Semi-annual water column monitoring report: August - December 1996

Massachusetts Water Resources Authority

Environmental Quality Department
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Semi-Annual Water Column Monitoring Report 96-2
August - December 1996

submitted to

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EXECUTIVE SUMMARY

Water quality data have been collected in Massachusetts and Cape Cod Bays by the Massachusetts Water Resources Authority (MWRA) Harbor and Outfall Monitoring (HOM) Program since 1992. This monitoring is in support of the HOM Program mission to assess the potential environmental effects of effluent discharge relocation from Boston Harbor into Massachusetts Bay. The data are being collected to establish baseline water quality conditions and ultimately to provide the means to detect significant departure from that baseline. The data include physical water properties, nutrients, biological production and respiration, and plankton measurements. Two types of surveys are performed: nearfield surveys with stations located in the area around the future outfall site, and more comprehensive combined nearfield/farfield surveys that include stations in Boston Harbor, Massachusetts Bay, and Cape Cod Bay.

Water quality monitoring data presented in this report were collected during the second half of 1996 in the Massachusetts Bay system. The scope of this semi-annual report includes a synthesis of water column data, and a brief analysis of integrated physical and biological results. The objective of the report is to provide a visual presentation of the monitoring data which are submitted to MWRA five times per year in tabular format, and to discuss key biological events which occurred. To this end, graphical presentations of the horizontal and vertical distribution of water column parameters in the farfield and nearfield from August through December 1996 are presented. An overview of the data from the second semi-annual period follows.

The Massachusetts Bay system undergoes strong seasonal stratification of the water column, and the timing of the onset and breakdown of vertical stratification influences seasonal nutrient cycling and biological activity, and their effects on critical issues such as seasonal dissolved oxygen minima. Results are discussed, therefore, in terms of the structure of the water column. In 1996, stratification began around the end of April and continued into September. During August, a coastal upwelling event was evident based on surface water temperature and salinity data. A series of strong storms weakened stratification during early September, particularly in more shallow coastal areas. A third storm event appeared to temporarily break down stratification, but the water column re-stratified shortly after the storm. Complete mixing of the water column in western Massachusetts Bay (including most of the nearfield) occurred by the first week of October. Mixing in deeper waters offshore appeared to occur later due to the continued presence of a strong nutricline in deeper water during the October combined survey.

The water column was vertically stratified throughout August, primarily due to the strong temperature differential between surface and bottom water. Nutrient concentrations in the surface mixed layer of all regions were low except for in Boston Harbor, which remained relatively well mixed. However, concentrations in Boston Harbor were low during August compared with subsequent results from harbor

surveys during October and December. This was attributed to the combined effects of high algal productivity in the harbor during August which apparently reduced nutrient concentrations, and to nutrient loading from runoff caused by heavy rainfall during October and December.

Outside of Boston Harbor and adjacent coastal stations, nutrient and chlorophyll concentrations were low until nutrients trapped in the stratified bottom layer began to be released by the storm activity during September. The first of two weekly hurricane events during early September (Eduoard and Fran), caused a partial release of bottom water nutrients to the surface. Continuous chlorophyll sensor readings showed a constant increase in nearfield chlorophyll concentrations from around September 10th. The passage of the former Pacific Hurricane Fausto, which caused the water column mixing event in mid-September, resulted in a more substantial release of nutrients, which appeared to initiate the fall bloom as evidenced by a marked increase in continuous chlorophyll sensor data. Survey results indicated that algal activity in shallower regions of Massachusetts Bay peaked during early October, but more offshore stations continued to bloom through the end of the month.

Dissolved oxygen concentrations in bottom water declined throughout the stratified period, with minimum concentrations in the nearfield recorded in early October. It appeared that the storm activity during September mitigated the severity of the seasonal decline in Massachusetts Bay due to ventilation. Minimum DO concentrations in the nearfield only fell from 7.9 mg/L in August to 7.2 mg/L in early October, and actually increased at coastal stations. However, minimum DO concentrations in Cape Cod Bay during this same period fell from 7.1 mg/L to 5.5 mg/L. DO concentrations in all other regions remained above 7.4 mg/L for seasonal minima.

Biological activity focused around two events during the semi-annual period: the August bloom in the harbor and adjacent coastal water, and the fall bloom in Massachusetts Bay in late September and early October. The harbor bloom in August was dominated by the centric diatoms *Rhizosolenia fragilissima* and *Leptocylindrus minimus*. The fall bloom in Massachusetts Bay appeared to initiated during September by cryptophytes, followed by a consortium of centric diatom whose composition changes with distance from shore. *Skeletonema costatum*, *Chaetoceros* spp., *R. fragilissima*, and *Cyclotella* sp. were the dominant centrics inshore, while an unidentified centric diatom (probably of the genus *Thalassiosira*) dominated the offshore assemblage along with the pennate diatom *Thalassionema nitzschoides*. While the inshore bloom diminished quickly, the offshore bloom appeared to persist into November with an apparent dominance by from *R. fragilissima*.

Measured rates for primary production and respiration during the August inshore bloom were the highest of the semi-annual reporting period. The fall bloom in offshore waters produced lower production rates, however, cloudy conditions were prevalent during these latter surveys. High-resolution production calculations, which incorporate daily irradiance to estimate production between surveys, indicated that productivity during the fall bloom was often two to three times higher than that for the specific survey

dates, and that a second peak in production at station N04 occurred during November. Overall, estimates of seasonal production based on survey data alone were about 60 percent lower than the estimates from the high-resolution calculations. Carbon-specific respiration within the nearfield, coupled with chlorophyll and productivity data, suggested that *in situ* carbon fixation, rather than import of detrital carbon, is the major source of organic matter throughout the nearfield.

Zooplankton densities peaked in the harbor and inshore stations concurrently with the August bloom, followed by a general decline thereafter. More seaward stations showed a general increase from early September through the end of October, apparently in response to the fall bloom in Massachusetts Bay. The numerical dominant was *Oithona similis*, while biomass was dominated by *Centropages typicus*. Substantial abundances of bivalve larvae were also observed during early October.

1.0 INTRODUCTION

1.1 Program Overview

The Massachusetts Water Resources Authority (MWRA) has implemented a long-term Harbor and Outfall Monitoring (HOM) Program in the Massachusetts Bay system. The objective of the HOM Program is to verify compliance with the discharge permit, and to assess the potential environmental effects of the relocated effluent discharge into Massachusetts Bay. To establish baseline water quality conditions with respect to nutrients, water properties, phytoplankton and zooplankton, and water-column respiration and productivity, ENSR is conducting water quality surveys in the nearfield and farfield region of Massachusetts and Cape Cod Bays.

This semi-annual report summarizes results from water quality monitoring conducted during the second half of the 1996 monitoring year (Table 1-1). Two types of surveys performed: eight nearfield surveys with stations located in the area over the future outfall site (Figure 1-1), and two more comprehensive nearfield/farfield combined surveys that included stations in Boston Harbor, Massachusetts Bay, and Cape Cod Bay (Figure 1-2). The stations in these surveys were further separated into regional groupings according to geographic location.

The November nearfield survey (W9616) included sampling at station F12 in Stellwagen Basin to assess late fall dissolved oxygen levels in the bottom water. The final winter survey, conducted in mid-December (W9617), included sampling coverage at stations outside of the nearfield to characterize winter nutrient levels in Massachusetts Bay.

Raw data summaries, along with specific field information, are available in individual survey reports submitted immediately following each survey. In addition, nutrient data reports (including calibration information, sensor and water chemistry data), plankton data reports, and productivity and respiration data reports are each submitted five times annually. Raw data summarized within this or any of the other reports are available from MWRA in hard copy or electronic formats.

1.2 Organization of the Semi-Annual Report

The scope of the semi-annual report is focused primarily towards providing a compilation of all of the water column data collected during the reporting period. Secondarily, integrated physical and biological results are discussed for key water column events.

The report provides a summary of the survey and laboratory methods (Section 2). In the results sections, data are first provided in summary tables (Section 3). The data summary tables include the major results of water column surveys in the semi-annual period. A description of data selection, integration information, and statistical analyses conducted are included with that section.

Each of the summary results sections (Section 4, 5) includes presentation of the horizontal and vertical distribution of water column parameters in both the farfield and nearfield. The horizontal distribution of physical parameters is presented through regional contour plots. The vertical distribution of water column parameters is presented using both time-series plots of averaged surface and bottom water column parameters, and along three farfield depth transects, and one nearfield transect, in the survey area (Figure 1-3). The time-series plots utilize average values of the surface water sample (the "A" depth, as described in Section 3), and the bottom water sample (the "E" depth). Examining data trends along the transects allows three-dimensional analysis of water column conditions during each survey.

Results of water column physical data, including water properties, nutrients, chlorophyll, and dissolved oxygen, are provided in Section 4. Survey results were organized according to the physical characteristics of the water column during the semi-annual period. For the second semi-annual period, the timing of the fall water column turnover is the key event that, to a large degree, controls the ecological water quality parameters that form much of the basis for assessing effects of the outfall. Because of the importance of this dynamic, this report describes the horizontal and vertical characterization of the water column during the pre-turnover stage, and processes which occurred during and subsequent to the fall turnover. Time-series data are commonly provided for the entire semi-annual period for clarity of data presentation.

Productivity, respiration, and plankton measurements, along with corresponding discussion of chlorophyll and dissolved oxygen results, are provided in Section 5. Discussion of the biological processes and trends during the semi-annual period are included in this section. A summary of the major water column events of the semi-annual period is presented in Section 6, and finally, references in Section 7.

TABLE 1-1

Water Quality Surveys for W9610-W9617
August to December, 1996

Event Number	Type of Survey	Date
W9610	Nearfield	August 5-6
W9611	Nearfield/Farfield	August 18-23
W9612	Nearfield	September 3-4
W9613	Nearfield	September 23-24
W9614	Nearfield/Farfield	October 6-11
W9615	Nearfield	October 29-30
W9616	Nearfield/Stellwagen Bank	November 17 - 19
W9617	Nearfield/Winter Nutrients	December 16-17

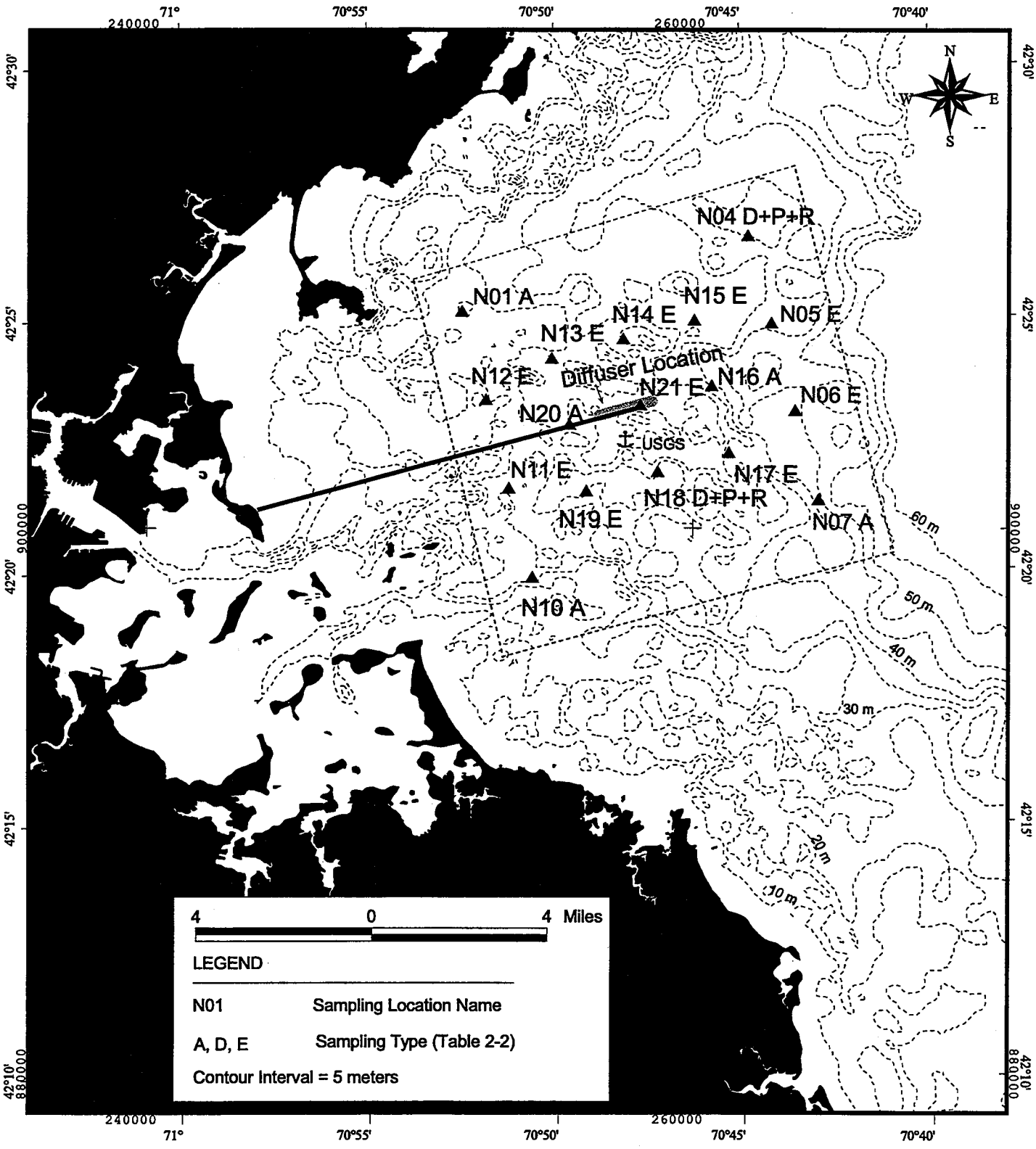


FIGURE 1-1
Location of Nearfield Stations and USGS Mooring

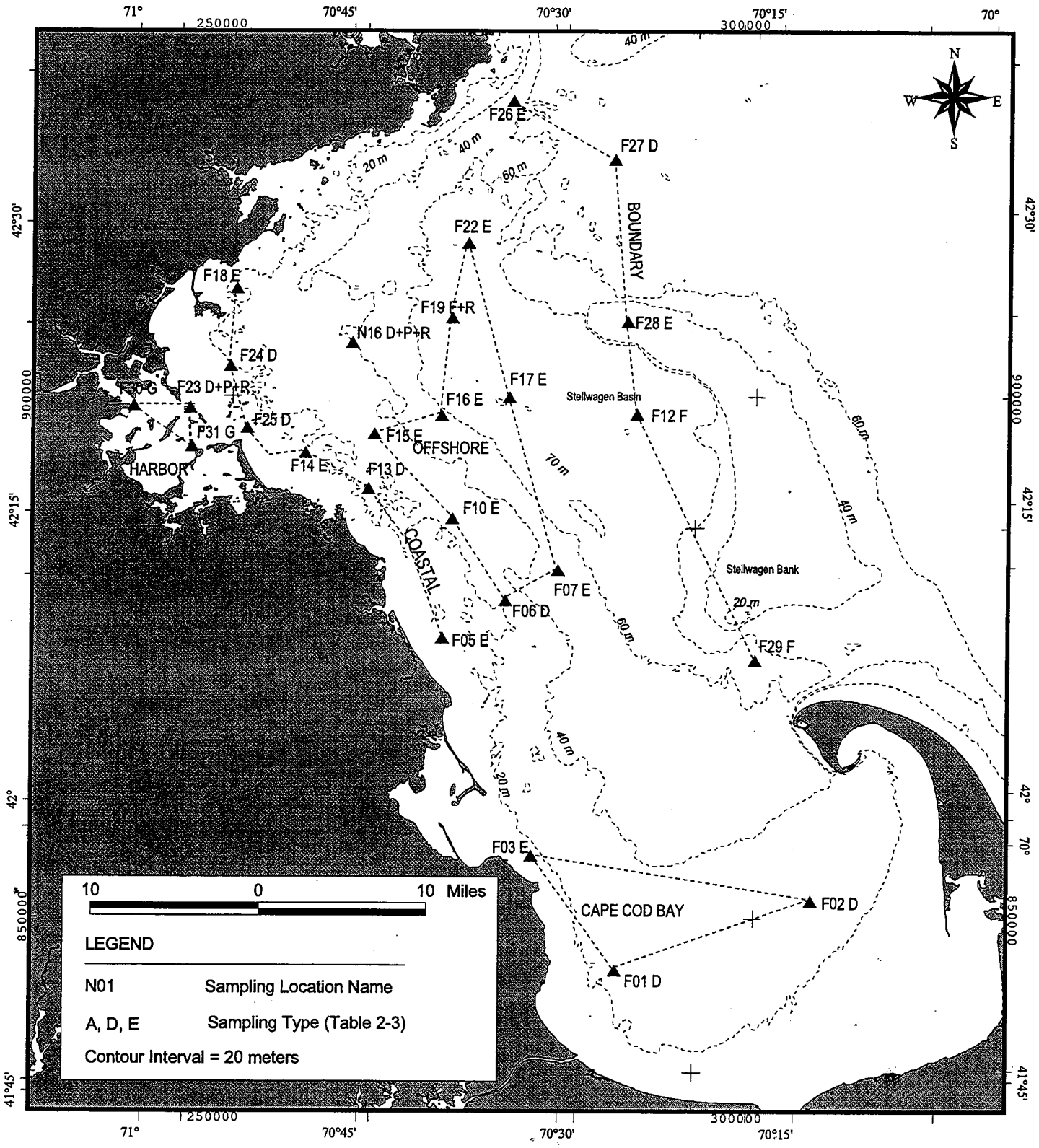


FIGURE 1-2
Location of Farfield Stations Showing Regional Geographic Classifications

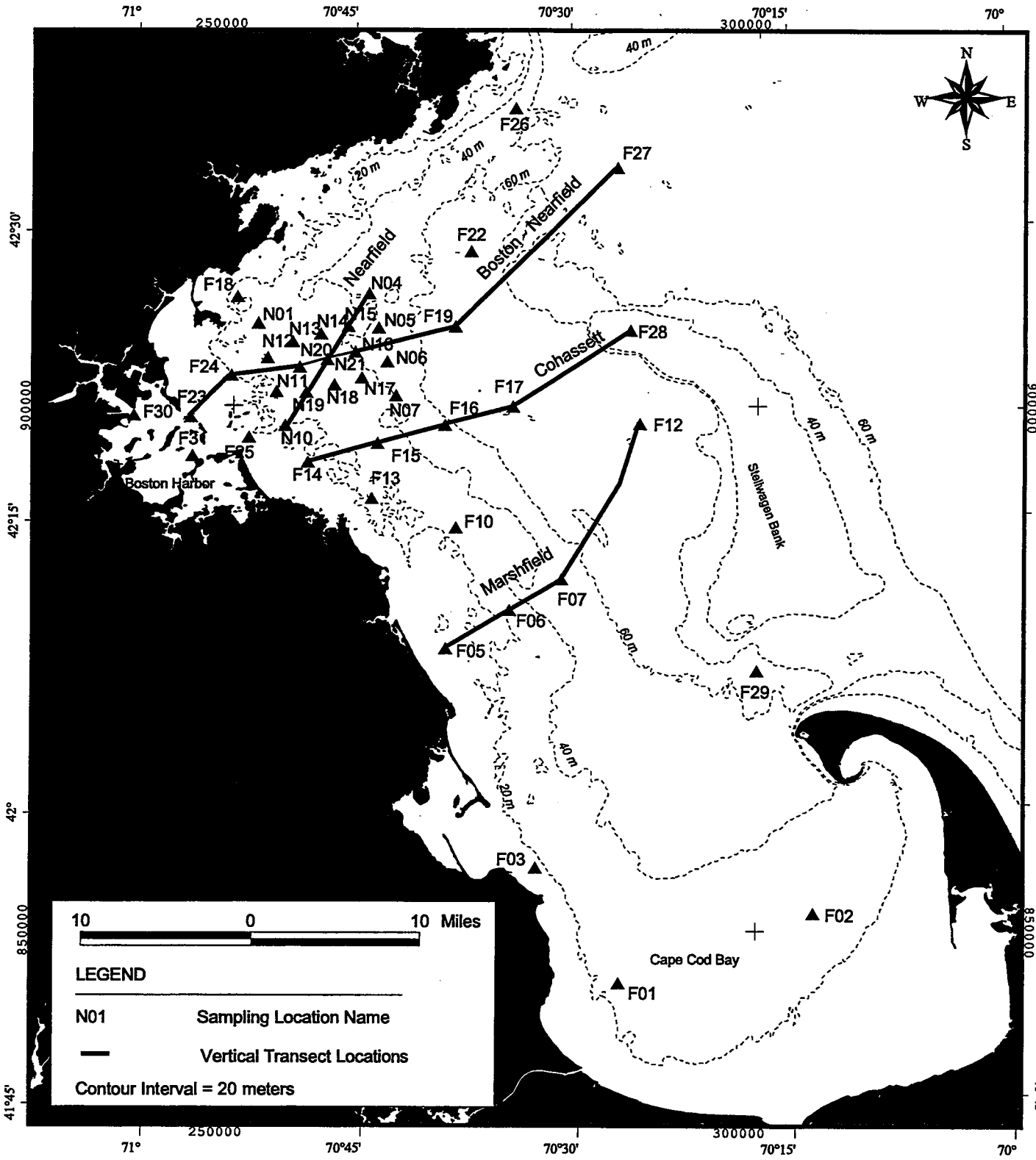


FIGURE 1-3
Location of Stations Selected for Vertical Transect Graphics Showing Transect Names

2.0 METHODS

This section describes general methods of data collection and sampling for the 1996 HOM Program surveys (refer to Table 1-1 for survey dates and type). Section 2.1 describes data collection methods, sampling platforms and analyses performed. Section 2.2 describes the sampling scheme, and Section 2.3 details specific operations for the second 1996 semi-annual period. More specific details on field sampling and analytical procedures, laboratory sample processing and analysis, sample handling and custody, calibration and preventive maintenance, documentation, data evaluation, and data quality procedures are discussed in the Water Quality Monitoring CW/QAPP (Bowen *et al.*, 1997). Details on productivity sampling procedures and analytical methods are available in Appendix A.

2.1 Data Collection

Water quality data presented in this report were collected from the sampling platforms *R/V Christopher Andrew* and *R/V Isabel S.* Continuous vertical profiles of the water column and discrete water samples for analysis were collected using a CTD/Niskin Bottle Rosette system. This system includes a deck unit to control and store data, and an underwater unit comprised of several environmental sensors, including conductivity/salinity, temperature, depth, dissolved oxygen, transmissometry, irradiance, and relative fluorescence. These measurements were obtained at each station by deploying the CTD; in general, one cast was made at each station. Water column profile data were collected during the downcast, and water samples were collected during the upcast by closing the Niskin bottles at selected depths, as discussed below.

Water samples were collected at five depths at each station. These depths were selected during CTD deployment based on positions relative to the subsurface chlorophyll maximum. The bottom depth (within 5 meters of the sea floor) and the surface depth (within 4 meters of the water surface) of each cast remained constant and the mid-bottom, middle and mid-surface depths were selected to represent any variability in the water column. In general, the selected middle depth corresponded with the chlorophyll maximum and/or pycnocline. Should the chlorophyll maximum have occurred closer to the surface or the bottom of the water column, the mid-surface or mid-bottom depths were selected to capture that layer. Exceptions to the water sampling procedure included productivity and respiration casts at Stations F23 and N16 during each farfield survey, and at Stations N04 and N10 during each nearfield survey. At these stations, two casts were necessary in order to obtain a sufficient amount of water for the additional analyses. Productivity samples are also light dependent, and a "split-bottom" cast was sometimes necessary during the respiration and productivity cast in an attempt to capture not only bottom water, but also water associated with the 0.5% light level. This resulted in six depths being sampled. These two

casts were made in succession during a station visit, with time in between to relocate the vessel within a 300 meter radius of the station location.

Samples from each depth at each station were collected by subsampling from the Niskin bottles into the appropriate sample container. Analyses performed on the water samples are summarized in Table 2-1. Samples for dissolved inorganic nutrients (DINuts), dissolved organic carbon (DOC), total dissolved nitrogen (TDN) and phosphorous (TDP), particulate organic carbon (POC), biogenic silica, chlorophyll *a* and phaeopigments, total suspended solids (TSS), urea, and phytoplankton were filtered and preserved immediately after obtaining water from the appropriate Niskin bottles. Whole water phytoplankton samples (unfiltered) were obtained directly from the Niskin bottles and immediately preserved. Zooplankton samples were obtained by deploying a zooplankton net overboard and making an oblique tow of two-thirds of the water column or up to 30 meters of depth. Productivity and respiration samples were collected from the Niskin bottles, maintained at *in situ* temperatures, and incubated on board the vessel within two hours of initial water collection.

2.2 Sampling Scheme

A synopsis of the sampling scheme for the analyses described above is outlined in Tables 2-1, 2-2, and 2-3. Stations were assigned a letter (A, D, E, F, or G) according to the types of analyses performed at that station. Productivity and respiration analyses were also conducted at certain stations and represented by the letters P and R, respectively. Because different analyses were performed at different depths, each depth at each station is assigned an analysis group (G1, G2, G3, G4, G5, G6, G7, G8, or G9; Table 2-1). Tables 2-2 (nearfield stations) and 2-3 (farfield stations) provide the station name and type, and give the analysis group that represents the analyses performed at each depth. Station N16 is considered both a nearfield station (where it is designated as type A) and a farfield station (where it is designated as type D+P+R).

2.3 Operations Summary

Changes in the 1996 sampling scheme from prior monitoring years included the reduction of the number of nearfield stations sampled, and a change in analyses at selected stations. During 1996, nearfield stations N02, N03, N08 and N09 were not sampled. At all type D stations, POC and PON analyses were expanded to include the bottom depth. Field operations for water column sampling and analysis during the second semi-annual period were conducted as described above, with the exceptions detailed below.

2.3.1 Deviations in Scope

Principal deviations from the CW/QAPP plan for each survey and the sampling scheme are described below. For additional information about a specific survey, the individual survey reports may be consulted. The following deviations were noted:

Early August Nearfield Survey (W9610)

- Only 14 of the planned 17 nearfield stations were sampled due to electrical problems on board the research vessel. Stations N13, N14, and N15 were not sampled.

Late August Nearfield/Farfield Survey (W9611)

- The discrete dissolved oxygen sample at Station N07 was not collected at the chlorophyll maximum depth; the mid-surface DOC result was not reported.

Early September Nearfield Survey (W9612)

- The bottom DINuts sample at Station N01 was not collected;
- The bottom TSS sample at Station N07 was not reported;
- Additional dissolved samples were collected at the bottom depth at Station N17 and at the surface and bottom depths at Station N19 in order to verify dissolved oxygen sensor data.

Early October Nearfield/Farfield Survey (W9614)

- Duplicate dissolved oxygen samples were not collected at Station F12;
- Insufficient water was available in the Nisken bottle to collect all samples At Station F23, thus no POC/PON samples or chlorophyll duplicate were collected. Extra dissolved oxygen samples were collected during the water quality cast at the surface, middle, mid-bottom and bottom depths;
- A precipitate formed in the zooplankton and screened phytoplankton samples at Stations F24 and N10 after they were preserved in formalin;

- Seven DOC samples were compromised during laboratory handling, with one lost (surface samples at Stations F06 and N07, mid-depth samples at F06, F23, F24 and N10, and the bottom samples at F31 and F23).

Late October Nearfield Survey (W9615)

- Extra dissolved oxygen samples were collected at Station N17 at the bottom depth;

- Due to declining weather conditions, at Station N04 only the productivity and respiration cast was performed. No samples were collected for whole water or screened phytoplankton and for urea;

- Also due to declining weather conditions, nine stations were dropped from the survey track (N05, N06, N07, N13, N14, N15, N16, N20, and N21).

Late November Nearfield/Stellwagen Bank Survey (W9616)

- Due to weather conditions, sampling at Station F12 (Stellwagen Bank) was accomplished one day prior to sampling in the nearfield;

- Also due to weather conditions, only ten stations in the nearfield were sampled (N01, N04, N05, N06, N07, N10, N11, N12, N16, and N20).

Mid-December Nearfield/Winter Nutrients Survey (W9617)

- Stations N04, N16, N10, F23, F06 and F05 were sampled;

- The mid-depth dissolved oxygen sample was lost at Station F06 due to breakage of the sample bottle.

TABLE 2-1

Water Column Sample Analyses

Analysis	Analysis Group										
	G1	G2	G3	G4	G5	G6	G7	G8	G9	P	R
Dissolved Inorganic Nutrients	X	X	X	X	X	X	X	X			
Dissolved Organic Carbon	X	X	X								
Total Dissolved N & P	X	X	X								
Particulate C & N	X	X	X								
Particulate P	X	X	X								
Biogenic Silica	X	X	X								
Chlorophyll & Phaeopigments	X	X	X	X	X	X			X		
Total Suspended Solids	X	X	X	X					X		
Dissolved Oxygen	X	X	X	X	X		X		X		
Urea	X	X									
All Phytoplankton	X	X									
Screened Phytoplankton	X	X									
Zooplankton	X										
Areal Productivity										X	
Respiration											X

TABLE 2-2

Analysis Group for Each Nearfield Station and Depth

Station Name	N01	N04	N05	N06	N07	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21
Station Type	**A**	**D+P+R**	**E**	**E**	**A**	**D+P+R**	**E**	**E**	**E**	**E**	**E**	**A**	**E**	**E**	**E**	**A**	**E**
Nearfield Stations																	
Surface	G3	G1 + P + R	G8	G8	G3	G1+P+R	G8	G8	G8	G8	G8	G3	G8	G8	G8	G3	G8
Mid-surface	G6	G6 + P	G8	G8	G6	G6+P	G8	G8	G8	G8	G8	G6	G8	G8	G8	G6	G8
Middle	G3	G2 + P + R	G8	G8	G3	G2+P+R	G8	G8	G8	G8	G8	G3	G8	G8	G8	G3	G8
Mid-bottom	G5	G5 + P	G8	G8	G5	G5+P	G8	G8	G8	G8	G8	G5	G8	G8	G8	G5	G8
Bottom	G4	G3 + P + R	G8	G8	G4	G3+P+R	G8	G8	G8	G8	G8	G4	G8	G8	G8	G4	G8

TABLE 2-3

Analysis Group for Each Farfield Station and Depth

Station Name[1]	F01	F02	F03	F05	F06	F07	F10	F12	F13	F14	F15	F16	F17	F18	F19	F22	F23	F24	F25	F26
Station Type	**D**	**D**	**E**	**E**	**D**	**E**	**E**	**F**	**D**	**E**	**E**	**E**	**E**	**E**	**F+R**	**E**	**D+P+R**	**D**	**D**	**E**
Farfield Stations																				
Surface	G1	G1	G8	G8	G1	G8	G8	G7	G1	G8	G8	G8	G8	G8	G7+R	G8	G1+P+R	G1	G1	G8
Mid-surface	G6	G6	G8	G8	G6	G8	G8	G8	G6	G8	G8	G8	G8	G8	G8	G8	G6+P	G6	G6	G8
Mid-depth	G2	G2	G8	G8	G2	G8	G8	G7	G2	G8	G8	G8	G8	G8	G7+R	G8	G2+P+R	G2	G2	G8
Mid-bottom	G5	G5	G8	G8	G5	G8	G8	G7	G5	G8	G8	G8	G8	G8	G7	G8	G5+P	G5	G5	G8
Bottom	G3	G3	G8	G8	G3	G8	G8	G7	G3	G8	G8	G8	G8	G8	G7+R	G8	G3+P+R	G3	G3	G8

Station Name	F27	F28	F29	F30	F31	N16
Station Type	**D**	**E**	**F**	**G**	**G**	**D+P+R**
Surface	G1	G8	G7	G1	G1	G1+P+R
Mid-surface	G6	G8	G8	G0	G0	G6+P
Mid-depth	G2	G8	G7	G2	G2	G2+P+R
Mid-bottom	G5	G8	G7	G0	G0	G5+P
Bottom	G3	G8	G7	G4	G4	G3+P+R

[1]Stations F04, F08, F09, F11, F20 and F21 have been replaced by or changed to stations F27, F28, F29, F30, F31 and N16.

3.0 DATA SUMMARY PRESENTATION

Data from each survey were compiled from the 1996 HOM database and organized to facilitate regional comparisons between surveys, and to allow a quick evaluation of results for contingency planning purposes (Tables 3-1 through 3-8). Each table provides summary data from one survey; the survey dates are provided at the top of each table. A discussion of which parameters were selected, how the data were grouped and integrated, and the assumptions behind the calculation of statistical values (average, minimum, and maximum), are provided below. All raw data summarized in this report are available from MWRA either in hard copy or electronic form.

The spatial summary of data follows the sample design over major geographic areas of interest in Massachusetts Bay, Cape Cod Bay, and Boston Harbor (Section 3.1). Compilation of data both horizontally by region and vertically over the entire water column was conducted in order to provide an efficient way of assessing the status of the regions during a particular survey. Maximum and minimum values are provided because of the need to assess extremes of pre-outfall conditions relative to criteria being developed for contingency planning purposes (MWRA, 1997).

Regional compilations of nutrient and biological water column data were conducted first by averaging individual laboratory replicates, followed by field duplicates, and then by station visit. Prior to regional compilation of the sensor data, the results were averaged by station visit. Significant figures for average values were selected based on the precision of the specific dataset. Detailed considerations for individual datasets are provided in the sections below.

3.1 Defined Geographic Areas

The primary partitioning of data is between the nearfield and farfield stations (Figures 1-1 and 1-2). Farfield data from surveys W9611 and W9614 were additionally segmented into five geographic areas: three stations in Boston Harbor (F23, F30, and F31), six coastal stations (F05, F13, F14, F18, F24, F25), eight offshore stations (F06, F07, F10, F15, F16, F17, F19, and F22), five boundary region stations (F12, F26, F27, F28, F29), and three Cape Cod Bay stations (F01, F02, and F03). Results from one boundary station (Stellwagen Basin, F12) are presented in the summary data from W9616. These regions are illustrated in Figure 1-2.

The data summary tables include data that are derived from all of the station data collected in each region. Average, maximum, and minimum values are reported from the cumulative horizontal and vertical dataset as described for each data type below.

3.2 Sensor Data

Six CTD profile parameters provided in the data summary tables include: temperature, salinity, density, fluorescence (chlorophyll *a*), transmissivity, and dissolved oxygen (DO) concentration. Statistical parameters (maximum, minimum, and average) were calculated from the five upcast sensor readings collected at five depths through the water column (defined as A-E). The five depth values, rather than the entire set of profile data, were selected in order to reduce the statistical weighting of deep water data at the offshore and boundary stations. Generally, the samples were collected in an even depth-distributed pattern. One of the mid-depth samples (B, C, or D) was typically located at the fluorescence (chlorophyll) peak in the water column, depending on the relative depth of the chlorophyll maximum. Details of the collection, calibration, and processing of CTD data are provided in the Water Column Monitoring CW/QAPP (Bowen *et al.*, 1997).

Following standard oceanographic practice, patterns of variability in water density will be described using the derived parameter σ_t, which is calculated by subtracting 1,000 kgm^{-3} from the recorded density. During this semi-annual period, density varied from 1,020.8 kgm^{-3} to 1,025.3 kgm^{-3}, meaning σ_t varied from 20.8 kgm^{-3} to 25.3 kgm^{-3}.

Fluorescence data were calibrated to the amount of chlorophyll *a* in discrete water samples collected at the depth of the sensor reading for a subset of the stations (see CW/QAPP or Tables 2-1, 2-2, 2-3). The calibrated chlorophyll sensor values were used for all discussions of chlorophyll in this report. The concentration of phaeopigments, included in the summary data tables as part of the nutrient parameters, also was included as part of the summary results.

In addition to DO concentration, the derived percent saturation was also provided. Percent saturation was calculated prior to averaging station visits from the potential saturation value of the water (a function of the physical properties of the water) and the calibrated DO concentration (see CW/QAPP). Finally, the derived beam attenuation coefficient from the transmissometer ("transmissivity") was provided on the summary tables. Beam attenuation was calculated from the ratio of light transmission relative to the initial light incidence, over a particular distance in the water column, and is provided in units of m^{-1}.

3.3 Nutrients

Analytical results for nutrient concentrations were extracted from the HOM database, and include: ammonia (NH_4), nitrite (NO_2), nitrite + nitrate ($NO_2 + NO_3$), phosphate (PO_4), and silicate (SiO_4). Nutrients were measured in water samples collected at each of the A-E depths during the CTD casts. Information on the collection, processing, and analysis of nutrient samples can be found in the CW/QAPP (Bowen *et al.*, 1997).

3.4 Biological Water Column Parameters

Three productivity parameters were selected for inclusion in the data summary tables. Areal production ($mgCm^{-2}d^{-1}$), which is determined by integrating the measured productivity over the photic zone, is included for the productivity stations (F23 representing the harbor, and N04, N10, and N16, representing the nearfield). Because areal production is already depth-integrated, averages were calculated only among productivity stations for the two regions sampled. The derived parameters α ($gC[gChla]^{-1}h^{-1}[\mu Em^{-2}s^{-1}]^{-1}$) and P_{max} ($gC[gChla]^{-1}h^{-1}$) were also included (Appendix A).

A suite of other water column biological parameters was summarized on the data tables. Respiration rates were averaged over the respiration stations (the same harbor and nearfield stations as productivity, and additionally one offshore station [F19]), and over the three water column depths sampled (upper, mid-, and lower water column). The water column depths of the respiration samples typically coincided with the water depths of the productivity measurements.

Dissolved and particulate organic parameters were also summarized for the tables, including: biogenic silica (BioSi), dissolved and particulate organic carbon (DOC and POC), particulate and total dissolved phosphate ($PP0_4$, TDP), particulate organic and total dissolved nitrogen (PON and TDN), and urea. Total suspended solids (TSS) data are provided as a baseline for total particulate matter in the water column. Dissolved and particulate constituents were measured from water samples collected from each of the five (A-E) depths during CTD casts. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Bowen *et al.*, 1997).

3.5 Plankton

Plankton results were extracted from the HOM database and include whole water phytoplankton, screened phytoplankton, and zooplankton. Phytoplankton measurements included whole-water collections at the surface (depth A) and at the water column chlorophyll *a* maximum (typically depth C) during the water column casts. Additional samples were taken at these two depths and screened through 20µm Nitex mesh to retain and concentrate larger dinoflagellate species. Zooplankton measurements were collected through oblique tows at all stations. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Bowen *et al.*, 1997).

Final plankton values were derived for each cast by first averaging analytical replicates, then averaging station visits. Values were calculated from the data for the following parameters: nuisance algae (*Alexandrium tamarense, Phaeocystis pouchetii, and Pseudo-nitzschia pungens*), total phytoplankton, total zooplankton, and total centric diatoms. Only the maximum of each plankton parameter is presented in the summary tables, due to the program emphasis on the magnitude of plankton response to nutrient concentrations.

Results for total phytoplankton and centric diatoms reported in Tables 3-1 through 3-8 were restricted to whole water surface samples. Results for the nuisance species *Phaeocystis pouchetii* and *Pseudo-nitzschia pungens* include the maximum of both whole water and screened analyses, at both the surface and mid-depth. Although the size and shape of both taxa might allow them to pass through the Nitex mesh, both have colonial forms which in low densities might be overlooked in the whole-water samples. For *Alexandrium tamarense*, only the screened sample results were reported.

3.6 Other Data Sources

Additional data sources were utilized during interpretation of HOM Program semi-annual water column data. Continuous monitoring data, collected from a mooring located between nearfield stations N21 and N18 (Figure 1-1), were provided by the USGS, as were discharge data for the Merrimack and Charles Rivers. Hourly temperature and salinity data from the surface (upper 5 m) and near-bottom (1m above bottom) were averaged over each day, and plotted with HOM survey data from station N16. Discrete data from N16 were selected from water depths that were most consistent with the depths of mooring data, and plotted with the continuous data for comparison. Information on meteorological events that occurred over the year, including hurricanes, northeasters, and records of precipitation, were obtained from the Northeast Regional Climate Center (NRCC) and used for additional data interpretation.

TABLE 3-1
Semi-Annual Data Summary Table
Event W9610 (8/6/96)
Nearfield Survey

		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
Physical				
Chlorophyll a	µg/L	0.01	0.85	0.29
Salinity	psu	30.1	31.9	31.0
Sigma_T	kg/m^3	21.0	25.1	23.3
Temperature	°C	6.1	20.3	12.8
Transmissivity	m-1	0.64	1.13	0.91
Nutrients				
NH_4	µM	0.01	1.26	0.31
NO_2	µM	0.01	0.43	0.15
$NO_2 + NO_3$	µM	0.0	6.8	1.1
PO_4	µM	0.13	0.91	0.40
SIO_4	µM	1.7	8.1	3.8
Phaeopigment	µg/L	0.03	0.27	0.10
DO				
Concentration	mg/l	8.4	9.7	9.1
Saturation	%	111%	96%	103%
Productivity				
Alpha	see text	0.01	0.03	0.02
Areal Production	$mgC/m^2/d$	1071.8	1234.5	1153.2
Pmax	see text	1.9	14.2	8.3
Respiration	µmol/h	0.03	0.24	0.14
Water Column				
BIOSI	µM	0.5	1.4	0.8
DOC	mg/L	1.0	1.4	1.1
PART P	µM	0.09	0.27	0.20
POC	µM	11.1	33.6	19.4
PON	µM	1.56	5.50	2.89
TDN	µM	6.5	17.2	9.0
TDP	µM	0.28	0.90	0.45
TSS	mg/L	0.4	2.1	1.0
Urea	µM	0.12	0.47	0.25
Plankton				
Total Phytoplankton	Mcell/L		1.74	
Centric diatoms	Mcell/L		0.10	
Alexandrium tamarense	Mcell/L		NP	
Phaeocystis pouchetii	Mcell/L		NP	
Pseudo-nitzschia sp	Mcell/L		NP	
Total Zooplankton	$\#/m^3$		35550	

NP - Not Present

TABLE 3-2
Semi-Annual Data Summary Table
Event W9611 (8/19/96 - 8/23/96)
Combined Nearfield/Farfield Survey

		Nearfield			Farfield														
Region					Harbor			Coastal			Offshore			Boundary			Cape Cod Bay		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Physical																			
Chlorophyll a	µg/L	0.00	4.31	0.85	1.48	7.55	4.00	0.07	4.15	1.60	0.00	1.96	0.48	0.00	3.51	0.54	0.02	2.14	0.61
Salinity	psu	30.8	31.8	31.3	30.2	31.2	30.8	30.8	31.5	31.1	30.8	32.0	31.5	30.4	32.1	31.5	30.9	31.6	31.2
Sigma_T	kg/m^3	21.6	25.0	23.6	21.4	23.7	22.6	22.0	24.3	23.3	21.7	25.2	24.0	21.6	25.3	24.0	21.7	24.7	23.4
Temperature	°C	6.5	19.8	12.1	11.8	18.9	15.7	9.2	18.4	13.5	5.2	19.5	10.5	4.8	20.1	10.4	7.7	19.6	13.2
Transmissivity	m-1	0.66	2.17	1.17	1.50	3.51	2.50	0.77	2.60	1.36	0.59	1.90	0.97	0.63	1.51	0.92	0.75	2.35	1.15
Nutrients																			
NH_4	µM	0.01	0.96	0.20	0.41	2.23	1.55	0.05	2.94	0.77	0.17	0.66	0.35	0.10	0.62	0.32	0.29	2.58	0.80
NO_2	µM	0.01	0.55	0.20	0.07	0.23	0.14	0.01	0.37	0.14	0.01	0.48	0.11	0.02	0.30	0.08	0.01	0.66	0.19
$NO_2 + NO_3$	µM	0.0	7.5	2.4	0.2	1.5	0.9	0.0	3.3	1.1	0.0	9.4	3.5	0.0	9.9	4.1	0.0	4.8	1.2
PO_4	µM	0.12	1.00	0.55	0.53	0.71	0.65	0.22	0.88	0.51	0.11	1.17	0.62	0.11	1.18	0.63	0.23	1.03	0.49
SIO_4	µM	0.2	10.2	4.5	0.8	4.0	2.3	0.1	6.7	3.2	0.2	12.8	3.8	0.5	11.6	4.1	0.8	13.8	4.3
Phaeopigment	µg/L	0.05	0.39	0.17	0.15	1.62	0.58	0.04	0.60	0.34	0.03	0.29	0.19	0.06	0.21	0.09	0.02	0.33	0.16
DO																			
Concentration	mg/l	7.9	10.0	8.8	7.7	8.7	8.0	7.3	9.7	8.7	7.6	9.9	8.7	8.1	9.9	8.7	7.1	9.4	8.6
Saturation	%	104%	100%	99%	99%	98%	97%	94%	103%	101%	100%	96%	95%	107%	96%	94%	93%	96%	99%
Productivity																			
Alpha	see text	0.01	0.26	0.08	0.22	0.27	0.24												
Areal Production	mgC/m^2/d	877.0	2898.4	1635.0	3472.8	3472.8	3472.8												
Pmax	see text	0.9	63.4	18.5	68.1	144.9	114.4												
Respiration	µmol/h	0.01	0.52	0.21	0.13	0.35	0.27				0.00	0.19	0.07						
Water Column																			
BIOSI	µM	0.6	3.4	1.7	3.1	5.8	4.6	1.2	4.2	2.4	0.4	0.7	0.5	0.3	2.0	0.9	0.5	6.0	2.5
DOC	mg/L	0.9	1.5	1.2	0.5	1.8	1.4	1.1	1.4	1.3	1.0	1.4	1.2	1.0	1.3	1.1	1.1	1.4	1.3
PART P	µM	0.14	0.64	0.33	0.54	0.91	0.72	0.23	0.78	0.42	0.14	0.21	0.18	0.15	0.48	0.28	0.17	0.35	0.27
POC	µM	7.3	60.1	27.0	29.8	64.5	47.8	16.4	46.9	29.7	7.9	24.5	14.4	7.0	18.9	12.5	11.3	26.7	17.7
PON	µM	1.06	10.42	4.31	4.89	10.24	8.08	3.39	7.44	4.92	1.54	3.63	2.57	1.07	2.78	1.88	1.79	4.13	2.82
TDN	µM	7.1	15.2	9.4	11.1	14.2	12.0	7.4	13.2	9.7	8.2	12.7	9.9	7.0	14.0	9.4	6.7	17.1	11.3
TDP	µM	0.29	1.00	0.57	0.78	1.06	0.89	0.44	0.84	0.63	0.26	0.65	0.51	0.27	0.96	0.61	0.37	1.00	0.64
TSS	mg/L	0.2	1.7	0.8	0.7	11.1	3.4	0.3	2.5	1.1	0.2	0.4	0.3	0.7	2.5	1.6	0.6	2.7	1.4
Urea	µM	0.02	0.39	0.23	0.15	0.40	0.29	0.15	0.36	0.25	0.16	0.27	0.21	0.28	0.36	0.32	0.21	0.47	0.32
Plankton																			
Total Phytoplankton	Mcell/L		4.06			5.38			3.92			0.99			0.87			1.14	
Centric diatoms	Mcell/L		1.81			1.96			1.66			0.08			0.01			0.39	
Alexandrium tamarense	Mcell/L		NP			NP			NP			NP			NP			NP	
Phaeocystis pouchetti	Mcell/L		NP			NP			NP			NP			NP			NP	
Pseudo-nitzschia sp	Mcell/L		1.40E-02			1.60E-02			5.70E-02			4.71E-04			NP			1.00E-03	
Total Zooplankton	#/m^3		32434			49580			44308			23518			19870			54509	

NP - Not Present

TABLE 3-3
Semi-Annual Data Summary Table
Event W9612 (9/5/96)
Nearfield Survey

		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
Physical				
Chlorophyll a	µg/L	0.00	1.77	0.41
Salinity	psu	31.0	31.8	31.3
Sigma_T	kg/m^3	22.4	24.9	23.2
Temperature	°C	7.2	17.4	14.2
Transmissivity	m-1	0.67	1.95	1.06
Nutrients				
NH_4	µM	0.01	3.34	0.50
NO_2	µM	0.01	0.41	0.13
$NO_2 + NO_3$	µM	0.0	8.1	1.3
PO_4	µM	0.20	1.00	0.40
SIO_4	µM	1.1	12.0	4.0
Phaeopigment	µg/L	0.02	0.52	0.20
DO				
Concentration	mg/l	7.4	8.9	8.4
Saturation	%	93%	91%	99%
Productivity				
Alpha	see text	0.02	0.05	0.03
Areal Production	$mgC/m^2/d$	997.1	1181.9	1089.5
Pmax	see text	1.5	20.6	7.5
Respiration	µmol/h	0.04	0.24	0.16
Water Column				
BIOSI	µM	0.1	2.5	0.8
DOC	mg/L	0.7	1.3	1.1
PART P	µM	0.11	0.32	0.19
POC	µM	12.6	28.2	18.7
PON	µM	1.56	4.42	2.72
TDN	µM	6.1	12.7	8.6
TDP	µM	0.33	0.90	0.48
TSS	mg/L	0.2	1.7	0.7
Urea	µM	0.11	0.23	0.18
Plankton				
Total Phytoplankton	Mcell/L		1.21	
Centric diatoms	Mcell/L		0.15	
Alexandrium tamarense	Mcell/L		NP	
Phaeocystis pouchetii	Mcell/L		NP	
Pseudo-nitzschia sp	Mcell/L		2.00E-03	
Total Zooplankton	$\#/m^3$		41818	

NP - Not Present

TABLE 3-4
Semi-Annual Data Summary Table
Event W9613 (9/25/96)
Nearfield Survey

		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
Physical				
Chlorophyll a	µg/L	0.02	1.33	0.47
Salinity	psu	30.4	31.8	31.2
Sigma_T	kg/m^3	22.3	24.2	23.1
Temperature	°C	11.3	15.9	14.5
Transmissivity	m-1	0.70	2.17	1.31
Nutrients				
NH_4	µM	0.20	8.60	1.18
NO_2	µM	0.01	0.82	0.23
$NO_2 + NO_3$	µM	0.0	4.9	1.4
PO_4	µM	0.20	1.05	0.45
SIO_4	µM	2.4	8.8	4.5
Phaeopigment	µg/L	0.07	0.26	0.14
DO				
Concentration	mg/l	7.3	9.0	8.1
Saturation	%	89%	101%	96%
Productivity				
Alpha	see text	0.03	0.15	0.09
Areal Production	$mgC/m^2/d$	1008.2	1921.7	1465.0
Pmax	see text	3.3	31.5	18.5
Respiration	µmol/h	0.06	0.23	0.13
Water Column				
BIOSI	µM	0.2	4.9	1.4
DOC	mg/L	1.2	1.6	1.3
PART P	µM	0.10	0.41	0.26
POC	µM	10.7	45.4	27.3
PON	µM	1.22	6.26	3.58
TDN	µM	7.2	23.3	10.8
TDP	µM	0.40	1.37	0.64
TSS	mg/L	0.3	3.9	1.0
Urea	µM	0.15	0.70	0.43
Plankton				
Total Phytoplankton	Mcell/L		2.81	
Centric diatoms	Mcell/L		0.16	
Alexandrium tamarense	Mcell/L		NP	
Phaeocystis pouchetii	Mcell/L		NP	
Pseudo-nitzschia sp	Mcell/L		NP	
Total Zooplankton	$\#/m^3$		22191	

NP - Not Present

TABLE 3-5
Semi-Annual Data Summary Table
Event W9614 (10/7/96 - 10/11/96)
Combined Nearfield/Farfield Survey

		Nearfield			Farfield														
Region					Harbor			Coastal			Offshore			Boundary			Cape Cod Bay		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Physical																			
Chlorophyll a	µg/L	0.00	11.50	3.71	0.98	7.72	2.06	2.35	7.77	3.90	0.00	4.22	1.81	0.00	6.46	1.70	0.00	3.60	2.30
Salinity	psu	31.0	32.0	31.5	28.1	31.1	30.4	30.7	31.5	31.2	31.1	32.2	31.6	31.4	32.3	31.8	30.9	31.6	31.1
Sigma_T	kg/m^3	23.2	24.5	23.7	20.8	23.4	22.8	23.0	23.8	23.4	23.1	24.8	23.8	23.4	25.0	24.1	22.8	23.8	23.1
Temperature	°C	11.0	13.8	12.8	12.8	14.6	13.2	12.6	13.6	13.2	9.7	14.4	12.5	8.7	13.9	12.0	12.9	15.0	14.3
Transmissivity	m-1	0.90	4.61	1.91	2.03	5.39	2.62	1.90	4.55	3.05	0.70	3.18	1.32	0.66	1.71	1.19	1.03	2.85	1.59
Nutrients																			
NH_4	µM	0.19	4.68	0.66	6.01	9.17	7.66	0.32	7.24	2.23	0.20	0.64	0.36	0.24	1.56	0.45	0.33	2.89	0.74
NO_2	µM	0.02	0.71	0.22	0.55	0.96	0.71	0.02	0.72	0.32	-0.01	0.63	0.17	0.01	0.51	0.16	0.01	0.55	0.18
$NO_2 + NO_3$	µM	0.1	7.4	1.6	4.0	8.6	5.6	0.1	5.5	2.2	0.1	8.0	2.3	0.0	8.5	2.6	0.0	4.3	0.9
PO_4	µM	0.22	0.93	0.45	1.00	1.20	1.07	0.28	1.03	0.58	0.26	0.92	0.48	0.20	0.97	0.48	0.27	0.98	0.47
SiO_4	µM	0.4	11.6	3.5	5.8	12.1	7.3	1.5	15.4	4.7	1.5	13.4	5.2	1.3	12.2	5.0	2.0	18.4	5.0
Phaeopigment	µg/L	0.04	0.95	0.44	0.04	1.63	1.13	0.38	2.71	1.29	0.10	0.80	0.49	0.01	0.15	0.08	0.08	0.72	0.36
DO																			
Concentration	mg/l	7.2	9.5	8.4	7.6	8.4	7.8	8.1	9.1	8.4	7.4	9.2	8.3	7.6	9.4	8.6	5.5	8.7	8.1
Saturation	%	84%	105%	97%	89%	97%	90%	94%	104%	97%	88%	100%	95%	90%	99%	97%	66%	100%	95%
Productivity																			
Alpha	see text	0.08	0.18	0.14	0.07	0.10	0.08												
Areal Production	mgC/m^2/d	762.4	2471.5	1468.8	705.2	705.2	705.2												
Pmax	see text	15.2	53.0	33.1	20.2	24.0	21.8												
Respiration	µmol/h	0.08	0.22	0.14	0.12	0.24	0.20				0.05	0.17	0.11						
Water Column																			
BIOSI	µM	2.0	9.3	4.7	4.2	11.2	6.2	6.9	9.5	7.9	2.6	3.2	3.0	1.6	1.9	1.8	2.2	6.8	4.4
DOC	mg/L	1.1	1.7	1.3	1.4	1.9	1.6	1.2	1.5	1.4	1.3	1.3	1.3	0.8	1.4	1.1	1.2	1.4	1.3
PART P	µM	0.18	0.62	0.39	0.51	1.19	0.72	0.40	1.01	0.67	0.25	0.29	0.27	0.08	0.22	0.14	0.23	0.33	0.28
POC	µM	14.6	50.5	31.7	36.7	90.2	49.2	33.9	67.6	53.0	15.3	31.6	24.5	13.2	29.9	18.9	24.4	33.8	28.4
PON	µM	1.68	9.74	4.88	5.57	14.10	7.87	4.12	10.34	7.95	2.19	4.74	3.60	1.51	3.70	2.68	3.57	4.75	3.96
TDN	µM	6.5	17.5	11.9	21.3	31.6	26.8	7.2	31.8	18.6	8.4	10.9	9.4	8.6	17.1	11.5	6.8	14.2	10.1
TDP	µM	0.40	1.15	0.75	1.25	1.93	1.48	0.54	1.85	1.22	0.45	0.48	0.46	0.44	0.89	0.62	0.40	1.11	0.64
TSS	mg/L	0.4	6.3	2.2	2.2	7.4	4.0	3.0	6.9	5.2	0.3	1.0	0.6	0.1	0.5	0.3	0.4	3.3	1.4
Urea	µM	0.50	1.83	1.13	0.95	2.53	1.77	0.30	2.43	1.18	0.87	1.31	1.09	0.35	3.17	1.76	0.50	8.58	3.42
Plankton																			
Total Phytoplankton	Mcell/L		3.35			8.74			4.04			2.51			2.11			2.57	
Centric diatoms	Mcell/L		1.16			1.93			2.37			0.82			0.06			0.66	
Alexandrium tamarense	Mcell/L		NP			NP			NP			NP			NP			NP	
Phaeocystis pouchetti	Mcell/L		NP			NP			NP			NP			NP			NP	
Pseudo-nitzschia sp	Mcell/L		4.71E-03			2.30E-05			1.33E-05			NP			6.16E-04			3.14E-03	
Total Zooplankton	#/m^3		61087			31298			42999			36943			50962			66487	

NP - Not Present

TABLE 3-6
Semi-Annual Data Summary Table
Event W9615 (10/30/96)
Nearfield Survey

		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
Physical				
Chlorophyll a	µg/L	0.25	3.86	1.85
Salinity	psu	30.1	31.7	31.0
Sigma_T	kg/m^3	22.9	24.1	23.6
Temperature	°C	11.3	11.8	11.5
Transmissivity	m-1	0.95	2.35	1.54
Nutrients				
NH_4	µM	0.12	7.54	1.51
NO_2	µM	0.20	0.58	0.35
$NO_2 + NO_3$	µM	0.3	5.4	2.3
PO_4	µM	0.49	1.04	0.66
SIO_4	µM	0.3	10.4	4.7
Phaeopigment	µg/L	0.04	0.72	0.32
DO				
Concentration	mg/l	7.9	9.1	8.6
Saturation	%	89%	101%	96%
Productivity				
Alpha	see text	0.06	0.15	0.09
Areal Production	$mgC/m^2/d$	226.6	498.4	362.5
Pmax	see text	17.7	61.2	34.6
Respiration	µmol/h	0.03	0.13	0.10
Water Column				
BIOSI	µM	1.8	3.8	3.2
DOC	mg/L	1.0	1.4	1.2
PART P	µM	0.08	0.32	0.24
POC	µM	9.5	50.2	29.4
PON	µM	1.17	6.12	4.25
TDN	µM	12.5	27.8	19.1
TDP	µM	0.59	1.14	0.77
TSS	mg/L	0.2	3.4	1.3
Urea	µM	1.01	1.69	1.35
Plankton				
Total Phytoplankton	Mcell/L		1.18	
Centric diatoms	Mcell/L		0.19	
Alexandrium tamarense	Mcell/L		NP	
Phaeocystis pouchetii	Mcell/L		NP	
Pseudo-nitzschia sp	Mcell/L		1.20E-04	
Total Zooplankton	$\#/m^3$		51103	

NP - Not Present

TABLE 3-7
Semi-Annual Data Summary Table
Event W9616 (11/18/96 - 11/19/96)
Nearfield Survey

Region		Nearfield			Boundary		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg
Physical							
Chlorophyll a	µg/L	0.00	1.73	0.74	0.00	0.75	0.44
Salinity	psu	31.0	32.1	31.5	31.5	32.0	31.7
Sigma_T	kg/m^3	24.08	24.69	24.31	24.21	24.70	24.41
Temperature	°C	8.33	9.95	9.22	9.59	9.83	9.71
Transmissivity	m-1	1.02	3.31	1.78	0.92	1.03	0.99
Nutrients							
NH_4	µM	0.01	5.67	0.66	0.04	0.14	0.08
NO_2	µM	0.18	0.55	0.29	0.16	0.25	0.21
$NO_2 + NO_3$	µM	0.08	8.47	4.45	3.21	6.83	4.50
PO_4	µM	0.52	1.24	0.83	0.70	1.02	0.82
SIO_4	µM	4.14	12.43	6.72	3.57	8.29	5.43
Phaeopigment	µg/L	0.01	0.36	0.13			
DO							
Concentration	mg/l	7.59	9.61	8.94	8.36	9.36	8.96
Saturation	%	82%	100%	95%	90%	101%	97%
Productivity							
Alpha	see text	0.04	0.19	0.10			
Areal Production	mgC/m^2/d	95.82	432.81	264.31			
Pmax	see text	8.23	27.31	15.75			
Respiration	µmol/h	0.03	0.10	0.07			
Water Column							
BIOSI	µM	2.54	8.48	4.18	1.69	2.37	2.06
DOC	mg/L	0.93	1.15	1.01	0.86	0.93	0.90
PART P	µM	0.20	0.43	0.29	0.13	0.22	0.17
POC	µM	17.84	37.99	26.33			
PON	µM	1.71	5.51	3.34			
TDN	µM	10.91	27.39	15.68	16.17	19.88	18.04
TDP	µM	0.87	1.28	1.02	0.91	1.09	0.98
TSS	mg/L	1.26	6.29	2.69	0.93	1.56	1.18
Urea	µM	0.65	2.11	1.38			
Plankton							
Total Phytoplankton	Mcell/L		2.43				
Centric diatoms	Mcell/L		0.65				
Alexandrium tamarense	Mcell/L		NP				
Phaeocystis pouchetii	Mcell/L		NP				
Pseudo-nitzschia sp	Mcell/L		1.47E-05				
Total Zooplankton	#/m^3		11862				

NP - Not Present

TABLE 3-8
Semi-Annual Data Summary Table
Event W9617 (12/17/96)
Nearfield Survey

Region		Nearfield			Farfield								
					Harbor			Coastal			Offshore		
Parameter	Unit	Min	Max	Avg									
Physical													
Chlorophyll a	µg/L	0.00	0.87	0.31	0.37	0.59	0.48	0.25	0.82	0.57	0.00	1.05	0.54
Salinity	psu	29.4	31.9	30.8	28.8	29.7	29.4	30.3	31.1	30.8	30.9	31.9	31.3
Sigma_T	kg/m^3	23.1	24.8	24.07	22.60	23.34	23.07	23.78	24.33	24.11	24.17	24.82	24.47
Temperature	°C	6.3	8.3	7.01	6.30	6.39	6.34	6.67	6.95	6.82	7.07	7.94	7.46
Transmissivity	m-1	0.97	2.80	1.64	2.58	4.01	3.46	1.31	2.19	1.69	0.74	2.12	1.14
Nutrients													
NH_4	µM	0.33	8.84	2.15	7.95	10.90	9.28	1.45	4.35	2.62	0.19	0.74	0.41
NO_2	µM	0.11	0.61	0.26	0.58	0.67	0.62	0.36	0.51	0.43	0.03	0.30	0.17
$NO_2 + NO_3$	µM	6.8	11.2	7.95	9.96	11.84	10.60	7.76	9.26	8.41	5.99	7.42	6.89
PO_4	µM	0.65	1.23	0.89	1.12	1.26	1.19	0.95	1.13	1.03	0.64	0.90	0.83
SIO_4	µM	6.7	14.3	9.48	14.01	18.85	15.65	8.76	11.63	9.89	4.96	8.83	7.44
Phaeopigment	µg/L	0.12	0.60	0.27	0.36	0.79	0.61				0.04	0.63	0.22
DO													
Concentration	mg/l	8.4	9.9	9.51	6.71	7.44	6.97	9.94	10.38	10.14	9.13	9.86	9.58
Saturation	%	88%	97%	96%	66%	73%	68%	100%	103%	102%	95%	100%	98%
Productivity													
Alpha	see text	0.01	0.02	0.02									
Areal Production	mgC/m^2/d	36.1	113.4	74.71									
Pmax	see text	1.4	3.1	2.19									
Respiration	µmol/h	0.03	0.10	0.06									
Water Column													
BIOSI	µM	1.5	4.8	2.62	3.76	7.12	5.82				1.69	4.95	2.83
DOC	mg/L	1.0	1.5	1.16	1.32	1.38	1.35				1.04	1.16	1.11
PART P	µM	0.09	0.26	0.16	0.39	0.50	0.45				0.11	0.23	0.15
POC	µM	8.5	22.4	15.60	32.54	42.93	36.98				13.68	17.19	15.19
PON	µM	1.05	2.60	1.77	3.89	4.71	4.27				1.37	2.11	1.77
TDN	µM	14.8	36.3	21.13	34.02	40.97	36.36				15.91	19.68	17.20
TDP	µM	0.83	1.32	0.99	1.16	1.46	1.28				0.87	0.94	0.91
TSS	mg/L	1.2	4.9	2.60	5.67	7.74	6.71				1.29	5.97	2.89
Urea	µM	0.68	1.53	1.03	1.68	3.33	2.50				1.17	1.57	1.37
Plankton													
Total Phytoplankton	Mcell/L		0.35			0.57						0.39	
Centric diatoms	Mcell/L		0.02			0.04						0.02	
Alexandrium tamarense	Mcell/L		NP			NP						NP	
Phaeocystis pouchetii	Mcell/L		NP			NP						NP	
Pseudo-nitzschia sp	Mcell/L		1.37E-05			NP						NP	
Total Zooplankton	#/m^3		13763			2524						27148	

NP - Not Present

4.0 RESULTS OF WATER COLUMN MEASUREMENTS

The timing of the annual setup and breakdown of vertical stratification in the water column is an important determinant of water quality, primarily because of the trend towards continuously decreasing DO and increasing dissolved nutrients in bottom water during the summer and early fall. These trends in DO and nutrient concentrations result from in-situ processes and terminate with the physical breakdown in stratification in the fall from cooling surface water and wind-driven mixing.

The summer pycnocline, defined as a shallow water depth interval over which density increases rapidly, is caused by a combination of freshwater input from riverine discharges and warming of surface water relative to bottom water during the spring and summer. Above the pycnocline the surface water layer is well-mixed, and below the pycnocline density tends to gradually increase to the bottom. For the purposes of this report, strong vertical stratification will be defined by the presence of a pycnocline with a density (σ_t) gradient of greater than 1.0 kgm^{-1} over a relatively narrow depth range (~10 m).

Two of the eight surveys conducted during the semi-annual period were combined nearfield/farfield surveys (W9611, W9614). While the system was strongly stratified during W9611 (mid-August), water column stratification ended by W9614 in early October (see Section 4.1). Data from these surveys were evaluated for trends in regional water masses within Boston Harbor, Massachusetts Bay, and Cape Cod Bay. The characteristics of regional surface water properties were evaluated using contour plots of surface water parameters, derived from the A (surface) water sample. Classifying data by region allowed comparison of the horizontal distribution of water mass properties over the farfield area.

The vertical distribution of water column parameters is presented in the following sections along three farfield transects in the farfield survey area, and one transect across the nearfield (see Figure 1-3 for transect locations). Examining data trends along transects provides a three-dimensional perspective of water column conditions during each survey. Nearfield surveys (W9610-W9617) were conducted more frequently than farfield surveys, allowing better temporal resolution of the changes in water column parameters and breakdown of stratification, especially when combined with continuous monitoring data provided by the USGS. Vertical structure in nearfield data is also examined by comparing surface and bottom water concentrations (A and E depths), and by plotting individual parameters with depth in the water column.

Results presented in this section were organized by the type of data. Physical data, including temperature, salinity, density, and beam attenuation are presented in Section 4.1. Nutrient data results are discussed in Section 4.2, chlorophyll *a* in Section 4.3, and dissolved oxygen in Section 4.4. Finally, a summary of

the major results of water column measurements (excepting biological measurements) are provided in Section 4.5.

4.1 Physical Characteristics

4.1.1 Horizontal Distribution

During the August combined nearfield/farfield survey (W9611), sea surface temperatures were between 16°C and 20°C, with coolest temperatures reported in the near-coastal region off Boston Harbor (Figure 4-1; see Appendix B for a complete set of contour plots). The cooler coastal water may have been the result of onshore advection and upwelling of colder bottom waters during August, which was also suggested by a drop in bottom temperatures (from around 8.75°C to 7.5°C) in the USGS mooring record (Figure 4-2). Surface salinity in late August ranged between 30.2 and 31.1 PSU, with slightly lower salinity in the innermost harbor station and off Cape Ann. The slightly elevated surface salinity in the coastal region was also suggestive of the occurrence of upwelling around the time of the survey (Figure 4-3).

By early October (W9614), regional surface temperatures had decreased from August, with the warmest surface temperatures in Cape Cod Bay (14-15°C), and cooler temperatures in northern Massachusetts Bay (12-14°C). Surface salinity exceeded 31 PSU at most stations, except for Boston Harbor and adjacent coastal stations. The minimum surface water salinity (28.1 PSU) was measured at the inner harbor station F30, which is proximate to the mouth of the Charles and Mystic Rivers. River discharge data for the Charles and Merrimack Rivers suggest only a modest effect on Massachusetts Bay salinities during September (Figure 4-4), followed by more notable influences in October when the remnants of Hurricane Lili (October 20-21) produced 8 to 12 inches of rainfall (NRCC, 1996), and again during December (Figures 4-2 and 4-4).

4.1.2 Vertical Distribution

Vertical cast data and cross-sections of west to east transects (located in Figure 1-3) in Massachusetts Bay illustrate the vertical distribution of physical characteristics within the water column. In mid-late August (W9611), density data indicated that the water column was strongly stratified in all regions of Massachusetts and Cape Cod Bay, and weakly stratified in Boston Harbor (Figure 4-5). Transect data also show the depth of the pycnocline at roughly 20m (Figure 4-6). A complete set of transect plots for water properties is provided in Appendix C.

The summer stratification was primarily a function of water temperature, which ranged from 4°C in bottom water to >19°C in surface water along the farfield transects (Figure 4-7). The salinity distribution also demonstrated the strong water column stratification in August, ranging from 30.5 PSU in surface

water, to >32 PSU in the bottom water of the offshore-boundary regions (Figure 4-8). By the October survey (W9614), density data indicated that substantial mixing had occurred in the water column (Figure 4-9).

The high-frequency measurements from the nearfield also demonstrated strong stratification during August (Figures 4-10 through 4-12). The passage of Hurricane Eduoard on September 2 appeared to cause a substantial erosion of the pycnocline (survey 12 in Figures 4-10a through c), especially at the more shallow inshore stations (see vertical profile for W9612 in Figure 4-11; Figure 4-12). While Hurricane Fran (September 6-9) also had a modest affect on water column structure (additional bottom temperature rise in Figure 4-2), the effects from the remnants of Pacific Hurricane Fausto on September 17th appeared to produce a temporary breakdown of the pycnocline (note convergence of surface and bottom temperature and salinity in Figure 4-2). The pycnocline appeared to re-establish somewhat by the end of September, but complete mixing was evident by early October (Figures 4-10 and 4-11).

Vertical structure in the water column after early October was due to a salinity gradient, as isothermal temperatures were evident throughout the nearfield (Figures 4-2 and 4-13). Substantial reductions in surface water salinity were evident during late October and December (Figure 4-2), coincidental with high rainfall and river discharge events (Figure 4-4).

4.1.3 Transmissometer Results

Profiles of water column beam attenuation were determined on each CTD cast at all nearfield and farfield stations. The transmissometer determines beam attenuation by measuring the percent transmission of light over a given path length in the water. Given that light transmission decays exponentially with beam attenuation and path length (which varies between instruments), the beam attenuation coefficient is computed for a standardized path length of 1 meter.

The beam attenuation coefficient is related to the particulate concentration in the water column. The two possible sources of particles in coastal waters are biogenic material (plankton or organic detritus), or suspended sediment. To evaluate the contribution of biogenic material in the total particulate matter, beam attenuation was compared to fluorescence data. Non-biogenic material may originate from suspended matter in river discharge and coastal runoff, or from resuspension of bottom sediment.

Transmissometer data from the combined nearfield/farfield surveys documented an inshore/offshore gradient (Figure 4-14). In August (W9611), the highest surface water beam attenuation (3.5 m^{-1}) was measured at harbor station F30 (likely associated with a phytoplankton bloom, Section 4.3), and the lowest (0.8 m^{-1}) was in Cape Cod Bay (Appendix B). The nearfield, offshore, and boundary regions showed little variation from approximately 1 m^{-1}. The distribution was similar during the early October survey

(W9614), although the nearfield and coastal regions showed higher attenuation both horizontally and vertically (Figure 4-15; Appendix C).

One consistent observation in all transects was the existence of clearer water at mid-depth than in the surface and near-bottom layers. While the beam attenuation in the surface layer was likely due to phytoplankton biomass, the low transmissivity of near-bottom water suggested a benthic boundary condition related to particulate settling or resuspension.

4.2 Nutrients

Regional and nearfield nutrient data during the second semi-annual period of 1996 demonstrate the typical conclusion of the seasonal nutrient cycle in the Massachusetts Bay system. During the stratified period, minimum surface nutrient concentrations occurred in surface water (due to photosynthetic uptake which exceeded resupply), whereas maximum concentrations occurred in the bottom water (due to nutrient regeneration). The response of nutrient-limited phytoplankton to the release of nutrients from the stratified bottom layer as stratification breaks down typically produces the fall bloom. The major events for the latter part of 1996 are summarized in the following sections.

Nutrient data were preliminarily analyzed using x/y plots of nutrient relationships (Appendix D). Nutrient data were organized for each survey showing the following relationships for regional areas (Figure 1-2): nutrients vs. depth, nutrient:nutrient relationships; and nutrient:salinity relationships. To parallel the analysis of the physical characteristics, surface water contour maps (Appendix B) and vertical cross sections (Appendix C) were also created using nutrient data.

4.2.1 Horizontal Distribution

Boston Harbor, followed by the coastal region, had the highest regional concentrations of all measured nutrients during the second semi-annual period. Results from the first combined farfield/nearfield survey in late August (W9611) showed that, with the exception of the harbor, surface waters across all regions were nutrient-depleted. Surface DIN concentrations ranged from 0.7 to 3.6 μM in the harbor and coastal waters, and typically less than 0.2 μM elsewhere (Figure 4-16). Similar distributions were found for other surface nutrient concentrations (Appendix B). Somewhat elevated surface concentrations of silicate and phosphate were found off Cape Ann, suggesting possible advection of nutrient-rich surface water from the boundary region (Figure 4-17; Appendix B).

By the October survey (W9614), surface water dissolved nutrient concentrations in the offshore and boundary stations remained relatively depleted of nutrients. However, DIN concentrations in the harbor and coastal waters had increased dramatically compared to August (4.9 to 17.6 μM, Figure 4-18). Silicate concentrations also showed a large increase in the harbor and coastal stations, with a general (though less

dramatic) increase system-wide (Appendix B). While the relative increase in harbor nutrients may have been partially due to reduced phytoplankton demand (see Section 4.3), nutrient increases may have also been related to increased nutrient delivery as evidenced by the parallel increase in freshwater input (Section 4.1). In contrast, nutrient:salinity plots from the August combined survey (W9611) showed a positive relationship between salinity and DIN, PO_4 and SiO_4 (Figure 4-19a; Appendix D), a result of the more saline, nutrient-rich bottom waters during the stratified period .

During the October combined survey (W9614), the nutrient:salinity relationship held for the more seaward stations, but increased nutrient concentrations were also apparent in less saline harbor and coastal water (Figure 4-19b). By the December survey, when the salinity response to riverine discharge was at its peak (Figures 4-3 and 4-4), the association of nutrients and fresher water was fully evident in harbor DIN concentrations which exceeded 20 µM (Figure 4-19c). Nutrient concentrations were vertically uniform at offshore, nearfield, and coastal stations except for N10 and F05, whose surface samples followed the trend seen in the harbor.

The temporally-intensive sampling within the nearfield also demonstrated horizontal trends in surface water nutrient results. Average surface nutrient concentrations for the inner (N10, N11) and outer (N04, N07, N16, and N20) nearfield stations were calculated for surface water samples and plotted for the semi-annual period (Figure 4-20). This approach showed little variation across the nearfield during August, and the more pronounced effect of the September hurricanes on the shallower inshore stations compared to the outer nearfield.

These results also indicate that the early October combined survey (W9614), while higher in nutrients compared with the August combined survey, was actually relatively low in surface nutrients compared with preceding and subsequent events for most parameters. The observed increases likely reflect both nutrient enrichment of surface water from the storm-driven release of bottom nutrients and riverine discharge in late September and October. The lower nutrient concentrations in early October may be indicative of nutrient utilization during the fall bloom (Section 4.3) and perhaps the re-establishment of stratification after Hurricane Fausto. After the seasonal breakdown in stratification in early October, surface nutrient concentrations increased throughout the remainder of the year in the more seaward stations.

4.2.2 Vertical Distribution

During the stratified period (August survey W9611), surface waters were nearly depleted of nutrients while bottom waters showed relatively high concentrations (e.g., NO_3+NO_2 in Figure 4-21; PO_4 and SiO_4 in Appendix C). Bottom water concentrations at offshore and boundary stations reached maximum NO_3+NO_2 concentrations of up to 10 µM compared to <2.0 µM at the surface. Stratification in this system effectively creates a multi-layer water column, with phytoplankton removing dissolved nutrients from the

surface layer, and with loss as organic nutrients through horizontal and vertical transport. In contrast, nutrients regenerated in the bottom water and sediments, which are below the photic zone, accumulate throughout the stratified interval.

By the October combined survey (W9614), surface concentrations remained low, but the coastal influence was evident in the Boston-Nearfield transect (Figure 4-22; Appendix C). Ammonium showed a different trend, with concentrations <0.5 μM throughout the entire water column except near the harbor in both the August and October surveys (Appendix C).

This vertical characterization is further illustrated in the series of depth vs. nutrient concentration plots included in Appendix D. For example, the higher temporal frequency of nearfield sampling showed that dissolved nutrients began to increase at the surface around W9613 in late September (e.g., NO_3+NO_2 in Figures 4-23d). As stated above, this increase was most likely due to the effects of the storm event just prior to the survey which temporarily mixed the water column, transporting nutrients to the surface. Some degree of nutrient depletion at the surface was evident during October (W9614-15, Figure 4-23e and f), after which surface nutrients were abundant during November and December (W9616 and W9617, Figures 4-23g and 4-23h). The utilization of nutrients is examined in subsequent sections with respect to chlorophyll (Section 4.3), and phytoplankton production (Section 5).

4.3 Chlorophyll *a*

4.3.1 Horizontal Distribution

In-situ fluorescence results calibrated to chlorophyll *a* during August (W9611), the first of two combined nearfield/farfield surveys during the reporting period, showed low regional chlorophyll concentrations outside of Boston Harbor (Figure 4-24). Stations outside of the harbor and adjacent coastal waters yielded chlorophyll concentrations less than 1 μgL^{-1}. In contrast, surface concentrations within Boston Harbor ranged from 4.4 μgL^{-1} to 7.6 μgL^{-1} at station F30, with coastal waters near the harbor ranging from roughly 2 to 4 μgL^{-1}.

Chlorophyll data collected during the Boston Harbor Water Quality Monitoring Program ("Harbor Studies Program") show that this survey coincided with the 1996 late-summer chlorophyll maximum in the harbor (D. Taylor, pers. comm.). Peak chlorophyll concentrations in the harbor during the second half of August ranged from 10 to 20 μgL^{-1}, with the highest concentrations found in the inner harbor. Following this summertime peak, the Harbor Studies Program data indicate that chlorophyll concentrations fell to generally less than 5 μgL^{-1} from September through the end of the year.

Results from the second combined survey in early October (W9614) demonstrated regional chlorophyll maxima in the nearfield, with the highest surface water concentrations off Nahant (7.5-9.3 μgL^{-1}, Figure

4-25). Most stations in the nearfield exceeded 5 μgL^{-1}, with more offshore areas of Massachusetts Bay generally in the 2 to 3 μgL^{-1} range. Lowest concentrations (less than 2 μgL^{-1}) were found in Cape Cod Bay and at the entrance to Boston Harbor. In contrast, Boston Harbor station F31 in Nantasket Roads showed a high concentration of 7.7 μgL^{-1}, one of the few late season maxima found by the Harbor Studies Program.

4.3.2 Vertical Distribution

The three farfield transects (Figure 1-3) were used to examine the vertical distribution of chlorophyll in the water column across regions. The cross sections from late August (W9611) show the influence of the harbor bloom on the near-coastal region, with maximum concentrations of around 4 μgL^{-1} near the surface (Figure 4-26). This mixed layer maximum extended into the western portion of the nearfield. A subsurface chlorophyll maximum was evident in eastern Massachusetts Bay (offshore stations F17 and F07, and in particular boundary stations F28 and F12), where chlorophyll concentrations of 1 to 4 μgL^{-1} were found just below the pycnocline at depths of 15-20m.

Vertical data from the Boston-Nearfield transect during October (W9614) revealed a strong subsurface chlorophyll maximum at depth in the coastal region (Figure 4-27), and perhaps the southern extent of the surface chlorophyll maximum off Nahant evident in Figure 4-25. Subsurface chlorophyll concentrations in excess of 5 μgL^{-1} were also evident at Boundary station F28. Within the nearfield, high levels of chlorophyll were distributed over greater depths, probably associated with the full mixing of the water column.

Sequential vertical chlorophyll results from nearfield surveys showed low concentrations prior to October other than that associated with the August harbor bloom (W9614, Figure 4-28), which affected the western nearfield stations. The development of the fall bloom during late September and early October is evident in results from surveys W9613 and W9614 (Figure 4-29). Results from W9613 suggest that the fall bloom initiated offshore based on the modest chlorophyll maximum documented around N15. The timing of this chlorophyll increase in the surface mixed layer closely followed the storm-driven mixing event. Vertical profiles from the subsequent survey, W9614, showed chlorophyll concentrations greater than 10 μgL^{-1} (maximum value 12.4 μgL^{-1}) at the surface in the central nearfield, and concentrations greater than 2 μgL^{-1} to a depth of 30m throughout most of the transect.

Available data from the WETLabs spectrophotometer, located at a depth of 13.5 meters on the USGS mooring near station N21 in the nearfield (Figure 1-1), provided additional temporal detail on chlorophyll concentrations. The sensor collected data from August through October 2, which were plotted along with survey results for the period (Figure 4-30). Daily average chlorophyll concentrations during August increased from around 1.5 μgL^{-1} in early August to a peak of 4 μgL^{-1} on August 17th, followed by a secondary peak of 3 μgL^{-1} in late August and a gradual decline through the rest of the month. Hourly

peaks during August exceeded 8 μgL^{-1}. Based on comparisons with plots of survey data collected between August 18-23 (W9611), the mid-August WETLabs sensor peak appeared to be associated with the harbor bloom (see Boston-Nearfield transect in Figure 4-26 and nearfield transect from W9611 in Figure 4-28).

The WETLabs data also indicate that the fall bloom originated in the nearfield in mid-September, with incremental steps evident (September 12th and 19th) which may have been produced by release of deeper-water nutrients caused by the hurricanes passing on September 2nd and 9th, and the temporary breakdown of stratification associated with Hurricane Fausto on September 17th. This latter event was followed by a substantial increase in chlorophyll around September 28th, just after survey W9613 and just prior to the end of the WETLabs record. This would suggest that the initiation of the main bloom event preceded the October farfield survey by at least one week.

By late October, chlorophyll concentrations had diminished to less than 1.5 μgL^{-1} throughout the nearfield, with a modest maximum at around 5m around N19 (nearfield transect for W9615 in Figure 4-29). The remaining two nearfield surveys (not shown) resulted in similarly low chlorophyll concentrations, with mid-November maxima of 1.8 μgL^{-1}, and mid-December maxima of 1 μgL^{-1}.

4.4 Dissolved Oxygen

Dissolved oxygen (DO) results have particular significance for this semi-annual reporting period because the seasonal decline in DO reaches the annual minimum just prior to the breakdown of water column stratification in Massachusetts Bay. These annual minima in the bottom waters typically occur in September or October. Since the surface mixed layer typically remains at or above saturation throughout the period, results reported here focus on the bottom layer, first for the farfield (Section 4.4.1) and then in the nearfield (Section 4.4.2), and their relationship to the seasonal changes in water column structure.

4.4.1 Regional Distribution

DO was measured regionally during the two combined farfield/nearfield surveys in August and October, and additionally in Stellwagen Basin (station F12) during the late November survey (W9616). In late August (W9611), average DO in bottom water ranged from 7.9 to 8.8 mgL^{-1} regionally, with the lowest concentrations measured in the harbor, and the highest in Cape Cod Bay (Figure 4-31). Bottom water was under-saturated with respect to DO in all regions due to uptake in the water column and sediments. The highest oxygen saturation in August was found in the harbor (average 94%), and the lowest in the boundary, offshore, and Cape Cod Bay regions.

The range of average DO concentrations during the October farfield survey (7.7-8.4 mgL^{-1}) was only slightly lower than that seen in August. Average DO concentrations increased from August to October in the harbor and coastal regions (Figure 4-31), but continued their seasonal decline in other regions.

Percent DO saturation actually increased in the offshore and boundary regions. The lowest individual DO concentration of the semi-annual reporting period was measured during early October in Cape Cod Bay (5.5 mgL^{-1}, saturation of 66%). It appeared that the temporary breakdown in water column stratification during mid-September resulted in enhanced ventilation of the bottom water prior to the seasonal mixing in early October. The resultant effect seemed to have been a slowing of the rate of oxygen decline in the late stratified period and higher oxygen minima throughout Massachusetts Bay.

4.4.2 Nearfield Distribution

Average nearfield bottom water DO concentrations showed a gradual decline from early August (W9610) to the semi-annual nearfield minima in late September (W9613; Figure 4-32). The minimum individual nearfield DO concentration (7.3 mgL^{-1}) and saturation (84 percent) was measured in early October (W9614). The data indicated that the fall turnover, as demonstrated by the seasonal upward inflection in DO concentration, occurred prior to the early October survey, consistent with physical data reported in Section 4.1. The upward inflection in average bottom water DO saturation seen in early September suggested some re-aeration occurred in the nearfield, however, this re-aeration appeared to be restricted to the shallower inshore stations of the nearfield (Figure 4-33).

4.5 Summary of Stratified Period

Physical Characteristics

- The water column exhibited strong vertical stratification through August of 1996;
- Coastal upwelling may have occurred during the second week of August, as evidenced by surface temperature and salinity distributions;
- A series of hurricanes caused considerable erosion of the pycnocline during September, with a temporary breakdown in stratification evident around the 20th of the month;
- Complete mixing of the water column was initiated by early October (W9614); and
- Substantial influx of fresh water into the Massachusetts Bay system occurred during late October and again during December.

Nutrients

- Surface waters outside of Boston Harbor and adjacent coastal stations were nutrient-depleted during the stratified period, and remained low into October despite the onset of mixing;

- Harbor nutrients increased dramatically from August to October, with further increases noted during December. This was attributed to high algal demand in August which stripped nutrients from the water column, and to potential additional loading from riverine discharge and coastal runoff associated with the series of September storms;

- Nutrient concentrations in the nearfield during early October were low compared with adjacent survey events, likely due to uptake by the fall phytoplankton bloom;

- Nutrient concentrations appeared to be vertically and horizontally uniform in the nearfield and offshore stations by the December survey.

Chlorophyll

- A large phytoplankton bloom during August dominated the harbor and adjacent coastal stations, with maximum chlorophyll concentrations in the harbor of around 7.5 μgL^{-1}. Harbor Studies Program data documented chlorophyll maxima in the harbor in excess of 20 μgL^{-1} during the period;

- Stations beyond the influence of the August harbor bloom had low chlorophyll concentrations (less than 1 μgL^{-1}) except for a subsurface (15 to 20m) chlorophyll maximum noted at the boundary stations;

- A fall bloom was documented in Massachusetts Bay during late September and early October, with surface chlorophyll concentrations ranging from 2 to 12 μgL^{-1}. Cape Cod Bay and Boston Harbor yielded concentrations lower than 2 μgL^{-1}. The Massachusetts Bay bloom appeared to have been initiated by the storm-related temporary breakdown of stratification, and further fueled by the fall turnover;

- Chlorophyll concentrations diminished to less than 2 μgL^{-1} by late October and remained low for the remainder of the year.

Dissolved Oxygen

- The minimum DO concentration (7.3 mgL^{-1}) in the nearfield was measured in both late September and early October surveys (W9613-14);

- Some mitigation of bottom water DO decline appeared to occur during September associated with storm-related ventilation of bottom waters;

- The lowest DO concentration (5.5 mgL^{-1}) and DO saturation (66 percent) of the period was reported in at the bottom in Cape Cod Bay during October;

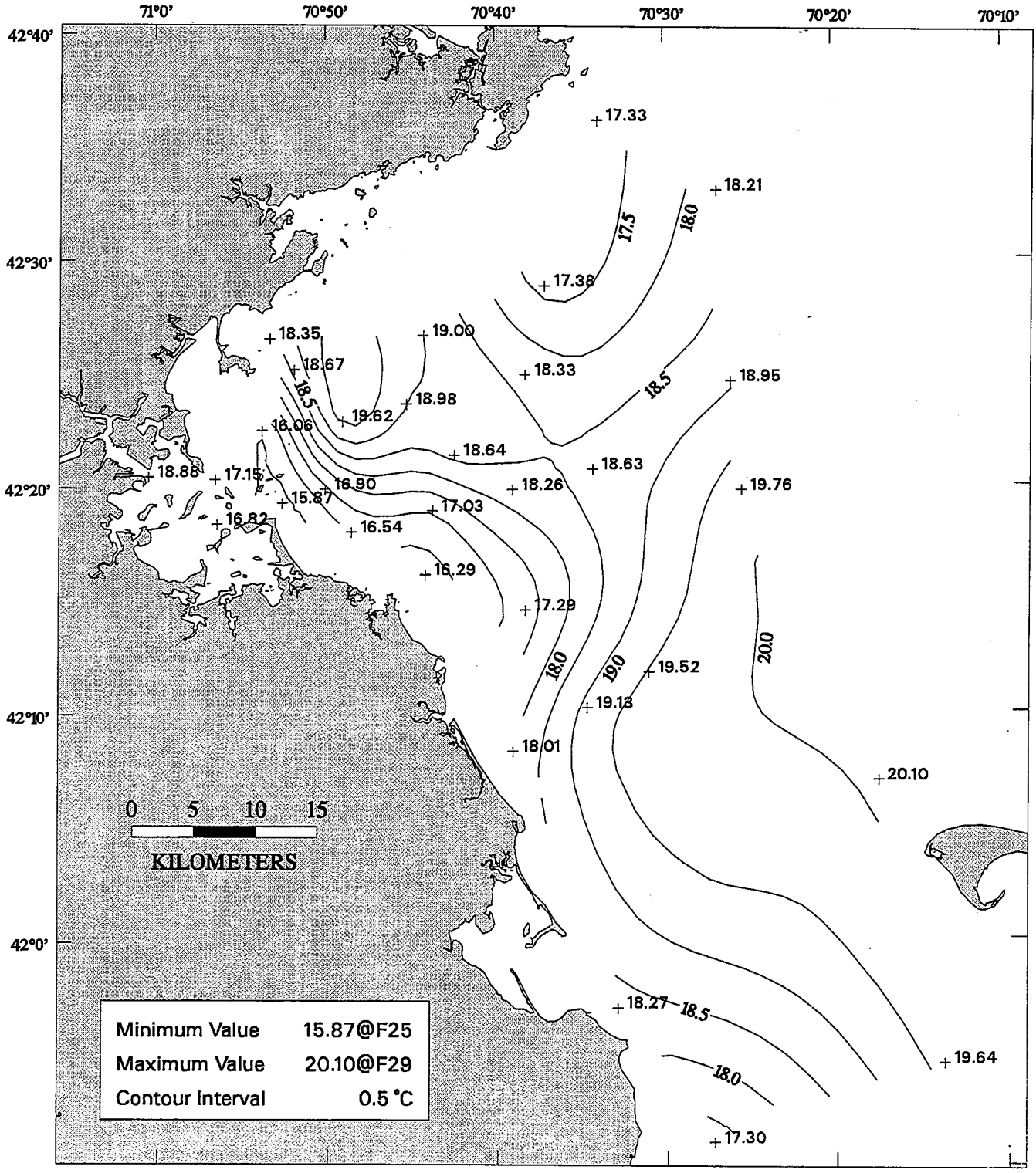


FIGURE 4-1
Surface Water Contour Plot of Temperature (°C) in Late August (W9611)

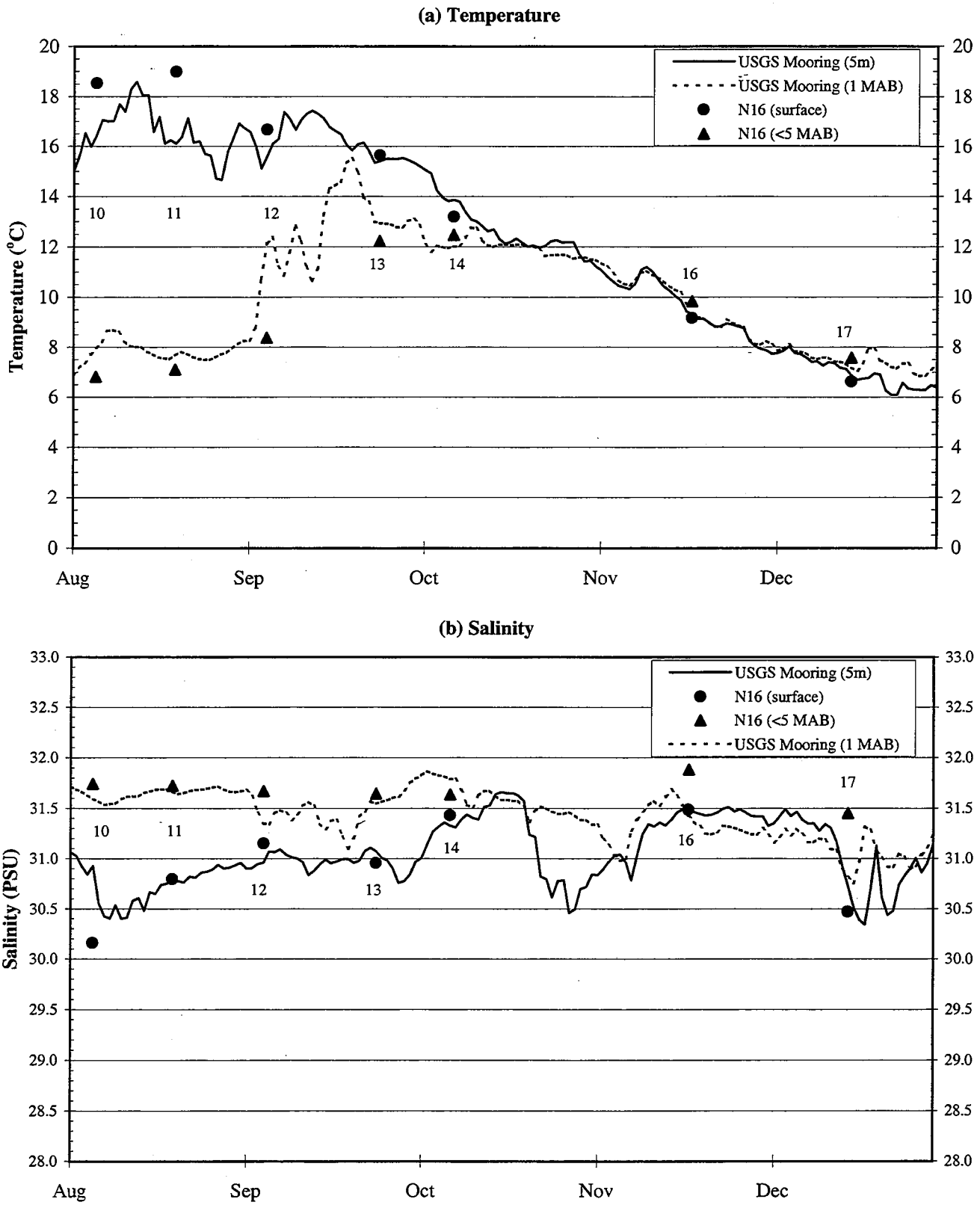


FIGURE 4-2
Moored Temperature and Salinity Sensor Data: August - December, 1996
(MAB = meters above bottom)

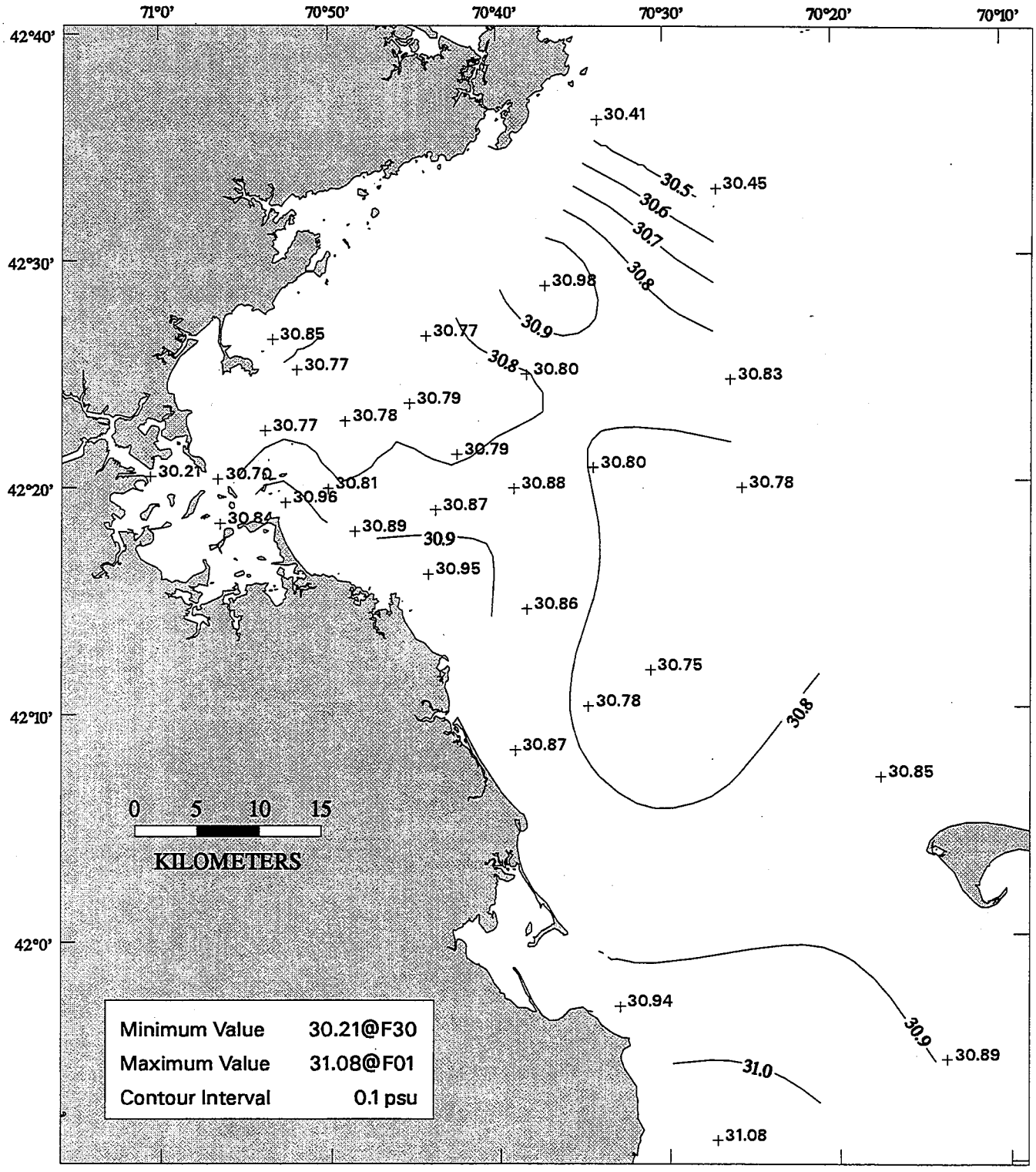


FIGURE 4-3
Surface Water Contour Plot of Salinity (PSU) in Late August (W9611)

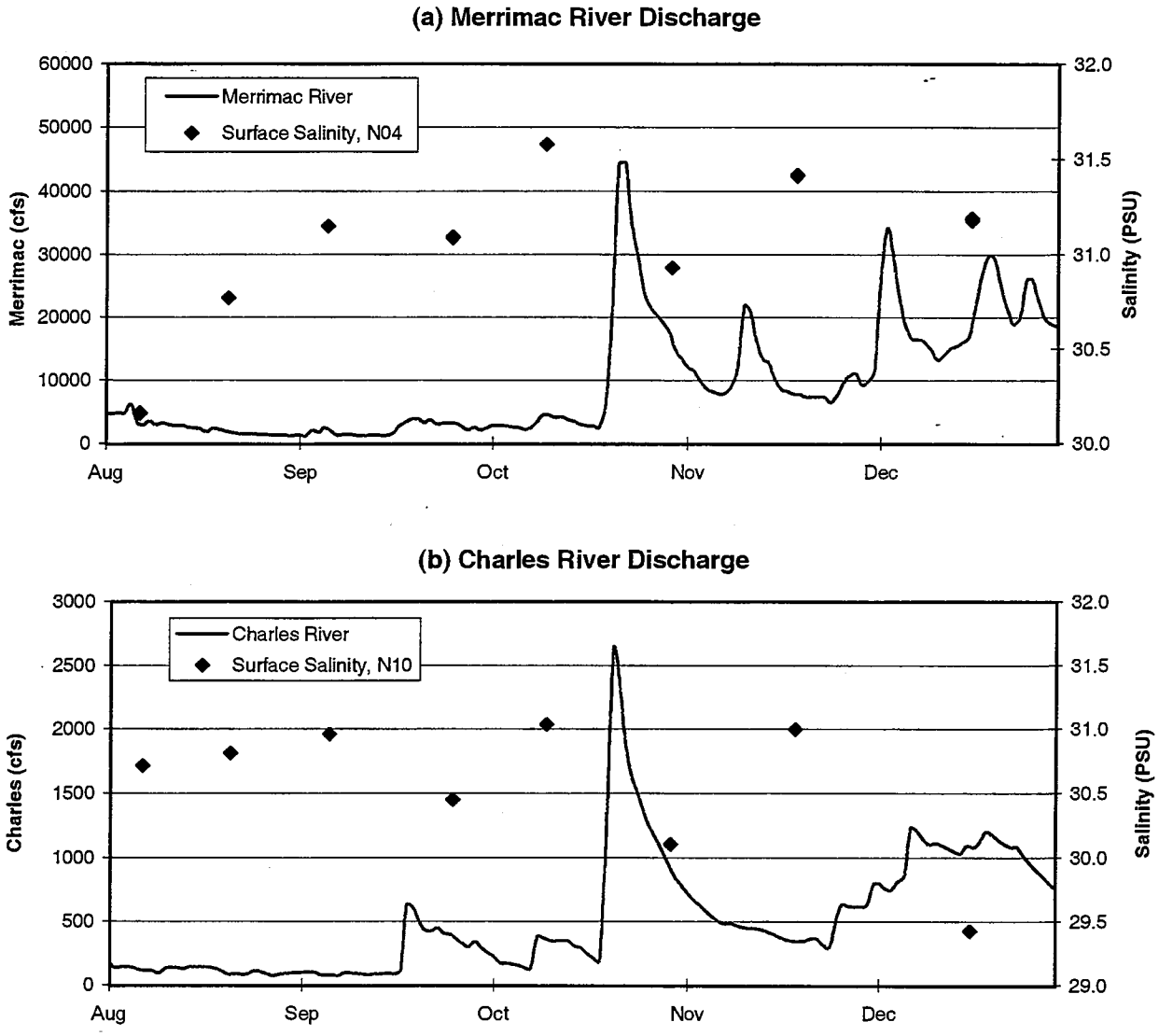


FIGURE 4-4
1996 River Discharge and Surface Salinity at Nearfield Stations N04 (top) and N10 (bottom)
Source: USGS

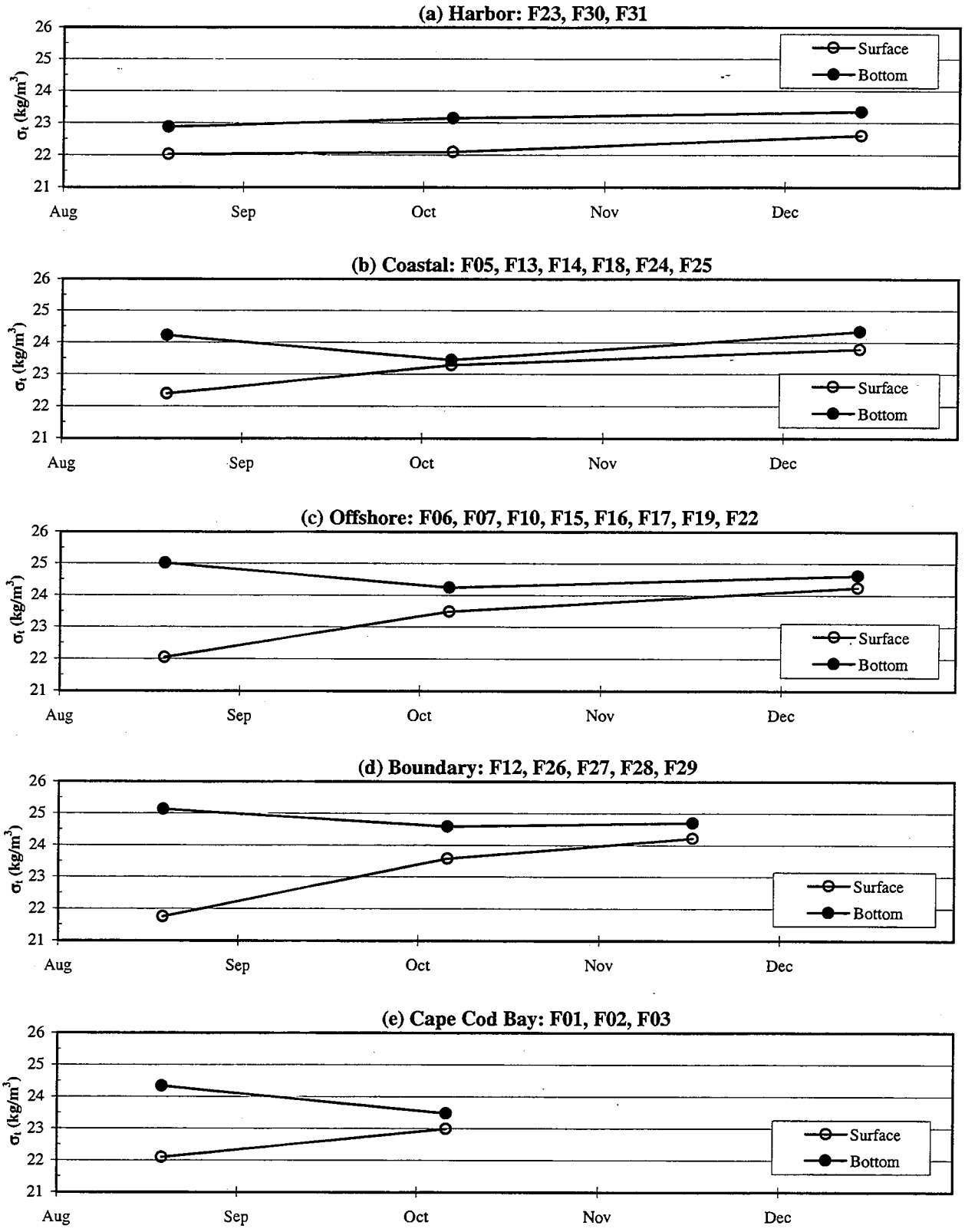


FIGURE 4-5
Time-Series of Average Surface and Bottom Water Density (σ_t) in the Farfield

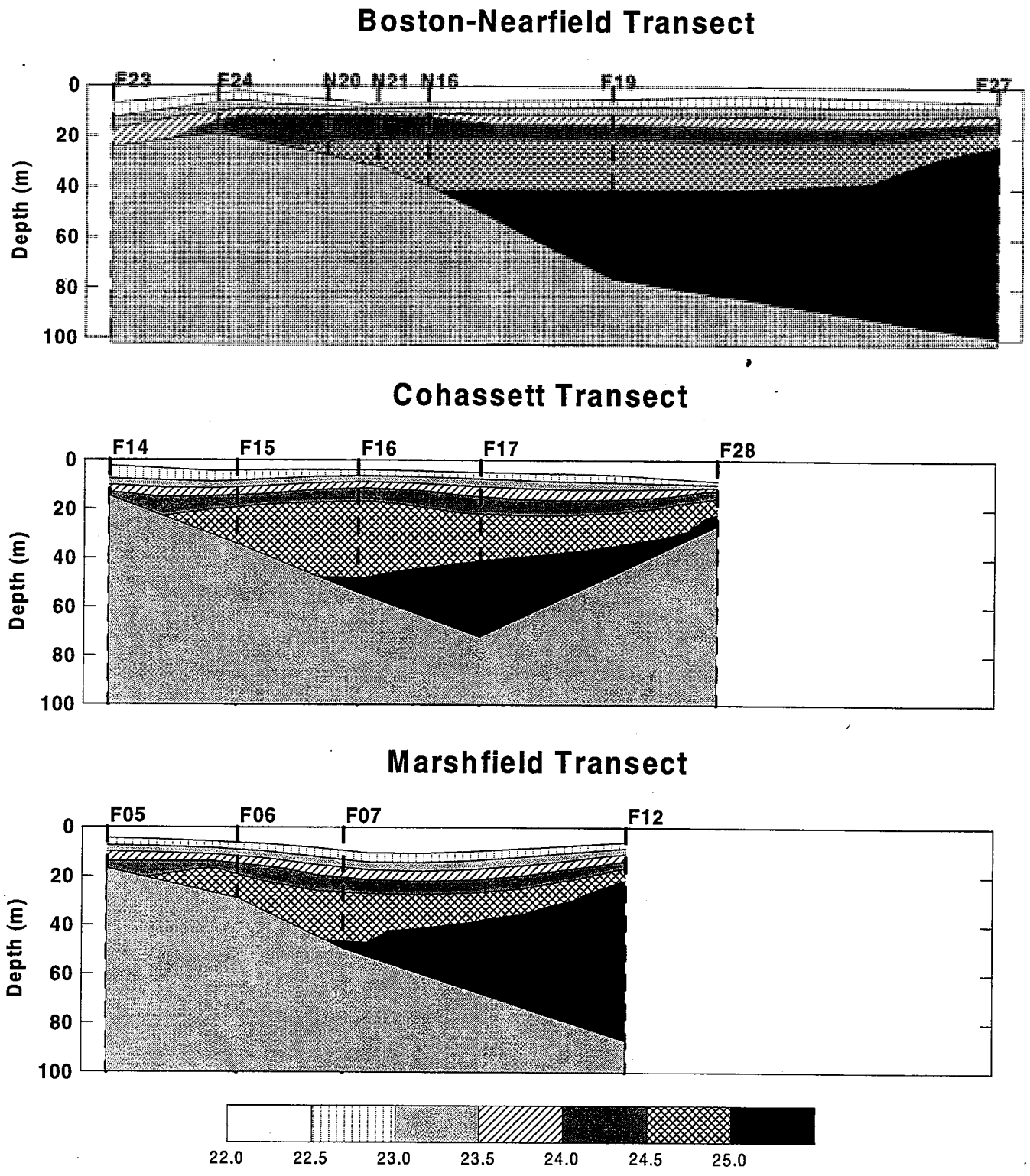


FIGURE 4-6
Density (σ_t) Contours Along Three Farfield Transects in Late August (W9611)

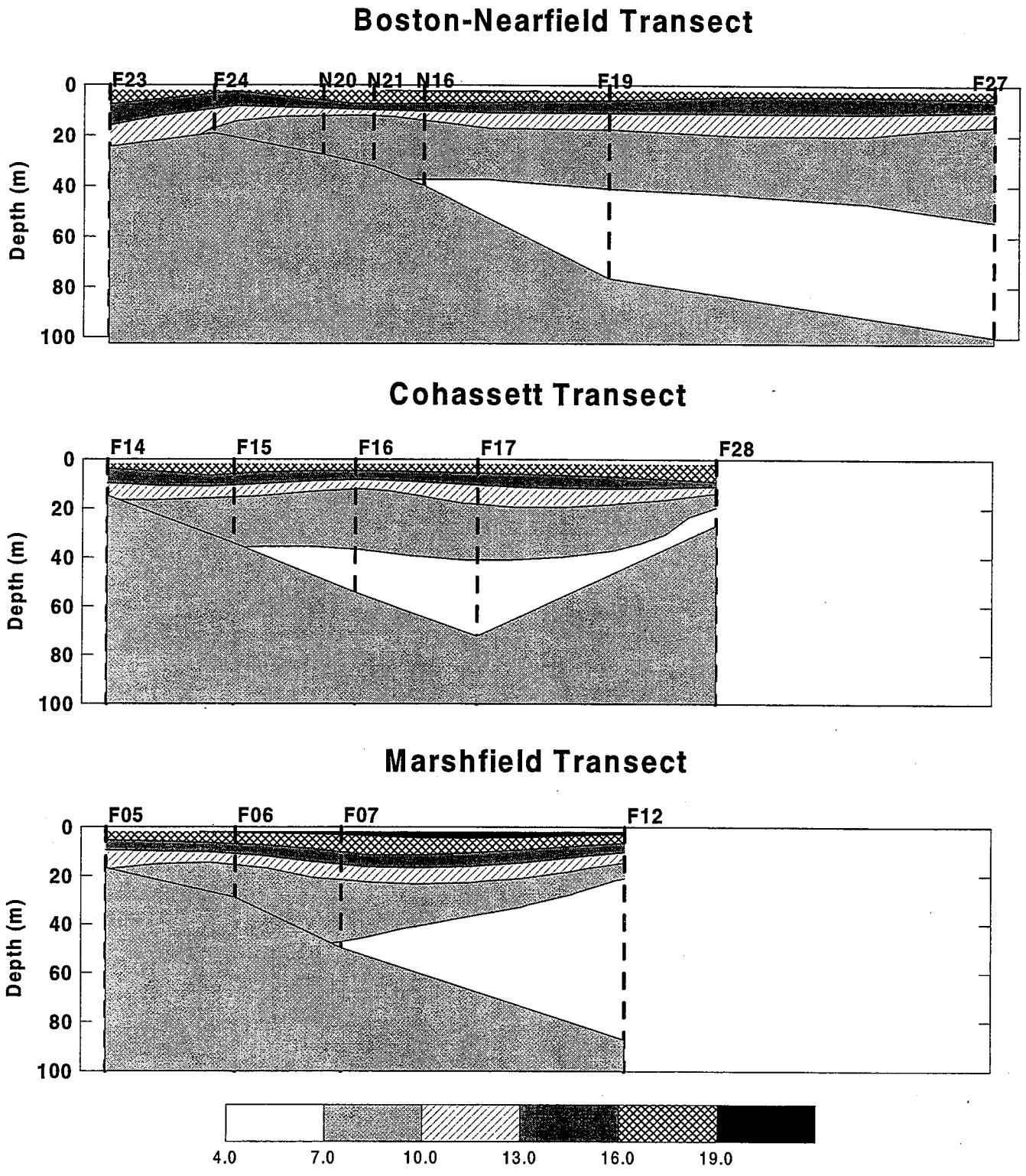


FIGURE 4-7
Temperature (°C) Along Three Farfield Transects in Late August (W9611)

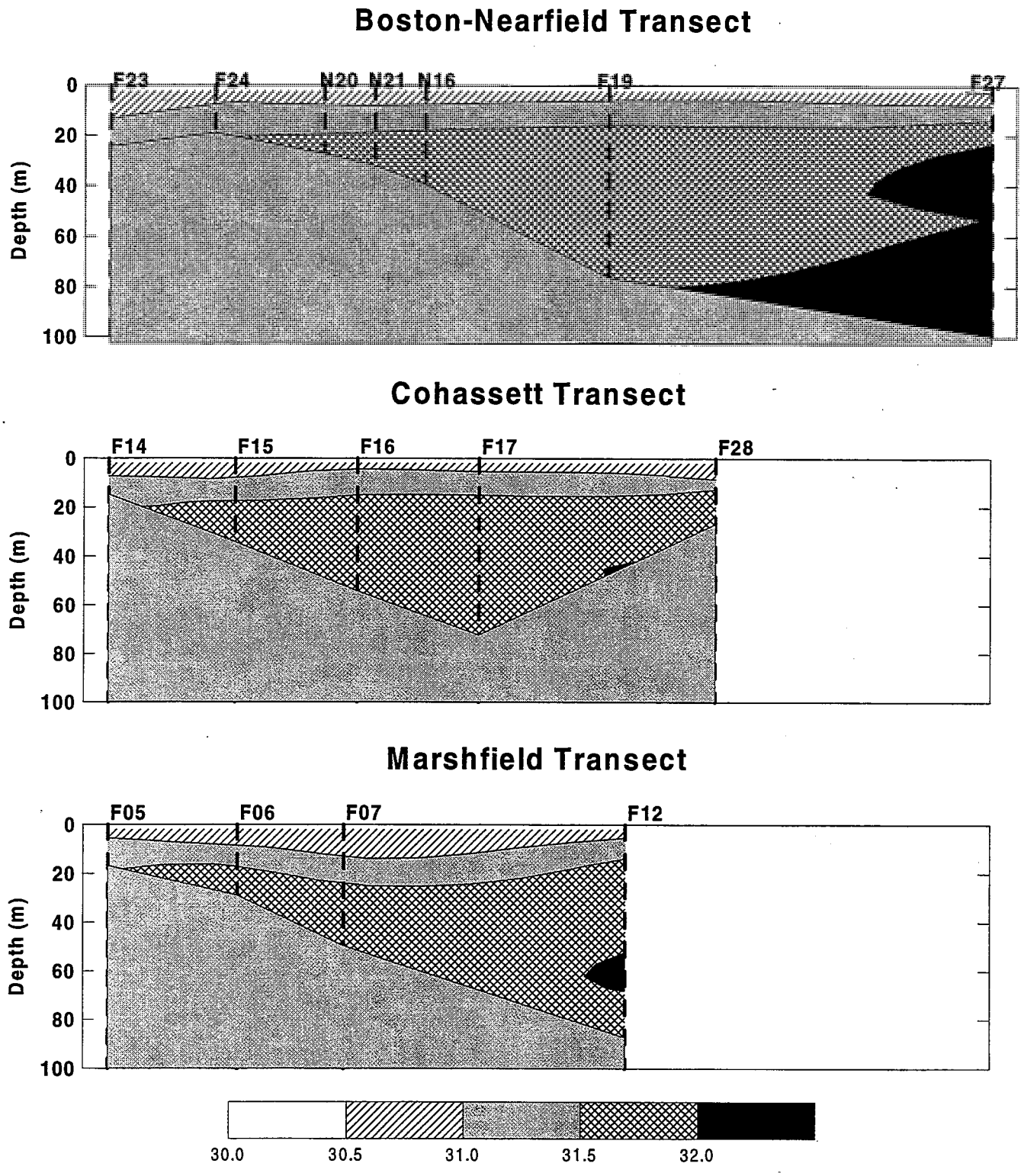


FIGURE 4-8
Salinity (PSU) Along Three Farfield Transects in Late August (W9611)

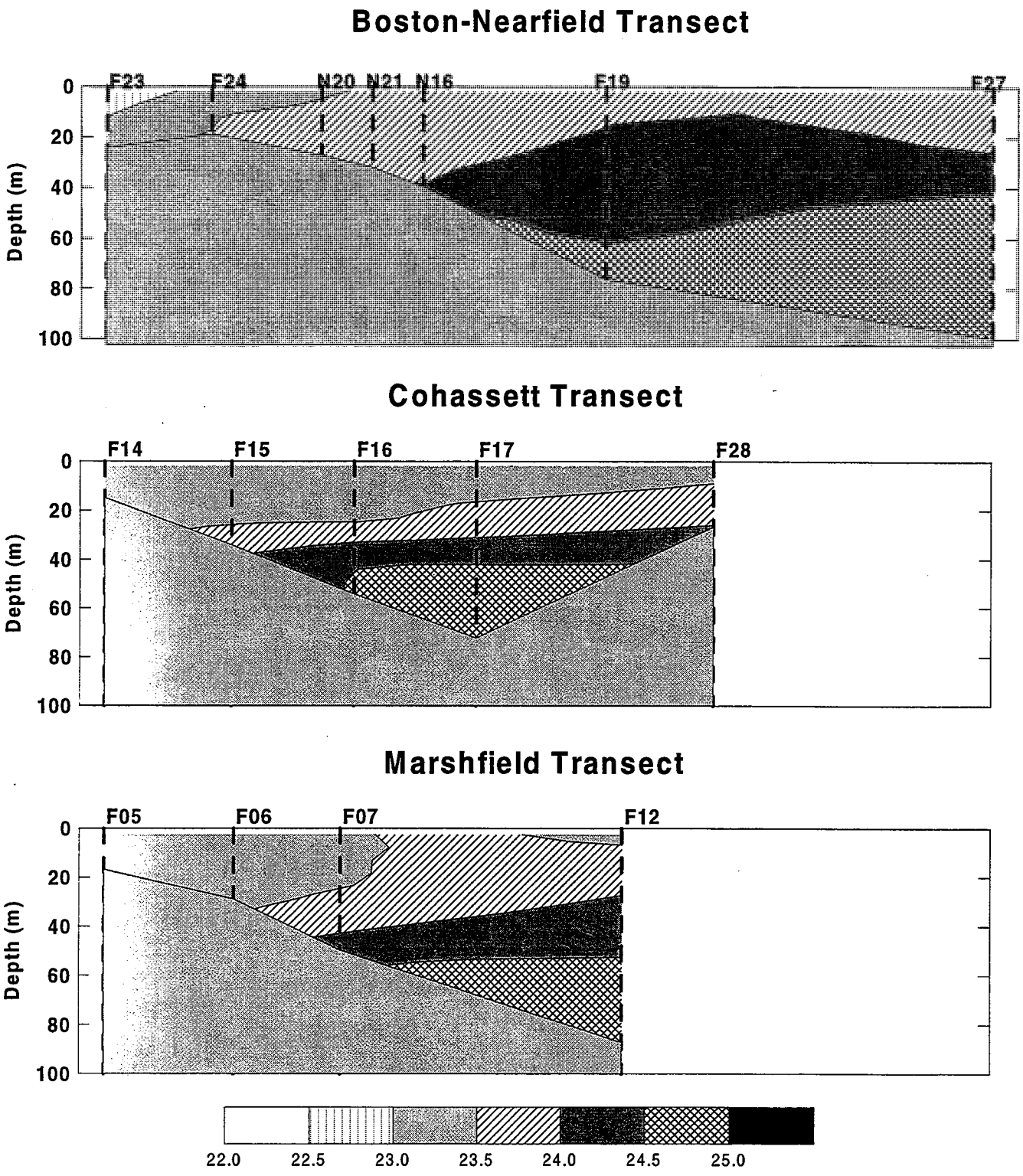


FIGURE 4-9
Density (σ_t) Contours Along Three Farfields Transects in October (W9614)

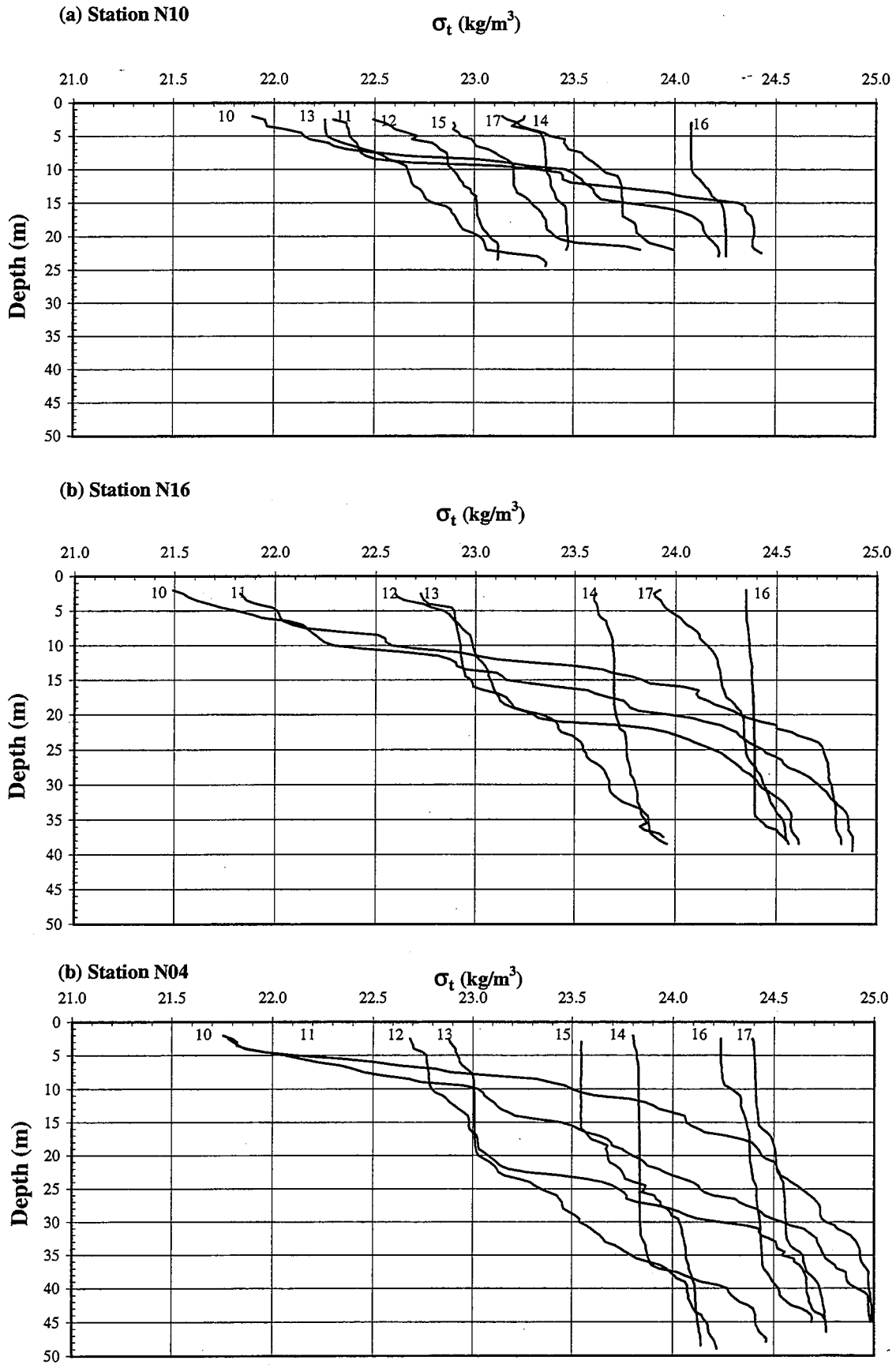


FIGURE 4-10

Density (σ_t) Profiles at Stations N10, N16, and N04

Numbers alongside profiles indicate survey number. Refer to Table 2-1 for survey dates

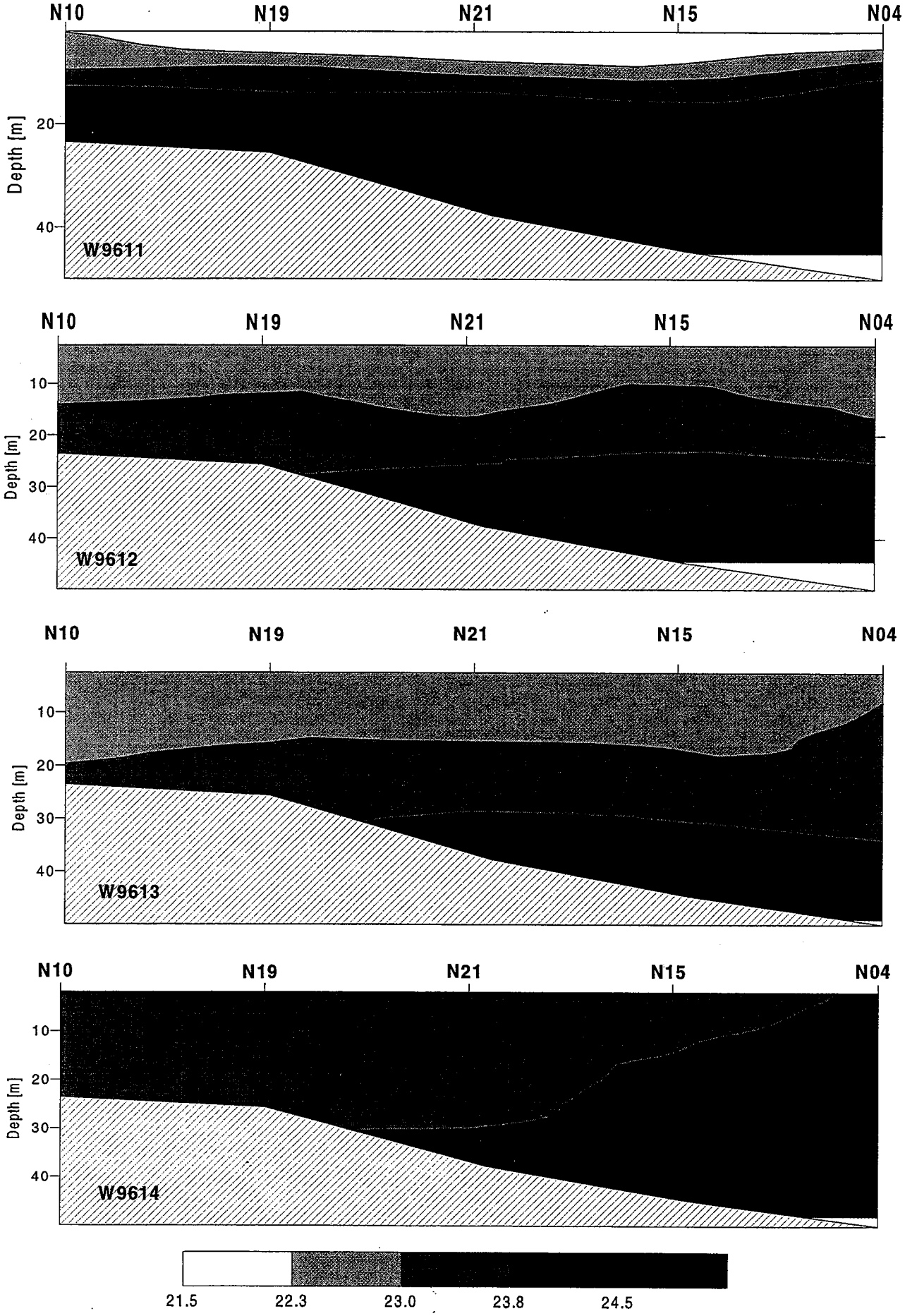


FIGURE 4-11
Density (σ_t) Contours Along Nearfield Transect W9611 - W9614

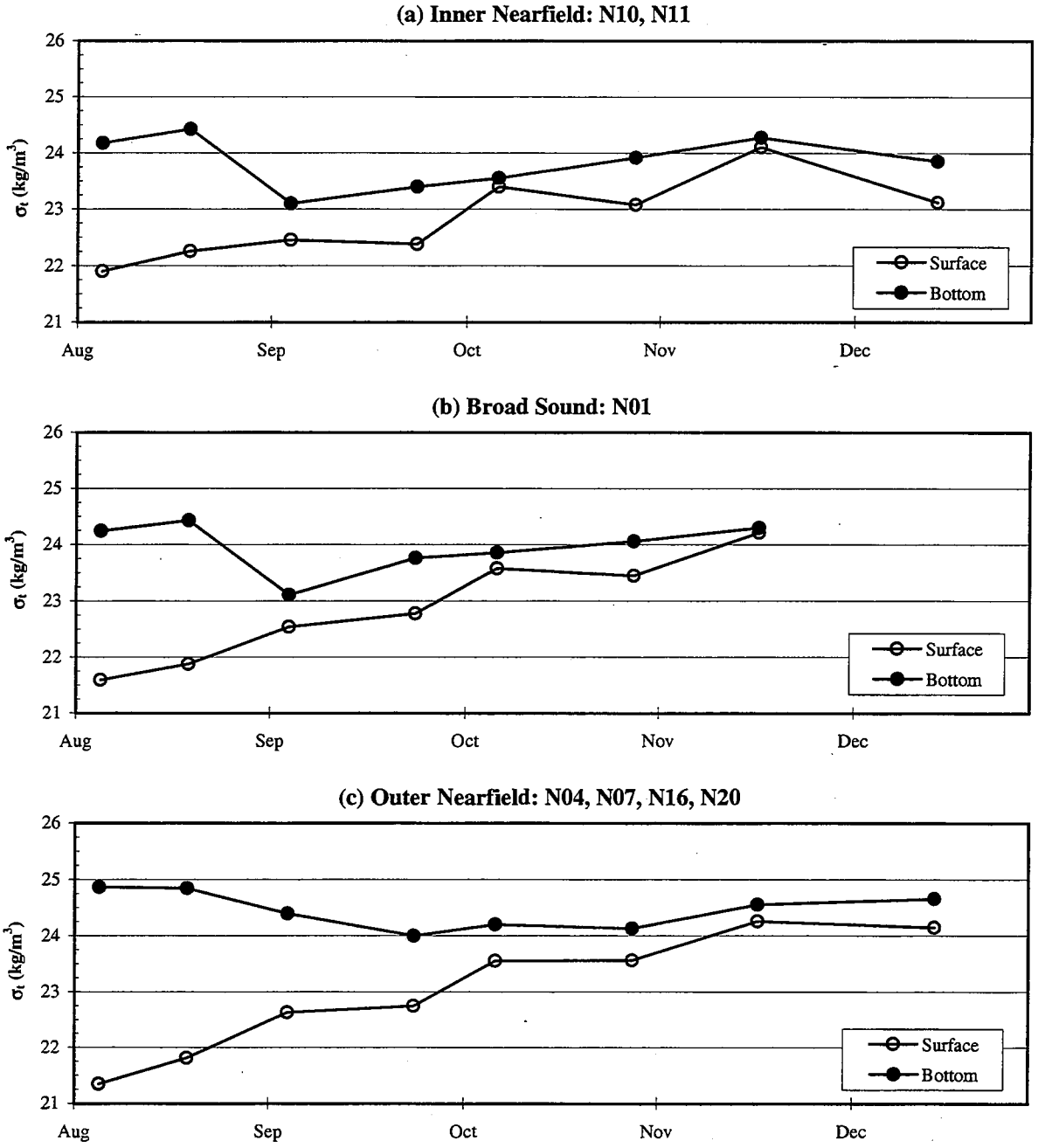


FIGURE 4-12
Time-Series of Average Surface and Bottom Water Density (σ_t) in the Nearfield

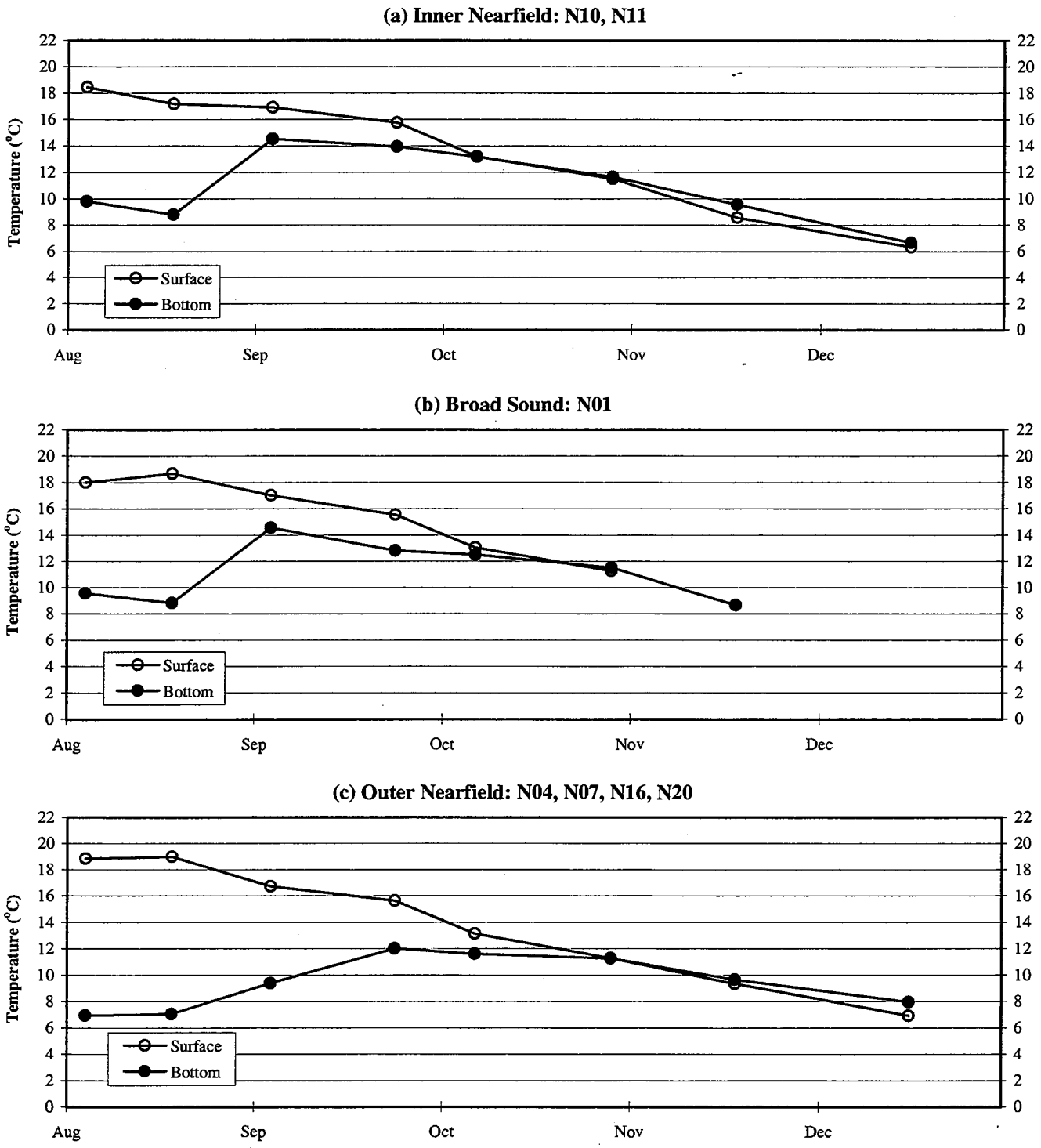


FIGURE 4-13
Time-Series of Average Surface and Bottom Water Temperature in the Nearfield

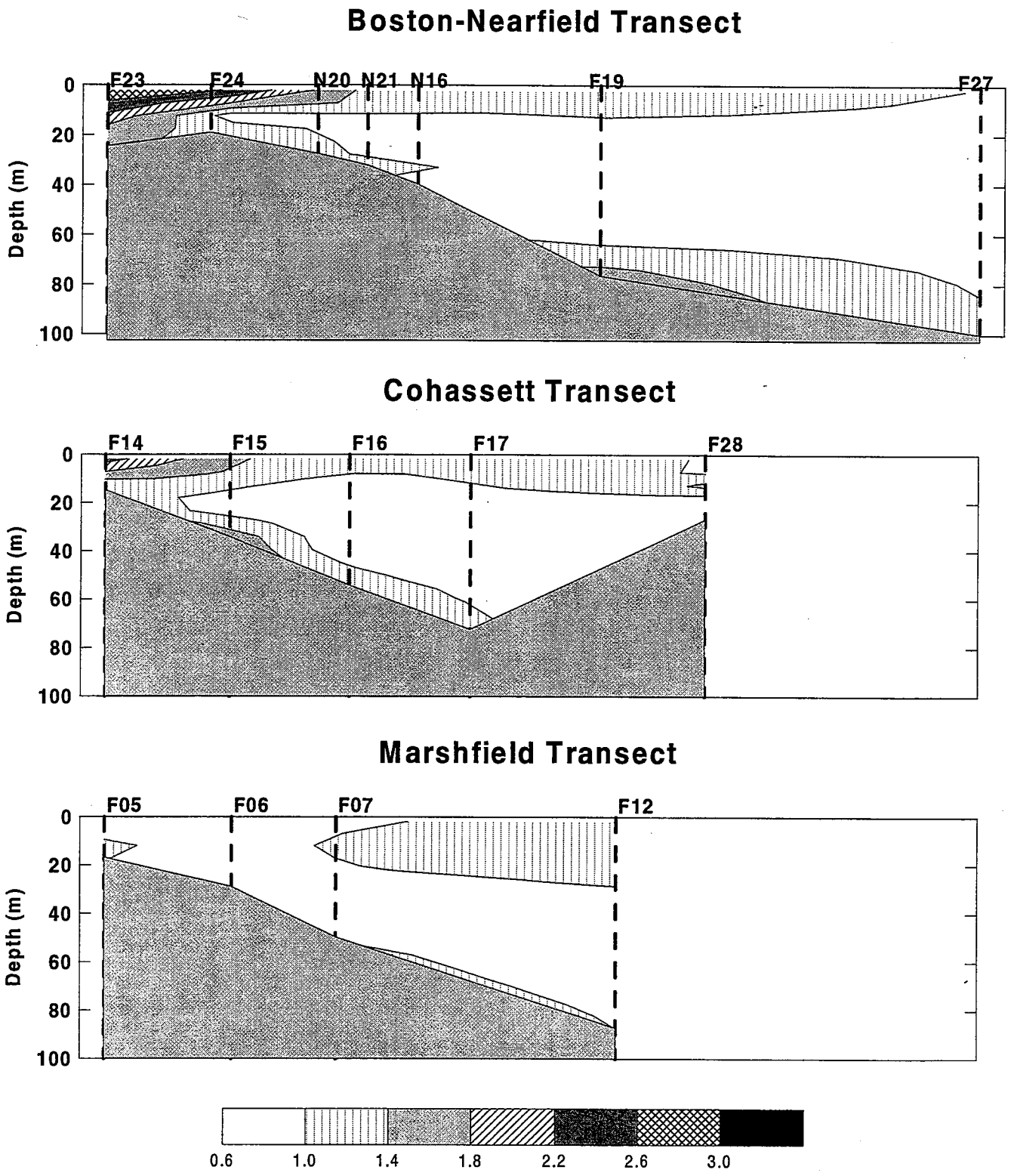


FIGURE 4-14
Beam Attenuation (/m) Along Three Farfield Transects in Late August (W9611)

