Semiannual water column monitoring report

February - June 2004

Massachusetts Water Resources Authority

Environmental Quality Department
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SEMIANNUAL WATER COLUMN MONITORING REPORT

February – June 2004

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. 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 2004.

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 2004. The most significant biological event in winter/spring 2004 was a major *Phaeocystis pouchetii* bloom with extraordinarily high abundances observed throughout Massachusetts and Cape Cod Bays in April. The bloom was most prominent at Boston Harbor and coastal stations (10 to 15 million cells L^{-1}). As in 2002 and 2003, *Phaeocystis* abundance continued to be present at relatively high abundances in the nearfield in May, but the colonies and cells appeared to be senescent. The magnitude and duration of the bloom resulted in exceedances of both the winter/spring and summer *Phaeocystis* caution thresholds.

The winter/spring of 2004 was marked by extremely low air and water temperatures. Air temperatures in January 2004 were the lowest observed since 1893 resulting in very cold water temperatures from early February through April before seasonal warming in May and June. Early April was characterized by a 50-year storm event that resulted in over four inches of rain with concomitant increases in runoff and peak river flow both locally and regionally. The April storm event and resulting high flow conditions likely led to increased nutrient inputs to the system and contributed to the magnitude of the *Phaeocystis* bloom. The increased precipitation, runoff, and resulting spring freshet led to lower surface water salinity and the onset of stratification of the water column throughout most of Massachusetts Bay. The high precipitation and river flow in April 2004 led to a relatively strong salinity gradient, yet the water temperatures remained low. As a result, a strong pycnocline was not observed in the nearfield until mid May and throughout the bays by June.

The nutrient data for February to June 2004 generally show the typical progress of seasonal events in Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in February when the water column was well mixed and biological uptake of nutrients limited. In general, the nutrient concentrations during the two February surveys were higher than typically measured in the past. This may have been due to meteorological and oceanographic conditions and lower biological utilization related to the lack of an early winter/spring diatom bloom in Massachusetts Bay. By mid March, nearfield nutrient concentrations decreased somewhat suggesting that a minor diatom bloom may have occurred earlier in the month. By the April, surface water nutrient concentrations had decreased in all areas due to uptake during the *Phaeocystis* bloom. Nutrient concentrations in the surface waters were generally depleted throughout the entire study area in June, although they remained high at stations F18 and N01 near Nahant. *In situ* and meteorological data from June suggests that the elevated nutrients at these stations may have been due to upwelling of bottom waters possibly including the effluent plume.

The maximum regional chlorophyll levels in February were observed in Cape Cod Bay, while levels were very low throughout Massachusetts Bay. This was coincident with elevated abundance of diatoms in Cape Cod Bay and the apparent lack of a winter/spring diatom bloom in Massachusetts Bay. The highest chlorophyll concentrations were measured in April at the harbor and coastal stations where *Phaeocystis* abundance was >10 million cells L^{-1}. Considering the magnitude of the *Phaeocystis* bloom, the chlorophyll concentrations were relatively low (≤10 μgL^{-1}). SeaWiFS images show an abrupt decline in the chlorophyll signal associated with the *Phaeocystis* bloom by mid to late April. Phytoplankton abundance and chlorophyll concentrations remained low from May to June.

Areal production in 2004 followed patterns typically observed in prior years, although the typical early February peak was not observed. Production rates were relatively low in the nearfield in February, before increasing in March and peaking during the April *Phaeocystis* bloom. The nearfield peak production rates in 2004 were somewhat higher than values observed during the winter-spring period in 2003, but generally lower than those observed between 1999 and 2002. In 2001 to 2003, production at the harbor station (F23) peaked during the winter/spring bloom, which was a change from the gradually increasing areal production observed prior to outfall diversion. In 2004, areal production in the harbor increased with the winter/spring *Phaeocystis* bloom in early April, but continued to increase into June. Thus, the seasonal cycle observed in 2004 was more similar to the pre-diversion trend, but at the lower end of the range in magnitude previously observed.

Dissolved oxygen measurements throughout the area during the first half of 2004 were typical of the trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the phytoplankton blooms in the bays. Bottom water DO concentrations generally rose between February and April, with only Cape Cod Bay peaking in late February. By April, when the *Phaeocystis* bloom was at its peak, bottom water DO concentrations had increased throughout Massachusetts Bay. When the *Phaeocystis* bloom crashed in mid to late April, it was coincident with the onset of stratification. The combination led to decreases in mean bottom water DO throughout all areas by June. All regions registered the lowest concentration of the report period during June (<10 mgL^{-1}). The mean bottom water DO concentrations in June 2004, however, were relatively high and uniform across the survey area.

Whole-water phytoplankton assemblages during the first half of 2004 were dominated by unidentified microflagellates and *Phaeocystis pouchetii*. The main deviation from the typical assemblage was the lack of dominance by centric diatoms at Massachusetts Bay stations. A minor winter/spring diatom bloom was observed in Cape Cod Bay in February, but diatom abundance remained very low throughout Massachusetts Bay waters from February to June. There were indications that diatoms may have been abundant in early to mid March (nearfield nutrient data and SeaWiFS), but none of the HOM samples recorded elevated diatom abundances. 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 2004 were comprised of taxa recorded for the same time of year in previous years. In April, the spatial distribution in zooplankton abundance was opposite to that for *Phaeocystis* – high *Phaeocystis* abundance in the harbor and coastal waters coincident with low zooplankton abundance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

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 period Monitoring Plan (MWRA 1991 and 1997). A comprehensive review of the data to date in June 2003 led to revisions to the Ambient Monitoring Plan that were first implemented in 2004 (MWRA 2004). The changes to the water column monitoring program include reducing the number of nearfield surveys from 17 to 12 and reducing the number of nearfield stations from 21 to 7. These changes were based on both a qualitative and statistical examination of baseline and post-discharge data (MWRA 2003). For the February to June time period, only the late April survey (WN0X5) was dropped.

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 and the farfield stations are located throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (**Figure** 1-1). 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 six surveys conducted from February through June 2004 (**Table** 1-1).

Table 1-1. Water Quality Surveys for WF041-WF047 February to June 2004

Survey #	Type of Survey	Survey Dates
WF041	Nearfield/Farfield	February 2-5
WF042	Nearfield/Farfield	February 23-25
WN043	Nearfield	March 23
WF044	Nearfield/Farfield	April 7-9
WN046*	Nearfield	May 14
WF047	Nearfield/Farfield	June 14-17

*The fifth survey (WN045) was dropped based on recommendations made by OMSAP (MWRA 2004).

The bay outfall became operational on September 6, 2000. The six surveys conducted during this semiannual period are the fourth 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 2004. Preliminary comparisons against baseline data are discussed and appropriate threshold values presented. A detailed evaluation of 2004 versus the baseline period (1992-2000) will be presented in the 2004 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 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 six surveys of 2004 (Sections 3-5). 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** 1-2). 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 (WF041 – WN043), the early stratification stage (WF044 – WN046), and once seasonal stratification was established (WF047). 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.

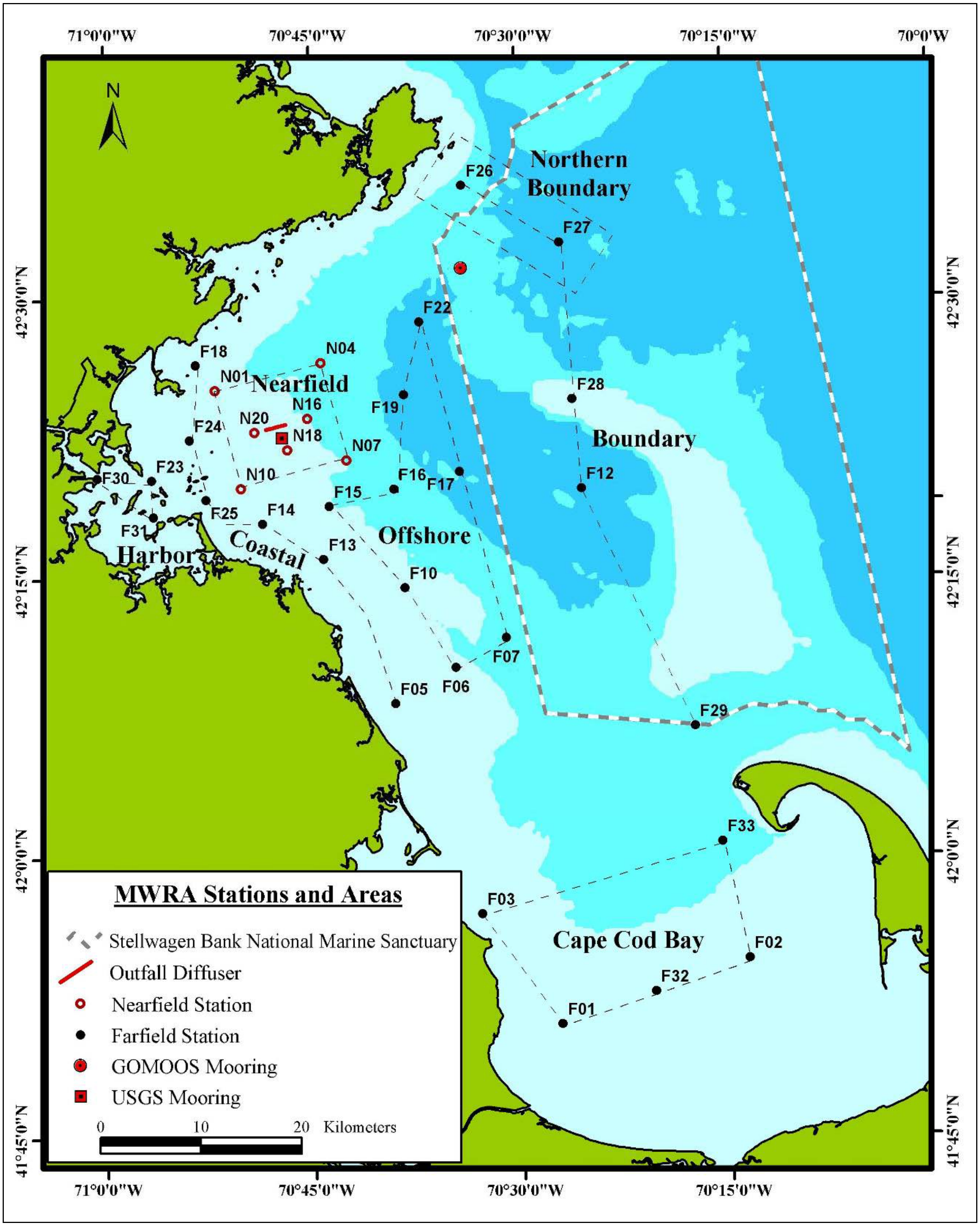


Figure 1-1. Locations of farfield stations and regional station groupings

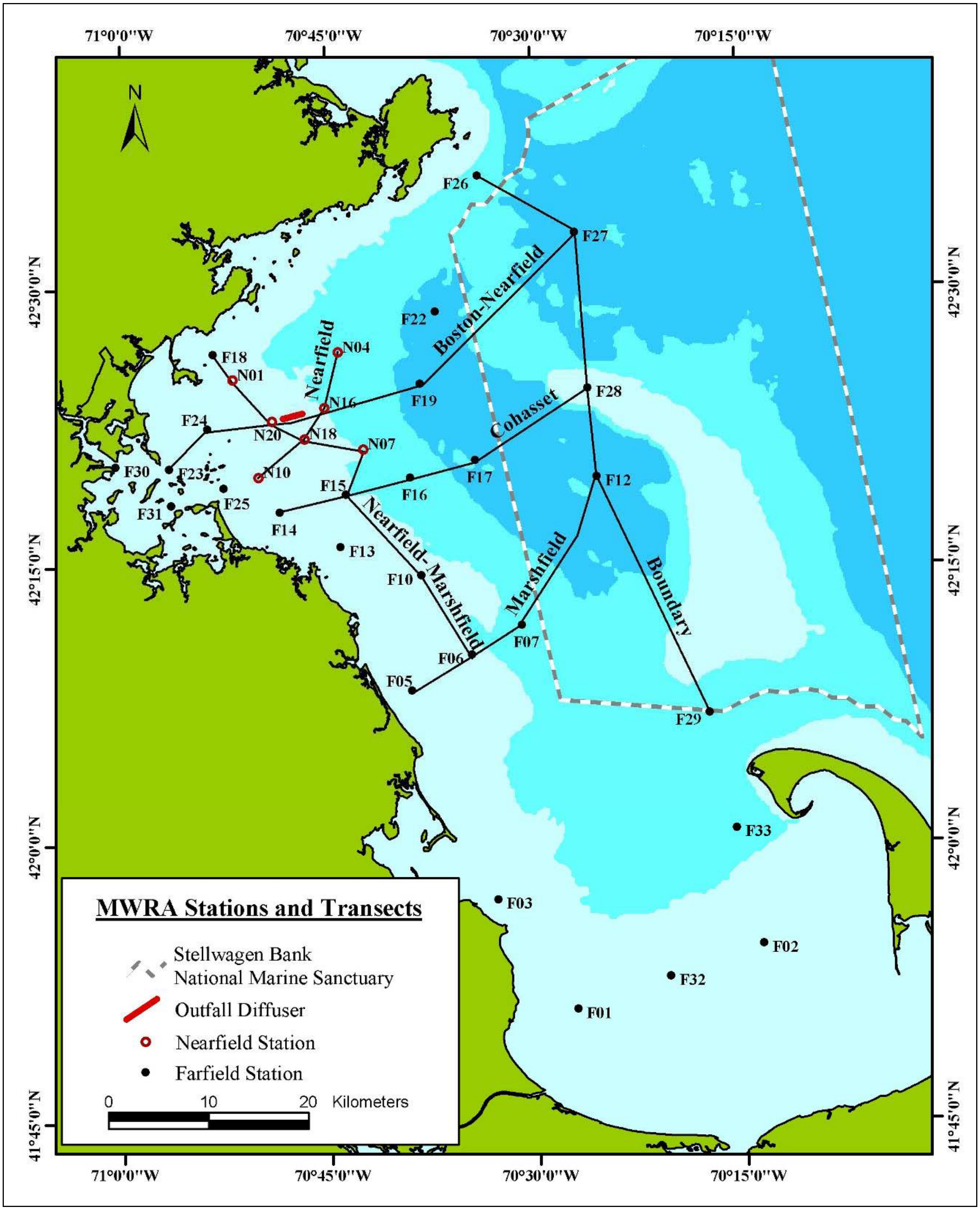


Figure 1-2. Locations of stations and selected transects

2.0 METHODS

This section describes general methods of data collection and sampling for the first six water column monitoring surveys of 2004. 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 2004 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.* 2002).

2.1 Data Collection

The farfield and nearfield water quality surveys for 2004 represent a continuation of the water quality monitoring conducted from 1992 - 2004. 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 five fall 2000 surveys represented the beginning of the outfall discharge monitoring period, which continued in 2001, 2002, 2003 and 2004. The data collected during outfall discharge monitoring are evaluated internally and against baseline data. Data collection methods and schema did not change from the baseline for the first three years after the outfall came online. In 2004, however, the number of nearfield surveys and stations was reduced (MWRA 2004). This change was supported by statistical analysis of baseline and post-discharge data collected from 1992-2002, which indicate that there will be little loss of information or in the ability of the monitoring program to detect changes.

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 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, and phytoplankton (screened and rapid assessment) were filtered and preserved immediately after obtaining water from the appropriate Go-Flo bottles. Total suspended solids (TSS) samples were collected in 1-liter bottles and transferred to the MWRA Deer Island Laboratory for processing and analysis. 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).

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 WF041, WF042, WN043, WF044, WN046, and WF047 had no effect on the data or data interpretation. For additional information about a specific survey, the individual survey reports may be consulted.

Table 2-1. 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	10	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

Table 2-2. Nearfield water column sampling plan

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 Phosphorus	Particulate Organic Carbon and Nitrogen	Particulate Phosphorus	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	1	3							
			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	1	3							
			1_Bottom	15.5	2	1	1	1	2	2	2	1	1						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	1			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	1			1	1		6	1	1
			6_Net Tow															1			
			1_Bottom	10.5	2	1	1	1	2	2	2	1	1	1							
			2_Mid-Bottom	2.5	1	1						1		1							
N07	52	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	1	1							
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	10.5	2	1	1	1	2	2	2	1	1	1							
			1_Bottom	8.5	2	1	1	1	2	2	2	1	1	3							
			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	1	3							
			1_Bottom	8.5	2	1	1	1	2	2	2	1	1	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	1	1							
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	8.5	2	1	1	1	2	2	2	1	1	1							
			1_Bottom	15.5	2	1	1	1	2	2	2	1	1						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	1		1	1	1		6	1	1
		P	4_Mid-Surface	4.5	1	1						1		1						1	1
			5_Surface	20.6	2	1	1	1	2	2	2	1	1			1	1		6	1	1
			6_Net Tow															1			
			1_Bottom	8.5	2	1	1	1	2	2	2	1	1	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	1	1							
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	8.5	2	1	1	1	2	2	2	1	1	1							
				Totals		41	22	22	42	42	42	42	23	37	1	4	4	2	36	10	10
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 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
					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	1	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	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	1	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	1	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	1	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	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	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	1	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	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	1	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	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
			6_Net Tow															1			
			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	1						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	1		1				6		
			1_Bottom	7.9	2	1	1	1	2	2	2	1	1	3							
			2_Mid-Bottom	2.5	1	1						1		1							
F22	80	D	3_Mid-Depth	14	2	2	1	1	2	2	2	2	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	18	3	1	1	1	2	2	2	1	1						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	1			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	1		1	1	1		6	1	1
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	1	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	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	9.9	2	1	1	1	2	2	2	1	1	1							
			2_Mid-Bottom	2.5	1	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	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
F25	15	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	15	2	1	1	1	2	2	2	1	1	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	1	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	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	1	1	1	1				
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	1	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	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	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	1	3							
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	1	1		1	1				
F30	15	G	5_Surface	15	2	1	1	1	2	2	2	1	1	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	9.9	2	1	1	1	2	2	2	1	1	3							
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	1	1		1	1				
F31	15	G	5_Surface	15	2	1	1	1	2	2	2	1	1	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	1	1	2	2	2	1	1	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	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	1	1	1	1				
			6_Net Tow															1			
					Totals	133	43	43	84	84	84	80	44	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 2004 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 WF041, WF042, WF044, and WF047. 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. 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 (**Figure** 1-1). 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** 1-1.

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.* 2002), 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 1022.1 to 1026.5 kg/m^3, meaning σ_t varied from 22.1 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 (BioSi), dissolved and particulate organic carbon (DOC and POC), total dissolved and particulate organic nitrogen (TDN and PON), total dissolved and particulate phosphorous (TDP and PartP), and total suspended solids (TSS). These data are presented in **Tables** 3-5 to 3-9. 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 ($gCm^{-3}h^{-1}[\mu Em^{-2}s^{-1}]^{-1}$) and Pmax ($gCm^{-3}h^{-1}$) 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.* 2002).

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.* 2002).

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 samples (surface and mid-depth. 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 the outfall and nearfield station N18 (see **Figure** 1-1). Daily averaged temperature and salinity data from mid-surface (6 m), mid-depth (13 m), mid-bottom (20 m) and near-bottom (1 m above bottom, 27 m) are plotted in **Figure** 3-1. Chlorophyll *a* data (as measured by *in situ* fluorescence) from the MWRA WETStar sensor mounted at mid-depth (13 m) on the nearfield USGS mooring are plotted in **Figure** 3-2. Data at comparable depths from station N18 are included in both figures for comparison. There were issues with the 20-m conductivity sensor and recovery of the near bottom tripod instrument array for the deployment ending in February 2004 and no data are presented. The WETStar fluorescence data for the September 2003 to February 2004 deployment are suspect. All data from the May to September 2004 deployment are currently under review and will be included in the second semiannual or annual reports 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
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 2004.

			Temperature (°C)			Salinity (PSU)			Sigma T		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF041	2/3	-0.43	2.68	2.04	32.0	32.6	32.4	25.6	26.0	25.9
Nearfield	WF042	2/25	1.11	2.36	1.89	31.4	32.8	32.3	25.1	26.2	25.8
Nearfield	WN043	3/23	2.32	3.04	2.75	31.3	32.7	32.5	25.0	26.1	25.9
Nearfield	WF044	4/8	2.89	4.05	3.29	31.0	32.7	31.9	24.6	26.0	25.4
Nearfield	WN046	5/14	3.44	9.03	6.50	30.9	32.3	31.6	24.0	25.7	24.8
Nearfield	WF047	6/17	3.97	16.84	8.78	30.5	31.9	31.3	22.1	25.3	24.2
Nearfield	ALL		-0.43	16.84	4.21	30.5	32.8	32.0	22.1	26.2	25.3
Boundary	WF041	2/2-5	2.23	4.56	2.88	32.5	33.4	32.7	26.0	26.4	26.1
Cape Cod Bay	WF041	2/2-5	-0.37	0.94	0.18	31.1	32.2	32.0	24.9	25.8	25.6
Coastal	WF041	2/2-5	-0.98	1.32	0.31	30.8	32.4	32.1	24.7	26.0	25.7
Harbor	WF041	2/2-5	-0.75	0.03	-0.35	31.4	32.0	31.8	25.2	25.7	25.5
Nearfield	WF041	2/2-5	-0.43	2.68	2.04	32.0	32.6	32.4	25.6	26.0	25.9
Offshore	WF041	2/2-5	0.35	2.94	2.38	31.3	32.7	32.4	25.0	26.1	25.9
All	ALL		-0.98	4.56	1.24	30.8	33.4	32.2	24.7	26.4	25.8
Boundary	WF042	2/23-25	2.39	3.98	2.83	32.5	33.3	32.8	26.0	26.5	26.2
Cape Cod Bay	WF042	2/23-25	-0.04	1.27	0.64	30.8	32.4	31.8	24.6	25.9	25.5
Coastal	WF042	2/23-25	1.20	1.78	1.46	32.1	32.6	32.4	25.7	26.1	25.9
Harbor	WF042	2/23-25	0.91	1.36	1.14	30.6	32.2	31.7	24.5	25.8	25.4
Nearfield	WF042	2/23-25	1.11	2.36	1.89	31.4	32.8	32.3	25.1	26.2	25.8
Offshore	WF042	2/23-25	1.57	3.00	2.07	32.4	33.0	32.7	26.0	26.3	26.1
All	ALL		-0.04	3.98	1.67	30.6	33.3	32.3	24.5	26.5	25.8
Boundary	WF044	4/7-9	2.76	4.47	3.25	28.6	32.9	32.2	22.7	26.3	25.6
Cape Cod Bay	WF044	4/7-9	2.99	3.73	3.38	31.6	32.3	32.0	25.1	25.7	25.4
Coastal	WF044	4/7-9	2.97	5.37	3.76	30.5	32.4	31.4	24.1	25.8	24.9
Harbor	WF044	4/7-9	3.75	4.54	4.11	29.5	30.8	30.2	23.4	24.5	23.9
Nearfield	WF044	4/7-9	2.89	4.05	3.29	31.0	32.7	31.9	24.6	26.0	25.4
Offshore	WF044	4/7-9	2.79	4.77	3.27	31.2	32.9	32.2	24.7	26.3	25.7
All	ALL		2.76	5.37	3.51	28.6	32.9	31.6	22.7	26.3	25.2
Boundary	WF047	6/14-17	3.14	14.68	7.25	30.4	32.4	31.6	22.6	25.8	24.6
Cape Cod Bay	WF047	6/14-17	6.64	13.77	10.14	30.4	31.6	31.0	22.7	24.8	23.8
Coastal	WF047	6/14-17	5.64	14.90	10.37	30.6	31.7	31.1	22.7	25.0	23.8
Harbor	WF047	6/14-17	8.14	15.16	12.66	30.2	31.4	30.8	22.4	24.4	23.2
Nearfield	WF047	6/14-17	3.97	16.84	8.78	30.5	31.9	31.3	22.1	25.3	24.2
Offshore	WF047	6/14-17	3.26	16.05	8.42	30.2	32.1	31.3	22.3	25.6	24.2
All	ALL		3.14	16.84	9.60	30.2	32.4	31.2	22.1	25.8	23.9

Table 3-3. Summary of *in situ* beam attenuation, dissolved oxygen concentration, and dissolved oxygen %saturation data for February - June 2004.

			Beam (m^{-1})			DO (mgL^{-1})			DO % Saturation		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF041	2/3	0.57	0.85	0.65	10.25	11.50	10.51	93.6	97.0	94.7
Nearfield	WF042	2/25	0.63	1.14	0.80	10.81	11.76	11.15	98.5	103.5	100.1
Nearfield	WN043	3/23	0.93	1.74	1.16	11.04	12.17	11.54	100.1	111.5	105.9
Nearfield	WF044	4/8	1.04	2.06	1.40	11.13	12.64	11.95	102.7	118.2	110.8
Nearfield	WN046	5/14	0.77	1.73	1.10	9.86	11.92	10.84	93.3	122.8	108.7
Nearfield	WF047	6/17	0.52	1.94	0.83	8.95	10.54	9.69	90.5	112.3	101.9
Nearfield	ALL		0.52	2.06	0.99	8.95	12.64	10.95	90.5	122.8	103.7
Boundary	WF041	2/2-5	0.60	0.77	0.65	9.53	10.63	10.27	91.6	96.4	94.7
Cape Cod Bay	WF041	2/2-5	0.68	0.82	0.74	11.01	11.42	11.21	95.6	96.4	95.9
Coastal	WF041	2/2-5	0.62	1.04	0.78	10.79	11.94	11.21	94.9	99.0	96.3
Harbor	WF041	2/2-5	0.70	1.07	0.80	11.41	12.07	11.69	97.2	100.0	98.2
Nearfield	WF041	2/2-5	0.57	0.85	0.65	10.25	11.50	10.51	93.6	97.0	94.7
Offshore	WF041	2/2-5	0.60	0.77	0.63	10.13	11.30	10.44	93.6	96.9	94.9
All	ALL		0.57	1.07	0.71	9.53	12.07	10.89	91.6	100.0	95.8
Boundary	WF042	2/23-25	0.65	1.14	0.75	10.29	10.97	10.77	97.6	100.3	99.3
Cape Cod Bay	WF042	2/23-25	0.85	1.69	1.27	11.55	12.21	11.92	102.0	104.2	103.2
Coastal	WF042	2/23-25	0.94	1.34	1.15	11.14	11.50	11.34	99.7	101.5	100.7
Harbor	WF042	2/23-25	1.12	1.51	1.27	11.53	11.99	11.75	101.9	104.5	103.0
Nearfield	WF042	2/23-25	0.63	1.14	0.80	10.81	11.76	11.15	98.5	103.5	100.1
Offshore	WF042	2/23-25	0.66	0.85	0.71	10.67	11.33	11.08	98.1	101.8	100.1
All	ALL		0.63	1.69	0.99	10.29	12.21	11.33	97.6	104.5	101.1
Boundary	WF044	4/7-9	0.89	1.70	1.19	10.42	12.27	11.53	96.5	114.4	107.0
Cape Cod Bay	WF044	4/7-9	1.26	2.27	1.62	11.07	11.76	11.41	103.8	109.2	106.1
Coastal	WF044	4/7-9	1.19	2.40	1.78	11.50	12.66	12.19	106.1	120.2	113.9
Harbor	WF044	4/7-9	2.25	2.57	2.38	11.81	12.11	12.00	109.8	114.6	112.3
Nearfield	WF044	4/7-9	1.04	2.06	1.40	11.13	12.64	11.95	102.7	118.2	110.8
Offshore	WF044	4/7-9	0.78	1.83	1.23	10.56	12.66	11.67	97.5	121.2	108.5
All	ALL		0.78	2.57	1.60	10.42	12.66	11.79	96.5	121.2	109.8
Boundary	WF047	6/14-17	0.52	1.15	0.71	9.09	10.97	9.93	85.8	112.9	101.0
Cape Cod Bay	WF047	6/14-17	0.67	1.97	0.94	8.31	9.74	9.08	83.4	106.5	98.5
Coastal	WF047	6/14-17	0.63	2.07	1.07	8.75	9.90	9.32	91.7	112.7	101.4
Harbor	WF047	6/14-17	1.10	2.67	2.02	8.78	9.39	9.01	95.0	106.6	102.9
Nearfield	WF047	6/14-17	0.52	1.94	0.83	8.95	10.54	9.69	90.5	112.3	101.9
Offshore	WF047	6/14-17	0.51	1.26	0.78	8.93	11.15	9.76	87.2	114.0	101.6
All	ALL		0.51	2.67	1.06	8.31	11.15	9.47	83.4	114.0	101.2

Table 3-4. Summary of *in situ* fluorescence, chlorophyll *a*, and phaeophytin data for February - June 2004.

			Fluorescence (μgL^{-1})			Chlorophyll *a* (μgL^{-1})			Phaeophytin (μgL^{-1})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF041	2/3	0.02	1.09	0.60	0.26	1.77	0.72	0.08	0.46	0.19
Nearfield	WF042	2/25	0.02	2.52	0.89	0.54	1.88	1.04	0.08	0.37	0.20
Nearfield	WN043	3/23	0.89	7.03	3.13	0.67	5.99	3.34	0.36	1.50	0.70
Nearfield	WF044	4/8	1.56	8.54	5.20	2.30	7.65	5.26	0.52	1.95	1.35
Nearfield	WN046	5/14	0.90	8.07	2.99	0.91	6.46	3.27	0.25	2.45	1.43
Nearfield	WF047	6/17	0.11	5.19	1.08	0.08	3.95	1.19	0.07	1.40	0.47
Nearfield	ALL		0.02	8.54	2.31	0.08	7.65	2.47	0.07	2.45	0.72
Boundary	WF041	2/2-5	0.02	2.91	0.83	0.31	0.53	0.43	0.13	0.22	0.17
Cape Cod Bay	WF041	2/2-5	0.02	3.36	1.40	1.16	2.06	1.59	0.19	0.76	0.31
Coastal	WF041	2/2-5	0.02	1.52	0.86	0.43	0.82	0.63	0.03	0.27	0.14
Harbor	WF041	2/2-5	0.53	0.95	0.72	0.30	0.65	0.53	0.03	0.16	0.11
Nearfield	WF041	2/2-5	0.02	1.09	0.60	0.26	1.77	0.72	0.08	0.46	0.19
Offshore	WF041	2/2-5	0.02	4.61	0.71	0.47	0.93	0.64	0.07	0.22	0.12
All	ALL		0.02	4.61	0.85	0.26	2.06	0.76	0.03	0.76	0.17
Boundary	WF042	2/23-25	0.00	1.12	0.56	0.36	0.61	0.48	0.12	0.33	0.22
Cape Cod Bay	WF042	2/23-25	0.96	5.22	3.36	2.92	4.73	3.50	0.20	0.95	0.51
Coastal	WF042	2/23-25	0.06	2.02	1.40	0.59	1.42	1.01	0.13	0.29	0.22
Harbor	WF042	2/23-25	0.77	2.38	1.83	0.98	5.05	2.06	0.20	1.29	0.45
Nearfield	WF042	2/23-25	0.02	2.52	0.89	0.54	1.88	1.04	0.08	0.37	0.20
Offshore	WF042	2/23-25	0.12	1.44	0.81	0.43	1.47	0.77	0.13	0.21	0.18
All	ALL		0.00	5.22	1.48	0.36	5.05	1.48	0.08	1.29	0.30
Boundary	WF044	4/7-9	1.00	9.43	4.17	1.25	7.75	5.01	0.36	1.83	1.10
Cape Cod Bay	WF044	4/7-9	1.76	9.64	4.60	1.27	5.06	2.68	0.52	1.54	0.91
Coastal	WF044	4/7-9	1.51	10.14	6.66	3.09	9.62	7.14	0.82	2.48	1.93
Harbor	WF044	4/7-9	5.56	9.88	7.65	6.02	8.52	7.30	1.54	2.68	2.23
Nearfield	WF044	4/7-9	1.56	8.54	5.20	2.30	7.65	5.26	0.52	1.95	1.35
Offshore	WF044	4/7-9	1.17	9.38	4.50	3.10	8.94	6.29	0.63	2.68	1.79
All	ALL		1.00	10.14	5.46	1.25	9.62	5.61	0.36	2.68	1.55
Boundary	WF047	6/14-17	0.00	1.97	0.62	0.05	1.31	0.63	0.11	0.54	0.29
Cape Cod Bay	WF047	6/14-17	0.32	1.75	0.89	0.43	1.51	0.98	0.10	0.72	0.45
Coastal	WF047	6/14-17	0.47	4.10	1.49	0.43	4.44	2.19	0.30	1.52	0.79
Harbor	WF047	6/14-17	1.32	6.31	3.81	0.98	6.13	3.74	0.89	2.59	1.67
Nearfield	WF047	6/14-17	0.11	5.19	1.08	0.08	3.95	1.19	0.07	1.40	0.47
Offshore	WF047	6/14-17	0.08	3.32	0.84	0.08	2.86	1.04	0.13	1.05	0.42
All	ALL		0.00	6.31	1.45	0.05	6.13	1.63	0.07	2.59	0.68

Table 3-5. Summary of ammonium, nitrite, and nitrite+nitrate data for February - June 2004.

				NH_4 (µM)			NO_2 (µM)			$NO_2 + NO_3$ (µM)	
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF041	2/3	0.03	6.82	1.41	0.07	0.12	0.09	10.20	12.60	11.93
Nearfield	WF042	2/25	0.09	10.30	2.01	0.10	0.20	0.12	9.49	12.80	11.61
Nearfield	WN043	3/23	0.39	5.74	1.81	0.04	0.13	0.09	1.07	6.30	3.54
Nearfield	WF044	4/8	0.06	4.25	1.21	0.02	0.19	0.09	0.08	5.13	1.89
Nearfield	WN046	5/14	0.05	10.70	2.45	0.01	0.21	0.08	0.03	6.62	1.67
Nearfield	WF047	6/17	0.09	9.85	2.17	0.01	0.19	0.11	0.05	4.33	1.72
Nearfield	ALL		0.03	10.70	1.84	0.01	0.21	0.10	0.03	12.80	5.39
Boundary	WF041	2/2-5	0.01	0.91	0.30	0.03	0.11	0.07	10.60	13.40	11.94
Cape Cod Bay	WF041	2/2-5	0.36	1.81	0.53	0.11	0.13	0.12	10.20	11.00	10.64
Coastal	WF041	2/2-5	0.01	1.18	0.43	0.03	0.14	0.09	8.64	11.60	10.64
Harbor	WF041	2/2-5	0.01	1.48	0.50	0.05	0.14	0.09	9.46	11.20	10.13
Nearfield	WF041	2/2-5	0.03	6.82	1.41	0.07	0.12	0.09	10.20	12.60	11.93
Offshore	WF041	2/2-5	0.01	2.42	0.19	0.02	0.15	0.08	8.21	12.20	11.39
All	ALL		0.01	6.82	0.56	0.02	0.15	0.09	8.21	13.40	11.11
Boundary	WF042	2/23-25	0.01	1.30	0.29	0.09	0.17	0.12	11.10	13.70	12.41
Cape Cod Bay	WF042	2/23-25	0.11	0.57	0.36	0.10	0.14	0.12	7.02	10.60	8.99
Coastal	WF042	2/23-25	0.46	2.32	1.35	0.10	0.20	0.15	9.31	12.10	10.54
Harbor	WF042	2/23-25	0.30	1.59	0.87	0.12	0.23	0.16	8.06	10.40	9.28
Nearfield	WF042	2/23-25	0.09	10.30	2.01	0.10	0.20	0.12	9.49	12.80	11.61
Offshore	WF042	2/23-25	0.01	0.57	0.15	0.13	0.21	0.16	9.51	11.60	10.50
All	ALL		0.01	10.30	0.84	0.09	0.23	0.14	7.02	13.70	10.55
Boundary	WF044	4/7-9	0.05	1.56	0.76	0.05	0.16	0.10	0.52	8.65	3.30
Cape Cod Bay	WF044	4/7-9	0.10	1.96	0.74	0.01	0.12	0.06	0.02	3.44	1.32
Coastal	WF044	4/7-9	0.01	1.94	0.47	0.01	0.10	0.04	0.02	2.82	0.51
Harbor	WF044	4/7-9	0.01	0.56	0.21	0.05	0.17	0.10	0.15	3.87	1.17
Nearfield	WF044	4/7-9	0.06	4.25	1.21	0.02	0.19	0.09	0.08	5.13	1.89
Offshore	WF044	4/7-9	0.01	2.69	0.73	0.01	0.16	0.09	0.03	8.67	2.95
All	ALL		0.01	4.25	0.69	0.01	0.19	0.08	0.02	8.67	1.86
Boundary	WF047	6/14-17	0.01	2.36	0.94	0.01	0.30	0.12	0.03	8.28	2.88
Cape Cod Bay	WF047	6/14-17	0.20	3.62	1.54	0.01	0.18	0.08	0.04	2.37	0.96
Coastal	WF047	6/14-17	0.01	8.00	1.49	0.03	0.20	0.12	0.04	3.15	1.45
Harbor	WF047	6/14-17	0.35	1.86	0.85	0.08	0.20	0.13	0.53	2.55	1.18
Nearfield	WF047	6/14-17	0.09	9.85	2.17	0.01	0.19	0.11	0.05	4.33	1.72
Offshore	WF047	6/14-17	0.01	2.14	0.79	0.02	0.28	0.11	0.03	6.24	1.81
All	ALL		0.01	9.85	1.30	0.01	0.30	0.11	0.03	8.28	1.67

Table 3-6. Summary of phosphate, silicate, and biogenic silica data for February - June 2004.

