Semiannual water column monitoring report

February - June 2005

Massachusetts Water Resources Authority

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SEMIANNUAL WATER COLUMN MONITORING REPORT

February – June 2005

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. Data were collected from 1992 through September 5, 2000 to establish baseline water quality conditions. Data since September 2000 has been collected to detect significant departures 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 2005.

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 typically characterized by a series of physical, biological, and chemical events: seasonal stratification, the winter/spring phytoplankton bloom, and nutrient depletion. This continued to be the case in 2005. The most significant biological event in winter/spring 2005 was an unprecedented *Alexandrium* bloom with abundances reaching 1,000's of cells L^{-1} throughout Massachusetts and Cape Cod Bays in May and June. This was the first *Alexandrium* bloom to be observed in the bays since 1993 and was part of the largest red tide event in New England since 1972. The bloom extended from Maine to south of Martha's Vineyard, and prompted shellfish closures throughout the region. Concentrations of *A. fundyense* in most years are <100 cells L^{-1}. Many samples collected during the May and June 2005 surveys had counts of >1,000 cells L^{-1} causing a major exceedance of the *Alexandrium* threshold for the nearfield samples during both months. Additional sampling during a series of eight *Alexandrium* Rapid Response Surveys showed counts >10,000 cells L^{-1}, with a maximum in Cape Cod Bay of >40,000 cells L^{-1}. Although the *Alexandrium* bloom was a significant event, the bloom level abundances were a minor portion of the overall phytoplankton assemblage and had little impact on trends observed in other water quality parameters such as chlorophyll and nutrient concentrations, production, and overall phytoplankton abundance.

The winter/spring of 2005 was also marked by high levels of precipitation in April and May and the atypical occurrence of Nor'easter storms in early and mid May. The water column began to stratify by April as surface waters warmed and the spring freshet decreased surface salinities further contributing to the stratification in many of the regions. In early May (5/7-5/9) a Nor'easter passed through the area with sustained winds of ~30 MPH and wave heights of 2-5m. In late May (5/24-5/26), a second Nor'easter imparted similar wind and wave conditions in the bays. This extended period of stormy weather, accented by two substantial storms, mixed the water column and broke down the developing stratification. Along with the strong mixing energy, these storms brought heavy precipitation which increased river flows and introduced large pulses of freshwater to the system. The influx of freshwater and associated nutrients have been implicated as contributing factors to both the *Alexandrium* bloom and a late spring diatom bloom in Massachusetts Bay. The early May Nor'easter has been cited as bringing the *Alexandrium* cells into the bays and the later storm with concentrating the cells to unprecedented levels along the shorelines of southern Massachusetts Bay and Cape Cod Bay.

The nutrient data for February to June 2005 generally followed the typical progression of seasonal events in Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. By late February there was substantial decrease in surface nutrient concentrations as diatom and *Phaeocystis* populations were increasing. There was little change in nearfield nutrient concentrations from late February to March. By April, surface water nutrient concentrations had decreased substantially in most areas as the *Phaeocystis* bloom reached peak measured values. Strong mixing events in mid April and early May weakened the developing stratification and likely supplied nutrients to the surface waters. By mid-May, however, surface water nutrients were relatively depleted and there was a significant reduction in nutrient concentrations (<3µM) down to nearly 30m. This widespread nutrient reduction was likely due to the rapid nutrient utilization of an increasing diatom population. By June, nutrient concentrations were generally depleted in the surface waters throughout the entire study area.

Chlorophyll fluorescence followed trends typically observed in the bays during the winter/spring. Low fluorescence values were seen in early February, but by late February chlorophyll fluorescence reached peak concentrations in association with the winter/spring diatom bloom and emerging *Phaeocystis* bloom. Fluorescence throughout the nearfield decreased considerably from late February to mid March. By April, the *Phaeocystis* bloom and total phytoplankton abundance was at its peak. However, fluorescence values had decreased in the surface and mid depth waters across the bays. An April increase in bottom water fluorescence values was associated with an increase in phaeophytin as a percentage of total pigments, which is indicative of senescent cells. Although there were minor peaks in *Phaeocystis* bloom chlorophyll concentrations, production rates and abundance in April, it appears that the bloom may have already begun to senesce and settle out of the water column. There was little change in nearfield chlorophyll levels from April to May even though phytoplankton abundance had decreased by 50% as a result of the major decline in the *Phaeocystis* population. This was due to an atypical late spring increase in diatom abundance. By June, chlorophyll fluorescence across the bays was either at a peak for the report period or was similar to the elevated values measured in late February.

Areal production in 2005 generally followed patterns observed in prior years. Distinct winter-spring phytoplankton blooms were observed at both nearfield stations during the sampling period reaching maximum values of ~1500 mg C m^{-2} d^{-1} with peaks observed in February, March and May. The late February and March peaks were similar to the patterns observed in the past and were representative of the early diatom bloom and the March *Phaeocystis* bloom. However, the *Phaeocystis* bloom peaked in abundance in April. The difference in production rates and abundance suggests that the April survey was conducted on the tail end of this bloom. The productivity peak in the nearfield in May was atypical and the result of the additional nutrients supporting a late spring diatom bloom. The peak productivity level observed in Boston Harbor for winter/spring 2005 was 574 mg C m^{-2} d^{-1}, which is the lowest peak production level seen for this period over all other years.

Dissolved oxygen measurements throughout the area during the first half of 2005 follow prior trends of declining bottom water DO concentrations after stratification setup and phytoplankton blooms in the bays declined. Bottom water DO concentrations were relatively constant from February to April before decreasing to minimum levels for this time period in June. Percent saturation levels were high throughout this period becoming only slightly undersaturated in June. Overall, the mean bottom water DO concentrations in June 2005 were relatively high and uniform across the survey area suggesting that seasonal minimum value in the fall will not be problematic.

Whole-water phytoplankton assemblages during the first half of 2005 were dominated by unidentified microflagellates and *Phaeocystis pouchetii*. This is the sixth year in a row that *Phaeocystis* has bloomed in the spring. From 1992-1999, only three *Phaeocystis* blooms were recorded in the bays. A minor winter/spring diatom bloom was observed in late February along with the beginning of the *Phaeocystis* bloom. *Phaeocystis* abundance increased in March and by April a nearfield maximum in *Phaeocystis* abundance of 2.7 x 10^6 cells L^{-1} was observed at station N18 in the mid-depth waters. Higher abundances (>3 x 10^6 cells L^{-1}) were measured at offshore station F22 and northern boundary stations F26 and F27 off of Cape Ann. As observed during the previous blooms, the 2005 *Phaeocystis* bloom was a regional event with elevated abundances measured throughout the bays. The main deviations from the typical assemblage were the secondary diatom bloom in late spring and the unprecedented *Alexandrium* bloom in Massachusetts and Cape Cod Bays in May and June.

Total zooplankton abundance generally increased from February through June as usual and zooplankton assemblages during the first half of 2005 were comprised of taxa recorded for the same time of year in previous years.

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1.0 INTRODUCTION

1.1 Program Overview

The Massachusetts Water Resources Authority (MWRA) continues to conduct a long-term Harbor and Outfall Monitoring (HOM) Program in Massachusetts and Cape Cod Bays in 2005. 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 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 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 included 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 2005 (**Table** 1-1).

Table 1-1. Water Quality Surveys for WF051-WF057 February to June 2005

Survey #	Type of Survey	Survey Dates
WF051	Nearfield/Farfield	February 1-2, 7
WF052	Nearfield/Farfield	February 23, 26-27
WN053	Nearfield	March 17
WF054	Nearfield/Farfield	April 4-7
WN056*	Nearfield	May 13
WF057	Nearfield/Farfield	June 13-14,17-18

*The fifth survey (WN055) 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 2005 semiannual period are the fifth 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 2005. Preliminary comparisons against baseline data are discussed and appropriate threshold values presented. A detailed evaluation of 2005 versus the baseline period (1992-2000) will be presented in the 2005 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 2005 (Sections 3-5). The major findings of the semiannual period are summarized in Section 6.

Section 3 (Data Summary Presentation) 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 (WF051 – WN053), the early stratification stage (WF054 – WN056), and once seasonal stratification was established (WF057). 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.

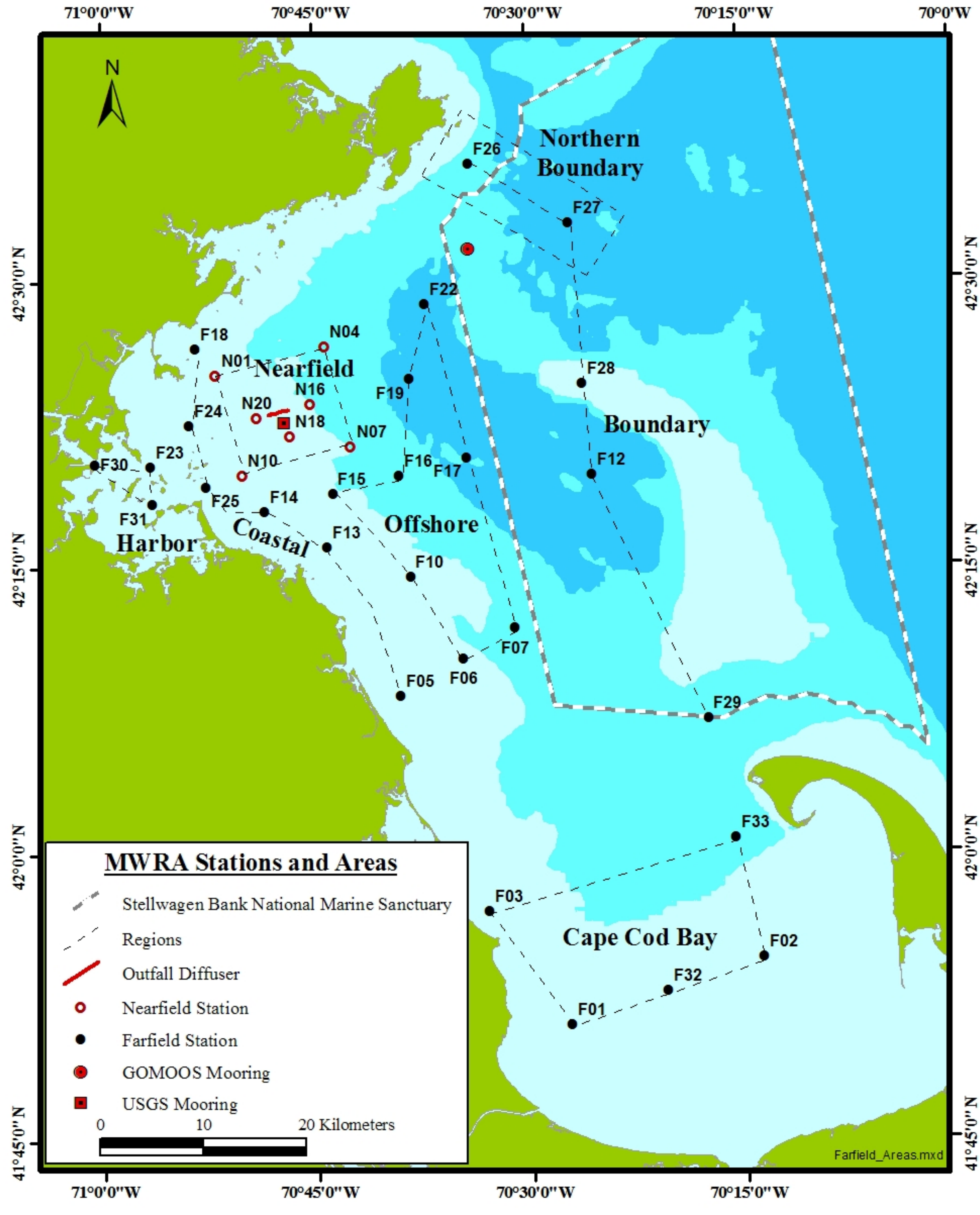


Figure 1-1. Locations of stations and regional station groupings

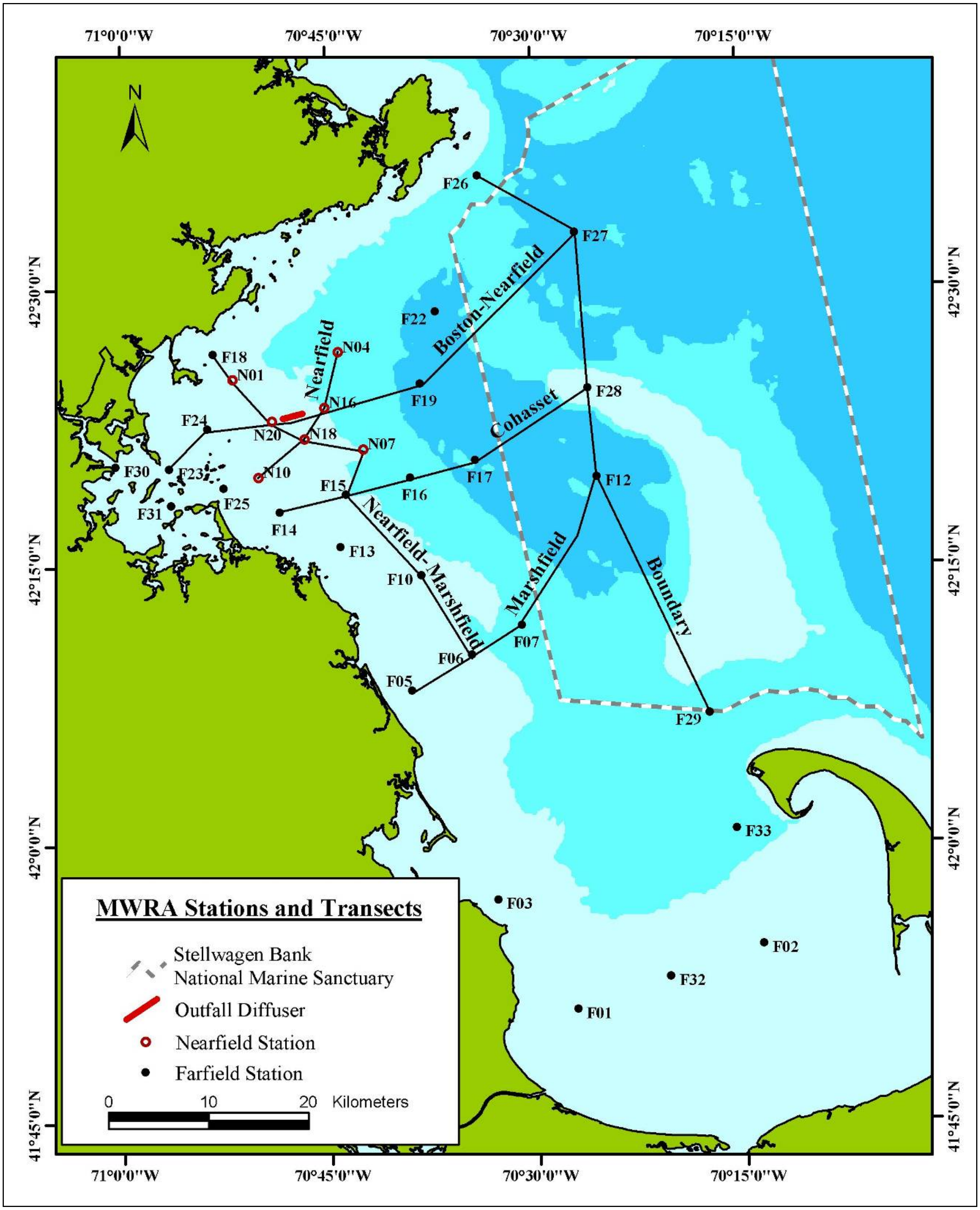


Figure 1-2. Locations of stations and selected transects

2.0 METHODS

This section describes general methods of data collection and sampling for the first six water column monitoring surveys of 2005. 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 2005 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.* 2005).

2.1 Data Collection

The farfield and nearfield water quality surveys for 2005 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 through 2005. 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. Starting 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 indicates 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 R/V *Tioga* 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 WF051, WF052, WN053, WF054, WN056, and WF057 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 Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.3	0.3	0.5	1	1	0	1	4	1	1	1	1
			1_Bottom	7.9	2	1	1	1	2	2	2	1	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 Phosphorus	Particulate Organic Carbon	Particulate Phosphorus	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	RE	AP	IC
			6_Net Tow															1			
			1_Bottom	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			
					otals	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 2005 database and organized to facilitate regional comparisons among 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 WF051, WF052, WF054, and WF057. 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.* 2005), and are summarized in Section 2.

Following standard oceanographic practice, patterns of variability in water density are described using the derived parameter sigma-t ($\sigma_{t,}$), which is calculated by subtracting 1,000 kg/m^3 from the recorded density. During this semiannual period, density varied from 1020.5 to 1025.7 kg/m^3, meaning σ_t varied from 20.5 to 25.7.

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 N05 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.* 2005).

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.* 2005).

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/fundyense, 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/fundyense*, 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 September 2004 to February 2005 deployment. The mid-surface and mid-depth units only recorded data for the first few months. The mid-bottom unit did not have any recoverable data at all. Thus, there are no January to February 2005 data for Temperature, salinity, or chlorophyll fluorescence at these depths. The chlorophyll fluorescence data for the May to September 2005 has been deemed invalid. Data for the other instruments for the May to September 2005 deployment will be included in the 2005 Annual Report.

Table 3-1. Method detection limits

Analysis	MDL
Dissolved ammonia (NH_4)	0.028 µM
Dissolved inorganic nitrate (NO_3)	0.025 µM
Dissolved inorganic nitrite (NO_2)	0.013 µM
Dissolved inorganic phosphorus (PO_4)	0.010 µM
Dissolved inorganic silicate (SIO_4)	0.036 µM
Dissolved organic carbon (DOC)	25 µM
Total dissolved nitrogen (TDN)	1.61 µM
Total dissolved phosphorus (TDP)	0.11 µM
Particulate carbon (POC)	0.78 µM
Particulate nitrogen (PON)	0.12 µM
Particulate phosphorus (PARTP)	0.006 µM
Biogenic silica (BIOSI)	0.003 µM
Chlorophyll *a* and phaeophytin	0.05 µg L^{-1}
Total suspended solids (TSS)	0.24 mg L^{-1}

Table 3-2. Summary of *in situ* temperature, salinity, and density data for February - June 2005.

			Temperature (°C)			Salinity (PSU)			Sigma T		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF051	2/2	0.23	3.16	2.28	31.1	31.9	31.7	24.9	25.4	25.3
Nearfield	WF052	2/27	2.10	3.52	2.31	31.4	32.1	31.6	25.1	25.6	25.2
Nearfield	WN053	3/17	1.92	2.40	2.16	31.3	31.9	31.6	25.0	25.5	25.3
Nearfield	WF054	4/6	2.75	5.53	3.85	30.0	32.0	31.2	23.7	25.5	24.8
Nearfield	WN056	5/13	5.20	8.50	6.89	29.6	31.1	30.3	23.0	24.6	23.7
Nearfield	WF057	6/17	5.88	16.46	9.66	29.1	31.6	30.3	21.6	24.9	23.3
Nearfield	ALL		0.23	16.46	4.53	29.1	32.1	31.1	21.6	25.6	24.6
Boundary	WF051	2/1-2, 7	1.26	4.68	3.12	30.8	32.5	31.9	24.6	25.7	25.4
Cape Cod Bay	WF051	2/1-2, 7	0.17	2.71	1.23	31.4	31.8	31.6	25.2	25.4	25.3
Coastal	WF051	2/1-2, 7	-0.54	2.73	1.01	30.8	31.8	31.4	24.7	25.4	25.2
Harbor	WF051	2/1-2, 7	-0.35	0.67	0.10	30.2	31.3	30.8	24.2	25.1	24.7
Nearfield	WF051	2/1-2, 7	0.23	3.16	2.28	31.1	31.9	31.7	24.9	25.4	25.3
Offshore	WF051	2/1-2, 7	2.09	3.24	2.86	31.6	32.0	31.9	25.2	25.5	25.4
All	ALL		-0.54	4.68	1.77	30.2	32.5	31.5	24.2	25.7	25.2
Boundary	WF052	2/23-27	1.83	3.78	2.71	30.8	32.4	31.9	24.6	25.7	25.4
Cape Cod Bay	WF052	2/23-27	1.58	2.10	1.88	31.3	31.6	31.5	25.0	25.3	25.1
Coastal	WF052	2/23-27	1.02	2.10	1.77	30.3	31.6	31.3	24.3	25.2	25.0
Harbor	WF052	2/23-27	0.98	1.34	1.13	28.9	30.4	30.0	23.1	24.3	24.0
Nearfield	WF052	2/23-27	2.10	3.52	2.31	31.4	32.1	31.6	25.1	25.6	25.2
Offshore	WF052	2/23-27	2.03	3.95	2.53	31.2	32.3	31.8	24.9	25.7	25.4
All	ALL		0.98	3.95	2.06	28.9	32.4	31.3	23.1	25.7	25.0
Boundary	WF054	4/4-7	2.62	5.02	3.49	26.2	32.3	31.5	20.7	25.7	25.0
Cape Cod Bay	WF054	4/4-7	2.20	4.11	3.46	31.1	31.6	31.3	24.7	25.2	24.9
Coastal	WF054	4/4-7	2.97	5.42	4.25	30.0	31.7	30.8	23.7	25.3	24.4
Harbor	WF054	4/4-7	3.98	6.42	5.25	28.0	30.9	29.7	22.0	24.5	23.5
Nearfield	WF054	4/4-7	2.75	5.53	3.85	30.0	32.0	31.2	23.7	25.5	24.8
Offshore	WF054	4/4-7	2.58	5.70	3.74	26.6	32.2	31.3	20.9	25.6	24.9
All	ALL		2.20	6.42	4.01	26.2	32.3	31.0	20.7	25.7	24.6
Boundary	WF057	6/13-18	5.55	17.67	8.47	28.5	31.9	31.0	20.5	25.1	24.0
Cape Cod Bay	WF057	6/13-18	6.30	15.71	11.65	29.7	31.1	30.1	21.8	24.5	22.8
Coastal	WF057	6/13-18	6.08	16.71	10.21	29.3	31.2	30.2	21.2	24.5	23.1
Harbor	WF057	6/13-18	8.93	15.55	12.20	28.3	30.5	29.6	21.0	23.6	22.4
Nearfield	WF057	6/13-18	5.88	16.46	9.66	29.1	31.6	30.3	21.6	24.9	23.3
Offshore	WF057	6/13-18	5.66	16.77	8.50	29.3	31.9	30.8	21.2	25.1	23.9
All	ALL		5.55	17.67	10.12	28.3	31.9	30.3	20.5	25.1	23.2

Table 3-3. Summary of *in situ* beam attenuation, dissolved oxygen concentration, and dissolved oxygen %saturation data for February - June 2005.

			Beam (m^{-1})			DO (mgL^{-1})			DO % Saturation		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF051	2/2	0.80	1.98	1.22	10.70	11.66	10.98	98.12	100.64	99.11
Nearfield	WF052	2/27	0.79	1.52	1.08	10.05	11.83	11.45	93.87	106.90	103.37
Nearfield	WN053	3/17	0.64	1.12	0.86	10.86	12.09	11.71	98.51	109.09	105.38
Nearfield	WF054	4/6	0.66	1.57	0.94	10.70	12.58	11.61	98.04	117.46	108.72
Nearfield	WN056	5/13	0.58	1.22	0.85	10.06	10.96	10.52	98.62	113.03	105.39
Nearfield	WF057	6/17	0.59	1.36	0.78	8.87	12.73	10.39	87.53	129.55	110.91
Nearfield	ALL		0.58	1.98	0.95	8.87	12.73	11.11	87.53	129.55	105.48
Boundary	WF051	2/1-2, 7	0.57	2.34	0.96	9.88	11.70	10.72	95.24	104.25	98.90
Cape Cod Bay	WF051	2/1-2, 7	1.23	4.96	2.37	10.87	11.86	11.42	98.60	101.95	100.17
Coastal	WF051	2/1-2, 7	1.15	2.39	1.90	10.82	11.81	11.37	98.37	100.33	99.10
Harbor	WF051	2/1-2, 7	1.73	3.37	2.39	11.51	11.94	11.66	97.59	99.97	98.79
Nearfield	WF051	2/1-2, 7	0.80	1.98	1.22	10.70	11.66	10.98	98.12	100.64	99.11
Offshore	WF051	2/1-2, 7	0.75	1.46	1.01	10.35	11.19	10.82	95.80	101.50	99.17
All	ALL		0.57	4.96	1.64	9.88	11.94	11.16	95.24	104.25	99.21
Boundary	WF052	2/23-27	0.58	1.26	0.83	10.16	11.99	10.83	94.49	106.84	98.88
Cape Cod Bay	WF052	2/23-27	0.90	2.02	1.32	10.94	11.42	11.12	98.07	101.22	99.14
Coastal	WF052	2/23-27	1.17	1.95	1.46	10.92	12.13	11.45	97.54	108.61	101.62
Harbor	WF052	2/23-27	1.49	2.43	1.86	11.28	11.92	11.52	97.21	102.86	99.75
Nearfield	WF052	2/23-27	0.79	1.52	1.08	10.05	11.83	11.45	93.87	106.90	103.37
Offshore	WF052	2/23-27	0.70	1.13	0.88	9.78	12.21	11.05	92.42	110.02	100.44
All	ALL		0.58	2.43	1.24	9.78	12.21	11.24	92.42	110.02	100.53
Boundary	WF054	4/4-7	0.41	1.33	0.75	10.31	11.93	11.25	94.89	111.80	104.53
Cape Cod Bay	WF054	4/4-7	0.43	0.76	0.59	10.72	11.66	11.26	96.43	108.67	104.45
Coastal	WF054	4/4-7	0.56	1.58	0.96	10.88	11.91	11.41	100.34	112.34	107.59
Harbor	WF054	4/4-7	1.06	1.93	1.48	10.97	11.34	11.11	103.19	111.55	106.63
Nearfield	WF054	4/4-7	0.66	1.57	0.94	10.70	12.58	11.61	98.04	117.46	108.72
Offshore	WF054	4/4-7	0.48	1.43	0.80	10.50	12.33	11.46	95.69	117.71	107.12
All	ALL		0.41	1.93	0.92	10.31	12.58	11.35	94.89	117.71	106.51
Boundary	WF057	6/13-18	0.50	1.94	0.85	8.74	12.76	10.30	90.86	130.84	107.30
Cape Cod Bay	WF057	6/13-18	0.66	1.32	0.86	8.09	10.74	9.20	80.78	116.45	102.57
Coastal	WF057	6/13-18	0.71	1.89	1.06	8.34	12.11	9.74	82.71	131.76	105.35
Harbor	WF057	6/13-18	0.97	1.72	1.47	9.12	10.12	9.40	99.92	117.90	105.44
Nearfield	WF057	6/13-18	0.59	1.36	0.78	8.87	12.73	10.39	87.53	129.55	110.91
Offshore	WF057	6/13-18	0.54	1.26	0.75	9.39	12.91	10.55	92.62	139.20	110.06
All	ALL		0.50	1.94	0.96	8.09	12.91	9.93	80.78	139.20	106.94

Table 3-4. Summary of *in situ* fluorescence, chlorophyll *a*, and phaeophytin data for February - June 2005.

			Fluorescence (μgL^{-1})			Chlorophyll *a* (μgL^{-1})			Phaeophytin (μgL^{-1})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF051	2/2	0.02	0.97	0.49	0.39	0.89	0.60	0.16	0.50	0.25
Nearfield	WF052	2/27	0.53	11.12	7.79	2.65	11.30	9.28	0.67	3.64	2.01
Nearfield	WN053	3/17	0.83	5.87	3.18	1.26	5.74	3.31	0.47	1.16	0.77
Nearfield	WF054	4/6	0.40	6.22	2.45	0.66	6.60	2.61	0.22	2.48	0.94
Nearfield	WN056	5/13	0.28	5.31	2.13	0.64	4.39	2.66	0.55	2.43	1.08
Nearfield	WF057	6/17	0.54	19.10	2.92	1.46	17.30	3.82	0.47	5.25	1.55
Nearfield	ALL		0.02	19.10	3.16	0.39	17.30	3.71	0.16	5.25	1.10
Boundary	WF051	2/1-2, 7	0.01	1.49	0.51	0.05	1.08	0.59	0.13	0.54	0.26
Cape Cod Bay	WF051	2/1-2, 7	0.20	1.27	0.71	0.60	1.49	0.82	0.23	0.38	0.30
Coastal	WF051	2/1-2, 7	0.00	0.77	0.53	0.37	0.67	0.52	0.24	0.45	0.34
Harbor	WF051	2/1-2, 7	0.46	0.78	0.57	0.33	0.64	0.51	0.26	0.71	0.43
Nearfield	WF051	2/1-2, 7	0.02	0.97	0.49	0.39	0.89	0.60	0.16	0.50	0.25
Offshore	WF051	2/1-2, 7	0.04	0.89	0.51	0.48	0.72	0.61	0.16	0.30	0.21
All	ALL		0.00	1.49	0.55	0.05	1.49	0.61	0.13	0.71	0.30
Boundary	WF052	2/23-27	0.02	12.98	3.19	1.46	11.30	6.04	0.41	2.50	1.43
Cape Cod Bay	WF052	2/23-27	1.11	9.94	3.96	2.64	7.10	4.58	0.52	0.96	0.70
Coastal	WF052	2/23-27	1.04	13.36	6.60	3.24	9.57	6.06	0.68	1.96	1.28
Harbor	WF052	2/23-27	3.01	6.11	4.50	3.07	4.75	3.97	0.65	1.25	0.83
Nearfield	WF052	2/23-27	0.53	11.12	7.79	2.65	11.30	9.28	0.67	3.64	2.01
Offshore	WF052	2/23-27	0.02	14.59	5.16	1.06	9.74	6.00	0.49	2.15	1.24
All	ALL		0.02	14.59	5.20	1.06	11.30	5.99	0.41	3.64	1.25
Boundary	WF054	4/4-7	0.31	4.64	1.47	0.16	5.35	2.22	0.16	1.93	0.83
Cape Cod Bay	WF054	4/4-7	0.30	0.94	0.47	0.21	0.84	0.32	0.12	0.57	0.22
Coastal	WF054	4/4-7	0.40	5.45	1.78	0.62	4.67	2.20	0.26	1.64	0.91
Harbor	WF054	4/4-7	0.73	4.10	2.35	1.28	3.61	2.31	0.56	1.57	1.03
Nearfield	WF054	4/4-7	0.40	6.22	2.45	0.66	6.60	2.61	0.22	2.48	0.94
Offshore	WF054	4/4-7	0.36	5.95	1.89	0.36	3.87	1.65	0.10	1.37	0.61
All	ALL		0.30	6.22	1.74	0.16	6.60	1.88	0.10	2.48	0.76
Boundary	WF057	6/13-18	0.25	16.04	3.80	0.14	12.20	5.02	0.27	4.88	2.00
Cape Cod Bay	WF057	6/13-18	0.39	4.12	2.05	0.71	3.23	2.05	0.34	1.79	0.99
Coastal	WF057	6/13-18	1.19	11.19	3.10	1.35	5.81	2.96	0.46	2.18	1.52
Harbor	WF057	6/13-18	1.73	5.25	2.87	1.73	3.67	2.39	1.00	1.91	1.35
Nearfield	WF057	6/13-18	0.54	19.10	2.92	1.46	17.30	3.82	0.47	5.25	1.55
Offshore	WF057	6/13-18	0.30	23.38	3.03	0.42	16.50	3.30	0.34	5.07	1.09
All	ALL		0.25	23.38	2.96	0.14	17.30	3.26	0.27	5.25	1.42

Table 3-5. Summary of ammonium, nitrite, and nitrite+nitrate data for February - June 2005.

				NH_4 (µM)			NO_2 (µM)			$NO_2 + NO_3$ (µM)	
Region	Survey	Dates	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Nearfield	WF051	2/2	0.24	5.87	1.98	0.13	0.22	0.16	8.07	9.57	8.54
Nearfield	WF052	2/27	0.01	2.96	0.64	0.10	0.20	0.14	1.51	7.50	3.63
Nearfield	WN053	3/17	0.31	6.13	1.37	0.10	0.18	0.12	2.09	5.58	3.49
Nearfield	WF054	4/6	0.14	6.93	1.17	0.02	0.25	0.08	0.05	5.75	2.01
Nearfield	WN056	5/13	0.01	1.80	0.41	0.03	0.15	0.08	0.17	2.84	1.16
Nearfield	WF057	6/17	0.01	2.94	0.72	0.01	0.32	0.10	0.05	6.53	1.26
Nearfield	ALL		0.01	6.93	1.05	0.01	0.32	0.11	0.05	9.57	3.35
Boundary	WF051	2/1-2, 7	0.01	0.55	0.15	0.08	0.13	0.12	7.92	8.64	8.44
Cape Cod Bay	WF051	2/1-2, 7	0.26	0.98	0.70	0.12	0.16	0.14	6.96	9.21	8.34
Coastal	WF051	2/1-2, 7	0.19	4.16	1.03	0.12	0.18	0.15	8.35	10.15	9.10
Harbor	WF051	2/1-2, 7	0.73	1.50	0.99	0.14	0.18	0.16	9.71	11.10	10.30
Nearfield	WF051	2/1-2, 7	0.24	5.87	1.98	0.13	0.22	0.16	8.07	9.57	8.54
Offshore	WF051	2/1-2, 7	0.01	0.94	0.25	0.12	0.16	0.14	7.78	8.57	8.21
All	ALL		0.01	5.87	0.85	0.08	0.22	0.14	6.96	11.10	8.82
Boundary	WF052	2/23-27	0.01	0.46	0.15	0.12	0.17	0.15	2.03	8.92	7.06
Cape Cod Bay	WF052	2/23-27	0.10	0.54	0.30	0.11	0.16	0.14	6.25	9.78	8.61
Coastal	WF052	2/23-27	0.01	0.74	0.27	0.10	0.21	0.18	0.71	9.21	5.97
Harbor	WF052	2/23-27	0.01	0.32	0.12	0.14	0.25	0.20	7.28	11.40	8.82
Nearfield	WF052	2/23-27	0.01	2.96	0.64	0.10	0.20	0.14	1.51	7.50	3.63
Offshore	WF052	2/23-27	0.01	0.93	0.16	0.12	0.21	0.15	1.50	8.92	6.11
All	ALL		0.01	2.96	0.28	0.10	0.25	0.16	0.71	11.40	6.70
Boundary	WF054	4/4-7	0.01	2.55	0.64	0.01	0.17	0.09	0.26	8.71	3.80
Cape Cod Bay	WF054	4/4-7	0.51	2.57	1.19	0.02	0.07	0.05	0.10	2.14	0.68
Coastal	WF054	4/4-7	0.10	1.48	0.47	0.02	0.12	0.06	0.03	3.47	1.01
Harbor	WF054	4/4-7	0.27	1.20	0.76	0.03	0.07	0.05	0.56	1.85	1.23
Nearfield	WF054	4/4-7	0.14	6.93	1.17	0.02	0.25	0.08	0.05	5.75	2.01
Offshore	WF054	4/4-7	0.07	4.26	0.62	0.01	0.17	0.09	0.06	8.50	2.97
All	ALL		0.01	6.93	0.81	0.01	0.25	0.07	0.03	8.71	1.95
Boundary	WF057	6/13-18	0.01	2.43	0.74	0.01	0.32	0.16	0.02	6.80	3.03
Cape Cod Bay	WF057	6/13-18	0.01	3.21	0.88	0.02	0.26	0.09	0.04	4.64	1.08
Coastal	WF057	6/13-18	0.01	5.18	1.19	0.02	0.36	0.14	0.03	5.50	1.53
Harbor	WF057	6/13-18	0.23	1.31	0.84	0.06	0.15	0.09	0.32	1.77	0.77
Nearfield	WF057	6/13-18	0.01	2.94	0.72	0.01	0.32	0.10	0.05	6.53	1.26
Offshore	WF057	6/13-18	0.01	3.18	0.94	0.01	0.31	0.14	0.02	6.83	2.37
All	ALL		0.01	5.18	0.88	0.01	0.36	0.12	0.02	6.83	1.67

Table 3-6. Summary of phosphate, silicate, and biogenic silica data for February - June 2005.

