Water quality monitoring in Massachusetts and Cape Cod Bays: December 1992, February and March 1993.

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FINAL REPORT

WATER QUALITY MONITORING IN MASSACHUSETTS AND CAPE COD BAYS: DECEMBER 1992, FEBRUARY AND MARCH 1993

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EXECUTIVE SUMMARY

This report is the first of five periodic water column reports for water quality monitoring conducted in 1993 by Battelle Ocean Sciences for the Massachusetts Water Resources Authority (MWRA) Harbor and Outfall Monitoring Program. The report includes results from four surveys conducted during December 1992 and February and March 1993; each of these surveys included sampling at stations in the nearfield area. The February and March surveys were combined farfield/nearfield surveys that covered 25 additional stations throughout Boston Harbor and Massachusetts and Cape Cod Bays. In this report, data on physical, chemical, and biological measurements are presented and interrelationships of these measurements are examined. The major results are summarized here.

The main feature observed during this period was a regional-scale differentiation between Massachusetts and Cape Cod Bays. Distinctions between the Bays were clearly evident in both the biological and chemical parameters, while there was little variation in the physical parameters (except near Boston Harbor). The primary regional feature was the distinctly different phytoplankton biomass across the Bays. During both the February and March farfield surveys, higher chlorophyll concentrations (>3.0 μg L^{-1} vs. <1 μg L^{-1}) and higher abundances of diatoms ($\sim 10^6$ vs. $\sim 10^5$) were observed in Cape Cod Bay compared to Massachusetts Bay. The observations in Cape Cod Bay were expected and are representative of winter-spring bloom conditions that often appear to be initiated early in this region. However, a winter-spring bloom was not observed during this period in Massachusetts Bay. Due to these biological differences, the nutrient regimes of the Bays were distinct. Dissolved inorganic nitrogen and phosphate concentrations were lower in Cape Cod Bay. The silicate concentrations were especially low and this was associated with the high numbers of diatoms present in Cape Cod Bay.

During both the farfield and nearfield surveys, the outflow from Boston Harbor and other coastal sources was readily observable in both the physical and chemical data. For a period that was marked by little variation in physical measurements on both regional (between the Bays) and local (vertical) scales, there were clear inshore-offshore gradients in both temperature and salinity. The cooler, fresher Harbor/coastal waters were observed during each of the early 1993 surveys. During the farfield surveys, the influence of Boston Harbor was evident at stations F23P and F24, while on the nearfield surveys similarly cooler and fresher waters were observed in the southwestern corner of the nearfield (stations N10P and N11). Also, higher concentrations of dissolved inorganic nutrients, especially ammonium, were measured at the Harbor-influenced stations.

Besides these general trends, specific findings were as follows:

- Nutrients - Concentrations were relatively high in most surface waters. Dissolved inorganic nitrogen, total nitrogen, and silicate were lower in Cape Cod Bay than in Massachusetts Bay. Nitrate was nearly depleted in a number of the samples taken in Cape Cod Bay. High ammonium concentrations were observed at the coastal stations and those stations influenced by the Harbor/coastal outflow. There was no apparent decrease in near-surface nutrients over the time period of these surveys. Low rates of biological utilization and/or sporadic vertical mixing events may have contributed to the consistent nutrient concentrations.

- Chlorophyll - During both of the farfield surveys, the difference in chlorophyll concentrations and phytoplankton species and numbers between Cape Cod and Massachusetts Bays required different calibrations for the conversion of fluorescence measurements for the two bays. Chlorophyll concentrations were consistently < 1 μg L^{-1} in the nearfield region over this period, though patches with higher concentrations were indicated during the late March high resolution tow-yo profiling. There was a seemingly strong relationship between phytoplankton abundance and chlorophyll concentration, but this was primarily due to the differences between the two Bays. This was also true for the production and chlorophyll comparison. There was no apparent relationship between total nitrogen concentration and chlorophyll concentration, even across the Bays.

- Phytoplankton - The winter-spring diatom bloom observed in Cape Cod Bay did not materialize at similar peak levels in Massachusetts Bay. The species composition at Massachusetts Bay stations was a mixed distribution of microflagellates, cryptomonads, and diatoms, but in Cape Cod Bay, while the other groups were present, the diatoms were the most abundant. The diatoms were dominated by several species of *Chaetoceros* in Cape Cod Bay, while in Massachusetts Bay the typical diatoms were *Cylindrotheca closterium*, *Skeletonema costatum* (February), and *Thalassiosira gravida/rotula* (March). In the screened ($> 20\mu m$) samples, individual abundances and number of taxa were higher in Cape Cod Bay compared to Massachusetts Bay. The majority of these were dinoflagellates. *Alexandrium tamarense*, an organism of interest with respect to its potential for Paralytic Shellfish Poisoning, was detected in Cape Cod Bay during both of the farfield surveys and in the surface waters at station N20P during the March survey.

- Zooplankton - *Oithona similis* was the most abundant copepod taxa at each of the stations during both of the farfield surveys. *Acartia hudsonica* was present at the Harbor-edge station F23P in February and March. Interestingly, this typically estuarine species was also observed at the Cape Cod Bay stations. Cape Cod Bay was also distinguished by the high numbers of the appendicularian, *Oikiopleura dioica*, that were observed at stations F01P and F02P during both surveys. Though Cape Cod Bay was clearly distinct from Massachusetts Bay based on a number of biological parameters, there was no apparent relationship between zooplankton abundance and either chlorophyll concentrations or phytoplankton abundance.

- Dissolved oxygen - There was little vertical structure evident in the dissolved oxygen (DO) profiles and DO was generally close to saturation in the nearfield during this period. However, there was a progressive increase in DO, as percent saturation, from 90-95% in December 1992 to ~100% in late March 1993. Lower concentrations of DO (<90% saturation) were found at the Harbor-edge stations and occasionally to the middle of the nearfield.

- Metabolism - Due to much higher chlorophyll concentrations, ^{14}C production at the Cape Cod Bay stations was higher than at the Massachusetts Bay stations during both farfield surveys. Production rates at stations F01P and F02P ranged from ~2.5 to 3.5 gC m^{-2} d^{-1} in February and ~1.5 to 2.0 gC m^{-2} d^{-1} in March. Elsewhere, ^{14}C production rates were usually less than 0.5 gC m^{-2} d^{-1} during both of the farfield surveys. In February, the chlorophyll-normalized P_{max} values, in addition to the chlorophyll concentrations, were high at the Cape Cod Bay stations. This was not the case in March when chlorophyll-normalized rates at stations F01P and F02P were low (3.75 to 5.26 μg C (μg Chl)$^{-1}$ hr^{-1}), compared with most Massachusetts Bay estimates (4.6-16 μg C (μg Chl)$^{-1}$ hr^{-1}). Due to the elevated chlorophyll concentrations, however, ^{14}C production was still higher at the two Cape Cod Bay stations. Except for the Harbor-edge station F23P, the estimates of primary production rates were lower at the Massachusetts Bay and Cape Cod Bay stations in March relative to February. There were no apparent relationships between the rate of production and nutrients or depth of the euphotic zone.

CONTENTS

Note to reader:

Appendices A-G are bound separately from this technical report. To request the Appendices, contact the MWRA and ask for one of the MWRA Miscellaneous Publications entitled "APPENDICES TO WATER QUALITY MONITORING IN MASSACHUSETTS AND CAPE COD BAYS: DECEMBER 1992, FEBRUARY and MARCH 1993".

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1.0 INTRODUCTION

This report is the first in a series of five Periodic Water Column Reports for water quality monitoring conducted in 1993 for the Massachusetts Water Resources Authority Harbor and Outfall Monitoring Program. The report includes results from four surveys, starting with a nearfield survey in December 1992 (Battelle, 1992) to the area near the future offshore outfall in Massachusetts Bay. Results are presented for three surveys conducted during February and March of 1993; each of these surveys included sampling at twenty-one stations in the nearfield area and two of these (one in February and one in March) were combined farfield/nearfield surveys that covered twenty-five other stations throughout Massachusetts Bay and Cape Cod Bay. Data on physical, chemical, and biological measurements at the stations are presented and interrelationships examined. The structure of the report is as follows.

Section 1.	Background information on the water quality surveys being conducted in 1993.
Section 2.	Field and laboratory methods for the surveys.
Sections 3-6.	Results by surveys, in chronological order (December nearfield survey, February farfield-nearfield survey, March farfield-nearfield survey, late March nearfield survey).
Section 7.	Discussion of the winter-spring period of surveys.
Section 8.	An addendum providing results obtained for phytoplankton monitoring at station N10P throughout 1992.

An extensive set of appendices are bound separately. The appendices provide supporting tables and plots that represent the data being stored in the MWRA database.

1.1 Background

The Massachusetts Water Resources Authority (MWRA) is implementing a long-term monitoring plan for the future MWRA effluent outfall that will be located in Massachusetts Bay (Figure 1-1; note that all tables and figures are at the end of each section). The purpose of the monitoring is to verify compliance with the discharge permit and to assess the potential environmental impact of effluent discharge into Massachusetts Bay. A detailed description of the monitoring and its rationale are given in the Effluent Outfall Monitoring Plan (MWRA, 1991).

To help establish the present conditions with respect to water properties, nutrients, and other important parameters of eutrophication, MWRA contracted with Battelle to conduct baseline water-quality surveys throughout Massachusetts Bay during 1992-1994. Studies in 1992, including the December survey covered in this report were described in Shea *et al.* (1992). Results of other 1992 surveys were presented in a series of three reports similar to this (Kelly *et al.* 1992, Kelly *et al.*, 1993a,b), summarized in an annual report (Kelly *et al.* 1993c), and used in examining nutrient issues with the offshore outfall (Kelly, 1994).

Serving the MWRA's need for rapid dissemination of data and information, the periodic report series also provides a preliminary synthesis of monitoring results. The technical approach used in 1993 to implement the water quality portion of this monitoring plan is presented in a Combined Work/Quality Assurance Project Plan (CW/QAPP), Albro *et al.* (1993) that was developed specifically for water quality monitoring. The CW/QAPP describes the technical activities performed at sea and in the laboratory, data quality requirements and assessments, project management, and a schedule of activities and deliverables. Survey plans are submitted to MWRA for each survey to provide important operational details. Survey reports submitted after each survey describe actual cruise tracks, samples collected, and other survey details (cf. Albro, 1993 a,b; Dragos and Albro, 1993). Reports should be consulted for pertinent details, for example, on sampling tracks and samples obtained at each station. Survey data reports on nutrients, plankton, and pelagic metabolism have been submitted to MWRA for the surveys during February and March 1993; these data reports form a portion of the appendices to this report.

1.2 Survey Objectives

The objectives of the water quality surveys are discussed in detail in the MWRA Effluent Outfall Monitoring Plan (MWRA, 1991) and are summarized as follows.

Physical Oceanography

- Obtain high-resolution measurements of water properties throughout Massachusetts Bay
- Use vertical-profile data on water properties at selected sites in Massachusetts and Cape Cod Bays for analysis of large-scale spatial (10s of km) and temporal (seasonal)

variability in water properties and to provide supporting data to help interpret biological and chemical data

- Use high-resolution, near-synoptic, water-property measurements along transects within the nearfield area for analysis of smaller-scale spatial (km) and temporal (semi-monthly) variability in water properties, and develop a three-dimensional picture of water properties near the future outfall.

Nutrients

- Obtain nutrient measurements in water that is representative of Massachusetts and Cape Cod Bays
- Use vertical-profile data on nutrients at selected sites in Massachusetts and Cape Cod Bays for analysis of large-scale spatial (10s of km) and temporal (seasonal) variability in nutrient concentrations and to provide supporting data to help to interpret biological data
- Use vertical-profile data on nutrients along transects of closely-spaced stations within the nearfield area for analysis of smaller-scale spatial (km) and temporal (semi-monthly) variability in nutrient concentrations, and develop a three-dimensional understanding of the nutrient field near the future outfall.

Plankton

- Obtain high-quality identification and enumeration of phytoplankton and zooplankton in water that is representative of Massachusetts and Cape Cod Bays
- Use vertical-profile data on plankton at selected sites in Massachusetts and Cape Cod Bays for analysis of large-scale spatial (10s of km) and temporal (seasonal) variability in plankton distribution.

Water Column Respiration and Production

- Using water that is representative of Massachusetts and Cape Cod Bays, obtain a reasonable estimate of the rates of water-column respiration and production as a function of irradiance.

General

- Evaluate the utility of various measurements to detect change or to help to explain observed change
- Provide data to help to modify the monitoring program to allow a more efficient means of attaining monitoring objectives
- Use the data appropriately to describe the water-quality conditions (over space and time) in Massachusetts and Cape Cod Bays.

1.3 Survey Schedule for 1993 Baseline Water Quality Monitoring Program

Throughout 1993 and 1994, Battelle and its subcontractors, the University of Rhode Island (URI) and the University of Massachusetts at Dartmouth (UMD) are conducting surveys similar to those initiated in 1992. The schedule of surveys in 1993 is given in Table 1-1. The survey schedule was designed to match the schedule conducted in 1992. In addition to the December 1992 survey, the surveys discussed in this report were conducted during the weeks planned: February 23-27 (Survey W9301), March 9-12 (Survey W9302), and late March 24-25 (W9303). Note that weather prohibited towing on the second day of the nearfield portion of the March farfield-nearfield survey, so no high-resolution data were obtained on that survey. Virtually all of the planned stations on all other surveys were completed.

1.4 Summary of Accomplishments: December 1992 to Late March 1993

For the two combined farfield-nearfield surveys, *in situ* measurements were taken and samples were collected at the stations shown in Figure 1-1, with minor exceptions. Samples for laboratory analyses were collected to obtain the following types of data.

- Dissolved inorganic nutrients: nitrate, nitrite, ammonium, phosphate, and silicate
- Chlorophyll *a* and phaeopigments in extracts of filtered water
- *In situ* fluorometric measurements of chlorophyll, optical-beam transmittance (attenuation), light irradiance, salinity, temperature, and dissolved oxygen
- Total suspended solids and dissolved oxygen in discrete water samples
- Organic nutrients: dissolved carbon, nitrogen, and phosphorus; particulate carbon and nitrogen
- Phytoplankton and zooplankton identification and enumeration
- Rates of water-column production (^{14}C) vs. irradiance from shipboard incubations.

For the nearfield surveys, the first day was dedicated to vertical profiling, including collection of the following data

- Dissolved inorganic nutrients: nitrate, nitrite, ammonium, phosphate, and silicate
- *In situ* fluorometric measurements of chlorophyll, optical-beam transmittance (attenuation), light irradiance, salinity, temperature, and dissolved oxygen

- Chlorophyll *a* and phaeopigments in extracts of filtered water, as well as oxygen samples for titration, all to be used to calibrate *in situ* readings
- Phytoplankton samples for analysis and archival purposes.

The second day of a nearfield survey was dedicated to high-resolution "tow-yo" profiling. A towfish containing *in situ* sensors (as above, minus irradiance) was performed along nearfield tracks set between the vertical stations with the towfish oscillating from near the surface to near the bottom as the ship progressed at about 4-7 kt. There are 8 standard legs for towing. Four legs form the outer box (see Figure 1-2), covering about a 40 km track (stations N01P-N04P-N07P-N10P). The inner track has as its corners stations N13, N15, N17 and N19.

Samples that were collected for analysis have been analyzed and *in situ* sensor measurements have been calibrated and processed. Both types of data are presented in this report and all are summarized in accompanying Appendices A to G.

Table 1-1. Schedule of water quality surveys for calendar year 1993. This report provides data from the surveys conducted from December 1992 through March 1993.

SURVEY	SURVEY DATES
W9301 (Combined Farfield/Nearfield)	Feb 23-27
W9302 (Combined Farfield/Nearfield)	Mar 09-12
W9303 (Nearfield)	Mar 24-25
W9304 (Combined Farfield/Nearfield)	Apr 06-10
W9305 (Nearfield)	Apr 29-May 1
W9306 (Nearfield)	May 20-21
W9307 (Combined Farfield/Nearfield)	Jun 22-26
W9308 (Nearfield)	Jul 07-08
W9309 (Nearfield)	Jul 28-29
W9310 (Nearfield)	Aug 11-12
W9311 (Combined Farfield/Nearfield)	Aug 24-28
W9312 (Nearfield)	Sep 08-09
W9313 (Nearfield)	Sep 28-29
W9314 (Combined Farfield/Nearfield)	Oct 12-16
W9315 (Nearfield)	Nov 03-04
W9316 (Nearfield)	Dec 01-02

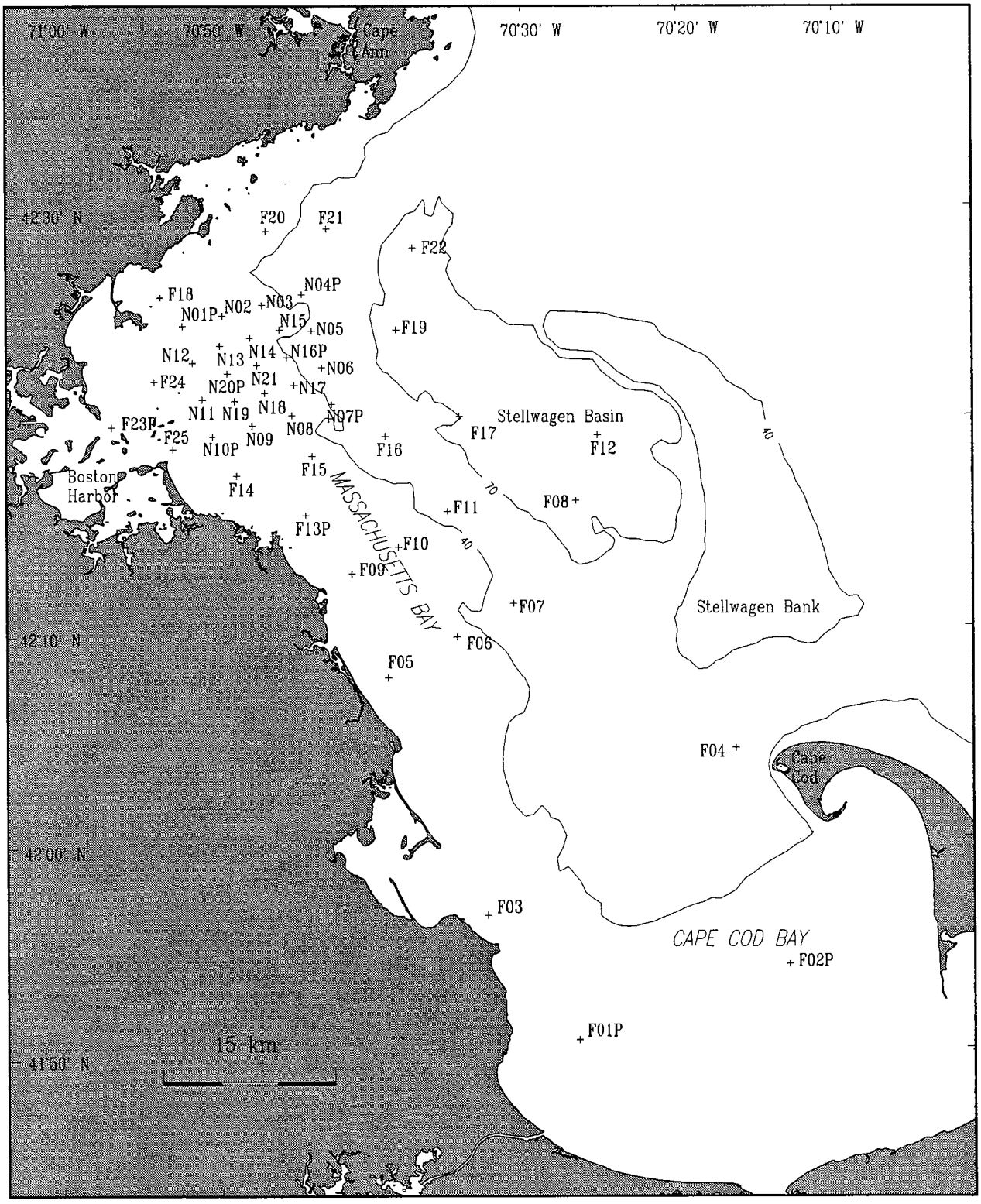


Figure 1-1. **Water quality sampling stations in Massachusetts and Cape Cod Bays. Station codes — F: Farfield, N: Nearfield, P: Biology/Productivity. Depth contours are in meters.**

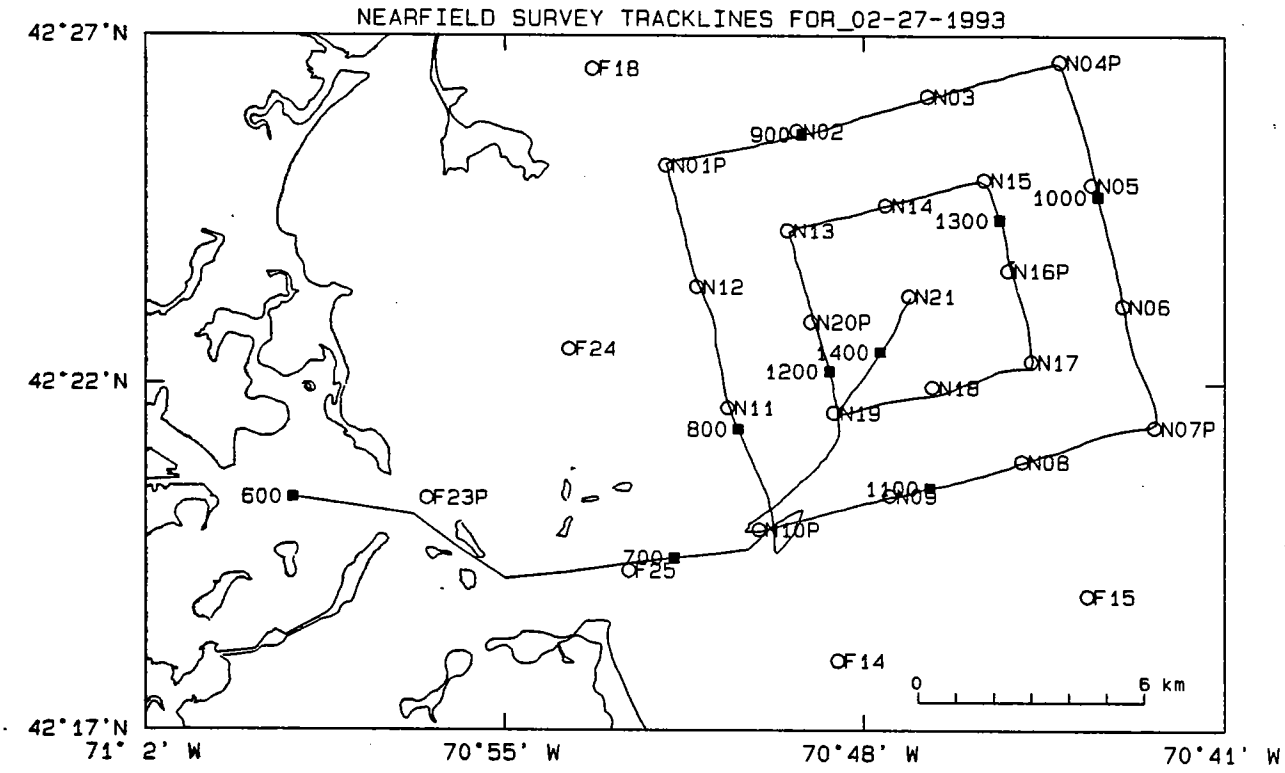


Figure 1-2. **Nearfield survey tracklines for February 27, 1993. Tow-yo operations were conducted clockwise from N10P to N10P, N19 to N19, and N19 to N21.**

2.0 METHODS

Field sampling equipment and procedures, sample handling and custody, sample processing and laboratory analysis, and instrument performance specifications and data quality objectives are discussed in the Combined Work/Quality Assurance Project Plan (CW/QAPP) for 1992 (Shea *et al.* 1992) and 1993 (Albro *et al.*, 1993). The plans are detailed and should be consulted for standard survey methods. In general, only deviations from the CW/QAPP are provided in this report.

2.1 Field Procedures

2.1.1 Hydrographic and Water Sampling Stations

Tables 2-1 and 2-2 provide summaries from the 1993 CW/QAPP (Albro *et al.* 1993) of the sampling performed and indicate the types of measurements and samples taken at nearfield and farfield stations. For a combined farfield/nearfield survey, a subset of ten stations (4 farfield and 6 nearfield) have additional biology/productivity measurements and henceforth, are termed "BioProductivity" stations and labeled with a "P" (see Figure 1-1). The six "P" stations in the nearfield are repeatedly sampled for a broad suite of parameters as part of the farfield survey, again as hydrographic profiling/ dissolved nutrient stations on the vertical sampling day of nearfield survey, and lastly as part of the towing track surveyed on the second day of the nearfield survey. Nearly all planned samples were collected (see survey reports). Deviations from the CW/QAPP plan for each survey are given below; most are reported in the appropriate survey report.

For the combined farfield/nearfield survey in February (W9301), the following methods were used.

- No samples were collected for oxygen incubations to determine production or respiration. Production measurements were made using ^{14}C (described below). However, oxygen samples were collected at 21 stations at 3 to 5 depths and were used to calibrate the dissolved oxygen sensors (Appendix A).

- Chlorophyll samples were taken at 15 stations (2 or 3 depths) and were used to calibrate the *in situ* fluorescence sensor (Appendix A). In addition to chlorophyll, a sample for total suspended solids was collected at station F25, as well as at the planned stations.

- On the second day of the survey, the irradiance sensor on the underwater unit was damaged. No light readings were made at stations F04, F09, F10, F11 or F25. The backup Licor light sensor system was used at the last two BioProductivity stations (F01P, F02P).

For the combined farfield/nearfield survey in mid-March (W9302), the following methods were used.

- No samples were collected for oxygen incubations to determine production or respiration. Production measurements were made using ^{14}C (described below). However, oxygen samples were collected at 21 stations at 3 to 5 depths and were used to calibrate the dissolved oxygen sensors (Appendix A).
- Chlorophyll samples were taken at 14 stations (2 or 3 depths) and were used to calibrate the *in situ* fluorescence sensor (Appendix A). In addition to chlorophyll, a sample for total suspended solids was collected at station F25, as well as at the planned stations.
- The backup Licor light sensor system was used and measurements were made only on the ten BioProductivity stations.
- Station F04 in Cape Cod bay was not sampled due to equipment malfunctions.
- Bad weather associated with the March 13 blizzard forced cancellation of the final day of the survey, the nearfield tow-yo sampling.

For the nearfield survey in late March (W9303), in addition to procedures described in the CW/QAPP, the following methods were used.

- Dissolved oxygen samples were collected at 6 "P" stations at 5 depths and used for calibrating the dissolved oxygen sensors (Appendix A).

2.1.2 Productivity Measurements

Productivity measurements differ slightly from those described in the CW/QAPP. First, at the request of the MWRA and due to the preference of the Outfall Monitoring Task Force, only the ^{14}C method was used to estimate primary production; the oxygen light-dark method was not used. At two depths of each BioProductivity station, ^{14}C Primary production was measured by exposure of samples to a light gradient as described by Albro *et al.* (1993) for oxygen. Fifteen 300 mL-BOD bottles were inoculated with 2.5 μCi of ^{14}C-sodium bicarbonate. Three bottles were incubated in the dark. The remaining 12 were exposed to irradiance levels ranging from about 20 to 2000 $\mu E\ m^{-2}\ sec^{-1}$, with several bottles exposed in the range of 200-600 $\mu E\ m^{-2}\ sec^{-1}$. Samples for dissolved inorganic carbon (DIC) were taken from the same GO-FLO bottle as samples used for productivity incubations. DIC

was measured as described in the next section, and used in calculating primary production rates (Section 2.3).

2.2 Laboratory Procedures

Table 2-3 summarizes laboratory methods for chemistry and biology samples as detailed in the CW/QAPP. The DIC method was not described in the CW/QAPP. The DIC analysis used by the University of Rhode Island is a "purge and trap" method (I.O. Corp., 1984). Samples are collected in a 40-mL screw cap VOC vial with a septum. The bottle is filled and overflown, the sample is then "killed" with mercury chloride, and the bottle sealed. In the laboratory, the vial is placed in a total carbon analyzer where the vial septum is pierced. A sample is then drawn, acidified, bubbled with N_2 and the CO_2 in the gas stream is caught on a molecular sieve. The sieve is heated to 200 °C, releasing the CO_2 into a new stream of N_2, the carrier gas that transports the CO_2 to an IR detector, where the CO_2 content is measured.

Two samples were taken from each GO-FLO bottle and analyzed twice for DIC. The average difference between analytical replicates was less than 1% ($x = 0.47\% \pm 0.73\%$, range = 0.08-2.68%, $n = 12$). The average difference between sampling replicates was also small and less than 1% ($x = 0.25\% \pm 0.31\%$, range = 0.01-0.81%, $n = 6$).

2.3 Data Analyses

To calculate ^{14}C production rates, the data for light bottles were first corrected by subtracting uptake measured in dark bottles. Volumetric production rates are then calculated, as described in the CW/QAPP. The dark bottle uptake was calculated as the mean of the three dark bottles, excluding samples where a value was an outlier and determined to be suspect by experienced professional judgement (Appendix E).

The P-I curve modeling for ^{14}C differed slightly from that described for oxygen in the CW/QAPP. A sequence of two models was used to fit data from ^{14}C incubations. Dark-corrected values were normalized to chlorophyll determined for the sample depth being measured. Following this, a sequence of two models was used to fit the data.

The first model fit 3 parameters, including a photoinhibition term, and followed Platt *et al.* (1980). The Platt *et al.* (1980) model to predict net production is

$$P_B = P_{SB} (1 - e^{-a}) e^{-b}$$

P_B = production (chlorophyll-normalized) and

P_{SB} = theoretical maximum production (chlorophyll-normalized) without photoinhibition

where $a = \alpha I/P_{SB}$, and $b = \beta I/P_{SB}$.

α = initial slope of the rise in net production with light increasing from zero irradiance [units of (μg C/μg Chl/hr)/(μE/m^2/sec)], calculated from I (light irradiance level, μE/m^2/sec) and P_{SB}.

For the second model, a hyperbolic tangent function (Platt and Jassby, 1976), two parameters were fit to predict net production. No photoinhibition term is included.

Here, $P_B = P_{max} * \text{Tanh} (\alpha I/P_{max})$.

The parameters in each model were fit simultaneously by least squares using the NLIN procedure in SAS (1985) for each incubation series that measured paired P_B and irradiance. Fitting was accomplished by the secant method where parameters were estimated if, within 50 iterations, the model converged on a suitable simultaneous fit (SAS, 1985). If the three-parameter model fitting did not converge on a fit, the hyperbolic model was used.

Volumetric production rates, chlorophyll-normalized P-I curves, and model coefficients (Appendix E), were used to calculate integrated water column rates of production, which were expressed as a rate per square meter of surface. Production rate calculations generally followed the procedure described by Kelly *et al.* (1993) and are described briefly in the following text.

Because irradiance varies throughout the day and stations are sampled at different times, the light conditions were standardized. Within a survey, the average incident irradiance (I_o) measured by the deck cell during a midday (1000 to 1400 h) period was used to standardize conditions. Then, for each station, an extinction coefficient (k) was determined by regressing $\ln(I_z/I_o)$ vs. depth, where I_z is the irradiance at depth z, and the slope of the resultant line estimates k. The coefficient (k) was then used with the survey I_o to generate the standardized light profile using the model $I_o = I_z e^{-kz}$ and to

determine $Z_{0.5\% Io}$, the depth where photosynthetically active radiation equals 0.5% I_o. Estimated rates were expressed per square meter of surface and integrated to $Z_{0.5\% Io}$. A 1% to 0.5% isolume is commonly accepted as the level to which net production (in excess of respiration) is achieved by plankton.

Next, for each station and each incubation series ("surface" or "chlorophyll maximum" sample), the fitted P-I model was combined with the standardized light profile to yield chlorophyll-normalized production rates (μg C μg Chl^{-1} h^{-1}) at 0.5-m intervals to coincide with 0.5-m BIN-averaged chlorophyll values generated from a vertical downcast. To calculate depth-integrated rates, the predicted hourly, chlorophyll-normalized rate was then multiplied by the chlorophyll fluorescence at each depth interval from the surface to the $Z_{0.5\% Io}$. The values were then appropriately summed over depth and units were converted to m^{-2} from a volumetric basis.

The above procedure estimated hourly midday rates (μg C m^{-2} h^{-1}). Conversion to full day-time rates was made by multiplying by a factor of 7 which recognizes that about 55-60% of the production generally occurs during the 4-h period (1000-1400 h) when the irradiance is highest (Vollenweider, 1966). Final modeled rates provide an estimate of daytime primary production as mg C m^{-2} d^{-1}.

The same procedure was applied to both surface and chlorophyll-maximum samples, each of which yielded independent estimates. For each productivity survey, these estimates are listed in a table that summarizes P-I modeling results (provided in detail in Appendix E).

Table 2-1. Field Samples and Measurements [From Albro et al. 1993]

Parameter	Stations	Sample Volume	Sample Containers	Shipboard Processing/ Preservation
Following samples are subsampled from water collected with Poly Vinyl Chloride Niskin GO-FLO Bottles				
Dissolved Inorganic Nutrients	All	60 mL	100 mL Polyethylene bottle	Pass through a filter. Fix with chloroform.
Dissolved Oxygen	10 Biology/ Productivity and 3 Nearfield	300 mL	300 mL Glass BOD	Fix per Oudot *et. al.* (1988). Titrate within 24 hours.
Dissolved Organic Carbon	10 Biology/ Productivity and F25	50 mL	100 mL amber glass bottle	Pass through a pre-ashed glass fiber filter. Fix with 0.5 mL of phosphoric acid.
Dissolved Organic Nitrogen	10 Biology/ Productivity and F25	20 mL	50 mL glass digestion tube	Pass through a filter. Digest within 8 hours.
Dissolved Organic Phosphorus	10 Biology/ Productivity and F25	20 mL	50 mL glass digestion tube	Pass through a filter. Digest within 8 hours.
Particulate Organic Carbon	10 Biology/ Productivity and F25	50 mL	Whatman GF/F glass fiber filter	Pass through a pre-ashed glass fiber filter. Freeze (-5 °C).
Particulate Organic Nitrogen	10 Biology/ Productivity and F25	50 mL	Whatman GF/F glass fiber filter	Pass through a pre-ashed glass fiber filter. Freeze (-5 °C).
Total Suspend Solids	10 Biology/ Productivity and 3 Nearfield	200 mL	Petri dish	Pass through a filter. Freeze (-5 °C)
Chlorophyll *a*/ Phaeopigments	10 Biology/ Productivity and 3 Nearfield	2 x 10 mL	Whatman GF/F glass fiber filter	Pass through filter. Fix with 1% $MgCO_3$ solution, wrap in foil, store over desiccant, and refrigerate.
Phytoplankton (Whole Water)	10 Biology/ Productivity	800 mL	1000 mL glass bottle	Preserve with Utermohl's solution.
Phytoplankton (Screened Water)	10 Biology/ Productivity	2000 mL	100 mL Polyethylene bottle	Strain through a 20 μm mesh; wash retained organism into a jar. Fix with Utermohl's solution.
^{14}C Production	10 Biology/ Productivity	300 mL	300 mL Glass BOD	Inoculate with 2.5 μCi of $NA_2{}^{14}CO_3$ and incubate.
Following sample is collected with a vertically towed net				
Zooplankton	10 Biology/ Productivity	800 mL	1000 mL glass bottle	Wash into jar. Fix with a 5-10% Formalin solution.
The following measurements are collected by the Battelle Ocean Sampling System				**Precision**
Conductivity	All	---	Floppy disk	0.01 mS/cm
Temperature	All	---	Floppy disk	0.001 °C
Pressure	All	---	Floppy disk	0.01 decibars
Dissolved Oxygen	All	---	Floppy disk	0.05 mg/L
Chlorophyll *a* Fluorescence	All	---	Floppy disk	0.01 μg/L
Transmissometry	All	---	Floppy disk	0.01 m^{-1}
In situ Irradiance	All	---	Floppy disk	1 $\mu E\ m^{-2}\ s^{-1}$
Surface Irradiance	All	---	Floppy disk	1 $\mu E\ m^{-2}\ s^{-1}$
Bottom Depth	All	---	Floppy disk	1 m
Navigational Position	All	---	Floppy disk	0.000017 deg

Table 2-2. Water Samples to be Collected from Niskin or GO-FLO Bottles (From Albro et al. 1993)

	Nearfield Nutrient/Hydrography Surveys							Biology/Productivity Surveys			Farfield Nutrient/ Hydrography Surveys				
Refer to Notes Below for Stations IDs	Note 1	Note 2	Note 3	Note 4	Note 5	Totals per Survey	Totals for 32 Surveys	Note 6	Totals per Survey	Totals for 12 Surveys	Note 7	Note 8	Totals per Survey	Totals for 12 Surveys	Totals for all Surveys
Number of Hydrographic Stations	1	5	3	3	9	21	672	10	10	120	20	1	21	252	1044
Dissolved Inorganic Nutrients	5	5	5	5	5	105	3360	5	50	600	5	5	105	1260	5220
Chlorophyll a and Phaeopigments (2 reps)			2			6	192	2	20	240				0	432
Total Suspended Solids (2 reps)			2			6	192	2	20	240				0	432
Dissolved Organic Nitrogen and Phosphorus (2 reps)								2	20	240		2	2	24	264
Dissolved Organic Carbon								2	20	240		2	2	24	264
Particulate Carbon and Nitrogen (2 reps)								2	20	240		2	2	24	264
Phytoplankton (whole water) to analyze	1					1	32	2	20	240					272
Phytoplankton (whole water) to archive		1				5	160	3	30	360					520
Phytoplankton (screened) to analyze	1					1	32	2	20	240					272
Phytoplankton (screened) to archive		1				5	160	3	30	360					520
Initial Dissolved Oxygen (Note 9)				2		6	192	9	90	1080					1272
Respiration (Note 9)								9	90	1080					1080
Pmax by Carbon-14 (Note 10)								12	120	1440					1440
Pmax by Oxygen (Note 11)								6	60	720					720
P(I) by Carbon-14 (Note 12)								20	200	2400					2400
P(I) by Oxygen (Note 12)								20	200	2400					2400
Zooplankton								1	10	120					120

Notes:

1 Station N10P
2 Stations N01P, N04P, N07P, N16P, and N20P
3 Any 3 nearfield stations
4 Any 3 nearfield stations (the same or different ones from Note 3)
5 Nine Stations not used for oxygen or chlorophyll a calibrations
6 Stations F01P, F02P, F13P, F23P, N01P, N04P, N07P, N10P, N16P, and N20P
7 All farfield stations except F25
8 Station F25
9 Collect 3 samples at 3 depths
10 Collect 6 samples at 2 depths
11 Collect 3 samples at 2 depths
12 Collect 10 samples at 2 depths

Table 2-3. Laboratory Analysis and Methods [From Albro et al. 1993]

Parameter	Units	Method	Reference[1]	Maximum Holding Time	Preservation
Dissolved Ammonia	μM	Technicon II AutoAnalyzer	Lambert and Oviatt (1986)	3 mo.	Chloroform
Dissolved Nitrate	μM	Technicon II AutoAnalyzer	Lambert and Oviatt (1986)	3 mo.	Chloroform
Dissolved Nitrite	μM	Technicon II AutoAnalyzer	Lambert and Oviatt (1986)	3 mo.	Chloroform
Dissolved Phosphate	μM	Technicon II AutoAnalyzer	Lambert and Oviatt (1986)	3 mo.	Chloroform
Dissolved Silicate	μM	Technicon II AutoAnalyzer	Lambert and Oviatt (1986)	3 mo.	Chloroform
Dissolved Oxygen	mg L^{-1}	Autotitrator	Oudot *et al.* (1988)	24 h	dark/cool
Dissolved Organic Carbon	μM	O.I. Model 700 TOC Analyzer	Menzel and Vaccaro (1964)	3 mo.	Fix with 0.5 mL of phosphoric acid.
Dissolved Organic Nitrogen	μM	Technicon II AutoAnalyzer	Valderrama (1981)	3 mo.	Add reagents immediately, heat to 100°C within 8 hours.
Dissolved Organic Phosphorus	μM	Technicon II AutoAnalyzer	Valderrama (1981)	3 mo.	Add reagents immediately, heat to 100°C within 8 hours.
Particulate Organic Carbon	μM	Carlo Erba Model 1106 CHN elmental analyzer	Lambert and Oviatt (1986)	3 mo.	Dry over desiccant.
Particulate Organic Nitrogen	μM	Carlo Erba Model 1106 CHN elemental analyzer	Lambert and Oviatt (1986)	3 mo.	Dry over desiccant.
Total Suspend Solids	mg L^{-1}	Cahn Electrobalance	See Section 12.7.7	6 mo.	Dry over desiccant.
Chlorophyll *a*/ Phaeopigments	μg L^{-1}	Model 111 Turner Fluorometer	Lorenzen (1966)	2 wk	Fix with 1% $MgCO_3$ solution, wrap in foil, store over desiccant, and refrigerate.
Phytoplankton (Whole Water)	Cells L^{-1}	Sedgwick-Rafter counting chambers	Turner *et al.* (1989)	3 y	Preserved with Utermohl's solution, store at room temperature.
Phytoplankton (Screened Water)	Cells L^{-1}	Sedgwick-Rafter counting chambers	Turner *et al.* (1989)	3 y	Fix with Utermohl's solution, store at room temperature.
^{14}C Production	^{14}C hr^{-1}	Liquid Scintillation Counter (Bechman LS-3801)	Strickland and Parsons (1972)	2 wk	Scintillation fluid
Zooplankton	Cells L^{-1}	Dissecting Microscope	Turner *et al.* (1989)	3 y	Fix with a 5-10% Formalin solution, store at room temperature.

[1]See Section 20 of Albro *et al.*, 1993 for literature references.

3.0 RESULTS OF DECEMBER 1992 NEARFIELD SURVEY

3.1 Distribution of Water Properties from Vertical Profiling

Vertical profiles were obtained at 13 nearfield stations (Appendix A). As shown by *in situ* sensor profile plots (Appendix B), the water column was well mixed from top to bottom. Only at station N10P, the southwest corner of the nearfield, was there vertical structure; at this location, the surface 10-12 m was slightly cooler but >1 PSU fresher than the bottom water. Over the water column, the very slight change in density (σ_T being slightly lower in the surface layer) was accompanied by higher beam attenuation at the surface. Chlorophyll fluorescence and dissolved oxygen were each fairly uniformly distributed (no pronounced maxima or minima) at station N10P as well as at other stations.

Temperature generally ranged between 5.5 and 7.5 °C across the stations (Figure 3-1a). Salinity ranged between 31 and 32 PSU (Figure 3-1a). For both parameters, slightly lower values were recorded at inshore stations along the western track of sampling — particularly at station N10P, but also at stations N11 and N12. Beam attenuation was generally low (<1 m^{-1}) and in a narrow range (Figures 3-1a and 3-1b). Slightly higher beam attenuation was noted at station N10P as indicated above, and the apparent strong correlation of beam attenuation and salinity shown in Figure 3-1a reflects the co-signature of these parameters in the surface water at that station.

Chlorophyll fluorescence was low (generally <2 μg L^{-1}) and generally varied between 1 and 2 μg L^{-1} over depth (Figure 3-1b). There was no distinctive co-variation of chlorophyll with other parameters measured *in situ* (Figures 3-1b and 3-1c). The chlorophyll maximum was similar at stations across the nearfield (Figure 3-2).

Dissolved oxygen (DO) concentrations were clustered around 9 mg L^{-1} (Figure 3-1c). DO was about 90-95% saturation (Appendix A).

Of the nutrients, nitrate and nitrite concentrations ranged narrowly over depth and across stations (5.01 to 7.59 μM and 0.26 to 0.73 μM, respectively). Wider ranges in concentrations were observed for other nutrients; phosphate (0.67 to 1.23 μM), silicate (5.91 to 9.09 μM), and particularly

ammonium (0.08 to 8.35 μM). DIN, the sum of inorganic nitrogen forms, ranged from 5.64 to 16.67 μM.

The distribution of nutrients as a function of depth is shown in Figures 3-3 and 3-4. With the exception of station N10P, there was little vertical variation in nutrient concentrations at a given station. Nutrient concentrations were strongly related to salinity (Figures 3-5 and 3-6). Nitrogen (DIN, NH_4) and phosphate appeared to vary almost conservatively throughout the field, with the higher nutrient concentration detected at station N10P—shown in three samples at lower salinity (<31.3 PSU) within the upper 15 m of the water column (cf. Figures 3-5 and 3-6). Silicate showed a slightly more complex distribution pattern; some of the highest silicate concentrations were found at station N01P, which was also relatively high in salinity. Three samples from several shallow stations near station N10P were also slightly enriched in nutrient concentrations.

3.2 Distribution of Water Properties from Towing

Although physical characteristics were vertically uniform, a slight and gradual horizontal thermal gradient was evident extending from the western edge (cooler) to the eastern edge (warmer) of the nearfield (Appendix D). For example, temperature along the western track (shallowest and closest to the Harbor and the shoreline) ranged between 6.42-6.99 °C. The range gradually increased to 7.15-7.25 °C along the eastern track. A general north-south thermal gradient was not apparent, but the southwest corner (stations N10P—N11) was slightly cooler. A very slight horizontal density (σ_T) gradient was also apparent, noticeable both north and east of station N10P in southwestern corner (Figure 3-7a,b).

Chlorophyll concentrations were comparable to those observed in the vertical profiles measured the previous day. Although values were all relatively low, the towing data (Figure 3-8a,b) suggested substantial small-scale patchiness, with more relative heterogeneity than was apparent for other water properties. Highest chlorophyll concentrations for most of the field occurred within the top 5 to 20 m of the water column, but there was not a gradual gradient in concentrations that paralleled the gradual physical gradients (T,S, σ_T) from shore. Instead, there were patches, such as those having slightly higher concentrations of chlorophyll (> 1.5 $\mu g\ L^{-1}$), between stations N10P and N09 on the outer southern track (Figure 3-8a) and at station N11 on the outer western track (Figure 3-8b).

Interestingly, these patches were located at approximately a boundary where some vertical density structure was noticeable (Figure 3-7a,b).

3.3 Water Types and Analysis of Small-Scale Variability

Even with the narrow range of concentrations for most parameters, the measurements were sensitive enough to discriminate spatial trends in the nearfield and, in particular, suggest the mixing of inshore and offshore water. For example, although there were detectable thermal trends, the relationship of parameters with salinity provided some of the best diagnostic power. Beam attenuation showed a strong signal with salinity (Figure 3-1a), the fresher water nearest the Harbor having higher attenuation and, by inference, higher suspended and/or dissolved organic concentrations. The nutrient patterns revealed a slight gradient increasing inshore and corresponding to fresher water presumably released from Boston Harbor, particularly through Nantasket Roads. Of the nutrients analyzed, the pattern of NH_4 concentrations (Figure 3-5) is the most convincing evidence of the Harbor as a nutrient source to Massachusetts Bay; deeper offshore waters, although enriched in NO_3, were very low in NH_4. The variability in nutrient concentrations was primarily a horizontally-graded feature; with the exception of station N10P, the concentrations of nutrients and salinity throughout depth at a given station were very similar.

The data showing the strong conservative relationship with salinity and the graded values of salinity as a function of position from shore suggest horizontal mixing. In contrast, the uniformity of conditions at each station indicate strong vertical mixing. These patterns could be achieved if vertical mixing was faster on average than horizontal mixing. In addition to mixing, horizontal advection was suggested by data collected around station N10P, where less dense, nutrient-enriched water was detected at the surface. The salinity-nutrient relationships (Figures 3-5 and 3-6) suggest that physical processes of advection and mixing in the nearfield generally occur faster than biological uptake and removal of nutrients. There was a slight suggestion from the towing data that some of the observed finer-scale chlorophyll patchiness may relate to physical heterogeneities near the southwest corner of the nearfield, but this could be as much due to physical processes fostering local concentrations of suspended particles and plankton cells as due to any local biological activity.

With respect to short-term temporal variability, note that station N10P was sampled at similar tidal stages — near full low tide on the vertical profiling day and near maximum ebb (about mid-way between high and low) on the towing day. Fairly similar results were observed for both days, although the resolution of patterns is much higher for the continuous towing data. Previously, observations have shown that the stage of the tide (e.g. high vs. low) can influence the physical, chemical, and biological conditions around this location (Kelly *et al.*, 1993).

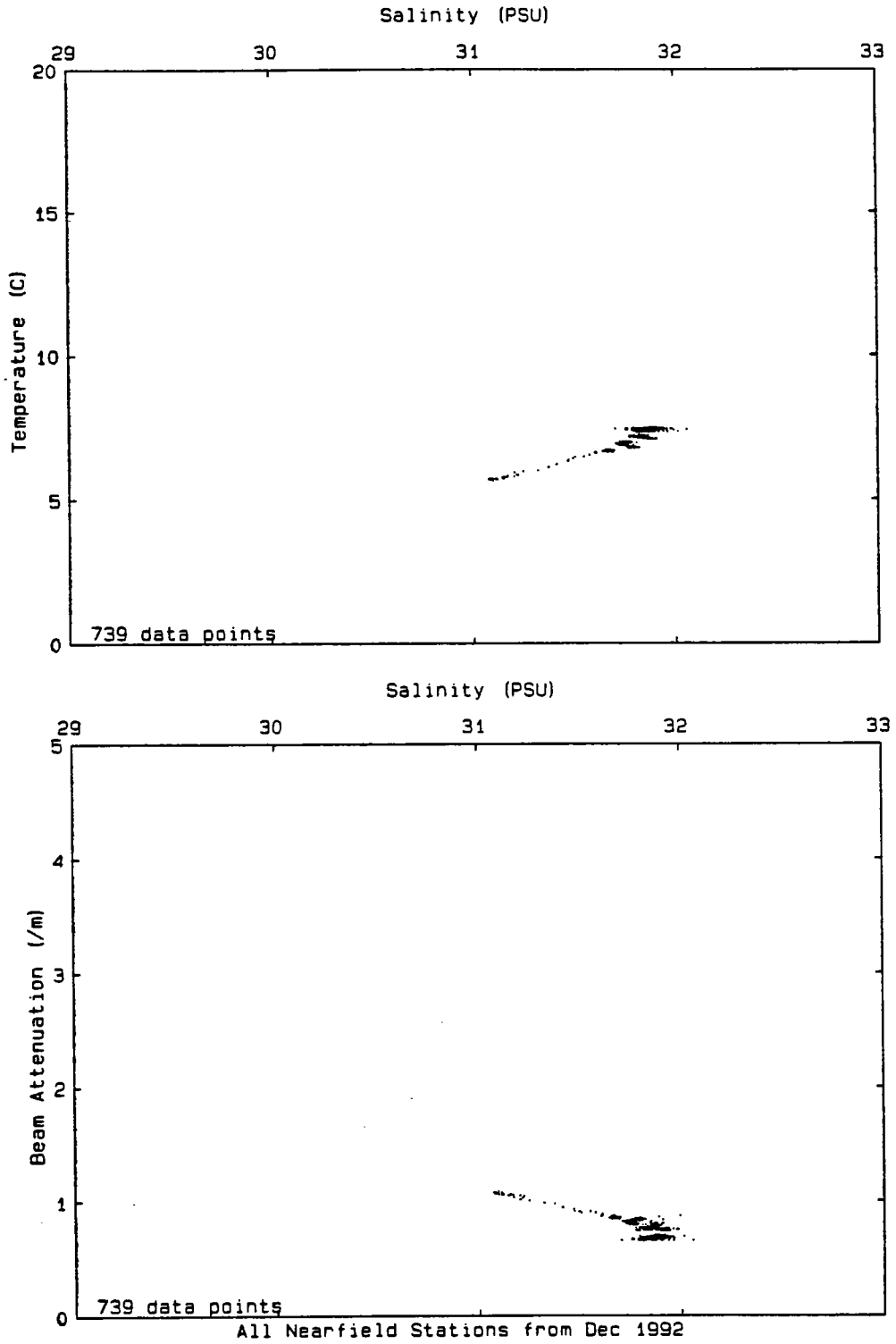


Figure 3-1a Scatter plots of data acquired by *in situ* sensor package during vertical downcasts at all nearfield stations occupied in December 1992. Individual station casts that were used to produce this composite are in Appendix B.

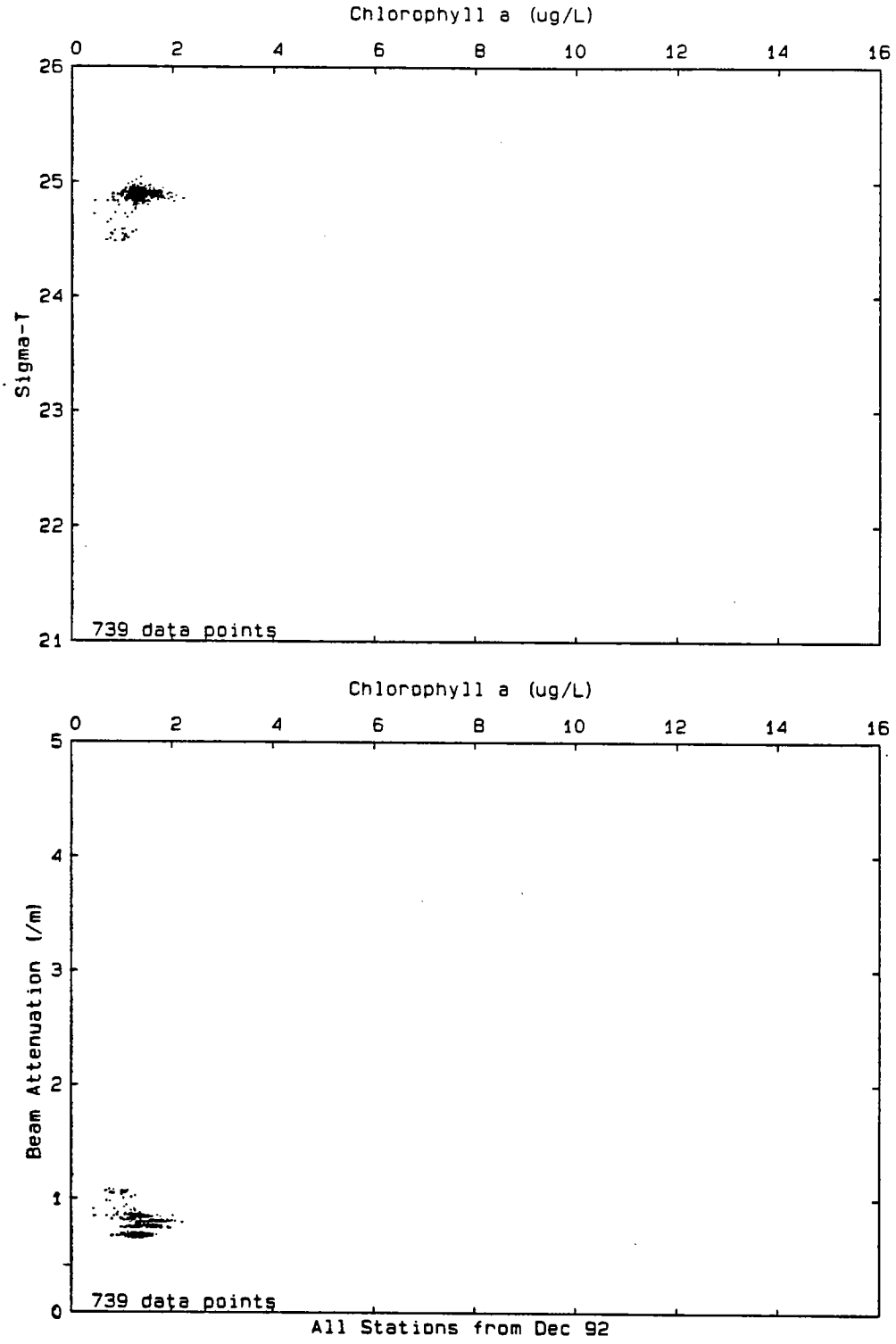


Figure 3-1b Scatter plots of data acquired by *in situ* sensor package during vertical downcasts at all nearfield stations occupied in December 1992. Individual station casts that were used to produce this composite are in Appendix B.

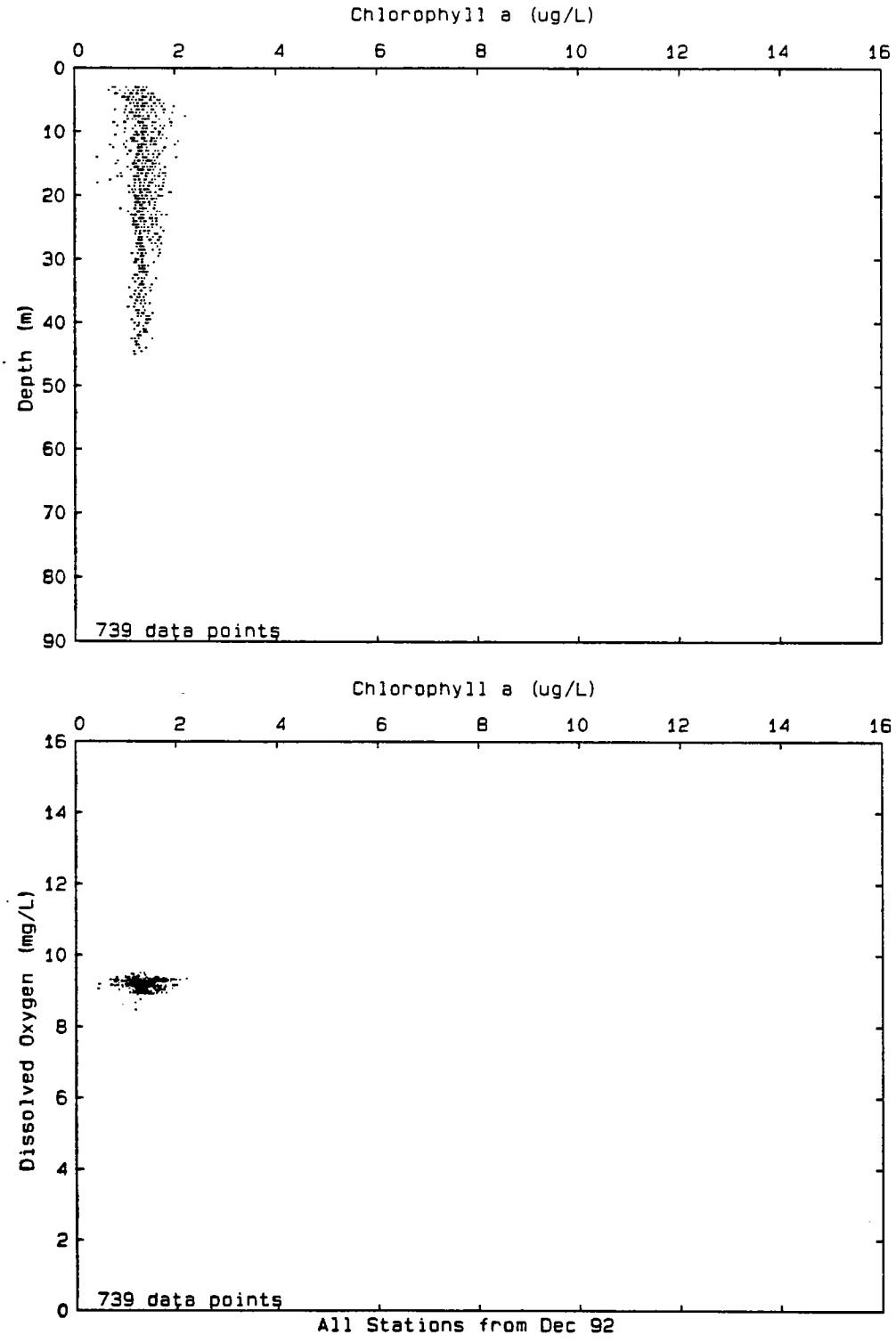


Figure 3-1c Scatter plots of data acquired by *in situ* sensor package during vertical downcasts at all nearfield stations occupied in December 1992. Individual station casts that were used to produce this composite are in Appendix B.

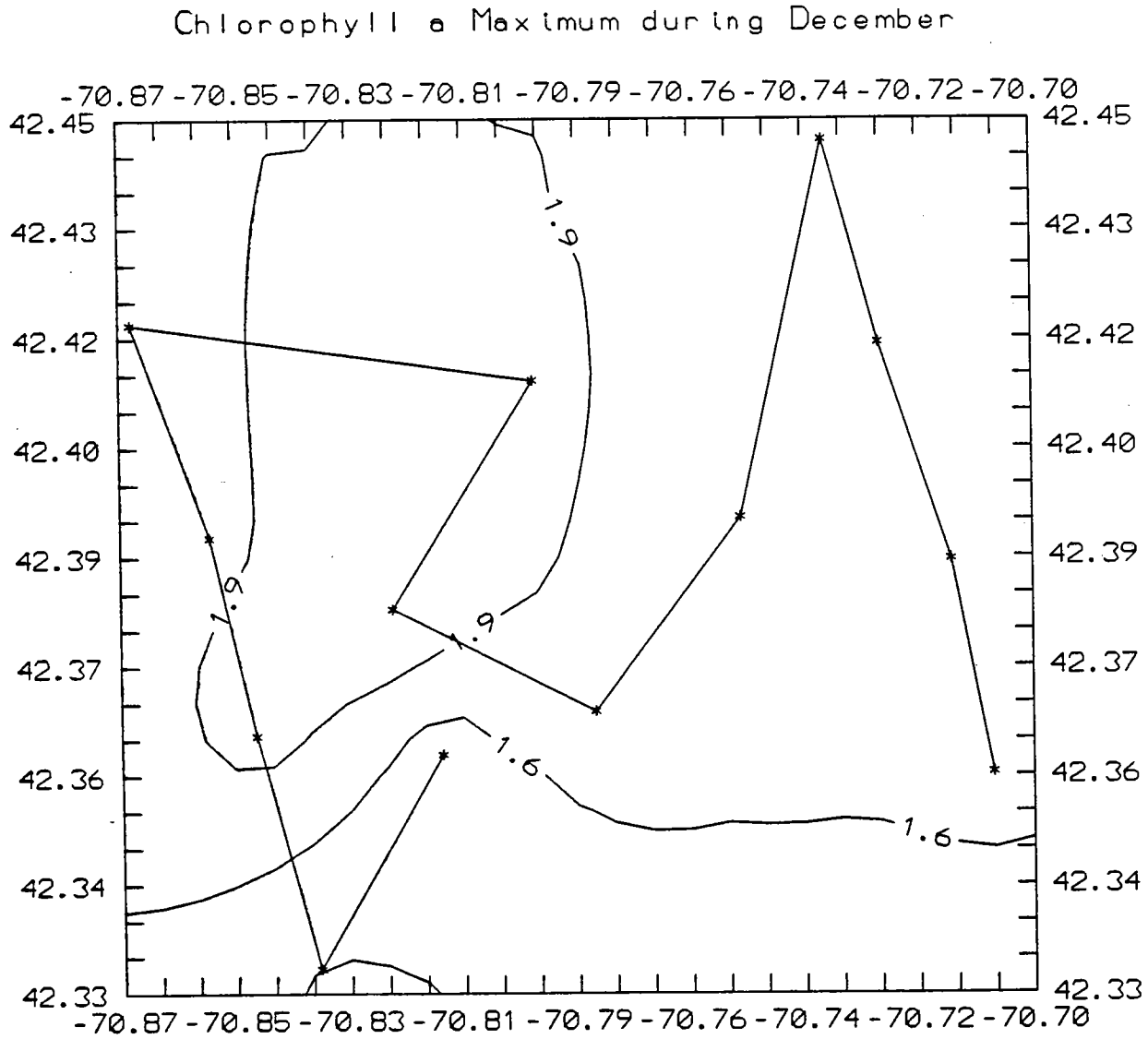


Figure 3-2 **Chlorophyll maximum at each nearfield station from vertical profile day (Appendix B). The plot shows sampled stations (asterisks) as a function of longitude (x - axis) and latitude (y - axis). The track shows sampling, starting at southeast corner of the nearfield. Not all 21 stations were sampled. Chlorophyll maximum may not be at the same depth at all stations.**

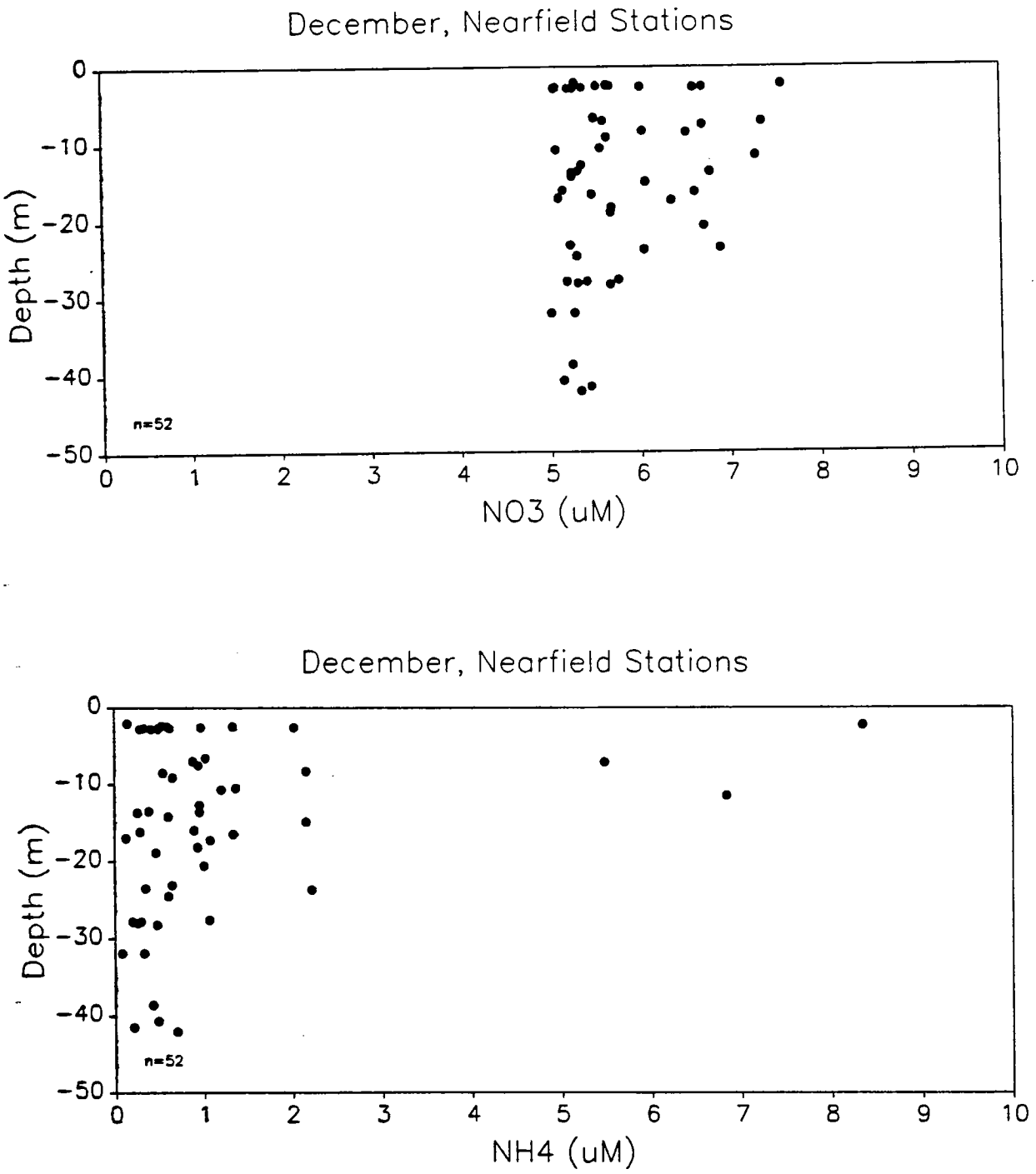
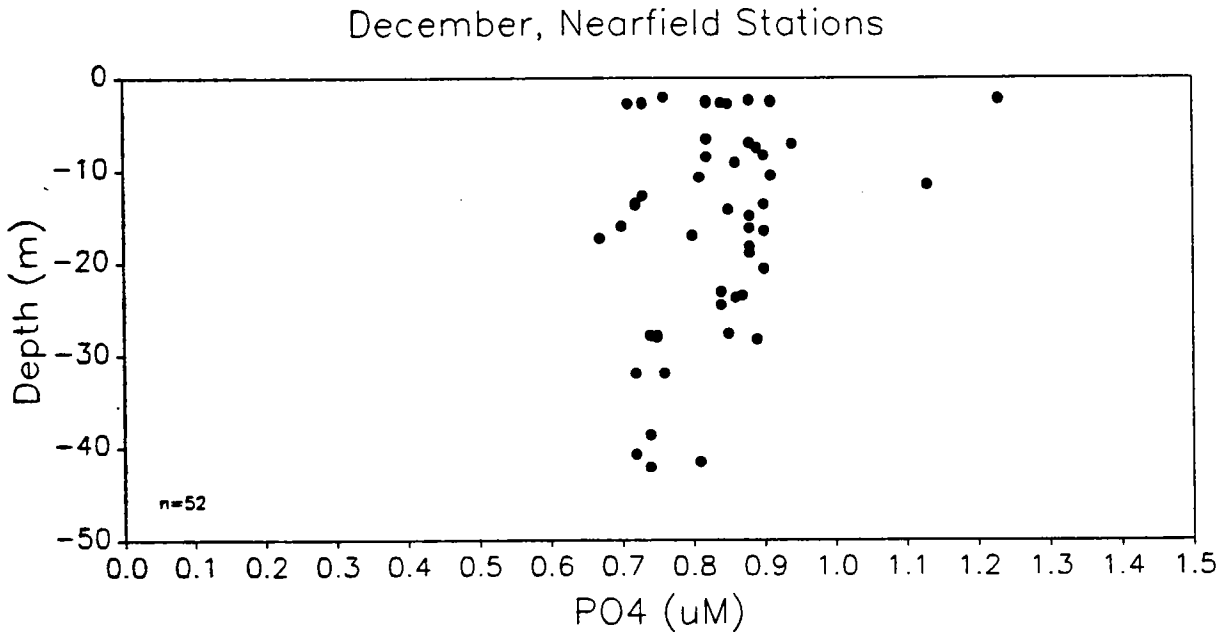


Figure 3-3 NH_4 and NO_3 vs. depth in December 1992.



