Summary of

Massachusetts Water Resources Authority

Water Quality Workshop

held

May 23, 1996

hosted by

MIT Sea Grant

prepared by
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ms-40

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OVERVIEW

The Water Quality workshop summarized in this document was held to present 1995 water column monitoring data from the MWRA Harbor and Outfall Monitoring Program (HOM), and provide an initial forum to integrate results across the various disciplines. In addition, the agenda included a review of questions and hypotheses posed in the Phase II Post Discharge Monitoring Plan (November 30, 1995). To stimulate discussion, meeting participants were provided with "score cards" containing relevant hypotheses, warning levels and action levels used in the MWRA monitoring program. Each participant was asked to evaluate these hypotheses, comment on their validity, and offer suggestions.

After each scientific presentation and during the discussion session which followed, relevant issues, questions and suggestions raised by participants were considered. These were incorporated into a set of issues and recommendations which were then discussed at the Outfall Monitoring Task Force meeting held on May 31, 1996.

INTRODUCTION

The 1996 Water Quality Workshop was held at MIT on May 23, 1996. This workshop presented 1995 HOM monitoring data and compared these results to previous data. There were approximately 50 attendees, including MWRA personnel, regulators, academics, nonprofit environmental groups, and project scientists (see Appendix A).

Jerry Schubel (New England Aquarium) moderated the workshop and presented the overall goals and objectives of the workshop. Mike Mickelson (MWRA) provided an overview and discussed the goals of the MWRA monitoring program. Summaries of 1995 water quality data and comparisons to previous years were presented by project scientists. Comments on the MWRA monitoring program were then presented by the Cape Cod Commission (CCC). A final discussion session led by Jerry Schubel helped to streamline issues and comments posed by workshop participants.

The goals of the workshop were to:

- present and discuss 1995 monitoring data, and provide an initial forum for integration of results by project scientists prior to drafting the annual report;

- determine the adequacy of baseline data in understanding the physical, chemical, and biological dynamics of the Boston Harbor, Massachusetts and Cape Cod Bay ecosystems in order to evaluate the effects of the relocated outfall;

- evaluate existing monitoring parameters and determine if additional (or reduced) set of parameters should be measured;

- assess the adequacy of spatial and temporal coverage to meet the goals of the HOM monitoring plan;

- discuss appropriate indicators of change, definition of meaningful levels of change, and assessment endpoints for the Boston Harbor, Massachusetts, and Cape Cod Bay ecosystems;

- review current methodology and identify any monitoring, data analysis or data interpretation issues; and

- review the overall goals of the monitoring program and determine whether they are being attained.

One focus of this workshop was to reevaluate the hypotheses used in the monitoring program. Project scientists were tasked with discussing relevant hypotheses, whether these hypotheses are appropriate questions for evaluating the effects of the relocated discharge, and whether the draft MWRA post-discharge monitoring design will be able to answer these questions.

The workshop agenda, abstracts from each scientific presentation, Phase II hypotheses, and a summary of key points and discussion items are provided after this section. The list of participants is provided in Appendix A, written correspondence pertaining to the workshop is provided in Appendix B, and copies of overheads and graphics from the presentations are provided in Appendix C.

WORKSHOP AGENDA AND ABSTRACTS

MWRA Harbor and Outfall Monitoring (HOM) Workshops, Friday May 24, 1996

Coordinated by ENSR, hosted by MIT Sea Grant Office

at MIT, Civil and Environmental Engineering Building (Parsons Lab, Bldg. 48, Room 316)

EFFLUENT, FISH AND SHELLFISH WORKSHOP AGENDA

WELCOME AND INTRODUCTION 08:30 AM - 08:55 AM

08:30 AM Jerry Schubel, New England Aquarium (10 min)

08:40 AM Ken Keay, MWRA: Overview & goals of monitoring program (15 min)

PRESENTATIONS 08:55 AM - 10:30 AM

08:55 AM Effluent Characterization Studies in Massachusetts Bay- Eric Butler, ENSR (20 min)

09:15 AM Stable isotope measurements in Boston Harbor and Massachusetts Bay - Anne Giblin, MBL (15 min)

09:30 AM Histopathology and Chemistry of Flounder - Michael Moore, WHOI (20 min)

09:50 AM Lobster tissue burdens: current status and trends - David Mitchell, ENSR (20 min)

10:10 AM Caged mussel studies - Phil Downey, Aquatec (20 min)

DISCUSSION 10:30 AM - 11:30 AM

LUNCH (provided) 11:30 AM - 12:00PM

BENTHIC WORKSHOP AGENDA

WELCOME AND INTRODUCTION 12:00 PM - 12:40 PM

12:00 PM Jerry Schubel, New England Aquarium (10 min)

12:10 PM Overview and goals of monitoring program - Ken Keay, MWRA (30 min)

PRESENTATIONS 12:40 PM - 03:55 PM

12:40 PM Physical and biological processes in the nearfield area as revealed by sediment profile imaging - Donald Rhoads (20 min)

01:00 PM U.S. Geological Survey Sediment Studies, Mike Bothner, USGS (15 min)

01:15 PM Metals Chemistry - Gordon Wallace, UMB (20 min)

01:35 PM Sediment Organics - Eric Butler, ENSR (20 min)

01:55 PM Break (30 min)

02:25 PM Softbottom benthic infauna in Massachusetts Bay - Jim Blake and Brigitte Hilbig, ENSR (40 min)

03:05 PM Benthic nutrient flux - Brian Howes, WHOI (30 min)

03:35 PM Results of video surveys in the vicinity of the Massachusetts Bay outfall site - Barbara Hecker (20 min)

DISCUSSION 03:55 PM - 05:00 PM
ADJOURN 05:00 PM

Overview of transport processes and preliminary results of boundary mixing dye study

Rocky Geyer, Jim Ledwell and Brian Connolly

1. Overview

The first half of this presentation is an overview of the physical transport processses in Massachusetts Bay that will influence the new outfall plume, based on the Massachusetts Bays Program observations in 1990-1991 as well as the USGS/Hydroqual modeling studies. The key results of the observational studies are listed below.

Stratification: The water column is well-mixed from November to April and strongly stratified during the summer months. The stratification inhibits vertical mixing and decouples the motion of the surface waters from the deeper water. The stratification will trap the effluent between 10 and 20-m depths. Transport of nutrients into the euphotic zone will depend on vertical mixing and/or upwelling in the near-shore zone.

Horizontal transport. The time-average velocity at the new outfall is weak, but the fluctuations of 10 cm/s are adequate to disperse the effluent further into Massachusetts Bay, where it will be entrained into the southward-flowing mean circulation cell. The southward motion in the Bay averages 5 km/day, but it may increase to 20-30 km/day during northerly wind events.

Dilution. Initial dilution by the diffusers is approximately 100:1. Dilution is slightly inhibited by the stratification, but the combination of vertical and horizontal mixing causes dilution to 800:1 by about 10-15 km from the diffusers. (information courtesy of Rich Signell, USGS).

2. Dye studies in Massachusetts Bay

Dye studies were performed in Massachusetts Bay to determine the magnitude of vertical and horizontal mixing. One dye release was performed in the summer of 1993 to measure the dispersion rate in the vicinity of the new outfall. Another release was performed in the summer of 1995 near Scituate, to quantify the influence of boundary mixing.

In the 1993 study, Rhodamine dye was injected into the center of the thermocline in two horizontal streaks that formed an "x" near the Boston weather buoy. The vertical and horizontal distributions of dye were monitored for the next four days, using a towed, profiling fluorometer. The vertical diffusion rate was found to be 0.04-0.08 cm^2/s. This compares with an estimate of approximately 0.1 cm^2/s determined from seasonal variations in temperature. The slow rate of vertical mixing indicates that the nutrients within the plume will tend to remain submerged as they transit the Bay, unless upwelling carries them to the surface along the perimeter.

In the 1995 study, dye was injected into the thermocline where it intersected the bottom near Scituate. Again the dye was sampled on successive days to document its horizontal and vertical spreading. A strong upwelling event caused a convergence of thermocline water during the dye study. Estimates of the vertical mixing rate were not available in time for this abstract. An estimate will be provided in the talk, and the implications of boundary mixing and upwelling for the fate of the effluent will be discussed.

Dissolved Oxygen in Massachusetts Bay

by James D. Bowen

Abstract

A review of dissolved oxygen (DO) measurements taken during 1992-1995 in Massachusetts Bay indicates that in 1995, temporal patterns of bottom-water DO concentration were most similar to the previous year, although the minimum concentrations were not quite as low as they were in 1994. Dissolved oxygen concentrations were measured at every station during each of the 17 nearfield and 6 farfield surveys using a DO sensor attached to the CTD/Rosette sampler. On the upcast of the rosette sampler, water samples were taken for laboratory analysis of DO using Winkler titrations at 14 farfield and 6 nearfield stations. Dissolved oxygen concentrations measured in the laboratory were used to calibrate the DO sensor on a survey-by-survey basis.

In 1995, as in all previous years, the average DO concentration in the Nearfield region varied seasonally, with the maximum value occurring in April and the minimum occurring in late September to mid-October. During summer and early fall, when the water column was stratified, bottom-water dissolved oxygen concentration declined steadily and were always lower than surface values. The minimum dissolved concentration in all four years of sampling occurred near the end of the stratified period. In 1995, the minimum Nearfield average value of 6.6 mg/l occurred during the late September survey. This survey average value was approximately 0.4 mg/l higher than the corresponding value from the previous year.

An analysis of the Nearfield data from the stratified period indicates that three factors influence how low the DO will be at the end of this period. These three factors are: 1) the duration of stratified period, 2) the starting DO concentration, and 3) the rate of DO decline. Of these three, the rate of DO decline has been the most consistent, with an average value of 0.028 mg/l/d, and a maximum value of 0.031 mg/l/d. The starting DO concentration has been quite variable, with 1994 and 1995 starting values approximately 1 mg/l below the previous two years. Not surprisingly, these two years also had the lowest DO values at the end of the stratified period. During 1992-1995, the duration of the stratified period seems to be of intermediate importance in determining how low the DO gets by the end of the stratified period. An analysis of the measurements taken in Stellwagen basin indicates a temporal pattern and year-to-year variability that is similar to that of the Nearfield region.

Nutrient Dynamics in Massachusetts Bay during 1995

Theodore C. Loder III and Robert Boudrow, Estuarine/Coastal Chemistry Laboratory, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, NH 03824 603-862-3151 ted.loder@unh.edu

As part of the Massachusetts Water Resource Authority's ongoing monitoring program in Massachusetts Bays, 17 cruises were conducted during 1995 from February to December. Eleven of these cruises (Nearfield cruises) focused on the immediate area surrounding the soon to be completed offshore sewage outfall. Six cruises included the above Nearfield area as well as Farfield areas throughout the Massachusetts Bays region from just south of Cape Ann, to Stellwagen Bank and into Cape Cod Bay. On all these cruises numerous physical, chemical, and biological parameters were collected. Our work at the University of New Hampshire has centered around the measurement of nutrient concentrations (incl. nitrate, nitrite, ammonium, phosphate, silicate, total dissolved nitrogen and phosphorus, particulate phosphorus and biogenic silica) and their changes throughout the sampling period.

The data will be presented in several parts: 1. changes in nutrient distributions throughout the year in Massachusetts Bays using nutrient/depth trends, nutrient/salinity trends, and nutrient/nutrient relationships; 2. seasonal nutrient trends at the Nearfield stations only, using both average surface, mid and bottom data as well as date-depth-concentration color contour plots showing seasonal trends with depth for averaged inner Nearfield stations (N11, N10) and outer Nearfield stations (N04, N05, N06, N07); 3. a comparison of nutrient changes in the Nearfield region over the past several years using the seasonal nutrient trend plots.

By the first cruise in early February, 1995 nutrient concentrations in the surface waters (down to 20-30m) of Massachusetts Bays had already begun to diverge. The highest values for all nutrients were found in Boston Harbor(BH) and along the coast(COA) which correlated with lower salinity; similar mid-level values were found in the Nearfield(NF), boundary(BOU) and offshore(OFF) regions, and slightly reduced values in all Cape Cod Bay(CCB) samples due to the early spring bloom there. By early March surface values further diverged following the February trends while deep water values dropped slightly. The nutrient patterns in early April were similar to those in early March except that nitrate values had decreased slightly at depth while ammonium values had increased at depth probably due to initial bloom remineralization. In late June all surface water nutrients at all locations were very low while near bottom values were still near those observed in the early spring. For both the August and October cruises, most of the surface values remained low, although high concentrations were observed in the BH and COA regions for ammonium and phosphate and to a lesser extent for nitrate and silicate, due to mixing of outfall waters into the Nearfield region. During this time period, the deep concentrations reached their maximum annual values (especially for nitrate and silicate). Although the DIN to phosphate relationship in October was very tight and had a slope of 16:1, plots of nitrate an ammonium vs. phosphate showed very strong bifurcation due to mixing of two separate water types (BH and BOU) in the Nearfield region. This bifurcation was also observed for the nutrients when plotted vs. salinity. By early December, the Nearfield water column was vertically well-mixed, although the influence of the high nutrient BH water could been seen at several of the stations down to a depth of ca. 30 m.

In order to present seasonal changes in the Nearfield region we have used nutrient averages as well as actual data, where appropriate. Annual trend plots are presented for averaged surface plus mid-surface data, middle depth data, and averaged mid-bottom plus bottom samples for all the dissolved nutrients. Although there was considerable variability in the averaged surface values, they diverged from the mid and bottom values during the March period and converged in early December at a slightly lower concentration after fall vertical mixing had occurred. Concentrations of all the nutrients except ammonium continued to increase slightly as more nutrient rich (and higher salinity) GOM water moved through the Nearfield region and Massachusetts Bays.

These overall trends were similar for all dissolved nutrients, although the times for minimum and maximum bottom water values differed between the nutrients. The minimum bottom values occurred in late February/early March for silicate, mid-May for nitrate+nitrite and phosphate, and in December for ammonium. These bottom water concentrations all increased during the summer months, reaching a maximum in early/mid September, except for ammonium which reached its maximum in early August. This was followed by a temporary decrease in all nutrients during a fall bloom in early October. Differential rates of nutrient regeneration and removal in the bottom waters caused late fall (November) average concentrations to be higher for nitrate+nitrite, the same for phosphate and lower for silicate than the late summer (September) values. Dissolved inorganic nitrogen (DIN - nitrate + nitrite + ammonium) to phosphorus ratios (DIN/P) showed that both surface and bottom waters were much lower than Redfield ratios of 16:1, ranging from ca. 12:1 during the winter to ca. 1-4:1 during the summer months. Even though the slope of the data was often close to 16:1, the intercept phosphate value was ca. 0.4 so that the actual ratio values were lower than 16:1. This suggests that these waters are depleted in nitrogen relative to phosphorus throughout much of the year. The DIN:Si ratios remained between 0.2 to 2 throughout almost the entire year with higher values during the winter and low values during the late spring and summer reflecting the impact of the early spring diatom blooms and the slow return of the dissolved silicate to the water column. Finally, a comparison of the Nearfield annual average trend plots with previous years indicates that there is significant inter annual variability, especially during the spring and fall seasons.

Phytoplankton Production in Massachusetts Bay During 1995

Craig D. Taylor and Brian L. Howes
Woods Hole Oceanographic Institution, Woods Hole Ma 02543

Phytoplankton production and water column respiration were measured at 4 and 5 stations, respectively, during the Massachusetts Water Resource Authority's (MWRA) ongoing monitoring program in the Massachusetts Bay region. Stations were visited 6 or 17 times throughout 1995. 14-C Production was determined at various light intensities on samples obtained at 5 depths throughout the euphotic zone. The resulting photosynthesis vs. light intensity (P vs. I) relationships, measurements of light attenuation with depth and incident light time series measurements were used to determine daily depth-dependent and areal production. Annual production in the nearfield (stations N04, N07, N16) was characterized by an increasing trend in production from 300 - 500 mgC/m2/d in Feb. - Apr. to between 1000 - 2500 mgC/m2/d in the summer period followed by decreases back into the 300 - 500 mgC/m2/d range in the winter months. At the outfall station (N16) this general trend was punctuated by an intense short duration bloom in late April that constituted 20% of total annual production. The 7-fold increase in production was not, however, observed at the Northeastern and Southeastern corner stations (N04 and N07, respectively), which suggests fairly short range (3 km) spatial heterogeneity in the region. Chlorophyll data for the same stations reflected similar patterns. Station N16 exhibited a 7-fold increase in chlorophyll biomass over levels found on either side of the bloom, while increases at station N04 were 1.9-fold, paralleling the 1.9-fold increase in measured activity. Chlorophyll at station N07 was similar to slightly higher than that found at station N04, but associated activity was missed by the low temporal resolution time series conducted for that station. Continued inspection of average photic zone chlorophyll indicated a short duration and intense fall bloom that, unlike the spring bloom was evident in all of the Eastern nearfield stations. Parallel increases in measured production, however, was not evident due to cloudiness on the day of sampling.

Given the way the production measurements are computed it is possible to experimentally manipulate the incident light field over the course of the day to determine the effect upon areal production. When a cloudless daily light field was substituted for the light field of the day of sampling, a measure of the maximum or "potential" areal production was obtained. When this was performed on the data, the fall bloom became a dominant feature of annual production. It is of interest to note that for station N16, 15% and 34% of "potential" annual production are encompassed by the spring and fall blooms. That is, potentially 50% of the year's production can result from bloom events occurring over time periods encompassing less than 16% of the annual cycle. Though somewhat of an exaggeration because not all days are sunny, the example does illustrate that in the Massachusetts Bay environment major portions of annual production can occur during abrupt and spatially heterogeneous blooms. Low temporal resolution sampling can easily miss these events, as was the case for station N07, where both the spring and fall bloom events were missed by the 6 point time series study.

Phytoplankton Dynamics in Massachusetts and Cape Cods Bays - 1995

Stephen J. Cibik
ENSR

The MWRA Harbor and Outfall Monitoring Program includes analysis of the phytoplankton community in Boston Harbor, Massachusetts Bay, and Cape Cod Bay during 17 surveys conducted from February to December. Both quantitative and taxonomic analyses were performed during 1995, continuing the monitoring record begun in 1992.

The objective of these analyses is to evaluate the potential effects of the 1998 relocation of the Deer Island discharge to its future discharge site in Massachusetts Bay. This evaluation focuses on the potential alteration in biomass or community structure that may result from the stimulatory effects of nutrient enrichment, or possibly from inhibitory effects due to effluent toxicity. Additionally, these data can support assessments of the phytoplankton community's effect on water clarity or color.

The 1995 nearfield data showed a successional pattern which included a delayed spring bloom (late April vs. March), several summer maxima, and a fall bloom. In most cases these peaks were numerically dominated by small (<10 μm) flagellated species. However, carbon equivalence estimates for the taxa present during these peaks indicated that diatom species contributed the greatest biomass (up to 97 percent of estimated carbon). Dominant taxa during these peaks included *Chaetoceros* and *Thalassiosira* spp. (spring), *Skeletonema costatum*, *Rhizosolenia fragilissima*, and *Leptocylindrus danicus* (summer periods), and *Asterionellopsis glacialis* (fall).

These multiple peaks were reflected in previous years, however such comparisons illustrate the considerable inter-annual variability which can occur in both abundance and seasonal distribution. In addition to the inter-annual differences exemplified by the delayed spring bloom, the fall nearfield bloom of *Asterionellopsis* occurred three weeks earlier in 1993, and was not reported at all during 1994.

Regionally, the 1995 record demonstrated a large gradient across the nearfield (i.e., between samples taken at N10 and N16), and large-scale differences between the nearfield and Cape Cod Bay. Although dominated early in the year by diatoms, Cape Cod Bay became dominated by small flagellates by mid-June, both numerically and in terms of estimated carbon biomass. As well, fluorometry data suggested that the phytoplankton community in Cape Cod Bay may have been in decline by the first survey, indicating the spring bloom occurred much earlier there.

Chlorophyll results for the 1992 to 1995 baseline period were evaluated against the hypotheses contained in the Draft Post-Discharge Monitoring Plan. Hypotheses based upon annual mean chlorophyll concentrations may not be sensitive enough to evaluate significant effects from short-term events. For example, large blooms of *Asterionellopsis* occurred in the nearfield during 1993 and again in 1995, resulting in average chlorophyll concentrations during the event of up to 10 μg/L and single-sample results of 21 to 22 μg/L. Despite the magnitude of these short-term events, the annual average for these two years differed from the non-bloom year of 1994 by no more than 0.4 μg/L.

It is recommended that the chlorophyll hypotheses be re-evaluated to encompass seasonal phenomena in order to test the effect of the discharge on these episodic events. Such an effect may be manifested as either increased (or decreased) biomass, or possibly by prolonged duration of the event. This evaluation should be linked to a carbon pathway assessment to determine whether enhanced biomass production is utilized by primary consumers, or contributes to oxygen deficits through microbial decomposition.

Harmful and Nuisance Algal Species

Donald M. Anderson
Woods Hole Oceanographic Institution

One of the concerns regarding the new MWRA outfall is that changes in nutrient loading will result in the stimulation of harmful or nuisance algae. In Massachusetts and Cape Cod Bays, several species which are known to cause harm or are toxic do occur (e.g. *Pseudo-nitzschia pungens, Pheocystis pouchetii, Dinophysis* spp., *Ceratium* spp.), but only the toxic dinoflagellate *Alexandrium tamarense* reaches concentrations which cause recurrent problems. *Alexandrium* populations within the bays are thought to originate from cells advected from the north in a buoyant coastal current. Entry into the bay is regulated by the timing of wind vents in relation to the patchiness of the *Alexandrium* populations within the coastal current. Thus, in some years, there is no toxicity whatsoever from *Alexandrium* within the bays, whereas other years the toxicity can be quite high. This talk will describe what is known about the mechanisms regulating the abundance of *Alexandrium* within Massachusetts Bay, with special emphasis on the degree of variability in the observed toxicity. This variability is of particular interest because of the need to document changes above baseline levels that might be attributed to the outfall.

This presentation will also describe the extent to which other harmful or nuisance algae occur within the bays and are detected by the monitoring program. A significant issue is the inability of any monitoring program to distinguish between morphologically similar strains or species which can either be toxic or non-toxic. Another concern is the patchiness of these blooms in both space and time and the ability of the monitoring program to adequately characterize them at a level of accuracy needed for the detection of long-term changes.

Abundance of Zooplankton in Boston Harbor and the Bays Region - 1995

Cabell S. Davis, Ph.D.
Woods Hole Oceanographic Institution

The zooplankton assemblage of the Bays region is characterized by two species groups: those that have affinities for nearshore areas (i.e., Harbor/Coastal species) and those that are prevalent in offshore waters (including the boundary region and Cape Cod Bay). The nearfield region represents a transition zone between the offshore and nearshore areas, with station N16 species composition similar to the offshore assemblage and station N10 having a nearshore character.

It is well-known that the nearfield species (eg. Acartia spp.) require high concentrations of food for population growth, thus food limitation restricts their distributions. A potential change in species composition at the nearfield site could occur if the outfall caused strong eutrophication in this region. In such a case it is possible that the nearshore species would become dominant in the nearfield region, displacing the offshore species assemblage. Since most of the zooplankton species are warm-water species, this displacement would likely be most pronounced in summer and fall.

Only two species are dominant during the winter/spring period, the cold-water copepods Calanus finmarchicus and Pseudocalanus newmani. These species occur in lower abundance in the Harbor/Coastal region and do not appear to do well under eutrophic conditions. These two species are the dominant prey of the Right whales which come into the Bays region during Feb-May to feed. Calanus and Pseudocalanus both store oil in sacs in their bodies and it is this oil that transfers, together with any associated toxic contaminants, to the whale blubber. Eutrophication of the nearfield region could cause a reduction in the relative abundance of Calanus and Pseudocalanus and thus a loss of Right Whale prey. Such reduction of prey in the nearfield region alone would likely have little effect on the whale feeding ground as a whole since most of the feeding occurs in Cape Cod Bay. Extensive eutrophication (which is unlikely) could reduce Calanus and Pseudocalanus abundance in farfield areas during winter/spring and shift the summer/fall species composition toward the coastal assemblage dominated by Acartia.

Although it was previously reported that Oithona similis was the most important member of the zooplankton because of its high abundance, when the body size of the various species are considered, the largest copepod, Calanus finmarchicus, is found to dominate the zooplankton biomass. Because this species occurs during winter/spring, its high biomass and growth rates imply that it is a dominant grazer of phytoplankton during the first half of the year. Calanus grazing could potentially account for the observed lower phytoplankton and chlorophyll concentrations at that time.

In summary, during the winter/spring period, eutrophication could cause reduction in Calanus and Pseudocalanus abundance in the nearfield region, reducing right whale food availability. The reduced Calanus abundance would result in a major loss of copepod biomass and could in turn decrease the grazing pressure on the phytoplankton during the first half of the year. Unless the eutrophication was extensive, the right whale food supply is not likely to be affected since the whale feed primarily in Cape Cod Bay. Eutrophication of Cape Cod Bay (highly unlikely) would be devastating. During summer/fall, eutrohpication could cause a shift from offshore to nearshore species assemblage. Species shifts should be detectable above natural variablity since the current geographic affinities of the species are pronounced.

PHASE II WATER COLUMN HYPOTHESES

Table 3.1 Hypotheses to be tested during Phase II of the MWRA Outfall Monitoring Program *(continued).*

WATER COLUMN

Dissolved oxygen - Nearfield Bottom Waters

W1: The seasonal rate of dissolved oxygen decrease in bottom waters (>20 m) of the nearfield area during the summer (July to October) will not increase more than a factor of two relative to the average rate during the baseline period.

W2: Average dissolved oxygen concentrations in the nearfield bottom water will not be depleted below 6.5 mg/L or 80% saturation for more than one month during the summer.

W3: The annual mean dissolved oxygen concentration in the nearfield bottom water will not change by more than one standard deviation relative to the baseline period for any three consecutive year period.

Dissolved oxygen - Farfield

W4: The seasonal rate of dissolved oxygen decrease in water below 50 m in Stellwagen Basin between June and October will not increase by more than 2 times the average rate during the baseline period.

W5: Average dissolved oxygen concentrations in the deep waters (>50 m) in Stellwagen Basin will not be depleted below 6.5 mg/L and 80% saturation for more than one month during the summer.

Table 3.1 **Hypotheses to be tested during Phase II of the MWRA Outfall Monitoring Program *(continued).***

WATER COLUMN

Chlorophyll a *- Nearfield*

W6: The annual mean chlorophyll *a* concentration in the nearfield region will not exceed 12 μg/L.

W7: The annual mean chlorophyll *a* concentration in the nearfield will not increase more than two times the baseline condition for any three consecutive year period.

W8: The relative standard deviation (coefficient of variation) of the annual mean chlorophyll *a* concentration in the nearfield will not increase more than twice the baseline conditions for any three consecutive year period.

W9: The annual pattern in the chlorophyll *a* concentration will not change from the baseline conditions.

W10: The annual average nearfield chlorophyll *a* concentration will not increase by more than 20% per year for any three consecutive year period.

W11: The variability in the area based annual mean photic zone chlorophyll *a* concentration in the nearfield will not increase more than a factor of two from the baseline mean or change its seasonal pattern.

Chlorophyll a *- Regional*

W12: The annual mean chlorophyll *a* concentrations in the Massachusetts and Cape Cod Bay System (all depths) will not exceed of 12 μg/L.

W13: The annual mean chlorophyll *a* concentration in the Massachusetts and Cape Cod Bay System will not increase more than two times the baseline average for any three consecutive year period.

W14: The relative standard deviation (coefficient of variation) of the mean annual chlorophyll *a* concentration in the Massachusetts Bay system will not increase more than twice the baseline condition for any three consecutive year period.

W15: The variability in the area based annual mean photic zone chlorophyll *a* concentration in the Massachusetts Bay system will not increase more than a factor of two from the baseline mean or change its seasonal pattern.

Table 3.1 **Hypotheses to be tested during Phase II of the MWRA Outfall Monitoring Program *(continued).***

WATER COLUMN

Contaminants

W16: Initial mixing will not be different than predicted in the NPDES permit.

Nuisance Algae

W17: The abundance of nuisance algae* will not increase by more than ten times the annual baseline mean for any three consecutive year period.

W18: The frequency of nuisance algae* occurrence in the Massachusetts Bay system will not increase relative to that observed during the baseline period.

W19: The algae community will not become dominated by nuisance algae*.

* *Alexandrium tamarense, Ceratium, Dinophysis, Gymnodinium, Gyrodinium, Heterocapsa triquetra, Heterosigma akashiwo, Prorocentrum. Protoperidinium,* and *Phaeocystis pouchetti.*

Pseudonitschia

COMMENTS FROM WORKSHOP DISCUSSION SESSION

After each scientific presentation and in the general discussion session in the afternoon, workshop participants discussed issues, questions, and comments relevant to the water quality monitoring program. The main themes from these discussion sessions are highlighted below.

MAJOR TOPICS FROM DISCUSSION SESSIONS:

Dissolved Oxygen

- Existing conditions occasionally violate state DO standards; therefore, DO standards need to be reevaluated based on existing conditions (potential establishment of site-specific DO standard based on baseline data).

- Two out of the five MWRA hypotheses have already been rejected; therefore, the DO hypotheses need to reevaluated.

- DO and stratification can be evaluated relative to meteorology and river flows.

- An operational definition of "bottom waters", "Stellwagen Basin" and "summer" with respect to depth of measurements, location, and time of year needs to be established.

- A doubling in DO rate of decline is not stringent enough as a standard.

- Averaging DO over time or space masks the DO minima which deserve more attention.

- The time scale of interest for DO (months vs. diurnal) needs to be confirmed.

- There is a need to improve the ability to predict DO declines based on modeling and existing baseline data.

Nutrients, Productivity and Respiration

- The hypothesis for nitrogen loading refers to an annual average. Several participants questioned whether there is a shorter-term pattern that might be of ecological concern.

- Remineralization is an important consideration. This process might be explained with a simple one dimensional model.

- Several participants suggested to integrate and link the DO, phytoplankton and carbon results and hypotheses.

- Metabolic measures give a better indicator of carbon flow through the system than static biomass measures.

- Under the future outfall scenario, the discharge will occur in the subsurface; therefore, nutrients will be trapped and accumulate below the pycnocline. A primary concern is whether these stored nutrients combined with an upwelling event would enhance productivity and result in a large bloom event.

- Primary production is dependent on many variables. Therefore, it is important to use the productivity-biomass-light model when interpreting the data. A suggestion was made to use Craig Taylor's model to predict productivity during non-monitoring periods using continuously recorded light data presently being collected.

- Previous data show that 25% of the total annual production can occur in one month. Therefore, sampling frequency should be optimized during bloom events and stratified periods. The sampling schedule could be modified to be more event-oriented.

Chlorophyll and Phytoplankton

- The averaging scheme in the chlorophyll hypothesis is not sensitive enough to capture ecosystem effects. According to some participants, the proposed annual mean of 12 ug/L chlorophyll is not protective and may lead to very low DO. An alternative would be to relate a hypothesis to the chlorophyll level expected from a specified increase in N load.

- A suggestion was made to develop seasonal chlorophyll hypotheses for each region to capture short term increases in chlorophyll.

- Moorings may be a useful tool to supplement monthly surveys and measure short-term phenomenon (such as bloom events) between surveys.

Nuisance algae

- The nuisance species list should include only *Alexandrium*, *Phaeocystis*, and *Pseudonitszchia*.

- Since existing monitoring will rarely find *Alexandrium*, MWRA should increase reliance on external data sources such as state PSP monitoring and special studies focusing on enumerating *Alexandrium*. State PSP data could be used to craft a hypothesis.

- The use of annual means does not capture the variability in blooms and could allow one large bloom during a certain time period to be overlooked.

- There was general dissatisfaction with the concepts underlying the 3 hypotheses presented by MWRA. The speaker pointed out that a 10x increase in abundance outlined in one of the hypotheses would not be protective.

Zooplankton

- If the zooplankton portion of the monitoring is driven by concern over impact to whales, the sampling should address the zooplankton community grazed by whales and the whale's grazing areas. Potential nearfield impacts should be related to significant whale feeding areas.

- A hypothesis should be developed to address any potential changes in trophic levels.

- Linkage needs to be made between phytoplankton and zooplankton in terms of carbon flow and utilization.

GENERAL COMMENTS AND QUESTIONS:

- Baseline monitoring should continue. Long data sets are valuable, but it may be appropriate to scale back in some areas and work on integrating the data that have already been collected. Efforts should be focused on detecting "predicted change" rather than on "endpoints" which are often arbitrary. Hypotheses can then be expressed in relation to the expected impact.

- Would super-hypotheses be useful?

- Hypotheses must be revised, especially those for DO and chlorophyll.

- It may be possible to cluster hypotheses which have obvious overlap and create "capstone" hypothesis for each cluster. Hypotheses should be created which cross programmatic lines.

- Linkages should be developed between hypotheses to integrate results and analysis of nutrients, chlorophyll, DO, and carbon.

- Should the sampling frequency be optimized during bloom and stratified periods?

- More time should be spent on data and information synthesis and interpretation.

- There is general support for running the Bays Eutrophication Model (BEM) for recent years; however, one dimensional and other simple models are also extremely useful and should be utilized.

- Carbon and nitrogen based numerical ecosystem models could be a useful tool for synthesizing data.

- There is a need for data dissemination and quicker turnaround of data.

APPENDIX A

Workshop Attendance

APPENDIX A

Attendance at the MWRA workshops

5/23/96 all day Water Quality	5/24/96 A.M. Effluent; Fish	5/24/96 P.M. Benthos	Name	Affiliation
X		X	Adams, Eric	MIT
X			Anderson, Don	WHOI
X			Anderson, Steve	Anderson & Kreiger
X	X	X	Benaway, Heather	UNH
X	X	X	Blake, Jim	ENSR
	X	X	Boehm, Paul	ADL
X			Bollens, Steve	WHOI
X			Borkman, Dave	URI
	X	X	Bothner, Mike	USGS
X	X	X	Boudrow, Rob	UNH
X			Bowen, Jim	UNC
X			Bridges, Leigh	MDMF
	X	X	Butler, Eric	ENSR
X	X	X	Butman, Brad	USGS
X			Cambareri, Tom	CCC
X	X		Carlisle, Bruce	MCZM
X	X	X	Chen, Bob	UMB
X			Cibik, Steve	ENSR
X			Coniaris, Cathy	UNH
X			Connelly, Brian	WHOI
X	X	X	Connor, Mike	MWRA
X			Daley, Patty	CCC
	X	X	Downey, Phil	Aquatec
	X	X	Estrella, Bruce	MDMF
	X	X	Fredette, Tom	COE
X	X	X	Gallagher, Gene	UMB
X		X	Galya, Don	ENSR
X			Geyer, Rocky	WHOI
	X	X	Giblin, Anne	MBL
X	X	X	Gould, Diane	MCZM
	X	X	Grob, Elizabeth	MCZM
X	X	X	Hall, Maury	MWRA
	X	X	Hecker, Barbara	Hecker Envir.
		X	Hilbig, Brigitte	ENSR
X	X	X	Ho, Nancy	APCC

x		x	Howes, Brian	WHOI
x	x	x	Hunt, Carlton	Battelle
	x	x	Ika, Ravi	Harvard
x			Isaac, Russell	MA DEP
x	x	x	Jaworski, Norbert	EPA
x	x	x	Keay, Ken	MWRA
x			Kelly, Jack	Battelle
		x	Kropp, Roy	Battelle
		x	Krueger, Elaine	MA DPH
x			Lacouture, Richard	ANS
x	x	x	Liebman, Matt	EPA
x	x	x	Loder, Ted	UNH
	x	x	MacLean, Sharon	NMFS
x	x		Malone, Tom	U MD
x			Mayo, Stormy	CCS
x	x	x	McCarthy, Susan	ENSR
	x	x	Menzie, Charlie	MCA
x	x	x	Mickelson, Mike	MWRA
	x	x	Mitchell, David	ENSR
	x	x	Moore, Michael	WHOI
x	x	x	Pederson, Judy	MIT
x	x	x	Redlich, Susan	WWAC
	x	x	Rojko, Alice	DEP
	x	x	Rhoads, Don	SAIC
x	x	x	Schubel, Jerry	NEAq
	x	x	Schwartz, Jack	MDMF
x	x	x	Shine, Jim	Harvard
x	x	x	Studer, Marie	MCZM
x			Sung, Windsor	Sung Assoc.
x		x	Taylor, Craig	WHOI
x	x	x	Taylor, Dave	MWRA
	x	x	Testaverde, Sal	NMFS
x			Tomey, Dave	EPA
x			Trowbridge, Phil	MDPH
	x	x	Tucker, Jane	MBL
x	x	x	Wallace, Gordon	UMB
		x	Watling, Les	U Maine
x			Zavistoski, Becky	ENSR

APPENDIX B

Written Correspondence pertaining to Workshop

HORN POINT
ENVIRONMENTAL
LABORATORY

University of Maryland System
Center for Environmental
and Estuarine Studies

Office of the Director

May 28, 1996

Dr. Jerry R. Schubel
President
New England Aquarium
Central Whart
Boston, MA 02110

Dear Jerry:

As promised, here is a summary of my thoughts on the draft of *"Massachusetts Water Resources Authority (MWRA) Effluent Outfall Monitoring Plan: Phase II Post Discharge Monitoring"* and on the presentations given as part of the water quality workshop on 23 May, 1996. As I indicated during discussions with you, Mike Mickelson, and others, a talented group of scientists are involved in the program. They have accomplished a lot in the last three years, and the timing is right to invest in a major effort to integrate and synthesize the data collected to date. As you and others suggested, this should be done in a comparative context (historically for the Harbor-Mass Bay region and with respect to other coastal embayments).

In my opinion, much of the current MWRA monitoring program would be better funded (by the MWRA or other agencies) as special projects based on peer reviewed proposals. Thus, the integration-synthesis effort should, among other things, quantify scales of variability and trends, identify key baseline variables (diagnostic and predictive) to be monitored, and define the temporal and spatial resolution required to quantify the effects of the outfall when it goes into operation. The distinction between monitoring (to quantify variability and trends) and special studies (to determine the causes of varibility and trends) becomes important here in the sense that successful monitoring requires a long-term commitment to making the right measurements on the right time and space scales while special studies require the clear definition of relevant problems that can be solved in a specific period of time (e.g., 1-3 years). I think there are two key aspects to this: (1) developing a positive feedback between research and monitoring; and (2) producing a product that engages the public and elected officials in ways that are meaningful to them. The rationale is presented in more detail in the proceedings of the Sarasota Workshop.

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(410) 221-8406 Voice; (410) 221-8473 Fax; (410) 228-8200 General

An important theme of the Phase II plan is the implementation of measurement programs that will allow "early detection of unacceptable change" through the monitoring of variables that are expected to be most sensitive to stressors in terms of both time (early warning) and the propagation of effects through the ecosystem (unacceptable change). As part of the integration-synthesis effort, quantitative definitions of both "early warning" and "unacceptable change" need to be formulated (that are not "shopping lists" variables and organisms to be monitored). The current focus on endpoints is not consistent with either of these goals, i.e., will not allow a proactive approach to be implemented. I believe that there are four additional gaps in the current program (based on what was presented at the workshop and what is in the draft phase II plan):

(1) Hypotheses need to be developed that go something like "If the effluent meets NPDES criteria, then . . ." with the "then" being some quantitative statement concerning expected effects of the outfall based on conceptual, statistical, or numerical models.

(2) Carbon- and nitrogen-based, ecosystem models are needed to quantify expected time scales of first order responses to perturbations (associated with the effluent discharge) and of the propagation of these responses through the ecosystem. The USGS model will be an important part of this and the development of annual carbon and nitrogen budgets will provide a framework for quantifying expected near- and far-field effects. Numerical ecosystem models are needed to interface between the results of monitoring and special projects (e.g., data on state variables can be feed directly to the model and special projects can help define important linkages and rate parameters). This will be critical to the synthesis and interpretation of data on complex systems, to the identification of critical variables for monitoring (through sensitivity analysis and studies of the effects of aggregation on the propagation of variability through the system), to the prediction of changes, and to early warning.

(3) A significantly greater effort is and will be needed for data management and synthesis. In addition to quality control, investigators and agencies (and models) need to have more rapid access to data and the visualization and interpretation of data.

(4) Finally, based on our current understanding of coastal dynamics, I believe that the goal of becoming proactive will require both high resolution times series and spatially synoptic measurements of temperature, salinity, dissolved oxygen, and chlorophyll and rapid access to and visual presentations of these data for scientists, environmental agencies, and the public. Although weather predictions often leave a lot to be desired, the relationship between climate monitoring and research and daily weather reports and forecasting is the best model in town.

Clearly the MWRA does not have the funds needed to launch a full scale interactive research and monitoring program. But the opportunity is there to use a well designed monitoring program to leverage funds for special projects (e.g., the Chesapeake Bay monitoring program was an important factor in obtaining funding for the Chesapeake Bay LMER and Exploratory Ecosystem Research Center). The CENR and organizations such as NAML and CORE are backing efforts to establish coordinated and integrated coastal monitoring-research programs (e.g., coastal GOOS and CoOP). The MWRA effort should be a part of this, both in helping to make it happen and in its regional implementation.

That's it in a nutshell. I hope you find my thoughts of some value.

Sincerely,

Thomas C. Malone
Director

cc: Mike Mickelson

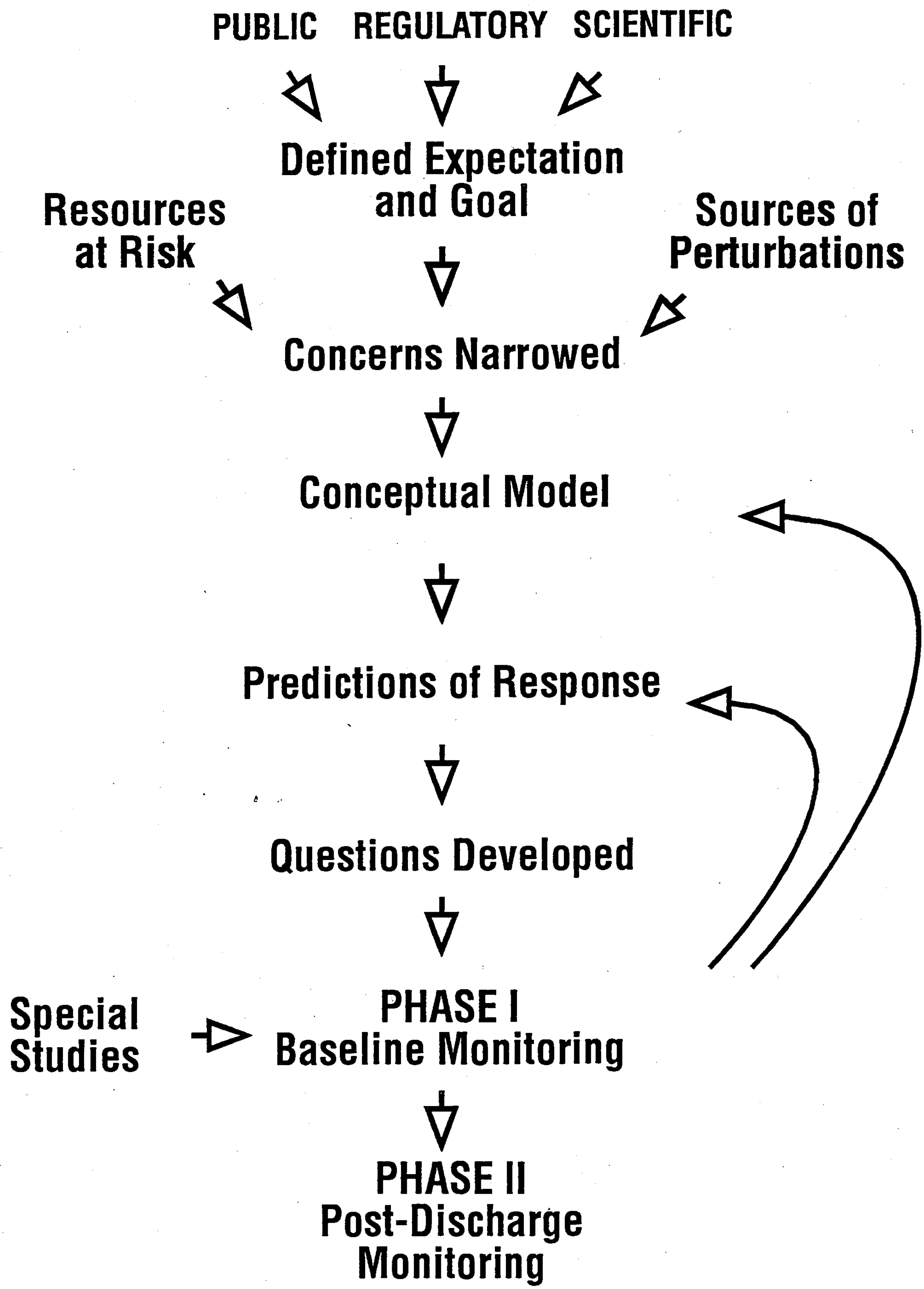
APPENDIX C

Overheads and Graphics from Presentations

APPENDIX C-1

Mike Mickelson
MWRA

MWRA Monitoring Plan Development



MWRA Harbor and Outfall Monitoring Program - History

1978 - 1985	301h waiver period: waiver denied
1986 - 1988	STFP/ Outfall siting studies
1989 - 1991	Preliminary Monitoring and research
1991 - 1992	Monitoring plan development
1992 - 1998	Baseline Monitoring
1994	Monitoring Plan revisions
1996	This workshop
1998 - ongoing	Outfall Phase II monitoring

Monitoring Program Goals

Phase I (baseline pre-discharge monitoring)

- Test for compliance with future NPDES permit.
- Test whether the impact of the discharge is within the bounds predicted by EPA's SEIS.

Phase II (discharge monitoring)

- Test for compliance with future NPDES permit.
- Test whether the impact of the discharge is within the bounds predicted by EPA's SEIS.
- Measure change within the system such that exceedence of defined warning thresholds is detected with sufficient warning to to implement contingency plans (management action) that prevent exceedence of unacceptable (endpoint) conditions.

		Biological components								Special habitats and life					Envir. quality	
		Phyto-plankton	Zoo-plankton	Fish eggs/ larvae	Pelagic fish	Demersal fish	Comm-ercial shellfish	Soft-bottom benthos	Hard-bottom benthos	Attached macro-algae	Submrgd aquatic vegetation	Marsh/ wetlands	Marine mammals	Marine/ estuarine birds	Water quality processes	Human health factors
MWRA Outfall	Nutrient loading	● / ●○ / ●	● / ●○ / ○	● / ●○ / —	● / ● / —	○ / ●○ / —	○ / ●○ / ○	● / ●○ / ●	● / ● / ○—						● / ● / ●	○— / ●○ / ●
MWRA Outfall	Carbon loading		○ / ● / —	?	○ / ● / —	●○ / ●○ / ○—	● / ● / ●○	● / ●○ / ●○	?						○ / ●○ / ●○	
MWRA Outfall	Suspended solids	● / ● / ●	○ / ● / ○	?			○ / ● / ○	●○ / ● / ●○	○ / ● / ○						● / ●○ / ●	
MWRA Outfall	Toxic chemicals	○ / ● / —	○ / ● / —	○ / ● / —	○ / ● / —	●○ / ●○ / ○	● / ● / ○—	○ / ●○ / ○	?				○— / — / —	○— / ●— / ○—	○ / ● / ○	● / ●○ / ●
MWRA Outfall	Pathogens or disease			○ / ●○ / ○	●○ / ●○ / ●○	●○ / ●○ / ●○	●○ / ●○ / ●○	○— / ●○ / —	?				○— / — / —	○— / ●— / ○—	?	● / ●○ / ●
	Other waste-water	● / ●○ / ●	●○ / ●○ / ○—	○ / ● / —	○ / ● / —	○ / ● / —	●○ / ● / ●○	●○ / ● / ●○	○— / ● / —	●○ / ● / ○	●○ / ● / ●	○ / ● / ○			● / ●○ / ●	● / ● / ●
	Storm-water runoff			○ / ● / —		○ / ● / —	○ / ● / ●	○ / ● / ○		○ / ● / ●○	○ / ● / ●○	○ / ● / ○			● / ● / ○—	○ / ● / ●○
	Fringing habitat loss			○ / ● / —	○ / ●○ / —	○ / ●○ / —	○ / ● / ○	○ / ●○ / —		○ / ● / —	○ / ● / ○	● / ● / ●		●○ / ●○ / ●○	?	?
	Dredging	● / ● / ○—	● / ● / ○—	?	?	?	● / ● / ○	● / ● / ○—	○ / ● / —		○— / ● / ○—				● / ● / ●	○— / ● / —
	Dredge disposal					○— / ● / ○—		● / ● / ●							○ / ● / ○	
	Accidental spills	● / ● / —	● / ● / —	● / ● / —		?	?	?	?	?	?	?	?	?	● / ● / ○—	?
	Fishing pressure				● / ○— / ●○	● / ○— / ●○	● / ●○ / ●						?	?		
	Exotic species/ invasion	?	?	?	?	?	?	?	?	?	?	?	?	?	?	
	Hydrologic changes (rivers)	● / ●○— / ○	● / ●○— / —	?	?	?					● / ● / ●	●○ / ● / ○—	?	?	○ / — / ○	
	Global climate change	● / — / ?	● / — / ?	● / — /	●○ / — / ?	●○ / — / ?	?	?	?	?	● / — / ●○—	● / — / ●○—	?	?	● / — / —	

	Potential influence on component.	Spatial scale of concern.	Probable utility of component as an indicator.
High, or local.	●	●	●
Medium, or mesoscale.	○	○	○
Low, or regional.	—	—	—

	Effluent	Water column	Benthos	Fish and shellfish
Nutrient loading	Nutrients	DO Chlorophyll Nuisance algae		
Carbon loading	BOD	DO	RPD; Community structure	
Suspended solids	TSS	(measured)		
Toxic chemicals	Toxics Toxicity	(Water quality criteria)	Sediment quality criteria	Tissue burden Flounder health
Pathogens or disease	Pathogens			
Aesthetics	Floatables Oil and grease	(anecdotal)		

Confirm initial mixing

Water Column Monitoring

Perturbations of Concern:

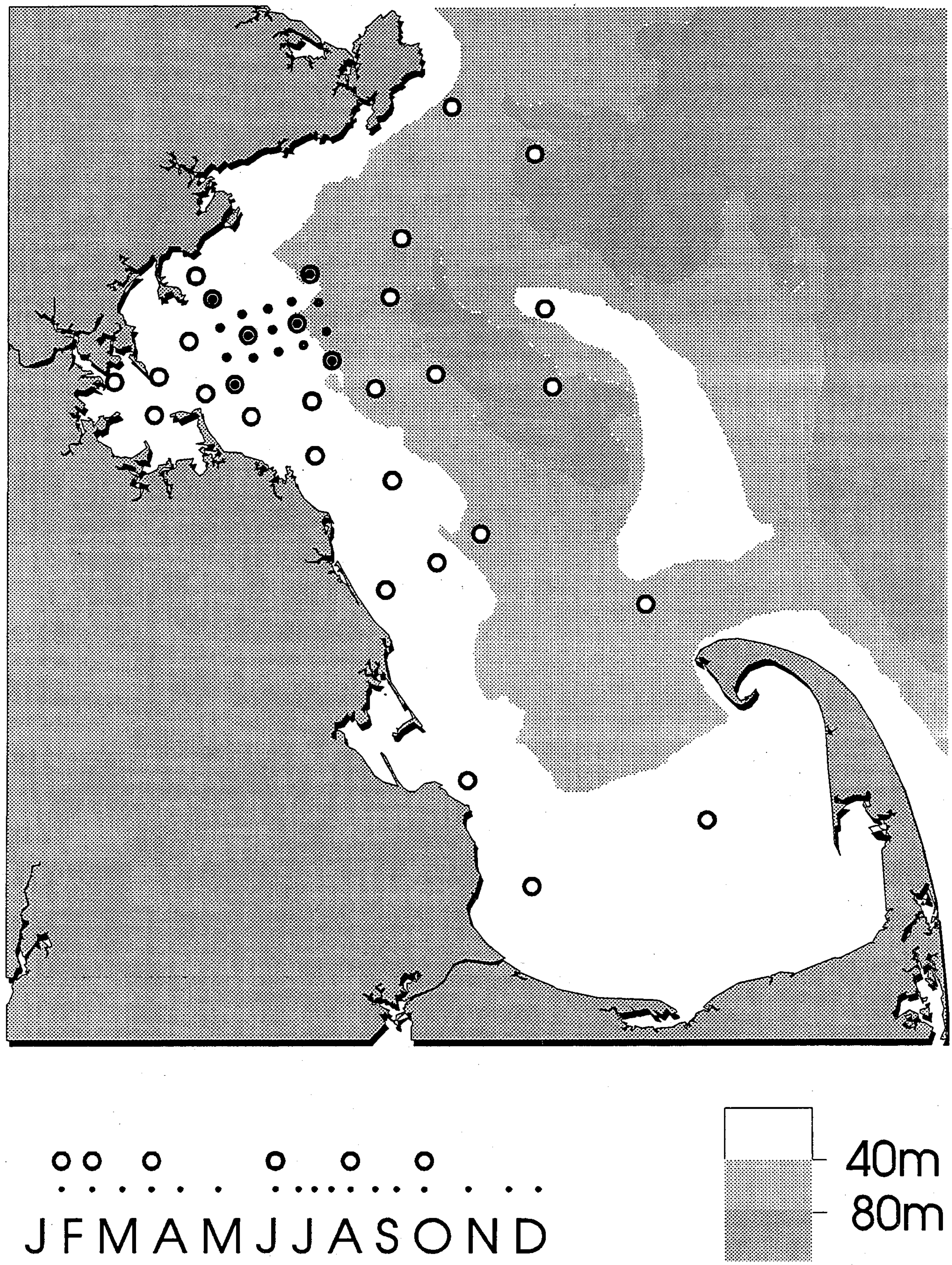
R3 Primary production increase.
R5 DO decrease.
R7 Plankton community change.
R15 Visible algal blooms.

	Hypotheses/warning levels	**Action levels**
W1	DO rate of decline over summer will not double (i.e. 2X baseline). (Nearfield bottom waters; July to October)	
W2	DO will not remain below 6.5 mg/L or 80% saturation for 30 consecutive days. (Survey mean nearfield bottom waters)	6 mg/L or 75% saturation
W3	DO will not remain below baseline by more than 1 standard deviation for 3 consecutive years. (Annual mean nearfield bottom waters)	
W4	Same as W1. (Stellwagen Basin waters below 50m; June to October)	
W5	Same as W2. (Survey mean Stellwagen Basin waters below 50m)	6 mg/L or 75% saturation
W6	Chlorophyll will not exceed 12 μg/L. (Annual mean nearfield)	15 μg/L
W7	Chlorophyll will not double and remain high for 3 consecutive years. (Annual mean nearfield)	
W8	Chlorophyll annual variability will not double and remain high for 3 consecutive years. (Nearfield)	
W9	Chlorophyll seasonal pattern will not change. (Nearfield)	
W10	Chlorophyll will not grow by more than 20% per year for 3 consecutive years. (Annual mean nearfield)	
W11	Same as W8 and W9. (Nearfield euphotic chlorophyll).	
W12	Same as W6. (Annual mean farfield)	15 μg/L
W13	Same as W7. (Annual mean farfield)	
W14	Same as W8. (Farfield)	

W15	Same as W11. (Farfield euphotic chlorophyll)	
W16	Initial mixing will comply with NPDES permit.	
W17	Nuisance algae will not be 10 times as abundant for 3 consecutive years. (Nearfield, farfield)	
W18	Nuisance algae will not occur more frequently. (Nearfield, farfield)	
W19	Nuisance algae will not dominate the algal community. (Nearfield, farfield)	

	Measurement program	Speaker
W16 (initial mixing)	Plume tracking when outfall is on-line. Special study of cross-pycnocline transport (in 1993 and 1995). Ongoing USGS studies of water and sediment processes.	Geyer
W1-W3 (nearfield DO) W4-W5 (Stellwagen DO)	Surveys: 17/yr at 17 nearfield stations. Measurements of DO and related parameters (water stratification, biomass, respiration, and productivity). Surveys: 6/yr at 3 Stellwagen Basin stations and 23 other stations. Measurements as above excluding productivity.	Bowen
none	Inorganic nutrient measurements at every station; particulate and organic forms of carbon, nitrogen, phosphorous, and silicon at 20 stations.	Loder
none	Primary productivity at 5 depths. Four stations 6/yr and 2 stations 11/yr.	Taylor
W6-W11 (nearfield chlorophyll) W12-W15 (farfield chlorophyll)	Nearfield Surveys: 17/yr at 17 stations for chlorophyll and related parameters; ~~11~~ 2 stations for phytoplankton at 2 depths. Farfield Surveys: 6/yr at 26 stations for chlorophyll and related parameters; 11 stations for phytoplankton at 2 depths.	Cibik
W17-W19 (nuisance algae)	Same as W6-W15 (see Cibik). Special study of transport of red tide organism through the Bays	Anderson
none	Zooplankton collected by oblique net tow at 2 nearfield stations 17/yr and at 11 farfield stations 6/yr.	Cibik

Water Quality Monitoring 1996



Summary of perturbations of concern identified in the MWRA (1991) draft Phase I monitoring plan.

Public Concern: is it safe to eat fish and shellfish?

Perturbation: Toxics

R-1 Will toxic chemicals accumulate in edible tissues of fish and shellfish, and thereby contribute to human health problems?

Perturbation: Pathogens

R-2 Will pathogens in the effluent be transported to shellfishing areas where they could accumulate in the edible tissue of shellfish and contribute to human health problems.

Public Concern: Are natural/living resources protected?

Perturbation: Enrichment

R-3 Will nutrient enrichment in the water column contribute to an increase in primary production?

R-4 Will enrichment of organic matter contribute to an increase in the benthic respiration and nutrient flux to the water column?

R-5 Will increased water-column and benthic respiration contribute to depressed oxygen levels in the water?

R-6 Will increased water-column and benthic respiration contribute to depressed oxygen levels in the sediment?

R-7 Will nutrient enrichment in the water column contribute to changes in plankton community structure (species composition, biomass, and vertical distribution)?

R-8 Will benthic enrichment contribute to changes in the community structure (species composition and biomass) of soft-bottom and hard-bottom macrofauna, possibly also affecting fisheries?

Summary of perturbations of concern identified in the MWRA (1991) draft Phase I monitoring plan. (Continued)

Perturbation: Toxics

R-9 Will the water column near the diffuser mixing zone have elevated levels of some contaminants?

R-10 Will contaminants affect some size classes or species of phytoplankton and thereby contribute to changes in community structure (species composition, biomass, and vertical distribution) and/or the marine food web?

R-11 Will finfish and shellfish that live near or migrate by the diffuser be exposed to elevated levels of some contaminants, potentially contributing to adverse health in some populations?

R-12 Will the benthos near the outfall mixing zone and in depositional areas further away accumulate some contaminants?

R-13 Will benthic macrofauna near the outfall mixing zone be exposed to some contaminants, potentially contributing to changes in community structure (species composition and biomass)?

Public Concern: Is it safe to swim?

Perturbation: Pathogens

R-14 Will pathogens in the effluent be transported to waters near swimming beaches, contributing to human health problems?

Public Concern: Are esthetics being maintained?

Perturbation: Visual degradation

R-15 Will changes in water clarity and/or color result from the direct input of effluent particles or other colored constituents, or indirectly through nutrient stimulation of nuisance plankton species?

R-16 Will loading of floatable debris (e.g., plastics) increase, contributing to visual degradation?

Presentation: "Overview and goals of monitoring program" by Mike Mickelson

	Hypotheses/warning levels	Action levels
E4	Total nitrogen load will not exceed 12,500 mt/yr	14,000 mt/yr

Perturbations of concern: Are natural/living resources protected?

- R3 Primary production increase.
- R4 Benthic respiration and nutrient flux increase.
- R5 DO decrease.
- R6 RPD decrease.
- R7 Plankton community change.
- R8 Benthic community change.
- R15 Visible algal blooms.

Measurement program:

Routine NPDES sampling.

1994-95 special study involving detailed breakdown of nutrient speciation in effluent.

Presentation: "Boundary mixing dye study - preliminary results" by Rocky Geyer

	Hypotheses/warning levels	Action levels
W16	Initial mixing will comply with NPDES permit.	

Perturbations of concern: Are natural/living resources protected?

R3 Primary production increase.

R5 DO decrease.

Measurement program:

- Plume tracking when outfall is on-line.
- Special study of cross-pycnocline transport (in 1993 and 1995).
- Ongoing USGS special studies of water and sediment processes.

Presentation: "Physical and chemical monitoring results" by Jim Bowen

	Hypotheses/warning levels	Action levels
W1	DO rate of decline over summer will not double (i.e. 2X baseline). (Nearfield bottom waters; July to October)	
W2	DO will not remain below 6.5 mg/L or 80% saturation for 30 consecutive days. (Survey mean nearfield bottom waters)	6 mg/L or 75% saturation
W3	DO will not remain below baseline by more than 1 standard deviation for 3 consecutive years. (Annual mean nearfield bottom waters)	
W4	Same as W1. (Stellwagen Basin waters below 50m; June to October)	
W5	Same as W2. (Survey mean Stellwagen Basin waters below 50m)	6 mg/L or 75% saturation

Perturbations of concern: Are natural/living resources protected?
R5 DO decrease.

Measurement program:

Nearfield Surveys: 17/yr at 17 stations. Measurements of DO and related parameters (water stratification, biomass, respiration, and productivity).

Farfield Surveys: 6/yr at 3 Stellwagen Basin stations and 23 other stations. Measurements as above excluding productivity.

Presentation: "Nutrient transfer" by Ted Loder

	Hypotheses/warning levels	Action levels
	none	

Perturbations of concern: Are natural/living resources protected?

R3 Primary production increase.
R5 DO decrease.
R7 Plankton community change.
R15 Visible algal blooms.

Measurement program:

Inorganic nutrient measurements at every station; particulate and organic forms of carbon, nitrogen, phosphorous, and silicon at 20 stations.

Presentation: "Productivity and respiration" by Craig Taylor

	Hypotheses/warning levels	Action levels
	none	

Perturbations of concern: Are natural/living resources protected?

R3 Primary production increase.
R5 DO decrease.
R15 Visible algal blooms.

Measurement program:

Primary productivity at 5 depths. Four stations 6/yr and 2 stations 11/yr.

Presentation: "Phytoplankton dynamics" by Steve Cibik

	Hypotheses/warning levels	Action levels
W6	Chlorophyll will not exceed 12 μg/L. (Annual mean nearfield)	15 μg/L
W7	Chlorophyll will not double and remain high for 3 consecutive years. (Annual mean nearfield)	
W8	Chlorophyll annual variability will not double and remain high for 3 consecutive years. (Nearfield)	
W9	Chlorophyll seasonal pattern will not change. (Nearfield)	
W10	Chlorophyll will not grow by more than 20% per year for 3 consecutive years. (Annual mean nearfield)	
W11	Same as W8 and W9. (Nearfield euphotic chlorophyll).	
W12	Same as W6. (Annual mean farfield)	15 μg/L
W13	Same as W7. (Annual mean farfield)	
W14	Same as W8. (Farfield)	
W15	Same as W11. (Farfield euphotic chlorophyll)	

Perturbations of concern: Are natural/living resources protected?

R7 Plankton community change.

R15 Visible algal blooms.

Measurement program:

Nearfield Surveys: 17/yr at 17 stations for chlorophyll and related parameters; 11 stations for phytoplankton at 2 depths.

Farfield Surveys: 6/yr at 26 stations for chlorophyll and related parameters; 11 stations for phytoplankton at 2 depths.

Presentation: "Toxic and potentially harmful phytoplankton species in Massachusetts and Cape Cod Bays" by Don Anderson

	Hypotheses/warning levels	Action levels
W17	Nuisance algae will not be 10 times as abundant for 3 consecutive years. (Nearfield, farfield)	
W18	Nuisance algae will not occur more frequently. (Nearfield, farfield)	
W19	Nuisance algae will not dominate the algal community. (Nearfield, farfield)	

Perturbations of concern: Are natural/living resources protected?

R7 Plankton community change.

R15 Visible algal blooms.

Measurement program:

Nearfield Surveys: 17/yr at 17 stations for chlorophyll and related parameters; ~~11~~ 2 stations for phytoplankton at 2 depths.

Farfield Surveys: 6/yr at 26 stations for chlorophyll and related parameters; 11 stations for phytoplankton at 2 depths.

Special study of transport of red tide organism through the Bays

Presentation: "Zooplankton Dynamics" by Steve Cibik (for Cabell Davis)

	Hypotheses/warning levels	**Action levels**
	none	

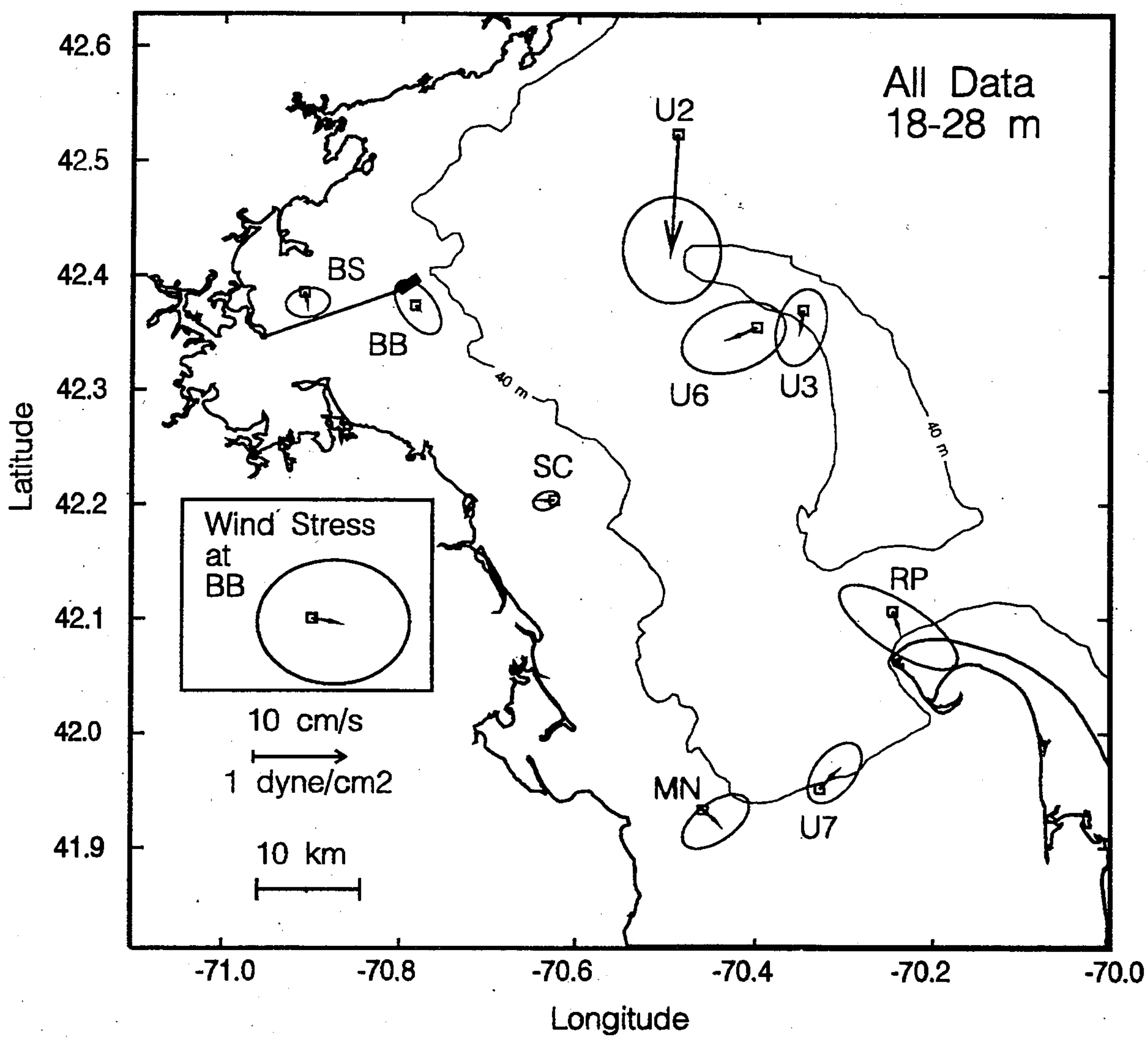
Perturbations of concern: Are natural/living resources protected?
R7 Plankton community change.

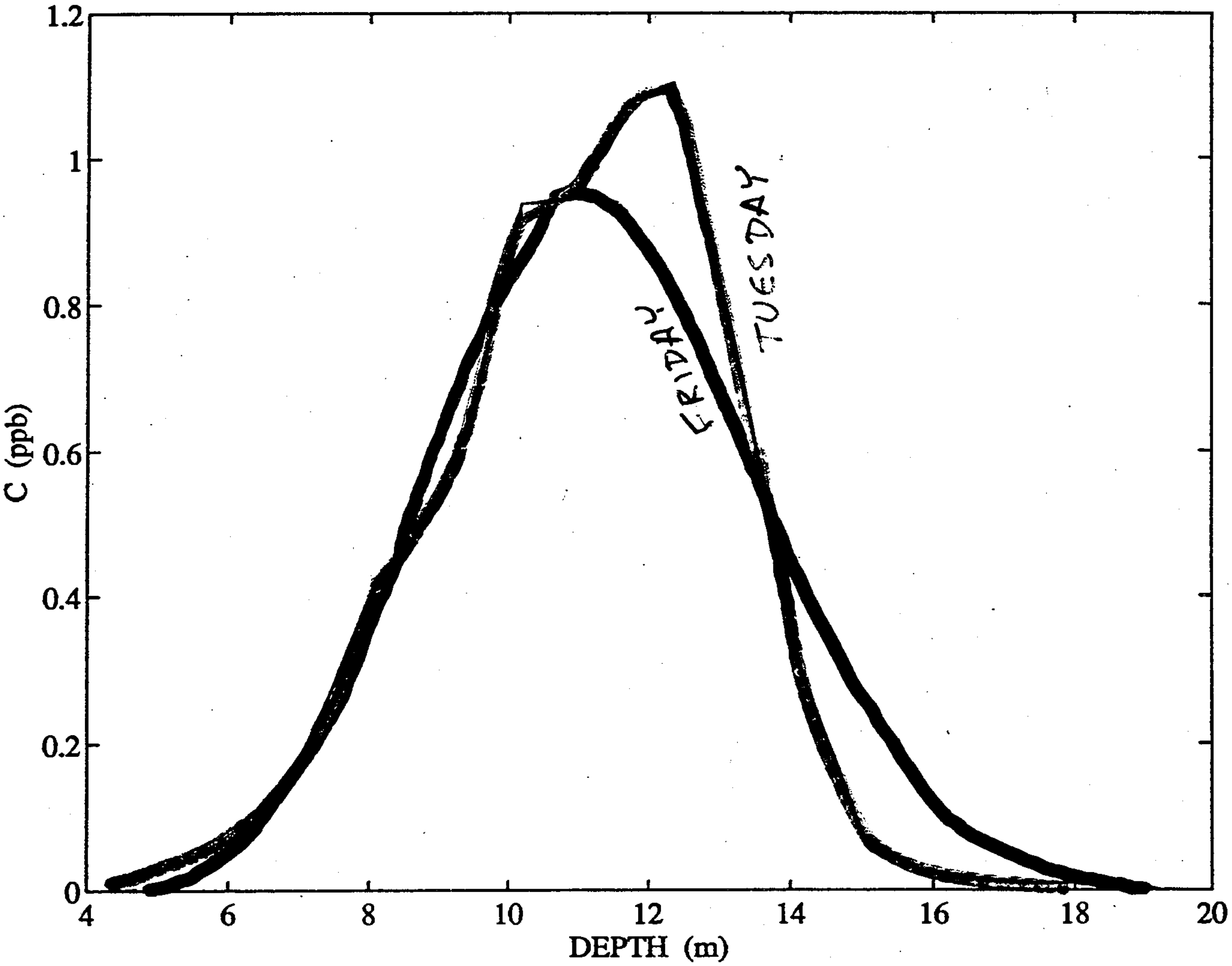
Measurement program:
Zooplankton collected by oblique net tow at 2 nearfield stations 17/yr and at 11 farfield stations 6/yr.

APPENDIX C-2

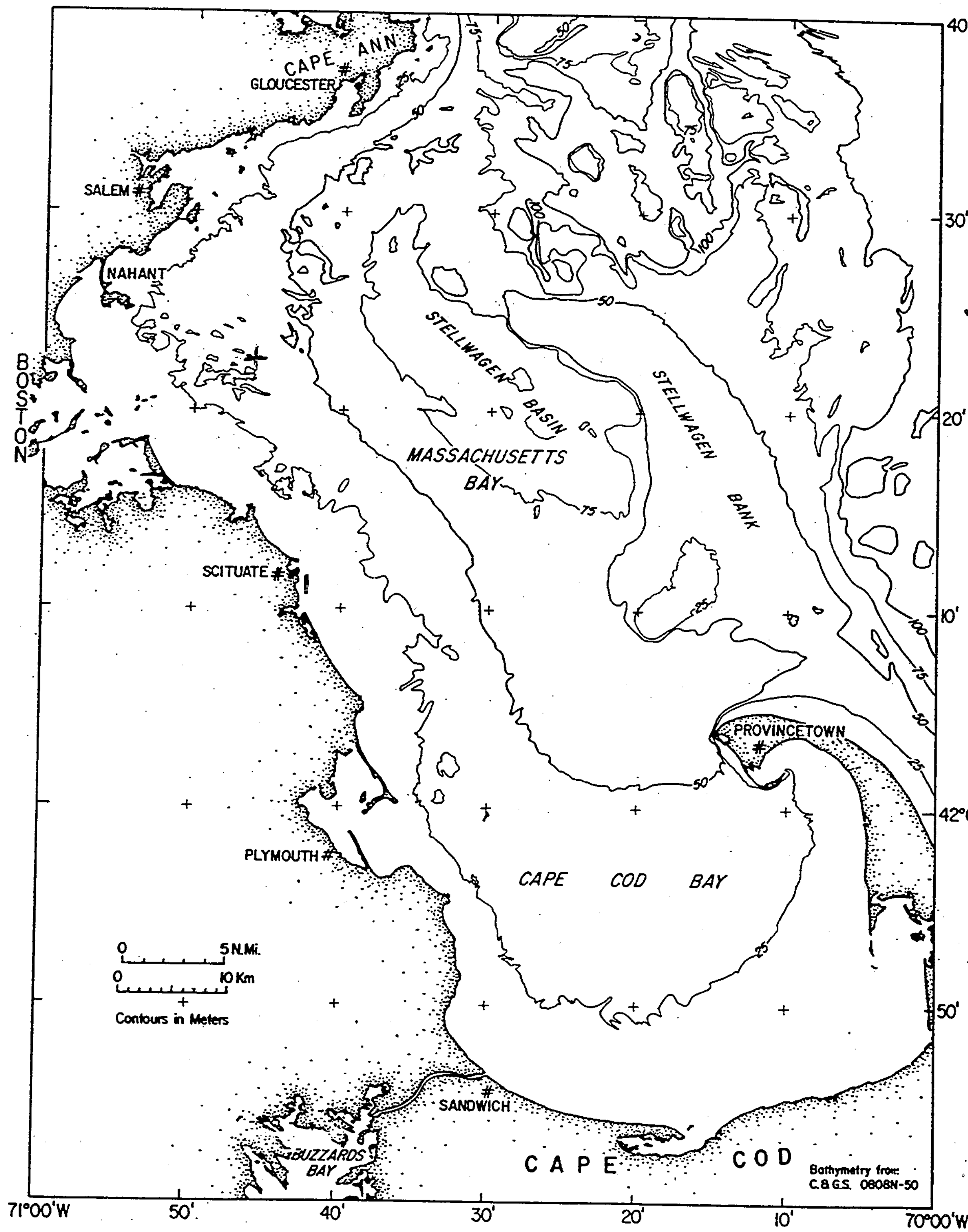
Rocky Geyer
WHOI

OBSERVED MID-DEPTH MEAN AND LOW-FREQUENCY FLOW (DECEMBER 1989 - SEPTEMBER 1991)





1.2
1
0.8
0.6
0.4
0.2
0
C (ppb)
4
6
8
10
12
14
16
18
20
DEPTH (m)
FRIDAY
TUESDAY


CAPE ANN
GLOUCESTER
SALEM
NAHANT
BOSTON
STELLWAGEN BASIN
STELLWAGEN BANK
MASSACHUSETTS BAY
SCITUATE
PROVINCETOWN
PLYMOUTH
CAPE COD BAY
SANDWICH
BUZZARDS BAY
CAPE COD
0 5 N.Mi.
0 10 Km
Contours in Meters
Bathymetry from: C.&G.S. 0808N-50
40'
30'
20'
10'
42°00'N
50'
71°00'W
50'
40'
30'
20'
10'
70°00'W

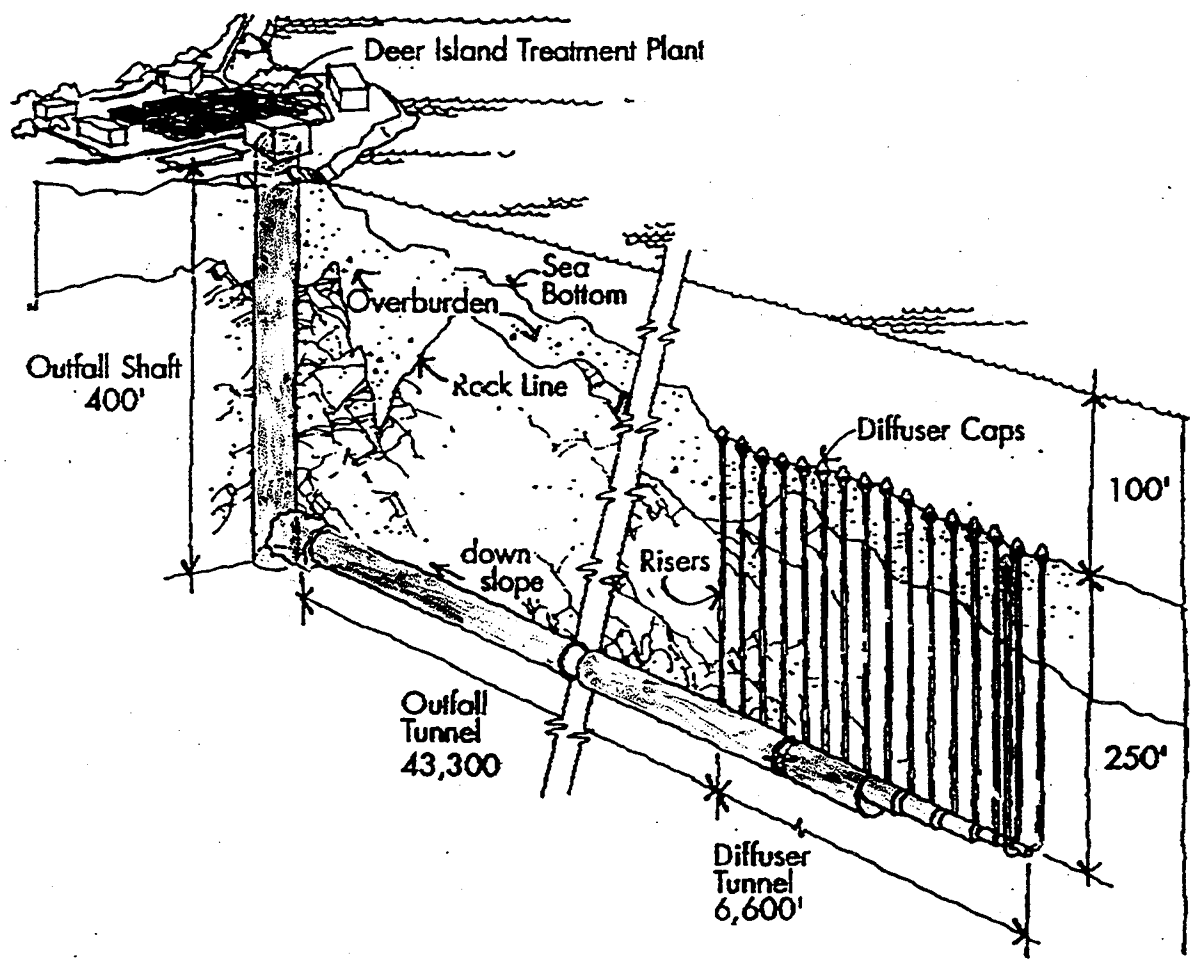
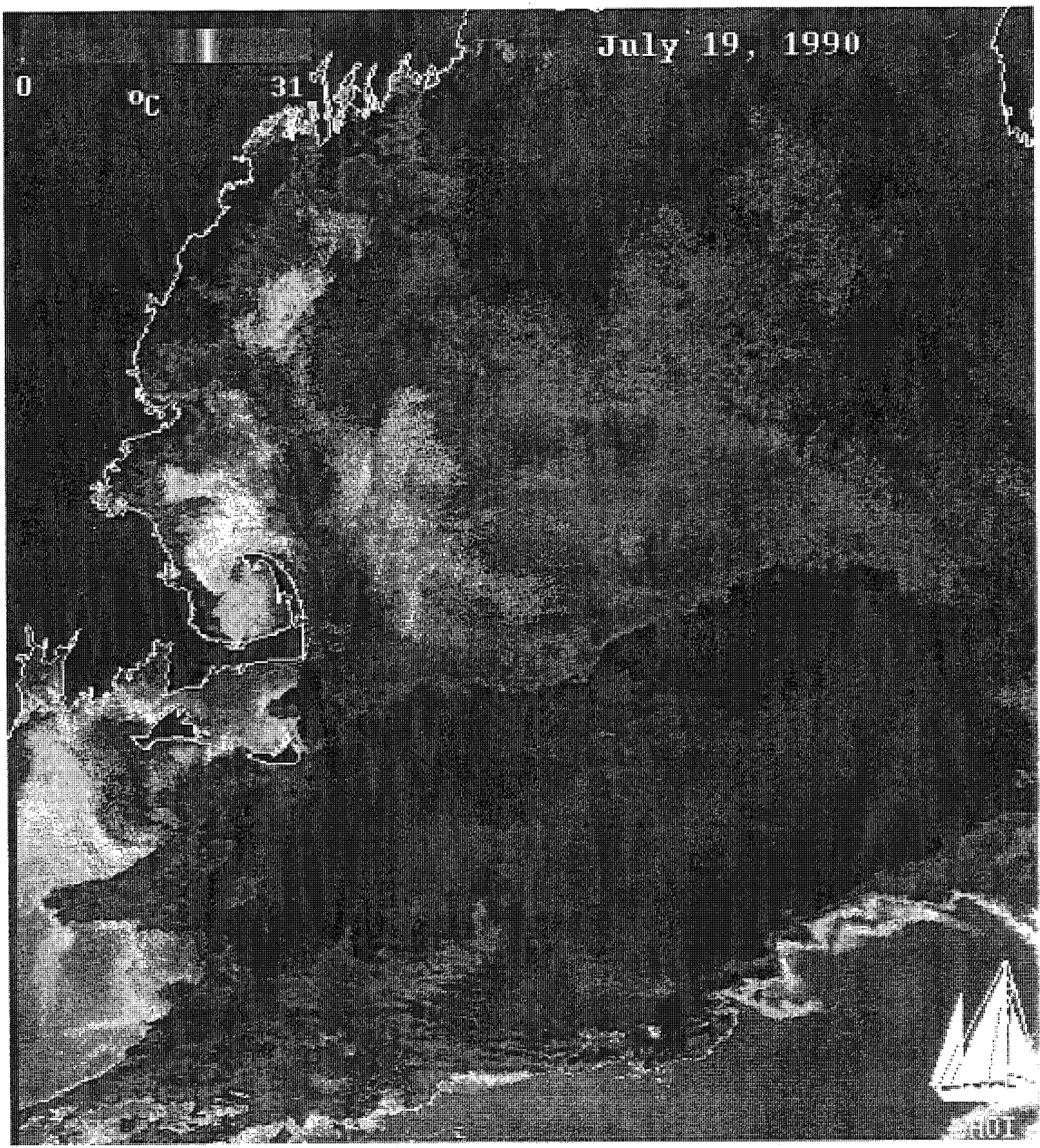
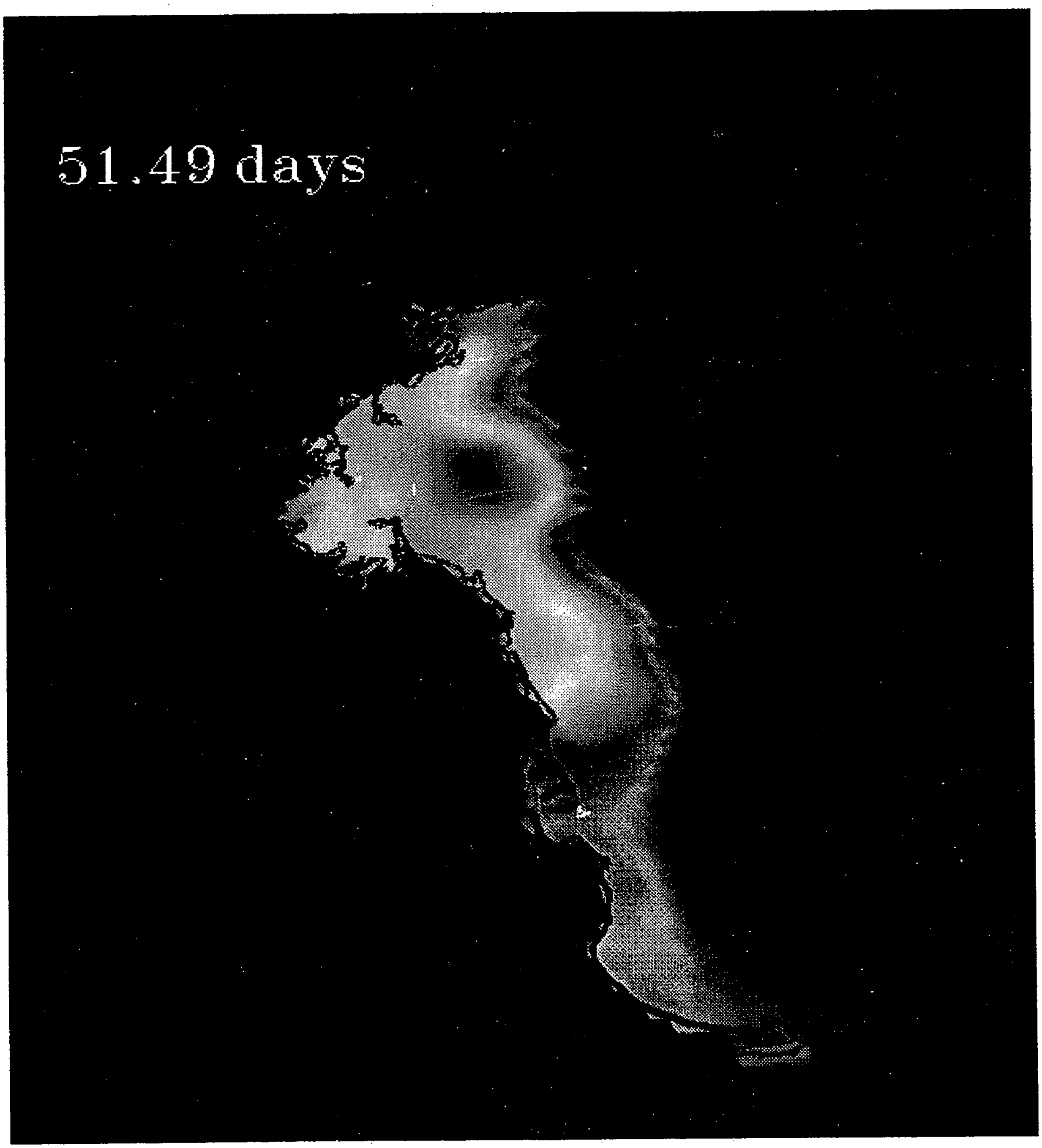


Figure 1.3. The outfall system consists of a tunnel to carry the effluent from Deer Island to the discharge site and a series of diffusers to release and disperse the material.


