Semiannual water column monitoring report

February - June 2003

Massachusetts Water Resources Authority

Environmental Quality Department
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SEMIANNUAL WATER COLUMN MONITORING REPORT

February – June 2003

Submitted to

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EXECUTIVE SUMMARY

The Massachusetts Water Resources Authority (MWRA) has collected water quality data in Massachusetts and Cape Cod Bays for the Harbor and Outfall Monitoring (HOM) Program since 1992. This monitoring is in support of the HOM Program mission to assess the environmental effects of the relocation of effluent discharge from Boston Harbor to Massachusetts Bay. The data from 1992 through September 5, 2000 were collected to establish baseline water quality conditions and to provide the means to detect significant departure from the baseline after the outfall becomes operational. The surveys are designed to evaluate water quality on both a high-frequency basis for a limited area in the vicinity of the outfall site (nearfield surveys) and a low-frequency basis over an extended area throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (farfield). This semiannual report summarizes water column monitoring results for the seven surveys conducted from February to June 2003.

Over the course of the HOM program, a general trend in water quality events has emerged from the data collected in Massachusetts and Cape Cod Bays. The trends are evident even though the timing and year-to-year manifestations of these events are variable. The winter to spring transition in Massachusetts and Cape Cod Bays is usually characterized by a series of physical, biological, and chemical events: seasonal stratification, the winter/spring phytoplankton bloom, and nutrient depletion. This was generally the case in 2003. There was a winter/spring bloom of diatoms in February that was most prominent in Cape Cod Bay, Boston Harbor, coastal and western nearfield waters. A prolonged bloom of *Phaeocystis pouchetii* was observed throughout Massachusetts and Cape Cod Bays from February to April that was most pronounced in northern Massachusetts Bay. The occurrence of these two substantial blooms led to high chlorophyll levels in the nearfield that approached, but did not exceed threshold levels.

The winter/spring of 2003 was marked by lower than normal air and water temperatures. Air temperatures were the coldest on record since 1977-1978 and surface waters remained cold throughout the winter/spring. In early April, increased precipitation, runoff and the spring freshet led to lower surface salinity and a weakly stratified water column across most of Massachusetts Bay. There was an inshore to offshore gradient of increasing stratification in the nearfield in early April and by the end of the month the entire nearfield was stratified. In 2003, the relatively high precipitation and river flow resulted in a strong salinity gradient, yet the very low air temperatures led to a delay in surface water warming and a strong pycnocline was not observed in the nearfield until mid May. By the June combined survey, a strong pycnocline was established throughout the bays.

The nutrient data for February to June 2003 generally followed the typical progress of seasonal events in Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. Nutrient concentrations in Cape Cod Bay surface waters were low in comparison to Massachusetts Bay due to elevated diatom abundance in early February and remained relatively low throughout the report period. Massachusetts Bay surface water nutrient concentrations decreased from early February through April. The exception to this was for silicate which tended to increase from late February/early March to April coincident with a transition from a diatom dominated bloom in February to a *Phaeocystis* bloom in April. Nutrient concentrations in the surface waters were depleted throughout much of the nearfield region by mid March. Nutrient concentrations in the surface waters were depleted throughout the entire study area by June. Ammonium continues to be an excellent tracer of the effluent plume in the nearfield. During well-mixed conditions a strong NH_4/effluent signal rises from the outfall and surfaces and once stratification sets up and the plume is trapped below the pycnocline. In addition to illustrating the vertical extent of the plume, the nutrient distributions continue to show that the plume is generally confined to within 20 km of the outfall and that the location of the plume is variable.

Regional chlorophyll maxima were observed in Cape Cod Bay, coastal and Boston Harbor waters in late February/early March during the diatom bloom. The highest chlorophyll concentrations of the semiannual period were recorded in the nearfield in April during the *Phaeocystis* bloom. Comparable chlorophyll levels were measured at station F26 during this bloom. SeaWiFS images for this time period suggest that these elevated chlorophyll values may have been due to or enhanced by entrainment of waters from the Gulf of Maine into northeastern Massachusetts Bay during the freshet. Overall, chlorophyll concentrations in the nearfield were relatively high and often present at elevated levels over most of the water column.

The nearfield mean areal chlorophyll for winter/spring 2003 was 178 mg m^{-2}, which is comparable to but below the seasonal caution threshold of 182 mg m^{-2}. This is the highest winter/spring value since the outfall went online. The 2003 areal chlorophyll value was comparable to the winter/spring means in 1999 and 2000, which were coincident with substantial region-wide winter/spring blooms (diatoms in1999 and *Phaeocystis* in 2000). Although 2003 lacked a major region-wide winter/spring bloom, elevated chlorophyll concentrations over much of the water column during both the nearshore diatom bloom and the offshore *Phaeocystis* bloom resulted in high areal chlorophyll levels in the nearfield. The 2003 winter/spring seasonal mean was higher than values observed over the rest of the baseline period (1992-1998) and was the second highest observed during the monitoring program.

In contrast to the high chlorophyll concentrations, productivity was relatively low in comparison to past years. Areal production in 2003 followed patterns typically observed with a distinct peak associated with the winter/spring phytoplankton bloom, but peak production values were lower that the range usually observed. The pattern in areal production at the Boston Harbor station F23 in 2003 continued the trend observed in 2001 and 2002 with peak production during the winter/spring bloom. Prior to the diversion from the harbor to the bay outfall the harbor station exhibited a gradual pattern of increasing areal production from winter through summer rather than the distinct winter/spring peaks observed at the nearfield sites. This shift in the production pattern in the harbor may be in response to diversion and a sign of harbor recovery.

Dissolved oxygen measurements throughout the area during the first half of 2003 were consistent with the typical trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the winter/spring bloom in the bays. Maximum concentrations occurred in February when the water column was well mixed. DO concentrations decreased from February to April and reached minima for the time period in June throughout Massachusetts and Cape Cod Bays. The mean bottom water DO concentrations in June 2003, however, were relatively high in comparison to past years. Nearfield waters reached a survey mean minimum for percent saturation in May (<90%). The lowest survey mean value was observed in the bottom waters along the boundary (89%). Even though there were two major winter/spring blooms in 2003 and chlorophyll (an indicator of phytoplankton biomass) was high in comparison to past years, DO concentrations and %saturation were relatively high. This may be due to higher flow through the system and relatively low respiration rates due the very low ambient water temperatures in 2003.

Whole-water phytoplankton assemblages were dominated by several species of centric diatoms and unidentified microflagellates as is typical for the first half of the year. Winter/spring blooms of centric diatoms and *Phaeocystis pouchetii* were observed over most of Massachusetts and Cape Cod Bays. There were no blooms of other harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during this time period. While the dinoflagellate *Alexandrium tamarense* and the diatom of *Pseudo-nitzschia pungens* were recorded, they were present in very low abundance. Total zooplankton abundance generally increased from February through June as usual, and zooplankton assemblages during the first half of 2003 were comprised of taxa recorded for the same time of year in previous years.

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1.0 INTRODUCTION

1.1 Program Overview

The Massachusetts Water Resources Authority (MWRA) is conducting a long-term Harbor and Outfall Monitoring (HOM) Program for Massachusetts and Cape Cod Bays. The objective of the HOM Program is to (1) verify compliance with National Pollutant Discharge Elimination System (NPDES) permit requirements; (2) evaluate whether the impact of the discharge on the environment is within the bounds projected by the EPA Supplemental Environmental Impact Statement (SEIS; EPA 1988), and (3) determine whether change within the system exceeds the Contingency Plan thresholds (MWRA 2001). A detailed description of the monitoring and its rationale is provided in the Effluent Outfall Monitoring Plan developed for the baseline period and the post discharge monitoring plan (MWRA 1991 and 1997).

The MWRA conducts ambient water quality surveys in Massachusetts and Cape Cod Bays to monitor water quality conditions with respect to nutrients, water properties, phytoplankton and zooplankton, and water-column respiration and productivity. The surveys have been designed to evaluate water quality on both a high-frequency basis for a limited area (nearfield) and a low-frequency basis for an extended area (farfield). The nearfield stations are located in the vicinity of the Massachusetts Bay outfall site (**Figure** 1-1) and the farfield stations are located throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (**Figure** 1-2). The stations for the farfield surveys have been further separated into regional groupings according to geographic location to simplify regional data comparisons. This semiannual report summarizes water column monitoring results for the seven surveys conducted from February through June 2003 (**Table** 1-1).

Table 1-1. Water Quality Surveys for WF031-WF037 February to June 2003

Survey #	Type of Survey	Survey Dates
WF031	Nearfield/Farfield	February 5-8
WF032	Nearfield/Farfield	February 26, March 1-4
WN033	Nearfield	March 20
WF034	Nearfield/Farfield	April 1-3, 7
WN035	Nearfield	April 23
WN036	Nearfield	May 15
WF037	Nearfield/Farfield	June 18-21

The bay outfall became operational on September 6, 2000. The seven surveys conducted during this semiannual period are the third set of winter/spring surveys conducted after discharge of secondary treated effluent from the outfall began. The data evaluated and discussed in this report focus on characterization of spatial and temporal trends for February to June 2003. Preliminary comparisons against baseline data are discussed and appropriate threshold values presented. A detailed evaluation of 2003 versus the baseline period (1992-2000) will be presented in the 2003 annual water column report.

Initial 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, and QC plots), plankton data reports, and productivity and respiration data reports are each submitted four times annually. Raw data summarized within this or any of the other reports are available from MWRA in hard copy and electronic formats.

1.2 Organization of the Semiannual Report

The scope of the semiannual report is focused primarily towards providing an initial compilation of the water column data collected during the reporting period. Secondarily, integrated physical and biological results are discussed for key water column events and potential areas for expanded discussion in the annual water column report are recommended. The report first provides a summary of the survey and laboratory methods (Section 2). The bulk of the report, as discussed in further detail below, presents results of water column data from the first seven surveys of 2003 (Sections 3-5). Finally, the major findings of the semiannual period are summarized in Section 6.

Section 3 includes data summary tables that present the major numeric results of water column surveys in the semiannual period by parameter. A description of data selection, integration information, and summary statistics are included with that section.

Sections 4 (Results of Water Column Measurements) and 5 (Productivity, Respiration, and Plankton Results) include preliminary interpretation of the data with selected graphic representations 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 time-series plots of averaged surface and bottom water column parameters and along vertical transects 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 collection depth (the "E" depth). Examining data trends along four farfield transects (Boston-Nearfield, Cohasset, Marshfield and Nearfield-Marshfield), and one nearfield transect, allows three-dimensional presentation of water column conditions during each survey. One offshore transect (Boundary) enables analysis of results in the outermost boundary of the survey area during farfield surveys.

Results of water column physical, nutrient, chlorophyll, and dissolved oxygen data are provided in Section 4. Survey results were organized according to the physical characteristics of the water column during the semiannual period. The timing of water column vertical stratification, and the physical and biological status of the water column during stratification, significantly affects the temporal response of the water quality parameters, which provide a major focus for assessing effects of the outfall. This report describes the horizontal and vertical characterization of the water column during pre-stratification stage (WF031 – WN033), the early stratification stage (WF034), and once seasonal stratification was established (WN035 – WF037). Time-series data are commonly provided for the entire semiannual period for clarity and context of the 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 semiannual period is included in this section. A summary of the major water column events and unusual features of the semiannual period is presented in Section 6. References are provided in Section 7.

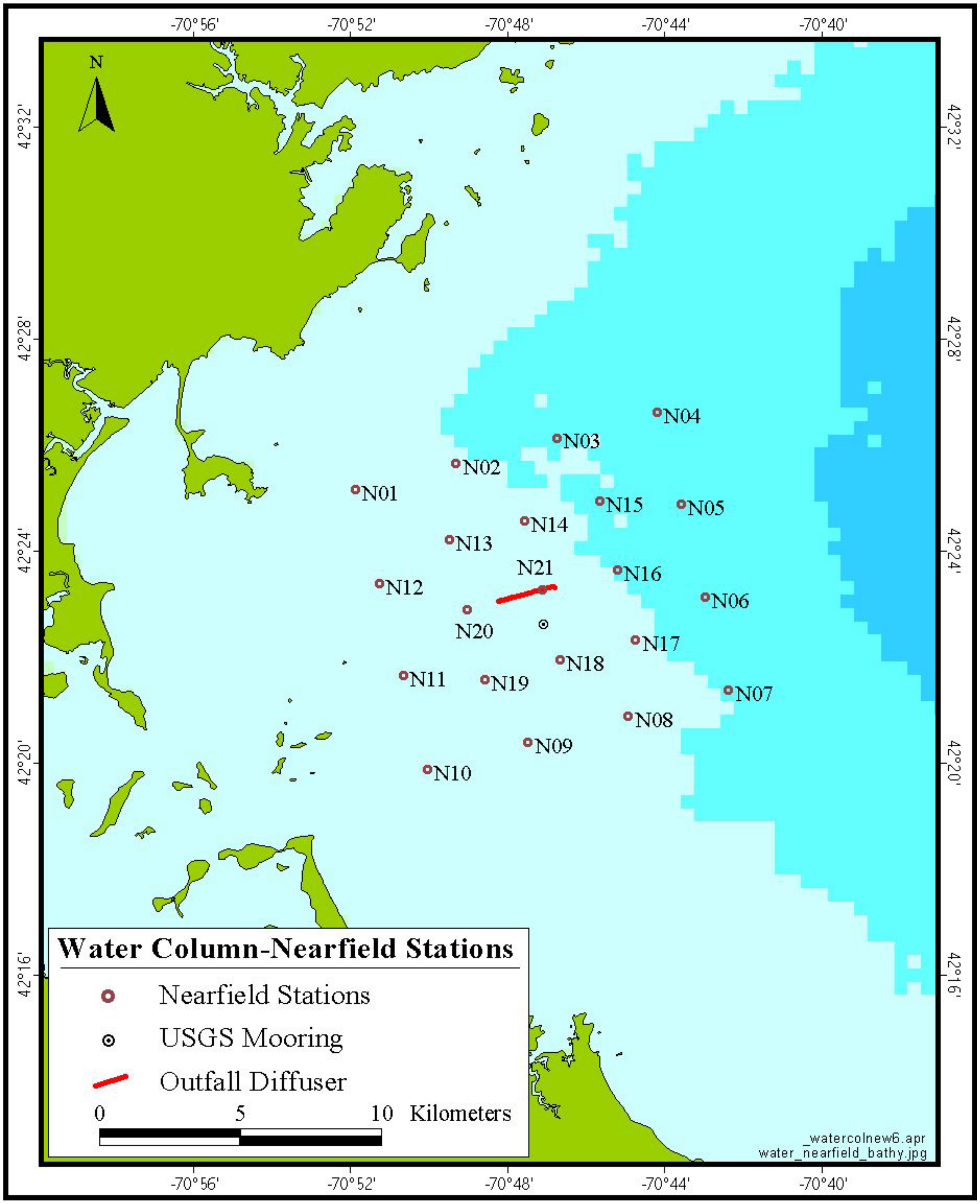


Figure 1-1. Locations of MWRA offshore outfall, nearfield stations and USGS mooring

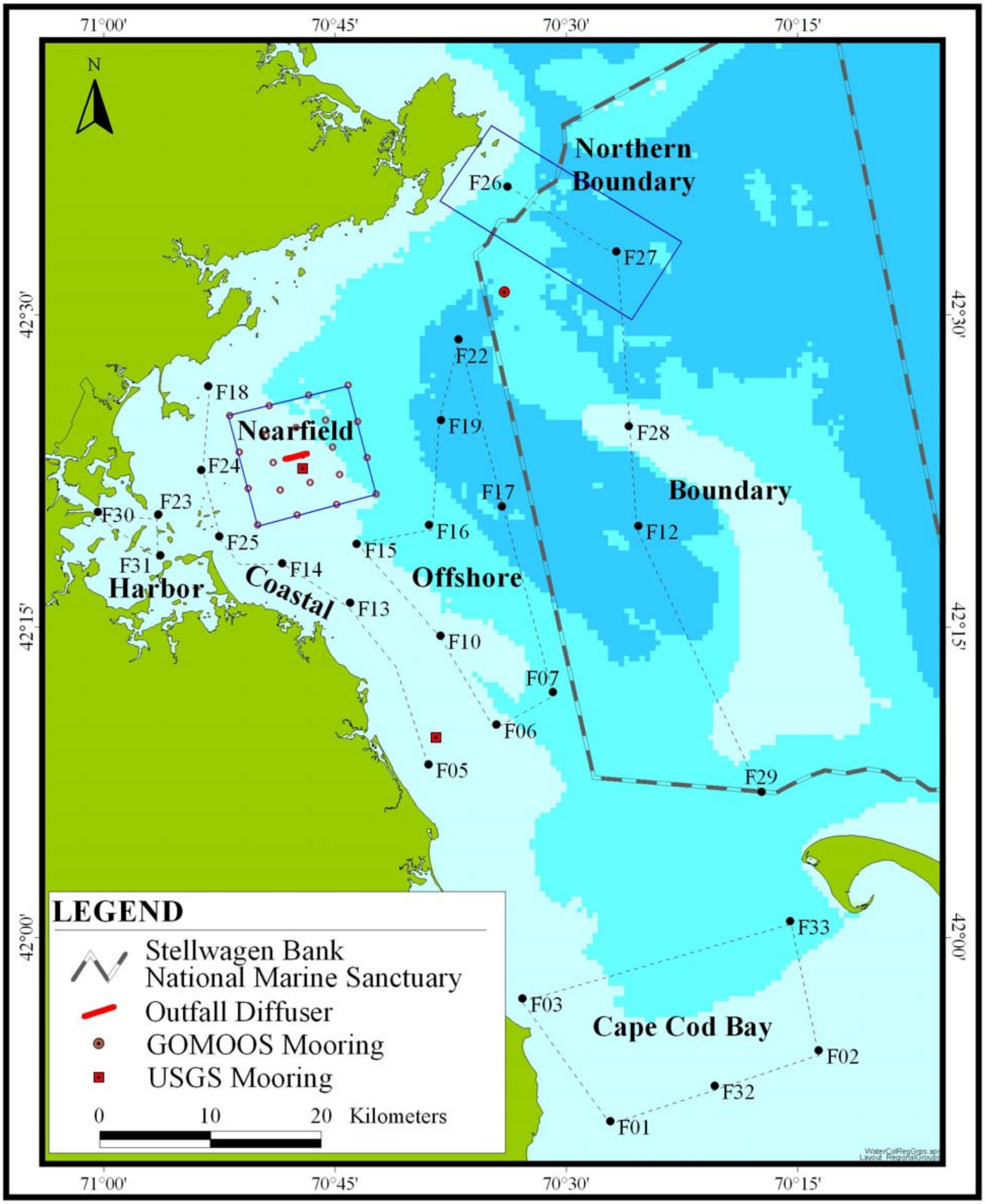


Figure 1-2. Locations of farfield stations and regional station groupings

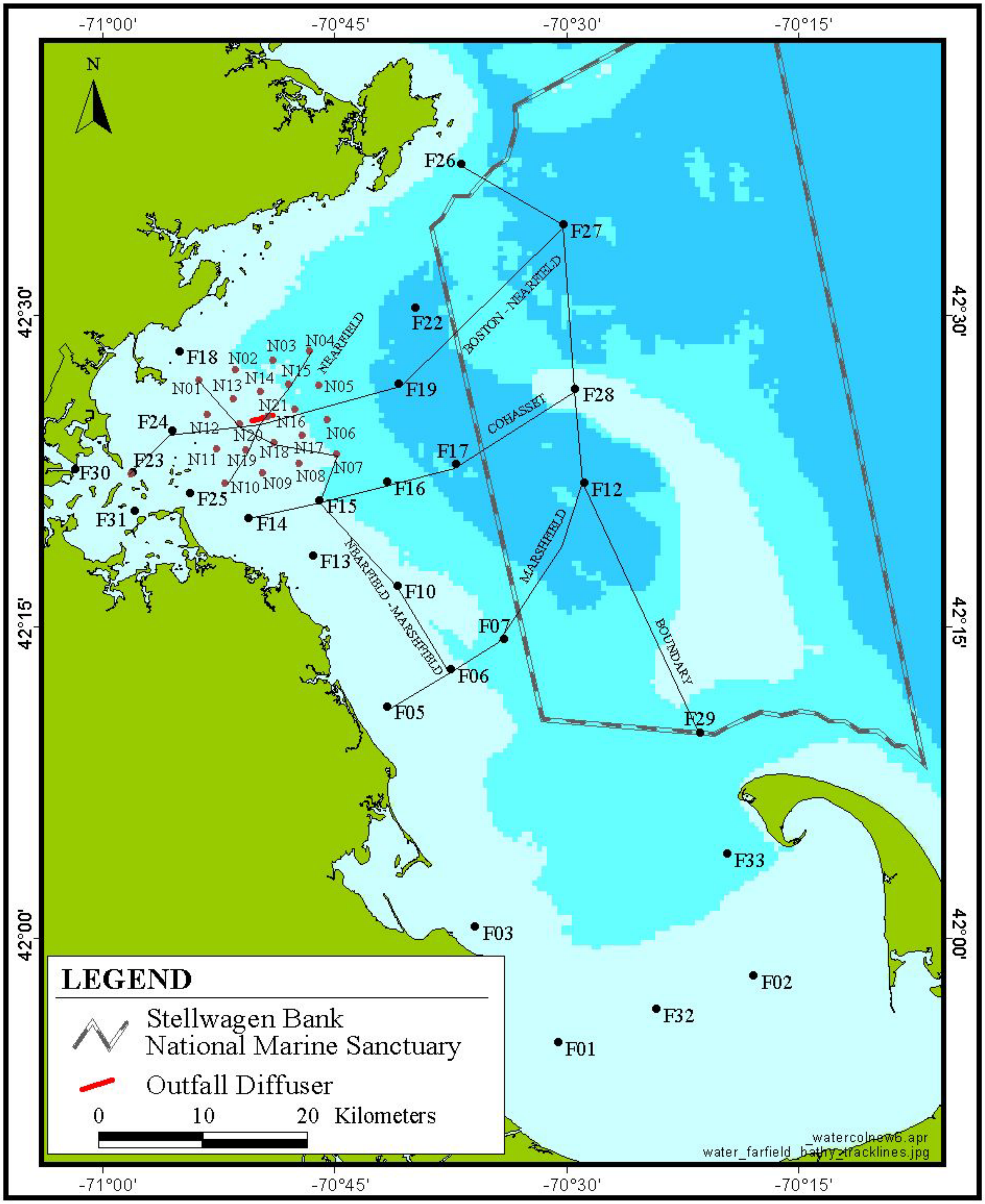


Figure 1-3. Locations of stations and selected transects

2.0 METHODS

This section describes general methods of data collection and sampling for the first seven water column monitoring surveys of 2003. Section 2.1 describes data collection methods, including survey dates, sampling platforms, and analyses performed. Section 2.2 describes the sampling schema undertaken, and Section 2.3 details specific operations for the first 2003 semiannual period. Specific details of field sampling and analytical procedures, laboratory sample processing and analysis, sample handling and custody, calibration and preventative maintenance, documentation, data evaluation, and data quality procedures are discussed in the Water Quality Monitoring CW/QAPP (Libby *et al.,* 2002a).

2.1 Data Collection

The farfield and nearfield water quality surveys for 2003 represent a continuation of the water quality monitoring conducted from 1992 - 2003. On September 6, 2000, the offshore outfall went online and began discharging effluent. The baseline monitoring period includes surveys from February 1992 to September 1, 2000. The last 5 fall 2000 surveys represented the beginning of the outfall discharge monitoring period, which continued in 2001, 2002 and 2003. The data collected during outfall discharge monitoring are evaluated internally and against baseline data. Data collection methods and schema have not changed from the baseline to the outfall discharge water quality monitoring periods.

Water quality data for this report were collected from the sampling platforms F/V *Isabel S*, F/V *Christopher Andrew*, and R/V *Aquamonitor.* Continuous vertical profiles of the water column and discrete water samples were collected using a CTD/Go-Flo Bottle Rosette system. This system includes a deck unit to control the system, display *in situ* data, and store the data, and an underwater unit comprised of several environmental sensors, including conductivity, temperature, depth, dissolved oxygen, transmissometry, irradiance, and 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 Go-Flo bottles at selected depths, as discussed below.

Water samples were collected at five depths at each station, except at stations F30, F31, F32, and F33. Stations F30 and F31 are shallow and require only three depths while only zooplankton samples are collected at F32 and F33. These depths were selected during CTD deployment based on positions relative to the pycnocline or subsurface chlorophyll maximum. The bottom depth (within 5 meters of the sea floor) and the surface depth (within 3 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. When the chlorophyll maximum occurred significantly below or above the middle depth, the mid-bottom or mid-surface sampling event was substituted with the mid-depth sampling event and the "mid-depth" sample was collected within the maximum. In essence, the "mid-depth" sample in these instances was not collected from the middle depth, but shallower or deeper in the water column in order to capture the chlorophyll maximum layer. These nomenclature semantics result from a combination of field logistics and scientific relevance. In the field, the switching of the "mid-depth" sample with the mid-surface or mid-bottom was transparent to everyone except the NavSam© operator who observed the subsurface chlorophyll structure and marked the events. The samples were processed in a consistent manner and a more comprehensive set of analyses was conducted for the surface, mid-depth/chlorophyll maximum, and bottom samples.

Samples from each depth at each station were collected by subsampling from the Go-Flo bottles into the appropriate sample container. Analyses performed on the water samples are summarized in **Table** 2-1. Samples for dissolved inorganic nutrients (DIN), dissolved organic carbon (DOC), total dissolved nitrogen (TDN) and phosphorus (TDP), particulate organic carbon (POC) and nitrogen

(PON), biogenic silica, particulate phosphorus (PP), chlorophyll *a* and phaeopigments, total suspended solids (TSS), urea, and phytoplankton (screened and rapid assessment) were filtered and preserved immediately after obtaining water from the appropriate Go-Flo bottles. Whole water phytoplankton samples (unfiltered) were obtained directly from the Go-Flo bottles and immediately preserved. Zooplankton samples were obtained by deploying a zooplankton net overboard and making an oblique tow of the upper two-thirds of the water column but with a maximum tow depth of 30 meters. Productivity samples were collected from the Go-Flo bottles, stored on ice and transferred to University of Rhode Island (URI) employees. Incubation was started no more that six hours after initial water collection at URI's laboratory. Respiration samples were collected from the Go-Flo bottles at four stations (F19, F23, N04, and N18). Incubations of the dark bottles were started within 30 minutes of sample collection. The dark bottle samples were maintained at a temperature within 2°C of the collection temperature for 7±2 days until analysis.

2.2 Sampling Schema

A synopsis of the sampling schema for the analyses described above is outlined in **Tables** 2-1, 2-2, and 2-3. Station designations were assigned according to the type of analyses performed at that station (see **Table** 2-1). Productivity and respiration analyses were also conducted at certain stations and represented by the letters P and R, respectively. **Table** 2-1 lists the different analyses performed at each station. **Tables** 2-2 (nearfield stations) and 2-3 (farfield stations) provide the station name and type, and show 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 a type D). Stations F32 and F33 are occupied during the first three farfield surveys of each year and collect zooplankton samples and hydrocast data only (designated as type Z).

Table 2-1. Station types and numbers (five depths collected unless otherwise noted)

Station Type	A	D	E	F	G[1]	P	R[4]	Z
Number of Stations	6	10	24	2	2	3	1	2
Analysis Type								
Dissolved inorganic nutrients	•	•	•	•	•	•		
Other nutrients (DOC, TDN, TDP, PC, PN, PP, Biogenic Si)[1]	•	•			•	•		
Chlorophyll [1]	•	•			•	•		
Total suspended solids [1]	•	•			•	•		
Dissolved oxygen	•	•		•	•	•		
Phytoplankton		•			•	•		
Zooplankton[3]		•			•	•		•
Respiration [1]						•	•	
Productivity, DIN						•		

[1]Samples collected at three depths (bottom, mid-depth, and surface)
[2]Samples collected at two depths (mid-depth and surface)
[3]Vertical tow samples collected
[4]Respiration samples collected at type A station F19

2.3 Operations Summary

Field operations for water column sampling and analysis during the first semiannual period were conducted as described above. Deviations from the CW/QAPP for surveys WF031, WF032, WN033, WF034, WN035, WN036, and WF037 had no effect on the data or data interpretation. For additional information about a specific survey, the individual survey reports may be consulted.

Table 2-2. Nearfield water column sampling plan (3 pages)

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.6	0.3	0.5	1	1	4	1	4	1	1	1	1
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
N01	30	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1							
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1							
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N02	40	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N03	44	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															
			1_Bottom	15.5	2	1	1	1	2	2	2	1	2						6	1	1
			2_Mid-Bottom	4.5	1	1						1		1						1	1
N04	50	D+	3_Mid-Depth	22.1	2	2	1	1	2	2	2	2	2			1	1		6	1	1
		R+	4_Mid-Surface	4.5	1	1						1		1						1	1
		P	5_Surface	20.6	2	1	1	1	2	2	2	1	2			1	1		6	1	1
			6_Net Tow															1			
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N05	55	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N06	52	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															
			1_Bottom	10.5	2	1	1	1	2	2	2	1	2	3							
			2_Mid-Bottom	2.5	1	1						1		1							
N07	52	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1							
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	10.5	2	1	1	1	2	2	2	1	2	3							
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N08	35	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	RE	AP	IC
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N09	32	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
N10	25	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1							
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1							
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N11	32	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N12	26	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N13	32	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N14	34	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N15	42	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
N16	40	A	3_Mid-Depth	10.2	2	2	2	2	2	2	2	2	2	1							
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1							
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N17	36	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	RE	AP	IC
			1_Bottom	15.5	2	1	1	1	2	2	2	1	2						6	1	1
		D+	2_Mid-Bottom	4.5	1	1						1		1						1	1
N18	30	R+	3_Mid-Depth	26.1	3	1	1	1	2	2	2	2	2		1	1	1		6	1	2
		P	4_Mid-Surface	4.5	1	1						1		1						1	1
			5_Surface	20.6	2	1	1	1	2	2	2	1	2			1	1		6	1	1
			6_Net Tow															1			
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N19	24	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
N20	32	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1							
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1							
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
N21	34	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1															
				Totals		111	22	22	42	42	42	42	42	33	1	4	4	2	36	10	11
Blanks A									1	1	1	1	1								

Table 2-3. Farfield water column sampling plan (3 pages)

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.3	0.3	0.5	1	1	0	1	4	1	1	1	1
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3							
			2_Mid-Bottom	2.5	1	1						1		1							
F01	27	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
F02	33	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1				
			6_Net Tow															1			
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F03	17	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F05	18	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3							
			2_Mid-Bottom	2.5	1	1						1		1							
F06	35	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F07	54	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F10	30	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	4	1	1								1							
			2_Mid-Bottom	2	1	1								1							
F12	90	F	3_Mid-Depth	2	1	1								1							
			4_Mid-Surface	2	1	1								1							
			5_Surface	4	1	1								1	1						
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
F13	25	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1				
			6_Net Tow															1			

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorus	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	RE	AP	IC
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F14	20	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F15	39	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F16	60	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F17	78	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F18	24	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	7	2	1	1	1	2	2	2	1	2						6		
			2_Mid-Bottom	2	1	1						1		1							
F19	81	A	3_Mid-Depth	7	2	1	1	1	2	2	2	2	2						6		
		+R	4_Mid-Surface	2	1	1						1		1							
			5_Surface	7	2	1	1	1	2	2	2	1	2		1				6		
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3							
			2_Mid-Bottom	2.5	1	1						1		1							
F22	80	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	18	3	1	1	1	2	2	2	1	2						6	1	1
		D	2_Mid-Bottom	8.5	1	1						1		1						1	2
F23	25	+R	3_Mid-Depth	24	3	1	1	1	2	2	2	2	2			1	1		6	1	1
		+P	4_Mid-Surface	7.5	1	1						1		1						1	1
			5_Surface	23	3	1	1	1	2	2	2	1	2		1	1	1		6	1	1
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3							
			2_Mid-Bottom	2.5	1	1						1		1							
F24	20	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
F25	15	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1				

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorus	Particulate Organic Carbon	Particulate Phosphorus	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	RE	AP	IC
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
F26	56	D	3_Mid-Depth	15	2	1	1	1	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1				
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
F27	108	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1				
			6_Net Tow															1			
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F28	33	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	2	1	1								1							
			2_Mid-Bottom	2	1	1								1							
F29	66	F	3_Mid-Depth	2	1	1								1							
			4_Mid-Surface	2	1	1								1							
			5_Surface	2	1	1								1	1						
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	3							
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1				
F30	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	3							
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1				
F31	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1				
			6_Net Tow															1			
F32	30	Z	5_Surface												1						
			6_Net Tow															1			
F33	30	Z	5_Surface												1						
			6_Net Tow															1			
			1_Bottom	8.1	2	1	2	2	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
N16	40	D	3_Mid-Depth	15	2	2	2	2	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1				
			6_Net Tow															1			
					Totals	132	44	44	84	84	84	80	84	96	28	26	26	15	36	5	6
			Blanks B						1	1	1	1	1								
			Blanks C						1	1	1	1	1								
			Blanks D						1	1	1	1	1								

3.0 DATA SUMMARY PRESENTATION

Data from each survey were compiled from the final HOM Program 2003 database and organized to facilitate regional comparisons between surveys, and to allow a quick evaluation of results for evaluating monitoring thresholds (**Table** 3-1 Method Detection Limits, Data **Tables** 3-2 through 3-13). Each data table provides summary data for each parameter over the course of the seven surveys. The nearfield data are presented separately and in combination with data from other farfield areas for surveys WF031, WF032, WF034, and WF037. 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) is provided below. Individual data summarized in this report are available from MWRA either in hard copy or electronic format.

The spatial pattern of data summary 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 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, 2001). Regional mean values for nutrient and biological water column data are calculated by averaging all samples collected at stations within each region. The "All" data summaries provide means based on the survey or regional mean values. Detailed considerations for individual data sets 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 were additionally segmented into five geographic areas: stations in Boston Harbor (F23, F30, and F31), coastal stations (F05, F13, F14, F18, F24, F25), offshore stations (F06, F07, F10, F15, F16, F17, F19, and F22), boundary region stations (F12, F26, F27, F28, F29), and Cape Cod Bay stations (F01, F02, and F03; and F32 and F33 as appropriate). These regions are shown in **Figure** 1-2.

The data summary tables include data 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** 3-2 to 3-4 include temperature, salinity, density (σ_t), fluorescence (chlorophyll a), transmissivity, and dissolved oxygen (DO) concentration. Statistical parameters (maximum, minimum, and average) were calculated from the sensor readings collected at five depths through the water column (defined as A-E). These depths were sampled on the upcast of the hydrographic profile. The five depth values, rather than the entire set of profile data, were selected 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. The mid-depth sample (C) was typically located at the subsurface 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 available in the Water Column Monitoring CW/QAPP (Libby *et al.,* 2002a), and are summarized in Section 2.

Following standard oceanographic practice, patterns of variability in water density are described using the derived parameter sigma-t ($\sigma_{t,}$), which is calculated by subtracting 1,000 kg/m^3 from the recorded density. During this semiannual period, density varied from 1020.9 to 1026.5, meaning σ_t varied from 20.9 to 26.5.

The beam attenuation coefficient from the transmissometer ("transmittance") is presented in **Table** 3-3. Beam attenuation is calculated from the natural logarithm of the ratio of light transmission relative to the initial light incidence, over the transmissometer path length, and is provided in units of m^{-1}.

Dissolved oxygen data are also presented in **Table** 3-3. In addition to DO concentration, the derived percent saturation is also presented. 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).

Fluorescence data presented in **Table** 3-4 were calibrated using concomitant *in vitro* chlorophyll *a* data from discrete water samples collected at a subset of the stations (see CW/QAPP or **Tables** 2-1, 2-2, 2-3). The calibrated fluorescence sensor values are used for all discussions of chlorophyll in this report except in the productivity section (5.1) where *in vitro* chlorophyll is presented. The concentrations of *in vitro* chlorophyll *a* and phaeopigments are included in **Table** 3-4 along with *in situ* fluorescence for direct comparison.

3.3 Nutrients

Analytical results for dissolved and particulate nutrient concentrations were extracted from the HOM database, and include: ammonium (NH_4), nitrite (NO_2), nitrate + nitrite (NO_3+NO_2), phosphate (PO_4), silicate (SiO_4), biogenic silica (BSI), dissolved and particulate organic carbon (DOC and POC), total dissolved and particulate organic nitrogen (TDN and PON), total dissolved and particulate phosphorous (TDP and PP), and total suspended solids (TSS). These data are presented in **Tables** 3-5 to 3-9. Note that the measurement of urea was discontinued in 2003 and is no longer included in the monitoring program. Dissolved inorganic nutrients (NH_4, NO_2, NO_3+NO_2, PO_4, and SiO_4) were measured from water samples collected from each of the five (A-E) depths during CTD casts. The dissolved organic and particulate constituents were measured from water samples collected from the surface (A), mid-depth (C), and bottom (E) sampling depths (see **Tables** 2-1, 2-2, and 2-3 for specific sampling depths and stations).

3.4 Biological Water Column Parameters

Four productivity parameters have been presented in the data summary tables. The parameters α ($gC[gChla]^{-1}h^{-1}[\mu Em^{-2}s^{-1}]^{-1}$) and Pmax ($gC[gChla]^{-1}h^{-1}$) that are derived from the photosynthesis-irradiance curves (Appendix C) are presented in **Table** 3-10. Areal production, which is determined by integrating the measured productivity over the photic zone, and depth-averaged chlorophyll-specific production are included for the productivity stations (F23 representing the harbor, and N04 and N18, representing the nearfield) in **Table** 3-11. Because areal production is already depth-integrated, averages were calculated only among productivity stations for the two regions sampled.

Respiration rates measured at the same harbor and nearfield stations as productivity, and additionally at offshore station F19 at three water column depths sampled (surface, mid-depth and bottom) are also presented in **Table** 3-11. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Libby *et al.,* 2002a).

3.5 Plankton

Plankton results were extracted from the HOM database and include whole water phytoplankton, screened phytoplankton, and zooplankton. Phytoplankton samples were collected for whole-water and screened measurements during the water column CTD casts at the surface (A) and mid-depth (C) sampling events. As discussed in Section 2.1, when a subsurface chlorophyll maximum is observed, the mid-depth sampling event is associated with this layer. The screened phytoplankton samples were filtered through 20-µm Nitex mesh to retain and concentrate larger dinoflagellate species. Zooplankton samples were collected by oblique tows using a 102-µm mesh at all plankton stations. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Libby *et al.,* 2002a).

Final plankton values were derived from each station by first averaging analytical replicates, then averaging station visits. Regional results were summarized for total phytoplankton, total centric diatoms, nuisance algae (*Alexandrium tamarense, Phaeocystis pouchetii,* and *Pseudo-nitzschia pungens*), and total zooplankton (**Tables** 3-12 and 3-13).

Results for total phytoplankton and centric diatoms reported in **Table** 3-12 are restricted to whole water surface samples. Results of 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 screen, both have colonial forms that in low densities might be overlooked in the whole-water samples. For *Alexandrium tamarense*, only the screened samples were reported.

3.6 Additional Data

Two additional data sources were utilized during interpretation of HOM Program semiannual water column data. Temperature and chlorophyll *a* satellite images collected near survey dates were preliminarily interpreted for evidence of surface water events, including intrusions of surface water masses from the Gulf of Maine and upwelling (Appendix D). U.S. Geological Service continuous *in situ* temperature and salinity data were collected from a mooring located between nearfield stations N21 and N18 (see **Figure** 1-1). At the time of draft report delivery no mooring data were available from USGS. There was a prolonged deployment from October 2002 to May 2003 and all data from the 1-m and 10-m above bottom arrays are compromised as is the WETStar data for this deployment. Any data that are salvageable from the 6-m and 13-m arrays will be added to the final report. Additionally data from the current deployment will be included in the final report if available.

Table 3-1. Method detection limits

Analysis	MDL
Dissolved ammonia (NH_4)	0.02 µM
Dissolved inorganic nitrate (NO_3)	0.01 µM
Dissolved inorganic nitrite (NO_2)	0.01 µM
Dissolved inorganic phosphorus (PO_4)	0.01 µM
Dissolved inorganic silicate (SIO_4)	0.02 µM
Dissolved organic carbon (DOC)	20 µM
Total dissolved nitrogen (TDN)	1.43 µM
Total dissolved phosphorus (TDP)	0.04 µM
Particulate carbon (POC)	5.27 µM
Particulate nitrogen (PON)	0.75 µM
Particulate phosphorus (PARTP)	0.04 µM
Biogenic silica (BIOSI)	0.32 µM
Urea	0.2 µM
Chlorophyll *a* and phaeophytin	0.036 µg L^{-1}
Total suspended solids (TSS)	0.1 mg L^{-1}

Table 3-2. Summary of *in situ* temperature, salinity, and density data for February - June 2003.

			Temperature (°C)			Salinity (PSU)			Sigma T		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF031	2/6	1.40	3.68	3.05	32.7	33.1	33.0	26.2	26.3	26.3
Nearfield	WF032	3/4	1.06	2.32	1.94	32.4	33.0	32.8	26.0	26.3	26.2
Nearfield	WN033	3/20	2.06	3.01	2.39	32.2	32.9	32.7	25.7	26.2	26.1
Nearfield	WF034	4/3	2.58	4.39	3.65	30.9	32.9	32.2	24.5	26.2	25.6
Nearfield	WN035	4/23	3.20	6.52	4.61	30.0	32.5	31.3	23.6	25.9	24.8
Nearfield	WN036	5/15	3.81	10.29	6.86	29.7	32.3	31.3	22.9	25.7	24.5
Nearfield	WF037	6/18	5.74	13.79	9.49	30.0	32.1	31.0	22.5	25.3	23.9
Nearfield	ALL		1.06	13.79	4.57	29.7	33.1	32.0	22.5	26.3	25.3
Boundary	WF031	2/5-8	2.64	4.49	3.54	32.9	33.2	33.1	26.2	26.3	26.3
Cape Cod Bay	WF031	2/5-8	0.58	2.31	1.26	31.5	33.3	32.4	25.1	26.5	25.9
Coastal	WF031	2/5-8	1.02	2.46	1.94	31.7	33.0	32.7	25.3	26.3	26.1
Harbor	WF031	2/5-8	0.58	1.05	0.83	32.0	32.6	32.3	25.6	26.1	25.9
Nearfield	WF031	2/5-8	1.40	3.68	3.05	32.7	33.1	33.0	26.2	26.3	26.3
Offshore	WF031	2/5-8	2.41	3.80	3.40	32.0	33.1	33.0	25.4	26.3	26.2
All	ALL		0.58	4.49	2.34	31.5	33.3	32.7	25.1	26.5	26.1
Boundary	WF032	2/26-3/4	0.37	3.14	2.25	32.4	33.1	32.9	25.9	26.4	26.3
Cape Cod Bay	WF032	2/26-3/4	-0.32	0.92	0.34	31.9	32.8	32.5	25.6	26.3	26.0
Coastal	WF032	2/26-3/4	0.66	1.76	1.04	32.3	32.9	32.6	25.9	26.3	26.1
Harbor	WF032	2/26-3/4	0.24	0.93	0.57	30.4	32.4	31.6	24.4	25.9	25.4
Nearfield	WF032	2/26-3/4	1.06	2.32	1.94	32.4	33.0	32.8	26.0	26.3	26.2
Offshore	WF032	2/26-3/4	1.33	2.68	2.23	32.7	33.2	33.0	26.2	26.4	26.3
All	ALL		-0.32	3.14	1.39	30.4	33.2	32.6	24.4	26.4	26.1
Boundary	WF034	4/1-7	1.81	3.55	2.95	30.5	32.9	32.5	24.3	26.3	25.9
Cape Cod Bay	WF034	4/1-7	2.85	3.89	3.48	32.0	32.4	32.2	25.4	25.8	25.6
Coastal	WF034	4/1-7	3.77	4.62	4.25	30.8	32.3	31.8	24.4	25.6	25.2
Harbor	WF034	4/1-7	4.01	5.17	4.59	30.1	31.8	30.9	23.9	25.2	24.5
Nearfield	WF034	4/1-7	2.58	4.39	3.65	30.9	32.9	32.2	24.5	26.2	25.6
Offshore	WF034	4/1-7	2.22	4.45	3.36	30.6	33.0	32.5	24.2	26.3	25.9
All	ALL		1.81	5.17	3.72	30.1	33.0	32.0	23.9	26.3	25.4
Boundary	WF037	6/18-21	4.21	13.77	8.92	30.3	32.4	31.4	22.6	25.7	24.3
Cape Cod Bay	WF037	6/18-21	6.91	15.48	11.12	30.5	31.7	31.0	22.4	24.9	23.6
Coastal	WF037	6/18-21	6.84	14.53	10.80	30.1	31.7	30.8	22.5	24.8	23.5
Harbor	WF037	6/18-21	11.79	14.47	13.17	28.2	30.6	29.8	20.9	23.2	22.3
Nearfield	WF037	6/18-21	5.74	13.79	9.49	30.0	32.1	31.0	22.5	25.3	23.9
Offshore	WF037	6/18-21	4.18	15.42	9.07	30.0	32.4	31.3	22.1	25.7	24.1
All	ALL		4.18	15.48	10.43	28.2	32.4	30.9	20.9	25.7	23.6

Table 3-3. Summary of *in situ* beam attenuation, dissolved oxygen concentration, and dissolved oxygen %saturation data for February - June 2003.

			Beam (m^{-1})			DO (mgL^{-1})			DO % Saturation		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF031	2/6	0.78	1.19	0.86	10.59	11.98	11.07	99.9	106.4	102.7
Nearfield	WF032	3/4	0.83	1.57	1.00	11.04	12.86	11.92	100.6	116.3	107.4
Nearfield	WN033	3/20	0.85	1.80	1.08	11.51	13.02	12.26	104.5	120.0	111.7
Nearfield	WF034	4/3	0.74	1.18	0.97	10.00	13.03	11.27	91.8	123.3	105.7
Nearfield	WN035	4/23	0.88	2.62	1.38	9.71	12.85	11.26	90.2	121.7	107.5
Nearfield	WN036	5/15	0.53	1.41	0.76	8.85	11.35	9.97	84.0	119.5	100.6
Nearfield	WF037	6/18	0.54	2.17	1.01	8.54	10.85	9.55	86.2	117.7	102.1
Nearfield	ALL		0.53	2.62	1.01	8.54	13.03	11.04	84.0	123.3	105.4
Boundary	WF031	2/5-8	0.68	0.87	0.79	10.05	11.60	10.64	94.2	106.5	100.0
Cape Cod Bay	WF031	2/5-8	1.08	1.35	1.18	11.56	12.28	11.93	101.7	106.8	105.3
Coastal	WF031	2/5-8	0.89	1.55	1.15	11.14	12.22	11.64	100.7	109.9	104.8
Harbor	WF031	2/5-8	1.47	1.82	1.61	11.55	12.26	12.05	101.5	106.8	105.2
Nearfield	WF031	2/5-8	0.78	1.19	0.86	10.59	11.98	11.07	99.9	106.4	102.7
Offshore	WF031	2/5-8	0.75	0.89	0.79	10.68	11.73	10.99	99.7	107.1	102.9
All	ALL		0.68	1.82	1.06	10.05	12.28	11.38	94.2	109.9	103.5
Boundary	WF032	2/26-3/4	0.74	1.04	0.90	10.06	11.89	10.79	93.5	102.7	98.1
Cape Cod Bay	WF032	2/26-3/4	0.82	1.53	1.10	11.06	12.43	11.78	96.8	105.3	101.6
Coastal	WF032	2/26-3/4	1.27	2.43	1.80	11.27	13.08	12.39	98.2	114.5	109.0
Harbor	WF032	2/26-3/4	1.98	2.36	2.17	11.23	13.27	12.14	96.0	114.7	104.8
Nearfield	WF032	2/26-3/4	0.83	1.57	1.00	11.04	12.86	11.92	100.6	116.3	107.4
Offshore	WF032	2/26-3/4	0.85	1.34	0.99	10.78	12.63	11.30	98.4	112.0	102.8
All	ALL		0.74	2.43	1.32	10.06	13.27	11.72	93.5	116.3	103.9
Boundary	WF034	4/1-7	0.61	1.41	0.90	10.07	11.82	10.86	90.6	108.9	100.3
Cape Cod Bay	WF034	4/1-7	0.65	1.00	0.86	10.20	11.57	11.02	95.6	109.0	103.0
Coastal	WF034	4/1-7	0.83	1.25	1.03	10.80	11.93	11.35	102.5	113.2	107.7
Harbor	WF034	4/1-7	1.04	1.76	1.41	10.49	11.08	10.82	98.7	105.7	103.0
Nearfield	WF034	4/1-7	0.74	1.18	0.97	10.00	13.03	11.27	91.8	123.3	105.7
Offshore	WF034	4/1-7	0.60	1.02	0.84	9.91	12.66	11.32	92.2	119.5	105.7
All	ALL		0.60	1.76	1.00	9.91	13.03	11.11	90.6	123.3	104.2
Boundary	WF037	6/18-21	0.53	1.29	0.75	8.51	11.03	9.89	81.0	117.4	104.7
Cape Cod Bay	WF037	6/18-21	0.67	1.34	1.02	8.77	9.74	9.20	88.7	110.3	101.8
Coastal	WF037	6/18-21	0.70	2.19	1.29	8.39	9.96	9.20	86.7	114.1	101.1
Harbor	WF037	6/18-21	1.40	2.71	2.37	8.50	9.36	9.06	95.3	107.2	103.9
Nearfield	WF037	6/18-21	0.54	2.17	1.01	8.54	10.85	9.55	86.2	117.7	102.1
Offshore	WF037	6/18-21	0.54	1.29	0.81	8.51	11.09	9.79	80.9	121.8	103.9
All	ALL		0.53	2.71	1.21	8.39	11.09	9.45	80.9	121.8	102.9

Table 3-4. Summary of *in situ* fluorescence, chlorophyll *a*, and phaeophytin data for February - June 2003.

