3	20.5	5.8	1.2	6.6	1.3
	M	2.0	> 6.0	9.0	3.0	0.8	1.1	1.0
	B	0.8	52.1	4.0	2.3	1.0	0.9	0.9

Appendix Table 6. (cont.)

13 Nov.	T	5.4	25.1	21.8	9.7	5.1	3.8	1.7
	M	5.6	17.6	6.9	4.9	4.6	3.5	2.2
	B	5.6	3.1	4.4	4.1	3.9	3.4	1.9
20	T	8.6	28.7	29.8	14.1	7.6	7.3	2.6
	M	-	12.3	15.0	8.5	7.1	7.9	2.8
	B	8.8	8.9	7.2	6.6	7.8	7.5	5.6
4 Dec.	T	11.0	28.4	26.7	19.6	12.0	10.4	8.4
	M	11.6	13.4	11.7	10.2	11.1	8.9	8.0
	B	10.2	13.0	7.7	7.3	10.1	9.4	7.9
18	T	9.0	34.4	22.5	21.0	9.6	8.2	6.8
	M	8.5	12.1	11.5	9.6	11.9	7.3	6.6
	B	8.5	10.0	8.4	7.8	10.9	8.7	6.3
1986								
8 Jan.	T	1.3	10.5	> 6.0	27.8	6.7	1.9	0.8
	M	1.7	13.2	7.6	2.1	7.2	1.2	1.4
	B	2.3	11.8	4.7	7.2	4.7	4.4	0.7
15	T	0.5	51.7	16.6	6.2	1.0	0.8	0.7
	M	0.5	17.8	4.9	2.1	1.3	0.6	1.4
	B	1.1	3.1	-	2.3	1.2	0.6	1.1
22	T	0.9	78.4	33.1	11.1	0.8	1.2	-
	M	1.3	8.1	3.3	1.9	0.9	0.5	-
	B	0.9	5.4	2.6	2.0	1.1	0.4	-
29	T	0.7	35.1	29.7	21.5	6.1	1.1	0.8
	M	0.9	1.7	2.5	4.0	1.2	1.4	0.6
	B	0.7	1.8	1.8	1.9	1.1	1.2	0.6
12 Feb.	T	0.6	28.7	19.9	6.9	4.1	2.0	1.5
	M	0.5	4.2	4.0	12.4	1.7	1.2	0.6
	B	0.5	3.5	3.1	2.7	1.7	1.2	0.5
5 Mar.	T	0.5	40.4	25.8	6.0	1.6	1.0	0.9
	M	0.4	3.8	1.7	0.9	1.2	1.1	0.8
	B	1.0	3.6	1.6	0.8	1.2	1.2	1.4
12	T	-	33.0	36.7	2.1	1.9	1.5	0.3
	M	-	1.5	3.7	3.1	1.7	5.3	0.6
	B	-	6.4	1.7	1.3	1.7	-	0.6
26	T	2.1	-	11.8	1.7	2.4	0.5	6.7
	M	2.4	-	-	0.9	-	-	0.8
	B	0.5	-	-	5.1	-	-	0.8
2 Apr.	T	1.3	23.2	0.4	0.6	1.0	1.1	0.6
	M	0.5	5.6	1.5	5.2	1.1	1.1	0.5
	B	0.8	1.0	0.7	0.6	1.1	1.2	0.5

Appendix Table 6. (cont.)

9	T	0.8	23.6	24.1	1.1	2.4	1.2	1.5
	M	0.8	3.4	2.2	0.7	1.2	5.7	1.0
	B	0.4	5.1	1.2	0.7	1.2	1.6	1.7
16	T	1.7	>15.0	>15.0	1.3	1.5	1.4	0.5
	M	1.7	7.8	2.1	4.6	1.4	1.4	1.0
	B	1.5	3.4	2.3	2.0	1.4	1.3	0.6
8 May	T	7.2	18.1	24.3	28.3	8.3	4.3	0.9
	M	4.8	8.4	8.9	3.9	-	4.2	1.3
	B	4.7	7.8	5.7	3.1	5.1	3.6	1.1
14	T	3.5	33.9	16.1	-	5.5	5.2	4.2
	M	4.1	12.6	5.0	5.7	4.1	6.0	3.9
	B	6.2	8.1	4.9	3.8	4.9	3.5	5.3
21	T	0.7	20.8	3.4	1.8	1.6	1.6	0.5
	M	0.6	11.6	2.5	1.6	1.6	1.8	1.2
	B	0.6	22.0	18.5	2.1	1.6	1.6	0.6
28	T	1.5	41.8	28.7	2.9	1.4	1.3	1.5
	M	1.5	10.8	3.1	2.5	1.3	1.3	1.4
	B	1.4	10.1	4.5	4.3	1.3	1.4	2.1
4 June	T	0.8	23.1	1.6	1.1	3.3	2.2	1.6
	M	0.9	14.1	10.0	6.1	4.8	2.1	1.6
	B	2.2	11.7	5.3	5.6	6.3	3.3	1.5
11	T	0.7	38.1	13.0	0.7	0.6	0.6	0.8
	M	0.5	16.2	3.0	4.1	0.8	0.7	0.5
	B	0.7	18.0	8.2	8.2	0.9	2.4	0.5
18	T	0.8	8.1	6.9	7.9	0.9	0.8	0.6
	M	0.8	4.9	8.1	2.2	1.0	0.8	0.7
	B	0.9	6.2	10.4	2.1	1.4	0.8	0.7

Appendix Table 7. NO_3-N CONCENTRATIONS (mg-at m^{-3}) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986) (T = Surface, M = Mid-depth, B = Bottom)