			PO_4 (µM)			SiO_4 (µM)			BioSi (µM)		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF051	2/2	0.97	1.25	1.08	8.72	12.20	10.13	1.51	9.04	2.61
Nearfield	WF052	2/27	0.43	0.89	0.58	1.60	8.37	3.51	3.24	9.08	6.99
Nearfield	WN053	3/17	0.48	0.83	0.64	2.31	5.80	3.92	1.58	3.22	2.39
Nearfield	WF054	4/6	0.24	0.86	0.52	1.88	8.19	4.92	1.52	5.59	2.72
Nearfield	WN056	5/13	0.17	0.54	0.29	1.83	5.23	3.45	1.98	4.34	3.20
Nearfield	WF057	6/17	0.12	0.89	0.32	0.02	6.77	0.93	0.79	8.98	2.65
Nearfield	ALL		0.12	1.25	0.57	0.02	12.20	4.48	0.79	9.08	3.43
Boundary	WF051	2/1-2, 7	0.91	1.05	0.99	8.90	13.00	9.83	0.86	5.09	2.37
Cape Cod Bay	WF051	2/1-2, 7	0.87	1.03	0.97	8.90	11.30	9.95	1.96	2.80	2.47
Coastal	WF051	2/1-2, 7	0.93	1.09	1.00	9.76	12.90	11.17	2.81	4.34	3.48
Harbor	WF051	2/1-2, 7	0.79	0.96	0.88	12.00	15.70	13.69	2.51	7.98	4.73
Nearfield	WF051	2/1-2, 7	0.97	1.25	1.08	8.72	12.20	10.13	1.51	9.04	2.61
Offshore	WF051	2/1-2, 7	0.98	1.06	1.03	8.72	11.00	9.33	1.12	7.12	2.72
All	ALL		0.79	1.25	0.99	8.72	15.70	10.68	0.86	9.04	3.07
Boundary	WF052	2/23-27	0.40	0.91	0.76	3.55	9.47	7.20	1.89	9.83	5.97
Cape Cod Bay	WF052	2/23-27	0.62	0.87	0.79	7.44	9.58	8.78	2.59	3.48	2.99
Coastal	WF052	2/23-27	0.32	0.87	0.58	0.67	9.22	5.61	4.52	8.47	6.60
Harbor	WF052	2/23-27	0.45	0.59	0.52	9.79	14.10	10.80	3.81	6.98	5.33
Nearfield	WF052	2/23-27	0.43	0.89	0.58	1.60	8.37	3.51	3.24	9.08	6.99
Offshore	WF052	2/23-27	0.39	0.94	0.71	2.76	9.86	6.09	2.89	7.26	5.30
All	ALL		0.32	0.94	0.66	0.67	14.10	7.00	1.89	9.83	5.53
Boundary	WF054	4/4-7	0.34	0.98	0.67	0.40	10.50	5.43	0.68	3.85	2.06
Cape Cod Bay	WF054	4/4-7	0.30	0.70	0.45	0.20	1.33	0.75	0.61	1.84	1.14
Coastal	WF054	4/4-7	0.25	0.67	0.41	0.45	5.31	2.40	1.39	5.13	3.07
Harbor	WF054	4/4-7	0.24	0.45	0.34	2.58	3.85	2.98	2.70	5.91	4.38
Nearfield	WF054	4/4-7	0.24	0.86	0.52	1.88	8.19	4.92	1.52	5.59	2.72
Offshore	WF054	4/4-7	0.29	0.99	0.58	0.38	14.00	5.35	1.09	4.98	2.06
All	ALL		0.24	0.99	0.49	0.20	14.00	3.64	0.61	5.91	2.57
Boundary	WF057	6/13-18	0.11	0.95	0.54	0.02	9.79	2.82	1.61	12.00	3.69
Cape Cod Bay	WF057	6/13-18	0.12	1.00	0.35	0.02	13.00	2.65	0.54	3.10	1.85
Coastal	WF057	6/13-18	0.12	1.00	0.44	0.02	7.55	2.30	1.64	4.98	3.64
Harbor	WF057	6/13-18	0.23	0.43	0.29	0.71	2.94	1.53	2.06	4.51	3.63
Nearfield	WF057	6/13-18	0.12	0.89	0.32	0.02	6.77	0.93	0.79	8.98	2.65
Offshore	WF057	6/13-18	0.12	0.92	0.49	0.02	7.62	2.34	0.86	3.27	1.79
All	ALL		0.11	1.00	0.41	0.02	13.00	2.09	0.54	12.00	2.87

Table 3-7. Summary of particulate carbon, nitrogen, and phosphorous data for February - June 2005.

			POC (µM)			PON (µM)			PartP (µM)		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF051	2/2	8.56	20.00	13.38	0.86	2.14	1.53	0.08	0.25	0.15
Nearfield	WF052	2/27	10.60	49.40	35.57	1.50	7.50	5.61	0.12	0.46	0.37
Nearfield	WN053	3/17	9.56	27.50	20.00	1.58	4.34	3.15	0.10	0.31	0.22
Nearfield	WF054	4/6	16.70	43.90	27.31	2.01	5.86	3.47	0.14	0.33	0.22
Nearfield	WN056	5/13	13.10	39.70	26.31	1.68	5.81	4.10	0.10	0.42	0.26
Nearfield	WF057	6/17	16.20	72.70	29.16	2.01	8.94	3.81	0.13	0.63	0.26
Nearfield	ALL		8.56	72.70	25.29	0.86	8.94	3.61	0.08	0.63	0.25
Boundary	WF051	2/1-2, 7	6.37	15.80	10.68	0.73	1.96	1.35	0.06	0.19	0.11
Cape Cod Bay	WF051	2/1-2, 7	12.90	17.00	14.74	1.47	2.02	1.77	0.11	0.17	0.14
Coastal	WF051	2/1-2, 7	15.90	24.60	19.99	1.81	2.73	2.20	0.15	0.29	0.22
Harbor	WF051	2/1-2, 7	13.90	39.70	22.79	1.72	4.48	2.75	0.20	0.50	0.31
Nearfield	WF051	2/1-2, 7	8.56	20.00	13.38	0.86	2.14	1.53	0.08	0.25	0.15
Offshore	WF051	2/1-2, 7	6.70	12.40	9.57	0.98	1.59	1.23	0.07	0.15	0.11
All	ALL		6.37	39.70	15.19	0.73	4.48	1.81	0.06	0.50	0.17
Boundary	WF052	2/23-27	21.40	50.00	33.52	3.40	8.12	5.18	0.08	0.47	0.28
Cape Cod Bay	WF052	2/23-27	19.00	36.40	24.30	2.57	4.99	3.50	0.20	0.35	0.26
Coastal	WF052	2/23-27	27.20	44.90	35.79	3.98	6.77	5.34	0.32	0.52	0.41
Harbor	WF052	2/23-27	26.50	39.50	33.26	3.76	5.82	4.92	0.29	0.51	0.41
Nearfield	WF052	2/23-27	10.60	49.40	35.57	1.50	7.50	5.61	0.12	0.46	0.37
Offshore	WF052	2/23-27	10.20	52.70	30.88	1.53	6.96	4.44	0.13	0.40	0.30
All	ALL		10.20	52.70	32.22	1.50	8.12	4.83	0.08	0.52	0.34
Boundary	WF054	4/4-7	7.72	31.90	22.45	0.78	4.00	2.79	0.05	0.27	0.19
Cape Cod Bay	WF054	4/4-7	9.76	27.90	17.39	1.05	3.61	2.23	0.11	0.27	0.16
Coastal	WF054	4/4-7	17.50	43.20	28.21	2.16	4.71	3.57	0.19	0.34	0.26
Harbor	WF054	4/4-7	23.60	38.20	34.43	3.15	4.93	4.38	0.22	0.43	0.33
Nearfield	WF054	4/4-7	16.70	43.90	27.31	2.01	5.86	3.47	0.14	0.33	0.22
Offshore	WF054	4/4-7	7.58	34.70	20.73	0.75	4.56	2.74	0.04	0.34	0.17
All	ALL		7.58	43.90	25.09	0.75	5.86	3.20	0.04	0.43	0.22
Boundary	WF057	6/13-18	6.52	53.70	27.74	0.83	6.29	3.69	0.06	0.61	0.24
Cape Cod Bay	WF057	6/13-18	12.80	29.00	20.97	1.45	3.96	2.76	0.16	0.27	0.21
Coastal	WF057	6/13-18	16.60	41.65	29.41	2.13	6.51	4.39	0.13	0.52	0.31
Harbor	WF057	6/13-18	27.30	47.20	33.06	3.75	7.47	4.71	0.29	0.61	0.36
Nearfield	WF057	6/13-18	16.20	72.70	29.16	2.01	8.94	3.81	0.13	0.63	0.26
Offshore	WF057	6/13-18	7.80	34.70	22.57	1.11	3.87	2.81	0.06	0.34	0.18
All	ALL		6.52	72.70	27.15	0.83	8.94	3.70	0.06	0.63	0.26

Table 3-8. Summary of dissolved organic carbon, nitrogen, and phosphorous data for February - June 2005.

			DOC (μM)			TDN (μM)			TDP (μM)		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF051	2/2	74.70	123.00	89.89	13.80	29.30	19.83	1.08	2.41	1.30
Nearfield	WF052	2/27	76.50	102.00	84.54	10.00	22.10	15.34	0.41	1.03	0.63
Nearfield	WN053	3/17	77.10	93.90	83.87	9.71	19.60	13.31	0.48	0.89	0.71
Nearfield	WF054	4/6	79.90	121.00	92.15	7.35	19.60	11.87	0.41	1.10	0.74
Nearfield	WN056	5/13	91.20	112.00	99.87	5.88	14.30	9.66	0.19	0.77	0.42
Nearfield	WF057	6/17	81.60	154.50	109.52	7.78	20.40	12.07	0.06	0.71	0.30
Nearfield	ALL		74.70	154.50	93.31	5.88	29.30	13.68	0.06	2.41	0.68
Boundary	WF051	2/1-2, 7	68.20	113.00	84.07	16.10	23.90	19.93	1.05	1.41	1.18
Cape Cod Bay	WF051	2/1-2, 7	74.40	85.00	80.38	13.20	25.40	16.57	1.02	1.19	1.12
Coastal	WF051	2/1-2, 7	78.40	91.00	84.40	16.70	24.20	20.27	1.12	1.51	1.30
Harbor	WF051	2/1-2, 7	83.30	90.00	86.61	20.90	27.80	23.61	1.24	1.63	1.36
Nearfield	WF051	2/1-2, 7	74.70	123.00	89.89	13.80	29.30	19.83	1.08	2.41	1.30
Offshore	WF051	2/1-2, 7	73.10	85.30	77.49	14.80	24.60	18.98	1.22	1.69	1.42
All	ALL		68.20	123.00	83.81	13.20	29.30	19.86	1.02	2.41	1.28
Boundary	WF052	2/23-27	70.40	120.00	92.92	11.90	16.70	13.93	0.45	1.05	0.72
Cape Cod Bay	WF052	2/23-27	107.00	133.00	119.50	12.60	21.00	16.30	0.68	1.02	0.88
Coastal	WF052	2/23-27	78.80	127.00	99.64	12.10	19.80	16.27	0.53	0.82	0.69
Harbor	WF052	2/23-27	95.00	108.00	102.56	17.60	21.60	19.62	0.56	0.71	0.66
Nearfield	WF052	2/23-27	76.50	102.00	84.54	10.00	22.10	15.34	0.41	1.03	0.63
Offshore	WF052	2/23-27	73.30	106.00	92.36	10.60	18.10	14.40	0.44	1.01	0.71
All	ALL		70.40	133.00	98.59	10.00	22.10	15.98	0.41	1.05	0.71
Boundary	WF054	4/4-7	75.30	95.30	84.40	8.85	16.30	12.28	0.60	1.10	0.85
Cape Cod Bay	WF054	4/4-7	89.80	95.50	92.55	8.85	15.60	10.69	0.45	0.70	0.58
Coastal	WF054	4/4-7	92.90	128.00	102.80	7.50	14.10	10.43	0.44	0.90	0.66
Harbor	WF054	4/4-7	99.50	134.00	117.06	9.28	13.50	10.91	0.38	0.62	0.48
Nearfield	WF054	4/4-7	79.90	121.00	92.15	7.35	19.60	11.87	0.41	1.10	0.74
Offshore	WF054	4/4-7	74.70	119.00	88.78	7.71	15.20	11.48	0.52	1.11	0.79
All	ALL		74.70	134.00	96.29	7.35	19.60	11.28	0.38	1.11	0.68
Boundary	WF057	6/13-18	97.20	134.00	118.03	8.28	15.10	11.36	0.06	0.59	0.35
Cape Cod Bay	WF057	6/13-18	91.50	114.00	106.08	7.50	20.10	11.52	0.12	0.89	0.34
Coastal	WF057	6/13-18	92.90	166.00	122.21	9.28	15.40	11.64	0.18	0.64	0.34
Harbor	WF057	6/13-18	108.00	143.00	124.67	10.10	14.10	11.69	0.19	0.43	0.32
Nearfield	WF057	6/13-18	81.60	154.50	109.52	7.78	20.40	12.07	0.06	0.71	0.30
Offshore	WF057	6/13-18	93.20	136.00	109.92	7.85	18.50	12.05	0.11	0.56	0.31
All	ALL		81.60	166.00	115.07	7.50	20.40	11.72	0.06	0.89	0.33

Table 3-9. Summary of total suspended solids data for February - June 2005.

Region	Survey	Dates	Min	TSS (mgL^{-1}) Max	Mean
Nearfield	WF051	2/2	0.69	4.88	1.67
Nearfield	WF052	2/27	0.98	2.65	1.85
Nearfield	WN053	3/17	0.47	1.56	0.84
Nearfield	WF054	4/6	0.61	2.41	1.01
Nearfield	WN056	5/13	0.12	2.19	0.94
Nearfield	WF057	6/17	0.12	1.86	0.98
Nearfield	ALL		0.12	4.88	1.22
Boundary	WF051	2/1-2, 7	0.41	3.33	1.33
Cape Cod Bay	WF051	2/1-2, 7	1.21	3.27	1.99
Coastal	WF051	2/1-2, 7	1.98	3.83	2.95
Harbor	WF051	2/1-2, 7	2.30	7.59	3.78
Nearfield	WF051	2/1-2, 7	0.69	4.88	1.67
Offshore	WF051	2/1-2, 7	0.57	2.35	1.48
All	ALL		0.41	7.59	2.20
Boundary	WF052	2/23-27	0.53	2.84	1.67
Cape Cod Bay	WF052	2/23-27	1.24	2.20	1.67
Coastal	WF052	2/23-27	2.46	6.92	3.89
Harbor	WF052	2/23-27	2.73	5.58	3.67
Nearfield	WF052	2/23-27	0.98	2.65	1.85
Offshore	WF052	2/23-27	1.28	1.84	1.59
All	ALL		0.53	6.92	2.39
Boundary	WF054	4/4-7	0.35	2.05	0.96
Cape Cod Bay	WF054	4/4-7	0.24	0.95	0.54
Coastal	WF054	4/4-7	0.59	1.90	1.30
Harbor	WF054	4/4-7	1.42	4.89	2.88
Nearfield	WF054	4/4-7	0.61	2.41	1.01
Offshore	WF054	4/4-7	0.39	1.58	0.73
All	ALL		0.24	4.89	1.24
Boundary	WF057	6/13-18	0.62	1.91	1.00
Cape Cod Bay	WF057	6/13-18	0.48	2.37	1.33
Coastal	WF057	6/13-18	0.79	3.23	1.79
Harbor	WF057	6/13-18	1.32	2.82	2.26
Nearfield	WF057	6/13-18	0.12	1.86	0.98
Offshore	WF057	6/13-18	0.49	1.31	0.82
All	ALL		0.12	3.23	1.36

Table 3-10. Summary of production parameters alpha and Pmax data for February - June 2005. Production is only measured in nearfield and Boston Harbor (stations N05, 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	WF051	2/2	0.008	0.016	0.012	0.77	2.18	1.31
Nearfield	WF052	2/27	0.027	0.123	0.077	5.42	18.47	11.93
Nearfield	WN053	3/17	0.020	0.110	0.081	2.27	8.40	6.65
Nearfield	WF054	4/6	0.013	0.081	0.043	1.59	6.35	3.74
Nearfield	WN056	5/13	0.016	0.168	0.073	1.50	14.81	8.12
Nearfield	WF057	6/17	0.016	0.085	0.046	1.90	8.14	4.75
Nearfield	ALL		0.008	0.168	0.055	0.77	18.47	6.08
Boundary	WF051	2/1-2, 7						
Cape Cod Bay	WF051	2/1-2, 7						
Coastal	WF051	2/1-2, 7						
Harbor	WF051	2/1-2, 7	0.008	0.046	0.018	0.92	1.35	1.15
Nearfield	WF051	2/1-2, 7	0.008	0.016	0.012	0.77	2.18	1.31
Offshore	WF051	2/1-2, 7						
All	ALL		0.008	0.046	0.015	0.77	2.18	1.23
Boundary	WF052	2/23-27						
Cape Cod Bay	WF052	2/23-27						
Coastal	WF052	2/23-27						
Harbor	WF052	2/23-27	0.051	0.071	0.064	6.57	15.43	10.78
Nearfield	WF052	2/23-27	0.027	0.123	0.077	5.42	18.47	11.93
Offshore	WF052	2/23-27						
All	ALL		0.027	0.123	0.070	5.42	18.47	11.35
Boundary	WF054	4/4-7						
Cape Cod Bay	WF054	4/4-7						
Coastal	WF054	4/4-7						
Harbor	WF054	4/4-7	0.045	0.129	0.089	5.87	9.96	7.93
Nearfield	WF054	4/4-7	0.013	0.081	0.043	1.59	6.35	3.74
Offshore	WF054	4/4-7						
All	ALL		0.013	0.129	0.066	1.59	9.96	5.84
Boundary	WF057	6/13-18						
Cape Cod Bay	WF057	6/13-18						
Coastal	WF057	6/13-18						
Harbor	WF057	6/13-18	0.017	0.042	0.027	2.80	4.60	3.97
Nearfield	WF057	6/13-18	0.016	0.085	0.046	1.90	8.14	4.75
Offshore	WF057	6/13-18						
All	ALL		0.016	0.085	0.037	1.90	8.14	4.36

Table 3-11. Summary of areal production, depth-averaged chlorophyll-specific production, and respiration data for February - June 2005. Production is only measured in nearfield and Boston Harbor (stations N05, N18, and F23). Respiration is measured at the production stations and at offshore station F19.

			Areal Production ($mgCm^{-2}d^{-1}$)			Depth-averaged Chlorophyll- specific Production ($mgCmgChla^{-1}d^{-1}$)			Respiration (μMO_2h^{-1})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WF051	2/2	158.7	264.1	211.4	9.0	11.5	10.3	0.006	0.049	0.021
Nearfield	WF052	2/27	1220.2	1386.4	1303.3	4.1	4.9	4.5	0.023	0.076	0.057
Nearfield	WN053	3/17	1073.4	1297.9	1185.7	8.7	18.4	13.6	0.011	0.042	0.022
Nearfield	WF054	4/6	346.0	586.7	466.4	7.9	12.3	10.1	0.010	0.068	0.033
Nearfield	WN056	5/13	1274.9	1490.5	1382.7	8.7	22.2	15.5	0.044	0.165	0.106
Nearfield	WF057	6/17	749.9	955.3	852.6	7.8	19.5	13.6	0.012	0.083	0.048
Nearfield	ALL		158.7	1490.5	900.3	4.1	22.2	11.2	0.006	0.165	0.048
Boundary	WF051	2/1-2, 7									
Cape Cod Bay	WF051	2/1-2, 7									
Coastal	WF051	2/1-2, 7									
Harbor	WF051	2/1-2, 7	43.4	43.4	43.4	3.5	3.5	3.5	0.018	0.050	0.031
Nearfield	WF051	2/1-2, 7	158.7	264.1	211.4	9.0	11.5	10.3	0.006	0.049	0.021
Offshore	WF051	2/1-2, 7							0.015	0.045	0.025
All	ALL		43.4	264.1	127.4	3.5	11.5	6.9	0.006	0.050	0.025
Boundary	WF052	2/23-27									
Cape Cod Bay	WF052	2/23-27									
Coastal	WF052	2/23-27									
Harbor	WF052	2/23-27	484.6	484.6	484.6	5.7	5.7	5.7	0.091	0.097	0.094
Nearfield	WF052	2/23-27	1220.2	1386.4	1303.3	4.1	4.9	4.5	0.023	0.076	0.057
Offshore	WF052	2/23-27							0.003	0.064	0.039
All	ALL		484.6	1386.4	894.0	4.1	5.7	5.1	0.003	0.097	0.064
Boundary	WF054	4/4-7									
Cape Cod Bay	WF054	4/4-7									
Coastal	WF054	4/4-7									
Harbor	WF054	4/4-7	524.1	524.1	524.1	10.6	10.6	10.6	0.062	0.082	0.069
Nearfield	WF054	4/4-7	346.0	586.7	466.4	7.9	12.3	10.1	0.010	0.068	0.033
Offshore	WF054	4/4-7							0.004	0.061	0.026
All	ALL		346.0	586.7	495.2	7.9	12.3	10.3	0.004	0.082	0.043
Boundary	WF057	6/13-18									
Cape Cod Bay	WF057	6/13-18									
Coastal	WF057	6/13-18									
Harbor	WF057	6/13-18	292.7	292.7	292.7	10.3	10.3	10.3	0.060	0.079	0.068
Nearfield	WF057	6/13-18	749.9	955.3	852.6	7.8	19.5	13.6	0.012	0.083	0.048
Offshore	WF057	6/13-18							0.023	0.158	0.111
All	ALL		292.7	955.3	572.7	7.8	19.5	12.0	0.012	0.158	0.075

Table 3-12. Summary of total phytoplankton, centric diatoms, and total zooplankton data for February - June 2005.

			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	WF051	2/2	0.388	0.974	0.640	0.002	0.025	0.009	5033	11804	8193
Nearfield	WF052	2/27	0.938	1.563	1.195	0.311	0.429	0.362	3678	9074	7122
Nearfield	WN053	3/17	0.851	1.360	1.054	0.069	0.255	0.149	6978	13333	10156
Nearfield	WF054	4/6	1.189	3.476	2.200	0.003	0.014	0.010	4912	23885	13580
Nearfield	WN056	5/13	0.763	1.235	1.065	0.166	0.236	0.198	728	20260	10494
Nearfield	WF057	6/17	0.802	1.694	1.289	0.085	0.578	0.204	20841	41907	32485
Nearfield	ALL		0.388	3.476	1.240	0.002	0.578	0.155	728	41907	13672
Boundary	WF051	2/1-2, 7	0.558	0.784	0.690	0.007	0.018	0.012	4745	8690	6718
Cape Cod Bay	WF051	2/1-2, 7	0.730	0.983	0.857	0.004	0.067	0.039	5725	12345	9193
Coastal	WF051	2/1-2, 7	0.571	1.194	0.799	0.002	0.028	0.011	1454	8249	4167
Harbor	WF051	2/1-2, 7	0.541	0.952	0.712	0.004	0.016	0.008	2467	3305	2851
Nearfield	WF051	2/1-2, 7	0.388	0.974	0.640	0.002	0.025	0.009	5033	11804	8193
Offshore	WF051	2/1-2, 7	0.537	0.911	0.692	0.003	0.011	0.007	7595	9916	8755
All	ALL		0.388	1.194	0.732	0.002	0.067	0.014	1454	12345	6646
Boundary	WF052	2/23-27	1.108	1.691	1.344	0.292	0.535	0.420	5085	12125	8605
Cape Cod Bay	WF052	2/23-27	1.183	1.343	1.291	0.071	0.251	0.170	6409	13988	9445
Coastal	WF052	2/23-27	0.850	1.387	1.057	0.133	0.334	0.215	4189	12613	7766
Harbor	WF052	2/23-27	0.801	1.344	1.101	0.101	0.176	0.129	6613	15672	9942
Nearfield	WF052	2/23-27	0.938	1.563	1.195	0.311	0.429	0.362	3678	9074	7122
Offshore	WF052	2/23-27	0.928	1.367	1.196	0.198	0.433	0.313	5105	13902	9503
All	ALL		0.801	1.691	1.197	0.071	0.535	0.268	3678	15672	8731
Boundary	WF054	4/4-7	2.495	5.427	3.693	0.005	0.018	0.011	742	14882	7812
Cape Cod Bay	WF054	4/4-7	0.426	1.119	0.740	0.000	0.004	0.002	9677	16710	13508
Coastal	WF054	4/4-7	1.211	2.240	1.837	0.017	0.130	0.072	7290	15512	11466
Harbor	WF054	4/4-7	1.203	2.408	1.803	0.025	0.115	0.080	4229	34296	15242
Nearfield	WF054	4/4-7	1.189	3.476	2.200	0.003	0.014	0.010	4912	23885	13580
Offshore	WF054	4/4-7	0.698	5.107	2.212	0.004	0.055	0.021	4264	18508	11386
All	ALL		0.426	5.427	2.081	0.000	0.130	0.033	742	34296	12166
Boundary	WF057	6/13-18	0.967	1.850	1.406	0.029	0.614	0.250	41000	44469	42735
Cape Cod Bay	WF057	6/13-18	0.858	1.371	1.085	0.003	0.235	0.069	34106	66966	50536
Coastal	WF057	6/13-18	1.023	1.486	1.142	0.018	0.307	0.108	29001	42504	37112
Harbor	WF057	6/13-18	1.102	1.931	1.493	0.051	0.203	0.095	45962	64294	57107
Nearfield	WF057	6/13-18	0.802	1.694	1.289	0.085	0.578	0.204	20841	41907	32485
Offshore	WF057	6/13-18	0.591	1.288	1.046	0.020	0.184	0.125	14992	35602	25297
All	ALL		0.591	1.931	1.244	0.003	0.614	0.142	14992	66966	40879

Table 3-13. Summary of *Alexandrium* spp., *Phaeocystis pouchetii*, and *Pseudo-nitzschia pungens* data for February - June 2005.

			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	WF051	2/2	0.00	0.00	0.00	0.0000	0.0000	0.0000	0.00000	0.00000	0.00000
Nearfield	WF052	2/27	0.00	0.00	0.00	0.0243	0.1749	0.0841	0.00000	0.00000	0.00000
Nearfield	WN053	3/17	0.00	0.00	0.00	0.2536	0.4924	0.3579	0.00000	0.00109	0.00027
Nearfield	WF054	4/6	0.00	0.00	0.00	0.2857	2.7101	1.2850	0.00000	0.00000	0.00000
Nearfield	WN056	5/13	50.75	3078.40	1335.95	0.0000	0.0000	0.0000	0.00000	0.00314	0.00127
Nearfield	WF057	6/17	375.94	5327.13	2447.98	0.0000	0.0103	0.0017	0.00392	0.03538	0.00993
Nearfield	ALL		0.00	5327.13	630.66	0.0000	2.7101	0.2881	0.00000	0.03538	0.00191
Boundary	WF051	2/1-2, 7	0.00	0.00	0.00	0.0000	0.0000	0.0000	0.00000	0.00029	0.00007
Cape Cod Bay	WF051	2/1-2, 7	0.00	0.00	0.00	0.0000	0.0000	0.0000	0.00000	0.00099	0.00025
Coastal	WF051	2/1-2, 7	0.00	0.00	0.00	0.0000	0.0000	0.0000	0.00000	0.00015	0.00003
Harbor	WF051	2/1-2, 7	0.00	0.00	0.00	0.0000	0.0000	0.0000	0.00000	0.00000	0.00000
Nearfield	WF051	2/1-2, 7	0.00	0.00	0.00	0.0000	0.0000	0.0000	0.00000	0.00000	0.00000
Offshore	WF051	2/1-2, 7	0.00	0.00	0.00	0.0000	0.0000	0.0000	0.00000	0.00000	0.00000
All	ALL		0.00	0.00	0.00	0.0000	0.0000	0.0000	0.00000	0.00099	0.00006
Boundary	WF052	2/23-27	0.00	0.00	0.00	0.1011	0.2822	0.1640	0.00000	0.00000	0.00000
Cape Cod Bay	WF052	2/23-27	0.00	0.00	0.00	0.0833	0.3081	0.1772	0.00000	0.00000	0.00000
Coastal	WF052	2/23-27	0.00	0.00	0.00	0.0000	0.1207	0.0491	0.00000	0.00000	0.00000
Harbor	WF052	2/23-27	0.00	0.00	0.00	0.0000	0.0000	0.0000	0.00000	0.00075	0.00013
Nearfield	WF052	2/23-27	0.00	0.00	0.00	0.0243	0.1749	0.0841	0.00000	0.00000	0.00000
Offshore	WF052	2/23-27	0.00	0.00	0.00	0.0669	0.1503	0.1023	0.00000	0.00000	0.00000
All	ALL		0.00	0.00	0.00	0.0000	0.3081	0.0961	0.00000	0.00075	0.00002
Boundary	WF054	4/4-7	0.00	0.00	0.00	0.3088	3.1685	1.8961	0.00000	0.00000	0.00000
Cape Cod Bay	WF054	4/4-7	0.00	0.00	0.00	0.0000	0.0358	0.0090	0.00000	0.00051	0.00013
Coastal	WF054	4/4-7	0.00	0.00	0.00	0.0627	0.7112	0.5095	0.00000	0.00056	0.00009
Harbor	WF054	4/4-7	0.00	0.00	0.00	0.2317	0.9929	0.5583	0.00000	0.00030	0.00008
Nearfield	WF054	4/4-7	0.00	0.00	0.00	0.2857	2.7101	1.2850	0.00000	0.00000	0.00000
Offshore	WF054	4/4-7	0.00	0.00	0.00	0.0000	4.0721	1.1035	0.00000	0.00000	0.00000
All	ALL		0.00	0.00	0.00	0.0000	4.0721	0.8936	0.00000	0.00056	0.00005
Boundary	WF057	6/13-18	10.00	1619.68	533.89	0.0000	0.0000	0.0000	0.00022	0.01505	0.00622
Cape Cod Bay	WF057	6/13-18	9.80	504.08	164.99	0.0000	0.0000	0.0000	0.00000	0.00099	0.00025
Coastal	WF057	6/13-18	0.00	520.63	280.80	0.0000	0.0000	0.0000	0.00000	0.00209	0.00137
Harbor	WF057	6/13-18	2.50	205.71	84.05	0.0000	0.0000	0.0000	0.00000	0.00316	0.00156
Nearfield	WF057	6/13-18	375.94	5327.13	2447.98	0.0000	0.0103	0.0017	0.00392	0.03538	0.00993
Offshore	WF057	6/13-18	502.90	2072.29	1538.41	0.0000	0.0000	0.0000	0.00147	0.00551	0.00364
All	ALL		0.00	5327.13	841.69	0.0000	0.0103	0.0003	0.00000	0.03538	0.00383

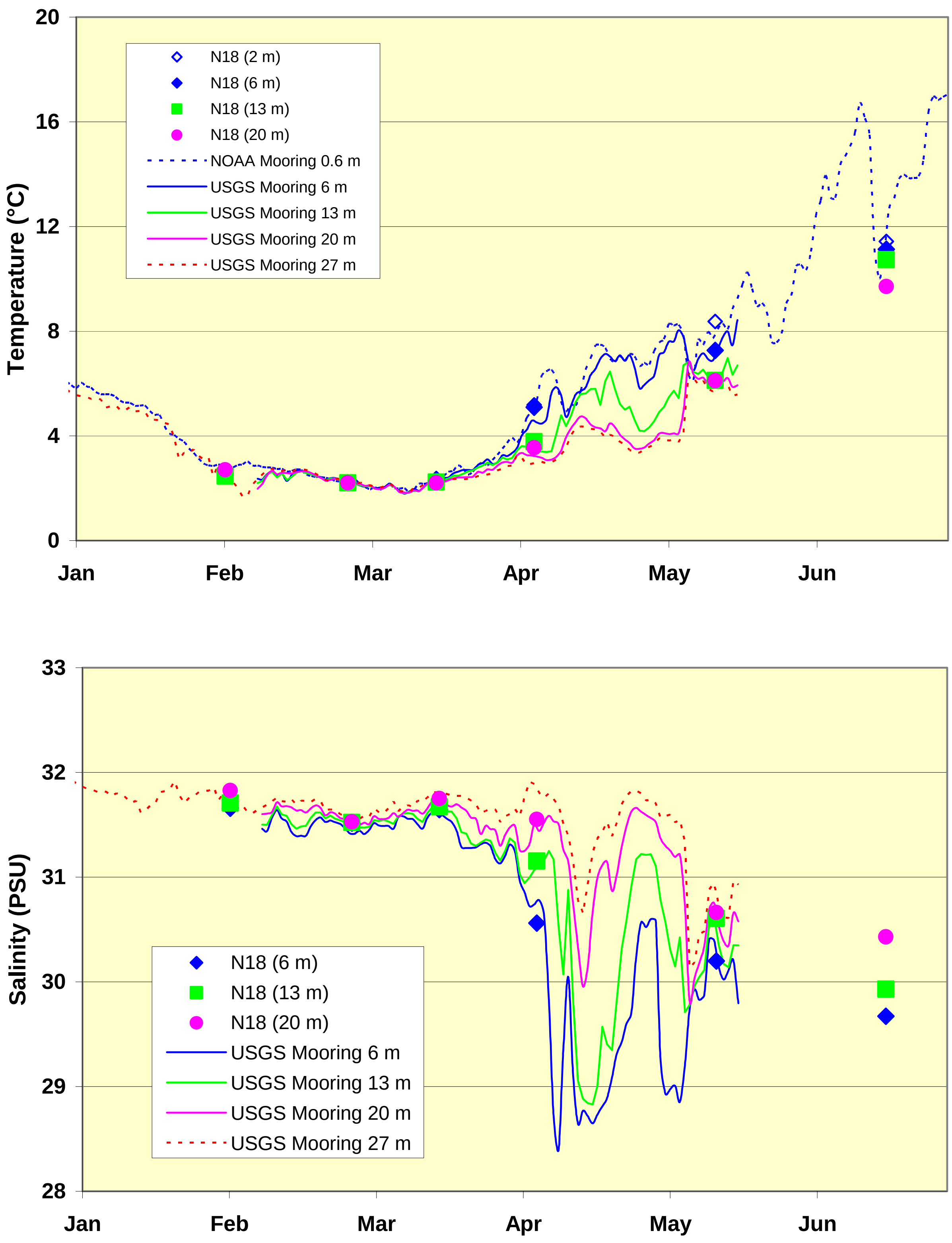


Figure 3-1. USGS Temperature and salinity mooring data compared with station N18 data.

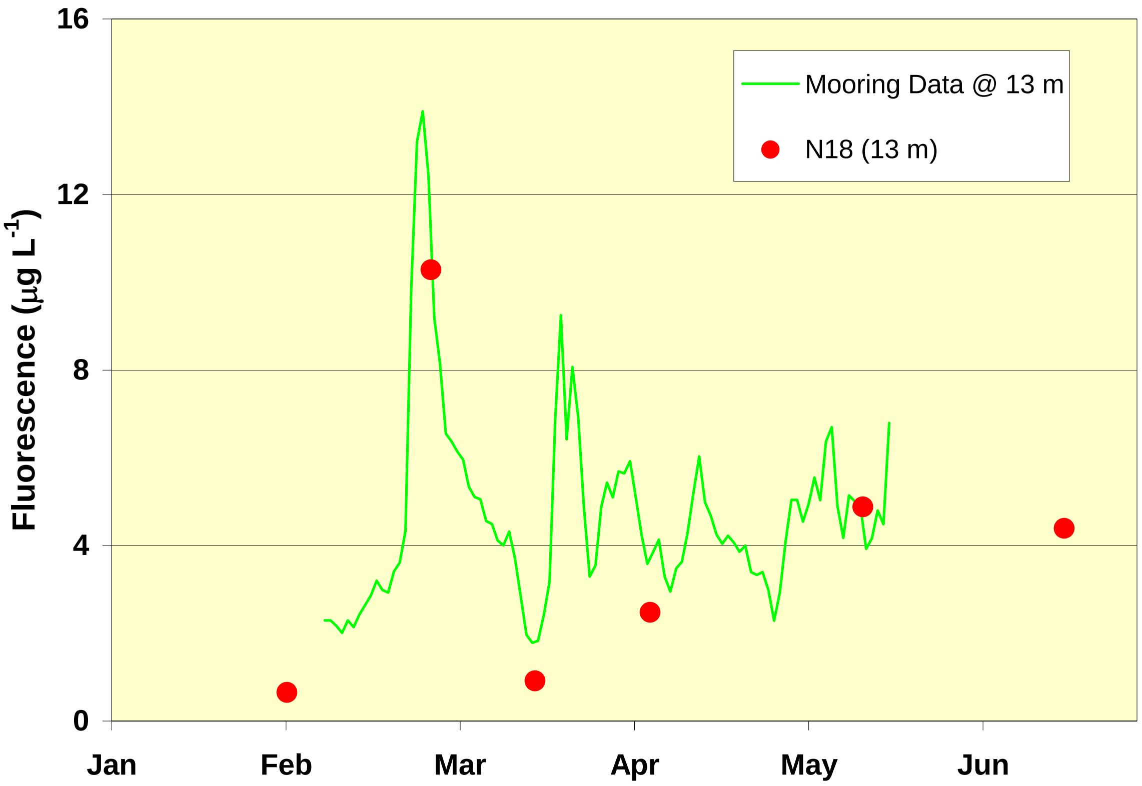


Figure 3-2. MWRA and Battelle *In Situ* Wetstar fluorescence data – MWRA data acquired at ~13 m on USGS mooring and Battelle data acquired at 13 m at station N18.