0
°C
31
July 19, 1990

Proposed Outfall



Conclusions

1. Vertical mixing rate was 0.04–0.08 cm^2s^{-1} (slightly less than seasonal average of 0.1 cm^2s^{-1}.)

2. Vertical mixing is slow! Vertical mixing timescale is 1 month or more.

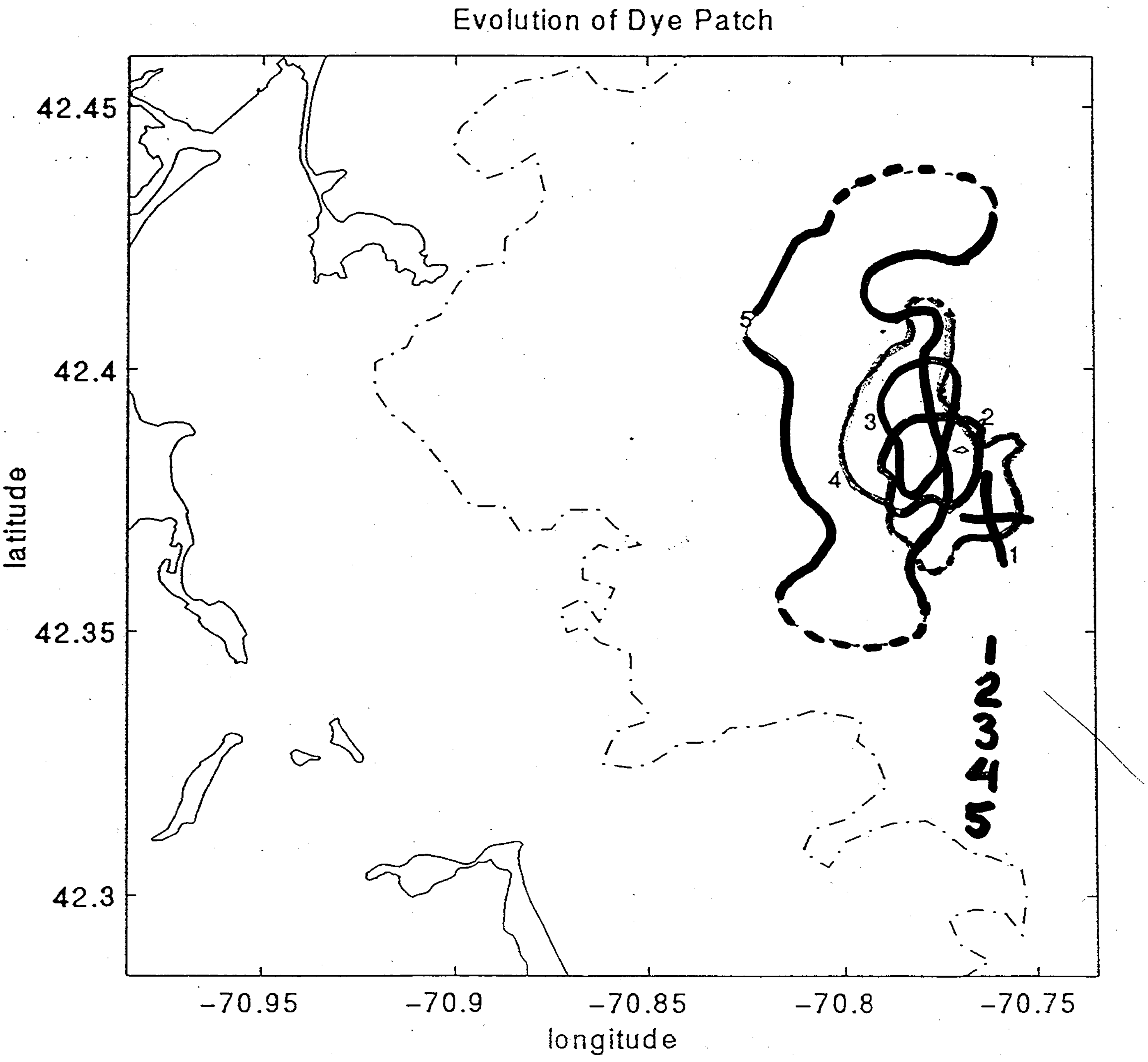
3. Internal tides provide most of shear for mixing.

Unresolved Issues

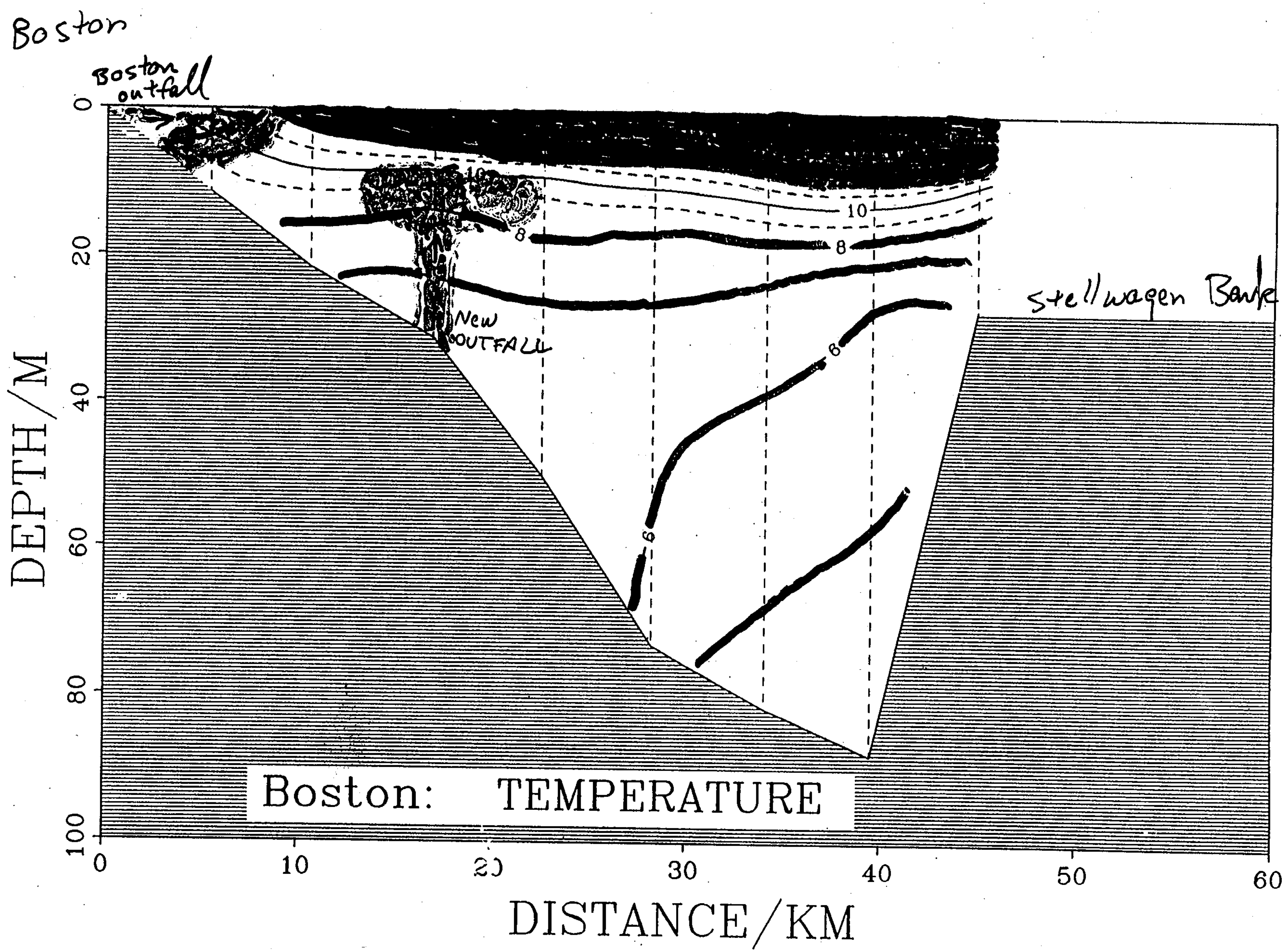
1. Is there more mixing elsewhere (e.g. boundaries)?

2. Do upwelling and downwelling have more influence on vertical transport than mixing?

3. Is the turbulence closure for the numerical model "right"?



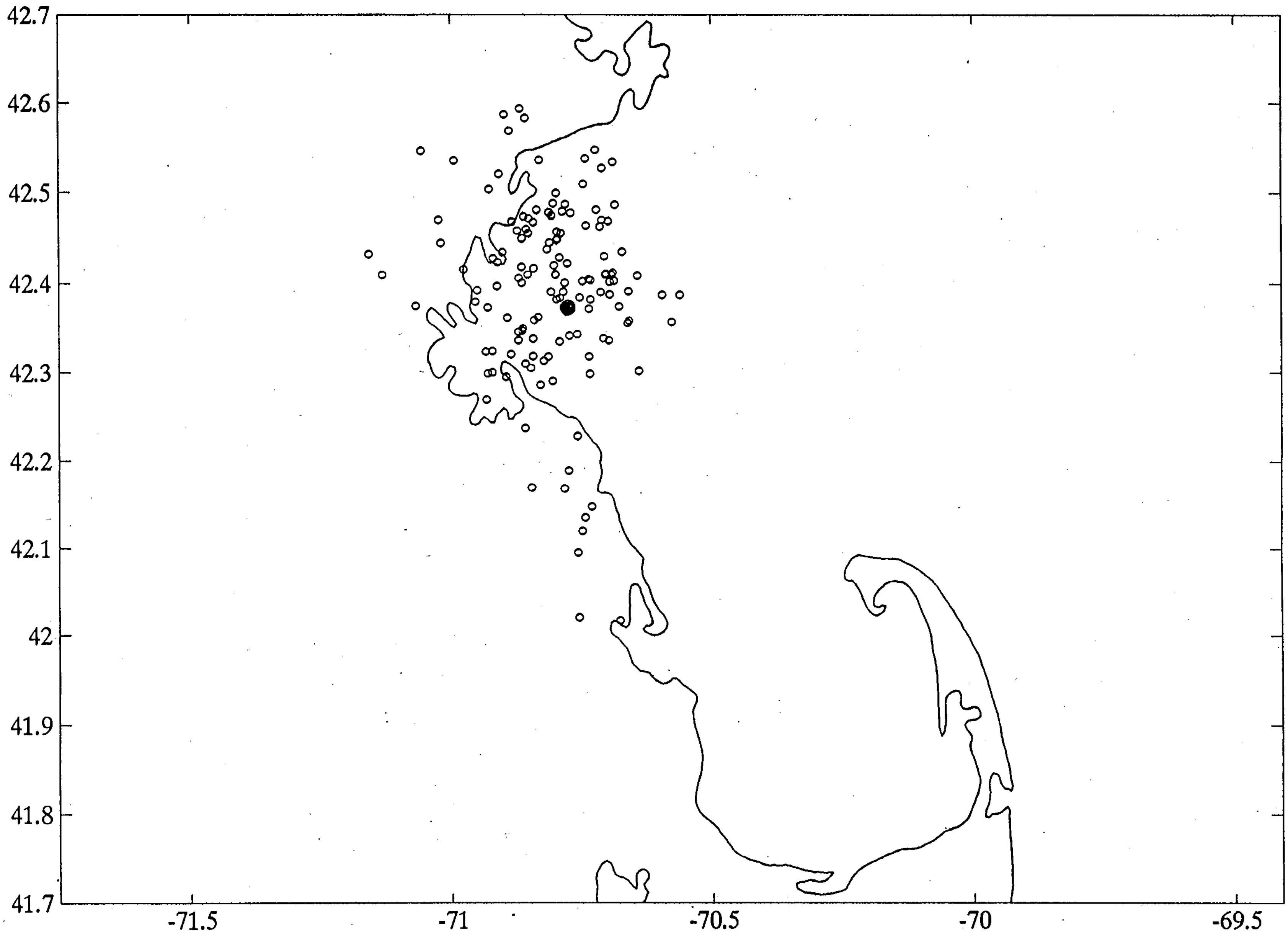
Evolution of Dye Patch
42.45
42.4
42.35
42.3
latitude
-70.95
-70.9
-70.85
-70.8
-70.75
longitude
1
2
3
4
5



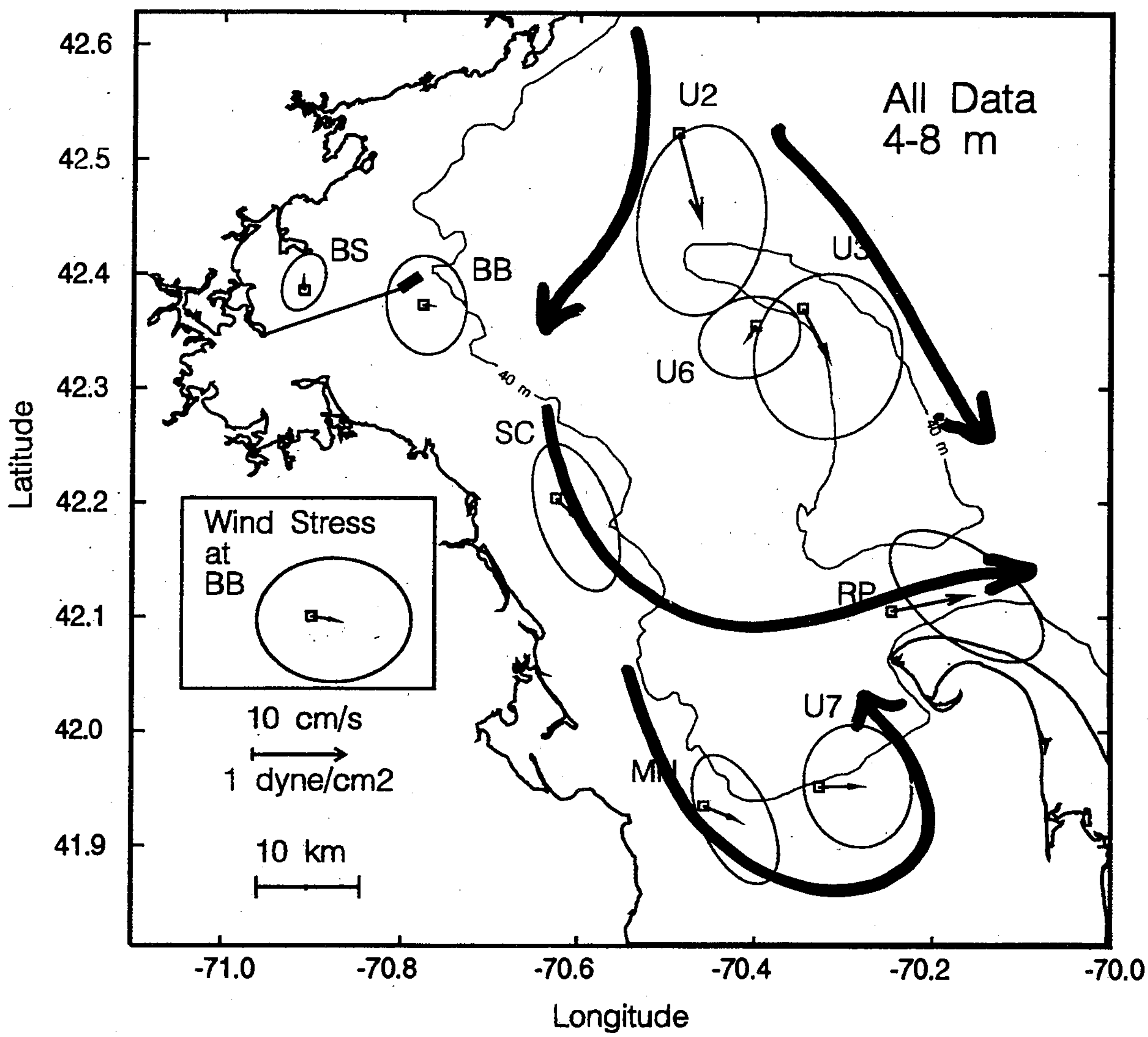
Seasonal average $K_z = 0.11 - 0.14\ cm^2 s^{-}$

MBPC2

3 day drift, spring, 1990, 5 m depth



OBSERVED NEAR-SURFACE MEAN AND LOW-FREQUENCY FLOW (DECEMBER 1989 - SEPTEMBER 1991)

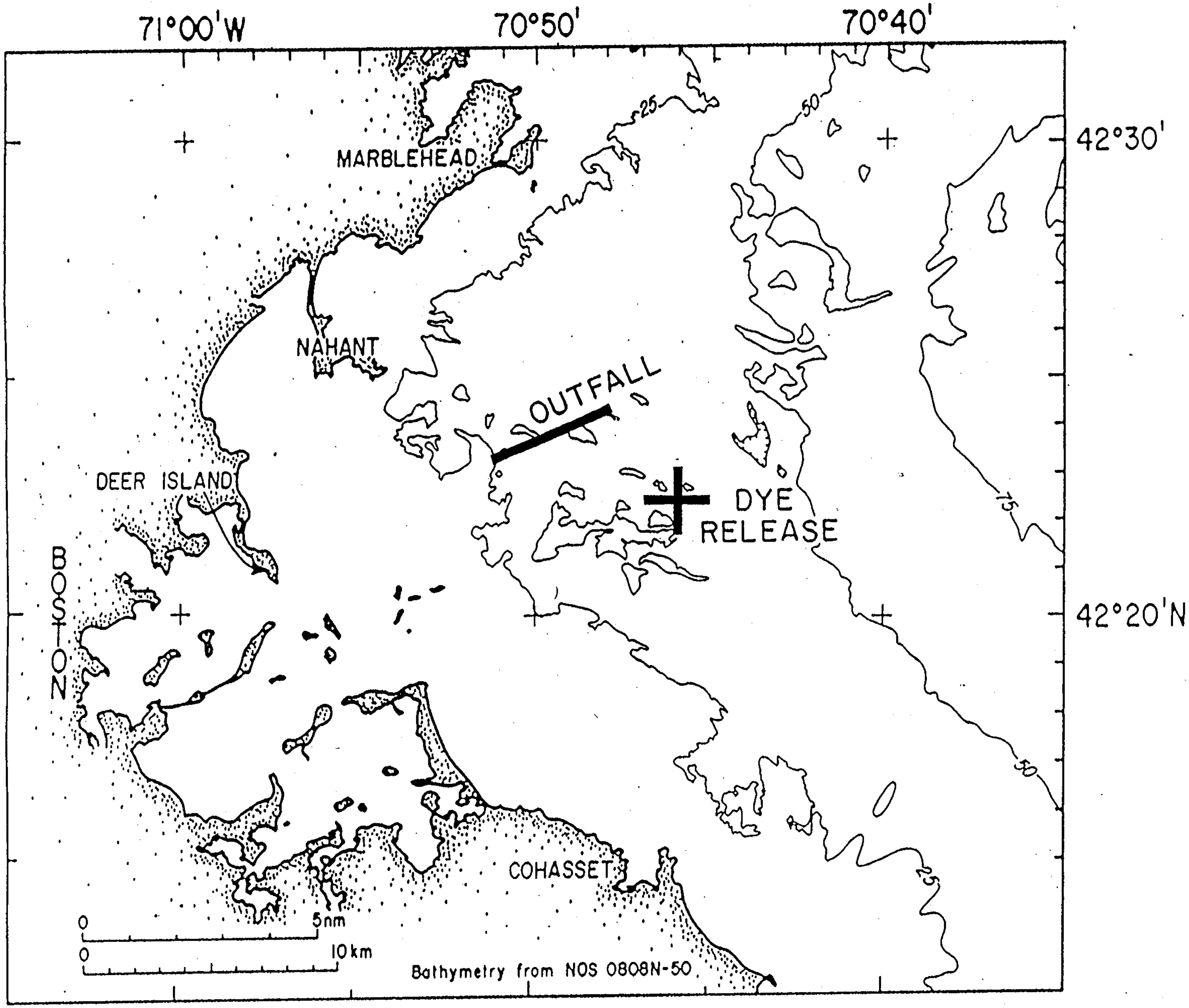


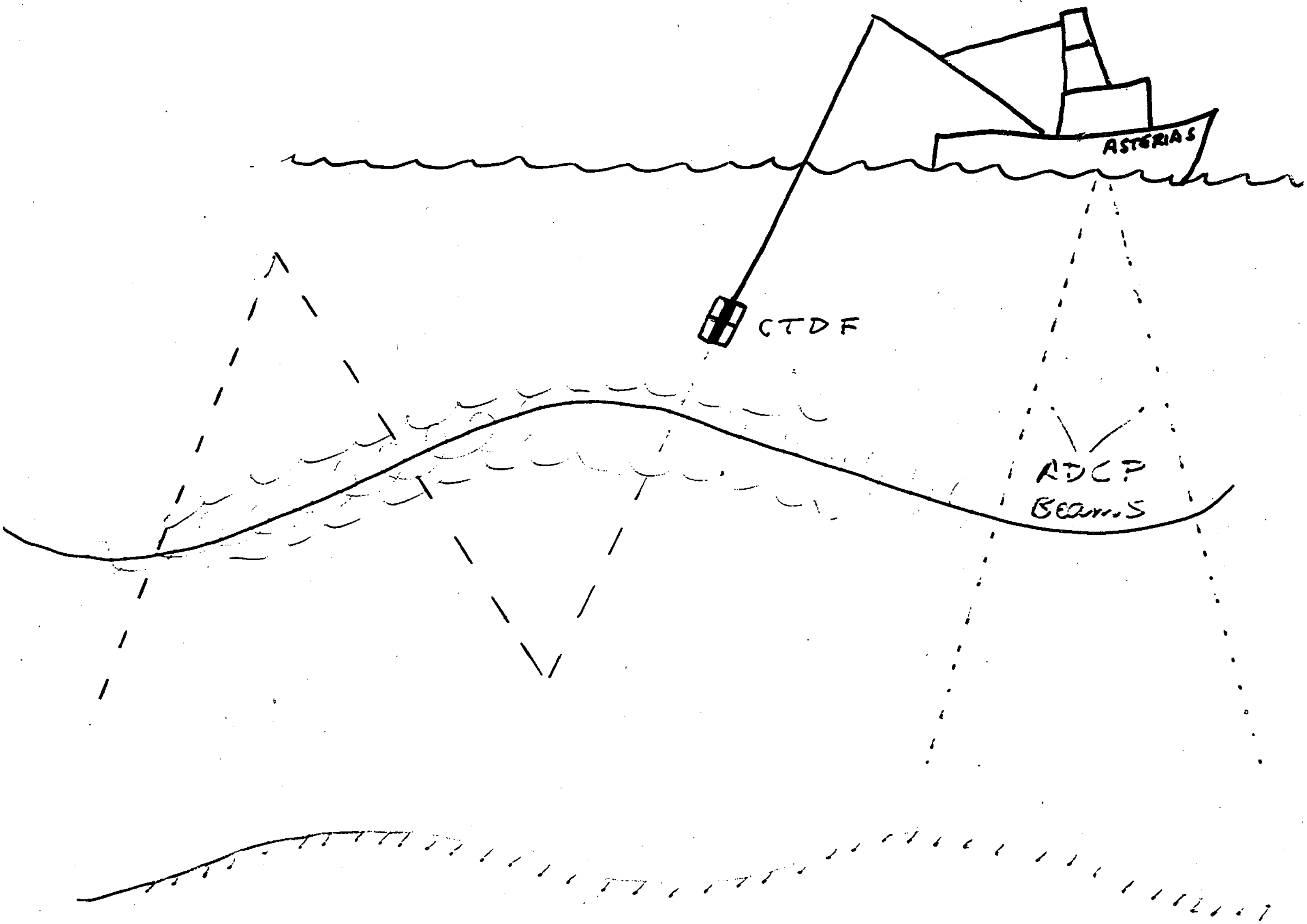
Transport Processes: Conclusions

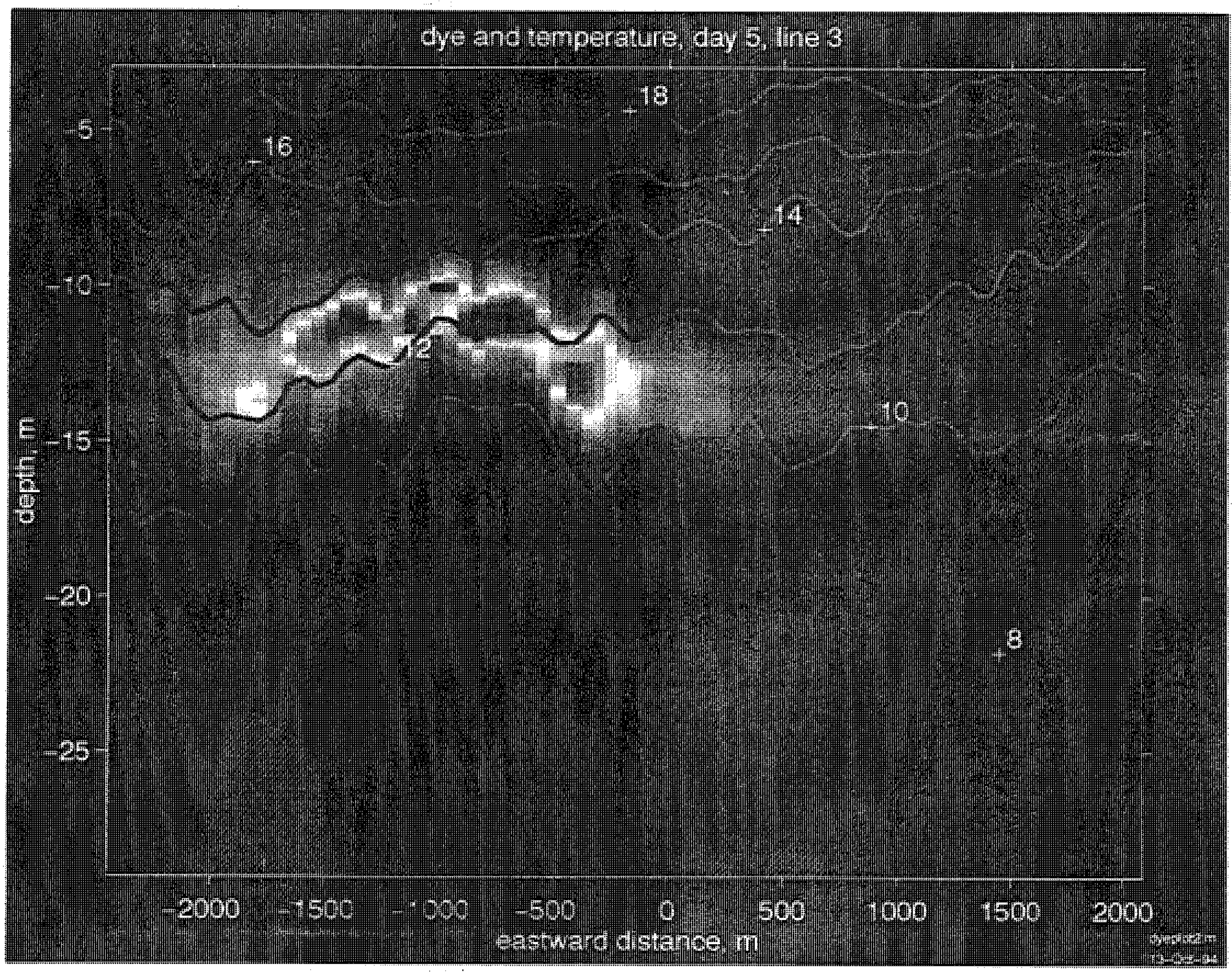
1. Stratification profoundly affects vertical exchange. Internal mixing is slow but non-zero (70–100 day mixing timescale).
2. Time-mean advection from outfall site is negligible, but wind-forced fluctuations carry water into the mean, southward through-flow (40–100 day baywide residence time).
3. The outfall will generate its own mean current of about 5 cm/s.
4. Model results indicate dilution of 400:1 within about 5 km of the outfall. This dilution will produce nitrogen levels about 20% above maximum ambient.

II. Dye mixing studies.

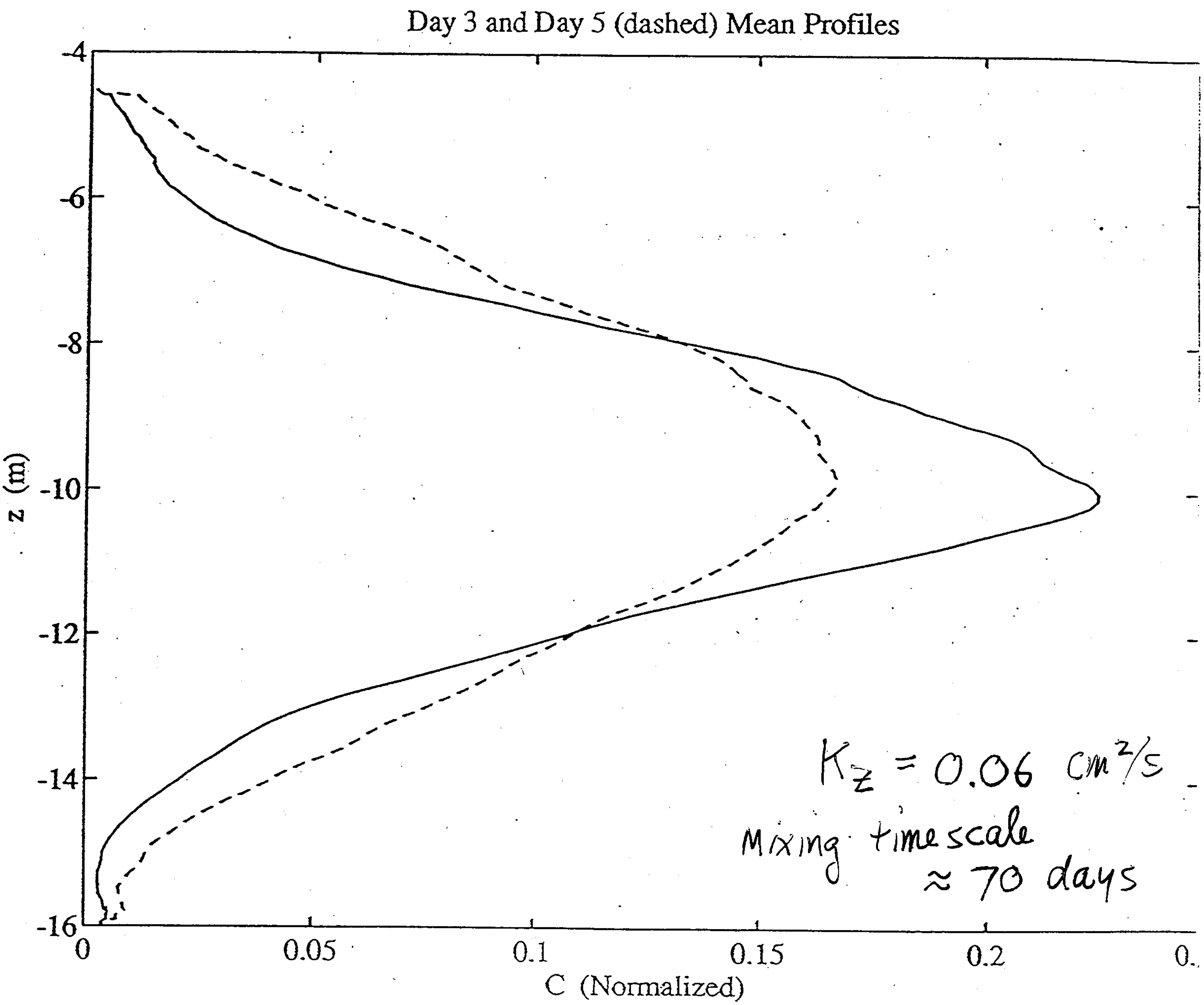
1. Internal mixing study, July, 1993
2. Boundary mixing study, July, 1995
   (preliminary results)


71°00'W
70°50'
70°40'
42°30'
42°20'N
MARBLEHEAD
NAHANT
DEER ISLAND
BOSTON
COHASSET
OUTFALL
DYE
RELEASE
25
50
75
0
5nm
0
10km
Bathymetry from NOS 0808N-50

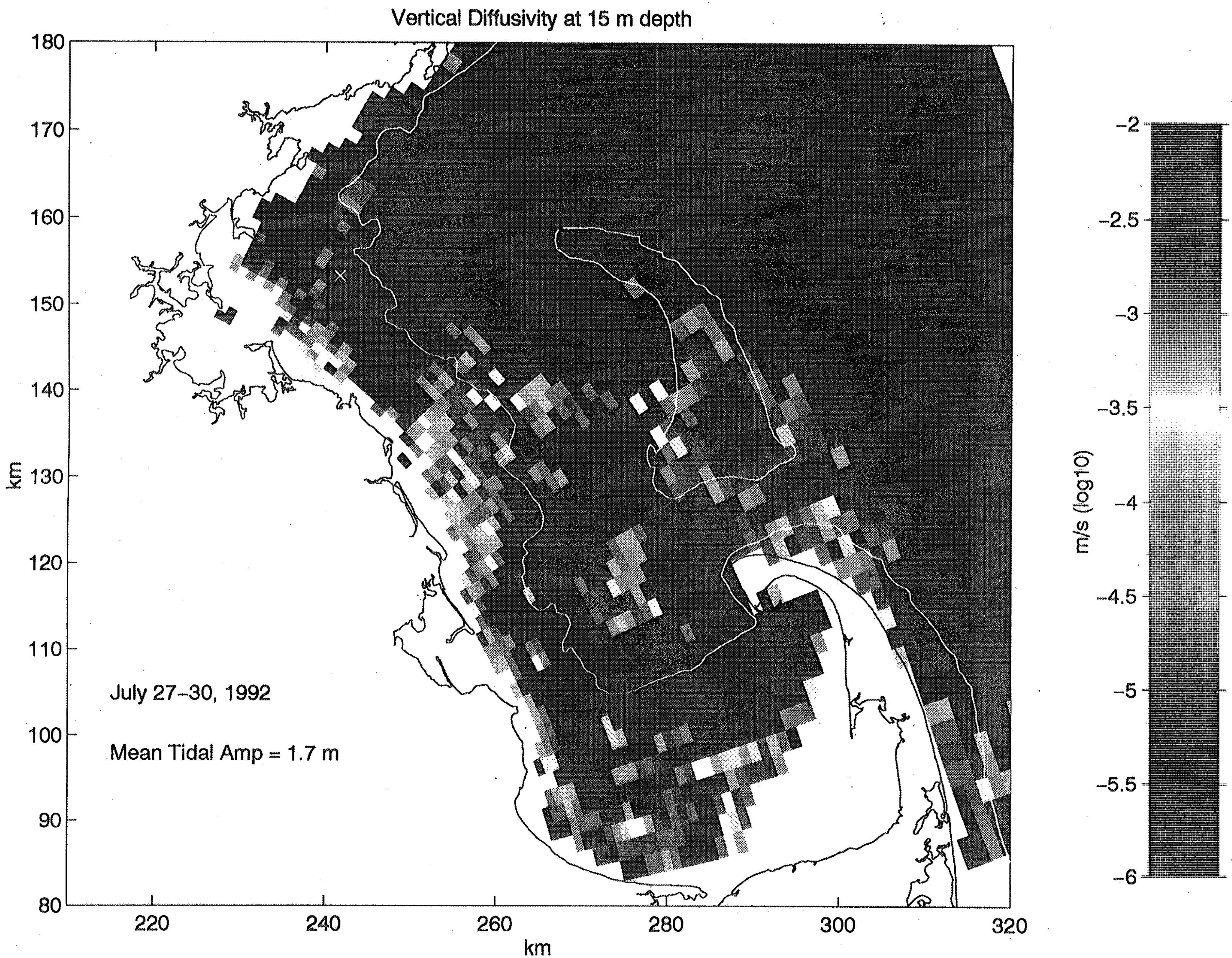

ASTERIAS
CTDF
ADCP
Beams



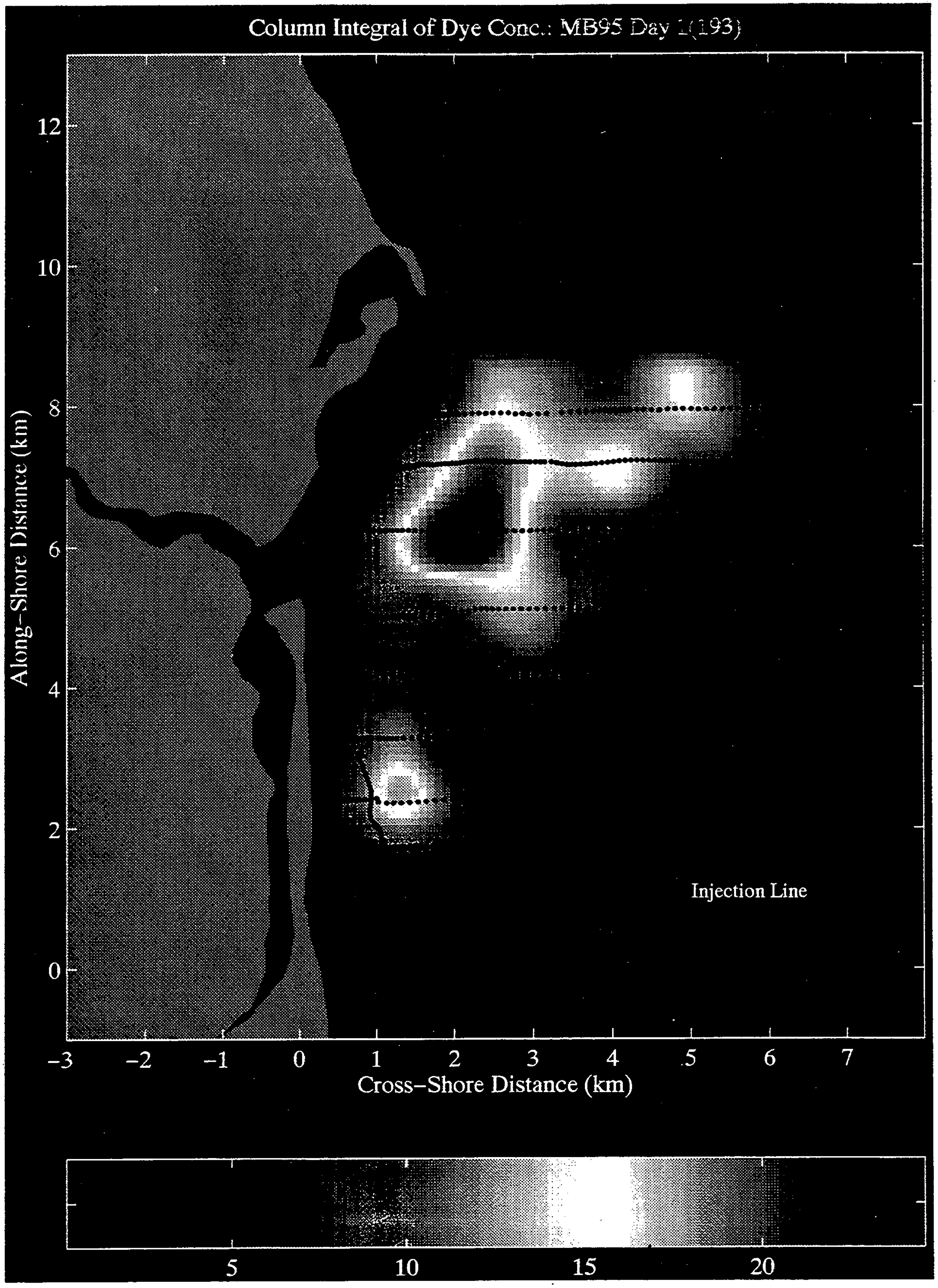
dye and temperature, day 5, line 3
18
16
14
12
10
8
-5
-10
-15
-20
-25
depth, m
-2000
-1500
-1000
-500
0
500
1000
1500
2000
eastward distance, m

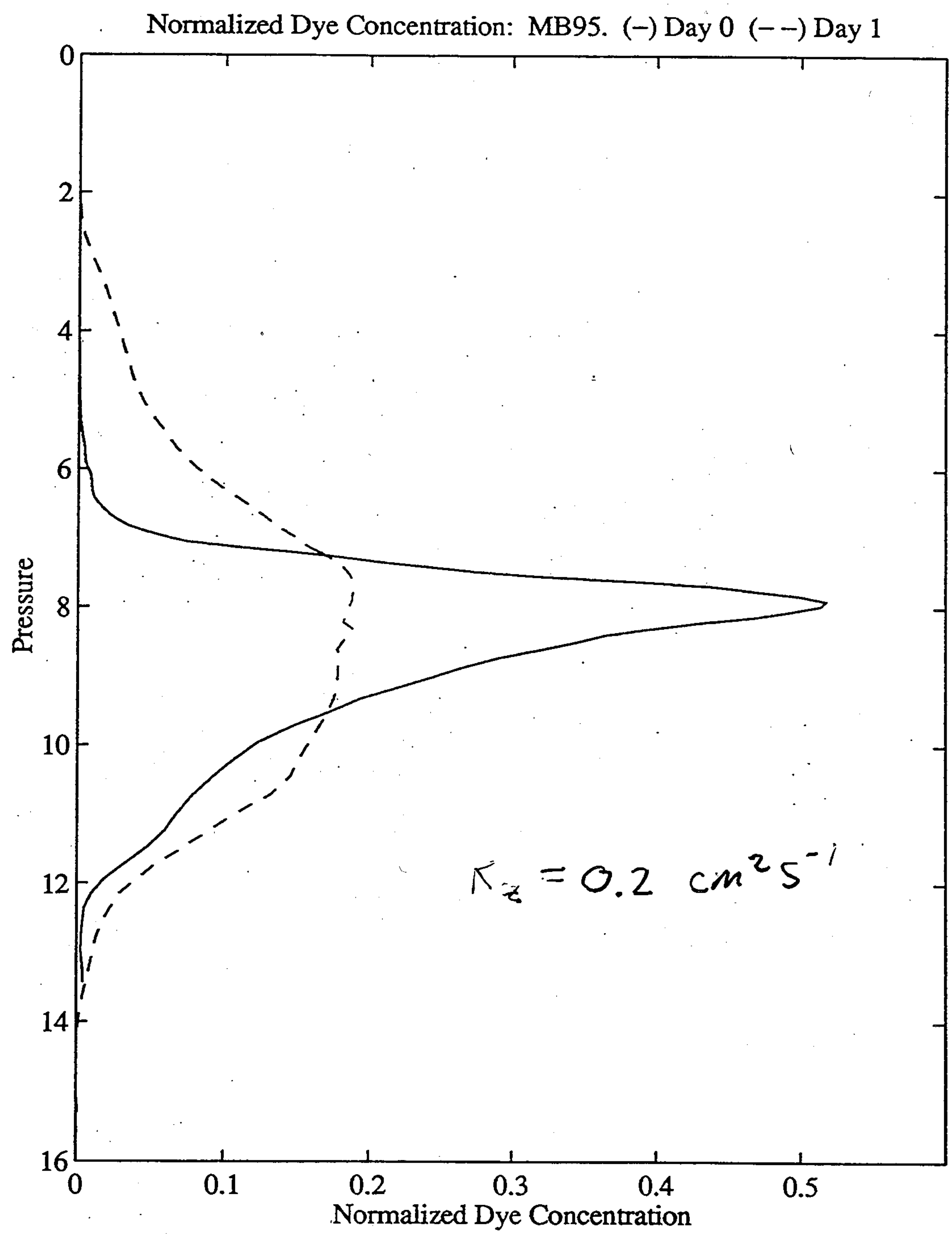


Day 3 and Day 5 (dashed) Mean Profiles
-4
-6
-8
-10
-12
-14
-16
z (m)
0
0.05
0.1
0.15
0.2
C (Normalized)
$K_z = 0.06$ cm²/s
Mixing timescale
≈ 70 days

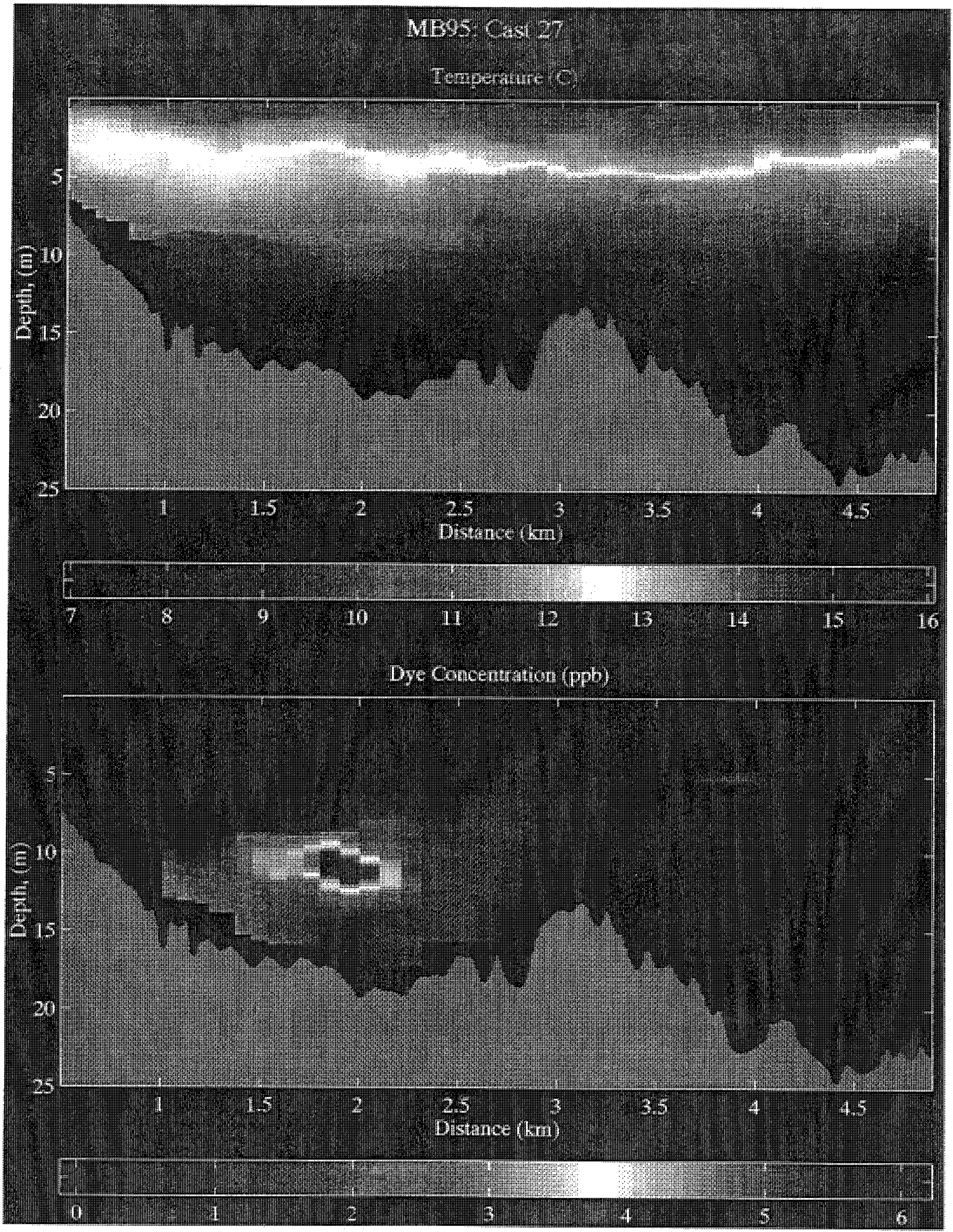


Vertical Diffusivity at 15 m depth
July 27–30, 1992
Mean Tidal Amp = 1.7 m
km
km
m/s (log10)
180
170
160
150
140
130
120
110
100
90
80
220
240
260
280
300
320
-2
-2.5
-3
-3.5
-4
-4.5
-5
-5.5
-6

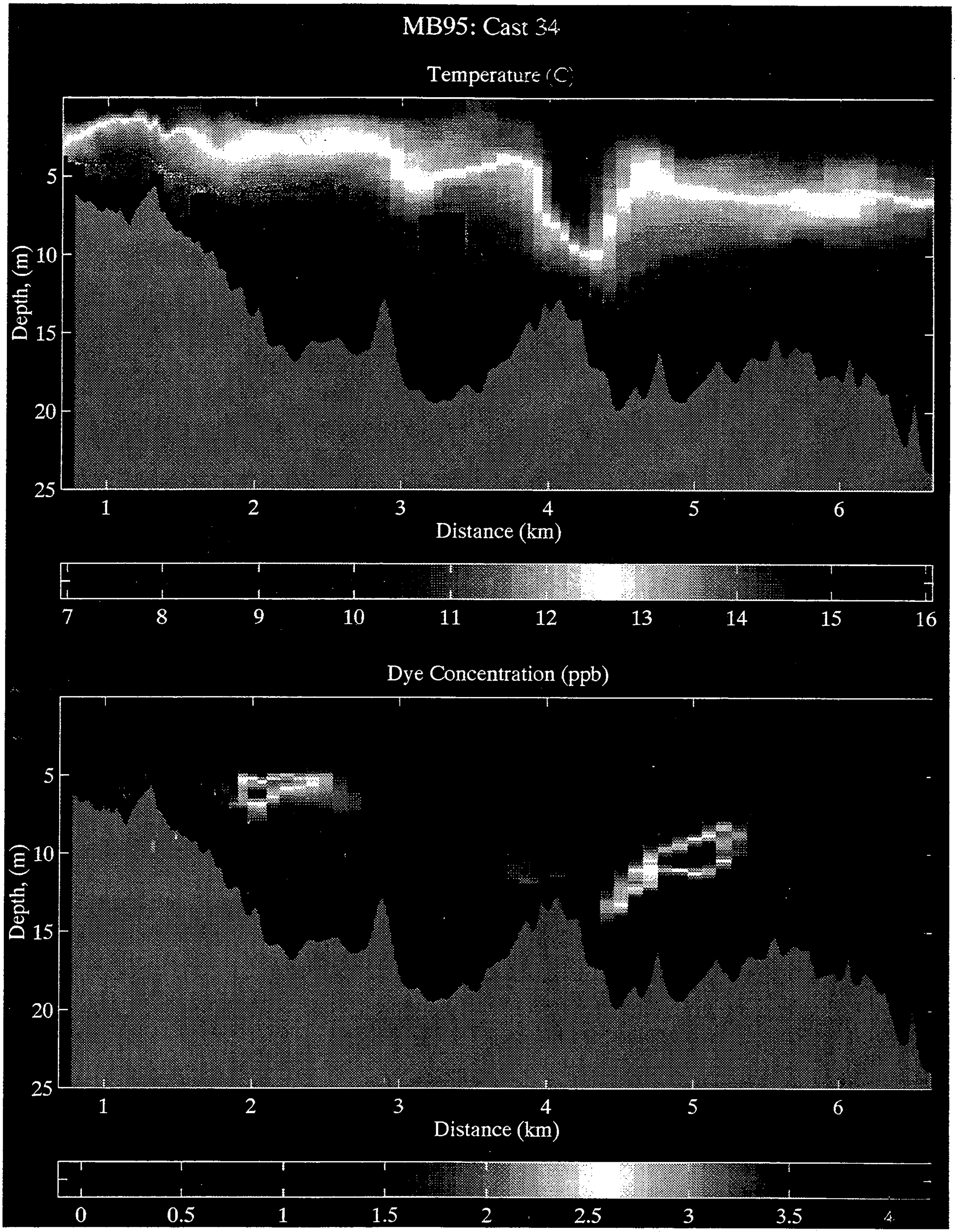

Column Integral of Dye Conc.: MB95 Day 1(193)
Along-Shore Distance (km)
Cross-Shore Distance (km)
Injection Line
12
10
8
6
4
2
0
-3
-2
-1
0
1
2
3
4
5
6
7
5
10
15
20



Normalized Dye Concentration: MB95. (–) Day 0 (– –) Day 1
Pressure
0
2
4
6
8
10
12
14
16
0
0.1
0.2
0.3
0.4
0.5
Normalized Dye Concentration
K_z = 0.2 cm^2 s^-1



MB95: Cast 27
Temperature (C)
Depth, (m)
5
10
15
20
25
1
1.5
2
2.5
3
3.5
4
4.5
Distance (km)
7
8
9
10
11
12
13
14
15
16
Dye Concentration (ppb)
Depth, (m)
5
10
15
20
25
1
1.5
2
2.5
3
3.5
4
4.5
Distance (km)
0
1
2
3
4
5
6


MB95: Cast 34
Temperature (C)
Depth, (m)
5
10
15
20
25
1
2
3
4
5
6
Distance (km)
7
8
9
10
11
12
13
14
15
16
Dye Concentration (ppb)
Depth, (m)
5
10
15
20
25
1
2
3
4
5
6
Distance (km)
0
0.5
1
1.5
2
2.5
3
3.5
4

Dye Studies: Conclusions

I. Internal Mixing (1993)

1. Vertical mixing rate near outfall was 0.04–0.08 cm^2s^{-1} (less than seasonal average of 0.1 cm^2s^{-1}.)
2. Vertical mixing is slow! Timescale of 70 days, comparable to transit time through Bay.
3. Internal tides provide most of shear for mixing.

II. Boundary Mixing (1995)

1. Vertical mixing rate near western boundary was 0.2 cm^2s^{-1} (three times the internal mixing rate.)
2. Mixing is caused by strong internal tidal motions near rough bottom topography.
3. Upwelling may make an important contribution to vertical exchange (stay tuned!)

APPENDIX C-3

Jim Bowen
UNC, Charlotte

MASSACHUSETTS WATER RESOURCES AUTHORITY

ENSR

Dissolved Oxygen in Massachusetts Bay

Topics

1. Measurement and Analysis Methods

2. Results

   a. DO in the Nearfield
   b. DO in Stellwagen Basin

3. Bottom Water DO Depletion During Summer

4. Comparison to DO Hypotheses

   a. DO decline rate
   b. duration of low DO
   c. annual mean DO concentration

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Methods

- General Survey Information (1995)
  - 6 Farfield Surveys
  - 17 Nearfield Surveys
  - 26 Farfield Stations
  - 21 Nearfield Stations
- Similar design in 1992, 1993, 1994
- Downcast profiles at every station
- Sensor measurements
  - DO + 6 others
- During upcast, sampling at 5 depths
- Sampling/analysis varies by station
- Analytes
  - DO + 20 others

Farfield Stations

③

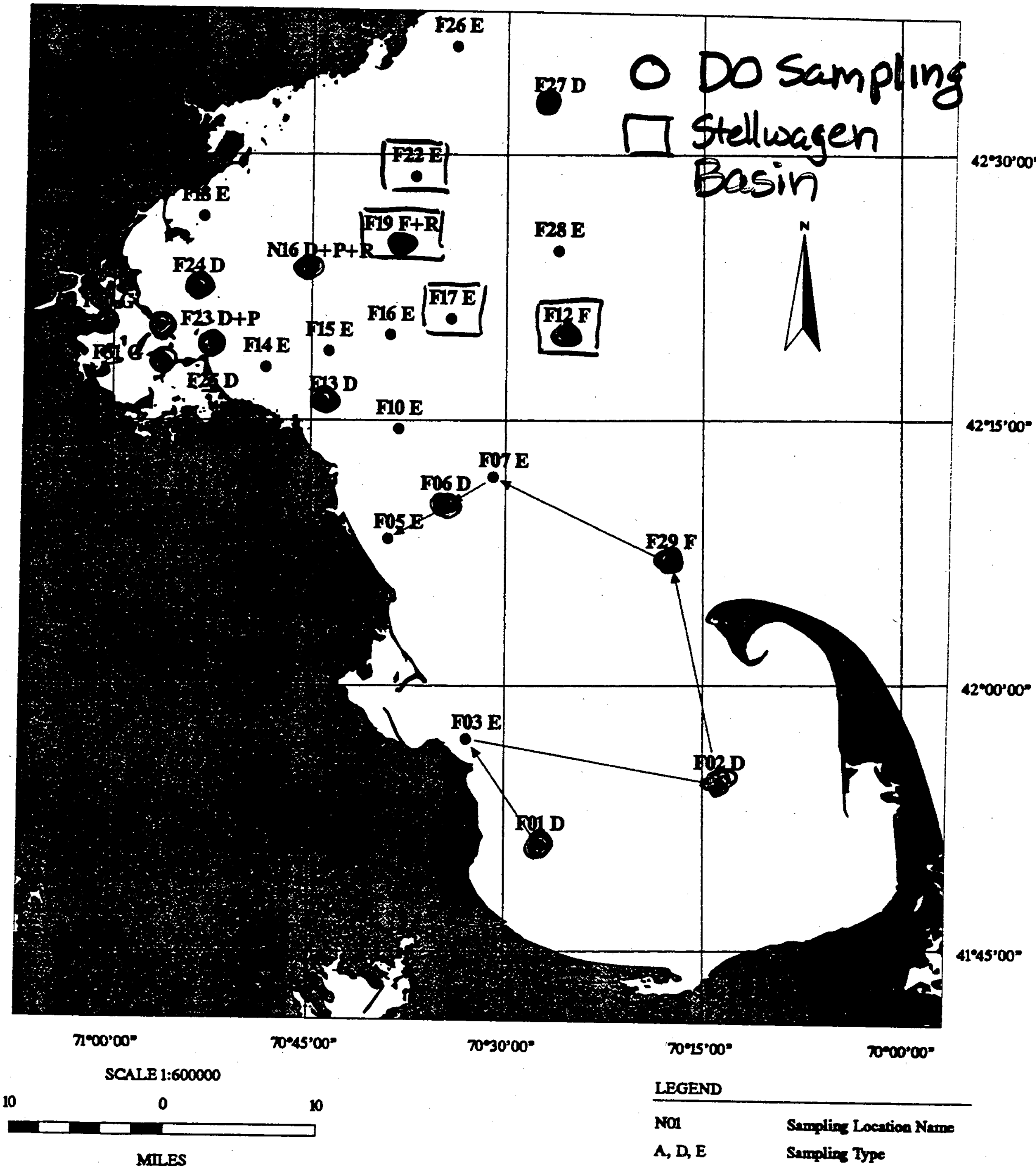


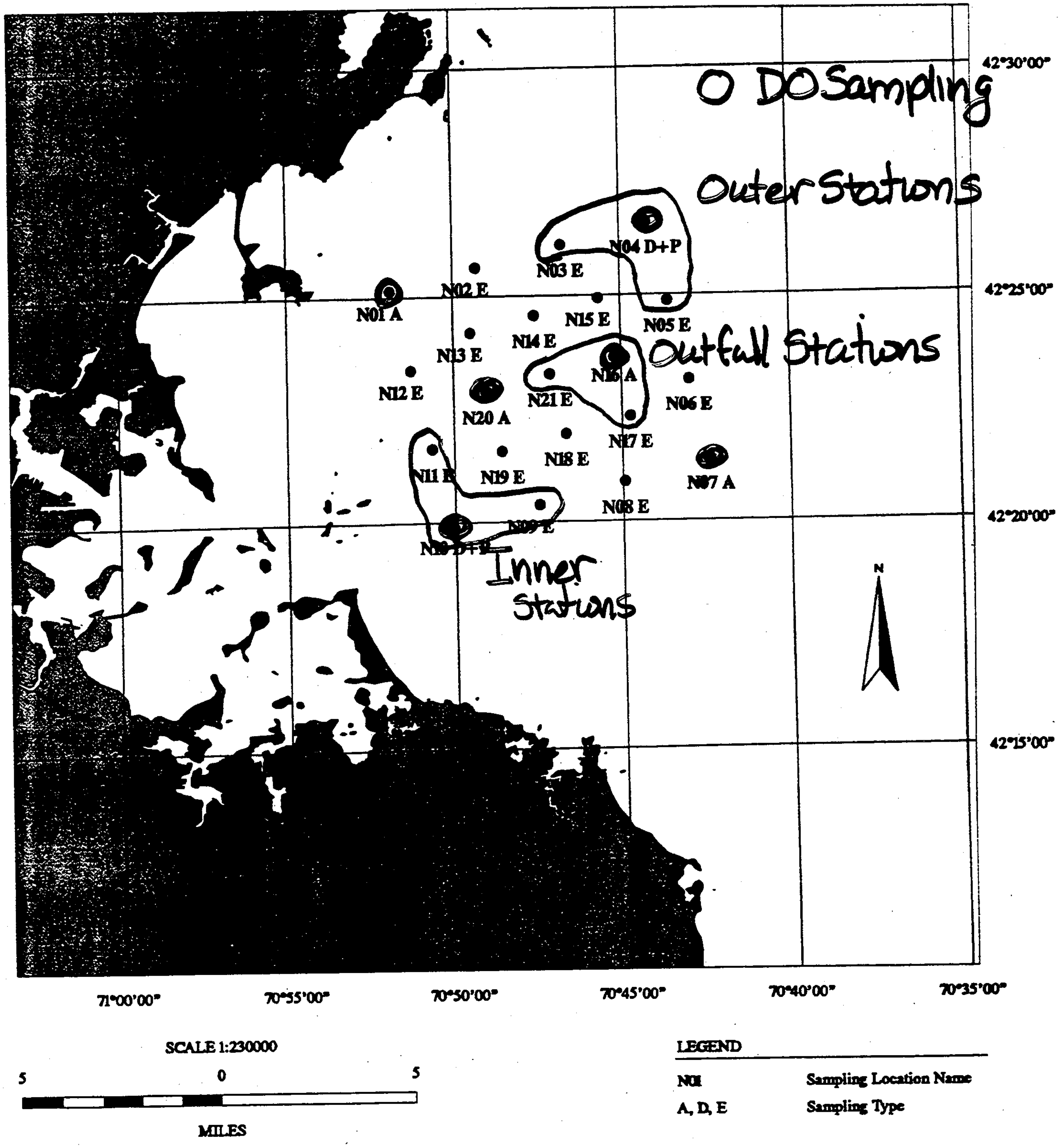
FIGURE 2

Planned Farfield Survey Track, W9602

Day 1

4

Nearfield Stations



Nearfield Survey Stations

DO Sampling Depths

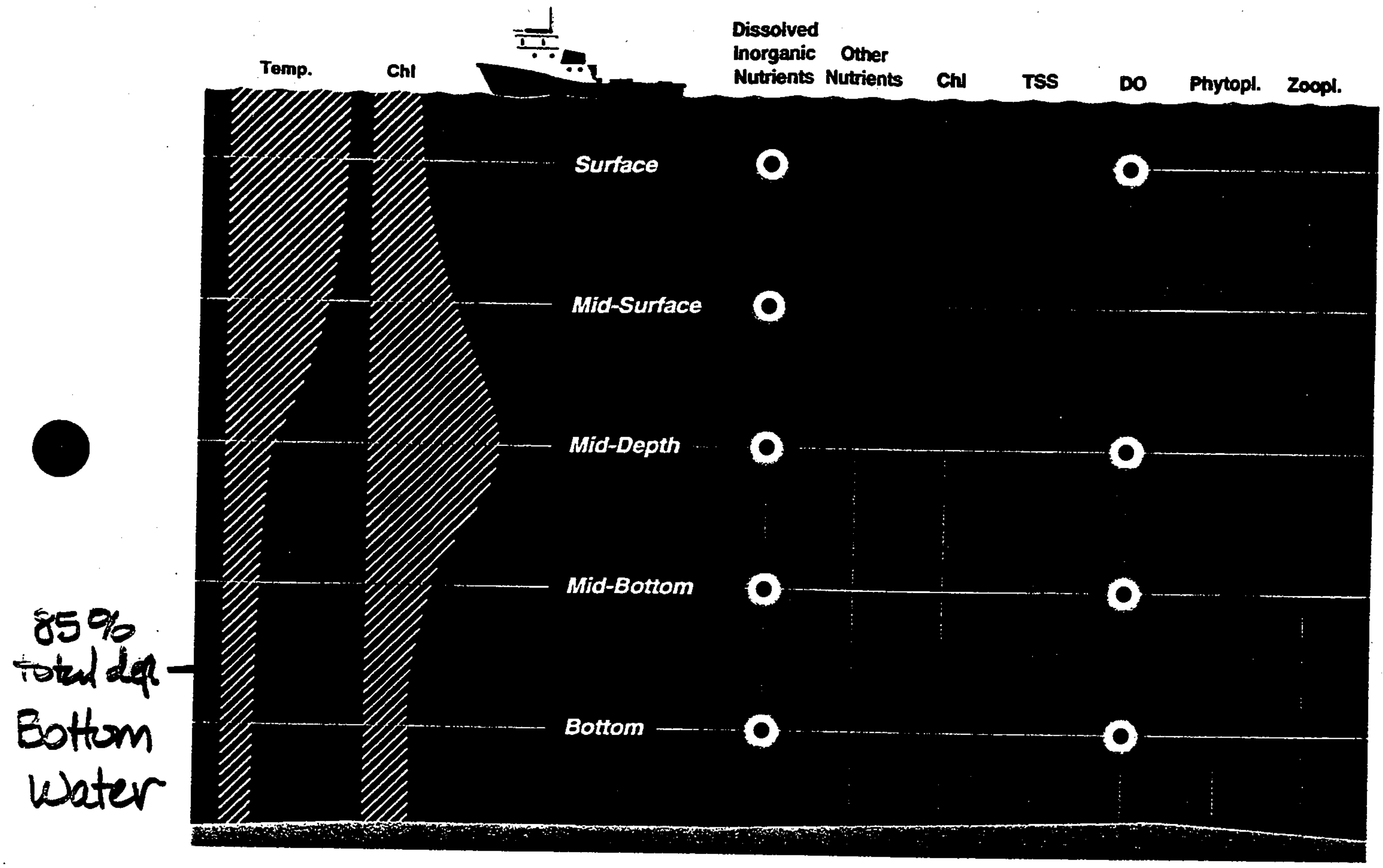


FIGURE 2-16
Farfield Station Type F - 3 Stations

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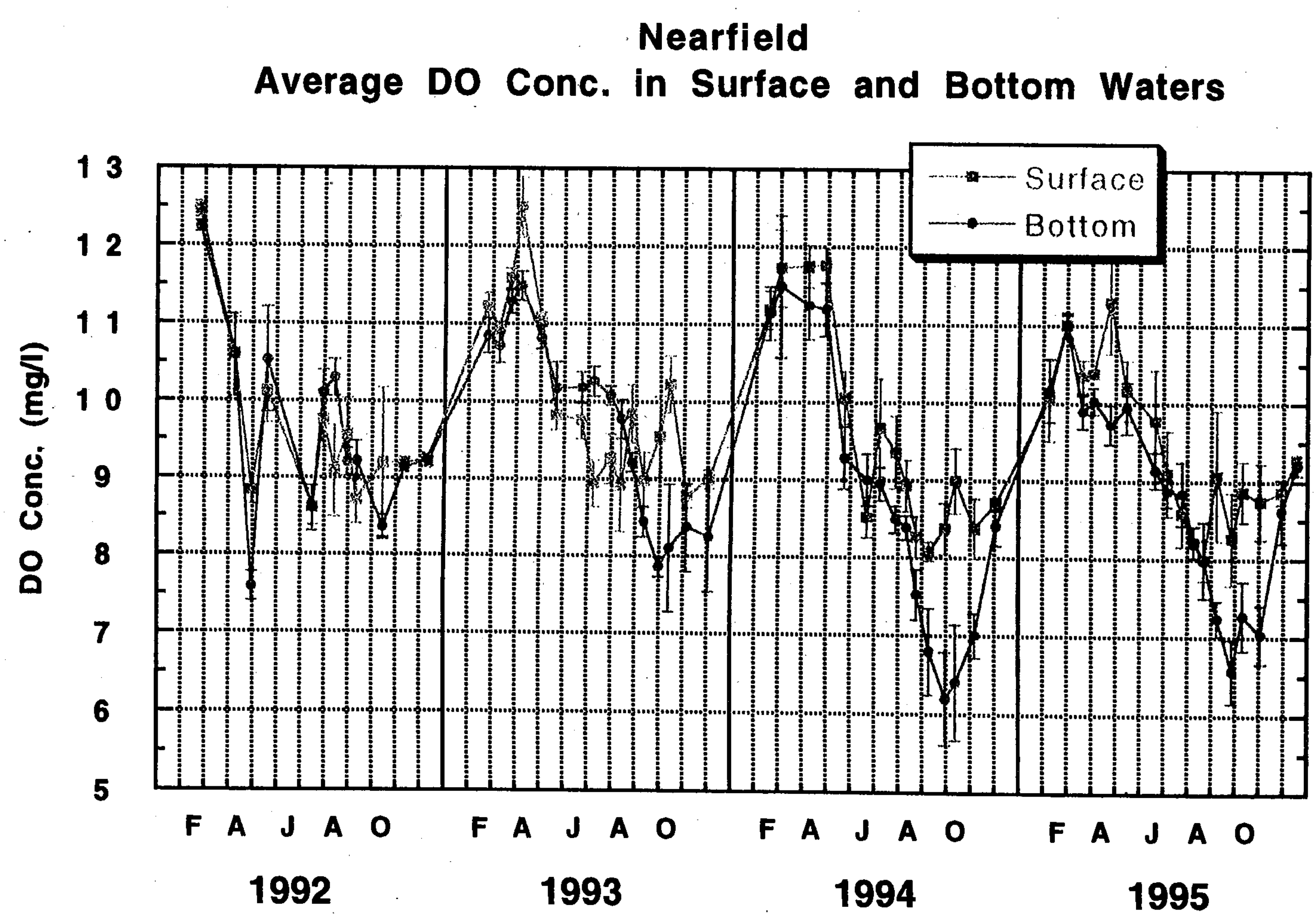
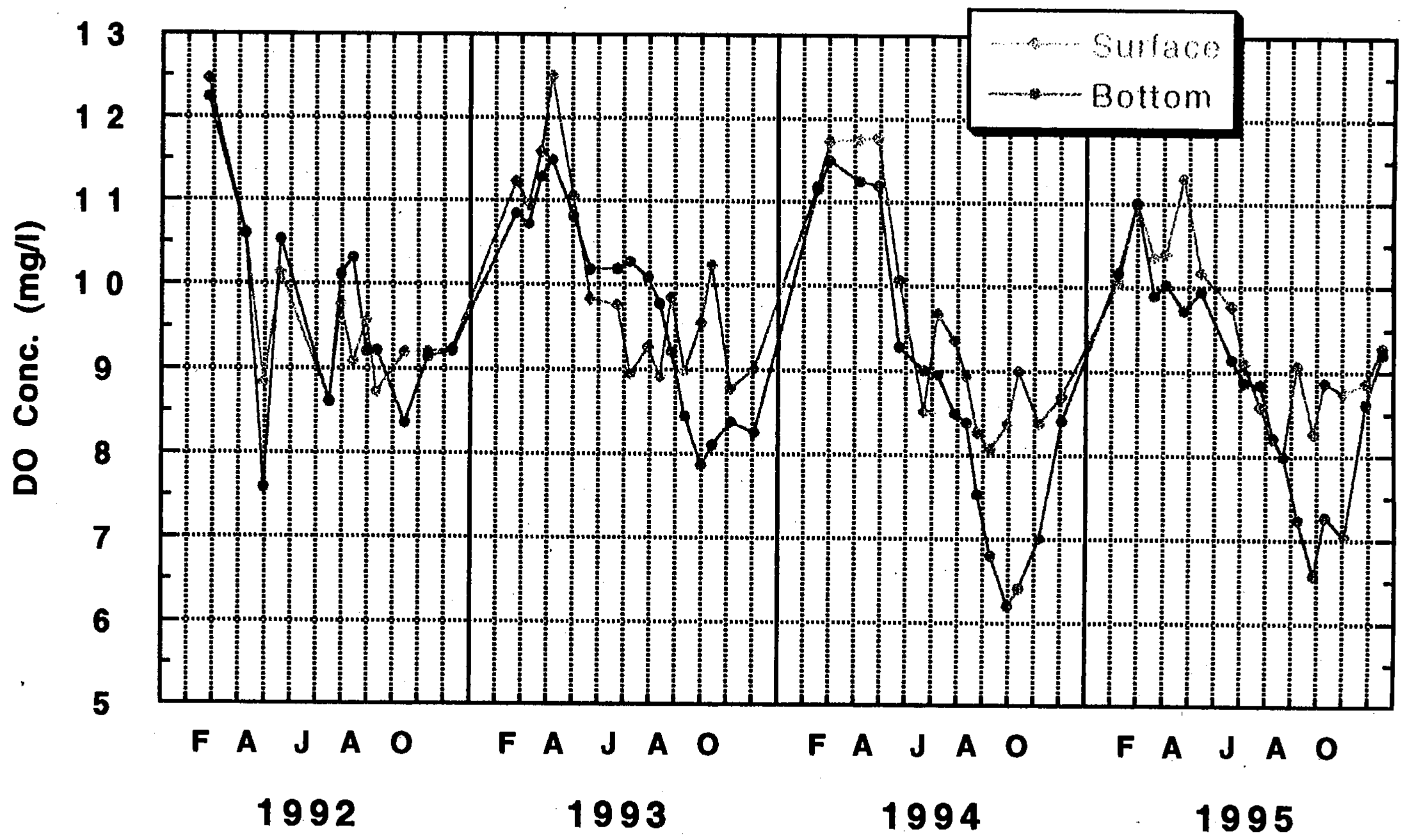
Methods, continued

- Data Analysis
  - Winkler DO's used to postcalibrate sensors
  - Results from sensor upcast values only
- Total Depth, Group Averages
  - Inner Nearfield = 30 m
  - Outfall = 37 m
  - Outer Nearfield = 50 m
  - Stellwagen = 82 m
- new bottom water definition
  - sample depth > 85% total depth (N & S)
- PDMR, bottom water definition
  - sample depth > 20 m (nearfield)
  - sample depth > 50 m (Stellwagen)