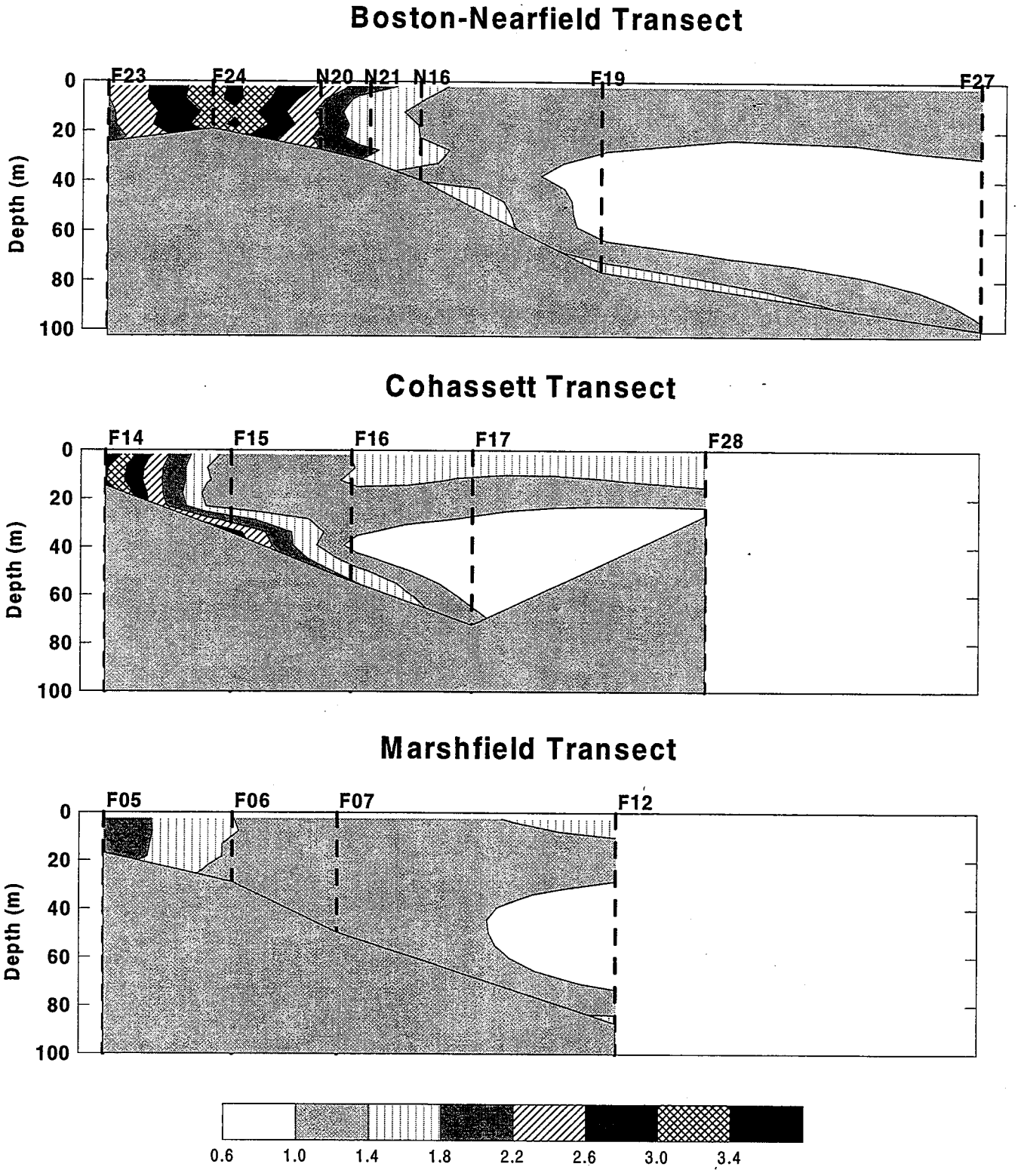


FIGURE 4-15
Beam Attenuation (/m) Along Three Farfield Transects in October (W9614)

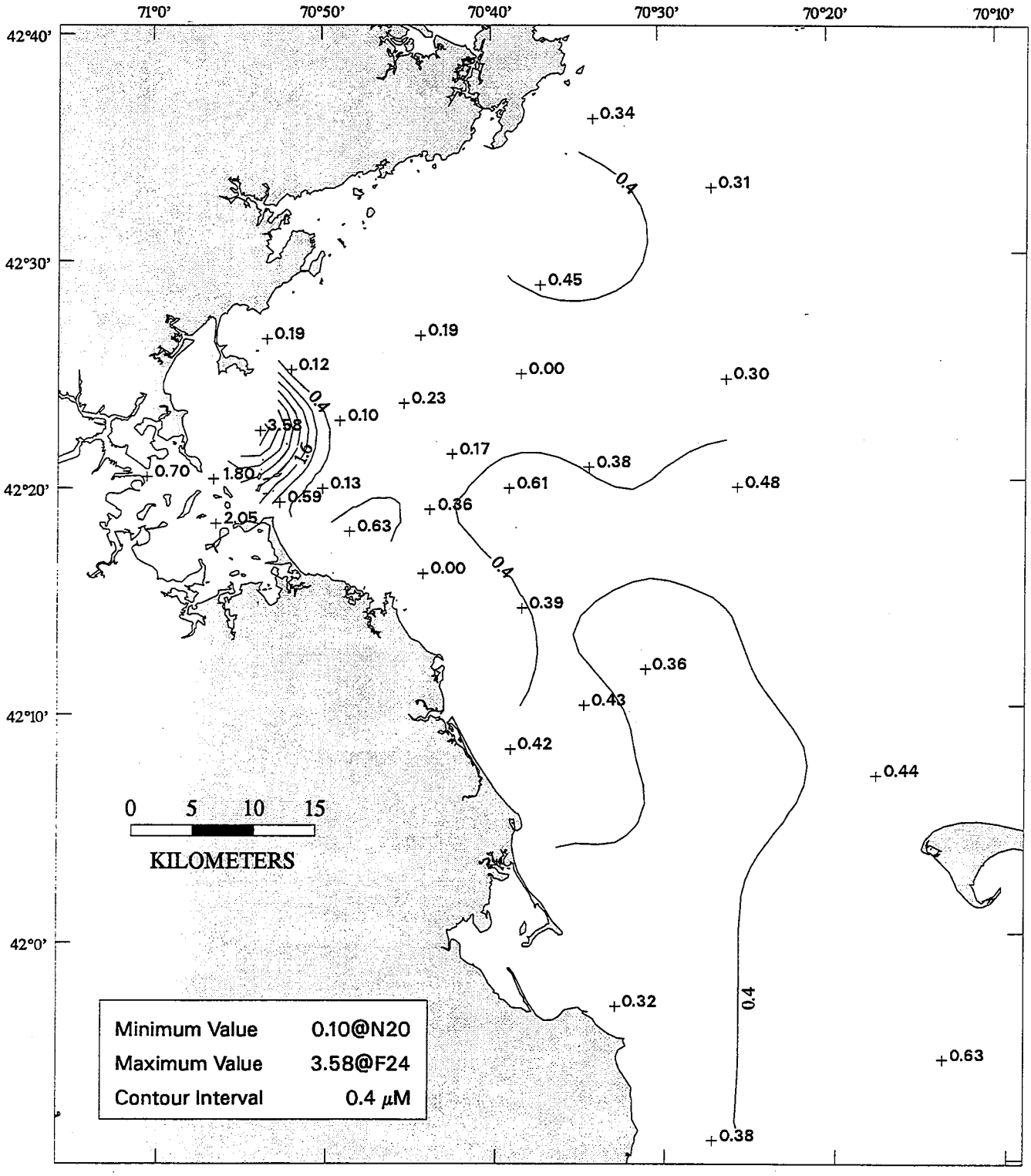


FIGURE 4-16
Surface Water Contour Plot of Dissolved Inorganic Nitrogen(μM) in Late August (W9611)

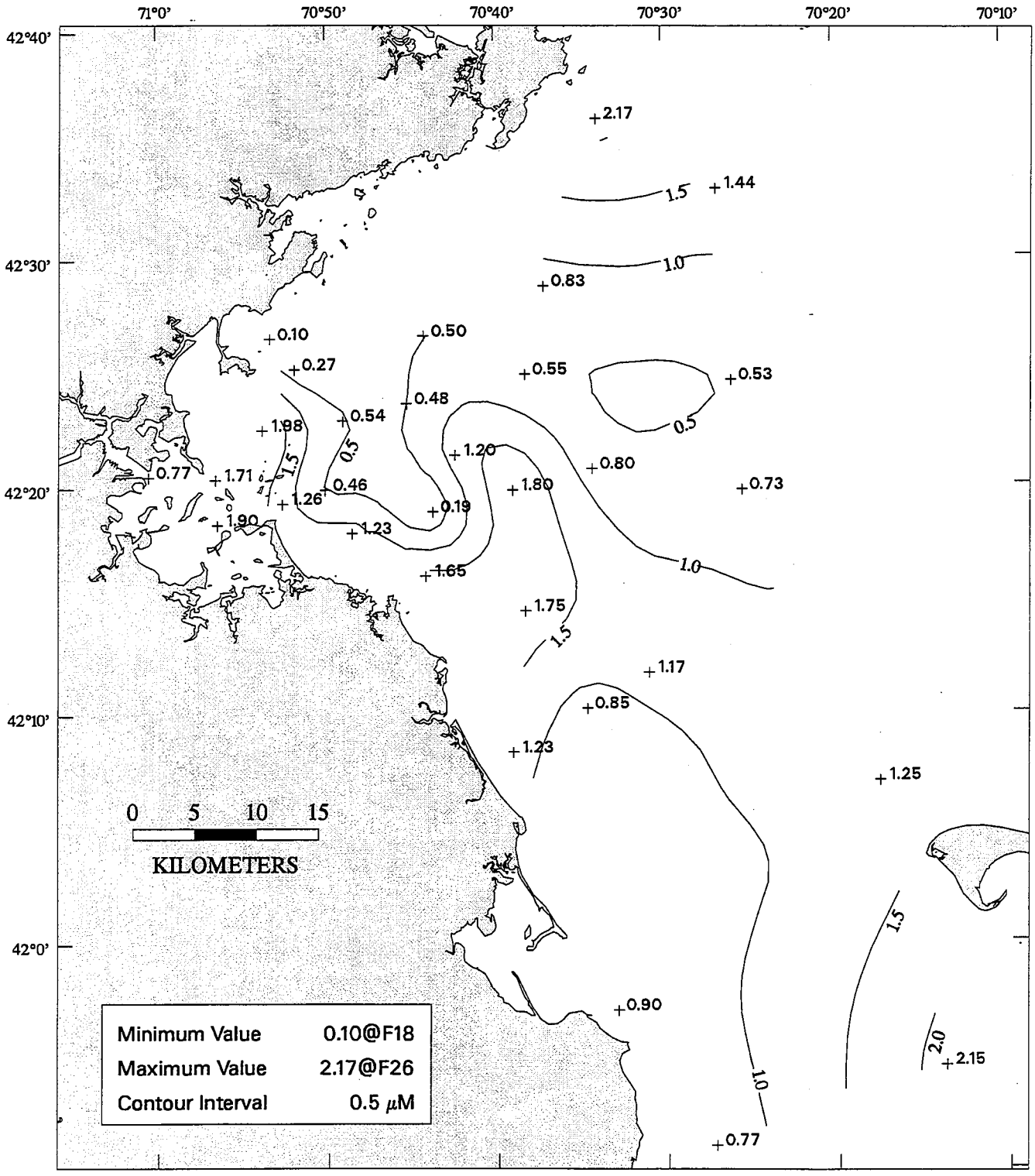


FIGURE 4-17
Surface Water Contour Plot of Silicate (μM) in Late August – (W9611)

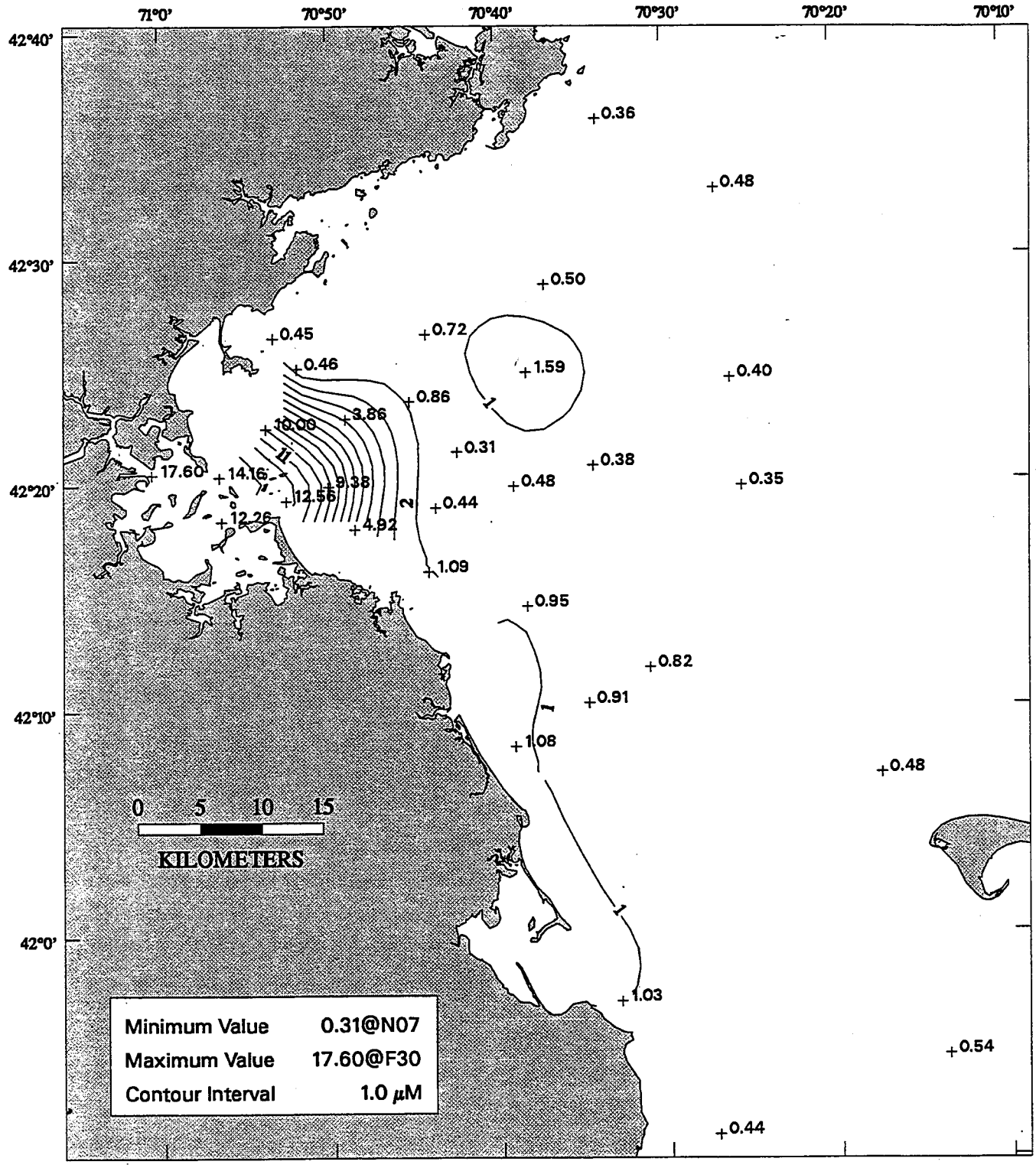


FIGURE 4-18
Surface Water Contour Plot of Dissolved Inorganic Nitrogen(μM) in October (W9614)

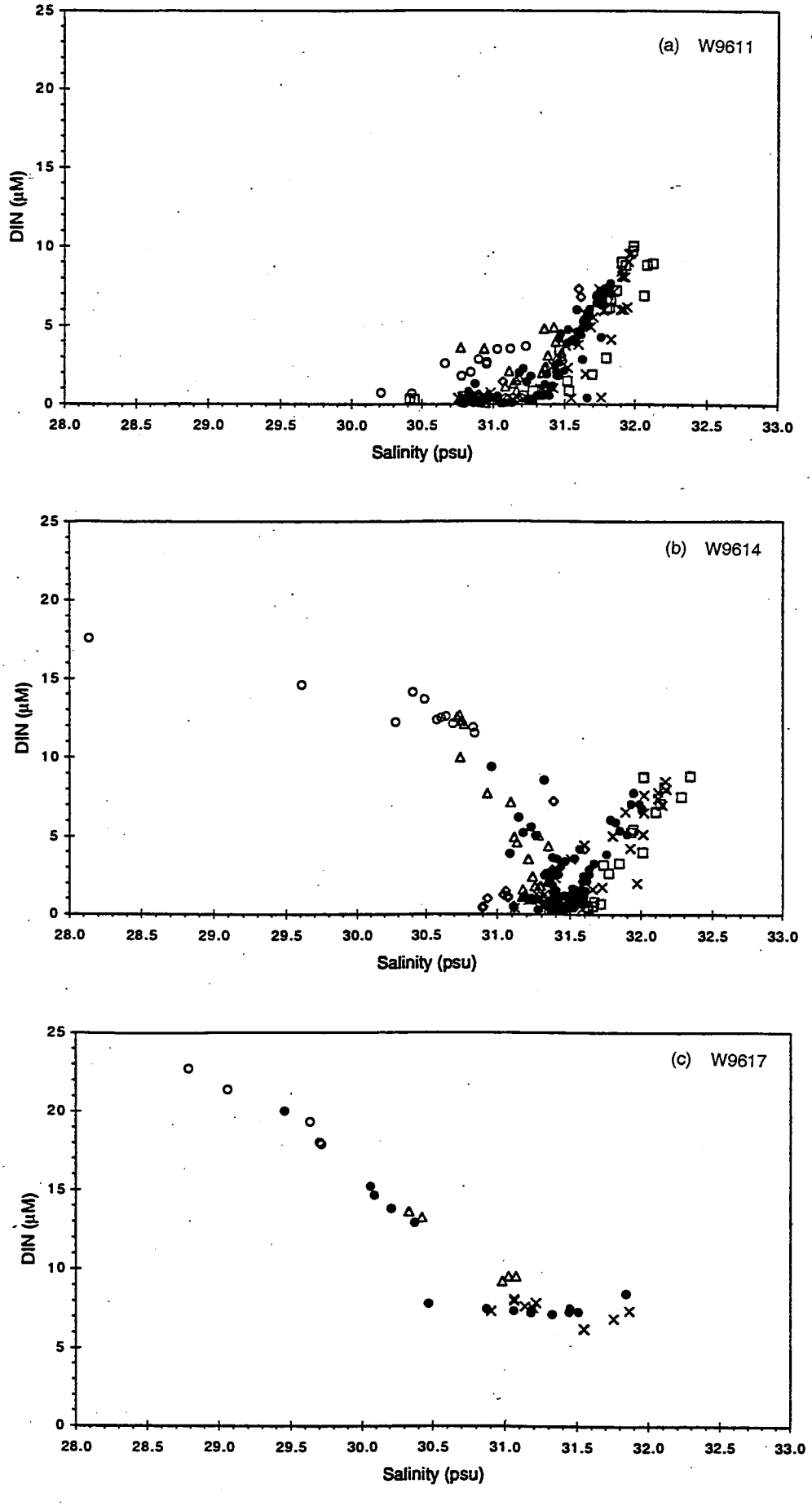


FIGURE 4-19
Salinity vs. Nutrient Relationships (W9611, W9614, and W9617)

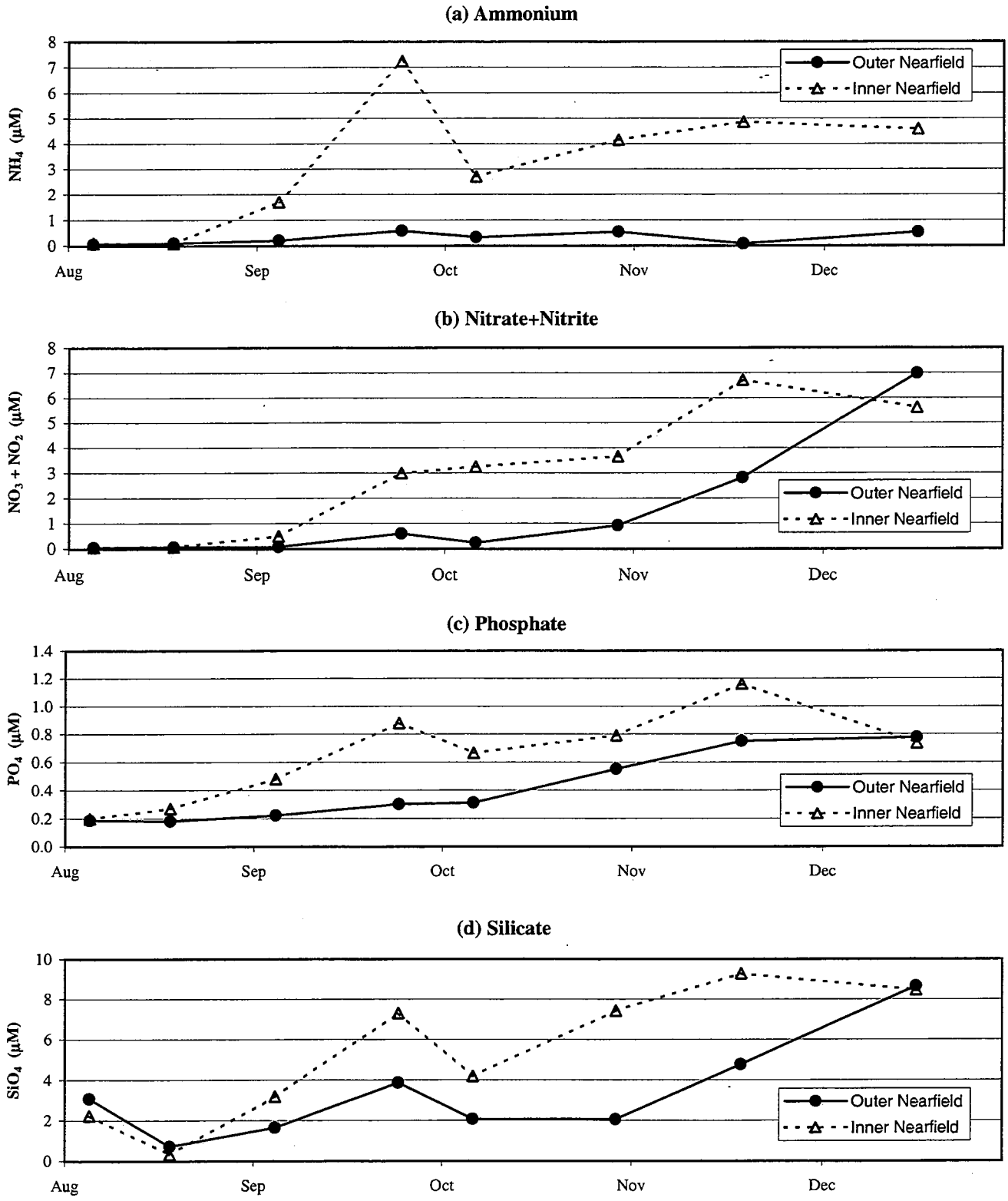


FIGURE 4-20
Time-Series of Nutrients in Surface Water in the Nearfield

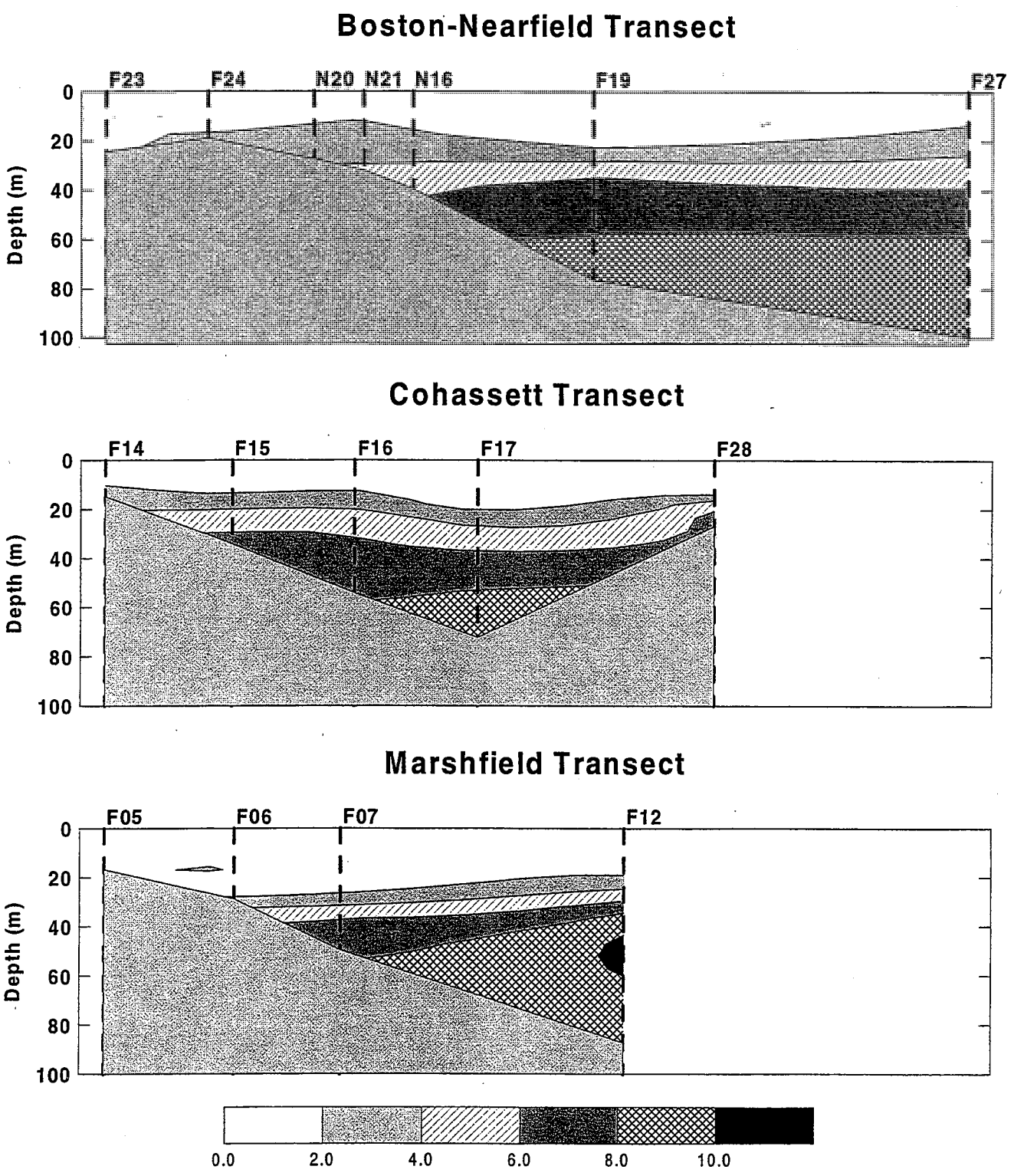


FIGURE 4-21
Nitrite + Nitrite (μM) Contours Along Three Farfield Transects in Late August (W9611)

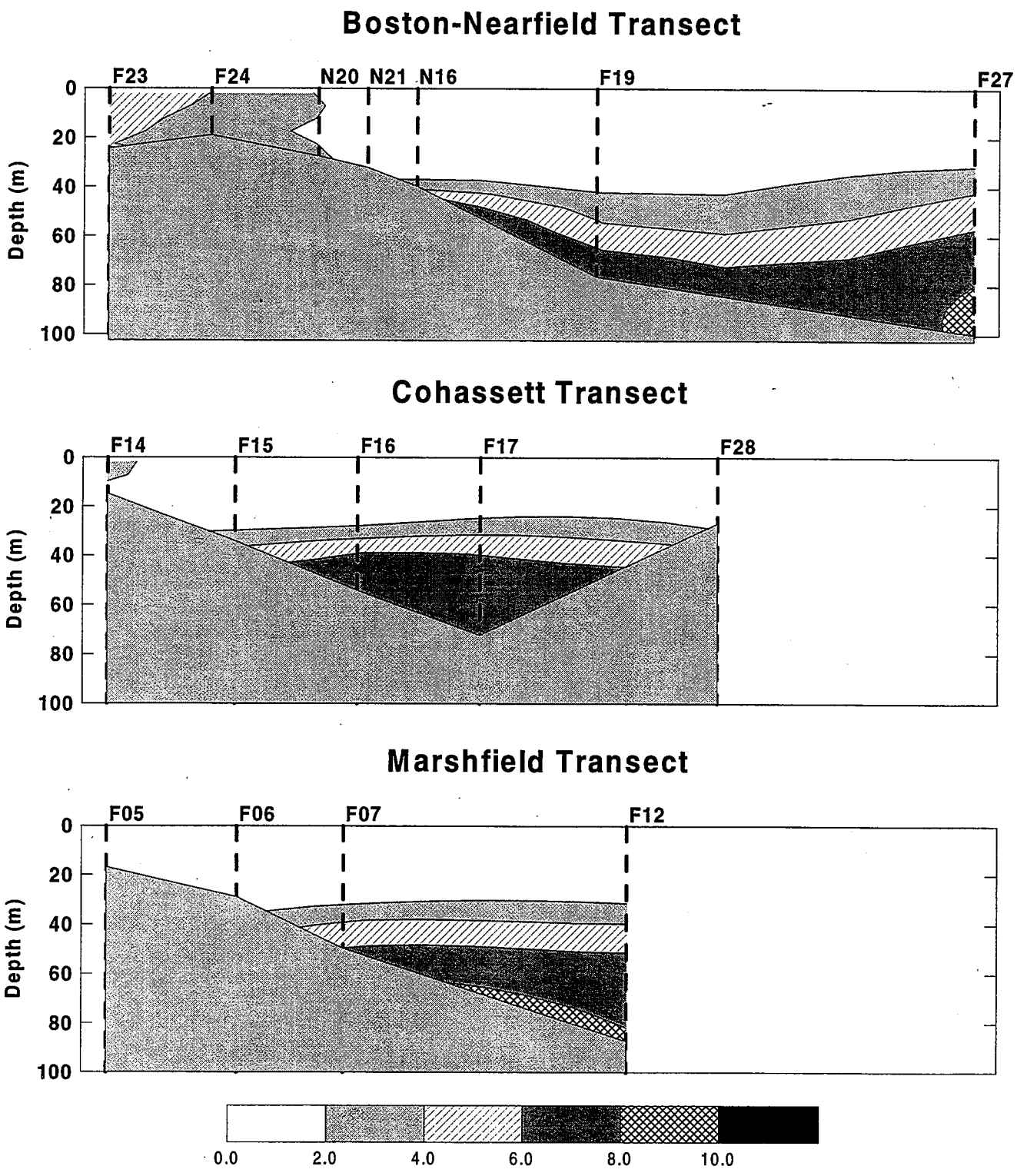


FIGURE 4-22
Nitrite + Nitrite (μM) Contours Along Three Farfield Transects in October (W9614)

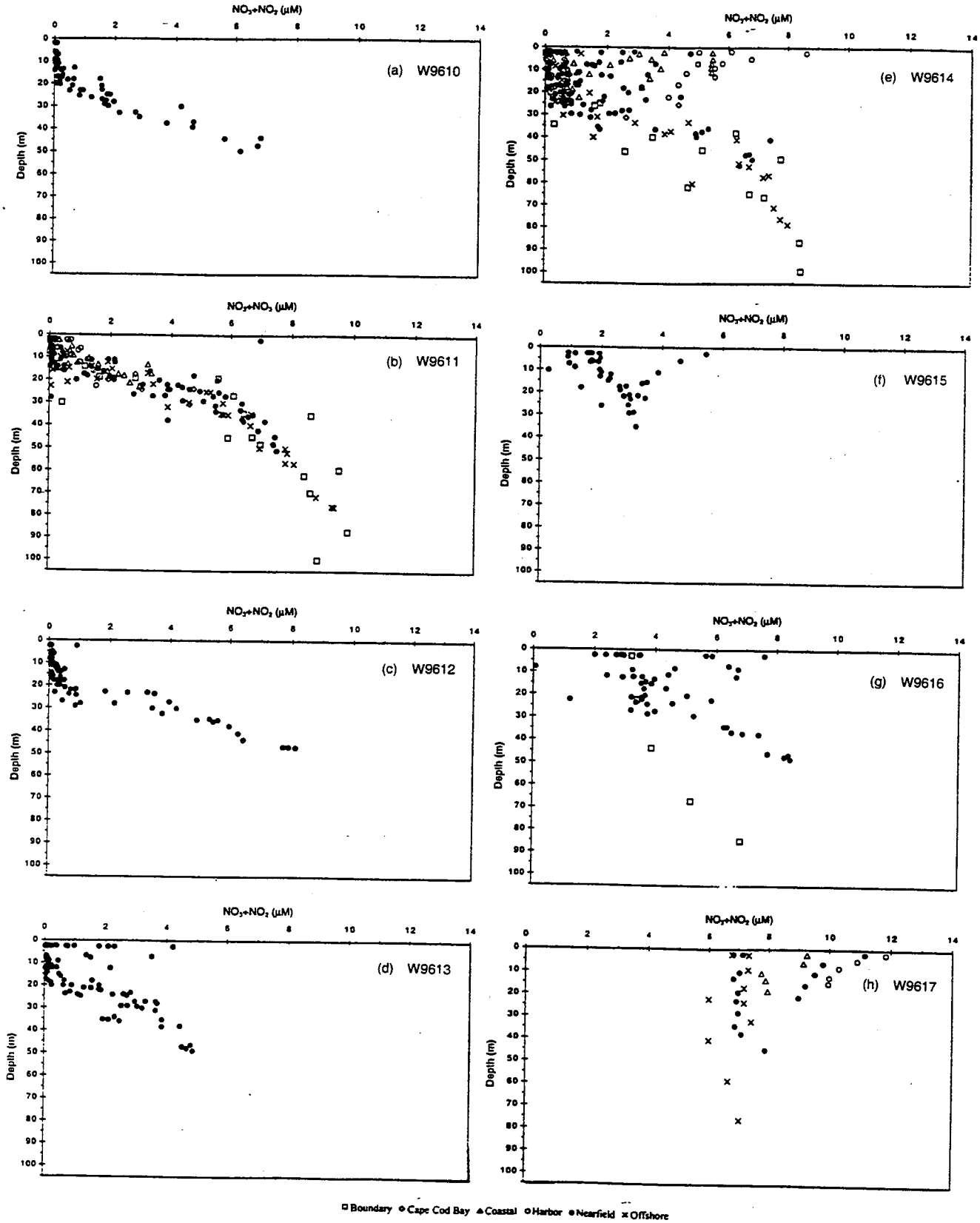


FIGURE 4-23
Depth vs. Nutrient Relationships (W9610-W9617)

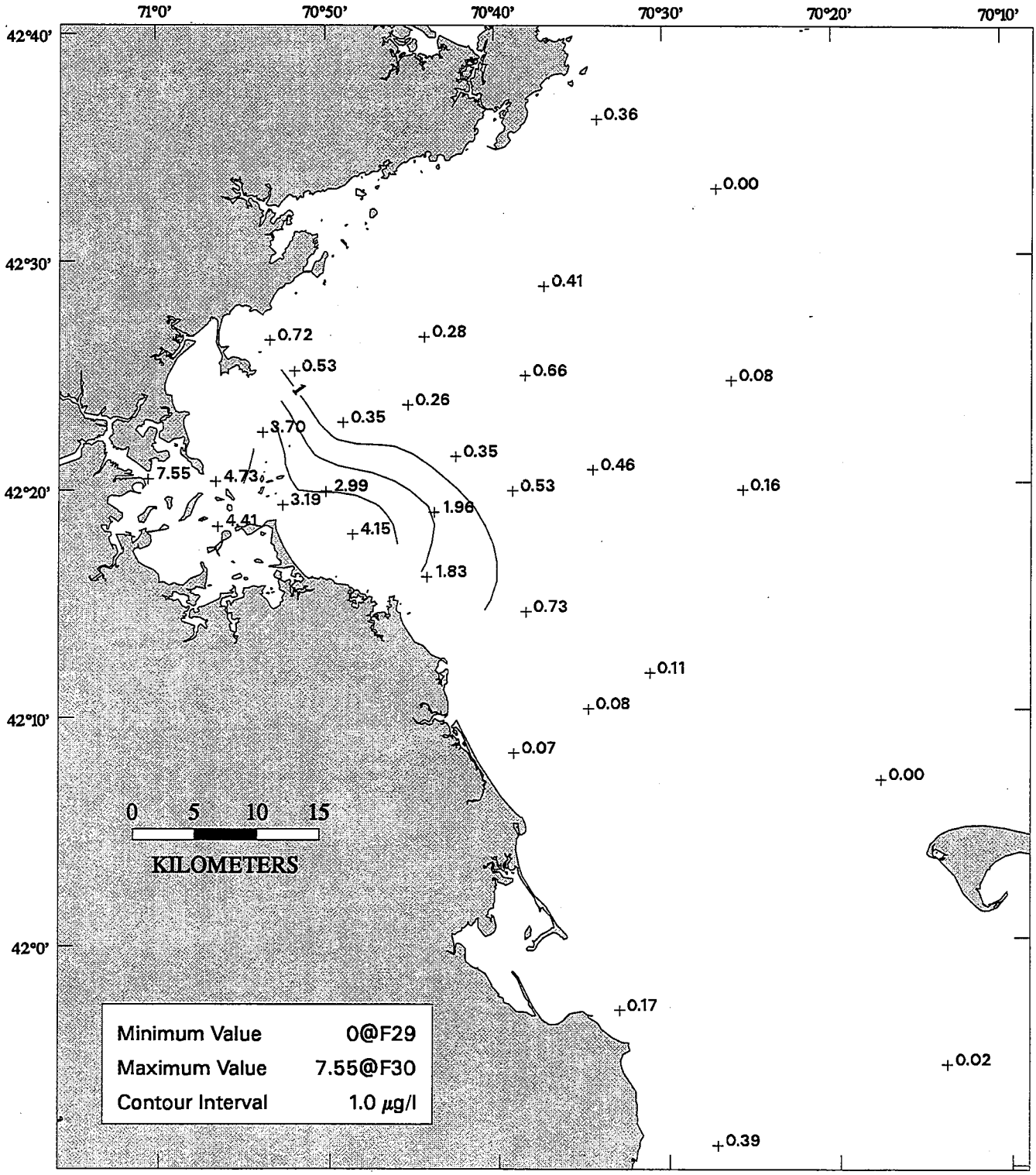


FIGURE 4-24
Surface Water Contour Plot of Chlorophyll *a* (µg/l) in Late August (W9611)

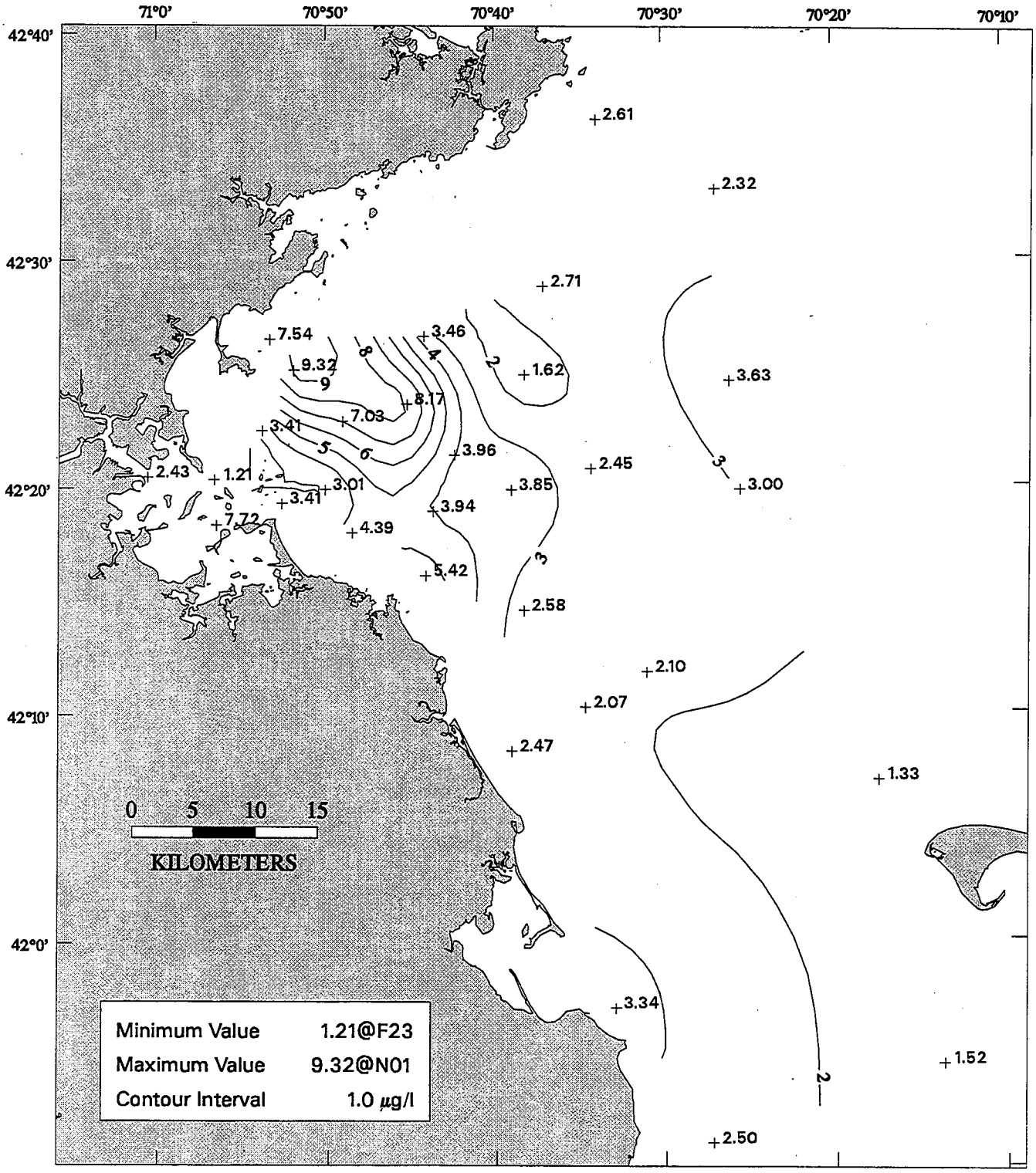


FIGURE 4-25
Surface Water Contour Plot of Chlorophyll *a* (µg/l) in October (W9614)

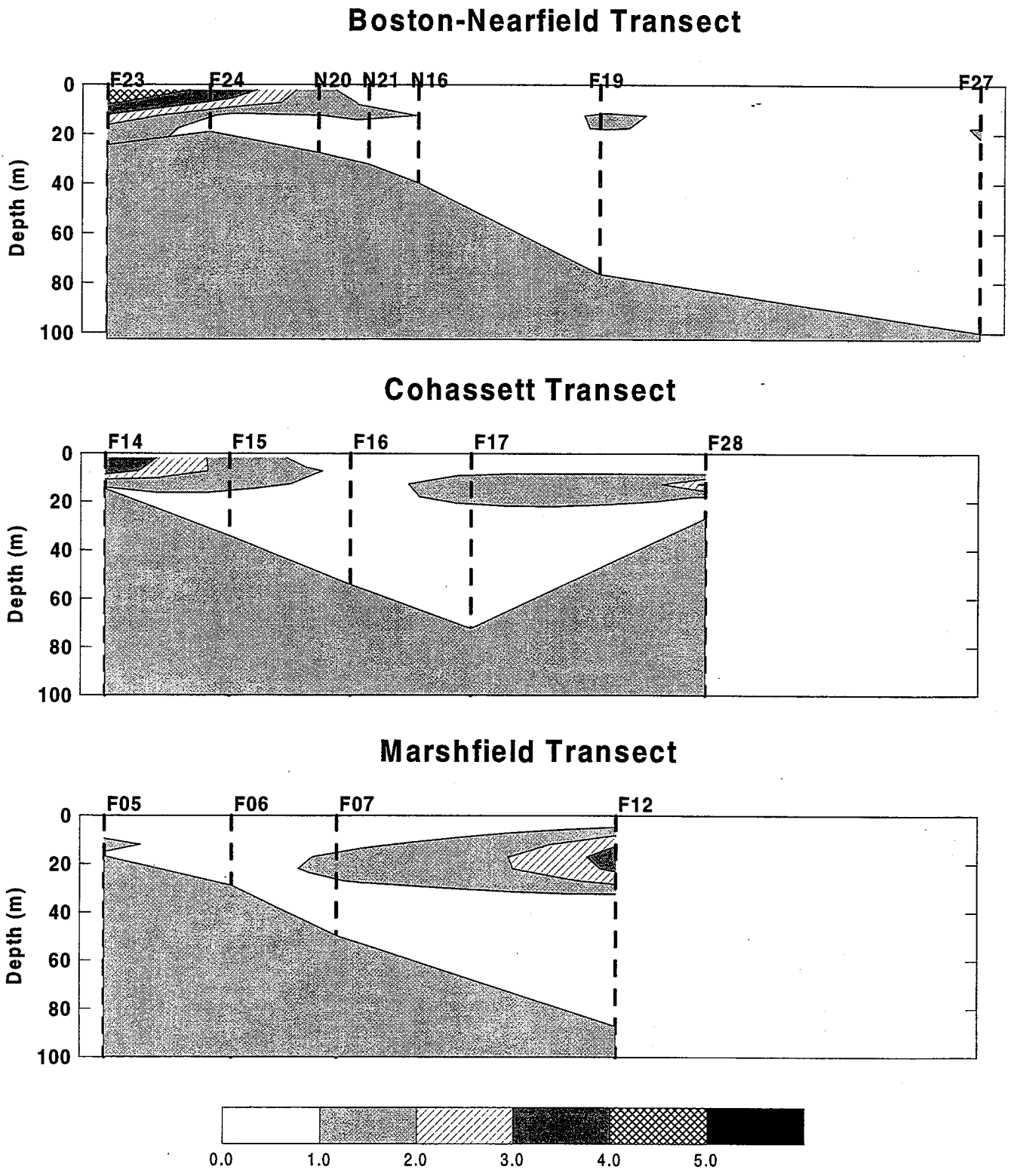


FIGURE 4-26
Chlorophyll *a* (µg/l) Contours Along Three Farfield Transects in Late August (W9611)

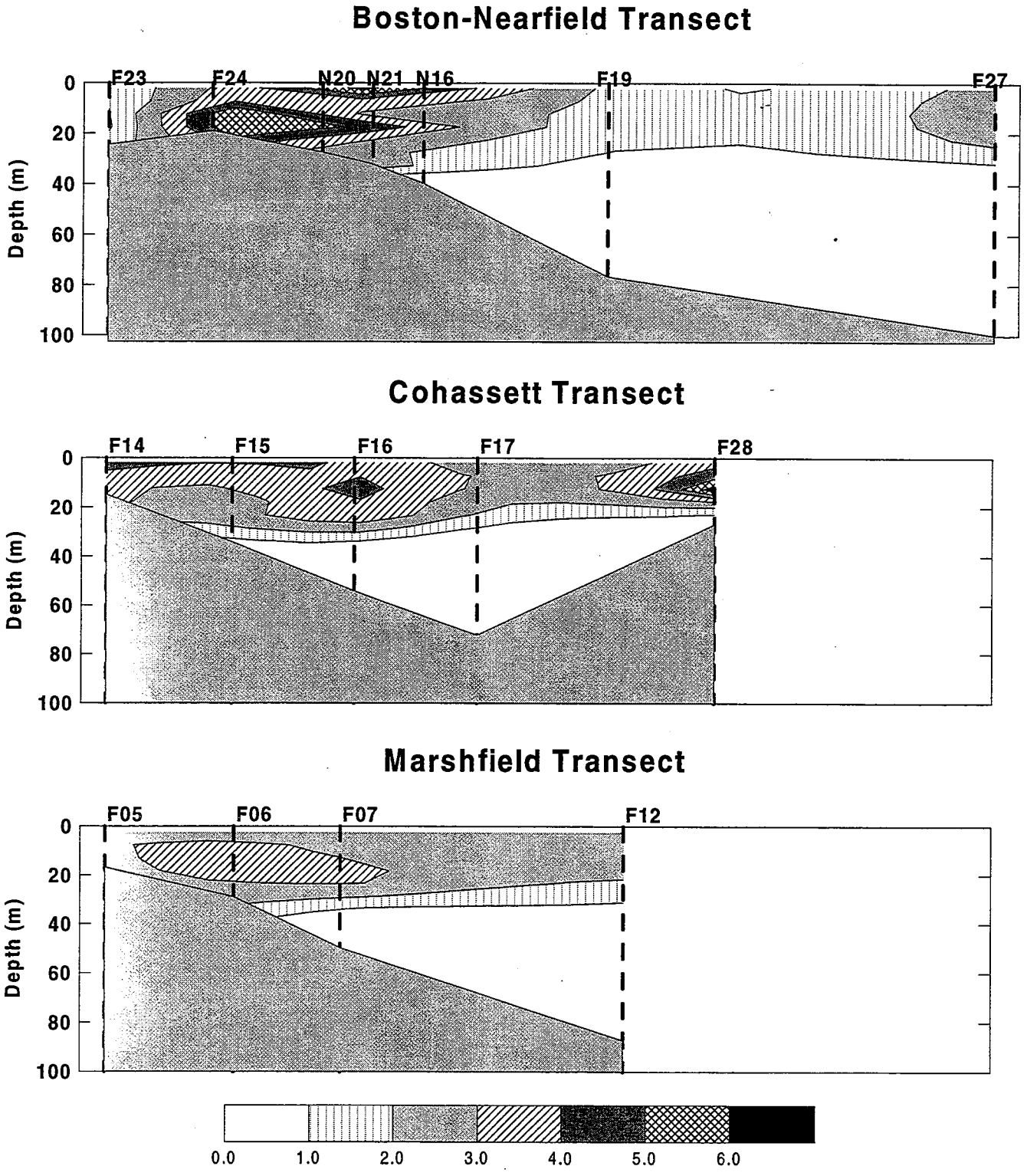


FIGURE 4-27
Chlorophyll *a* (µg/l) Contours Along Three Farfield Transects in October (W9614)

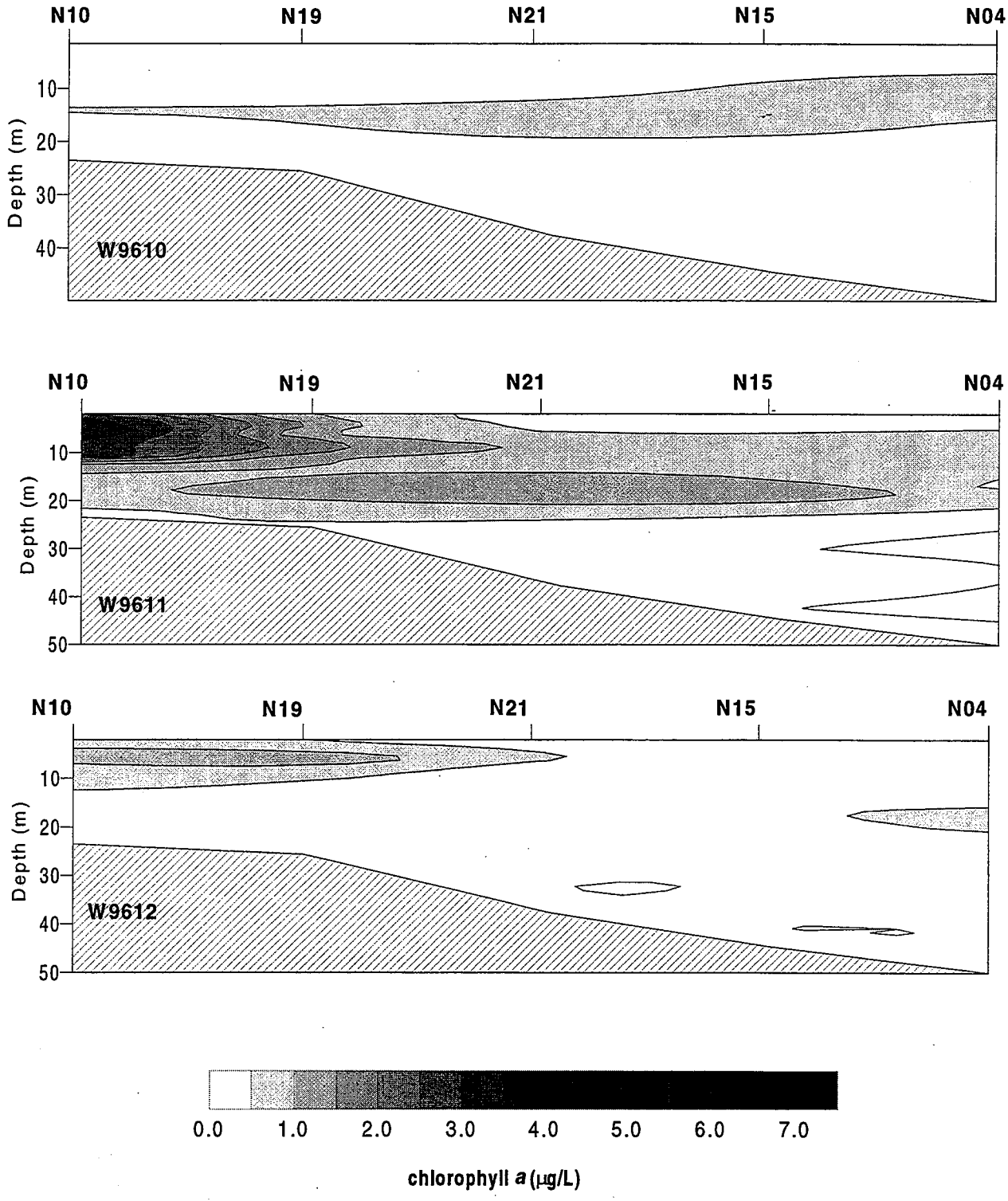


FIGURE 4-28
Chlorophyll *a* (µg/L) Contours Along Nearfield Transect,W6910 - W9612

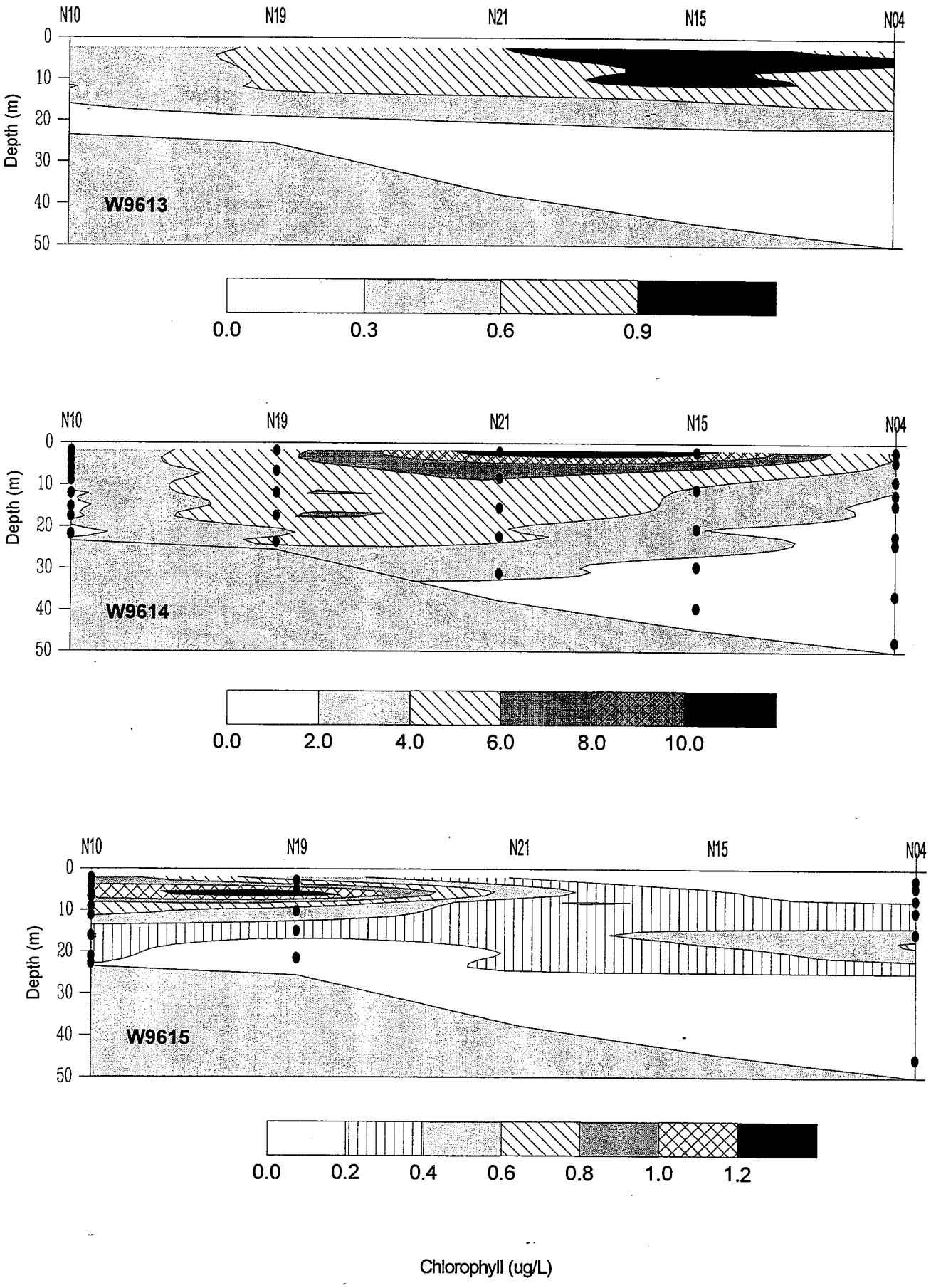


FIGURE 4-29
Chlorophyll *a* (µg/L) Contours Along Nearfield Transect,W6913 - W9615

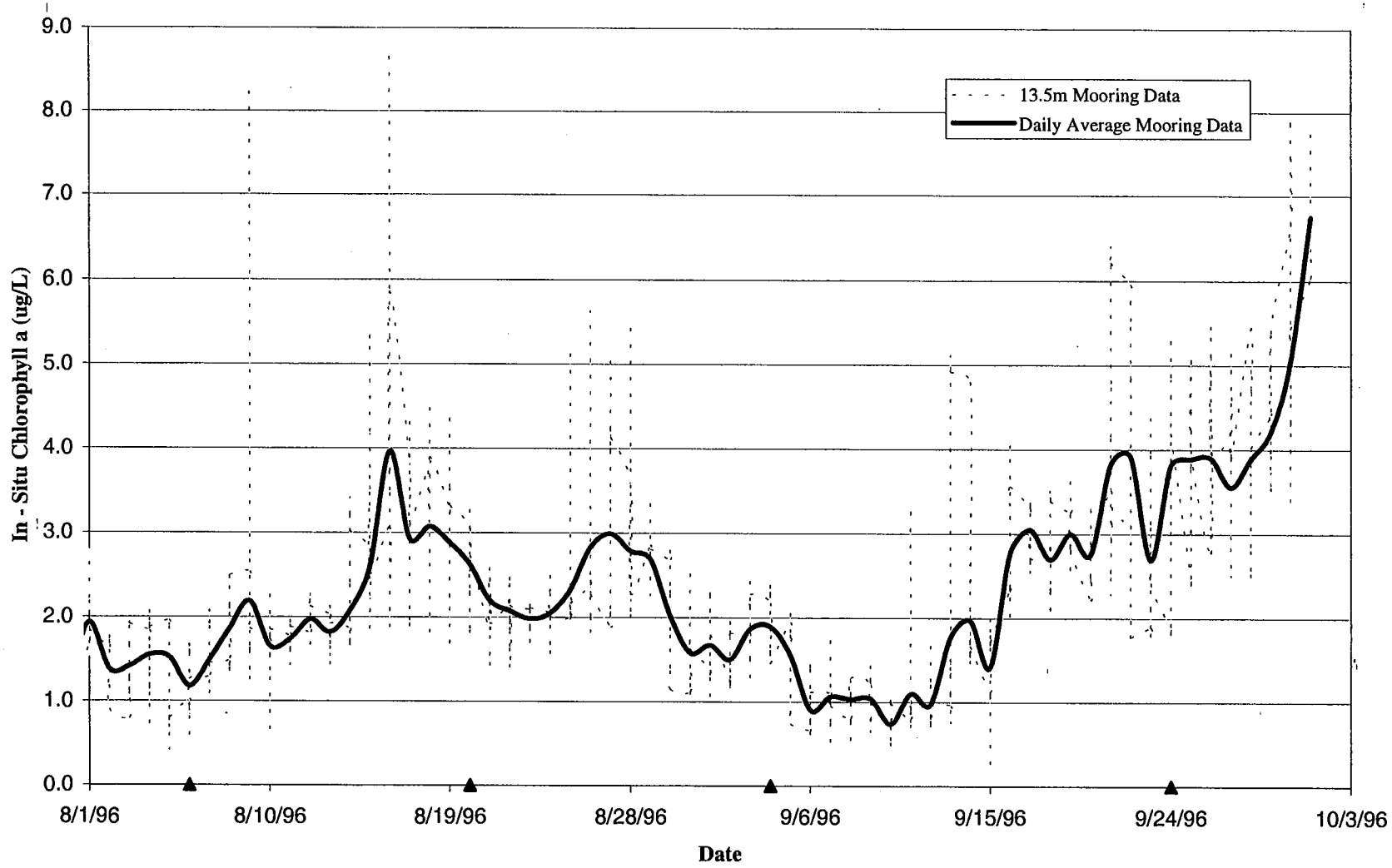


FIGURE 4-30
Wetlabs 13.5 Sensor Chlorophyll Results
August 1, 1996 to October 2, 1996
Triangles on x-axis mark survey dates

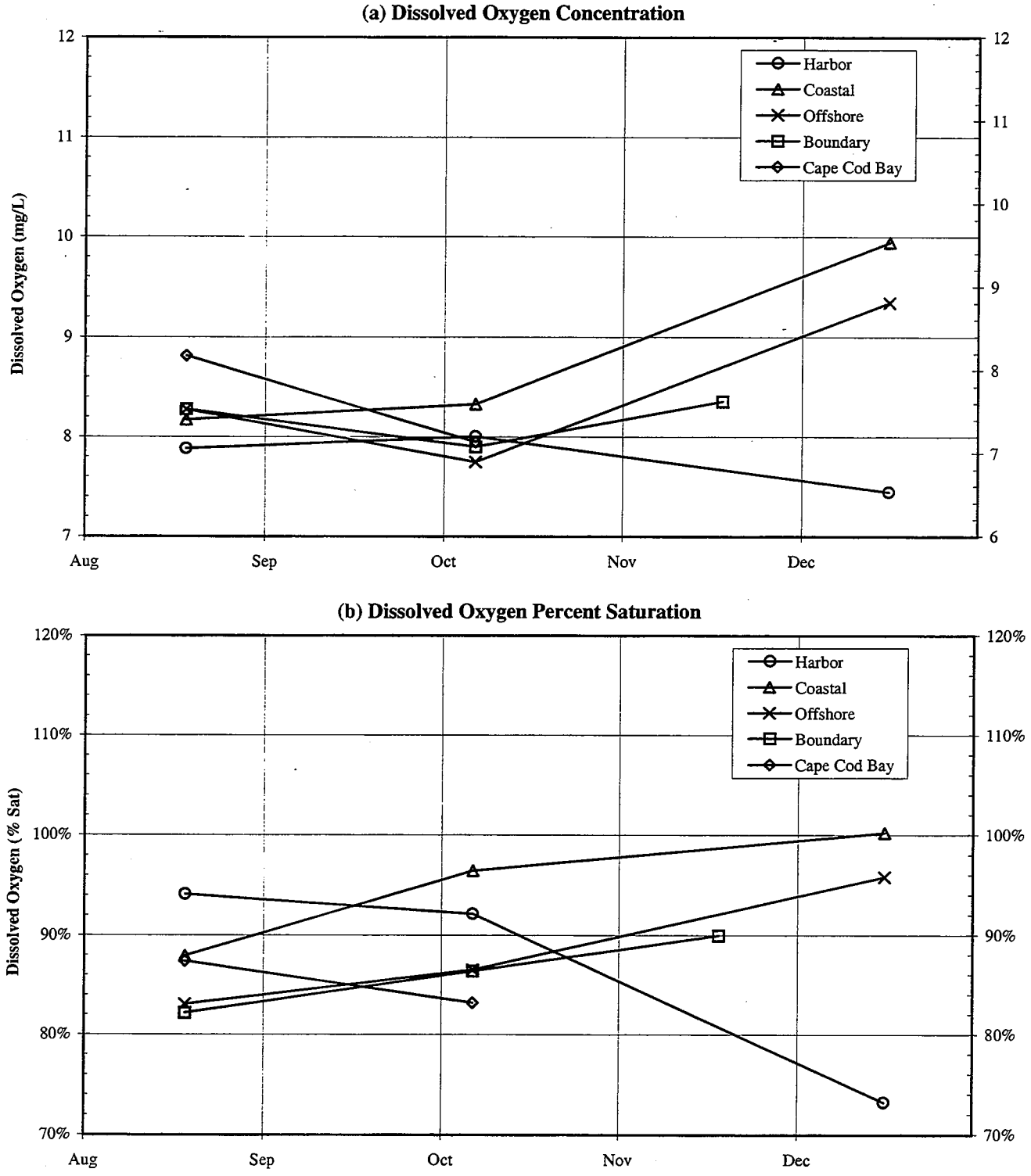


FIGURE 4-31
Time-Series of Average Bottom Water Dissolved Oxygen Concentration (mg/L) and Saturation (%) in the Farfield

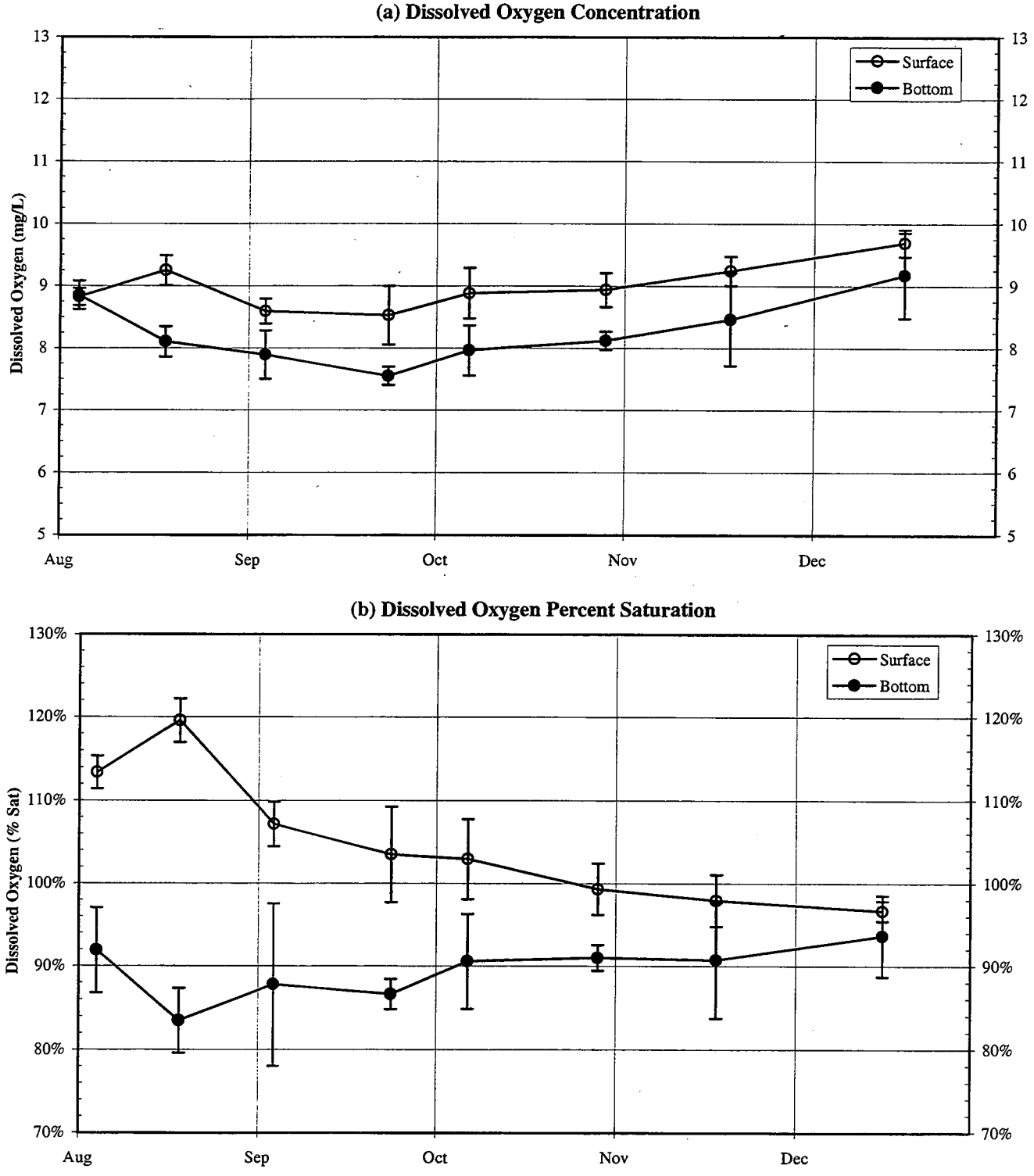
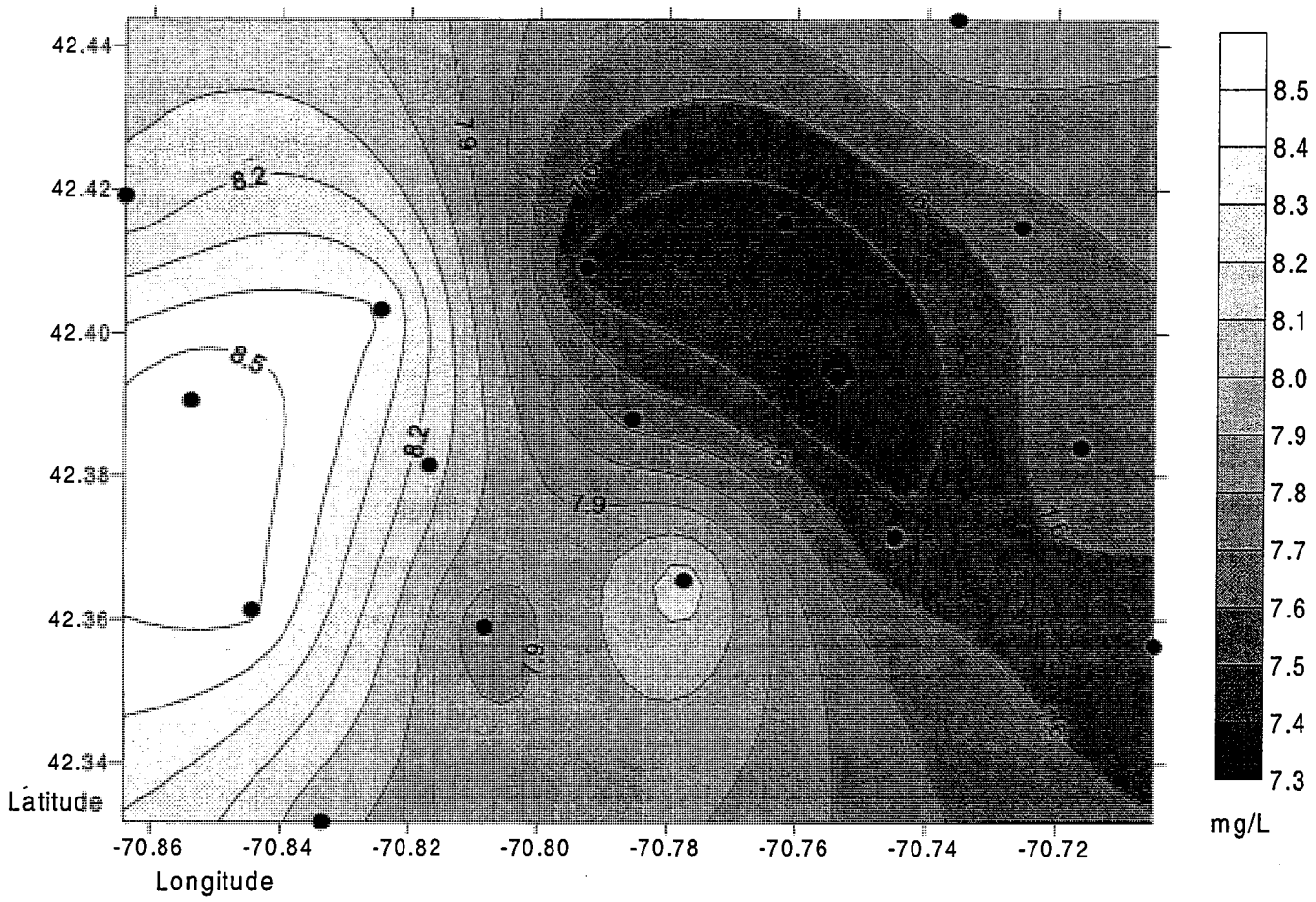


FIGURE 4-32

Time-Series Average of Surface and Bottom Water Dissolved Oxygen Concentration (mg/L) and Saturation (%) Among all Nearfield Stations



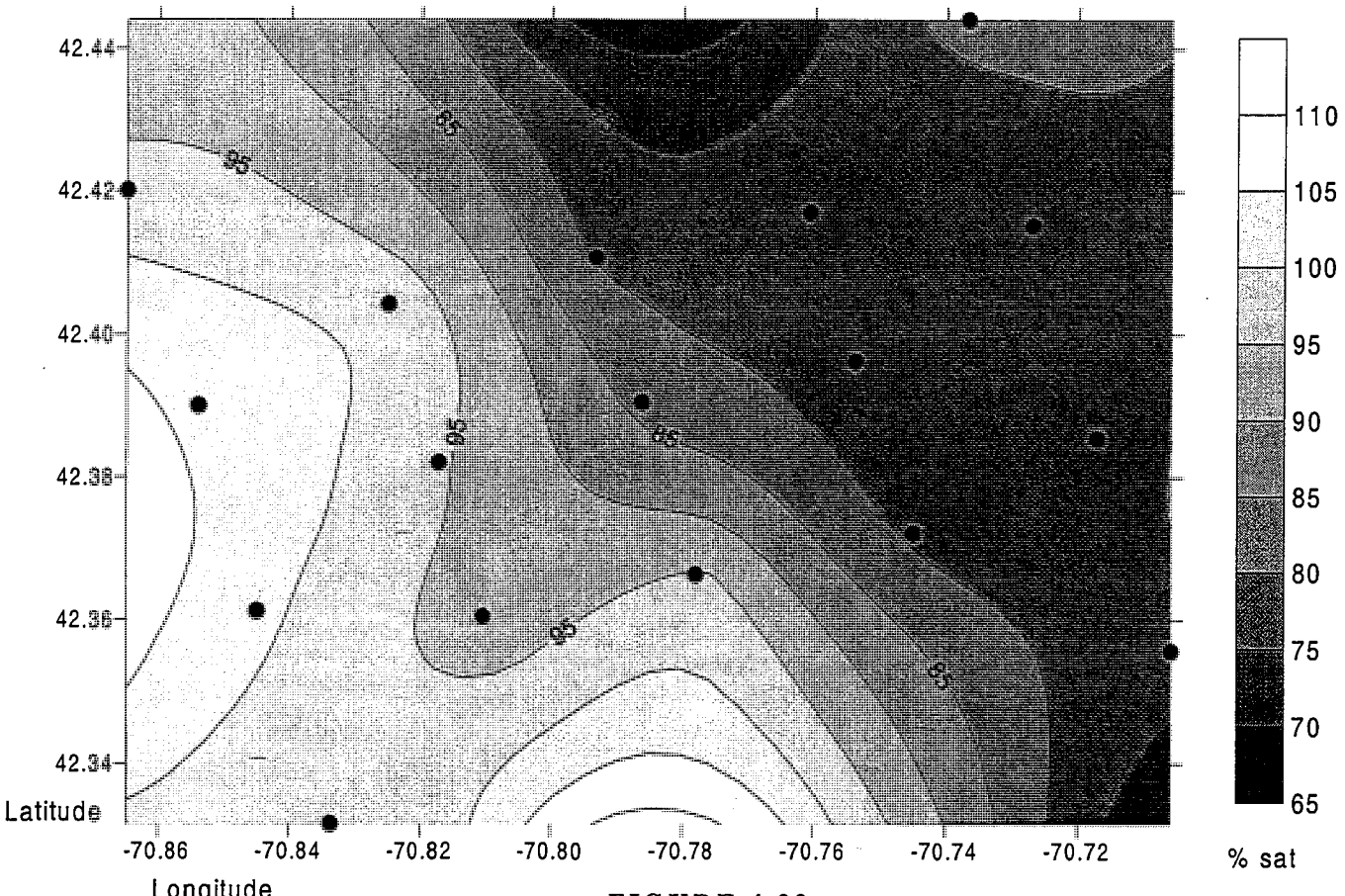


FIGURE 4-33
Bottom Water DO Concentration and Saturation
September 4, 1996 (W9612)

5.0 PRODUCTIVITY, RESPIRATION, AND PLANKTON RESULTS

5.1 Productivity

Production measurements were taken at three nearfield stations (N04, N10, N16) and one farfield station (F23), at the entrance to Boston Harbor. All stations were sampled during the two combined nearfield/farfield surveys conducted during this semi-annual reporting period; stations N04 and N10 were sampled during the additional six nearfield surveys during the period. Samples were collected at five depths throughout the euphotic zone. Production was determined by measuring ^{14}C incorporation over a range of light intensities as summarized below and in Appendix A.

In addition to samples collected from the water column, productivity calculations also utilized light attenuation data from a CTD-mounted 4π sensor, and incident light time-series data from an on-deck 2π irradiance sensor. Upon collection of the productivity samples and addition of ^{14}C-bicarbonate, samples were incubated in a temperature-controlled incubator which provided a range of light intensities. The resulting photosynthesis versus light intensity (P-I) curves (Figure 5-1, with additional detail in Appendix E) were used, in combination with ambient light attenuation and incident light data, to calculate hourly production for each sampling depth for determination of daily areal rates of phytoplankton productivity.

For this semi-annual report, areal production ($mgCm^{-2}d^{-1}$) is presented, determined by integrating the measured productivity over the euphotic zone. In addition, calibrated chlorophyll *a* sensor data were used to normalize daily productivity (at each of five sample depths) for calculation of chlorophyll-specific production, a measurement of the efficiency of production and physiological status of the phytoplankton population.

To address the issue of aliasing of photosynthesis measurements due to day-to-day variation in incident light, a rooftop 2π scalar light sensor (Biospherical QSR-240) was installed in August of 1996 at Deer Island to provide continuous measurement of incident light. Data were collected every minute and the average incident light recorded at 15-minute intervals. High resolution production was calculated using a computer program written in Microsoft Quick BASIC 4.5. Parameters computed were daily production ($mgCm^{-3}d^{-1}$) vs. depth (1m intervals) over the season (resolved to the day), and areal production down to the 0.5% light level ($mgCm^{-2}hr^{-1}$) vs. hour of day (resolved to 15-minute intervals) over the season (resolved to the day). The following data were required for these computations:

- Deer Island incident light measurements (15-minute intervals) collected over the photoperiod 0600 - 1800 hrs, standard time;

- percent incident light reaching each depth ($I_z/I_{z=0}$ * 100) over the season, where I_z is the 4π light field at depth z recorded by the CTD, $I_{z=0}$ is the 4π light field just under the sea surface at depth zero;

- chlorophyll *a* concentration, [chl*a*], vs. depth over the season;

- chlorophyll-specific α vs. depth over the season;

- chlorophyll-specific P_{max} vs. depth over the season; and

- α^* and P_{max}^* computed as the products α * [chl*a*] and P_{max} * [chl*a*] at each depth over the season.

Daily estimates of photosynthesis-related parameters other than measured incident light were obtained by gridding respective cruise and computational data from stations N04 and N10 using Surfer for Windows. Areal photosynthesis resolved to the day was computed in a manner identical to the standard computations except that a BASIC program was used.

5.1.1 Areal Production

The highest areal production for the second semi-annual period (3,473 $mgCm^{-2}d^{-1}$) was measured at the Boston Harbor productivity station (F23) during the August combined farfield/nearfield survey (W9611; Figure 5-2). Station F23 is located at the mouth of the harbor near the present MWRA outfall. Carbon fixation rates at the inner nearfield station N10 were nearly as high (2,898 $mgCm^{-2}d^{-1}$) as F23. These measurements were consistent with the distribution of chlorophyll in the harbor and adjacent coastal stations during the August harbor bloom (Section 4.3). Areal production rates at N10 during the prior and subsequent surveys (W9610 and W9612) were only around 1,000 $mgCm^{-2}d^{-1}$, a period of lower chlorophyll concentrations ($\leq$1 μgL^{-1}, Figures 4-28 and 4-30) but similar incident light.

Production rates at other, more seaward nearfield stations were also around 1,000 $mgCm^{-2}d^{-1}$ during August and early September (Figure 5-2), a period when nutrient concentrations in the surface mixed layer were very low. A peak in productivity was noted at station N04 during the late September nearfield survey (W9613), reaching 1,922 $mgCm^{-2}d^{-1}$. Elevated production was noted at station N16 during the October combined survey (W9614), with a reported rate of 2,471 $mgCm^{-2}d^{-1}$. These two maxima coincided with the location of peak chlorophyll concentrations, which moved from N04 during W9613 to around N16 during W9614 (Figure 4-29). They were also associated with water column mixing events which enhanced nutrient delivery from the hypolimnion.

After the October combined survey production rates at the two nearfield stations fell to <500 $mgCm^{-2}d^{-1}$, and continued to decline throughout November and December (Figure 5-2). Shown also in Figure 5-2, however, is the fact that aliasing contributed dramatically to the perceived magnitude and pattern of photosynthesis at N04 and N10 during the fall bloom. Surveys from W9612 to W9617 were by chance conducted on cloudy days, which resulted in 2-5 fold lower estimates of production relative to the prior or subsequent day. The tenfold fluctuations in the incident light field need to be accounted for to avoid substantial underestimation of seasonal production.

Not accounting for the variability in incident light intensity would have had dramatic effects on estimates of integrated production over the August-December season. At stations N04 and N10, seasonal production (as estimated from survey dates) was 118 and 107 gCm^{-2}, respectively, whereas the estimates using high resolution computations based on daily light fields were 202 and 168 gCm^{-2}. Hence, fall production determined for stations N04 and N10 from survey data was only 58% and 64%, respectively, of that determined from the high resolution data set. For station N04, survey data represented the fall bloom as a single peak which occurred in the latter part of September (Figure 5-2). In reality, it appears that the fall bloom at N04 consisted of two maxima, one sharply peaking in early October and the second broadly peaking in late October and November.

When represented by survey data only, the October bloom at station N04 was underestimated by approximately twofold, and the November peak in photosynthesis was missed altogether. The dip in production in mid-October was the result of a decrease in photosynthesis efficiency (as reflected in an approximately two-fold reduction in α and P_{max} during the biomass maximum. At station N10, the October bloom was missed entirely by the survey data, even though phytoplankton counts indicated a bloom (Section 5.3.1). The second bloom was not strongly manifest inshore, but subtle physiological indications of it were evident. The high-resolution data also provide further evidence that the late August photosynthesis peak at station N10 was unrelated to the fall bloom in Massachusetts Bay.

These data suggest that use of the high resolution light field for computation of production will significantly improve the ability to detect short-term bloom events and provide more reliable estimates of seasonal and annual production than estimates based on survey dates alone.

5.1.2 Chlorophyll-Specific Production

Chlorophyll-specific production (daily production normalized to chlorophyll concentrations over the water column) was calculated to further evaluate production with respect to the observed chlorophyll concentrations and yield information on the physiological state of the phytoplankton. The spatial and temporal distribution of both daily production on a volumetric basis ($mgCm^{-3}d^{-1}$) and chlorophyll-specific production ($mgC[mgChl\mathit{a}]^{-1}d^{-1}$) was examined by contouring production in the nearfield (stations N04 and N10) through the second half of 1996 (Figures 5-3 and 5-4).

Daily production at both stations was concentrated in the upper 10m of the water column (Figure 5-3). Station N04 exhibited productive surface water (>100 mgC[mgChl*a*]$^{-1}$d^{-1}) during the stratified period prior to mixing, and surface production in excess of 200 mgC[mgChl*a*]$^{-1}$d^{-1} associated with nutrient release in late September and early October. Due to its proximity to the harbor, peak surface production at station N10 (>400 mgC[mgChl*a*]$^{-1}$d^{-1} was in late August, however, the extent to which the production at N10 was associated with the harbor bloom remains unclear. A second surface peak (>200 mgC[mgChl*a*]$^{-1}$d^{-1}) was also evident during late September and early October. The seasonal decline in daily production rates appeared to occur earlier at the inshore station N10, caused by a combination of reduced biomass levels and reduced efficiency of production.

Chlorophyll-specific production is an estimate of the efficiency of photosynthesis. The distribution of chlorophyll-specific production indicates that during August and early September, the efficiency of production was high relative to the amount of biomass present (as measured by total chlorophyll *a*). At the outer nearfield station N04, chlorophyll-specific production was over 500 mgC[mgChl*a*]$^{-1}$d^{-1} during the late August survey (W9611, Figure 5-4). A peak of similar magnitude occurred during the following survey at station N10.

5.2 Water Column Respiration

Respiration was measured at the same three nearfield stations (N04, N10, and N16) and one harbor station (F23) as productivity, as well as at farfield station F19, in Stellwagen Basin (Figure 1-2). All stations were sampled during the two combined nearfield/farfield surveys; additionally, N04 and N10 were sampled during the six additional nearfield surveys during the period. Measurements were made on samples collected at three depths (surface, mid-water, and bottom). Samples were incubated without light and at *in situ* temperatures.

Both respiration (in units of $\mu MO_2 hr^{-1}$) and carbon-specific respiration ($\mu MO_2 \mu MC^{-1} hr^{-1}$) rates at surface and bottom depths are presented here. Carbon-specific respiration was calculated by normalizing respiration rates to the total measured particulate organic carbon (POC) at each respiration depth. Carbon-specific respiration provides an indicator of how biologically available (labile) the POC substrate material is for microbial breakdown. Respiration is primarily controlled by the amount of biologically available organic matter and environmental temperature.

5.2.1 Spatial and Temporal Patterns

Respiration rates were higher in surface than bottom waters throughout the semi-annual period (Figure 5-5). This pattern results from both the warmer temperatures (Figure 4-13) and higher organic matter (POC) and chlorophyll levels (Figure 4-28) in the surface layers versus in near bottom waters. These relation ships are supported by temporal changes in the vertical distribution of respiration at the eastern

most nearfield station, N04. During the period of strong stratification was 3-4 times higher in the surface versus bottom waters. However, as stratification, respiration weakened and broke down, respiration became more constant with depth. In contrast, at the western-most nearfield station, N10, which appeared to be periodically influenced by Harbor processes, convergence of surface and bottom rates occurred earlier (early September vs. early October). It is likely that this difference between N04 and N10 relates to their nearly 2 fold difference in station depth which partly underlies the apparent earlier advent of vertical mixing at N10 (Figure 4-9). In addition, the proximity of N10 to the Harbor appears to influence its productivity as there was a bloom at N10 possibly associated in some way with the large August bloom in the Harbor, but which was not in evidence at N04. This August bloom at N10 (which tripled surface photosynthesis rates) resulted in the highest rates of watercolumn respiration for the study period (Figure 5-5), 0.50 $\mu MO2h^{-1}$. These rates were higher than those at F23, the harbor mouth, (0.35 $\mu MO2h^{-1}$) which had comparable carbon fixation rates during the August survey (Figure 5-2). N04 also showed highest rates in the surface waters in August which is consistent with the high POC, the distribution of photosynthesis and the maximum annual surface water temperatures.

While proximity to the Harbor may have enhanced carbon availability at N10 versus N04, the enhancement in surface water respiration was generally small indicating the importance of in situ production versus the import of detrial materials from inshore. Accounting for the deeper water column where respiration can occur at N04 (areal respiration rates), indicates that relatively similar amounts of carbon were respired in the water column at the opposite margins of the nearfield over the semi-annual period. A respiration gradient does appear to exist, however, as Stellwagen Basin surface waters had rates < 0.20 $\mu MOh2^{-1}$.

During the fall surveys as the surface waters cooled, respiration gradually declined reaching the lowest levels in December when production and POC levels were also low.

5.2.2 Carbon-Specific Respiration

Carbon-specific respiration normalizes microbial activity for variations in the size of the carbon pool. Differences in carbon-specific respiration result from variations in the quality of the available organic matter or from environmental conditions such as temperature. Sources of organic carbon which are more easily oxidized (i.e., recently produced phytoplankton) will result in higher carbon-specific respiration. By comparing respiration rates relative to the source material, the availability (pathways) of fresh plankton can be inferred. In addition, since in some regions (e.g., bottom water during stratification) organic matter is of relatively low quality, carbon-specific rates can be sensitive indicators for even small inputs of "fresh" organic matter.

Overall, carbon-specific respiration rates in the surface water of the two intensively samples nearfield stations (N10 and N04) were highest during August and early September, with the maximum rate of

around 0.014 $\mu MO_2 \mu MC^{-1} hr^{-1}$ at station N04 in the early September survey (W9612, Figure 5-6). During these first three surveys (W9610-W9612), surface rates ranged from 0.012-0.014 $\mu MO_2 \mu MC^{-1} hr^{-1}$ at N04 and from 0.007-0.010 $\mu MO_2 \mu MC^{-1} hr^{-1}$ at N10. Thereafter, a general decrease in carbon-specific rates was evident through November, followed by a slight increase during December. Bottom rates during the entire semi-annual period at these two stations were typically less than 0.004 $\mu MO_2 \mu MC^{-1} hr^{-1}$, with exceptions evident at N04 during late August and N10 during early September.

Carbon-specific respiration rates track the pattern of non-carbon adjusted rates, but give a clearer view of seasonal patterns (Figures 5-5 and 5-6). The rates were during summer, with rapidly declining rates in fall, closely parallel changes in water column structure (strong stratification and the fall advent of vertical mixing). The similarity in seasonal pattern and absolute rates between N04 and N10 suggest that *in situ* production of organic matter (versus import of detrital carbon) is the overwhelming basis for the measured respiration rates. It also appears that the deeper water column at N04 does not impart a significant enough delay in the transport of carbon to the near-bottom waters to yield observable reductions in respiration.

The less frequently sampled nearfield station N16 was more similar to N10 during the August combined event, but exceeded rates at N10 and N04 in both the surface and bottom during the October combined survey (Figure 5-6). Station F19 in Stellwagen Basin also showed an increase in bottom water carbon-specific respiration rate during early October. Harbor station F23 showed only a slight decrease at both the surface and bottom between these two surveys.

In terms of particulate carbon substrate (Figure 5-7), results from N10 showed peaks at both the surface and the bottom during mid-August (W9611), late September/early October (W9612-13), and in the bottom water during mid-November (W9616). N04 showed a similar pattern, although the maximum surface water concentration occurred in late October (W9615), coincident with the secondary peak in the fall bloom evident from high-resolution production estimates (Figure 5-2). Since the water column was isothermal after the early October survey (W9614, see Figure 4-12), temporal and spatial changes in carbon-specific respiration from late October on were attributable to differences in carbon quality.

5.3 Plankton Results

The 1996 HOM Program included analysis of the plankton community in Boston Harbor, Massachusetts Bay, and Cape Cod Bay during 11 nearfield and six combined farfield surveys conducted from February to December. Two stations (N04 and N10) were occupied in the nearfield surveys, while an additional ten locations were sampled during the combined events (Figure 5-8). During 1996, station N16 continued to be sampled during the farfield segment of the combined events in lieu of a station revisit at one of the two nearfield stations.

In this report, the second half of the 1996 plankton record is presented (surveys W9610 to W9617), including two of the six annual combined sampling events (W9611 in mid-August and W9614 in early October). Two additional stations (F23 at the mouth of Boston Harbor, and F06 in the Offshore region off Scituate) were sampled for plankton during the winter nutrient survey W9617. Comprehensive tabulations of results are available in periodic Plankton Data Reports.

Whole water and screened phytoplankton samples were collected at the surface and at mid-depth, with the latter often selected to coincide with the presence of a sub-surface chlorophyll maximum (as determined by *in vivo* fluorometry). Zooplankton samples were collected at each station by oblique tow. Details regarding sampling and analysis can be found in the Combined Work Plan/QAPP for water column monitoring (Bowen *et al.*, 1997). Quantitative taxonomic analyses and carbon equivalence estimates were made for the plankton communities using species-specific carbon data from the literature.

In this section, the plankton data are presented through an assessment of their seasonal and regional characteristics. Total abundance, relative abundance of major groups, and estimated carbon equivalence are presented for each plankton community. Nuisance algae issues are also addressed. Appendix F-1 tabulates dominant phytoplankton species (>5% of total abundance) for whole water surface samples, along with the associated cell densities and percent abundance. Appendix F-2 provides similar information for the mid-depth samples. Appendix G-1 and G-2 includes information for screened phytoplankton results, while Appendix H presents zooplankton results.

5.3.1 Phytoplankton

5.3.1.1 Seasonal Trends in Total Phytoplankton Abundance

Total phytoplankton densities in nearfield whole water surface samples (averaged results) showed two peaks, one in mid-August (W9611) prior to fall mixing, and a second peak of similar magnitude in early October (W9614) during the fall bloom (Figure 5-9a). Cell densities appeared to decline for the remainder of the reporting period after W9614, although the lack of data from N04 during W9615 (not sampled due to deteriorating weather) required that individual station results be examined rather than station averages (see following section). Densities typically ranged from 1 to 3 millon cellsL^{-1}, diminishing by the final survey in December to densities of only around 300,000 cellsL^{-1}. The pattern was similar at mid-depth (Figure 5-9b).

During the two combined surveys, Boston Harbor yielded the highest regional densities at both the surface and at mid-depth (Figure 5-9a and 5-9b). Average surface densities for the three harbor stations were between 4 and 5 million cellsL^{-1} for both combined surveys, with mid-depth results only slightly lower. Coastal station surface densities were slightly higher than the nearfield, with the Offshore, Cape Cod Bay, and Boundary station results found to be the lowest regionally.

Harbor densities were still highest regionally during the winter nutrient survey (W9617), but with an order of magnitude reduction relative to the two combined surveys. The surface and mid-depth results from Offshore station F06 were only slightly higher than that seen in the nearfield.

5.3.1.2 Nearfield Phytoplankton Community Structure

Phytoplankton abundance and community composition at the three nearfield stations were plotted for surface (Figure 5-10) and mid-depth (Figure 5-11). Note again that station N16 was only sampled during the two combined surveys conducted during the reporting period. Overall density patterns between stations and depths varied, but generally densities at N10 were highest, and surface densities generally exceeded mid-depth results.

The mid-August peak in nearfield average total abundance (see Figure 5-9) appeared to be driven by the harbor bloom as indicated by whole water phytoplankton results from station N10 (Figures 5-10 and 5-11), as well as chlorophyll results (see Figure 4-24). Almost half the surface total count was due to centric diatoms (*Rhizosolenia fragilissima, Leptocylindrus minimus*, and a small unidentified centric). Densities of *R. fragilissima* at N10 reached 1 million cellsL^{-1}, four times the densities reported from the more seaward nearfield stations N16 and N04 (Appendix F). The gradient seen in *L. minimus* and the small centric were much more pronounced, with N10 yielding surface densities of around 350,000 cellsL^{-1}, whereas the more seaward stations had less than 10,000 cellsL^{-1} reported for each taxon (Lemieux, 1997a). The assemblages at stations N16 and N04 were more characteristic of a summer complex, with microflagellates, cryptophytes, and small dinoflagellates (*Gymnodinium* and *Katodinium*) dominant (Appendix F).

The mid-August inshore centric diatom bloom had disappeared by the early September survey (W9612), perhaps dispersed by wind and the 4.5 meter waves generated by Hurricane Eduoard (Section 4). The inshore assemblage was drastically altered, now dominated by cryptophytes (540,000 cellsL^{-1}, or approximately 50 percent of total surface water cell count) and microflagellates (Figure 5-10; Appendix F). The results from N04 showed a similar reduction in centric diatoms, but the increase in cryptophyte densities seen at N10 did not appear at N04 until late September (W9613, Figure 5-10). Cryptophyte domination continued at N10 during W9613, especially at the surface. As detailed in Section 4, survey W9613 followed a second sequence of storms, consisting of Hurricane Fran (second week of September) and the remnants of Hurricane Fausto (September 17th), the latter event again producing 4 to 5 meter waves.

By the October 7th survey (W9614), the overall contribution from centric diatoms increased dramatically (Figures 5-10 and 5-11). Inshore, the dominant taxa were *Skeletonema costatum* and a small (<10µm) unidentified centric (Appendix F). Subdominant centric diatoms included *Cyclotella* sp., *R. fragilissima*, *Chaetoceros*, and *Thalassiosira* (Lemieux, 1997b). At the more seaward stations N04 and N16, *S.*

costatum, and to a lesser extent *Cyclotella*, were much less prevalent and the small unidentified centric (probably *Thalassiosira*) dominated. Other subdominant taxa included cryptophytes, the pennate diatom *Thallassionema nitzschioides*, and a small *Gymnodinium* (especially at the surface at N04 where it was reported at 410,000 cellsL^{-1}).

Following the bloom documented during W9614, inshore (i.e., station N10) phytoplankton densities decreased, and centric diatoms became less important to the overall assemblage (Figures 5-10 and 5-11; Appendix F). The one exception was the presence of *R. fragilissima* at N10 during mid-November (W9616), primarily at mid-depth where it was reported at a density of just under 200,000 cellsL^{-1}. At the more seaward station N04, the absence of phytoplankton results from W9615 hinder the assessment of the fate of the fall bloom. However, *R. fragilissima* was found in abundance during survey W9616, where it co-dominated with the unidentified centric diatom and reached around 220,000 cellsL^{-1}. Coupled with the results of high-resolution productivity calculations during the period, *R. fragilissima* may have driven a continuation of the fall bloom in the nearfield. By the December survey, however, any evidence of a fall bloom was gone.

Plots of estimated phytoplankton carbon indicate that the August peak in inshore phytoplankton abundance was more productive at N10 than any other event during the period (Figures 5-12 and 5-13). The centric diatoms described above dominated the carbon contribution, although the small *Gymnodinium* had a noticeable contribution as well, especially at the surface. Phytoplankton carbon production was less pronounced in the more seaward stations of the nearfield, which peaked during the November survey (W9616).

Dominant dinoflagellate species detected in screened sample results included *Ceratium longipes*, *C. fusus*, *C. tripos*, and *Dinophysis norvegica* (Appendix G). However, densities rarely exceeded one thousand cellsL^{-1} throughout the reporting period. The exception was an occurrence of *C. tripos* in the mid-depth sample from N10 during late October (W9615), when densities reached 21,000 cellsL^{-1}.

5.3.1.3 Regional Phytoplankton Assemblages

Abundance plots from farfield station whole water samples were used to demonstrate the differences in regional successional patterns (Figures 5-14 through 5-15). Nearfield results were included to facilitate regional comparisons. These results further illustrate the harbor and near-coastal nature of the August nearfield peak (see previous section). Stations in Boston Harbor (F23, F30, and F31) and in the adjacent coastal region (F24 and F25) showed a similar pattern as that seen at nearfield station N10, with a large contribution from centric diatoms (Figure 5-14). The Boundary and eastern Cape Cod Bay stations (F27 and F02, respectively), as well as Offshore station F06, had a relatively small contribution from centric diatoms.

As with N10, dominant centric taxa were *Rhizosolenia fragilissima* and *Leptocylindrus minimus* (Appendix F). Cell densities were similar in magnitude as that reported from station N10. *R. fragilissima* was also dominant at Coastal station F13 and western Cape Cod Bay station F01. Station F30, at the mouth of the Inner Harbor, had an additional contribution from *Skeletonema costatum*, unique in the results from all stations sampled during W9611. Cryptophyte densities of around 1 million cellsL^{-1}, comprising around 20 percent of total cell densities, also contributed to the overall standing stock of phytoplankton in the harbor.

Results from the October farfield survey W9614 also showed a gradient in phytoplankton assemblage character from the harbor and coastal stations seaward. Harbor and coastal stations still had a large centric diatom component, but as was seen at station N10 in the inner nearfield, the dominant taxon was now *Skeletonema costatum* (Figure 5-15). Maximum densities of *S. costatum* were around 2 million cellsL^{-1} at Coastal station F24 and Harbor station F30 (Appendix F-1 and F-2). More seaward samples yielded comparatively few *S. costatum*, which was replaced by a small (<10μm) unidentified centric diatom. Cryptophyte densities increased relative to August, reaching almost 3 million cellsL^{-1} at Boston Harbor station F31 (Figure 5-15, Appendix F-1). The dominant pennate diatom, *Thalassionema nitzschioides*, also exhibited diminishing densities offshore, with maximum densities of 410,000 cellsL^{-1} reported at Coastal station F24.

Phytoplankton results from the winter nutrient survey W9617 showed a similar composition at Harbor station F23, Offshore station F06 and the two nearfield stations N10 and N16 (Figure 5-16). The assemblages were dominated by microflagellates and cryptophytes, with little contribution from diatoms to total abundance.

The dinoflagellate flora in the late season farfield samples exhibited dominant taxa similar to those reported for the nearfield stations (*Ceratium longipes*, *C. fusus*, *C. tripos*, and *Dinophysis norvegica*) (Appendix G-1). No horizontal patterns were evident in these taxa, however, *Protoperidinium* spp. were reported in low numbers (<50 cellsL^{-1}) in Boston Harbor and adjacent coastal water but not at more seaward stations. Densities for all dinoflagellate taxa were occasionally elevated at mid-depth, but overall these densities were low (typically less than 1,000 cellsL^{-1}).

5.3.1.4 Nuisance Algae

Three nuisance algae species have been targeted in the HOM Program: *Alexandrium tamarense*, *Phaeocystis pouchetii*, and *Pseudo-nitzschia multiseries*. The seasonal distribution for *A. tamarense* and *P. pouchetii* includes the late winter and spring periods, and thus would not be expected to occur during this time of the year. Neither species was reported during the surveys reported herein.

This semi-annual reporting period does encompass the seasonal distribution of *Pseudo-nitzschia multiseries*. It was not present in any great abundance, however, as its indicator species, *Pseudo-nitzschia pungens*, did not exceed 14,000 cellsL^{-1} (reported from station N10 at mid-depth during W9611; Appendix F-1). These results are well below the 100,000 cellL^{-1} threshold tentatively being used by the HOM Program based on domoic acid toxicity levels observed in Canadian waters (S. Bates, pers. comm.).

5.3.2 Zooplankton

5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Zooplankton densities in the nearfield also exhibited dissimilar patterns among stations, with station N10 exhibiting fluctuating, but generally decreasing abundance through the reporting period (Figure 5-17). Initial total densities of around 80,000 m^{-3} in early August decreased to around 20,000 m^{-3} by December, with periodic increases seen during early September and again in late October. Each of these increases followed maxima in phytoplankton abundance (Section 5.3.1).

The more seaward station N04 generally increased through the early October survey (W9615), while the results from the two surveys which captured station N16 seemed to also show an increase into early October (Figure 5-17). Initial total abundances during mid-August ranged from around 40,000 m^{-3} (station N04) to 50,000 m^{-3} (station N16). Peak densities by W9615 at N04 exceeded 90,000 m^{-3}.

5.3.2.2 Nearfield Zooplankton Community Structure

Zooplankton community composition during the surveys was dominated by copepod adults and copepod nauplii (Figure 5-18). All nearfield station results included a substantial contribution from bivalve larvae (densities of up to 18,500 m^{-3}), comprising from around 10 percent to as much as 40 percent of the total assemblage (Appendix H).

The numerically dominant species among the copepods during the reporting period was *Oithona similis*, with copepodite densities doubling to around 32,000 m^{-3} during the zooplankton abundance peak in late October (W9615; Appendix H). Other dominant copepods included *Pseudocalanus newmani* during the early part of the period, and *Centropages typicus*, *Temora longicuris*, and *Centropages* sp. later in the period. In terms of estimated biomass, *Centropages typicus* was the dominant species.

5.3.2.3 Regional Zooplankton Assemblages

Regional data for the first combined nearfield/farfield survey of the reporting period (W9611) showed highest zooplankton densities (around 140,000 m^{-3}) within Boston Harbor (Figure 5-19). Cape Cod Bay also exhibited relatively high zooplankton densities, exceeding 105,000 m^{-3} at station F01. Densities at

all other stations were less than 80,000 m^{-3}, with the greatest relative densities reported from Coastal station F24 and F13. Each station was numerically dominated by copepod adults and nauplii. The copepod component was dominated by *Oithona similis* (Appendix H).

By the early October combined survey (W9614), the highest densities were found at Cape Cod Bay stations F01 and F02, Boundary station F27, and nearfield station N16 (Figure 5-20). At least one station in each region included peaks greater than 50,000 m^{-3}. The lowest densities were reported in the harbor and adjacent coastal stations, with the exception of Harbor station F23. Copepod adults and nauplii dominated the zooplankton community, with a substantial influence by Bivalvia larvae (notably at station F13, Appendix H). *Oithona similis* was the dominant copepod species present.

Zooplankton results from the winter nutrient survey W9617 showed a similar composition at the four stations sampled (stations F23, F06 and nearfield stations N10 and N04), although densities were lower in the harbor and inshore nearfield station (Figure 5-21). The assemblages were dominated by copepod adults and nauplii. *Oithona similis* was numerically the dominant copepod species, followed by *Pseudocalanus newmani*. The highest densities were reported at the Offshore station F06.

5.4 Summary of Water Column Biological Events

Productivity

- The highest production rates for the period were measured in Boston Harbor (3,473 $mgCm^{-2}d^{-1}$) and inner nearfield (2,898 $mgCm^{2}d^{-1}$) during mid-August, concurrently with a phytoplankton bloom in the harbor and near-coastal waters;

- Peak productivity elsewhere in the nearfield occurred in late September (station N04) and early October (station N16) during the fall bloom;

- High-resolution productivity estimates indicate that the fall bloom peaked around the first week in October, with a secondary event evident in Massachusetts Bay during November;

- Estimates of seasonal production based on high-resolution productivity indicate that survey results underestimated fall production by 58% at station N04 and 64% at station N10;

Respiration

- Peak surface water respiration rates occurred in the inner nearfield (station N10) during the August harbor/coastal bloom. The strong seasonal pattern in rates followed water column temperature, and to a lesser extent, POC, chlorophyll, and productivity;

- Secondary peaks in nearfield surface water respiration occurred in late September (station N04) and early October (station N16) during the fall bloom;

- Bottom water respiration in the nearfield generally increased through early October, then stabilized at a slightly lower rate for the remainder of the year;

- Carbon-specific respiration in the nearfield was highest during the stratified period of August and early September except for station N16, which peaked during early October;

- Vertical distribution of both respiration and carbon-specific respiration showed 3-4 times higher rates in surface vs. bottom water during stratification, but comparable rates after fall mixing;

- Carbon-specific respiration within the nearfield, coupled with chlorophyll and productivity data, suggested that *in situ* carbon fixation, rather than import of detrital carbon, is the major source of organic matter throughout the nearfield.

Phytoplankton

- Peak phytoplankton abundance occurred in the harbor and inner nearfield (station N10) during August, and in the outer nearfield (N16 and N04) during October;

- The inshore bloom in August was produced by the centric diatoms *Rhizosolenia fragilissima* and *Leptocylindrus minimus*, which substantially decreased in abundance offshore;

- Cryptophytes appeared to initiate the fall bloom inshore, dominating the inner nearfield assemblage (N10) by early September, and the outer nearfield (N04) by late September;

- Centric diatoms dominated the fall bloom by early October, with *Skeletonema costatum* and *Cyclotella* sp. dominant inshore and small unidentified centric (tentatively identified as *Thalassiosira* sp.) dominant at the more seaward stations. Cryptophytes continued to an important component of the harbor assemblage;

- The fall bloom appeared to diminish inshore by the end of October, but *Rhizosolenia fragilissima* may have continued the bloom offshore into November based on chlorophyll and productivity data;

- A subsurface bloom of the dinoflagellate *Ceratium tripos* was reported at station N10 during late October, which reached a density of 21,000 cellsL^{-1};

Zooplankton

- Peak inshore zooplankton abundance occurred in August and September, while offshore abundances steadily increased through October;

- Farfield results showed greatest densities in Boston Harbor and near-coastal stations, including Cape Cod Bay station F01, during August, at the more seaward stations reaching peak abundance during October;

- The zooplankton community was dominated by copepod adults and copepod nauplii, with the numerical dominant being *Oithona similis*, and the biomass dominant being *Centropages typicus*. Bivalve larvae contributed substantially to the assemblage during early October.

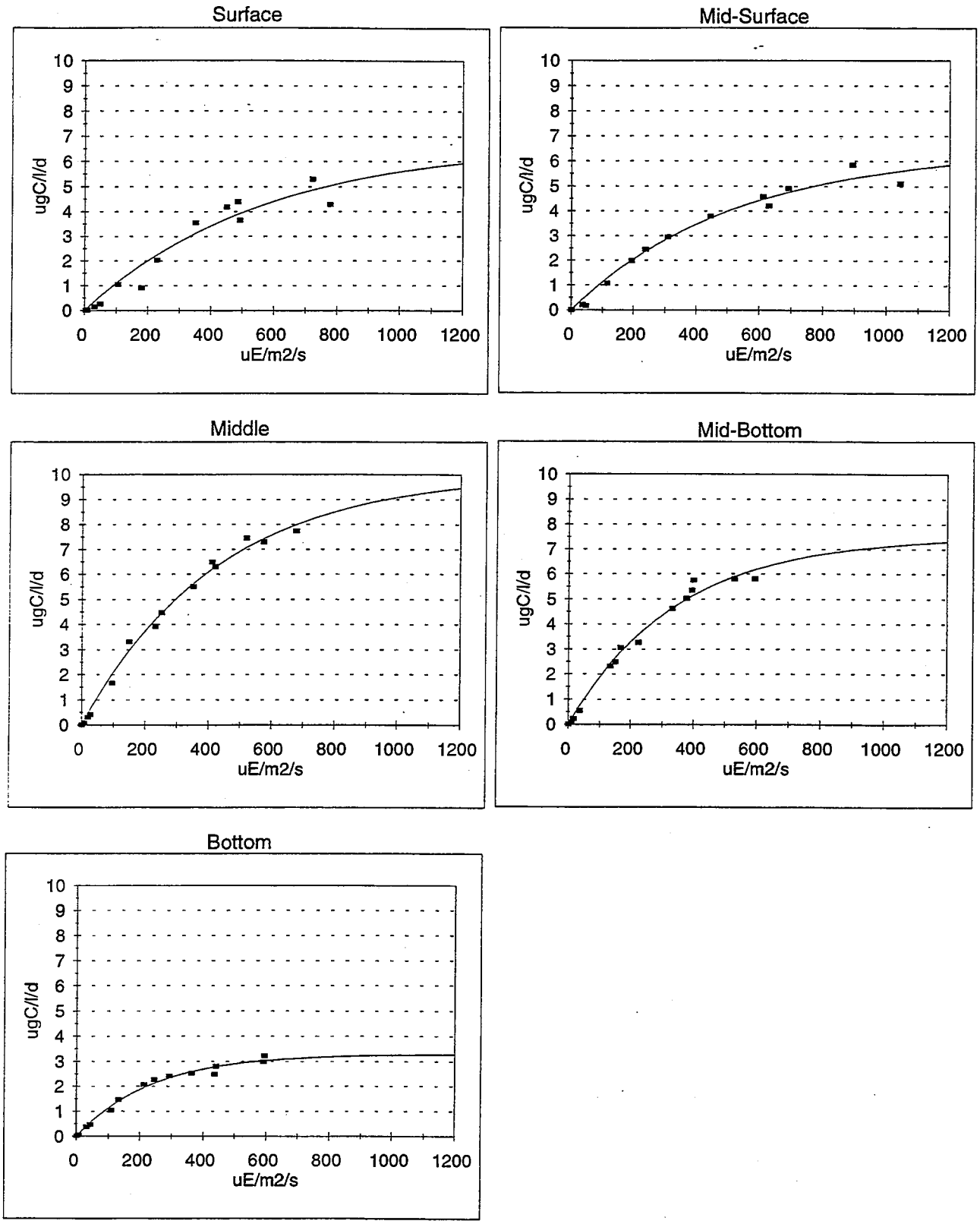
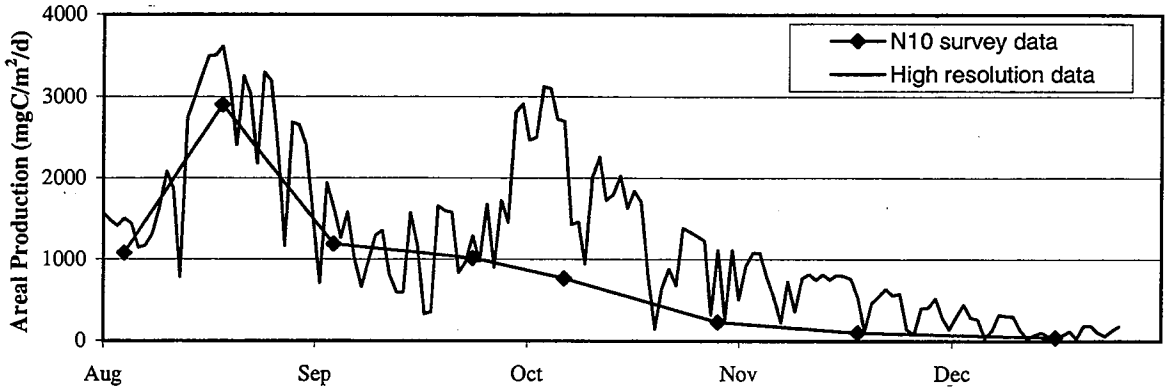
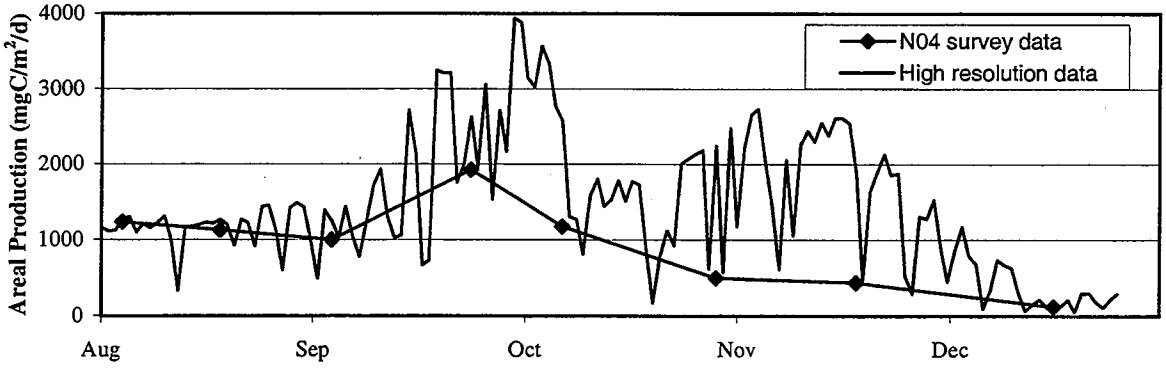


FIGURE 5-1
An Example Photosynthesis-Irradiance Curve from Station N10 Collected in August 1996





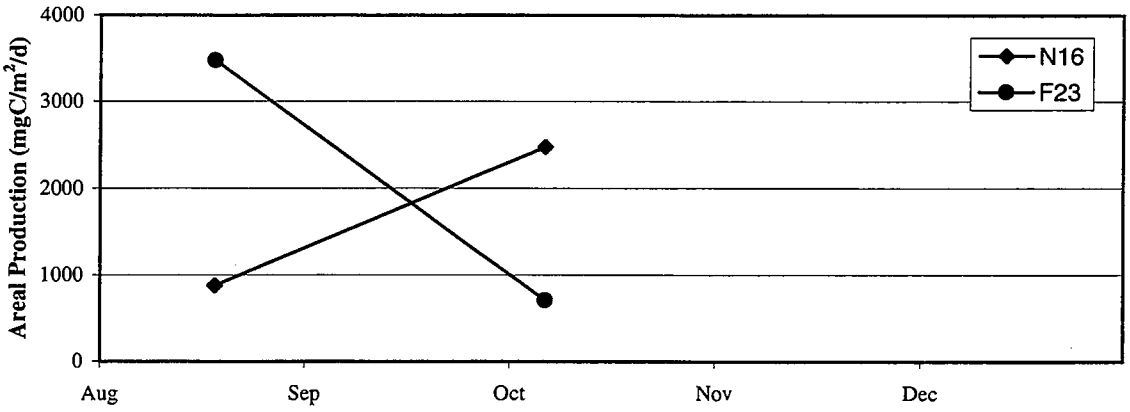


FIGURE 5-2
Time-Series of Areal Production for Productivity/Respiration Stations

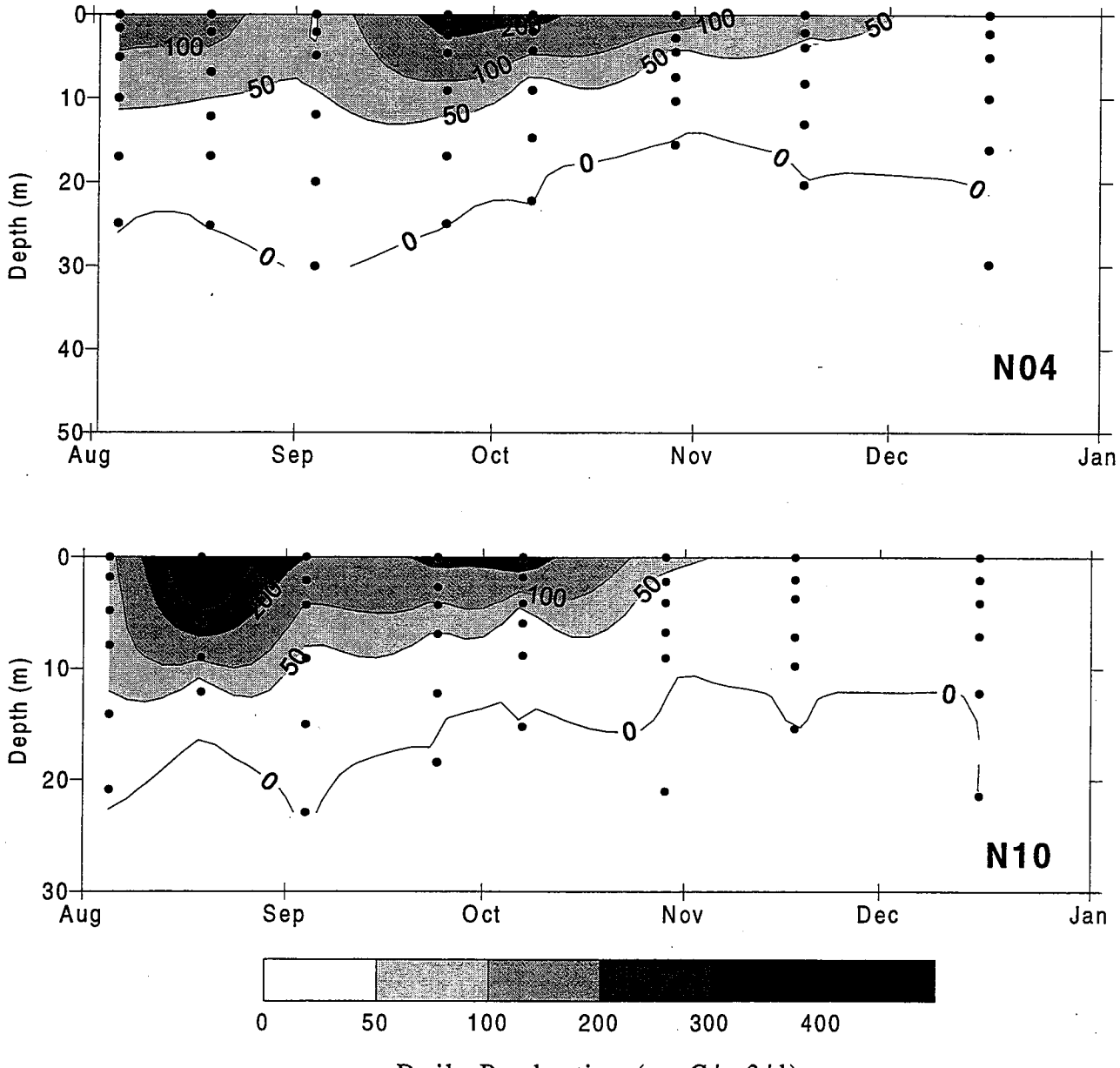


FIGURE 5-3
Time - Series of Contoured Daily Production (mgC/m³/d) at Productivity/Respiration Stations

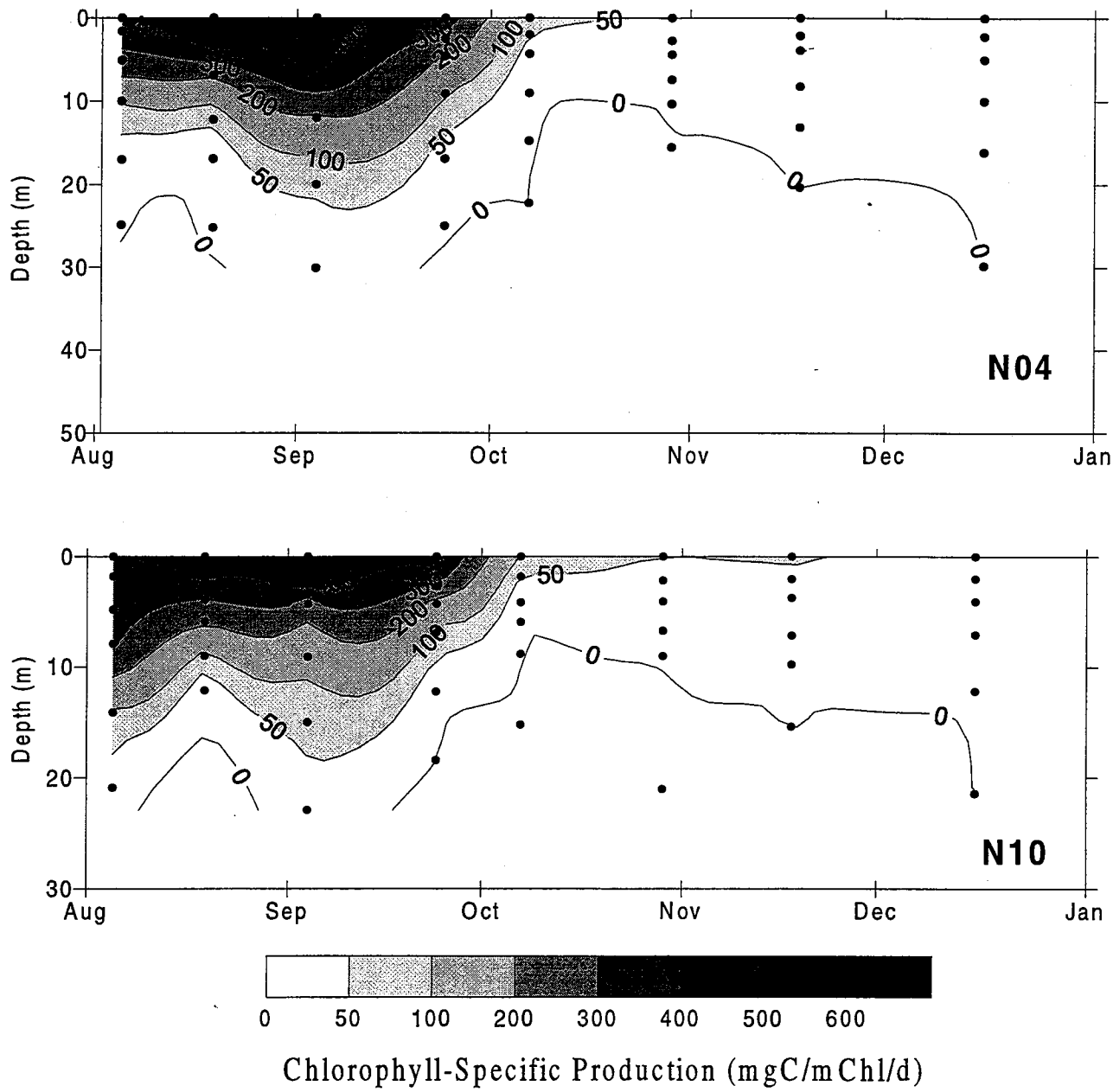


FIGURE 5-4
Time - Series of Contoured Chlorophyll - Specific Production (mgC/mgChl/d)
at Production Respiration Stations

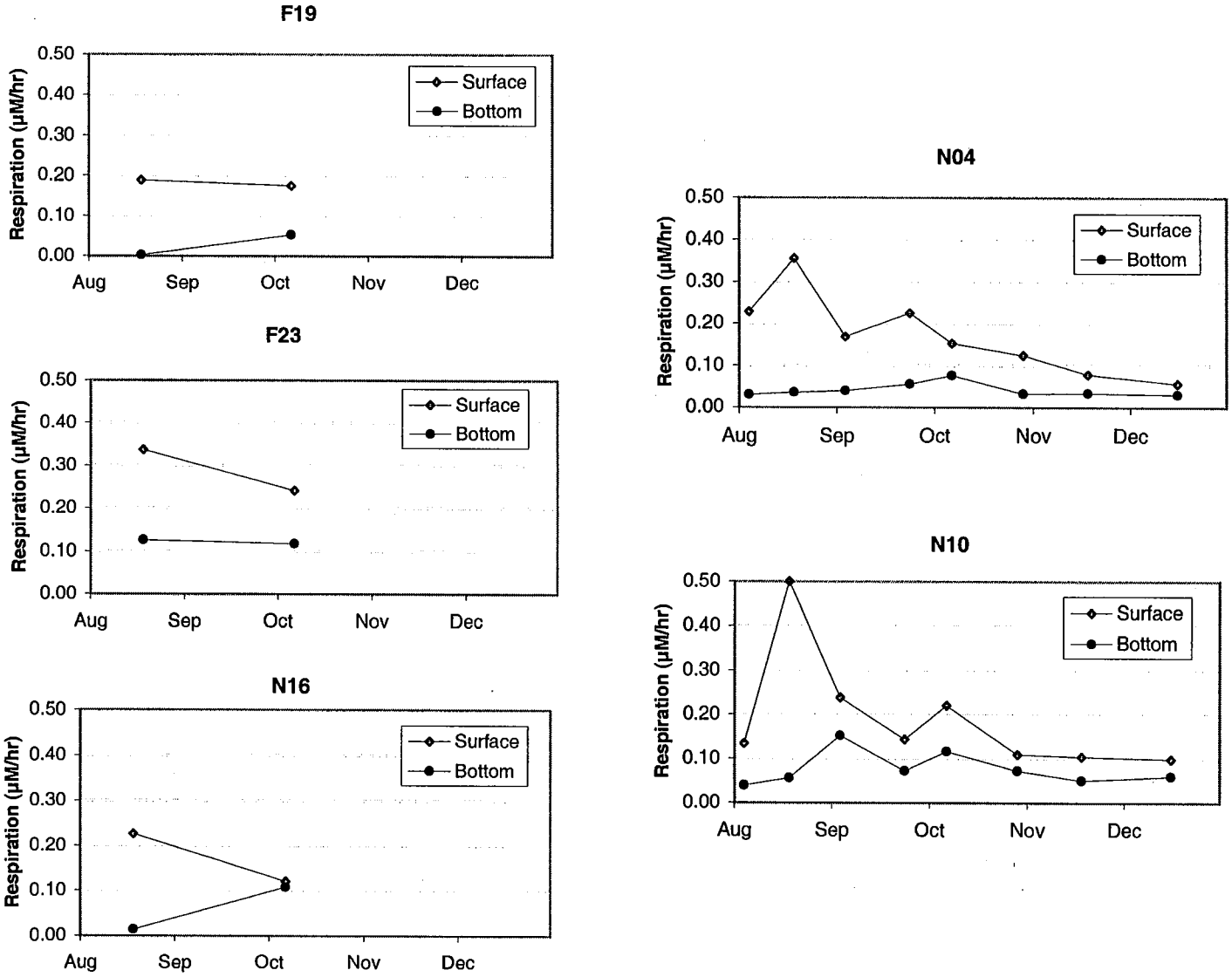


FIGURE 5-5
Time-Series of Water Column Respiration at Productivity/Respiration Stations

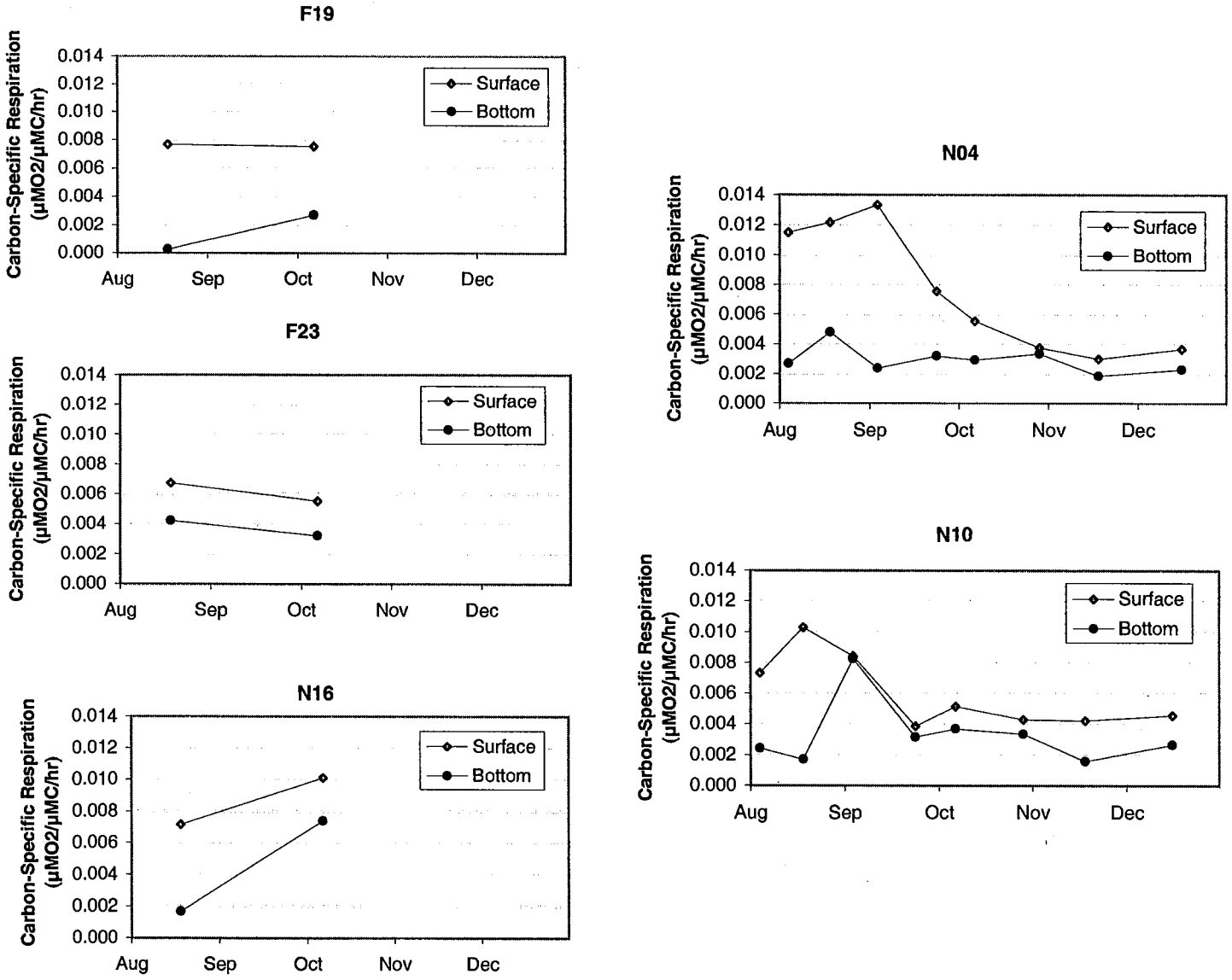


FIGURE 5-6
Time-Series of Carbon-Specific Respiration at Productivity/Respiration Stations

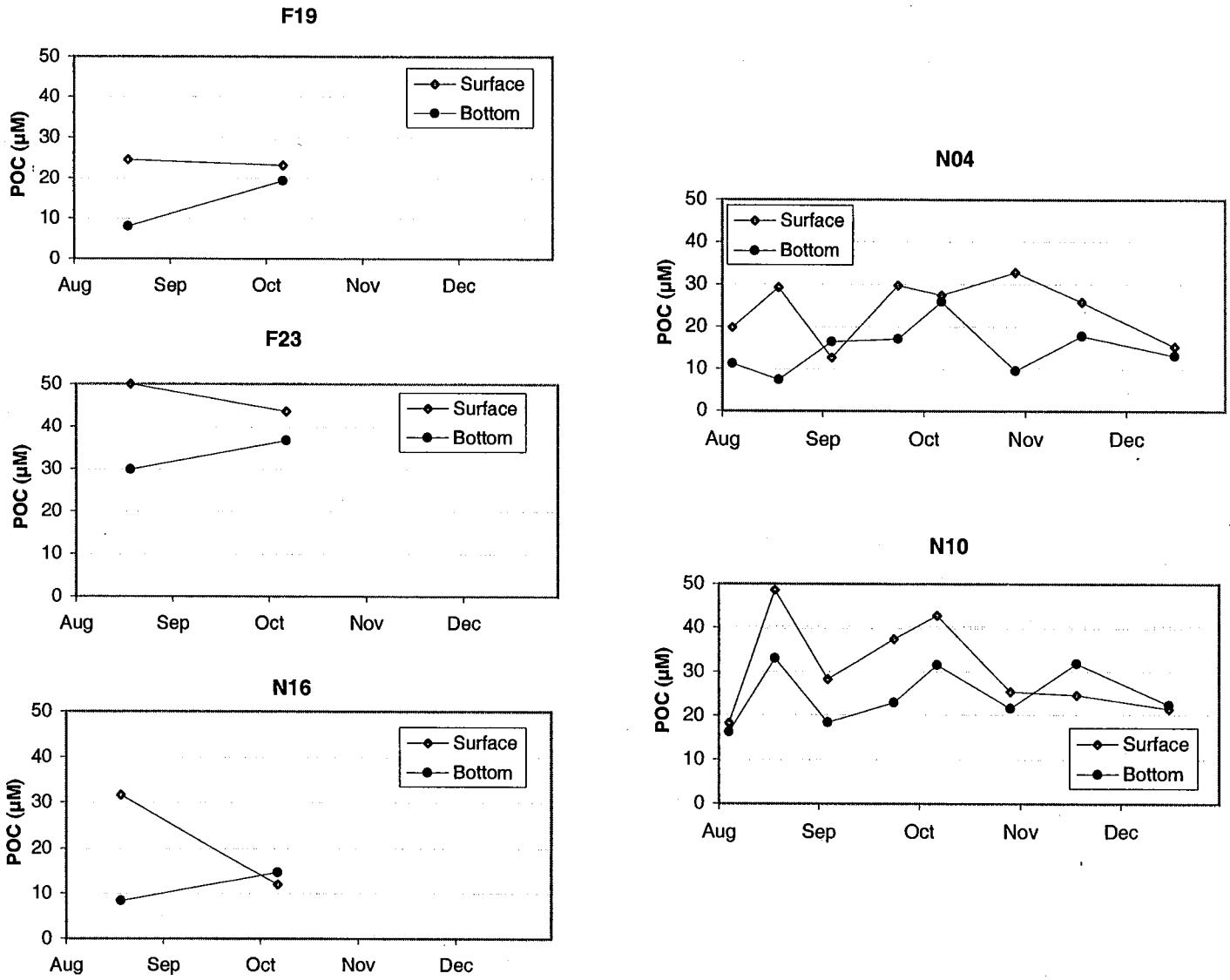


FIGURE 5-7
Time Series of Particulate Organic Carbon at Productivity/Respiration Stations

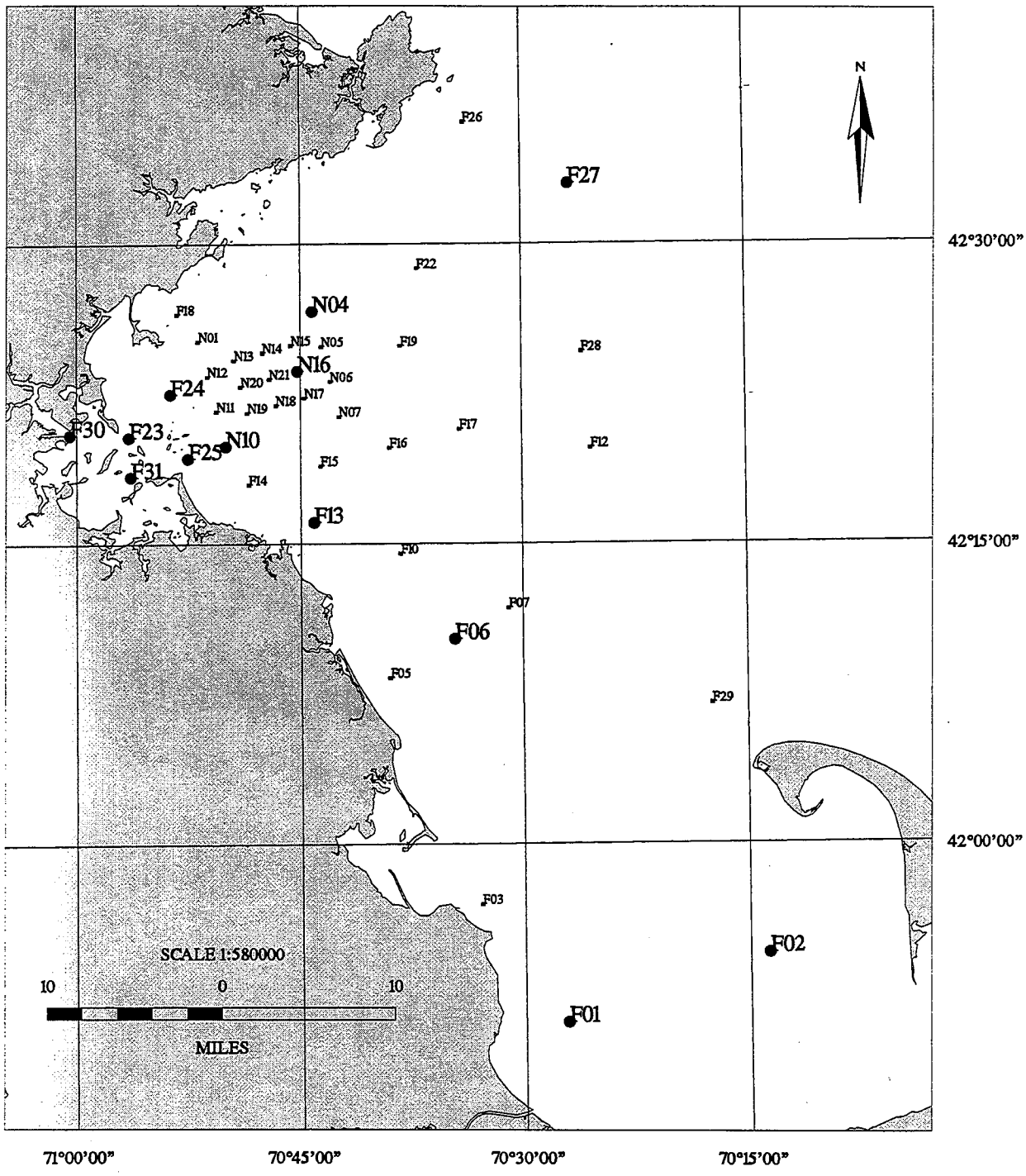
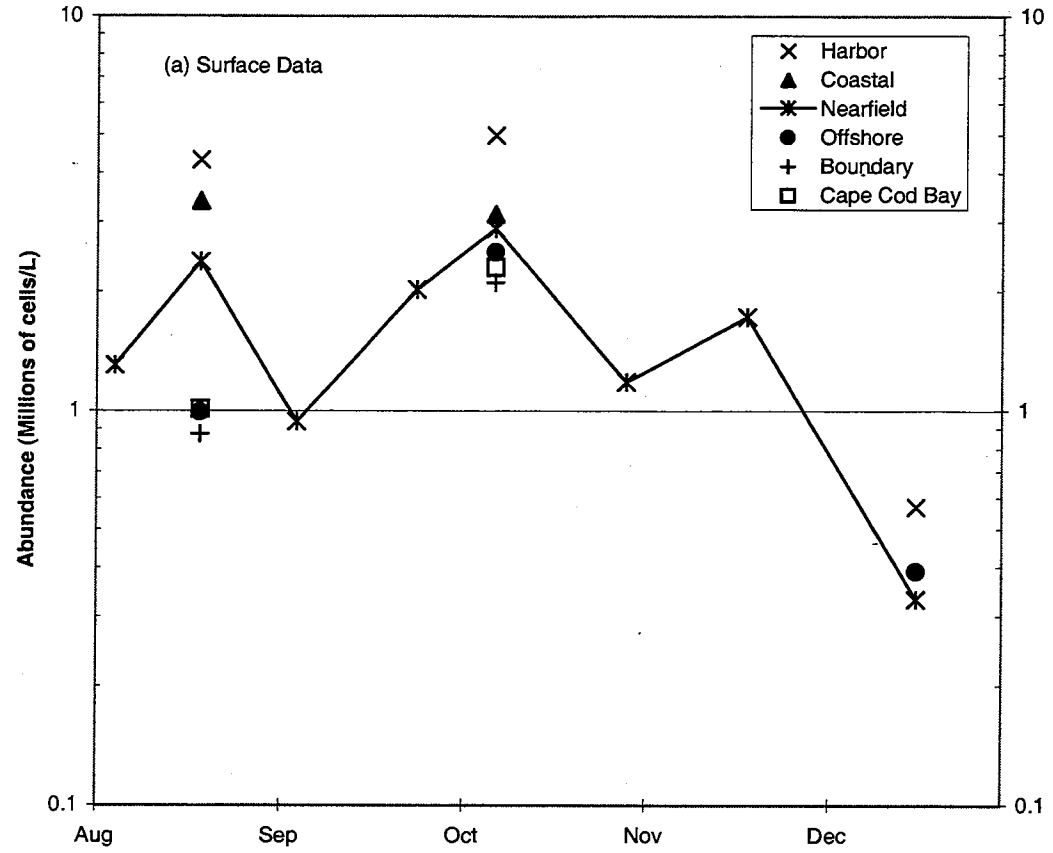


FIGURE 5-8
1996 Plankton Station Locations (Enlarged Text)