Region	Survey	Dates	PO_4 (µM) Min	Max	Mean	SiO_4 (µM) Min	Max	Mean	BioSi (µM) Min	Max	Mean
Nearfield	WF041	2/3	1.04	1.52	1.21	11.10	13.40	12.70	0.71	1.60	0.99
Nearfield	WF042	2/25	0.92	1.72	1.22	8.98	12.60	11.29	0.85	1.99	1.23
Nearfield	WN043	3/23	0.39	0.84	0.59	1.36	4.22	2.61	1.55	3.94	2.46
Nearfield	WF044	4/8	0.22	0.74	0.48	4.57	6.09	5.39	0.85	1.72	1.39
Nearfield	WN046	5/14	0.27	1.10	0.59	0.71	6.12	3.26	0.85	2.51	1.82
Nearfield	WF047	6/17	0.26	1.37	0.66	2.41	7.66	4.43	0.53	1.50	0.87
Nearfield	ALL		0.22	1.72	0.79	0.71	13.40	6.61	0.53	3.94	1.46
Boundary	WF041	2/2-5	1.10	1.37	1.17	10.80	13.90	12.53	0.57	1.74	1.12
Cape Cod Bay	WF041	2/2-5	1.08	1.15	1.12	11.30	12.40	11.87	1.24	1.99	1.53
Coastal	WF041	2/2-5	0.95	1.25	1.12	10.60	13.00	12.26	0.63	2.07	1.03
Harbor	WF041	2/2-5	1.01	1.08	1.04	10.60	13.50	11.92	0.62	0.90	0.74
Nearfield	WF041	2/2-5	1.04	1.52	1.21	11.10	13.40	12.70	0.71	1.60	0.99
Offshore	WF041	2/2-5	1.04	1.22	1.15	9.16	14.00	12.71	0.68	1.41	0.93
All	ALL		0.95	1.52	1.14	9.16	14.00	12.33	0.57	2.07	1.06
Boundary	WF042	2/23-25	1.13	1.24	1.19	11.10	14.10	11.98	0.64	2.18	1.38
Cape Cod Bay	WF042	2/23-25	0.78	1.04	0.90	5.99	10.40	8.58	3.03	4.46	3.68
Coastal	WF042	2/23-25	1.03	1.23	1.14	9.66	11.70	10.59	1.31	2.23	1.77
Harbor	WF042	2/23-25	0.81	1.04	0.92	8.90	9.55	9.19	1.14	2.60	1.95
Nearfield	WF042	2/23-25	0.92	1.72	1.22	8.98	12.60	11.29	0.85	1.99	1.23
Offshore	WF042	2/23-25	1.04	1.36	1.14	9.30	12.50	10.86	0.41	1.80	1.21
All	ALL		0.78	1.72	1.09	5.99	14.10	10.41	0.41	4.46	1.87
Boundary	WF044	4/7-9	0.34	1.09	0.60	3.16	8.43	5.16	1.06	1.76	1.39
Cape Cod Bay	WF044	4/7-9	0.37	0.64	0.47	2.62	4.04	3.49	1.30	1.84	1.71
Coastal	WF044	4/7-9	0.18	0.77	0.33	4.48	7.31	5.64	1.31	2.63	1.88
Harbor	WF044	4/7-9	0.15	0.22	0.18	6.81	10.10	8.07	2.77	4.13	3.44
Nearfield	WF044	4/7-9	0.22	0.74	0.48	4.57	6.09	5.39	0.85	1.72	1.39
Offshore	WF044	4/7-9	0.24	1.02	0.55	3.63	7.71	5.30	1.18	1.99	1.52
All	ALL		0.15	1.09	0.43	2.62	10.10	5.51	0.85	4.13	1.89
Boundary	WF047	6/14-17	0.21	1.19	0.64	1.33	11.50	4.61	0.30	0.95	0.67
Cape Cod Bay	WF047	6/14-17	0.24	0.93	0.52	2.17	9.44	4.41	0.43	4.91	1.62
Coastal	WF047	6/14-17	0.24	1.31	0.63	2.17	6.34	4.26	0.63	2.77	1.53
Harbor	WF047	6/14-17	0.47	0.84	0.61	4.74	5.84	5.13	1.58	6.09	3.66
Nearfield	WF047	6/14-17	0.26	1.37	0.66	2.41	7.66	4.43	0.53	1.50	0.87
Offshore	WF047	6/14-17	0.21	1.13	0.59	1.31	11.40	3.88	0.39	2.21	0.88
All	ALL		0.21	1.37	0.61	1.31	11.50	4.45	0.30	6.09	1.54

Table 3-7. Summary of particulate carbon, nitrogen, and phosphorous data for February - June 2004.

				POC (µM)			PON (µM)			PartP (µM)	
Region	Survey	Dates	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Nearfield	WF041	2/3	4.17	11.20	6.71	0.47	1.70	0.94	0.06	0.12	0.08
Nearfield	WF042	2/25	3.23	18.60	9.41	0.30	2.30	1.12	0.07	0.26	0.12
Nearfield	WN043	3/23	19.00	42.20	26.75	2.39	6.38	3.80	0.20	0.34	0.28
Nearfield	WF044	4/8	24.70	54.30	41.03	3.01	7.83	5.54	0.17	0.35	0.26
Nearfield	WN046	5/14	11.10	77.90	33.98	1.46	12.85	4.87	0.12	0.50	0.29
Nearfield	WF047	6/17	4.34	34.20	16.42	0.54	5.91	2.53	0.05	0.35	0.15
Nearfield	ALL		3.23	77.90	22.38	0.30	12.85	3.13	0.05	0.50	0.20
Boundary	WF041	2/2-5	3.90	18.80	8.30	0.47	2.75	1.26	0.05	0.13	0.08
Cape Cod Bay	WF041	2/2-5	10.20	12.20	11.43	1.51	1.98	1.83	0.12	0.22	0.15
Coastal	WF041	2/2-5	5.78	9.10	7.38	0.78	1.61	1.12	0.08	0.13	0.10
Harbor	WF041	2/2-5	6.30	12.10	7.74	0.90	1.85	1.16	0.07	0.16	0.11
Nearfield	WF041	2/2-5	4.17	11.20	6.71	0.47	1.70	0.94	0.06	0.12	0.08
Offshore	WF041	2/2-5	3.40	8.28	5.92	0.59	1.21	0.84	0.03	0.06	0.06
All	ALL		3.40	18.80	7.91	0.47	2.75	1.19	0.03	0.22	0.10
Boundary	WF042	2/23-25	3.38	11.80	7.83	0.30	1.64	0.85	0.06	0.14	0.09
Cape Cod Bay	WF042	2/23-25	19.30	37.00	25.90	2.65	5.53	3.67	0.12	0.41	0.30
Coastal	WF042	2/23-25	9.57	12.10	10.83	1.08	1.74	1.39	0.14	0.23	0.16
Harbor	WF042	2/23-25	9.96	38.80	18.89	1.21	6.34	2.38	0.14	0.29	0.21
Nearfield	WF042	2/23-25	3.23	18.60	9.41	0.30	2.30	1.12	0.07	0.26	0.12
Offshore	WF042	2/23-25	4.95	10.20	7.17	0.55	1.30	0.87	0.08	0.14	0.10
All	ALL		3.23	38.80	13.34	0.30	6.34	1.71	0.06	0.41	0.16
Boundary	WF044	4/7-9	19.00	43.00	29.50	2.52	5.69	3.91	0.21	0.34	0.27
Cape Cod Bay	WF044	4/7-9	15.80	103.00	55.63	2.18	10.00	5.97	0.23	0.63	0.40
Coastal	WF044	4/7-9	31.70	63.50	51.44	3.62	7.67	6.31	0.18	0.44	0.33
Harbor	WF044	4/7-9	51.90	69.00	59.67	6.76	8.52	7.82	0.32	0.50	0.44
Nearfield	WF044	4/7-9	24.70	54.30	41.03	3.01	7.83	5.54	0.17	0.35	0.26
Offshore	WF044	4/7-9	22.30	49.60	39.27	3.33	6.14	5.01	0.12	0.33	0.21
All	ALL		15.80	103.00	46.09	2.18	10.00	5.76	0.12	0.63	0.32
Boundary	WF047	6/14-17	5.28	19.40	12.96	0.74	2.91	1.92	0.05	0.12	0.09
Cape Cod Bay	WF047	6/14-17	15.60	22.60	18.66	1.86	3.51	2.40	0.13	0.23	0.16
Coastal	WF047	6/14-17	8.23	38.00	24.09	0.83	5.49	3.42	0.08	0.37	0.24
Harbor	WF047	6/14-17	24.90	49.80	37.27	3.87	7.97	6.01	0.24	0.69	0.49
Nearfield	WF047	6/14-17	4.34	34.20	16.42	0.54	5.91	2.53	0.05	0.35	0.15
Offshore	WF047	6/14-17	6.77	38.90	16.53	0.74	4.99	2.10	0.06	0.23	0.13
All	ALL		4.34	49.80	20.99	0.54	7.97	3.06	0.05	0.69	0.21

Table 3-8. Summary of dissolved organic carbon, nitrogen, and phosphorous data for February - June 2004.

			DOC (µM)			TDN (µM)			TDP (µM)		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF041	2/3	67.40	158.00	94.76	17.10	35.60	24.17	1.14	1.83	1.40
Nearfield	WF042	2/25	69.20	176.00	103.01	18.10	43.30	27.65	1.38	2.07	1.61
Nearfield	WN043	3/23	73.40	151.00	88.34	6.24	18.30	10.96	0.38	0.82	0.55
Nearfield	WF044	4/8	76.00	189.00	101.98	6.13	24.70	10.99	0.34	0.85	0.56
Nearfield	WN046	5/14	76.10	128.50	105.13	9.14	29.10	16.49	0.35	1.13	0.77
Nearfield	WF047	6/17	73.50	143.00	92.52	6.97	21.20	13.20	0.60	1.49	0.97
Nearfield	ALL		67.40	189.00	97.62	6.13	43.30	17.24	0.34	2.07	0.98
Boundary	WF041	2/2-5	66.00	107.00	79.92	18.50	25.00	21.00	1.22	1.38	1.32
Cape Cod Bay	WF041	2/2-5	70.10	81.40	74.12	15.70	26.30	19.33	1.02	1.28	1.13
Coastal	WF041	2/2-5	65.90	86.50	73.22	16.80	20.80	18.12	1.09	1.39	1.21
Harbor	WF041	2/2-5	71.00	86.90	79.61	17.30	24.20	19.00	1.08	1.27	1.20
Nearfield	WF041	2/2-5	67.40	158.00	94.76	17.10	35.60	24.17	1.14	1.83	1.40
Offshore	WF041	2/2-5	64.90	99.90	76.23	16.50	24.20	18.51	1.15	1.33	1.24
All	ALL		64.90	158.00	79.64	15.70	35.60	20.02	1.02	1.83	1.25
Boundary	WF042	2/23-25	70.60	92.20	82.17	18.50	22.20	20.17	1.23	1.45	1.37
Cape Cod Bay	WF042	2/23-25	79.60	90.70	85.75	17.60	26.50	20.48	1.16	1.52	1.35
Coastal	WF042	2/23-25	83.70	158.00	109.43	20.40	39.30	28.37	1.32	1.69	1.52
Harbor	WF042	2/23-25	82.20	215.00	115.98	18.40	32.60	24.30	1.16	1.43	1.27
Nearfield	WF042	2/23-25	69.20	176.00	103.01	18.10	43.30	27.65	1.38	2.07	1.61
Offshore	WF042	2/23-25	71.20	130.00	89.08	18.20	27.00	21.31	1.41	1.65	1.46
All	ALL		69.20	215.00	97.57	17.60	43.30	23.71	1.16	2.07	1.43
Boundary	WF044	4/7-9	76.60	133.00	93.05	7.95	12.10	9.76	0.45	0.82	0.58
Cape Cod Bay	WF044	4/7-9	79.90	134.00	95.98	8.37	15.90	12.88	0.57	0.74	0.70
Coastal	WF044	4/7-9	71.30	202.00	112.63	4.88	9.34	8.03	0.43	0.65	0.52
Harbor	WF044	4/7-9	101.00	132.00	110.89	5.27	19.50	10.22	0.31	0.60	0.45
Nearfield	WF044	4/7-9	76.00	189.00	101.98	6.13	24.70	10.99	0.34	0.85	0.56
Offshore	WF044	4/7-9	69.80	241.00	115.54	5.94	17.50	11.60	0.43	1.14	0.80
All	ALL		69.80	241.00	105.01	4.88	24.70	10.58	0.31	1.14	0.60
Boundary	WF047	6/14-17	72.20	100.00	83.42	8.00	15.70	10.81	0.54	1.25	0.85
Cape Cod Bay	WF047	6/14-17	86.60	123.00	105.67	8.57	15.80	13.31	0.64	1.33	0.95
Coastal	WF047	6/14-17	80.20	109.00	95.24	9.14	17.30	12.13	0.72	1.28	0.93
Harbor	WF047	6/14-17	84.00	125.00	103.90	9.57	13.40	11.96	0.81	1.13	0.96
Nearfield	WF047	6/14-17	73.50	143.00	92.52	6.97	21.20	13.20	0.60	1.49	0.97
Offshore	WF047	6/14-17	74.50	111.00	87.89	7.50	22.20	11.64	0.58	1.59	0.92
All	ALL		72.20	143.00	94.77	6.97	22.20	12.18	0.54	1.59	0.93

Table 3-9. Summary of total suspended solids data for February - June 2004.

Region	Survey	Dates	TSS (mgL^{-1}) Min	Max	Mean
Nearfield	WF041	2/3	0.12	0.62	0.42
Nearfield	WF042	2/25	0.12	1.19	0.55
Nearfield	WN043	3/23	0.85	2.39	1.34
Nearfield	WF044	4/8	0.66	1.56	1.03
Nearfield	WN046	5/14	0.41	1.40	0.84
Nearfield	WF047	6/17	0.12	0.90	0.32
Nearfield	ALL		0.12	2.39	0.75
Boundary	WF041	2/2-5	0.56	1.07	0.78
Cape Cod Bay	WF041	2/2-5	0.12	0.41	0.22
Coastal	WF041	2/2-5	0.12	1.94	0.47
Harbor	WF041	2/2-5	0.12	0.82	0.28
Nearfield	WF041	2/2-5	0.12	0.62	0.42
Offshore	WF041	2/2-5	0.12	0.41	0.17
All	ALL		0.12	1.94	0.39
Boundary	WF042	2/23-25	0.57	1.49	0.90
Cape Cod Bay	WF042	2/23-25	0.97	1.55	1.30
Coastal	WF042	2/23-25	0.76	1.41	1.12
Harbor	WF042	2/23-25	0.93	1.69	1.30
Nearfield	WF042	2/23-25	0.12	1.19	0.55
Offshore	WF042	2/23-25	0.38	0.97	0.58
All	ALL		0.12	1.69	0.96
Boundary	WF044	4/7-9	1.05	2.05	1.53
Cape Cod Bay	WF044	4/7-9	1.33	2.25	1.80
Coastal	WF044	4/7-9	1.20	3.90	2.06
Harbor	WF044	4/7-9	2.35	3.13	2.77
Nearfield	WF044	4/7-9	0.66	1.56	1.03
Offshore	WF044	4/7-9	1.15	2.77	1.73
All	ALL		0.66	3.90	1.82
Boundary	WF047	6/14-17	0.12	0.44	0.23
Cape Cod Bay	WF047	6/14-17	0.12	3.04	0.92
Coastal	WF047	6/14-17	0.12	1.92	0.80
Harbor	WF047	6/14-17	0.79	4.00	2.22
Nearfield	WF047	6/14-17	0.12	0.90	0.32
Offshore	WF047	6/14-17	0.12	1.14	0.33
All	ALL		0.12	4.00	0.80

Table 3-10. Summary of production parameters alpha and Pmax data for February - June 2004. 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	WF041	2/3	0.008	0.018	0.012	0.99	2.07	1.32
Nearfield	WF042	2/25	0.014	0.058	0.032	1.60	4.43	2.84
Nearfield	WN043	3/23	0.021	0.131	0.060	1.95	11.05	5.80
Nearfield	WF044	4/8	0.120	0.235	0.160	9.50	19.30	13.58
Nearfield	WN046	5/14	0.013	0.089	0.037	1.60	5.98	3.37
Nearfield	WF047	6/17	0.004	0.050	0.021	0.70	4.26	2.13
Nearfield	ALL		0.004	0.235	0.054	0.70	19.30	4.84
Boundary	WF041	2/2-5						
Cape Cod Bay	WF041	2/2-5						
Coastal	WF041	2/2-5						
Harbor	WF041	2/2-5	0.013	0.042	0.023	1.33	2.05	1.74
Nearfield	WF041	2/2-5	0.008	0.018	0.012	0.99	2.07	1.32
Offshore	WF041	2/2-5						
All	ALL		0.013	0.042	0.018	0.99	2.07	1.53
Boundary	WF042	2/23-25						
Cape Cod Bay	WF042	2/23-25						
Coastal	WF042	2/23-25						
Harbor	WF042	2/23-25	0.054	0.109	0.080	4.78	6.32	5.76
Nearfield	WF042	2/23-25	0.014	0.058	0.032	1.60	4.43	2.84
Offshore	WF042	2/23-25						
All	ALL		0.014	0.109	0.056	1.60	6.32	4.30
Boundary	WF044	4/7-9						
Cape Cod Bay	WF044	4/7-9						
Coastal	WF044	4/7-9						
Harbor	WF044	4/7-9	0.099	0.320	0.207	17.80	27.70	23.12
Nearfield	WF044	4/7-9	0.120	0.235	0.160	9.50	19.30	13.58
Offshore	WF044	4/7-9						
All	ALL		0.099	0.320	0.184	9.50	27.70	18.35
Boundary	WF047	6/14-17						
Cape Cod Bay	WF047	6/14-17						
Coastal	WF047	6/14-17						
Harbor	WF047	6/14-17	0.044	0.128	0.067	4.45	16.77	9.29
Nearfield	WF047	6/14-17	0.004	0.050	0.021	0.70	4.26	2.13
Offshore	WF047	6/14-17						
All	ALL		0.004	0.128	0.044	0.70	16.77	5.71

Table 3-11. Summary of areal production, depth-averaged chlorophyll-specific production, and respiration data for February - June 2004. 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 ($mgCmgChl a^{-1}d^{-1}$)			Respiration (μMO_2h^{-1})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF041	2/3	116.5	135.6	126.1	5.3	8.1	6.7	0.007	0.019	0.012
Nearfield	WF042	2/25	765.3	902.8	834.1	21.4	28.8	25.1	0.006	0.058	0.025
Nearfield	WN043	3/23	410.8	1366.6	888.7	6.1	13.6	9.9	0.039	0.091	0.064
Nearfield	WF044	4/8	1336.6	2175.0	1755.8	10.4	11.8	11.1	0.051	0.137	0.088
Nearfield	WN046	5/14	512.8	743.3	628.1	7.9	9.0	8.4	0.060	0.162	0.106
Nearfield	WF047	6/17	472.6	690.0	581.3	16.6	18.8	17.7	0.085	0.120	0.099
Nearfield	ALL		116.5	2175.0	802.3	5.3	28.8	13.2	0.007	0.162	0.066
Boundary	WF041	2/2-5									
Cape Cod Bay	WF041	2/2-5									
Coastal	WF041	2/2-5									
Harbor	WF041	2/2-5	154.9	154.9	154.9	16.6	16.6	16.6	0.034	0.039	0.038
Nearfield	WF041	2/2-5	116.5	135.6	126.1	5.3	8.1	6.7	0.007	0.019	0.012
Offshore	WF041	2/2-5							0.006	0.024	0.012
All	ALL		116.5	154.9	140.5	5.3	16.6	11.7	0.006	0.039	0.021
Boundary	WF042	2/23-25									
Cape Cod Bay	WF042	2/23-25									
Coastal	WF042	2/23-25									
Harbor	WF042	2/23-25	860.8	860.8	860.8	16.2	16.2	16.2	0.038	0.050	0.044
Nearfield	WF042	2/23-25	765.3	902.8	834.1	21.4	28.8	25.1	0.006	0.058	0.025
Offshore	WF042	2/23-25							0.007	0.014	0.010
All	ALL		765.3	902.8	847.4	16.2	28.8	20.7	0.007	0.058	0.026
Boundary	WF044	4/7-9									
Cape Cod Bay	WF044	4/7-9									
Coastal	WF044	4/7-9									
Harbor	WF044	4/7-9	1099.6	1099.6	1099.6	7.9	7.9	7.9	0.101	0.137	0.119
Nearfield	WF044	4/7-9	1336.6	2175.0	1755.8	10.4	11.8	11.1	0.051	0.137	0.088
Offshore	WF044	4/7-9							0.059	0.129	0.101
All	ALL		1099.6	2175.0	1427.7	7.9	11.8	9.5	0.051	0.137	0.103
Boundary	WF047	6/14-17									
Cape Cod Bay	WF047	6/14-17									
Coastal	WF047	6/14-17									
Harbor	WF047	6/14-17	1302.8	1302.8	1302.8	14.6	14.6	14.6	0.086	0.209	0.156
Nearfield	WF047	6/14-17	472.6	690.0	581.3	16.6	18.8	17.7	0.085	0.120	0.099
Offshore	WF047	6/14-17							0.010	0.076	0.048
All	ALL		472.6	1302.8	942.1	14.6	18.8	16.1	0.010	0.209	0.101

Table 3-12. Summary of total phytoplankton, centric diatoms, and total zooplankton data for February - June 2004.

			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	WF041	2/3	0.458	0.999	0.682	0.003	0.016	0.008	5579	8191	7236
Nearfield	WF042	2/25	0.414	0.835	0.645	0.001	0.012	0.006	12503	17067	14903
Nearfield	WN043	3/23	1.737	6.722	4.441	0.007	0.053	0.034	7618	22412	15015
Nearfield	WF044	4/8	3.594	14.214	9.415	0.001	0.086	0.021	13631	26736	21901
Nearfield	WN046	5/14	0.967	2.674	1.930	0.005	0.036	0.023	24833	31249	28041
Nearfield	WF047	6/17	0.769	2.243	1.226	0.000	0.052	0.018	21144	45094	29888
Nearfield	ALL		0.414	14.214	3.057	0.000	0.086	0.018	5579	45094	19497
Boundary	WF041	2/2-5	0.475	0.862	0.617	0.001	0.004	0.003	5030	14855	9943
Cape Cod Bay	WF041	2/2-5	0.815	1.347	1.109	0.019	0.067	0.044	3471	22739	13974
Coastal	WF041	2/2-5	0.680	1.380	0.875	0.003	0.008	0.006	2569	6108	4719
Harbor	WF041	2/2-5	0.583	1.273	0.957	0.002	0.040	0.012	6252	7511	7083
Nearfield	WF041	2/2-5	0.458	0.999	0.682	0.003	0.016	0.008	5579	8191	7236
Offshore	WF041	2/2-5	0.342	0.868	0.591	0.002	0.008	0.005	4166	9334	6750
All	ALL		0.342	1.380	0.805	0.001	0.067	0.013	2569	22739	8284
Boundary	WF042	2/23-25	0.674	0.829	0.750	0.001	0.006	0.004	1476	3253	2365
Cape Cod Bay	WF042	2/23-25	1.040	1.388	1.262	0.126	0.182	0.164	6924	25693	16418
Coastal	WF042	2/23-25	0.648	1.081	0.842	0.014	0.051	0.032	10651	28939	17425
Harbor	WF042	2/23-25	0.585	1.004	0.811	0.025	0.131	0.076	13054	20619	17421
Nearfield	WF042	2/23-25	0.414	0.835	0.645	0.001	0.012	0.006	12503	17067	14903
Offshore	WF042	2/23-25	0.425	0.787	0.566	0.002	0.010	0.006	6304	12821	9562
All	ALL		0.414	1.388	0.813	0.001	0.182	0.048	1476	28939	13016
Boundary	WF044	4/7-9	3.151	9.311	6.563	0.001	0.004	0.003	5677	13941	9809
Cape Cod Bay	WF044	4/7-9	2.770	8.490	5.530	0.001	0.002	0.001	28701	86213	54418
Coastal	WF044	4/7-9	7.315	16.814	12.620	0.001	0.010	0.004	3200	10119	6170
Harbor	WF044	4/7-9	11.540	15.855	13.038	0.003	0.016	0.008	2504	3536	3119
Nearfield	WF044	4/7-9	3.594	14.214	9.415	0.001	0.086	0.021	13631	26736	21901
Offshore	WF044	4/7-9	8.377	13.790	10.275	0.001	0.005	0.003	13984	14269	14126
All	ALL		2.770	16.814	9.574	0.001	0.086	0.007	2504	86213	18257
Boundary	WF047	6/14-17	0.425	0.927	0.627	0.000	0.002	0.001	22638	31979	27309
Cape Cod Bay	WF047	6/14-17	0.565	1.392	1.021	0.000	0.000	0.000	22392	22392	22392
Coastal	WF047	6/14-17	1.185	2.954	2.009	0.001	0.078	0.031	18567	26713	22814
Harbor	WF047	6/14-17	1.205	2.740	2.022	0.019	0.068	0.049	28686	38664	35187
Nearfield	WF047	6/14-17	0.769	2.243	1.226	0.000	0.052	0.018	21144	45094	29888
Offshore	WF047	6/14-17	0.506	1.332	0.814	0.000	0.004	0.002	27389	27786	27588
All	ALL		0.425	2.954	1.287	0.000	0.078	0.017	18567	45094	27530

Table 3-13. Summary of *Alexandrium* spp., *Phaeocystis pouchetii*, and *Pseudo-nitzschia pungens* data for February - June 2004.

			Alexandrium spp. (cells L^{-1})			*Phaeocystis pouchetii* (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	WF041	2/3	0	0	0	0	0	0	0	0.0002	0.0000
Nearfield	WF042	2/25	0	0	0	0	0	0	0	0	0
Nearfield	WN043	3/23	0	0	0	0.972	6.042	3.747	0	0	0
Nearfield	WF044	4/8	0	0	0	2.934	11.228	8.015	0	0	0
Nearfield	WN046	5/14	0	0	0	0.230	1.270	0.822	0	0	0
Nearfield	WF047	6/17	0	4.7	0.8	0	0	0	0	0.0019	0.0003
Nearfield	ALL		0	4.7	0.1	0	11.228	2.097	0	0.0019	0.0001
Boundary	WF041	2/2-5	0	0	0	0	0	0	0	0.0001	0.0000
Cape Cod Bay	WF041	2/2-5	0	0	0	0	0	0	0	0	0
Coastal	WF041	2/2-5	0	0	0	0	0	0	0	0	0
Harbor	WF041	2/2-5	0	0	0	0	0	0	0	0.0001	0.0000
Nearfield	WF041	2/2-5	0	0	0	0	0	0	0	0.0002	0.0000
Offshore	WF041	2/2-5	0	0	0	0	0	0	0	0.0001	0.0000
All	ALL		0	0	0	0	0	0	0	0	0.0000
Boundary	WF042	2/23-25	0	0	0	0	0	0	0	0	0
Cape Cod Bay	WF042	2/23-25	0	0	0	0	0	0	0	0	0
Coastal	WF042	2/23-25	0	0	0	0	0	0	0	0	0
Harbor	WF042	2/23-25	0	0	0	0	0	0	0	0	0
Nearfield	WF042	2/23-25	0	0	0	0	0	0	0	0	0
Offshore	WF042	2/23-25	0	0	0	0	0	0	0	0	0
All	ALL		0	0	0	0	0	0	0	0	0
Boundary	WF044	4/7-9	0	0	0	2.434	8.836	5.921	0	0	0
Cape Cod Bay	WF044	4/7-9	0	0	0	2.022	5.358	3.139	0	0	0
Coastal	WF044	4/7-9	0	0	0	6.435	15.533	11.673	0	0	0
Harbor	WF044	4/7-9	0	0	0	10.219	13.894	11.662	0	0	0
Nearfield	WF044	4/7-9	0	0	0	2.934	11.228	8.015	0	0	0
Offshore	WF044	4/7-9	0	0	0	7.872	13.076	9.607	0	0	0
All	ALL		0	0	0	2.022	15.533	8.336	0	0	0
Boundary	WF047	6/14-17	0	12.0	4.0	0	0	0	0	0	0
Cape Cod Bay	WF047	6/14-17	0	6.9	1.7	0	0	0	0	0	0
Coastal	WF047	6/14-17	0	2.2	0.4	0	0	0	0	0.0010	0.0002
Harbor	WF047	6/14-17	0	3.7	0.6	0	0	0	0	0	0
Nearfield	WF047	6/14-17	0	4.7	0.8	0	0	0	0	0.0019	0.0003
Offshore	WF047	6/14-17	0	7.9	2.0	0	0	0	0	0	0
All	ALL		0	12.0	1.6	0	0	0	0	0	0.0001

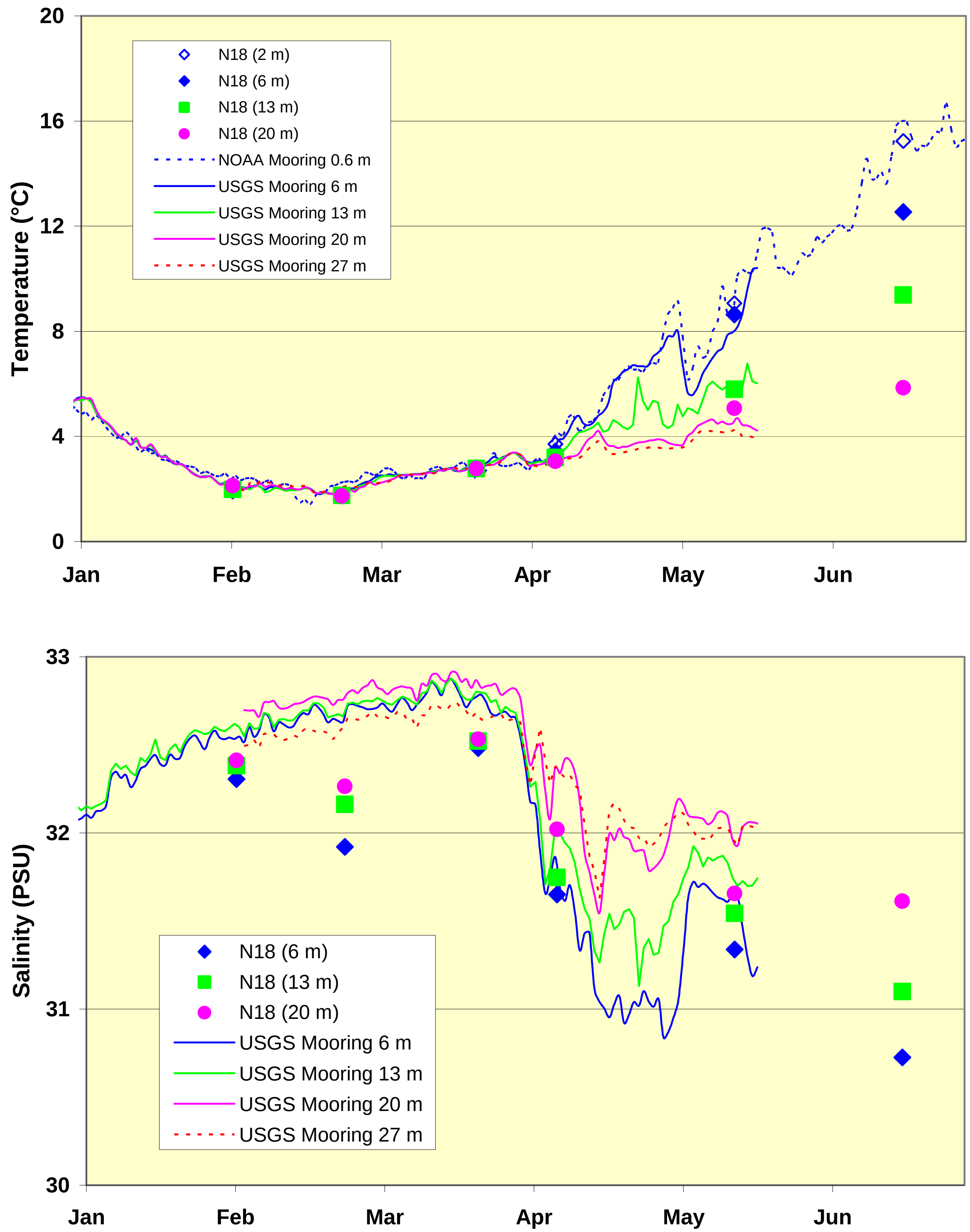


Figure 3-1. USGS Temperature and salinity mooring data compared with station N18 data.

(Note: The 20-m and 27-m conductivity sensor failed during the September 2003 to February 2004 deployment and the data from the May to September 2004 deployment was not available at time of submission.)

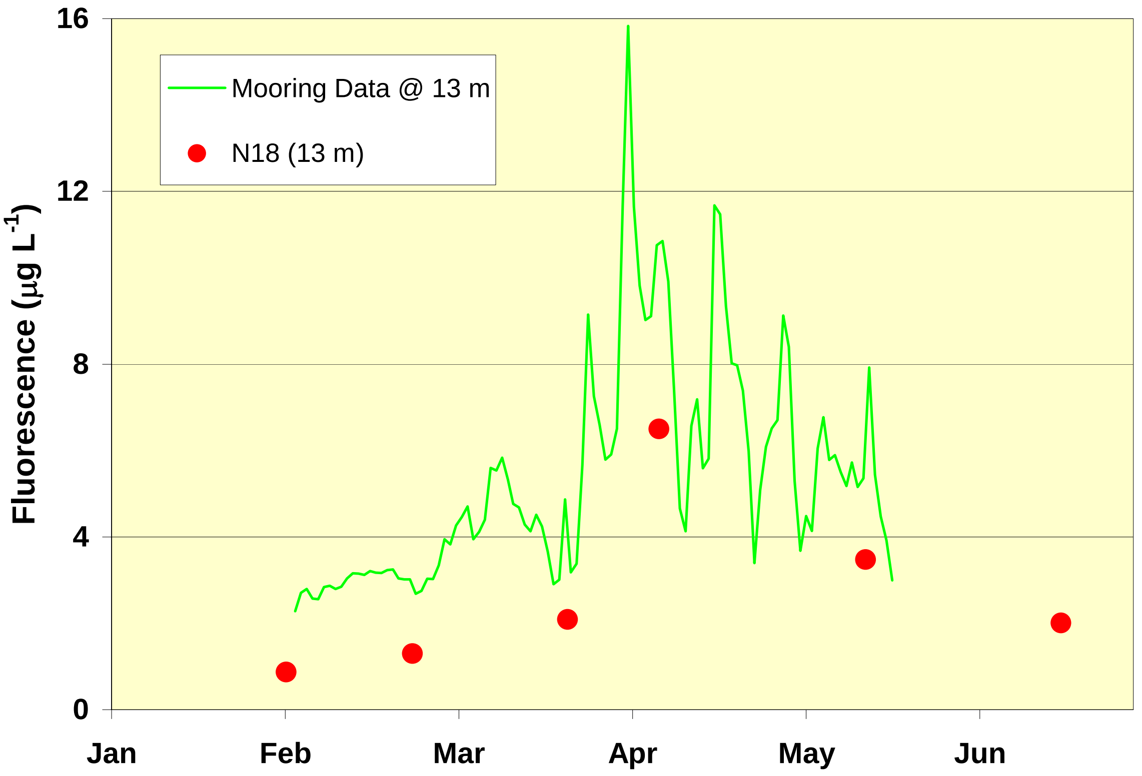


Figure 3-2. MWRA and Battelle *In Situ* Wetstar fluorescence data – MWRA data acquired at ~13 m on USGS mooring and Battelle data acquired at 13 m at station N18.

(Note that the data from the September 2003 to February 2004 and May to September 2004 deployments were compromised and efforts are underway at USGS to recover some information)

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 two nearfield only surveys. This represents a reduction in the number of winter/spring nearfield surveys as the late April survey (WN0X5) has been removed from the monitoring program. The first two combined surveys were conducted in early and late February (WF041 and WF042 respectively) during well-mixed winter conditions. Early indications of stratification were seen in some areas in April (WF044) and in the nearfield in May (WN046). Temperature and salinity data from the USGS mooring suggest that the onset of stratification in the nearfield occurred in mid to late April after the early April survey was conducted (see **Figure** 3-1). By June (WF047), a strong pycnocline was observed throughout the bays.

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** 1-2). 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. 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 in May (WN046; **Figure** 4-1). Stratification throughout the entire nearfield area did not set up until June (WN047), when a strong pycnocline was established throughout the bays.

4.1.1.1 Horizontal Distribution

Air temperatures in January were the coldest on record since 1893 (NWS Logan), which contributed to extremely cold surface water temperatures across Massachusetts and Cape Cod Bays in early

February (-0.97 – 2.91 °C). Surface water temperatures continued to be very cold during the late February survey (0.10 – 3.8°C, see Appendix A). There was a clear inshore to offshore temperature gradient across this area with the coldest waters in Boston Harbor, shallow coastal and Cape Cod Bay waters while slightly warmer surface waters were located further offshore. Surface water salinity also exhibited an inshore to offshore increase during the February surveys. Lower salinity waters were observed in Boston Harbor and southern coastal waters, with a gradient extending out to the offshore and boundary stations (see Appendix A).

In April (WF044), surface water temperatures had increased (3.07 – 5.37°C). The gradient had also changed. The coldest waters were found in Cape Cod Bay. The clearest 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 near Cape Ann, but salinities of <30 PSU were also observed in Boston Harbor. Both the Merrimack and Charles Rivers were at peak flow for the report period in early April (48,200 cfs and 1,470 cfs respectively). As expected, these peak freshwater flows were coincident with the peak precipitation for the report period of 4.22 inches on April 1 (**Figure** 4-3). The increased nutrient inputs to the system during the April storm events and resulting high flow conditions likely contributed to the major *Phaeocystis* bloom observed throughout the bays in April. During January, February, and March precipitation had been well below normal with the three month cumulative values at state-wide average of only 55% of normal (http://www.mass.gov/dem/programs/rainfall/). However, this precipitation deficit was made up quickly in April when 183% of the normal state-wide precipitation was received.

By June (WF047), surface water temperature had increased considerably across the survey area to a range of 11.39 to 16.84°C. Surface temperatures were generally homogeneous across the area with no clear gradients present. Salinity in the surface waters was homogeneous across the bays (30.18 to 30.96 PSU). Stream flow had decreased to more normal levels in May and June although precipitation was well below normal in June.

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. The coldest temperatures (≤1°C) were observed in harbor, coastal, and Cape Cod Bay waters where 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 with increasing salinities. This created a slight density gradient throughout the bays. This transition towards stratification was most pronounced at the deeper offshore and boundary stations where salinity differences began to create the density gradient. By June, typical 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). Throughout February there was little variation in these parameters over the water column, although there was a slight freshwater signature along the south coast and in the harbor. By April (WF044), while temperatures remained cold, surface salinity decreased resulting in larger density gradients setting 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 2004. The dramatic increase in freshwater inputs in April initiated stratification. This was followed by a ~10°C increase in surface water temperatures which 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 mid May (WN046). In 2003, and in other years, this transition has occurred somewhat earlier and the progression has been captured by the early and late April surveys. Although the late April survey has been discontinued from the sampling program, the initiation of stratification can be seen in data collected at the USGS mooring located to the south of the outfall in the nearfield (see **Figure** 3-1). The temperature and salinity data from the mooring suggest that the onset of stratification occurred in mid to late April after the early April survey (WF044) was conducted). The early stages of stratification were dominated by the salinity gradient, as temperatures were still cold and relatively homogeneous throughout the water column in April (**Figures** 4-7 and 4-8). By May, both salinity and temperature were beginning to develop gradients in the water column which set the stage for strong stratification in June resulting from increasingly warm surface waters and limited mixing.

Higher temporal resolution salinity and temperature data are available from the USGS mooring in the nearfield (see **Figure** 3-1). The mooring data compares very well with the temperature data, showing the extremely low water temperatures through February and the development of stratification from April through May and into June. Salinity data from the mooring follows the same trends as the survey data, although values from the mooring are somewhat higher. Both capture the freshwater signature from the large storm event in early April.

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 was generally low and homogenous throughout the area (0.60 – 1.08 m^{-1}; see Appendix A). By late February, slightly elevated surface water beam attenuation values (>1.2 m^{-1}) were measured in Boston Harbor, coastal and Cape Cod Bay waters (max = 1.69 m^{-1} at station F03). This was coincident with increasing chlorophyll values observed in these areas. By April, beam attenuation values had increased to a range of 0.89 – 2.38 m^{-1} with the highest values found in the harbor and levels generally decreasing towards the boundary stations. This corresponded to highly elevated fluorescence and phytoplankton abundance during the major, system wide *Phaeocystis* bloom (see Appendix A and Section 5). 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).