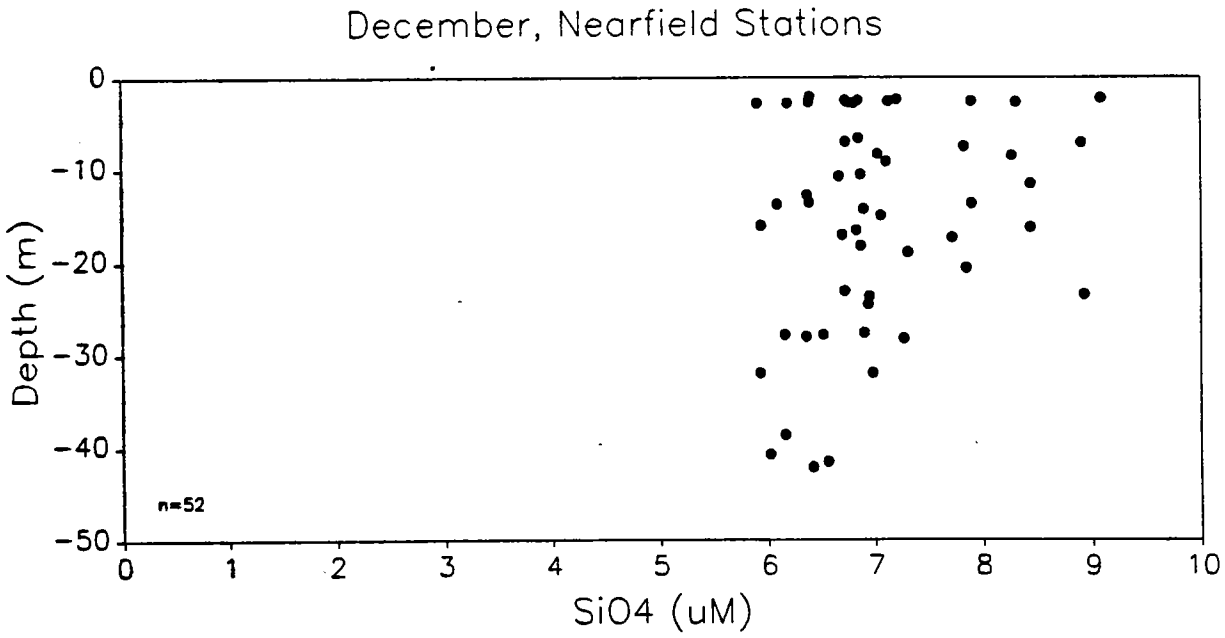
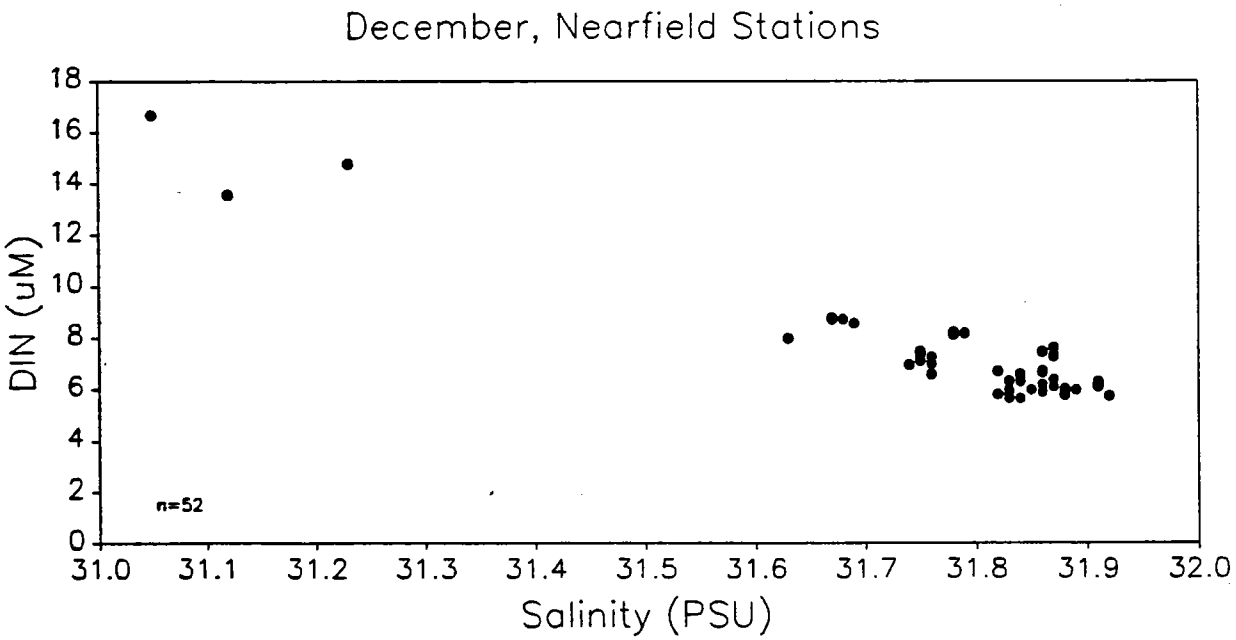


Figure 3-4 PO_4 and SiO_4 vs. depth in December 1992.



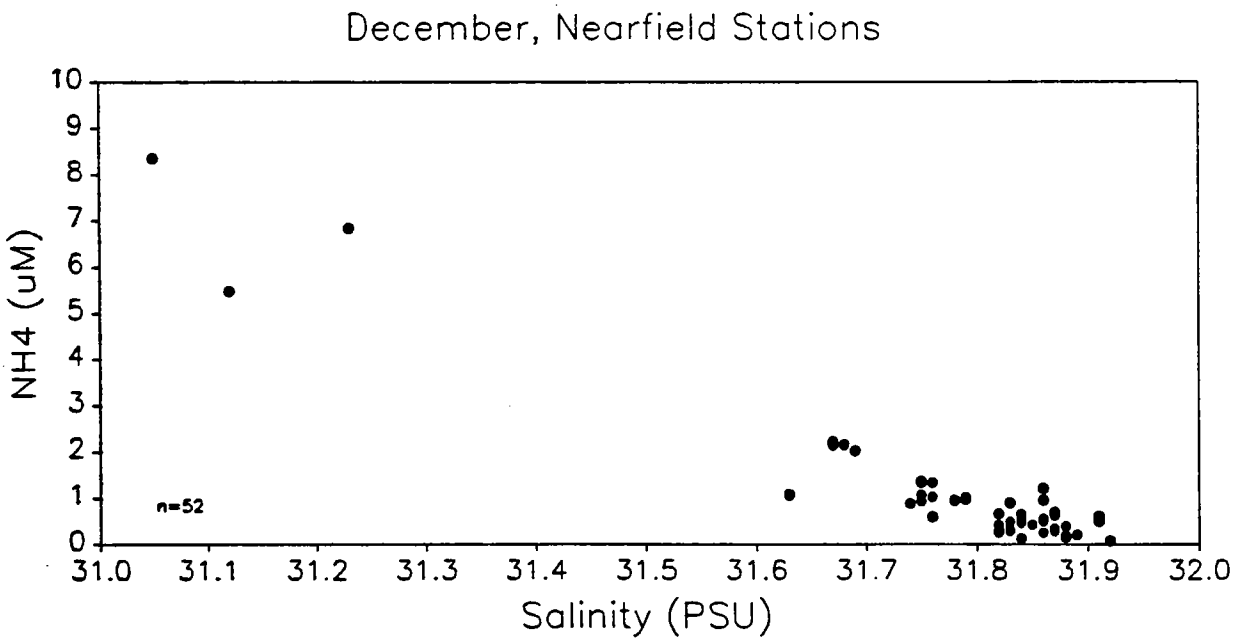
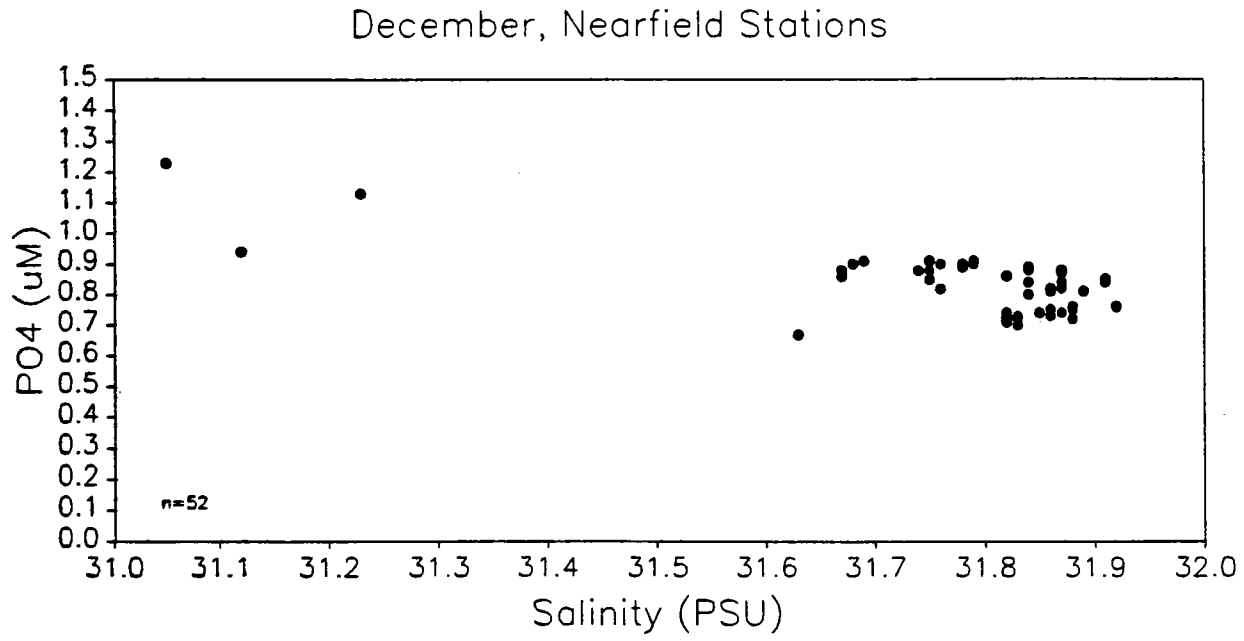


Figure 3-5 DIN and NH_4 vs. salinity in December 1992.



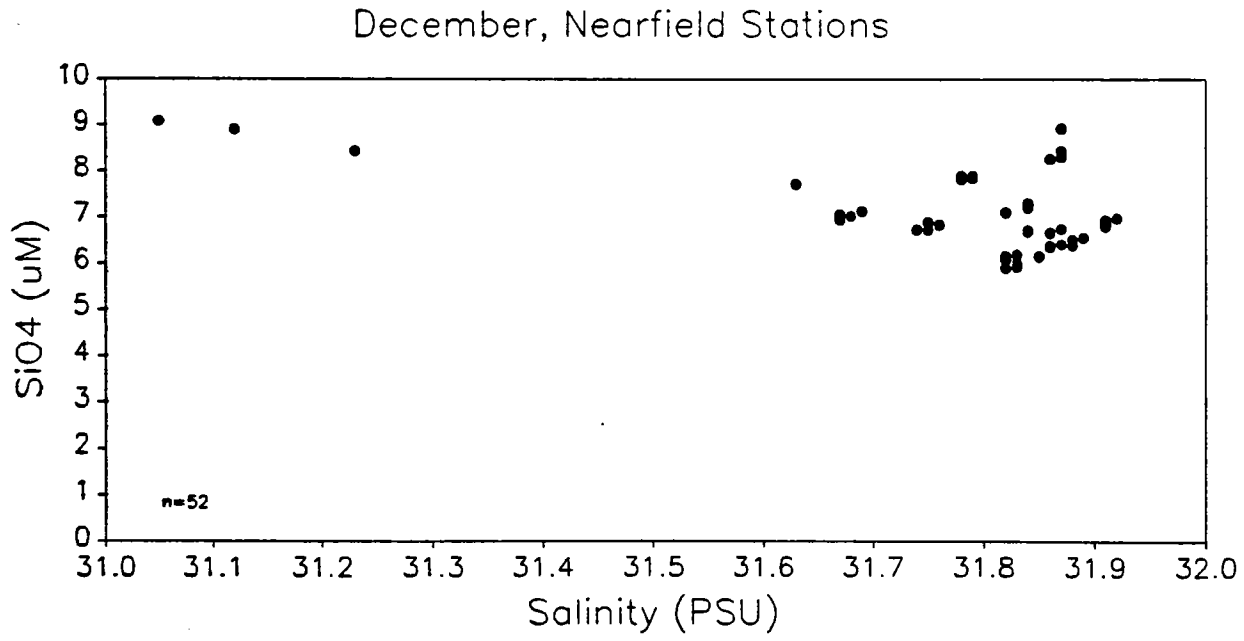


Figure 3-6 PO_4 and SiO_4 vs. salinity in December 1992.

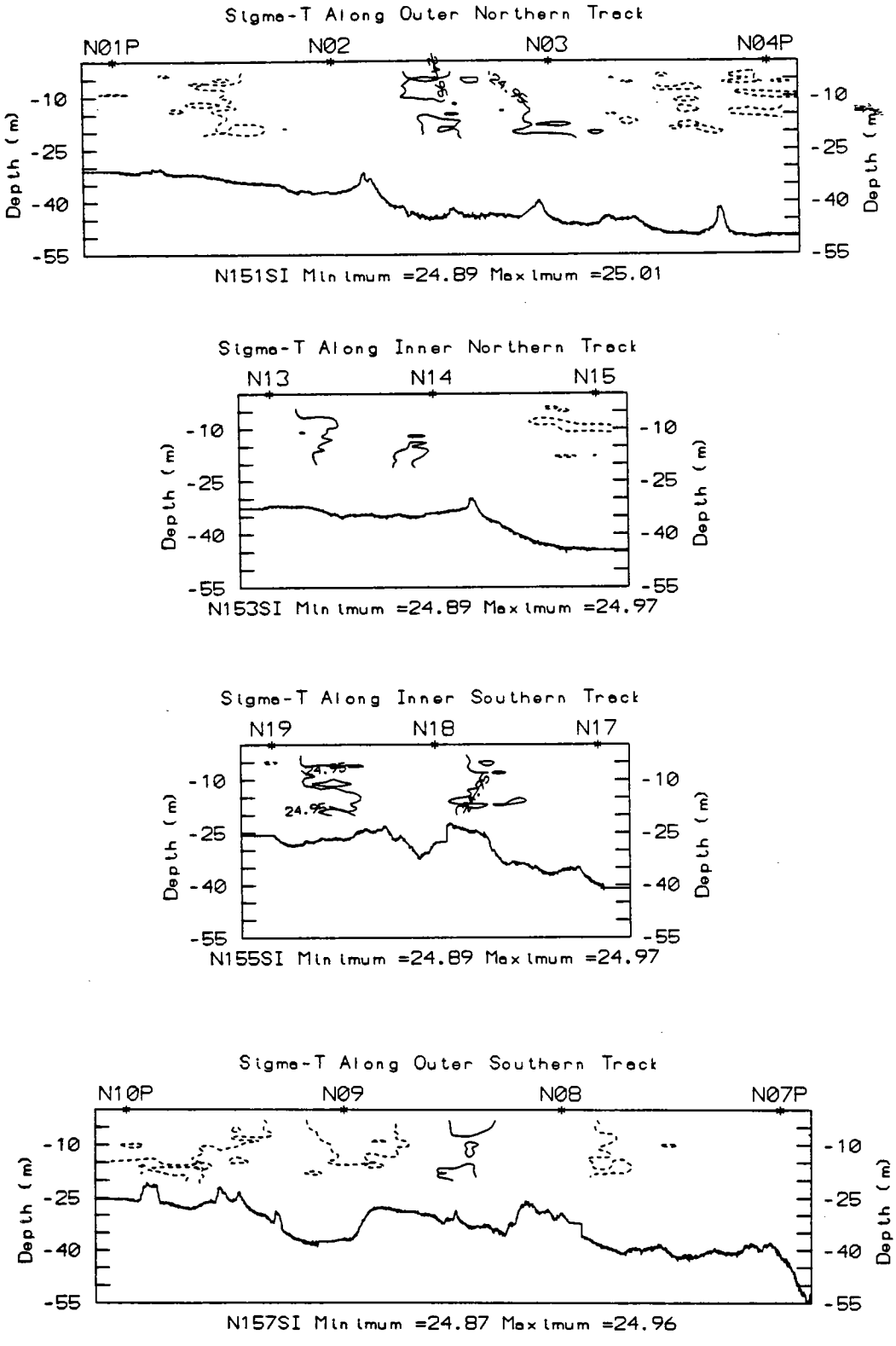


Figure 3-7a Vertical section contours of σ_T generated for tow-yos made in December 1992. The view is towards the north. Well-mixed conditions existed as shown by the small range between minimim and maximum values on a track. Contour interval = 0.05 σ_T.

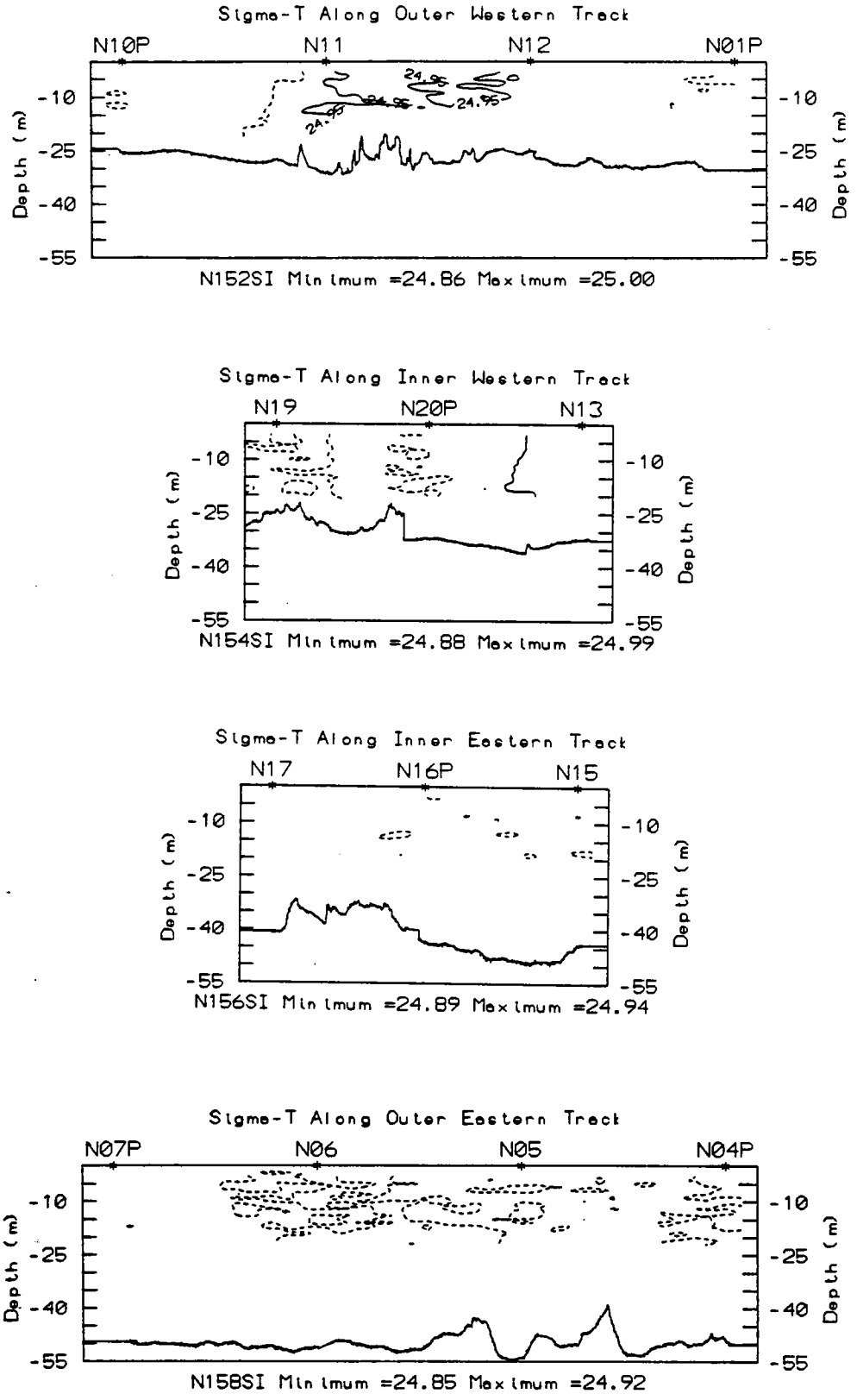


Figure 3-7b Vertical section contours of σ_T generated for tow-yos made in December 1992. The view is towards Boston Harbor. Well-mixed conditions existed as shown by the small range between minimim and maximum values on a track. Contour interval = 0.05 σ_T.

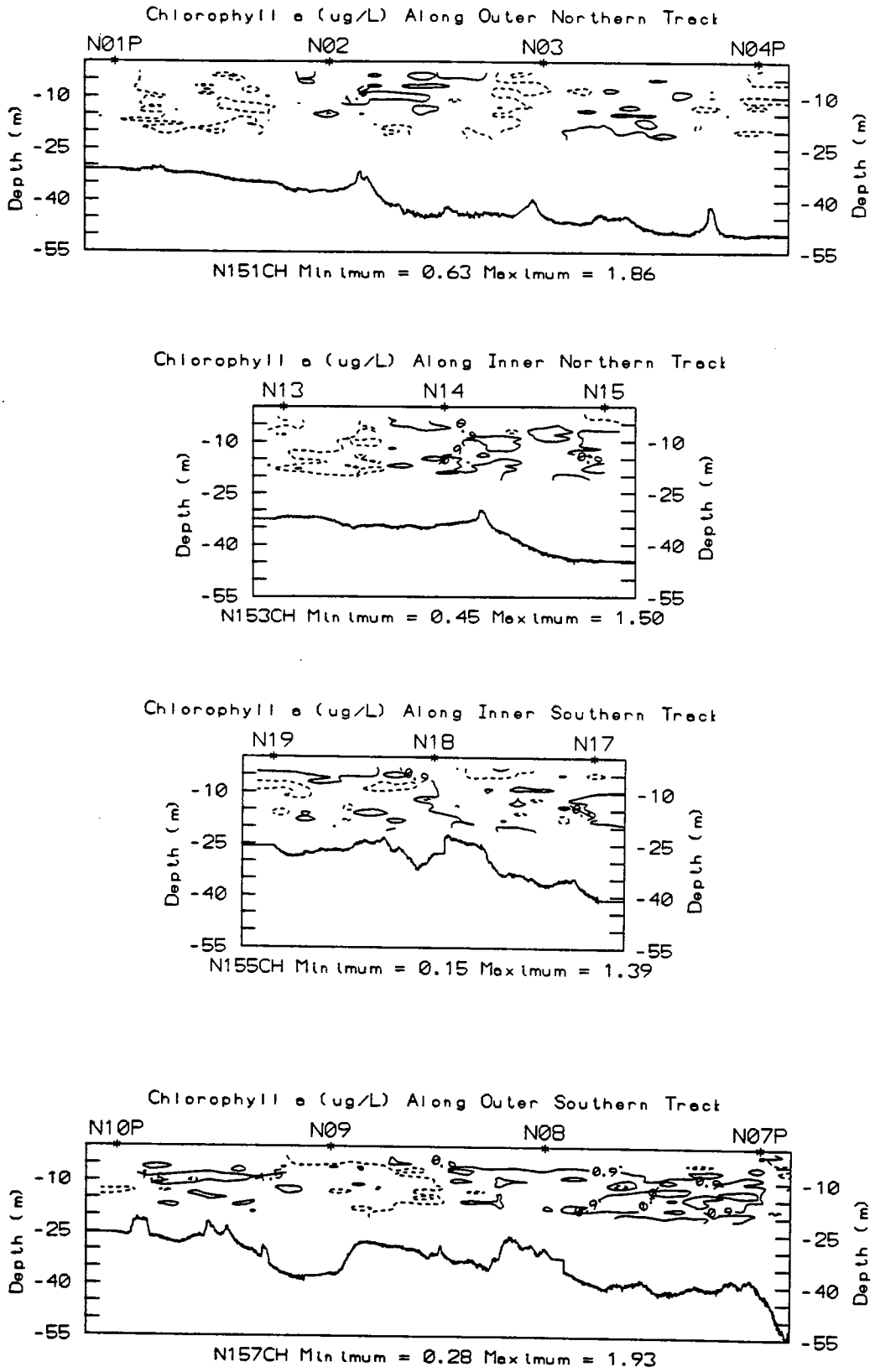


Figure 3-8a Vertical section contours of fluorescence (as μg Chl L^{-1}) generated for tow-yos made in December 1992. The view is towards the north. Contour interval = 0.3 μg Chl L^{-1}.

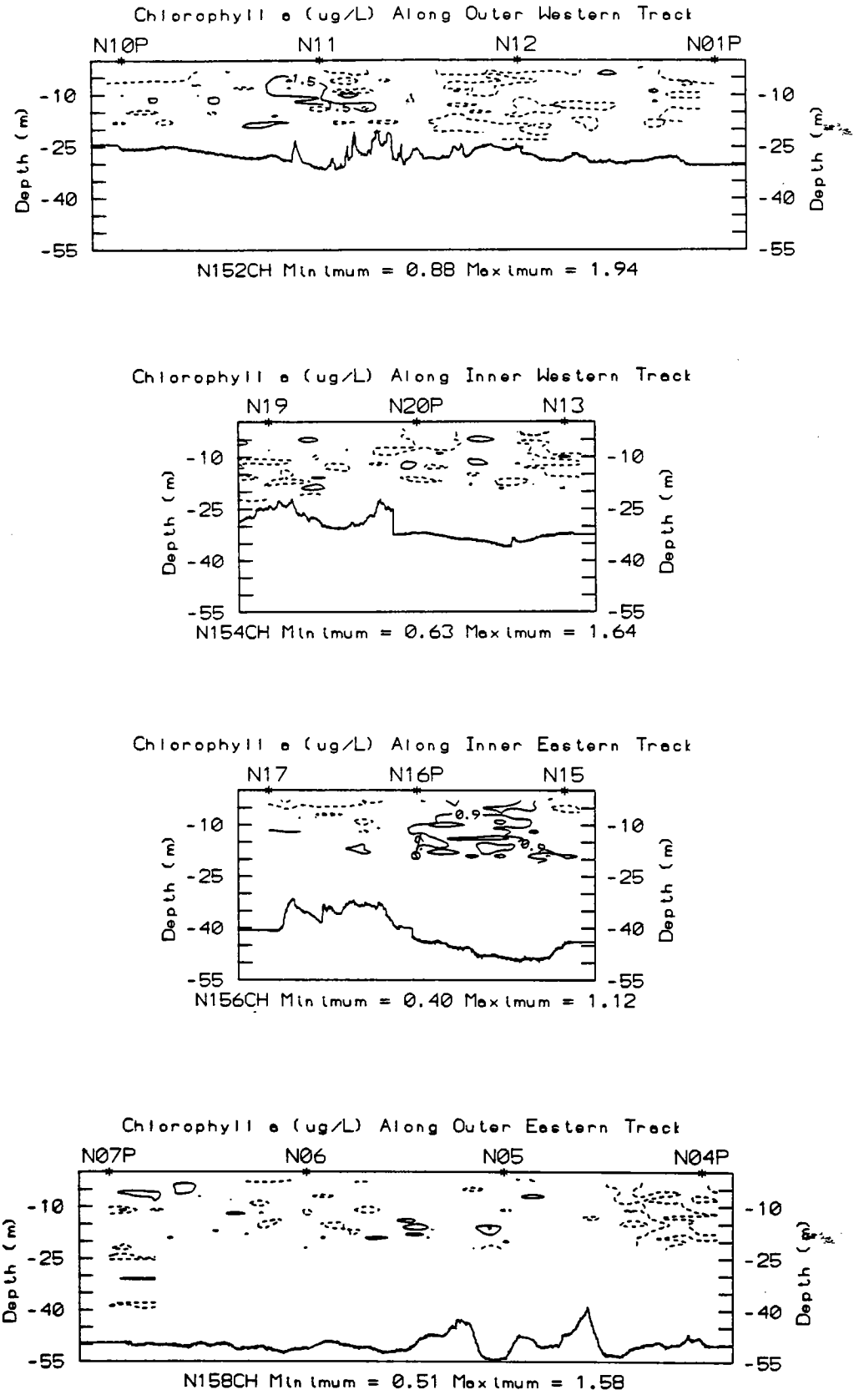


Figure 3-8b Vertical section contours of fluorescence (as μg Chl L^{-1}) generated for tow-yos made in December 1992. The view is towards Boston Harbor. Contour interval = 0.3 μg Chl L^{-1}.

4.0 RESULTS OF FEBRUARY 1993 COMBINED FARFIELD AND NEARFIELD SURVEY (W9301)

4.1 Farfield Survey

4.1.1 Horizontal Distribution of Surface Water Properties

In February 1993, the surface nearshore waters just east of Boston Harbor were colder than offshore waters (Figure 4-1). Cold water (< 1.2 °C) also hugged the coastline south of Boston and was found at the surface of Cape Cod Bay stations. The warmest location was the most northeasterly station (F22). Offshore, in surface waters over Stellwagen Basin, there was a north-to-south temperature decrease of over 2 °C. A shore-to-sea temperature gradient (cool-to-warmer) of nearly 3 °C was evident from Boston Harbor to east of the nearfield area.

Salinity in surface waters exhibited the same regional features as temperature (Figure 4-2). Lowest salinity was measured at the edge of the Harbor. Low values (< 32 PSU) extended along the South Shore and into Cape Cod Bay. Highest values (> 32.5 PSU) were located offshore in northeastern Massachusetts Bay.

Beam attenuation showed regional features similar to temperature and salinity, but the gradients were reversed. For example, the highest values were near the Harbor (Figure 4-3). Intermediate values in general were found at shallow coastal stations as well as in Cape Cod Bay. Lowest values were found in offshore water. Regional differences in beam attenuation are only partially attributable to attenuation by phytoplankton, since fluorescence was highest in Cape Cod Bay (> 2 μg Chl L^{-1}) and uniformly low elsewhere (Figure 4-4).

There were also regional trends, both shore-to-sea and north-south, with respect to dissolved inorganic nutrients in surface waters. A decreasing gradient in DIN concentrations was evident from the Harbor to the nearfield area (Figure 4-5). Other than within about 10-15 km out from the harbor, the regional DIN pattern was primarily due to a nitrate (NO_3) gradient (Figure 4-6). A nitrate gradient from the Harbor was present, but the enrichment in DIN around the Harbor was also due to ammonium (NH_4) (see Appendix A). NH_4 was nearly half of the 21.08 μM DIN measured at station

F23P. Phosphate (PO_4) showed little Harbor-Bay gradient, but a slight gradient for silicate (SiO_4) was evident (Figures 4-7 and 4-8).

For all nutrients (N, P, Si) the warmer northeastern area of Massachusetts Bay was not distinct from the nearfield area. The main geographic trend was a decrease in nutrient concentrations from north to south. Thus, Cape Cod Bay, with higher chlorophyll had lowest nutrients. This geographic trend was strong for DIN, NO_3, and SiO_4, but not phosphate.

4.1.2 Water Properties Along Selected Vertical Sections

Station plots for all continuous vertical profiles are given in Appendix B. Most stations and parameters were rather uniform in the vertical dimension with some minor exceptions. Four transect section plots were generated across a series of stations (Figure 4-9) from vertical profile data for temperature, salinity, density, chlorophyll (from fluorescence), beam attenuation, dissolved oxygen (as percent of saturation), DIN, and silicate (Figures 4-10 through 4-14). For these plots, the interval ranges for concentrations that were used in developing contour plots were set to roughly cover the range for the entire survey. Pattern details would vary with a different choice of range and intervals, but the relative trends across parameters would remain similar.

In general, the water column was physically well-mixed (Figures 4-10, 4-11). An inshore-offshore gradient was seen at each transect, although it was most pronounced at the Boston-Nearfield transect. Also, some vertical layering was evident inshore (e.g. Figure 4-11).

All chlorophyll values were low and the distinctions are minor. Slightly higher chlorophyll was noted throughout the water column in shallower water on transects where an inshore station was less than 30 m (Figure 4-12). Chlorophyll was elevated from shore out to the middle of the nearfield (station N20P) on the Boston-Nearfield transect. Beam attenuation was also higher through most of the water column at the inshore station of all but the northern transect (Figure 4-12b). Interestingly, a surface layer of more turbid water was apparent at station F24 outside the Harbor, that was underlain by a near bottom layer with high turbidity. High near-bottom beam attenuation was also seen at stations F14 and F05 down the coast to the south.

Dissolved oxygen (DO) was near saturation throughout the transects (Figure 4-12c) and was distributed uniformly over depth. DO was lowest (85-90% saturation) in the area from the Harbor to the middle of the nearfield; these lower values coincided with samples showing high beam attenuation and slightly elevated chlorophyll relative to offshore stations.

The nutrient plots (Figures 4-13 and 4-14) show enriched DIN and silicate along the coastal margin. Nutrients were highest in surface waters outside of Boston Harbor and off Cohasset. Further southward a slightly higher DIN was suggested near the bottom (e.g. stations F05 and F06).

4.1.3 Analysis of Water Types

In general, most water quality distinctions were more evident in the horizontal, rather than in the vertical dimension, and more regional (i.e, inshore vs. offshore and Massachusetts Bay vs. Cape Cod Bay) than local. The range for most physical parameters was narrow throughout both Bays, as expected for this time of year. Ranges, based on 0.5-m depth-averaged data from vertical profiles at all stations for the February survey, are shown in Figure 4-15. The T-S diagram helps illustrate what was described above for surface data only; data points at colder temperature ($< 1.5\,°C$) and at salinity less than about 32.25 PSU are from the shallower coastal region or Cape Cod Bay. The rest of the stations had higher salinity. In general, higher salinity and warmer water was found northward, offshore, and at also at the greatest depths of sampling (e.g., stations F22, F19). Thus, Figure 4-15 is striking in that the water masses converge into a single type represented by the high T-S in deep water offshore.

The composite of all stations suggests that beam attenuation was related to salinity (Figure 4-15), suggesting that fresher inshore water and shallow-water mixing act to disperse turbidity to Massachusetts Bay. Excepting the Cape Cod Bay stations, each with chlorophyll $> 1.5\ \mu g\ L^{-1}$ and beam attenuation $< 3\ m^{-1}$ (Figure 4-15a, bottom panel), a roughly linear relationship was apparent between chlorophyll and beam attenuation.

Chlorophyll could be used to separate all Cape Cod Bay stations from Massachusetts Bay stations (Figure 4-15). Only one Massachusetts Bay station (F24) had chlorophyll exceeding $1\ \mu g\ L^{-1}$. Besides the Bay-to-Bay differences in concentration and in the beam attenuation—chlorophyll

relationship, it was also noted that the extracted chlorophyll—fluorescence calibration coefficients differed markedly between Cape Cod Bay and Massachusetts Bay (Appendix A). In fact, the differences were so strong that separate chlorophyll—fluorescence calibrations were applied to data from the two Bays. Highest chlorophyll values were subsurface in Cape Cod Bay. Interestingly, the one station (F04) of the four sampled in Cape Cod Bay that had a sharp thermocline/halocline (about 12-15 m) also had the highest chlorophyll concentrations, peaking near 6 $\mu g\ L^{-1}$ above the thermocline (Appendix B).

As noted previously, DO was generally near 100% saturation (Figure 4-15b). The few stations where DO was lower than 90% were all at the edge of the Harbor (stations F23P, F24, F25).

To assess further the distinction among water types, stations were grouped by geographic location (Figure 4-16). Data from discrete bottle sampling for nutrients were used, as was salinity collected by *in situ* sensors at the sample bottle closing (Appendix A), to facilitate a geographic comparison.

For nitrogen and phosphorus, there appear minor regional differences (Figure 4-17). Variations in nutrient concentrations were as large horizontally as they were vertically, in part due to the generally well-mixed conditions. Many of the coastal stations samples (near Boston Harbor) were enriched in DIN relative to phosphate compared to most nearfield and other regions' stations. The relative enrichment in DIN appears primarily to be caused by NH_4. The northern and offshore stations did not appear to be distinct from the nearfield set of stations. Cape Cod Bay stations were lower in both DIN and PO_4, but follow the main N/P trend. Overall, the points have individual N/P ratios between about 4:1 to 16:1. However, the bulk of points (using NO_3 or DIN) parallel a 16:1 N/P isopleth, with an offset (a positive P-intercept) because PO_4 was present at very low DIN.

The variation in silicate was small relative to nitrogen and no strong relation between the two was apparent considering all stations (Figure 4-18). Most samples had DIN/SiO_4 ratios that fell in a range between 1:2 and 2:1, with the near Harbor coastal stations more enriched in N than other regions. The central distinction evident in Figure 4-18 is the relatively low silicate in most samples of Cape Cod Bay.

The distribution of nutrients were examined relative to salinity. Salinity can indicate the relative contribution of fresher water at a location and salinity—nutrient plots are a tool for examining how nutrients from fresher inshore sources may be mixed into more saline waters. Figure 4-19, showing a strong pattern of higher nutrients at lower salinity, suggests roughly conservative mixing from the coastal edge near the Harbor to the offshore, including the nearfield. Outliers in this plot are samples from stations in Cape Cod Bay (F01P, F02P and surface layer samples from station F04). There, DIN was removed by plankton growth (markedly higher chlorophyll) and the position of these points below the main trend line for Massachusetts Bay would suggest an active "sink" for DIN. Weaker linear trends with salinity are evident when one partitions the nitrogen into ammonia and nitrate (Figure 4-20). However, a sink for nitrate seems suggested for the three Cape Cod Bay stations singled out above.

Phosphate did not show a striking trend with salinity (Figure 4-21). Perhaps a slight PO_4 decrease with increasing salinity was indicated for the bulk of samples as there was with the silicate-salinity relationship (Figure 4-21). As observed for DIN, the three Cape Cod Bay stations suggest a strong sink for silicate.

Using DIN in combination with other organic forms of nitrogen, the Cape Cod Bay station data still fell below the general trend line for nitrogen relative to salinity (Figure 4-22). One explanation of this "anomaly" is that the phytoplankton bloom caused some sedimentation of nitrogen from the surface water due to biological uptake and particle sinking. Because bottom waters in Cape Cod Bay had nutrients that were similar to the rest of the Bays at a given salinity level, the simplest interpretation, i.e. net removal of surface-water nitrogen and (probably) silicate by this stage of the winter-spring bloom, is a tenable hypothesis only if "removed" nutrients were not being remineralized at the cold bottom-water temperatures. However, the group of "P" stations in Figure 4-22 are spatially distant and it would be an oversimplification to invoke strict one-source (Harbor) mixing from inshore to all places in the Bays. Thus, the Cape Cod Bay surface layer samples may fall off the line for Harbor-nearfield stations for reasons other than a removal term.

In summary, the following overall observations relative to water mass distinctions were made for February 1993. Slight temperature and salinity differences were sufficient to allow water mass typing both between the two Bays and by region within Massachusetts Bay (shallower inshore vs. deeper

offshore). At this time, biological differences (as chlorophyll) were more pronounced between the two Bays than between any areas within Massachusetts Bay. Nutrient concentrations and nutrient—salinity patterns were a useful diagnostic for inshore-offshore regions and for discrimination of the two Bays' water quality. Nutrient ratios offered an additional diagnostic for distinguishing the Harbor source area and Cape Cod Bay from other regions.

4.1.4 Distribution of Chlorophyll and Phytoplankton

The previously described distinction between Cape Cod Bay stations and the nearfield/coastal Massachusetts Bay region was confirmed using only the extracted chlorophyll samples (Figure 4-23). For these same locations, phytoplankton species were identified, enumerated and are related to chlorophyll in Figure 4-24. Cell counts at the Cape Cod Bay stations were indeed high, approaching or exceeding 1 million cells L^{-1} (Figure 4-25). The Massachusetts Bay stations all had low counts near 0.2 to 0.3 million cells L^{-1}. In all cases, diatoms were the major component and few dinoflagellates were detected.

With respect to dominant taxa, refer to Table 4-1 for comparison of stations based on surface and chlorophyll maximum sampling depths. Microflagellates and cryptomonads were numerically dominant at most stations. Cyanophyceae were the dominant taxa at the subsurface chlorophyll maximum sampling depth at stations N04P and N07P on the eastern corners of the nearfield. Otherwise, the remaining dominants were diatoms — the normal community present during the winter-spring bloom period — and the differences between surface and deeper samples were slight.

For diatoms, the counts for dominants in Cape Cod Bay were higher than in Massachusetts Bay but there also seemed to be a few community differences. Several species of *Chaetoceros* were prevalent across many stations, but the *Chaetoceros* spp. (10-20 μm) in Cape Cod Bay was not among dominants in Massachusetts Bay. *Leptocylindrus danicus* was among dominants at F02P, but not F01P and also not elsewhere. In contrast, other diatoms were among dominants at most or all Massachusetts Bay stations, but not Cape Cod Bay — principal species in Massachusetts Bay included *Cylindrotheca closterium* and *Skeletonema costatum*. Note that the Bay-to-Bay differences in species composition may help explain why the chlorophyll—fluorescence relationship appeared different in the two Bays (Appendix A).

Tables 4-2 and 4-3 provide taxonomic data from 20-μm screened samples, taken to reveal larger-sized, but less numerous individuals. The majority of these were dinoflagellates, which in terms of the total (see above) were a very minor fraction — note that numbers are in cells L^{-1} rather than 10^6 cells L^{-1}. In general, the fewest taxa from screened samples were at station F23P at the Harbor edge. Stations F01P and F02P had similar overall composition, the most extensive number of taxa, and generally highest numbers of individuals. *Alexandrium tamarense*, a concern for its Paralytic Shellfish Poisoning (PSP) potential, was detected at the chlorophyll maximum at both Cape Cod Bay stations.

4.1.5 Distribution of Zooplankton

Total numbers of zooplankton varied nearly five-fold across the stations (Figure 4-26). Cape Cod Bay stations, with higher levels of phytoplankton, did not have distinctly high total zooplankton counts or counts of copepods. The inshore western Massachusetts Bay stations (F13P, N01P, N10P, N20P) had counts higher than at the offshore stations (N04P, N07P, N16P), but the Harbor edge station (F23P) had low total counts as well as low copepod counts.

In terms of group composition, the copepods and their nauplii represented over one-half of the total abundance in all cases (Figure 4-26). Barnacle larvae were a substantial component at the more inshore stations in Massachusetts Bay (stations F13P, F23P, N01P, N10P, and N20P). Where the "other" category (Figure 4-26) was significant, it was dominated by polychaete larvae; the stations where this occurred were in Cape Cod Bay or, excepting F23P, the same coastal stations where barnacle larvae were higher.

With respect to taxa, the dominant copepod species at each station was the small copepod, *Oithona similis*. A secondary dominant at many stations was *Paracalanus parvus*. The most prevalent of the larger copepods included *Tortanus discaudatus*, *Calanus finmarchicus*, and *Pseudocalanus newmani*; their numbers were much lower than *Oithona* and their distributions more variable (Appendix G). Overall, the distributions of zooplankton suggested a fairly well-mixed pool of species across the two Bays.

Two features of the Cape Cod Bay station zooplankton community were noteworthy. The copepod *Acartia hudsonica* was present at station F23P at the Harbor edge, and both stations F01P and F02P in Cape Cod Bay, but not elsewhere. This species is more characteristic of estuarine conditions than coastal shelf environs. Cape Cod Bay station salinities were lower than the nearfield area stations but not lower than station F13P off Cohasset, where there was no *Acartia* detected, so salinity differences alone cannot explain the odd distribution. Also, *Oikiopleura dioica*, an appendicularian often thought of as a shelf-oceanic species was present at many stations, but reached highest numbers at F01P and F02P.

4.1.6 ^{14}C Production Measurements

Using the P-I incubations, and light and fluorescence profiles at each station, modeling was performed to estimate integrated daily ^{14}C production (see Section 2). All P-I data and curve-fitting results are in Appendix E; an example curve is shown in Figure 4-27. Table 4-4 provides a summary of modeled rates by station. The water column depth and the depth over which production was integrated ($Z_{0.5\%Io}$) are given. For each station, two estimates were obtained based on P-I curves for either the surface or chlorophyll maximum sample incubation. Both estimates at each station used the same vertical light and chlorophyll data, so integrated rate differences are due only to differences in incubation P-I data and statistical modeling.

As suggested by beam attenuation data, the 0.5% level was shallowest near the Harbor (stations F23P, N10P, F13P), intermediate in Cape Cod Bay, and deepest on the east side of the nearfield. Not surprisingly, with much higher chlorophyll (as well as chlorophyll-normalized P_{max} values, Appendix E), ^{14}C production at the two Cape Cod Bay stations was highest, ≥ 2.5 gC m^{-2} d^{-1}. Elsewhere ^{14}C production was below 1 gC m^{-2} d^{-1}, except perhaps for station N07P. Most rates were less than 0.5 gC m^{-2} d^{-1}. Rates appeared to be the lowest near the Harbor (station F23P) and off Cohasset (F13P).

Production rates across nearfield stations varied by a factor of 2-4. Higher estimates occurred at the southern inshore and offshore corners (N10P and N07P) and lower rates were estimated for stations in the middle of the region. Note, for station N10P that the goodness-of-fit for P-I modeling was poor (Appendix E). The model fit was good in other cases. In general, the success of the curve

fitting when the second model (Platt and Jassby, 1976), but not the first model (Platt *et al.* 1980), converged on a set of coefficients, was lower as judged by the coefficient of determination — a result seemingly more a function of the data than of the different models.

4.2 Nearfield Survey

4.2.1 Distribution of Water Properties from Vertical Profiling

Vertical profiling was performed at the planned twenty-one nearfield stations (Appendices A,B). Scatter plots using *in situ* sensor data are shown in Figure 4-28. There was a small range in most parameters.

Throughout the nearfield chlorophyll was lower than 1 $\mu g\ L^{-1}$ and there was little vertical structure indicated (Figure 4-29). Oxygen was between about 90 and 105% of saturation, and fairly uniform over depth at most stations (Figure 4-29).

Nutrient concentrations as a function of depth are shown in Figure 4-30. Data for the nearfield are shown relative to data from other regions sampled during the farfield survey. For DIN, a strong pattern over depth was not found. Concentrations ranged from about 0.8 to 12.2 μM, with the mean being 6.1 μM (stnd. dev. = 1.95, n=105). Nearfield DIN values were intermediate between some of the coastal (higher) and Cape Cod Bay stations (lower), while the nearfield region had roughly the same range as offshore and northern transect stations. NH_4 was generally below 1 μM in the nearfield, but values as high as 6.2 μM were detected. These were more typical of coastal, near-Harbor stations. The range for NO_3 in the nearfield (0.1 to 9.7 μM) was typical of the other regions, and less than some coastal stations.

PO_4 and SiO_4, as well as nitrogen, showed little pattern with depth (Figure 4-30). Nearfield stations and stations in other regions had fairly similar PO_4 ranges. Silicate concentrations in the nearfield was within a rather remarkably small range, about 8.2 to 11.5 μM, uniform over depth, and intermediate to some coastal and Cape Cod Bay stations (as DIN).

Previous graphics (Figures 4-19 to 4-21) showed nearfield nutrients vs. salinity. Within the nearfield data by itself, the scatter of concentration vs. salinity was rather high. Silicate showed perhaps the strongest pattern with salinity across the nearfield.

4.2.2 Distribution of Water Properties from Towing

With little apparent vertical structure (physical, chemical, or biological) indicated from vertical profiling, it was not surprising that contoured sections developed from the data along tracks of oscillating "tow-yos" gave a picture mainly of uniformity. In terms of temperature (Figure 4-13), there were only three variations outside the interval of 2-2.5 °C. One variation was that of a slightly cooler region towards the surface near station N10P, which receives tidal export from the Harbor. The other two variations were the slightly warmer (top-to bottom) patches offshore — one around station N03 on the northern edge and the other at station N07P at the southeast corner of the nearfield. Density contours showed extreme uniformity or only very minor patchiness throughout the field, except the surface cell shoaling offshore from N10P (Figure 4-32a). Chlorophyll showed uniformly low values and very minor patchiness, with values slightly above and below 0.5 μg L-1 used as the lowest interval maximum (Figure 4-33). There was no striking chlorophyll "signature" seen to compliment the physical structure at station N10P (Figure 4-33a).

4.2.3 Water Types and Analysis of Small-Scale Variability

The nearfield region was extremely well-mixed. With regard to a number of parameters, the region could be seen as a mixing area between cooler, fresher, higher-nutrient water along the coast and slightly warmer and more saline water to the north and east. From the towing data, however, there were not strong inshore-offshore gradients apparent across the nearfield itself. Thus, the picture of inshore-offshore gradients is only apparent looking across the entire transect from coastal to deep stations (e.g. F23P to F19) that cross through the nearfield.

Some short-term variability was apparent, indicating for one, tidal action. Note that the cool surface water cell at station N10P was there at one occupation during towing, but not the next (Figure 4-31a vs. Figure 4-31b). Past studies have noted the relation between water quality and the stage of the tide near this station. Secondly, a review of vertical profiles from "P" stations during the farfield survey

and then the nearfield survey, about two days apart, suggested temporal changes (see Appendix B). For example, at station N04P (NE corner of nearfield), a thermocline that was apparent at 20-25 m on 24-Feb was weaker and deeper and the whole water column was cooler on 26-Feb. In contrast, station N07P about 10 km to the south was isothermal the first day and had deep thermocline (45 m) the second day. Other stations (e.g. N16P) had >0.5 °C temperature shifts (cooling) over the upper 30 m. Still other stations (e.g. N01P) shifted from a slight vertical structure (minor thermocline at 20 m) on the first day to being completely isothermal the next day. The time-series observations may indicate some bottom tidal variation, local responses to weather and water column mixing, or advection with passage of surface currents. The variations are mentioned here merely to point out that the nearfield at this time was physically dynamic. The presence and strength of any gradients from offshore or inshore, being fairly small, could vary substantially. A monitoring strategy of sequential sampling over several days helps document this changeable environment.

Table 4-1a. Abundance of the top five dominant phytoplankton taxa in samples collected near the surface in February 1993.

	Coastal Stations		Nearfield Stations						Cape Cod Bay Stations	
	F23P	F13P	N01P	N04P	N07P	N10P	N16P	N20P	F01P	F02P
	Feb 23	Feb 24	Feb 24	Feb 24	Feb 24	Feb 23	Feb 23	Feb 23	Feb 25	Feb 25
MICROFLAGELLATES	.05 (1)	.046 (1)	.053 (1)	.054 (1)	.067 (2)	.025 (4)	.03 (3)	.053 (1)	.096 (1)	
CYLINDROTHECA CLOSTERIUM	.014 (5)	.035 (2)	.027 (3)	.049 (2)	.068 (1)	.018 (5)	.063 (1)	.047 (2)		
CHAETOCEROS SOCIALIS				.013 (5)	.017 (5)	.03 (3)	.063 (1)		.092 (2)	.156 (3)
CRYPTOMONADS	.031 (3)	.033 (4)	.05 (2)	.037 (4)	.025 (4)			.022 (5)		
SKELETONEMA COSTATUM	.043 (2)	.034 (3)	.009 (5)			.073 (1)	.046 (2)	.029 (4)		
CHAETOCEROS DEBILIS		.019 (5)	.012 (4)			.047 (2)		.039 (3)		.176 (1)
CHAETOCEROS COMPRESSUS									.084 (3)	.079 (5)
CHAETOCEROS SPP. (10-20UM)									.07 (4)	.094 (4)
NITZSCHIA (CF) DELICATISSIMA				.047 (3)	.032 (3)					
CHAETOCEROS DECIPIENS							.016 (4)			
LEPTOCYLINDRUS DANICUS										.163 (2)
NITZSCHIA SERIATA	.015 (4)									
THALASSIONEMA NITZSCHOIDES	.014 (5)									
THALASSIOSIRA (cf) GRAVIDA/ROTULA							.014 (5)			
THALASSIOSIRA NORDENSKIOELDII									.068 (5)	

Units are millions of cells L^{-1}.

Table 4-1b. Abundance of the top five dominant phytoplankton taxa in samples collected near the chlorophyll maximum in February 1993.

	Coastal Stations		Nearfield Stations						Cape Cod Bay Stations	
	F23P	F13P	N01P	N04P	N07P	N10P	N16P	N20P	F01P	F02P
	Feb 23	Feb 24	Feb 24	Feb 24	Feb 24	Feb 23	Feb 23	Feb 23	Feb 25	Feb 25
MICROFLAGELLATES	.04 (2)	.081 (1)	.048 (2)	.044 (2)	.04 (3)	.049 (1)	.059 (1)	.039 (2)	.086 (3)	.072 (5)
CYLINDROTHECA CLOSTERIUM	.031 (4)	.033 (4)	.041 (4)	.031 (3)	.052 (2)	.034 (4)	.043 (2)	.035 (3)		
CHAETOCEROS DEBILIS	.025 (5)		.069 (1)			.041 (2)	.032 (4)	.033 (4)	.119 (1)	.165 (1)
CRYPTOMONADS	.032 (3)	.052 (3)	.047 (3)	.029 (4)	.031 (4)					
SKELETONEMA COSTATUM	.086 (1)	.057 (2)	.033 (5)			.039 (3)	.038 (3)	.045 (1)		
CHAETOCEROS SOCIALIS						.03 (5)		.02 (5)		.153 (2)
CHAETOCEROS COMPRESSUS									.061 (5)	
CHAETOCEROS SPP. (10-20UM)									.1 (2)	.145 (3)
CYANOPHYCEAE				.091 (1)	.056 (1)					
NITZSCHIA (CF) DELICATISSIMA		.024 (5)		.017 (5)						
THALASSIOSIRA (cf) GRAVIDA/ROTULA					.013 (5)		.03 (5)			
ASTERIONELLOPSIS GLACIALIS									.07 (4)	
LEPTOCYLINDRUS DANICUS										.089 (4)

Units are millions of cells L^{-1}.

Table 4-2a. Abundance of all identified taxa in screened (20um) samples collected near the surface in February 1993.

	Coastal Stations		Nearfield Stations						Cape Cod Bay Stations	
	F23P	F13P	N01P	N04P	N07P	N10P	N16P	N20P	F01P	F02P
	Feb 23	Feb 24	Feb 24	Feb 24	Feb 24	Feb 23	Feb 23	Feb 23	Feb 25	Feb 25
ALORICATE CILIATES	5	23	10		15	10	48	8	23	10
CERATIUM FUSUS				3					8	3
CERATIUM LINEATUM			3	3	3			3	18	
CERATIUM LONGIPES			3	5	10				8	
CERATIUM SPP.				3						
CERATIUM TRIPOS					5		3			
DINOPHYSIS ACUTA			3		3					
DINOPHYSIS NORVEGICA			3		3	3	8		28	45
DISTEPHANUS SPECULUM		3		28	18				8	3
GYRODINIUM SPIRALE		3	5						8	30
GYRODINIUM SPP.			3	3				3	20	15
KATODINIUM ROTUNDATUM		8								
PROTOPERIDINIUM DENTICULATUM			10					5		
PROTOPERIDINIUM DEPRESSUM				3	5		3		20	28
PROTOPERIDINIUM PELLUCIDUM										3
PROTOPERIDINIUM SPP.				3					8	20
TINTINNIDS		33	58	88	63	30		18	8	5
UNID. ATHECATE DINOFLAGELLATE		20	8	3	3			3		13
UNID. THECATE DINOFLAGELLATES		5	10		8	3	3	3	90	145

Units are cells L^{-1}

Table 4-2b. Abundance of all identified taxa in screened (20um) samples collected near the chlorophyll maximum in February 1993.

	Coastal Stations		Nearfield Stations						Cape Cod Bay Stations	
	F23P	F13P	N01P	N04P	N07P	N10P	N16P	N20P	F01P	F02P
	Feb 23	Feb 24	Feb 24	Feb 24	Feb 24	Feb 23	Feb 23	Feb 23	Feb 25	Feb 25
ALEXANDRIUM TAMARENSE									5	5
ALORICATE CILIATES	34	25	5	13	15	13	18	20	23	20
CERATIUM FUSUS									5	5
CERATIUM LINEATUM			3		3	5		3	10	15
CERATIUM LONGIPES				8	5	3	3		5	8
CERATIUM TRIPOS					5			8		
DICTYOCHA FIBULA					3					
DINOPHYSIS ACUMINATA									3	
DINOPHYSIS ACUTA									3	8
DINOPHYSIS NORVEGICA		5		3		10	3	10	43	43
DISTEPHANUS SPECULUM		3		13	23				5	8
GONYAULAX SPP.							10			
GYRODINIUM SPIRALE					3	3			10	5
GYRODINIUM SPP.			3			3	3		10	25
KATODINIUM ROTUNDATUM							3			
PROROCENTRUM MICANS						3				

Units are cells L^{-1}

Table 4-2b. Continued.

	Coastal Stations		Nearfield Stations						Cape Cod Bay Stations	
	F23P	F13P	N01P	N04P	N07P	N10P	N16P	N20P	F01P	F02P
	Feb 23	Feb 24	Feb 24	Feb 24	Feb 24	Feb 23	Feb 23	Feb 23	Feb 25	Feb 25
PROTOPERIDINIUM DENTICULATUM								10		5
PROTOPERIDINIUM DEPRESSUM							8	3	20	20
PROTOPERIDINIUM PALLIDUM										3
PROTOPERIDINIUM SPP.			3		3		5		20	18
TINTINNIDS		95	45	28	63	20	3	18	10	30
UNID. ATHECATE DINOFLAGELLATE	4	33	13	3	5	3			10	3
UNID. THECATE DINOFLAGELLATES		8	18	5	8	5	3		103	113

Units are cells L^{-1}

Table 4-3. ^{14}C production (mg C m^{-2} d^{-1}) estimated for the euphotic layer at BioProductivity stations in February 1993.

	Coastal Stations				Nearfield Stations												Cape Cod Bay Stations			
	F23P		F13P		N01P[6]		N04P		N07P		N10P		N16P		N20P		F01P		F02P	
Water depth (m)	26.5		26		31.5		50		50		27		44		32		27		33	
$Z_{(0.5\%Io)}$ (m)	10.5		14		-		24		28		14.5		26		19.5		18.5		20	
Samples[1]	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C
Rate (mg C $m^{-2}d^{-1}$)	164	156	263	290	-	-	328	560	830	1304	888	388	367	521	360	432	2628	2633	2885	3536
Model[2]	P	P	P	P	-	-	P&J	P	P	P	P&J	P	P	P	P&J	P	P	P	P	P
P_{SB} or P_{MAX}[3]	4.00	5.85	9.50	49.13	-	-	9.76	27.18	19.54	32.93	12.89	6.77	7.97	22.27	5.29	9.74	49.25	57.15	14.40	25.74
α[4]	0.050	0.031	0.080	0.090	-	-	0.051	0.147	0.424	0.642	2.605	0.192	0.071	0.101	0.342	0.109	0.067	0.062	0.063	0.067
β[5]	0.000	0.002	0.001	0.104	-	-	-	0.026	0.000	0.005	-	0.000	0.001	0.024	-	0.002	0.063	0.068	0.009	0.022

[1] S: Surface sample and P-I incubations on it.
C: Chlorophyll max sample and P-I incubations on it.
[2] P: Platt *et al.* (1980).
P&J: Platt and Jassby (1976).
[3] P_{SB}: Production parameter for Platt *et al.* model.
P_{MAX}: Production parameter for Platt and Jassby model.
[4] Parameter for both models.
[5] Parameter for Platt *et al.* model.
[6] No light data available for station N01P.

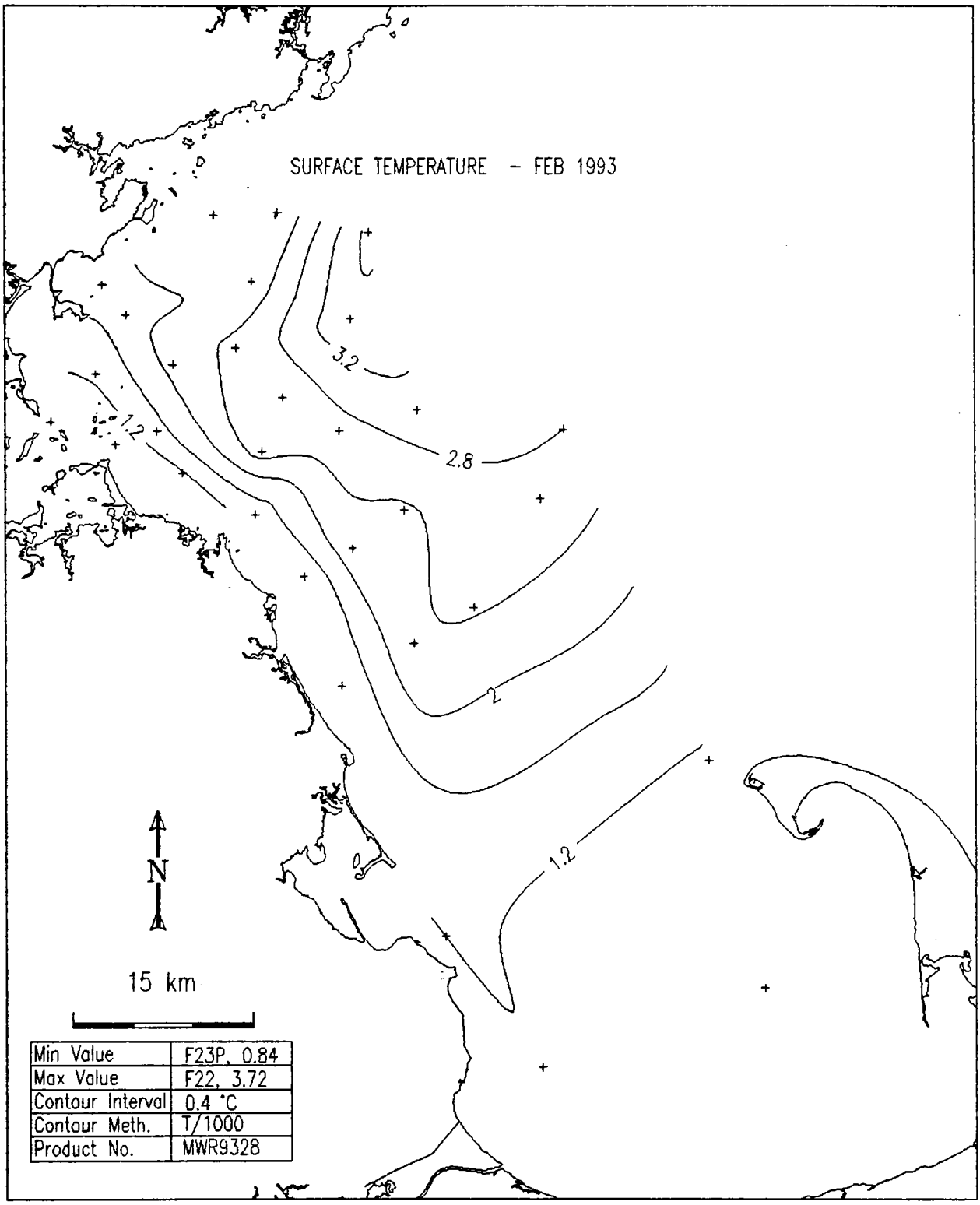


Figure 4-1. **Surface temperature (°C) in the region in February 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

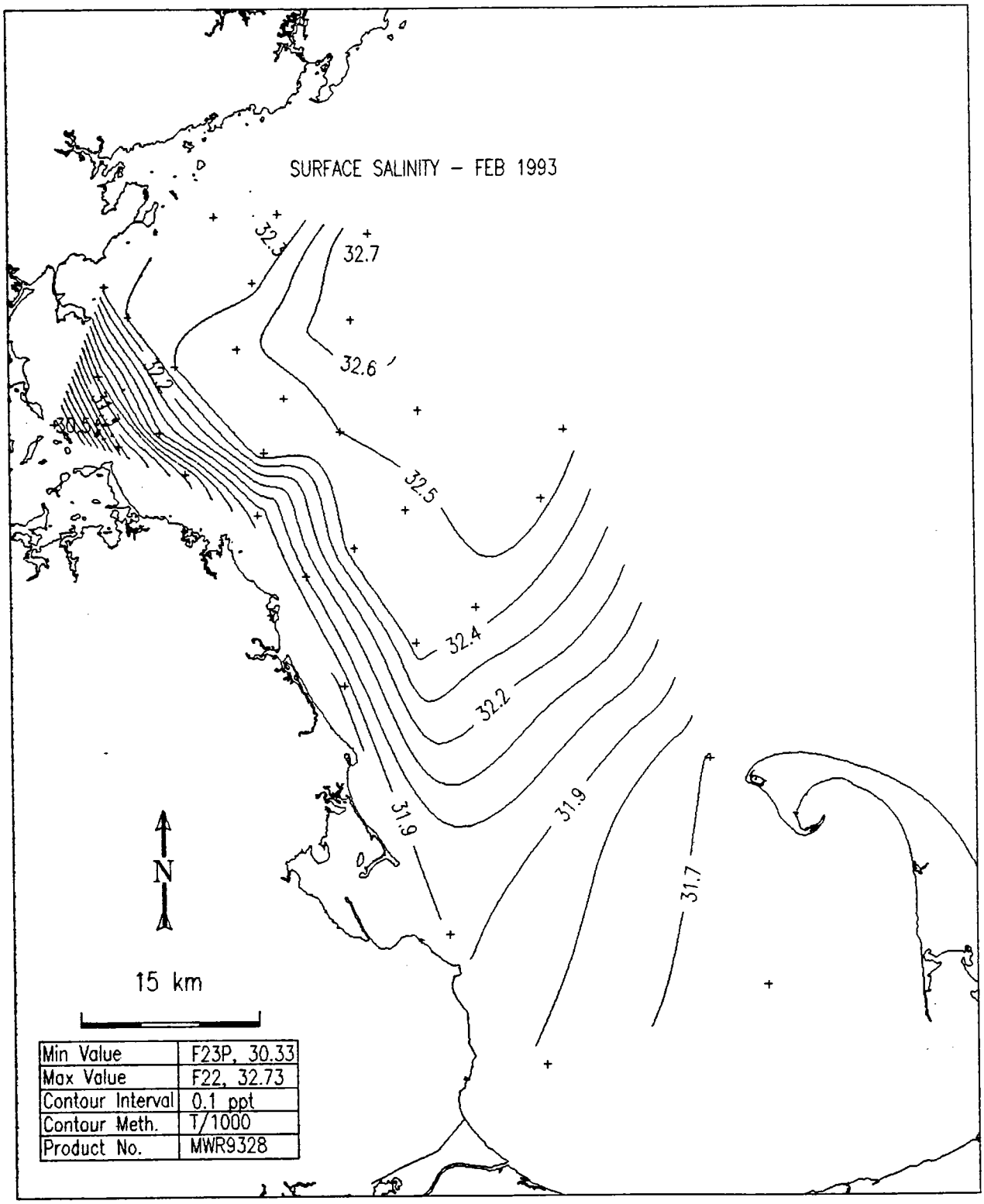


Figure 4-2. **Surface salinity (PSU) in the region in February 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

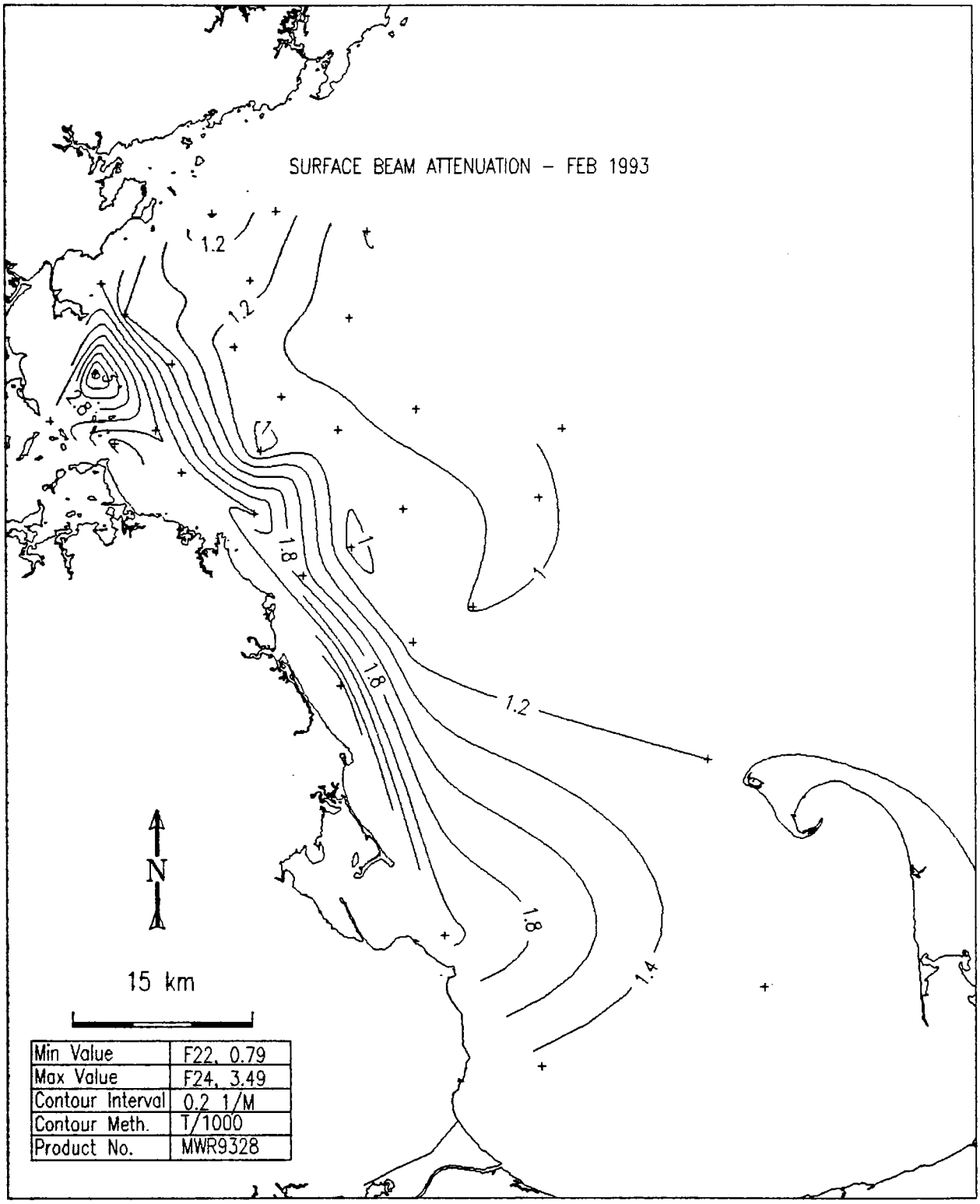


Figure 4-3. **Surface beam attenuation (m^{-1}) in the region in February 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

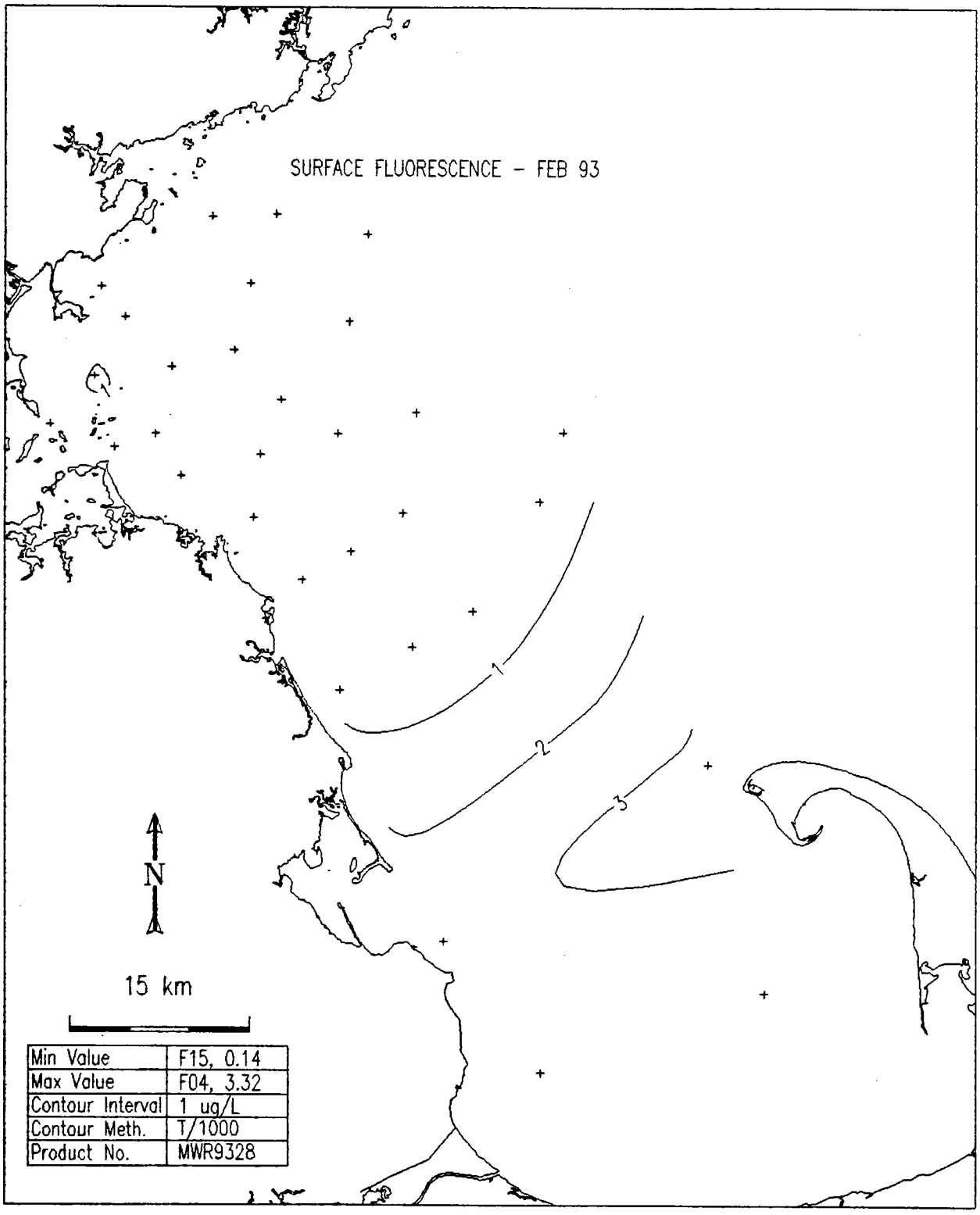


Figure 4-4. **Surface *in situ* fluorescence (as μg Chl L^{-1}) in the region in February 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