STATION:		1	2	3	4	5	6	7
1985								
25 July	T	0.2	24.2	13.4	6.2	2.6	1.6	-
	M	0.3	3.2	2.8	3.1	1.5	1.3	0.2
	B	0.2	2.2	2.0	1.4	2.5	0.9	0.8
2 Aug.	T	1.0	5.4	0.1	0.1	0.3	0.2	0.2
	M	0.2	3.1	0.6	0.3	0.3	0.2	0.2
	B	0.2	2.5	1.2	1.1	0.9	0.3	0.4
9	T	0.1	-	-	-	9.3	-	-
	M	0.1	-	-	-	0.6	-	-
	B	0.2	-	-	-	0.6	-	-
15	T	0.1	9.4	1.8	0.2	0.2	0.1	0.4
	M	0.3	7.4	1.8	1.8	0.3	0.5	0.1
	B	1.0	2.8	1.9	2.4	0.6	0.8	0.6
22		-	-	-	-	-	-	-
28	T	0.2	19.1	12.2	7.5	-	0.2	0.1
	M	0.3	1.4	1.5	1.1	0.3	0.2	0.3
	B	0.2	1.5	1.8	1.1	0.4	0.2	0.7
11 Sept.	T	0.2	24.1	15.2	13.7	4.2	1.6	0.7
	M	0.2	6.3	6.8	6.3	1.6	1.3	0.8
	B	0.3	5.7	4.9	-	2.4	1.3	0.7
2 Oct.	T	0.1	21.5	20.3	10.5	4.4	0.8	0.2
	M	0.2	7.9	9.8	7.3	4.0	0.3	0.1
	B	0.2	5.5	5.6	3.5	3.9	1.3	0.1
9	T	0.6	43.5	10.2	6.0	3.5	0.2	0.4
	M	0.6	7.2	3.2	5.9	3.5	0.1	0.7
	B	0.8	3.1	2.7	3.0	3.3	0.7	3.3
18	T	0.4	-	16.0	7.5	3.2	0.9	2.6
	M	0.3	6.9	5.3	4.2	3.1	0.5	0.7
	B	0.7	3.6	5.2	-	3.4	0.6	0.6
23	T	1.0	18.0	27.8	14.8	7.8	3.8	0.1
	M	1.0	41.8	50.2	5.3	5.9	1.8	0.1
	B	0.9	3.6	4.3	4.3	5.8	0.4	0.3
30	T	0.3	7.7	13.4	7.7	3.9	0.4	0.2
	M	0.3	6.9	6.8	5.7	0.6	0.3	0.2
	B	0.2	4.2	2.9	3.6	0.3	0.2	0.2
13 Nov.	T	5.7	17.0	15.0	10.3	5.4	3.9	1.6
	M	5.9	6.3	5.9	5.1	5.0	3.4	1.6
	B	5.7	4.3	4.5	4.3	4.6	3.5	1.6

Appendix Table 7. (cont.)

20	T	7.8	24.3	15.6	14.7	7.0	6.7	3.4
	M	-	6.9	6.0	7.2	5.9	5.8	3.0
	B	11.4	5.2	4.6	4.7	6.5	6.1	3.7
4 Dec.	T	11.9	28.2	18.7	18.6	12.7	10.8	9.2
	M	12.3	6.9	11.0	11.4	11.7	9.4	9.4
	B	10.7	4.2	9.2	10.7	11.0	11.3	9.4
18	T	10.0	27.5	20.2	19.7	13.9	13.5	12.1
	M	15.0	12.6	13.9	14.8	15.4	14.0	11.5
	B	15.3	14.1	11.8	13.2	14.9	13.5	11.0
1986								
8 Jan.	T	3.6	10.5	2.9	15.9	11.4	7.9	0.5
	M	3.0	4.9	>10.0	12.0	11.7	6.4	0.8
	B	3.8	4.2	9.8	10.5	11.3	6.1	0.7
15	T	0.6	17.6	11.7	9.5	2.2	0.3	0.2
	M	0.5	12.1	8.7	8.0	2.9	0.2	0.2
	B	0.3	7.9	-	8.3	2.2	0.2	0.1
22	T	0.3	29.1	20.7	8.9	0.3	0.3	-
	M	0.2	7.7	5.0	2.1	0.3	0.2	-
	B	0.2	6.7	3.6	2.2	0.4	0.2	-
29	T	0.2	29.0	25.2	19.1	7.1	0.2	0.1
	M	0.1	1.9	2.0	2.5	0.3	0.2	0.1
	B	0.1	1.5	1.0	0.5	0.2	0.2	0.1
12 Feb.	T	0.1	12.5	12.6	4.0	1.7	0.3	0.3
	M	0.2	2.8	2.6	2.0	1.9	0.2	0.2
	B	0.2	2.3	3.3	1.4	1.9	0.2	0.3
5 Mar.	T	0.6	28.4	15.0	11.5	1.1	0.2	0.1
	M	0.2	1.1	0.4	0.5	0.3	0.2	0.3
	B	0.2	0.8	0.3	0.2	0.3	0.3	0.3
12	T	-	12.3	19.8	0.9	0.7	0.1	0.2
	M	-	0.6	2.7	0.2	0.4	0.2	0.1
	B	-	0.9	0.3	0.2	0.2	0.2	0.1
26	T	0.2	19.7	10.4	1.0	0.2	0.2	0.2
	M	0.3	-	-	0.9	-	-	0.2
	B	0.2	-	-	5.0	-	-	0.2
2 Apr.	T	0.3	22.2	10.7	0.2	0.2	0.2	0.3
	M	0.1	2.7	5.6	5.6	0.2	0.2	0.3
	B	0.1	0.3	0.1	0.2	0.2	0.2	0.3
9	T	0.7	22.6	17.7	0.2	4.1	0.2	0.3
	M	0.1	0.6	0.3	0.5	0.2	0.1	0.3
	B	0.1	0.4	0.3	0.3	0.2	0.2	0.3

Appendix Table 7. (cont.)

16	T	0.5	>20.0	14.4	2.5	0.2	0.1	0.1
	M	0.3	1.4	0.4	0.4	0.1	0.2	0.2
	B	0.1	0.4	0.4	0.6	0.1	0.1	0.2
8 May	T	2.6	12.4	11.1	10.4	4.3	2.0	0.2
	M	1.7	3.2	3.0	1.2	3.9	1.9	0.2
	B	1.3	2.4	1.4	1.4	1.3	1.4	0.1
14	T	1.8	20.0	11.6	11.6	3.4	3.0	2.7
	M	2.9	4.3	2.5	2.5	2.7	2.6	2.5
	B	3.1	2.7	1.7	1.7	2.3	2.1	2.5
21	T	0.2	32.9	11.9	1.6	0.2	0.2	0.2
	M	0.2	3.6	1.9	0.6	0.2	0.2	0.2
	B	0.2	4.0	2.9	0.6	0.2	0.2	0.2
28	T	0.3	31.9	19.9	4.1	0.2	0.2	0.2
	M	0.2	8.1	4.3	1.4	0.2	0.2	0.2
	B	0.2	3.6	2.5	1.0	0.2	0.2	0.3
4 June	T	0.4	16.1	5.7	2.5	1.0	0.5	0.4
	M	0.3	9.5	3.9	2.2	1.0	0.5	0.3
	B	0.6	2.0	1.5	1.2	1.1	0.6	0.4
11	T	0.3	22.8	12.2	0.4	0.2	0.2	0.4
	M	0.2	3.7	3.8	1.6	0.4	0.2	0.2
	B	0.2	2.0	2.7	2.5	0.4	0.8	0.2
18	T	0.1	11.2	3.6	10.7	0.2	0.1	0.1
	M	0.1	2.6	1.3	0.7	0.1	0.1	0.1
	B	0.2	2.6	1.5	0.4	0.2	0.1	0.1