In June, surface beam attenuation remained elevated in the harbor but declined in all other areas. During the June survey (WF047), 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** 4-10).

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 2004 is 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 2004 generally followed the typical progress of seasonal events in Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in February when the water column was well mixed and biological uptake of nutrients was limited. Concentrations were generally similar in Massachusetts Bay during both February surveys, but there was a slight decrease in concentration inside Cape Cod Bay in late February when the diatoms began to increase. By mid March (WN043), nearfield nutrient concentrations had decreased suggesting that a bloom may have occurred earlier in the month. By the April survey all surface water nutrient concentrations had decreased drastically in all areas. This was the result of the major *Phaeocystis* bloom in April. By June (WF047), nutrient concentrations in the surface waters were depleted throughout the entire study area, with the exception of stations F18 and N01 near Nahant, where all nutrients were at elevated concentrations relative to the rest of the area.

In the nearfield, nutrient levels decreased in the surface waters as stratification was developing. Nutrient concentrations in the nearfield surface waters declined dramatically with the onset of the *Phaeocystis* bloom in April and were generally depleted throughout much of the nearfield region by mid May. 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 May into June 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. 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 (WF041). In February, the highest NH_4 and PO_4 concentrations were generally found in the outfall area with the remaining survey areas slightly lower and homogeneous (see Appendix A). The highest SiO_4 and NO_3 concentrations tended to be found offshore at boundary stations and in Boston Harbor. In general, the nutrient concentrations measured during the two February surveys were higher than have typically been seen in the past and may have been due to meterological/oceanographic conditions and lower biological utilization due to the lack of an early winter/spring diatom bloom in Massachusetts Bay.

In April, a series of physical and biological factors resulted in substantial changes in surface nutrient distribution. The differing impacts of these factors are illustrated in contour plots of SiO_4 and NO_3 across the bays (**Figures** 4-11 and 4-12). From February to April, nutrient levels had decreased dramatically. In April, the highest concentrations were found in Boston Harbor and in Cape Cod Bay. The elevated SiO_4 concentrations in Boston Harbor were the result of very high precipitation and stream flow levels which brought terrestrial nutrients into the region. Moderate SiO_4 concentrations were also seen along the Boundary stations as a result of increased Merrimack River flows. The extremely high *Phaeocystis* abundances that were measured at these stations and others in Massachusetts Bay kept NO_3 levels very low. The elevated NO_3 concentrations in Cape Cod Bay (station F01) resulted from a combination of increased runoff and lower *Phaeocystis* numbers as compared to the other survey areas.

By June (WF047), nutrients were generally depleted in the surface waters throughout the bays, except for stations F18 and N01 near Nahant (discussed below). Silicate had decreased considerably from winter levels but remained available in surface waters at concentration of 1.3 – 5.1 µM. The low nutrient concentrations in June were coincident with low chlorophyll concentrations and are typical of stratified summer conditions in the bays.

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, Cohassett, 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. Throughout February (WF041 and WF042), NO_3 concentrations were >7 across the entire Boston-Nearfield transect (**Figure** 4-13). Silicate and phosphate (PO_4) were also present in at high concentrations. The measurements of SiO_4 and NO_3 concentrations >10 µM throughout the water column during these surveys is high compared to previous years and is likely due to influences of offshore waters and the very low levels of biological utilization in winter 2004. Ammonium concentrations were generally low and only elevated in the effluent plume in the nearfield.

By April (WF044) nutrient concentrations were low in the surface waters along the transects and depleted throughout the nearfield portions, (**Figure** 4-13) except for SiO_4 (see Appendix B). Weak stratification was just beginning to develop in the farfield by this time and reduced mixing of the water column combined with the *Phaeocystis* bloom resulted in the depletion of nutrients (except SiO_4) in surface waters. A strong fluorescence signal was concomitant with these areas of decreasing nutrients (see **Figure** 4-9). A clear effluent signal surfacing through the weak stratification was apparent for both NH_4 and PO_4 in the nearfield. In June (WF047) nutrient levels, except for SiO_4, were generally depleted in the surface waters along each of the transects (**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 an effluent signal below the pycnocline in the outfall area.

The main exception to this trend in June was the elevated concentrations observed at stations F18 and N01 near Nahant. Nutrient data along the Nearfield-Marshfield transect show a gradient of high nutrients at stations F18, N01 and N20 before decreasing rapidly south of the outfall area at station N18 suggesting that the outfall may have been one of the sources of nutrients (**Figure** 4-14). All dissolved inorganic nutrient concentrations were elevated in the surface waters at stations F18 and N01, which suggests that the outfall was not the only contributor. The elevated NH_4 and PO_4 were likely due to the outfall plume, but the higher NO_3 and SiO_4 were more likely to have been associated with ambient bottom water concentrations. This suggests that upwelling may have supplied these nutrients to the surface waters at these stations to the northwest of the outfall. Physical data along this same transect show somewhat weaker stratification in this area, with slightly elevated salinities and slightly lower temperatures (**Figure** 4-15). Winds were generally out of the west during the survey period which favors upwelling in this region. This suggests that upwelling may have been occurring in this area allowing deeper, nutrient rich waters to mix into the surface layers and also entraining the effluent plume. Upwelling signatures, however, were not seen at other coastal areas during this time. Therefore, it is possible that other factors such as terrestrial sources (other than the MWRA outfall) or regeneration of nutrients from the senescent *Phaeocystis* biomass may have contributed to elevated nutrients.

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** 4-16). There was no apparent relationship between DIN and salinity as concentrations remained relatively constant (9-15 µM) over an inshore to offshore range of 31 to 33 PSU. The difference between the bays was somewhat evident, although not as apparent as in previous years. There were clear salinity differences with harbor and coastal stations lower than the offshore and boundary stations. Nutrients levels were generally well distributed except for the effluent plume signal of elevated DIN (as NH_4) concentrations in the nearfield. Very little change in the DIN/salinity relationship was observed in late February. DIN concentrations had diminished slightly in the harbor and Cape Cod Bay, but overall salinities and nutrient levels remained the same as earlier in the month.

By April, the DIN versus salinity signal exhibited a slight inverse relationship at the Boston Harbor and some coastal stations due to increased DIN concentrations in low salinity water (<31 PSU), which was likely associated with runoff (**Figure** 4-17a). In other areas surface water concentrations became depleted 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. 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** 4-17b).

Throughout the first half of 2004, surface waters were relatively low in available DIN as compared to PO_4. Based on Redfield ratios, DIN levels in February were low relative to PO_4 and SiO_4 but concentrations of all nutrients were high and certainly not growth limiting. It was not until April that many areas became limited by nitrogen availability. In general, coastal, Cape Cod Bay, and offshore areas were the most limited. By June, surface water nitrogen levels were limiting throughout most of the bays and SiO_4 concentrations were decreasing but still remained available.

Nearfield. The nearfield surveys are conducted more frequently and provide higher 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 nutrient concentrations over time at five representative nearfield stations – N01, N04, N18, N10 and N07. These stations represent each of the four corners and the center of the nearfield "box". Station N18 is located to the south of the outfall and contours of the nutrients from that station are shown as an example of the trends in **Figure** 4-18. In general, nutrients throughout the nearfield did not start declining until the March survey, although a slight decrease was seen in late February in the surface waters at station N10. In March, the decrease in NO_3 was limited, but there was a commensurate decrease in SiO4 suggesting that diatoms may have bloomed earlier in March prior to *Phaeocystis* dominating the phytoplankton assemblage (**Figure** 4-18). By April, with the onset of stratification and the *Phaeocystis* bloom at its peak, substantial changes in nutrient concentrations were observed. Nitrate levels were depleted in the surface waters across the entire nearfield and only the deeper waters (>20m) contained any significant amounts of NO_3. Phosphate, like NO_3, did not change noticeably until late March. Concentrations of PO_4 rebounded somewhat in June, although surface waters remained low. Silicate concentrations actually increased from March to April as the *Phaeocystis* bloom progressed. Ammonium concentrations were generally low throughout the nearfield water column in February at stations N01, N04, N07 and N10 away from the outfall. At station N18, concentrations of NH_4 (and PO_4) were high in February, decreased in March/April during the *Phaeocystis* bloom, and then increased in bottom waters after the senescence of the bloom and the onset of stratification (**Figure** 4-18). In June, as discussed previously, there was also a fairly strong nutrient signal moving into the northwestern portion of the nearfield in the surface and near surface waters.

The usefulness of NH_4 as a tracer of the effluent plume has been shown for previous monitoring periods (e.g. Libby *et al.* 2004). 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 the winter, elevated NH_4 concentrations, representing the effluent plume, can be seen rising through the water column, spreading as it ascends. This is typical of the NH_4/effluent dynamics under well-mixed conditions. Once stratification sets up later in the spring and early summer, a strong NH_4/effluent signal rises from the outfall and is trapped below the pycnocline, spreading horizontally in the deeper waters.

4.2.2 Chlorophyll a

The highest chlorophyll concentrations of the semiannual period were recorded in the nearfield in April during the *Phaeocystis* 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 2004 was 101mg m^{-2}, which is less than half the seasonal caution threshold of 238 mg m^{-2} (note threshold values revised based on new survey schedule in 2004). This marks a return to lower winter/spring values seen in 2001 and 2002 in comparison to the high seasonal value measured in 2003 when there was both a diatom and *Phaeocystis* bloom. Even with the extraordinarily high *Phaeocystis* abundance and long duration of the bloom in 2004, the areal chlorophyll values seen winter/spring 2004 do not compare to those measured during previous years with major winter/spring blooms – 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

2004 had a major regional *Phaeocystis* bloom, the chlorophyll concentrations were not exceedingly high. There appears to be a difference in the ecological dynamics associated with winter/spring diatom and *Phaeocystis* blooms. This will be examined in more detail in the 2004 annual report.

4.2.2.1 Horizontal Distribution

Surface chlorophyll concentrations were l generally very low (<1 μgL^{-1}) across most of the region during both February surveys. The only location with a concentration greater than 3 μgL^{-1} was station F03 near Plymouth (4.49 μgL^{-1}) during the second February survey. Surface fluorescence in April was <3 μgL^{-1} in most areas, although near the harbor concentration increased considerably reaching a maximum of 7.20 μgL^{-1} at F31. Considering the magnitude of the *Phaeocystis* bloom in April, the surface values were fairly low. Bloom concentrations, and the associated fluorescence, were somewhat higher at the mid-depth sampling level with concentrations ranging from 2.26 to 10.14 μgL^{-1} (**Figure** 4-19). The highest concentrations were observed in the harbor and coastal waters where *Phaeocystis* abundance was >10 million cells L^{-1}. These details are discussed further below under "vertical distribution" and in Section 5. By June, surface fluorescence dropped to very low levels (<1μgL^{-1}) throughout the bays, although harbor stations ranged from 3.6 to 6.8μgL^{-1}.

The fluorescence trends over the first six months of 2004 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 elevated in Cape Cod Bay and southeastern Massachusetts Bay in January. This event occurred earlier in the year than the surveys discussed in this report. Through February, fluorescence decreased considerably and only in Cape Cod Bay were values even moderately elevated. In March, areas of high fluorescence were expanding out of Cape Cod Bay and emerging in the north around Cape Ann. This was the onset of the *Phaeocystis* bloom that was detected on subsequent surveys and can be seen in the March nearfield data (discussed below and in Section 5). Phytoplankton data from the Center for Coastal Studies indicates that *Phaeocystis* was increasing in abundance by early to mid March in Cape Cod Bay. Nutrient data collected in March in the nearfield suggests that diatoms may have increased in abundance earlier in the month as both NO_3 and SiO_4 concentrations had decreased from late February levels. By early April, the system wide bloom can be seen with high fluorescence values throughout all report areas and extending well to the south of Cape Cod. The combination of SeaWiFS images and monitoring data (fluorescence, phytoplankton and productivity) illustrate the spatial and temporal progression of the winter/spring bloom in 2003 which was dominated by the *Phaeocystis* bloom. The SeaWiFS images show an abrupt end to the chlorophyll signal from the *Phaeocystis* bloom by mid to late April. Throughout May and June the satellite data shows very little fluorescence throughout the region, which corresponds to low phytoplankton abundance and low *in situ* fluorescence measurements.

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 and 4-10. In February, chlorophyll concentrations were low in all areas. The only, even slightly, elevated concentrations (2-4 μgL^{-1}) were found east of Scituate at station F07. Dramatic increases in fluorescence were seen along all transects during the April survey (see **Figure** 4-9 and Appendix B). The highest concentrations were generally found at approximately 15m, although in the shallow areas in and near Boston Harbor the entire water column had fluorescence values in excess of 8 μgL^{-1}. This broad layer of high fluorescence thinned somewhat further offshore although concentrations were still >5μgL^{-1} out to the boundary stations (**Figure** 4-9). These concentrations and distributions compared well with the plankton abundance data. During the

April survey, mid-depth phytoplankton counts exceeded 10 million cells L^{-1} in most areas, and even at boundary and offshore locations abundance was >8 million cells L^{-1}.

By June, phytoplankton abundance had decreased substantially across most of the survey area. At all depths along each of the farfield transects fluorescence was low. The highest concentrations (3-5 μgL^{-1}) were observed in the surface waters near Boston Harbor (**Figure** 4-10). Along the pycnocline there was a subtle fluorescence signature (>1μgL^{-1}) as compared to the rest of the water column (<1μgL^{-1}). 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 the early stages of the bloom that was developing between the late February and early April farfield surveys. As observed for the rest of Massachusetts Bay, chlorophyll concentrations were relatively low (~2 μgL^{-1}) throughout February (**Figure** 4-20). By March, the start for the *Phaeocystis* bloom led to a considerable increase of chlorophyll concentrations in the nearfield across all depths. By early April, the *Phaeocystis* bloom was at its peak and both chlorophyll and production reached seasonal maxima for the nearfield (see **Figure** 5-2). Mean nearfield concentrations at the mid-depth reached a period high of 7 μgL^{-1}. There was also a sharp increase in chlorophyll concentrations in the bottom waters from mid March to April that was coincident with an increase in bottom water phaeophytin as a percentage of total pigments, which is indicative of senescent cells. Although peak bloom concentrations, rates and *Phaeocystis* abundance were measured in April, it appears that the bloom may have already begun to senesce and settle out of the water column. Phytoplankton abundance and fluorescence declined in May, and continued the trend into June where levels returned to early season values.

4.2.3 Dissolved Oxygen

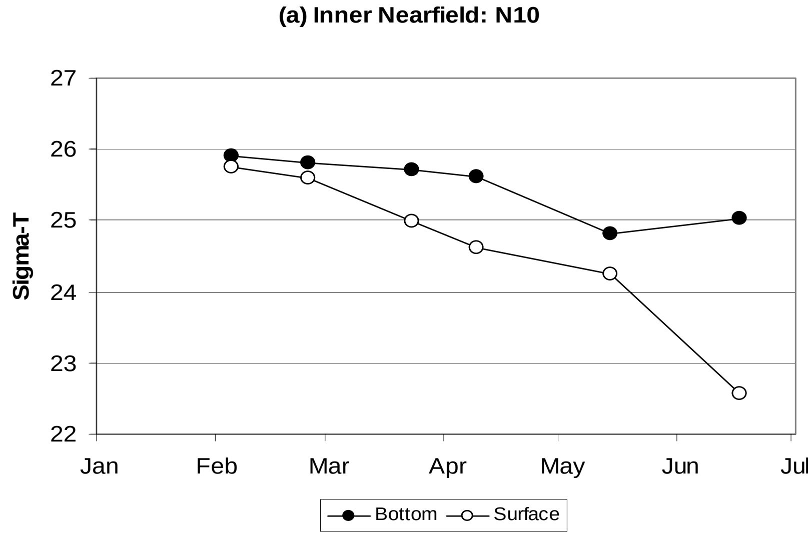
Spatial and temporal trends in dissolved oxygen (DO) concentrations were evaluated for the entire region. Due to the relative importance of identifying low DO conditions, bottom water DO minima were examined for the water sampling events. DO concentrations were within the range of values observed during previous years. The minimum DO concentration of 8.31 mgL^{-1} was measured in Cape Cod Bay in June. The nearfield minimum DO concentration of 8.95 mgL^{-1} was also observed in June. The June 2004 bottom water concentrations were fairly consistent across the survey area.

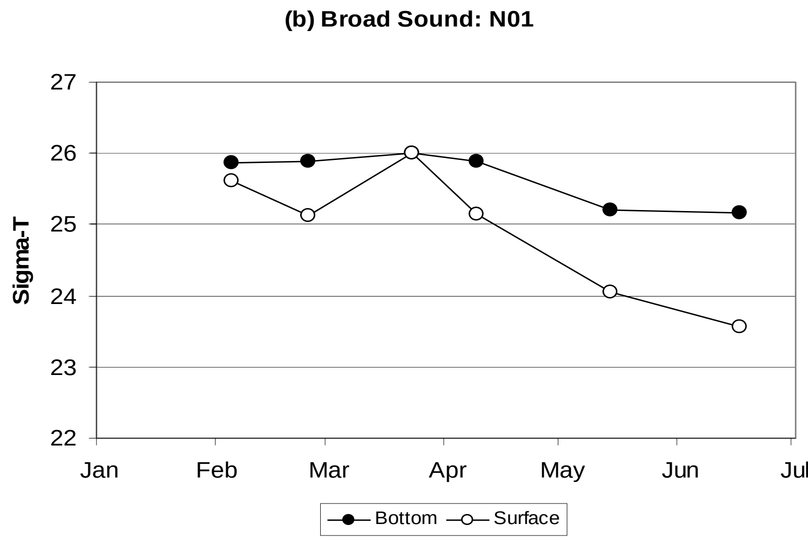
The DO in bottom waters was compared among areas and over the course of the February to June time period. Mean bottom water DO concentrations ranged from a high of 12 mgL^{-1} in Boston Harbor in April to a low of 8.6 mgL^{-1} in Cape Cod Bay in June (**Figure** 4-21a). In general, bottom water DO concentrations rose somewhat from February to a peak in April, with only Cape Cod Bay peaking in late February. Lower concentrations were observed at the deeper offshore and boundary areas over the first three farfield surveys than in the other areas. By April, the *Phaeocystis* bloom was at its peak with elevated concentrations through the water column resulting in increased bottom water DO concentrations throughout Massachusetts Bay. The *Phaeocystis* bloom crashed in mid to late April coincident with the onset of stratification. The combination led to a rapid decrease in mean bottom water DO throughout all areas by June. All regions registered the lowest concentration of the report period during June (<10 mgL^{-1}) and lower concentrations were measured in the shallow waters of Cape Cod Bay, Boston Harbor and coastal areas compared to the nearfield, offshore and boundary stations.

Dissolved oxygen measurements throughout the area during the first half of 2004 are typical of the trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the phytoplankton blooms in the bays. This trend in bottom water DO was also apparent in the DO %saturation data (**Figure** 4-21b). DO % saturation increased from February to April in each of the survey areas. Bottom waters were saturated to supersaturated during the February surveys and were supersaturated in all areas during the April survey. Following the crash of the *Phaeocystis* bloom, DO %saturation in the bottom waters declined rapidly to a minimum in June. However, DO %saturation remained fairly high even in June with only Cape Cod Bay station below 90%.

4.3 Summary of Water Column Results

- Precipitation levels were low for the first three months of the year. However the deficit was made up quickly with large rain events in early April. This resulted in a large spring freshet as river flow was well above normal levels in April.
- Stratification occurred relatively late in the year, and fully stratified conditions were not measured throughout the area until the June survey. However, the early stages of stratification were developing in early April and most of the nearfield showed stratification by mid-May.
- The nutrient data for February to June 2004 generally followed the "typical" progression of seasonal events in the Massachusetts and Cape Cod Bays.
  - Maximum nutrient concentrations were observed in February when the water column was well mixed and biological uptake of nutrients was limited.
  - Although the typical winter/spring diatom bloom was not observed, a major system-wide *Phaeocystis* bloom reduced nutrient concentrations throughout the area by April.
- The effluent nutrient signal was clearly evident in the nearfield as elevated NH_4 and PO_4 concentrations.
- Chlorophyll concentrations peaked in all areas in April and distributions were comparable to trends observed in *Phaeocystis* abundance.
- DO concentrations in 2004 were within the range of values observed during previous years and followed the typical trends. Given the major bloom, the DO concentrations and %saturation values in the bottom waters throughout the bays was relatively high in June (>90%).





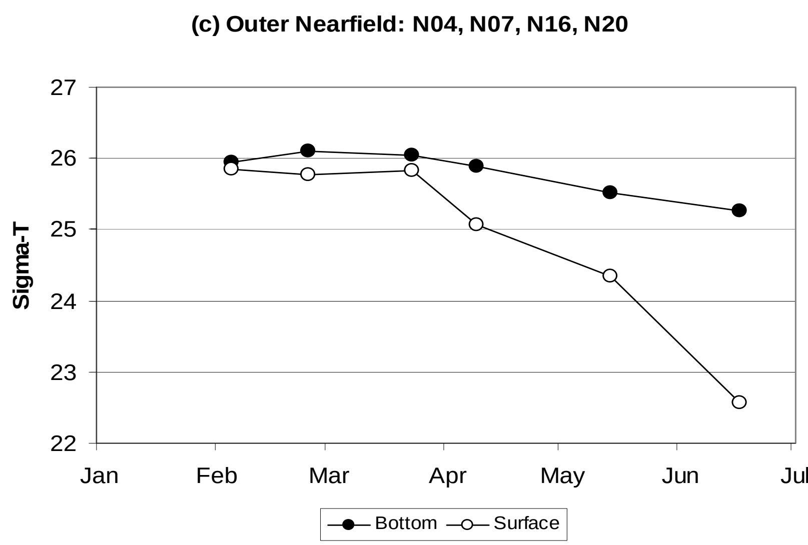


Figure 4-1. Time-series of average surface and bottom water density (σ_t) in the nearfield

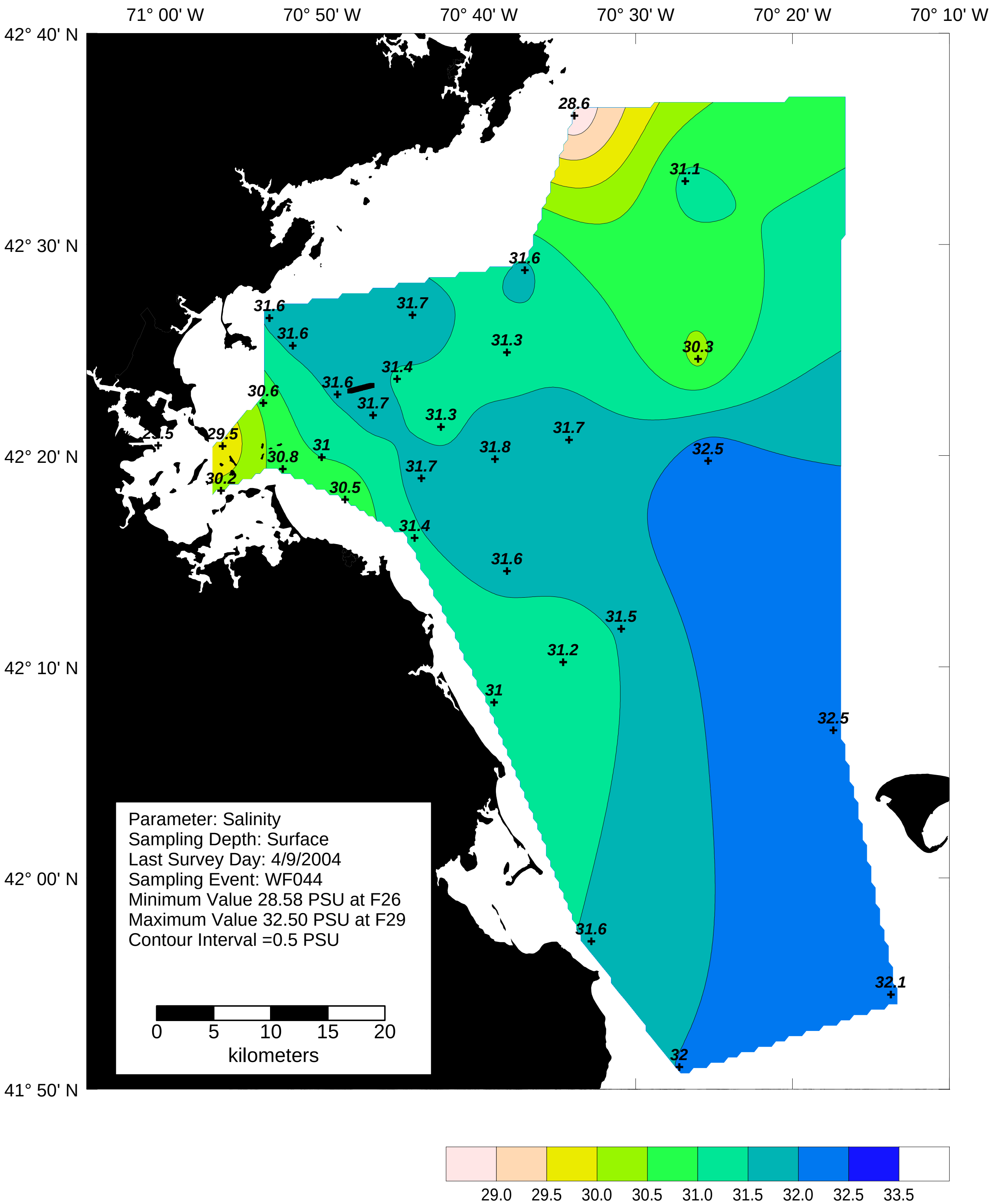


Figure 4-2. Salinity surface contour plot for farfield survey WF044 (Apr 04)

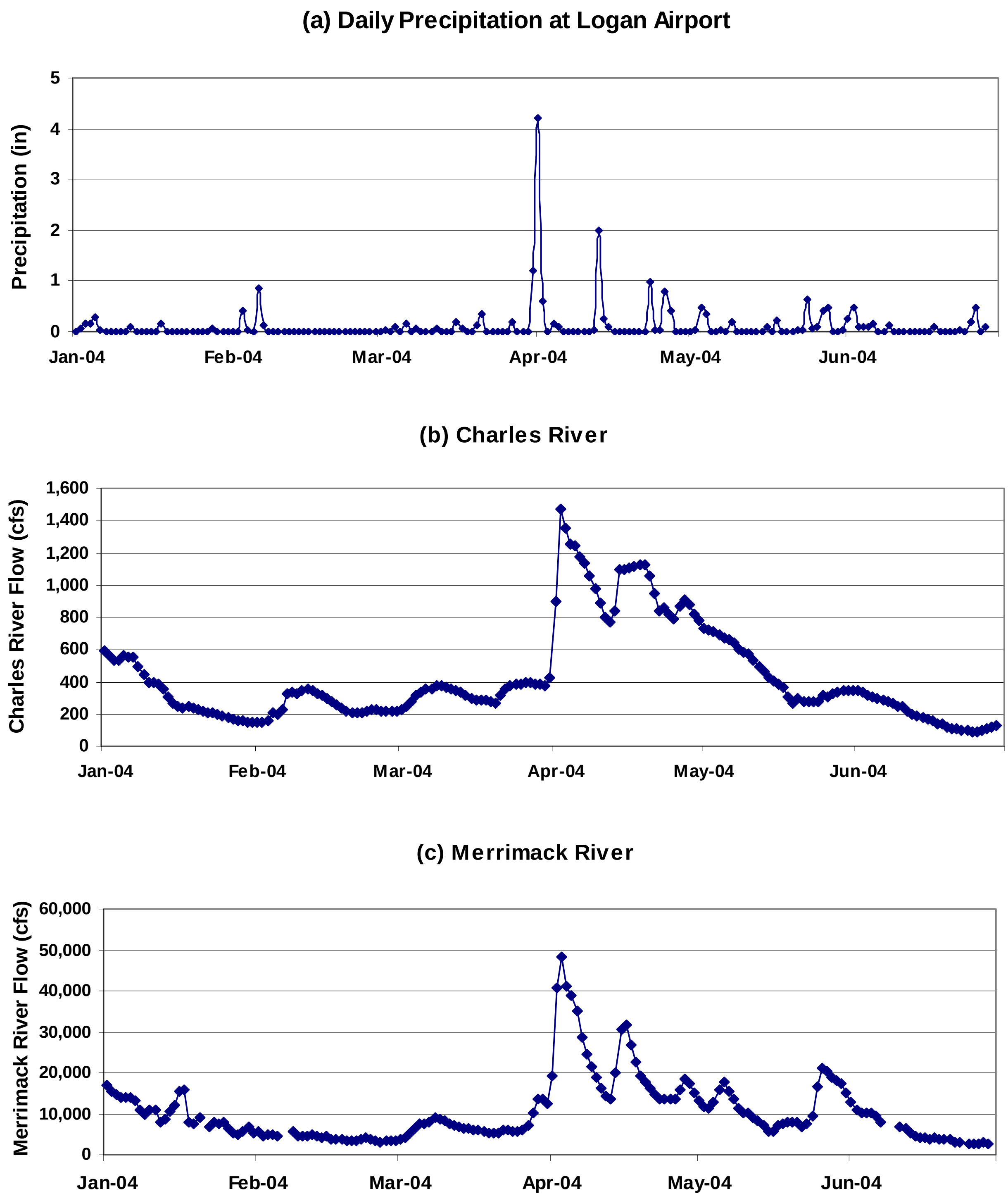
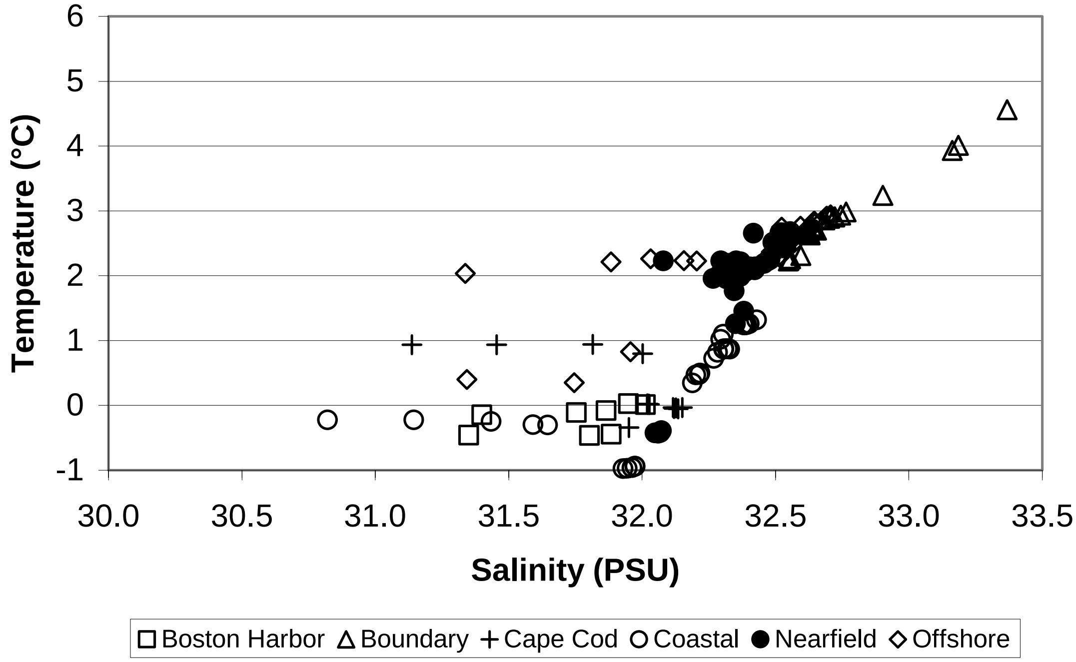


Figure 4-3. Precipitation at Logan Airport and river discharges for the Charles and Merrimack Rivers

(a) WF041: Early February



(b) WF042: Late February

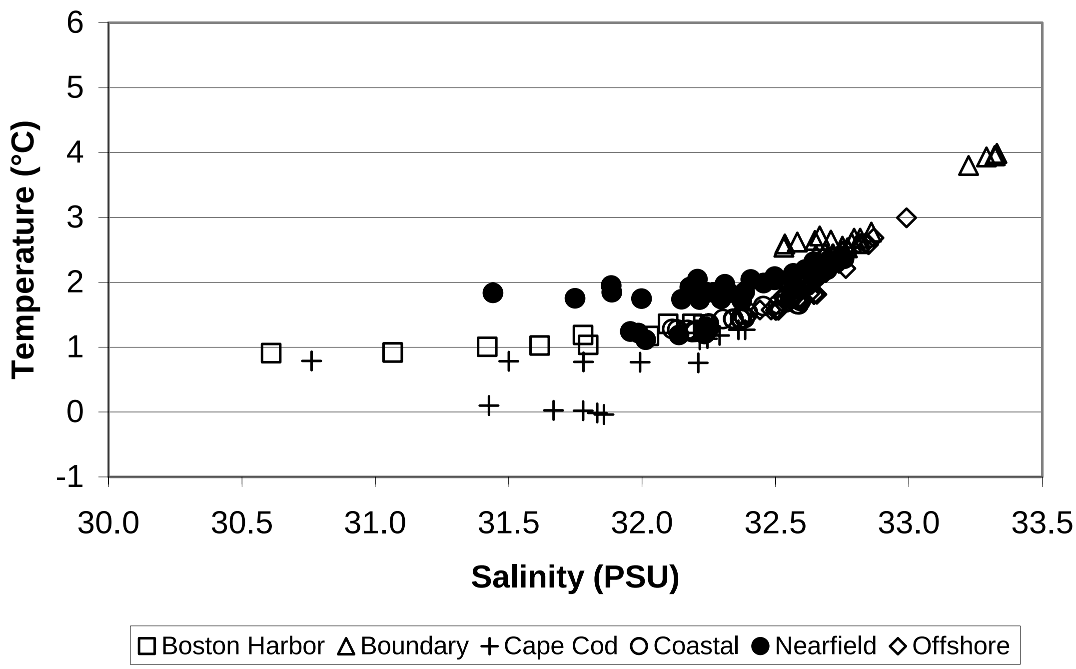
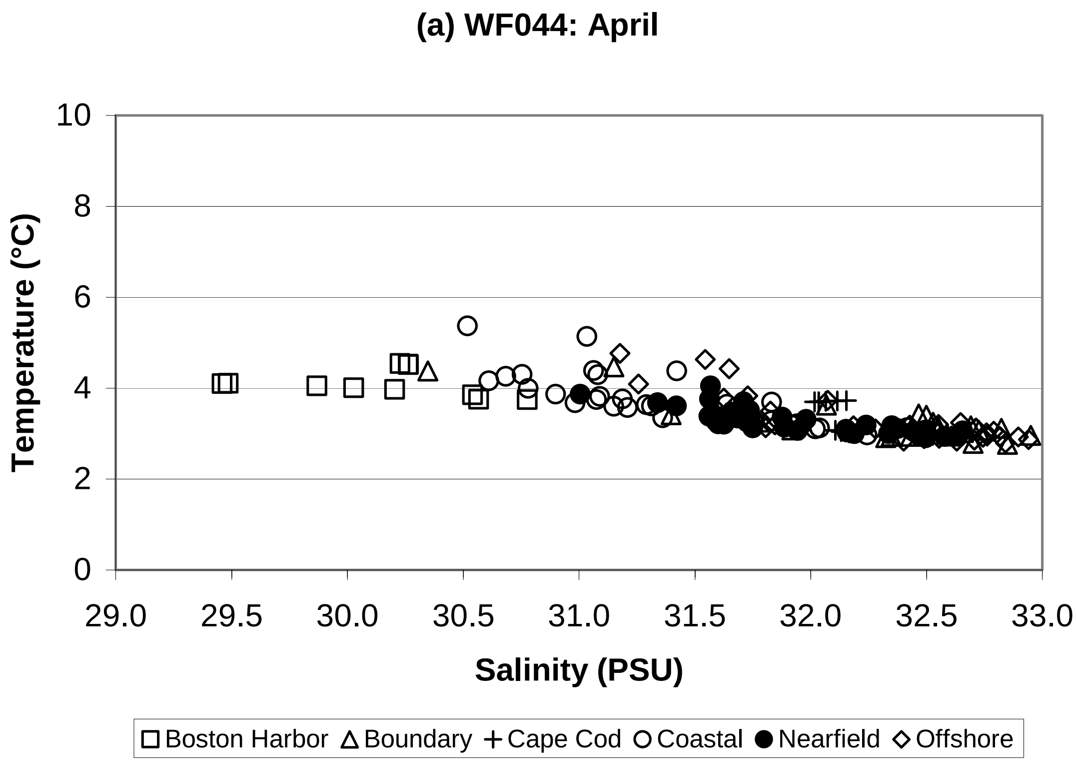


Figure 4-4. Temperature/salinity distribution for all depths during WF041 and WF042 (Feb 04) surveys



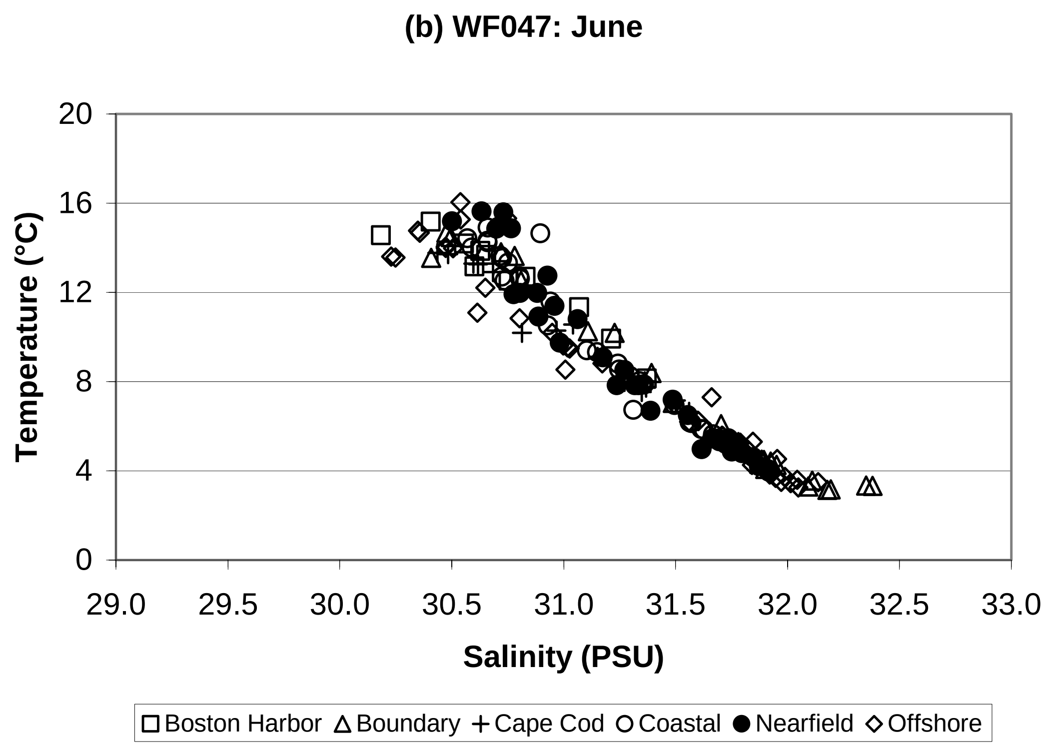


Figure 4-5. Temperature/salinity distribution for all depths during WF044 (Apr 04) and WF047 (Jun 04) surveys