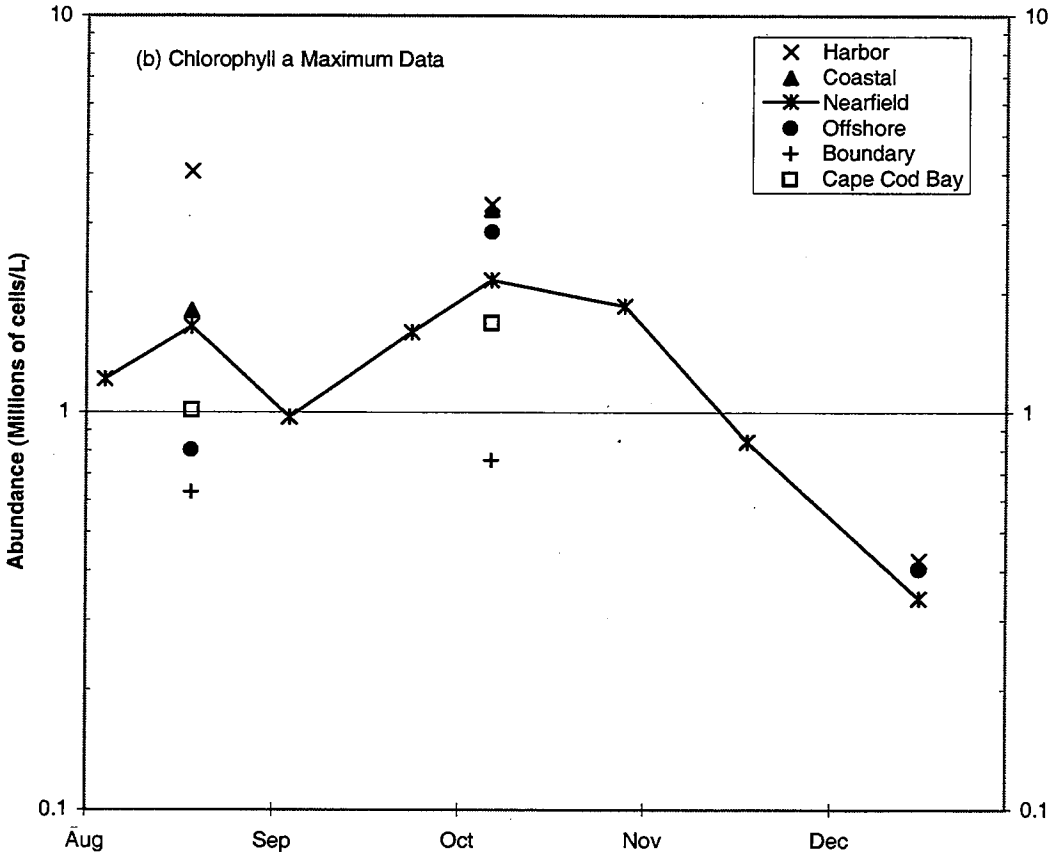


FIGURE 5-9
Regional Phytoplankton Abundance, Surveys W9610 - W9617

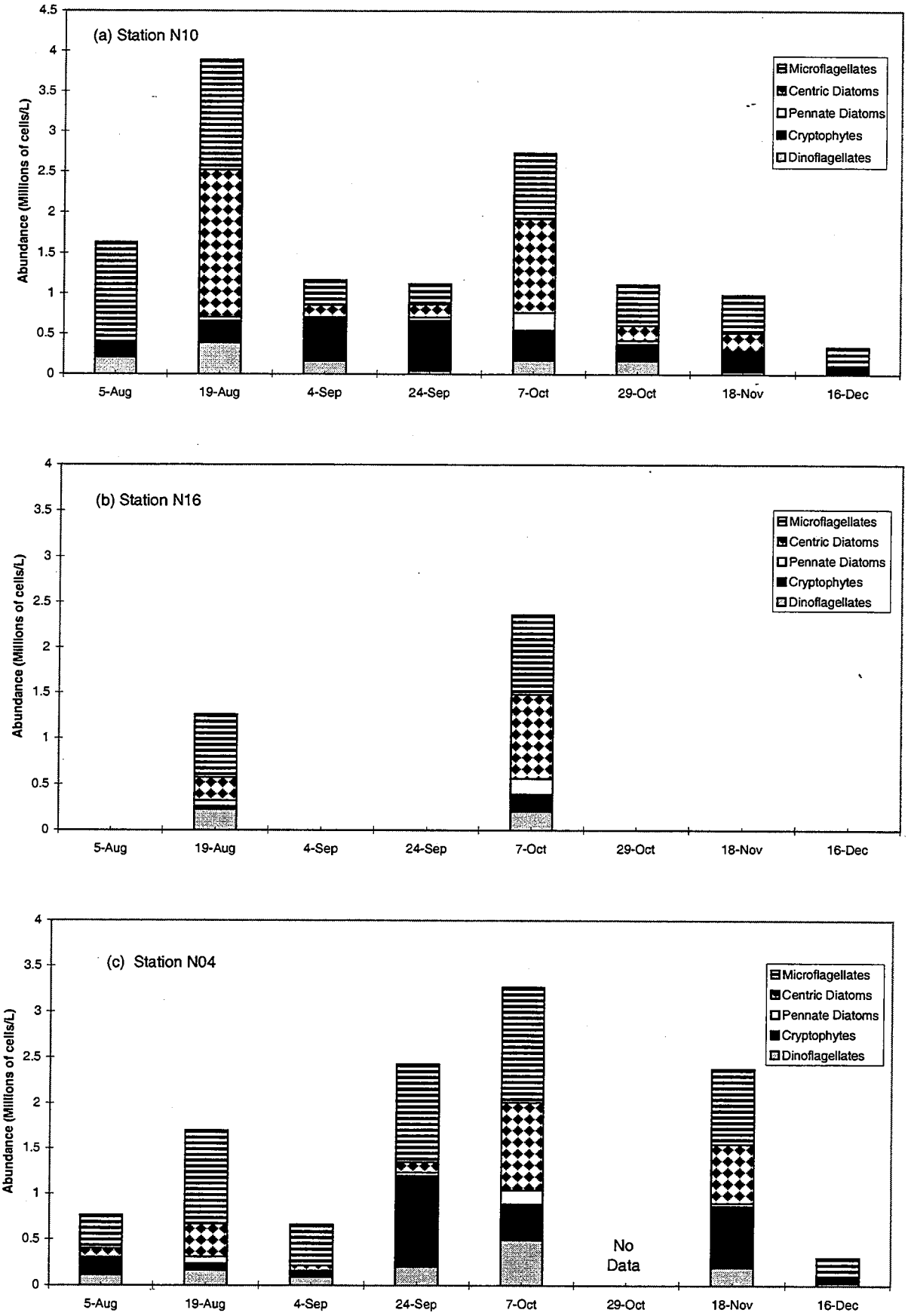


FIGURE 5-10
Phytoplankton Abundance by Major Taxonomic Group, Nearfield Surface Samples

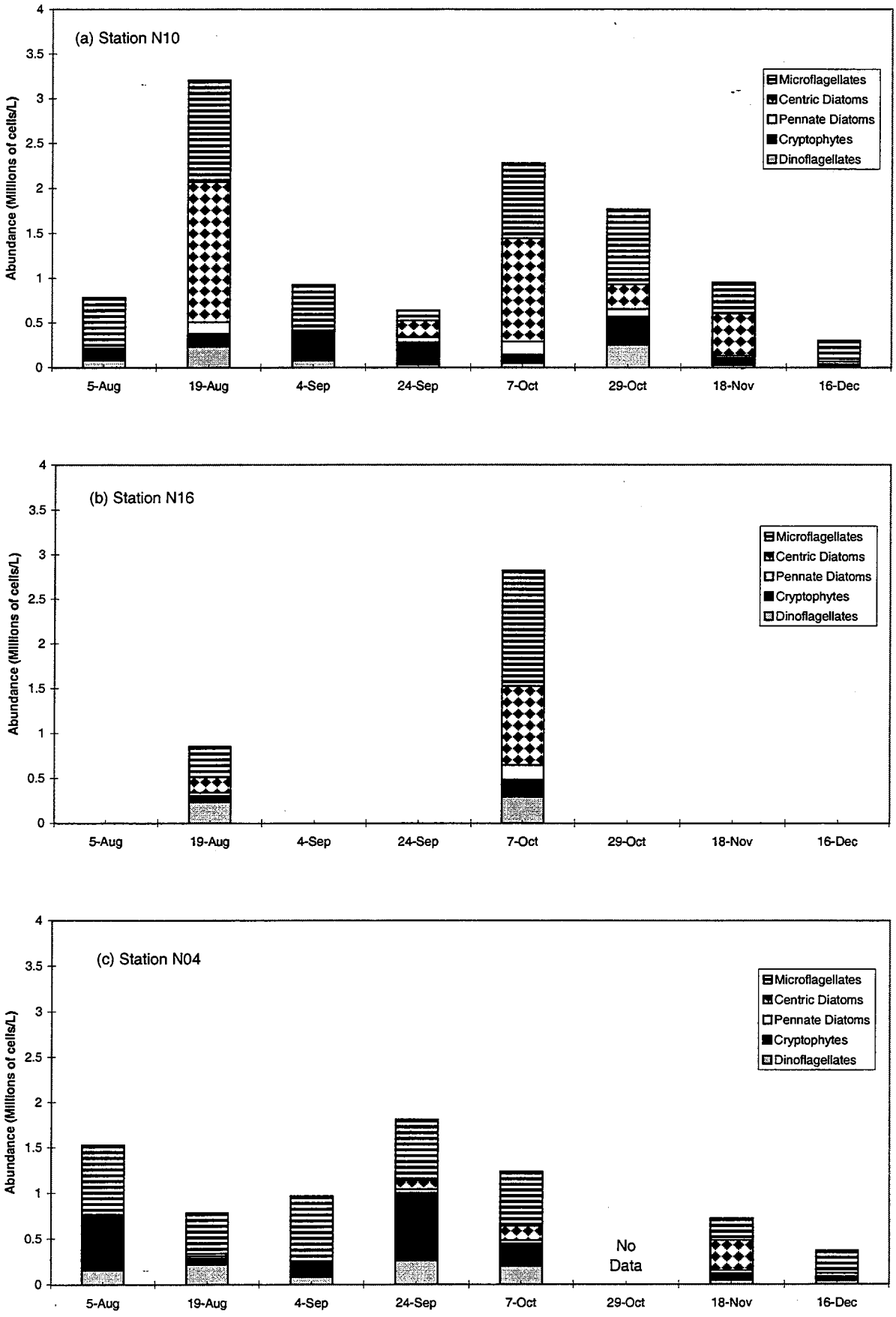


FIGURE 5-11
Phytoplankton Abundance by Major Taxonomic Group, Nearfield Chlorophyll a Maximum Samples

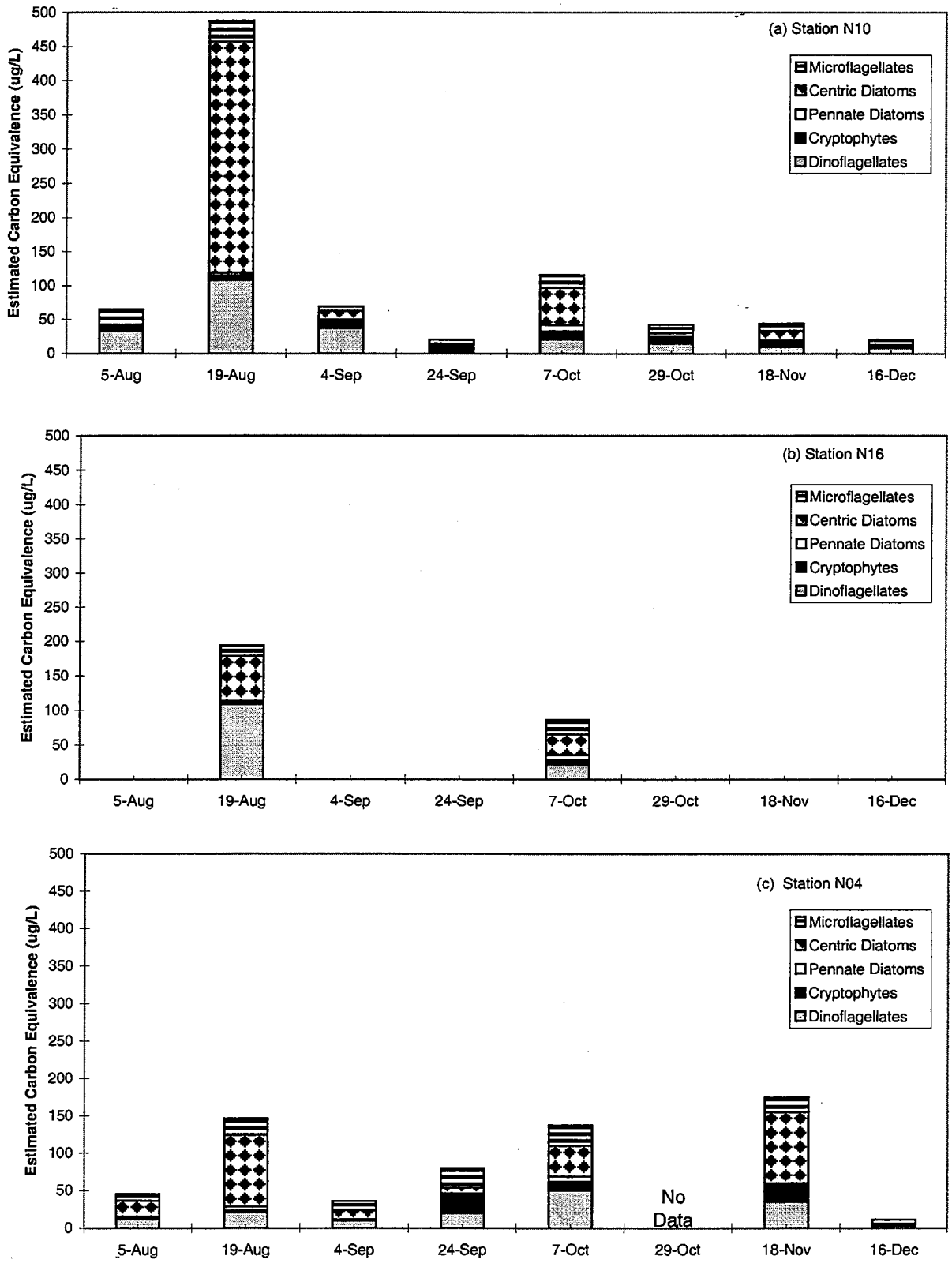


FIGURE 5-12
Phytoplankton Carbon by Major Taxonomic Group, Nearfield Surface Samples

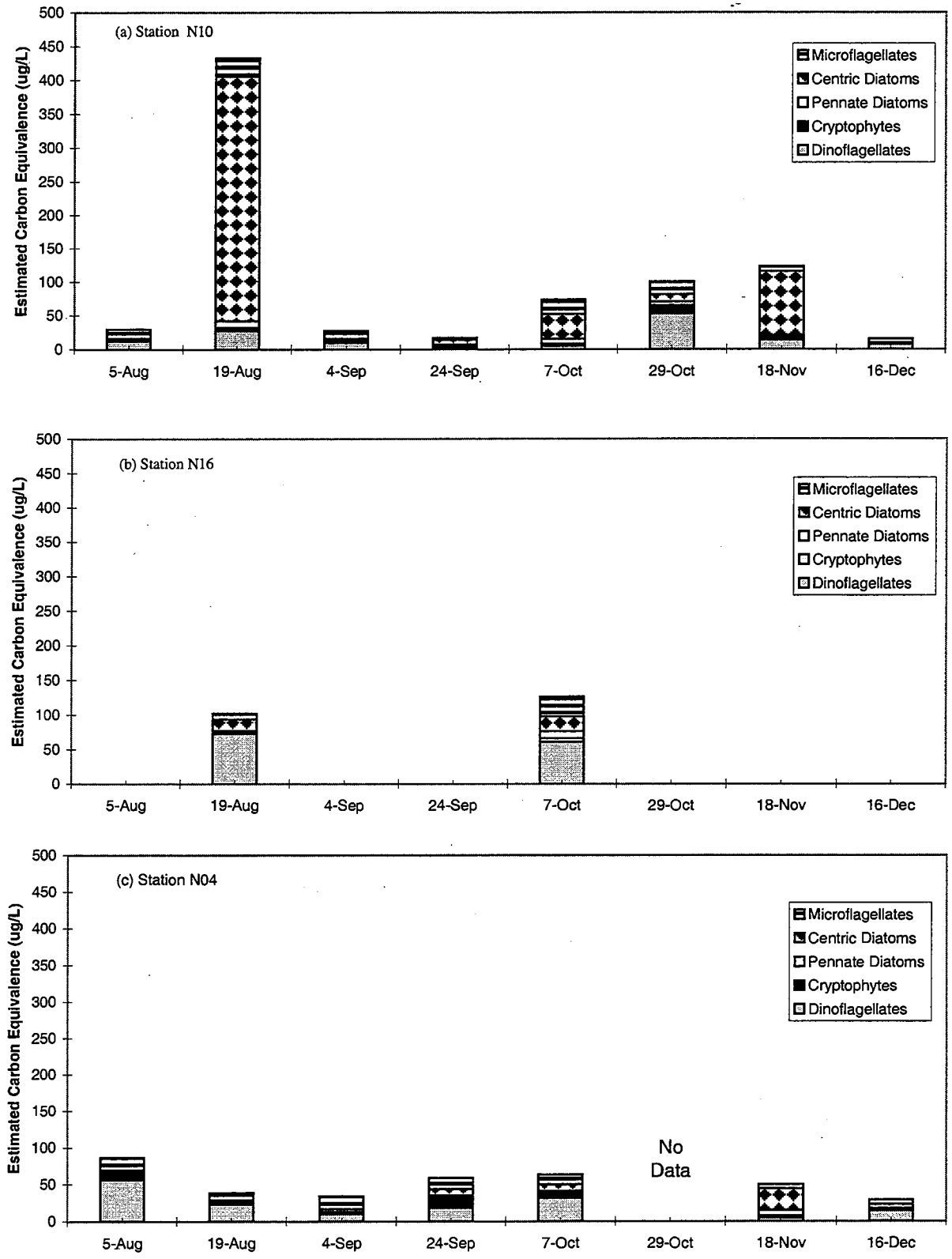
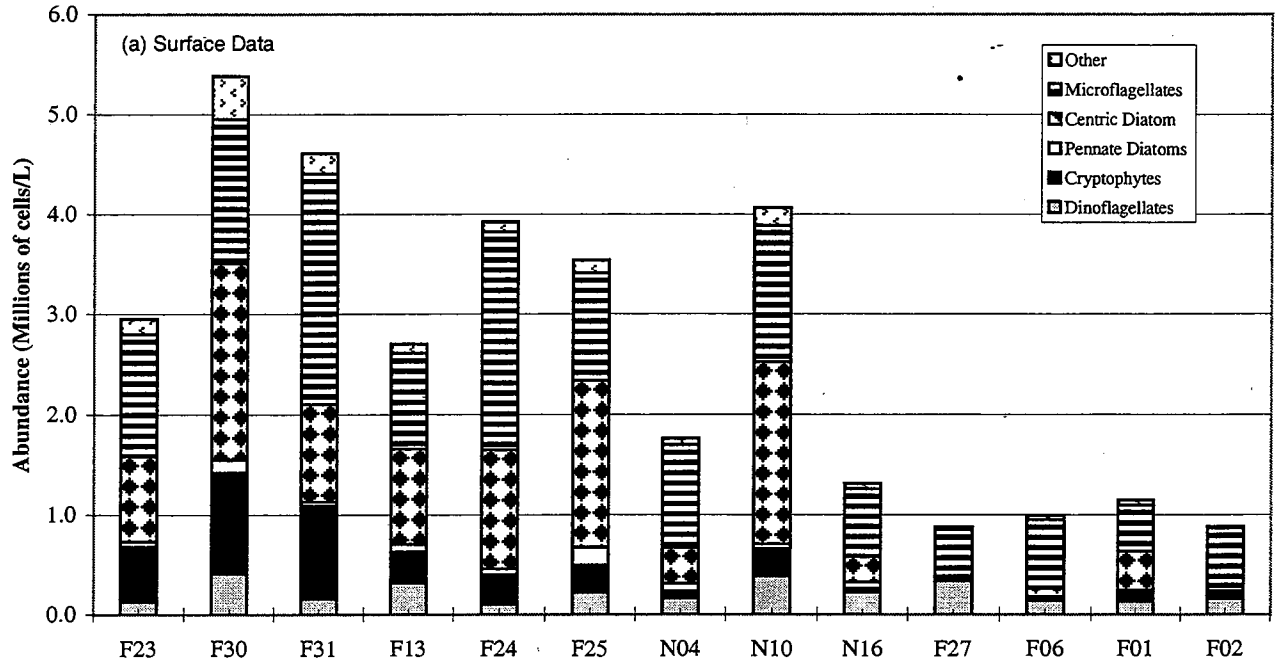


FIGURE 5-13
Phytoplankton Carbon by Major Taxonomic Group, Nearfield Chlorophyll a Maximum Samples



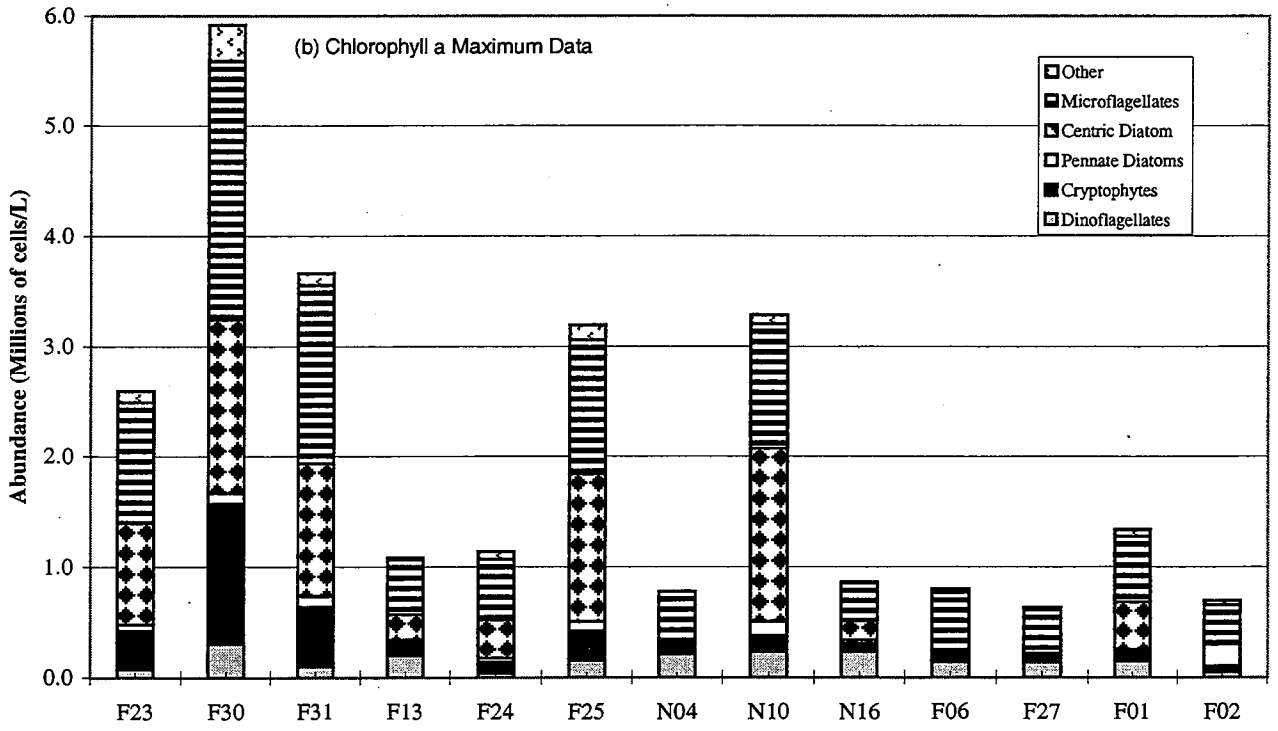
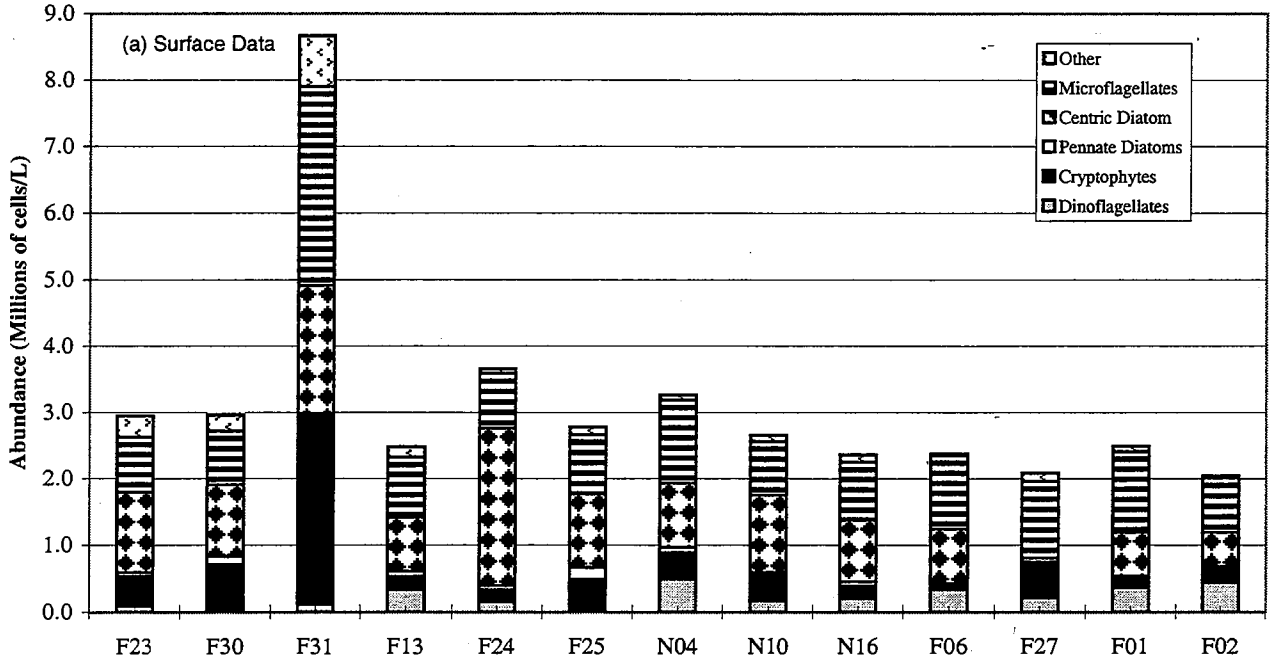


FIGURE 5-14
Phytoplankton Abundance by Major Taxonomic Group - W9611 Farfield Survey Results
August 19-22, 1996



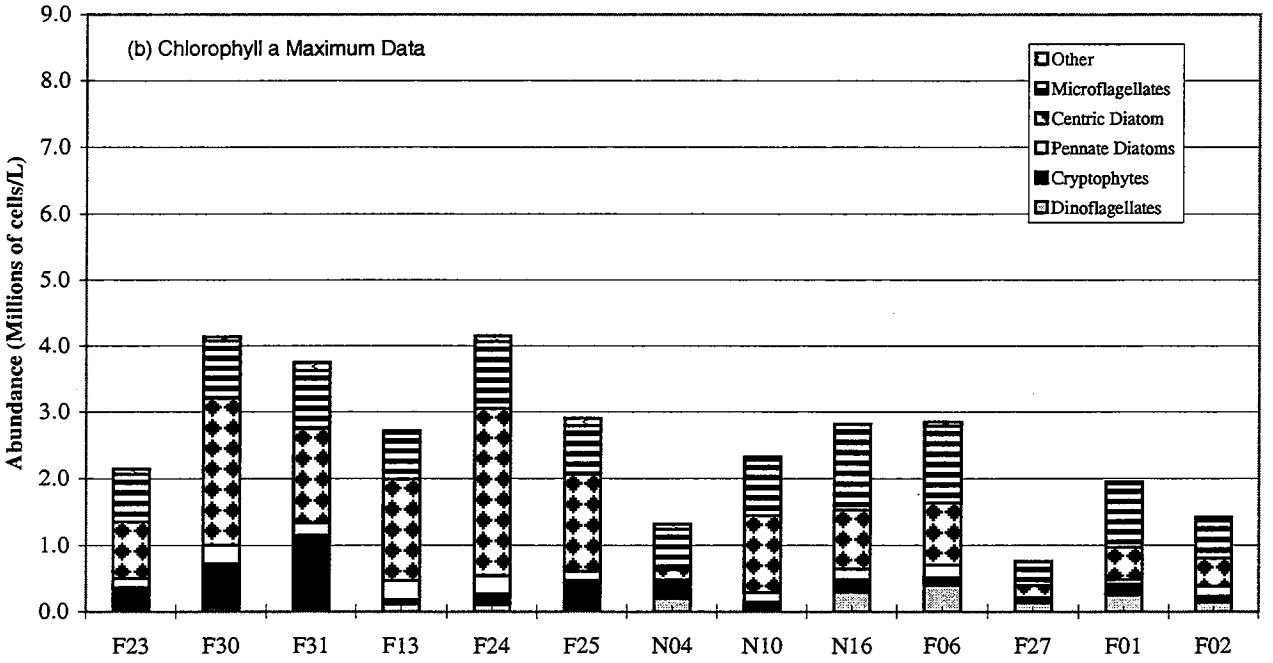
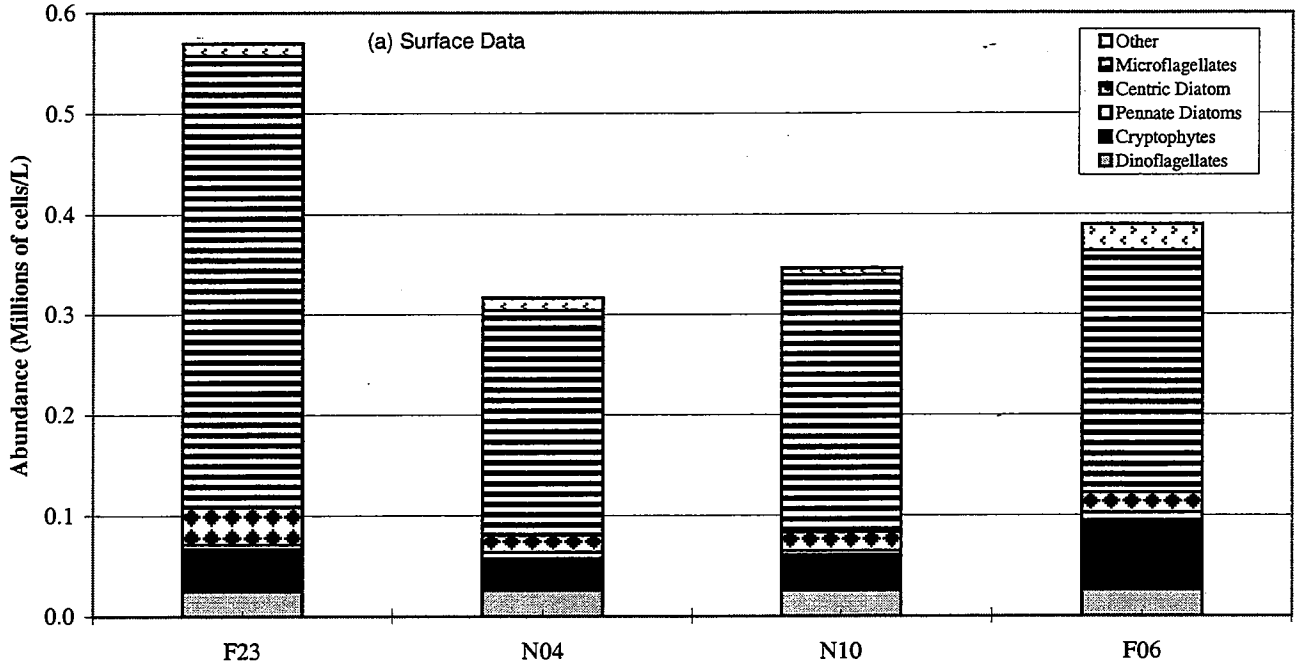


FIGURE 5-15
Phytoplankton Abundance by Major Taxonomic Group - W9614 Farfield Survey Results
October 7 - 10, 1996



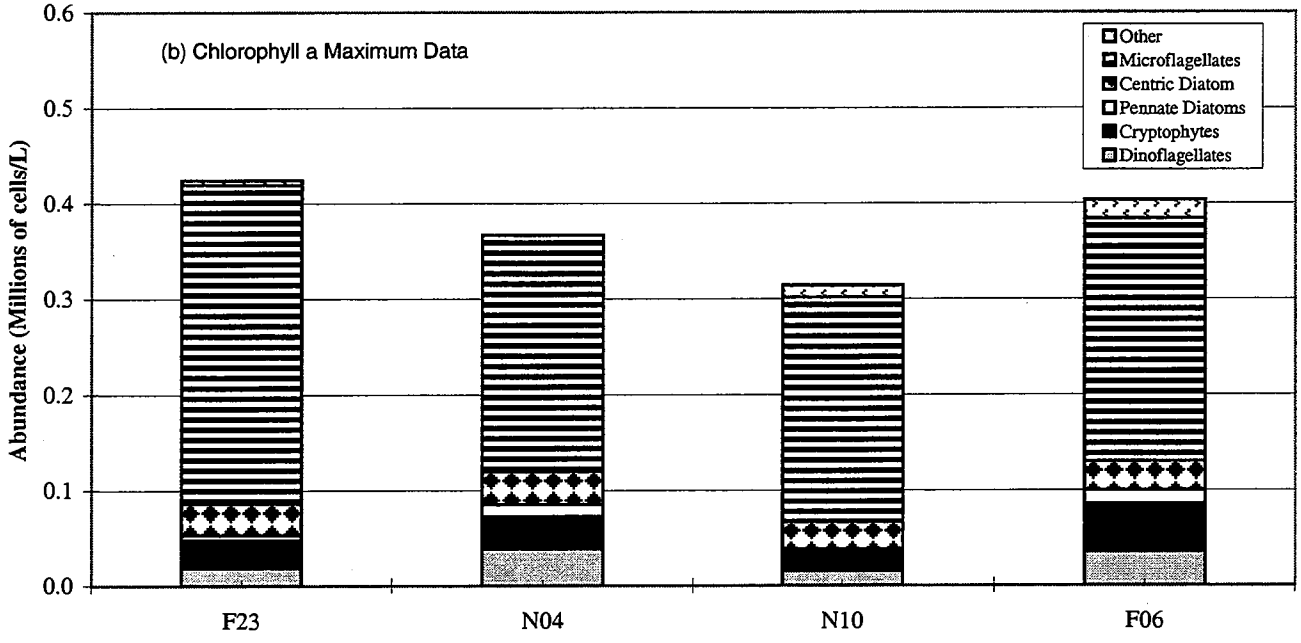
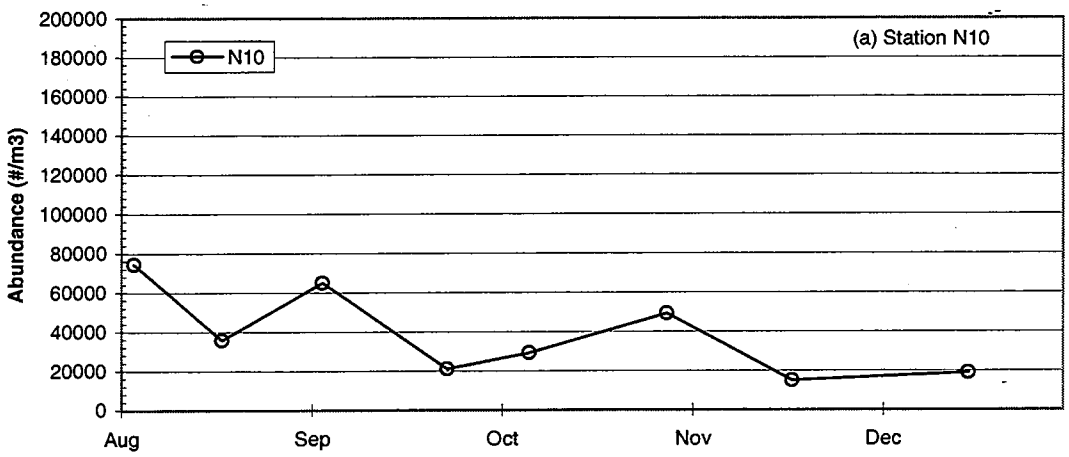
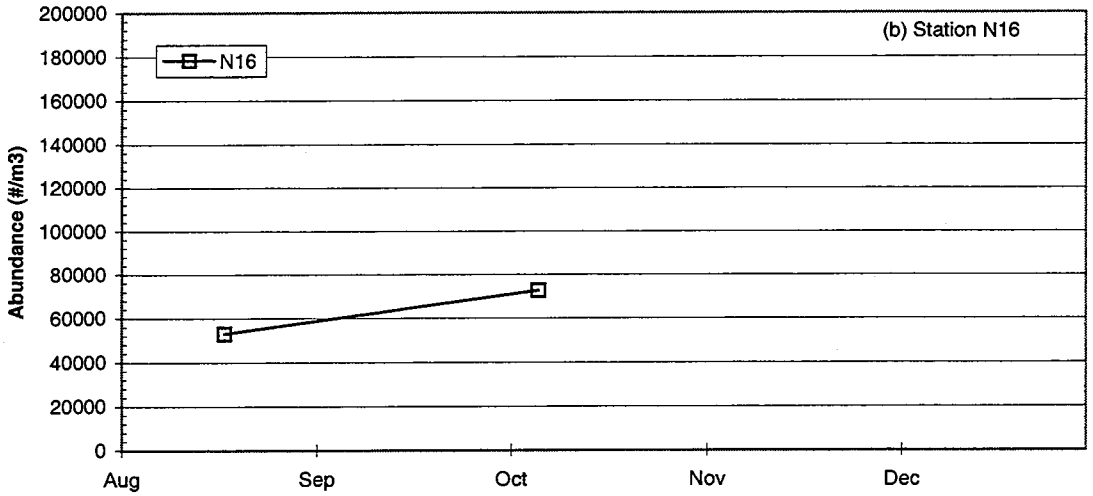


FIGURE 5-16
Phytoplankton Abundance by Major Taxonomic Group - W9617 Farfield Survey Results
December 17, 1996





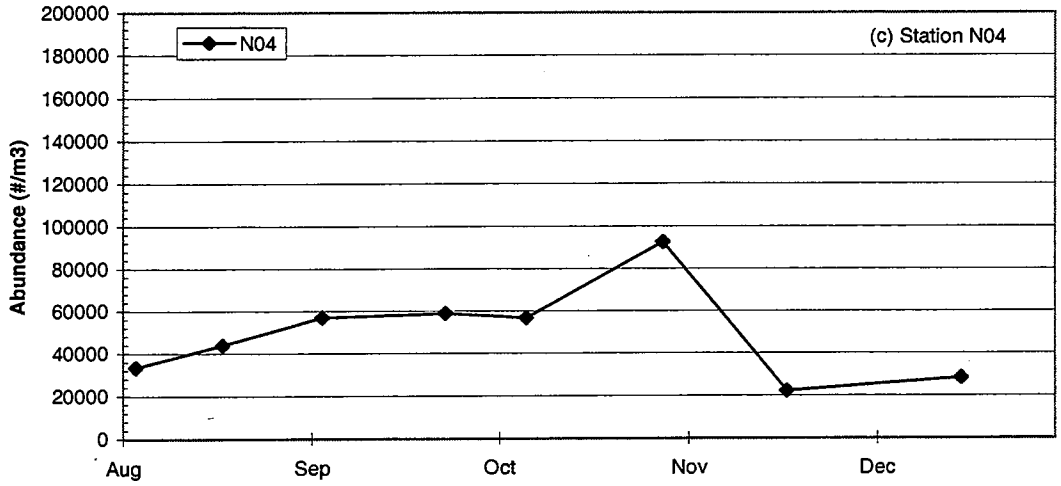


FIGURE 5-17
Nearfield Zooplankton Abundance, Surveys W9610 - W9617

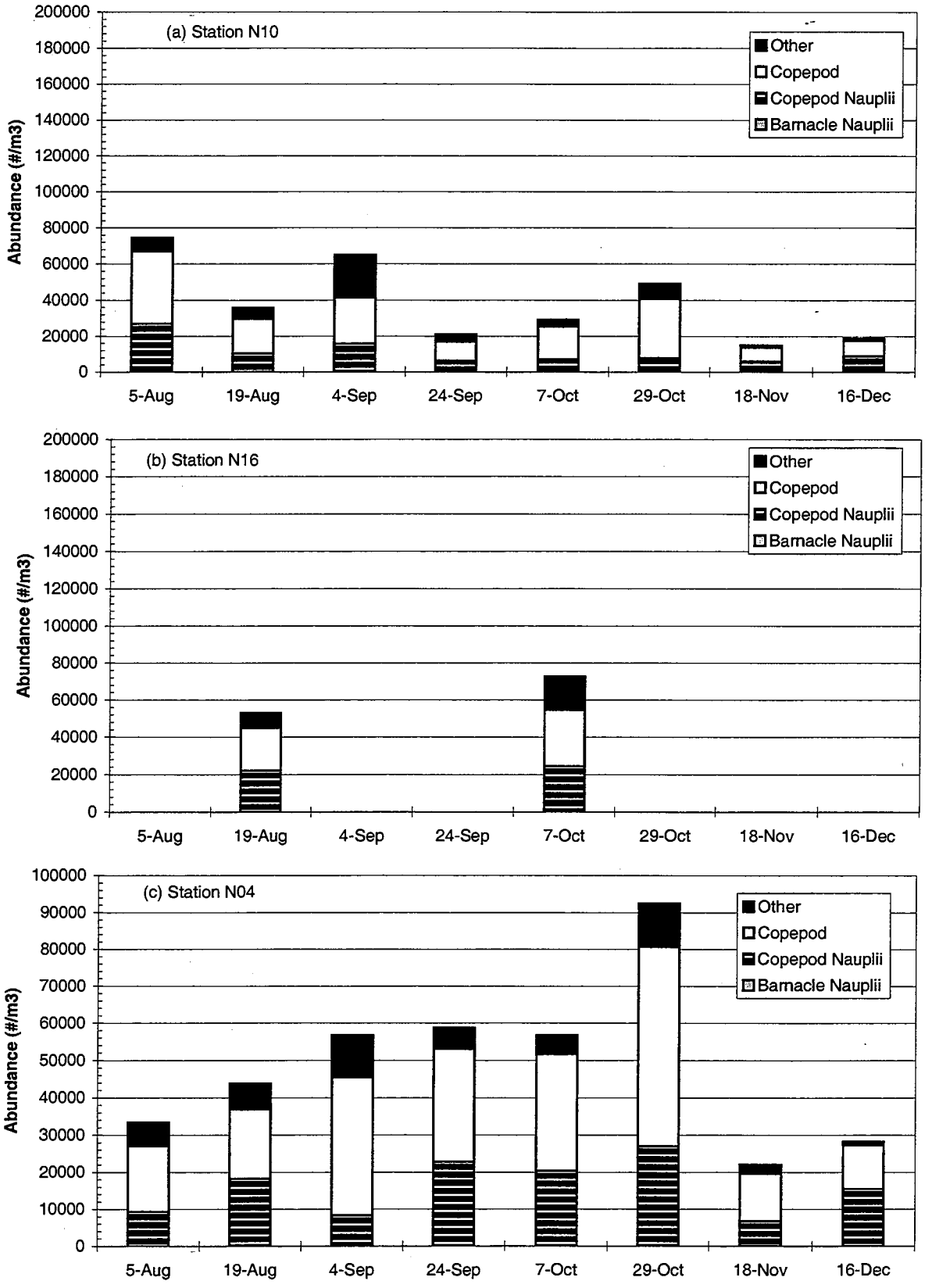


FIGURE 5-18
Nearfield Zooplankton Abundance by Major Taxonomic Group

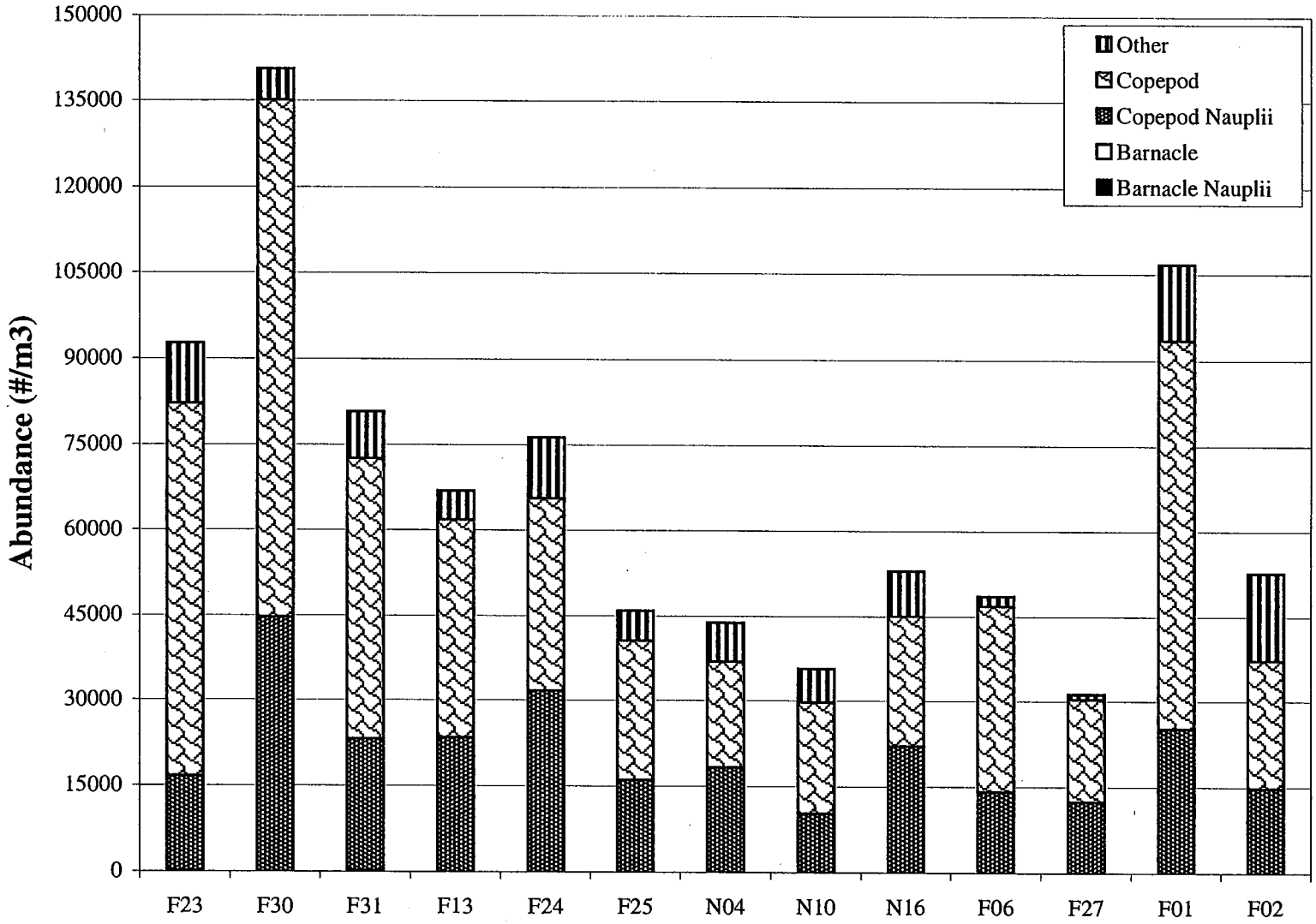


FIGURE 5-19
Zooplankton Abundance by Major Taxonomic Group - W9611 Farfield Survey Results
August 19 - 22, 1996

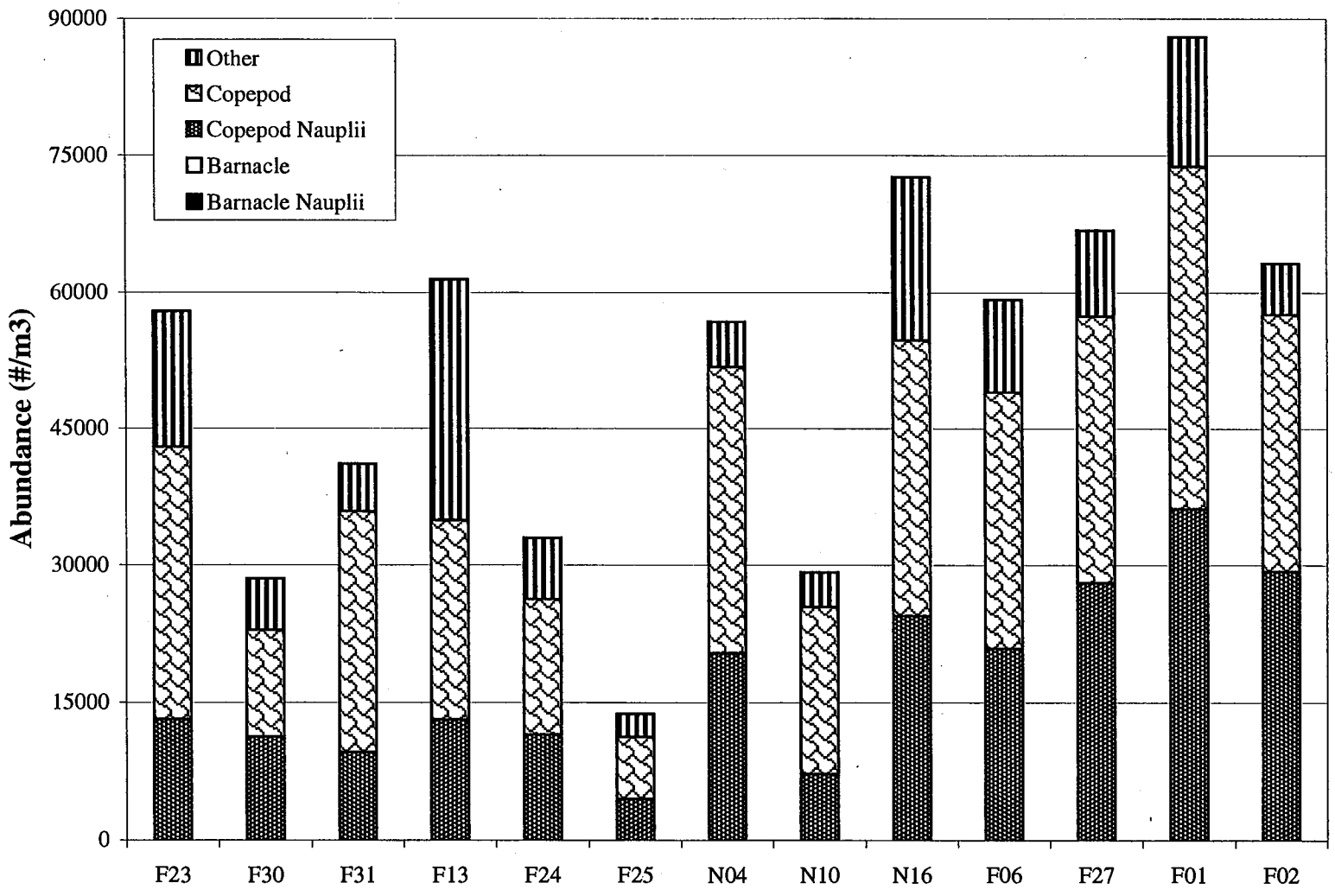


FIGURE 5-20
Zooplankton Abundance by Major Taxonomic Group - W9614 Farfield Survey Results
October 7 - 10, 1996

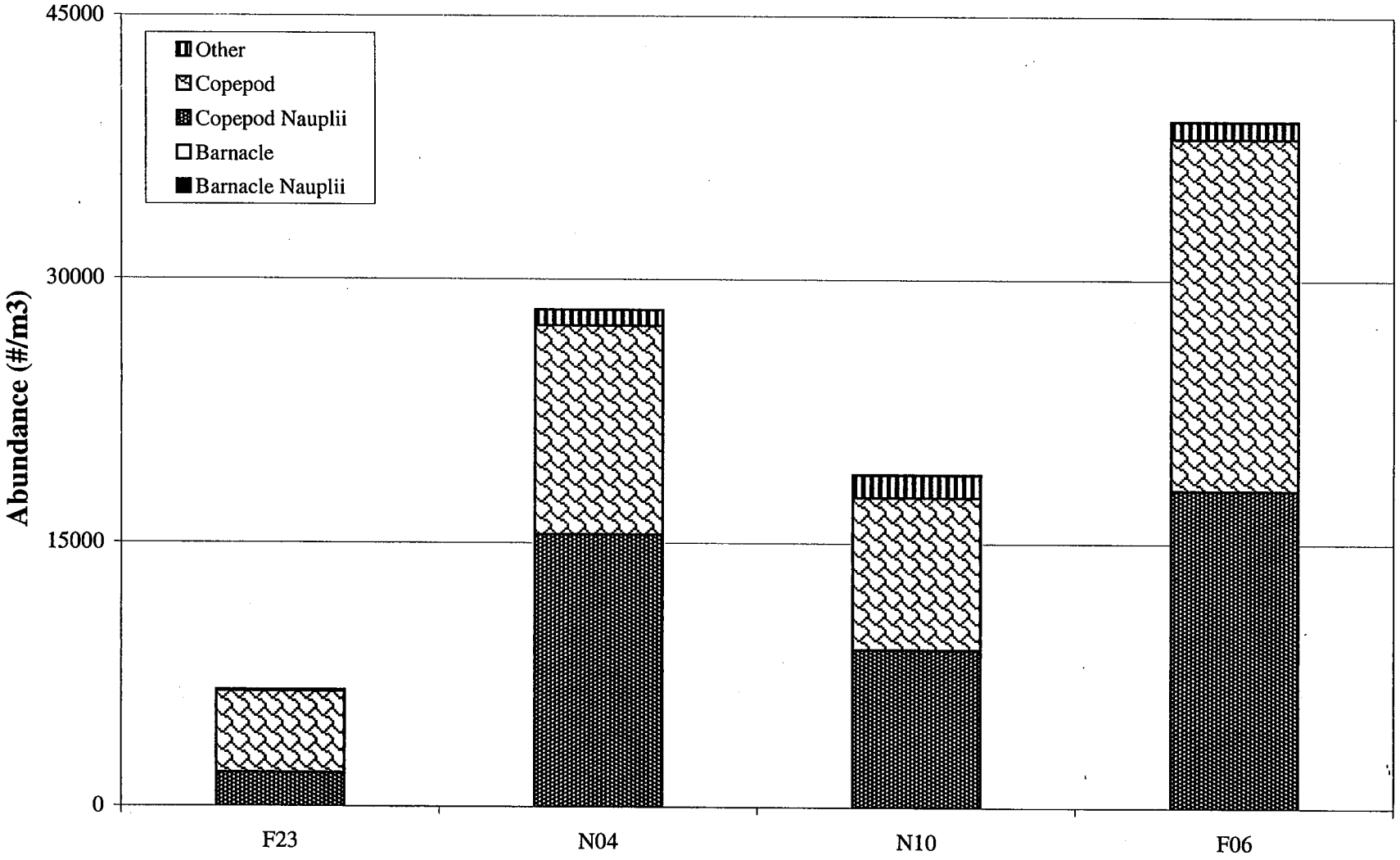


FIGURE 5-21
Zooplankton Abundance by Major Taxonomic Group - W9617 Farfield Survey Results
December 17, 1996

6.0 SUMMARY OF MAJOR WATER COLUMN EVENTS

The purpose of this section is to provide an integrated summary of the physical, chemical, and biological events which were documented by monitoring during the latter part of 1996. Two outstanding physical events were observed during the period: a coastal upwelling event during August, and a succession of storm events which caused a temporary vertical mixing of the water column. This latter event caused an early release of bottom water nutrients to the surface and initiated the fall bloom during September. In addition, this mixing event mitigated the seasonal decline in bottom water DO concentration and annual oxygen minimum.

A substantial phytoplankton bloom occurred in Boston Harbor during August. This event produced the highest rates of production and respiration measured during the reporting period. Chlorophyll concentrations measured by the Harbor Studies Program during August often exceeded 20 μg/L throughout the harbor, with phytoplankton densities from HOM samples exceeding 6 million cells/L. Algal activity was apparently high enough to deplete nutrient concentrations in the inner harbor to levels comparable to offshore surface water. Zooplankton densities in the harbor during the period were at least double those found during the October survey. Productivity was also high outside of the harbor during this bloom, however, it is uncertain whether this was entirely associated with the harbor event or partially a result of the observed coastal upwelling.

A series of storms during September initiated the release of nutrients trapped in the stratified bottom water, with complete mixing evident by the first week in October. This initial release of nutrients resulted in increased productivity throughout September, ultimately culminating in the fall bloom which peaked inshore during early October. All available evidence indicates that the fall bloom continued into November in the more offshore waters of Massachusetts Bay. Phytoplankton taxonomy suggests that this sequence was caused by a succession of dominant taxa, dominated by cryptophytes in the early stages (September) followed by a consortium of centric diatoms (early October), and ending with an offshore bloom of the centric diatom *Rhizosolenia fragilissima*.

The development of the bloom, progressing from inshore to offshore, may have been accentuated by the early release of nutrients in shallow coastal waters by the progression of September storm. Complete mixing throughout most of the nearfield by early October certainly contributed to the chlorophyll maxima seen in western Massachusetts Bay, comprising the peak of the bloom there. However, a nutricline was still evident below 30m beyond the nearfield during the period, suggesting that the deeper offshore regions of Massachusetts Bay continued to fuel production well into November, at which time light may have become the limiting factor for phytoplankton growth.

7.0 REFERENCES

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APPENDIX A

Productivity Methods

Methods

Production Analyses by ^{14}C - Field Procedures.

From each of the 5 productivity depths at each productivity station, samples were obtained by filtration through 300 mm Nitex screen (to remove zooplankton) from the Niskin bottles into opaque 1 gal polyethylene bottles. Under subdued green light, sub-samples were transferred by siphon into individual 75 ml acid cleaned polycarbonate bottles. Each bottle was flushed with approximately 250 ml of sample. A total of 16 bottles (14 light bottles, 2 dark bottles) were filled for each depth and incubated in a light and temperature controlled incubator. Light bottles from each depth are incubated at 14 light intensities (250 W tungsten-halogen lamps attenuated with Rosco neutral density filters) and all bottles incubated within 2° C of the *in situ* temperature at each depth for 4-6 hr (actual time was recorded). Single bottles of sample collected from each depth was assayed for background (time-zero) activity.

The 75 ml samples were incubated with 5-10 μCi ^{14}C-bicarbonate (higher activity during winter and spring season) and biological activity terminated by filtration of the entire contents of the bottles through 2.5 cm diameter Whatman GF/F glass fiber filters and immediate contact of the filters with 0.2 ml of a 20% aqueous solution of acetic acid contained in pre-prepared 20 ml glass scintillation vials (vials immediately recapped). For specific activity determination 0.1 ml aliquots of sample were placed in pre-prepared 20 ml scintillation vials containing 0.2 ml of benzethonium hydroxide (approximately 1.0 M solution in methanol; Sigma Chemical Company) to covalently sequester the ^{14}C inorganic carbon (vials immediately recapped). Specific activity was determined from the measured activity and measurements of DIC.

Samples for DIC analysis were collected from the Niskin bottles into 300 ml BOD bottles, following collection procedures used for oxygen analyses. Within 6 hr. of BOD sample collection, duplicate 10 ml samples were injected into 20 ml crimp-sealed serum bottles containing 0.5 ml of a 2N aqueous solution of sulfuric acid for subsequent I.R. analysis (Beckman IR-315 infrared analyzer) of the gaseous phase (5 - 150 ml samples) at the W.H.O.I. laboratory.

During summer months 1995 some of the ^{14}C incubations (W9508-W9513) were incubated on shore in the MWRA laboratory at Deer Island. Samples were collected in opaque bottles and maintained at *in situ* temperature until transport to the lab. The ^{14}C incubations were begun approximately 2 - 3 hr from sample collection and should compare favorably with samples that are incubated aboard the ship.

Production Analyses by ^{14}C - Laboratory Procedures.

Sample processing. Upon arrival to the W.H.O.I. laboratory scintillation cocktail (10 ml Scintiverse II) were added to the scintillation vials containing the specific activity samples and analyzed using a Packard Tricarb 4000 liquid scintillation counter which possesses automated routines for quench correction. Vials containing acidified filters were opened and placed in a

ventilator in the hood for overnight to allow the filters to dry and excess ^{14}C carbon dioxide dissipate. The vials containing the filters were analyzed by scintillation spectroscopy as described above.

Calculation of Primary production. Volume specific primary production was calculated using equations similar to that of Strickland and Parsons (1972) as follows:

$$P(i) = \frac{1.05(DPM(i)-DPM(blk))}{V_s A_{sp} T}$$

$$P(d) = \frac{1.05(DPM(d)-DPM(blk))}{V_s A_{sp} T}$$

$$A_{sp} = \frac{DPM(sa)-DPM(back)}{V_{sa} DIC}$$

where:

P(i) = primary production rate at light intensity i, ($\mu gC\ l^{-1}h^{-1}$ or $mgC\ m^{-3}h^{-1}$)
P(d) = dark production, ($\mu gC\ l^{-1}h^{-1}$ or $mgC\ m^{-3}h^{-1}$)
A_{sp} = specific activity (DPM/μgC)
DPM(i) = dpm in sample incubated at light intensity i
DPM(blk) = dpm in zero time blank (sample filtered immediately after addition of tracer)
DPM(d) = dpm in dark incubated sample
DPM(back) = background dpm in vial containing only scintillation cocktail
V_s = volume of incubated sample (l)
T = incubation time (h)
V_{sa} = volume counted of specific activity sample (ml)
DIC = concentration of dissolved inorganic carbon (μg/ml)

P-I curves. For each of the 5 depths for each photosynthesis station a P-I curve was obtained from the data P(I) = P(i)-P(d) vs. the irradiance (I, $\mu E\ m^{-2}s^{-1}$) that the incubating sample is exposed. The P-I curves were fit via one of two possible models, depending upon whether or not significant photoinhibition occurs. In cases where photoinhibition is evident the model of Platt et al. (1980) was fit (SAAM II, 1994) to obtain the theoretical maximum production, and terms for light-dependent rise in production and degree of photoinhibition:

$$P(I) = P_{sb}"(1 - e^{-a})e^{-b}$$

$$P\max" = P_{sb}"[a"/(a" + \beta")][\beta"/(a" + \beta")]^{\beta"/}$$ (Lohrenz et al., 1994)

where:

P(I) = primary production at irradiance I, corrected for dark fixation (P(i)-P(d))
P_{sb}"= theoretical maximum production without photoinhibition
a = α"I/Psb", and α"is the initial slope the light-dependent rise in production

b = β"I/Psb", and β"is a term relaying the degree of photoinhibition
P_{max}"= light saturated maximum production

If it is not possible to converge upon a solution the model of Webb et al. (1974) was similarly fit to obtain the maximum production and the term for light-dependent rise in production:

$$P(I) = P_{max}"\left(1 - e^{-a'}\right)$$

where:

P(I) = primary production at irradiance I corrected for dark fixation (P(i)-P(d))
P_{max}"= light saturated maximum production
a' = α"I/Pmax", and α"is the initial slope the light-dependent rise in production

Nearly all P-I curves obtained did not show evidence of photoinhibition and were fit according to the Webb model.

Light vs. depth profiles. To obtain a numerical representation of the light field throughout the water column bin averaged CTD light profiles (0.5 m intervals) was fit (SAAM II, 1994) to an empirical sum of exponentials equation of the form:

$$I_Z = A_1 e^{-a_1 Z} + A_2 e^{-a_2 Z}$$

which is an expansion of the standard irradiance vs. depth equation:

$$I_Z = I_0 e^{-kZ}$$

where:

I_Z = light irradiance at depth Z
I_0 = incident irradiance (Z=0)
k = extinction coefficient
A_1, A_2 = factors relating to incident irradiance ($I_0 = A_1+A_2$)
a_1, a_2 = coefficients relating to the extinction coefficient ($k = a_1+a_2$)

The expanded equation was used as pigment absorption and other factors usually resulted in significant deviation from the idealized standard irradiance vs. depth equation. The best fit profiles were used to compute percent light attenuation for each of the sampling depths.

Daily incident light field. During normal CTD hydrocasts the incident light field was routinely measured via a deck light sensor at high temporal resolution. The average incident light intensity was determined for each of the CTD casts to provide, over the course of the photoperiod (12 hr period centered upon solar noon), a reasonably well resolved irradiance time series consisting of 12-17 data points. A 48 point time series (every 15 min.) of incident was obtained from these data by linear interpolation.

Calculation of daily primary production. Given the best fit parameters (Pmax", α", β") of the P-I curves obtained for each of the 5 sampling depths, percent *in situ* light attenuation at each depth determined from the sum of exponential fits of the *in situ* light field, and the photoperiod incident light (I_0) time series it was possible to compute daily volumetric production for each depth. To do this at a given depth, hourly production was determined for the *in situ* light intensity computed for each 15 min. interval of the photoperiod, using the appropriate P-I parameters and *in situ* irradiance computed from the percent attenuation and incident irradiance. Daily production ($\mu gC\ l^{-1}d^{-1}$) was obtained by integration of the determined activity throughout the 12 hr photoperiod. An advantage of this approach is that seasonal changes in photoperiod length are automatically incorporated into the integral computation. For example, during winter months computed early morning and late afternoon production contributes minimally to whole day production, whereas during summer months the relative contribution during these hours is more significant. The investigator does not have to decide which factor to employ when converting hourly production to daily production. The primary assumption for the approach is that the P-I relationship obtained at the time of sample procurement (towards the middle of the photoperiod) is representative of the majority of production occurring during the photoperiod.

Calculation of daily areal production. Areal production ($mgC\ m^{-2}d^{-1}$) was obtained by trapezoidal integration of daily volumetric production vs. depth from the sea surface down to the 0.5% light level. The P-I factors from the uppermost sampling depth (approximately 1.2 - 2.7 m, depending upon weather state) were used to compute the contribution of the portion of the water column between the sea surface interface and uppermost sampling depth to areal production (rather than to assume that the activity in the uppermost sample is representative of that section of the water column, which is not always the case).

Calculation of chlorophyll-specific parameters. Chlorophyll-specific measures of the various parameters were determined by dividing by the appropriate chlorophyll term obtained from independent measurements:

$$\alpha = \frac{\alpha''}{[chla]}$$

$$P\max = \frac{P\max''}{[chla]}$$

where:

α = chlorophyll-a-specific initial slope of light-dependent production $[(gC(gchla)^{-1}h^{-1}(\mu Em^{-2}s^{-1})^{-1}]$

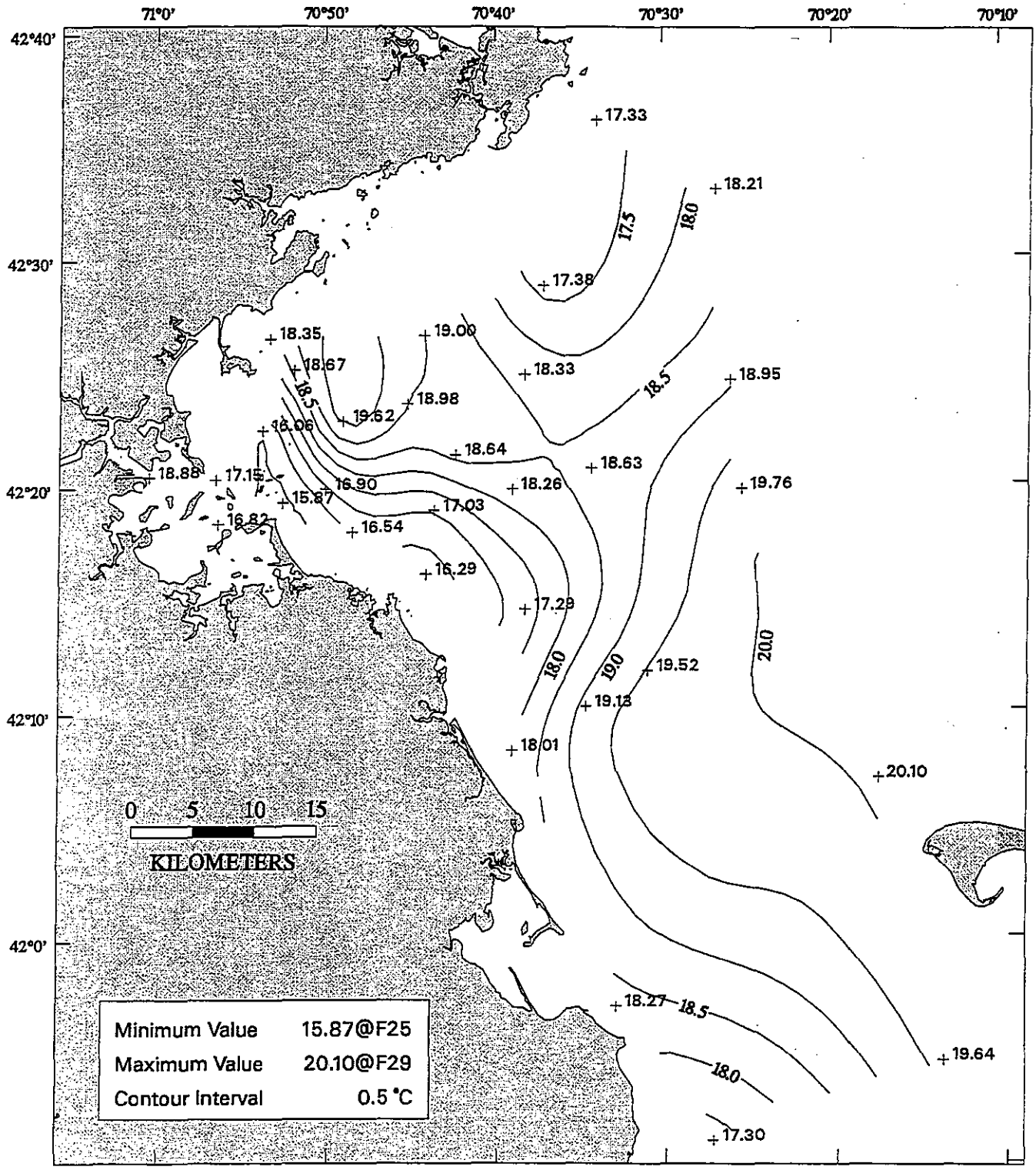
Pmax = light saturated chlorophyll-specific production $[gC(gchla)^{-1}h^{-1}]$

APPENDIX B
Surface Contour Plots - Farfield Surveys

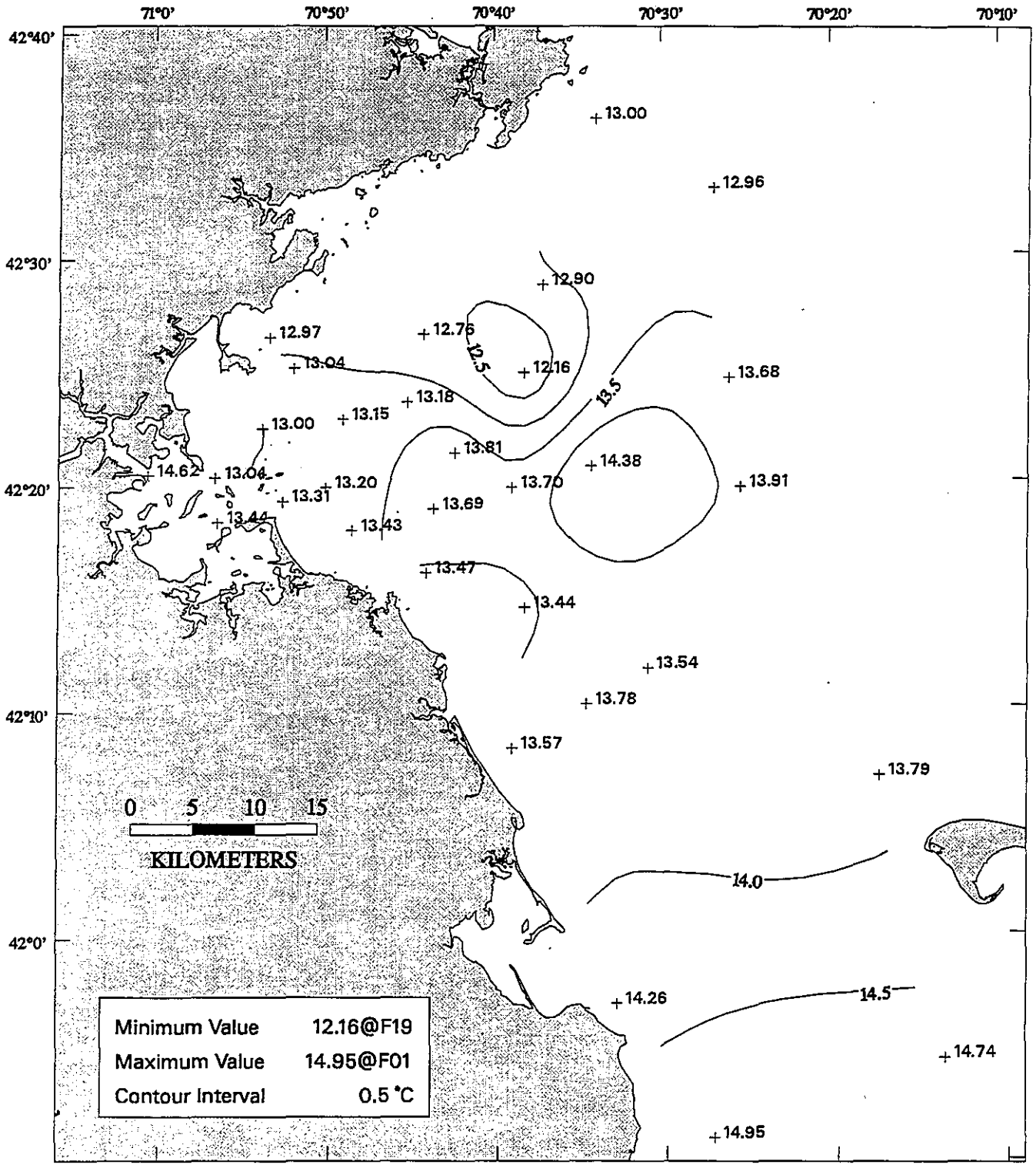
All contour plots were created using data from the surface bottle sample (A). Each plot is labelled on the bottom right with the survey number ("9601"), and parameter as listed below. The minimum and maximum value, and the station where the value was measured, is provided for each plot, as well as the contour interval and parameter units.

Appendix B: Table of Contents

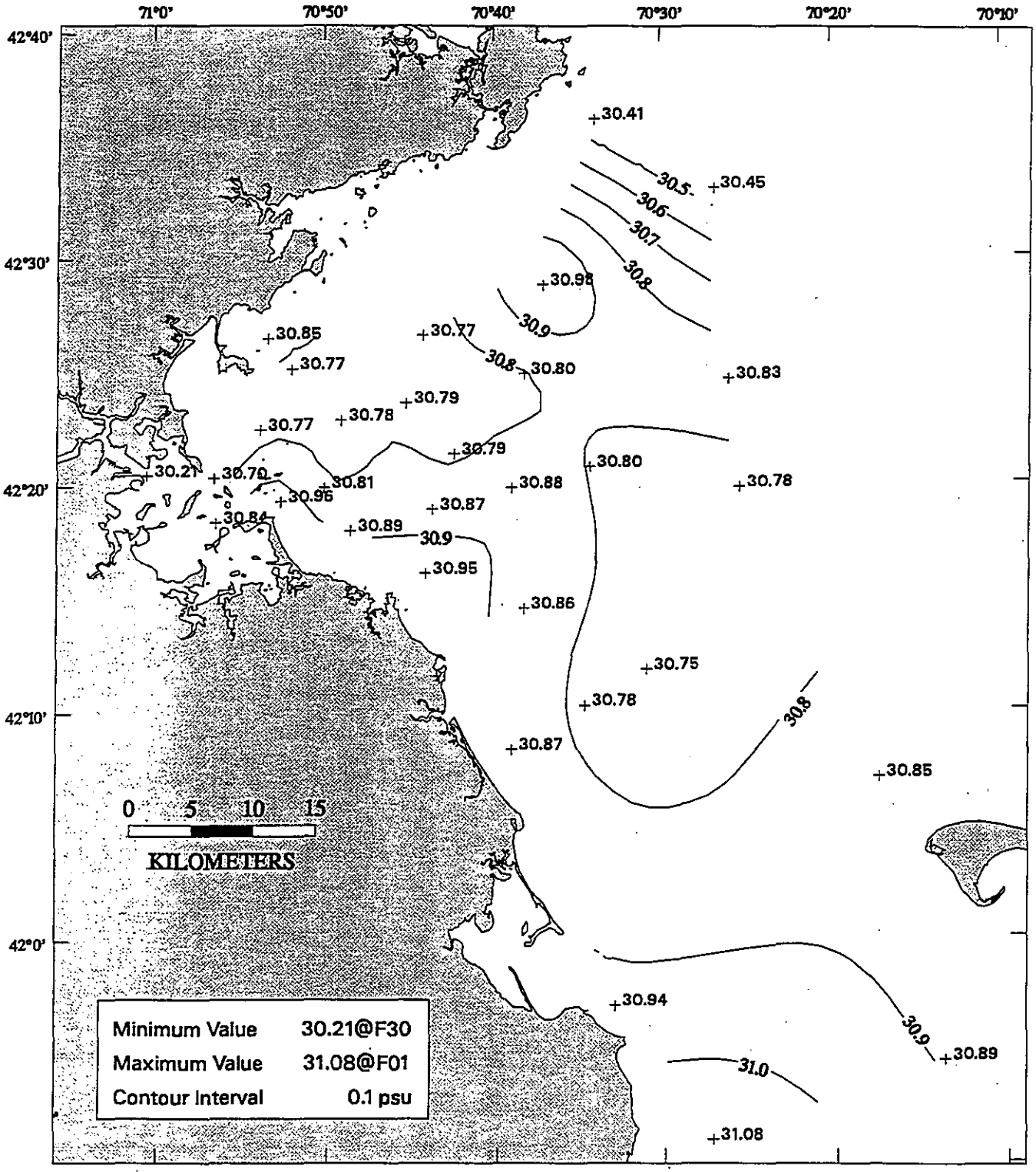
*$NO_3 + NO_2 + NH_4$



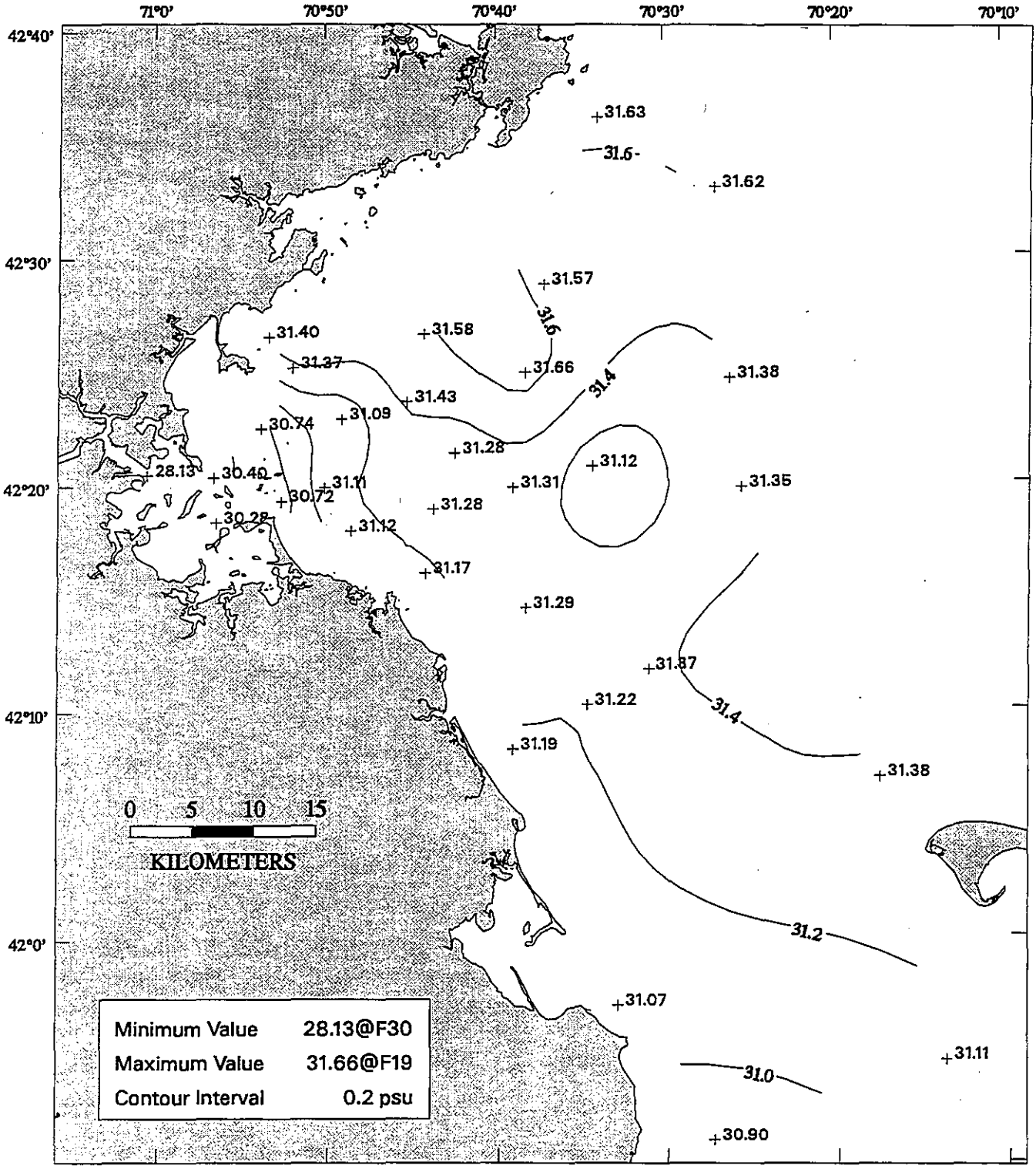
9611temp_lin
TEMP



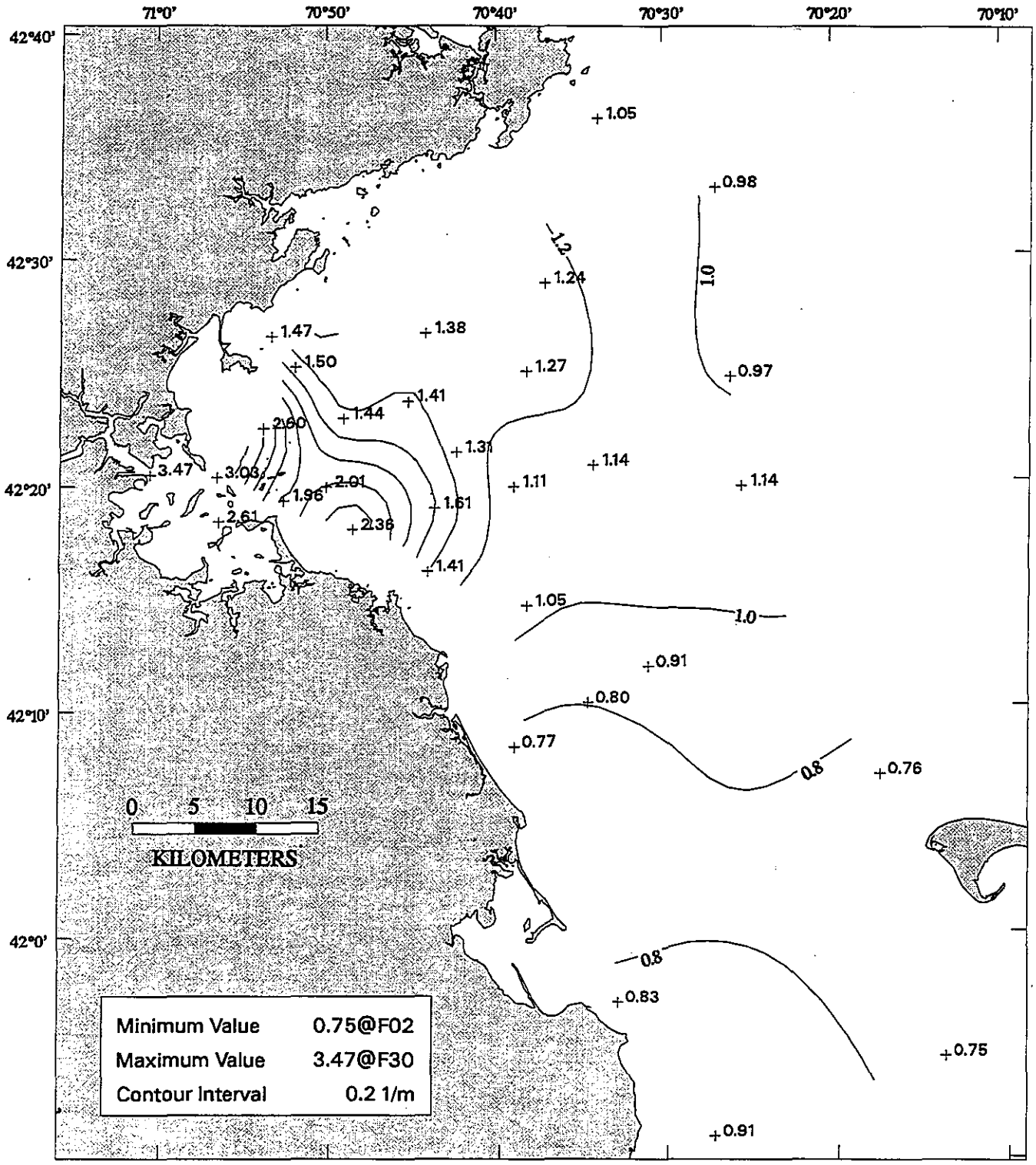
9614temp_lin
TEMP



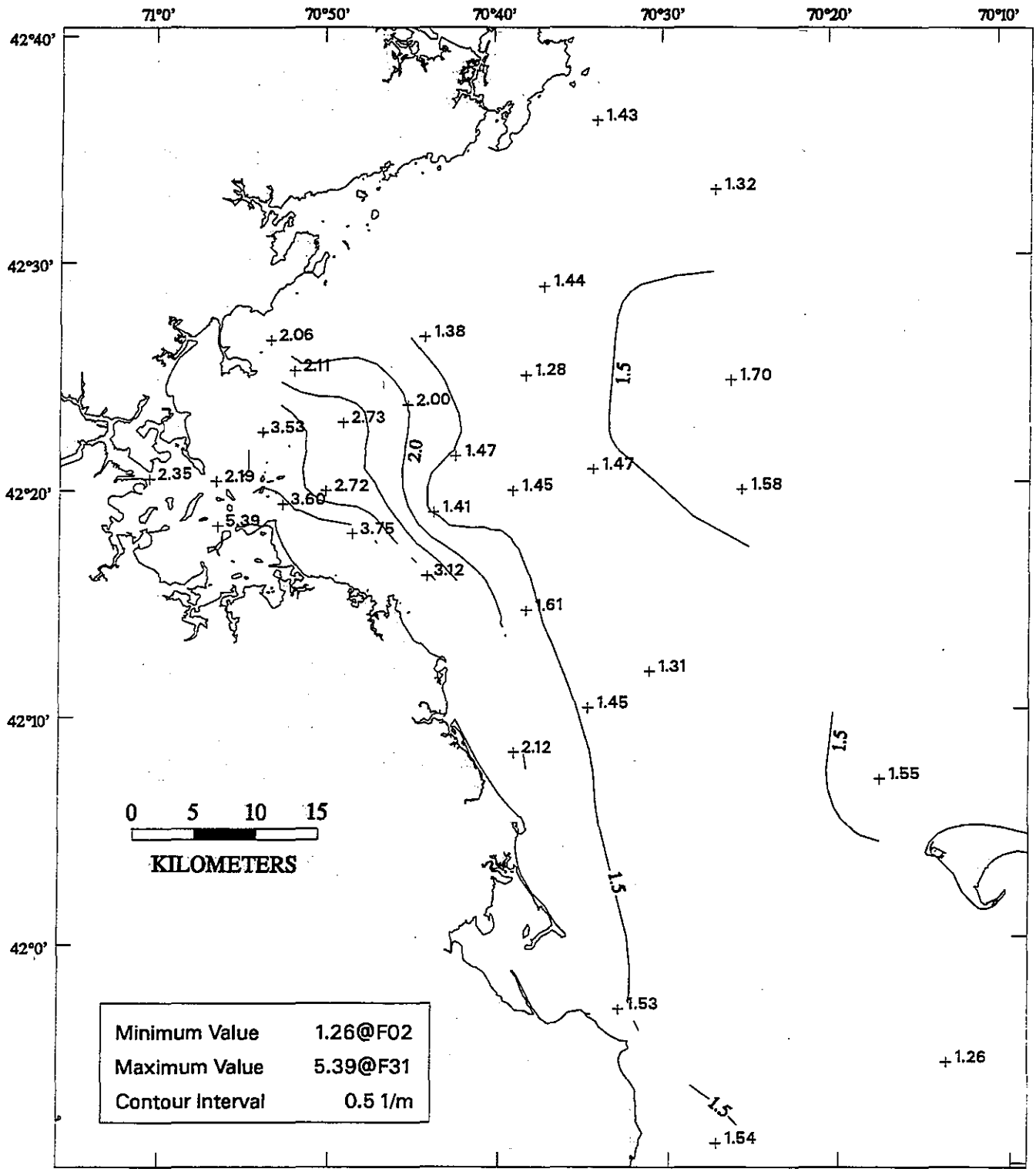
9611sal_lin
SAL



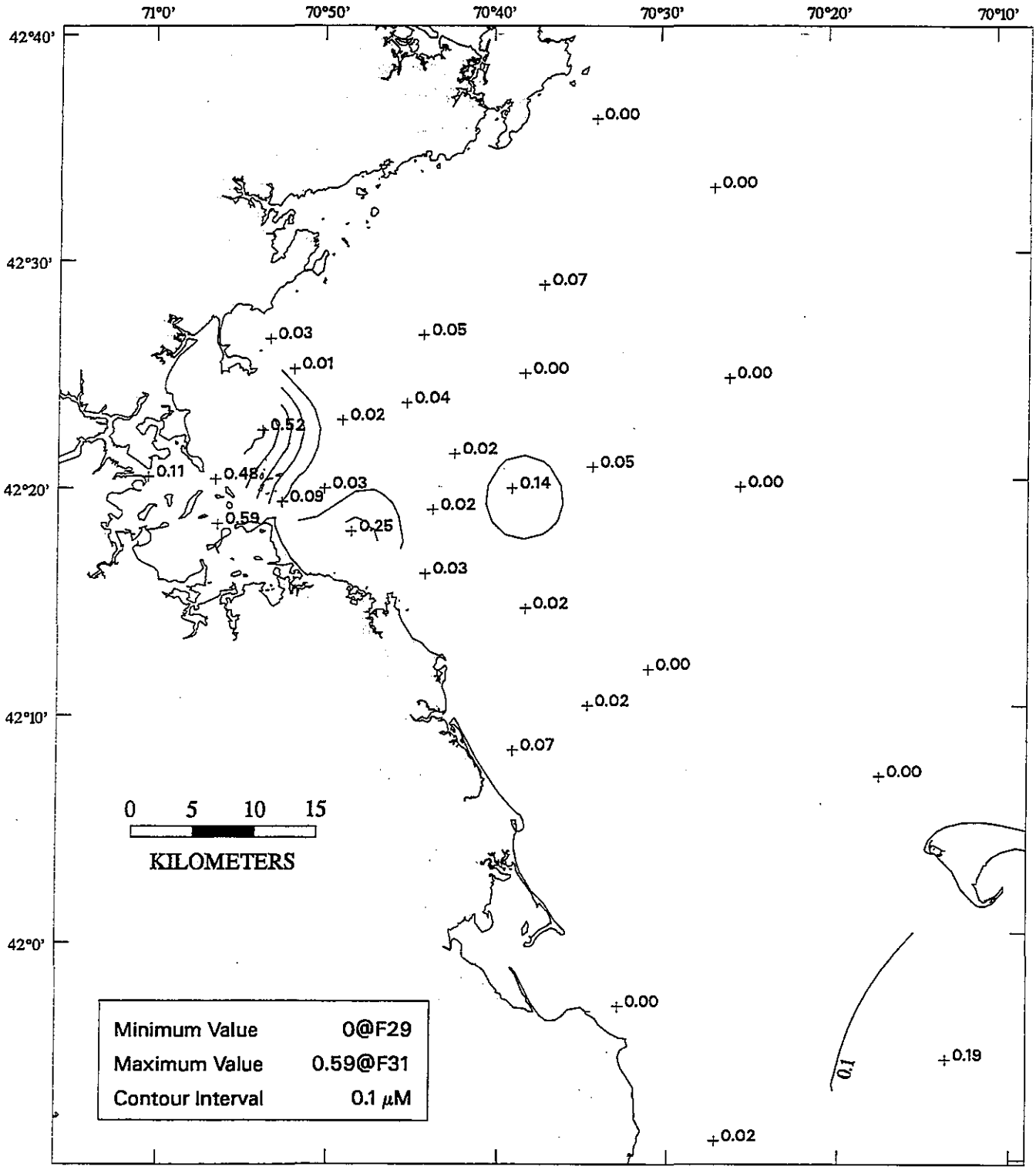
9614sal_lin
SAL



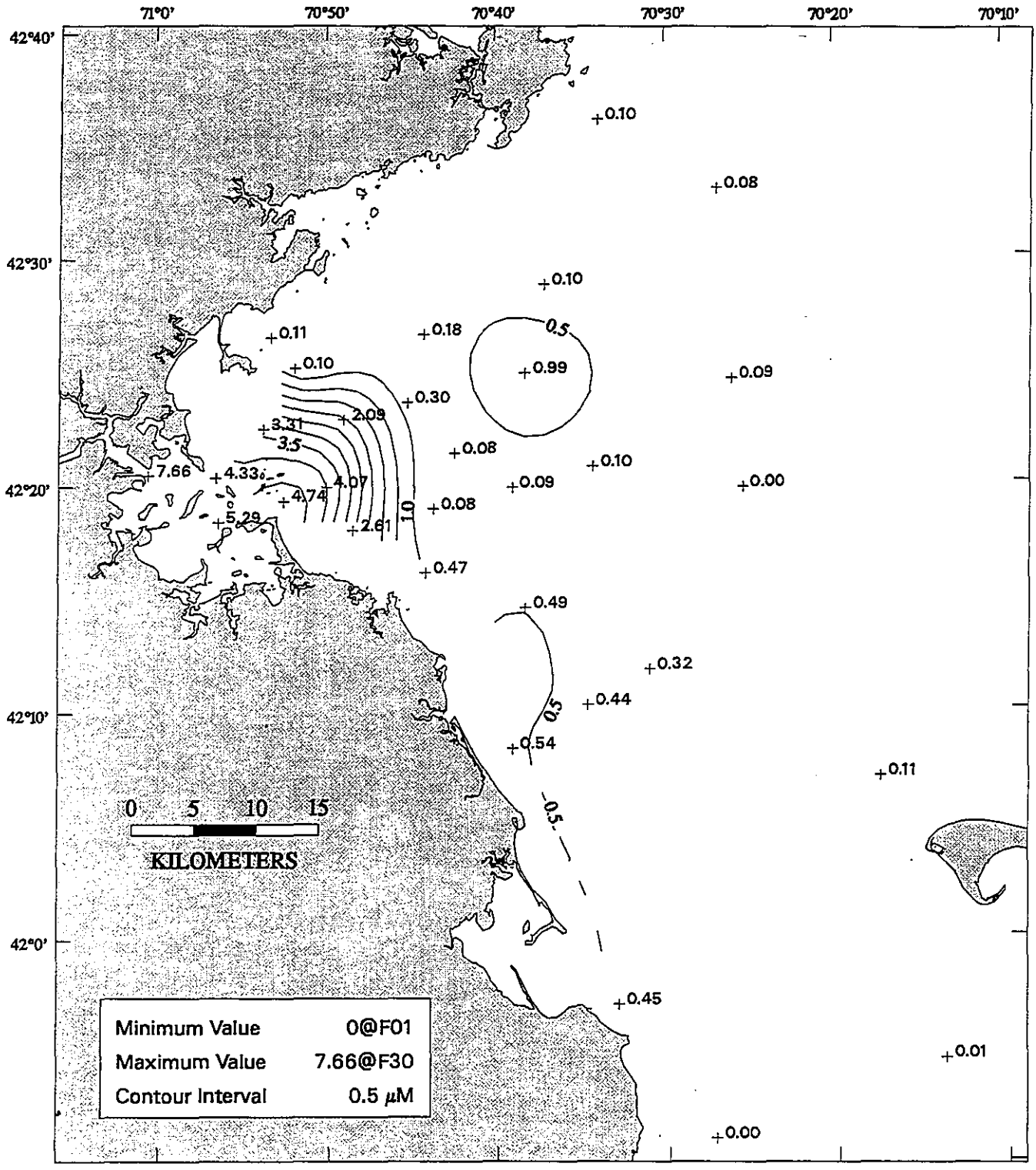
9611beam_lin
TRAN



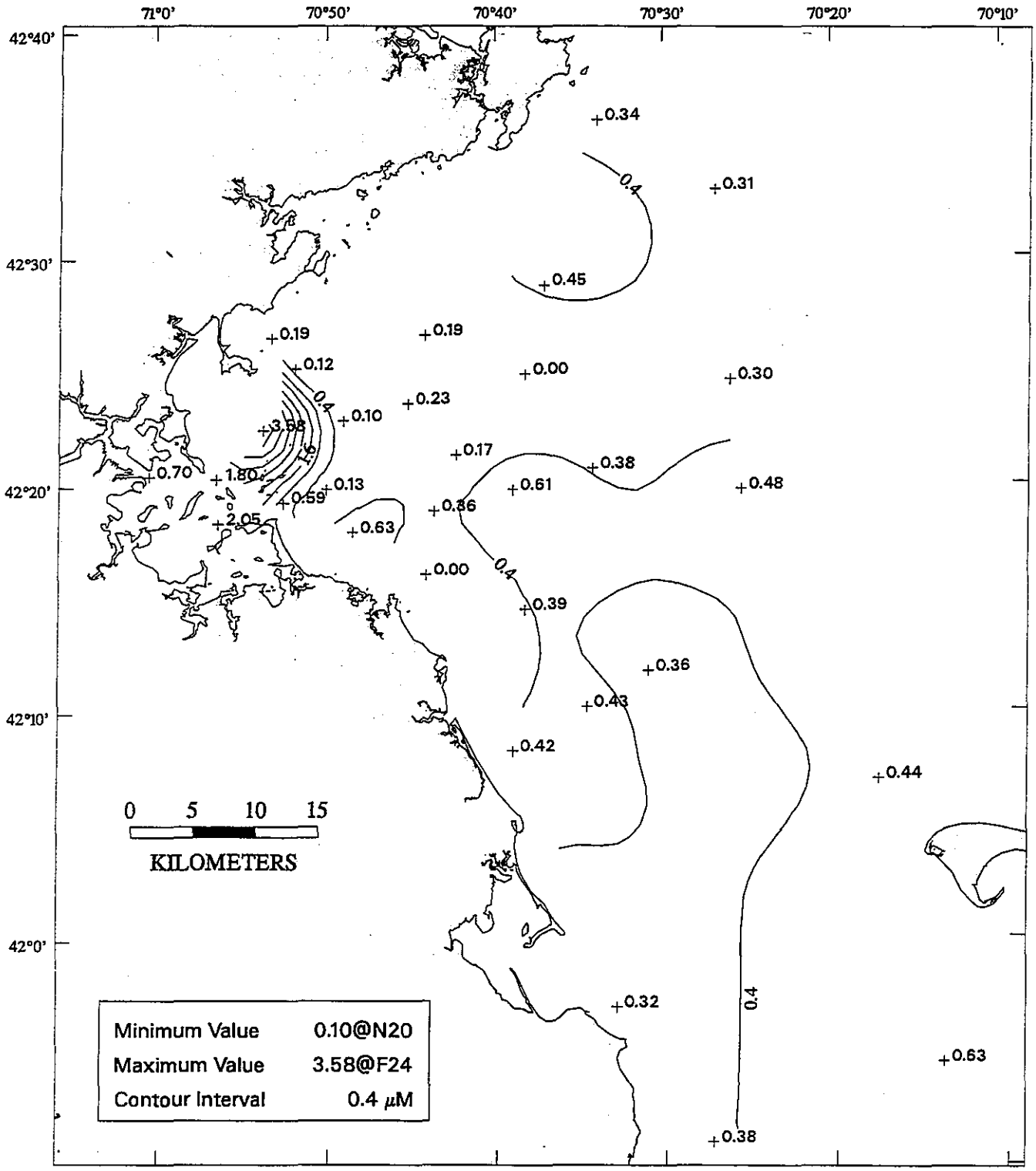
9614beam_lin
TRAN



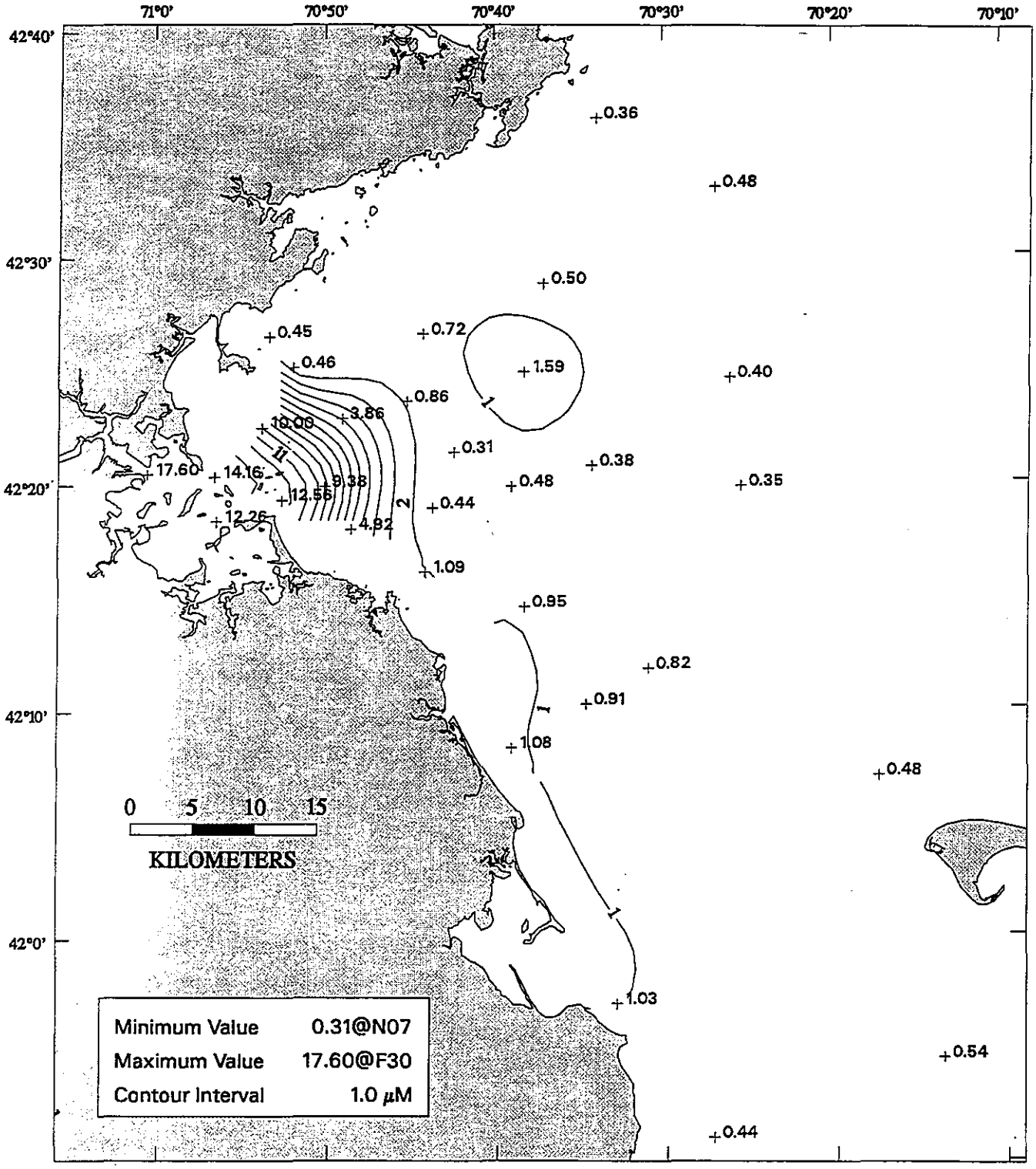
9611no3_lin
NO3



9614no3_lin
NO3



9611din_lin
DIN



9614din_lin
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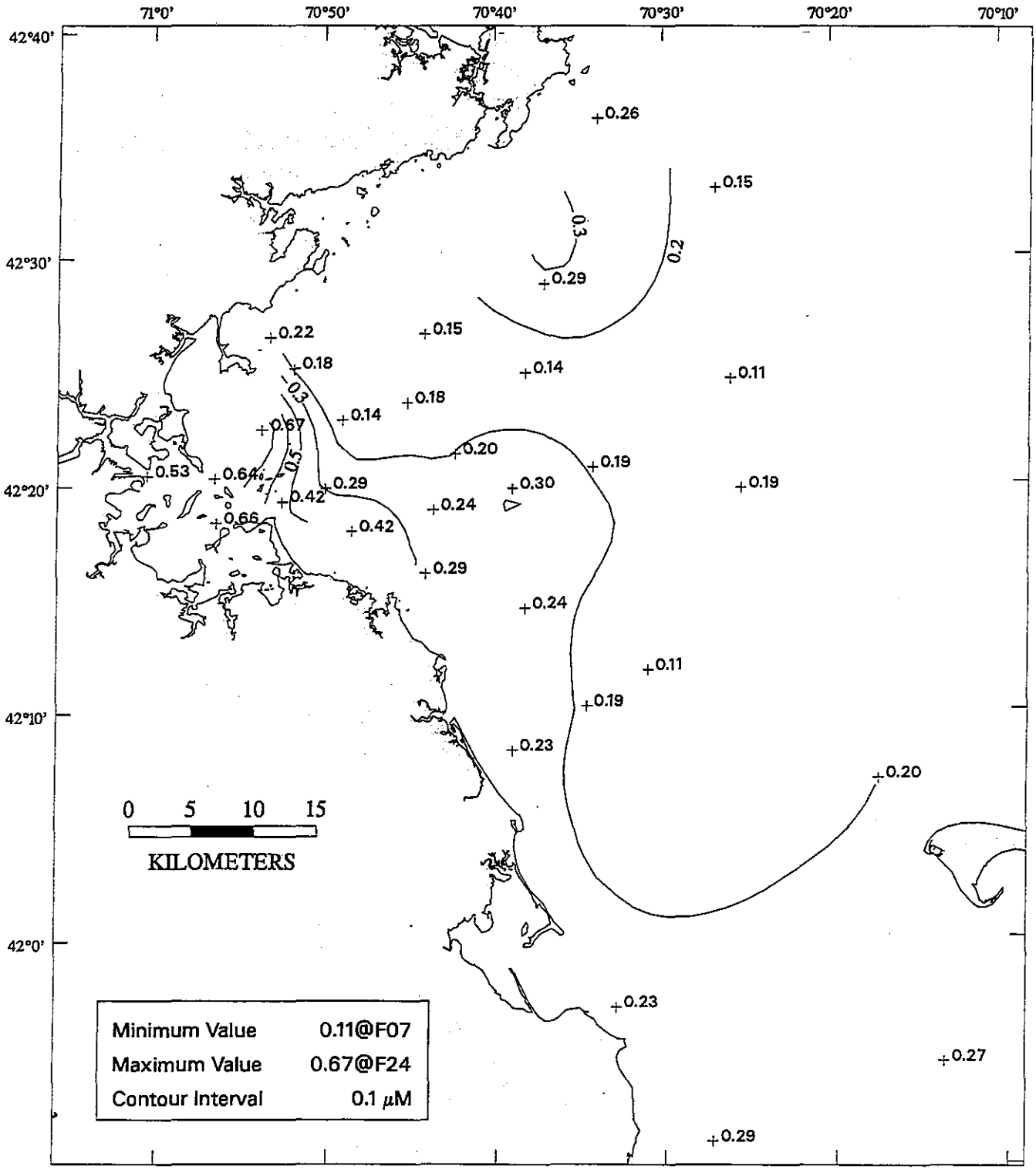
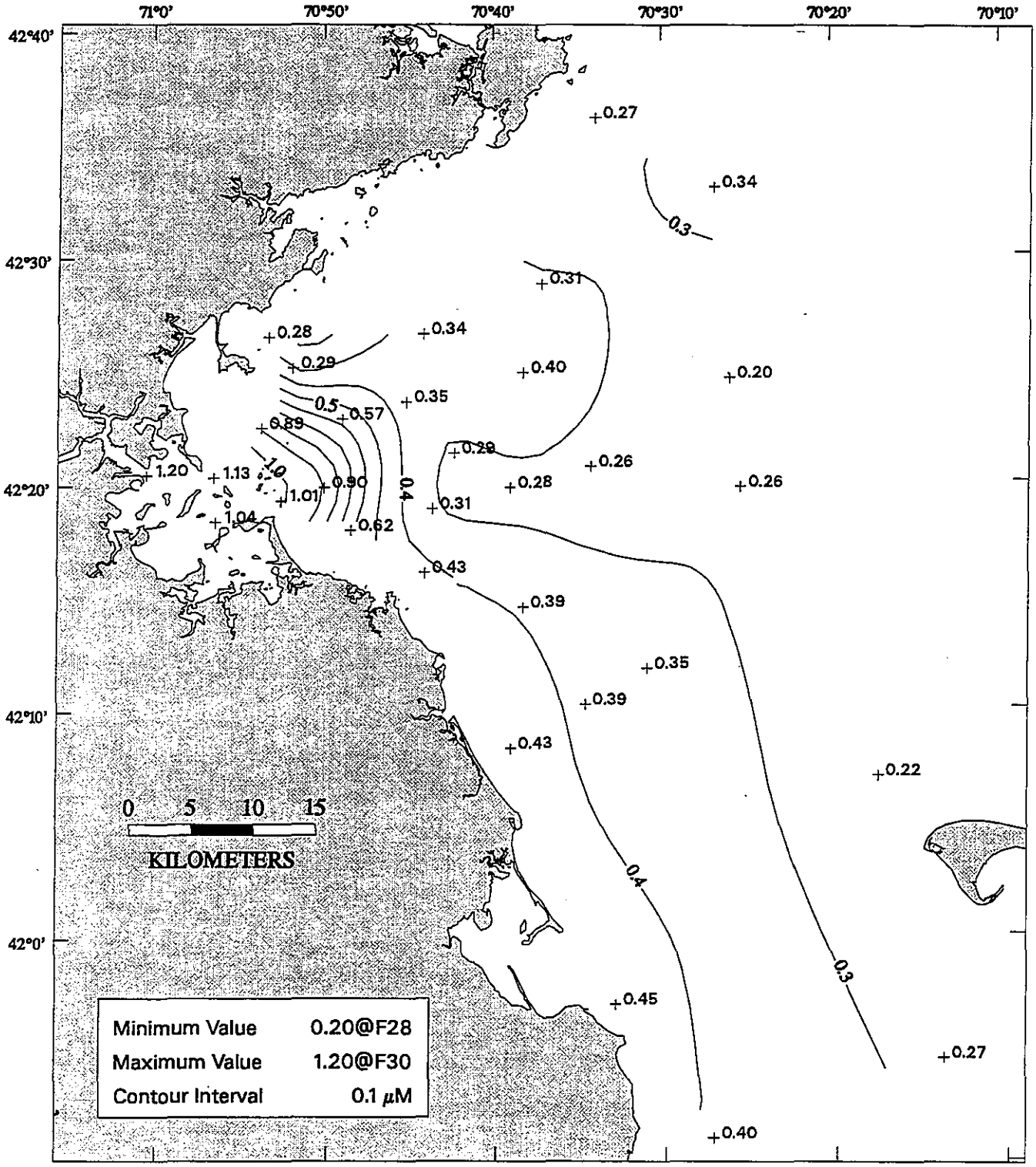


9611po4_lin
PO4



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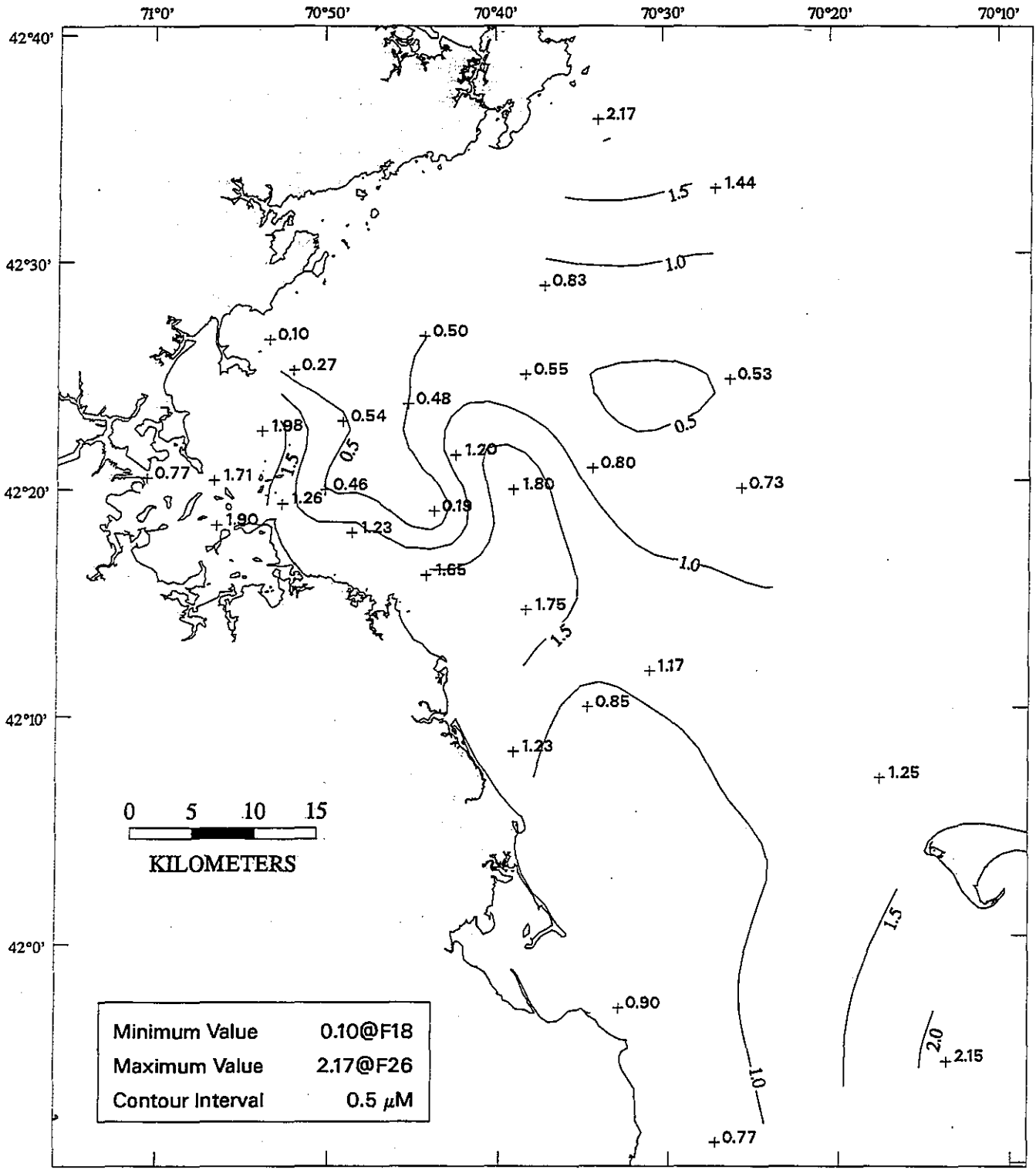
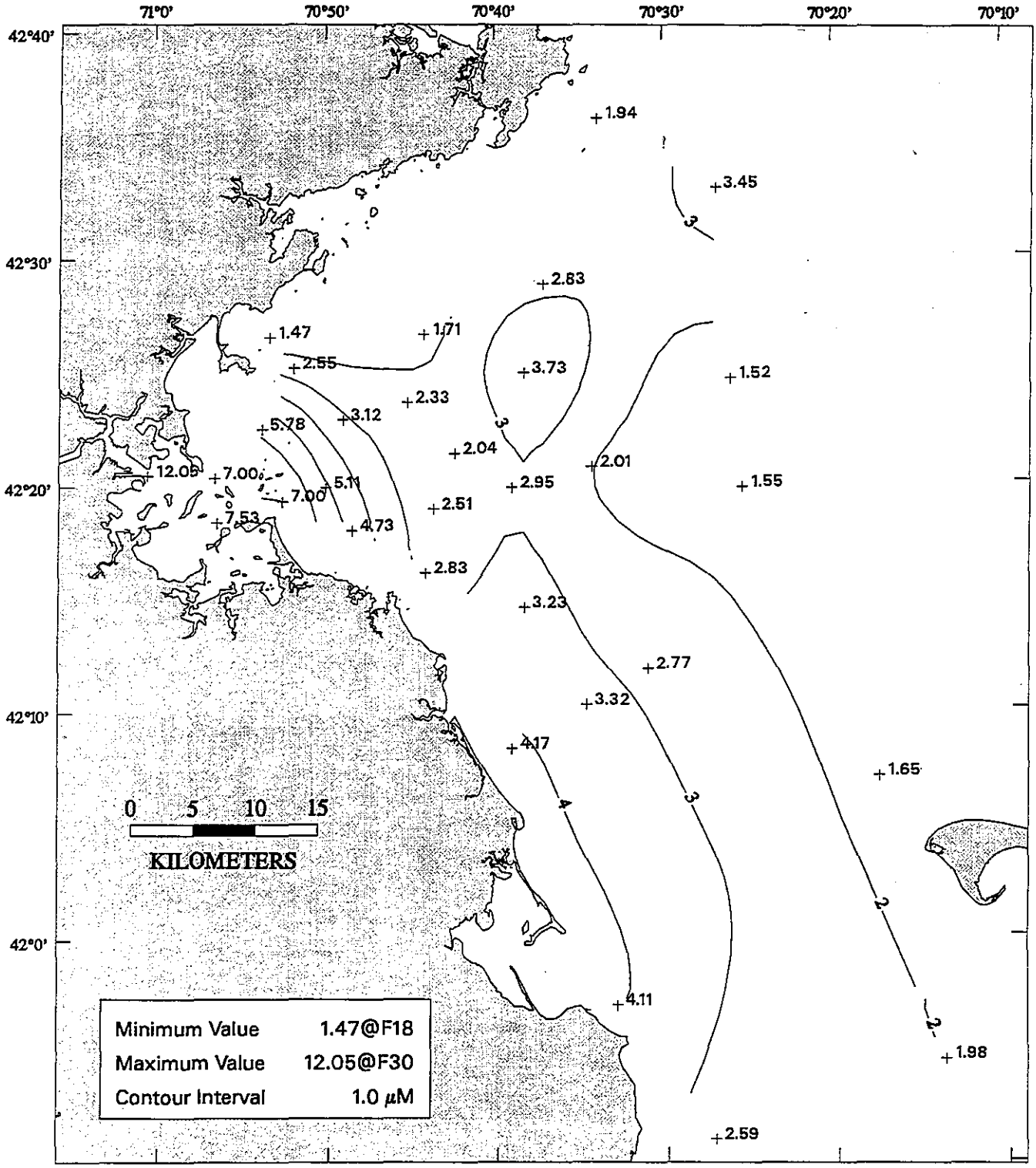
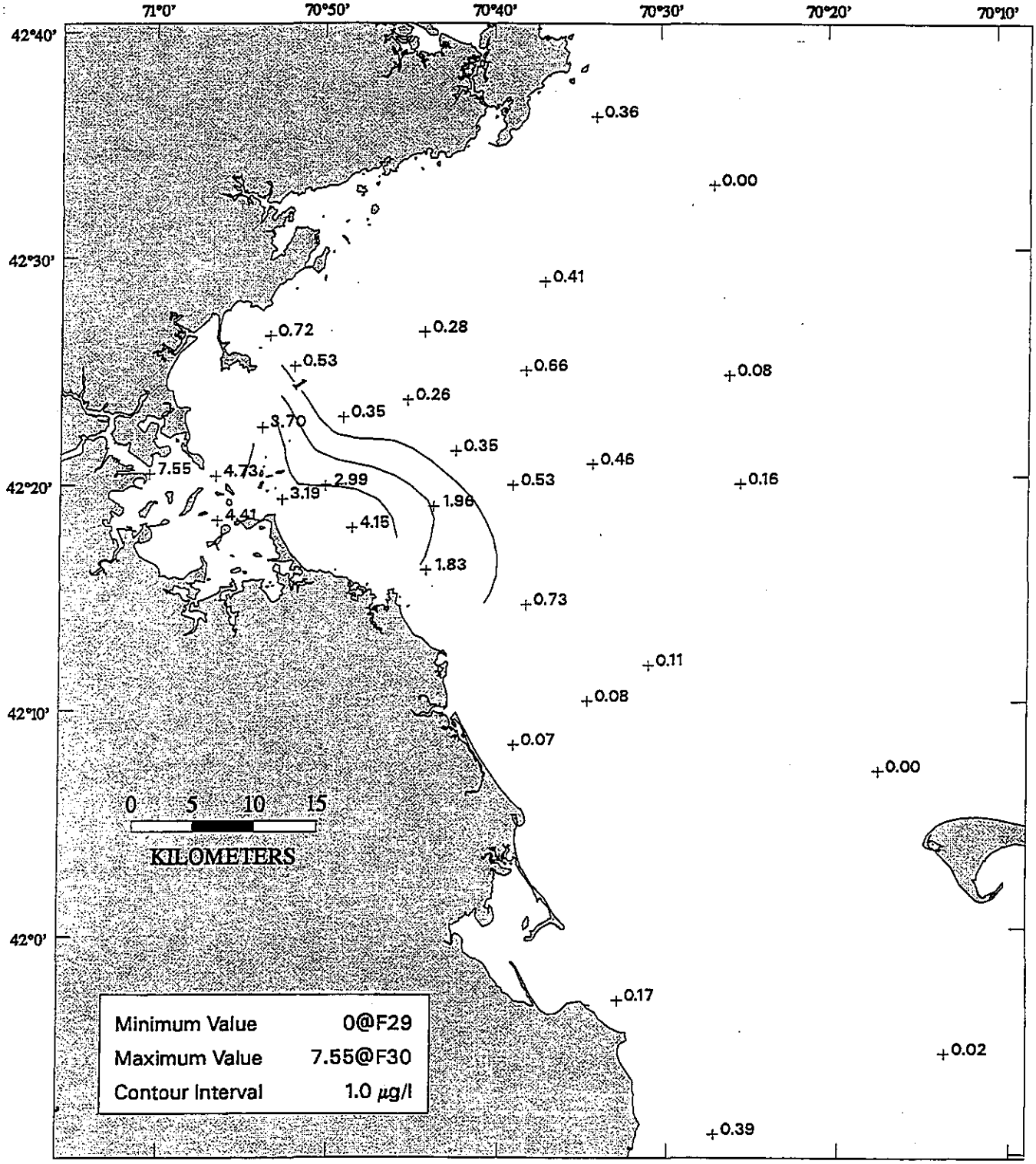
PO4



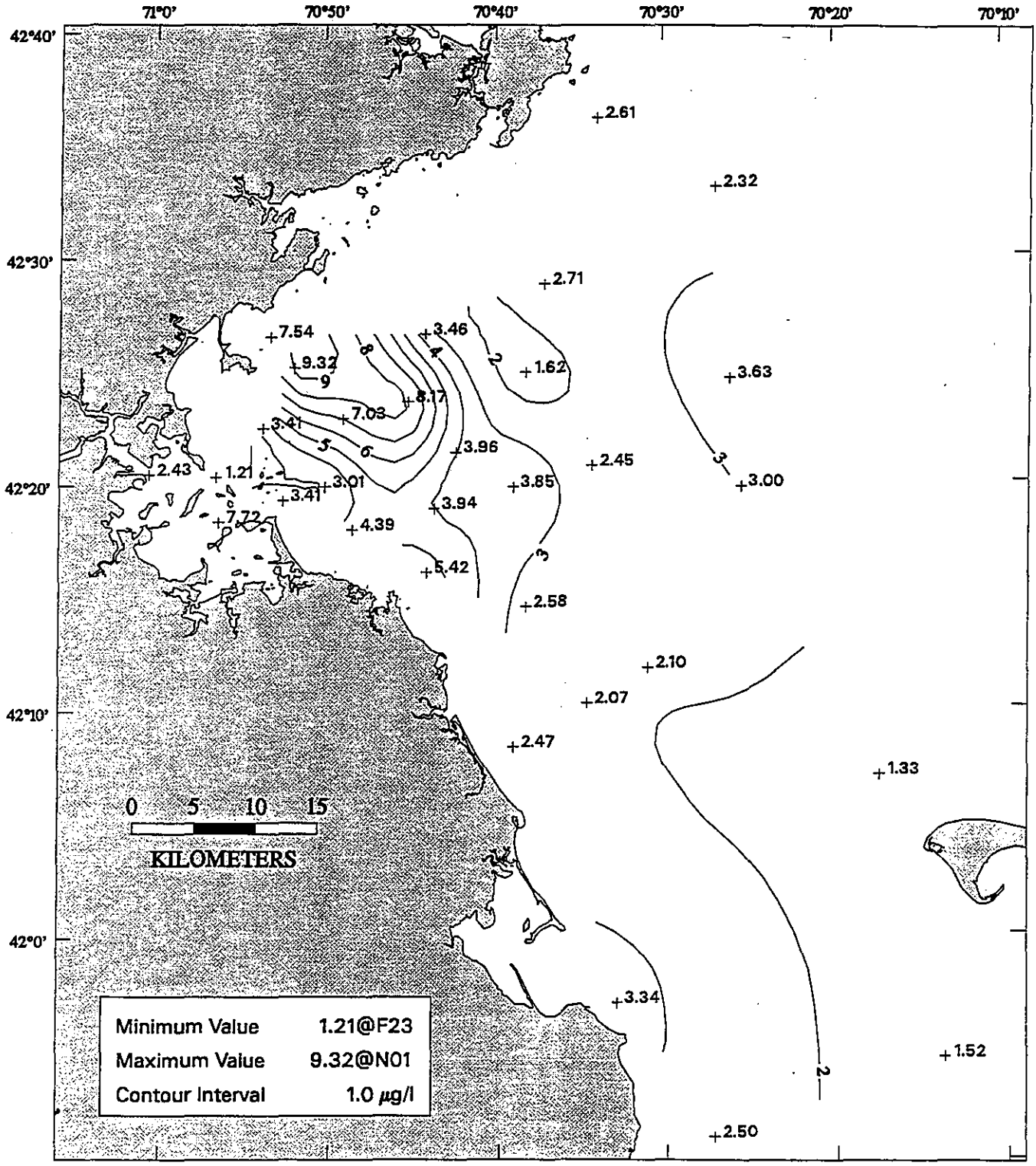
9611sio4_lin
SIO4



9614sio4_lin
SIO4



9611fluo_lin
FLUO



9614fluo_lin
FLUO

APPENDIX C

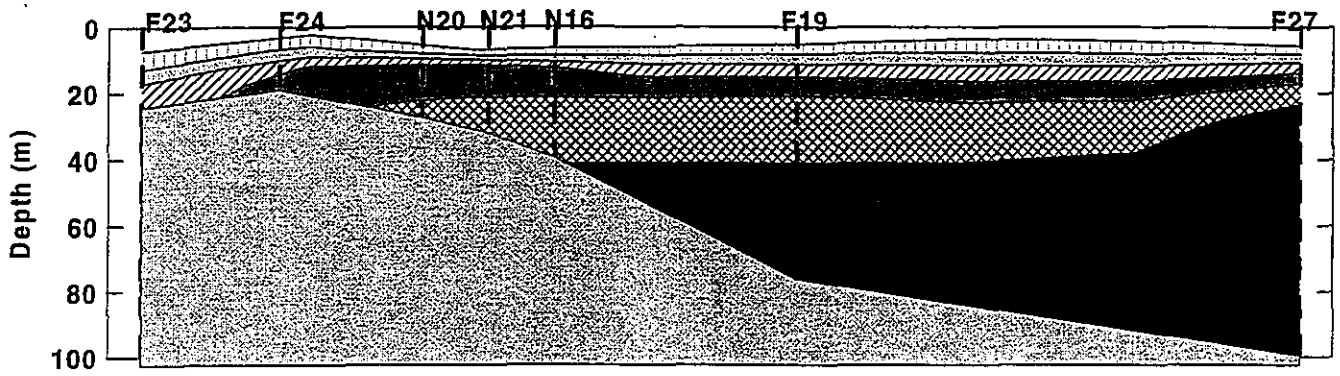
Transect Plots

Data were contoured relative to water depth and distance between stations as shown on the transects (Figure 1-3, text). Relative distances between stations and water depth at each station is shown on the transect. Water depth is labelled with negative values in meters, with zero depth at the sea surface, and shaded. Three transects (Boston-Nearfield, Cohasset, and Marshfield) are provided on each plot, as well as shaded contour levels on the scale bar at the bottom of the plot. Contour units are as noted on the table below. Each plot is labelled on the bottom right with the parameter as listed below, and the survey number ("9601").