Appendix Table 8. SiO_3-Si CONCENTRATIONS (mg-at m^{-3}) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986) (T - Surface, M = Mid-depth, B = Bottom)

STATION:		1	2	3	4	5	6	7
1985								
25 July	T	34.4	55.9	43.3	26.0	22.5	29.8	-
	M	32.1	39.6	32.4	29.6	32.2	34.6	33.7
	B	32.4	25.7	41.8	33.5	35.5	25.7	36.3
2 Aug.	T	83.1	26.9	28.0	35.3	40.8	42.2	42.2
	M	35.0	31.8	33.9	36.8	40.5	43.4	39.7
	B	52.0	42.2	37.8	35.6	45.5	43.7	40.7
9	T	36.5	-	-	-	32.1	-	-
	M	50.5	-	-	-	26.9	-	-
	B	29.1	-	-	-	29.7	-	-
15	T	26.1	36.3	5.3	5.0	14.3	32.8	30.2
	M	28.9	41.9	40.6	36.0	28.3	35.0	32.4
	B	44.1	44.0	41.3	40.2	34.6	40.9	34.4
22	T	37.5	47.0	41.6	34.2	32.2	33.6	34.2
	M	39.4	42.8	37.3	37.6	35.9	33.3	41.2
	B	37.7	41.1	35.4	33.0	34.7	34.2	34.1
28	T	26.8	41.0	36.1	17.6	-	23.1	26.3
	M	27.3	26.2	22.9	18.8	17.8	24.0	26.9
	B	26.1	28.2	25.8	29.9	20.1	26.0	29.7
11 Sept.	T	21.4	51.5	34.6	29.4	18.2	18.5	13.3
	M	21.8	26.4	30.0	21.6	27.0	20.8	16.6
	B	25.0	26.3	36.5	-	23.6	18.4	13.5
2 Oct.	T	7.1	46.5	35.9	26.1	20.3	13.6	12.1
	M	12.1	32.5	25.7	25.6	20.7	13.5	11.2
	B	12.6	32.2	30.5	26.0	20.2	16.3	11.4
9	T	9.9	57.1	21.6	10.8	9.5	0.8	2.6
	M	9.9	23.7	17.5	11.8	10.1	1.2	3.3
	B	12.0	47.1	17.5	17.6	16.6	1.1	13.2
18	T	30.3	32.9	30.7	16.2	12.4	9.7	8.9
	M	25.0	22.1	18.0	13.6	12.4	9.4	8.3
	B	13.9	16.4	19.5	-	13.9	9.5	7.2
23	T	16.5	32.0	44.5	22.7	18.6	12.8	9.3
	M	17.1	16.7	66.2	16.9	18.9	13.1	8.7
	B	17.6	17.5	20.0	15.1	20.6	13.9	9.2
30	T	17.8	37.1	23.4	17.1	13.4	13.8	13.2
	M	21.2	18.8	19.7	18.6	11.8	12.6	12.1
	B	16.6	15.3	16.0	12.2	13.9	12.0	9.3

Appendix Table 8. (cont.)

13 Nov.	T	22.0	46.1	59.0	29.2	22.3	19.8	17.3
	M	23.5	29.1	39.5	20.6	20.6	19.0	16.8
	B	23.5	25.1	19.6	19.4	19.0	19.0	18.3
20	T	26.3	19.1	29.3	27.0	22.4	23.6	15.9
	M	-	29.6	24.3	30.5	19.9	20.9	14.3
	B	23.3	22.9	24.0	16.8	21.0	24.1	19.8
4 Dec.	T	27.2	54.2	70.1	38.5	27.0	24.9	21.1
	M	27.7	26.1	41.7	23.5	25.2	21.5	21.5
	B	24.0	56.5	34.9	20.4	24.4	25.2	20.6
18	T	32.0	33.4	69.7	36.9	27.1	24.5	21.5
	M	25.7	29.4	43.1	25.7	26.3	25.3	20.8
	B	27.6	15.3	38.1	23.0	26.5	24.2	19.8
1986								
8 Jan.	T	2.0	19.7	28.1	24.7	17.4	4.7	0.6
	M	1.1	21.3	17.6	13.3	17.4	3.1	1.0
	B	1.3	17.6	14.8	12.3	14.3	3.0	0.7
15	T	0.0	29.5	15.1	6.2	0.2	0.0	0.0
	M	0.0	14.3	6.7	3.1	1.3	0.0	0.0
	B	0.0	6.3	-	4.5	1.2	0.0	0.0
22	T	0.0	74.0	39.7	12.2	0.0	0.0	-
	M	0.0	4.7	1.0	1.1	0.0	0.0	-
	B	0.0	2.7	2.5	1.3	0.0	0.0	-
29	T	0.3	11.0	24.5	28.0	9.6	0.6	0.2
	M	0.0	0.0	1.5	1.1	1.6	0.4	0.1
	B	0.0	0.0	1.2	0.0	1.4	0.4	0.0
12 Feb.	T	0.2	22.5	21.2	4.8	1.3	0.0	0.0
	M	0.4	2.6	4.2	2.1	1.0	0.0	0.0
	B	0.5	1.7	2.2	1.5	1.0	0.1	0.0
5 Mar.	T	0.7	28.8	29.2	22.7	1.9	0.1	0.0
	M	0.3	0.7	0.0	0.0	0.1	0.1	0.1
	B	0.0	4.2	0.0	0.0	0.1	0.3	0.5
12	T	-	35.1	18.5	1.4	0.8	0.0	0.6
	M	-	1.8	2.6	0.1	0.4	0.0	0.7
	B	-	1.0	0.0	0.8	0.0	0.1	1.3
26	T	0.5	39.9	24.7	3.7	0.0	0.1	0.1
	M	0.4	-	-	1.9	-	-	0.2
	B	0.1	-	-	1.5	-	-	0.2
2 Apr.	T	3.2	20.9	8.3	0.0	0.0	0.2	0.0
	M	0.4	3.0	0.5	2.1	0.1	0.0	0.0
	B	0.1	0.0	0.1	0.0	0.1	0.5	0.0

Appendix Table 8. (cont.)