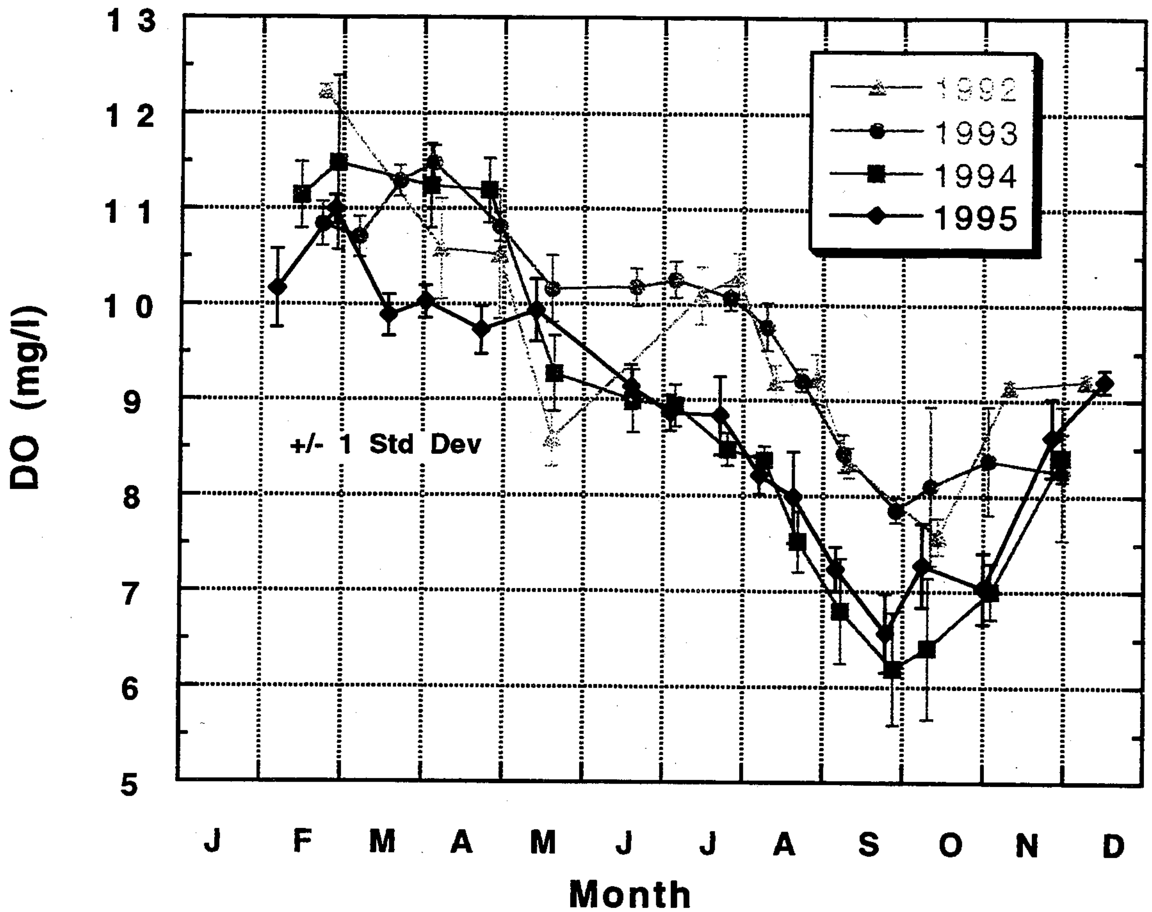

Nearfield
Average DO Conc. in Surface and Bottom Waters
Surface
Bottom
DO Conc. (mg/l)
13
12
11
10
9
8
7
6
5
F A J A O
1992
F A J A O
1993
F A J A O
1994
F A J A O
1995

Nearfield
Average DO Conc. in Surface and Bottom Waters

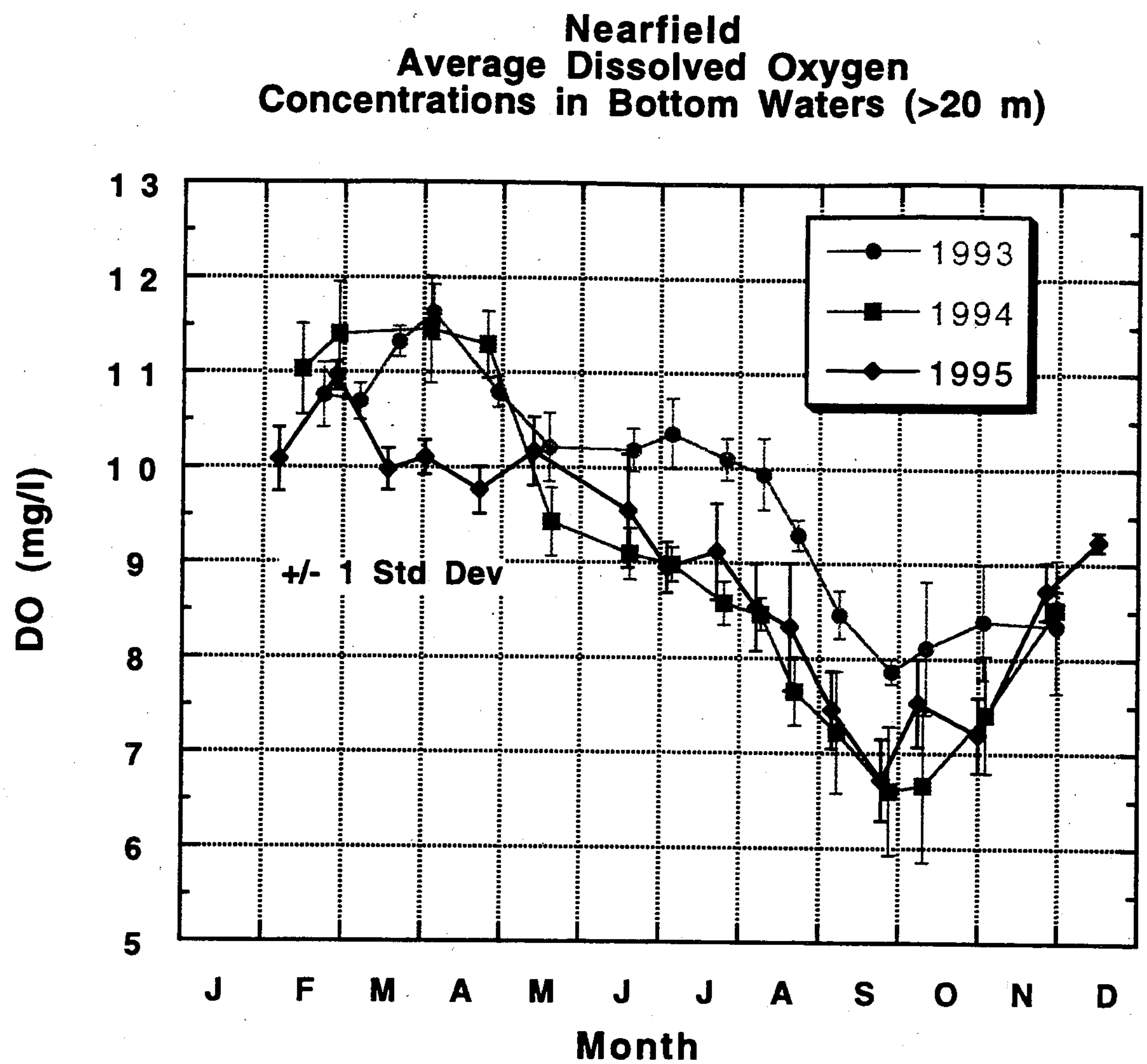


(9)

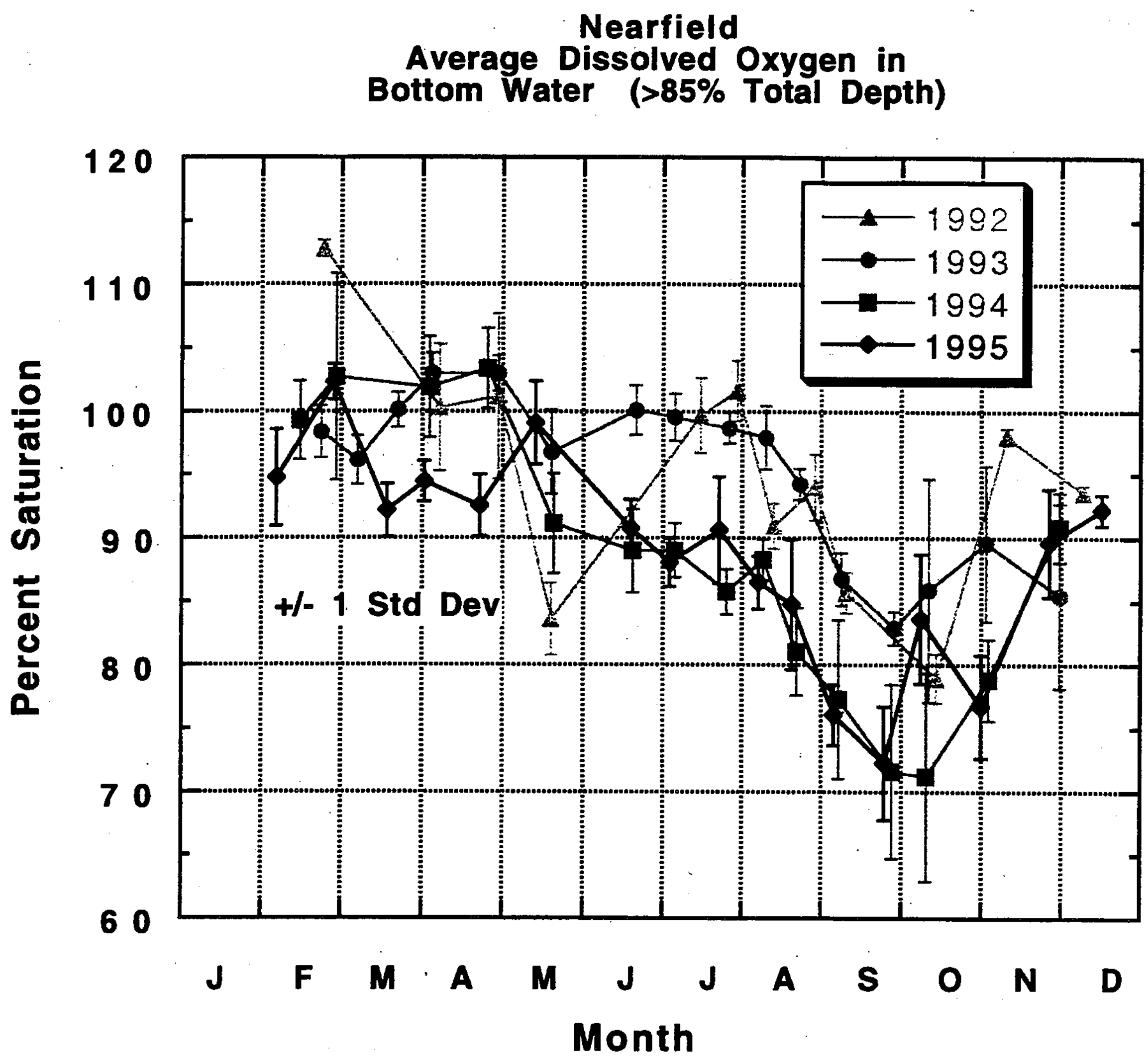
Nearfield
Average Dissolved Oxygen Concentrations in Bottom Waters (>85% Total Depth)



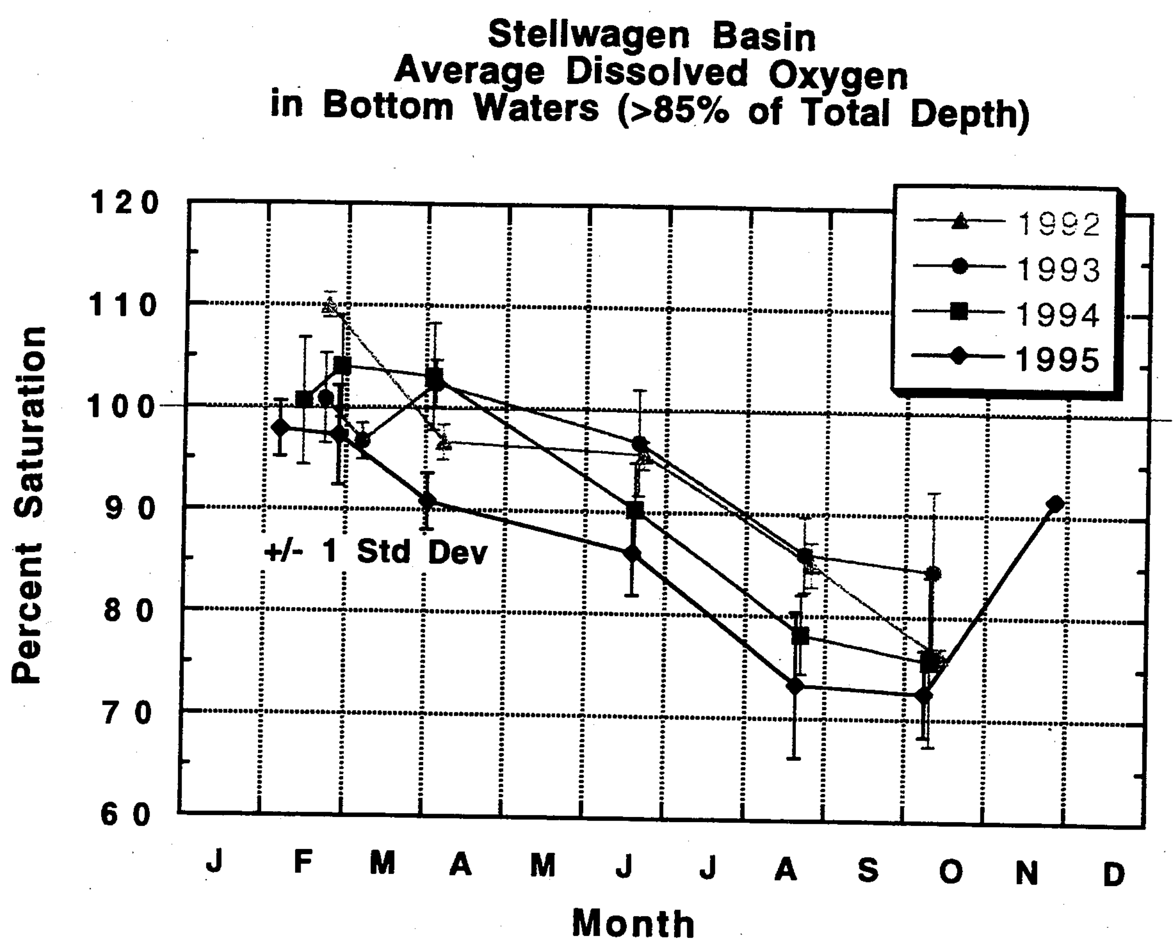
*


Nearfield
Average Dissolved Oxygen
Concentrations in Bottom Waters (>20 m)
1993
1994
1995
+/- 1 Std Dev
DO (mg/l)
13
12
11
10
9
8
7
6
5
J
F
M
A
M
J
J
A
S
O
N
D
Month

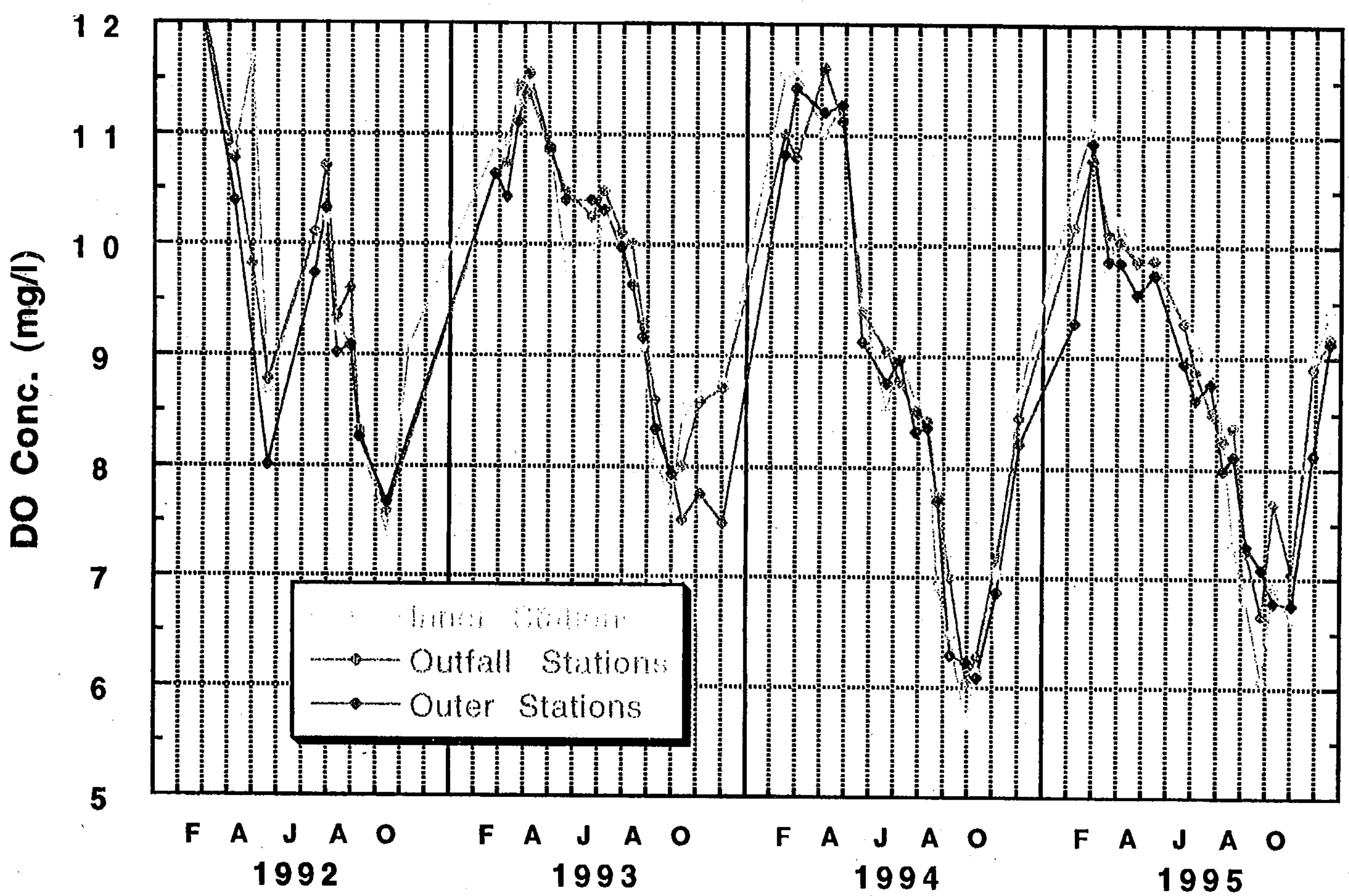
Nearfield Percent Saturation

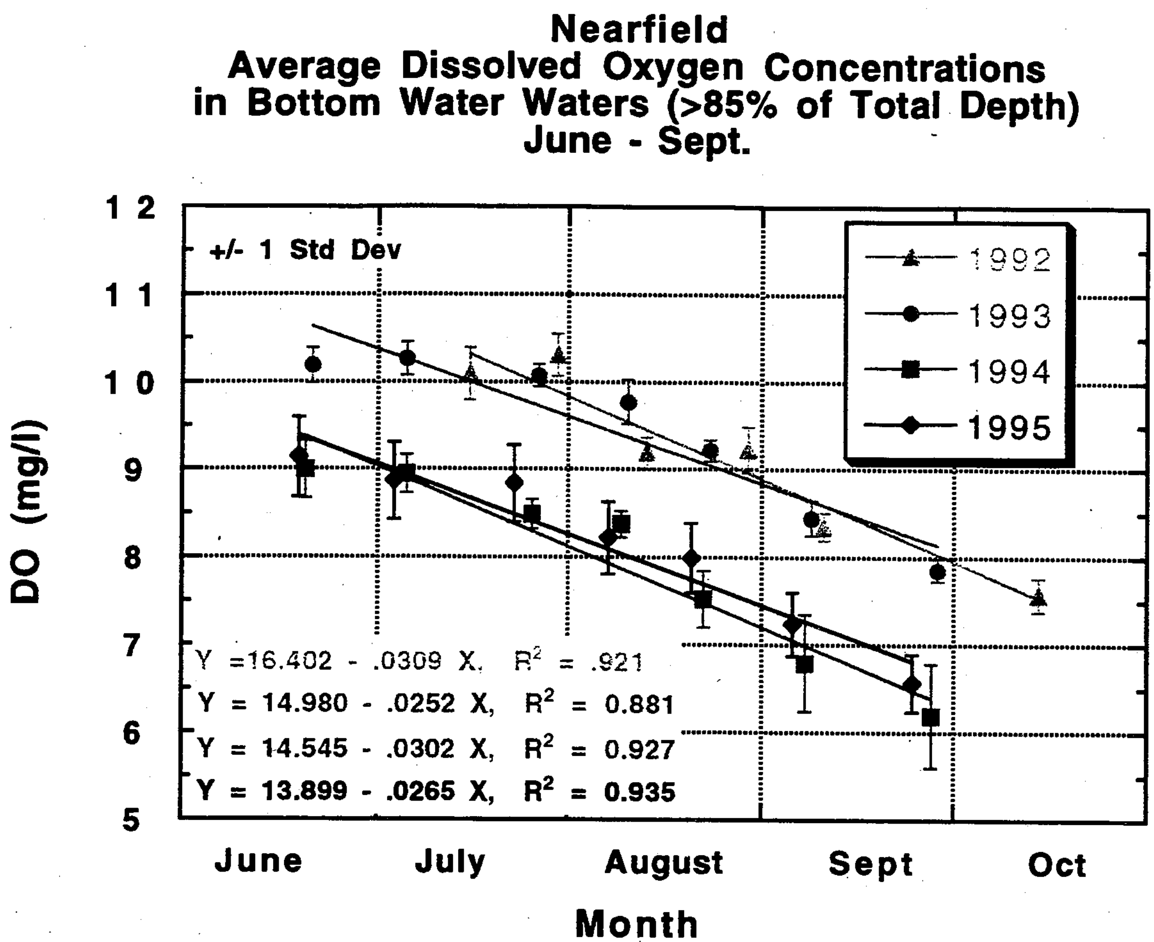


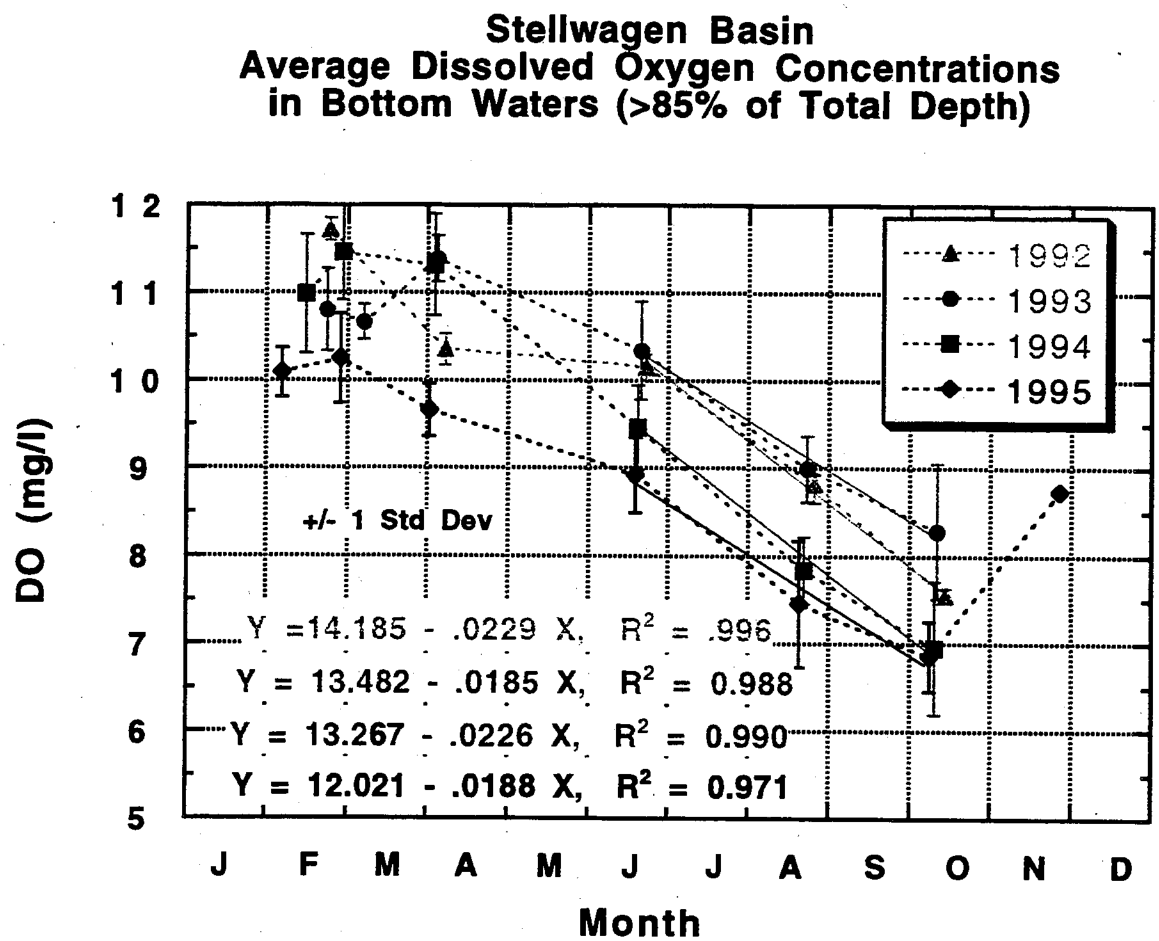
Stellwagen Percent Saturation



Nearfield DO Concentrations, by Station Groups

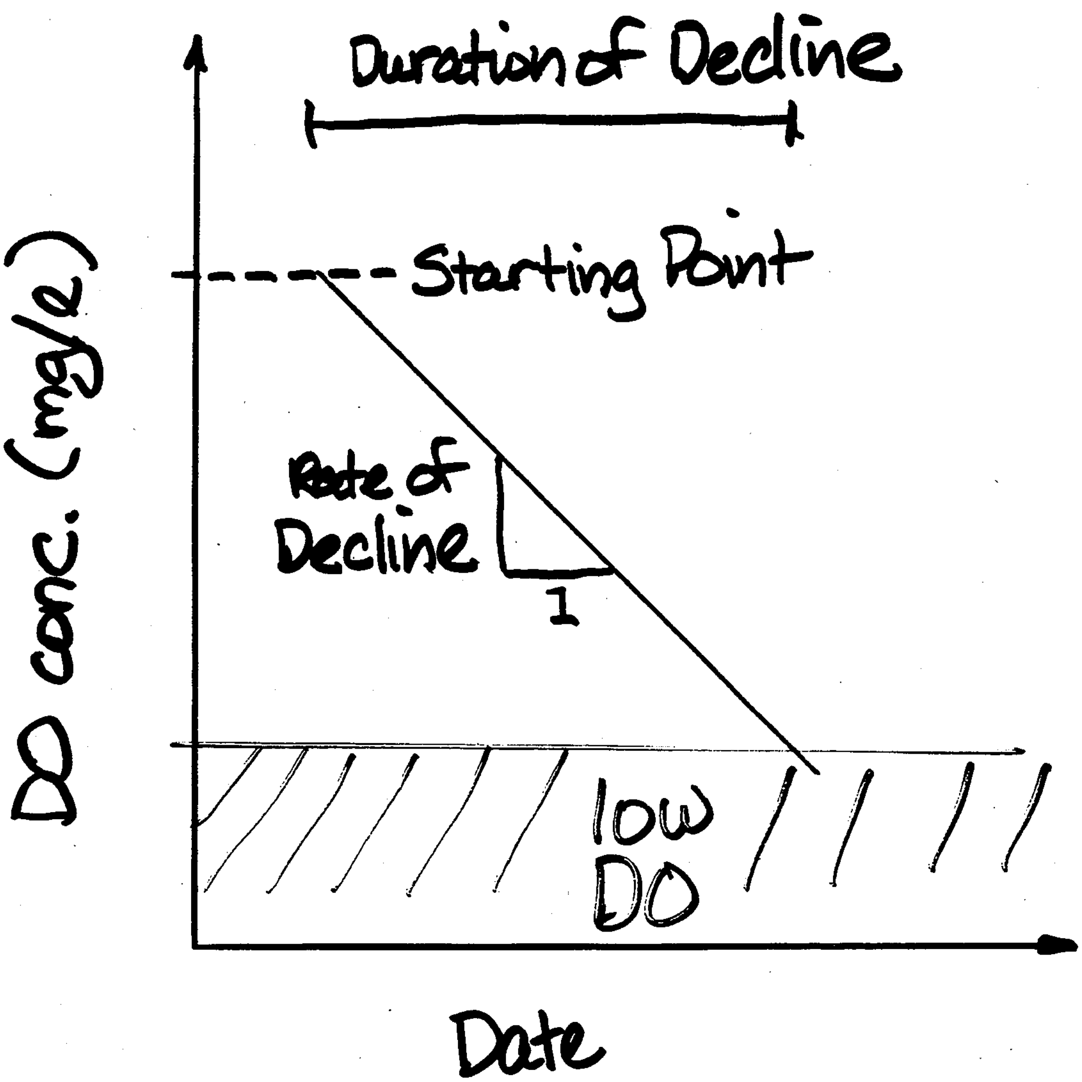


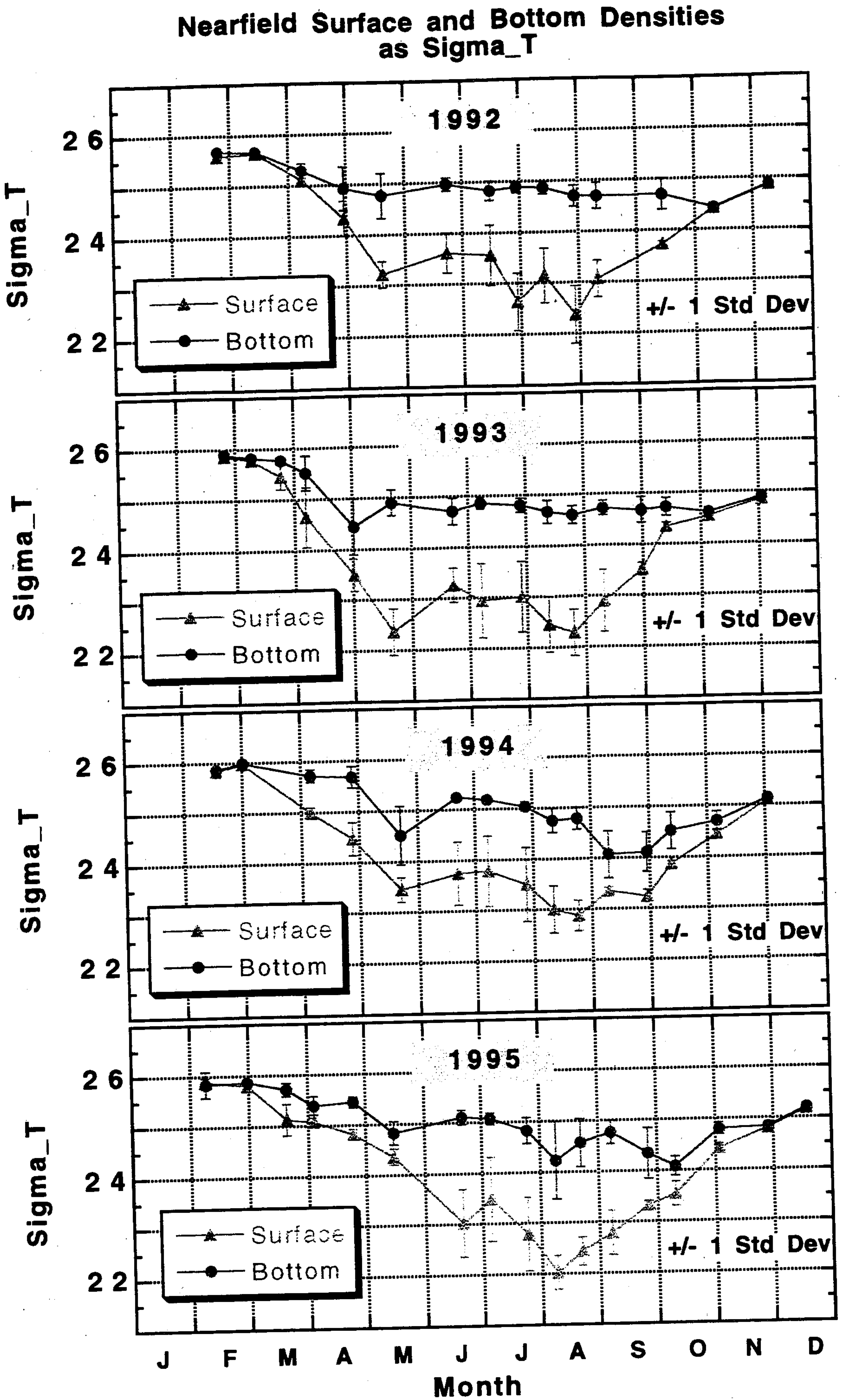

Nearfield
Average Dissolved Oxygen Concentrations
in Bottom Water Waters (>85% of Total Depth)
June - Sept.
+/- 1 Std Dev
1992
1993
1994
1995
Y =16.402 - .0309 X, R² = .921
Y = 14.980 - .0252 X, R² = 0.881
Y = 14.545 - .0302 X, R² = 0.927
Y = 13.899 - .0265 X, R² = 0.935
DO (mg/l)
12
11
10
9
8
7
6
5
June
July
August
Sept
Oct
Month


Stellwagen Basin
Average Dissolved Oxygen Concentrations
in Bottom Waters (>85% of Total Depth)
1992
1993
1994
1995
+/- 1 Std Dev
Y =14.185 - .0229 X, R² = .996
Y = 13.482 - .0185 X, R² = 0.988
Y = 13.267 - .0226 X, R² = 0.990
Y = 12.021 - .0188 X, R² = 0.971
DO (mg/l)
12
11
10
9
8
7
6
5
J F M A M J J A S O N D
Month

Bottom Water DO Depletion During Summer

- 3 Factors





Nearfield Surface and Bottom Densities
as Sigma_T
1992
1993
1994
1995
Sigma_T
26
24
22
Surface
Bottom
+/- 1 Std Dev
J
F
M
A
M
J
J
A
S
O
N
D
Month

Comparison of DO Decline Factors

Parameter	Minimum Value (Year)	Maximum Value (Year)	Typical Value	DO deviation (mg/l)
Duration of Decline (days)	80 (1992)	135 (1995)	95	1.5
Starting DO conc. (mg/l)	9.0 (1994)	10.2 (1993)	9.6	1.2
DO decline rate (mg/l/d)	0.025 (1993)	0.031 (1992)	0.028	0.6

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Comparison to DO Hypotheses

Rate of DO Decline

W1: The DO decline rate in the nearfield bottom waters will not double from the baseline average.

1992-1995 Average = 0.028 mg/l/d
Maximum Value = 0.031 mg/l/d
Max/Avg. = 111%
DO dev. w/doubling = 2.7 mg/l

W4: The DO decline rate in the Stellwagen basin bottom waters will not double from the baseline value.

1992-1995 Average = 0.021 mg/l/d
Maximum Value = 0.023 mg/l/d
Max/Avg. = 110%
DO dev. w/doubling = 2.0 mg/l

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Comparison to DO Hypotheses

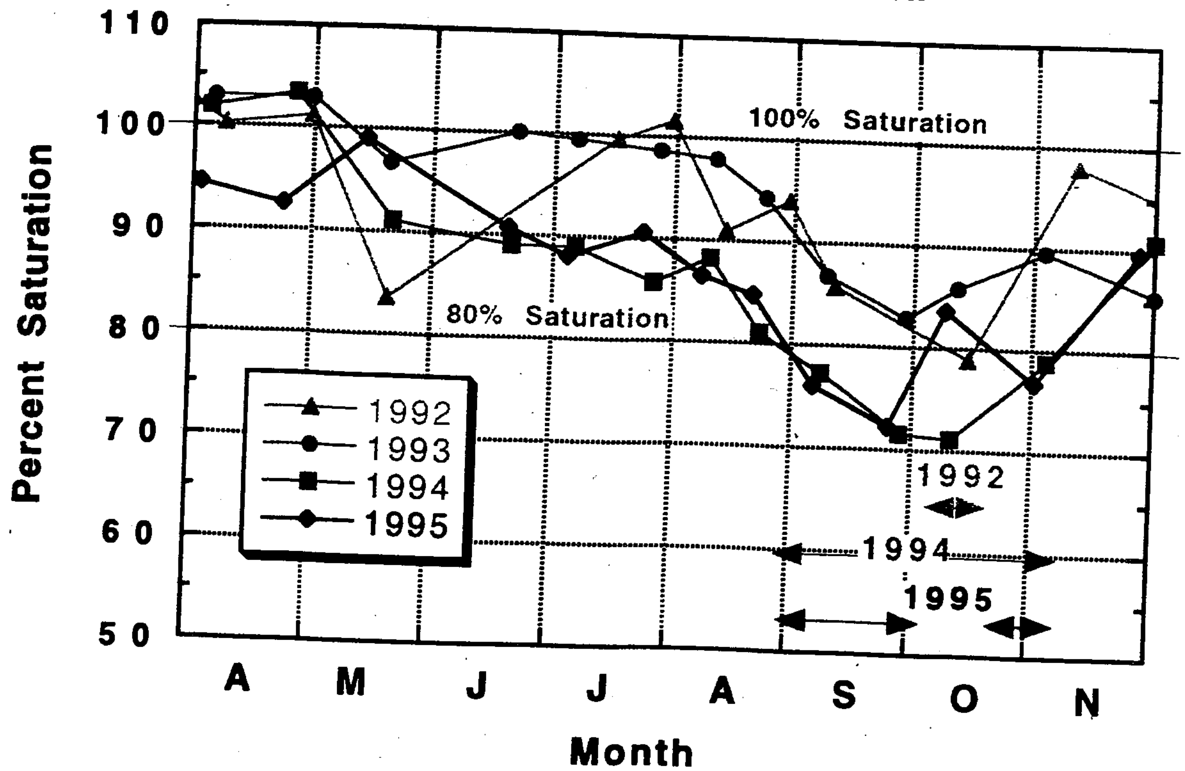
Duration of Depressed DO conc.

W2: Nearfield average DO conc. will not go below 6.5 mg/l or 80% saturation for more than one month.

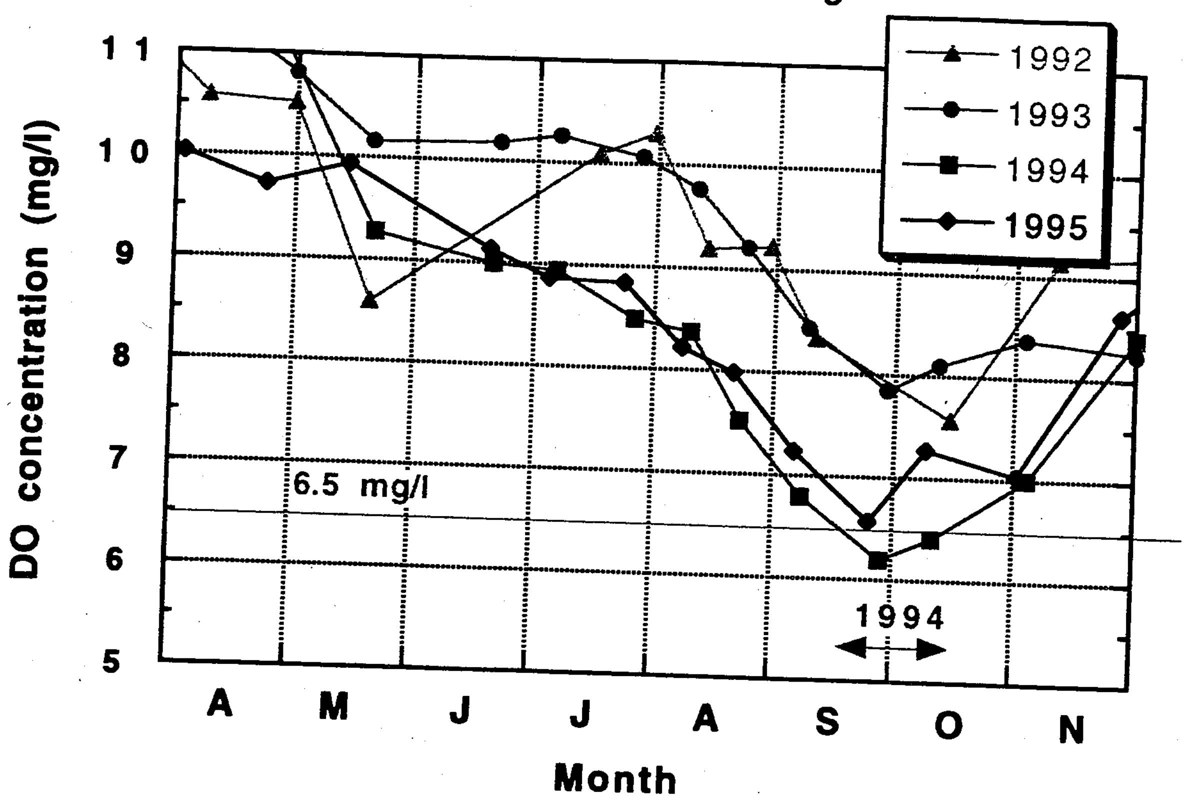
W5: Stellwagen basin average DO conc. will not go below 6.5 mg/l or 80% saturation for more than one month.

Nearfield
DO in Bottom Waters (>85% of Total Depth)

Duration below 80% Saturation

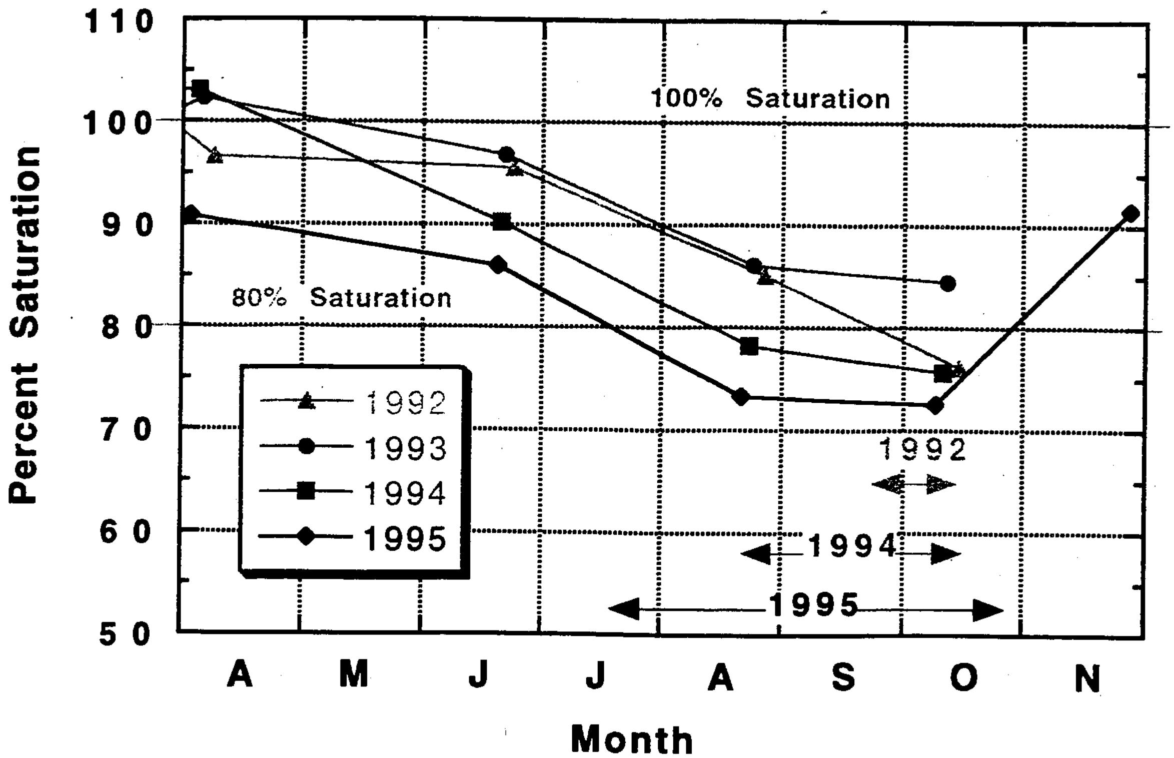


Duration below 6.5 mg/l

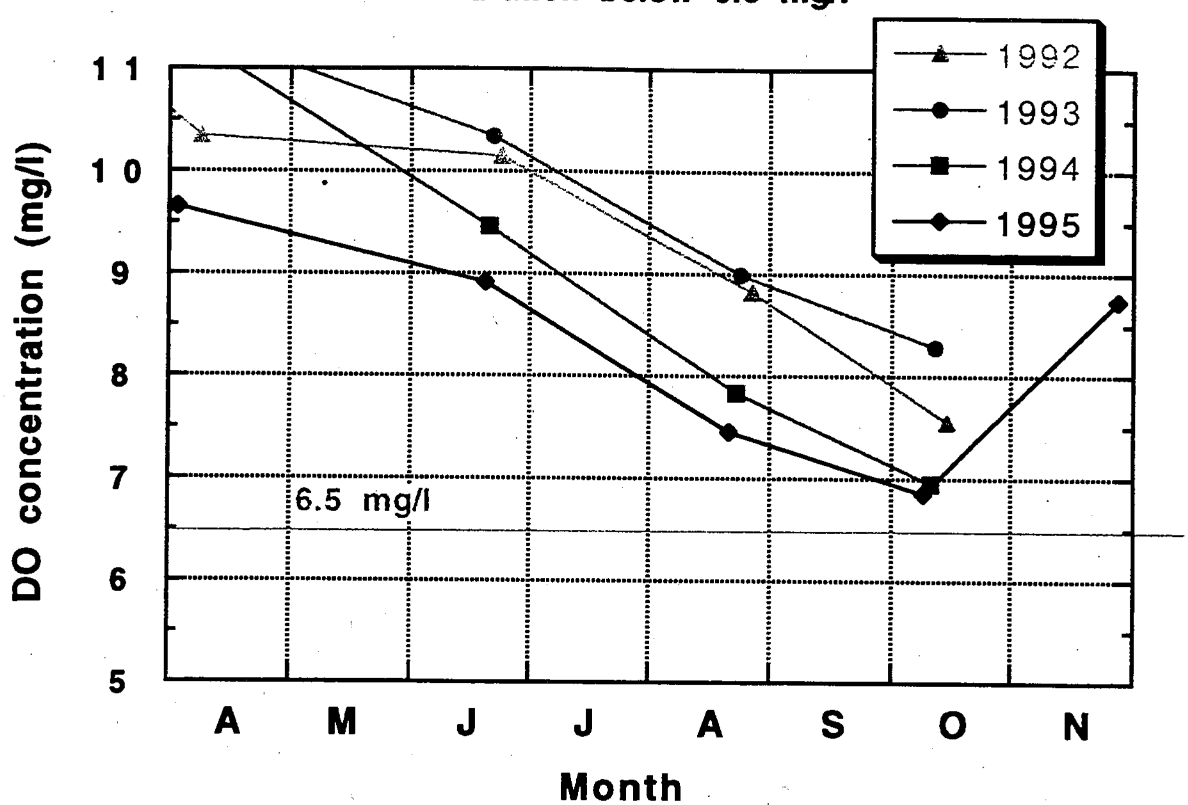


Stellwagen Basin
DO in Bottom Waters (>85% of Total Depth)

Duration below 80% Saturation



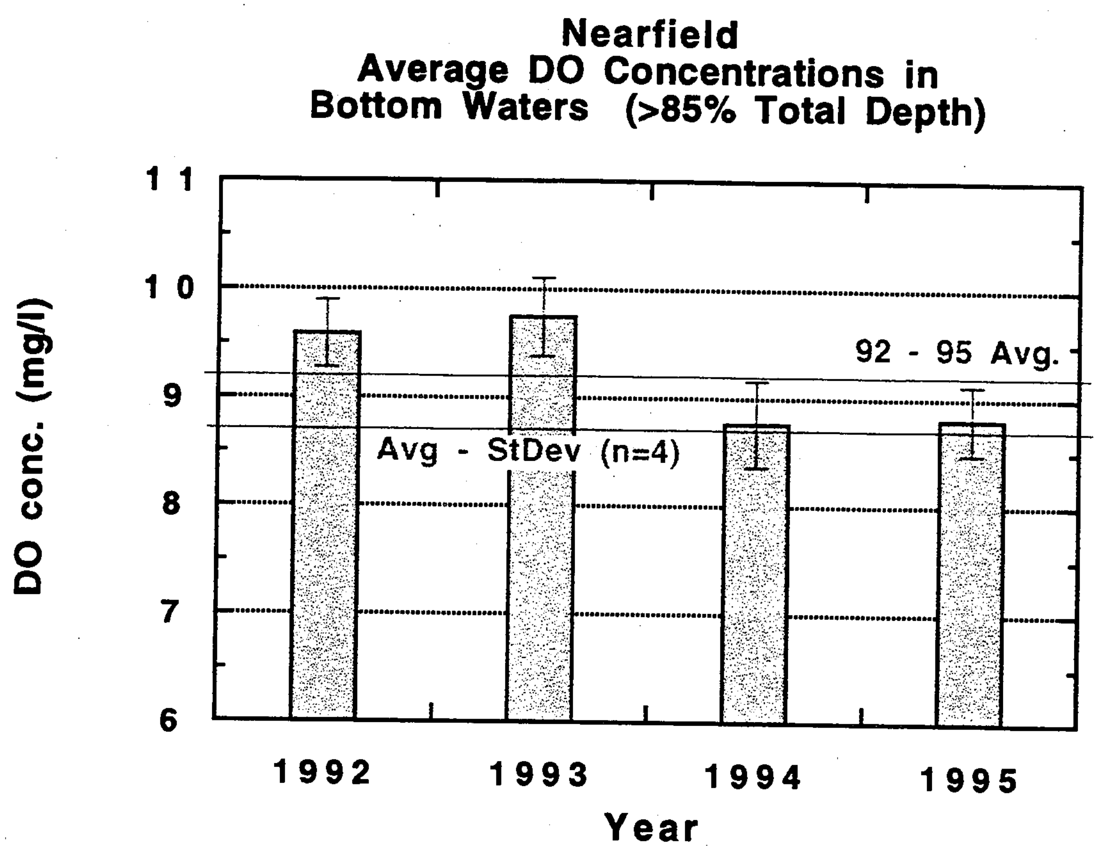
Duration below 6.5 mg/l



ENSR

Comparison to DO Hypotheses

W3: Annual average DO conc. in the nearfield will not be more than 1 standard deviation below the baseline average for three years in a row.


Nearfield
Average DO Concentrations in
Bottom Waters (>85% Total Depth)
11
10
9
8
7
6
DO conc. (mg/l)
92 - 95 Avg.
Avg - StDev (n=4)
1992
1993
1994
1995
Year

ENSR

Summary and Conclusions

- DO temporal patterns in 1995 are similar to 1994
- Seasonal rate of DO decline very similar from year to year
- duration of decline and starting DO have varied significantly from year to year
- both these measures could be used to forecast low DO concentrations
- 2 of the 5 DO hypotheses have been rejected during the baseline period

APPENDIX C-4

Ted Loder
UNH

Nutrient Dynamics in Massachusetts Bay during 1995

Theodore C. Loder III and Robert Boudrow
Estuarine/Coastal Chemistry Laboratory
Institute for the Study of Earth, Oceans, and Space
University of New Hampshire, Durham, NH 03824

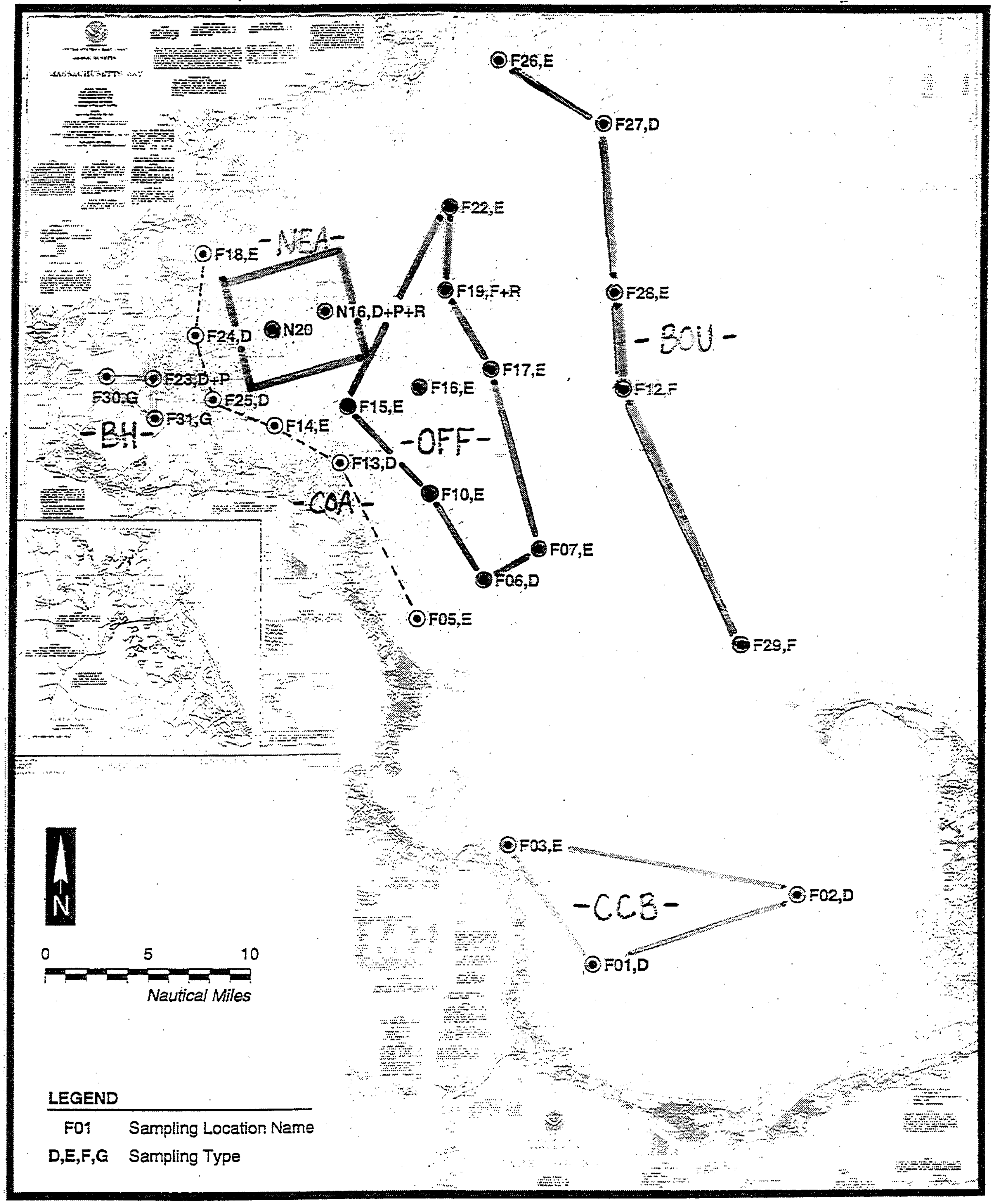
The data will be presented in several parts:

1. changes in nutrient distributions throughout the year in Massachusetts Bays using nutrient/depth trends, nutrient/salinity trends, and nutrient/ nutrient relationships

2. seasonal nutrient trends at selected Nearfield stations

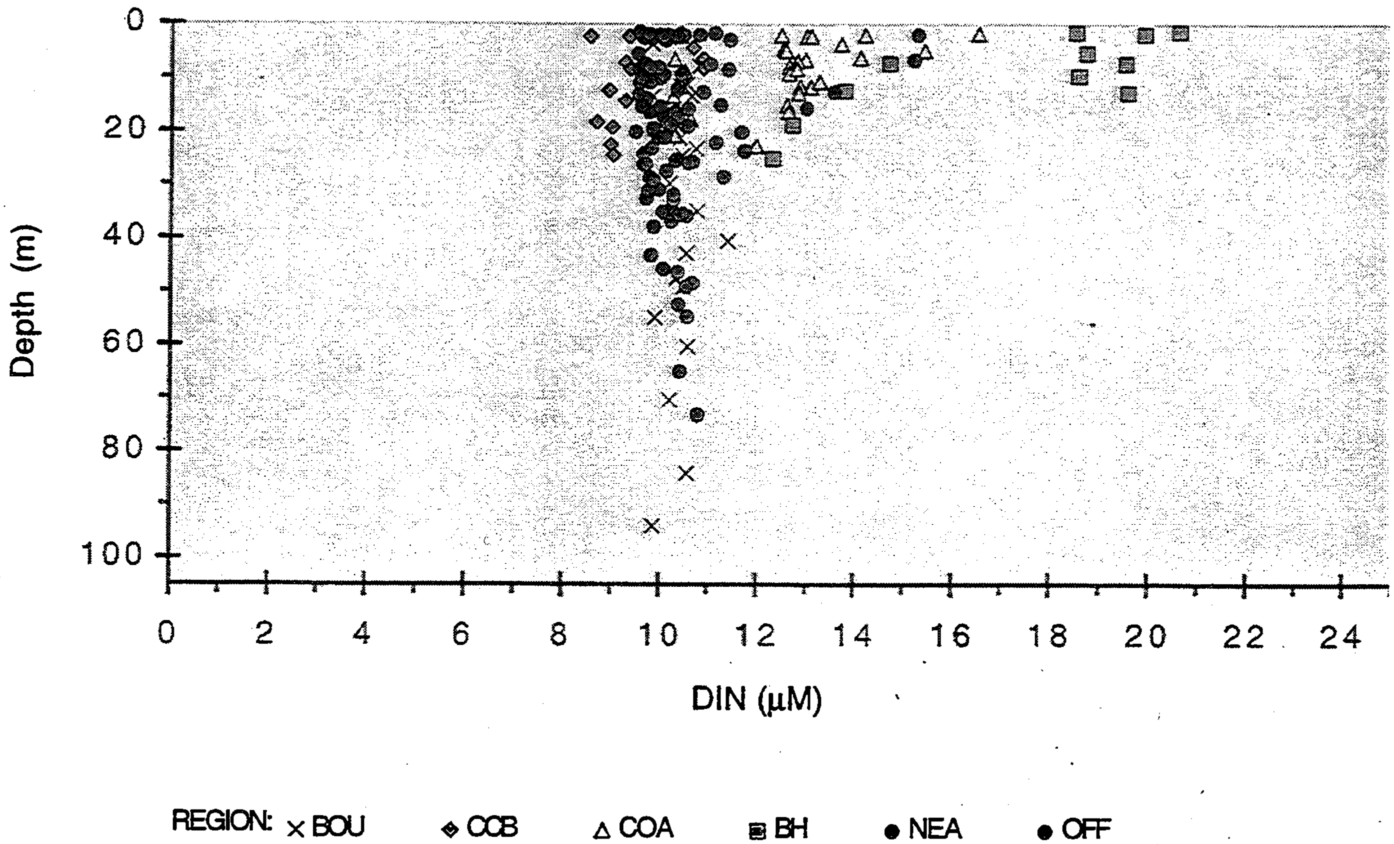
3. a comparison of nutrient changes in the Nearfield region over the past several years using the seasonal nutrient trend plots.

Station Map

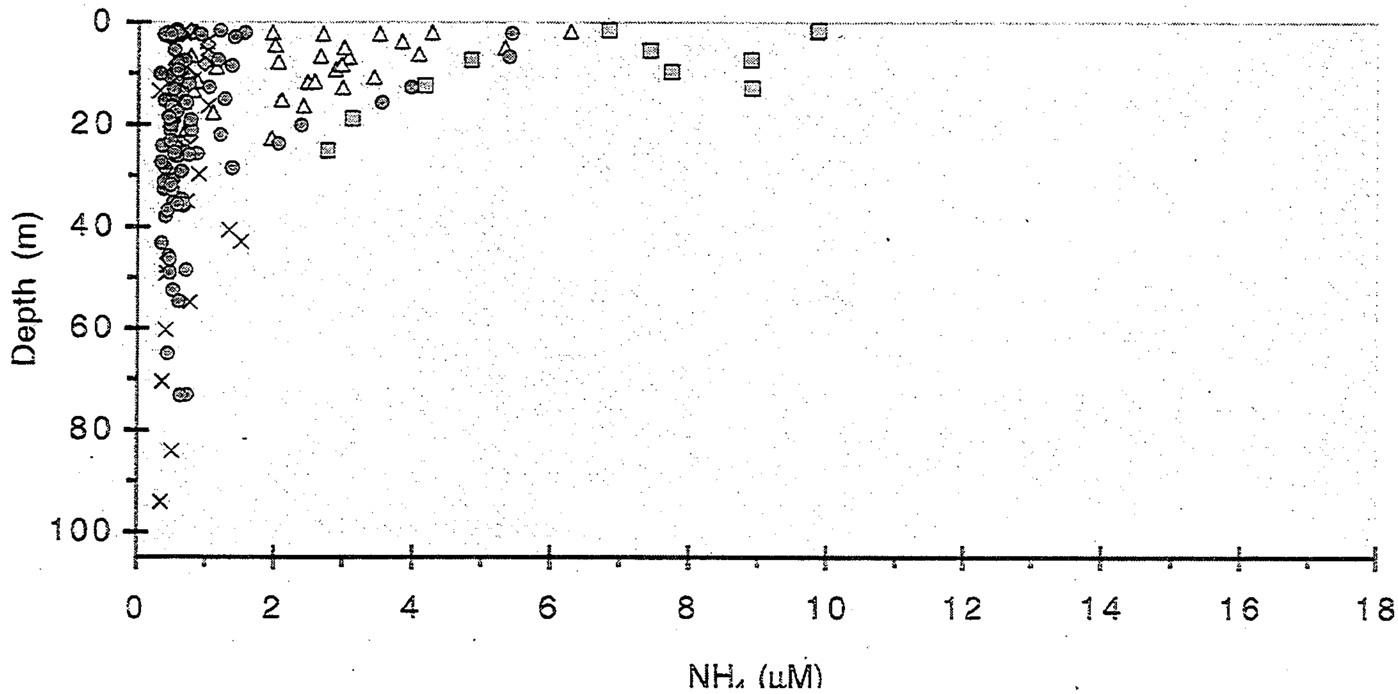


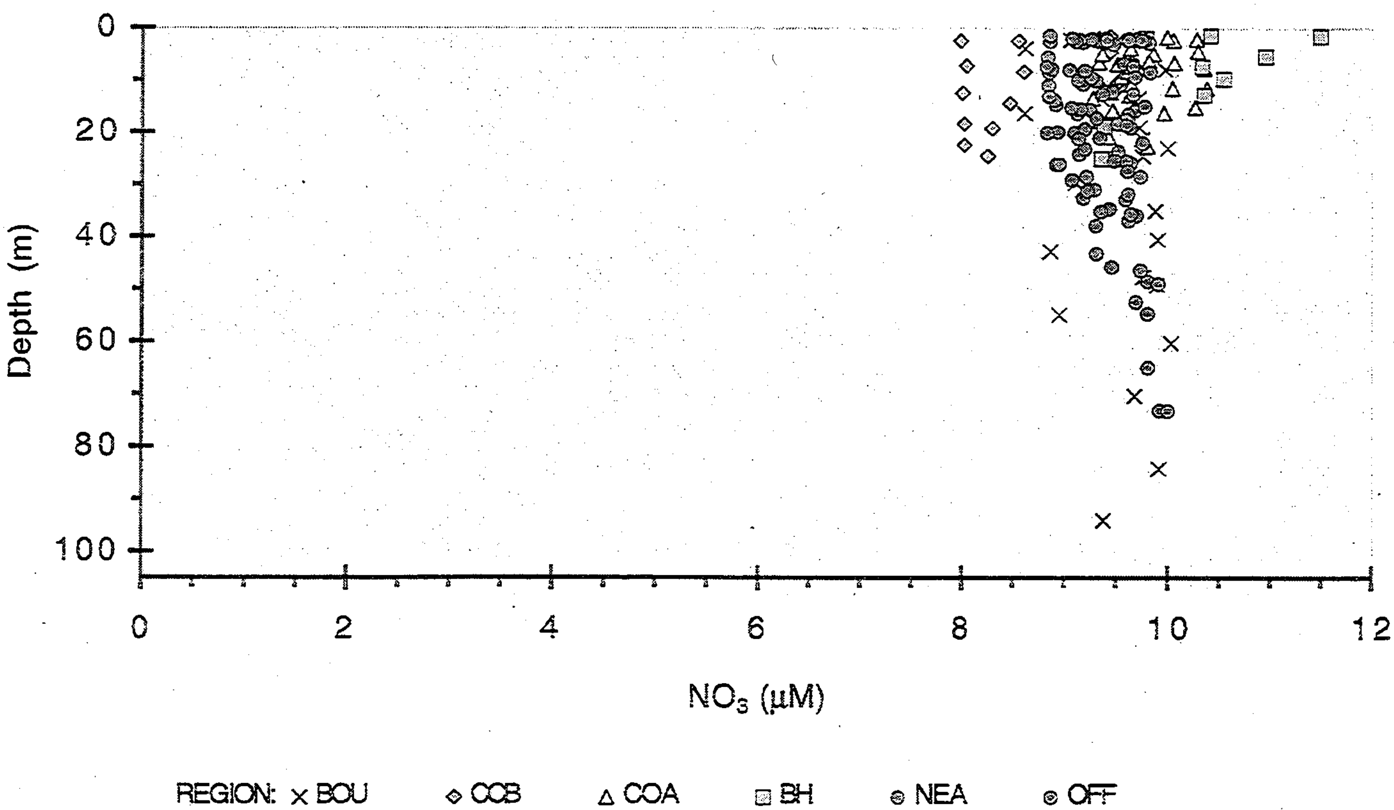
Station Map courtesy of ENSR Consulting & Engineering

W9501, Feb 13

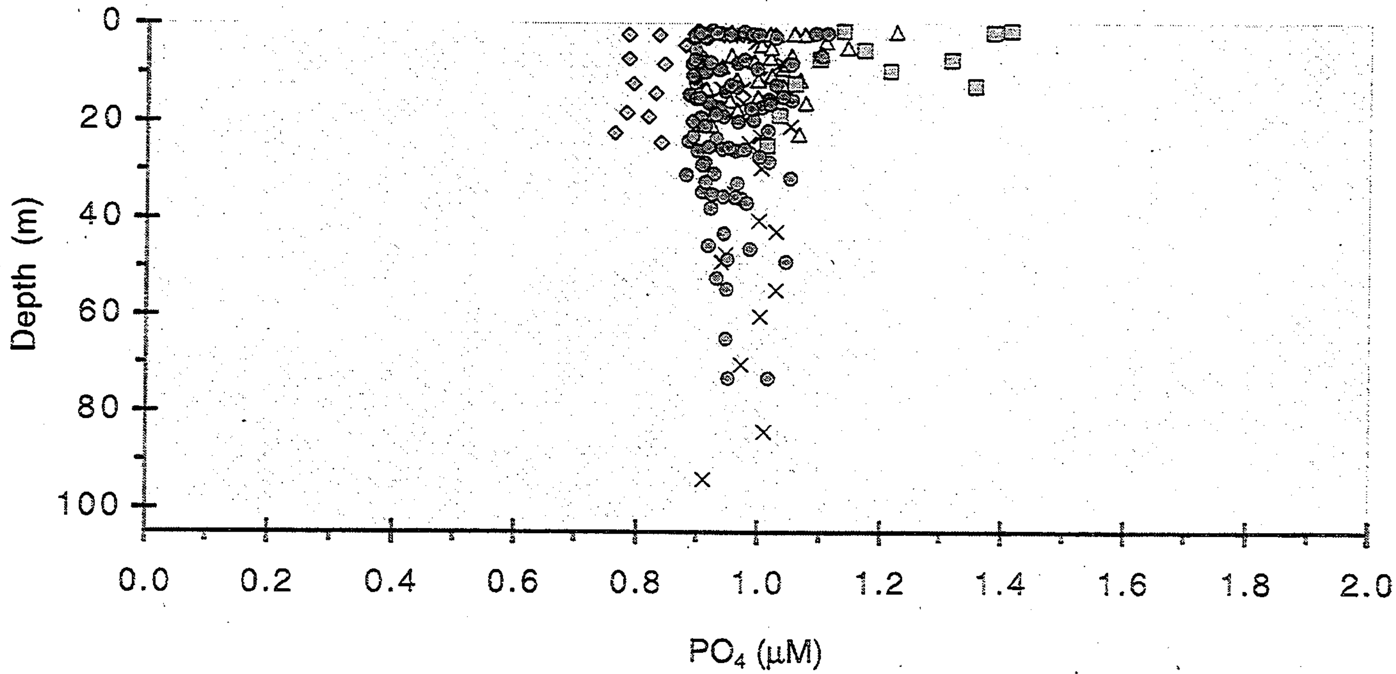

0
20
40
60
80
100
Depth (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
DIN (µM)
REGION: × BOU ◈ CCB △ COA ▣ BH ● NEA ● OFF

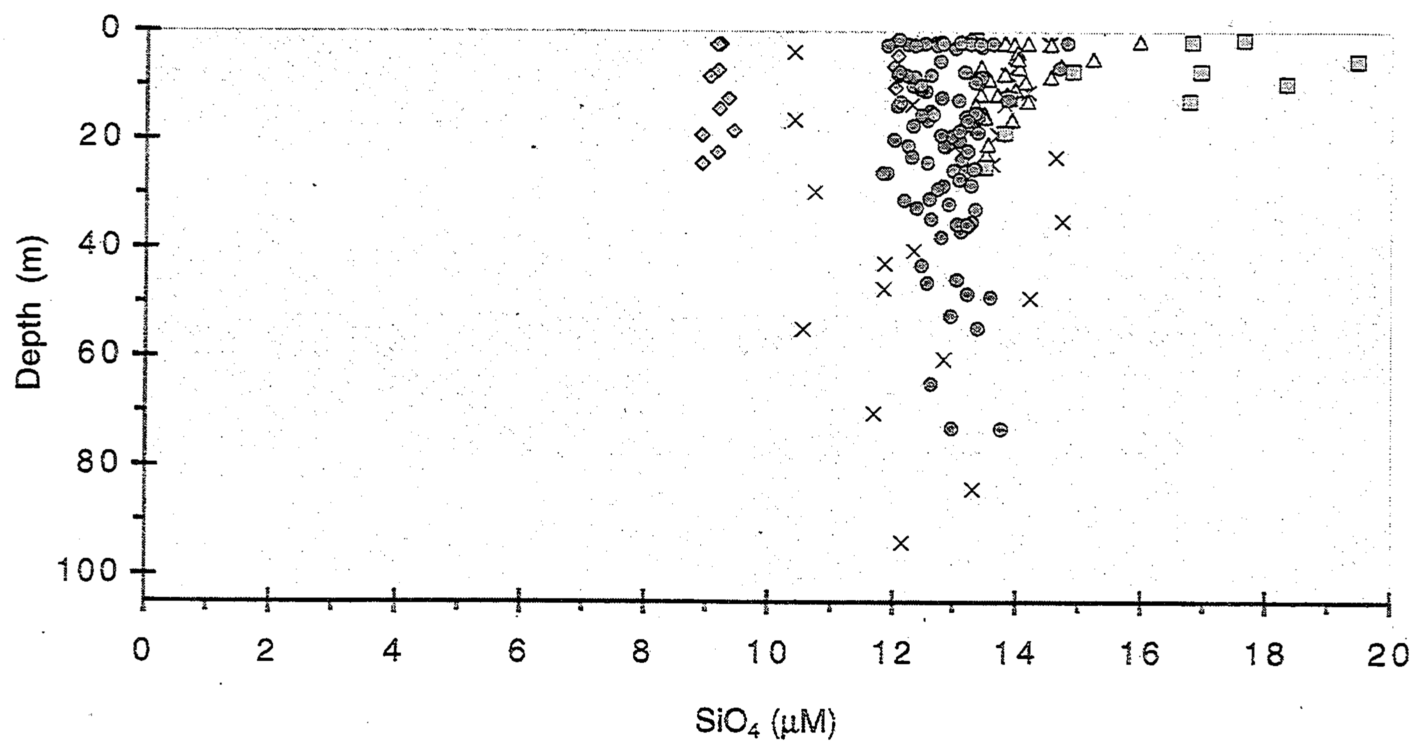
W9501, Feb 13


Depth (m)
0
20
40
60
80
100
0
2
4
6
8
10
12
14
16
18
NH4 (µM)

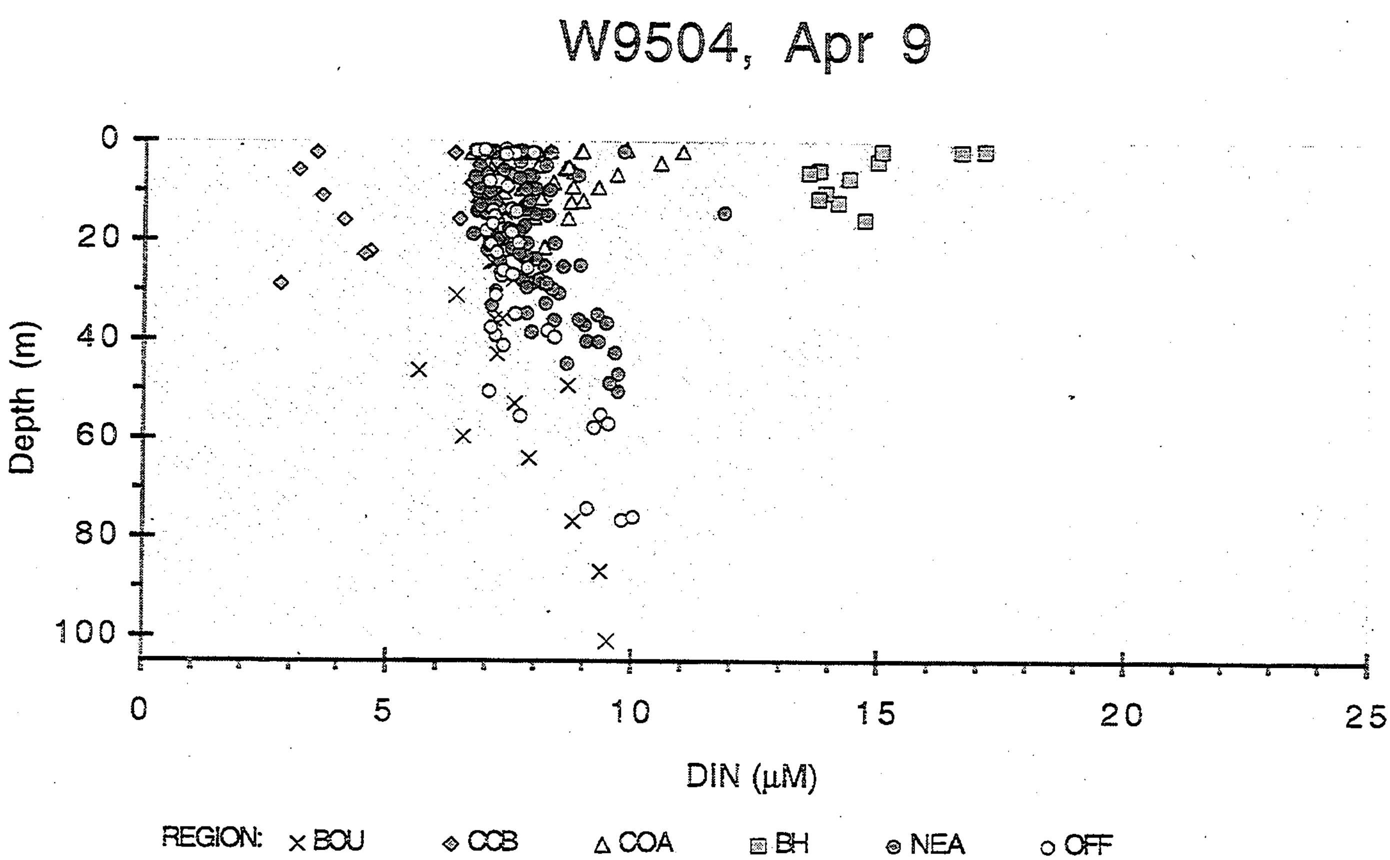

Depth (m)
0
20
40
60
80
100
0
2
4
6
8
10
12
NO3 (µM)
REGION: × BOU ◇ CCB △ COA ▢ BH ⊚ NEA ⊚ OFF

W9501, Feb 13

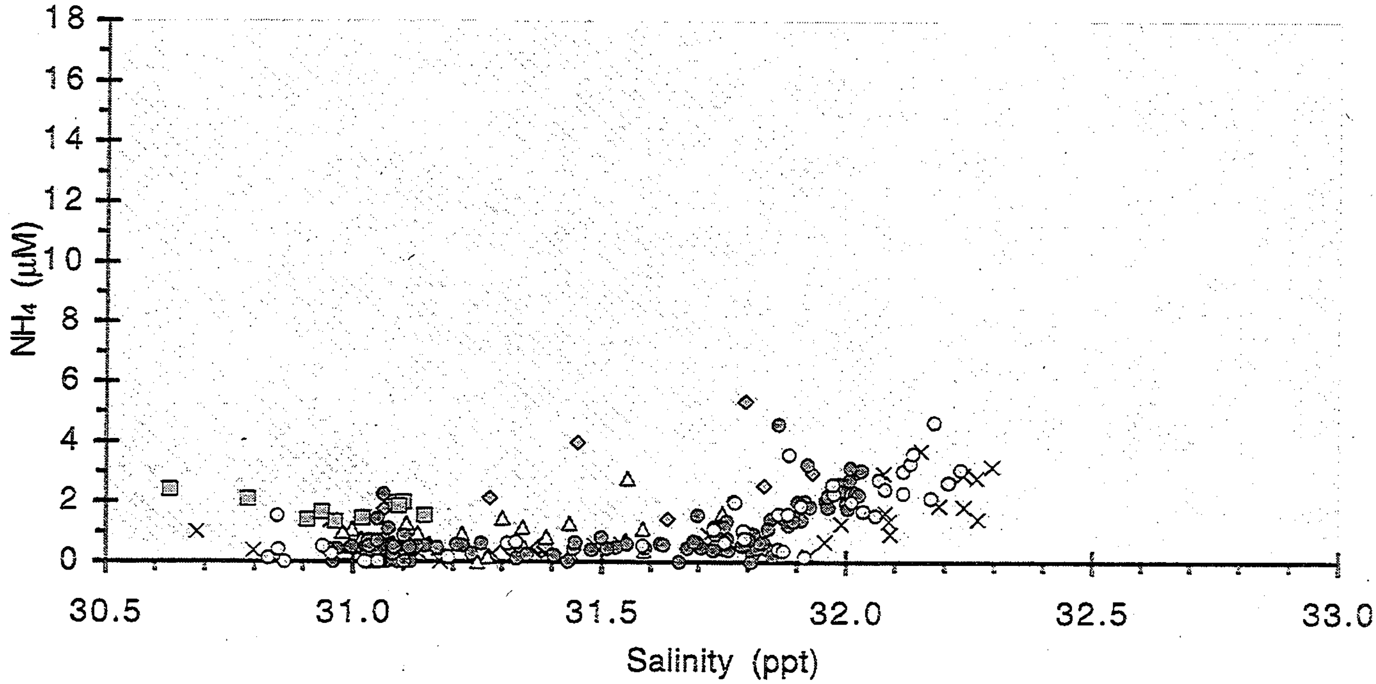


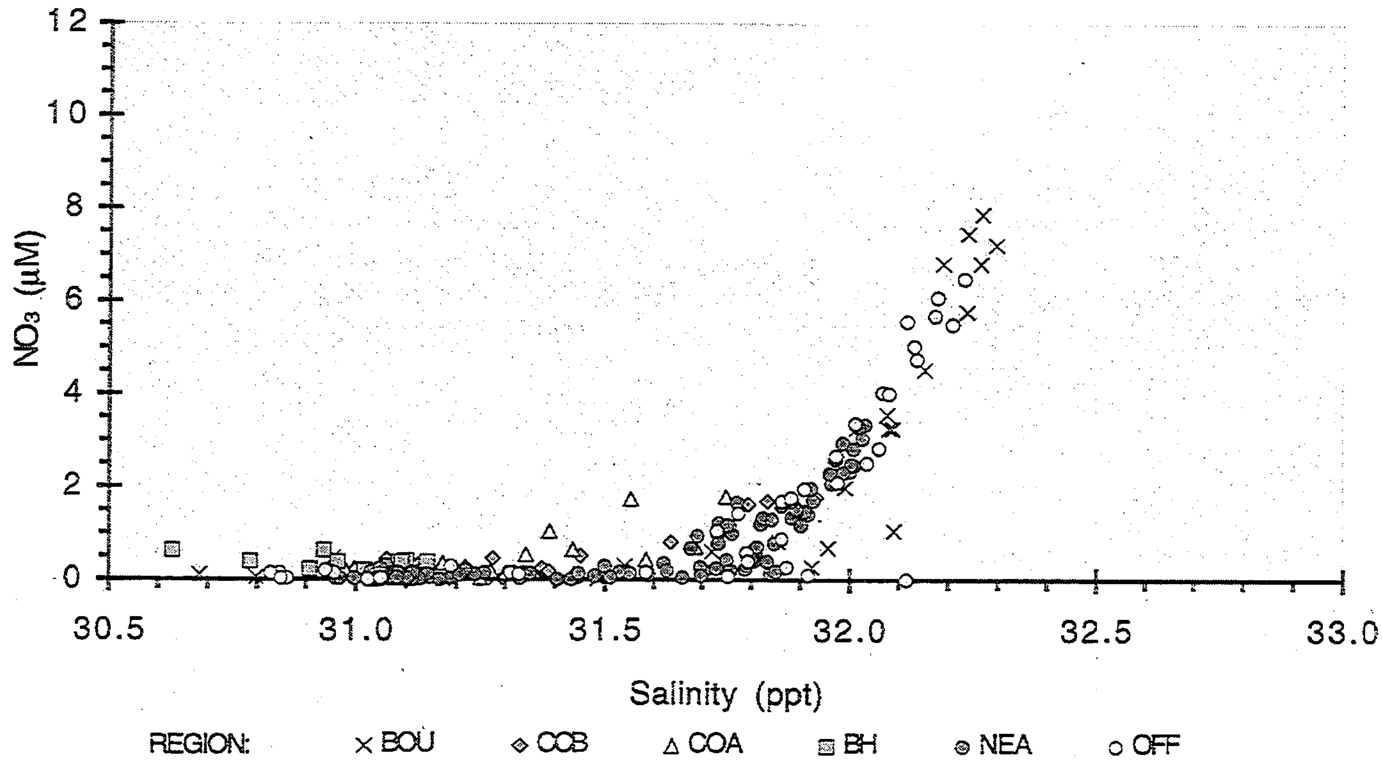


REGION: × BOU ◇ CCB △ COA ▫ BH ◉ NEA ◎ OFF

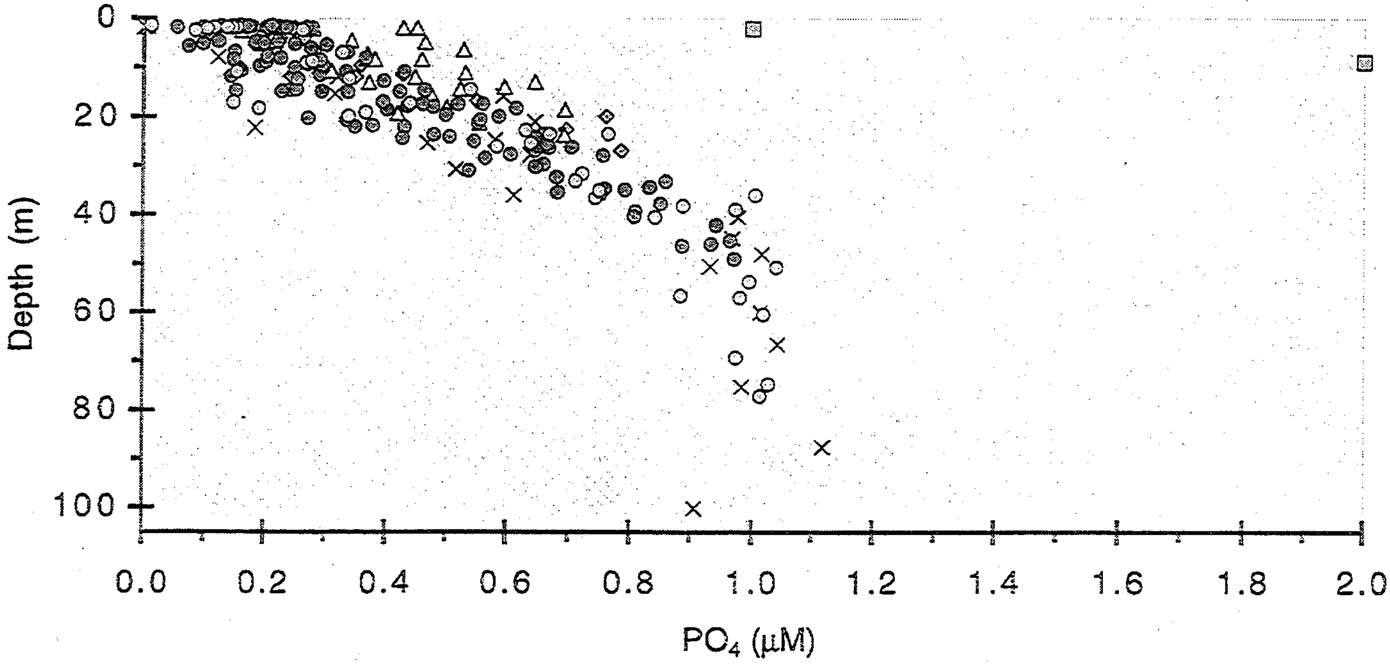

W9504, Apr 9
Depth (m)
0
20
40
60
80
100
0
5
10
15
20
25
DIN (µM)
REGION: × BOU ◇ CCB △ COA ▣ BH ⊙ NEA ○ OFF