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 (WN055) was been removed from the monitoring program in 2004. The first two combined surveys were conducted in early and late February (WF051 and WF052 respectively) during well-mixed winter conditions. Stratification was developing throughout the region by April (WF054). Temperature and salinity data from the USGS mooring confirms this and also reveal a series of mixing events which occurred in mid April through May disrupting the development of a strong density gradient (see **Figure** 3-1). By June (WF057), 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) (see **Figure** 1-2). Nearfield vertical data is examined 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 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 had developed throughout many areas, including the nearfield, by April (WN054; **Figure** 4-1). Strong Northeast storms in early May provided the energy to mix the water column and weaken early season stratification. During the May nearfield survey only moderate levels of stratification were observed. By June (WN057) stratification had become fairly well established throughout the bays, although a mid June storm event mixed the water column and was well characterized in the survey data.

4.1.1.1 Horizontal Distribution

Surface water temperatures across Massachusetts and Cape Cod Bays in early February were low (-0.54 to 3.40°C; see Appendix A) with a clear inshore to offshore temperature gradient with the coldest waters in Boston Harbor, coastal, and Cape Cod Bay waters. The same gradient and low surface temperatures (0.98 to 3.11°C) were present in the late February survey. 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.

In April (WF054), surface water temperatures had increased (3.70 to 6.42°C). The gradient had also changed, with the coldest waters 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 (26.2 PSU), 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 (47,700 cfs and 1,410 cfs respectively). As expected, these peak freshwater flows were coincident with elevated precipitation in April (**Figure** 4-3). The high flow conditions during April likely led to increased nutrient inputs to the system which contributed to the phytoplankton blooms (including *Phaeocystis*) seen throughout the area. April precipitation was approximately 136% of normal and the majority of this rainfall came early in the month just prior to the survey. May continued to be very wet with eastern portions of Massachusetts receiving 145 to 196% of normal rainfall for the month (http://www.mass.gov/dcr/waterSupply/rainfall/). Although no farfield survey was conducted in May, the nearfield data reveals low salinity surface waters (29.6 to 30.4 PSU). May 2005 temperatures were also within the top five coolest for May in at least 100 years.

By June (WF057), surface water temperature had increased considerably across the survey area to a range of 11.35 to 17.67°C. The wide range of surface temperature values measured on this survey and the patchiness seen in the contour plot (Appendix A) is result of weather changes during the course of the survey. During the first two days of the survey, the North Shore and boundary stations were sampled. These two survey days came at the end of a period of fair weather and light Southwesterly winds. As a result, the late spring surface waters were stable and warming, and the measurements at those stations were generally >15°C. The survey was then interrupted by a two day period of moderate Northerly winds and rough seas which mixed the water column and broke up the shallow thermal stratification. The survey resumed under light easterly winds, and stations in the nearfield, South Shore, and Cape Cod Bay were sampled to complete the survey. The colder surface temperatures seen at these stations (generally <15°C) reflect the recently mixed water column. A similar, although somewhat less pronounced pattern was seen in the surface salinities. The timing of this survey provides an excellent example of the strong influence that day-to-day weather has on physical water column properties, particularly during transitional periods such as late spring and fall.

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 <5°C. The coldest temperatures (<2°C) were observed in Boston Harbor where there was little variation in temperature. In the other regions, 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. By the April, survey surface waters had warmed somewhat and in many regions the stratification was setting up. The influx of fresh water from the spring freshet decreased surface salinities further contributing to the stratification in many parts of Massachusetts Bay. Virtually the entire month of May was dominated by a series of storms with predominately north and east winds. In early May (5/7-5/9), a Nor'easter passed through the area with sustained winds of ~30 MPH and wave heights of 2-5m measured at NDBC Station 44013 which is 16 nautical miles East of Boston (4.5 nm SE of the outfall). In late May (5/24-5/26), a second significant Nor'easter brought similar wind and wave conditions. This extended period of rough weather, accented by two substantial storms, mixed the water column and broke down the developing stratification. Along with the strong mixing energy, these storms brought heavy precipitation which increased river flows (**Figure** 4-3) and introduced a large pulse of freshwater to the system. Although no farfield surveys were conducted during this period, the influence of the first storm, in terms of mixing and low salinity, can be seen in the May nearfield survey results (WN056) and in the mooring data from USGS. The persistence of northeast winds and the influx of freshwater have been implicated as contributing factors to a major bloom of the toxic dinoflagellete *Alexandrium* in Massachusetts Bay. The bloom was first observed in early May and persisted at very high concentrations for several weeks. This is discussed further in section 5 and will be the focus of a special report on the 2005 *Alexandrium* bloom event. 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 (**Figure** 4-5). 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 (WF054), a moderate thermocline was developing in the near-surface waters of most areas and a salinity gradient associated with the spring freshet was present at northern boundary stations. These factors combined to establish a weak stratification in many areas that was more pronounced than often observed this early in the year. By June a strong, shallow 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 generally the case in 2005, although heavy precipitation and cool air temperatures in May continued to make salinity as much of an influence as temperature. 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 **Figures** 4-1 and 4-6, stratification was beginning to develop in the nearfield by April (WN054). The April surveys have typically captured this transition towards a stratified water column. 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 corroborate the early stratification measured during the WN054 survey. The mooring data show the continuing development of stratification in the week following the survey until a strong mixing event in mid April (4/13). While water temperatures continued to increase overall, a series of storms in April and May (discussed above) kept the water-column fairly well mixed. As the weather pattern changed to calmer conditions in June, stratification was re-established. However, as discussed in Section 4.1.1.1, day-to-day changes in wind direction and intensity can strongly influence the water column during the late spring and early summer. A fairly strong mixing event which occurred in the middle of the June survey reduced the degree of stratification in nearfield and offshore areas. This can be seen in several of the transects (see Appendix **Figures** B-7 and B-8).

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 low water temperatures in early February, the development of early stratification in April, and the series of spring mixing events. The mooring data is only available up to May 18. Salinity data from the mooring follows the same trends as the survey data. Both capture the freshwater signature from the freshet in early April, and again show the spring mixing events.

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 throughout the area (see Appendix A). There was a noticeable increase in beam attenuation along the coastline with values >2 m^{-1} as opposed to <2 m^{-1} further offshore. This was likely a product of sediment resuspension due to strong Northeast winds and waves in the days and hours leading up to sampling the shallow coastal stations. A maximum surface value of 3.57 m^{-1} was measured at station F03. This station is one of the closest to shore and most susceptible to the influence of Northeast wind and waves. Fluorescence values were very low during this survey (<2μgL^{-1}) and contributed little if anything to the beam attenuation signal. Surface beam attenuation values and gradients during the second February survey (WF052) were similar to those observed at the beginning of the month (range = 0.58 to 2.02 m^{-1}) with elevated values found primarily along the shore. Surface fluorescence had increased considerably by this survey exceeding 7μgL^{-1} in many regions, although the gradients did not follow the same trends as beam attenuation. Because they capture the chlorophyll maximum, the vertical contour plots in Appendix B reveal more about the beam attenuation/fluorescence relationship than the surface plots. In late February the fluorescence signal was >10 μgL^{-1} in many areas at about 10m deep. This was primarily associated with a minor winter/spring diatom bloom. However, the beam attenuation values were generally uncoupled from this fluorescence signal and instead showed gradients of high values near-shore decreasing to offshore at all depths. An example of this comparison is shown in **Figure** 4-7, and plots for all transects are provided in Appendix B. During both February surveys the beam attenuation trends were uncoupled from the fluorescence trends, suggesting that the source was suspended sediments rather than biogenic. In April the surface beam attenuation values were still low (0.41 to 1.48 m^{-1}). There was a weak gradient with slighter higher readings towards the north. The gradients and values were fairly well coupled with fluorescence readings which were also low but showed a slight trend of increasing towards the north. 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** 4-8).

In June, surface beam attenuation remained slightly elevated (1.1 to 1.9m^{-1}) in, and near, the harbor but was very low (<1 m^{-1}) in all other areas. The surface beam attenuation values were well coupled with surface fluorescence which also showed slightly elevated values near then harbor relative to areas further offshore. The transect contours (Appendix B) reveal that relatively high fluorescence (10-20μgL^{-1}) was present at the C-max (~15-20m) which was also associated with increased beam attenuation readings. Phytoplankton abundance data from the June survey shows comparable phytoplankton concentrations in both the harbor and further east. However, the offshore areas had a much larger diatom component (as opposed to microflagellates) which contributed to the higher fluorescence values. In general it appears that the June beam attenuation signal in and around Boston Harbor was a combination of non-biogenic sources and small phytoplankton, while the offshore areas were dominated by large plankton. This comparison is again best seen in along the Boston-Nearfield transect line (**Figure** 4-9). Note that the apparently high beam and fluorescence at station N16 in the nearfield is the result of the timing of sampling rather than any localized effect. Station N16 was sampled on June 13, while the other nearfield stations were sampled on June 17 after a storm had passed through the area mixing up the water column.

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 2005 generally followed the typical progression of seasonal events in Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. By late February, there was substantial decrease in surface nutrient concentrations as diatom and *Phaeocystis* populations were increasing. The increase in phytoplankton was primarily seen in the northern regions of the survey area and influence on nutrient concentrations followed accordingly. The mid March (WN053) nearfield nutrient concentrations were nearly identical to those of late February. Stratification had not set up yet so nutrients were generally available, and the total phytoplankton abundance had changed very little, with a slight shift towards *Phaeocystis* versus diatom abundance as the most noticeable population characteristic. By the April survey surface water nutrient concentrations had decreased substantially in most areas as the *Phaeocystis* bloom reached peak measured values. Despite the high abundances, it appears that the April survey actually captured the decline of the *Phaeocystis* bloom. This is discussed in more detail in Section 4.2.2. The condition of the bloom in April produced a broad fluorescence signature in the nearfield from 15m to near the bottom. Strong mixing events in mid April and early May weakened the developing stratification and likely resupplied moderate levels of nutrients throughout the water column. The May nearfield survey revealed a depletion of surface nutrients and a significant reduction in nutrient concentrations ($<3\mu M$) down to nearly 30m. This widespread nutrient reduction was likely due to the down-mixing of nutrient depleted surface waters and the rapid nutrient consumption of an increasing diatom population. By June (WF057), nutrient concentrations were generally depleted in the surface waters throughout the entire study area.

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 (WF051). In early 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 in Boston Harbor and at the northernmost boundary station. In late February nutrient values declined substantially in all survey areas as a result of utilization by the developing *Phaeocystis* and diatom populations. NH_4 was reduced to less than 1 µM in all areas except for the immediate vicinity of the outfall where concentrations reached a maximum of 3 µM. Nitrate was still elevated in the southern portions of the area, but was reduced to <4 µM in the surface waters at the northern stations where the peak fluorescence was also measured. Surface water concentrations of SiO_4 and PO_4 were reduced across all areas but showed a similar trend to NO_3 with the greatest reductions in the northern regions.

In April the surface nutrient trends had changed considerably from the late February patterns. Southerly areas like Cape Cod Bay were depleted of all nutrients and offshore, coastal, and nearfield regions were generally depleted except for silicate. Harbor and northern boundary stations showed moderate to high nutrient levels as the spring freshet provided a source through local rivers (**Figures** 4-10 and 4-11). By June (WF057), nutrients were generally depleted in the surface waters throughout the bays, except for a low level signal emerging from Boston Harbor.

4.2.1.2 Vertical Distribution

Farfield. The vertical distribution of nutrients was evaluated using vertical contours of nutrient data collected along three transects in the farfield: Boston-Nearfield, Cohasset, and Marshfield (see **Figure** 1-3; Appendix B). Nitrate (NO_3) concentrations along the Boston-Nearfield transect are presented to highlight the vertical nutrient trends. In early February (WF051), NO_3 concentrations were >8 µM across the entire Boston-Nearfield transect (**Figure** 4-12). Concentrations were especially high in harbor (although not noticeable at the scale of the figure). Silicate followed the same trends as NO_3 with concentrations >8 µM across the entire transect and reaching in excess of 15µM in the harbor. Phosphate was also elevated along this transect (>0.8µM), but was at its peak directly around the outfall (>1µM). Ammonium concentrations were generally low and were only elevated in the effluent plume in the nearfield.

The late February survey showed a substantial shift in the nutrient concentrations and gradients. The developing diatom and *Phaeocystis* blooms were consuming nutrients in the upper water column. Nitrate had decreased to <5µM in the surface waters surrounding the outfall. This was coincident with elevated fluorescence values and phytoplankton abundance. In regions where the plankton blooms were less concentrated (Harbor, Cape Cod Bay, Boundary) nitrate remained elevated throughout the water column, and in all regions nitrate remained high in the deeper waters. Due to the presence of diatoms in the community structure, silicate again followed the nitrate trends and was reduced to <5µM in the areas of high fluorescence/abundance. Phosphate also showed reductions although the gradients were less clear. A clear plume signature could still be seen in the ammonium concentrations although phytoplankton consumption had reduced levels approximately in half to <3µM.

By April (WF054) nutrient concentrations were generally low in the surface waters along the transects and depleted in the nearfield portions, (**Figure** 4-12) 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. Elevated fluorescence was concomitant with these areas of decreasing nutrients although the bloom was nearing its end and fluorescence was generally deeper in the water column as plankton settled out (see **Figure** 4-8). A minor effluent signal for both NH_4 and PO_4 can be seen in the waters just below the pycnocline. In June (WF057) nutrient levels as shown for NO_3, but including SiO_4, were generally depleted in the surface waters along each of the transects (**Figure** 4-12 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. Neither phosphate nor ammonium showed a clear effluent signal in the outfall area along the Boston-nearfield transect.

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 were regional differences 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** 4-13). There was a weak but apparent inverse relationship between DIN and salinity overall. A difference between the bays was also noted. There were clear salinity differences with harbor and coastal stations generally lower than most other areas. Nutrient levels were generally well distributed except for the effluent plume signal of elevated DIN (as NH_4) concentrations in the nearfield. In late February an inverse DIN/salinity relationship appeared to be present (**Figure** 4-13). However, based on fluorescence and phytoplankton abundance data it appears that this relationship was somewhat coincidental. For example, while Boston Harbor did show lower salinity, higher nutrient signatures as compared to other regions, the nutrient gradients were driven more by consumption by the emerging phytoplankton blooms than by supply sources.

By April, the DIN versus salinity signal exhibited a clear positive relationship. Low salinity surface waters were generally depleted in nutrients while the deeper waters still had high concentrations. The spring freshet did supply some low salinity, moderate nutrient waters to the Harbor, northern boundary, and northern offshore stations. These can be seen as the low salinity outliers in **Figure** 4-14. In June, a fairly strong positive DIN/salinity relationship was apparent. 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** 4-14).

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 early February were low relative to PO_4 and SiO_4 but concentrations of all nutrients were high and certainly not growth limiting. In late February a moderate diatom and *Phaeocystis* blooms were developing. As a result DIN was fairly low relative to PO_4 and was near limiting in some of the areas where the abundances were greatest. The *Phaeocystis* bloom increased in to March and April, and by survey WF054 nitrogen was limiting in most areas. By June, all nutrient levels were low in the surface waters. Nitrogen was still somewhat limiting relative to PO_4, but had increased relative to SiO_4 as diatoms again became a major component of the community structure.

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** 4-15. In general, nutrients in the nearfield began declining during the late February survey. Both NO_3 and SiO_4 declined in a similar fashion through mid March reflecting the influence of diatoms in the community structure as well as the dominant *Phaeocystis*. 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. Silicate concentrations showed little change during this period as diatoms no longer comprised a significant portion of the community structure. Phosphate showed similar trends to NO_3, generally declining throughout the report period (**Figure** 4-15). 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 were elevated in the surface waters in early February, decreased in late February with the onset of the blooms, then showed a confined yet distinctive effluent signal in March and April. This signal was in the surface waters in March then confined in the subsurface waters in April. In May and June the ammonium effluent signal was not as distinctive as seen in previous years.

4.2.2 Chlorophyll a

The nearfield mean areal chlorophyll (basis for chlorophyll threshold) for the winter/spring (February through April) of 2005 was 133mg m^{-2}, which is about half the seasonal caution threshold of 238 mg m^{-2}. The 2005 value was somewhat higher than the winter/spring values seen in 2004 (101 mg m^{-2}) and previously in 2001 and 2002 (69 and 112 mg m^{-2}). In 2003, the high seasonal value (178 mg m^{-2}) was measured when there was both a diatom and *Phaeocystis* bloom. Although not as high as 2003, the combination of diatom and *Phaeocystis* blooms in 2005 resulted in an increase in winter/spring seasonal chlorophyll levels in comparison to 2004 when an extraordinarily large *Phaeocystis* boom occurred. The areal chlorophyll values seen winter/spring 2005 are much lower than those measured during recent baseline 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 region-wide winter/spring diatom (1999) or *Phaeocystis* (2000) blooms. 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 2005 Nutrient Issues Report.

4.2.2.1 Horizontal Distribution

Surface chlorophyll concentrations were generally low ($\leq$1 μgL^{-1}) in all regions during the first survey of the year (WF051). During the late February survey (WF052) a minor winter/spring diatom bloom was underway (see Section 5) and surface fluorescence had increased substantially in many regions. The highest values were generally found at the more northerly stations especially in the Offshore and Coastal regions where values reached ~5-12μgL^{-1}. Surface fluorescence had dropped considerably by the April survey to <2 μgL^{-1}. Although total phytoplankton abundance was at a peak for the report period during April, the community was dominated by *Phaeocystis* and may have been toward the end of the bloom contributing less to the fluoresce signal. In June, surface fluorescence was slightly higher than April, but still low ($\leq$5 μgL^{-1}). Peak values were found in and near the harbor. However, the June survey did have the highest mid-depth fluorescence values of the report period – this is discussed further in the “vertical distribution” section below and in Section 5.

The fluorescence trends over the first six months of 2005 are also evident in the MODIS satellite images captured from mid January through June (see Appendix D). The MODIS images reveal very low surface fluorescence in early February. In late February surface fluorescence was increasing with what appears to be a bloom working its way south from Maine in mid February and developing in Massachusetts Bay shortly afterwards (**Figure** 4-16). On the date of the March nearfield survey (WN053) the satellite imagery shows moderate fluorescence values in the harbor, along the coastline, and in Cape Cod Bay. The nearfield survey did not capture this event. As March continued, the surface fluorescence signature increased and in late March relatively high values appear in most of the report area. This was likely due to a combination of the *Phaeocystis* bloom and a minor diatom bloom, both of which had initiated in late February. In fact, comparisons of the February through April MODIS images suggest that the *Phaeocystis* bloom may have been at its peak in mid to late March although not captured by any of the scheduled surveys (**Figure** 4-17). This may be particularly true in Cape Cod Bay where high fluorescence was seen in late March but very low fluorescence and measured phytoplankton abundance was seen on the April survey. In early April the MODIS images still show elevated fluorescence in the northern portions of the study area, as well as much higher values just to the north. Surface fluorescence remained at moderate levels through April and into May. By early June surface fluorescence had dropped considerably, but as seen in the WF057 data, by late June fluorescence values had again increased throughout most of the survey area.

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** 4-7, 4-8 and 4-9. In early February, chlorophyll concentrations were low (≤1.5 μgL^{-1}) in all areas. Dramatic increases in fluorescence were seen along all transects by the late February survey (see **Figure** 4-7 and Appendix B). Peak concentrations were generally found at approximately 15m, although without any stratification in place the areas of elevated fluorescence were quite broad, and often exceeded 5μgL^{-1} from the surface to below 20m. These concentrations and distributions compared well with the plankton abundance data and were associated with emerging blooms of *Phaeocystis* and diatoms.

Phaeocystis continued to increase and the greatest abundances, for both this species and total phytoplankton, for the report period were measured on the April survey. However, diatoms did not follow this pattern and made up only a very small portion of the community structure. As a result of this community make-up and low chlorophyll content of *Phaeocystis*, April fluorescence values were lower than the late February levels despite the peak in total phytoplankton (**Figure** 4-8). The weak fluorescence signature was deep in the water column (15-40m) revealing a senescent and settling bloom. By June, total phytoplankton abundance had decreased across all of the survey areas except Cape Cod Bay (which was already fairly low). However, this decrease was almost entirely due to the crash of the *Phaeocystis* bloom. Other components of the community, including diatoms, had increased and as a result fluorescence had increased dramatically. In all areas fluorescence was either at a peak for the report period or was similar to the elevated values measured in late February. In contrast to the broad band of fluorescence seen in late February, the areas of elevated fluorescence were now a narrow subsurface band at approximately 15 to 20m. The best example of this vertical fluorescence distribution is provided in (**Figure** 4-9).

As discussed in Section 4.1.1.1, the June farfield survey was interrupted by a two day period of strong Northeast winds and waves. This provided a good example of how influential local weather can be on water column properties, particularly during transitional seasons. Station N16 is visited twice during a combined nearfield/farfield survey. It is sampled as a component of the nearfield region and also as part of the larger farfield survey area. During the June survey N16 was first visited on June 13 as part of the farfield survey. The rough weather which broke up the survey prevented the nearfield portion from being conducted until June 17. As a result station N16 provides a pre and post-storm evaluation of the water column at a single location. **Figure** 4-18 provides profiles of temperature and fluorescence during both sampling events at station N16. On June 13, prior to the storm, a fairly strong thermocline was present with temperatures declining from 14ºC to 7ºC in the top 10m. Just below the thermocline was a strong fluorescence signal with a peak value of 19µg/L which was the highest fluorescence value recorded at a nearfield station in the entire report period. The two day storm event provided strong mixing of the water column. When station N16 was revisited four days later, only a weak thermocline was present with a broad temperature transition over the upper 28m. The phytoplankton had been well mixed as well, and fluorescence was fairly uniform at ~3µg/L throughout the water column. These changes can also be seen in the horizontal and vertical contour plots of Appendices A and B.

Nearfield. Chlorophyll concentrations in the nearfield generally followed the trends described above for the farfield. The timing of the nearfield only surveys, however, provides some additional information about the status of the *Phaeocystis* and diatom populations in March and May. **Figure** 4-19 depicts the progression of surface, mid-depth, and bottom chlorophyll values throughout the report period in the nearfield. As described above, the broad band of fluorescence associated with emerging diatom and *Phaeocystis* populations lead to a fluorescence maximum throughout the nearfield water column in late February. Fluorescence throughout the nearfield decreased considerably from late February to mid March. This supports the phytoplankton abundance data taken at stations N04 and N18 which show that although *Phaeocystis* populations were increasing, diatom presence had declined substantially. By April, the *Phaeocystis* bloom and total phytoplankton abundance was at its peak. However, fluorescence values at the surface and mid depths displayed a decrease while the bottom waters showed an increase. In April the bottom water fluorescence values were associated with an increase in phaeophytin as a percentage of total pigments, which is indicative of senescent cells. Although peak *Phaeocystis* abundances were measured in April, it appears that the bloom may have already begun to senesce and settle out of the water column.

The May nearfield survey again provided some supporting information regarding the community structure. Although total phytoplankton abundance was less than half what it had been in April, fluorescence at mid-depth (C-max) had changed very little. This was result of the major decline in the *Phaeocystis* population and an increase in diatom abundance. The considerable drop in fluorescence in the bottom waters also reflects the final full removal of *Phaeocystis* from the phytoplankton assemblage. Fluorescence increased at all depths, and particularly mid depth, in June. This was indicative of the moderate rebound of large diatoms and the highest nearfield fluorescence values of the report period were recorded (19 μgL^{-1}).

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 8.09 mgL^{-1} was measured in Cape Cod Bay in June. The nearfield minimum DO concentration of 8.87 mgL^{-1} was also observed in June. The June 2005 bottom water concentrations were 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 11.5 mgL^{-1} in Boston Harbor in February to a low of 8.8 mgL^{-1} in Cape Cod Bay in June (**Figure** 4-20a). In general, bottom water DO concentrations declined throughout the survey period. Lower concentrations were observed at the deeper offshore and boundary areas over the first three farfield surveys than in the other areas. In the past few years, the peak of the *Phaeocystis* bloom has corresponded with increased bottom water DO concentrations throughout Massachusetts Bay. This feature was not seen the 2005 farfield data. However, as previously discussed, it appears that the peak of the *Phaeocystis* bloom may have actually occurred a few weeks early than the April survey and was not fully captured in the survey data. The plot of nearfield DO concentrations (**Figure** 4-21a) supports this, showing the peak DO values in mid March. Following the crash of the *Phaeocystis* bloom in mid to late April there was a steady decline in DO concentration through June when all regions registered the lowest concentrations of the reporting period (<10 mgL^{-1}).

Dissolved oxygen measurements throughout the area during the first half of 2005 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 (**Figures** 4-20 and 4-21). DO % saturation increased from February to April in each of the survey areas. Bottom waters were generally saturated to supersaturated during the April survey. Following the crash of the *Phaeocystis* bloom, DO %saturation in the bottom waters declined to a minimum in June. However, DO %saturation remained fairly high even in June with all areas above 90%.

4.3 Summary of Water Column Results

- Precipitation and stream flow levels were normal to above normal for the first four months of the year. This supported a fairly strong spring freshet in April (precipitation ~136% of normal) which carried low salinity, elevated nutrient waters into the region.
- Stratification began in most areas by early April through a combination of the freshwater inputs and warming of surface waters. However, a series of strong Northeast storms dominated the weather from mid April through May interrupting further stratification. It was not until June that stratification was observed throughout the region and even then stratification was disrupted by a mid-survey northeast storm.
- The persistence of northeast winds and the influx of freshwater in April through May have been implicated as contributing factors to the major bloom of the toxic dinoflagellete *Alexandrium* in Massachusetts Bay.
- The nutrient data for February to June 2005 generally followed the "typical" progression of seasonal events in the Massachusetts and Cape Cod Bays.
  - Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited.
  - Nutrients declined in the surface waters from late February through the June in relationship the phytoplankton abundance and community structure.
- The effluent nutrient signal was clearly evident in the nearfield as elevated NH_4 and PO_4 concentrations.
- Elevated chlorophyll concentrations in late February were coincident with elevated productivity rates, a minor winter/spring diatom bloom and the initiation of the spring *Phaeocystis* bloom.
- Chlorophyll levels were relatively low in April given the peak *Phaeocystis* abundances observed and suggest that the bloom as senescing.
- Chlorophyll was also elevated in many regions in June. Although total phytoplankton abundance was lower during this period than in April, large centric diatoms contributed a relatively substantial portion of the community adding to the fluorescence values.
- DO concentrations in 2005 were within the range of values observed during previous years and followed the typical trends.

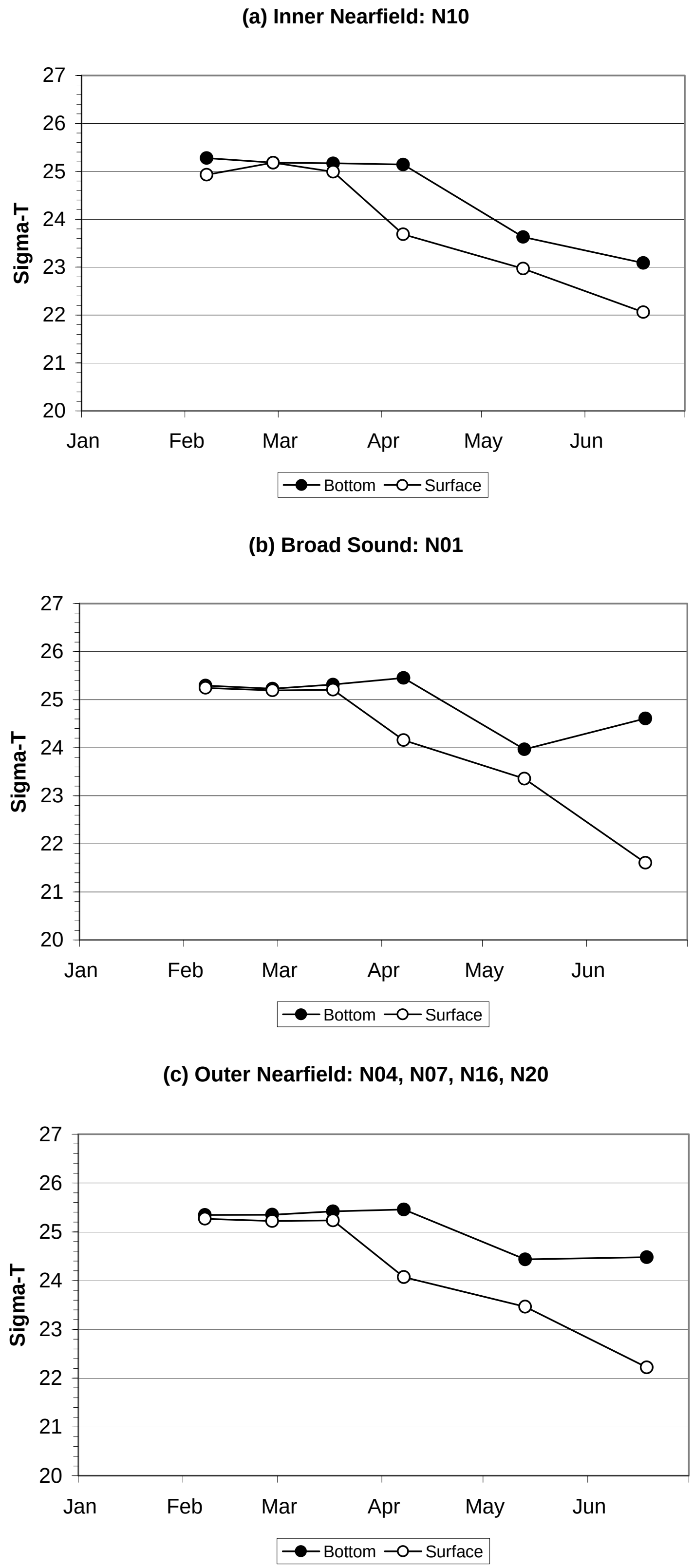


Figure 4-1. Time-series of average surface and bottom water density (σ_t) in the nearfield.

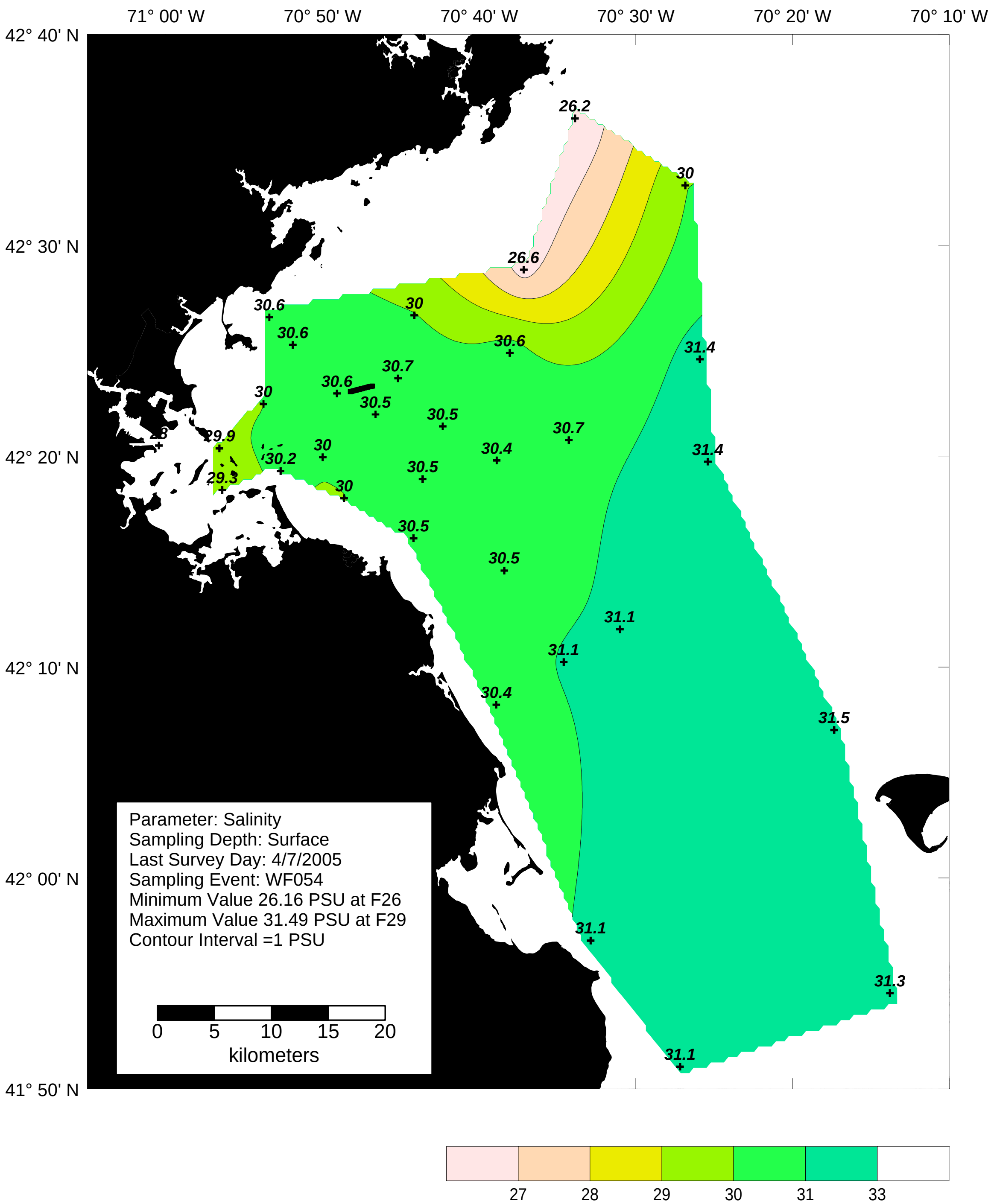


Figure 4-2. Salinity surface contour plot for farfield survey WF054 (Apr 05)