9	T	1.5	22.2	19.0	0.0	1.7	0.1	0.3
	M	0.5	0.8	1.4	0.0	0.2	0.4	0.5
	B	0.8	0.9	1.9	1.3	1.2	0.6	0.8
16	T	0.6	22.5	7.0	0.0	0.1	0.2	1.8
	M	0.9	0.8	1.2	1.5	0.4	0.1	0.4
	B	1.0	0.4	2.4	1.7	0.6	0.9	0.3
8 May	T	7.0	18.8	11.6	12.7	7.4	6.5	4.6
	M	7.3	14.0	7.6	7.2	7.4	6.6	4.4
	B	7.8	20.3	7.4	7.9	7.3	6.4	4.3
14	T	11.9	28.4	17.7	14.7	7.5	8.7	8.1
	M	10.2	14.9	8.3	6.8	7.6	7.9	8.5
	B	9.8	13.8	7.8	7.2	8.8	8.0	8.8
21	T	7.1	14.5	1.3	0.7	2.4	2.0	0.4
	M	3.2	9.6	4.3	2.5	2.1	2.1	0.6
	B	3.7	19 3	13.4	6.9	3.3	1.9	2.4
28	T	0.3	38.7	23.7	5.8	1.0	0.7	1.1
	M	0.7	10.3	5.2	4.6	1.0	0.6	1.1
	B	1.4	11.8	6.4	7.7	0.9	2.1	3.3
4 June	T	4.8	20.1	2.4	1.0	5.4	6.1	5.0
	M	4.8	10.8	7.1	6.8	7.1	6.0	5.0
	B	7.3	10.2	11.1	9.3	9.6	7.7	6.3
11	T	25.4	48.8	31.5	19.7	17.0	13.0	17.3
	M	23.0	23.4	23.2	21.3	17.8	13.4	16.4
	B	22.7	19.8	10.1	20.2	17.8	13.1	17.0
18	T	24.5	34.7	30.8	44.7	24.5	24.9	22.9
	M	24.5	33.4	26.9	24.1	25.4	23.6	22.0
	B	28.1	31.9	27.9	24.3	25.9	23.6	19.2

Appendix Table 9. ABUNDANCE (x 10^{-6} cells ml^{-1}) OF BROWN TIDE-PRODUCING PHYTOPLANKTER AT NARRAGANSETT BAY TRANSECT STATIONS FROM 25 July - 9 October 1985 (T = Top, M = Mid, B = Bottom Depth)

	July	Aug					Sept	Oct	
	25	2	9	15	22	28	11	2	9
STATION:									
1T	1304	629	945	403	1521	377	277	34	-
M	1228	669	1008	386	1005	464	208	39	-
B	1225	724	610	240	880	439	34	14	-
2T	1000	83	-	168	37	98	36	17	-
M	689	70	-	123	37	56	54	10	-
B	402	112	-	83	18	51	36	9	-
3T	950	56	-	199	84	52	19	1	-
M	752	81	-	142	68	44	22	7	-
B	506	160	-	119	73	48	16	2	-
4T	662	121	-	169	306	100	30	6	-
M	685	72	-	47	284	108	20	12	-
B	811	110	-	68	210	108	4	9	-
5T	717	82	153	276	411	149	32	6	-
M	708	182	401	397	291	178	20	8	-
B	925	140	358	292	384	204	6	2	-
6T	908	226	-	366	520	273	23	16	-
M	948	270	-	362	434	196	24	22	-
B	810	351	-	330	526	420	30	17	-
7T	842	423	-	398	480	253	90	7	-
M	854	511	-	427	507	228	101	13	-
B	771	458	-	425	303	97	94	14	-

Appendix Table 10. AVERAGE CONDITIONS (x) DURING BROWN-TIDE BLOOM EVENT (25 July - 2 October 1985 transects)

STATION:		1	2	3	4	5	6	7
1. Temperature (°C)								
	x	22.6	22.3	22.7	22.3	22.6	22.1	22.1
	σ	(2.5)	(2.3)	(2.7)	(2.6)	(2.2)	(2.1)	(2.3)
	Sx	(0.9)	(1.0)	(1.1)	(1.1)	(0.8)	(0.9)	(0.9)
2. Salinity (o/oo)								
	x	29.5	24.0	25.4	27.6	28.3	30.5	30.3
	σ	(0.7)	(3.1)	(2.1)	(1.3)	(2.0)	(0.5)	(0.9)
	Sx	(0.3)	(1.4)	(0.9)	(0.6)	(0.8)	(0.2)	(0.4)
3. sfc NH_4-N (mg-at m-3)								
	x	2.7	38.5	30.5	16.2	6.2	2.8	1.5
	σ	(3.0)	(17.4)	(21.4)	(16.1)	(5.8)	(2.6)	(0.9)
	Sx	(1.1)	(6.6)	(8.1)	(6.1)	(2.2)	(1.0)	(0.4)
4. sfc NO_3-N (mg-at m-3)								
	x	0.3	17.3	10.5	6.4	3.5	0.8	0.3
	σ	(0.3)	(8.0)	(7.9)	(5.5)	(3.4)	(0.7)	(0.2)
	Sx	(0.1)	(3.3)	(3.2)	(2.2)	(1.4)	(0.3)	(0.1)
5. NH_4+NO_3 (mg-at m-3)								
	x	3.3	50.1	41.4	22.6	9.9	3.4	1.4
	σ	(3.2)	(29.8)	(29.4)	(21.0)	(10.1)	(3.4)	(0.5)
	Sx	(1.2)	(12.2)	(12.0)	(8.6)	(4.5)	(1.4)	(0.3)
6. PO_4 (mg-at m-3)								
	x	3.4	13.5	9.0	8.2	3.2	2.9	2.1
	σ	(3.2)	(10.3)	(7.2)	(7.0)	(1.2)	(1.4)	(0.8)
	Sx	(1.2)	(4.2)	(3.0)	(2.9)	(0.5)	(0.6)	(0.4)
7. SiO_2 (mg-at m-3)								
	x	34.1	43.6	32.1	24.8	25.8	27.7	26.4
	σ	(22.1)	(9.8)	(12.8)	(10.5)	(9.5)	(9.8)	(11.8)
	Sx	(7.8)	(3.7)	(4.9)	(4.0)	(3.6)	(3.7)	(4.8)
8. Secchi Disc (m)								
	x	1.04	1.5	1.42	1.38	1.61	1.42	1.50
	σ	(0.34)	(0.55)	(0.68)	(0.52)	(0.70)	0.61	(0.47)
	Sx	(0.13)	(0.22)	(0.28)	(0.21)	(0.27)	0.25	(0.19)
9. Chlorophyll (mg m-3)								
	x	23.4	19.6	36.9	39.3	30.6	22.8	21.5
	σ	(7.8)	(23.6)	(47.0)	(22.6)	(16.5)	(12.4)	(9.5)
	Sx	(2.9)	(8.9)	(17.8)	(8.5)	(6.7)	(5.1)	(3.6)

Appendix Table 10. (cont.)