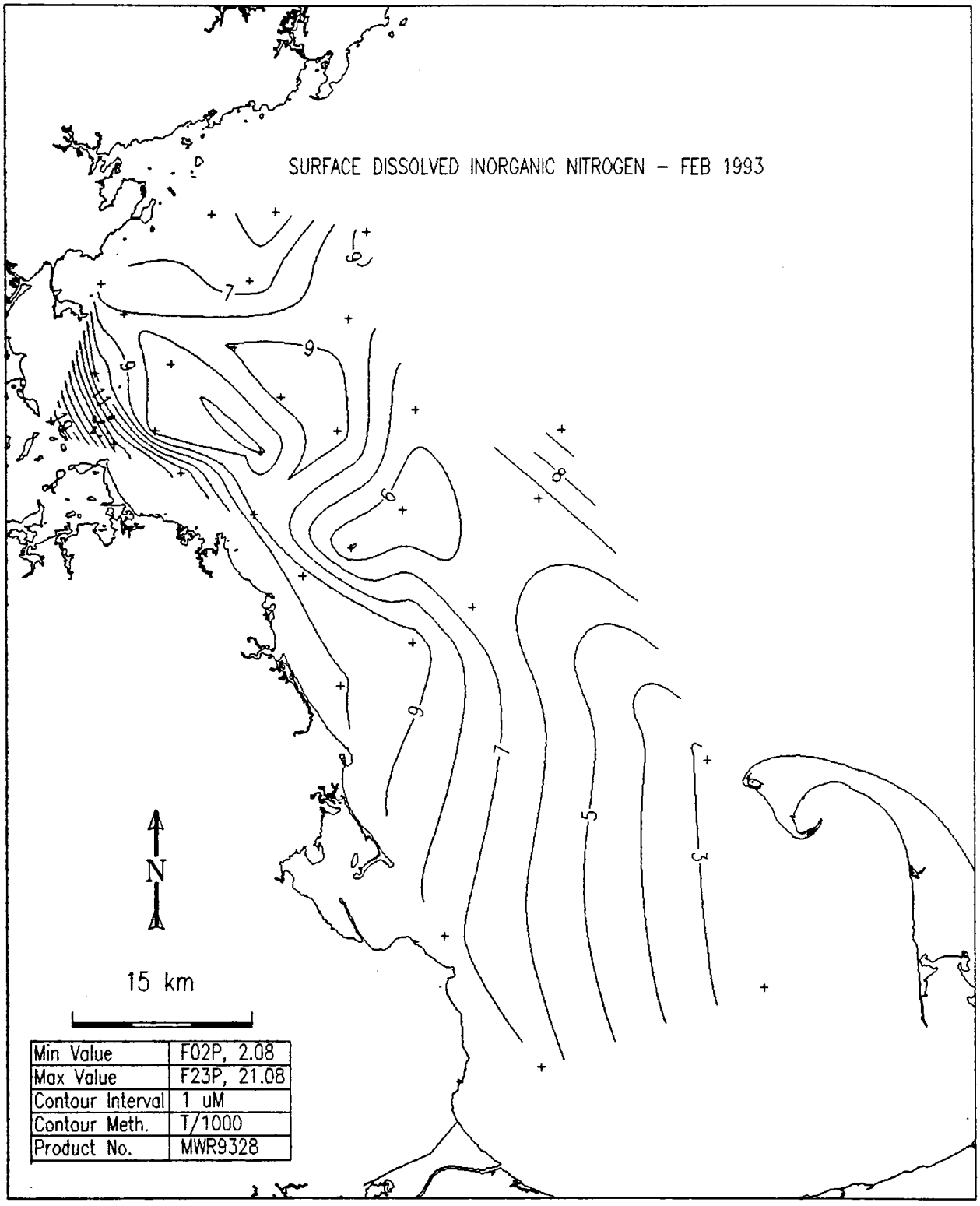


Figure 4-5. **Surface dissolved inorganic nitrogen (DIN, μM) in the region in February 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

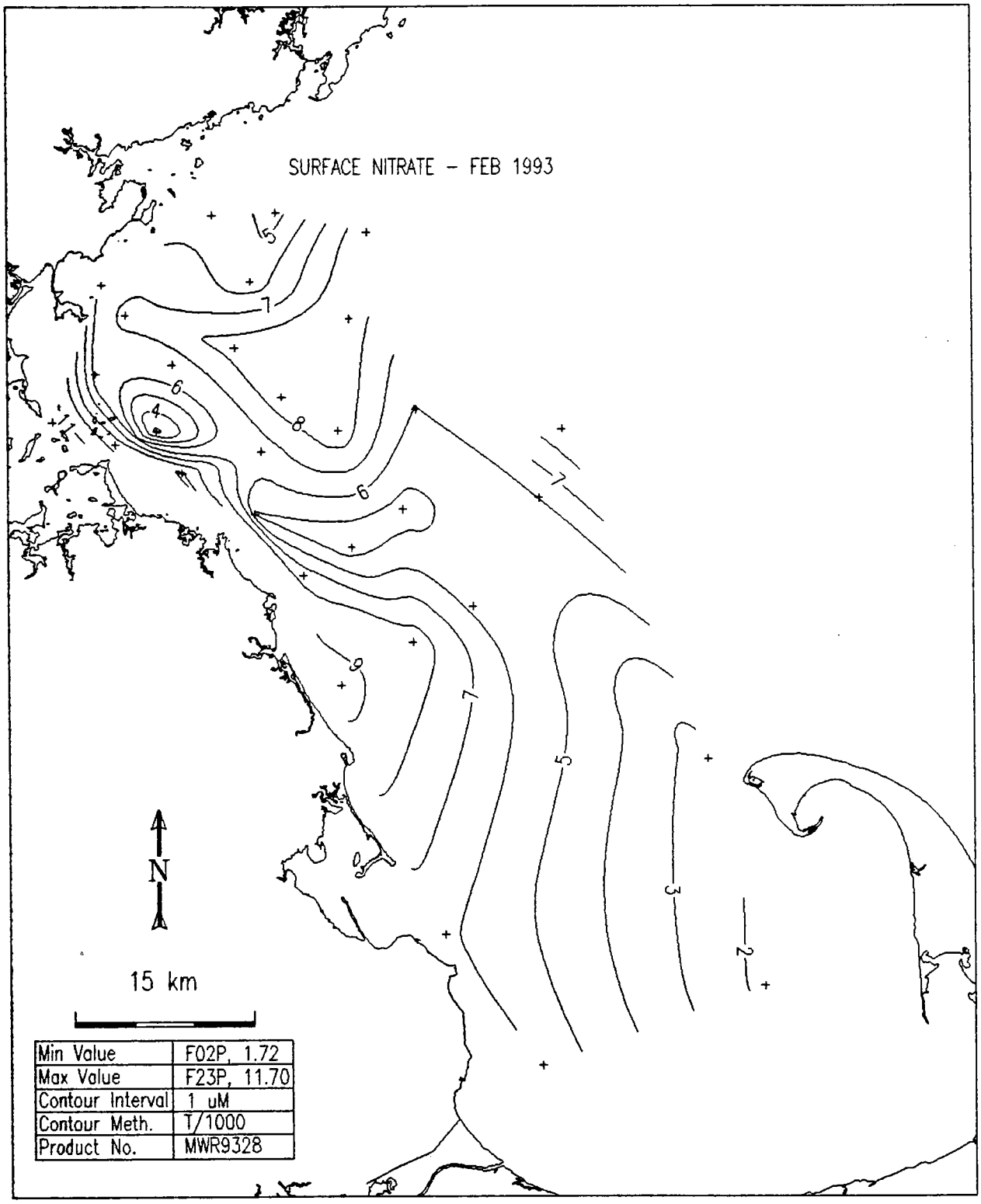


Figure 4-6. **Surface nitrate (NO_3, μM) in the region in February 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

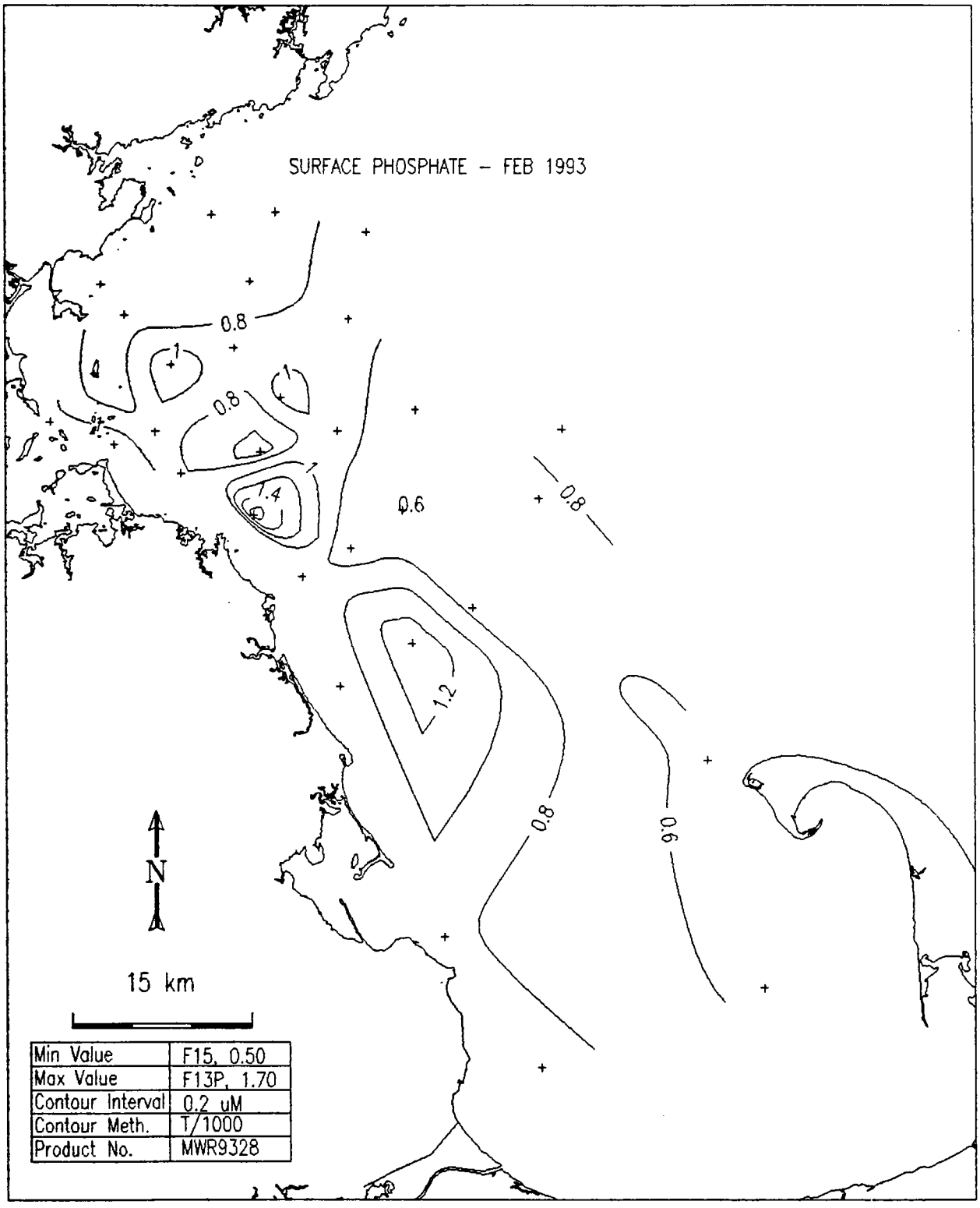


Figure 4-7. **Surface phosphate (PO_4, μM) in the region in February 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

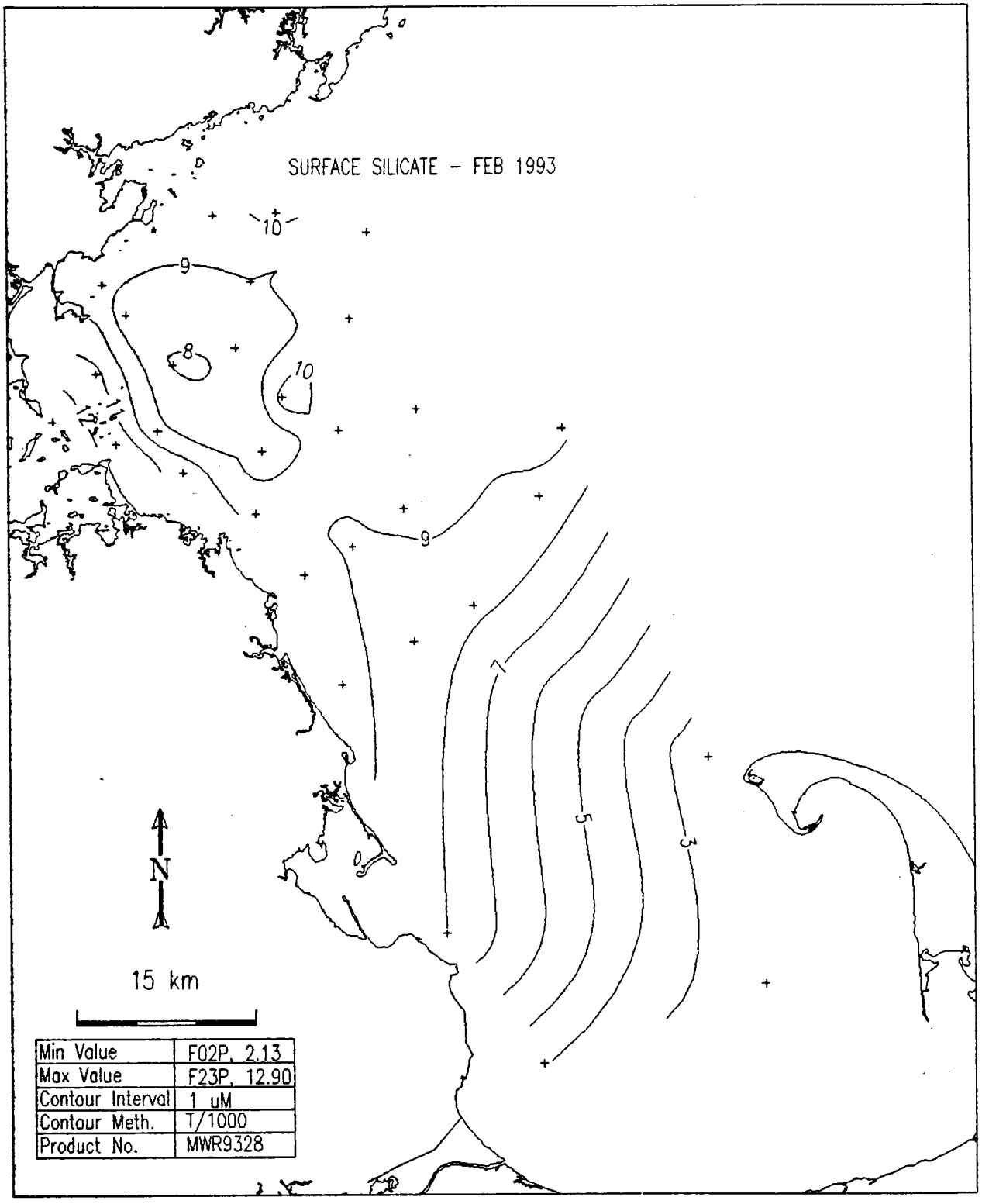


Figure 4-8. **Surface silicate (SiO_4, μM) in the region in February 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

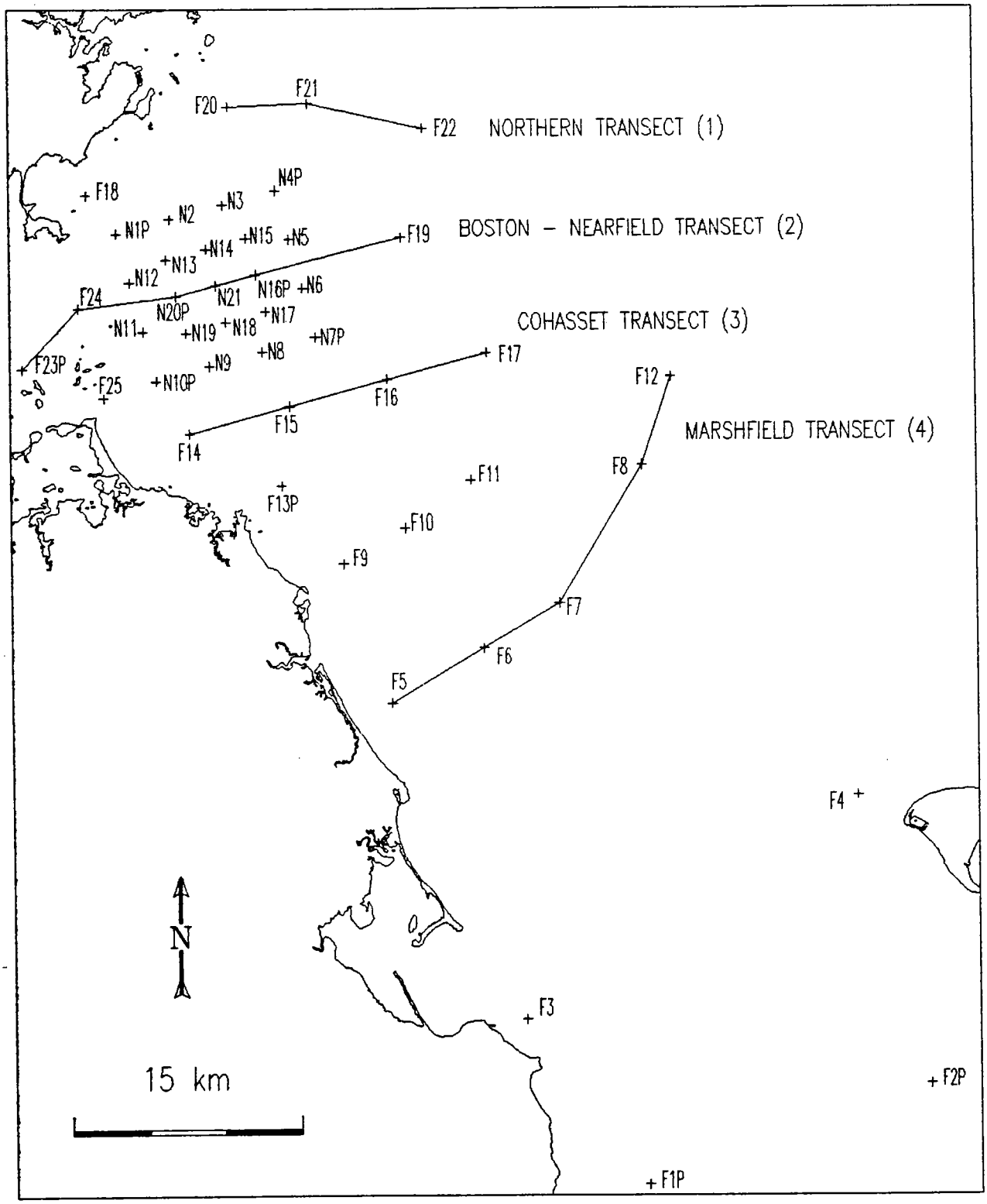


Figure 4-9. **Map showing position of four standard transects for which vertical contour plots were produced in following Figures 4-10 to 4-14.**

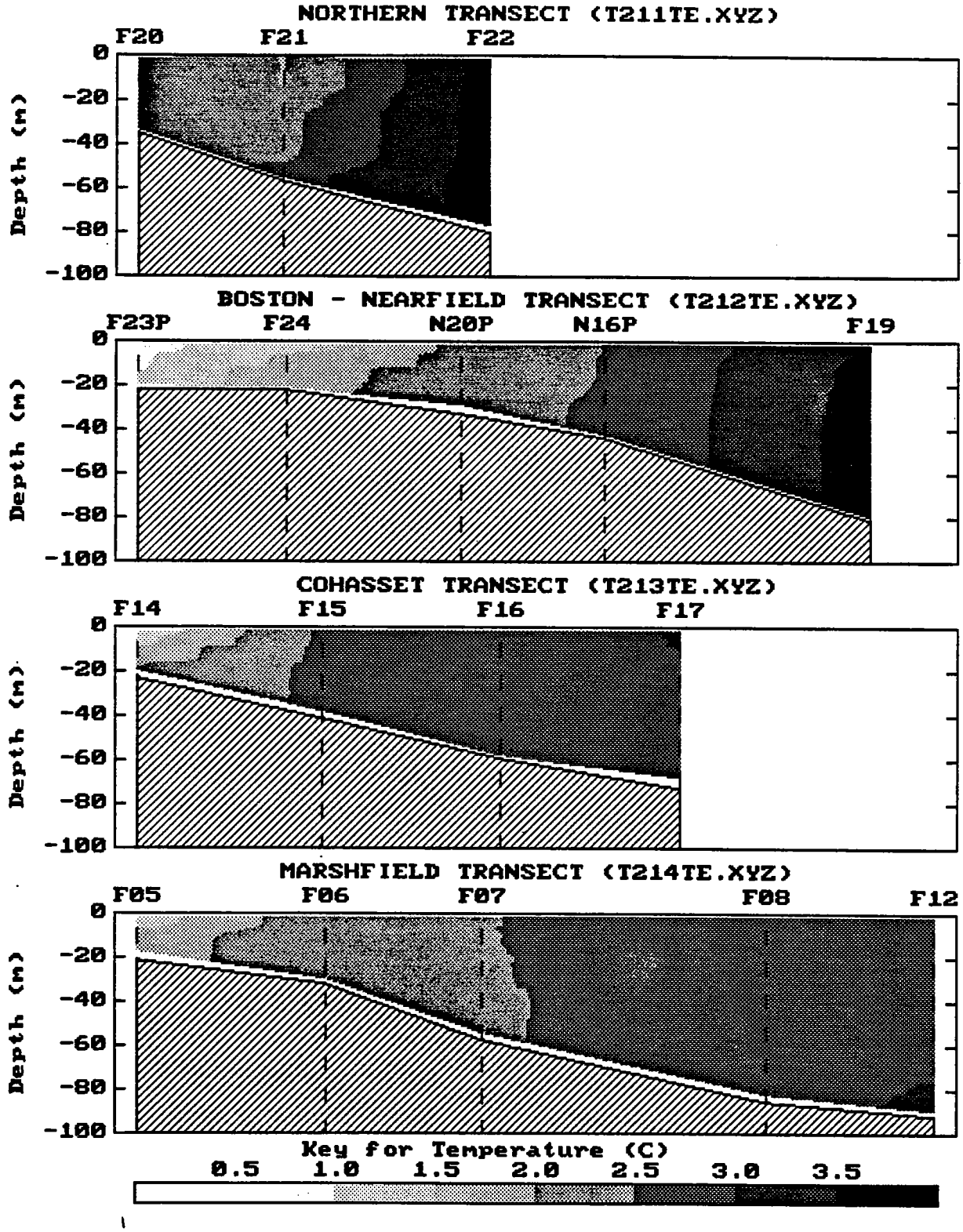


Figure 4-10a. Vertical section contours of temperature in February 1993 for standard transects (see Figure 4-9). The data used to produce contours are from high-resolution continuous vertical profiles taken from the downcast at each station.

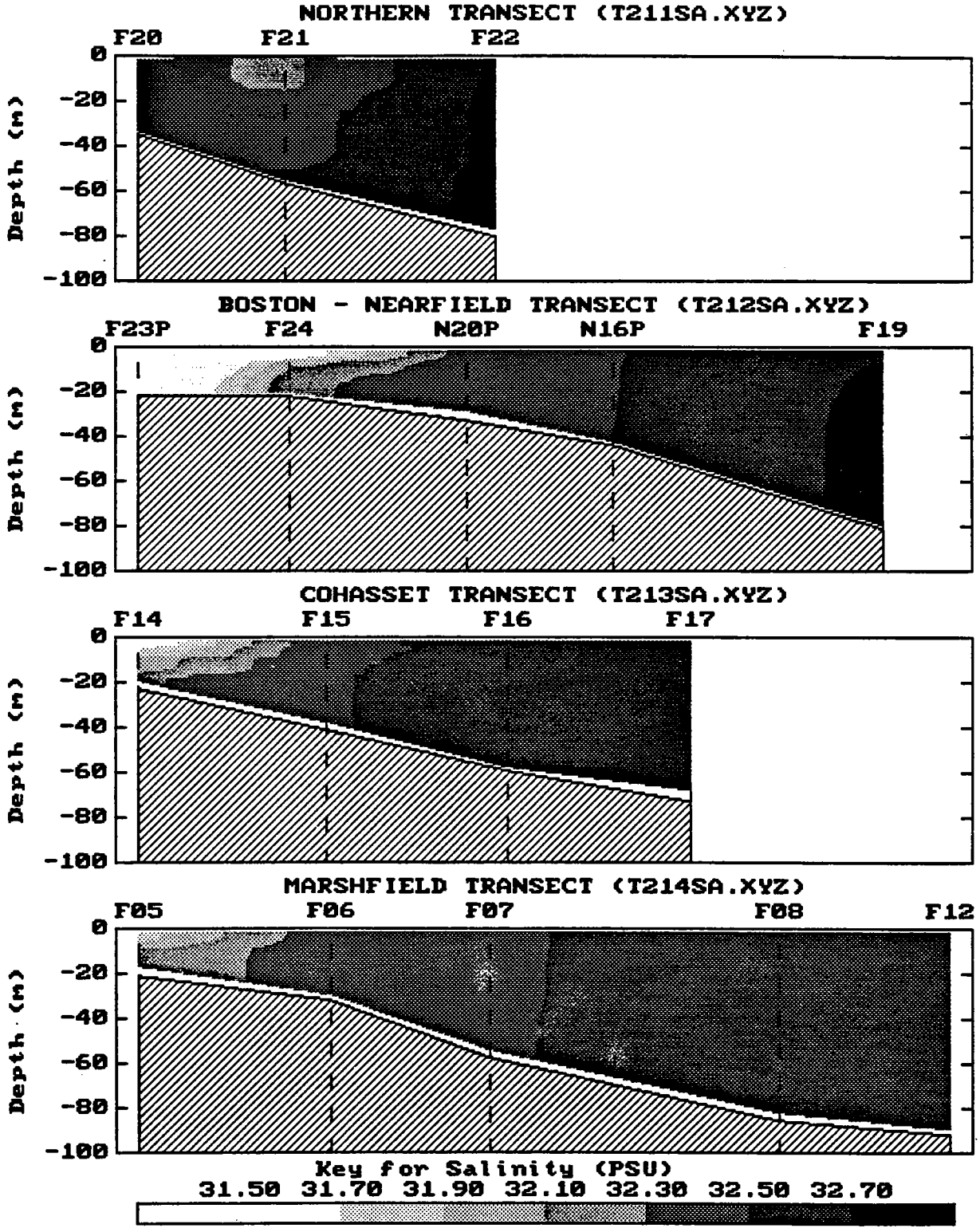


Figure 4-10b. Vertical section contours of salinity in February 1993 for standard transects (see Figure 4-9). The data used to produce contours are from high-resolution continuous vertical profiles taken from the downcast at each station.

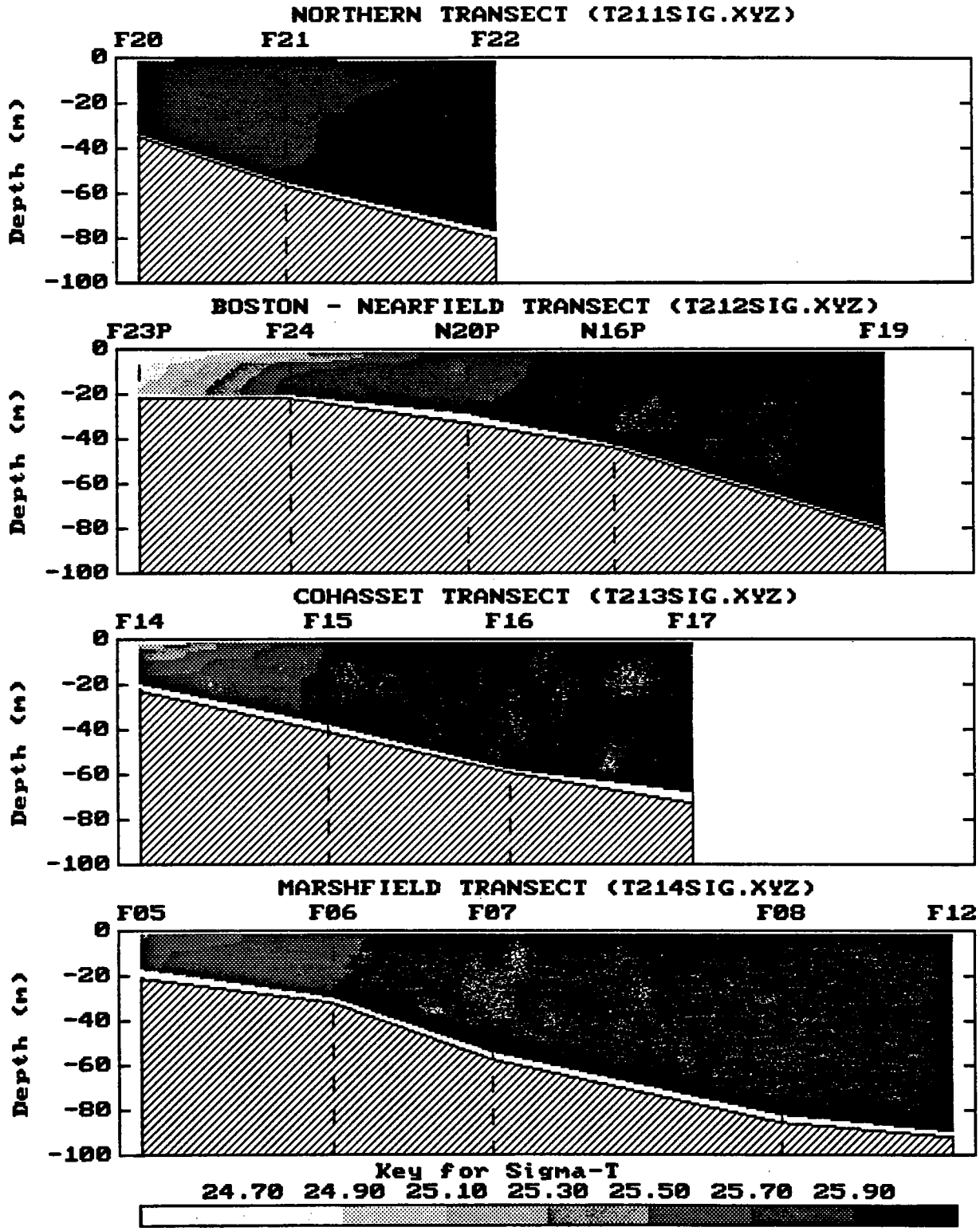


Figure 4-11. Vertical section contours of density (σ_T) in February 1993 for standard transects (see Figure 4-9). The data used to produce contours are from high-resolution continuous vertical profiles taken from the downcast at each station.

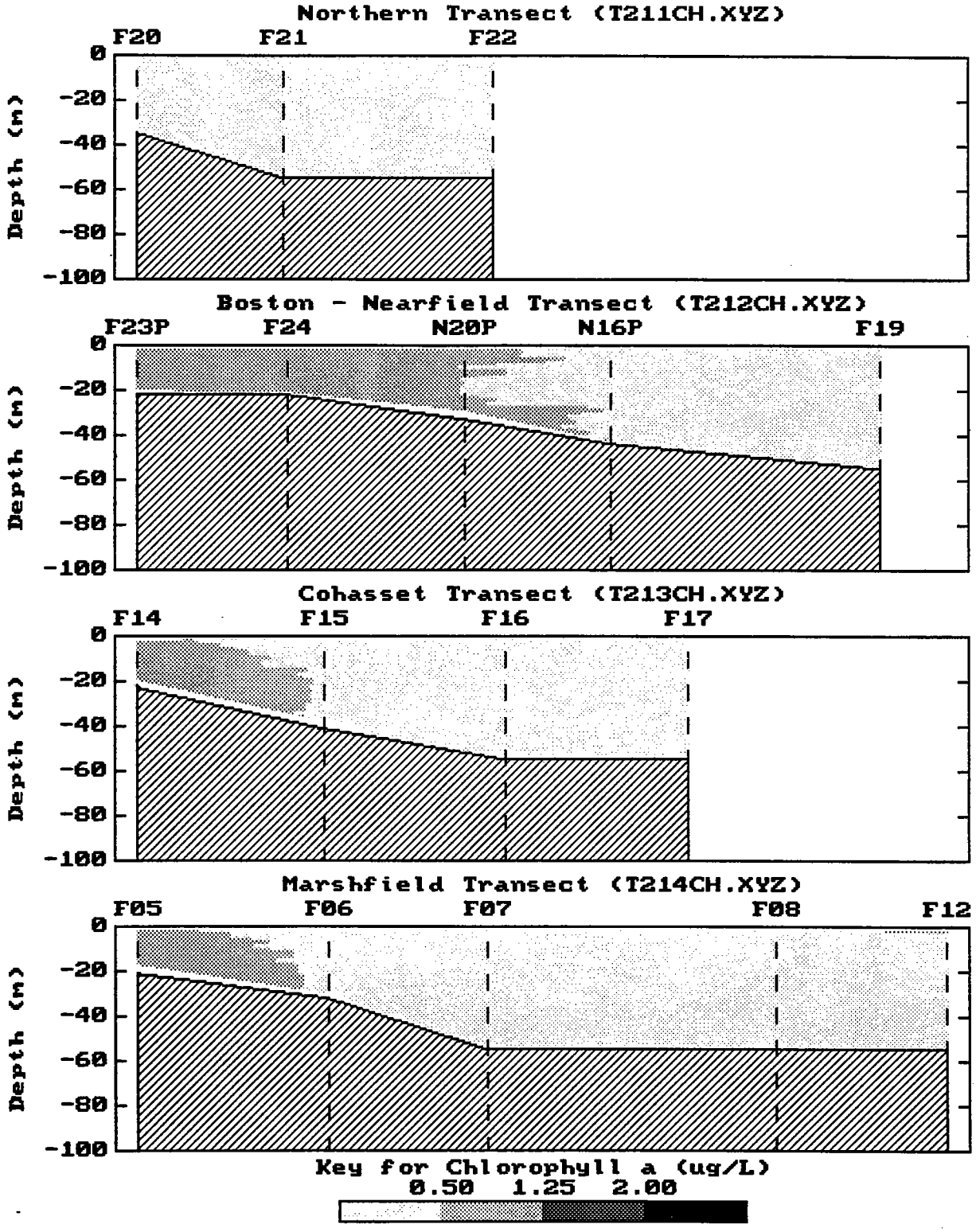


Figure 4-12a. Vertical section contours of fluorescence (as μg Chl L^{-1}) in February 1993 for standard transects (see Figure 4-9). The data used to produce contours are from high-resolution continuous vertical profiles taken from the downcast at each station.

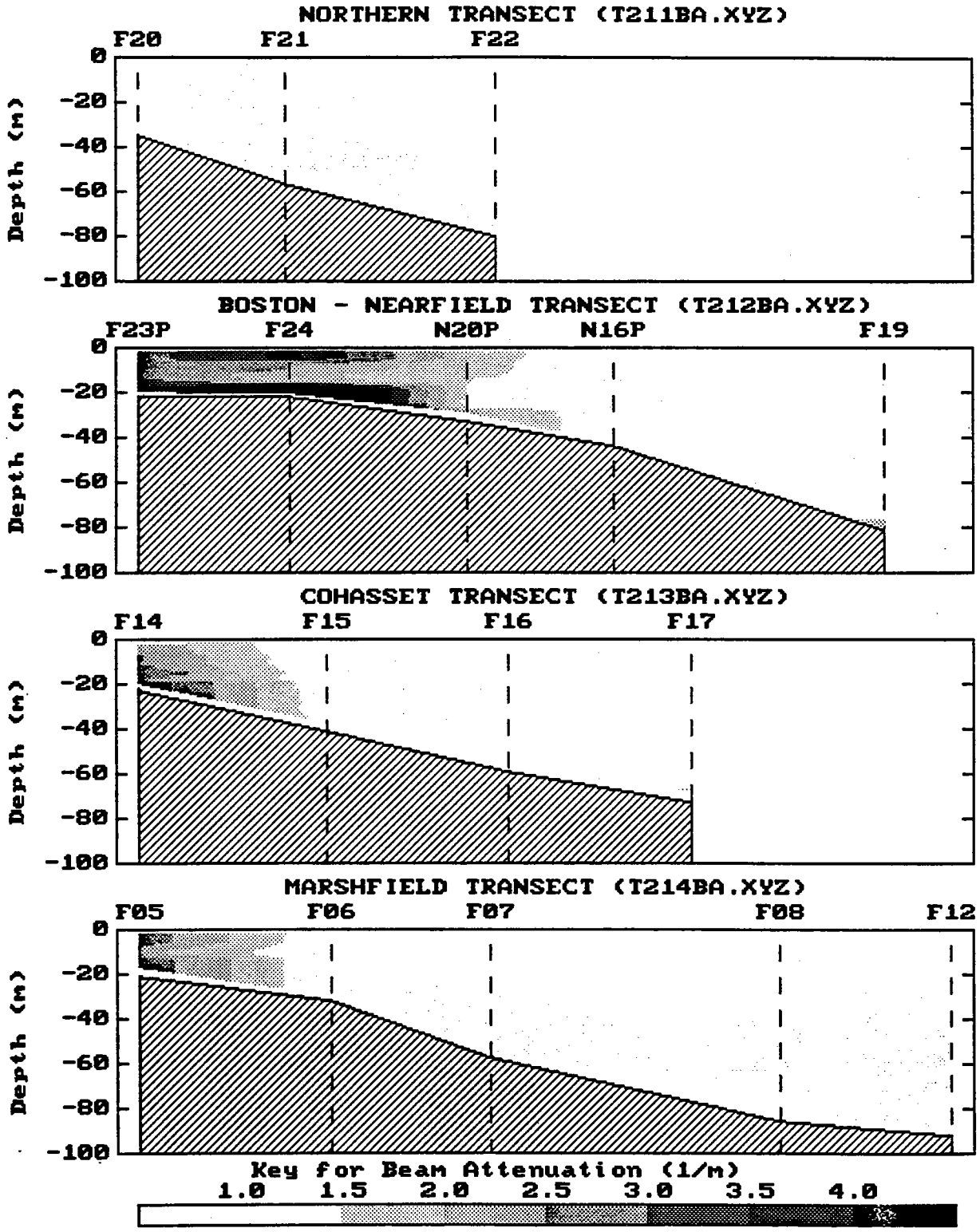


Figure 4-12b. Vertical section contours of beam attenuation in February 1993 for standard transects (see Figure 4-9). The data used to produce contours are from high-resolution continuous vertical profiles taken from the downcast at each station.

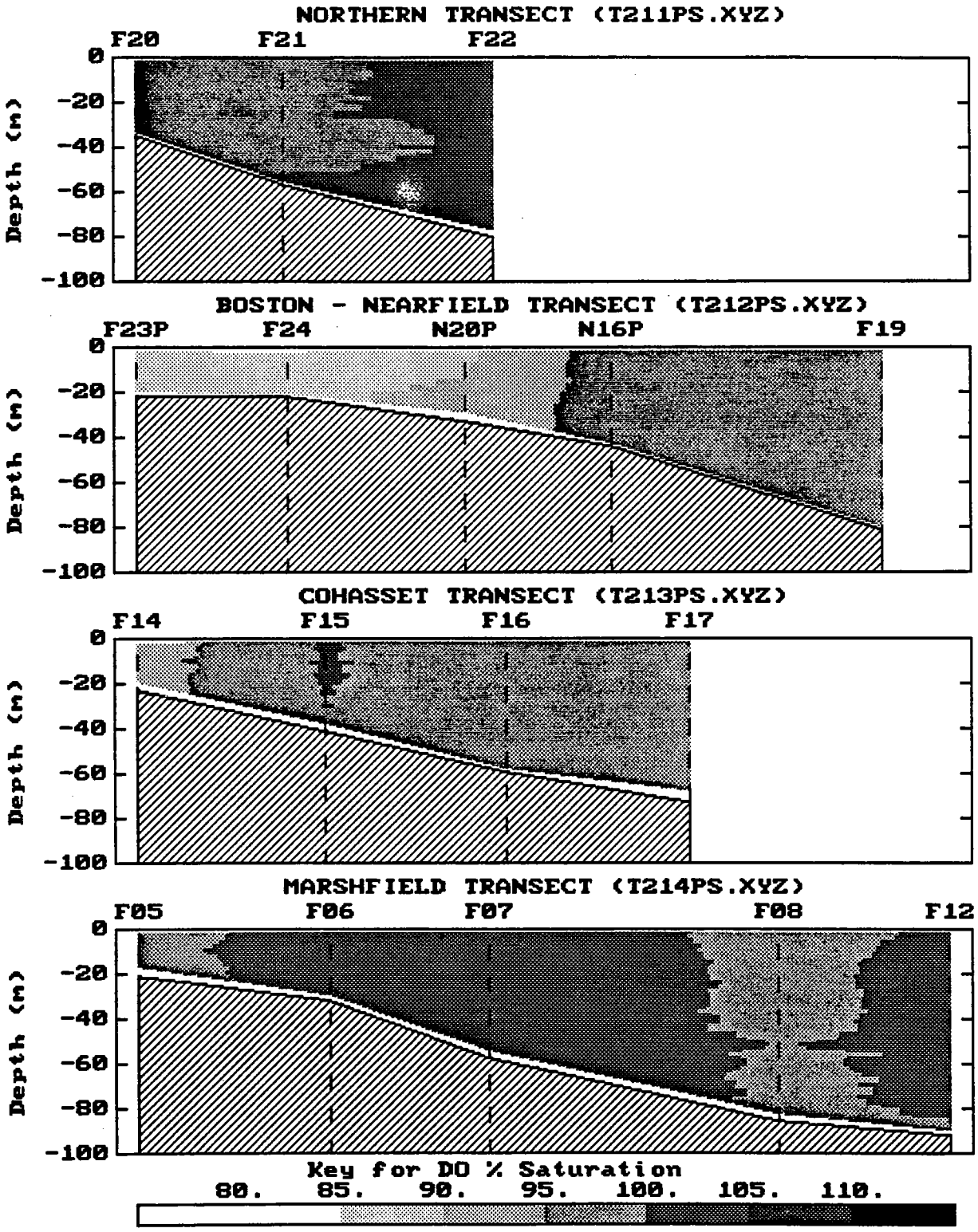


Figure 4-12c. Vertical section contours of dissolved oxygen (% saturation) in February 1993 for standard transects (see Figure 4-9). The data used to produce contours are from high-resolution continuous vertical profiles taken from the downcast at each station.

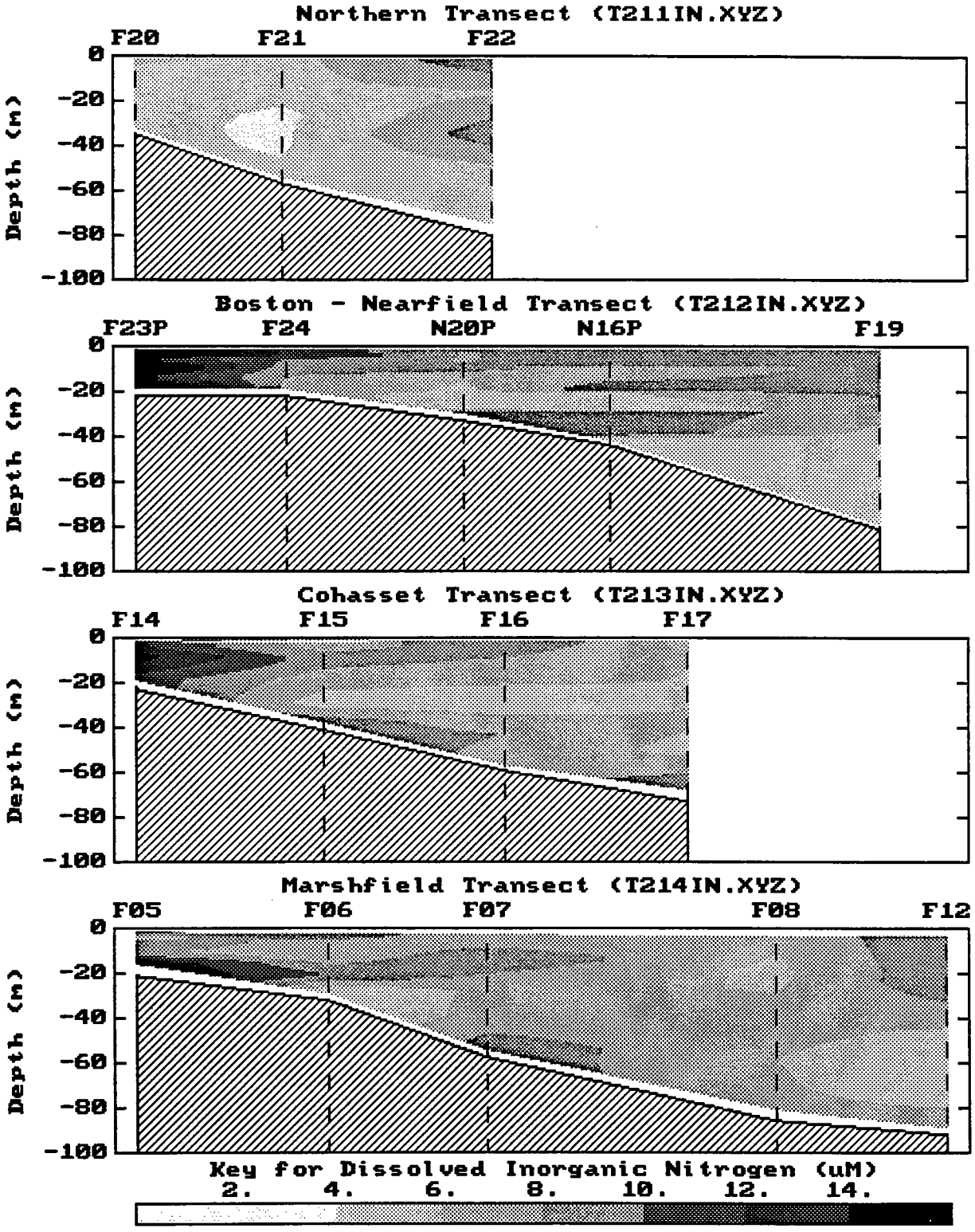


Figure 4-13. Vertical section contours of dissolved inorganic nitrogen (DIN, μM) in February 1993 for standard transects (see Figure 4-9). The data used to produce contours are from discrete bottle samples as given in Appendix A.

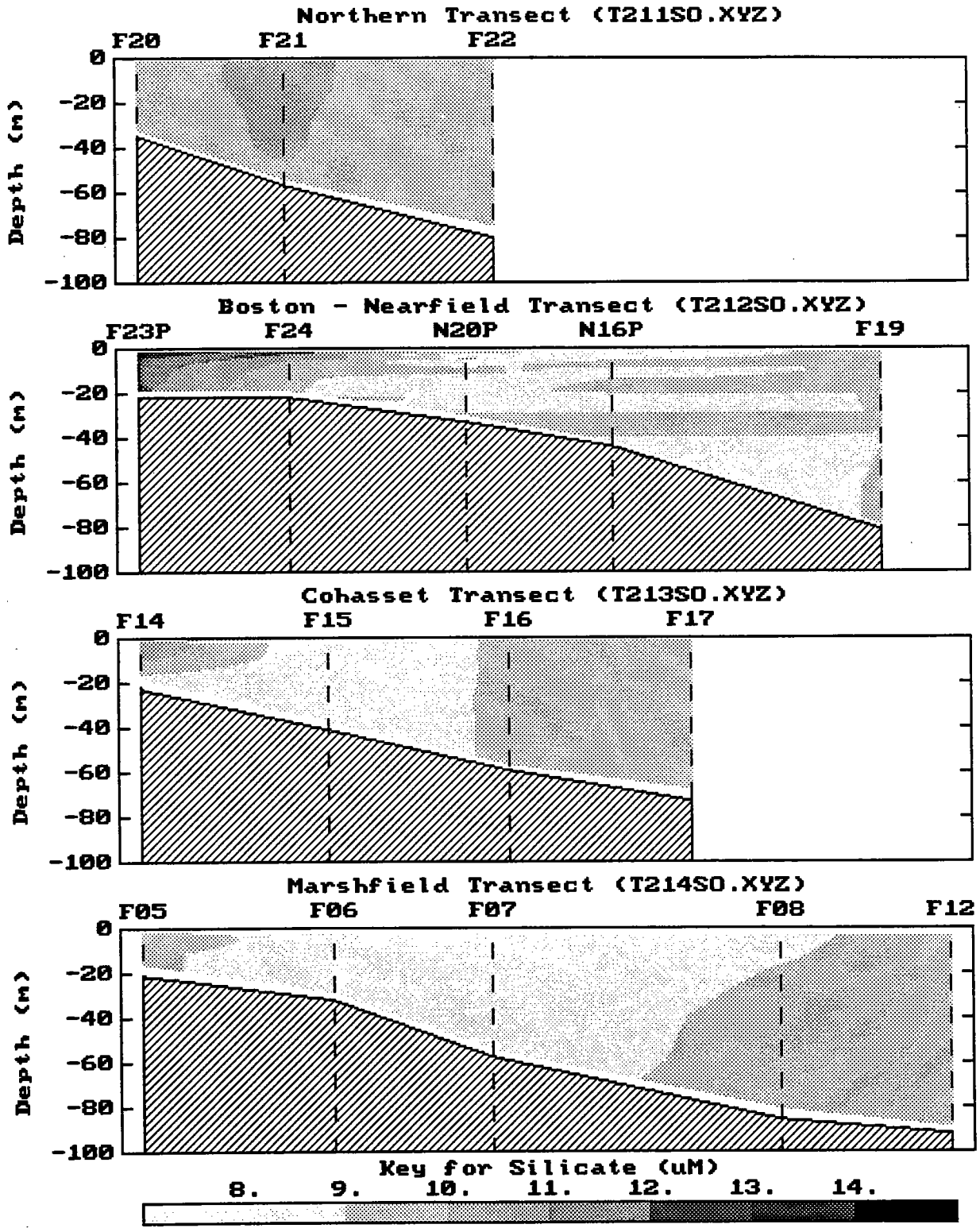


Figure 4-14. Vertical section contours of silicate (SiO_4, μM) in February 1993 for standard transects (see Figure 4-9). The data used to produce contours are from discrete bottle samples as given in Appendix A.

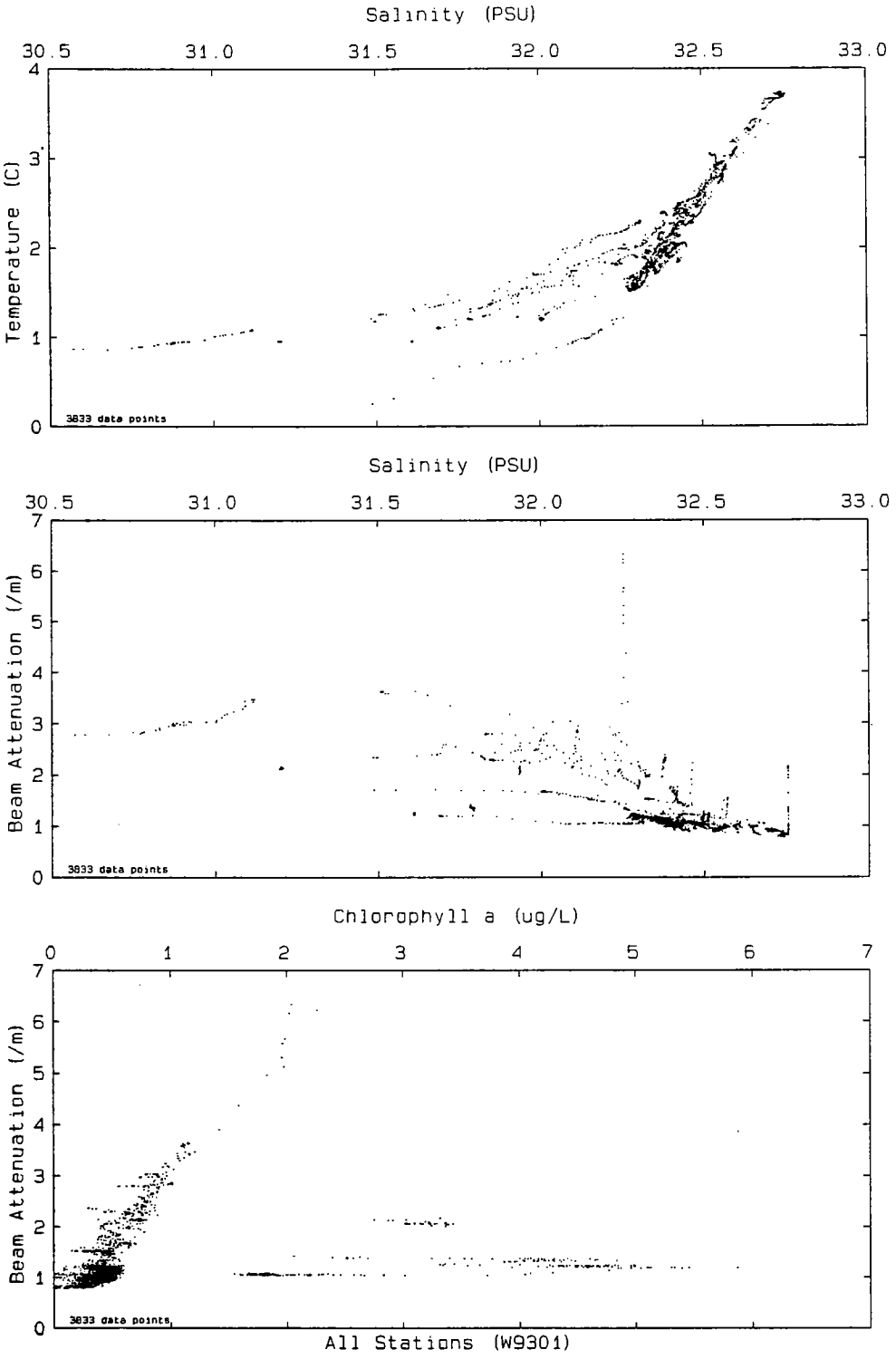


Figure 4-15a. Scatter plots of data acquired by *in situ* sensor package during vertical casts at all farfield and nearfield stations occupied in February 1993. Regional plots are in Appendix C.

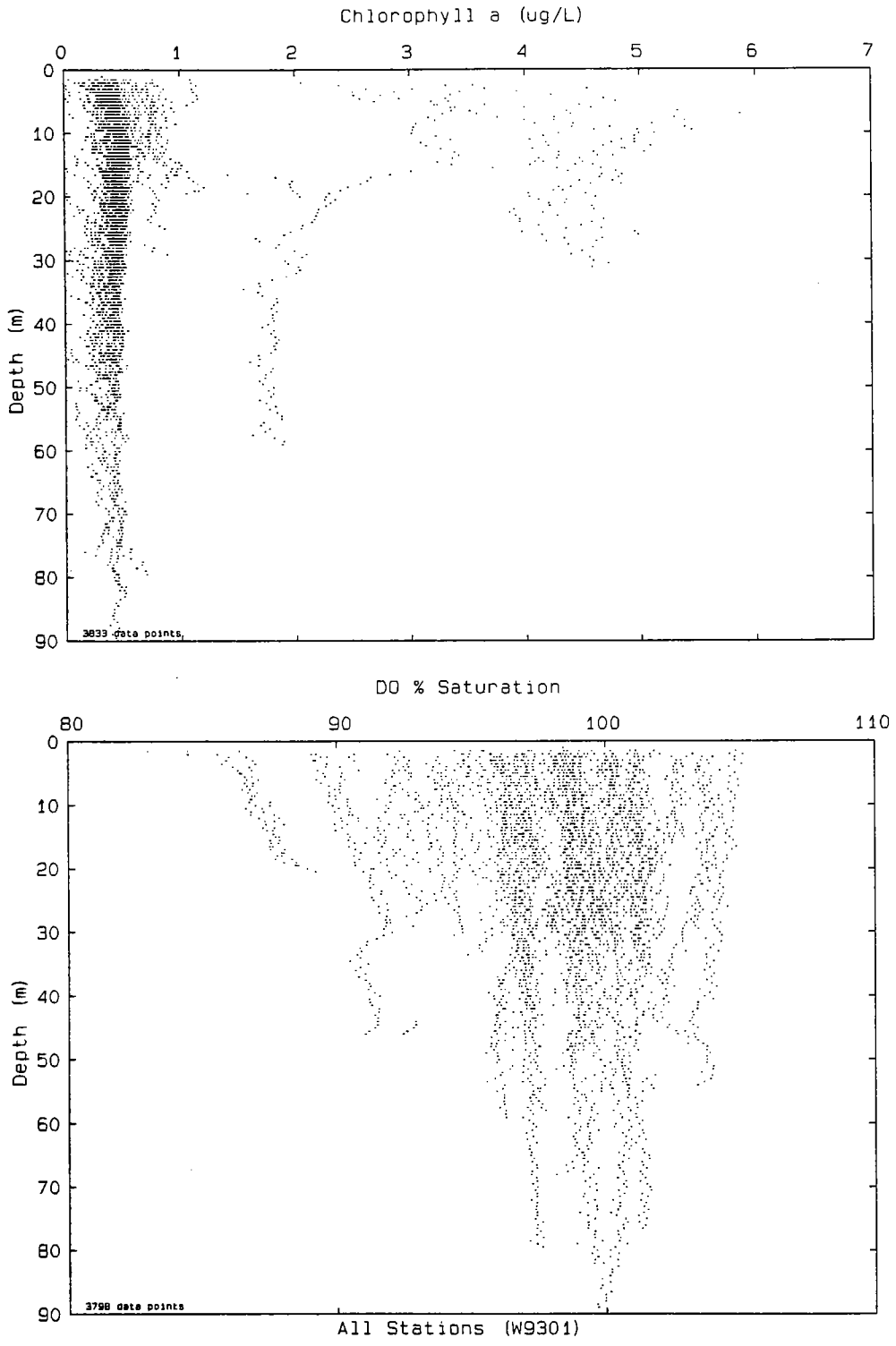


Figure 4-15b. Scatter plots of data acquired by *in situ* sensor package during vertical casts at all farfield and nearfield stations occupied in February 1993. Regional plots are in Appendix C.

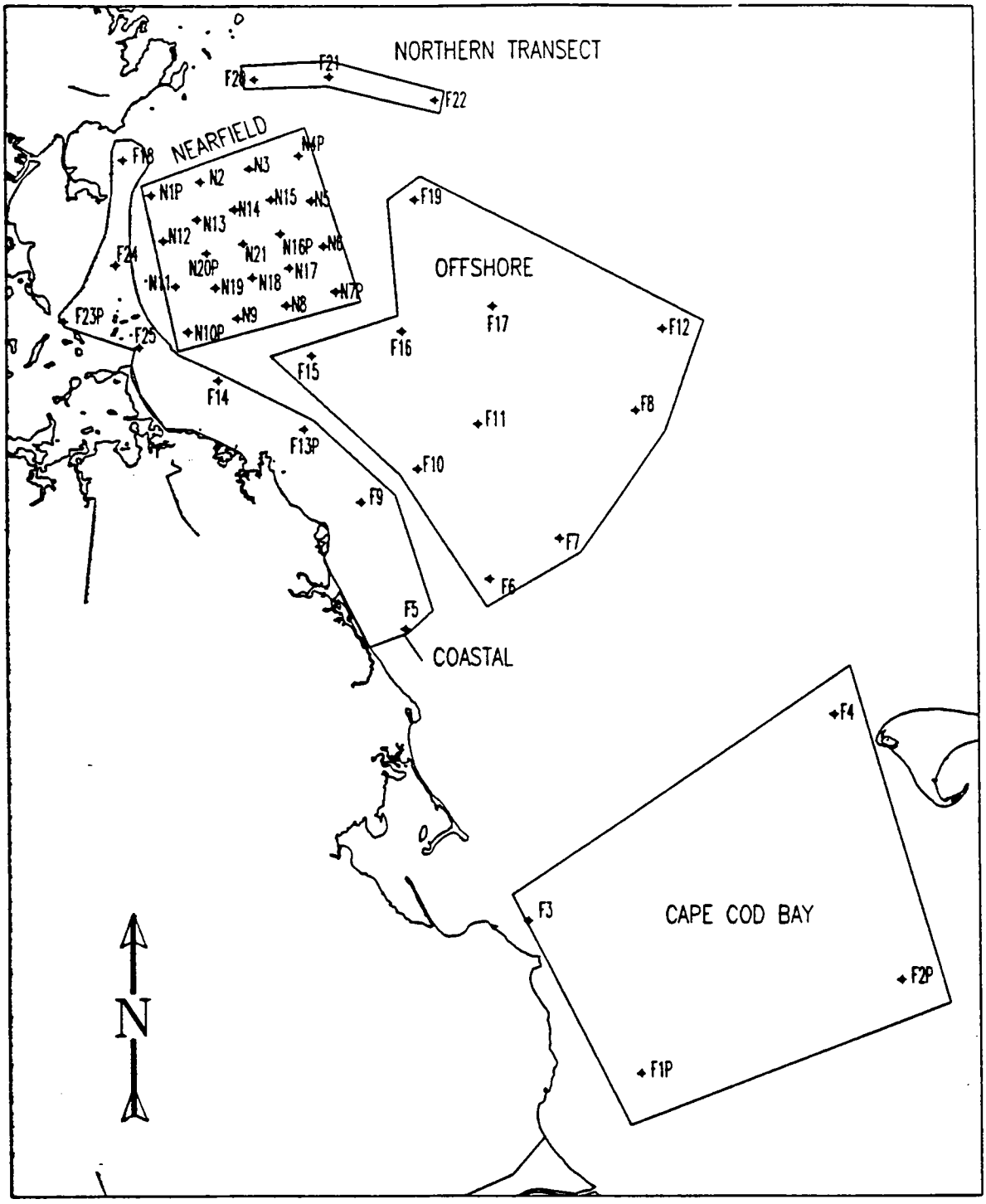


Figure 4-16. **Map to show station groups designated in Figures 4-17 through 4-22. Massachusetts Bay stations were separated into four groups based on water depth and geographic position; Cape Cod Bay has four stations.**

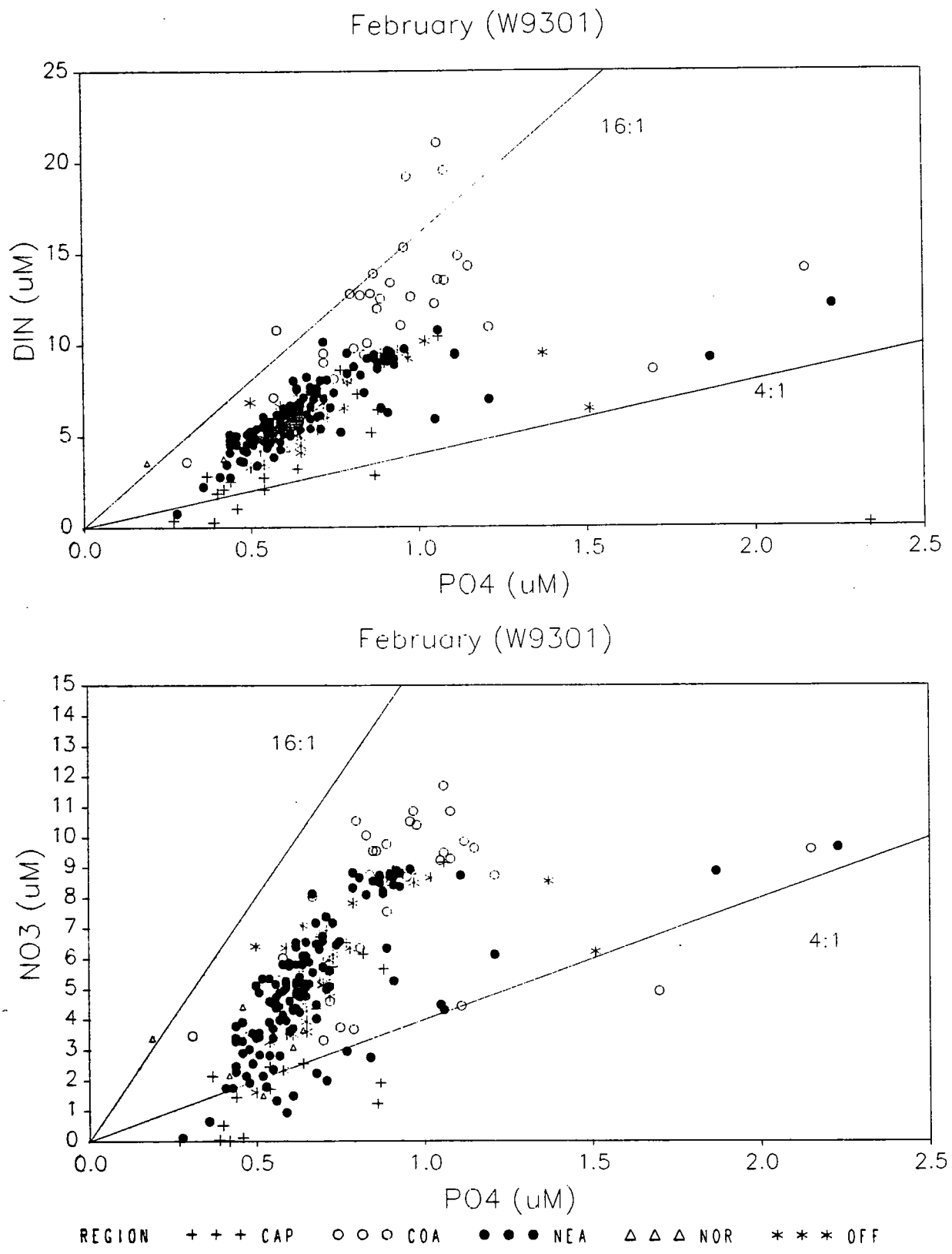


Figure 4-17. **Scatter plots of nitrogen forms vs. phosphate during February 1993. All stations and depths are included, and data are given in Appendix A. Lines show constant proportions of nitrogen relative to phosphorous.**

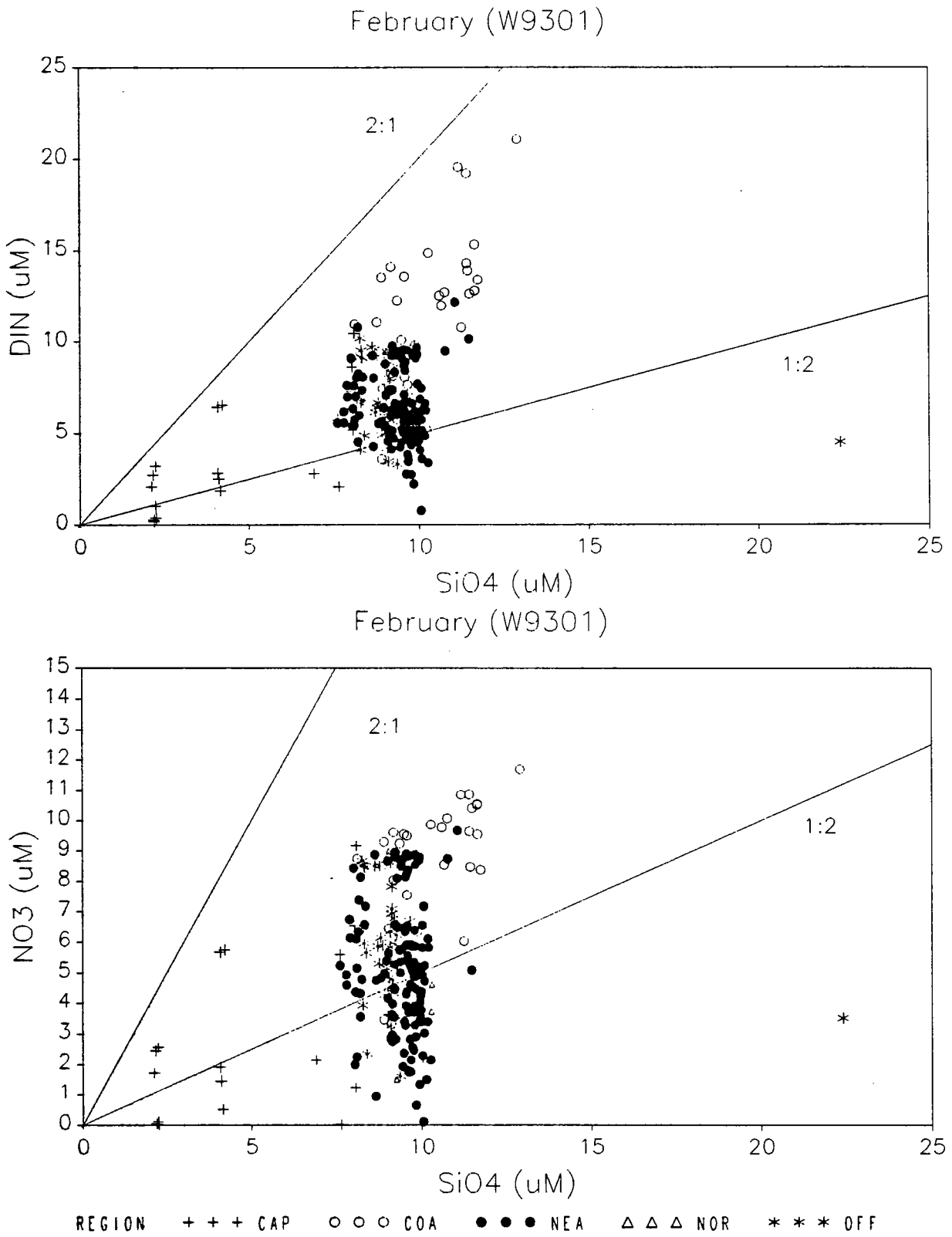


Figure 4-18. Scatter plots of nitrogen forms vs. silicate during February 1993. All stations and depths are included, and data are given in Appendix A. Lines show constant proportions of nitrogen relative to silicate.