			Fluorescence (μgL^{-1})			Chlorophyll *a* (μgL^{-1})			Phaeophytin (μgL^{-1})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF031	2/6	0.56	2.99	2.03	1.75	3.08	2.33	1.81	3.15	2.41
Nearfield	WF032	3/4	1.95	10.41	5.13	3.76	10.46	6.27	3.68	9.36	6.07
Nearfield	WN033	3/20	1.10	14.98	6.47	2.81	10.69	7.00	2.95	10.07	7.21
Nearfield	WF034	4/3	0.46	20.90	7.87	2.37	16.55	9.15	0.59	1.66	1.07
Nearfield	WN035	4/23	0.01	11.45	2.89	0.53	10.83	3.61	0.44	8.13	1.78
Nearfield	WN036	5/15	0.01	14.03	1.64	0.37	3.63	1.40	0.24	3.65	1.32
Nearfield	WF037	6/18	0.01	6.39	1.70	0.07	6.14	1.94	0.22	1.63	0.77
Nearfield	ALL		0.01	20.90	3.96	0.07	16.55	4.53	0.22	10.07	2.95
Boundary	WF031	2/5-8	0.65	4.21	2.52	0.61	2.48	1.51	0.73	2.61	1.65
Cape Cod Bay	WF031	2/5-8	1.71	11.07	5.34	5.46	10.34	8.03	5.11	9.16	7.18
Coastal	WF031	2/5-8	1.50	2.92	2.24	1.37	2.92	2.02	1.57	2.96	2.14
Harbor	WF031	2/5-8	2.01	3.47	2.77	1.63	2.93	2.29	1.75	3.25	2.46
Nearfield	WF031	2/5-8	0.56	2.99	2.03	1.75	3.08	2.33	1.81	3.15	2.41
Offshore	WF031	2/5-8	1.18	3.40	2.19	1.52	2.35	2.04	1.60	2.47	2.17
All	ALL		0.56	11.07	2.85	0.61	10.34	3.03	0.73	9.16	3.00
Boundary	WF032	2/26-3/4	1.05	7.68	3.26	0.40	2.94	1.44	0.69	3.36	1.77
Cape Cod Bay	WF032	2/26-3/4	0.77	19.80	7.76	1.10	15.44	10.09	1.18	17.36	10.91
Coastal	WF032	2/26-3/4	2.91	13.94	8.43	6.02	12.00	9.12	7.77	12.46	10.39
Harbor	WF032	2/26-3/4	9.50	15.77	12.47	8.72	14.05	11.26	10.21	16.09	11.99
Nearfield	WF032	2/26-3/4	1.95	10.41	5.13	3.76	10.46	6.27	3.68	9.36	6.07
Offshore	WF032	2/26-3/4	2.43	12.13	5.47	1.70	8.86	4.10	2.18	9.21	4.50
All	ALL		0.77	19.80	7.09	0.40	15.44	7.05	0.69	17.36	7.61
Boundary	WF034	4/1-7	0.02	18.36	4.25	0.28	3.84	2.38	0.39	1.31	0.90
Cape Cod Bay	WF034	4/1-7	0.02	1.44	0.22	0.51	1.06	0.72	0.24	1.01	0.59
Coastal	WF034	4/1-7	0.08	13.07	3.78	1.43	13.25	2.67	0.36	0.89	0.67
Harbor	WF034	4/1-7	1.43	3.20	2.38	0.97	2.46	1.69	0.55	1.43	0.86
Nearfield	WF034	4/1-7	0.46	20.90	7.87	2.37	16.55	9.15	0.59	1.66	1.07
Offshore	WF034	4/1-7	0.02	14.33	4.87	0.69	11.74	6.03	0.35	1.40	0.86
All	ALL		0.02	20.90	3.89	0.28	16.55	3.78	0.24	1.66	0.83
Boundary	WF037	6/18-21	0.02	5.69	0.71	0.11	6.03	1.48	0.12	1.33	0.58
Cape Cod Bay	WF037	6/18-21	0.15	3.64	1.51	0.43	3.59	1.53	0.21	1.29	0.60
Coastal	WF037	6/18-21	0.19	5.81	2.05	0.32	4.40	2.47	0.51	1.61	1.09
Harbor	WF037	6/18-21	2.23	5.77	3.88	2.99	6.69	4.30	1.12	2.08	1.67
Nearfield	WF037	6/18-21	0.01	6.39	1.70	0.07	6.14	1.94	0.22	1.63	0.77
Offshore	WF037	6/18-21	0.02	6.13	1.14	0.12	5.27	1.66	0.16	2.26	0.81
All	ALL		0.01	6.39	1.83	0.07	6.69	2.23	0.12	2.26	0.92

Table 3-5. Summary of ammonium, nitrite, and nitrite+nitrate data for February - June 2003.

			NH_4 (μM)			NO_2 (μM)			$NO_2 + NO_3$ (μM)		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF031	2/6	0.37	10.15	2.59	0.17	0.59	0.26	8.77	11.20	9.78
Nearfield	WF032	3/4	0.03	7.07	2.15	0.04	0.31	0.13	0.36	7.29	4.99
Nearfield	WN033	3/20	0.32	7.49	1.18	0.01	0.11	0.04	0.06	3.88	1.21
Nearfield	WF034	4/3	0.22	7.94	1.46	0.01	0.20	0.09	0.05	9.63	3.08
Nearfield	WN035	4/23	0.22	8.74	2.32	0.01	0.14	0.06	0.01	6.17	1.50
Nearfield	WN036	5/15	0.36	25.12	4.69	0.01	0.19	0.05	0.03	5.57	1.65
Nearfield	WF037	6/18	0.22	28.81	4.55	0.01	0.27	0.09	0.02	3.54	1.18
Nearfield	ALL		0.03	28.81	2.71	0.01	0.59	0.10	0.01	11.20	3.34
Boundary	WF031	2/5-8	0.33	5.55	1.30	0.09	0.29	0.21	8.36	11.25	9.74
Cape Cod Bay	WF031	2/5-8	0.16	2.12	0.94	0.10	0.21	0.15	0.94	9.51	4.75
Coastal	WF031	2/5-8	0.72	3.30	1.92	0.12	0.32	0.22	8.59	10.09	9.44
Harbor	WF031	2/5-8	0.55	3.85	1.77	0.23	0.39	0.31	8.33	11.01	9.67
Nearfield	WF031	2/5-8	0.37	10.15	2.59	0.17	0.59	0.26	8.77	11.20	9.78
Offshore	WF031	2/5-8	0.40	5.15	1.34	0.08	0.27	0.19	8.37	10.57	9.57
All	ALL		0.16	10.15	1.64	0.08	0.59	0.22	0.94	11.25	8.83
Boundary	WF032	2/26-3/4	0.73	3.14	1.33	0.03	0.12	0.08	0.22	12.05	8.02
Cape Cod Bay	WF032	2/26-3/4	0.47	3.86	1.45	0.01	0.12	0.05	0.09	3.37	1.35
Coastal	WF032	2/26-3/4	0.45	6.49	1.82	0.02	0.26	0.09	0.22	4.27	1.66
Harbor	WF032	2/26-3/4	0.34	3.95	1.51	0.01	0.11	0.06	0.30	1.17	0.64
Nearfield	WF032	2/26-3/4	0.03	7.07	2.15	0.04	0.31	0.13	0.36	7.29	4.99
Offshore	WF032	2/26-3/4	0.25	6.79	1.18	0.06	0.17	0.11	1.24	8.73	6.24
All	ALL		0.03	7.07	1.57	0.01	0.31	0.09	0.09	12.05	3.82
Boundary	WF034	4/1-7	0.15	3.76	1.25	0.01	0.21	0.08	0.96	10.58	4.11
Cape Cod Bay	WF034	4/1-7	0.87	2.11	1.32	0.01	0.11	0.04	0.01	2.11	1.00
Coastal	WF034	4/1-7	0.48	3.26	1.43	0.02	0.17	0.08	0.48	3.03	1.17
Harbor	WF034	4/1-7	0.35	3.49	1.45	0.07	0.19	0.10	1.10	8.04	2.57
Nearfield	WF034	4/1-7	0.22	7.94	1.46	0.01	0.20	0.09	0.05	9.63	3.08
Offshore	WF034	4/1-7	0.39	2.73	1.07	0.01	0.19	0.08	0.49	10.55	3.37
All	ALL		0.15	7.94	1.33	0.01	0.21	0.08	0.01	10.58	2.55
Boundary	WF037	6/18-21	0.01	4.01	1.51	0.01	0.26	0.09	0.02	6.68	1.40
Cape Cod Bay	WF037	6/18-21	0.03	4.36	1.15	0.01	0.13	0.04	0.01	1.96	0.48
Coastal	WF037	6/18-21	0.01	5.35	2.28	0.01	0.28	0.13	0.12	3.32	1.26
Harbor	WF037	6/18-21	0.76	3.14	1.71	0.07	0.28	0.13	0.54	3.47	1.40
Nearfield	WF037	6/18-21	0.22	28.81	4.55	0.01	0.27	0.09	0.02	3.54	1.18
Offshore	WF037	6/18-21	0.14	6.28	1.85	0.01	0.30	0.09	0.01	6.04	1.44
All	ALL		0.01	28.81	2.18	0.01	0.30	0.09	0.01	6.68	1.19

Table 3-6. Summary of phosphate, silicate, and biogenic silica data for February - June 2003.

			PO_4 (µM)			SiO_4 (µM)			BioSi (µM)		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF031	2/6	0.74	1.18	0.90	4.65	9.41	6.13	3.22	5.13	4.23
Nearfield	WF032	3/4	0.24	0.91	0.58	0.71	11.39	3.30	1.42	7.64	5.94
Nearfield	WN033	3/20	0.09	2.32	0.44	1.35	8.80	3.83	1.96	10.09	4.83
Nearfield	WF034	4/3	0.09	1.06	0.44	0.70	12.73	4.13	2.83	8.41	5.57
Nearfield	WN035	4/23	0.15	0.78	0.38	6.15	9.87	8.06	0.49	2.93	1.49
Nearfield	WN036	5/15	0.08	0.95	0.40	2.25	11.48	7.02	0.32	3.64	1.42
Nearfield	WF037	6/18	0.07	1.63	0.51	0.43	10.72	4.57	0.80	5.60	2.80
Nearfield	ALL		0.07	2.32	0.52	0.43	12.73	5.29	0.32	10.09	3.76
Boundary	WF031	2/5-8	0.54	0.97	0.83	5.15	10.89	6.97	1.35	5.14	3.17
Cape Cod Bay	WF031	2/5-8	0.39	0.96	0.64	0.63	6.62	3.21	4.72	6.74	5.77
Coastal	WF031	2/5-8	0.67	1.00	0.87	4.86	8.77	5.96	3.61	5.19	4.36
Harbor	WF031	2/5-8	0.59	0.69	0.65	6.19	8.52	7.01	4.00	5.45	5.04
Nearfield	WF031	2/5-8	0.74	1.18	0.90	4.65	9.41	6.13	3.22	5.13	4.23
Offshore	WF031	2/5-8	0.64	1.08	0.90	4.93	9.71	6.35	3.49	4.69	3.96
All	ALL		0.39	1.18	0.80	0.63	10.89	5.94	1.35	6.74	4.42
Boundary	WF032	2/26-3/4	0.20	0.86	0.66	0.39	11.52	5.53	0.47	4.89	2.52
Cape Cod Bay	WF032	2/26-3/4	0.14	0.35	0.26	0.18	1.80	0.62	1.02	10.77	7.12
Coastal	WF032	2/26-3/4	0.14	0.54	0.32	0.33	6.09	0.91	6.89	10.71	8.37
Harbor	WF032	2/26-3/4	0.01	0.19	0.12	0.47	6.60	2.20	7.22	10.96	9.37
Nearfield	WF032	2/26-3/4	0.24	0.91	0.58	0.71	11.39	3.30	1.42	7.64	5.94
Offshore	WF032	2/26-3/4	0.23	0.99	0.66	0.55	7.44	3.37	4.71	7.67	5.71
All	ALL		0.01	0.99	0.43	0.18	11.52	2.66	0.47	10.96	6.51
Boundary	WF034	4/1-7	0.28	1.56	0.67	0.71	13.32	5.08	1.43	2.47	1.90
Cape Cod Bay	WF034	4/1-7	0.14	0.50	0.27	1.21	5.13	2.79	0.70	2.55	1.68
Coastal	WF034	4/1-7	0.18	0.38	0.27	0.70	7.84	3.39	1.83	3.64	2.47
Harbor	WF034	4/1-7	0.17	0.86	0.39	2.55	14.39	6.99	2.48	5.03	3.65
Nearfield	WF034	4/1-7	0.09	1.06	0.44	0.70	12.73	4.13	2.83	8.41	5.57
Offshore	WF034	4/1-7	0.12	0.99	0.43	0.70	14.43	3.84	2.23	6.91	3.77
All	ALL		0.09	1.56	0.41	0.70	14.43	4.37	0.70	8.41	3.17
Boundary	WF037	6/18-21	0.08	0.91	0.37	0.14	11.02	3.13	0.50	3.90	2.17
Cape Cod Bay	WF037	6/18-21	0.13	0.68	0.32	2.30	11.39	5.18	0.16	4.80	2.31
Coastal	WF037	6/18-21	0.15	0.81	0.46	1.04	9.69	4.45	2.00	6.30	4.46
Harbor	WF037	6/18-21	0.14	0.38	0.24	2.43	8.40	4.23	3.10	6.80	5.56
Nearfield	WF037	6/18-21	0.07	1.63	0.51	0.43	10.72	4.57	0.80	5.60	2.80
Offshore	WF037	6/18-21	0.05	1.00	0.38	0.15	12.50	3.92	0.50	7.20	2.58
All	ALL		0.05	1.63	0.38	0.14	12.50	4.25	0.16	7.20	3.31

Table 3-7. Summary of particulate carbon, nitrogen, and phosphorous data for February - June 2003.

			POC (µM)			PON (µM)			PartP (µM)		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF031	2/6	11.30	42.90	17.78	2.01	3.77	2.70	0.07	0.20	0.14
Nearfield	WF032	3/4	18.80	56.80	31.03	3.56	8.43	5.71	0.18	0.67	0.32
Nearfield	WN033	3/20	30.30	55.80	42.65	4.50	9.57	6.74	0.26	0.53	0.38
Nearfield	WF034	4/3	18.30	89.20	43.42	2.64	13.40	7.06	0.11	0.75	0.40
Nearfield	WN035	4/23	16.40	67.80	35.63	2.85	18.30	7.27	0.13	0.54	0.22
Nearfield	WN036	5/15	10.90	45.90	20.55	1.97	6.17	3.36	0.08	0.30	0.15
Nearfield	WF037	6/18	5.59	52.80	25.71	1.05	8.14	4.07	0.05	0.39	0.21
Nearfield	ALL		5.59	89.20	30.97	1.05	18.30	5.27	0.05	0.75	0.26
Boundary	WF031	2/5-8	5.66	15.80	9.44	0.84	2.43	1.43	0.05	0.16	0.11
Cape Cod Bay	WF031	2/5-8	31.20	58.00	42.82	5.41	7.71	6.64	0.36	0.55	0.47
Coastal	WF031	2/5-8	15.70	26.30	18.81	2.52	3.19	2.83	0.14	0.29	0.18
Harbor	WF031	2/5-8	23.70	28.80	25.89	3.03	4.40	3.85	0.21	0.36	0.27
Nearfield	WF031	2/5-8	11.30	42.90	17.78	2.01	3.77	2.70	0.07	0.20	0.14
Offshore	WF031	2/5-8	10.90	20.00	13.70	1.82	3.27	2.30	0.11	0.19	0.14
All	ALL		5.66	58.00	21.40	0.84	7.71	3.29	0.05	0.55	0.22
Boundary	WF032	2/26-3/4	10.10	26.00	17.55	1.69	4.44	2.96	0.07	0.29	0.17
Cape Cod Bay	WF032	2/26-3/4	25.60	85.00	69.00	3.01	13.93	10.68	0.21	1.16	0.73
Coastal	WF032	2/26-3/4	40.70	61.70	47.43	7.50	9.64	8.21	0.47	0.82	0.64
Harbor	WF032	2/26-3/4	49.20	83.30	65.50	7.93	14.43	10.87	0.50	1.01	0.85
Nearfield	WF032	2/26-3/4	18.80	56.80	31.03	3.56	8.43	5.71	0.18	0.67	0.32
Offshore	WF032	2/26-3/4	15.80	28.20	21.03	2.86	5.29	3.83	0.17	0.33	0.24
All	ALL		10.10	85.00	41.92	1.69	14.43	7.04	0.07	1.16	0.49
Boundary	WF034	4/1-7	9.25	33.90	24.81	0.38	5.06	3.67	0.06	0.24	0.19
Cape Cod Bay	WF034	4/1-7	15.40	25.30	20.45	2.60	4.08	3.22	0.13	0.36	0.23
Coastal	WF034	4/1-7	18.60	40.60	29.21	2.99	6.11	4.32	0.15	0.35	0.24
Harbor	WF034	4/1-7	23.10	32.80	30.16	4.04	5.60	4.83	0.22	0.41	0.34
Nearfield	WF034	4/1-7	18.30	89.20	43.42	2.64	13.40	7.06	0.11	0.75	0.40
Offshore	WF034	4/1-7	9.75	49.90	31.63	1.35	6.27	4.55	0.09	0.42	0.25
All	ALL		9.25	89.20	29.95	0.38	13.40	4.61	0.06	0.75	0.28
Boundary	WF037	6/18-21	7.71	29.80	15.57	1.46	5.11	2.60	0.07	0.33	0.15
Cape Cod Bay	WF037	6/18-21	12.80	61.00	24.85	2.64	11.57	4.69	0.09	0.25	0.16
Coastal	WF037	6/18-21	9.25	47.10	27.47	1.71	7.50	4.74	0.10	0.48	0.27
Harbor	WF037	6/18-21	24.60	63.60	41.30	5.28	9.00	7.23	0.24	0.50	0.39
Nearfield	WF037	6/18-21	5.59	52.80	25.71	1.05	8.14	4.07	0.05	0.39	0.21
Offshore	WF037	6/18-21	9.83	37.50	21.46	1.90	6.99	4.08	0.11	0.26	0.17
All	ALL		5.59	63.60	26.06	1.05	11.57	4.57	0.05	0.50	0.22

Table 3-8. Summary of dissolved organic carbon, nitrogen, and phosphorous data for February - June 2003.

				DOC (µM)			TDN (µM)			TDP (µM)	
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF031	2/6	97.90	265.20	135.73	21.70	42.21	28.29	1.01	1.83	1.23
Nearfield	WF032	3/4	115.50	456.70	211.03	12.37	26.59	20.17	0.46	1.06	0.88
Nearfield	WN033	3/20	120.50	334.50	183.29	10.23	15.79	12.56	0.37	0.77	0.56
Nearfield	WF034	4/3	94.00	353.80	136.22	13.97	35.87	20.78	0.40	1.20	0.71
Nearfield	WN035	4/23	151.10	229.90	180.15	9.09	20.84	15.47	0.41	1.47	0.77
Nearfield	WN036	5/15	116.40	242.40	159.21	14.59	30.53	20.47	0.43	1.42	0.86
Nearfield	WF037	6/18	136.60	260.00	198.69	16.35	43.15	23.49	0.41	1.49	0.76
Nearfield	ALL		94.00	456.70	172.05	9.09	43.15	20.18	0.37	1.83	0.82
Boundary	WF031	2/5-8	101.40	191.40	136.52	21.98	27.77	25.15	1.09	1.28	1.20
Cape Cod Bay	WF031	2/5-8	112.00	149.20	126.40	11.44	22.32	15.29	0.72	0.82	0.75
Coastal	WF031	2/5-8	100.40	214.10	143.33	21.47	45.68	28.52	1.04	1.32	1.14
Harbor	WF031	2/5-8	104.70	179.60	137.82	21.35	36.71	27.89	0.93	1.59	1.09
Nearfield	WF031	2/5-8	97.90	265.20	135.73	21.70	42.21	28.29	1.01	1.83	1.23
Offshore	WF031	2/5-8	104.40	222.20	131.47	20.16	39.76	28.85	1.09	1.76	1.20
All	ALL		97.90	265.20	135.21	11.44	45.68	25.67	0.72	1.83	1.10
Boundary	WF032	2/26-3/4	107.50	262.50	140.00	19.72	28.20	23.17	0.92	1.14	1.03
Cape Cod Bay	WF032	2/26-3/4	119.20	327.60	202.47	11.20	15.69	13.81	0.47	0.72	0.59
Coastal	WF032	2/26-3/4	116.10	558.40	267.19	12.67	22.58	17.12	0.47	0.74	0.57
Harbor	WF032	2/26-3/4	133.30	514.10	268.74	13.90	16.64	14.90	0.33	0.52	0.39
Nearfield	WF032	2/26-3/4	115.50	456.70	211.03	12.37	26.59	20.17	0.46	1.06	0.88
Offshore	WF032	2/26-3/4	115.90	521.70	251.04	16.85	26.63	22.30	0.84	1.12	1.00
All	ALL		107.50	558.40	223.41	11.20	28.20	18.58	0.33	1.14	0.74
Boundary	WF034	4/1-7	104.00	872.30	263.28	16.58	25.54	20.53	0.67	1.16	0.89
Cape Cod Bay	WF034	4/1-7	113.20	182.00	133.08	16.14	33.22	24.79	0.57	0.81	0.69
Coastal	WF034	4/1-7	95.50	221.90	131.72	12.43	30.71	18.31	0.47	0.74	0.61
Harbor	WF034	4/1-7	110.20	271.10	154.52	13.59	32.20	22.89	0.59	0.64	0.62
Nearfield	WF034	4/1-7	94.00	353.80	136.22	13.97	35.87	20.78	0.40	1.20	0.71
Offshore	WF034	4/1-7	91.70	196.00	120.57	15.32	28.39	21.30	0.53	1.28	0.81
All	ALL		91.70	872.30	156.57	12.43	35.87	21.43	0.40	1.28	0.72
Boundary	WF037	6/18-21	130.60	176.40	150.22	12.67	28.07	17.62	0.42	1.16	0.71
Cape Cod Bay	WF037	6/18-21	119.70	160.10	141.53	10.25	16.61	13.55	0.43	0.96	0.69
Coastal	WF037	6/18-21	135.60	314.50	211.86	17.08	29.05	21.48	0.54	1.25	0.74
Harbor	WF037	6/18-21	157.00	245.00	188.76	13.93	40.94	21.67	0.54	0.74	0.63
Nearfield	WF037	6/18-21	136.60	260.00	198.69	16.35	43.15	23.49	0.41	1.49	0.76
Offshore	WF037	6/18-21	139.80	178.80	150.74	12.12	26.26	17.69	0.43	1.35	0.79
All	ALL		119.70	314.50	173.63	10.25	43.15	19.25	0.41	1.49	0.72

Table 3-9. Summary of total suspended solids data for February - June 2003.

Region	Survey	Dates	TSS (mgL^{-1}) Min	Max	Mean
Nearfield	WF031	2/6	0.05	2.40	1.22
Nearfield	WF032	3/4	1.21	4.69	1.99
Nearfield	WN033	3/20	1.15	4.54	2.06
Nearfield	WF034	4/3	0.99	2.82	1.54
Nearfield	WN035	4/23	0.30	3.72	1.29
Nearfield	WN036	5/15	0.46	2.32	0.87
Nearfield	WF037	6/18	0.30	2.54	1.05
Nearfield	ALL		0.05	4.69	1.43
Boundary	WF031	2/5-8	0.65	2.02	1.13
Cape Cod Bay	WF031	2/5-8	1.29	1.70	1.50
Coastal	WF031	2/5-8	0.94	2.49	1.70
Harbor	WF031	2/5-8	2.07	3.18	2.51
Nearfield	WF031	2/5-8	0.05	2.40	1.22
Offshore	WF031	2/5-8	0.83	2.03	1.20
All	ALL		0.05	3.18	1.54
Boundary	WF032	2/26-3/4	0.81	1.31	0.98
Cape Cod Bay	WF032	2/26-3/4	1.16	3.08	2.21
Coastal	WF032	2/26-3/4	2.34	7.59	3.94
Harbor	WF032	2/26-3/4	3.01	4.79	3.80
Nearfield	WF032	2/26-3/4	1.21	4.69	1.99
Offshore	WF032	2/26-3/4	1.02	1.97	1.36
All	ALL		0.81	7.59	2.38
Boundary	WF034	4/1-7	0.69	1.39	1.05
Cape Cod Bay	WF034	4/1-7	0.64	1.42	1.06
Coastal	WF034	4/1-7	0.74	1.69	1.13
Harbor	WF034	4/1-7	1.08	2.79	1.86
Nearfield	WF034	4/1-7	0.99	2.82	1.54
Offshore	WF034	4/1-7	0.90	2.64	1.44
All	ALL		0.64	2.82	1.35
Boundary	WF037	6/18-21	0.31	0.98	0.62
Cape Cod Bay	WF037	6/18-21	0.27	1.68	1.17
Coastal	WF037	6/18-21	0.72	3.00	1.77
Harbor	WF037	6/18-21	1.65	3.14	2.34
Nearfield	WF037	6/18-21	0.30	2.54	1.05
Offshore	WF037	6/18-21	0.36	1.87	0.93
All	ALL		0.27	3.14	1.31

Table 3-10. Summary of production parameters alpha and Pmax data for February - June 2003. Production is only measured in nearfield and Boston Harbor (stations N04, N18, and F23).

			Alpha $[mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}]$			Pmax $(mgCm^{-3}h^{-1})$		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF031	2/6	0.006	0.013	0.010	0.88	1.95	1.23
Nearfield	WF032	3/4	0.033	0.144	0.072	4.37	9.78	7.14
Nearfield	WN033	3/20	0.037	0.193	0.080	5.64	13.49	8.47
Nearfield	WF034	4/3	0.033	0.193	0.103	5.63	15.46	9.86
Nearfield	WN035	4/23	0.002	0.110	0.033	0.45	10.20	3.38
Nearfield	WN036	5/15	0.003	0.017	0.009	0.50	1.86	1.01
Nearfield	WF037	6/18	0.015	0.614	0.161	1.59	24.65	9.09
Nearfield	ALL		0.002	0.614	0.067	0.45	24.65	5.74
Boundary	WF031	2/5-8						
Cape Cod Bay	WF031	2/5-8						
Coastal	WF031	2/5-8						
Harbor	WF031	2/5-8	0.008	0.018	0.013	1.83	2.44	2.07
Nearfield	WF031	2/5-8	0.006	0.013	0.010	0.88	1.95	1.23
Offshore	WF031	2/5-8						
All	ALL		0.006	0.018	0.011	0.88	2.44	1.65
Boundary	WF032	2/26-3/4						
Cape Cod Bay	WF032	2/26-3/4						
Coastal	WF032	2/26-3/4						
Harbor	WF032	2/26-3/4	0.222	0.498	0.308	24.70	38.60	29.10
Nearfield	WF032	2/26-3/4	0.033	0.144	0.072	4.37	9.78	7.14
Offshore	WF032	2/26-3/4						
All	ALL		0.033	0.498	0.190	4.37	38.60	18.12
Boundary	WF034	4/1-7						
Cape Cod Bay	WF034	4/1-7						
Coastal	WF034	4/1-7						
Harbor	WF034	4/1-7	0.025	0.048	0.038	2.74	3.87	3.19
Nearfield	WF034	4/1-7	0.033	0.193	0.103	5.63	15.46	9.86
Offshore	WF034	4/1-7						
All	ALL		0.025	0.193	0.070	2.74	15.46	6.53
Boundary	WF037	6/18-21						
Cape Cod Bay	WF037	6/18-21						
Coastal	WF037	6/18-21						
Harbor	WF037	6/18-21	0.084	0.123	0.097	14.29	19.07	16.05
Nearfield	WF037	6/18-21	0.015	0.614	0.161	1.59	24.65	9.09
Offshore	WF037	6/18-21						
All	ALL		0.015	0.614	0.129	1.59	24.65	12.57

Table 3-11. Summary of areal production, depth-averaged chlorophyll-specific production, and respiration data for February - June 2003. Production is only measured in nearfield and Boston Harbor (stations N04, N18, and F23). Respiration is measured at the production stations and at offshore station F19.

			Areal Production ($mgCm^{-2}d^{-1}$)			Depth-averaged Chlorophyll- specific Production ($mgCmgChla^{-1}d^{-1}$)			Respiration (μMO_2h^{-1})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF031	2/6	104.3	310.2	207.3	1.9	3.5	2.7	0.018	0.105	0.052
Nearfield	WF032	3/4	690.1	943.4	816.8	4.5	4.5	4.5	0.010	0.036	0.020
Nearfield	WN033	3/20	1021.7	1381.1	1201.4	3.2	15.2	9.2	0.081	0.120	0.103
Nearfield	WF034	4/3	547.1	600.9	574.0	2.1	2.1	2.1	0.013	0.195	0.091
Nearfield	WN035	4/23	256.0	1024.9	640.5	7.9	17.3	12.6	0.054	0.129	0.094
Nearfield	WN036	5/15	141.8	312.9	227.4	2.1	18.9	10.5	0.043	0.126	0.081
Nearfield	WF037	6/18	331.9	383.5	357.7	5.9	6.7	6.3	0.041	0.205	0.125
Nearfield	ALL		104.3	1381.1	575.0	1.9	18.9	6.8	0.010	0.205	0.081
Boundary	WF031	2/5-8									
Cape Cod Bay	WF031	2/5-8									
Coastal	WF031	2/5-8									
Harbor	WF031	2/5-8	152.9	152.9	152.9	3.1	3.1	3.1	0.011	0.044	0.024
Nearfield	WF031	2/5-8	104.3	310.2	207.3	1.9	3.5	2.7	0.018	0.105	0.052
Offshore	WF031	2/5-8							0.033	0.093	0.068
All	ALL		104.3	310.2	180.1	1.9	3.5	2.9	0.011	0.105	0.048
Boundary	WF032	2/26-3/4									
Cape Cod Bay	WF032	2/26-3/4									
Coastal	WF032	2/26-3/4									
Harbor	WF032	2/26-3/4	1467.0	1467.0	1467.0	8.1	8.1	8.1	0.043	0.102	0.076
Nearfield	WF032	2/26-3/4	690.1	943.4	816.8	4.5	4.5	4.5	0.010	0.036	0.020
Offshore	WF032	2/26-3/4							0.024	0.053	0.039
All	ALL		690.1	1467.0	1141.9	4.5	8.1	6.3	0.010	0.102	0.045
Boundary	WF034	4/1-7									
Cape Cod Bay	WF034	4/1-7									
Coastal	WF034	4/1-7									
Harbor	WF034	4/1-7	209.2	209.2	209.2	5.4	5.4	5.4	0.018	0.076	0.043
Nearfield	WF034	4/1-7	547.1	600.9	574.0	2.1	2.1	2.1	0.013	0.195	0.091
Offshore	WF034	4/1-7							0.022	0.060	0.043
All	ALL		209.2	600.9	391.6	2.1	5.4	3.7	0.013	0.195	0.059
Boundary	WF037	6/18-21									
Cape Cod Bay	WF037	6/18-21									
Coastal	WF037	6/18-21									
Harbor	WF037	6/18-21	795.2	795.2	795.2	7.5	7.5	7.5	0.149	0.195	0.176
Nearfield	WF037	6/18-21	331.9	383.5	357.7	5.9	6.7	6.3	0.041	0.205	0.125
Offshore	WF037	6/18-21							0.027	0.095	0.067
All	ALL		331.9	795.2	576.5	5.9	7.5	6.9	0.027	0.205	0.123

Table 3-12. Summary of total phytoplankton, centric diatoms, and total zooplankton data for February - June 2003.

			Total Phytoplankton (10^6 cells L^{-1})			Centric Diatoms (10^6 cells L^{-1})			Total Zooplankton (Individuals m^{-3})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF031	2/6	0.194	1.037	0.413	0.033	0.066	0.049	5213	9081	7175
Nearfield	WF032	3/4	0.431	0.653	0.546	0.093	0.290	0.190	4142	8824	6040
Nearfield	WN033	3/20	0.688	0.889	0.804	0.070	0.249	0.164	8278	11489	9884
Nearfield	WF034	4/3	1.120	1.867	1.461	0.112	0.275	0.194	23338	40254	30363
Nearfield	WN035	4/23	1.093	7.958	2.979	0.000	0.002	0.001	26518	27181	26850
Nearfield	WN036	5/15	0.474	0.755	0.626	0.005	0.029	0.016	30336	44687	37511
Nearfield	WF037	6/18	1.077	2.200	1.601	0.016	0.367	0.133	36079	42632	38464
Nearfield	ALL		0.194	7.958	1.204	0.000	0.367	0.107	4142	44687	22327
Boundary	WF031	2/5-8	0.142	0.234	0.201	0.010	0.071	0.038	11055	13886	12470
Cape Cod Bay	WF031	2/5-8	0.597	1.230	0.968	0.349	0.811	0.572	10608	16435	13911
Coastal	WF031	2/5-8	0.143	0.329	0.251	0.031	0.089	0.061	9438	32616	17816
Harbor	WF031	2/5-8	0.238	0.397	0.291	0.053	0.088	0.075	3143	32624	13450
Nearfield	WF031	2/5-8	0.194	1.037	0.413	0.033	0.066	0.049	5213	9081	7175
Offshore	WF031	2/5-8	0.260	0.354	0.316	0.047	0.082	0.059	7470	8493	7982
All	ALL		0.142	1.230	0.407	0.010	0.811	0.142	3143	32624	12134
Boundary	WF032	2/26-3/4	0.228	0.480	0.333	0.046	0.096	0.070	14930	39422	27176
Cape Cod Bay	WF032	2/26-3/4	0.571	1.476	1.036	0.164	1.066	0.622	9382	19377	13463
Coastal	WF032	2/26-3/4	0.723	1.027	0.875	0.159	0.329	0.254	5527	12003	9374
Harbor	WF032	2/26-3/4	0.638	1.062	0.861	0.248	0.464	0.349	6311	12082	9504
Nearfield	WF032	2/26-3/4	0.431	0.653	0.546	0.093	0.290	0.190	4142	8824	6040
Offshore	WF032	2/26-3/4	0.319	0.515	0.404	0.107	0.133	0.123	7271	9282	8276
All	ALL		0.228	1.476	0.676	0.046	1.066	0.268	4142	39422	12305
Boundary	WF034	4/1-7	2.140	10.754	5.069	0.002	0.009	0.006	5504	13142	9323
Cape Cod Bay	WF034	4/1-7	0.541	0.807	0.669	0.013	0.083	0.032	13049	43886	25622
Coastal	WF034	4/1-7	0.779	1.310	1.015	0.019	0.077	0.034	18610	32159	27027
Harbor	WF034	4/1-7	0.923	1.940	1.274	0.015	0.068	0.029	9450	9971	9669
Nearfield	WF034	4/1-7	1.120	1.867	1.461	0.112	0.275	0.194	23338	40254	30363
Offshore	WF034	4/1-7	0.760	1.162	0.954	0.046	0.199	0.112	14094	14780	14437
All	ALL		0.541	10.754	1.740	0.002	0.275	0.068	5504	43886	19407
Boundary	WF037	6/18-21	0.706	1.692	1.070	0.005	0.282	0.092	30892	41755	36324
Cape Cod Bay	WF037	6/18-21	1.198	2.122	1.561	0.001	0.017	0.006	30187	31424	30806
Coastal	WF037	6/18-21	1.881	3.235	2.380	0.082	0.539	0.304	18731	34651	25739
Harbor	WF037	6/18-21	2.169	3.867	2.551	0.231	0.492	0.314	44848	81208	61315
Nearfield	WF037	6/18-21	1.077	2.200	1.601	0.016	0.367	0.133	36079	42632	38464
Offshore	WF037	6/18-21	0.517	1.242	1.007	0.001	0.318	0.083	33637	39758	36697
All	ALL		0.517	3.867	1.695	0.001	0.539	0.155	18731	81208	38224

Table 3-13. Summary of *Alexandrium* spp., *Phaeocystis pouchetii*, and *Pseudo-nitzschia pungens* data for February - June 2003.

			Alexandrium spp. (cells L^{-1})			*Phaeocystis* (10^6 cells L^{-1})			*Pseudo-nitzschia pungens* (10^6 cells L^{-1})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF031	2/6	0	0	0	0	0.025	0.005	0	0.0013	0.0004
Nearfield	WF032	3/4	0	2.1	0.3	0	0.242	0.073	0	0.0016	0.0006
Nearfield	WN033	3/20	0	0	0	0.095	0.189	0.143	0	0	0
Nearfield	WF034	4/3	0	4.8	0.8	0.278	1.185	0.625	0	0	0
Nearfield	WN035	4/23	0	6.6	1.7	0.183	6.976	1.934	0	0	0
Nearfield	WN036	5/15	0	5.5	1.4	0	0.048	0.012	0	0	0
Nearfield	WF037	6/18	0	0	0	0	0	0	0	0.0015	0.0003
Nearfield	ALL		0	6.6	0.6	0	6.976	0.399	0	0.0016	0.0002
Boundary	WF031	2/5-8	0	0	0	0	0	0	0	0.0020	0.0006
Cape Cod Bay	WF031	2/5-8	0	0	0	0	0	0	0.0017	0.0095	0.0046
Coastal	WF031	2/5-8	0	0	0	0	0	0	0	0	0
Harbor	WF031	2/5-8	0	0	0	0	0	0	0	0	0
Nearfield	WF031	2/5-8	0	0	0	0	0.025	0.005	0	0.0013	0.0004
Offshore	WF031	2/5-8	0	0	0	0	0	0	0	0.0011	0.0006
All	ALL		0	0	0	0	0.025	0.001	0	0.0095	0.0010
				0	0						
Boundary	WF032	2/26-3/4	0	0	0	0	0	0	0	0.0007	0.0003
Cape Cod Bay	WF032	2/26-3/4	0	0	0	0	0	0	0	0.0032	0.0014
Coastal	WF032	2/26-3/4	0	0	0	0	0.108	0.044	0	0.0015	0.0006
Harbor	WF032	2/26-3/4	0	3.8	0.6	0.050	0.189	0.110	0	0.0017	0.0005
Nearfield	WF032	2/26-3/4	0	2.1	0.3	0	0.242	0.073	0	0.0016	0.0006
Offshore	WF032	2/26-3/4	0	0	0	0	0	0	0	0.0016	0.0008
All	ALL		0	3.8	0.2	0	0.242	0.038	0	0.0032	0.0007
Boundary	WF034	4/1-7	0	0	0	1.489	10.221	4.443	0	0	0
Cape Cod Bay	WF034	4/1-7	0	0	0	0.038	0.145	0.089	0	0.0007	0.0002
Coastal	WF034	4/1-7	0	0	0	0.215	0.678	0.439	0	0	0
Harbor	WF034	4/1-7	0	4.1	0.7	0.269	1.037	0.611	0	0	0
Nearfield	WF034	4/1-7	0	4.8	0.8	0.278	1.185	0.625	0	0	0
Offshore	WF034	4/1-7	0	0	0	0.157	0.570	0.311	0	0.0017	0.0004
All	ALL		0	4.8	0.2	0.038	10.221	1.086	0	0.0017	0.0001
Boundary	WF037	6/18-21	0	15.4	7.5	0	0	0	0.0002	0.0065	0.0022
Cape Cod Bay	WF037	6/18-21	0	0	0	0	0	0	0	0	0
Coastal	WF037	6/18-21	0	5.7	2.2	0	0	0	0	0.0016	0.0003
Harbor	WF037	6/18-21	0	4.0	1.2	0	0	0	0	0	0
Nearfield	WF037	6/18-21	0	0	0	0	0	0	0	0.0015	0.0003
Offshore	WF037	6/18-21	0	6.6	1.7	0	0	0	0	0	0
All	ALL		0	15.4	2.1	0	0	0	0	0.0065	0.0004

4.0 RESULTS OF WATER COLUMN MEASUREMENTS

Data presented in this section are organized by type of data and survey. Physical data, including temperature, salinity, density, and beam attenuation are presented in Section 4.1. Nutrients, chlorophyll *a*, and dissolved oxygen are discussed in Section 4.2. A summary of the major results of water column measurements (excepting biological measurements which are presented in Section 5) is provided in Section 4.3.

Surveys conducted during the semiannual period consisted of four combined farfield/nearfield surveys and three nearfield only surveys. The first two combined surveys were conducted in early February (WF031) and late February/early March (WF032) during well-mixed winter conditions. Early indications of stratification were seen in some areas in April (WF034), but it was not until June (WF037) that a strong pycnocline had developed.

The variation of regional surface water properties is presented using contour plots of water parameters derived from the surface (A) water sample. Classifying data by regions allows 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 west/east farfield transects (Boston-Nearfield, Cohasset, and Marshfield) and two north/south transects. (Nearfield-Marshfield and Boundary) (**Figure** 1-3). Nearfield vertical data is presented across one transect which runs from the southwest corner (N10) to the northeast corner (N04) of the nearfield area. Examining data trends along transects provides a three-dimensional perspective of water column conditions during each survey. Nearfield surveys were conducted more frequently than farfield surveys allowing better temporal resolution of the changes in water column parameters and the onset of stratification. In addition to the nearfield vertical transect, vertical variability in nearfield data is examined and presented by comparing surface and bottom water concentrations (A and E depths) and by plotting individual parameters with depth in the water column. A complete set of surface contour maps and vertical transect plots are provided in Appendices A and B respectively.

4.1 Physical Characteristics

4.1.1 Temperature\Salinity\Density

The timing of the annual setup of vertical stratification in the water column is an important determinant of water quality, primarily because of the trend towards continuously decreasing dissolved oxygen in bottom water during the summer and early fall. The pycnocline, defined as a narrow water depth interval over which density increases rapidly, is caused by a combination of freshwater input during spring runoff and warming of surface water in the summer. Above the pycnocline the surface water is well mixed, and below the pycnocline density increases more gradually. For the purposes of this report, the water column is considered stratified when the difference between surface and bottom water density is greater than 1.0 sigma-t units (σ_t). Using this definition, stratification was developing in the nearfield by the beginning of April (WF034; **Figure** 4-1). Stratification throughout the entire nearfield area did not set up until later in April (WN035), and the vertical density gradient continued to increase from April to June when a strong pycnocline was established throughout the bays.

4.1.1.1 Horizontal Distribution

Surface water temperatures were very cold across Massachusetts and Cape Cod Bays in early February (0.6 – 4.4 °C) and were even colder during the late February/early March survey (0.24 - 2.8°C, see Appendix A) in response to the coldest winter temperatures on record since 1977-1978. There was a clear inshore to offshore temperature gradient across this area with the coldest waters in Boston Harbor and shallow coastal and Cape Cod Bay waters while the warmest surface waters were located furthest offshore. Surface water salinity also exhibited an inshore to offshore increase during the February/March surveys WF031 and WF032. Lower salinity waters (≤32 PSU) were observed in Boston Harbor and southern coastal waters, with a gradient extending out to the offshore and boundary stations (~33 PSU).

In April (WF034), surface water temperatures had increased (2.9 – 5.2°C), but continued to be cold in comparison to previous years (e.g. range of 5.6 – 8.1°C for surface waters in 2002, Libby *et al.,* 2002b). The gradient had also shifted with the warmest surface temperatures found in Boston Harbor and the coldest along the boundary. The most evident change in physical characteristics in the bays was the presence of lower salinity waters in northeastern Massachusetts Bay that were associated with the spring freshet (**Figure** 4-2). The lowest surface water salinity was measured in Boston Harbor, but salinities of <31 PSU were observed along the north shore extending from Cape Ann to the harbor. Peak March/April flows were 30 m^3/s in the Charles River and 1,000 m^3/s in the Merrimack River. These peak freshwater flows were coincident with an increase in precipitation (**Figure** 4-3) and a strong warming trend in late March. The heavy snow pack to the north likely contributed to a higher river flow than one based solely on the spring precipitation levels. Peak freshwater inputs to the system were about 50% higher than the historical average peak flows in both the Charles and Merrimack rivers (Libby *et al.,* 2003).

By June (WF037), surface water temperature had increased substantially across the survey area to 14°C ± 2°C. Surface temperatures were mostly homogeneous across the area, although southern Massachusetts Bay and Cape Cod Bay stations were slightly warmer (>14.5°C) than the more northern stations (<13°C). Salinity in the surface waters was homogeneous across the bays (30 to 30.7 PSU) with only Boston Harbor stations F23 and F30 showing a freshwater influence (29.2 and 28.2 PSU, respectively). Precipitation and river flow had decreased to more normal levels in May, but heavier than normal precipitation in late May and June resulted in above normal river flows during this time period (**Figure** 4-3). Overall, the winter/spring of 2003 was colder and wetter than normal and a departure from the trends that had been observed over the previous year and a half when drought conditions were observed.

4.1.1.2 Vertical Distribution

The changes observed in surface temperatures and salinity from February to April to June are indicative of the onset of seasonal stratification. The temperature-salinity (T-S) plots show a clear change in the relationship between these two parameters from early February to late June (**Figures** 4-4 and 4-5). During the first two surveys, water temperatures were very cold with all values <4°C except in the deepest waters in the boundary area. The coldest temperatures (≤1°C) were observed in harbor, coastal, and Cape Cod Bay waters and there was little variation in temperature. In the nearfield, offshore, and boundary waters, there was a trend of increasing temperatures concurrent with increasing salinity. The surface waters were generally cooler yet less saline than bottom waters and thus the density gradient was not significant. During the April survey, the waters were beginning to stratify. Surface waters had warmed slightly leading to a trend of decreasing temperature corresponding to increasing salinities. This created a slight density gradient throughout the bays. This transition to stratification was most pronounced at the deeper nearfield, offshore, and boundary stations where salinity differences began to create the density gradient. By June, seasonal stratified conditions had been established throughout the bays with a warmer, less saline surface layer and cooler, more saline bottom waters. These patterns have been consistently observed over the baseline monitoring period.

The seasonal establishment of stratified conditions across the bays is also illustrated in the vertical contour plots of sigma-T, salinity, and temperature (see Appendix B). In February and March, there was little variation in these parameters over the water column, although there was a slight freshwater signature in the harbor. By April (WF034), while temperatures remained cold, surface salinity decreased which increased the density gradient and set the stage for stratification. By June, a strong pycnocline had developed throughout the region. The onset of stratification in the spring is usually related to a freshening of the surface waters and then, as the surface temperatures increase, the density gradient or degree of stratification increases. This was the case in 2003 as increased freshwater inputs in April initiated stratification and the continued freshwater inputs in late May and June combined with a 10°C increase in surface water temperatures led to strongly stratified waters in June. A complete set of farfield transect plots of physical water properties is provided in Appendix B.

The onset of stratification can be observed more clearly from the data collected in the nearfield area. The nearfield surveys are conducted on a more frequent basis and thus provide a more detailed picture of the physical characteristics of the water column. As illustrated in **Figure** 4-6, stratification was beginning to develop in the nearfield by the beginning of April. This early stage of stratification was dominated by the salinity gradient, as temperatures were still cold and relatively homogeneous throughout the water column (**Figures** 4-7 and 4-8). The change in the physical data profiles from early to late April show the relative impact of salinity (increasing gradient) and temperature (little change) on the initial stratification of the water column. From late April to mid May, although there was little change in salinity, increases in surface water temperature strengthened the density gradient. By mid June the entire nearfield area was strongly stratified.