W9507, May 24

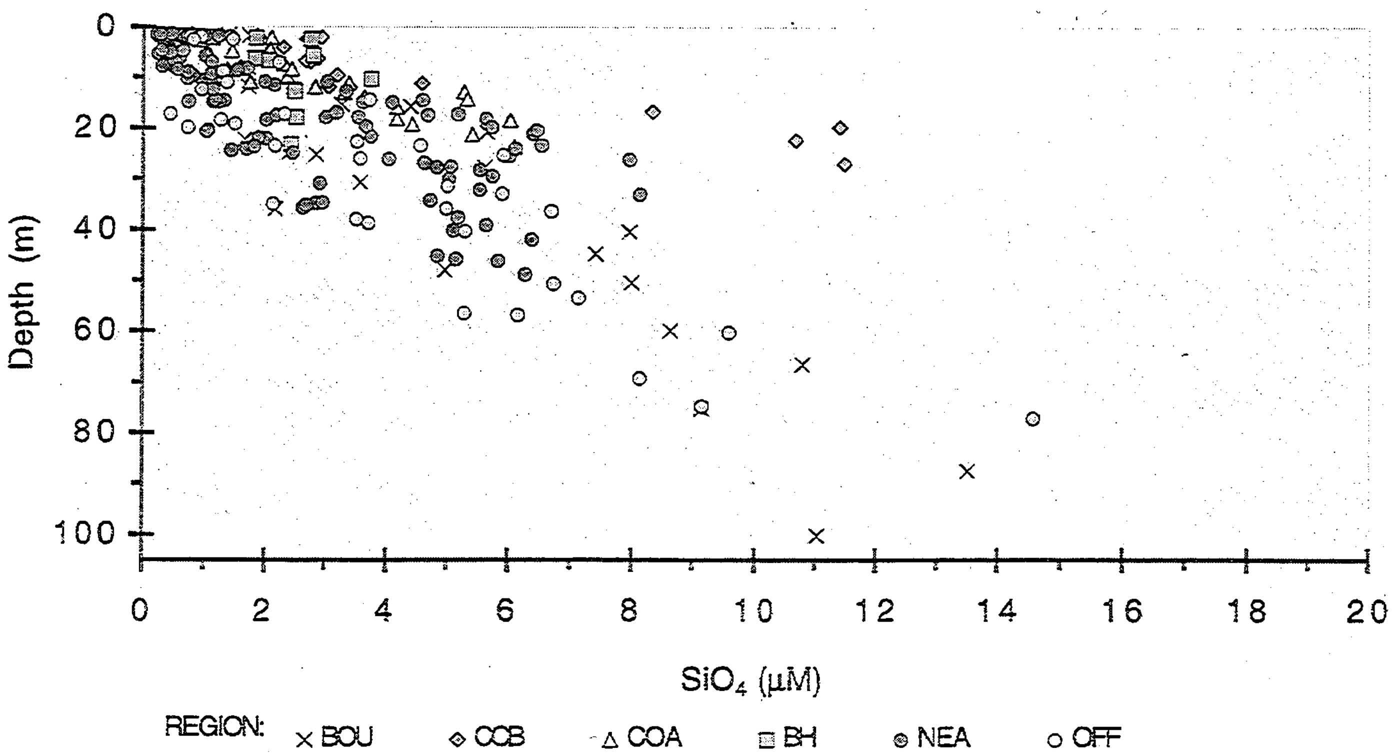

18
16
14
12
10
8
6
4
2
0
NH4 (μM)
30.5
31.0
31.5
32.0
32.5
33.0
Salinity (ppt)


12
10
8
6
4
2
0
NO3 (μM)
30.5
31.0
31.5
32.0
32.5
33.0
Salinity (ppt)
REGION:
× BOU
◇ CCB
△ COA
▨ BH
◉ NEA
○ OFF

W9507, May 24

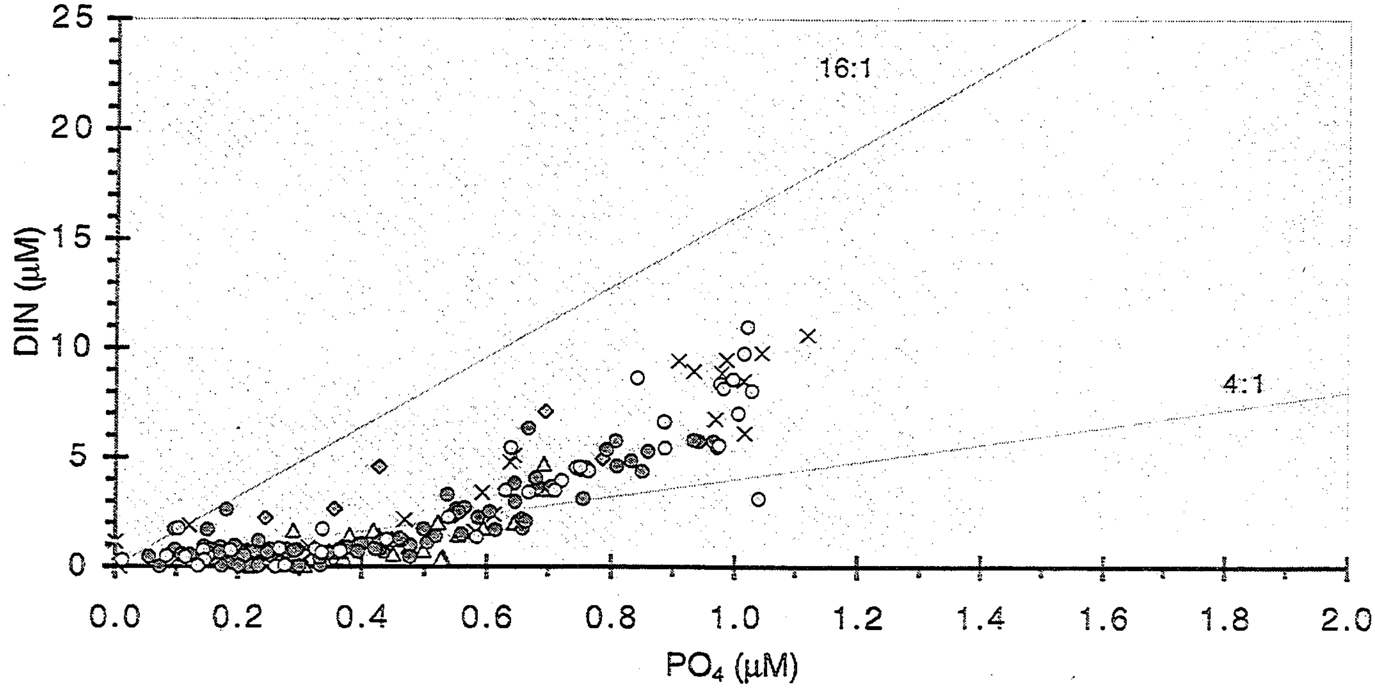


Depth (m)
0
20
40
60
80
100
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
PO4 (µM)

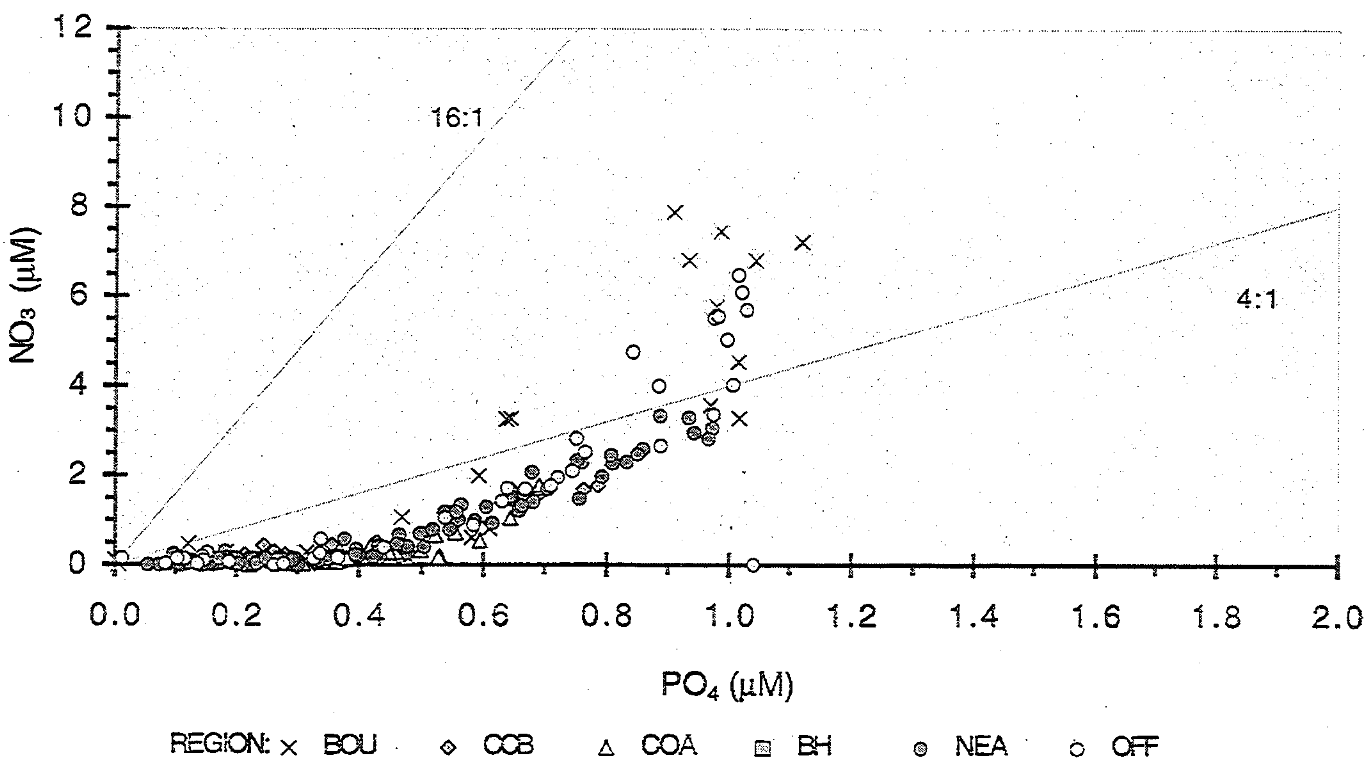


Depth (m)
0
20
40
60
80
100
0
2
4
6
8
10
12
14
16
18
20
SiO4 (µM)
REGION: × BOU ◇ CCB △ COA □ BH ● NEA ○ OFF

W9507, May 24

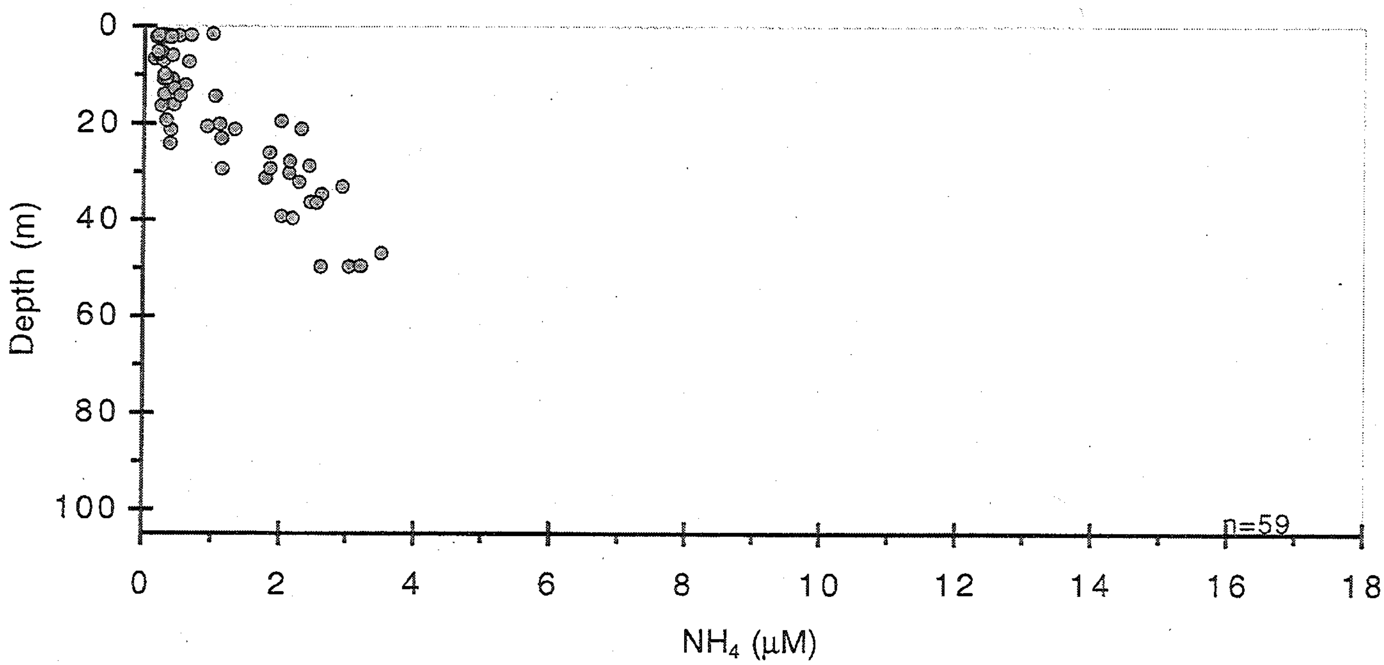


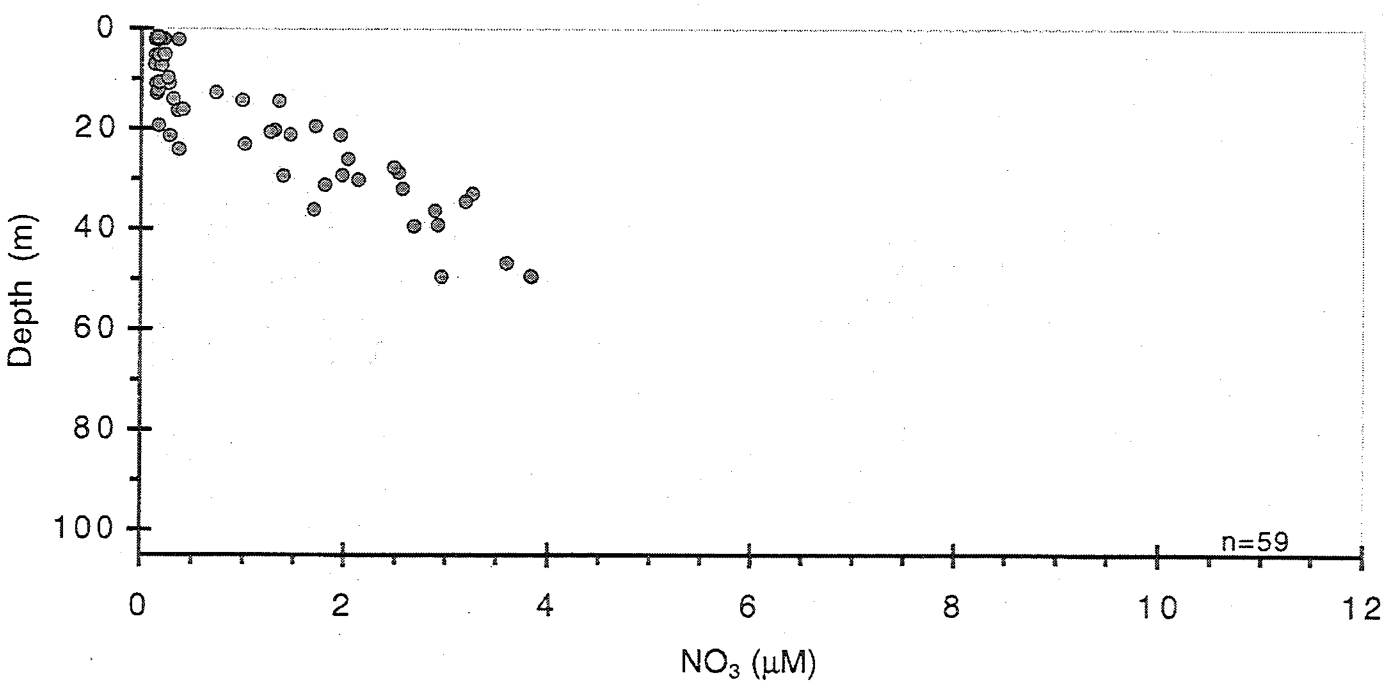
16:1
4:1
DIN (µM)
PO4 (µM)



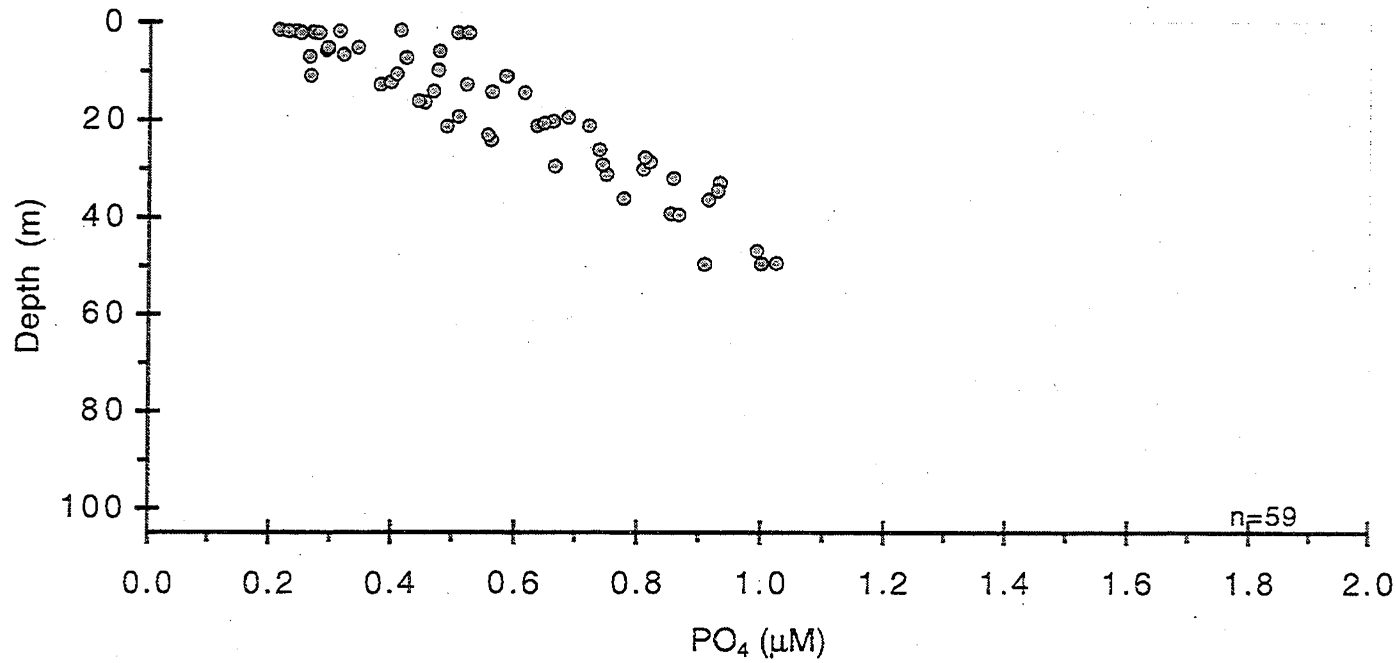
16:1
4:1
NO3 (µM)
PO4 (µM)
REGION: × BOU ◇ CCB △ COA ▩ BH ● NEA ○ OFF

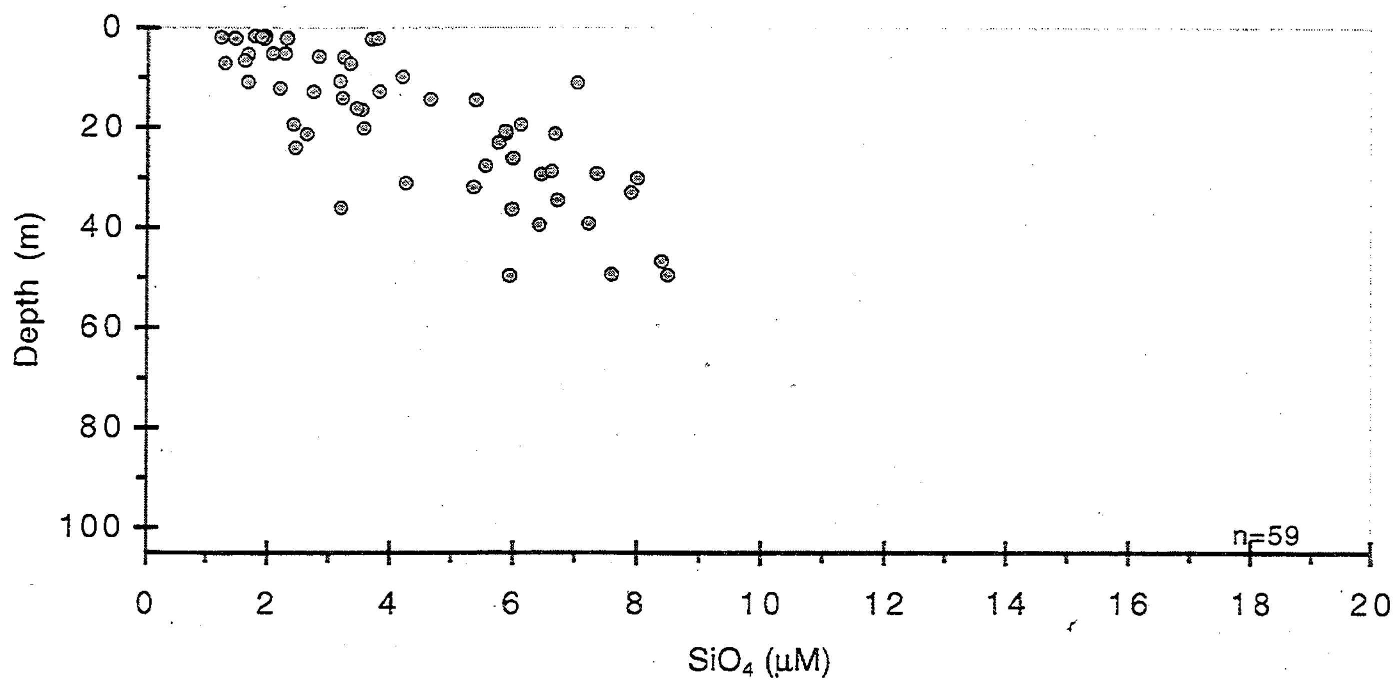
W9508, Jun 6

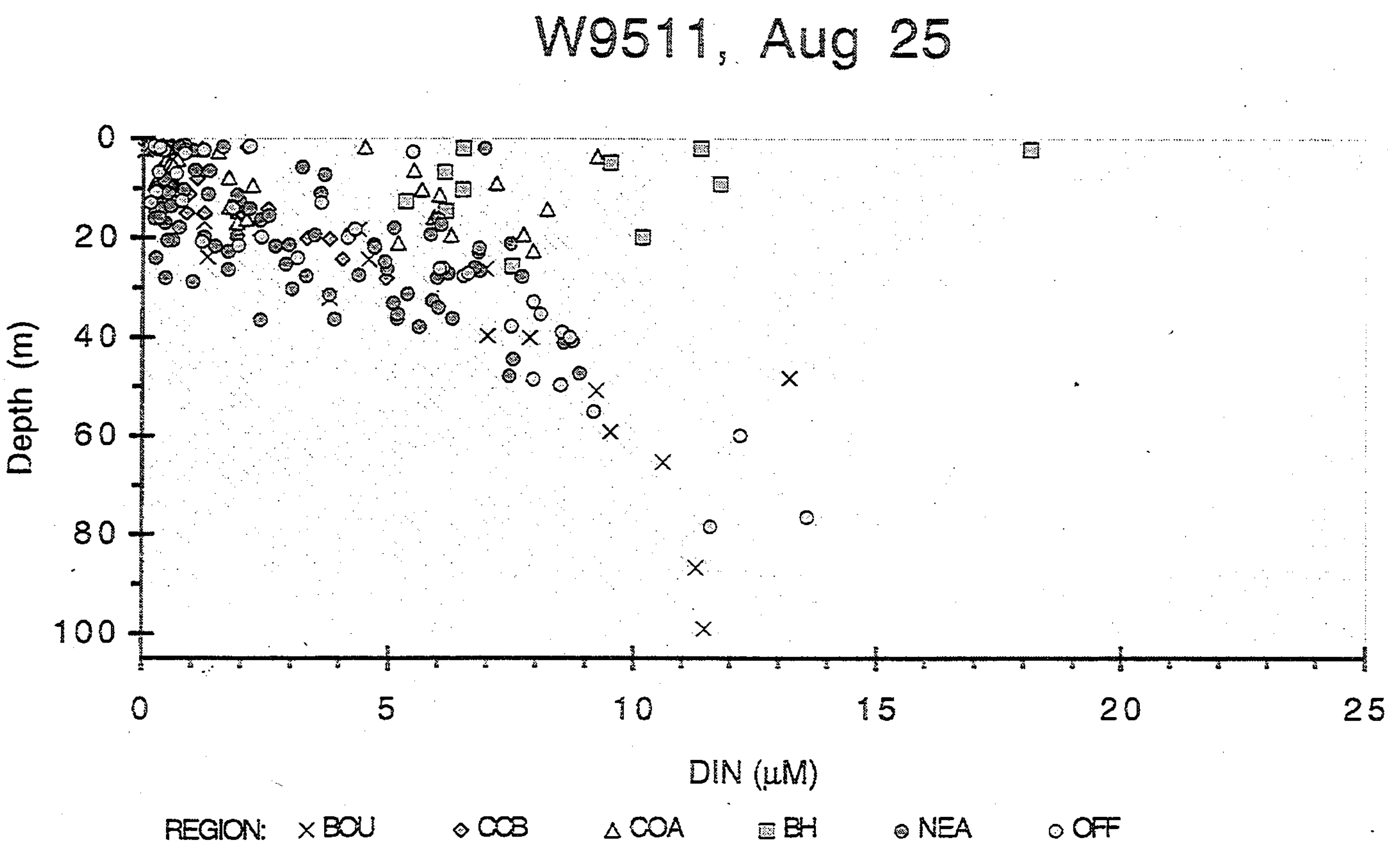

0
20
40
60
80
100
Depth (m)
n=59
0
2
4
6
8
10
12
14
16
18
NH4 (µM)


0
20
40
60
80
100
Depth (m)
n=59
0
2
4
6
8
10
12
NO3 (µM)

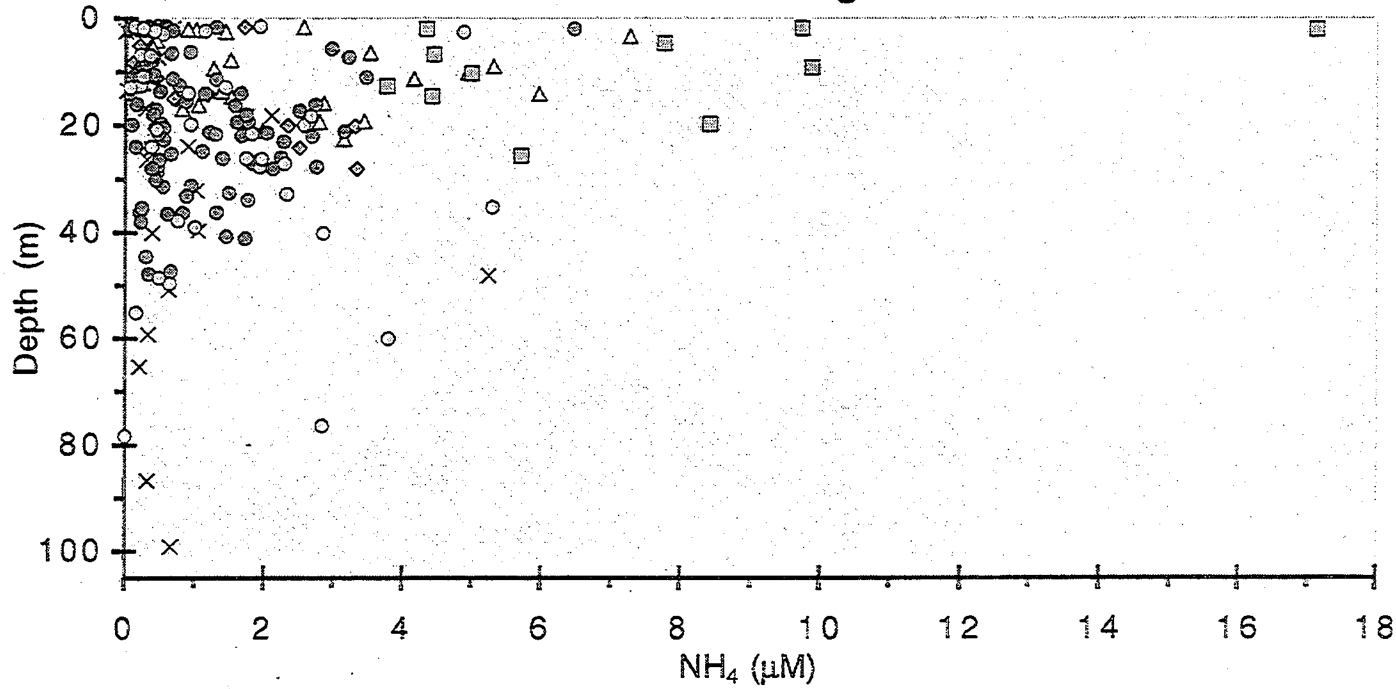
W9508, Jun 6

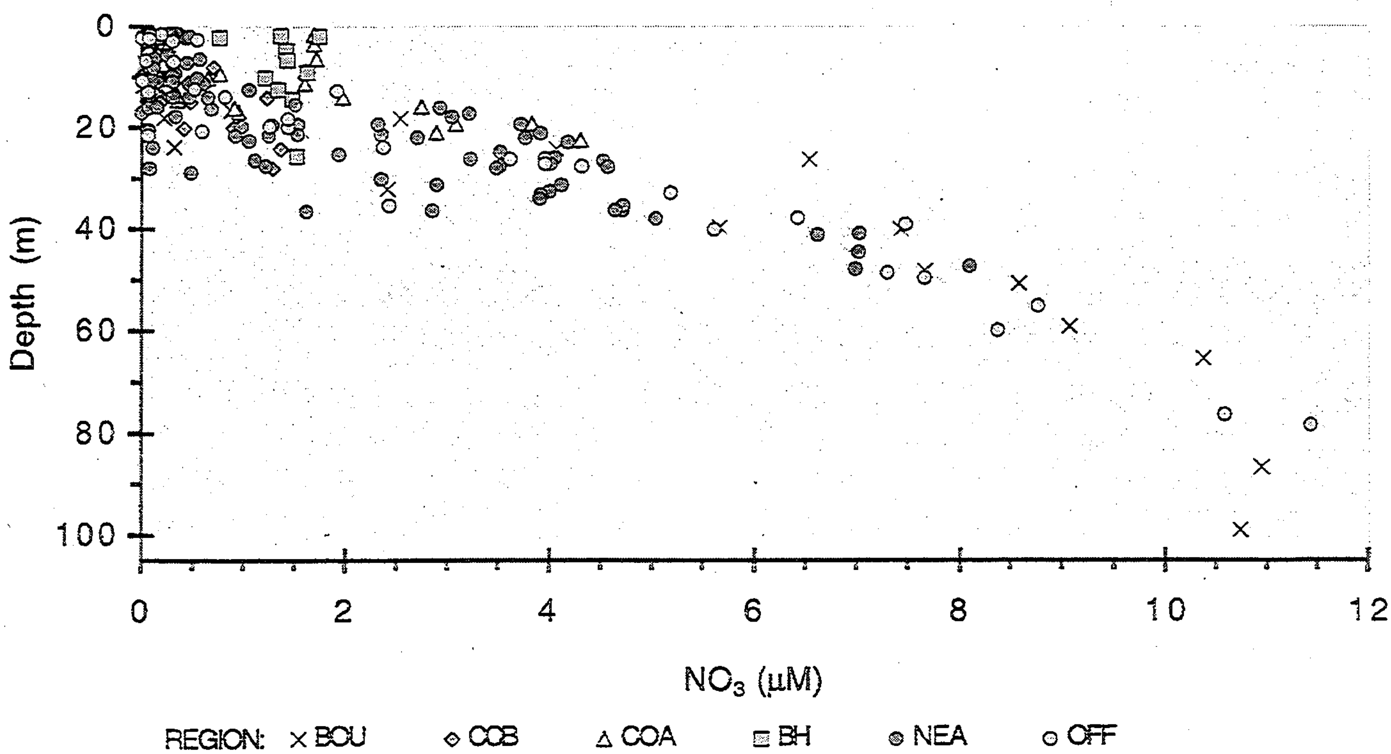

0
20
40
60
80
100
Depth (m)
n=59
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
PO4 (µM)


0
20
40
60
80
100
Depth (m)
n=59
0
2
4
6
8
10
12
14
16
18
20
SiO4 (µM)

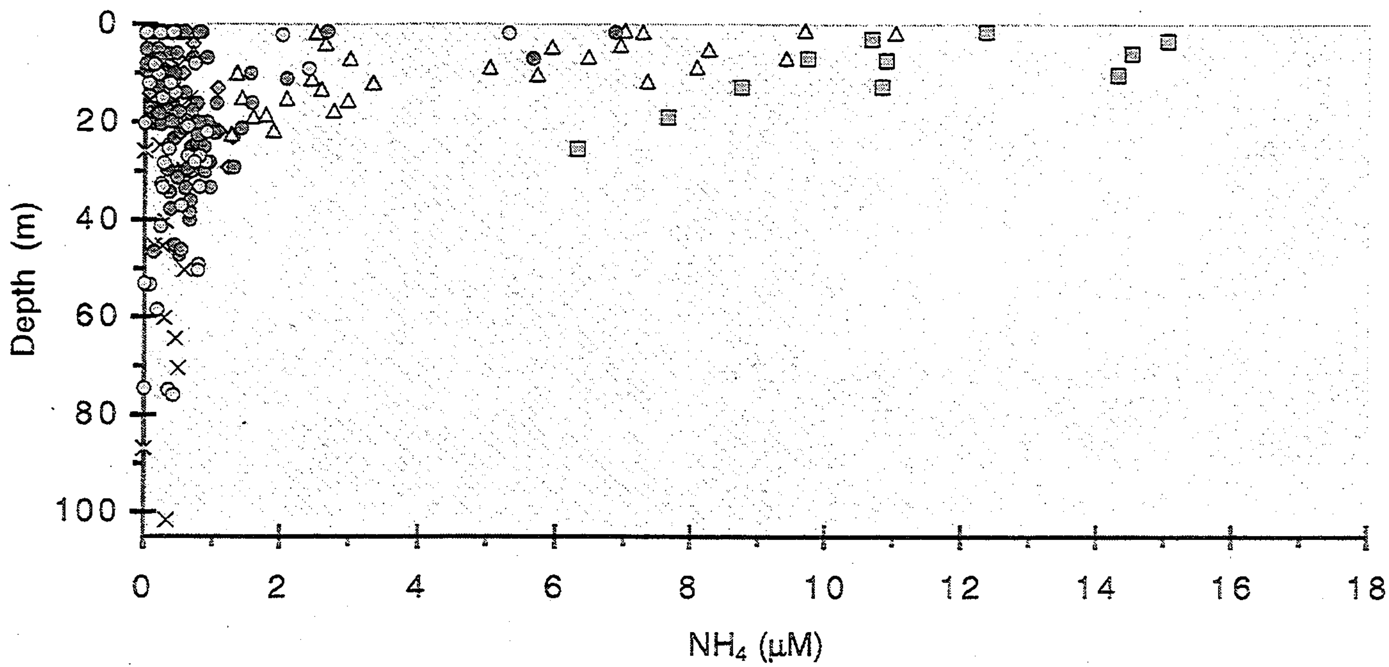

W9511, Aug 25
Depth (m)
0
20
40
60
80
100
0
5
10
15
20
25
DIN (µM)
REGION: × BOU ◇ CCB △ COA ▣ BH ⊚ NEA ○ OFF

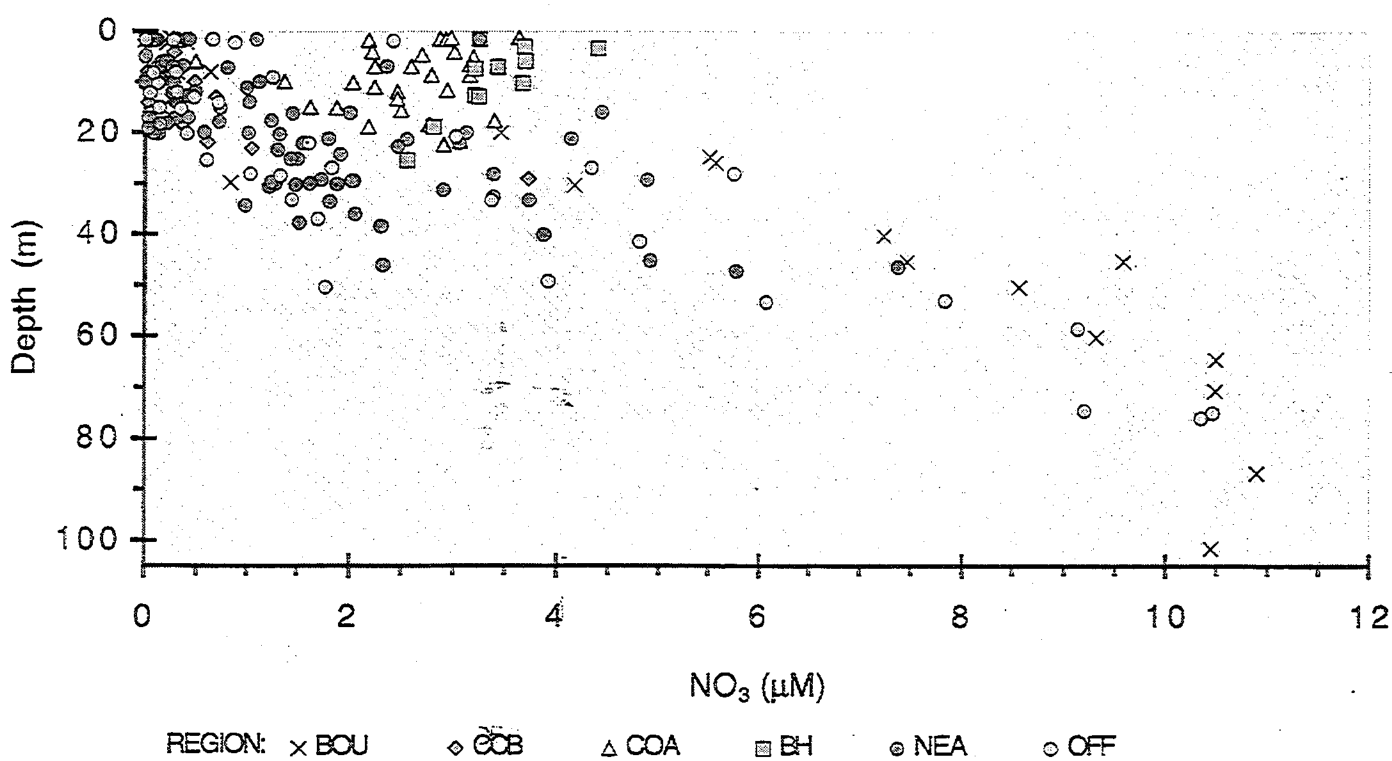
W9511, Aug 25


Depth (m)
0
20
40
60
80
100
0
2
4
6
8
10
12
14
16
18
NH4 (µM)

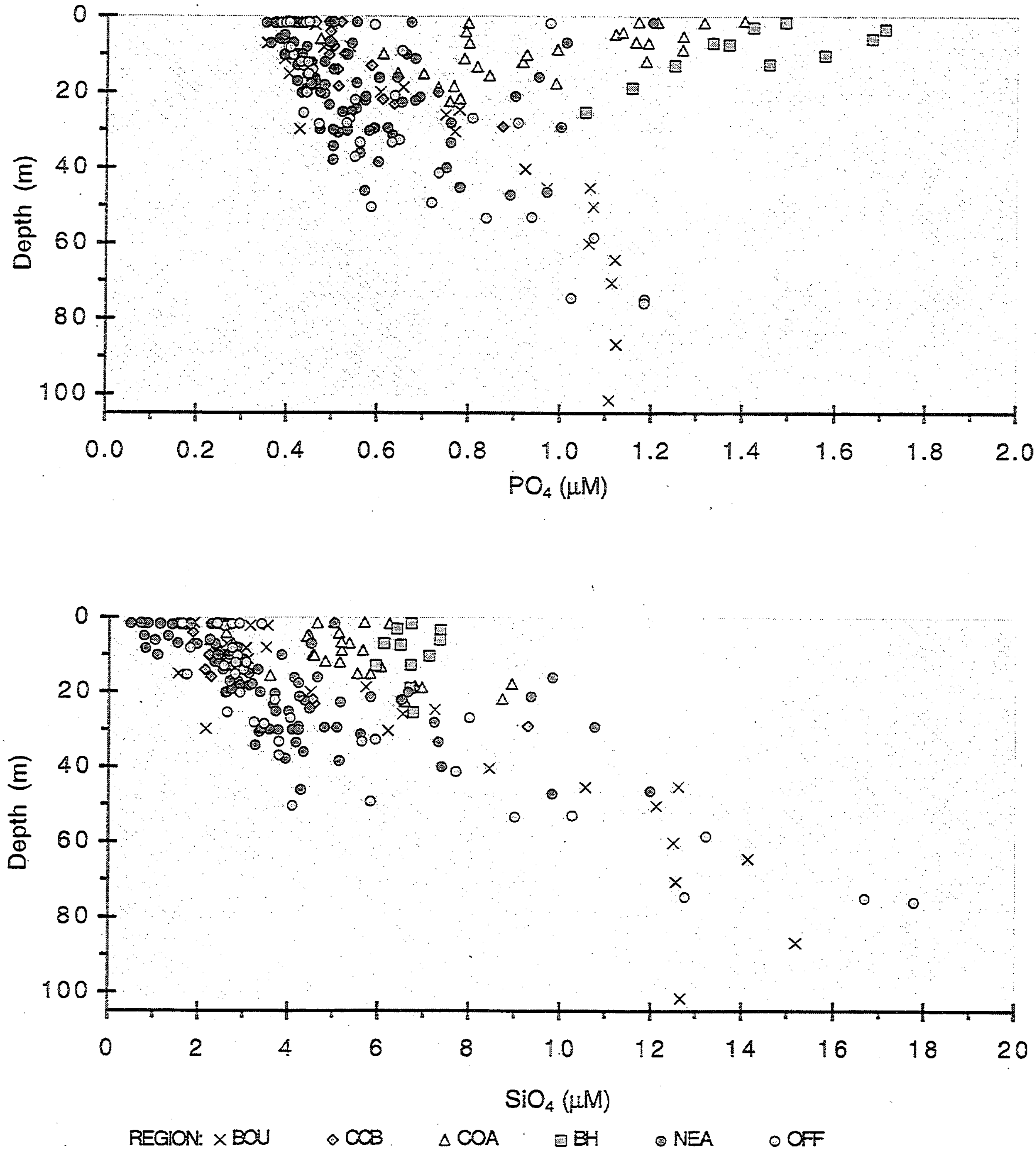

Depth (m)
0
20
40
60
80
100
0
2
4
6
8
10
12
NO3 (µM)
REGION: × BOU ◇ CCB △ COA ▣ BH ◉ NEA ○ OFF

W9514, Oct 13


0
20
40
60
80
100
Depth (m)
0
2
4
6
8
10
12
14
16
18
NH₄ (µM)

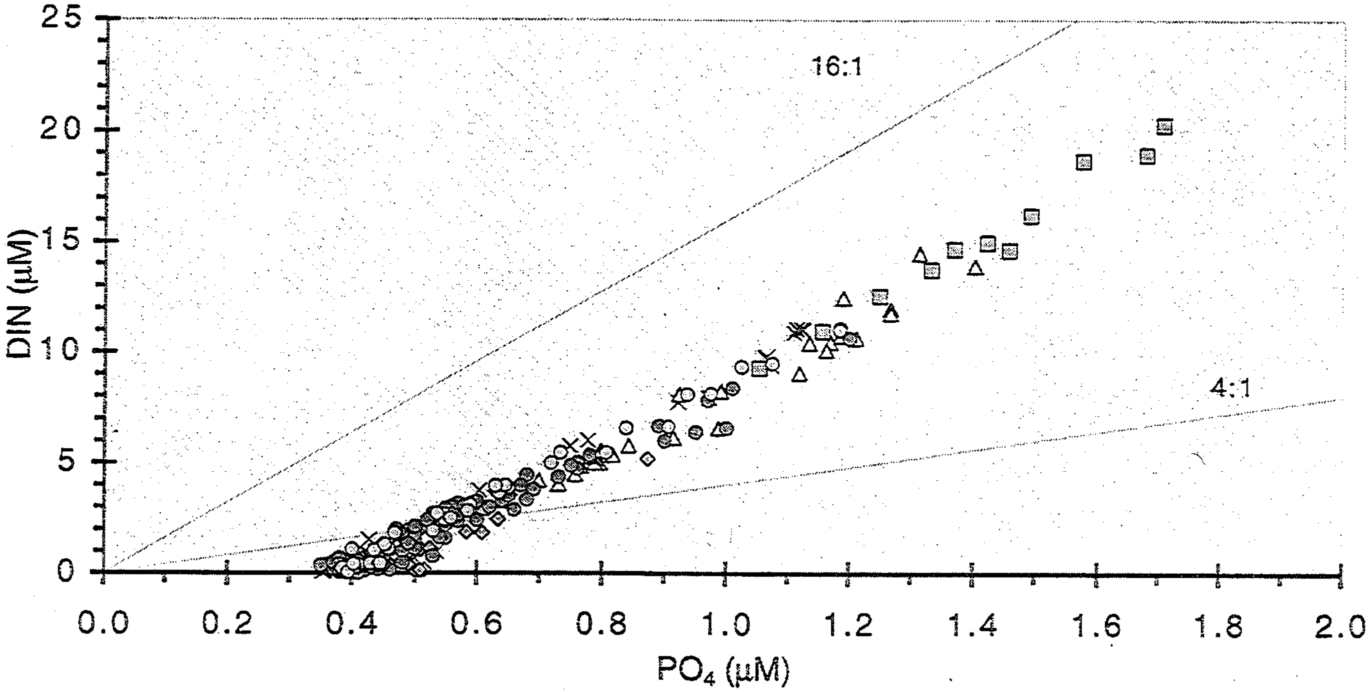

0
20
40
60
80
100
Depth (m)
0
2
4
6
8
10
12
NO₃ (µM)
REGION: × BOU ◇ CCB △ COA ▣ BH ◎ NEA ○ OFF

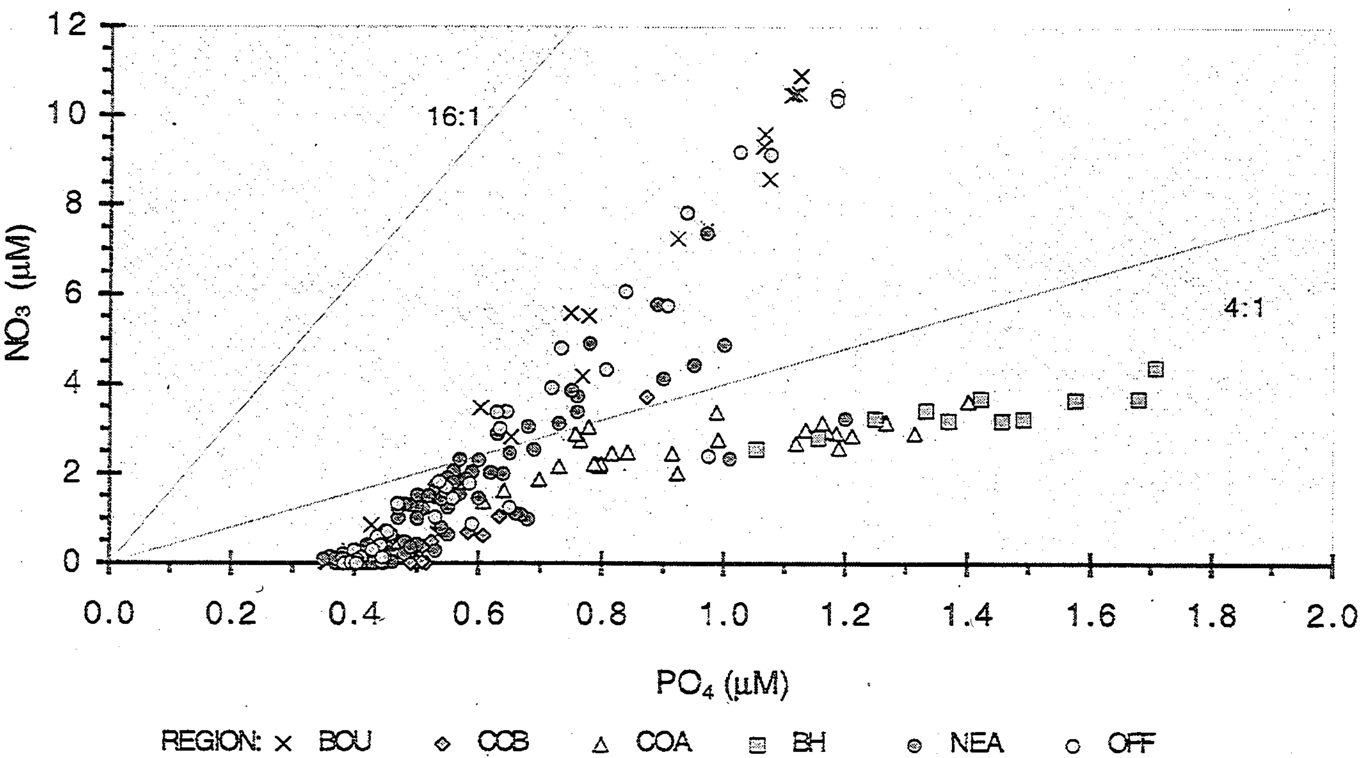
W9514, Oct 13



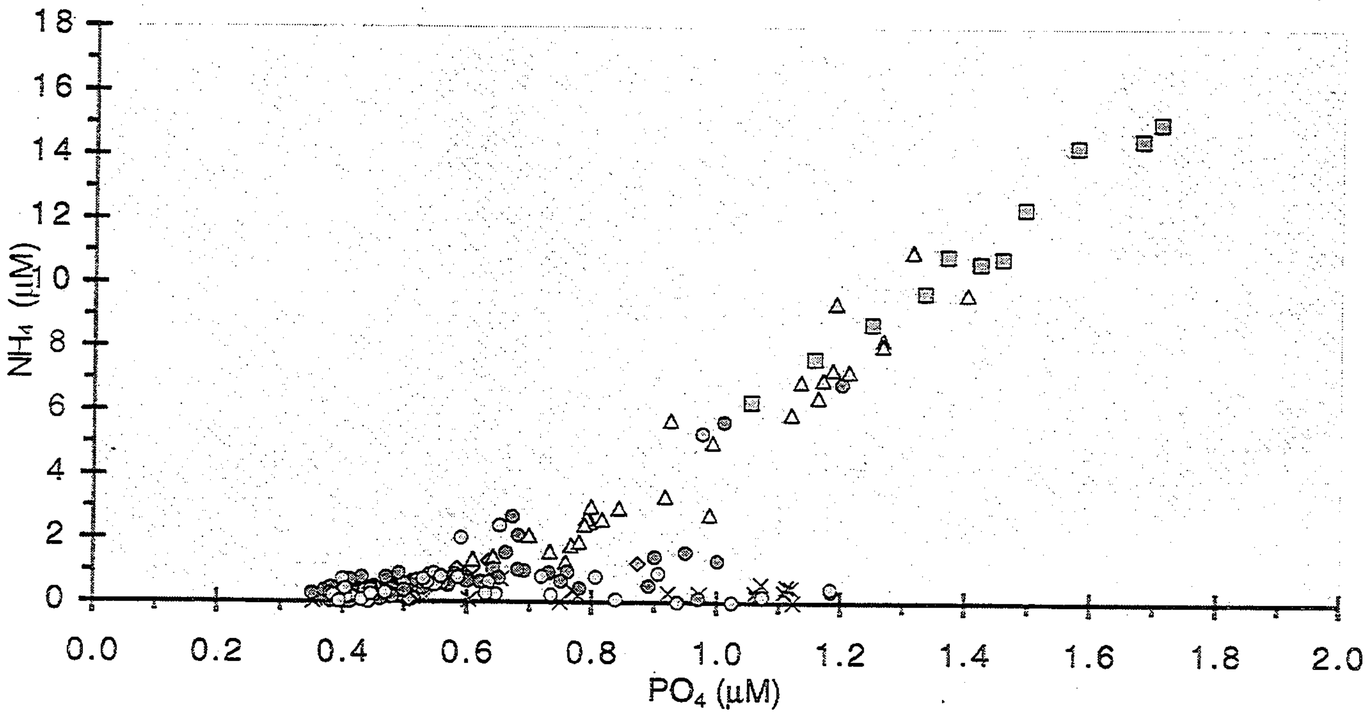
Depth (m)
0
20
40
60
80
100
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
PO4 (µM)
Depth (m)
0
20
40
60
80
100
0
2
4
6
8
10
12
14
16
18
20
SiO4 (µM)
REGION: × BOU ◇ CCB △ COA ▣ BH ◉ NEA ○ OFF

W9514, Oct 13

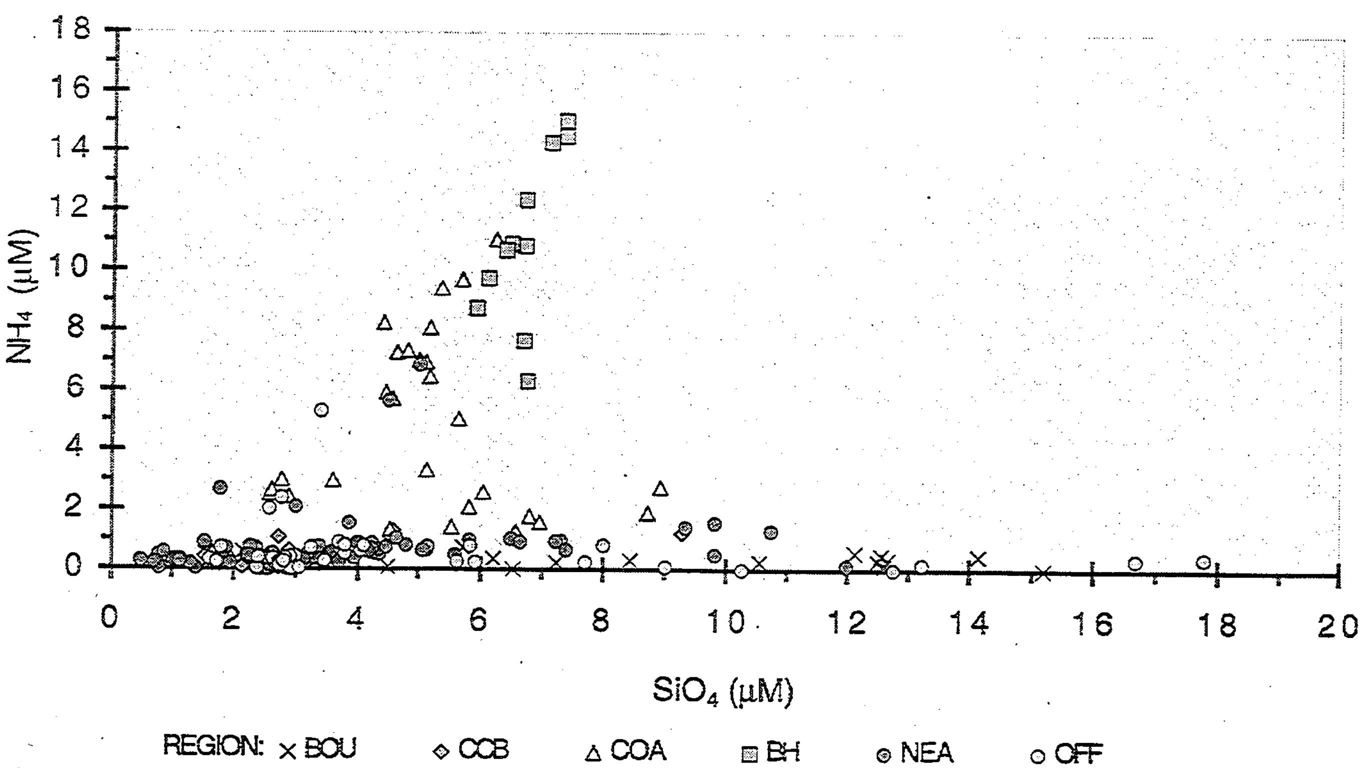

16:1
4:1
DIN (μM)
PO4 (μM)
25
20
15
10
5
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0


16:1
4:1
NO3 (μM)
PO4 (μM)
12
10
8
6
4
2
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
REGION: × BOU ◇ CCB △ COA ▣ BH ◉ NEA ○ OFF

W9514, Oct 13

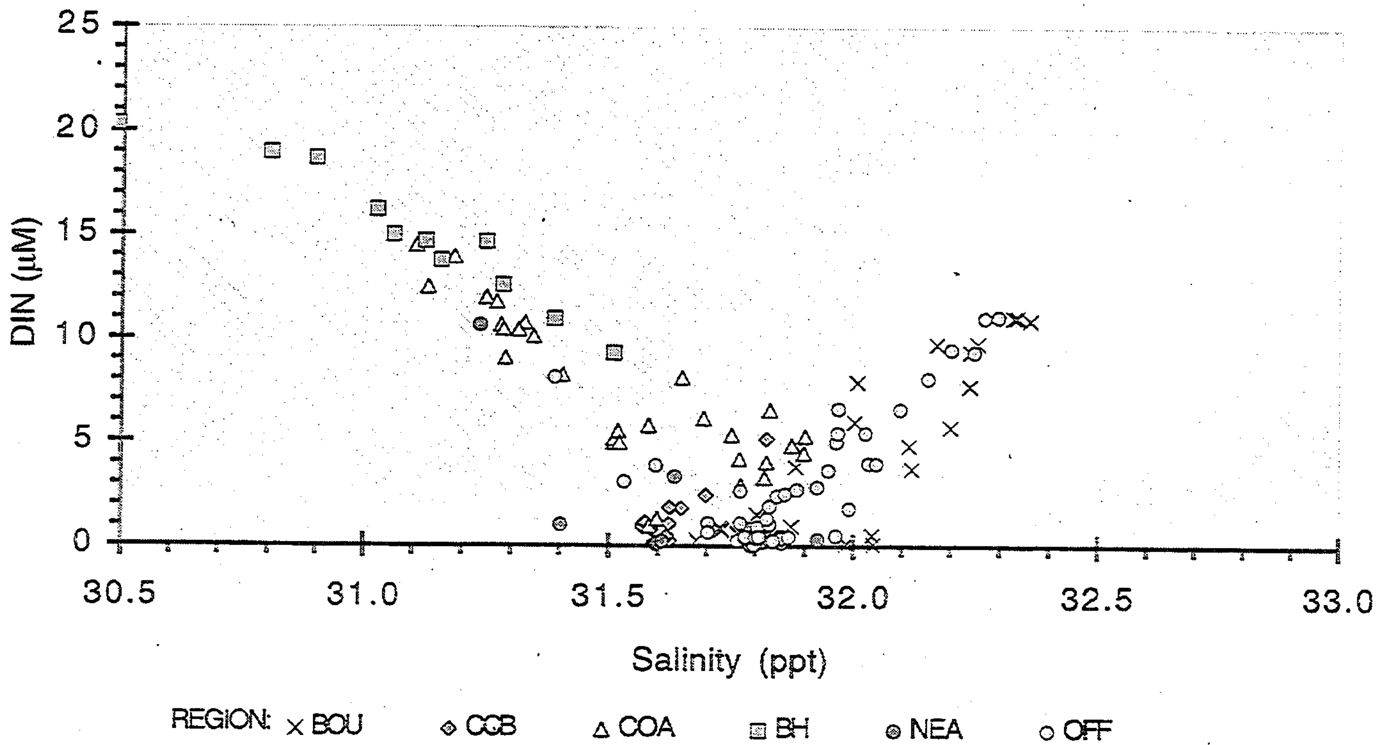


NH4 (µM)
PO4 (µM)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
2
4
6
8
10
12
14
16
18

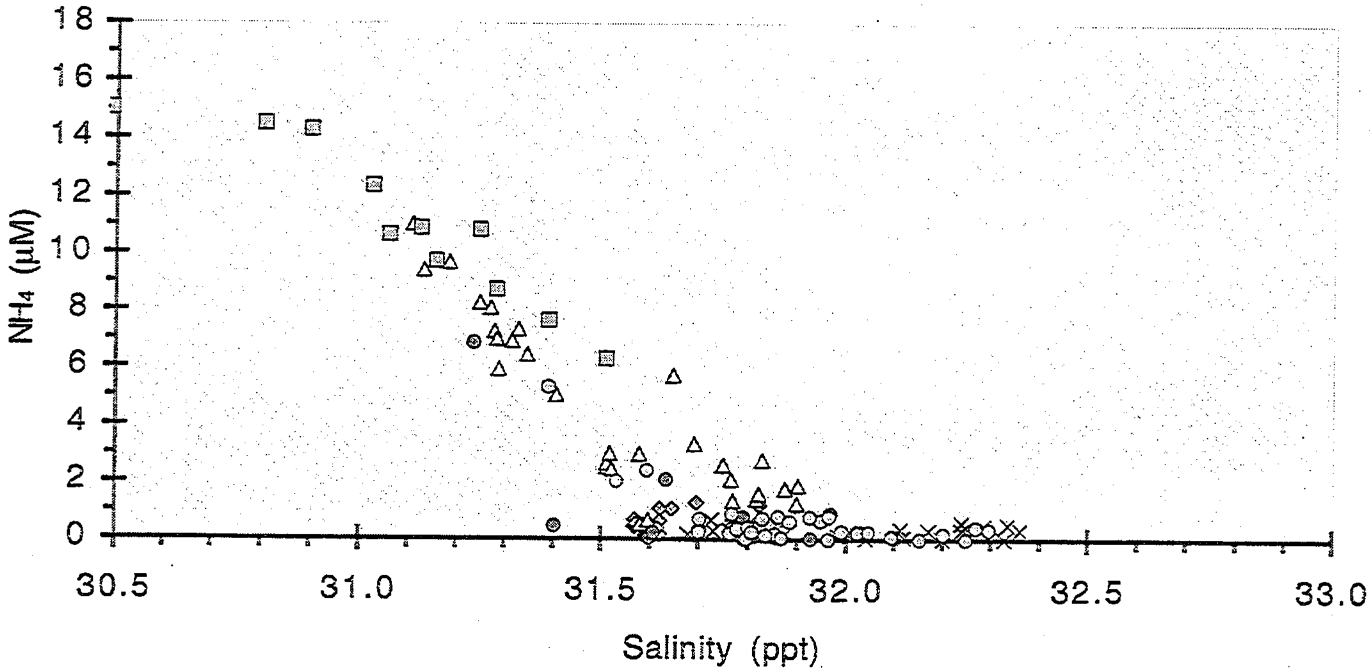


NH4 (µM)
SiO4 (µM)
0
2
4
6
8
10
12
14
16
18
20
REGION: × BOU ◇ CCB △ COA ▣ BH ⊙ NEA ○ OFF

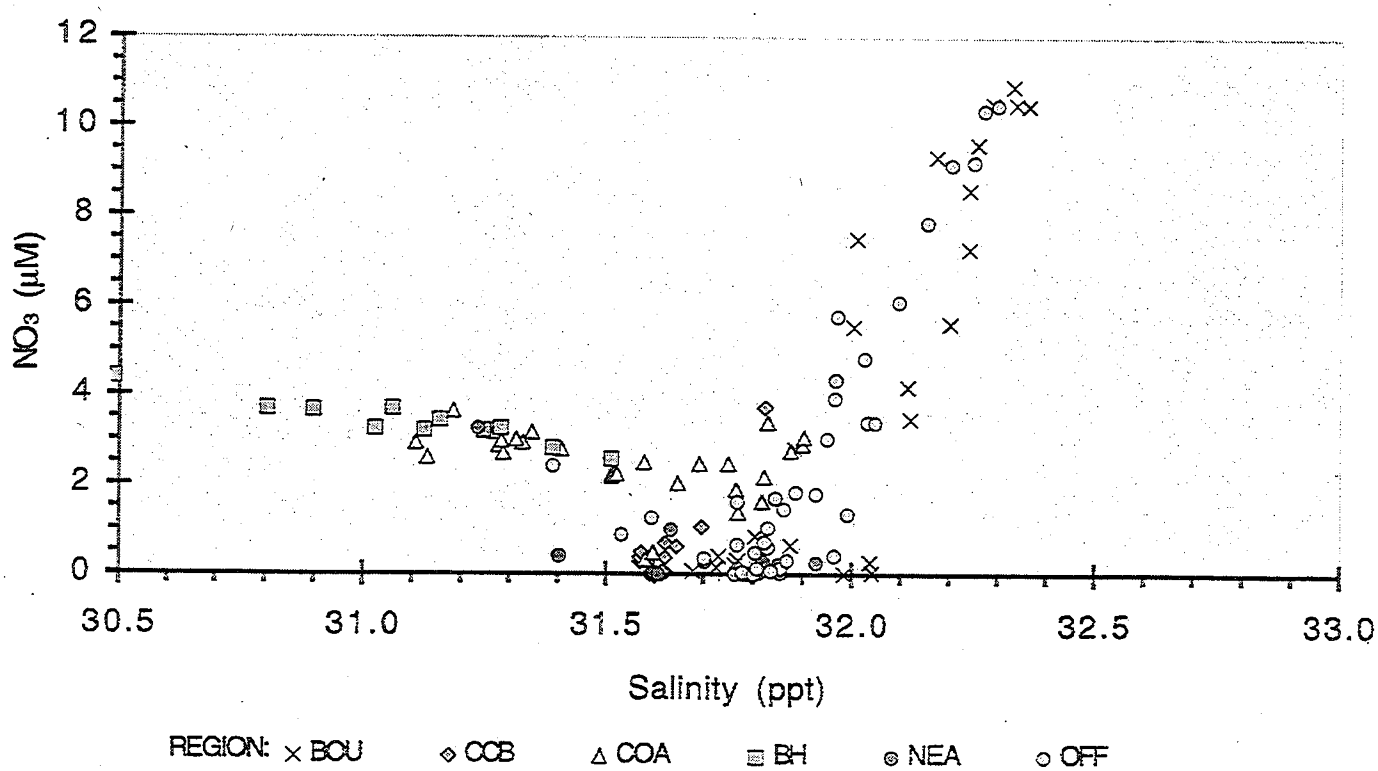
W9514, Oct 13


25
20
15
10
5
0
DIN (µM)
30.5
31.0
31.5
32.0
32.5
33.0
Salinity (ppt)
REGION: × BOU
◇ CCB
△ COA
▢ BH
◉ NEA
○ OFF

W9514, Oct 13

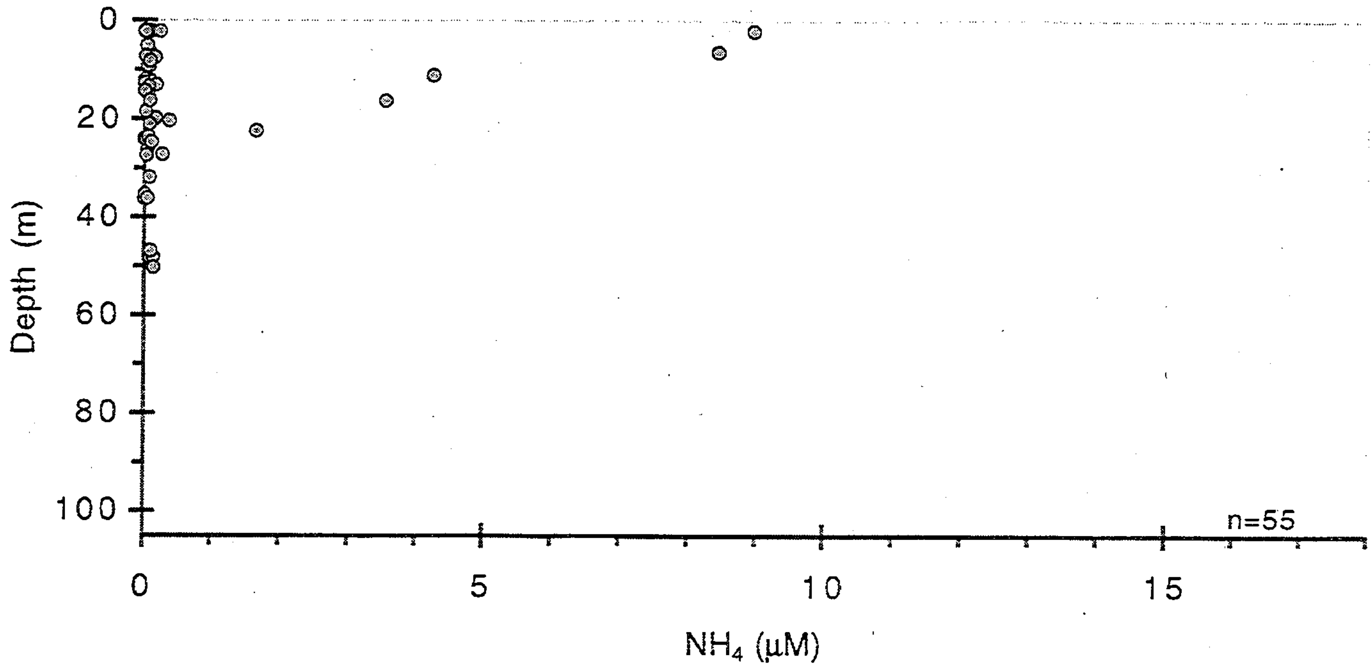


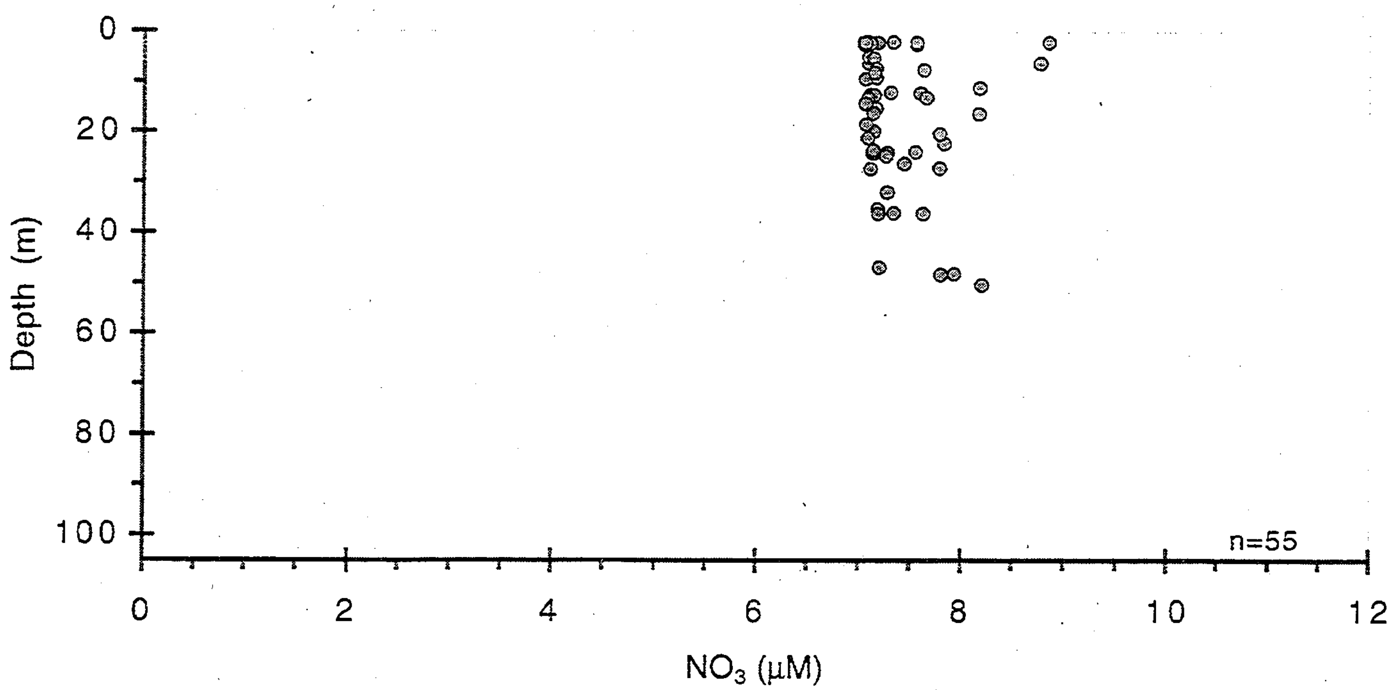
NH4 (µM)
18
16
14
12
10
8
6
4
2
0
30.5
31.0
31.5
32.0
32.5
33.0
Salinity (ppt)



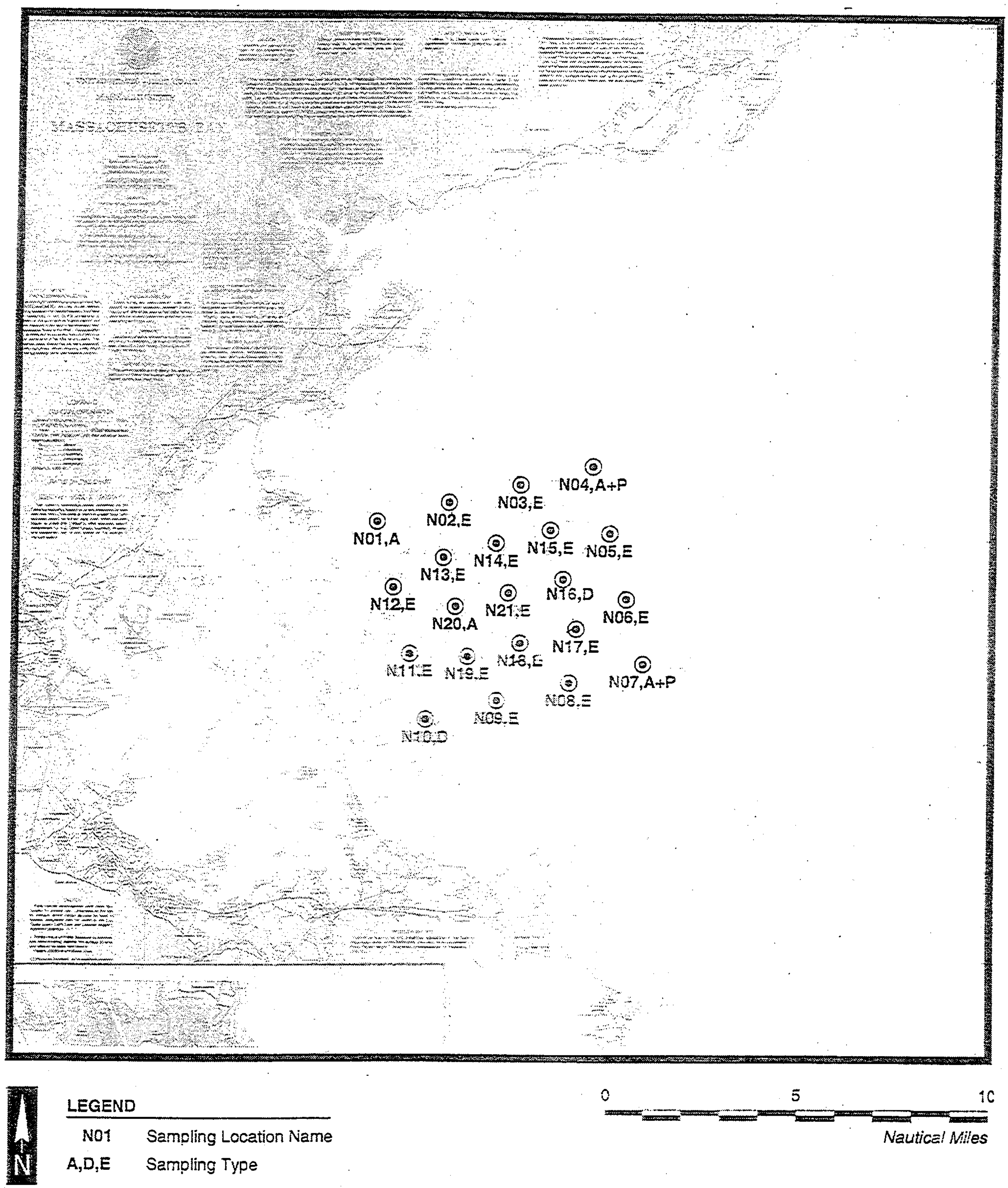
NO3 (µM)
12
10
8
6
4
2
0
30.5
31.0
31.5
32.0
32.5
33.0
Salinity (ppt)
REGION: × BOU ◇ CCB △ COA ▨ BH ◎ NEA ○ OFF