Note: Scale for WF047 is different reflecting the higher temperature in June

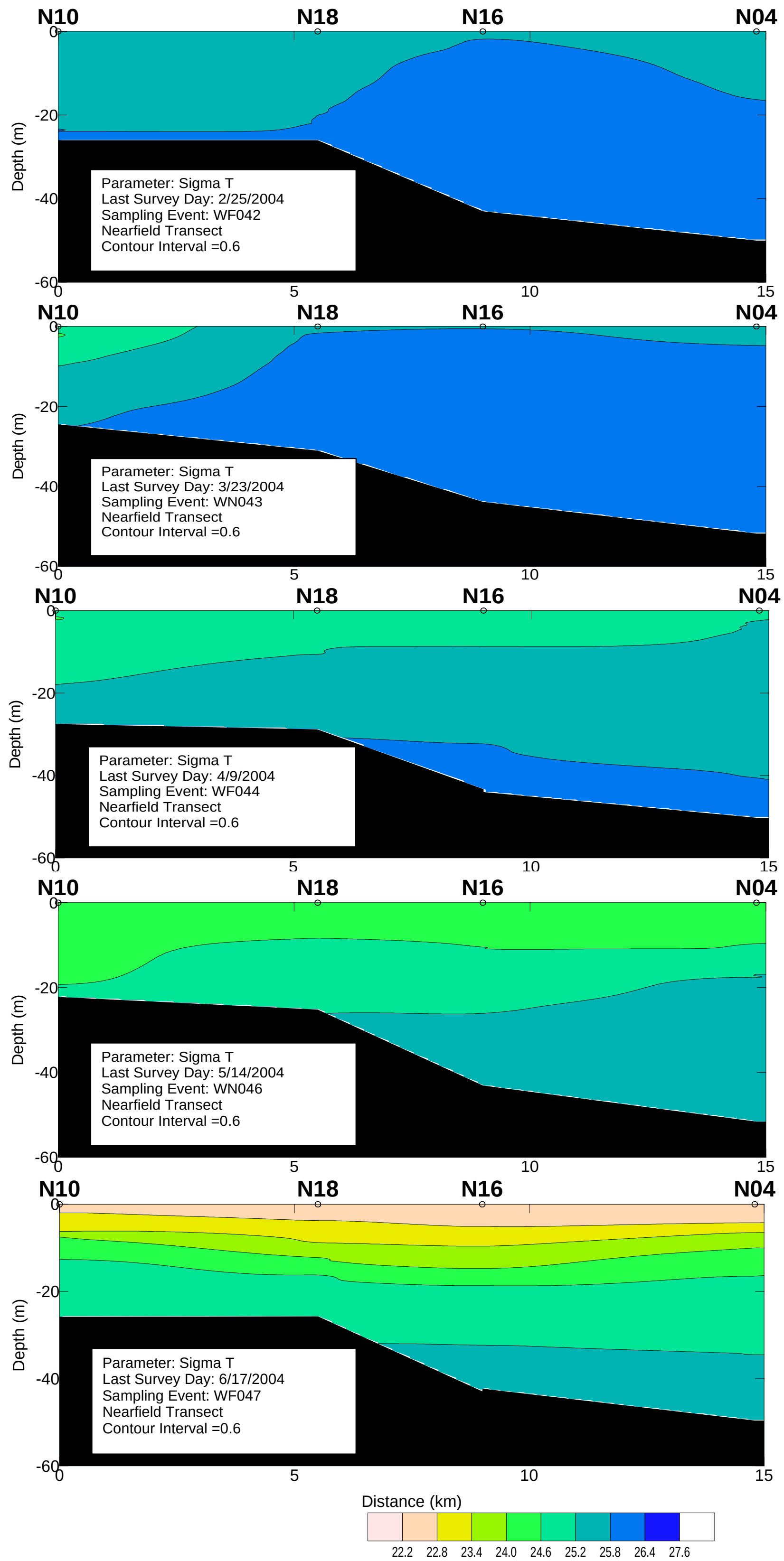


Figure 4-6. Density vertical contour plots across the nearfield transect for surveys WF042, WN043, WF044, WN046, and WF047

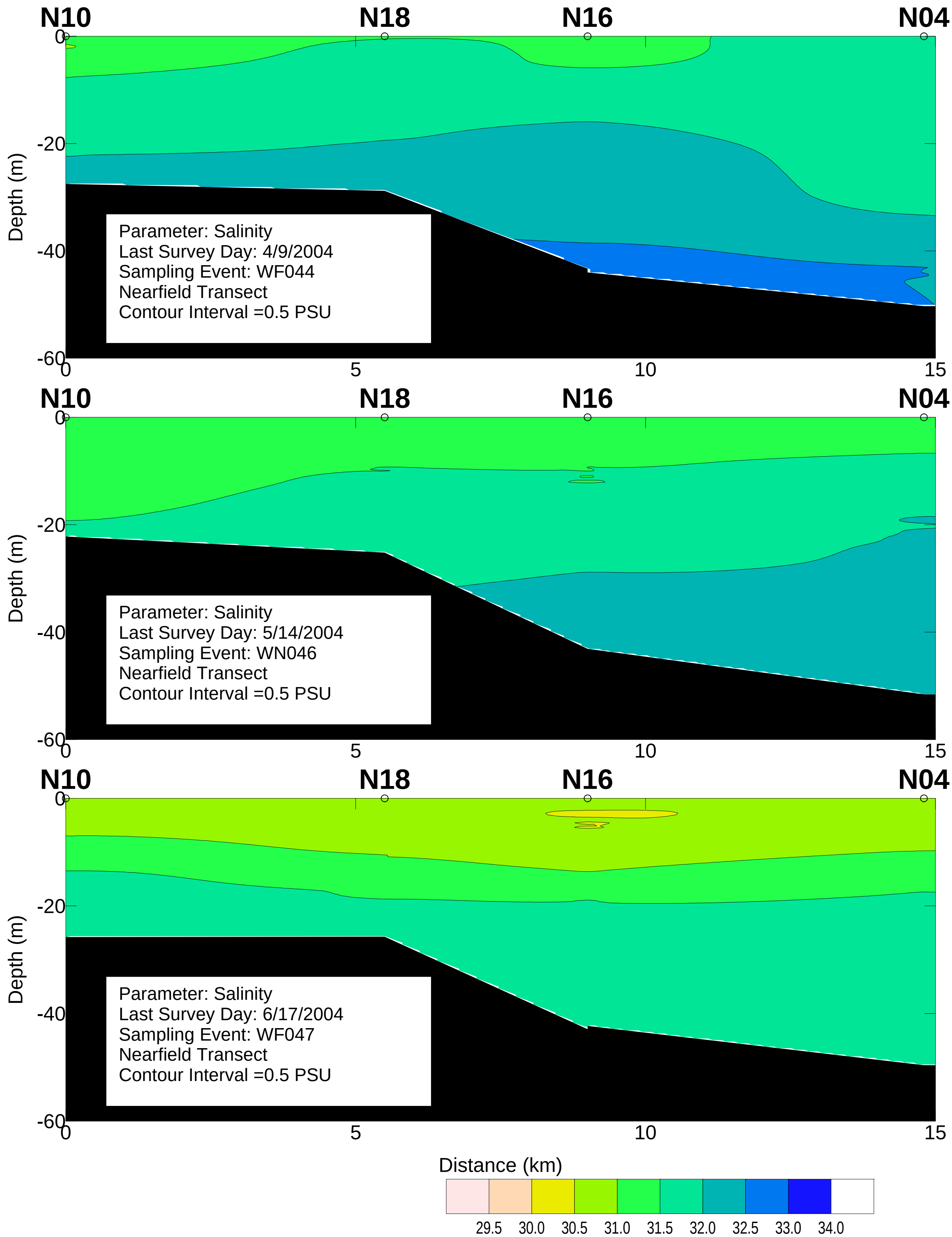


Figure 4-7. Salinity vertical contour plots across the nearfield transect for surveys WF044, WN046, and WF047

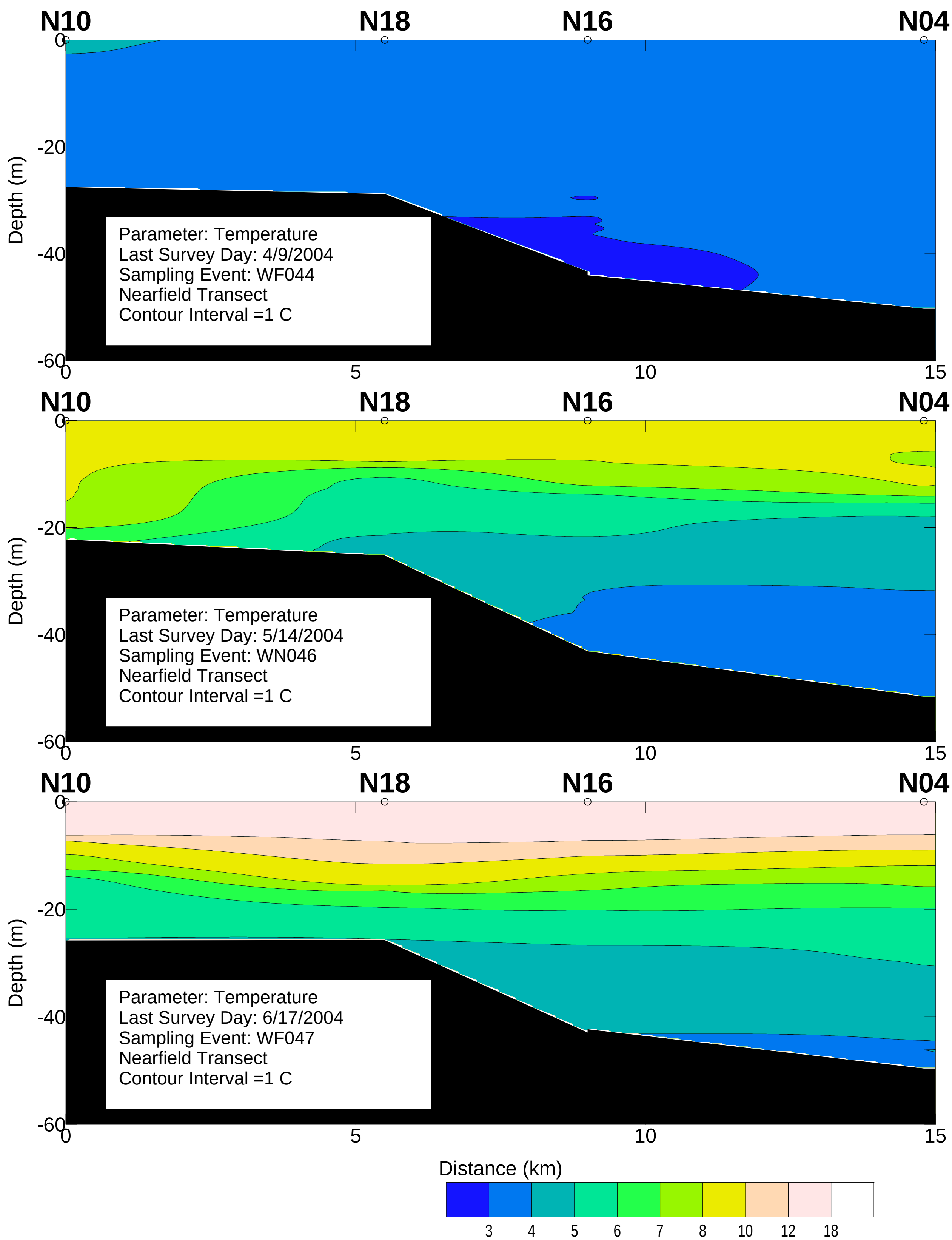
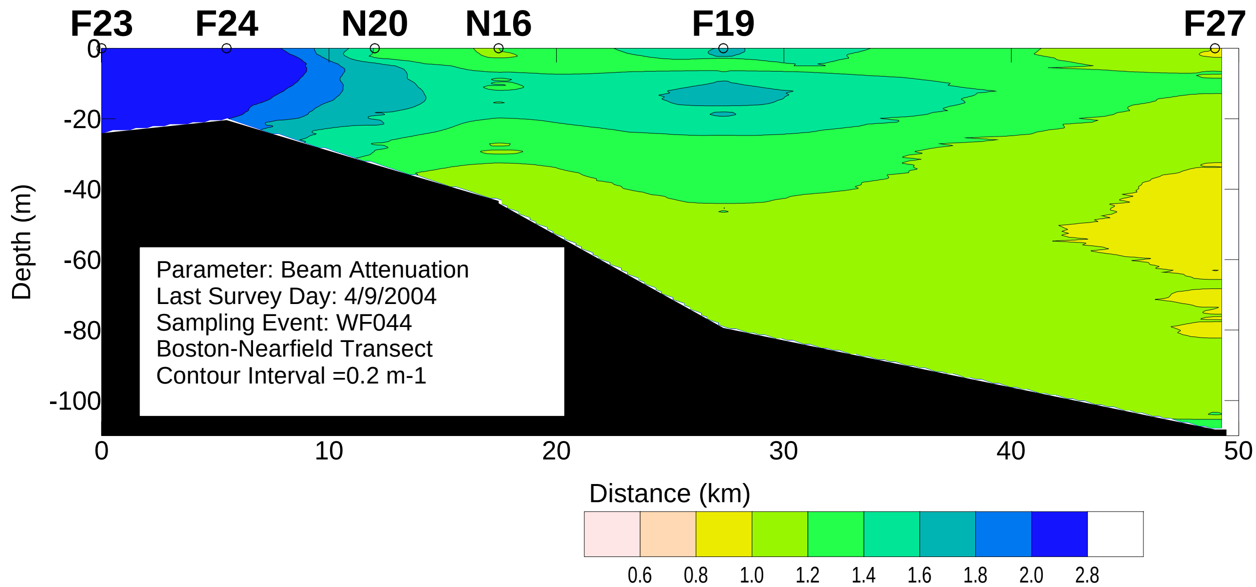


Figure 4-8. Temperature vertical contour plots across the nearfield transect for surveys WF044, WN046, and WF047



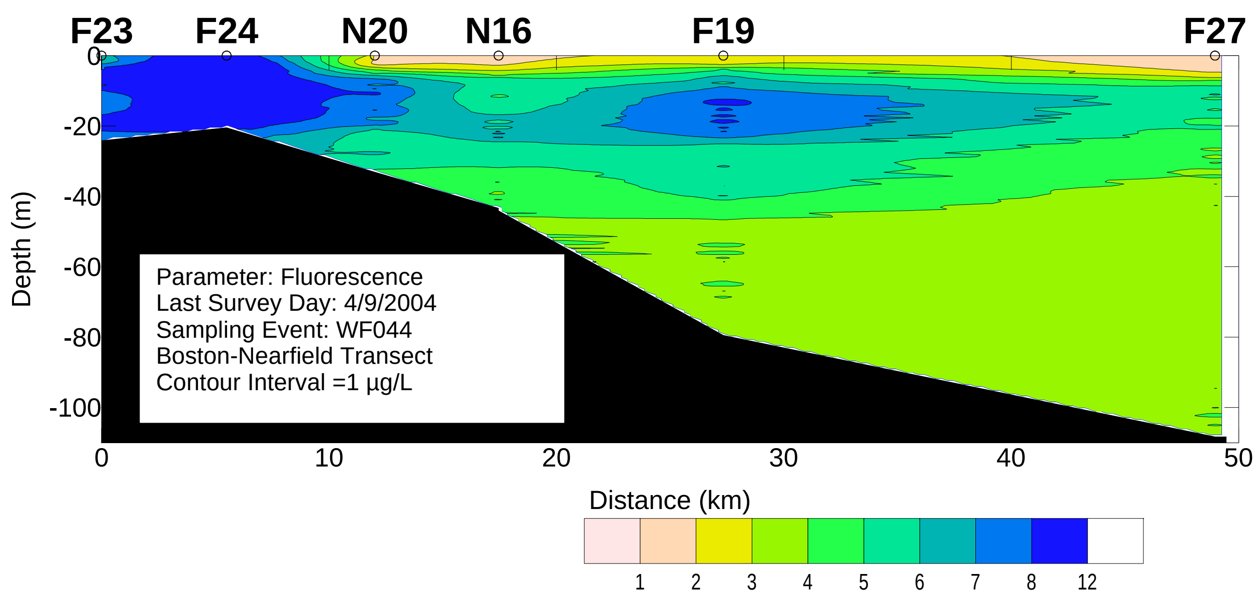
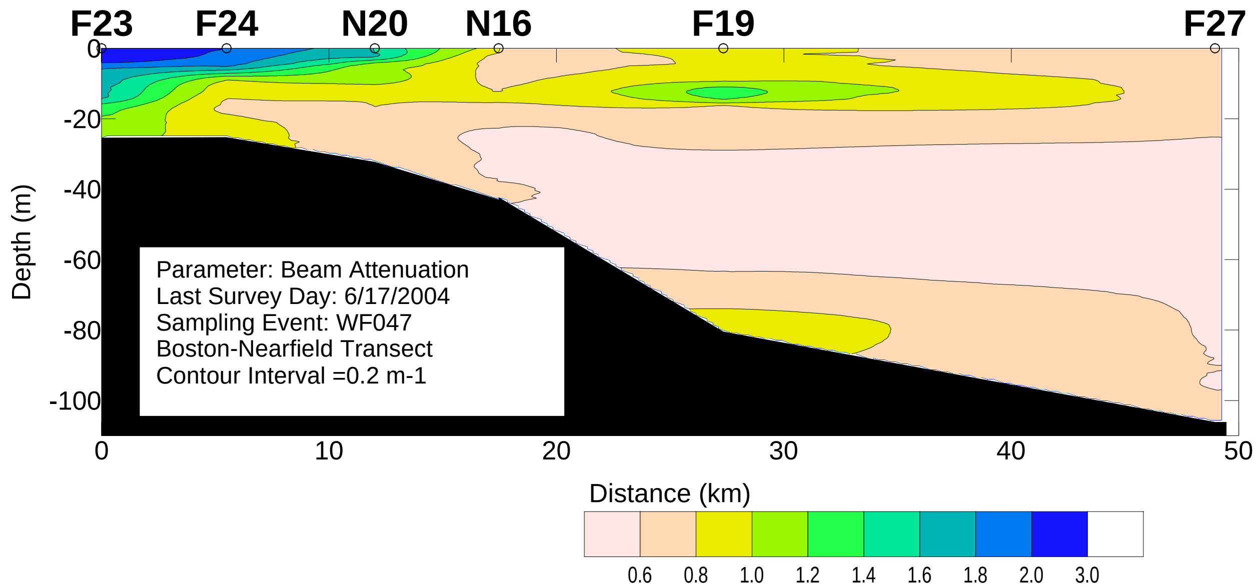


Figure 4-9. Beam attenuation and fluorescence vertical contour plots along the Boston-Nearfield transect for farfield survey WF044 (Apr 04)



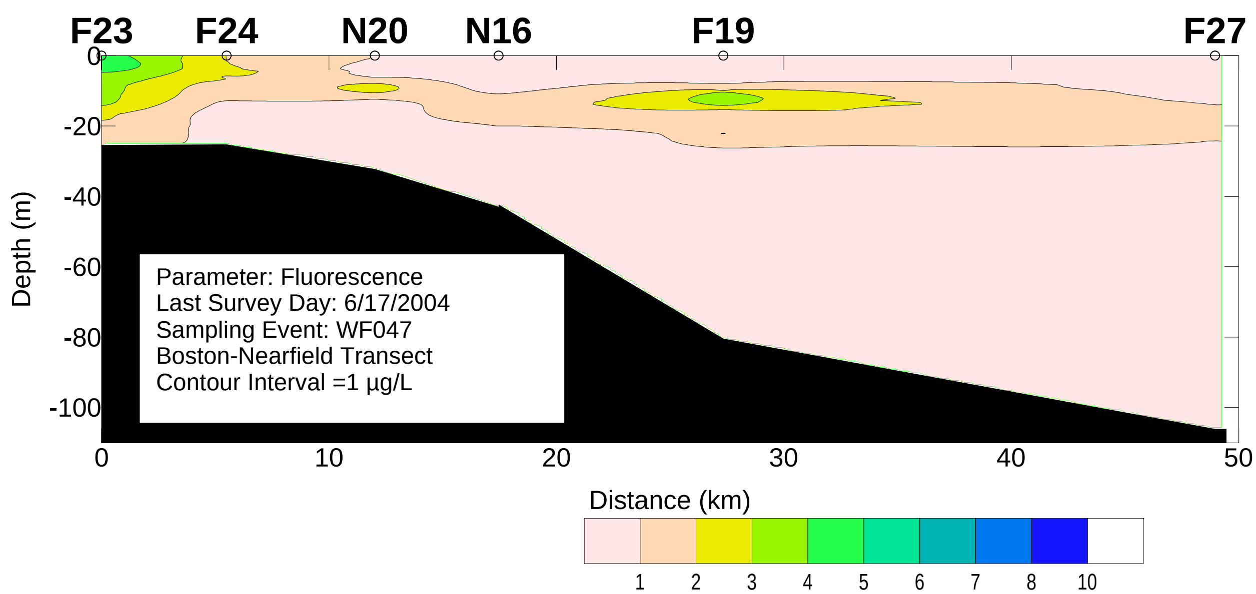


Figure 4-10. Beam attenuation and fluorescence vertical contour plots along the Boston-Nearfield transect for farfield survey WF047 (Jun 04)

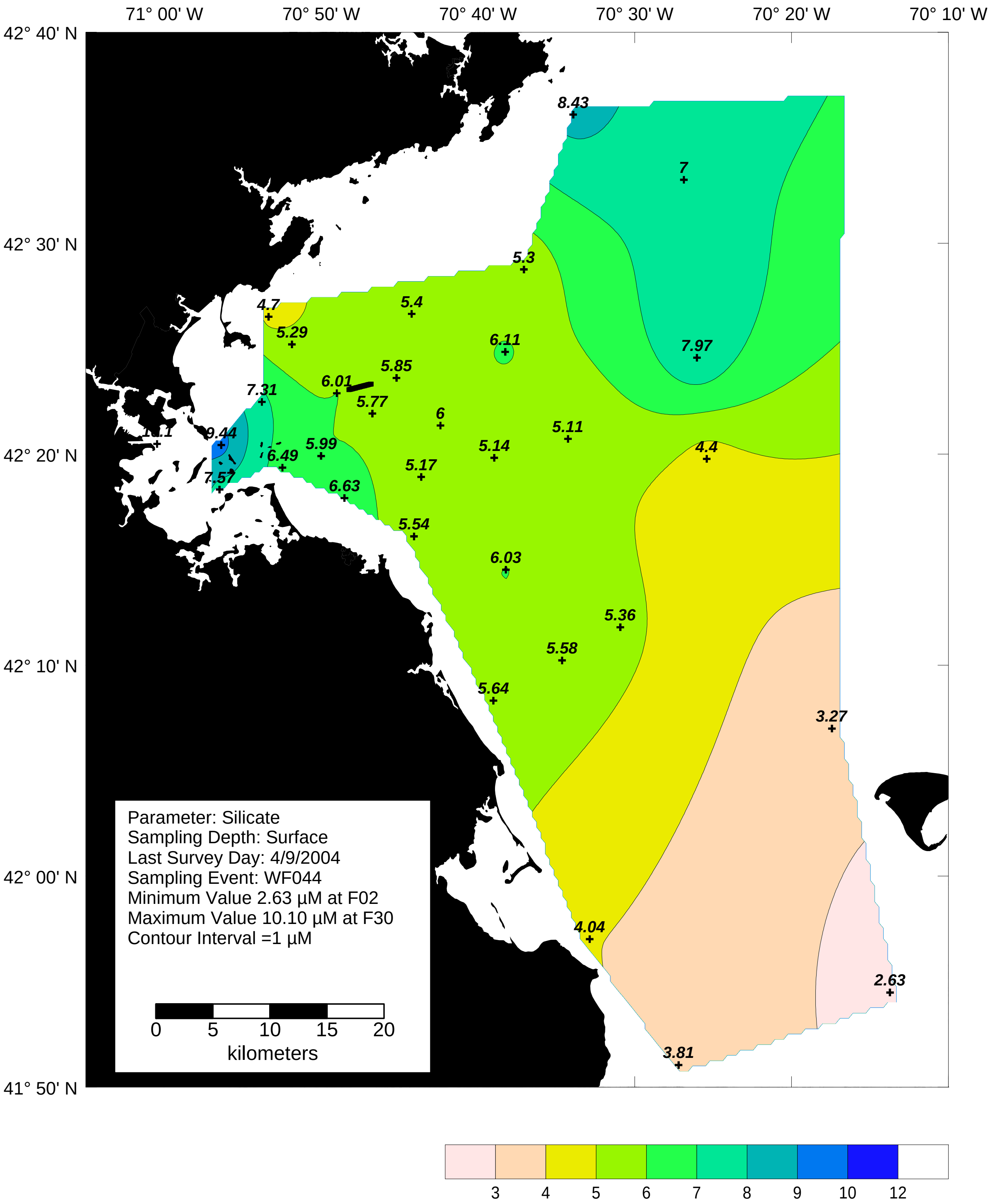


Figure 4-11. Silicate surface contour plot for farfield survey WF044 (Apr 04)

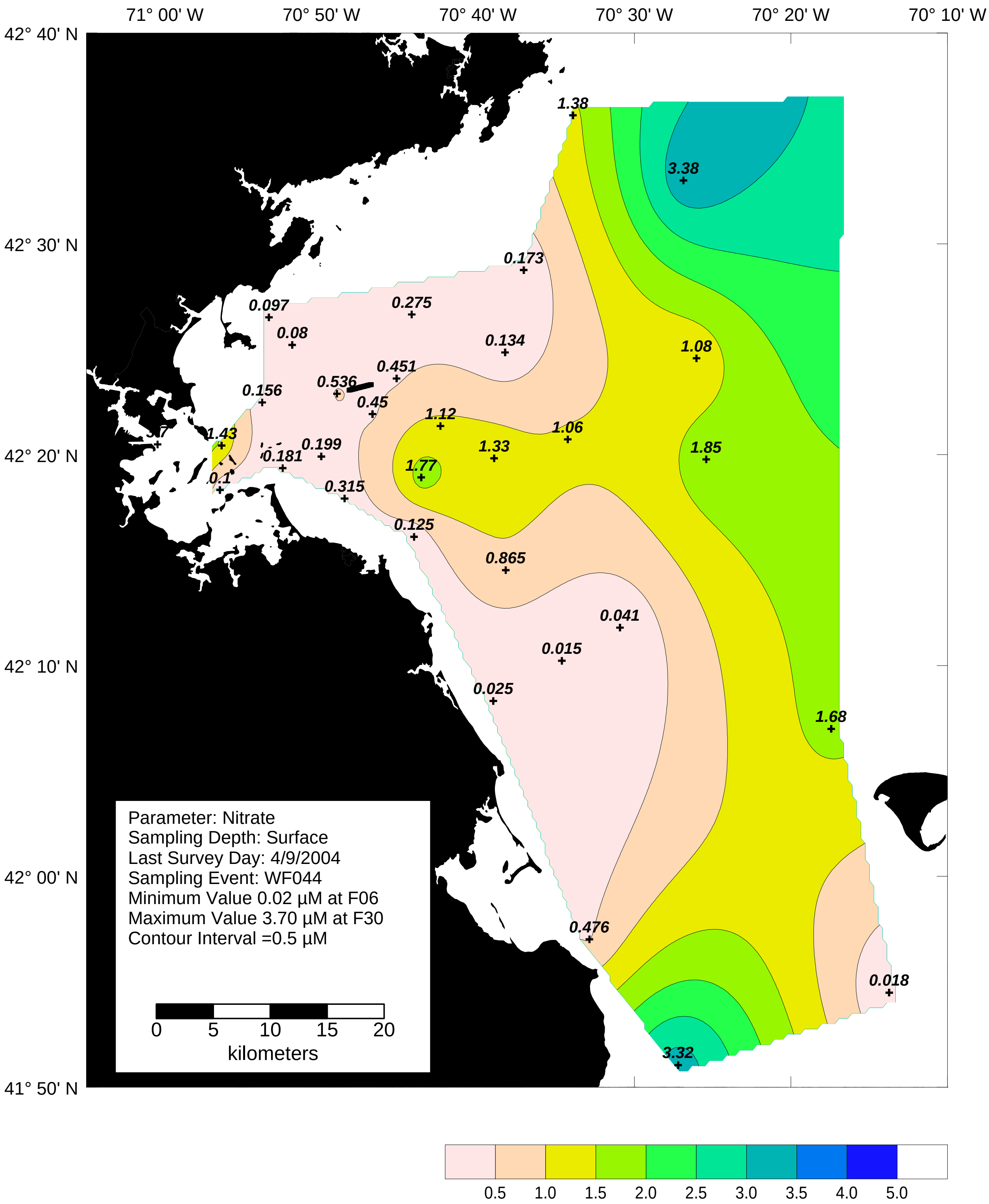


Figure 4-12. Nitrate surface contour plot for farfield survey WF044 (Apr 04)

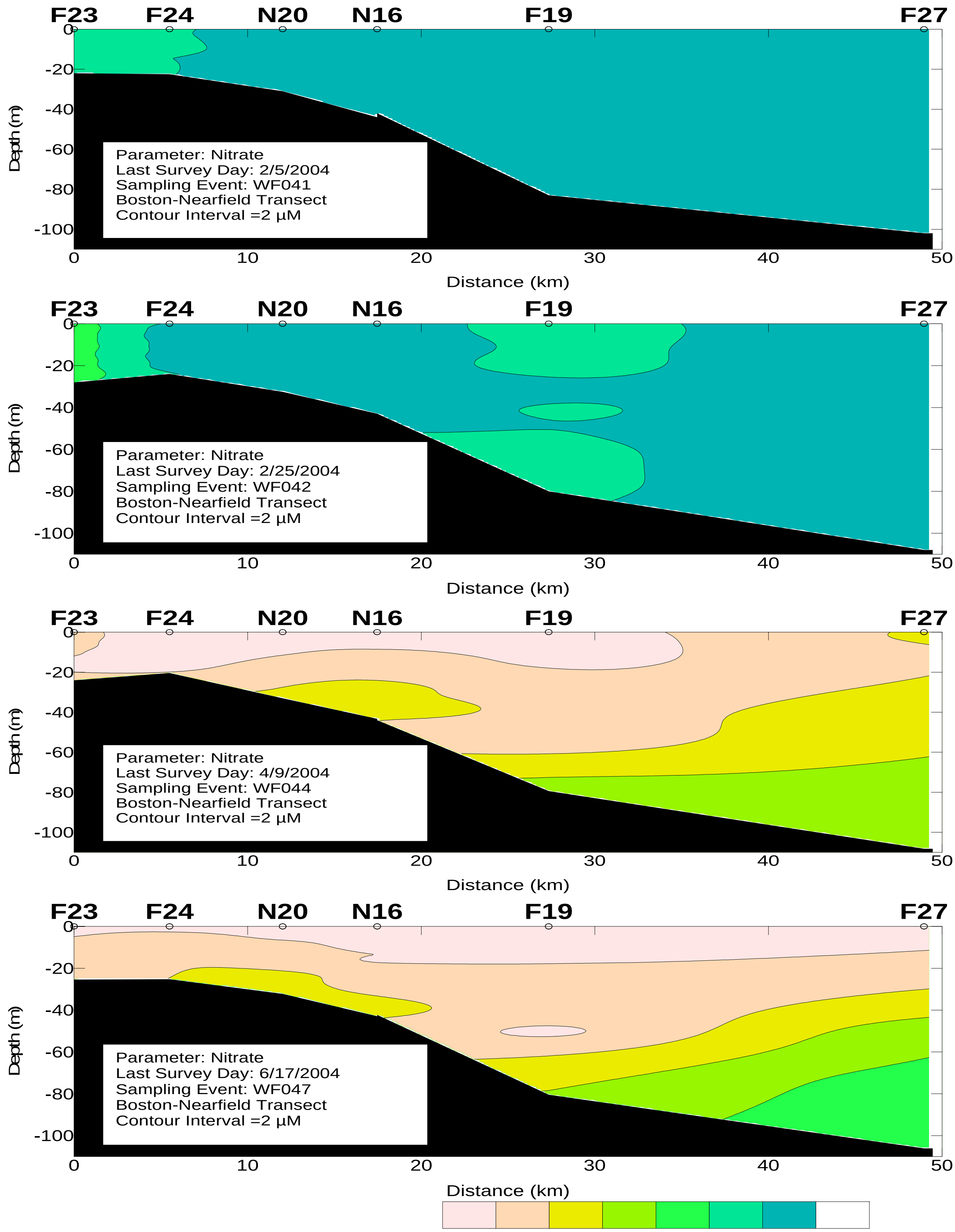


Figure 4-13. Nitrate vertical contour plots along the Boston-Nearfield transect for surveys WF041, WF042, WF044, and WF047

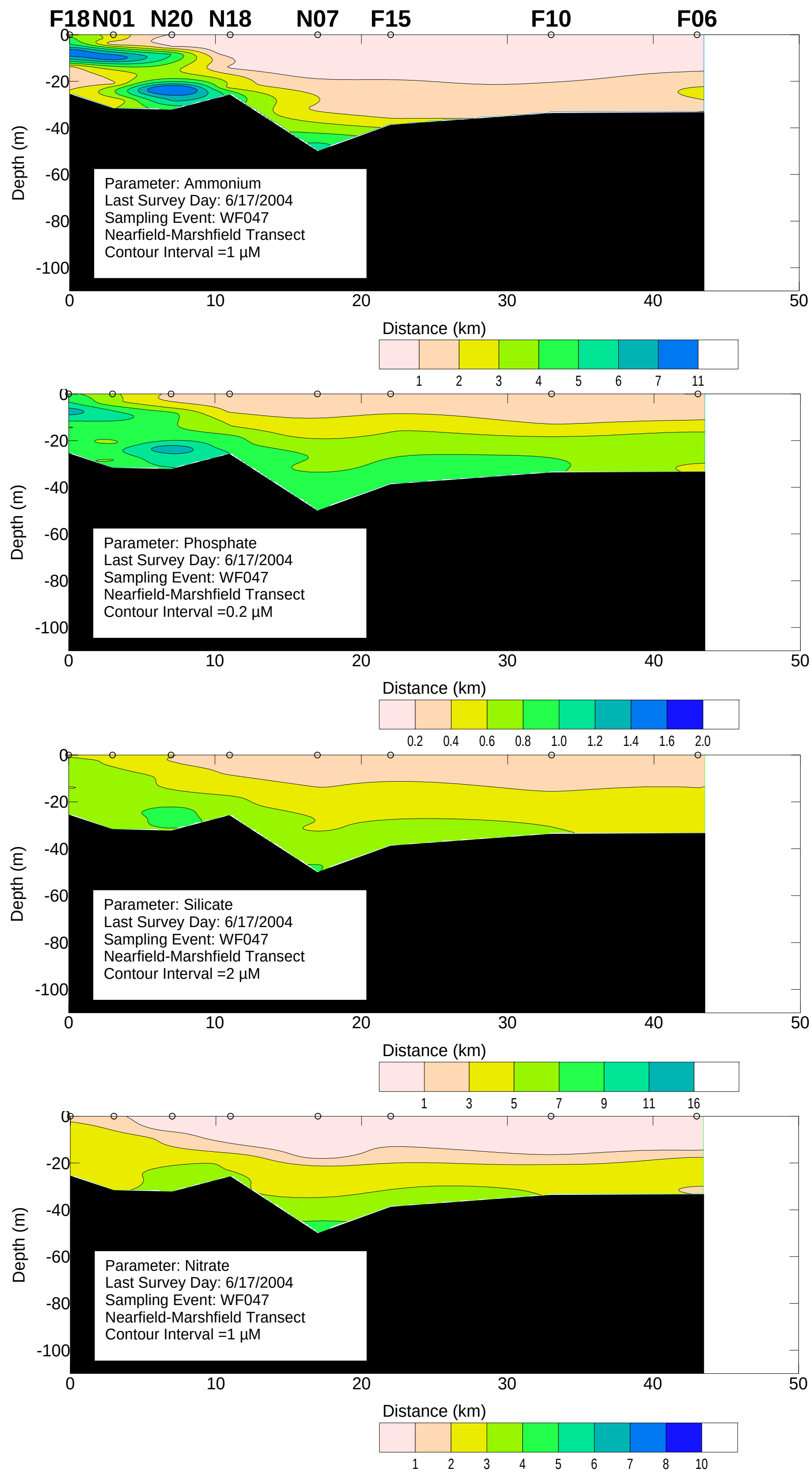


Figure 4-14. Ammonium, Phosphate, Silicate and Nitrate vertical contour plots along the Nearfield-Marshfield transect for survey WF047