Higher temporal resolution salinity and temperature data are normally available from the USGS mooring in the nearfield (see **Figure** 1-1). Unfortunately only limited data were recovered for this time period (January to March at only 2 depths) and the available data do not provide additional insight into the physical characteristics of the region.

4.1.2 Transmissometer Results

Water column beam attenuation was measured along with the other *in situ* measurements 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. The beam attenuation coefficient (m^{-1}) is indicative of the concentration of particulate matter in the water column. The two primary sources of particles in coastal waters are biogenic material (plankton or detritus) or suspended sediments. Beam attenuation data are often evaluated in conjunction with fluorescence data to ascertain the source of the particulate materials (phytoplankton versus detritus or suspended sediments).

In early February, surface water beam attenuation exhibited a clear inshore to offshore trend decreasing from 1.8 m^{-1} in Boston Harbor to <1 m^{-1} in the nearfield and even lower further offshore (see Appendix A). By late February/early March, elevated surface water beam attenuation values (>1.5 m^{-1}) were measured in both Boston Harbor and coastal waters. This was coincident with elevated chlorophyll and phytoplankton abundance during the winter/spring diatom bloom that was primarily observed in nearshore waters. Vertical contour plots along the Boston-Nearfield transect show the strong relationship between beam attenuation and fluorescence during this survey, and the gradient of each extending from Boston Harbor to boundary station F27 (**Figure** 4-9)

By April, surface beam attenuation values had decreased in the nearshore waters of Boston Harbor and the coastal stations, but increased further offshore. This coincided with the transition from a coastal diatom bloom in late February/early March to a system wide *Phaeocystis* bloom in April (see Section 5.3). The relatively high beam attenuation values observed in surface waters at the offshore stations in April were concomitant with high surface water fluorescence values associated with the *Phaeocystis* bloom (**Figure** 4-10). This was especially evident along the boundary transect with very high beam attenuation and fluorescence levels at station F26 off of Cape Ann (see Appendix B). Elevated beam attenuation values also continued to be seen in the harbor due to the influence of suspended sediments and detritus due to the shallow depths and storm/river runoff.

During the June survey (WF037), beam attenuation in the surface water exhibited a very strong gradient of decreasing values from inshore (>2 m^{-1}) to offshore (<1 m^{-1}) stations and was indicative of an increase in water clarity away from Boston Harbor (see Appendix B). The patterns in beam attenuation continued to be similar to those for fluorescence, but the relative correspondence between the two parameters had changed as the impact of non phytoplankton material increased beam attenuation values in and near the harbor (**Figure** 4-11).

As in past years, beam attenuation exhibited strong inshore to offshore and vertical gradients that were associated with both nearshore inputs of sediments and detrital material and phytoplankton production in coastal waters. The comparison with fluorescence data in 2003 is more indicative of the relative impact that phytoplankton may have on the beam attenuation signal.

4.2 Biological Characteristics

4.2.1 Nutrients

Nutrient data were analyzed using surface water contour maps (Appendix A) and vertical contours from select transects (Appendix B) to illustrate the spatial variability of these parameters. In addition, x/y plots of nutrient depth distribution, nutrient/nutrient relationships, and nutrient/salinity relationships were examined.

The nutrient data for February to June 2003 generally followed the typical progress of seasonal events in Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. Nutrient concentrations in Cape Cod Bay surface waters were low in comparison to Massachusetts Bay due to elevated diatom abundance in early February and remained relatively low throughout the report period. Massachusetts Bay surface water nutrient concentrations decreased from early February through April. The exception to this was for silicate which tended to increase from late February/early March to April coincident with a transition from a diatom dominated bloom in February to a *Phaeocystis* bloom in April. Nutrient concentrations in the surface waters were depleted throughout the entire study area by June (WF037). In the nearfield, nutrient levels decreased in the surface waters as stratification was developing. Nutrient concentrations in the surface waters were depleted throughout much of the nearfield region by mid March. The effluent nutrient signal continues to be clearly evident in the nearfield, particularly as ammonium (NH_4). Nutrients associated with the discharge were able to surface in the well-mixed winter waters and following the onset of stratification in April the effluent/nutrient signal was restricted to below the pycnocline.

4.2.1.1 Horizontal Distribution

The horizontal distribution of nutrients is displayed through a series of surface contour plots in Appendix A. As has often been the case in the past, Boston Harbor often had the highest nutrient concentrations during this semiannual period with a decreasing gradient in concentrations from inshore to offshore predominating, although high concentrations were also found in the nearfield and at the boundary stations. The distribution of surface water nutrients was governed by a combination of inputs (runoff, freshet, and outfall) and biological utilization. Surface water dissolved inorganic nutrients were generally highest during the first survey (WF031). As observed since the fall of 2000, nearfield NH_4 concentrations were consistently elevated with respect to farfield stations and compared to previous baseline monitoring years. Nutrient concentrations were lower in Cape Cod Bay than in Massachusetts Bay during the first two farfield surveys due to the winter/spring diatom bloom that occurred in Cape Cod Bay in February. There was also a sharp decrease in surface nutrient concentrations from early to late February in the nearshore harbor and coastal waters that was associated with the winter/spring diatom bloom. By April (WF034), nutrient concentrations had decreased in Massachusetts Bay, except for silicate (SiO_4) which remained relatively high and variable. The highest surface SiO_4 concentrations were associated with the spring freshet that was present in northeastern Massachusetts Bay and most pronounced at stations F26 and F22 (see Appendix A for salinity and silicate). By June (WF037), nutrients were generally depleted in the surface waters throughout the bays, except for stations in Boston Harbor. The low nutrient concentrations in June were coincident with low chlorophyll concentrations and are typical of stratified summer conditions in the bays.

Ammonium concentrations continued to be a very good tracer of the effluent plume within the nearfield. A combination of rapid dilution in well-mixed waters and biological consumption of NH_4 usually confines this plume signature to within 20 km of the outfall. An examination of horizontal contour plots over the five sampling depths for the four farfield surveys confirms this finding (**Figure** 4-12). The two plots in **Figure** 4-12 represent the farthest extent of the plume as suggested by NH_4 levels measured during both well-mixed and stratified conditions at surface and mid-depths, respectively. These plots also suggest that the direction of flow in the nearfield area is quite variable as previously observed.

4.2.1.2 Vertical Distribution

Farfield. The vertical distribution of nutrients was evaluated using vertical contours of nutrient data collected along three transects in the farfield: Boston-Nearfield, Cohasset, and Marshfield (see **Figure** 1-3; Appendix B). Nitrate (NO_3) concentrations along the Boston-Nearfield transect are presented to highlight the vertical nutrient trends. In early February (WF031), NO_3 concentrations were >9 across the entire Boston-Nearfield transect (**Figure** 4-13). Silicate and phosphate (PO_4) were also replete, but NH_4 concentrations were generally low and only elevated in the effluent plume in the nearfield. By late February/early March (WF032), the coastal diatom bloom had sharply reduced nutrient concentrations in the harbor, coastal and western nearfield waters. This decrease in nutrients was most evident for NO_3 (**Figure** 4-13). The low nutrients were concomitant with elevated fluorescence and phytoplankton abundance (see **Figures** 4-9 and 5-18). Ammonium remained low throughout the farfield, and was measurable only in the immediate area of the outfall. The preferential and rapid uptake of NH_4 by phytoplankton tends to keep NH_4 levels low throughout all areas of the water column except in close proximity to the outfall.

By April (WF034) nutrient concentrations had become generally depleted in the surface waters along the entire transect (**Figure** 4-13), except for SiO_4 (see Appendix B). Weak stratification was developing throughout the farfield by this time and reduced mixing of the water column combined with the *Phaeocystis* bloom resulted in the depletion of nutrients in surface waters. A strong fluorescence signal was concomitant with these areas of decreasing nutrients (see **Figure** 4-10). A clear effluent signal surfacing through the weak stratification was apparent for both NH_4 and PO_4 in the nearfield. In June (WF037), nutrient levels were depleted in the surface waters along each of the transects (see **Figure** 4-13 and Appendix B). Typical of stratified conditions, there was a strong vertical nutrient gradient with very low concentrations above the pycnocline (~20 m) and higher concentrations below. Phosphate and ammonium continued to show a strong effluent signal below the pycnocline in the outfall area.

Nutrient-salinity plots are often useful in distinguishing water mass characteristics and in examining regional linkages between water masses. Dissolved inorganic nitrogen (DIN) plotted as a function of salinity has been used in past reports to illustrate the transition from winter to summer conditions and back again. Typically winter conditions in this region are represented by a negative correlation between DIN and salinity as the harbor and coastal waters are a source of low salinity, nutrient rich waters and the water column is well mixed. The summer is normally characterized by a positive relationship between DIN and salinity as biological utilization and stratification reduce nutrients to low concentrations in surface waters and concentrations increase with salinity at depth. In many regions of Massachusetts and Cape Cod Bays these trends were apparent. However, as in past years, there was a regional mix of relationships between DIN and salinity. Also, effluent emerging from the outfall creates a wide range of DIN concentrations in the nearfield.

In early February, nutrient concentrations were high throughout Massachusetts Bay over a range of salinities (**Figure** 4-14). There was no apparent relationship between DIN and salinity as concentrations remained relatively constant (10-12 µM) over an inshore to offshore range of 31.5 to 33 PSU. The difference between the bays was evident with Cape Cod Bay exhibiting lower DIN values (1-6 µM) at the southernmost stations. The other feature of **Figure** 4-14a that is evident is the effluent plume signal of elevated DIN (as NH_4) concentrations in the nearfield. By late February/early March, DIN concentrations had dramatically decreased in Boston Harbor and surface waters at coastal and western nearfield stations (**Figure** 4-12b). A slightly positive relationship between DIN and salinity was seen in Massachusetts Bay waters, but the salinity range was very small.

By April, the DIN versus salinity signal exhibited an inverse relationship at the Boston Harbor and coastal stations due to increased DIN concentrations in low salinity water (<31 PSU), which was likely associated with runoff (**Figure** 4-13a). A similar feature was observed at some offshore and nearfield stations that were impacted by the spring freshet, while at Station F26 the lower salinity surface waters (~30.5 PSU) had a relatively low DIN concentration due to the major bloom of *Phaeocystis* that was observed at this station off of Cape Ann (see **Figure** 5-19). Surface water concentrations became depleted in other regions and with the onset of stratification the increase in both DIN and salinity with depth became a more pronounced feature of the plot. In June, a fairly strong positive DIN/salinity relationship was apparent in most areas except Boston Harbor. This relationship was established as typical summer conditions developed with depleted DIN in the surface waters and increasing concentrations at depth with increasing salinity (**Figure** 4-13b). Harbor stations exhibited an inverse relationship as DIN concentrations were highest in harbor surface waters that had lower salinities due to precipitation and runoff. The stratified water column in June also resulted in very high DIN concentrations (>15 µM) in the nearfield bottom waters. This is because the effluent plume was trapped below the pycnocline reducing both dilution and biological utilization of the high NH_4 waters.

Throughout the first half of 2003, surface waters were relatively low in available DIN as compared to PO_4 and SiO_4. Cape Cod Bay stations were nitrogen limited from as early as the beginning of February through the whole period due to the early initiation of the diatom bloom in Cape Cod Bay. Harbor, coastal and western nearfield stations became nitrogen limited later in February as phytoplankton blooms in these areas progressed through the month. Silicate concentrations were also very low in these waters during the February surveys. By April, surface water nitrogen levels were limiting throughout most of the bays and SiO_4 concentrations had rebounded. In June, surface nutrient concentrations were low and often depleted.

Nearfield. The nearfield surveys are conducted more frequently and provide a high resolution of the temporal variation in nutrient concentrations over the semiannual period. In previous sections, the transition from winter to summer physical and nutrient characteristics was considered. For the nearfield, the transition from winter to summer nutrient regimes can be demonstrated by examining contour plots of NO_3 concentrations over time at five representative nearfield stations – N01, N04, N18, N10 and N07 (**Figure** 4-16). These stations represent each of the four corners and the center of the nearfield "box". Station N10, in the southwestern portion of the nearfield is strongly influenced by conditions in the harbor. As with other harbor and coastal stations, nutrients at station N10 and somewhat at station N01 began to decrease in late February/early March with the occurrence of the nearshore diatom bloom. By mid-March, NO_3 concentrations had decreased across the nearfield with the lowest concentrations (<1 µM) measured over much of the water column at stations N01, N10 and N18. By late April, NO_3 levels were depleted in the surface waters across the entire nearfield and only the deeper waters (>20m) contained any significant amounts of NO_3. The distribution of SiO_4 showed a late February/early March decrease at the inshore stations that was similar to that of NO_3, but there was a subsequent increase in SiO_4 in late March and levels remained relatively high through May. Phosphate, like NO_3, became depleted in the surface waters in March/April and remained low through June. Ammonium concentrations were low in the surface waters in February at stations N01, N04, N07 and N10 away from the outfall, but high at station N18 until March. Low NH_4 concentrations were measured from April to June in nearfield surface waters. Concentrations of NH_4 and PO_4 increased in the bottom waters once the water column became stratified as the bay outfall provided a direct source of NH_4 and PO_4 to the nearfield.

The usefulness of NH_4 as a tracer of the effluent plume has been shown for previous monitoring periods (Libby *et al.,* 2001). Although it is not a conservative tracer due to biological utilization, NH_4 does provide a natural tracer of the effluent plume in the nearfield area especially in low light conditions where biological activity is minimal (*i.e.,* during the winter and below the pycnocline during stratified conditions). In early February, the NH_4 pattern, representing the effluent plume, can be seen rising through the water column, spreading as it ascends (**Figure** 4-17). This is typical of the NH_4/effluent dynamics under well-mixed conditions. The distribution of NH_4 concentration during the May nearfield survey is representative of the typical distribution during stratified conditions (**Figure** 4-18). Plots of NH_4 concentrations across the nearfield typically show a strong NH_4/effluent signal rising from the outfall and surfacing, until stratification sets up and the plume is trapped below the pycnocline. It should be noted that this representation of the NH_4 data distort the 3-dimensional aspect of the nearfield as all data in **Figures** 4-17 and 4-18 are presented on the same five planes when in actuality all of the sampling depths below the surface sample are collected at various depths (tending towards deeper depths to the east).

4.2.2 Chlorophyll a

The highest chlorophyll concentrations of the semiannual period were recorded in the nearfield in April during the *Phaeocystis* bloom. Comparable chlorophyll levels were measured at station F26 during this bloom and regional chlorophyll maxima were observed in Cape Cod Bay, coastal and Boston Harbor waters in late February/early March during the diatom bloom. Chlorophyll descriptions are derived from *in situ* fluorescence data and satellite images (SeaWiFS; Appendix D). The nearfield mean areal chlorophyll (basis for chlorophyll threshold) for the winter/spring (February through April) of 2003 was 178 mg m^{-2}, which is comparable to but below the seasonal caution threshold of 182 mg m^{-2}, and marks the highest winter/spring value since the outfall went online. Although this year showed an increase from 2001 and 2002 (69 and 112 mg m^{-2}, respectively), it was comparable to the areal chlorophyll values seen winter/spring 1999 (176 mg m^{-2}) and 2000 (191 mg m^{-2}). In 1999 and 2000, the high winter/spring chlorophyll concentrations were coincident with substantial a region-wide winter/spring diatom (1999) or *Phaeocystis* (2000) blooms. Although 2003 lacked a major regional winter/spring bloom, the combination of elevated chlorophyll concentrations over much of the water column during both the nearshore diatom bloom and offshore *Phaeocystis* bloom resulted in high chlorophyll concentrations in the nearfield comparable to 1999 and 2000. The 2003 winter/spring seasonal mean was higher then the values observed over the rest of the baseline period (1992-1998) and was the second highest value that has been observed during the monitoring program.

4.2.2.1 Horizontal Distribution

Surface chlorophyll concentrations were low across most of the region during the early February survey. The highest concentrations (>3 μgL^{-1}) were measured in Cape Cod Bay where a winter/spring diatom bloom was also observed. Slightly elevated chlorophyll concentrations were also observed sporadically in Boston Harbor, coastal and boundary waters. The chlorophyll, nutrient and production data in 2001 and 2002 suggested that the winter/spring bloom in the bays was initiated prior to the first survey in early February (Libby *et al.,* 2002b and 2002c). In 2003, however, the winter/spring diatom bloom was underway in early February in Cape Cod Bay, but had not yet begun in Massachusetts Bay waters. By late February/early March, the winter/spring diatom bloom had spread to Massachusetts Bay and *Phaeocystis pouchetii* was also beginning to be observed. The diatom bloom and early *Phaeocystis* bloom led to elevated chlorophyll concentrations with the highest measured in the coastal and Boston Harbor surface waters where they ranged from 5 to 15 μgL^{-1} (**Figure** 4-19). The fluorescence trends over the first three months of 2003 are also evident in the SeaWiFS images captured from mid January through early March (see Appendix D). The SeaWiFS images reveal that fluorescence values were low throughout the bays in January, increased in Cape Cod Bay in early February, and by mid to late February were elevated throughout the bays. The combination of SeaWiFS images and monitoring data (fluorescence, phytoplankton and productivity) show the spatial and temporal progression of the winter/spring diatom bloom in 2003. This bloom, unlike the *Phaeocystis* bloom that is discussed below, appeared to be confined to waters within the bays and was not a region-wide event (see Appendix D).

The April survey showed a fairly dramatic shift from the late February/early March chlorophyll concentrations and distributions. Chlorophyll concentrations were lowest (<0.02 μgL^{-1}) in Cape Cod Bay and had decreased to <3 μgL^{-1} in Boston Harbor and southern coastal and offshore Massachusetts Bay waters (**Figure** 4-20). There was a sharp increase in chlorophyll levels in the nearfield to >10 μgL^{-1} and concentrations remained relatively high off of Cape Ann. This shift in chlorophyll levels from early March to early April was coincident with the shift in phytoplankton species blooms. The phytoplankton data suggest that the *Phaeocystis* bloom may have been transported or enhanced by the spring freshet as *Phaeocystis* abundance was highest (~10 million cells L^{-1}) at station F26 and seemed to decrease across the nearfield and to the south (barely observed in Cape Cod Bay; see **Figure** 5-19). SeaWiFS images for this time period also suggest an influence from the western Gulf of Maine during the spring freshet. On March 27, a filament of higher chlorophyll concentrations (5 to 10 mg m^{-3}) was observed extending from the western Gulf of Maine around Cape Ann and into northern Massachusetts Bay, extending over the location of boundary stations F26 and F27 (**Figure** 4-21). Later images indicate that the bloom extended throughout Massachusetts Bay in April (see Appendix D).

Nearfield data and SeaWiFS images from late April and May indicate that the *Phaeocystis* bloom continued through April. In fact, nearfield *Phaeocystis* abundance reached a maximum (~7 million cells L^{-1}) at station N04 and productivity remained high at this station during the late April survey. By May, there was a sharp decrease in chlorophyll concentrations in the surface waters throughout Massachusetts and Cape Cod Bays (see Appendix D). In May, low chlorophyll values were observed across the nearfield. The decrease in nearfield chlorophyll concentrations from mid April to mid May was also associated with a steady decrease in phytoplankton abundance and production at stations N04 and N18.

By June, the productivity and phytoplankton abundance (dominated by microflagellates) had increased in the nearfield from the May lows and there had been a slight increase in surface chlorophyll concentrations from May to June. In comparison to the winter/spring bloom periods, however, surface chlorophyll concentrations remained relatively low throughout the farfield except in and near Boston Harbor where they were 3-6 μgL^{-1}. SeaWiFS images corroborate this trend in surface chlorophyll concentrations from May to mid June and also indicate that by the end of June chlorophyll concentrations had once again decreased to <3 μgL^{-1} throughout the bays (**Figure** 4-22).

4.2.2.2 Vertical Distribution

Farfield. The vertical distribution of chlorophyll was evaluated using vertical contours of *in situ* fluorescence data collected along three east/west transects in the farfield: Boston-Nearfield, Cohasset, and Marshfield; and two north/south transects: inner farfield and outer farfield (Appendix B). The fluorescence contours along the Boston-Nearfield transect were presented in comparison to beam attenuation in **Figures** 4-9 to 4-11. In early February, chlorophyll concentrations along the Boston-Nearfield transect were relatively low with the highest levels (>3 μgL^{-1}) found only at harbor station F23. By late February, chlorophyll concentrations were >9 μgL^{-1} over the entire water column at stations F23 and F24 and elevated concentrations (3-9 μgL^{-1}) were also observed from surface to bottom at the three nearfield stations, but low levels were present further offshore (see **Figure** 4-9). This area of high fluorescence is attributed to the bloom of diatoms that was predominantly a nearshore event.

In April, chlorophyll concentrations had decreased substantially in and near Boston Harbor, but increased offshore (see **Figure** 4-10). A strong subsurface chlorophyll maximum was seen from station N16 to station F27 with concentrations exceeding 13 μgL^{-1}. Similarly high chlorophyll concentrations were observed over most of the water column at station F26 (**Figure** 4-23) and in the nearfield surface waters (**Figures** 4-23 and 4-10). Along the Nearfield-Marshfield transect, there was a north-south difference observed with high chlorophyll concentrations in the surface waters in the nearfield and at depth at stations further to the south (**Figure** 4-23). The patterns observed in the chlorophyll data suggest an influence of the spring freshet in the northeast portion of Massachusetts Bay, as elevated nutrient concentrations and high chlorophyll levels were associated with the lower density surface waters of the freshet (**Figure** 4-23c). The southern Massachusetts Bay offshore stations appear to be less affected by the influx of lower salinity water.

By June, phytoplankton abundance had decreased across most of the survey area (see **Figure** 4-11). At all depths along each of the farfield transects chlorophyll concentrations were relatively low. The highest concentrations (3-5 μgL^{-1}) were observed in the surface waters near Boston Harbor and over a narrow subsurface chlorophyll maximum further offshore. The pattern of elevated surface chlorophyll concentrations near Boston Harbor and clearly defined subsurface maxima along the pycnocline further offshore is typical of the progression to summer conditions.

Nearfield. Chlorophyll concentrations in the nearfield closely followed the trends described above for the farfield. The timing of the nearfield only surveys, however, provides a glimpse at what occurred between the two winter/spring blooms and establishment of seasonal stratification. As observed for the rest of Massachusetts Bay, chlorophyll concentrations were relatively low (2 μgL^{-1}) in early February prior to the development of the winter/spring bloom (**Figure** 4-24). By early March, the combination of the nearshore diatom bloom and the start for the *Phaeocystis* bloom (see **Figures** 5-15 and 5-16) led to a doubling of chlorophyll concentrations in the nearfield. This was also coincident with a sharp increase in production. The mixed diatom and *Phaeocystis* bloom continued to be present during the mid March survey. During both March surveys, the nearfield continued to be relatively well mixed and chlorophyll concentrations were highest below the surface (**Figures** 4-24 and 4-25).

By early April, the *Phaeocystis* bloom was at its peak and both chlorophyll and production reached seasonal maxima for the nearfield. There was a sharp increase in surface chlorophyll concentrations from mid March to April as the water column was becoming stratified and the bloom was concentrated primarily in the surface layer above the pycnocline. Over the course of the month, there was a sharp decrease in chlorophyll concentrations in the nearfield. Mean surface water concentration decreased from 10.5 to <1 μgL^{-1} while concentrations decreased by more than 50% at mid depth (**Figure** 4-24). Bottom water chlorophyll concentrations actually doubled from early to late April. These changes were coincident with a sharp decrease in production at station N18, while productivity remained high at station N04 (see **Figure** 5-2). Phytoplankton abundance, particularly *Phaeocystis*, decreased at station N18, while remaining relatively high in surface waters at station N04 and increasing dramatically to 8 million cells L^{-1} at mid depth. An evaluation of various parameters along the nearfield transect indicates that along with elevated chlorophyll levels (**Figure** 4-25) the bottom waters had elevated beam attenuation and phaeophytin concentrations.

These data suggest that the *Phaeocystis* bloom had begun to senesce and settle out of the water column. By May and into June, fluorescence was relatively low throughout the nearfield with a subsurface maximum found at most stations around 10 m.

Nearfield chlorophyll concentrations were relatively high during the winter/spring blooms from early March to later April. During the March and early April surveys, the elevated chlorophyll concentrations were measured over nearly the entire water column as shown for the nearfield transect in **Figure** 4-25. The prolonged duration of the diatom and *Phaeocystis* blooms in 2003 combined with the presence of elevated chlorophyll concentrations in both surface and bottom waters over much of the nearfield resulted in very high areal chlorophyll levels. This resulted in the highest winter/spring mean areal chlorophyll concentration (178 mg m^{-2}) since the outfall went online and was just below the seasonal caution threshold of 182 mg m^{-2}.

4.2.3 Dissolved Oxygen

Spatial and temporal trends in dissolved oxygen (DO) concentrations were evaluated for the entire region. Due to the relative importance of identifying low DO conditions, bottom water DO minima were examined for the water sampling events. DO concentrations were within the range of values observed during previous years. The minimum measured DO concentration was 8.39 mgL^{-1} in coastal waters in June. The nearfield minimum DO concentration of 8.54 mgL^{-1} was also observed in June. The June 2003 bottom water concentrations were fairly consistent across the survey area. This was a departure from June 2001 when DO in the bottom waters showed a gradient of low concentrations in the harbor increasing towards the offshore stations.

The DO in bottom waters was compared among areas and over the course of the February to June time period. Mean bottom water DO concentrations ranged from a high of 12 mgL^{-1} in Boston Harbor in early February, in coastal and harbor waters in late February, and mid March in the nearfield to a low of 9 mgL^{-1} over most of Massachusetts and Cape Cod Bays in June (**Figure** 4-26a). Bottom water DO concentrations were highest (10.5 to 12.2 mgL^{-1}) during the first two surveys. Lower concentrations were observed at the deeper offshore and boundary areas over these two surveys than in the other areas. Bottom water DO concentrations in Boston Harbor, coastal and nearfield areas increased from early February to March (and to mid March in the nearfield) concomitant with the nearshore diatom bloom. By April, bottom water DO concentrations had decreased throughout Massachusetts Bay. Mean bottom water DO had decreased by 1.5 mgL^{-1} in the harbor, coastal and nearfield waters. This was likely related to the decline of the diatom bloom. The offshore, boundary, and Cape Cod Bay showed only slight decreases (<0.3 mgL^{-1}) over this time period. Nearfield bottom water DO concentrations remained steady from early to late April, before declining by 1 mgL^{-1} in May. From April to June, bottom water DO concentrations declined by 1-2 mgL^{-1}. In June, the mean bottom water DO concentrations were relatively high in comparison to past years and uniform across the survey area (9-9.5 mgL^{-1}).

Dissolved oxygen measurements throughout the area during the first half of 2003 are typical of the trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the winter/spring bloom in the bays. The trend of decreasing DO in the bottom waters was also apparent in the DO %saturation data (**Figure** 4-26b). In general, DO % saturation decreased from February to June in each of the survey areas, although there was some fluctuation. Bottom waters were generally saturated to supersaturated during the February surveys and then decreasing through April and June. DO %saturation did increase from late February to April in Cape Cod Bay and there was a relatively large increase in DO %saturation from early February to mid March in the nearfield. Boundary bottom waters were under saturated during the entire semiannual period. By June, DO %saturation in the bottom waters was at a minimum for the first half of 2003 throughout the area except for nearfield waters, which reached a survey mean minimum of <90% in May. Harbor waters remained saturated in June and the other area (except the boundary) waters were slightly under saturated (92-95%). The lowest survey mean value was observed in the bottom waters along the boundary (89%). Even though there were two major winter/spring blooms in 2003 and chlorophyll as an indicator of biomass was high in comparison to past years, DO concentrations and %saturation were relatively high. This might be as expected based on the findings of Geyer *et al.* (2002) that indicated that there was an inverse relationship between winter/spring salinity and bottom water DO concentrations. The underlying hypothesis is that during years with high runoff and low salinity waters there is higher flow through the system and less of a decrease in DO concentrations. This will be evaluated in more detail for the 2003 data in second semiannual report and 2003 annual report.

4.3 Summary of Water Column Results

- Precipitation levels were near or above normal and there was a large spring freshet as river flow was well above normal levels.
- Stratification occurred in April as is typical for this system. Onset of stratification was driven by the salinity gradient resulting from the spring runoff and spring freshet. By mid May, surface waters had begun to warm considerably and seasonal stratification was taking hold as the temperature gradient increased.
- The nutrient data for February to June 2003 generally followed the "typical" progression of seasonal events in the Massachusetts and Cape Cod Bays.
  - Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited.
  - A winter/spring 'diatom bloom' reduced nutrient concentrations in Cape Cod Bay surface waters in February. Cape Cod Bay waters remained nitrogen limited during the majority of the period.
  - Massachusetts Bay nutrient concentrations decreased from early February through April when depleted levels were measured in the surface waters.
- The effluent nutrient signal was clearly evident in the nearfield as elevated NH_4 and PO_4 concentrations.
- The prolonged duration of the blooms in 2003 combined with the presence of elevated chlorophyll concentrations in both surface and bottom waters over much of the nearfield resulted in very high areal chlorophyll levels.
- The nearfield mean areal chlorophyll for winter/spring 2003 was 178 mg m^{-2} which is below, but comparable to the caution threshold of 182 mg m^{-2}. These levels are also comparable to the high chlorophyll values measured in 1999 and 2000 and higher than seasonal means for 1992 to 1998 and 2001–2002.
- Chlorophyll concentrations peaked in the harbor and coastal waters in late February and in the nearfield in April. There was a great deal of spatial and temporal variability due in part to the February nearshore diatom bloom and the predominantly offshore *Phaeocystis* bloom in March/April.
- The *Phaeocystis* bloom appeared to be a regional event that may have been influenced or at least enhanced by the spring freshet as the highest abundances (10 million cells L^{-1}) were measured at the northern boundary stations. This Gulf of Maine influence was also suggested by SeaWiFS imagery showing an area of elevated chlorophyll concentrations off of Cape Ann.
- DO concentrations in 2003 were within the range of values observed during previous years and followed the typical trends. Given the blooms and high chlorophyll concentrations, the DO concentrations and %saturation values in the bottom waters throughout the bays was relatively high in June (89-95%).

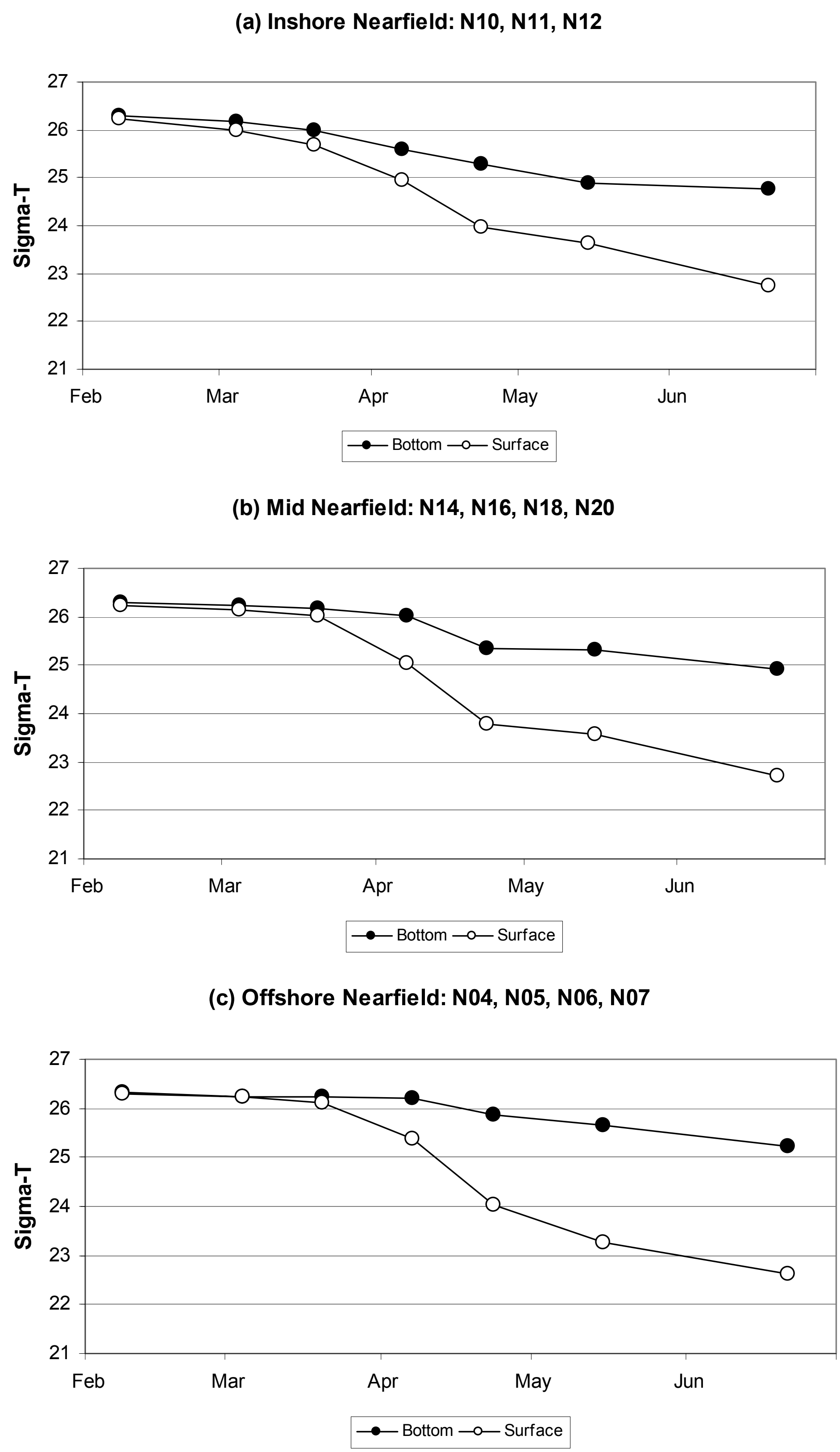


Figure 4-1. Time-series of average surface and bottom water density (σ_t) in the nearfield

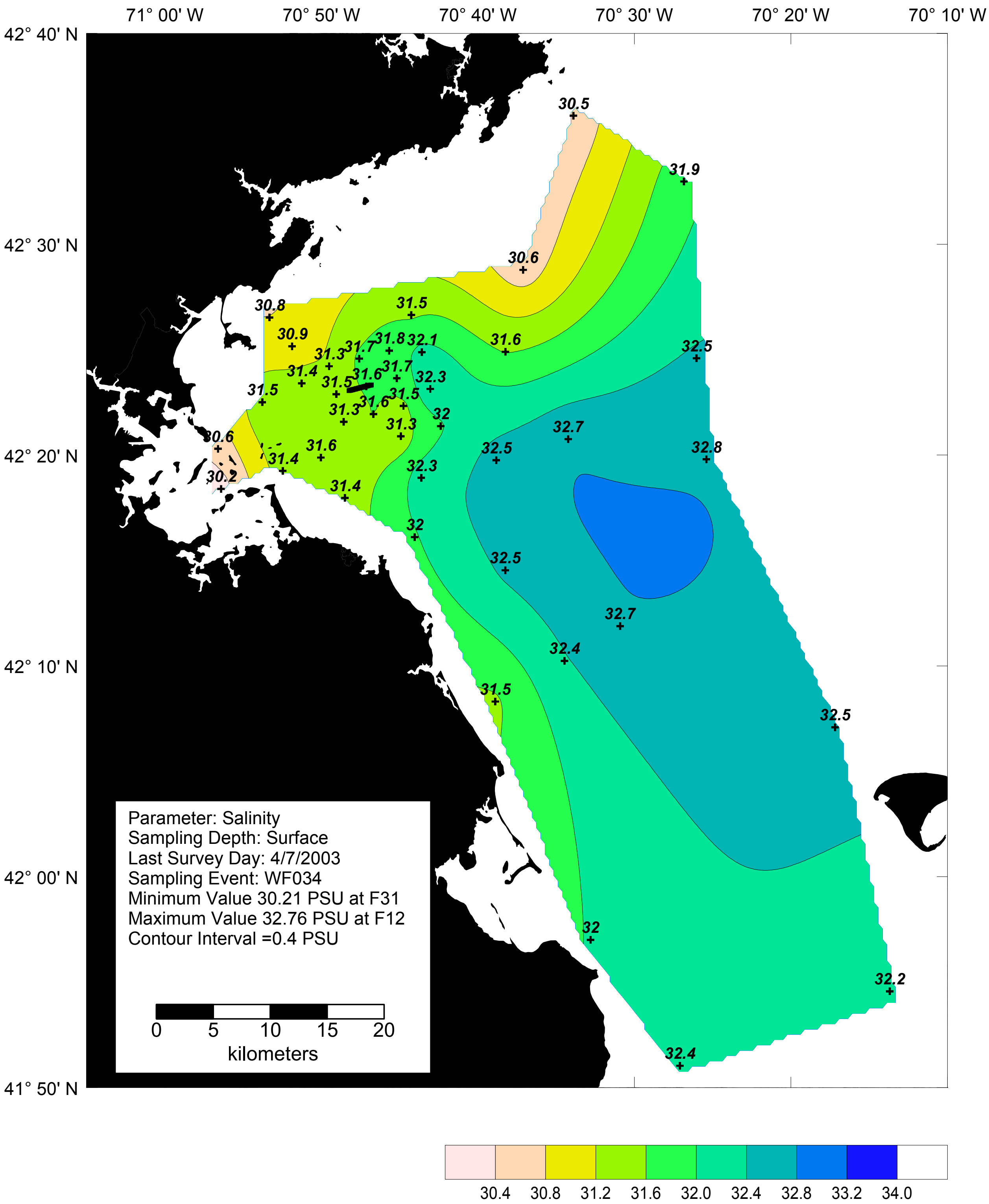


Figure 4-2. Salinity surface contour plot for farfield survey WF034 (Apr 03)

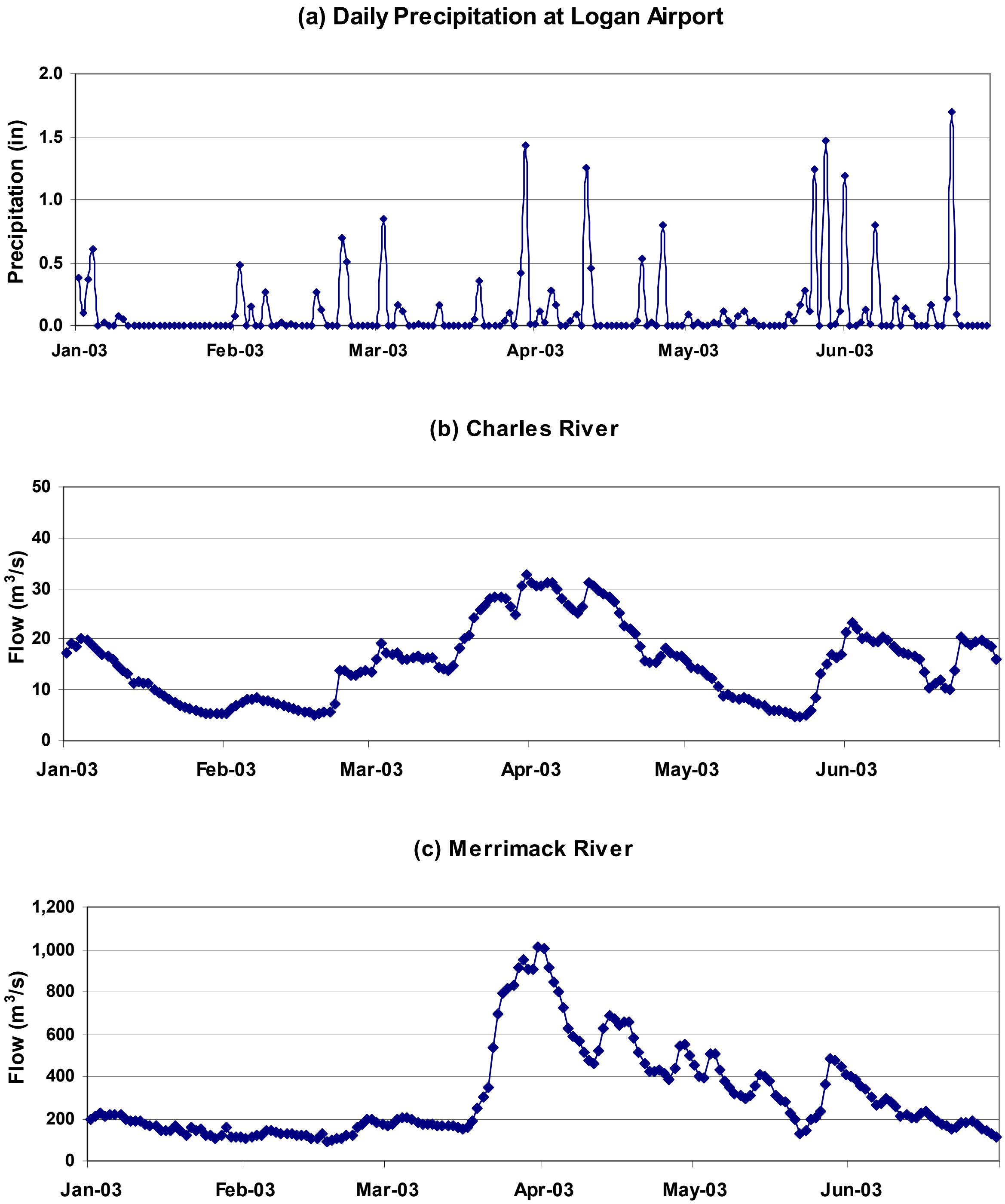
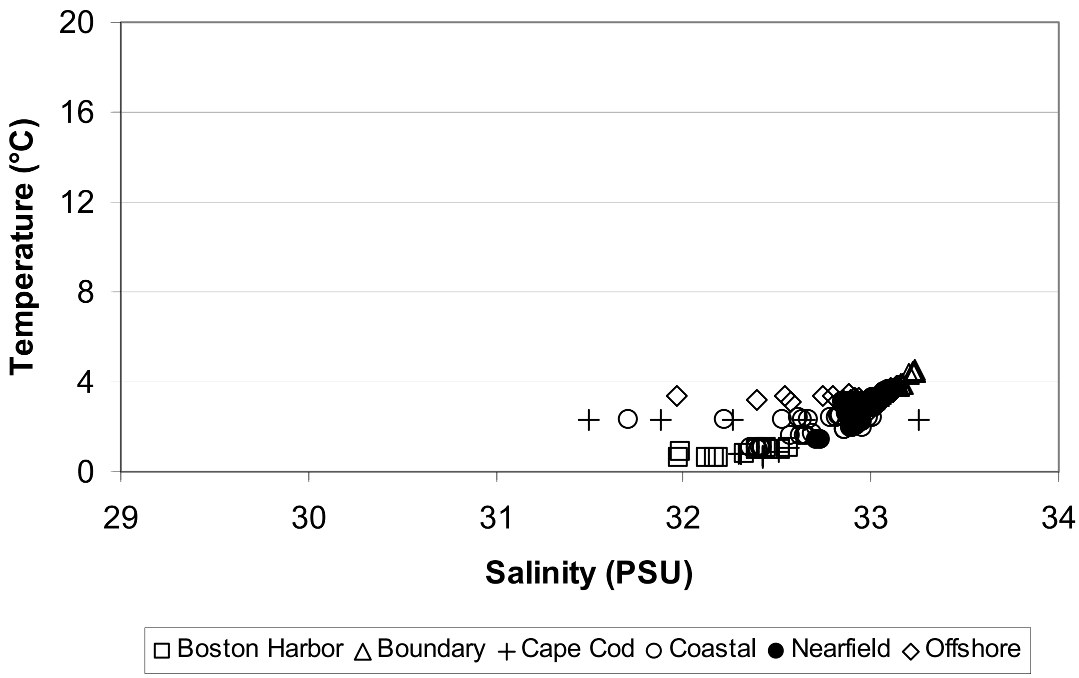


Figure 4-3. Precipitation at Logan Airport and river discharges for the Charles and Merrimack Rivers

(a) WF031: February



(b) WF032: February/March

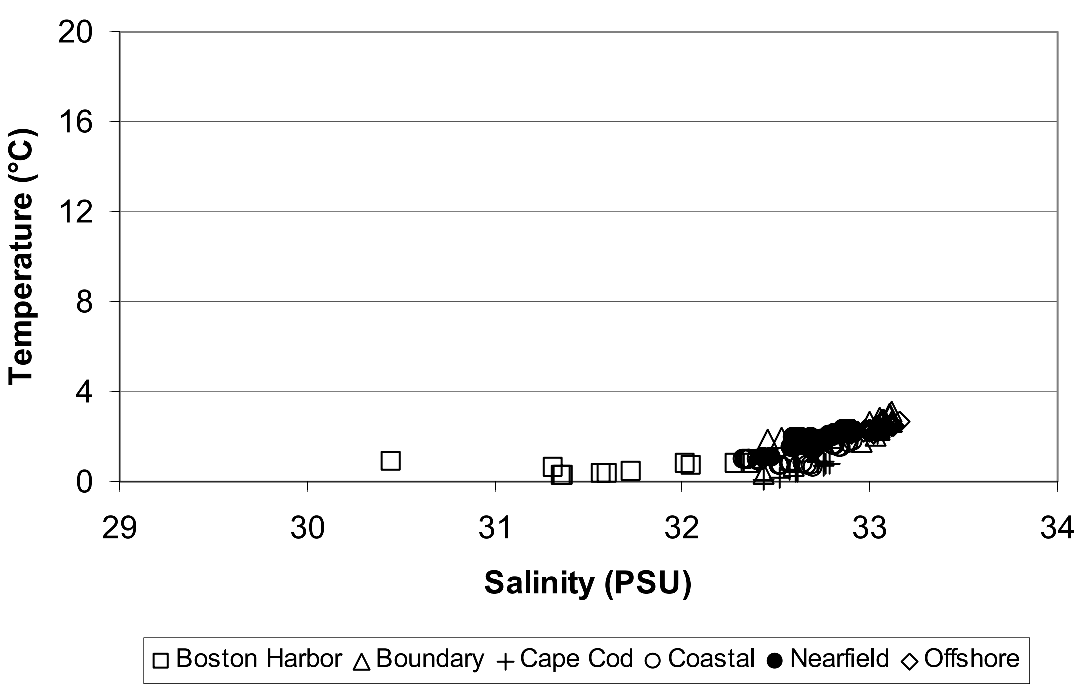
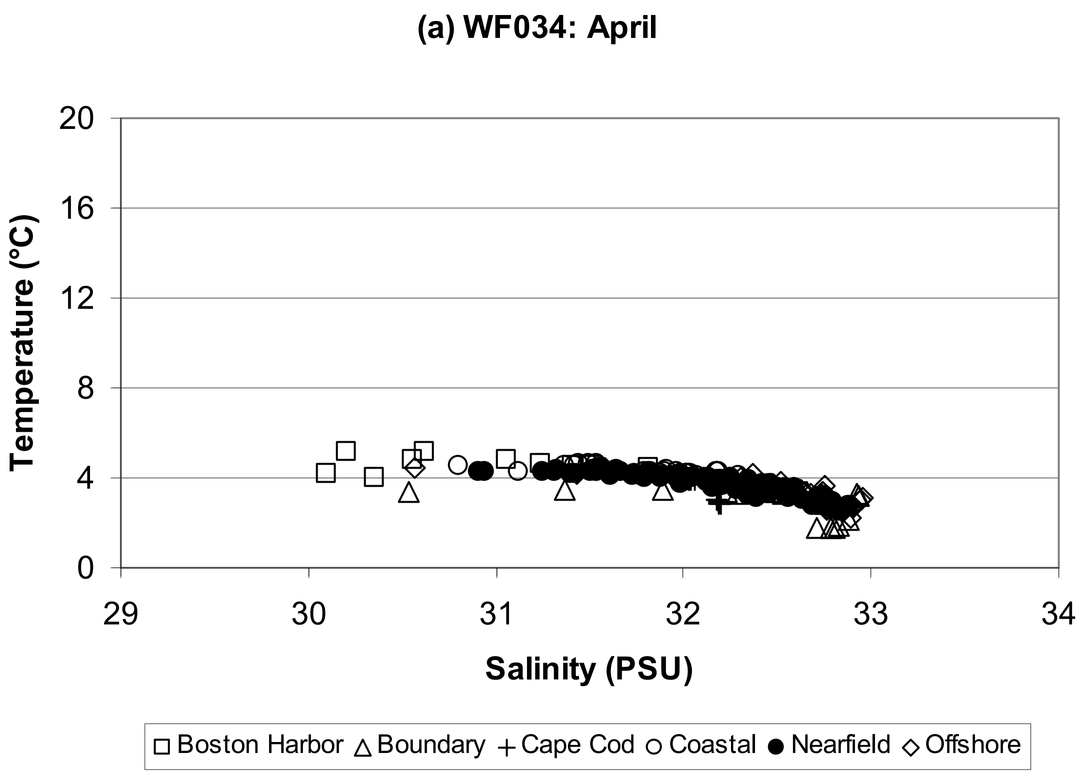