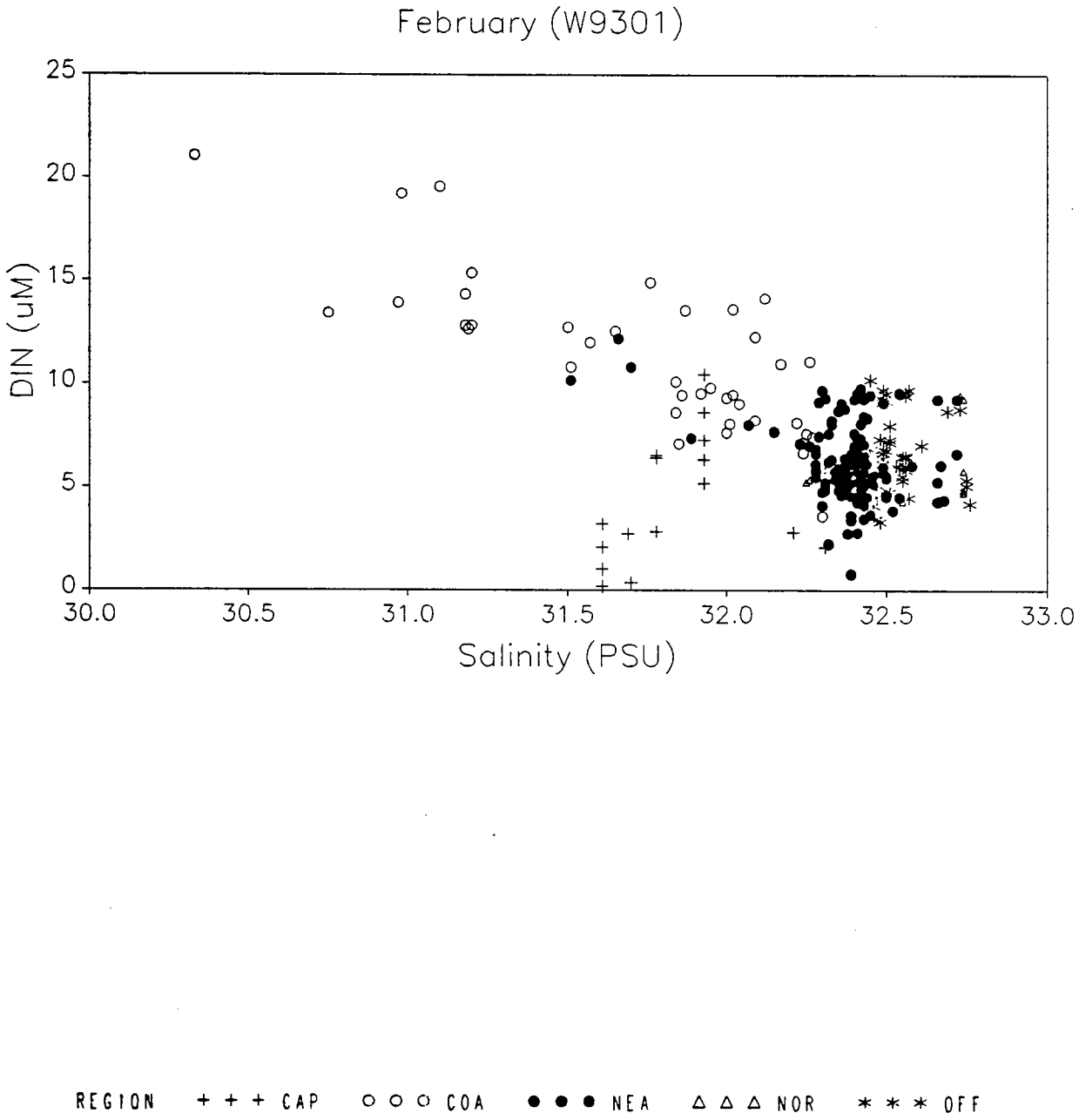


Figure 4-19. **Dissolved inorganic nitrogen vs. salinity in February 1993. All stations and depths are included, and data are given in Appendix A.**

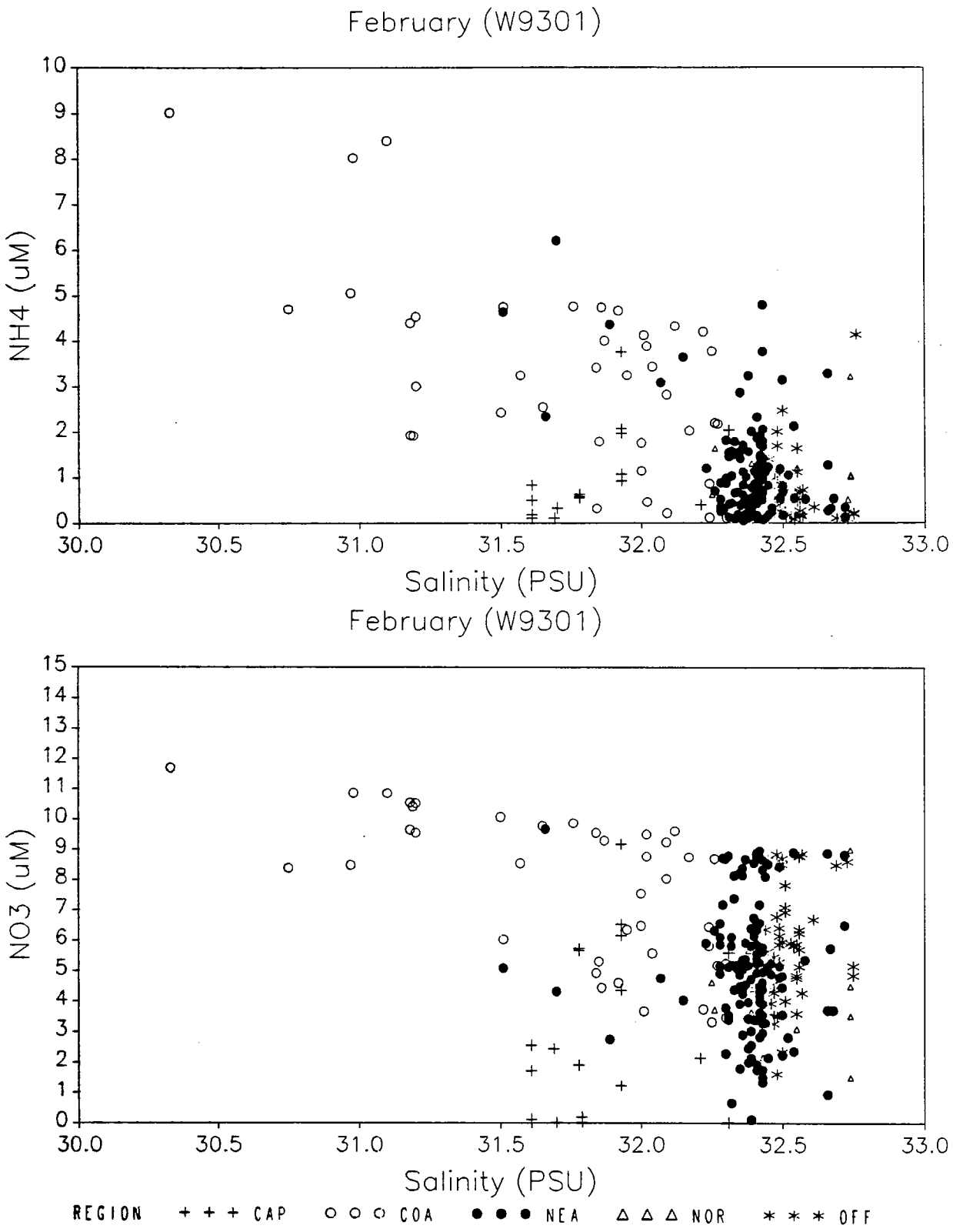


Figure 4-20. **Ammonia and nitrate vs. salinity in February 1993. All stations and depths are included, and data are given in Appendix A.**

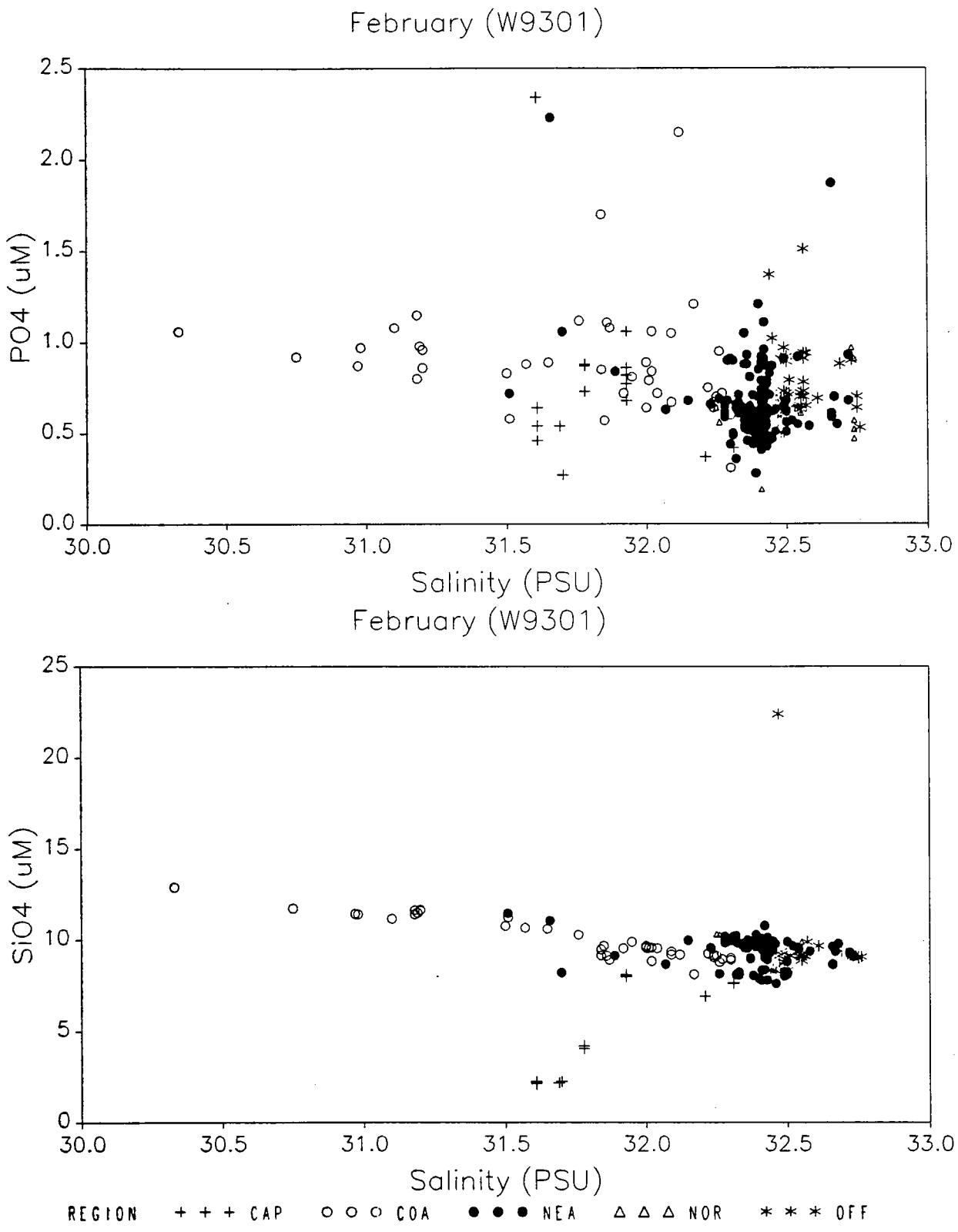


Figure 4-21. Phosphate and silicate vs. salinity in February 1993. All stations and depths are included, and data are given in Appendix A.

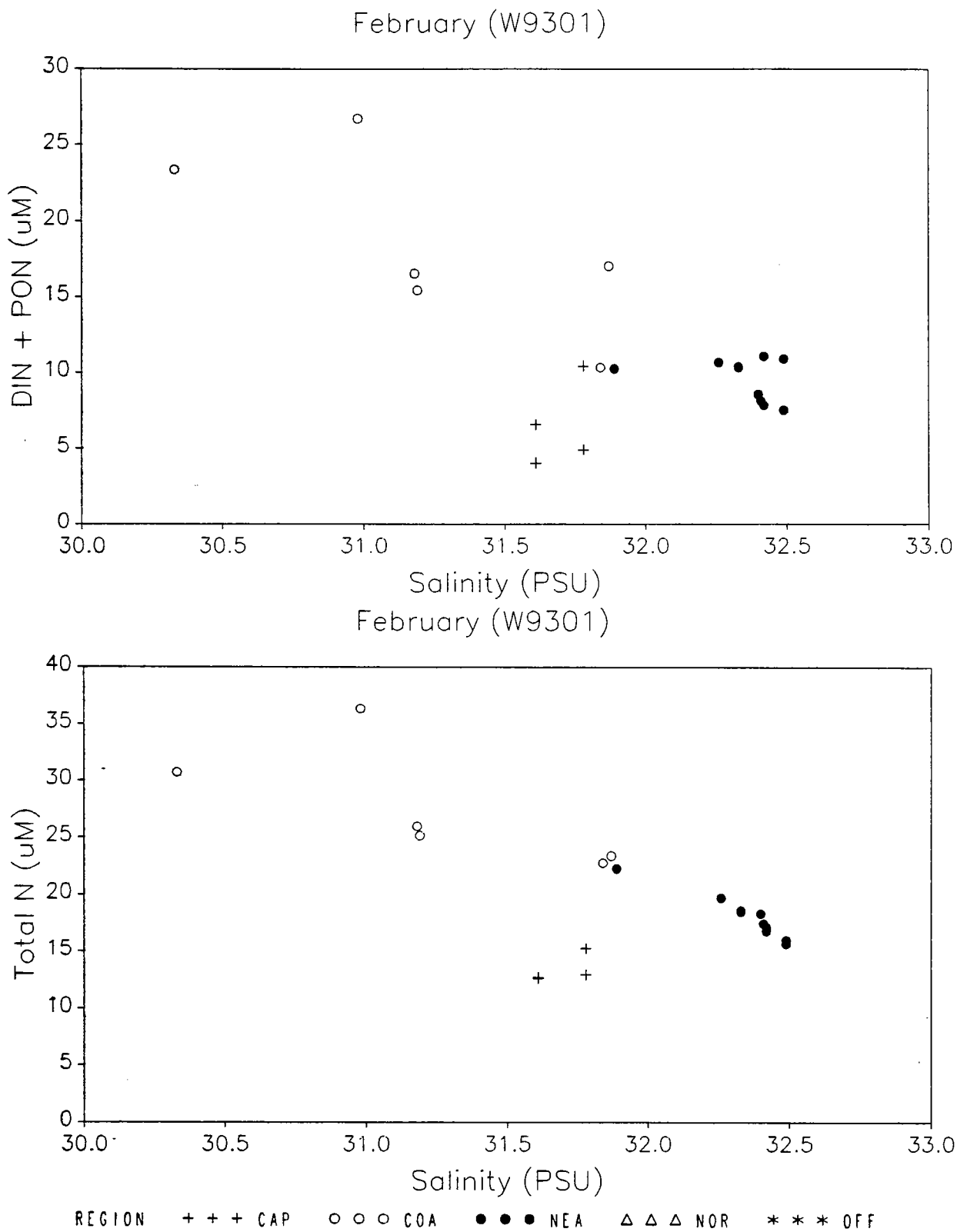


Figure 4-22. **Nitrogen forms vs. salinity in February 1993. Data are from BioProductivity stations and special station F25 and are given in Appendix A. The station groups are coded as given in Figure 4-16; there are no BioProductivity stations in the offshore or northern transect groups. Dissolved inorganic nitrogen = DIN, particulate organic nitrogen = PON, and total nitrogen (TN) = total dissolved nitrogen (TDN) + PON.**

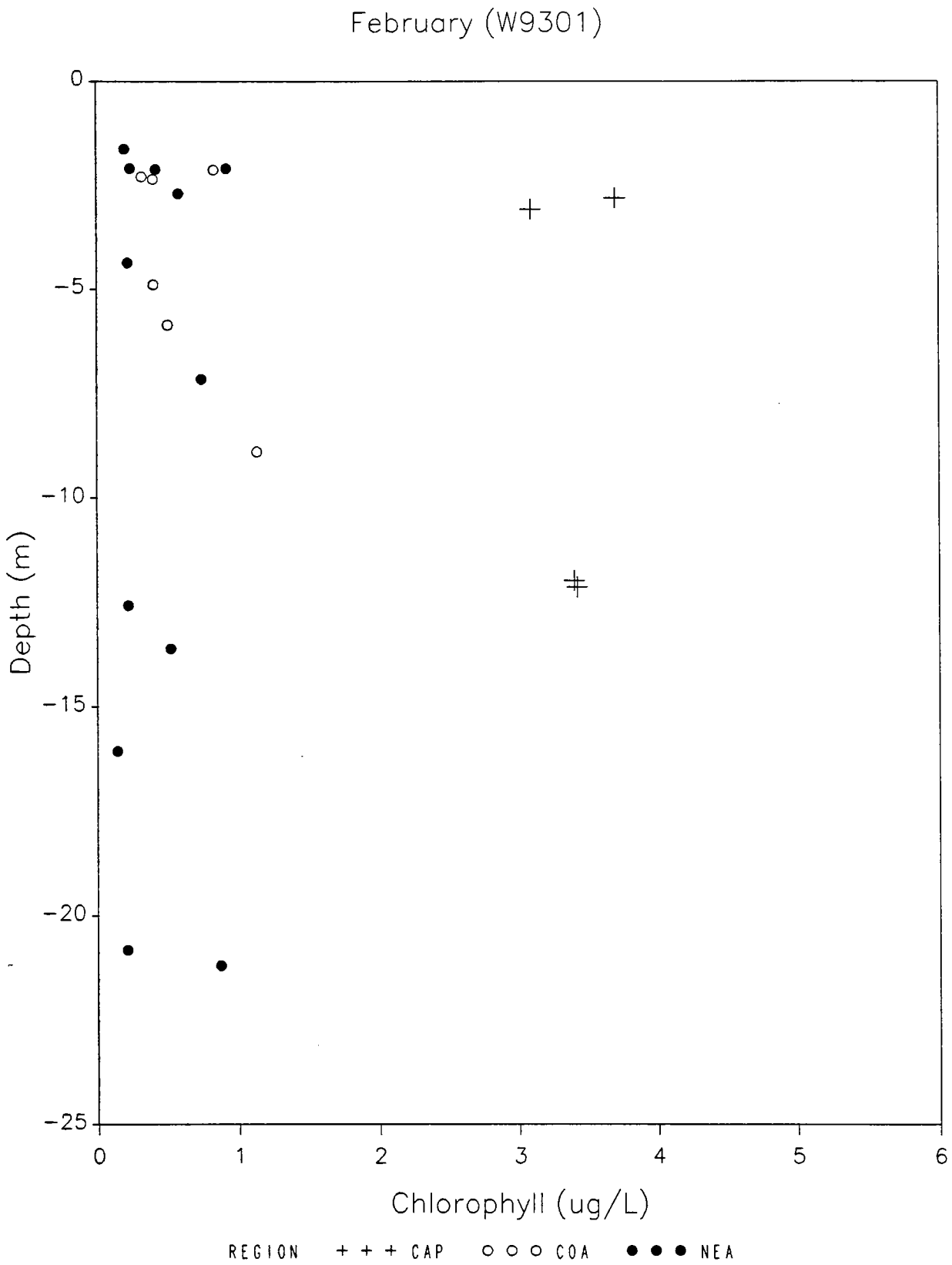


Figure 4-23. Surface and deeper chlorophyll (extracted samples) at BioProductivity stations and special station F25 as a function of depth in February 1993.

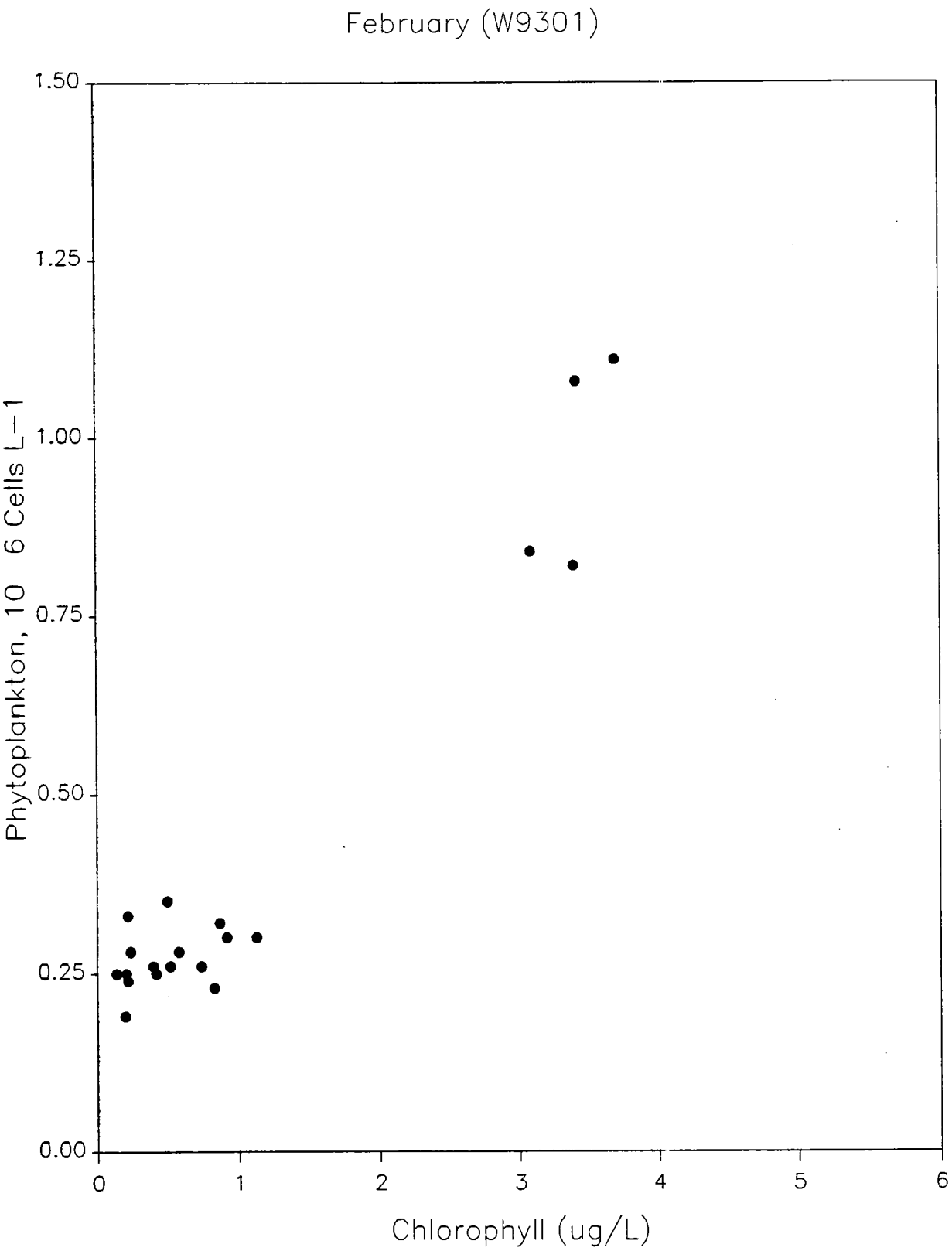


Figure 4-24. **Total phytoplankton abundance vs. chlorophyll (extracted samples) at BioProductivity stations in February 1993. Data are given in Appendices A and F.**

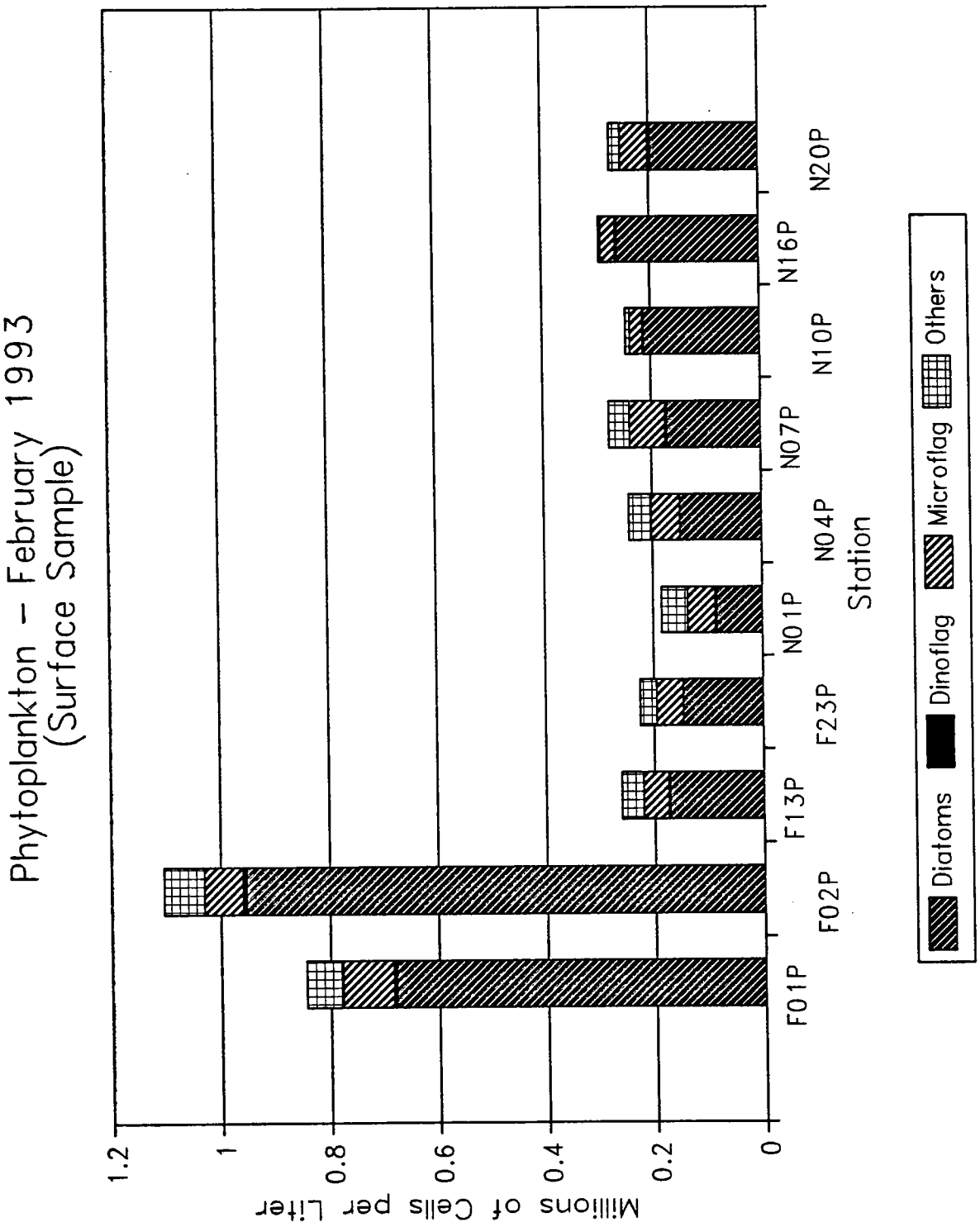


Figure 4-25. **Total phytoplankton abundance, by taxonomic groups, at BioProductivity stations in February 1993. Data are given in Appendix F.**

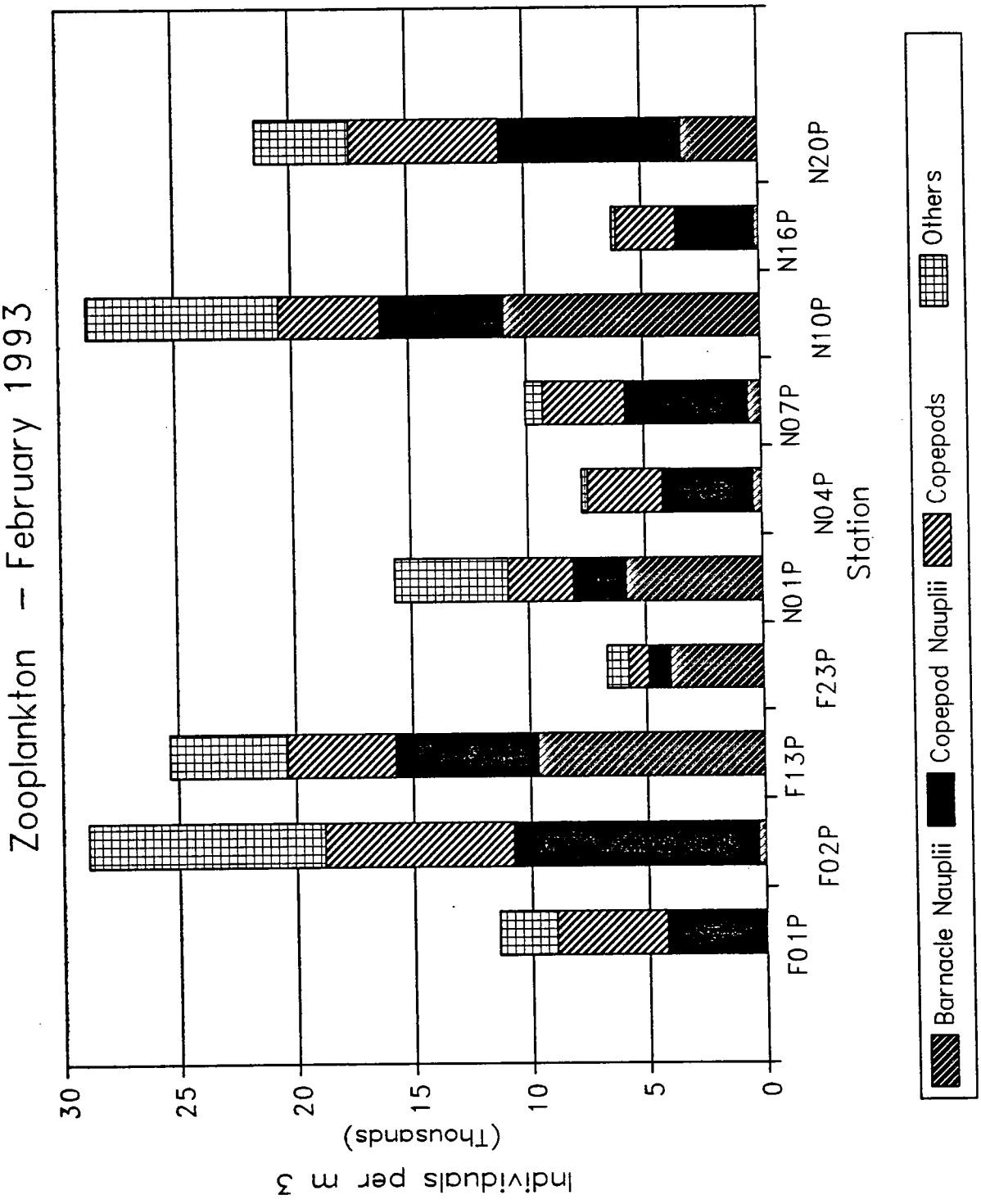


Figure 4-26. **Zooplankton abundance, by groups, at BioProductivity stations in February 1993. Data are given in Appendix G.**

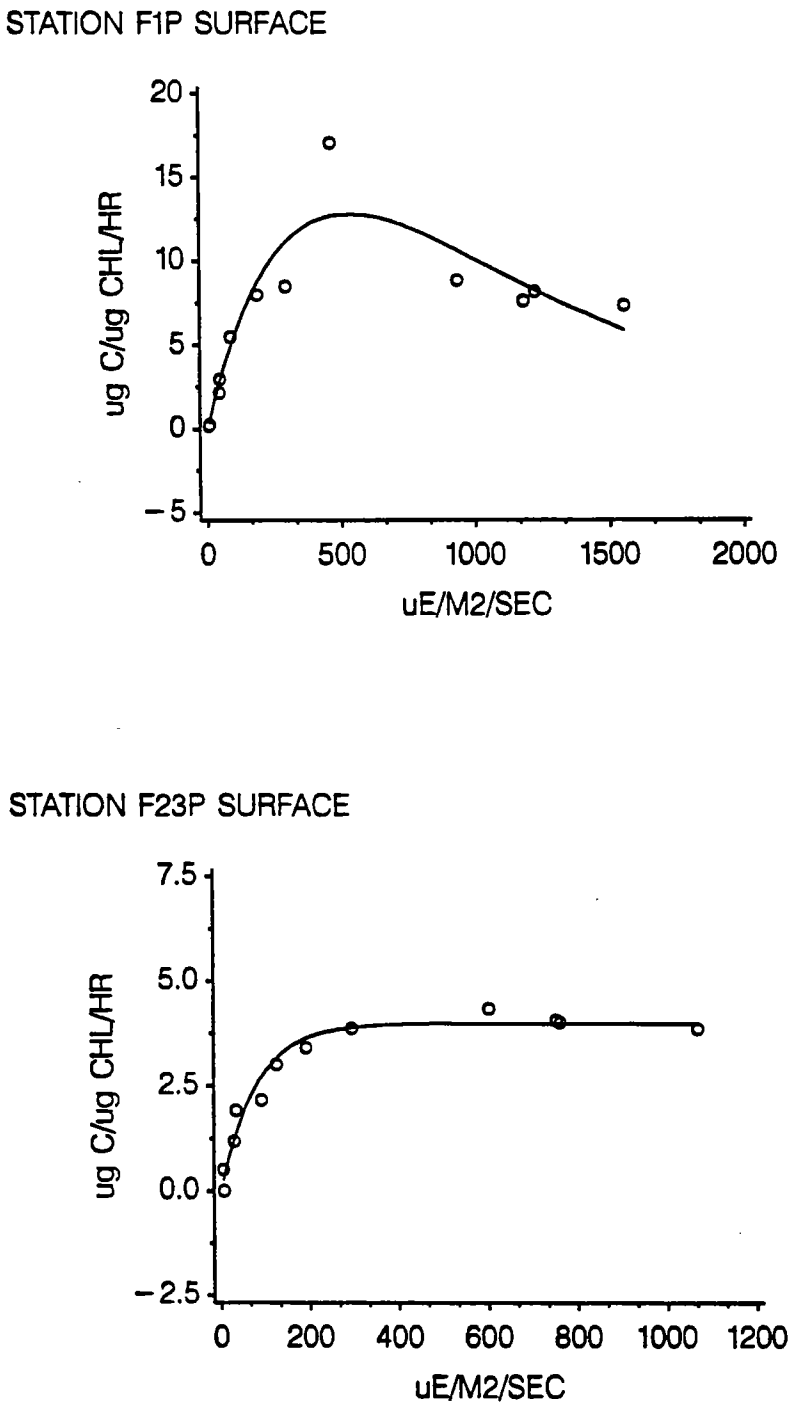


Figure 4-27. **Selected net production (P) vs. irradiance (I) curves in February 1993. Data are chlorophyll-normalized rates, see Appendix E.**

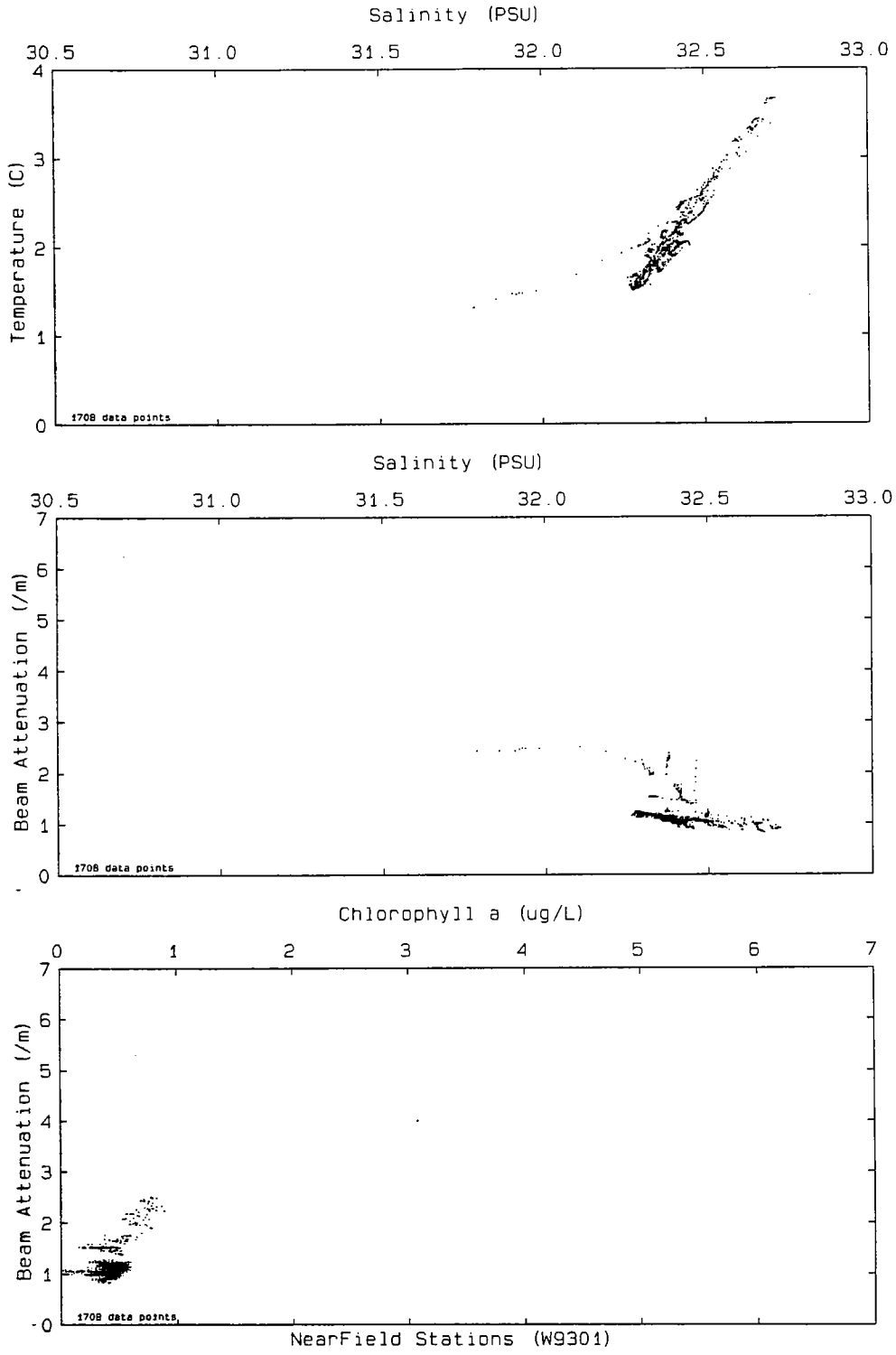


Figure 4-28. Scatter plots for nearfield stations in February 1993. Compare to Figure 4-15.

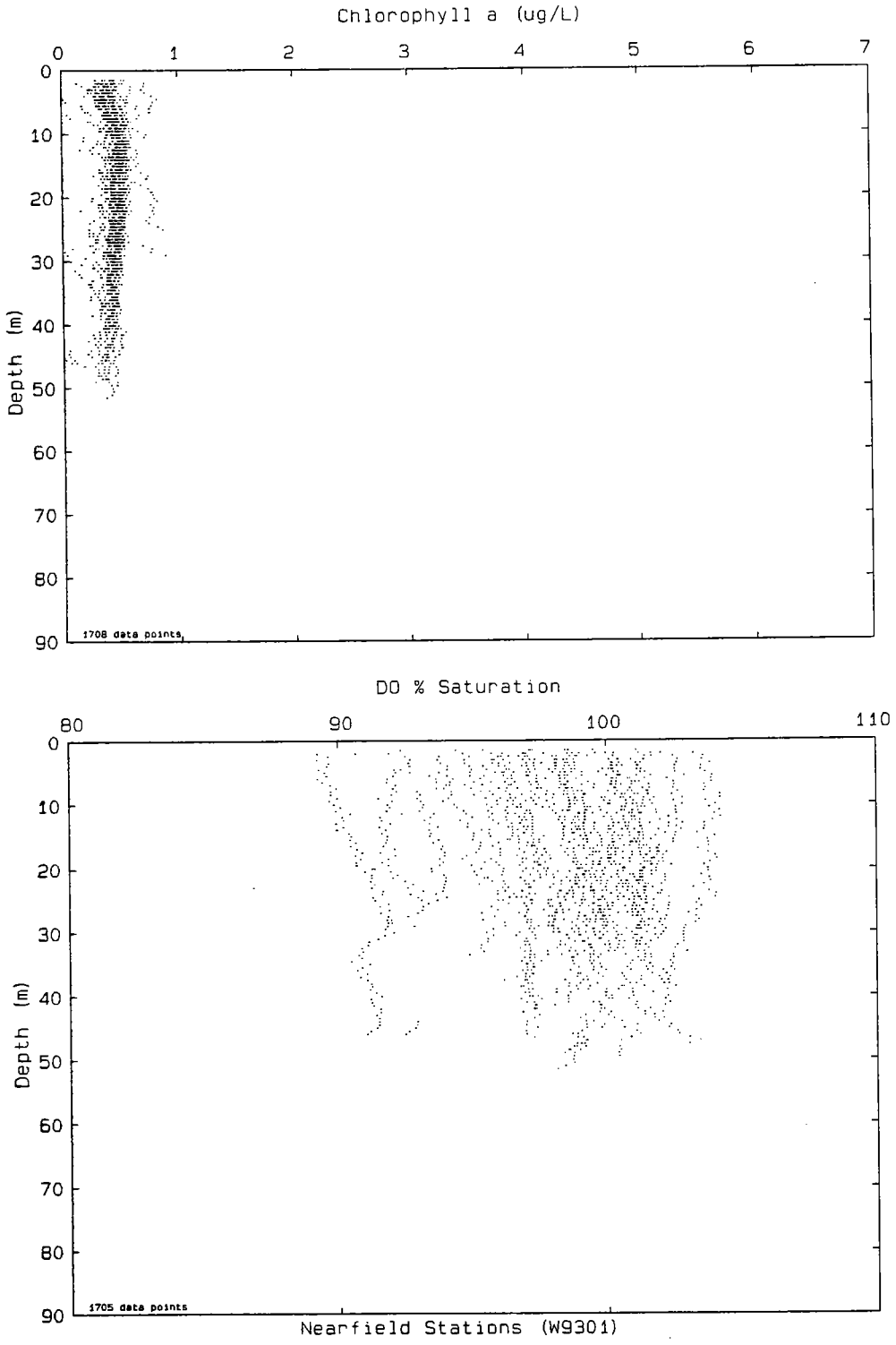


Figure 4-29. Scatter plots for nearfield stations in February 1993. Compare to Figure 4-15.

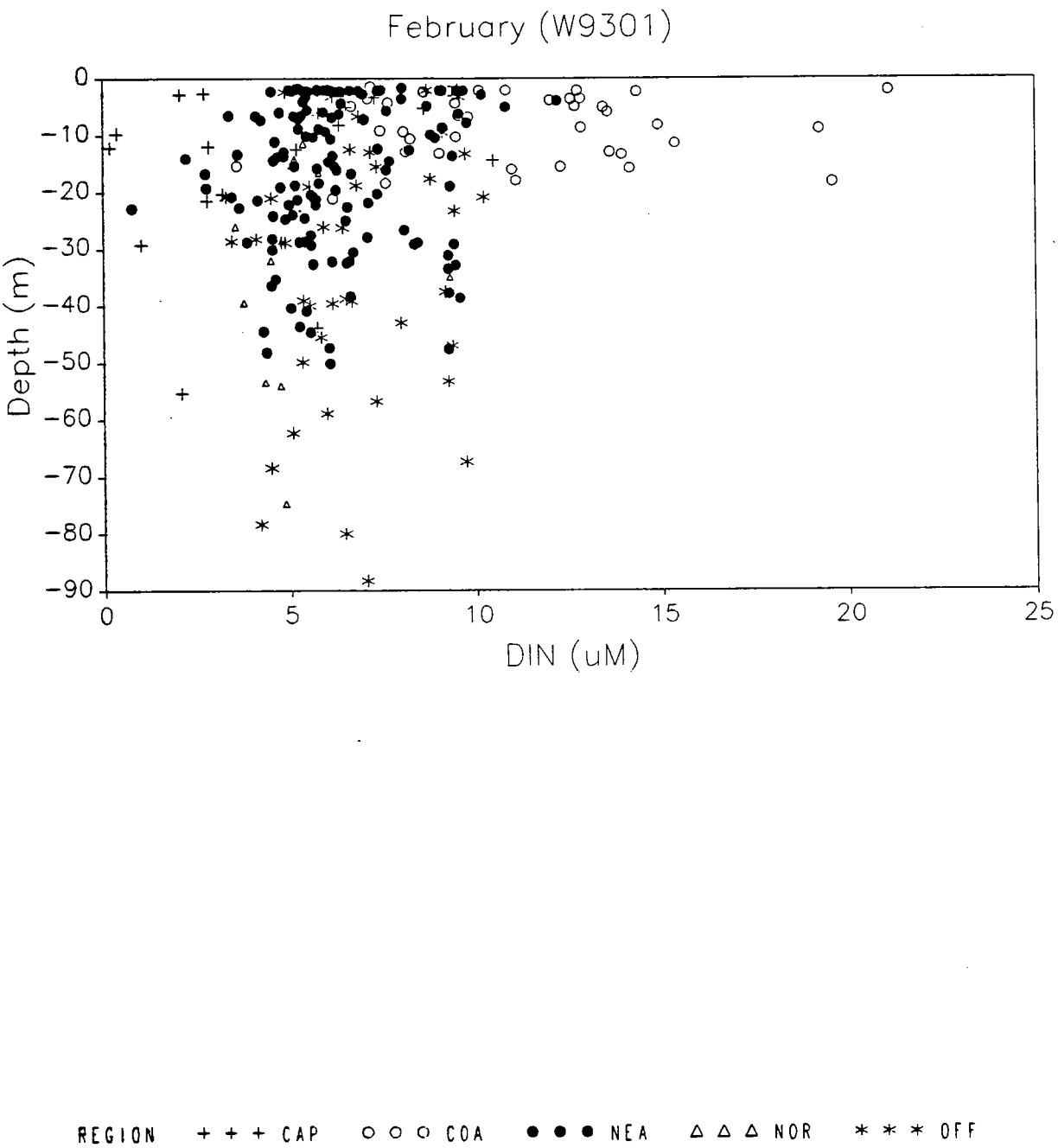


Figure 4-30a. DIN vs. depth in February 1993.

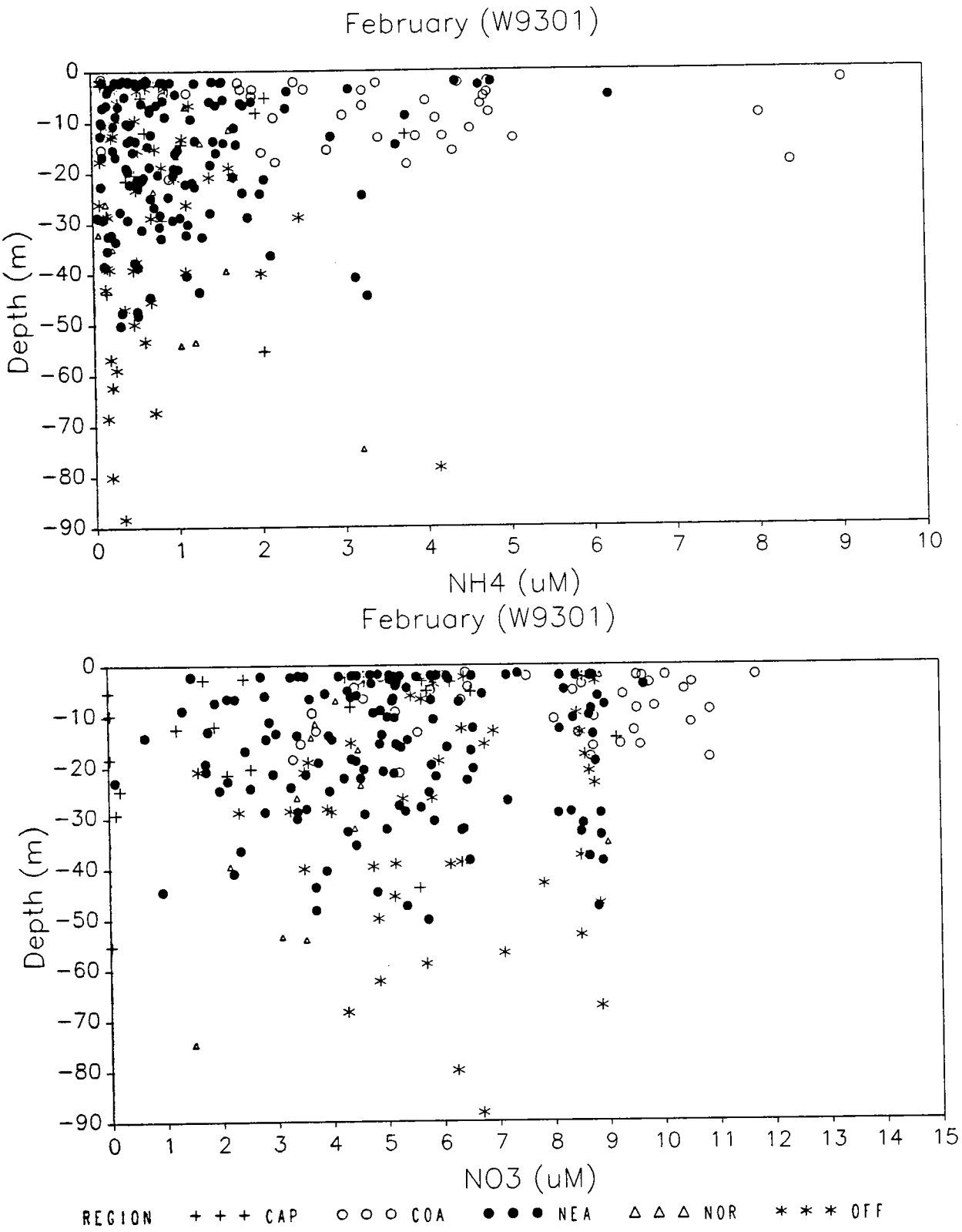


Figure 4-30b. NH_4 and NO_3 vs. depth in February 1993.

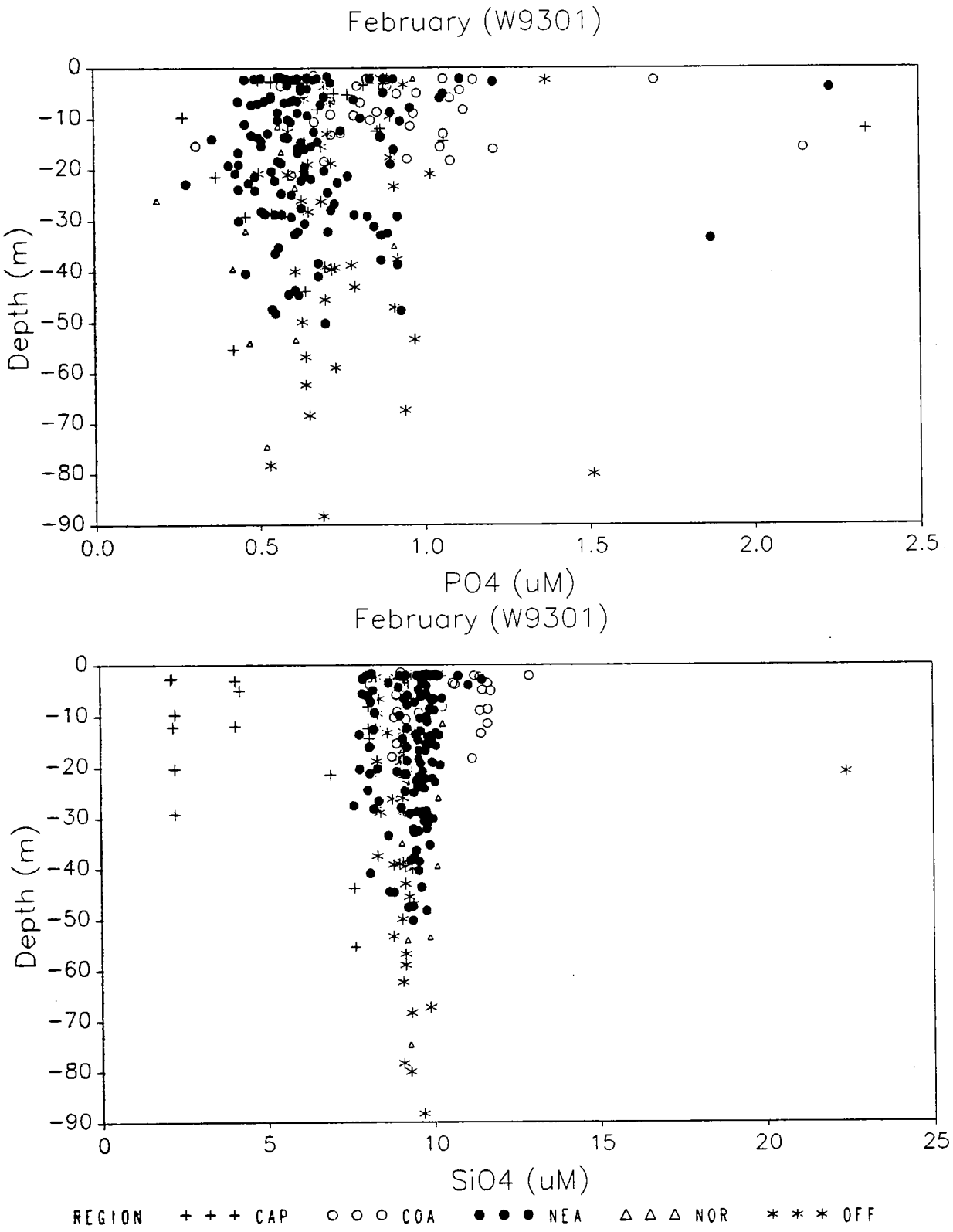


Figure 4-30c. PO_4 and SiO_4 vs. depth in February 1993.

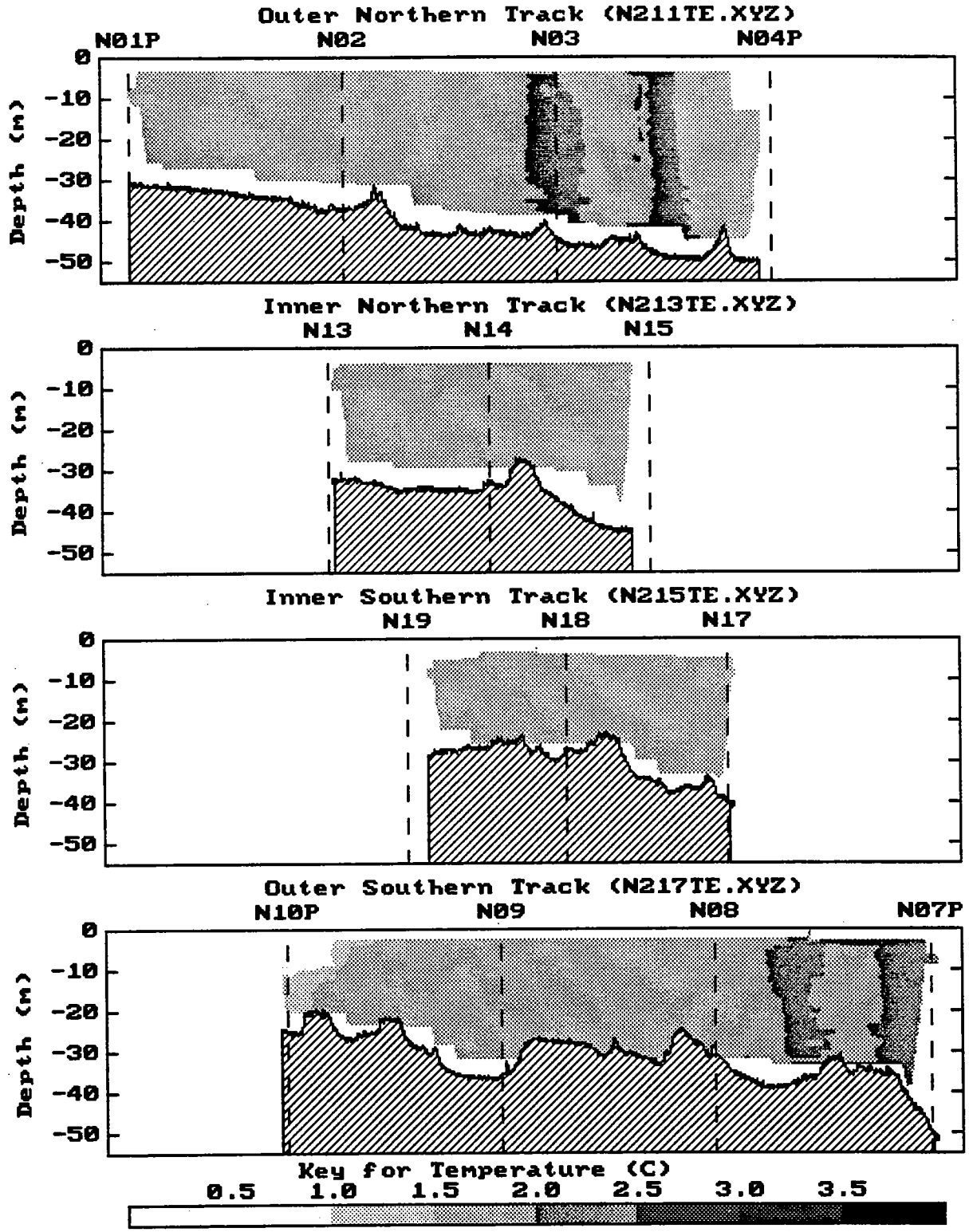


Figure 4-31a. Vertical section contours of temperature generated for tow-yos in February 1993. The view is towards the North.

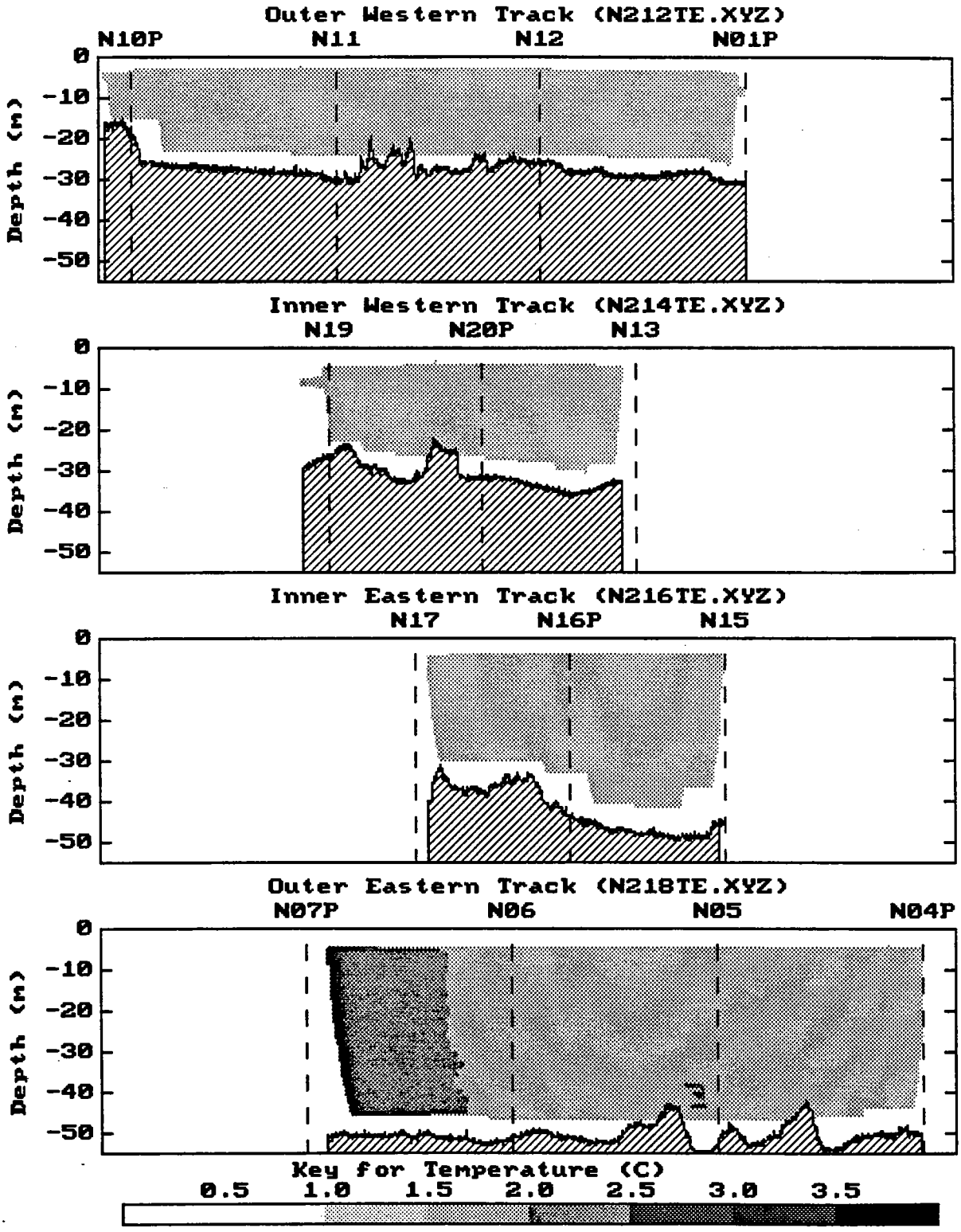


Figure 4-31b. Vertical section contours of temperature generated for tow-yos in February 1993. The view is towards Boston Harbor.

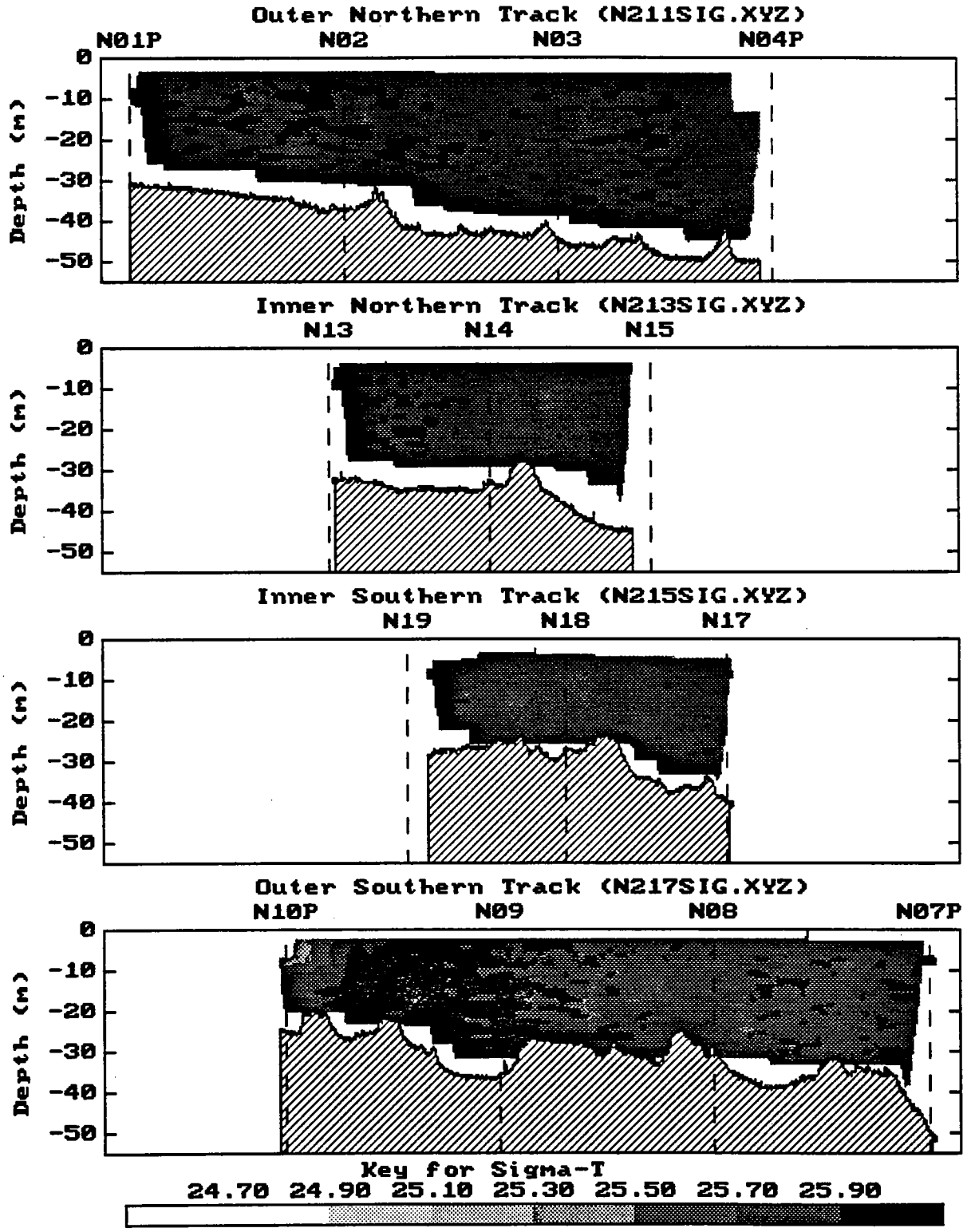


Figure 4-32a. Vertical section contours of σ_T generated for tow-yos in February 1993. The view is towards the North.

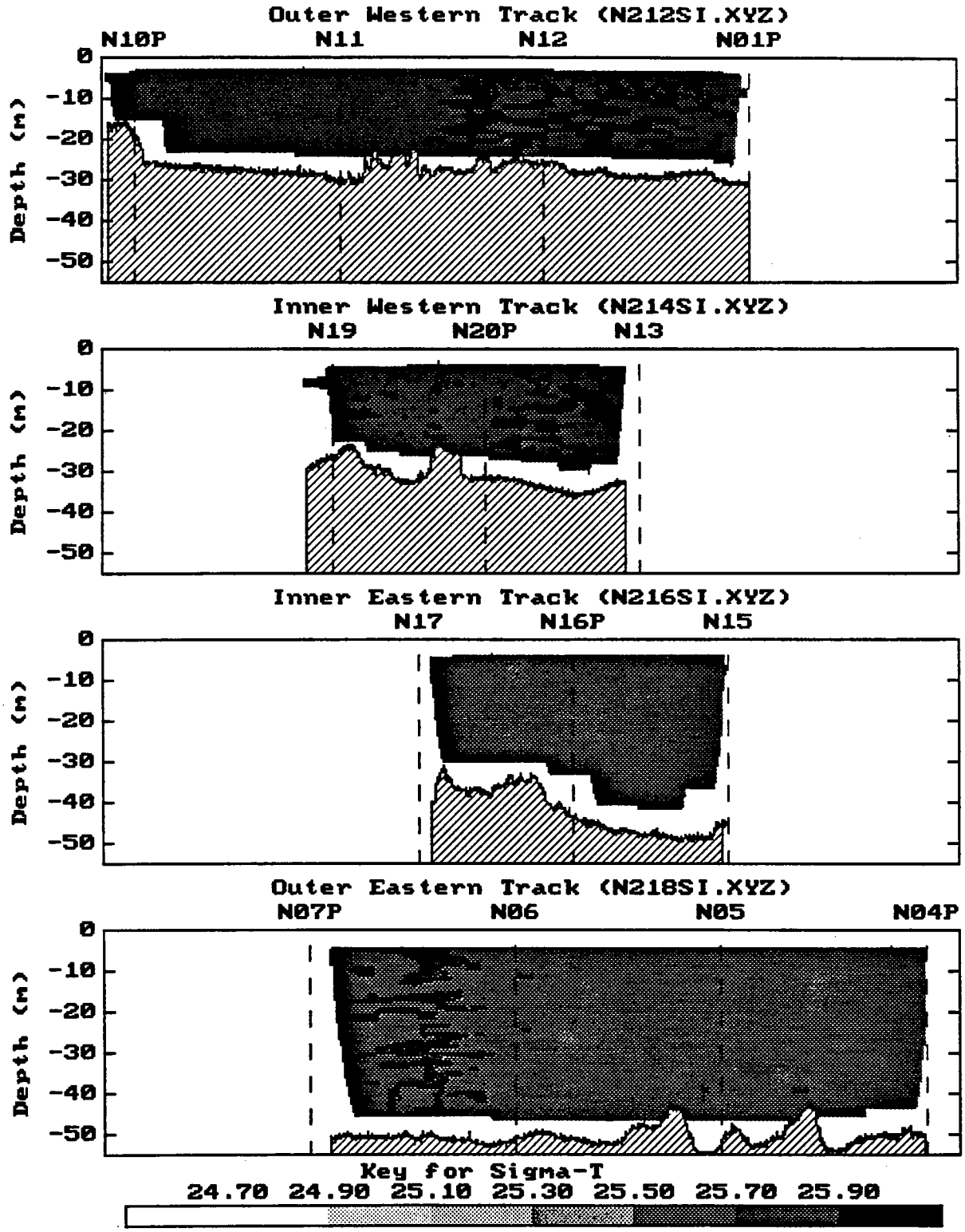


Figure 4-32b. Vertical section contours of σ_T generated for tow-yos in February 1993. The view is towards Boston Harbor.

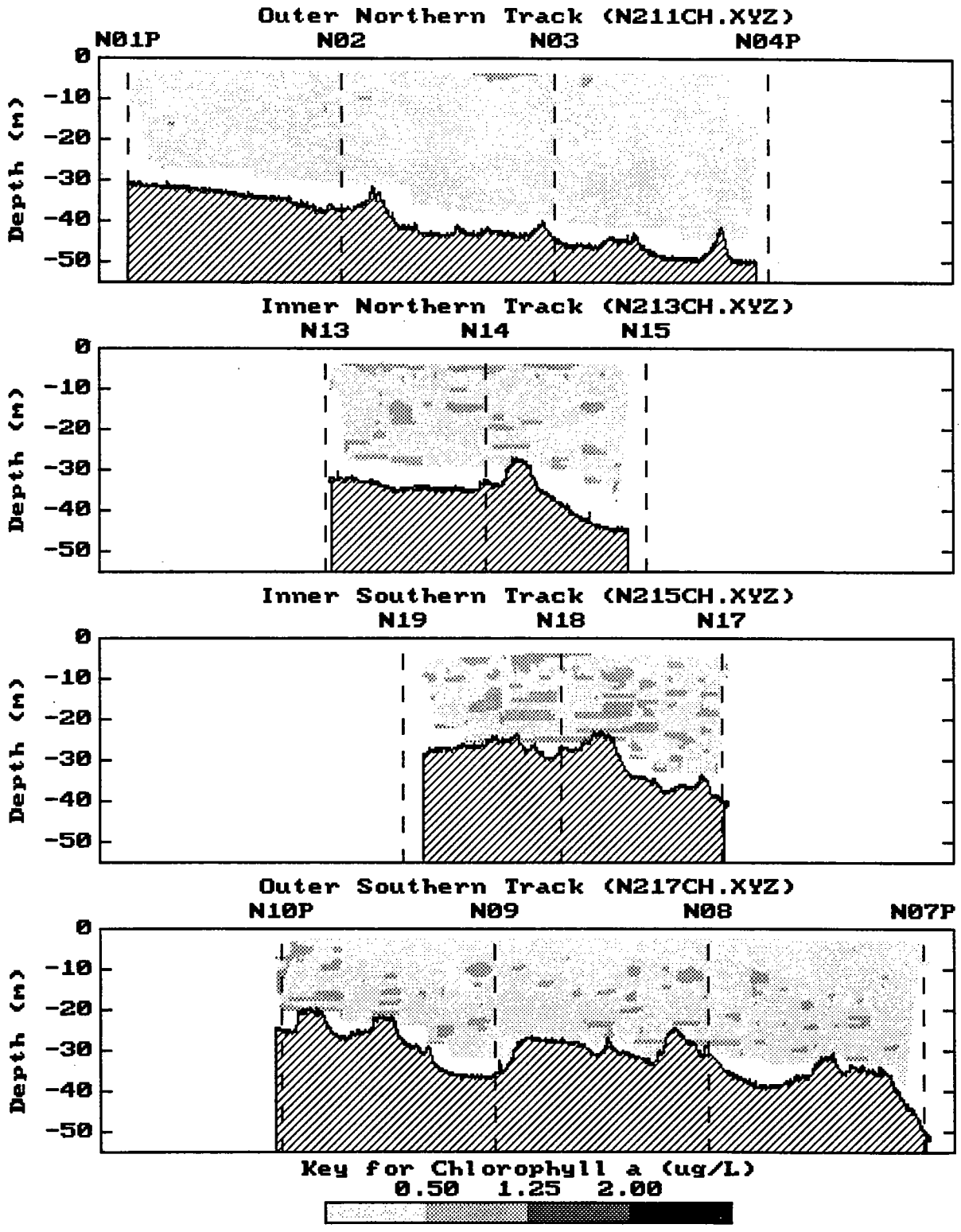


Figure 4-33a. Vertical section contours of fluorescence (as μg Chl L^{-1}) generated for tow-yos in February 1993. The view is towards the North.