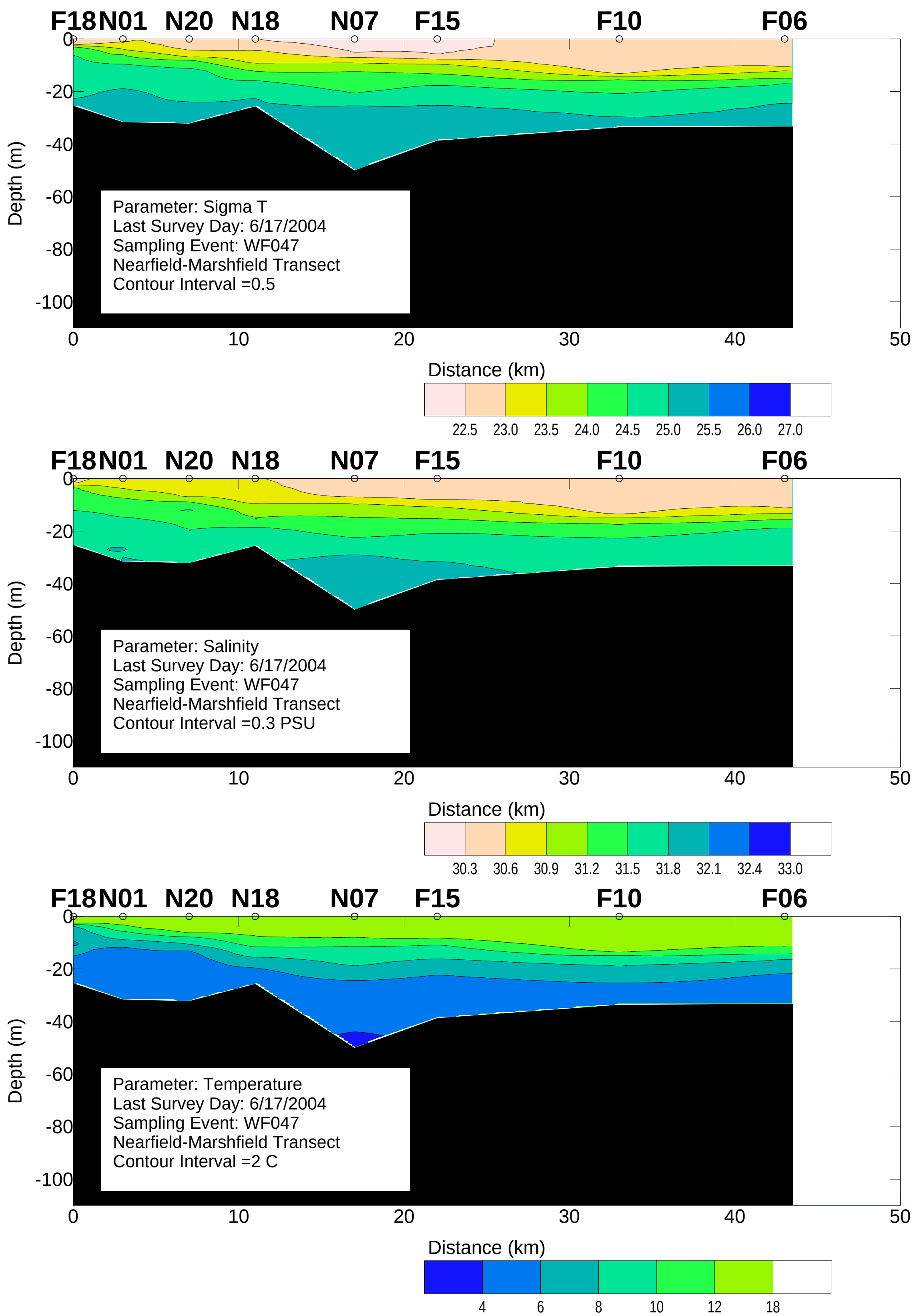
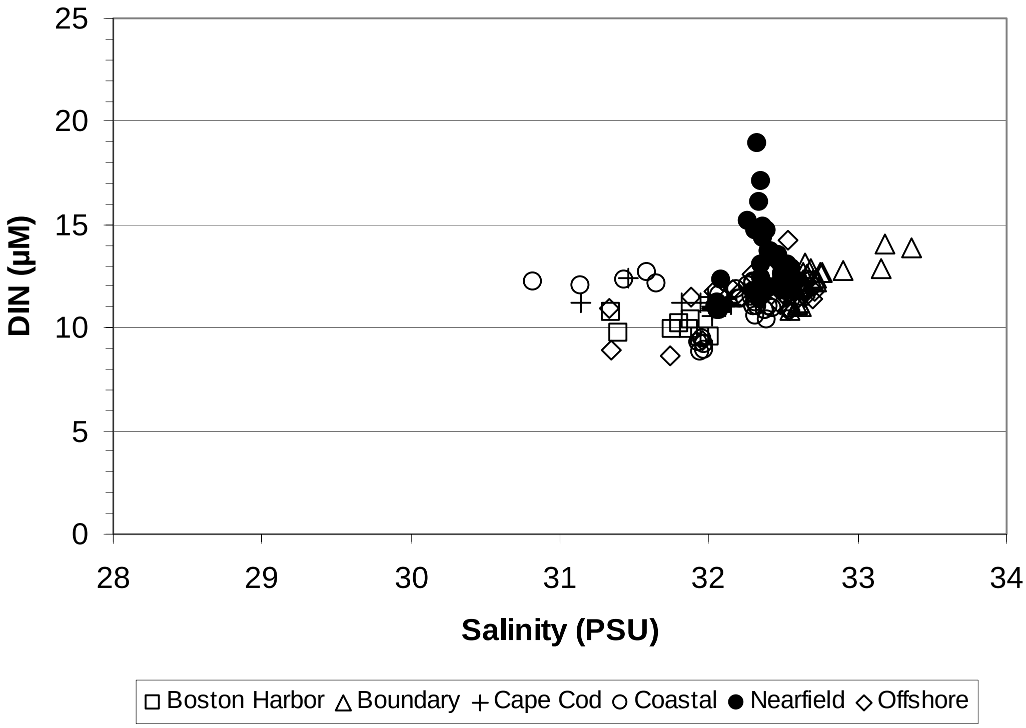


Figure 4-15. Density, Salinity, and Temperature vertical contour plots along the Nearfield-Marshfield transect for survey WF047

(a) WF041



(b) WF042

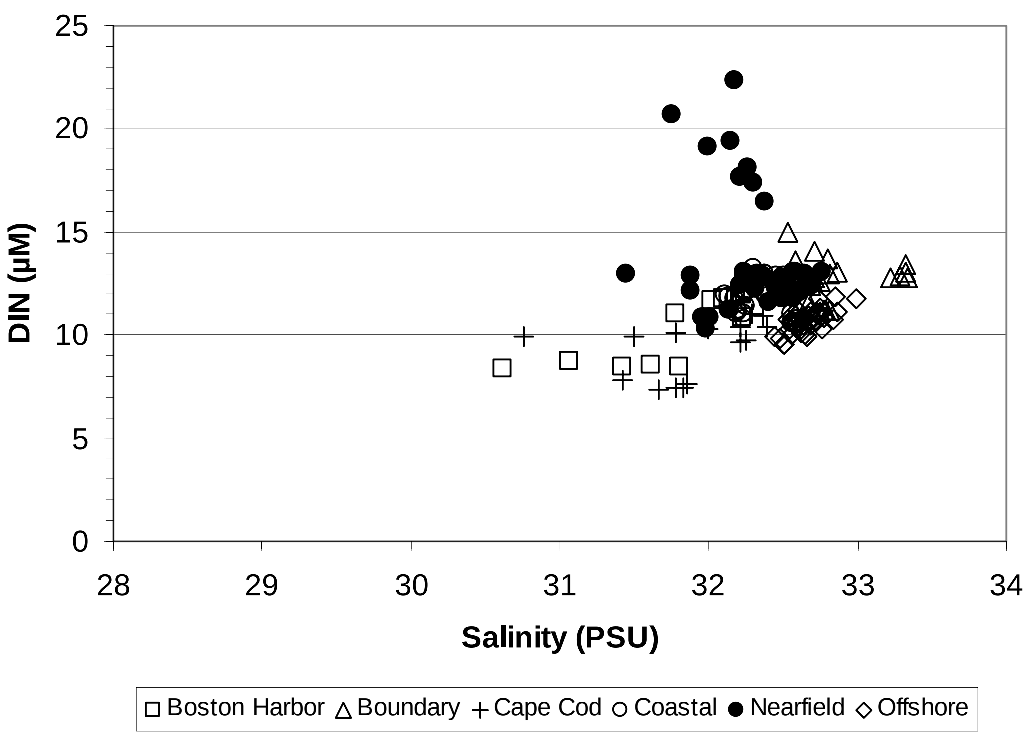
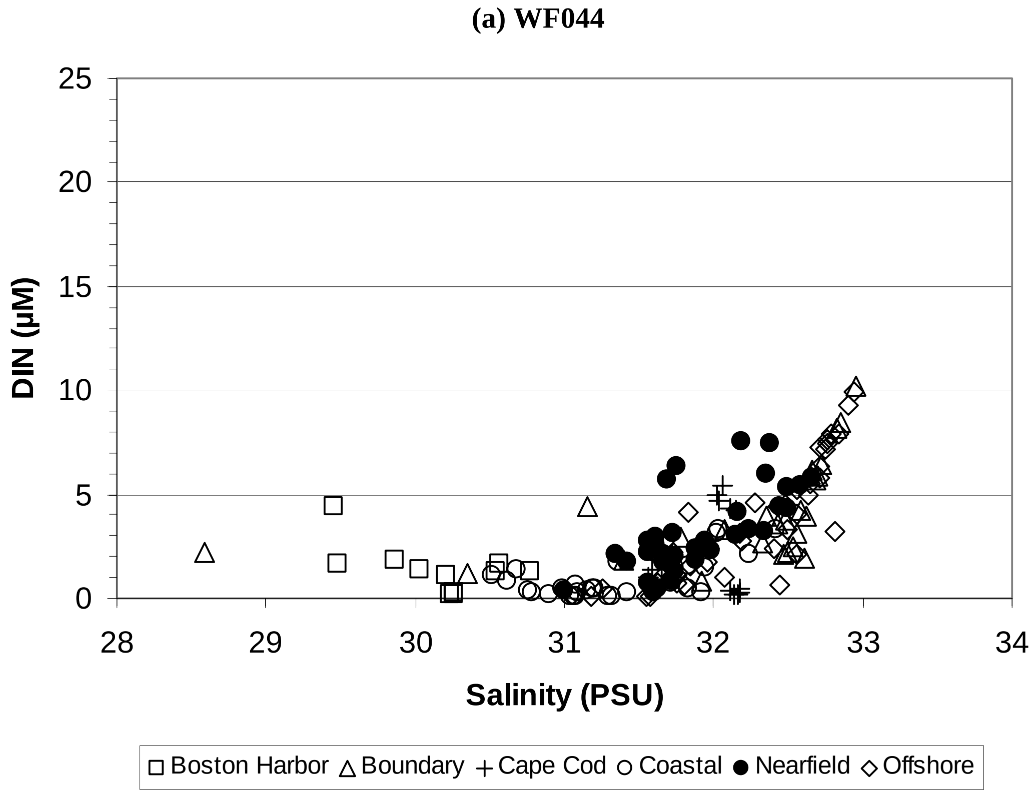


Figure 4-16. DIN vs. salinity for all depths during farfield surveys WF041 and WF042 (Feb 04)



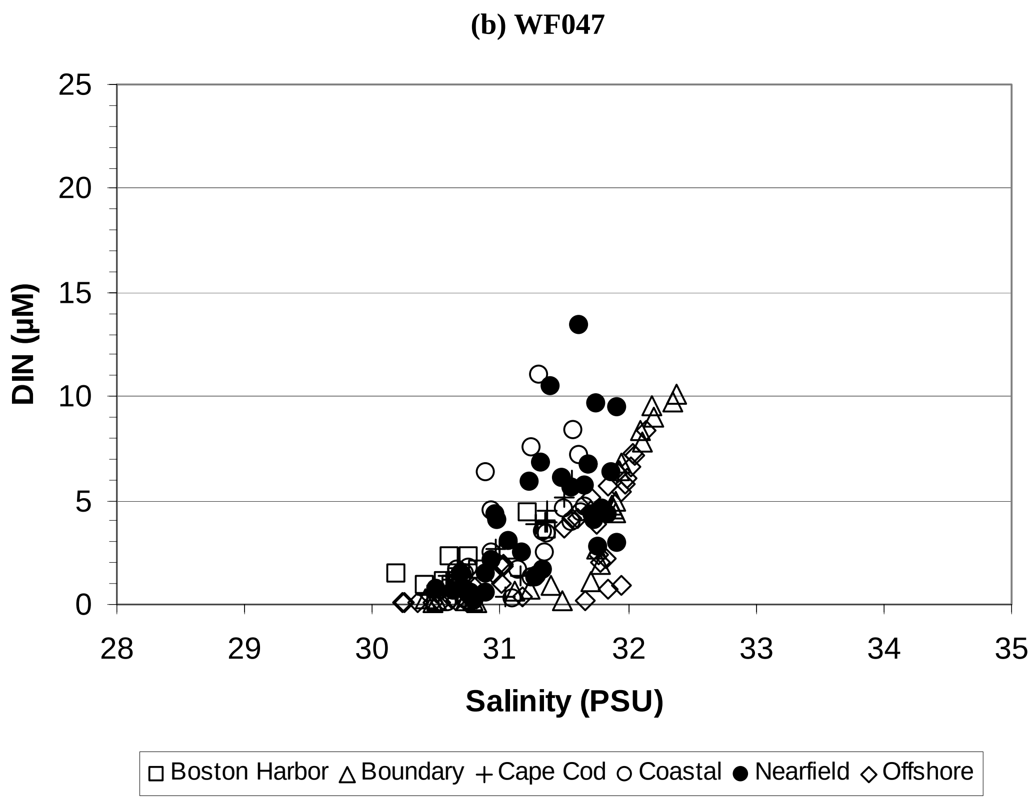


Figure 4-17. DIN vs. salinity for all depths during farfield surveys WF044 (Apr 04) and WF047 (Jun 04)

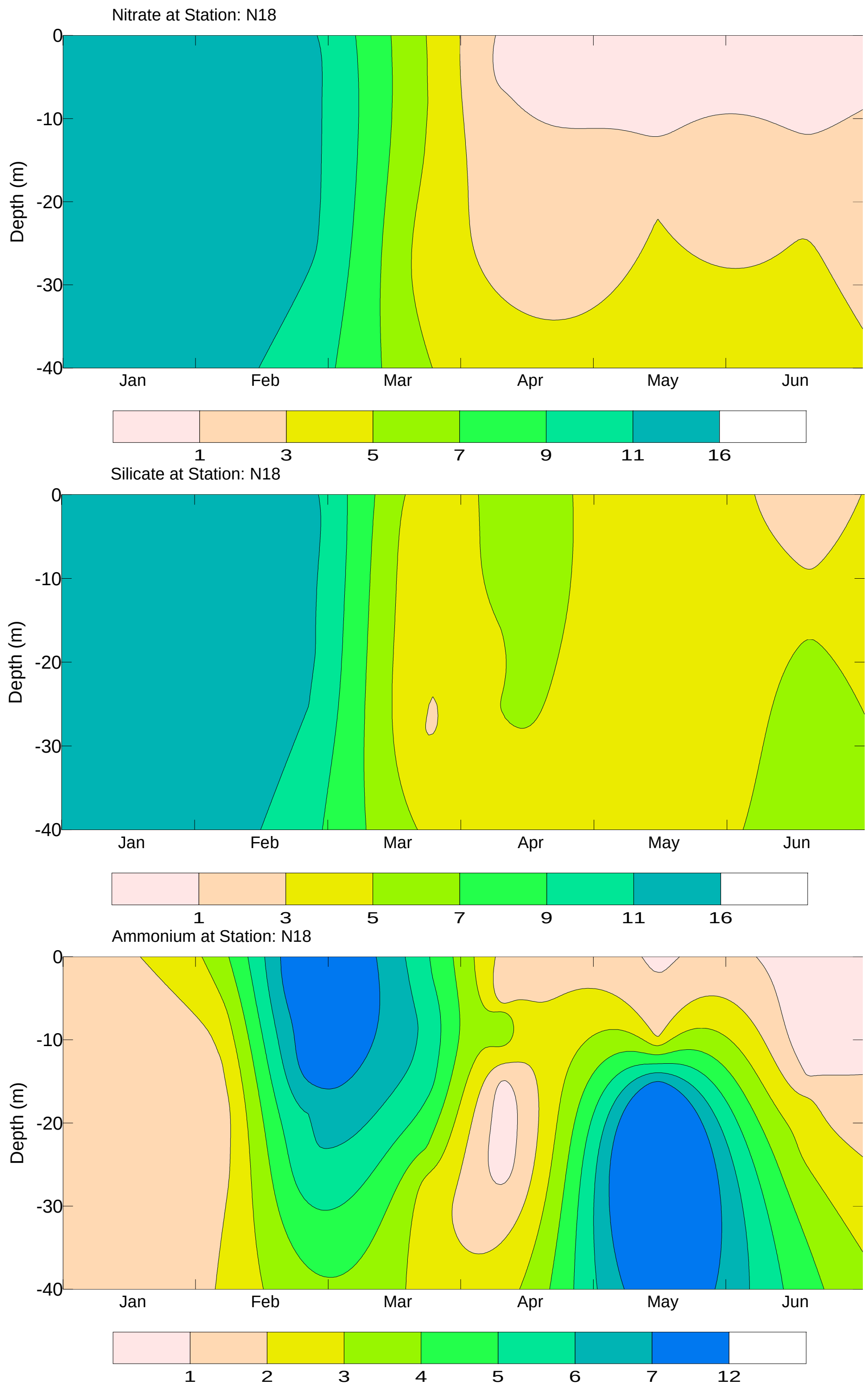


Figure 4-18. Station N18 depth vs. time contour plots of nitrate, silicate, and ammonium

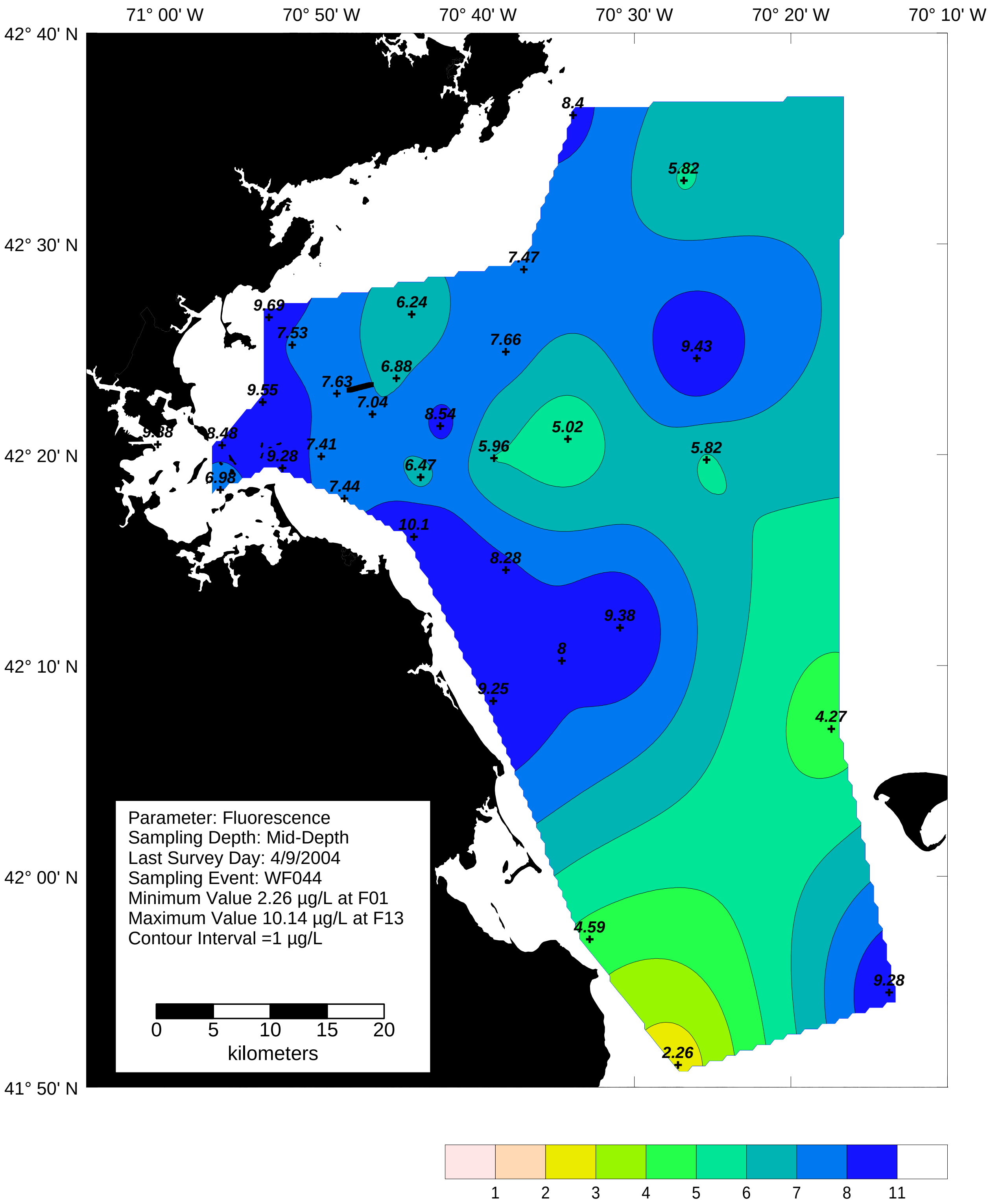


Figure 4-19. Fluorescence mid-depth contour plot for farfield survey WF044 (Apr 04)

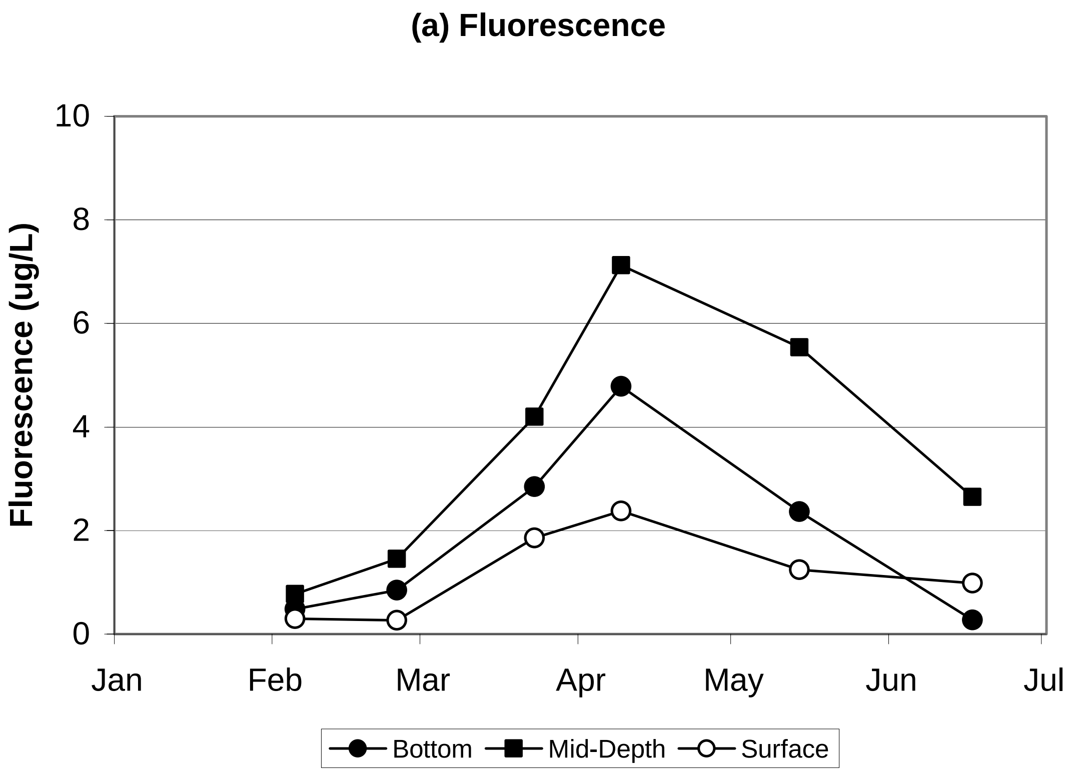


Figure 4-20. Time-series of bottom, mid-depth, and surface survey mean chlorophyll concentration in the nearfield

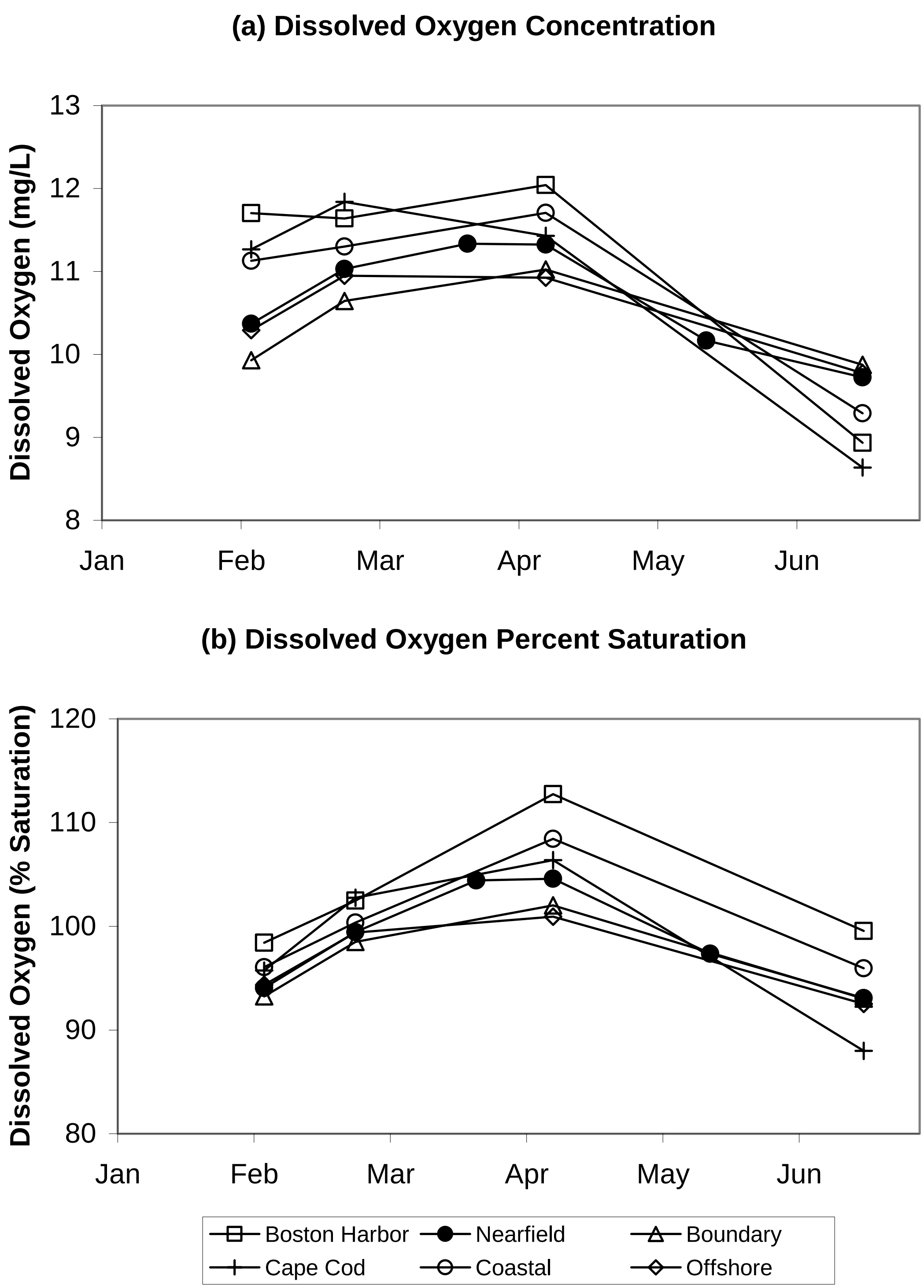


Figure 4-21. Time-series of bottom water average DO concentration and percentage saturation in Massachusetts and Cape Cod Bay

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 3 (WF041), February 25 (WF042), April 8 (WF044) and June 17 (WF047). Stations N04 and N18 were additionally sampled on March 23 (WN043) and May 14 (WN046). 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*. (2002).

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*. Potential productivity, chlorophyll-specific potential productivity and chlorophyll *a* for each depth are also presented as contour plots (**Figures** 5-4 to 5-6). 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 the beginning and end of the semiannual sampling period but diverged somewhat during the spring bloom (**Figure** 5-2). Areal production at the two sites was low (~200 – 300 mg C m^{-2} d^{-1}) during the initial survey in February. Values increased at both sites to ~750 – 900 mg C m^{-2} d^{-1} by late February. Productivity increased to winter-spring bloom levels (>1350 mg C m^{-2} d^{-1}) at station N04 by late March but decreased to about 400 mg C m^{-2} d^{-1} at station N18. During the early April survey, areal productivity reached peak bloom values at both stations N04 and N18 (2250 and 1400 mg C m^{-2} d^{-1}, respectively). By mid-May productivity was lower and again similar (~500 – 700 mg C m^{-2} d^{-1}) at both stations. Productivity increased moderately to ~700 mg C m^{-2} d^{-1} at station N04 and decreased somewhat to ~475 mg C m^{-2} d^{-1} at station N18 during the survey in June.

The magnitude of the winter/spring productivity peak differed somewhat at the nearfield stations. The maximum productivity at station N04 occurred in early April with a peak production of 2241 mg C m^{-2} d^{-1} while the maximum seasonal value at N18 was somewhat lower (1403 mg C m^{-2} d^{-1}). The magnitude of the maximum winter/spring productivity at the nearfield stations was somewhat higher than peaks observed in 2003 (1230 –1618 mg C m^{-2} d^{-1}), but considerably lower than winter/spring bloom maxima in 2002 when values of 3688 – 4860 mg C m^{-2} d^{-1} were observed. Peak productivity at both stations was also somewhat lower than levels observed in 2001 (2265 –2705 mg C m^{-2} d^{-1}). The minimum production at both stations (191 and 320 mg C m^{-2} d^{-1}) was observed in February. The decrease in productivity at both stations in May coincided with the decline in abundance of a *Phaeocystis* bloom, which peaked in the nearfield during April.

Unlike prior years, productivity at station N18 was elevated relative to station N04 only once thus far in 2004. During a similar period in 2003 productivity was higher at station N18 during 4 out of 7 surveys, while in 2002, areal productivity at N18 was greater than the values observed at N04 on 5 of 7 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. In general peak productivity coincided with elevated chlorophyll and low chlorophyll levels were associated with lower areal production. By comparison, winter/spring 2003 had relatively low production, but elevated chlorophyll levels. The patterns observed in 2004 are more closely related to those seen in 2001 and 2002.

At the Boston Harbor station F23, areal production was similar to both nearfield sites during early and late February (**Figure** 5-2). During April potential areal productivity at F23 was less than that observed in the nearfield, while during the final sampling in June productivity at F23 was greater than both nearfield sites. Maximum bloom productivity at F23 occurred in June although rates were only slightly lower in April when peak productivity levels were measured in the nearfield. Productivity was low (~325 mg C m^{-2} d^{-1}) during the initial February survey then increased to ~860 mg C m^{-2} d^{-1} by late February. Areal productivity then increased in early April to bloom levels at station F23 (1116 mg C m^{-2} d^{-1}). 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 WF042 (mean 2.43 µg l^{-1}) was associated with increased productivity compared with values observed during WF041 (mean 0.5 µg l^{-1}). The peak chlorophyll level (mean 7.4 µg l^{-1}) observed at F23 during WF044 was associated with elevated productivity. During WF047 average chlorophyll decreased markedly over the water column to 2.89 µg l^{-1}concomittent with a slight increase in potential productivity to 1306 mg C m^{-2} d^{-1}.

Areal production in 2004 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 1995-2003 generally reached values of 1200 to 4500 mg C m^{-2} d^{-1}, with bimodal peaks often occurring in February - April. The bloom in 2004 reached maximum values at the nearfield sites of ~1400-2250 mg C m^{-2} d^{-1} with a single peak in early April. Unlike many years, an early February peak was not observed. SeaWiFS images for Massachusetts Bay indicate that chlorophyll levels were low from January through February (Appendix D) indicating that an early bloom was not missed due to the sampling schedule. These images do, however, suggest that an earlier bloom was occurring in Cape Cod Bay in February/March. The winter-spring bloom peaks at both nearfield sites in 2004 were somewhat higher than values observed during the winter-spring period in 2003 but generally lower than those observed in earlier 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. Peak areal production observed in 2002 and 2003 reached similar magnitudes (1300 - 3200 mg C m^{-2} d^{-1}), but occurred in February or early March. In 2004, areal production was elevated during the winter/spring *Phaeocystis* bloom in early April and increased slightly in June (**Figure** 5-2). Thus, the seasonal cycle observed in 2004 in Boston Harbor was similar to the pre-transfer trend, although the magnitude of the bloom was on the low end of the range previously observed. The variability in the production rates and seasonal pattern in the harbor will be the focus of more intense examination in future reports.

5.1.2 Depth-Averaged Chlorophyll-Specific Production

Depth-averaged chlorophyll-specific potential production peaked at the nearfield productivity stations during late February then decline to moderate levels throughout the next three surveys before increasing again in June (**Figure** 5- 3). Values were similar at both stations (11 - 14 mg C mg Chl a^{-1} d^{-1}) in early February then increased at both sites (21 - 29 mg C mg Chl a^{-1} d^{-1}) in late February. Values decreased in March to 13.6 mg C mg Chl a^{-1} d^{-1} at station N18 and 6.1 mg C mg Chl a^{-1} d^{-1} at station N04. During April and May values ranged from to 7.8 to 12.1 mg C mg Chl a^{-1} d^{-1} at the nearfield sites. Increases to ~17 – 19 mg C mg Chl a^{-1} d^{-1} were observed in June. Throughout most of the seasonal period depth-averaged chlorophyll-specific potential was greater at station N18 relative to N04. Peak depth-averaged chlorophyll-specific potential production (~30 mg C mg Chl a^{-1} d^{-1}) occurred during late February at station N18 while the seasonal minimum (~6 mg C mg Chl a^{-1} d^{-1}) was observed during late March at station N04. By comparison depth-averaged chlorophyll-specific rates at harbor station F23 tended to decrease gradually from a seasonal maximum of ~28 mg C mg Chl a^{-1} d^{-1} in early February to a seasonal minimum in early April (~8 mg C mg Chl a^{-1} d^{-1}; **Figure** 5-3). A slight increase in depth-averaged chlorophyll-specific potential was observed at station F23 in June.

5.1.3 Production at Specified Depths

The spatial and temporal distribution of potential production, chlorophyll and chlorophyll-specific potential production on a volumetric basis were summarized by showing contoured values over the sampling period (**Figures** 5-4 to 5-6). 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.

Potential production at the nearfield sites was similar throughout the semiannual sampling period. These similarities are illustrated by the increasing productivity from February to April at both sites and the concentration of elevated levels of productivity in the upper portion of the water column (**Figure** 5-4). The potential productivity peaks observed during late March and April 2004 at stations N04 and N18 were concentrated in the upper 10 m of the water column and were typical of the pattern observed in prior years. At station N04, potential production was highest (88 mg C m^{-3} d^{-1}) in the surface water during the peak bloom period in late March. In April, the peak potential productivity occurred at mid-surface depth (106 mg C m^{-3} d^{-1}). 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 (141 mg C m^{-3} d^{-1}) located at mid-surface depths during the April winter-spring bloom peak. Elevated levels (~105 mg C m^{-3} d^{-1}) were also observed at mid-depth 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 similar to the depth-specific potential productivity at the nearfield sites (**Figure** 5-4). Potential productivity increased at station F23 from February through April and decreased from surface to depth. During the winter/spring bloom period elevated potential productivity was concentrated in the upper portion of the water with a seasonal maximum of 286 mg C m^{-3} observed in the surface water. During June, the harbor site was characterized by high levels of productivity in both surface and mid-surface depths. Unlike station N18, no subsurface productivity maxima were observed at the harbor site throughout the sampling period.

The productivity pattern at specified depths observed in 2004 was similar to that observed in prior years, although the magnitude was less. At station N04 potential productivity as high as 23 mg C m^{-3} d^{-1} occurred to depths of 25 m; during prior years productivity as great as 45 mg C m^{-3} d^{-1} occurred at these depths. At station N18 potential productivity >50 mg C m^{-3} d^{-1} was not observed at depths >25 m. As in most prior years, elevated productivity (>50 mg C m^{-3} d^{-1}) in the harbor was generally restricted to the upper 10 m of the water column (**Figure** 5-4).

Elevated production values tended to correspond with the occurrence of the highest chlorophyll *a* measurements during the winter/spring bloom period at stations N04 and N18 (**Figure** 5-5). At both nearfield sites, chlorophyll concentrations were elevated throughout the water column during the winter-spring bloom period. At station N18 a 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 5.6 mg m^{-3} were observed at depths as great as 45 m. At station F23, chlorophyll concentrations were elevated during the April *Phaeocystis* bloom then decreased in June. The subsurface chlorophyll maximum observed during the winter bloom period was not associated with a subsurface productivity peak (**Figure** 5-5).

Chlorophyll-specific potential production at depth followed similar seasonal patterns at stations N04 and N18 (**Figure** 5-6). Chlorophyll-specific production at both sites tended to be elevated throughout the water column during the initial sampling periods. As the season progressed elevated chlorophyll-specific production tended to be concentrated in the upper levels of the water column and decrease with 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 surface depths during June. A similar trend was observed at station N18 where elevated depth-specific potential production per unit chlorophyll *a* occurred in surface water during June. 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 June did not lead to elevated phytoplankton biomass (**Figure** 5-5). 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 increased with depth during February, a period characterized by low productivity levels. In contrast, during periods of elevated productivity, chlorophyll-specific production generally decreased with depth. Additionally, chlorophyll-specific production in surface waters tended to increase over the sampling season at the harbor site (**Figure** 5-6).

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 two 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 2004 due to the very cold water temperatures that were observed. During the surveys conducted in February (WF041 and WF042), respiration rates were low in both the nearfield and farfield areas of Massachusetts Bay ($\leq 0.05\ \mu MO_2 hr^{-1}$; **Figures** 5-7 and 5-8). Nearfield respiration rates began to increase at station N18 from early to late February and at both nearfield stations from February to March. By April, nearfield surface water rates had increased to $0.14\ \mu MO_2 hr^{-1}$ while mid-depth and bottom water rates remained relatively low (0.05 to $0.08\ \mu MO_2 hr^{-1}$). In Boston Harbor and offshore, respiration rates followed a similar trend increasing to 0.1 to $0.14\ \mu MO_2 hr^{-1}$ over the entire water column at station F23 and the surface and mid-depth waters at station F19 in April. From April to May, respiration rates in the nearfield mid-depth and bottom waters continued to increase reaching a seasonal peak of $0.16\ \mu MO_2 hr^{-1}$ at mid-depth at station N18. In June, a sample processing error resulted in the loss of data from the surface and bottom waters at station N18, but the rate for the mid-depth sample decreased to $0.1\ \mu MO_2 hr^{-1}$. At station N04, rates increased from May to June at all three depths. A similar trend was seen at station F23 where surface and mid-depth respiration rates nearly doubled from April to maxima for the time period in June (0.21 and $0.17\ \mu MO_2 hr^{-1}$, respectively). At offshore station F19 respiration rates decreased from April peaks to low values in June ($\leq 0.08\ \mu MO_2 hr^{-1}$).

The respiration rates in the winter/spring of 2004 followed trends observed from February to April in POC (**Figures** 5-9 and 5-10) and chlorophyll concentrations (see Section 4.3.2). The large increases in POC and chlorophyll associated with the *Phaeocystis* bloom that were observed in the nearfield (March/April), harbor and offshore (April) were coincident with the trend of increasing respiration rates. The relationship is less clear in June when POC concentrations decreased at all four stations, but respiration rates increased at stations N04 and F23, while decreasing at N18 and F19. As might be expected, both POC and temperature were correlated with respiration rate even when all data from the four stations were grouped for comparison (**Figure** 5-11). Respiration was more highly correlated with POC ($R^2 = 0.56$) than temperature ($R^2 = 0.35$). The major *Phaeocystis* bloom in 2004 provided ample newly produced POC, which likely fueled the slightly elevated rates of respiration. The relationships between respiration and both temperature and POC in winter/spring 2004 are significant ($P<0.001$). There was no significant relationship between dissolved organic carbon and respiration during this 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.