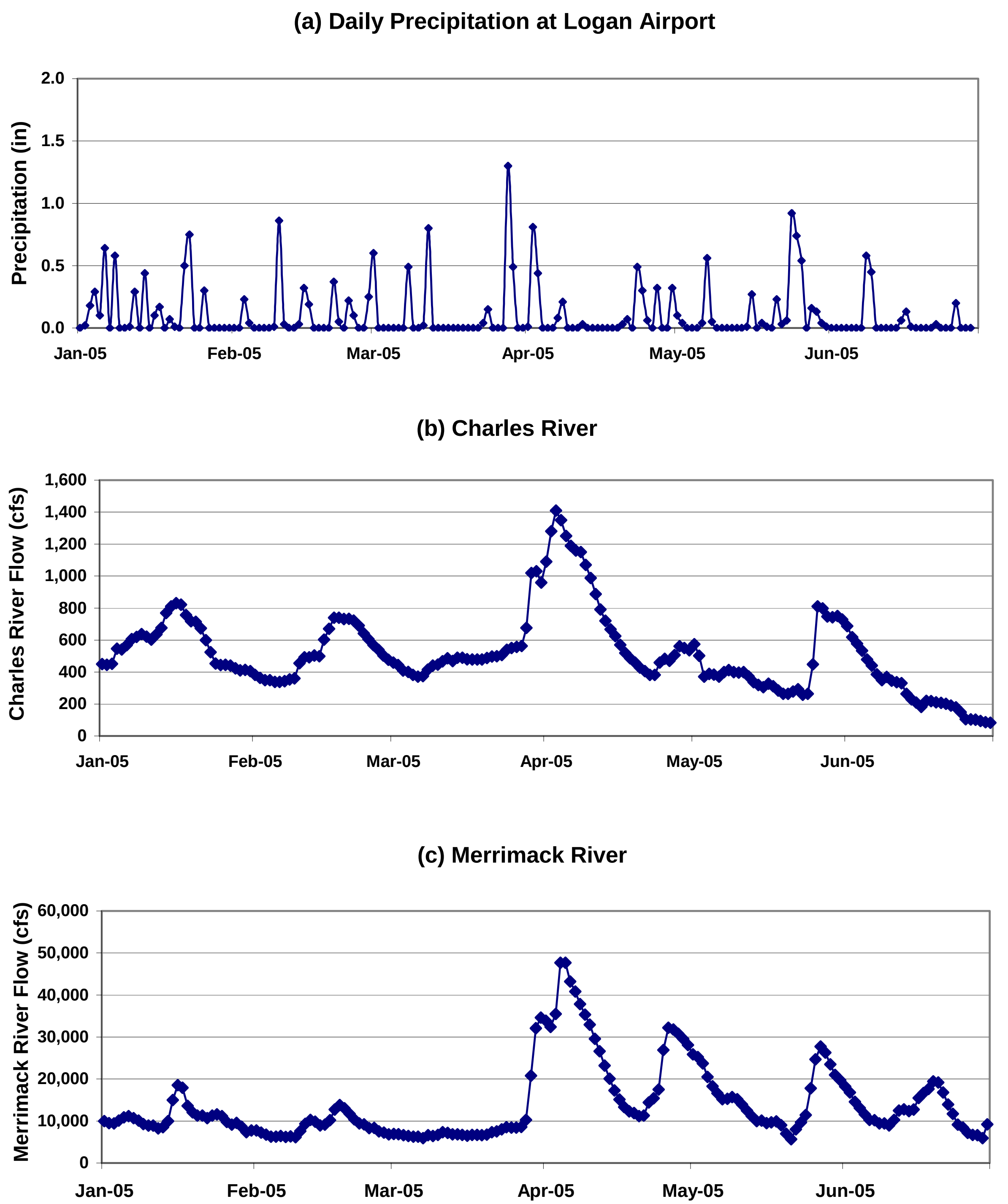
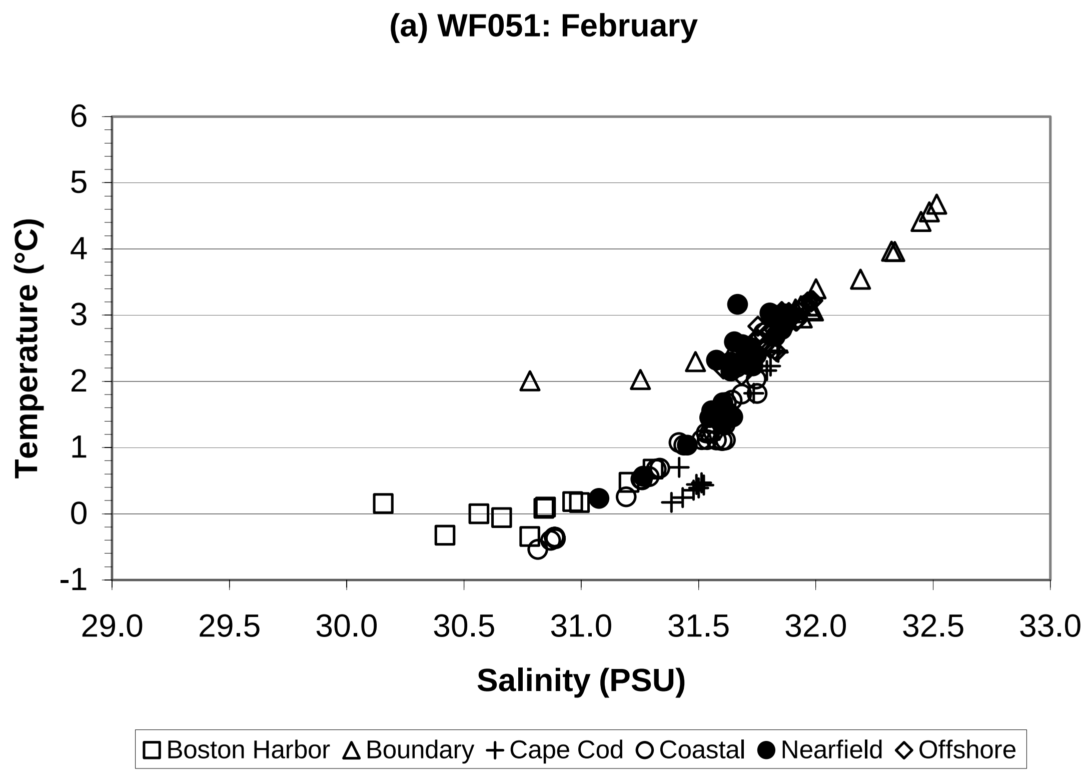


Figure 4-3. Precipitation at Logan Airport and river discharges for the Charles and Merrimack Rivers



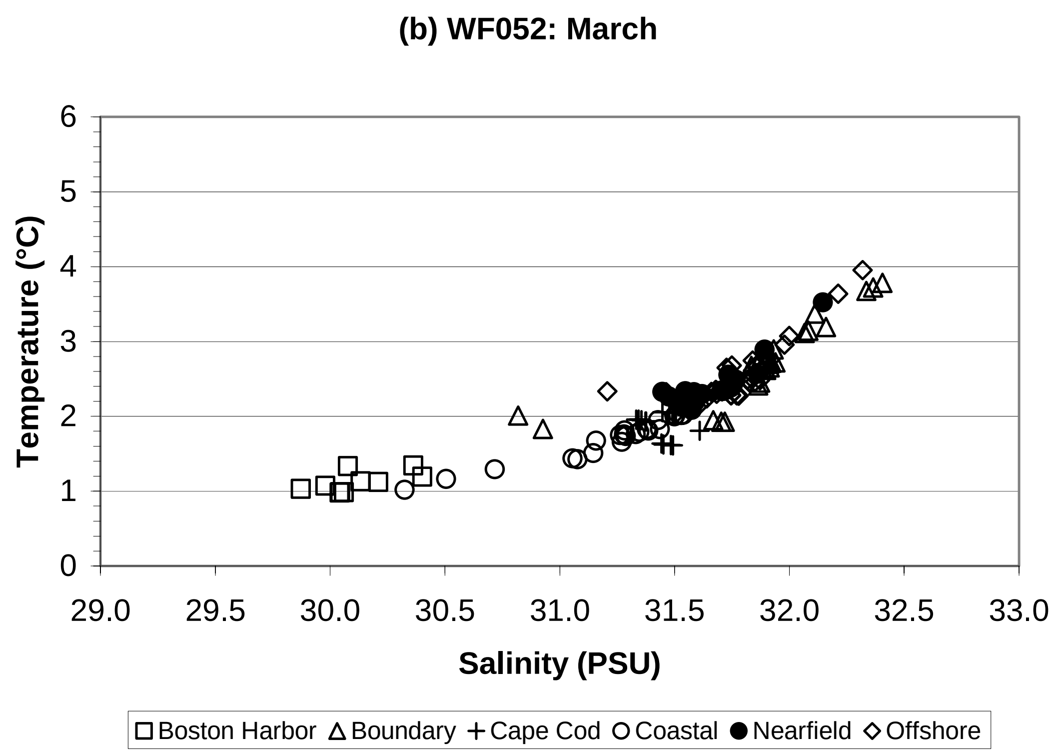
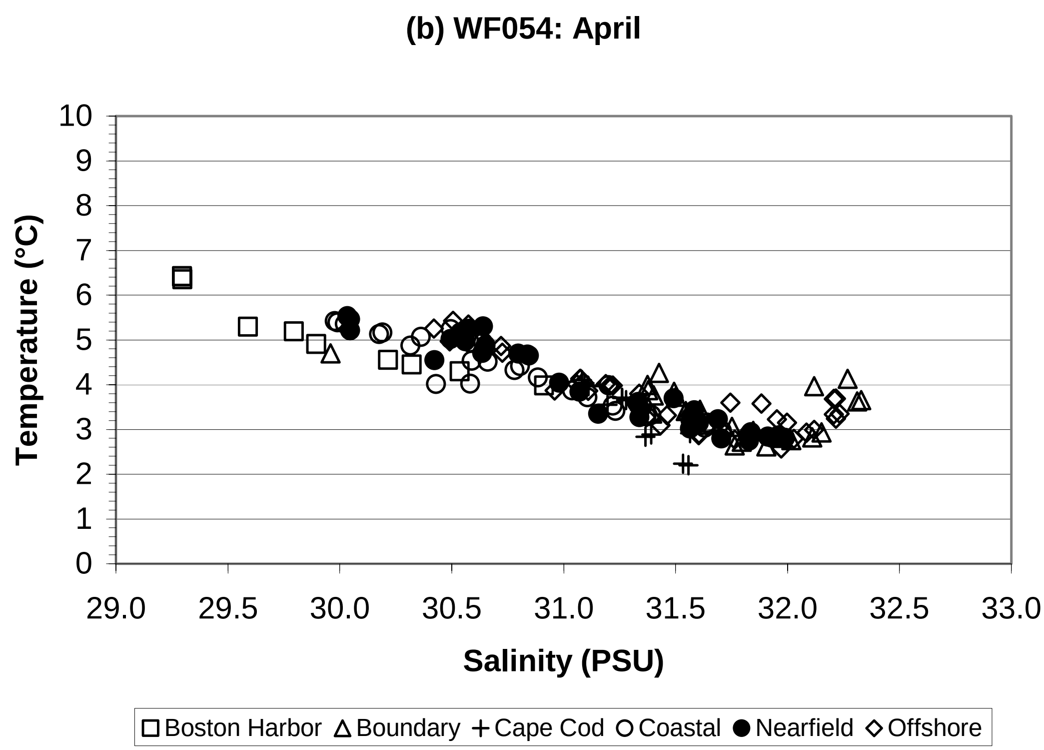


Figure 4-4. Temperature/salinity distribution for all depths during WF051 and WF052 (Feb 05) surveys



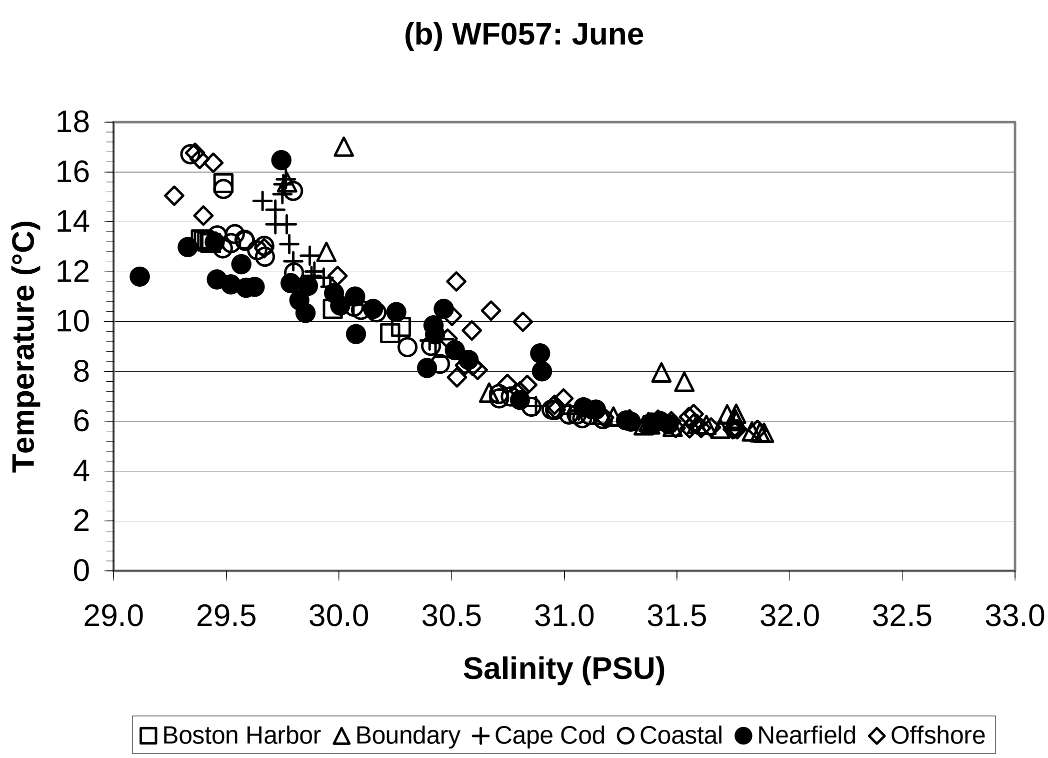


Figure 4-5. Temperature/salinity distribution for all depths during WF054 (Apr 05) and WF057 (Jun 05) surveys

Note: Scale for WF057 is different reflecting the higher temperature in June

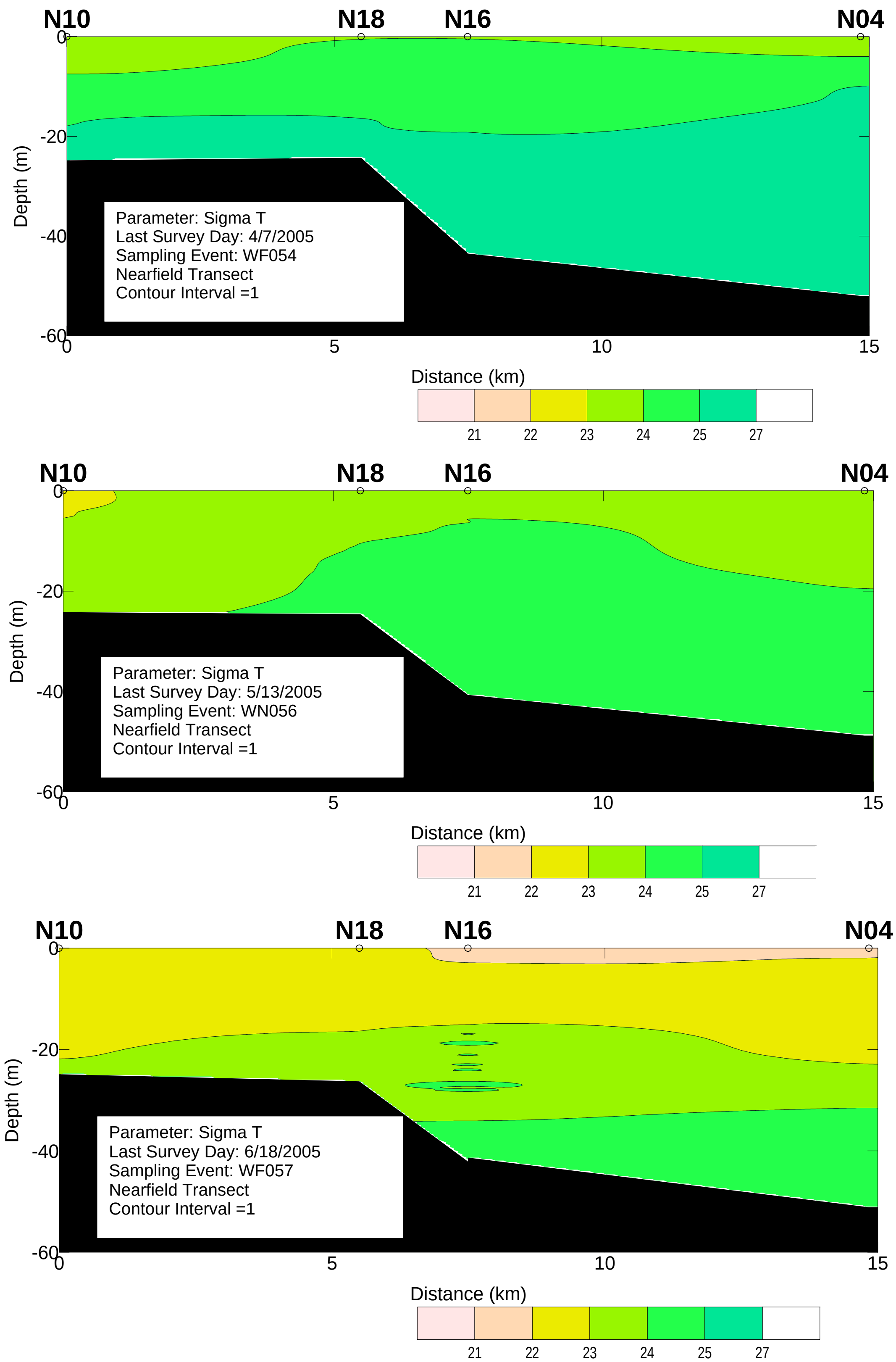


Figure 4-6. Density vertical contour plots across the nearfield transect for surveys WF054, WN056, and WF057

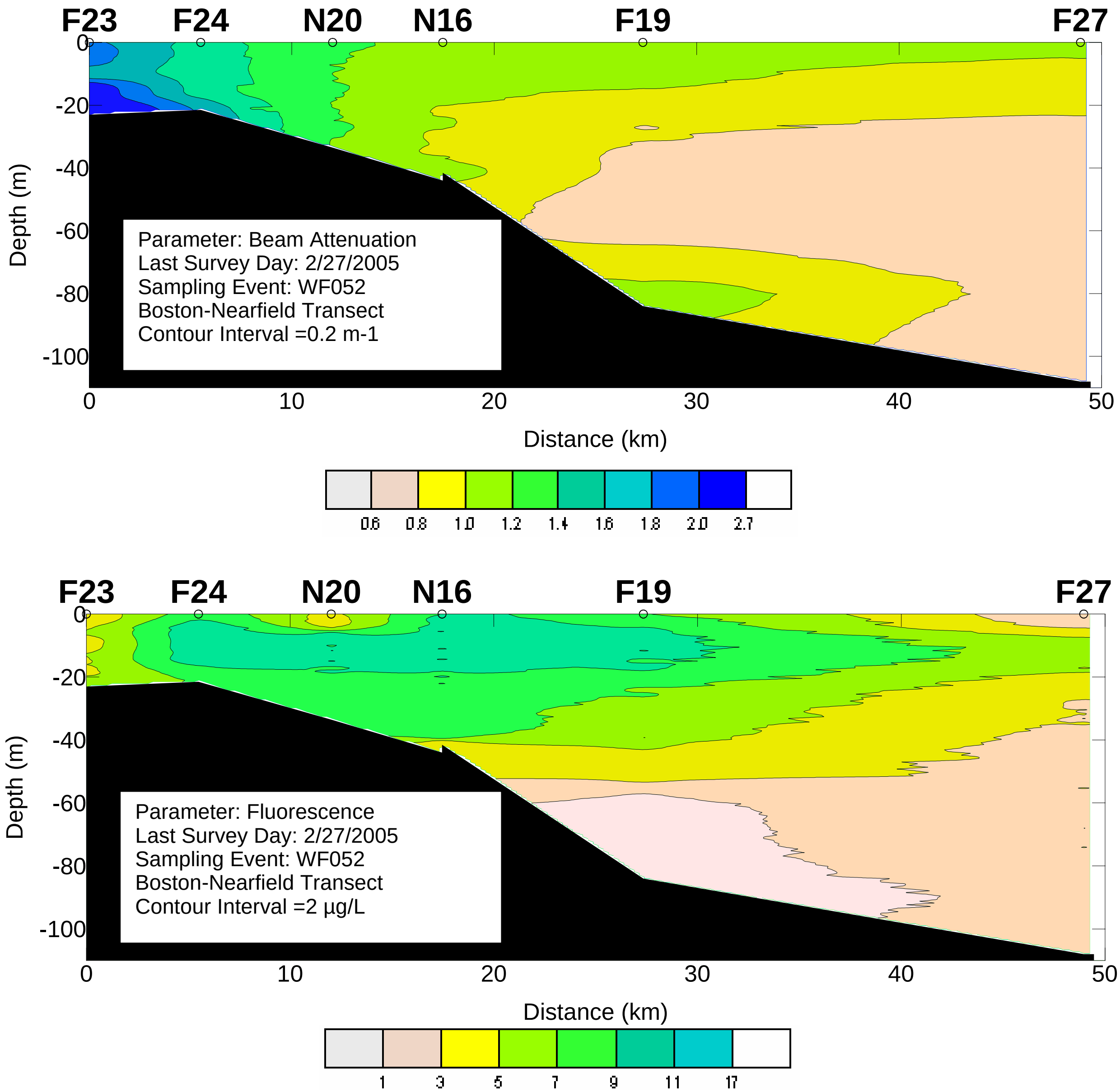
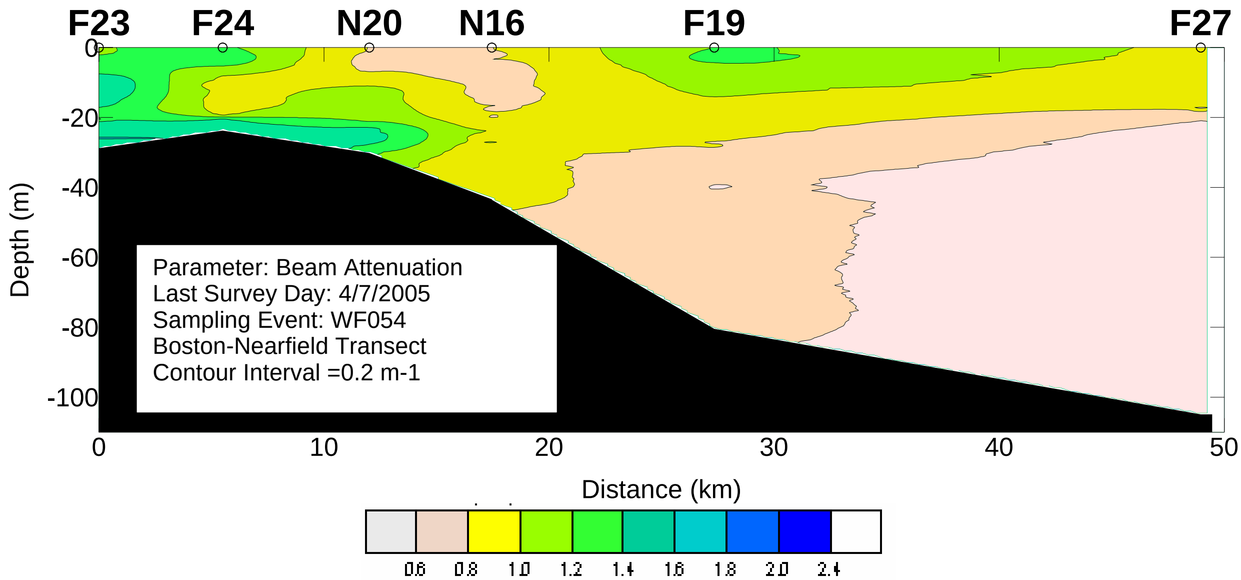


Figure 4-7. Beam attenuation and fluorescence vertical contour plots along the Boston-Nearfield transect for farfield survey WF052 (Late Feb 05)



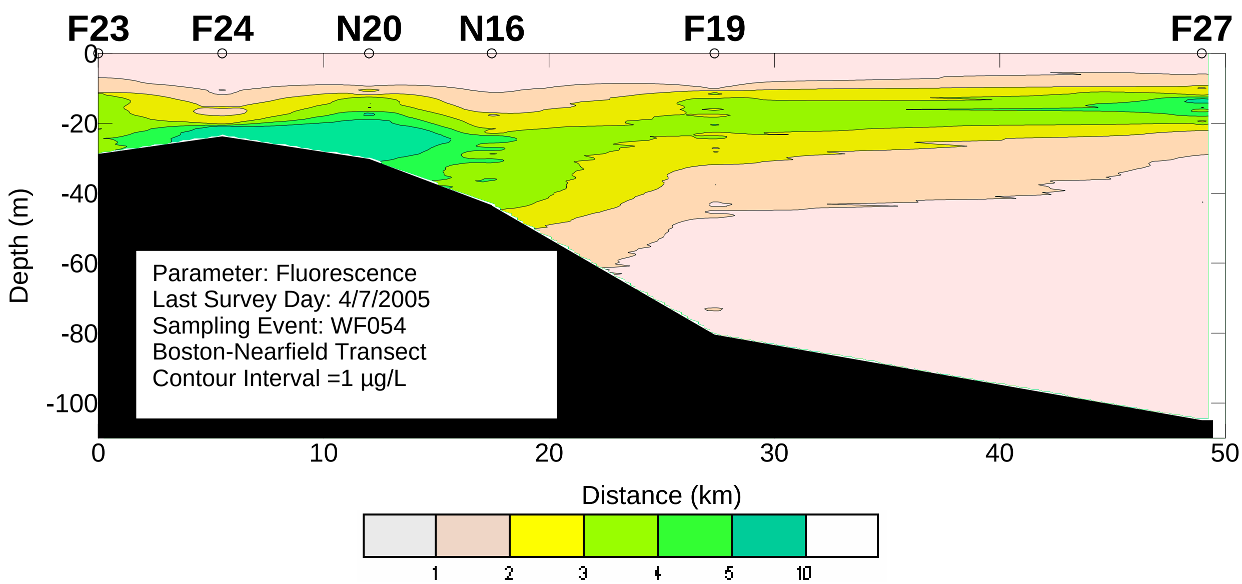


Figure 4-8. Beam attenuation and fluorescence vertical contour plots along the Boston-Nearfield transect for farfield survey WF054 (April 05)

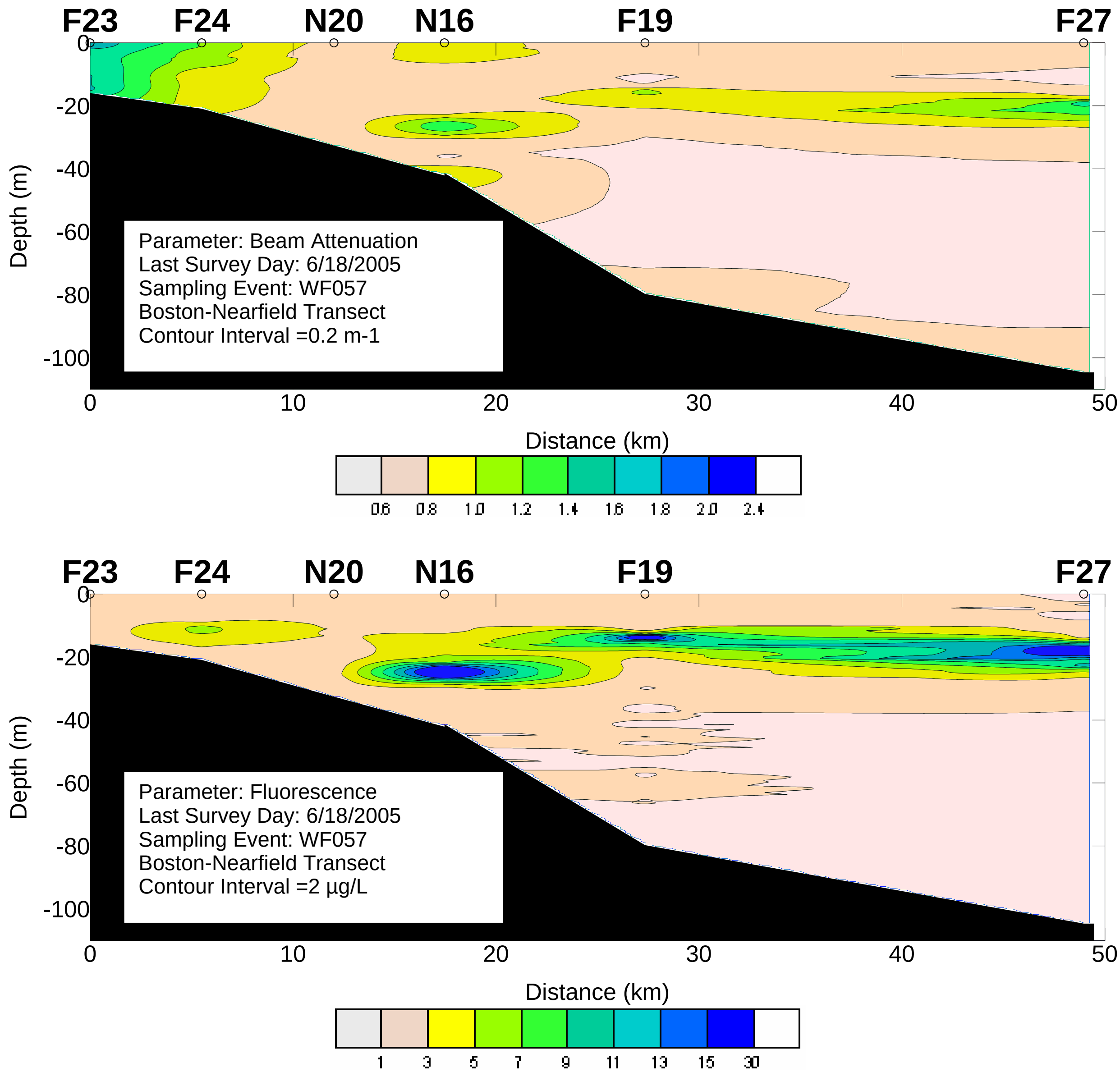


Figure 4-9. Beam attenuation and fluorescence vertical contour plots along the Boston-Nearfield transect for farfield survey WF057 (June 05)

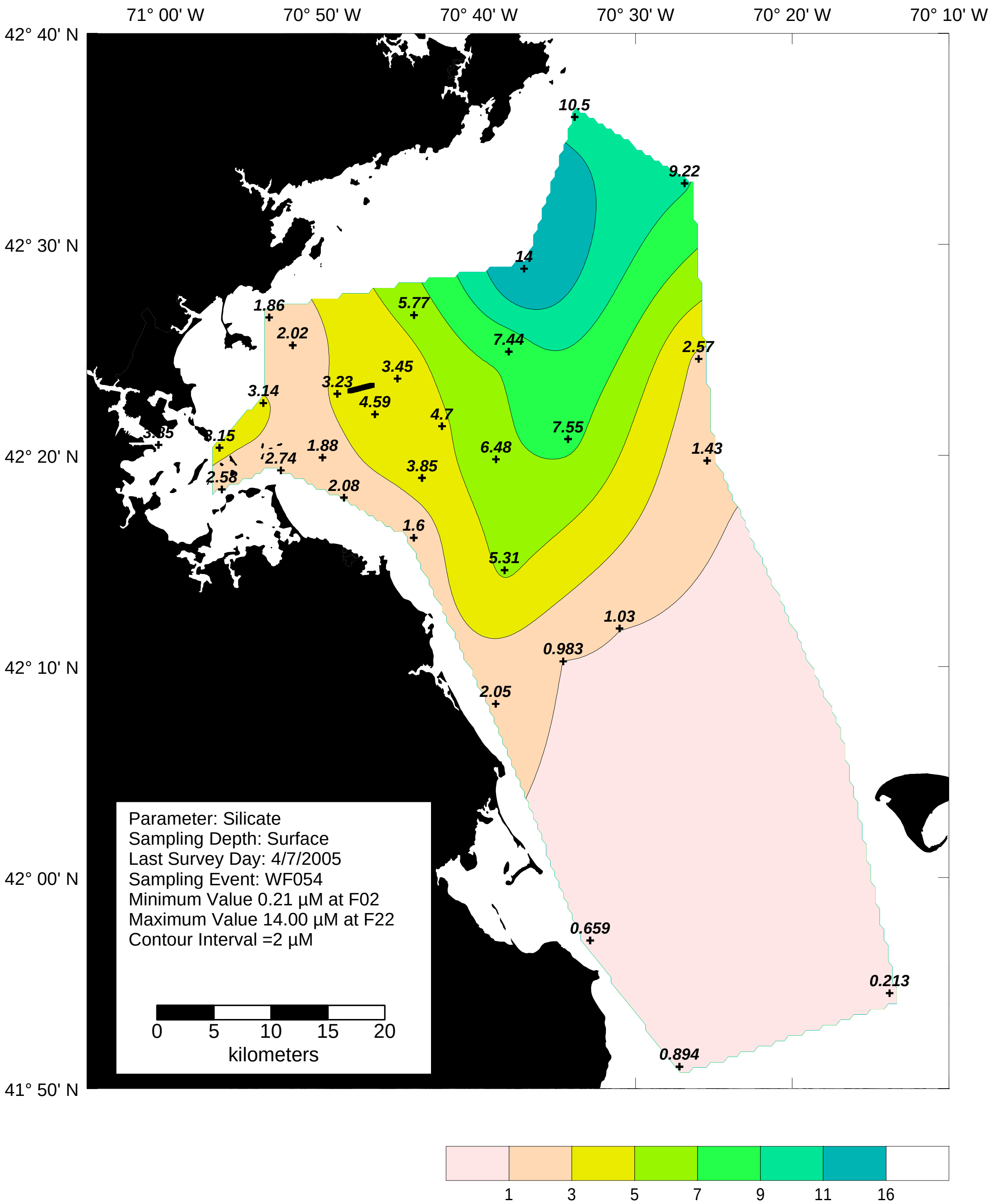


Figure 4-10. Silicate surface contour plot for farfield survey WF054 (Apr 05)

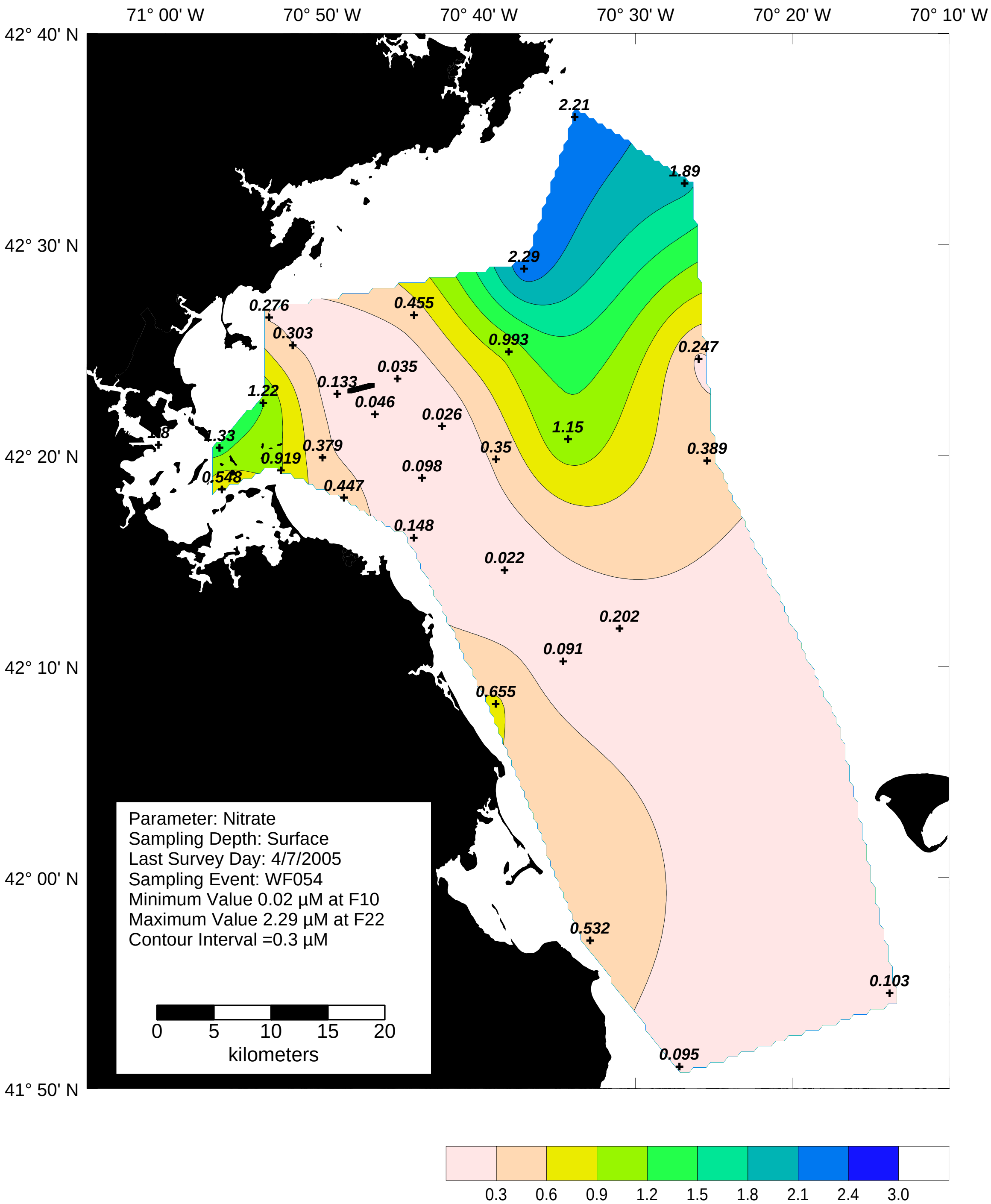


Figure 4-11. Nitrate surface contour plot for farfield survey WF054 (Apr 05)