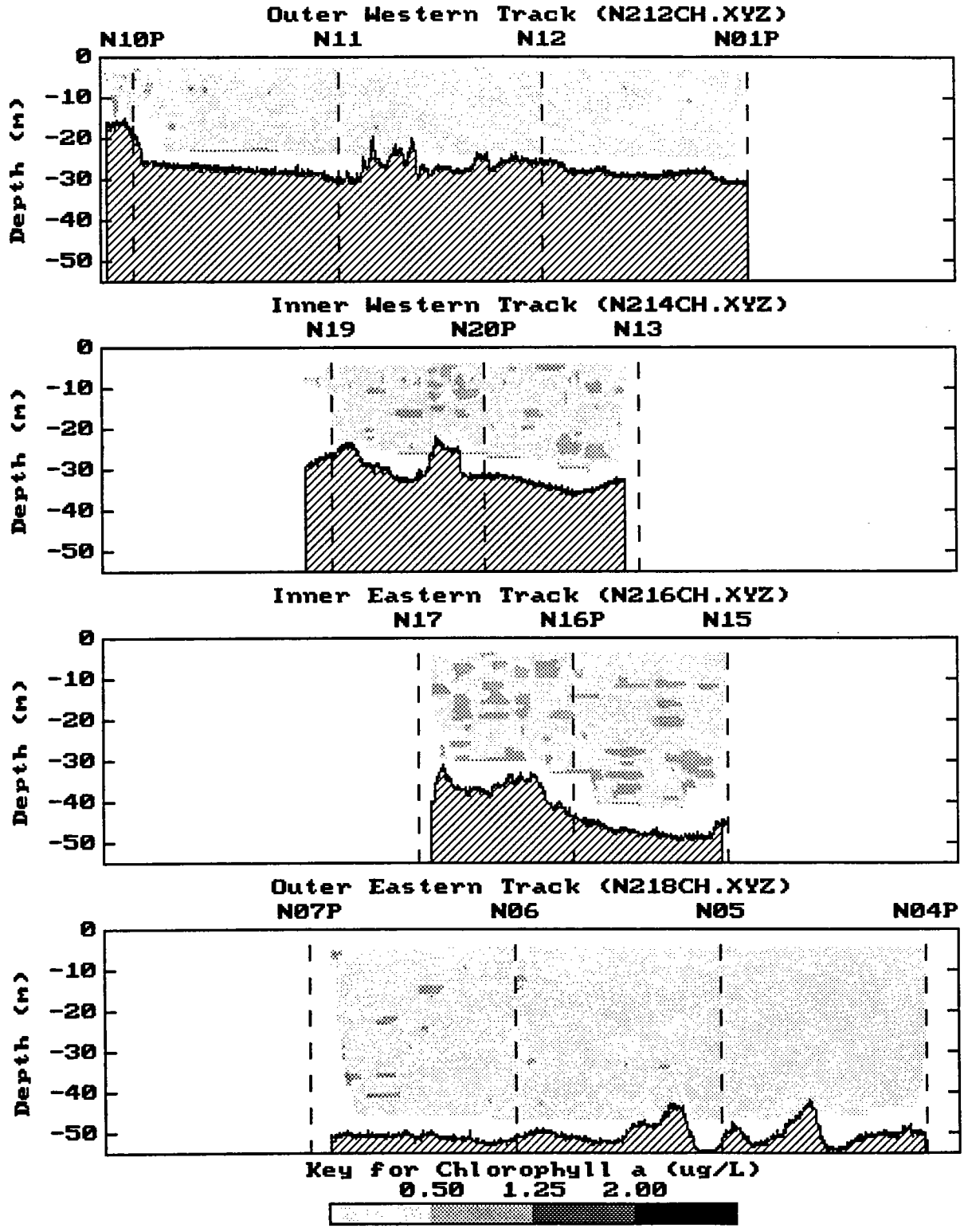


Figure 4-33b. Vertical section contours of fluorescence (as μg Chl L^{-1}) generated for tow-yos in February 1993. The view is towards Boston Harbor.

5.0 RESULTS OF MARCH 1993 COMBINED FARFIELD AND NEARFIELD SURVEY (W9302)

5.1 Farfield Survey

5.1.1 Horizontal Distribution of Surface Water Properties

On average, the water column in the region was slightly colder in mid-March than it was during the February 1993 survey about two weeks earlier. In terms of surface temperatures, nearly all of Massachusetts Bay was less than 2.5 °C, with the warmest surface water in the middle of the region (Figure 5-1). Throughout the Harbor-nearfield area and the northeast stations in the Bay, the temperature was less than 2 °C. In contrast to other stations, the surface water in Cape Cod Bay had warmed since February and was $\approx$1.6 to 2 °C in mid-March. The overall spatial pattern showed a similar surface temperature in western-northern Massachusetts Bay and that hugged the coast into Cape Cod Bay. Slightly warmer (0.5 to 1 °C) water offshore in the mid-region between the two Bays was evident.

The salinity distribution in surface waters during the mid-March survey was striking (Figure 5-2) and suggested a freshwater source from the Harbor stretching south down the coast. Salinity was highest offshore in the mid-Bay region, but the total range in surface salinity was less than 1.5 PSU.

Beam attenuation showed a surface water distribution that was similar to salinity (Figure 5-3). Highest values were detected near the shore in all cases. A sharp decline in turbidity characteristically extended more than 10-15 km offshore.

Chlorophyll in surface waters was below 1 μg L^{-1} in Massachusetts Bay, as it had been in February. The winter-spring bloom in Cape Cod Bay continued, with chlorophyll concentrations above 3 μg L^{-1}. The highest surface reading was at F01P. Note that station F04P, which had the highest chlorophyll in February, was not sampled.

With respect to dissolved inorganic nutrients in surface waters, DIN had a distributional pattern quite similar to salinity and beam attenuation (Figure 5-5). Surface-water DIN was lowest in Cape Cod

Bay in general, and at station F02P in particular (0.7 μM). The highest DIN was found at the three Harbor-edge stations (F23P, F25, F24), all with DIN ≥ 13 μM. Nitrate accounted for nearly 70% of the DIN at station F25 and was a substantial fraction most everywhere (Figure 5-6).

Phosphate, with one exception, was < 1 μM in surface waters. The PO_4 concentration did not vary much and did not have a discernible spatial pattern (Figure 5-7). In contrast, silicate was strongly depleted to the south into the open waters of Cape Cod Bay (Figure 5-8). A slight silicate enrichment was again seen from the Harbor out to the nearfield, a pattern roughly mimicking salinity, beam attenuation, and DIN.

5.1.2 Water Properties Along Selected Vertical Sections

Station plots for all continuous vertical profiles are given in Appendix B. Four transect section plots across a series of stations (Figure 5-9) were generated from vertical profile data for temperature, salinity, density, chlorophyll, beam attenuation, dissolved oxygen (as percent of saturation), DIN, and silicate (Figures 5-10 through 5-14). For these plots, the contour interval range was the same as used for the February survey plots.

With respect to temperature and salinity, some transect features were notable. For temperature, the transition from inshore to offshore was less regular and progressive than in February. In some cases (e.g., the Boston—Nearfield transect) the transition was sharper in bottom waters than in surface waters. For salinity, the transition from inshore to offshore was more horizontally- and vertically-graded than for temperature (Figure 5-10b). A tongue of fresher water protruded well out from the Harbor into the nearfield and to station F15 east of Cohasset. Density contours (Figure 5-11) generally showed a mild vertical stratification, with the Marshfield transect and the very middle of the nearfield (station N20P) being the unstratified exceptions.

The chlorophyll pattern for transects (Figure 5-12a) was essentially the same as for February, with slightly higher concentrations at shallow coastal stations. There was little vertical structure anywhere and all concentrations were low, less than about 1 $\mu g\ L^{-1}$. Beam attenuation, except at the northern transect, showed a progressive decrease from inshore to offshore (Figure 5-12b). In contrast to salinity and density, however, beam attenuation had virtually no vertical variation at a station.

With respect to oxygen, percent saturation values were extremely uniform (Figure 5-12c). Only station F23P and the surface of station F24, at the Harbor, had DO between 90-95% saturation; everywhere else, DO concentrations were between 95 and 100% saturation.

For DIN, inshore—offshore gradients were evident, as were slight vertical gradients (Figure 5-13). Inshore, excepting the northern transect, the concentrations were highest near the surface (> 12 μM) and lower near the bottom. The gradient seen in deeper water differed from this in that concentrations were usually lowest at the surface and up to 2-4 μM higher at depth. Note that the middle of the nearfield was vertically uniform and apparently was a transition zone between the shallow and deeper conditions just described. Finally, the range in silicate concentration was less than for DIN, but slight coastal enrichment and horizontal/vertical gradients from the Harbor were apparent (Figure 5-14).

5.1.3 Analysis of Water Types

The range for most physical measurements throughout the Bays was even smaller in March than in February. Coastal stations had the lower temperatures and data from them comprise the string of data showing lower salinity in Figure 5-15a. Cape Cod Bay stations were nearly isothermal and isohaline at about 32 PSU. Offshore and northern transect stations generally had higher salinities (> 32 PSU) and temperature gradually increased with depth. The nearfield was a mixing zone having some stations similar to the coastal region and others approaching, at their bottom waters, the higher T-S signature of deeper stations.

A gross graphical relationship existed between beam attenuation and salinity (Figure 5-15a), with any coastal water having lower salinity (i.e. below 32 PSU) showing beam attenuation > 2 m^{-1}. Surface water at deep-water stations of the offshore or northern transects was only slightly more turbid than bottom water. A relationship between chlorophyll and salinity additionally was implied by the strong linear trend between beam attenuation and chlorophyll that becomes evident if the Cape Cod Bay stations are excluded. As in February, the Cape Cod Bay stations had higher chlorophyll, but not particularly high beam attenuation, and a regional distinction between Massachusetts Bay and Cape Cod Bay was apparent in the turbidity—chlorophyll plot. Also, as in February, separate

fluorescence—extracted chlorophyll curves were used to calibrate Massachusetts Bay and Cape Cod Bay station data (Appendix A).

The difference between Bays is illustrated in Figure 5-15b, where all three Cape Cod Bay stations had chlorophyll between 3.5 and 6.5 $\mu g\ L^{-1}$ throughout depth. Peak values at those stations were found slightly below the surface. All Massachusetts Bay stations had uniformly low chlorophyll over depth ($\approx 0.5\ \mu g\ L^{-1}$). A few coastal and western-nearfield stations had chlorophyll concentrations between 0.5 and 1 $\mu g\ L^{-1}$. With respect to dissolved oxygen, the two Cape Cod Bay stations with highest chlorophyll (F01P and F02P) had highest levels and were slightly supersaturated (Figure 5-15). Most stations were between 95-100% saturated and exhibited fairly uniform vertical profiles.

In general, the weak density stratification and nutrient gradients with depth that were apparent at many locations in Massachusetts Bay did not appear to cause significant layering in biology as judged by chlorophyll and oxygen profiles. Regardless, the levels of chlorophyll provide some discrimination of the two Bays and of coastal vs. offshore waters.

Plots of nitrogen versus phosphate and silicate are given in Figures 5-17 and 5-18. Regional distinctions could be made with these data. Many coastal stations were distinctive for a higher DIN relative to phosphate. For the nearfield stations, offshore stations, and northern transect stations, nutrient concentration ranges and N/P ratios were essentially overlapping. Some of the Cape Cod Bay samples were virtually depleted in nitrate and had very low DIN, whereas phosphate was low but still easily detectable. In contrast, a few nearfield samples had 3-5 μM DIN at low phosphate.

Many Cape Cod Bay samples had especially low silicate (Figure 5-18). Interestingly, there were other stations with DIN or nitrate as low as the Cape Cod Bay cases, but associated silicate concentrations remained about 9-10 μM. Most DIN/silicate ratios fell in the range of 1:4 to 1:1, with the coastal stations often showing ratios at the higher end of this range.

The distribution of nutrients was examined relative to salinity (Figures 5-19 to 5-21). The salinity—nutrient plots for DIN and silicate yielded a pattern of higher nutrients in lower salinity water. For DIN, there was considerable variability for the more saline samples. This included many nearfield locations, as well as all the offshore and northern transect data. The scatter for ammonium, nitrate,

and phosphate vs. salinity was very high. A principal feature in the DIN and silicate plots is the Cape Cod Bay station data at intermediate salinity that fall well below the main trend line. The data thus repeat the feature seen for this region in February.

Using combinations of DIN and other organic forms of nitrogen, the Cape Cod Bay station's nitrogen concentrations were low (Figure 5-22), but within the range of the nearfield stations having comparably high salinity. Thus, in contrast to February, the data less surely offer an indication that Cape Cod Bay was a "sink" for nitrogen. Total N values for most of the nearfield and Cape Cod Bay stations were roughly similar to February (15-20 μM) and month-month trends are discussed later (Section 7).

In summary, with respect to water mass distinctions, the same general observations made for February still held in March 1993. Massachusetts Bay stations had cooled slightly, but a slight vertical stratification was seen. Chlorophyll differences were still pronounced between the two Bays, more pronounced than between any geographic regions within Massachusetts Bay. Nutrients were useful to discriminate inshore-offshore regions and define differences between the two Bays.

5.1.4 Distribution of Chlorophyll and Phytoplankton

Evaluation of the extracted chlorophyll samples and cell counts showed the Cape Cod Bay stations and the nearfield/coastal Massachusetts Bay region formed distinct groups (Figures 5-23 and 5-24). Phytoplankton abundance, as in February, was at or above 1 million cells per liter in Cape Cod Bay, and near or below 0.2 millions cells per liter in all Massachusetts Bay stations.

Figure 5-25 indicates the overwhelming dominance by diatoms at Cape Cod Bay stations (F01P and F02P). Elsewhere, diatoms were still a major component. The other groups (dinoflagellates, microflagellates, others) were found at fairly constant levels throughout both Bays; dinoflagellates were more numerous, though still very minor, in Cape Cod Bay.

The phytoplankton community composition, indicated by dominant taxa at each station, was similar at surface and deeper samples (Table 5-1). Coastal and nearfield samples were quite similar, a small difference being that coastal stations tended to have the diatom *Skeletonema costatum* as a minor

dominant. The principal diatom in Massachusetts Bay was *Cylindrotheca closterium. Thalassiosira (cf) gravida/rotula* was also dominant in all nearfield station samples. The central difference between Cape Cod Bay and Massachusetts Bay samples is well illustrated in Table 5-1. The dominant taxa in Cape Cod Bay did not include the two groups, microflagellates and cryptomonads. Instead all major dominants were diatoms — several species of *Chaetoceros* (especially *C. debilis*), *Leptocylindrus danicus*, and (at the surface) *Thalassiosira nordenskioeldii*. The continued Bay-to-Bay differences in species composition may explain why the chlorophyll—fluorescence relationship in mid-March was again different in the two Bays (Appendix A).

Tables 5-2 and 5-3 provide taxonomic data from the 20-μm screened samples. Note that counts in for these organisms are cells L^{-1} rather than millions of cells L^{-1}. The notable features of the data include the presence of more taxa and higher numbers of cells at the two cape Cod Bay stations. Some taxa, e.g. *Ceratium longipes*, were present throughout the Bays. *Alexandrium tamarense* was detected only at one Cape Cod Bay station and at one station in the middle of the nearfield.

5.1.5 Distribution of Zooplankton

Total numbers of zooplankton varied about five-fold across the stations (Figure 5-26). In spite of the distinct and continuing higher chlorophyll and diatom bloom in Cape Cod Bay, total zooplankton numbers did not reflect the Bay-to-Bay differences. Stations N16P and N20P in the center of the nearfield had abundances similar to stations F01P and F02P in Cape Cod Bay. Counts were lowest at stations F23P and N10P, at the Harbor and at the edge of the Harbor's tidal excursion, respectively.

With respect to composition, barnacle nauplii were everywhere a small component. The majority of organism counts were due to copepods and their nauplii. In terms of taxa, the small copepod *Oithona similis* continued to be dominant (Appendix G). *Tortanus discaudatus*, a larger copepod, was abundant at the Harbor (F23P) and was present, although less numerous, elsewhere. Interestingly, *Acartia hudsonica*, the characteristically more estuarine species, was again at the Harbor and both Cape Cod Bay stations, and also at station N04P.

Cape Cod Bay stations did have taxonomic distinctiveness. The appendicularian, *Oikiopleura dioica*, was present in substantial numbers. Also, greater numbers of taxa and often higher abundance, of the

larger-sized copepods were present: including *Calanus finmarchicus*, *Centropages* species, *Pseudocalanus newmani*, *Temora longicornis*, and *Tortanus discaudatus*. All of these taxa were present elsewhere, but not usually all in the full aggregation seen at stations F01P and F02P.

5.1.6 ^{14}C Production Measurements

Using the P-I incubations, and light and fluorescence profiles at each station, modeling was performed to estimate integrated daily ^{14}C production (see Section 2). All P-I data and curve-fitting results are in Appendix E; an example curve is shown in Figure 5-27. The depth over which production was integrated is given as the $Z_{0.5\%Io}$ depth (Table 5-4). In general, the goodness-of-fit for P-I modeling was excellent (Appendix E). Both samples at a station used the same vertical light and chlorophyll data, so integrated rate differences are due only to differences in P-I data and statistical modeling.

Confirming the beam attenuation gradient suggested earlier, the 0.5% level was shallowest near the Harbor and deepest on the east side of the nearfield. Cape Cod Bay stations were intermediate. The estimated 0.5% level was within several meters of each station's estimate for February.

Chlorophyll-normalized P_{max} values for Cape Cod Bay stations were low (3.75 to 5.26 μg C (μg Chl)$^{-1}$ hr^{-1}), compared with most Massachusetts Bay estimates (4.6-16 μg C (μg Chl)$^{-1}$ hr^{-1}; Table 5-3). ^{14}C production was still high at the two Cape Cod Bay stations because chlorophyll was much higher than in Massachusetts Bay. Table 5-4 shows productivity estimates for Cape Cod Bay stations in the range of 1.5 to 1.8 g C m^{-2} d^{-1}. Elsewhere ^{14}C production was uniformly low, generally below 0.25 gC m^{-2} d^{-1}. There was no apparent relation between the 0.5% depth and integrated production.

5.2 Nearfield Survey

5.2.1 Distribution of Water Properties from Vertical Profiling

Vertical profiling was performed at all twenty-one nearfield stations (Appendices A,B). Scatter plots using *in situ* sensor data are shown in Figure 5-28 and 5-29. There was small variability across the stations and most stations had little or only subtle vertical stratification. Only the southwest corner of the nearfield (including stations N10P and N11) was strongly distinct from the other stations. Station

N10P in particular had lower salinity (<32 PSU), higher beam attenuation (≈ 3 m^{-1}) and slightly higher chlorophyll (≈ 0.8 μg L^{-1}). Station N11 was intermediate to N10P and the rest of the stations with regard to parameters shown in Figure 5-28 and 5-29.

Nutrient concentrations are shown as a function of depth for the nearfield and, for reference, other regions (Figure 5-30). For DIN there was no distinct pattern over depth, except perhaps that the range of concentrations was constricted below about 20 m. Previously (Figure 5-19), it was shown that nutrient concentrations related to salinity and were higher in Harbor outflow water. The higher DIN concentrations within the top 25 m were at more inshore nearfield stations, including N10P, and are similar to many of the coastal stations (Figure 5-30a). Overall, DIN on the nearfield survey day sampling ranged from 1.25 to 13.2 μM, with a mean and standard deviation of 6.2 $\pm$ 2.06 μM (n=103). Thus, on average, the concentration was the same as in February (cf. Section 4.2.1).

Ammonium concentrations in the nearfield ranged from virtually zero to 4.45 μM, again with no consistent pattern over depth. Nitrate concentrations ranged from 0 to over 9 μM, nearly spanning the range seen throughout the Bays (Figure 5-30b). Phosphate was similar to nitrate — its range spanned that of the Bays and there was no pattern with depth. However, phosphate was never fully depleted (Figure 5-30c).

The silicate distribution in the nearfield was very different from nitrogen forms and phosphate. Silicate showed a uniform distribution over depth and narrow concentration range across all stations (8.75 to 11.1 μM, mean and standard deviation of 9.3 $\pm$ 0.4 μM (n=103). Previously (Figure 5-21) it was shown that silicate was related to salinity; slightly higher silicate concentrations in the nearfield were recorded at stations receiving some fresher water from inshore. The nearfield silicate concentrations over depth were very similar to offshore and northern transect stations, less than coastal (Harbor) stations, and higher than two of the three Cape Cod Bay stations. Note that the Cape Cod Bay station having higher silicate and thus being at the low end of the nearfield range was station F03 off Plymouth, not in the more central body of Cape Cod Bay.

5.2.2 Distribution of Water Properties from Towing

A developing winter blizzard prompted cancellation of the tow day activities for this survey.

5.2.3 Water Types and Analysis of Small-Scale Variability

Weak salinity-driven gradients in nutrient and chlorophyll were noted from the southwest corner across the nearfield. Overall, the dynamic range of the physical, chemical, and biological gradients in the nearfield was rather small. Without high-resolution towing data, few comments can be made on the degree of small-scale patchiness, e.g. such as comparing variations in weak vertical physical structure to chlorophyll patchiness. Variability over time, however, can be described by examining vertical profiles of the "P" stations visited twice as part of the farfield, and then nearfield survey (about two days later).

Vertical profiles are given in Appendix B. In general, the changes noted were rather subtle. On the one hand, considering all parameters, different "concerts" of change were seen at different stations. For example, minor shifts in physical variables (T,S, density) were seen at stations N01P; curiously, beam attenuation, DO, and chlorophyll changed even more markedly. In contrast, station N10P had more marked temporal differences in the vertical structure of physical variables but with little apparent corresponding change on other parameters. This station historically has high variability (for many parameters) on tidal timeframes.

On the other hand, some "subregions" (i.e. station couplets) acted somewhat in concert with each other. For example, station N04P, at the second sampling, had sharper water column layering based on temperature and salinity without much change in other parameters. The same was true at the other deep offshore station, N07P. The second example is from the two mid-nearfield stations. Station N16P initially had a shallow, but well-defined surface layer, with higher chlorophyll and beam attenuation, that was either advected or dissipated two days later. Concomitantly, a slighter and deeper surface layer was present at station N20P on the first sampling but not two days later.

These simple examples lend additional definition to subregions of the nearfield, from a physical-dynamic perspective, that compliment the general spatial inshore-offshore gradients described earlier. Moreover, the examples illustrate some of the (undoubtedly) many subtle water mass variations in space and time and hint of couplings between physical and biological aspects that the accumulated data can be used to reveal.

Table 5-1a. Abundance of the top five dominant phytoplankton taxa in samples collected near the surface in March 1993.

	Coastal Stations		Nearfield Stations						Cape Cod Bay Stations	
	F23P	F13P	N01P	N04P	N07P	N10P	N16P	N20P	F01P	F02P
	Mar 09	Mar 10	Mar 10	Mar 10	Mar 10	Mar 09	Mar 09	Mar 09	Mar 11	Mar 11
CRYPTOMONADS	.084 (1)	.02 (2)	.011 (4)	.012 (4)	.014 (5)	.035 (1)	.016 (4)	.03 (2)		
CYLINDROTHECA CLOSTERIUM	.018 (3)	.017 (3)	.02 (3)	.014 (2)	.028 (2)	.011 (5)	.02 (2)	.03 (2)		
MICROFLAGELLATES	.038 (2)	.047 (1)	.031 (1)	.04 (1)	.032 (1)	.031 (2)	.025 (1)	.034 (1)		
THALASSIOSIRA (cf) GRAVIDA/ROTULA		.008 (5)	.011 (4)	.013 (3)	.017 (3)	.013 (3)	.018 (3)	.007 (5)		
NITZSCHIA (CF) DELICATISSIMA		.014 (4)	.023 (2)	.013 (3)	.016 (4)		.015 (5)	.017 (3)		
CHAETOCEROS SOCIALIS	.015 (4)							.013 (4)	.055 (5)	
SKELETONEMA COSTATUM	.009 (5)	.008 (5)	.009 (5)							
CHAETOCEROS COMPRESSUS									.088 (3)	.106 (5)
CHAETOCEROS DEBILIS									.271 (1)	.28 (1)
CHAETOCEROS SPP. (10-20UM)									.08 (4)	.142 (4)
NAVICULOID DIATOMS						.012 (4)		.007 (5)		
THALASSIOSIRA NORDENSKIOELDII									.18 (2)	.229 (2)
CHAETOCEROS SPP.(<10UM)				.006 (5)						
LEPTOCYLINDRUS DANICUS										.177 (3)
THALASSIONEMA NITZSCHOIDES								.007 (5)		

Units are millions of cells L^{-1}.

Table 5-1b. Abundance of the top five dominant phytoplankton taxa in samples collected near the chlorophyll maximum in March 1993.

	Coastal Stations		Nearfield Stations						Cape Cod Bay Stations	
	F23P	F13P	N01P	N04P	N07P	N10P	N16P	N20P	F01P	F02P
	Mar 09	Mar 10	Mar 10	Mar 10	Mar 10	Mar 09	Mar 09	Mar 09	Mar 11	Mar 11
CRYPTOMONADS	.051 (2)	.035 (2)	.015 (4)	.027 (2)	.023 (4)	.045 (2)	.02 (3)	.025 (2)		
CYLINDROTHECA CLOSTERIUM	.019 (3)	.014 (4)	.022 (2)	.024 (3)	.039 (2)	.014 (4)	.017 (4)	.016 (3)		
MICROFLAGELLATES	.065 (1)	.056 (1)	.03 (1)	.053 (1)	.06 (1)	.049 (1)	.038 (1)	.031 (1)		
NITZSCHIA (CF) DELICATISSIMA	.009 (5)	.016 (3)	.019 (3)				.017 (4)	.01 (4)		
THALASSIOSIRA (cf) GRAVIDA/ROTULA			.008 (5)	.019 (4)	.027 (3)	.011 (5)	.023 (2)	.01 (4)		
CHAETOCEROS SPP. (10-20UM)					.01 (5)		.012 (5)		.083 (4)	.091 (5)
CHAETOCEROS DEBILIS				.01 (5)					.222 (1)	.283 (1)
CHAETOCEROS SOCIALIS									.113 (3)	.118 (4)
LEPTOCYLINDRUS DANICUS									.07 (5)	.121 (3)
NAVICULOID DIATOMS	.016 (4)					.015 (3)				
SKELETONEMA COSTATUM	.016 (4)	.011 (5)								
THALASSIOSIRA NORDENSKIOELDII									.18 (2)	.148 (2)
THALASSIONEMA NITZSCHOIDES								.009 (5)		

Units are millions of cells L^{-1}.

Table 5-2a. Abundance of all identified taxa in screened (20um) samples collected near the surface in March 1993.

	Coastal Stations		Nearfield Stations						Cape Cod Bay Stations	
	F23P	F13P	N01P	N04P	N07P	N10P	N16P	N20P	F01P	F02P
	Mar 09	Mar 10	Mar 10	Mar 10	Mar 10	Mar 09	Mar 09	Mar 09	Mar 11	Mar 11
ALEXANDRIUM TAMARENSE								3	3	
ALORICATE CILIATES	80	8	25			10	10	5	28	75
CERATIUM FUSUS		3								
CERATIUM LINEATUM			3		3			3	8	
CERATIUM LONGIPES	3		5	8	10	3	3		5	8
CERATIUM TRIPOS					3					
DICTYOCHA FIBULA		3								
DINOPHYSIS ACUMINATA							3			
DINOPHYSIS ACUTA									8	
DINOPHYSIS NORVEGICA		3		3	3	3	3	5	25	23
DISTEPHANUS SPECULUM	5		3	3			5	5	3	3
GYRODINIUM SPIRALE	3	8	5	5	3	5		3	3	
GYRODINIUM SPP.	3	8	10	3		3	5		8	13
PROTOPERIDINIUM DENTICULATUM			5	5					8	10
PROTOPERIDINIUM DEPRESSUM									10	8
PROTOPERIDINIUM PELLUCIDUM						3				
PROTOPERIDINIUM SPP.			3		5		20			10
TINTINNIDS	33	25	18		5	15	8	8	88	40
UNID. ATHECATE DINOFLAGELLATE			5			3		5	5	
UNID. THECATE DINOFLAGELLATES	5			5	10		15	5	43	45

Units are cells L^{-1}

Table 5-2b. Abundance of all identified taxa in screened (20um) samples collected near the chlorophyll maximum in March 1993.

	Coastal Stations		Nearfield Stations						Cape Cod Bay Stations	
	F23P	F13P	N01P	N04P	N07P	N10P	N16P	N20P	F01P	F02P
	Mar 09	Mar 10	Mar 10	Mar 10	Mar 10	Mar 09	Mar 09	Mar 09	Mar 11	Mar 11
ALORICATE CILIATES	73	5	33	10		38	8	30	15	18
CERATIUM FUSUS			3				3		8	
CERATIUM LINEATUM				3		5				3
CERATIUM LONGIPES		5	5	3	8	3	3	5	10	8
DICTYOCHA FIBULA	3					3				
DINOPHYSIS ACUMINATA										3
DINOPHYSIS ACUTA									5	3
DINOPHYSIS NORVEGICA			13				5	3	23	28
DISTEPHANUS SPECULUM	5		5	8	13	3	5	3		3
GYRODINIUM SPIRALE	3			3	5	5	5	8	3	18
GYRODINIUM SPP.									8	8
PROROCENTRUM MICANS					3					
PROTOPERIDINIUM DENTICULATUM	5						5			
PROTOPERIDINIUM DEPRESSUM							3		8	
PROTOPERIDINIUM LEONIS										3
PROTOPERIDINIUM PELLUCIDUM			3							
PROTOPERIDINIUM SPP.			3	5			3		8	5
TINTINNIDS	23	10	23	30	40	15	18	18	33	23
UNID. ATHECATE DINOFLAGELLATE	3		8	5				3	3	3
UNID. THECATE DINOFLAGELLATES	3		5	5	5	3	10	5	65	65

Units are cells L^{-1}

Table 5-3. ^{14}C production (mg C m^{-2} d^{-1}) estimated for the euphotic layer at BioProductivity stations in March 1993.

	Coastal Stations				Nearfield Stations												Cape Cod Bay Stations			
	F23P		F13P		N01P		N04P		N07P		N10P		N16P		N20P		F01P		F02P	
Water depth (m)	22		26		31		52		50		26.5		44		33		29		34	
$Z_{(0.5\%Io)}$ (m)	12		13.5		14		22.5		25		15		21.5		19.5		19		24.5	
Samples[1]	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C
Rate (mg C $m^{-2}d^{-1}$)	259	265	168	258	243	136	181	150	305	108	189	146	167	235	300	269	1751	1585	1896	1967
Model[2]	P	P	P	P	P	P	P	P&J	P	P	P	P	P	P&J	P&J	P&J	P	P	P	P
P_{SB} or P_{MAX}[3]	7.21	14.90	6.83	8.42	7.84	6.83	6.54	4.55	11.06	16.00	7.21	13.29	49.74	7.25	9.18	7.59	5.26	5.23	4.75	3.75
α[4]	0.054	0.048	0.053	0.109	0.083	0.028	0.045	0.034	0.094	0.019	0.023	0.016	0.024	0.040	0.041	0.042	0.034	0.032	0.032	0.044
β[5]	0.000	0.013	0.001	0.000	0.001	0.002	0.001		0.001	0.013	0.001	0.009	0.060				0.001	0.002	0.001	0.000

[1] S: Surface sample and P-I incubations on it.
C: Chlorophyll max sample and P-I incubations on it.
[2] P: Platt *et al.* (1980).
P&J: Platt and Jassby (1976).
[3] P_{SB}: Production parameter for Platt *et al.* model.
P_{MAX}: Production parameter for Platt and Jassby model.
[4] Parameter for both models.
[5] Parameter for Platt *et al.* model.

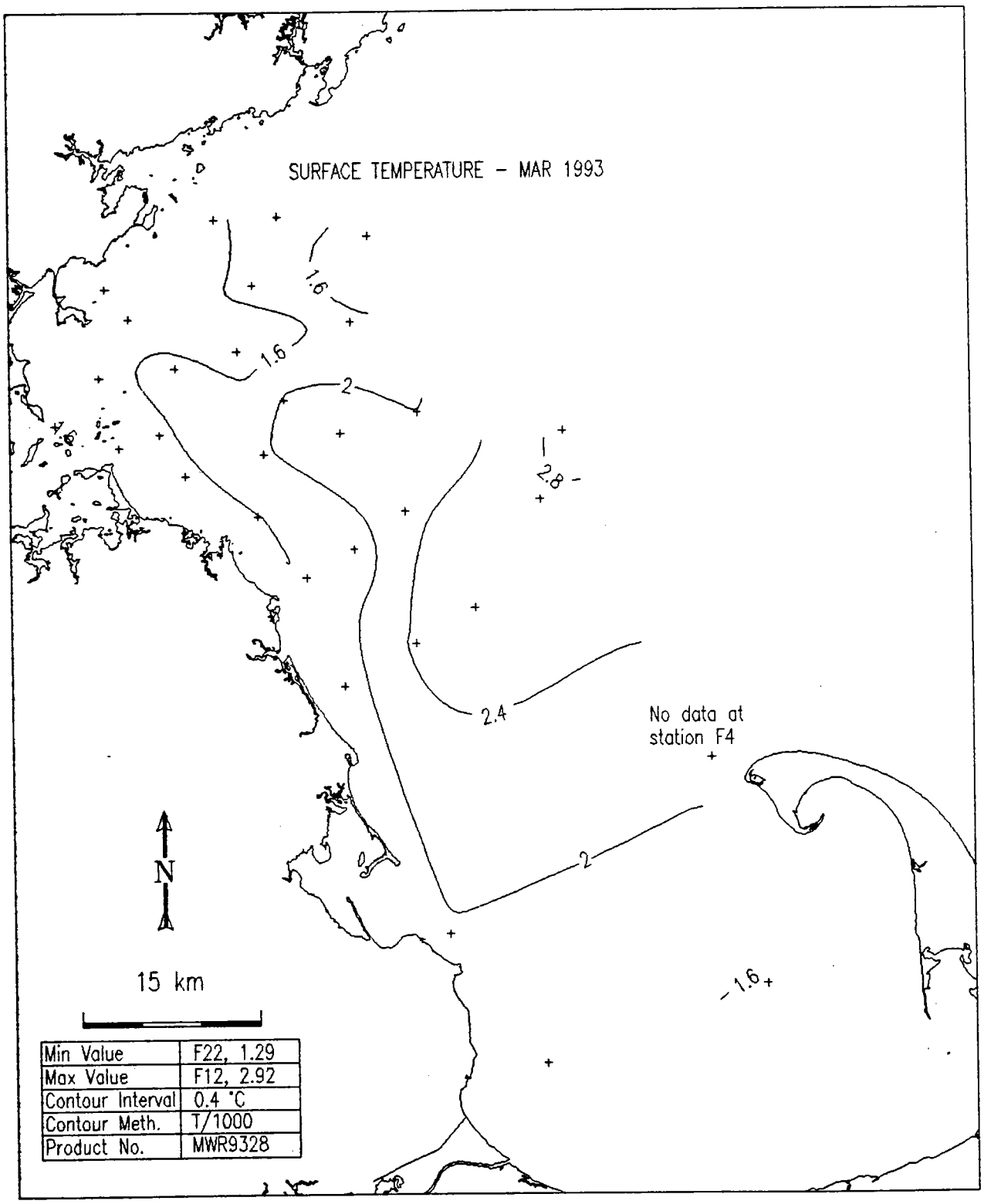


Figure 5-1. **Surface temperature (°C) in the region in March 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

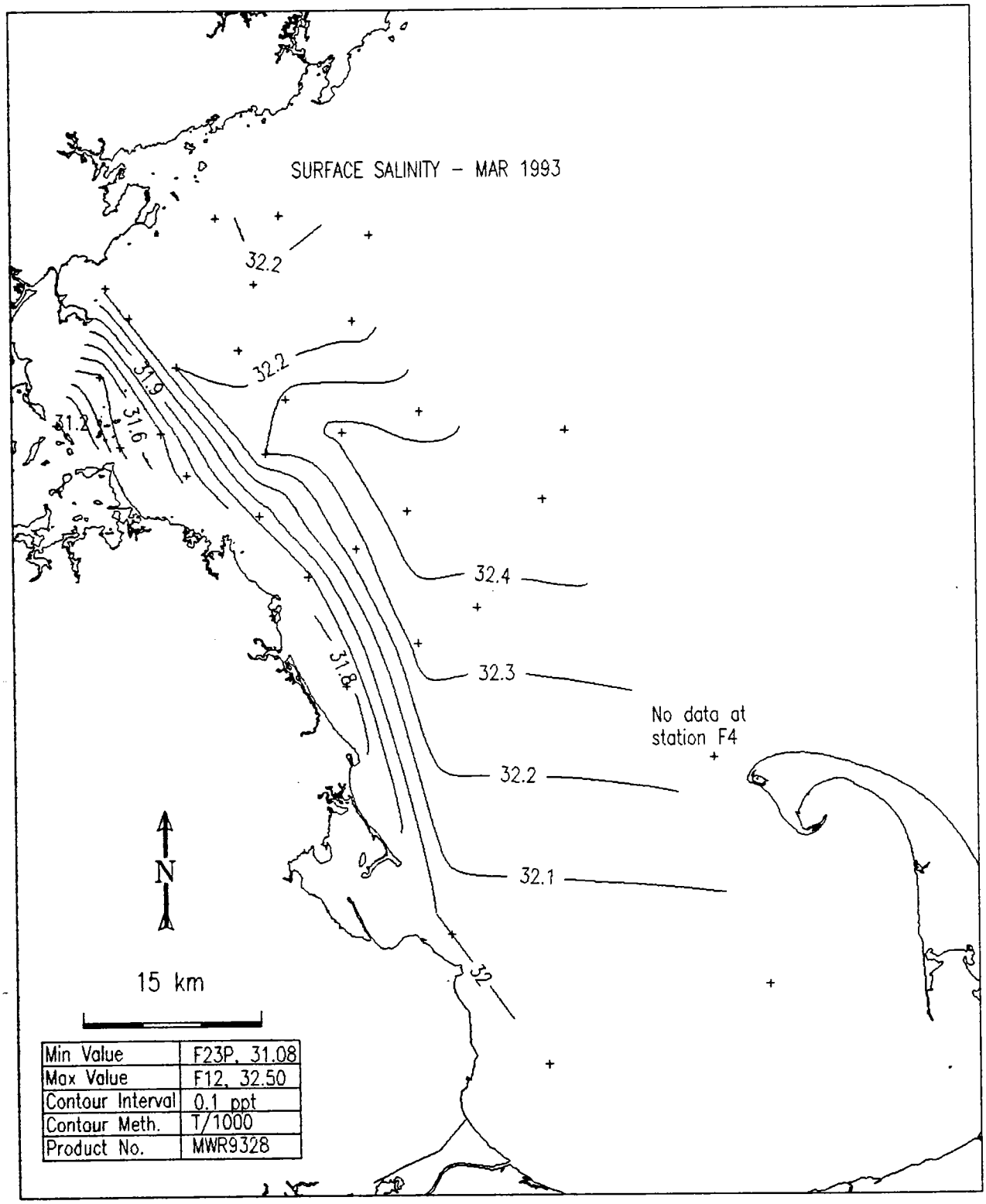


Figure 5-2. **Surface salinity (PSU) in the region in March 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

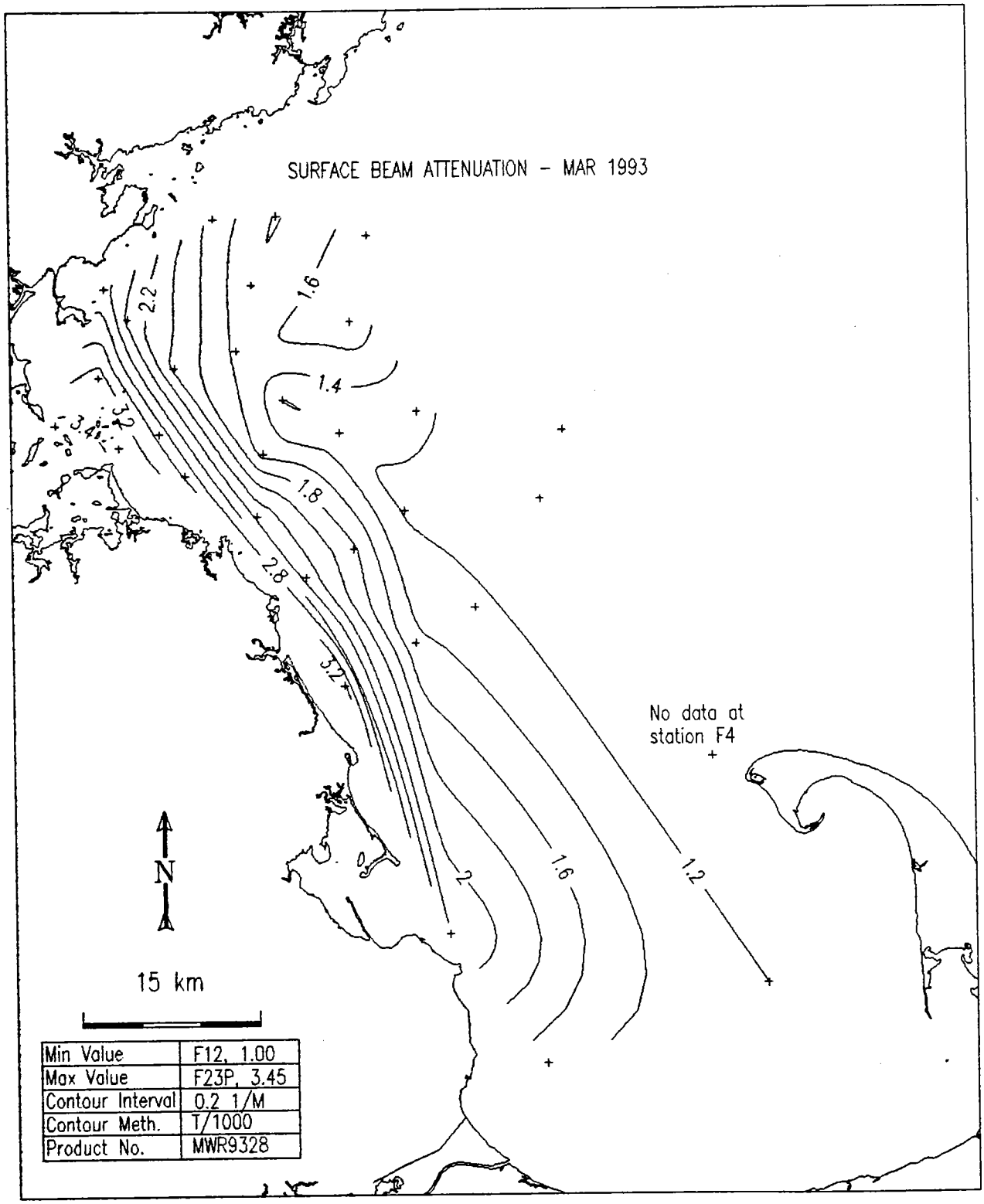


Figure 5-3. **Surface beam attenuation (m^{-1}) in the region in March 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

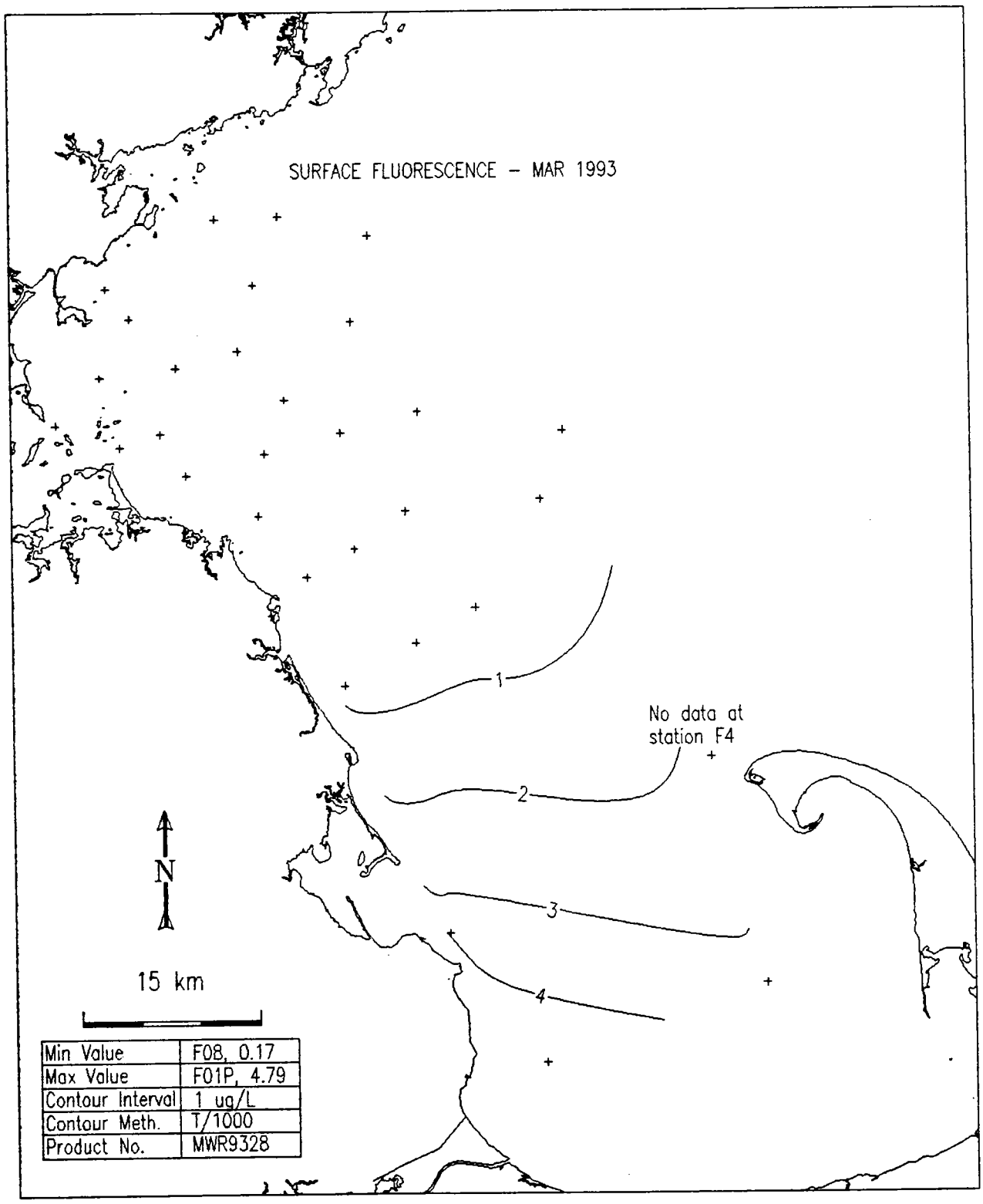


Figure 5-4. **Surface *in situ* fluorescence (as μg Chl L^{-1}) in the region in March 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

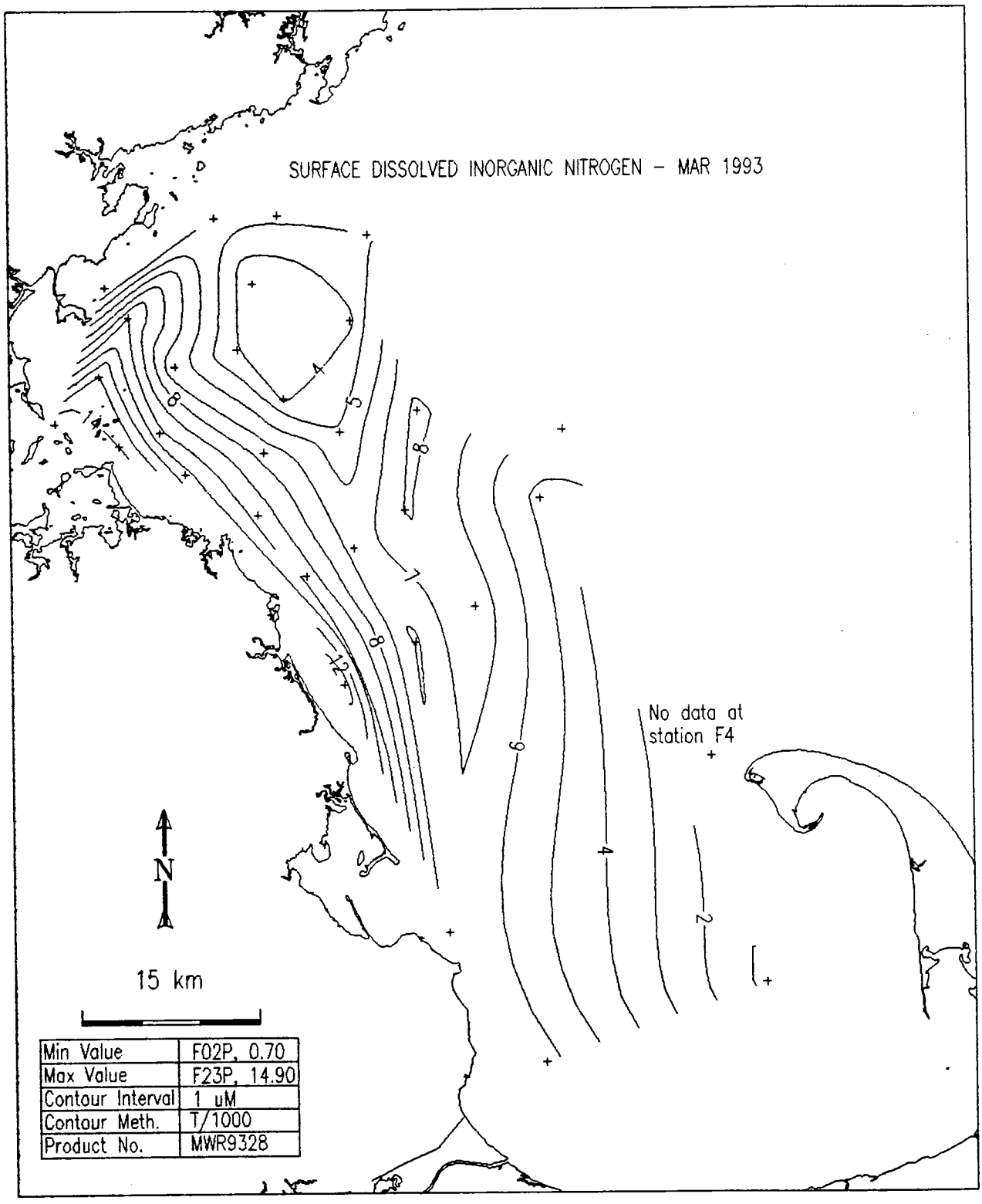


Figure 5-5. **Surface dissolved inorganic nitrogen (DIN, μM) in the region in March 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

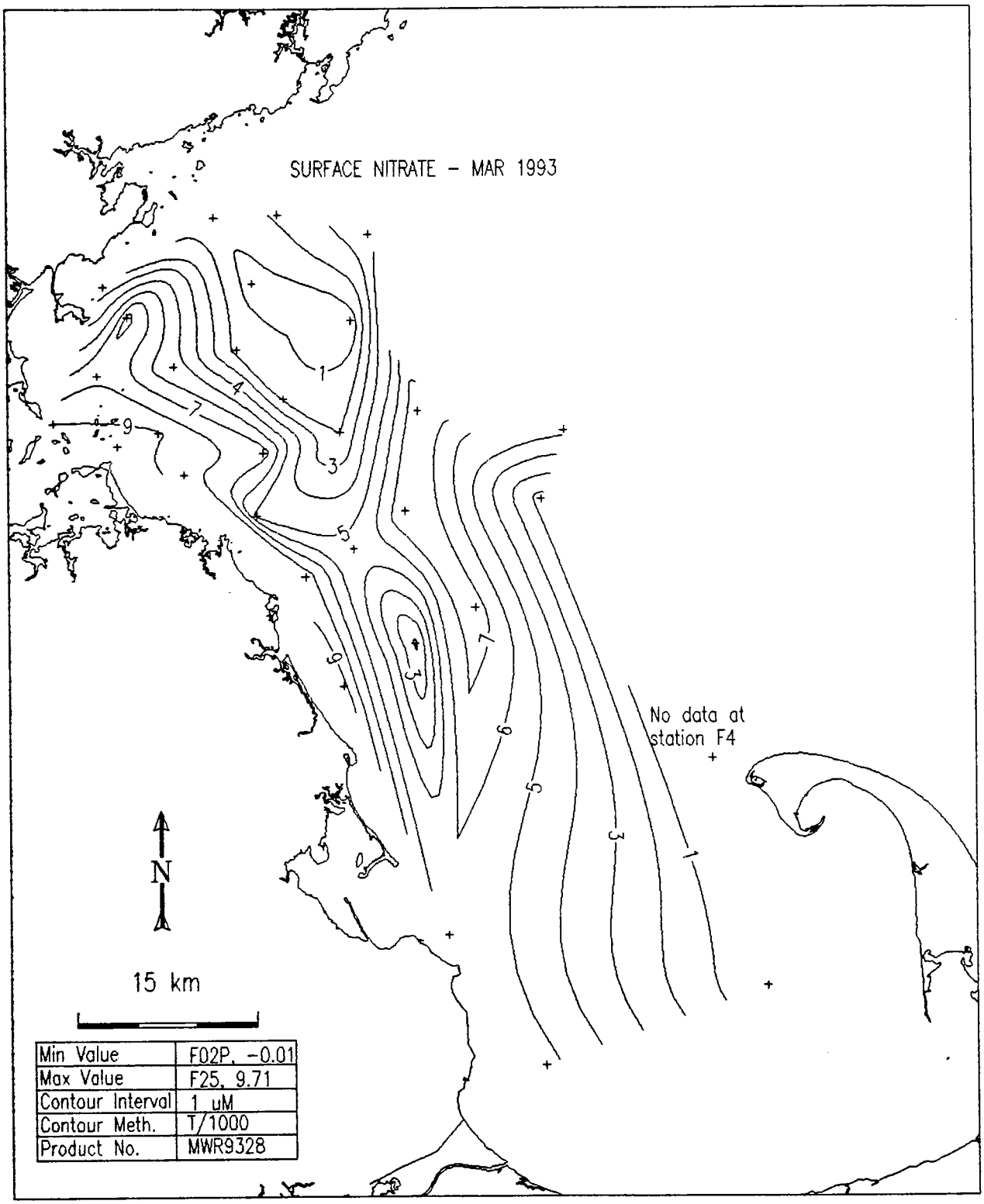


Figure 5-6. **Surface nitrate (NO_3, μM) in the region in March 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

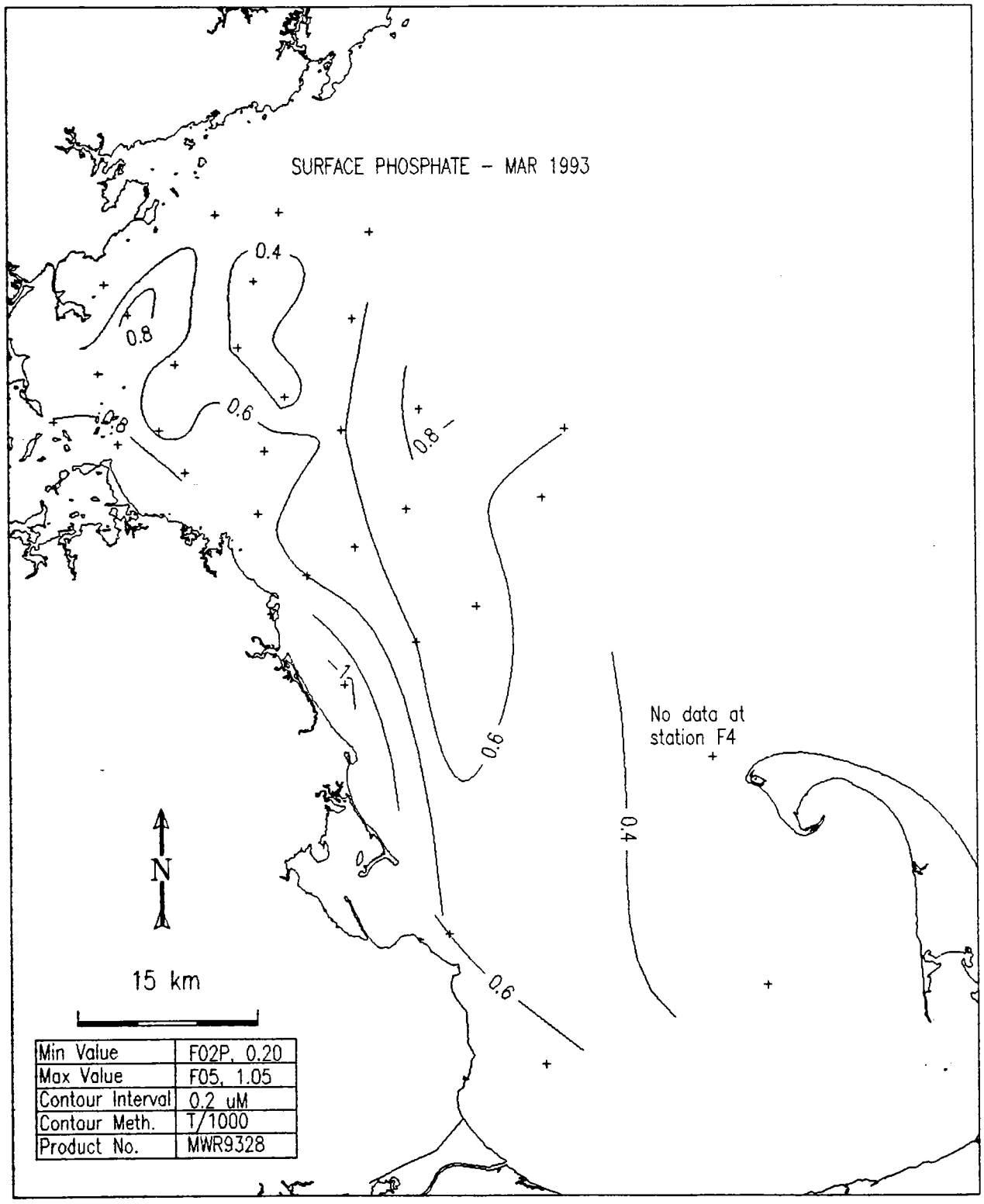


Figure 5-7. **Surface phosphate (PO_4, μM) in the region in March 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

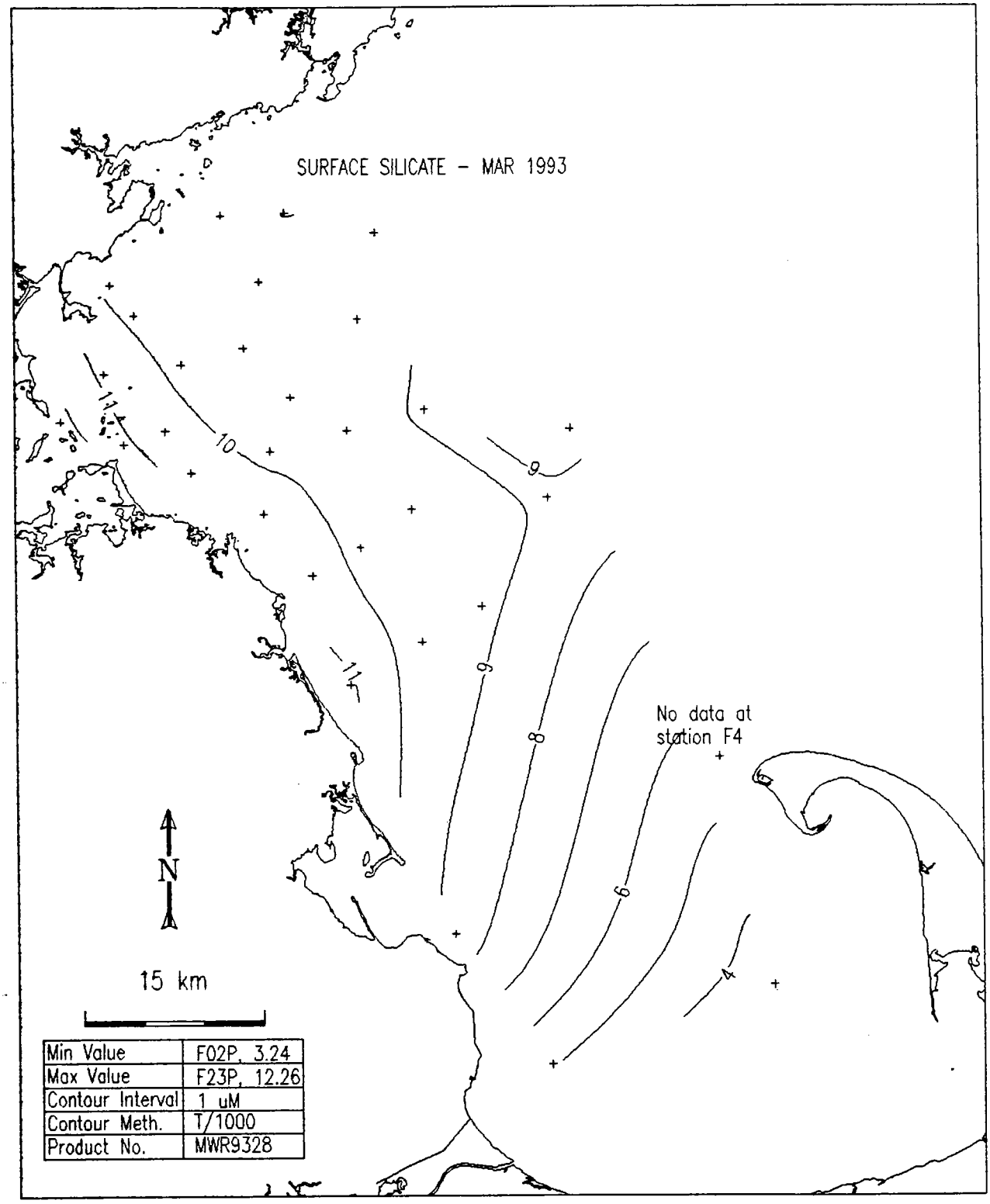


Figure 5-8. **Surface silicate (SiO_4, μM) in the region in March 1993. Data are from Appendix A, the surfacemost sample at all farfield survey stations, including the BioProductivity stations within the nearfield grid.**

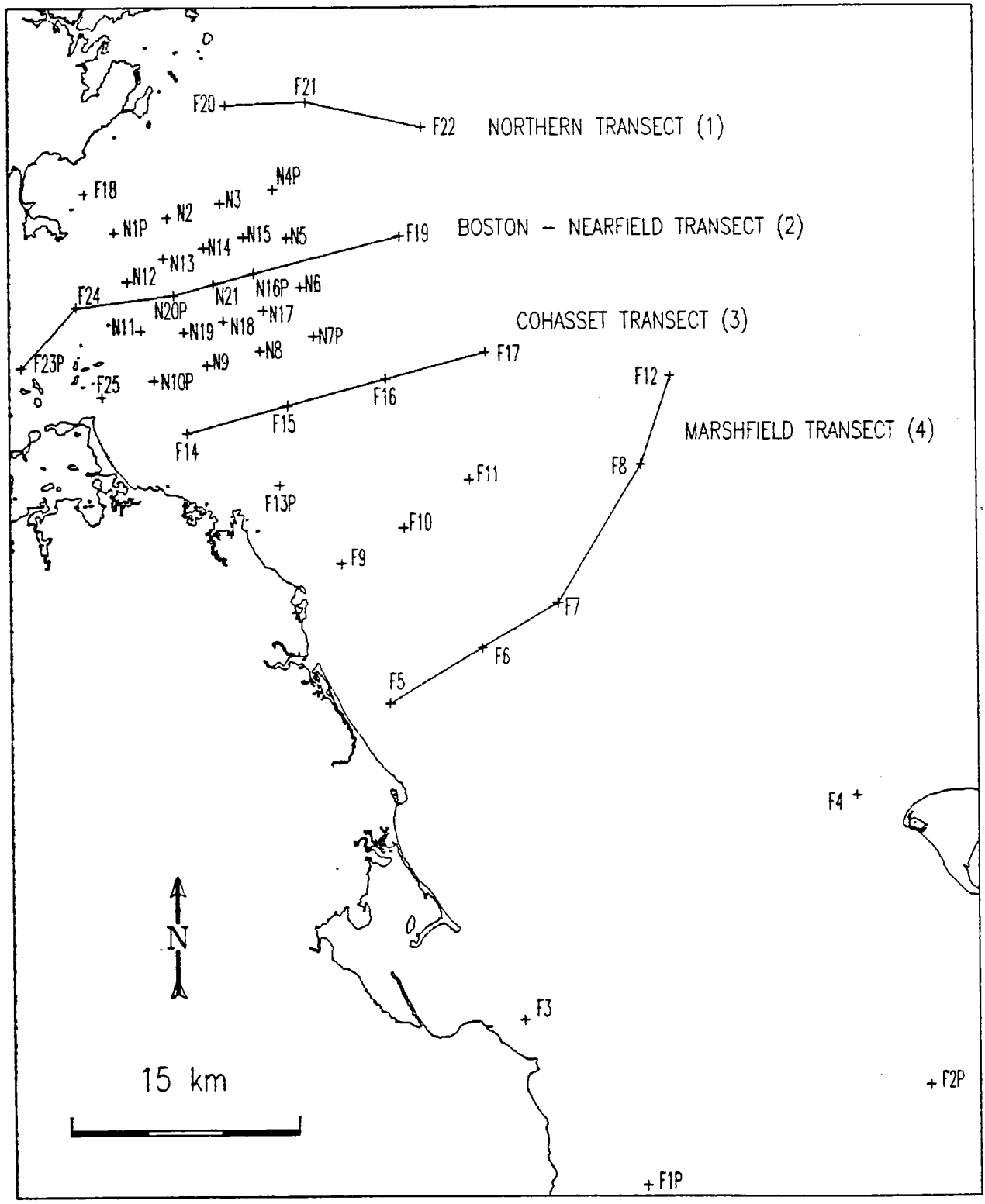


Figure 5-9. **Map showing position of four standard transects for which vertical contour plots were produced in following Figures 5-10 to 5-14.**

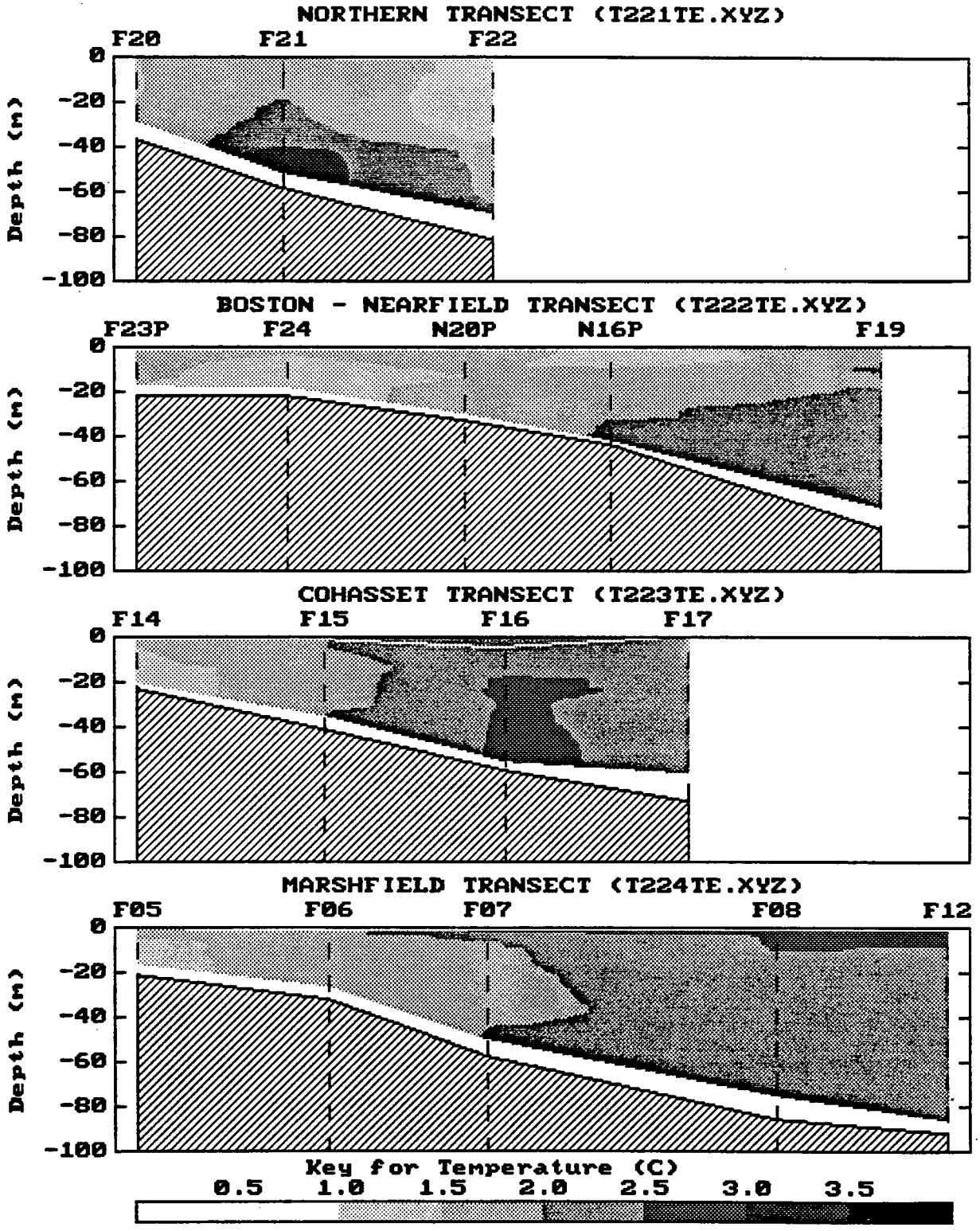


Figure 5-10a. Vertical section contours of temperature in March 1993 for standard transects (see Figure 5-9). The data used to produce contours are from high-resolution continuous vertical profiles taken from the downcast at each station.