The carbon-specific respiration rates were low (≤0.005 $\mu MO_2 \mu MC^{-1}hr^{-1}$) at station N18 in the nearfield from early February to June (**Figure** 5-12). At station N04, rates also remained low from February to May, but in June rates increased reaching maxima in bottom and mid-depth waters for the time period (0.011 and 0.07 $\mu MO_2 \mu MC^{-1}hr^{-1}$, respectively). Carbon specific respiration rates were low (≤0.005 $\mu MO_2 \mu MC^{-1}hr^{-1}$) from February to June at both Boston Harbor station F23 and offshore station F19 (**Figure** 5-13). Respiration rates were relatively low during the first half of 2004 and tended to increase with increasing POC concentrations during the *Phaeocystis* bloom when the availability of more labile POC might be expected. However, these low rates were likely due to 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 six 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 (WF041, WF042, and WF044). One zooplankton sample was lost due to a broken jar from station F01 during survey WF047. 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*. (2002).

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 were variable from February through June (**Table** 5-1; **Figures** 5-14 and 5-15). Total abundances were relatively low and varied between 0.41-1.0 x 10^6 cells L^{-1} in February (WF041 and WF042), increasing to levels of 1.7-6.7 x 10^6 cells L^{-1} in March (WN043) as the spring bloom of *Phaeocystis pouchetii* was beginning. Abundances continued to increase in April (WF044) to levels very high levels of 3.6-14.2 x 10^6 cells L^{-1} as the bloom of *Phaeocystis pouchetii* continued. Levels declined to 0.97-2.7 x 10^6 cells L^{-1} in May (WN046) as the *Phaeocystis* bloom was declining, and total abundances dropped further to 0.77-2.2 x 10^6 cells L^{-1} by mid-June (WF047) when *Phaeocystis* was no longer observed.

Total phytoplankton abundance in farfield whole water samples showed similar low abundances in early February and late February (0.34-1.4 x 10^6 cells L^{-1}) (**Table** 5-1; **Figures** 5-16 and 5-17). By early April during the *Phaeocystis* bloom, farfield abundances had increased to 2.8-16.8 x 10^6 cells L^{-1} with elevated abundances observed throughout Massachusetts Bay (**Figure** 5-18). By June, phytoplankton abundances had declined to levels of 0.42 - 3.0 x 10^6 cells L^{-1}, with high abundance levels concentrated in the harbor and nearshore stations (**Figure** 5-19).

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, silicoflagellates and protozoans in nearfield and farfield screened phytoplankton samples were 144 - 529 cells L^{-1} from February through 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 (2004)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF041	2/2-5	0.68	0.46-1.00	0.84	0.34-1.38
WF042	2/23-25	0.64	0.41-0.83	0.84	0.42-1.39
WN043	3/23	4.44	1.74-6.72	–	–
WF044	4/7-9	9.41	3.59-14.21	10.14	2.77-16.81
WN046	5/14	1.93	0.97-2.67	–	–
WF047	6/14-17	1.23	0.77-2.24	1.42	0.42-2.95

Monitoring program revised for 2004 – no survey WN045 conducted.

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

Survey	Dates (2004)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF041	2/2-5	271	203-337	273	165-420
WF042	2/23-25	261	158-375	353	257-495
WN043	3/23	392	322-480	–	–
WF044	4/7-9	352	213-459	402	282-490
WN046	5/14	393	316-529	–	–
WF047	6/14-17	338	268-414	287	144-467

Monitoring program revised for 2004 – no survey WN045 conducted.

5.3.1.2 Nearfield Phytoplankton Community Structure

Whole-Water Phytoplankton – In early and late February, nearfield whole-water phytoplankton assemblages from both depths were dominated by unidentified microflagellates <10 µm in diameter (77-94% of cells counted) and cryptomonads <10 µm in diameter (up to 21%). By late March, the spring bloom of *Phaeocystis pouchetii* was beginning and this species represented from 56 to 90% of the phytoplankton assemblage (marked as "Other" in **Figures** 5-14 and 5-15). In April, *Phaeocystis* was even more dominant (69-93%) with microflagellates making up most of the rest of the community (5-29%). In May, dominance had switched back to microflagellates (36-61%), with lesser contributions by *Phaeocystis* (24-48%) and cryptomonads (up to 15%). Indications were that not only was *Phaeocystis* becoming less abundant, but the cells and colonies observed appeared to be indicative of a senescent bloom (i.e. 'empty' *Phaeocystis* cells, lower density of cells, and many fragmented/broken colonies. In June, microflagellates were dominant (63-81%), with lesser contributions by cryptomonads (14-32%). Uncharacteristically, diatoms never comprised >5% of cells counted, during the entire period of February through June.

Screened Phytoplankton – In early February, nearfield screened samples consisted of a mixed assemblage that included the silicoflagellates *Distephanus speculum* and *Dictyocha fibula*, tintinnids, aloricate ciliates and a mixture of thecate dinoflagellates such as *Ceratium* spp., *Dinophysis norvegica*, *Gonyaulax* sp., *Prorocentrum micans, P. minimum*, *Protoperidinium* spp., *P. depressum*, and unidentified thecate dinoflagellates and athecate dinoflagellates. From late February to early April various combinations of the abovementioned taxa continued to be dominant, with lesser contributions by additional dinoflagellates such as *Gyrodinium spirale* and the photosynthetic ciliate *Mesodinium rubrum*. In May and June, this combination of taxa persisted, but there was increasing dominance by *Ceratium* spp., with various combinations of *Ceratium longipes*, *C. tripos*, and *C. fusus* comprising up to 38-49% of the cells counted. Additional dinoflagellate taxa which appeared during these two months included *Dinophysis acuminata*, *Gymnodinium* sp., and *Scrippsiella trochoidea*.

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, most farfield station assemblages were dominated at both depths by unidentified microflagellates (65-95% of cells counted) and cryptomonads (up to 20%; **Figure** 5-16). There were trace recordings of unidentified centric diatoms (up to 7% at station F31 in Boston Harbor) and athecate dinoflagellates of the genus *Gymnodinium* (up to 9%) at stations F01 and F22. In late February, farfield assemblages remained generally similar to the nearfield with unidentified microflagellates (69-98%), cryptomonads (up to 14%), and lesser contributions by unidentified small centric diatoms (up to 9%), a larger unidentified species of the centric diatom genus *Thalassiosira* (up to 9%), and the dinoflagellate *Heterocapsa rotundata* (up to 10%). The centric diatoms were most abundant at the Cape Cod Bay stations suggesting a minor winter/spring diatom bloom may have occurred (**Figure** 5-17). In April (WF044) the spring bloom of *Phaeocystis pouchetii* was underway throughout the study area (**Figure** 5-18). *Phaeocystis* comprised 37-96% of cells counted. The highest abundances of *Phaeocystis* were observed in Boston Harbor and at near-harbor coastal stations. The remainder of the assemblage was similar to that of the nearfield, mostly comprised by unidentified microflagellates (<5-59%).

By June, the *Phaeocystis* bloom had ended and assemblages at both depths at most farfield stations were dominated by the same small microflagellates (59-90%) and cryptomonads (up to 32%), that dominated the nearfield (**Figure** 5-19). Subdominant taxa included unidentified larger (> 10 µm in longest dimension) microflagellates (up to 6%), cryptomonads (up to 7%) and *H. rotundata* (up to 9%).

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

From February to June, 20 µm-screened phytoplankton samples from the farfield contained tintinnids, aloricate ciliates, the photosynthetic ciliate *Mesodinium rubrum*, and the silicoflagellates *Distephanus speculum* and *Dictyocha fibula*. There were also varying contributions by the dinoflagellates *Ceratium fusus, C. lineatum, C. longipes, C. machoceros, C. tripos, Dinophysis acuminata*, *D. norvegica, Prorocentrum micans, P. minimum, Protoperidinium depressum*, *Scrippsiella trochoidea*, unidentified species of the genera *Ceratium*, *Gonyaulax*, *Gymnodinium, Gyrodinium,* and *Protoperidinium*, as well as other unidentified thecate and athecate dinoflagellates. The only instance in which *Alexandrium* spp. was recorded at > 5% of cells counted was for a single sample (surface waters at station F27 off of Cape Ann) during June, at an abundance level of 12 cells liter^{-1}.

Nuisance Algae - The primary bloom of harmful or nuisance phytoplankton species abundant in Massachusetts and Cape Cod Bays during February – June, 2004 was the *Phaeocystis pouchetii* bloom. This bloom was first recorded in the nearfield whole water phytoplankton samples from stations N04 and N18 in late March at levels of 1.0-6.0 x 10^6 cells L^{-1} (56-90% of cells counted; **Figures** 5-14 and 5-15). By April, *Phaeocystis* was observed at all stations in the survey area at abundance levels of 2.0 - 15.5 x 10^6 cells L^{-1} (37-96% of cells counted; **Figure** 5-18). The bloom persisted in the nearfield into May with nearfield abundances of 0.23 -1.3 x 10^6 cells L^{-1}, comprising 24-48% of cells counted. *Phaeocystis* was not recorded in any sample collected during survey WF047 in June.

In April 2004, *Phaeocystis* abundances were >10 x 10^6 cells L^{-1} at most stations in Massachusetts Bay and reached a maximum of 15.5 x 10^6 cells L^{-1} in the surface waters at coastal station F24. The 2004 *Phaeocystis* bloom achieved much higher abundances than during the 2001, 2002 and 2003 blooms (maxima of 3.1, 1.6, and 10.2 x 10^6 cells L^{-1}, respectively). In fact, the 2004 bloom exceeded the previous maximum levels for the program observed during the 2000 bloom (12.3 x 10^6 cells L^{-1}). As observed during the previous blooms, the 2004 bloom was a regional event with elevated abundances measured throughout the bays. During the April survey, Cape Cod Bay counts were clearly lower than those in Massachusetts Bay, but data collected by the Center for Coastal Studies in Cape Cod Bay indicates that *Phaeocystis* was present at abundances of >5 x 10^6 cells L^{-1} in late March. The continued occurrence of spring *Phaeocystis* blooms in consecutive years (2000 to 2004) 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 very high abundances of *Phaeocystis* in the nearfield in March and April and the protracted duration of the bloom into May led to an exceedance of both the winter/spring and summer *Phaeocystis* caution thresholds.

The toxic dinoflagellate *Alexandrium tamarense* was not recorded for February through June 2004. Cells of *Alexandrium* spp. that were not clearly distinguishable as *A. tamarense*, were only sporadically recorded at trace levels. Records of "*Alexandrium* spp." in screened samples that were not positively identified as *A. tamarense* included abundances of 2.2-12.0 cells L^{-1} from seven stations (F02, F22, F23, F25, F26, F27, and N18) in June. Thus, abundance of *Alexandrium* spp. in screened samples in 2004 was typically low, as in most previous years.

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 2004. However, these cells never comprised >5% of cells counted in a given sample. Cells of the *Pseudo-nitzschia delicatissima* complex were recorded during each of the surveys, but usually at abundances of <0.01 x 10^6 cells L^{-1} peaking at ~0.03 x 10^6 cells L^{-1} in late March. Cells designated as *Pseudo-nitzschia pungens* were only recorded for 7 samples during this time period and never at abundances above 1,000 cells L^{-1}.

Although *Phaeocystis, Alexandrium* spp. and *Pseudo-nitzschia* spp. were all observed in February to June 2004, only *Phaeocystis* exceeded the caution threshold values (discussed in Section 6).

5.3.2 Zooplankton

5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Total zooplankton abundance at nearfield stations generally was <30 x 10^3 animals m^{-3} from February through April (**Table** 5-3; **Figure** 5-20). Values increased somewhat in May, to levels of 25-31 x 10^3 animals m^{-3} and remained comparatively high (21-45 x 10^3 animals m^{-3}) in June.

Total zooplankton abundance at farfield stations in early February ranged widely from 1.5 - 86 x 10^3 animals m^{-3} (**Table** 5-3). Zooplankton abundance was highest at boundary station F26 and Cape Cod Bay stations F01, F02, and F33, with values more than double those of most other stations during the same survey (**Figure** 5-21a). In late February, total abundance values had increased, but remained <20 x 10^3 animals m^{-3} for all stations except station F23 in Boston Harbor, station F25 in the coastal zone, and station F02 in Cape Cod Bay (**Figure** 5-21b). The reason(s) for this variability is unclear. By early April, variability in total zooplankton abundance had increased ranging from minima of ≤5 x 10^3 animals m^{-3} in Boston Harbor and nearby coastal stations to maxima of >75 x 10^3 animals m^{-3} at stations F01 and F02 in Cape Cod Bay (**Figure** 5-22a). Interestingly, this distribution in zooplankton abundance was the reverse of that observed for *Phaeocystis* – high *Phaeocystis* coincident with low zooplankton abundance. This trend and the ecological dynamics associated with it will be examined in more detail in the 2004 annual report. By June, zooplankton abundance had increased to 20 to >30 x 10^3 animals m^{-3} throughout Massachusetts Bay, but had decreased to <23 x 10^3 animals m^{-3} in Cape Cod Bay (**Figure** 5-22b).

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

Survey	Dates (2004)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF041	2/2-5	7.2	5.6-8.2	8.9	2.6-22.7
WF042	2/23-25	14.9	12.5-17.1	13.9	1.5-28.9
WN043	3/23	15.0	7.6-22.4	–	–
WF044	4/7-9	21.9	13.6-26.7	21.0	2.5-86.2
WN046	5/14	28.0	24.8-31.2	–	–
WF047	6/14-17	29.9	21.1-45.1	27.8	18.6-38.7

Monitoring program revised for 2004 – no survey WN045 conducted.

In 1998, two additional stations in Cape Cod Bay were added to the monitoring program to better address spatial variability in winter. For the four zooplankton stations (F01, F02, F32, and F33) in Cape Cod Bay during the three surveys in early February, late February and April, abundances of total zooplankton ranged from 3.5-23 x 10^3 animals m^{-3}, 6.9-26 x 10^3 animals m^{-3}, and 29-86 x 10^3 animals m^{-3}, respectively (**Figures** 5-21 and 5-22). This was variability of ± 75.2%, 57.8%, and 58.4% of the mean abundances, respectively, for these 4 stations, during these three surveys. Assemblages at the four Cape Cod Bay stations were generally similar during a given survey, dominated by varying proportions of copepod nauplii, and copepodites of *Oithona similis* and *Pseudocalanus* spp. during surveys WF041 and WF042, and copepod nauplii, and copepodites of *Calanus finmarchicus* and *Pseudocalanus* spp., and barnacle nauplii during survey WF044.

5.3.2.2 Nearfield Zooplankton Community Structure

Nearfield zooplankton assemblages (**Figure** 5-20) in early February were dominated by copepod nauplii (38-43%), as well as copepodites of *Oithona similis* (13-23%) and *Pseudocalanus* spp. copepodites (10-21%). Females of *O. similis*, *Pseudocalanus*, *Centropages* sp. copepodites, and combined stages of *Microsetella norvegica* individually comprised up to 6-7% at some stations. Assemblages were similar in late February comprised of copepod nauplii (71-81%), *O. similis* copepodites (9-13%), and *Pseudocalanus* spp. copepodites (up to 9%). In March, there had been a shift to dominance by copepod nauplii (52-81%) and barnacle nauplii (9-37%). During April, dominance continued for copepod nauplii (46-92%) and barnacle nauplii (up to 45%), with lesser contributions by *Calanus finmarchicus* copepodites (up to 5%). In May, there was continued nearfield dominance by copepod nauplii (52% at both stations), *Calanus finmarchicus* copepodites (19-30%), and bivalve veligers (up to 10%). At nearfield stations in June, zooplankton assemblages contained a mixture of copepod nauplii (13-18%), and copepodites of *Oithona similis* (15-29%), *Pseudocalanus* spp. (10-14%) and *Calanus finmarchicus* (8-24%). Additional contributions were from *Temora longicornis* copepodites (up to 6%) and bivalve veligers (up to 35%).

Regional Zooplankton Assemblages

Zooplankton assemblages at farfield stations during early February were generally similar to those in the nearfield (**Figures** 5-21a). Abundant taxa throughout the area included copepod nauplii (19-60%) and copepodites of *Oithona similis* (6-19%), and *Pseudocalanus* spp. (11-48%). *Centropages* spp. copepodites (up to 11%) and *Microsetella norvegica* (up to 27%) made up most of the remainder.

In late February (**Figure** 5-21b), assemblages contained copepod nauplii (17-74%), *Oithona similis* copepodites (up to 19%) and females (up to 6%); *Calanus finmarchicus* copepodites (up to 18% at boundary station F27, and up to 7% at F26, but < 5% elsewhere), females (up to 28% at F27, but < 5% elsewhere) and males (up to 9% at F27, but < 5% elsewhere); and *Pseudocalanus* spp. copepodites (up to 36%), females (up to 15%) and males (up to 5%). *Microsetella norvegica* comprised 21% of animals recorded at boundary station F26, but < 5% elsewhere. Barnacle nauplii comprised 12-15% of abundance at stations F23 and F30 in Boston Harbor, but < 6% elsewhere.

In early April (**Figure** 5-22a), assemblages contained copepod nauplii (20-80%), *Calanus finmarchicus* copepodites (up to 40%) and *Pseudocalanus* spp. copepodites (up to 29%) and females (up to 6%). Harpacticoid copepods comprised 8% of abundance at station F31 in Boston Harbor, but < 5% elsewhere. Barnacle nauplii comprised 5-70% of total abundance everywhere except for station F33 in Cape Cod Bay.

During the June survey, farfield zooplankton assemblages (**Figure** 5-22b) contained copepod nauplii (6-35%), *Oithona similis* copepodites (6-39% except for < 5% at Boston Harbor stations F23, F30, and F31) and females (up to 10%), *Calanus finmarchicus* copepodites (up to 43% at F02, but < 23% elsewhere), *Pseudocalanus* spp. copepodites (up to 18%) and females (up to 5%), and *Temora longicornis* copepodites (up to 22%) and males (up to 6%). Centropages spp. copepodites comprised up to 7%, except for 18% at station F31. *Acartia hudsonica* adults and *Acartia* spp. copepodites were abundant at stations F23, F30 and F31 in Boston Harbor, but generally absent elsewhere. Bivalve veligers comprised up to 17% of abundance at some stations.

Overall, zooplankton assemblages during the first half of 2004 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 2004 followed patterns typically observed in prior years with moderate peak levels during the winter-spring *Phaeocystis* bloom

- The winter-spring bloom peaks at both nearfield sites in 2004 were somewhat higher than values observed during the winter-spring period in 2003 but generally lower than those observed in earlier years (1999 to 2002).
- Potential productivity at station F23 increased during the winter/spring bloom in 2004, but unlike 2002 and 2003, productivity continued to increase into June. The trend of increasing productivity from February to June is similar to the pattern observed prior to effluent diversion offshore and is a departure from the winter/spring bloom dominated seasonal cycle noted in 2002-2003.
- Elevated production values tended to be correlated with the occurrence of the highest chlorophyll measurements
- Chlorophyll-specific potential production reached higher levels at station N18 compared with N04
- Respiration rates were low and may have been inhibited by the unusually low ambient water temperatures present winter/spring 2004.
- Respiration rates were significantly correlated with POC concentrations and temperature. Rates generally peaked in April during the *Phaeocystis* bloom, but did increase into June at stations F23 and N04.
- Carbon-specific respiration rates were low throughout the first half of 2004.
- Whole-water phytoplankton assemblages were dominated by unidentified microflagellates except during the spring *Phaeocystis* bloom. This is typical for the first half of the year in terms of taxonomic composition.
- Atypically, the centric diatoms that usually bloom in Massachusetts Bay in the winter and spring were in low abundance in 2004. A small increase in diatom abundance from early to late February was noted at the Cape Cod Bay stations.
- A major *Phaeocystis* bloom occurred in spring 2004 that was more abundant than the blooms of this species during the same period in previous years. *Phaeocystis* abundance exceeded both the winter/spring and summer thresholds. The appearance of *Phaeocystis* blooms in five consecutive years (2000-2004) continues a departure from the 3-year cycle for these blooms previously observed during the baseline period since 1992.
- There were no other blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during February – June 2004. While dinoflagellates of the genus *Alexandrium* and diatoms characterized as *Pseudo-nitzschia pungens* and members of the *P. delicatissima* complex were recorded, they were generally present in low abundance. Except for *Phaeocystis*, 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 2004 were comprised of taxa recorded for the same time of year in previous years.
- The station to station variability in zooplankton abundance in April 2004 was the reverse of that observed for *Phaeocystis* – high *Phaeocystis* abundance coincident with low zooplankton abundance suggesting bottom up control of grazers by *Phaeocystis*.
- High variability in zooplankton abundance was observed among stations within given winter-spring surveys in Cape Cod Bay.

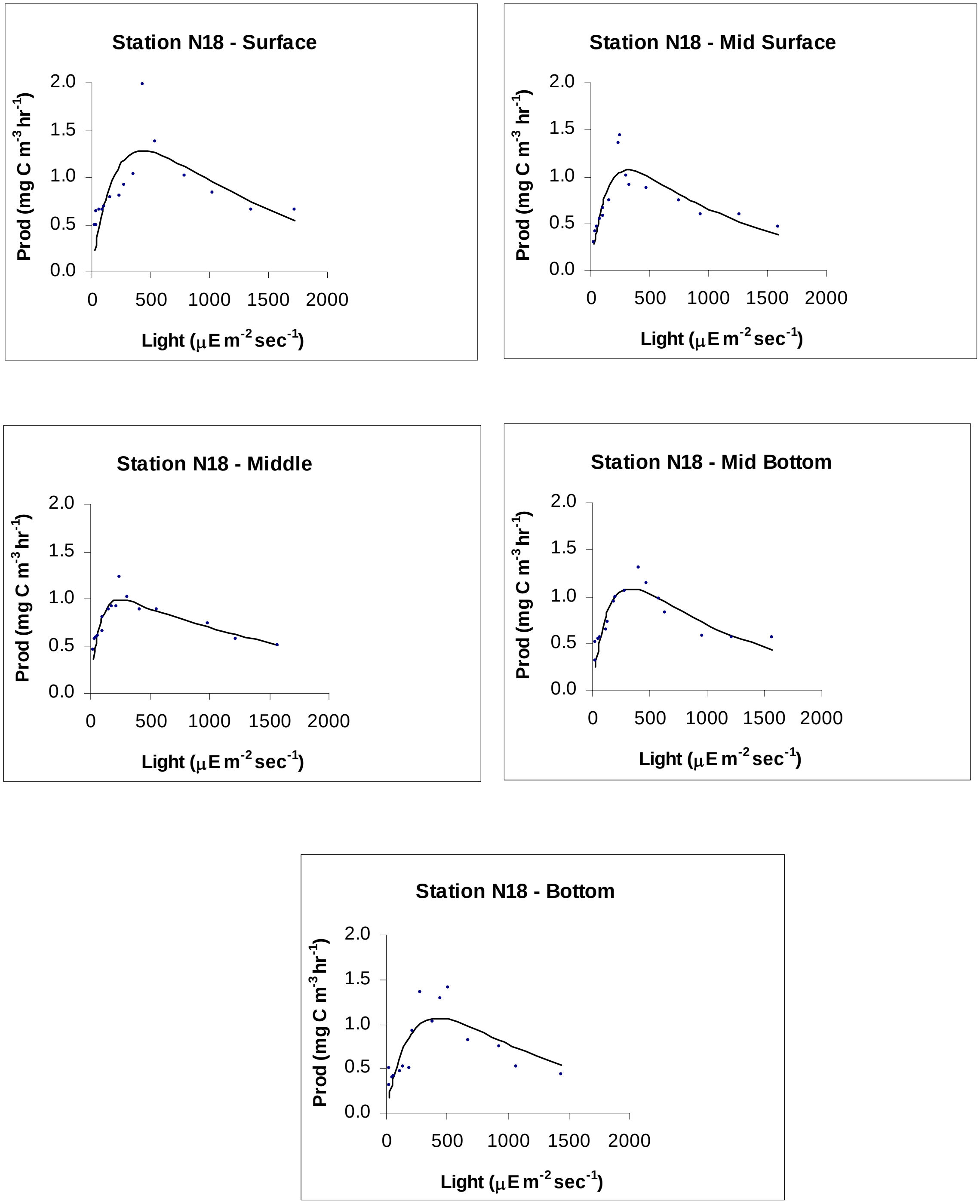


Figure 5-1. An example photosynthesis irradiance curve from station N18 collected February 2004 (WF041)

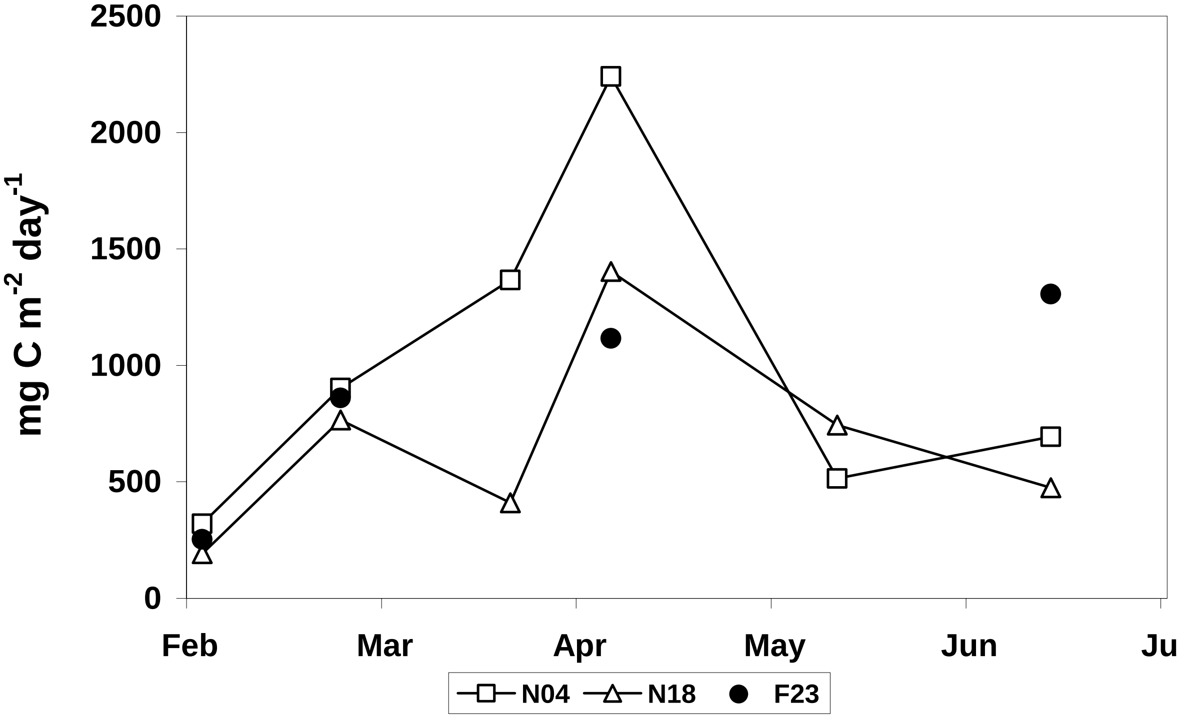


Figure 5-2. Time series of areal potential production (mg C m^{-2} d^{-1}) for stations N04, N18 and F23

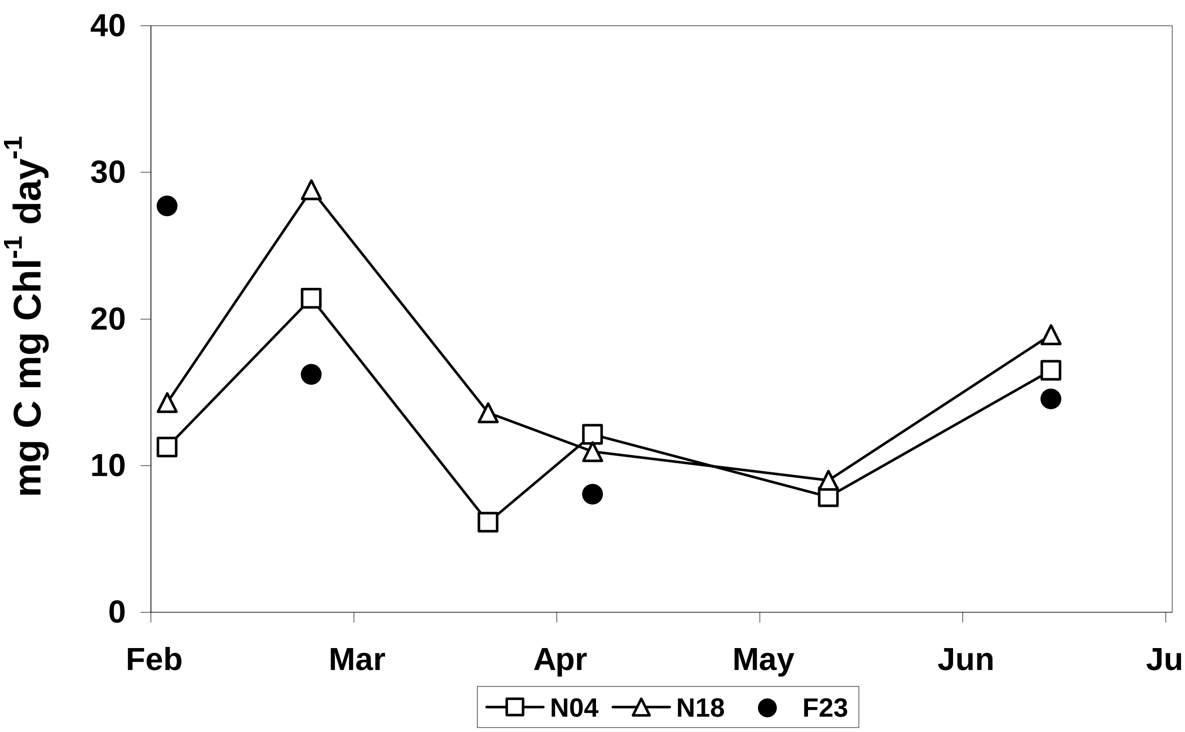


Figure 5-3. Time series of depth-averaged chlorophyll-specific potential production (mg C mg Chl*a*$^{-1}$ d^{-1}) for stations N04, N18 and F23

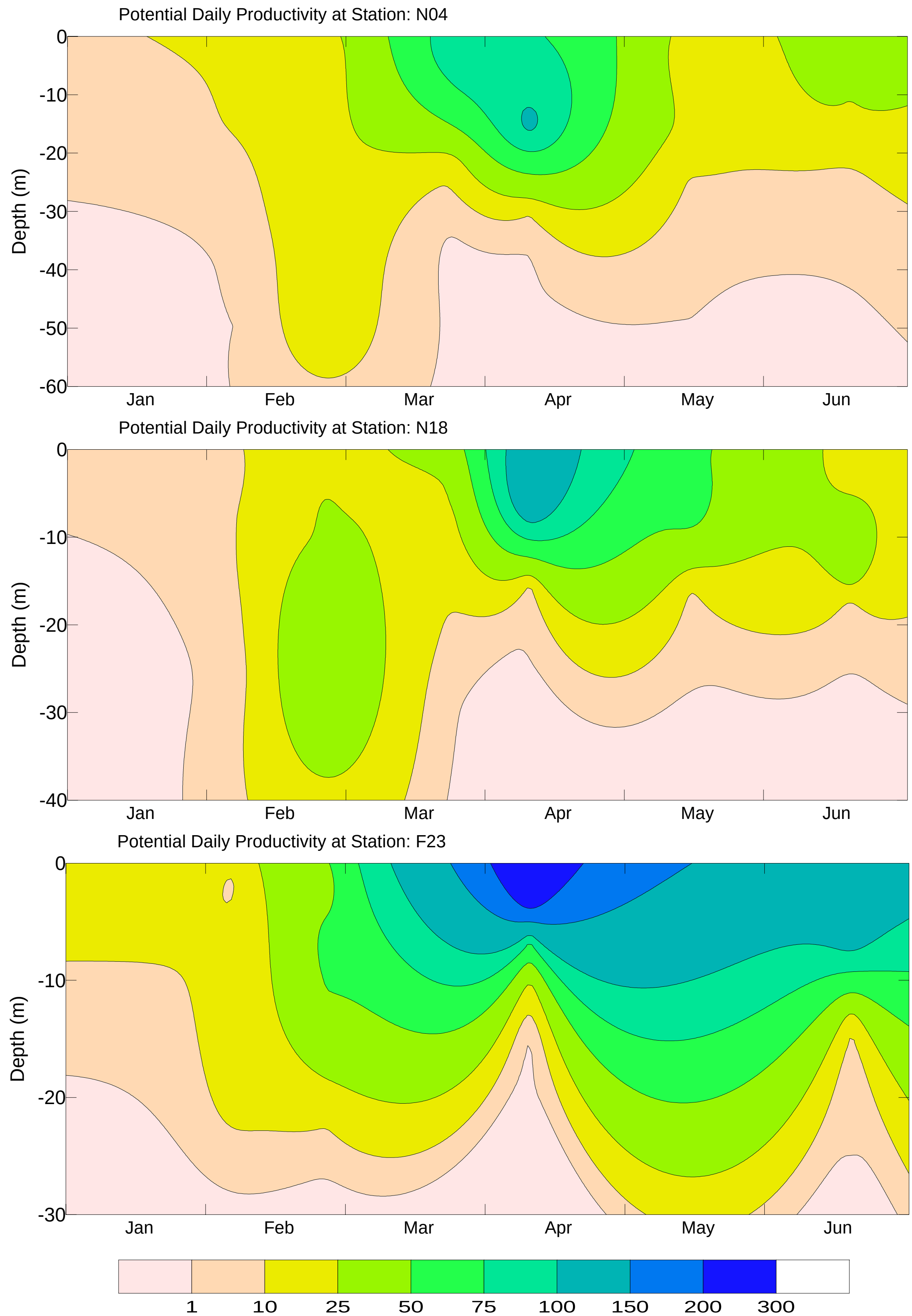


Figure 5-4. Time-series of contoured potential daily production ($mgCm^{-3}d^{-1}$) over depth at stations N04, N18 and F23

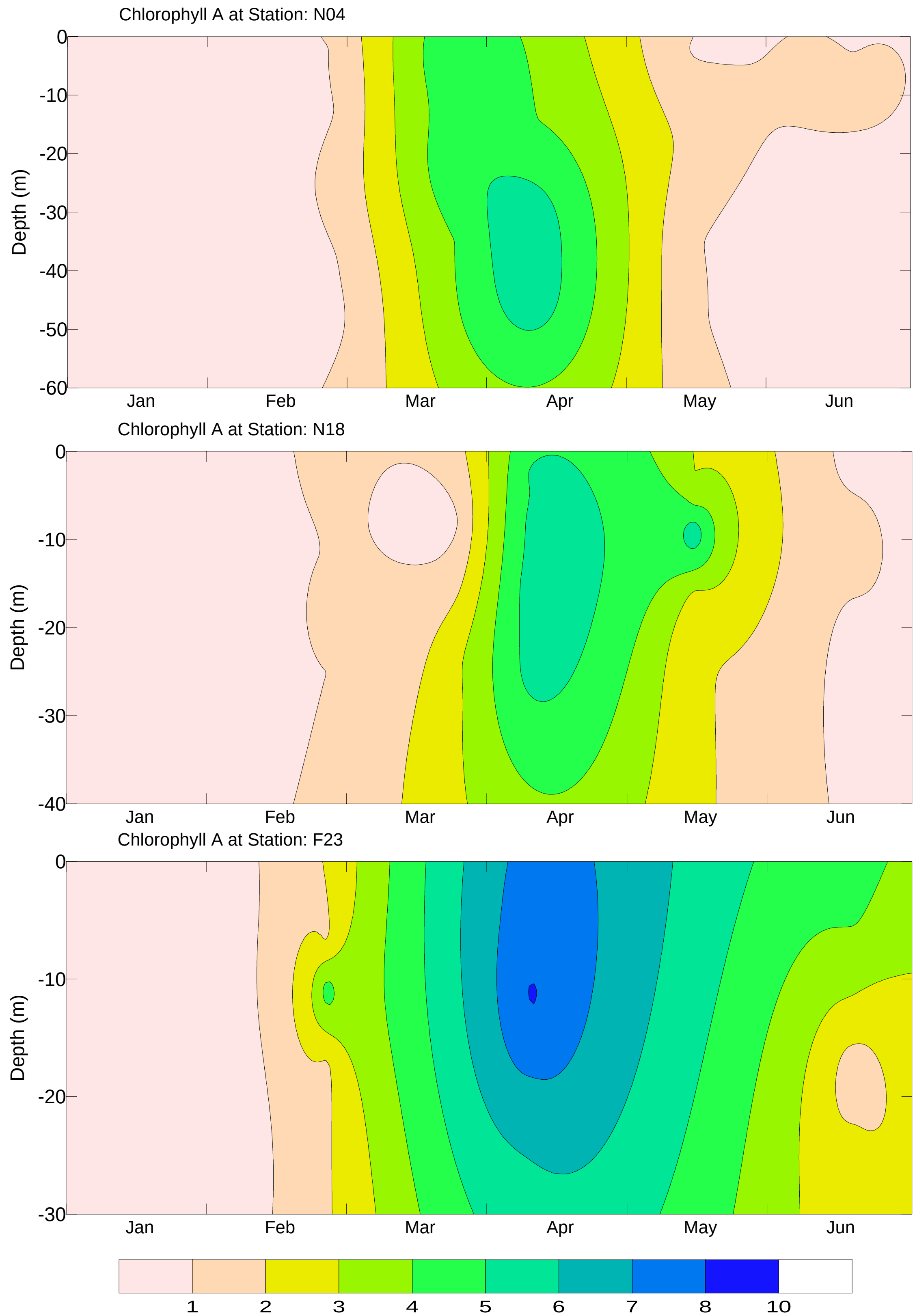


Figure 5-5. Time-series of contoured *in vitro* chlorophyll *a* concentration (μgL^{-1}) over depth at stations N04, N18, and F23