Figure 4-4. Temperature/salinity distribution for all depths during WF031 (Feb 03) and WF032 (Feb/Mar 03) surveys



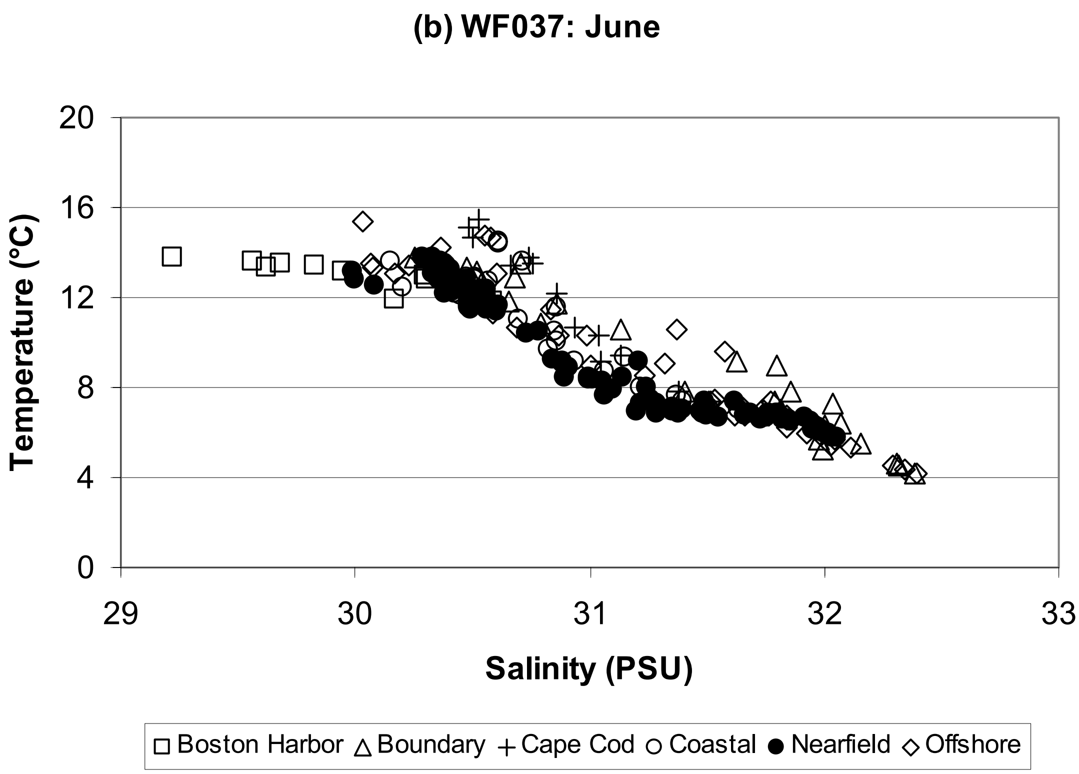


Figure 4-5. Temperature/salinity distribution for all depths during WF034 (Apr 03) and WF037 (Jun 03) surveys

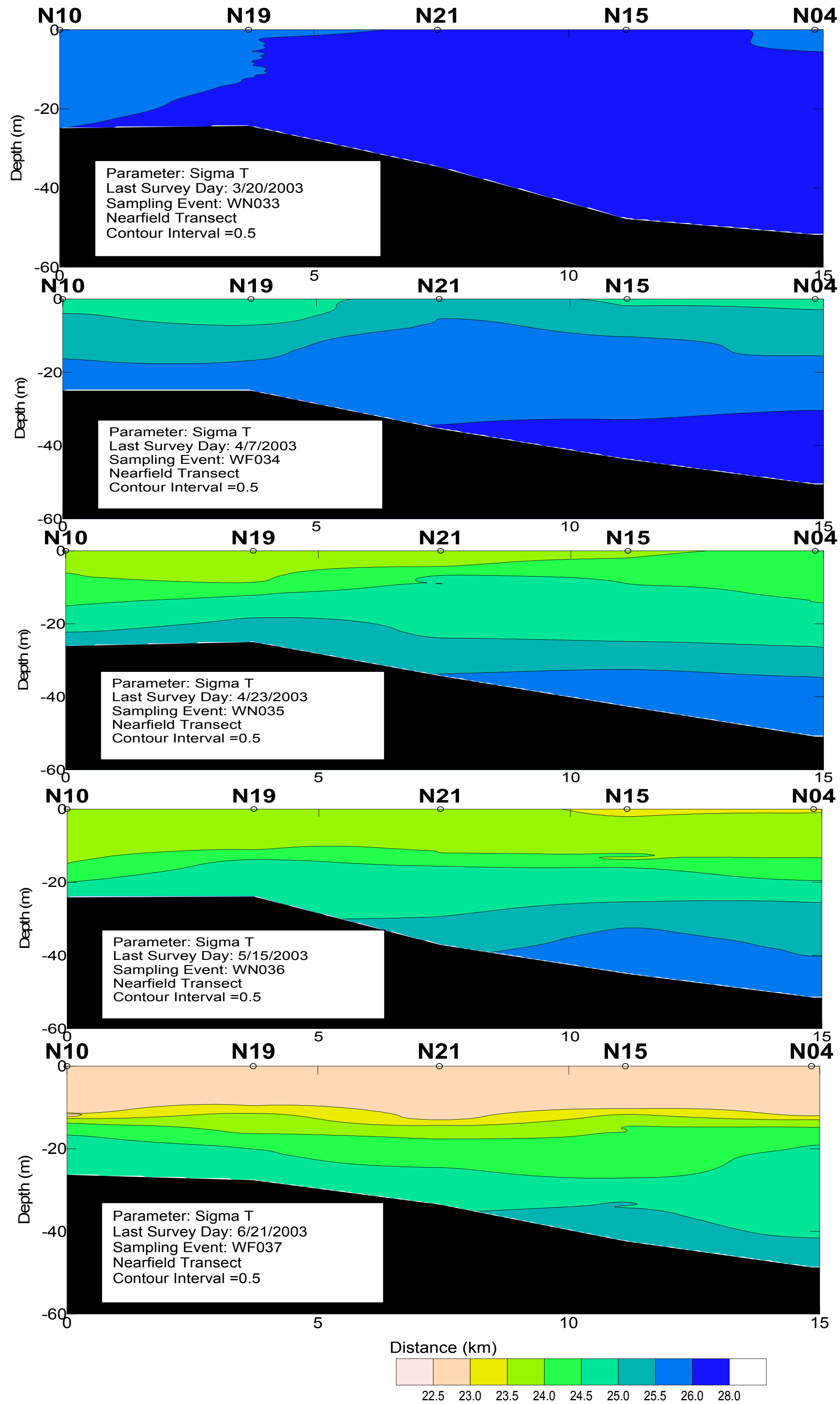


Figure 4-6. Density vertical contour plots across the nearfield transect for surveys WN033, WF034, WN035, WN036, and WF037

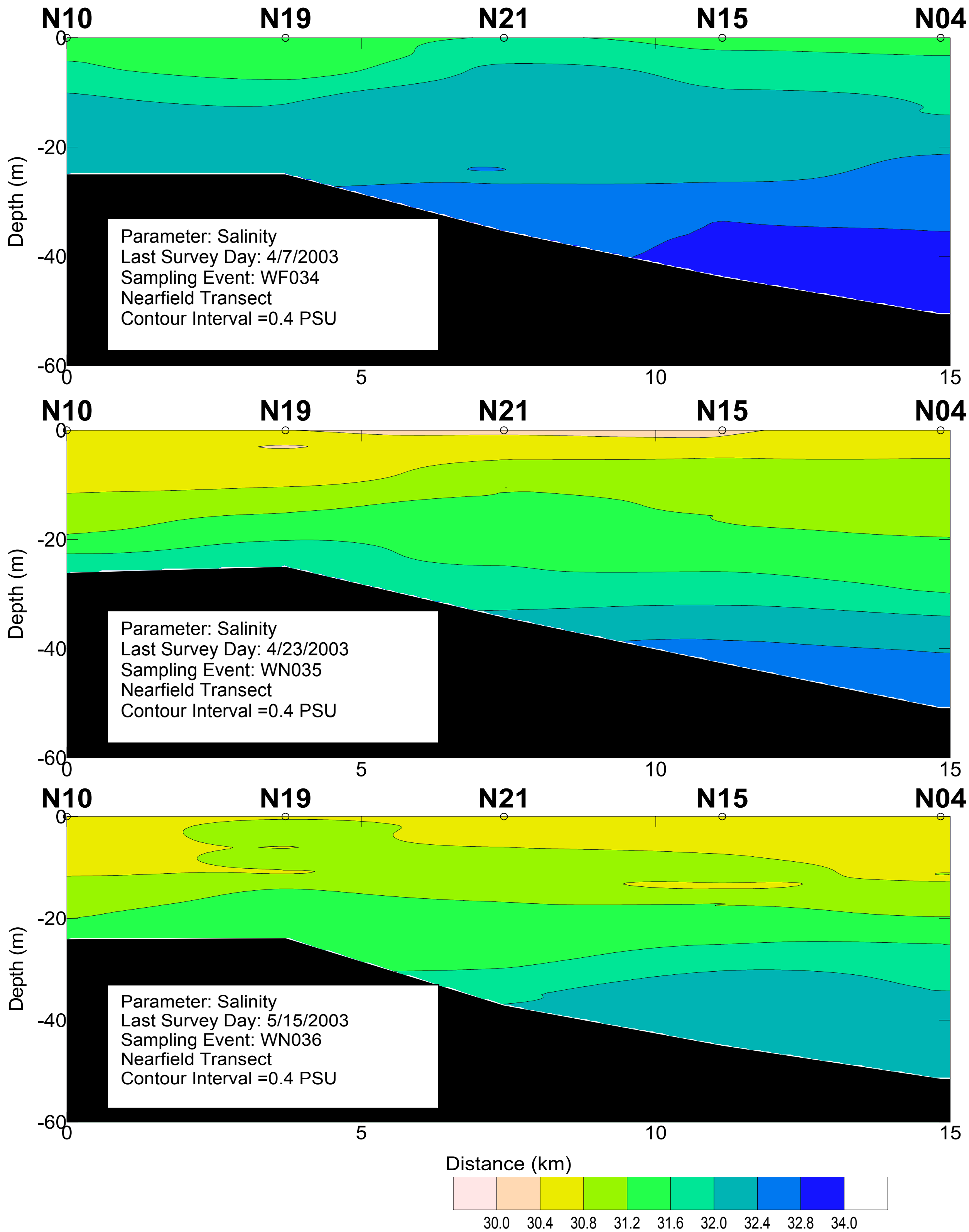


Figure 4-7. Salinity vertical contour plots across the nearfield transect for surveys WF034, WN035, and WN036

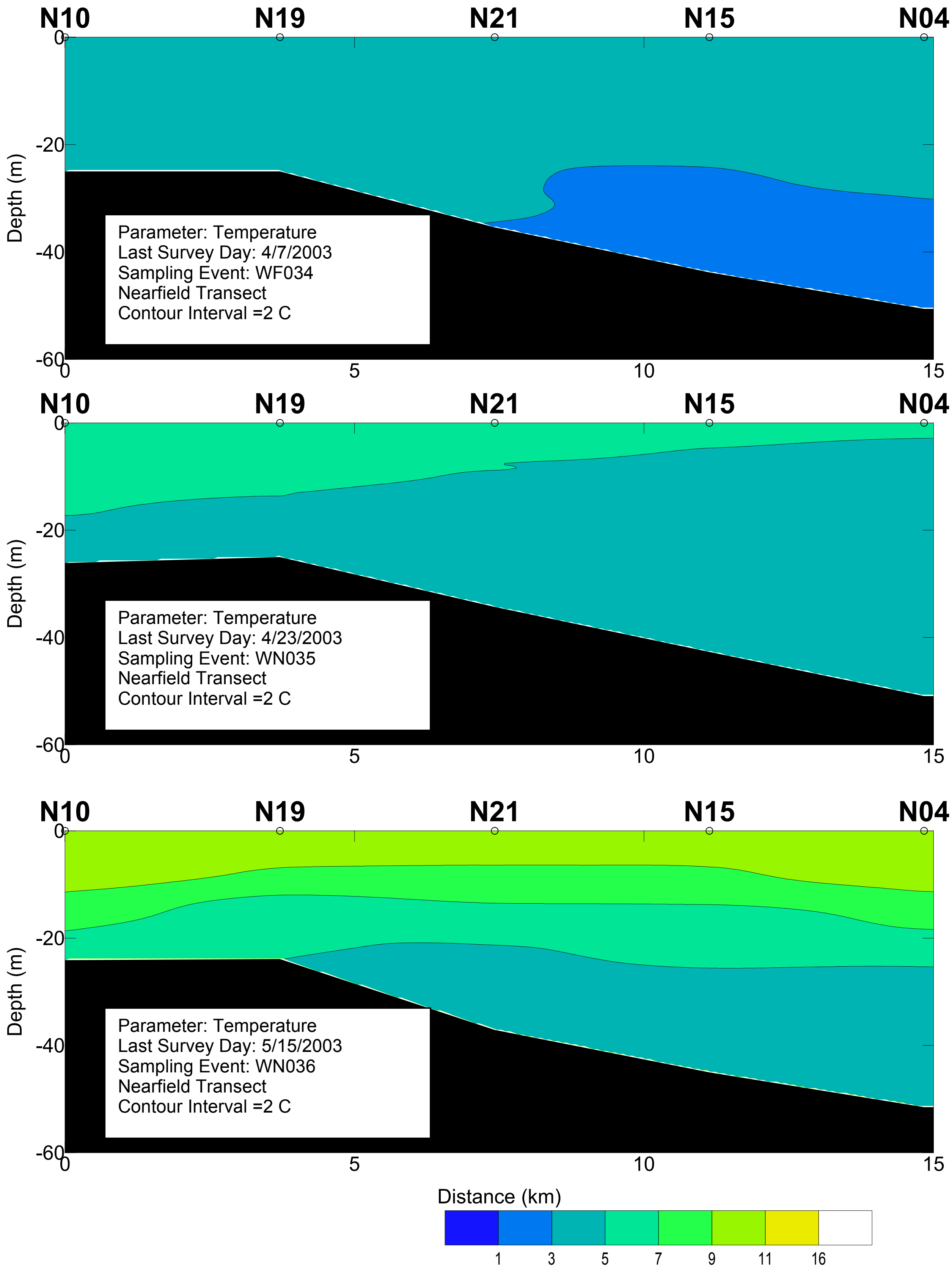
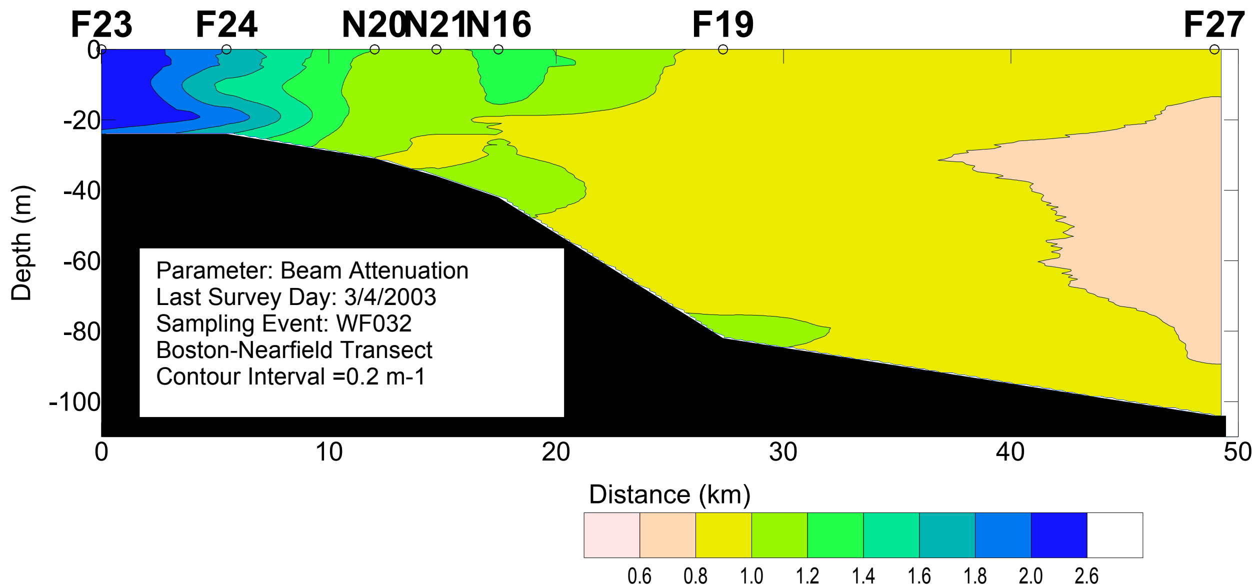


Figure 4-8. Temperature vertical contour plots across the nearfield transect for surveys WF034, WN035, and WN036



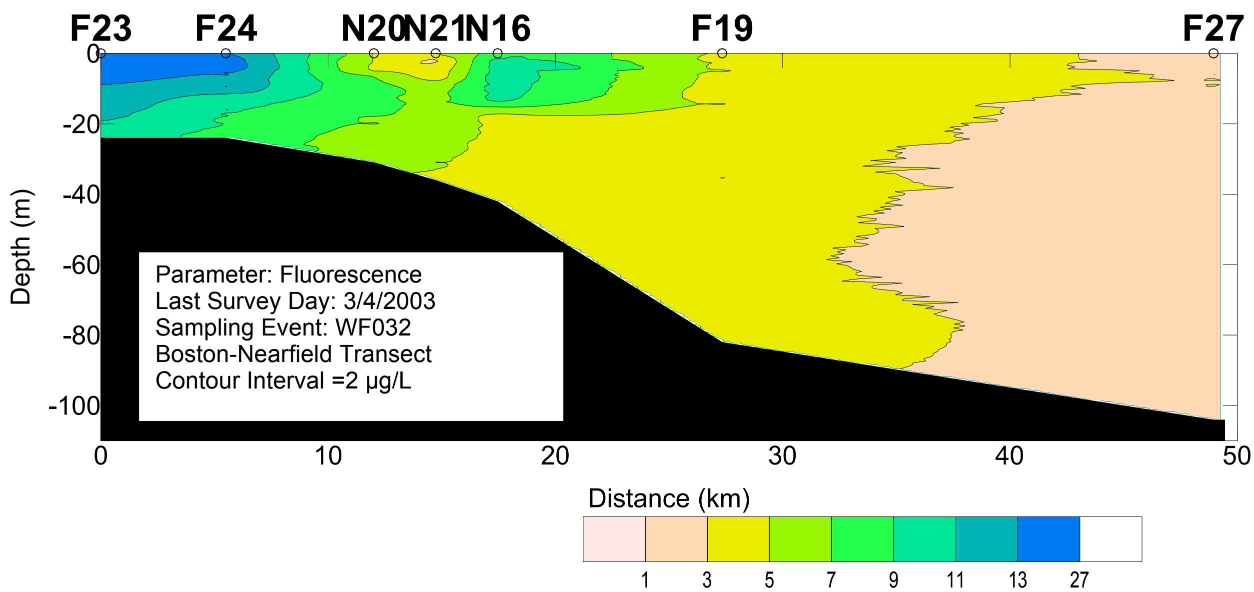


Figure 4-9. Beam attenuation and fluorescence vertical contour plots along the Boston-Nearfield transect for farfield survey WF032 (Feb/Mar 03)

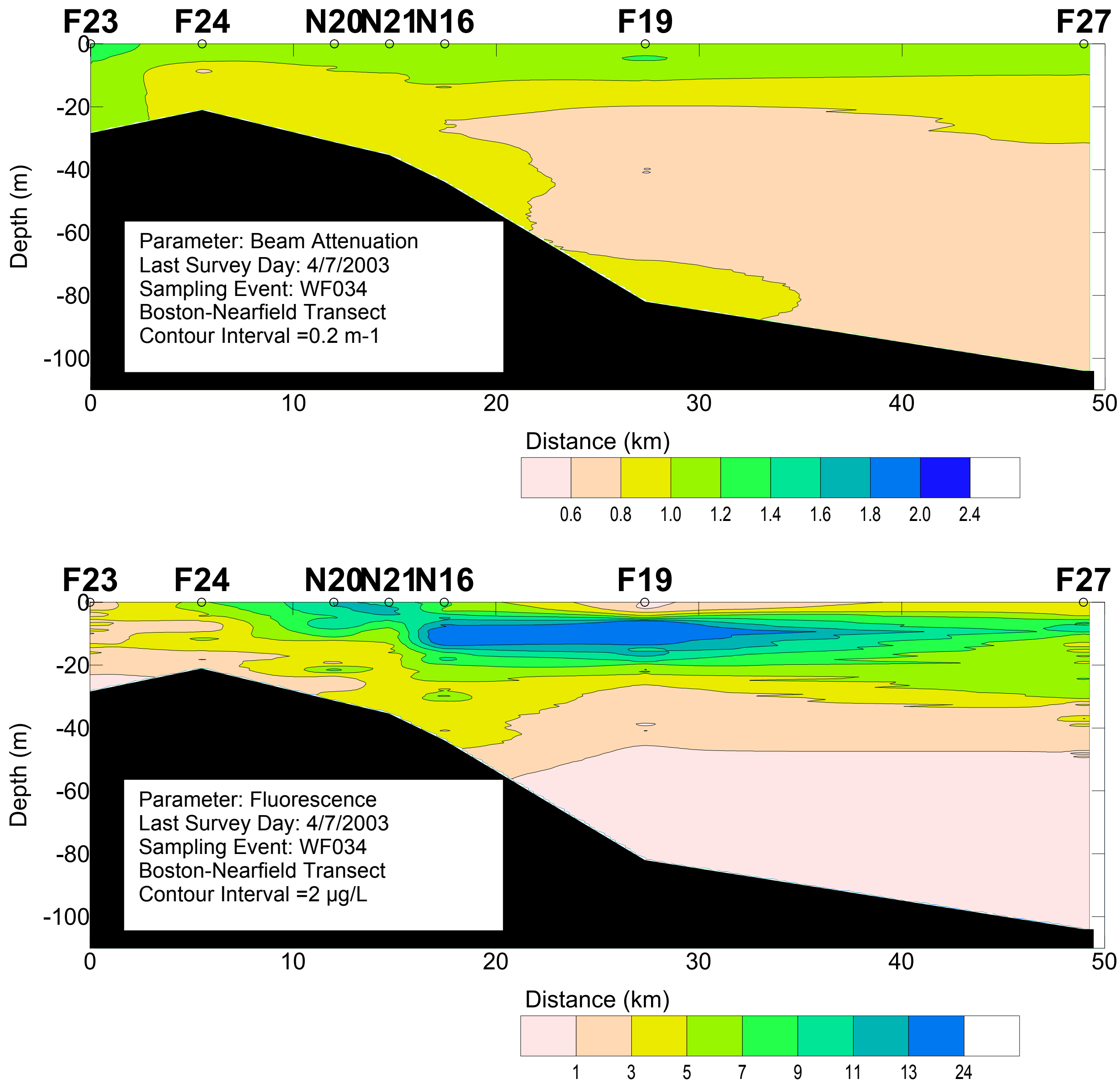


Figure 4-10. Beam attenuation and fluorescence vertical contour plots along the Boston-Nearfield transect for farfield survey WF034 (Apr 03)

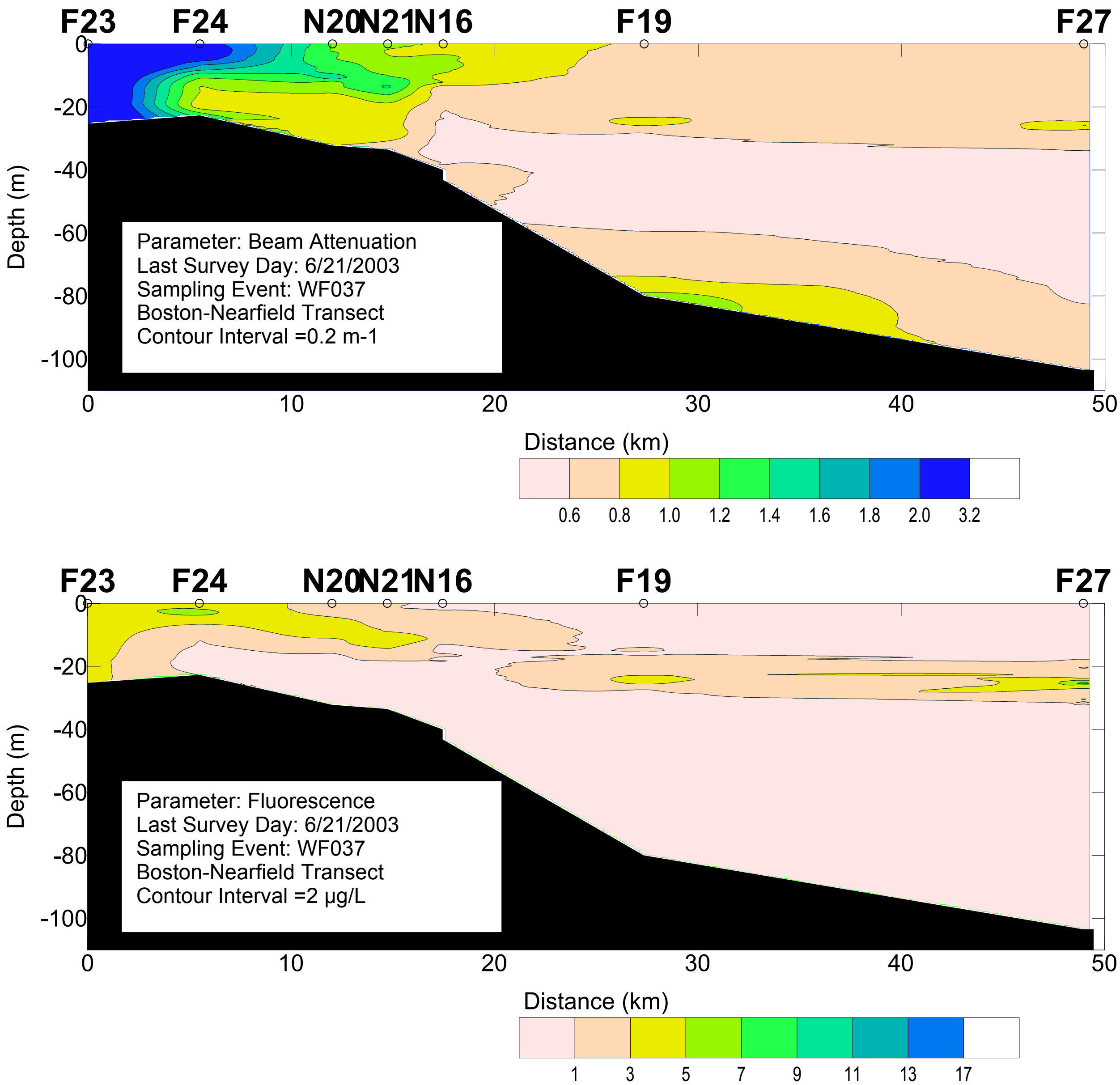
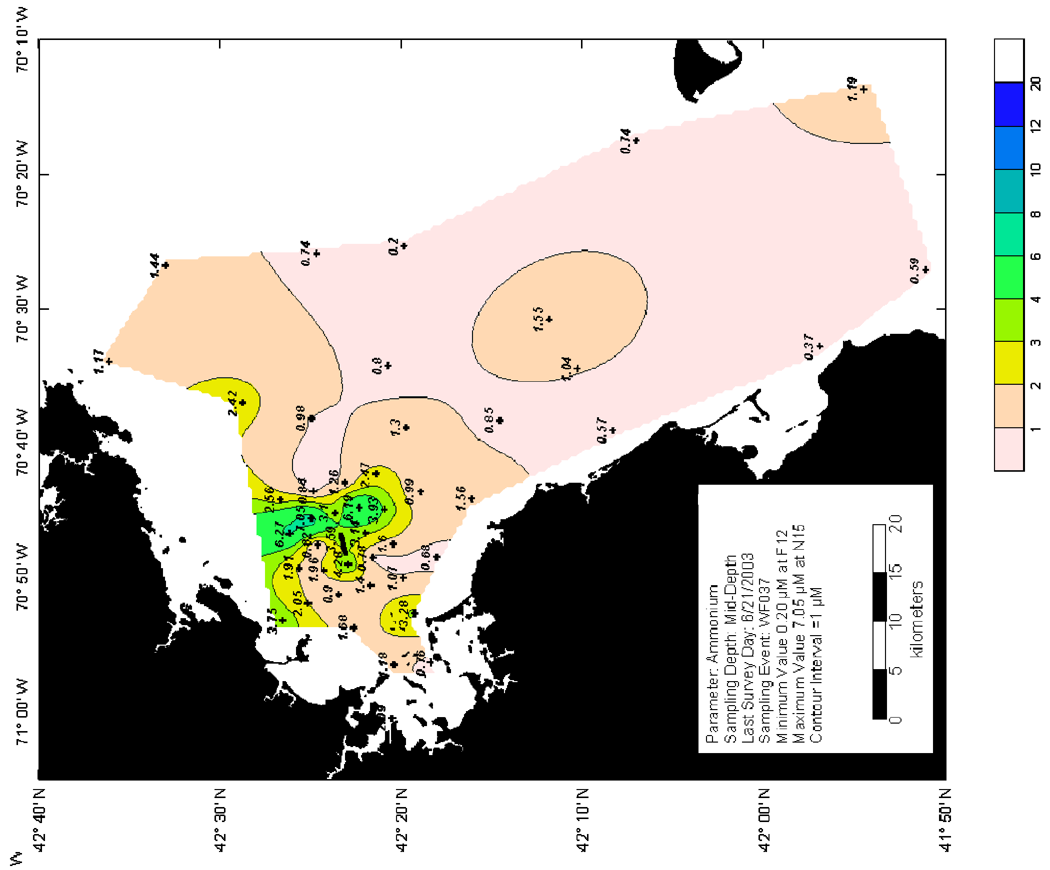


Figure 4-11. Beam attenuation and fluorescence vertical contour plots along the Boston-Nearfield transect for farfield survey WF037 (Jun 03)



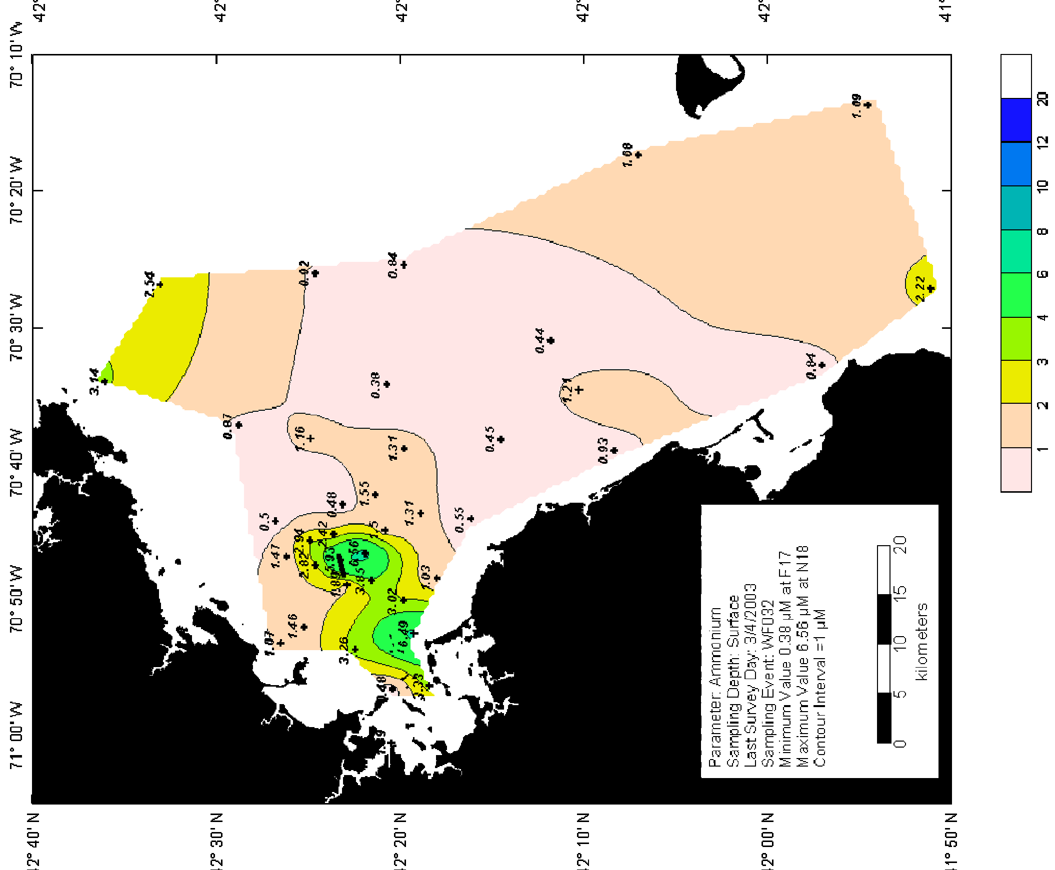


Figure 4-12. Ammonium contour plots for farfield survey a) WF032 – surface (Feb/Mar 03) and b) WF037 – mid depth (Jun 03)

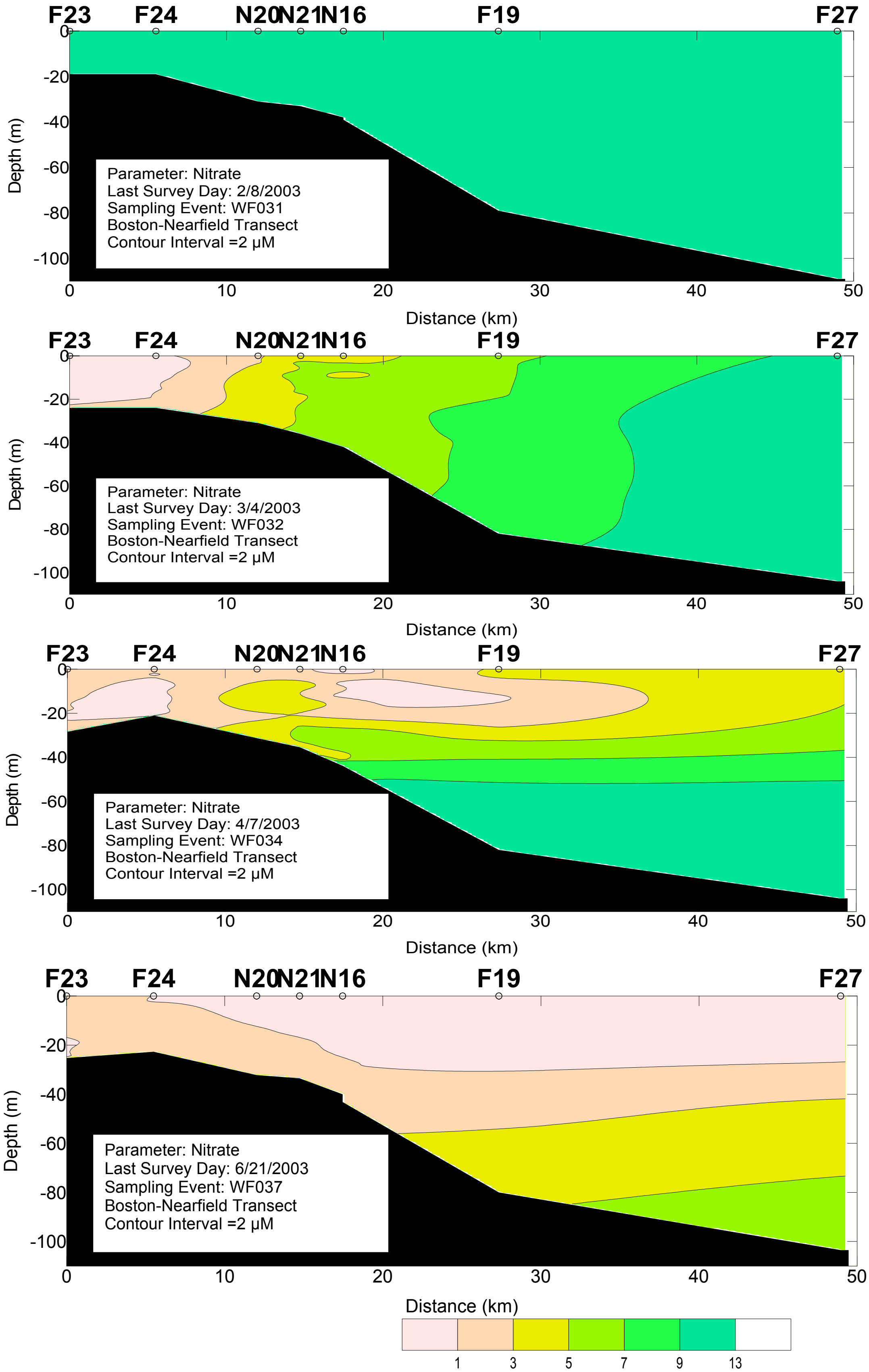
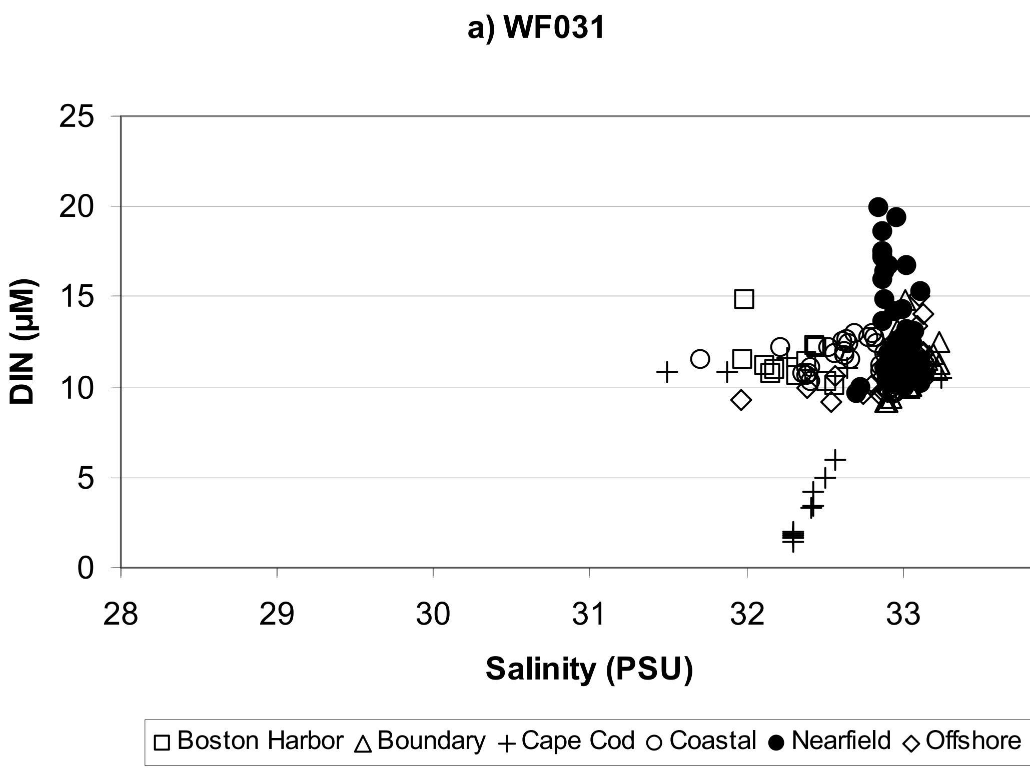


Figure 4-13. Nitrate vertical contour plots along the Boston-Nearfield transect for surveys WF031, WF032, WF034, and WF037



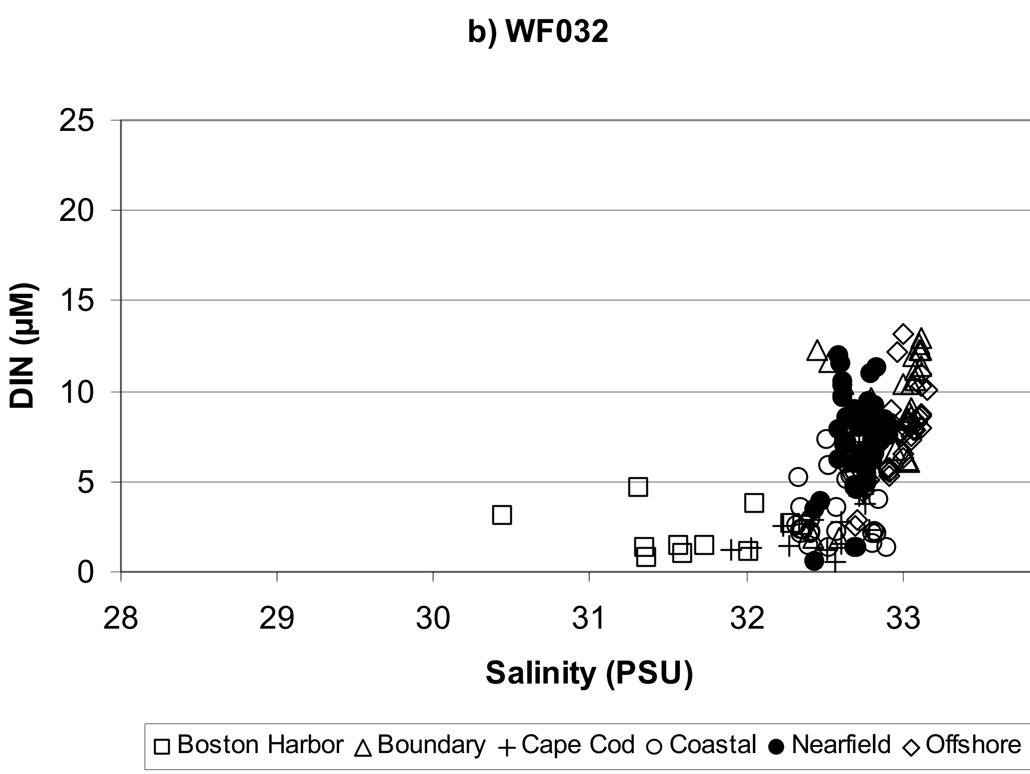


Figure 4-14. DIN vs. salinity for all depths during farfield surveys WF031 (Feb 03) and WF032 (Feb/Mar 03)

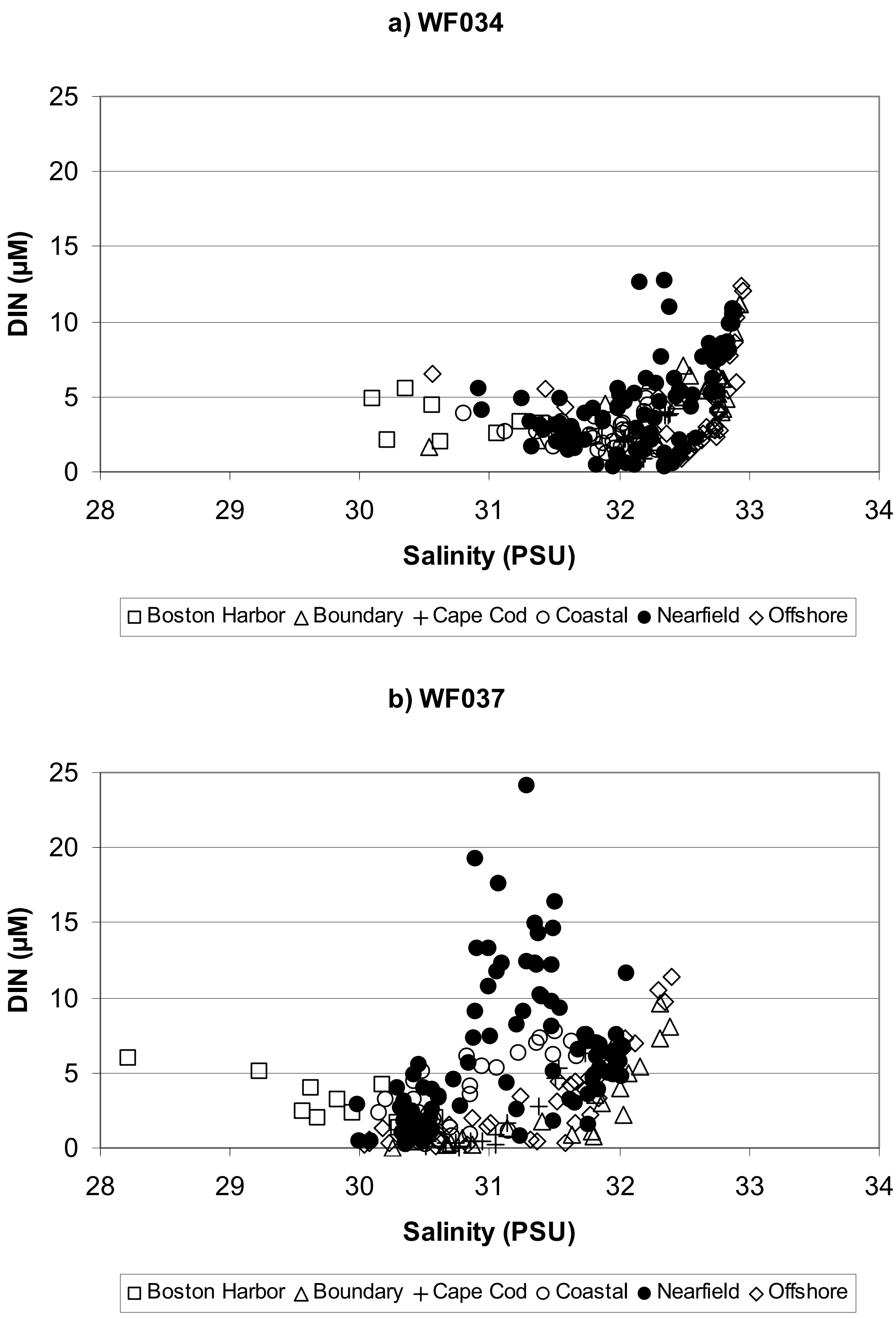


Figure 4-15. DIN vs. salinity for all depths during farfield surveys WF034 (Apr 03) and WF037 (Jun 03)