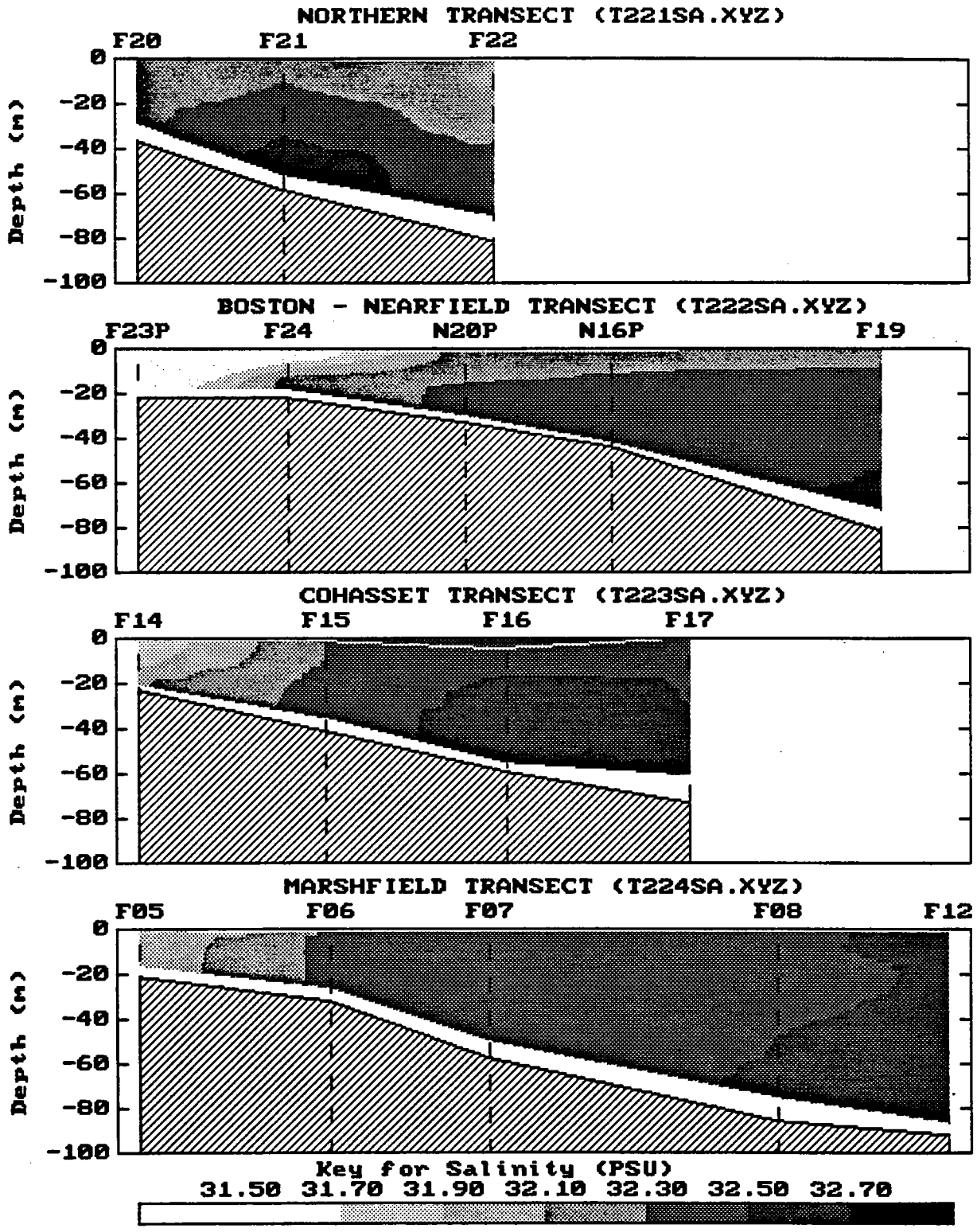


Figure 5-10b. Vertical section contours of salinity in March 1993 for standard transects (see Figure 5-9). The data used to produce contours are from high-resolution continuous vertical profiles taken from the downcast at each station.

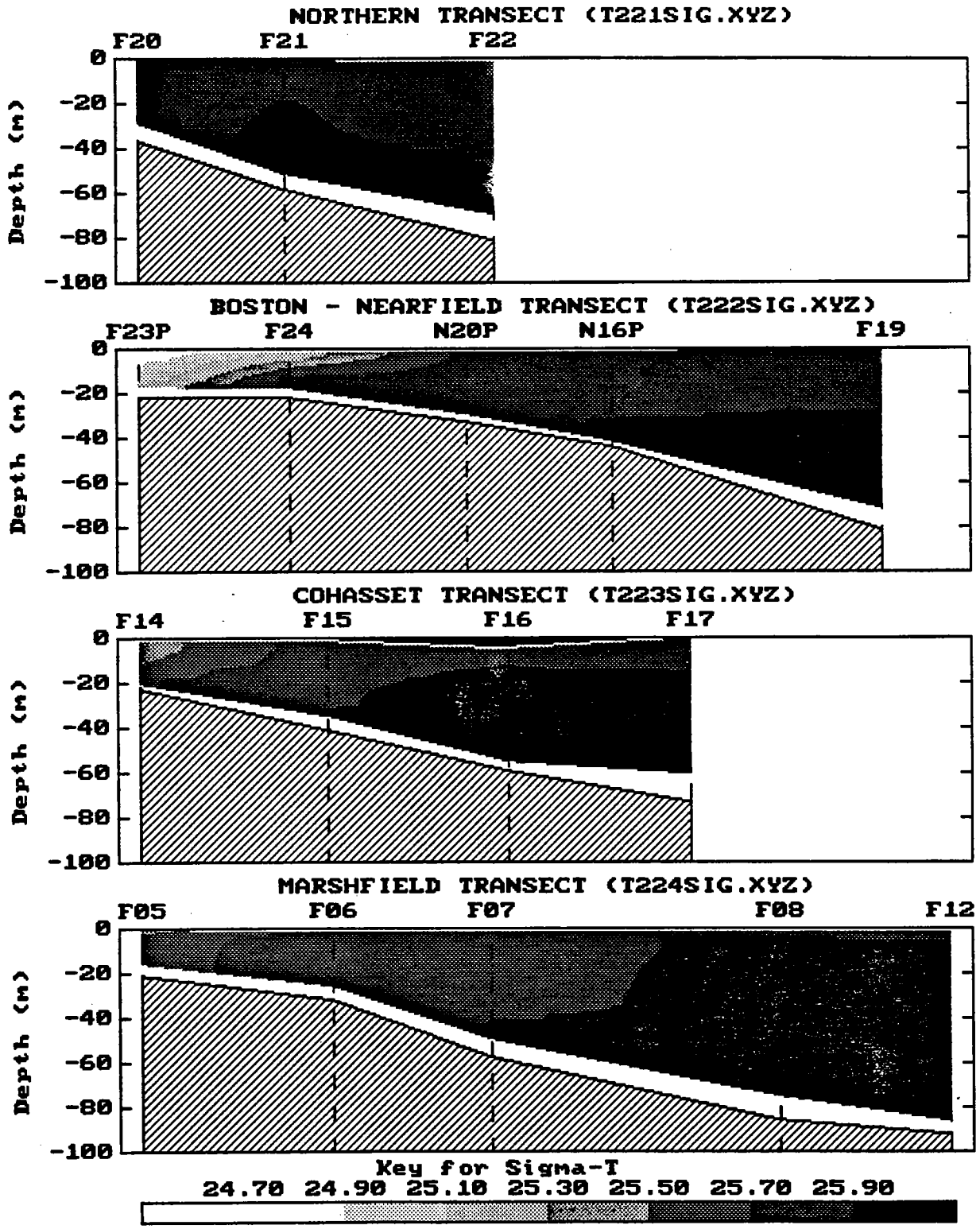


Figure 5-11. Vertical section contours of density (σ_T) in March 1993 for standard transects (see Figure 5-9). The data used to produce contours are from high-resolution continuous vertical profiles taken from the downcast at each station.

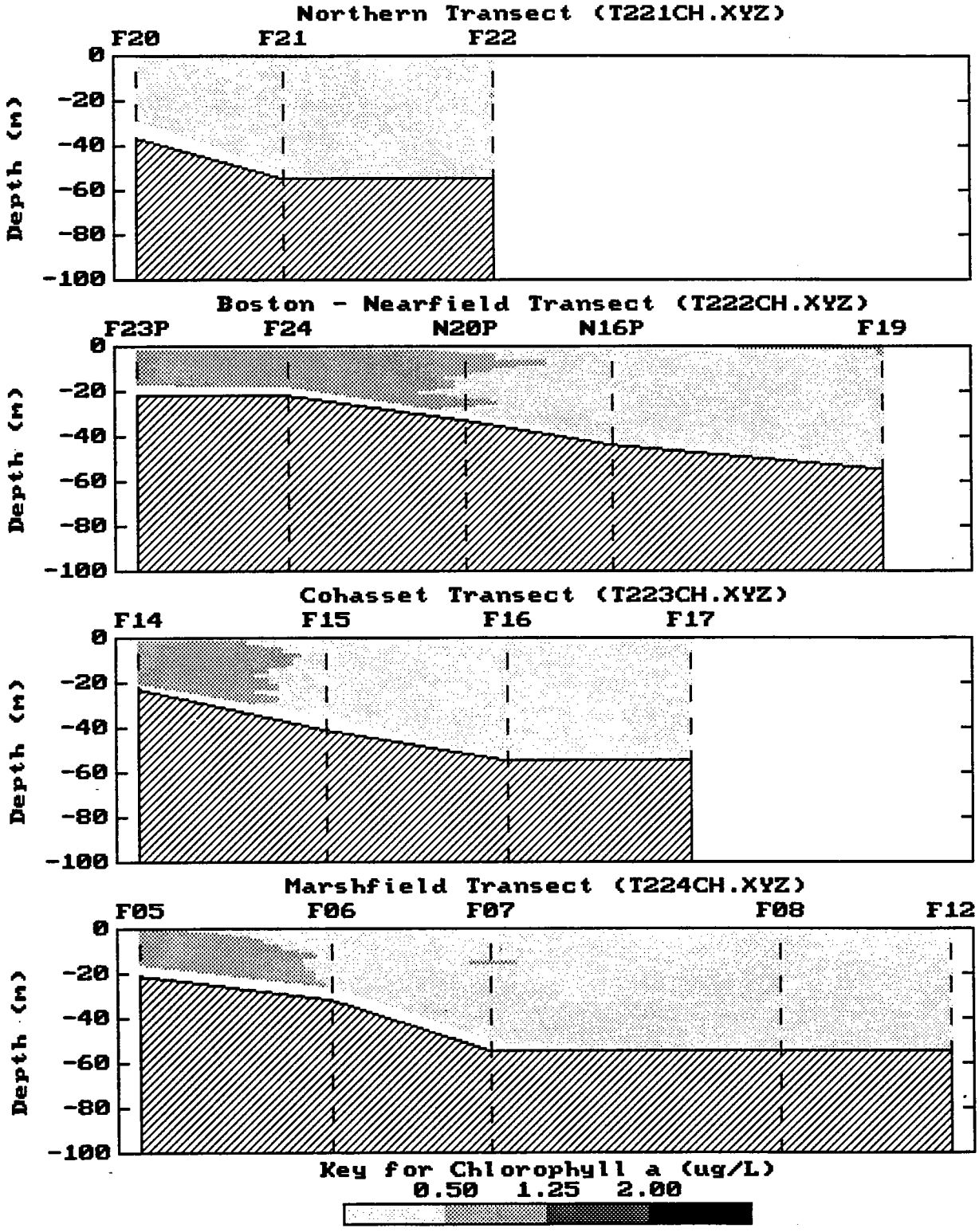


Figure 5-12a. Vertical section contours of fluorescence (as μg Chl L^{-1}) in March 1993 for standard transects (see Figure 5-9). The data used to produce contours are from high-resolution continuous vertical profiles taken from the downcast at each station.

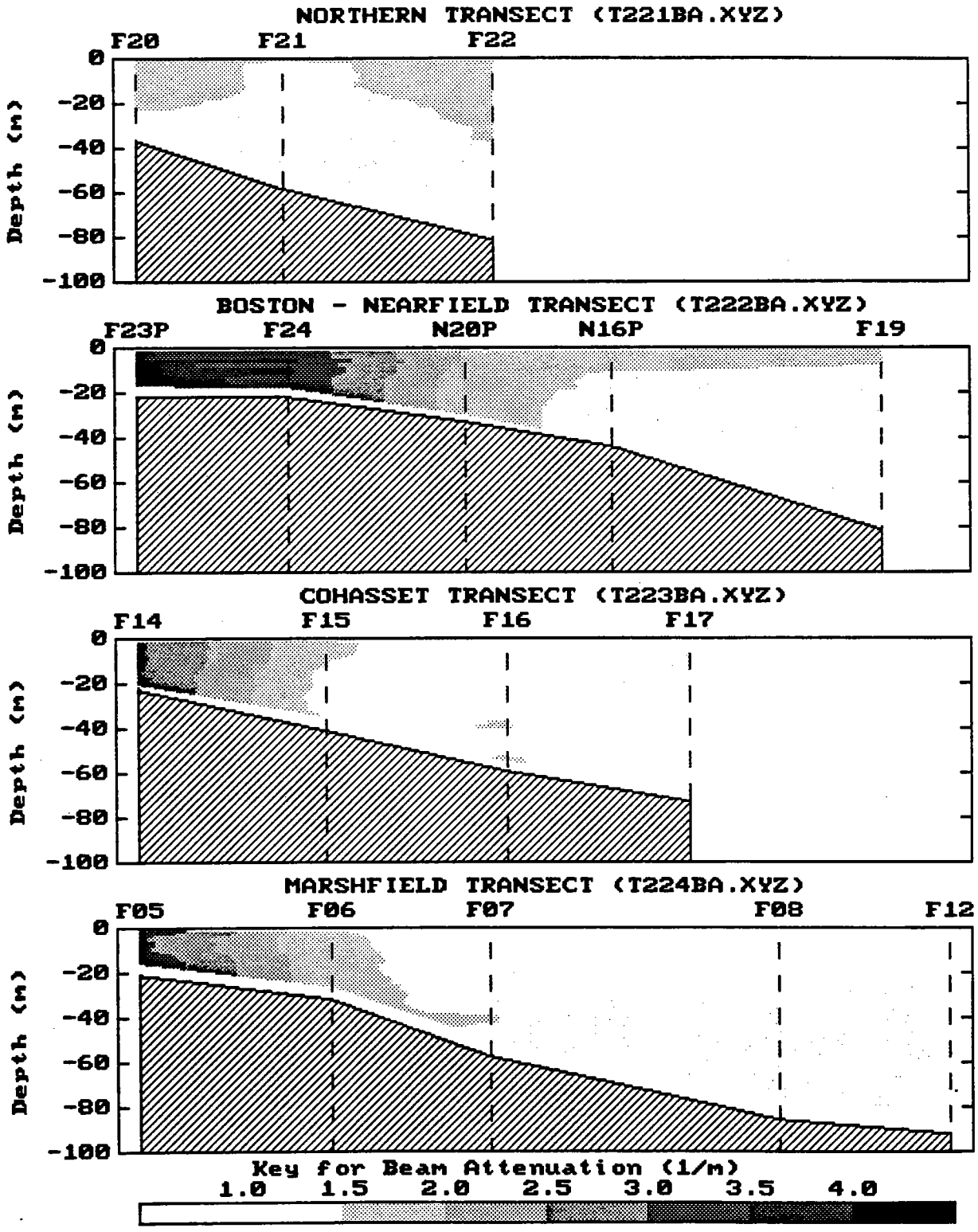


Figure 5-12b. Vertical section contours of beam attenuation in March 1993 for standard transects (see Figure 5-9). The data used to produce contours are from high-resolution continuous vertical profiles taken from the downcast at each station.

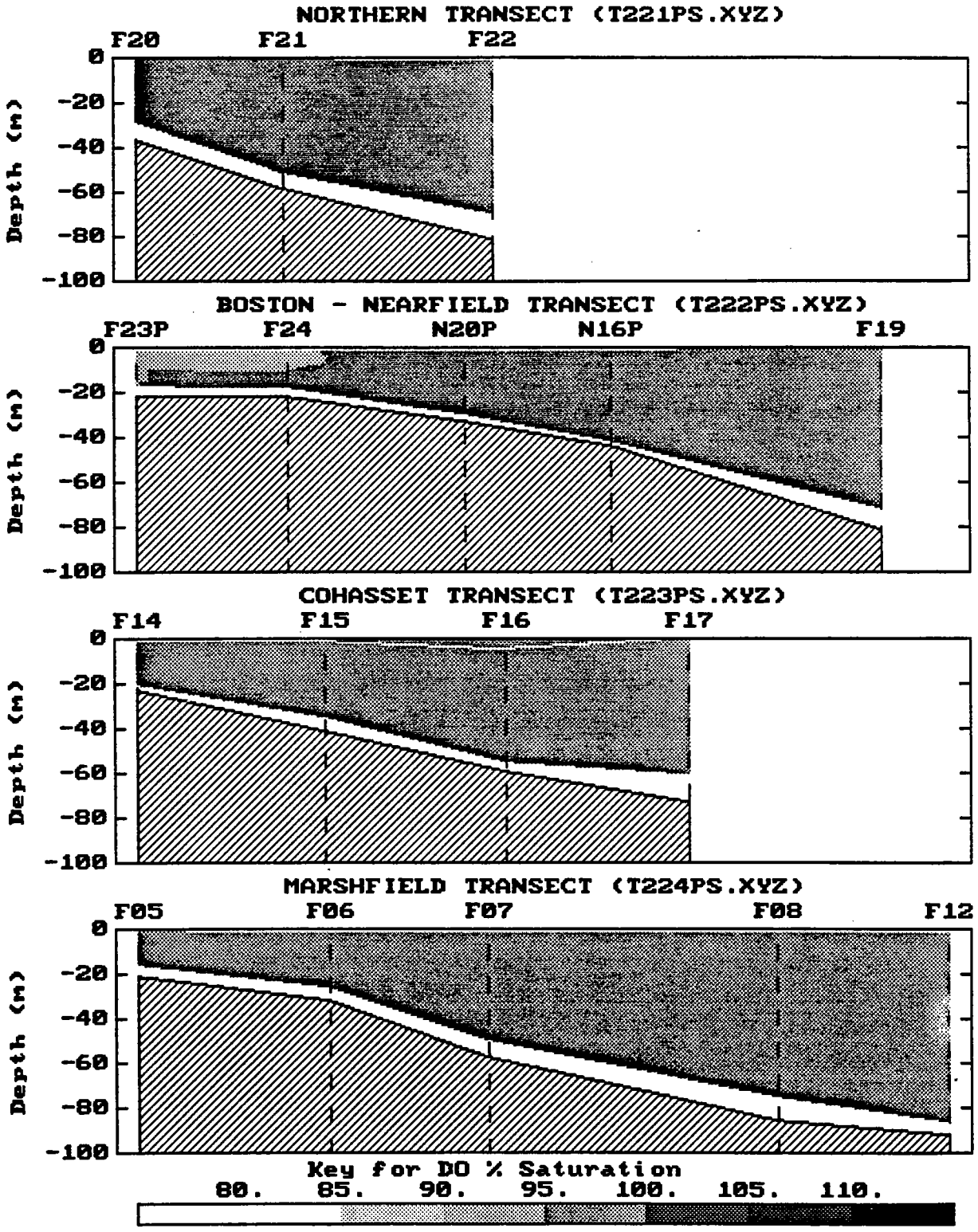


Figure 5-12c. Vertical section contours of dissolved oxygen (% saturation) in March 1993 for standard transects (see Figure 5-9). The data used to produce contours are from high-resolution continuous vertical profiles taken from the downcast at each station.

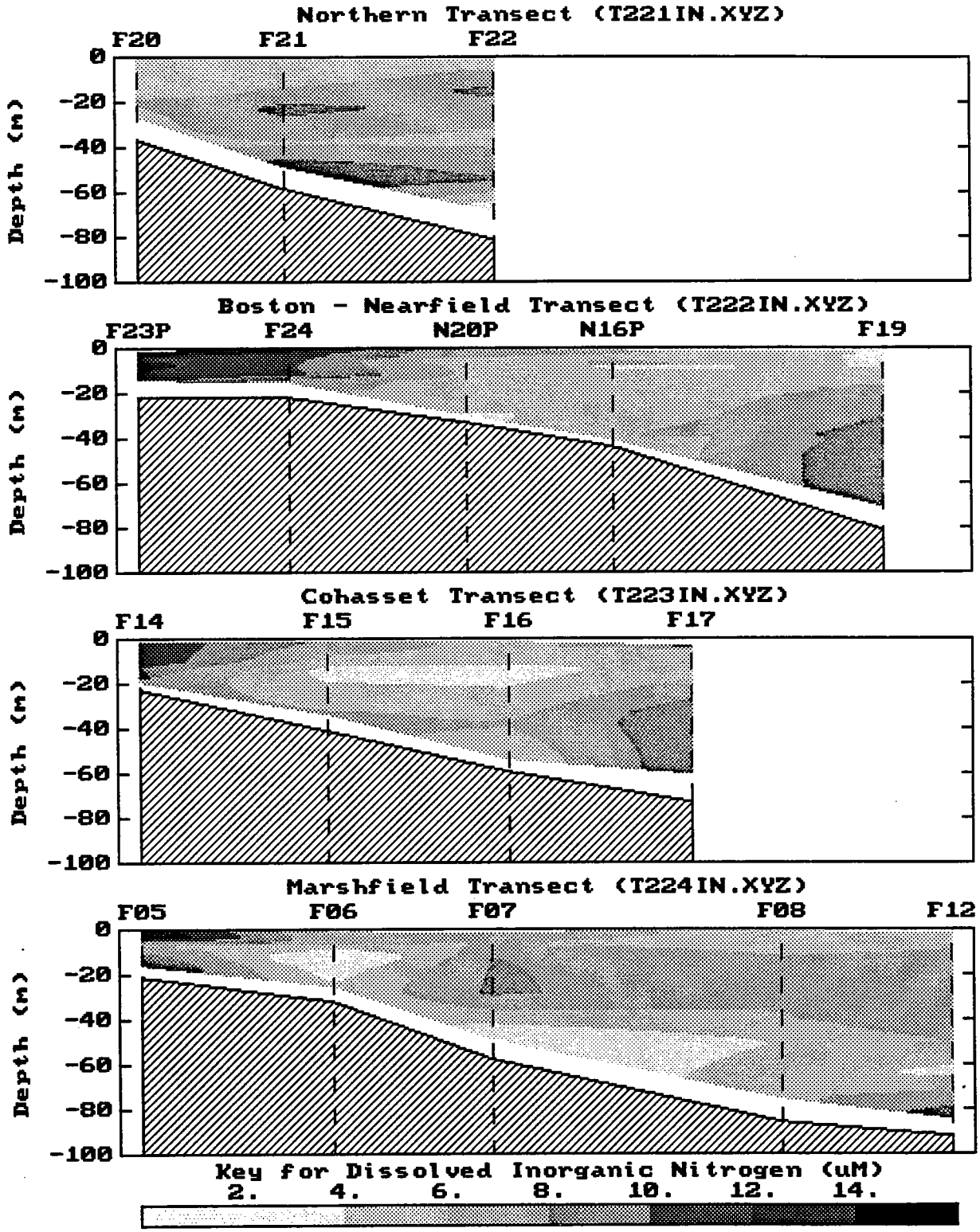


Figure 5-13. Vertical section contours of dissolved inorganic nitrogen (DIN, μM) in March 1993 for standard transects (see Figure 5-9). The data used to produce contours are from discrete bottle samples as given in Appendix A.

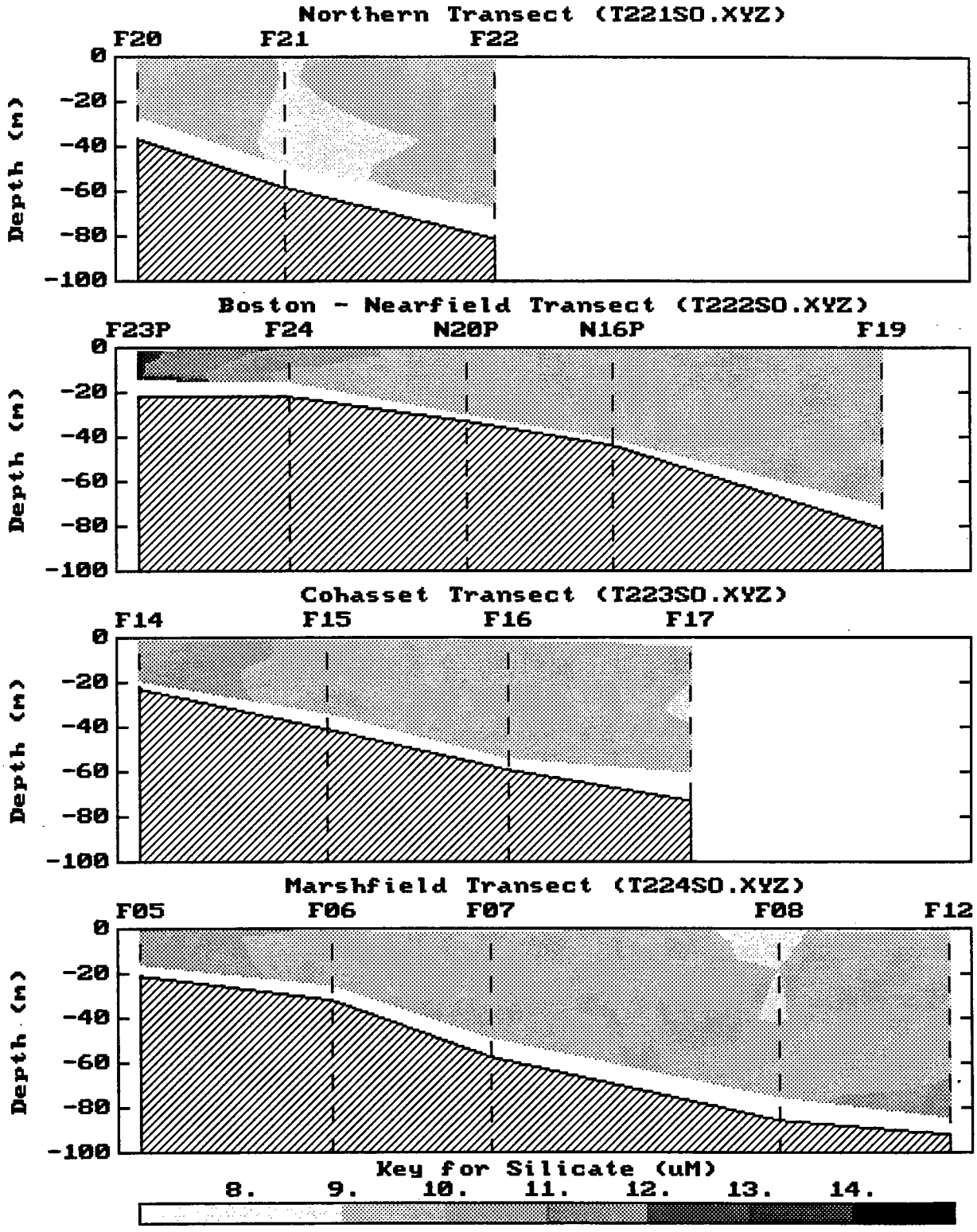


Figure 5-14. Vertical section contours of silicate (SiO_4, μM) in March 1993 for standard transects (see Figure 5-9). The data used to produce contours are from discrete bottle samples as given in Appendix A.

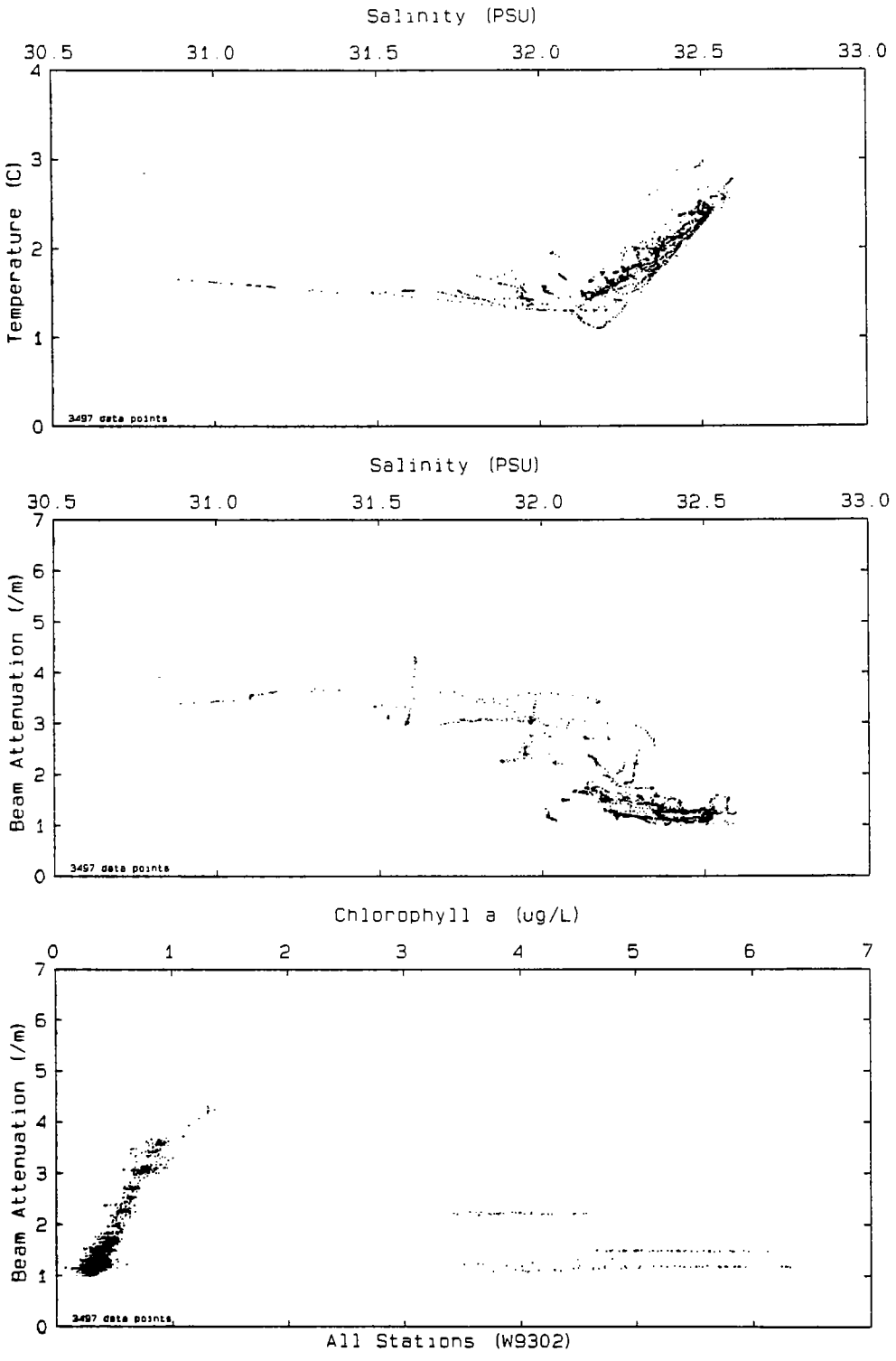


Figure 5-15a. Scatter plots of data acquired by *in situ* sensor package during vertical casts at all farfield and nearfield stations occupied in March 1993. Regional plots are in Appendix C.

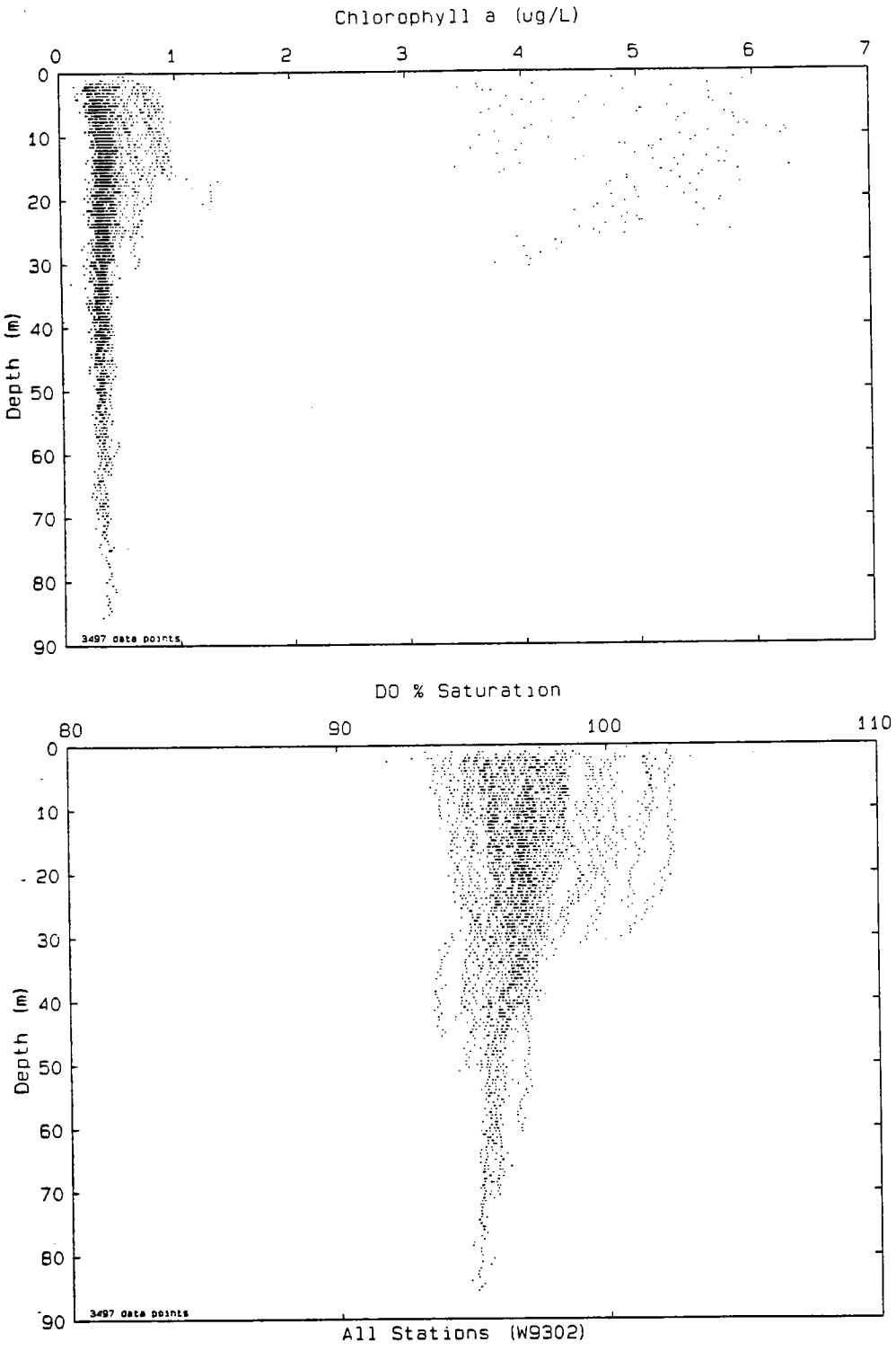


Figure 5-15b. Scatter plots of data acquired by *in situ* sensor package during vertical casts at all farfield and nearfield stations occupied in March 1993. Regional plots are in Appendix C.

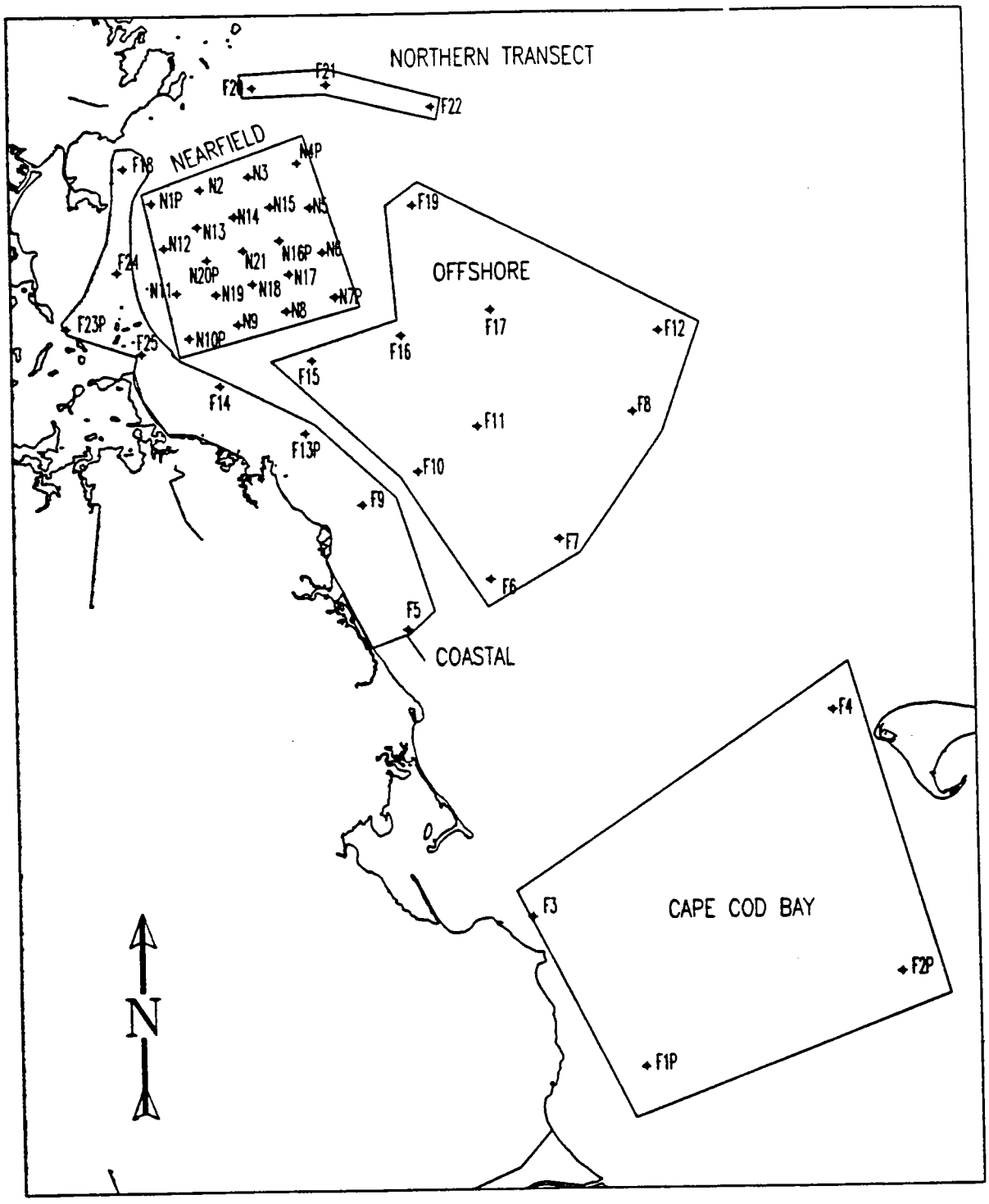


Figure 5-16. **Map to show station groups designated in Figures 5-17 through 5-22. Massachusetts Bay stations were separated into four groups based on water depth and geographic position; Cape Cod Bay has four stations.**

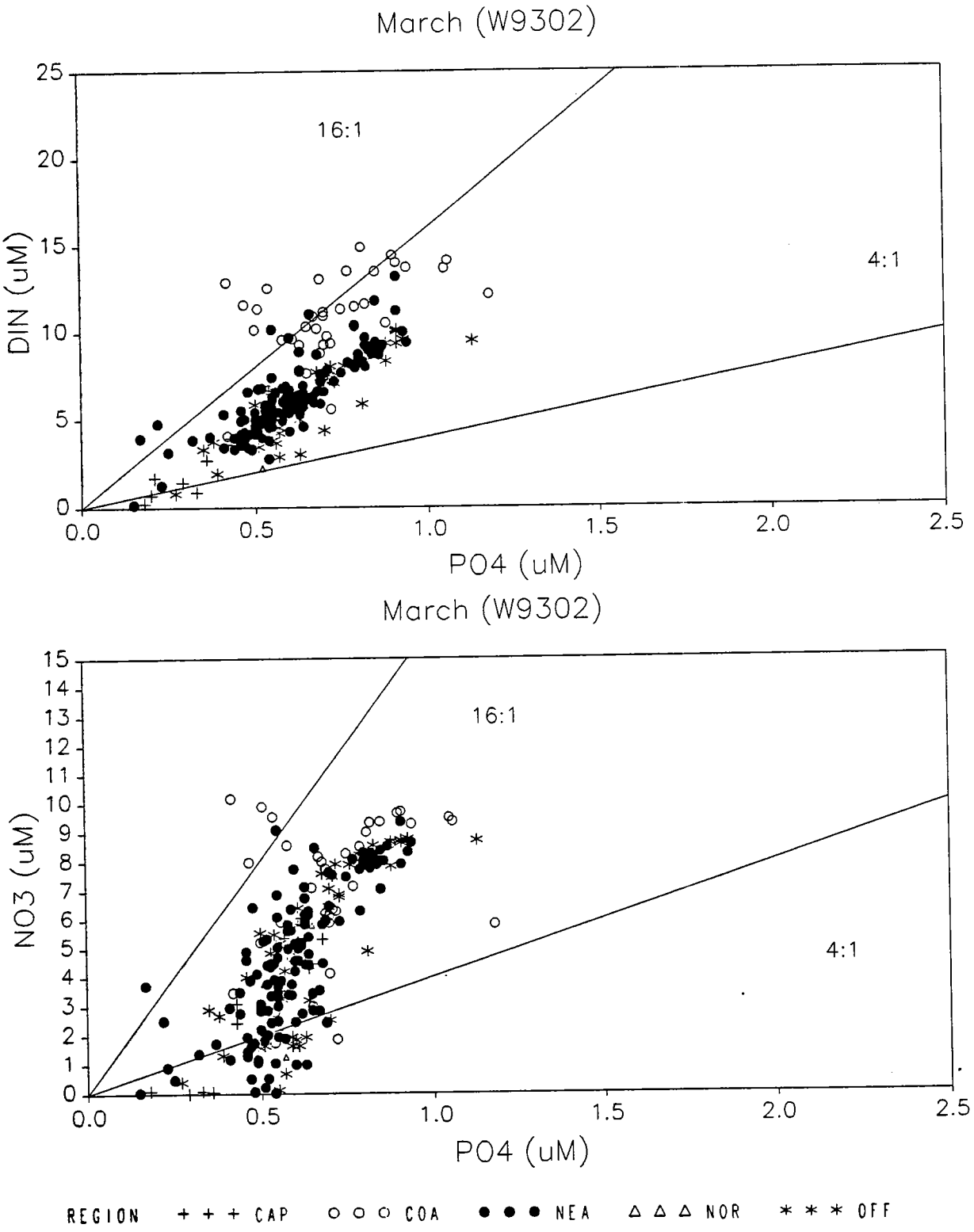


Figure 5-17. **Scatter plots of nitrogen forms vs. phosphate during March 1993. All stations and depths are included, and data are given in Appendix A. Lines show constant proportions of nitrogen relative to phosphorous.**

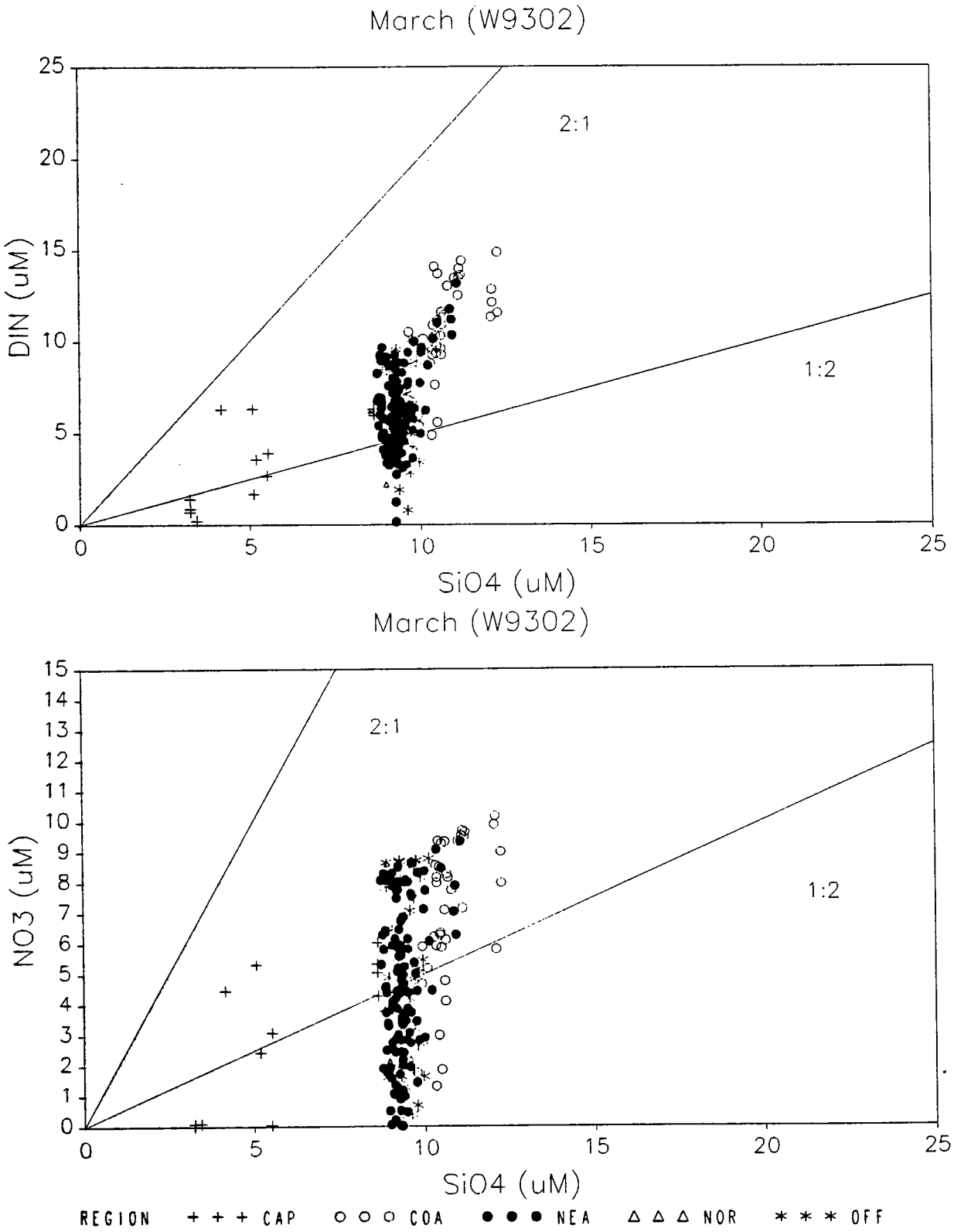


Figure 5-18. **Scatter plots of nitrogen forms vs. silicate during March 1993. All stations and depths are included, and data are given in Appendix A. Lines show constant proportions of nitrogen relative to silicate.**

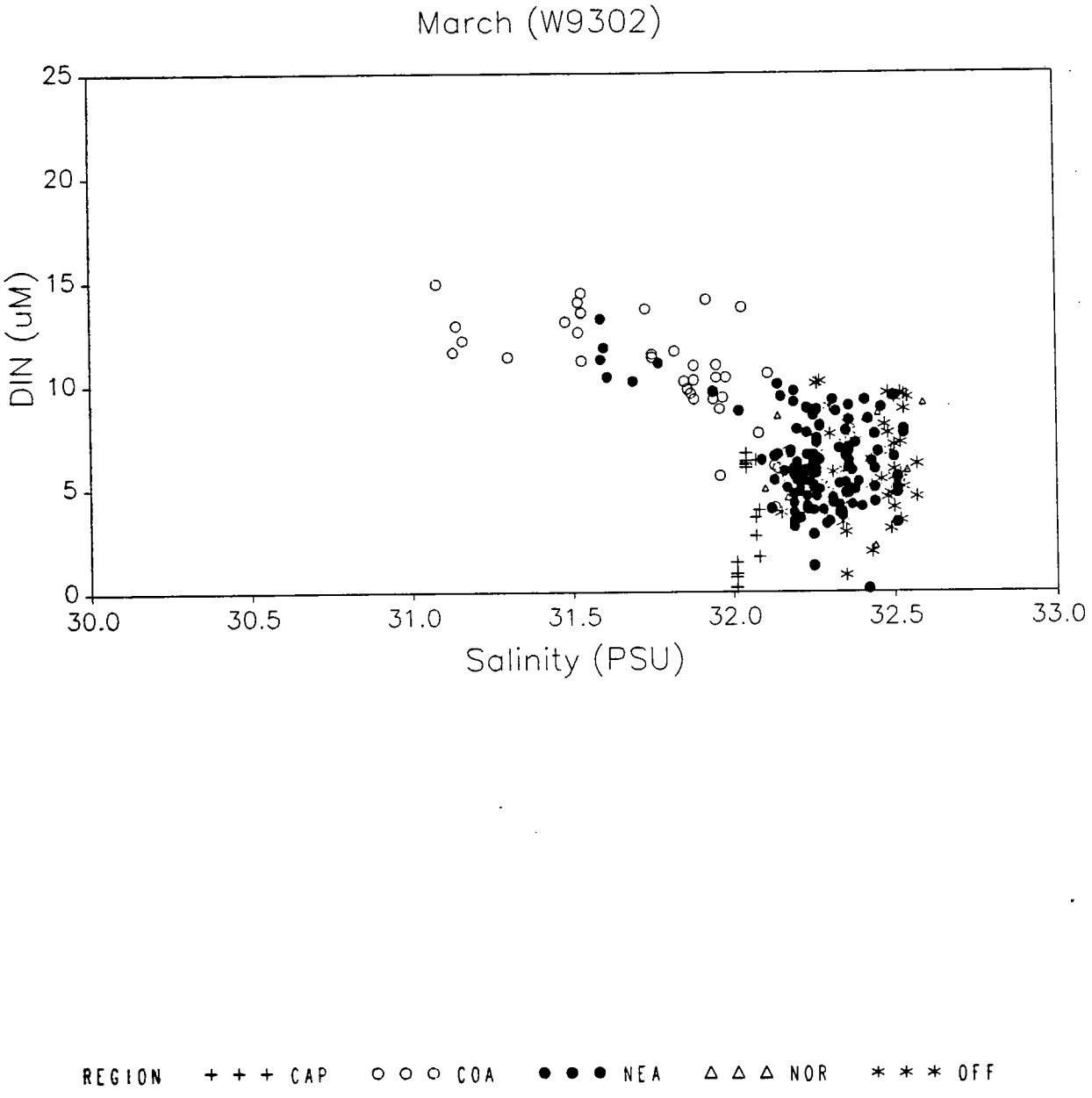


Figure 5-19. **Dissolved inorganic nitrogen vs. salinity in March 1993. All stations and depths are included, and data are given in Appendix A.**

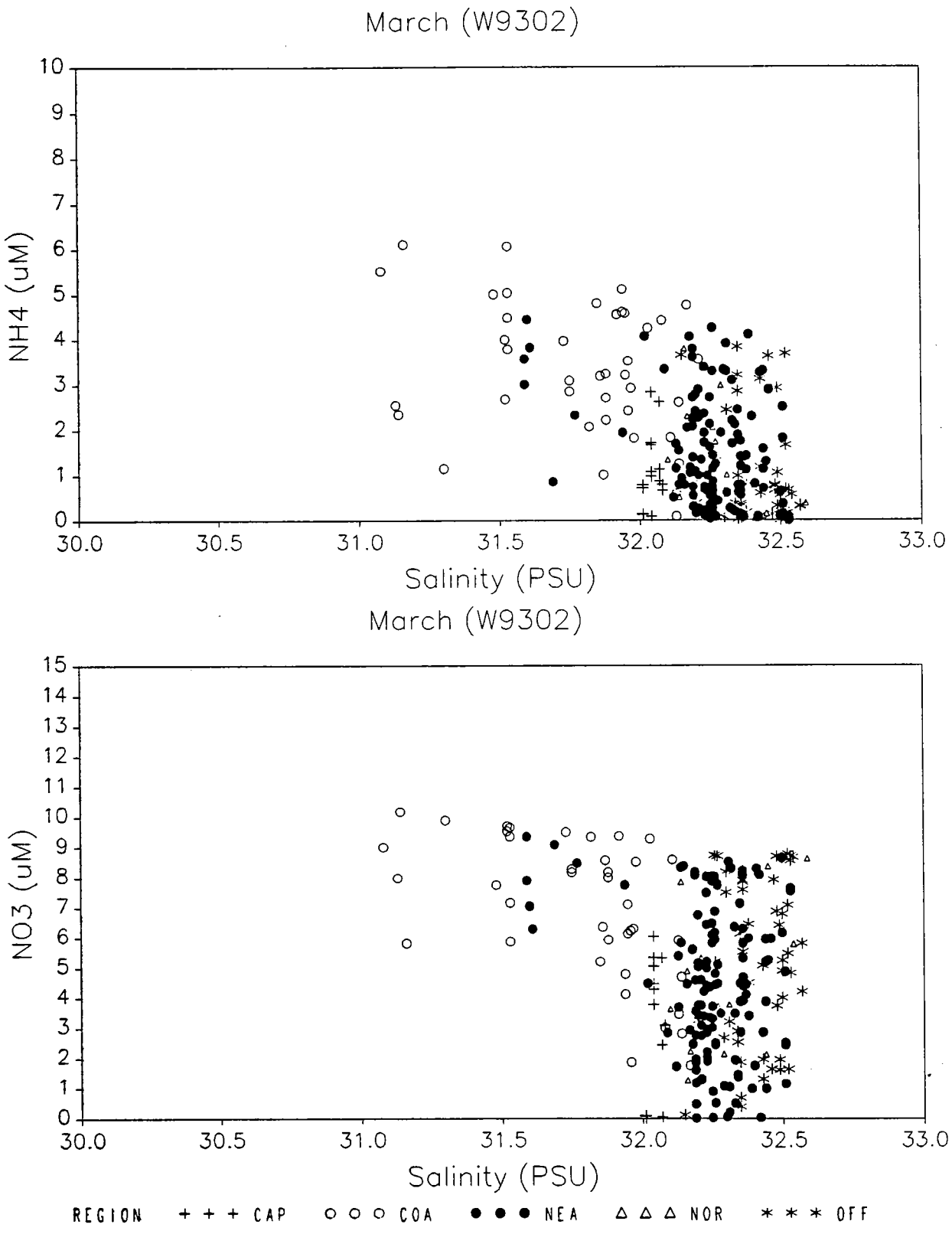


Figure 5-20. **NH_4 and NO_3 vs. salinity in March 1993. All stations and depths are included, and data are given in Appendix A.**

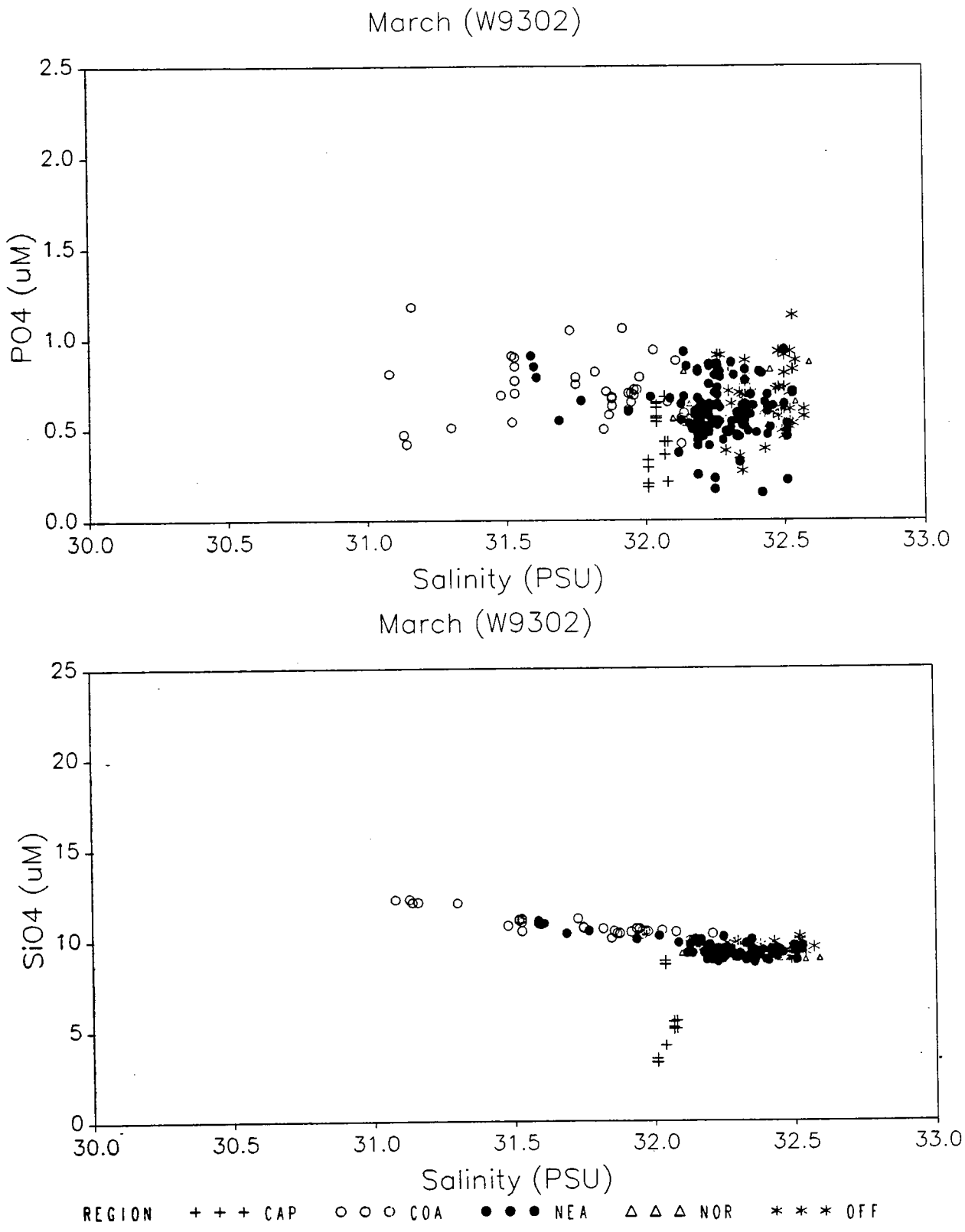


Figure 5-21. **PO_4 and SiO_4 vs. salinity in March 1993. All stations and depths are included, and data are given in Appendix A.**

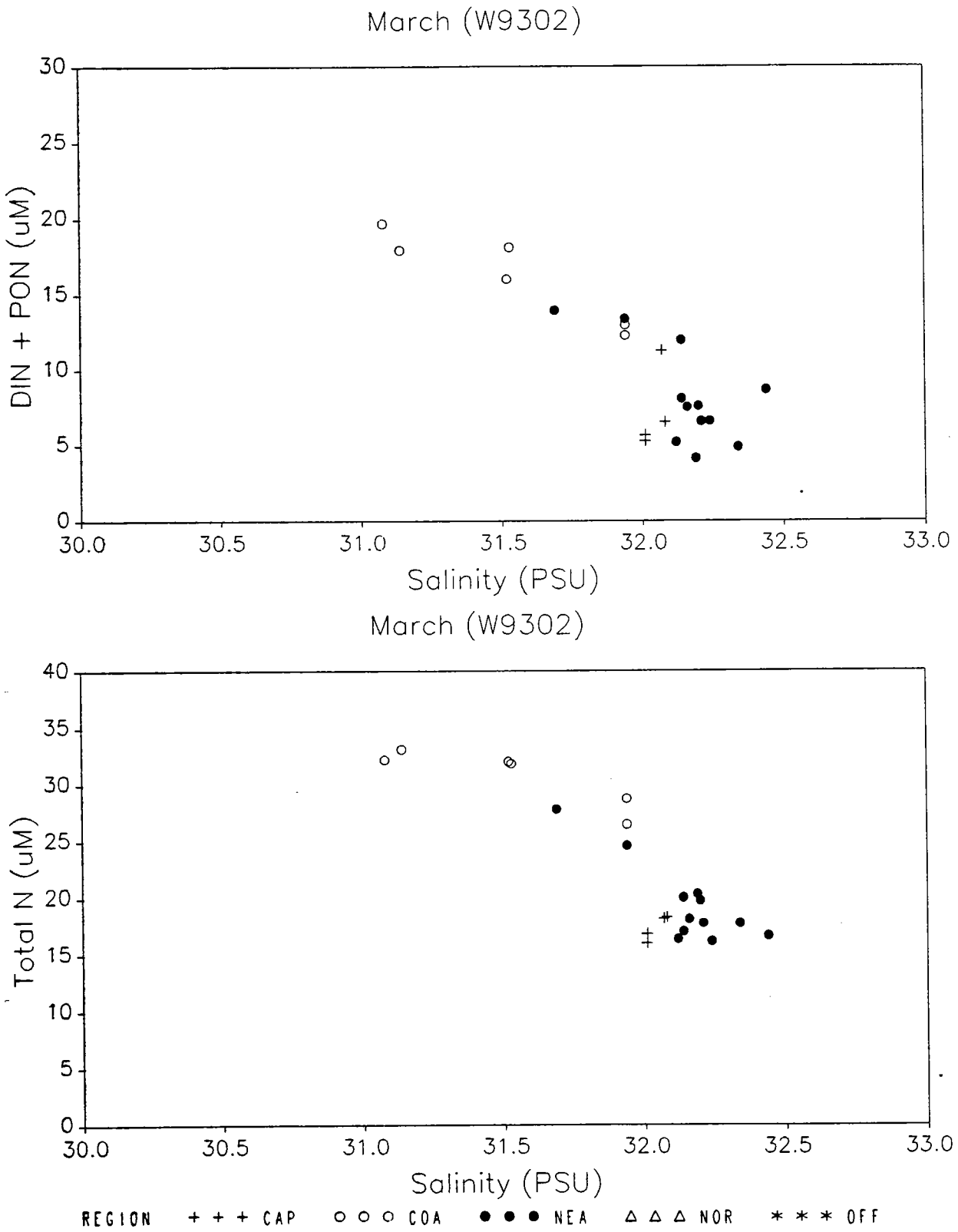


Figure 5-22. **Nitrogen forms vs. salinity in March 1993. Data are from BioProductivity stations and special station F25 and are given in Appendix A. The station groups are coded as given in Figure 5-16; there are no BioProductivity stations in the offshore or northern transect groups. Dissolved inorganic nitrogen = DIN, particulate organic nitrogen = PON, and total nitrogen (TN) = total dissolved nitrogen (TDN) + PON.**

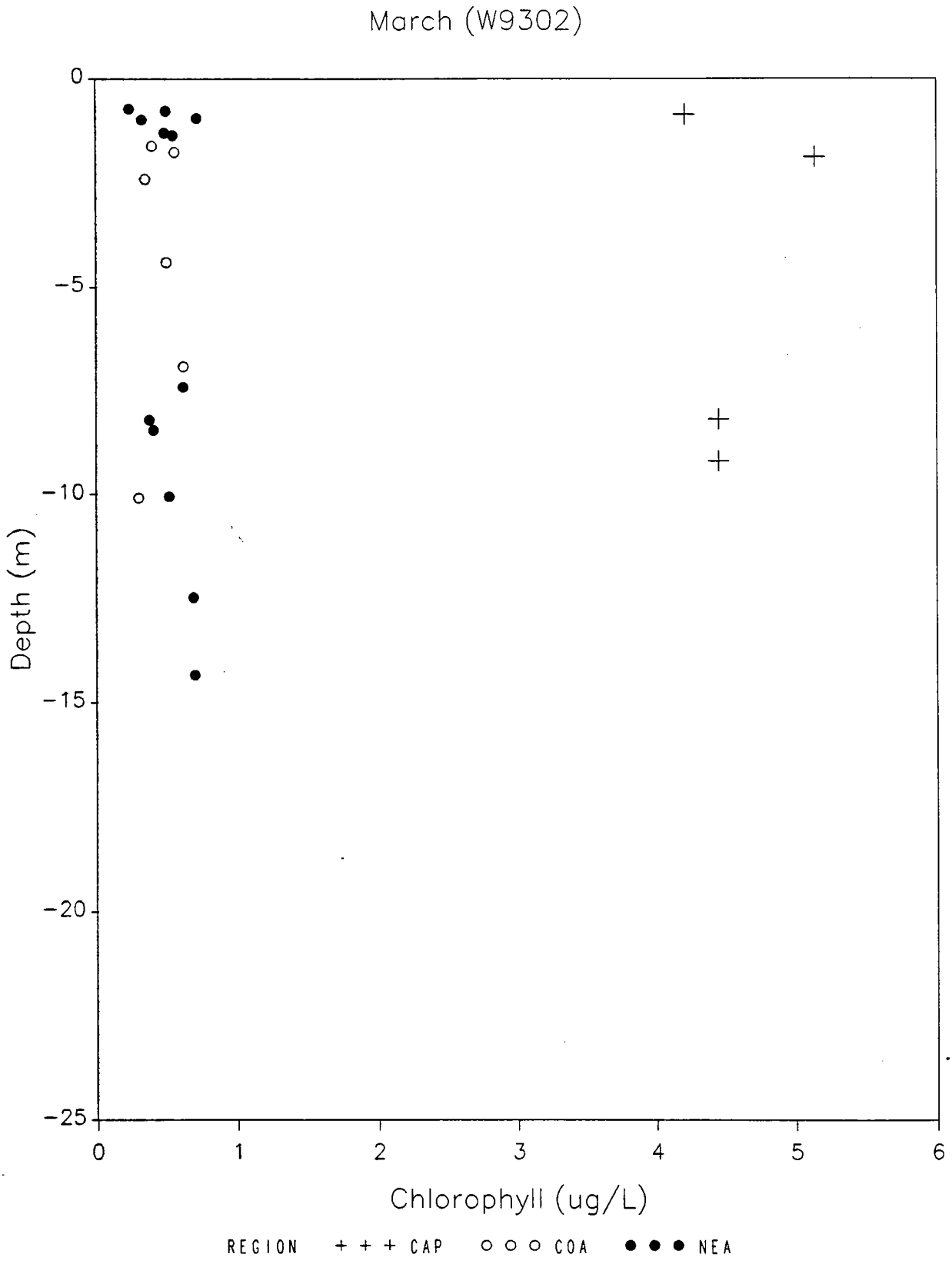


Figure 5-23. Surface and deeper chlorophyll (extracted samples) at BioProductivity stations and special station F25 as a function of depth in March 1993.