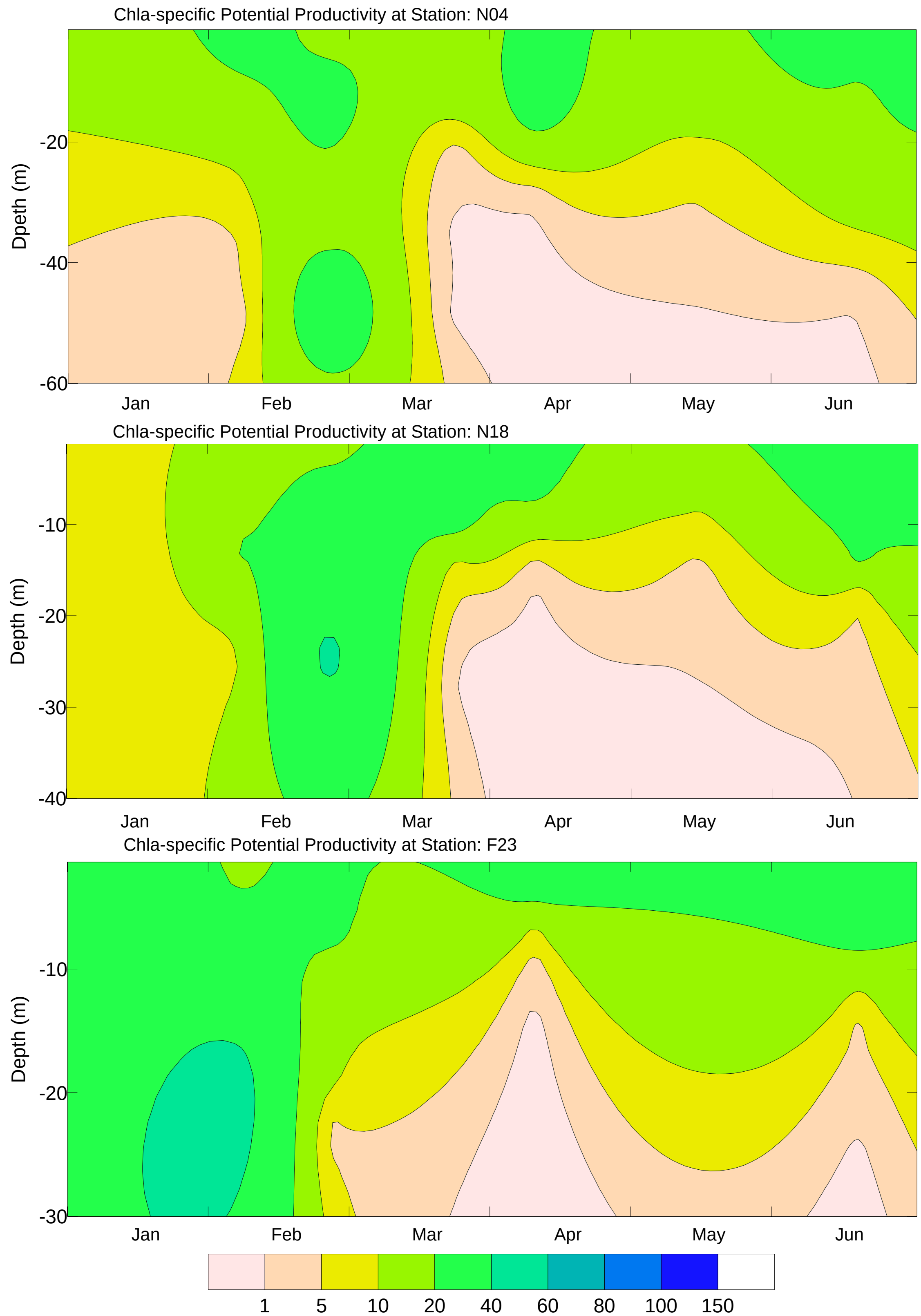


Figure 5-6. Time-series of contoured chlorophyll-specific potential production ($mgCmgChl\textit{a}^{-1}d^{-1}$) over depth at station N04, N18, and F23

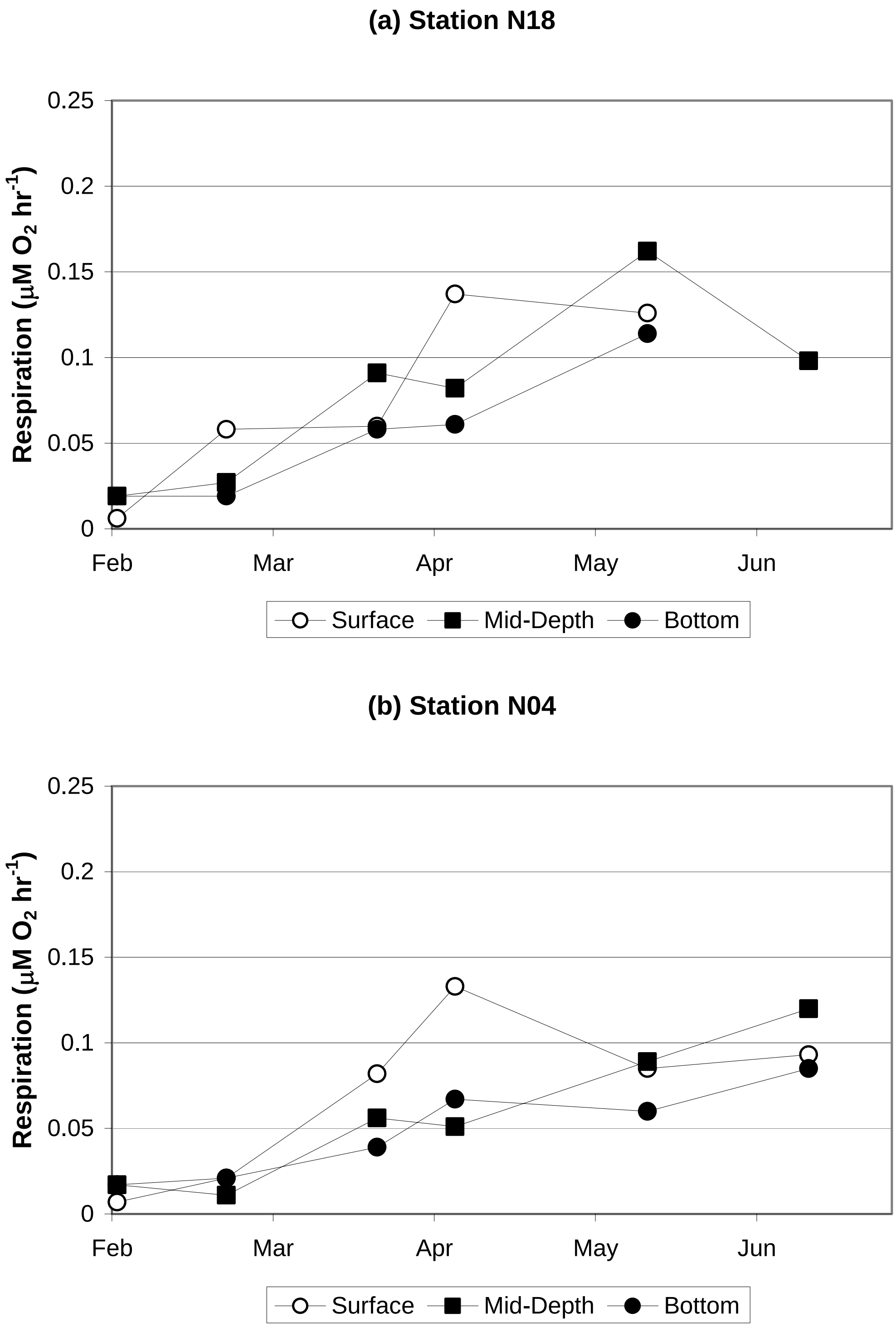
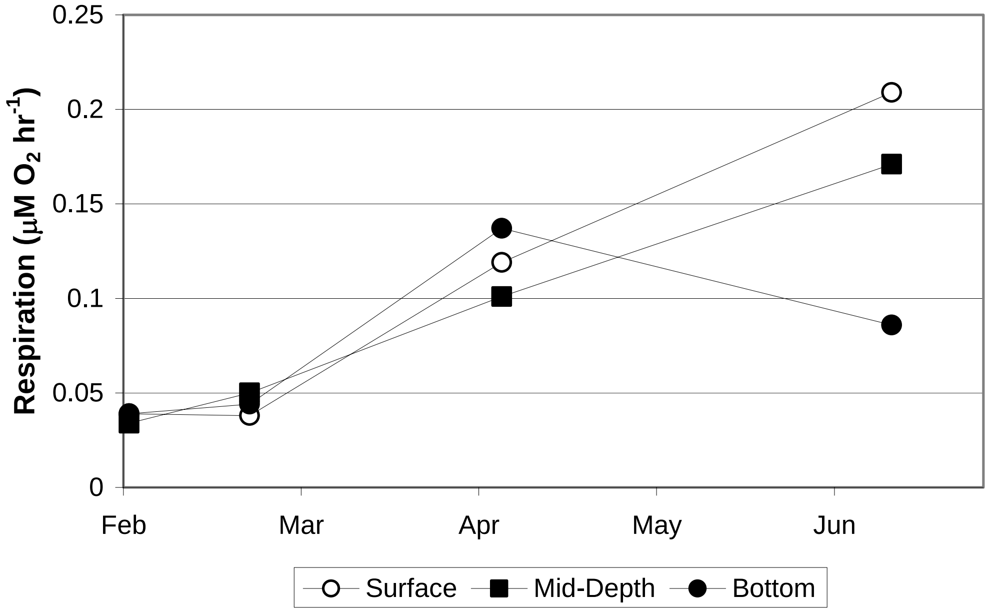


Figure 5-7. Time-series plots of respiration (μMO_2hr^{-1}) at stations N18 and N04

(a) Station F23



(b) Station F19

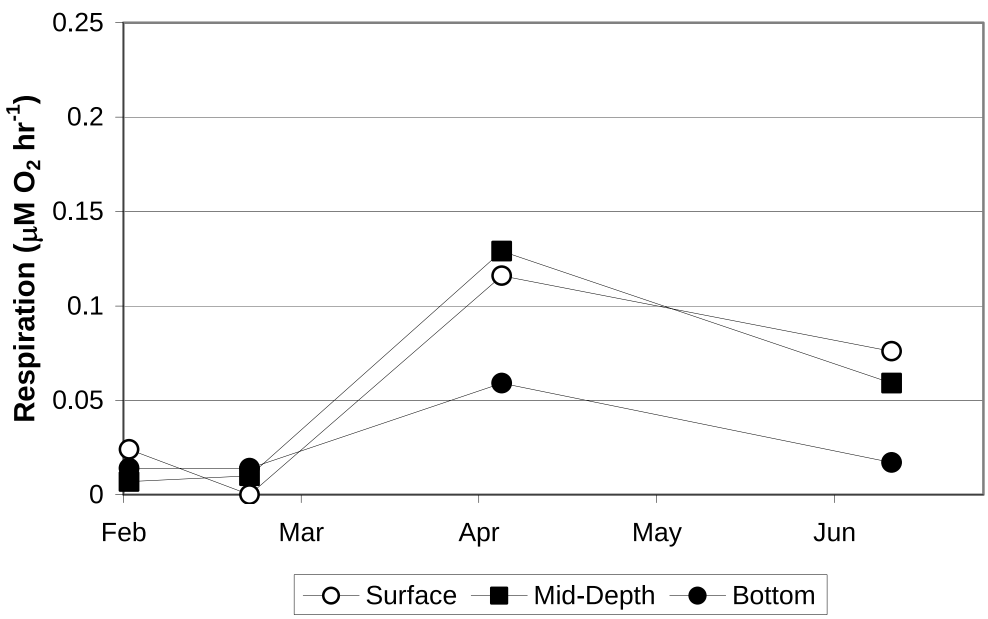
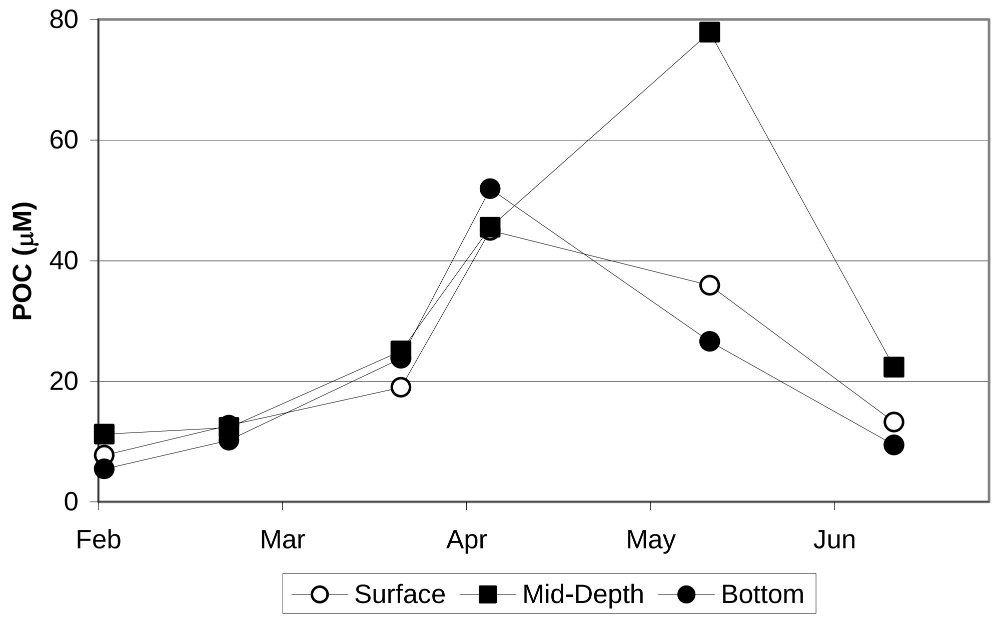


Figure 5-8. Time-series plots of respiration (μMO_2hr^{-1}) at stations F23 and F19

(a) Station N18



(b) Station N04

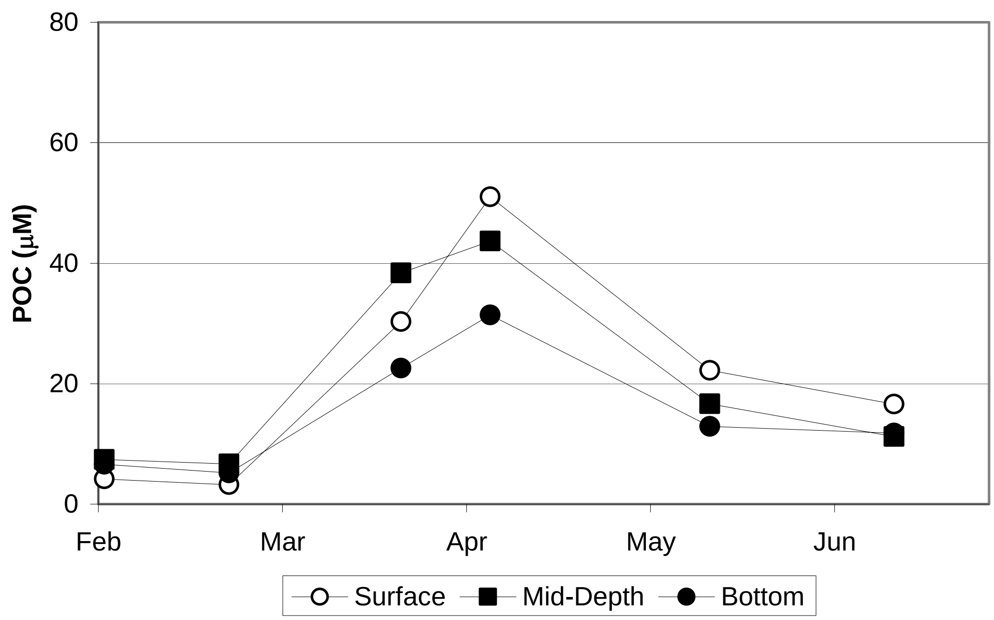
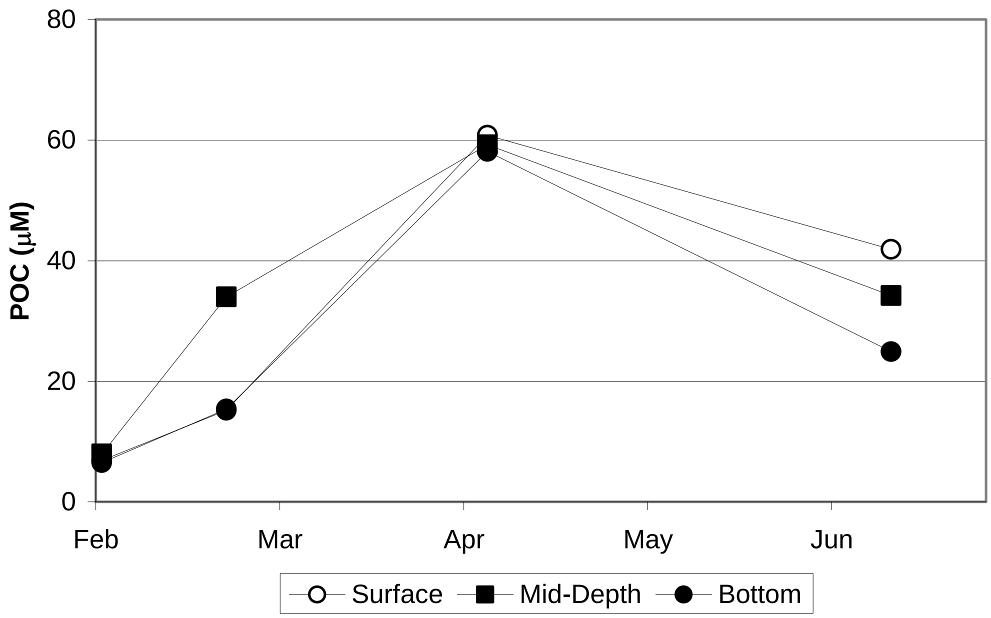


Figure 5-9. Time-series plots of POC (μM) at stations N18 and N04

(a) Station F23



(b) Station F19

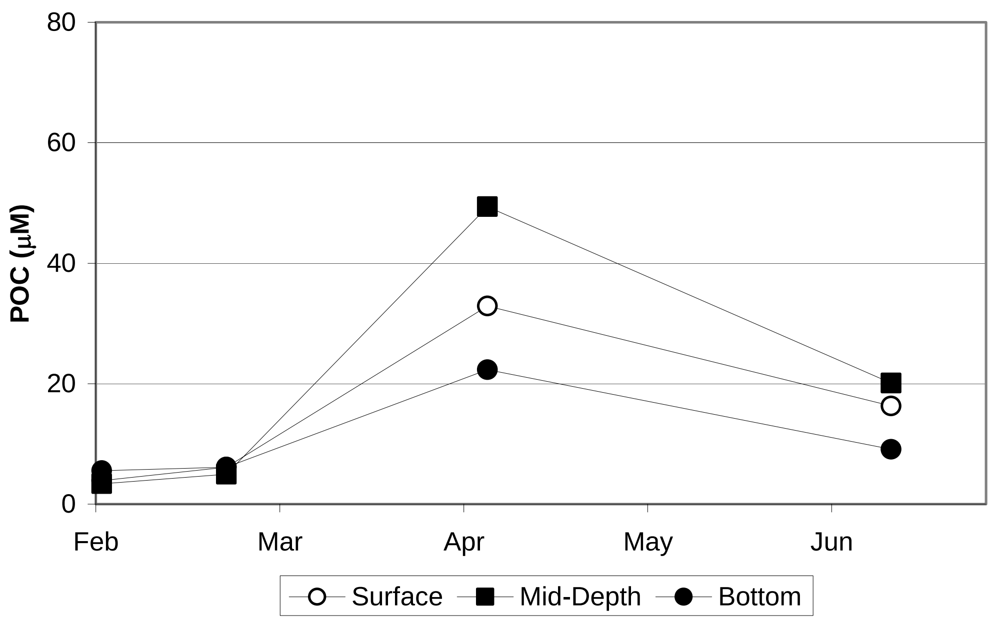


Figure 5-10. Time-series plots of POC (µM) at stations F23 and F19

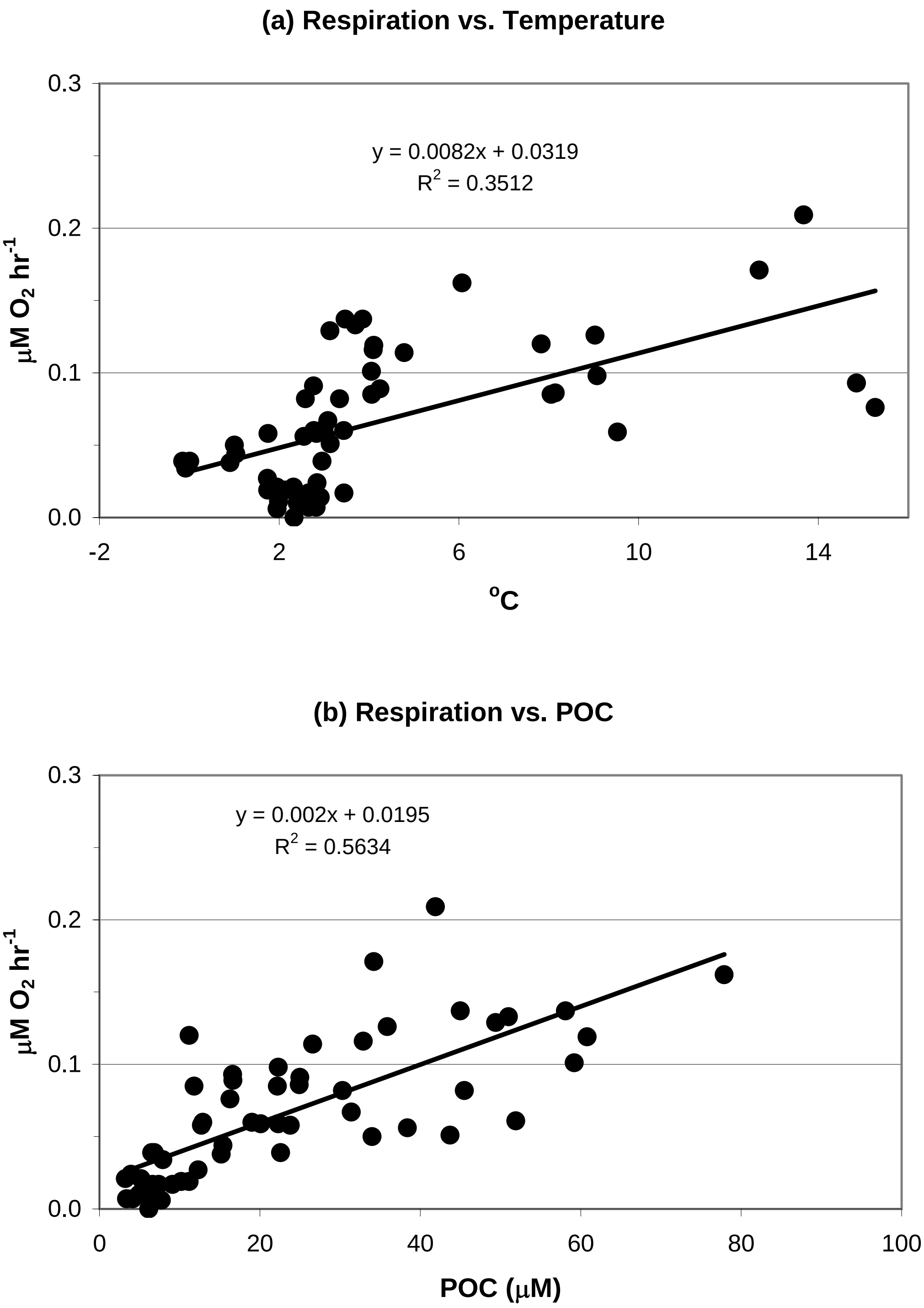
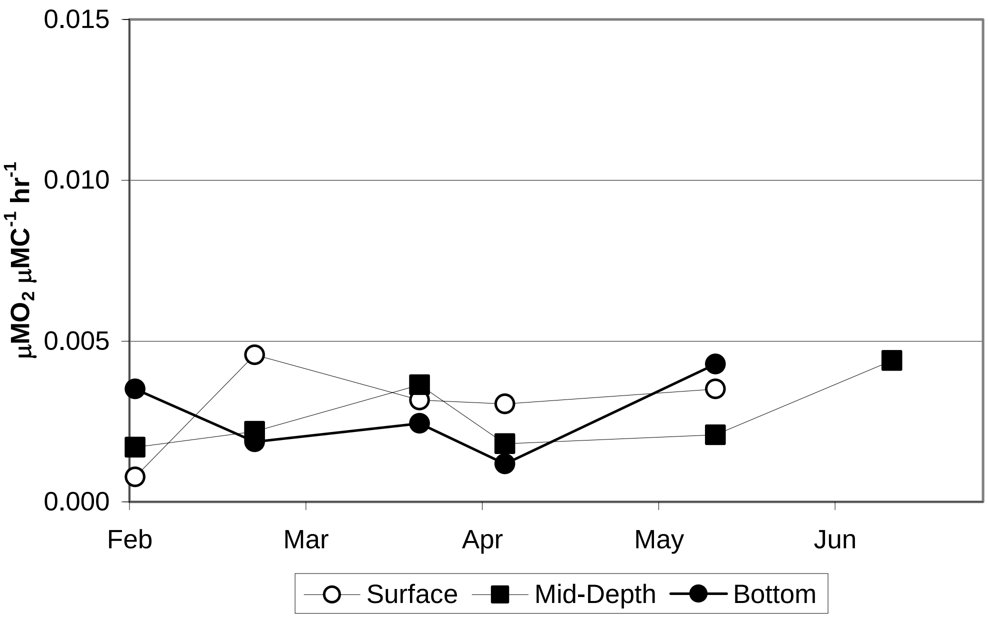


Figure 5-11. Comparison of respiration rate versus a) temperature and b) POC concentration for data collected at stations N04, N18, F19 and F23 in February – June 2004

(a) Station N18



(b) Station N04

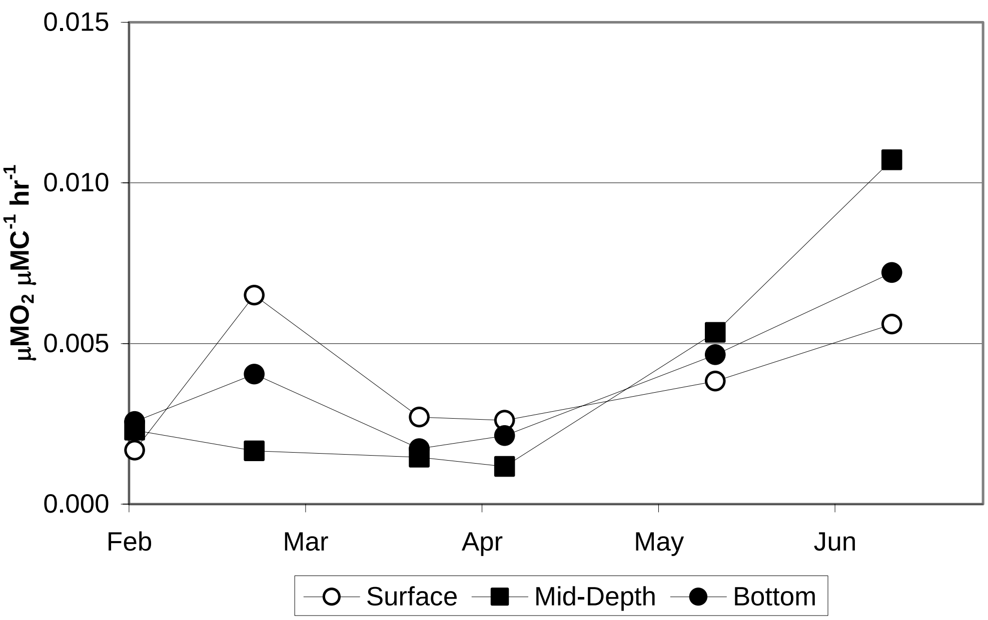
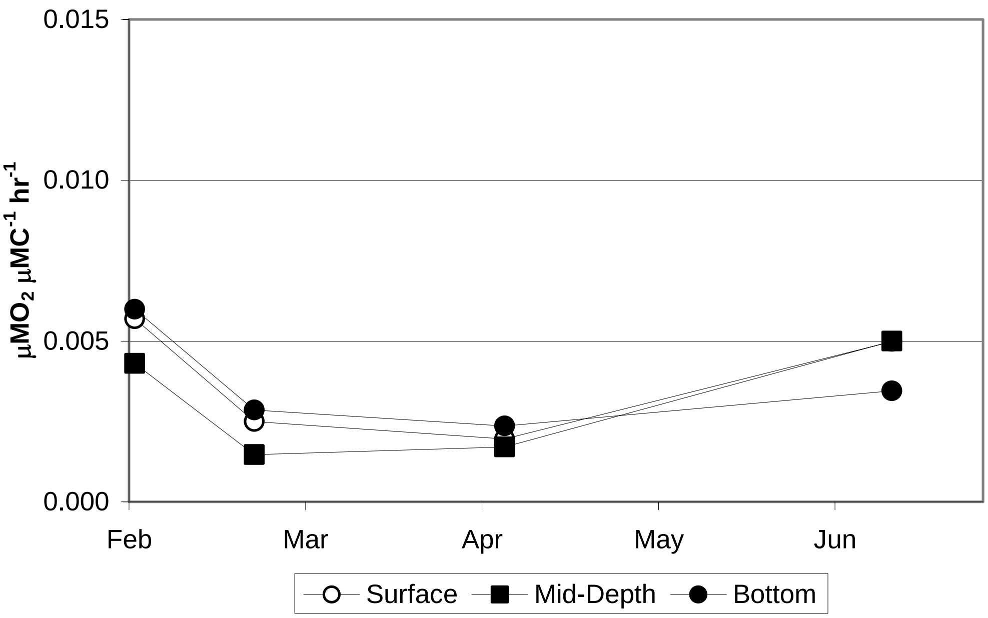


Figure 5-12. Time-series plots of carbon-specific respiration ($\mu MO_2 \mu MC^{-1} hr^{-1}$) at stations N18 and N04

(a) Station F23



(b) Station F19

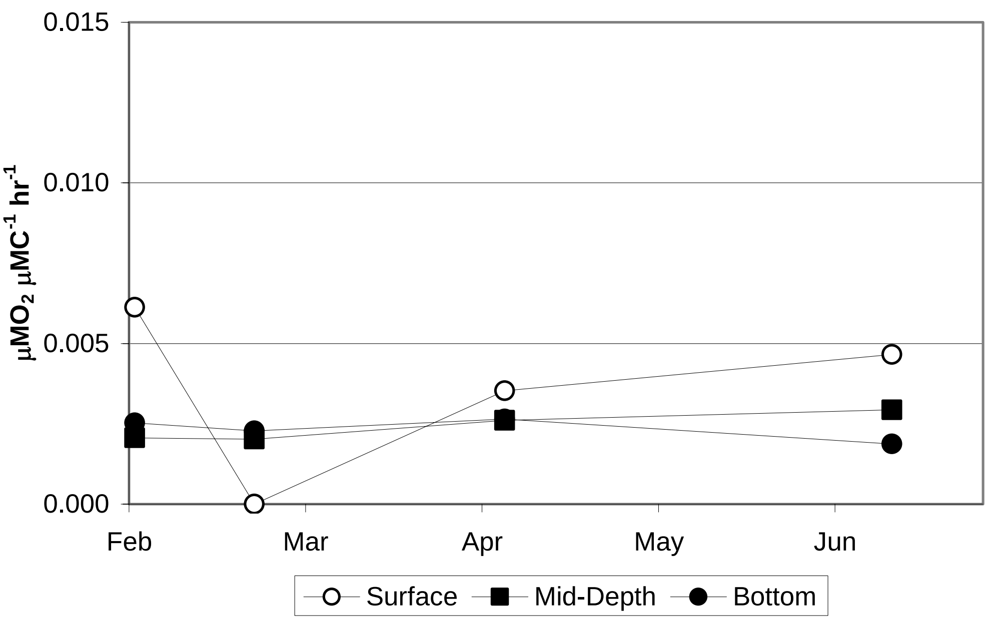


Figure 5-13. Time-series plots of carbon-specific respiration ($\mu MO_2 \mu MC^{-1} hr^{-1}$) at stations F23 and F19

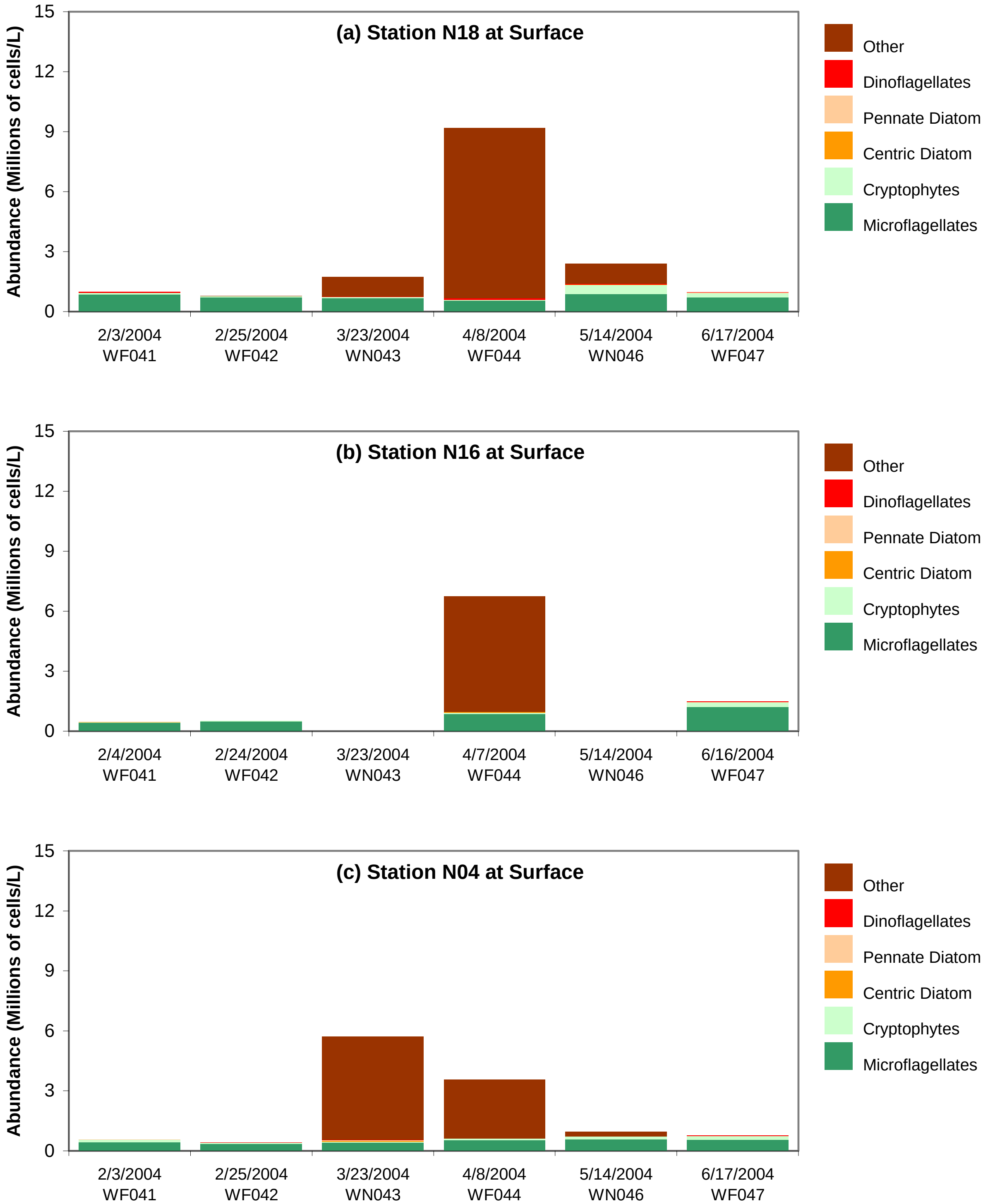


Figure 5-14. Phytoplankton abundance by major taxonomic group, nearfield surface samples

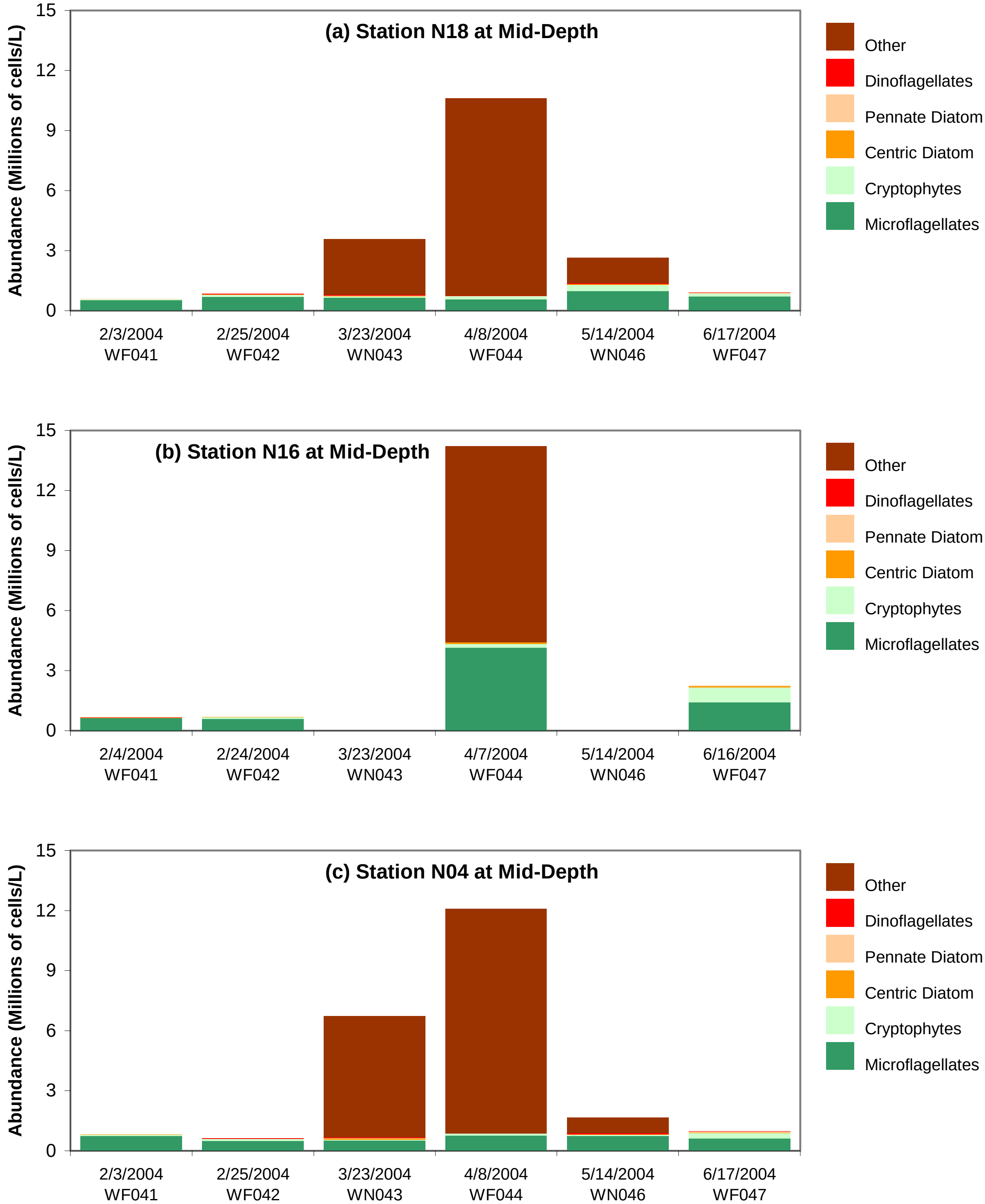


Figure 5-15. Phytoplankton abundance by major taxonomic group, nearfield mid-depth samples