10. Zpl dry wt (mg m^{-2})

x	144	494	341	462	436	197	215
σ	(177)	(331)	(165)	(414)	(458)	(188)	(251)
Sx	(72)	(135)	(67)	(169)	(173)	(77)	(102)

11. Copepods (nos. m^{-3})

x	3215	7257	6225	7309	4317	5093	7261
σ	(2921)	(3740)	(2850)	(5140)	(5353)	(5408)	(8457)
Sx	(1104)	(1414)	(1077)	(1943)	(2185)	(2044)	(3196)

12. Acartia tonsa (nos. m^{-3})

x	2493	6175	5592	6464	3932	4559	6342
σ	(2249)	(3204)	(2661)	(4718)	(4902)	(4812)	(6813)
x	(850)	(1211)	(1006)	(1783)	(2001)	(1819)	(2575)
nos. m^{-2}	19944	75335	74933	69811	26738	31001	44394

13. Benthic larvae (nos. m^{-3})

x	182	1279	786	386	545	344	385
σ	(162)	(1619)	(562)	(199)	(463)	(426)	(454)
Sx	(61)	(612)	(212)	(75)	(189)	(161)	(172)
nos. m^{-2}	1456	15603	10532	5211	5886	2339	2695

14. Benthic Larvae as % Σ zp

x	15.2	16.0	12.7	10.1	19.2	10.8	7.1
σ	(21.0)	(14.6)	(10.3)	(14.2)	(24.3)	(13.1)	(8.1)
Sx	(8.0)	(5.5)	(3.9)	(5.4)	(9.9)	(5.0)	(2.9)

15. Ctenophore Abundance (nos. m^{-3})

x	9.1	7.2	6.1	5.6	5.5	6.1	4.8
σ	(5.6)	(7.1)	(5.2)	(5.2)	(5.5)	(5.9)	(3.1)
Sx	(2.0)	(2.7)	(2.0)	(2.0)	(1.9)	(2.2)	(1.2)

16. Brown Tide Species (nos. m^{-3} at 0 m x 10^9)

x	686	206	194	199	216	333	356
σ	(523)	(354)	(339)	(227)	(244)	(310)	(277)
Sx	(185)	(134)	(128)	(86)	(87)	(117)	(105)

17. Brown Tide Species (nos. m^{-2} x 10^9)

x	4918	1842	2162	2493	2871	2265	2484
σ	(3507)	(2960)	(3481)	(3341)	(2628)	(2053)	(1942)
Sx	(1240)	(1119)	(1316)	(1262)	(929)	(776)	(734)

Appendix Table 11. SURFACE CHLOROPHYLL LEVELS (mg m-3) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986)

STATION:	1	2	3	4	5	6	7
1985							
25 July	20.4	67.9	54.3	40.7	38.0	18.6	17.0
2 Aug.	37.6	4.3	12.4	38.3	46.2	34.8	34.4
9							
15	21.9	31.7	137.3	84.5	-	-	34.0
22	20.1	6.4	17.2	30.8	30.1	20.1	14.3
28	20.1	17.2	19.4	35.1	46.6	22.9	20.1
11 Sept.	14.0	2.2	4.9	8.9	5.7	2.9	9.6
2 Oct.	29.7	7.2	13.0	37.2	16.9	37.2	21.3
9							
18							
23	6.9	3.0	2.0	18.1	20.3	6.3	16.6
30	6.9	7.8	6.9	23.6	24.0	13.9	5.9
13 Nov.	7.8	0.9	2.8	5.1	7.8	6.7	6.4
20	5.2	0.6	0.9	2.7	4.8	4.3	4.9
4 Dec.	1.1	0.4	0.8	0.3	0.4	0.9	0.5
18	3.2	0.6	1.4	2.1	2.6	2.6	2.7
1986							
8 Jan.	47.0	7.5	9.3	10.3	14.1	21.3	21.6
15	49.7	23.6	27.7	38.2	48.0	42.2	27.4
22	42.2	19.6	38.2	55.9	47.3	29.7	20.9
29	29.7	18.5	11.9	22.0	31.4	17.2	10.9
12 Feb.	23.5	12.7	11.4	18.1	19.1	21.7	11.6
5 Mar.	8.7	18.1	17.4	19.8	20.3	11.8	3.5
12	8.0	14.5	10.0	23.0	16.2	8.3	2.5
26	7.3	4.2	18.4	14.2		7.7	3.2
2 Apr.	7.5	18.6	60.5	32.4	13.2	4.2	2.7
9	2.1	5.5	11.7	23.0	19.9	5.8	0.7
16	3.7	20.1	31.6	38.8	2.0	2.3	2.1
8 May	2.9	2.0	1.4	2.7	1.9	3.0	2.2
14	2.8	0.9	3.5	2.5	1.1	2.3	2.1
21	5.8	36.6	30.7	12.8	3.0	3.9	3.5
28	16.2	8.4	13.7	21.8	10.8	8.8	7.1
4 June	10.0	11.2	21.3	23.5	5.1	6.1	3.1
11	22.6	6.5	44.6	54.2	42.6	26.7	13.2
18	9.8	53.3	14.9	23.0	54.2	22.3	7.8

Appendix Table 12. SURFACE ATP-C LEVELS (mg C m-3) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986)