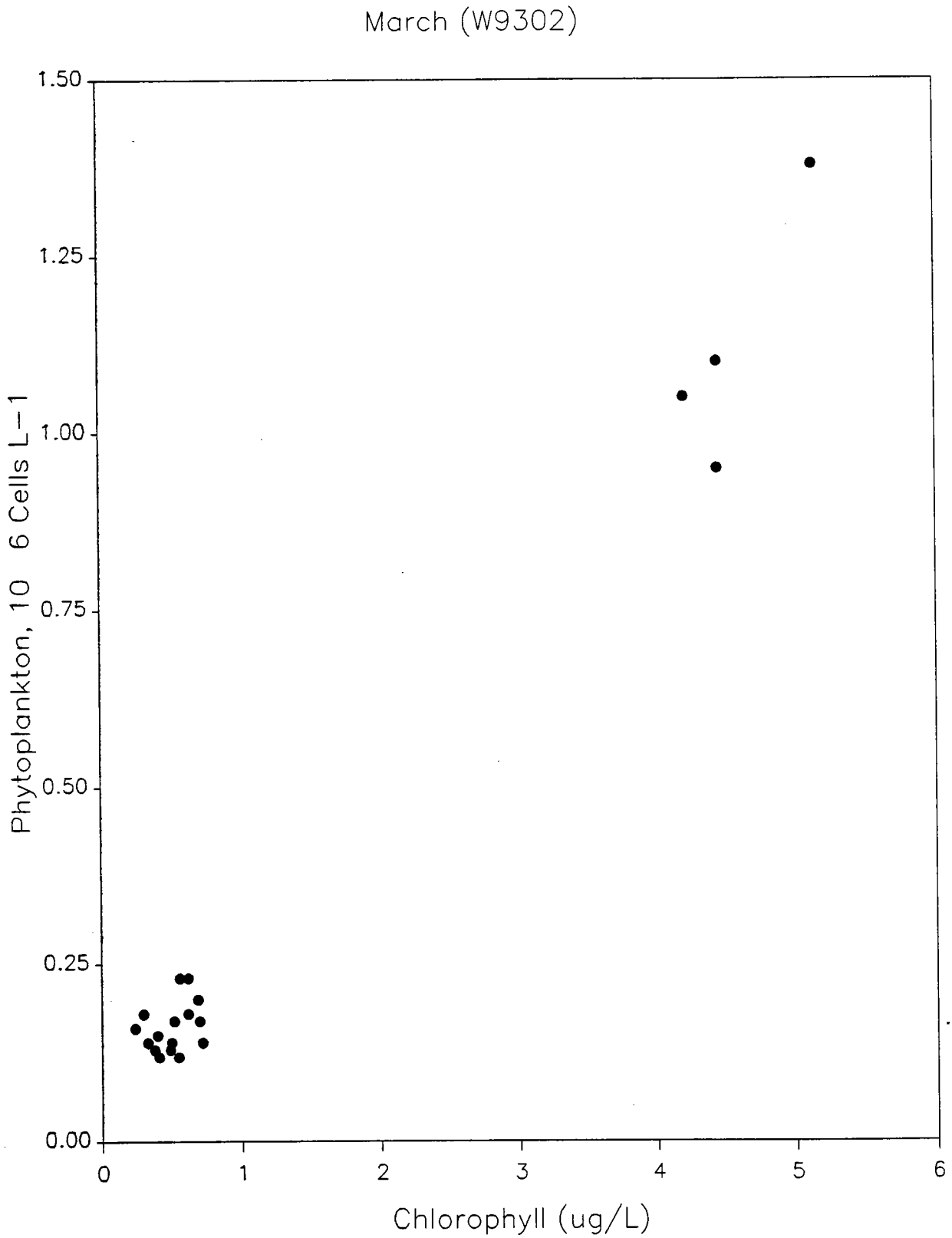


Figure 5-24. **Total phytoplankton abundance vs. chlorophyll (extracted samples) at BioProductivity stations in March 1993. Data are given in Appendices A and F.**

Figure 5-25. **Total phytoplankton abundance, by taxonomic groups, at BioProductivity stations in March 1993. Data are given in Appendix F.**

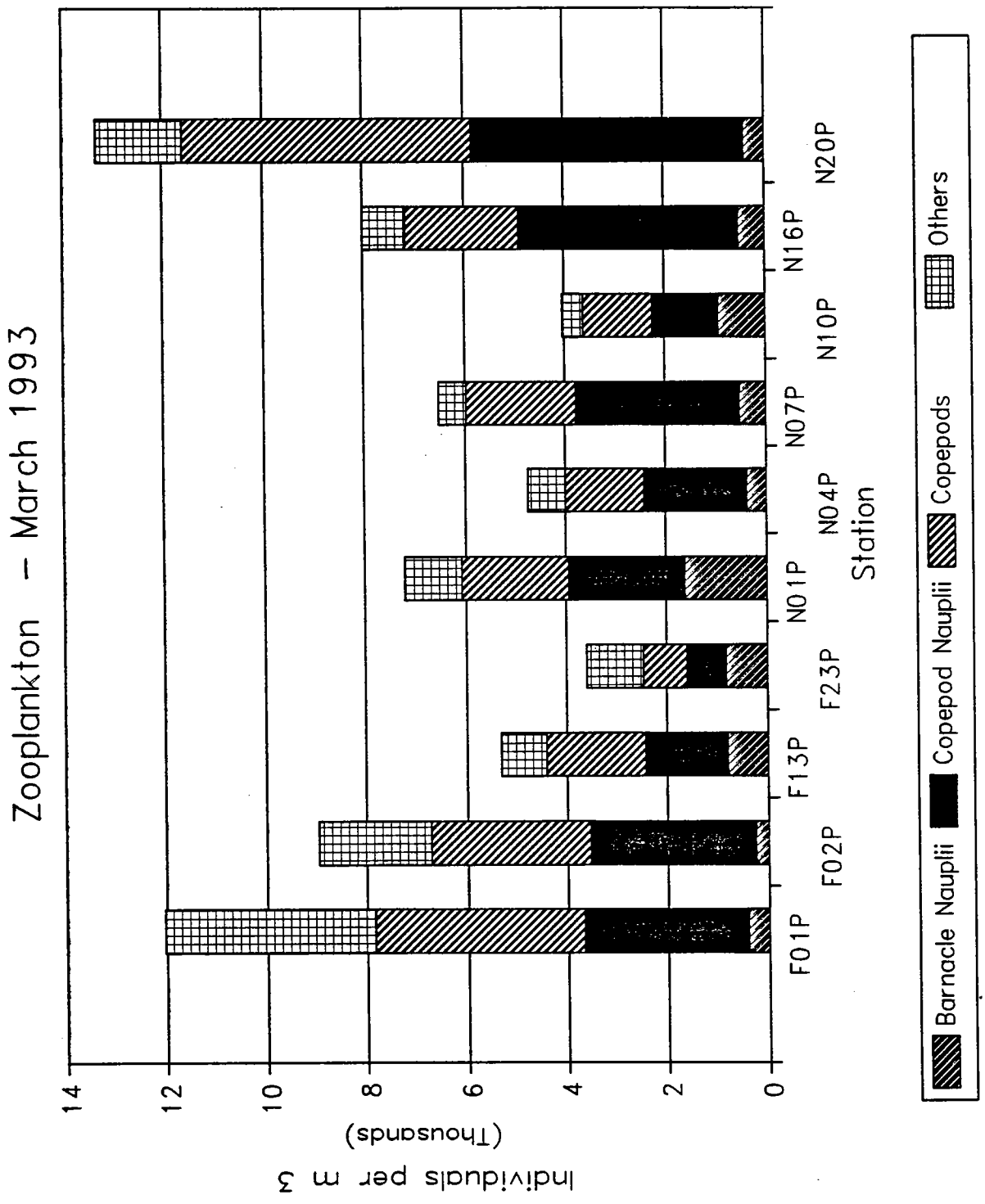


Figure 5-26. **Zooplankton abundance, by groups, at BioProductivity stations in March 1993. Data are given in Appendix G.**

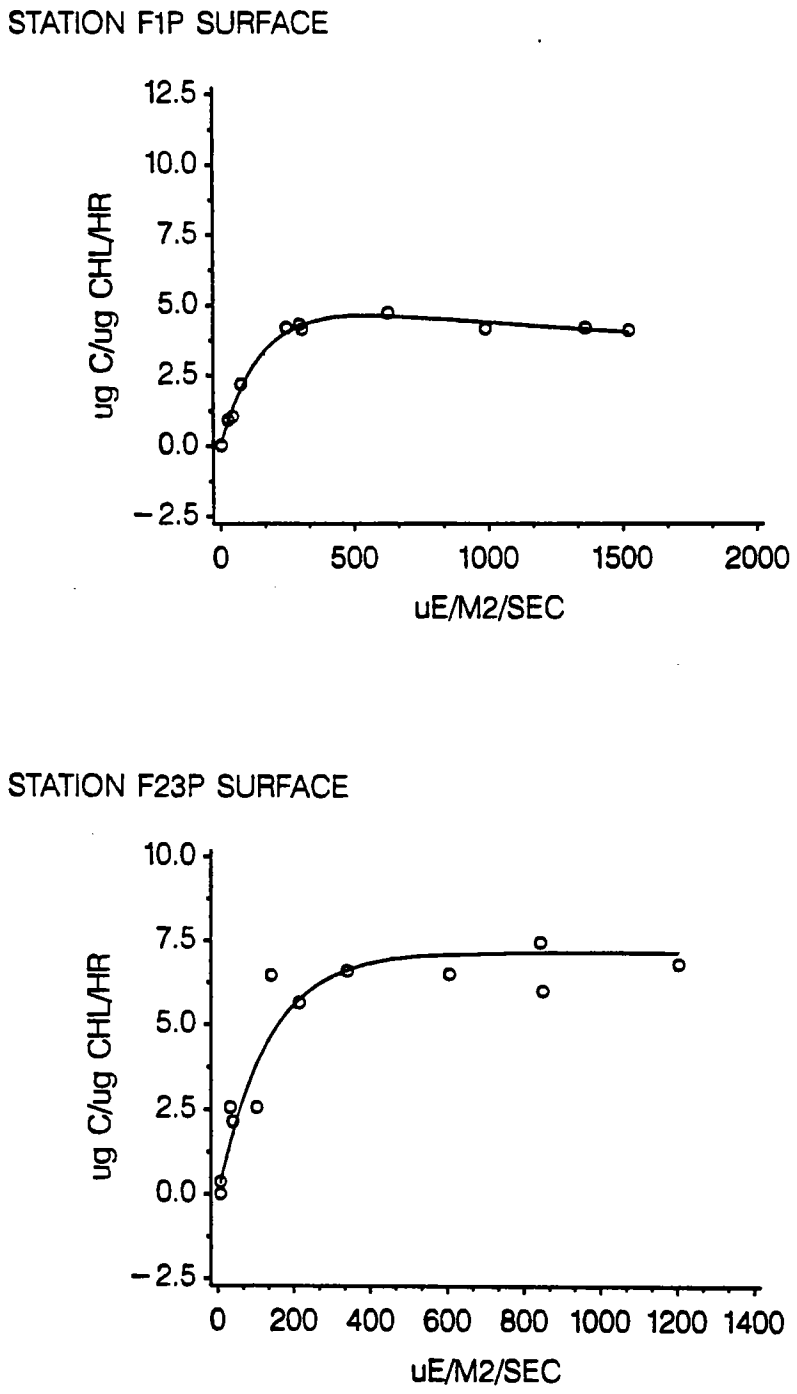


Figure 5-27. **Selected net production (P) vs. irradiance (I) curves in March 1993. Data are chlorophyll-normalized rates, see Appendix E.**

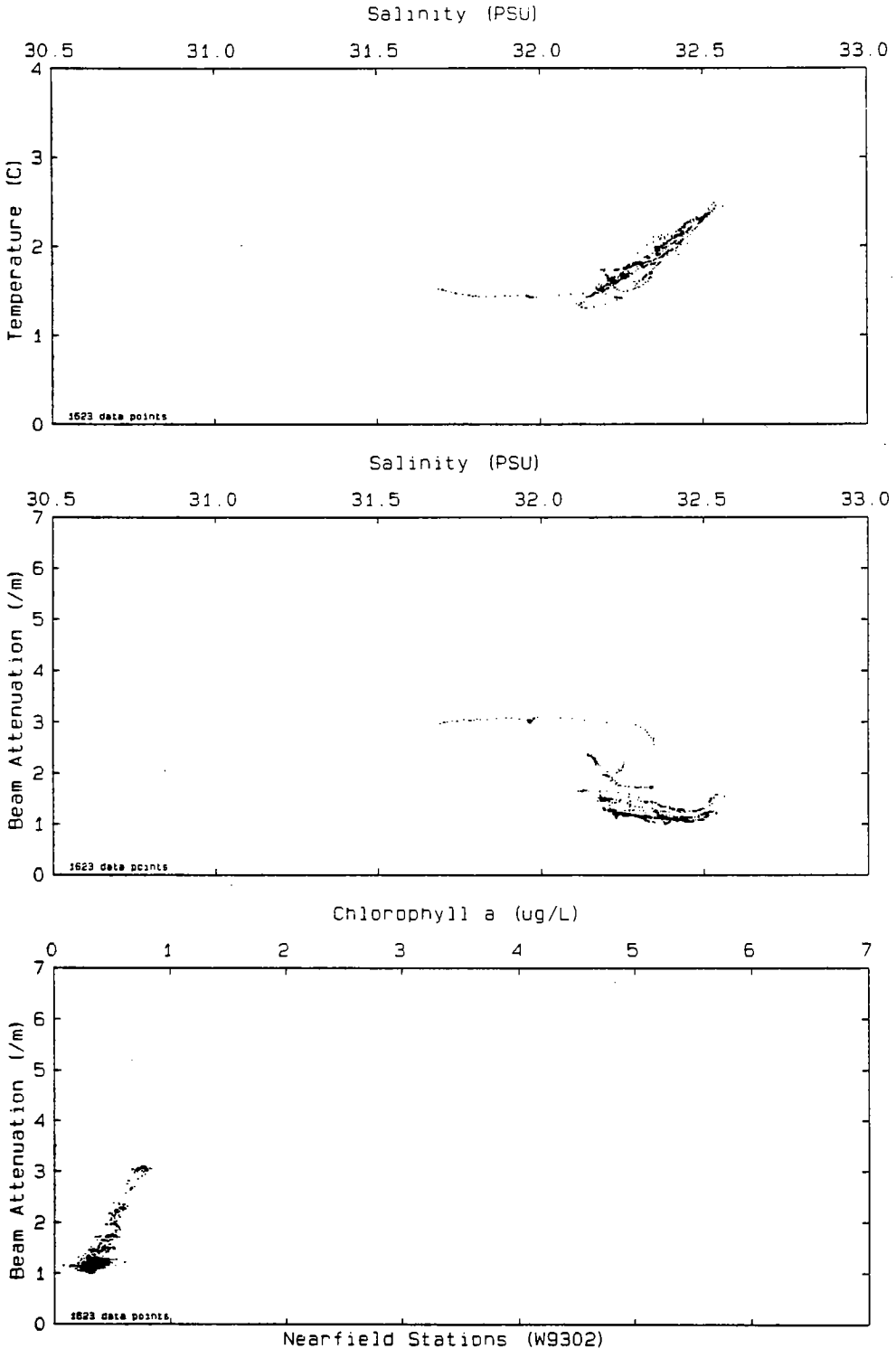


Figure 5-28. Scatter plots for nearfield stations in March 1993. Compare to Figure 5-15.

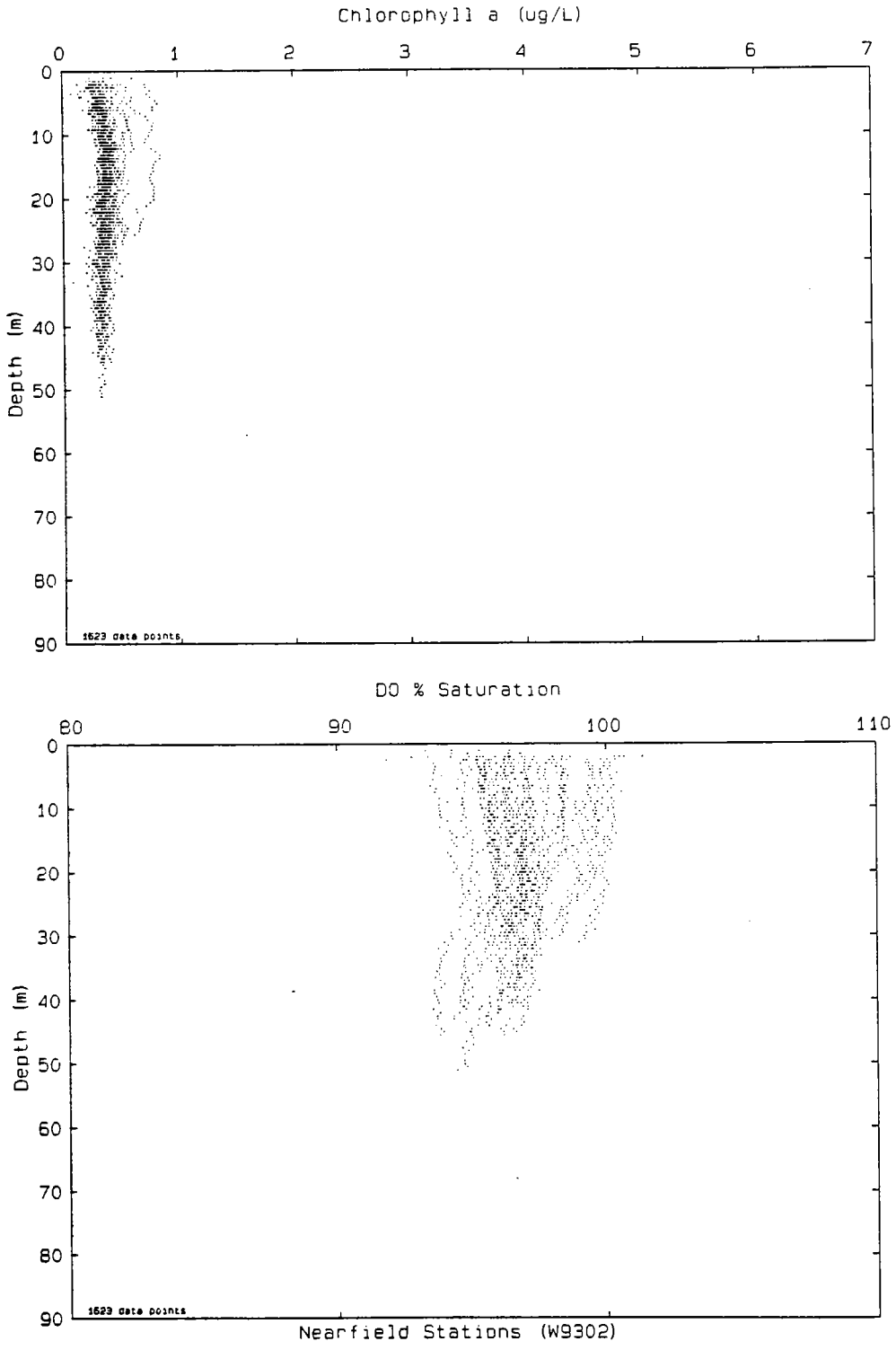


Figure 5-29. Scatter plots for nearfield stations in March 1993. Compare to Figure 5-15.

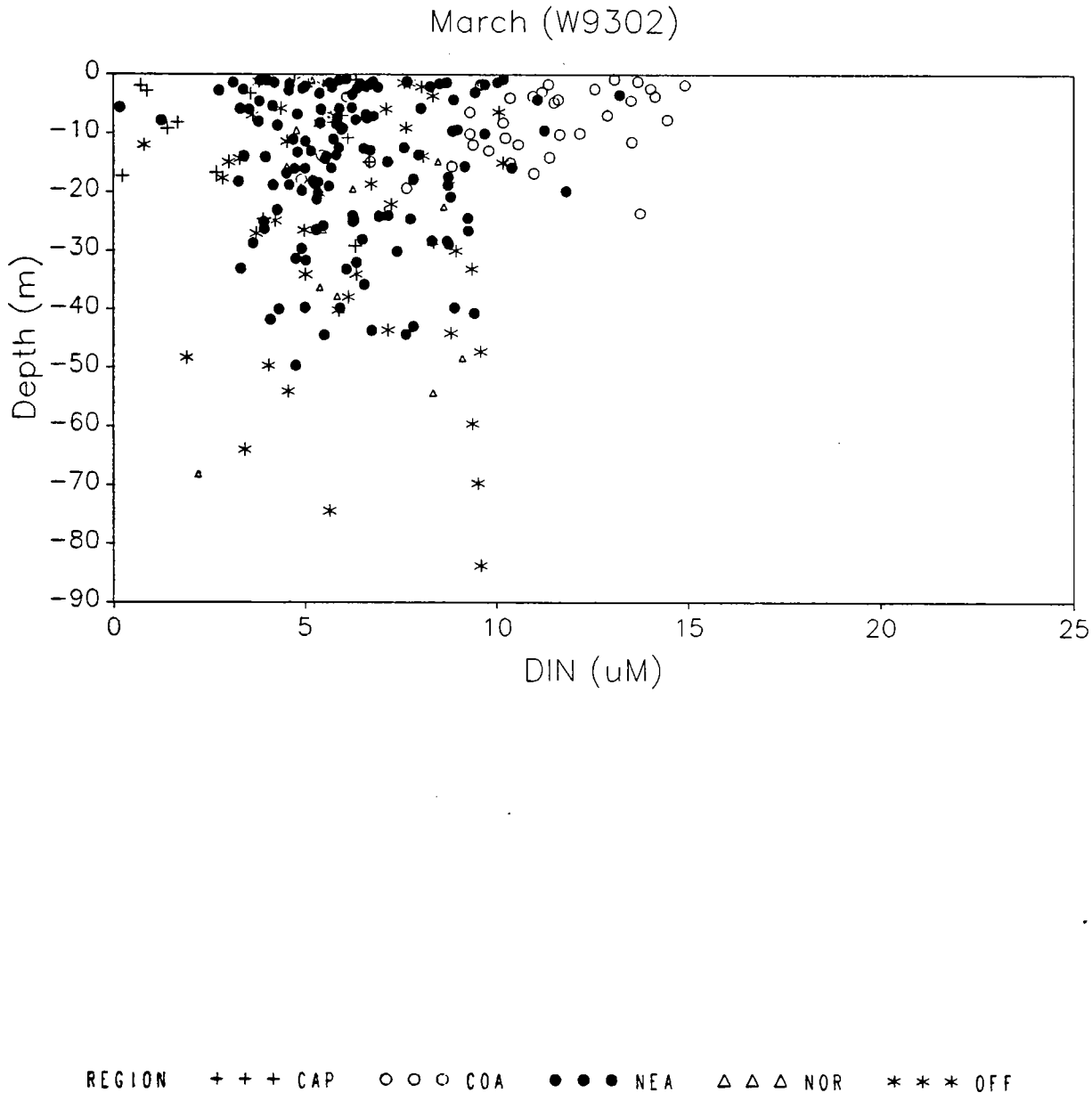


Figure 5-30a. DIN vs. depth in March 1993.

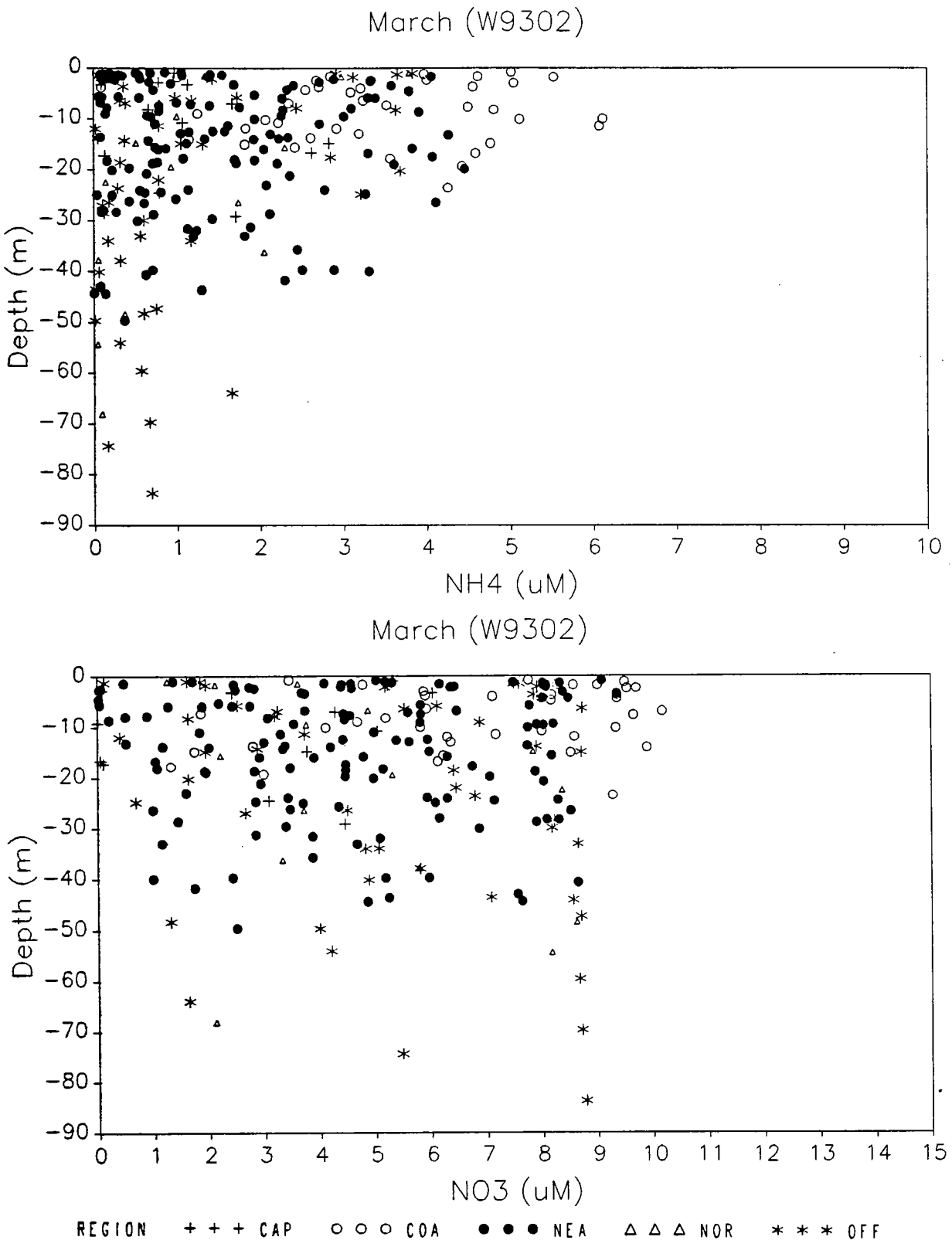


Figure 5-30b. NH_4 and NO_3 vs. depth in March 1993.

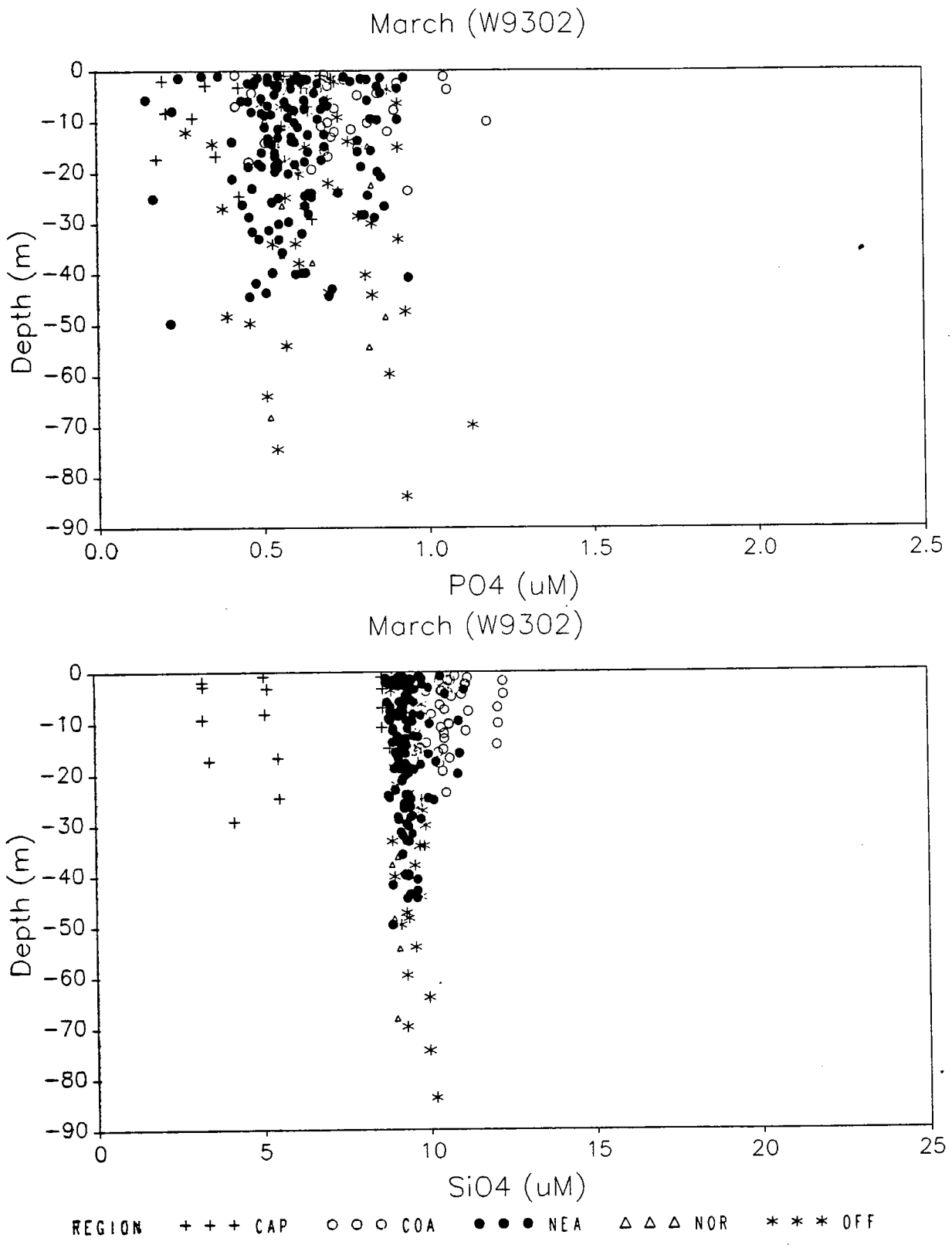


Figure 5-30c. PO_4 and SiO_4 vs. depth in March 1993.

6.0 RESULTS OF LATE MARCH 1993 NEARFIELD SURVEY (W9303)

6.1 Distribution of Water Properties from Vertical Profiling

Vertical profiles were obtained at all twenty-one nearfield stations (Appendices A, B). Scatter plots using *in situ* sensor data are shown in Figure 6-1. The range in temperature was narrow, from about 1 to 2 °C (Figure 6-1a). Salinity, for the most part was 32 PSU or higher, but a few stations had salinity between 31 and 32 PSU. Examination of vertical profiles (Appendix B) revealed many stations had a very shallow (5-8 m) cold and fresh surface layer, less dense than the uniform-density bottom layer. Apparently, surface cooling and freshening had occurred since mid-March (cf. Section 5.2), and thus produced this feature. The feature was most striking along the western half of the nearfield. A more saline surface layer, indicating mild stratification, was also evident along the northern and eastern edges of the nearfield. Deeper stations along the eastern edge of the nearfield had a minor, secondary deep thermocline at about 30-35 m.

The range in beam attenuation (about 0.8 to 1.7 m^{-1}) and chlorophyll (0.45 to 1.25 $\mu g\ L^{-1}$) was also small, but higher turbidity and chlorophyll were usually found at lower salinity. Chlorophyll was about 0.8 $\mu g\ L^{-1}$ on average and never much higher than 1 $\mu g\ L^{-1}$. There was little vertical structure found (Figure 6-1b). Oxygen was uniformly close to 100% saturation (95 to 105%) throughout depth.

Nutrient concentrations are related to depth in Figure 6-2. As observed previously in 1993, the range in DIN and its component forms was large (Figure 6-2a,b), but there was no overall pattern with depth. For DIN, the mean for the nearfield was 6.5 μM (stnd. dev.= 2.42, n=103), and thus, not different than that found in February or mid-March. NH_4 ranged from 0 to 5.8 μM, and the range for NO_3 (0.03 to 8.3 μM) was typical of that observed on the preceding two surveys.

PO_4 and SiO_4 concentrations also had little pattern as a function of depth (Figure 6-2c). The range for phosphate was similar to the previous nearfield survey (mid-March), as was silicate. Silicate concentrations, 7.3 to 11.6 μM, in the nearfield had a slightly greater range (a few lower values) than in mid March. The higher silicate in this region indicated that the initiation of silica depletion seen in Cape Cod Bay (Figure 5-30c) had not yet developed.

Figure 6-3 and 6-4 show salinity—nutrient plots for this survey. The scatter in the concentration at higher salinity is large for DIN, and some higher salinity samples had DIN at levels that were equal to the levels in the lower salinity samples. The pattern may suggest some mixing of inshore water with the nearfield; alternatively the relationship may also indicate water masses of different history within the nearfield at this time. PO_4 showed no relationship with salinity and highest values were seen at high salinity. In contrast, the salinity—silicate covariance was strong with slightly higher silicate associated with less saline water.

6.2 Distribution of Water Properties from Towing

There was very little vertical temperature or density structure apparent from the tow-yo profiling (Figures 6-5 and 6-6). The most obvious feature was a horizontally-graded transition from cooler, but less dense, water inshore to slightly warmer, denser water offshore (Figure 6-6b). Only at station N10P was a small anomalous water mass seen to disrupt the otherwise graded uniformity. Density differences at N10P were driven by salinity differences and not the temperature, which was similar to surrounding waters (Figure 6-5a). Significant north-south gradients were not observed.

Chlorophyll from towing showed general uniformity throughout the field, with many values ranging from 0.5 to 1.25 $\mu g\ L^{-1}$ as in Figure 6-1b. However, the most striking aspect of the data was the fairly uniform distribution of small patches of chlorophyll with concentrations $>3.5\ \mu g\ L^{-1}$; this distribution created the mottled pattern shown in Figure 6-7. There was no striking chlorophyll anomaly to compliment the physical feature at station N10P (Figure 6-7).

6.3 Water Types and Analysis of Small-Scale Variability

As is typical for this area, some general inshore-offshore distinctions were noted. These included cooler, higher salinity, and to a limited extent, slightly higher DIN and silicate concentrations towards the shoreward side of the nearfield. In detail, however, the spatial distributions and profiles suggested some complex physical dynamics in space and time.

Perhaps the most interesting feature of the survey was the presence of a weakly defined physical structure in vertical profiles on March 24 that was not at all apparent in towing performed the next

day. The salinity, temperature, and density differences seen particularly in surface (5-8 m) vs. bottom waters on the vertical-profile day were large enough to be evident with the contour interval scheme used for towing section profiles. It is possible that the surface layer was very thin and not well sampled by towing. During the survey, with moderate seas, the towfish commonly shoaled at 4-6 m below the surface at the top of an oscillation (Albro, 1993b). The dynamics of the system are such that advection of a fairly extensive surface feature from the nearfield is unlikely over a single day. However, this cannot be discounted fully either. On the other hand, given the complete lack of suggestion of any near-surface feature on the tow day it seems just as likely that physical processes were active enough to rapidly mix such a feature in less than a day. At this time of year, when fresh waters are probably pulsed from inshore (and from the north) and sharp variation in daily weather and insolation can cool or heat the upper water column, there are probably a number of "false starts" at seasonal initiation of stratification. The data from this survey may have detected such variability.

Most importantly, however, there seemed very little reaction, judging by chlorophyll, to the noted spatial or temporal gradients or short-term variations in physical and chemical properties.

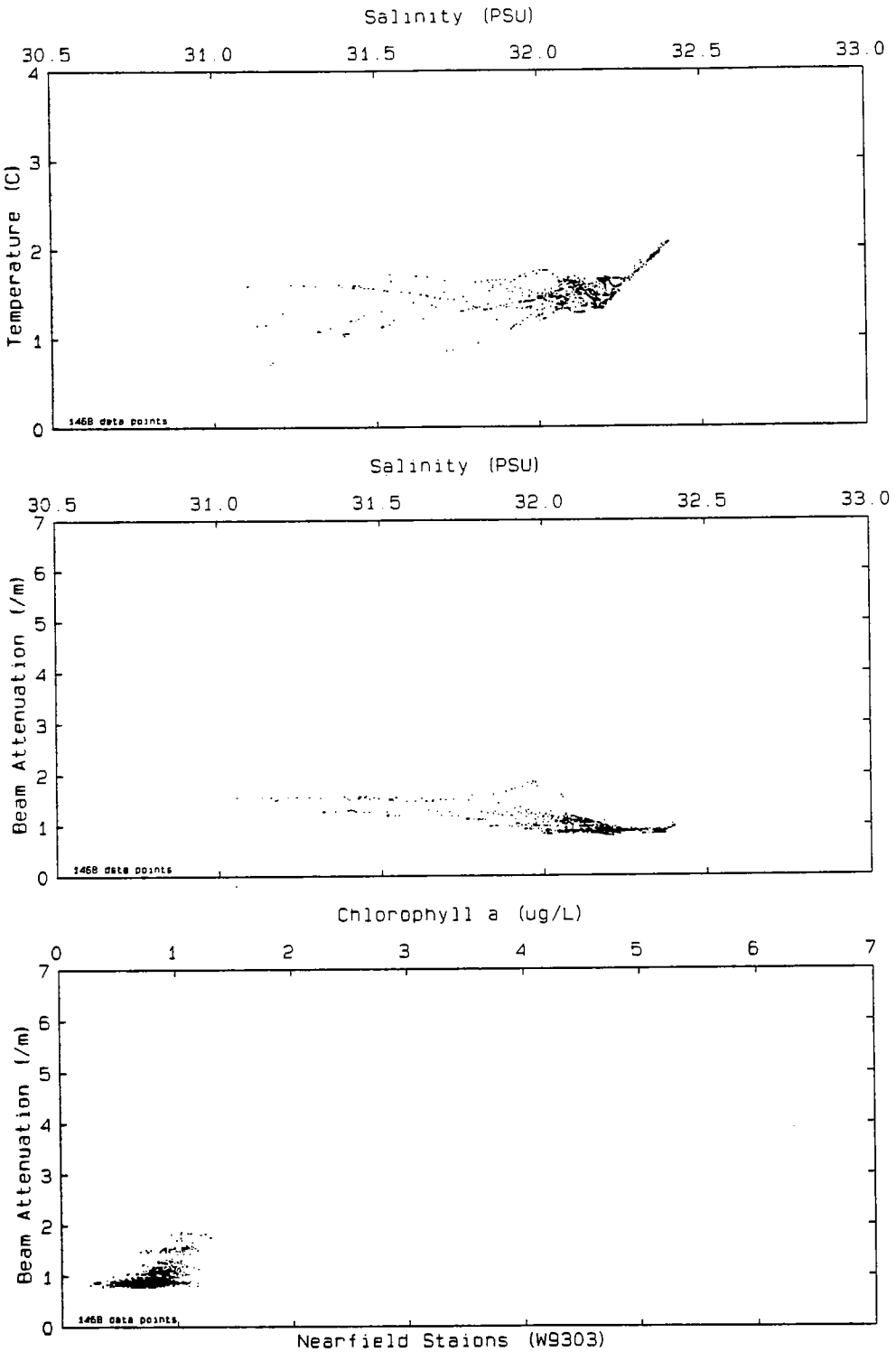


Figure 6-1a. **Scatter plots of data acquired by *in situ* sensor package during vertical downcasts at all nearfield stations occupied in late March 1993. Individual station casts that were used to produce this composite are in Appendix B.**

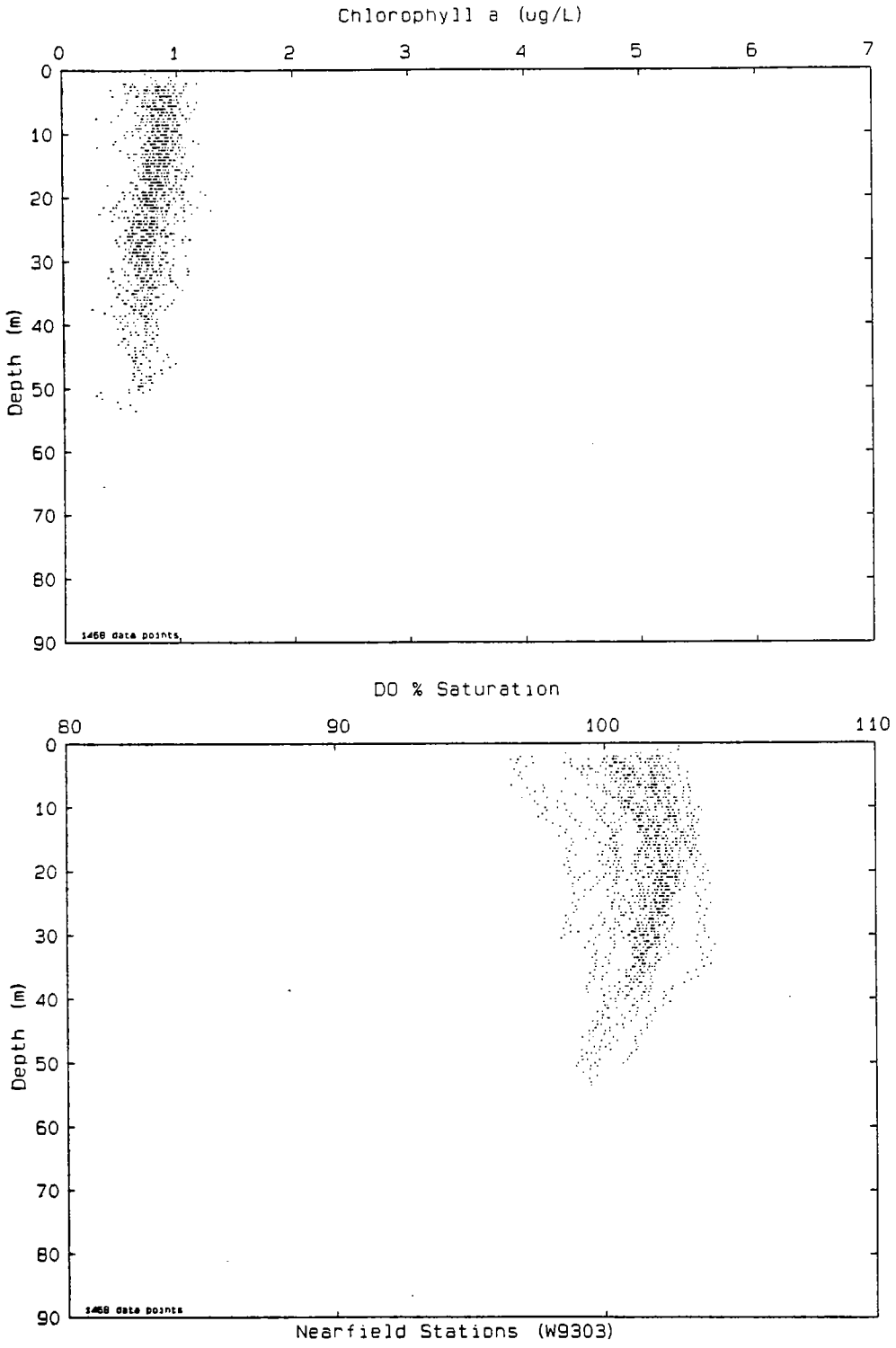


Figure 6-1b. **Scatter plots of data acquired by *in situ* sensor package during vertical downcasts at all nearfield stations occupied in late March 1993. Individual station casts that were used to produce this composite are in Appendix B.**

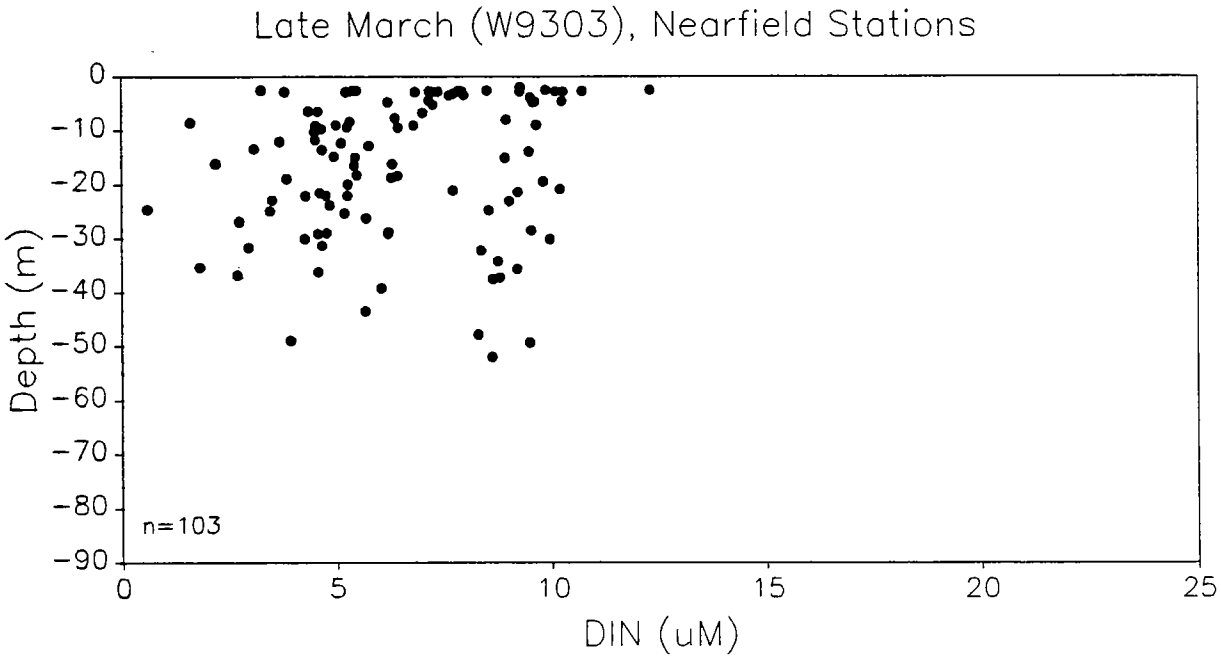
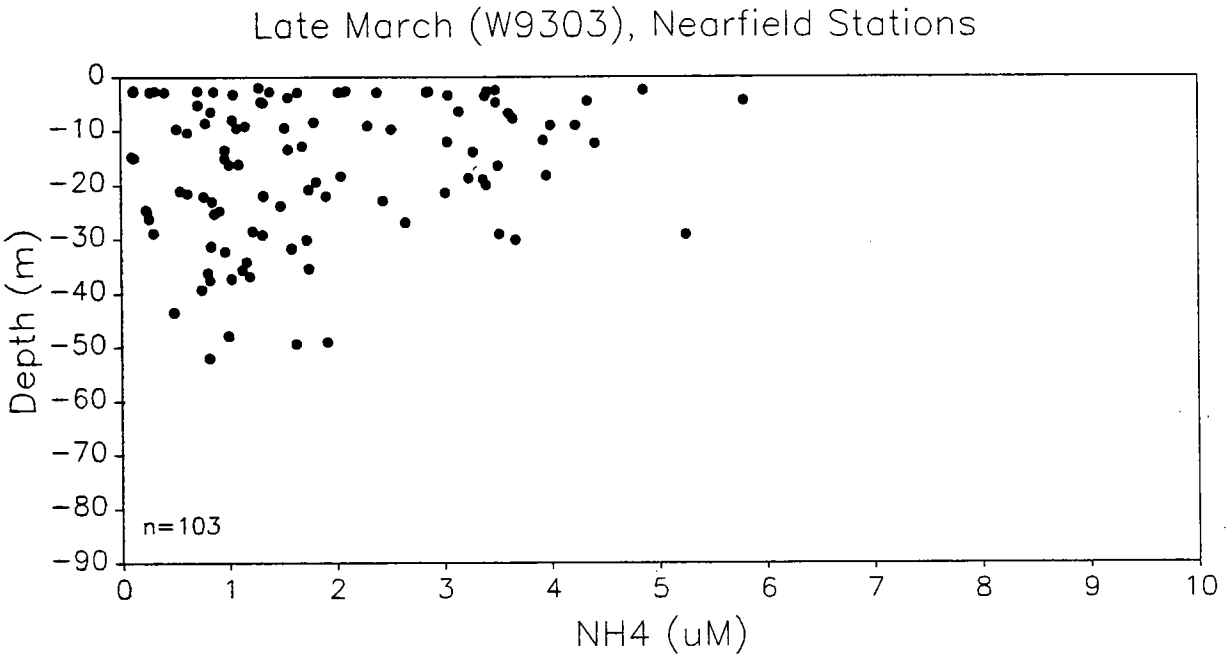


Figure 6-2a. DIN vs. depth in late March 1993.



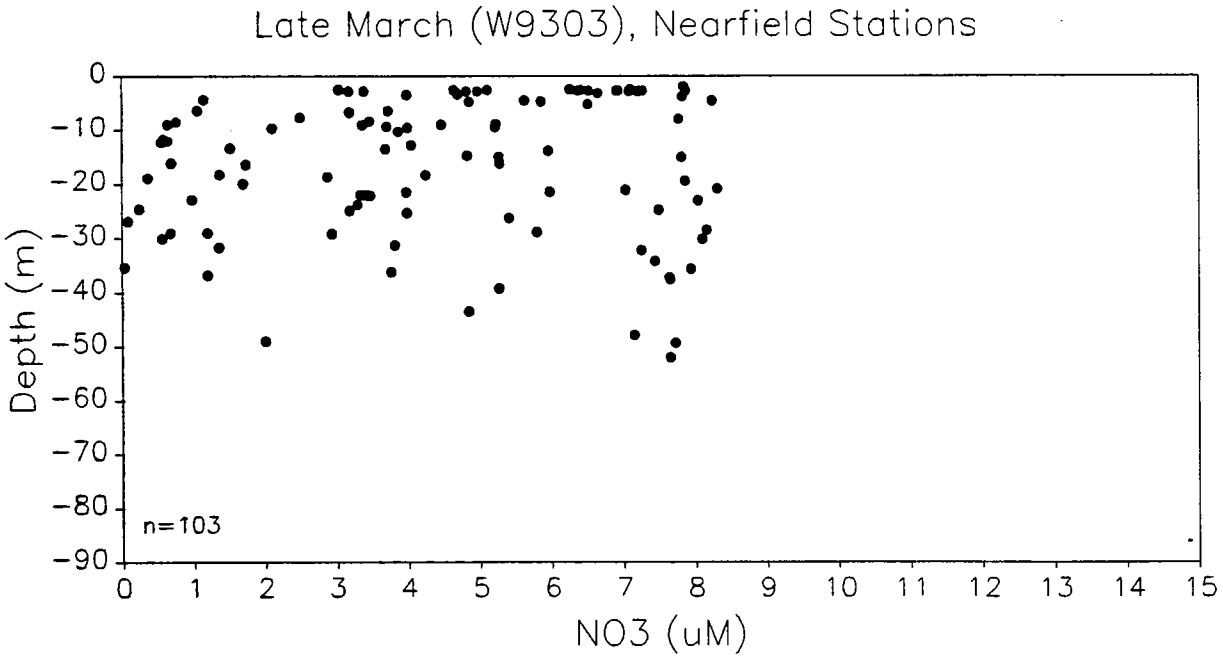
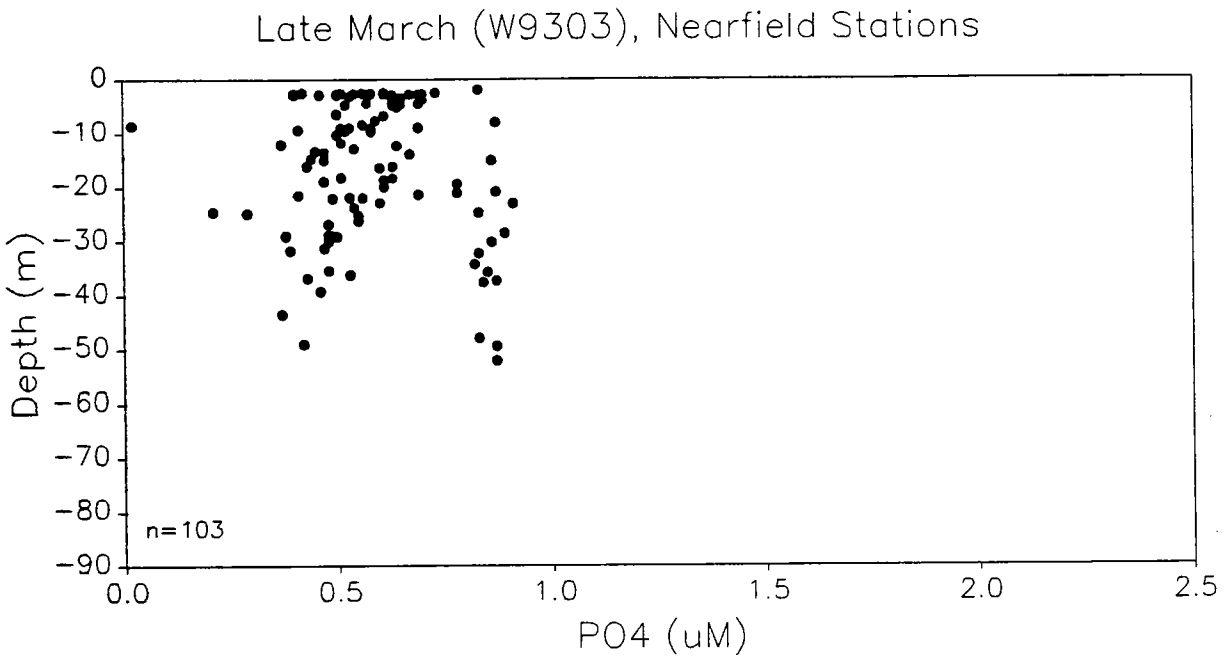


Figure 6-2b. NH_4 and NO_3 vs. depth in late March 1993.



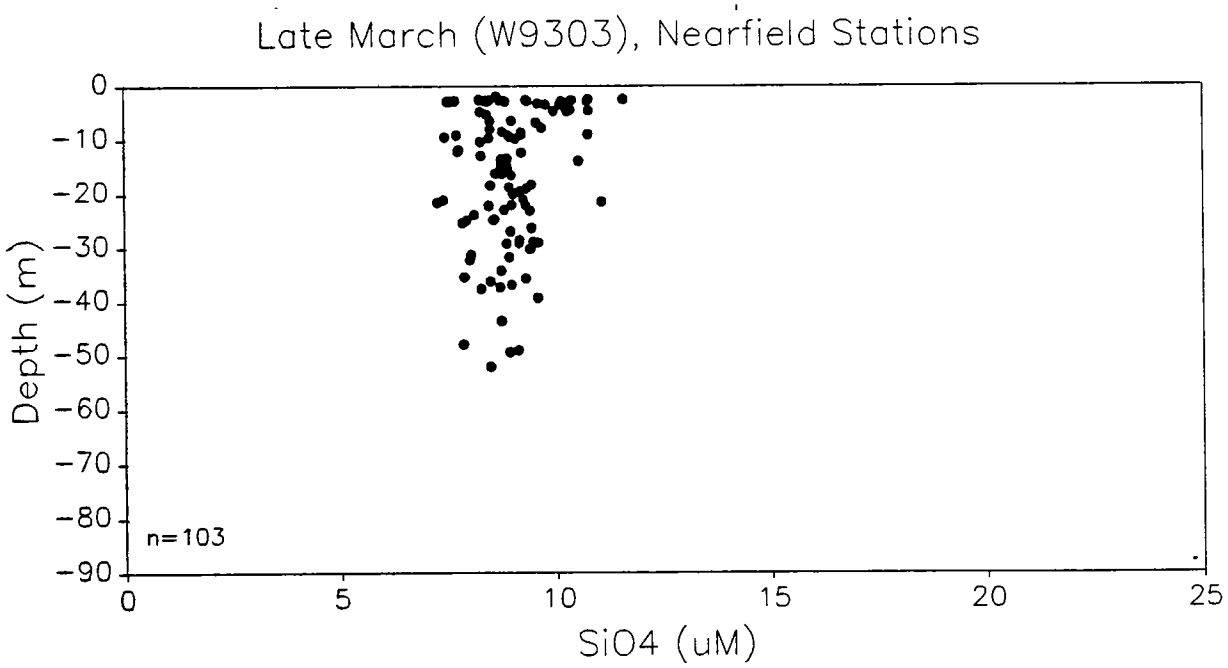
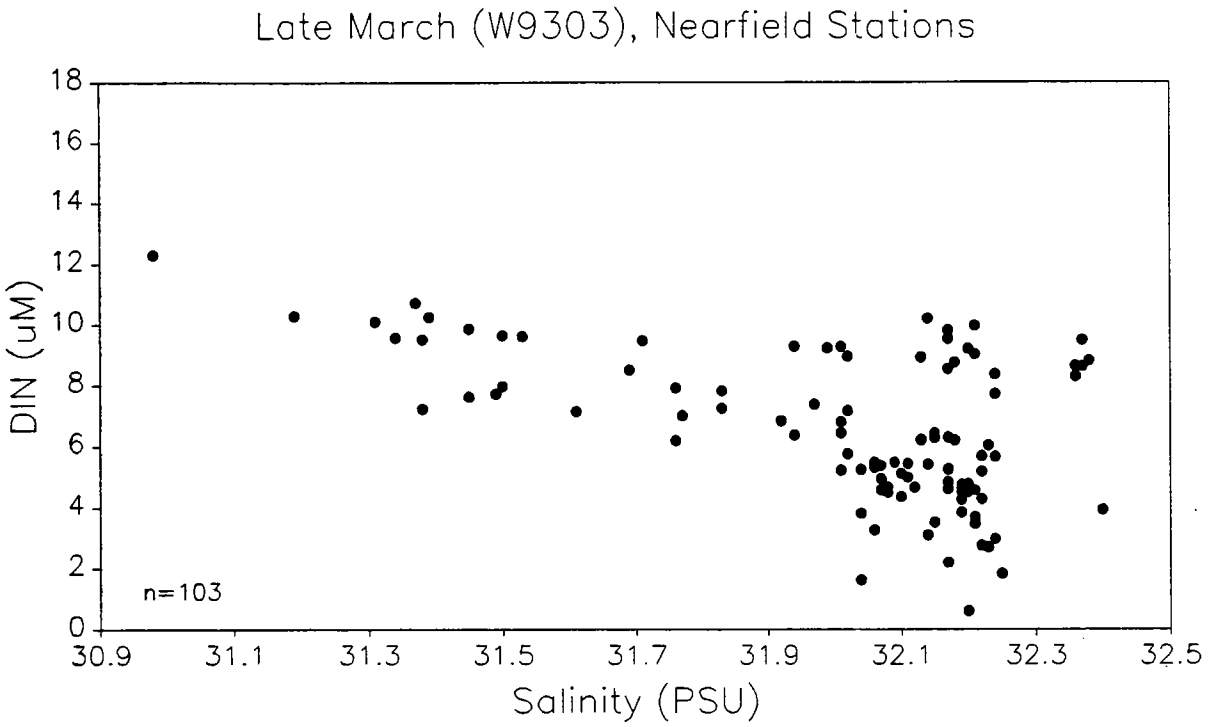


Figure 6-2c. PO_4 and SiO_4 vs. depth in late March 1993.



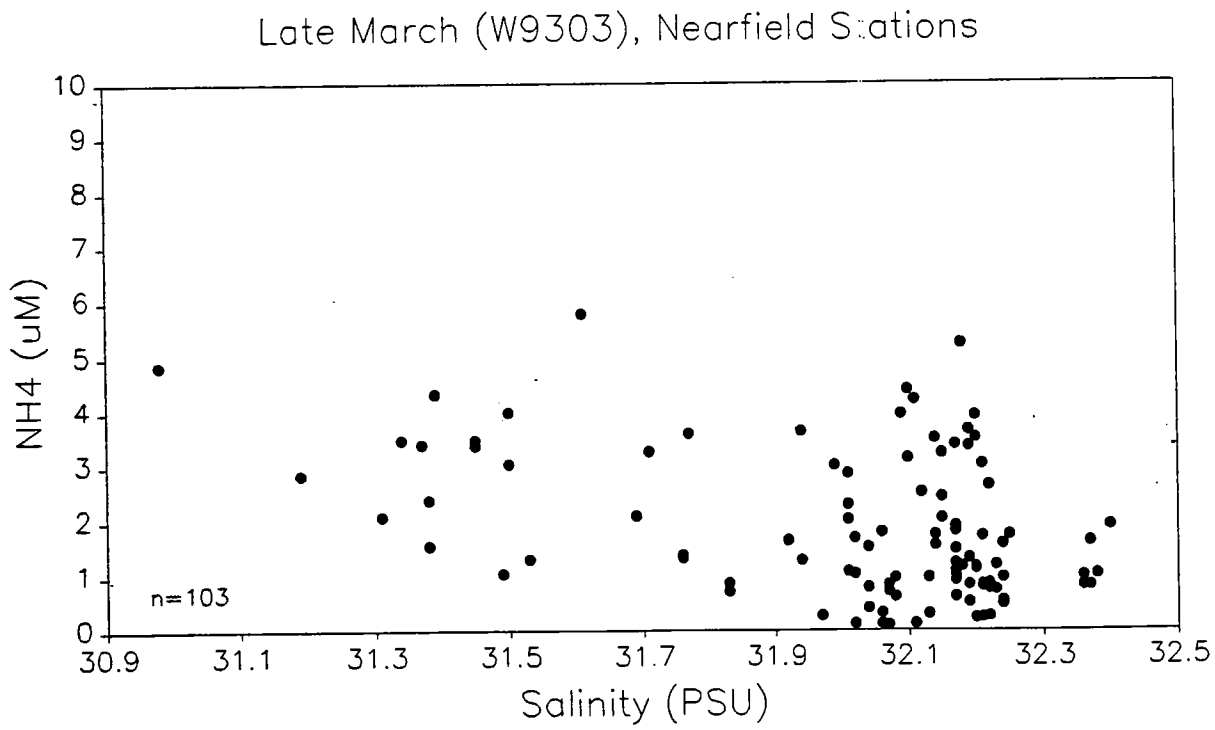
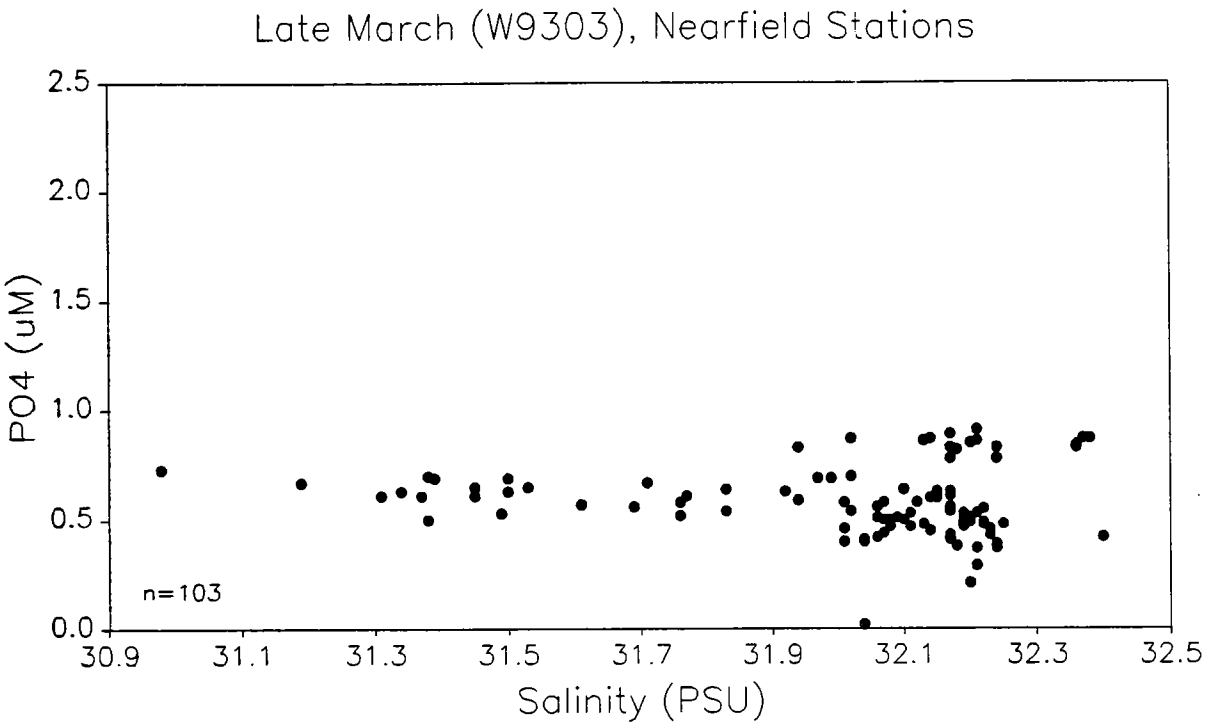


Figure 6-3. DIN and NH_4 vs. salinity in late March 1993.



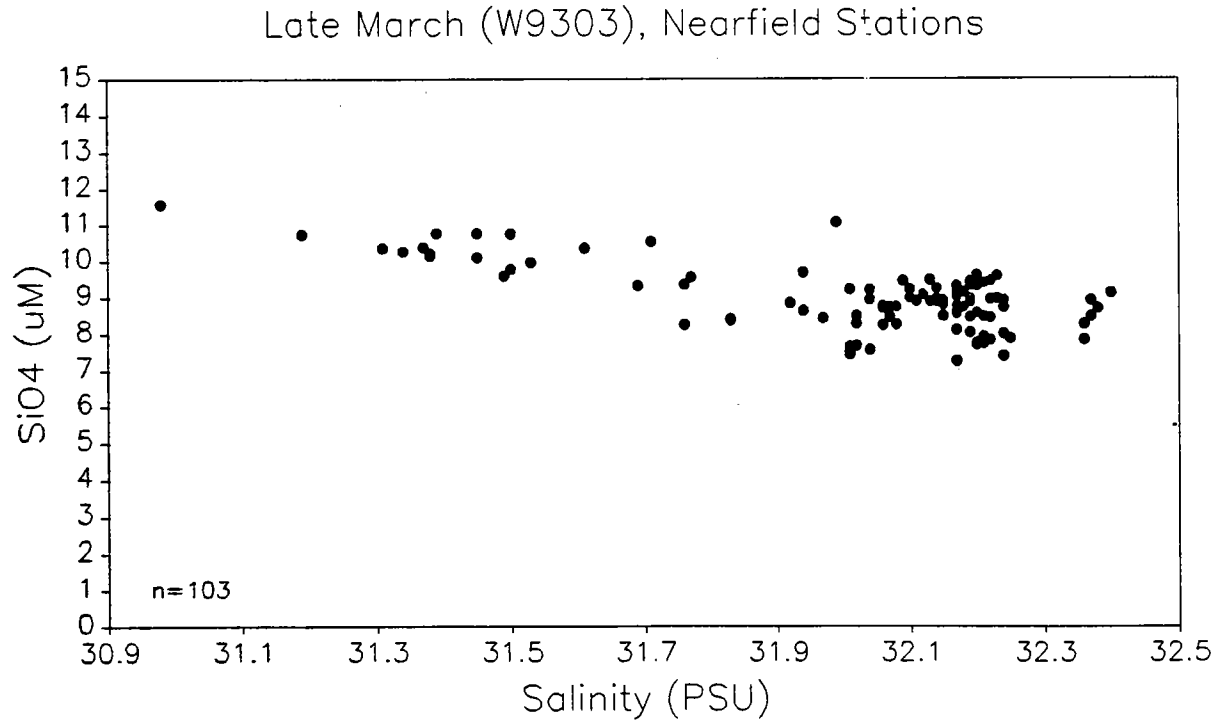


Figure 6-4. PO_4 and SiO_4 vs. salinity in late March 1993.

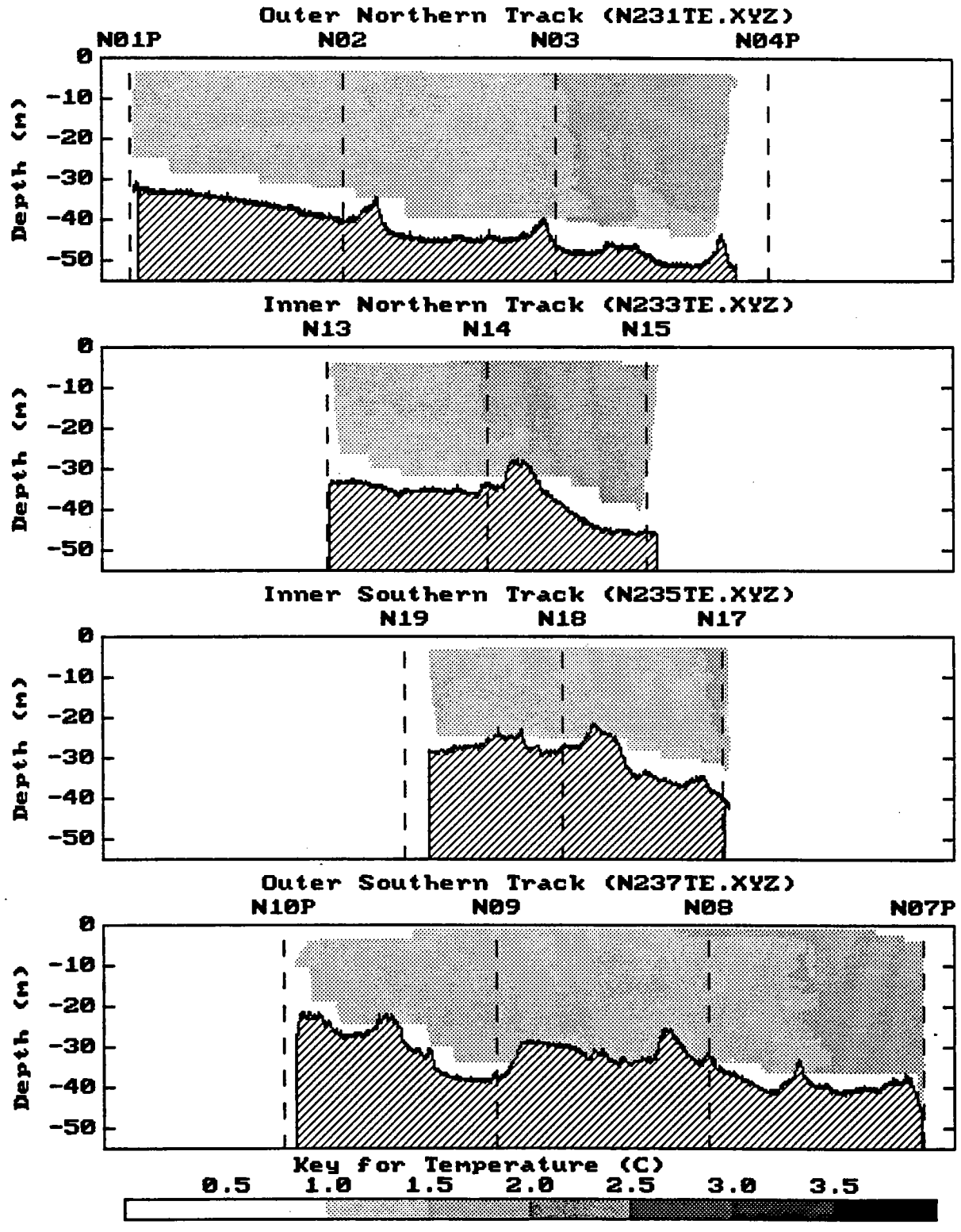


Figure 6-5a. Vertical section contours of temperature generated for tow-yos in late March 1993. The view is towards the North.

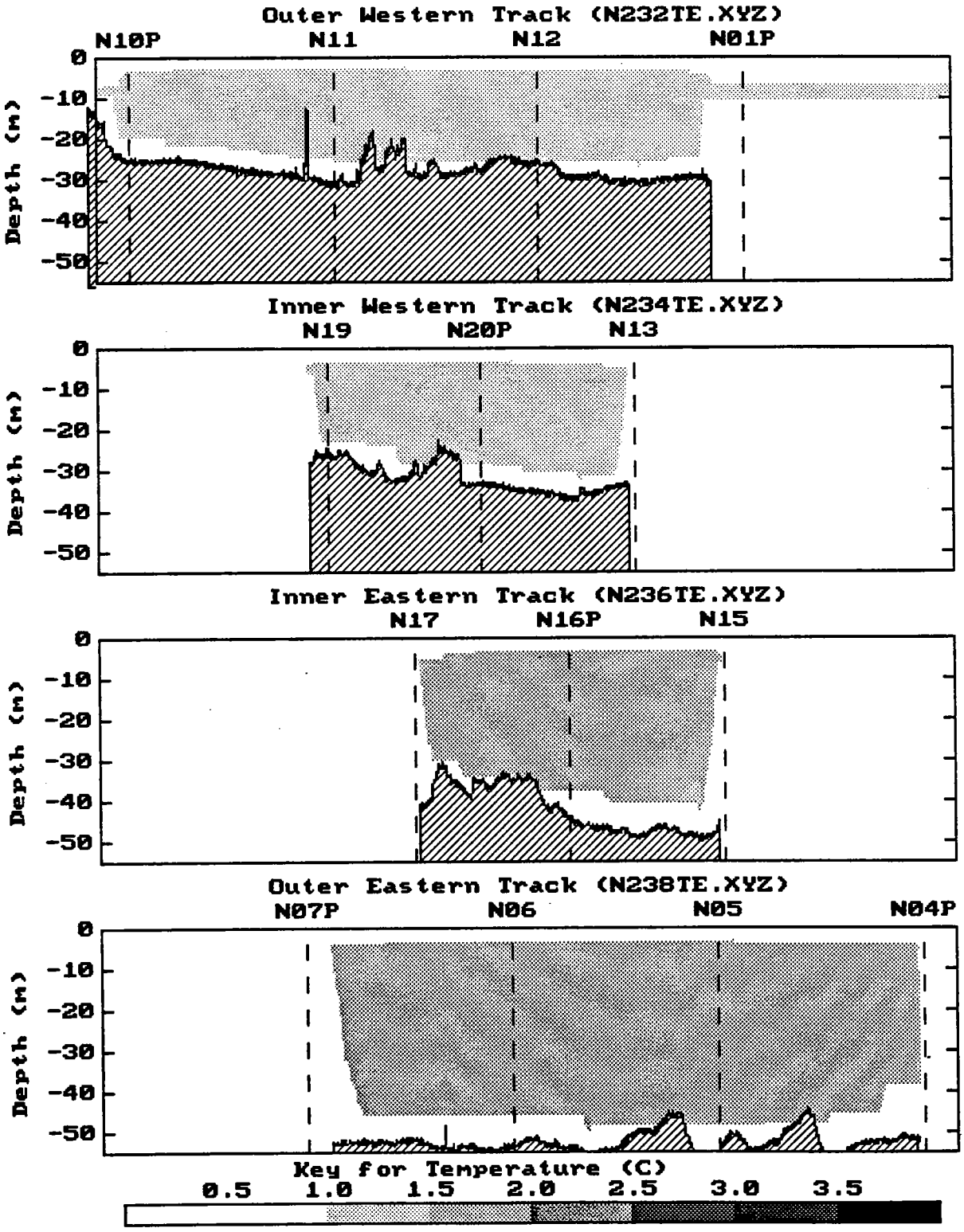


Figure 6-5b. Vertical section contours of temperature generated for tow-yos in late March 1993. The view is towards Boston Harbor.