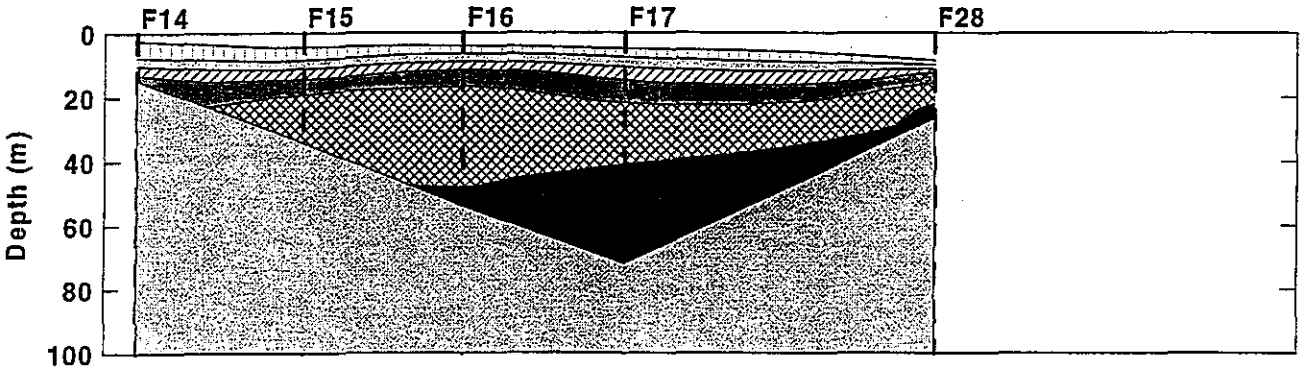
Appendix C: Table of Contents

*$NO_3 + NO_2 + NH_4$

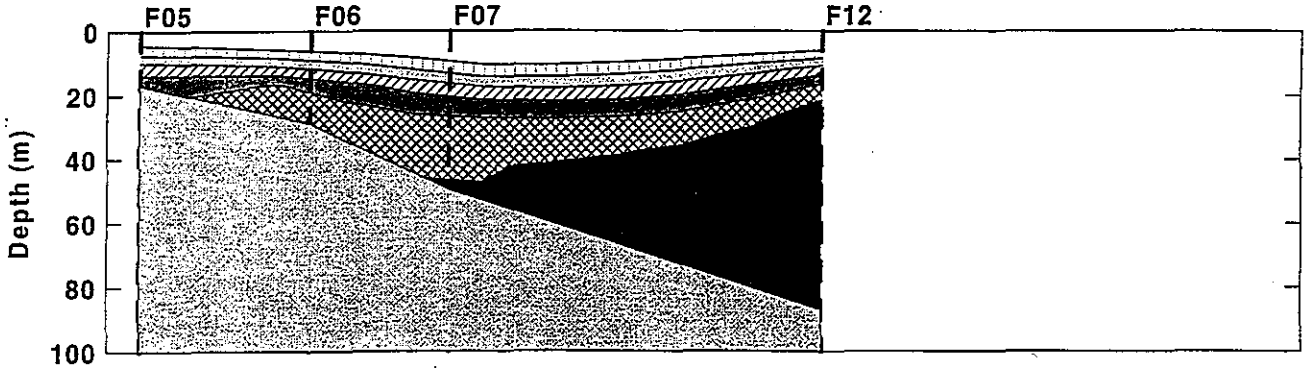
Boston-Nearfield Transect

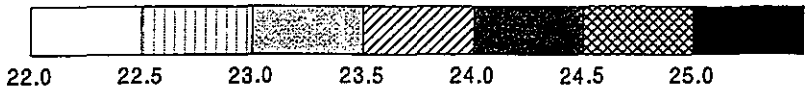


Cohassett Transect



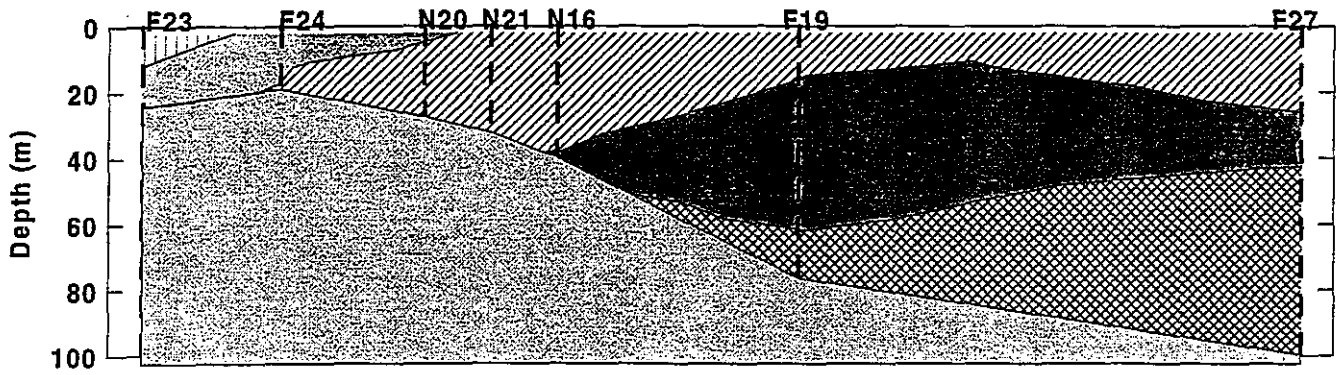
Marshfield Transect



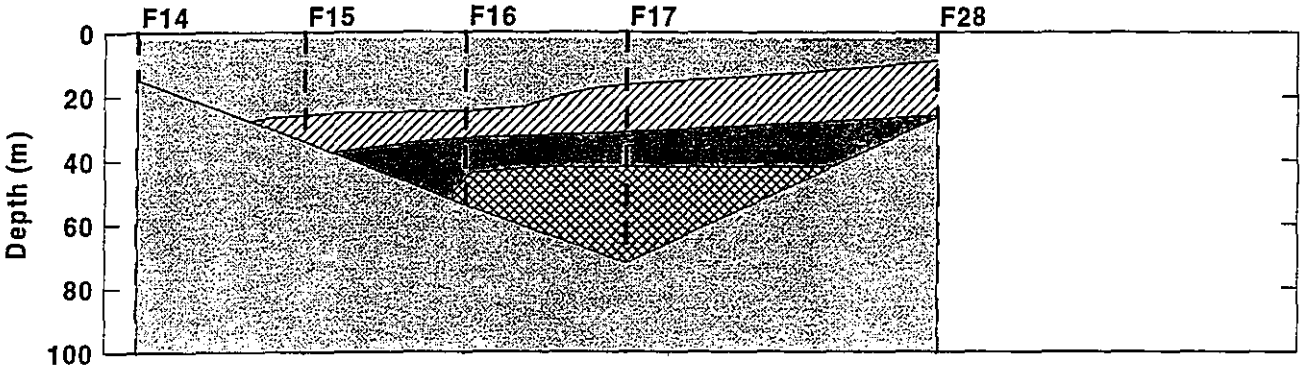


Parameter: Sigma-T
Survey: 9611

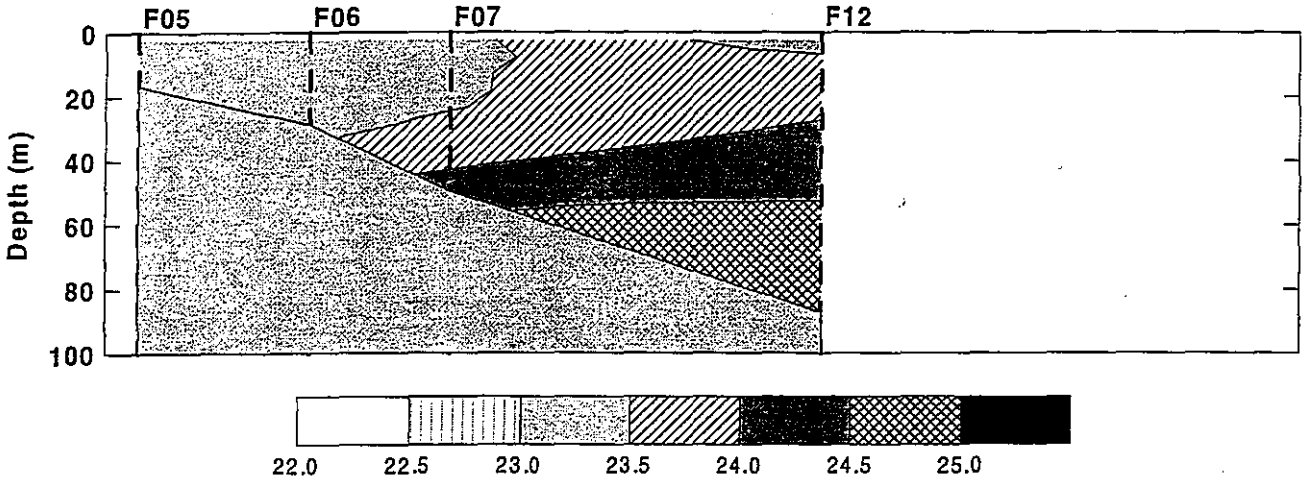
Boston-Nearfield Transect



Cohassett Transect

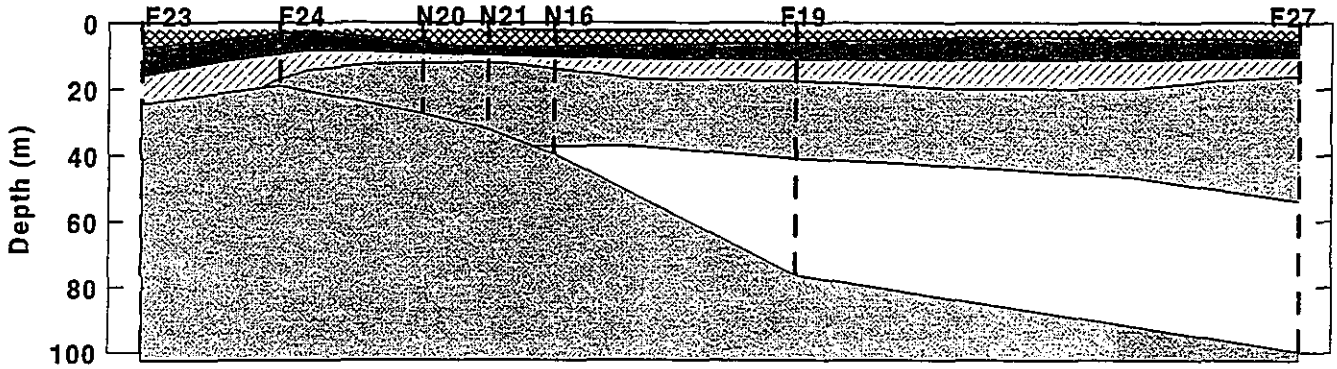


Marshfield Transect

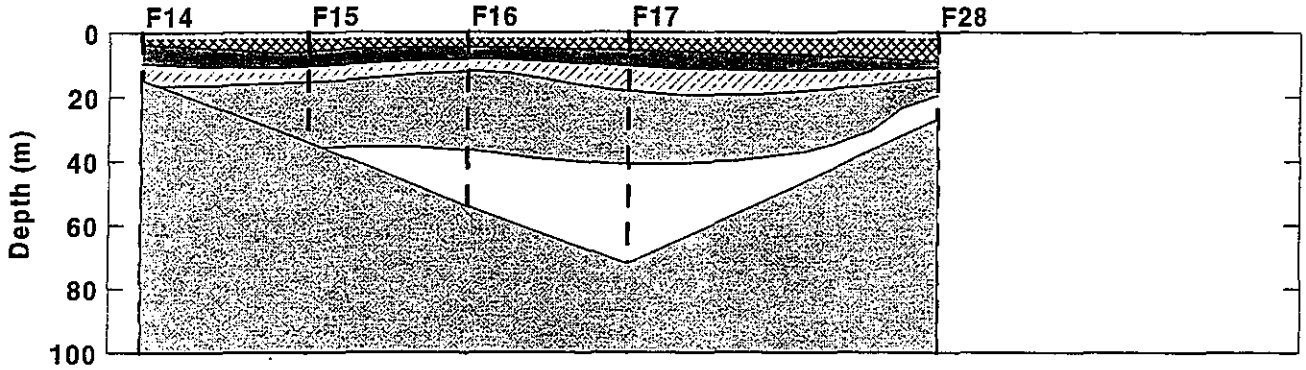


Parameter: Sigma-T
Survey: 9614

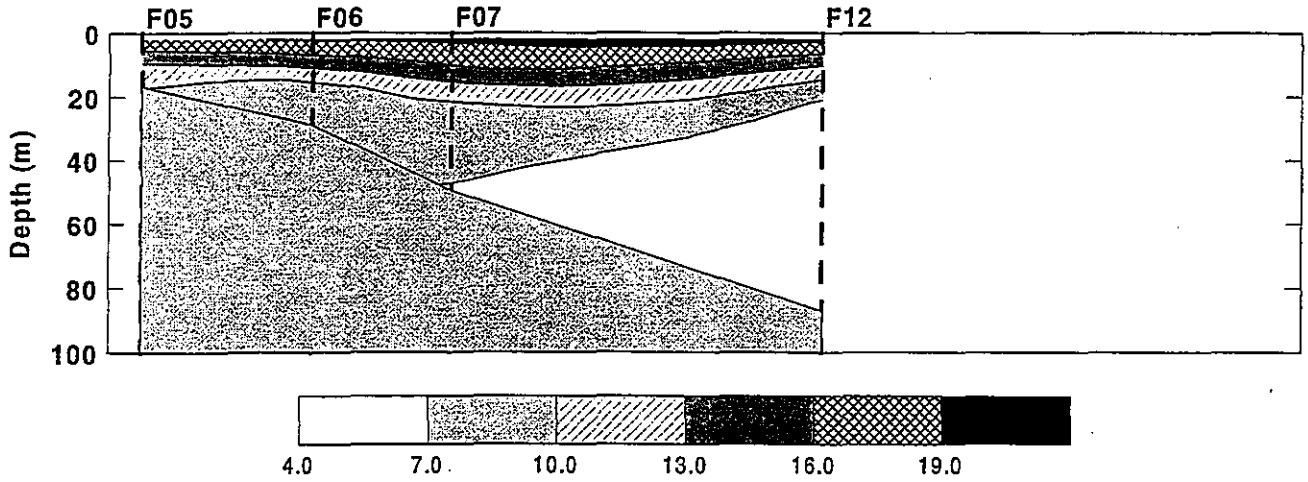
Boston-Nearfield Transect



Cohassett Transect

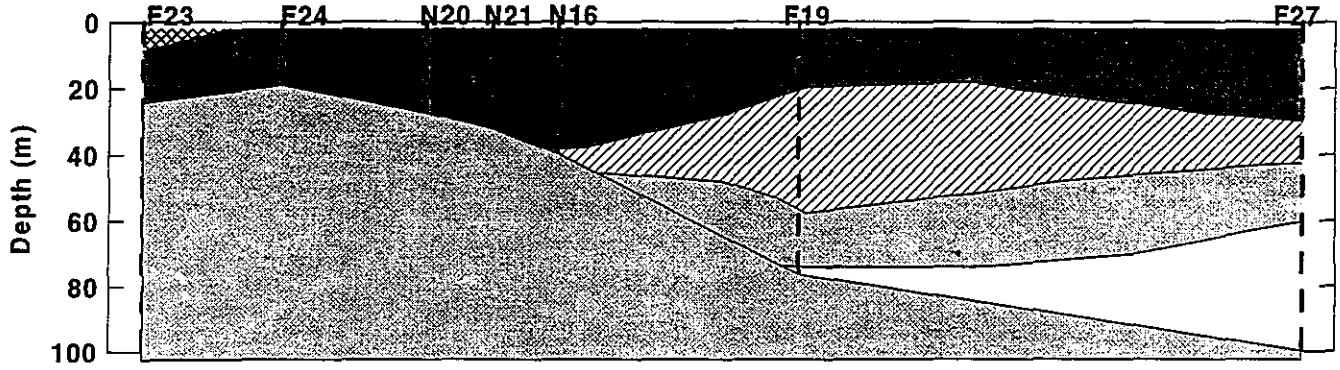


Marshfield Transect

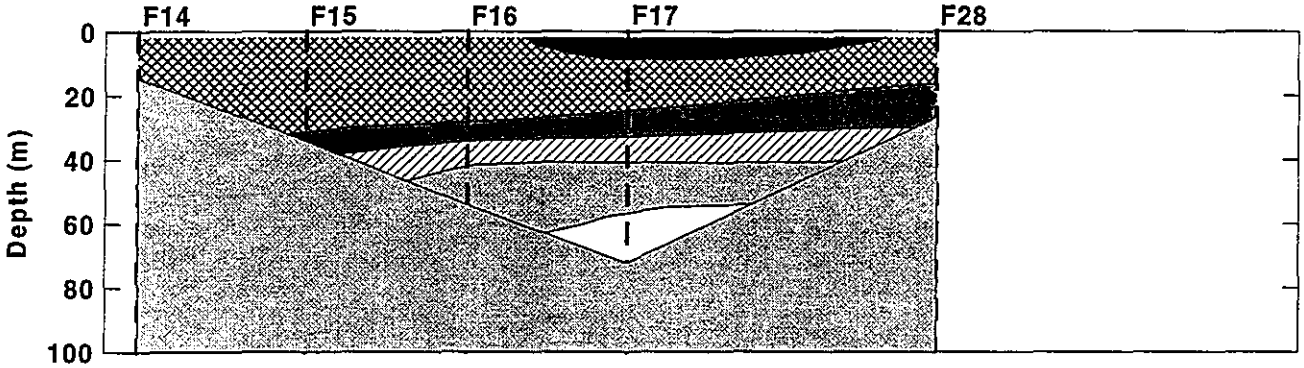


Parameter: Temperature
Survey: 9611

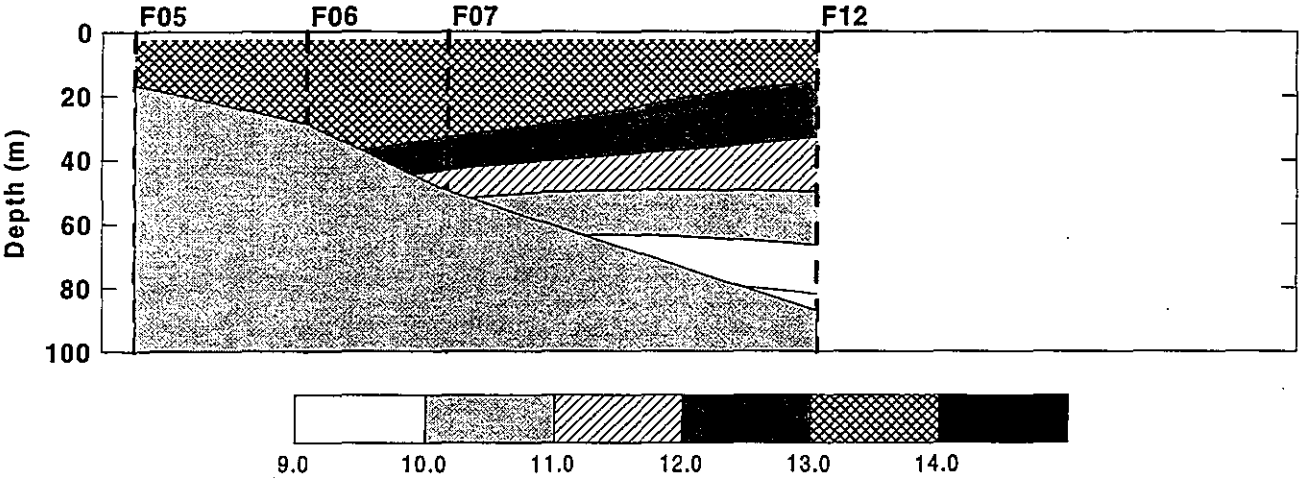
Boston-Nearfield Transect



Cohassett Transect

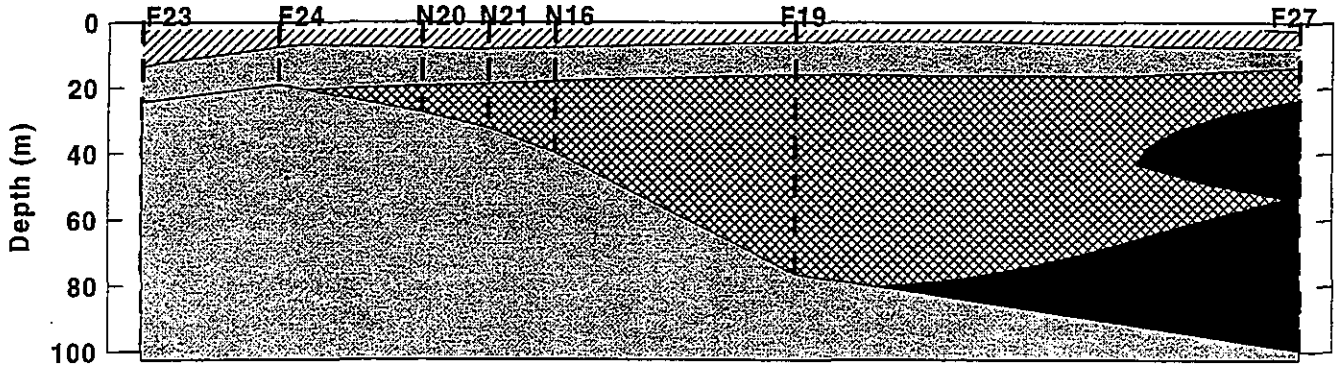


Marshfield Transect

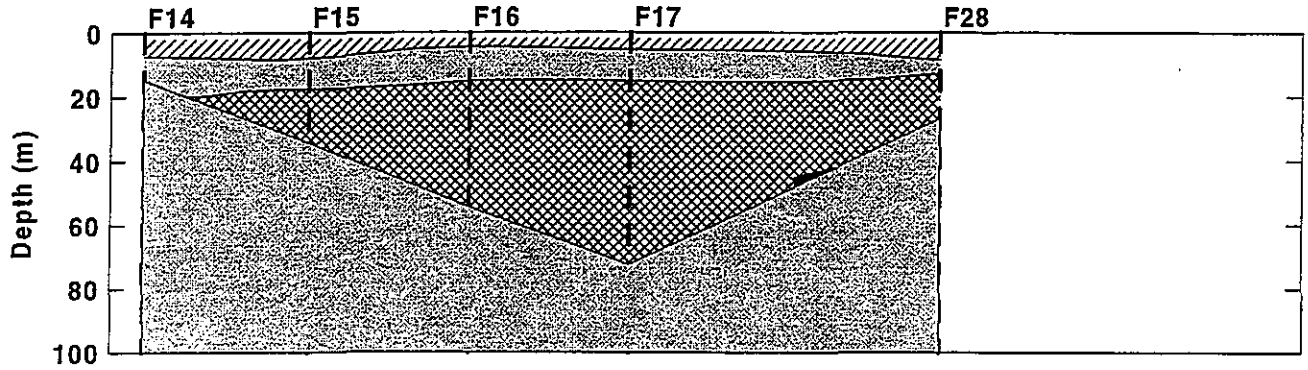


Parameter: Temperature
Survey: 9614

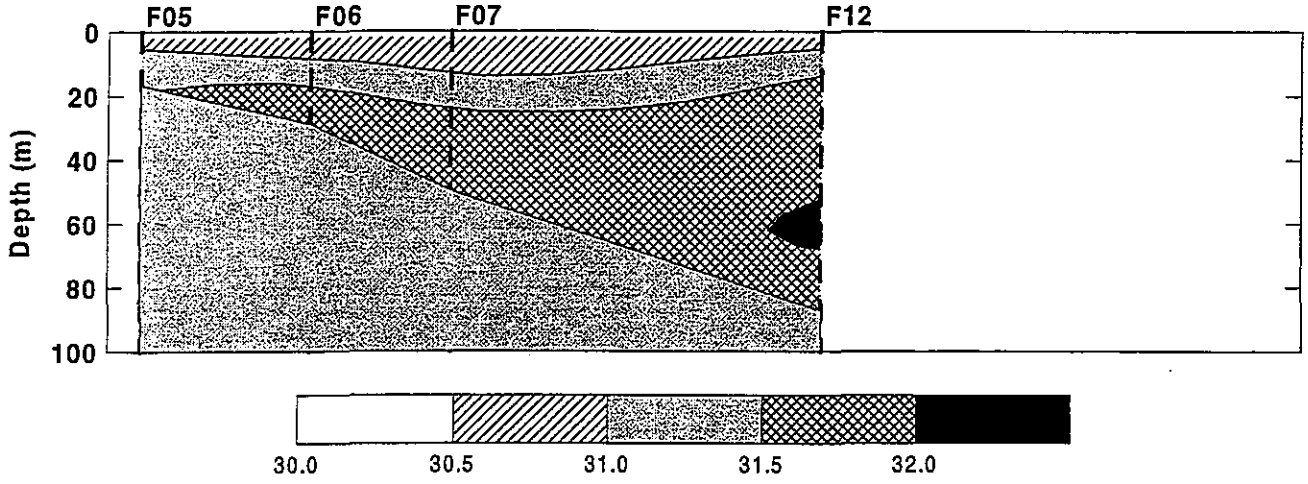
Boston-Nearfield Transect



Cohassett Transect

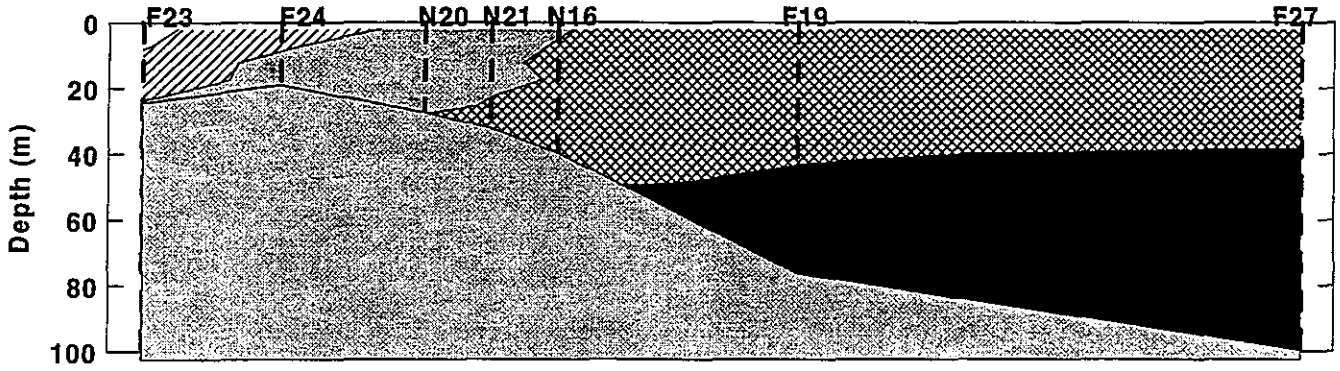


Marshfield Transect

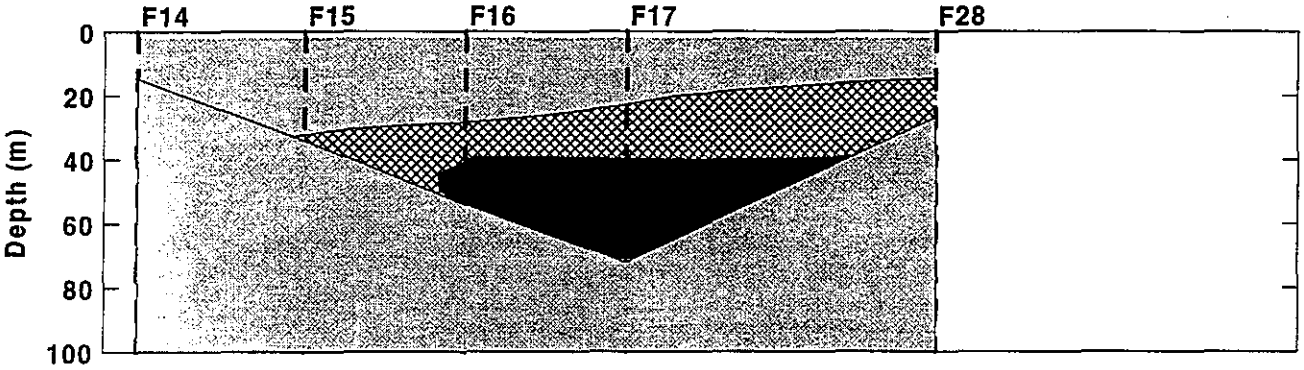


Parameter: Salin
Survey: 96

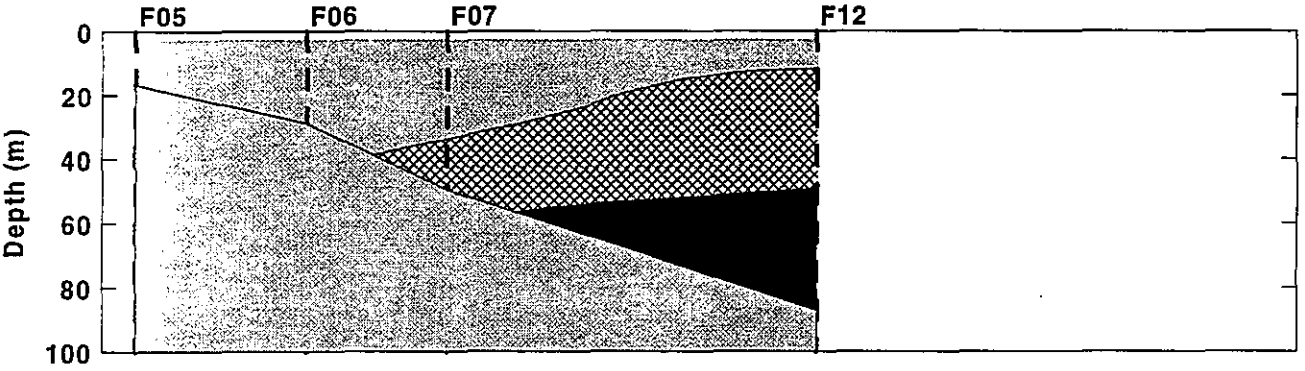
Boston-Nearfield Transect



Cohassett Transect

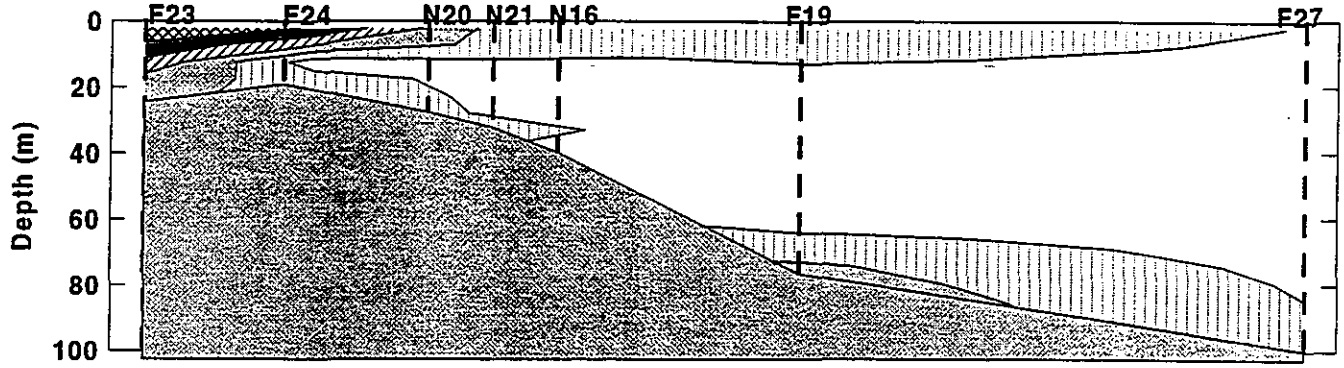


Marshfield Transect

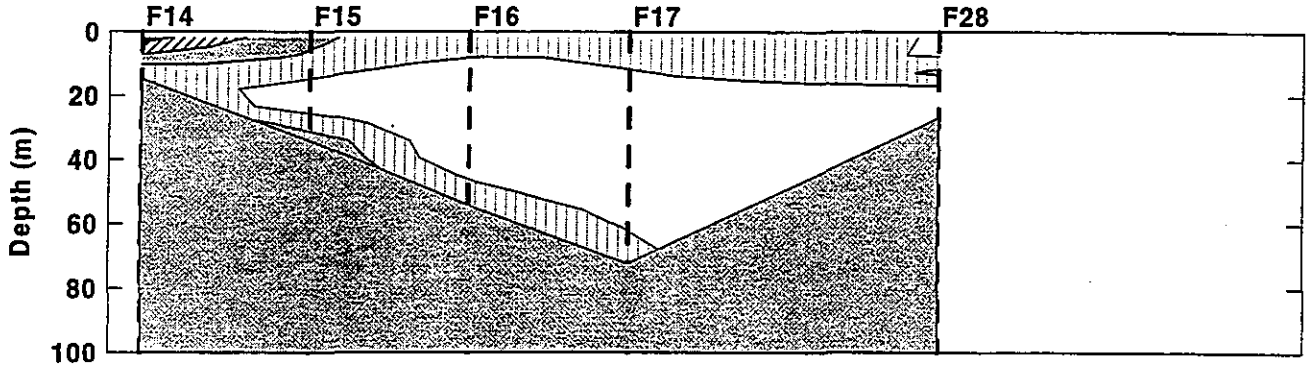


Parameter: Salinity
Survey: 9614

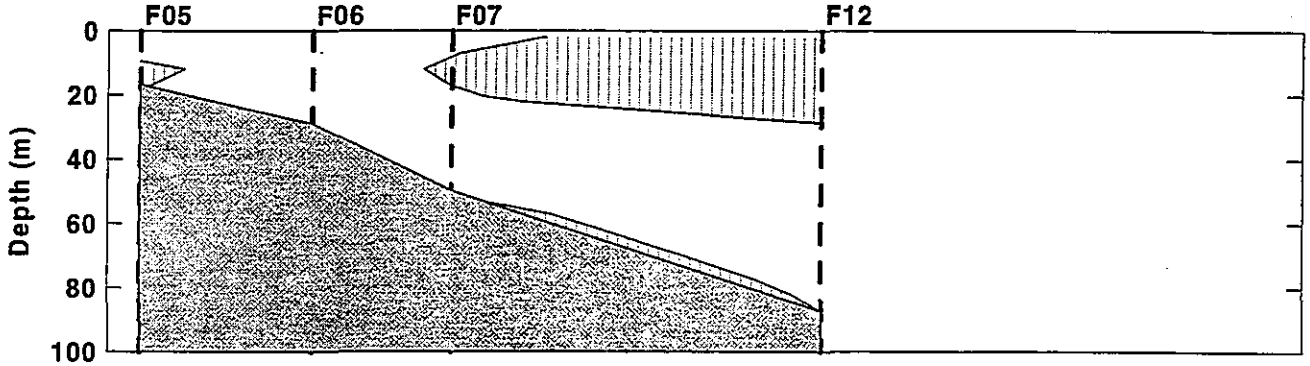
Boston-Nearfield Transect

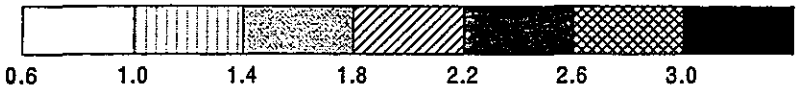


Cohassett Transect



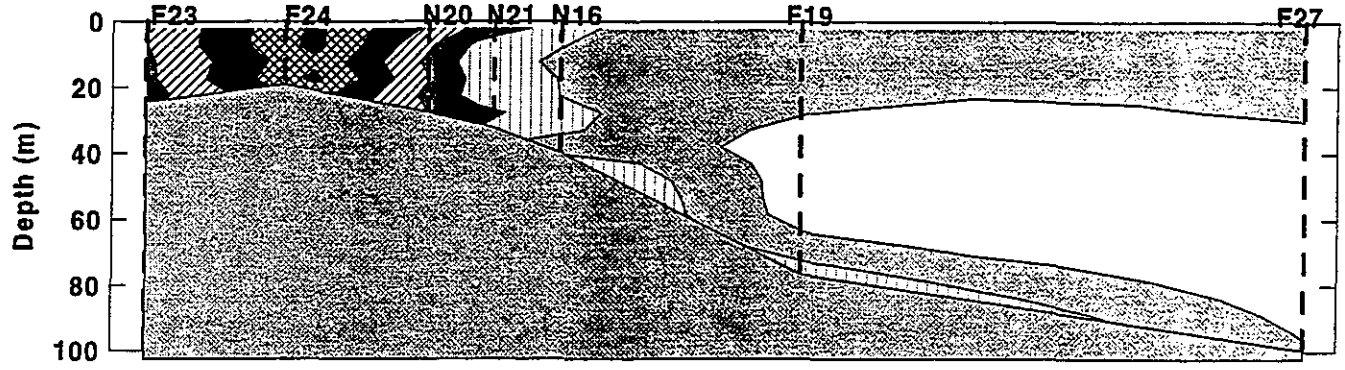
Marshfield Transect



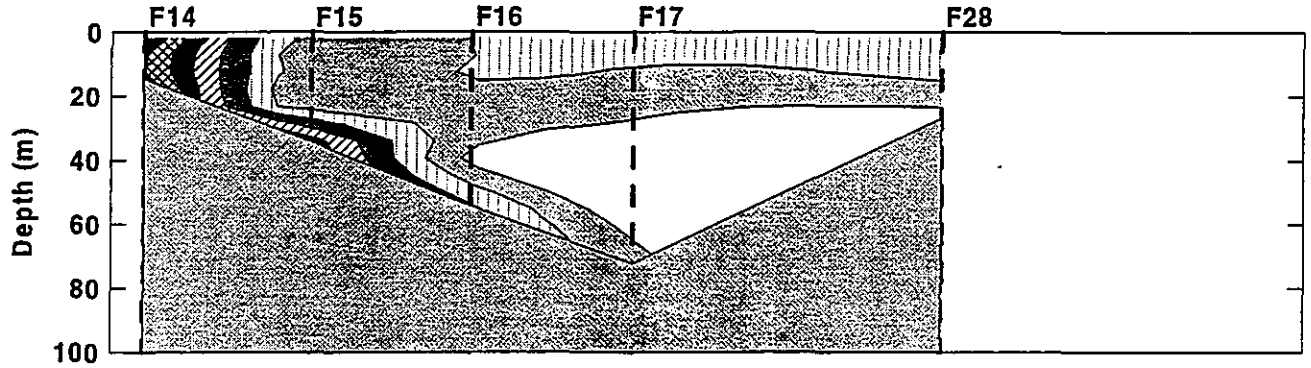


Parameter: Beam Attenuation
Survey: 9611

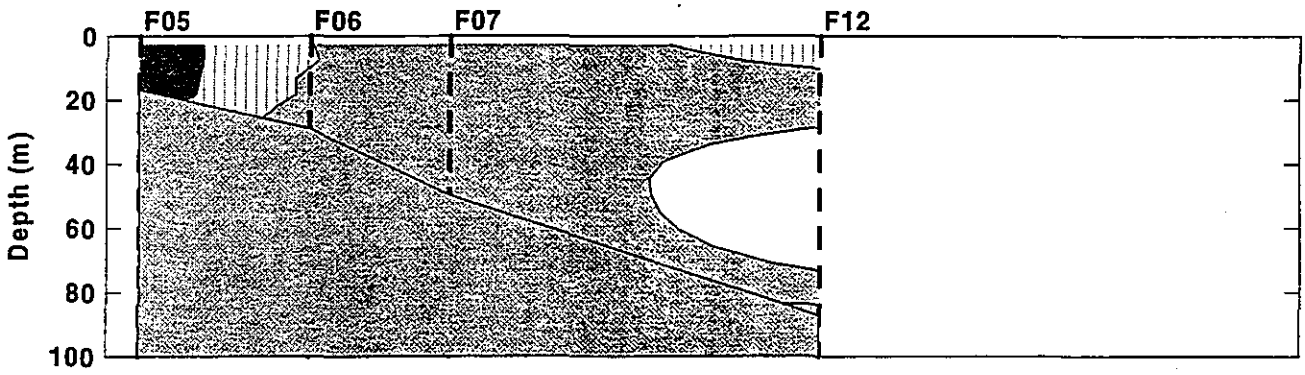
Boston-Nearfield Transect



Cohassett Transect

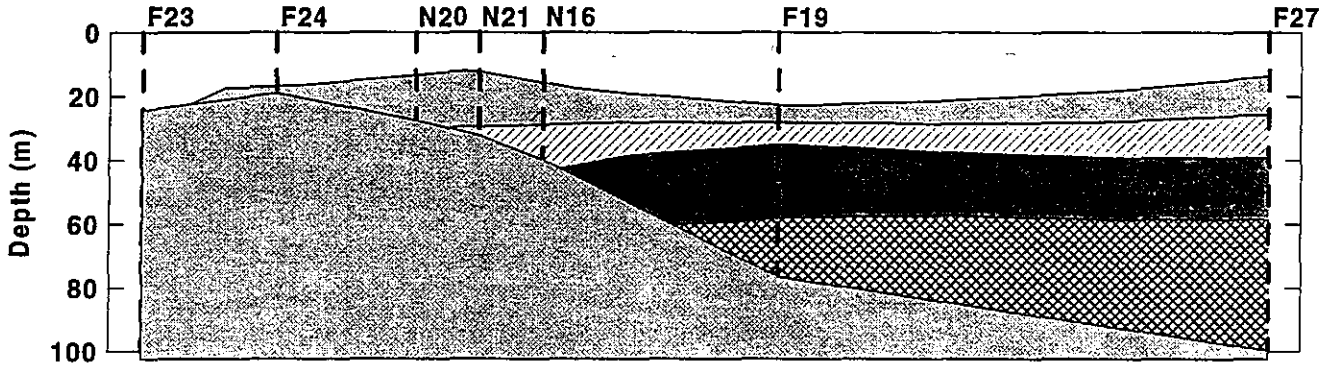


Marshfield Transect

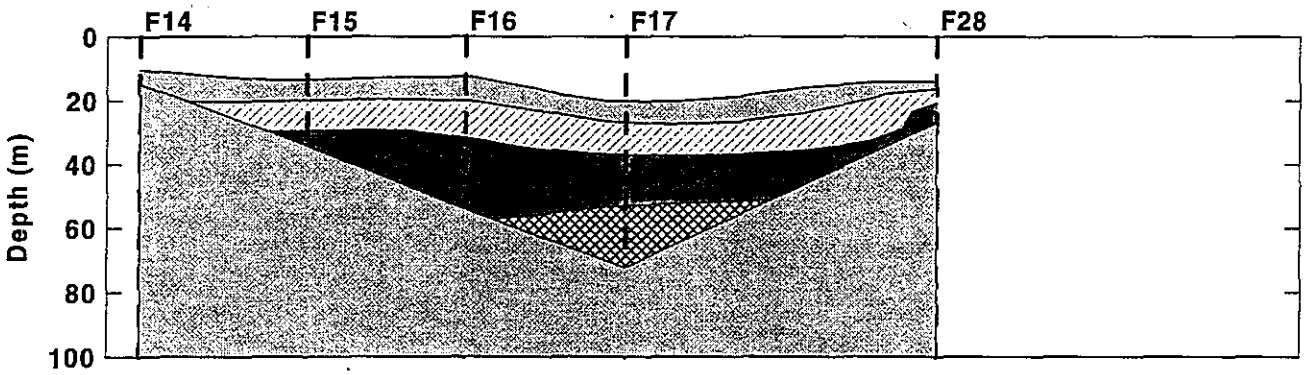


Parameter: Beam Attenuation
Survey: 9614

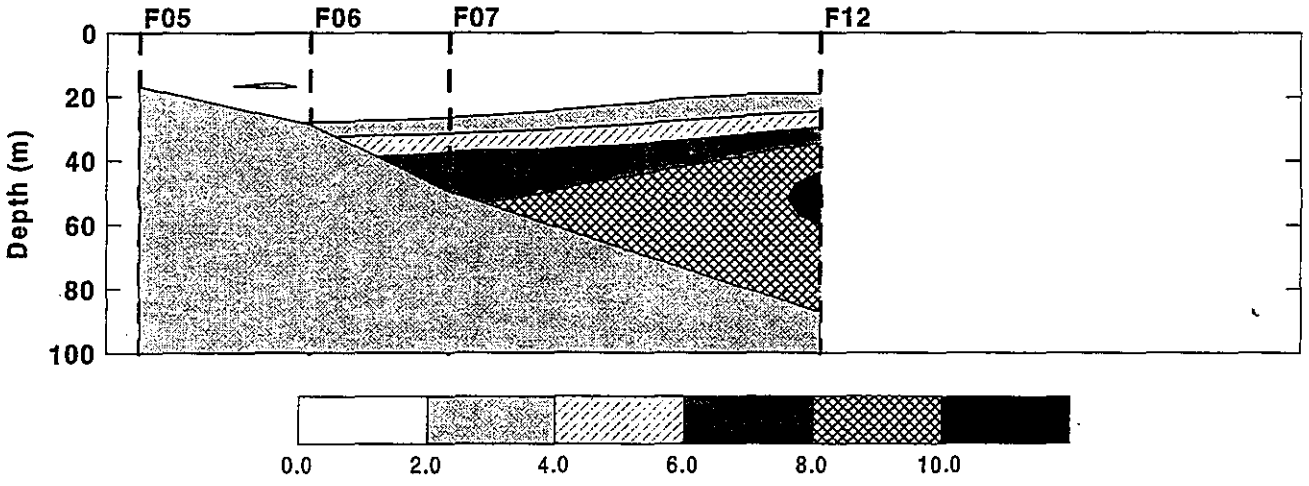
Boston-Nearfield Transect



Cohassett Transect

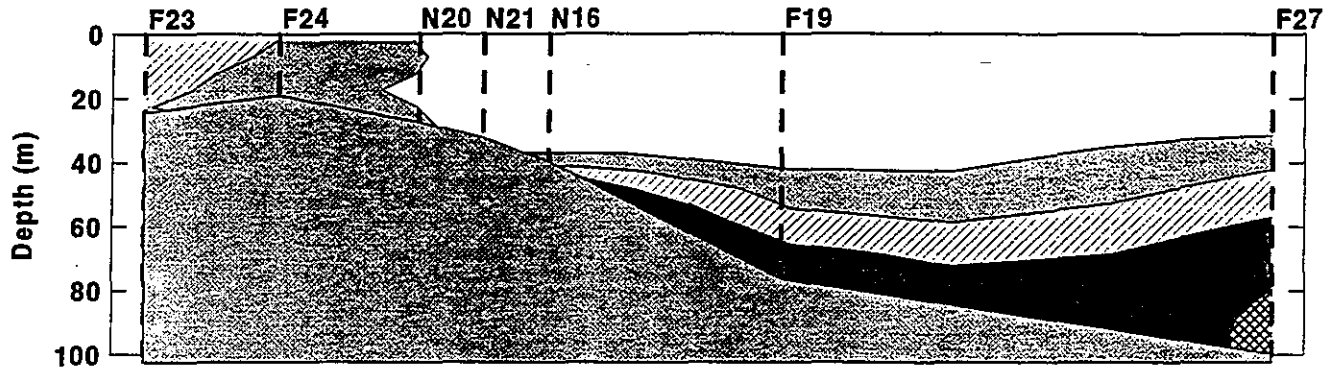


Marshfield Transect

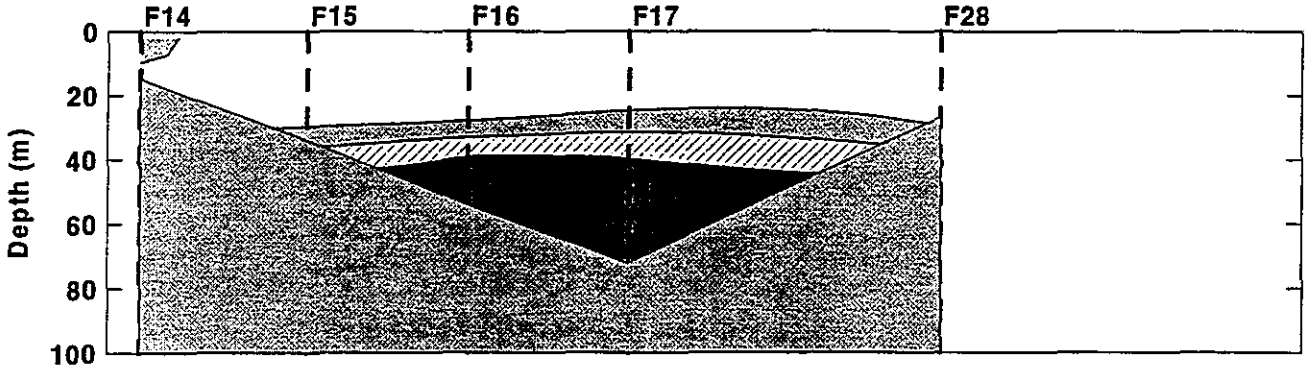


Parameter: Nitrite+Nitrate
Survey: 9611

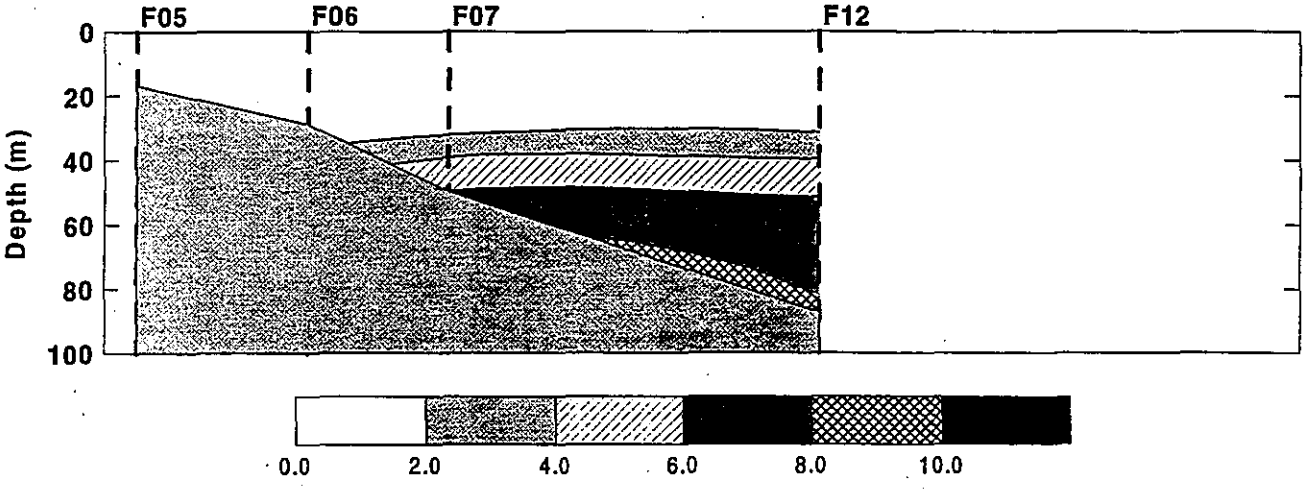
Boston-Nearfield Transect



Cohassett Transect

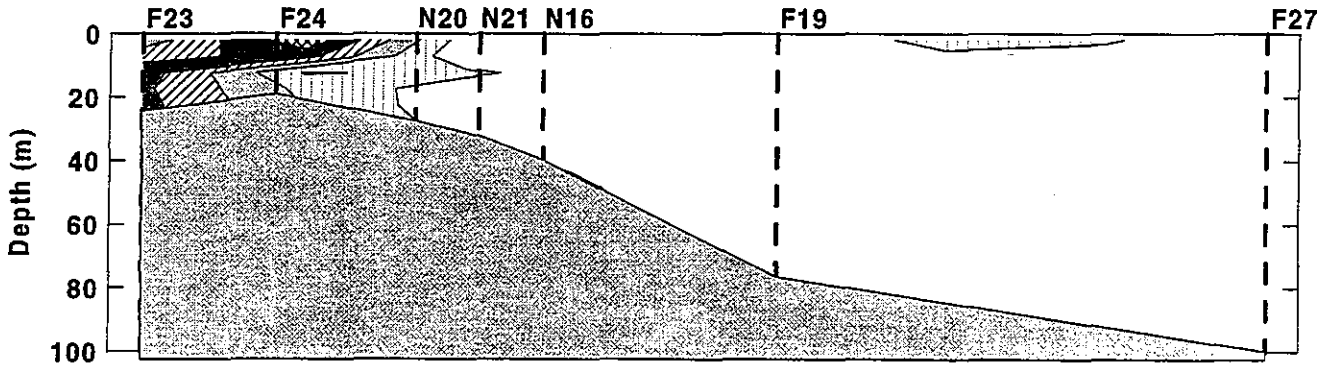


Marshfield Transect

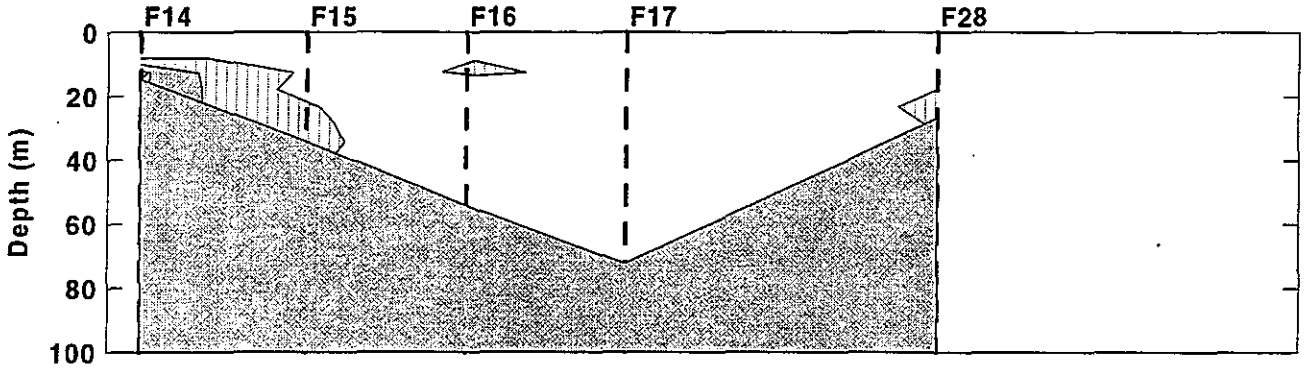


Parameter: Nitrite+Nitrate
Survey: 9614

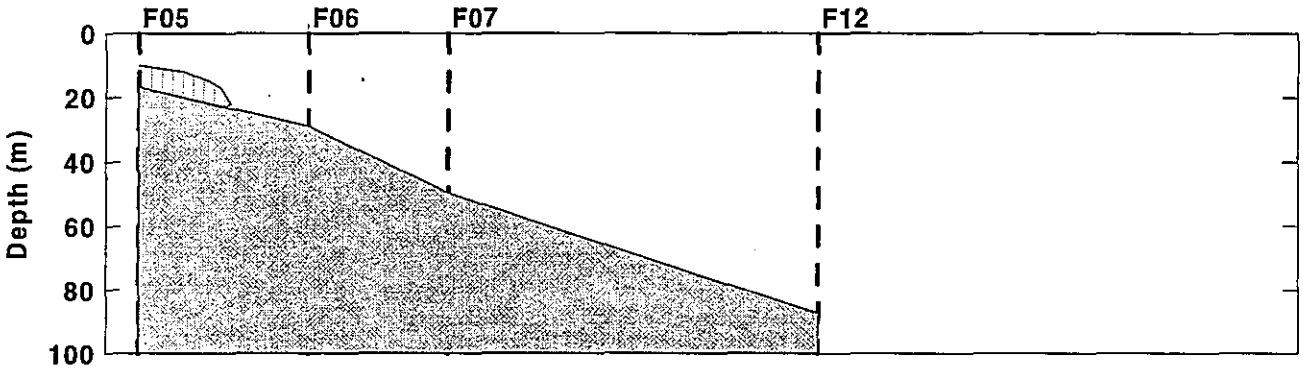
Boston-Nearfield Transect

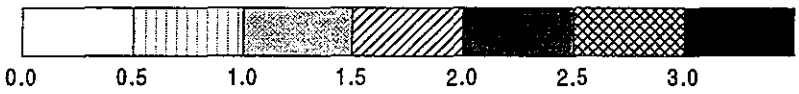


Cohassett Transect



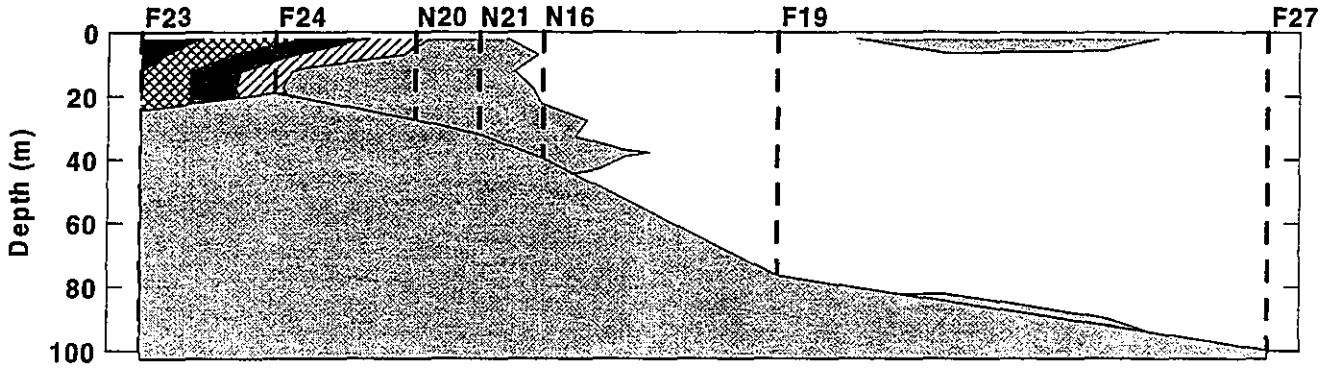
Marshfield Transect



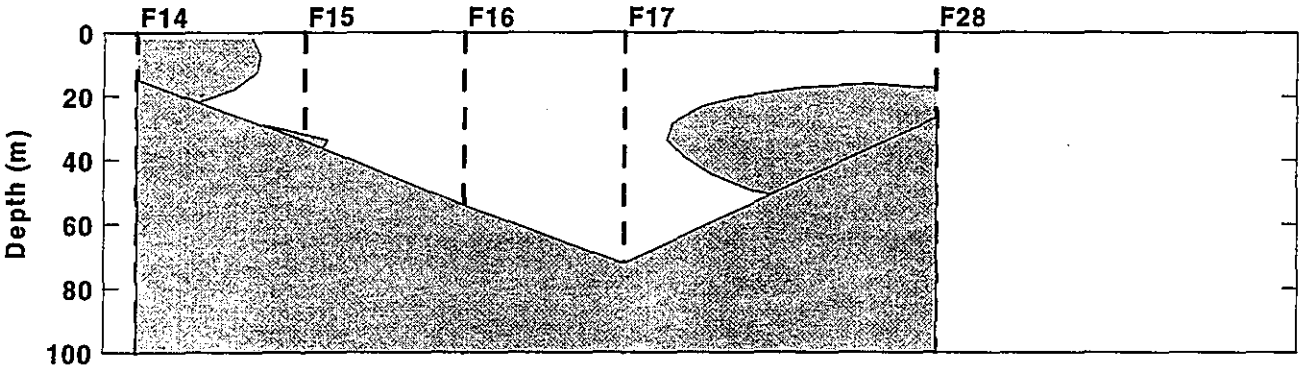


Parameter: Ammonium
Survey: 9611

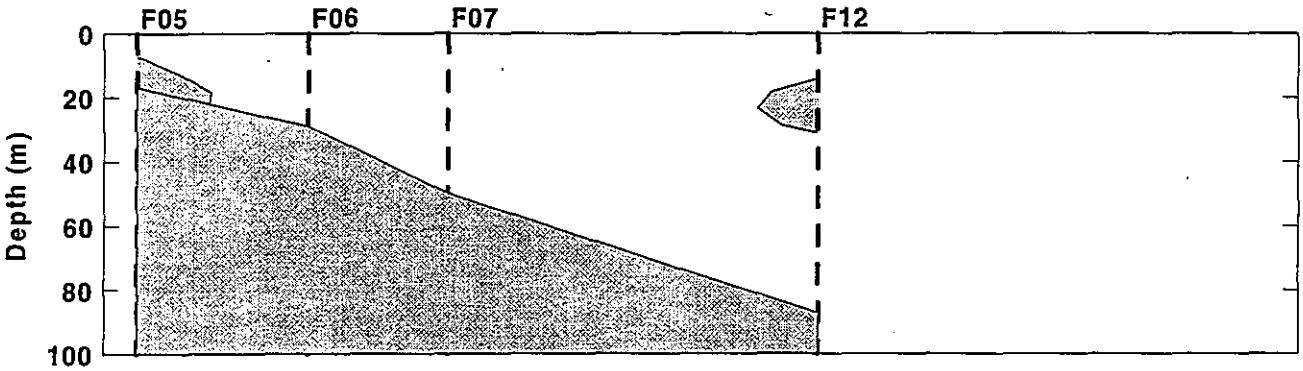
Boston-Nearfield Transect

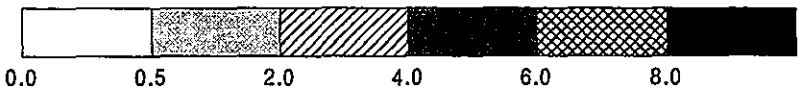


Cohassett Transect



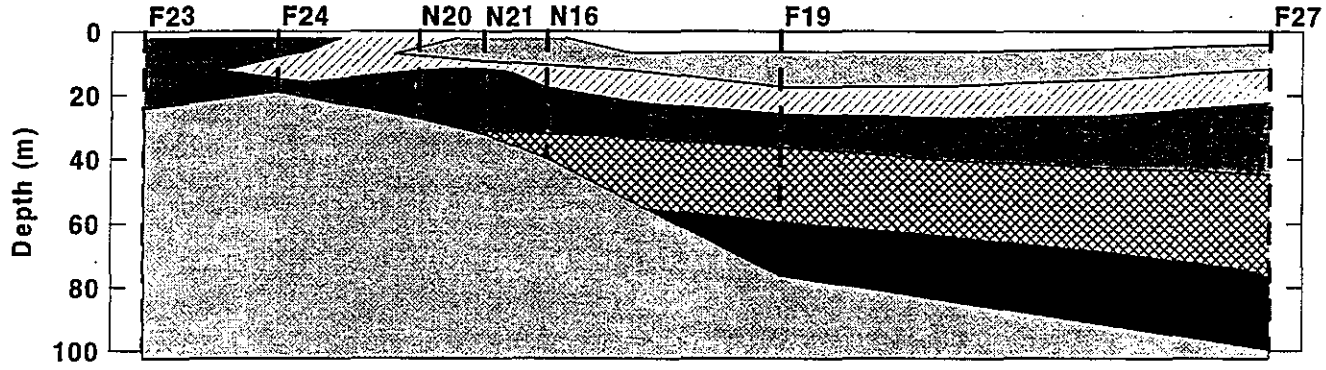
Marshfield Transect



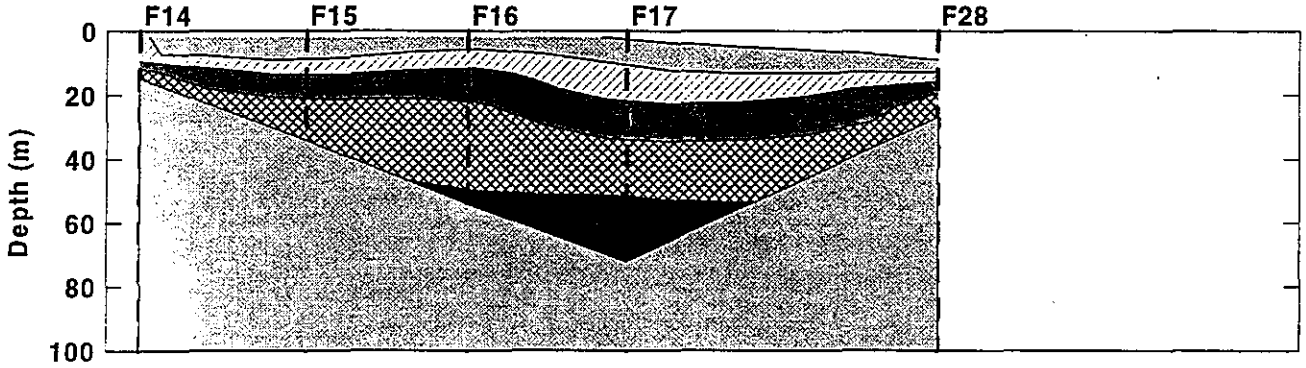


Parameter: Ammonium
Survey: 9614

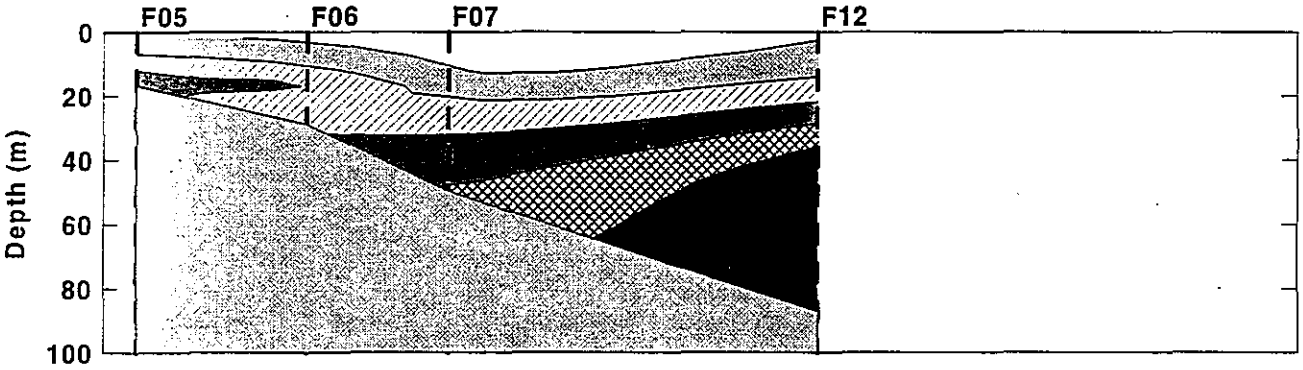
Boston-Nearfield Transect

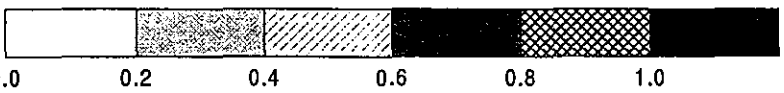


Cohassett Transect



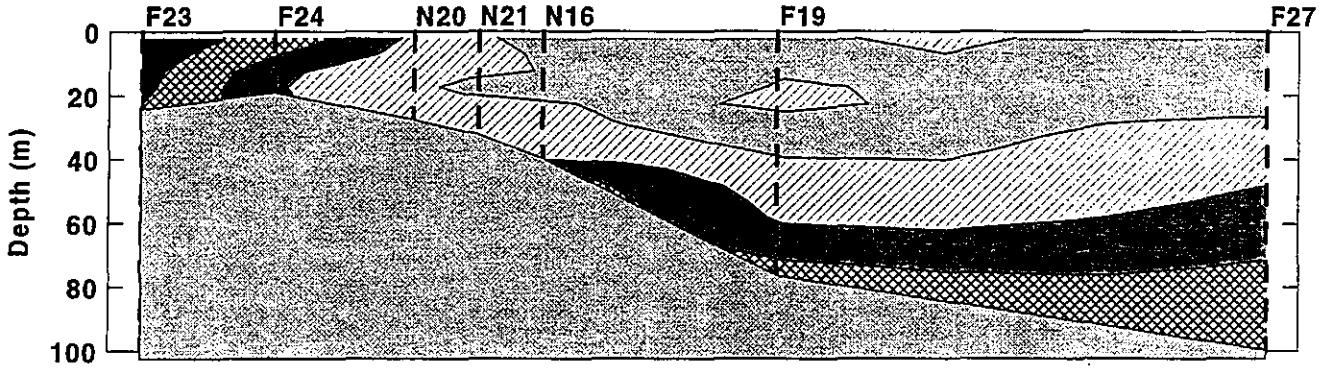
Marshfield Transect



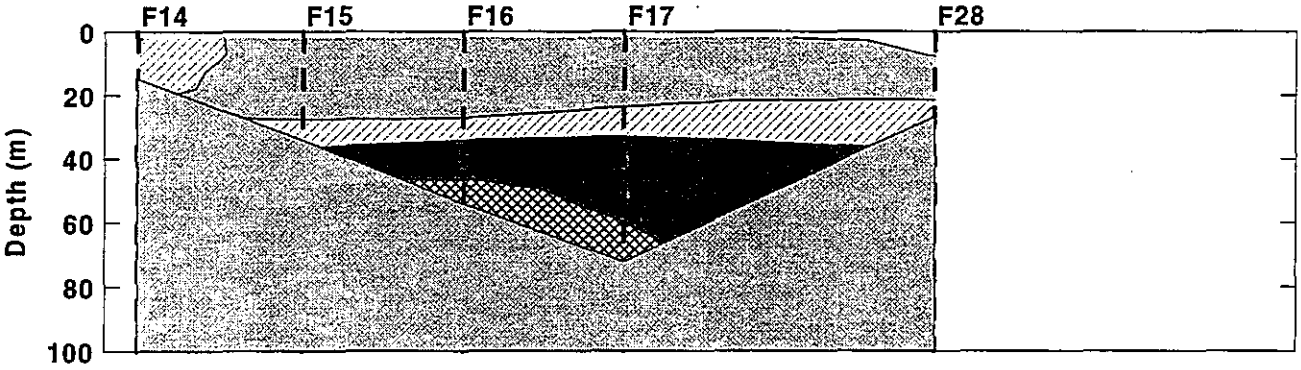


Parameter: Phosphate
Survey: 9611

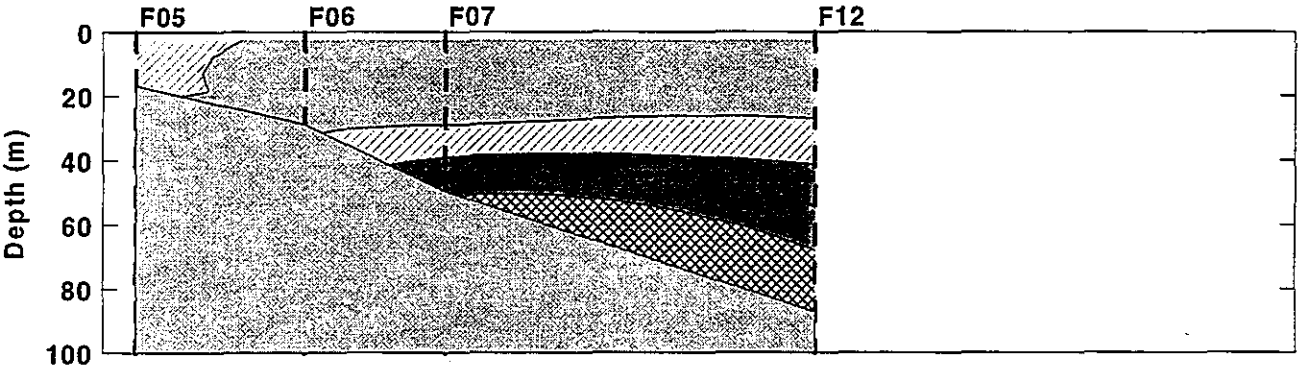
Boston-Nearfield Transect

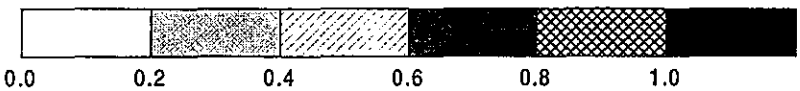


Cohassett Transect



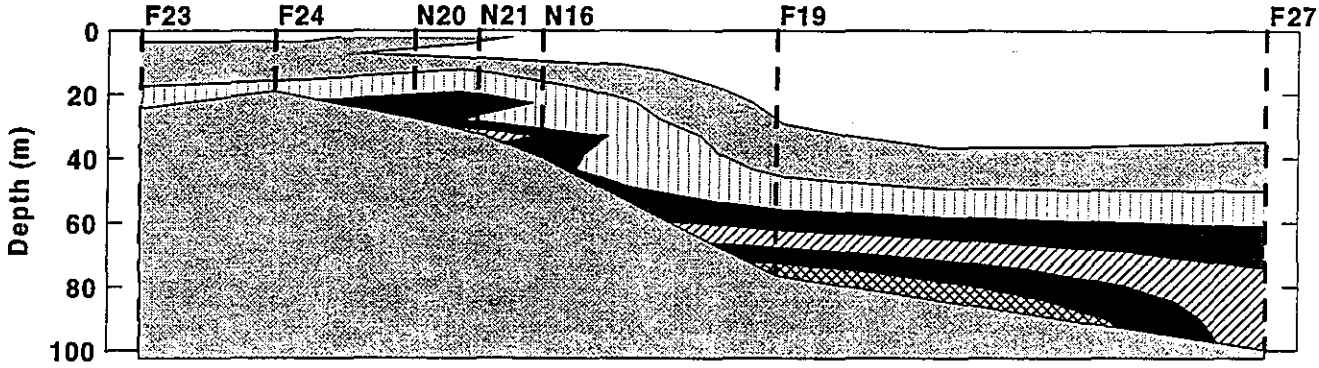
Marshfield Transect



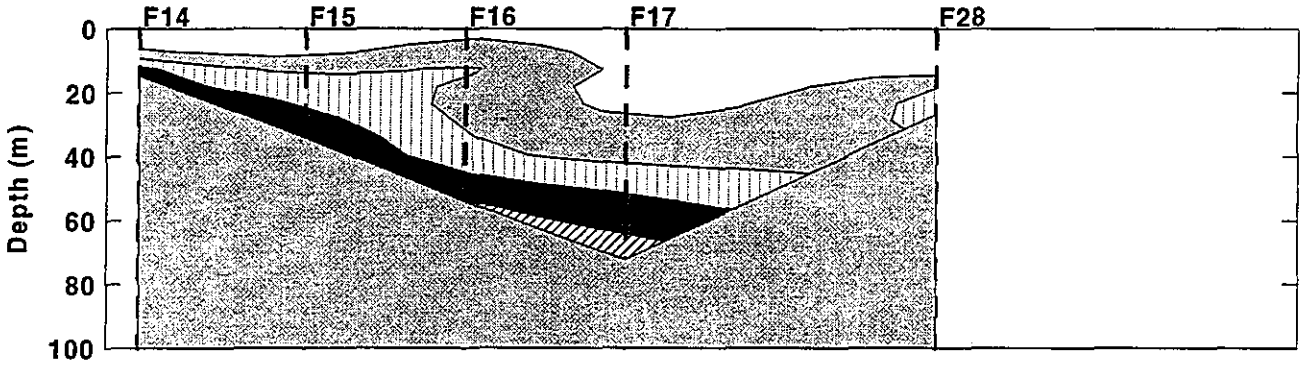


Parameter: Phosphate
Survey: 9614

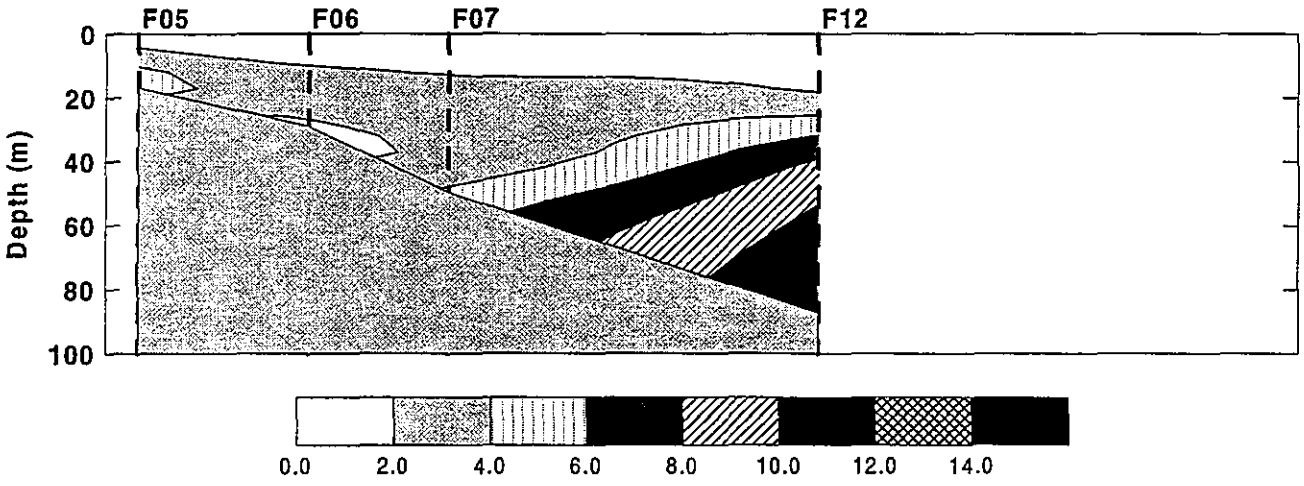
Boston-Nearfield Transect



Cohassett Transect

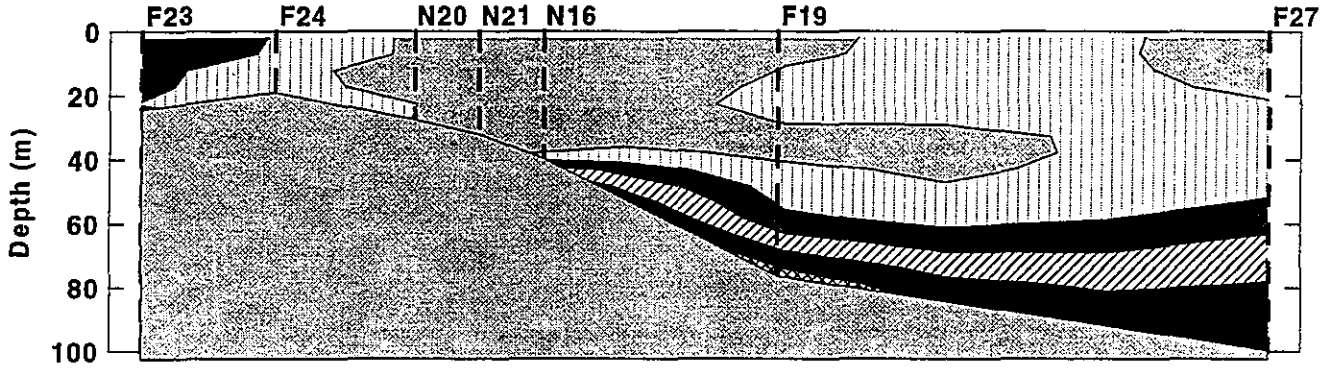


Marshfield Transect



Parameter: Silicate
Survey: 9611

Boston-Nearfield Transect



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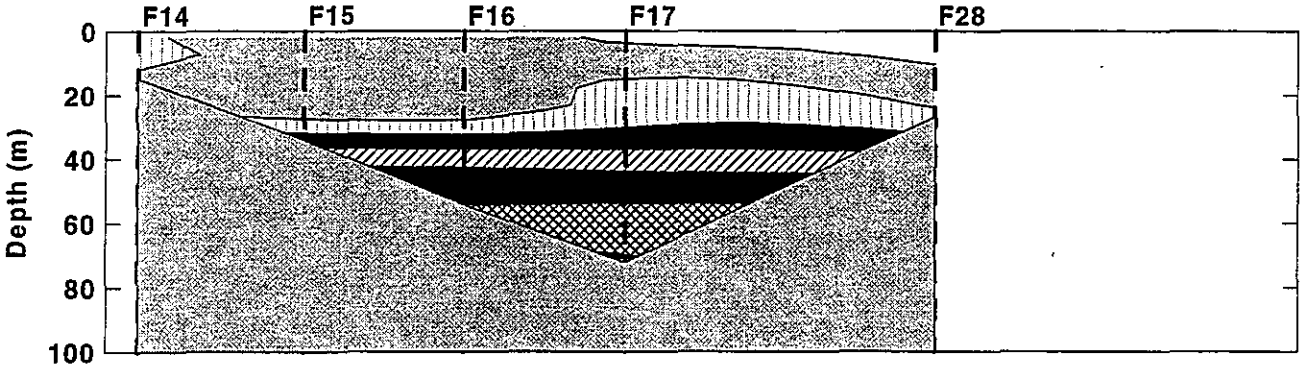
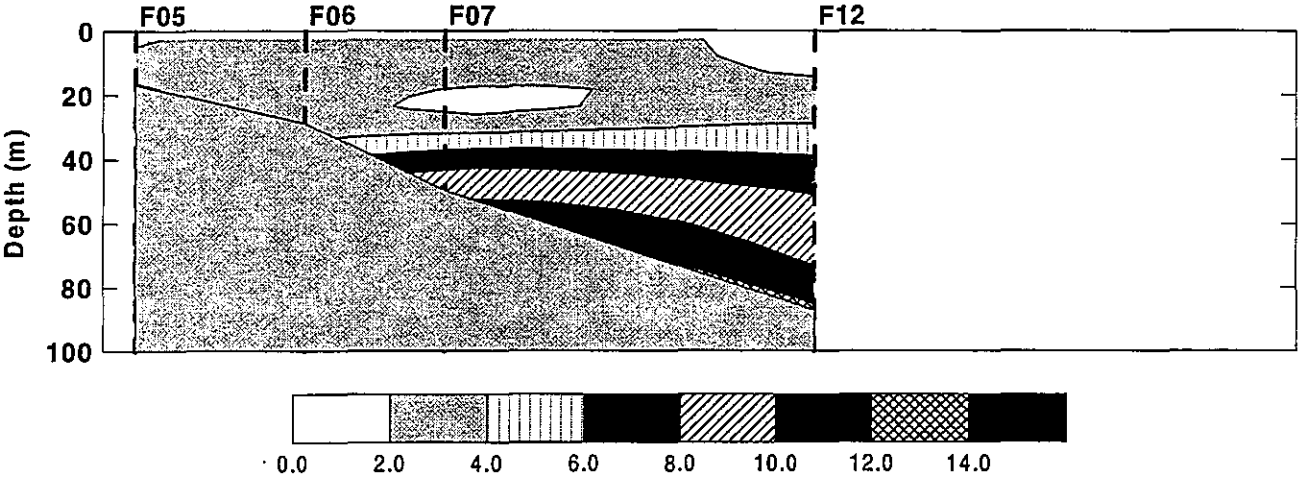
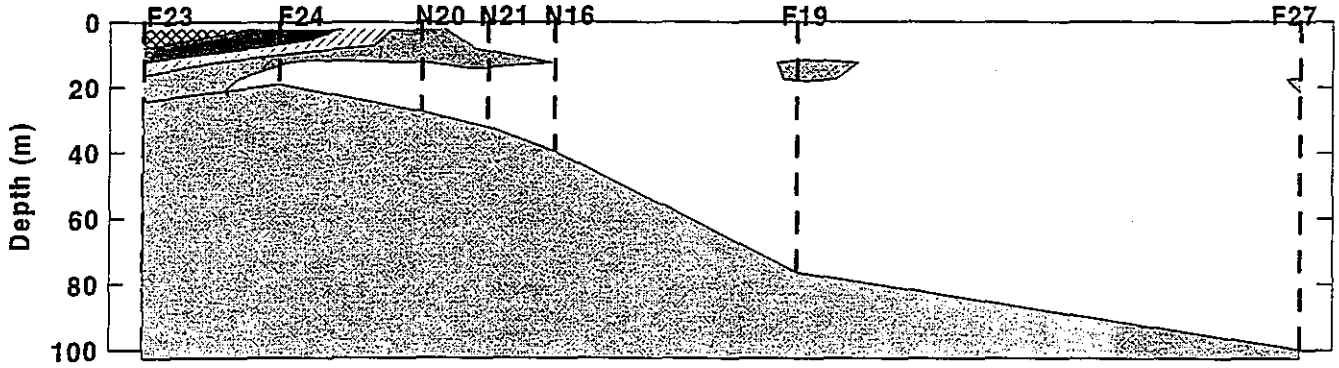


Marshfield Transect



Parameter: Silicate
Survey: 9614

Boston-Nearfield Transect



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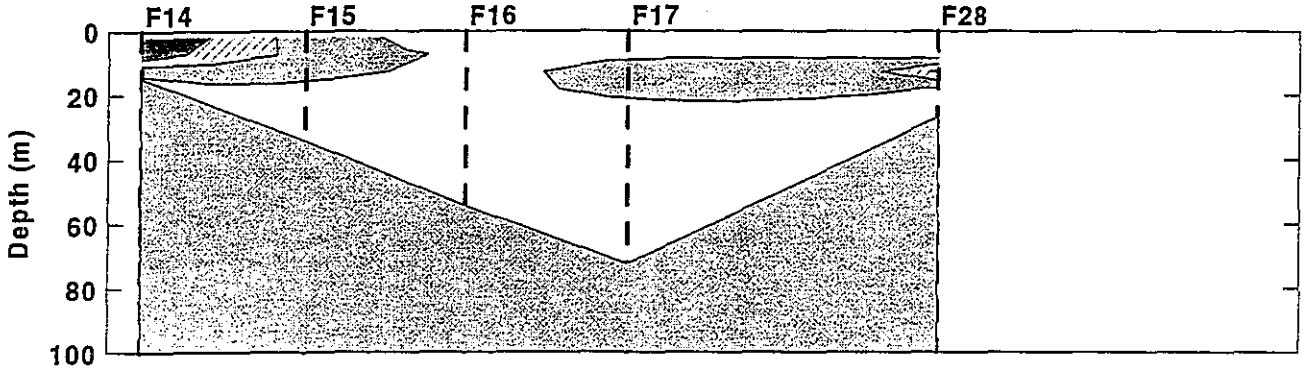
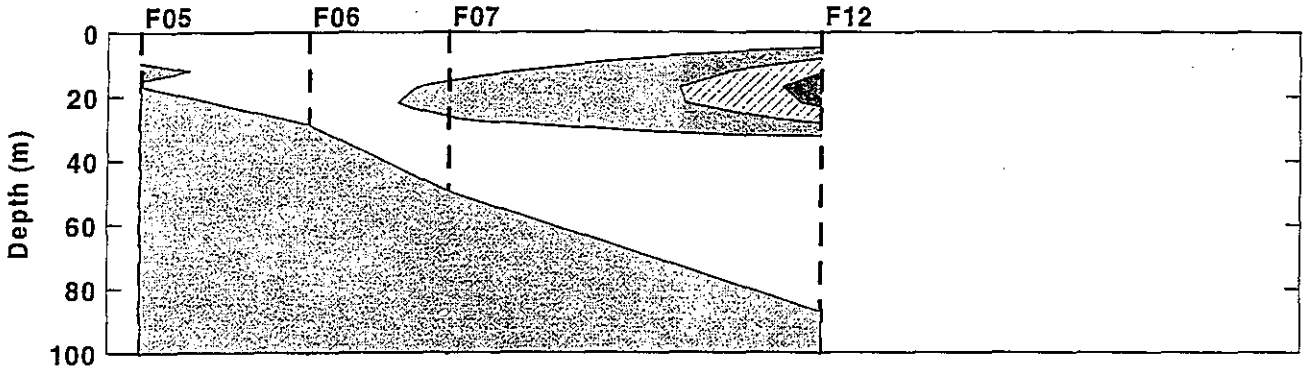
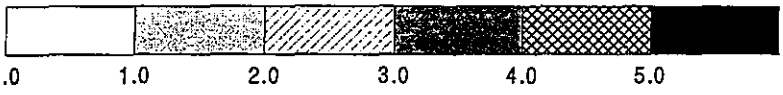


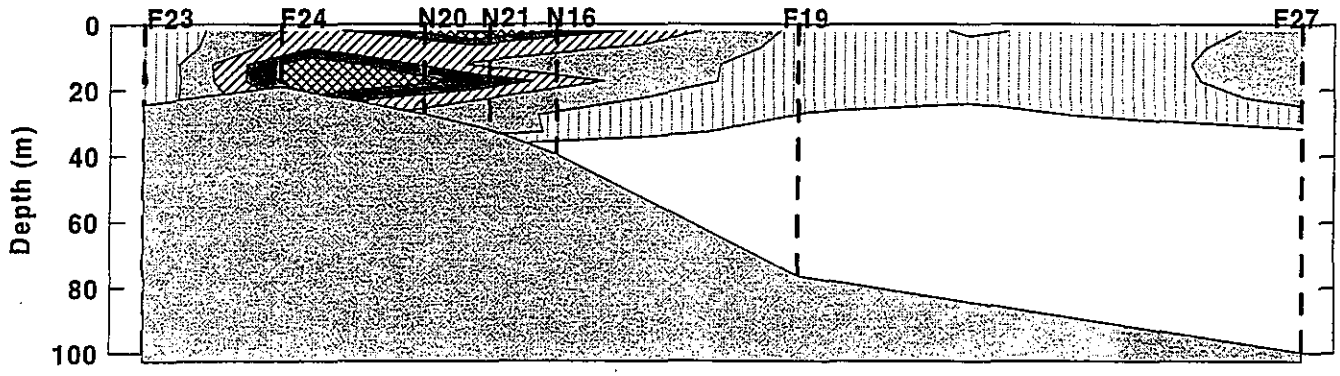
Marshfield Transect



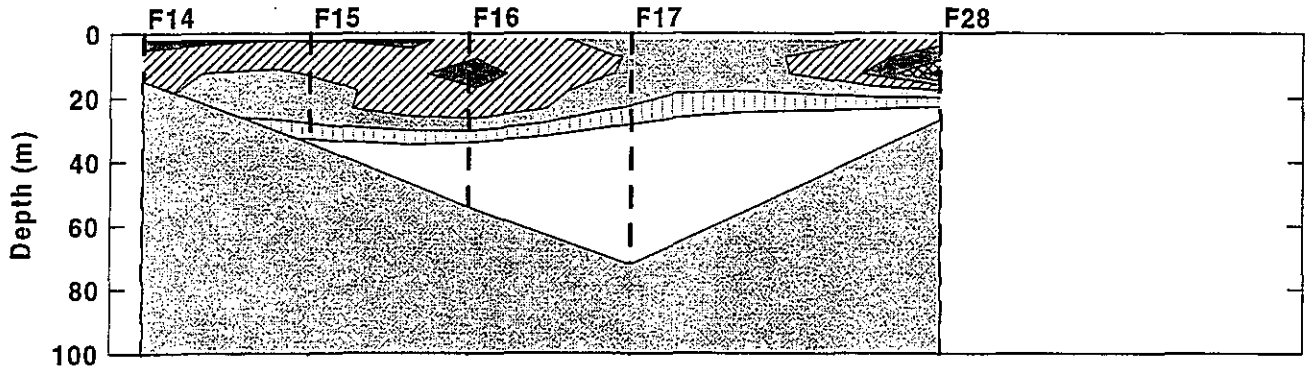


Parameter: Fluorescence
Survey: 9611

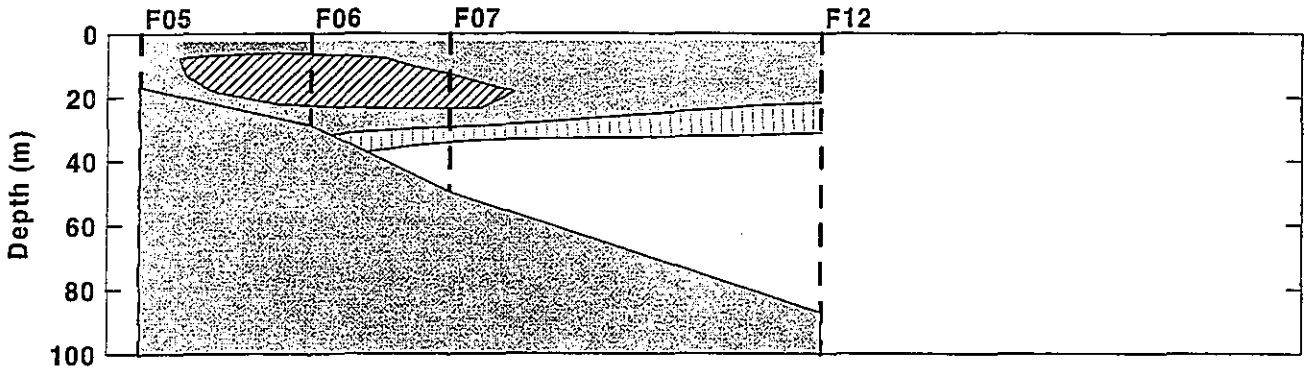
Boston-Nearfield Transect

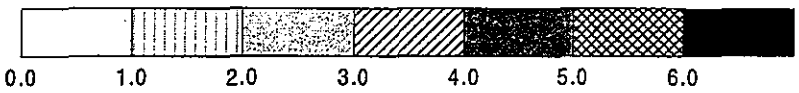


Cohassett Transect



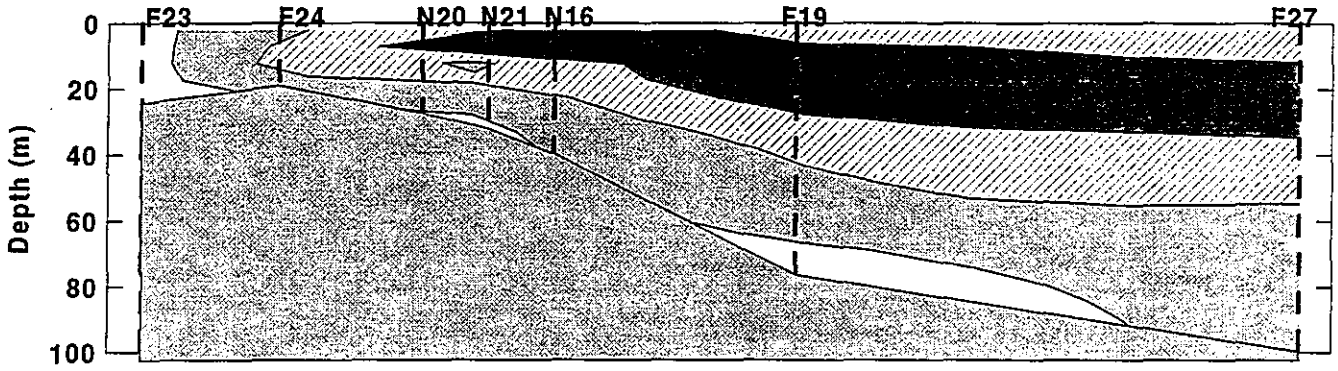
Marshfield Transect



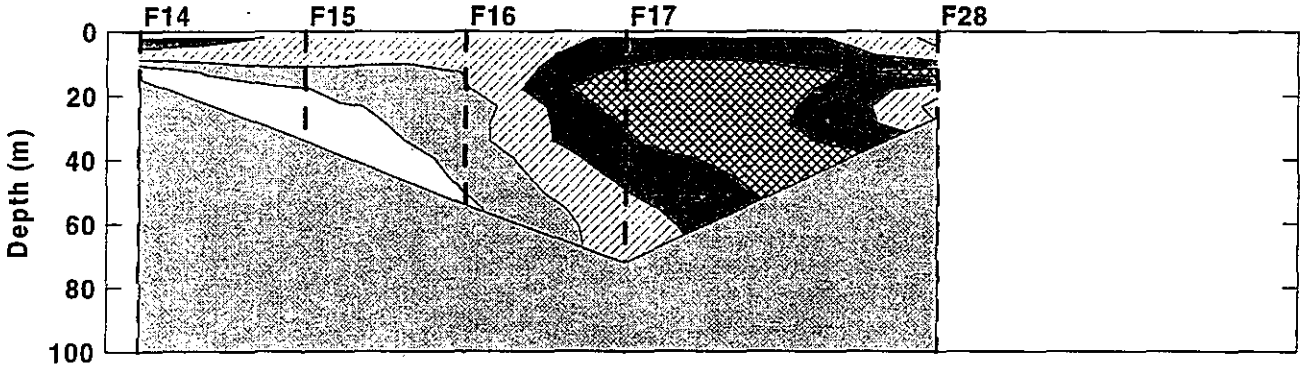


Parameter: Fluorescence
Survey: 9614

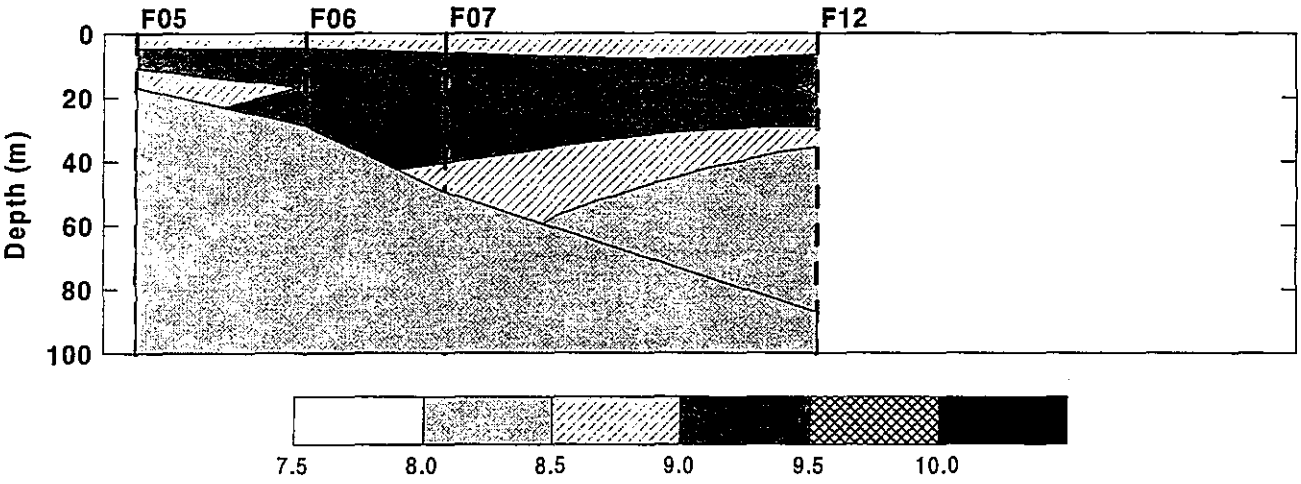
Boston-Nearfield Transect



Cohassett Transect

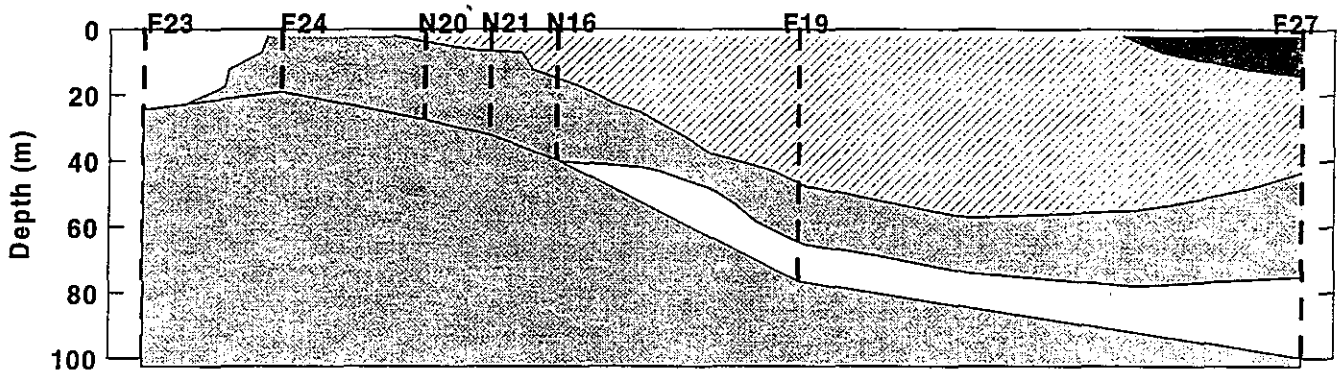


Marshfield Transect

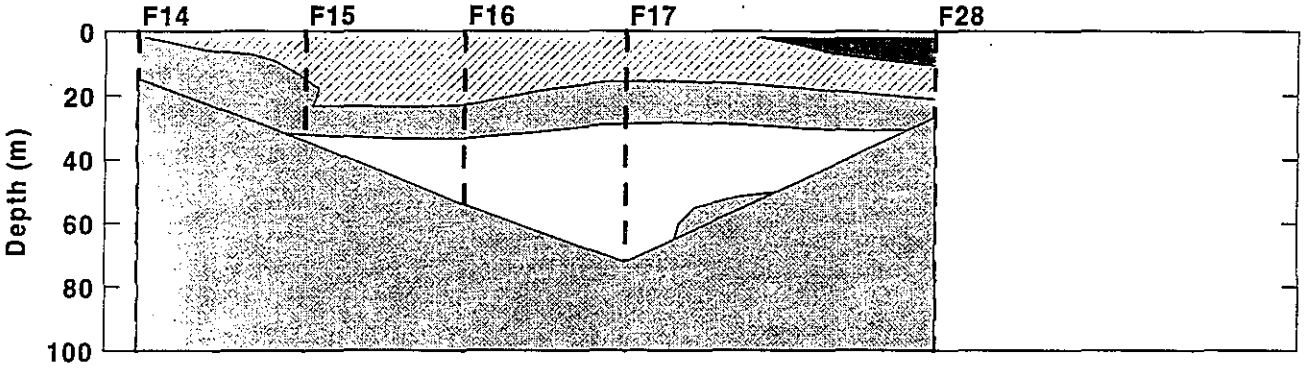


Parameter: Dissolved Oxygen (mg/L)
Survey: 9611

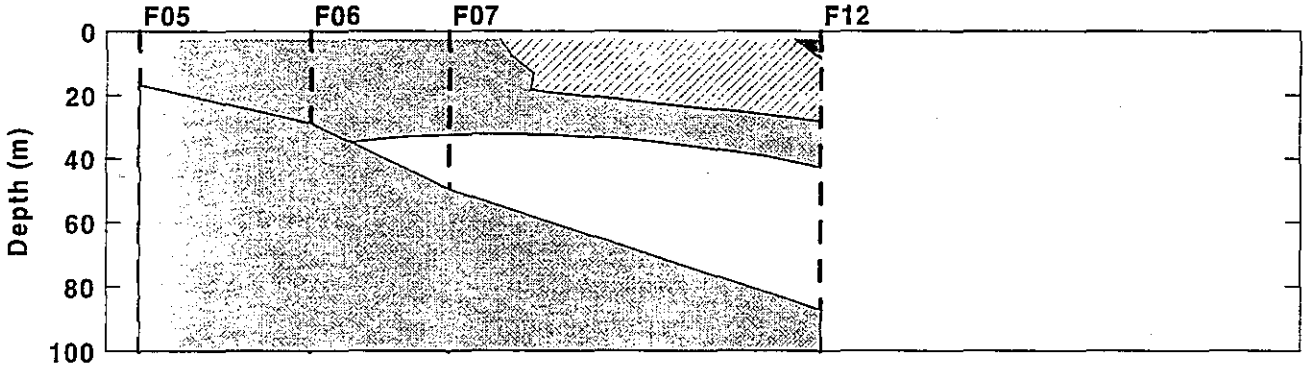
Boston-Nearfield Transect

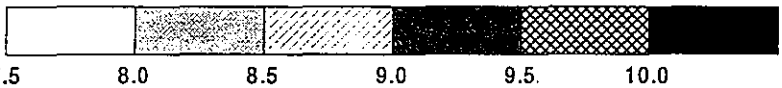


Cohassett Transect



Marshfield Transect





Parameter: Dissolved Oxygen (mg/L)
Survey: 9614

APPENDIX D

Nutrient Scatter Plots

Scatter plots are included for every survey conducted during the semi-annual period. Each plot includes all stations and all depths. The plots are organized by type of plot, and then by survey. Combined nearfield/farfield surveys show the regions with different symbols, including Boundary, Cape Cod Bay, Coastal, Boston Harbor, Nearfield, and Offshore. Available plots are summarized in the text.

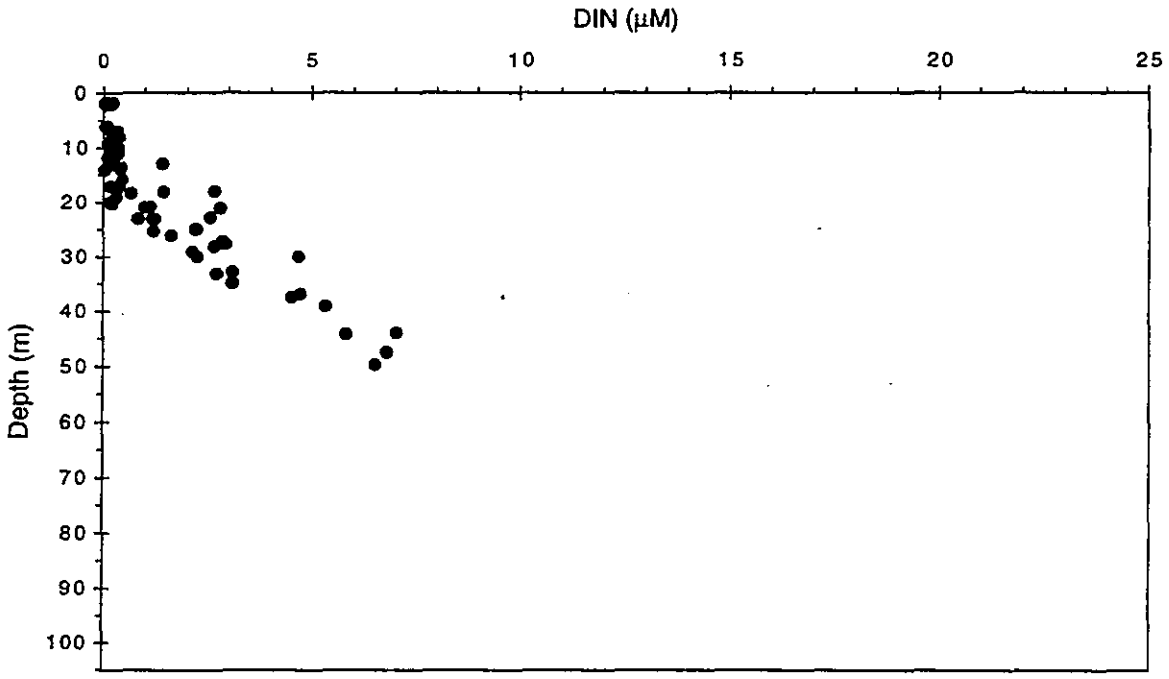


FIGURE 4-136
Depth vs. nutrient plots for nearfield survey W9610, (Aug 96).

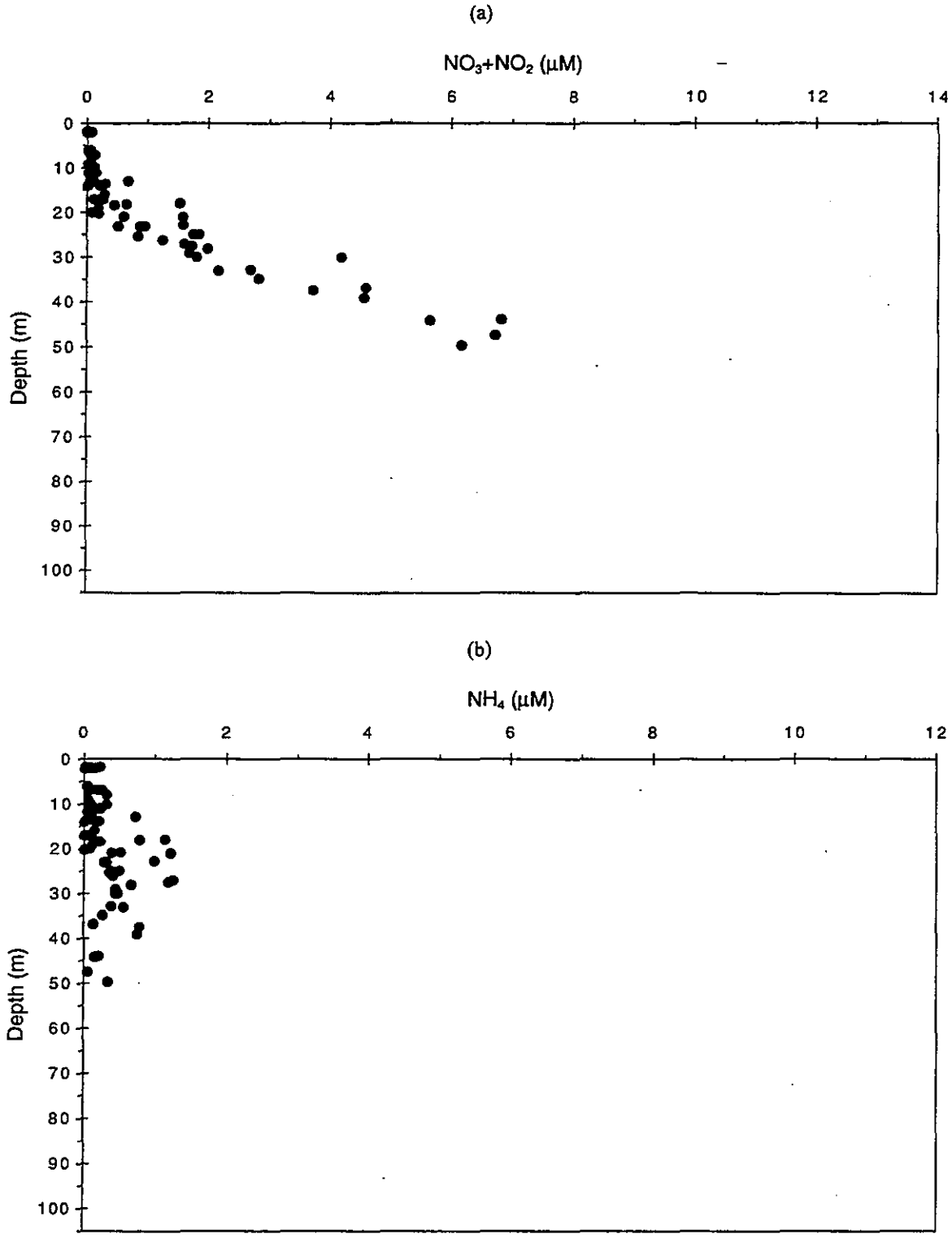


FIGURE 4-137
Depth vs. nutrient plots for nearfield survey W9610, (Aug 96).

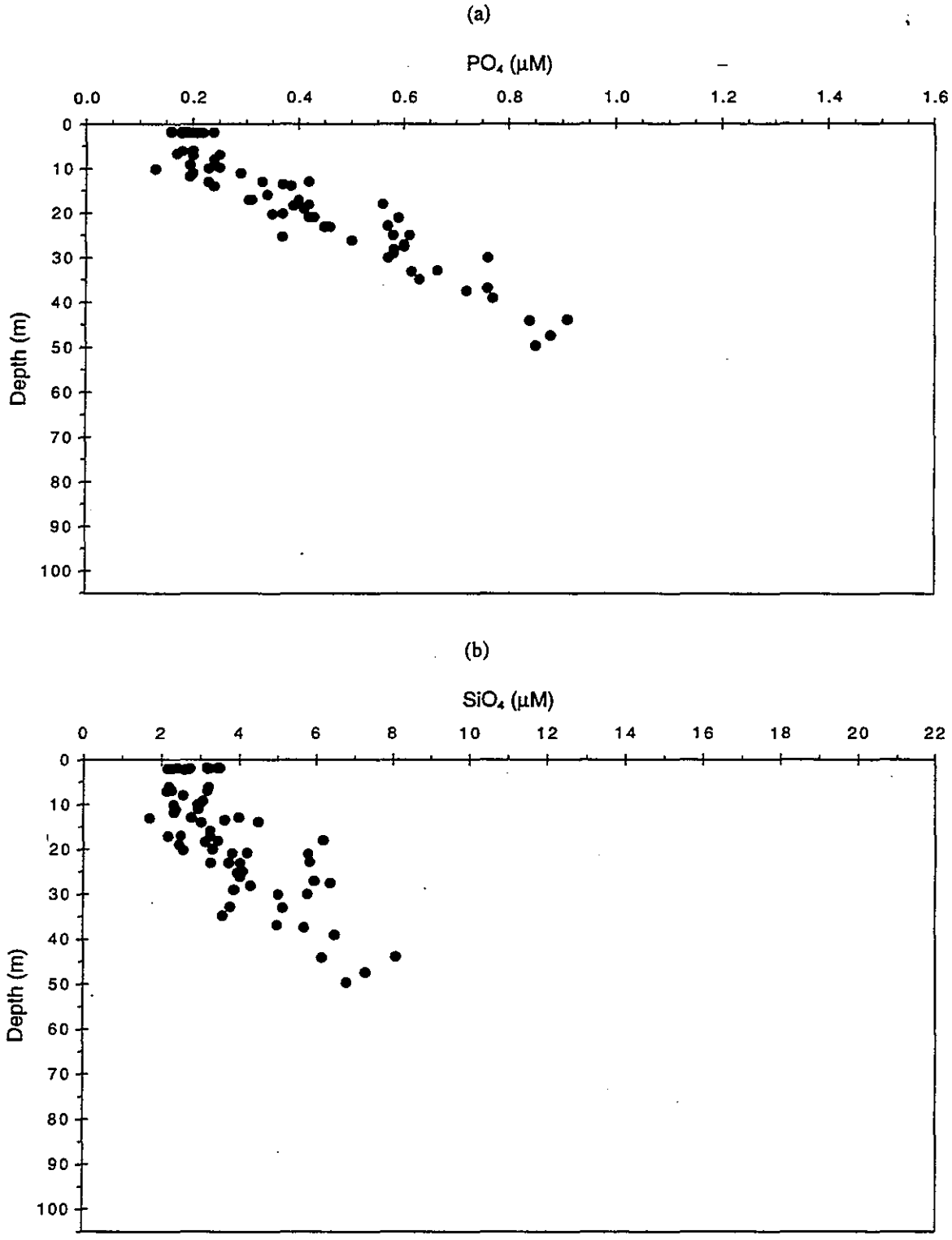


FIGURE 4-138
Depth vs. nutrient plots for nearfield survey W9610, (Aug 96).

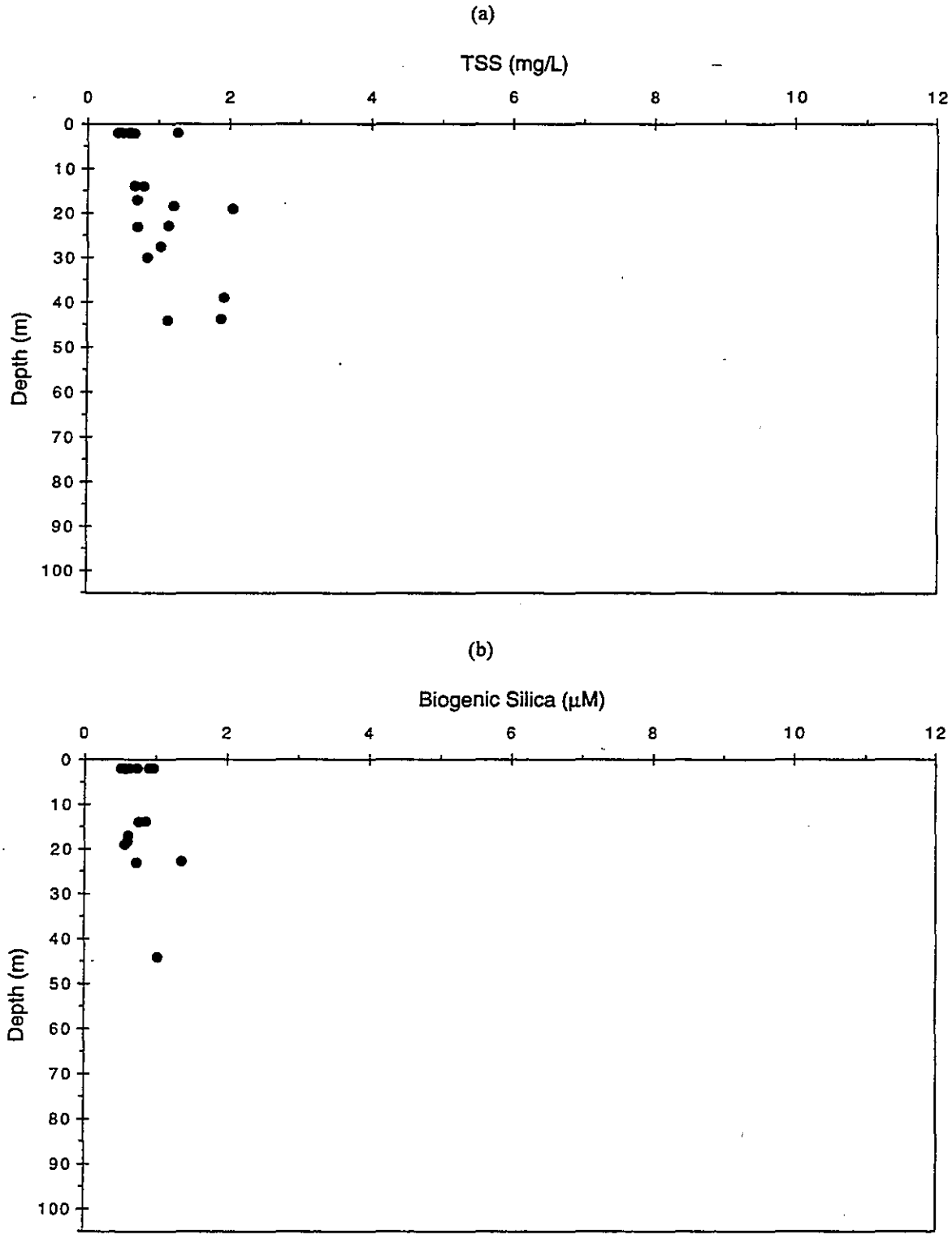


FIGURE 4-139
Depth vs. nutrient plots for nearfield survey W9610, (Aug 96).

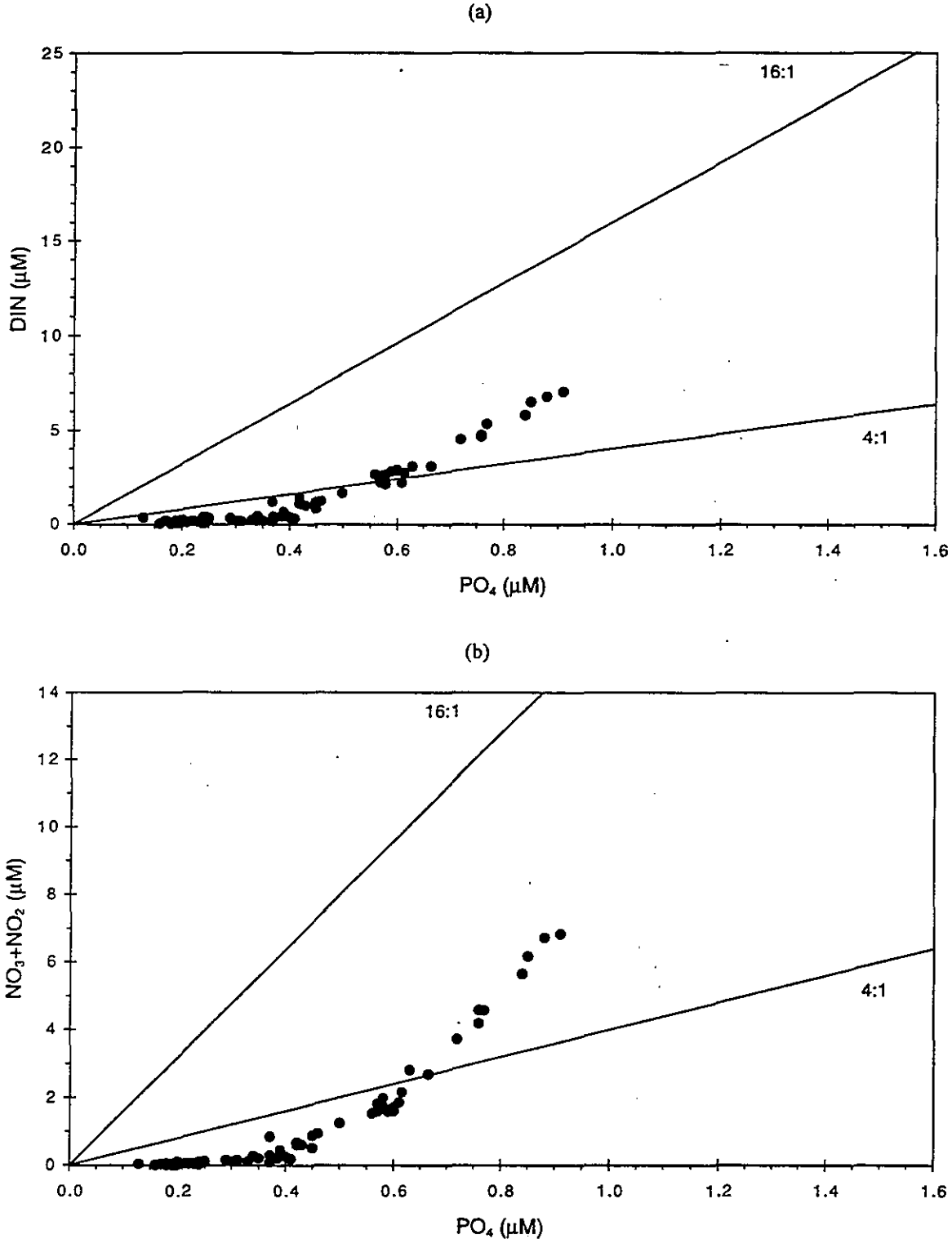


FIGURE 4-140
Nutrient vs. nutrient plots for nearfield survey W9610, (Aug 96).

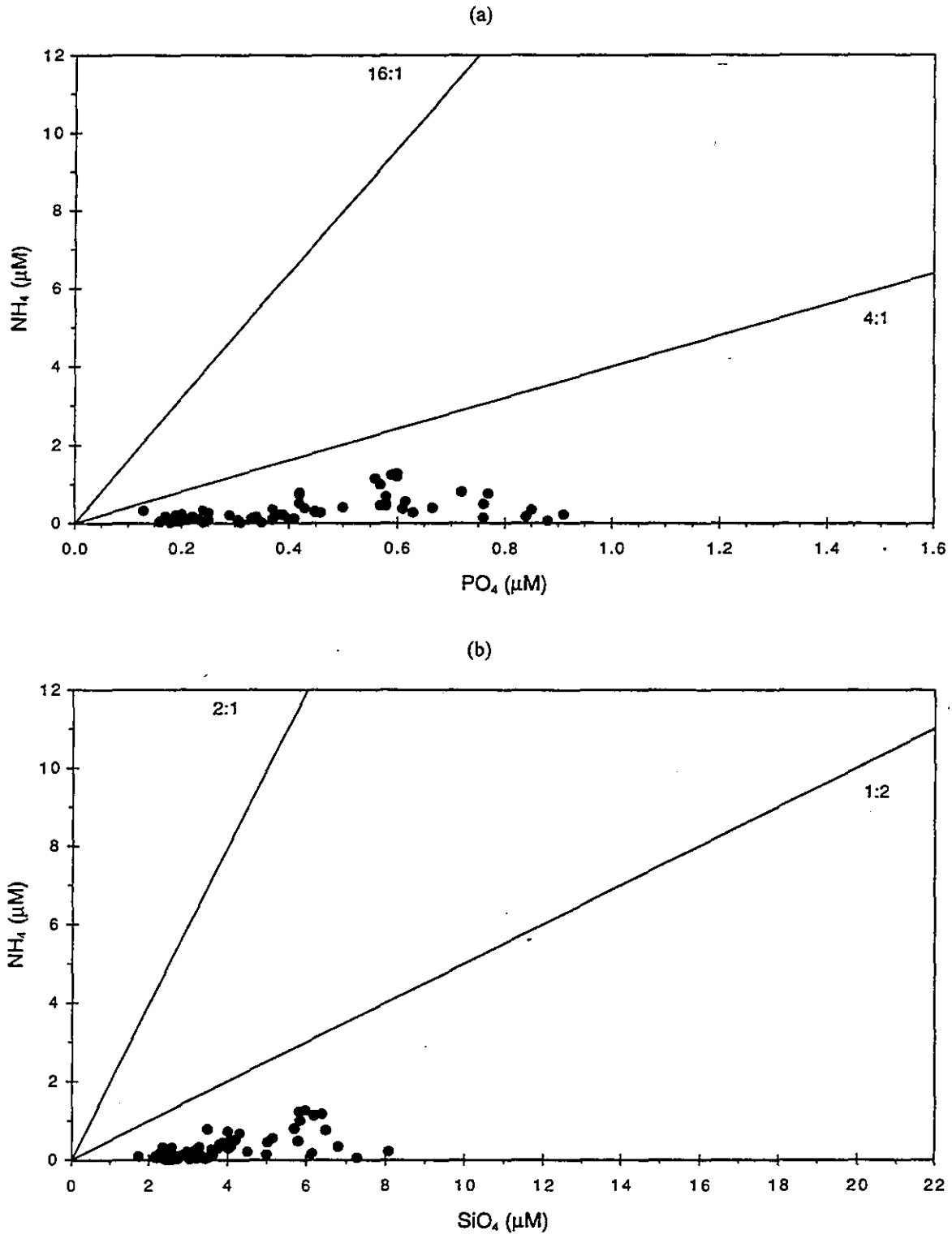


FIGURE 4-141
Nutrient vs. nutrient plots for nearfield survey W9610, (Aug 96).

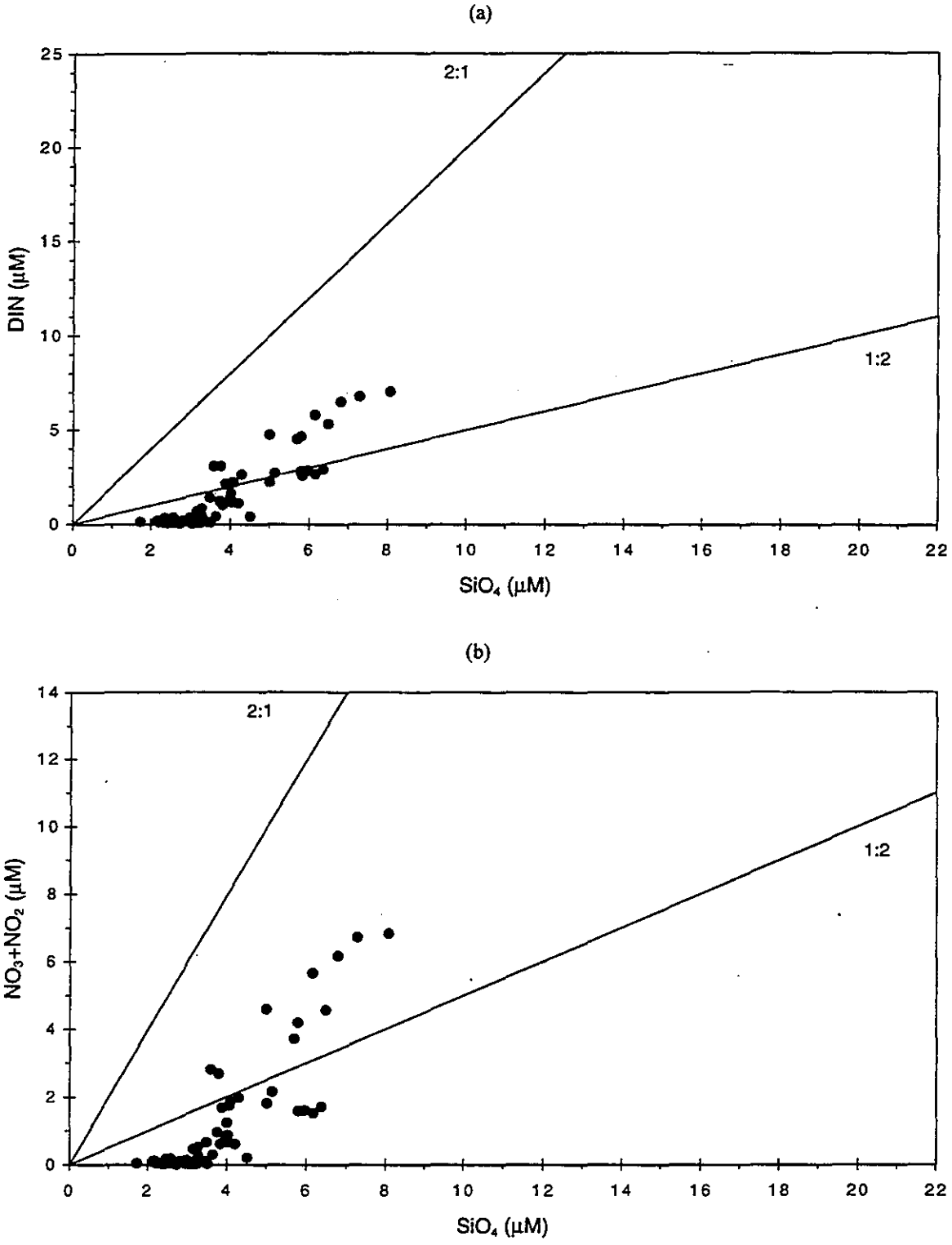


FIGURE 4-142
Nutrient vs. nutrient plots for nearfield survey W9610, (Aug 96).

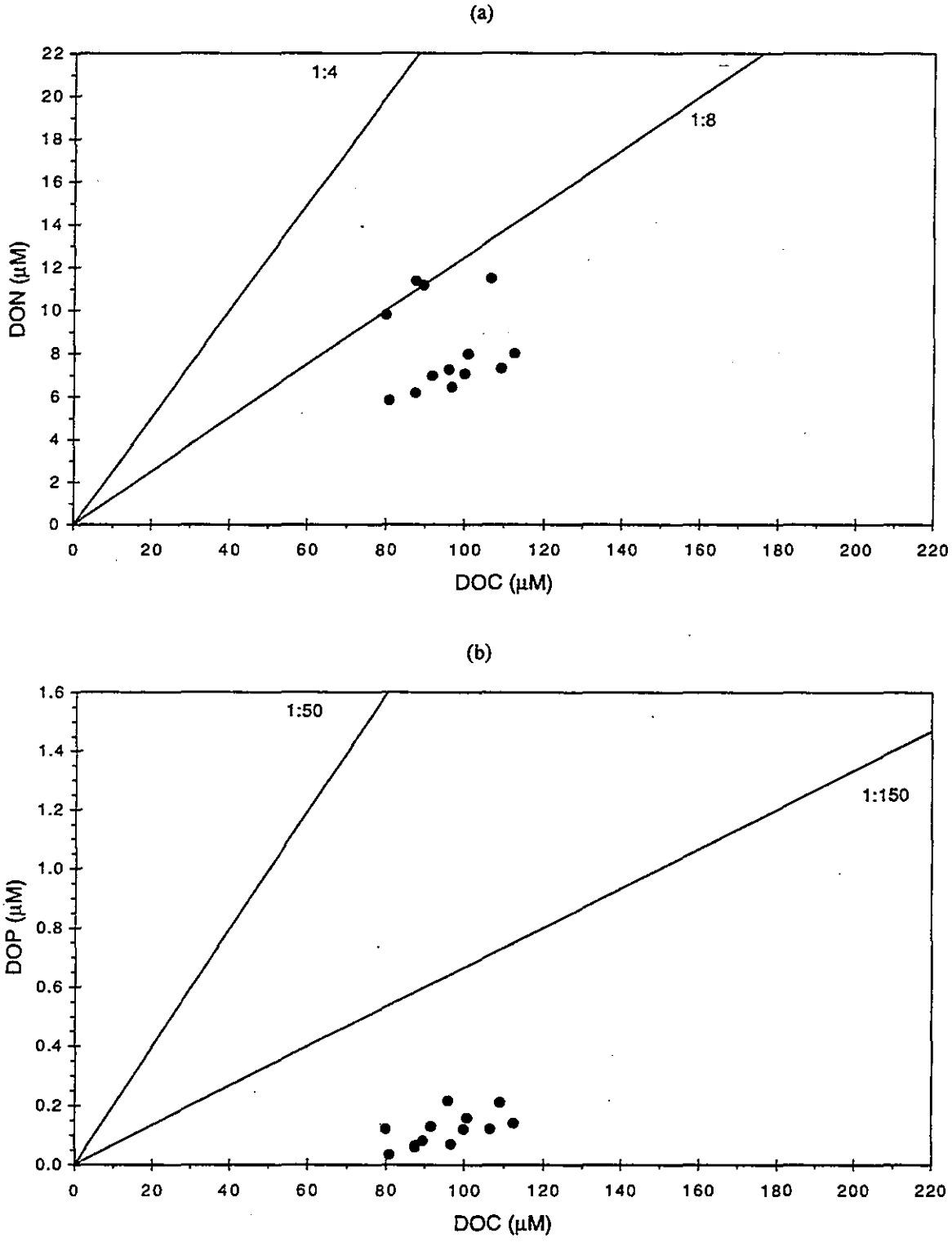
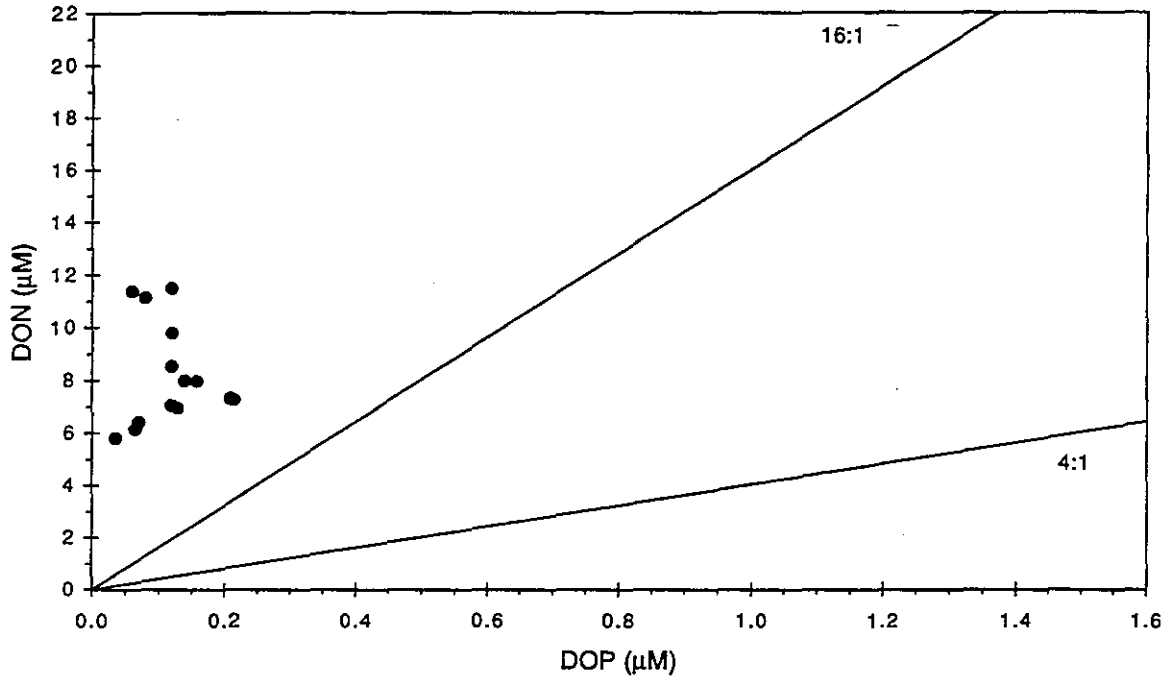


FIGURE 4-143
Nutrient vs. nutrient plots for nearfield survey W9610, (Aug 96).

(a)



(b)

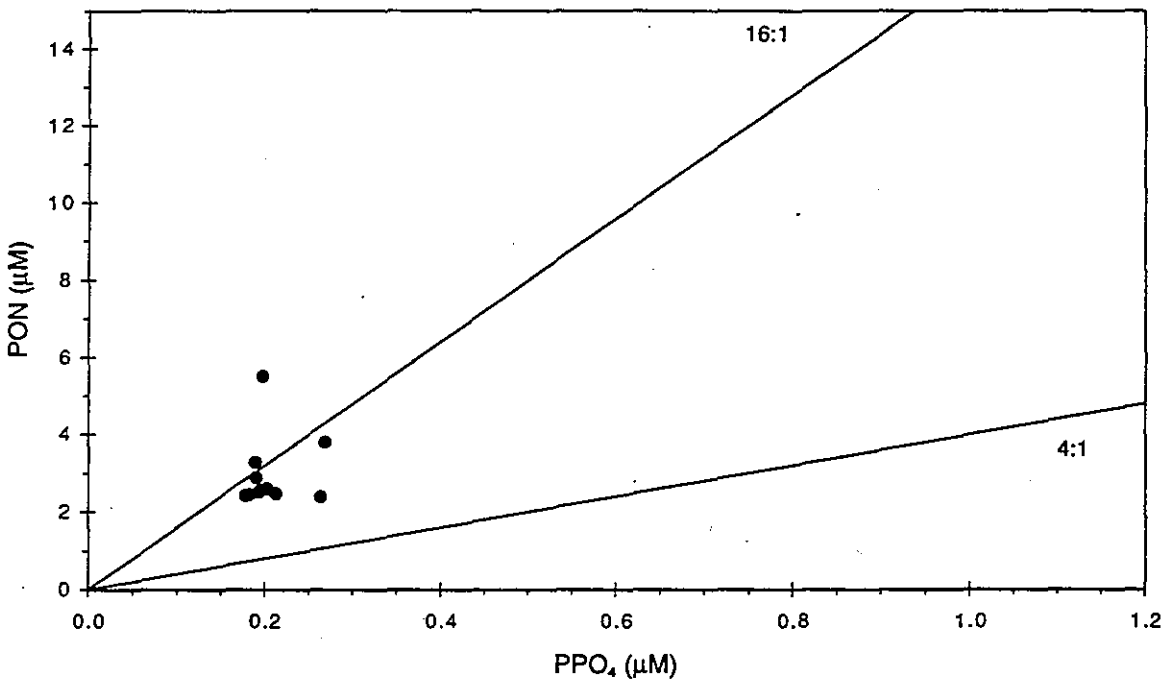
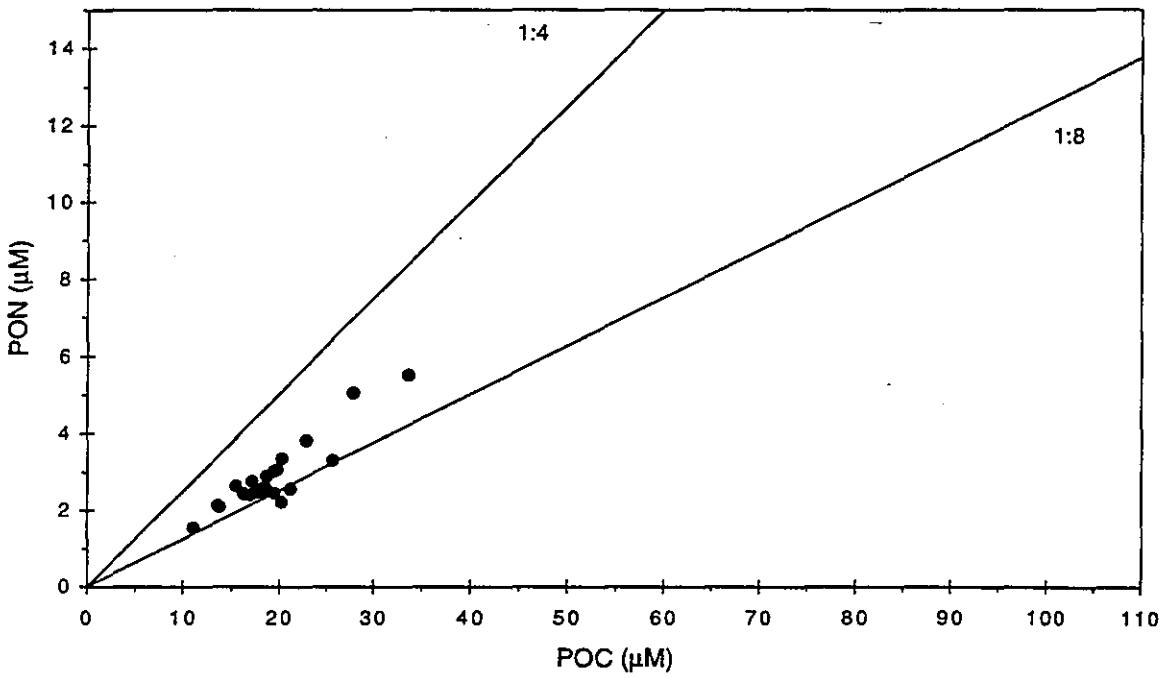


FIGURE 4-144
Nutrient vs. nutrient plots for nearfield survey W9610, (Aug 96).

(a)



(b)

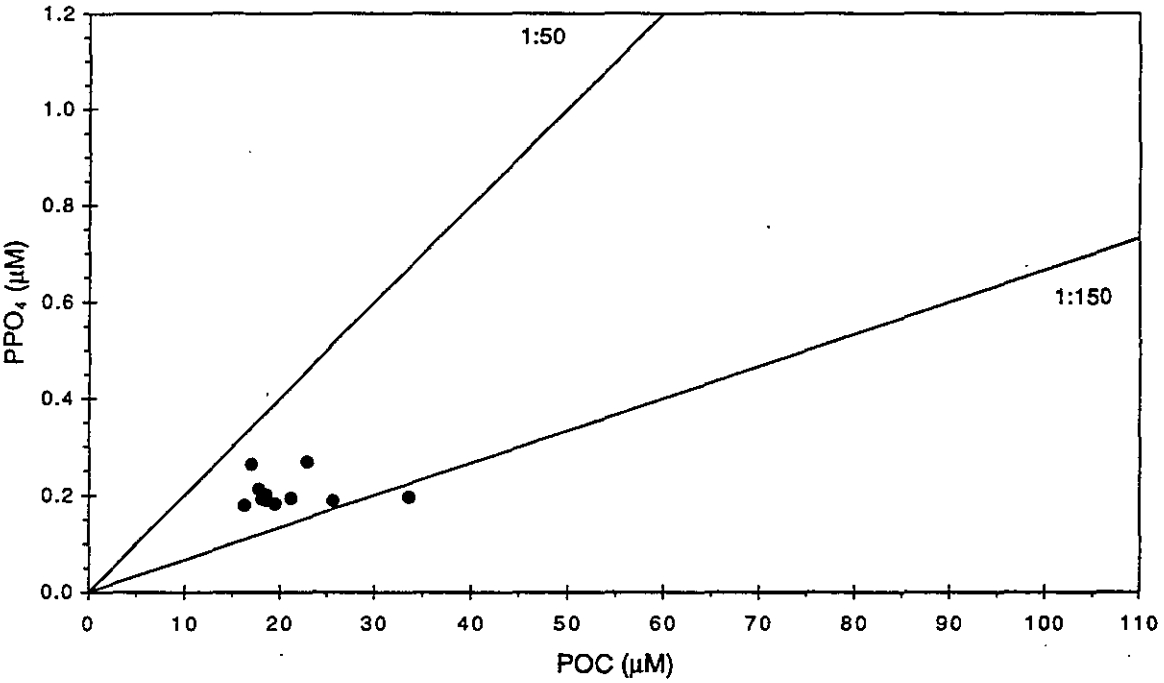
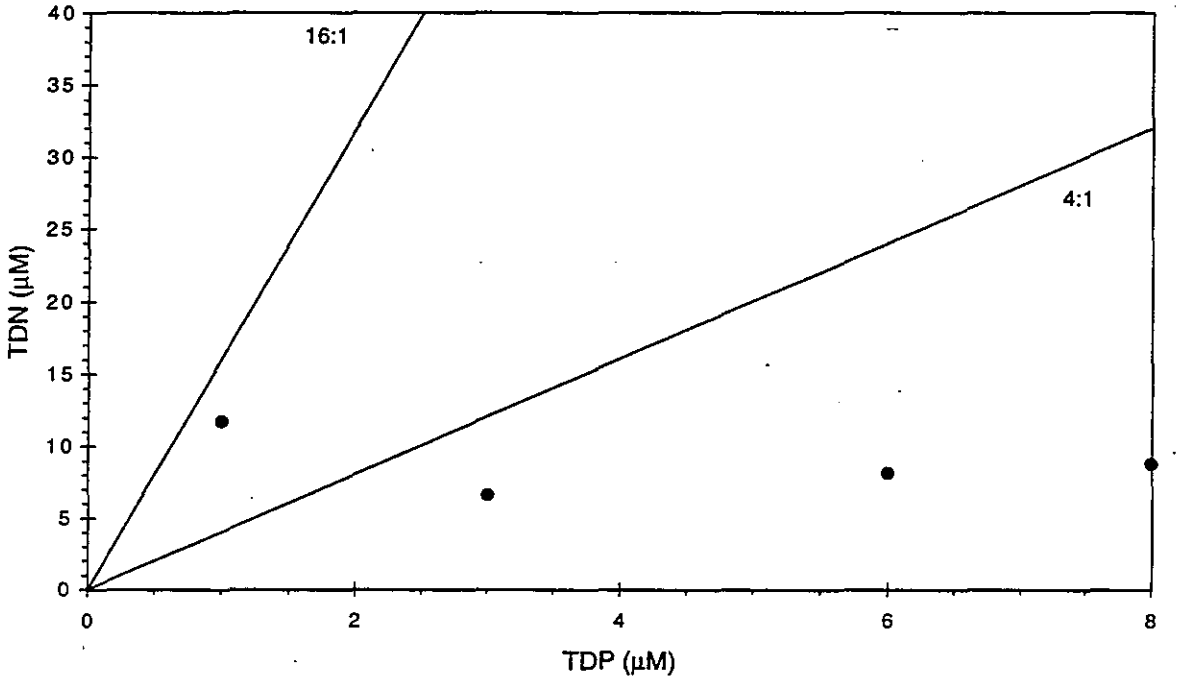


FIGURE 4-145
Nutrient vs. nutrient plots for nearfield survey W9610, (Aug 96).

(a)



(b)

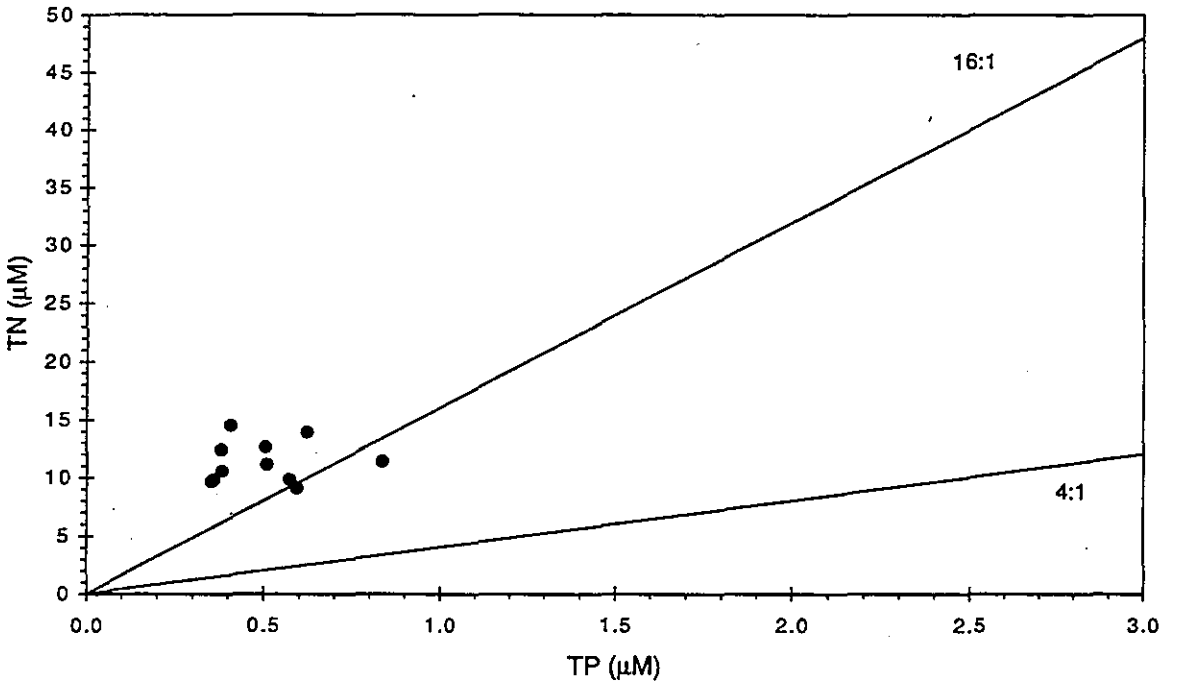
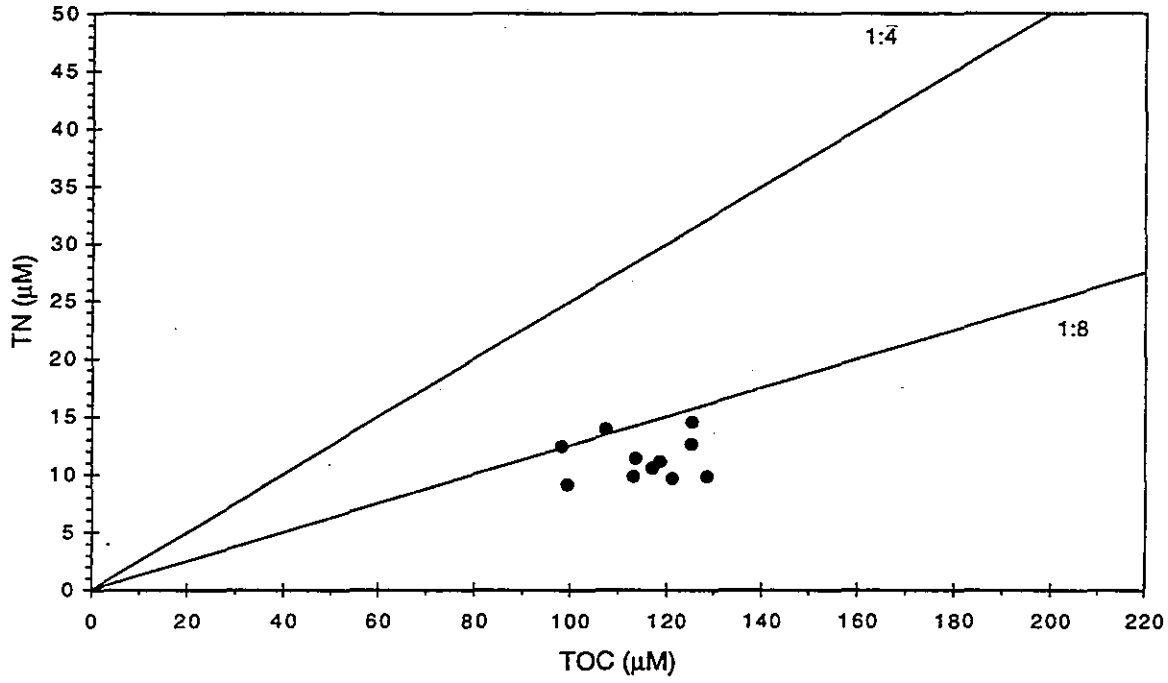


FIGURE 4-146
Nutrient vs. nutrient plots for nearfield survey W9610, (Aug 96).

(a)



(b)

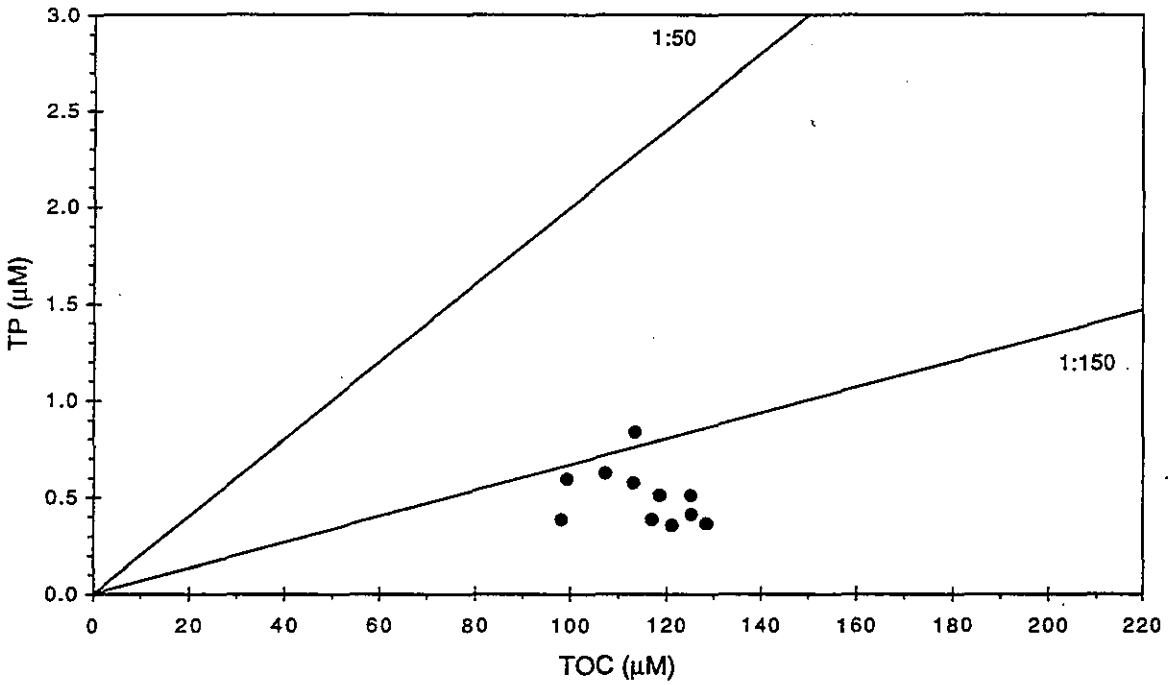


FIGURE 4-147
Nutrient vs. nutrient plots for nearfield survey W9610, (Aug 96).

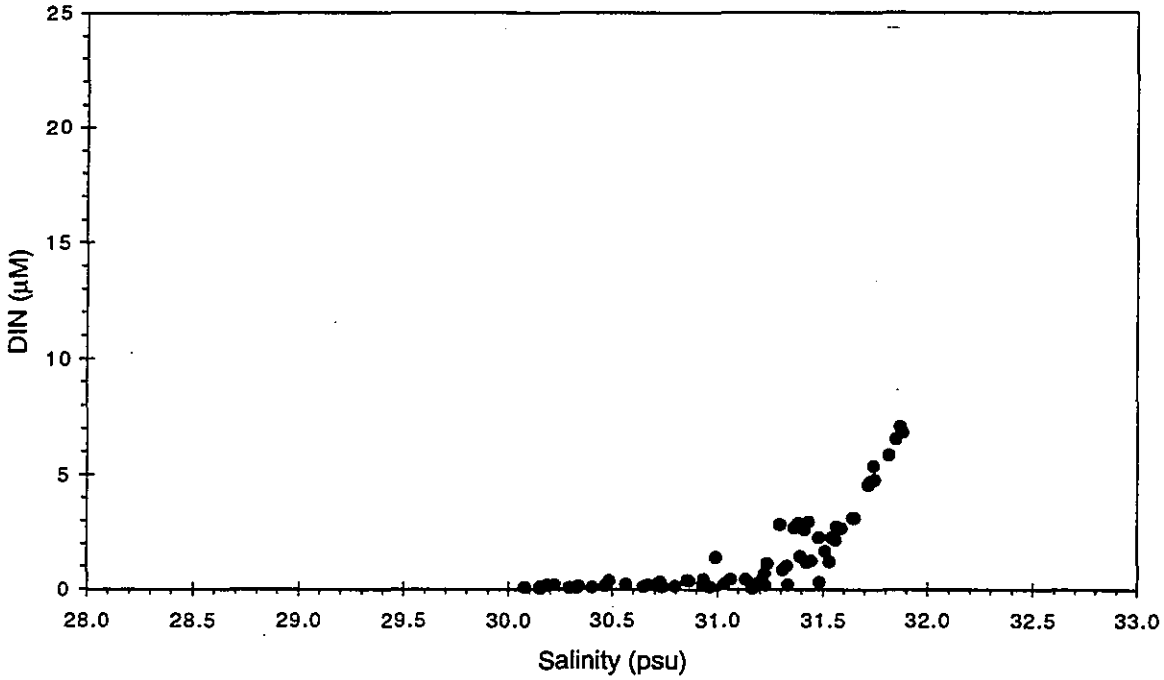
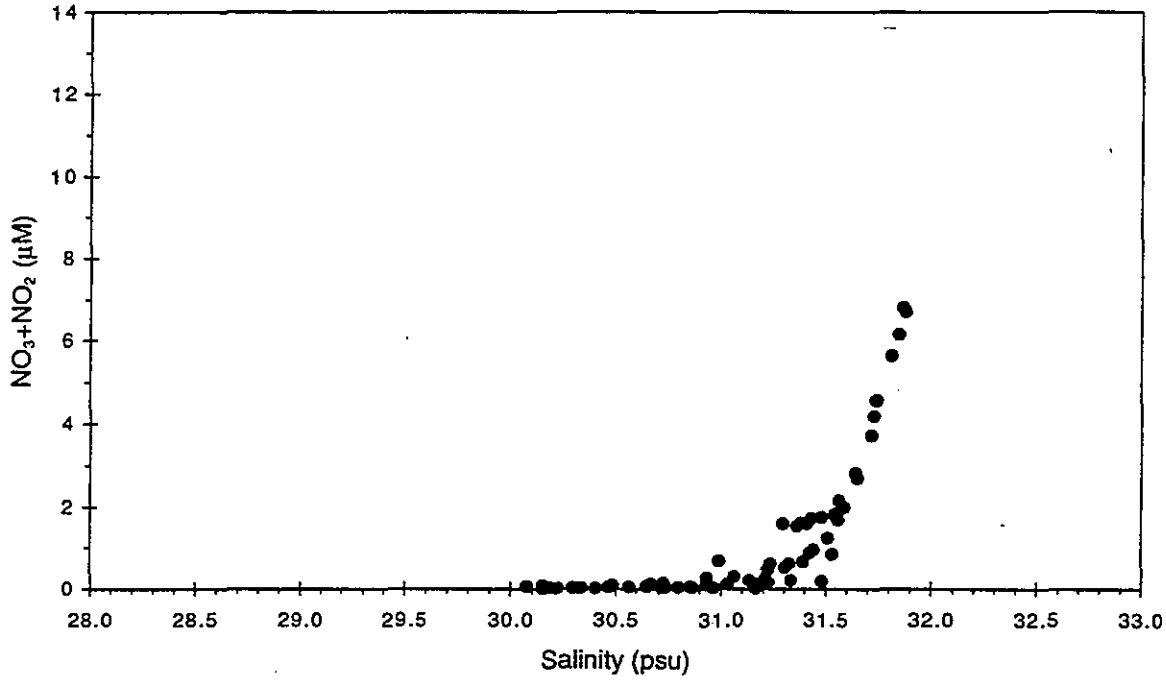


FIGURE 4-148
Nutrient vs. salinity plots for nearfield survey W9610, (Aug 96).