W9516, Dec 3


Depth (m)
0
20
40
60
80
100
n=55
0
5
10
15
NH4 (µM)

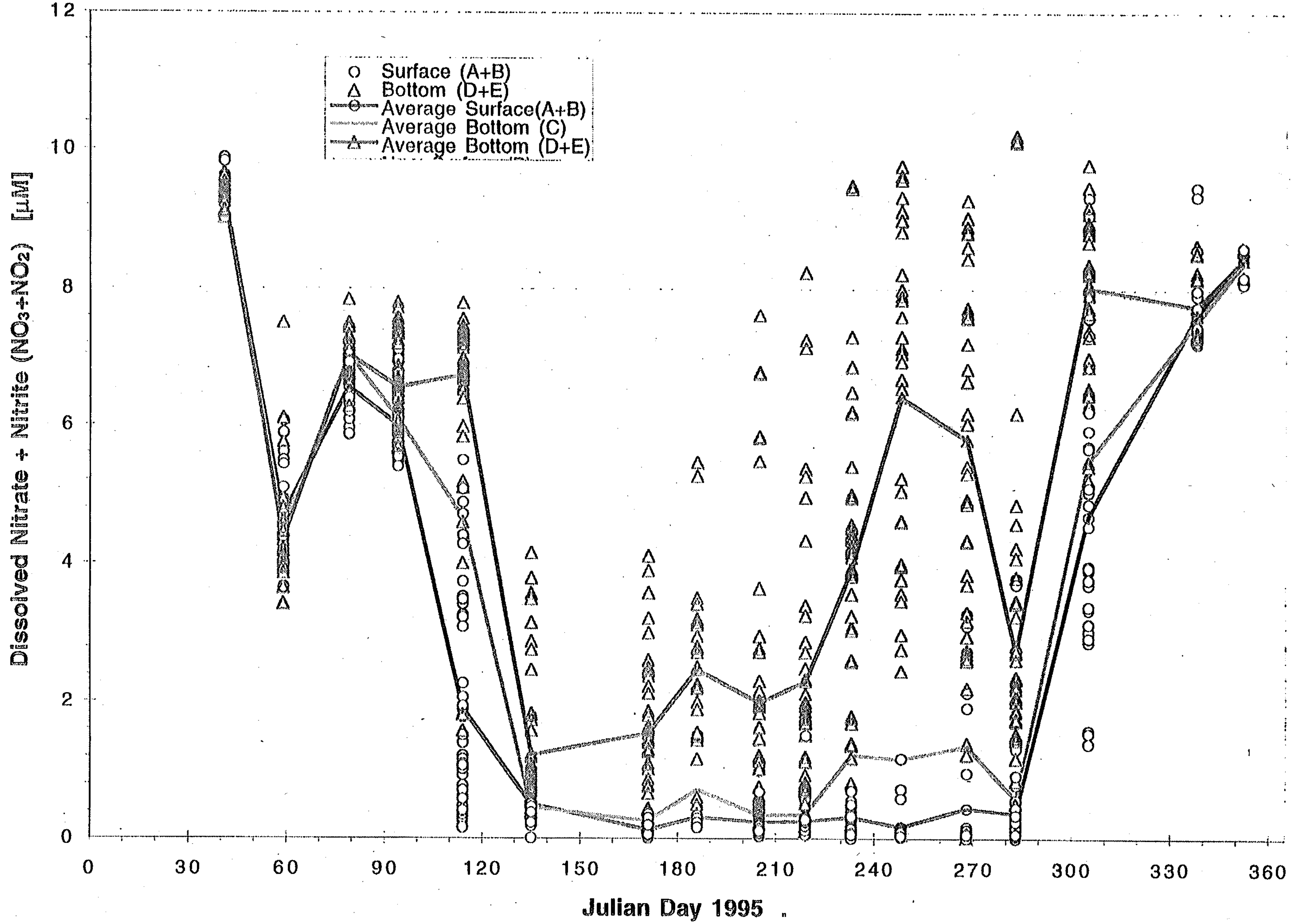

Depth (m)
0
20
40
60
80
100
n=55
0
2
4
6
8
10
12
NO3 (µM)

Station Map

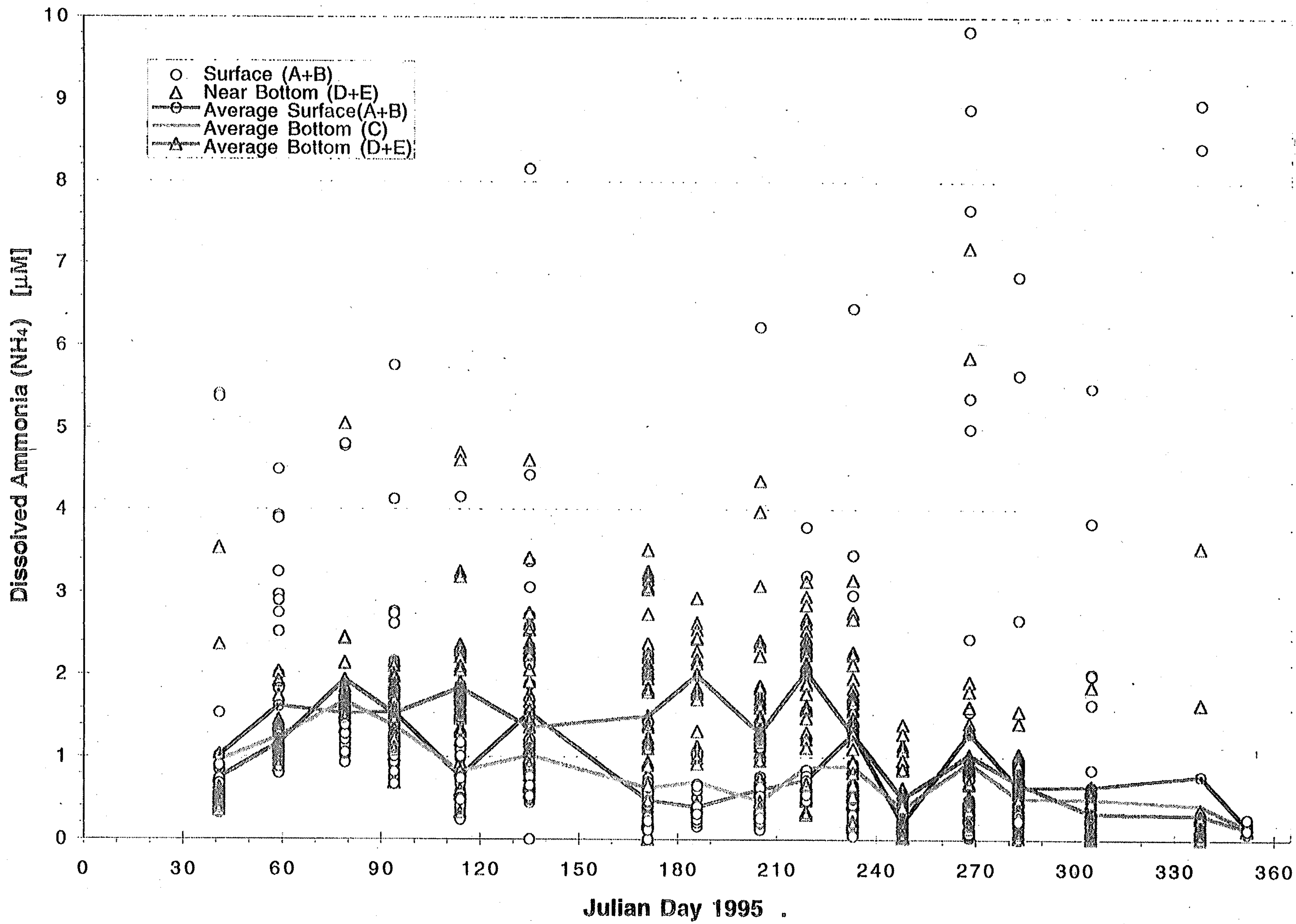


Station Map courtesy of ENSR Consulting & Engineering

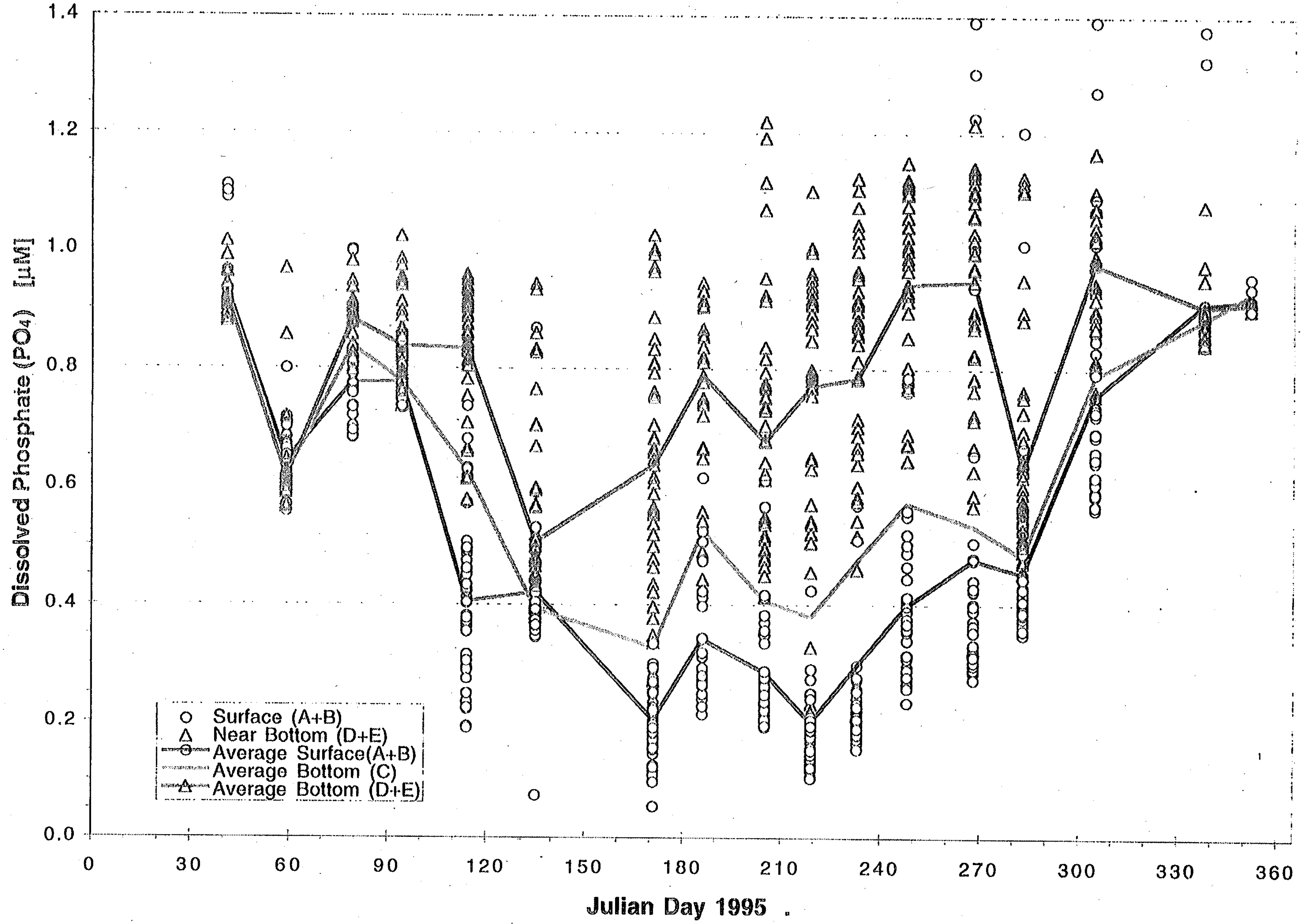
Nitrate + Nitrite ($NO_3 + NO_2$) vs. Julian Day



Ammonia (NH_4) vs. Julian Day

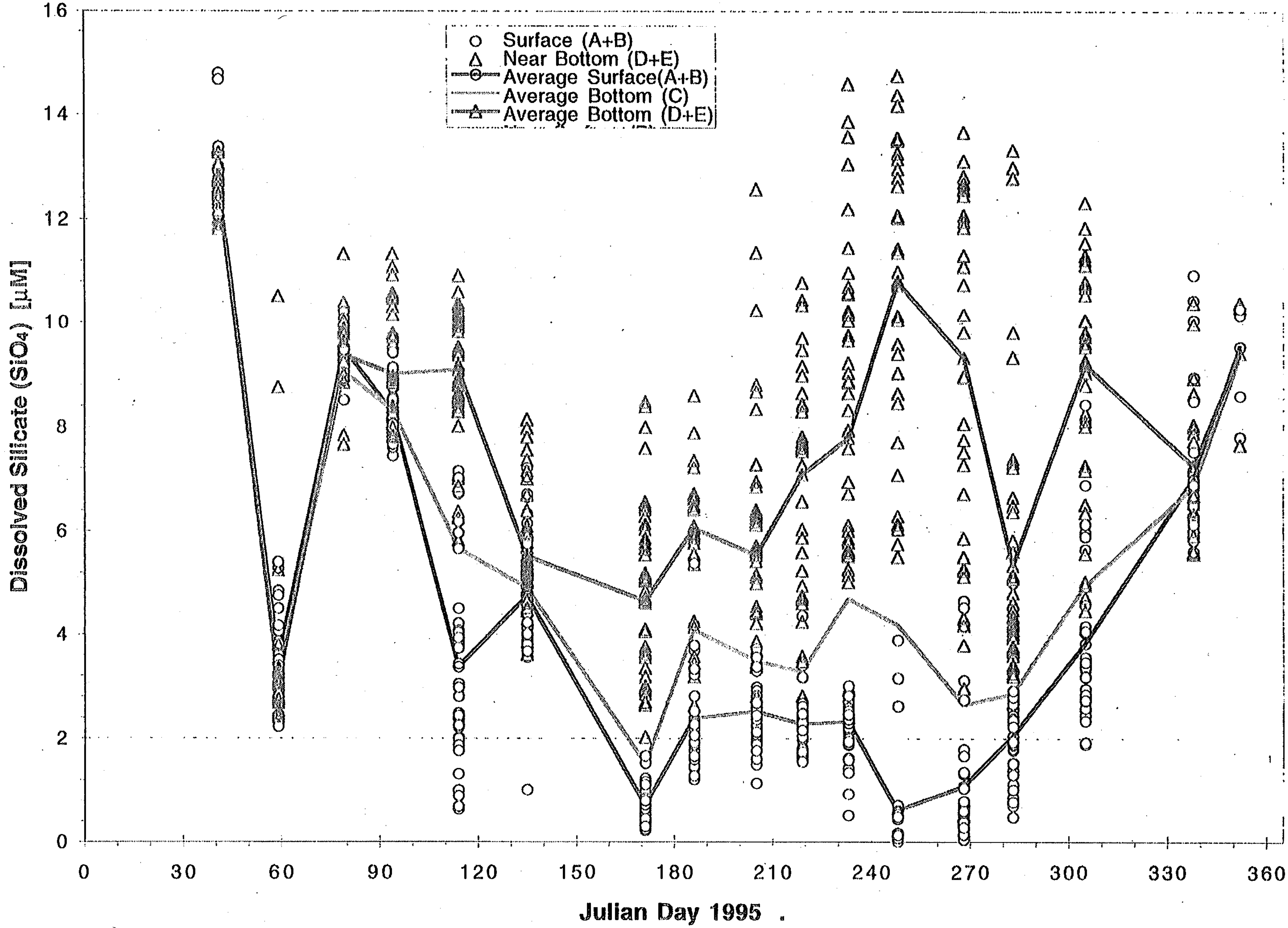


Phosphate (PO_4) vs. Julian Day

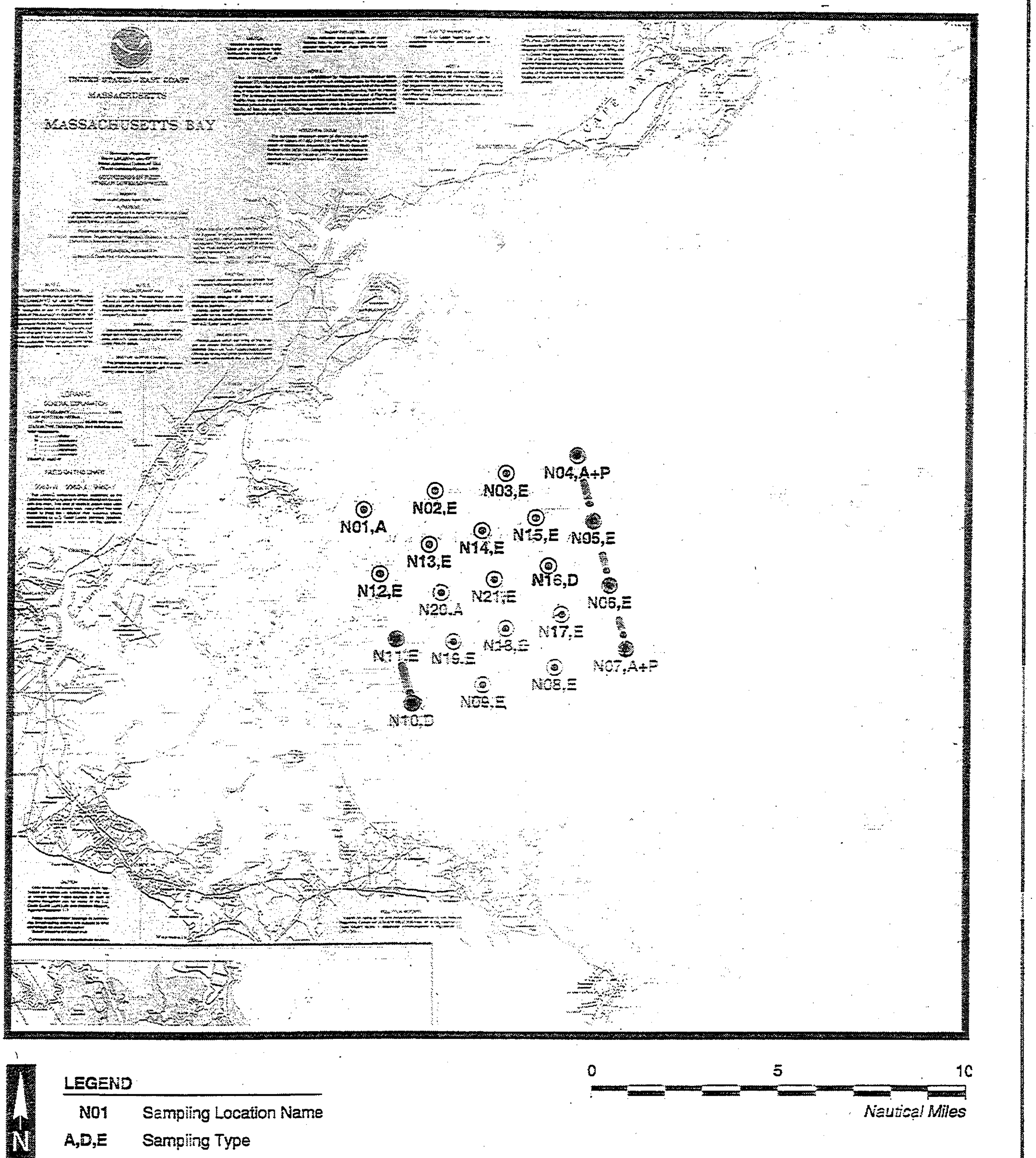


24

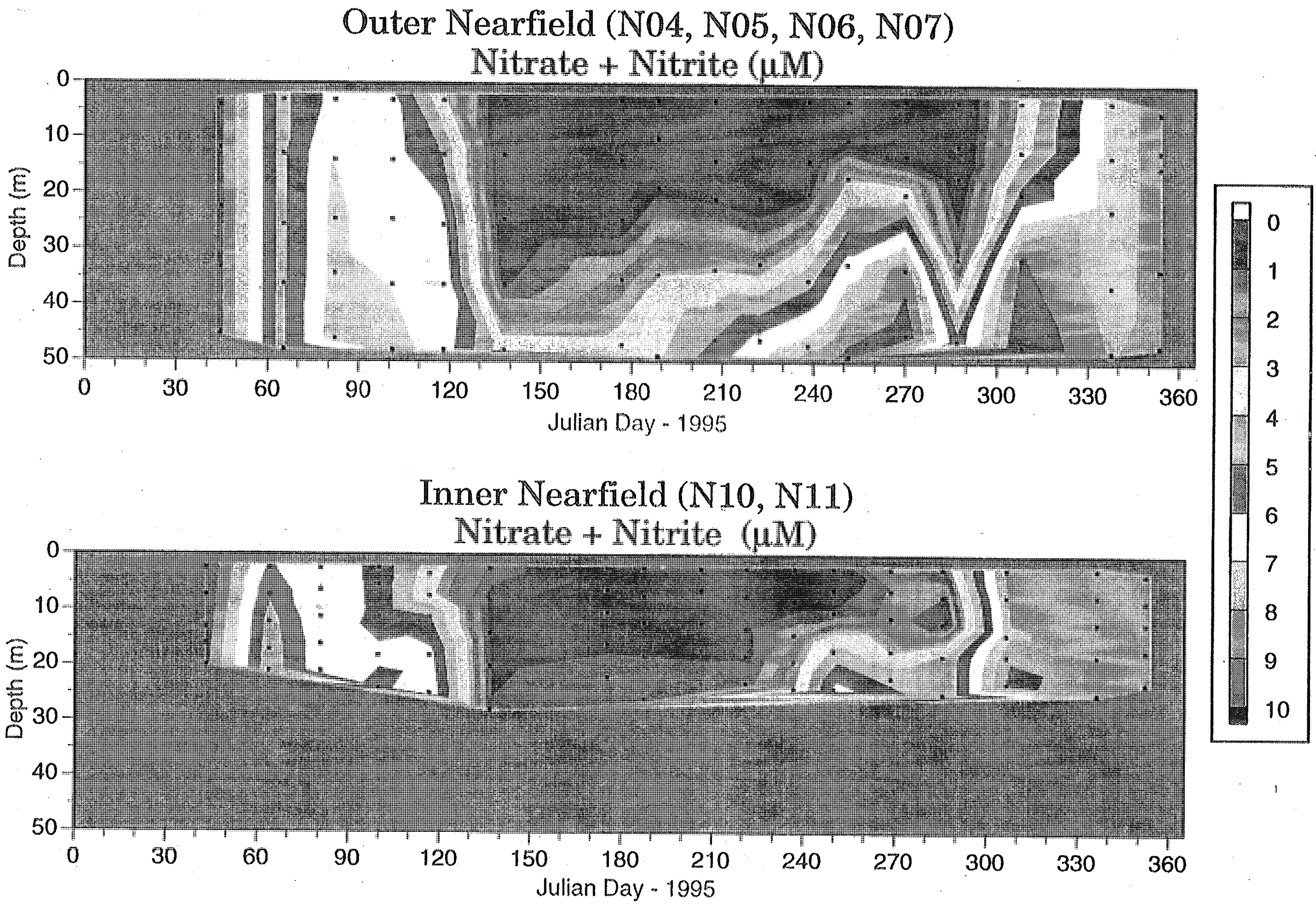
Silicate (SiO_4) vs. Julian Day

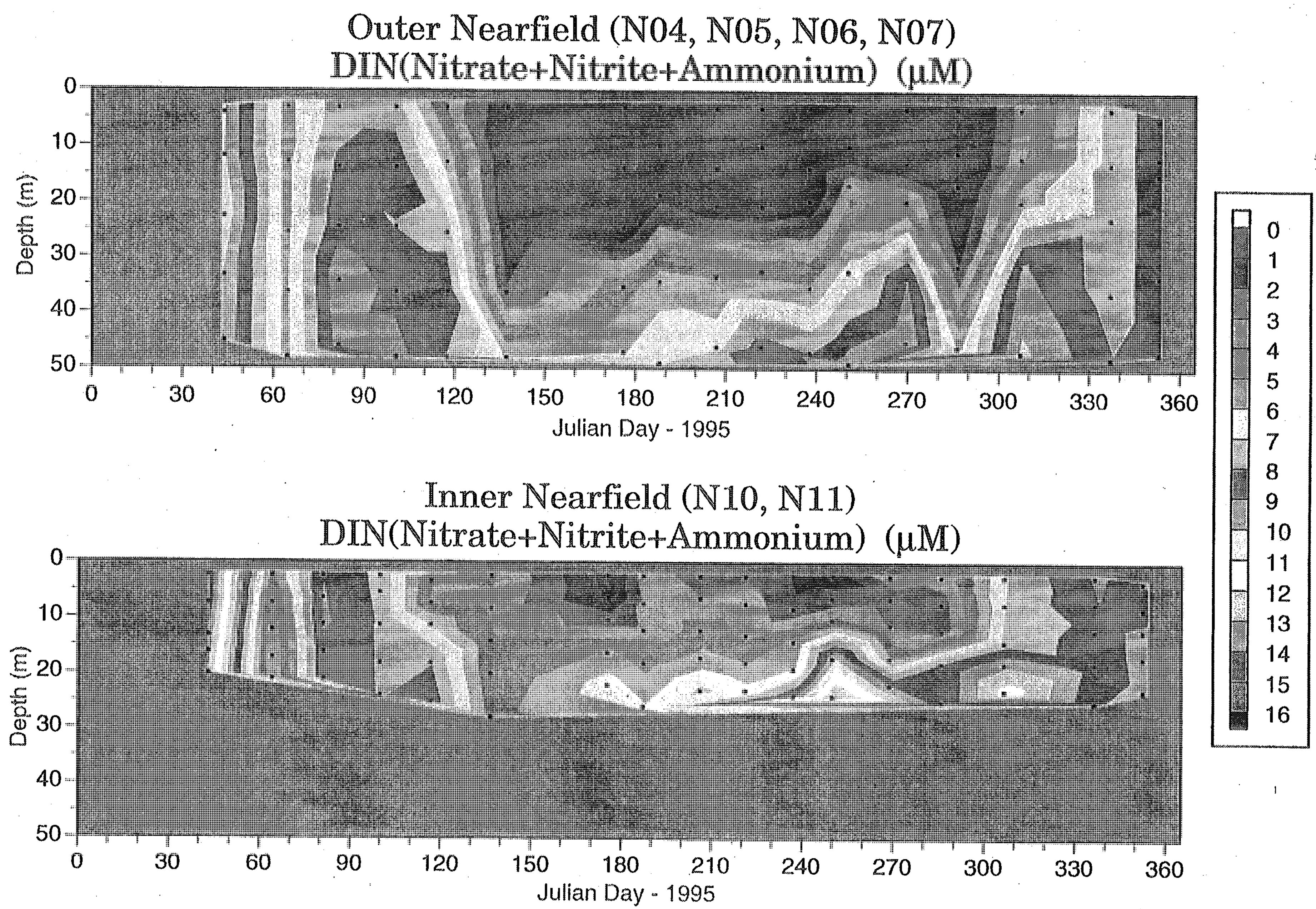


Station Map



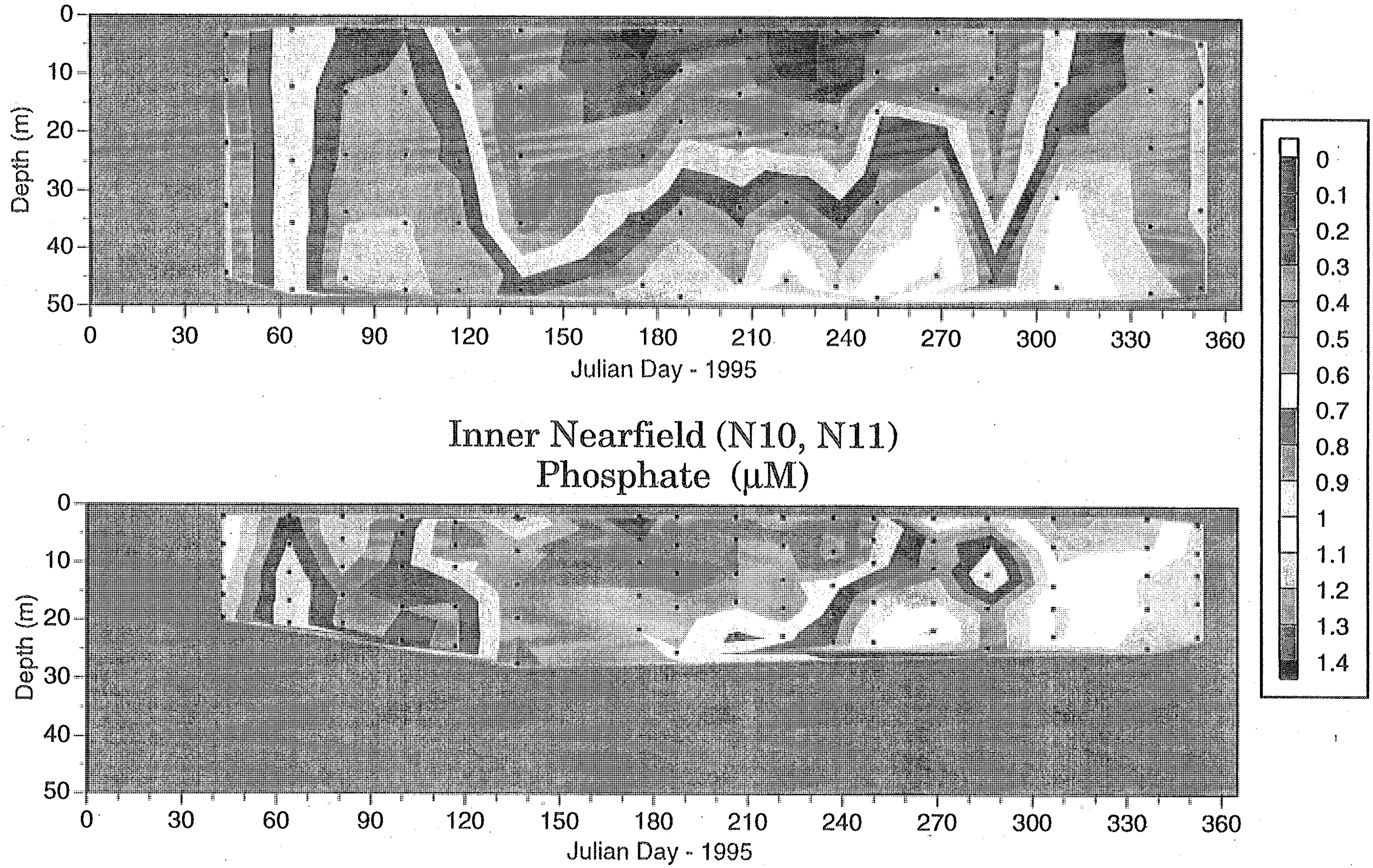
Station Map courtesy of ENSR Consulting & Engineering


Outer Nearfield (N04, N05, N06, N07)
Nitrate + Nitrite (µM)
Depth (m)
0
10
20
30
40
50
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day - 1995
Inner Nearfield (N10, N11)
Nitrate + Nitrite (µM)
Depth (m)
0
10
20
30
40
50
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day - 1995
0
1
2
3
4
5
6
7
8
9
10

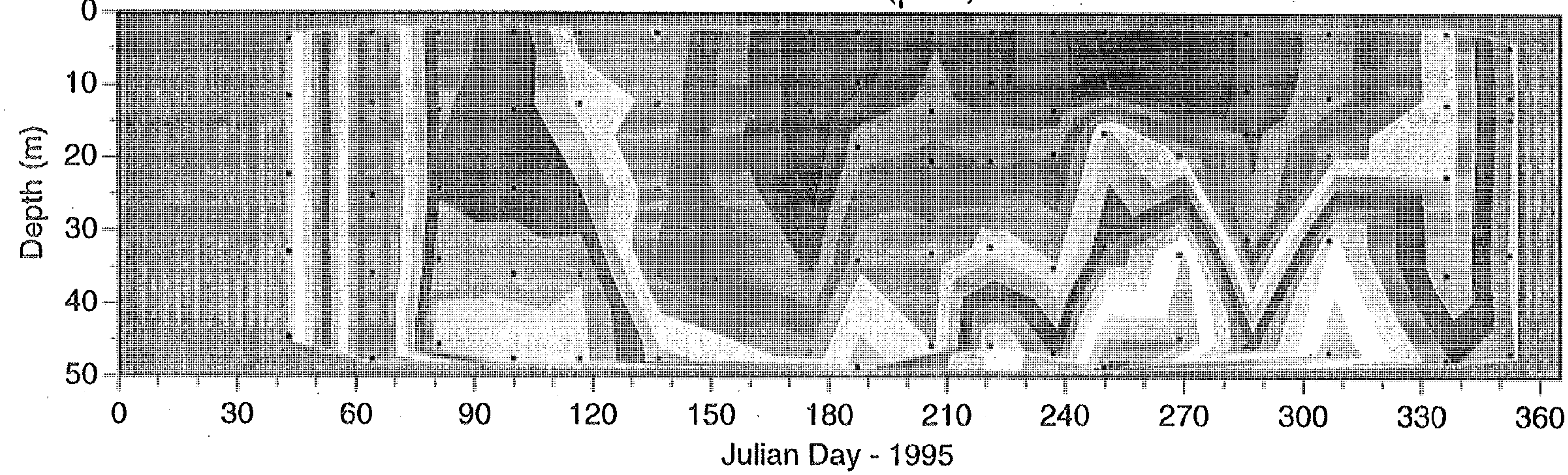

Outer Nearfield (N04, N05, N06, N07)
DIN(Nitrate+Nitrite+Ammonium) (µM)
Depth (m)
0
10
20
30
40
50
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day - 1995
Inner Nearfield (N10, N11)
DIN(Nitrate+Nitrite+Ammonium) (µM)
Depth (m)
Julian Day - 1995
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Outer Nearfield (N04, N05, N06, N07) Phosphate (μM)

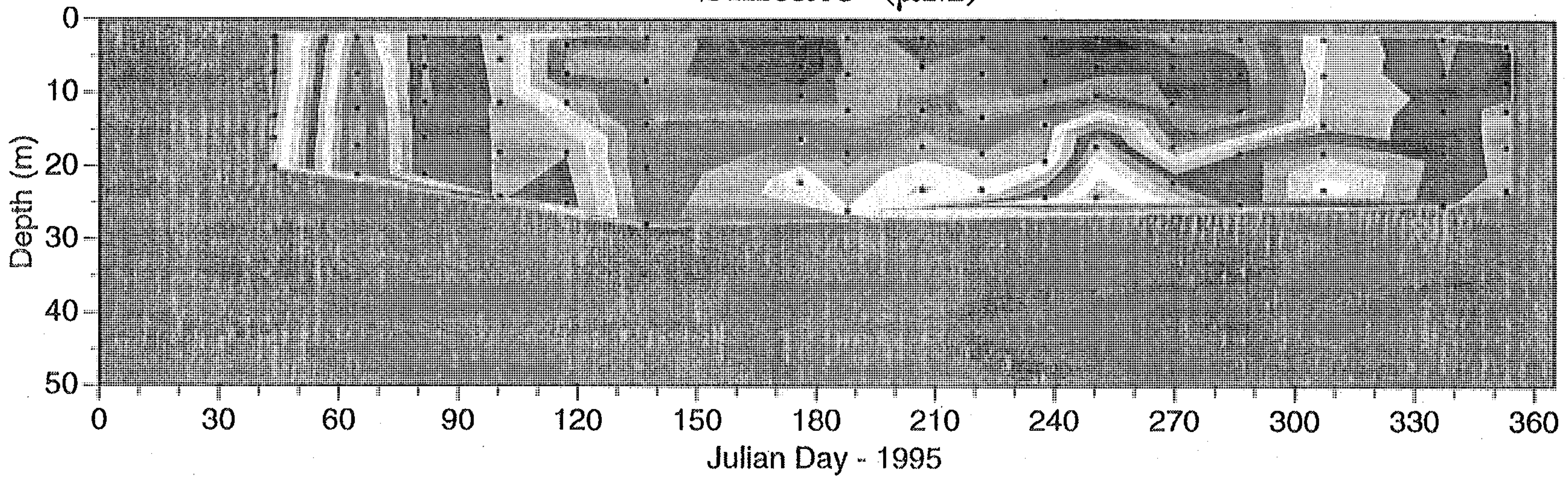
Inner Nearfield (N10, N11) Phosphate (μM)

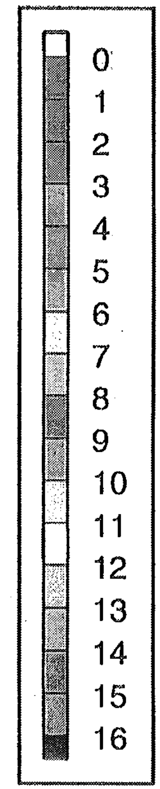


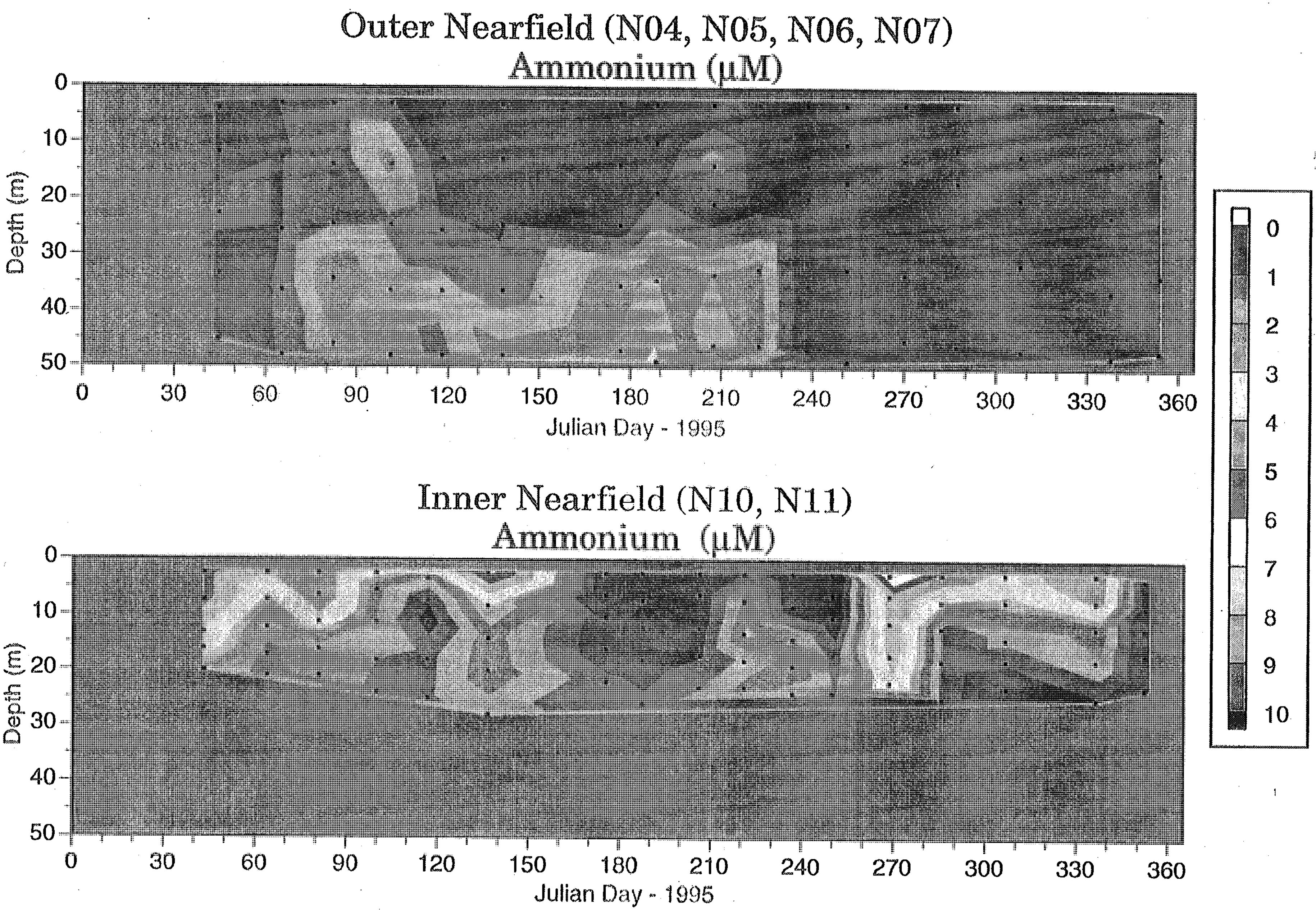
Outer Nearfield (N04, N05, N06, N07)
Silicate (µM)

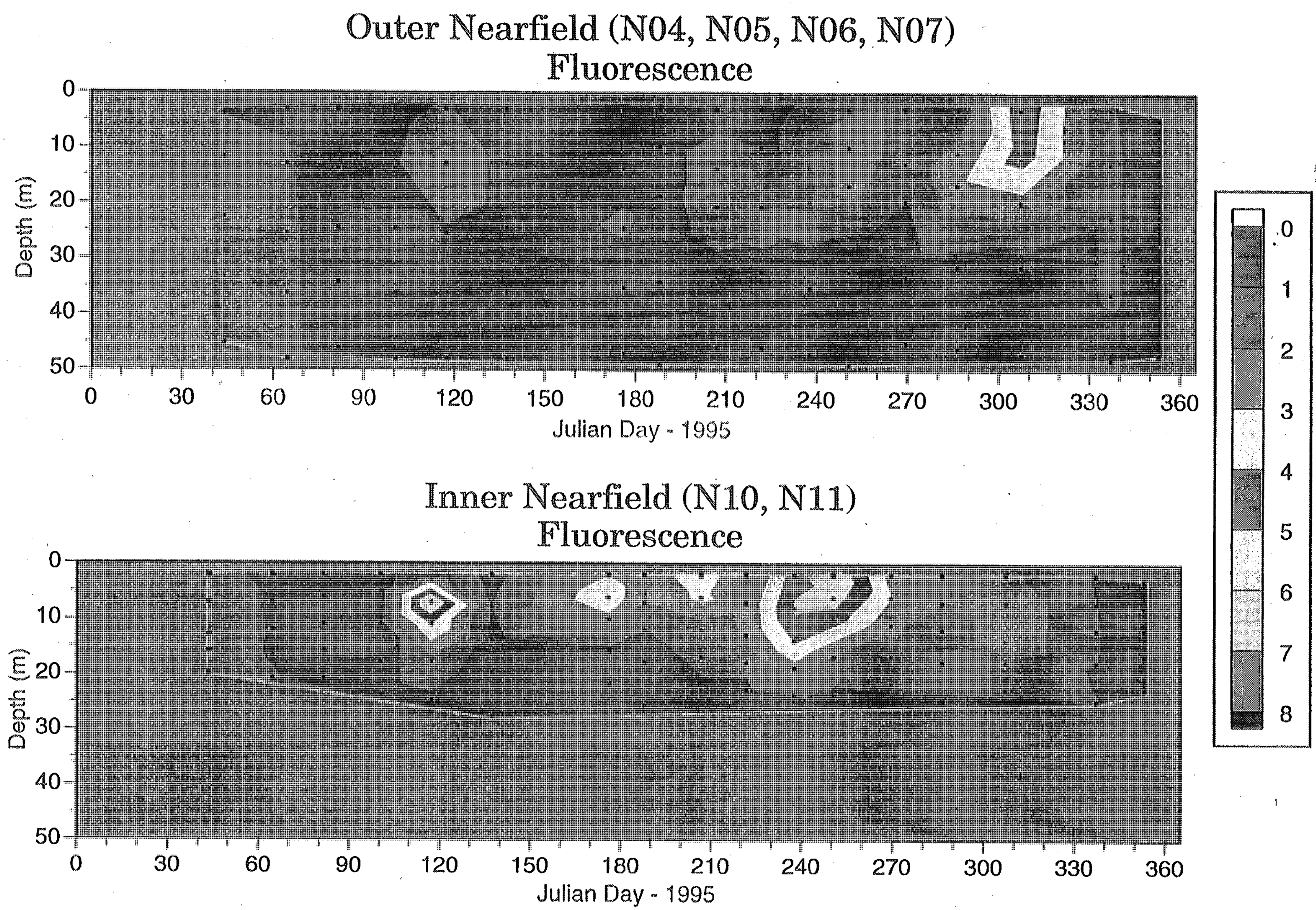


Inner Nearfield (N10, N11)
Silicate (µM)

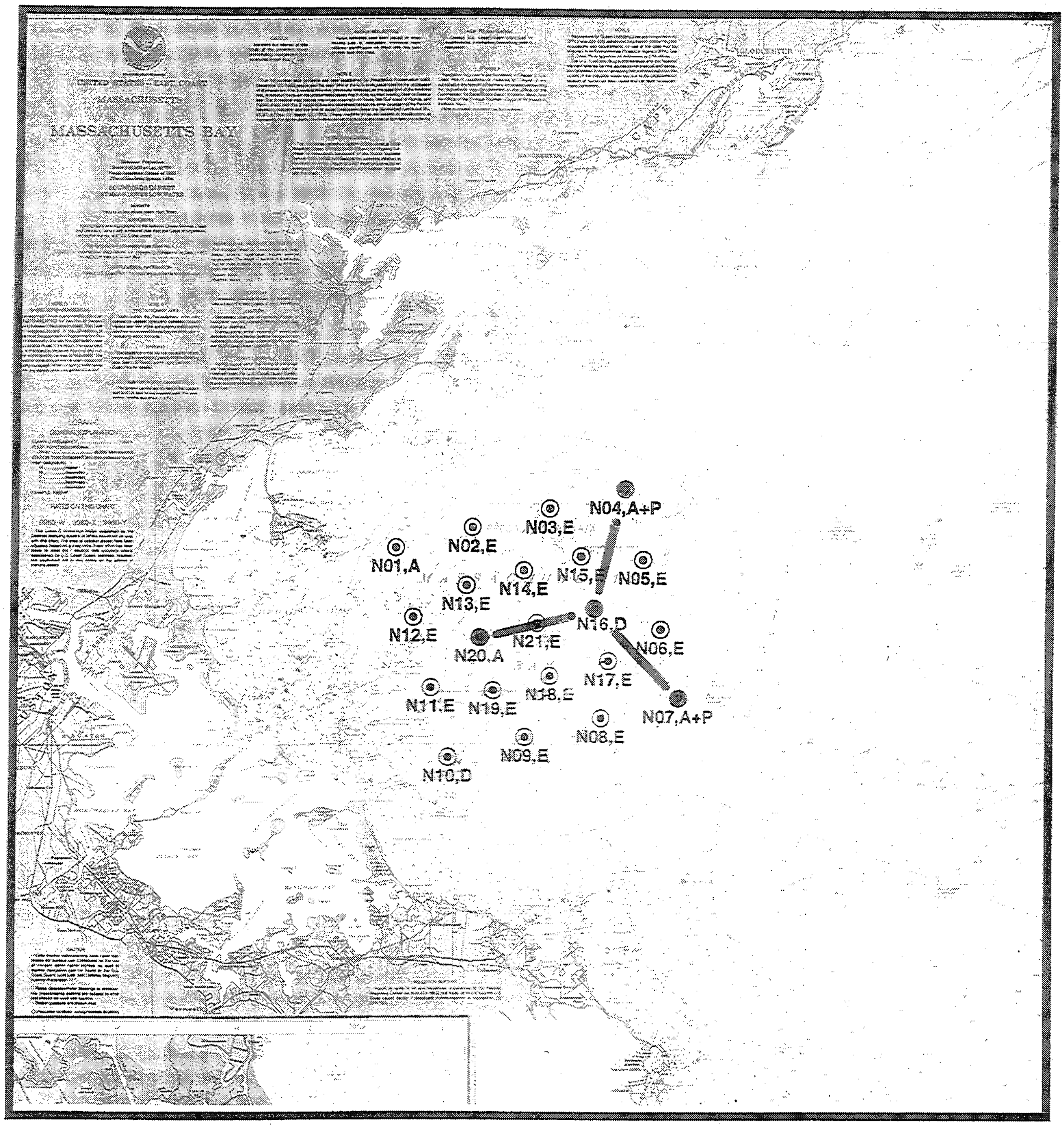





Outer Nearfield (N04, N05, N06, N07)
Ammonium (µM)
Depth (m)
0
10
20
30
40
50
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day - 1995
Inner Nearfield (N10, N11)
Ammonium (µM)
Depth (m)
0
10
20
30
40
50
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day - 1995
0
1
2
3
4
5
6
7
8
9
10


Outer Nearfield (N04, N05, N06, N07)
Fluorescence
Depth (m)
0
10
20
30
40
50
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day - 1995
Inner Nearfield (N10, N11)
Fluorescence
Depth (m)
0
10
20
30
40
50
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day - 1995
0
1
2
3
4
5
6
7
8

Station Map



N

LEGEND

N01 Sampling Location Name

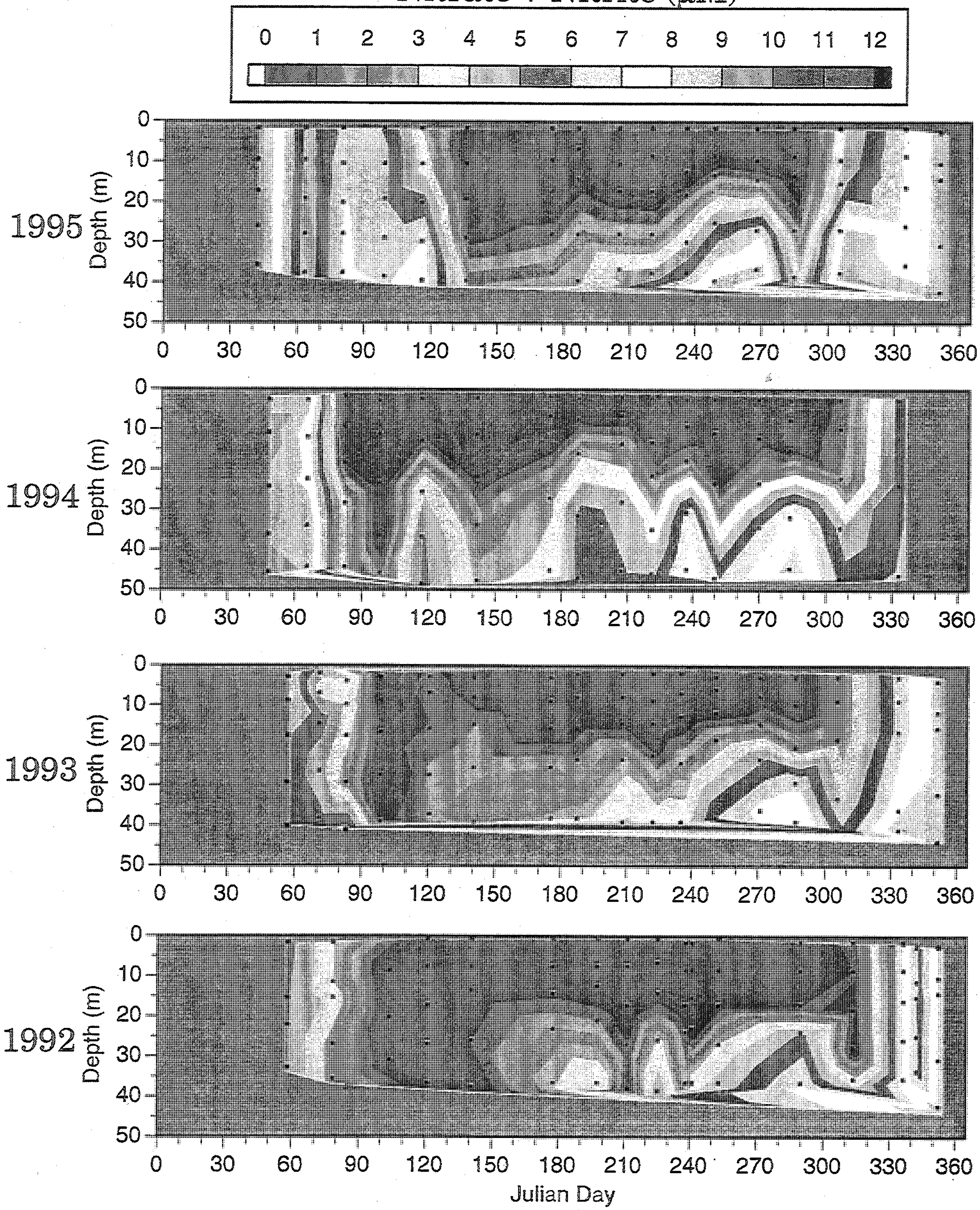
A,D,E Sampling Type

0 5 10

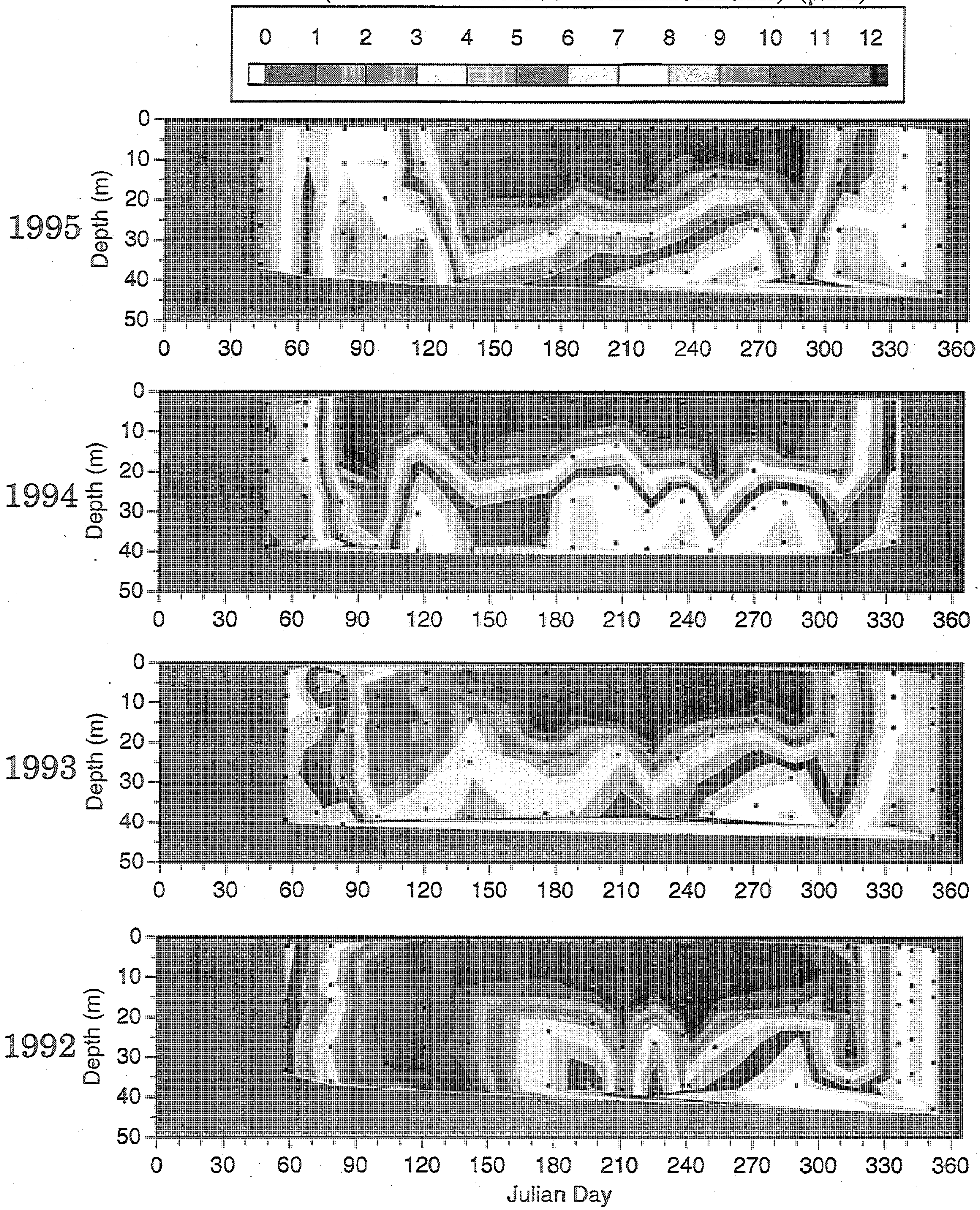
Nautical Miles

Station Map courtesy of ENSR Consulting & Engineering

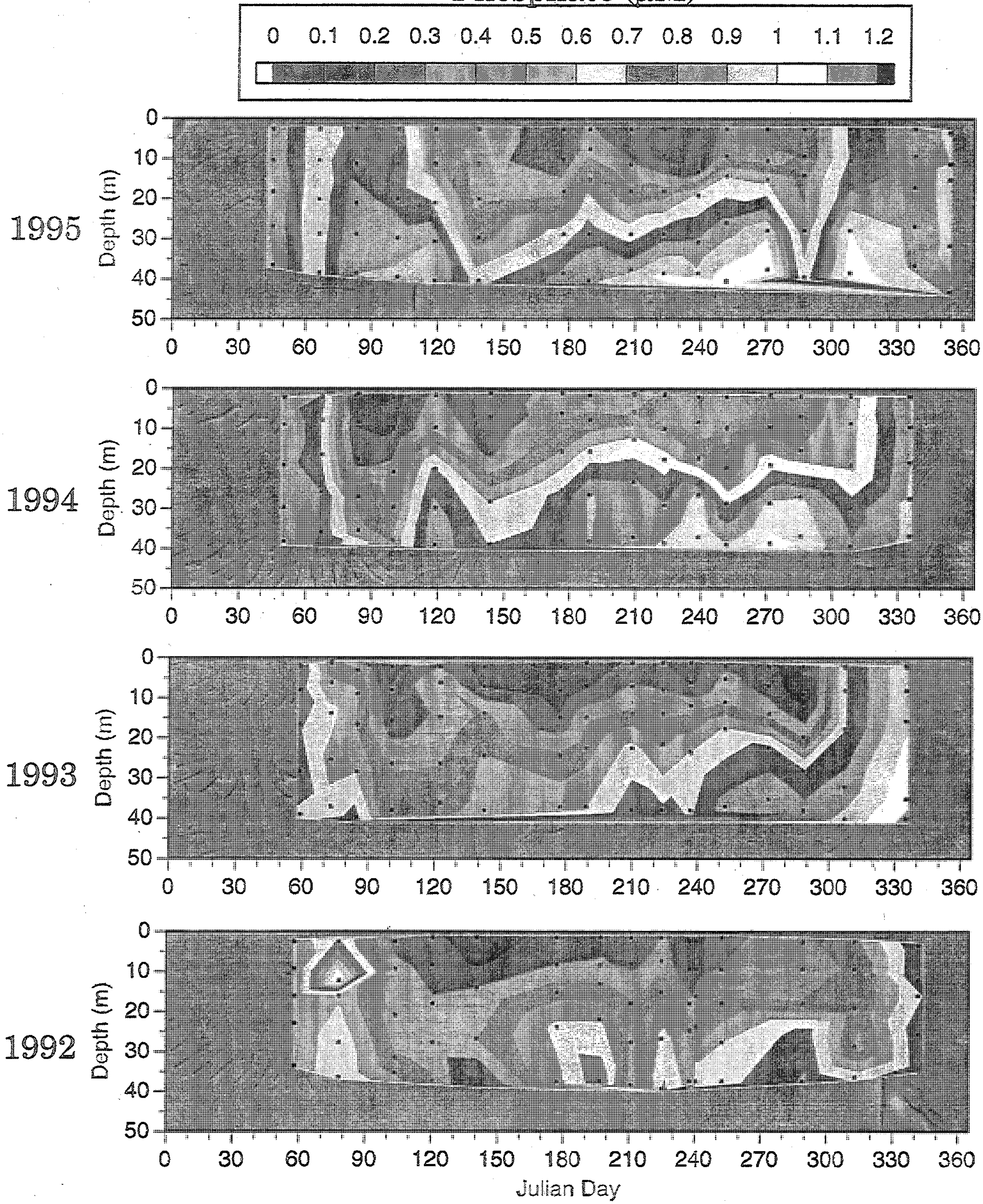
Nearfield (N16, N04, N07, N20)
Nitrate + Nitrite (µM)



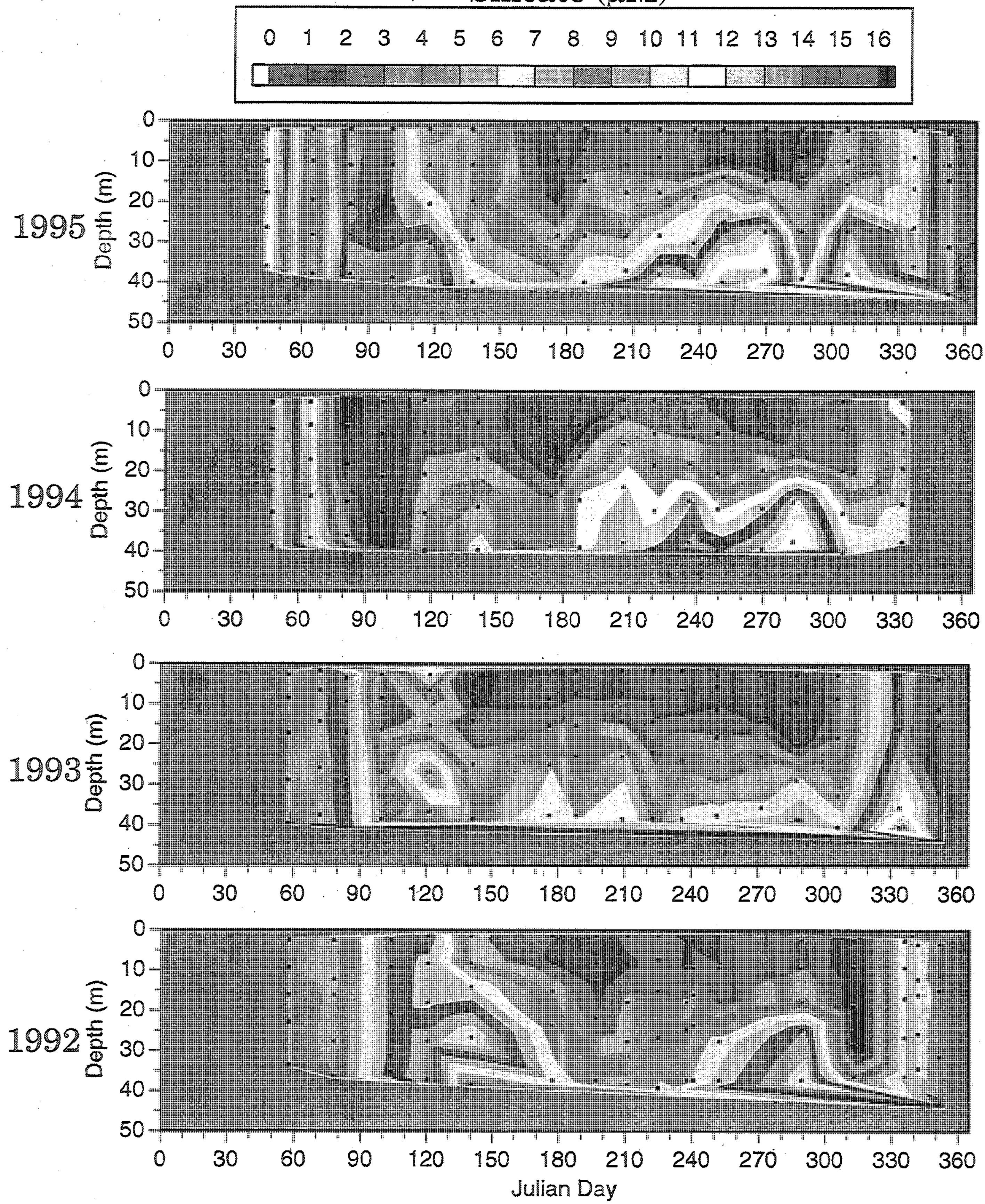
Nearfield (N16, N04, N07, N20)
DIN(Nitrate+nitrite +Ammonium) (µM)



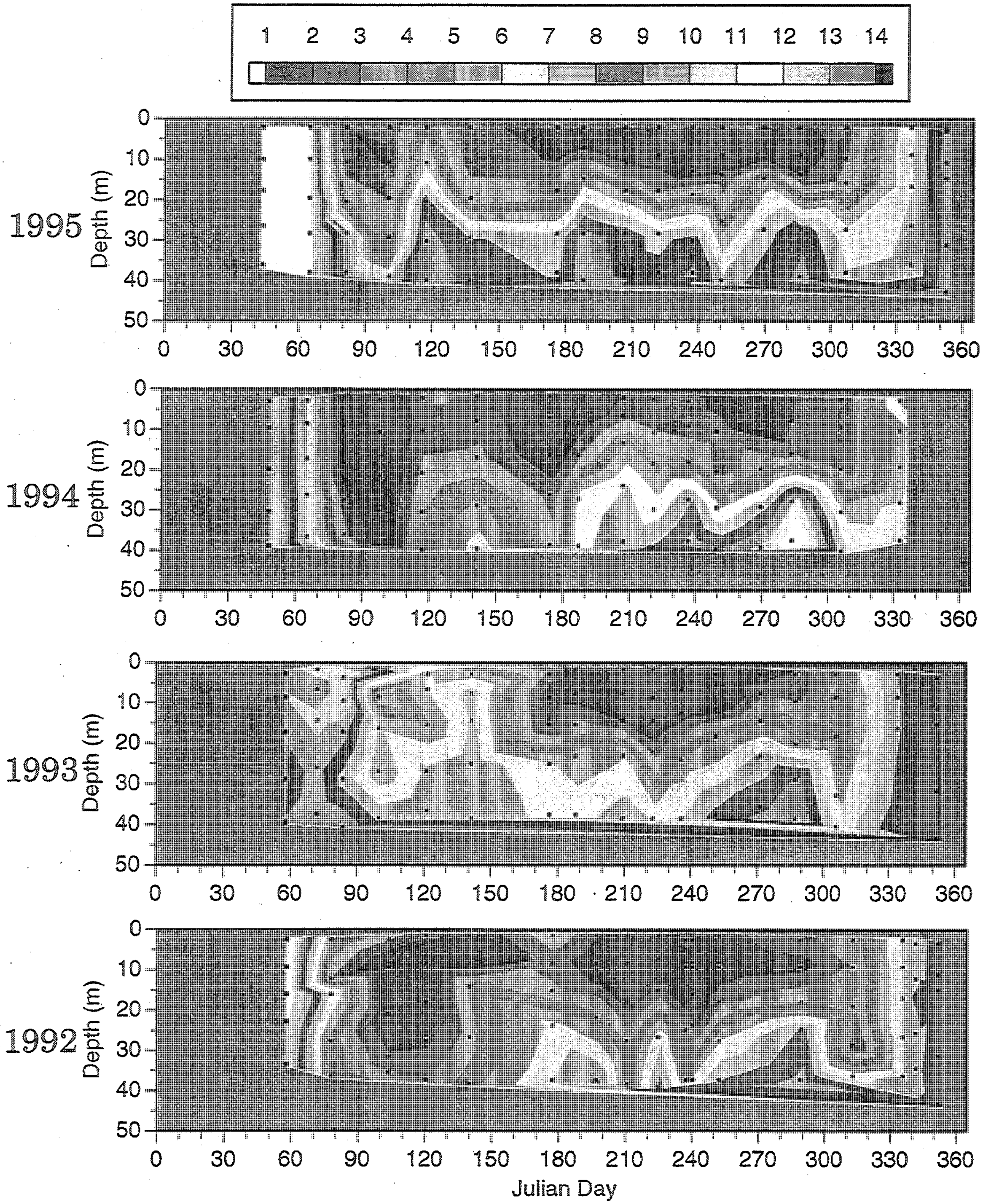
Nearfield (N16, N04, N07, N20)
Phosphate (µM)



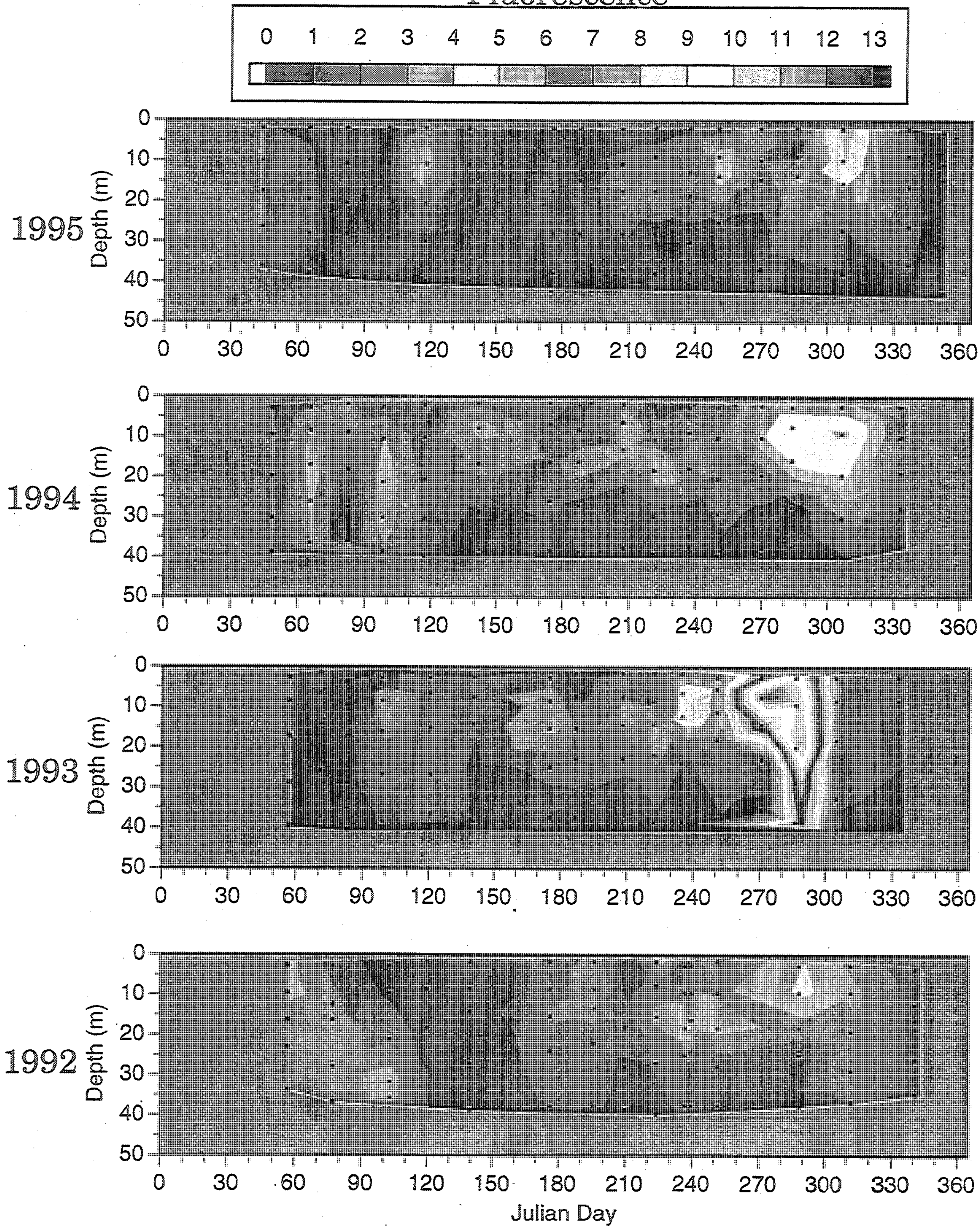
Nearfield (N16, N04, N07, N20)
Silicate (µM)



Nearfield (N16, N04, N07, N20)
DIN/PO4 Ratio



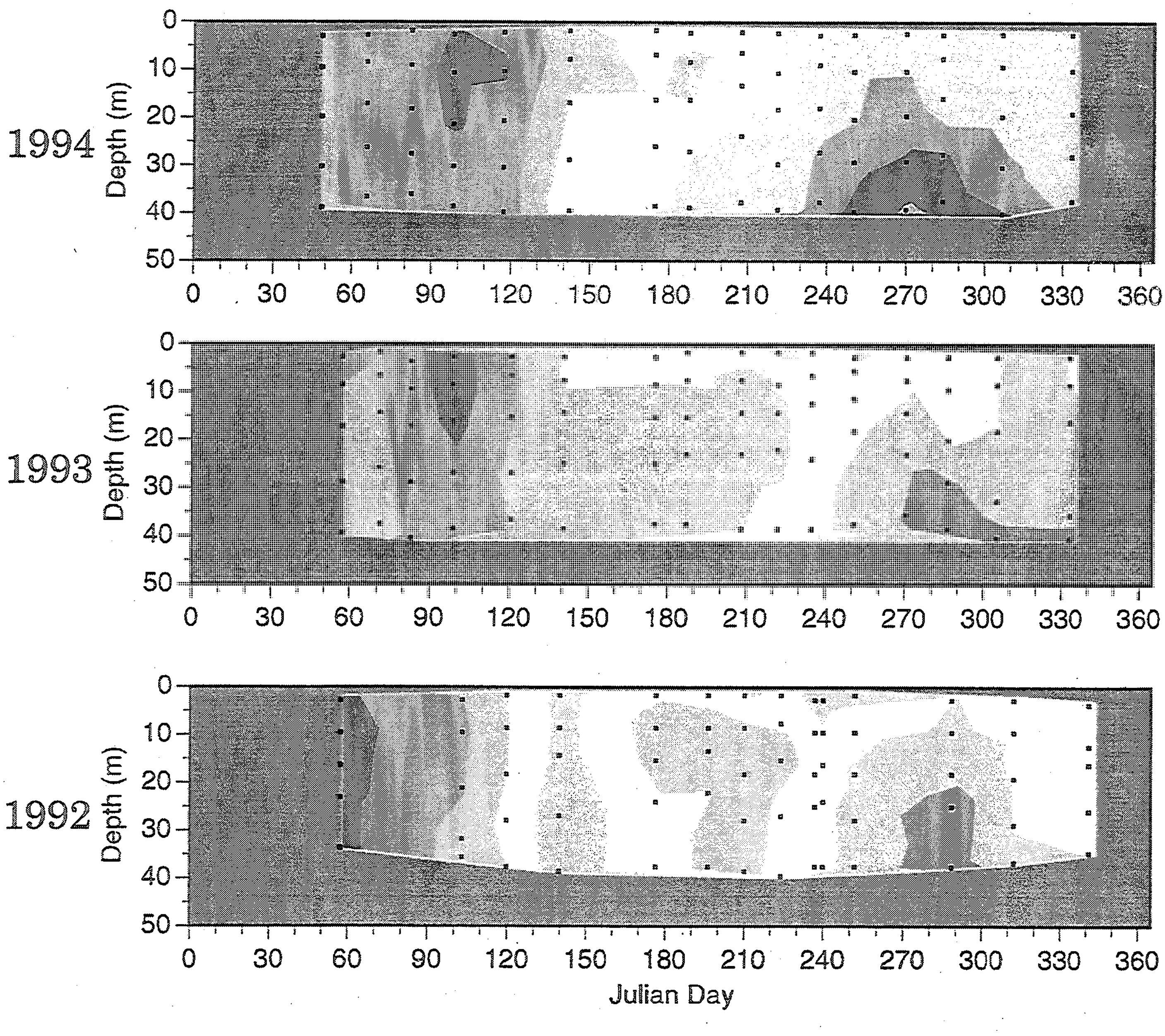
Nearfield (N16, N04, N07, N20)
Fluorescence



Nearfield (N16, N04, N07, N20)
Dissolved Oxygen (mg/L)

0 1 2 3 4 5 6 7 8 9 10 11 12 13

1995

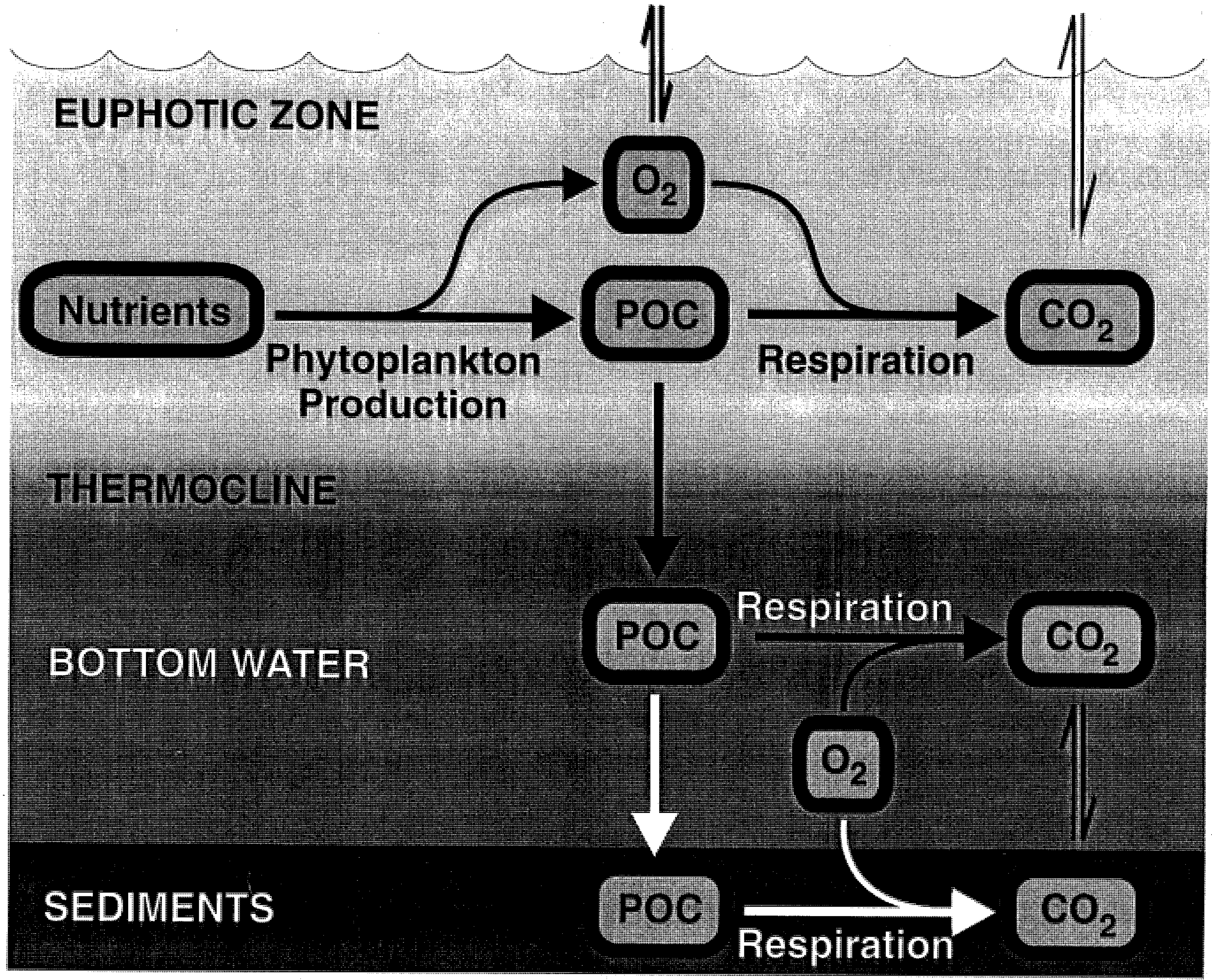


Whole year average values for stations N16, N04, N07, and N20 in the Nearfield region.