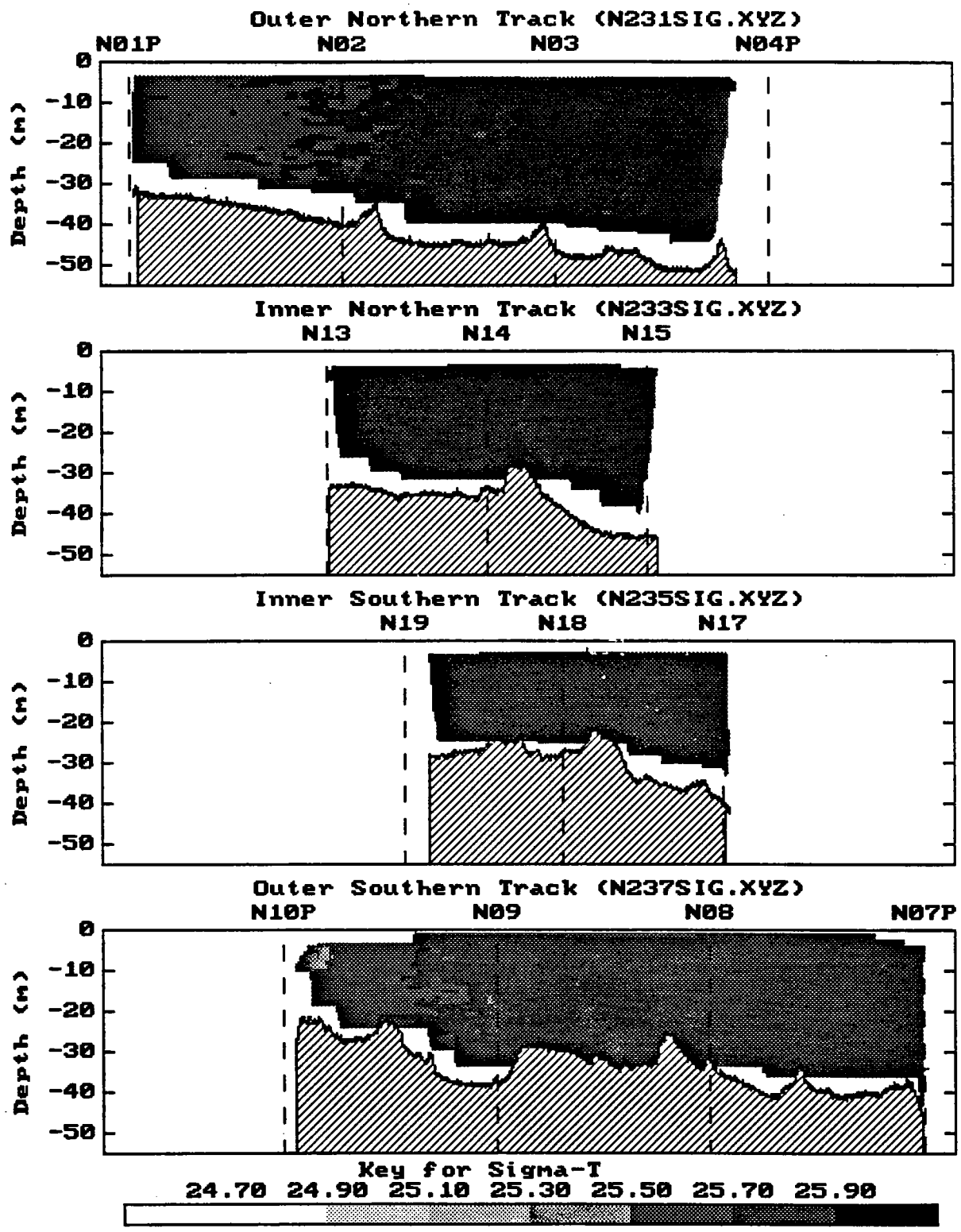


Figure 6-6a. Vertical section contours of σ_T generated for tow-yos in late March 1993. The view is towards the North.

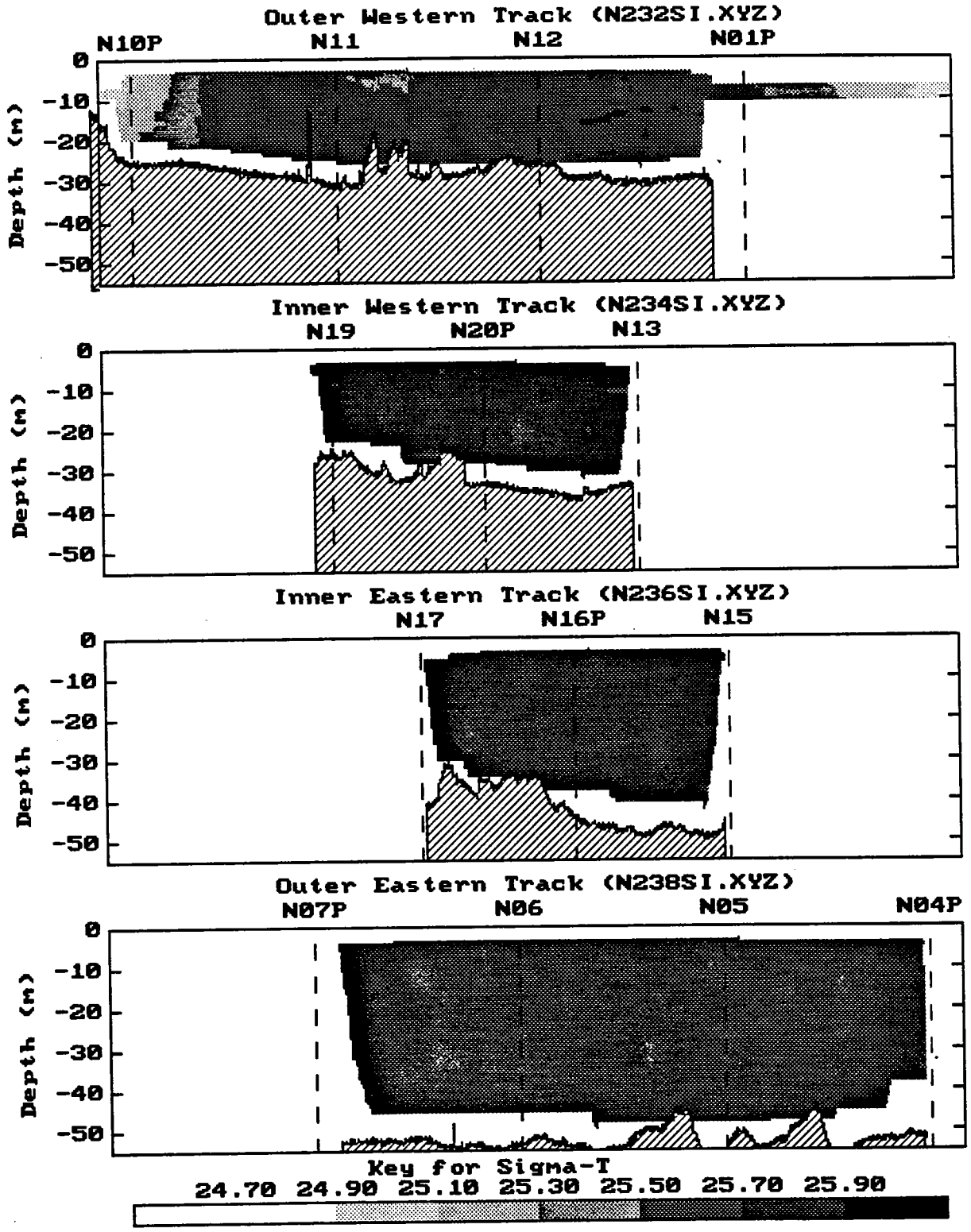


Figure 6-6b. Vertical section contours of σ_T generated for tow-yos in late March 1993. The view is towards Boston Harbor.

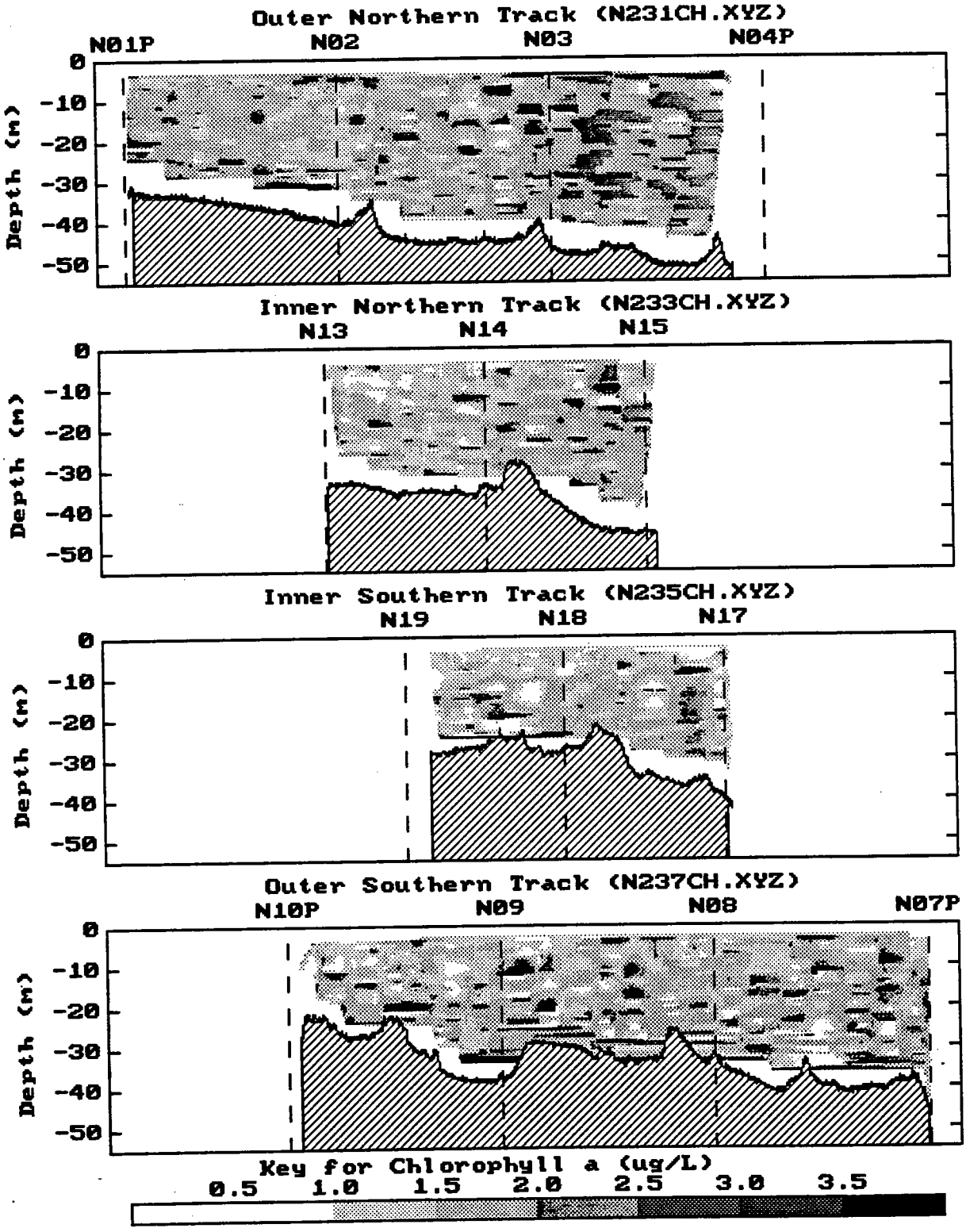


Figure 6-7a. Vertical section contours of fluorescence (as μg Chl L^{-1}) generated for tow-yos in late March 1993. The view is towards the North.

7.0 DISCUSSION OF THE WINTER-SPRING PERIOD OF SURVEYS

7.1 Water Properties

7.1.1 Variability at the Regional Scale

For February and March of 1993, the two principal regional-scale distinctions clearly evident in the data were 1) between inshore and offshore stations and 2) between Massachusetts Bay and Cape Cod Bay. Only minor temporal changes occurred in physical and chemical parameters between the two farfield surveys, while the geographic distinctions remained strong. Vertical gradients were weak or nonexistent at virtually all stations, except where estuarine outflow was suggested (e.g., just outside Boston Harbor).

The nearshore, shallower water was generally colder, less saline, and more turbid than offshore. Especially within the nearshore area influenced by Boston Harbor, nutrients (DIN and silicate) were higher. The surface features for temperature, salinity, and density in both months suggest outflow of water from the Harbor, mixing with more offshore water in the nearfield, and some flow of harbor water along the coast to the south.

Cape Cod Bay was like much of the western nearfield in terms of physical parameters (in terms of absolute values and vertical uniformity). However, for many parameters Cape Cod Bay was intermediate to the coastal and offshore stations. DIN, total nitrogen, and silicate all were lower in central Cape Cod Bay than anywhere in Massachusetts Bay. In general, the Bays-level distinctions were more obvious in parameters affected by biology than by physics.

The condition of low nutrient concentrations in Cape Cod Bay can be explained as a consequence of the bloom of diatoms in this Bay, which was not happening in Massachusetts Bay, at this time. The earlier and more intense development of phytoplankton populations, accompanied by lower nutrients concentrations in Cape Cod Bay, suggests the two Bays operate differently biologically/ecologically even though there are only rather small differences in physical conditions defined by temperature and salinity. Unfortunately, since farfield surveys are not conducted from November through January, the

comparability of the two Bays cannot be assessed directly with respect to winter-season maximum nutrient levels attained prior to strong phytoplankton growth.

7.1.2 Variability in the Nearfield

Several short-term fluctuations in physical properties within the nearfield were noted, including a weak, transient water column stratification. The region, of course, has an array of stations sufficient to allow description of some of the gradual change from inshore to offshore conditions — slight gradients in salinity, nutrients, chlorophyll and beam attenuation all were present from December 1992 through March 1993. In general, the spatial variability in physical properties (horizontal and physical) was small at each survey. Moreover, other than the sharp cooling from December 1992 to March 1993 (Figure 7-1), the region as a whole had few temporal trends in most parameters over the period.

7.1.3 Coherence of Nearfield and Farfield Station Properties

Spatial coherence among many water-quality characteristics was rather strong among stations in the nearfield even though the region was, as commonly observed in prior surveys, a mixing zone between offshore and inshore waters. In spite of station similarity during the February-March period, the majority of stations within the nearfield region were still distinct from near-Harbor waters and from Cape Cod Bay stations, but less distinct from offshore stations.

With respect to coherence of time trends across regions of the Bays, salinity at many more offshore nearfield stations decreased from February to March, while salinity in Cape Cod Bay increased during this period. Concomitantly, the Cape Cod Bay stations warmed slightly over this period while the nearfield cooled. This type of mesoscale change could be due to progressive movement of parcels of surface water, such as pulsed shoreline or offshore "currents", from the north. However, the data from the monitoring do not allow resolution of cause. Nevertheless, the observation of asynchronous events in time suggests the two areas are subject to physical/meteorological events that are fundamentally different in nature, certainly in timing, but perhaps also in quality.

7.1.4 Special Features: Comparison of 1993 with 1992

Figure 7-1 compares the annual temperature cycle in surface water observed at nearfield stations monitored during 1992, including the December data reported in Section 3. The cooling from December 1992 to February 1993 was about 4-5 °C. Winter-spring surveys for both years demonstrated only small variation across stations and slight cooling from February to March. In 1993, a gradual downward trend continued to the end of March. The notable difference between years was that temperature in February—March 1993 was 1-2 °C lower than in 1992.

Data for dissolved oxygen were not available during March 1992. However, the comparison of February 1992 to 1993 shows significantly higher values in 1992 (Figure 7-2). These may be partially attributable to higher accumulations of chlorophyll in 1992 (see below). Interestingly, in 1993 the DO trend, even in these bottom waters is upwards at this time; the trend may be due to a combination of increasing plant activity and decreasing temperature.

7.2 Water Column Nutrient Dynamics

7.2.1 Vertical Structure and Initiation of Seasonal Stratification

Little vertical stratification was found in the Bays during the period of December 1992 through March 1993. This may be due in part to the cold atmospheric conditions. The atmospheric conditions also may be partially responsible for the lack of regional vertical variability in nutrient concentrations. The lack of stratification did not inhibit development of a diatom bloom in Cape Cod Bay. Interestingly, however, the highest chlorophyll concentrations were noted in surface waters at the one instance in Cape Cod Bay where some vertical layering was apparent. Additionally, the diatom bloom, without stratification, did not appear to create any marked depletion of nutrients in surface waters, relative to bottom waters, in Cape Cod Bay.

7.2.2 Inshore-Offshore Gradients

The inshore-offshore gradients in nutrients were similar to that of the physical parameters and in general covaried with salinity rather strongly in western Massachusetts Bay. As described for 1992,

the conditions suggest that the biological activity was operating on timescales that are slower than those for physical mixing processes. Nutrient gradients were strongest in the nearshore area with lower salinity and a known strong source (the Harbor) — this gives evidence that higher nutrients are not just a function of shallowness, which inherently promotes greater mixing and resuspension.

7.2.3 Influence of Northern Rivers

The water quality conditions at stations offshore and along the northern transect were similar to the nearfield and, for the most part, the distinctions between the nearfield and more northeasterly regions were minor. These observations imply there was no significant excess nutrient delivery or import of anomalous biology communities from the north. Of course, there is no monitoring data suitable to determine whether influences may be more profound further offshore.

7.2.4 Special Features: Comparison of 1993 with 1992

The general Bays-wide spatial distribution of nutrients, as well as salinity and turbidity were remarkably similar for the February—March period in 1992 and 1993. Notably, the 1993 north-south patterns between Bays and the salinity-nutrient relationships were a repeat of 1992. Some of the coastal station nutrient concentrations were slightly higher in 1993 than in 1992, probably a consequence of the lack of bloom conditions being initiated throughout Massachusetts Bay.

Using the nearfield surface waters for comparison, the DIN concentrations for 1992 and 1993 sampling are shown in Figure 7-3. Peak annual 1992 values were in December and were essentially undiminished in February and March. The range in nutrients was generally large across the nearfield in this winter period, a partial consequence of the freshwater and nutrient export from the Harbor creating a gradient across the field. Interestingly, DIN did not decrease in the nearfield in early 1993. In contrast, over the first three months of 1992 a decrease in the mean DIN was discernible.

7.3 Biology in Relation to Water Properties and Nutrient Dynamics

7.3.1 Phytoplankton—Zooplankton Relationships

There was a strong relationship between phytoplankton cell counts and chlorophyll over the early months of 1993 (Figure 7-4). This resulted almost solely from the difference between stations in Cape Cod Bay relative to those in Massachusetts Bay. Considering Massachusetts Bay only, the "noise" in the correspondence overwhelmed any relationship between the two parameters.

There was no obvious relationship between zooplankton numbers and phytoplankton abundance. Figure 7-5 shows data for total zooplankton, but preliminary analysis of the abundance of different zooplankton groups as a function of chlorophyll was no more revealing of a broad pattern. The decrease in zooplankton numbers from February to March at most stations was not specific to a broad taxonomic category, but cut across all taxa, so that the relative composition was similar.
The station trends over time were different, and the only obvious constant was a relatively low abundance of zooplankton at station F23P at the Harbor edge.

In general, the zooplankton—chlorophyll comparisons indicate poor correspondence between phyto- and zooplankton. The influence of herbivory as an important control on primary producers at this time is unknown. However, the data trends suggest that it was low.

7.3.2 Plankton Species and Water Properties

A significant taxonomic variation was observed in the phytoplankton community. Specifically a continuing diatom bloom in Cape Cod Bay that was not seen anywhere in Massachusetts Bay was present. In relation to nutrients, the interpretation of the difference between the Bays is, of course, that the nutrient (DIN, silicate) concentrations in Cape Cod Bay were a consequence of the plankton community developed there, and not the converse (i.e., the plankton were not a consequence of the nutrients). Thus, other variables must be examined. Primarily those affecting light availability, e.g., turbidity, vertical mixing depths and rates, and insolation factors, must be examined as the main factors responsible for promoting the earlier spring bloom in Cape Cod Bay.

At station N10P, plankton samples were collected from the surface on February 23 and 26 and March 9, 12, and 24. The abundances of identified plankton in screened (>20μm) surface-water samples are given in Table 7-1. The screened plankton abundances were low and there was little change in this plankton community at station N10P over the survey period. For February and March, the species composition in the whole-water samples was diverse and abundances were low (Appendix F). There was a general progression from numerical dominance of various diatom species on February 23 (Table 4-1a) to a more varied community of microflagellates, cryptomonads, and diatoms during the rest of the period. The expected winter-spring bloom, however, was not observed at station N10P nor at other Massachusetts Bay stations. At the Cape Cod Bay stations, diatom abundances were high ($\sim 10^6$) during both the February and March farfield surveys (Figures 4-25 and 5-25).

7.3.3 Chlorophyll Biomass, Nutrients, and Dissolved Oxygen Distribution

In both February and March, the pattern of DIN and chlorophyll was similar and showed only that the higher chlorophyll in Cape Cod Bay was associated with lower nutrients. Slightly higher DIN in coastal waters did not appear to stimulate higher chlorophyll; a pattern between chlorophyll and nutrients within the Massachusetts Bay was not found. The scatterplot for DIN was similar to that of total nitrogen and chlorophyll that is presented in Figure 7-6.

Perhaps the most interesting facet of Figure 7-6 relates to Cape Cod Bay. Total nitrogen values there were consistently low, but increased from February to March. Since DIN did not increase, the increase is due to organic forms, not surprising since chlorophyll increased also. But the temporal increase in total nitrogen seems at odds with a possible interpretation, using salinity-nutrient diagrams, of the Cape Cod Bay region as an active nitrogen sink. The question of nitrogen removal from the water column is not easily answered with the monitoring data, but it is clear that care must be used when interpretating simple mixing diagrams outside of the Harbor-nearfield region (see below).

7.3.4 Metabolism and Environment

The estimates of primary production rates were lower at Massachusetts Bay stations, as well as Cape Cod Bay stations, in March relative to February (Figure 7-7). It is apparent from Figure 7-7, that

higher production during this period was related to higher standing biomass of chlorophyll. Rates for high-chlorophyll stations in Cape Cod Bay were among higher values reported for the Bays during the same period of 1992. Other strong relations between the rate of production as a function of nutrients or depth of the euphotic zone were not obvious from the data.

7.3.5 Special Features: Comparison of 1993 with 1992

The lack of a zooplankton-phytoplankton relationship, in terms of numbers, was not apparent in either the February-March period in 1993 . As in 1993, data from 1992 did not indicate strong nutrient chlorophyll patterns.

With respect to chlorophyll, the annual cycle in the nearfield in 1992 and the trend for early 1993 are compared in Figure 7-8. Most notable differences were that chlorophyll in 1993 was uniformly low, whereas in 1992 a greater range and higher average concentration of chlorophyll were recorded, especially in February.

7.4 Summary and Recommendations

In general, many of the physical, chemical, and biological features apparent in February and March of 1993 were also seen in that period of 1992. Most striking were gradients from Boston Harbor and between the two Bays.

Interannual differences were also suggested. There was a sustained and generally colder temperature in surface waters during early 1993. This was accompanied by a lack of any development of vertical stratification and also a lack of initiation of a strong winter-spring bloom in Massachusetts Bay. Because of these conditions, nutrients remained at typical high winter levels except in Cape Cod Bay.

To allow for assessment of winter conditions prior to initiation of winter—spring bloom conditions in Cape Cod Bay sampling should be conducted earlier in the winter. Whether such an assessment is warranted must be further evaluated.

Finally, simple interpretation of mixing diagrams may be a convenient tool for examining data within the Harbor—nearfield region. However, the patterns must be interpreted with great care where water masses extend over some distance from the harbor and are dynamic. In these regions there may be multiple sources being mixed, and endmembers are also subject to change.

Table 7-1. **Abundance of all identified phytoplankton taxa in screened (20μm) samples collected near the surface at station N10P in February and March 1993.**

	N10P	N10P	N10P	N10P	N10P
	Feb 23	Feb 26	Mar 09	Mar 12	Mar 24
ALORICATE CILIATES	10	13	10	8	5
CERATIUM LONGIPES			3		
DICTYOCHA FIBULA				3	
DINOPHYSIS ACUMINATA		3			
DINOPHYSIS NORVEGICA	3	3	3		
DISTEPHANUS SPECULUM		3		3	5
GYRODINIUM SPIRALE		5	5	3	
GYRODINIUM SPP.			3	3	
PROTOPERIDINIUM PELLUCIDUM			3		
TINTINNIDS	30	5	15	5	15
UNID. ATHECATE DINOFLAGELLATE			3	3	
UNID. THECATE DINOFLAGELLATES	3	8			3

Units are cells L^{-1}

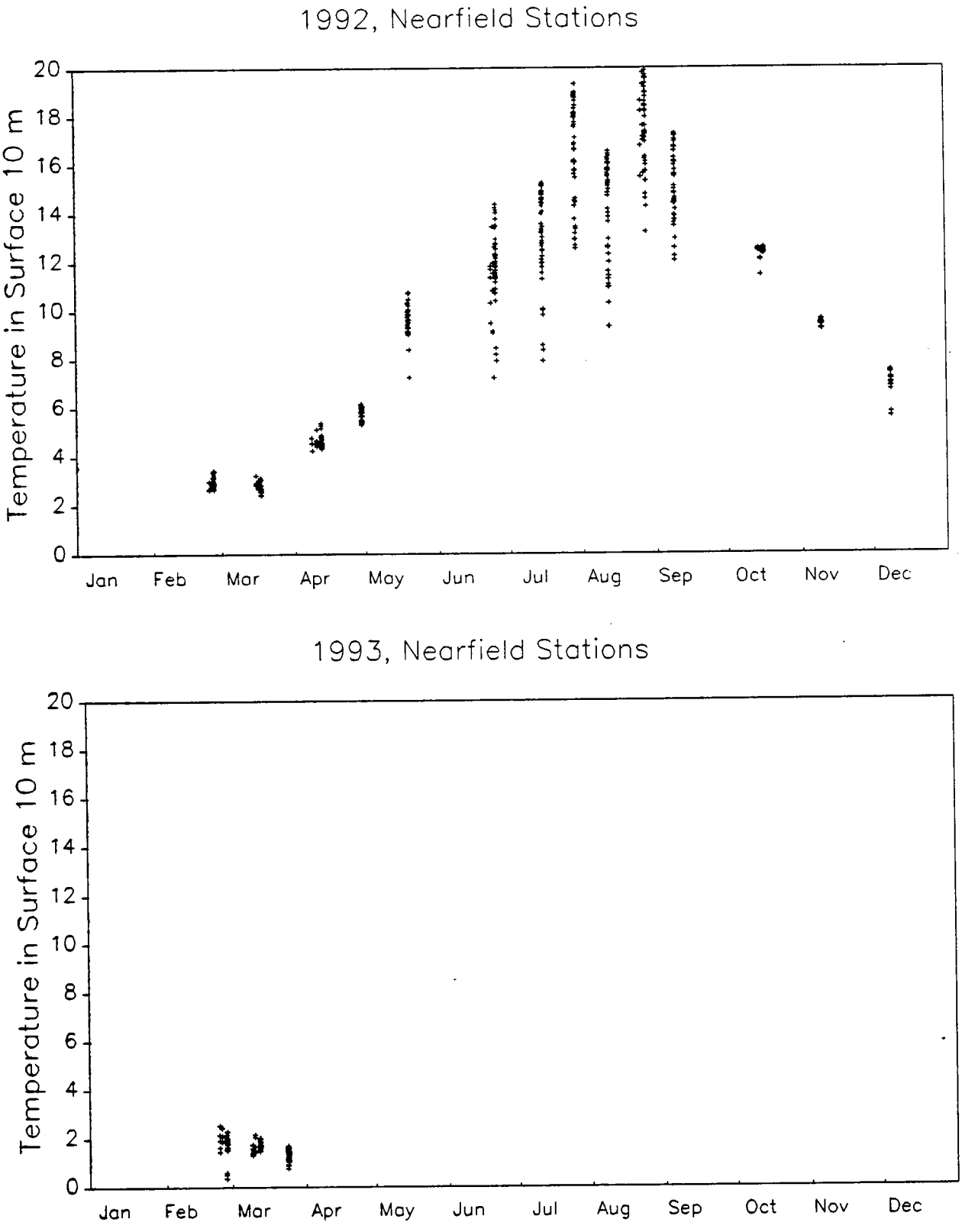


Figure 7-1. **Comparison of the nearfield region in 1993 to the annual cycle of 1992: temperature (°C).**

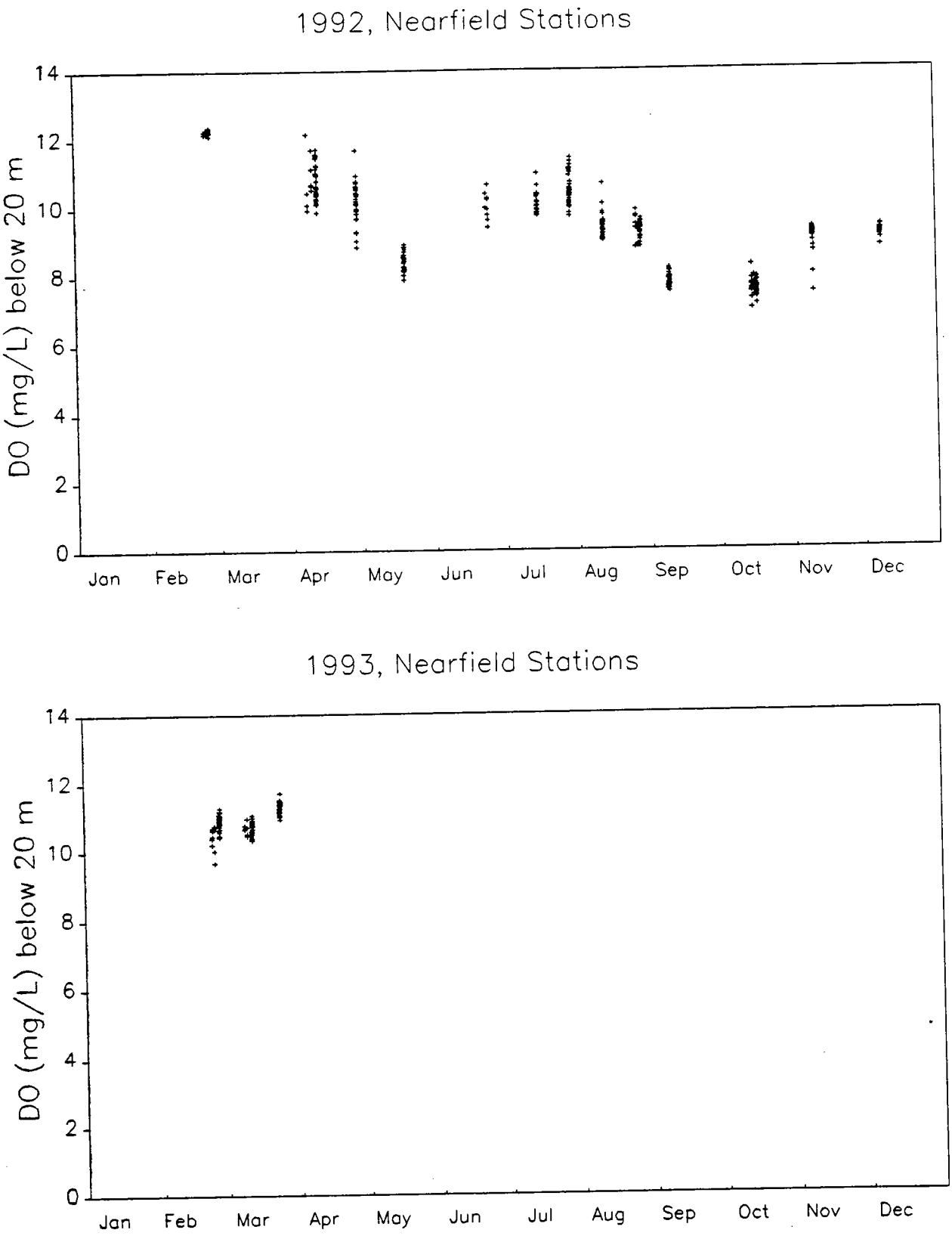


Figure 7-2. **Comparison of the nearfield region in 1993 to the annual cycle of 1992: dissolved oxygen (mg/L).**

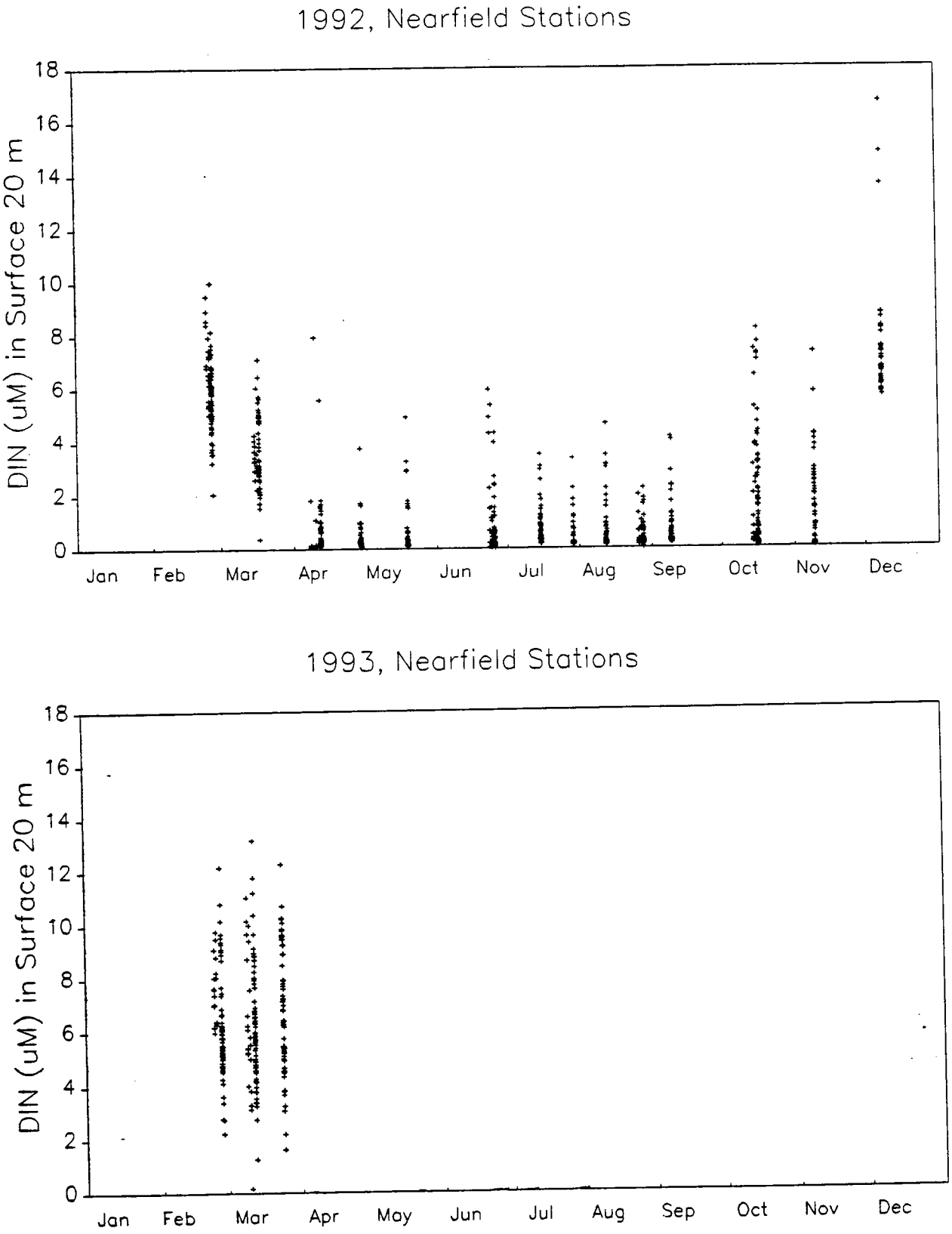


Figure 7-3. **Comparison of the nearfield region in 1993 to the annual cycle of 1992: dissolved inorganic nitrogen (μm).**

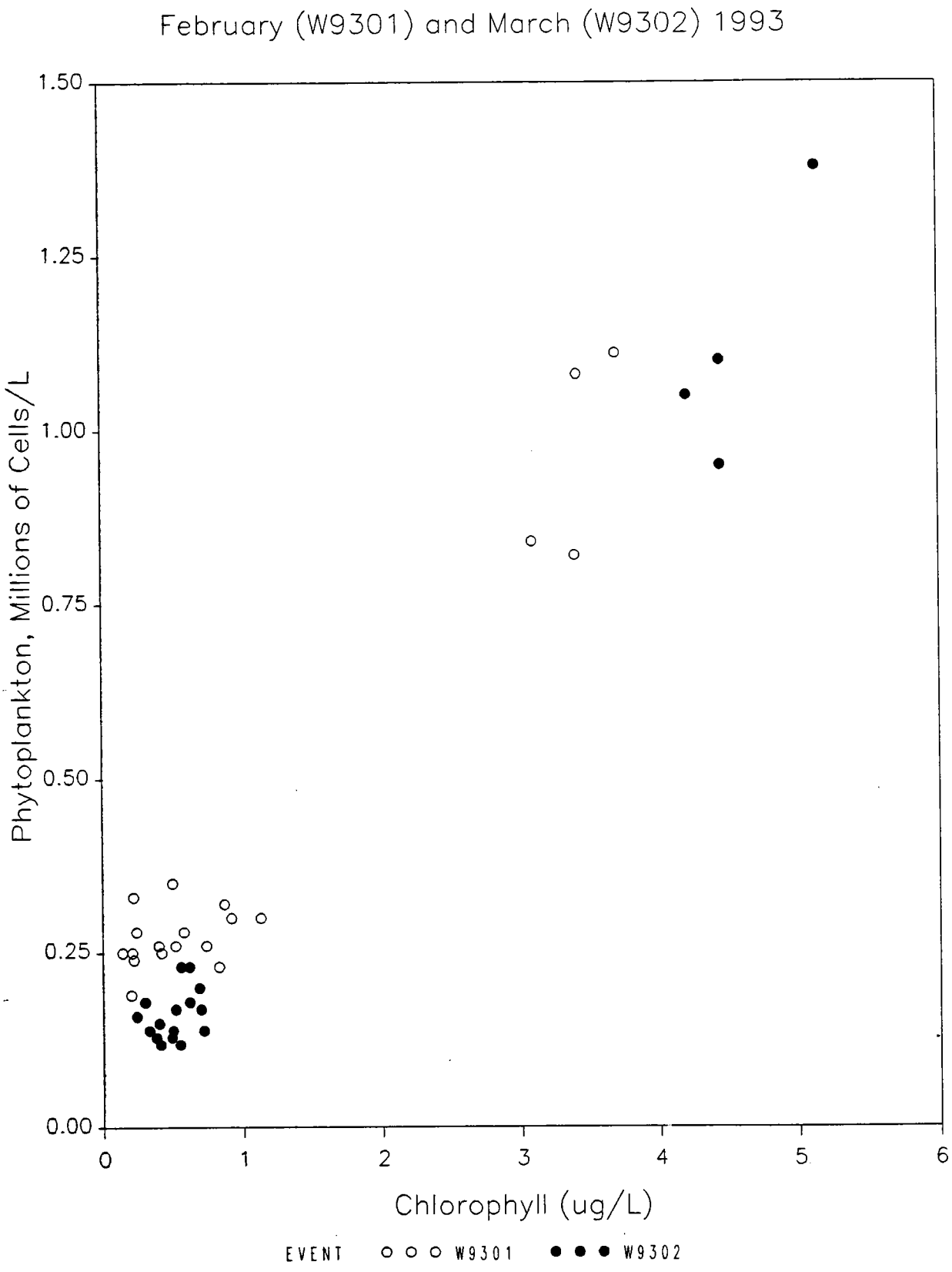


Figure 7-4. **Phytoplankton abundance compared to chlorophyll concentrations in samples from February and March 1993.**

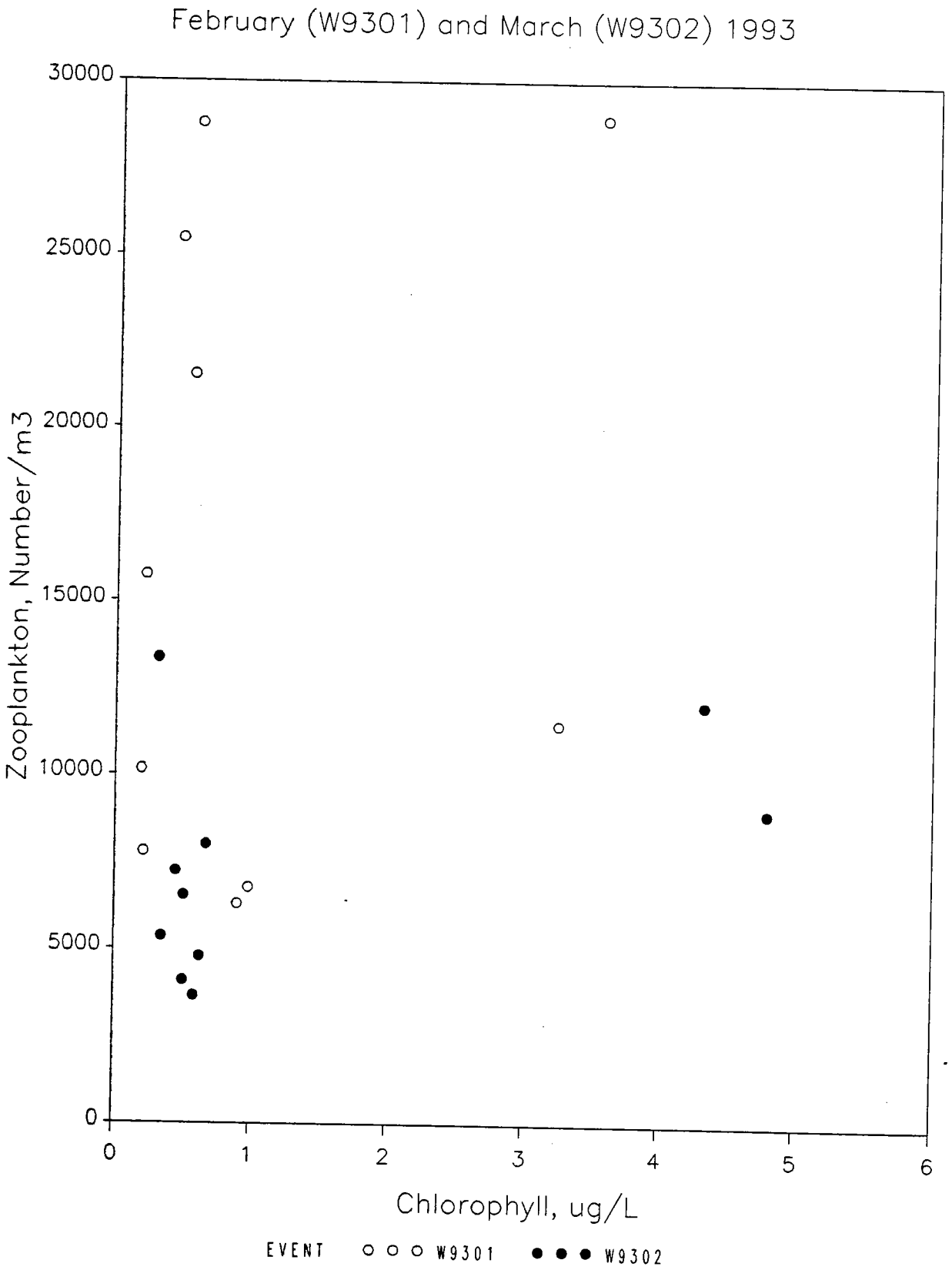


Figure 7-5. **Zooplankton abundance compared to the average chlorophyll (extracted) concentration (n=2 depths) in the water column in February and March 1993.**

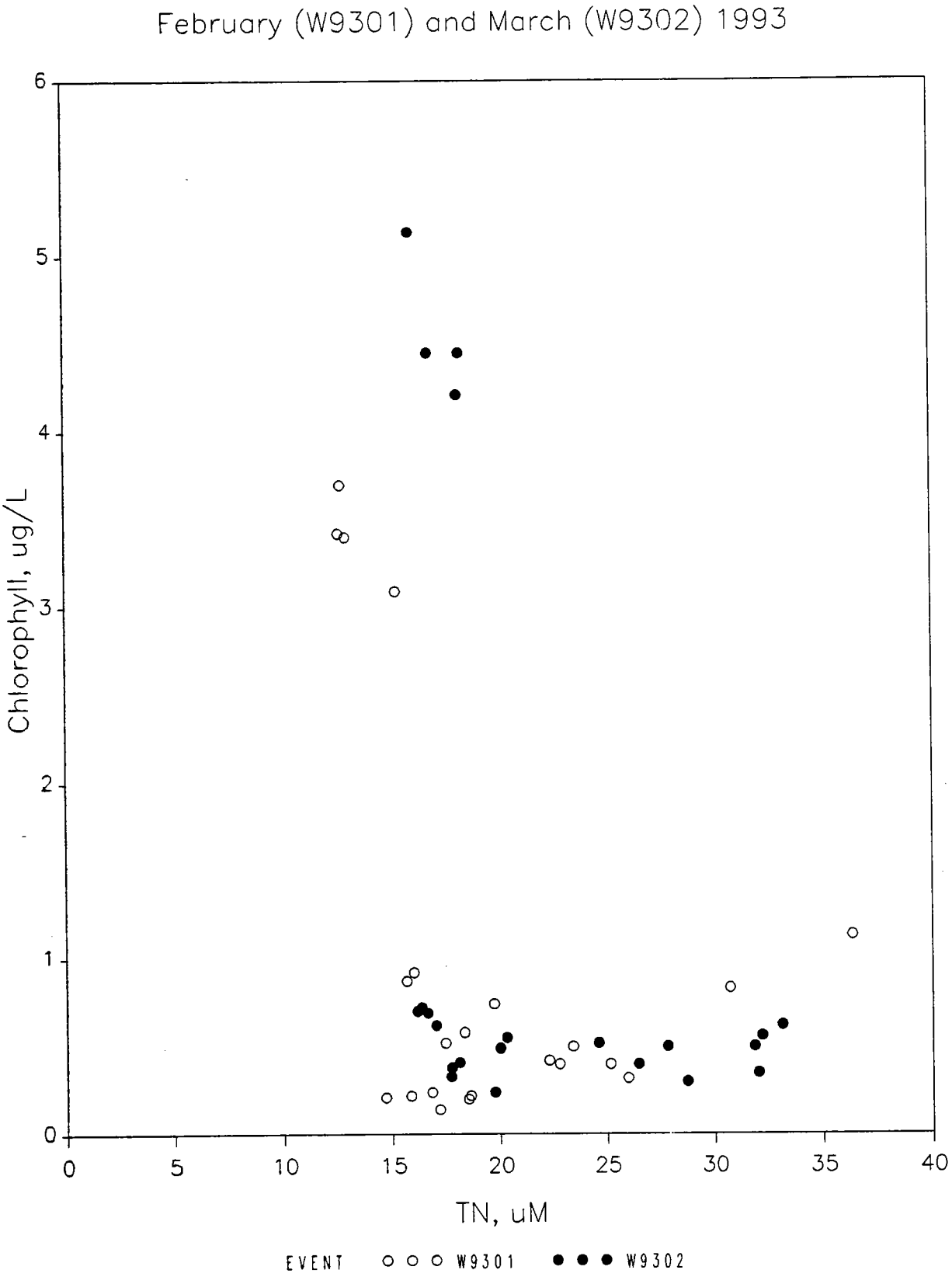


Figure 7-6. **Chlorophyll (extracted) and total nitrogen in samples from February and March 1993.**

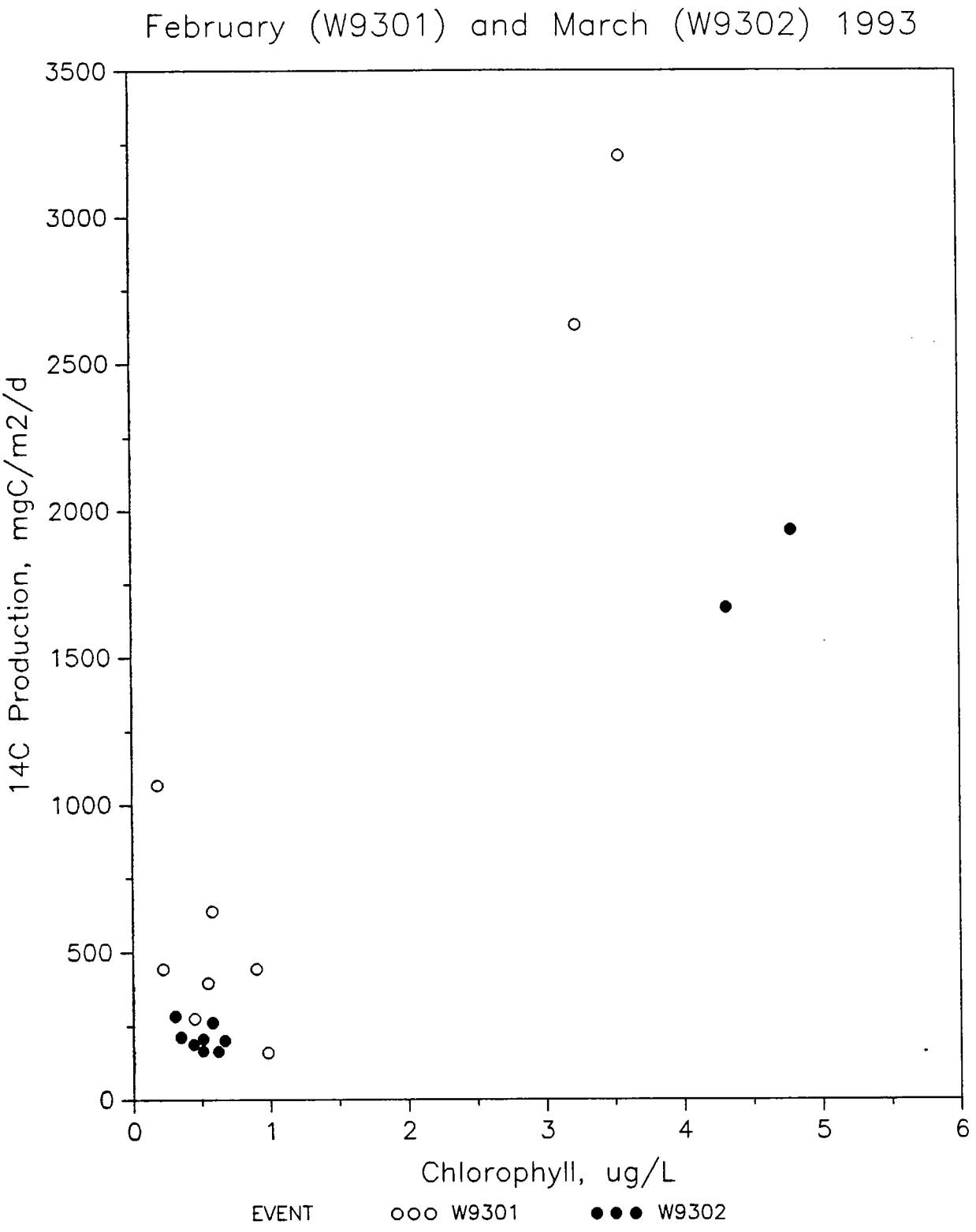


Figure 7-7. Integrated water column production (mean of surface and chl max incubations) compared to chlorophyll (mean of surface and chl max sample extractions, n=4) for February and March 1993.

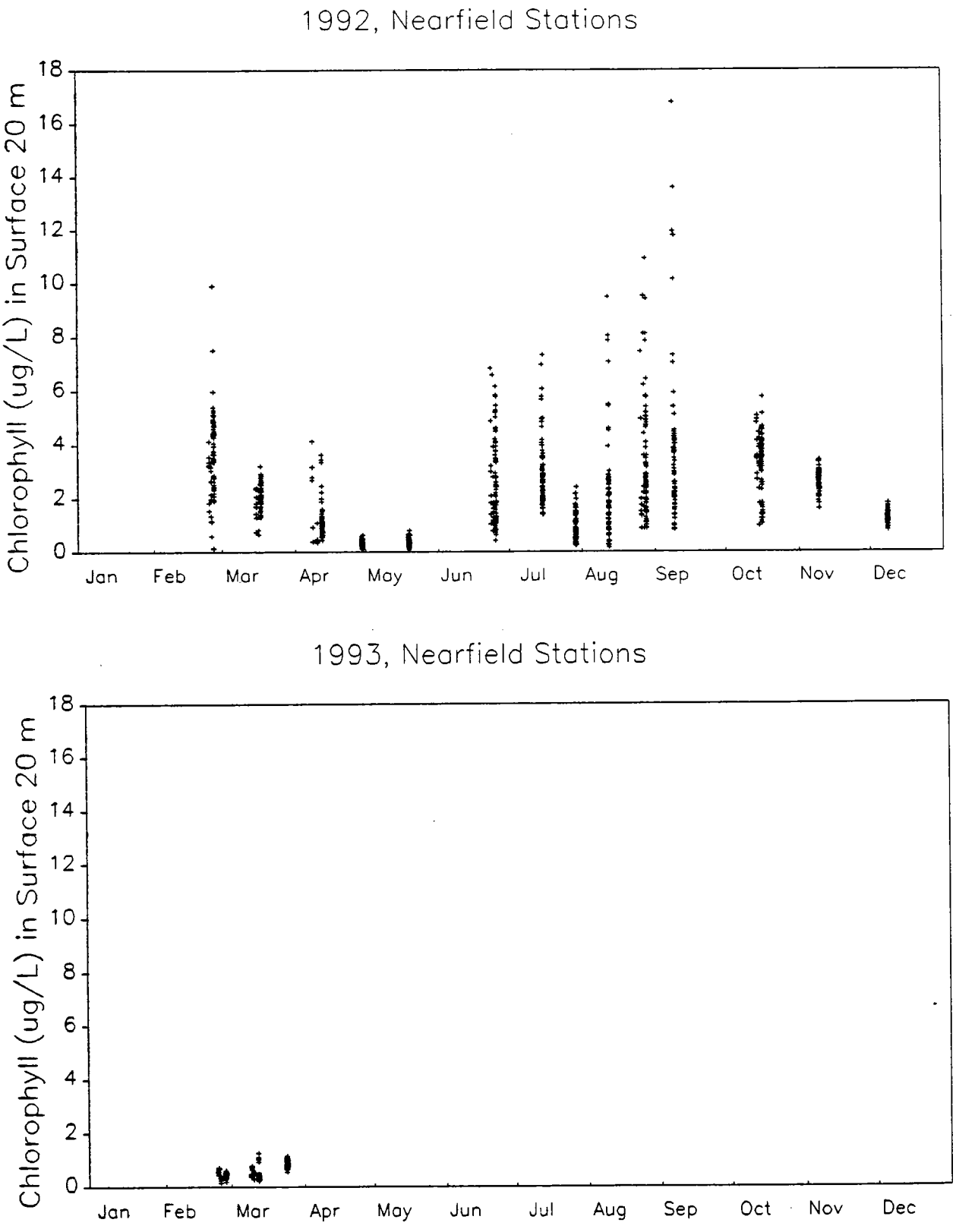


Figure 7-8. **Comparison of the nearfield region in 1993 to the annual cycle of 1992: chlorophyll (μg/L).**

8.0 ADDENDUM: PHYTOPLANKTON AT STATION N10P THROUGHOUT 1992

Phytoplankton species composition and annual patterns for all ten BioProductivity stations have been reported in Kelly *et al.* 1992; 1993a,b,c. At station N10P, the southwest corner of the nearfield, samples were also taken at each nearfield survey. Studies through 1992 and 1993 have shown that this station receives tidal ebb flow from Nantasket Roads and South Boston Harbor, especially in the upper part of the water column. Analysis of whole-water samples taken at the surface have been completed for the nearfield surveys conducted in 1992 and are presented here for the first time.

Sampling of the surface of N10P on the six farfield surveys seemed to capture maxima in cell counts from April to October (Figure 8-1). The previously reported nearfield samples showed transitions and minima between these maxima. The time series not only shows the high level of short-term variability in cell counts, but also highlights the short temporal scales over which community changes can occur. Table 8-1 provides the complete matrix of taxa by survey, and thus includes data from the six farfield/nearfield surveys (February, March, early April, June, late August, October) interspersed with data from the eight additional nearfield surveys (late April, May, mid-July, late July, mid-August, September, November, and December). Briefly, the station N10P sampling, with a focus on additional surveys being transitional periods, are described here.

The "winter-spring bloom period" was terminated in April. The farfield survey in early April had revealed high cell counts (>3 millions cells/L), which at this station, like everywhere else in the Bays, was mostly (78%) *Phaeocystis pouchetii*. In late April, *Phaeocystis pouchetii* was still present at N10P, but three orders of magnitude lower in cell density than in early April. The diatoms present in late April were less abundant, but taxonomically similar to earlier in the month, and increased proportions of microflagellates and cryptomonads suggested that the seasonal transition from winter-spring, diatom-dominated to warm-season, flagellate-dominated assemblages was underway.

These latter trends continued into May. *Phaeocystis* had disappeared, and microflagellates and cryptomonads comprised, respectively 13 and 55% of total cells. The major diatom change was that *Skeletonema costatum* had increased to comprise 22% of total cells.

The mid-July nearfield sample appeared both similar to, and distinct from the June and late August farfield samples. Similarities included abundance of diatoms such as *Leptocylindrus danicus, Ceratulina pelagica* and *Chaetoceros* spp., and presence of numerous dinoflagellates, including *Ceratium longipes* which bloomed at Cape Cod Bay stations in June. Conversely, the diatom *Skeletonema costatum* which was a dominant at some stations in both the June and August farfield surveys was not recorded at N10P in July. Also, the colonial diatom *Thalassiosira subtilis,* which comprised nearly a third of the cells recorded in July was not recorded in adjacent months. Finally, microflagellates and cryptomonads which dominated most June and late August farfield samples comprised only about a tenth of the cells recorded in mid-July. By late July, however, microflagellates and cryptomonads together comprised $>80\%$ of total cells.

The mid-August nearfield sample exhibited differences and similarities with adjacent surveys. The diatom *Rhizosolenia delicatula* comprised nearly a third of recorded cells in mid-August, even though it was absent only two weeks before in the late July survey. Its presence continued through the late August farfield survey, where it was a dominant species at this, and many other, stations. Both numbers and relative proportions of microflagellates and cryptomonads were lower in mid-August than in late July or late August. Also *Thalassiosira subtilis* had reappeared in mid-August, comprising a tenth of cells counted.

By September, *Rhizosolenia delicatula* had taken over the assemblage, comprising over three-fourths of the cells present. As expected with autumnal cooling, microflagellates, cryptomonads, and dinoflagellates declined relative to their summer levels. However, microflagellates and cryptomonads resurged, becoming dominant at most stations of the October farfield cruise, and this trend continued through November and December at station N10P.

In summary, the intensive phytoplankton sampling at station N10P filled in transitional gaps between main seasonal blooms detected by the farfield surveys, providing a higher-resolution to the sequences of species and community succession. This would appear to lend credence to the conclusion that the farfield sampling program, as presently designed, captures most peak phytoplankton events of interest, particularly in terms of **presence** or **absence** of various species. Conversely, the rapid floristic transitions in terms of **relative abundance**, highlights how quickly numbers can fluctuate. In general from farfield surveys, station N10P was similar to others in the nearfield region of western

Massachusetts Bay. Whether the fluctuations evident in the time series at N10P provide indication of bay-wide events or are simply a function of spatial patchiness would, of course, require sampling at more than a single station. Interpretation must be viewed from the perspective that, hydrographically, this station is one of those Bioproductivity stations that vary substantially on tidal time scales.

Table 8-1. Abundance of phytoplankton taxa in samples collected near the surface at station N10P throughout 1992. All entries are in millions of cells per litre. Farfield/nearfield surveys in bold were previously reported.

SURVEY ID/ MONTH TAXON	MFF01 Feb 92	MFF02 Mar 92	MFF03 Apr 92	MNF04 Apr 92	MNF05 May 92	MFF04 Jun 92	MNF07 Jul 92	MNF08 Jul 92	MNF09 Aug 92	MFF05 Aug 92	MNF11 Sep 92	MFF06 Oct 92	MNF14 Nov 92	MNF15 Dec 92
DIATOM														
ASTERIONELLOPSIS GLACIALIS		0.005												
BIDDULPHIA SINENSIS	0.004													
CERATAULINA PELAGICA						0.091	0.104		0.078	0.080	0.022	0.015		
CHAETOCEROS ATLANTICUS														0.002
CHAETOCEROS COMPRESSUS			0.030		0.002		0.003							
CHAETOCEROS DEBILIS	0.060	0.214	0.103		0.014	0.016	0.005		0.010					
CHAETOCEROS DIDYMUS										0.056	0.003			
CHAETOCEROS DIDYMUS (UNICELL FORM)												0.004		
CHAETOCEROS SEPTENTRIONALIS	0.009								0.003					
CHAETOCEROS SOCIALIS	0.047	0.053		0.005		0.011	0.023	0.008	0.031					0.009
CHAETOCEROS SPP.	0.051									0.016				
CHAETOCEROS SPP. (10-20UM)				0.005	0.002		0.013	0.010	0.018				0.003	0.003
CHAETOCEROS SPP. (<10UM)		0.091	0.052			0.187						0.008		

Table 8-1. Abundance of phytoplankton taxa in samples collected near the surface at station N10P throughout 1992. All entries are in millions of cells per litre. Farfield/nearfield surveys in bold were previously reported *(continued)*.

SURVEY ID/ MONTH TAXON	MFF01 Feb 92	MFF02 Mar 92	MFF03 Apr 92	MNF04 Apr 92	MNF05 May 92	MFF04 Jun 92	MNF07 Jul 92	MNF08 Jul 92	MNF09 Aug 92	MFF05 Aug 92	MNF11 Sep 92	MFF06 Oct 92	MNF14 Nov 92	MNF15 Dec 92
CHAETOCEROS SPP. (>10UM)		0.003	0.030			0.021								
COCCONEIS SCUTELLUM	0.004					0.005								
CYLINDROTHECA CLOSTERIUM	0.004					0.005			0.036	0.201		0.008	0.004	0.001
DETONULA CONFERVACEA			0.074											
DITYLUM BRIGHTWELLII	0.004													
EUCAMPIA ZODIACUS												0.004		
GRAMMATOPHORA MARINA	0.004													
GUINARDIA FLACCIDA														0.003
GYRO/ PLEUROSIGMA SPP.												0.008		
LEPTOCYLINDRUS DANICUS				0.001		0.032	0.064	0.003		0.184				
LEPTOCYLINDRUS MINIMUS	0.009	0.015				0.021						0.087		
LICMOPHORA SPP.				0.000					0.003		0.003			
LITHODESMIUM SPP.										0.032				
NAVICULOID DIATOMS	0.013	0.013			0.004		0.003	0.001		0.016		0.008		0.001

Table 8-1. Abundance of phytoplankton taxa in samples collected near the surface at station N10P throughout 1992. All entries are in millions of cells per litre. Farfield/nearfield surveys in bold were previously reported *(continued)*.

SURVEY ID/ MONTH TAXON	MFF01 Feb 92	MFF02 Mar 92	MFF03 Apr 92	MNF04 Apr 92	MNF05 May 92	MFF04 Jun 92	MNF07 Jul 92	MNF08 Jul 92	MNF09 Aug 92	MFF05 Aug 92	MNF11 Sep 92	MFF06 Oct 92	MNF14 Nov 92	MNF15 Dec 92
NAVICULOIDS (LYRATE)	0.004												0.001	
NITZSCHIA (CF) DELICATISSIMA					0.004	0.086		0.003	0.083				0.023	
NITZSCHIA LONGISSIMA						0.064				0.024				
NITZSCHIA SPP.		0.003	0.007			0.091								
PARALIA MARINA									0.005					
PLEUROSIGMA AESTUARII		0.003												
PLEUROSIGMA SPP.	0.009													0.002
PROBOSCIA (=RHIZOSELENIA) ALATA									0.003					0.001
RHIZOSOLENIA DELICATULA						0.011	0.058		0.324	0.770	0.891	0.616	0.070	0.118
RHIZOSOLENIA FRAGILISSIMA	0.009										0.014			
RHIZOSOLENIA HEBETATA F. SEMISPINA	0.009			0.001				0.001					0.082	0.009
RHIZOSOLENIA SETIGERA												0.004		
SKELETONEMA COSTATUM	0.017		0.015	0.005	0.178	0.299			0.005	0.136				

Table 8-1. Abundance of phytoplankton taxa in samples collected near the surface at station N10P throughout 1992. All entries are in millions of cells per litre. Farfield/nearfield surveys in bold were previously reported *(continued)*.

SURVEY ID/ MONTH / TAXON	MFF01 Feb 92	MFF02 Mar 92	MFF03 Apr 92	MNF04 Apr 92	MNF05 May 92	MFF04 Jun 92	MNF07 Jul 92	MNF08 Jul 92	MNF09 Aug 92	MFF05 Aug 92	MNF11 Sep 92	MFF06 Oct 92	MNF14 Nov 92	MNF15 Dec 92
STRIATELLA UNIPUNCTATA				0.000			0.002							
THALASSIONEMA NITZSCHOIDES	0.090	0.035			0.002				0.003		0.014	0.015	0.026	0.001
THALASSIOSIRA (CF) AESTIVALIS					0.008									
THALASSIOSIRA (cf) GRAVIDA/ROTULA					0.012		0.046		0.003					
THALASSIOSIRA GRAVIDA	0.043													
THALASSIOSIRA NORDENSKIOLDII	0.051	0.005	0.066											
THALASSIOSIRA SPP.	0.038				0.012	0.005	0.046		0.047	0.040	0.014	0.023	0.013	0.001
THALASSIOSIRA SUBTILIS							0.200		0.101					
UNID. CENTRALES	0.038	0.005	0.030	0.001	0.008	0.021	0.013		0.005	0.040	0.006	0.030	0.007	0.002
UNID. PENNALES										0.008				
DINOFLAGELLATES														
CERATIUM FUSUS														0.001
CERATIUM LINEATUM														0.001
CERATIUM LONGIPES							0.003							
DINOPHYSIS NORVEGICA							0.002							

Table 8-1. Abundance of phytoplankton taxa in samples collected near the surface at station N10P throughout 1992. All entries are in millions of cells per litre. Farfield/nearfield surveys in bold were previously reported *(continued)*.

SURVEY ID/ MONTH TAXON	MFF01 Feb 92	MFF02 Mar 92	MFF03 Apr 92	MNF04 Apr 92	MNF05 May 92	MFF04 Jun 92	MNF07 Jul 92	MNF08 Jul 92	MNF09 Aug 92	MFF05 Aug 92	MNF11 Sep 92	MFF06 Oct 92	MNF14 Nov 92	MNF15 Dec 92
GLENODINIUM ROTUNDUM						0.005								
GYMNODINIUM SPP.								0.005	0.005		0.014	0.011	0.003	
GYRODINIUM ESTUARIALE		0.003												
GYRODINIUM SPIRALE		0.005	0.007			0.011	0.002	0.001	0.003					
GYRODINIUM SPP.					0.002			0.003	0.003		0.006			
HETEROCAPSA TRIQUETRA						0.096	0.010		0.008					
PROROCENTRUM MICANS								0.001		0.016				
PROROCENTRUM MINIMUM								0.003	0.003		0.003	0.015	0.001	
PROTOPERIDINIUM BIPES		0.003				0.005			0.003					
PROTOPERIDINIUM PELLUCIDUM						0.005								
PROTOPERIDINIUM SPP.				0.000	0.002			0.001	0.003					
SCRIPPSIELLA TROCHOIDEA							0.003	0.001						
UNID. DINOFLAGELLATES				0.002	0.002	0.005					0.006			
UNID. NAKED DINOFLAGELLATE	0.004				0.004	0.005		0.004	0.042	0.048	0.014	0.011	0.001	0.002

Table 8-1. Abundance of phytoplankton taxa in samples collected near the surface at station N10P throughout 1992. All entries are in millions of cells per litre. Farfield/nearfield surveys in bold were previously reported *(continued)*.

SURVEY ID/ MONTH / TAXON	MFF01 Feb 92	MFF02 Mar 92	MFF03 Apr 92	MNF04 Apr 92	MNF05 May 92	MFF04 Jun 92	MNF07 Jul 92	MNF08 Jul 92	MNF09 Aug 92	MFF05 Aug 92	MNF11 Sep 92	MFF06 Oct 92	MNF14 Nov 92	MNF15 Dec 92
MICROFLAGELLATES														
MICROFLAGELLATES	0.277	0.158	0.089	0.070	0.107	0.834	0.045	0.162	0.078	1.412	0.100	0.435	0.342	0.228
PYRAMIMONAS/ TETRASELMIS SPP.								0.001						
OTHER														
CRYPTOMONADS	0.068	0.020	0.118	0.015	0.445	0.235	0.026	0.069	0.125	0.393	0.061	0.253	0.013	0.052
CYANOPHYCEAE	0.021		0.030							0.008				0.020
DICTYOCHA SPECULUM				0.000	0.002									
EBRIA TRIPARTITIA								0.001	0.003		0.008	0.004	0.001	
EUTREPTIA SPP.						0.005				0.040				
EUTREPTIA/ EUTREPTIELLA SPP.					0.002			0.003	0.013					
MESODINIUM RUBRUM					0.012		0.003							0.002
PHAEOCYSTIS POUCHETII			2.423	0.007										
TOTAL														
TOTAL PHYTOPLANKTON	0.887	0.634	3.074	0.112	0.824	2.172	0.674	0.281	1.047	3.52	1.179	1.559	0.59	0.459

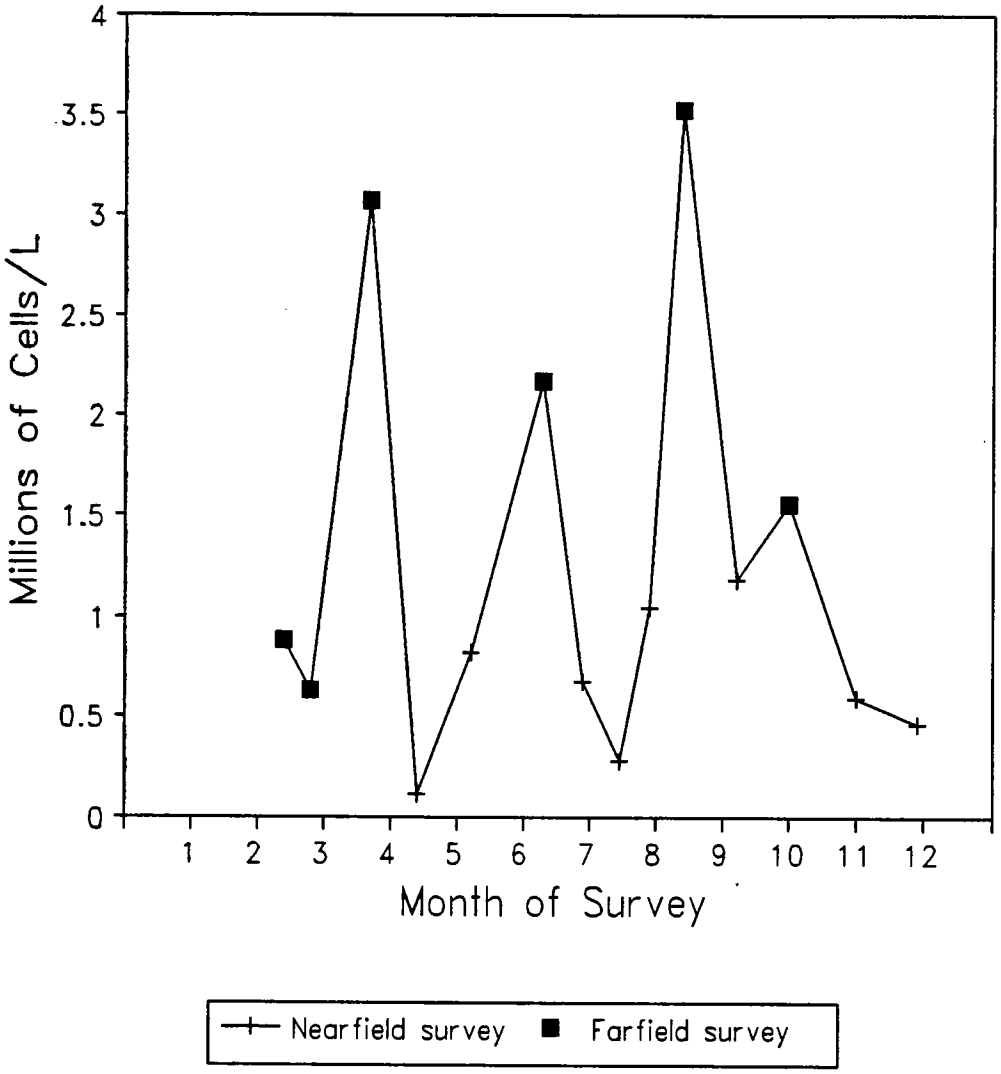


Figure 8-1. **Total phytoplankton counts in whole-water samples taken throughout 1992 at station N10P. Note that the x-axis has tick-marks at mid-month (i.e. the surveys in late February and early March are between months 2 and 3).**

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