(a)



(b)

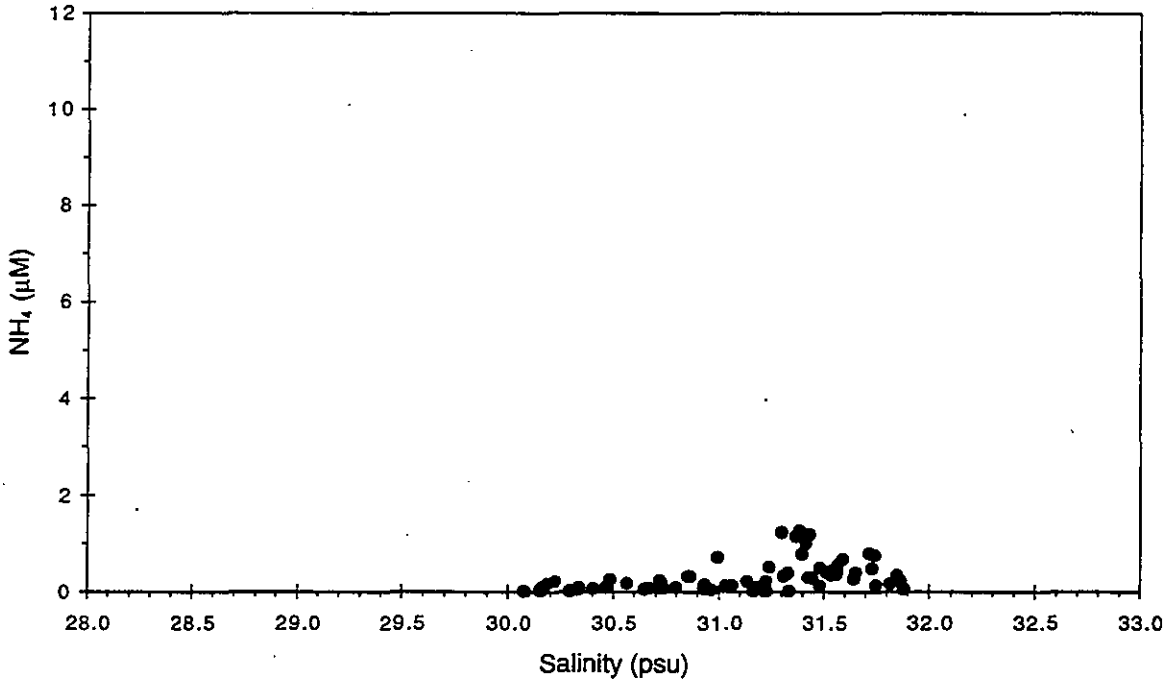
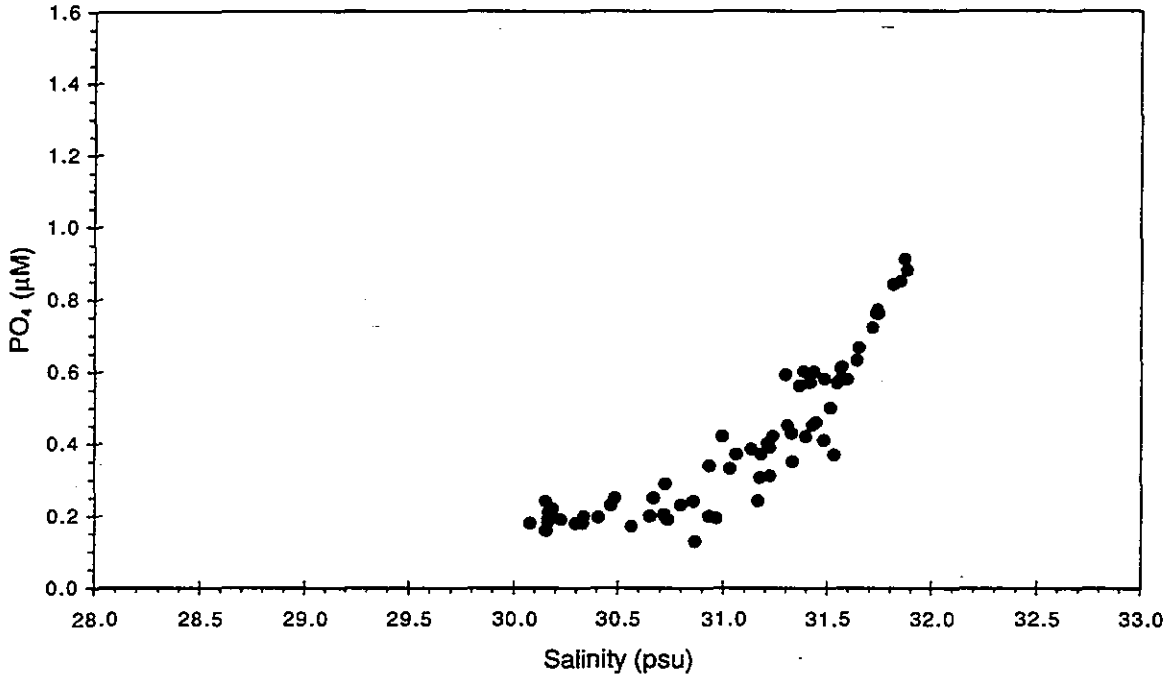


FIGURE 4-149
Nutrient vs. salinity plots for nearfield survey W9610, (Aug 96).

(a)



(b)

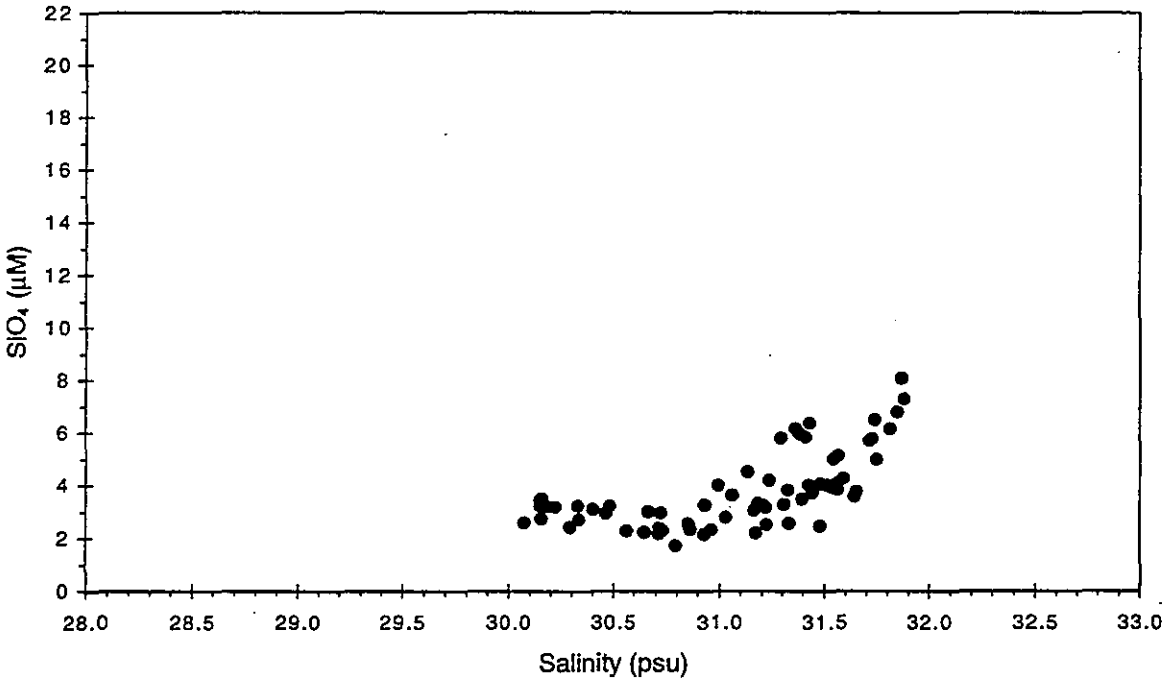
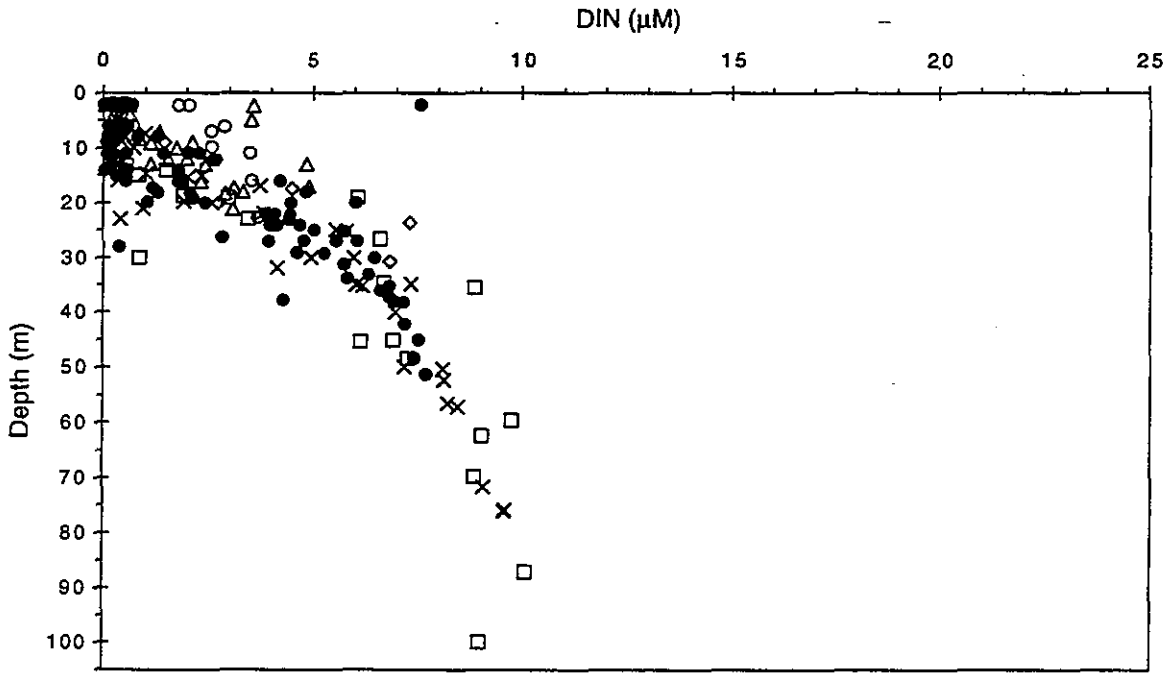


FIGURE 4-150
Nutrient vs. salinity plots for nearfield survey W9610, (Aug 96).



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-151
Depth vs. nutrient plots for farfield survey W9611, (Aug 96).

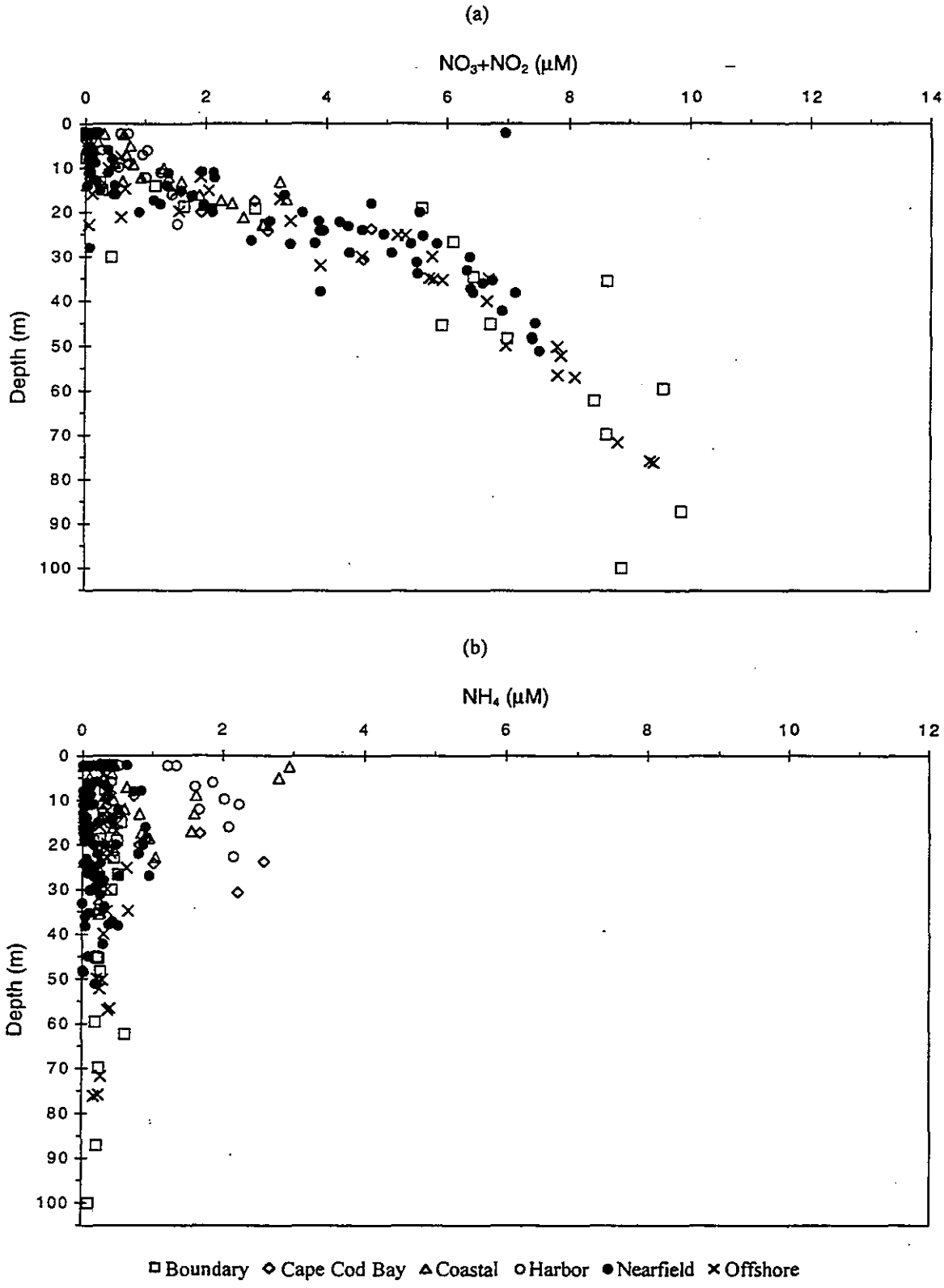


FIGURE 4-152
Depth vs. nutrient plots for farfield survey W9611, (Aug 96).

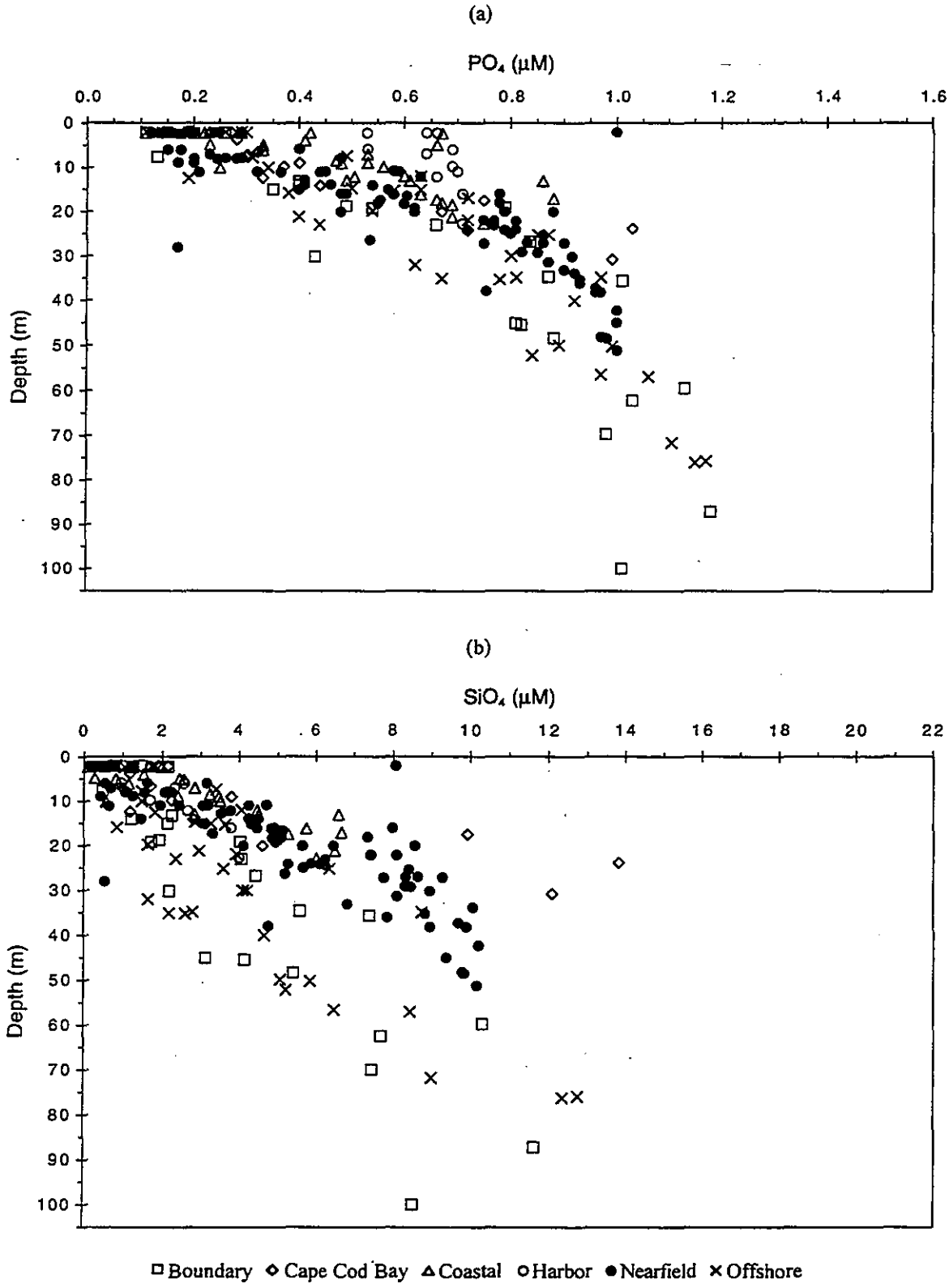


FIGURE 4-153
Depth vs. nutrient plots for farfield survey W9611, (Aug 96).

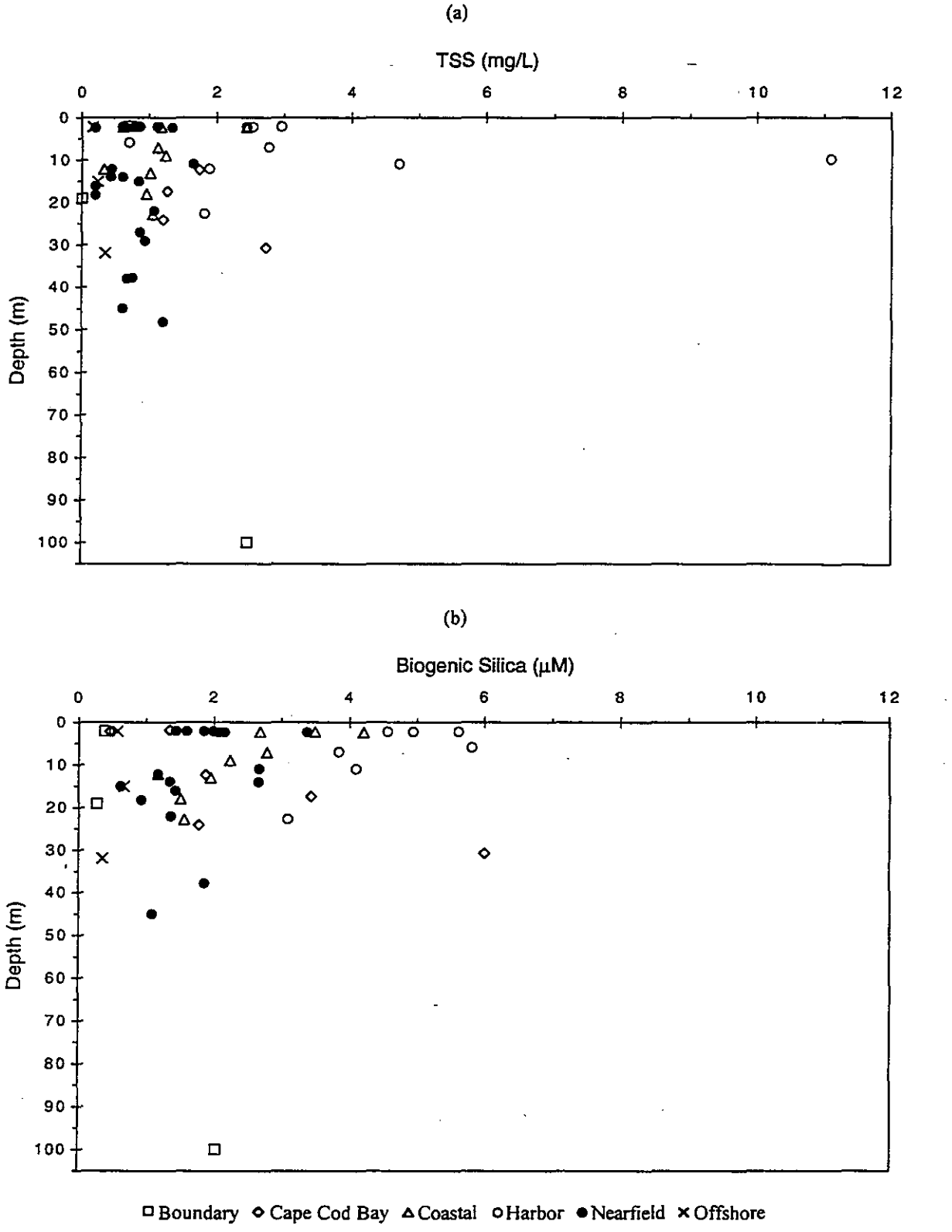


FIGURE 4-154
Depth vs. nutrient plots for farfield survey W9611, (Aug 96).

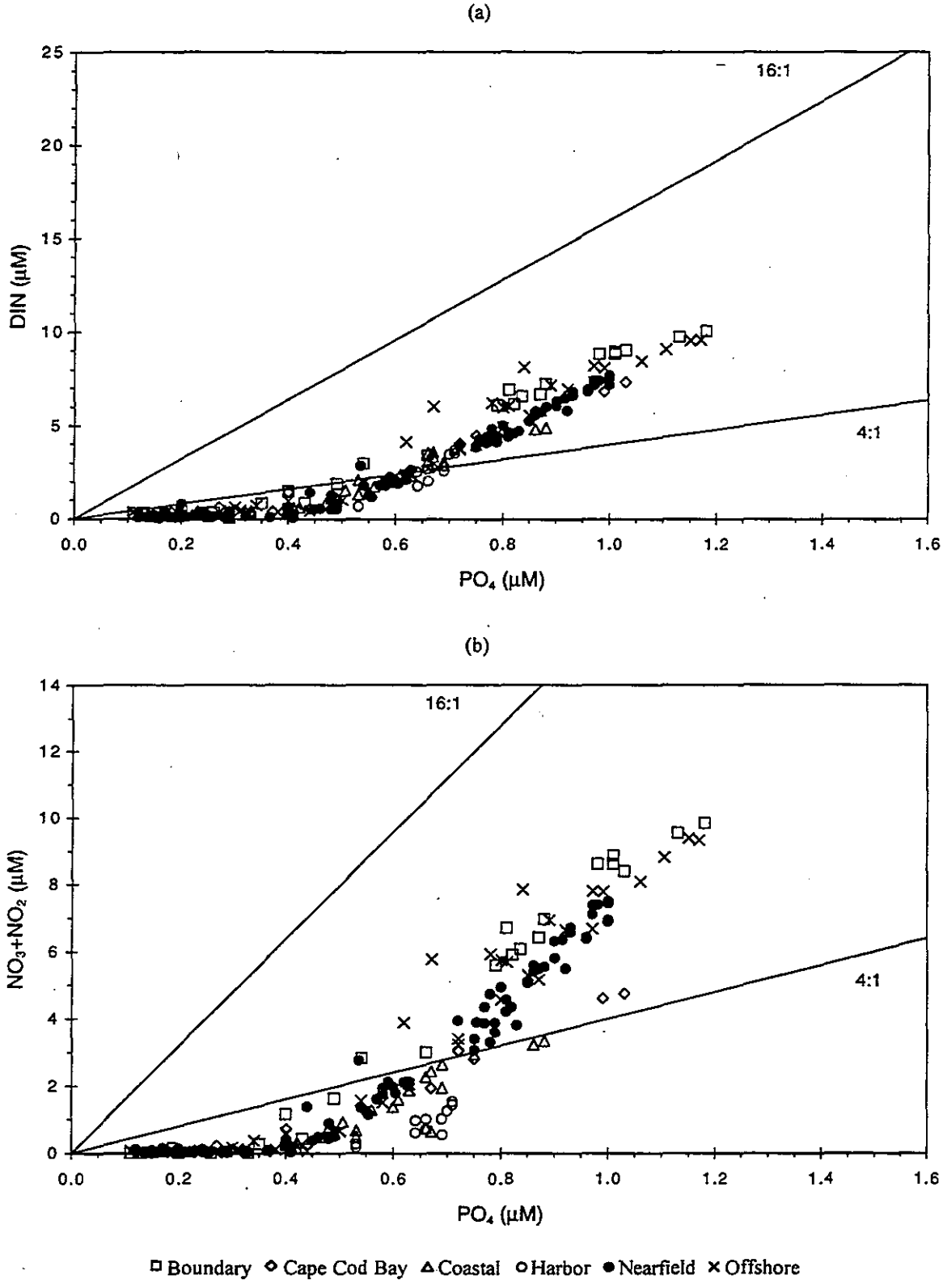


FIGURE 4-155
Nutrient vs. nutrient plots for farfield survey W9611, (Aug 96).

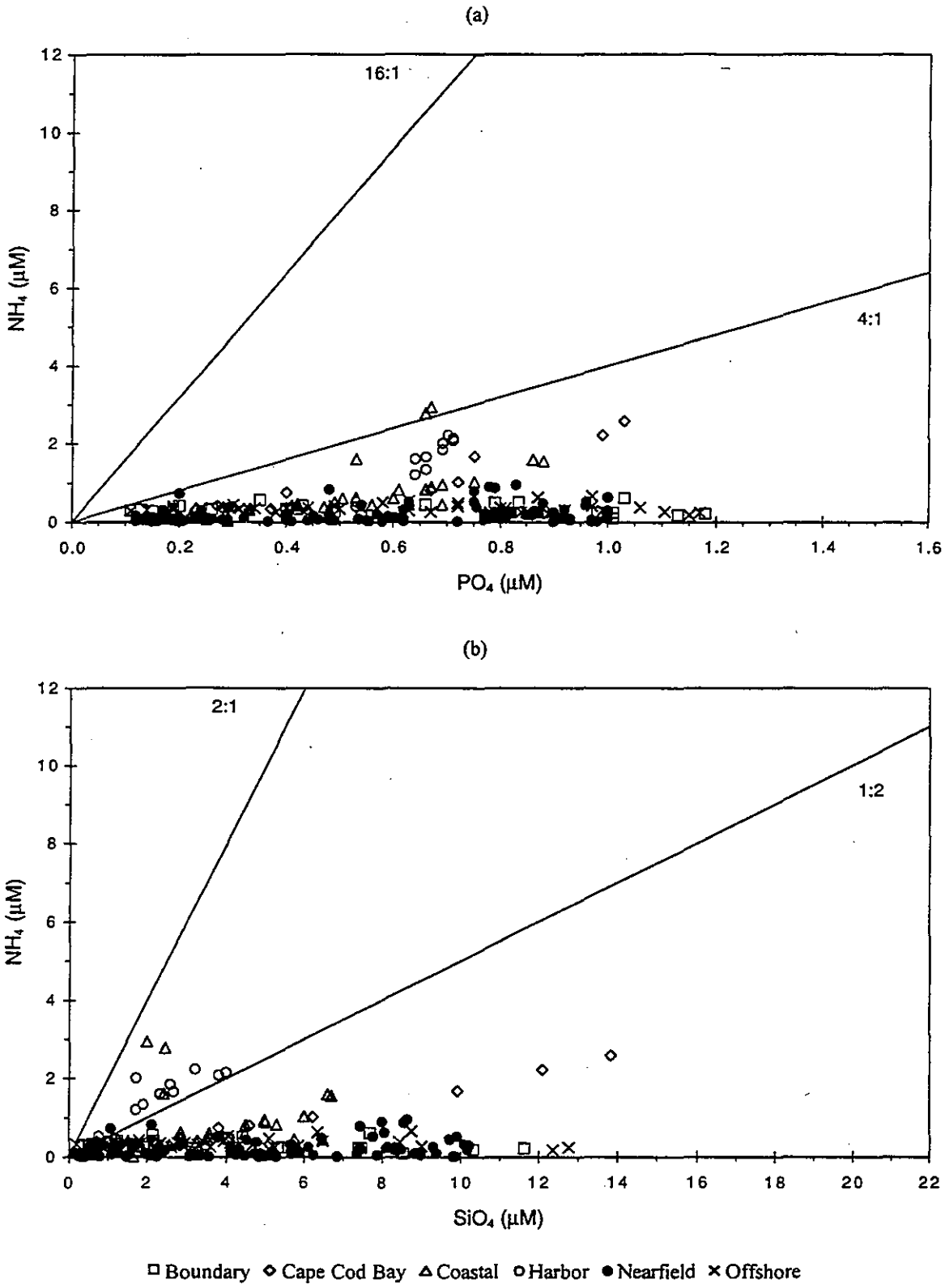


FIGURE 4-156
Nutrient vs. nutrient plots for farfield survey W9611, (Aug 96).

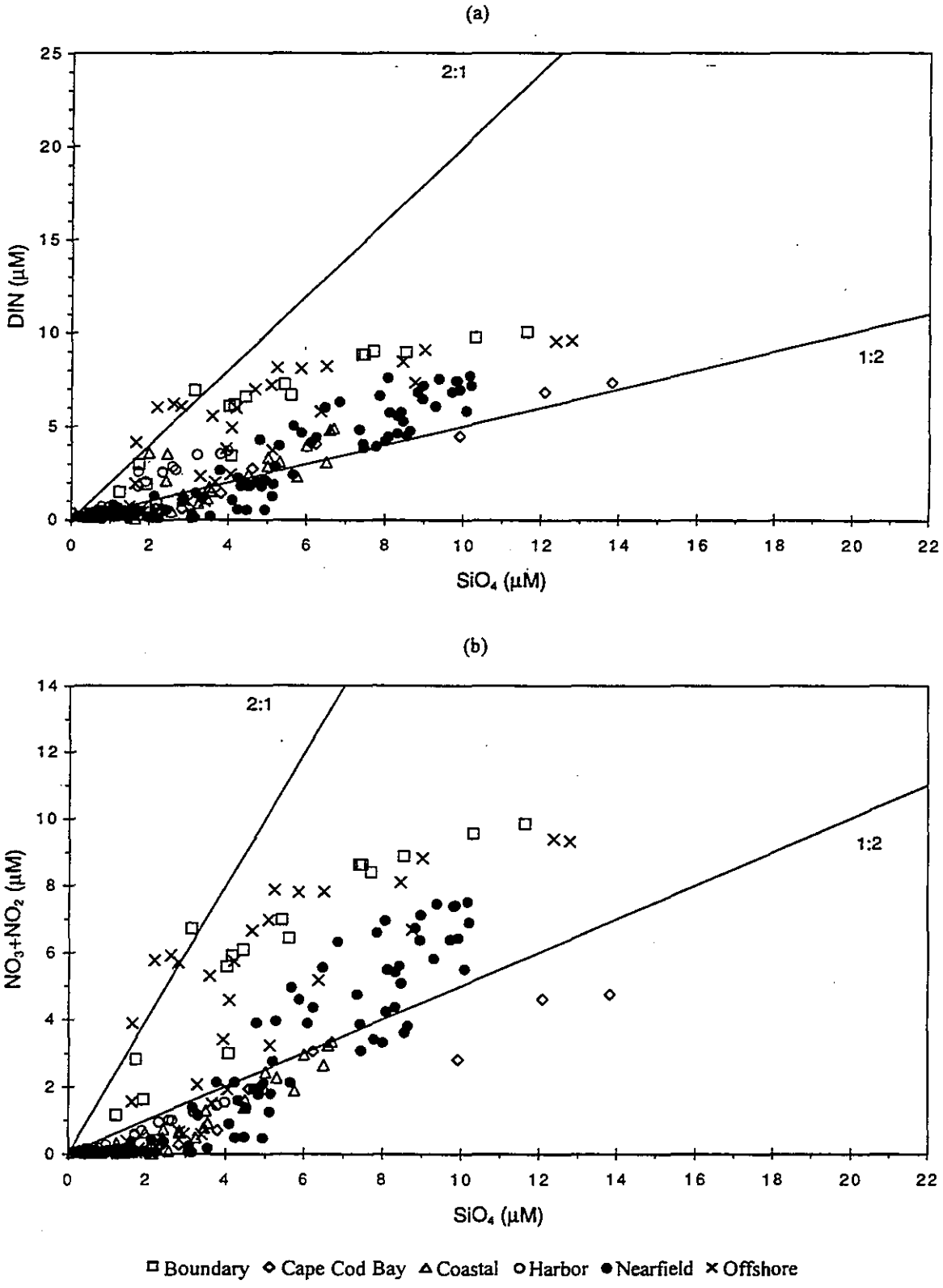


FIGURE 4-157
Nutrient vs. nutrient plots for farfield survey W9611, (Aug 96).

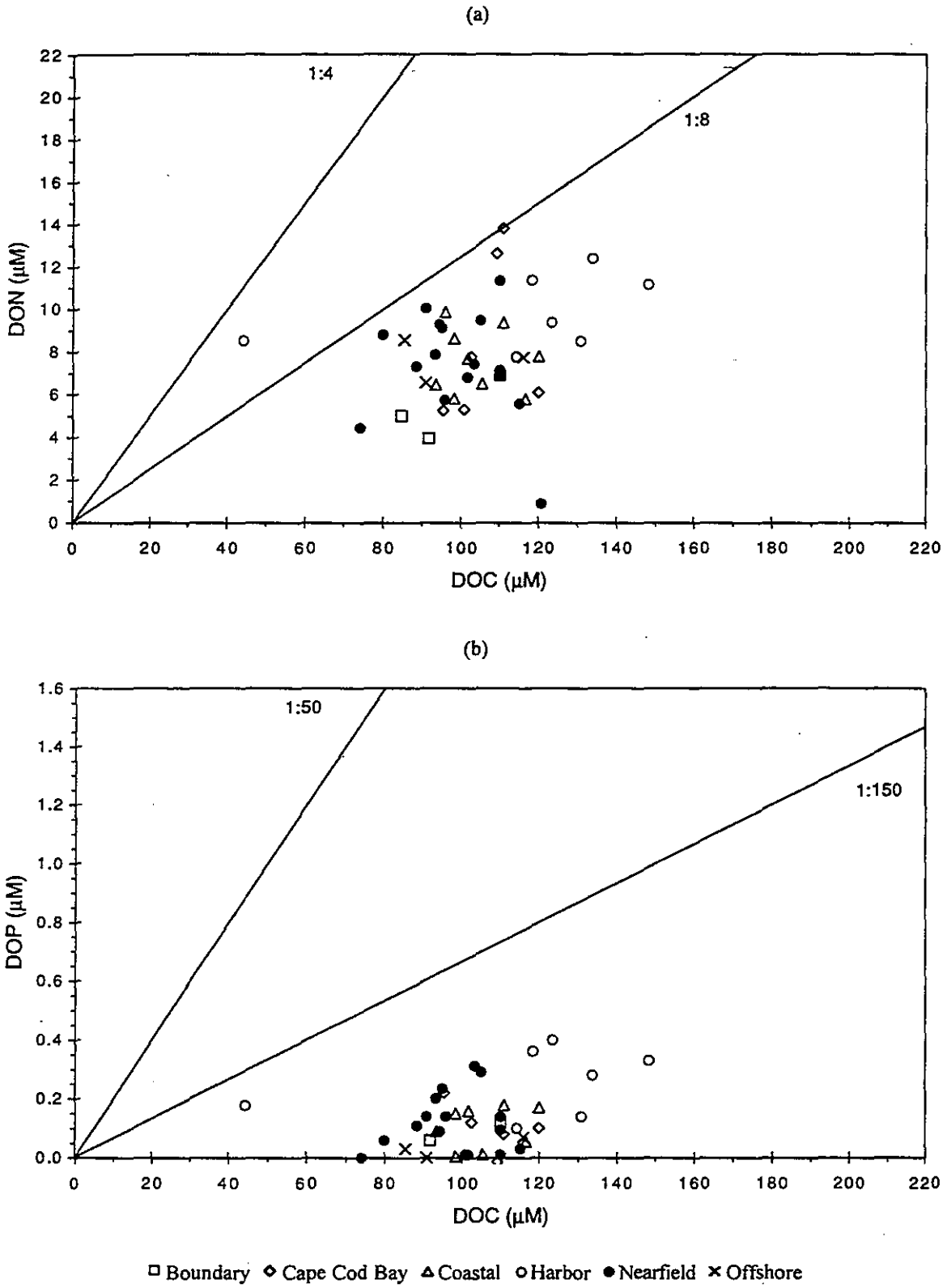


FIGURE 4-158
Nutrient vs. nutrient plots for farfield survey W9611, (Aug 96).

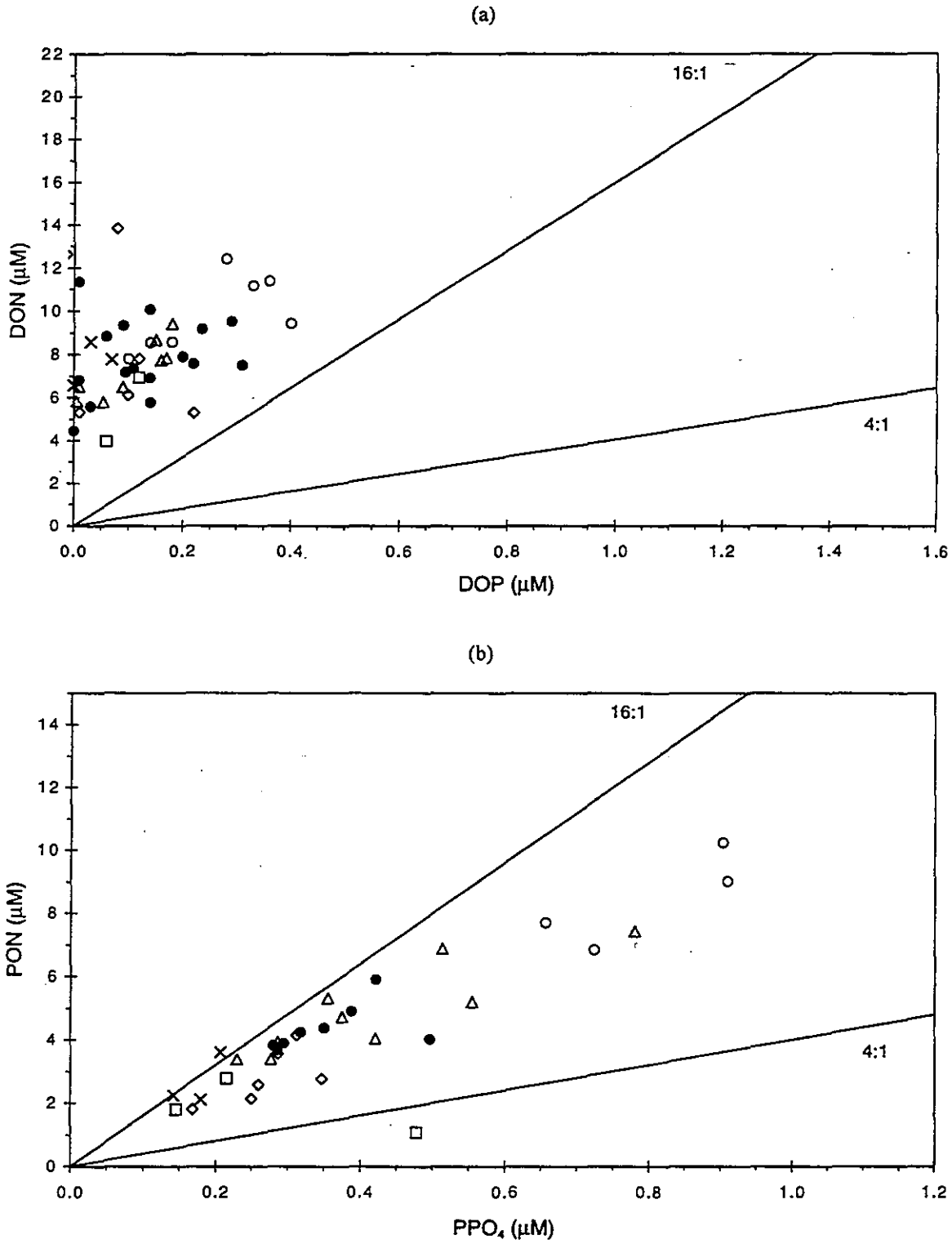


FIGURE 4-159
Nutrient vs. nutrient plots for farfield survey W9611, (Aug 96).

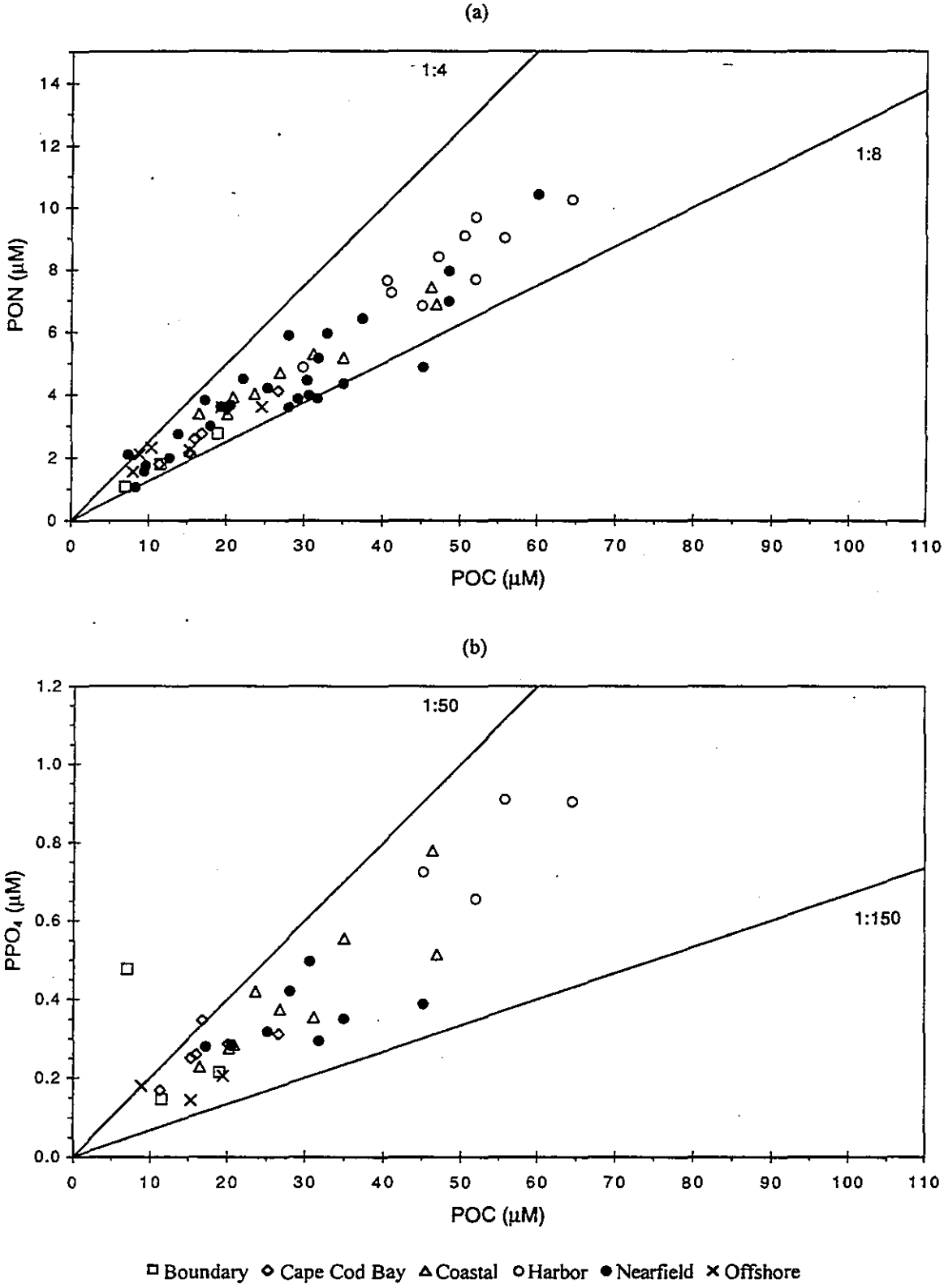


FIGURE 4-160
Nutrient vs. nutrient plots for farfield survey W9611, (Aug 96).

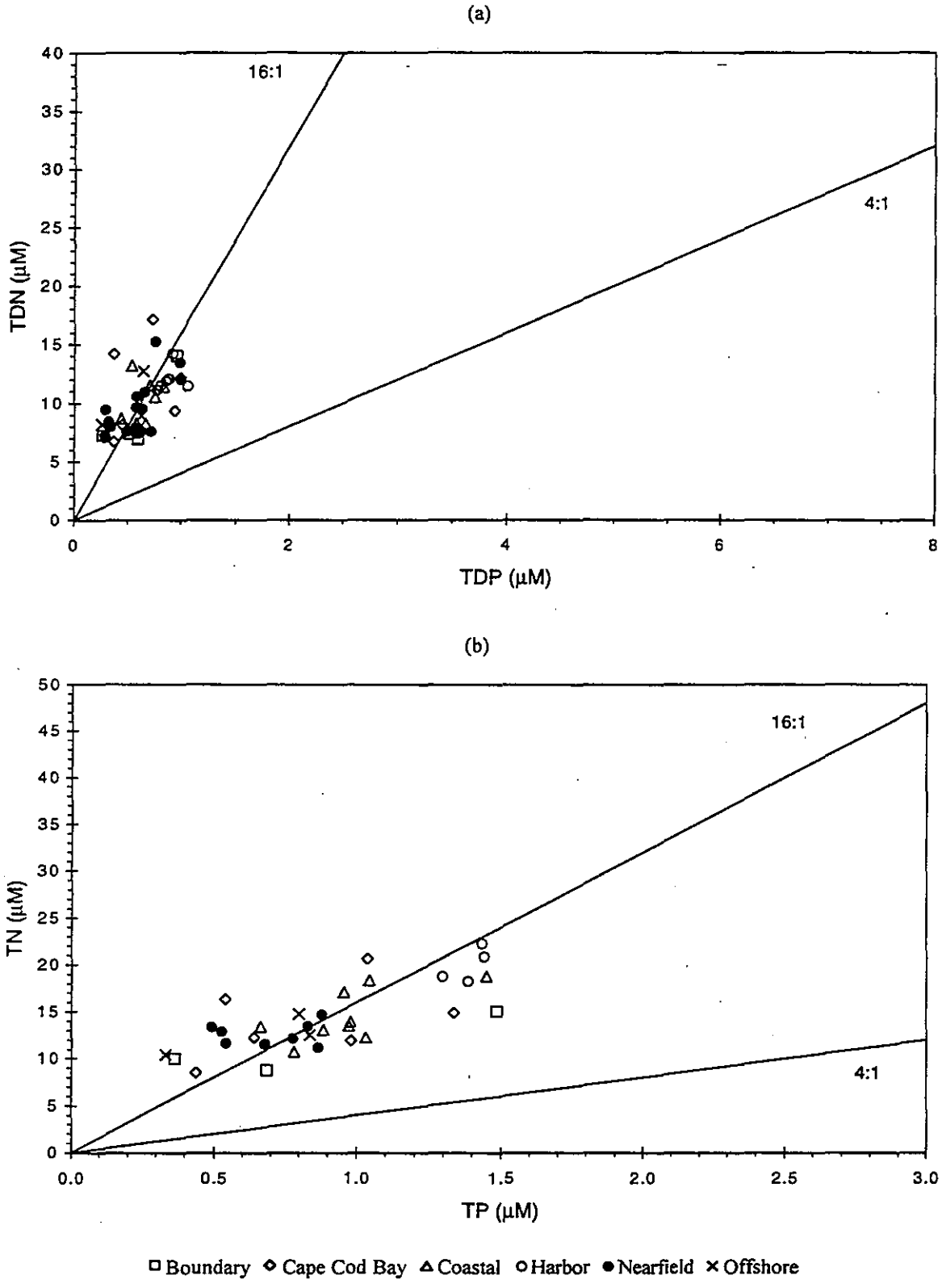
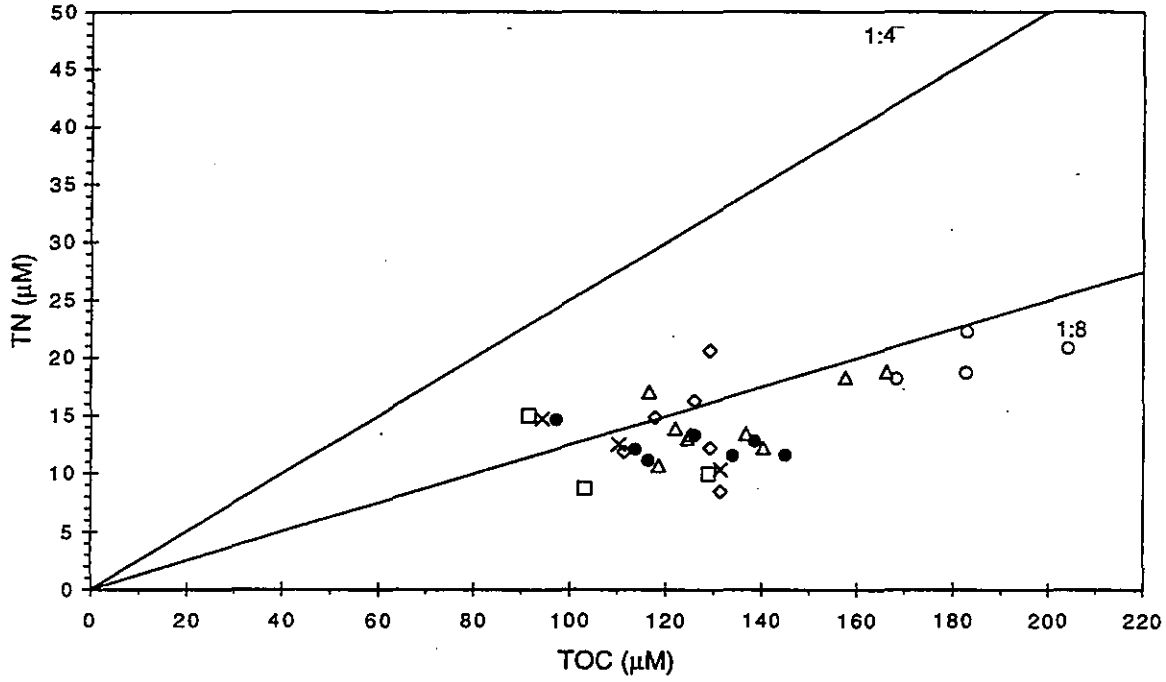
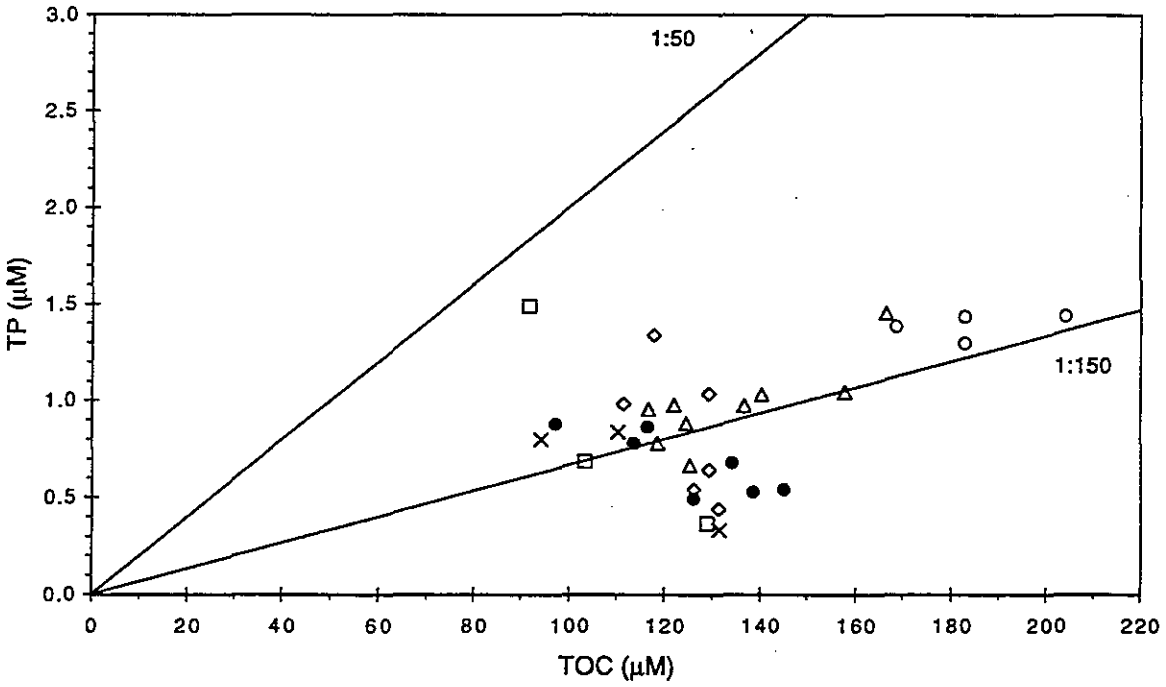


FIGURE 4-161
Nutrient vs. nutrient plots for farfield survey W9611, (Aug 96).

(a)

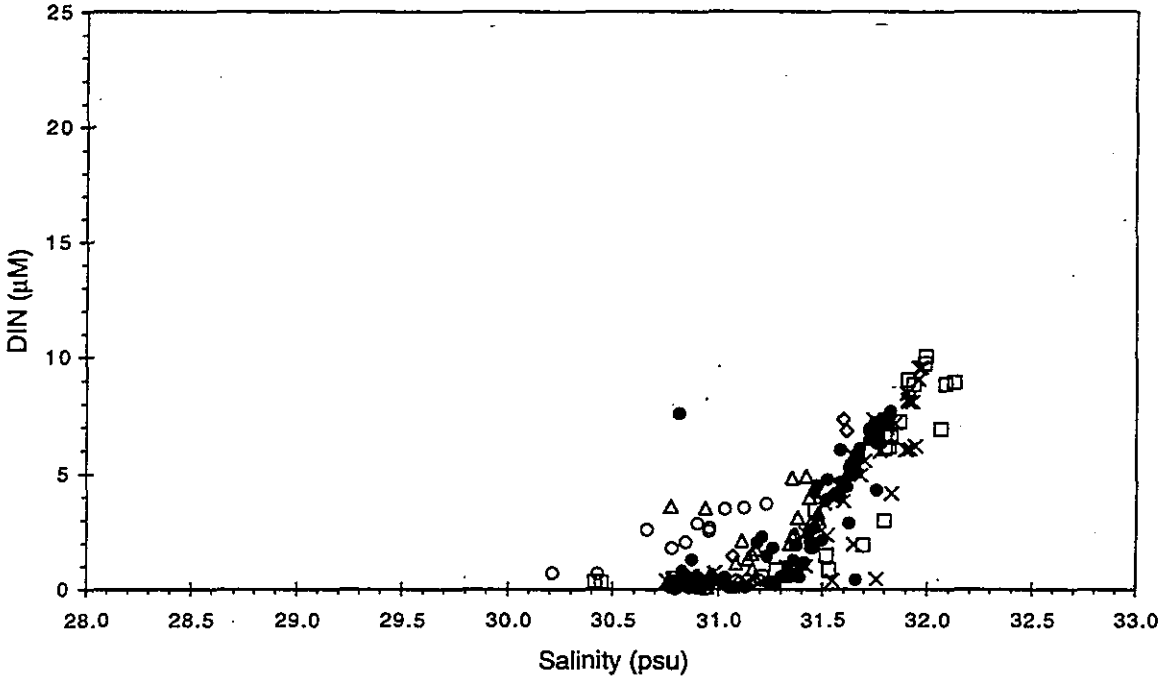


(b)



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-162
Nutrient vs. nutrient plots for farfield survey W9611, (Aug 96).



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-163
Nutrient vs. salinity plots for farfield survey W9611, (Aug 96).

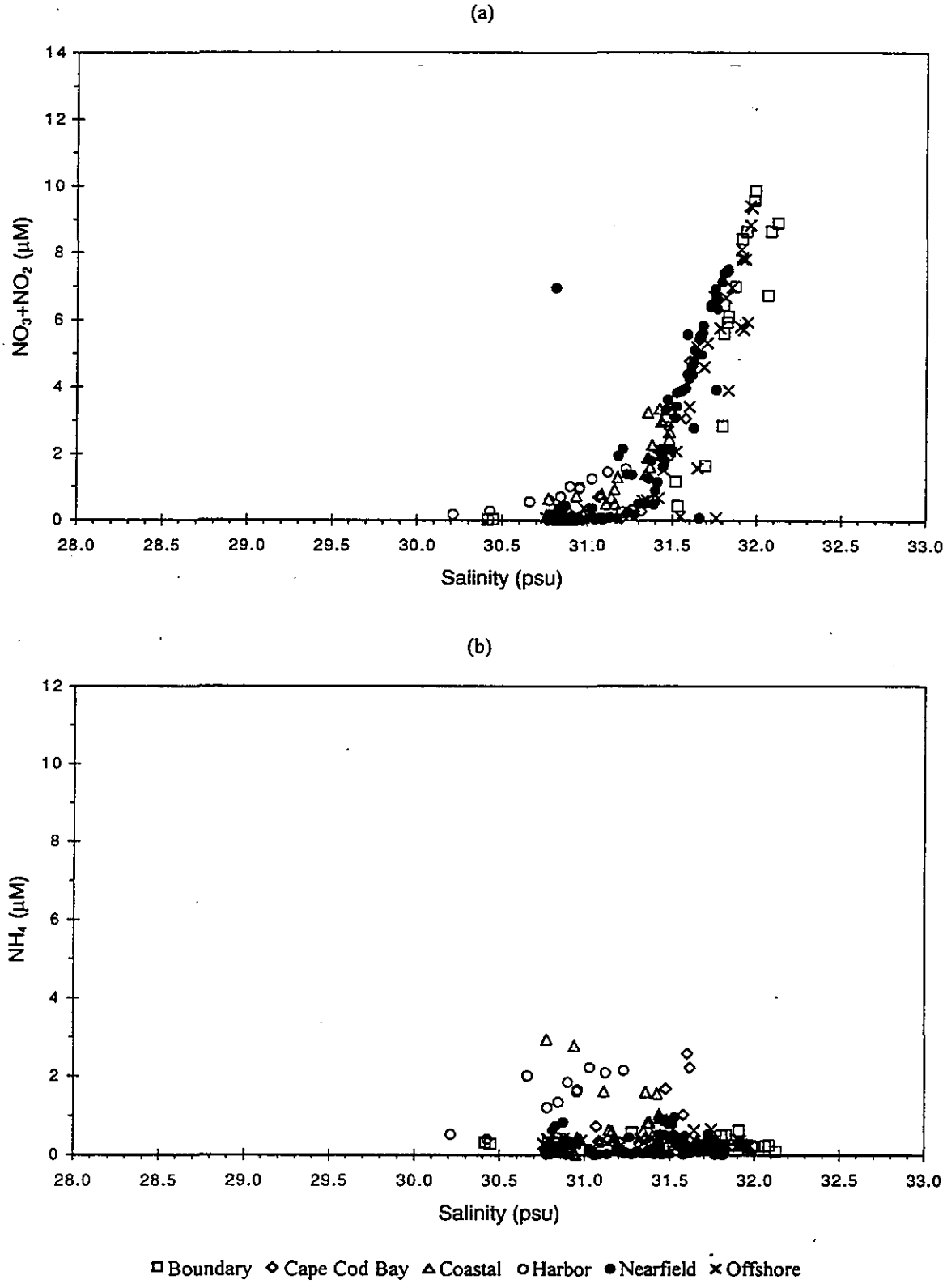
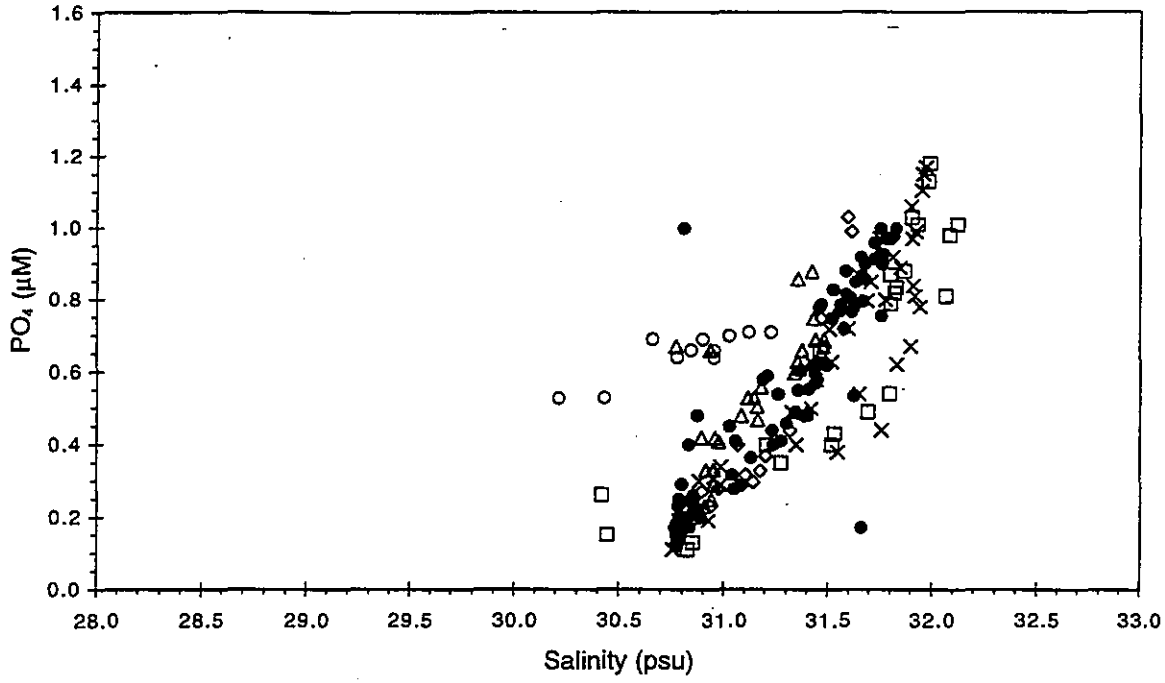
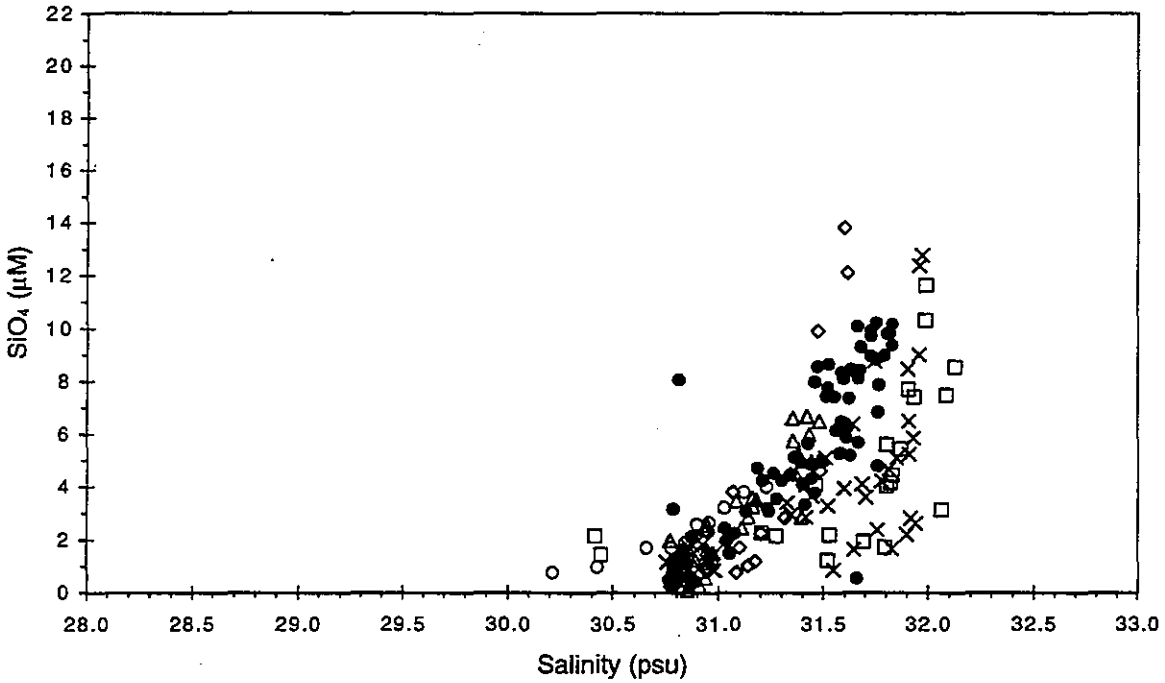


FIGURE 4-164
Nutrient vs. salinity plots for farfield survey W9611, (Aug 96).

(a)



(b)



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-165
Nutrient vs. salinity plots for farfield survey W9611, (Aug 96).

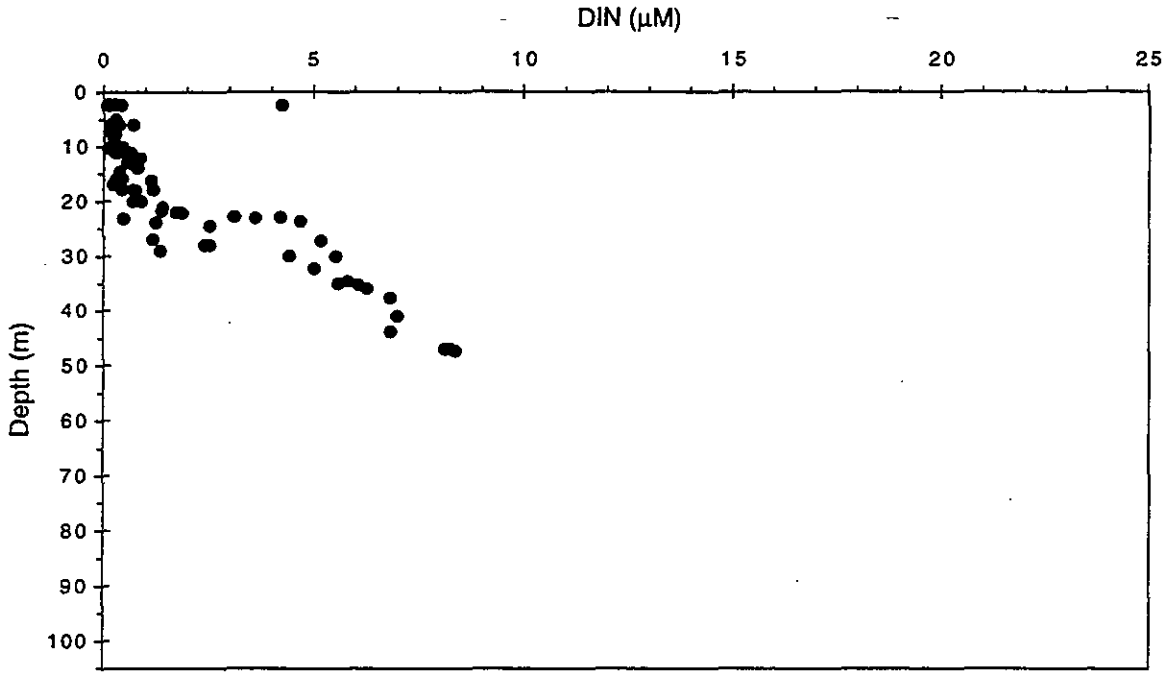


FIGURE 4-166
Depth vs. nutrient plots for nearfield survey W9612, (Sep 96).

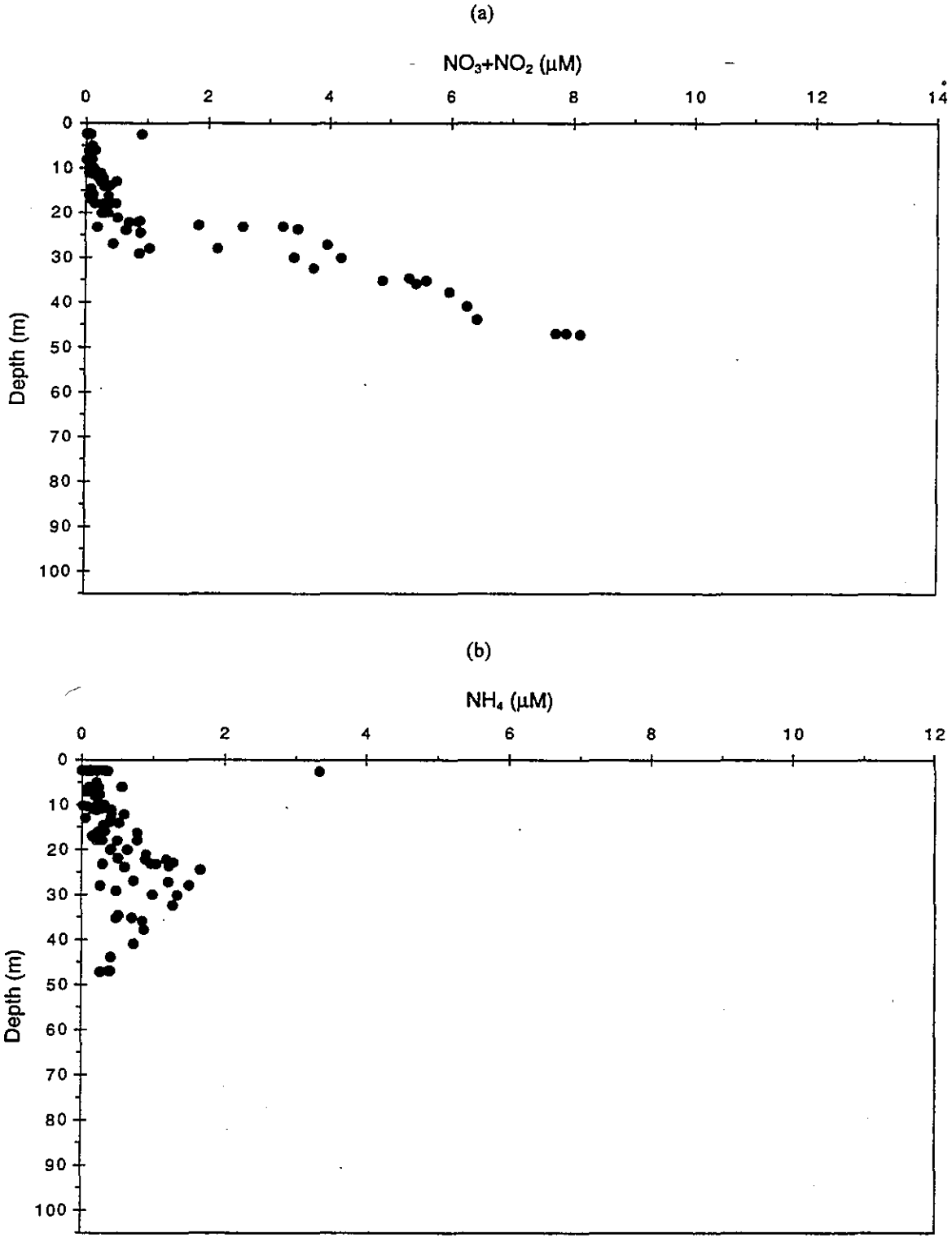


FIGURE 4-167
Depth vs. nutrient plots for nearfield survey W9612, (Sep 96).

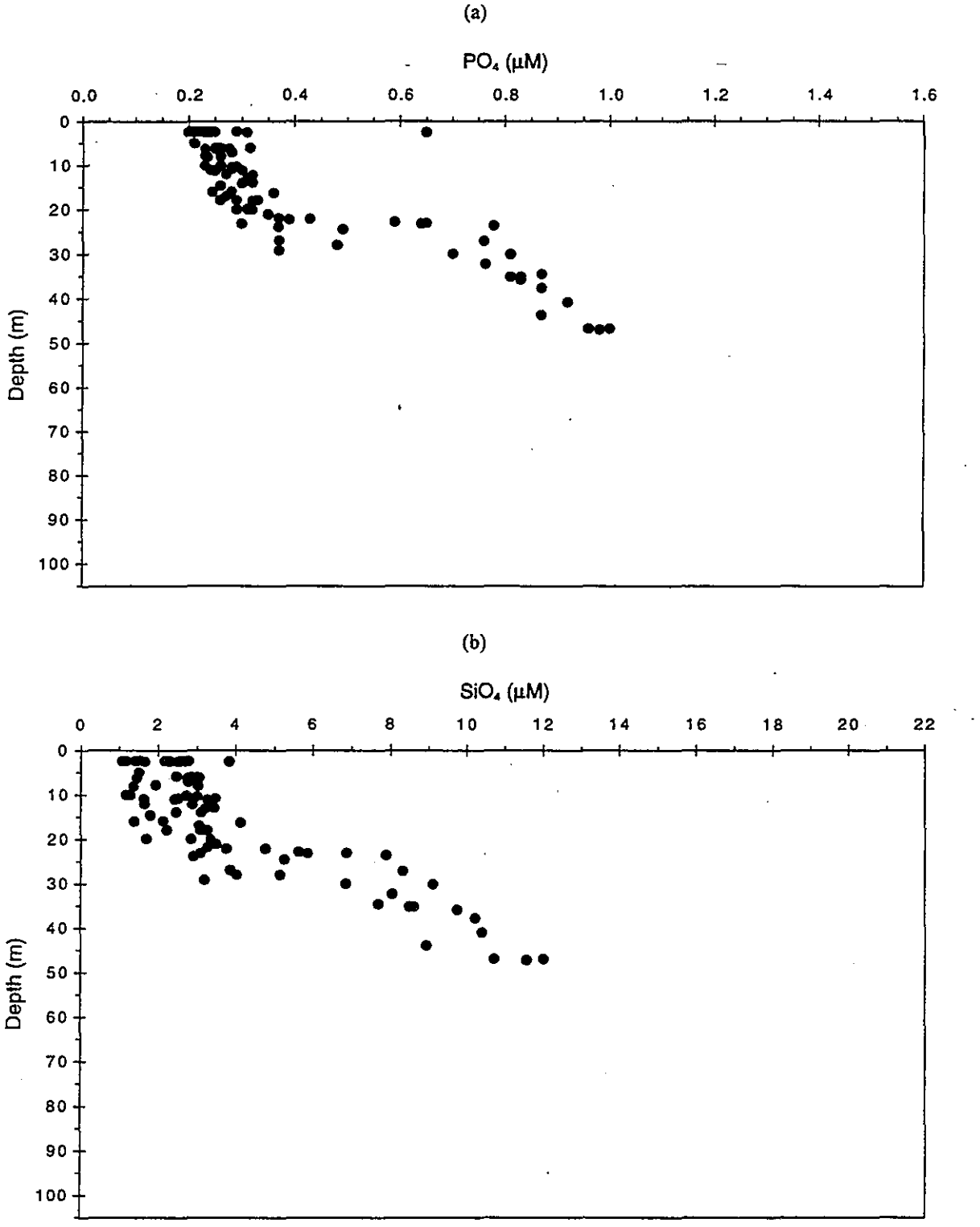
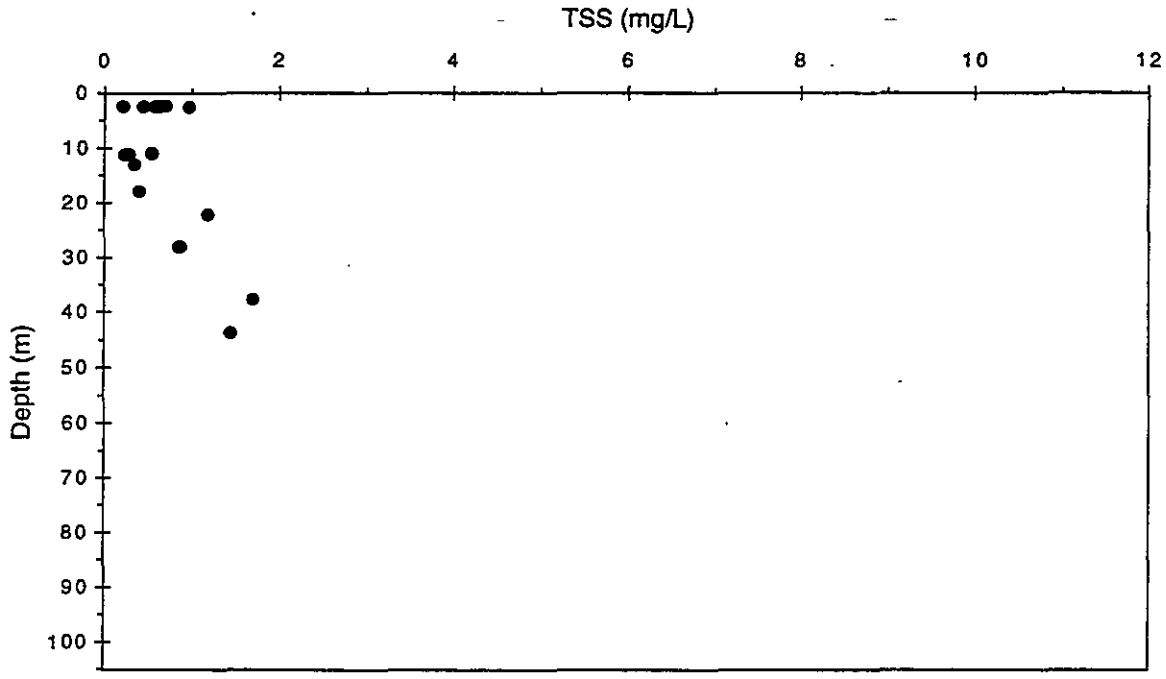


FIGURE 4-168
Depth vs. nutrient plots for nearfield survey W9612, (Sep 96).

(a)



(b)

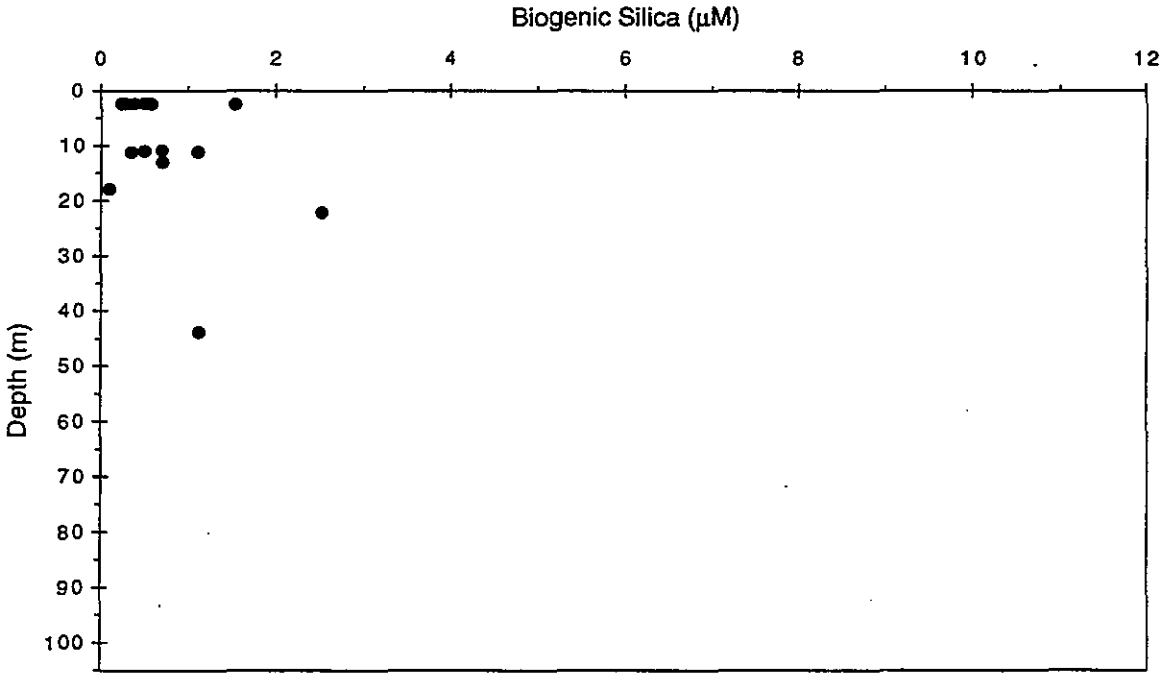


FIGURE 4-169
Depth vs. nutrient plots for nearfield survey W9612, (Sep 96).

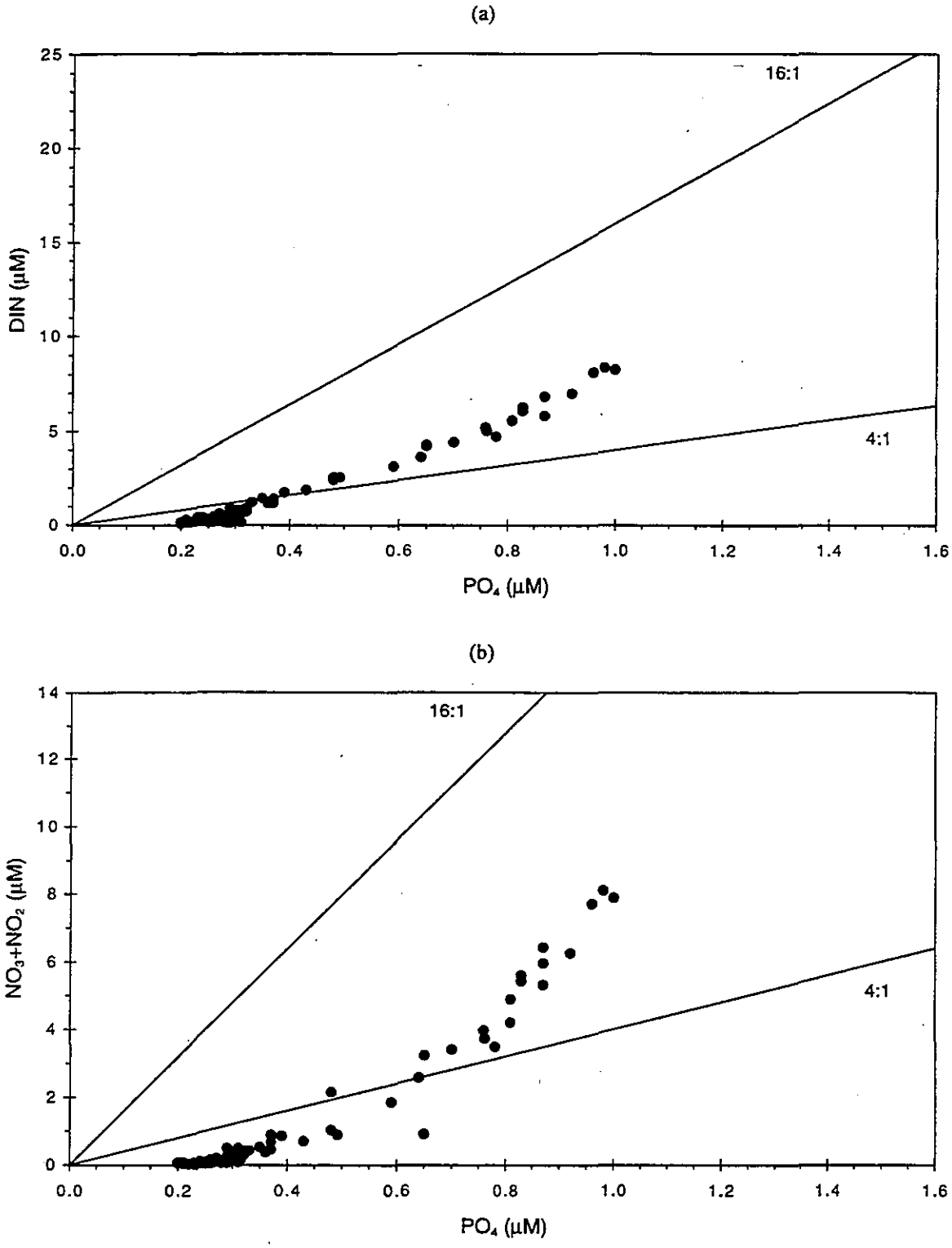


FIGURE 4-170
Nutrient vs. nutrient plots for nearfield survey W9612, (Sep 96).

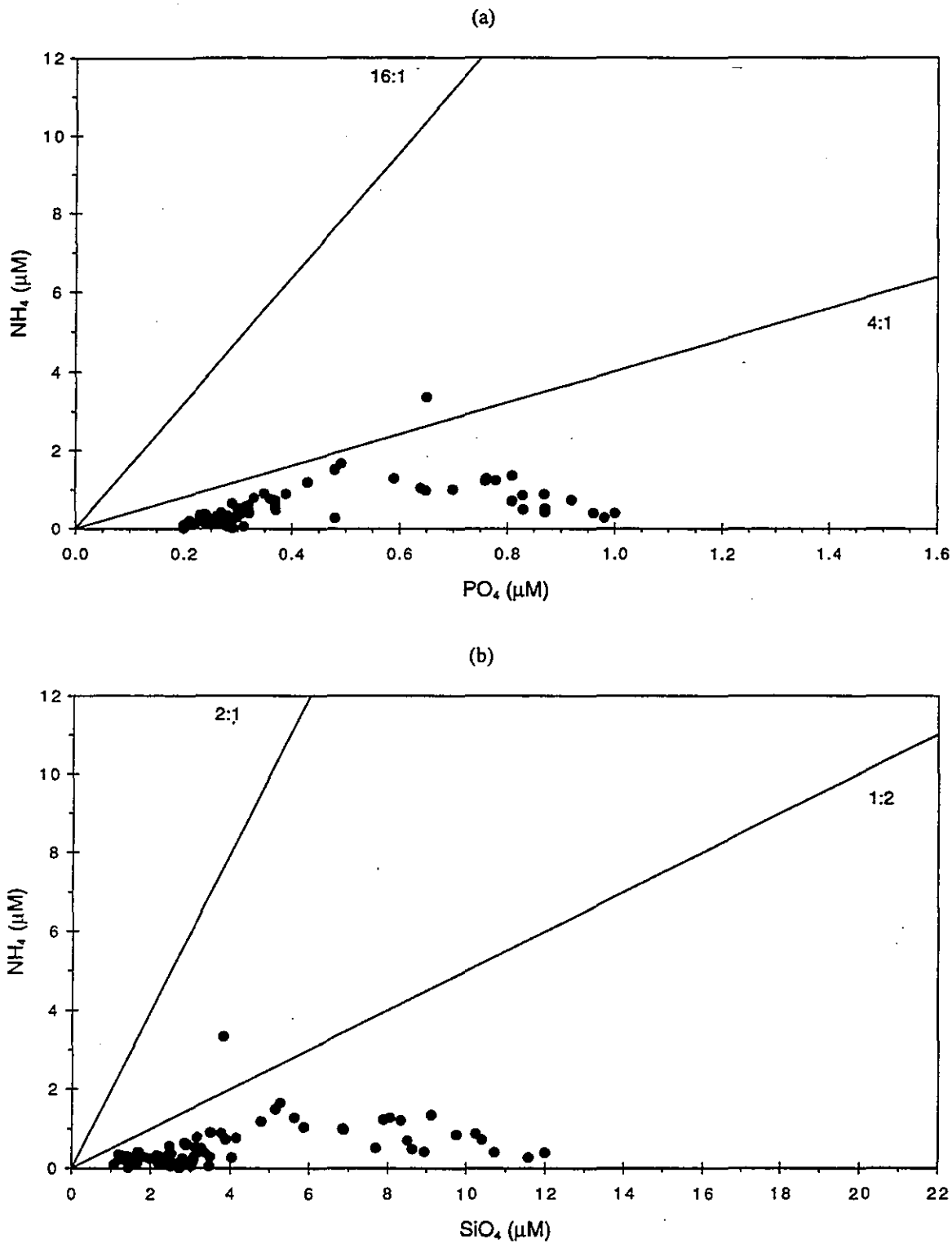


FIGURE 4-171
Nutrient vs. nutrient plots for nearfield survey W9612, (Sep 96).

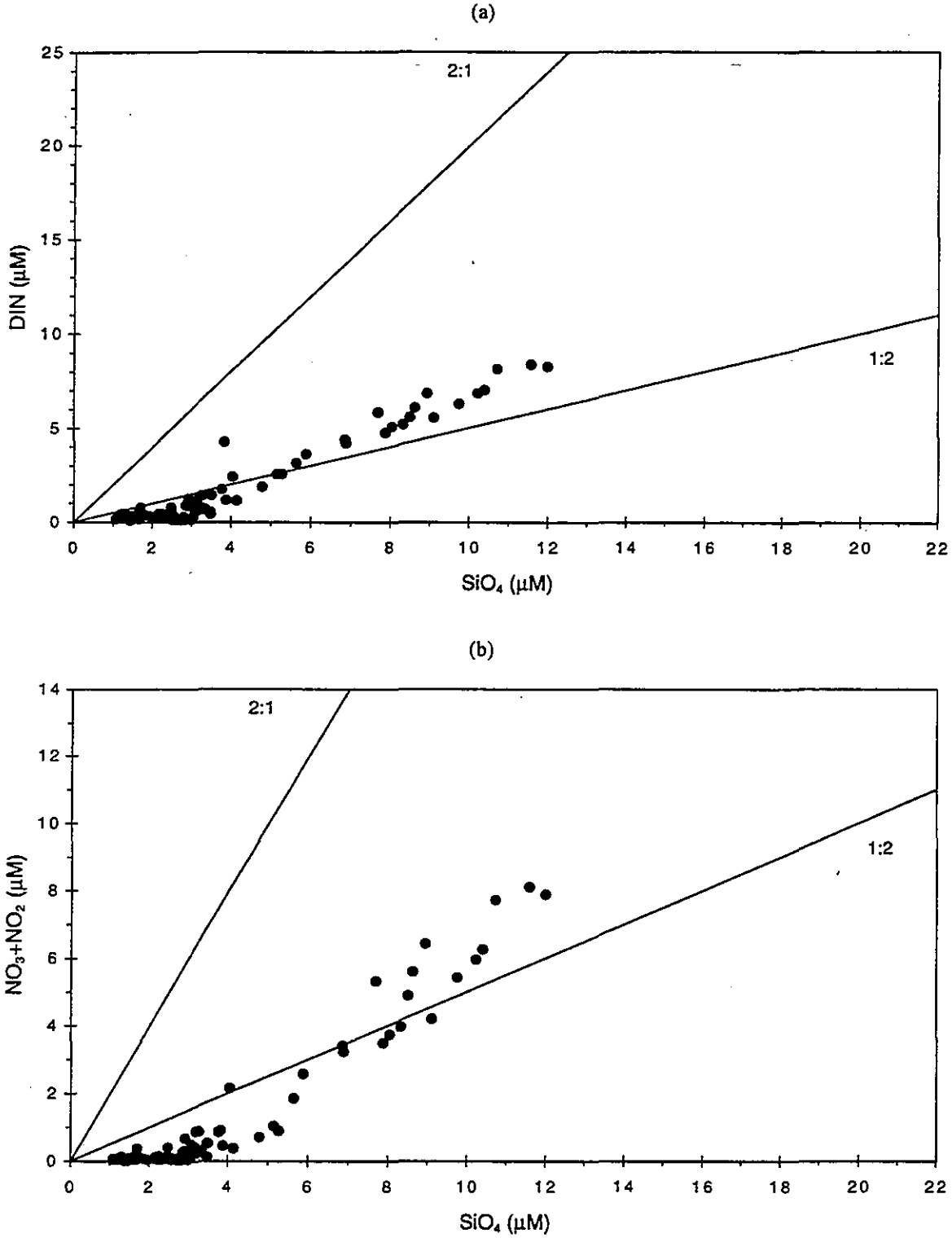
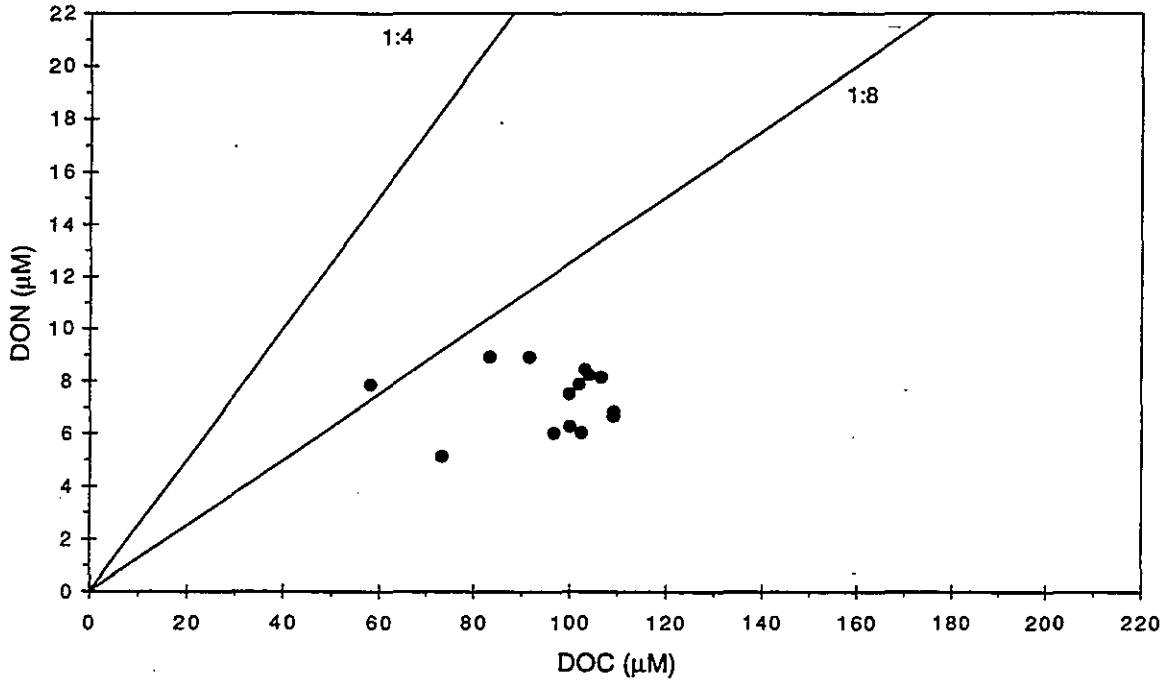


FIGURE 4-172
Nutrient vs. nutrient plots for nearfield survey W9612, (Sep 96).

(a)



(b)

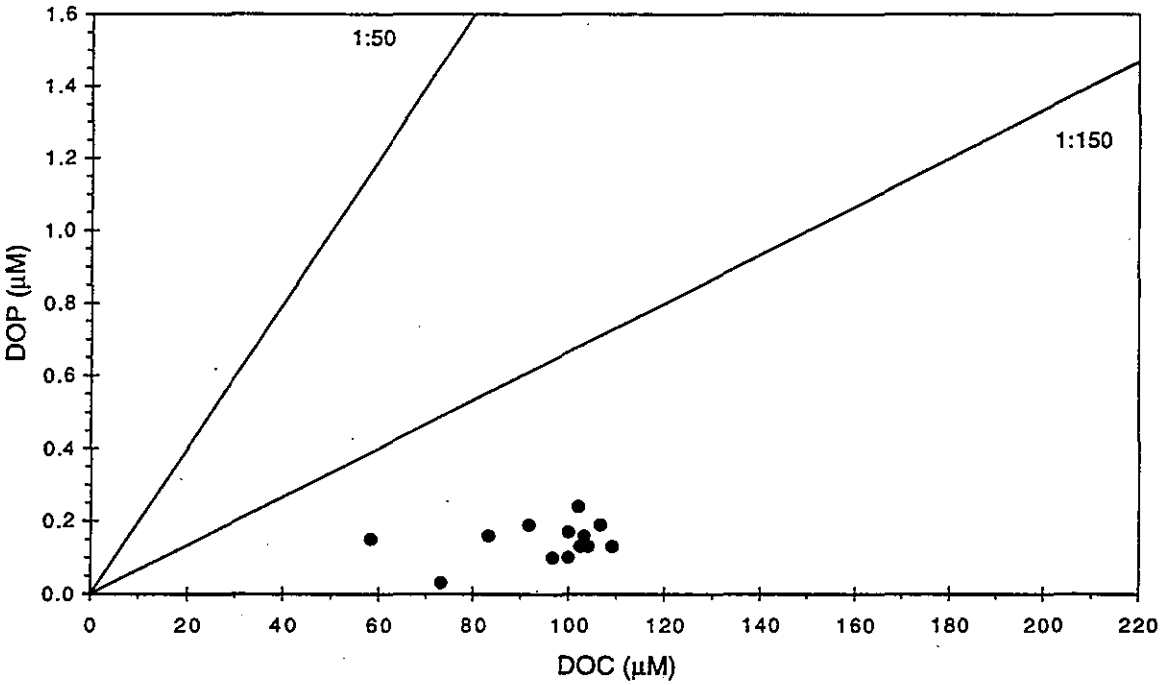
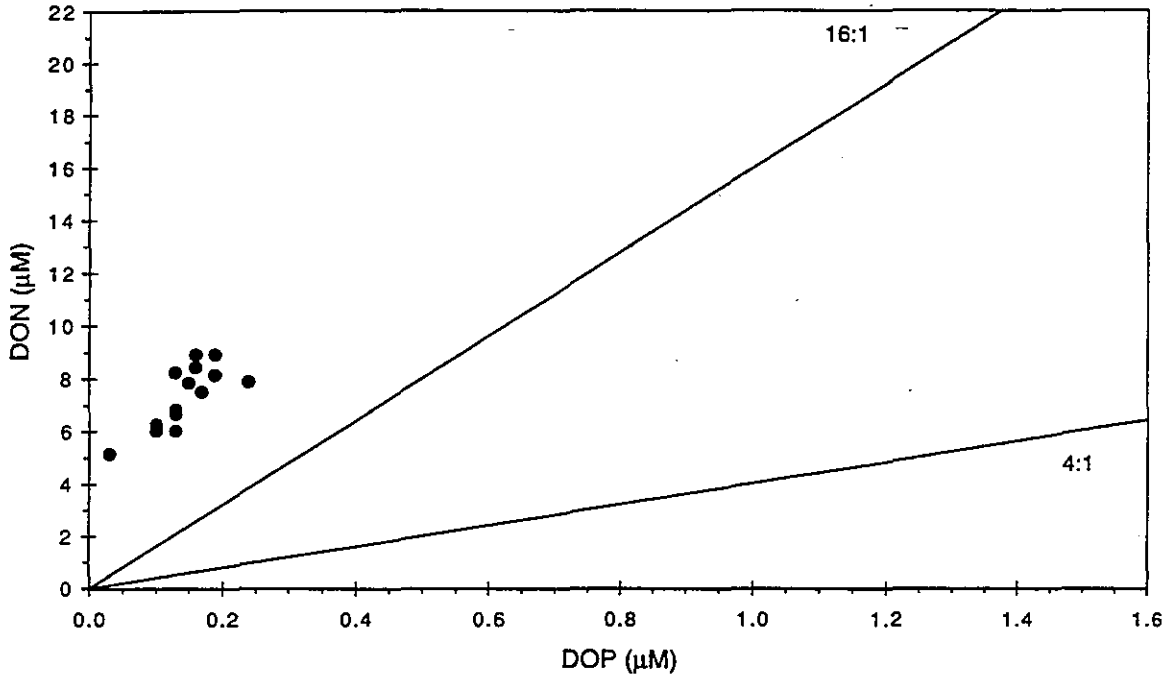


FIGURE 4-173
Nutrient vs. nutrient plots for nearfield survey W9612, (Sep 96).

(a)



(b)

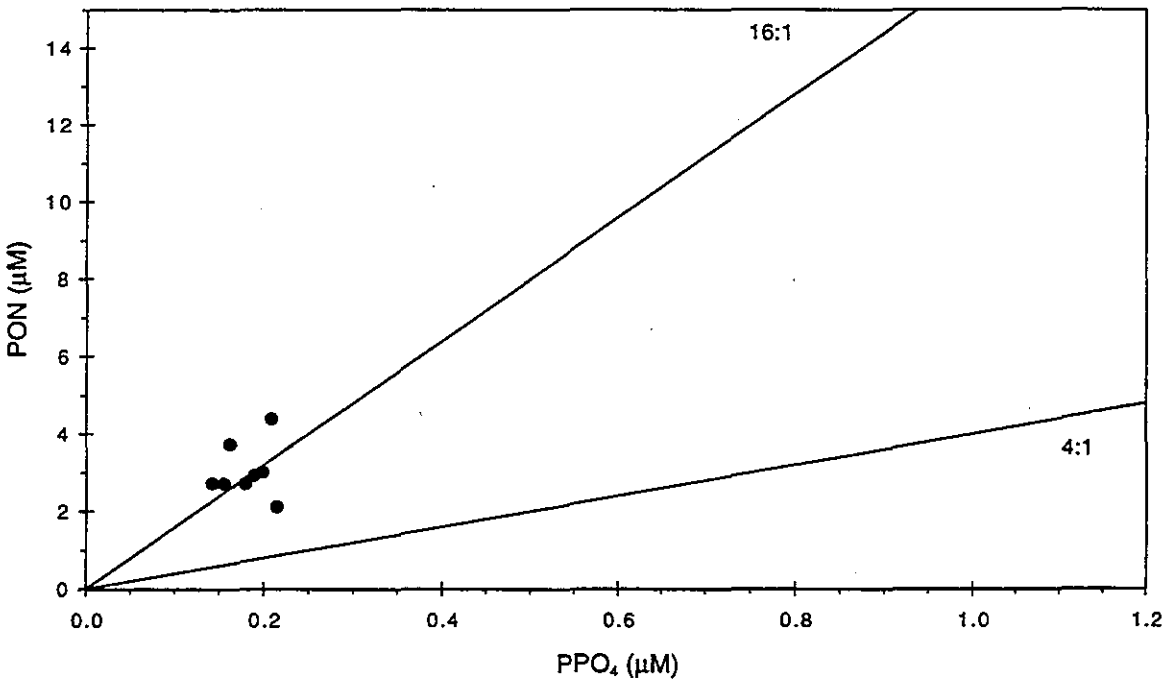


FIGURE 4-174
Nutrient vs. nutrient plots for nearfield survey W9612, (Sep 96).

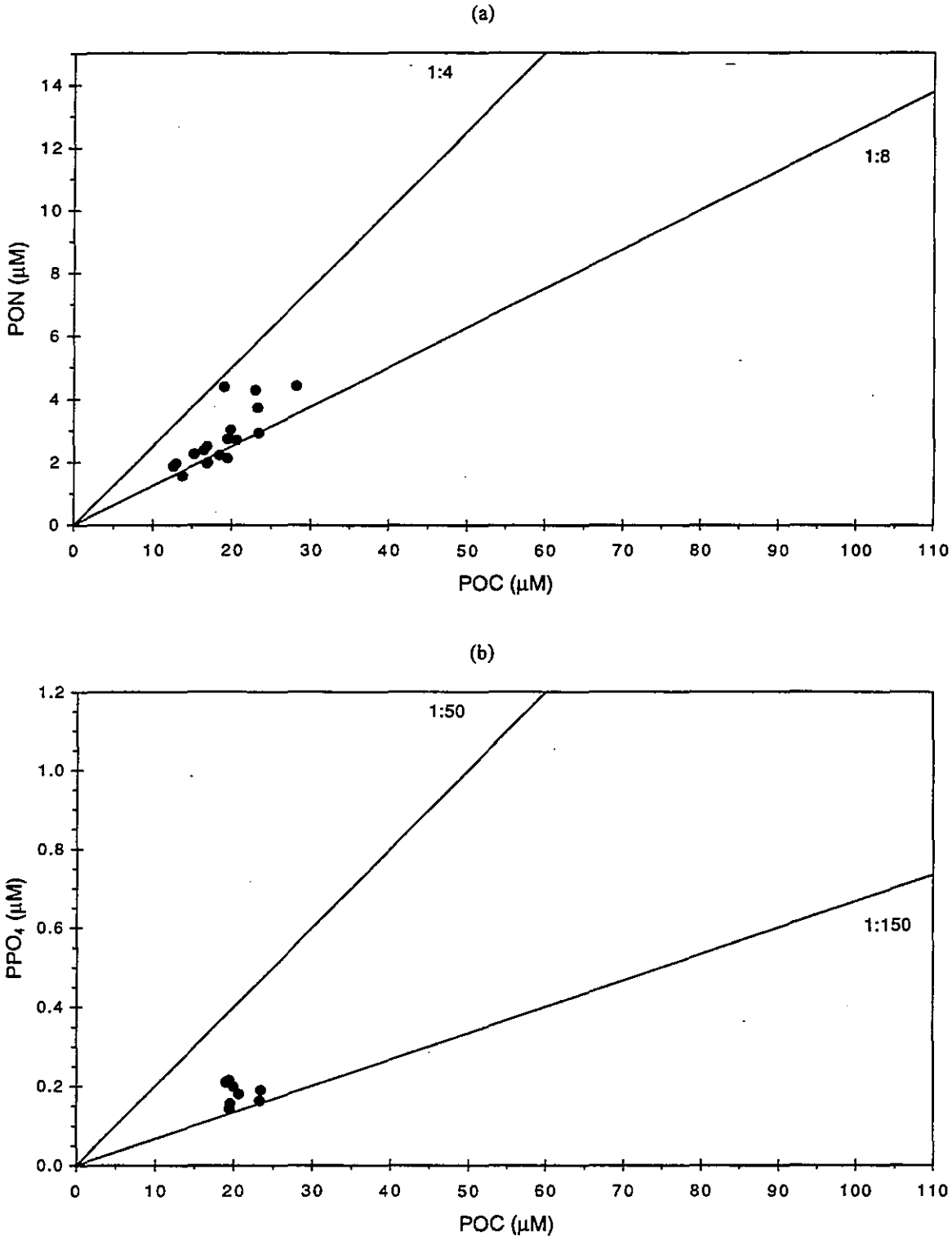
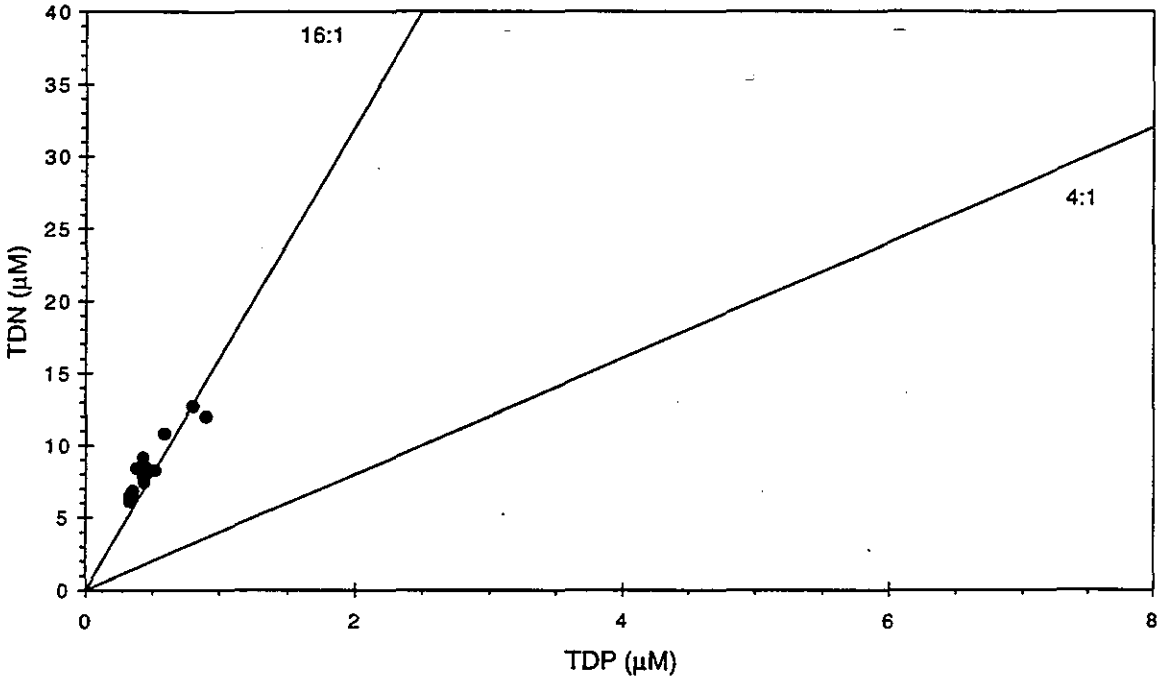


FIGURE 4-175
Nutrient vs. nutrient plots for nearfield survey W9612, (Sep 96).

(a)



(b)

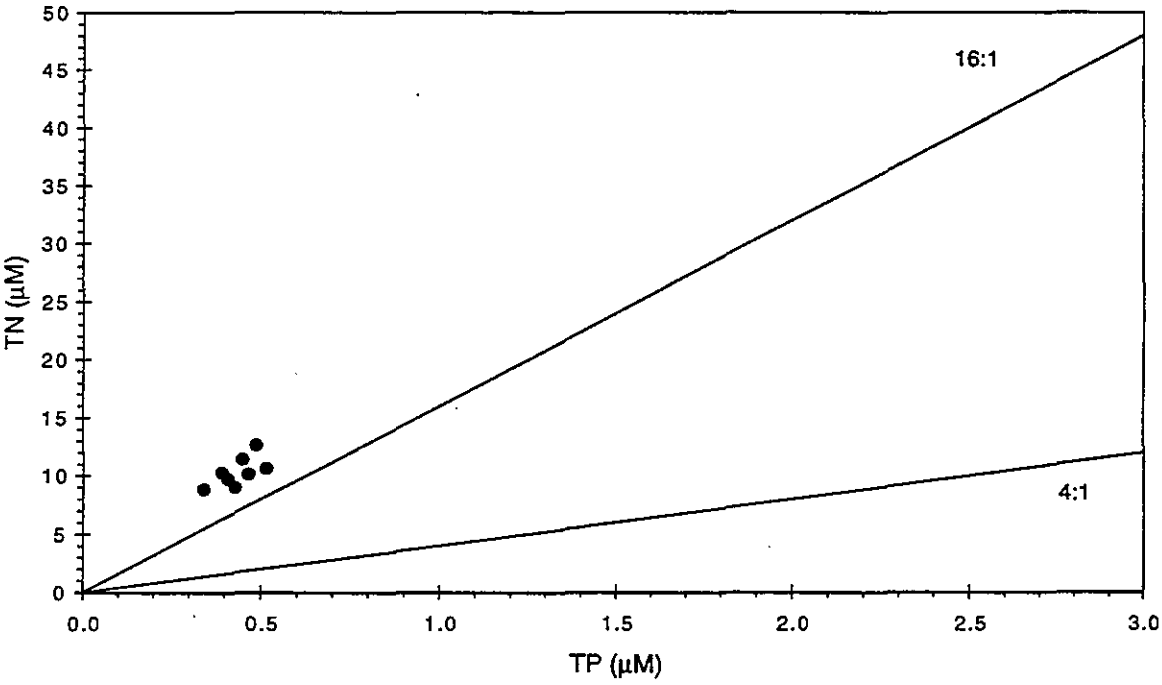
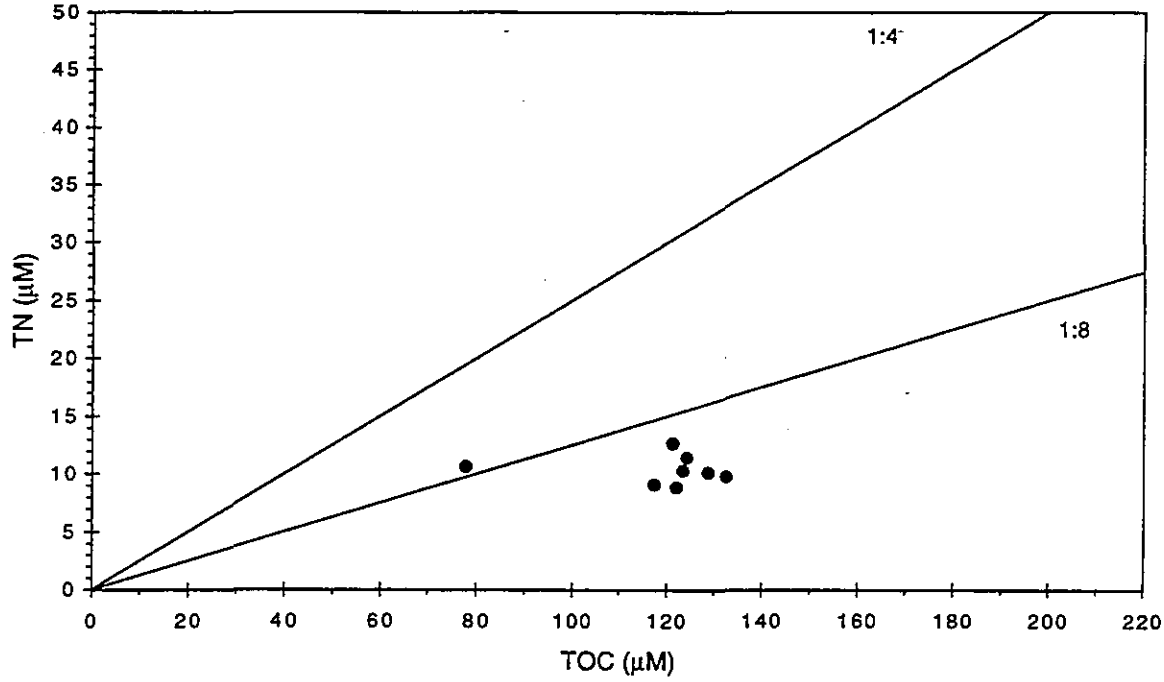


FIGURE 4-176
Nutrient vs. nutrient plots for nearfield survey W9612, (Sep 96).

(a)



(b)

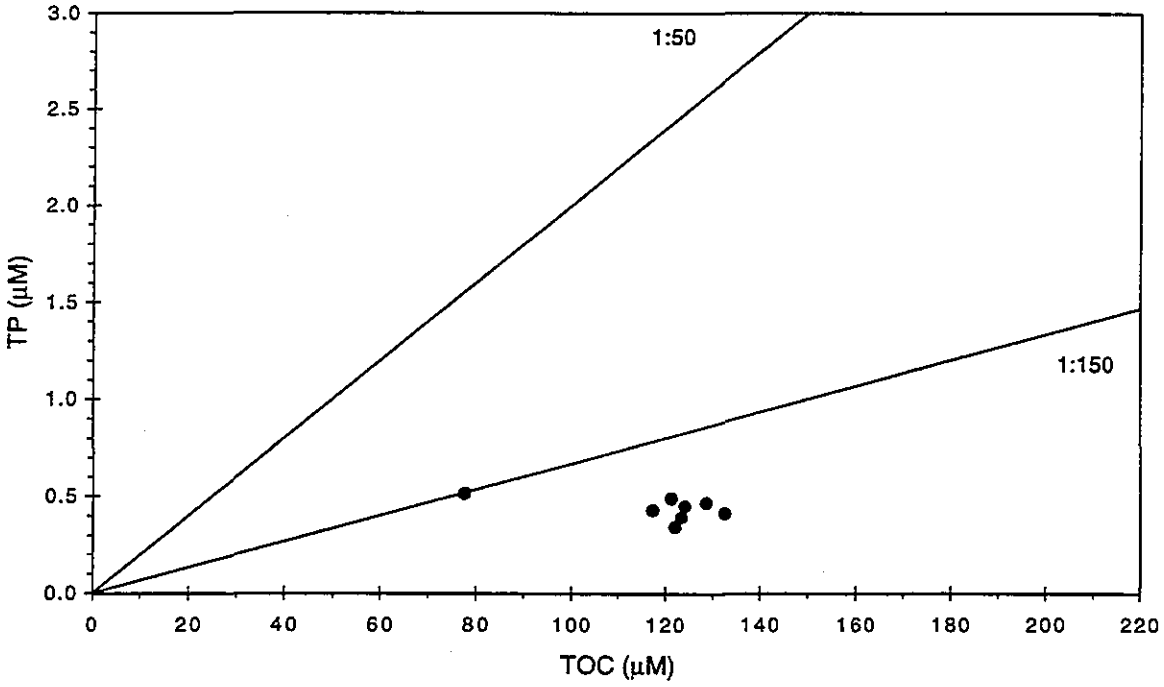


FIGURE 4-177
Nutrient vs. nutrient plots for nearfield survey W9612, (Sep 96).

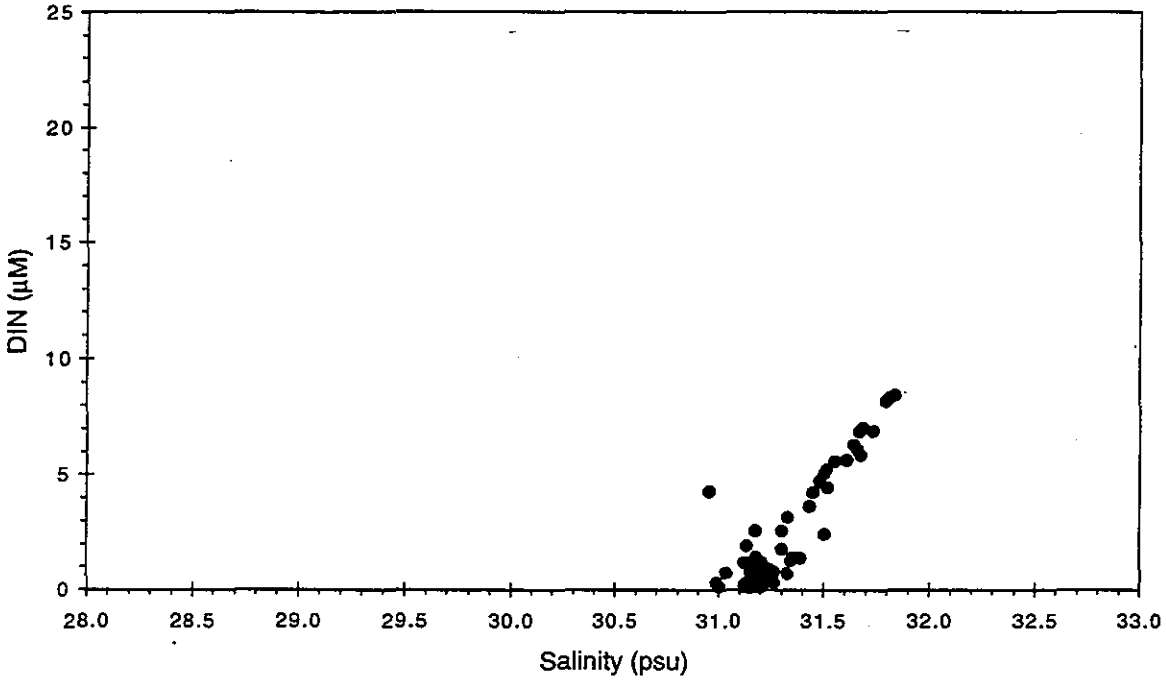
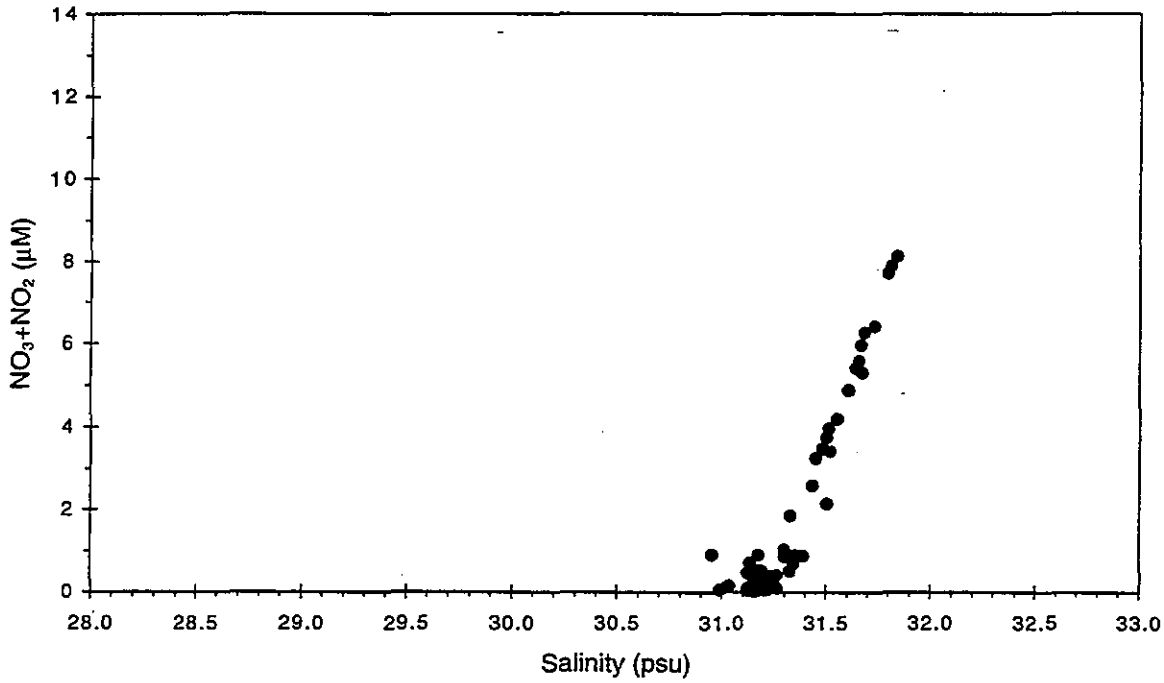


FIGURE 4-178
Nutrient vs. salinity plots for nearfield survey W9612, (Sep 96).

(a)



(b)

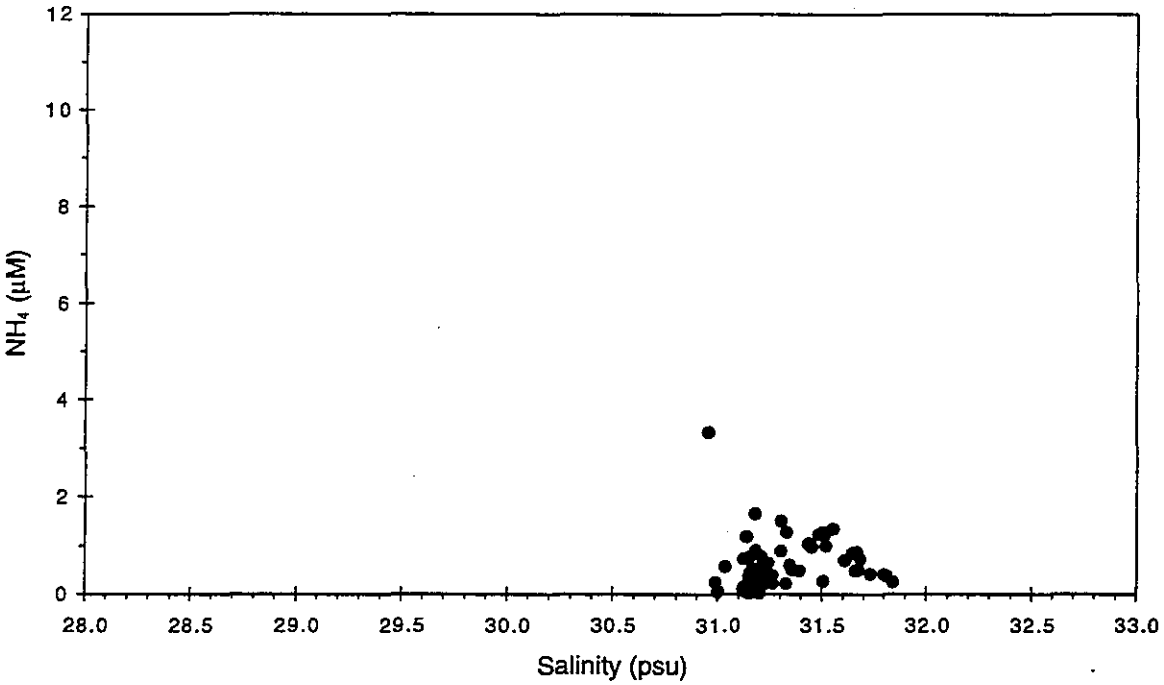
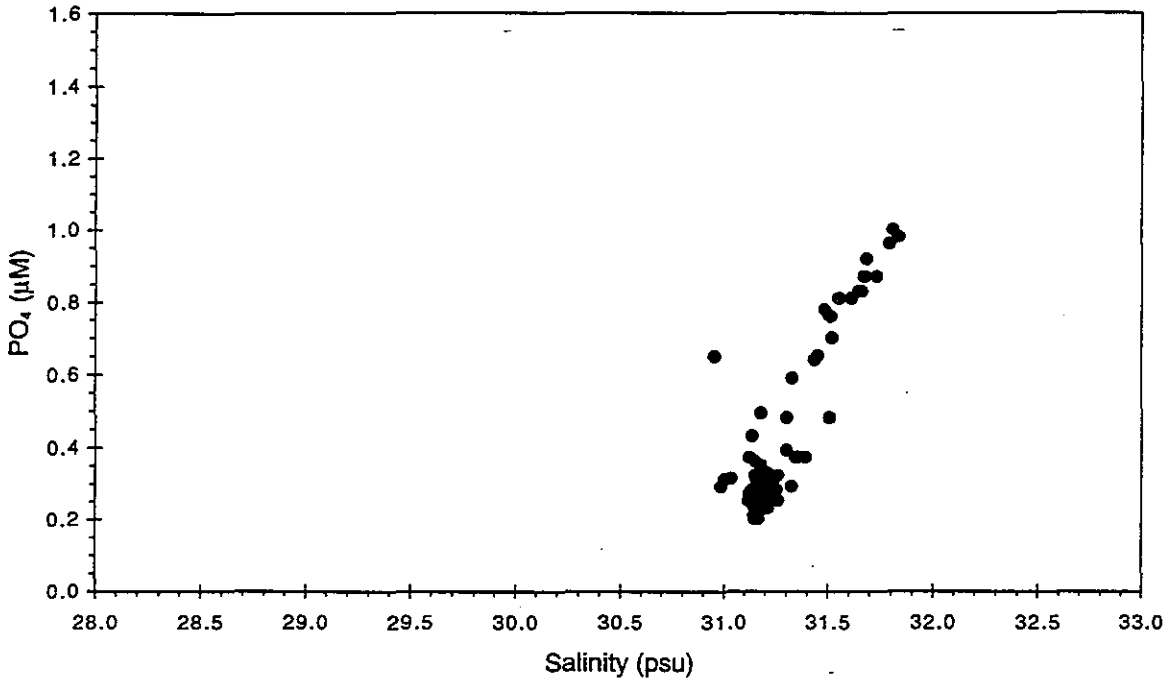


FIGURE 4-179
Nutrient vs. salinity plots for nearfield survey W9612, (Sep 96).

(a)



(b)

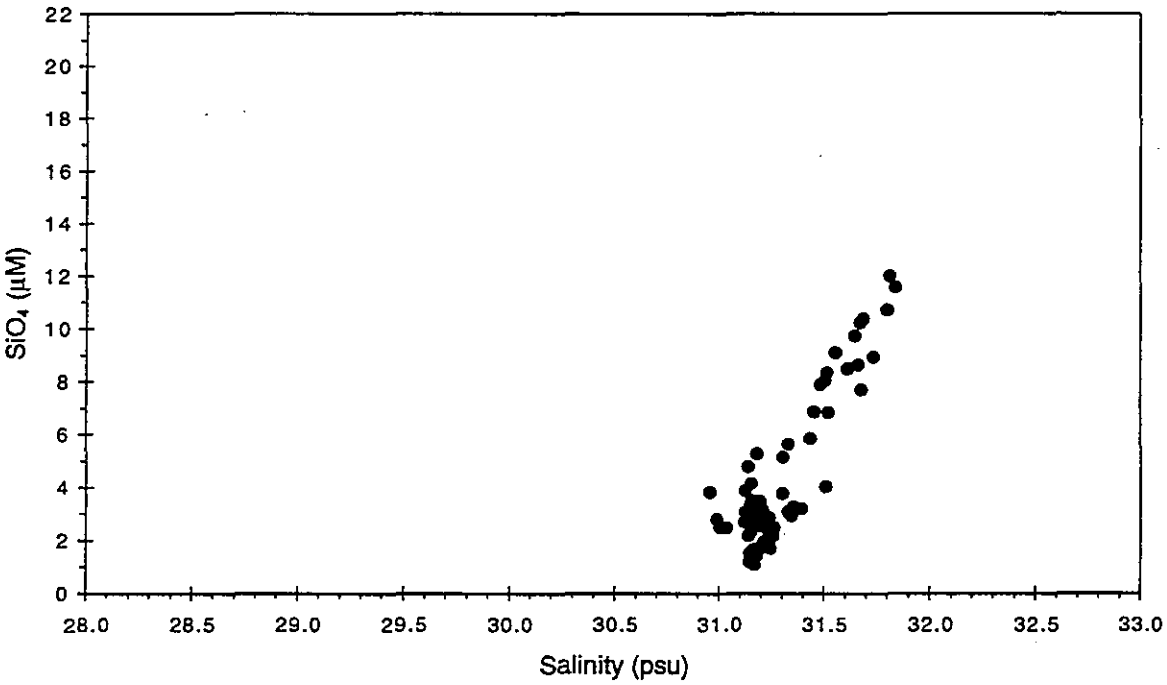


FIGURE 4-180
Nutrient vs. salinity plots for nearfield survey W9612, (Sep 96).

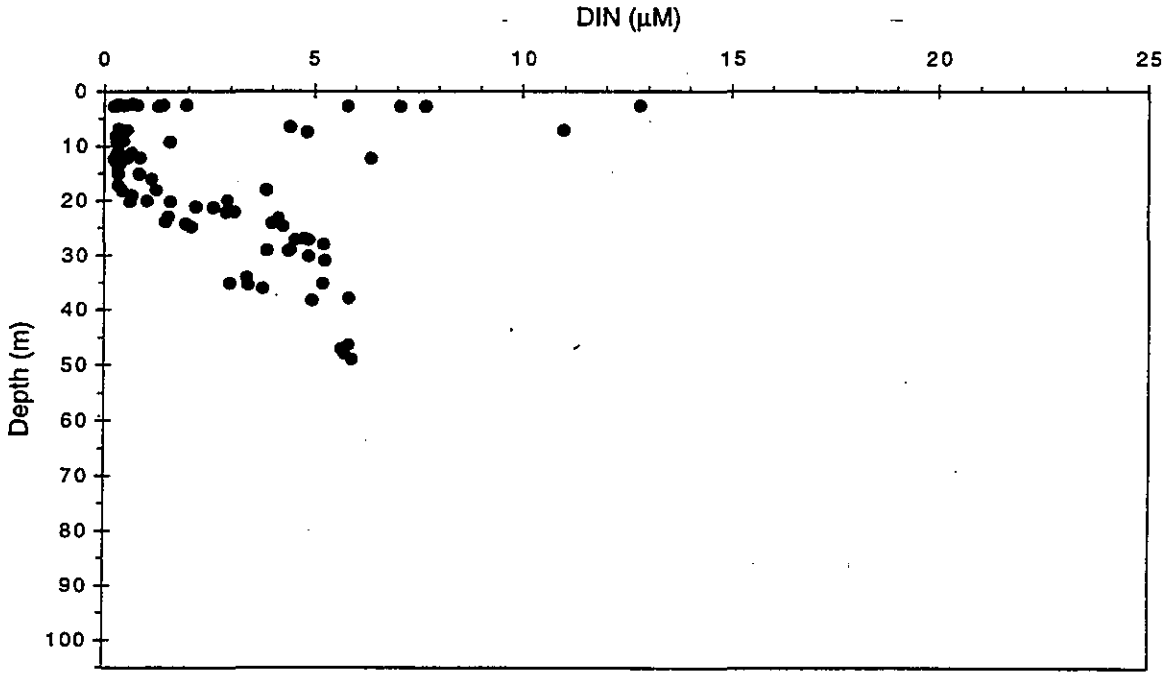


FIGURE 4-181
Depth vs. nutrient plots for nearfield survey W9613, (Sep 96).

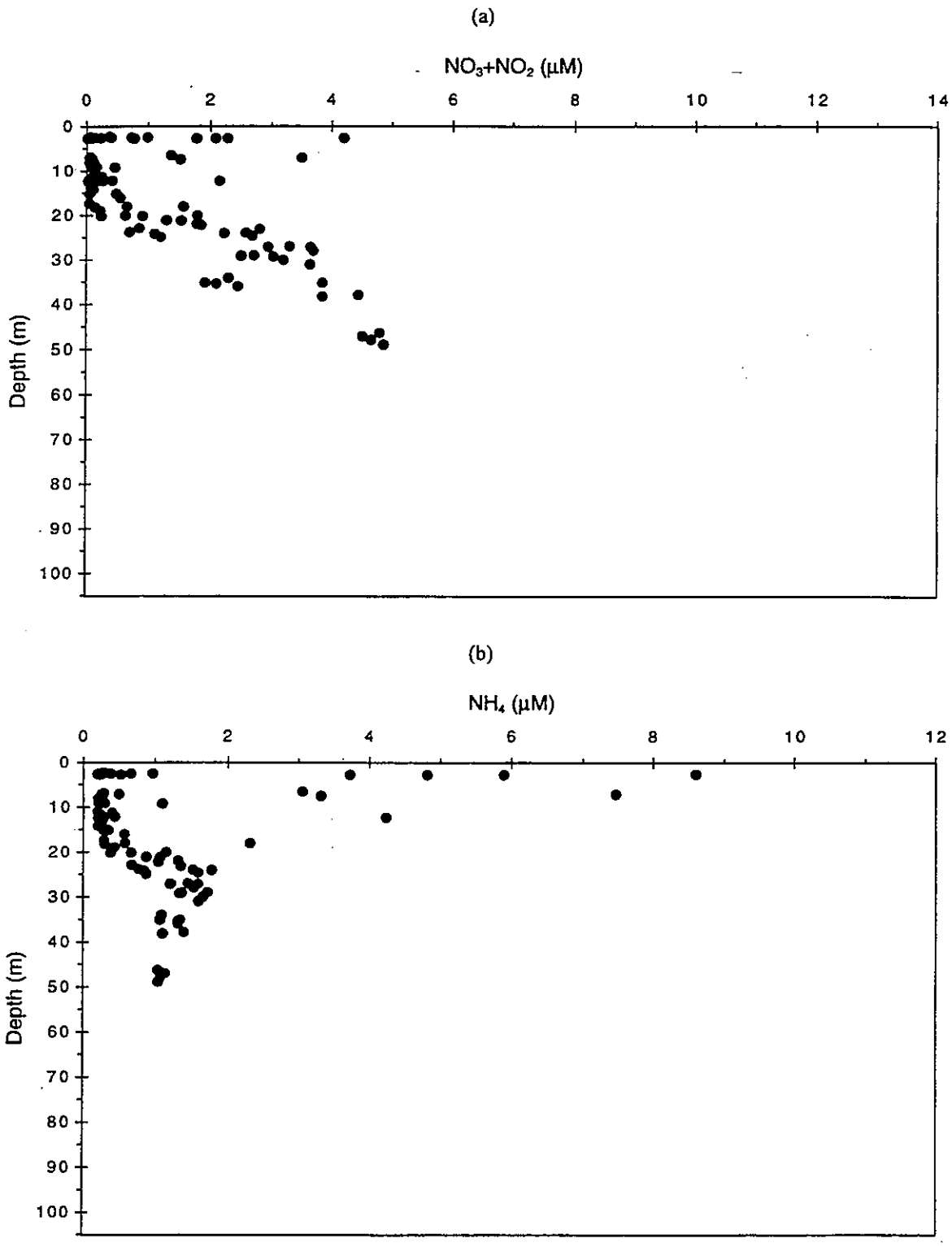


FIGURE 4-182
Depth vs. nutrient plots for nearfield survey W9613, (Sep 96).

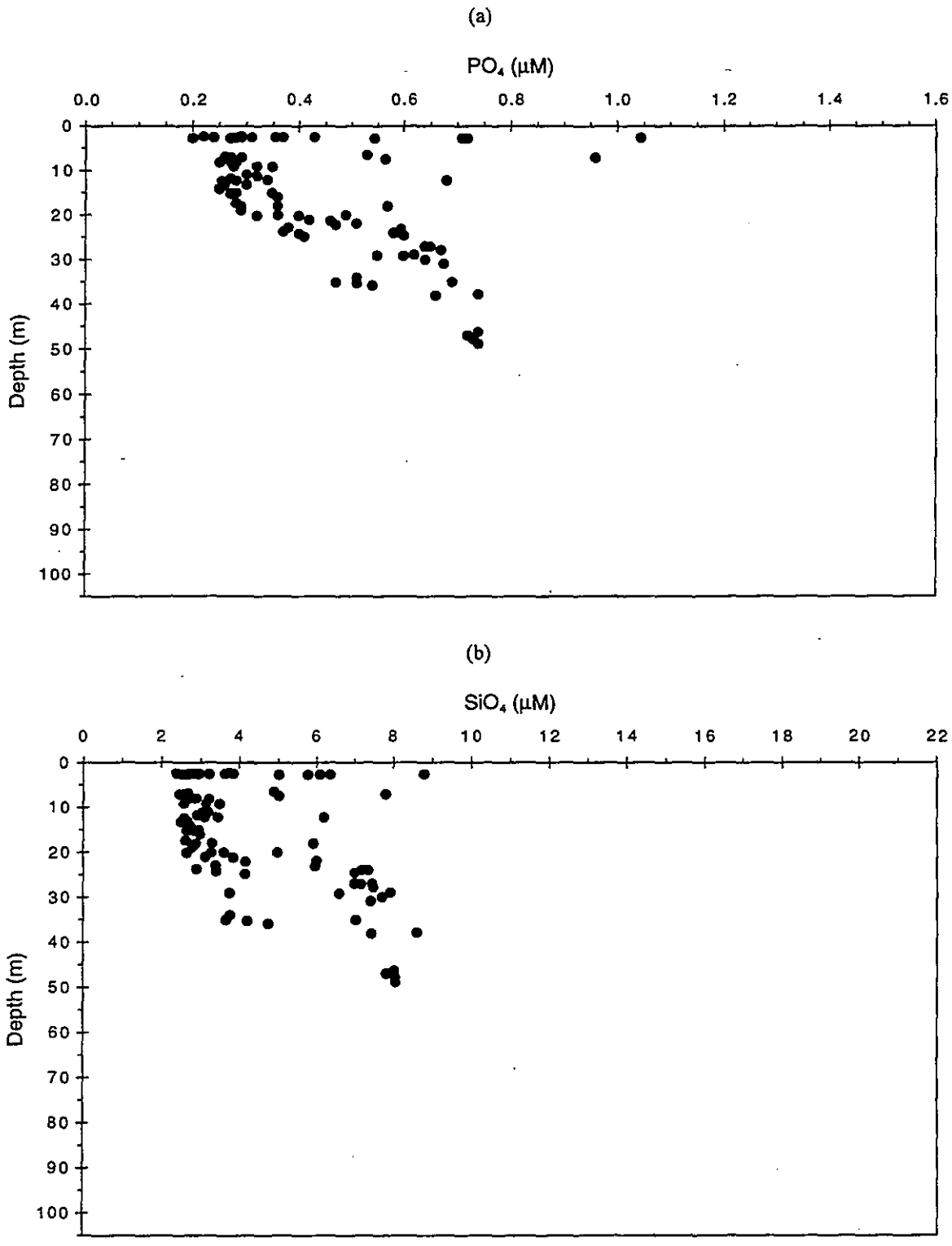


FIGURE 4-183
Depth vs. nutrient plots for nearfield survey W9613, (Sep 96).

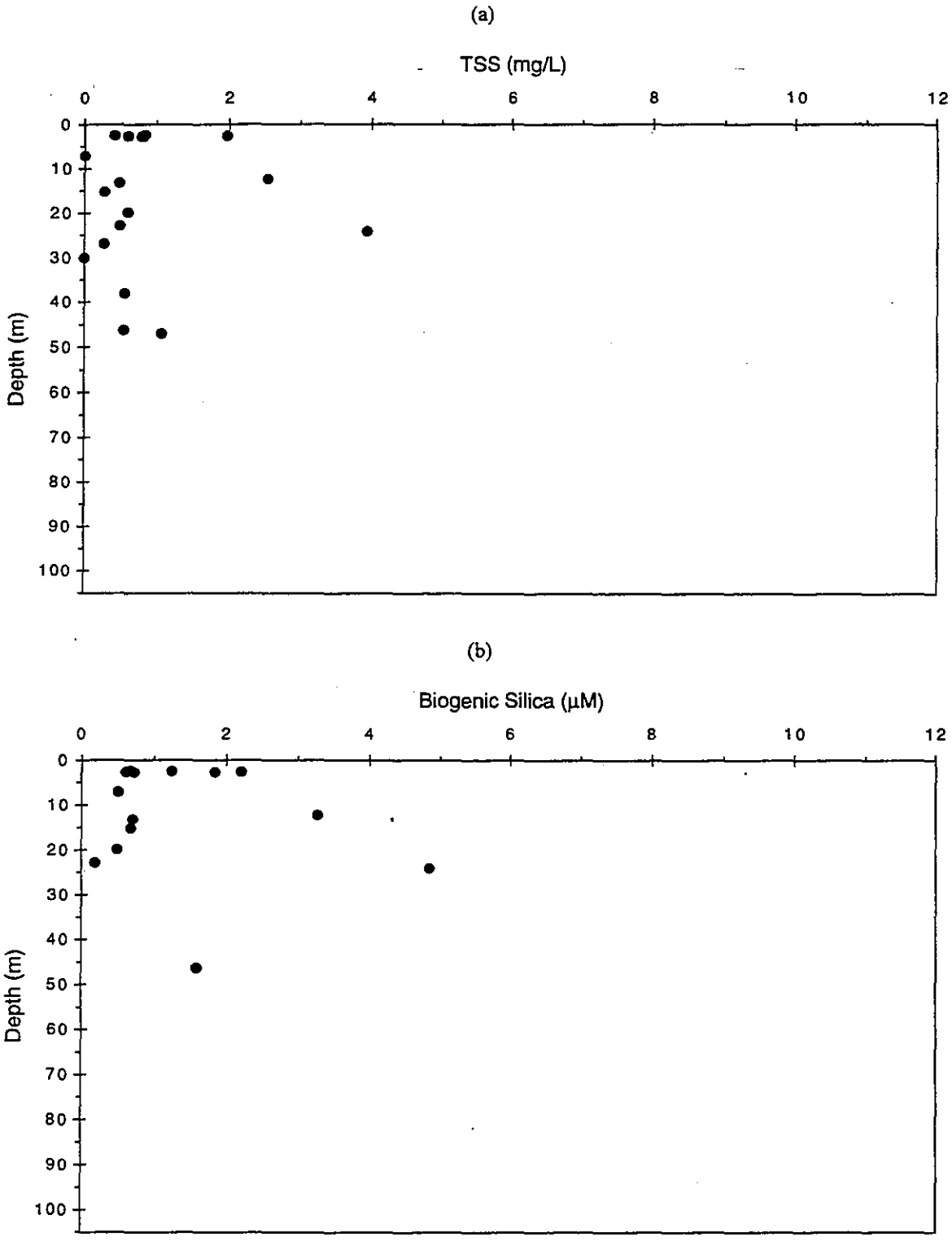
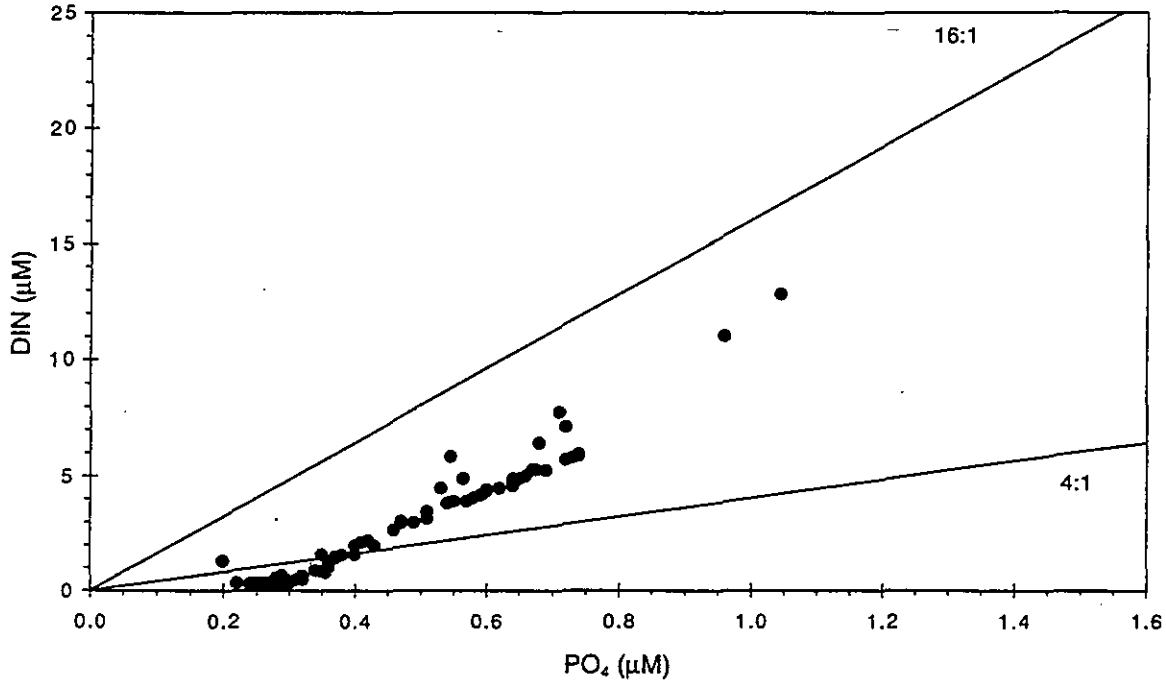


FIGURE 4-184
Depth vs. nutrient plots for nearfield survey W9613, (Sep 96).