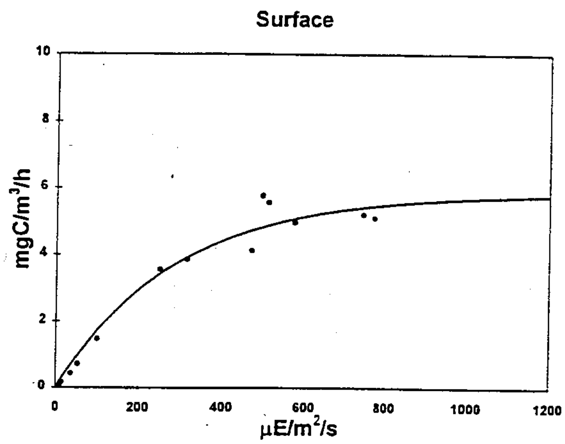
Year	n	Depth	DIN	N+N	NH4	PO4	SiO4	DissO	Fluor	SAL	Temp	DIN/P
1995	83-85	19.6	5.02	4.17	0.85	0.67	6.22		1.16	31.89	8.73	6.56
1994	77-80	19.1	4.20	3.23	0.96	0.62	4.54	9.35	1.77	31.99	8.65	5.76
1993	79-80	17.8	3.44	2.61	0.79	0.50	4.85	9.96	2.12	31.52	7.90	5.63
1992	70-75	18.2	2.32	1.78	0.55	0.46	4.66	9.65	1.82	31.57	8.23	4.13

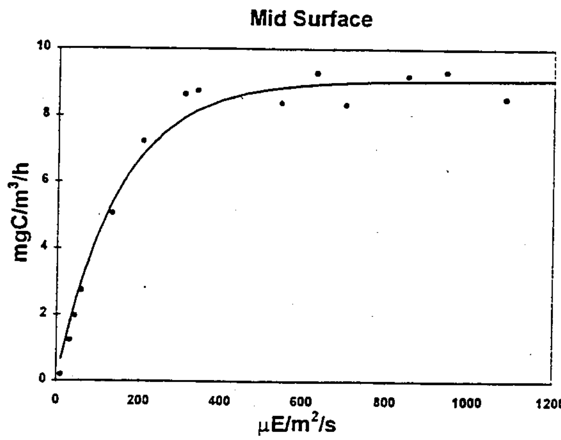
APPENDIX C-5

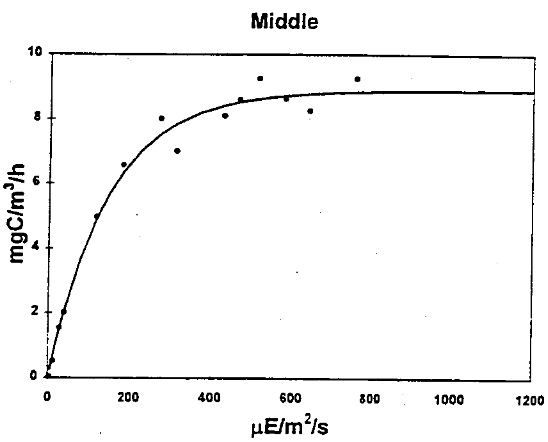
Craig Taylor
WHOI

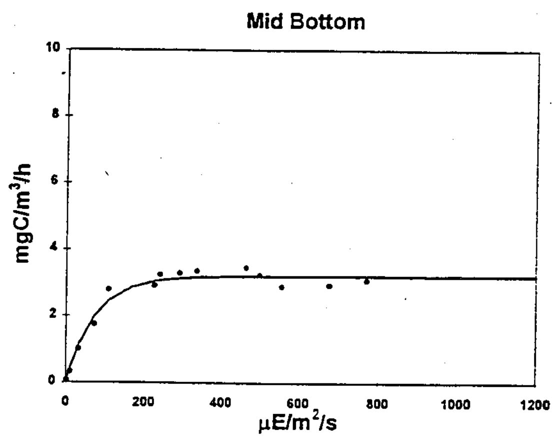

EUPHOTIC ZONE
O2
Nutrients
POC
CO2
Phytoplankton Production
Respiration
THERMOCLINE
POC
Respiration
CO2
BOTTOM WATER
O2
SEDIMENTS
POC
CO2
Respiration

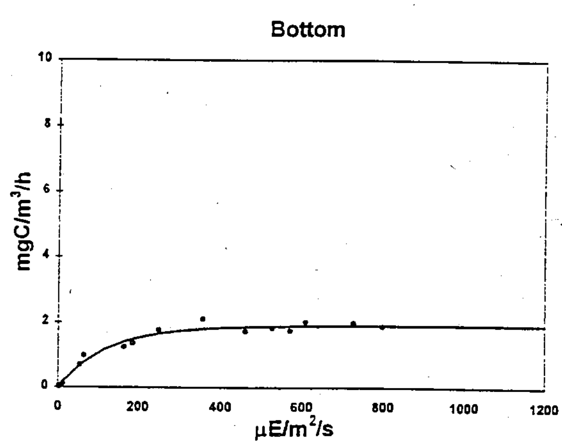
W9510 Station N04



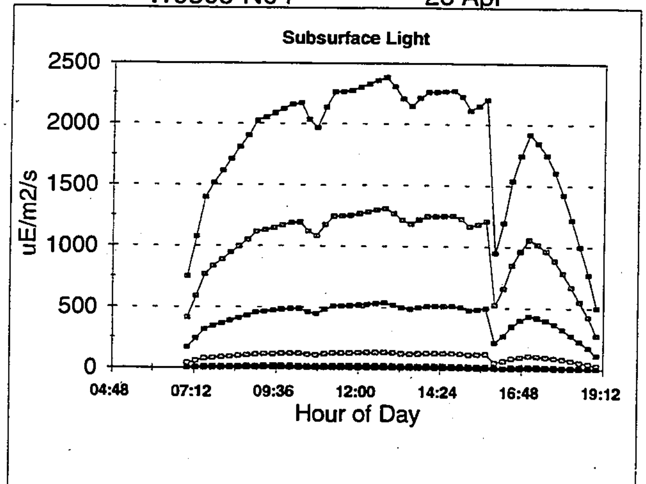


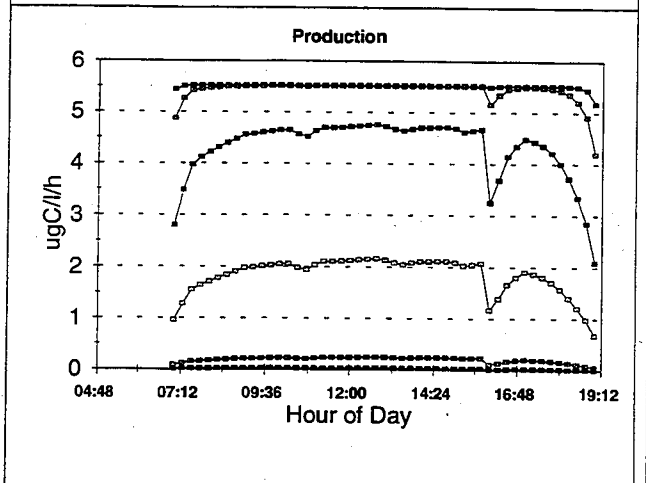


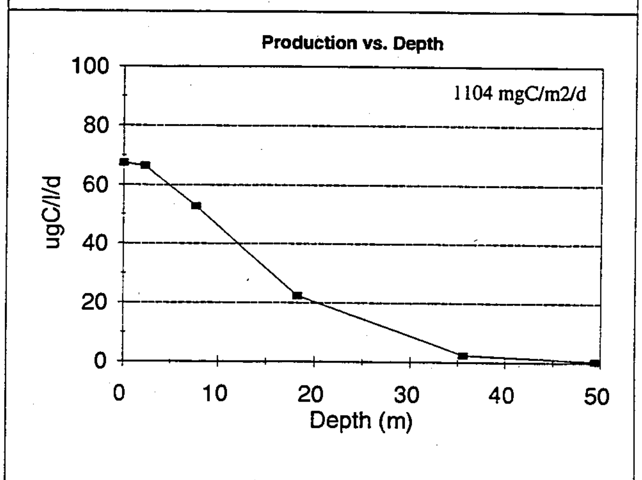


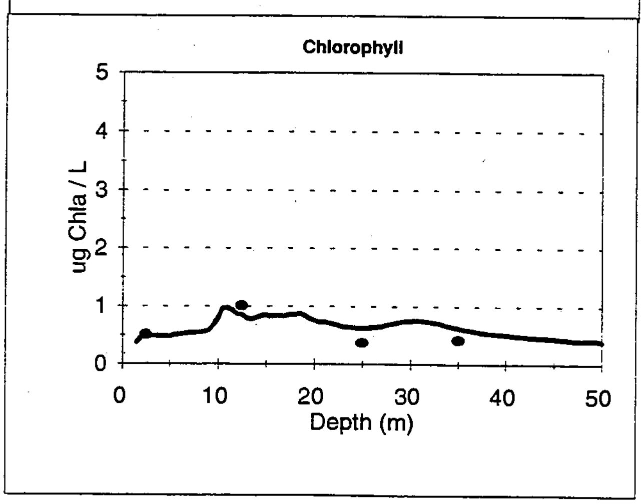


W9505-N04 26 Apr

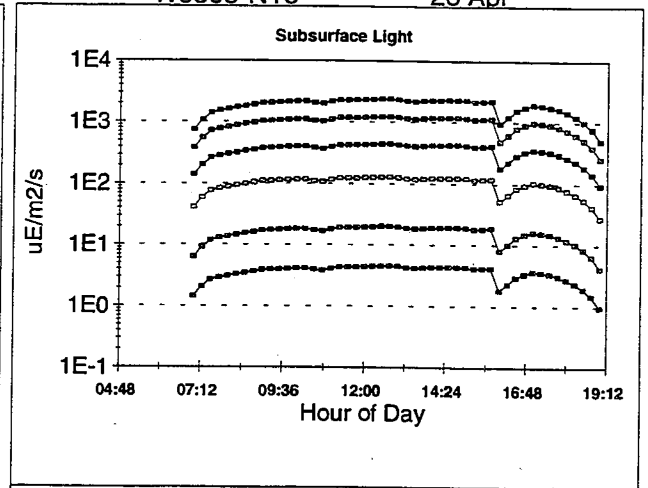


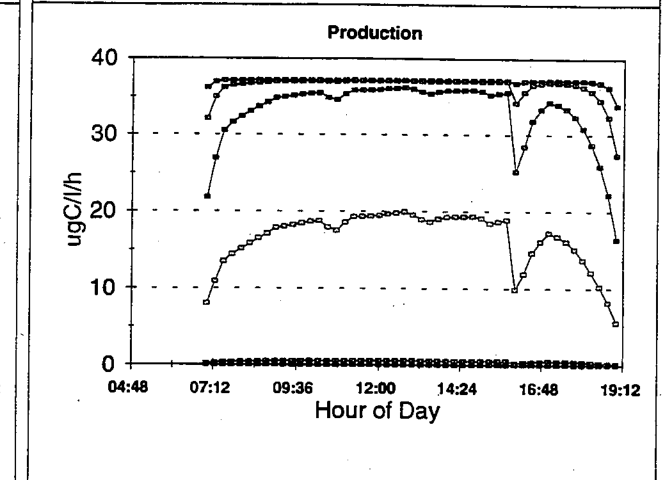


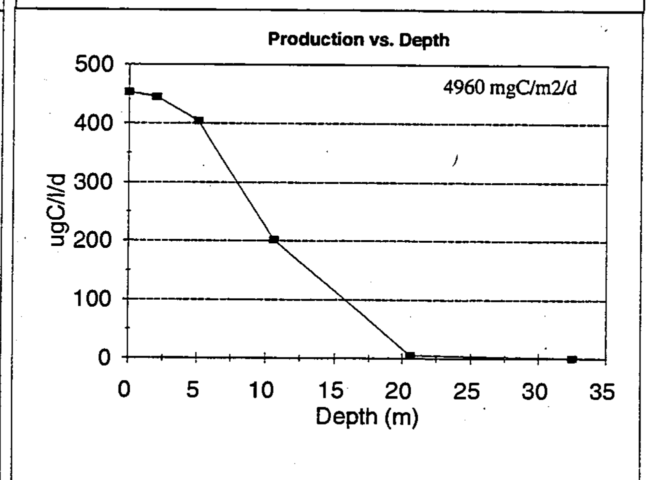


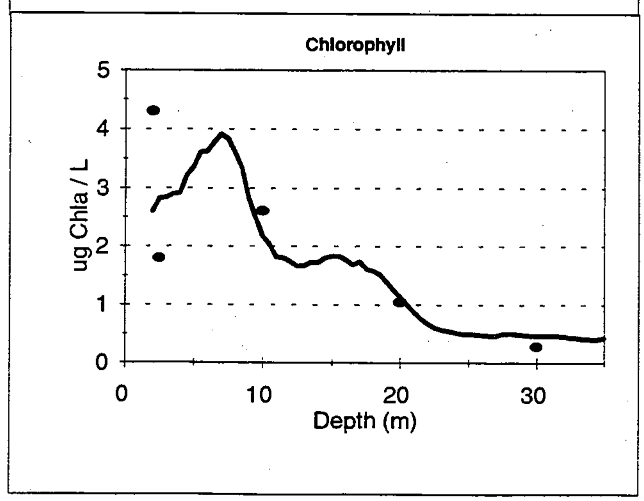


W9505-N16 26 Apr

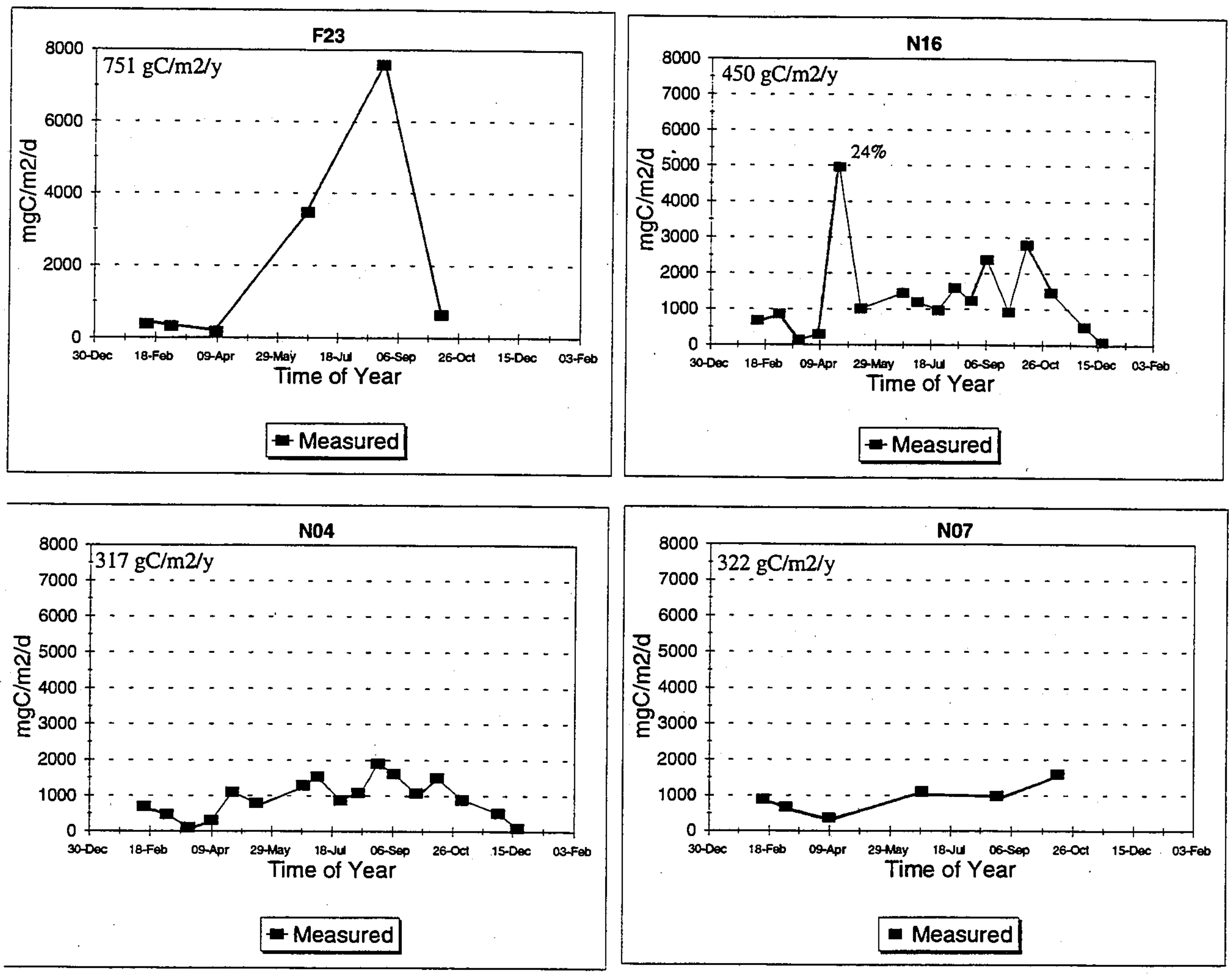




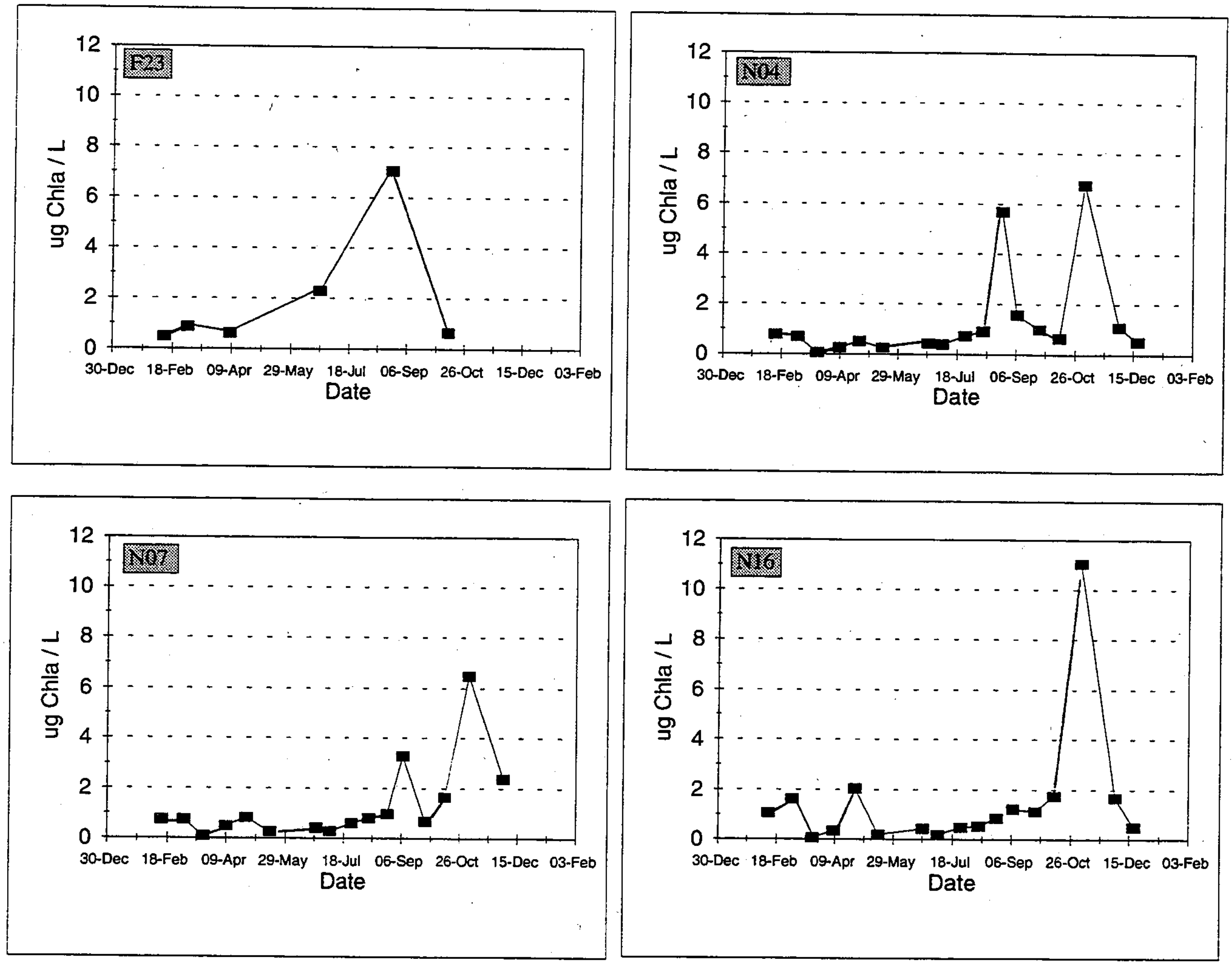




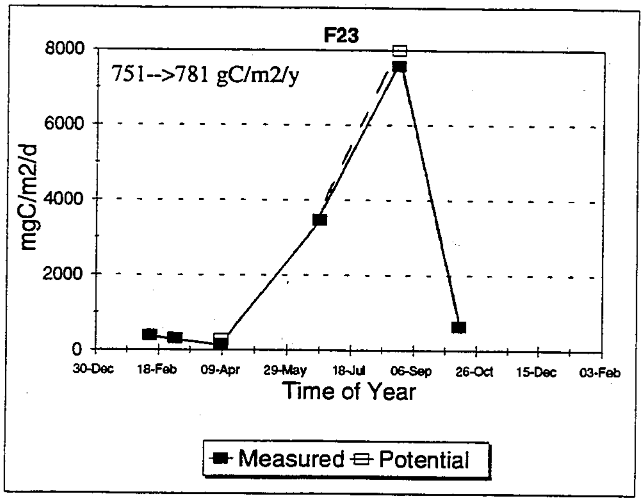
Phytoplankton Production

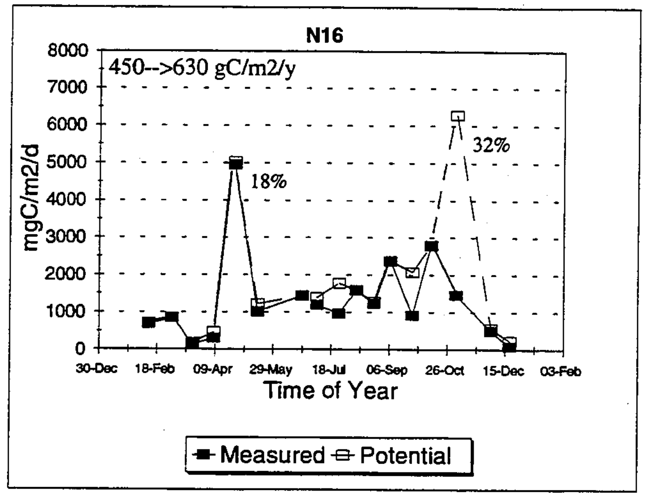


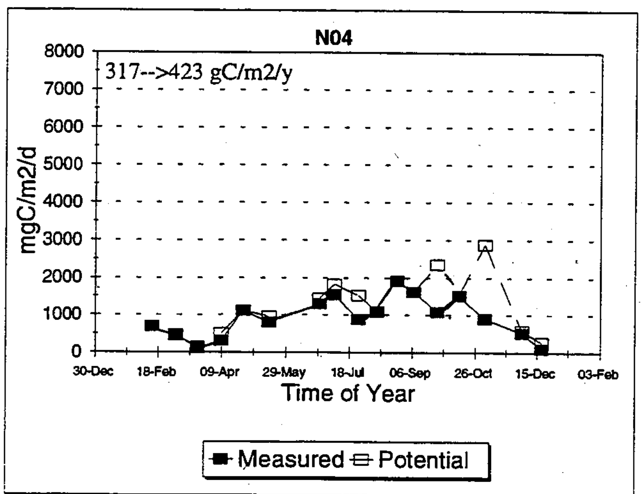
Average Photic Zone Chla

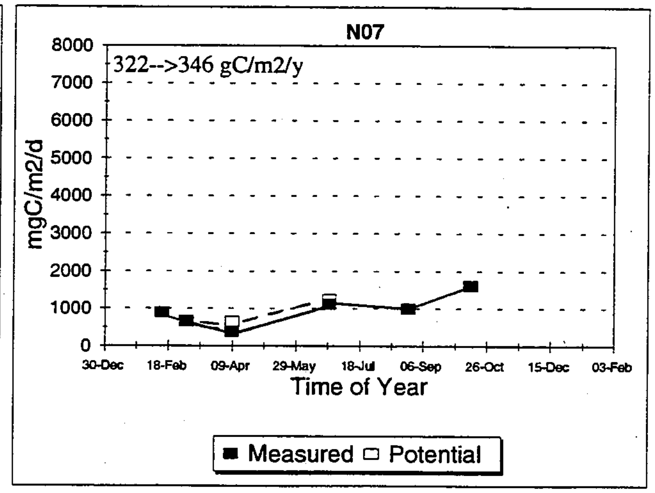


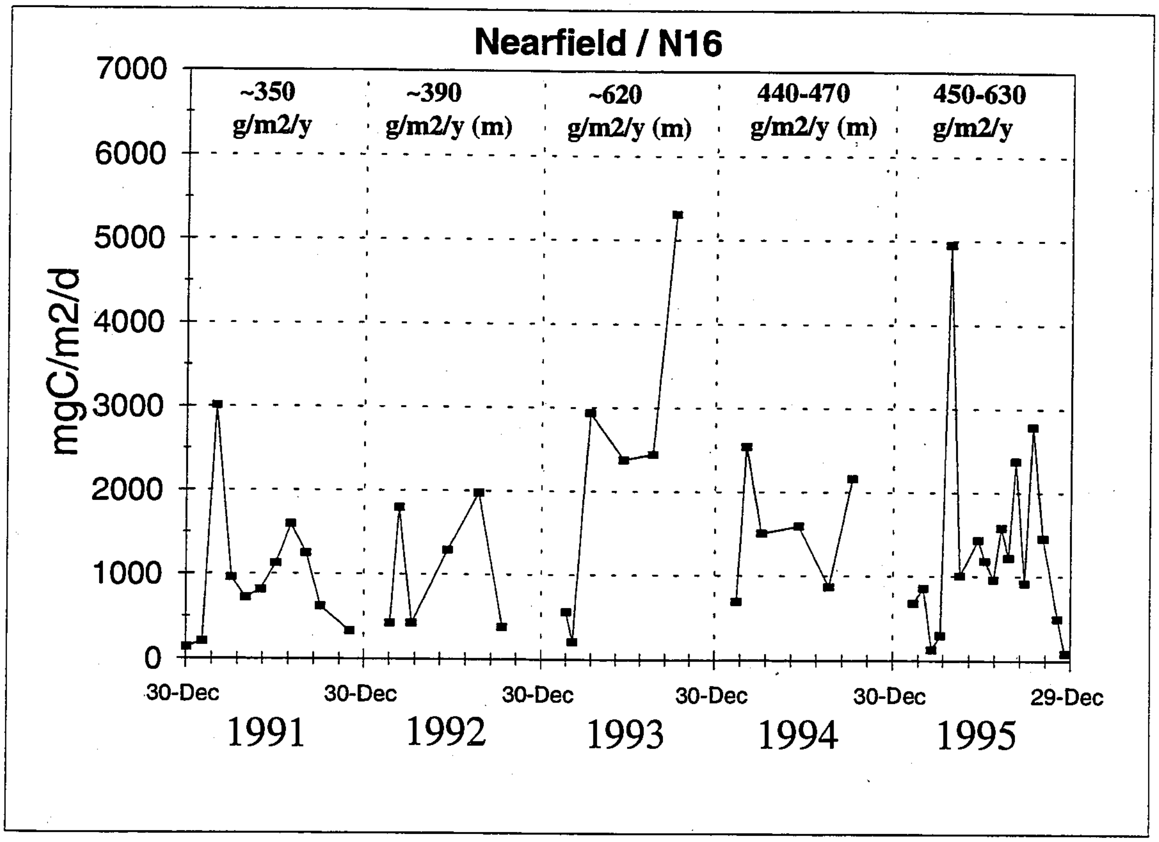
Phytoplankton Production



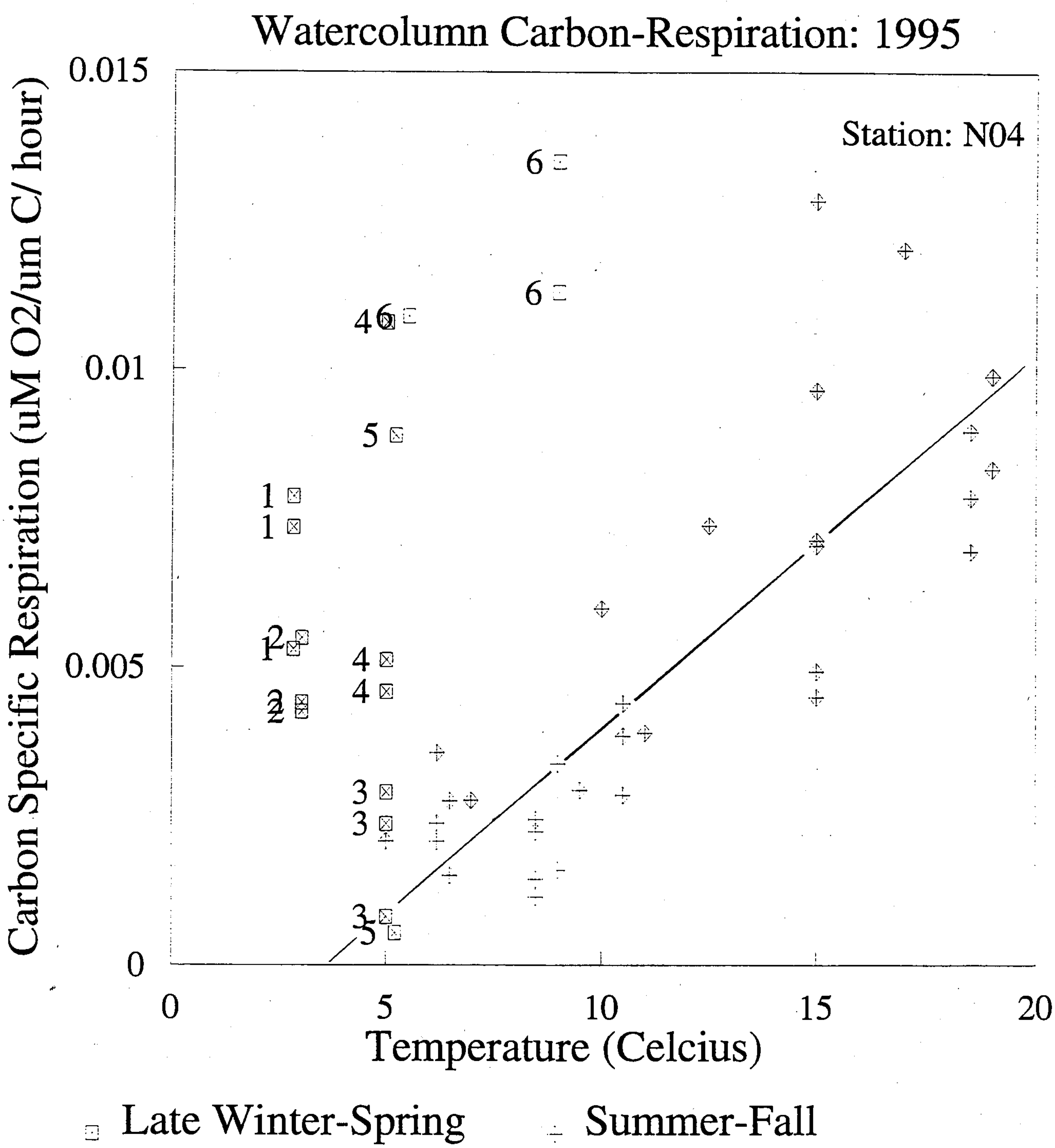






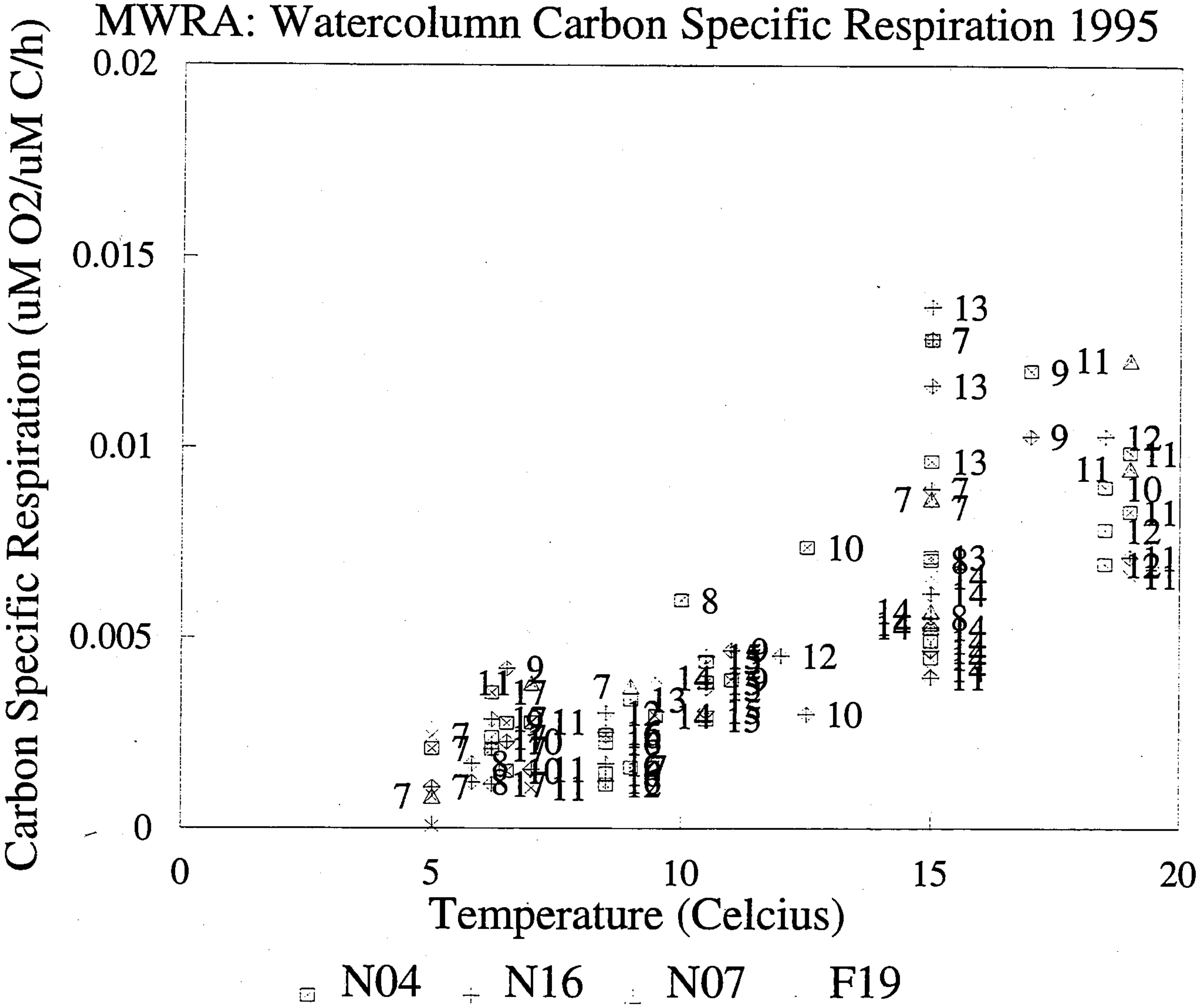


Nearfield / N16
~350 g/m2/y
~390 g/m2/y (m)
~620 g/m2/y (m)
440-470 g/m2/y (m)
450-630 g/m2/y
mgC/m2/d
7000
6000
5000
4000
3000
2000
1000
0
30-Dec
30-Dec
30-Dec
30-Dec
30-Dec
29-Dec
1991
1992
1993
1994
1995

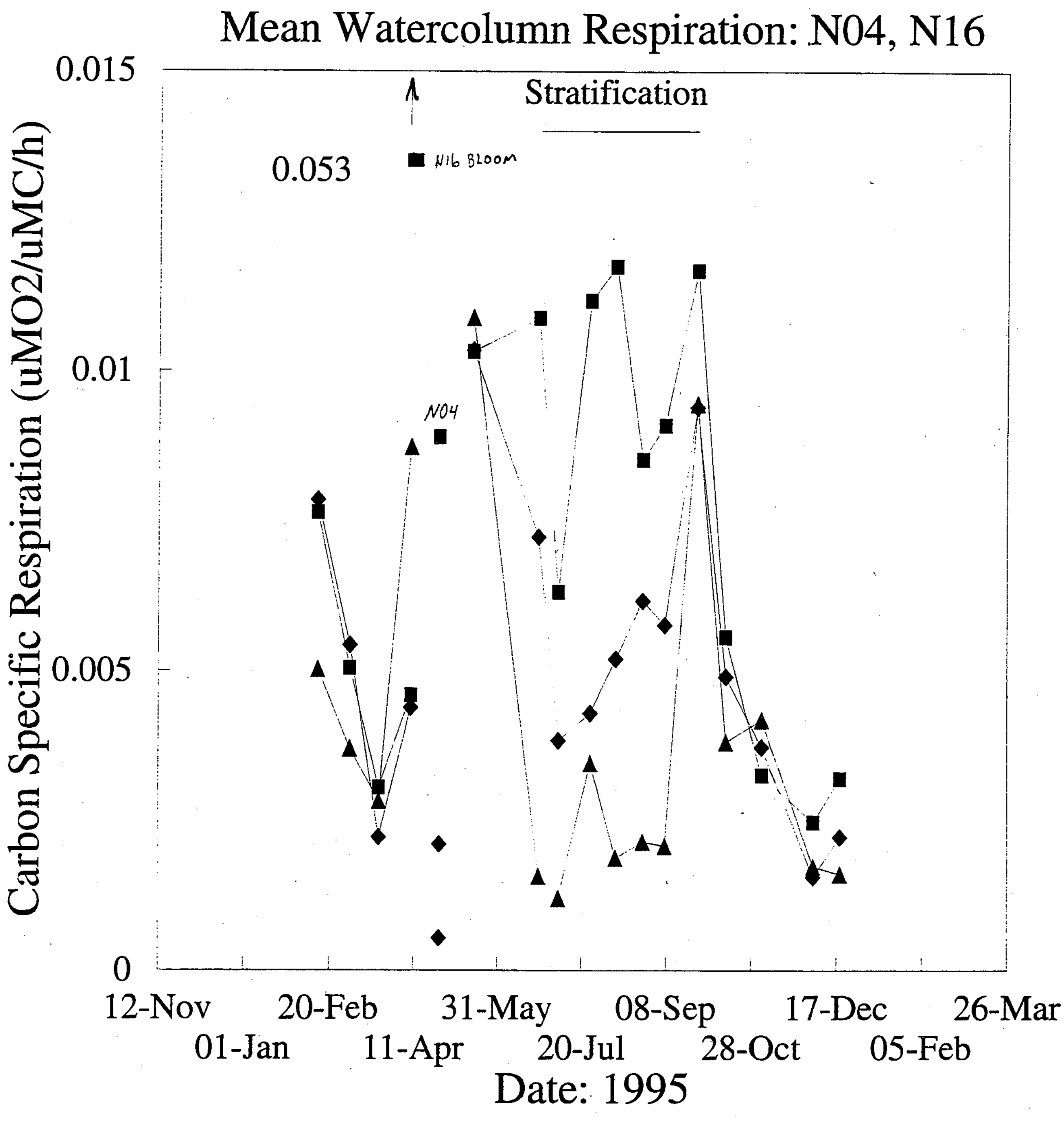


Numbers refer to Cruises.
Cruises 1-6: February-May; 7-17: June-December

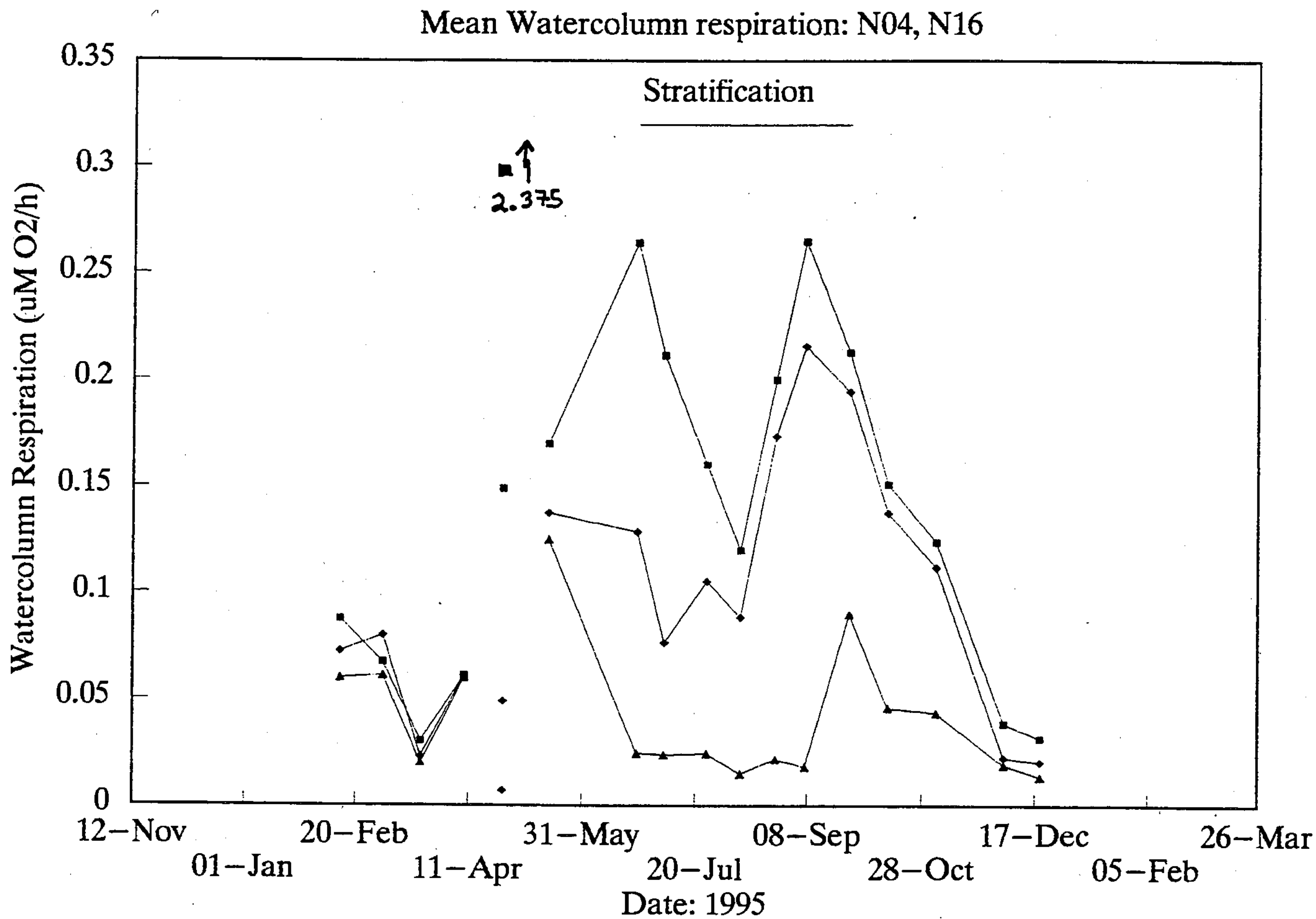
MWRA: Watercolumn Carbon Specific Respiration 1995



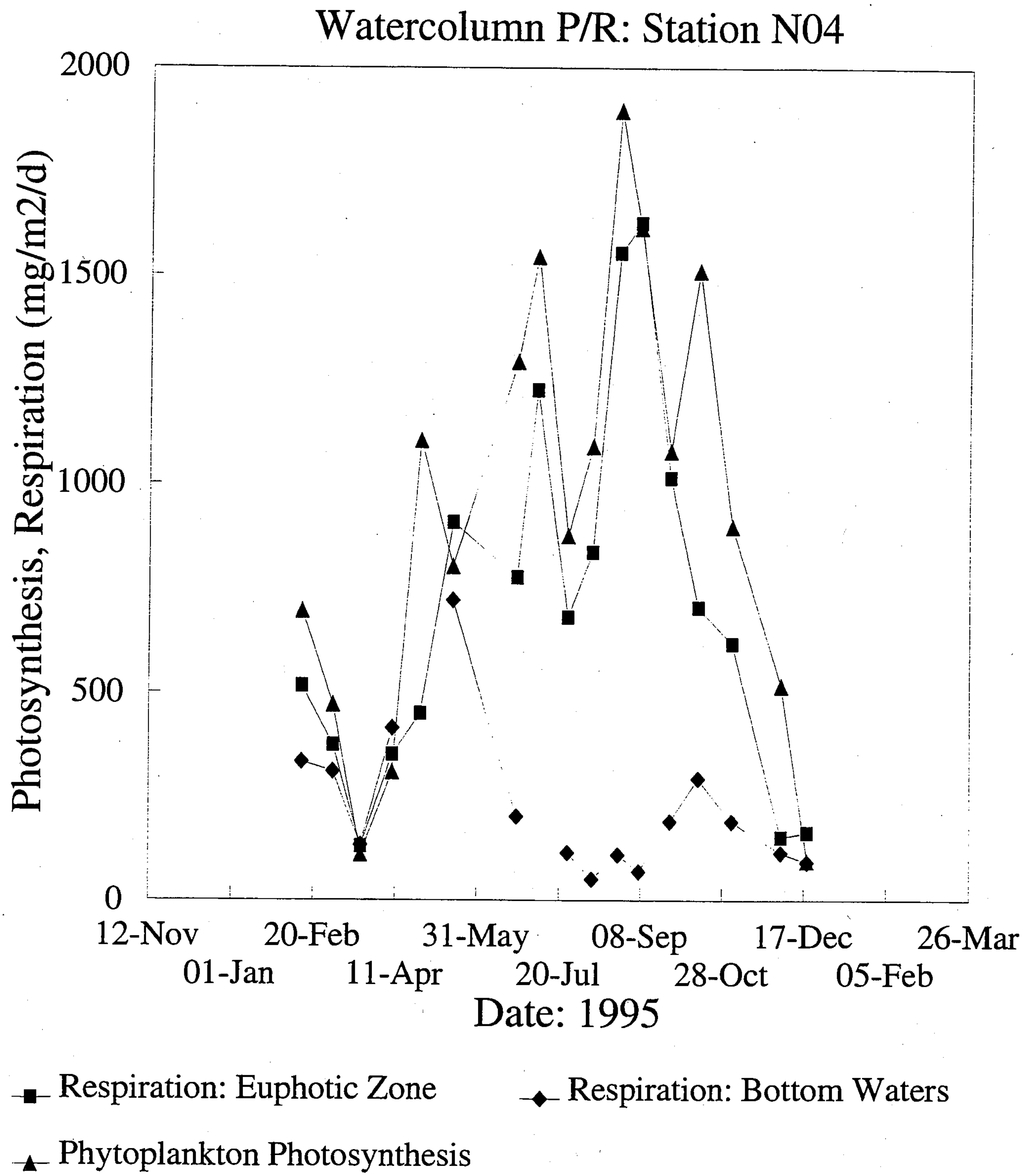
Post-Stratification Data 1995
Carbon Specific Resp = 0.000608 (Temp) - 0.002025; R2=0.67, N=82

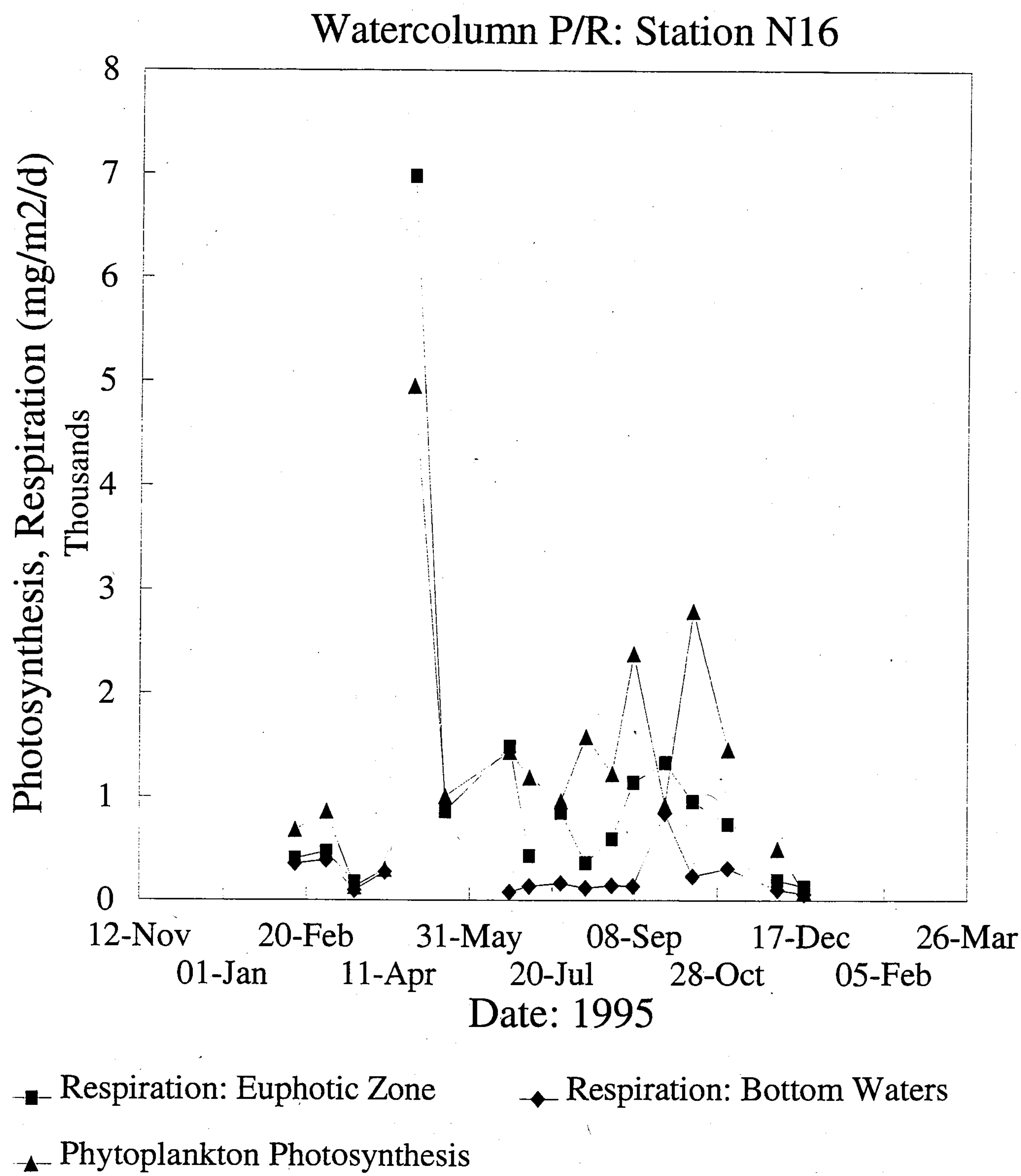


Note: Vertical distribution controlled primarily by temperature.



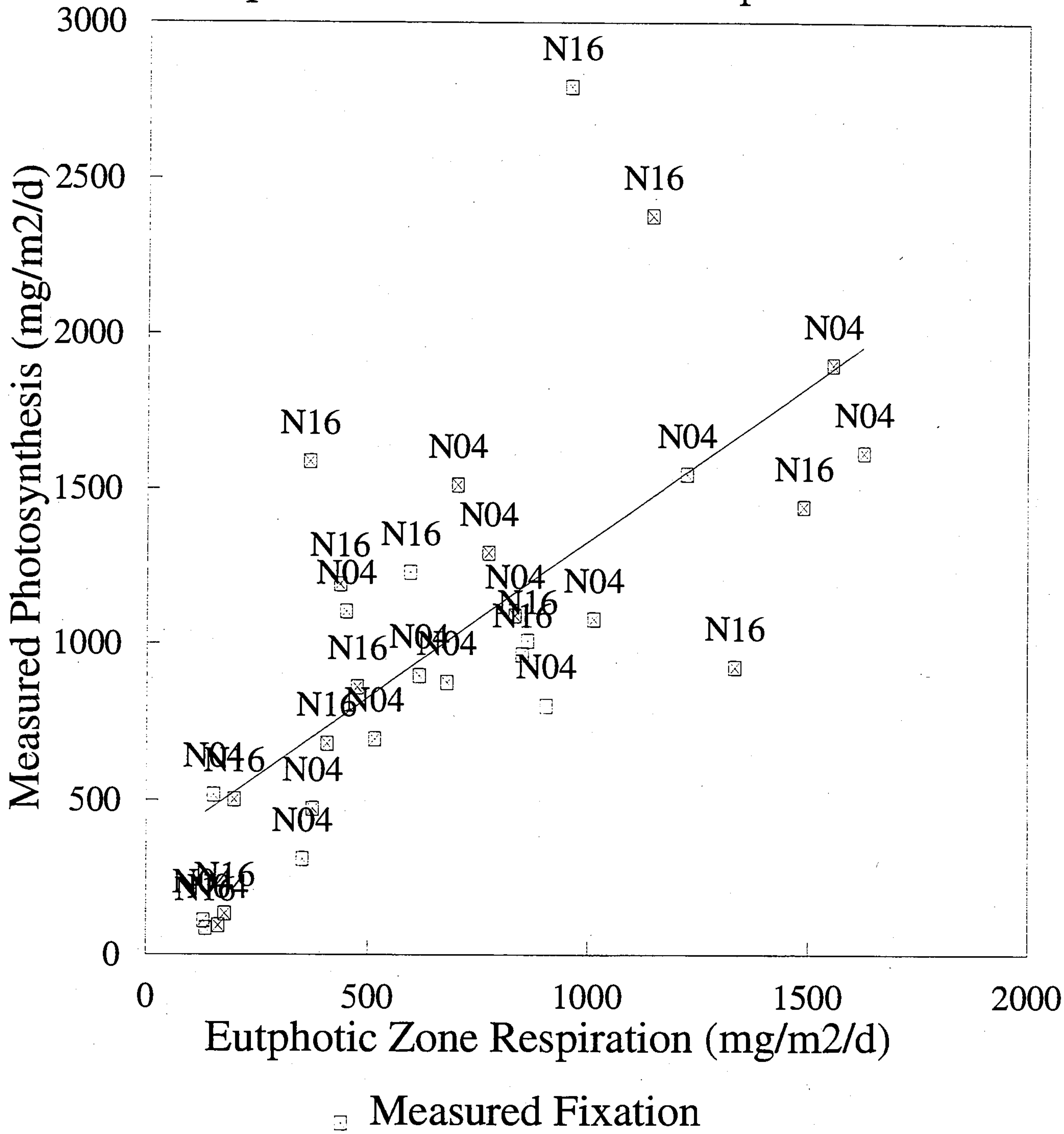
Note: Vertical distribution of respiration is controlled by temperature and organic matter. High respiration rates at N16 in April were co−incident with a bloom.


Watercolumn P/R: Station N04
Photosynthesis, Respiration (mg/m2/d)
2000
1500
1000
500
0
12-Nov
20-Feb
31-May
08-Sep
17-Dec
26-Mar
01-Jan
11-Apr
20-Jul
28-Oct
05-Feb
Date: 1995
Respiration: Euphotic Zone
Respiration: Bottom Waters
Phytoplankton Photosynthesis



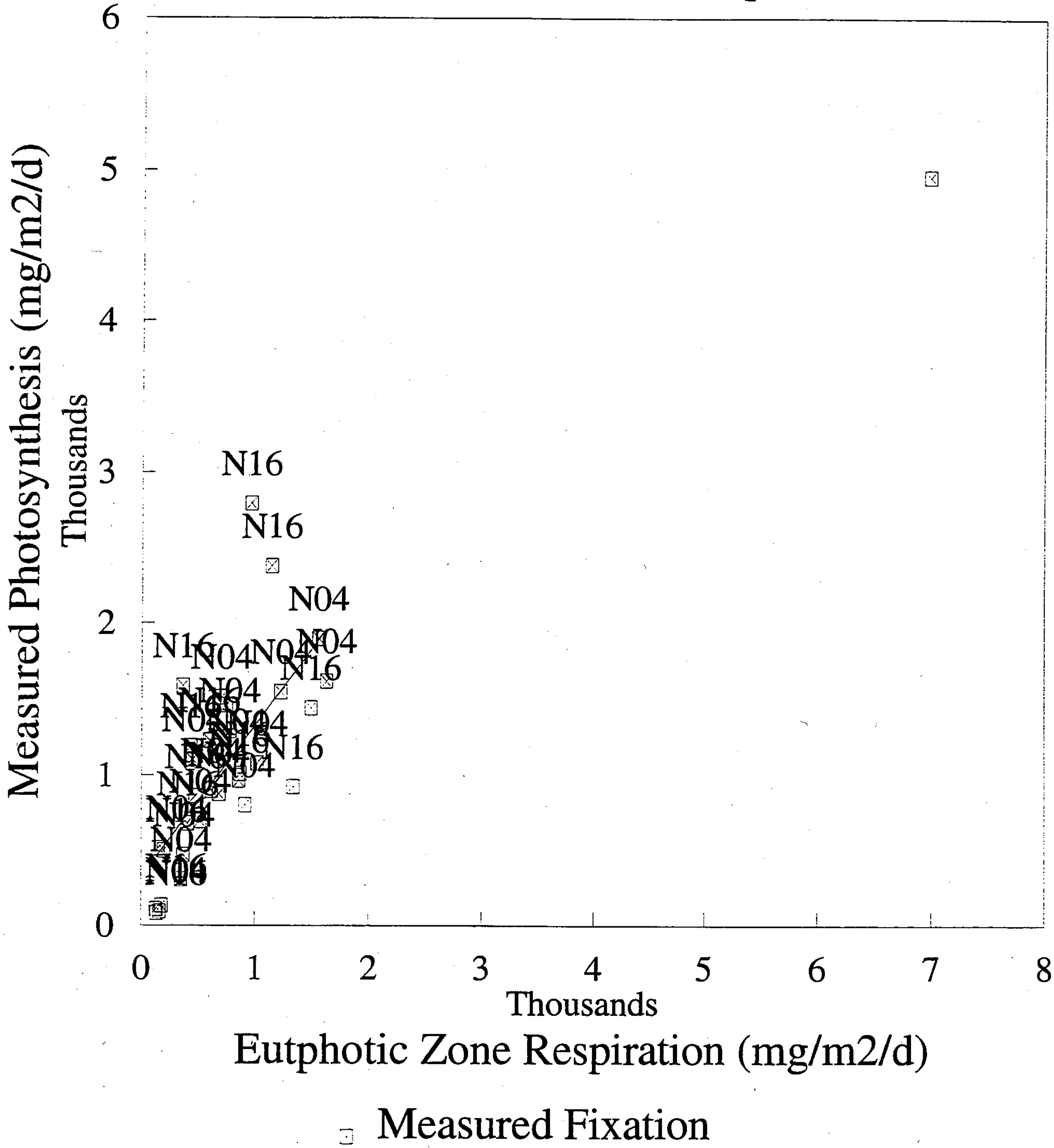
Watercolumn P/R: Station N16
Photosynthesis, Respiration (mg/m2/d)
Thousands
8
7
6
5
4
3
2
1
0
12-Nov
01-Jan
20-Feb
11-Apr
31-May
20-Jul
08-Sep
28-Oct
17-Dec
05-Feb
26-Mar
Date: 1995
Respiration: Euphotic Zone
Respiration: Bottom Waters
Phytoplankton Photosynthesis

Euphotic Zone Production/Respiration: 1995

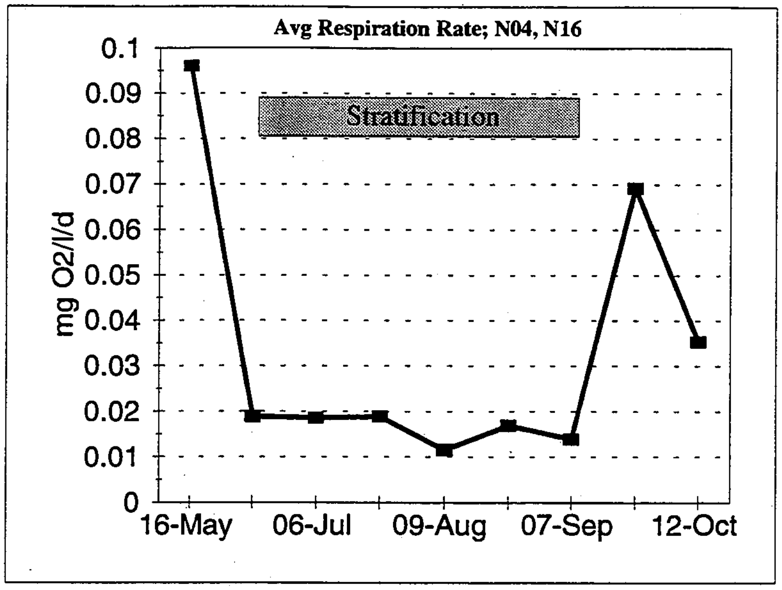


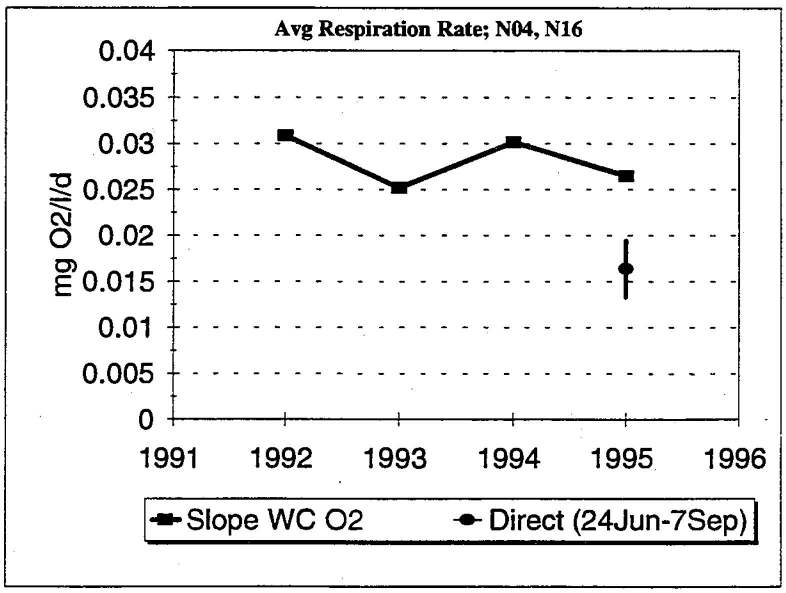
Indicates that about 50% of the measured production is availble for vertical and horizontal transpor

Euphotic Zone Production/Respiration: 1995



Indicates that about 50% of the measured production is availble for vertical and horizontal transpor


Avg Respiration Rate; N04, N16
Stratification
mg O2/l/d
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
16-May
06-Jul
09-Aug
07-Sep
12-Oct


Avg Respiration Rate; N04, N16
mg O2/l/d
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
1991
1992
1993
1994
1995
1996
Slope WC O2
Direct (24Jun-7Sep)

APPENDIX C-6

Steve Cibik
ENSR

ENSR

MWRA Harbor & Outfall Monitoring Program
1996 Water Quality Workshop

Phytoplankton Dynamics

Stephen J. Cibik
Kristyn B. Lemieux
Rebecca A. Zavistoski

ENSR
35 Nagog Park
Acton, MA 01720

ENSR

Presentation Overview

- Potential Concerns Regarding Plankton
- Summary of Methods
- Phytoplankton Abundance
  - Total Densities of Surface Phytoplankton
  - Surface Chlorophyll *a*
- Phytoplankton Seasonal Succession
  - Seasonal Patterns of Major Groups
- Spatial and Temporal Variability
- Discussion of Chlorophyll Hypotheses

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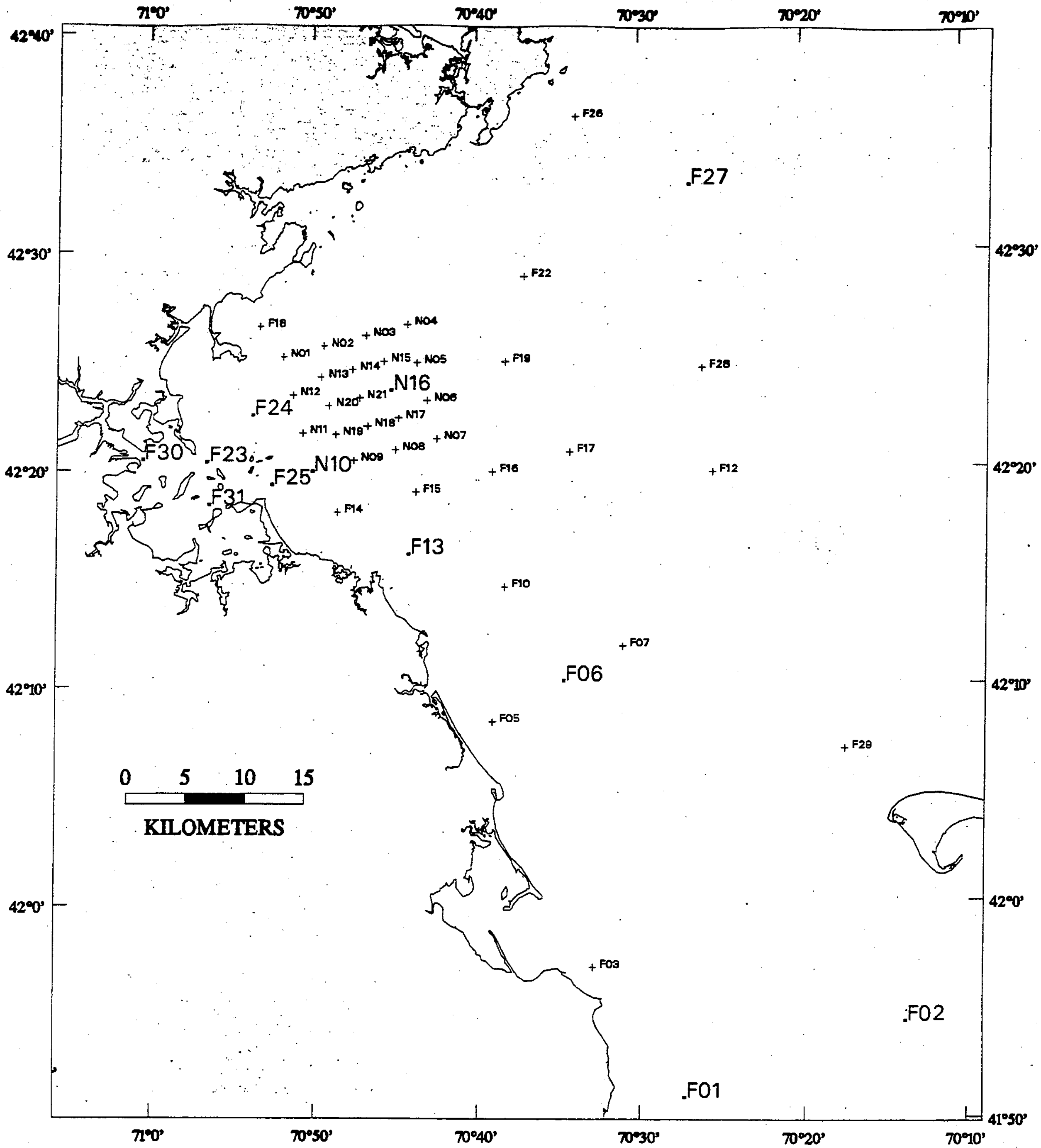
Concerns Regarding Plankton Community

- **Will Enrichment Alter Community Structure?**
  - Species Composition
  - Biomass
  - Vertical Distribution
  - Enhancement of Toxic or Nuisance Species
- **Will Toxicants Alter Community Structure or Marine Food Web?**
- **Will Effects on Plankton Influence Water Clarity/Color?**

ENSR

Summary of 1995 Methods

- **Phytoplankton Collection**
  - Surface and Mid-Depth Niskins at 12 Stations
  - 1-L Whole-Water Sample (Utermohl's)
  - 2-L Screened Sample (20μm Nitex; Formalin)
- **Cell Identification and Enumeration**
  - Inverted Microscopy Followed by Sample Archival
  - Carbon Equivalence Estimate
- **Chlorophyll *a***
  - In-situ Fluorometry, Post-Calibrated to Discrete Sample Results

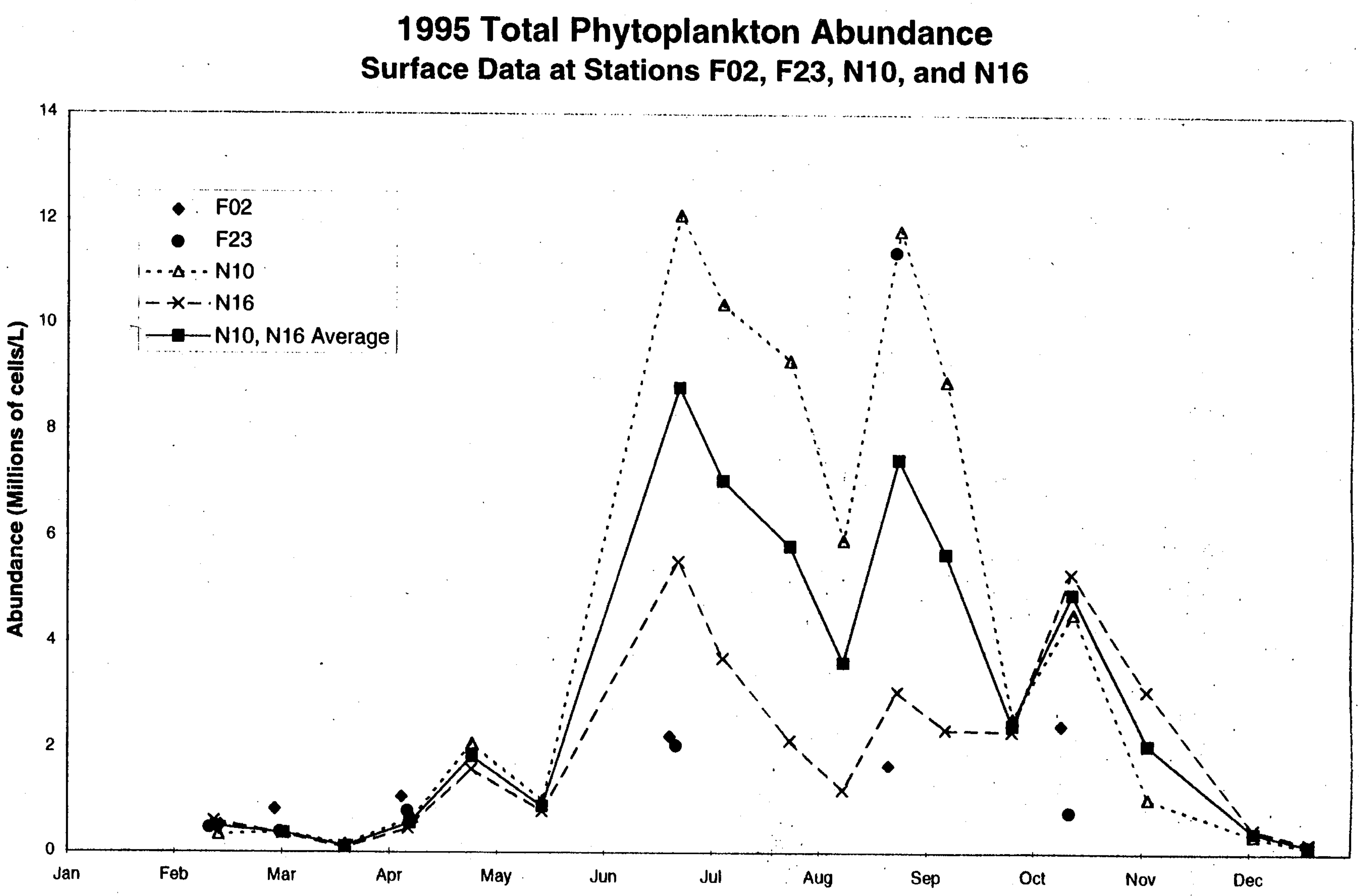


Plankton station locations

ENSR

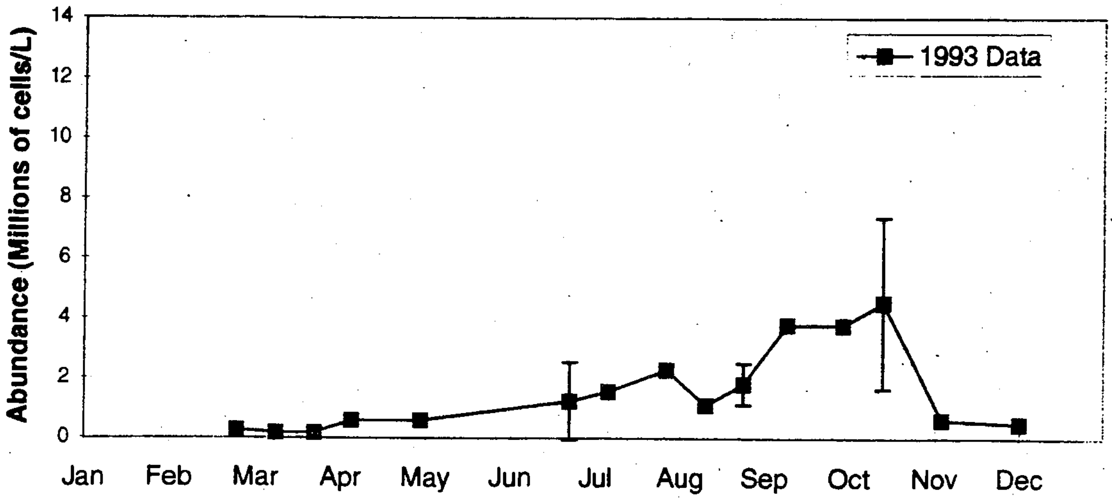
1995 Total Phytoplankton Abundance

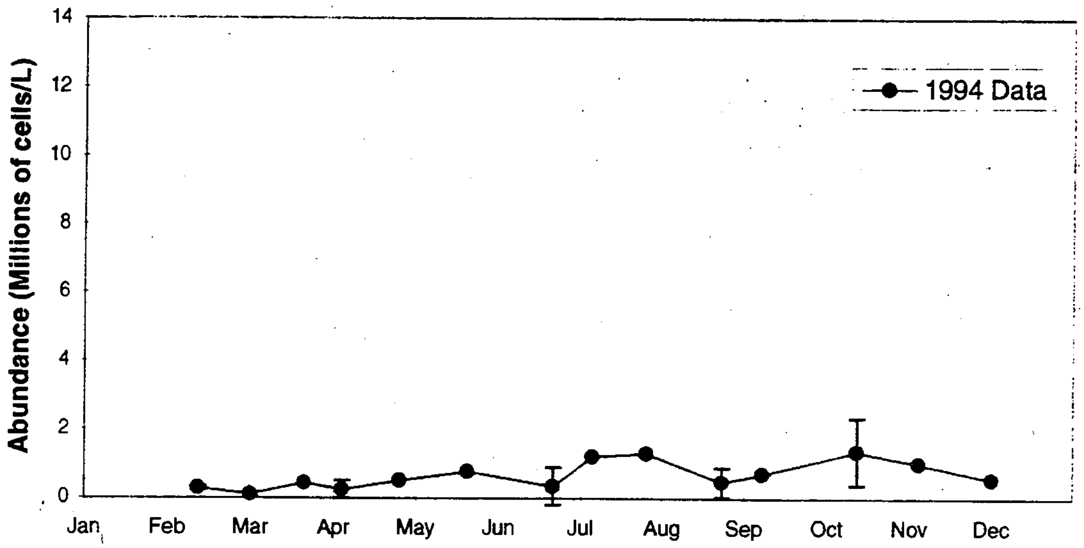
- Delayed Spring Bloom in Nearfield (Late April vs. March)
- Peaks in Abundance Also Evident in Summer and Fall
- Peak Chlorophyll Concentrations in Late Summer and Fall
- Highly Variable Across Nearfield (N10 → N16)

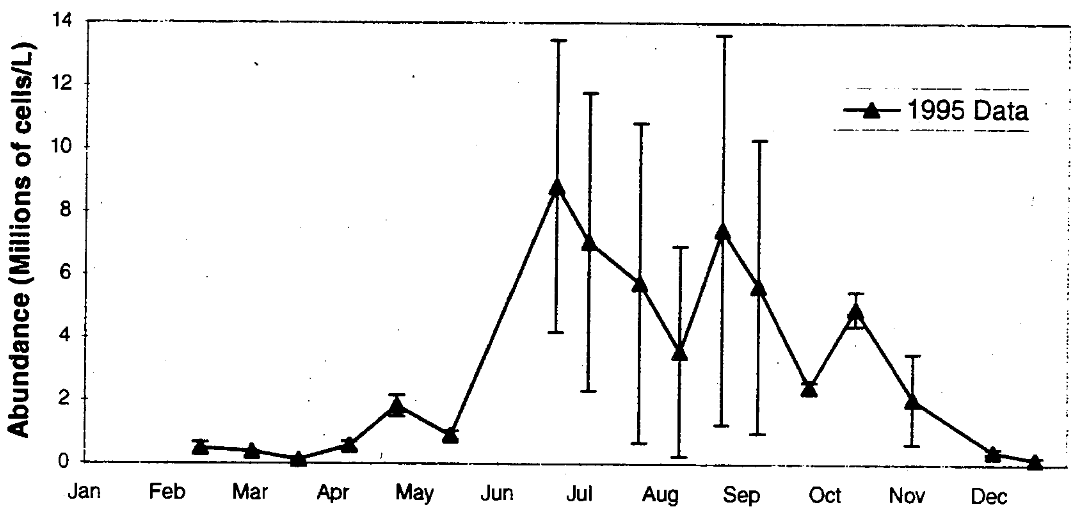


1995 Total Phytoplankton Abundance
Surface Data at Stations F02, F23, N10, and N16
Abundance (Millions of cells/L)
14
12
10
8
6
4
2
0
F02
F23
N10
N16
N10, N16 Average
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

1993-1995 Average Nearfield Total Phytoplankton Abundance Data (with Standard Deviations)



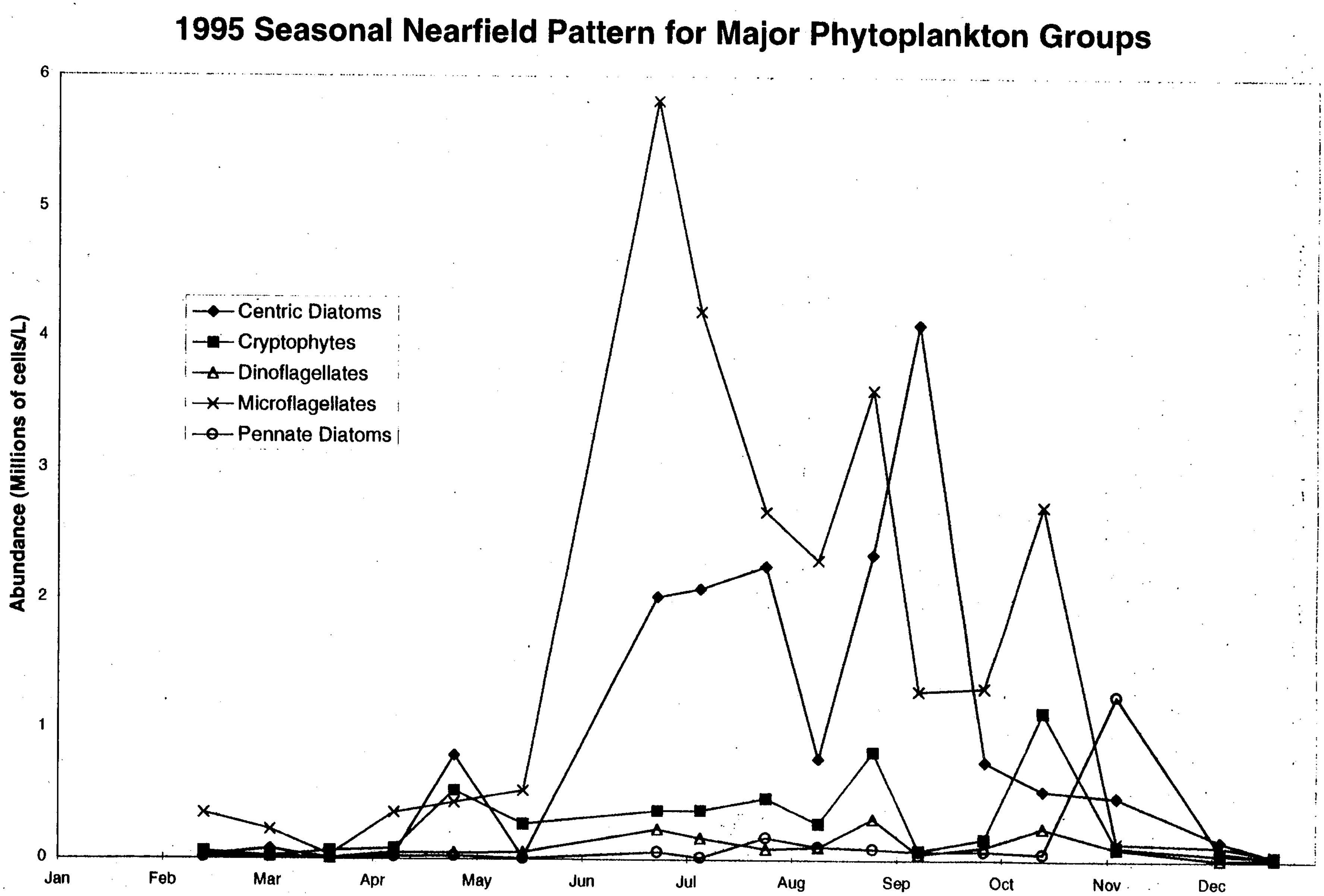




ENSR

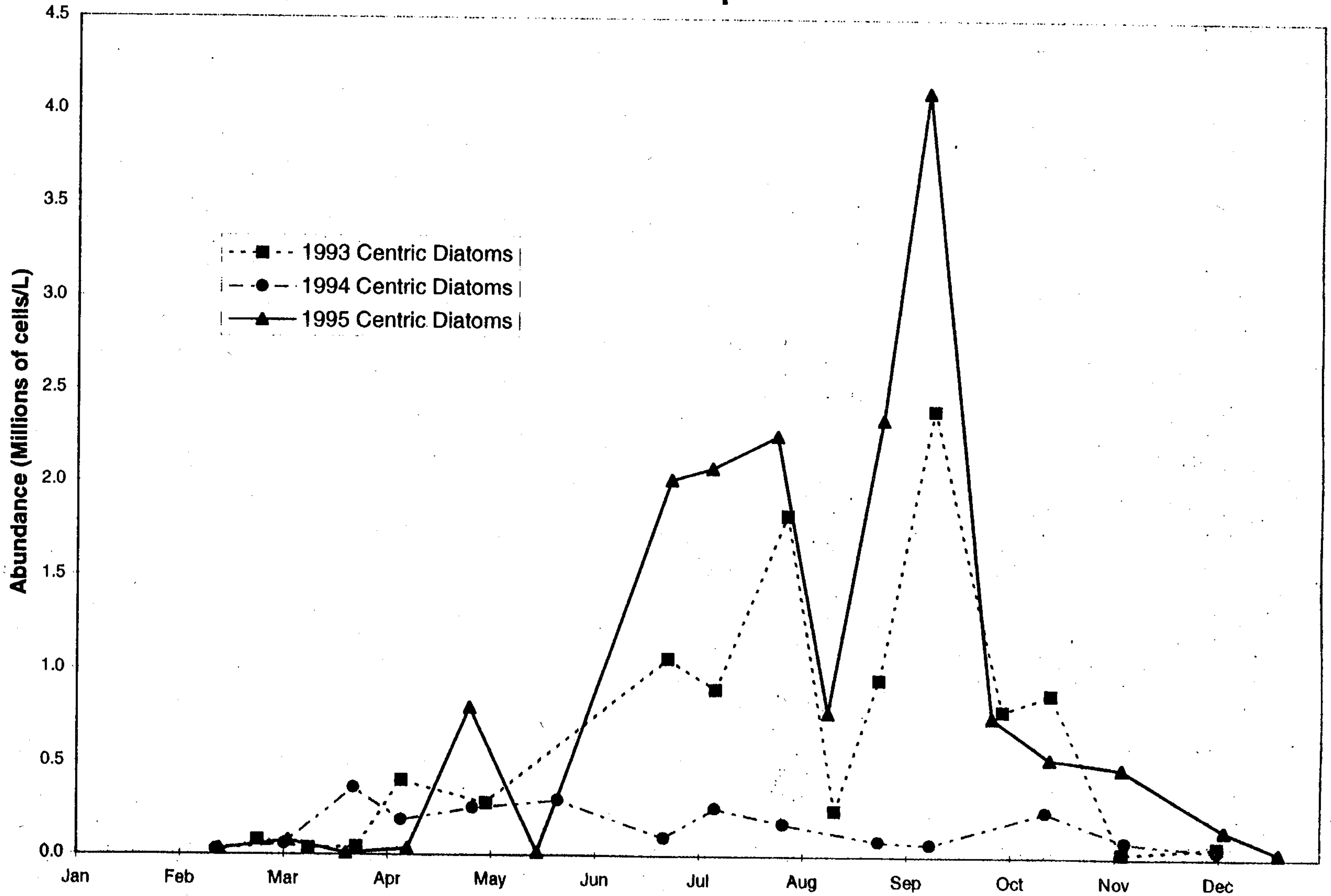
Seasonal Succession of Major Groups

- Overall Numerical Dominance by Microflagellates
  - Dominance by Diatoms During Episodic (Bloom) Events
- Biomass Dominants Vary by Region and Season
  - Centric Diatom/Flagellate Doominance in Harbor, CC Bay
  - More Complex in Nearfield
- Consistent Interannual Patterns
- Large Interannual Variability