STATION:	1	2	3	4	5	6	7
1985							
25 July	-	-	-	-	-	-	-
2 Aug.	-	-	-	-	-	-	-
9	2435	-	-	-	1598	-	-
15	1783	1655	5430	4693	3375	695	1513
22	980	385	423	1020	1873	1398	1163
28	470	1423	1250	3095	2515	1248	1450
11 Sept.	410	278	625	775	590	423	1025
2 Oct.	2910	250	1158	2993	1043	2983	1248
9	905	238	2803	-	1045	1118	1023
18	668	213	173	1125	520	1468	1418
23	175	70	93	1498	1528	338	2123
30	468	255	2570	3350	3643	1700	808
13 Nov.	395	85	345	683	770	590	683
20	323	50	105	298	425	590	785
4 Dec.	93	45	68	45	65	95	68
18	180	48	80	105	203	88	133
1986							
8 Jan.	780	273	420	508	588	690	605
15	3908	955	903	1188	1165	850	738
22	1410	820	1423	1730	1945	1308	918
29	415	520	403	620	1445	970	958
12 Feb.	958	550	640	873	685	1025	610
5 Mar.	510	515	648	715	578	563	243
12	510	288	360	763	558	550	370
26	1288	348	1768	1310	950	803	348
2 Apr.	973	1505	3600	2548	1713	763	450
9	630	470	880	1328	1445	518	158
16	453	1323	2598	2435	348	323	320
8 May	760	210	168	393	290	448	370
14	535	168	220	303	188	63	243
21	690	1105	2343	2168	590	405	395
28	1338	458	623	1285	668	955	548
4 June	970	1093	2230	1803	885	748	413
11	1480	460	1988	2038	1173	1218	748
18	1038	1753	1430	2550	3868	2143	695

Appendix Table 13. SURFACE PRIMARY PRODUCTION RATES (mg C m-3 d-1) AT NARRAGANSETT BAY TRANSECT STATIONS (28 August 1985 - 18 June 1986)

STATION:	1	2	3	4	5	6	7
1985							
28 Aug.	203	686	2288	2709	1109	589	343
11 Sept.	33	78	410	122	23	22	40
2 Oct.	644	103	263	641	299	573	421
9	610	279	1605	773	681	795	716
18	48	41	47	84	97	310	210
23	134	70	84	143	278	232	251
30	134	251	339	452	489	170	153
13 Nov.	68	21	38	65	100	65	91
20	33	6	17	22	64	115	76
4 Dec.	11	2	6	6	7	9	5
18	60	9	11	17	47	43	61
1986							
8 Jan.	643	85	311	421	420	671	620
15	847	432	492	709	785	692	382
22	831	742	817	983	898	751	524
29	691	852	839	913	608	351	273
12 Feb.	481	345	306	395	549	567	303
5 Mar.	228	1008	914	740	546	100	32
12	202	485	434	516	438	172	31
26	372	51	1075	768	414	252	127
2 Apr.	563	987	1646	961	470	287	107
9	21	239	347	402	697	185	9
16	229	1258	1578	1324	141	144	84
8 May	177	62	108	83	114	149	191
14	205	123	567	350	208	237	211
21	205	1290	1411	386	196	195	206
28	1075	1007	1660	1517	625	330	405
4 June	281	1621	1791	1326	146	268	79
11	371	62	747	830	651	405	25
18	172	441	611	701	937	276	102

Appendix Table 14. ZOOPLANKTON BIOMASS AS DRY WEIGHT (mg m-2) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986)

STATION:	1	2	3	4	5	6	7
1985							
25 July	-	503	442	1088	677	488	565
2 Aug.	495	998	475	691	1347	359	509
9	46	-	-	-	443	-	-
15	139	706	306	660	289	84	44
22	104	421	333	110	192	52	71
28	-	-	-	-	-	-	-
11 Sept.	31	289	459	182	32	18	36
2 Oct.	51	44	36	46	74	178	62
9	35	25	136	469	163	57	57
18	23	47	90	77	148	89	96
23	2	10	8	65	48	3	135
30	12	105	80	38	81	36	22
13 Nov.	34	71	311	274	38	29	73
20	115	50	173	144	121	168	171
4 Dec.	129	96	102	199	-	151	223
18	339	22	330	322	176	14	138
1986							
8 Jan.	257	-	511	700	338	186	58
15	70	486	495	535	152	216	103
22	254	288	219	194	127	492	509
29	131	221	233	203	399	130	334
12 Feb.	-	272	255	191	155	267	301
5 Mar.	1070	200	75	-	1137	893	143
12	931	418	300	679	822	542	575
26	514	337	865	531	1076	-	391
2 Apr.	805	330	722	1702	1364	366	805
9	507	779	729	845	1869	371	431
16	153	505	491	451	714	799	109
8 May	139	925	620	790	303	378	380
14	307	575	317	355	218	199	113
21	262	257	609	853	285	552	875
28	809	975	1025	1470	1028	942	637
4 June	1620	680	1091	1736	1638	861	806
11	230	376	2513	1318	430	369	212
18	593	708	2802	2019	1247	841	210

Appendix Table 15. COPEPOD ABUNDANCE (animals m-3) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986)

STATION:	1	2	3	4	5	6	7
1985							
25 July	5989	7417	9367	15857	1133	14914	22912
2 Aug.	7875	12780	8372	8151	14943	10565	14994
15	1001	6135	7310	11399	-	2706	1214
22	767	7345	7838	2563	2684	2460	2539
28	2755	7588	5106	5720	2992	2310	5876
11 Sept.	4060	9220	4471	6695	3768	1924	1148
2 Oct.	60	316	1111	781	381	774	2141
9	836	1091	783	6878	2263	1191	2214
18	209	310	145	422	696	1165	1935
23	98	509	58	2293	942	1174	2666
30	591	903	152	1377	1710	1512	3948
12 Nov.	1921	-	4971	4326	4568	948	2381
20	1187	966	1848	1216	878	750	2046
4 Dec.	732	1371	928	2190	-	3276	2101
18	2296	249	5964	8011	3877	598	2360
1986							
8 Jan.	7393	-	3162	2821	3926	3426	1293
15	698	2508	1951	2589	2311	1868	1234
22	1781	2402	1071	1231	1113	3998	2909
29	1477	1093	1094	1229	3776	2020	1263
12 Feb.	-	2953	3070	2228	4350	6143	3840
5 Mar.	30719	1436	1700	4596	23114	20540	11075
12	13635	2149	2875	12470	10282	13746	8880
26	5440	2976	3339	4149	10283	-	8585
2 Apr.	9891	2483	8413	11060	15660	7828	9373
9	34080	2758	8506	8196	14300	11999	15295
16	8683	7074	6424	5324	11544	29302	6904
8 May	4932	15618	13685	8528	8418	17759	16556
14	7877	3686	4583	20200	6147	6302	6899
21	5724	7906	3767	8798	8857	20452	40050
28	24416	4774	13296	7205	5964	36846	47748
4 June	46768	10003	9670	18258	31376	25788	51300
11	9169	4773	21204	19670	9386	13759	9910
18	11782	8534	13568	12960	17575	15453	10270