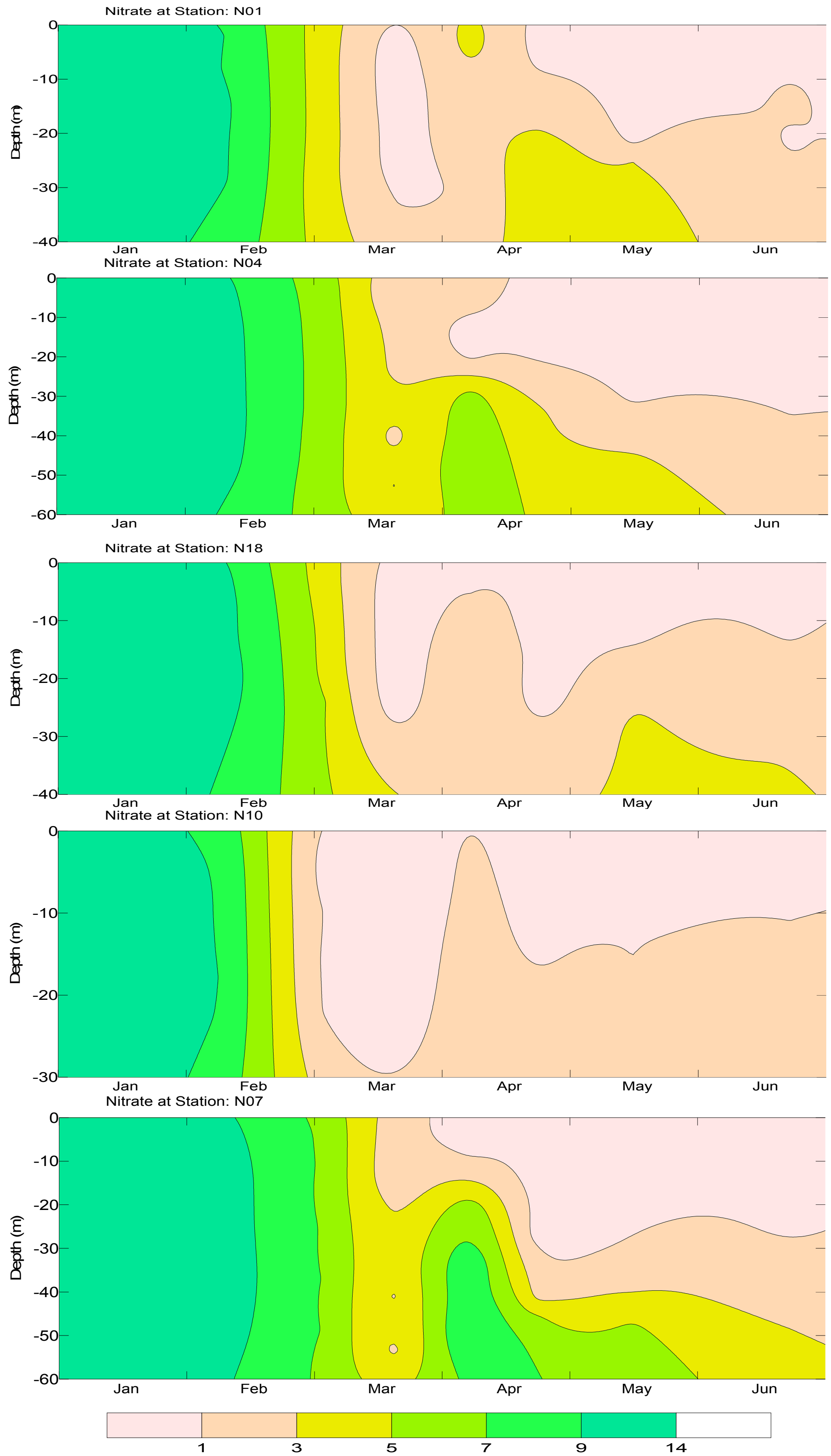


Figure 4-16. Nearfield depth vs. time contour plots of nitrate for stations N01, N04, N18, N10 and N07

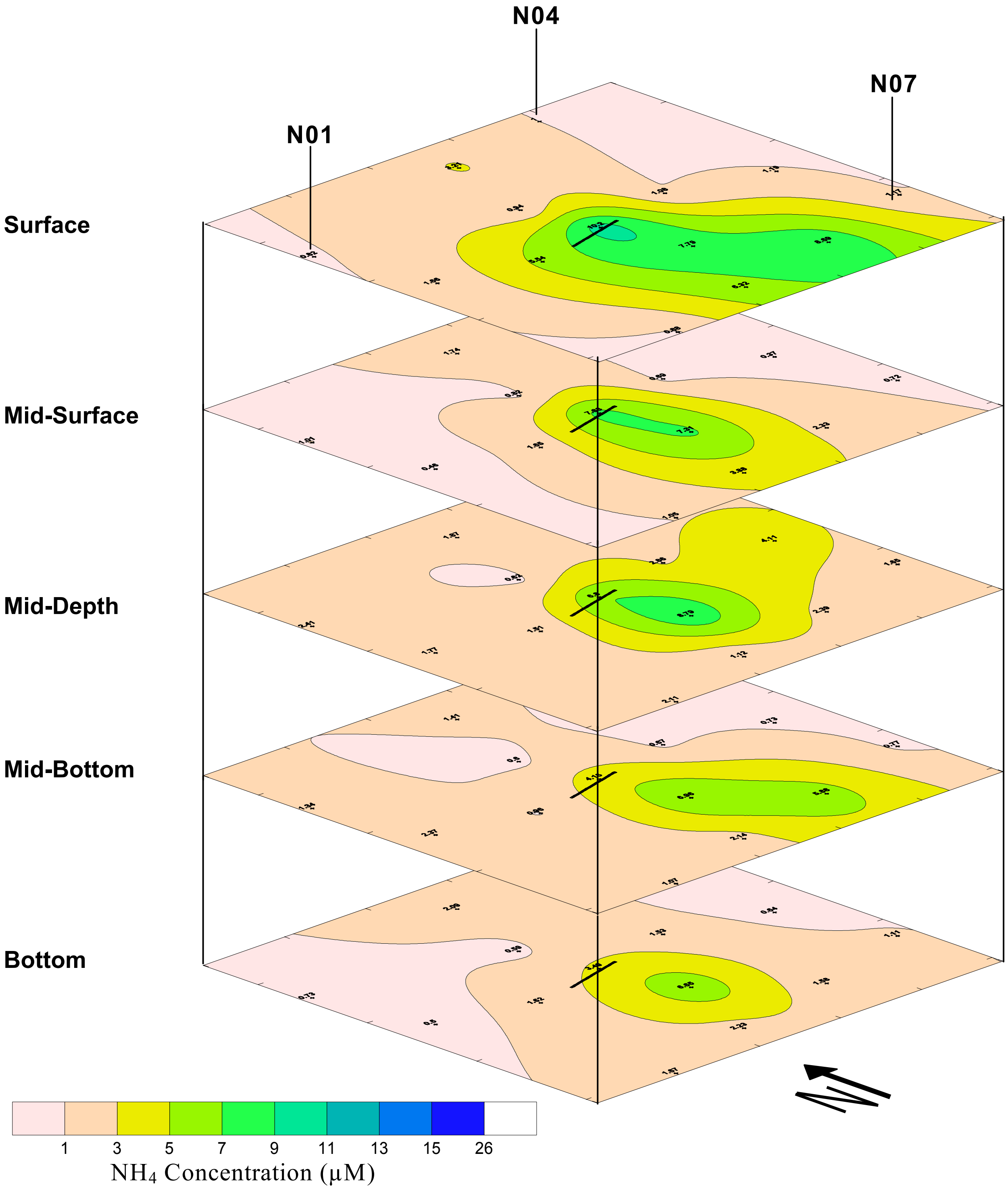


Figure 4-17. Ammonium concentrations at each of the five sampling depths for all nearfield stations during WF031 (Note: displayed depths are a representation, actual sampling depths vary for each station)

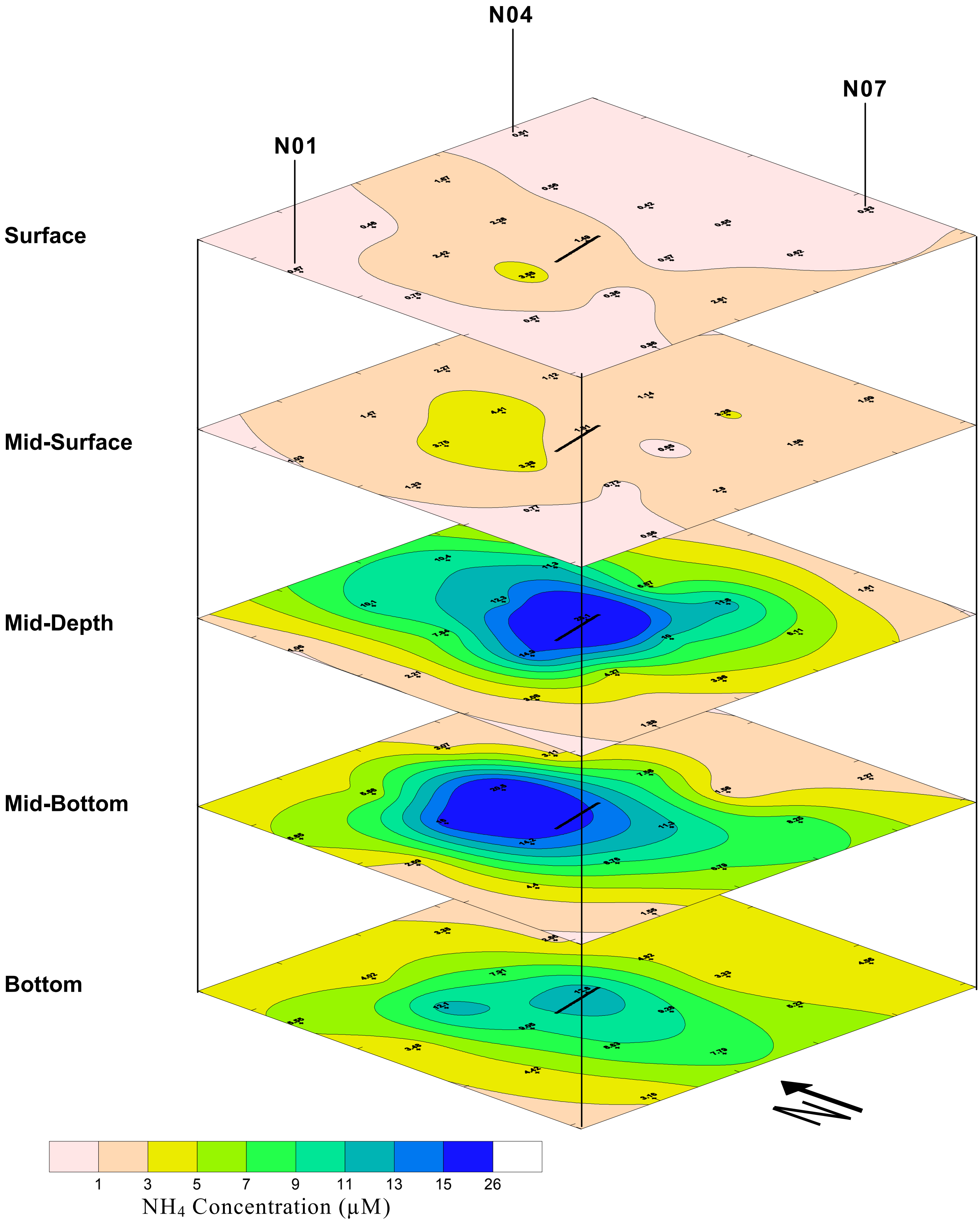


Figure 4-18. Ammonium concentrations at each of the five sampling depths for all nearfield stations during WN036 (Note: displayed depths are a representation, actual sampling depths vary for each station)

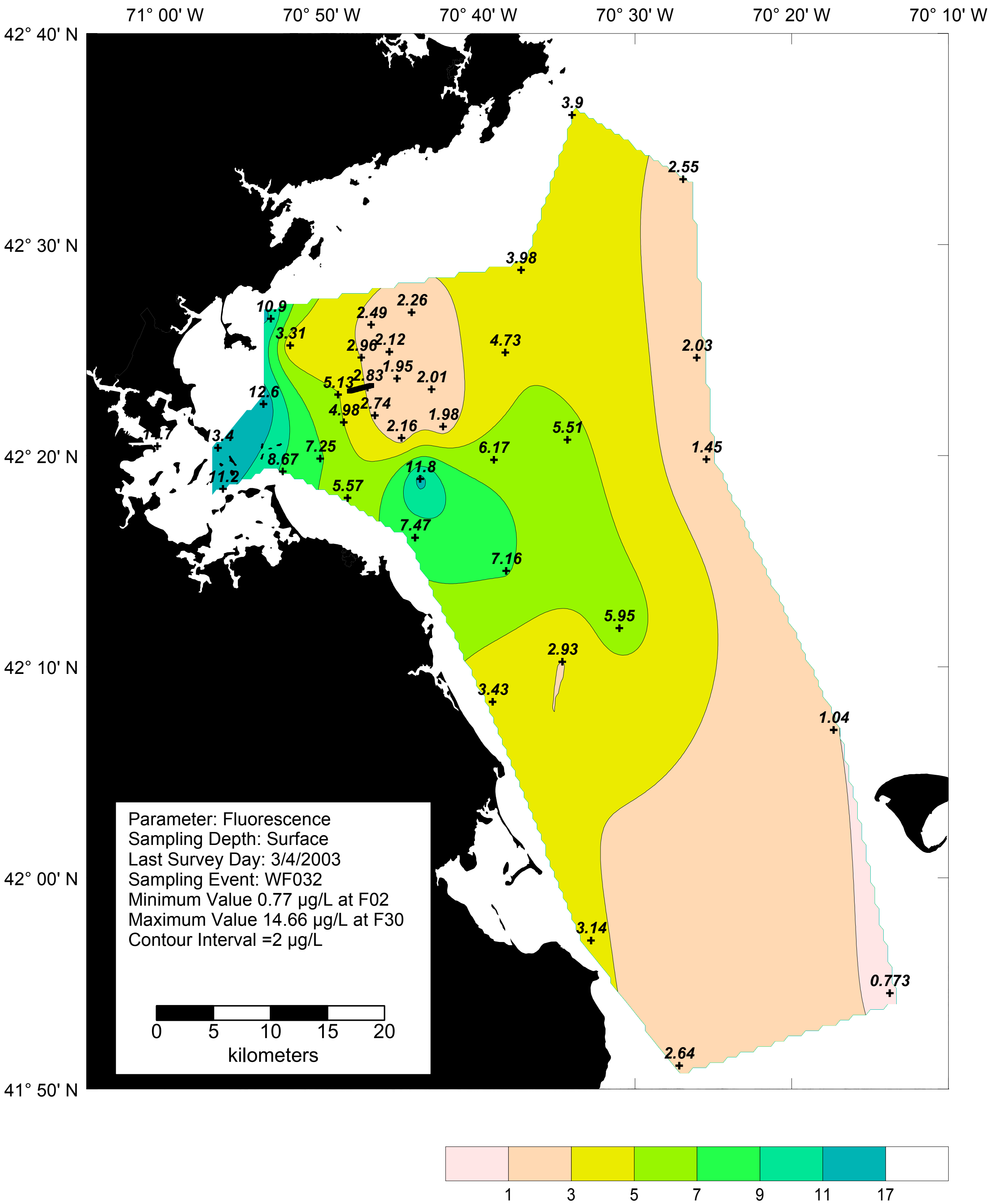


Figure 4-19. Fluorescence surface contour plot for farfield survey WF032 (Feb/Mar 03)

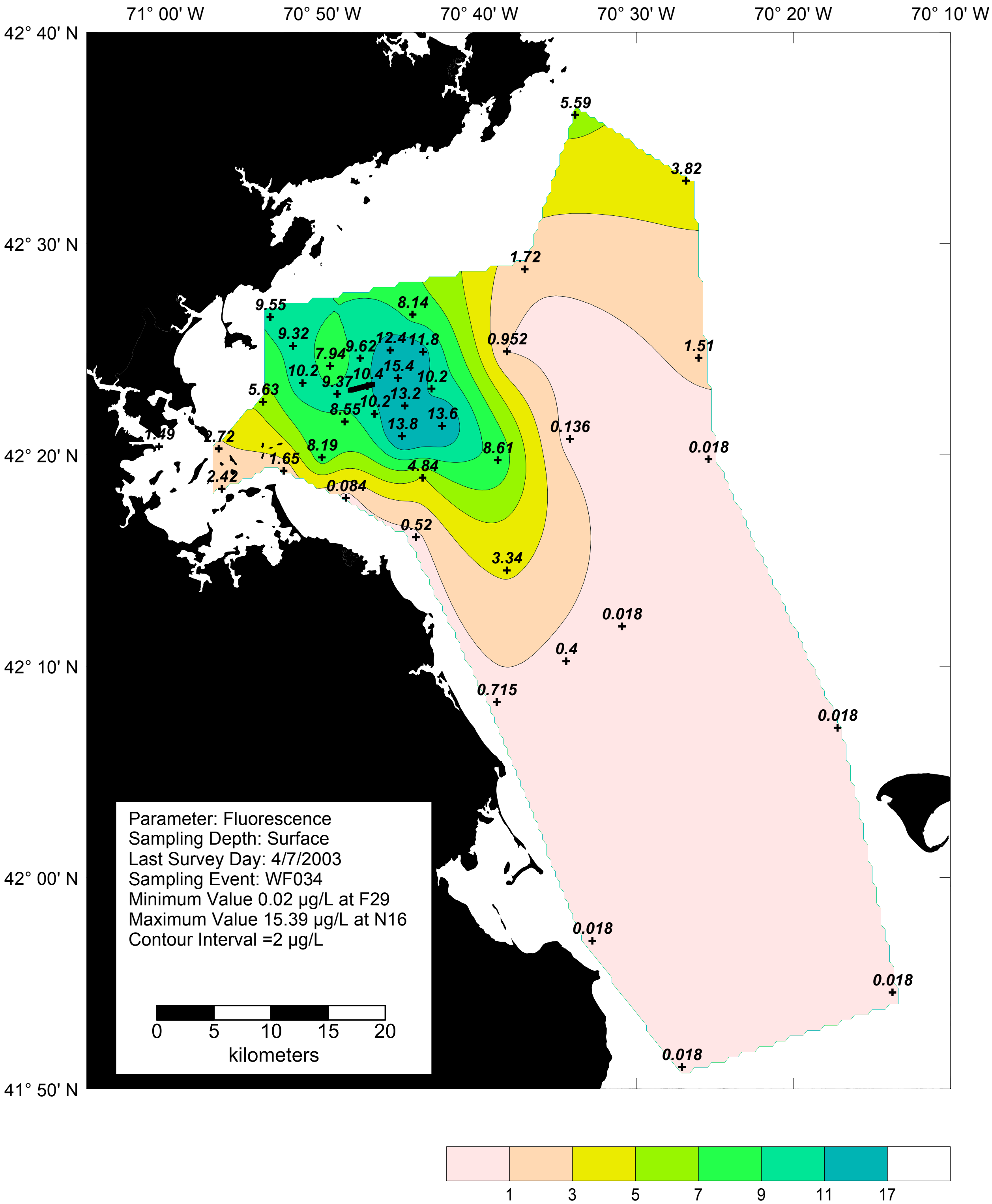


Figure 4-20. Fluorescence surface contour plot for farfield survey WF034 (Apr 03)

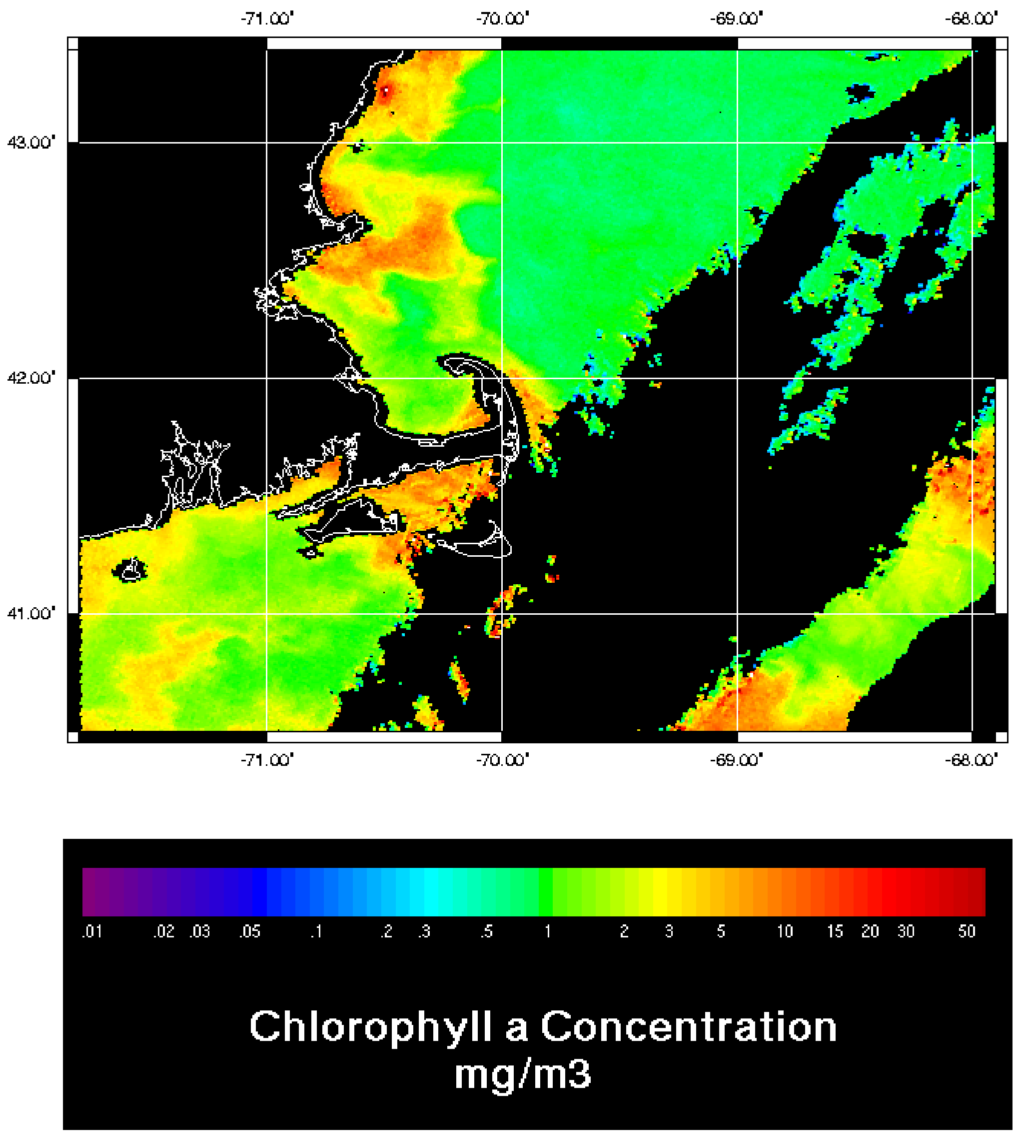


Figure 4-21. SeaWiFS chlorophyll image for southwestern Gulf of Maine for March 27, 2003

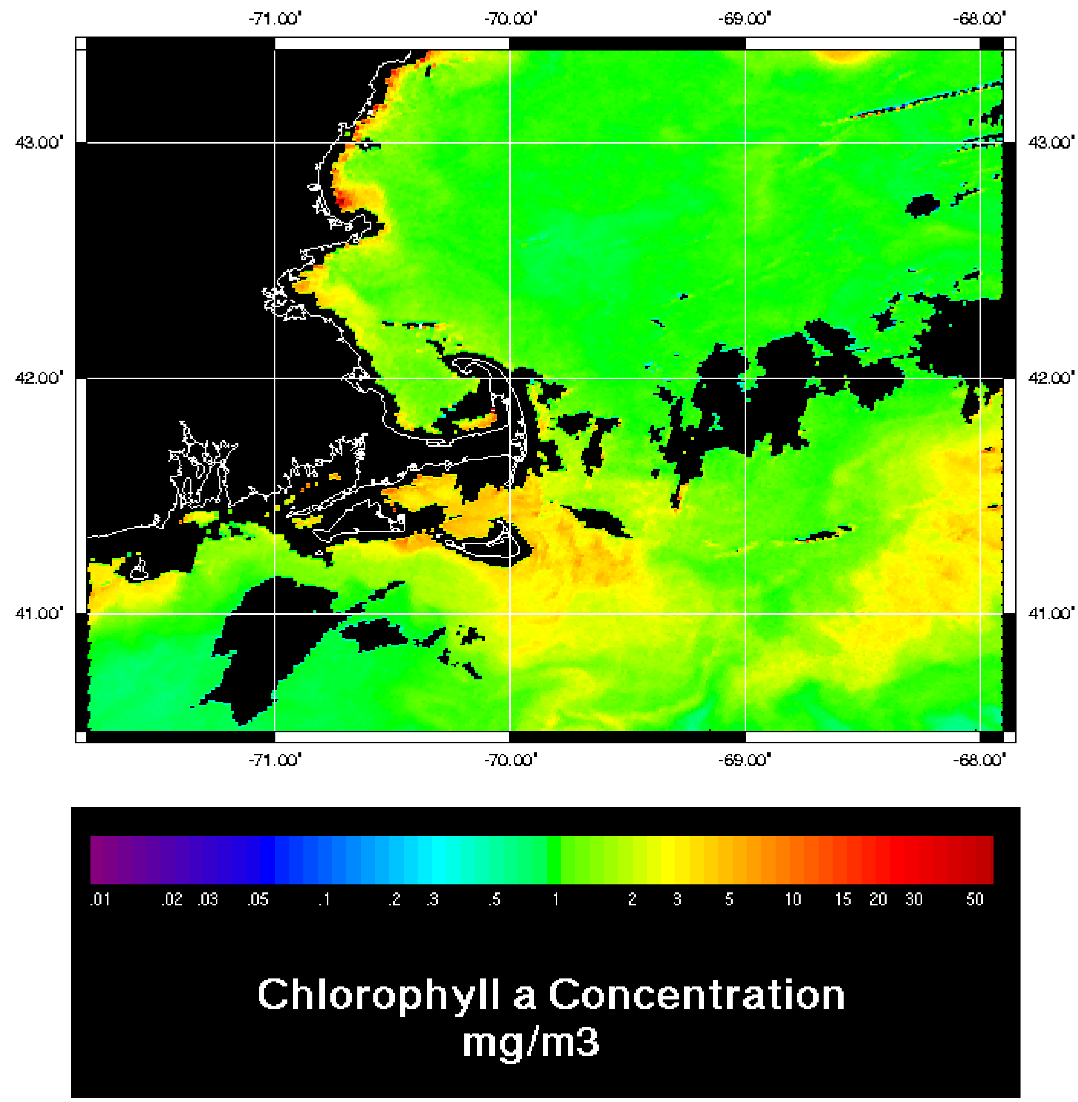


Figure 4-22. SeaWiFS chlorophyll image for southwestern Gulf of Maine for June 26, 2003

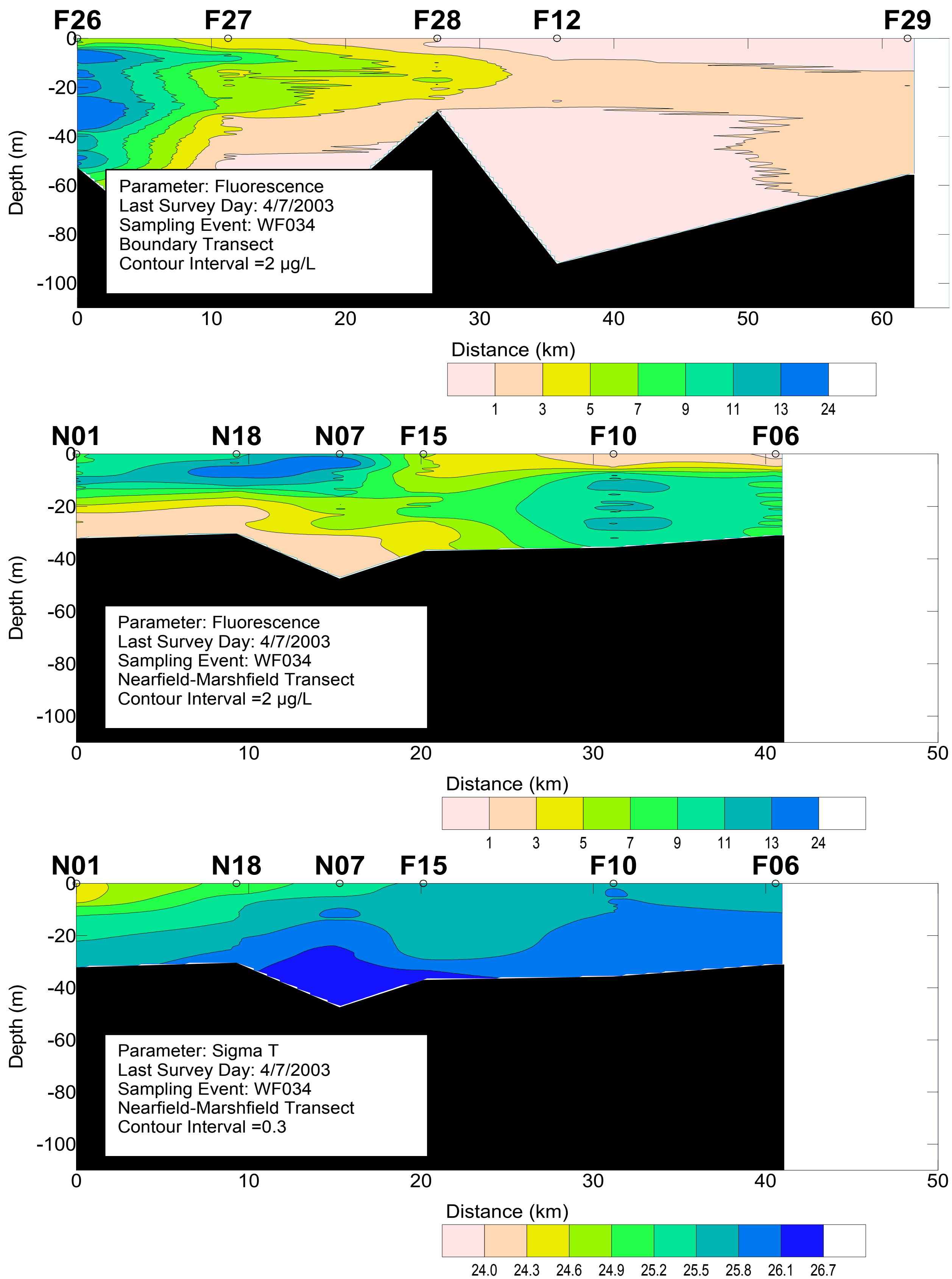


Figure 4-23. Vertical contour plots of a) fluorescence along the Boundary transect and b) fluorescence and c) density along the Nearfield-Marshfield transect for survey WF034 (Apr 03)

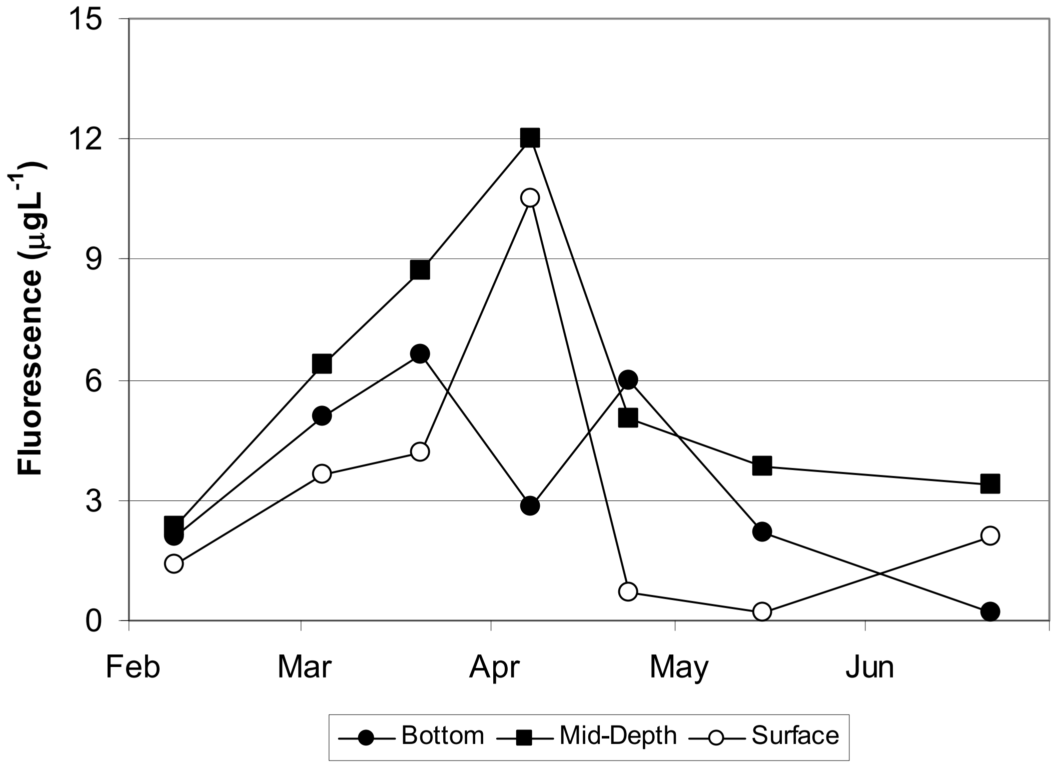


Figure 4-24. Time-series of bottom, mid-depth, and surface survey mean chlorophyll concentration in the nearfield

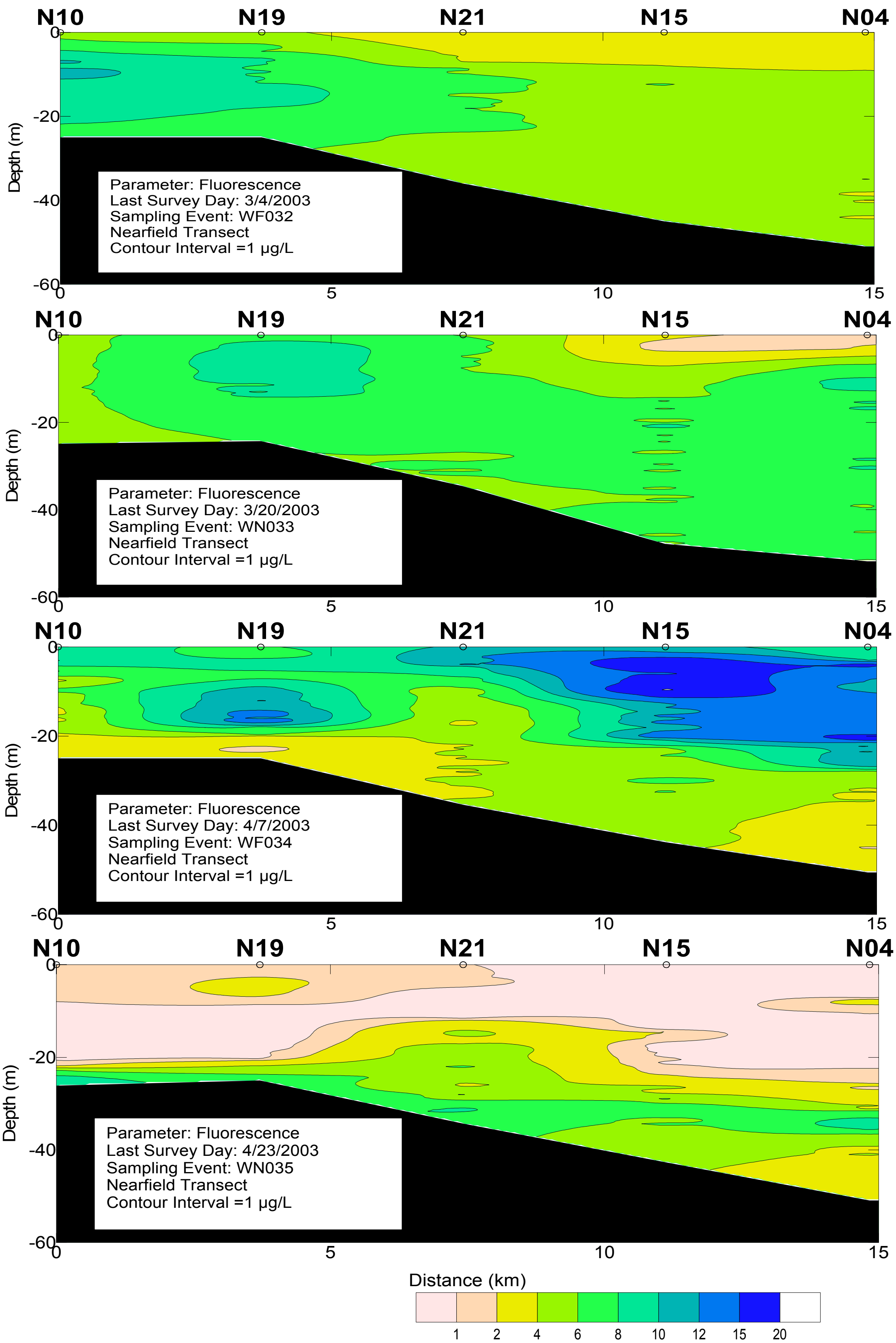
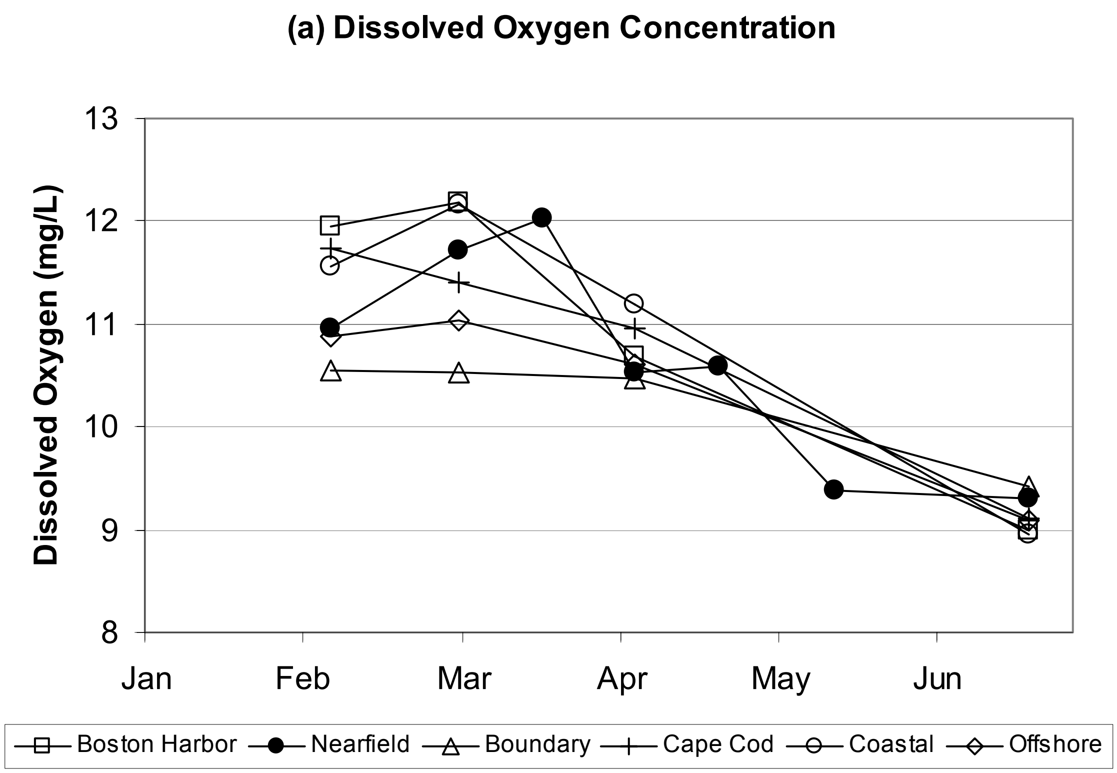


Figure 4-25. Fluorescence vertical contour plots along the nearfield transect for nearfield surveys WF032, WN033, WF034, and WN035



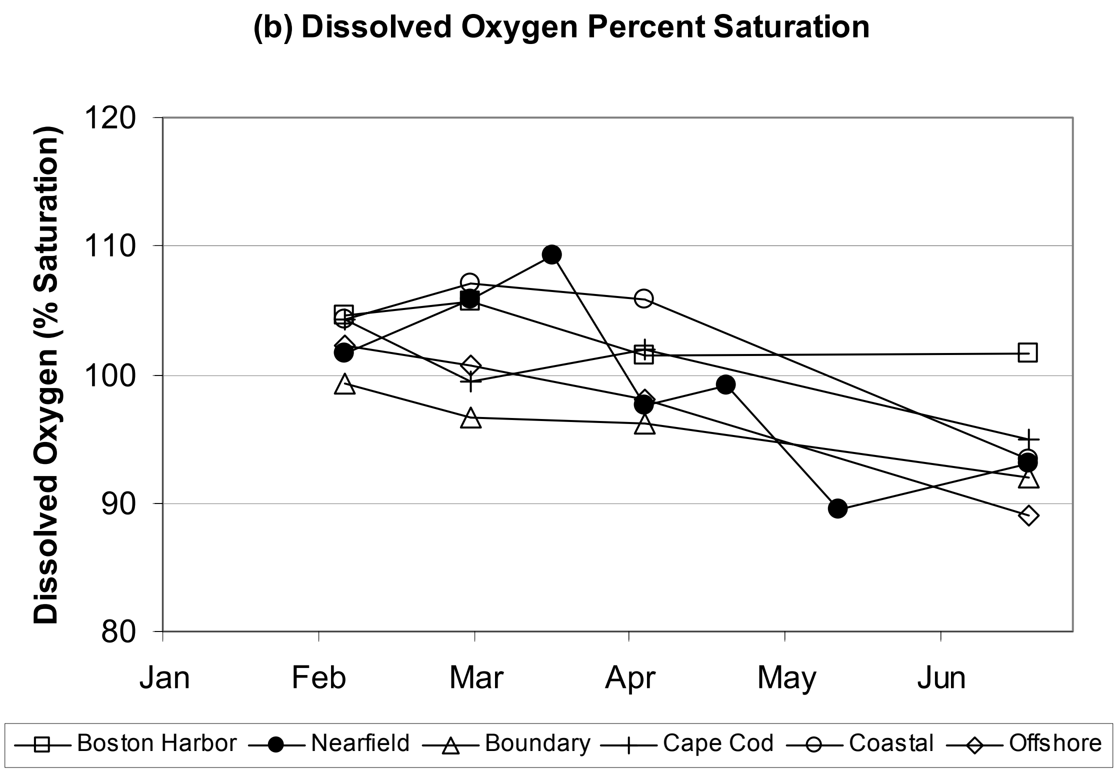


Figure 4-26. Time-series of bottom water average DO concentration and percentage saturation in Massachusetts and Cape Cod Bay

5.0 PRODUCTIVITY, RESPIRATION AND PLANKTON RESULTS

5.1 Productivity

Production measurements were taken at two nearfield stations (N04 and N18) and one farfield station (F23) near the entrance of Boston Harbor. All three stations were sampled on February 6 (WF031), March 4 (WF032), April 3 (WF034) and June 18 (WF037). Stations N04 and N18 were additionally sampled on March 20 (WN033), April 23 (WN035), and May 15 (WN036). Samples were collected at five depths throughout the euphotic zone. Production was determined by measuring ^{14}C at varying light intensities as summarized below and in Libby *et al*. (2002a).

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 a 2π irradiance sensor located on Deer Island, MA. After collection, productivity samples were returned to the Marine Ecosystems Research Laboratory (MERL) in Rhode Island and incubated in temperature controlled incubators. The resulting photosynthesis versus light intensity (P-I) curves (**Figure** 5-1 and comprehensively in Appendix C) were used, in combination with light attenuation and incident light information, to determine hourly production at 15-min intervals throughout the day for each sampling depth. By selecting irradiance data from a sunny day close in time to the monitoring cruise and substituting these values in the productivity calculations, potential production (under maximum light) was determined for each sample day.

For this semiannual report, potential areal production (mg C m^{-2} d^{-1}) and depth averaged chlorophyll-specific potential production (mg C mg Chl^{-1} d^{-1}) are presented (**Figures** 5-2 and 5-3). Areal productions are determined by integrating potential productivity (and chlorophyll-specific potential productivity) over the depth interval. Chlorophyll-specific potential productivity for each depth was first determined by normalizing potential productivity by measured chlorophyll *a*. Productivity (potential and measured), chlorophyll-specific potential productivity and chlorophyll *a* for each depth are also presented as contour plots (**Figures** 5-4 to 5-8). References to production in Section 5.1.1 are specifically to potential areal production, but the term ‘potential’ has been dropped for clarity. It is recommended that the parameter names be changed for clarity from areal production and potential areal production to measured areal production and areal production, respectively, both in the database and in future reports.

5.1.1 Areal Production

Areal production at the nearfield stations N04 and N18 was similar throughout much of the semiannual sampling period (**Figure** 5-2). Areal production at the two sites was low (~100 – 300 mg C m^{-2} d^{-1}) during the initial survey in February. Values increased at both sites to ~700 – 1000 mg C m^{-2} d^{-1} by early March. Productivity increased to winter-spring bloom levels (>1200 mg C m^{-2} d^{-1}) at both sites by late March and remained elevated (1200 –1600 mg C m^{-2} d^{-1}) at both stations during the early April survey. Areal productivity then decreased to about 400 mg C m^{-2} d^{-1} in late-April at station N18 while remaining elevated (~1100 mg C m^{-2} d^{-1}) at station N04. By mid-May productivity was again similar and low at both stations. Productivity increased moderately to ~700 mg C m^{-2} d^{-1} at both sites during the survey in June.

The timing and magnitude of the maximum winter/spring productivity was similar at both stations. The maximum productivity at station N04 occurred in late March with a peak production of 1230 mg C m^{-2} d^{-1}. Station N18 reached its maximum seasonal value (1618 mg C m^{-2} d^{-1}) during the following survey in early April. These spring peaks at both sites were considerably lower than winter/spring bloom maxima in 2002 when values of 3688 – 4860 mg C m^{-2} d^{-1} were observed and somewhat lower than levels observed in 2001 (2265 –2705 mg C m^{-2} d^{-1}). The initial productivity peaks in 2003 occurred simultaneously at both stations in late March but ultimately reached a higher level (1618 mg

C m^{-2} d^{-1}) at station N18 compared with N04 (1230 mg C m^{-2} d^{-1}). The bloom period extended from late March through late April at station N04 but ended earlier at station N18. The minimum production at station N18 (105 mg C m^{-2} d^{-1}) was observed in February. At station N04 the minimum seasonal level (159 mg C m^{-2} d^{-1}) was observed later in mid-May. The decrease in productivity at both stations in May coincided with the decline in abundance of a *Phaeocystis* bloom, present in the nearfield during April.

Productivity at station N18 was elevated relative to station N04 during 4 of the 7 cruises thus far in 2003. During a similar period in 2002, areal productivity at N18 was greater than the values observed at N04 on 5 occasions. The patterns observed at the nearfield sites were consistent with those observed during prior years although the magnitude and timing of events varied. The patterns were also consistent with patterns seen in chlorophyll distributions, but in comparison to previous years there was a disconnect in the relationship between trends in production and chlorophyll concentrations. Winter/spring 2003 had relatively low production, but elevated chlorophyll levels in comparison to 2001 and 2002 (Section 4.2.2). The factors that may have been controlling the initiation and magnitude of the 2003 winter-spring bloom and chlorophyll concentrations will be examined in more detail in the annual report.

At the Boston Harbor station F23, areal production was elevated relative to the nearfield sites during early March (**Figure** 5-2). These results suggest that the bloom started earlier in the harbor. However the maximum extent of the bloom may have been missed if peak production in the harbor coincided with the nearfield peak occurrence in late March (WN033). Productivity was low (~150 mg C m^{-2} d^{-1}) during the initial February survey then increased markedly to ~1500 mg C m^{-2} d^{-1} by early March. Areal productivity then decreased to moderate levels in early April. During the June survey areal production in the harbor increased to ~1300 mg C m^{-2} d^{-1}. The production data at station F23 are in general agreement with the chlorophyll data throughout the semiannual period. Elevated chlorophyll during WF032 (mean 11.2 µg l^{-1}) was associated with increased productivity. During WF034 average chlorophyll decreased over the water column to 1.62 µg l^{-1} and potential productivity decreased to 454 mg C m^{-2} d^{-1}. During WF037 average chlorophyll values at station F23 were higher (4.3 µg l^{-1}), and productivity increased but not to the level observed during WF032.

Areal production in 2003 followed patterns typically observed in prior years. Distinct winter-spring phytoplankton blooms were observed at both nearfield stations during the sampling period (**Figure** 5-2). In general, nearfield stations are characterized by the occurrence of a winter-spring bloom. The winter-spring blooms observed at nearfield stations in 1995-2002 generally reached values of 2000 to 4500 mg C m^{-2} d^{-1}, with bimodal peaks often occurring in February - April. The bloom in 2003 reached maximum values at the nearfield sites of ~1200-1600 mg C m^{-2} d^{-1} with peaks observed in late March/early April. Unlike many years, an early February peak was not observed. SeaWiFS images indicate that chlorophyll levels were low from January through most of February (Appendix D) indicating that an early bloom was not missed due to the sampling schedule. The winter-spring bloom peaks at both nearfield sites in 2003 were lower than values observed during the winter-spring period in recent years (1999 to 2002).

Prior to the diversion of effluent offshore, Boston Harbor station F23 exhibited a gradual pattern of increasing areal production from winter through summer rather than the distinct winter/spring peaks observed at the nearfield sites. During 1995-2001, peak areal productions at station F23 ranged from 1000 to 5000 mg C m^{-2} d^{-1} in June-July. The peak areal production observed in 2002 was a similar magnitude (3200 mg C m^{-2} d^{-1}) but occurred in February. In 2003, areal production peaked during the winter bloom in early March, decreased in April before increasing again in June (**Figure** 5-2). The shift in seasonal cycle in 2003 at station F23 is similar to the pattern observed in 2001 – 2002, although the magnitude of the bloom varies among years.