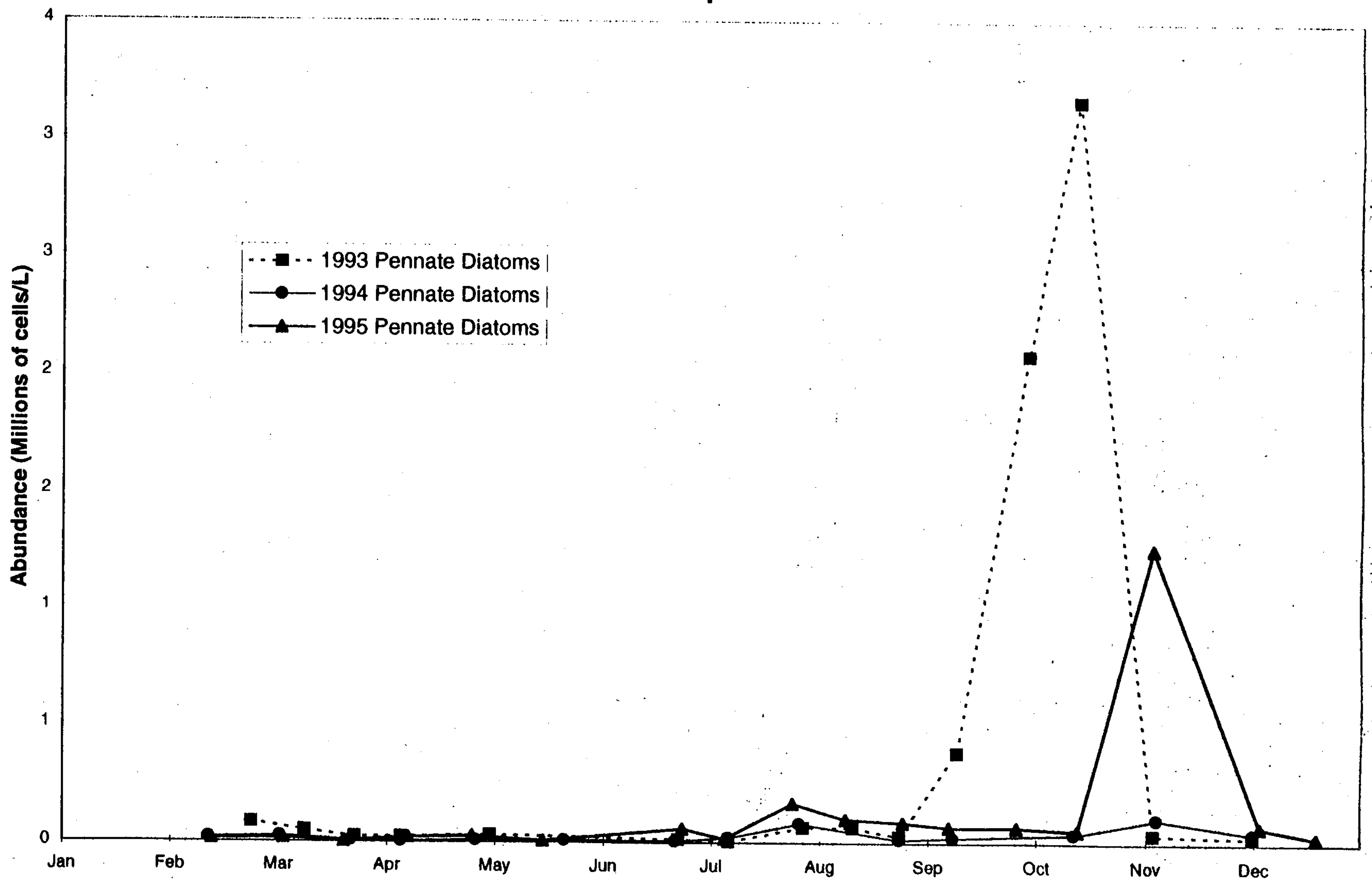


1995 Seasonal Nearfield Pattern for Major Phytoplankton Groups
Abundance (Millions of cells/L)
0
1
2
3
4
5
6
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Centric Diatoms
Cryptophytes
Dinoflagellates
Microflagellates
Pennate Diatoms

1993 - 1995 Seasonal Nearfield Pattern for Major Phytoplankton Groups



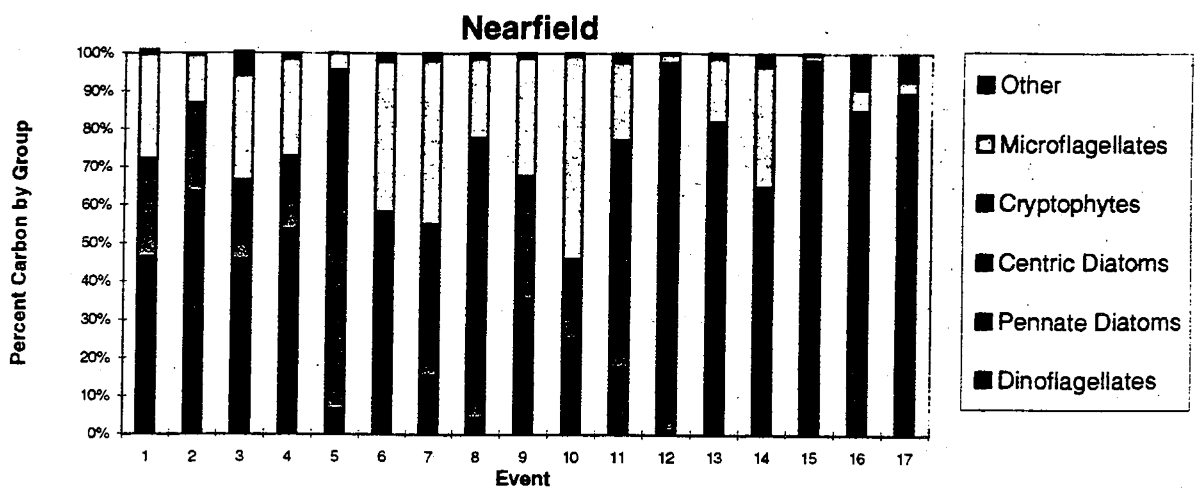
1993 - 1995 Seasonal Nearfield Pattern for Major Phytoplankton Groups

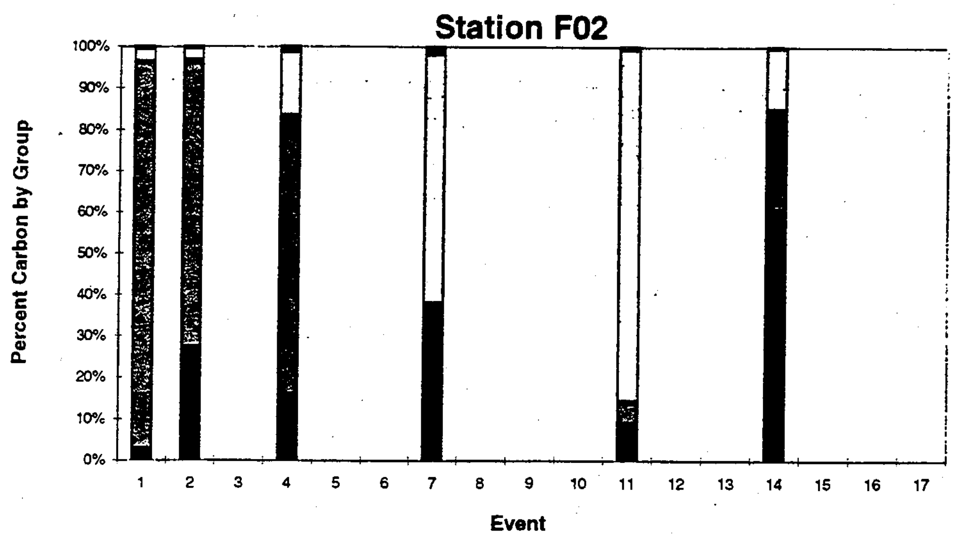


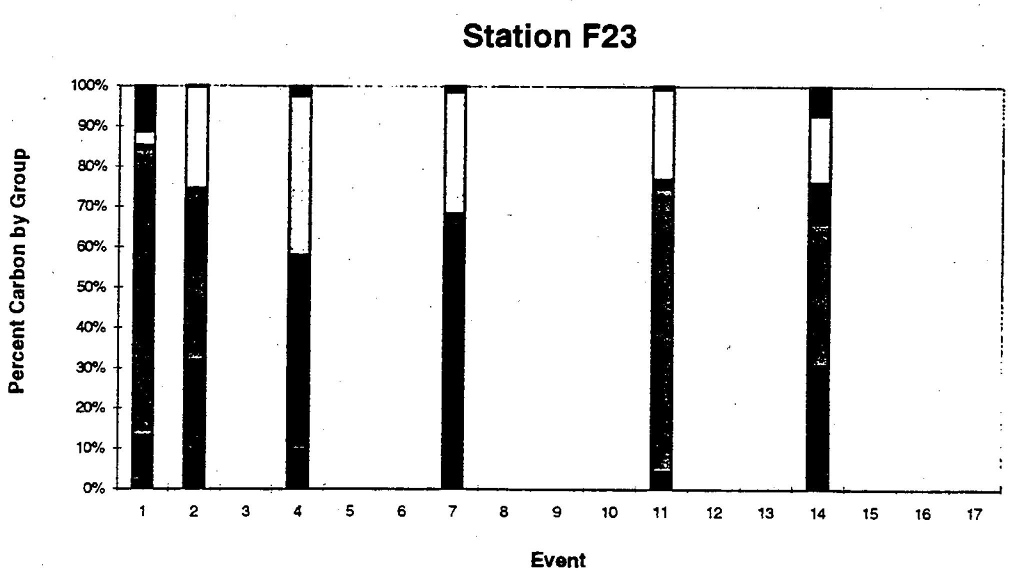
Dominance Based on Estimated Carbon

- Cape Cod Bay Has Different Seasonal Character
  - Centric Diatom Dominance in Harbor/CC Bay Early in Year
  - Microflagellate Dominance in Mid-Year
  - Elsewhere MF Rarely > 30% Contribution of Estimated C
- More Complex in Nearfield
  - Four Diatom Maxima Evident in Biomass
  - Larger Forms (e.g. Dinoflagellates) Dominate when Cell Densities Low
- Harbor Mouth Like CC Bay Early, NF After Spring

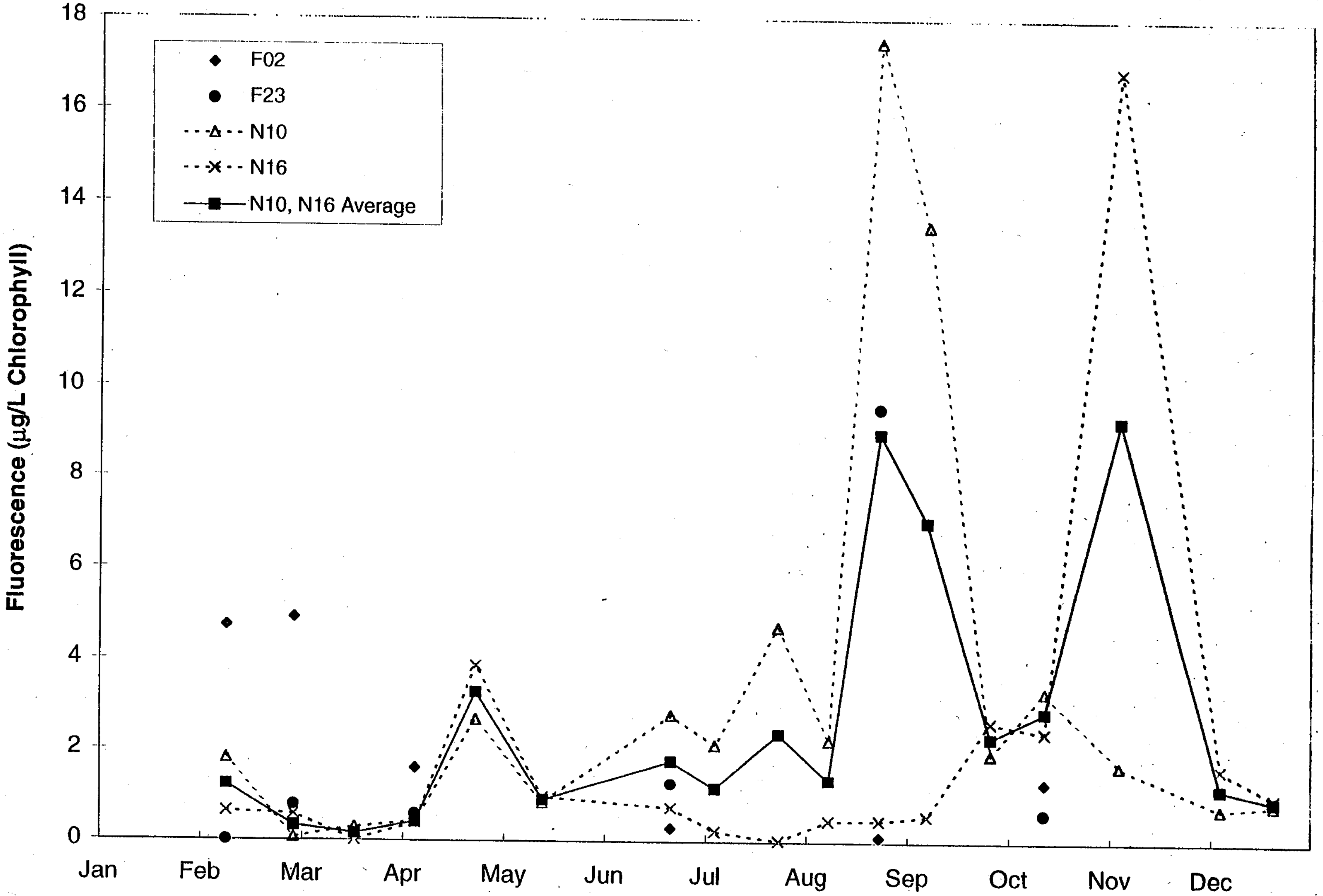
1995 Phytoplankton Group Dominance by Estimated Carbon Content



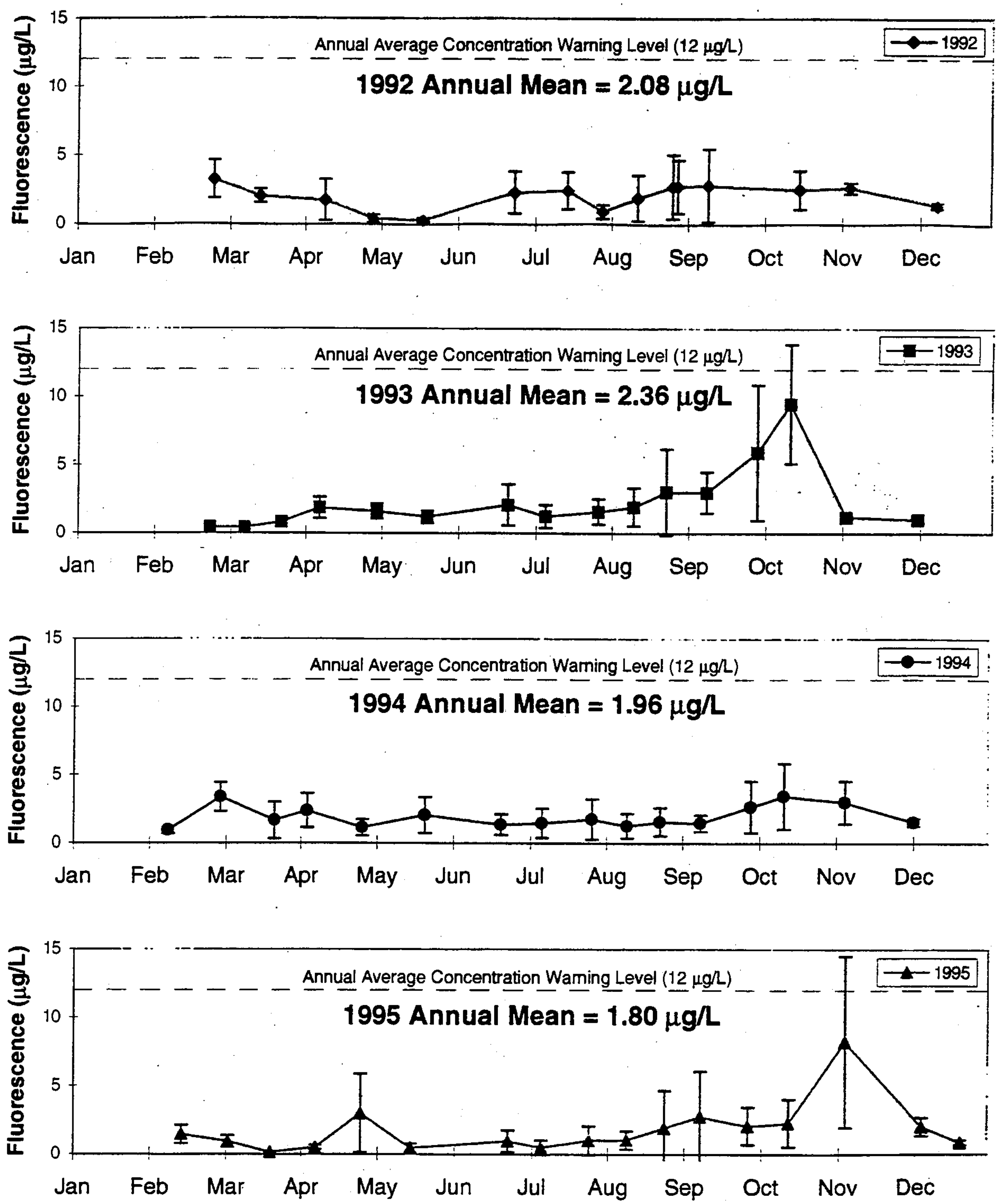




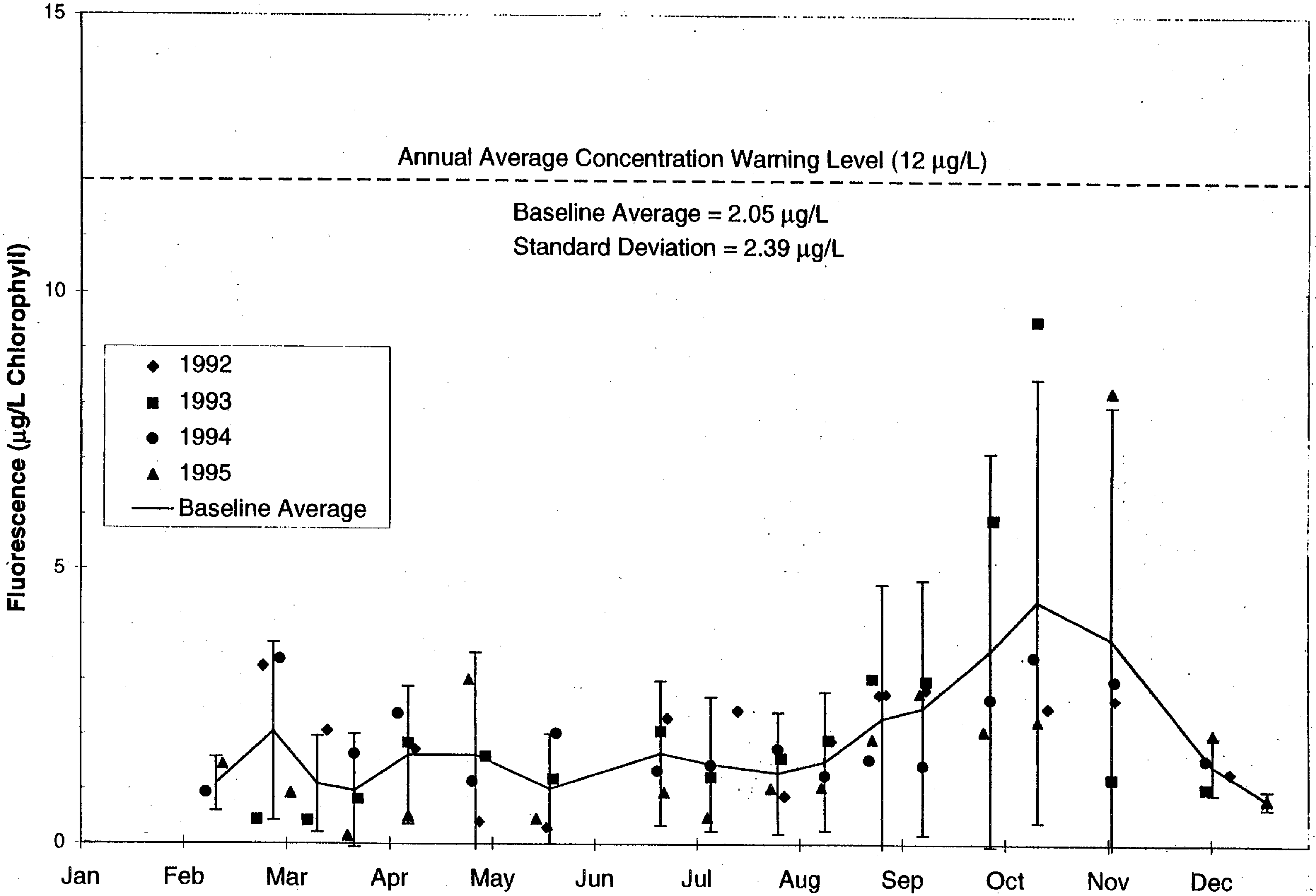
1995 Fluorescence Sensor Data
Surface values from stations F02, F23, N10 and N16



1992-1995 Average Nearfield Fluorescence Data
with Standard Deviations



1992-1995 Baseline Nearfield Fluorescence Data
Yearly and Baseline Averages



Comparison of Annual Chlorophyll Characteristics In Massachusetts Bay and the Nearfield Region

Nearfield	Mean	Standard Deviation	N	Maximum
1992	2.08	1.69	1465	17
1993	2.36	3.11	1850	20.5
1994	1.96	1.48	1863	13.7
1995	1.80	2.78	1682	21.51
Massachusetts Bay				
1992	2.24	1.75	2200	
1993	2.84	3.85	1103	21.1
1994	2.27	2	1132	16.9
1995	1.61	2.21	1102	18.82
Nearfield Baseline				
1992-1995	2.05	2.39	6864	21.51

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Chlorophyll *a* Hypotheses (Annual)

- Mean $\ngtr$ 12μg/L (Nearfield and Mass Bay)
- Mean Concentration Will Not Double and Remain High for 3 Consecutive Years (NF & MB)
- Variability (CV) Will Not Double and Remain High for 3 Consecutive Years (NF & MB)
- Pattern in Nearfield Will Not Change
- Average in NF Will Not Increase by More Than 20% per year for any 3 Consecutive Years
- Variability in Photic Zone Will Not Increase More Than 2x or Change Seasonal Pattern

ENSR

Conclusions on Phytoplankton

- System is Highly Variable in Space and Time
- Large Gradient between N10 and N16
  - Yielded Large Standard Deviation for Most of Year
- Assessment of Outfall Effects Should Include Size Frequency Analysis of Reported Taxa

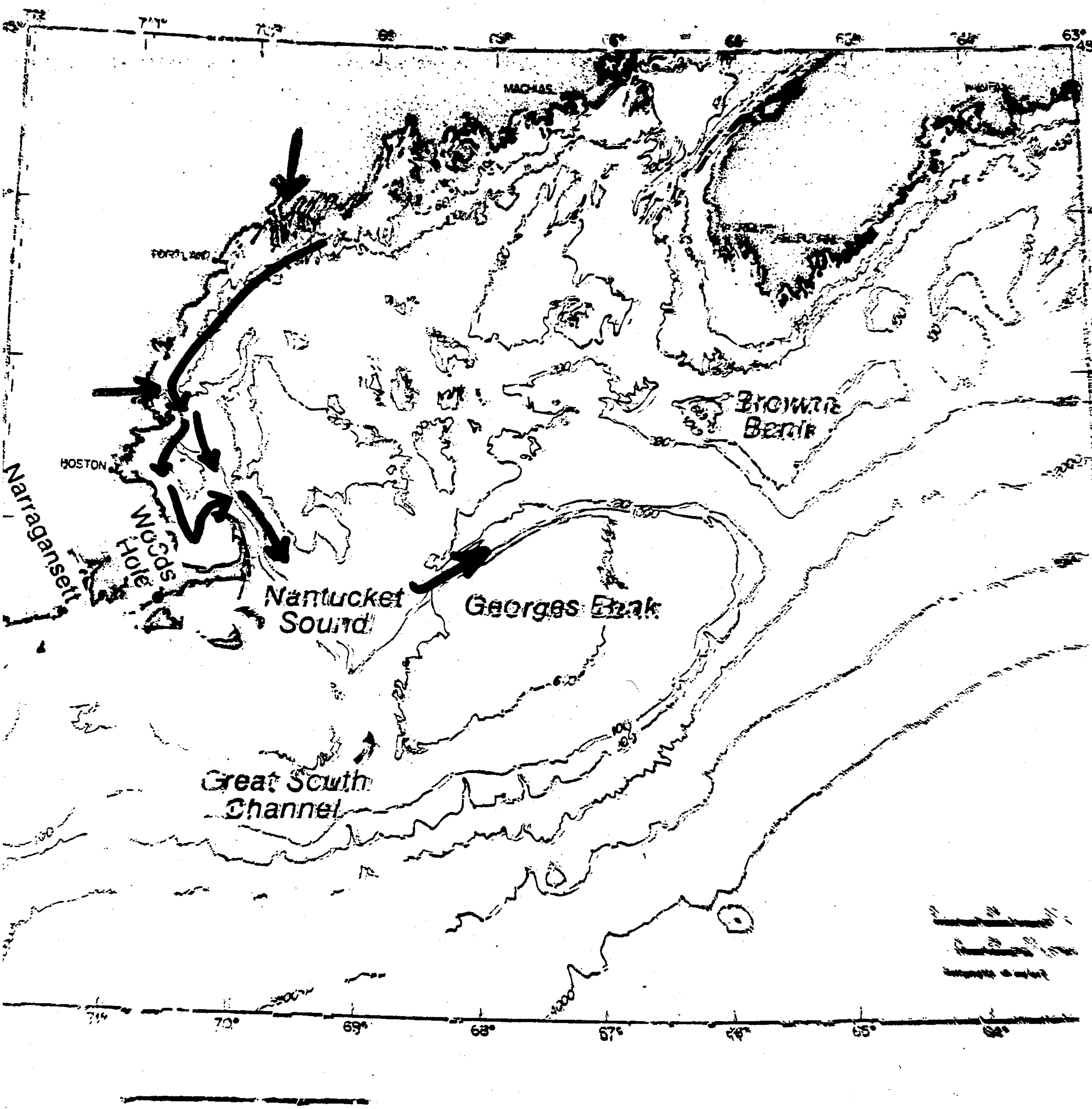
APPENDIX C-7

Don Anderson
WHOI

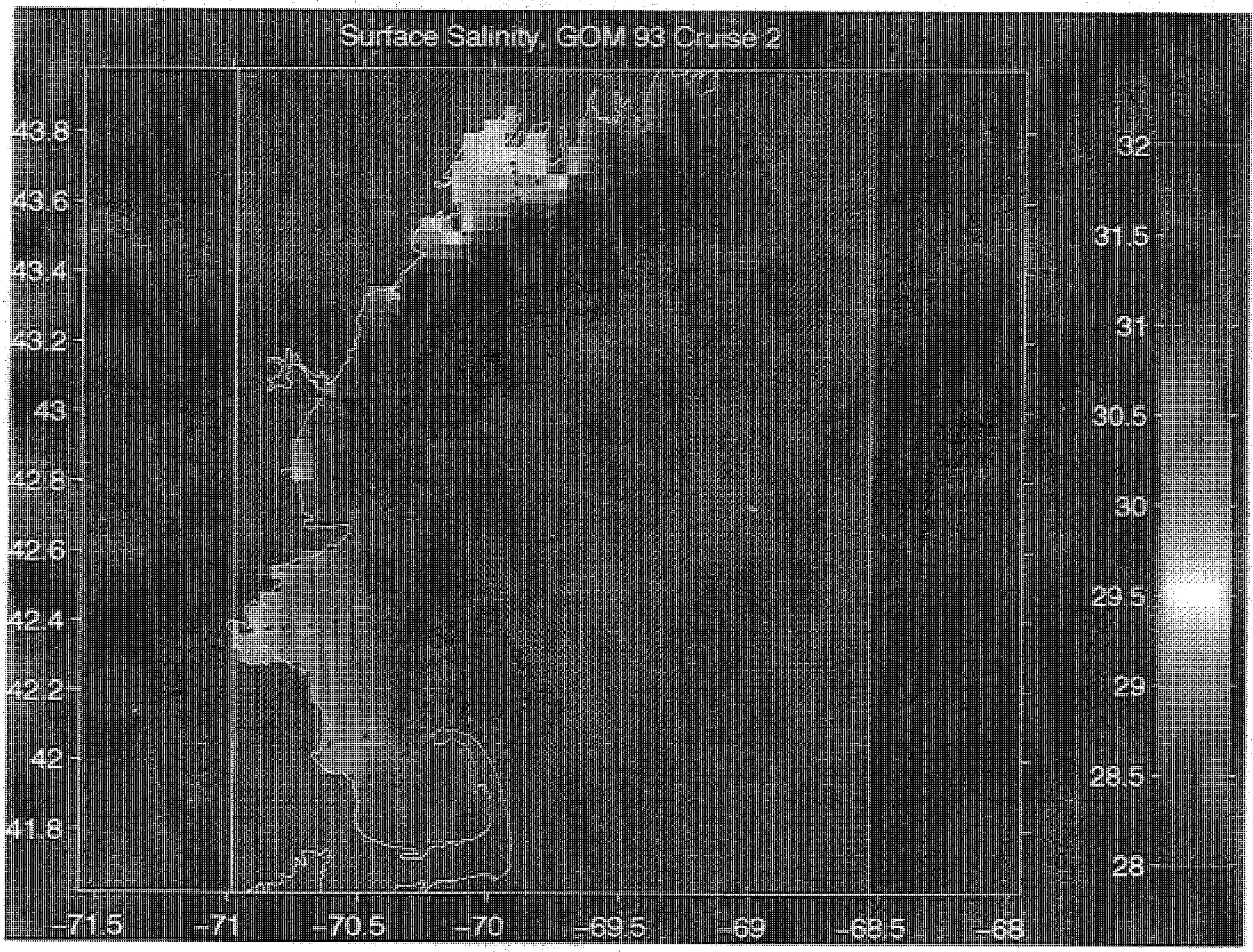
Noxious or harmful algal species in the MWRA plankton monitoring program

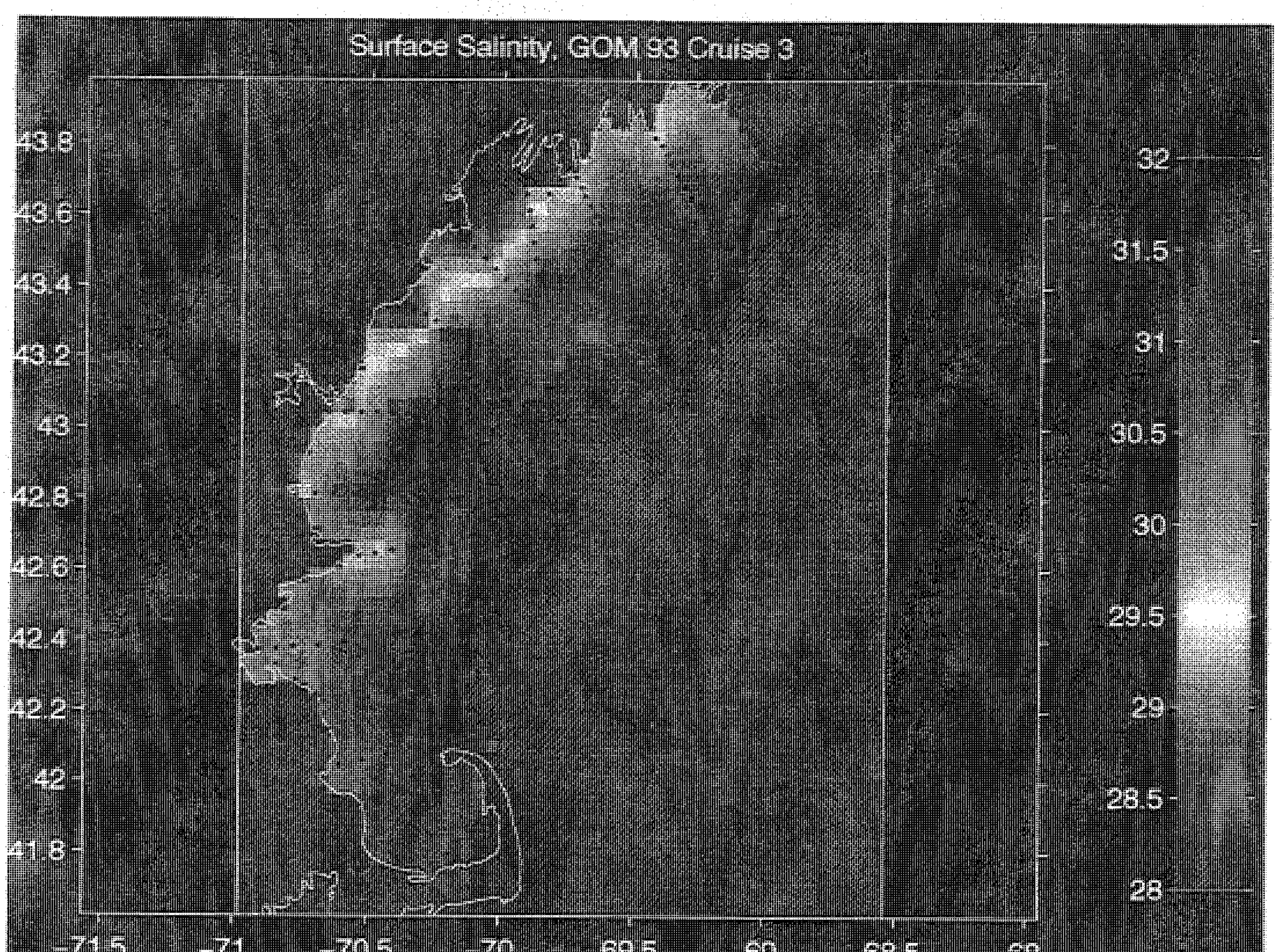
Species	Effect	Status in Mass Bay
Alexandrium tamarense	PSP; ecosystem damage; marine mammal mortalities	recurrent problem, relatively low levels of toxicity
Aurreococcus anophagefferens	brown tide; larval mortalities, eelgrass die-off	species present; no problems thus far
Ceratium spp.	large biomass, DO problems	none thus far
Dinophysis spp.	Diarrhetic shellfish poisoning (DSP)	none thus far in U.S.
Gymnodinium spp.	fish kills, benthic mortalities	none thus far
Gyrodinium spp.	fish kills, benthic mortalities	none thus far
Heterocapsa triquetra	oyster mortalities in Japan	none thus far
Heterosigma carterii	fish kills	none thus far
Prorocentrum spp.	large biomass; DO problems	red tides observed
Pheocystis pouchetti	aesthetics, slime, foam production	occasional problem for fishermen
Protoperidinium spp. (?)	????	common
Pseudo-nitzschia pungens	Amnesiac shellfish poisoning (ASP)	toxic strains detected; no serious shellfish toxicity
Pilayella littoralis	seaweed; fouls beaches at Nahant	recurrent

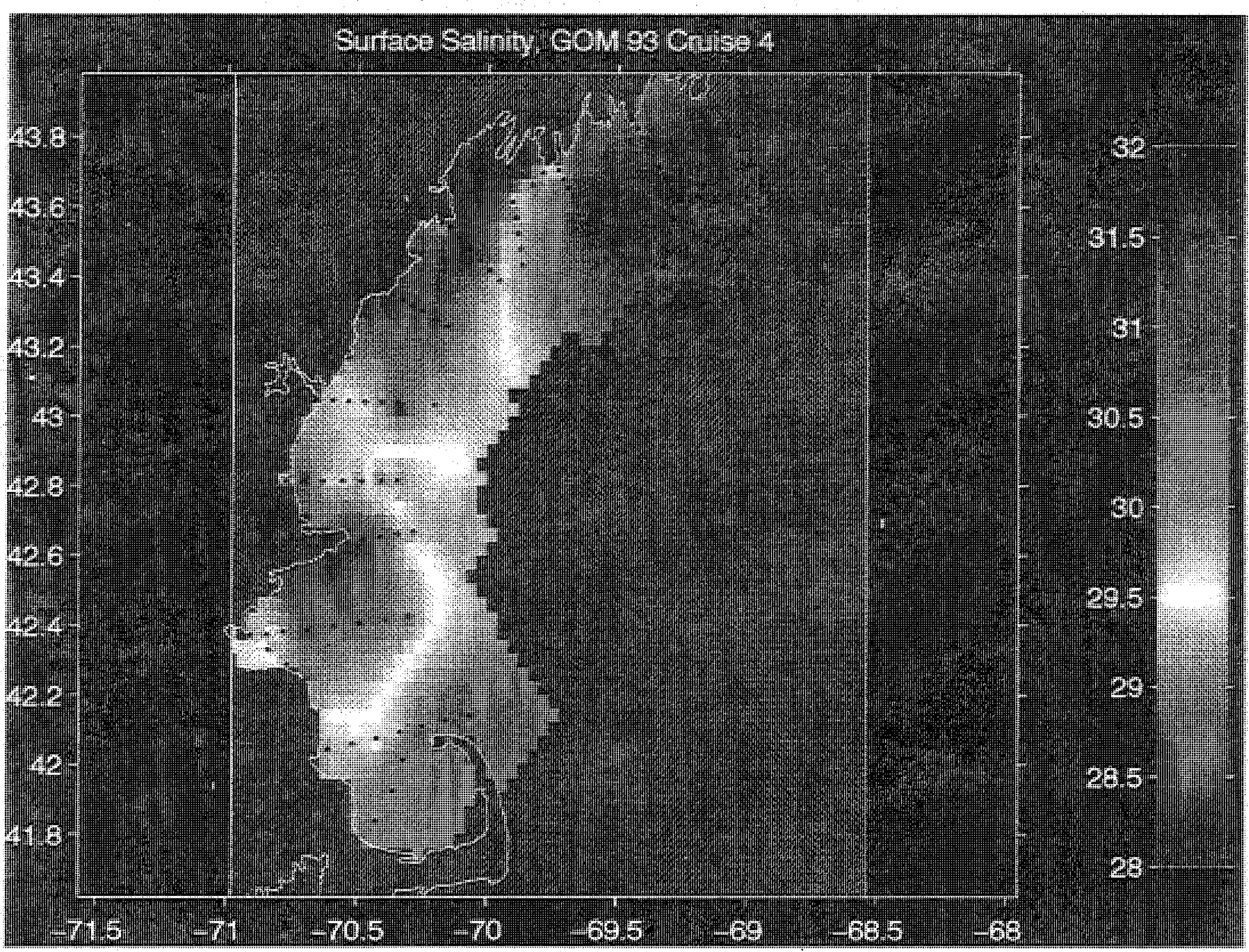
2



MACHIAS
PORTLAND
BOSTON
Narragansett
Woods Hole
Nantucket Sound
Georges Bank
Browns Bank
Great South Channel
70°
69°
68°
67°
65°
63°

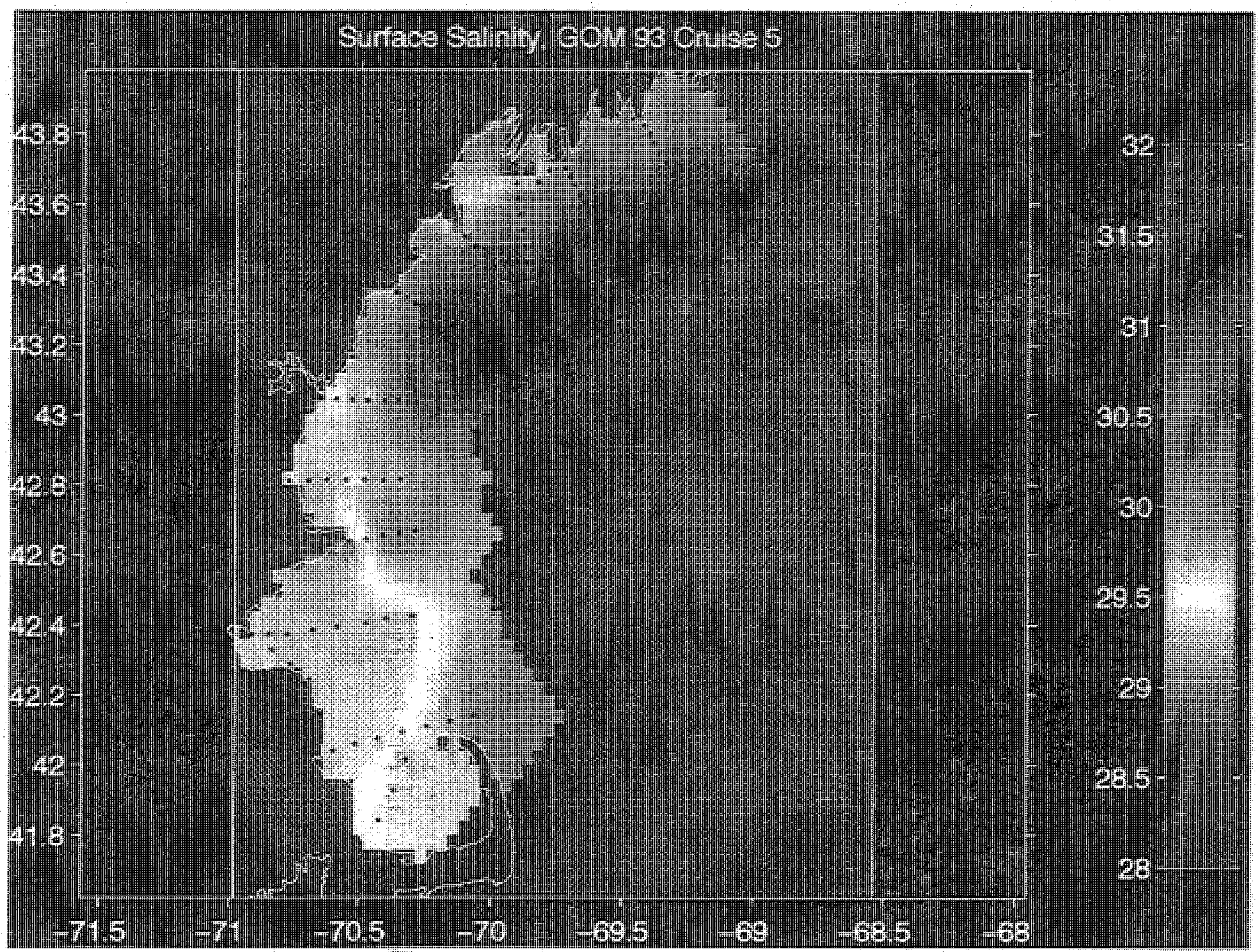

Surface Salinity, GOM 93 Cruise 2
43.8
43.6
43.4
43.2
43
42.8
42.6
42.4
42.2
42
41.8
-71.5
-71
-70.5
-70
-69.5
-69
-68.5
-68
32
31.5
31
30.5
30
29.5
29
28.5
28


Surface Salinity, GOM 93 Cruise 3
43.8
43.6
43.4
43.2
43
42.8
42.6
42.4
42.2
42
41.8
−71.5
−71
−70.5
−70
−69.5
−69
−68.5
−68
32
31.5
31
30.5
30
29.5
29
28.5
28



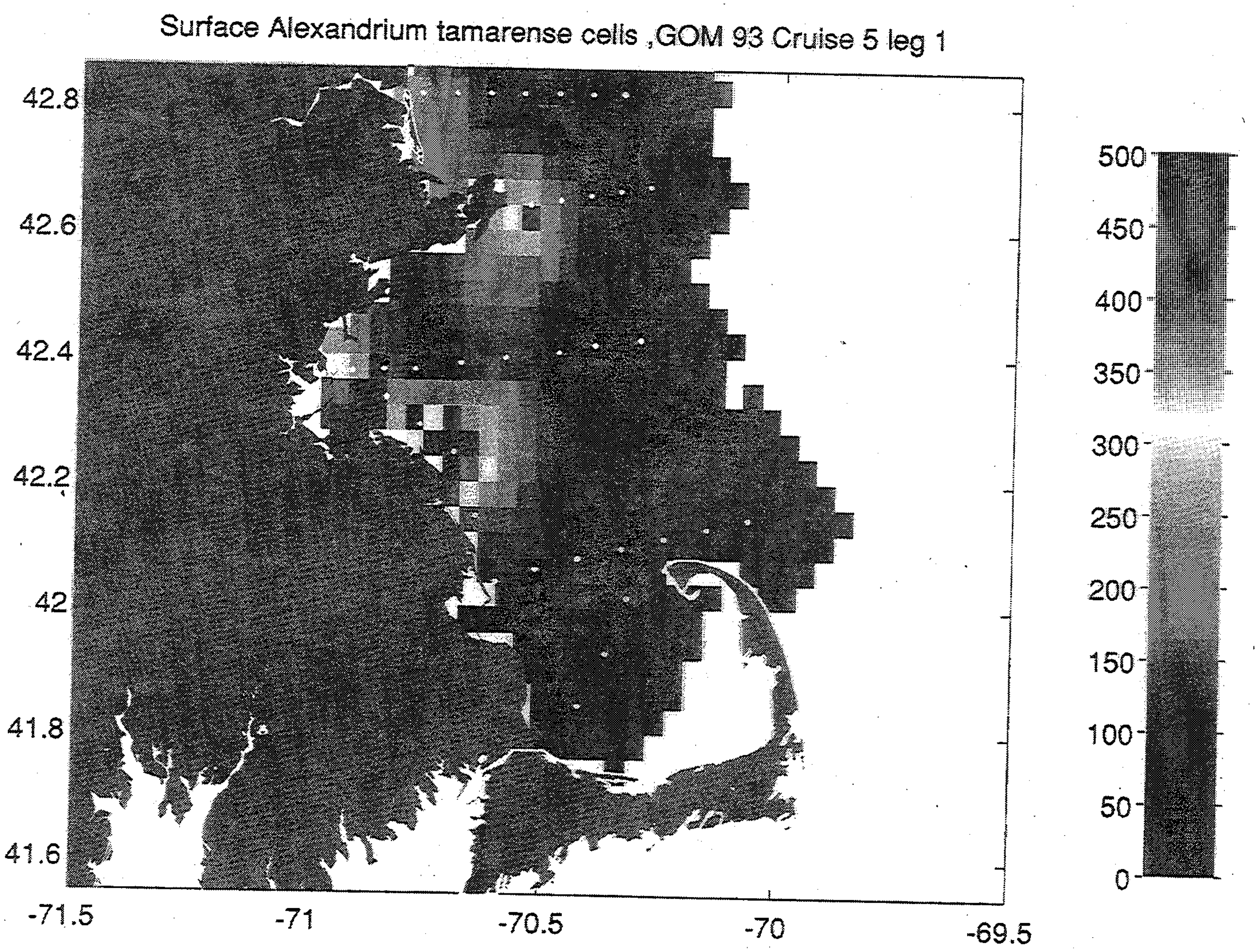
Surface Salinity, GOM 93 Cruise 4
43.8
43.6
43.4
43.2
43
42.8
42.6
42.4
42.2
42
41.8
-71.5
-71
-70.5
-70
-69.5
-69
-68.5
-68
32
31.5
31
30.5
30
29.5
29
28.5
28

6



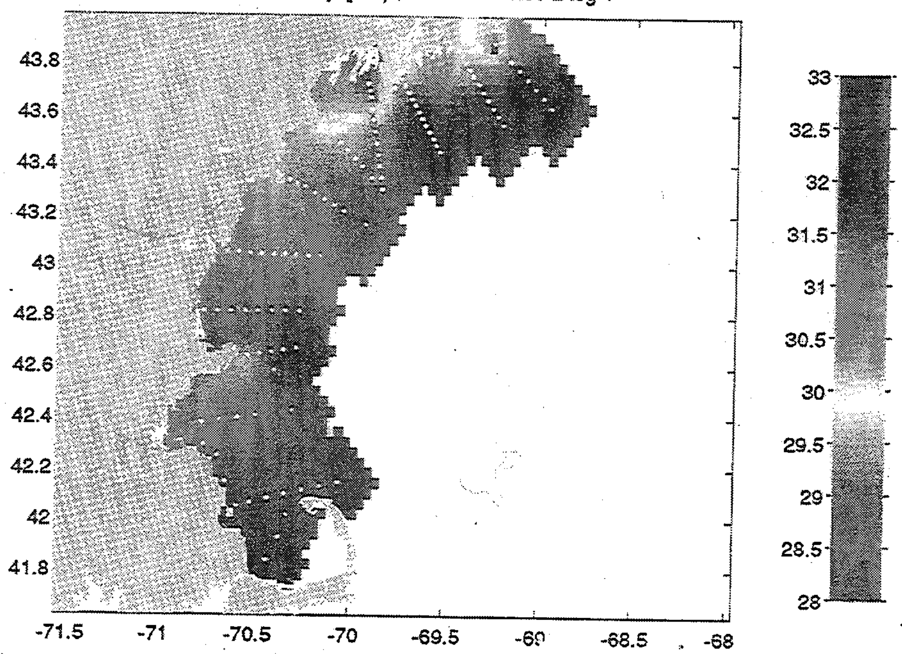
Surface Salinity, GOM 93 Cruise 5
43.8
43.6
43.4
43.2
43
42.8
42.6
42.4
42.2
42
41.8
-71.5
-71
-70.5
-70
-69.5
-69
-68.5
-68
32
31.5
31
30.5
30
29.5
29
28.5
28

24-27 MAY 93

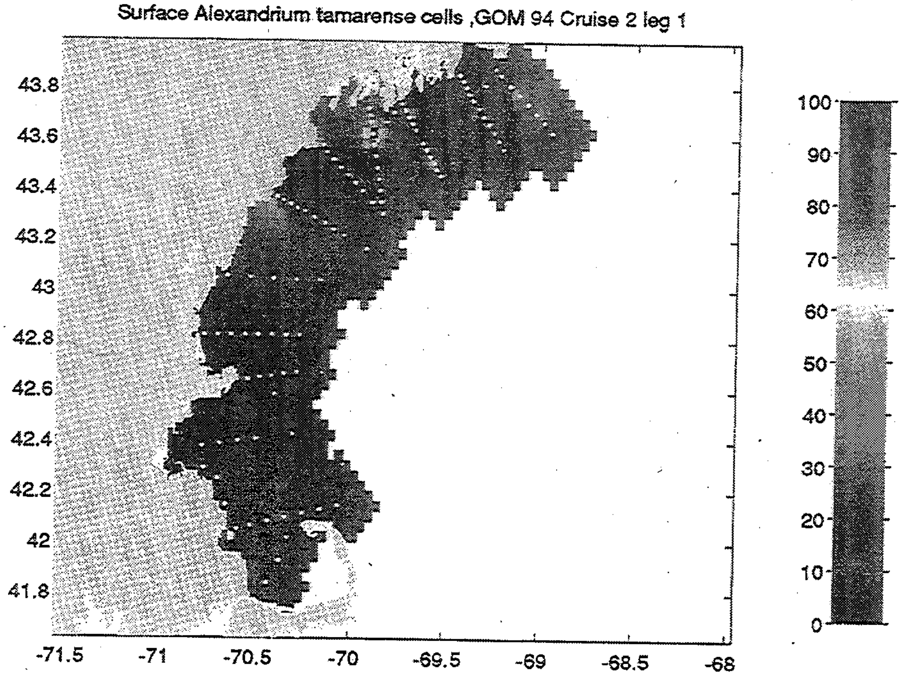


Surface Alexandrium tamarense cells ,GOM 93 Cruise 5 leg 1
42.8
42.6
42.4
42.2
42
41.8
41.6
-71.5
-71
-70.5
-70
-69.5
500
450
400
350
300
250
200
150
100
50
0

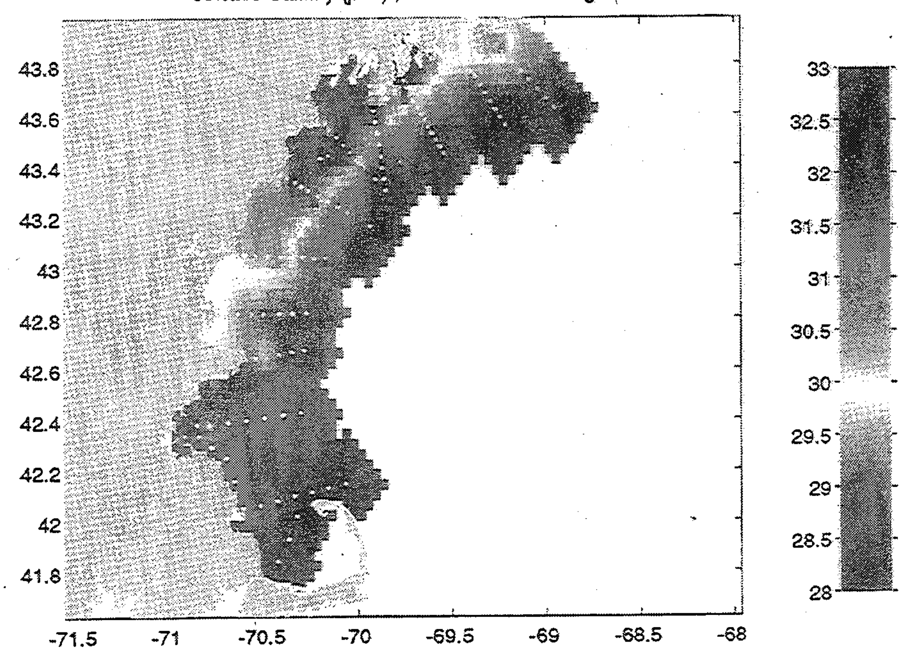
Surface Salinity (psu) ,GOM 94 Cruise 2 leg 1



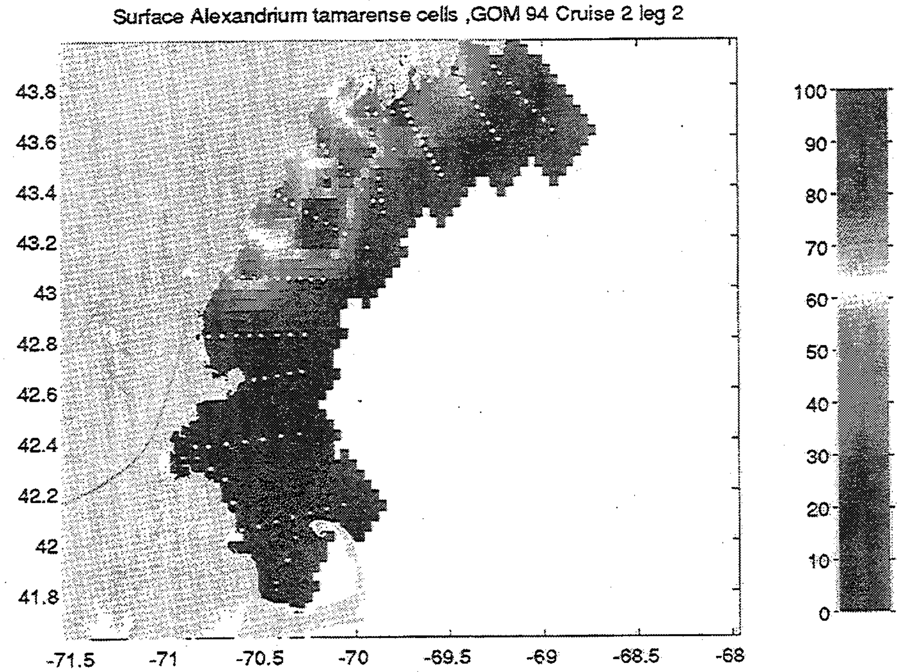
Surface Alexandrium tamarense cells ,GOM 94 Cruise 2 leg 1



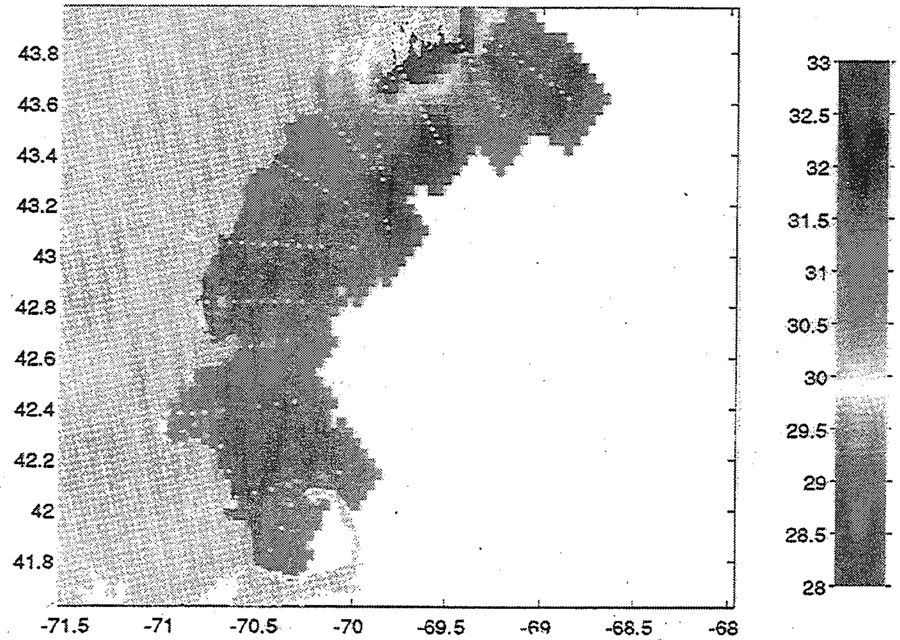
Surface Salinity (psu) ,GOM 94 Cruise 2 leg 2



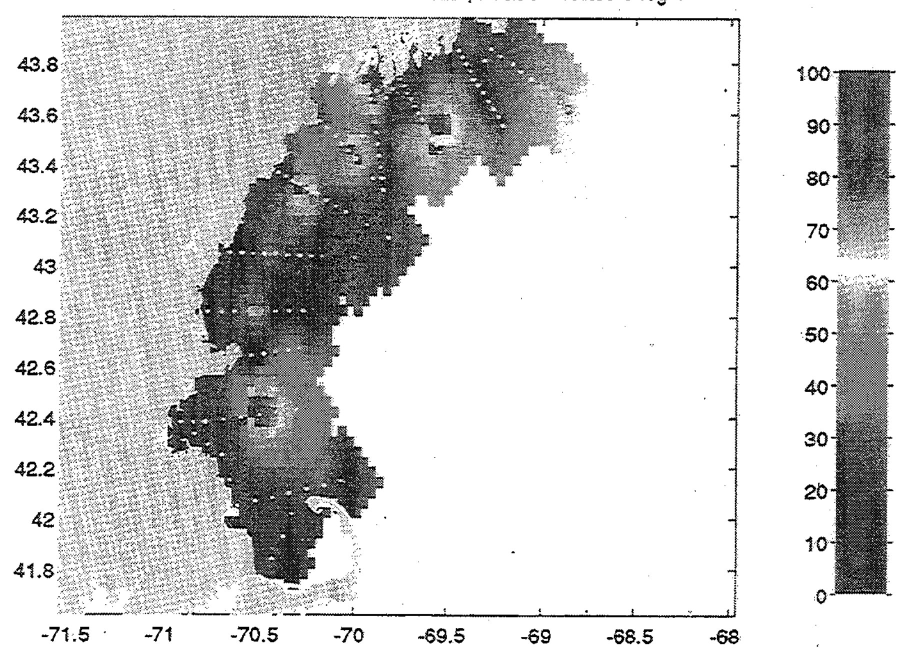
Surface Alexandrium tamarense cells ,GOM 94 Cruise 2 leg 2

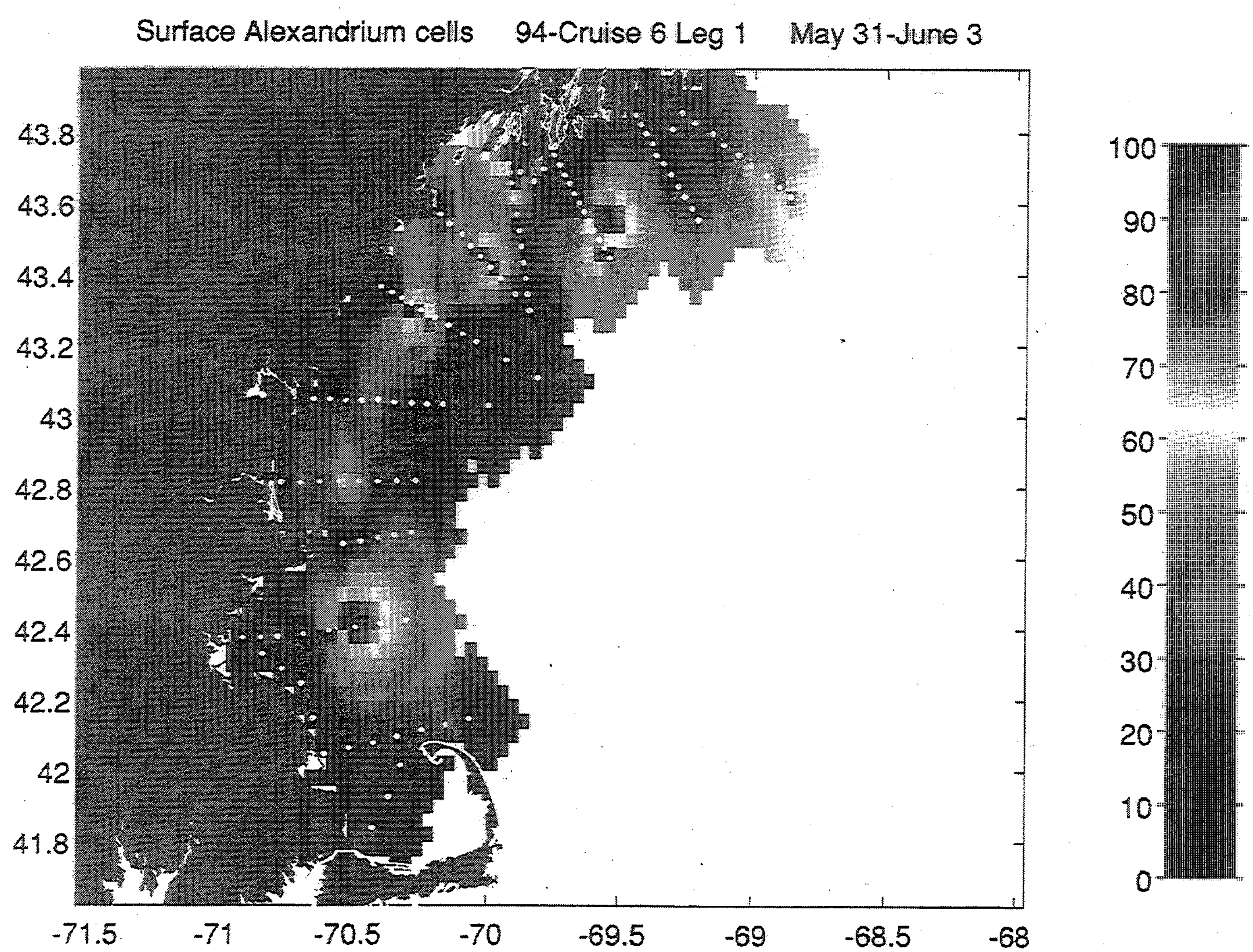


Surface Salinity (psu) ,GOM 94 Cruise 6 leg 1

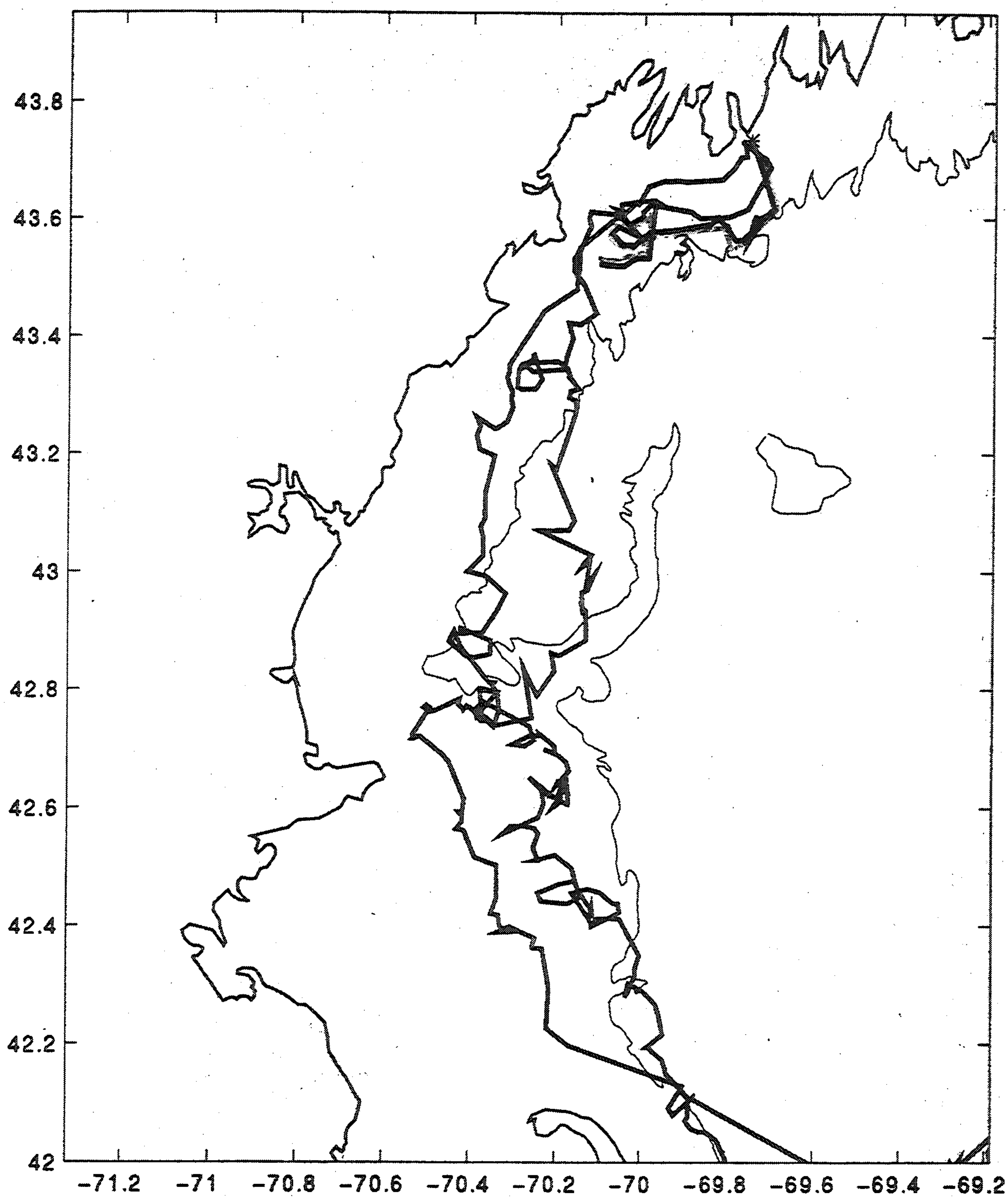


Surface Alexandrium tamarense cells ,GOM 94 Cruise 6 leg 1

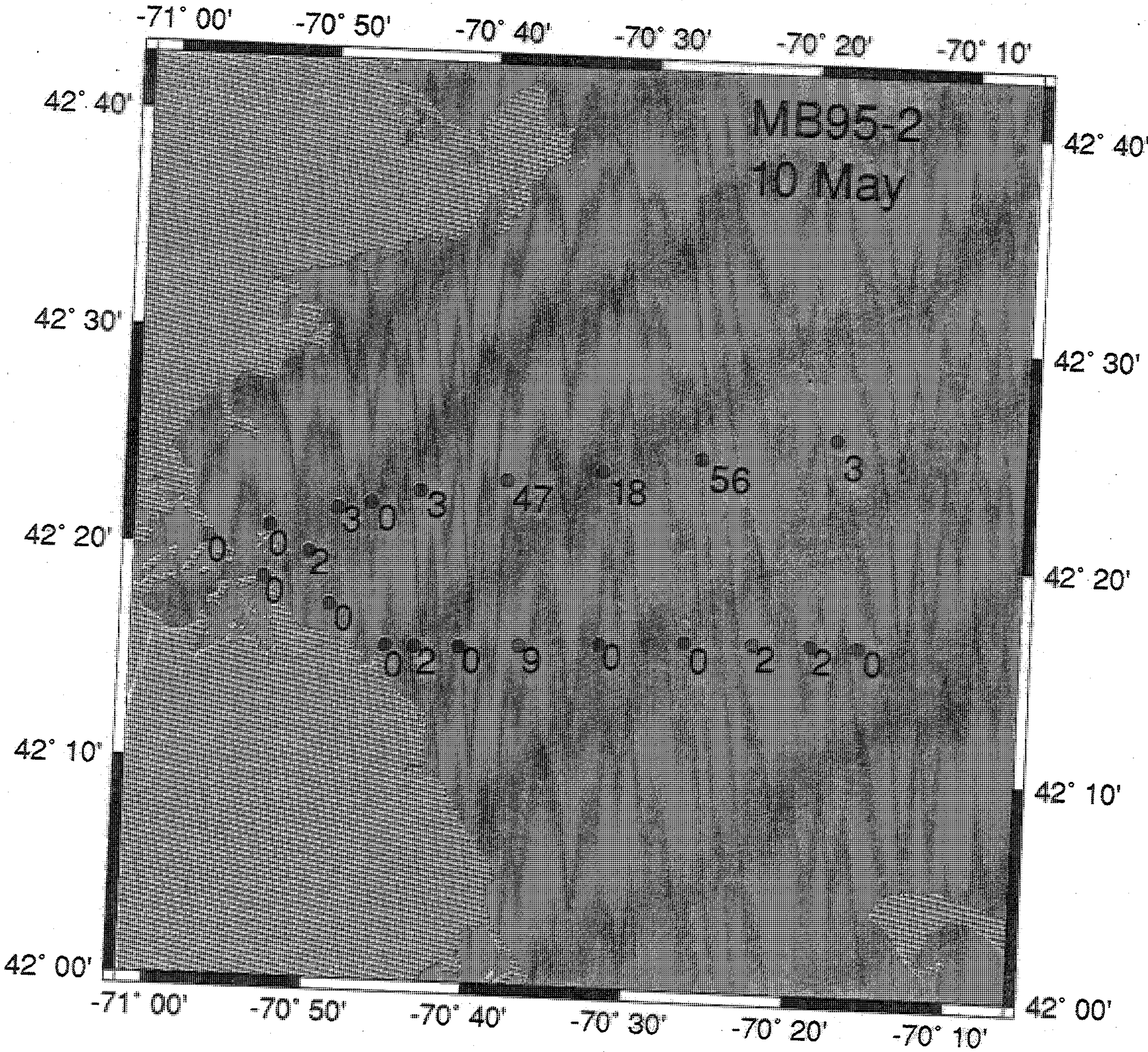


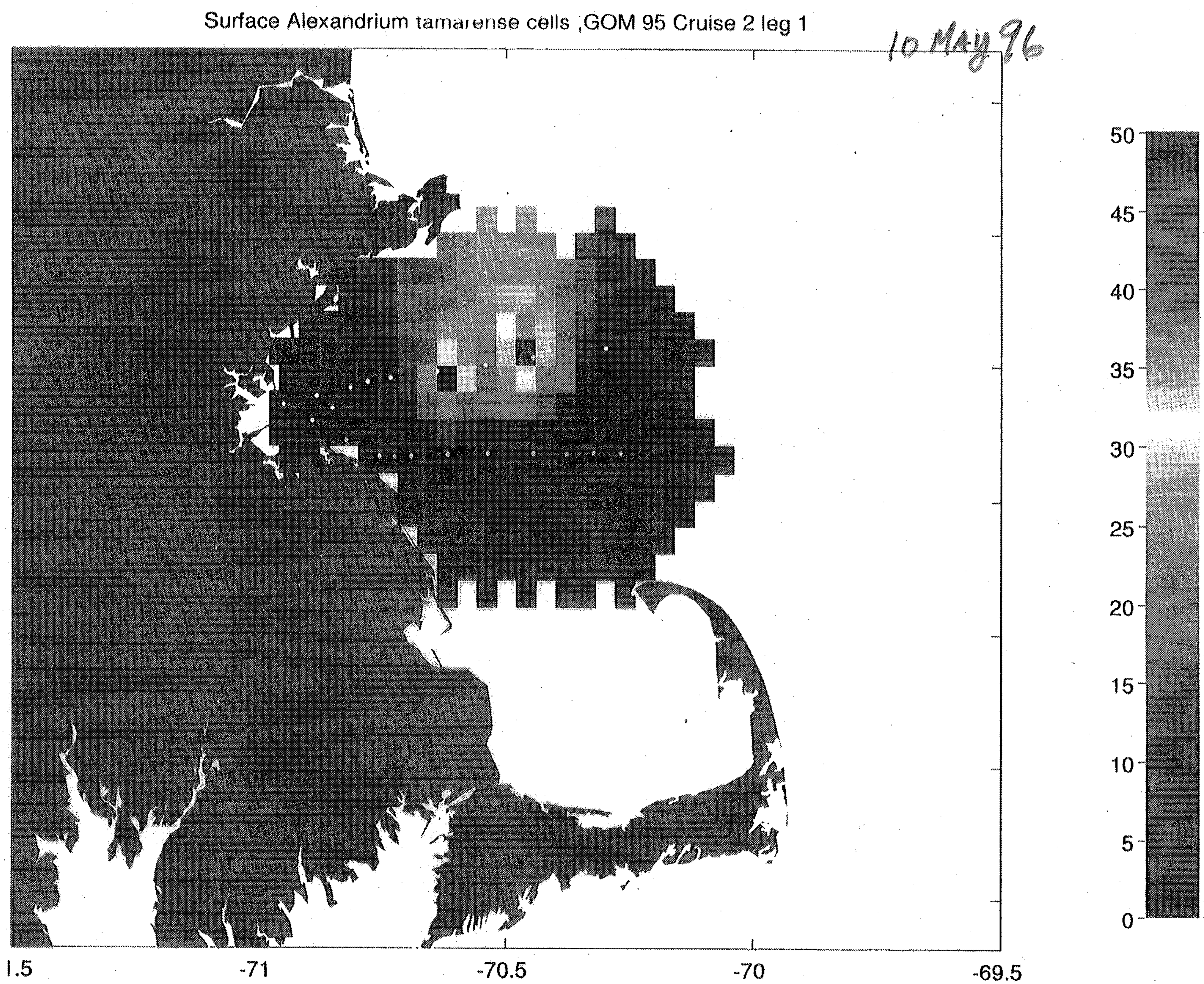

Surface Alexandrium cells 94-Cruise 6 Leg 1 May 31-June 3
43.8
43.6
43.4
43.2
43
42.8
42.6
42.4
42.2
42
41.8
-71.5
-71
-70.5
-70
-69.5
-69
-68.5
-68
100
90
80
70
60
50
40
30
20
10
0

Drifter trajectories, 1993



drifter	start	end
0	5/11	7/1
1	5/25	7/16
→ 3	4/14	4/18


MB95-2
10 May
-71° 00'
-70° 50'
-70° 40'
-70° 30'
-70° 20'
-70° 10'
42° 40'
42° 30'
42° 20'
42° 10'
42° 00'
3
56
18
47
3
3
0
0
0
2
0
0
0
2
0
9
0
0
2
2
0


Surface Alexandrium tamarense cells ,GOM 95 Cruise 2 leg 1
10 May 96
1.5
-71
-70.5
-70
-69.5
50
45
40
35
30
25
20
15
10
5
0

Will *Alexandrium* be well-sampled by the outfall monitoring program?