Appendix Table 16. Acartia hudsonica ABUNDANCE (animals m-3) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986)

STATION:	1	2	3	4	5	6	7
1985							
25 July	0	0	0	0	8	0	0
2 Aug.	46	0	0	0	0	0	0
15	0	0	0	0	-	0	0
22	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0
11 Sept.	0	0	0	0	0	0	0
2 Oct.	0	1	0	0	0	0	20
9	6	7	0	29	24	6	104
18	17	14	3	7	0	8	0
23	13	117	6	75	67	126	121
30	66	40	3	41	46	144	28
12 Nov.	208	-	454	399	201	46	74
20	191	56	132	112	81	69	133
4 Dec.	97	109	168	85	-	382	268
18	462	37	682	1509	946	35	266
1986							
8 Jan.	4363	-	638	1693	2184	1505	505
15	382	1106	940	1670	1626	1073	330
22	1126	455	302	828	690	2709	1909
29	1165	288	410	690	3442	1802	835
12 Feb.	-	1027	2499	1643	3633	4823	2880
5 Mar.	26126	900	821	3276	21476	18330	8614
12	12635	1090	1748	10219	8951	12561	6897
26	4832	1290	1892	3618	9029	-	6839
2 Apr.	6359	960	3096	8374	12760	7623	8195
9	24566	966	6158	5714	11180	9362	14375
16	7360	3872	4748	4050	10817	27118	6483
8 May	4608	12996	12632	7922	8008	16520	15408
14	7538	2776	3694	17069	5130	5171	6522
21	5247	7137	3154	8502	8327	19118	36312
28	22846	4111	11732	6257	5532	32040	41174
4 June	43512	8807	7892	16468	29256	21222	48600
11	7976	3352	17784	16017	7657	13010	8978
18	9781	4534	10388	9540	14615	12087	7663

Appendix Table 17. Acartia tonsa ABUNDANCE (animals m-3) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986)

STATION:	1	2	3	4	5	6	7
1985							
25 July	5245	6825	8738	14847	990	13653	17287
2 Aug.	7510	10978	7508	7524	13654	8833	14688
15	788	5234	6195	9209	-	2645	1205
22	701	6598	7327	2250	2371	2310	2925
28	1740	5878	4554	5512	2992	2079	5650
11 Sept.	3444	7476	3866	5330	3291	1670	1082
2 Oct.	24	238	957	574	291	720	1555
9	527	791	561	5260	1997	1036	1695
18	97	204	76	250	437	810	1155
23	63	308	31	1250	700	766	2303
30	326	712	108	1013	1254	994	2968
12 Nov.	1263	-	3654	2814	3840	652	1250
20	900	461	948	776	735	629	1694
4 Dec.	486	744	611	1755	-	2330	1788
18	1638	134	4090	5263	2475	520	1948
1986							
8 Jan.	2586	-	2174	1001	1352	1713	687
15	277	1089	729	774	535	640	748
22	537	1529	645	311	351	1131	1000
29	250	541	517	304	191	109	235
12 Feb.	-	471	190	111	48	319	66
5 Mar.	191	17	19	0	0	0	54
12	91	47	23	87	46	158	0
26	0	0	0	0	0	-	0
2 Apr.	0	0	0	0	0	51	0
9	0	0	0	0	0	0	0
16	58	0	0	0	0	0	0
8 May	0	0	0	0	0	0	96
14	0	46	0	0	0	0	0
21	0	0	88	0	0	0	0
28	174	0	142	47	0	0	692
4 June	0	0	0	179	212	162	600
11	251	259	342	0	494	0	169
18	889	356	212	720	1295	612	632

Appendix Table 18. COPEPOD ABUNDANCE (animals m-3) OTHER THAN *Acartia* spp. AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986)

STATION:	1	2	3	4	5	6	7
1985							
25 July	743	592	629	1010	135	1261	5625
2 Aug.	365	1802	864	627	762	1732	306
15	266	901	1115	2190	-	61	27
22	66	747	511	313	313	150	188
28	1015	1710	552	208	0	231	226
11 Sept.	616	1744	605	1365	477	254	66
2 Oct.	36	77	154	781	381	774	2141
9	303	283	222	1589	242	149	415
18	95	92	66	165	259	347	780
23	22	84	20	968	175	282	242
30	199	151	41	323	410	374	952
12 Nov.	450	-	863	1113	527	250	1057
20	96	449	768	328	62	52	219
4 Dec.	149	518	149	350	-	564	45
18	196	78	1192	1239	456	13	146
1986							
8 Jan.	444	-	348	127	390	208	101
15	39	313	282	145	150	155	154
22	118	418	124	92	72	158	0
29	62	264	167	235	143	109	193
12 Feb.	-	278	381	474	717	1001	894
5 Mar.	4402	519	860	1320	1638	2210	2407
12	907	1059	1104	2164	1285	948	1983
26	508	1686	1447	531	1254	-	1846
2 Apr.	3532	1523	5317	2686	2900	205	1178
9	9514	1792	2348	2482	3120	2637	920
16	1265	3202	1676	1274	727	2184	421
8 May	324	2622	1053	606	410	1239	1052
14	339	864	889	3131	1017	1131	377
21	477	769	525	296	530	1334	3738
28	1396	464	1564	901	432	4806	5882
4 June	3256	1196	1778	1790	1908	4374	2100
11	942	961	3078	3653	1235	749	763
18	1111	3644	2368	2700	1665	2754	1975

Appendix Table 19. BENTHIC LARVAE NUMBERS (m^{-3}) AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986)