5.1.2 Depth-Averaged Chlorophyll-Specific Production

Depth-averaged chlorophyll-specific potential production was generally low at the nearfield productivity stations throughout the first four cruises of this semiannual reporting period (**Figure** 5- 3). Values were similar and relatively low at both stations (~2 - 5 mg C mg Chl a^{-1} d^{-1}) in February and early March. Values diverged in late March to 15.6 mg C mg Chl a^{-1} d^{-1} at station N18 and ~3 mg C mg Chl a^{-1} d^{-1} at station N04. During early April values were again similar and low (~3-6 mg C mg Chl a^{-1} d^{-1}) at the nearfield sites. A slight increase was observed at station N18 during late April with a major increase to ~31 mg C mg Chl a^{-1} d^{-1} at station N04. The increase at station N04 coincided with the occurrence of a deep *Phaeocystis* bloom at this site. Peak depth-averaged chlorophyll-specific potential production (~20 mg C mg Chl a^{-1} d^{-1}) occurred during mid-May at station N18 while the seasonal minimum (~2 mg C mg Chl a^{-1} d^{-1}) was observed during this cruise (WN036) at station N04. Depth-averaged chlorophyll-specific productivity was similar and moderate (~11 C mg Chl a^{-1} d^{-1}) at both nearfield sites in June. By comparison depth-averaged chlorophyll-specific rates at harbor station F23 tended to increase gradually from a seasonal minimum of ~3 mg C mg Chl a^{-1} d^{-1} in February to a seasonal maximum in June (~12 mg C mg Chl a^{-1} d^{-1}; **Figure** 5-3).

5.1.3 Production at Specified Depths

The spatial and temporal distribution of production (measured and potential), chlorophyll and chlorophyll-specific potential production on a volumetric basis were summarized by showing contoured values over the sampling period (**Figures** 5-4 to 5-8). Chlorophyll-specific potential productions (daily potential production normalized to chlorophyll concentration at each depth) were calculated to compare potential production with chlorophyll concentrations. Chlorophyll-specific potential production can be used as an indicator of the optimal conditions necessary for photosynthesis.

Major differences were observed in measured and potential production at the nearfield sites during the winter-spring bloom periods. These differences are illustrated by the deepening and widening of the elevated potential productivity contours seen in the lower portion of **Figures** 5-4 and 5-5. The measured areal productivity peaks observed during late March and April 2003 at stations N04 and N18 were concentrated in the upper 5 m of the water column, while elevated potential productivity extended to beyond 10 m and was more typical of the pattern observed in prior years. At station N04, potential production was highest (75 mg C m^{-3} d^{-1}) in the surface water during late March but elevated potential productivity extended to mid-surface levels (72 mg C m^{-3} d^{-1}) in April. Unlike prior years, the peak bloom period at station N04 was not characterized by a subsurface productivity maximum. Depth-specific potential production at station N18 was characterized by a subsurface productivity maximum (146 mg C m^{-3} d^{-1}) located at mid-water depths during the April winter-spring bloom peak. Similar levels were observed at mid-surface depths (~122 mg C m^{-3} d^{-1}) during this peak bloom period. At both nearfield stations potential productivity tended to decrease following the spring peak values.

The pattern at the harbor station F23 was somewhat different from the depth-specific potential productivity at the nearfield sites (**Figure** 5-6). Measured and potential productivity were similar at station F23 during the winter/spring bloom period but elevated potential productivity extended deeper into the water column during June at the harbor site. Additionally, the depth-specific potential productivity values during early March at station F23 reflect the early initiation of the winter/spring bloom noted previously at this site. The depth-specific potential productivity values further emphasize the elevated productivity observed at station F23 during June (**Figures** 5-4 to 5-6).

The productivity pattern at specified depths observed in 2003 was similar to that observed in prior years, although the magnitude was less. At station N04 potential productivity as high as 17 mg C m^{-3} d^{-1} occurred to depths of 18 m; during prior years productivity as great as 45 mg C m^{-3} d^{-1} occurred at these depths. At station N18 potential productivity >20 mg C m^{-3} d^{-1} was not observed at depths

>20 m. As in most prior years, elevated productivity (>25 mg C m^{-3} d^{-1}) in the harbor was generally restricted to the upper 10 m of the water column (**Figure** 5-6).

Elevated production values tended to correspond with the occurrence of the highest chlorophyll *a* measurements during the winter/spring bloom periods at stations N04 and N18 (**Figure** 5-7). At both nearfield sites, chlorophyll concentrations were highest in the mid-surface and mid-water depths with elevated values at similar maxima (12.7 – 13.5 mg m^{-3}). At station N18 the sub-surface chlorophyll maximum was associated with a subsurface peak in potential productivity. However, the elevated chlorophyll *a* concentrations at depth at N04 were generally not reflected in higher potential production suggesting a decrease in the efficiency of production at these depths. At station N04, chlorophyll concentrations as great as 7.9 mg m^{-3} were observed at depths as great as 52 m. At station N18 chlorophyll concentrations greater than 7 mg m^{-3} were confined to the upper 25 m. At station F23, chlorophyll concentrations were elevated during the winter period of peak productivity then decreased in April and June. During the latter portion of the sampling period, the depth-specific concentration of chlorophyll *a* was relatively constant throughout the water column at station F23 (**Figure** 5-7c).

Chlorophyll-specific potential production at depth followed similar seasonal patterns at stations N04 and N18 (**Figure** 5-8). Chlorophyll-specific production at both sites tended to be concentrated in the upper portions of the water column, particularly during the initial sampling periods. As the season progressed chlorophyll-specific production tended to increase with time and over depth. Values were somewhat elevated in March and April, coinciding with the peak of the winter-spring bloom. At station N04, values increased to a maximum at mid-surface depth during late April followed by a secondary, deep-water peak in June. The subsurface maximum at N04 occurred during the declining phase of the *Phaeocystis* bloom. A similar trend was observed at station N18. The peak depth-specific potential production per unit chlorophyll *a* occurred in surface water during mid-May at station N18. The elevated chlorophyll-specific potential production observed in March and April was associated with increased phytoplankton biomass as measured by chlorophyll *a*. However, the increased chlorophyll-specific potential production observed at stations N04 and N18 in May and June did not lead to elevated phytoplankton biomass (**Figure** 5-7). When the efficiency of photosynthesis is high but not reflected in higher phytoplankton biomass (measured as total chlorophyll *a*), it suggests that other processes (such as predation by zooplankton) are important in controlling the patterns observed. At station F23, chlorophyll-specific potential production decreased with depth and increased over the sampling season, reaching a peak in June (**Figure** 5-8c). The June peak at F23 was also not associated with increased chlorophyll *a*.

5.2 Respiration

Respiration measurements were made at the same nearfield (N04 and N18) and farfield (F23) stations as productivity and at an additional station in Stellwagen Basin (F19). All four stations were sampled during each of the combined farfield/nearfield surveys. Stations N04 and N18 were also sampled during the three nearfield only surveys. Respiration samples were collected from three depths (surface, mid-depth, and bottom) and were incubated in the dark at *in situ* temperatures for 7±2 days.

Both respiration (in units of $\mu MO_2\ hr^{-1}$) and carbon-specific respiration ($\mu MO_2\ \mu MC^{-1}\ hr^{-1}$) rates are presented in the following sections. Carbon-specific respiration was calculated by normalizing respiration rates to the coincident particulate organic carbon (POC) concentrations. Carbon-specific respiration rates provide a relative indication of the biological availability (labile) of the particulate organic material for microbial degradation.

5.2.1 Water Column Respiration

Overall respiration rates were relatively low during the first half of 2003 due to the unusually low water temperatures that were observed from February to April. During the surveys conducted in

February (WF031 and WF032), respiration rates were low in both the nearfield and farfield areas of Massachusetts Bay ($\leq$0.10 μMO_2hr^{-1}; **Figures** 5-9 and 5-10). Nearfield respiration rates remained low in March and increased in the surface waters at both stations during the *Phaeocystis* bloom in April (0.15 to 0.2 μMO_2hr^{-1}). In Boston Harbor and at offshore station F19, respiration rates remained low (<0.1 μMO_2hr^{-1}) in April. The respiration rates in the winter/spring of 2003 did not follow the trends observed in POC (**Figures** 5-11 and 5-12) and chlorophyll concentrations (see Section 4.3.2). The large increases in POC and chlorophyll that were observed in the harbor (late February) and nearfield (March/April) were coincident with the trend of slightly increasing respiration rates, but did not result in an appreciable increase. Respiration rates at nearfield stations remained low later in April and May before reaching seasonal maxima in surface waters in June (0.17 to 0.21 μMO_2hr^{-1}). In Boston Harbor, respiration rates increased to 0.15 to 0.2 μMO_2hr^{-1} across the water column. At offshore station F19 respiration rates remained low ($\leq$0.10 μMO_2hr^{-1}) for the entire semiannual period.

5.2.2 Carbon-Specific Respiration

Carbon-specific respiration accounts for the effect of variations in the size of the particulate organic carbon (POC) pool has on respiration. Differences in carbon-specific respiration result from variations in the quality of the available particulate organic material or from environmental conditions such as temperature. Particulate organic material that is more easily degraded (more labile) will result in higher carbon-specific respiration. In general, newly produced organic material is the most labile. Water temperature is the main physical characteristic that controls the rate of microbial oxidation of organic material – the lower the temperature the lower the rate of oxidation. When stratified conditions exist, the productive, warmer surface and/or mid-depth waters usually exhibit higher carbon-specific respiration rates and bottom waters have lower carbon-specific respiration rates due to both lower water temperature and lower substrate quality due to the degradation of particulate organic material during sinking.

POC concentrations were low ($\leq$20 μM) in early February (**Figures** 5-11 and 5-12). Concentrations increased by late February concomitant with increasing productivity and phytoplankton abundance. Seasonal maximum POC concentrations (65-71 μM) were measured at station F23 during the late February survey in association with the nearshore coastal bloom. Nearfield POC concentrations continued to increase at station N04 from February to April when peak concentrations were observed at mid-depth (52 μM). POC concentrations were more variable at station N18 ranging from 30 to 50 μM over the water column from late February to late April with a maximum of 52 μM in the mid-depth waters in late April. There was a sharp decrease in POC at station F23 from February to April that reflected the predominant inshore to offshore differences between the coastal diatom bloom in February and the more offshore bloom of Phaeocystis in March/April. This was also evident at the offshore station F19 where POC concentrations peaked in April (~40 μM). By June POC concentrations in the nearfield and station F19 had decreased to <40, while there was an increase in the harbor (>60 μM in surface waters).

The carbon-specific respiration rates were low ($\leq$0.005 $\mu MO_2\mu MC^{-1}hr^{-1}$) in the nearfield from early February to May (**Figure** 5-13). In May and June, rates in the nearfield surface waters increased slightly, but were low (0.005 to 0.010 $\mu MO_2\mu MC^{-1}hr^{-1}$). Carbon specific respiration rates were low ($\leq$0.005 $\mu MO_2\mu MC^{-1}hr^{-1}$) from February to June at Boston Harbor station F23 (**Figure** 5-14). At station F19, carbon specific rates were at a maximum in early February (0.006 to 0.008 $\mu MO_2\mu MC^{-1}hr^{-1}$) in the surface and mid-depth waters, and decreased to $\leq$0.005 $\mu MO_2\mu MC^{-1}hr^{-1}$ from late February through June. Respiration rates were relatively low during the first half of 2003 and did not increase to the same extent as POC concentrations during the blooms when the availability of more labile POC might be expected. Carbon-specific respiration rates were low during the winter/spring of 2003 suggesting that there were limited supplies of labile POC available. However, these low rates were likely due to the inhibition of biological respiration at the unusually low ambient water temperatures rather than a lack of available labile POC.

5.3 Plankton Results

Plankton samples were collected on each of the seven surveys conducted during this reporting period. Phytoplankton and zooplankton samples were collected at two stations during each nearfield survey (N04 and N18) and at 13 farfield and the two nearfield stations (total = 15) during the farfield surveys. Two additional stations were sampled for zooplankton in Cape Cod Bay (F32 and F33) during the first three farfield surveys (WF031, WF032, and WF034). Phytoplankton samples included both whole-water and 20 µm-mesh screened samples, from the surface and subsurface chlorophyll maximum depths. Zooplankton samples were collected by vertical/oblique tows with 102 µm-mesh nets. Methods of sample collection and analyses are detailed in Libby *et al*. (2002a).

In this section, the seasonal trends in plankton abundance and regional characteristics of the plankton assemblages are evaluated. Total abundance and relative abundances of major taxonomic groups are presented for each phytoplankton and zooplankton community. Tables submitted previously in quarterly data reports provide data on cell and animal densities and relative abundance for all dominant plankton species (>5% abundance): whole water phytoplankton, 20-µm screened phytoplankton, and zooplankton.

5.3.1 Phytoplankton

5.3.1.1 Seasonal Trends in Total Phytoplankton Abundance

Total phytoplankton abundances in nearfield whole water samples (surface and mid-depth) were variable from February through June (**Table** 5-1; **Figures** 5-15 and 5-16). Total abundances were relatively low and varied between 0.19 –1.04 x 10^6 cells L^{-1} in February and March (WF031, WF032, and WN033). Abundances increased in April (WF034 & WN035) to levels of 1-2 x 10^6 cells L^{-1} during a bloom of *Phaeocystis pouchetii*, except for a single high value of 7.96 x 10^6 cells L^{-1} in the mid-depth sample at station N04 during survey WN035 (**Figure** 5-16). The *Phaeocystis* bloom was over by mid-May (WN036), and total abundances dropped to 0.47-0.75 x 10^6 cells L^{-1}. By mid-June, total phytoplankton abundance increased to levels of 1.08-2.2 x 10^6 cells L^{-1}.

Total phytoplankton abundance in farfield whole water samples (surface and mid-depth) showed similar low abundances in early February (0.14-1.23 x 10^6 cells L^{-1}). By late February/early March, abundances had increased slightly to levels of 0.23-1.48 x 10^6 cells L^{-1} with much of the increase due to the centric diatoms (**Table** 5-1; **Figures** 5-17 and 5-18). The highest abundances during WF031 were in Cape Cod Bay. During WF032 abundances were more uniformly high in Boston Harbor, Cape Cod Bay and the coastal domain, with somewhat lower abundances at the nearfield, offshore and boundary locations (**Figure** 5-18). By early April during the *Phaeocystis* bloom, farfield abundances were 0.52-10.75 x 10^6 cells L^{-1} (**Figure** 5-19) with the highest abundances measured off of Cape Ann at stations F26 and F27. By June phytoplankton abundances had declined to levels of 0.52-3.87 x 10^6 cells L^{-1}, with both high and low abundance levels scattered throughout most regions of the farfield (**Figure** 5-20).

Total abundances of dinoflagellates, silicoflagellates and protozoans in 20 µm-mesh-screened water samples were considerably lower than those recorded for total phytoplankton in whole-water samples, due to the screening technique which selects for larger, albeit rarer cells. Dinoflagellates and silicoflagellates in nearfield and farfield screened phytoplankton samples were <1.6 x 10^3 cells L^{-1} from February through May, increasing to maximum levels of 2.147-3.628 x 10^3 cells L^{-1} in June (**Table** 5-2).

Table 5-1. Nearfield and farfield averages and ranges of abundance (10^6 cells L^{-1}) of whole-water phytoplankton

Survey	Dates (2003)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF031	2/5-8	0.41	0.19-1.04	0.38	0.14-1.23
WF032	2/26, 3/1-4	0.55	0.43-0.65	0.73	0.23-1.48
WN033	3/20	0.80	0.69-0.89	–	–
WF034	4/1-3, 4/7	1.46	1.12-1.87	1.69	0.54-10.75
WN035	4/23	2.98	1.09-7.96	–	–
WN036	5/15	0.63	0.47 -0.75	–	–
WF037	6/18-21	1.60	1.08-2.20	1.84	0.52 -3.87

Table 5-2. Nearfield and farfield average and ranges of abundance (cells L^{-1}) for >20 μm-screened dinoflagellates

Survey	Dates (2003)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF031	2/5-8	243	169-340	271	78-752
WF032	2/26, 3/1-4	320	151-489	481	189-1076
WN033	3/20	356	300-425	–	–
WF034	4/1-3, 4/7	535	318-855	651	108-1570
WN035	4/23	316	184-458	–	–
WN036	5/15	347	264-416	–	–
WF037	6/18-21	1349	365-3628	680	164-2147

5.3.1.2 Nearfield Phytoplankton Community Structure

Whole-Water Phytoplankton – In early February (WF031) nearfield whole-water phytoplankton assemblages from both depths were dominated by unidentified microflagellates <10 μm in diameter and the chain-forming centric diatom *Stephanopyxis turris.* By late February-early March (WF032) dominant taxa were, again, microflagellates and *S. turris*, with the beginnings of the spring bloom of *Phaeocystis pouchetii* (up to 37%) (marked as "Other" in **Figure** 5-18). In late March (WN033), abundant microflagellates and *S. turris* shared dominance with the centric diatom *Thalassiosira nordenskioldii* (up to 9%) and *Phaeocystis* (14-21%). In early April (WF034), dominants were microflagellates (26-43%), *Phaeocystis* (24-63%), with lesser contributions by cryptomonads, *S. turris*, *T. nordenskioldii*, and the dinoflagellate *Heterocapsa rotundata*. By late April (WN035), dominants were microflagellates (12-61%) and *Phaeocystis* (12-83%), with lesser contributions by cryptomonads and *H. rotundata*. By mid-May (WN036), the *Phaeocystis* bloom was nearly over (only up to 7% at one station), with overwhelming dominance by microflagellates (70-85%), and lesser contributions by cryptomonads and *H. rotundata*. In June (WF037), microflagellates <10 μm in diameter were dominant, with lesser contributions by microflagellates >10 μm in diameter, cryptomonads, a dinoflagellate of the genus *Gymnodinium*, diatoms of the genus *Thalassiosira,* and members of the *Pseudonitzschia delicatissima* complex (up to 6%).

Screened Phytoplankton - In early February (WF031), nearfield screened samples were dominated by the silicoflagellate *Distephanus speculum* (27-57%), tintinnids (9-43%), and thecate dinoflagellates such as *Ceratium fusus*, *C. lineatum*, *Prorocentrum micans*, unidentified thecate dinoflagellates and athecate dinoflagellates. From late February to early April (WF032, WN033 and WF034) tintinnids continued to be dominant, with lesser contributions by aloricate ciliates, *Distephanus speculum*, *Mesodinium rubrum* and various dinoflagellates such as *Ceratium lineatum*, *C. tripos*, *Gonyaulax* sp. and *Protoperidinium* spp., *P. micans* and unidentified thecate and athecate dinoflagellates.

By late April (WN035), while tintinnids, aloricate ciliates, and *Distephanus speculum* continued to make up a majority of the taxa, there was an increase in the dominance of dinoflagellates such as *Ceratium longipes*, *C. tripos*, *Prorocentrum minimum*, *Protoperidinium* sp., and unidentified thecate and athecate dinoflagellates. This continued to be the case in May as the various dinoflagellates became a larger percentage of the screened phytoplankton community. By June (WF037), the assemblage was dominated by dinoflagellates such as *Ceratium fusus*, *C. longipes* (up to 78%), *C. tripos*, *Dinophysis acuminata*, *D. norvegica*, *P. minimum*, *Protoperidinium depressum* (up to 6%), and unidentified thecate and athecate dinoflagellates. There were minor contributions from non-dinoflagellate taxa such as *Distephanus speculum* and aloricate ciliates.

5.3.1.3 Regional Phytoplankton Assemblages

Whole-Water Phytoplankton - Whole-water phytoplankton assemblages at farfield stations were generally similar to those in the nearfield during the same time periods, in terms of composition, abundance, and the major *Phaeocystis* bloom in April.

During early February (WF031), most farfield station assemblages were dominated at both depths by unidentified microflagellates <10 µm in diameter (25-88% of cells counted), cryptomonads, and centric diatoms such as *Eucampia zodiacus*, *Guinardia delicatula*, *Skeletonema costatum*, *Stephanopyxis turris*, *Thalassiosira* sp., and *Thalassionema nitzschoides*. In Cape Cod Bay, centric diatoms such as *G. delicatula* (33-50%) and *E. zodiacus* (6-10%) were co-dominants with microflagellates (**Figure** 5-17). In late February-early March (WF032) farfield assemblages remained similar to the nearfield and early February with unidentified microflagellates, cryptomonads, and a variety of centric diatoms present (**Figure** 5-18). Additionally, the spring bloom of *Phaeocystis pouchetii* was also beginning at some of the harbor, coastal, and nearfield stations.

In early April (WF034), most farfield stations had substantial levels of *Phaeocystis* (7-95%), with the highest abundance and dominance at the northern boundary stations F26 and F27 (**Figure** 5-19). The remainder of the assemblage was similar to that of the nearfield, including major contributions by unidentified microflagellates and much lesser contributions by cryptomonads, centric diatoms such as *G. delicatula*, *S. turris*, and *T. nordenskioldii*, and the dinoflagellate *Heterocapsa rotundata*.

By June (WF037), assemblages at both depths at most farfield stations were dominated by the same microflagellates (40-91%) and cryptomonads (up to 41%), that dominated the nearfield (**Figure** 5-20). Subdominant taxa included unidentified species of the diatom genus *Thalassiosira* and lower numbers of the diatoms *Chaetoceros debilis*, *Chaetoceros* spp., *S. costatum*, *T. nitzschoides*, and an unidentified centric diatom, and the dinoflagellates *H. rotundata* and *Gymnodinium* spp. Potentially-toxic diatoms of the *Pseudonitzschia delicatissima* complex comprised 8-14% of cells at 3 stations in the northeastern portion of Massachusetts Bay (F22, F26, and F27).

Screened Phytoplankton - Screened-water dinoflagellate assemblages at farfield stations were similar to those in the nearfield during the same time periods.

In February and early March (WF031 and WF032), 20 µm-screened phytoplankton samples from the farfield were dominated by tintinnids, aloricate ciliates, and the silicoflagellates *Distephanus speculum* and *Dictyocha fibula*. There were also varying contributions by the dinoflagellates *Ceratium fusus, C. lineatum, C. tripos, Prorocentrum micans, Dinophysis acuminata*, *Protoperidinium depressum*, unidentified species of the genera *Gyrodinium, Protoperidinium*, and *Gonyaulax*, and other unidentified thecate and athecate dinoflagellates. The 20 µm-screened phytoplankton assemblage was similar in April (WF034) with the addition of the photosynthetic ciliate *Mesodinium rubrum* (up to 10%) as one of the dominant species. By June, the farfield samples, like the nearfield samples, contained mainly dinoflagellates. Abundant dinoflagellates included various *Ceratium, Dinophysis,* and *Prorocentrum* species*, Protoperidinium depressum*, and other unidentified thecate and athecate dinoflagellates.

5.3.1.4 Nuisance Algae

The only bloom of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during February – June, 2003 was the *Phaeocystis pouchetii* bloom. This bloom was first recorded in the two samples from station N04 in early February at very low levels (0.0025-0.0035 x 10^6 cells L^{-1}). By late February-early March, *Phaeocystis* was observed at seven stations in the harbor, coastal and nearfield areas at a higher abundance (0.05-0.19 x 10^6 cells L^{-1}) and continued to be observed at this level in the nearfield in late March (**Figures** 5-15 and 5-16). In early April, the *Phaeocystis* bloom was observed at all of the plankton stations in Massachusetts and Cape Cod Bays at levels of 0.04-10.2 x 10^6 cells L^{-1} (**Figure** 5-19). There was a clear pattern in the distribution of *Phaeocystis* with the lowest abundance in Cape Cod Bay (0.04-0.15 x 10^6 cells L^{-1}), low to moderate abundances throughout most of Massachusetts Bay (0.15-1.2 x 10^6 cells L^{-1}), and the highest levels at stations F26 and F27 off of Cape Ann (1.5 to 10.2 x 10^6 cells L^{-1}). By late April, there was a small decrease in *Phaeocystis* abundance at station N18, but a large increase in the levels at station N04 with a maximum of 7.0 x 10^6 cells L^{-1} for the mid-depth sample. The bloom was over by mid-May, with *Phaeocystis* present at only a single station at 0.048 x 10^6 cells L^{-1} (mid depth station N04).

With an overall range of cell concentrations of 0.038 to 10.22 x 10^6 cells L^{-1} at stations where *Phaeocystis pouchetii* was present, the 2003 bloom gave much higher maximum concentrations than during the 2001 and 2002 blooms (maxima of 3.13 x 10^6 cells L^{-1} and 1.59 x 10^6 cells L^{-1}, respectively). However, the 2003 bloom did not reach the high levels observed during the 2000 bloom (0.233-12.258 x 10^6 cells L^{-1}). The high levels in 2003 were only observed at the northern boundary stations, while in 2000 *Phaeocystis* was present at abundances of >5 x 10^6 cells L^{-1} at all but the Cape Cod Bay stations. The continued occurrence of *Phaeocystis* blooms in consecutive years (2000 to 2003) is a change from the pattern that had been observed during earlier baseline monitoring of these blooms occurring in single years in cycles of about 3 years – 1992, 1994, 1997, and 2000 (Libby *et al.,* 2001).

The toxic dinoflagellate *Alexandrium tamarense* or cells of *Alexandrium* sp. that were not clearly distinguishable as *A. tamarense*, were only sporadically recorded in trace levels. *Alexandrium tamarense* was recorded for a single whole-water sample (station F22) during WF032, three samples (at stations F30 and F31) in WN033, both samples at station F25 in WF034, and at a station N16 during WF037. These occurrences were at extremely low abundance levels (0.2-1.5 cells L^{-1}). There were additional occurrences of "*Alexandrium* spp." in screened samples that were not positively identified as *A. tamarense*. These included abundances of 2.1-3.8 cells L^{-1} from two samples in late February-early March (WF032), 4.10-6.65 cells L^{-1} for three samples in early April (WF034), 5.5 cells L^{-1} for a single sample in May (WN036), and 3.0-12.5 cells L^{-1} in five samples in June (WF037). There were four occurrences in screened-water samples of cells identified as *A. tamarense* in June at stations F13, F24, F26 and F27 (1.9-15.4 cells L^{-1}). Thus, abundance of *Alexandrium tamarense* plus *Alexandrium* spp. in screened samples in 2003 was typically low, as in most previous years. Levels since 1994 have not approached those of 1993.

Potentially-toxic diatoms designated *Pseudo-nitzschia pungens* (which could also include cells of *Pseudo-nitzschia multiseries*) or members of the *Pseudo-nitzschia delicatissima* complex, including *P. delicatissima* and *P. pseudodelicatissima*, which cannot be reliably distinguished with light microscopy, were recorded for many whole-water phytoplankton samples between February and June, 2002. However, these cells comprised >5% of cells counted in a given sample only during survey WF037 in June when the abundance for the *Pseudo-nitzschia delicatissima* complex ranged from 70,000 to 143,000 cells L^{-1} in subsurface chlorophyll maximum layer samples at stations F22, F26, F27, and N04.

Although *Phaeocystis, Alexandrium tamarense and Pseudo-nitzshia* spp. were all observed in February to June 2003, none of their abundances exceeded the caution threshold values.

5.3.2 Zooplankton

5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Total zooplankton abundance at nearfield stations generally were low (< 11.5 x 10^3 animals m^{-3}) from February through March (**Table** 5-3; **Figure** 5-21). Values increased in April and May, to levels of 23.3-44.7 x 10^3 animals m^{-3}, and remained comparatively high (36.1-42.6 x 10^3 animals m^{-3}) in June.

Total zooplankton abundance at farfield stations in early February ranged widely from 3.1-32.6 x 10^3 animals m^{-3} (**Table** 5-3). Zooplankton abundance was maximal during WF031 at Boston Harbor station F23 and coastal station F24, with values more than double those of most other stations during the same survey (**Figure** 5-22a). The cause is unclear. In late February-early March, total abundance values were < 20 x 10^3 animals m^{-3} for all stations except station F26, which had 39.4 x 10^3 animals m^{-3} (**Figure** 5-22b). Again, the reason for this is unclear. By early April, total zooplankton abundance at farfield stations was variable at 5.5-43.9 x 10^3 animals m^{-3} (**Figure** 5-23a). Zooplankton abundance continued to increase through June to a wide range of 18.7-81.29 x 10^3 animals m^{-3} (**Figure** 5-23b). The spatial distribution was variable with all values >40 x 10^3 animals m^{-3} occurring at the nearfield and boundary stations in Massachusetts Bay, and in Boston Harbor. The cause of this spatial distribution in zooplankton abundance is unknown and it may be within the variability of the system.

Table 5-3. Nearfield and farfield average and ranges of abundance (10^3 animals m^{-3}) for zooplankton

Survey	Dates (2003)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF031	2/5-8	7.2	5.2-9.1	13.6	3.1-32.6
WF032	2/26, 3/1-4	6.0	4.1-8.8	13.0	5.5-39.4
WN033	3/20	9.9	8.3-11.5	–	–
WF034	4/1-3, 4/7	30.4	23.3-40.3	18.6	5.5 -43.9
WN035	4/23	26.8	26.5-27.2	–	–
WN036	5/15	37.5	30.3-44.7	–	–
WF037	6/18-21	38.5	36.1-42.6	39.1	18.7-81.2

In 1998, two additional stations in Cape Cod Bay were added to the monitoring program to better address spatial variability in winter. During survey WF031 in early February, abundances of total zooplankton for the four zooplankton stations (F01, F02, F32, and F33) in Cape Cod Bay ranged from 10.6-16.4 x 10^3 animals m^{-3} (**Figure** 5-22a). This was a variability of $\pm$ 23.7% of the mean (13.9 x 10^3 animals m^{-3}). Contributions of major taxa were remarkably similar, with 38-46% for copepod nauplii, 21-30% for *Oithona similis* copepodites, and < 5-10% for *Pseudocalanus* spp. copepodites. In late February-early March, abundance of total zooplankton at these four stations was similar ranging from 9.4-19.4 x 10^3 animals m^{-3} (**Figure** 5-22b), but there was an increase in variability ($\pm$ 43.9% of the mean of 13.5 x 10^3 animals m^{-3}). Contributions of major taxa were 55-59% for copepod nauplii, <5-24% for *Oithona similis* copepodites, and 7-14% for *Pseudocalanus* spp. copepodites. Thus, part of the increased variability of overall abundance, was due to variations in abundance of individual taxa, particularly *O. similis*.

In early April, abundances of total zooplankton for the four Cape Cod Bay zooplankton stations ranged from 13.0-43.9 x 10^3 animals m^{-3} (**Figure** 5-23a). This was variability of $\pm$ 71.4% of the mean (25.6 x 10^3 animals m^{-3}). Contributions of major taxa were 36-47% for copepod nauplii, <5-12% for *Oithona similis* copepodites, but 13-47% for *Pseudocalanus* spp. copepodites. Thus, much of the considerable variability in total zooplankton abundance in Cape Cod Bay during this survey was due to comparative variability of *Pseudocalanus* spp. copepodites. The only winter-early spring Cape Cod Bay sample for which *Calanus finmarchicus* copepodites comprised > 5% of the total assemblage was 9% at station F32 during Survey WF034.

5.3.2.2 Nearfield Zooplankton Community Structure

Nearfield zooplankton assemblages (**Figure** 5-21) in early February were dominated by copepod nauplii (51-58%), as well as copepodites of *Oithona similis* (15-31%) and *Pseudocalanus* spp. copepodites (up to 8%). In early March, similar patterns occurred with dominance by copepod nauplii (51-73%), *Oithona similis* copepodites (10-15%) and *Pseudocalanus* spp. copepodites (up to 13%). Additional subdominants included *Calanus finmarchicus* copepodites (up to 10%) and barnacle nauplii (up to 5%). A similar assortment was found in late March with nearfield dominance by copepod nauplii (30-65%), *Pseudocalanus* spp. copepodites (up to 12%), *Calanus finmarchicus* copepodites (up to 13%), and barnacle nauplii (< 5% at station N04, but 46% at station N18).

At nearfield stations in early April, zooplankton assemblages were dominated by copepod nauplii (50-72%) and copepodites of *Pseudocalanus* spp. (7-11%) and Calanus finmarchicus (8-11%). Additional contributions were from *Oithona similis* copepodites (up to 7%), barnacle nauplii (up to 15%), and the appendicularian *Oikopleura dioica* (up to 13%). A similar community was observed in late April as dominance of copepod nauplii (48-55%) was shared with copepodites of *Calanus finmarchicus* (18% at each station), *Pseudocalanus spp*. (9-12%), and *Oithona similis* (up to 6%). In May, nearfield zooplankton assemblages continued to be dominated by the combination of copepod nauplii (39-50%), copepodites of *Oithona similis* (up to 6%), *Pseudocalanus* spp. (8-14%) and *Calanus finmarchicus* (8-25%), and *Oikopleura dioica* (up to 9%). At nearfield stations during June, zooplankton assemblages were dominated by copepod nauplii (36-41%), copepodites of *Oithona similis* (8-18%), *Temora longicornis* (8-11%), *Calanus finmarchicus* (up to 9%), and the marine cladoceran *Evadne nordmani* (up to 12%) and bivalve veligers (up to 19%).

5.3.2.3 Regional Zooplankton Assemblages

Zooplankton assemblages at farfield stations during early February were generally similar to those in the nearfield (**Figure** 5-22a). Abundant taxa throughout the area included copepod nauplii (19-71%) and *Oithona similis* copepodites (6-30% for all stations except F30 and F31 in Boston Harbor). Lesser contributions at certain stations came from copepodites of *Pseudocalanus* spp. (up to 11%) and *Centropages* spp. copepodites (up to 9%), *Centropages typicus* females (up to 6%), and Microsetella norvegica (up to 8%). Barnacle nauplii comprised only up to 7% of total counts outside of Boston Harbor, but 35-64% at stations in Boston Harbor (stations F23, F30 & F31) and immediately outside of the harbor (station F25).

In late February-early March (**Figure** 5-22b), assemblages contained copepod nauplii (23-80%), *Oithona similis* copepodites (up to 24%), *Calanus finmarchicus* copepodites (up to 98%) and *Pseudocalanus* spp. copepodites (up to 23%). *Acartia hudsonica* females comprised 6% of total abundance at station F30 in Boston Harbor. Barnacle nauplii comprised 19-56% of total abundance at 9 or 14 farfield stations (where they accounted for > 5% of total abundance).

In early April (**Figure** 5-23a), assemblages contained copepod nauplii (27-69%), *Oithona similis* copepodites (up to 12%), *Calanus finmarchicus* copepodites (up to 58%) and *Pseudocalanus* spp. copepodites (up to 47%). *Acartia* spp. copepodites comprised 15% of total abundance at station F30 in Boston Harbor. Barnacle nauplii comprised 9-45% of total abundance at 9 of 14 farfield stations (where they accounted for > 5% of total abundance). There were also sporadic occurrences of *Oikopleura dioica* (up to 7%) and polychaete larvae (6-11% at three stations, F23, F24 and F30).

During the June survey, farfield zooplankton assemblages (**Figure** 5-23b) contained copepod nauplii (6-45%), *Oithona similis* copepodites (up to 16%) and females (up to 5%), *Calanus finmarchicus* copepodites (up to 46%), *Pseudocalanus* spp. copepodites (up to 14%), and *Temora longicornis* copepodites (up to 24%) and males (up to 10%). *Acartia hudsonica* adults and *Acartia* spp. copepodites were abundant at stations F23 and F30 in Boston Harbor. Males were, respectively, 9% and 6% at station F23 and F30. Females were, respectively 12% and 9% at stations F23 and F30. Copepodites were, respectively, 24% and 22% at stations F23 and F30. In addition, *Acartia* spp. copepodites comprised 5% of total abundance at stations F24 and F25, just offshore from Boston Harbor. There were also sporadic occurrences of bivalve veligers (up to 24%), and the marine cladocerans *Evadne nordmani* (up to 9%) and *Podon polyphmeoides* (up to 7%).

Overall, zooplankton assemblages during the first half of 2003 were comprised of taxa typically recorded for the same time of year in previous years.

5.4 Summary of Biological Results

- Potential areal production in 2003 followed patterns typically observed in prior years with distinct winter-spring phytoplankton blooms observed at both nearfield stations
- Productivity at station N18 was elevated relative to station N04 during 4 of the 7 cruises between February and June in 2003
- The winter-spring bloom peaks in productivity at both nearfield sites in 2003 were generally lower than values previously calculated for potential production from 1995 to 2002 but similar to measured peak productivity in 1995, 1999 and 2001
- Potential productivity at station F23 was again characterized by a distinct winter bloom continuing the change in the seasonal productivity cycle first observed following effluent diversion offshore
- Elevated production values tended to be correlated with the occurrence of the highest chlorophyll *a* measurements
- Chlorophyll-specific potential production typically reached higher levels at station N18 compared with N04, although the seasonal maximum was recorded in mid-surface water at station N04
- Respiration rates were low and may have been inhibited by the unusually low ambient water temperatures present winter/spring 2003.
- Respiration rates tended to increase with increasing POC (and chlorophyll and phytoplankton biomass), but not appreciably.
- Carbon-specific respiration rates were low throughout the first half of 2003.
- Whole-water phytoplankton assemblages were dominated by unidentified microflagellates and several species of centric diatoms except during the spring *Phaeocystis* bloom. This is typical for the first half of the year in terms of taxonomic composition.
- A centric diatom bloom occurred in Massachusetts Bay in February-early March with the highest abundances of diatoms observed in Cape Cod Bay.
- A *Phaeocystis pouchetii* bloom occurred in spring 2003 that was more abundant than the blooms of this species during the same period in the previous two years (2001 and 2002). However, maximum levels were lower in 2003 than in 2000 and the elevated levels were not

as widespread in 2003 compared to 2000. The appearance of *Phaeocystis* blooms in four consecutive years is a departure from the 3-year cycle for these blooms observed during the baseline period (1992-2000).

- There were no other blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during February – June, 2003. While the dinoflagellate *Alexandrium tamarense* and diatoms of the genus *Pseudo-nitzschia pungens* and members of the *P. delicatissima* complex were recorded, they were generally present in low abundance. None of the nuisance algae caution thresholds were exceeded during this period.
- Total zooplankton abundance generally increased from February through June as typically observed. Zooplankton assemblages during the first half of 2003 were comprised of taxa recorded for the same time of year in previous years.
- High variability in zooplankton abundance was observed among stations within given surveys in Cape Cod Bay.

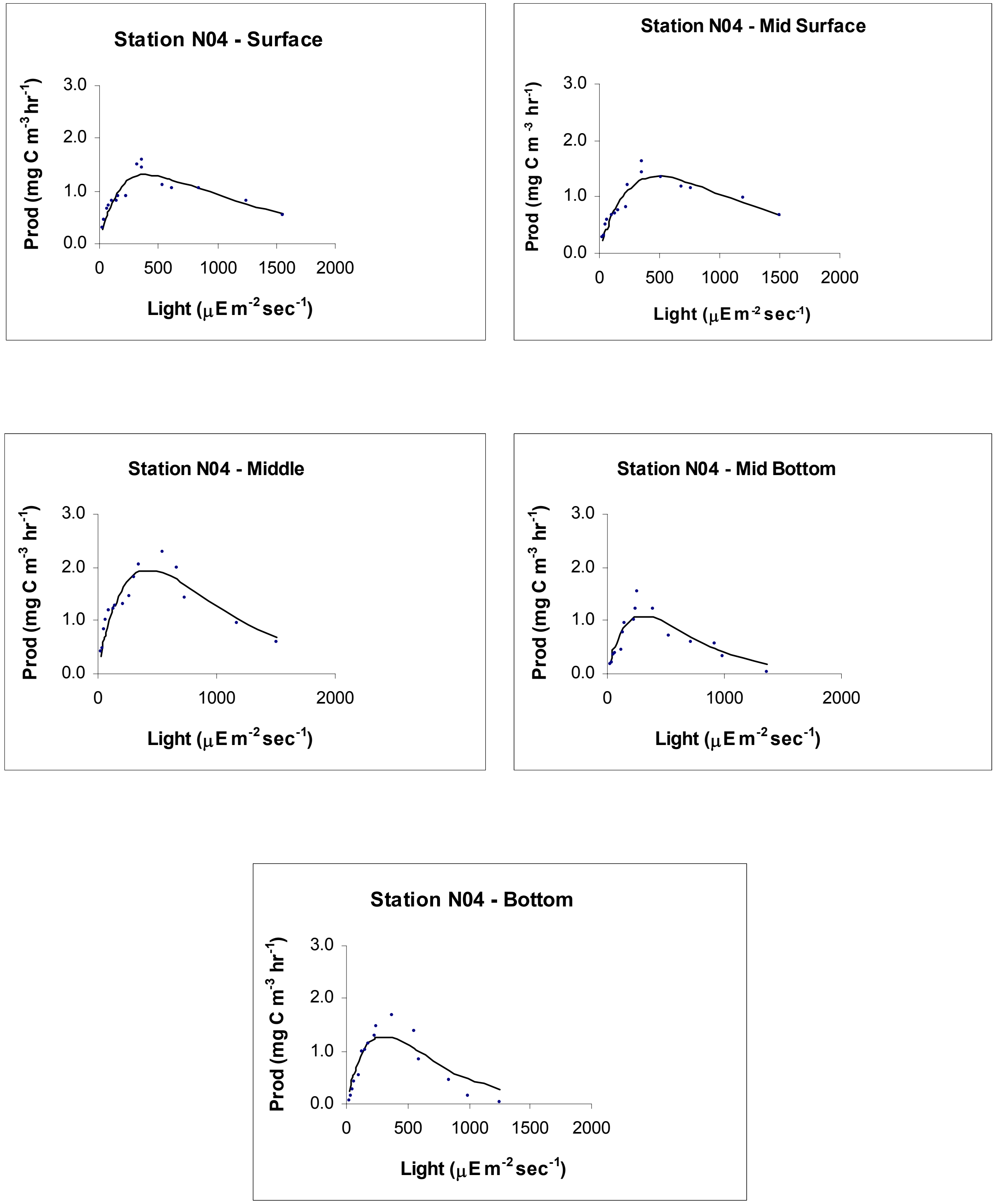


Figure 5-1. An example photosynthesis irradiance curve from station N04 collected February 2003

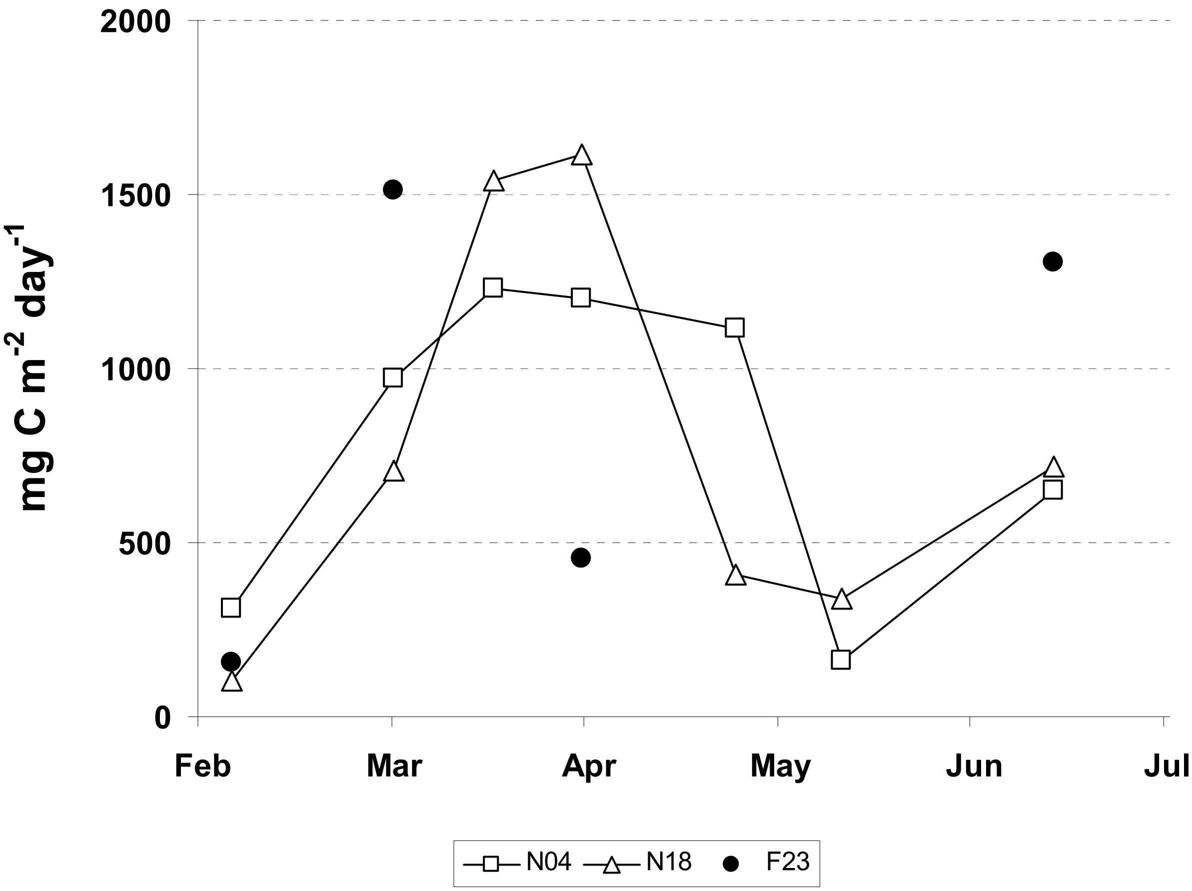


Figure 5-2. Time series of areal potential production (mg C m^{-2} d^{-1}) for stations N04, N18 and F23

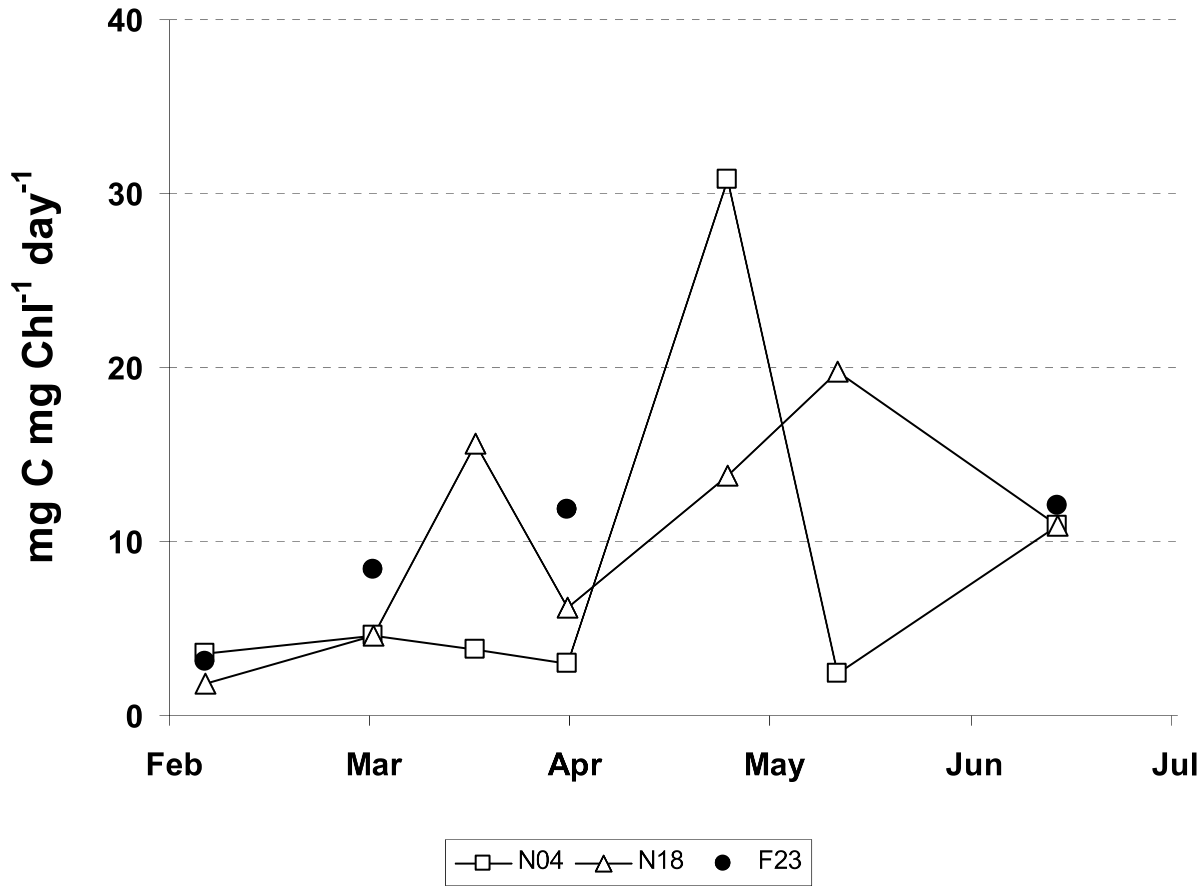


Figure 5-3. Time series of depth-averaged chlorophyll-specific potential production (mg C mg Chla^{-1} d^{-1}) for stations N04, N18 and F23