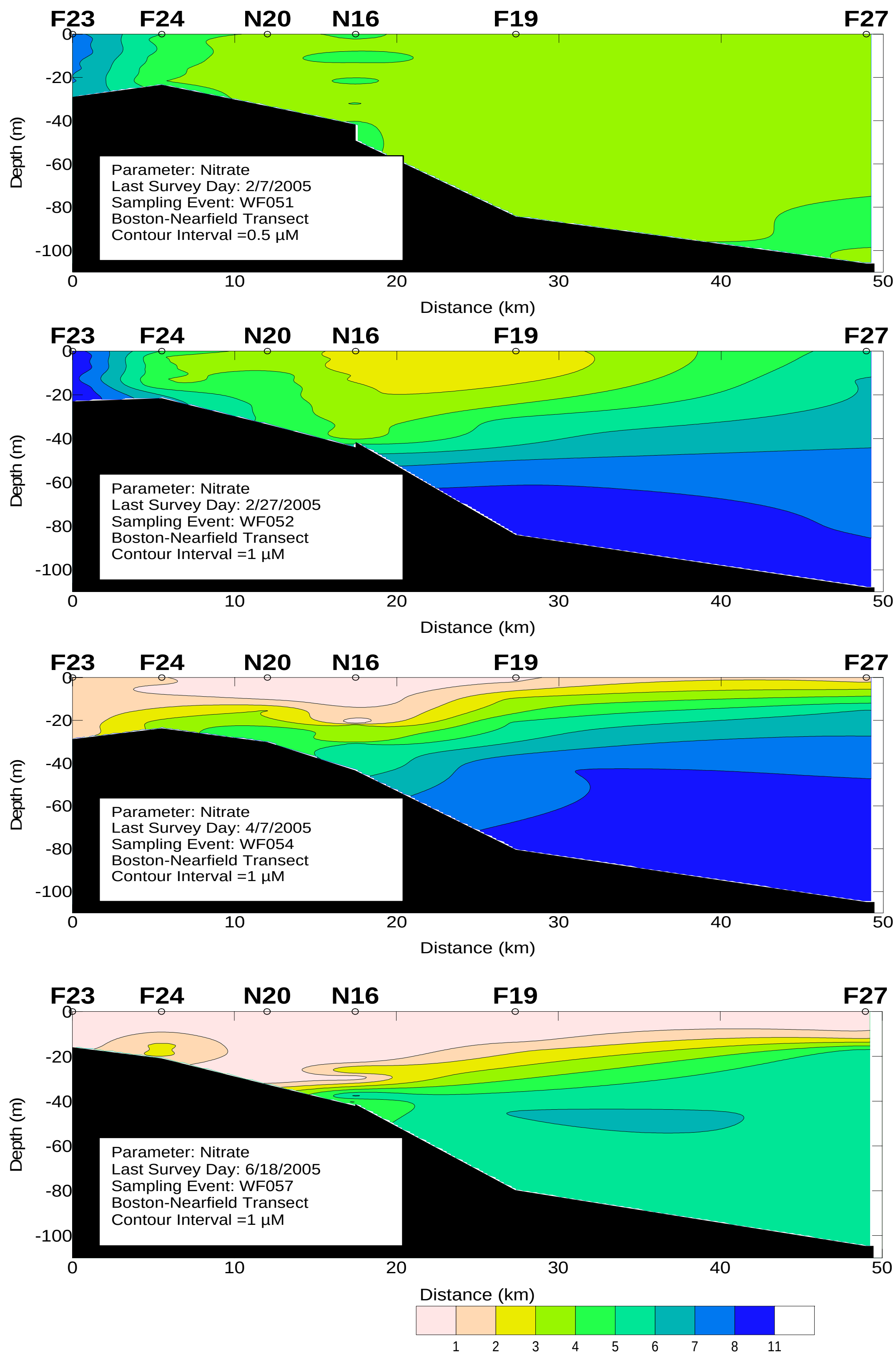
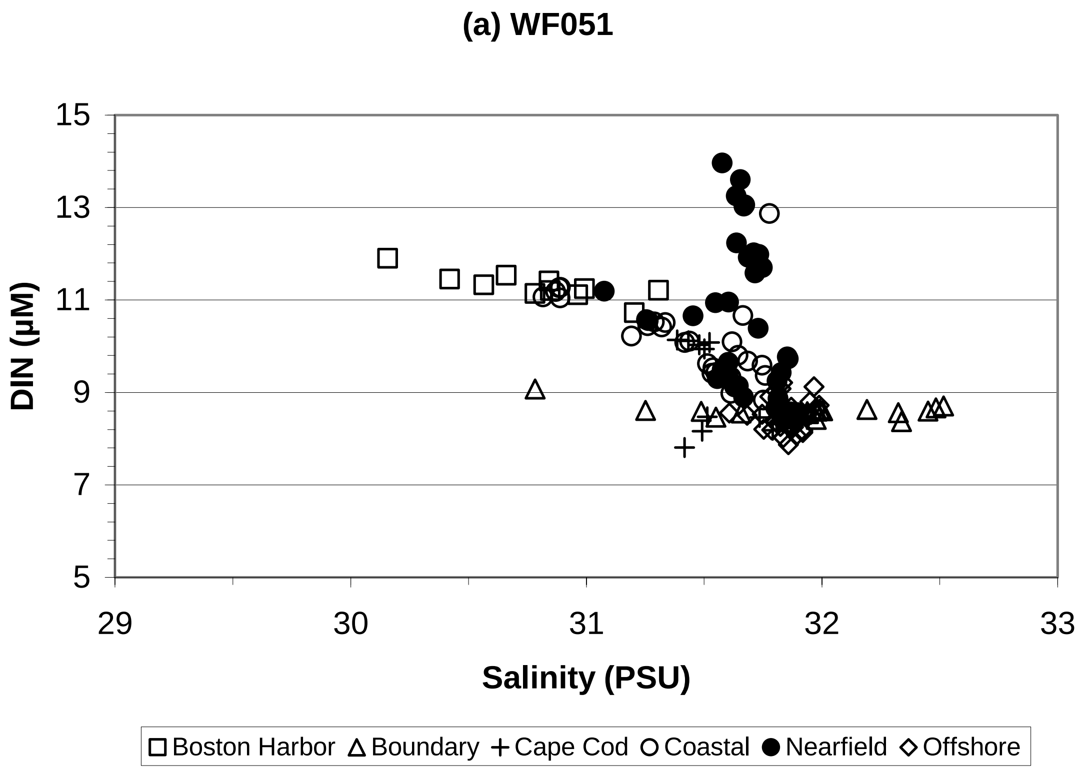


Figure 4-12. Nitrate vertical contour plots along the Boston-Nearfield transect for surveys WF051, WF052, WF054, and WF057



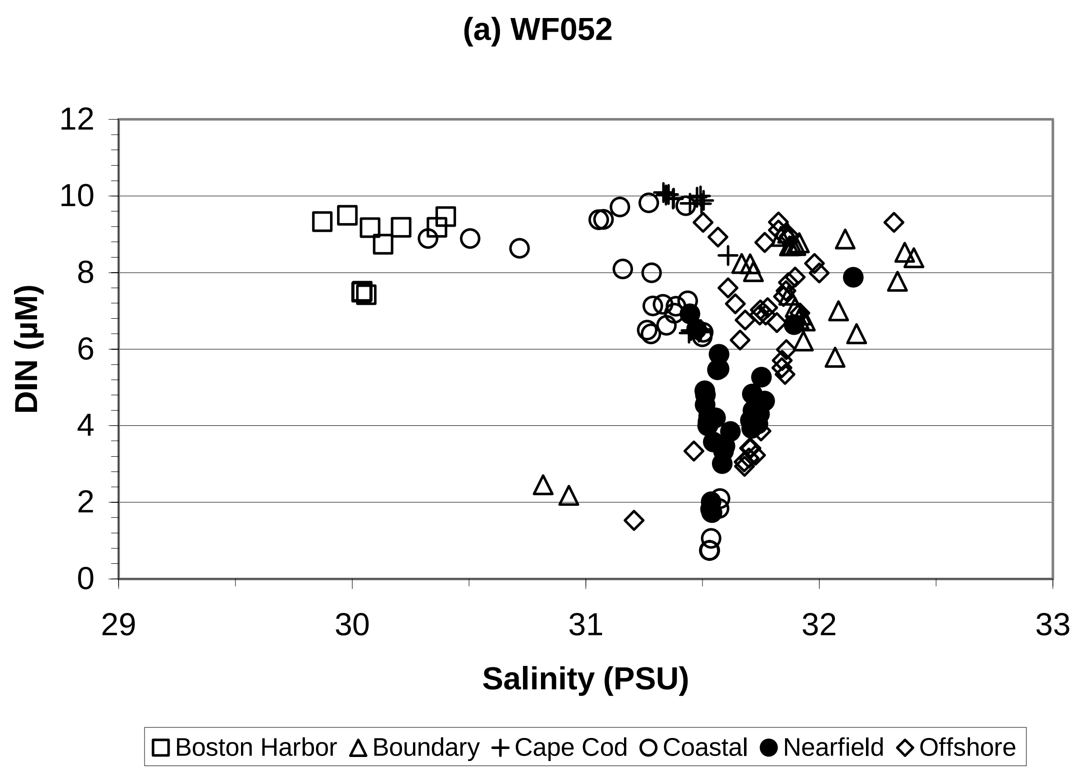
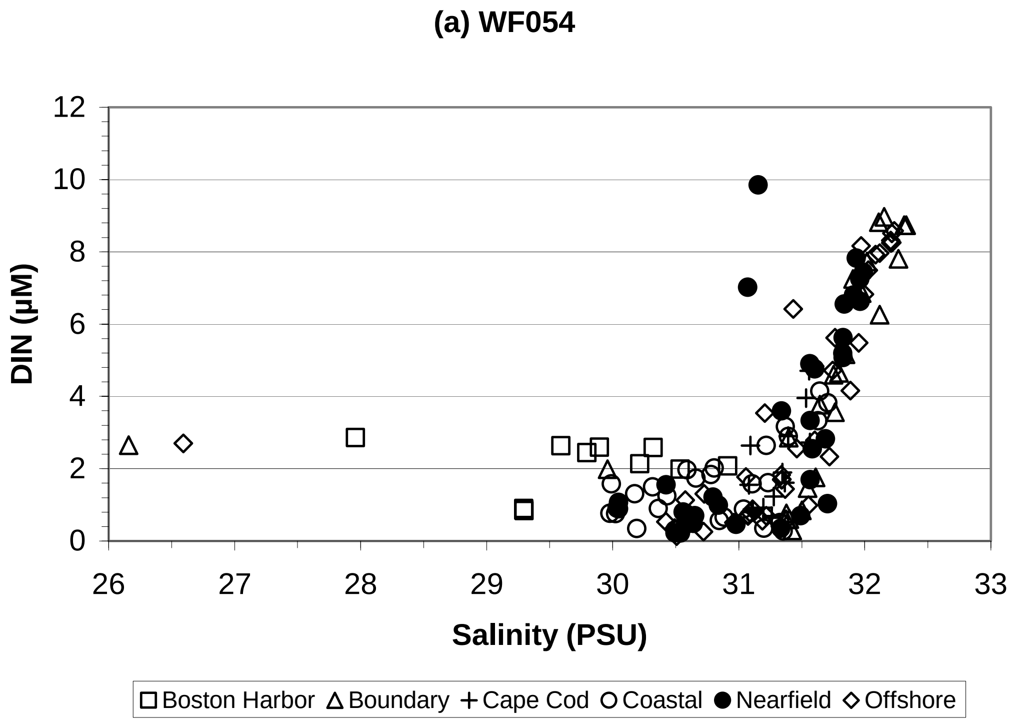


Figure 4-13. DIN vs. salinity for all depths during farfield surveys WF051 and WF052 (Feb 05)

Note scale changes.



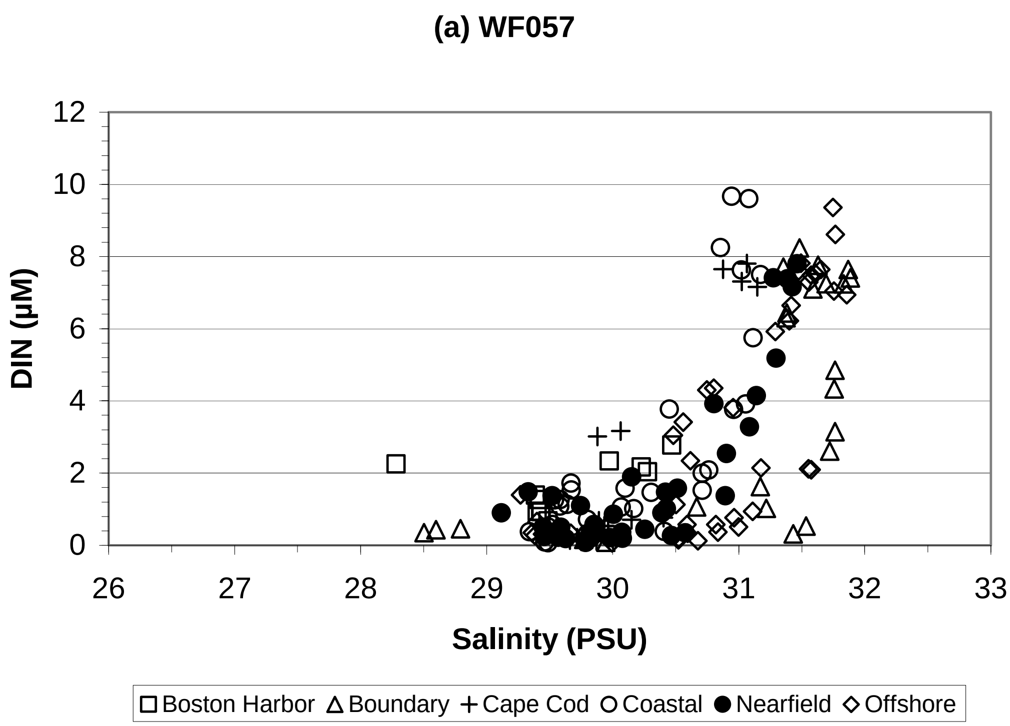


Figure 4-14. DIN vs. salinity for all depths during farfield surveys WF054 (Apr 05) and WF057 (Jun 05)

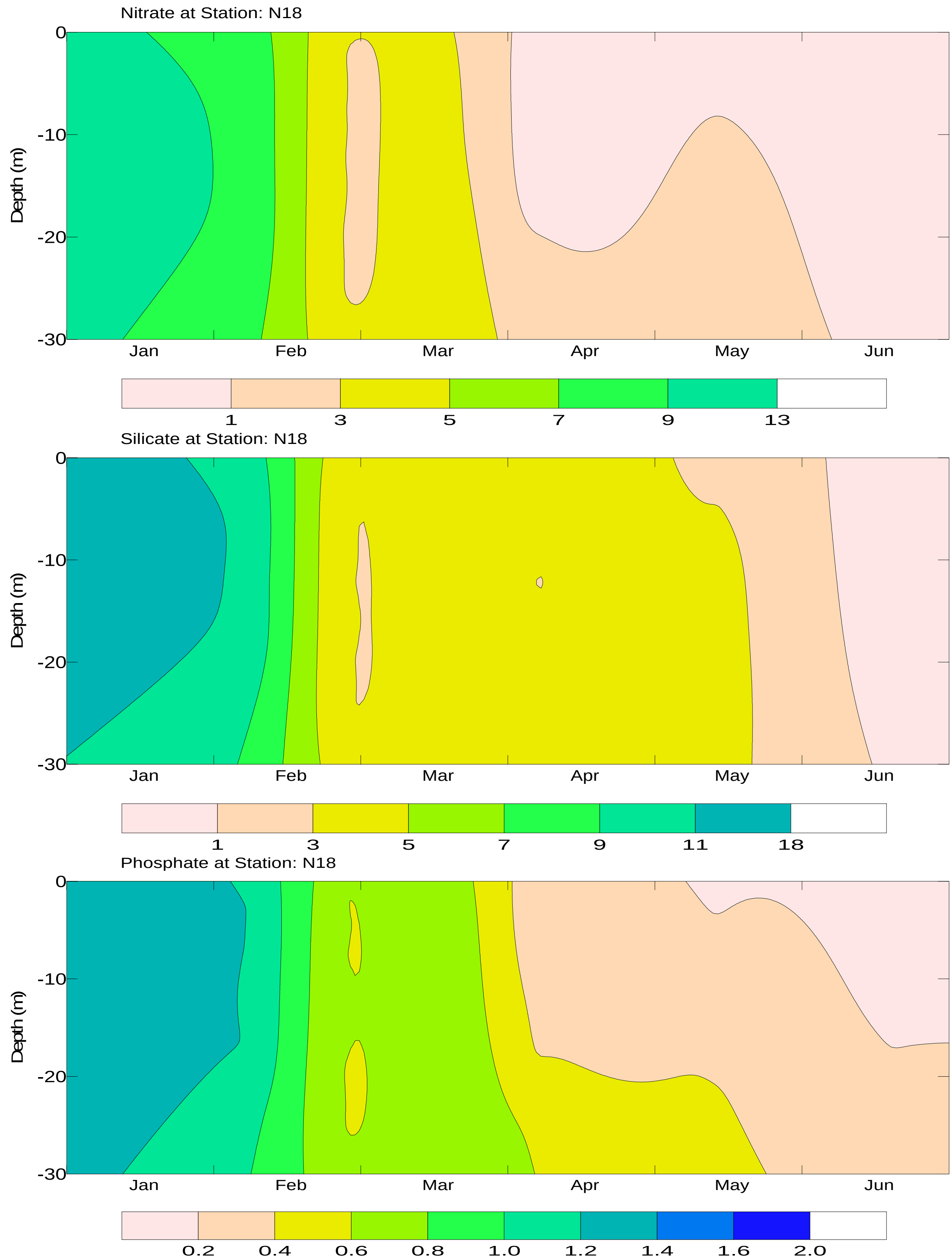


Figure 4-15. Station N18 depth vs. time contour plots of nitrate, silicate, and phosphate

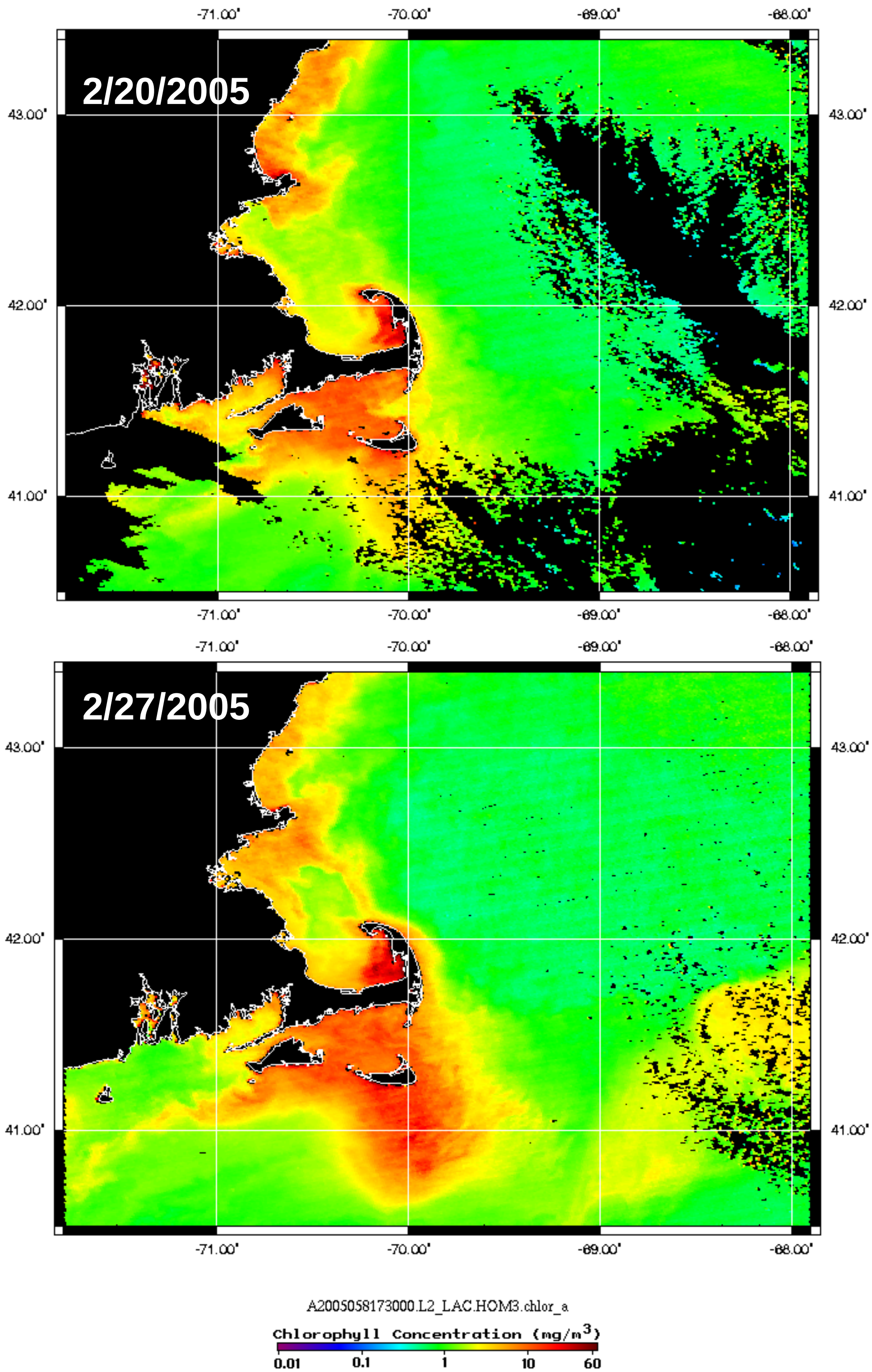


Figure 4-16. MODIS images of chlorophyll fluorescence for February 20 and 27, 2005

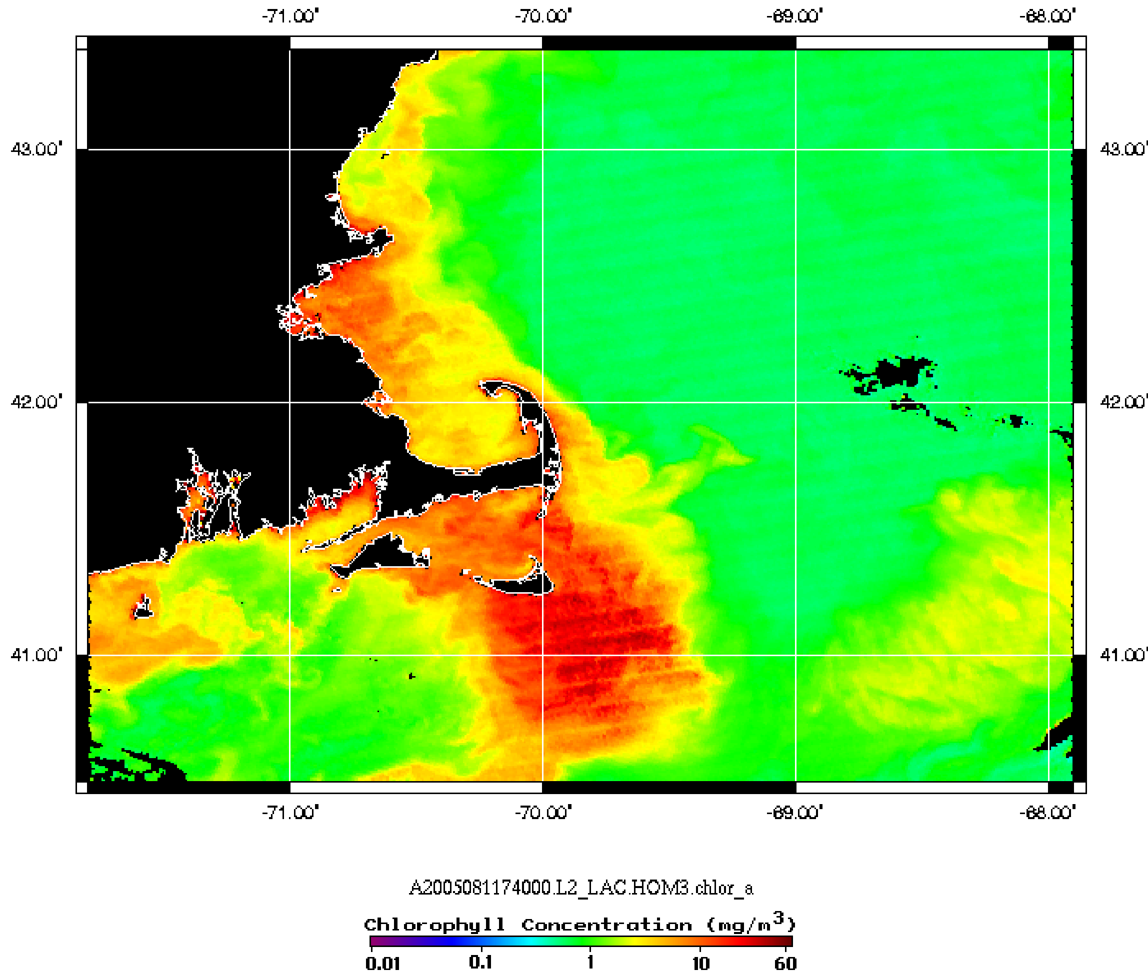


Figure 4-17. MODIS image of chlorophyll fluorescence for March 22, 2005

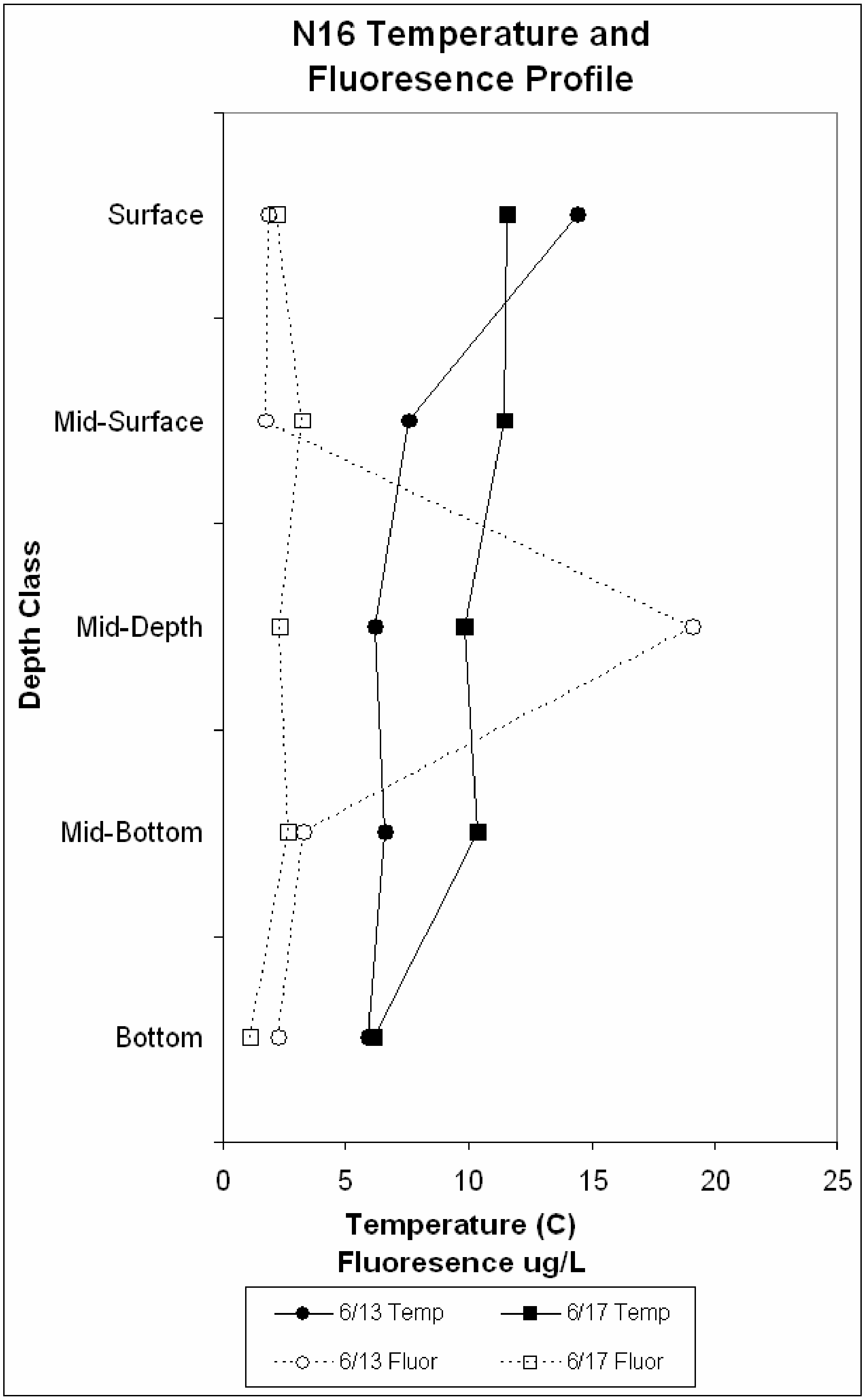


Figure 4-18. Temperature and fluorescence profiles from the nearfield and farfield sampling events during WF057/WN057

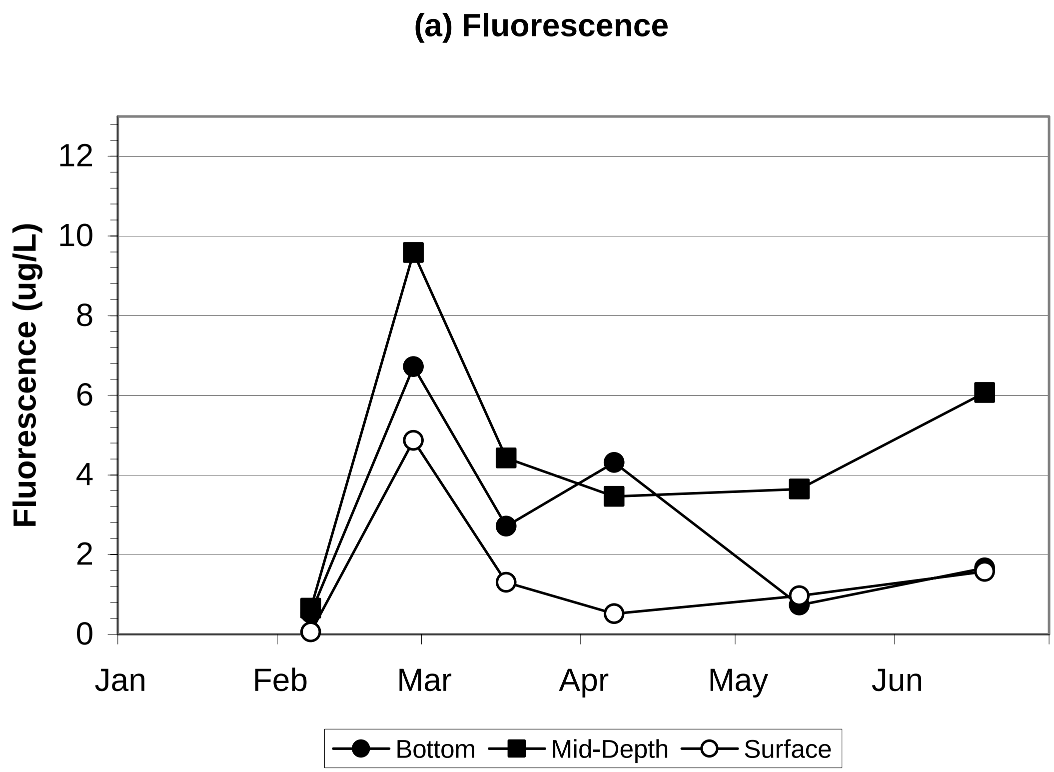


Figure 4-19. Time-series of bottom, mid-depth, and surface survey mean chlorophyll concentration in the nearfield

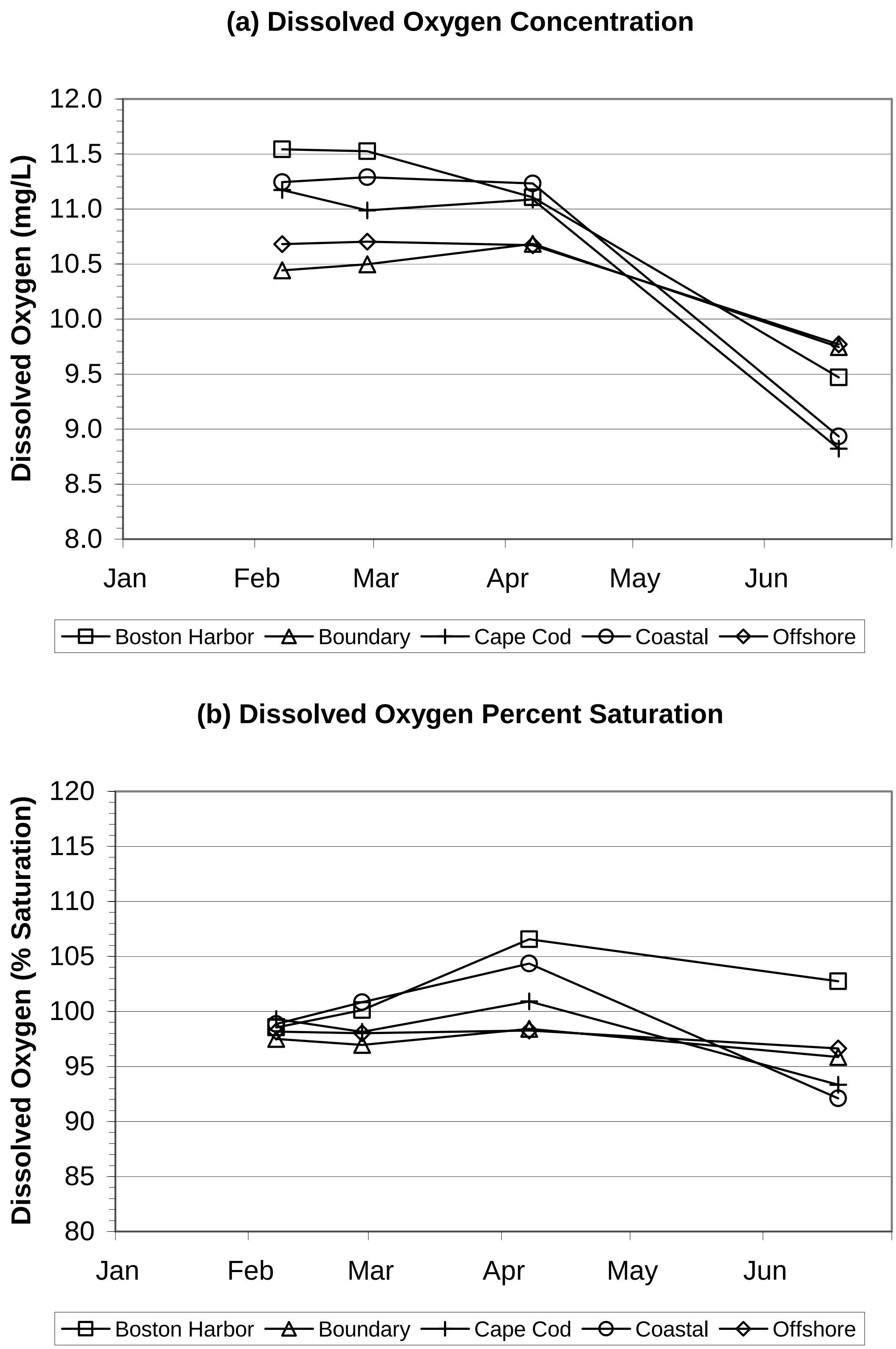
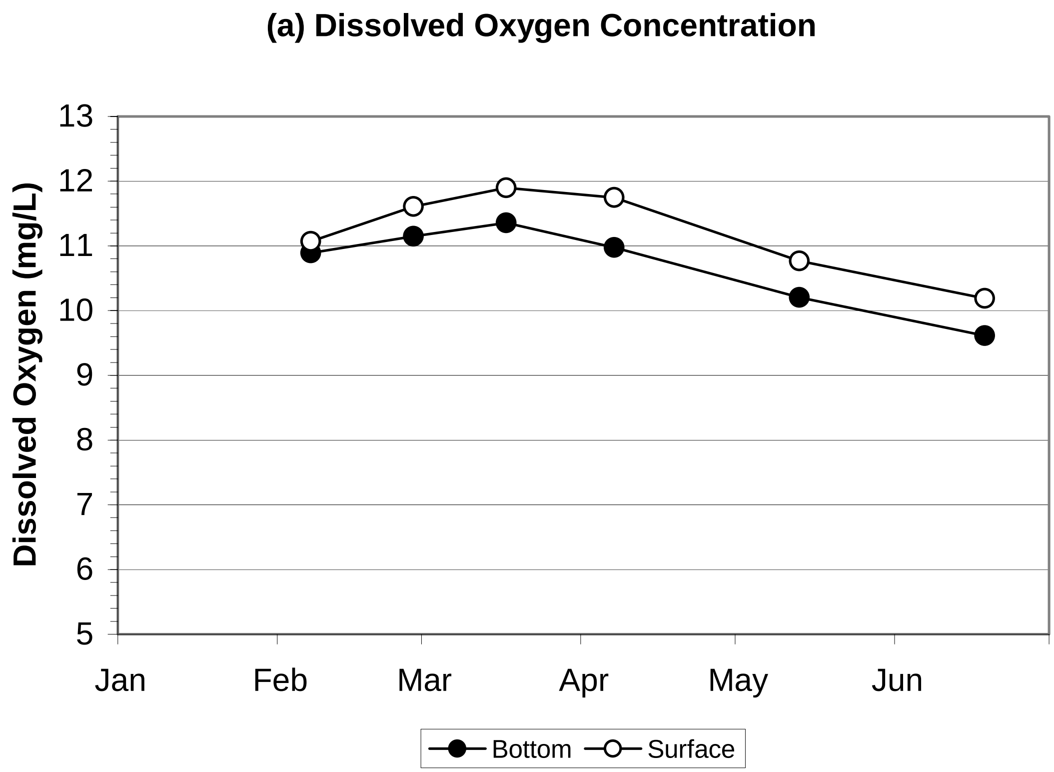


Figure 4-20. Time-series of bottom water average DO concentration and percentage saturation in Massachusetts and Cape Cod Bay



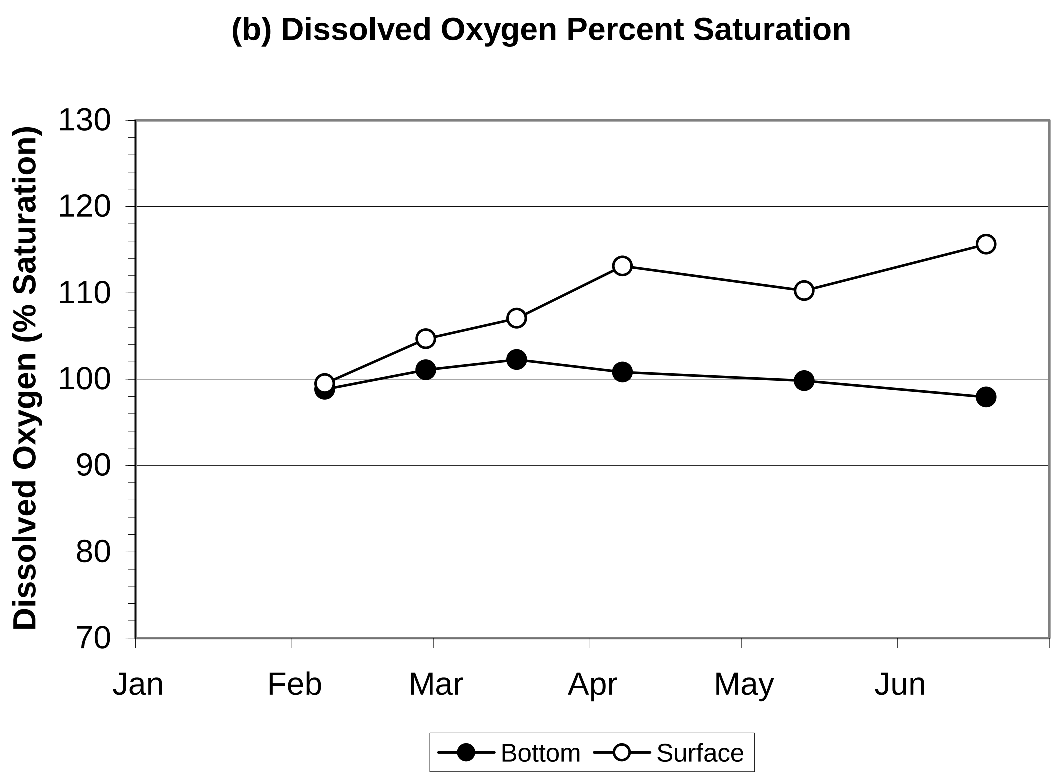


Figure 4-21. Time-series of average surface and bottom DO concentration and percentage saturation in the nearfield.