(a)



(b)

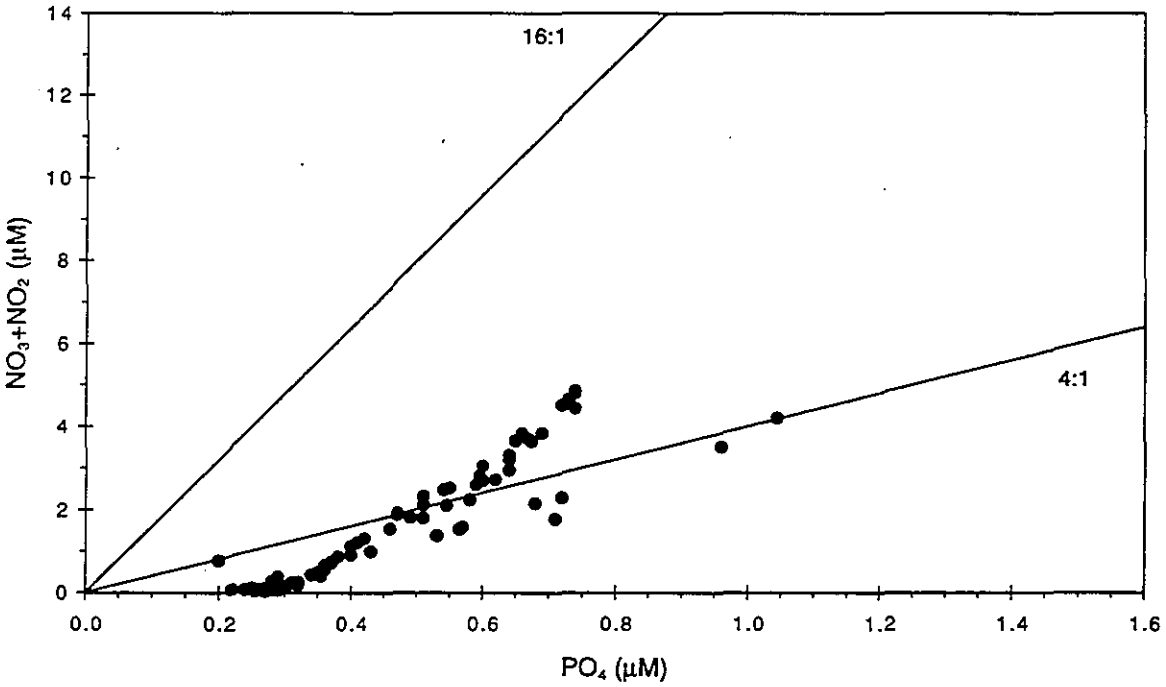


FIGURE 4-185
Nutrient vs. nutrient plots for nearfield survey W9613, (Sep 96).

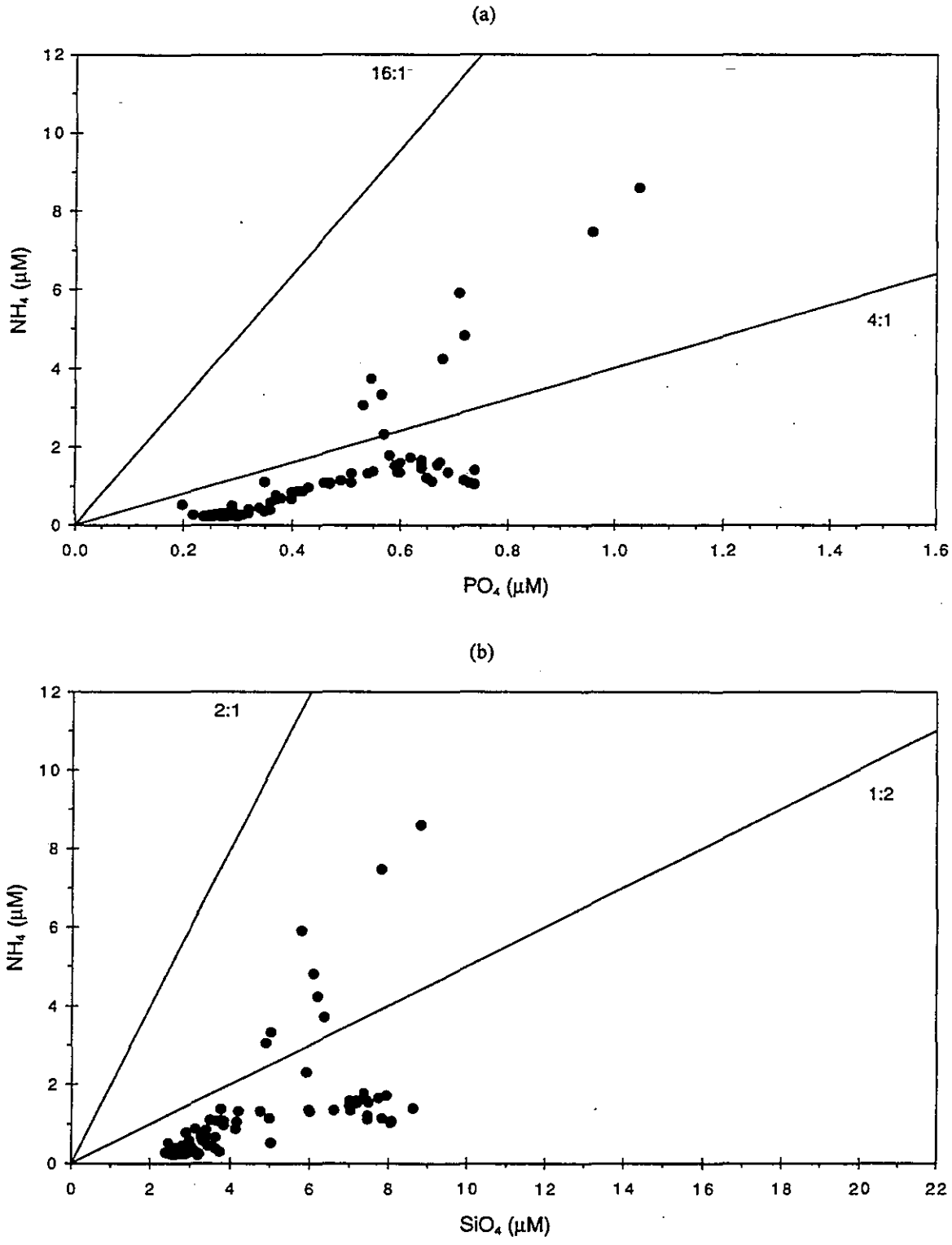


FIGURE 4-186
Nutrient vs. nutrient plots for nearfield survey W9613, (Sep 96).

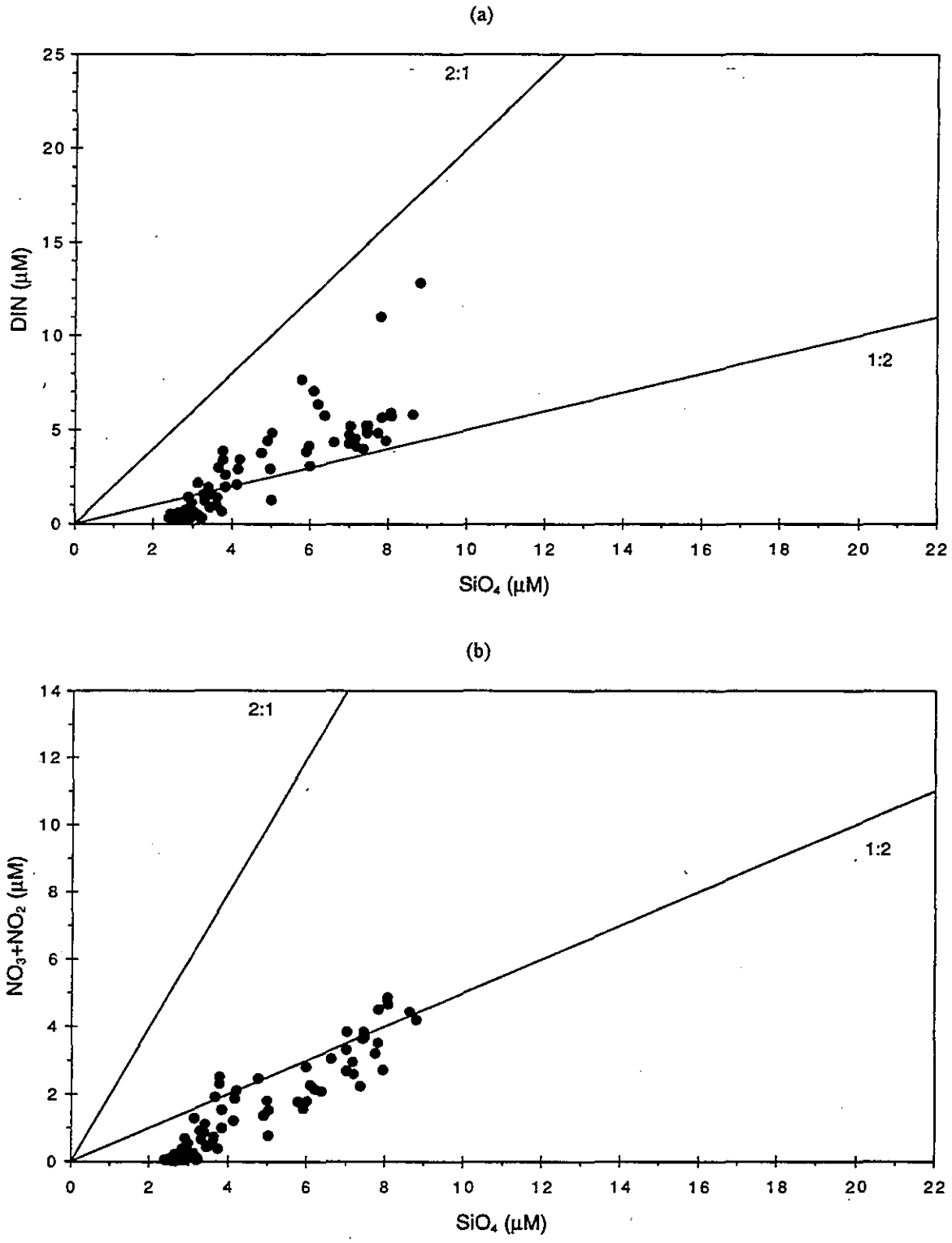


FIGURE 4-187
Nutrient vs. nutrient plots for nearfield survey W9613, (Sep 96).

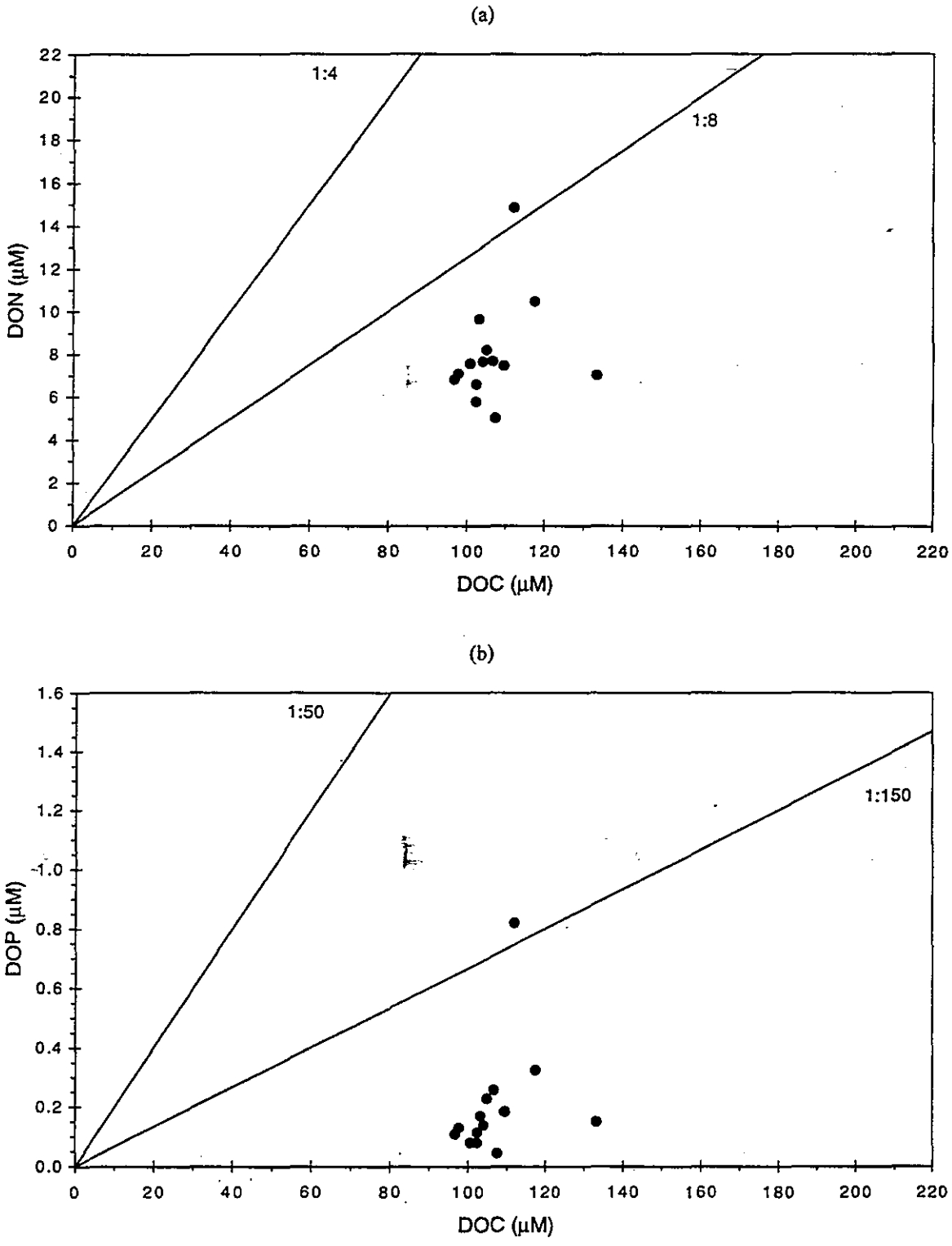


FIGURE 4-188
Nutrient vs. nutrient plots for nearfield survey W9613, (Sep 96).

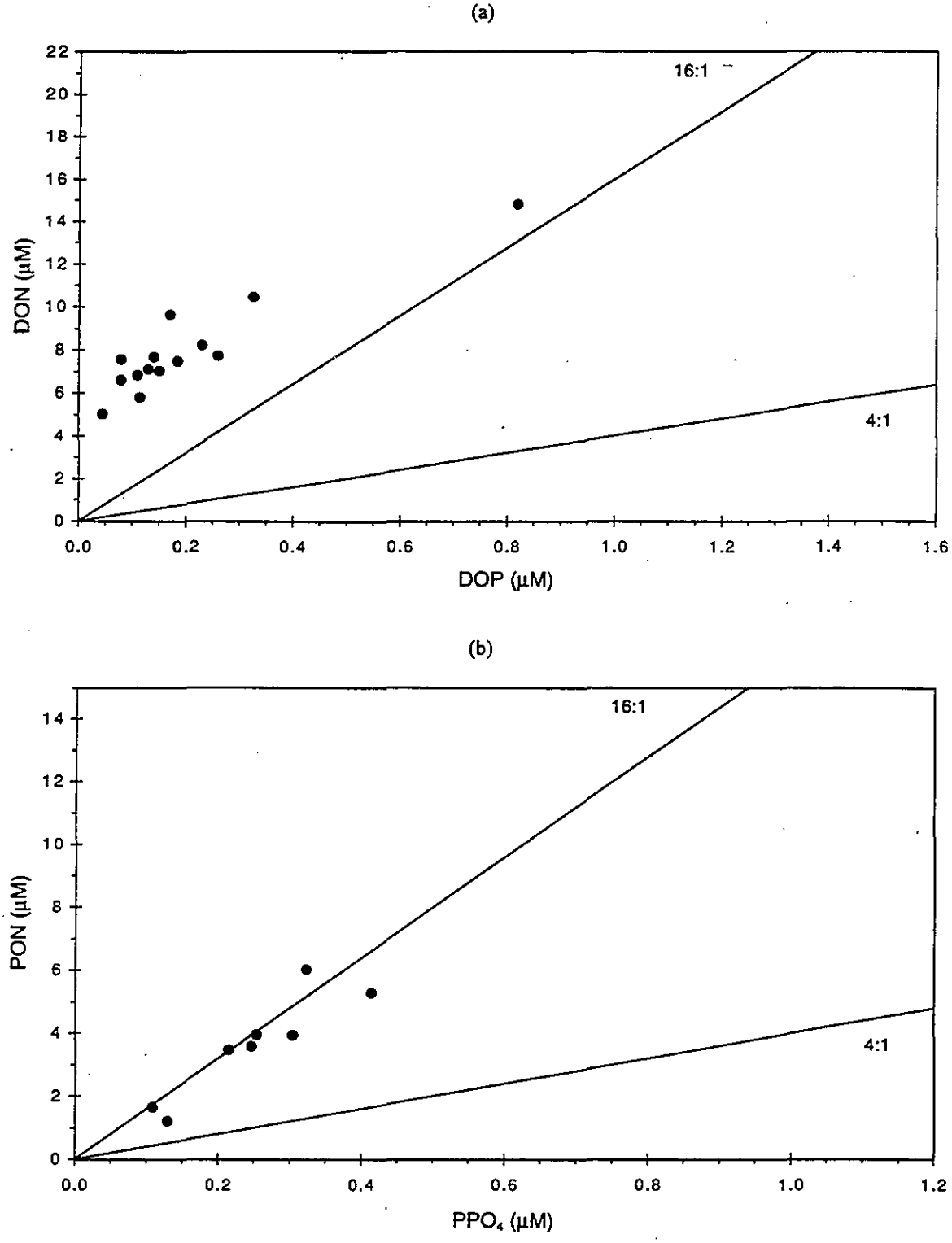


FIGURE 4-189
Nutrient vs. nutrient plots for nearfield survey W9613, (Sep 96).

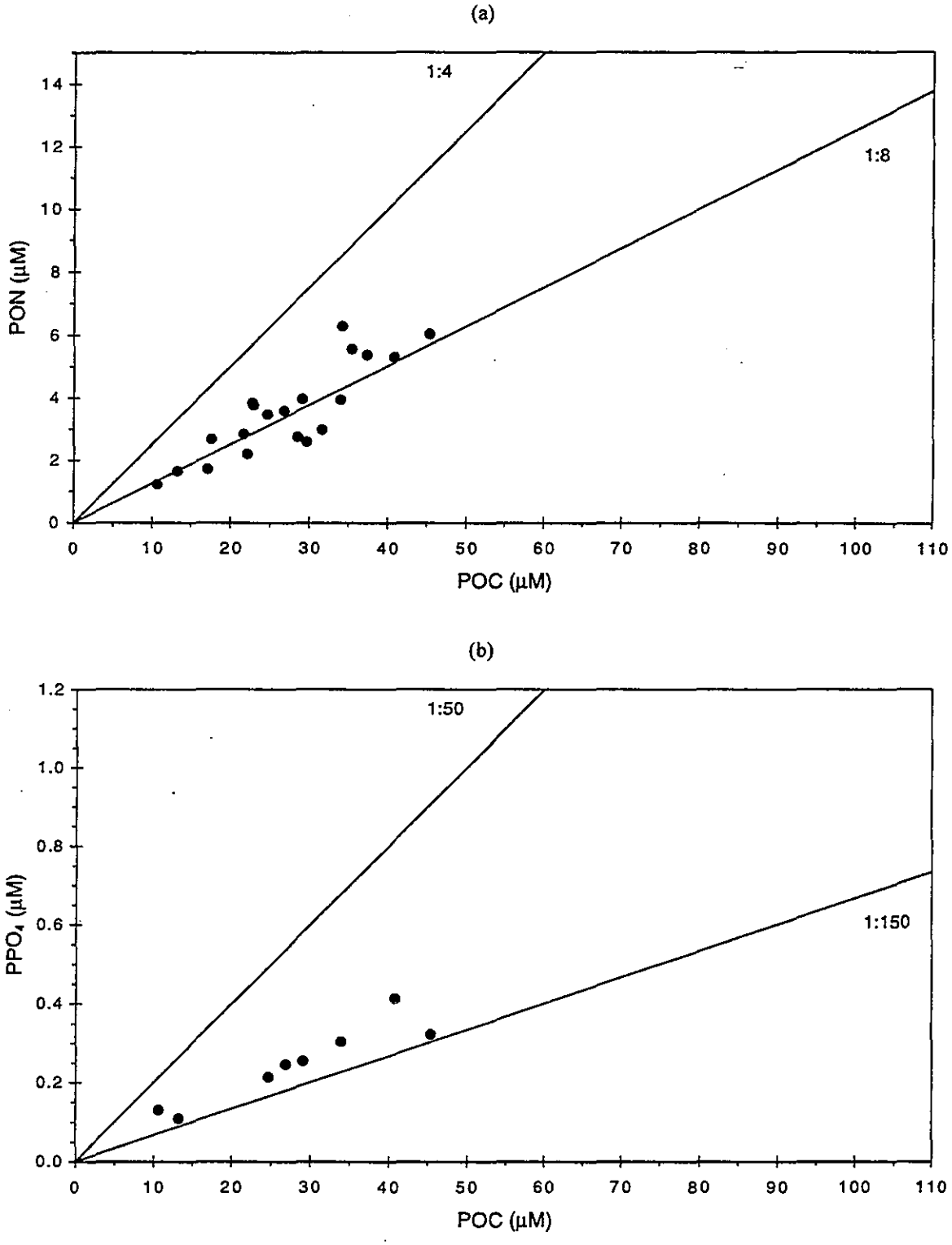
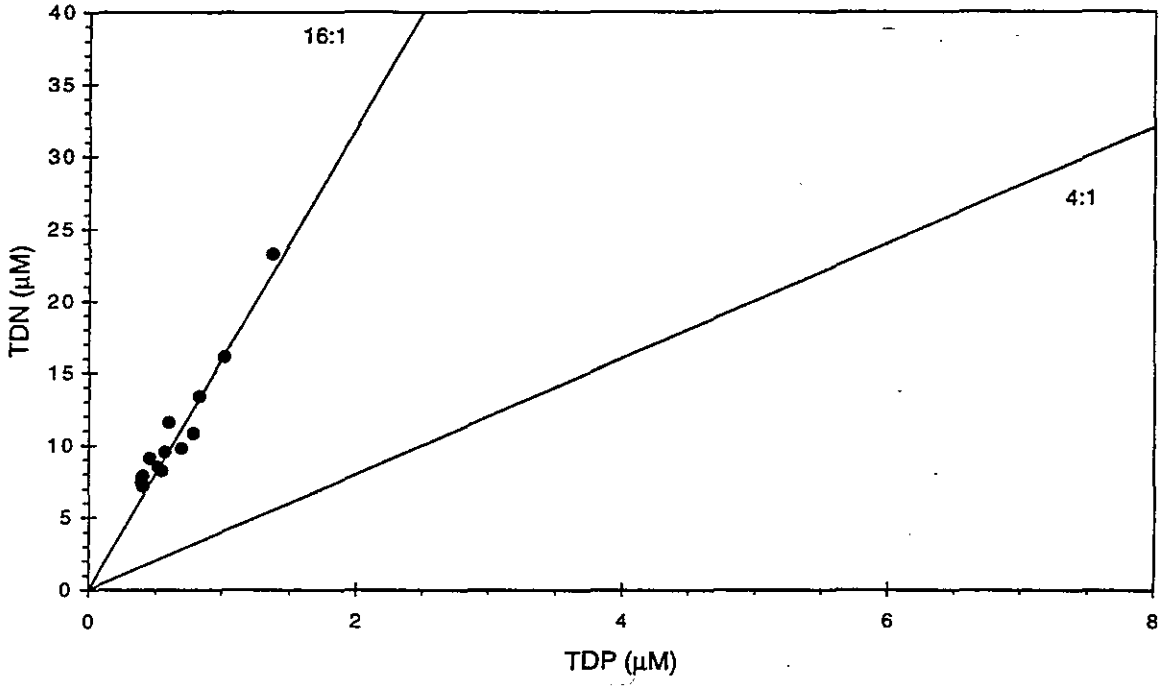


FIGURE 4-190
Nutrient vs. nutrient plots for nearfield survey W9613, (Sep 96).

(a)



(b)

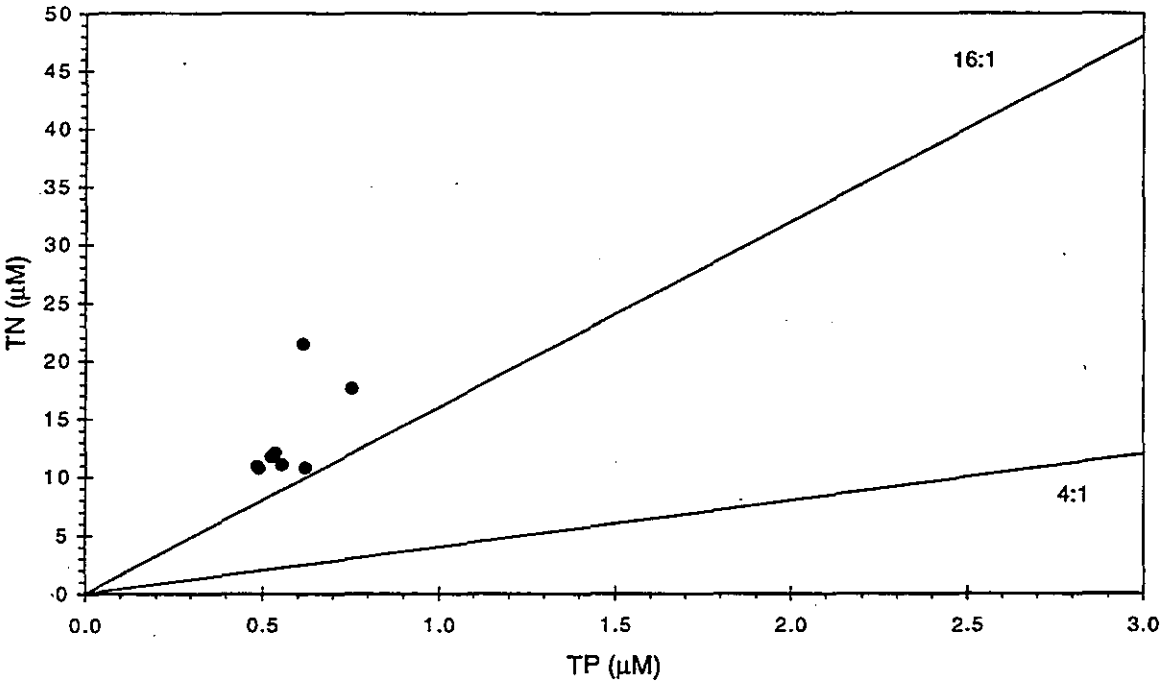
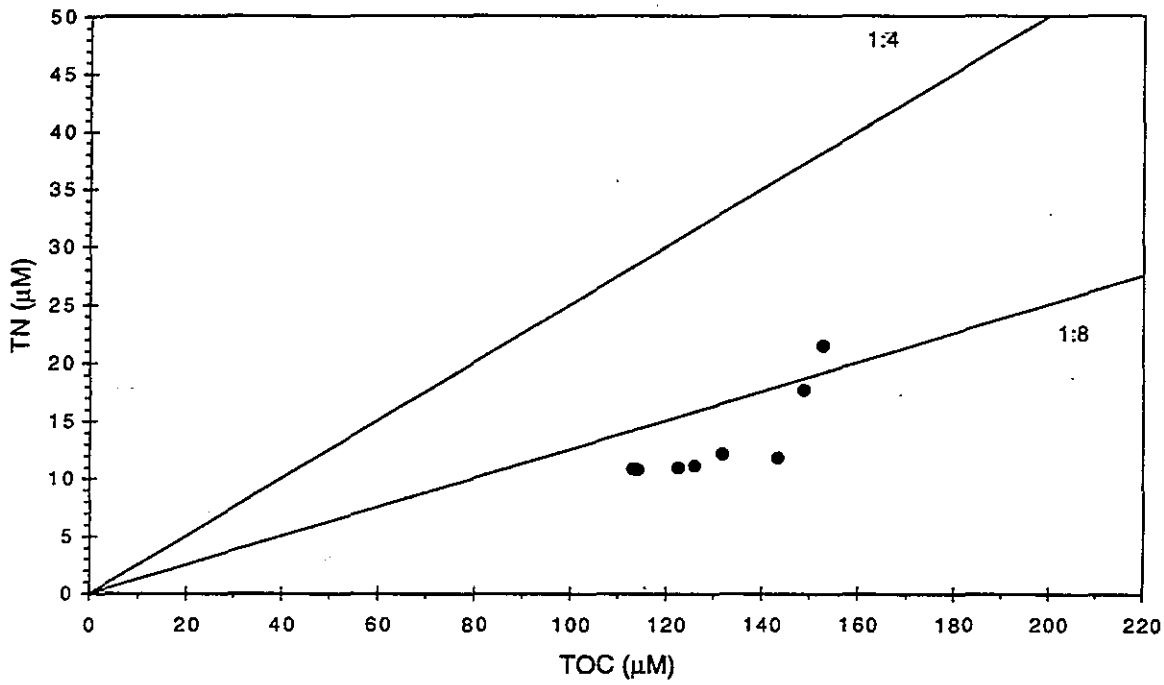


FIGURE 4-191
Nutrient vs. nutrient plots for nearfield survey W9613, (Sep 96).

(a)



(b)

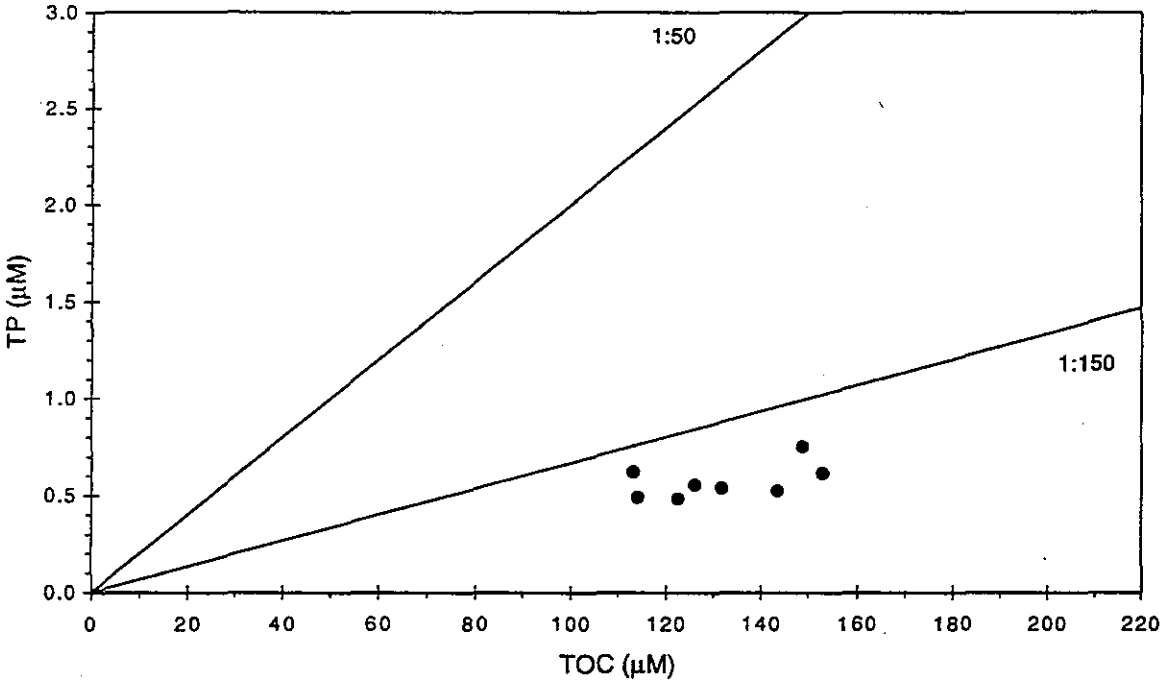


FIGURE 4-192
Nutrient vs. nutrient plots for nearfield survey W9613, (Sep 96).

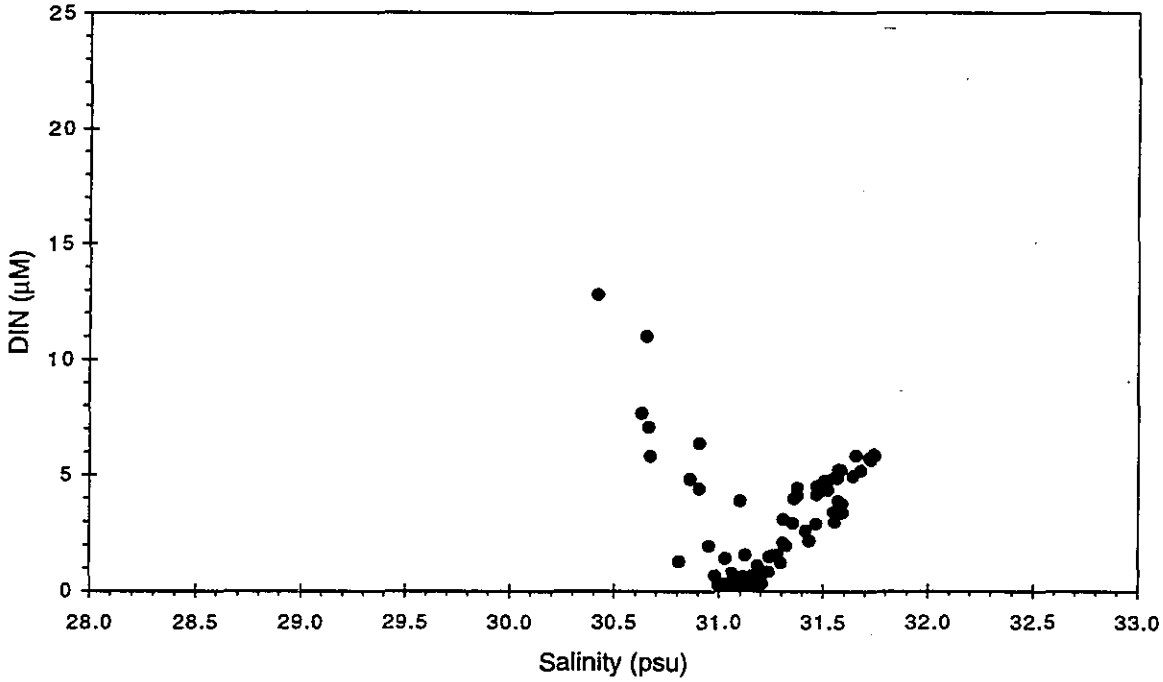
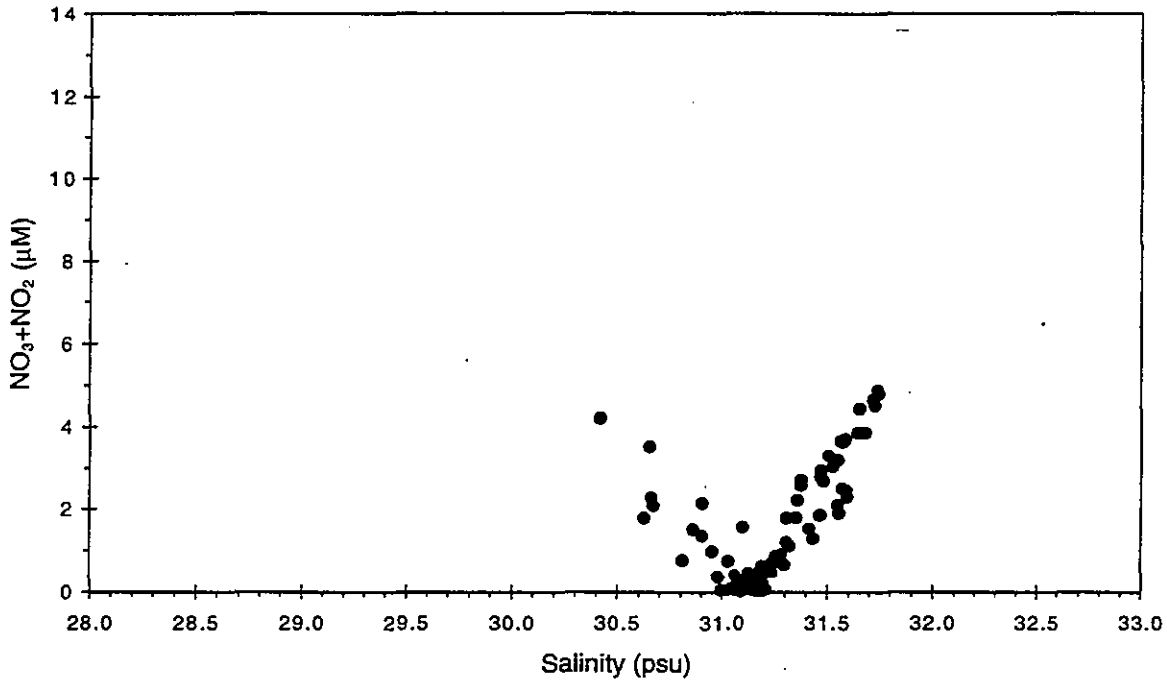


FIGURE 4-193
Nutrient vs. salinity plots for nearfield survey W9613, (Sep 96).

(a)



(b)

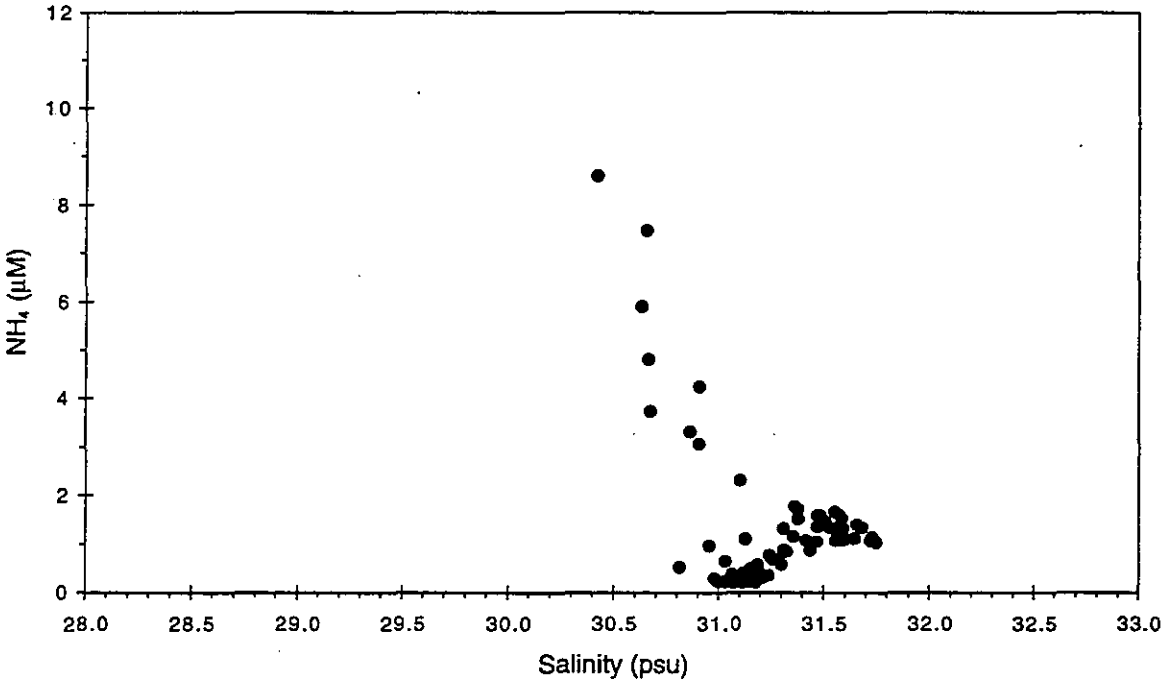
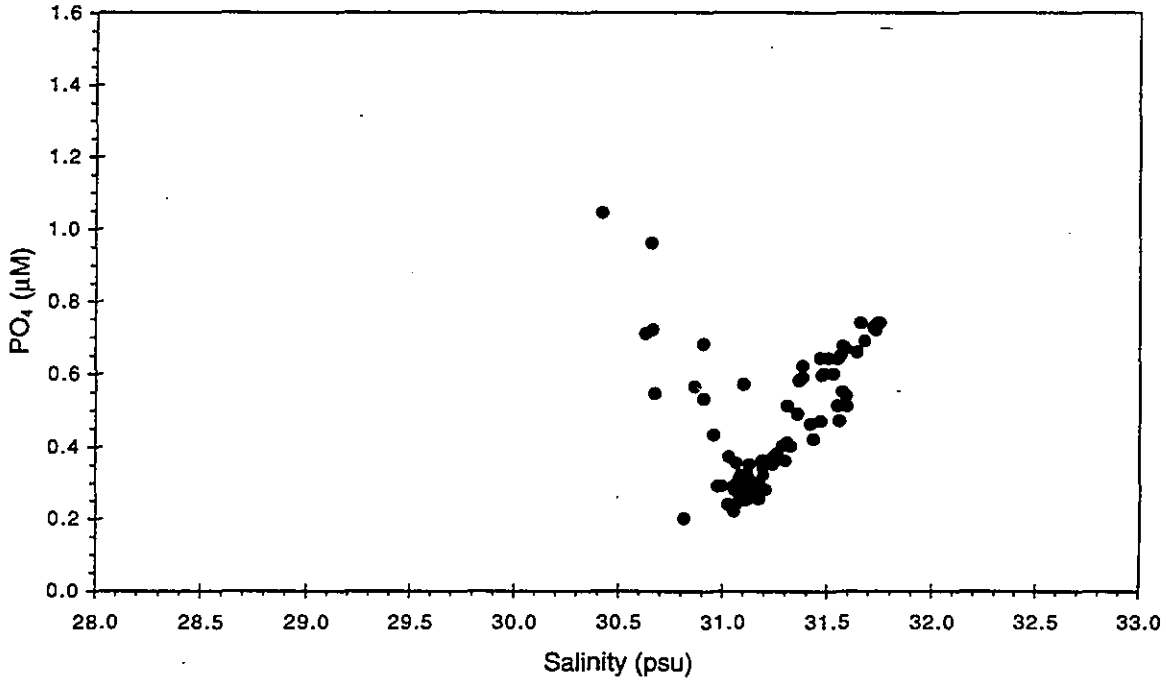


FIGURE 4-194
Nutrient vs. salinity plots for nearfield survey W9613, (Sep 96).

(a)



(b)

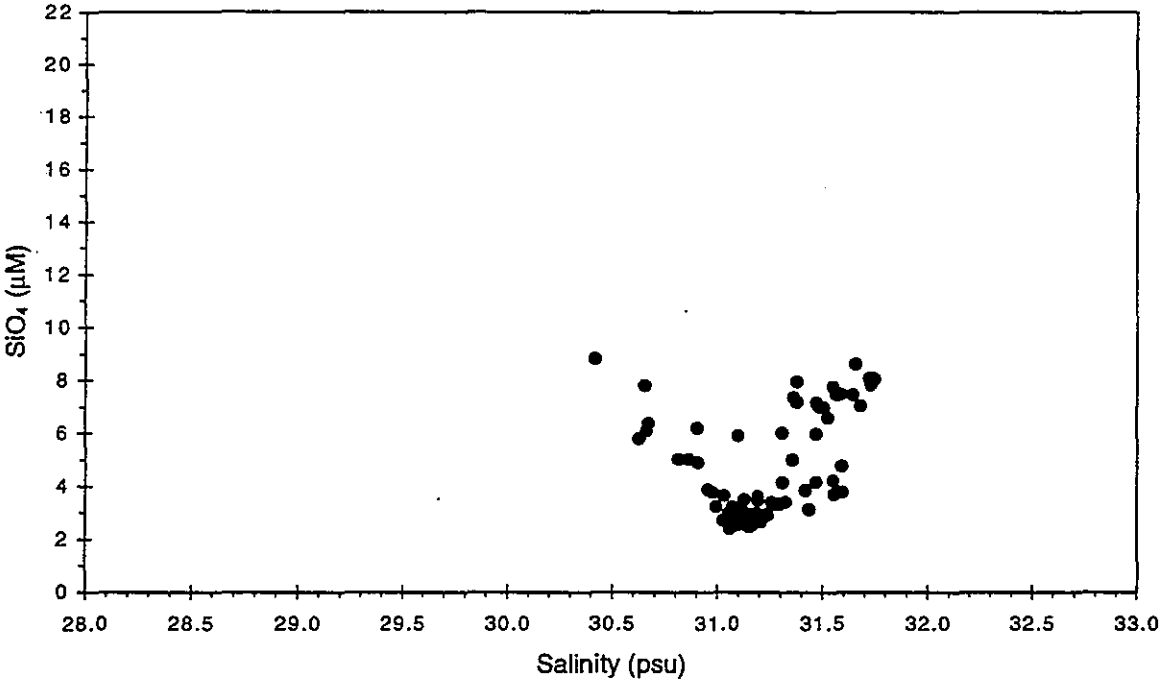
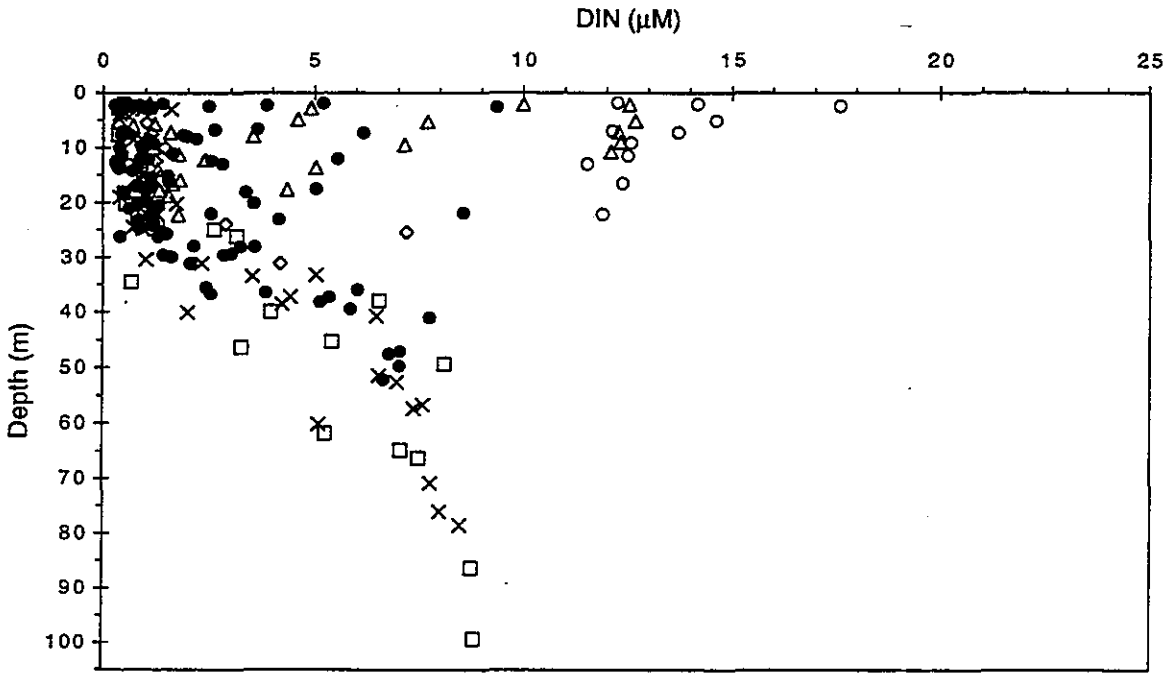


FIGURE 4-195
Nutrient vs. salinity plots for nearfield survey W9613, (Sep 96).



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-196
Depth vs. nutrient plots for farfield survey W9614, (Oct 96).

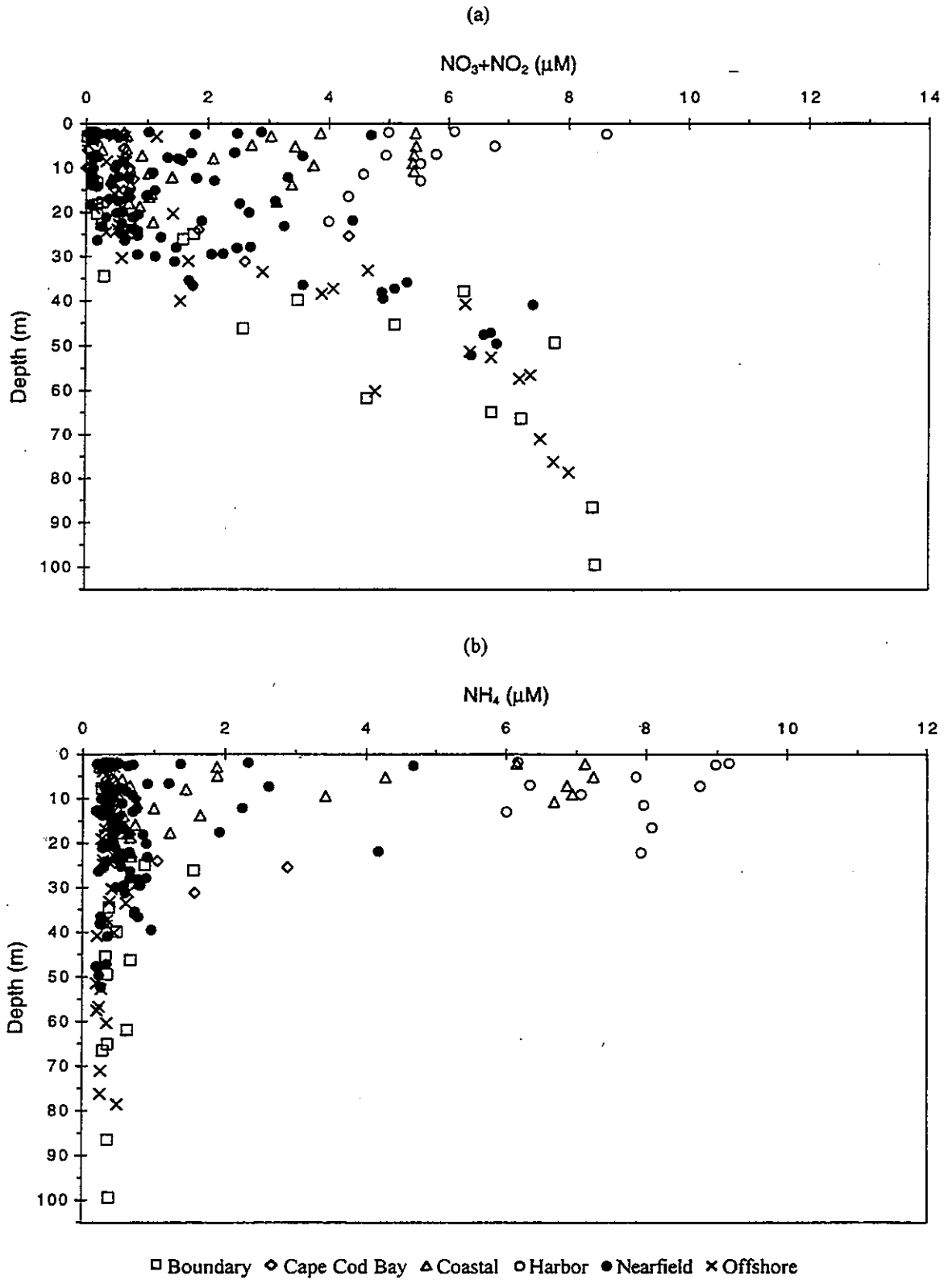


FIGURE 4-197
Depth vs. nutrient plots for farfield survey W9614, (Oct 96).

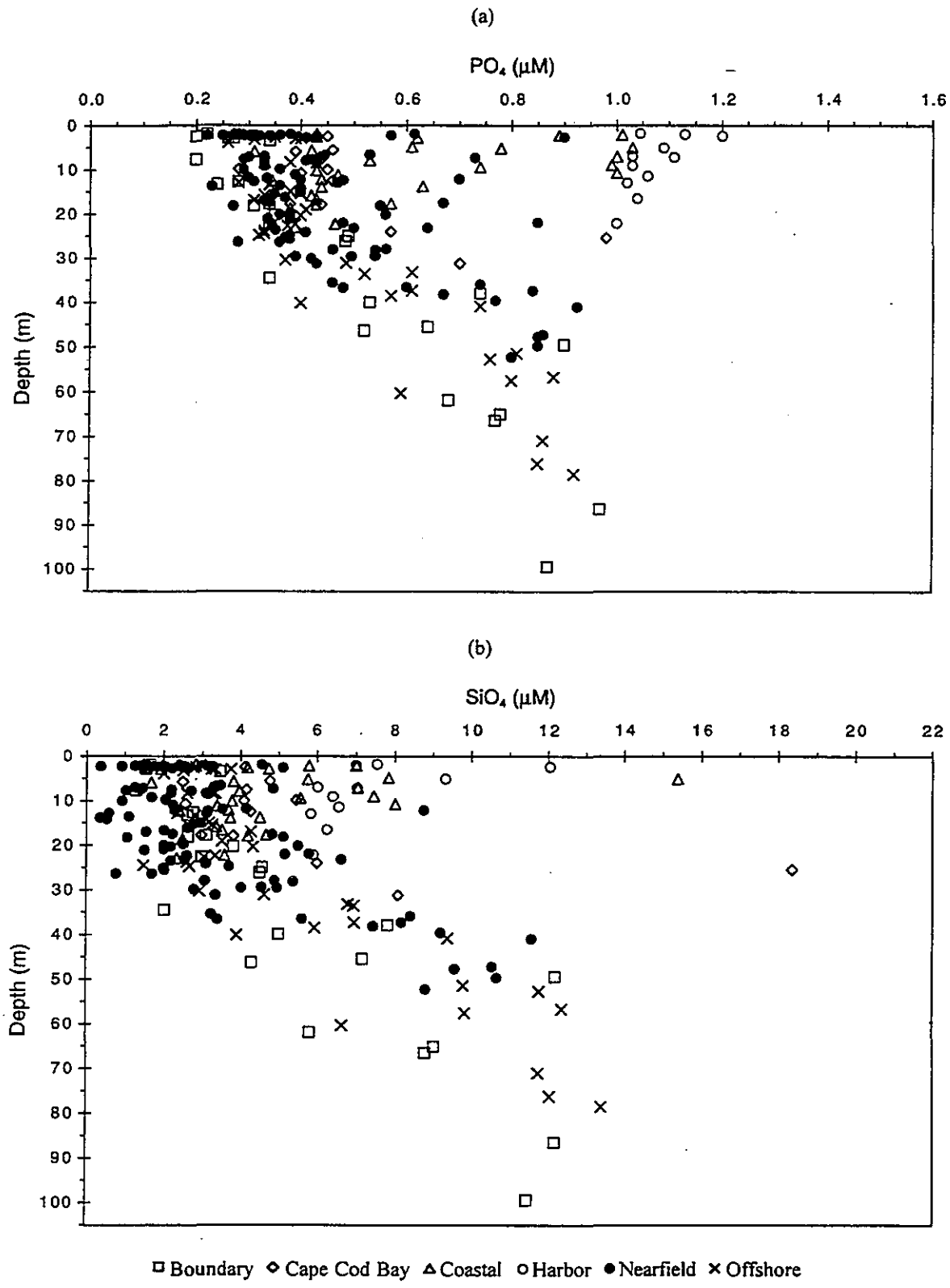


FIGURE 4-198
Depth vs. nutrient plots for farfield survey W9614, (Oct 96).

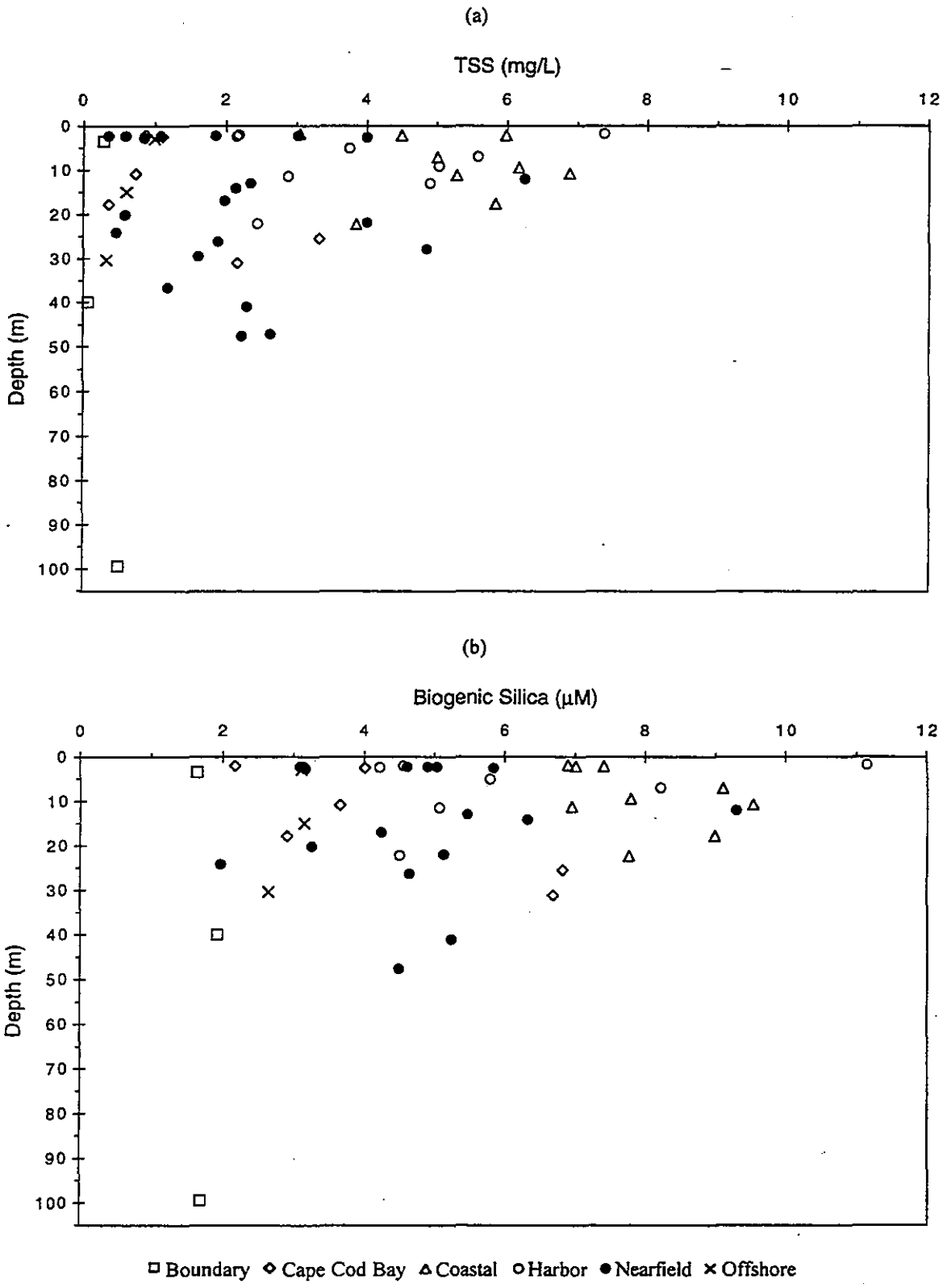


FIGURE 4-199
Depth vs. nutrient plots for farfield survey W9614, (Oct 96).

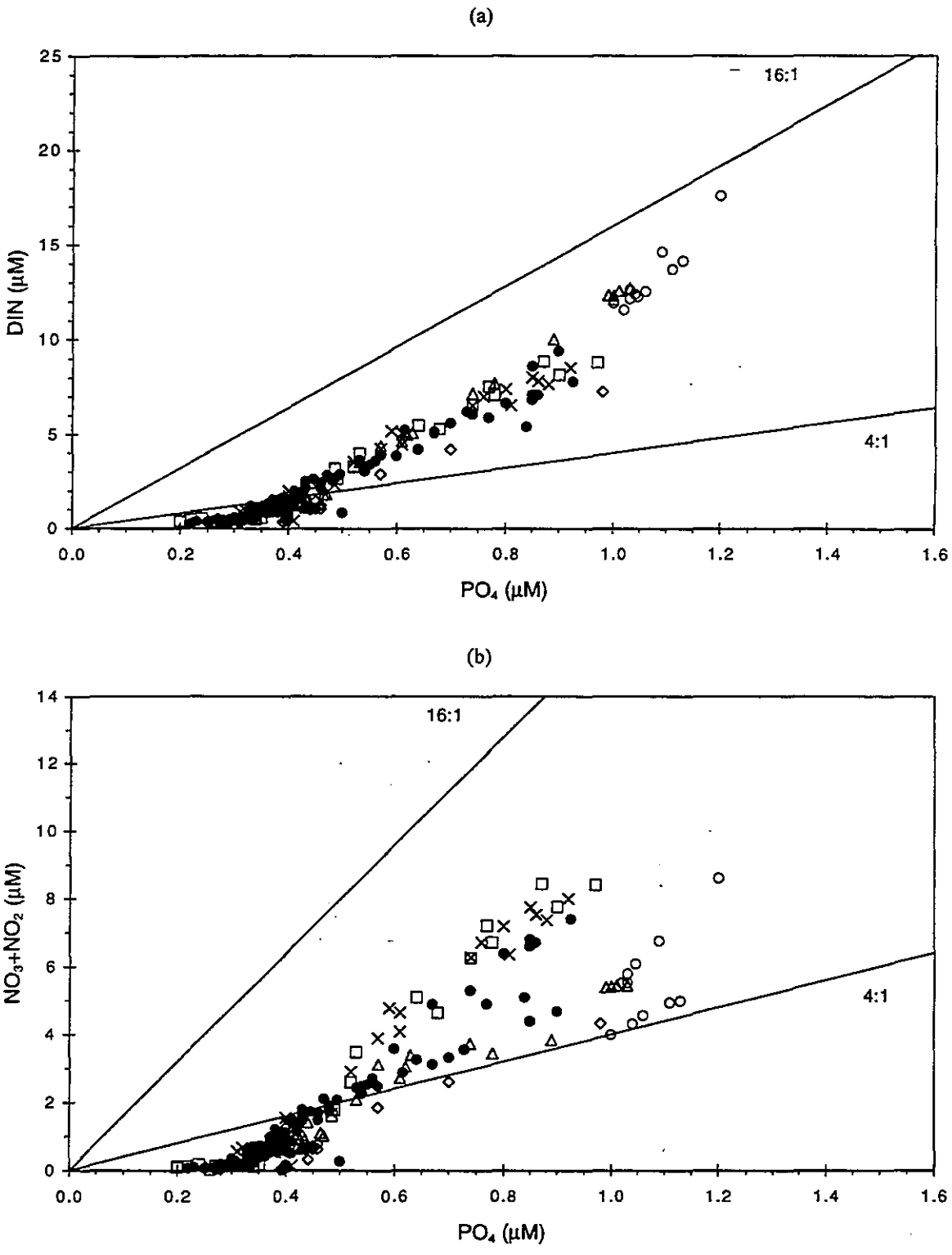


FIGURE 4-200
Nutrient vs. nutrient plots for farfield survey W9614, (Oct 96).

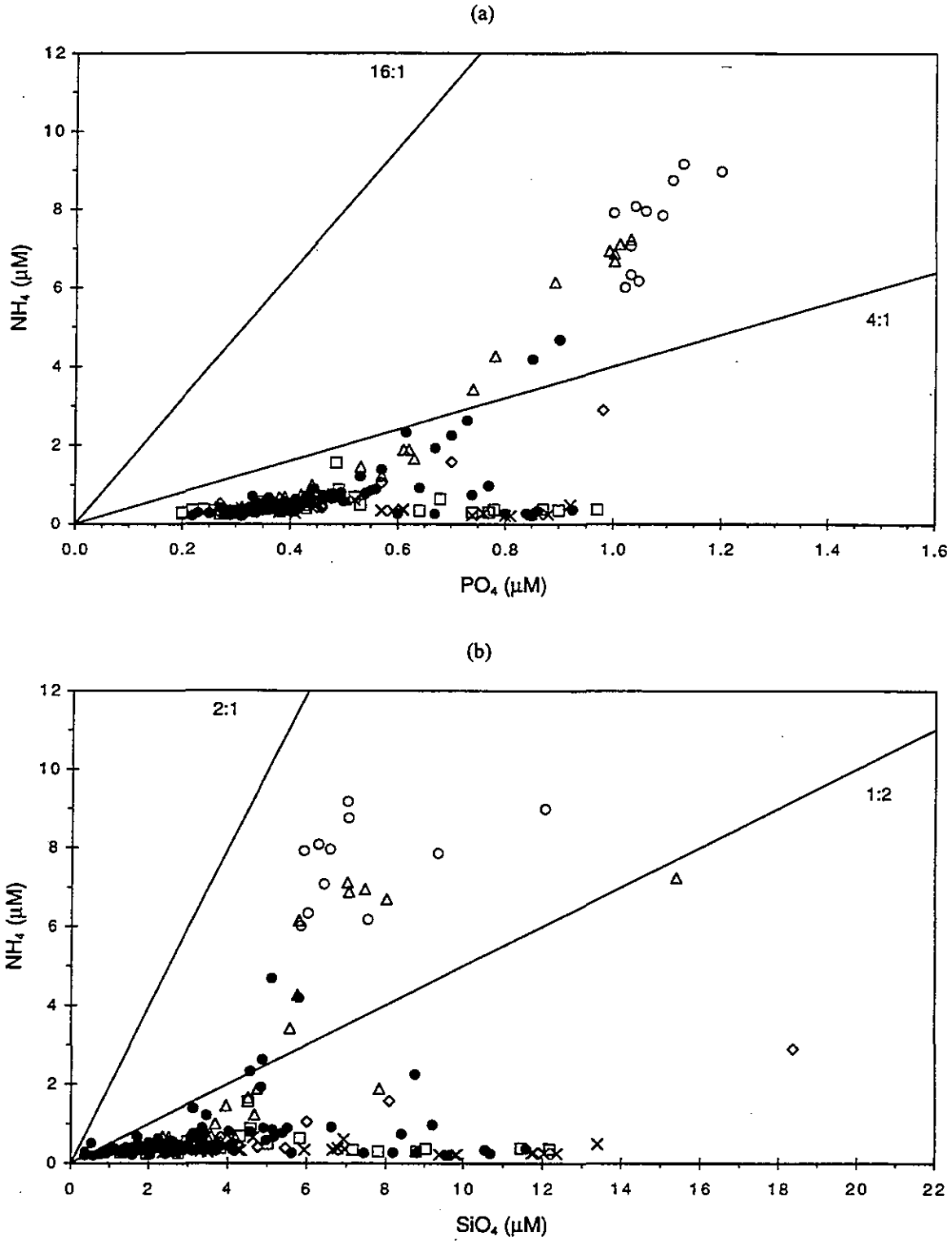


FIGURE 4-201
Nutrient vs. nutrient plots for farfield survey W9614, (Oct 96).

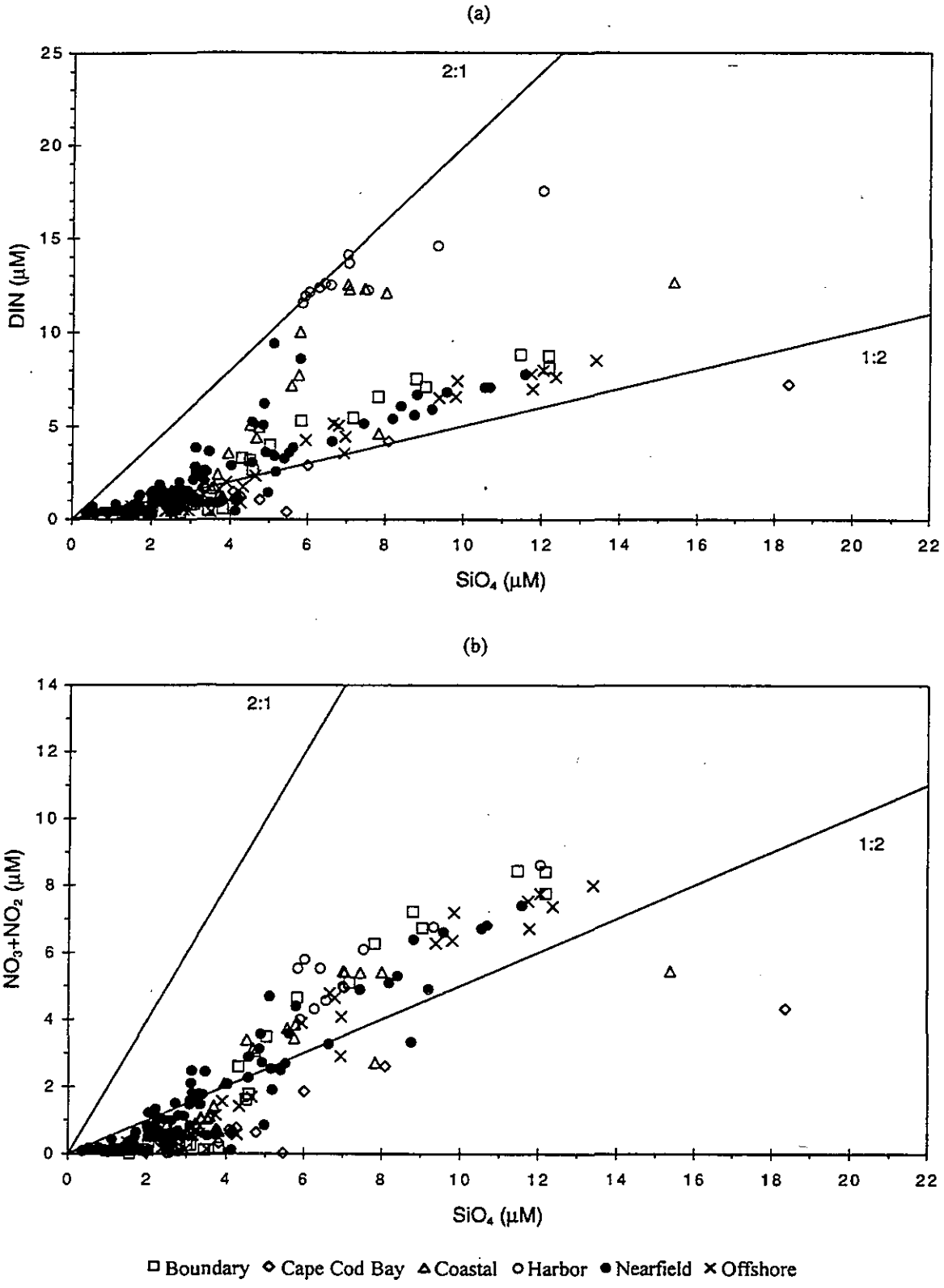


FIGURE 4-202
Nutrient vs. nutrient plots for farfield survey W9614, (Oct 96).

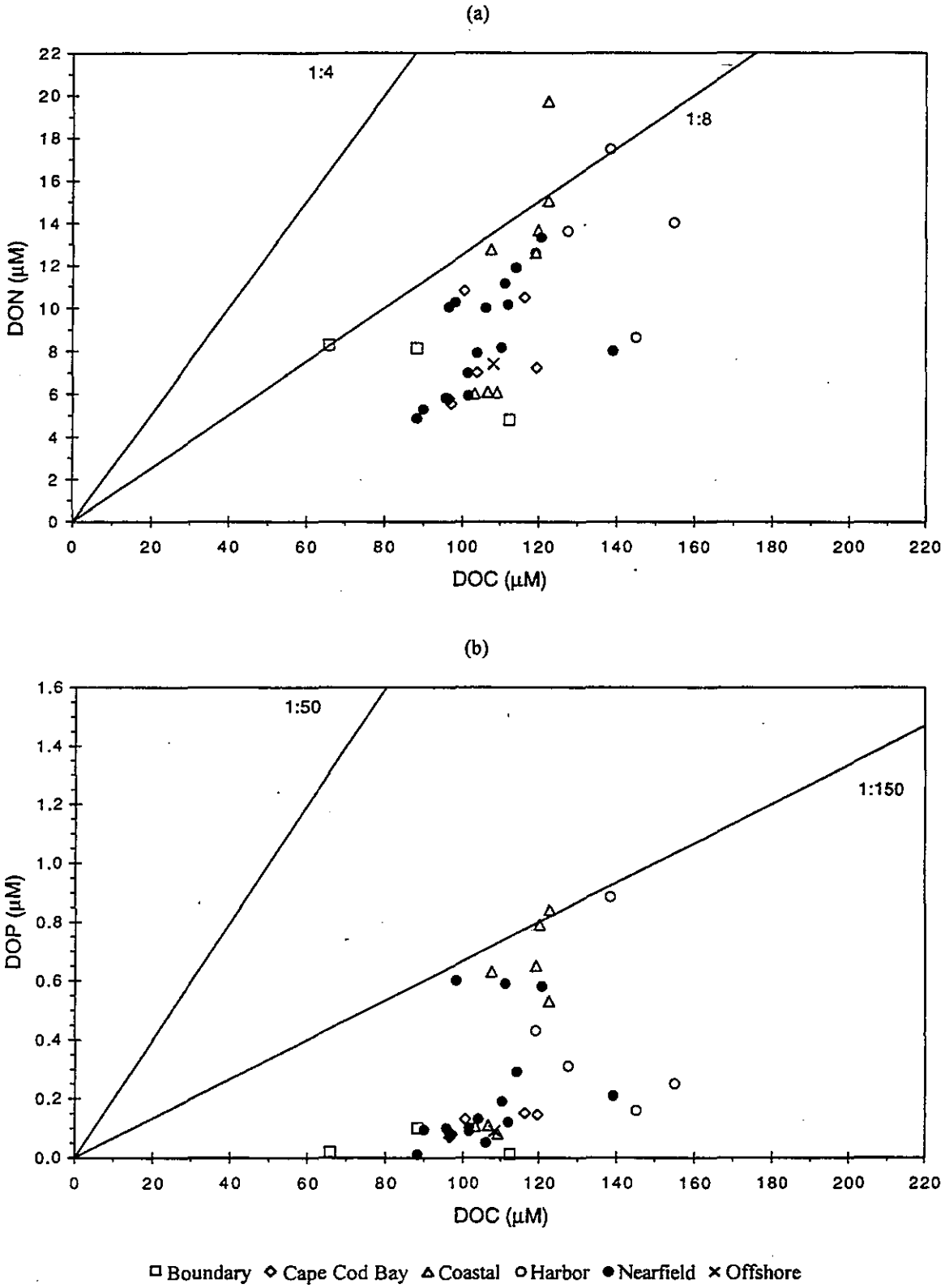


FIGURE 4-203
Nutrient vs. nutrient plots for farfield survey W9614, (Oct 96).

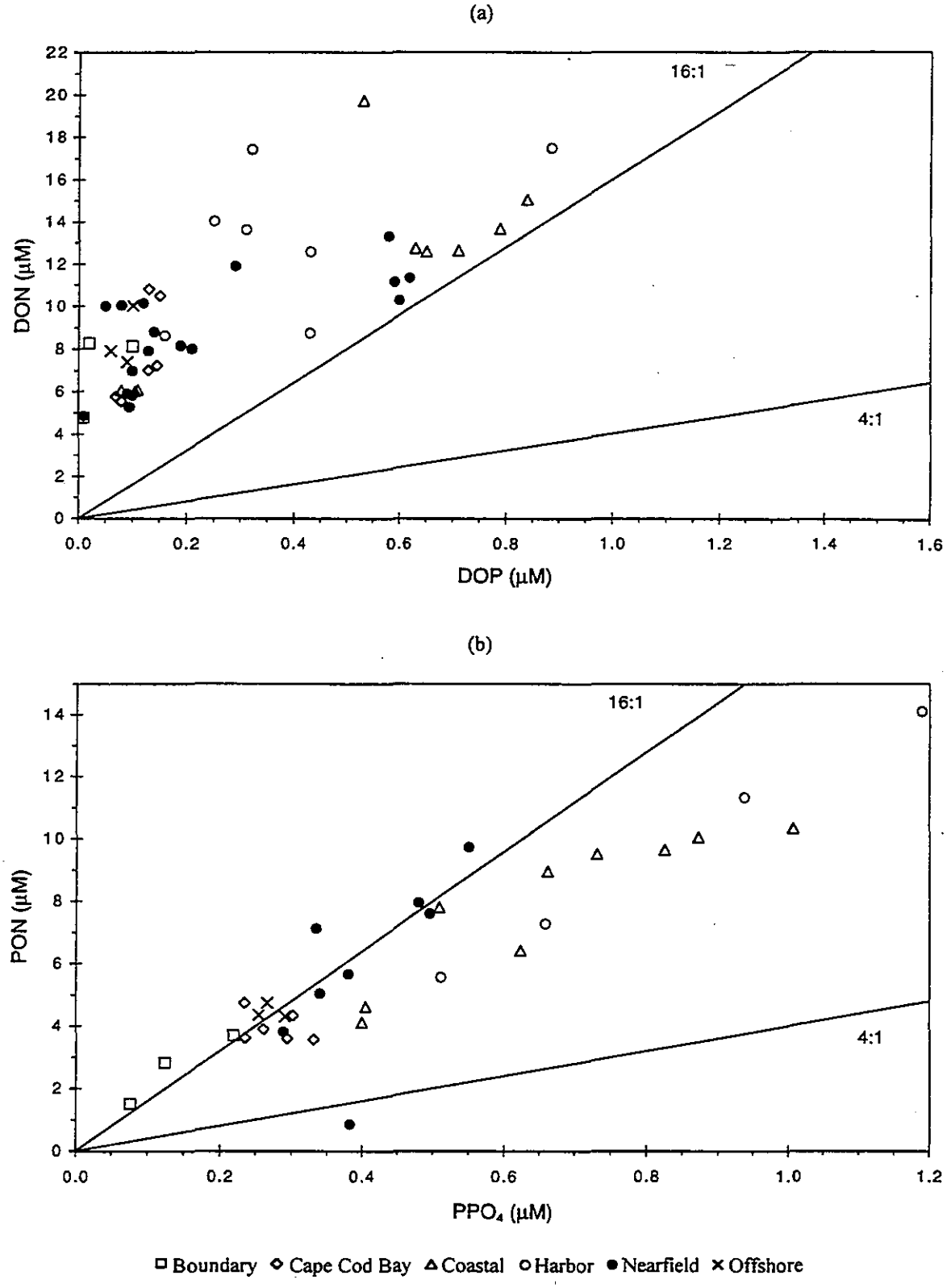


FIGURE 4-204
Nutrient vs. nutrient plots for farfield survey W9614, (Oct 96).

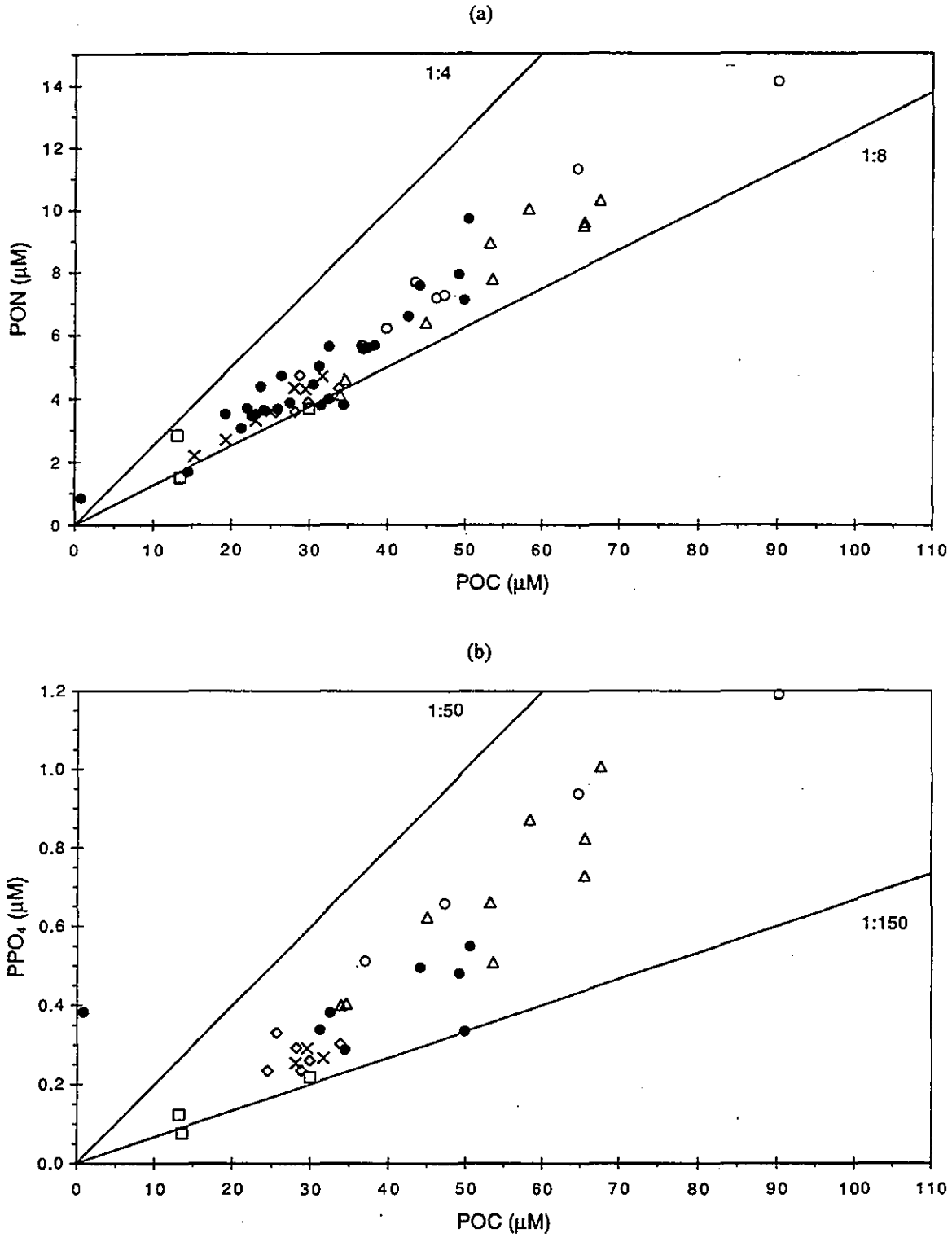


FIGURE 4-205
Nutrient vs. nutrient plots for farfield survey W9614, (Oct 96).

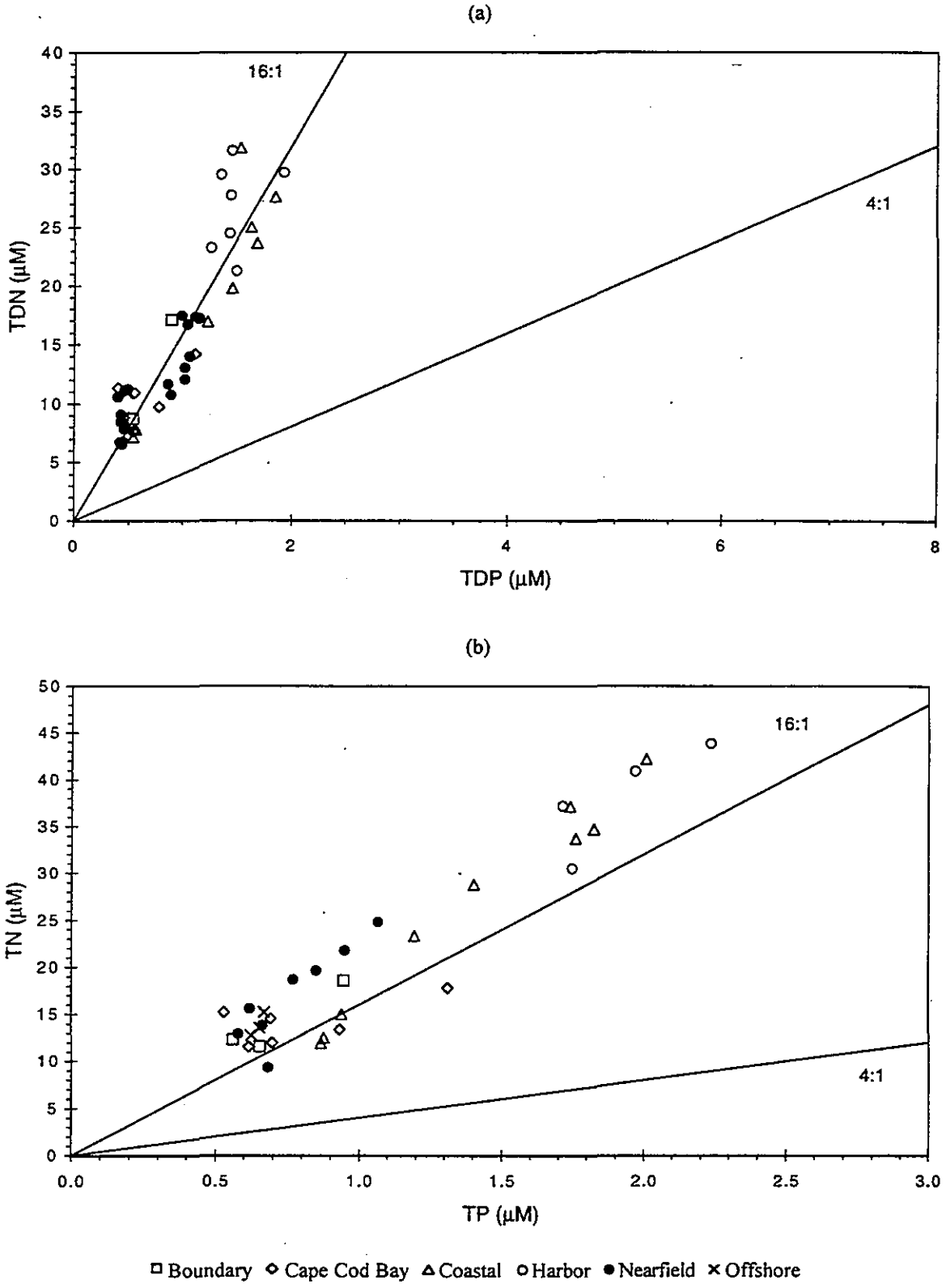


FIGURE 4-206
Nutrient vs. nutrient plots for farfield survey W9614, (Oct 96).

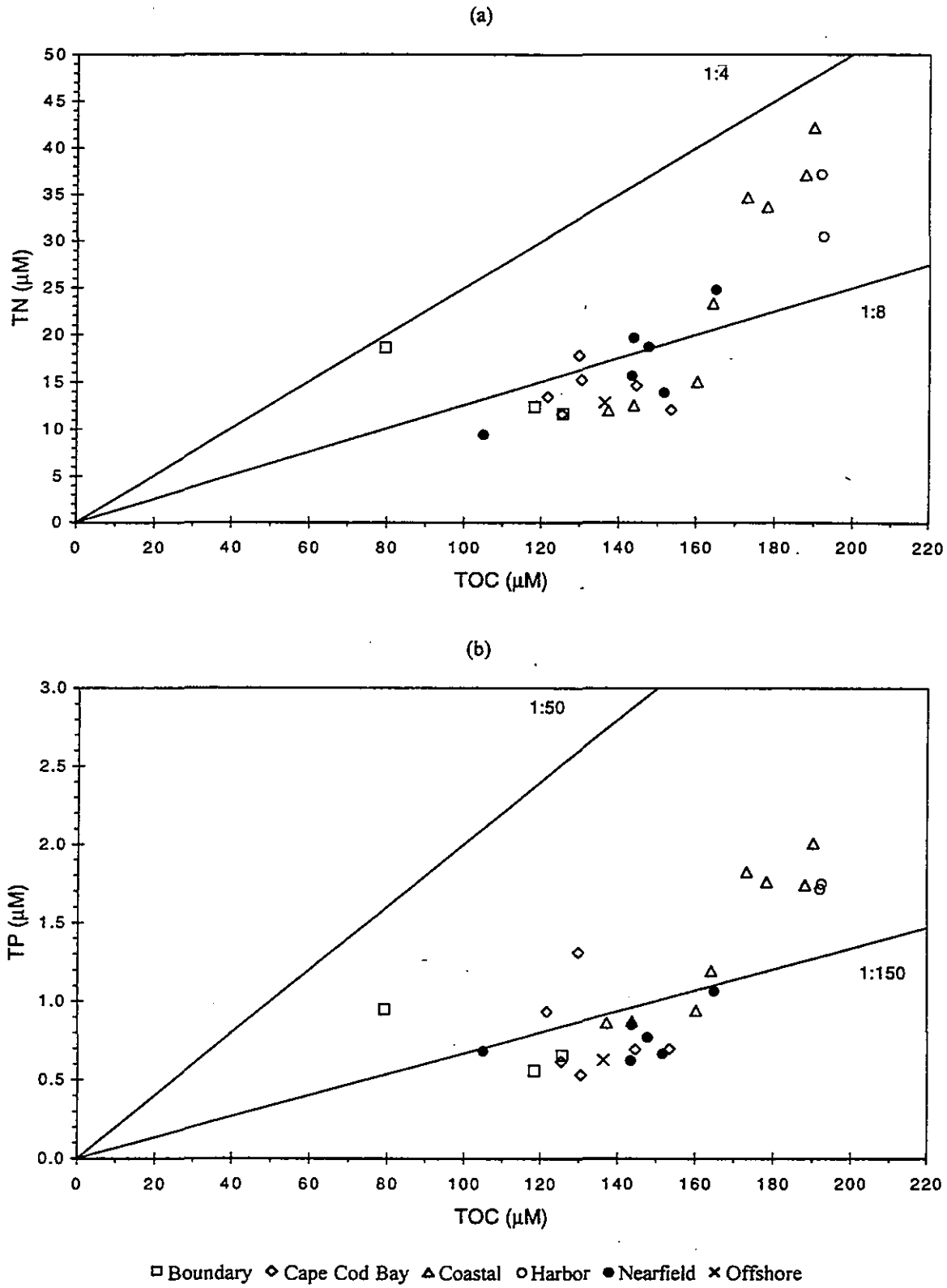


FIGURE 4-207
Nutrient vs. nutrient plots for farfield survey W9614, (Oct 96).

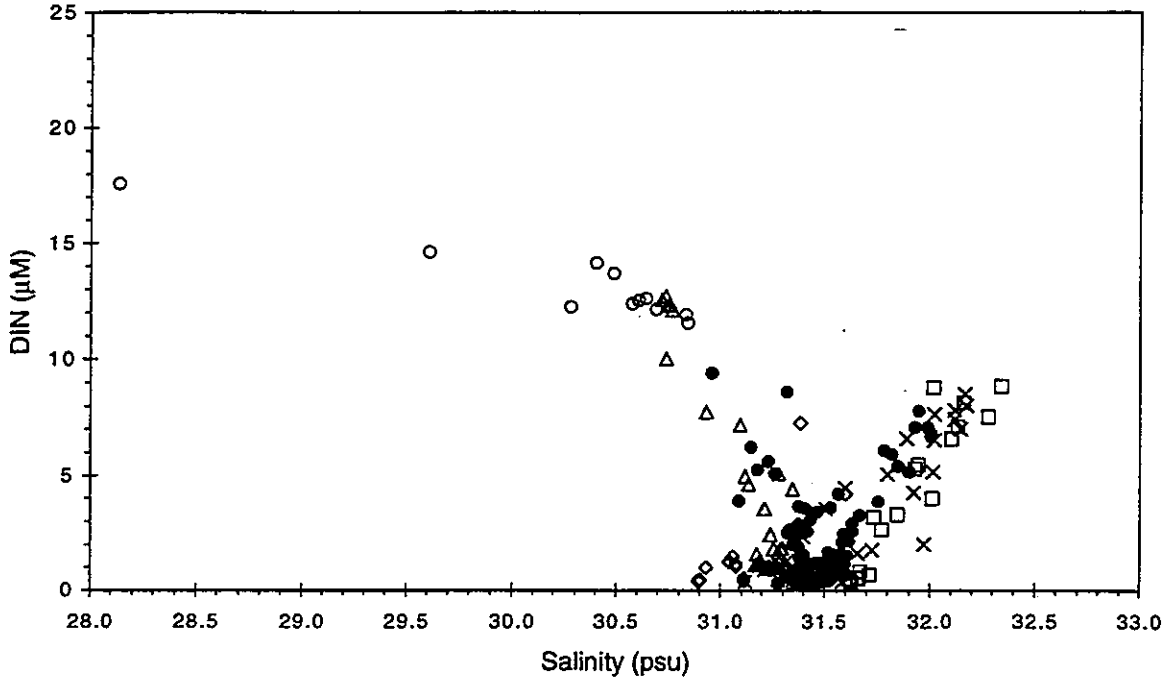
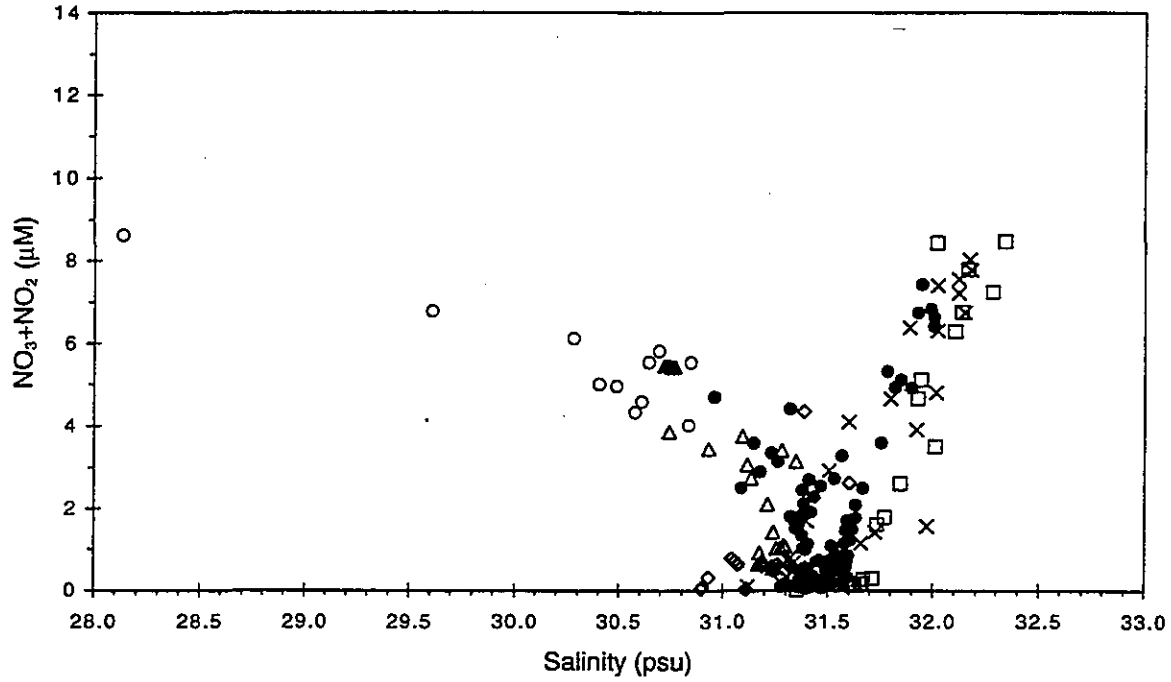
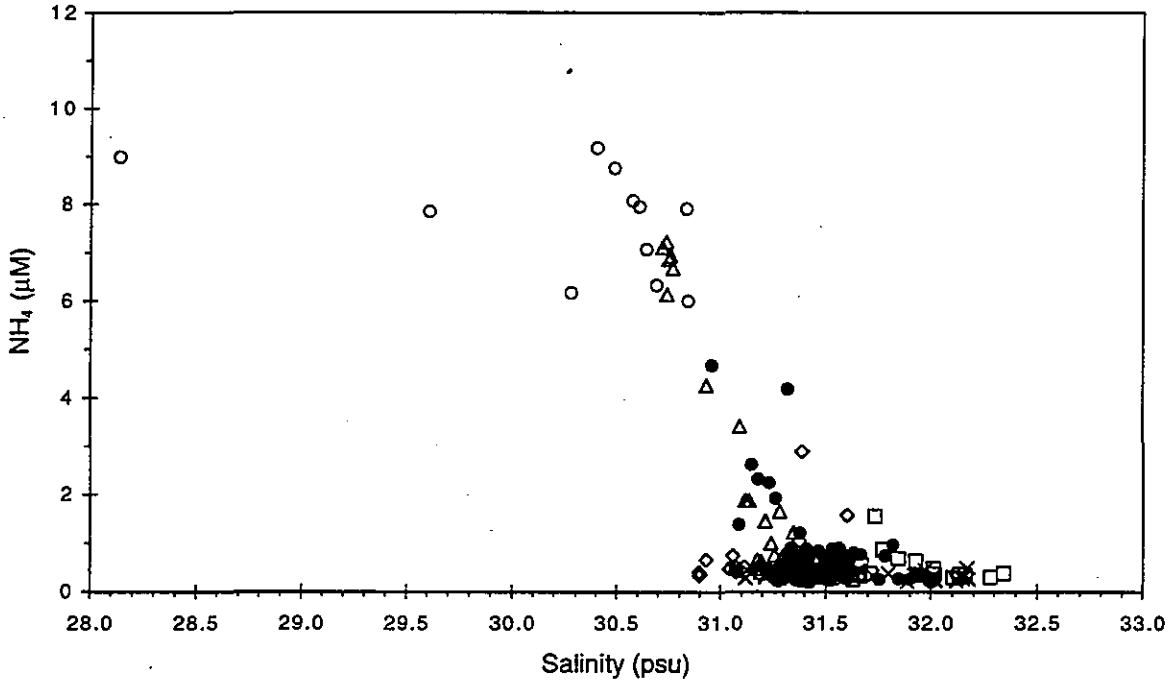


FIGURE 4-208
Nutrient vs. salinity plots for farfield survey W9614, (Oct 96).

(a)



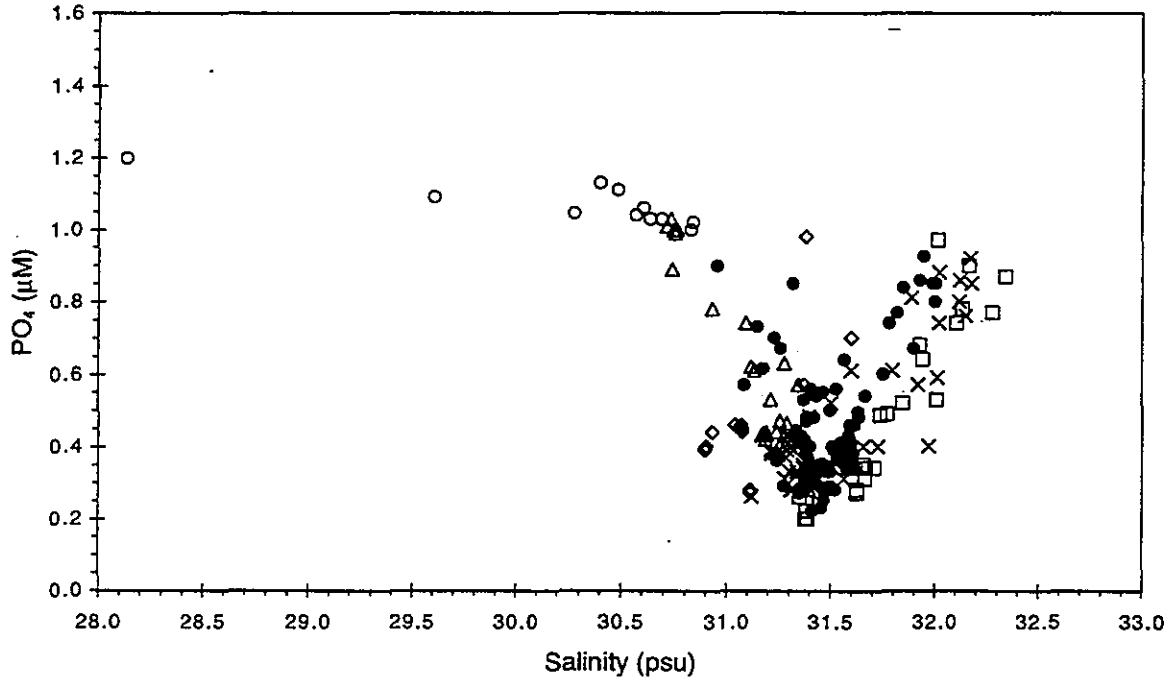
(b)



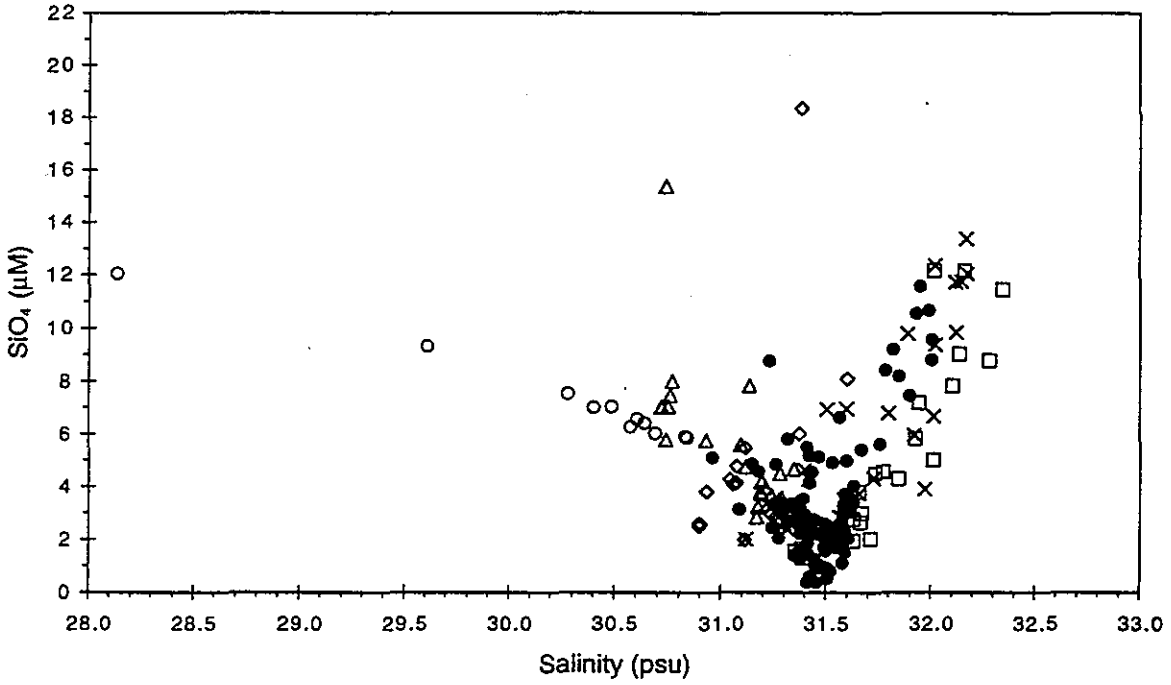
□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-209
Nutrient vs. salinity plots for farfield survey W9614, (Oct 96).

(a)



(b)



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-210
Nutrient vs. salinity plots for farfield survey W9614, (Oct 96).

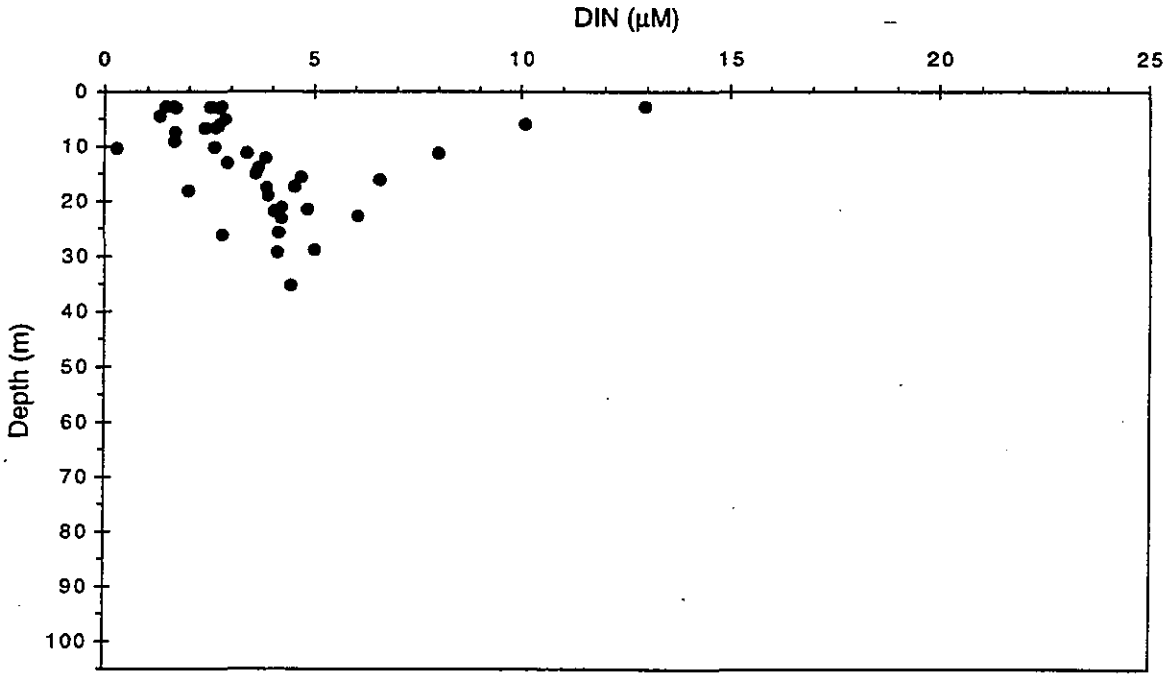


FIGURE 4-211
Depth vs. nutrient plots for nearfield survey W9615, (Oct 96).

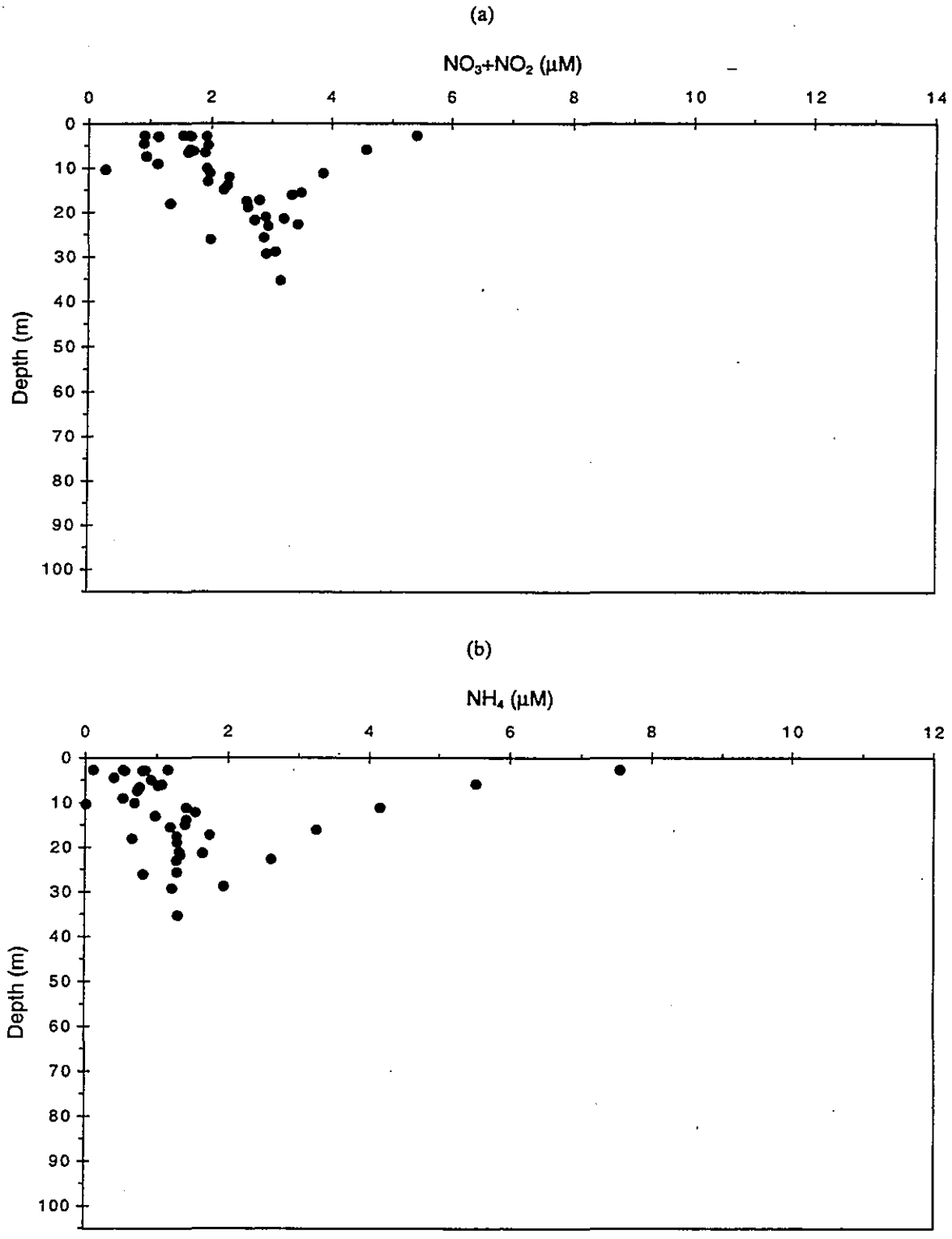


FIGURE 4-212
Depth vs. nutrient plots for nearfield survey W9615, (Oct 96).

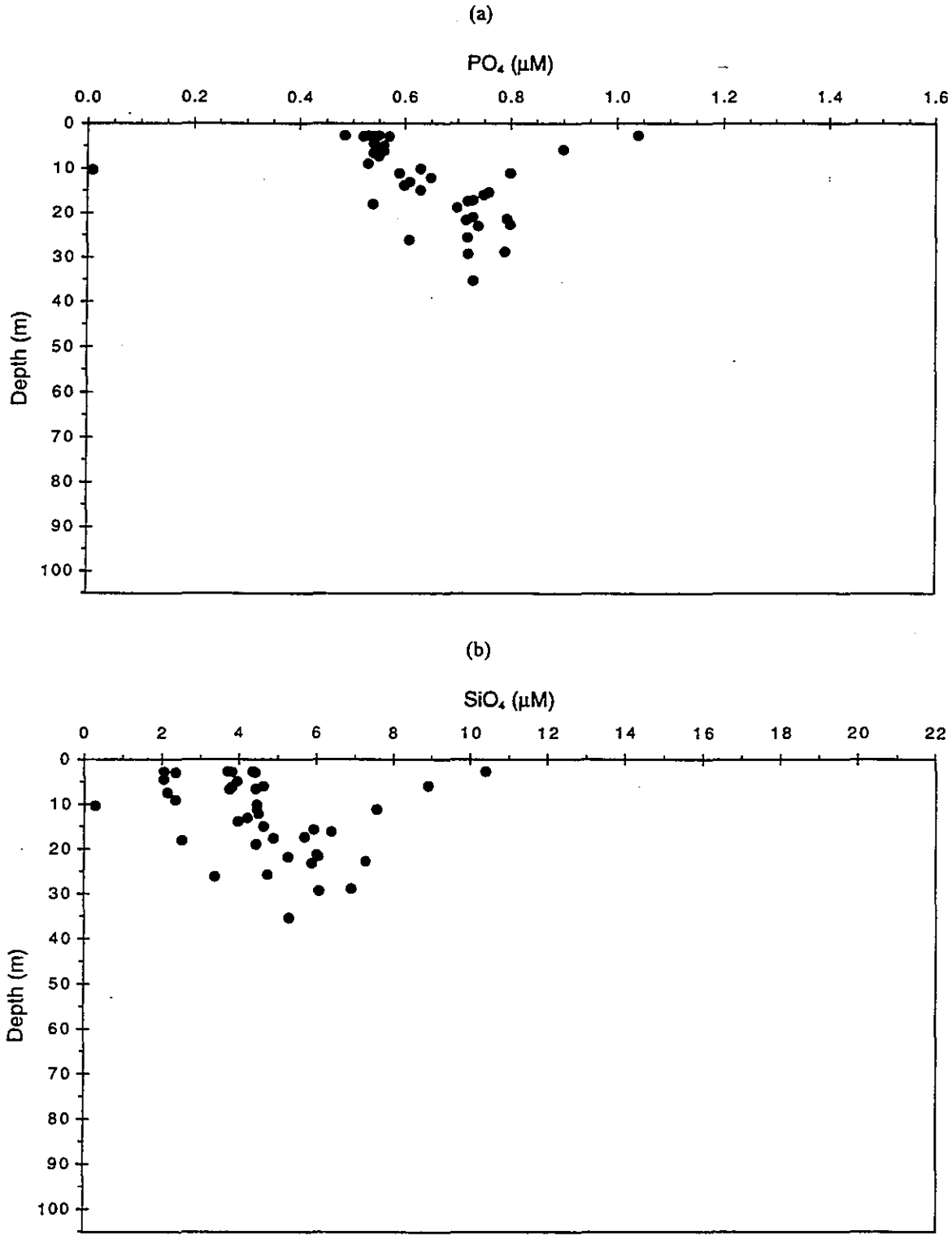


FIGURE 4-213
Depth vs. nutrient plots for nearfield survey W9615, (Oct 96).

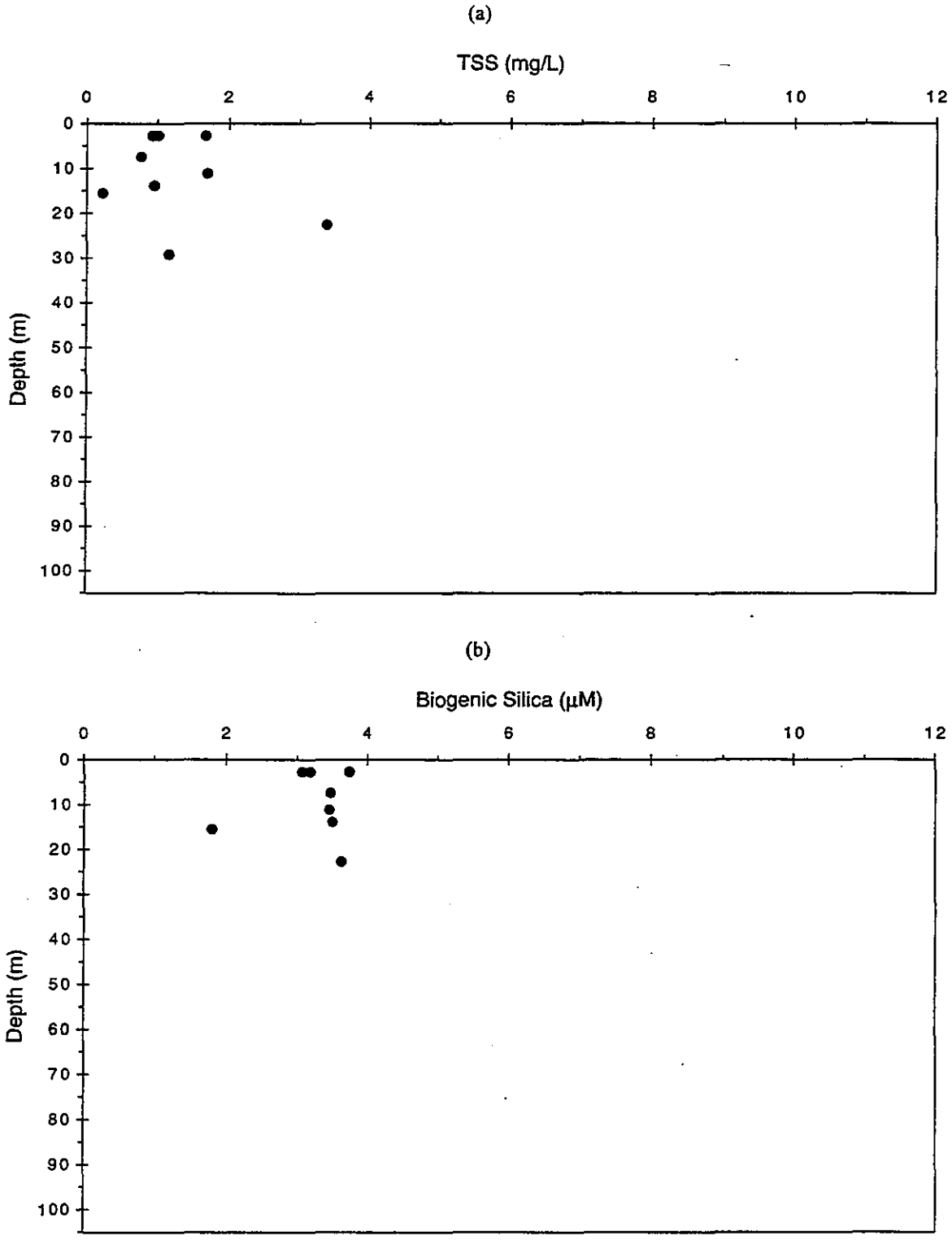


FIGURE 4-214
Depth vs. nutrient plots for nearfield survey W9615, (Oct 96).

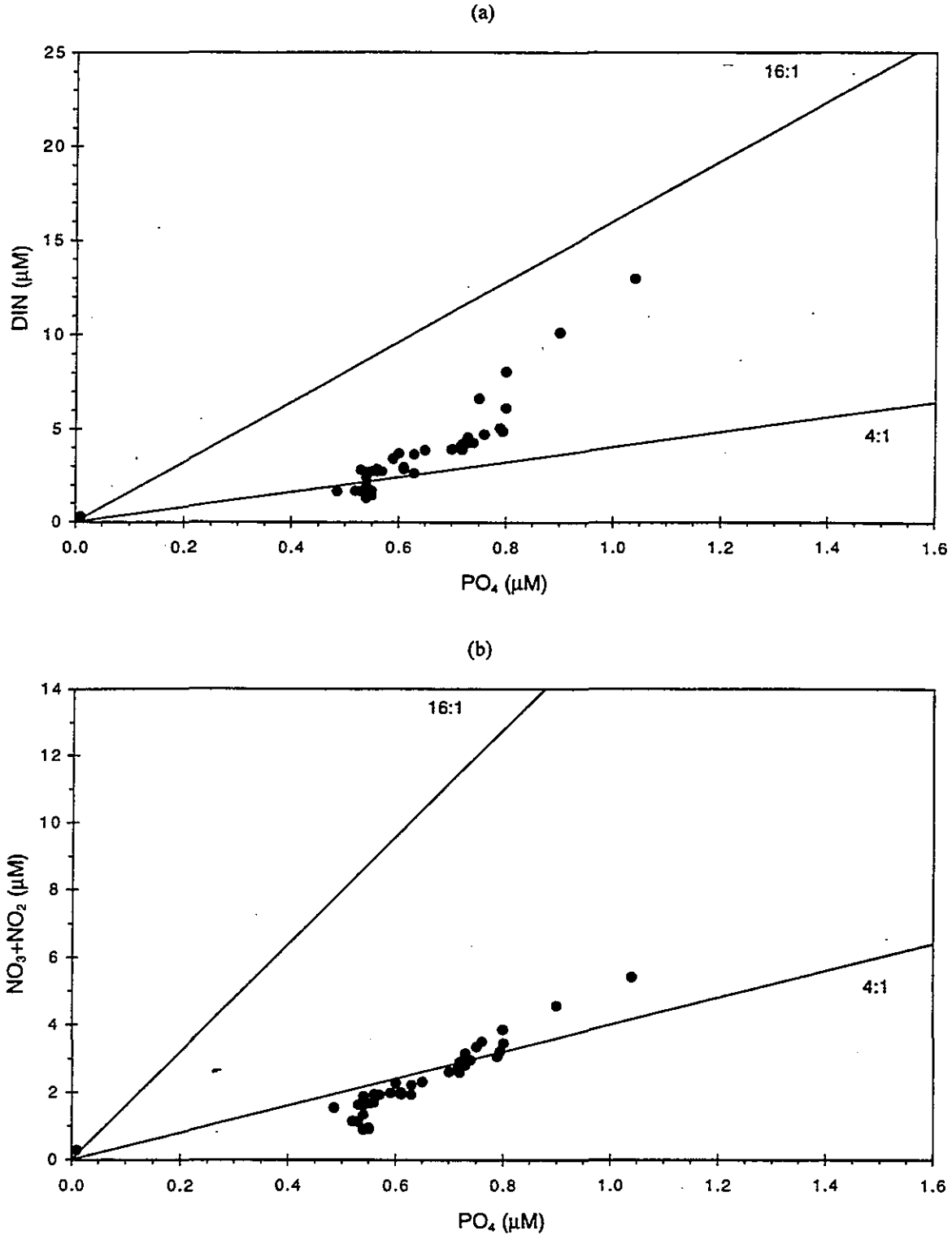


FIGURE 4-215
Nutrient vs. nutrient plots for nearfield survey W9615, (Oct 96).

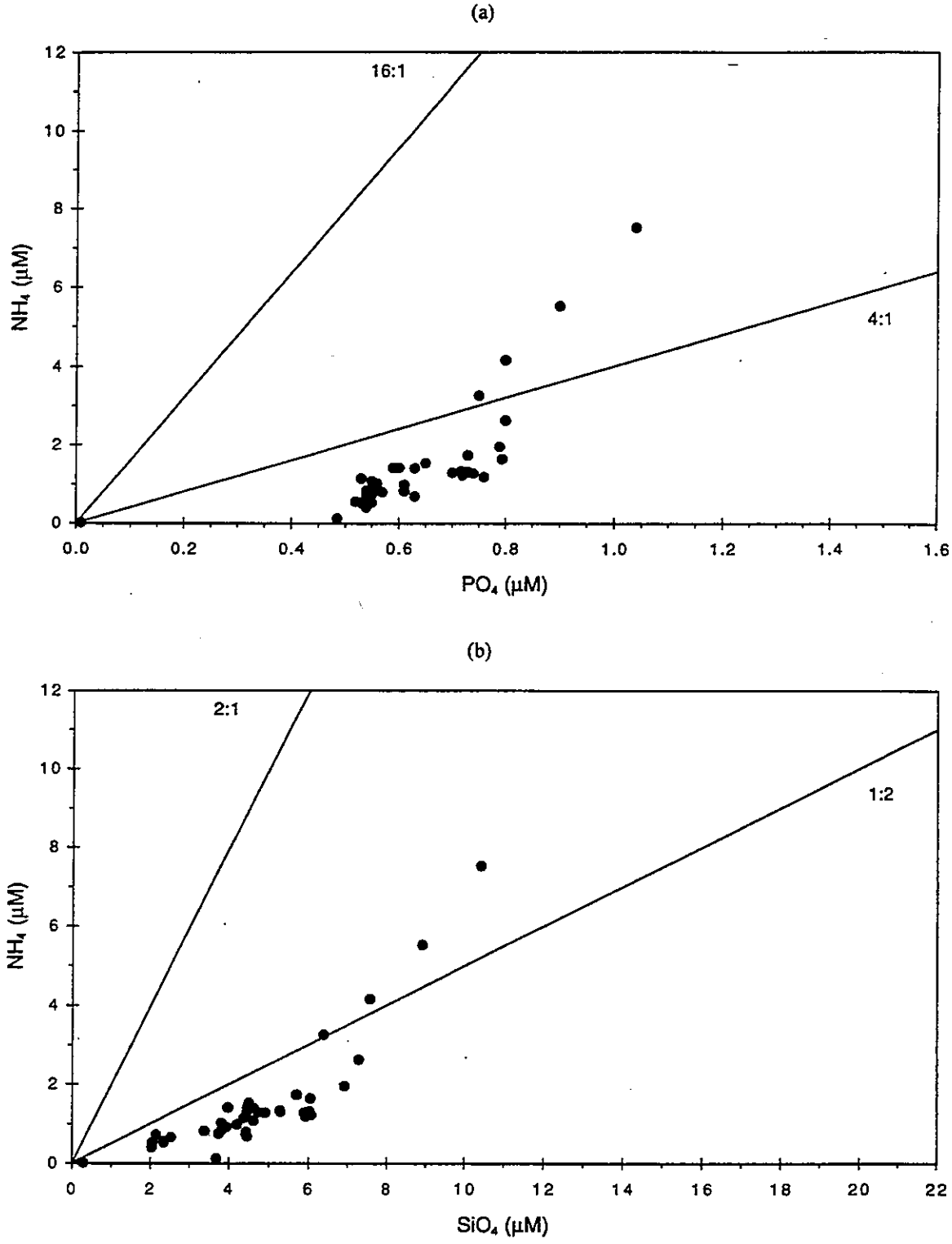


FIGURE 4-216
Nutrient vs. nutrient plots for nearfield survey W9615, (Oct 96).

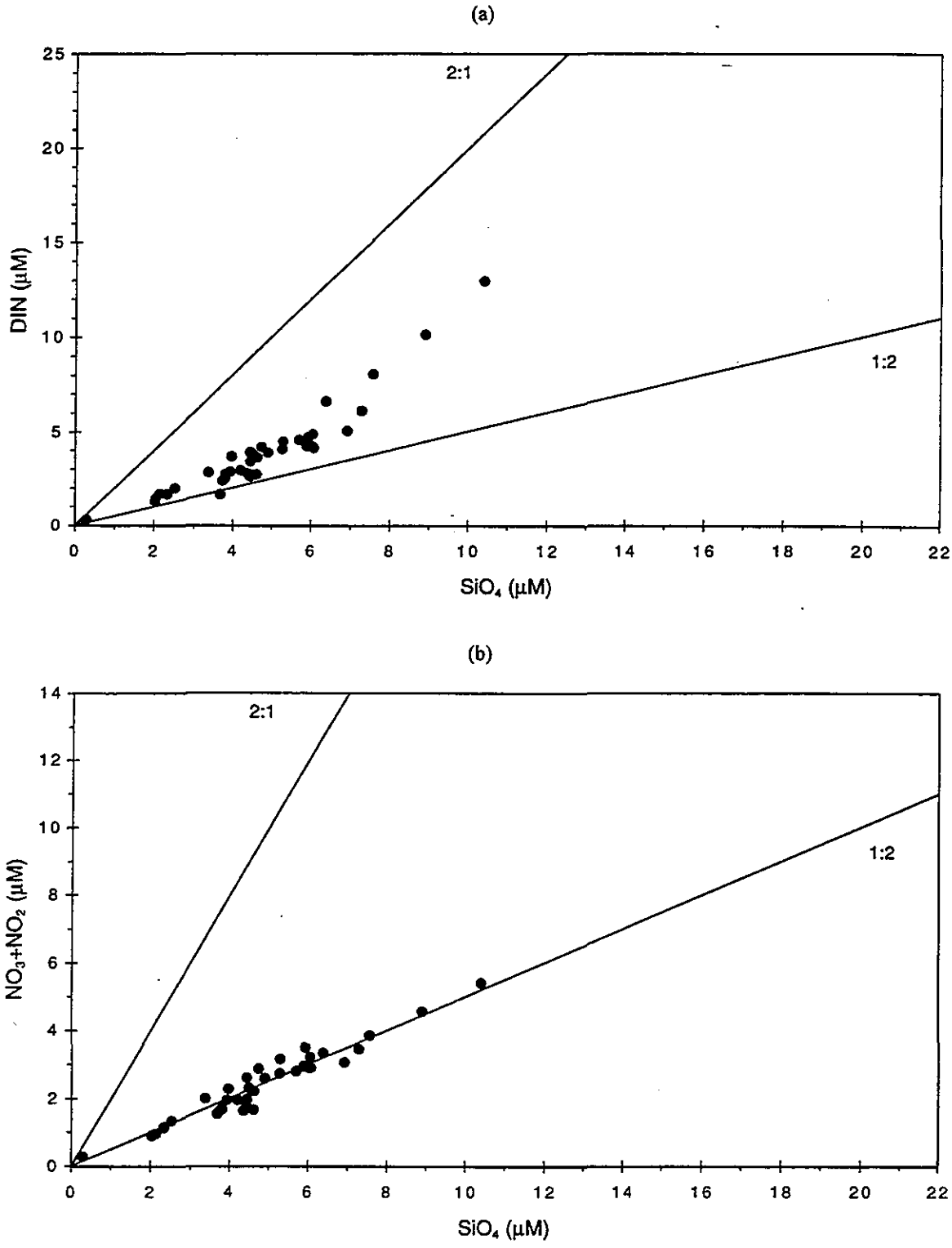


FIGURE 4-217
Nutrient vs. nutrient plots for nearfield survey W9615, (Oct 96).

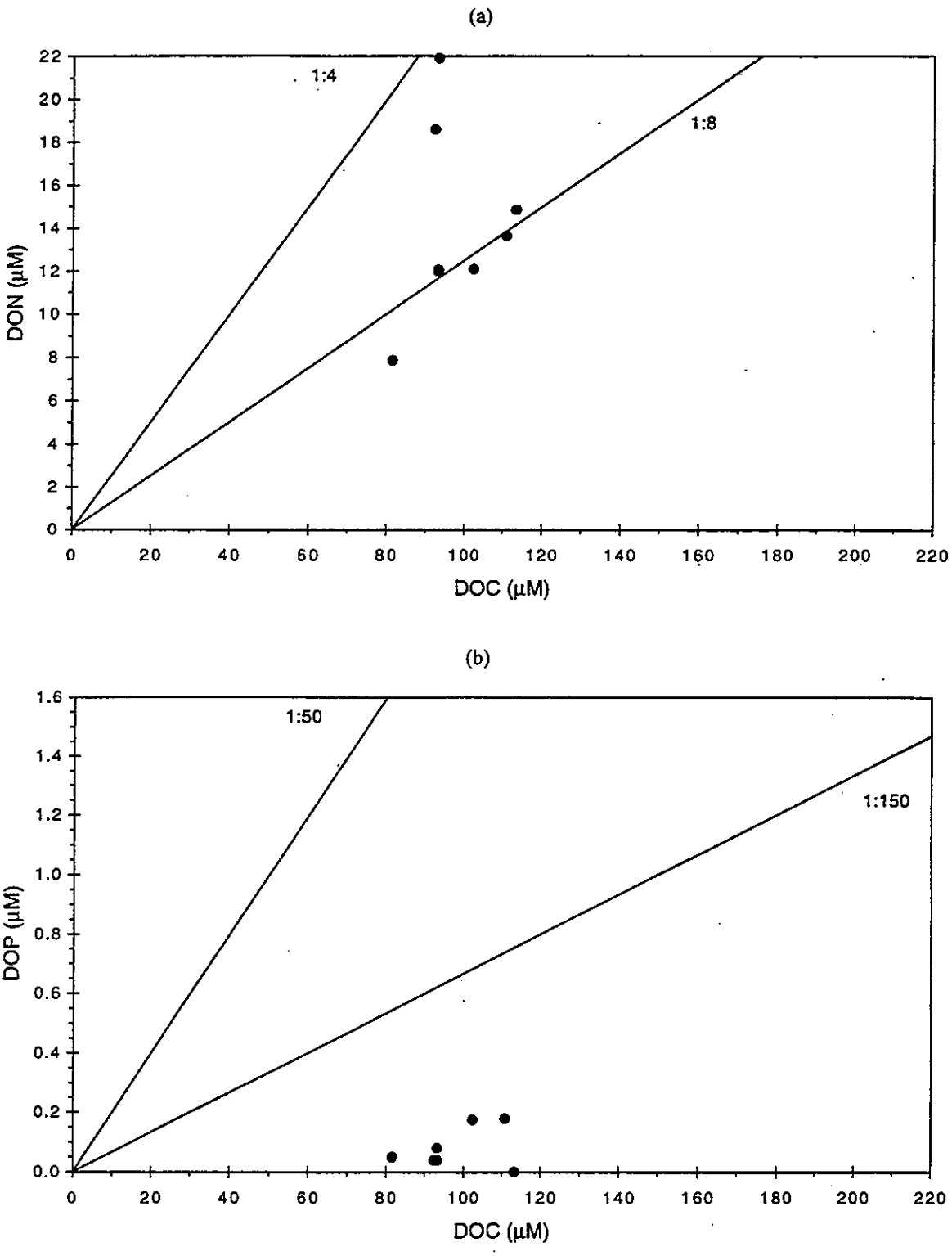
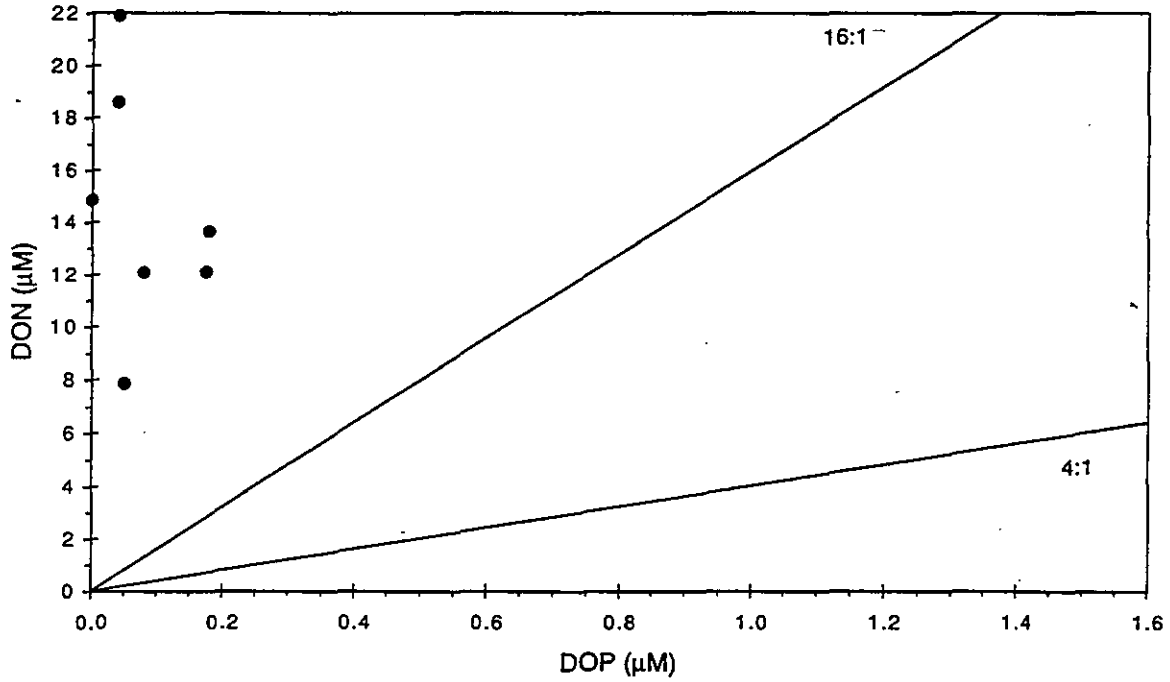


FIGURE 4-218
Nutrient vs. nutrient plots for nearfield survey W9615, (Oct 96).

(a)



(b)

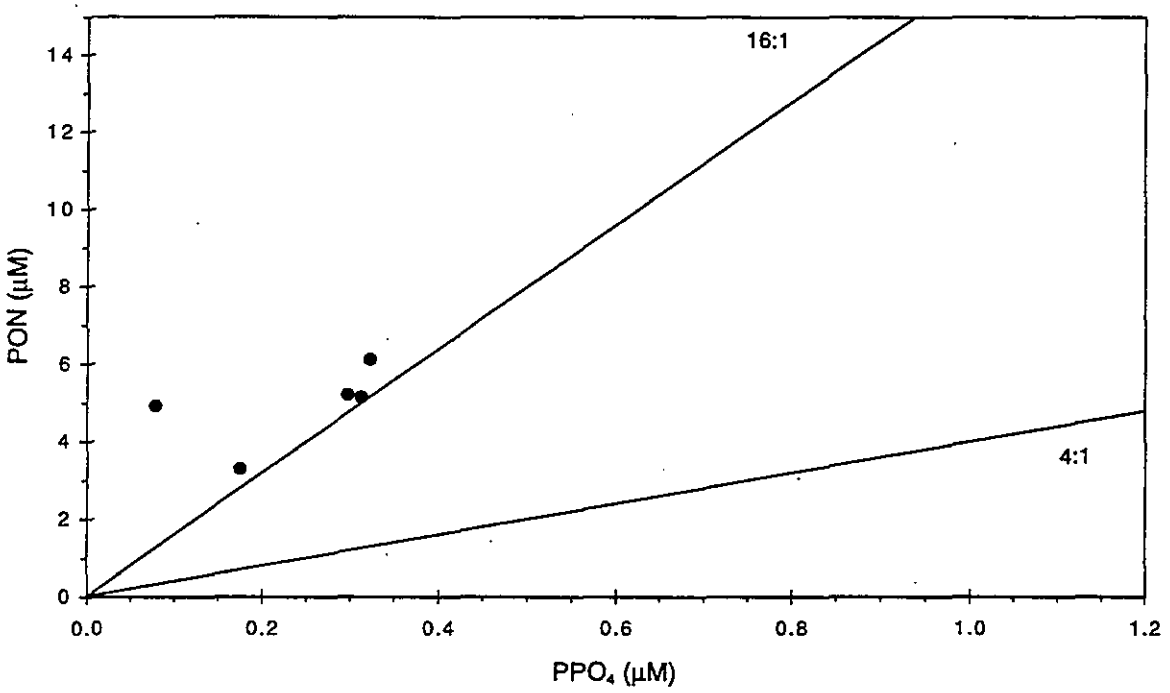


FIGURE 4-219
Nutrient vs. nutrient plots for nearfield survey W9615, (Oct 96).

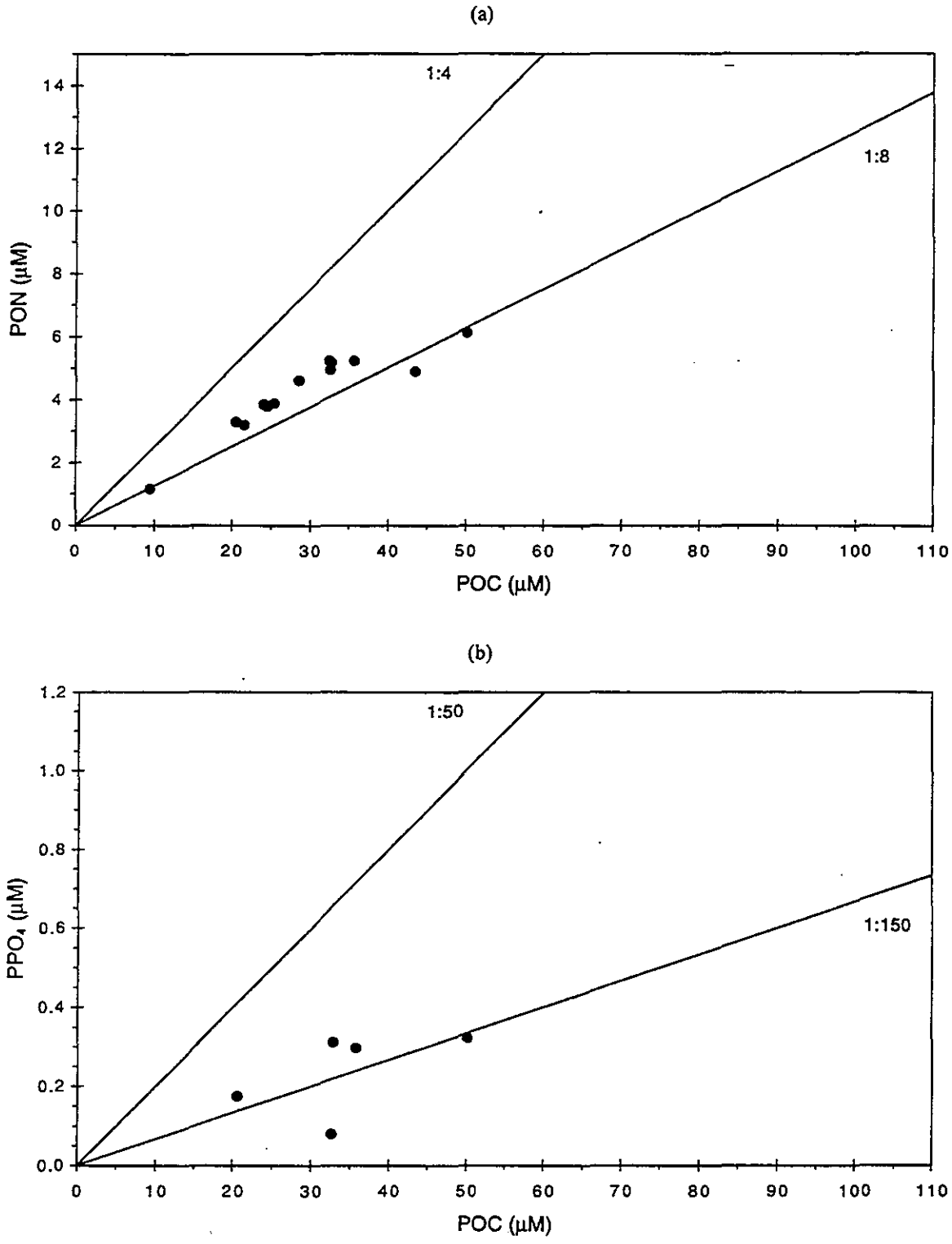


FIGURE 4-220
Nutrient vs. nutrient plots for nearfield survey W9615, (Oct 96).