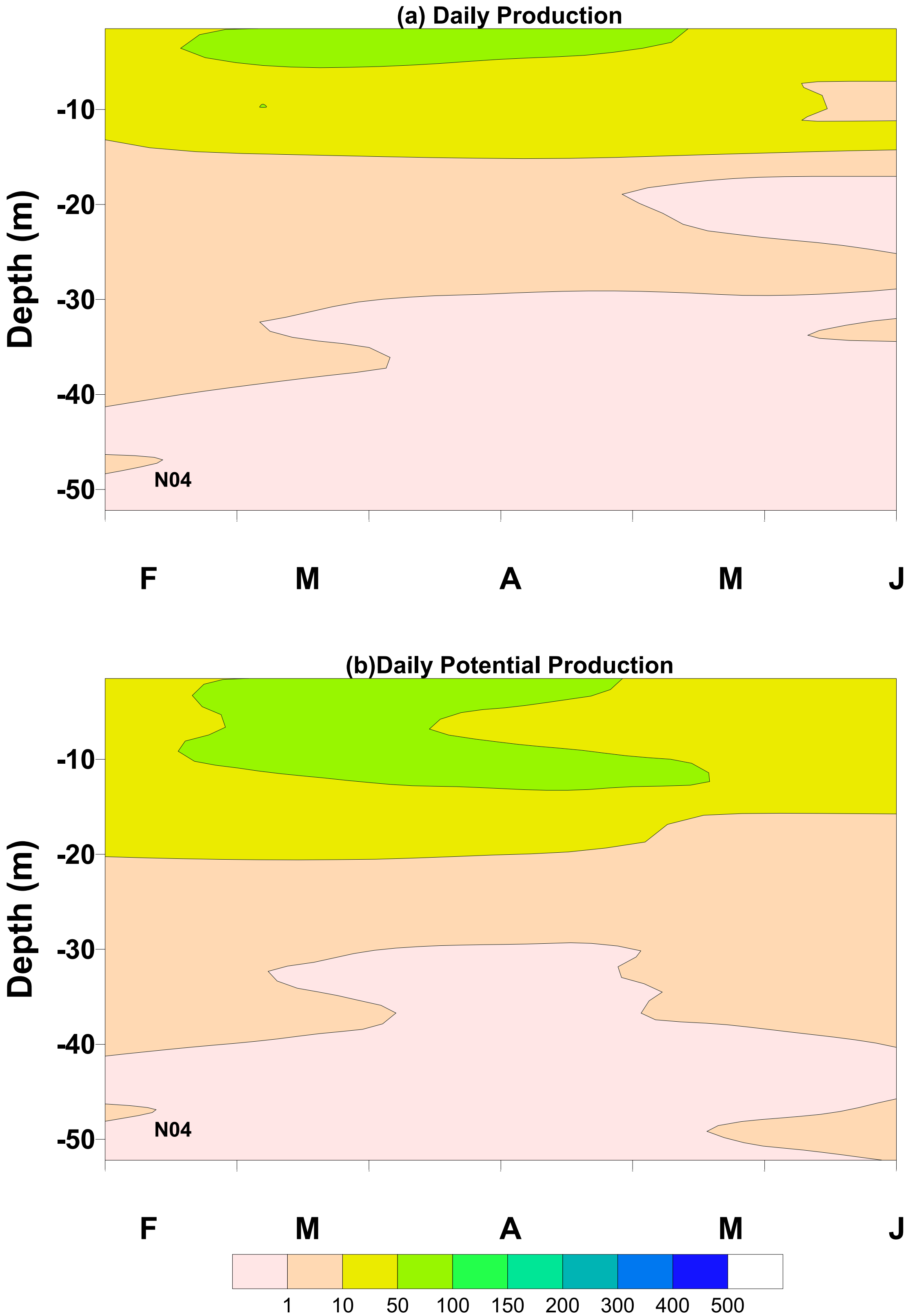


Figure 5-4. Time-series of contoured daily production and potential production ($mgCm^{-3}d^{-1}$) over depth at station N04

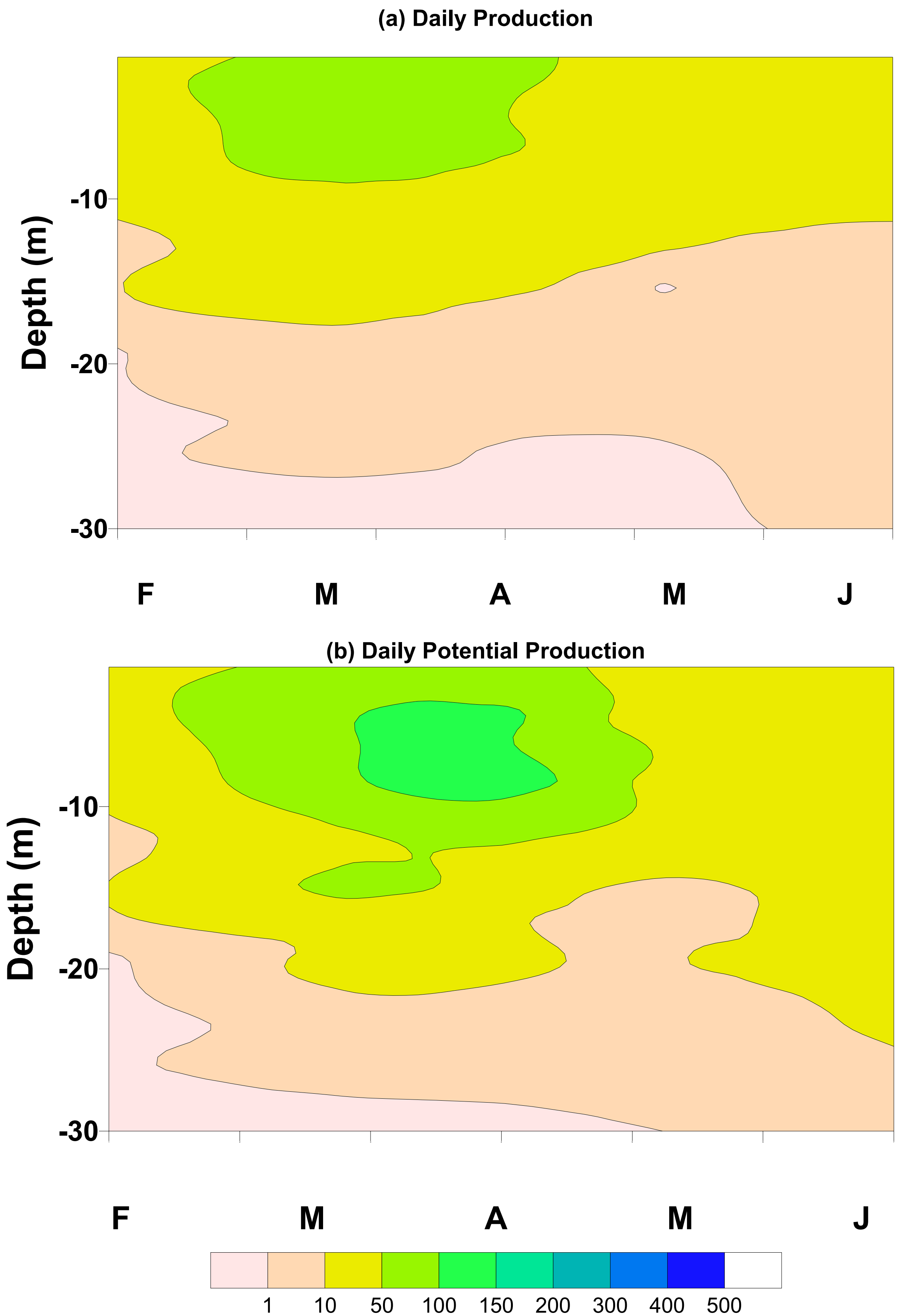


Figure 5-5. Time-series of contoured daily production and potential production ($mgCm^{-3}d^{-1}$) over depth at station N18

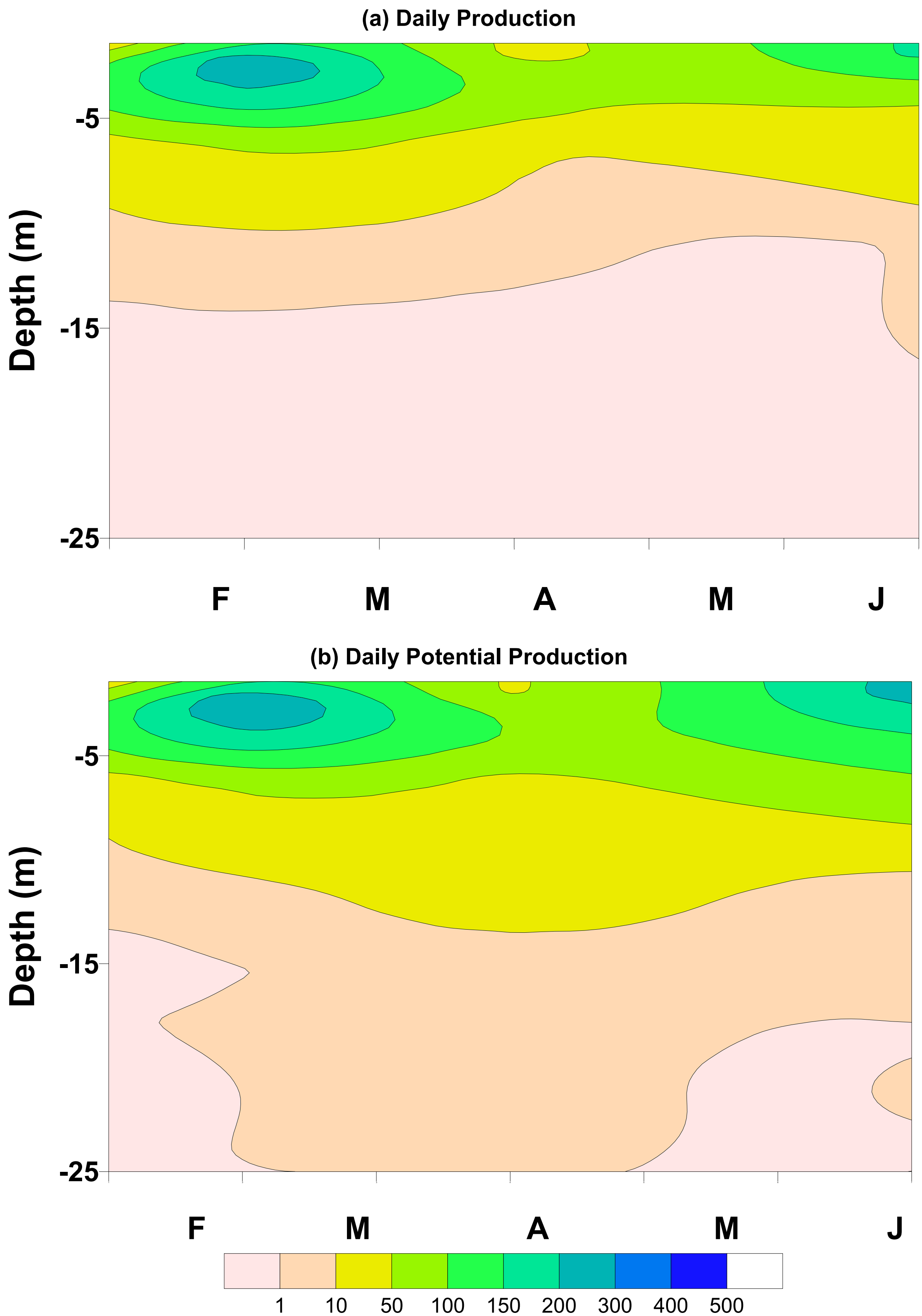


Figure 5-6. Time-series of contoured daily production and potential production ($mgCm^{-3}d^{-1}$) over depth at station F23

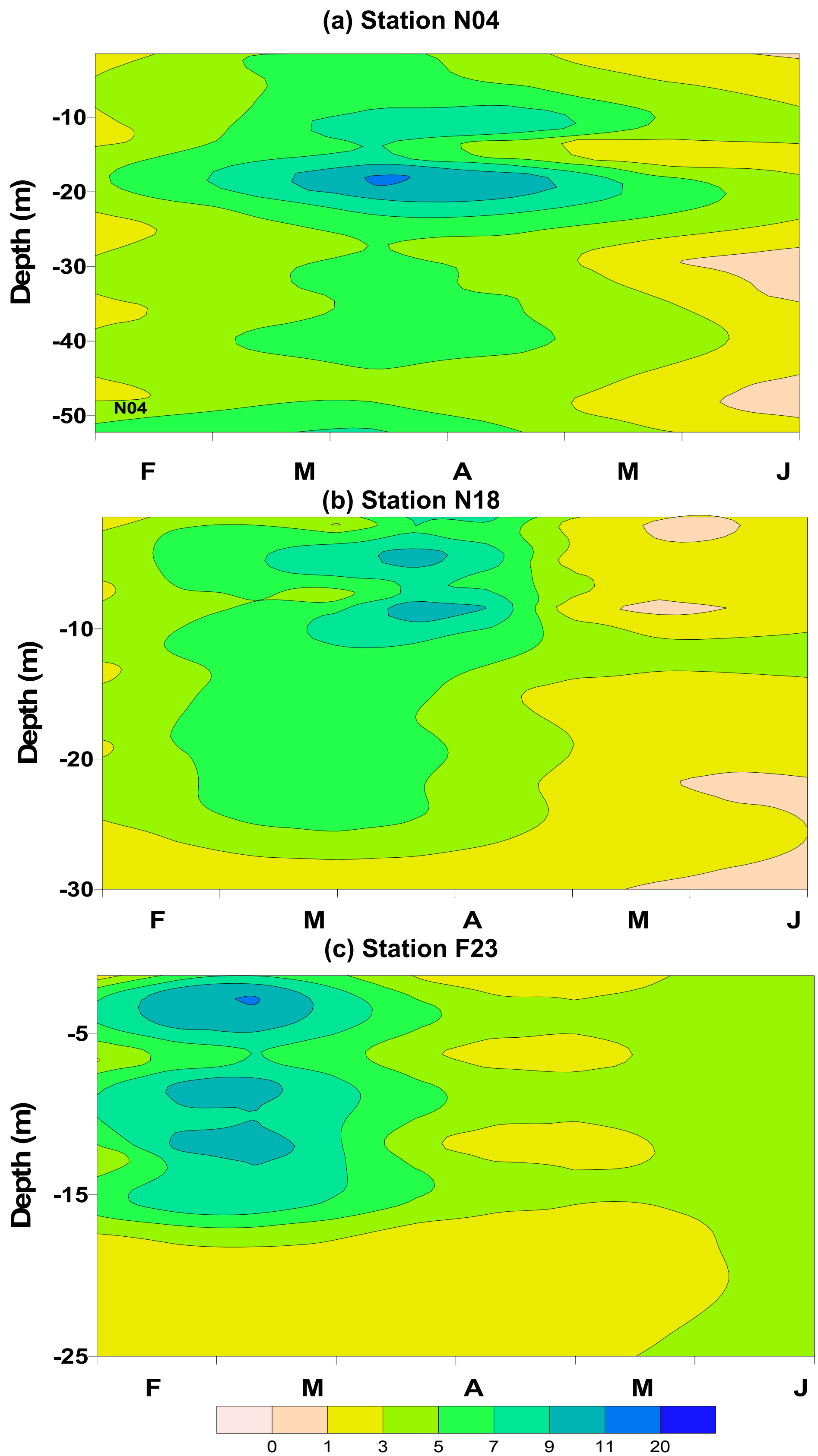


Figure 5-7. Time-series of contoured *in vitro* chlorophyll *a* concentration (μgL^{-1}) over depth at station N04, N18, and F23

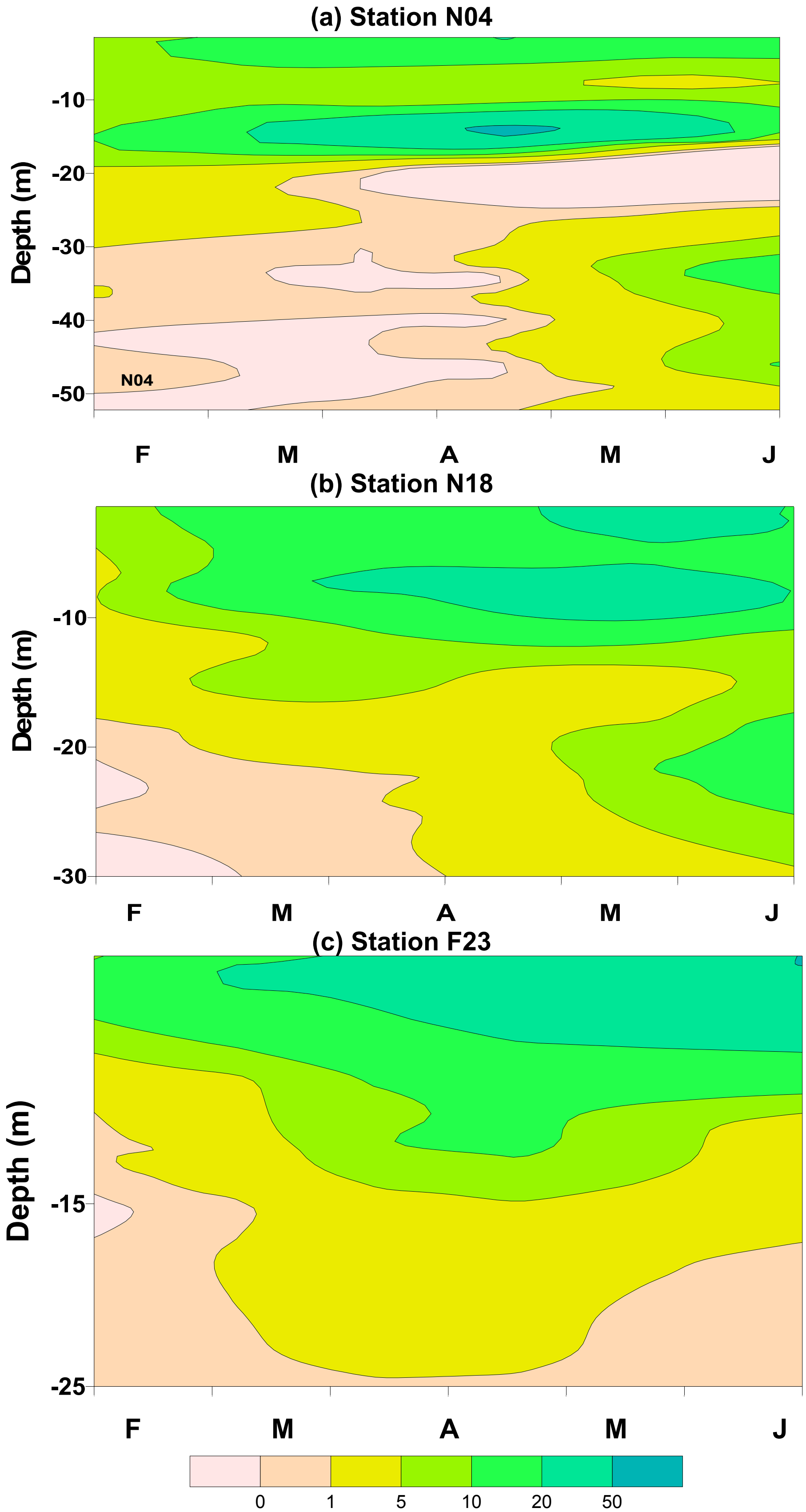
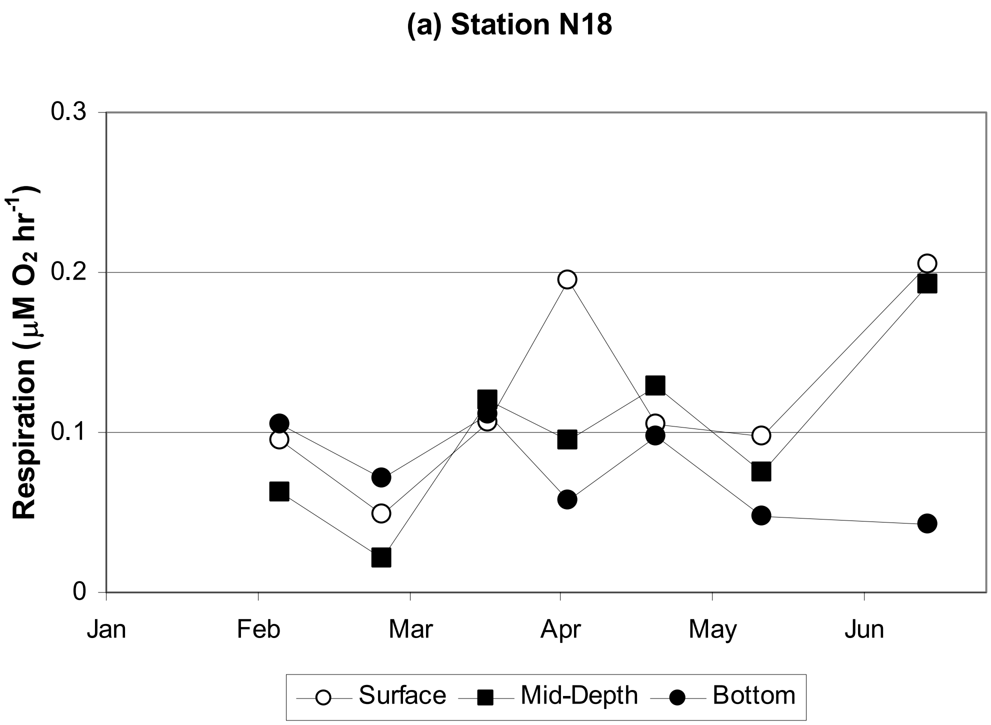


Figure 5-8. Time-series of contoured chlorophyll-specific potential production ($mgCmgChl a^{-1} d^{-1}$) over depth at station N04, N18, and F23



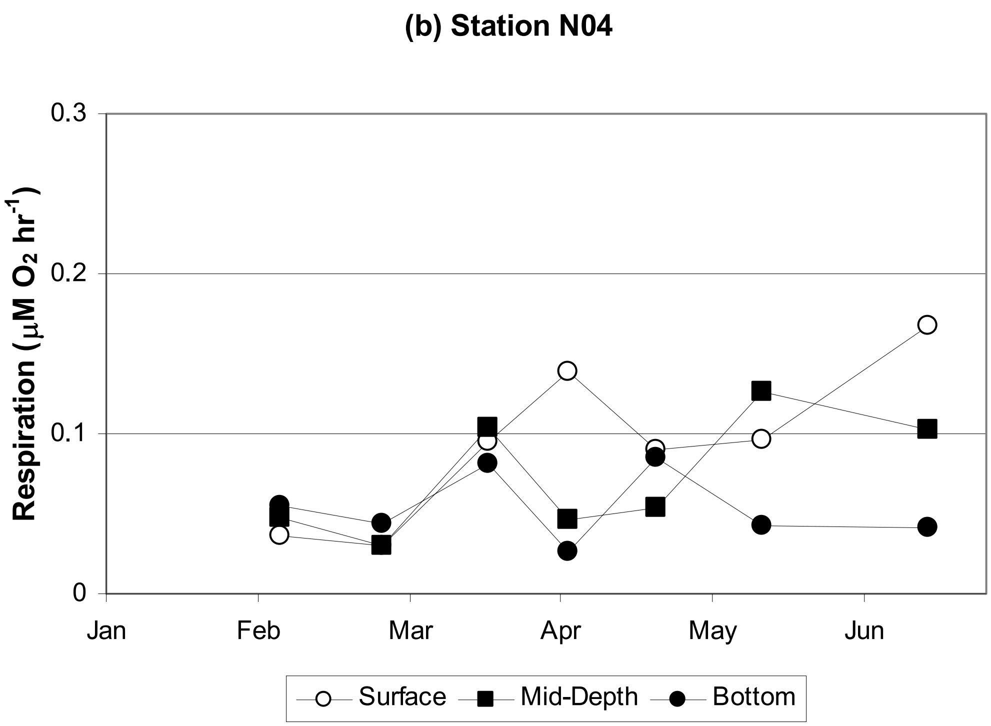
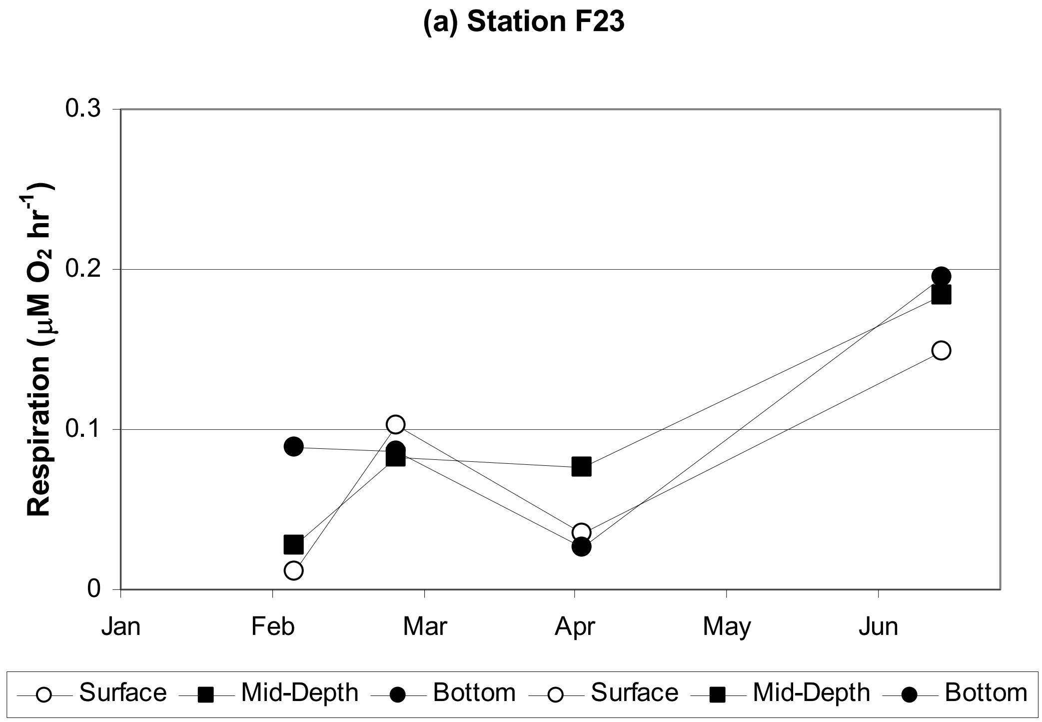


Figure 5-9. Time-series plots of respiration (μMO_2hr^{-1}) at stations N18 and N04



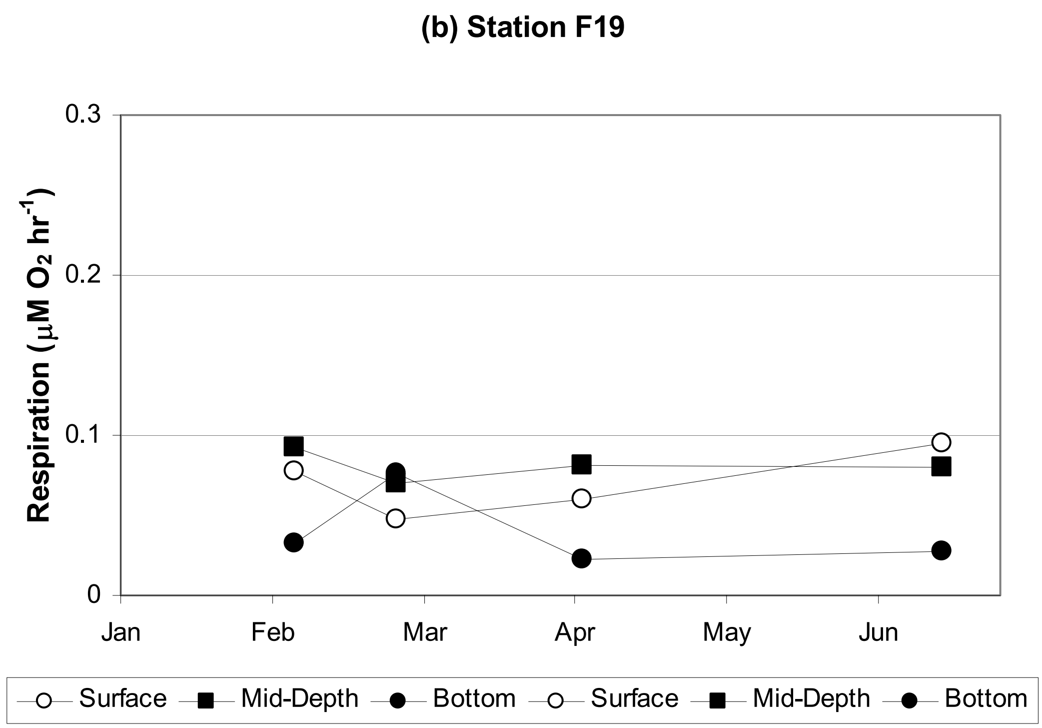


Figure 5-10. Time-series plots of respiration (μMO_2hr^{-1}) at stations F23 and F19

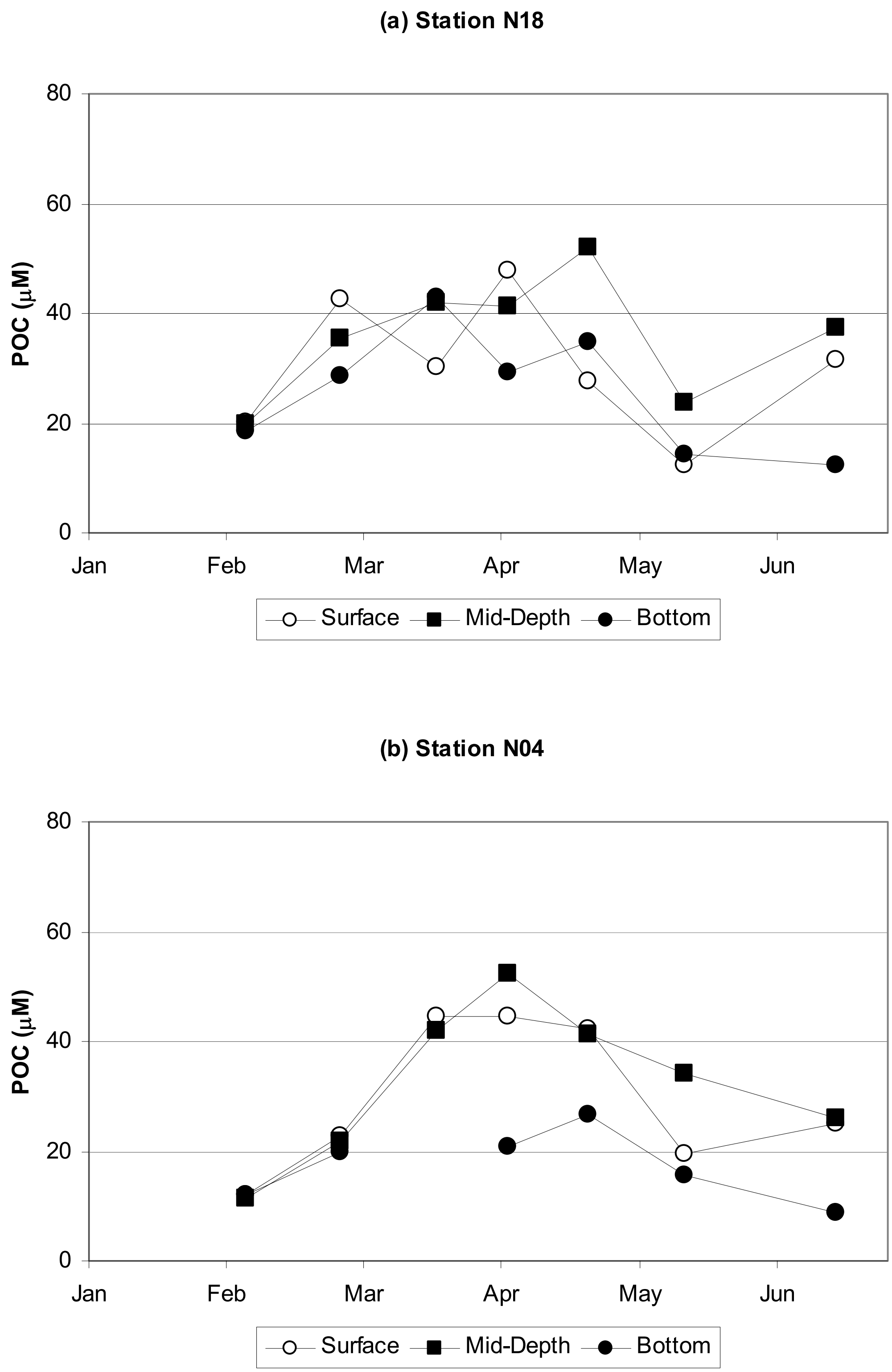
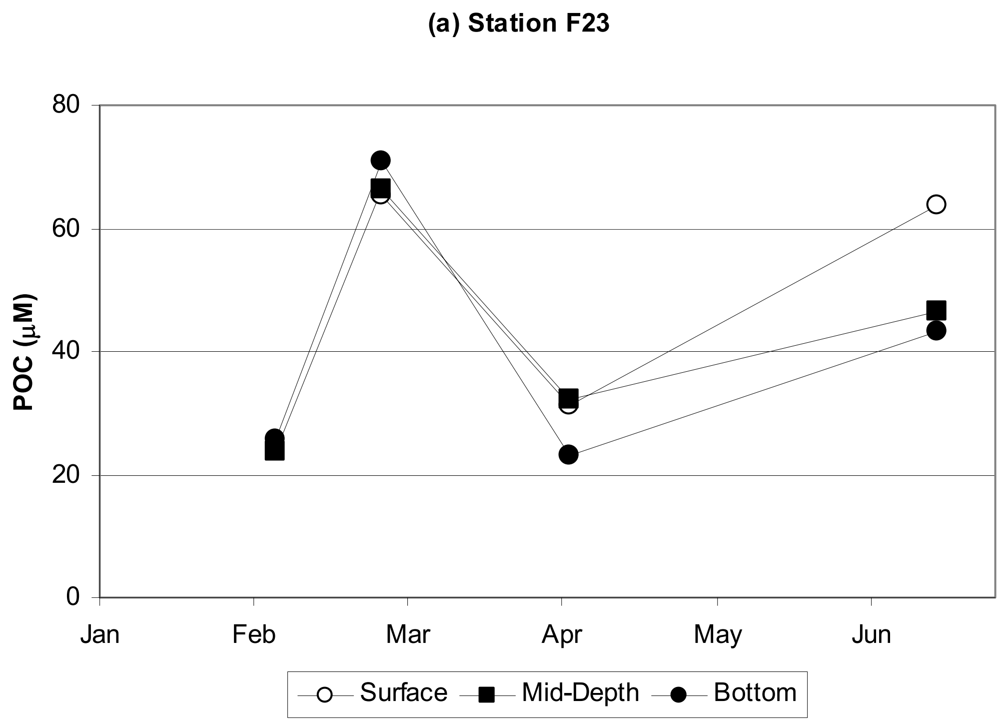


Figure 5-11. Time-series plots of POC (μM) at stations N18 and N04



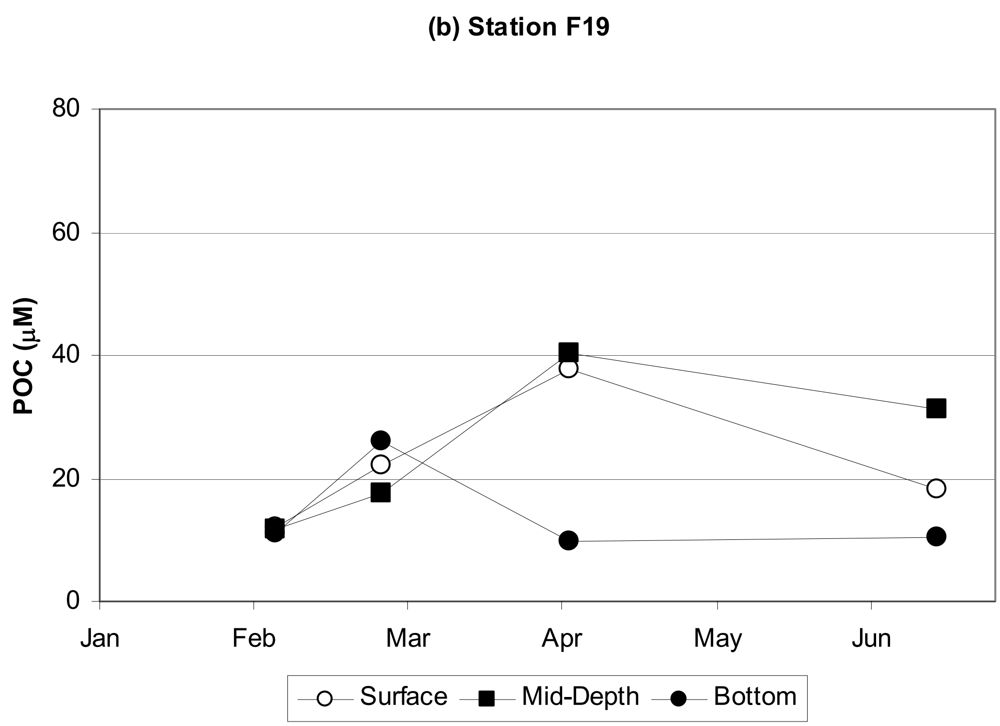


Figure 5-12. Time-series plots of POC (µM) at stations F23 and F19

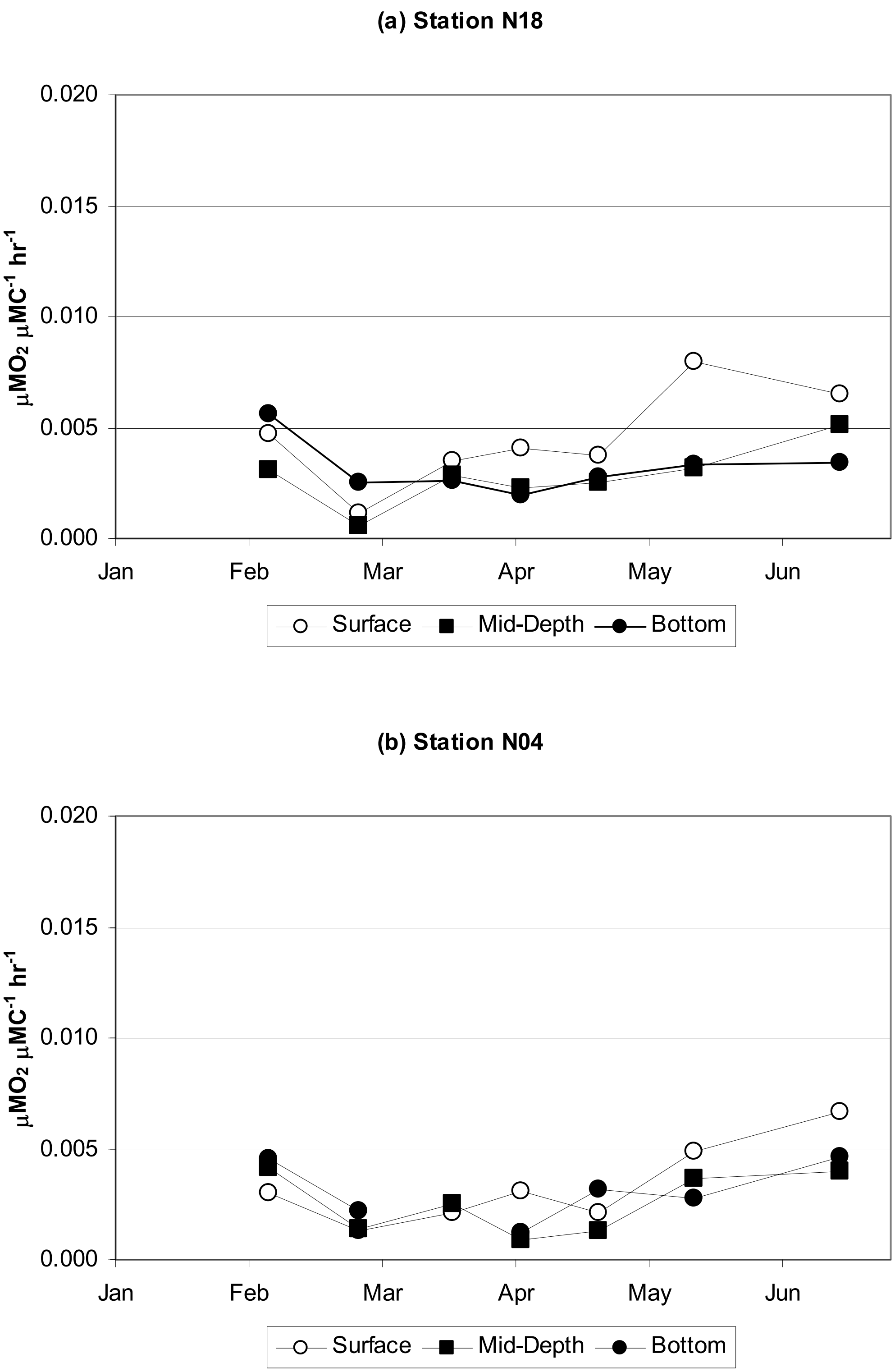
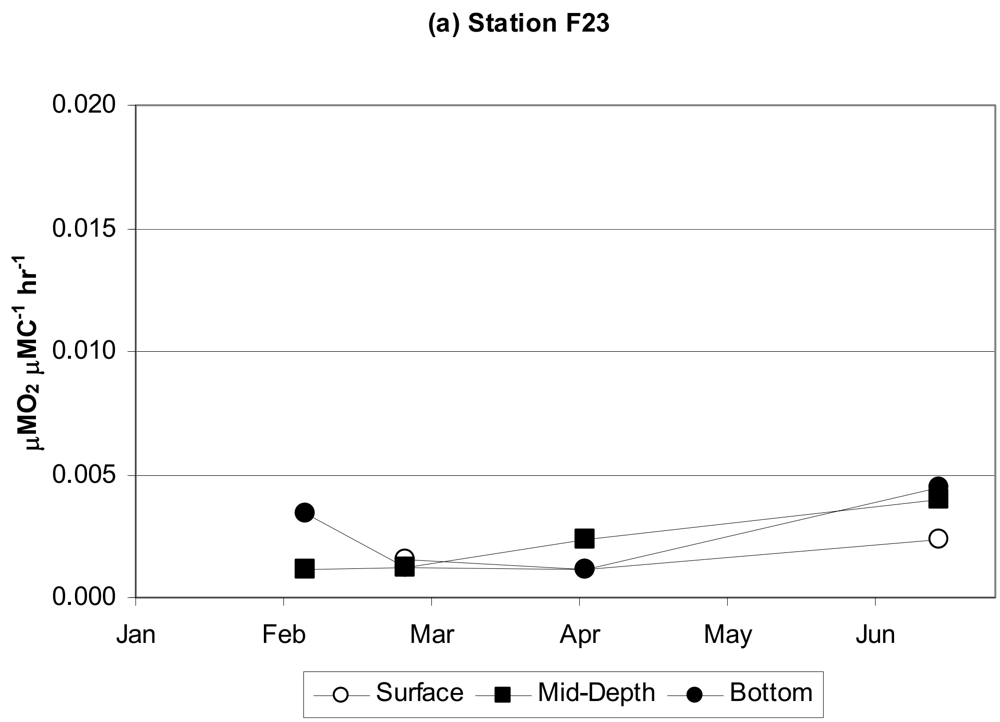


Figure 5-13. Time-series plots of carbon-specific respiration ($\mu MO_2 \mu MC^{-1} hr^{-1}$) at stations N18 and N04



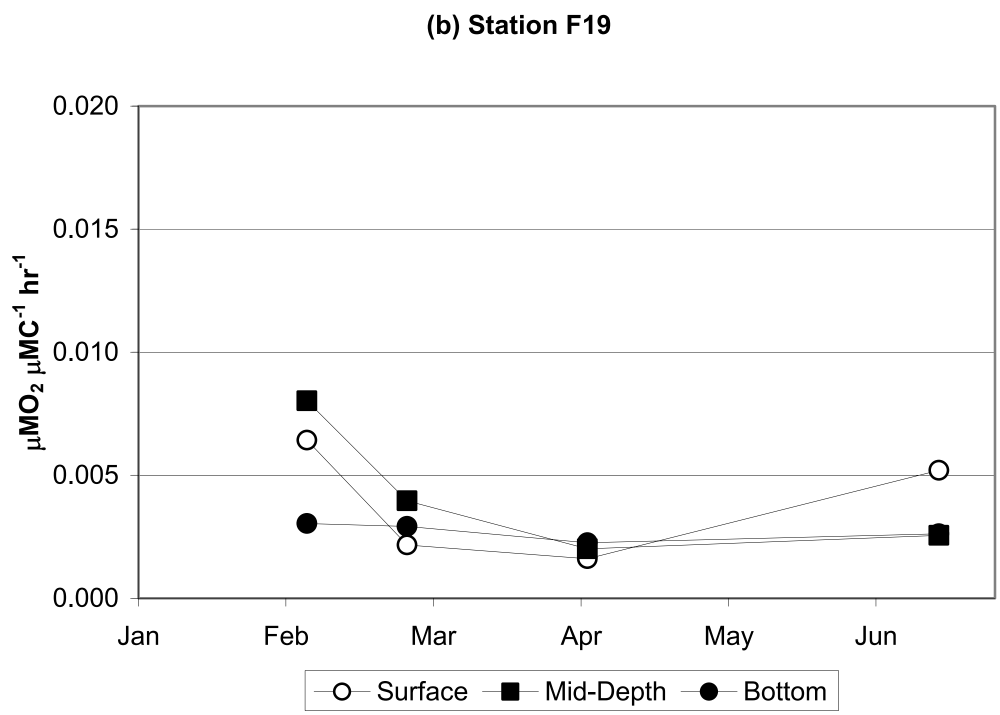


Figure 5-14. Time-series plots of carbon-specific respiration ($\mu MO_2 \mu MC^{-1} hr^{-1}$) at stations F23 and F19

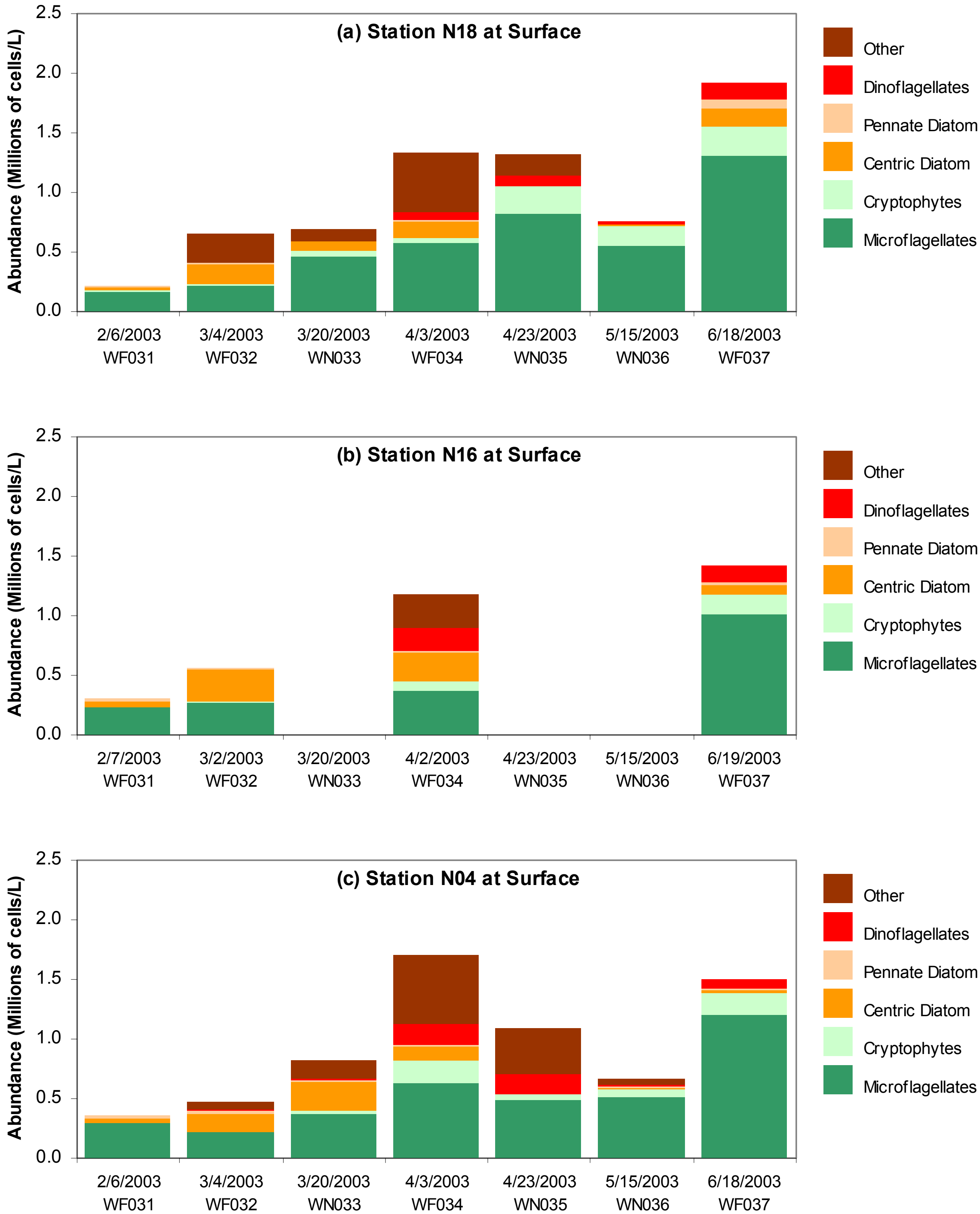


Figure 5-15. Phytoplankton abundance by major taxonomic group, nearfield surface samples