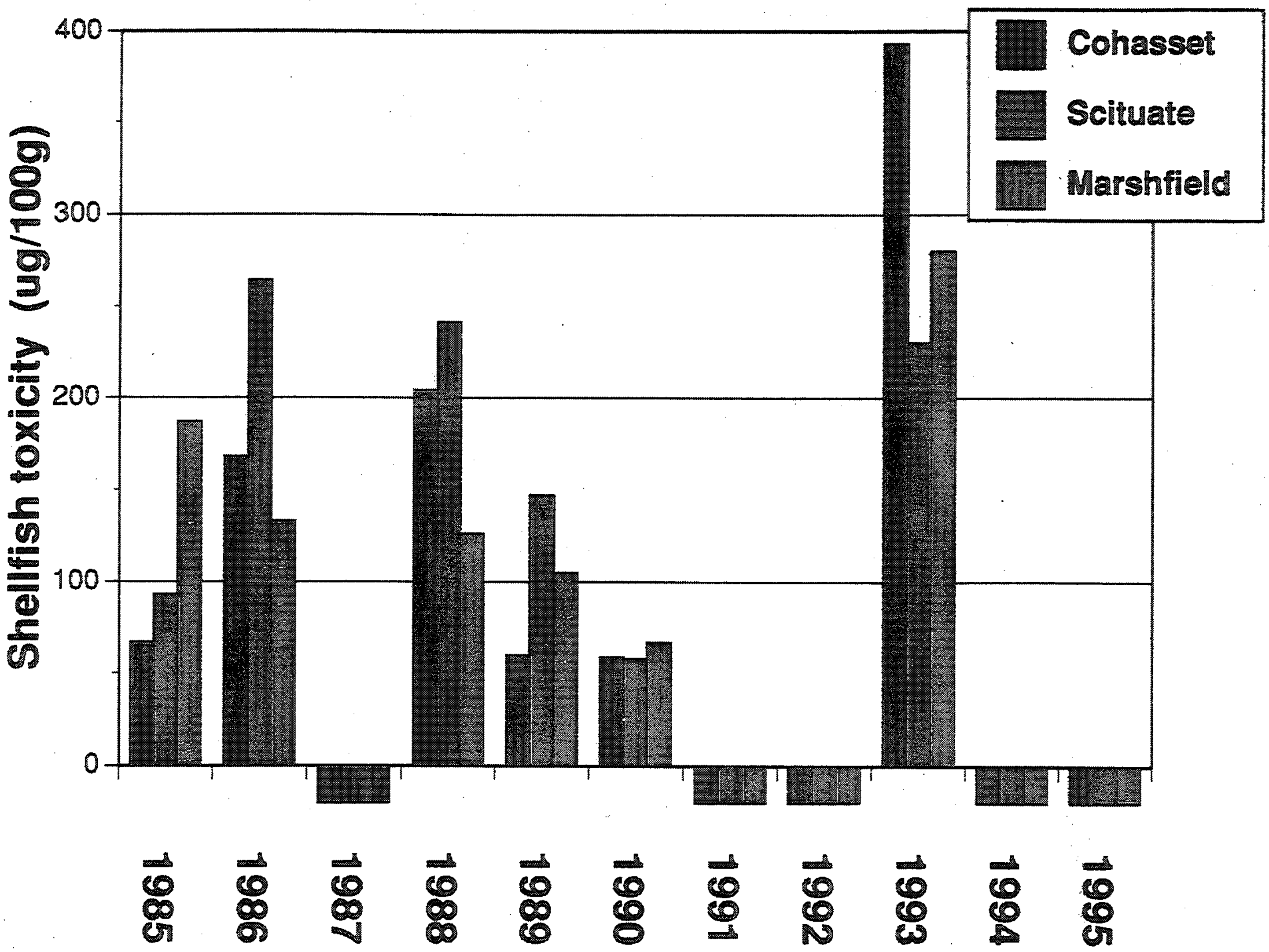
Not likely, because:

1) timing;
2) nearshore, patchiness

Solutions:

1) re-schedule cruises
2) rely on external data sources

Maximum Annual Shellfish Toxcity



Noxious or harmful algal species in the MWRA plankton monitoring program

Species	Effect	Status in Mass Bay
Alexandrium tamarense	PSP; ecosystem damage; marine mammal mortalities	recurrent problem, relatively low levels of toxicity
Aurreococcus anophagefferens	brown tide; larval mortalities, eelgrass die-off	species present; no problems thus far
Ceratium spp.	large biomass, DO problems	none thus far
Dinophysis spp.	Diarrhetic shellfish poisoning (DSP)	none thus far in U.S.
Gymnodinium spp.	fish kills, benthic mortalities	none thus far
Gyrodinium spp.	fish kills, benthic mortalities	none thus far
Heterocapsa triquetra	oyster mortalities in Japan	none thus far
Heterosigma carterii	fish kills	none thus far
Prorocentrum spp.	large biomass; DO problems	red tides observed
Pheocystis pouchetti	aesthetics, slime, foam production	occasional problem for fishermen
Protoperidinium spp. (?)	????	common
Pseudo-nitzschia pungens	Amnesiac shellfish poisoning (ASP)	toxic strains detected; no serious shellfish toxicity
Pilayella littoralis	seaweed; fouls beaches at Nahant	recurrent

95 - 5

Ceratium Species		**Prorocentrum Species**	
Count (N)	692	Count (N)	66
Minimum	2.5	Minimum	2.5
Maximum	14557.06	Maximum	969.01
Mean	221.43	Mean	39.15
Standard Deviation	971.13	Standard Deviation	135.14
Dinophysis Species		**Protoperidinium Species**	
Count (N)	350	Count (N)	787
Minimum	2.5	Minimum	1.5
Maximum	2867.10	Maximum	5439.44
Mean	80.76	Mean	54.19
Standard Deviation	263.20	Standard Deviation	264.39
Gymnodinium Species		**Heterosigma Species ***	
Count (N)	54	Count (N)	10
Minimum	2.5	Minimum	0.001
Maximum	26424.10	Maximum	0.03
Mean	1471.04	Mean	0.01
Standard Deviation	4696.90	Standard Deviation	0.01
Gryodinium Species		**Phaeocystis Species ***	
Count (N)	213	Count (N)	18
Minimum	2.5	Minimum	0.001
Maximum	77.58	Maximum	3.02
Mean	10.11	Mean	0.62
Standard Deviation	11.19	Standard Deviation	1.19
Heterocapsa Species		**Nitzschia Species ***	
Count (N)	21	Count (N)	58
Minimum	2.503	Minimum	6.65E-04
Maximum	790.79	Maximum	0.09
Mean	42.74	Mean	0.01
Standard Deviation	171.46	Standard Deviation	0.02

* Whole water phytoplankton

Hypothesis W17: The abundance of nuisance algae will not increase by more than ten times the annual baseline mean for any three consecutive year period.

Problems:

1) It is difficult to define what a nuisance algal species is, given that toxic and non-toxic strains of the same species exist, and that some cause harm only because of their biomass. In one sense, all phytoplankton species have the potential to be harmful.

2) The annual mean damps out bloom events; a short-lived, spectacular red tide might not be reflected in an annual mean in proportion to its impact.

3) Many nuisance species are highly seasonal, and are not being well-sampled by the monitoring program.

4) Inter-annual variability in the abundance of individual species can span several orders of magnitude under natural conditions. How does one detect meaningful change?

Hypothesis W18: The frequency of nuisance algae occurrence in the Massachusetts Bay system will not increase relative to that observed during the baseline period.

Problems:

1) Bloom "frequency" will not be determined by the monitoring program.

2) The number of samples containing a nuisance species during each year (relative to the total samples collected) would provide an estimate of "prevalence", but not frequency.

3) There is no allowance for "normal" fluctuations here.

Hypothesis W19: The algal community will not become dominated by nuisance algae.

Problems:

1) Dominance in terms of numbers, or in terms of biomass? Dominance for how long?

Other problems:

1) What about macroalgae, such as *Pilayella*?

2) How can we incorporate PSP monitoring data into the process?

CERATIUM ANNUAL MEANS

	1993	1994	1995	1993-95	1993 "+1 200K"	1993 "+ 2 200K"	1993 "+3 200K"	1993 "+10 200K"
Count (N)	386.0	292.0	15.0	692.0	386	386	386	
Minimum	2.5	2.5	72.6	2.5	2.5	2.5	2.5	2.5
Maximum	14557.1	1456.5	846.6	14557.1	200000	200000	200000	200000
Mean	341.1	44.6	572.6	221.4	821.6	1339.7	1857.7	5476.0
Standard Deviation	1279.7	121.8	164.2	971.1				

APPENDIX C-8

Cabell Davis
WHOI

MWRA Harbor & Outfall Monitoring Program
1996 Water Quality Workshop

Abundance of Zooplankton in Boston Harbor and the Bays Region - 1995

Cabell S. Davis
Woods Hole Oceanographic Institution

Stephen J. Cibik
ENSR

ENSR

Overview of Presentation

- Potential Concerns Regarding Plankton
- Summary of Methods
- Spatial Distributions of Dominant Taxa
- Seasonal Assemblages by Region
- Abundance vs. Biomass

Concerns Regarding Plankton Community

- **Will Enrichment Alter Community Structure?**
  - Species Composition
  - Biomass
  - Vertical Distribution
- **Will Toxicants Alter Community Structure or Marine Food Web?**
- **Will Effects on Plankton Influence Water Clarity/Color?**

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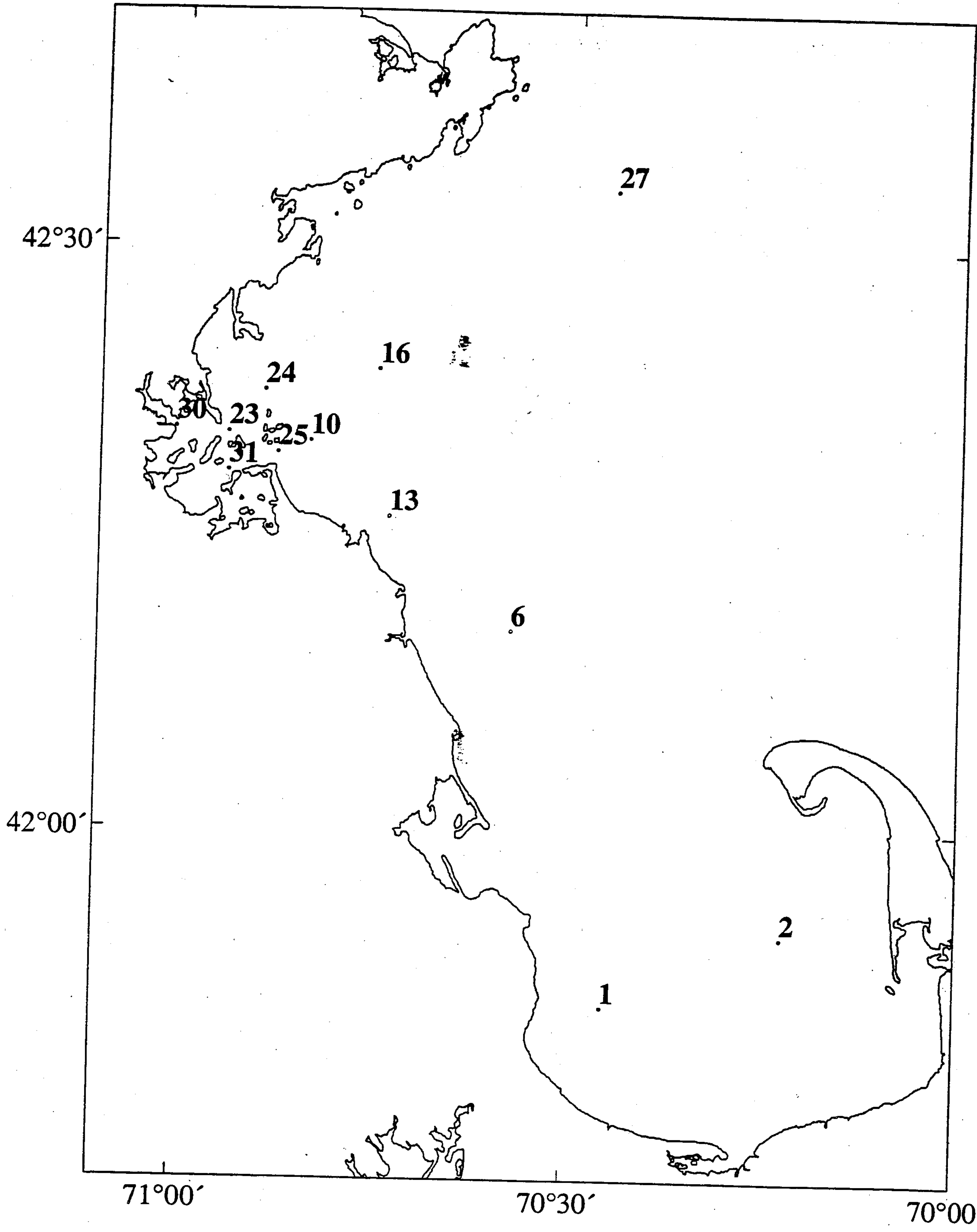
Summary of Methods

- **Zooplankton Collection**
  - Vertical Oblique Tows of Upper 30m
  - 0.5m Diameter, 102μm Mesh Net, GO Flow Meter
  - Formalin Preservative
- **Zooplankton Identification and Enumeration**
  - Folsom Plankton Splitter, Aliquot by Hensen-Stepmel Pipette
  - Wild Dissecting Microscope
  - Adults Identified to Spp., Copepodite and Nauplii Grouped
- **Estimated Carbon Equivalence (μgC/M^3)**
  - #/m^3 * Adult Body Weight (μgC)

Zooplankton Sampling Stations 1995



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Spatial Distribution of Dominant Taxa

- Distinctive Grouping of Taxa by Region
  - Nearshore (Harbor/Coastal)
  - Offshore/Boundary/Cape Cod Bay
- Harbor/Coastal Taxa Typical of Eutrophic Environments (e.g. *Acartia* spp.)
- Nearfield Represents a Transition Zone
  - Offshore Taxa Dominate N16
  - Coastal Taxa Dominate N10

Centropages hamatus Abundance 1995 (max=4469/m3)

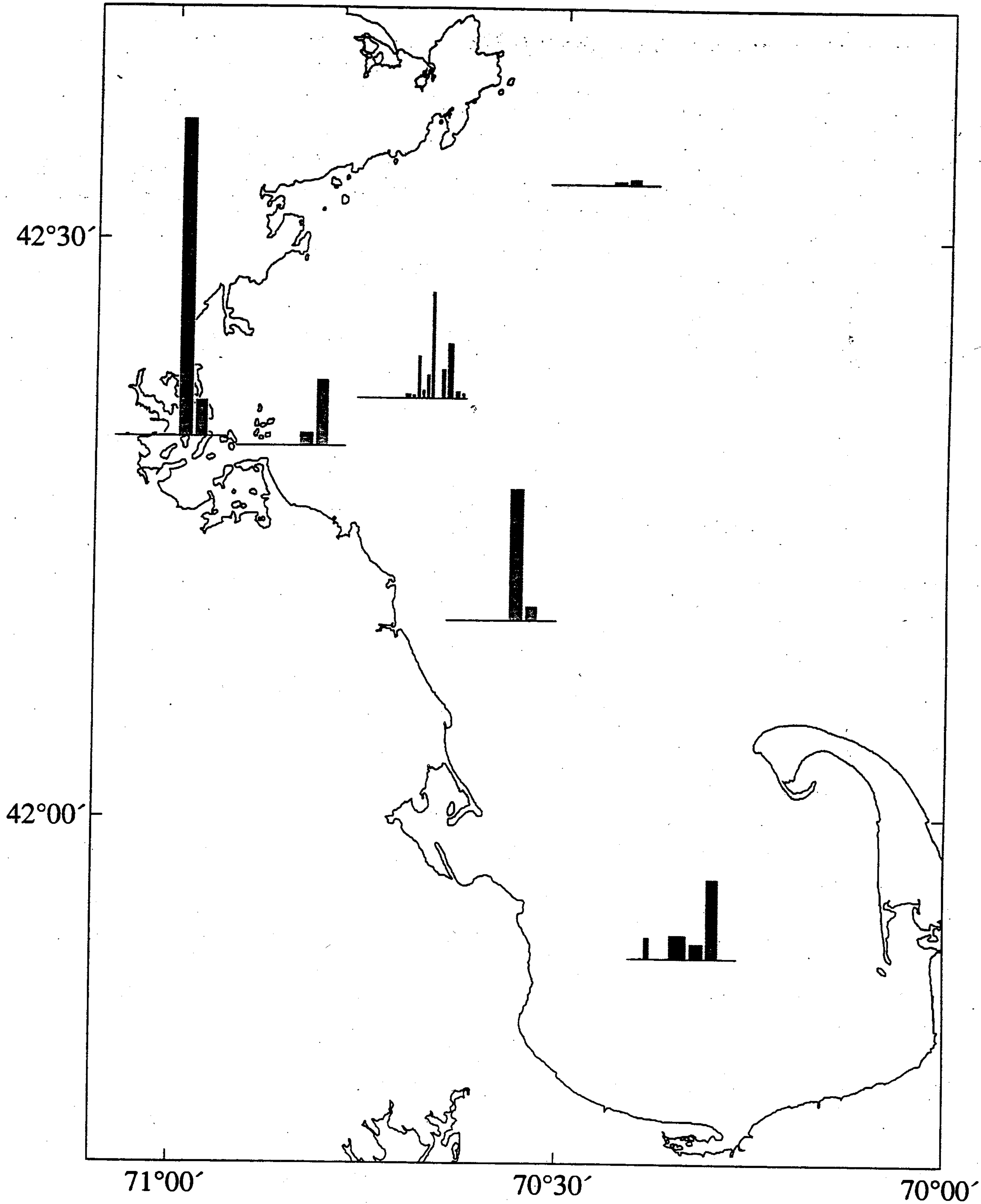
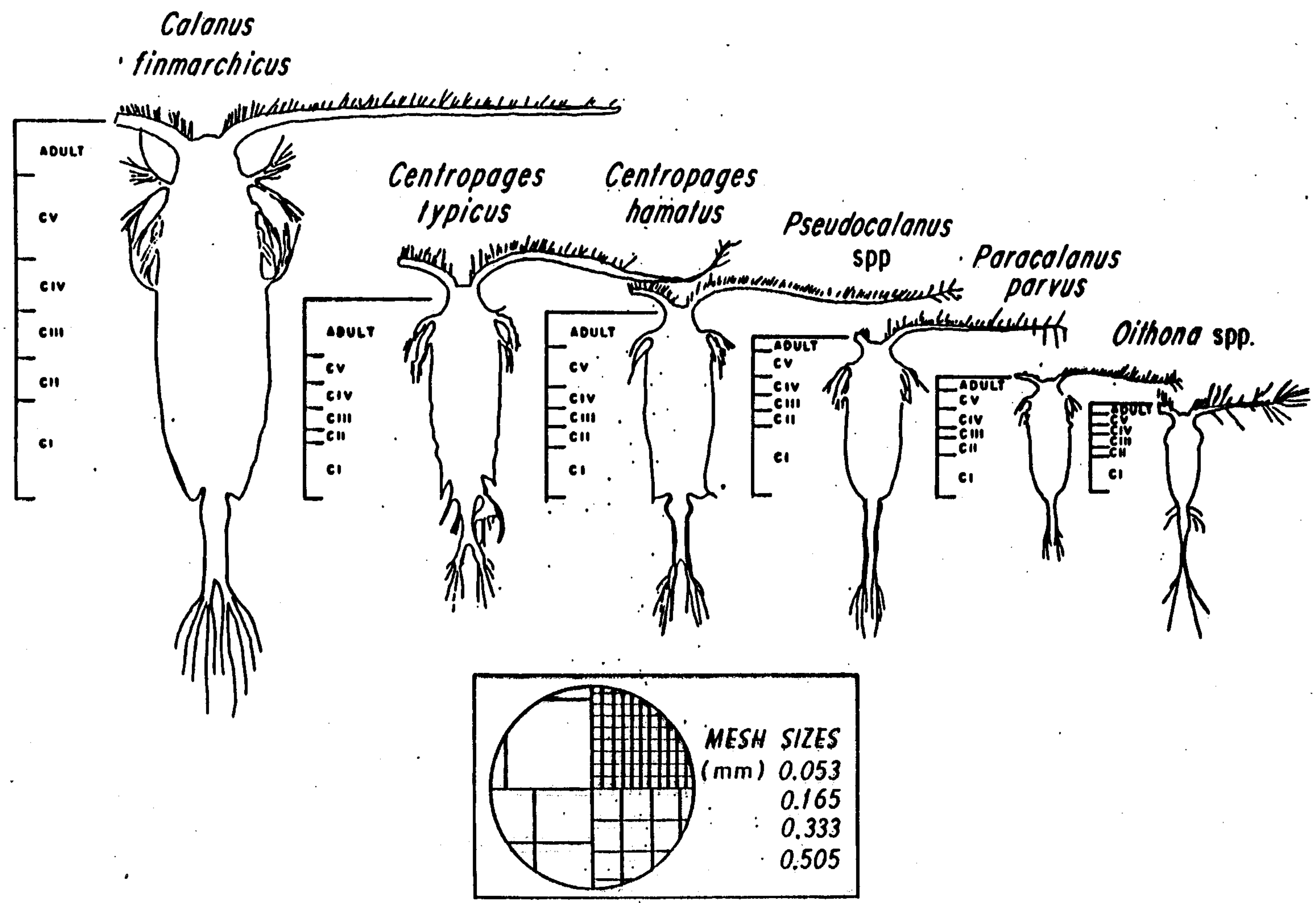


Table I. Geographical Affinity of Zooplankton Taxa

Harbor/Coastal	Offshore/Boundary/CCbay
Acartia tonsa	*Oithona similis*
Acartia hudsonica	*Pseudocalanus newmani*
Centropages hamatus	*Centropages typicus*
Eurytemora herdmani	*Calanus finmarchicus*
Polychaete Larvae	*Oikopleura dioica*
Podon spp.	*Microsetella norvegica*
	Paracalanus parvus

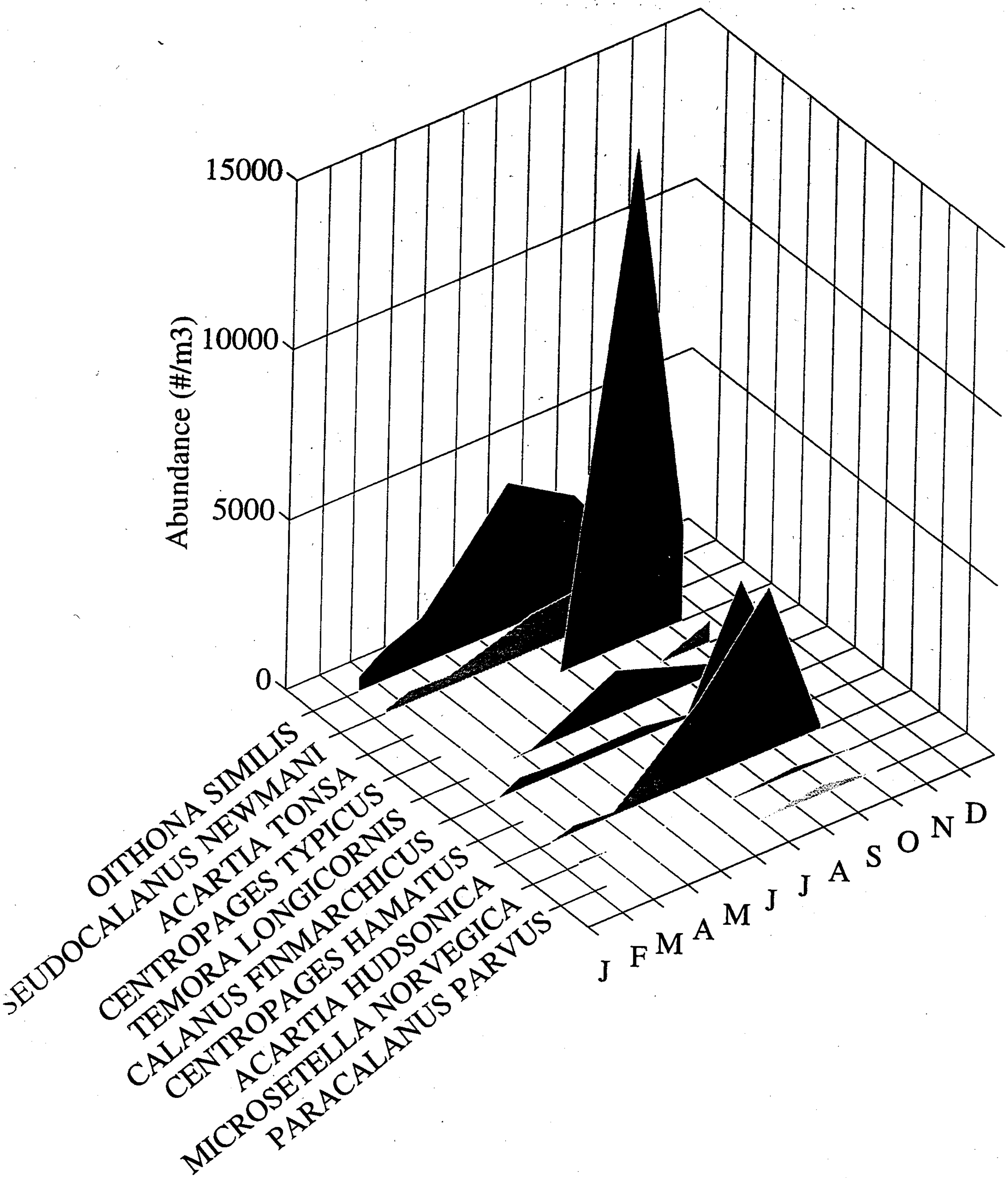

Calanus finmarchicus
Centropages typicus
Centropages hamatus
Pseudocalanus spp
Paracalanus parvus
Oithona spp.
ADULT
CV
CIV
CIII
CII
CI
MESH SIZES
(mm) 0.053
0.165
0.333
0.505

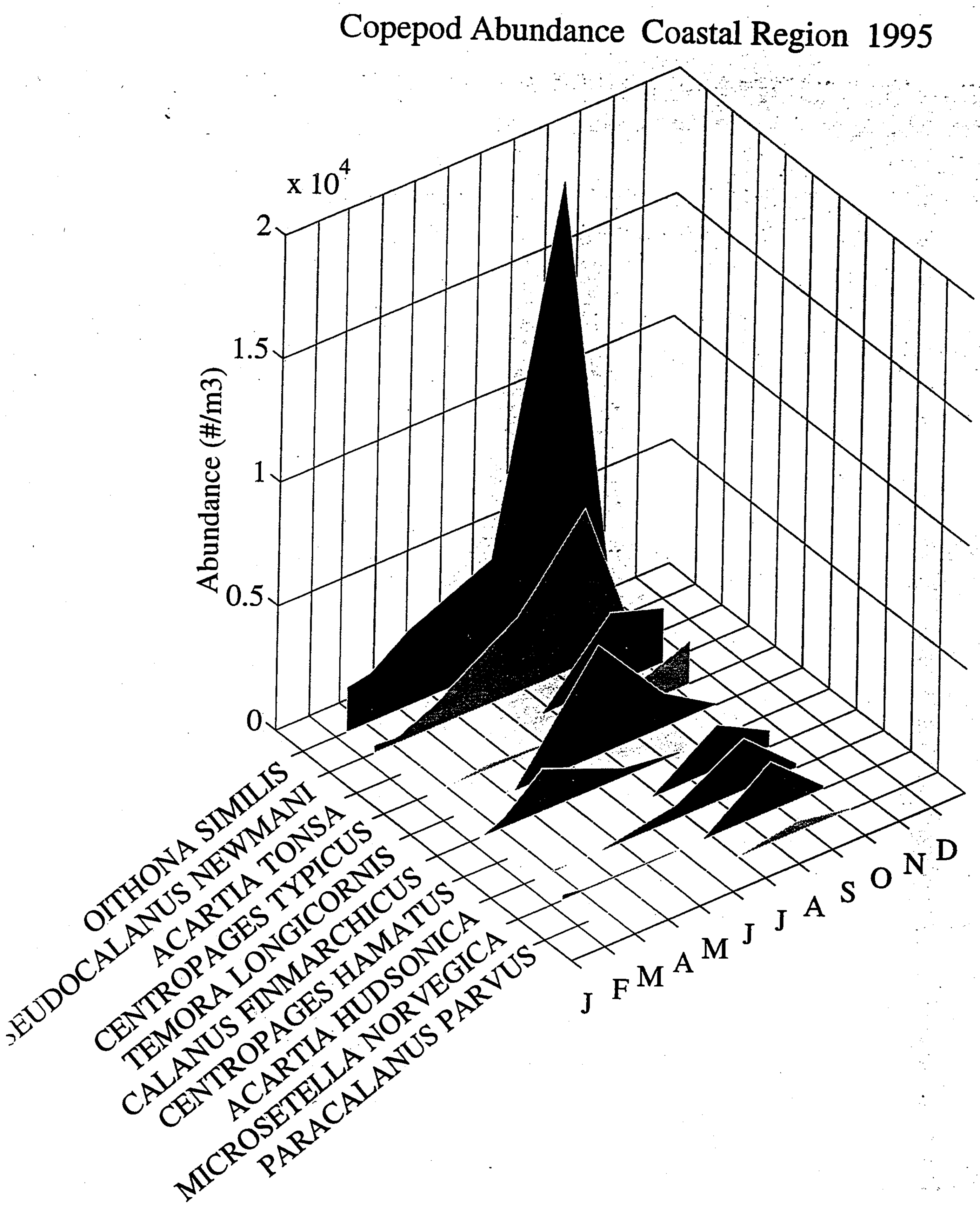
Seasonal Distribution of Dominant Taxa

- **Winter/Spring Assemblage**
  - ***Calanus Finmarchicus*** **and** ***Pseudocalanus newmani***
  - **Both Dominant Prey of Right Whale**
  - **Most Abundant in Offshore Stations**
- **Summer/Fall Assemblage**
  - ***Oithona similis*****,** ***Acartia*** **spp.,** ***Centropages*** **spp.,** ***Paracalanus parvus*****,** ***Microsetella norvegica***

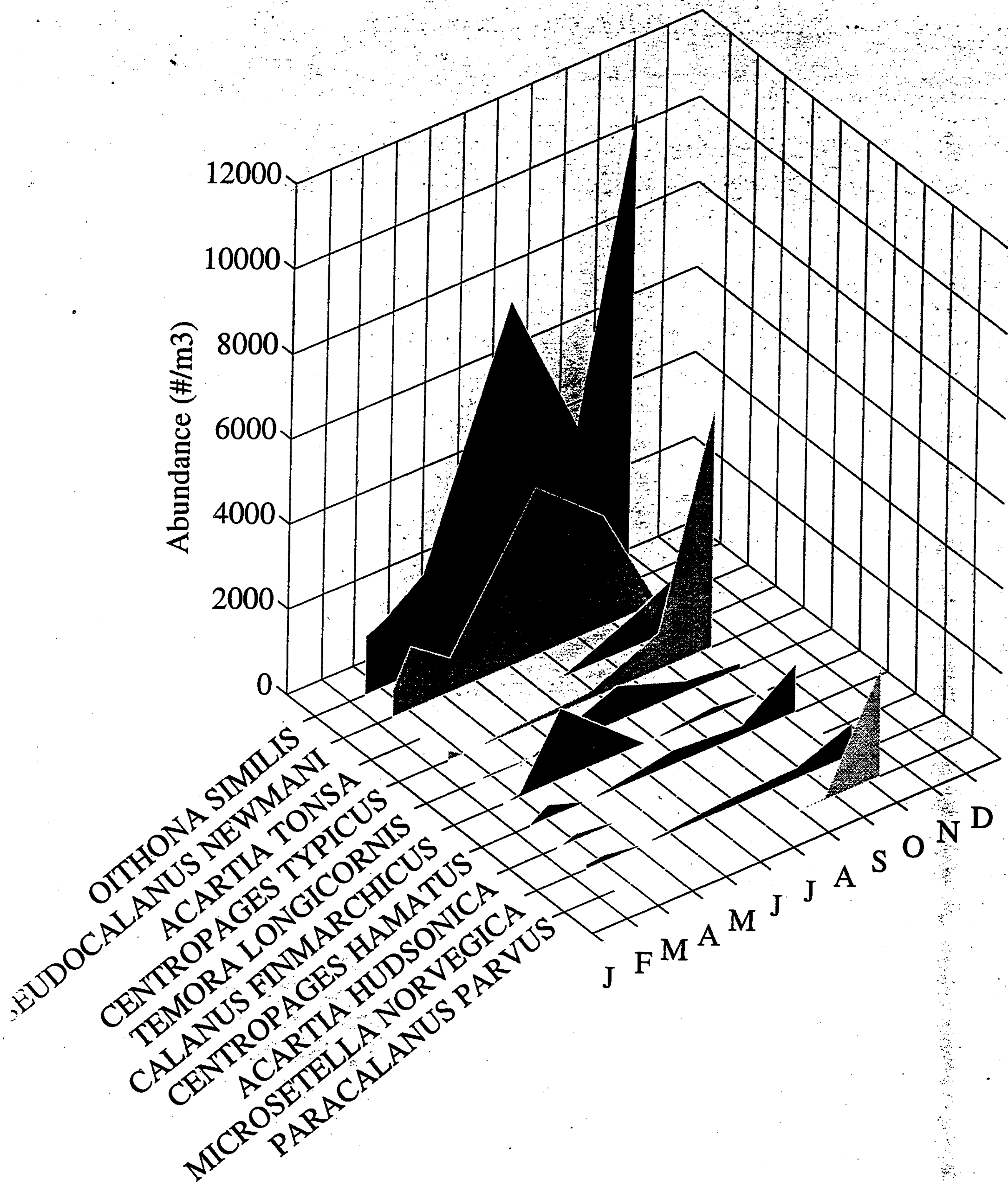
Most Abundant in Coastal Areas

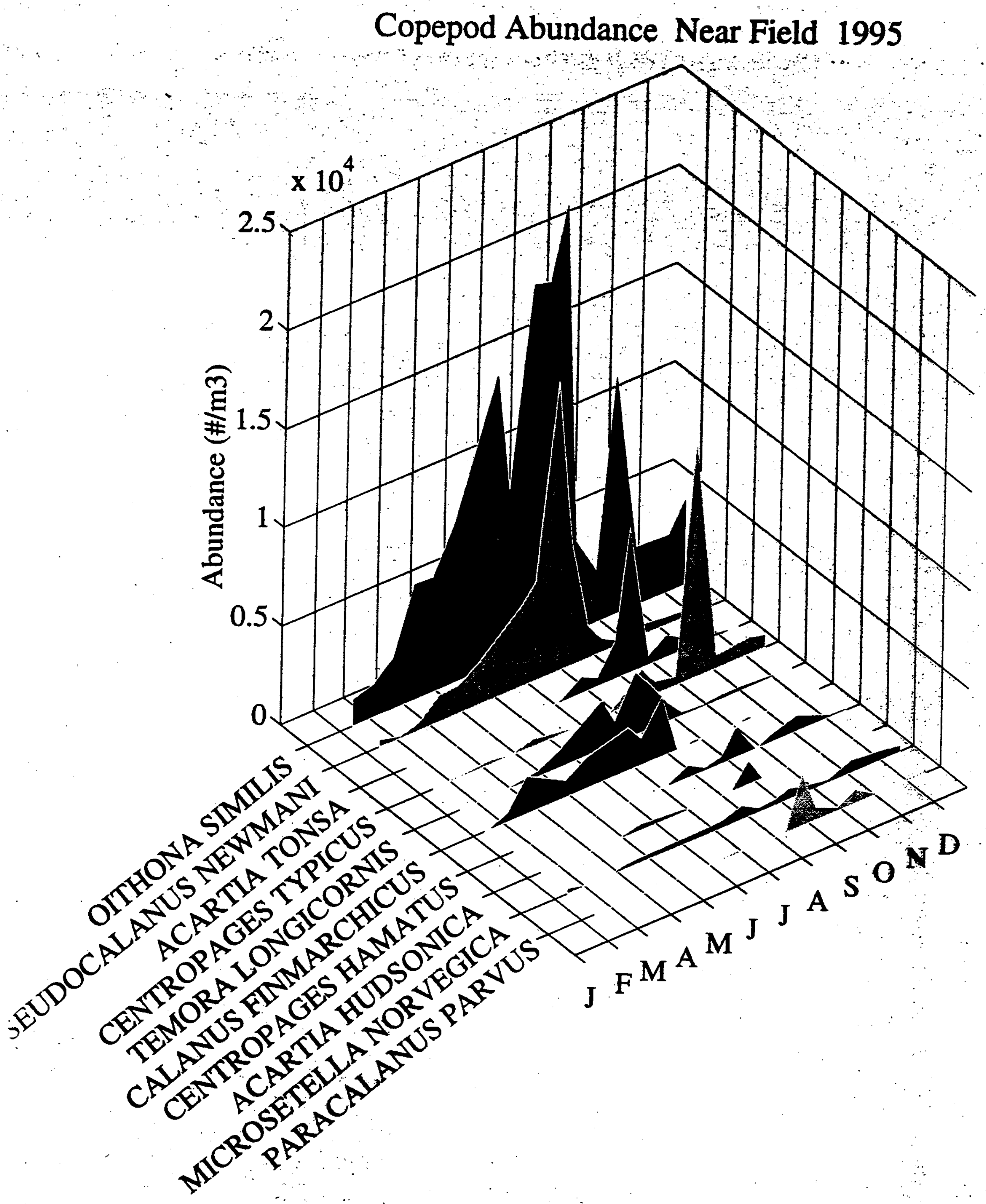
Copepod Abundance Boston Harbor 1995



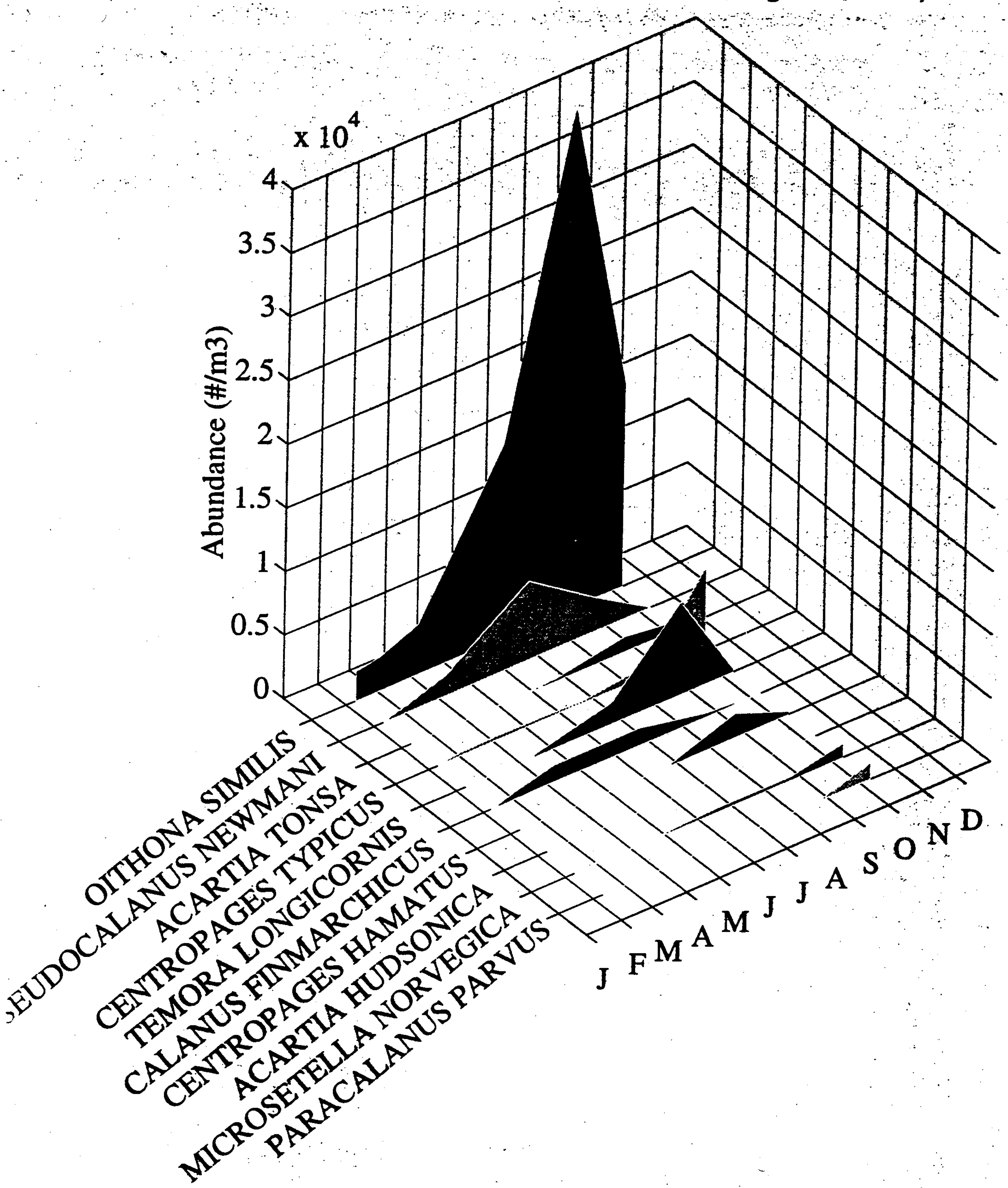

Copepod Abundance Coastal Region 1995
x 10^4
2
1.5
1
0.5
0
Abundance (#/m3)
OITHONA SIMILIS
SEUDOCALANUS NEWMANI
ACARTIA TONSA
CENTROPAGES TYPICUS
TEMORA LONGICORNIS
CALANUS FINMARCHICUS
CENTROPAGES HAMATUS
ACARTIA HUDSONICA
MICROSETELLA NORVEGICA
PARACALANUS PARVUS
J
F
M
A
M
J
J
A
S
O
N
D

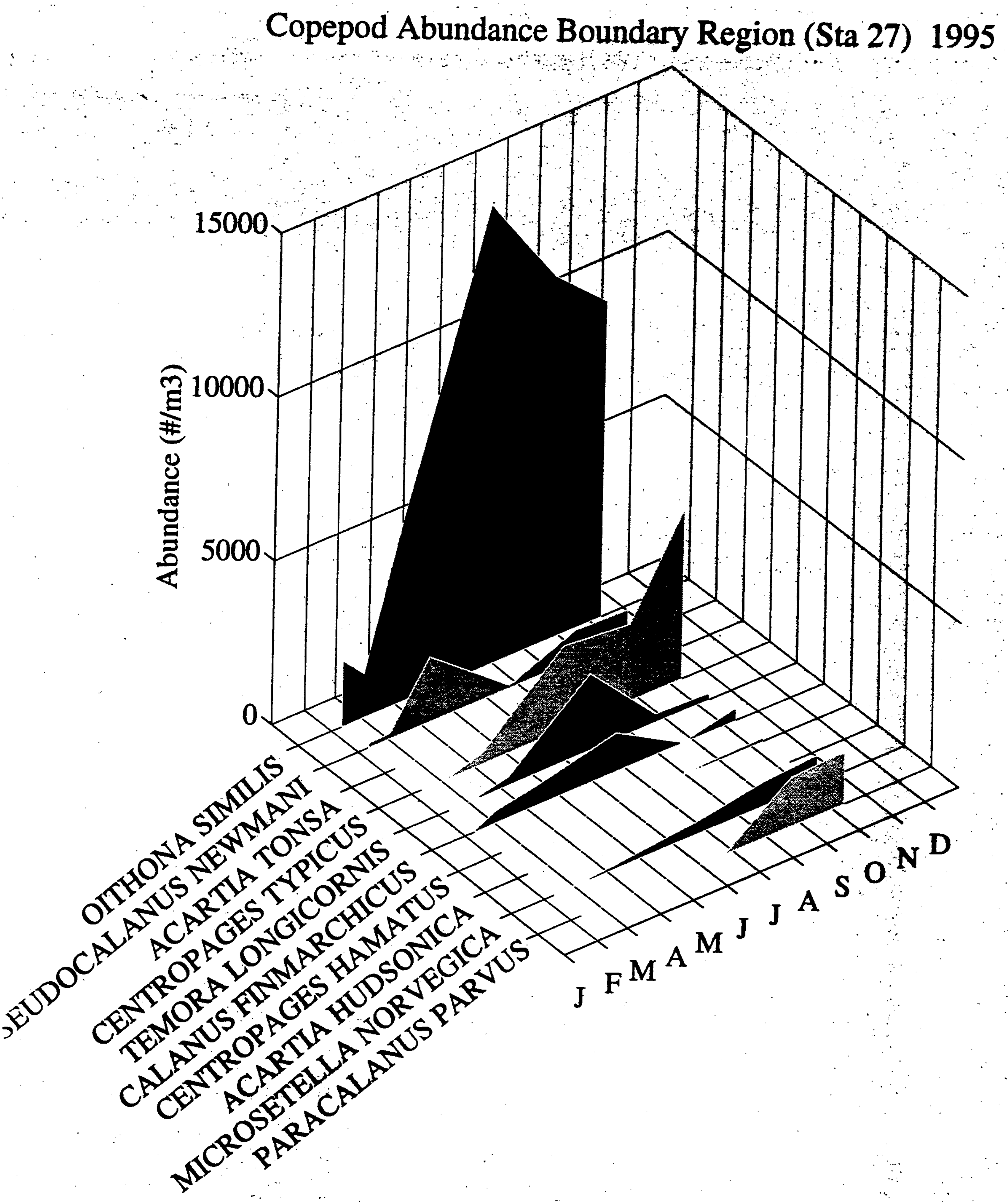
Copepod Abundance Cape Cod Bay 1995




Copepod Abundance Near Field 1995
x 10^4
2.5
2
1.5
1
0.5
0
Abundance (#/m3)
OITHONA SIMILIS
SEUDOCALANUS NEWMANI
ACARTIA TONSA
CENTROPAGES TYPICUS
TEMORA LONGICORNIS
CALANUS FINMARCHICUS
CENTROPAGES HAMATUS
ACARTIA HUDSONICA
MICROSETELLA NORVEGICA
PARACALANUS PARVUS
J F M A M J J A S O N D

Copepod Abundance Offshore Region (Sta 6) 1995



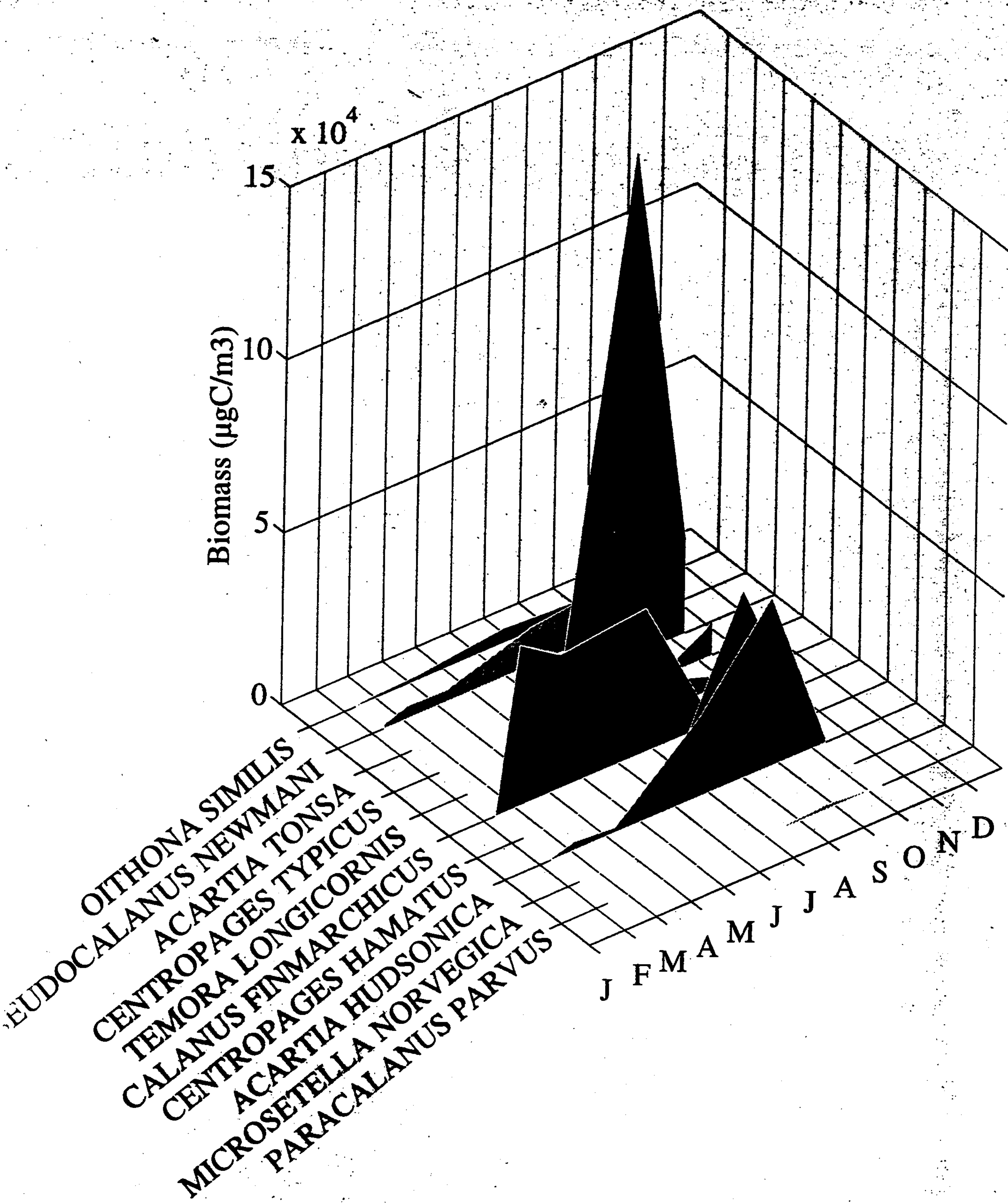


Copepod Abundance Boundary Region (Sta 27) 1995
Abundance (#/m3)
15000
10000
5000
0
OITHONA SIMILIS
SEUDOCALANUS NEWMANI
ACARTIA TONSA
CENTROPAGES TYPICUS
TEMORA LONGICORNIS
CALANUS FINMARCHICUS
CENTROPAGES HAMATUS
ACARTIA HUDSONICA
MICROSETELLA NORVEGICA
PARACALANUS PARVUS
J F M A M J J A S O N D

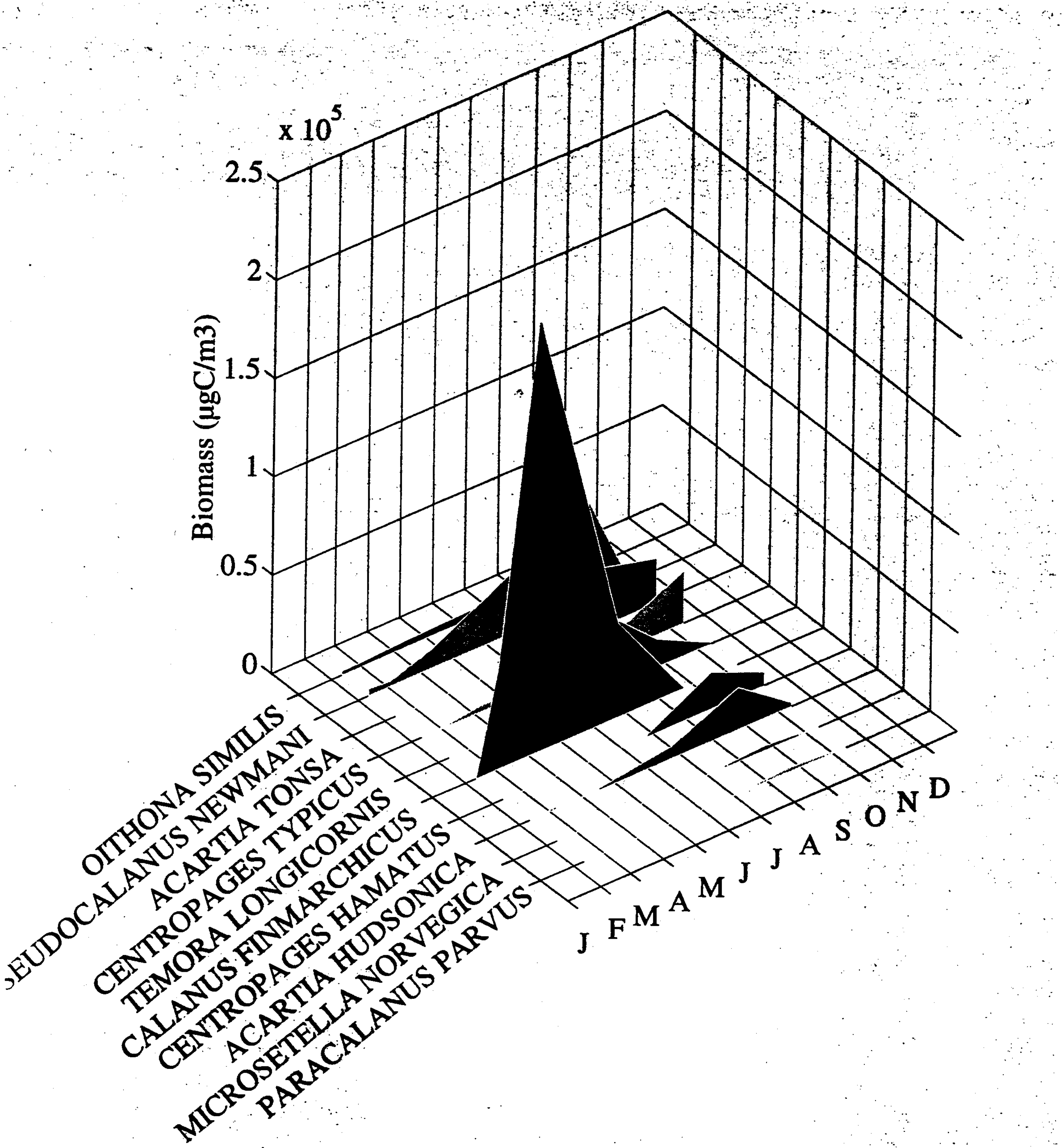
Numerical Dominance vs Biomass

- **Numerical Dominance Often by Oithona similis**
  - Peak Densities Frequently Around $20k/m^3$
  - Estimated Carbon Equivalence < $50gC/m^3$
- **Biomass Dominance by *Calanus finmarchicus***
  - Peak Densities Around $4k/m^3$
  - Estimated Carbon Equivalence 150 to 300 gC/m^3

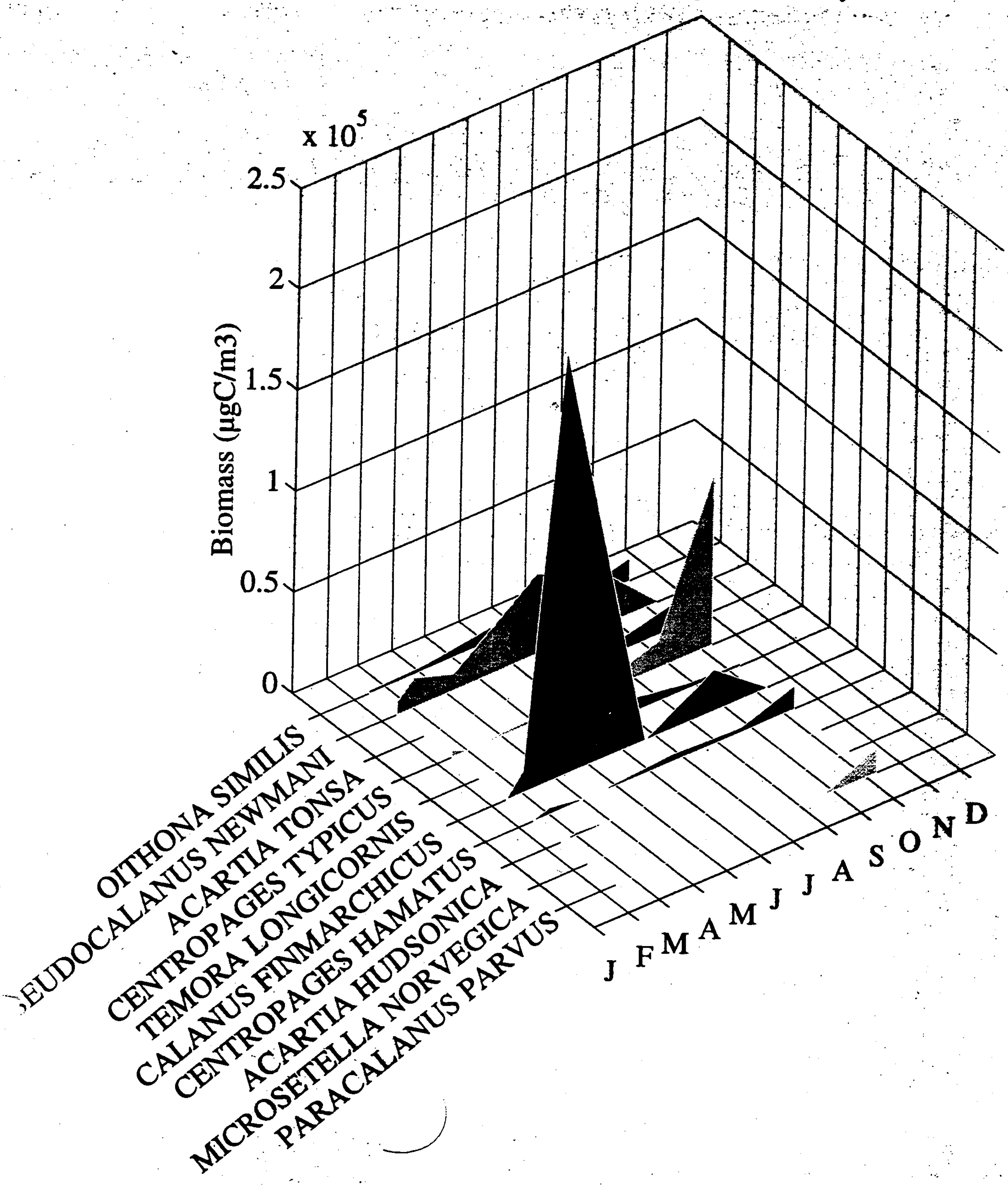
Copepod Biomass Boston Harbor 1995

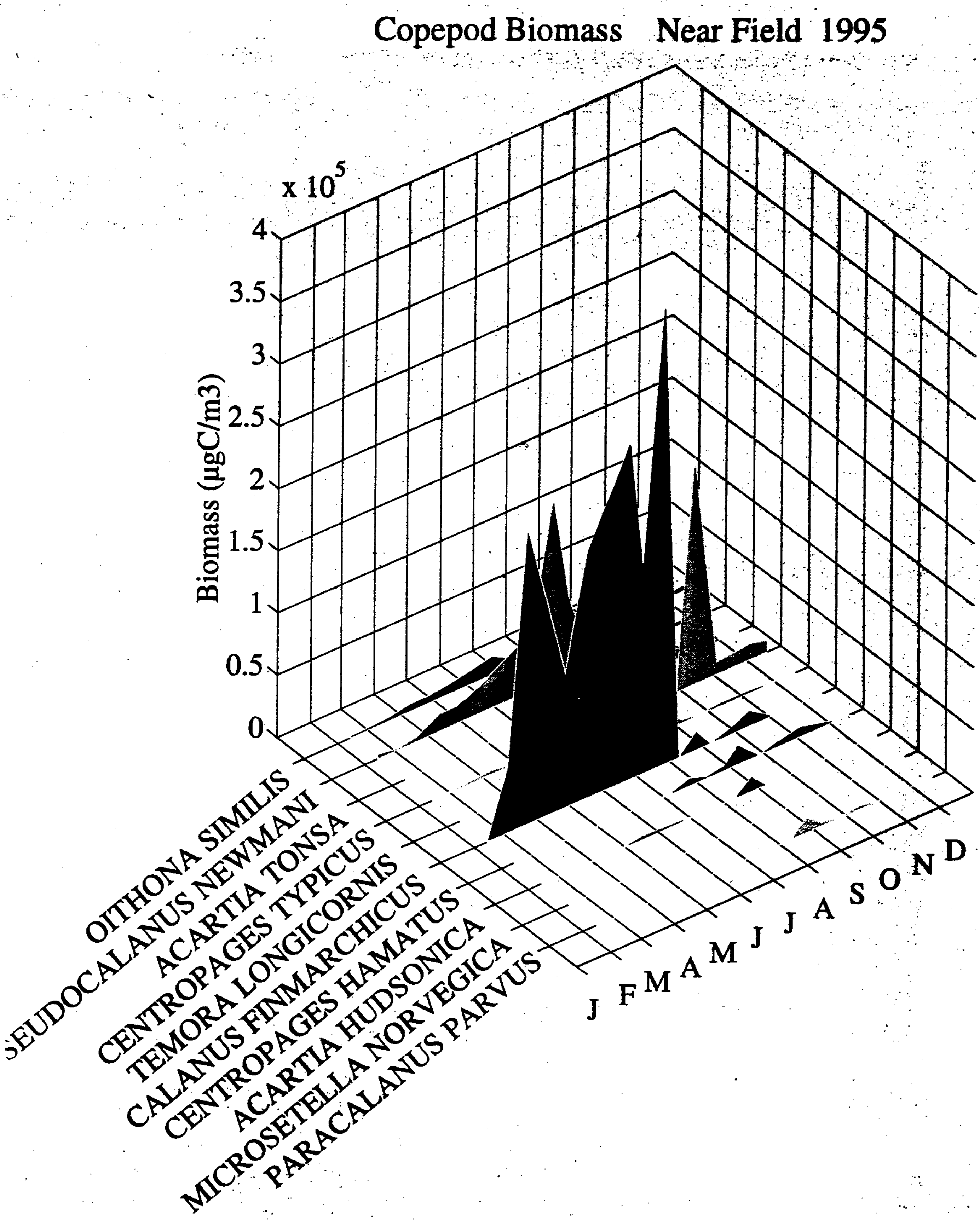


Copepod Biomass Coastal Region 1995



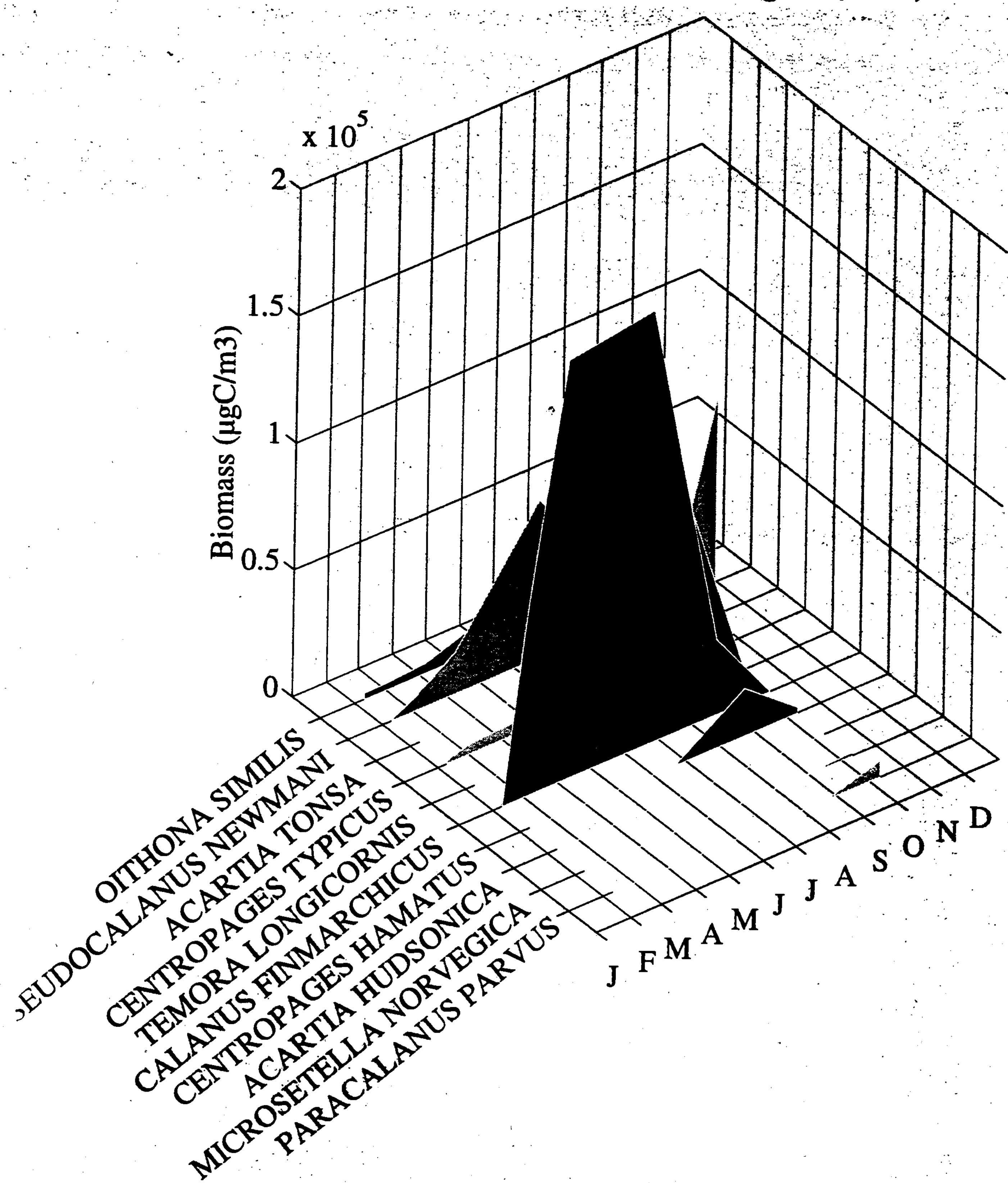
Copepod Biomass   Cape Cod Bay 1995

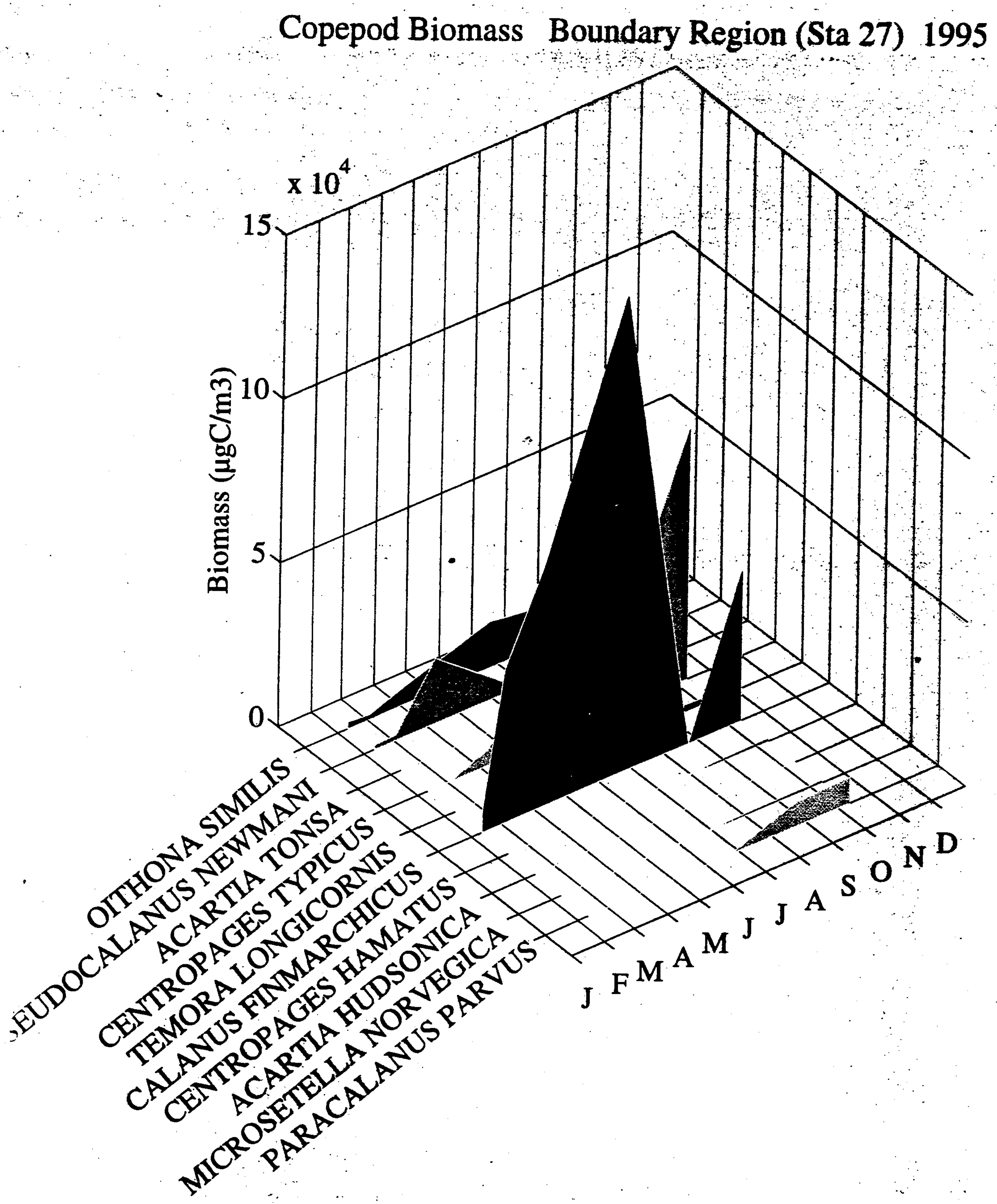




Copepod Biomass Near Field 1995
x 10^5
4
3.5
3
2.5
2
1.5
1
0.5
0
Biomass (µgC/m3)
OITHONA SIMILIS
SEUDOCALANUS NEWMANI
ACARTIA TONSA
CENTROPAGES TYPICUS
TEMORA LONGICORNIS
CALANUS FINMARCHICUS
CENTROPAGES HAMATUS
ACARTIA HUDSONICA
MICROSETELLA NORVEGICA
PARACALANUS PARVUS
J F M A M J J A S O N D

Copepod Biomass Offshore Region (Sta 6) 1995





Copepod Biomass Boundary Region (Sta 27) 1995
x 10^4
15
10
5
0
Biomass (µgC/m3)
OITHONA SIMILIS
PSEUDOCALANUS NEWMANI
ACARTIA TONSA
CENTROPAGES TYPICUS
TEMORA LONGICORNIS
CALANUS FINMARCHICUS
CENTROPAGES HAMATUS
ACARTIA HUDSONICA
MICROSETELLA NORVEGICA
PARACALANUS PARVUS
J F M A M J J A S O N D

Conclusions

- Post-Discharge Monitoring Should Focus on:
  - Potential Shift Toward Coastal Assemblage in Nearfield
  - Departure from Seasonal Baseline Densities
  - Alteration of Seasonal Carbon Budget

APPENDIX C-9

Cape Cod Commission
Scientific Advisory Board

EXCERPTS FROM THE

SCIENTIFIC ADVISORY PANEL (SAP) COMMENTS ON THE

MWRA DRAFT CONTINGENCY PLAN

September 1995

Executive Summary

Barnstable County, by and through the Cape Cod Commission, ("the Commission") submits the following comments on the MWRA's March 8, 1995 Draft Contingency Plan ("DCP") regarding the proposed discharge from the MWRA's Deer Island Treatment Facility to Massachusetts and Cape Cod Bays. These comments are based primarily on the technical review of the DCP conducted by the Barnstable County Science Advisory Panel (SAP). The Commission welcomes the opportunity to submit these comments and looks forward to discussing them and the DCP with the Massachusetts Water Resources Authority (MWRA), the National Marine Fisheries Service (NMFS), the Environmental Protection Agency (EPA), and the Department of Environmental Protection (DEP).

In general, the DCP represents a positive first step in addressing some of the questions of monitoring for the effects of the MWRA discharge on the bays' ecosystem. The DCP does present a framework for refining a program to measure and respond to changes in the ecosystem. However, there are several important additional elements which must be considered in the final contingency plan for it to be an effective, comprehensive plan. First, there are significant discrepancies in the DCP relating to National Pollutant Discharge Elimination System (NPDES) permit compliance issues and certain problems with the DCP's approach to these issues, which must be corrected. Second, the DCP fails to address the potential adverse effects of the discharge on the endangered species present in the Massachusetts and Cape Cod Bay ecosystems or to establish a meaningful mechanism to assess such effects. Third, the monitoring provided for or relied upon in the DCP is inadequate to assess the potential adverse effects of the discharge on the Bays' ecosystems, particularly with regard to the endangered species in the Bays.

The Commission and its SAP recommend that the March 1995 DCP be restructured and supplemented to provide a more comprehensive approach and to address more fully the following important issues: (1) Contingencies for NPDES compliance; (2) Monitoring; and (3) Ecological effects-based decision making process. Each of these issues is discussed in more detail below. The strongest recommendation addresses the need for an ecological effects-based decision making process, rather than a dose-yield approach.

The basic premise of the SAP approach is that the ecology of the system, including the multiple interactions between physical, chemical, and biological parameters determines in presently unpredictable fashion, the consequence of the nutrient perturbation, including the impact on endangered species. The SAP believes the contingency plan must address the dose-trophic consequences of nutrient enrichment, rather than focusing on dose-yield impacts, as is done in the DCP.

The SAP proposal includes a peer-review process that is integral to the contingency plan process. External critical review of the monitoring program design and protocols, of the analysis and interpretation of the data, and the review of these data for the purposes of contingency planning is essential to the overall environmental monitoring program associated with the outfall. The ecological effects-based decision making process must include continual review and evaluation of the monitoring data, and continual assessment of ecological parameters to determine whether changes in the bays system that may be cause for concern, are occurring.

The Cape Cod Commission and its SAP believe the contingency plan should include a decision making process that details how the plan will be implemented. The decision making process must be well-posed, rigorous, able to treat multivariate stochastic data with considerable uncertainties (scientific data as well as social and economic constraints), and retain a flexibility to include new "rules" as our understanding of bays-wide processes improves.

The contingency planning approach detailed below is very extensive. The SAP has presented an approach that more specifically addressses the question of how changes in the bays system may impact endangered whales. The Commission believes that technologies and data management systems exist to implement an ecological effects-based decision making process. Implementation of such a process will require collaboration among a number of agencies and institutions. It will also require funding support from outside of the MWRA.

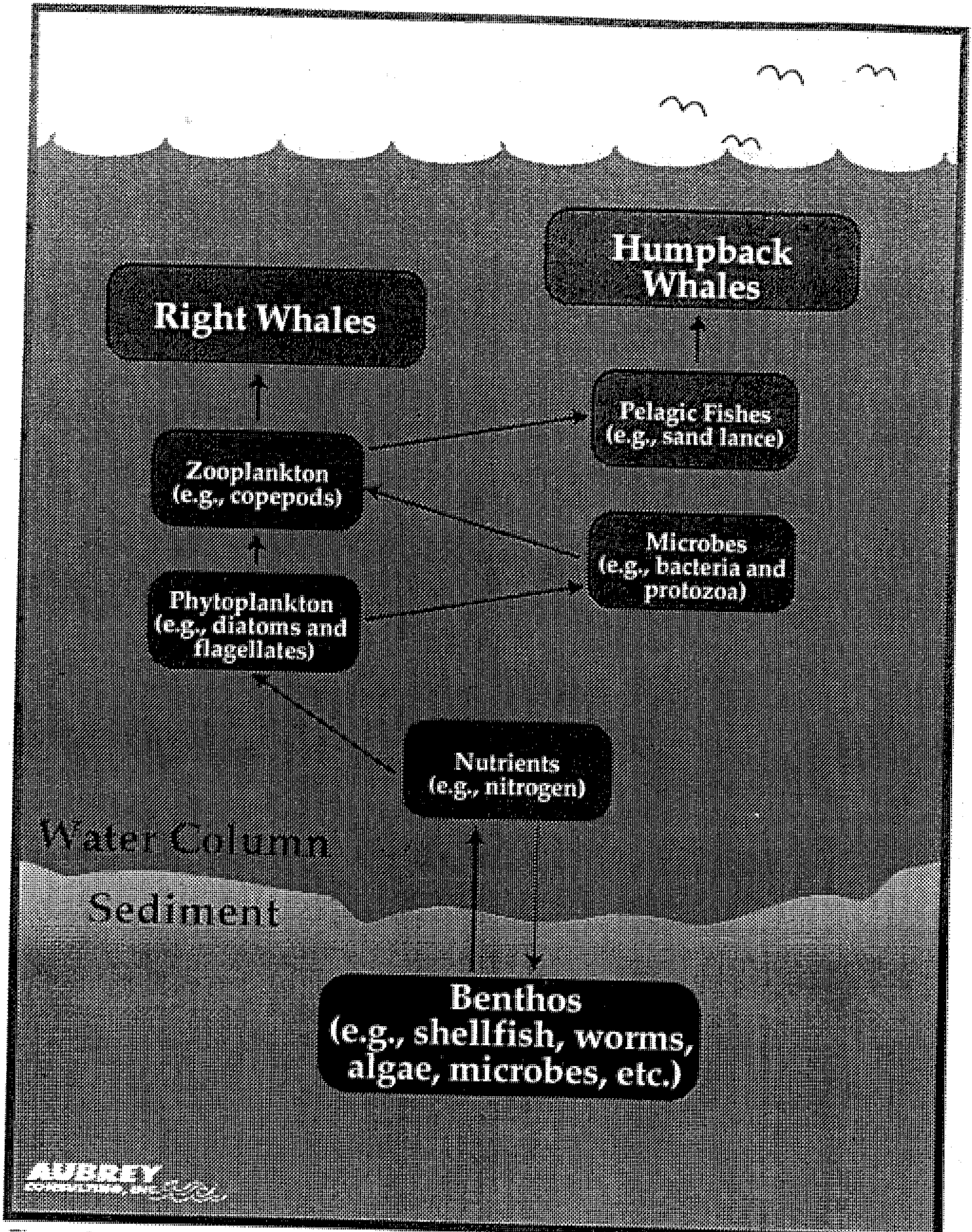


Figure 1: A simple, conceptual diagram of the pelagic food web in Cape Cod and Massachusetts Bays. Arrows indicate flow of nutrients and energy from lower to higher trophic levels, or in the case of the water-sediment interface, simply between benthic and pelagic food webs. Nutrient regeneration is not shown, but occurs between all functional groups and the nutrient pool.

II. Monitoring

It is not possible to evaluate the DCP separate from the present outfall monitoring program, since the monitoring program will provide much of the data used to determine the environmental status and trends of the Bays' ecosystems. The MWRA has acknowledged the connection between monitoring and the contingency plan in its January 1995 draft of the post-discharge monitoring program, in which it states that the "focus [of these hypotheses] is on detecting exceedence of warning level thresholds such that potential unacceptable impacts are identified before system-level or other undesirable conditions develop" (page 3-1)

The Commission and the SAP have identified several areas of environmental monitoring which it believes need to be addressed to assess environmental change and to assess whether the trends are significant to necessitate further action. Although the current Baseline Monitoring Program generally allows detailed assessment of issues close to the proposed outfall site, it is not focused on far-field monitoring issues or monitoring specifically designed to ensure the protection of endangered or threatened species.

A. Adequacy of Existing Baseline and Proposed Post-discharge Monitoring Programs

1. Space-time Scales of Sampling

The number of stations and the frequency of sampling at these stations are not sufficient to define the spatial and temporal variability of biological and chemical parameters. Members of the SAP and the Cape Cod Commission agree that the current sampling regime is simply inadequate for establishing a baseline against which to measure future conditions and possible changes in the bays' system. Since the system has been undersampled, the limited statistical analyses that have been applied to particular parameters (Hunt et al., 1995) to further refine, i.e., reduce, the sampling grid are erroneous. A separate report by A. Solow of the Woods Hole Oceanographic Institution's Marine Policy Center addresses the statistical errors more thoroughly.

The sampling effort of 70 days per year reported in the DCP [only 50 sampling days are reported by Kelly & Turner, *Water Column Monitoring in Massachusetts and Cape Cod Bays: Annual Report for 1993*, Draft Report, 1995] exaggerates the actual sampling frequency. The sampling days given are actually the total number of survey days used to sample the station grid. The actual sampling frequency at each station was considerably lower, and below that needed for parameter quantification: elucidation of environmental and plankton community status, patterns and trends, and application of ecological statistical procedures. For Massachusetts Bay, each station was sampled 16 times per year. The four widely spaced Cape Cod stations were sampled only six times per year. Both the temporal and spatial scales of sampling, particularly in Cape Cod Bay, fall far short of the time and space scales characterizing plankton dynamics and their distributional features.

2. The Need for More Intense Summer-Fall Sampling

It is well known from field and experimental evidence that the four month period from June - September in New England coastal waters is characterized by highly unpredictable phytoplankton bloom events, including toxic blooms, whose growth is tightly coupled to nutrient levels and grazing. The DCP and ongoing monitoring effort seriously neglect this critical season. For Cape Cod Bay, each of the four stations are sampled only twice, with a two month gap between sampling dates, in the four months from June - September (Kelly and Turner, 1995). A minimum twice monthly sampling frequency at all monitoring stations is needed during the critical summer-fall season. This period requires an even greater monitoring focus than that currently applied to the winter-spring bloom period.

3. Adequacy of Data Base for All Variables

The undersampling of the existing monitoring program renders the entire biological and chemical data sets suspect for their intended purpose of evaluation of changes in the bays' system that may be indicative of environmental disturbances. This data base is also inadequate, particularly in Cape Cod Bay, to establish the degree of temporal and spatial coherence within the regions, and coherence and linkages between regions (i.e., between Cape Cod and Massachusetts Bay). These limitations are further aggravated by failure to include critical biological measurements in the monitoring program [see Section III C].

4. Discrete Depth vs. Averaged Depth Analyses

A common practice in MWRA reports is to use averaged data in the analyses, rather than the actual data from the discrete sampling depths. This practice seriously blurs recognition and assessment of the vertical gradients and patchiness in physical, chemical and biological variables. It is antithetical to the needed ecological assessment which the Cape Cod Commission and Scientific Advisory Panel believe should be the thrust of the MWRA monitoring program, rather than its current focus on mass balance approaches and the use of averaged data. The use of averaged data can not be justified for statistical reasons. Many suitable techniques are available and appropriate for discrete data analyses.

The criteria of selection of the five discrete sampling depths should also be revised. MWRA proposes routine collection of surface and bottom samples (i.e. based on depth) supplemented by two mid-depth samples "*spanning the pycnocline when It exists*" (i.e., based on a physical feature) and a mid-depth sample at the chlorophyll maximum (i.e., based on a biological feature). This hodgepodge of three different sampling depth criteria compromises adequate ecological description of the phytoplankton--zooplankton--habitat relationships, their trends and potential changes. The unreliability of this approach is further exacerbated by the current practice of averaging the data. Taken together, the sampling depth selection protocol applied (independent of the overall sampling program) and the use of averaged data are expected to provide a distorted picture of actual *in situ* (i.e., ecological) conditions. MWRA therefore should be obliged to demonstrate that their sampling and analytical procedures adequately represent actual conditions. It is also suggested that MWRA base its sampling depth selection on sigma-t levels which should provide more representative samples of the integrated physical, chemical and biological processes operative within the water column. Selection of sigma-t levels should be facilitated by a retrospective analysis of existing data sets.

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