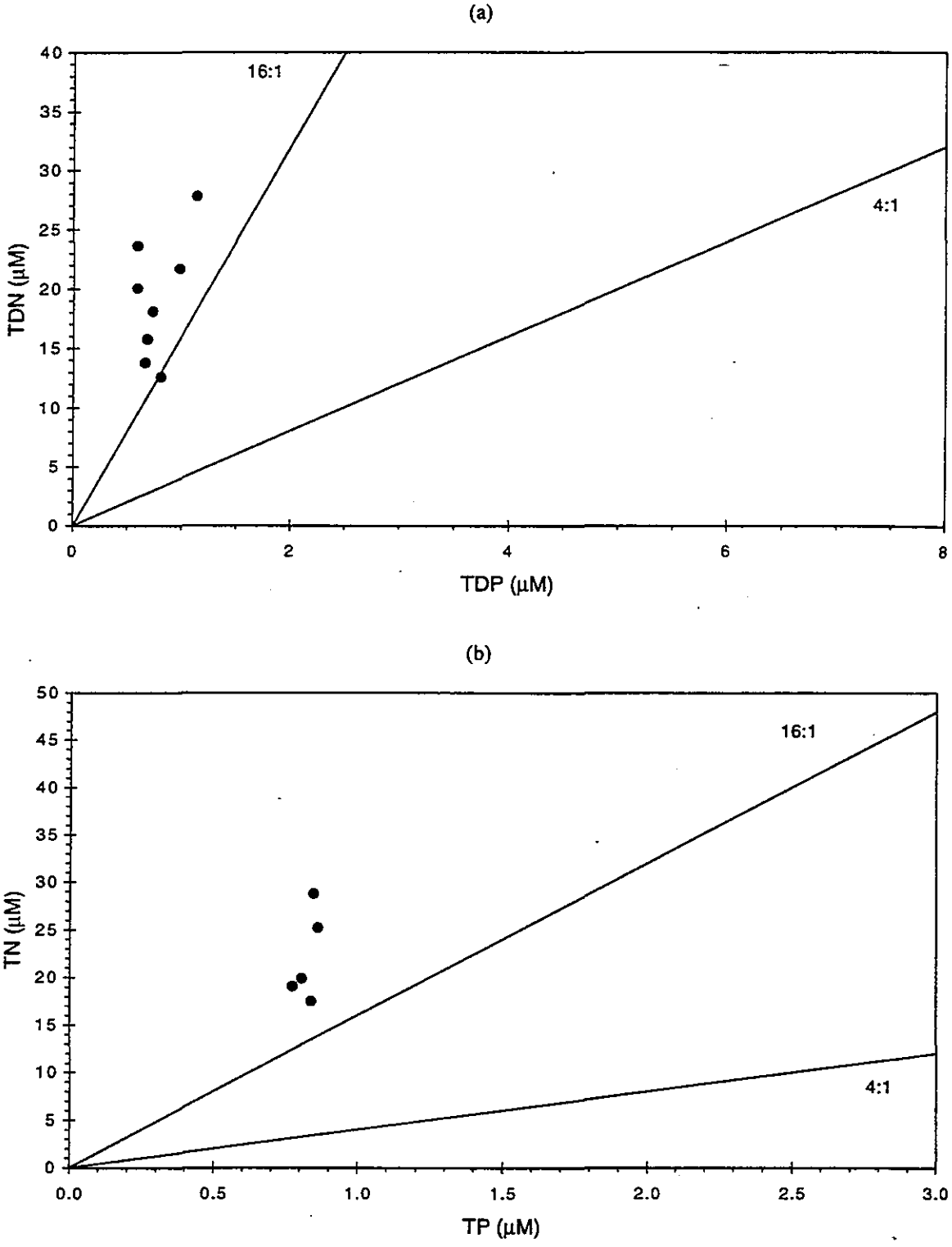
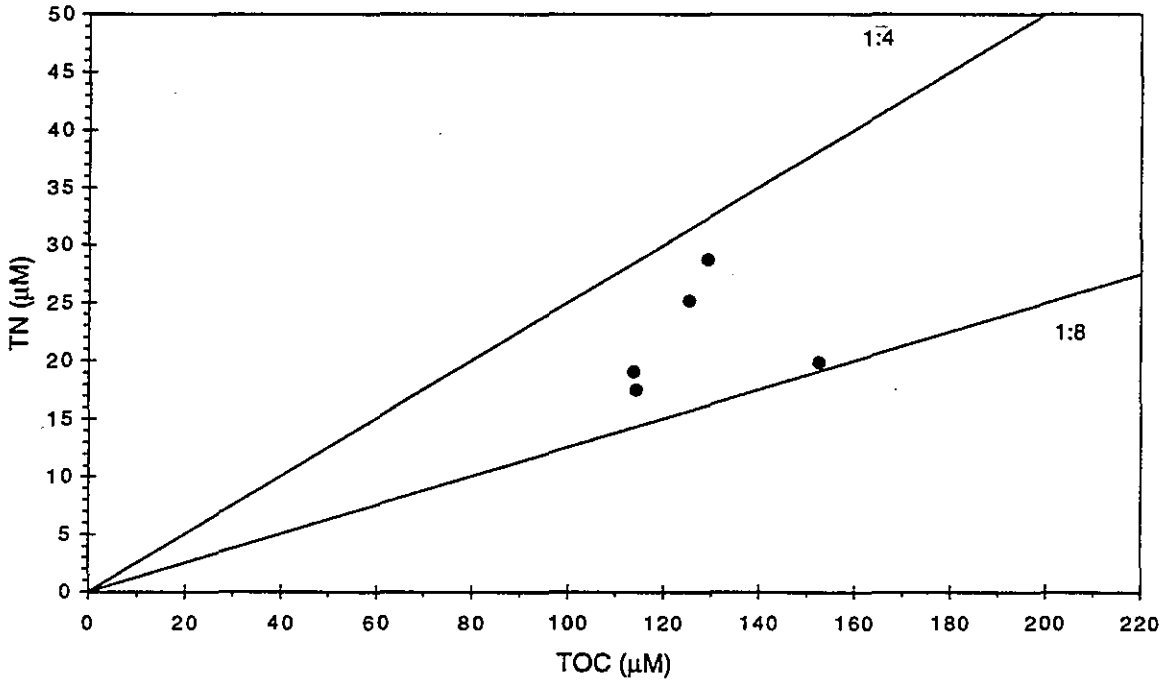


FIGURE 4-221
Nutrient vs. nutrient plots for nearfield survey W9615, (Oct 96).

(a)



(b)

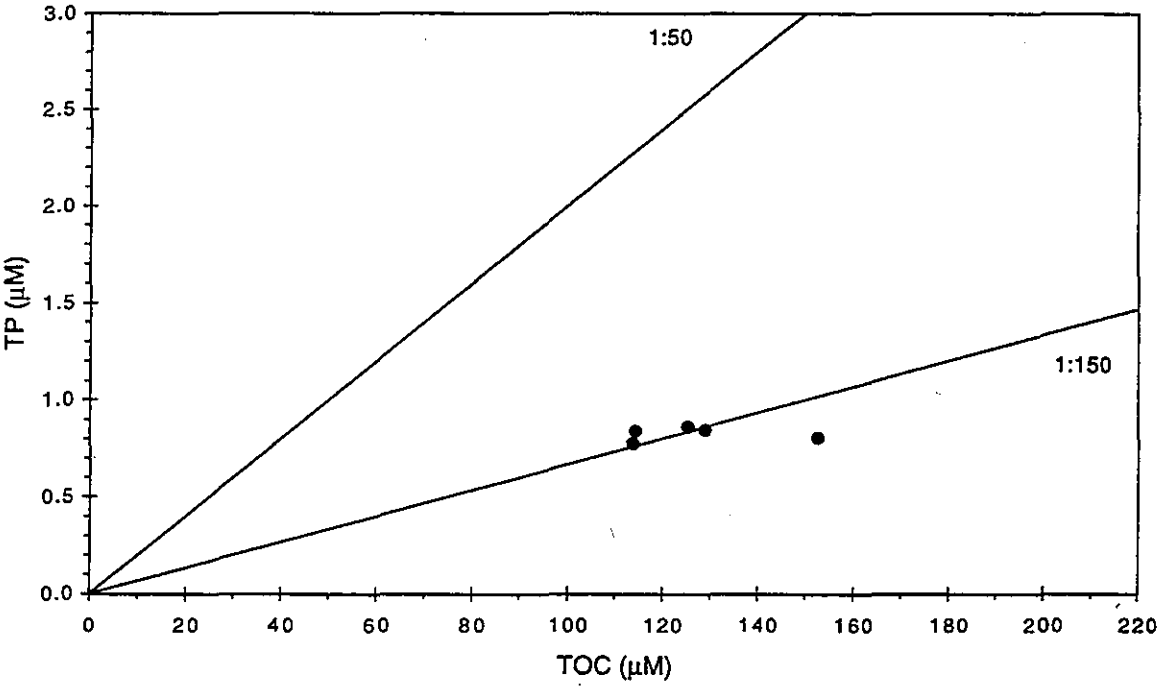


FIGURE 4-222
Nutrient vs. nutrient plots for nearfield survey W9615, (Oct 96).

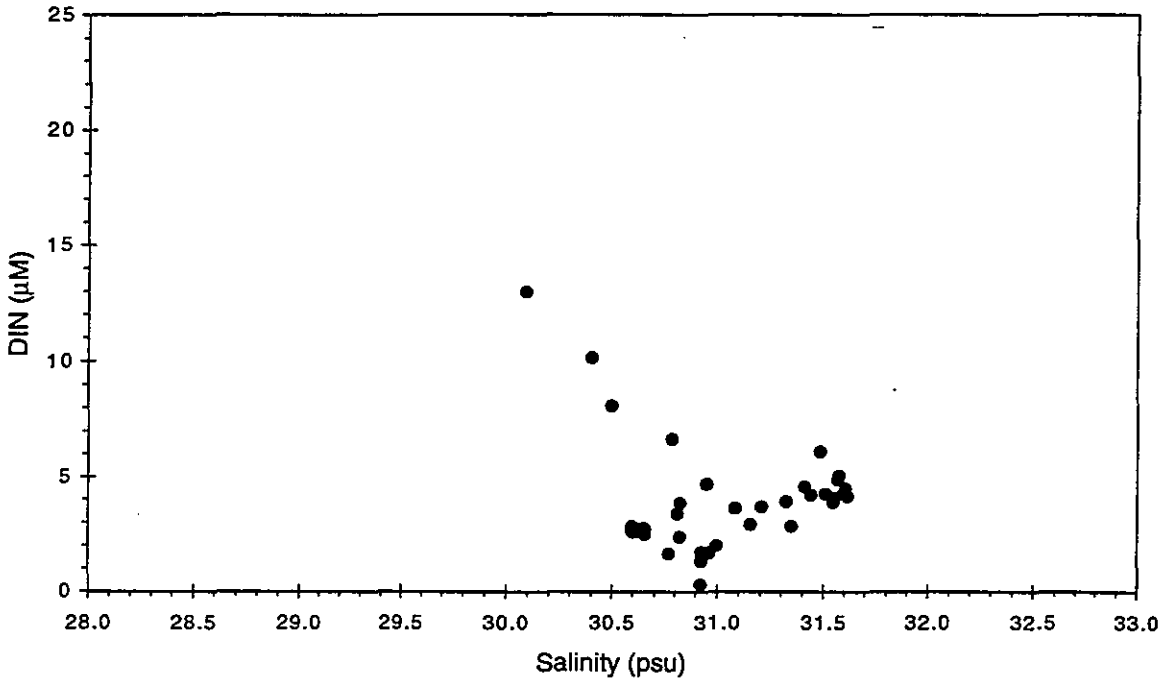


FIGURE 4-223
Nutrient vs. salinity plots for nearfield survey W9615, (Oct 96).

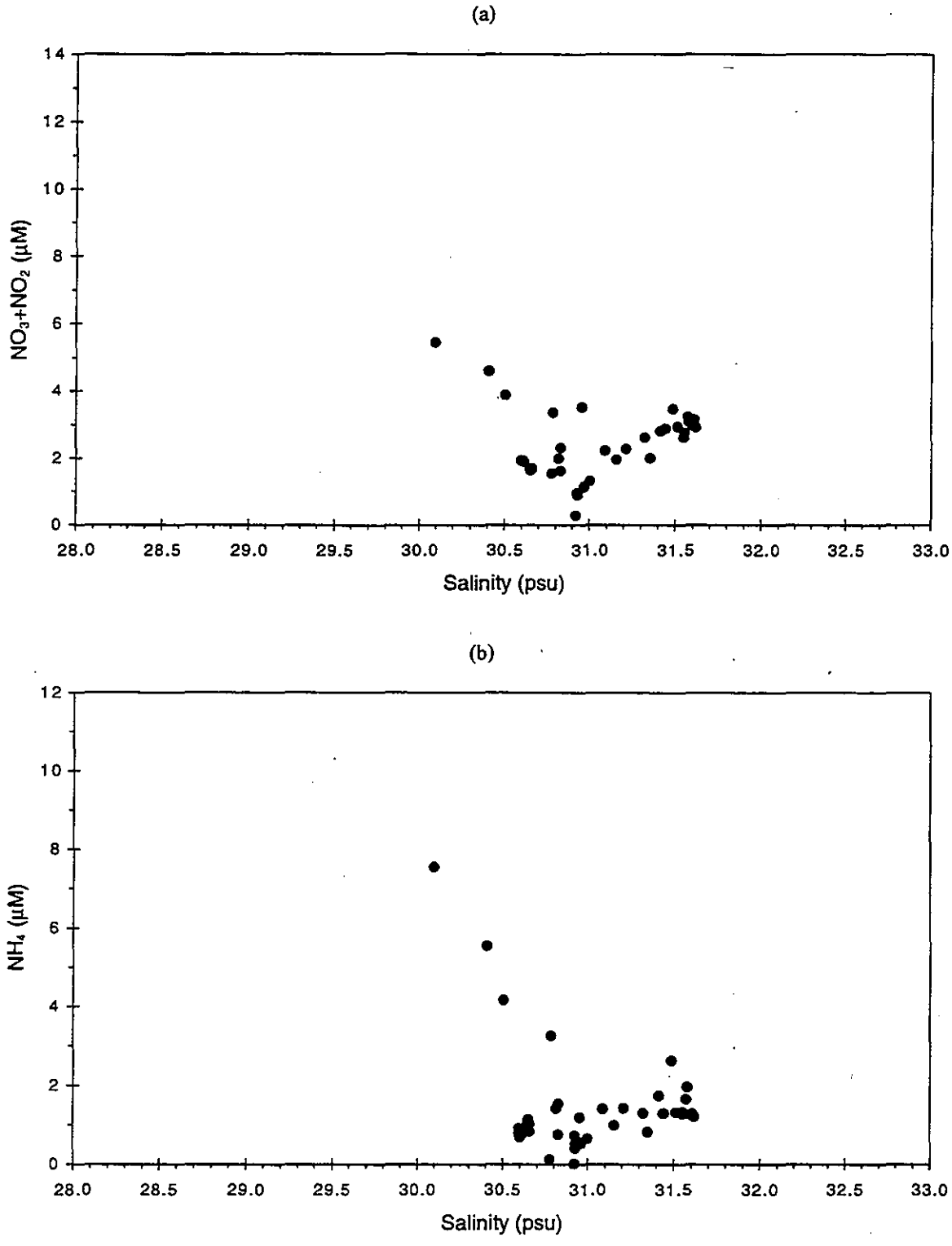
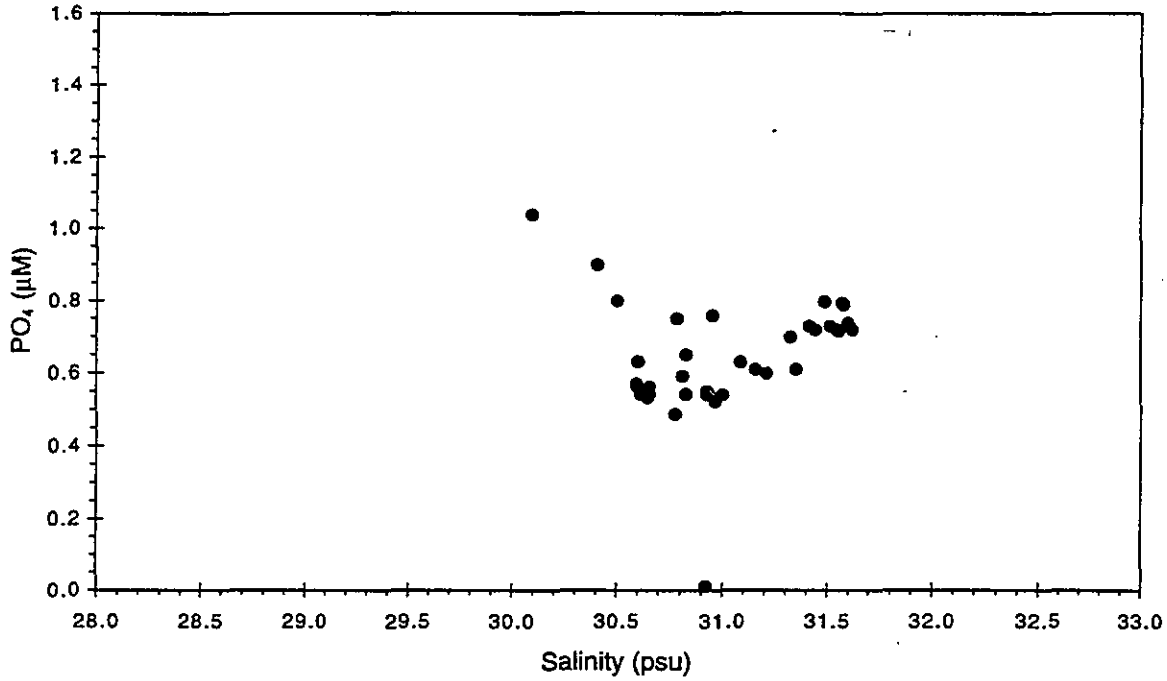


FIGURE 4-224
Nutrient vs. salinity plots for nearfield survey W9615, (Oct 96).

(a)



(b)

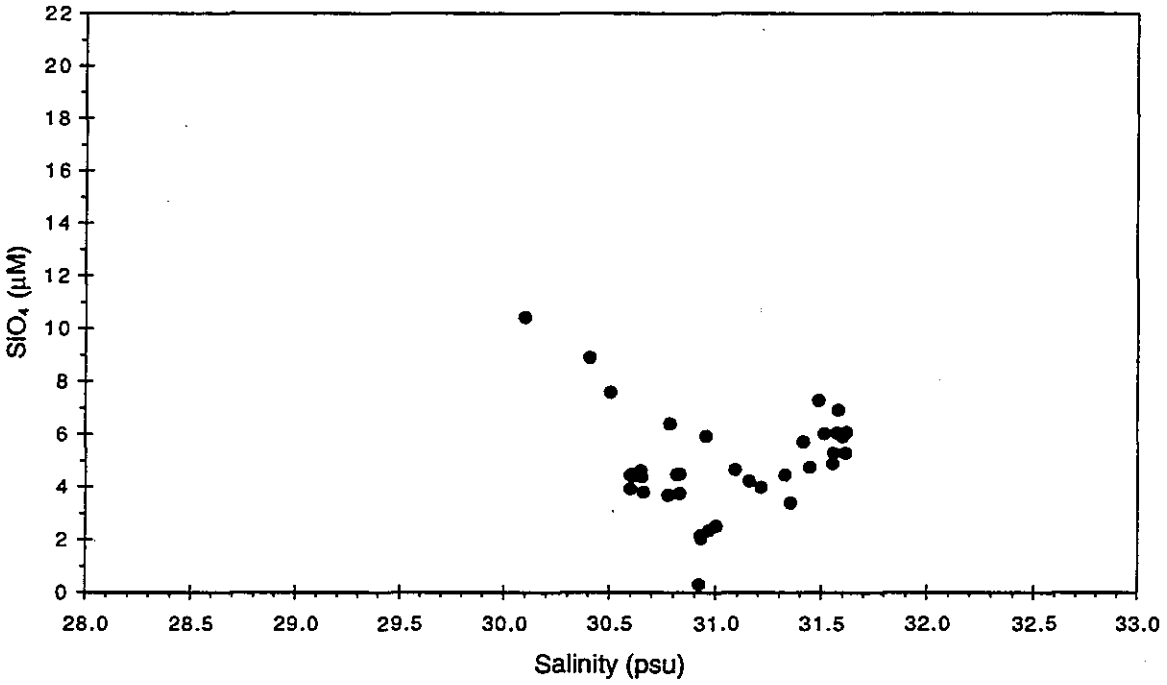


FIGURE 4-225
Nutrient vs. salinity plots for nearfield survey W9615, (Oct 96).

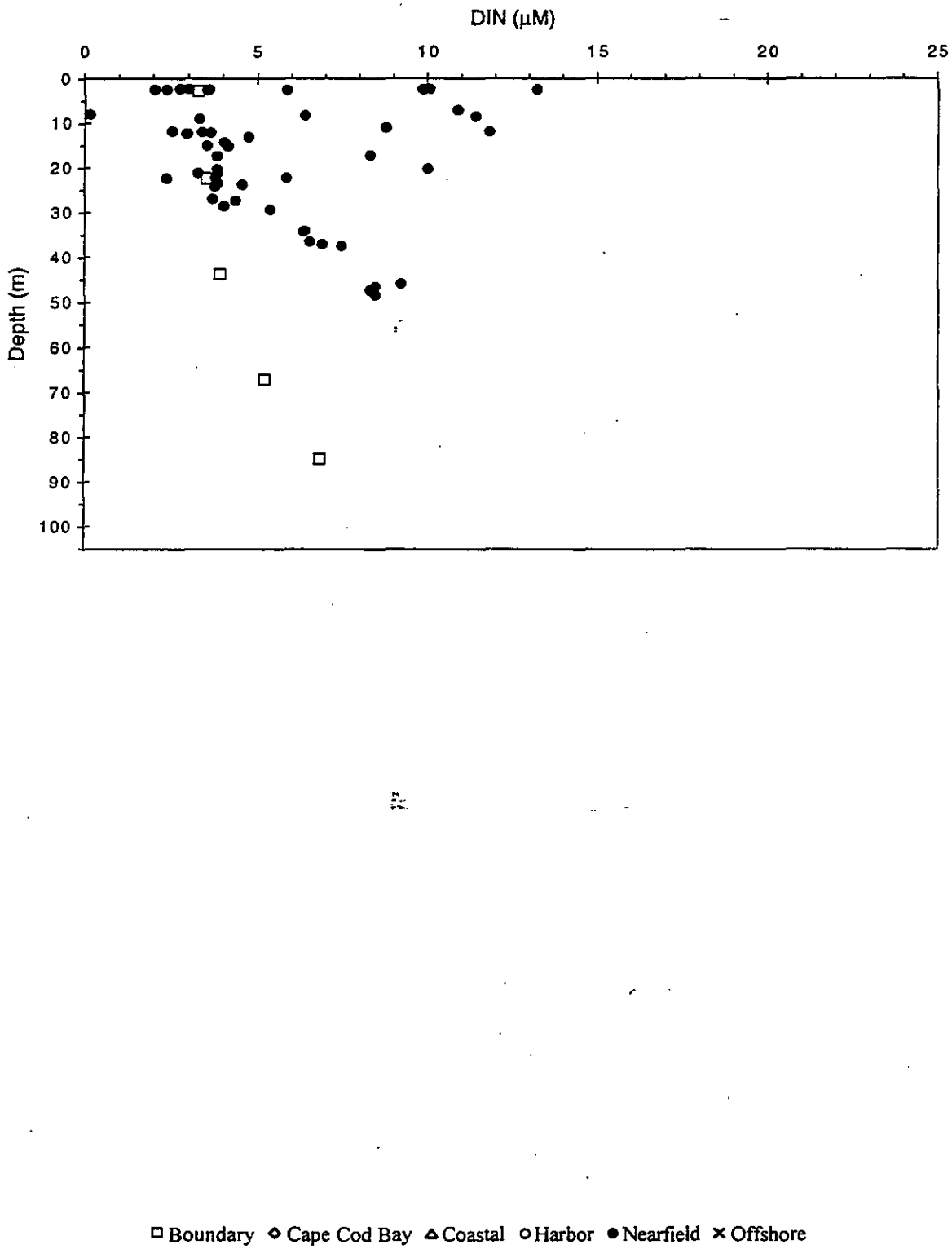


FIGURE 4-226
Depth vs. nutrient plots for winter nutrients survey W9616, (Nov 96).

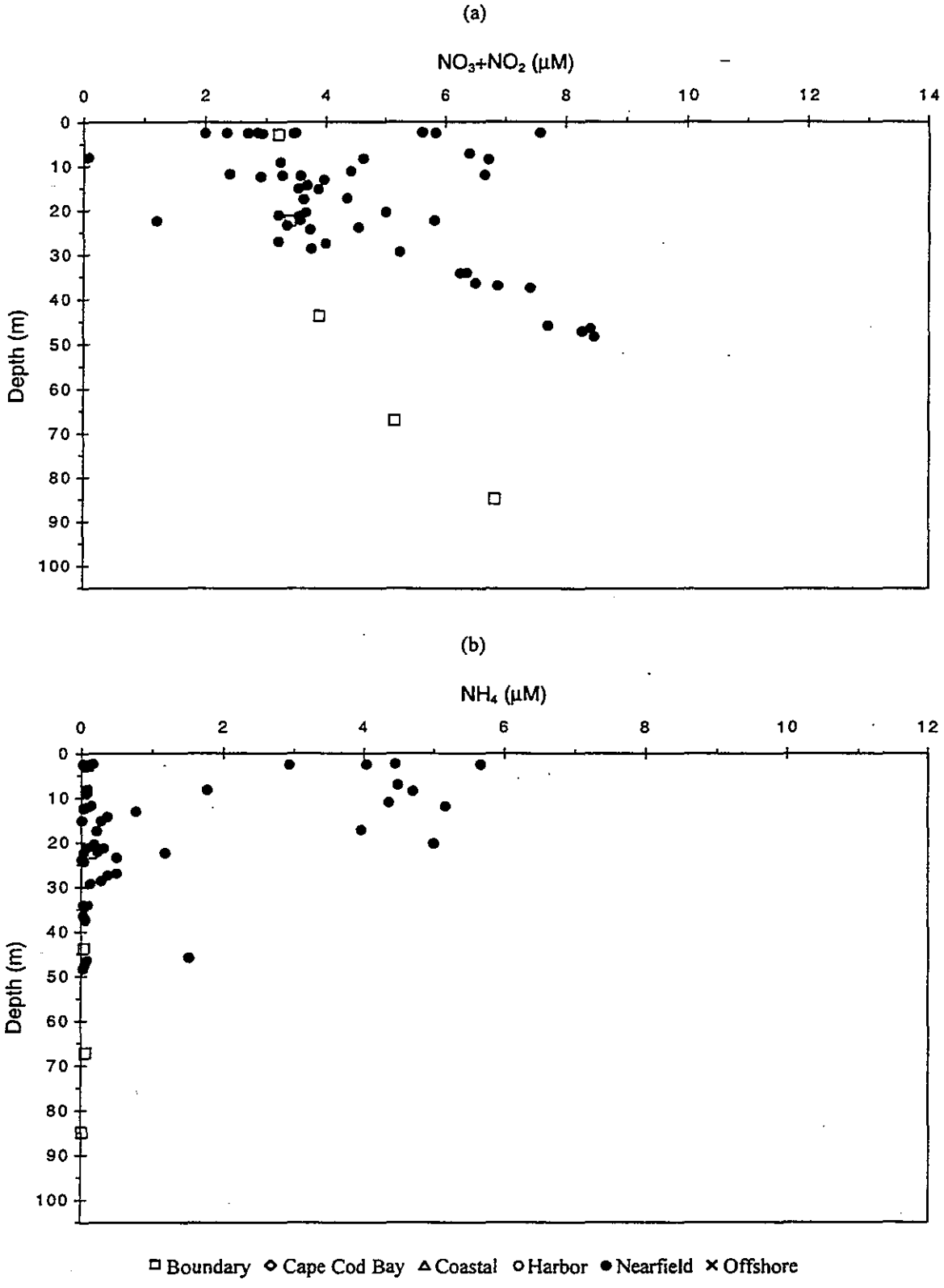


FIGURE 4-227
Depth vs. nutrient plots for winter nutrients survey W9616, (Nov 96).

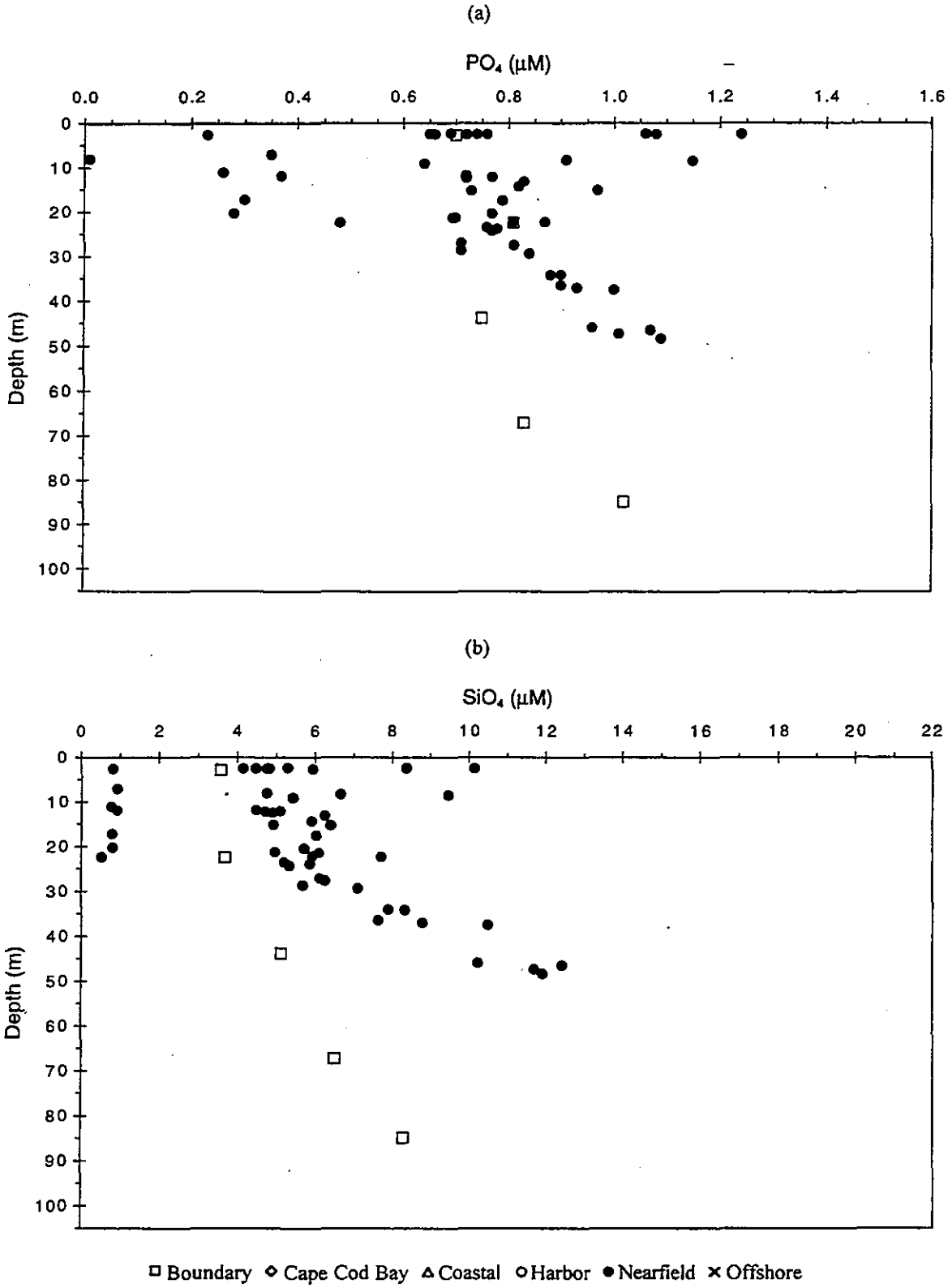


FIGURE 4-228
Depth vs. nutrient plots for winter nutrients survey W9616, (Nov 96).

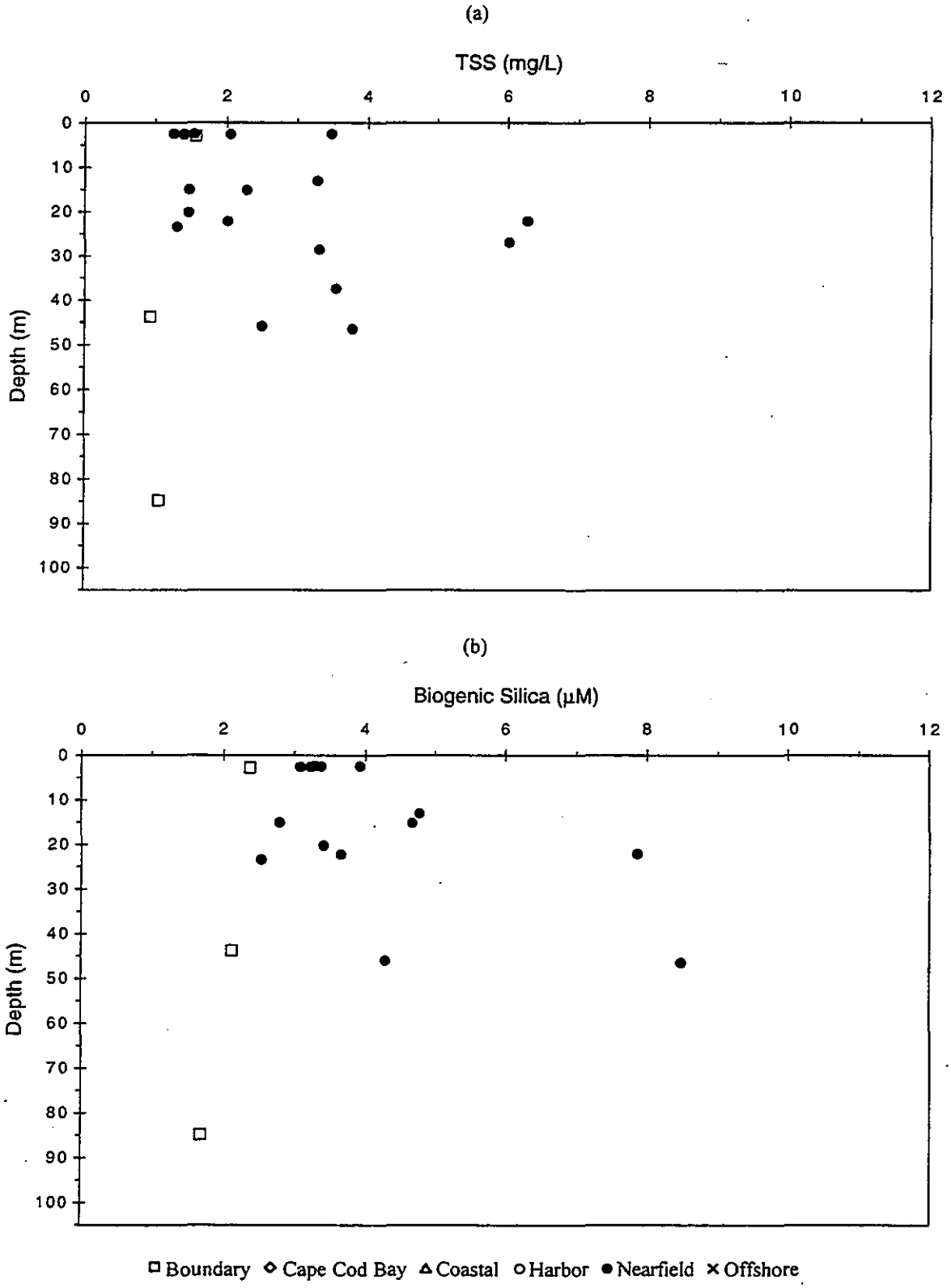
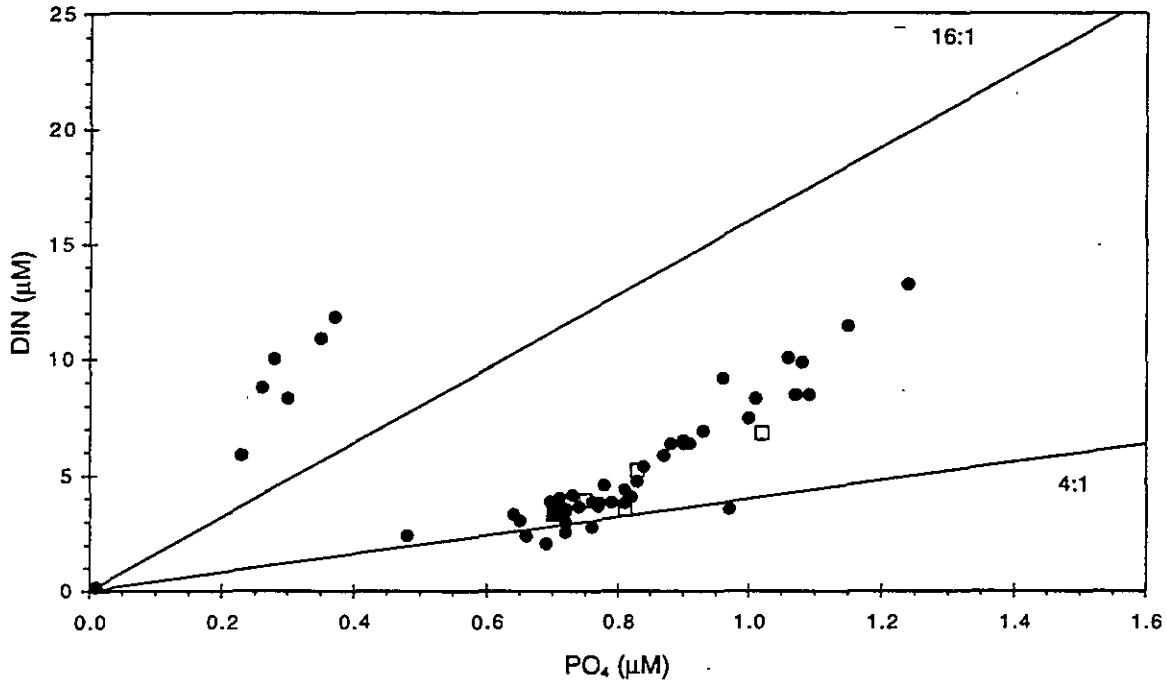
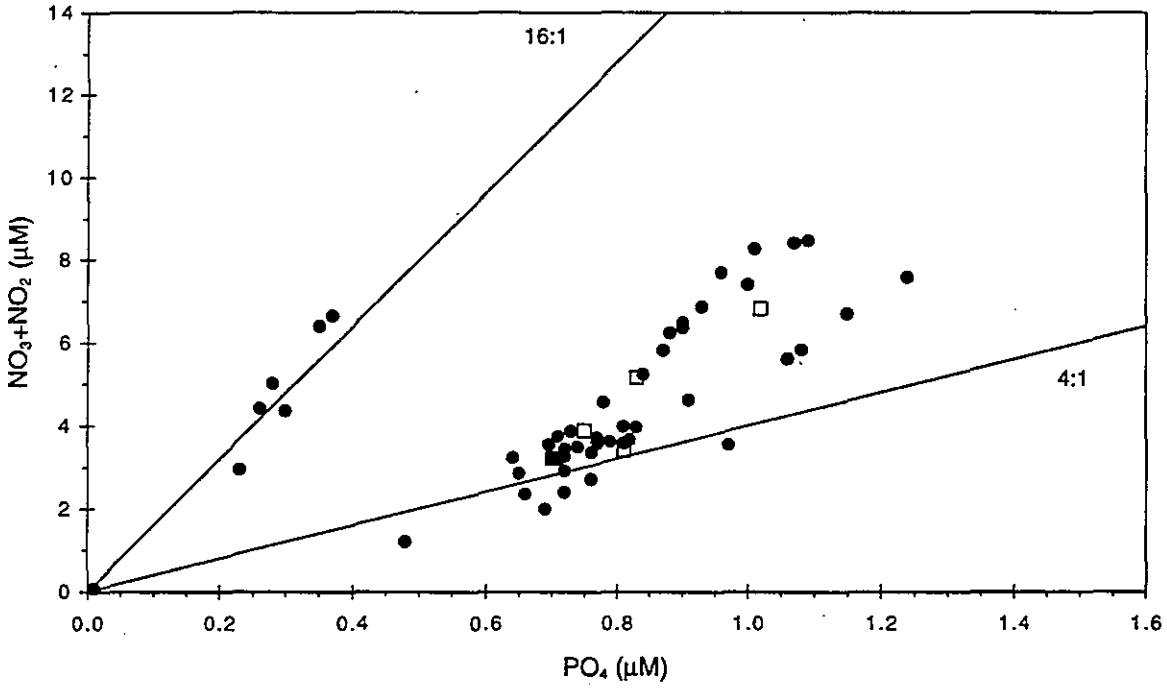


FIGURE 4-229
Depth vs. nutrient plots for winter nutrients survey W9616, (Nov 96).

(a)



(b)



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-230
Nutrient vs. nutrient plots for nearfield/Stellwagen Basin survey W9616, (Nov 96).

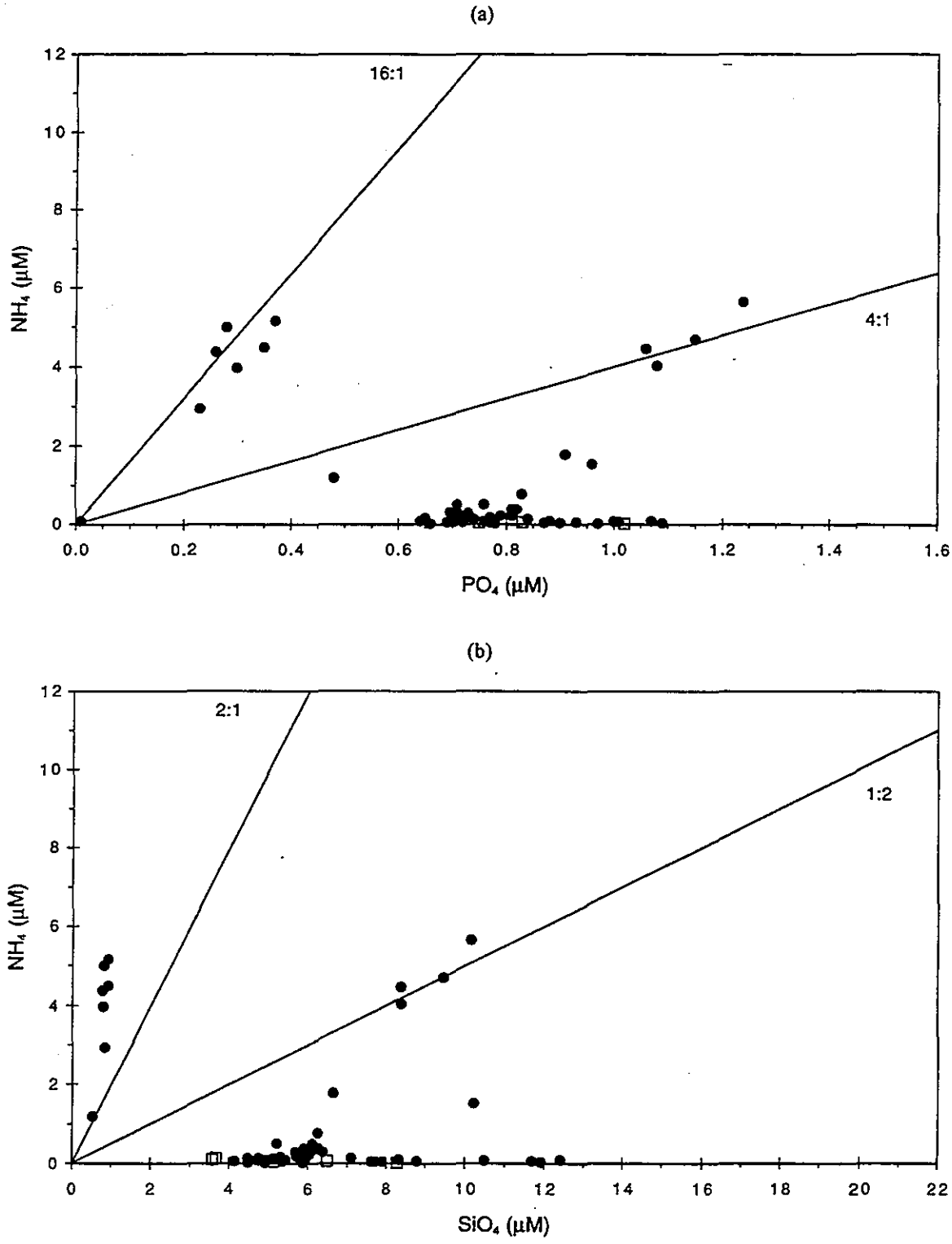


FIGURE 4-231
Nutrient vs. nutrient plots for nearfield/Stellwagen Basin survey W9616, (Nov 96).

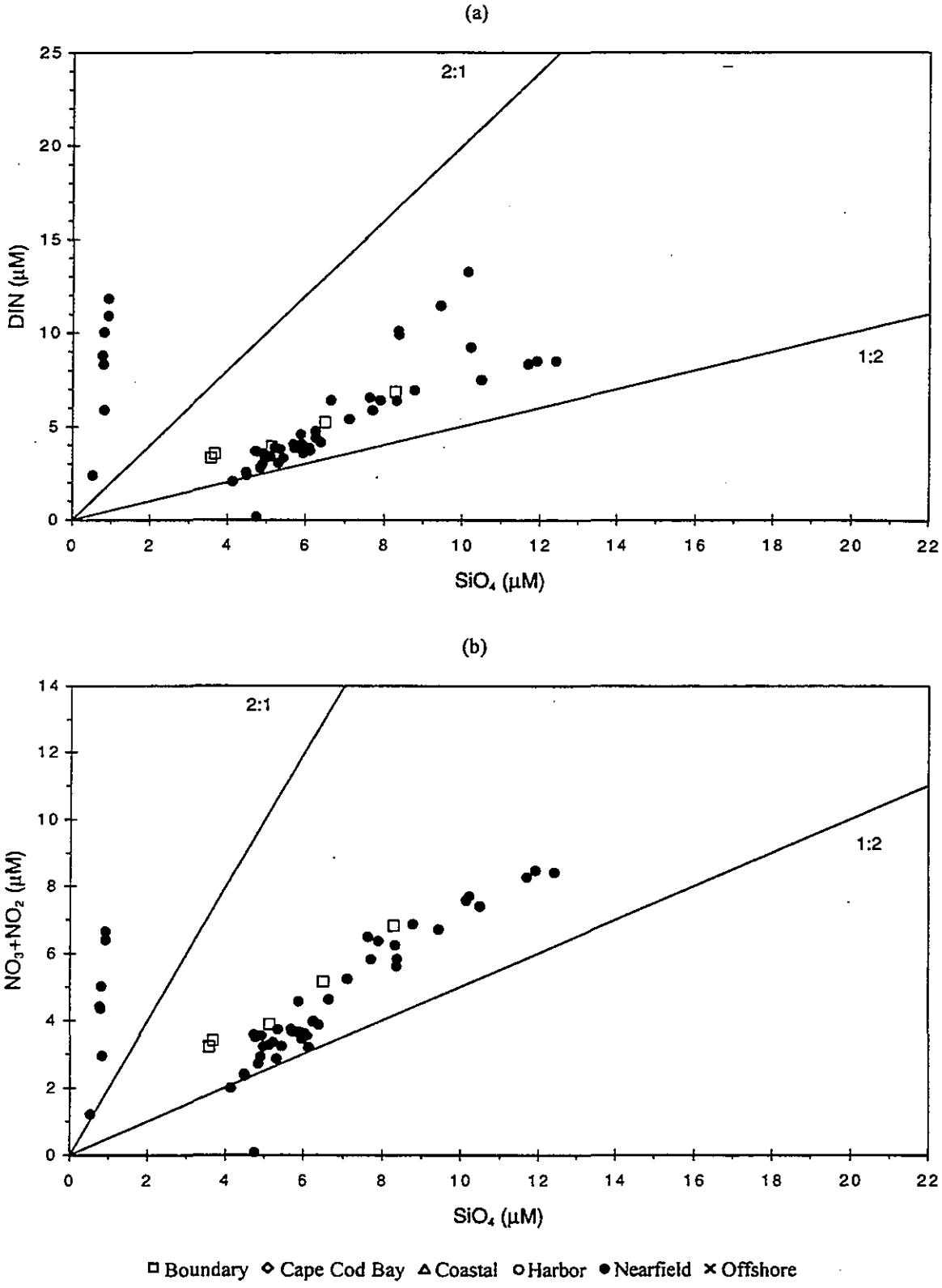


FIGURE 4-232
Nutrient vs. nutrient plots for nearfield/Stellwagen Basin survey W9616, (Nov 96).

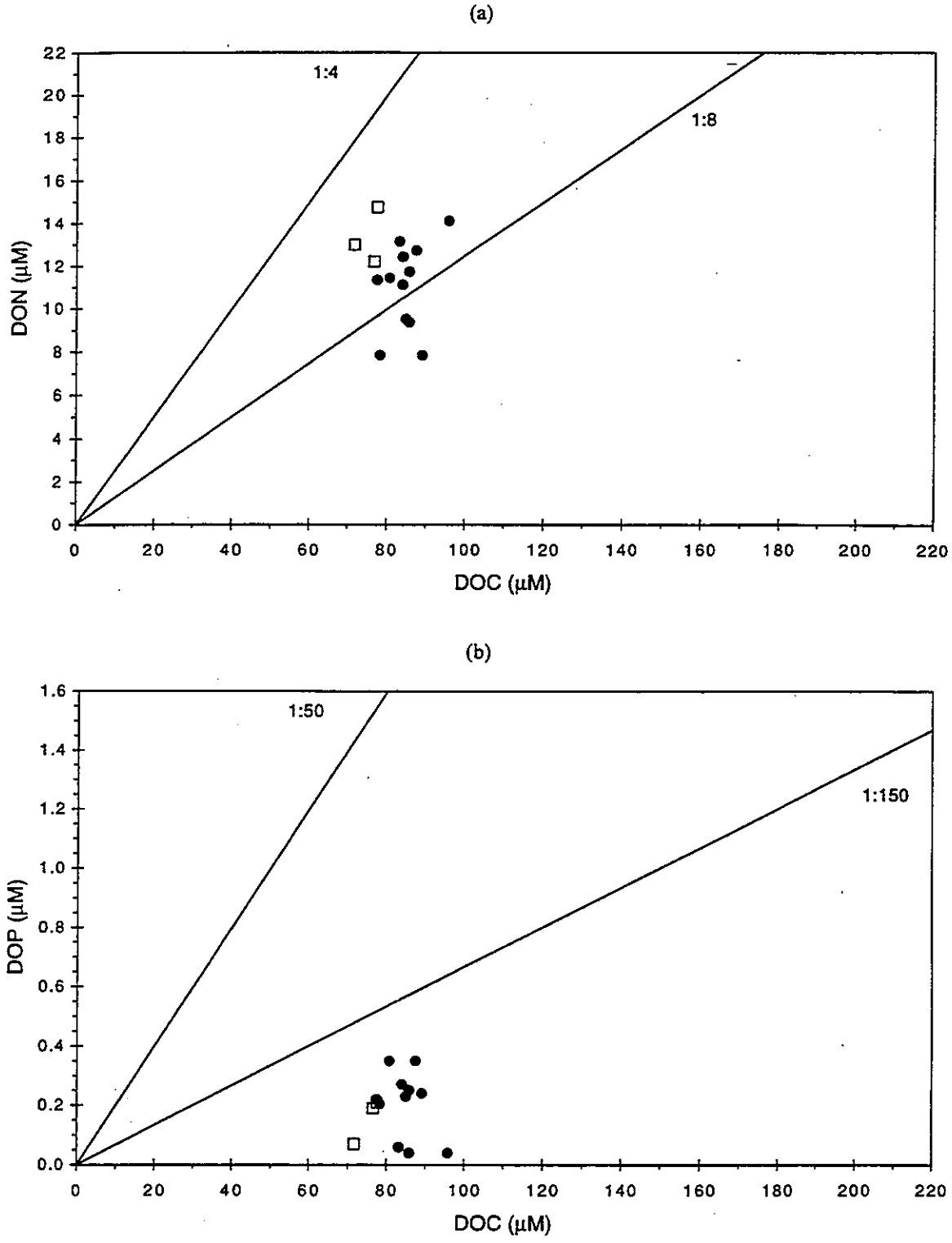


FIGURE 4-233
Nutrient vs. nutrient plots for nearfield/Stellwagen Basin survey W9616, (Nov 96).

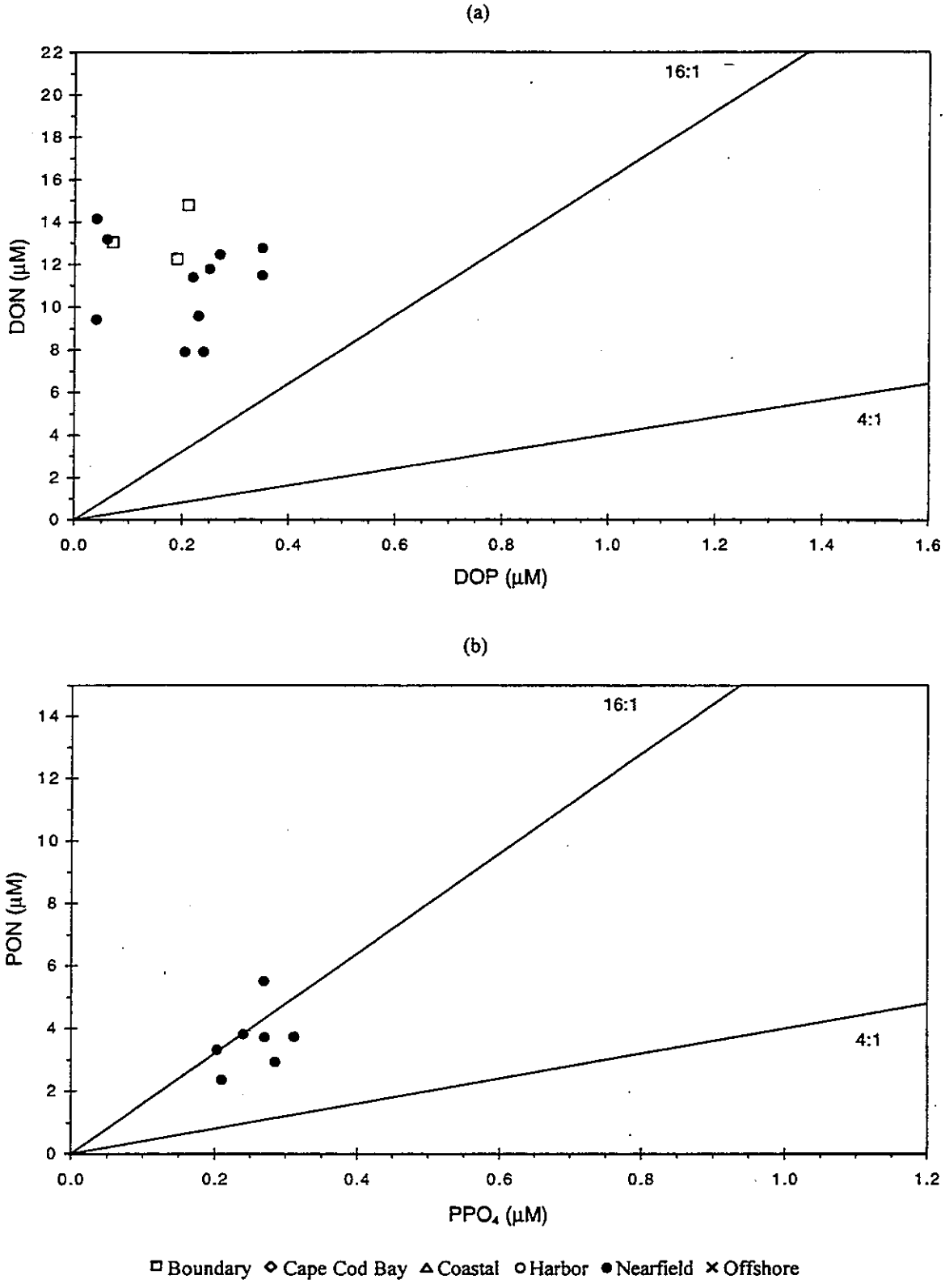


FIGURE 4-234
Nutrient vs. nutrient plots for nearfield/Stellwagen Basin survey W9616, (Nov 96).

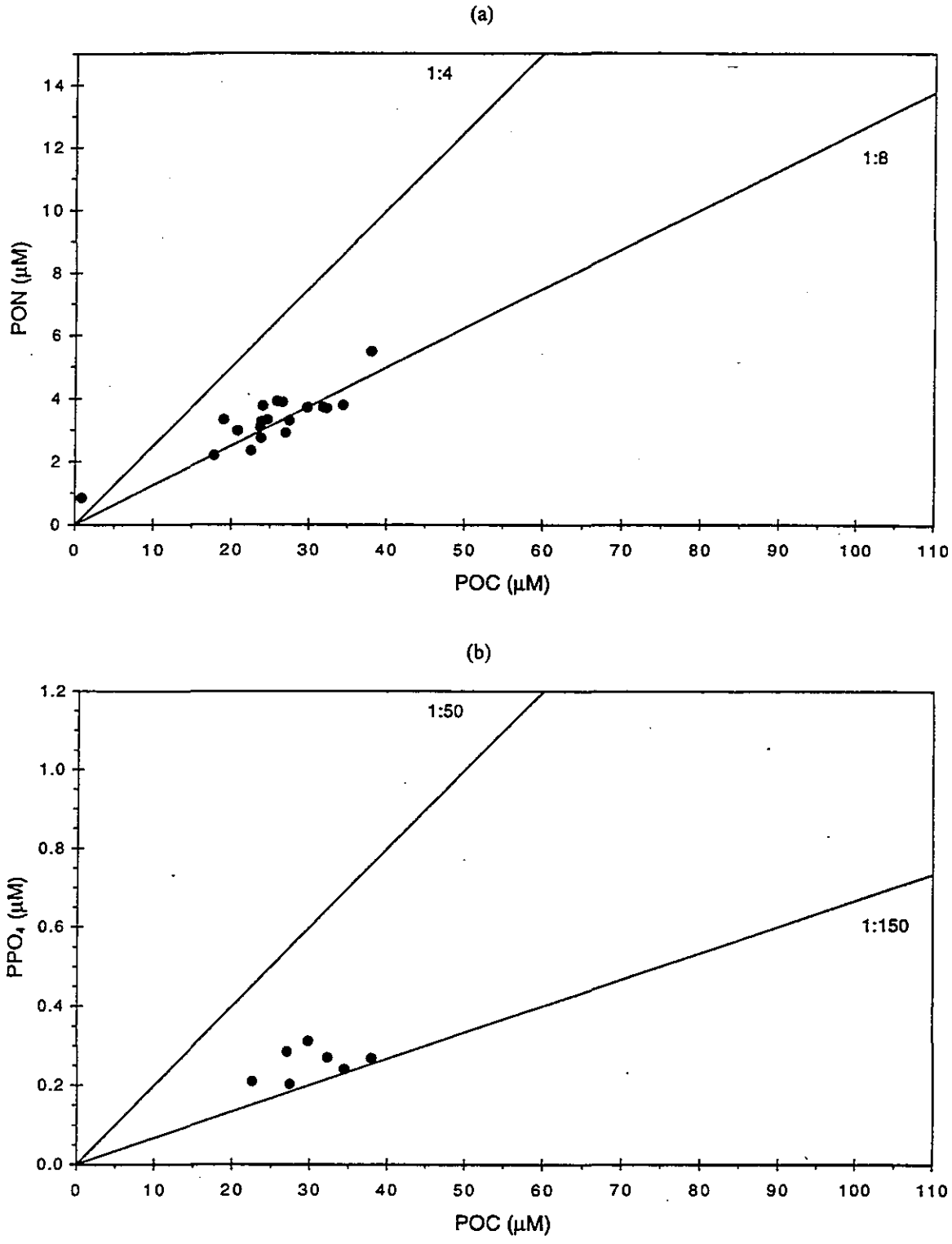


FIGURE 4-235
Nutrient vs. nutrient plots for nearfield/Stellwagen Basin survey W9616, (Nov 96).

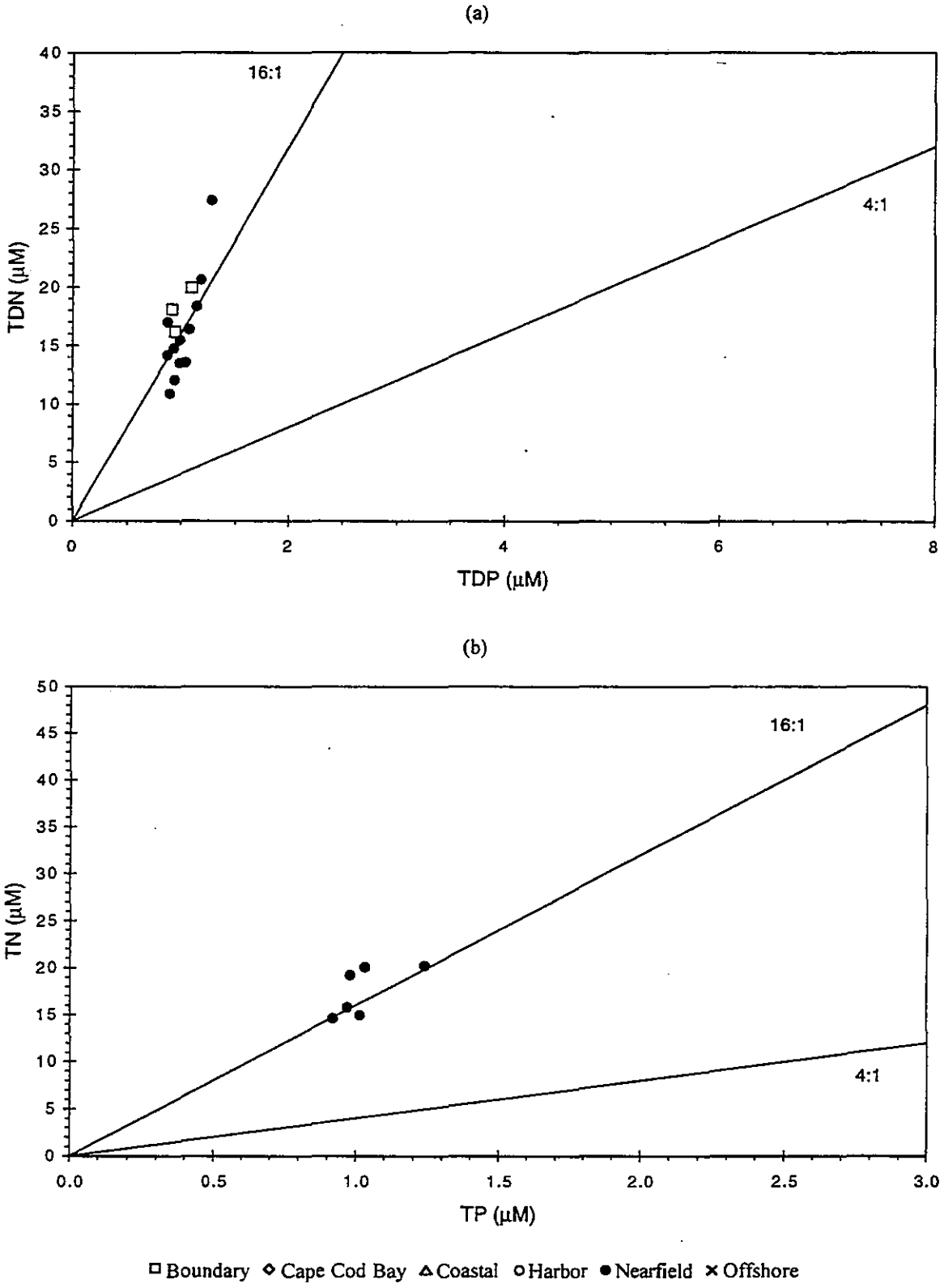


FIGURE 4-236
Nutrient vs. nutrient plots for nearfield/Stellwagen Basin survey W9616, (Nov 96).

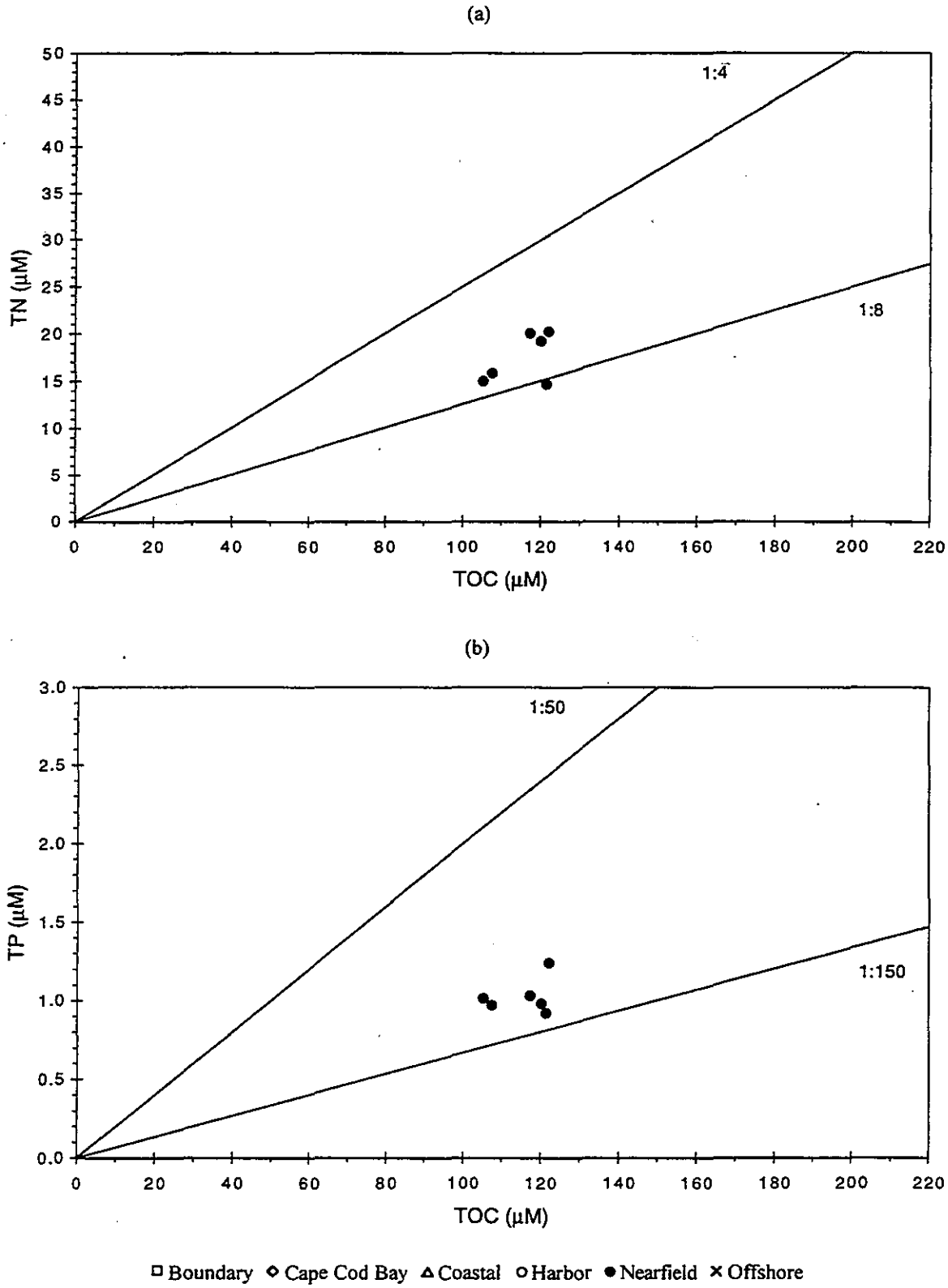
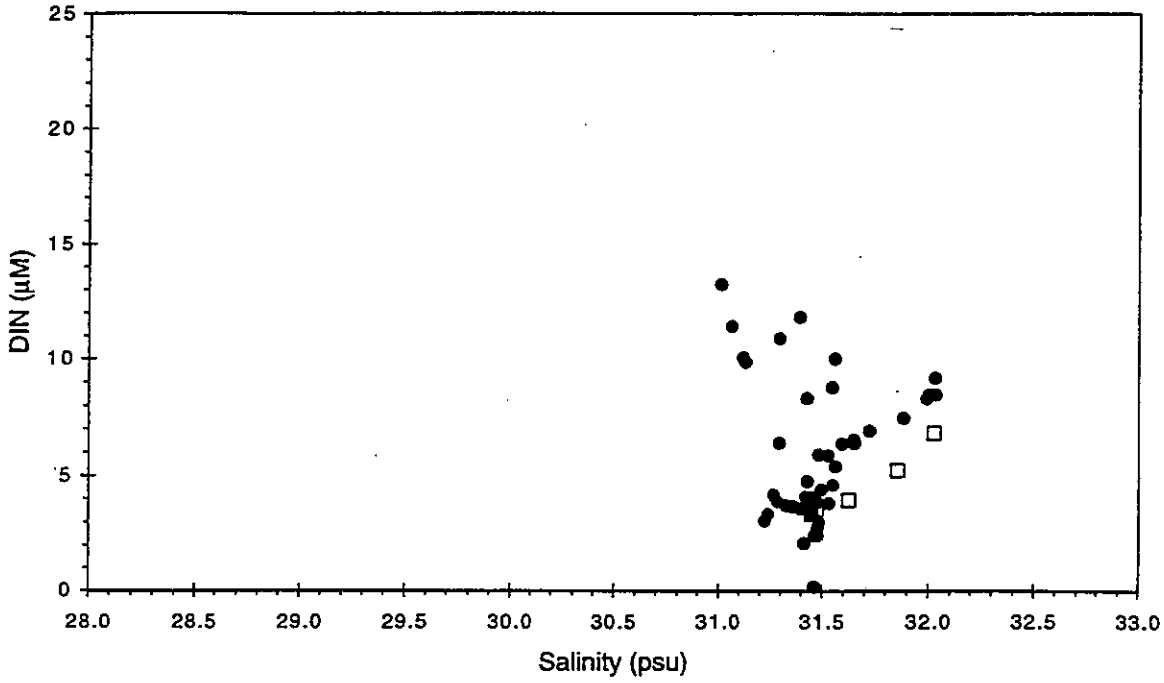


FIGURE 4-237
Nutrient vs. nutrient plots for nearfield/Stellwagen Basin survey W9616, (Nov 96).



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-238
Nutrient vs. salinity plots for nearfield/Stellwagen Basin survey W9616, (Nov 96).

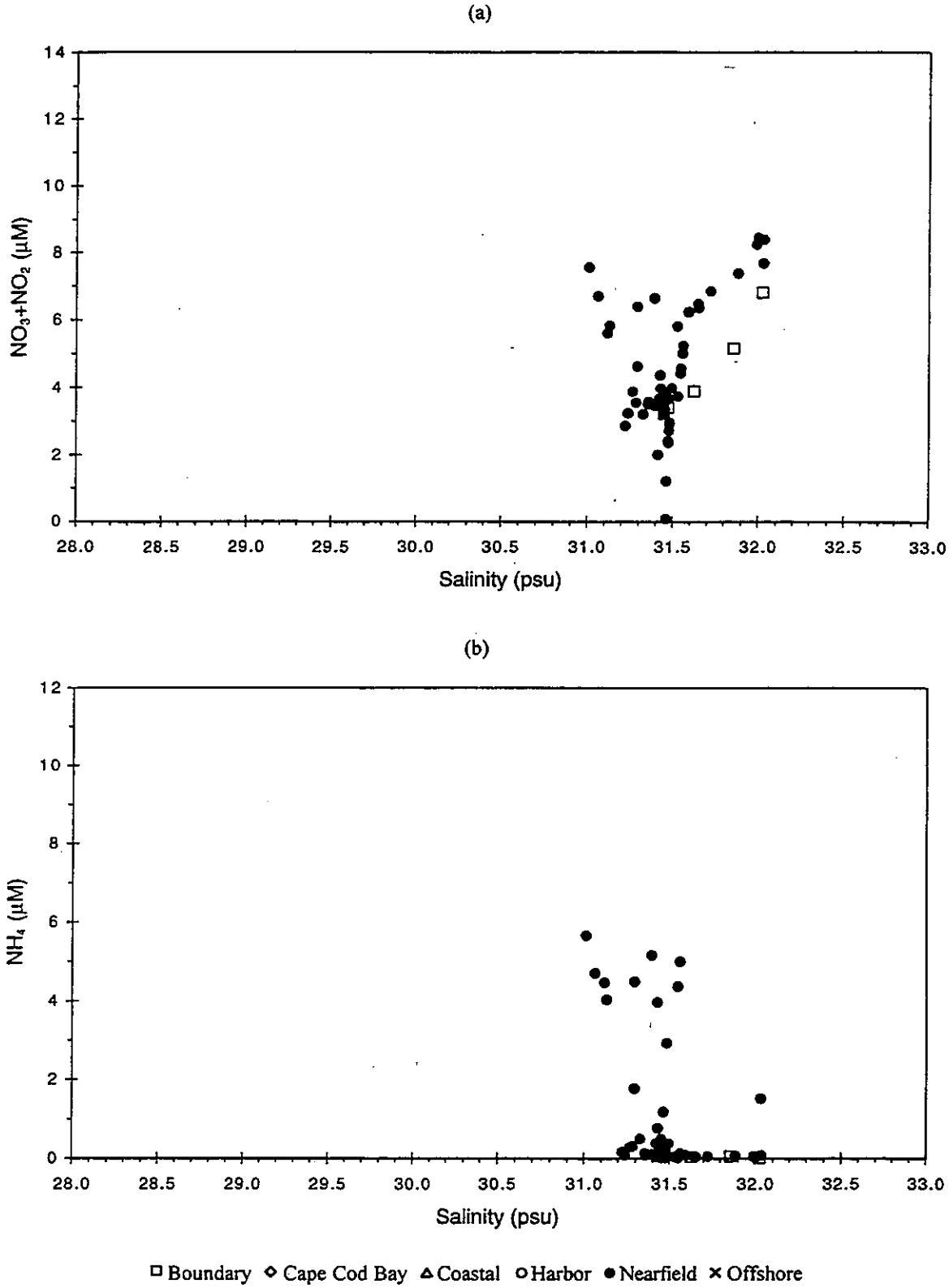
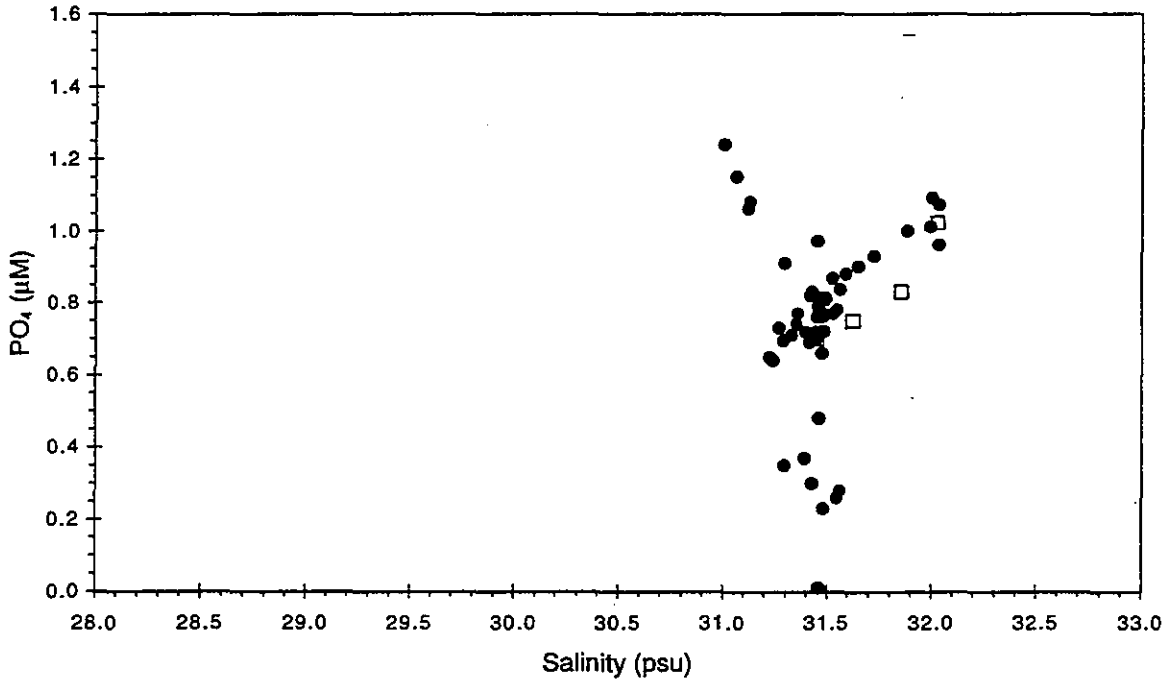
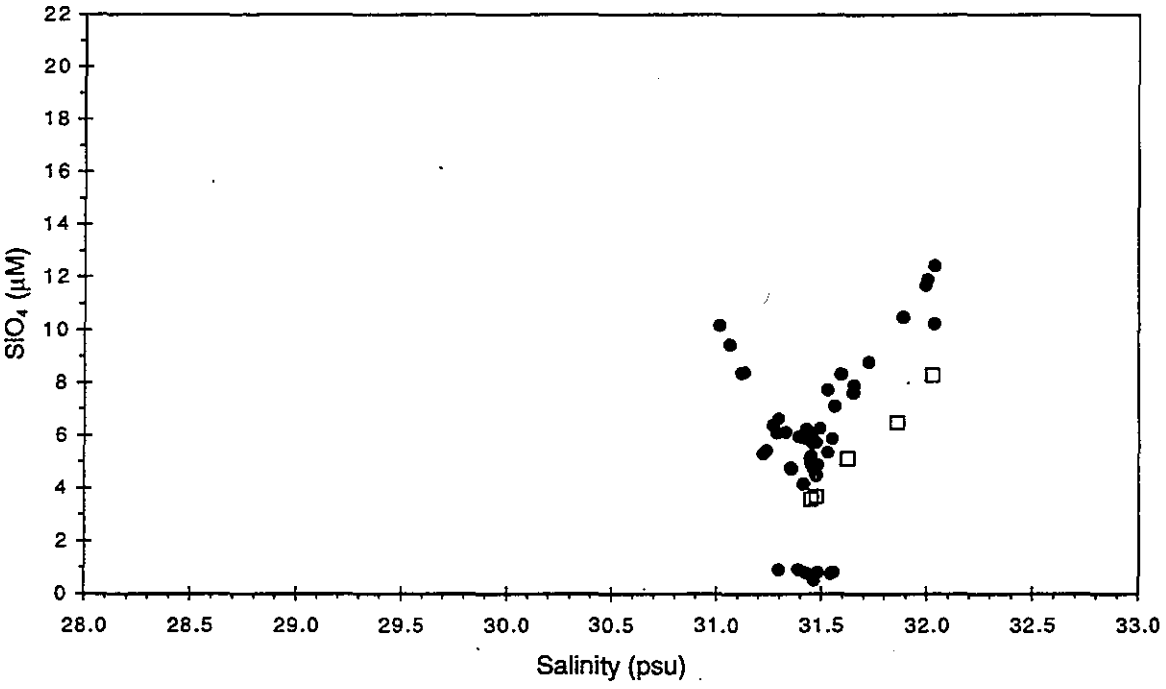


FIGURE 4-239
Nutrient vs. salinity plots for nearfield/Stellwagen Basin survey W9616, (Nov 96).

(a)

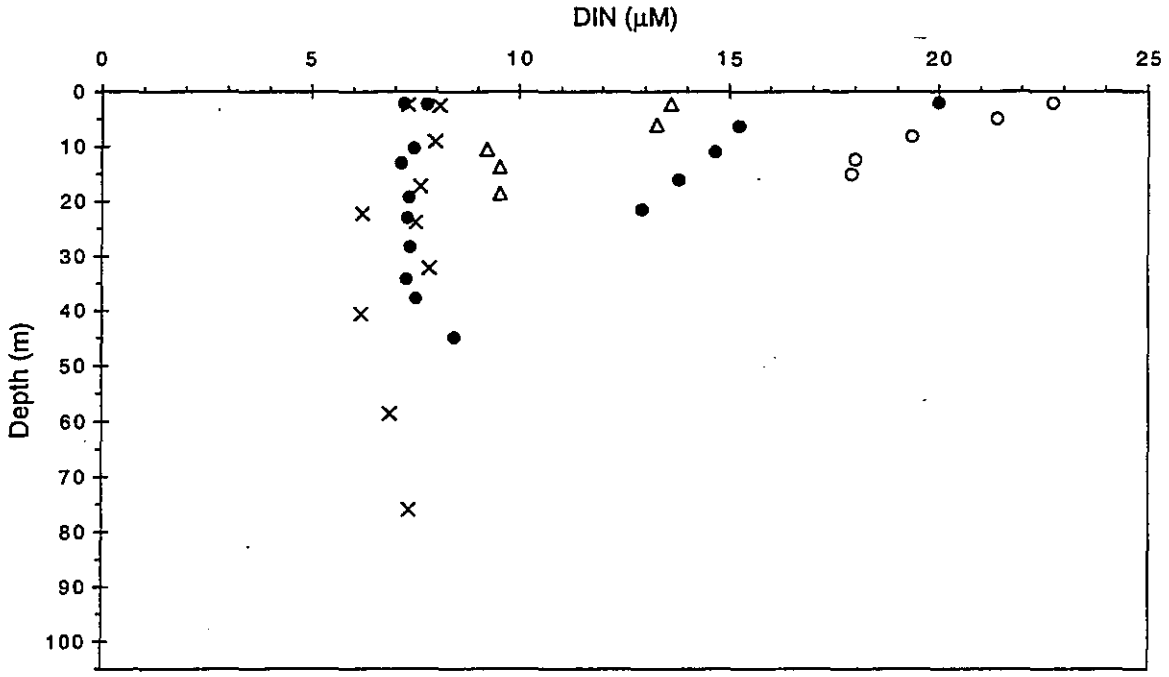


(b)



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-240
Nutrient vs. salinity plots for nearfield/Stellwagen Basin survey W9616, (Nov 96).



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-241
Depth vs. nutrient plots for nearfield/winter nutrients survey W9617, (Dec 96).

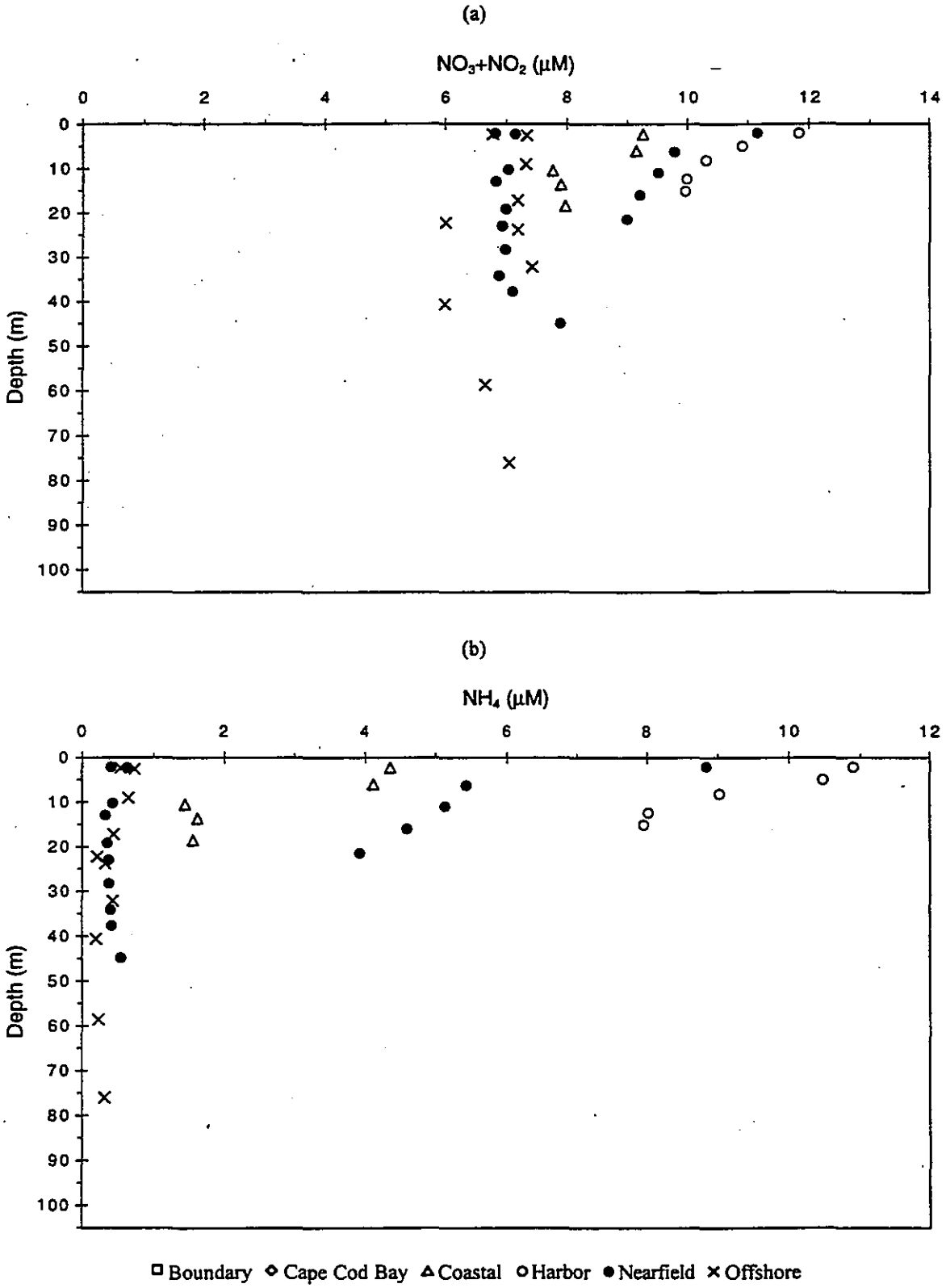


FIGURE 4-242
Depth vs. nutrient plots for nearfield/winter nutrients survey W9617, (Dec 96).

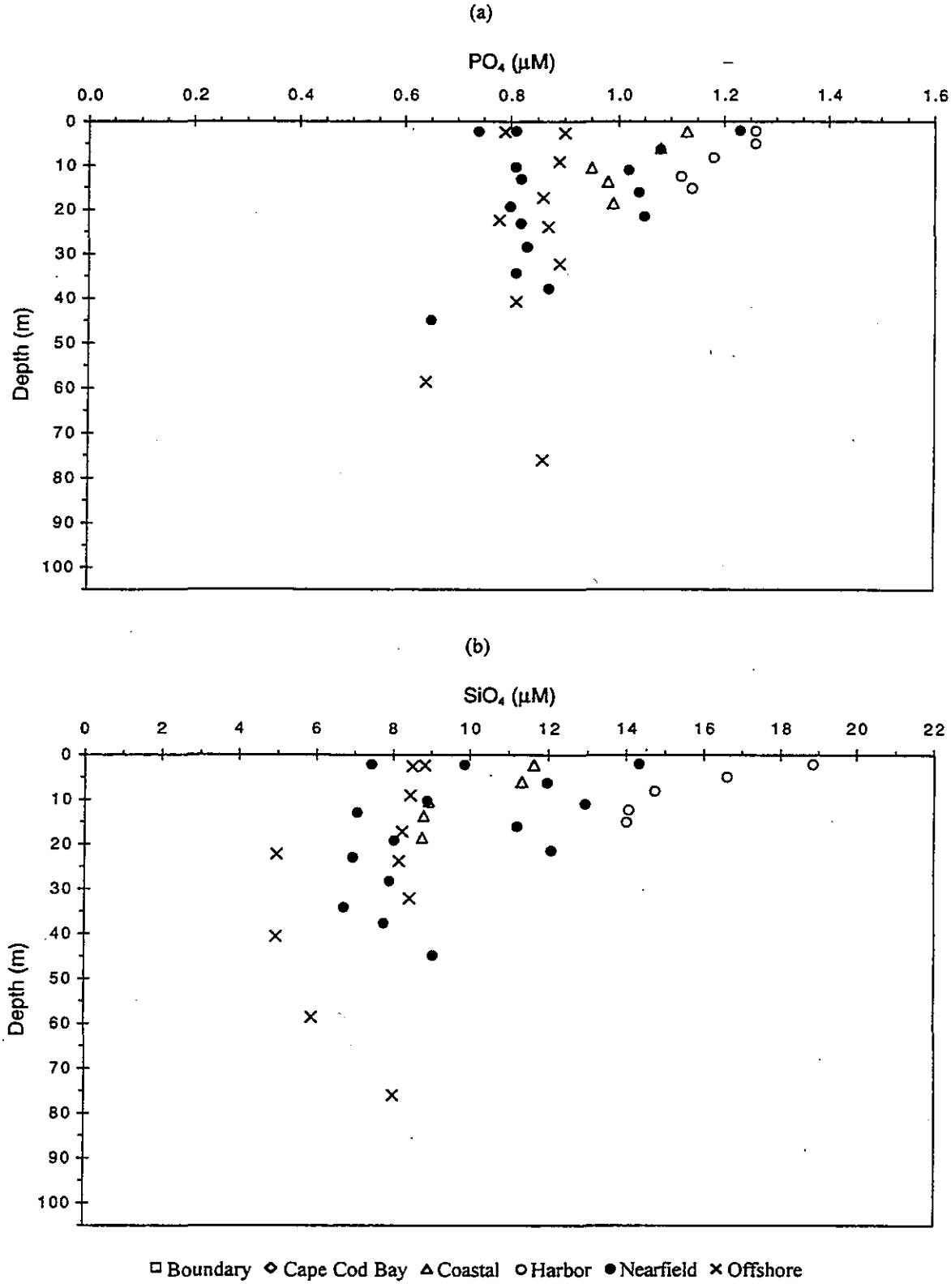


FIGURE 4-243
Depth vs. nutrient plots for nearfield/winter nutrients survey W9617, (Dec 96).

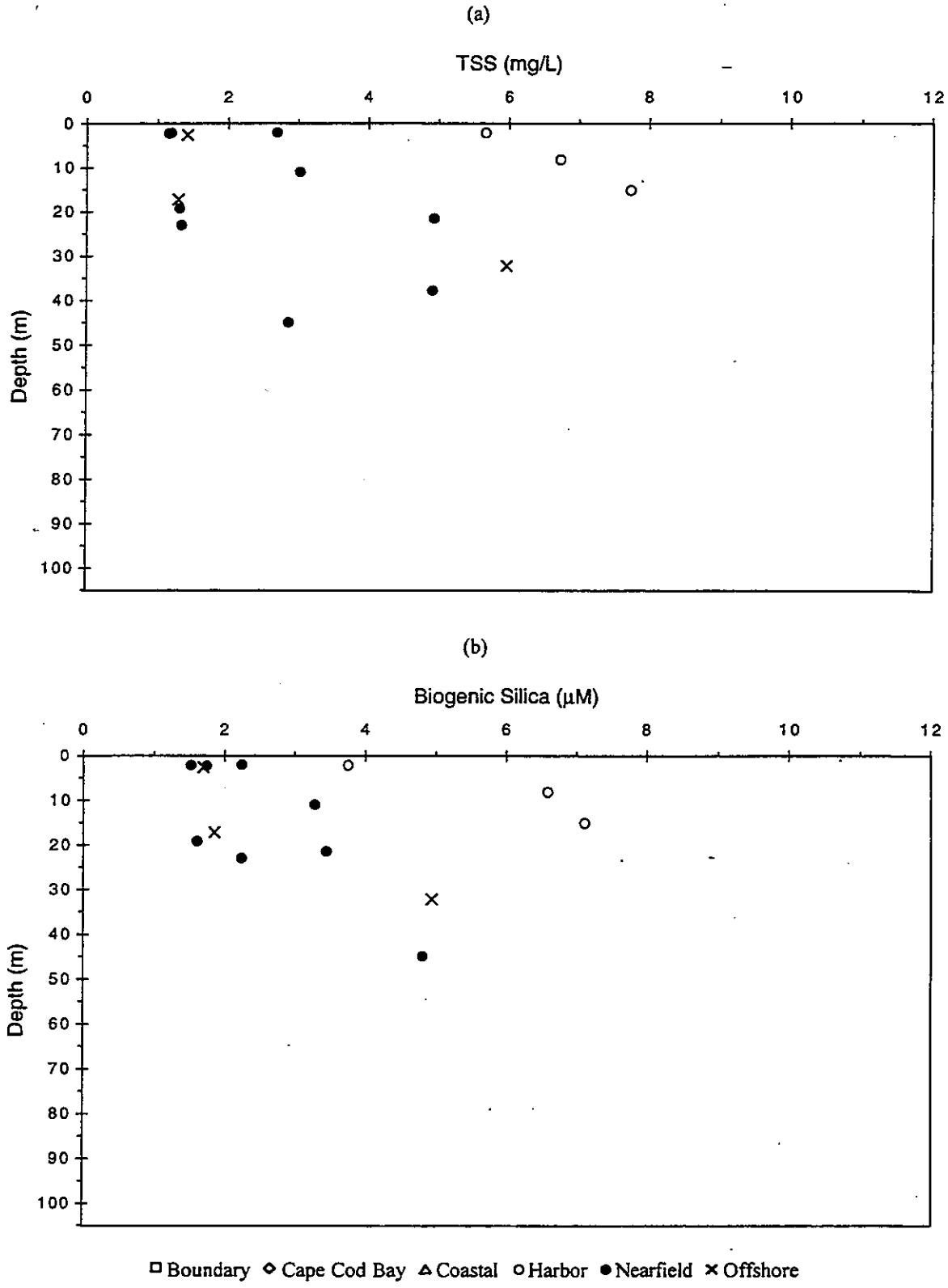
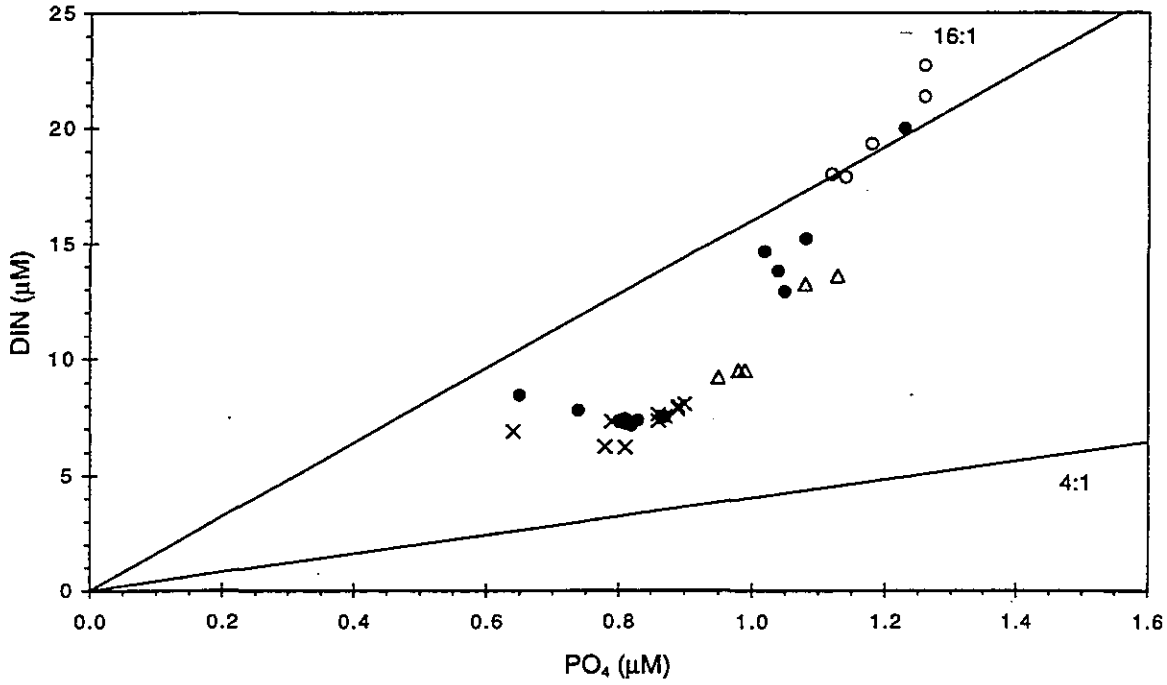
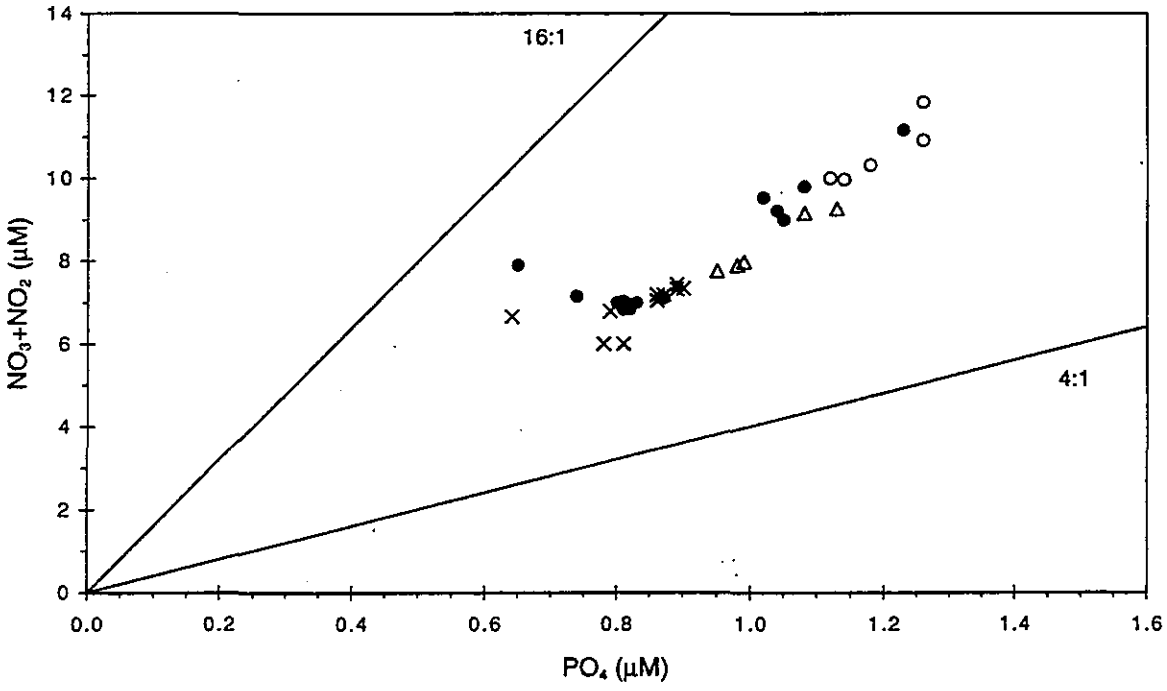


FIGURE 4-244
Depth vs. nutrient plots for nearfield/winter nutrients survey W9617, (Dec 96).

(a)



(b)



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-245
Nutrient vs. nutrient plots for nearfield/winter nutrients survey W9617, (Dec 96).

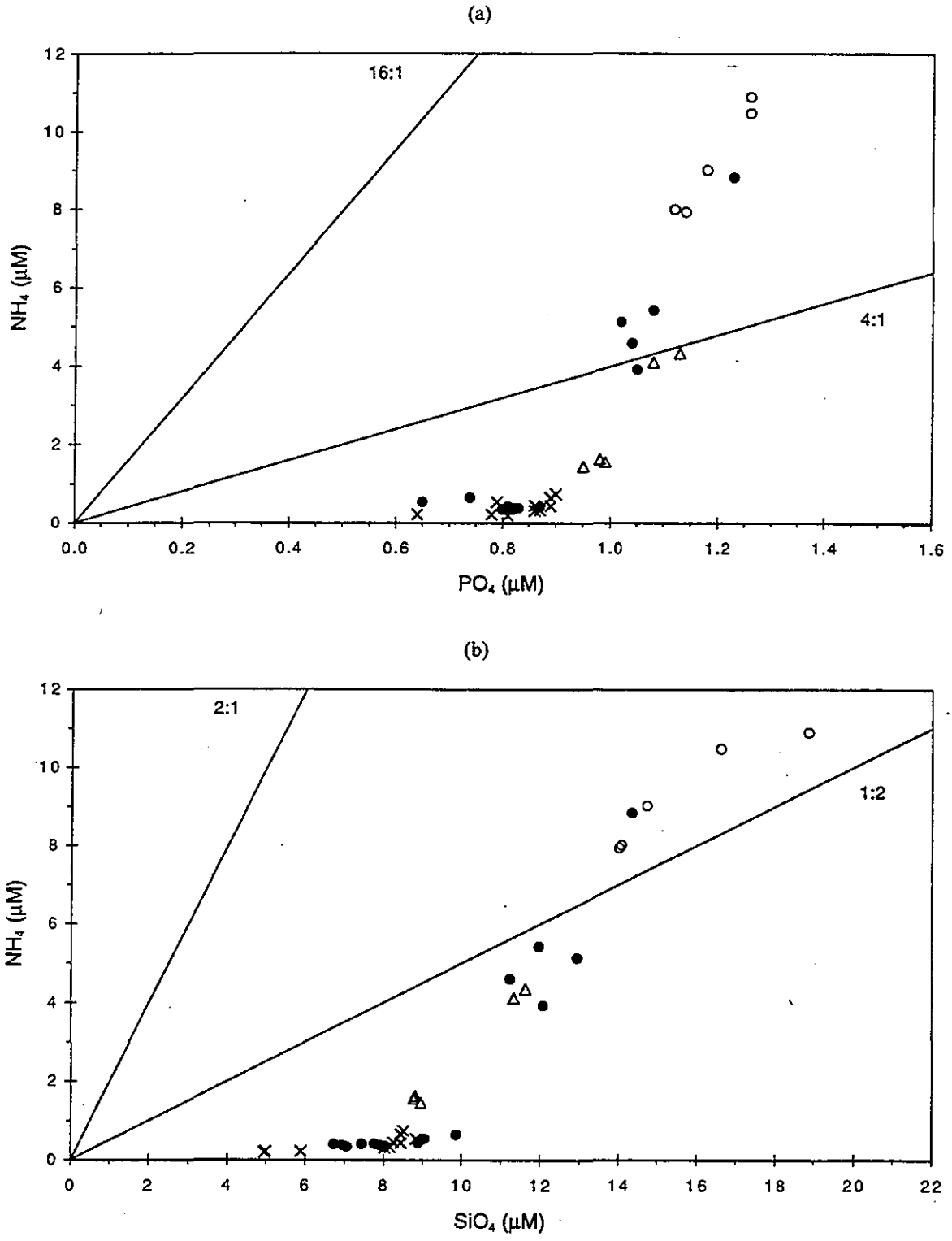


FIGURE 4-246
Nutrient vs. nutrient plots for nearfield/winter nutrients survey W9617; (Dec 96).

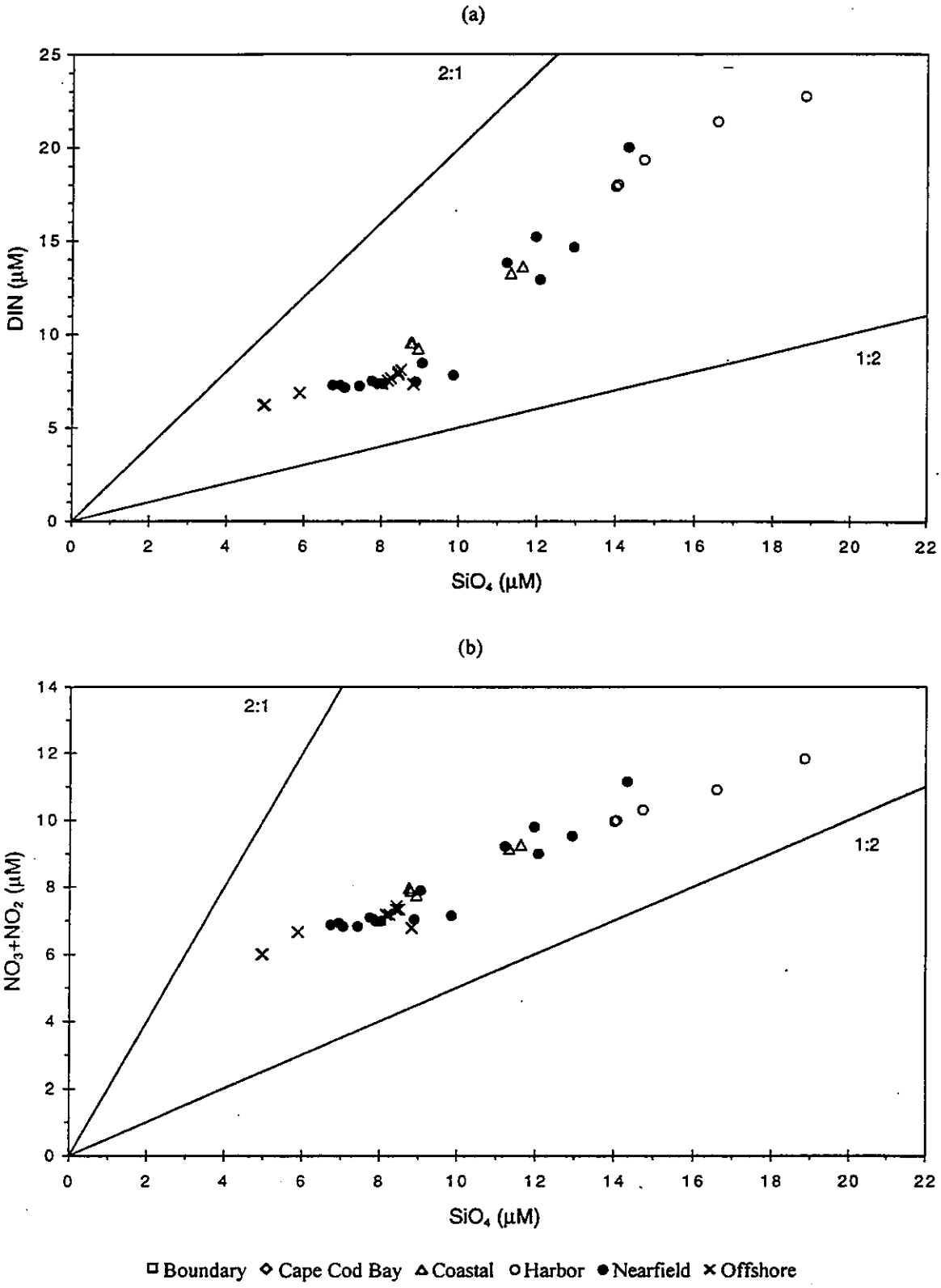


FIGURE 4-247
Nutrient vs. nutrient plots for nearfield/winter nutrients survey W9617, (Dec 96).

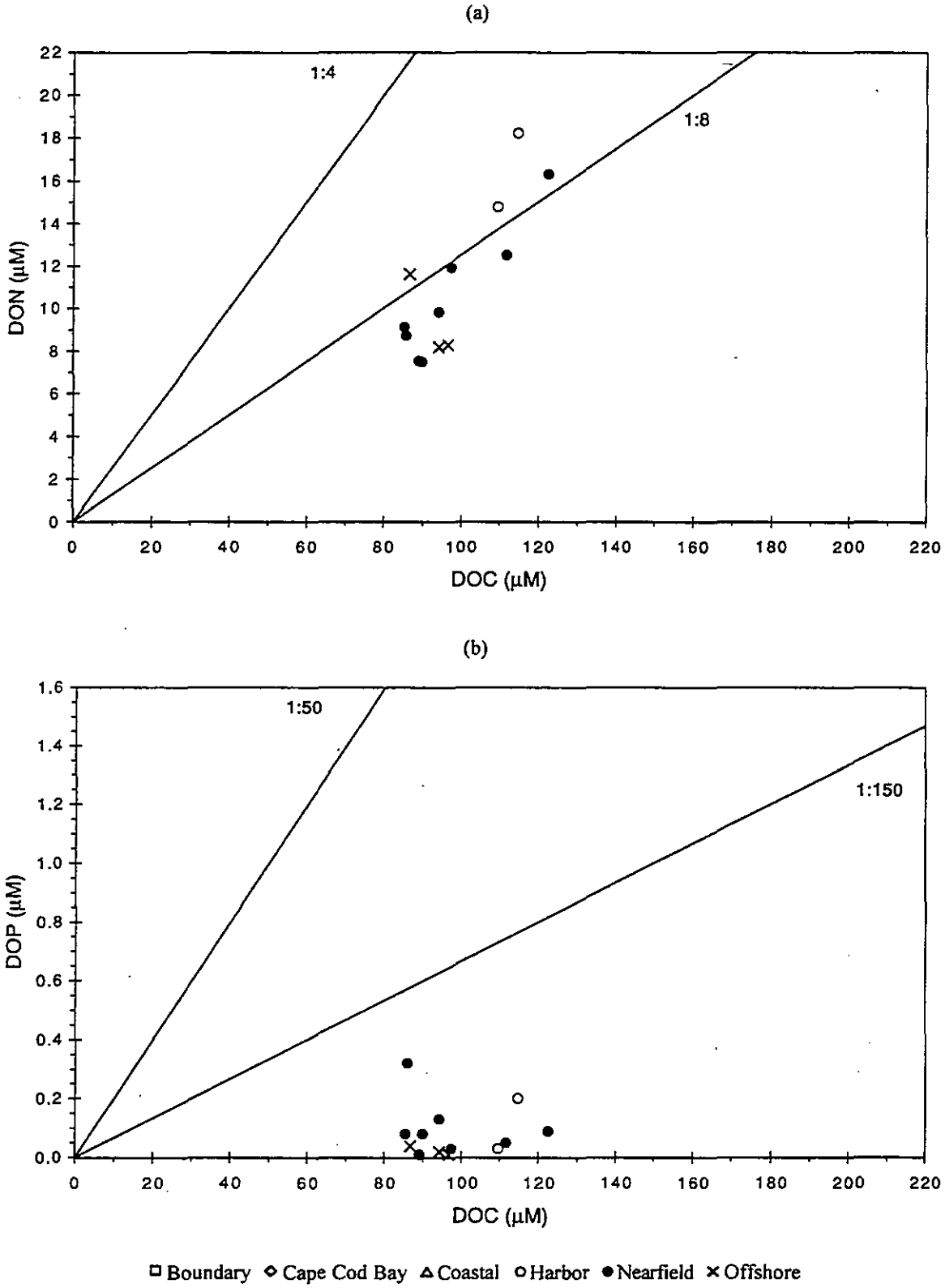
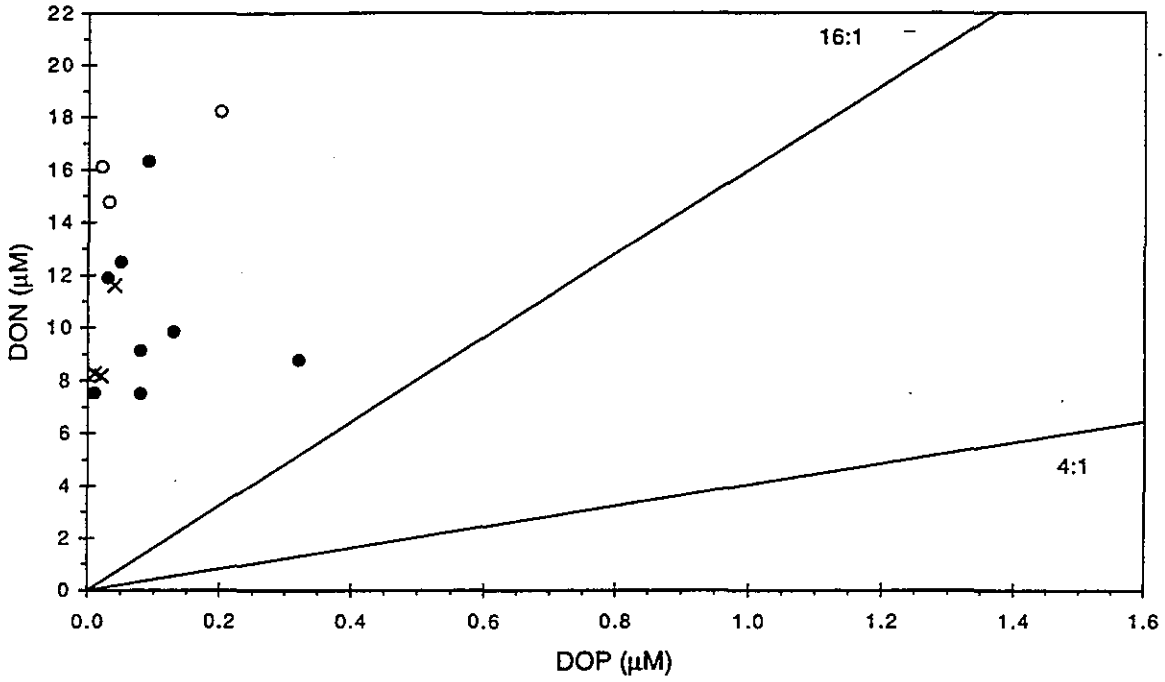
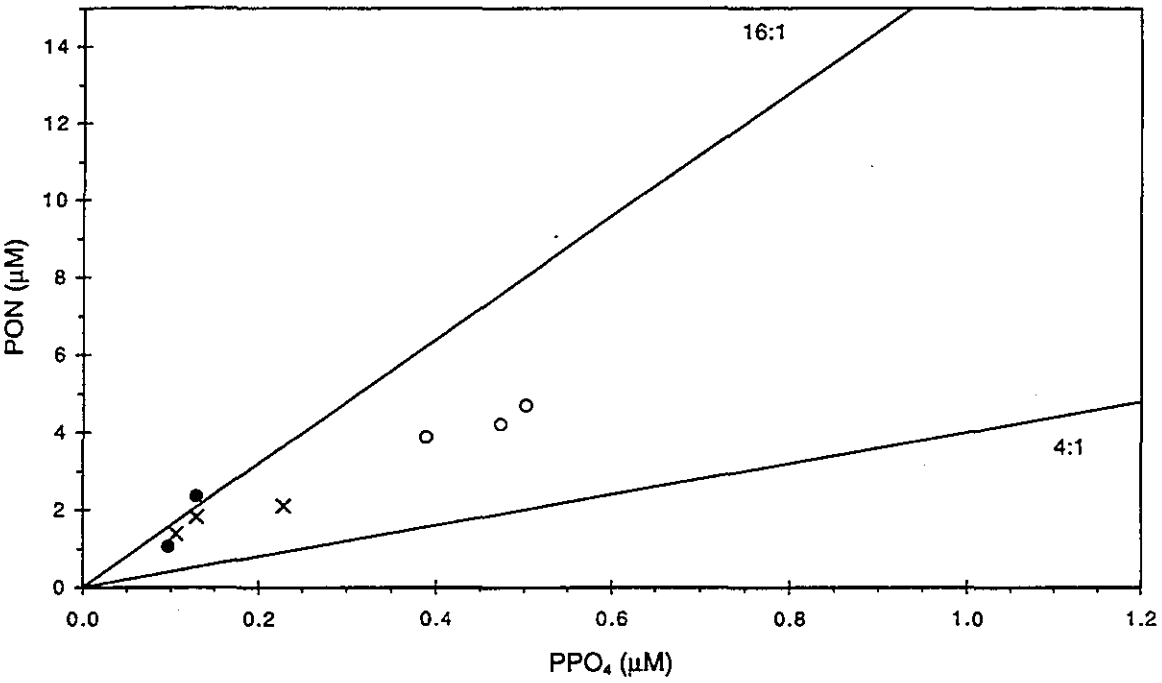


FIGURE 4-248
Nutrient vs. nutrient plots for nearfield/winter nutrients survey W9617, (Dec 96).

(a)



(b)



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-249
Nutrient vs. nutrient plots for nearfield/winter nutrients survey W9617, (Dec 96).

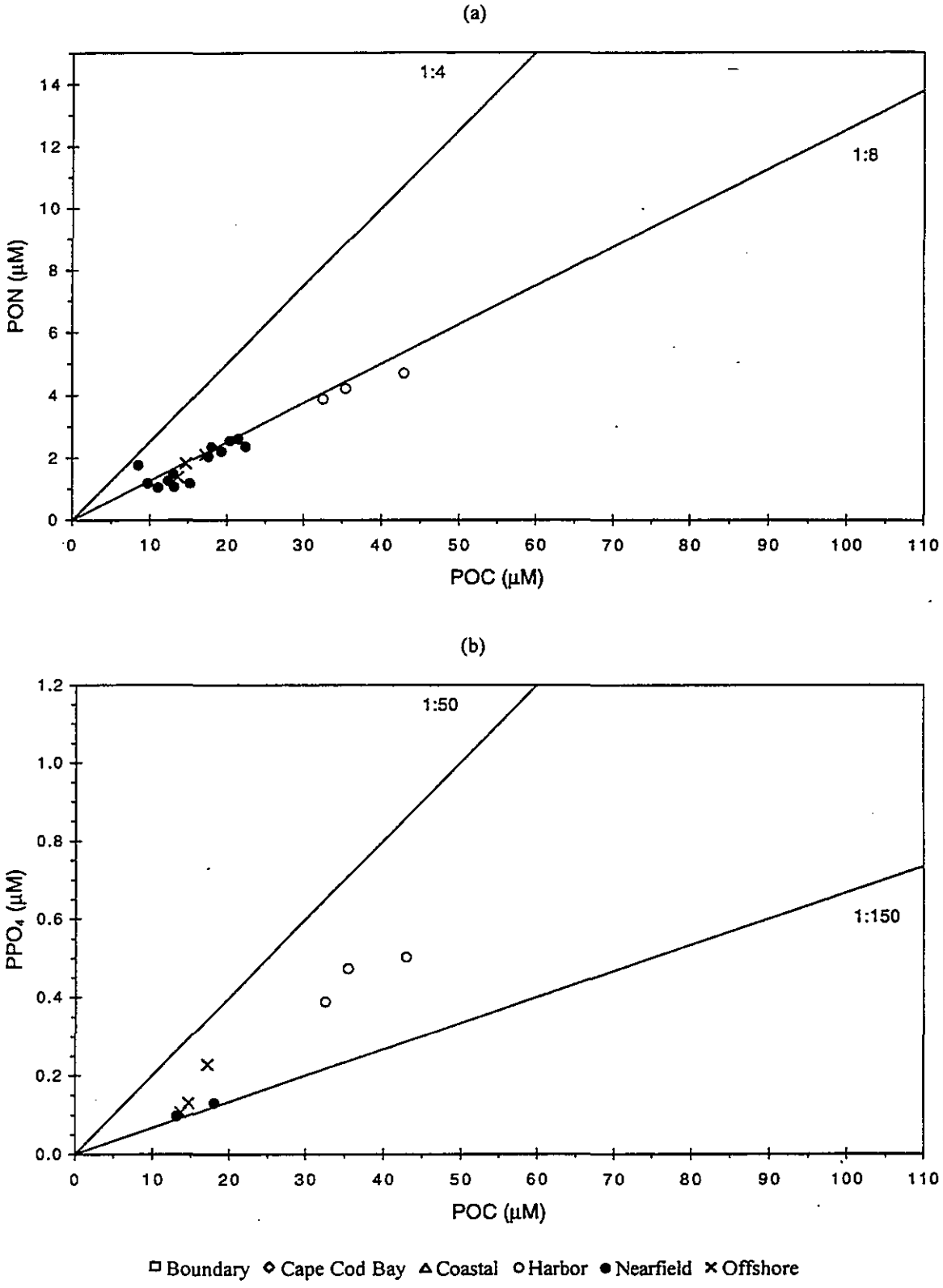
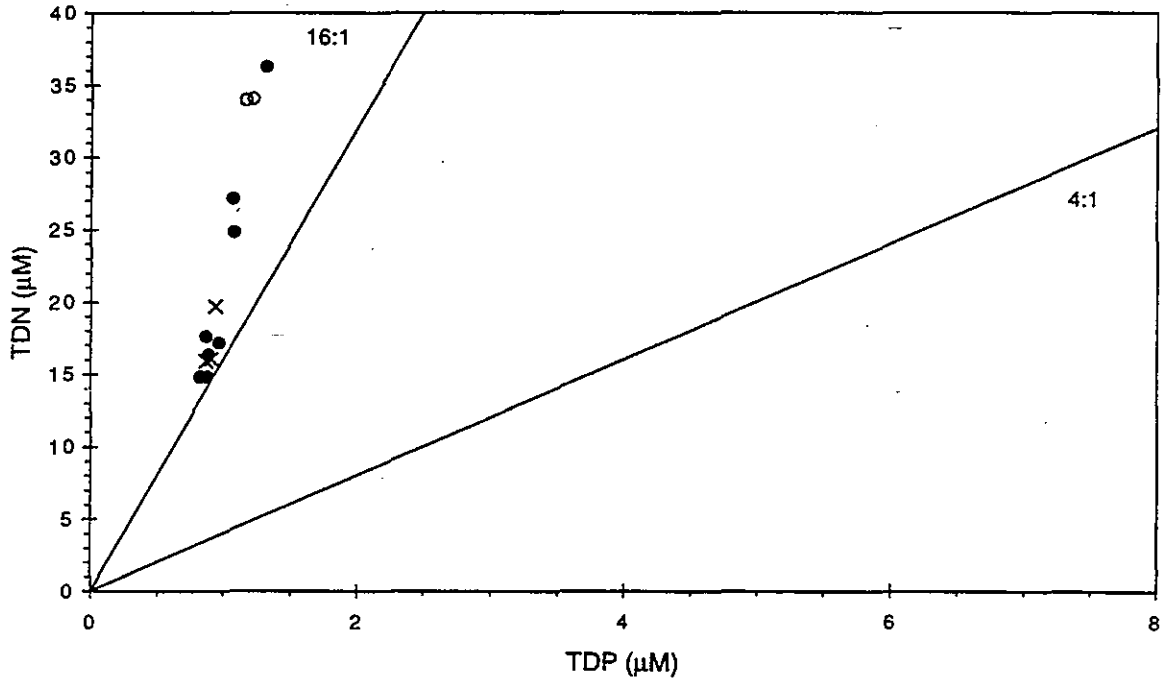
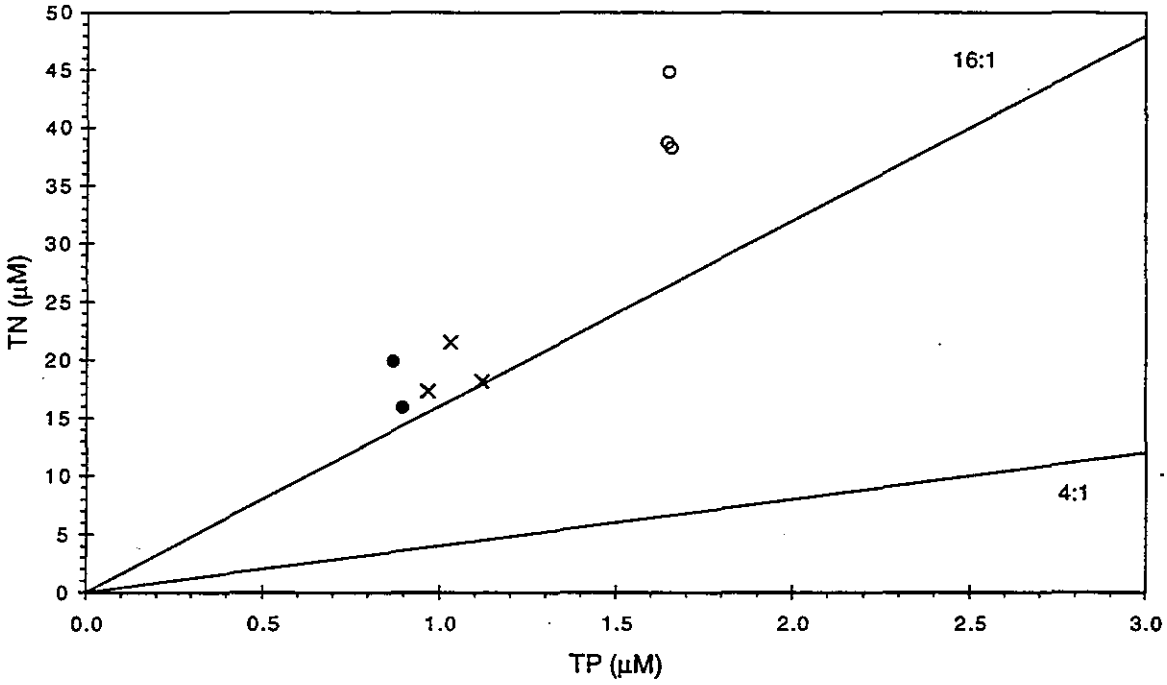


FIGURE 4-250
Nutrient vs. nutrient plots for nearfield/winter nutrients survey W9617, (Dec 96).

(a)



(b)



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-251
Nutrient vs. nutrient plots for nearfield/winter nutrients survey W9617, (Dec 96).

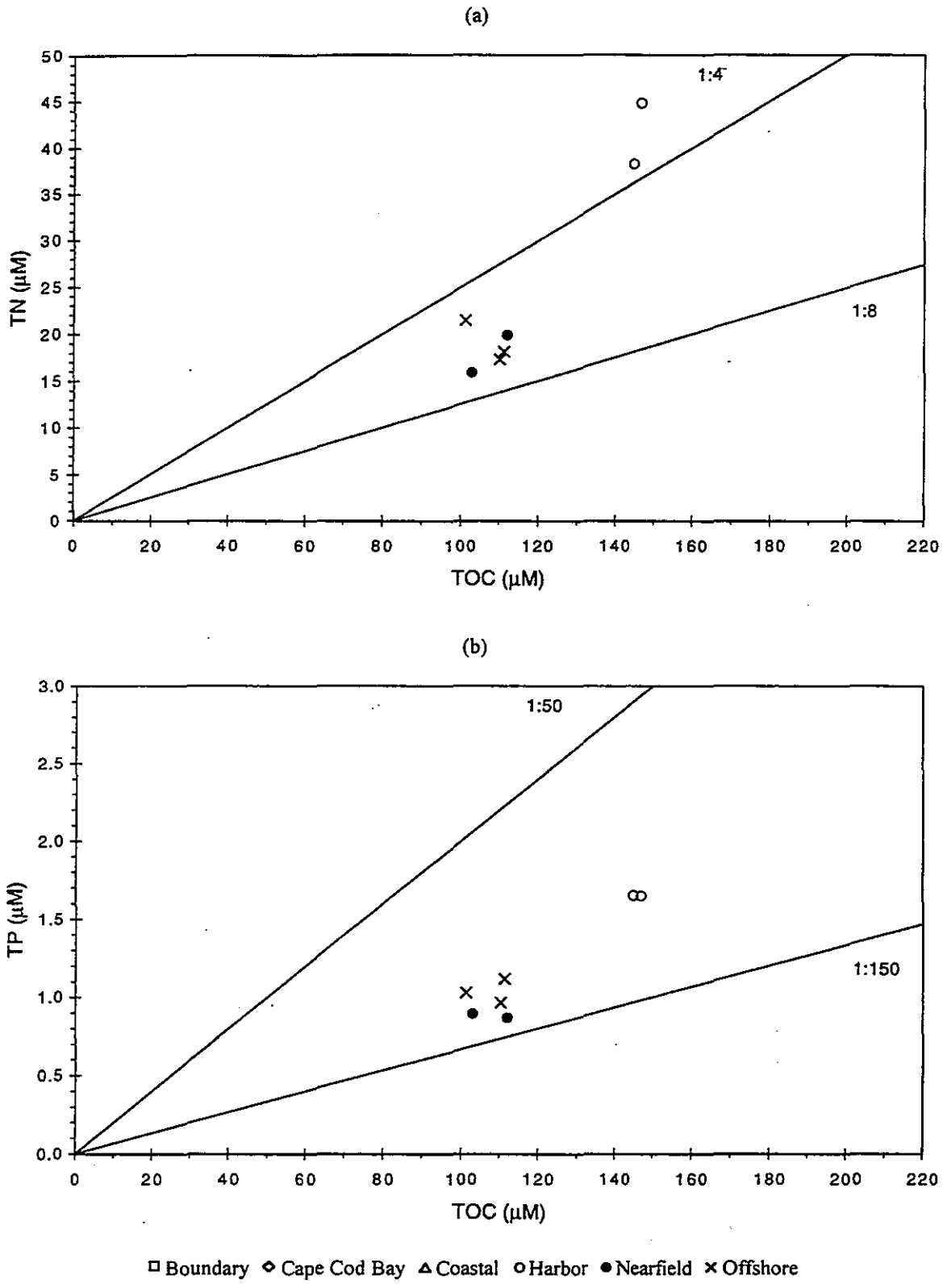
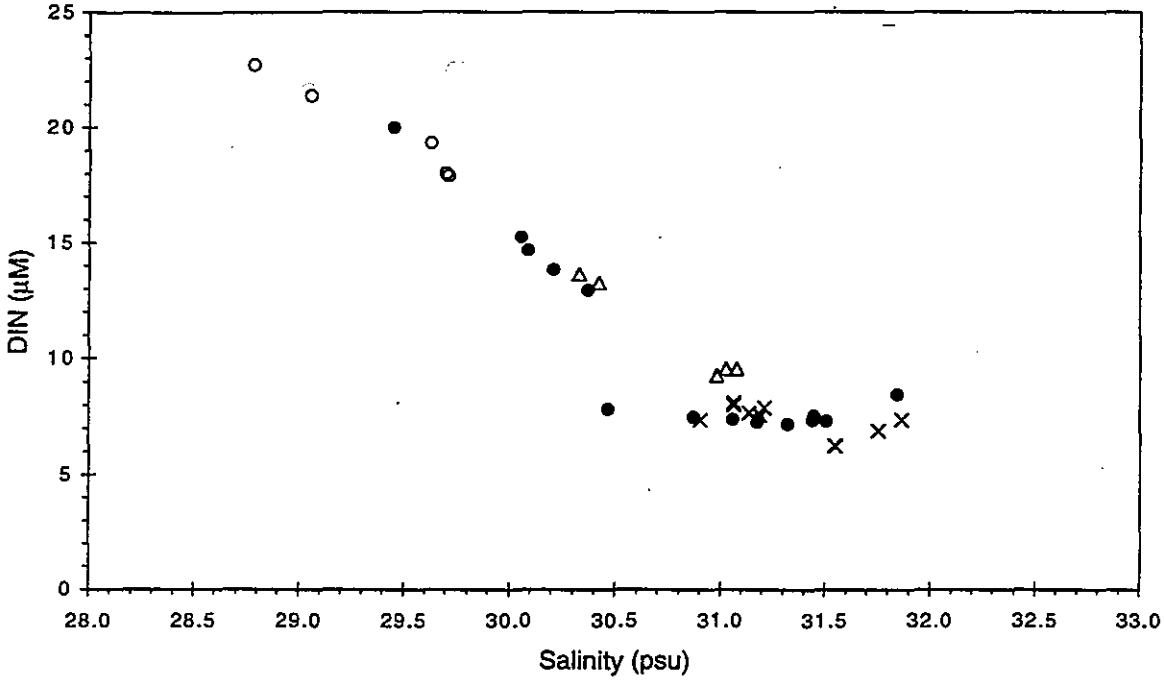


FIGURE 4-252
Nutrient vs. nutrient plots for nearfield/winter nutrients survey W9617, (Dec 96).



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-253
Nutrient vs. salinity plots for nearfield/winter nutrients survey W9617, (Dec 96).

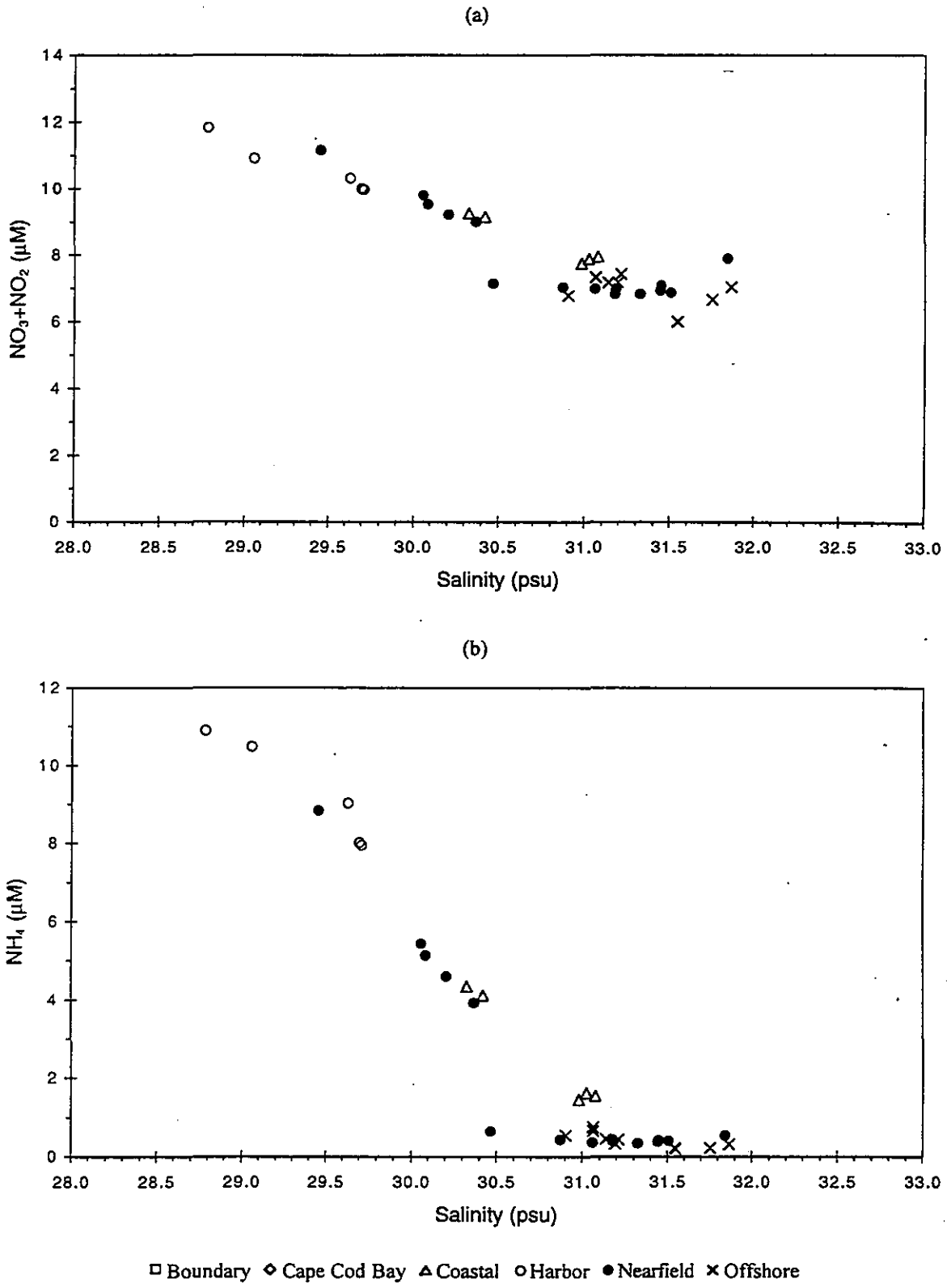
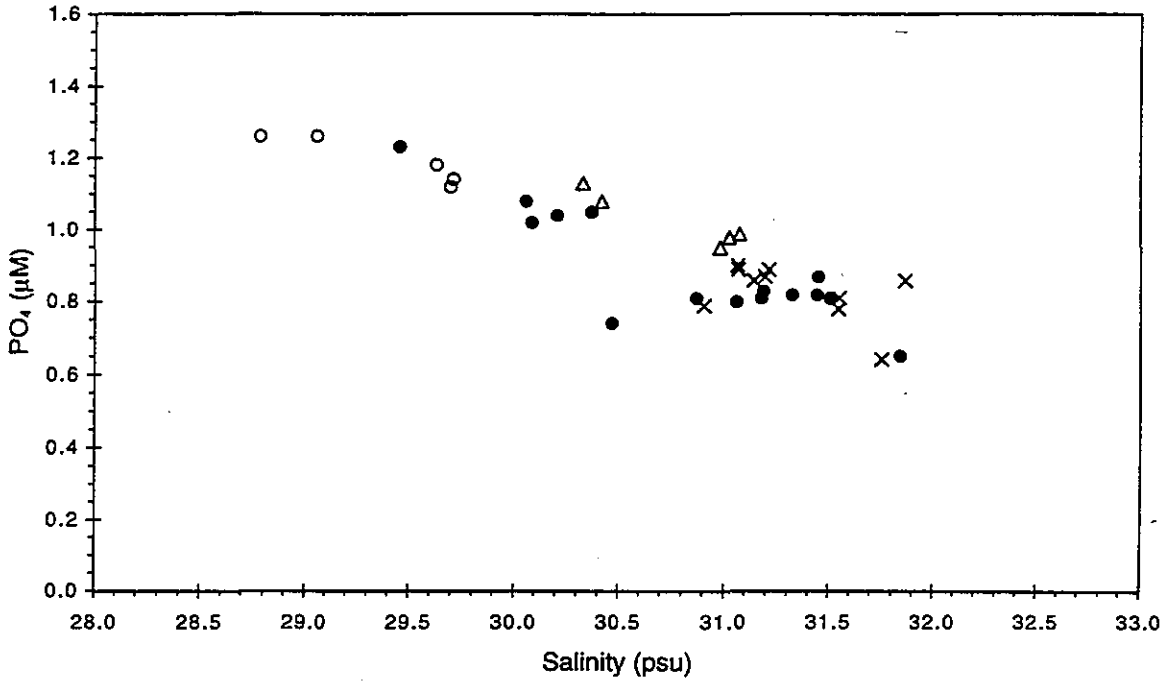
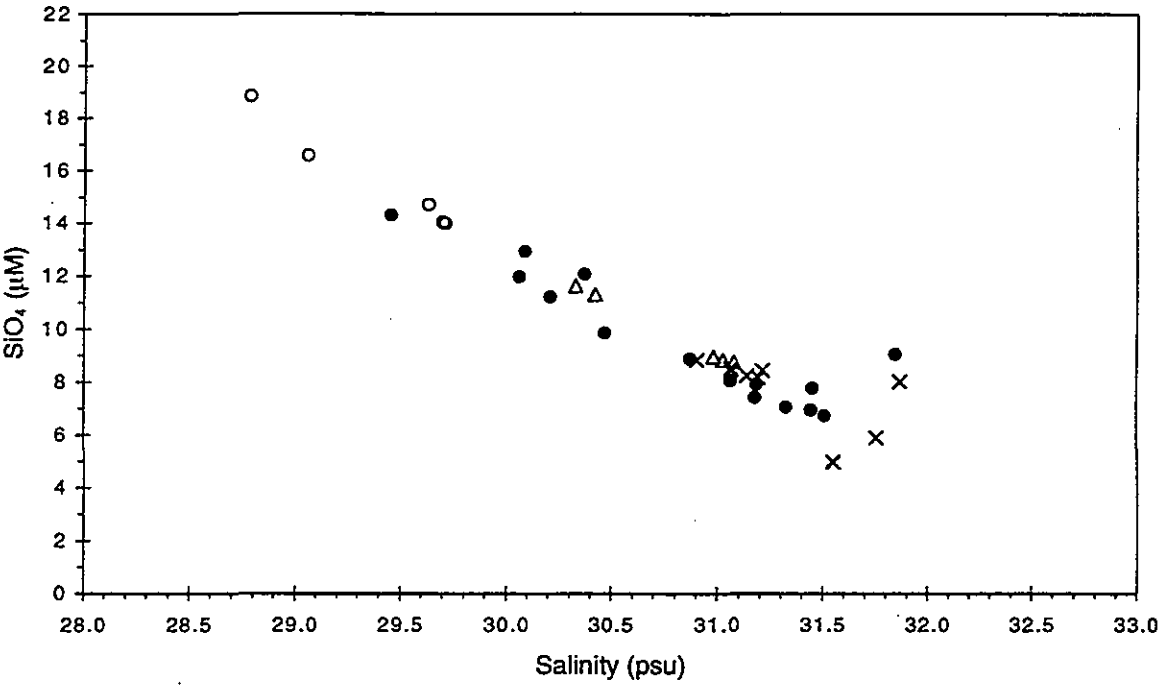


FIGURE 4-254
Nutrient vs. salinity plots for nearfield/winter nutrients survey W9617, (Dec 96).

(a)



(b)



□ Boundary ◇ Cape Cod Bay △ Coastal ○ Harbor ● Nearfield × Offshore

FIGURE 4-255
Nutrient vs. salinity plots for nearfield/winter nutrients survey W9617, (Dec 96).

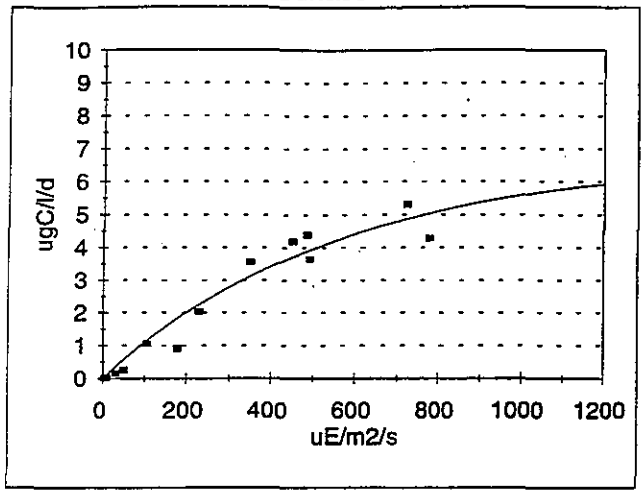
APPENDIX E

Photosynthesis-Irradiance (P-I) Curves

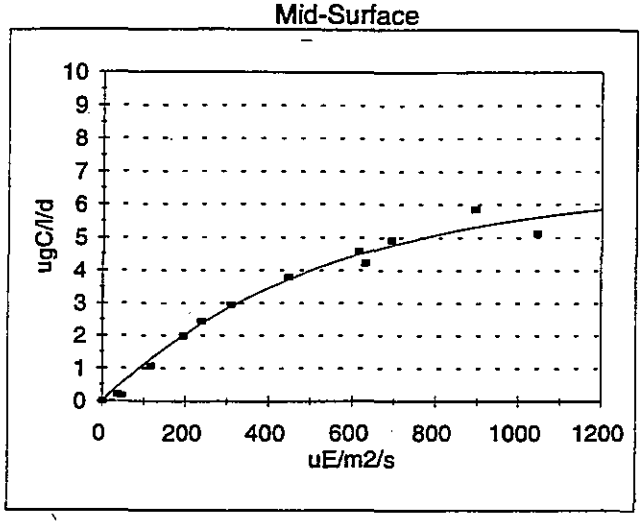
Productivity calculations (Appendix A) utilized light attenuation data from a CTD-mounted 4π sensor and incident light time-series data from an on-deck 2π irradiance sensor. After collection of the productivity samples, they were incubated in a temperature-controlled incubator. The resulting photosynthesis ($mgC/m^3/h$) versus light irradiance ($\mu E/m^2/s$, P-I) curves are comprehensively presented in this appendix. These data were used to determine hourly production at intervals throughout the day for each sampling depth.