STATION:	1	2	3	4	5	6	7
1985							
25 July	541	8/8	1324	386	121	19	1274
2 Aug.	182	1553	657	414	1299	1212	216
15	148	4808	1747	685	-	152	44
22	134	589	687	330	163	108	190
28	80	566	266	66	656	297	102
11 Sept.	93	436	186	268	230	95	134
2 Oct.	95	123	637	554	806	499	735
9	93	55	100	301	109	88	34
18	89	48	55	110	487	793	632
23	63	30	40	417	433	126	384
30	138	158	85	405	445	698	476
12 Nov.	467	-	251	315	629	167	279
20	38	25	72	168	75	63	230
4 Dec.	80	109	94	121	-	437	298
18	28	8	0	116	73	0	48
1986							
8 Jan.	4565	-	471	619	1066	6695	934
15	1175	1980	752	1452	2227	4671	814
22	1764	638	427	575	496	5076	10817
29	1165	473	593	749	1674	1438	1584
12 Feb.	-	819	595	586	478	1228	1125
5 Mar.	3447	521	573	1411	2184	1693	1124
12	727	365	391	1734	781	793	1198
26	177	297	509	304	564	-	485
2 Apr.	756	927	2366	1185	1885	0	237
9	7825	440	760	1030	1583	1466	345
16	2300	2498	2322	1002	1183	1092	168
8 May	3440	13988	3751	2252	2832	3236	2011
14	5430	4780	4251	12133	778	2306	116
21	1443	2394	4527	4806	2134	2603	3939
28	2626	7961	12963	12236	5580	4457	7447
4 June	4288	6096	11214	9680	5944	4701	1829
11	4097	2654	30528	12092	3955	2631	1875
18	5925	8942	18073	14965	8150	3534	2465

Appendix Table 20. BENTHIC LARVAE AS PERCENTAGE OF TOTAL ZOOPLANKTON ABUNDANCE EXCLUDING NAUPLII AND CTENOPHORES AT NARRAGANSETT BAY TRANSECT STATIONS (25 July 1985 - 18 June 1986)

STATION:	1	2	3	4	5	6	7
1985							
25 July	8.3	10.6	12.4	2.4	9.5	0.1	5.3
2 Aug.	2.2	10.8	7.3	4.8	8.0	8.6	1.4
15	12.9	44.0	19.3	5.7	-	5.4	3.5
22	16.0	7.4	8.1	11.4	5.7	4.2	7.0
28	2.8	6.9	5.0	1.1	18.0	11.4	1.7
11 Sept.	2.2	4.5	4.0	3.9	5.8	4.7	10.5
2 Oct.	61.3	28.0	32.9	41.5	67.9	39.2	25.6
9	10.0	4.8	11.3	4.2	4.6	6.8	1.5
18	29.8	13.4	27.5	20.6	41.2	40.5	24.6
23	39.1	5.6	40.8	15.4	31.5	9.7	12.6
30	18.9	14.8	35.6	22.7	20.6	31.6	10.8
12 Nov.	19.6	-	4.8	6.8	12.1	15.0	10.1
20	3.1	2.5	3.8	12.1	7.9	7.7	10.1
4 Dec.	9.9	7.4	9.2	5.2	-	11.8	12.4
18	1.2	3.1	0	1.4	1.8	0	2.0
1986							
8 Jan.	38.2	-	12.9	18.0	21.3	66.1	41.7
15	61.4	44.1	27.8	35.6	49.0	71.4	39.7
22	49.6	20.6	28.2	31.6	30.8	55.9	78.8
29	44.1	30.0	35.0	37.8	30.4	41.5	55.5
12 Feb.	-	21.4	15.9	26.3	9.9	16.4	22.7
5 Mar.	10.1	22.1	21.6	22.0	8.6	7.6	9.2
12	4.9	11.5	9.1	11.1	6.9	5.4	11.9
26	3.6	6.3	4.9	6.0	4.7	-	5.3
2 Apr.	6.5	16.9	14.3	7.8	6.4	0	2.2
9	18.6	12.9	7.1	9.0	9.3	9.7	2.2
16	20.9	25.1	22.6	13.3	8.3	3.6	2.3
8 May	40.7	47.2	21.5	20.8	25.2	15.4	10.4
14	40.8	56.3	48.0	36.6	11.1	26.7	1.7
21	19.8	22.5	54.2	34.5	19.3	11.3	8.8
28	9.6	62.2	48.2	62.1	46.9	9.9	12.7
4 June	7.8	36.5	48.7	25.4	14.4	13.6	3.4
11	25.9	33.1	46.5	26.7	10.7	13.0	14.5
18	26.7	46.0	41.5	36.7	25.9	7.4	13.4

Appendix Table 21. NUMERICAL ABUNDANCE OF THE CTENOPHORE <u>Mnemiopsis</u> <u>leidyi</u> (animals m-3) AT NARRAGANSETT TRANSECT STATIONS (25 July 1985 - 18 June 1986)

STATION:	1	2	3	4	5	6	7
1985							
25 July	10.2	3.8	5.8	3.0	14.0	2.6	1.5
2 Aug.	15.5	4.9	1.3	3.6	2.9	2.8	5.2
9	8.9	-	-	-	1.0	-	-
15	1.3	5.9	4.1	5.2	3.2	1.7	7.2
22	6.0	1.8	6.0	3.0	6.9	12.3	9.6
28	5.6	3.0	3.4	4.0	0.9	7.5	5.0
11 Sept.	6.5	8.9	4.5	3.3	1.7	0.4	0.8
2 Oct.	18.4	22.4	17.4	17.4	13.6	15.7	4.6
9	39.5	22.0	45.0	13.2	14.6	25.6	8.7
18	43.1	35.8	25.7	10.8	74.9	7.9	4.2
23	?	16.2	55.5	18.1	7.5	11.2	5.9
30	29.2	6.5	6.9	5.4	35.8	41.4	5.4
13 Nov.	?	?	?	?	?	?	?
20	1.7	1.6	2.6	1.6	1.5	0	0
4 Dec.	2.1	0.4	2.9	4.1	0.6	0.2	0.9
18	0.7	4.9	8.9	39.4	3.4	3.7	1.1
1986							
8 Jan.	2.5	?	8.0	?	?	0.3	0.4
15	0.24	4.0	2.0	1.1	?	?	?
22	4.5	2.2	13.4	12.2	4.8	2.0	1.5
29	0.89	5.0	4.1	0.7	1.4	1.2	2.54
12 Feb.	0.7	3.7	1.3	2.7	1.8	1.4	0.93
5 Mar.	0.3	0.08	0.1	0.32	0.05	0.16	0.07
12	0	0.04	?	0.15	0	0	0
26	0.07	0	0	0.08	0	?	0
2 Apr.	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0
8 May	0	0.04	0	0.06	0	0	0.13
14	0.12	0.04	0.07	0.03	0.05	0.07	0
21	0	0.08	0.26	0.14	0.1	0.38	0.46
28	0.04	0	0.47	0.54	0.1	0.07	0.07
4 June	0	0.04	0.08	0.07	0.05	0	0.07
11	0	0.04	0.08	0.03	0.1	0	0.89
18	0	0.07	0.38	0.22	0.05	0.07	0