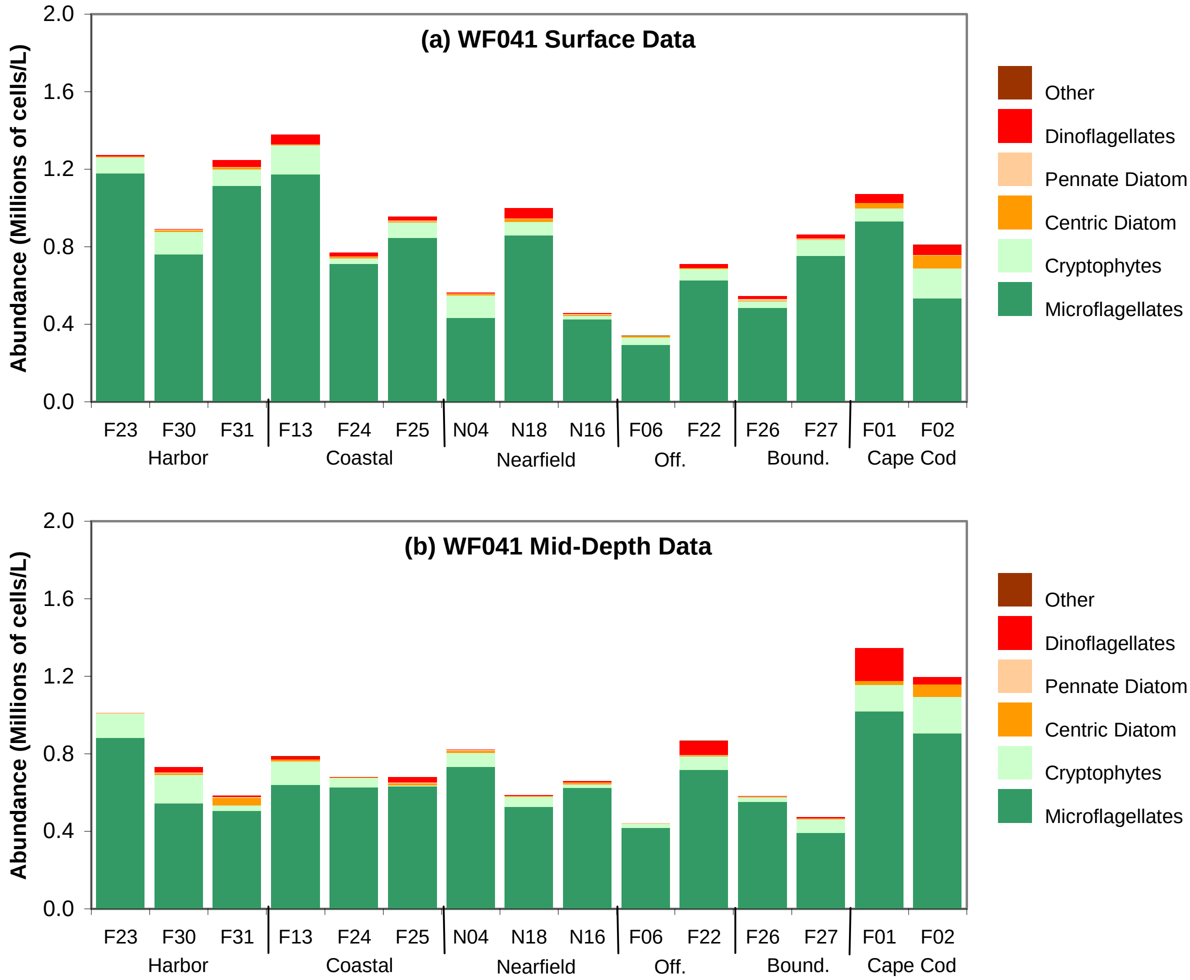


Figure 5-16. Phytoplankton abundance by major taxonomic group – WF041 farfield survey results (February 2 – 5)

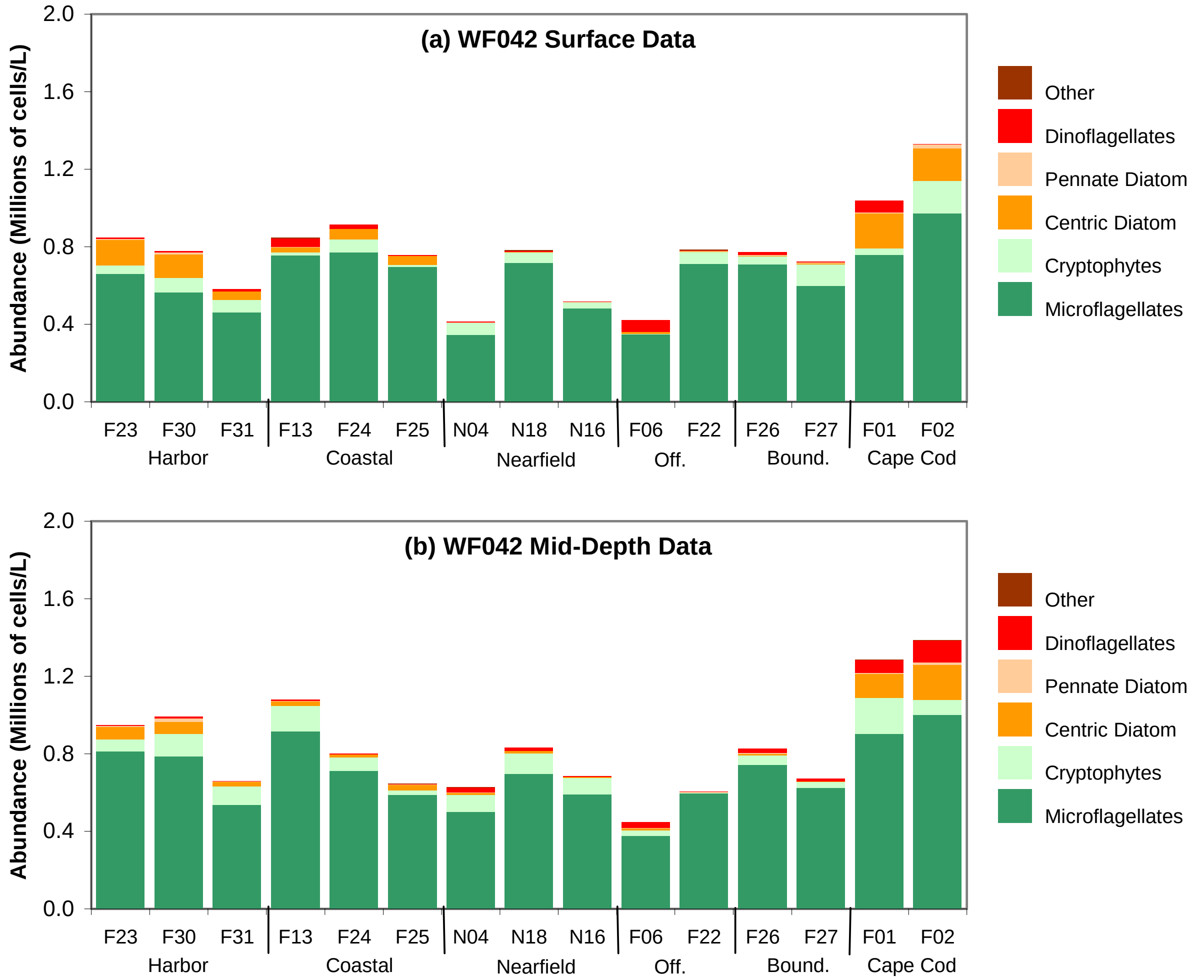
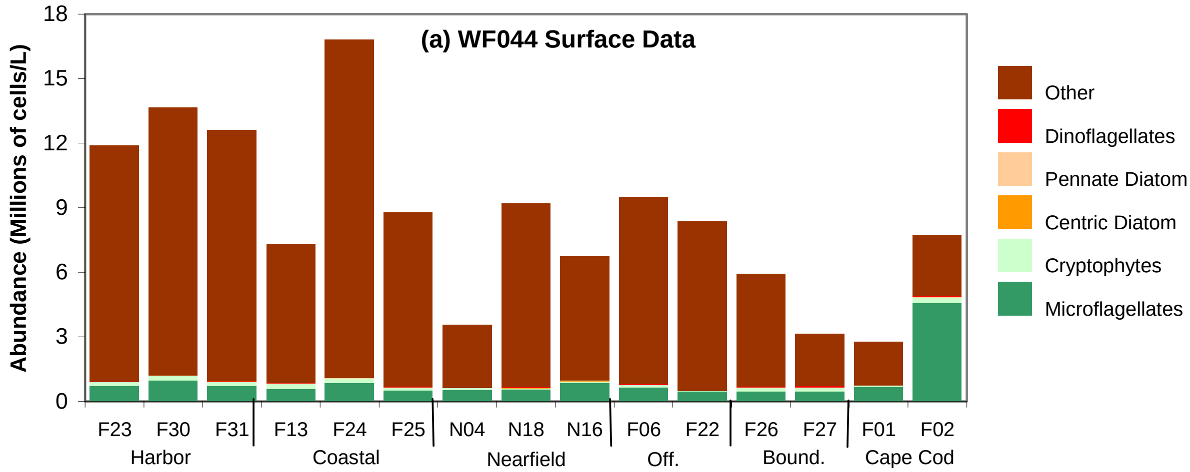


Figure 5-17. Phytoplankton abundance by major taxonomic group – WF042 farfield survey results (February 23 – 25)



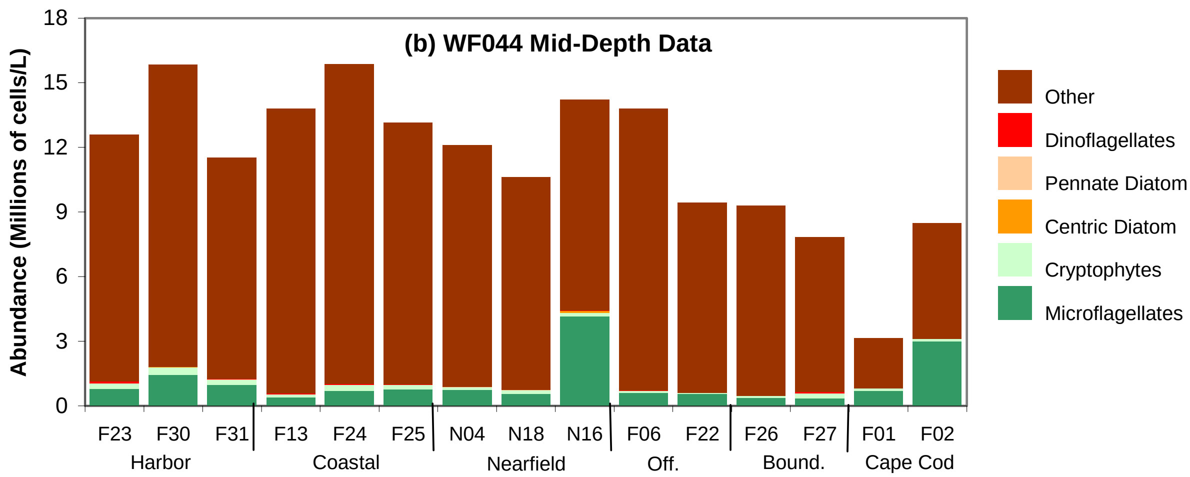


Figure 5-18. Phytoplankton abundance by major taxonomic group – WF044 farfield survey results (April 7 – 9)

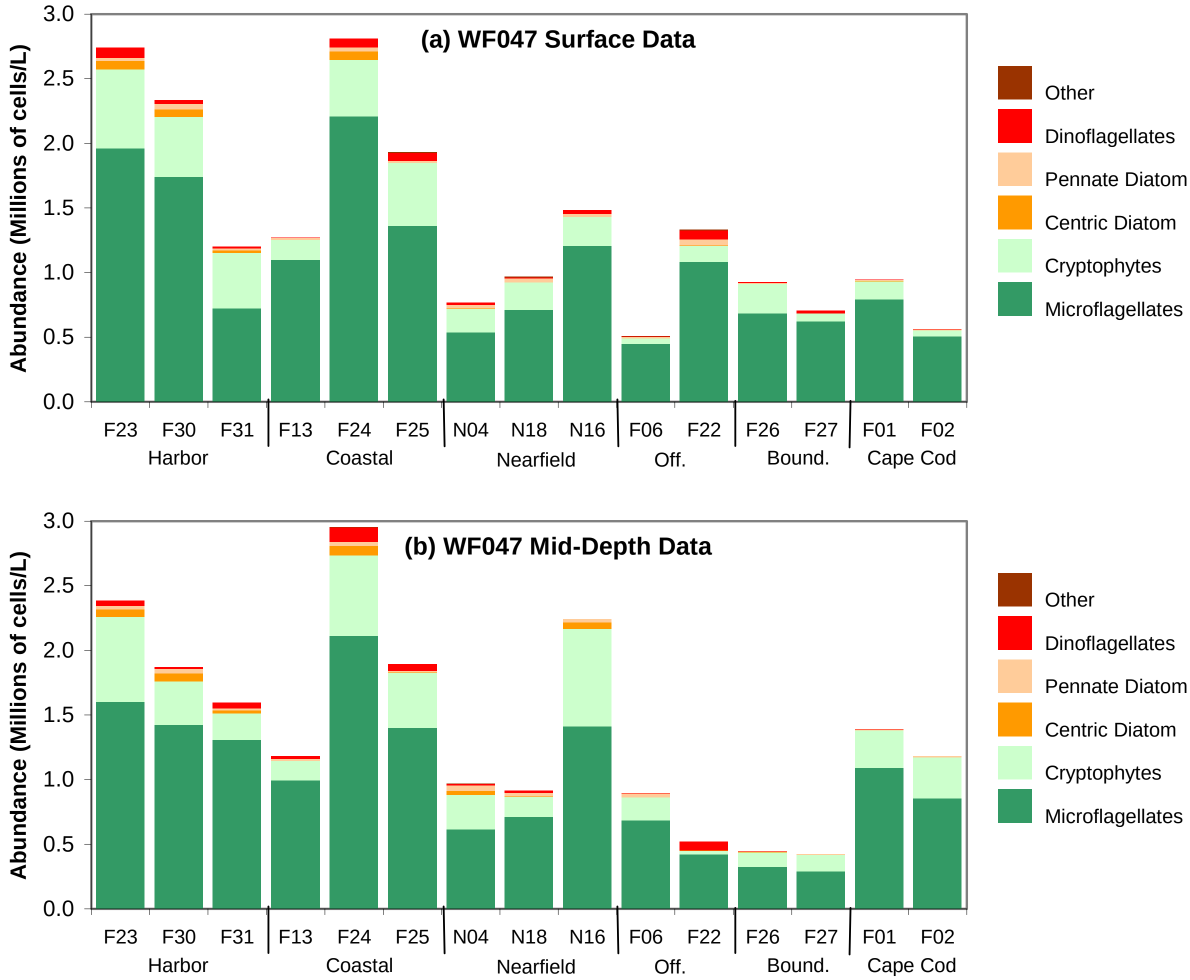


Figure 5-19. Phytoplankton abundance by major taxonomic group – WF047 farfield survey results (June 14 – 17)

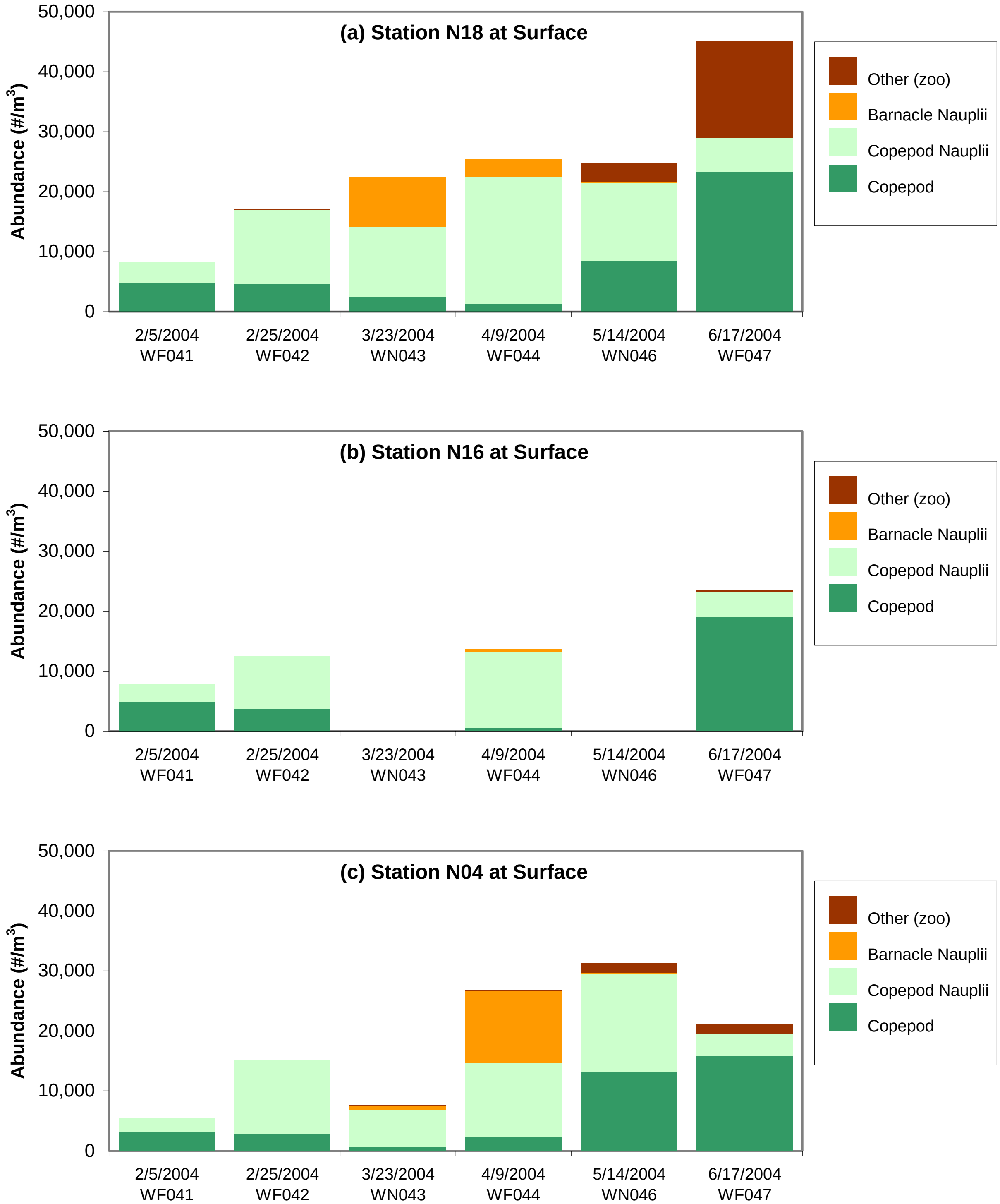
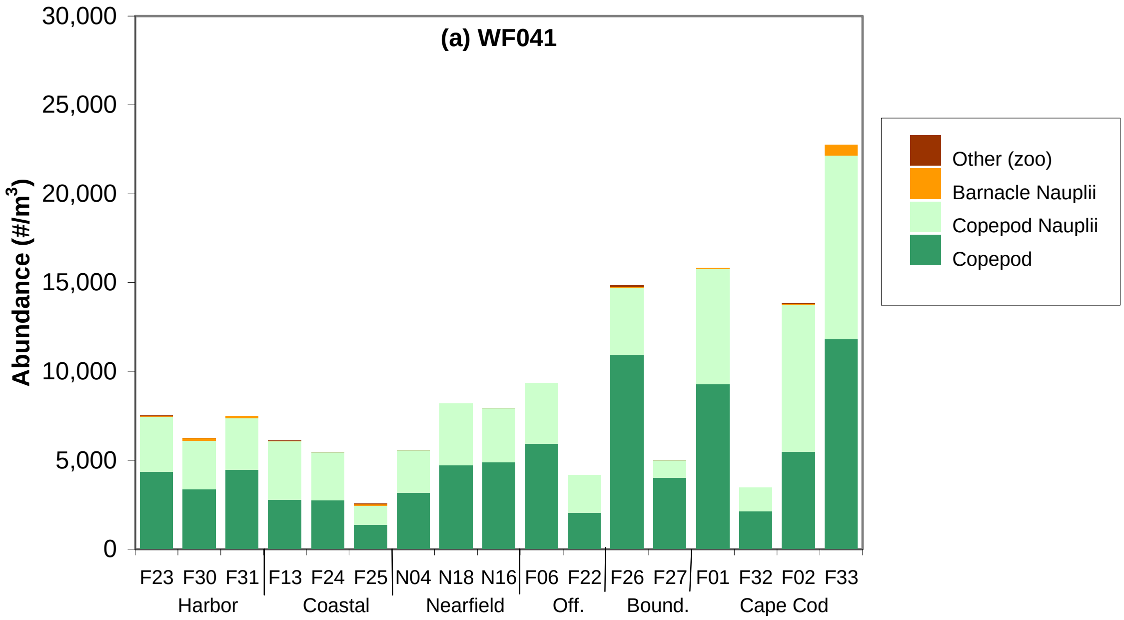


Figure 5-20. Zooplankton abundance by major taxonomic group at stations N18, N16 and N04.



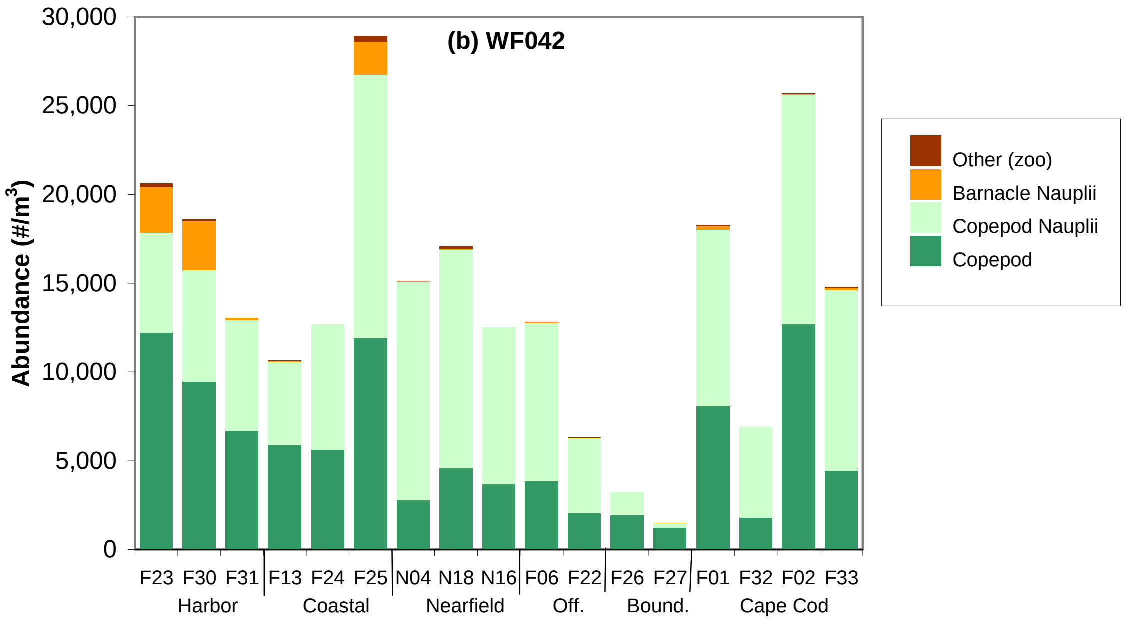


Figure 5-21. Zooplankton abundance by major taxonomic group during (a) WF041 (February 2-5) and (b) WF042 (February 23 – 25) farfield surveys

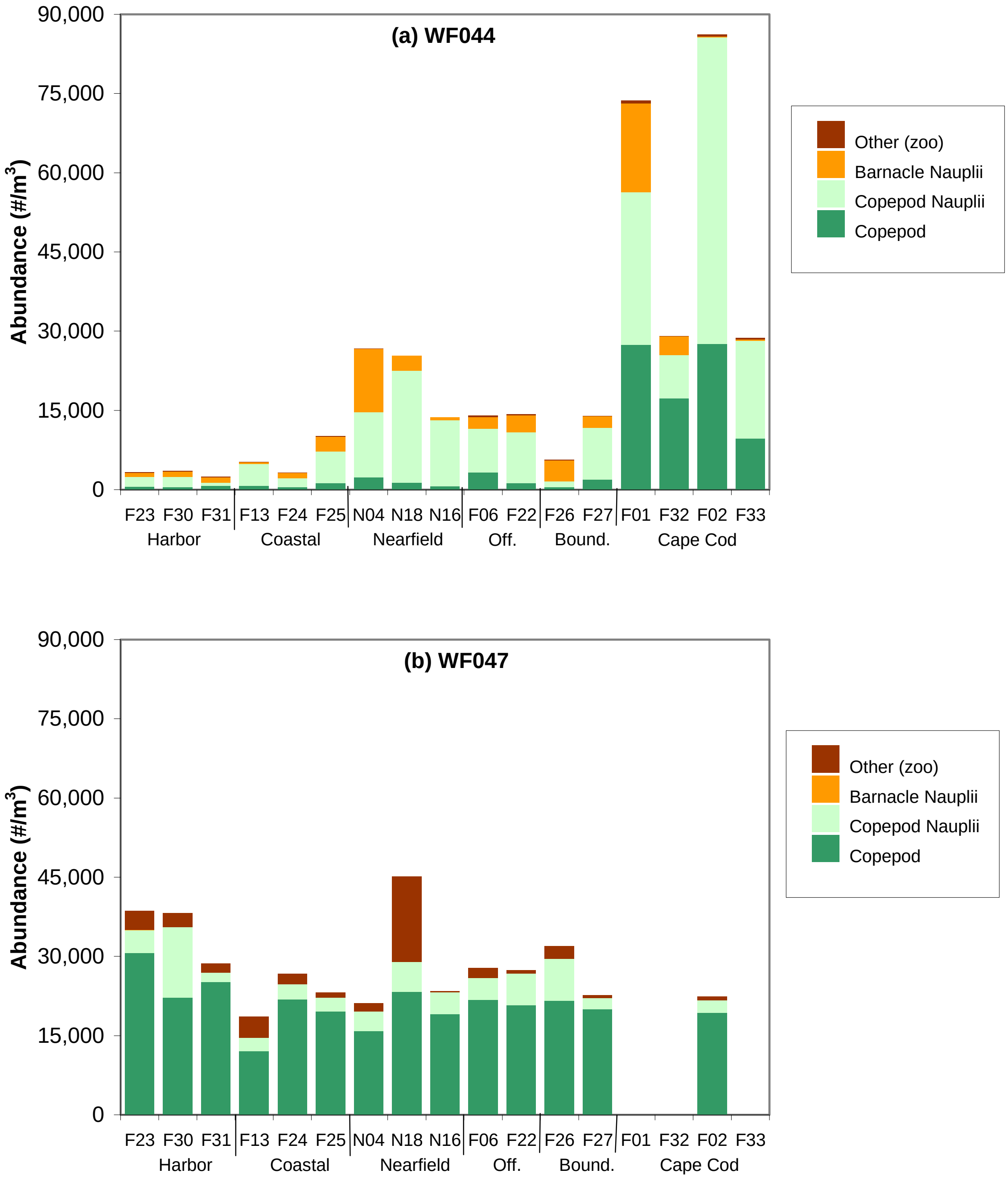


Figure 5-22. Zooplankton abundance by major taxonomic group during (a) WF044 (April 7 – 9) and (b) WF047 (June 14 – 17) farfield surveys

6.0 PRODUCTIVITY, RESPIRATION AND PLANKTON RESULTS

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 2004. The most significant biological event in winter/spring 2004 was a major *Phaeocystis pouchetii* bloom with extraordinarily high abundances observed throughout Massachusetts and Cape Cod Bays in April. The bloom was most prominent at Boston Harbor and coastal stations (10 to 15 million cells L^{-1}). As in 2002 and 2003, *Phaeocystis* abundance continued to be present at relatively high abundances in the nearfield in May, but the colonies and cells appeared to be senescent. The magnitude and duration of the bloom resulted in exceedances of both the winter/spring and summer *Phaeocystis* caution thresholds.

The winter/spring of 2004 was marked by extremely low air and water temperatures. Air temperatures in January 2004 were the lowest observed since 1893 (NWS Logan) resulting in very cold water temperatures. The lowest surface water temperatures were observed in early February (-1.0-2.9°C) and comparably low temperatures were measured in late February (0.1-3.8°C). Surface water temperatures remained cold (3.1-5.4°C) through April before seasonal warming in May and June. Early April was characterized by a 50-year storm event that resulted in over four inches of rain with concomitant increases in runoff and peak river flow both locally and regionally. The April storm event and resulting high flow conditions likely led to increased nutrient inputs to the system and contributed to the magnitude of the *Phaeocystis* bloom. The increased precipitation, runoff, and resulting spring freshet led to lower surface water salinity and the onset of stratification of the water column throughout most of Massachusetts Bay. The high precipitation and river flow in April 2004 led to a relatively strong salinity gradient, yet the water temperatures remained low. As a result, a strong pycnocline was not observed in the nearfield until mid May and throughout the bays by June.

The nutrient data for February to June 2004 generally show the typical progress of seasonal events in Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in February when the water column was well mixed and biological uptake of nutrients limited. In general, the nutrient concentrations during the two February surveys were higher than typically measured in the past. This may have been due to meteorological and oceanographic conditions and lower biological utilization related to the lack of an early winter/spring diatom bloom in Massachusetts Bay. By mid March, nearfield nutrient concentrations decreased somewhat suggesting that a minor diatom bloom may have occurred earlier in the month. By the April, surface water nutrient concentrations had decreased in all areas due to uptake during the *Phaeocystis* bloom. Nutrient concentrations in the surface waters were generally depleted throughout the entire study area in June, although they remained high at stations F18 and N01 near Nahant. *In situ* and meteorological data from June suggests that the elevated nutrients at these stations may have been due to upwelling of bottom waters possibly including the effluent plume. The higher NO_3 and SiO_4 concentrations were likely to have been associated with ambient bottom water levels, and the elevated NH_4 and PO_4 concentrations were likely enhanced by the outfall plume.

The maximum regional chlorophyll levels in February were observed in Cape Cod Bay, while levels were very low throughout Massachusetts Bay. This was coincident with elevated abundance of diatoms in Cape Cod Bay and the apparent lack of a winter/spring diatom bloom in Massachusetts Bay. The highest chlorophyll concentrations were measured in April at the harbor and coastal stations where *Phaeocystis* abundance was >10 million cells L^{-1}. Considering the magnitude of the *Phaeocystis* bloom, the chlorophyll concentrations were relatively low ($\leq$10 μgL^{-1}). SeaWiFS images show an abrupt decline in the chlorophyll signal associated with the *Phaeocystis* bloom by mid to late April. Phytoplankton abundance and chlorophyll concentrations remained low from May to June.

Areal production in 2004 followed patterns typically observed in prior years. In general, nearfield stations are characterized by the occurrence of a winter-spring bloom. The winter-spring blooms observed at nearfield stations in 1995-2003 generally reached values of 1200 to 4500 mg C m^{-2} d^{-1}, with bimodal peaks often occurring in February - April. The bloom in 2004 reached maximum values at the nearfield sites of ~1400-2250 mg C m^{-2} d^{-1} in early April. Unlike many years, an early February peak was not observed. SeaWiFS images for Massachusetts Bay indicate that chlorophyll levels were low from January through February indicating that an early bloom was not missed due to the sampling schedule. These images do, however, suggest that an earlier bloom was occurring in Cape Cod Bay in February/March. The winter-spring bloom peaks at both nearfield sites in 2004 were somewhat higher than values observed during the winter-spring period in 2003, but generally lower than those observed between 1999 and 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 1995-2000, peak areal productions at station F23 ranged from 1000 to 5000 mg C m^{-2} d^{-1} in June-July. Peak areal production observed in 2001 - 2003 reached similar magnitudes (1300 - 3200 mg C m^{-2} d^{-1}), but occurred in February or early March. In 2004, Boston Harbor station areal production increased with the winter/spring *Phaeocystis* bloom in early April (1100 mg C m^{-2} d^{-1}) and continued to increase into June (1300 mg C m^{-2} d^{-1}). Thus, the seasonal cycle observed in 2004 was more similar to the pre-diversion trend, but at the lower end of the range in magnitude previously observed. The variability in the production rates and seasonal pattern in the harbor will be the focus of more intense examination in future reports.

Dissolved oxygen measurements throughout the area during the first half of 2004 were typical of the trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the phytoplankton blooms in the bays. Bottom water DO concentrations generally rose between February and April, with only Cape Cod Bay peaking in late February. By April, when the *Phaeocystis* bloom was at its peak, bottom water DO concentrations had increased throughout Massachusetts Bay. When the *Phaeocystis* bloom crashed in mid to late April, it was coincident with the onset of stratification. The combination led to decreases in mean bottom water DO throughout all areas by June. All regions registered the lowest concentration of the report period during June (<10 mgL^{-1}). The mean bottom water DO concentrations in June 2004, however, were relatively high and uniform across the survey area.

Whole-water phytoplankton assemblages during the first half of 2004 were dominated by unidentified microflagellates and *Phaeocystis pouchetii*. The main deviation from the typical assemblage was the lack of dominance by centric diatoms at Massachusetts Bay stations. A minor winter/spring diatom bloom was observed in Cape Cod Bay in February, but diatom abundance remained very low throughout Massachusetts Bay waters from February to June. There were indications that diatoms may have been abundant in early to mid March (nearfield nutrient data and SeaWiFS), but none of the HOM samples recorded elevated diatom abundances. During the April 2004 bloom, *Phaeocystis* abundances were >10 x 10^6 cells L^{-1} at most stations in Massachusetts Bay and reached a maximum of 15.5 x 10^6 cells L^{-1} in the surface waters at coastal station F24. The 2004 *Phaeocystis* bloom achieved much higher abundances than during the 2001, 2002 and 2003 blooms (maxima of 3.1, 1.6, and 10.2 x 10^6 cells L^{-1}, respectively). In fact, the 2004 bloom exceeded the previous maximum levels for the program observed during the 2000 bloom (12.3 x 10^6 cells L^{-1}). As observed during the previous blooms, the 2004 bloom was a regional event with elevated abundances measured throughout the bays. During the April survey, Cape Cod Bay counts were clearly lower than those in

Massachusetts Bay, but data collected by the Center for Coastal Studies in Cape Cod Bay indicates that *Phaeocystis* was present at abundances of >5 x 10^6 cells L^{-1} in late March. The continued occurrence of spring *Phaeocystis* blooms in consecutive years (2000 to 2004) 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).

Total zooplankton abundance generally increased from February through June as usual and zooplankton assemblages during the first half of 2004 were comprised of taxa recorded for the same time of year in previous years. In April, variability in total zooplankton abundance ranged from minima of ≤5 x 10^3 animals m^{-3} in Boston Harbor and nearby coastal stations to maxima of >75 x 10^3 animals m^{-3} at stations F01 and F02 in Cape Cod Bay. Interestingly, this spatial distribution in zooplankton abundance was the reverse of that observed for *Phaeocystis* – high *Phaeocystis* abundance in the harbor and coastal waters was coincident with low zooplankton abundance. This trend and the ecological dynamics associated with it will be examined in more detail in the 2004 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}.

The dissolved oxygen concentration and percent saturation survey mean minimum for June 2004 were well above the threshold standard for both the nearfield and Stellwagen Basin (**Table** 6-1). These relatively high minima suggest that DO thresholds should not be exceeded in the fall. The nearfield mean areal chlorophyll value for winter/spring 2004 was moderate and well below the threshold. The extraordinarily high abundances of *Phaeocystis* did not manifest as correspondingly high chlorophyll biomass nor did the prolonged duration in the bloom lead to elevated seasonal mean values. The winter/spring mean areal chlorophyll in 2004 was comparable to those measured in 1992-1998 and 2001-2002 and well below those for 1999, 2000, and 2003. However, the very high abundances of *Phaeocystis* in the nearfield in March and April and the protracted duration of the bloom into May did lead to exceedances of both the winter/spring and summer *Phaeocystis* caution thresholds. The factors involved in initiation, magnitude and duration of *Phaeocystis* blooms in Massachusetts Bay will be examined in more detail in the 2004 annual report. *Alexandrium* and *Pseudo-nitzschia* were observed intermittently, but at very low abundance.

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

Parameter	Time Period	Caution Level	Warning Level	Background	2004
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 – 9.72 mg/l Stellwagen - 9.62 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 - 93.2% Stellwagen – 89.6%
Chlorophyll	Annual	118 mg/m^2	158 mg/m^2	--	--
	Winter/spring	238 mg/m^2	--	--	101 mg/m^2
	Summer	93 mg/m^2	--	--	--
	Autumn	212 mg/m^2	--	--	--
Phaeocystis pouchetii	Winter/spring	2,020,000 cells l^{-1}	--	--	2,870,000 cells l^{-1}
	Summer	357 cells l^{-1}	--	--	164,000 cells l^{-1}
	Autumn	2,540 cells l^{-1}	--	--	--
Pseudo-nitzschia pungens	Winter/spring	21,000 cells l^{-1}	--	--	11 cells l^{-1}
	Summer	43,100 cells l^{-1}	--	--	--
	Autumn	24,700 cells l^{-1}	--	--	--
Alexandrium tamarense	Any nearfield sample	100 cells l^{-1}	--	--	5 cells l^{-1}

Several topics called out in this report will be discussed in greater detail in the 2004 annual water column report. These include:

- Effect of 2003-2004 extremely low air and water temperatures and other metrological conditions on water quality in Massachusetts and Cape Cod Bays. Influence of offshore waters contributing to high nutrient concentrations in February
- Closer examination of *Phaeocystis* blooms in Massachusetts Bay
  - → The factors involved in initiation, magnitude and duration of *Phaeocystis* blooms
  - → Impact on ecological dynamics associated with winter/spring diatom and *Phaeocystis* blooms.
  - → The relationships between temperature, phytoplankton biomass, zooplankton abundance (and presumed grazing), and presence of *Phaeocystis* in comparison to previous winter/spring bloom hypotheses (i.e. Keller *et al*., 2001)
- Reexamine seasonal trends in productivity at Boston Harbor station F23 in light of apparent return to pre-diversion pattern in winter/spring 2004 albeit at lower levels.

7.0 REFERENCES

EPA. 1988. Boston Harbor Wastewater Conveyance System. Supplemental Environmental Impact Statement (SEIS). Boston: Environmental Protection Agency Region 1.

Libby PS, Hunt CD, McLeod LA, Geyer WR, Keller AA, Oviatt CA, Borkman D, Turner JT. 2001. 2000 Annual Water Column Monitoring Report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2001-17. 196 p.

Libby PS, Gagnon C, Albro C, Mickelson M, Keller A, Borkman D, Turner J, Oviatt CA. 2002. Combined work/quality assurance plan for baseline water quality monitoring: 2002-2005. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-074. 79 p.

Libby PS, Geyer WR, Keller AA, Turner JT, Borkman D, Oviatt CA. 2004. 2003 Annual Water Column Monitoring Report. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2004-07. 150 p.

MWRA. 1991. Massachusetts Water Resources Authority effluent outfall monitoring plan: Phase I baseline studies. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-02. 95p.

MWRA. 1997. Massachusetts Water Resources Authority effluent outfall monitoring plan: Phase II post discharge monitoring. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-044. 61 p.

MWRA. 2001. Massachusetts Water Resources Authority Contingency Plan Revision 1. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-071. 47 p.

MWRA. 2003. Briefing for OMSAP workshop on ambient monitoring revisions: June 18-19, 2003. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-085. 250 p.

MWRA. 2004. Massachusetts Water Resources Authority effluent outfall ambient monitoring plan Revision 1 March, 2004. Boston: Massachusetts Water Resources Authority. Report ENQUAD ms-092. 65 p.

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