W9610 Station N10

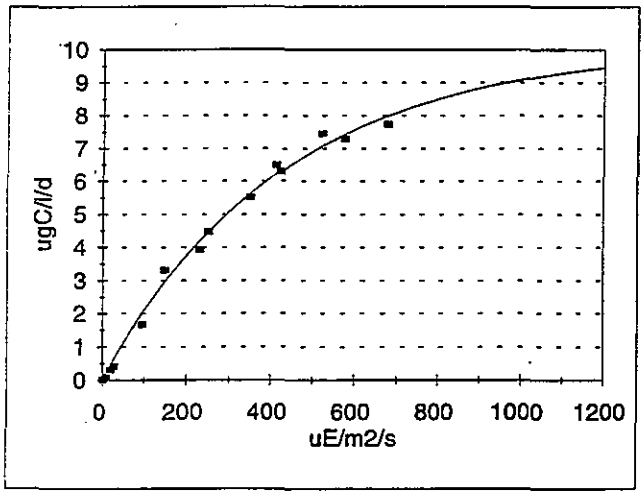
Surface



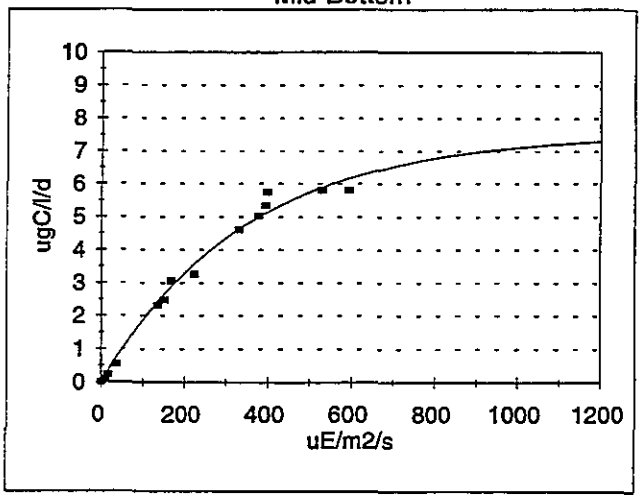
Mid-Surface



Middle



Mid-Bottom



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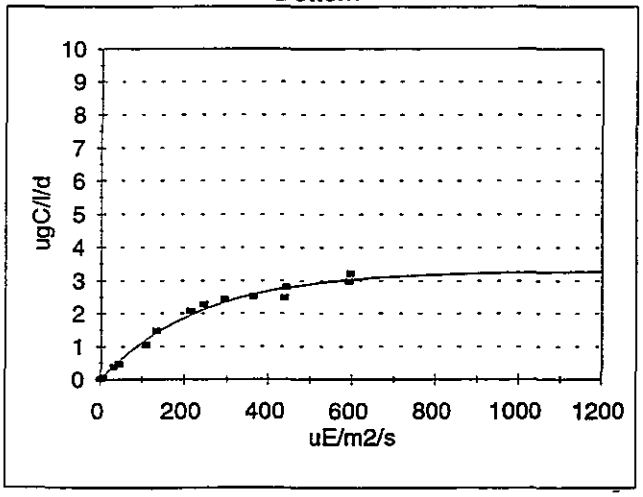
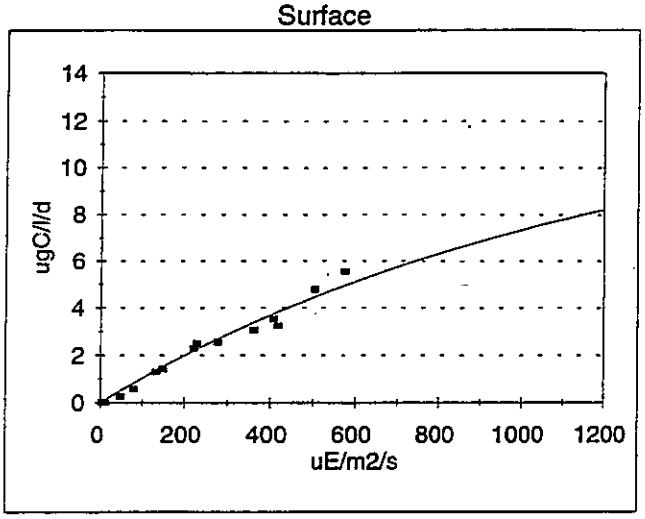
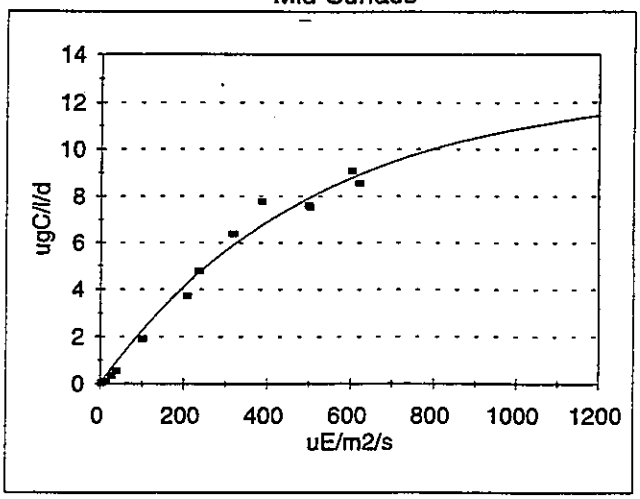


W9610 Station N04

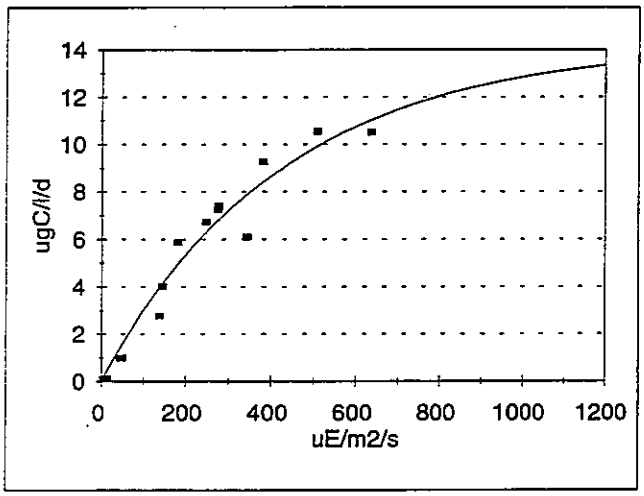
Surface



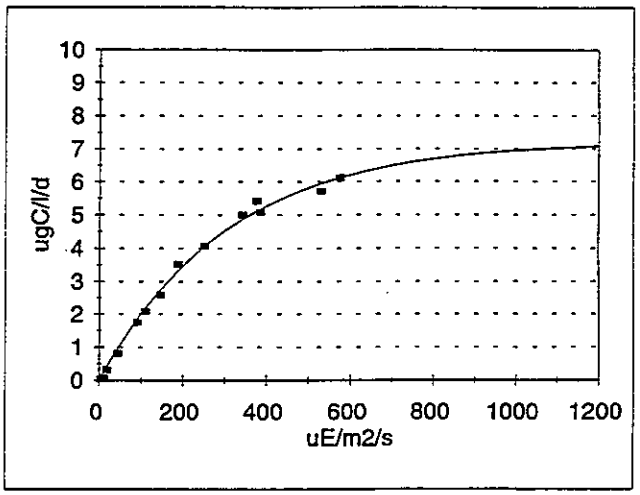
Mid-Surface



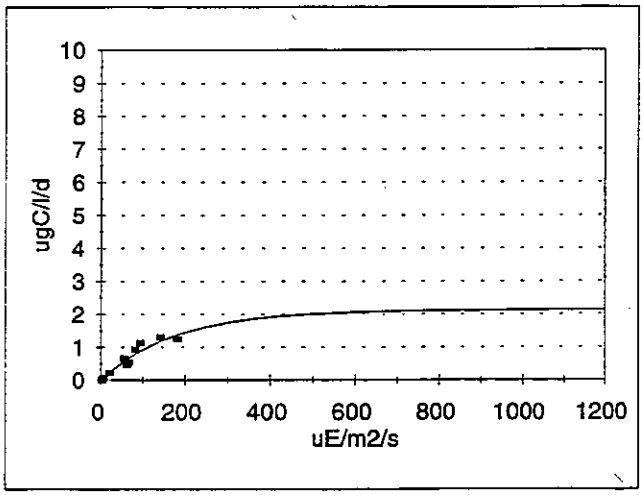
Middle



Mid-Bottom

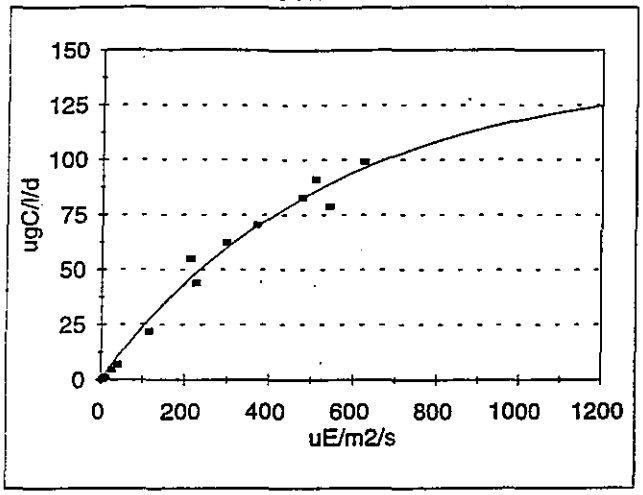


Bottom

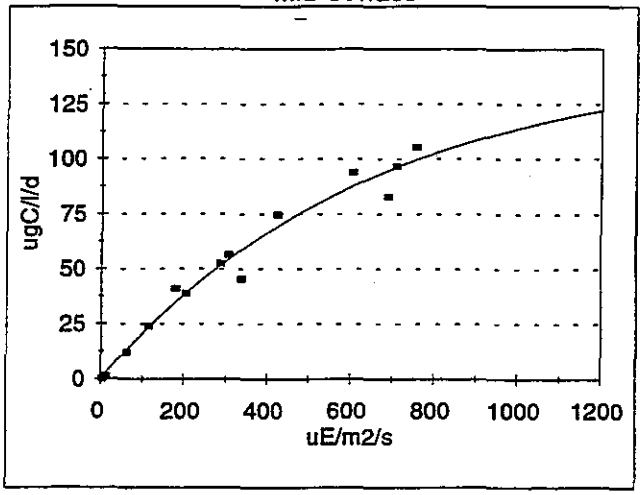


W9611 Station F23

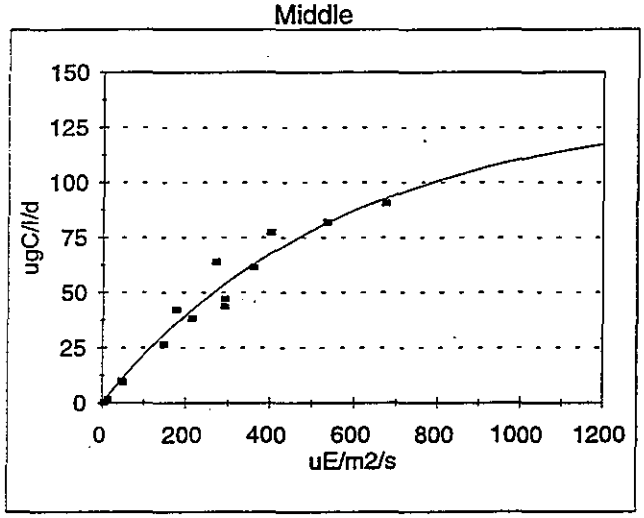
Surface



Mid-Surface



Middle



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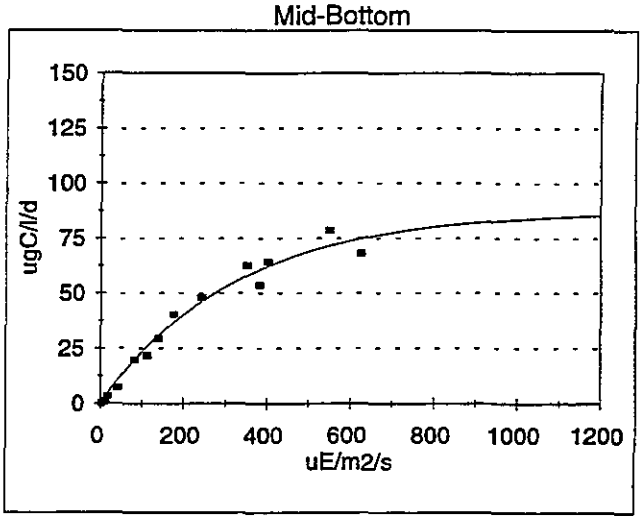
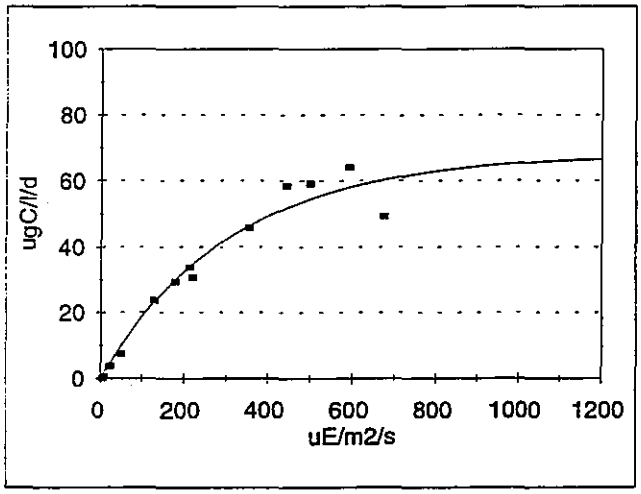
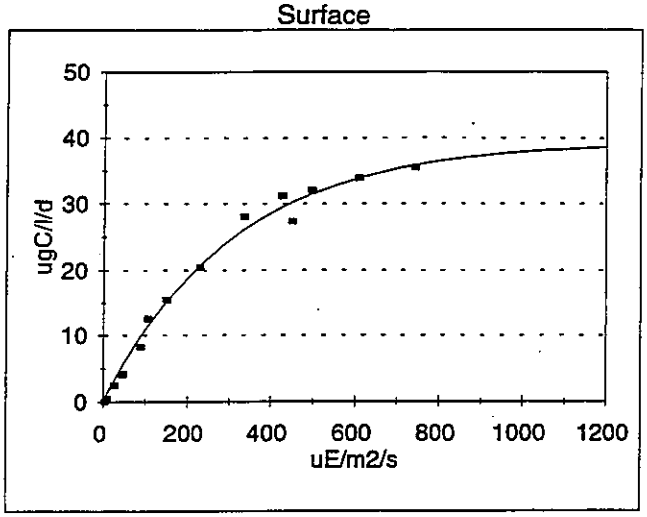


Bottom

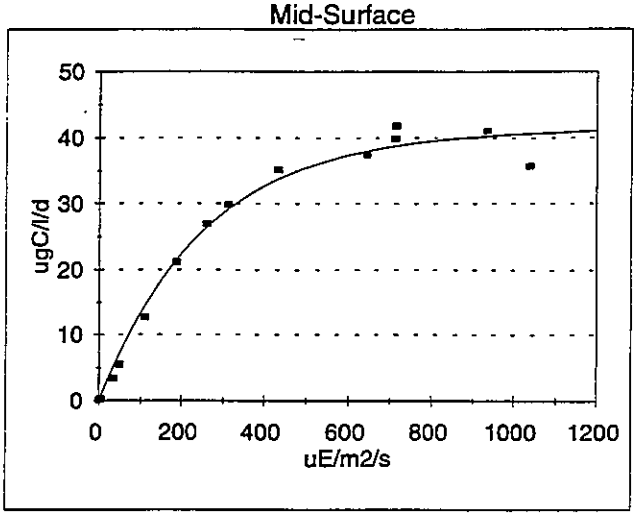


W9611 Station N10

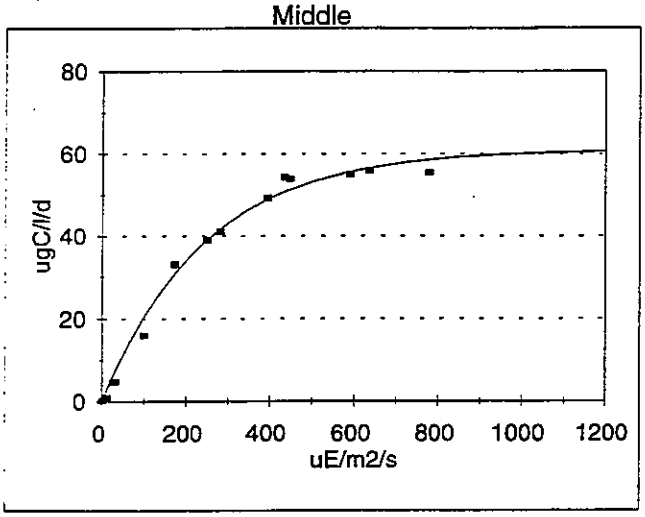
Surface



Mid-Surface



Middle



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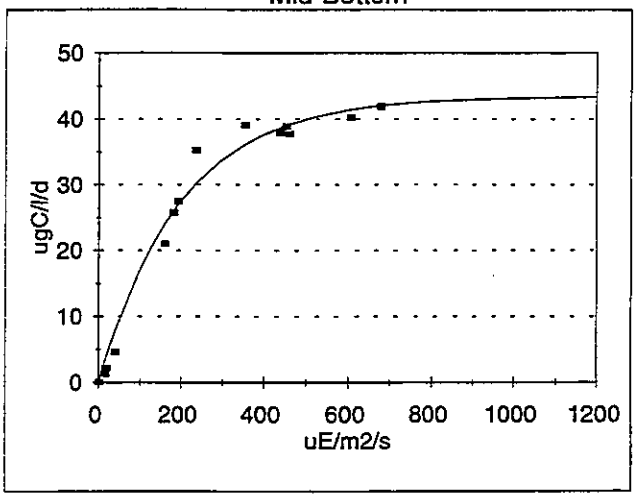

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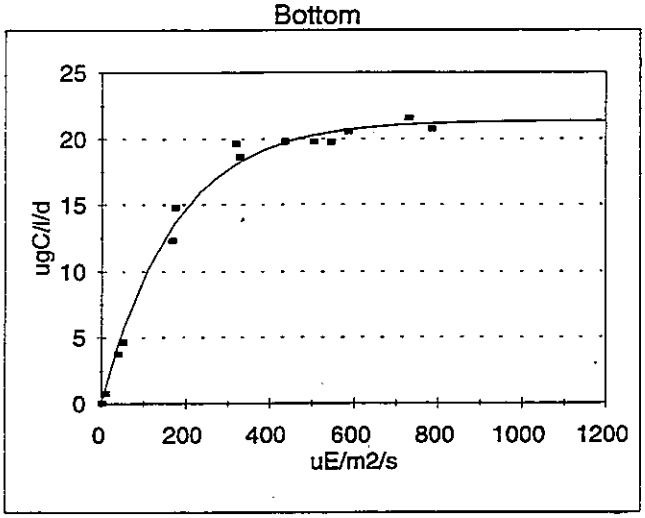
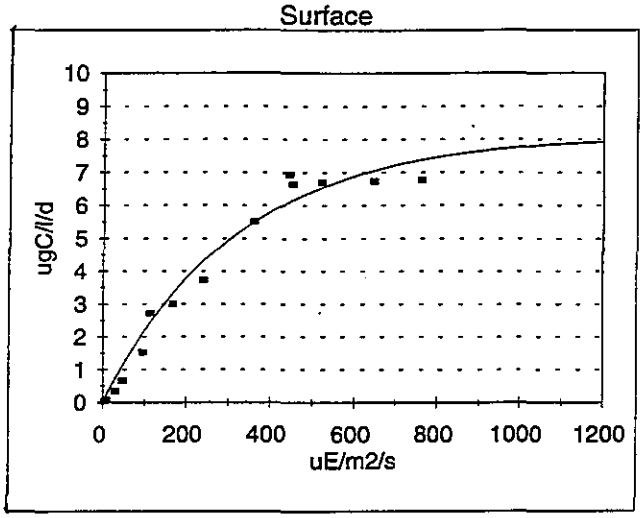
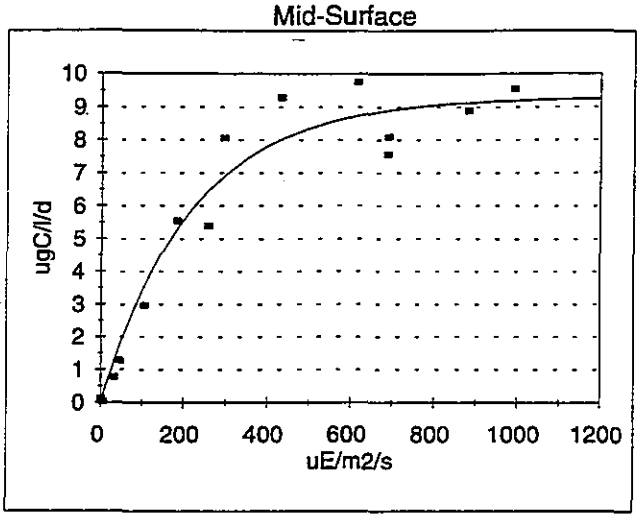


W9611 Station N16

Surface



Mid-Surface



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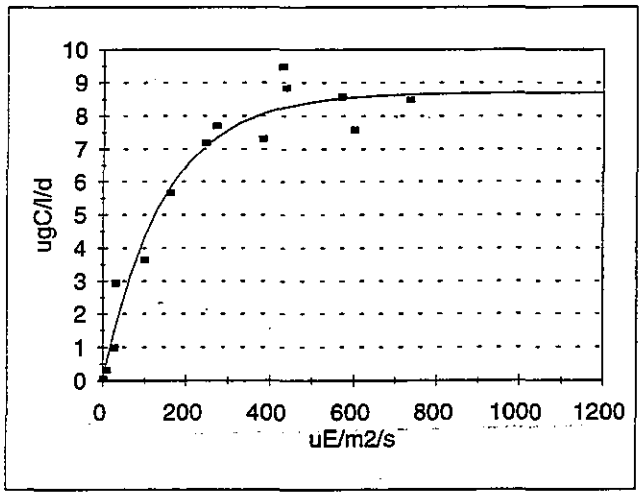
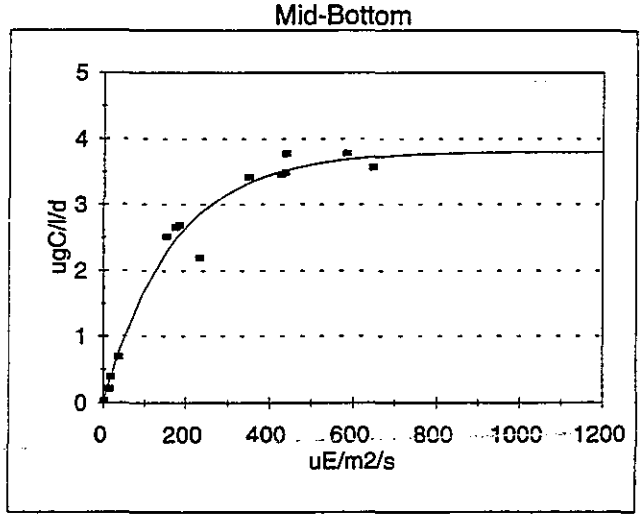


Mid-Bottom



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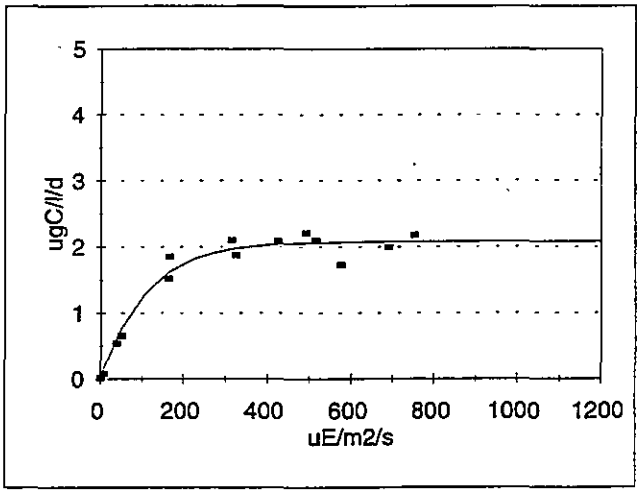
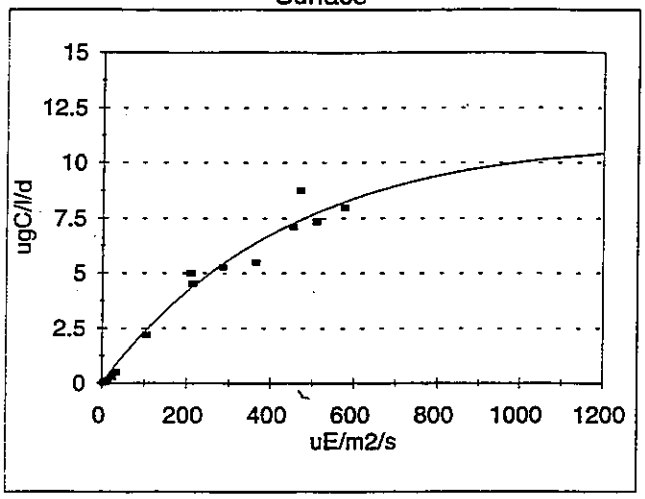
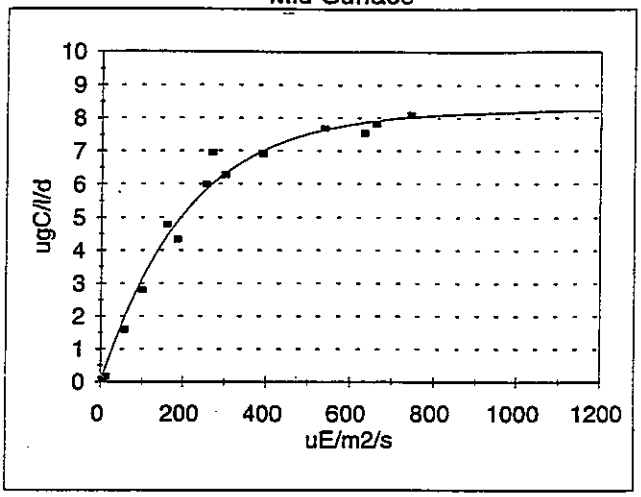


W9611 Station N04

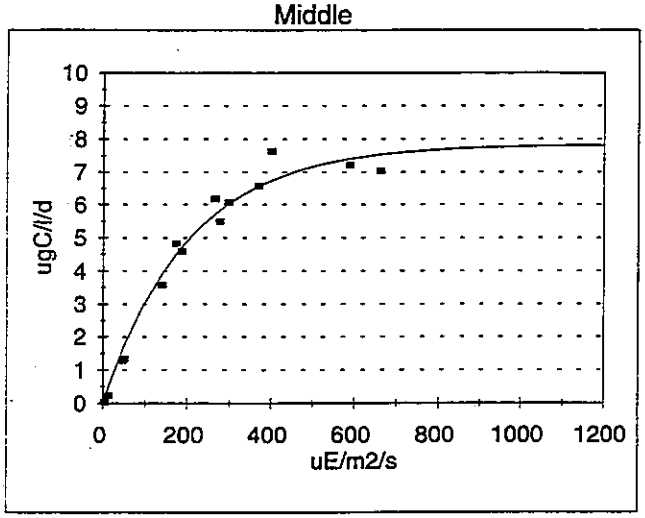
Surface



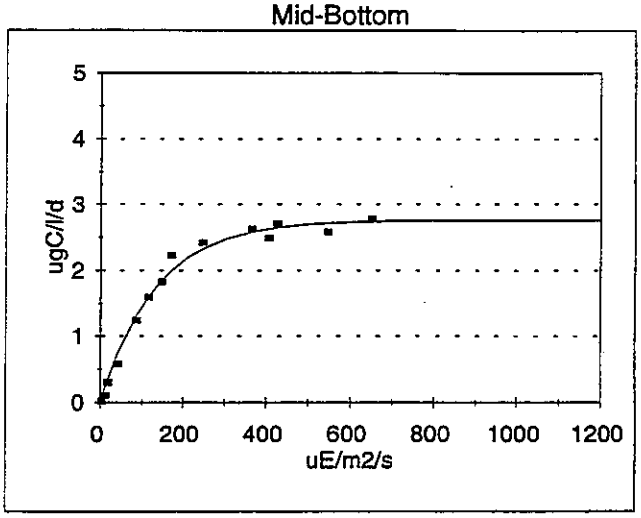
Mid-Surface



Middle



Mid-Bottom



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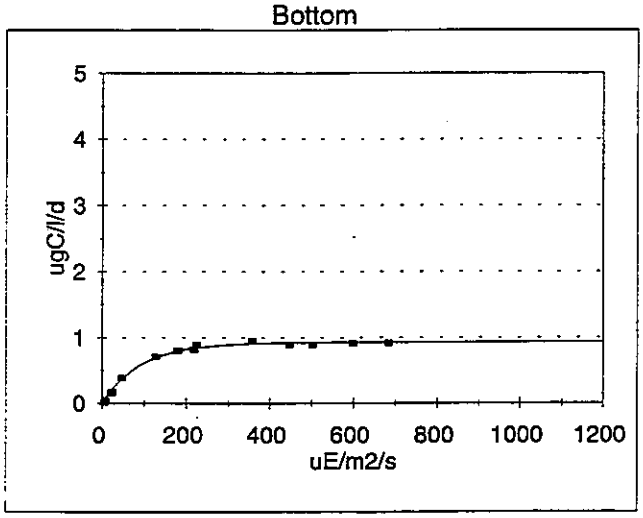
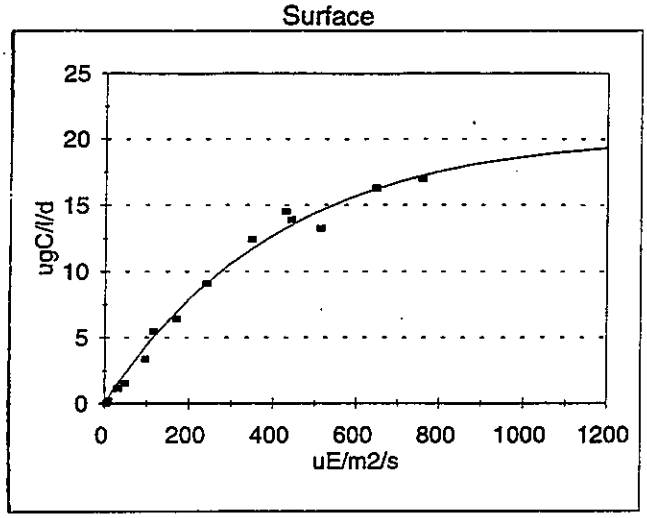
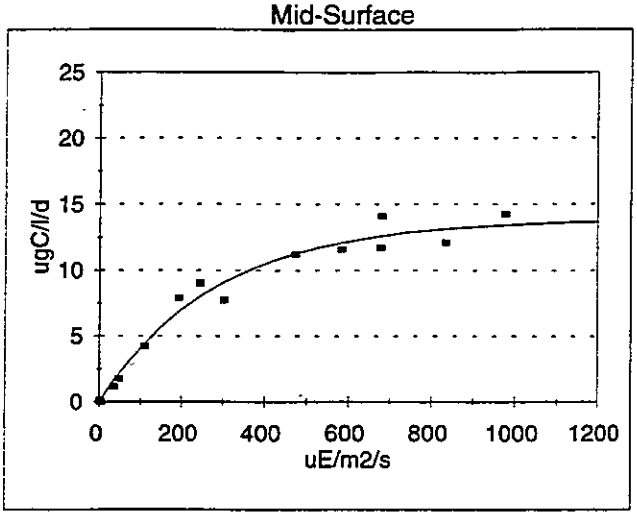


W9612 Station N10

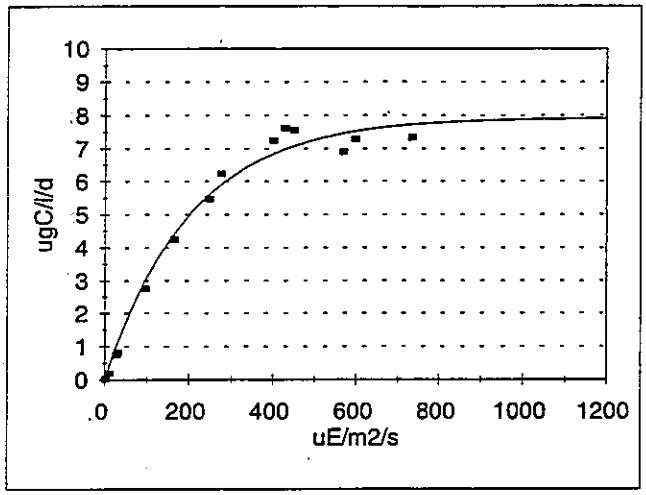
Surface



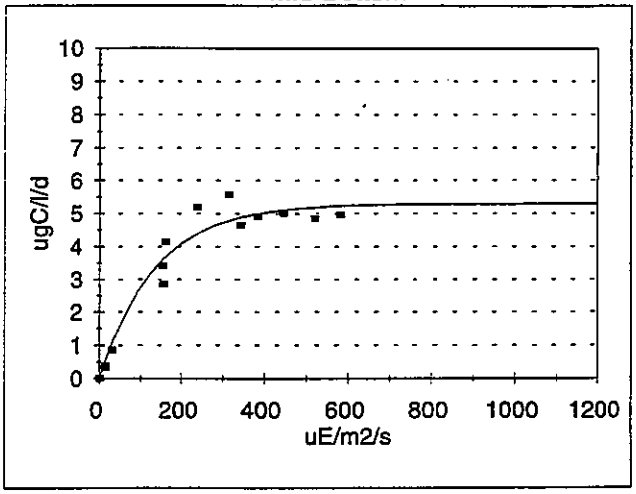
Mid-Surface



Middle



Mid-Bottom



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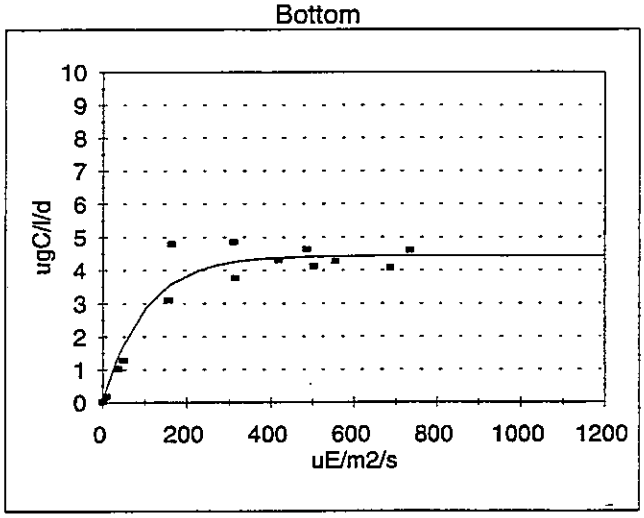
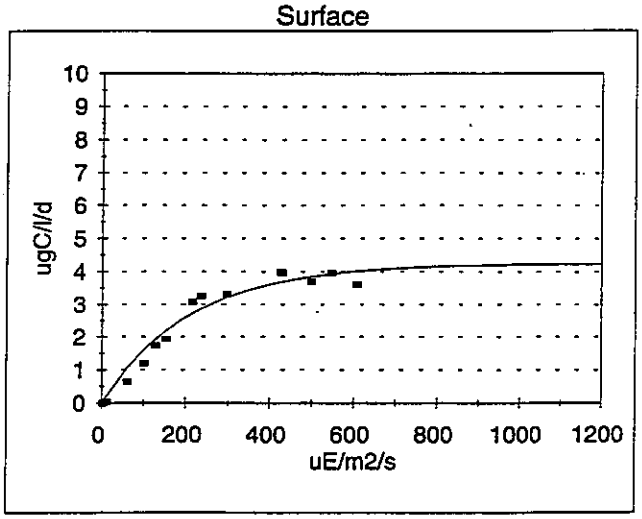
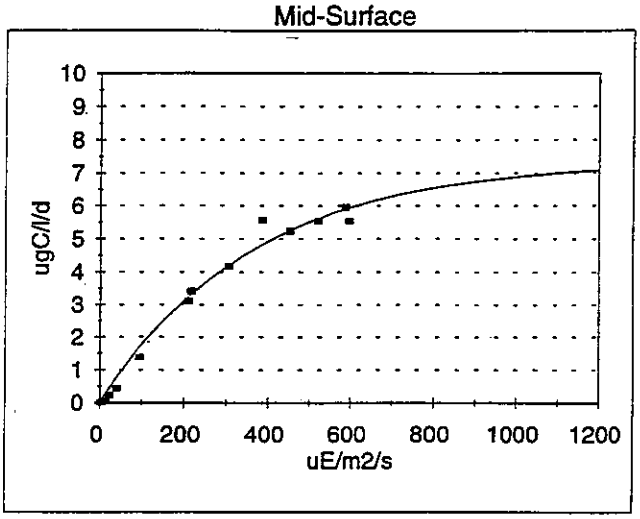


W9612 Station N04

Surface



Mid-Surface



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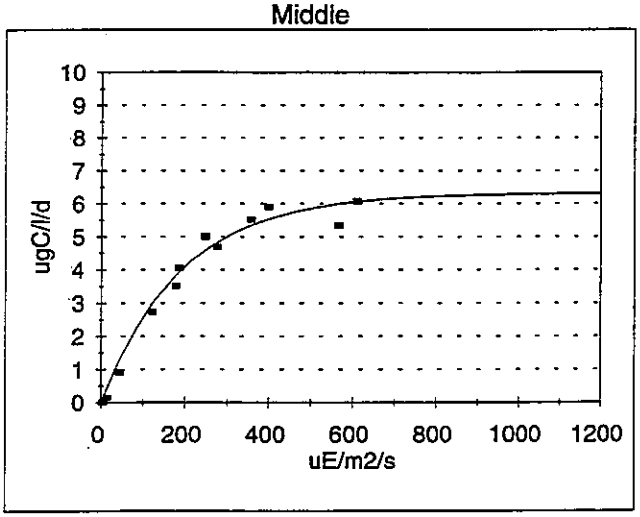

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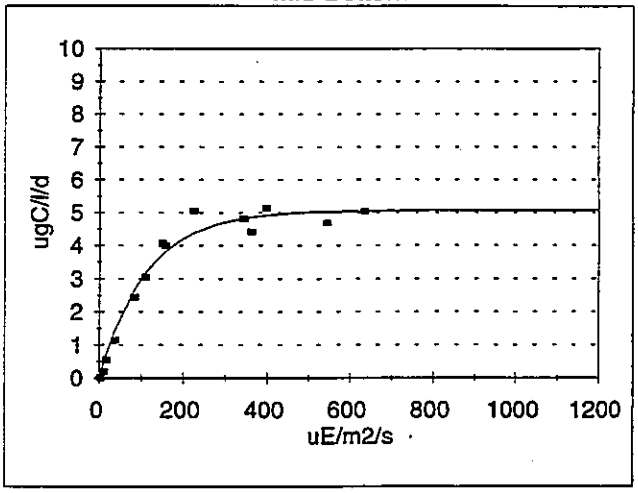

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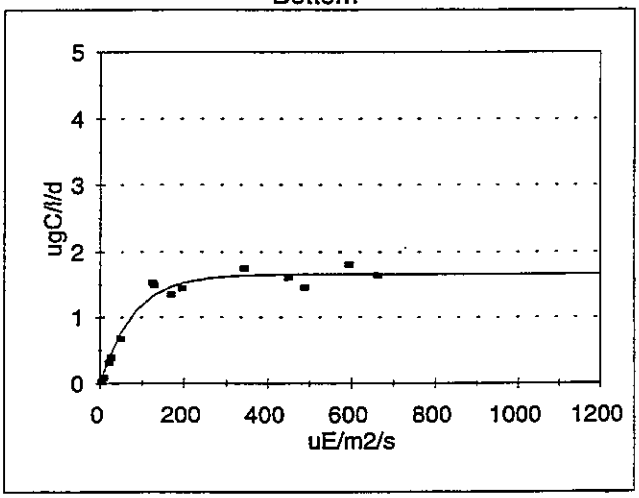
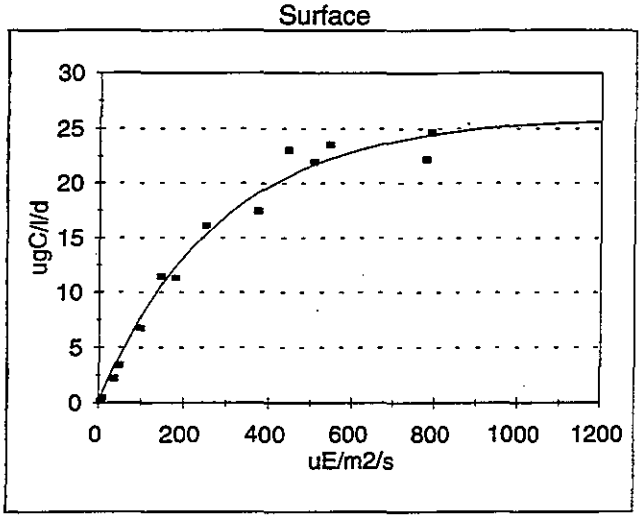


W9613 Station N10

Surface



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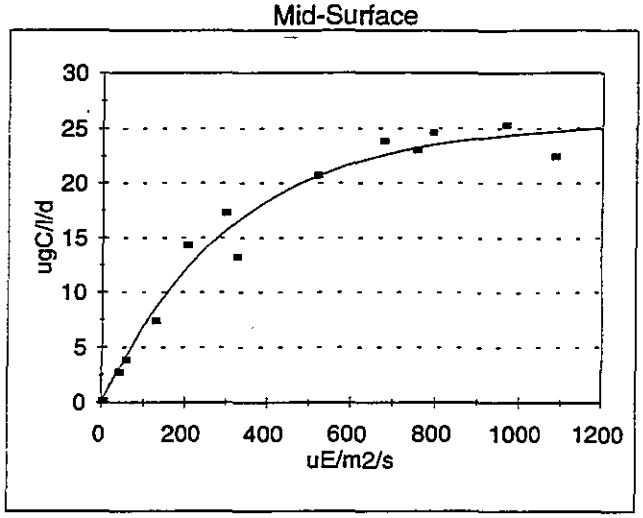

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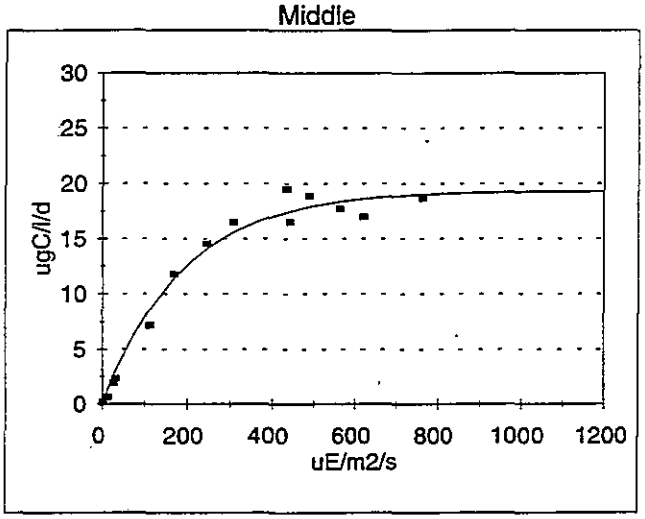
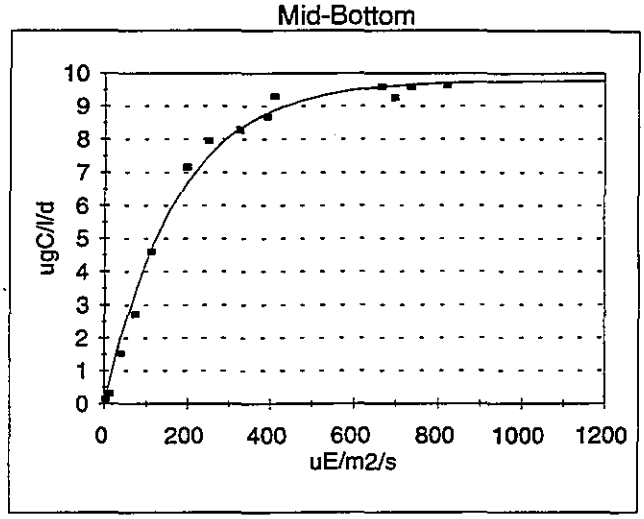


Mid-Bottom



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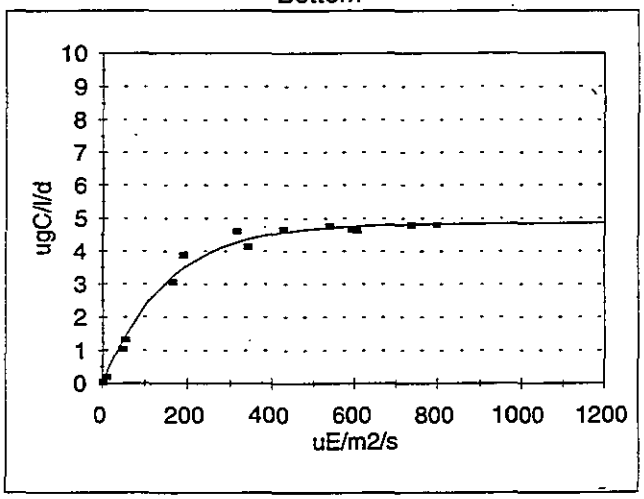
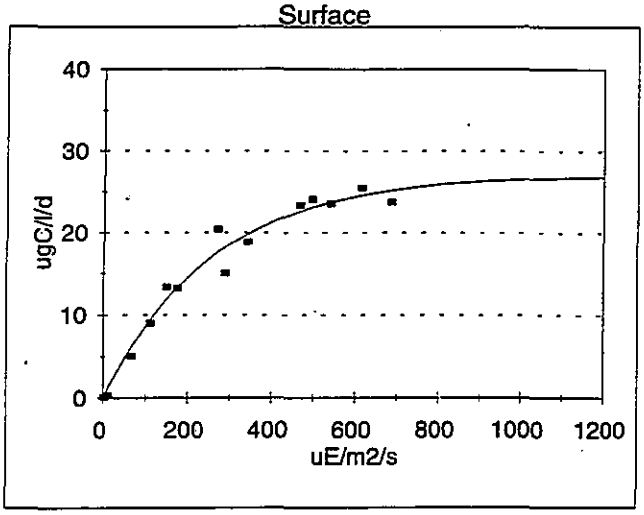
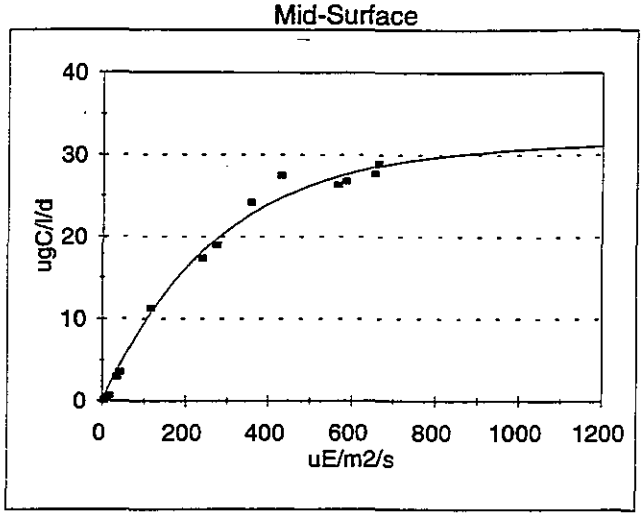


W9613 Station N04

Surface



Mid-Surface



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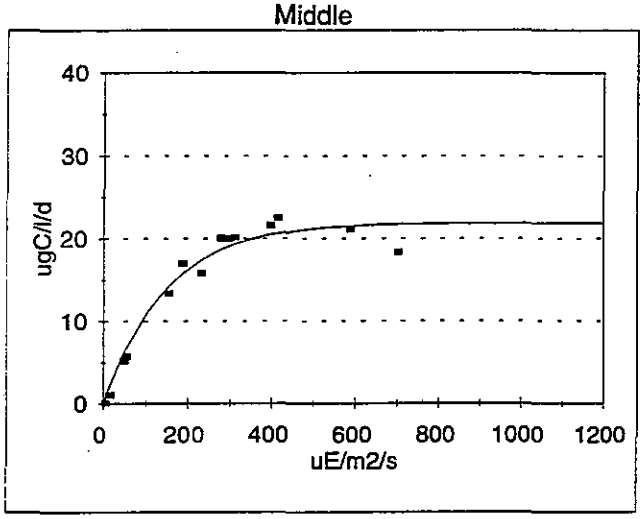

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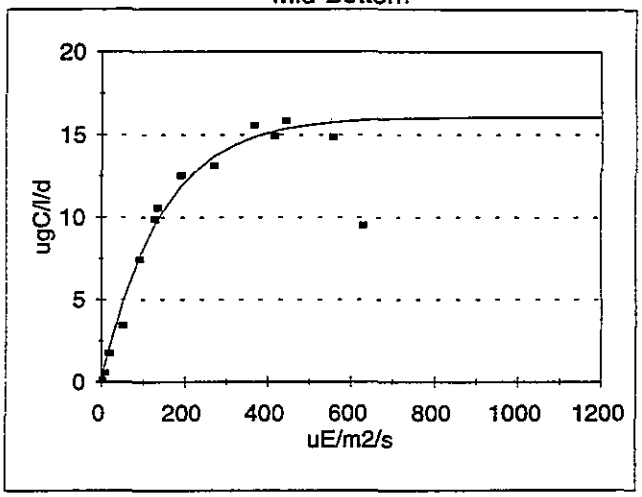

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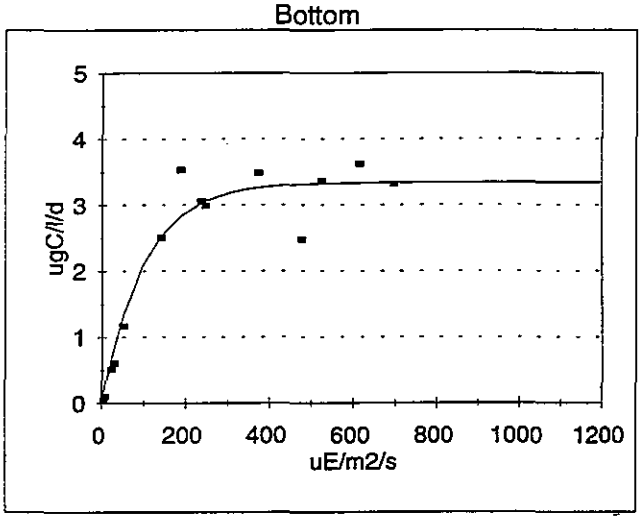
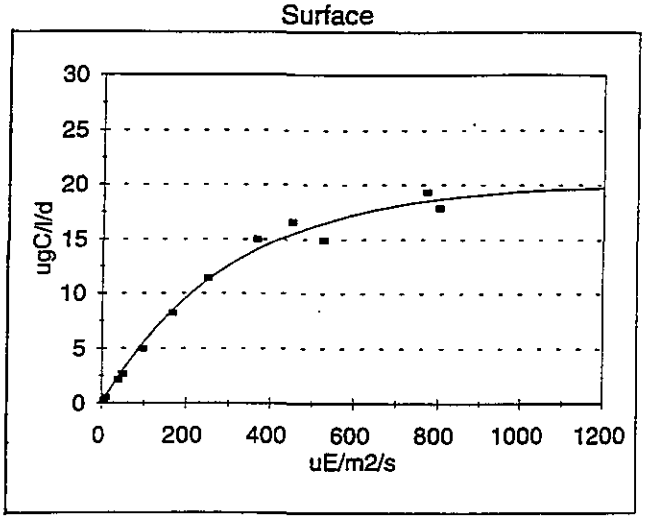
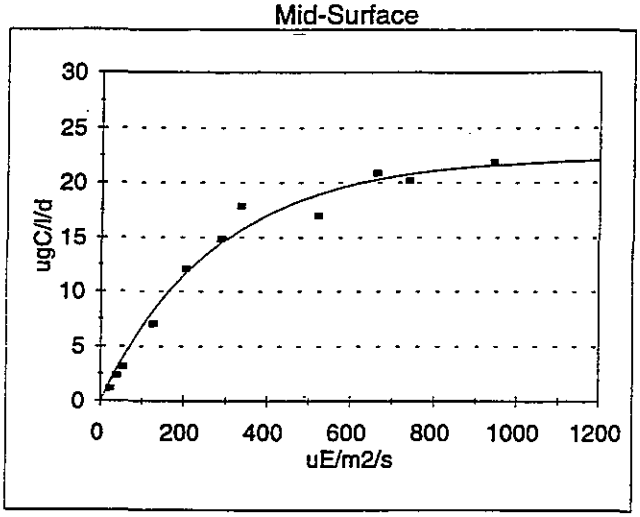


W9614 Station F23

Surface



Mid-Surface



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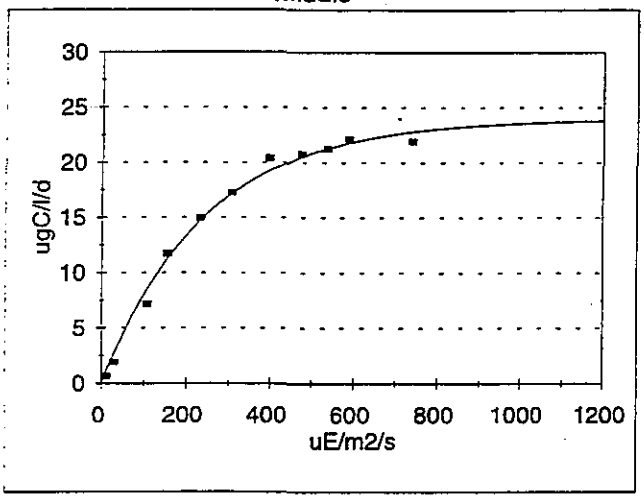

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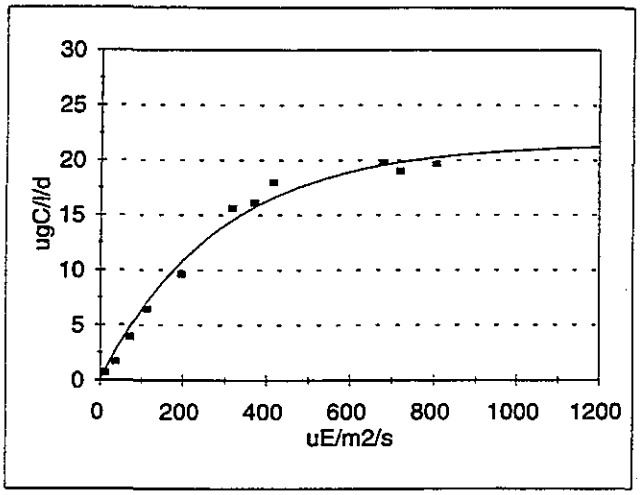

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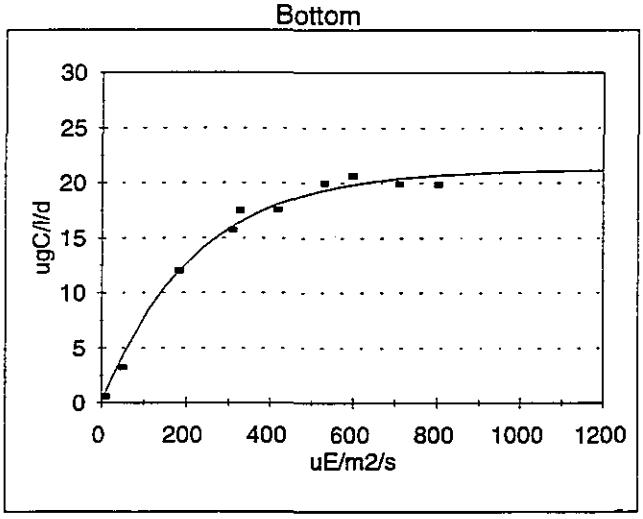
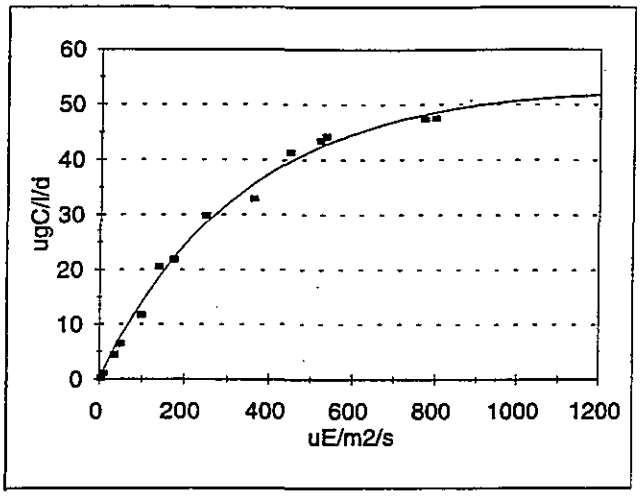
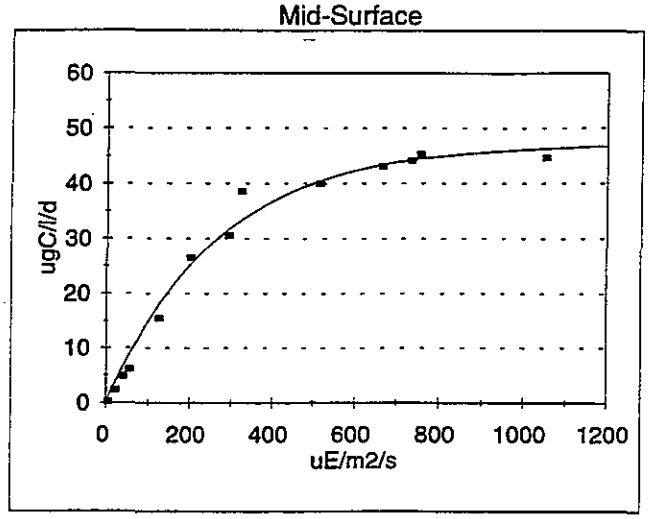


W9614 Station N10

Surface



Mid-Surface



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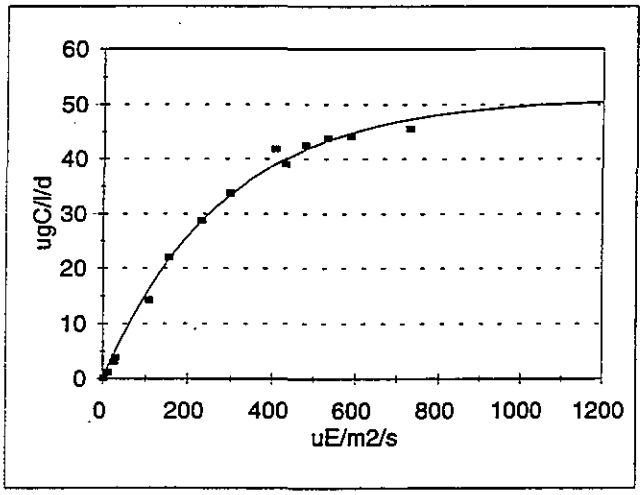
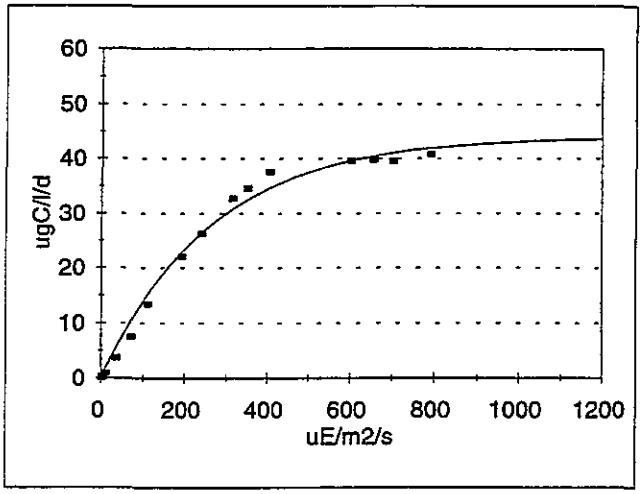


Mid-Bottom



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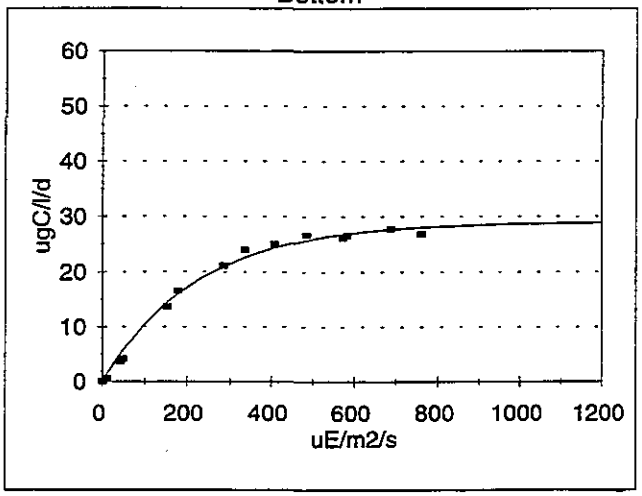
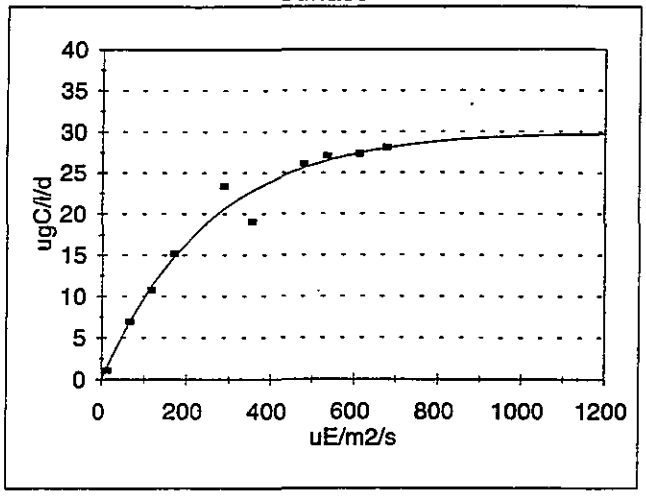
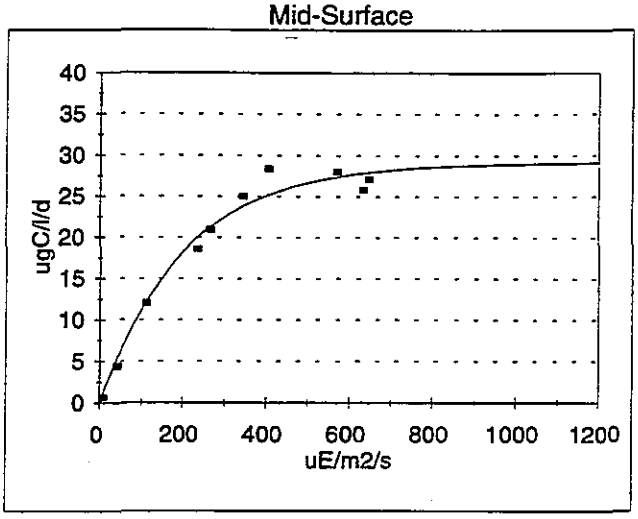


W9614 Station N16

Surface



Mid-Surface



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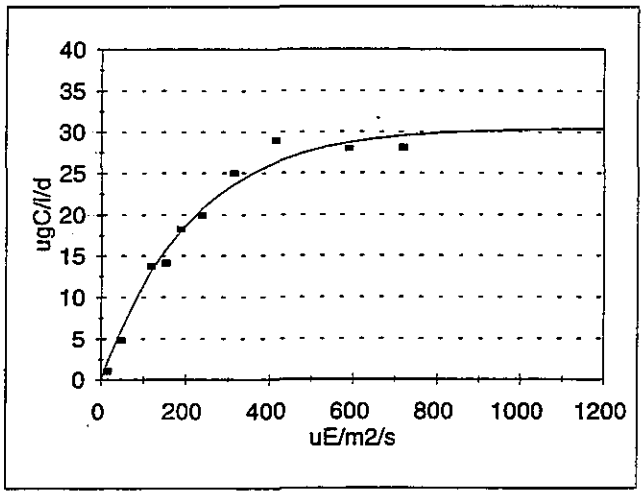
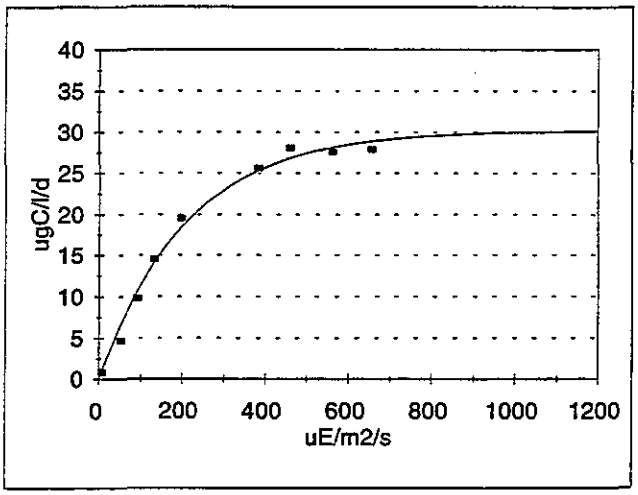


Mid-Bottom



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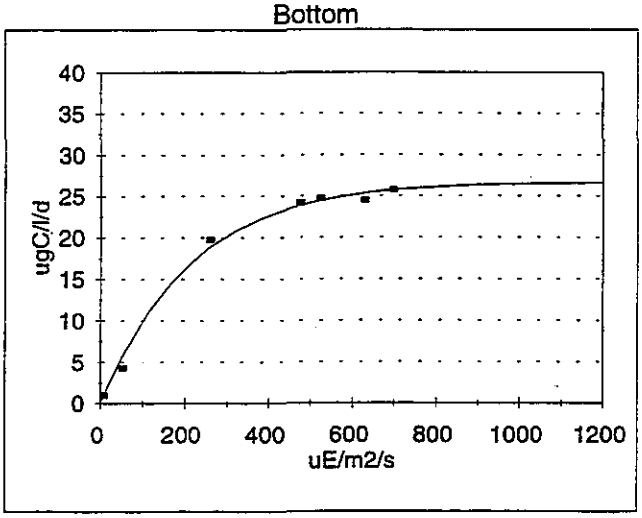
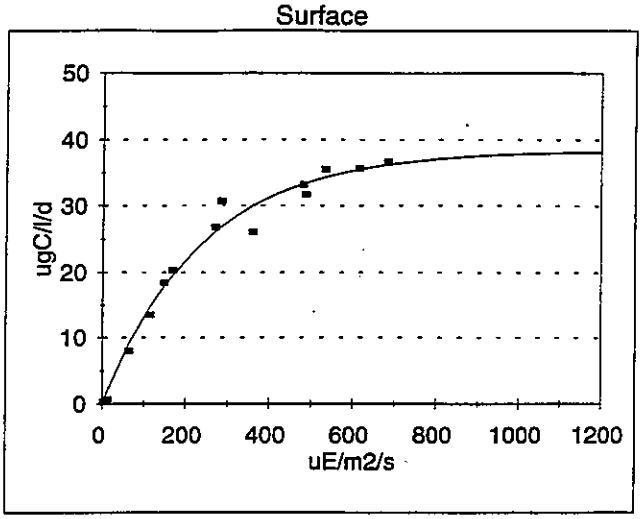
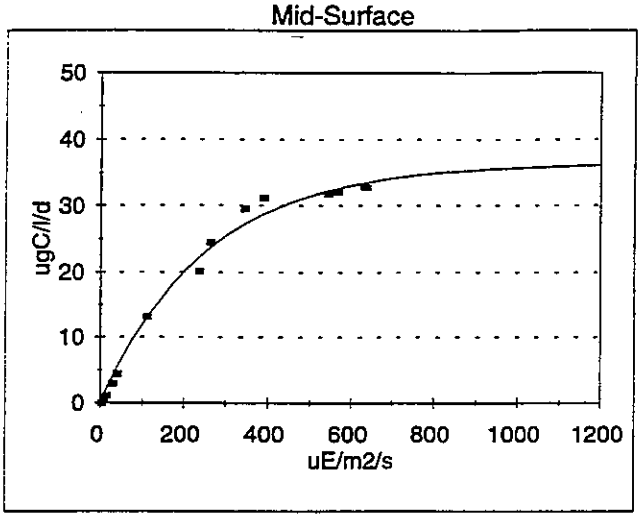


W9614 Station N04

Surface



Mid-Surface



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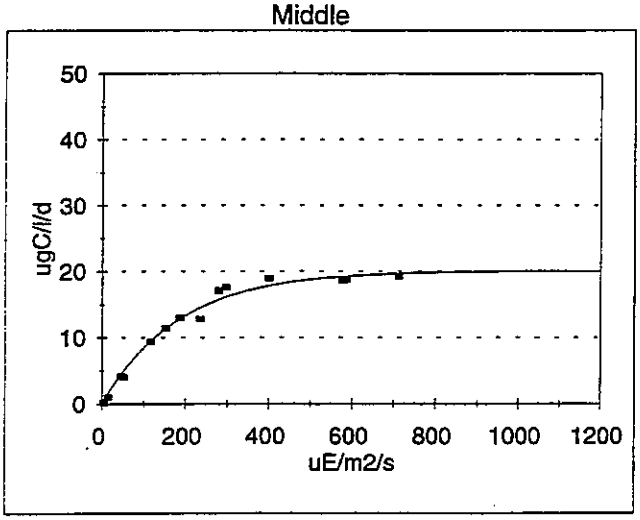
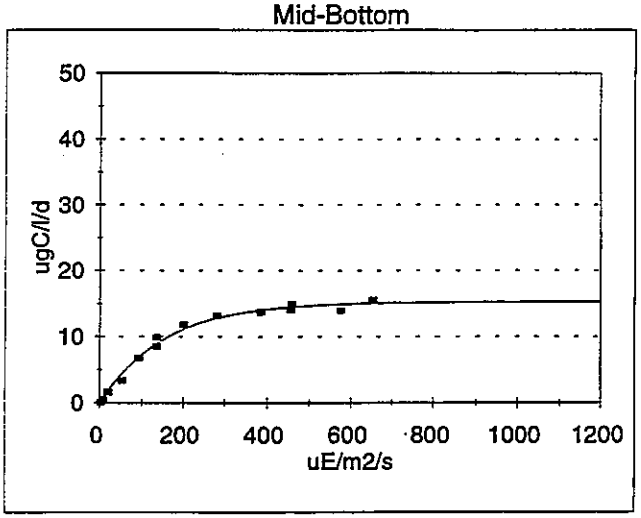


Mid-Bottom



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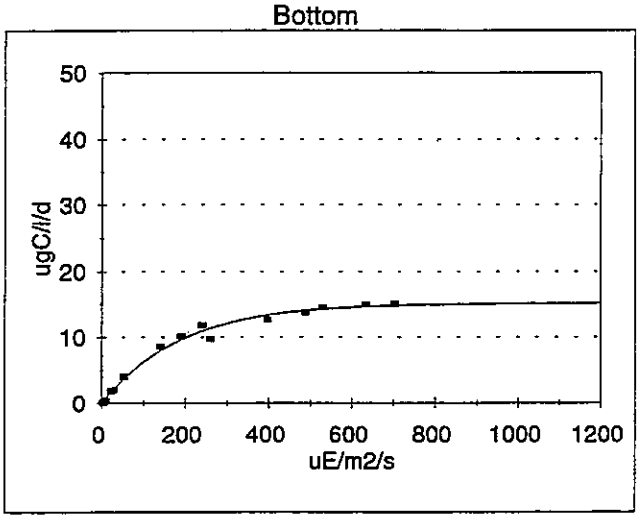
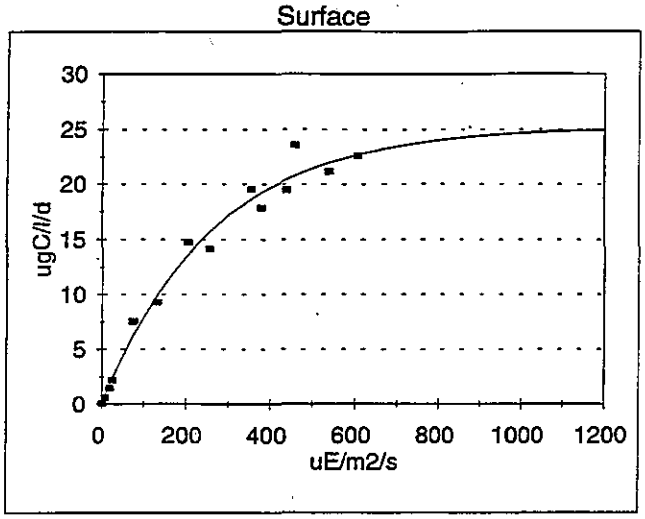
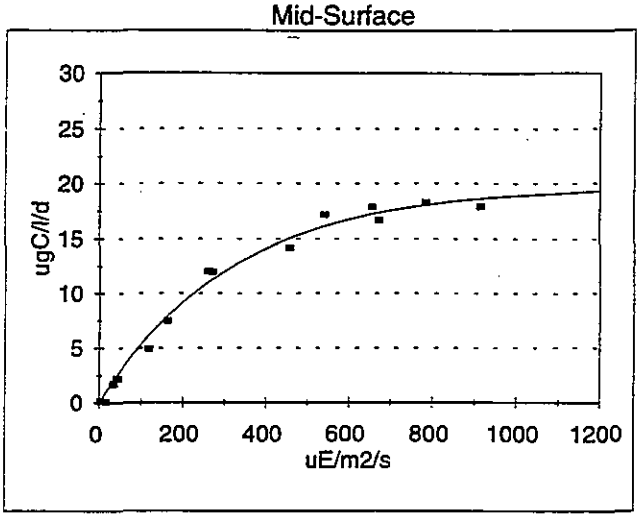


W9615 Station N10

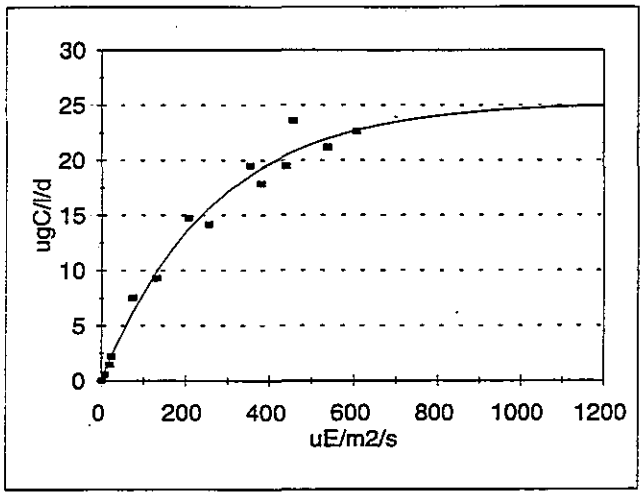
Surface



Mid-Surface



Middle



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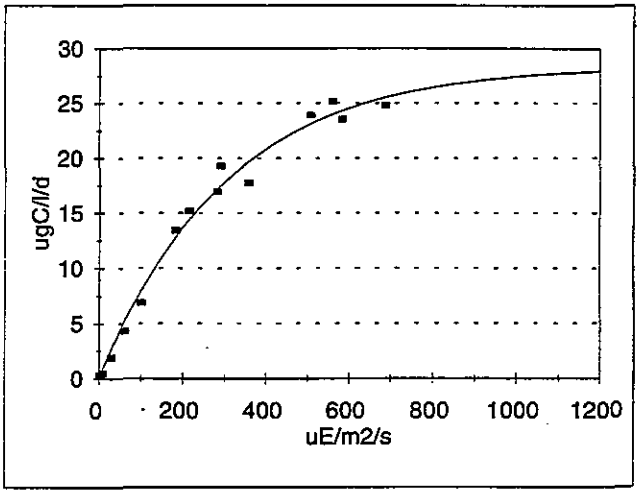

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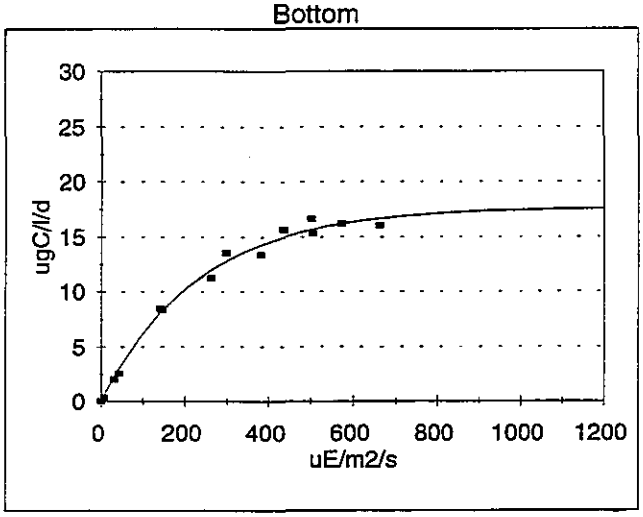
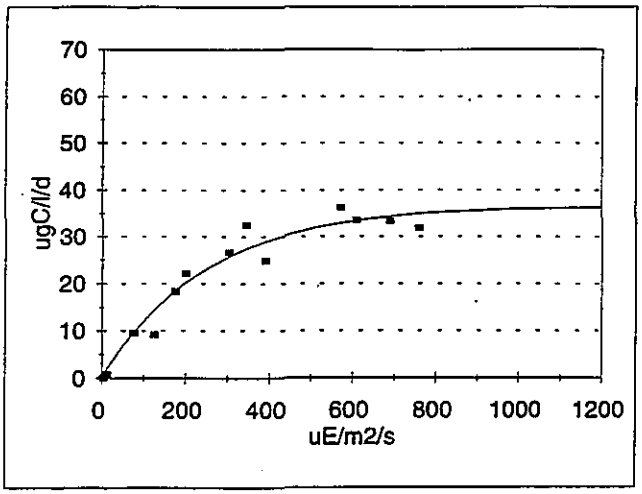
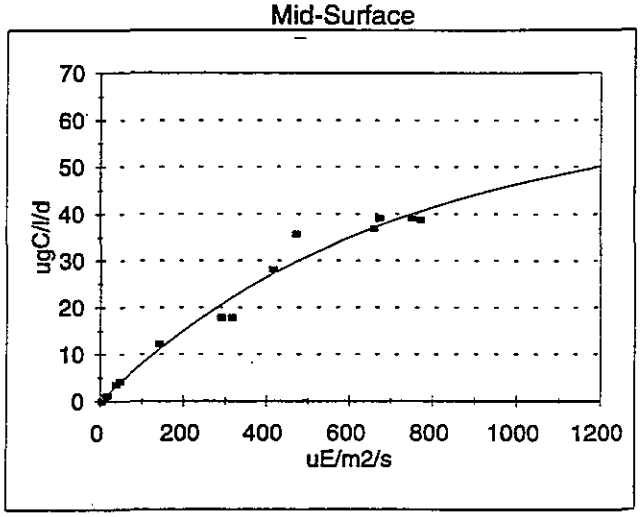


W9615 Station N04

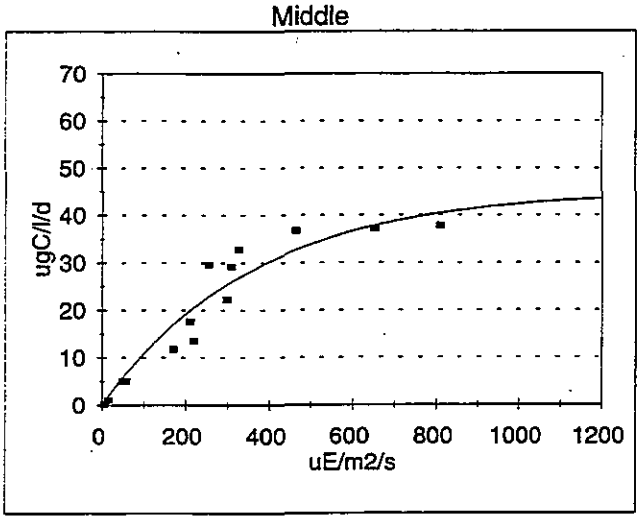
Surface



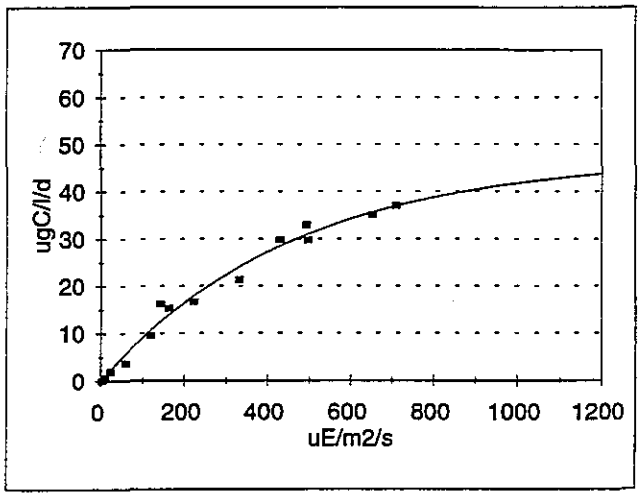
Mid-Surface



Middle



Mid-Bottom



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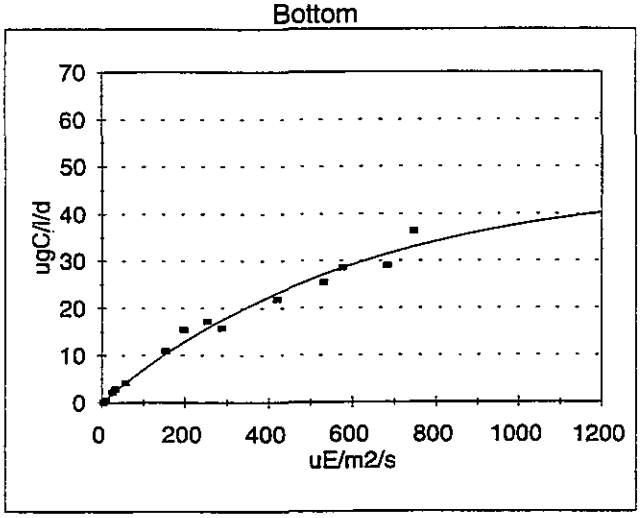
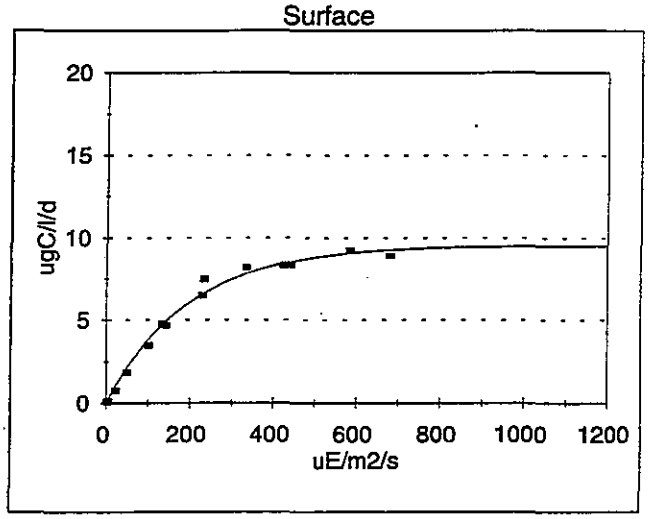
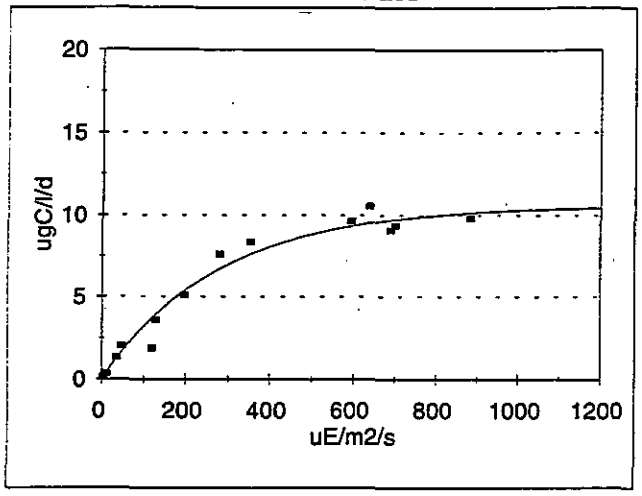


W9616 Station N10

Surface



Mid-Surface



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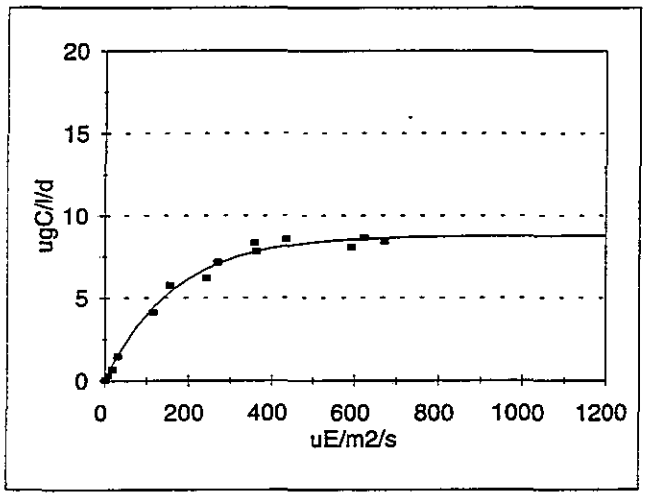
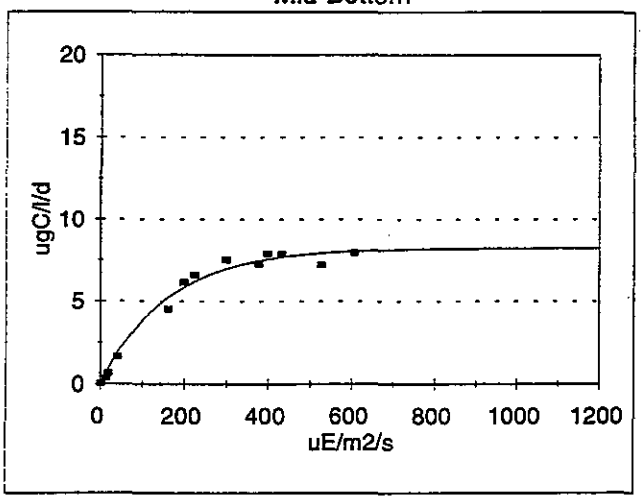


Mid-Bottom



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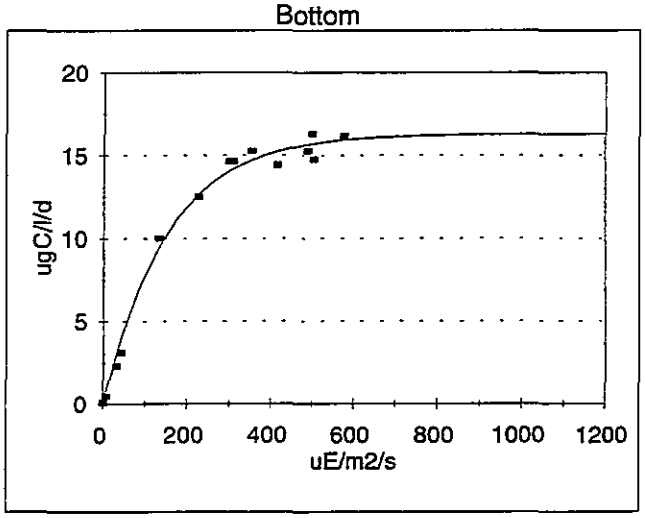
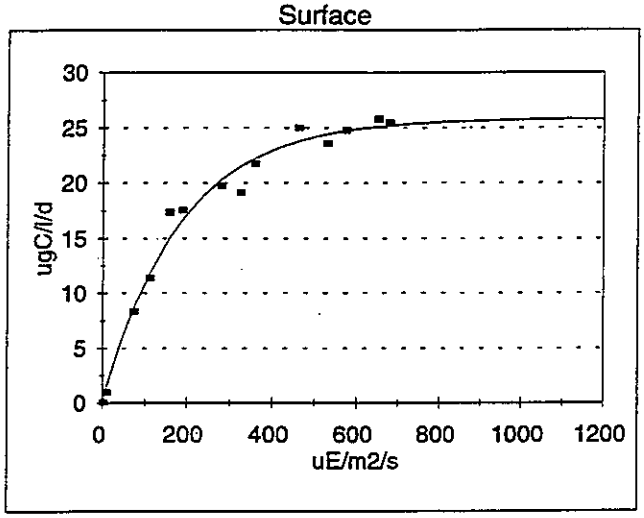


W9616 Station N04

Surface



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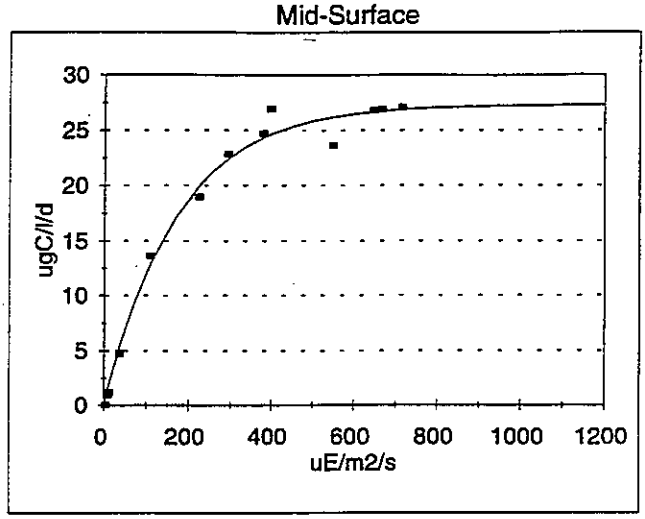

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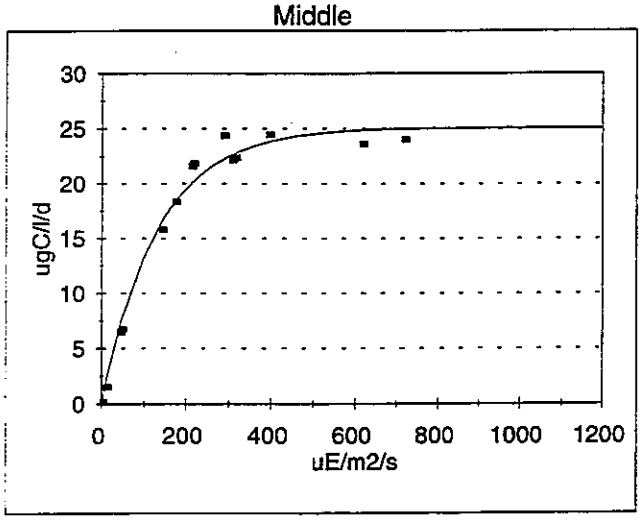

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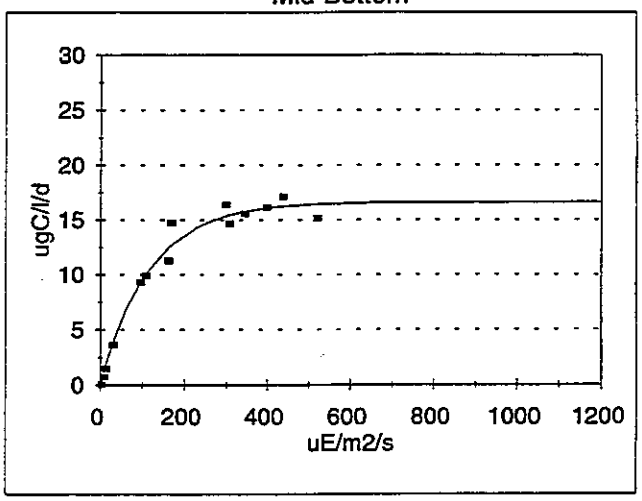

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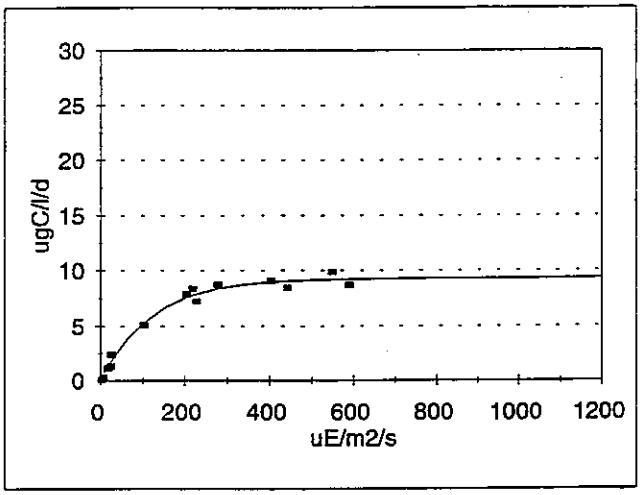
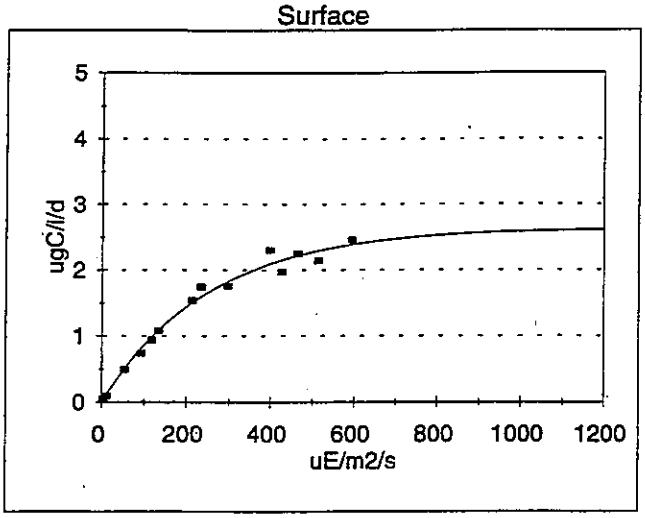


W9617 Station N10

Surface



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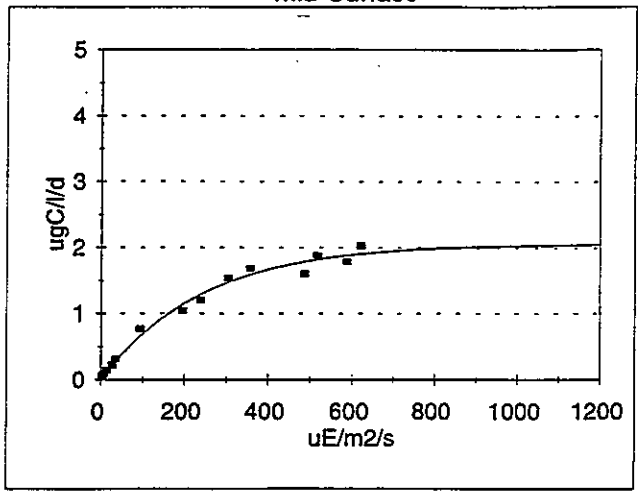

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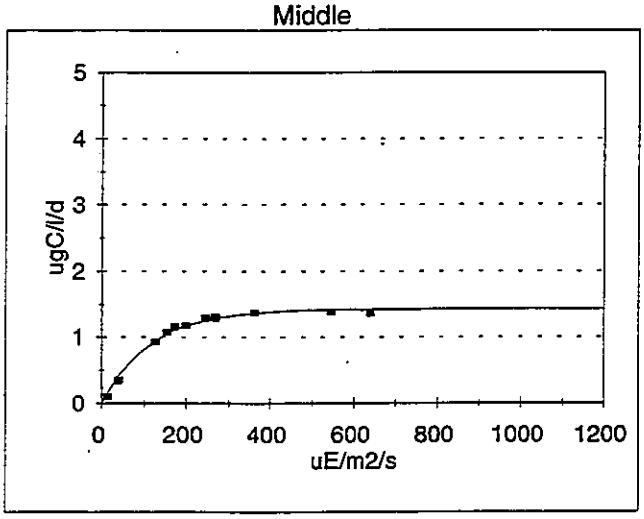

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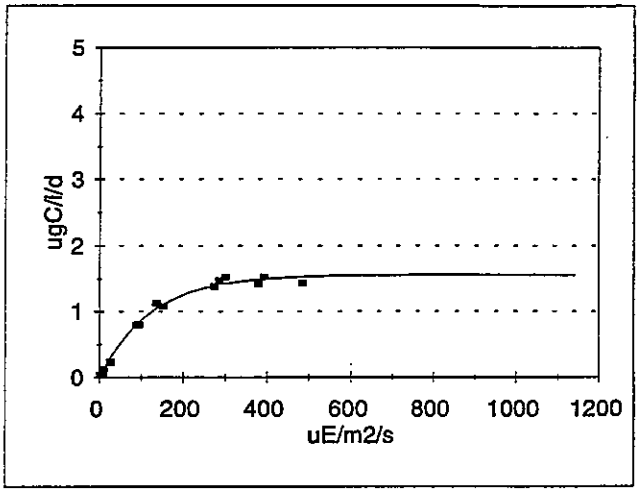

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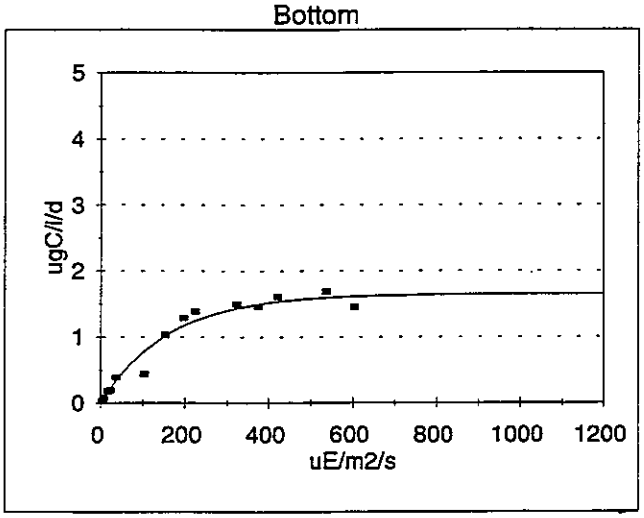
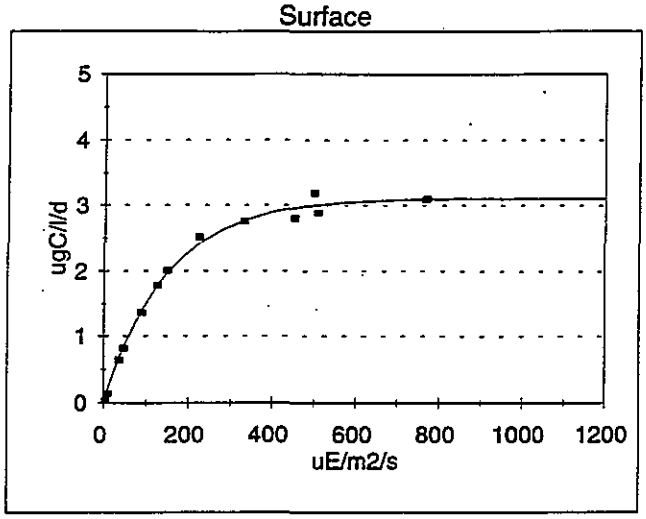
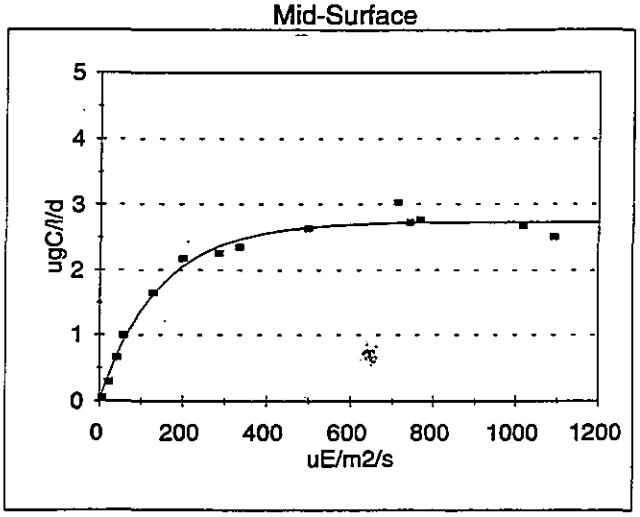


W9617 Station N04

Surface



Mid-Surface



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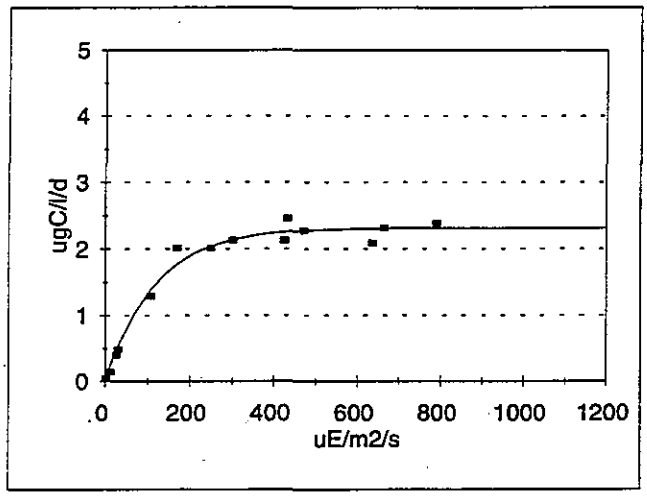

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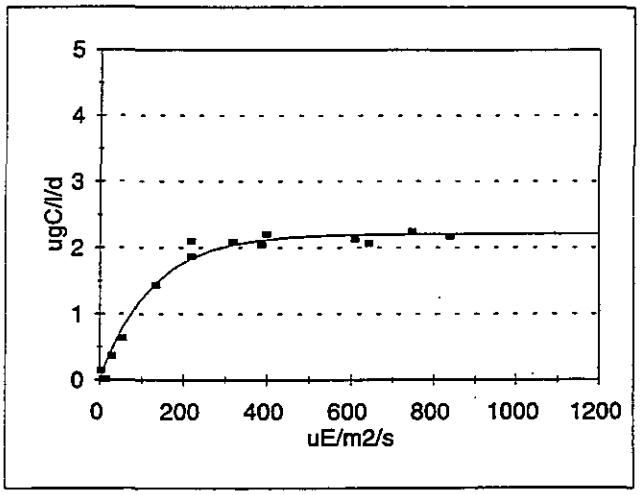

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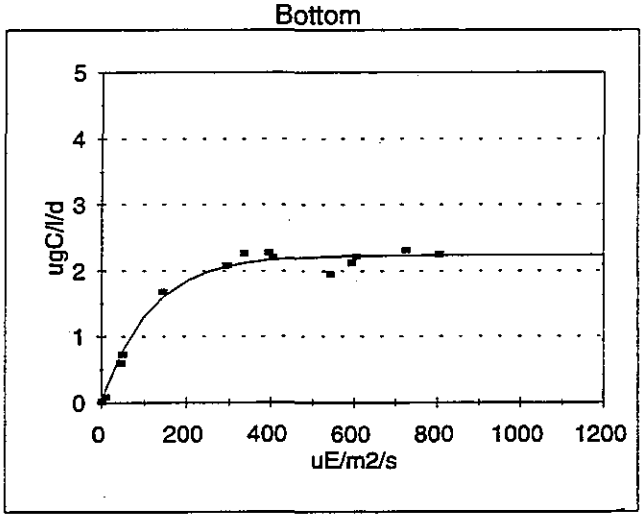

APPENDIX F-1

Abundance of Prevalent Whole-Water Phytoplankton Species in Surface Sample

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Whole Water Phytoplankton, Survey W9610
August 5-6, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	CR	10^6Cells/L							0.15	0.10					
		%							17	6					
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	CR	10^6Cells/L							0.05						
		%							5						
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6Cells/L							0.10	0.20					
		%							12	12					
PYRAMIMONAS SPP.	PR	10^6Cells/L							0.06						
		%							7						
RHIZOSOLENIA FRAGILISSIMA	CD	10^6Cells/L							0.06						
		%							7						
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6Cells/L							0.36	1.23					
		%							41	71					

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Whole Water Phytoplankton, Survey W9611
August 18-23, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CHAETOCEROS SP#1 DIAM <10 MICRONS	CD	10^6Cells/L		0.28											
		%		5											
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	CR	10^6Cells/L	0.29	0.48	0.34										
		%	10	9	7										
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	CR	10^6Cells/L	0.27	0.54	0.60	0.19		0.20						0.07	
		%	9	10	13	7		6						6	
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6Cells/L				0.27			0.15	0.33	0.19	0.13	0.31	0.13	0.16
		%				10			8	8	15	13	36	11	18
LEPTOCYLINDRUS MINIMUS	CD	10^6Cells/L	0.20		0.34	0.21	0.38			0.34				0.13	
		%	7		7	8	10			8				12	
PYRAMIMONAS SPP.	PR	10^6Cells/L		0.28											
		%		5											
RHIZOSOLENIA FRAGILISSIMA	CD	10^6Cells/L	0.31	0.75	0.31	0.50	0.37	1.03	0.25	0.87	0.15			0.23	
		%	10	14	7	18	9	29	14	21	12			20	
SKELETONEMA COSTATUM GREV+CLEVE	CD	10^6Cells/L		0.47											
		%		9											
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6Cells/L	0.22				0.27	0.39		0.37					
		%	7				7	11		9					
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6Cells/L	1.18	1.42	2.27	0.93	2.16	1.05	1.02	1.34	0.68	0.68	0.46	0.44	0.56
		%	39	26	49	34	55	30	58	33	52	69	53	39	63

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Whole Water Phytoplankton, Survey W9612
September 3-4, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	CR	10^6Cells/L							0.04	0.29					
		%							7	24					
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	CR	10^6Cells/L								0.25					
		%								21					
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6Cells/L							0.07	0.13					
		%							11	11					
LEPTOCYLINDRUS MINIMUS	CD	10^6Cells/L								0.07					
		%								5					
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6Cells/L							0.43	0.31					
		%							64	25					

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Whole Water Phytoplankton, Survey W9613
September 23-24, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	CR	10^6Cells/L							0.47	0.52					
		%							17	43					
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	CR	10^6Cells/L							0.53	0.10					
		%							19	8					
CYCLOTELLA SP#1 DIAM <10 MICRONS	CD	10^6Cells/L								0.08					
		%								7					
PYRAMIMONAS SPP.	PR	10^6Cells/L							0.36						
		%							13						
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6Cells/L								0.06					
		%								5					
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6Cells/L							1.04	0.26					
		%							37	21					

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Whole Water Phytoplankton, Survey W9614
October 6-11, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	CR	10^6 Cells/L			0.45								0.16		
		%			5								8		
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	CR	10^6 Cells/L	0.36	0.53	2.38	0.18		0.38	0.25	0.28	0.15		0.37		0.16
		%	12	17	27	7		14	8	10	6		17		8
CYCLOTELLA SP#1 DIAM <10 MICRONS	CD	10^6 Cells/L				0.15						0.13		0.13	0.13
		%				6						5		5	6
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L				0.29			0.41	0.15	0.17	0.33	0.17	0.30	0.39
		%				11			12	5	7	13	8	12	19
PYRAMIMONAS SPP.	PR	10^6 Cells/L			0.61										
		%			6.97										
SKELETONEMA COSTATUM GREV+CLEVE	CD	10^6 Cells/L	0.87	0.83	0.90		2.00	0.47		0.60	0.19				
		%	30	27	10.24		50	17		21	8				
THALASSIONEMA NITZSCHIOIDES	PD	10^6 Cells/L	0.160			0.27	0.41			0.21	0.17	0.13			
		%	5			10	10			8	7	5			
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L	0.17			0.40	0.20	0.28	0.52	0.27	0.46	0.51		0.34	0.28
		%	6			15	5	10	15	10	19	20		13	14
UNID. CENTRIC DIATOM DIAM 10-30 MICRONS	CD	10^6 Cells/L				0.15			0.188	0.151					
		%				6			6	5					
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L	0.84	0.79	2.84	0.88	0.79	0.89	1.24	0.79	0.85	1.10	1.13	1.21	0.81
		%	29	25	32	33	20	33	37	28	35	44	54	47	40

Group Definitions:

CD	Centric Diatom
DF	Dinoflagellate
MF	Microflagellate
O	Other
PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Whole Water Phytoplankton, Survey W9615
October 29-30, 1996

Species	Group	Parameter	Station Cast	
			N10	N04
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	O	10^6 Cells/L	0.18	
		%	16	
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L	0.09	
		%	7	
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L	0.12	
		%	10.37	
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L	0.49	
		%	42	
CERATIUM LONGIPES	DF	10^6 Cells/L		
		%		
CERATIUM TRIPOS	DF	10^6 Cells/L		
		%		

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Whole Water Phytoplankton, Survey W9616
November 17-19, 1996

Species	Group	Parameter	Station Cast	
			N10	N04
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	O	10^6 Cells/L		0.16
		%		7
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	O	10^6 Cells/L	0.21	0.51
		%	21	21
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L		
		%		
RHIZOSOLENIA FRAGILISSIMA	CD	10^6 Cells/L		0.22
		%		9
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L	0.14	0.26
		%	13	11
UNID. CENTRIC DIATOM DIAM 10-30 MICRONS	CD	10^6 Cells/L		
		%		
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L	0.46	0.80
		%	45	33
CERATIUM FUSUS	DF	10^6 Cells/L		
		%		
CERATIUM LONGIPES	DF	10^6 Cells/L		
		%		
CERATIUM TRIPOS	DF	10^6 Cells/L		
		%		
DINOPHYSIS NORVEGICA	DF	10^6 Cells/L		
		%		
NITZSCHIA PUNGENS	PD	10^6 Cells/L		
		%		

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Whole Water Phytoplankton, Survey W9617
December 16-17, 1996

Species	Group	Parameter	Station Cast			
			F06	F23	N10	N04
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	O	10^6 Cells/L	0.02			
		%	6			
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	O	10^6 Cells/L	0.04	0.04	0.02	0.02
		%	11	6	7	7
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L			0.02	0.02
		%			7	7
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L	0.23	0.43	0.24	0.22
		%	59	75	69	69
UNID. MICRO-PHYTOFLAG LENGTH >10 MICRONS	MF	10^6 Cells/L			0.02	
		%			5	
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L				
		%				
CERATIUM FUSUS	DF	10^6 Cells/L				
		%				
CERATIUM LONGIPES	DF	10^6 Cells/L				
		%				
CERATIUM TRIPOS	DF	10^6 Cells/L				
		%				
DINOPHYSIS NORVEGICA	DF	10^6 Cells/L				
		%				

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

APPENDIX F-2

Abundance of Prevalent Whole-Water Phytoplankton Species in Chlorophyll *a* Maximum Sample

Abundance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Whole Water Phytoplankton, Survey W9610
August 5-6, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	CR	10^6Cells/L							0.33	0.08					
		%							21	9					
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	CR	10^6Cells/L							0.26	0.05					
		%							17	5					
KATODINIUM ROTUNDATUM	DF	10^6Cells/L							0.08						
		%							5						
PYRAMIMONAS SPP.	PR	10^6Cells/L								0.06					
		%								6					
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6Cells/L							0.76	0.55					
		%							48	65					
Group Definitions:	CD	Centric Diatom													
	DF	Dinoflagellate													
	MF	Microflagellate													
	O	Other													
	PD	Pennate Diatom													

Abundance of Prevalent Species (> 5% Total Count) In Chlorophyll *a* Maximum Sample
Whole Water Phytoplankton, Survey W9611
August 18-23, 1996

Species	Group	Parameter	Station Cast											
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CHAETOCEROS SP#1 DIAM <10 MICRONS	CD	10^6Cells/L									0.06				
		%									7				
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	CR	10^6Cells/L	0.14	0.63	0.26										
		%	5	11	7										
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	CR	10^6Cells/L	0.21	0.64	0.28	0.08	0.07	0.16	0.05		0.05	0.05	0.04		0.04
		%	8	11	8	7	6	5	6		5	6	6		5
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6Cells/L				0.15			0.13	0.19	0.14	0.08	0.12	0.13	0.04
		%				14			17	6	16	10	19	10	6
KATODINIUM ROTUNDATUM	DF	10^6Cells/L							0.08		0.08	0.05			
		%							11		10	7			
LEPTOCYLINDRUS MINIMUS	CD	10^6Cells/L	0.34		0.25		0.10	0.29						0.12	
		%	13		7		9	9						10	
RHIZOSOLENIA DELICATULA	CD	10^6Cells/L				0.07									
		%				6									
RHIZOSOLENIA FRAGILISSIMA	CD	10^6Cells/L	0.30	0.50	0.53	0.12	0.16	0.58		0.99				0.26	
		%	11	8	15	11	14	18		30				20	
SKELETONEMA COSTATUM GREV+CLEVE	CD	10^6Cells/L		0.37											
		%		6											
THALASSIONEMA NITZSCHIOIDES	PD	10^6Cells/L													0.19
		%													27
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6Cells/L	0		0.23			0.28		0.37					
		%	7		6			9		11					
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6Cells/L	1.07	2.32	1.61	0.49	0.53	1.18	0.44	1.10	0.33	0.52	0.39	0.55	0
		%	41	39	44	45	47	37	56	33	38	65	61	42	49

Group Definitions:	
CD	Centric Diatom
DF	Dinoflagellate
MF	Microflagellate
O	Other
PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Whole Water Phytoplankton, Survey W9612
September 3-4, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	CR	10^6Cells/L							0.10	0.24					
		%							10	25					
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	CR	10^6Cells/L							0.05	0.08					
		%							5	8					
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6Cells/L							0.07	0.06					
		%							7	7					
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6Cells/L							0.69	0.50					
		%							71	51					
Group Definitions:	CD	Centric Diatom													
	DF	Dinoflagellate													
	MF	Microflagellate													
	O	Other													
	PD	Pennate Diatom													

Abundance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Whole Water Phytoplankton, Survey W9613
September 23-24, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	CR	10^6Cells/L							0.45	0.23					
		%							18	34					
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	CR	10^6Cells/L							0.29						
		%							12						
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6Cells/L							0.13						
		%							5						
PYRAMIMONAS SPP.	PR	10^6Cells/L							0.64						
		%							26						
THALASSIONEMA NITZSCHIOIDES	PD	10^6Cells/L								0.05					
		%								7					
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6Cells/L								0.11					
		%								16					
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6Cells/L							0.67	0.12					
		%							27	17					

Group Definitions:	
CD	Centric Diatom
DF	Dinoflagellate
MF	Microflagellate
O	Other
PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Whole Water Phytoplankton, Survey W9614
October 6-11, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	CR	10^6 Cells/L			0.32										
		%			9										
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	CR	10^6 Cells/L	0.27	0.56	0.79			0.40	0.19				0.04	0.13	
		%	12	14	21			14	15				5	7	
CYCLOTELLA SP#1 DIAM <10 MICRONS	CD	10^6 Cells/L				0.20		0.21		0.14	0.16				
		%				7		7		6	6				
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L							0.16		0.27	0.37	0.13	0.23	0.13
		%							13		10	13	18	12	9
RHIZOSOLENIA DELICATULA	CD	10^6 Cells/L											0.06		
		%											8		
SKELETONEMA COSTATUM GREV+CLEVE	CD	10^6 Cells/L	0.490	1.880	0.79	0.15	2.18	0.81		0.41	0.22		0.05		
		%	23	45	21	6	52	28		18	8		7		
THALASSIONEMA NITZSCHIOIDES	PD	10^6 Cells/L	0.113			0.28	0.25			0.13	0.15	0.20			0.14
		%	5			10	6			6	5	7			10
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L	0.21		0.28	0.80	0.21	0.19	0.07	0.40	0.45	0.67		0.30	0.18
		%	10		7	30	5	6	5	17	16	24		15	13
UNID. CENTRIC DIATOM DIAM 10-30 MICRONS	CD	10^6 Cells/L				0.32		0.16							0.08
		%				11.82		5.36							5.44
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L	0.69	0.86	0.85	0.68	1.00	0.71	0.59	0.79	1.27	1.12	0.34	0.95	0.55
		%	32	21	23	25	24	25	45	34	45	39	44	48	39

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Whole Water Phytoplankton, Survey W9615
October 29-30, 1996

Species	Group	Parameter	Station Cast	
			N10	N04
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	O	10^6 Cells/L	0.30	
		%	16	
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L	0.18	
		%	9	
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L	0.20	
		%	10.36	
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L	0.84	
		%	44	
CERATIUM LONGIPES	DF	10^6 Cells/L		
		%		
CERATIUM TRIPOS	DF	10^6 Cells/L		
		%		

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

ndance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Whole Water Phytoplankton, Survey W9616
November 17-19, 1996

Species	Group	Parameter	Station Cast	
			N10	N04
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	O	10^6 Cells/L		
		%		
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	O	10^6 Cells/L	0.07	0.07
		%	8	9
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L		0.04
		%		5.5656
RHIZOSOLENIA FRAGILISSIMA	CD	10^6 Cells/L	0.1948	0.05
		%	20	6
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L	0.16	0.16
		%	16	23
UNID. CENTRIC DIATOM DIAM 10-30 MICRONS	CD	10^6 Cells/L		0
		%		6
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L	0.34	0.23
		%	36	32
CERATIUM FUSUS	DF	10^6 Cells/L		
		%		
CERATIUM LONGIPES	DF	10^6 Cells/L		
		%		
CERATIUM TRIPOS	DF	10^6 Cells/L		
		%		
DINOPHYSIS NORVEGICA	DF	10^6 Cells/L		
		%		
NITZSCHIA PUNGENS	PD	10^6 Cells/L		
		%		

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Whole Water Phytoplankton, Survey W9617
December 16-17, 1996

Species	Group	Parameter	Station Cast			
			F06	F23	N10	N04
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	O	10^6 Cells/L				
		%				
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	O	10^6 Cells/L	0.03	0.02		0.02
		%	8	5		6
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L	0.03			0.03
		%	7.36			9
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L	0.25	0.32	0.23	0.24
		%	61	76	72	65
UNID. MICRO-PHYTOFLAG LENGTH >10 MICRONS	MF	10^6 Cells/L				
		%				
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L			0.02	0.02
		%			5	5
CERATIUM FUSUS	DF	10^6 Cells/L				
		%				
CERATIUM LONGIPES	DF	10^6 Cells/L				
		%				
CERATIUM TRIPOS	DF	10^6 Cells/L				
		%				
DINOPHYSIS NORVEGICA	DF	10^6 Cells/L				
		%				

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

APPENDIX G-1

Abundance of all Identified Taxa in Screened Samples Near the Surface

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Screened Phytoplankton, Survey W9610
August 5-6, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CERATIUM FUSUS	DF	10^6Cells/L							0.00005	0.00023					
		%							17	62					
CERATIUM LONGIPES	DF	10^6Cells/L							0.00018	0.00009					
		%							60	25					
CERATIUM TRIPOS	DF	10^6Cells/L							0.00002	0.00002					
		%							6	6					
DINOPHYSIS NORVEGICA	DF	10^6Cells/L							0.00005						
		%							16						

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Screened Phytoplankton, Survey W9611
August 18-23, 1996

Species	Group	Parameter	Station Cast											
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CERATIUM FUSUS	DF	10^6Cells/L						0.00003	0.00005			0.00005	0.00015	0.00006	0.00013
		%						9	11			22	46	36	60
CERATIUM LONGIPES	DF	10^6Cells/L	0.00003	0.00001	0.00001		0.00009	0.00011	0.00006				0.00004	0.00005	0.00003
		%	19	11	31		15	36	14				12	32	15
CERATIUM TRIPOS	DF	10^6Cells/L	0.00001		0.000004			0.00005	0.00012			0.00014	0.00012	0.00004	0.00003
		%	5		10			17	29			64	38	25	14
DINOPHYSIS NORVEGICA	DF	10^6Cells/L			0.00001			0.00002							
		%			16			7							
GONYAULAX SPP.	DF	10^6Cells/L		0.00001											
		%		6											
NITZSCHIA PUNGENS	PD	10^6Cells/L	0.00010	0.00007		0.00600	0.00043		0.00018	0.00500	0.00300				
		%	59	56		98	74		43	78	89				
NITZSCHIA SERIATA	PD	10^6Cells/L								0.00100					
		%								16					
PROTOPERIDINIUM SP.#1 10-30W 10-40L	DF	10^6Cells/L		0.00001	0.00001										
		%		7	16										
PROTOPERIDINIUM SP.#2 31-75W 41-80L	DF	10^6Cells/L			0.000004			0.00004							
		%			10			14							
SCRIPPSIELLA TROCHOIDEA	DF	10^6Cells/L						0.00002							
		%						7							

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Screened Phytoplankton, Survey W9612
September 3-4, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CERATIUM FUSUS	DF	10^6Cells/L							0.00008	0.00015					
		%							36	19					
CERATIUM LONGIPES	DF	10^6Cells/L							0.00003	0.00013					
		%							12	16					
CERATIUM TRIPOS	DF	10^6Cells/L							0.00011	0.00049					
		%							48	61					
Group Definitions:	CD	Centric Diatom													
	DF	Dinoflagellate													
	MF	Microflagellate													
	O	Other													
	PD	Pennate Diatom													

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Screened Phytoplankton, Survey W9613
September 23-24, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CERATIUM FUSUS	DF	10^6Cells/L							0.00003	0.00001					
		%							12	7					
CERATIUM LONGIPES	DF	10^6Cells/L							0.00004	0.00002					
		%							14	9					
CERATIUM TRIPOS	DF	10^6Cells/L							0.00019	0.00014					
		%							68	75					
DINOPHYSIS NORVEGICA	DF	10^6Cells/L								0.00001					
		%								7					
Group Definitions:	CD	Centric Diatom													
	DF	Dinoflagellate													
	MF	Microflagellate													
	O	Other													
	PD	Pennate Diatom													

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Screened Phytoplankton, Survey W9614
October 6-11, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CERATIUM FUSUS	DF	10^6 Cells/L				0.00005		0.000002	0.0001	0.00002	0.00004		0.00008	0.00004	0.00004
		%				8		6	7	8	9		8	6	8
CERATIUM LINEATUM	DF	10^6 Cells/L							0.0002				0.0001		
		%							11				13		
CERATIUM LONGIPES	DF	10^6 Cells/L	0.00003	0.00003	0.00001	0.00005	0.00002		0.0002	0.00002	0.00005	0.00023	0.00008		0.00004
		%	18	10	13	8	12		14	7	11	10	8		8
CERATIUM TRIPOS	DF	10^6 Cells/L	0.0001	0.0002	0.00004	0.001	0.0001	0.00002	0.0008	0.0002	0.0003	0.00201	0.001	0.0006	0.0004
		%	56	76	70	81	84	87	60	83	69	86	58	87	81
DINOPHYSIS NORVEGICA	DF	10^6 Cells/L							0.0001		0.00003		0.0001		
		%							5		6		7		
NITZSCHIA PUNGENS	PD	10^6 Cells/L	0.00002	0.00002											
		%	15	9											
UNID. DINOFLAGELLATE	DF	10^6 Cells/L			0.00001										
		%			12										

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Screened Phytoplankton, Survey W9615
October 29-30, 1996

Species	Group	Parameter	Station Cast	
			N10	N04
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	O	10^6 Cells/L		
		%		
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L		
		%		
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L		
		%		
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L		
		%		
CERATIUM LONGIPES	DF	10^6 Cells/L	0.00003	
		%	6	
CERATIUM TRIPOS	DF	10^6 Cells/L	0.0004	
		%	83	

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Screened Phytoplankton, Survey W9616
November 17-19, 1996

Species	Group	Parameter	Station Cast	
			N10	N04
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	O	10^6 Cells/L		
		%		
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	O	10^6 Cells/L		
		%		
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L		
		%		
RHIZOSOLENIA FRAGILISSIMA	CD	10^6 Cells/L		
		%		
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L		
		%		
UNID. CENTRIC DIATOM DIAM 10-30 MICRONS	CD	10^6 Cells/L		
		%		
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L		
		%		
CERATIUM FUSUS	DF	10^6 Cells/L		0.00003
		%		6
CERATIUM LONGIPES	DF	10^6 Cells/L	0.0001	0.00004
		%	14	7
CERATIUM TRIPOS	DF	10^6 Cells/L	0.0003	0.0004
		%	79	83
DINOPHYSIS NORVEGICA	DF	10^6 Cells/L	0.00002	
		%	5	
NITZSCHIA PUNGENS	PD	10^6 Cells/L		
		%		

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Surface Sample
Screened Phytoplankton, Survey W9617
December 16-17, 1996

Species	Group	Parameter	Station Cast			
			F06	F23	N10	N04
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	O	10^6 Cells/L				
		%				
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	O	10^6 Cells/L				
		%				
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L				
		%				
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L				
		%				
UNID. MICRO-PHYTOFLAG LENGTH >10 MICRONS	MF	10^6 Cells/L				
		%				
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L				
		%				
CERATIUM FUSUS	DF	10^6 Cells/L	0.0001	0.00002	0.00003	0.00006
		%	8	8	14	12
CERATIUM LONGIPES	DF	10^6 Cells/L	0.0001	0.00003	0.00002	0.00004
		%	11	13	8	7
CERATIUM TRIPOS	DF	10^6 Cells/L	0.0005	0.0001	0.0001	0.0004
		%	75	73	66	71
DINOPHYSIS NORVEGICA	DF	10^6 Cells/L			0.00001	
		%			5	

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

APPENDIX G-2

Abundance of all Identified Taxa in Screened Samples Near the Chlorophyll Maximum

Abundance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Screened Phytoplankton, Survey W9610
August 5-6, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CERATIUM FUSUS	DF	10^6Cells/L								0.00004					
		%								7					
CERATIUM LONGIPES	DF	10^6Cells/L							0.00100	0.00047					
		%							79	85					
DINOPHYSIS NORVEGICA	DF	10^6Cells/L							0.00019						
		%							15						
Group Definitions:	CD	Centric Diatom													
	DF	Dinoflagellate													
	MF	Microflagellate													
	O	Other													
	PD	Pennate Diatom													

Abundance of Prevalent Species (> 5% Total Count) In Chlorophyll a Maximum Sample
Screened Phytoplankton, Survey W9611
August 18-23, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
AMYLAX TRIACANTHA	DF	10^6Cells/L													0.00006
		%													19
CERATIUM FUSUS	DF	10^6Cells/L		0.00001		0.00004		0.00003	0.00002			0.00008		0.00012	
		%		5		24		11	6			12		32	
CERATIUM LONGIPES	DF	10^6Cells/L	0.00007		0.00002	0.00004	0.00030	0.00010	0.00031	0.00028	0.00047	0.00041	0.00022	0.00012	0.00017
		%	18		13	24	71	33	69	52	77	63	86	32	57
CERATIUM TRIPOS	DF	10^6Cells/L			0.00001	0.00004		0.00003	0.00004		0.00003	0.00012	0.00002	0.00006	
		%			7	27		11	9		5	18	9	17	
DINOPHYSIS NORVEGICA	DF	10^6Cells/L		0.00003	0.00001		0.00002	0.00003		0.00014					
		%		20	5		6	9		27					
DIPLOPSALIS SPP.	DF	10^6Cells/L		0.00002											
		%		16											
GONYAULAX SPINIFERA	DF	10^6Cells/L			0.00001										
		%			9										
GONYAULAX SPP.	DF	10^6Cells/L		0.00001	0.00002			0.00002							
		%		5	14			7							
NITZSCHIA PUNGENS	PD	10^6Cells/L	0.00028			0.00003									
		%	75			19									
PROTOPERIDINIUM SP.#2 31-75W 41-80L	DF	10^6Cells/L		0.00005	0.00003			0.00003							
		%		34	21			9							
SCRIPPSIELLA TROCHOIDEA	DF	10^6Cells/L			0.00001										
		%			5										

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Screened Phytoplankton, Survey W9612
September 3-4, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F08	F27	F01	F02
CERATIUM FUSUS	DF	10^6Cells/L							0.00007	0.00006					
		%							20	12					
CERATIUM LONGIPES	DF	10^6Cells/L							0.00009	0.00015					
		%							25	30					
CERATIUM TRIPOS	DF	10^6Cells/L							0.00015	0.00019					
		%							44	39					
DINOPHYSIS NORVEGICA	DF	10^6Cells/L								0.00008					
		%								17					

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) In Chlorophyll *a* Maximum Sample
Screened Phytoplankton, Survey W9613
September 23-24, 1996

Species	Group	Parameter	Station Cast											
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CERATIUM FUSUS	DF	10^6Cells/L							0.00013	0.00002					
		%							8	15					
CERATIUM LONGIPES	DF	10^6Cells/L							0.00031	0.00002					
		%							21	13					
CERATIUM TRIPOS	DF	10^6Cells/L							0.00100	0.00009					
		%							67	60					
DINOPHYSIS NORVEGICA	DF	10^6Cells/L								0.00002					
		%								10					
Group Definitions:	CD	Centric Diatom													
	DF	Dinoflagellate													
	MF	Microflagellate													
	O	Other													
	PD	Pennate Diatom													

Abundance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Screened Phytoplankton, Survey W9614
October 6-11, 1996

Species	Group	Parameter	Station Cast												
			F23	F30	F31	F13	F24	F25	N04	N10	N16	F06	F27	F01	F02
CERATIUM FUSUS	DF	10^6 Cells/L		0.00001		0.00004	0.000012		0.000053	0.000016	0.00007	0.000121		0.00015	0.00008
		%		5		10	8		6	7	10	6		8	7
CERATIUM LONGIPES	DF	10^6 Cells/L	0.00002	0.00001	0.000006		0.00002	0.00001	0.00013	0.00002	0.00016			0.00013	0.0002
		%	14	10	15		13	18	14	9	24			7	16
CERATIUM TRIPOS	DF	10^6 Cells/L	0.0001	0.0001	0.00003	0.0003	0.0001	0.00005	0.00064	0.0002	0.0004	0.00177	0.0001	0.0016	0.0009
		%	68	73	60	81	62	78	73	83	60	91	13	85	76
NITZSCHIA PUNGENS	PD	10^6 Cells/L		0.00001			0.00001						0.001		
		%		10			6						78		
UNID. DINOFLAGELLATE	DF	10^6 Cells/L	0.00002		0.00001										
		%	14		23										

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Screened Phytoplankton, Survey W9615
October 29-30, 1996

Species	Group	Parameter	Station Cast	
			N10	N04
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	O	10^6 Cells/L		
		%		
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L		
		%		
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L		
		%		
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L		
		%		
CERATIUM LONGIPES	DF	10^6 Cells/L	0.00260	
		%	10	
CERATIUM TRIPOS	DF	10^6 Cells/L	0.0214	
		%	82	

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Screened Phytoplankton, Survey W9616
November 17-19, 1996

Species	Group	Parameter	Station Cast	
			N10	N04
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	O	10^6 Cells/L		
		%		
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	O	10^6 Cells/L		
		%		
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L		
		%		
RHIZOSOLENIA FRAGILISSIMA	CD	10^6 Cells/L		
		%		
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L		
		%		
UNID. CENTRIC DIATOM DIAM 10-30 MICRONS	CD	10^6 Cells/L		
		%		
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L		
		%		
CERATIUM FUSUS	DF	10^6 Cells/L		
		%		
CERATIUM LONGIPES	DF	10^6 Cells/L	0.0000	0.00003
		%	7	9
CERATIUM TRIPOS	DF	10^6 Cells/L	0.0002	0.0002
		%	83	79
DINOPHYSIS NORVEGICA	DF	10^6 Cells/L		
		%		
NITZSCHIA PUNGENS	PD	10^6 Cells/L		0.0000
		%		5

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

Abundance of Prevalent Species (> 5% Total Count) in Chlorophyll *a* Maximum Sample
Screened Phytoplankton, Survey W9617
December 16-17, 1996

Species	Group	Parameter	Station Cast			
			F06	F23	N10	N04
CRYPTOMONAS SP#1 LENGTH <10 MICRONS	O	10^6 Cells/L				
		%				
CRYPTOMONAS SP#2 LENGTH >10 MICRONS	O	10^6 Cells/L				
		%				
GYMNODINIUM SP.#1 5-20UM W 10-20UM L	DF	10^6 Cells/L				
		%				
UNID. MICRO-PHYTOFLAG LENGTH <10 MICRONS	MF	10^6 Cells/L				
		%				
UNID. MICRO-PHYTOFLAG LENGTH >10 MICRONS	MF	10^6 Cells/L				
		%				
UNID. CENTRIC DIATOM DIAM <10 MICRONS	CD	10^6 Cells/L				
		%				
CERATIUM FUSUS	DF	10^6 Cells/L	0.00004		0.00002	0.00004
		%	7		8	7
CERATIUM LONGIPES	DF	10^6 Cells/L	0.00005	0.00001	0.00003	0.0001
		%	8	6	12	15
CERATIUM TRIPOS	DF	10^6 Cells/L	0.0005	0.0001	0.0002	0.0004
		%	79	85	68	70
DINOPHYSIS NORVEGICA	DF	10^6 Cells/L				
		%				

Group Definitions:		
	CD	Centric Diatom
	DF	Dinoflagellate
	MF	Microflagellate
	O	Other
	PD	Pennate Diatom

APPENDIX H

Zooplankton Species Data

Abundance of Prevalent Species (> 5% Total Count)
Zooplankton, Survey W9610
August 5-6, 1996

Species	Life Stage	Group	Parameter	Station Cast													
				F23	F30	F31	F13	F24	F25	N04	N10	N16	N18	F27	F06	F01	F02
BIVALVIA SPP.	L	OZ	ind/m^3							5543							
			%							8							
COPEPOD SPP.	N	C	ind/m^3							9317	26900						
			%							14	18						
OITHONA SIMILIS CLAUS	C	C	ind/m^3							9435	21930						
			%							14	15						

Life Stage Definitions:		Group Definitions:	
C	Copepodite stages I-V	B	Barnacle
F	Copepoda adult female	C	Copepod
L	Larva	OZ	Other Zooplankton
M	Copepoda adult male		
N	Nauplii		
T	Trochophore (larval stage of polychaete)		
Y	Cypris Larva of Barnacle		

Abundance of Prevalent Species (> 5% Total Count)
Zooplankton, Survey W9611
August 18-23, 1996

Species	Life Stage	Group	Parameter	Station Cast													
				F23	F30	F31	F13	F24	F25	N04	N10	N16	N18	F27	F06	F01	F02
ACARTIA HUDSONICA	C	C	ind/m^3	8202	20704												
			%	9	15												
ACARTIA HUDSONICA	M	C	ind/m^3	5601	7628												
			%	6	5												
ACARTIA TONSA	C	C	ind/m^3	11403	25063												
			%	12	18												
ACARTIA TONSA	F	C	ind/m^3			4217											
			%			5											
ACARTIA TONSA	M	C	ind/m^3	6401	8717	4439											
			%	7	6	5											
BIVALVIA SPP.	L	OZ	ind/m^3					6694	3206	6238	5242	5386				7503	9583
			%					9	7	14	15	10				7	18
COPEPOD SPP.	N	C	ind/m^3	16404	44677	24415	23442	31685	16029	18245	10342	22762		12405	14163	25237	14792
			%	18	32	30	35	42	35	42	29	42		40	29	24	28
MICROSETELLA NORVEGICA		C	ind/m^3														3750
			%														7
OITHONA SIMILIS CLAUS	C	C	ind/m^3			11320	15118	14950	7577	8421	4250	11120		11491	13464	24214	6667
			%			14	23	20	17	19	12	21		37	28	23	13
OITHONA SIMILIS CLAUS	F	C	ind/m^3	5201		8212	7304	5802	2914	2963	3967	2954		2677	3847	7503	2917
			%	6		10	11	8	6	7	11	6		9	8	7	6
POLYCHAETE SPP.	T	OZ	ind/m^3														2708
			%														5
PSEUDOCALANUS NEWMANI	C	C	ind/m^3			4439			2332	2495		3475			3497		3750
			%			5			5	6		6			7		7
TEMORA LONGICORNIS	C	C	ind/m^3													5798	
			%													5	

Life Stage Definitions:

- C Copepodite stages I-V
- F Copepoda adult female
- L Larva
- M Copepoda adult male
- N Nauplii
- T Trochophore (larval stage of polychaete)
- Y Cypris Larva of Barnacle

Group Definitions:

- B Barnacle
- C Copepod
- OZ Other Zooplankton

Abundance of Prevalent Species (> 5% Total Count)
Zooplankton, Survey W9612
September 3-4, 1996

Species	Life Stage	Group	Parameter	Station Cast F23	F30	F31	F13	F24	F25	N04	N10	N16	N18	F27	F06	F01	F02
BIVALVIA SPP.	L	OZ	ind/m^3							6805	18586						
			%							12	29						
COPEPOD SPP.	N	C	ind/m^3							8361	15770						
			%							15	24						
OIKOPLEURA DIOICA		OZ	ind/m^3							3889							
			%							7							
OITHONA SIMILIS CLAUS	C	C	ind/m^3							16527	8730						
			%							29	13						
OITHONA SIMILIS CLAUS	F	C	ind/m^3								3661						
			%								6						
PSEUDOCALANUS NEWMANI	C	C	ind/m^3							3694	3520						
			%							7	5						
TEMORA LONGICORNIS	C	C	ind/m^3							5444							
			%							10							

Life Stage Definitions:		Group Definitions:	
C	Copepodite stages I-V	B	Barnacle
F	Copepoda adult female	C	Copepod
L	Larva	OZ	Other Zooplankton
M	Copepoda adult male		
N	Nauplii		
T	Trochophore (larval stage of polychaete)		
Y	Cypris Larva of Barnacle		

Abundance of Prevalent Species (> 5% Total Count)
Zooplankton, Survey W9613
September 23-24, 1996

Species	Life Stage	Group	Parameter	Station Cast F23	F30	F31	F13	F24	F25	N04	N10	N16	N18	F27	F06	F01	F02
BIVALVIA SPP.	L	OZ	ind/m^3							5108	2584						
			%							9	12						
CENTROPAGES TYPICUS		C	ind/m^3							3746							
			%							6							
COPEPOD SPP.	N	C	ind/m^3							22815	6251						
			%							39	30						
OITHONA SIMILIS CLAUS	C	C	ind/m^3							17367	3417						
			%							30	16						
OITHONA SIMILIS CLAUS	F	C	ind/m^3							4767	1083						
			%							8	5						

Life Stage Definitions:

- C Copepodite stages I-V
- F Copepoda adult female
- L Larva
- M Copepoda adult male
- N Nauplii
- T Trochophore (larval stage of polychaete)
- Y Cypris Larva of Barnacle

Group Definitions:

- B Barnacle
- C Copepod
- OZ Other Zooplankton

Abundance of Prevalent Species (> 5% Total Count)
Zooplankton, Survey W9614
October 6-11, 1996

Species	Life Stage	Group	Parameter	Station Cast													
				F23	F30	F31	F13	F24	F25	N04	N10	N16	N18	F27	F06	F01	F02
ACARTIA TONSA	C	C	ind/m^3		2022	4613											
			%		7	11											
ACARTIA TONSA	F	C	ind/m^3			2661											
			%			6											
ACARTIA TONSA	M	C	ind/m^3		1596	3371											
			%		6	8											
BIVALVIA SPP.	L	OZ	ind/m^3	8201	3830		24593	3692	879	4430	1927	16765		8676	9628	12536	4747
			%	14	13		40	11	6	8	7	23		13	16	14	8
CENTROPAGES SPP.		C	ind/m^3							3138		4432		4522			
			%							6		6		7			
CENTROPAGES TYPICUS		C	ind/m^3							6645		7130		7199			
			%							12		10		11			
COPEPOD SPP.	N	C	ind/m^3	13222	11278	9581	13147	11538	4467	20397	7172	24473		28058	20896	36215	29335
			%	23	40	23	21	35	32	36	25	34		42	35	41	46
GASTROPODA;MOLLUSCA		OZ	ind/m^3						1098								
			%						8								
OITHONA SIMILIS CLAUS	C	C	ind/m^3	12385		5234	11137	6692	1831	16428	8136	14645		12644	15160	16715	15580
			%	21		13	18	20	13	29	28	20		19	26	19	25
OITHONA SIMILIS CLAUS	F	C	ind/m^3		1915			2308							4302	8357	7060
			%		7			7							7	9	11
POLYCHAETE SPP.	L	OZ	ind/m^3	4017													
			%	7													
Pseudodiaptomus coronatus	C	C	ind/m^3		1809												
			%		6												

Life Stage Definitions:

C	Copepodite stages I-V
F	Copepoda adult female
L	Larva
M	Copepoda adult male
N	Nauplii
T	Trochophore (larval stage of polychaete)
Y	Cypris Larva of Barnacle

Group Definitions:

B	Barnacle
C	Copepod
OZ	Other Zooplankton

Abundance of Prevalent Species (> 5% Total Count)
Zooplankton, Survey W9615
October 29-30, 1996

Species	Life Stage	Group	Parameter	Station Cast	
				N04	N10
BIVALVIA SPP.	L	OZ	ind/m^3	8760	7075
			%	9	14
CENTROPAGES SPP.		C	ind/m^3	7398	
			%	8	
CENTROPAGES TYPICUS		C	ind/m^3	7203	11290
			%	8	23
COPEPOD SPP.	N	C	ind/m^3	27060	7828
			%	29	16
OITHONA SIMILIS CLAUS	C	C	ind/m^3	32122	12194
			%	35	25

Life Stage Definitions:

- C Copepodite stages I-V
- F Copepoda adult female
- L Larva
- M Copepoda adult male
- N Nauplii
- T Trochophore (larval stage of polychaete)
- Y Cypris Larva of Barnacle

Group Definitions:

- B Barnacle
- C Copepod
- OZ Other Zooplankton

Abundance of Prevalent Species (> 5% Total Count)
Zooplankton, Survey W9616
November 17-19, 1996

Species	Life Stage	Group	Parameter	Station Cast	
				N04	N10
BIVALVIA SPP.	L	OZ	ind/m^3	2091	836
			%	9	6
CENTROPAGES TYPICUS		C	ind/m^3	1206	
			%	5	
COPEPOD SPP.	N	C	ind/m^3	6755	6029
			%	31	40
MICROSETELLA NORVEGICA		C	ind/m^3		1313
			%		9
OITHONA SIMILIS CLAUS	C	C	ind/m^3	6755	2865
			%	31	19

Life Stage Definitions:

- C Copepodite stages I-V
- F Copepoda adult female
- L Larva
- M Copepoda adult male
- N Nauplii
- T Trochophore (larval stage of polychaete)
- Y Cypris Larva of Barnacle

Group Definitions:

- B Barnacle
- C Copepod
- OZ Other Zooplankton

Abundance of Prevalent Species (> 5% Total Count)
Zooplankton, Survey W9617
December 16-17, 1997

Species	Life Stage	Group	Parameter	Station Cast			
				F23	N04	N10	F06
ACARTIA HUDSONICA	C	C	ind/m^3	713			
			%	11			
ACARTIA HUDSONICA	F	C	ind/m^3	757			
			%	11			
COPEPOD SPP.	C	C	ind/m^3	445			
			%	7			
COPEPOD SPP.	N	C	ind/m^3	1915	15495	8938	18040
			%	29	55	47	46
OITHONA SIMILIS CLAUS	C	C	ind/m^3	891	6280	4390	12810
			%	14	22	23	33
OITHONA SIMILIS CLAUS	F	C	ind/m^3			1164	
			%			6	
PSEUDOCALANUS NEWMANI	C	C	ind/m^3		1702	1164	2274
			%		6	6	6

Life Stage Definitions:

- C Copepodite stages I-V
- F Copepoda adult female
- L Larva
- M Copepoda adult male
- N Nauplii
- T Trochophore (larval stage of polychaete)
- Y Cypris Larva of Barnacle

Group Definitions:

- B Barnacle
- C Copepod
- OZ Other Zooplankton

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