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 2 (WF051), February 27 (WF052), April 6 (WF054) and June 17 (WF057). Stations N04 and N18 were additionally sampled on March 17 (WN053) and May 13 (WN056). 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*. (2005).

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.

5.1.1 Areal Production

Areal production at the nearfield stations (N04 and N18) was similar throughout much of the semi-annual sampling period (**Figure** 5-2). Areal production at the two sites was low (~150 – 275 mg C m^{-2} d^{-1}) during the initial survey in February (WF051). Values increased to winter-spring bloom levels (1200 - 1400 mg C m^{-2} d^{-1}) at both sites by late February and remained elevated (>1100 g C m^{-2} d^{-1}) through mid-March. Areal productivity decreased to about 380 mg C m^{-2} d^{-1} in early-April (WF054) at station N18 while remaining somewhat higher (~650 mg C m^{-2} d^{-1}) at station N04. By mid-May (WN056) areal productivity was elevated again at both stations. Areal productivity decreased to ~850 mg C m^{-2} d^{-1} at station N18 during the survey in mid-June (WF057) but remained elevated (~1125 mg C m^{-2} d^{-1}) at station N04.

The timing and magnitude of the winter-spring bloom was similar at both stations. The maximum productivity at station N04 occurred in late February with a peak production of 1386 mg C m^{-2} d^{-1} while the late February value at N18 was lower (1220 mg C m^{-2} d^{-1}). These early spring peaks were both lower than peaks observed at the respective sites in 2004 (1403 – 2241 mg C m^{-2} d^{-1}) but close to those seen in 2003 (1230 –1618 mg C m^{-2} d^{-1}). At both sites the bloom extended over two consecutive sampling periods (late-February to mid-March) followed by a decline. The bloom included a mixture of phytoplankton including diatoms and *Phaeocystis* early on (WF052) and later developed into a *Phaeocystis* dominated bloom (WN053 and WN054) with virtually no diatom component. A secondary bloom in productivity was observed at both sites in mid-May. However during this sampling period the peak observed at station N04 (1490 mg C m^{-2} d^{-1}) was elevated relative to N18 (1275 mg C m^{-2} d^{-1}). The May productivity peak was coincident with an atypical post-*Phaeocystis* diatom bloom that likely resulted due to the increased nutrient inputs (especially SiO4) that resulted from early May storm events. The productivity rate observed at station N04 in May was the maximum value seen at this site during the semi-annual reporting period. The minimum production at both stations (N04 164 and N18 276 mg C m^{-2} d^{-1}) was observed in early February.

Areal productivity was elevated at station N04 relative to N18 during all of the surveys conducted thus far in 2005 (February through June). A similar pattern was observed in 2004. However, 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.

At the Boston Harbor station F23, areal production was less than areal production at both nearfield sites throughout much of the sampling period (**Figure** 5-2). During February and June areal productivity at F23 was less than that observed at both nearfield stations, while during the April sampling productivity at F23 was greater than the value recorded at station N18 but less than the value at N04. Maximum productivity at F23 did not occur at the same time as peak productivity at N04 and N18 and no productivity peak was observed at F23, despite elevated phytoplankton biomass during the winter-spring bloom period (**Figure** 5-3). Productivity was low (~45 mg C m^{-2} d^{-1}) during the initial February survey then increased to ~485 mg C m^{-2} d^{-1} by late February. Areal productivity then increased in early April to the seasonal peak level at station F23 (574 mg C m^{-2} d^{-1}). During the June survey areal production in the harbor decreased to ~333 mg C m^{-2} d^{-1}. The production data at station F23 were not always in agreement with the chlorophyll data throughout the semiannual period. The minimum chlorophyll level (mean 0.54 µg l^{-1}) observed at F23 during WF051 was associated with low productivity. However, elevated chlorophyll during WF052 (mean 4.27 µg l^{-1}) was associated with lower productivity compared with values observed during WF054 (mean 2.76 µg l^{-1}) when peak production occurred. During WF057 average chlorophyll decreased over the water column to 1.88µg l^{-1} concomittent with a decrease in areal productivity to 333 mg C m^{-2} d^{-1}.

Areal production at the nearfield sites in 2005 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 1995-2004 generally reached values of 1200 to 4500 mg C m^{-2} d^{-1}, with bimodal peaks often occurring in February - April. The bloom in 2005 reached maximum values at the nearfield sites of ~1500 mg C m^{-2} d^{-1} with peaks observed in February, March and May.

The winter-spring bloom peaks at both nearfield sites in 2005 were somewhat lower than values observed during the winter-spring period in 2004 but within the range observed in earlier years (1999 to 2003).

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 typically ranged from 2000 to 5000 mg C m^{-2} d^{-1} in June-July. Peak areal production values observed in 2001 - 2004 tended to be lower (1100 - 3200 mg C m^{-2} d^{-1}) and to occur earlier in the season. The peak productivity level observed in Boston Harbor thus far in 2005 is lower than those seen in all other years.

5.1.2 Depth-Averaged Chlorophyll-Specific Production

Depth-averaged chlorophyll-specific potential production values were similar at both stations (~9 - 12 mg C mg Chl a^{-1} d^{-1}) in early February then decreased at both sites (4 - 5 mg C mg Chl a^{-1} d^{-1}) in late February (**Figure** 5-3). Values increased in March to 19 mg C mg Chl a^{-1} d^{-1} at station N18 and 9 mg C mg Chl a^{-1} d^{-1} at station N04. During April values ranged from 8.6 to 12.9 mg C mg Chl a^{-1} d^{-1} at the nearfield sites. Increases to ~22 mg C mg Chl a^{-1} d^{-1} were observed in May and June at N18, while values at N04 remained close to 9 mg C mg Chl a^{-1} d^{-1}. Throughout the seasonal period depth-averaged chlorophyll-specific potential tended to be greater at station N18 relative to N04. Peak depth-averaged chlorophyll-specific potential production (~22 mg C mg Chl a^{-1} d^{-1}) occurred during mid-May at station N18 while the seasonal minimum (~4 - 5 mg C mg Chl a^{-1} d^{-1}) was observed at both stations during late February. At station N04, the season peak of 9.2 mg C mg Chl a^{-1} d^{-1} occurred in June. By comparison depth-averaged chlorophyll-specific rates at harbor station F23 tended to increase gradually from a seasonal minimum of 3.6 mg C mg Chl a^{-1} d^{-1} in early February to 11.0 mg C mg Chl a^{-1} d^{-1} in early April; **Figure** 5-3). A slight increase in depth-averaged chlorophyll-specific potential to the seasonal maximum of 11.9 mg C mg Chl a^{-1} d^{-1} 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.

Depth-specific production at the nearfield sites was similar throughout the semiannual sampling period. These similarities are illustrated by the increasing productivity from early February to late February at both sites and the concentration of elevated levels of productivity in the upper portion of the water column **Figures** 5-4a and 5-4b. The areal productivity peaks observed during late February and March 2005 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 in the surface water during the winter-spring bloom period in late February (124 mg C m^{-3} d^{-1}) and mid-March (76 mg C m^{-3} d^{-1}). In April, the highest potential productivity occurred at mid-surface depth (49 mg C m^{-3} d^{-1}). Unlike most prior years, the peak bloom period at station N04 was not characterized by a subsurface productivity maximum. Depth-specific potential production at station N18 followed a similar pattern. Potential production was highest in the surface water in late February (110 mg C m^{-3} d^{-1}) and mid-March (75 mg C m^{-3} d^{-1}) but highest at the mid-water depth in April (39 mg C m^{-3} d^{-1}). At both nearfield stations potential productivity increased in mid-May and remained elevated in June with the maximum productivity for the current reporting period observed at both sites in the surface waters in May (150 mg C m^{-3} d^{-1} at station N04 and 140 mg C m^{-3} d^{-1} at station N18).

The depth-specific potential productivity recorded at the harbor station F23 differed from the pattern observed at the nearfield sites (**Figure** 5-4c). Potential productivity increased at station F23 from February through April and then declined. A surface productivity maximum (68 mg C m^{-3} d^{-1}) was observed in late February with a sub-surface productivity maximum (56 mg C m^{-3} d^{-1}) observed at mid-surface depth in April. Although surface productivity in early April was less than the surface value in late February, mid-surface values were greater. Unlike the nearfield sites there was no increase in depth-specific productivity at the harbor station in June although productivity systematically decreased from the surface water to the bottom depths at all three sites during the June sample period.

The productivity pattern observed in 2005 at specified depths was similar to that observed in prior years, although the magnitude was less. At station N04 potential productivity as high as 25 mg C m^{-3} d^{-1} occurred to depths of 14 m; during prior years productivity as great as 45 mg C m^{-3} d^{-1} occurred at depths greater than 25 m. At station N18 potential productivity >28 mg C m^{-3} d^{-1} was not observed at depths >17 m. As in most prior years, elevated productivity (>50 mg C m^{-3} d^{-1}) in the harbor was 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 periods at stations N04 and N18 (**Figure** 5-5). At both nearfield sites, chlorophyll concentrations were elevated throughout much of the water column during the winter-spring bloom period. In mid-March the maxima at both stations occurred at the mid-surface depth. A deep sub-surface chlorophyll maximum was additionally observed at station N04 in June. In all cases the elevated sub-surface chlorophyll *a* concentrations were not reflected in higher potential production suggesting a decrease in the efficiency of production at depth. At station N04, chlorophyll concentrations as great as 5.1 mg m^{-3} were observed at depths as great as 36 m. At station F23, chlorophyll concentrations were highest during the winter period of elevated productivity and characterized by sub-surface chlorophyll maxima in the mid-water depths from February through April. The subsurface chlorophyll maxima were not associated subsurface productivity peaks. Within the harbor, depth-specific biomass decreased in June and tended to be uniform with depth (**Figure** 5-5c).

Chlorophyll-specific potential production at depth followed similar seasonal patterns at stations N04 and N18 (**Figure** 5-6). Chlorophyll-specific production tended to increase over time and decrease with depth. At the nearfield sites, moderate levels of chlorophyll-specific potential production occurred throughout the upper 20-25 m of the water column and then decreased with depth. Values were somewhat elevated in mid-March, coinciding with the secondary winter-spring bloom peak at the nearfield sites. As the season progressed elevated chlorophyll-specific production tended to be concentrated in the upper levels of the water column. At station N04, values increased to a maximum (40 mg C mg chl a^{-1} d^{-1}) at surface depths during May. A similar trend was observed at station N18 where a seasonal maximum of 68 mg C mg chl a^{-1} d^{-1} also occurred in surface water during May. The moderate levels of chlorophyll-specific potential production observed in March and May were not associated with increased phytoplankton biomass as measured by chlorophyll *a* (**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 from February through April, then declined in June (**Figure** 5-6c). Throughout the seasonal cycle chlorophyll-specific production decreased with depth. At the harbor station chlorophyll-specific production levels during the February bloom period were similar to the levels seen at the nearfield sites but were confined to the upper 5 m rather than extending into the 20 – 25 m range.

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 low during the first half of 2005. During the surveys conducted in February, March and April, respiration rates were low in both the nearfield and farfield areas (<0.10 μMO_2hr^{-1}; **Figures** 5-7 and 5-8). The apparently 'high' respiration rate for the bottom waters at station F19 in early February are discounted as this value represents the MDL for that set of measurements as the data are qualified as "a" (not detected or negative). Respiration rates increased at each station from early to late February coincident with increasing production and biomass as indicated by both Chlorophyll (**Figure** 5-3) and POC concentrations (**Figures** 5-9 and 5-10). Respiration peaked during the late February survey at the Boston Harbor station with rates of ~0.1 μMO_2hr^{-1} at each depth. From February to April, respiration rates tended to decrease along with the production rates even though the *Phaeocystis* bloom continued. Nearfield respiration rates increased to period maxima by the May survey in conjunction with a second peak in production and POC that occurred during the atypically late diatom bloom. Nearfield surface and mid-depth water rates reached levels of 0.12-0.17 μMO_2hr^{-1} in May. By June, the nearfield respiration rates had decreased to 0.03 to 0.08 μMO_2hr^{-1}. Respiration rates at the Boston Harbor station F23 were comparably low (0.06-0.08 μMO_2hr^{-1}), but at the offshore station F19 rates in the surface and mid-depth waters increased to 0.15 μMO_2hr^{-1} in June. These June values were the maximum farfield respiration rates for the February to June 2005 time period.

The respiration rates in the winter/spring of 2005 followed trends observed from February to April in POC (**Figures** 5-9 and 5-10) and chlorophyll concentrations (see **Figure** 3 and section 4.3.3). The large increases in POC and chlorophyll associated with the diatom bloom and onset of the *Phaeocystis* bloom that were observed in the nearfield and offshore at station F19 in late February were coincident with the trend of increasing respiration rates. By March and April, POC levels had decreased as did respiration rates and subsequently in May (nearfield) and June (station F19) coincident increases were observed in both parameters. Both respiration rates and POC concentration were less variable in Boston Harbor during this time period, though both peaked during the late February bloom. 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 ($R^2 = 0.38$) than temperature ($R^2 = 0.16$). The relationships between respiration and POC, however, was not significant, while the respiration versus temperature regression in winter/spring 2005 was 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 have 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 ($\leq$0.005 $\mu MO_2 \mu MC^{-1} hr^{-1}$) in the nearfield from early February to June (**Figure** 5-12). Carbon-specific rates 'peaked' in the nearfield during the May survey at 0.004 to 0.005 $\mu MO_2 \mu MC^{-1} hr^{-1}$. At station F23, carbon-specific respiration rates remained even lower ($\leq$0.003 $\mu MO_2 \mu MC^{-1} hr^{-1}$) from February to June (**Figure** 5-13). At offshore station F19, there was more variability in these rates with a relatively high value in the bottom waters in early February due to the use of the MDL for respiration. Otherwise, station F19 exhibited a steady increase in carbon-specific respiration rates from February to June when the maximum rates for the time period were measured in the surface waters (0.006 $\mu MO_2 \mu MC^{-1} hr^{-1}$). Overall, respiration rates were relatively low during the first half of 2005 and tended to increase with increasing POC (and chlorophyll) concentrations during the diatom blooms 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 (WF051, WF052, and WF054). 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*. (2005).

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 abundance and relative abundance for all dominant plankton taxa (>5% of total 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 0.39-1.56 x 10^6 cells L^{-1} in February (WF051 and WF052) and March (WN053), increasing to levels of 1.19-3.48 x 10^6 cells L^{-1} in April (WF054) during the spring bloom of *Phaeocystis pouchetii*. Levels declined to 0.76-1.23 x 10^6 cells L^{-1} in May (WN056) after the *Phaeocystis* bloom, and total abundances remained in a similar range of 0.80-1.69 x 10^6 cells L^{-1} by mid-June (WF047).

Total phytoplankton abundance in farfield whole water samples increased by approximately 50% from early to late February in most of the regions (**Table** 5-1; **Figures** 5-16 and 5-17). By April during the *Phaeocystis* bloom, farfield abundances had increased to 0.43-5.43 x 10^6 cells L^{-1} with elevated abundances observed at mid-depth, especially in the northern offshore and boundary stations. (**Figure** 5-18). By June, phytoplankton abundances had declined to levels of 0.59 - 1.93 x 10^6 cells L^{-1}, with fairly well distributed abundance levels throughout the regions (**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 175 - 4151 cells L^{-1} from February through April (**Table** 5-2), but increased to 344-9484 cells L^{-1} in June during the 2005 *Alexandrium* red tide.

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

Survey	Dates (2005)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF051	2/1-2/7	0.64	0.39-0.97	0.75	0.54-1.19
WF052	2/23-2/27	1.19	0.94-1.56	1.18	0.8-1.69
WN053	3/17	1.05	0.85-1.36	–	–
WF054	4/4-4/7	2.20	1.19-3.48	2.02	0.43-5.43
WN056	5/13	1.07	0.76-1.23	–	–
WF057	6/13-6/18	1.29	0.80-1.69	1.26	0.59-1.93

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

Survey	Dates (2005)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF051	2/1-2/7	414	281-637	451	257-816
WF052	2/23-2/27	2146	873-4151	776	236-2911
WN053	3/17	512	325-741	–	–
WF054	4/4-4/7	415	199-633	353	175-565
WN056	5/13	2625	481-5032	–	–
WF057	6/13-6/18	5523	2111-9484	1824	344-4680

5.3.1.2 Nearfield Phytoplankton Community Structure

Whole-Water Phytoplankton – In early February, nearfield whole-water phytoplankton assemblages from both depths were dominated by unidentified microflagellates <10 µm in diameter (80-94% of cells counted) and cryptomonads <10 µm in diameter (up to 17%). By late February, microflagellate dominance had declined to 49-64%, and cryptomonads comprised only up to 7% of abundance. By this time the spring bloom of *Phaeocystis pouchetii* was just beginning and this species represented up to 15% of the phytoplankton assemblage (marked as "Other" in **Figures** 5-14 and 5-15). Diatoms also provided a considerable contribution to the community in late February including *Thalassiosira nordenskioldii* (5-25%) and an unidentified species of *Thalassiosira* that was 10-20 µm in diameter (up to 19%). In March, *Phaeocystis* was even more dominant (28-44%) with microflagellates making up most of the rest of the community (40-50%). Also, cryptomonads comprised up to 7% of abundance, and the diatom *Chaetoceros socialis* comprised up to 17% at some stations. In April, the *Phaeocystis* bloom was at its peak (24-77%) and diatoms were virtually absent with subdominance by microflagellates (16-55%), and lesser contributions by cryptomonads (up to 10%) and the dinoflagellate *Heterocapsa rotundata* (6-14%). By May the *Phaeocystis* bloom was over, with dominance by microflagellates (50-76%), cryptomonads (up to 9%), and the diatom *Chaetoceros debilis* (8-17%). In June, microflagellates were dominant (49-69%), with lesser contributions by cryptomonads (up to 17%). There was also a rebound in diatom abundance in June (up to 43% of the total community) with various diatom species contributing to the total, including *Chaetoceros debilis* (up to 7%), an unidentified species of *Chaetoceros* 10-30 µm in diameter (up to 8%), *Thalassiosira rotula* (up to 16%), *Thalassionema nitzschoides* (up to 6%). An unidentified species of the dinoflagellate genus *Gymnodinium* (up to 6%) was also present.

Screened Phytoplankton – In early February (WF051), nearfield screened samples consisted of a mixed assemblage that included the silicoflagellate *Distephanus speculum* (up to 26% of cells recorded), tintinnids (6-35%), aloricate ciliates (up to 17%), the photosynthetic ciliate *Mesodinium rubrum* (up to 6%), and a mixture of thecate dinoflagellates such as *Ceratium fusus* (6-22%), *C. longipes* (up to 12%), *Protoperidinium* spp. (up to 34%), and others which individually never comprised > 10%, including *Ceratium tripos*, *Dinophysis norvegica*, *Prorocentrum micans, Ceratium* spp., and unidentified thecate dinoflagellates. Athecate dinoflagellates of the genus *Gymnodinium* comprised up to 20%, and other athecate dinoflagellates comprised up to 10% of cells recorded. In late February (WF052), *Protoperidinium* spp. comprised 58-94% of cells recorded, and unidentified thecate and athecate dinoflagellates, aloricate ciliates and tintinnids each comprised up to 10% of cells in various samples. In March (WN053), dominants were *Protoperidinium* spp. (7-30%), unidentified thecate (12-19%) and athecate (10-21%) dinoflagellates, tintinnid (6-13%) and aloricate (8-18%) ciliates, with the dinoflagellates *Amylax triacantha* and *Gonyaulax* sp. comprising < 10% in samples where they were recorded. In April (WF054), tintinnids comprised 8-31% of cells recorded, and *D. speculum* comprised up to 20% of cells recorded for some samples. Other taxa which never comprised > 15% of cells recorded for samples where they were present included *Ceratium fusus*, *C. longipes*, *C. tripos*, *D. norvegica*, *Protoperidinium* spp., *Gymnodinium* sp., unidentified thecate and athecate dinoflagellates, and aloricate ciliates.

In May and June of 2005, there was a red tide of toxic dinoflagellates of the genus *Alexandrium*. During WN056 in May, cells designated as *Alexandrium* spp. comprised 10-61% of cells recorded for nearfield samples. Other taxa included *Protoperidinium* spp. (23-54%), aloricate ciliates (6-10%), and tintinnids (up to 13%).

Within the last year, a consensus has emerged among researchers investigating red tides in the Gulf of Maine region during the ECOHAB program, that there are two species of PSP-producing dinoflagellates of the genus *Alexandrium* in the Gulf of Maine, *A. tamarense* and *A. fundyense*. These are now considered by Dr. Don Anderson's group at Woods Hole to be varieties of the same species, since neither antibody nor oligonucleotide probes can distinguish between them. There is an additional *Alexandrium* species in the Gulf of Maine, *A. ostenfeldii*, which does not produce PSP toxins, and with larger cells than *A. fundyense*. Thus, for *Alexandrium* cells recorded for screened samples during the main red tide bloom in June of 2005 (Survey WF057), the now preferred designation of *A. fundyense* was used for cells that would have previously been called *Alexandrium tamarense* during the MWRA monitoring program. Cells of *A. ostenfeldii*, though rare, were distinguishable by their larger size (>60 µm) than cells of *A. fundyense* (diameter approximately 40-50 µm).

In June (WF057), *A. fundyense* comprised 16-54% of cells recorded for nearfield samples. Other dinoflagellates included *C. longipes* (up to 12%), *D. norvegica* (up to 30%), *Protoperidinium* spp. (up to 27%), *Scrippsiella trochoidea* (up to 11%), and unidentified thecate dinoflagellates (up to 12%). Tintinnids comprised up to 15% of cells recorded.

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 *Phaeocystis* bloom in April.

During early February, most farfield station assemblages were dominated at both depths by unidentified microflagellates (71-95% of cells counted) and cryptomonads (up to 23%; **Figure** 5-16). In late February, farfield assemblages remained generally similar to the nearfield with unidentified microflagellates (37-78%), small cryptomonads < 10 µm long (up to 16%), larger cryptomonads > 10 µm long (up to 8%), and lesser contributions by a larger (10-20 µm diameter) unidentified species of the centric diatom genus *Thalassiosira* (up to 19%), and other diatoms, including *Chaetoceros socialis* (up to 7%), *Dactyliosolen fragilissimus* (up to 5%), and *Thalassiosira nordenskioldii* (up to 23%). Unlike the previous year, these centric diatoms were not most abundant at the Cape Cod Bay at this time, but rather were widespread throughout the study area, suggesting that a minor winter/spring diatom bloom may have occurred (**Figure** 5-17). Also in late February, the *Phaeocystis* bloom was starting throughout most of the study area (up to 23%), except for Boston Harbor.

In April (WF054) the spring bloom of *Phaeocystis pouchetii* was underway throughout the study area (**Figure** 5-18). *Phaeocystis* comprised up to 80% of cells counted. The highest abundances of *Phaeocystis* were observed in the nearfield and boundary zones, particularly at depth. As discussed in section 4, fluorescence data from satellite imagery and the chlorophyll:phaeopigment ratio observed *in situ*, as well as productivity calculations, suggest that despite the maximum measured abundances in April, the *Phaeocystis* bloom may actually have peaked in late March. The remainder of the April assemblage was similar to that of the nearfield, comprised of unidentified microflagellates (17-91%), small cryptomonads (up to 14%), *Chaetoceros socialis* (up to 5%), *Heterocapsa rotundata* (up to 20%), and *Gymnodinium* sp. (up to 7%).

By June, the *Phaeocystis* bloom had ended and assemblages at both depths at most farfield stations were dominated by the same small microflagellates (48-85%) and cryptomonads (up to 23%), that dominated the nearfield (**Figure** 5-19). Diatoms comprised as large a percentage of the community in June as during the winter/spring bloom in late February. Diatom taxa included the *Chaetoceros debilis* (up to 19%), *C. socialis* (up to 5%), an unidentified large (10-30 µm diameter) species of *Chaetoceros*, *Thalassionema nitzschoides* (up to 8%), and *Thalassiosira rotula* (up to 18%), and *Skeletonema costatum* which comprised < 5% of abundance at all locations except for 13% of abundance at Station F30 in Boston Harbor. A dinoflagellate of the genus *Gymnodinium* comprised up to 11% of abundance at some stations.

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

From February to April, 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.

In June, during WF057, *Alexandrium fundyense* comprised up to 59% of cells recorded for farfield samples. Other dinoflagellates included *C. longipes*, *D. acuminata*, *D. norvegica*, *Gymnodinium* sp., *Gyrodinium* sp., *Heterocapsa triquetra*, *Protoperidinium* spp., and *Scrippsiella trochoidea*. Also recorded were the flagellate *Ebria tripartita*, tintinnids and aloricate ciliates.

Nuisance Algae – There were two major blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during the first half of 2005: (1) the late February, March and April bloom of *Phaeocystis pouchetii* and (2) the May and June red tide of *Alexandrium fundyense*. These blooms are discussed separately, below.

The *Phaeocystis* bloom was first recorded in late February (WF052) in whole water phytoplankton samples from 11 of 15 stations throughout the study area except in Boston Harbor (< 5% of cells counted; **Figures** 5-17a and 5-17b). *Phaeocystis* abundance was at levels of 0.0243-0.3081 x 10^6 cells L^{-1}. In March, nearfield abundance of *Phaeocystis* was 0.254-0.492 x 10^6 cells L^{-1} (28-44% 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 0.0003 – 4.072 x 10^6 cells L^{-1} (<5% - 80% of cells counted; **Figure** 5-18). The bloom had ended by May and no *Phaeocystis* cells were recorded for survey WN056. However, *Phaeocystis* was observed in a single sample from station N18 in June (~10,000 cells L^{-1}). The mid-depth sample from N18 was the only sample from the WF057 survey with *Phaeocystis* present and indications are that the cells were in poor condition.

In April 2005, maximum *Phaeocystis* abundance was 4.072 x 10^6 cells L^{-1} with all but five samples < 1.0 x 10^6 cells L^{-1}. These levels were much lower than those of the previous year of >10 x 10^6 cells L^{-1} at most stations in Massachusetts Bay, with a 2004 maximum of 15.5 x 10^6 cells L^{-1}. The 2005 *Phaeocystis* bloom was more typical of previous blooms during 2001, 2002 and 2003 (maxima of 3.1, 1.6, and 10.2 x 10^6 cells L^{-1}, respectively). In fact, the only previous bloom of this species that even approached the height of the 2004 bloom was during the previous maximum level for the program observed during the 2000 bloom (12.3 x 10^6 cells L^{-1}). As observed during the previous blooms, the 2005 bloom was a regional event with elevated abundances measured throughout the bays. The continued occurrence of spring *Phaeocystis* blooms in six consecutive years (2000 to 2005) is a change from the pattern that had been observed during earlier baseline monitoring of these blooms occurring in single years in cycles of about 3 years – 1992, 1994, 1997, and 2000 (Libby *et al.* 2001).

The toxic dinoflagellate *Alexandrium fundyense* bloomed in 2005, producing the largest red tide in New England since 1972. The bloom extended from Maine to south of Martha's Vineyard, and prompted shellfish closures throughout the region. Typical concentrations of *A. fundyense* in most years are < 100 cells L^{-1}, but in 2005, many samples analyzed by Anderson's group at WHOI had counts of > 1,000 cells L^{-1}, with some maxima in Cape Cod Bay of > 40,000 cells L^{-1} (New Bedford Standard Times, June 4, 2005).

During the routine MWRA sampling in May (WN056), *Alexandrium* spp. were present in screened water samples at concentrations of 2,059-3,078 cells L^{-1} in both surface nearfield samples, but only at levels of 51-156 cells L^{-1} in both chlorophyll maximum samples. Cells identified as *Alexandrium fundyense* in June (WF057) were present in nearfield screened water samples at levels of 2,060-5,162 cells L^{-1} at the 3 surface samples, and at levels of 376-1,758 cells L^{-1} in the 3 samples from chlorophyll maximum depths. Thus, red tide cells were more abundant in the nearfield screened samples at the surface than at depth. This was not as clearly the case at several farfield locations.

Abundances of *A. fundyense* in 10 of 12 screened water samples where this species was recorded were 49-2,050 cells L^{-1} at the surface, and 97-1,512 cells L^{-1} in 7 of 12 chlorophyll maximum depth screened samples where this species was recorded.

The ranges of tens to hundreds to low thousands of *Alexandrium* cells L^{-1} recorded for screened samples agrees with a similar range of hundreds to low thousands of cells L^{-1} recorded for whole water samples where red tide cells were recorded. During WN056, *Alexandrium* spp. cells were present in both nearfield whole water surface samples at levels of 4,800-6,300 cells L^{-1}, and in both chlorophyll maximum depth samples at levels of 600-800 cells L^{-1}. During WF057, *Alexandrium fundyense* cells were recorded at levels of 500-4,600 cells L^{-1} in the 2 nearfield and 4 farfield surface samples where this species was recorded, and at levels of 1,000-2,000 cells L^{-1} in the 2 nearfield and 5 farfield chlorophyll maximum depth samples where this species was recorded. *Alexandrium* spp. cells were recorded at levels of 400-1,100 cells L^{-1} in the 3 surface and 1 chlorophyll maximum depth samples where this taxon was recorded. Both screened water and whole water samples were analyzed by the same analyst (David Borkman). Thus, records for screened water samples were in the range of tens to thousands of cells L^{-1}, whereas those for whole water samples were only in the range of hundreds to thousands of cells L^{-1}. This confirms that, as expected, screened water samples are better than whole water samples for quantifying extremely low levels of red tide cells, such as those typically seen in all previous years of MWRA monitoring.

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 more than 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 $<0.0100 \times 10^6$ cells L^{-1} except for levels of $0.0117\text{-}0.1820 \times 10^6$ cells L^{-1} in May and up to 0.0430×10^6 cells L^{-1} in June. Cells designated as *Pseudo-nitzschia pungens* were only recorded for 12 samples through May and never at abundances above 3,100 cells L^{-1}. In June (WF057), this species was recorded for 26 samples, at abundance levels of $0.0002\text{-}0.0345 \times 10^6$ cells L^{-1} (mean = 0.0090×10^6 cells L^{-1}).

5.3.2 Zooplankton

5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Total zooplankton abundance at nearfield stations was $<24 \times 10^3$ animals m^{-3} from February through May (**Table** 5-3; **Figure** 5-20). Values increased in June, to levels of $21\text{-}42 \times 10^3$ animals m^{-3}. These June 2005 values are remarkably similar to those of the previous year ($21\text{-}45 \times 10^3$ animals m^{-3}).

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

Survey	Dates (2005)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF051	2/1-2/7	8.2	5.0-11.8	6.3	1.5-12.3
WF052	2/23-2/27	7.1	3.7-9.1	9.1	4.2-15.7
WN053	3/17	10.2	7.0-13.3	–	–
WF054	4/4-4/7	13.6	4.9-23.9	12.3	0.7-34.3
WN056	5/13	10.5	0.7-20.3	–	–
WF057	6/13-6/18	32.5	20.8-41.9	43.3	15.0-67.0

Total zooplankton abundance at farfield stations in early and late February ranged from 1.5 – 15.7 x 10^3 animals m^{-3} (**Table** 5-3) (**Figure** 5-21a, b). By early April, variability in total zooplankton abundance had increased ranging from 0.7-34.3 x 10^3 animals m^{-3} (**Figure** 5-22a). By June, zooplankton abundance had increased to 15 to 67 x 10^3 animals m^{-3} (**Figure** 5-22b).

Since 1998, two additional stations in Cape Cod Bay have been sampled to better address spatial variability in this region during the winter/spring period. 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 4.67-14.94 x 10^3 animals m^{-3} (**Figures** 5-21 and 5-22). There was a variability of $\pm$ 42.3%, 47.7%, and 30.9% 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, females and copepodites of *Oithona similis,* and *Pseudocalanus* spp. copepodites during all three surveys. During WF052, the copepod *Microsetella norvegic*a was also dominant. *Calanus finmarchicus* copepodites, polychaete trochophores, and *Oikopleura dioica* were noted during WF054.

Nearfield Zooplankton Community Structure

Nearfield zooplankton assemblages (**Figure** 5-20) in early February were dominated by copepod nauplii (29-48%), as well as copepodites of *Oithona similis* (27-34%), combined stages of *Microsetella norvegica* (6-14%) and *Pseudocalanus* spp. copepodites (up to 12%). Assemblages were similar in late February comprised of copepod nauplii (65-76%), *O. similis* copepodites (up to 9%), *Calanus finmarchicus* copepodites (up to 5%), *M. norvegica* (up to 6%), and the appendicularian *Oikopleura dioica* (up to 20%). In March, there was dominance by copepod nauplii (70-79%) and barnacle nauplii (5-12%), with lesser contributions by copepodites of *C. finmarchicus* (up to 8%) and *O. similis* (up to 6%). During April, dominance continued for copepod nauplii (28-63%) and barnacle nauplii (up to 30%), with lesser contributions by copepodites of *Calanus finmarchicus* (14-20%) and *O. dioica* (up to 18%). In May, there was continued nearfield dominance by copepod nauplii (47%) and rotifers (41%) at the single station N04 for which there was a preserved zooplankton sample. At nearfield stations in June, zooplankton assemblages contained a mixture of copepod nauplii (33-42%), copepodites of *Oithona similis* (7-22%), *Acartia* spp. (up to 11%) and *Temora longicornis* (up to 8%), bivalve veligers (up to 7%), the cladocerans *Evadne nordmani* (6-11%) and *Podon polyphemoides* (up to 6%), and *O. dioica* (up to 9%).