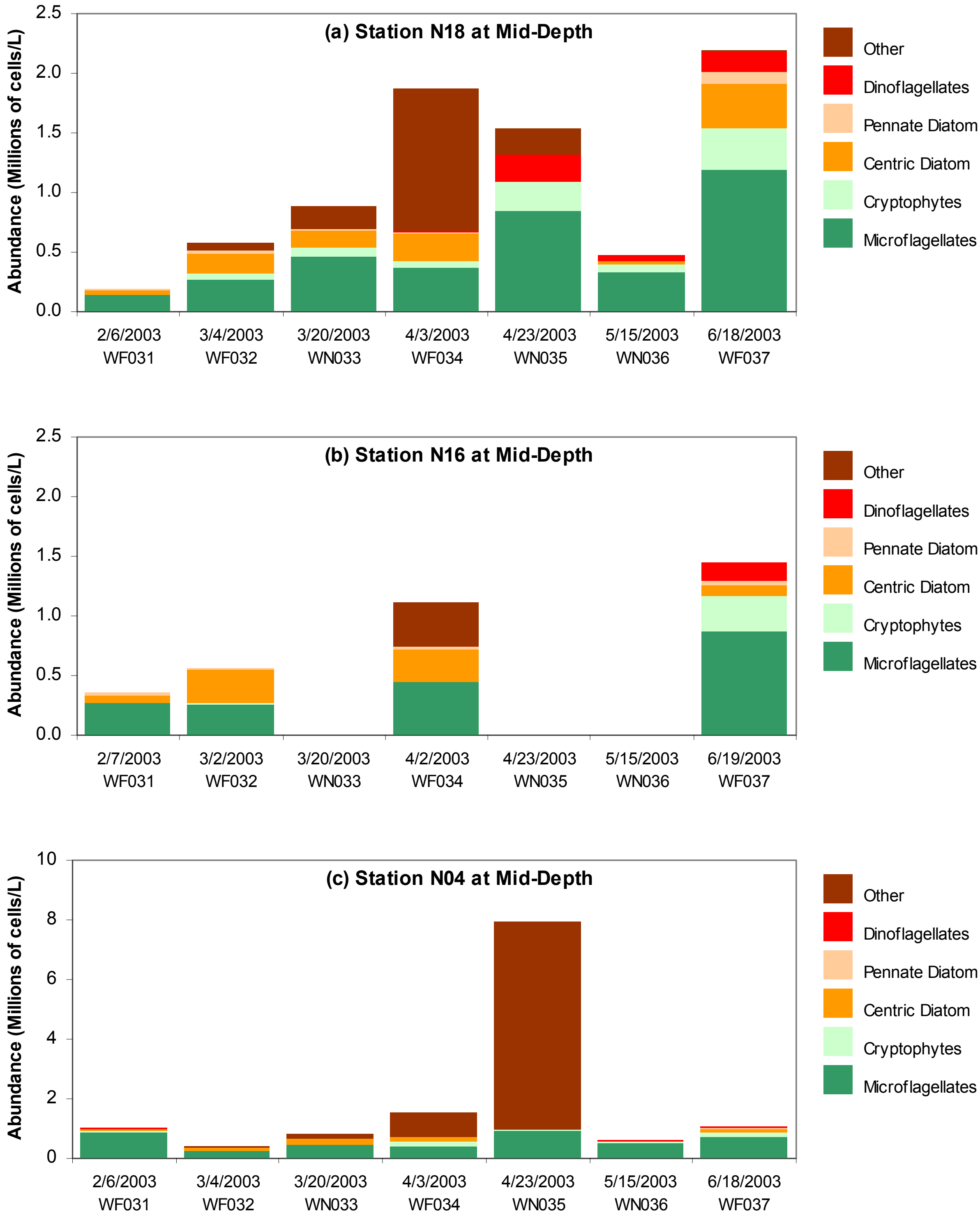


Figure 5-16. Phytoplankton abundance by major taxonomic group, nearfield mid-depth samples

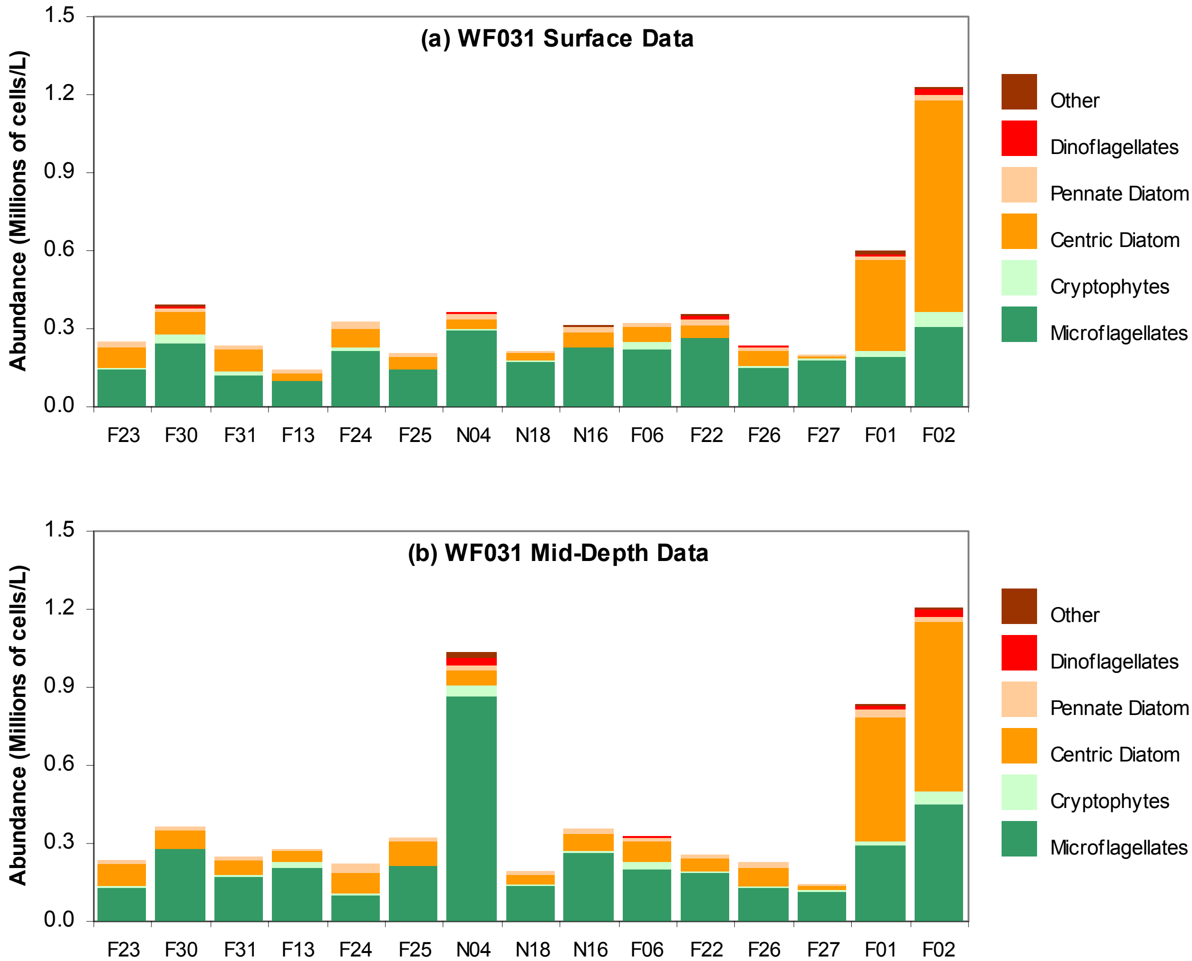


Figure 5-17. Phytoplankton abundance by major taxonomic group – WF031 farfield survey results (February 5 – 8)

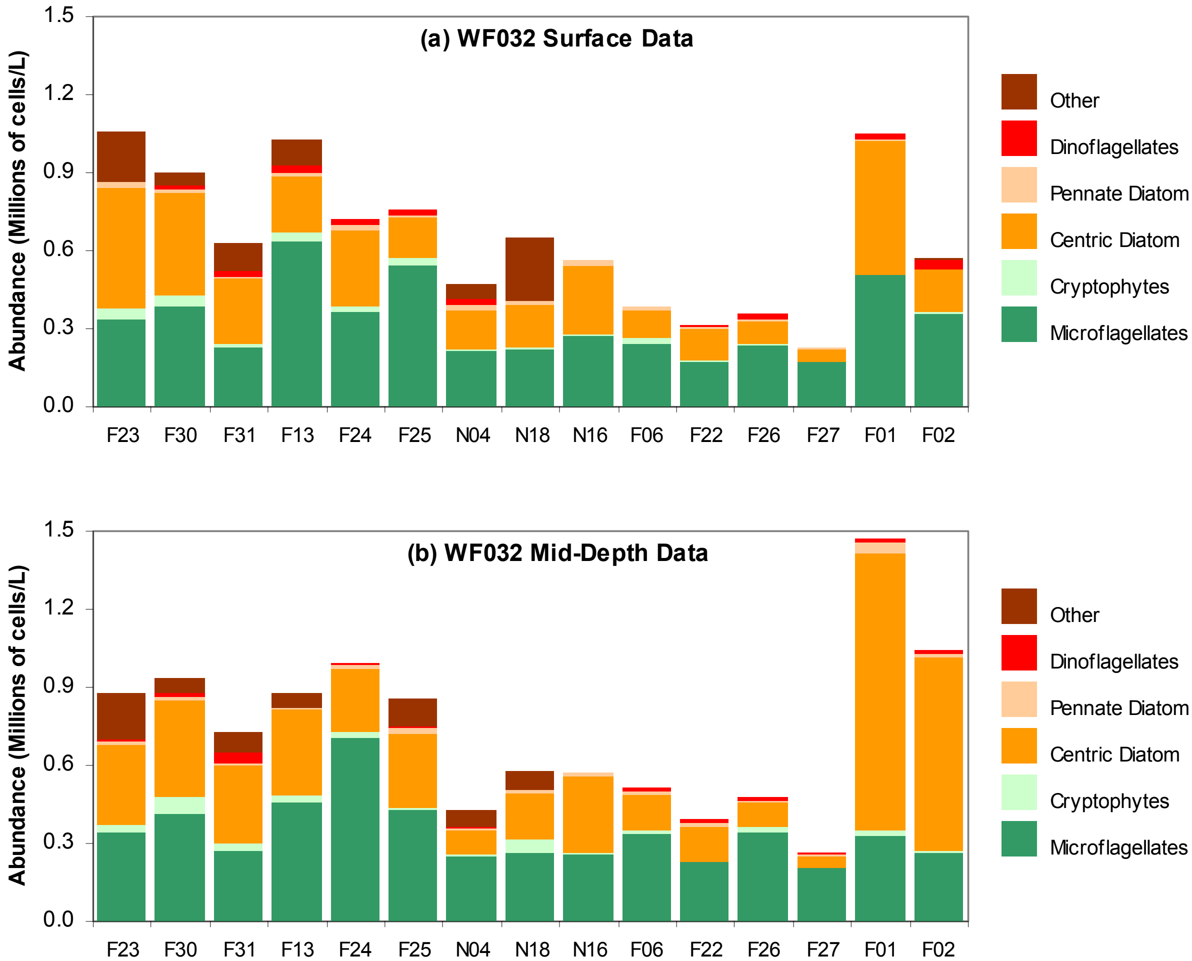


Figure 5-18. Phytoplankton abundance by major taxonomic group – WF032 farfield survey results (February 26 – March 4)

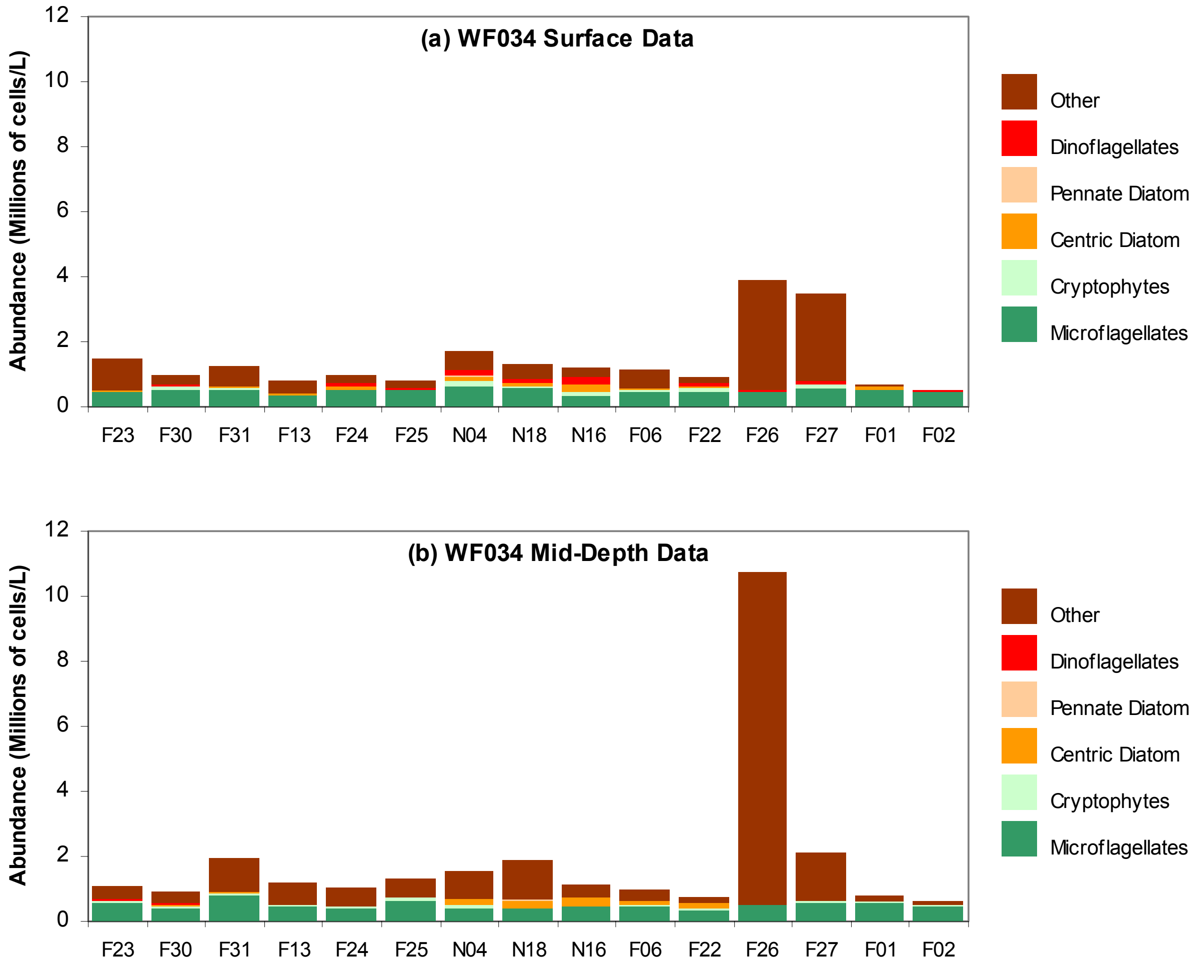


Figure 5-19. Phytoplankton abundance by major taxonomic group – WF034 farfield survey results (April 1 – 7)

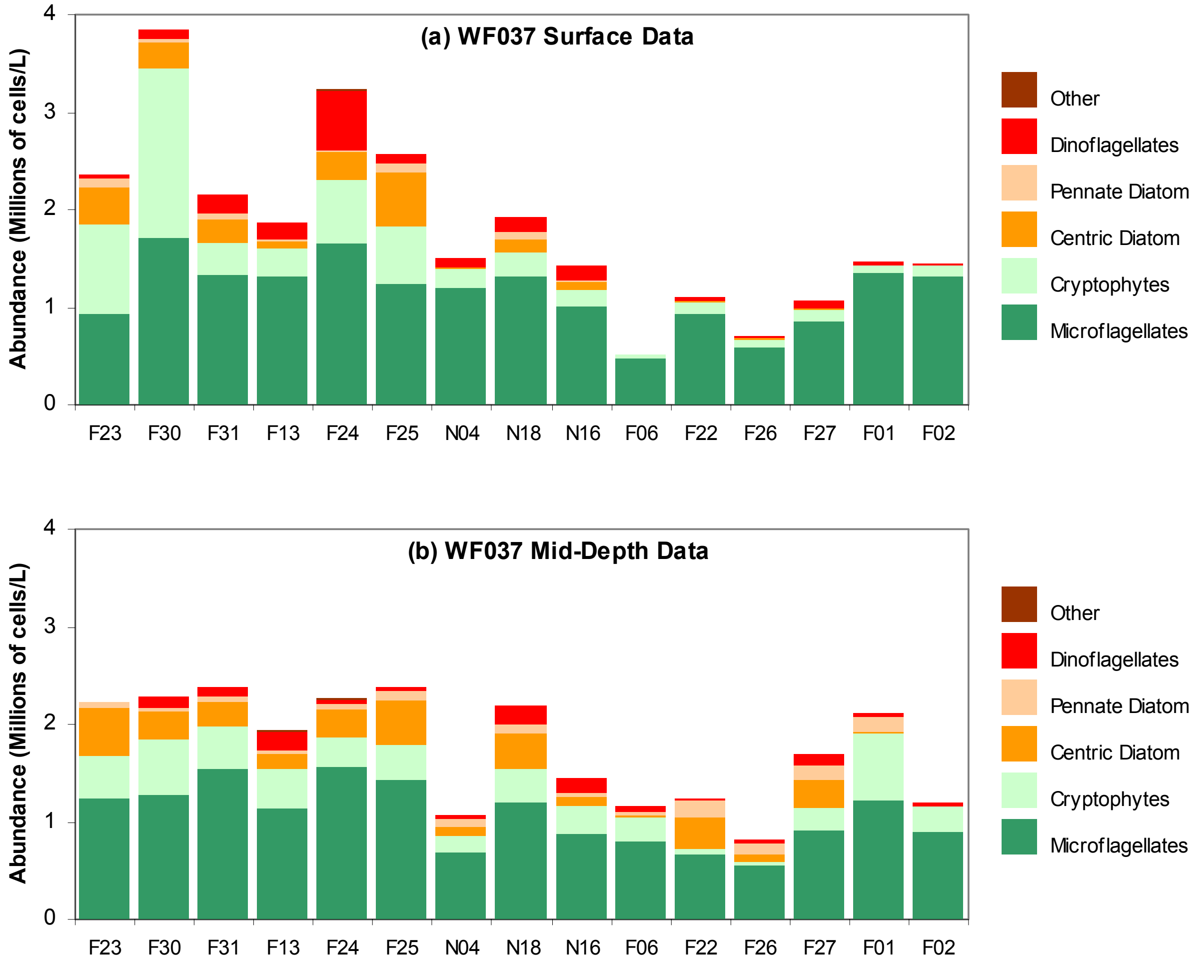


Figure 5-20. Phytoplankton abundance by major taxonomic group – WF037 farfield survey results (June 18 – 21)

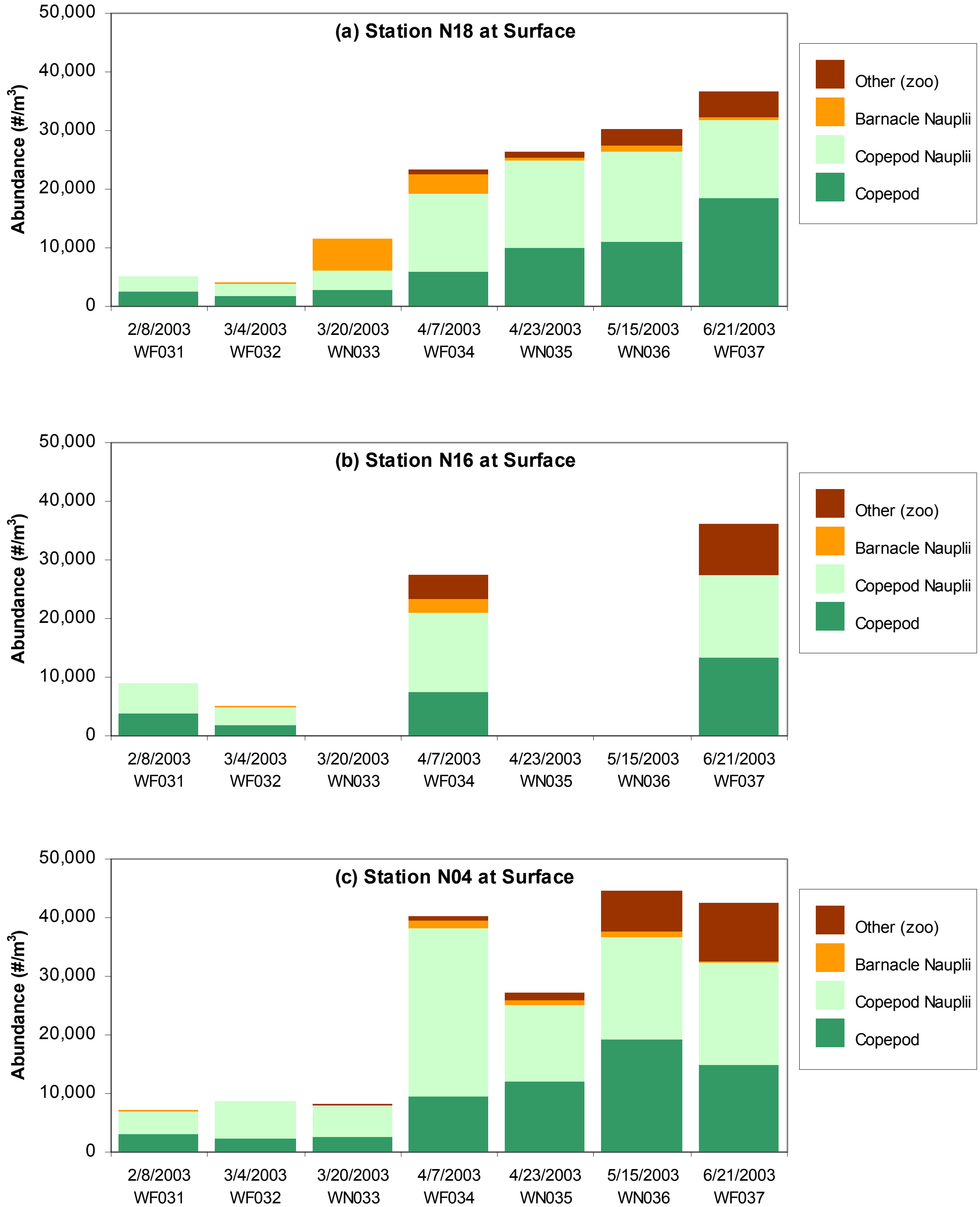


Figure 5-21. Zooplankton abundance by major taxonomic group at stations N18, N16 and N04.

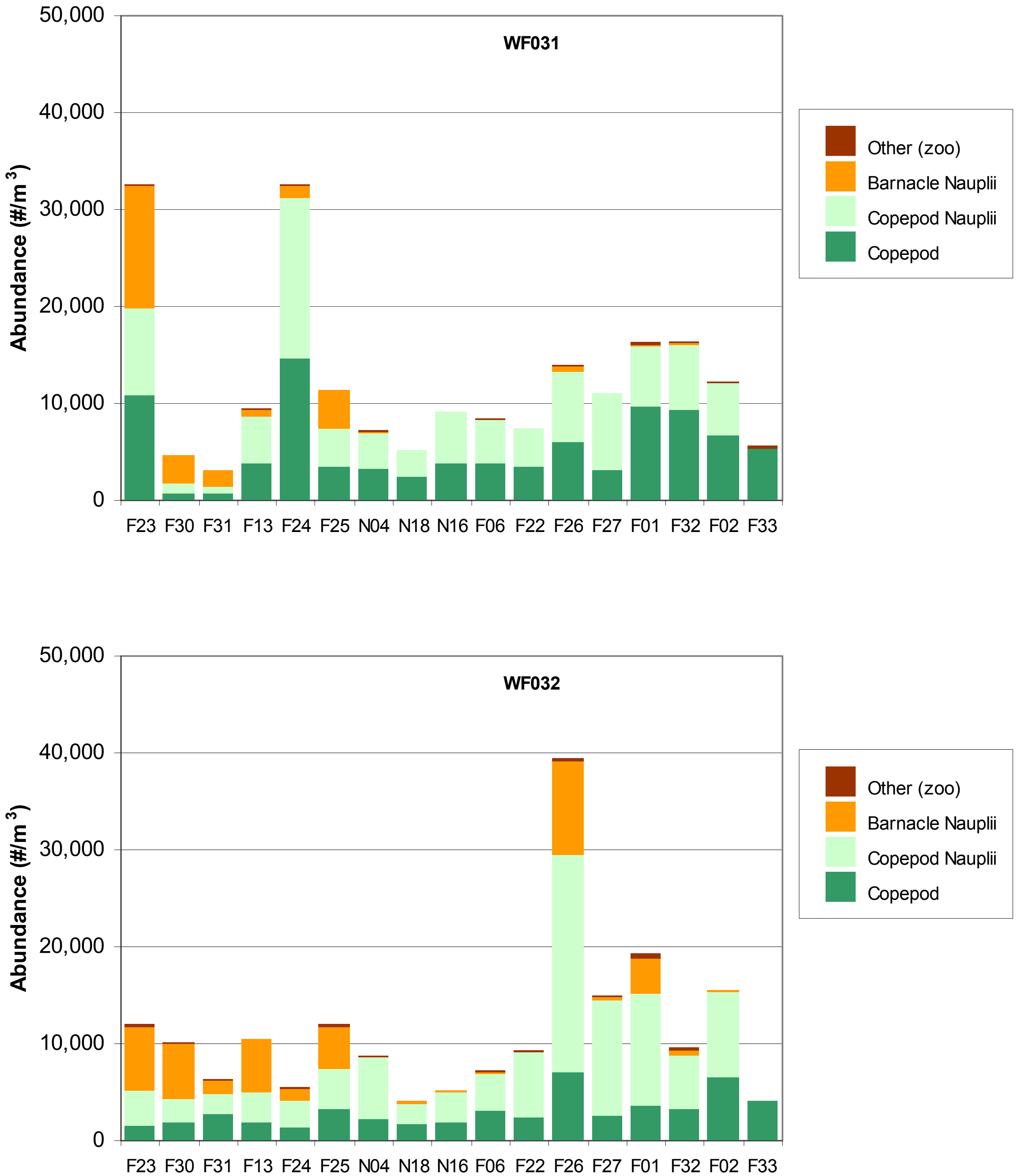
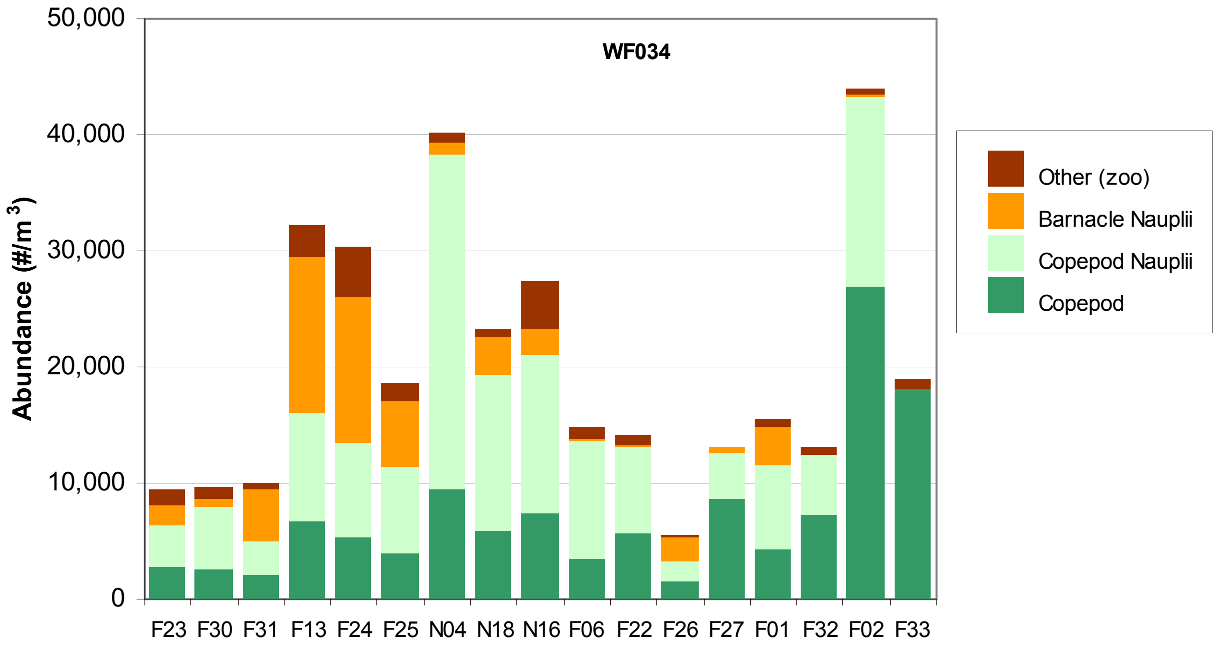


Figure 5-22. Zooplankton abundance by major taxonomic group during (a) WF031 (February 5-8) and (b) WF032 (February 26 – March 4) farfield surveys



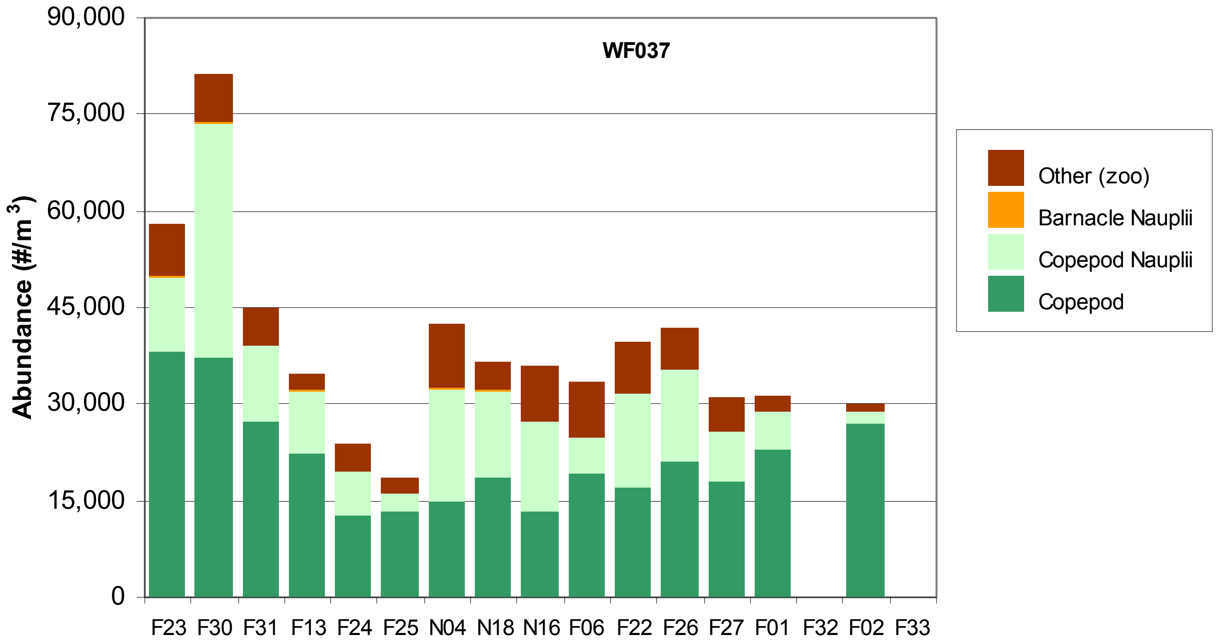


Figure 5-23. Zooplankton abundance by major taxonomic group during (a) WF034 (April 1 – 7) and (b) WF037 (June 18 – 21) farfield surveys

6.0 SUMMARY OF MAJOR WATER COLUMN EVENTS

The winter to spring transition in Massachusetts and Cape Cod Bays is characterized by a series of physical, biological, and chemical events: seasonal stratification, the winter/spring phytoplankton bloom, and nutrient depletion. This was generally the case in 2003. There was a winter/spring diatom bloom in February that was most prominent in Cape Cod Bay, Boston Harbor, coastal and western nearfield waters. A prolonged bloom of *Phaeocystis pouchetii* was observed throughout Massachusetts and Cape Cod Bays from February to April that was most pronounced in northern Massachusetts Bay. The occurrence of these two substantial blooms led to sustained high chlorophyll levels in the nearfield that approached, but did not exceed threshold levels.

The winter/spring of 2003 was marked by low air and water temperatures. Air temperatures were the coldest on record since 1977-1978 and were below normal for the first six months of the year (plus during the preceding three months in 2002; NWS Logan Airport). Surface waters were cold throughout the winter/spring and reached a minimum (0.2-2.8°C) during the late February/early March survey. Surface water temperatures remained cold (3-5°C) though early April when increased precipitation, runoff, and the spring freshet led to lower surface salinity. The freshening of the surface waters resulted in a weakly stratified water column throughout most of Massachusetts Bay with a slight increase in stratification from inshore to the deeper offshore stations. The inshore to offshore gradient in stratification was also observed in the nearfield in early April and by the end of the month the entire nearfield was stratified. Freshwater input to surface waters typically drives the establishment of stratified conditions in March and April. In 2003, the relatively high precipitation and river flow resulted in a strong salinity gradient, while the very low air temperatures led to a delay in surface water warming. As a result, a strong pycnocline was not observed in the nearfield until mid May. However, by June, a strong pycnocline was established throughout the bays.

The nutrient data for February to June 2003 generally followed the typical progress of seasonal events in Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. Nutrient concentrations in Cape Cod Bay surface waters were low in comparison to Massachusetts Bay due to elevated diatom abundance in early February and remained relatively low throughout the report period. Massachusetts Bay surface water nutrient concentrations decreased from early February through April. An exception was noted for silicate which tended to increase from late February/early March to April coincident with a transition from a diatom dominated bloom in February to a *Phaeocystis* bloom in April. In the nearfield, nutrient levels decreased in the surface waters as stratification was developing. Nutrient concentrations in the surface waters were depleted throughout much of the nearfield region by mid March. Nutrient concentrations in the surface waters were depleted throughout the entire study area by June.

The usefulness of NH_4 as a tracer of the effluent plume has been shown for previous monitoring periods (Libby *et al*., 2001). Although it is not a conservative tracer due to biological utilization, NH_4 does provide a natural tracer of the effluent plume in the nearfield area especially in low light conditions where biological activity is minimal (i.e. during the winter and below the pycnocline during stratified conditions). Plots of NH_4 concentrations across the nearfield typically show a strong NH_4/effluent signal rising from the outfall and surfacing, until stratification sets up and the plume is trapped below the pycnocline. This was again the case in 2003 as elevated NH_4 and PO_4 concentrations were found in the surface waters from early February through March. Once the waters began to stratify in April, the pycnocline prevented the effluent (and elevated NH_4 and PO_4 concentrations) from reaching surface waters. In addition to illustrating the vertical extent of the plume, the nutrient distributions continue to show that the plume is generally confined to within 20 km of the outfall and that the location of the plume is variable.

Regional chlorophyll maxima were observed in Cape Cod Bay, coastal and Boston Harbor waters in late February/early March during the diatom bloom. The highest chlorophyll concentrations of the semi-annual period were recorded in the nearfield in April during the *Phaeocystis* bloom. Elevated chlorophyll levels were also measured in northeastern Massachusetts Bay during this bloom. SeaWiFS images for this time period suggest that these elevated chlorophyll values may have been due to or enhanced by entrainment of waters from the Gulf of Maine into northeastern Massachusetts Bay during the spring freshet. Overall, chlorophyll concentrations in the nearfield were relatively high in comparison to other areas and previous years and often present at elevated levels over most of the water column.

The nearfield mean areal chlorophyll for winter/spring 2003 was 178 mg m^{-2}, which is comparable to but below the seasonal caution threshold of 182 mg m^{-2}. This is the highest winter/spring value since the outfall went online. Although this year showed an increase from 2001 and 2002, it was comparable to the areal chlorophyll values seen winter/spring 1999 and 2000. In 1999 and 2000, the high winter/spring chlorophyll concentrations were coincident with a substantial region-wide winter/spring diatom (1999) or *Phaeocystis* (2000) bloom. Although 2003 lacked a major regional winter/spring bloom, the combination of elevated chlorophyll concentrations over much of the water column during both the nearshore diatom bloom and the offshore *Phaeocystis* bloom resulted in sustained high chlorophyll concentrations in the nearfield. The 2003 winter/spring seasonal mean was higher then the values observed over the rest of the baseline period (1992-1998) and was the second highest value that has been observed during the monitoring program.

In contrast to the high chlorophyll concentrations, productivity was relatively low in comparison to past years. Areal production in 2003 followed patterns typically observed with a distinct peak associated with the winter/spring phytoplankton bloom, but peak production values were lower than the range usually observed. The winter/spring blooms observed in the nearfield in 1995-2002 generally reached values of 2000 to 4500 mg C m^{-2} d^{-1}, while the bloom in 2003 reached maximum values of only 1200-1600 mg C m^{-2} d^{-1}. Another deviation from trends observed over the last few years was the absence of an early February peak in nearfield production. SeaWiFS images show that chlorophyll levels were low from January through most of February indicating that an early bloom was not missed due to the sampling schedule. It was expected that the low water temperatures in 2003 would lead to high peak productivity values (Keller *et al.*, 2001). The cause for the incongruity between chlorophyll concentrations and production rates will be examined in more detail in the 2003 annual report.

Prior to the diversion of effluent offshore, Boston Harbor station F23 exhibited a gradual pattern of increasing areal production from winter through summer rather than the distinct winter/spring peaks observed at the nearfield sites. During 1995-2001, peak areal production at station F23 ranged from 1000 to 5000 mg C m^{-2} d^{-1} in June-July. The peak areal production observed in 2002 was of a similar magnitude (3200 mg C m^{-2} d^{-1}) but occurred in February. In 2003, areal production peaked during the winter diatom bloom in early March, decreased in April before increasing again in June. The shift in seasonal cycle in 2003 at station F23 is similar to the pattern observed in 2001 – 2002, although the magnitude of the bloom varies among years. This shift in the production pattern in the harbor may be in response to diversion and a sign of harbor recovery. This will be the focus of more intense examination in future reports.

Dissolved oxygen measurements throughout the area during the first half of 2003 were consistent with the typical trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the winter/spring bloom in the bays. Maximum concentrations occurred in February when the water column was well mixed. By April, bottom water DO concentrations had decreased throughout Massachusetts Bay. Mean bottom water DO had decreased by 1.5 mgL^{-1} in the harbor, coastal and nearfield waters. This was likely related to the decline of the diatom bloom and the onset of stratification – increased respiration in the bottom waters combined with a reduction in mixing. From April to June, bottom water DO concentrations declined by 1-2 mgL^{-1} reaching minima for this time period in June throughout Massachusetts and Cape Cod Bays. The mean bottom water DO concentrations in June 2003, however, were relatively high in comparison to past years and uniform across the survey area (9-9.5 mgL^{-1}).

The trend of decreasing DO in the bottom waters was also apparent in the DO %saturation data. By June, DO %saturation in the bottom waters was at a minimum for the first half of 2003 throughout the area except for nearfield waters, which reached a survey mean minimum of <90% in May. The lowest survey mean value was observed in the bottom waters along the boundary (89%). Even though there were two major winter/spring blooms in 2003 and chlorophyll (an indicator of phytoplankton biomass) was high in comparison to past years, DO concentrations and %saturation were relatively high. This might be as expected based on the findings of Geyer *et al.* (2002) which indicated that there was an inverse relationship between winter/spring salinity and bottom water DO concentrations. The underlying hypothesis is that during years with high runoff and low salinity waters there is higher flow through the system and less of a decrease in DO concentrations. Another factor that may have contributed to the relatively high bottom water DO was that respiration rates were generally low due to inhibition of biological activity by the very low ambient water temperatures in early 2003.

Whole-water phytoplankton assemblages were dominated by several species of centric diatoms, *Phaeocystis pouchetii*, and unidentified microflagellates as is typical for the first half of the year. The winter/spring diatom bloom was observed in Cape Cod Bay and nearshore Massachusetts Bay waters in February/early March. The highest abundances were found in Cape Cod Bay. *Phaeocystis* was first observed in the nearfield in early February at low abundances. By late February/early March, it was present at stations in Boston Harbor, coastal and nearfield. By April the *Phaeocystis* bloom was observed across Massachusetts Bay and low levels were seen in Cape Cod Bay. The data suggest that the *Phaeocystis* bloom may have been transported or enhanced by the spring freshet as *Phaeocystis* abundance was highest (~10 million cells L^{-1}) at station F26 and seemed to decrease to the south. SeaWiFS images for this time period also suggest an influence from the western Gulf of Maine during the spring freshet. By late April *Phaeocystis* abundance had decreased at station N18, but remained relatively high in surface waters at station N04 and increasing dramatically to 8 million cells L^{-1} at mid depth. An evaluation of data for other parameters suggests that although *Phaeocystis* abundance was high at depth at station N04, the bloom was senescent and settling out of the water column in late April. This was the fourth consecutive year that a *Phaeocystis* bloom was observed in Massachusetts Bay and is a departure from the 3-year cycle for these blooms that had been observed during the baseline period (Libby *et al*., 2001). There were no blooms of other harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during this time period. The dinoflagellate *Alexandrium tamarense* and the diatom of *Pseudo-nitzschia pungens* were recorded, but they were present in very low abundance.

Total zooplankton abundance generally increased from February through June as usual and zooplankton assemblages during the first half of 2003 were comprised of taxa recorded for the same time of year in previous years. Beginning in 1998, zooplankton data have been collected in Cape Cod Bay at two "winter zooplankton" stations (F32, F33) in addition to the "normal" farfield zooplankton stations (F01, F02). The main impetus for collecting data at these two additional stations was to better understand zooplankton abundance patterns in Cape Cod Bay during the winter and early spring when right whales are feeding on zooplankton in Cape Cod Bay. Such variability could be in terms of variability of important components of the entire assemblage, or in terms of abundance of the entire assemblage. This was the case in 2003 as the variability in total abundance and in both the presence and abundance of particular zooplankton species was high across the four stations. This will be evaluated in more detail for the complete 1998-2003 dataset in the 2003 annual report.

September 6, 2000 marked the end of the baseline period, completing the data set for MWRA to calculate the threshold values used to compare monitoring results to baseline conditions. The water quality parameters included as thresholds are dissolved oxygen concentrations and percent saturation in bottom waters of the nearfield and Stellwagen Basin, annual and seasonal chlorophyll levels in the nearfield, seasonal averages of the nuisance algae *Phaeocystis pouchetii* and *Pseudo-nitzschia pungens* in the nearfield, and individual sample counts of *Alexandrium tamarense* in the nearfield (**Table** 6-1). The DO values compared against thresholds are calculated based on the mean of bottom water values for surveys conducted from June to October. The chlorophyll values are calculated as survey means of areal chlorophyll (mg m^{-2}) and then averaged over seasonal and annual time periods. For chlorophyll and nuisance algae the seasons are defined as the following 4-month periods: winter/spring from January to April, summer from May to August, and fall from September to December. The *Phaeocystis* and *Pseudo-nitzschia* seasonal values are calculated as the mean of the nearfield station means (includes surface and mid-depth samples at stations N04 and N18, and N16 for farfield surveys). For *Alexandrium* each individual sample value is compared against the threshold of 100 cells L^{-1}.

Table 6-1. Contingency plan threshold values for water column monitoring.

Parameter	Time Period	Caution Level	Warning Level	Background	2003
Bottom Water DO concentration	Survey Mean in June-October	< 6.5 mg/l (unless background lower)	< 6.0 mg/l (unless background lower)	Nearfield - 5.75 mg/l Stellwagen - 6.2 mg/l	(June only) Nearfield – 9.28 mg/l Stellwagen - 8.64 mg/l
Bottom Water DO %saturation	Survey Mean in June-October	< 80% (unless background lower)	< 75% (unless background lower)	Nearfield - 64.3% Stellwagen - 66.3%	(June only) Nearfield - 92.9% Stellwagen – 82.5%
Chlorophyll	Annual	107 mg/m^2	143 mg/m^2	--	--
	Winter/spring	182 mg/m^2	--	--	178 mg/m^2
	Summer	80 mg/m^2	--	--	--
	Autumn	161 mg/m^2	--	--	--
Phaeocystis pouchetii	Winter/spring	2,020,000 cells l^{-1}	--	--	482,000 cells l^{-1}
	Summer	334 cells l^{-1}	--	--	--
	Autumn	2,370 cells l^{-1}	--	--	--
Pseudo-nitzschia pungens	Winter/spring	21,000 cells l^{-1}	--	--	200 cells l^{-1}
	Summer	38,000 cells l^{-1}	--	--	--
	Autumn	24,600 cells l^{-1}	--	--	--
Alexandrium tamarense	Any nearfield sample	100 cells l^{-1}	--	--	6.6 cells l^{-1}

The dissolved oxygen concentration survey mean minimum for June 2003 was well above the threshold standard for both the nearfield and Stellwagen Basin. The percent saturation values were above the caution threshold of 80% in each area, but the survey mean minimum in Stellwagen Basin (82.5%) approached this level and was lower than that for the nearfield (92.9%). Such a low value in Stellwagen Basin in June suggests that the DO percent saturation will be below the caution threshold later in the fall. This has been the case all but one year (1993) during the MWRA monitoring program, but a threshold exceedance for DO is not triggered until levels below baseline background are reached. The nearfield mean areal chlorophyll value for winter/spring 2003 was high, but below the threshold. The prolonged winter/spring bloom led to areal chlorophyll values on par with 1999 and 2000, which each had major region-wide blooms, and higher than all other years 1992-1998 and 2001-2002. Although there was a substantial and prolonged *Phaeocystis* bloom from February to April 2003, the nearfield mean abundance was well below the threshold. The presence of *Phaeocystis* in one sample during the May survey will likely result in a summer mean value of greater than 334 cells l^{-1}. This will be discussed in detail in the second semiannual report for 2003. *Alexandrium* and *Pseudo-nitzschia* were observed intermittently, but at very low abundance. There were no threshold exceedances for water quality parameters over the first half of 2003.

Several topics were called out in this report that will be discussed in greater detail in the 2003 annual water column report including the following:

- Effect of 2002-2003 extremely low air and water temperatures and other metrological conditions on water quality in Massachusetts and Cape Cod Bays.
  - → Impact of cold temperatures (and other factors – light, *Phaeocystis*, zooplankton grazing) on production and winter/spring bloom hypothesis (Keller *et al*., 2001)
  - → Examination of regional DO control hypothesis (Geyer *et al*., 2002) based on high flow and low surface salinity in winter/spring 2003
- Closer examination of the variability in zooplankton abundance and community structure in Cape Cod Bay. Has the sampling at the two additional zooplankton stations from February to April enhanced our understanding of the system?
- Recommend that parameter names be changed for areal production and potential areal production to measured areal production and areal production, respectively, both in the database and in future reports.

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