Regional Zooplankton Assemblages

Zooplankton assemblages at farfield stations during early February were generally similar to those in the nearfield (**Figure** 5-21a). Abundant taxa throughout the area included copepod nauplii (18-710%), females (up to 8%) and copepodites of *Oithona similis* (4-42%), *Pseudocalanus* spp. copepodites (up to 14%), *Microsetella norvegica* (up to 33%), and *Temora longicornis* females (up to 13%) and males (up to 18%). *Acartia hudsonica* females (12%), males (6%) and copepodites (11%) were abundant at Station 31 in Boston Harbor.

In late February (**Figure** 5-21b), assemblages contained copepod nauplii (19-78%, except for only 8-21% at stations in Boston Harbor), *Oithona similis* copepodites (up to 28%) and females (up to 9%), *Calanus finmarchicus* copepodites (up to 6%), *Pseudocalanus* spp. copepodites (up to 10%) and females (up to 6%), *Microsetella norvegica* (up to 11%), *T. longicornis* females (up to 6%) and males (up to 8%), and *O. dioica* (up to 23%). Barnacle nauplii comprised < 33% of abundance at stations outside Boston Harbor, but 58-79% at Stations F23, F30 and F31 in the harbor.

In early April (**Figure** 5-22a), assemblages contained copepod nauplii (24-77%), *Calanus finmarchicus* copepodites (up to 40%) and females (up to 17%), *Microsetella norvegica* (up to 11%), and copepodites of *O. similis* (up to 18%), *Pseudocalanus* spp. (up to 11%), and *Eurytemora herdmani* (up to 9%). Non-copepod dominants included barnacle nauplii (up to 63%), *O. dioica*, and polychaete larvae (up to 15%).

During the June survey, farfield zooplankton assemblages (**Figure** 5-22b) contained copepod nauplii (24-56%), *Eurytemora herdmani* copepodites (up to 17%) and males (up to 7%), and copepodites of *Oithona similis* (up to 21%), *Acartia hudsonica* (10%), *Calanus finmarchicus* (up to 5%), *Temora longicornis* (up to 10%), and *Centropages* spp. (up to 7%). Non-copepod dominants included bivalve veligers (up to 13%), *Evadne nordmani* (up to 20%), *O. dioica* (up to 15%0, rotifers (up to 8%), and polychaete larvae (up to 27%).

Overall, zooplankton assemblages during the first half of 2005 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 2005 followed patterns typically observed in prior years with moderate winter-spring phytoplankton blooms observed at both nearfield stations.
- A secondary peak in production in May 2005 was coincident with a late diatom bloom.
- The winter-spring bloom peaks at both nearfield sites in 2005 were somewhat lower than values observed during the winter-spring period in earlier years (1999 to 2004).
- Areal productivity at station F23 was not characterized by a winter bloom in 2005 as was observed at this site in all years following effluent diversion offshore.
- The peak productivity level observed in Boston Harbor thus far in 2005 is lower than seen in all other years.
- Elevated production values tended to be correlated with the occurrence of the highest chlorophyll *a* measurements at the nearfield sites but not at the Harbor station.
- Depth-averaged chlorophyll-specific potential production generally reached higher levels at station N18 compared with N04.
- Respiration rates were low during winter/spring 2005.
- Respiration rates were significantly correlated with temperature, but not POC during winter/spring 2005. Rates generally peaked in late February and May during the diatom blooms, but did increase into June at station F19.
- Carbon-specific respiration rates were low throughout the first half of 2005.
- 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.
- A minor winter/spring diatom bloom occurred in late February. Elevated diatom populations again appeared during the June survey.

- A *Phaeocystis* bloom occurred in spring 2005 that was similar to the blooms of this alga during the same period in previous years, but not with the extraordinary abundance levels of the 2004 bloom.
- The appearance of *Phaeocystis* blooms in six consecutive years (2000-2005) continues the departure from the 3-year cycle for these blooms previously observed during the baseline period since 1992-1999.
- There was a major red tide in May and June throughout the New England region due to dinoflagellates of the genus *Alexandrium.* This was the largest red tide in this region in over three decades.
- Comparisons of *Alexandrium* counts from screened water and whole water phytoplankton samples from the MWRA monitoring, were similar to each other, except that screened water samples were better at detecting extremely low concentrations of these cells, such as the concentrations observed by both the MWRA monitoring and Anderson's group during *Alexandrium* blooms in all previous years of the MWRA monitoring program.
- Diatoms characterized as *Pseudo-nitzschia pungens* and members of the *P. delicatissima* complex were recorded, but they were generally present in low abundance.
- Total zooplankton abundance generally increased from February through June as typically observed. Zooplankton assemblages during the first half of 2005 were comprised of taxa recorded for the same time of year in previous years.
- Variability in zooplankton abundance was observed among stations within given winter-spring surveys in Cape Cod Bay.

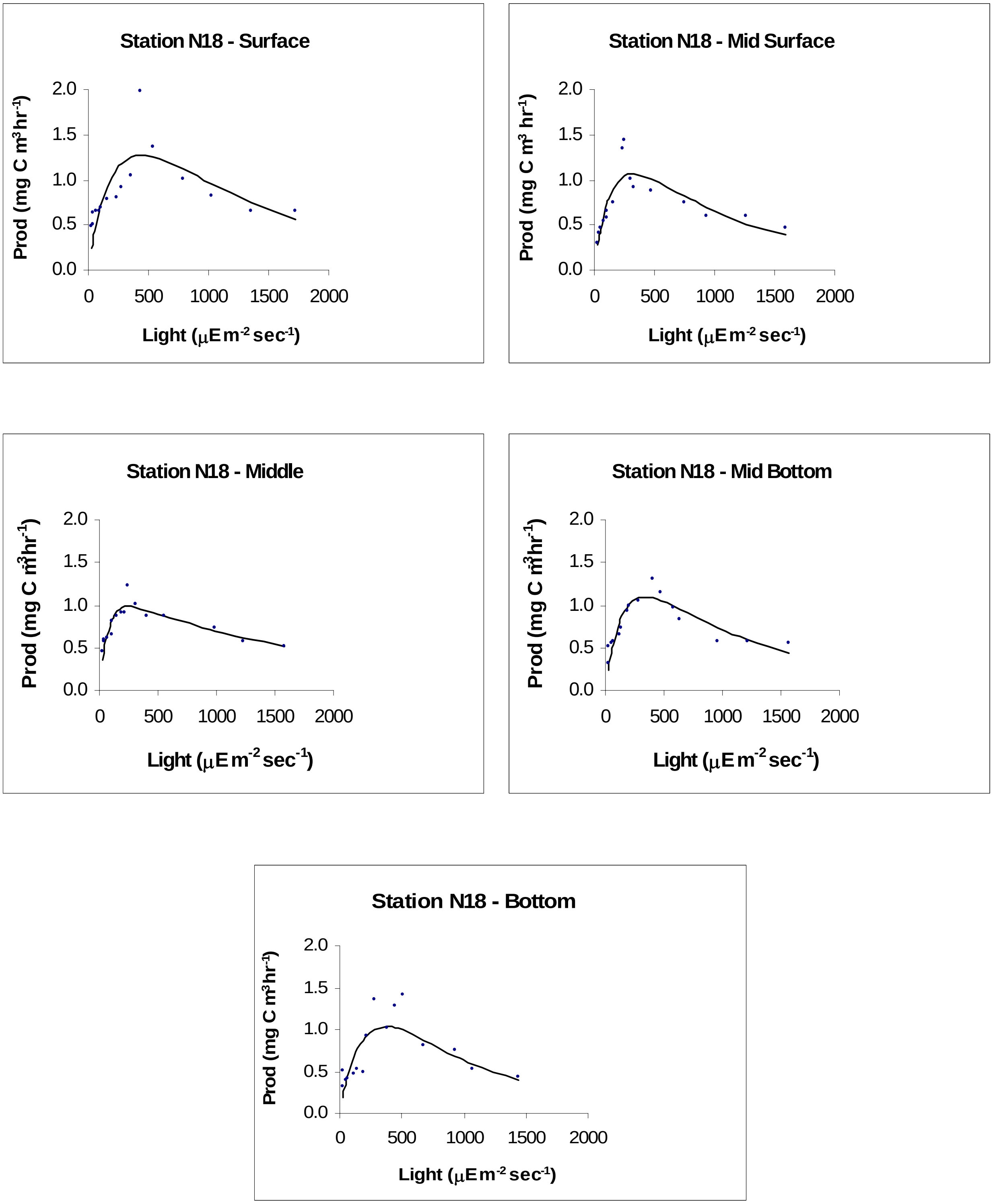


Figure 5-1. An example photosynthesis irradiance curve from station N18 collected February 2005 (WF051)

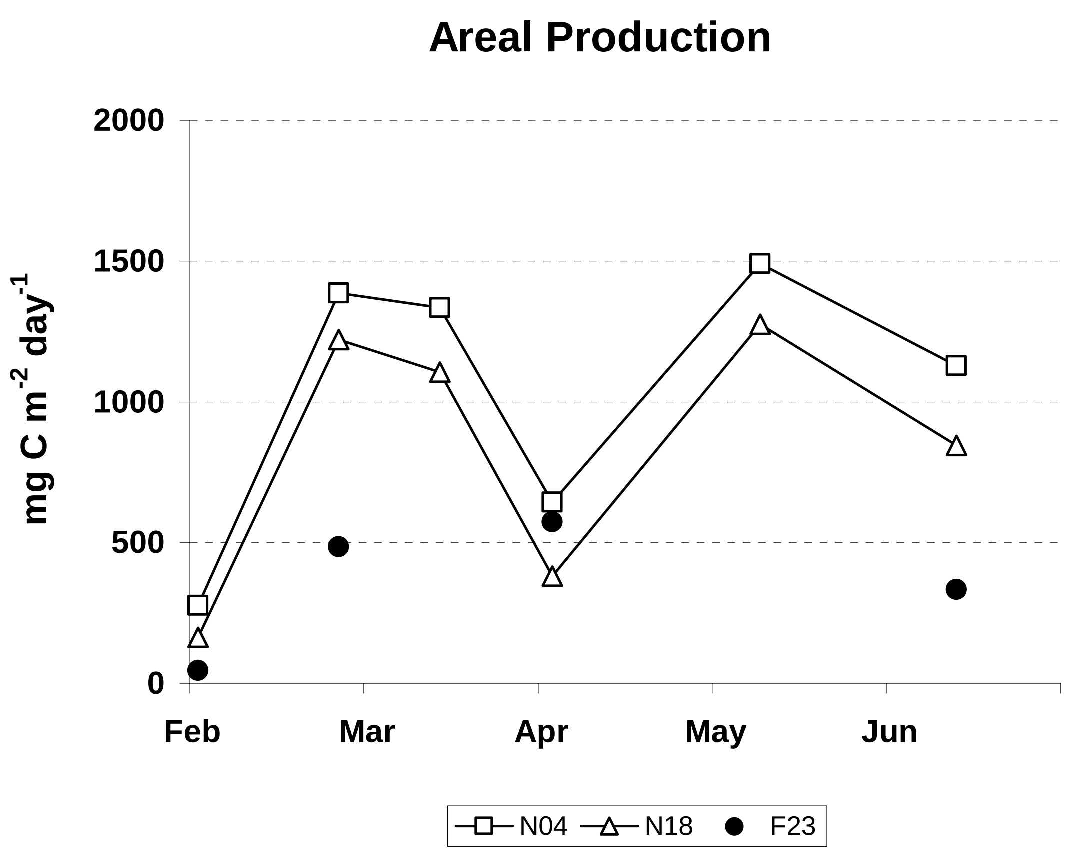


Figure 5-2. Time series of areal potential production (mg C m^{-2} d^{-1}) for stations N04, N18 and F23

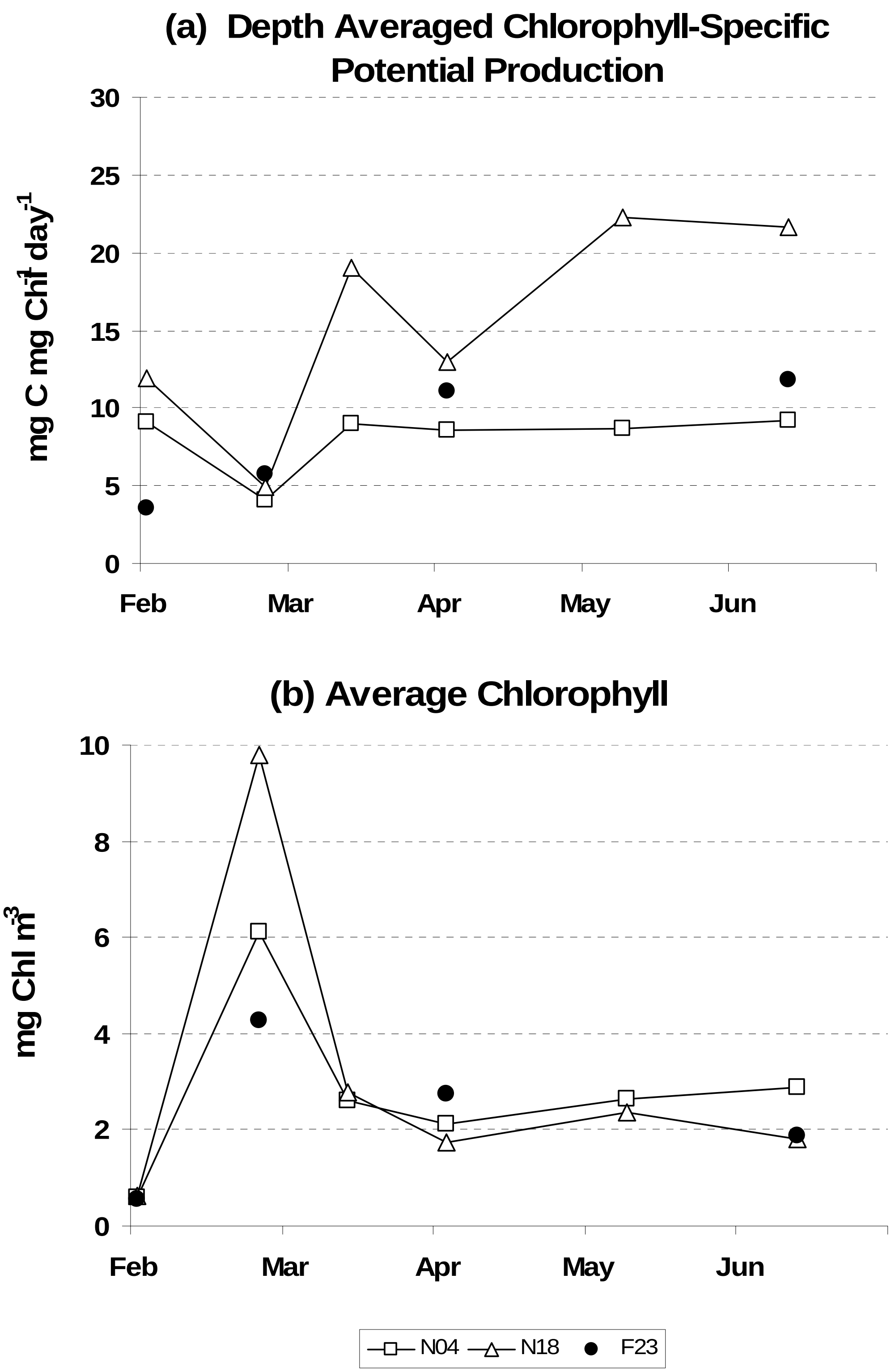


Figure 5-3. Time series of (a) depth-averaged chlorophyll-specific potential production (mg C mg Chl*a*$^{-1}$ d^{-1}) and (b) chlorophyll concentration (extracted) for stations N04, N18 and F23

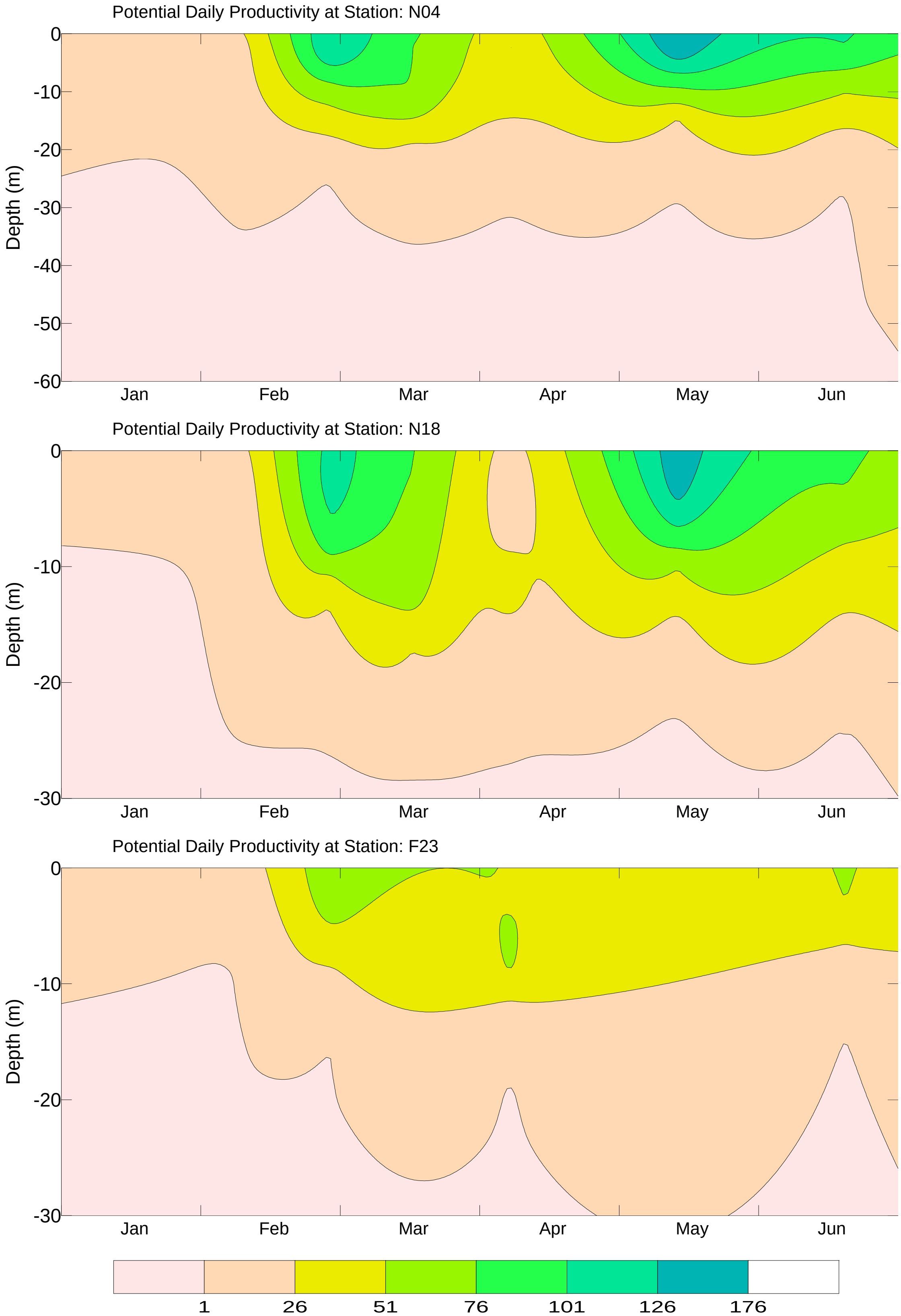


Figure 5-4. Time-series of contoured potential daily production ($mgCm^{-3}d^{-1}$) over depth (m)at stations N04, N18 and F23.

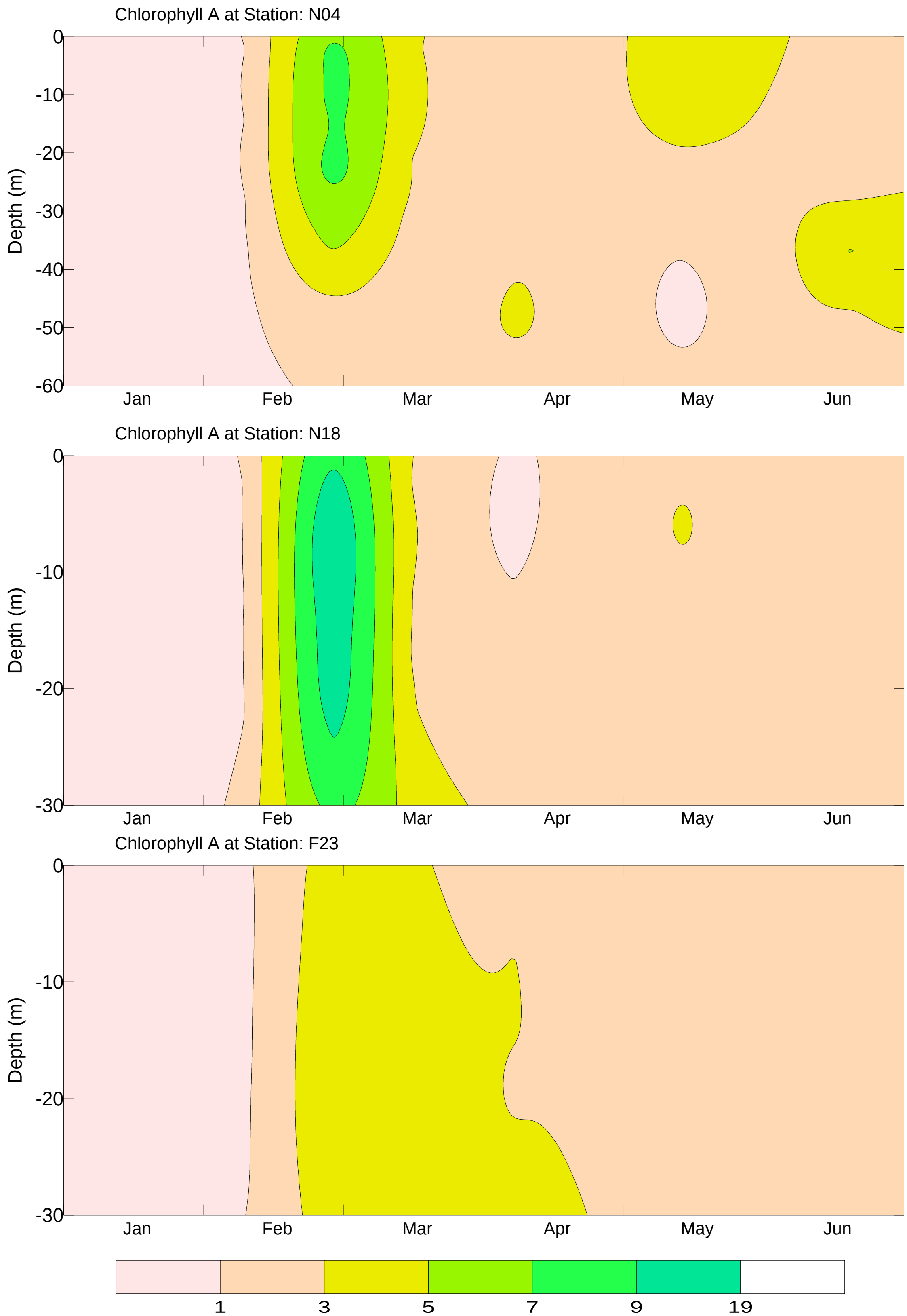


Figure 5-5. Time-series of contoured *in vitro* chlorophyll *a* concentration (μgL^{-1}) over depth at stations N04, N18, and F23

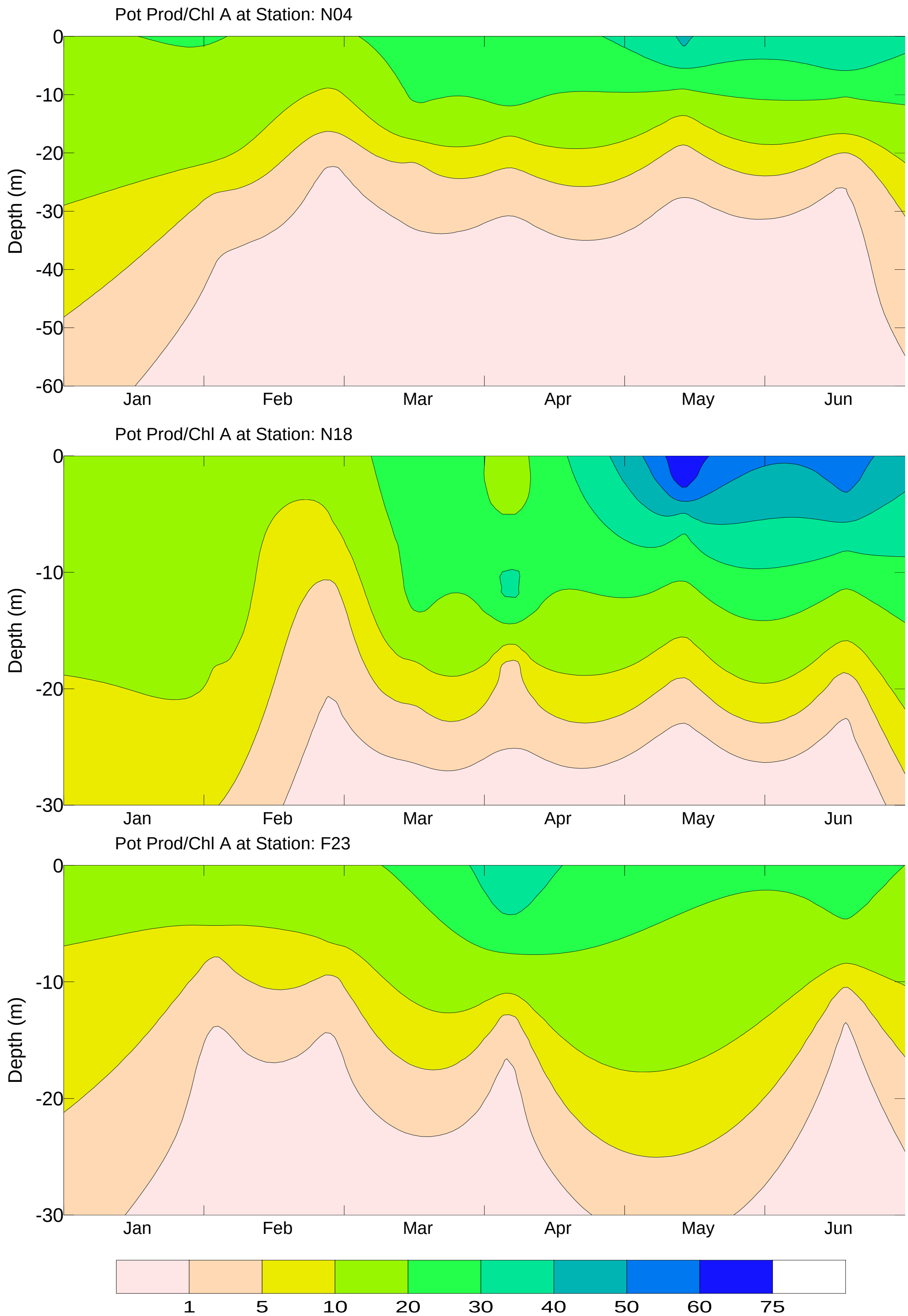
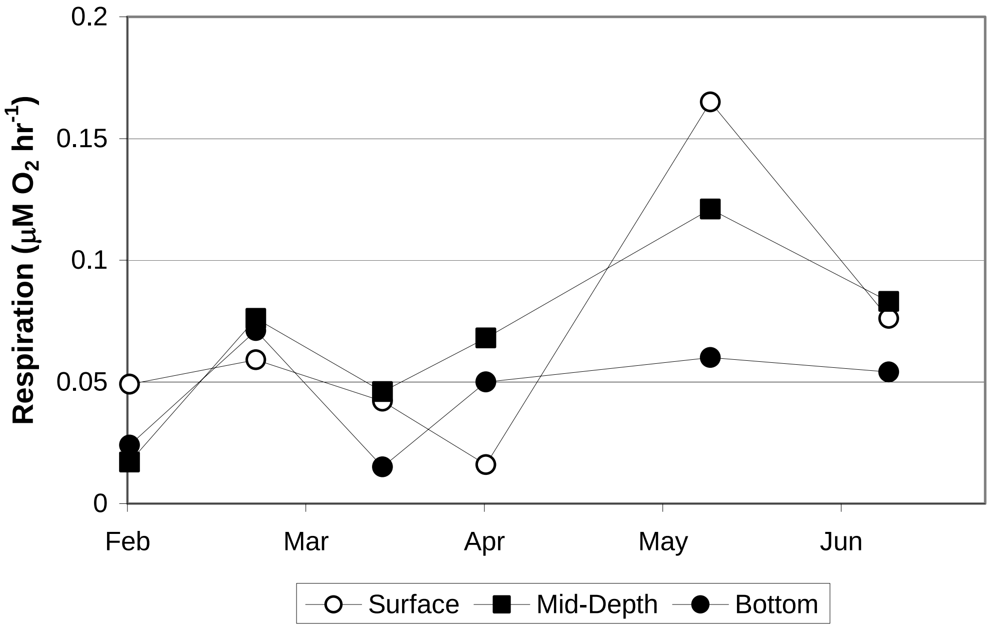


Figure 5-6. Time-series of contoured chlorophyll-specific potential production ($mgCmgChla^{-1}d^{-1}$) over depth at station N04, N18, and F23

(a) Station N18



(b) Station N04

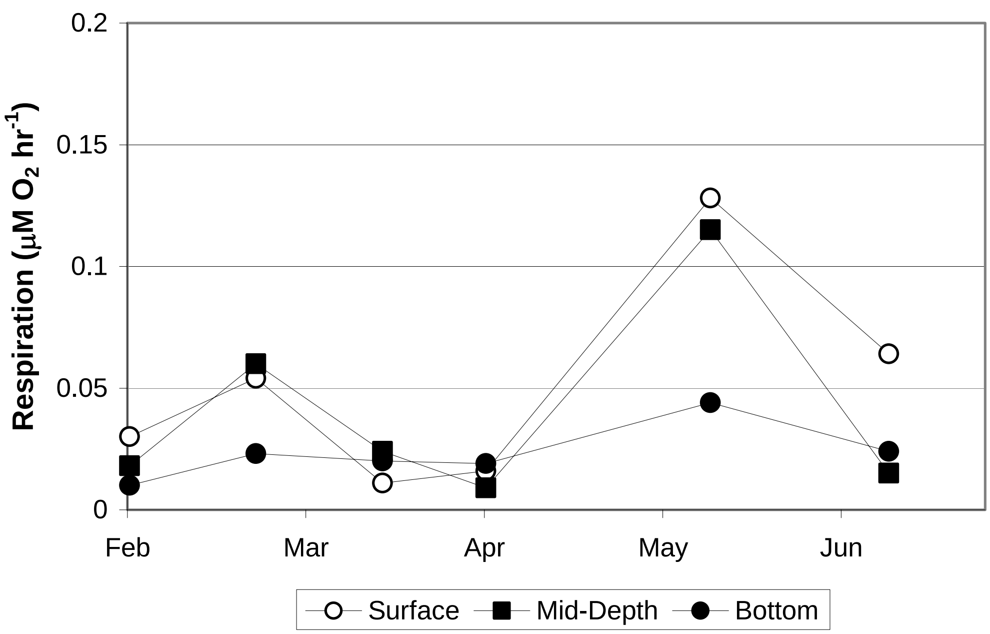
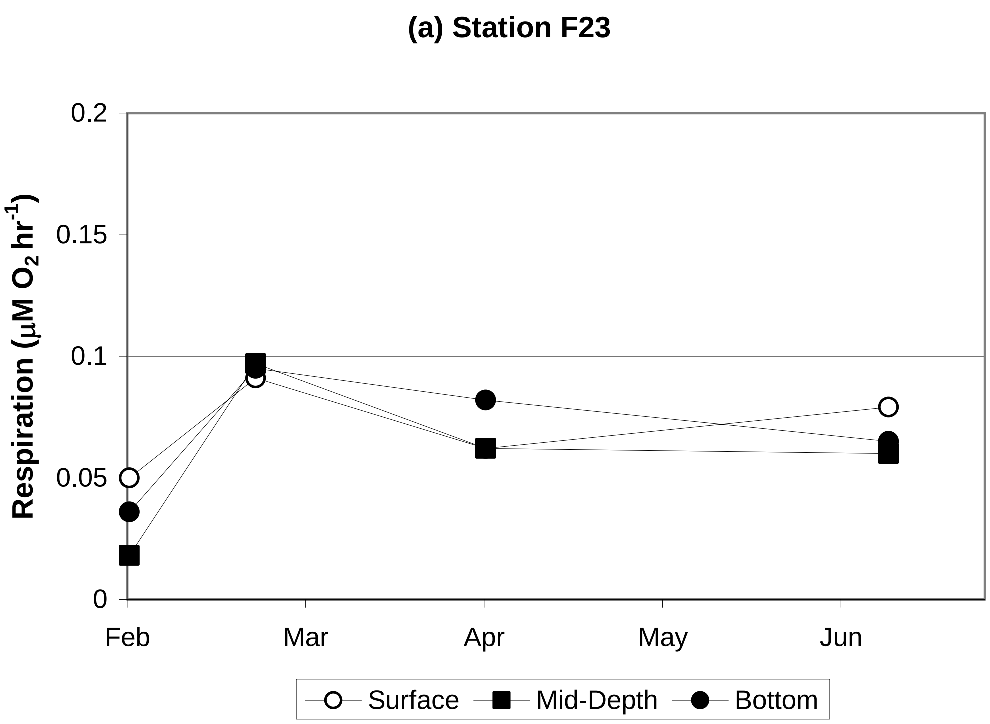


Figure 5-7. Time-series plots of respiration (μMO_2hr^{-1}) at stations N18 and N04



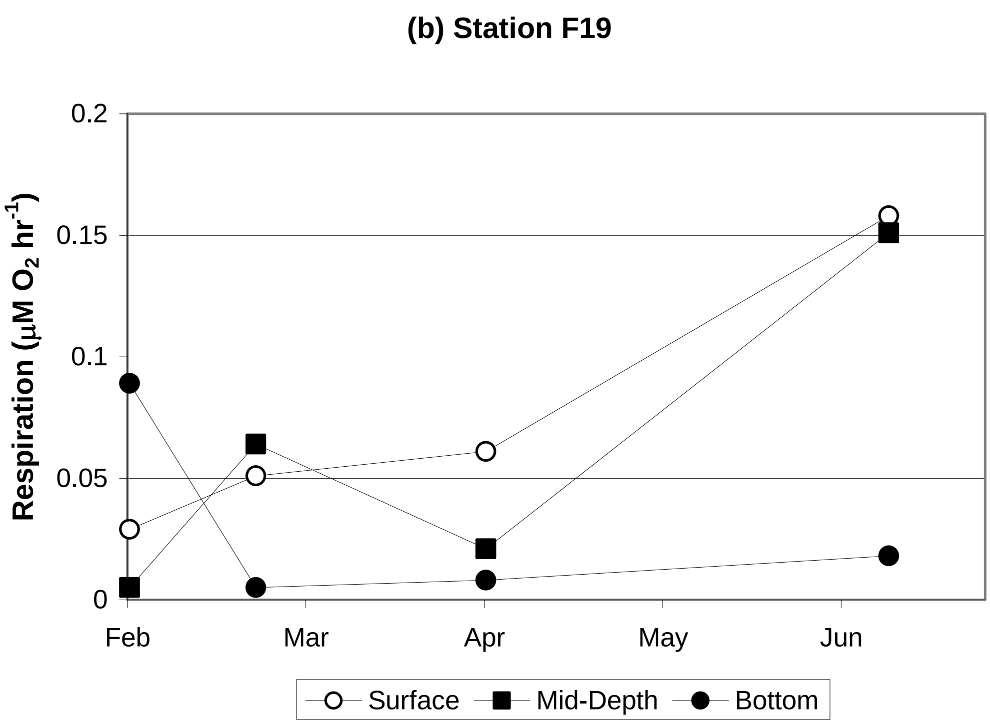
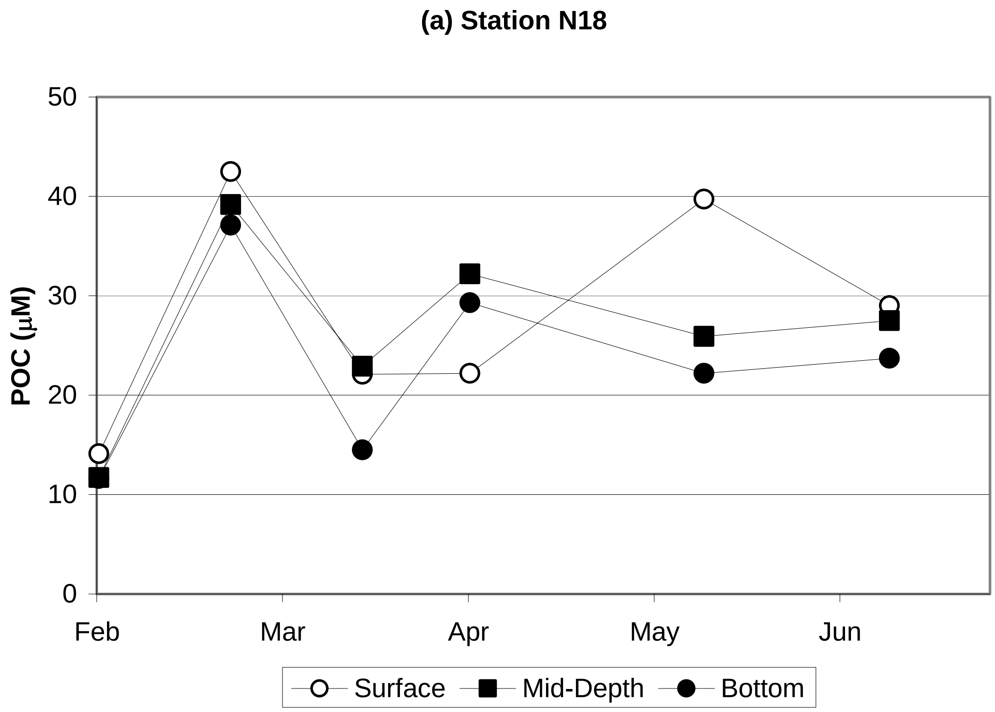


Figure 5-8. Time-series plots of respiration (μMO_2hr^{-1}) at stations F23 and F19



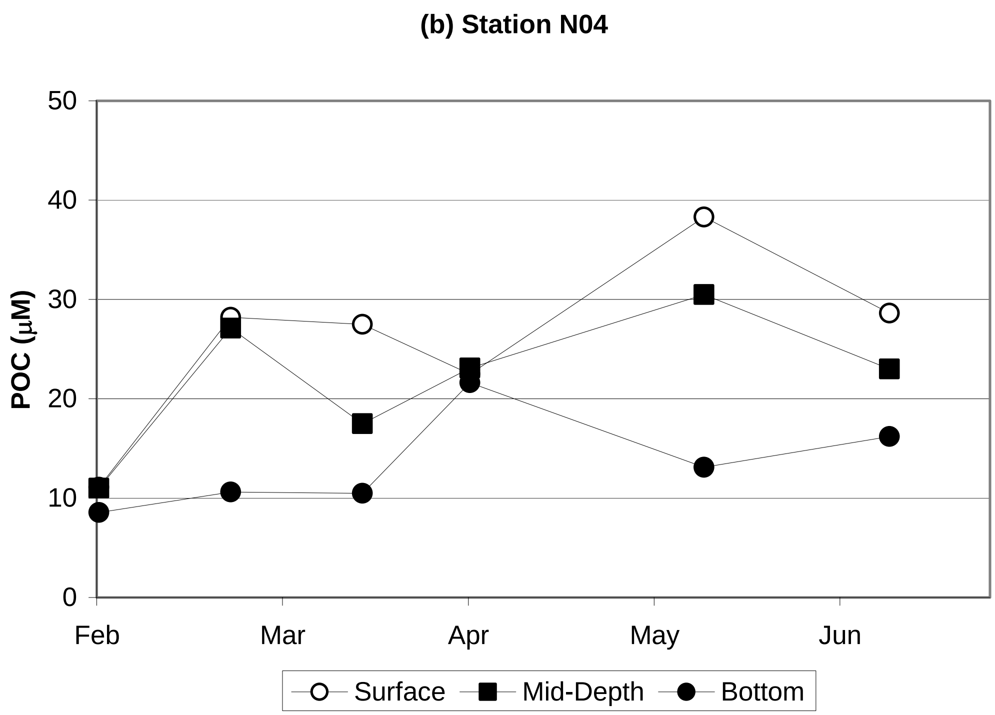


Figure 5-9. Time-series plots of POC (µM) at stations N18 and N04

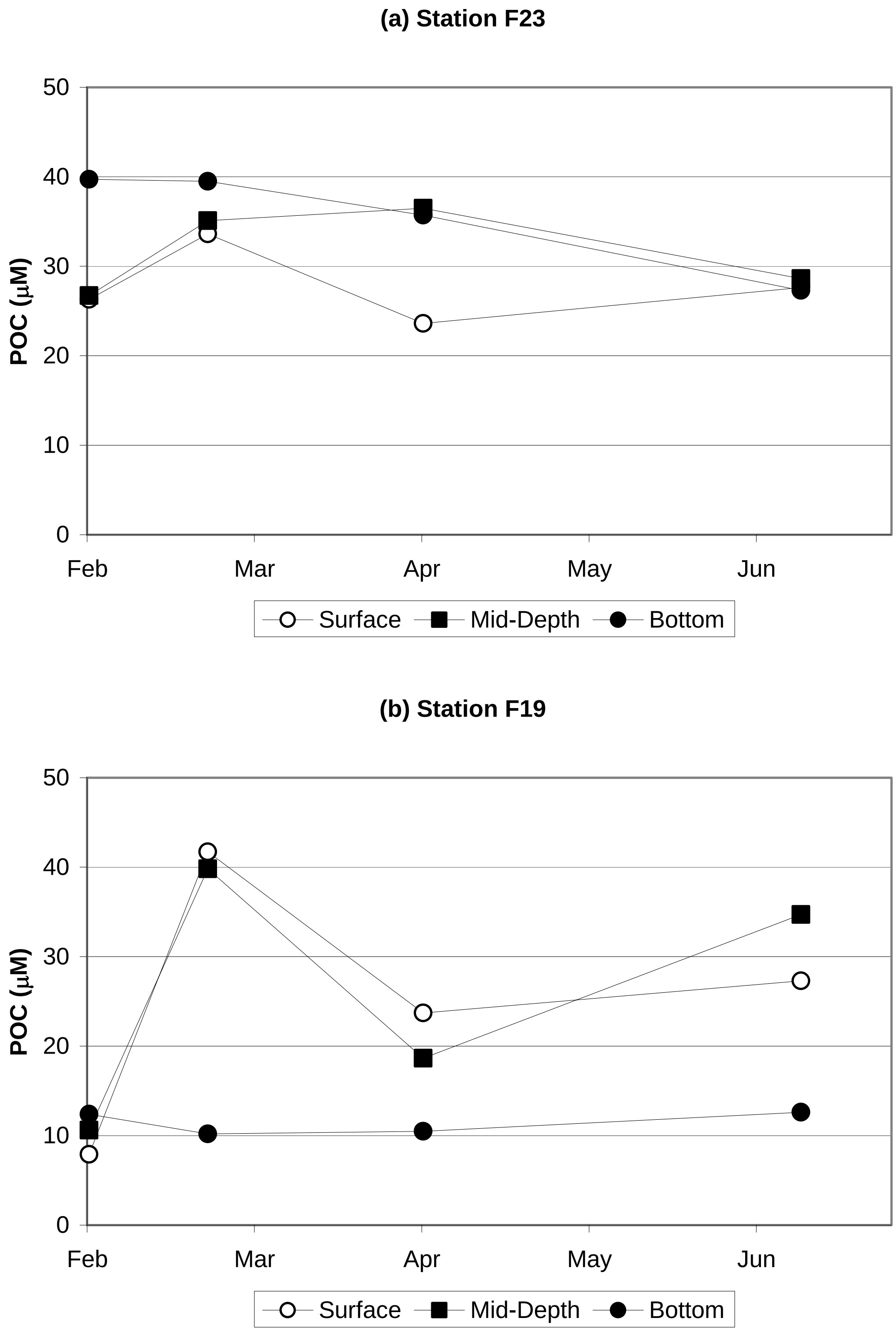
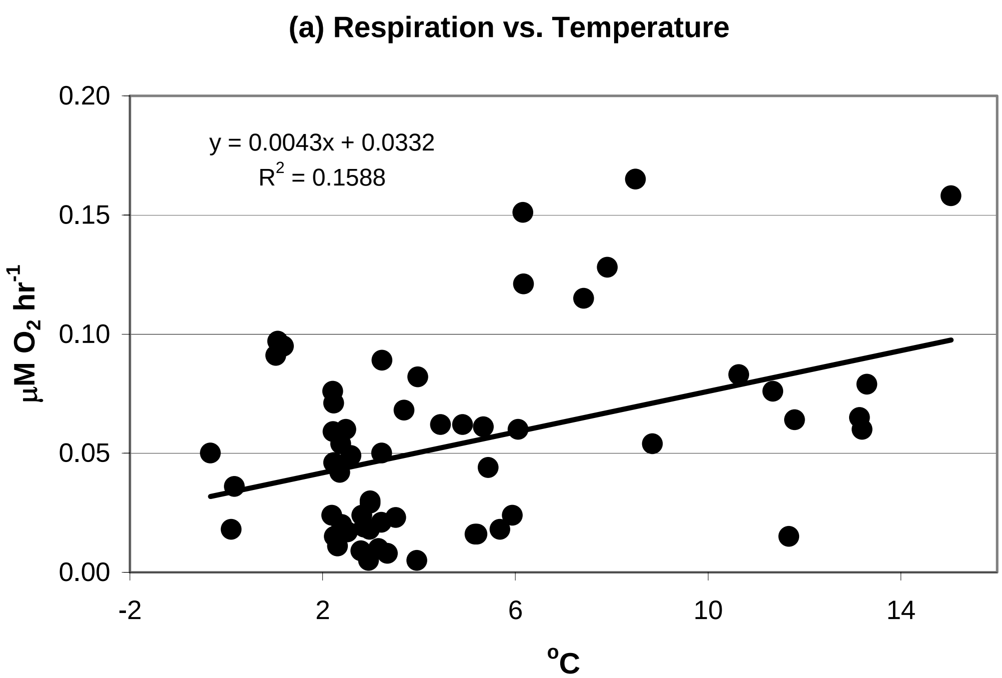


Figure 5-10. Time-series plots of POC (µM) at stations F23 and F19



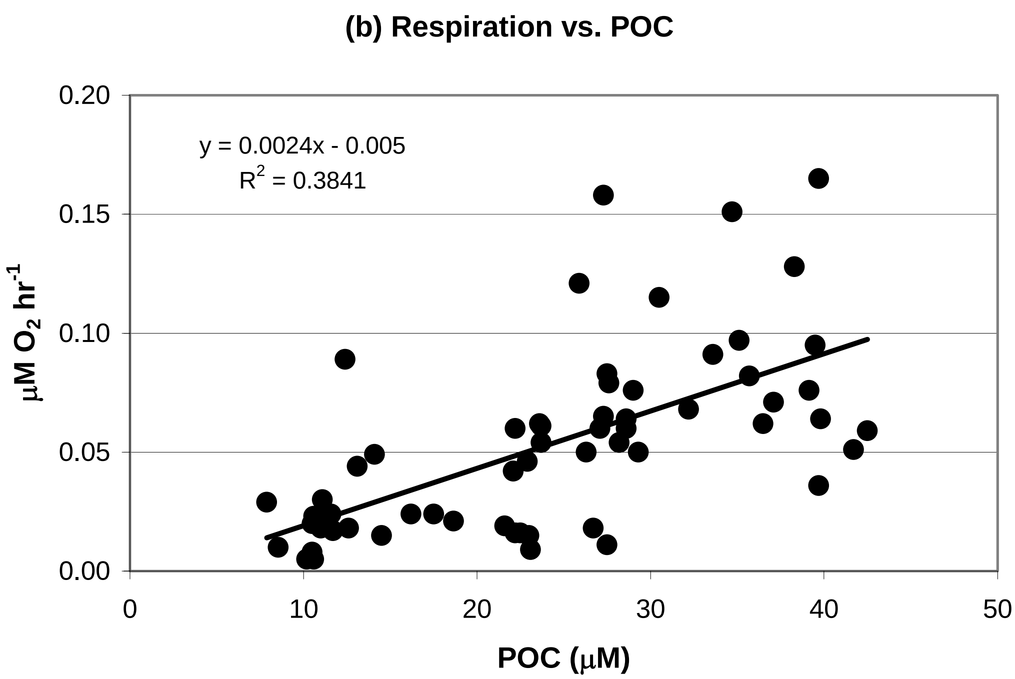


Figure 5-11. Comparison of respiration rate versus a) temperature and b) POC concentration for data collected at stations N04, N18, F19 and F23 in February – June 2005

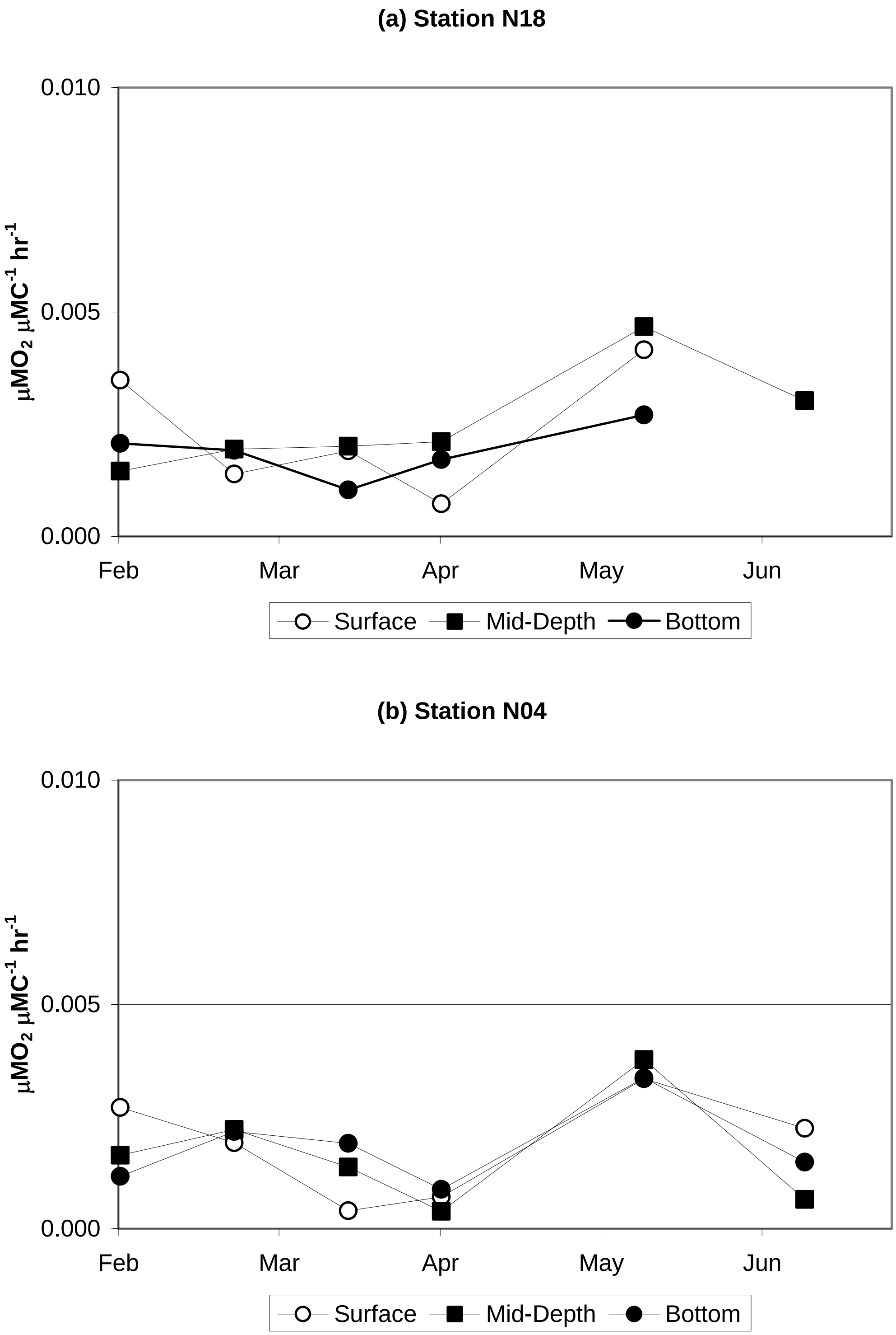
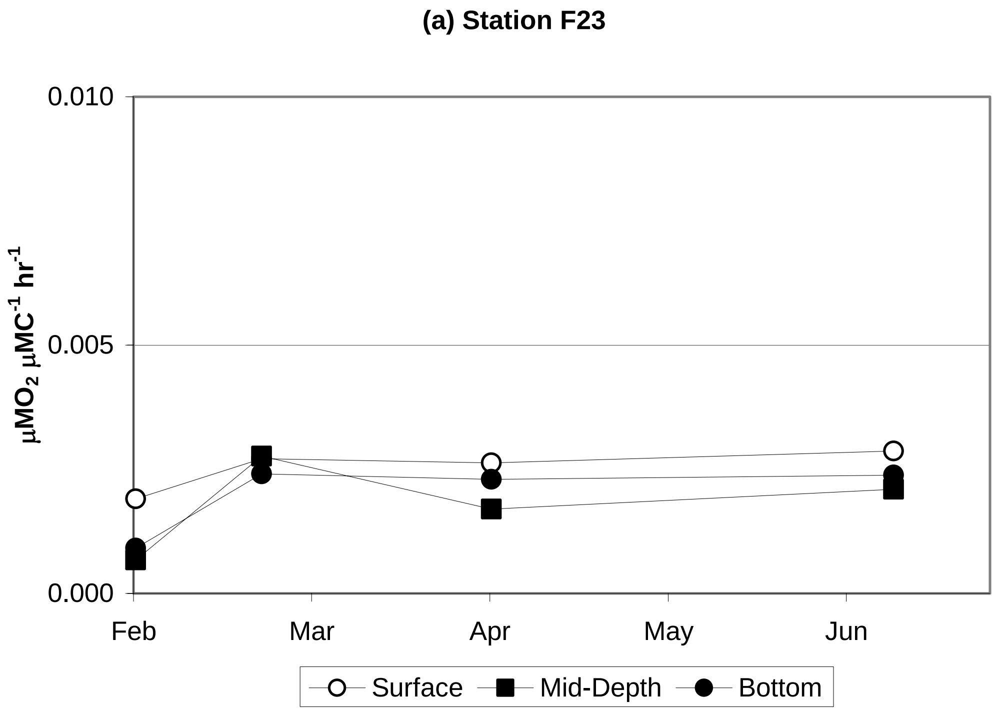


Figure 5-12. Time-series plots of carbon-specific respiration ($\mu MO_2 \mu MC^{-1} hr^{-1}$) at stations N18 and N04



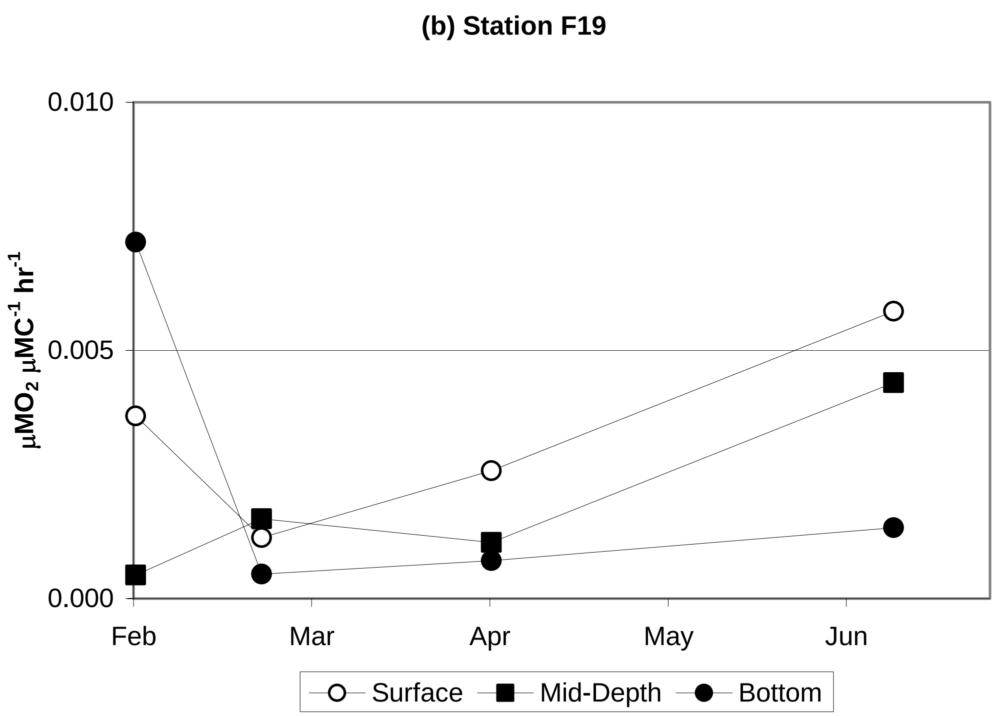


Figure 5-13. Time-series plots of carbon-specific respiration ($\mu MO_2 \mu MC^{-1}hr^{-1}$) at stations F23 and F19

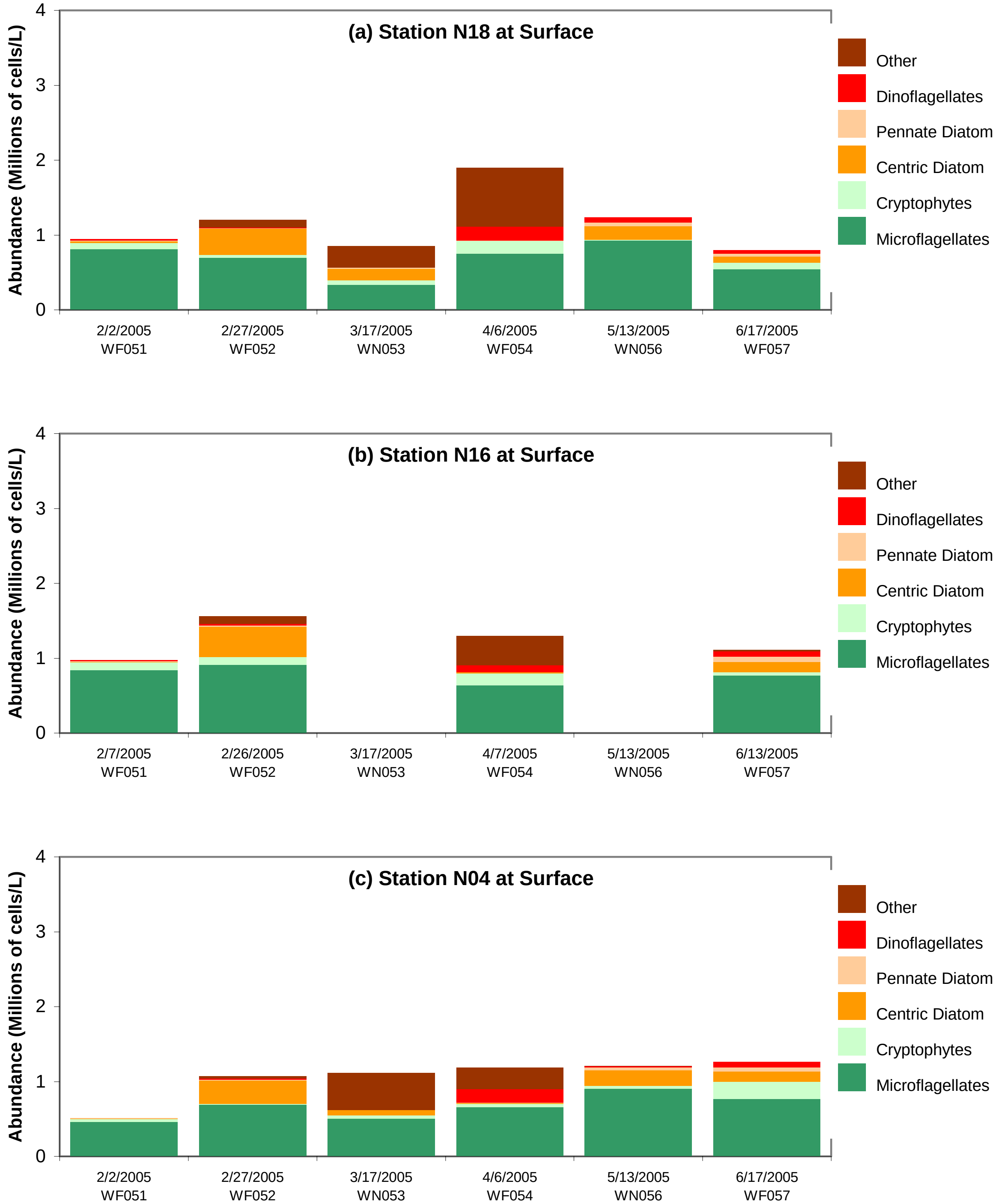


Figure 5-14. Phytoplankton abundance by major taxonomic group, nearfield surface samples

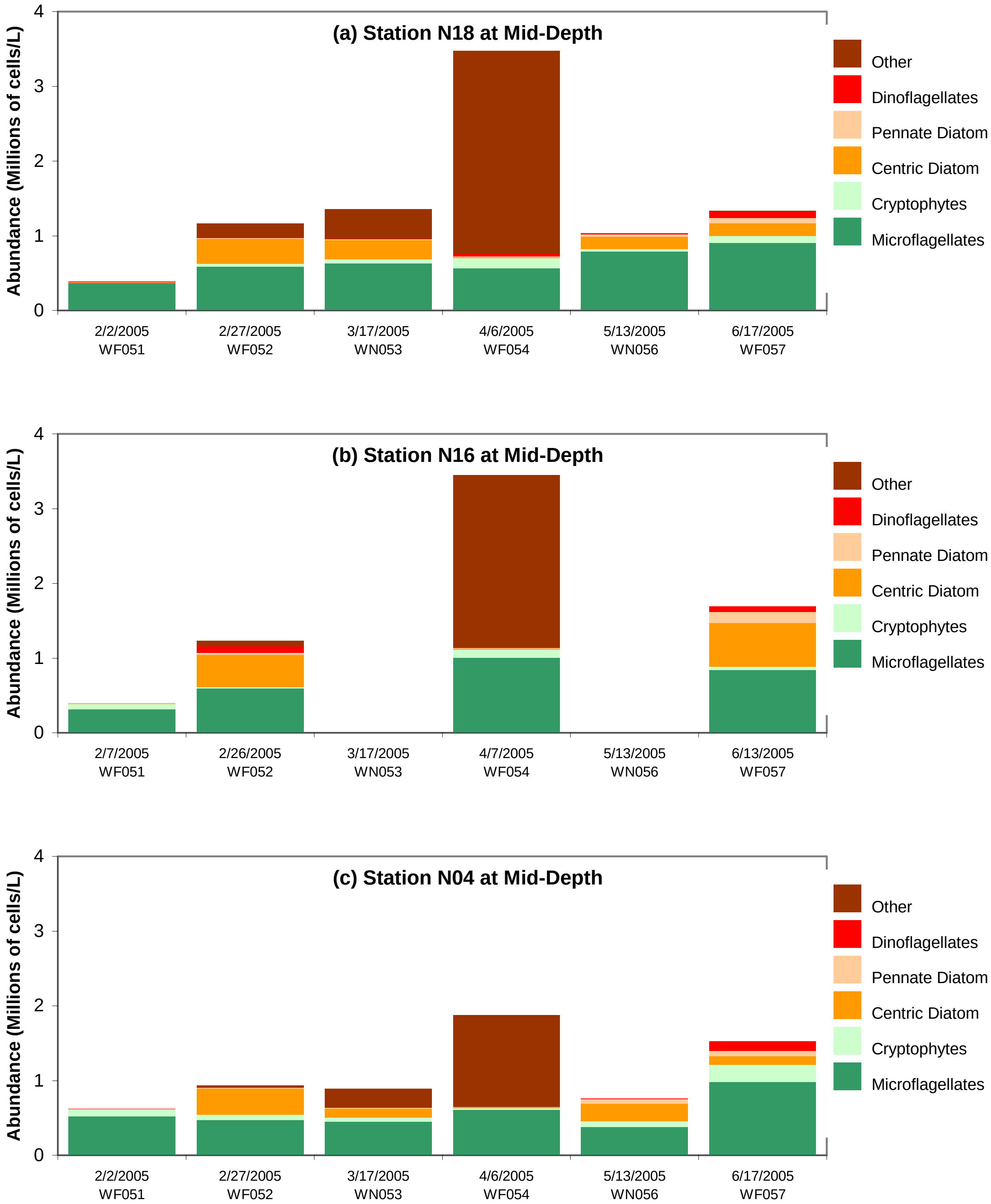


Figure 5-15. Phytoplankton abundance by major taxonomic group, nearfield mid-depth samples

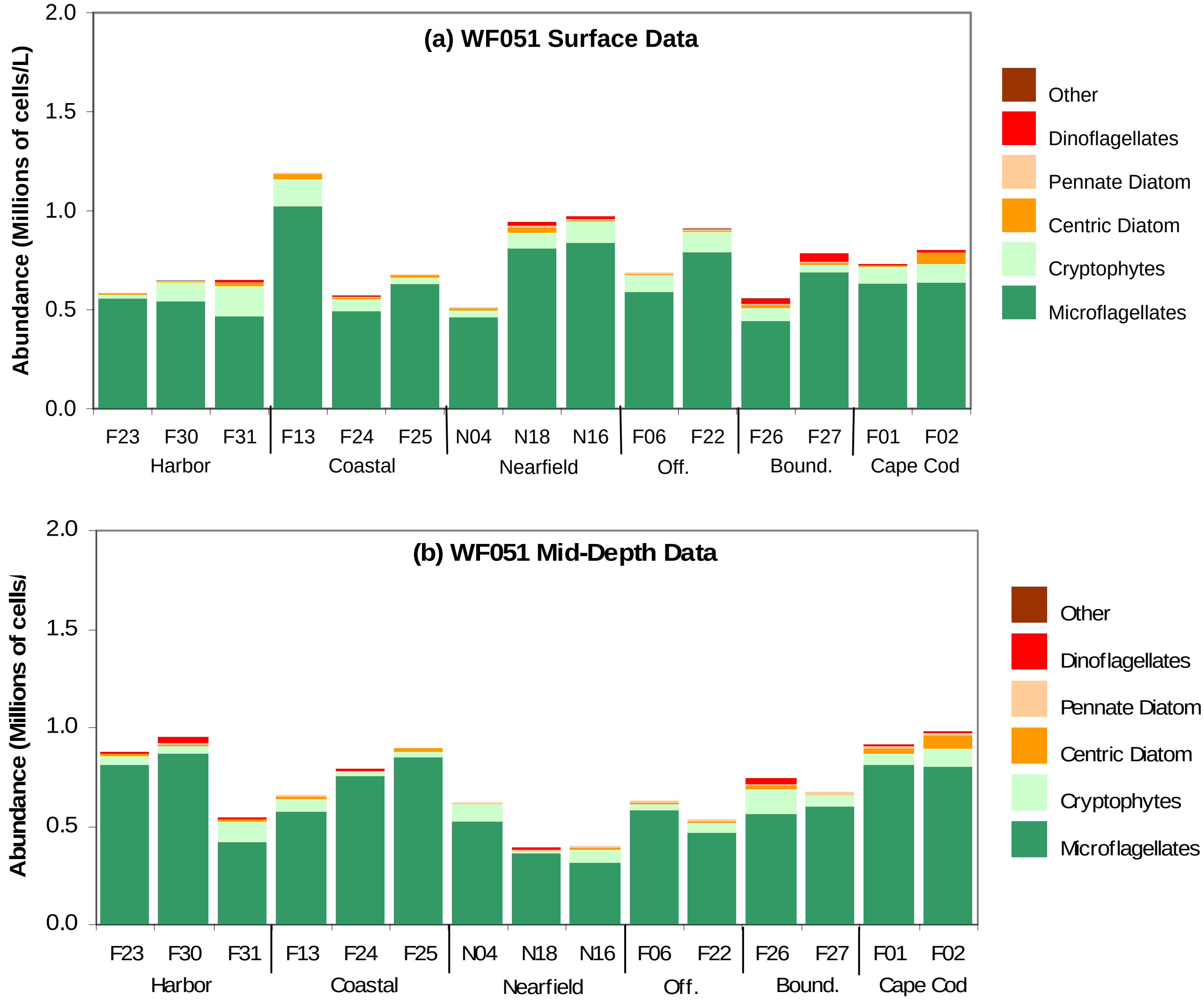


Figure 5-16. Phytoplankton abundance by major taxonomic group – WF051 farfield survey results (February 1 – 7)

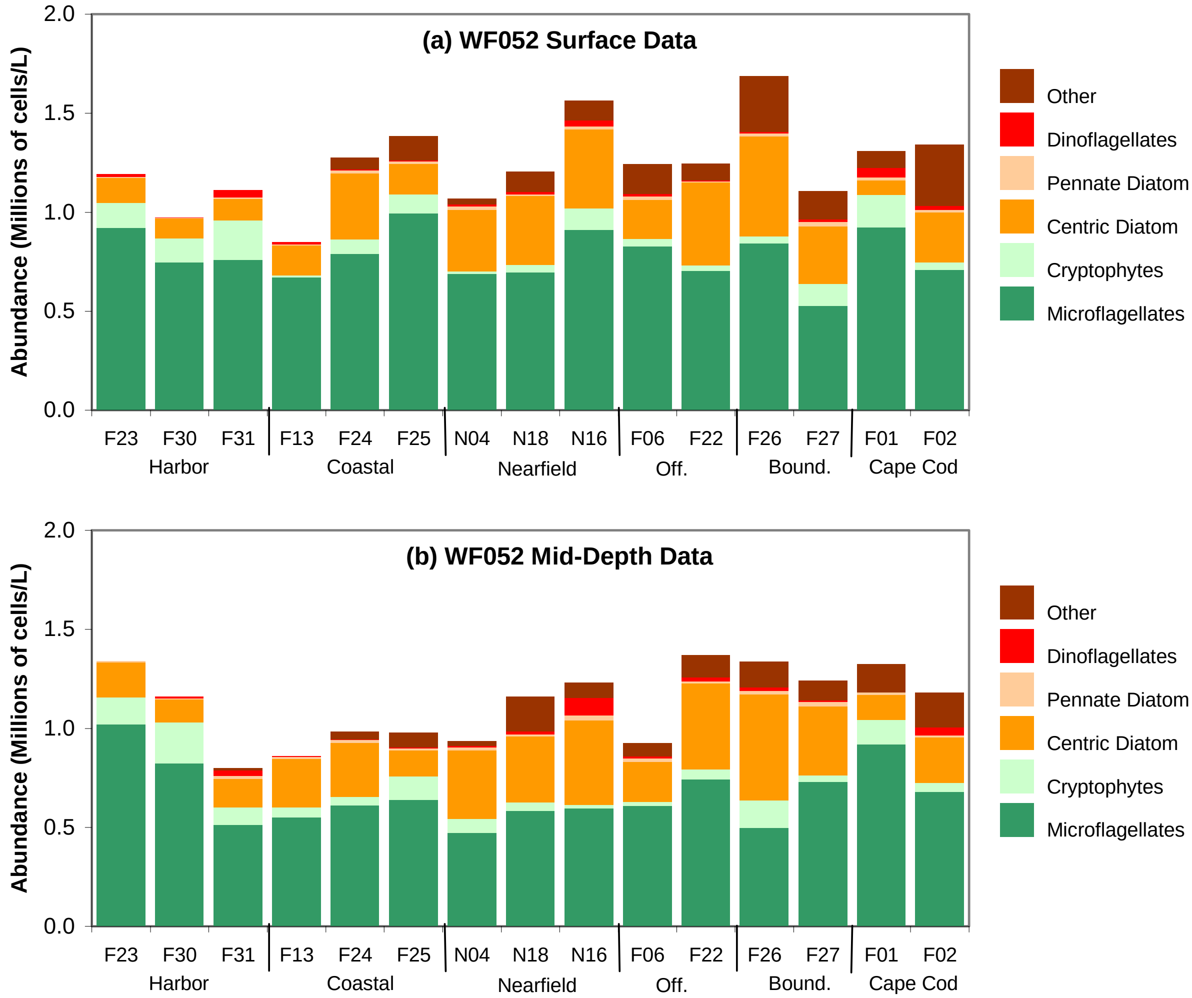


Figure 5-17. Phytoplankton abundance by major taxonomic group – WF052 farfield survey results (February 23 – 27)

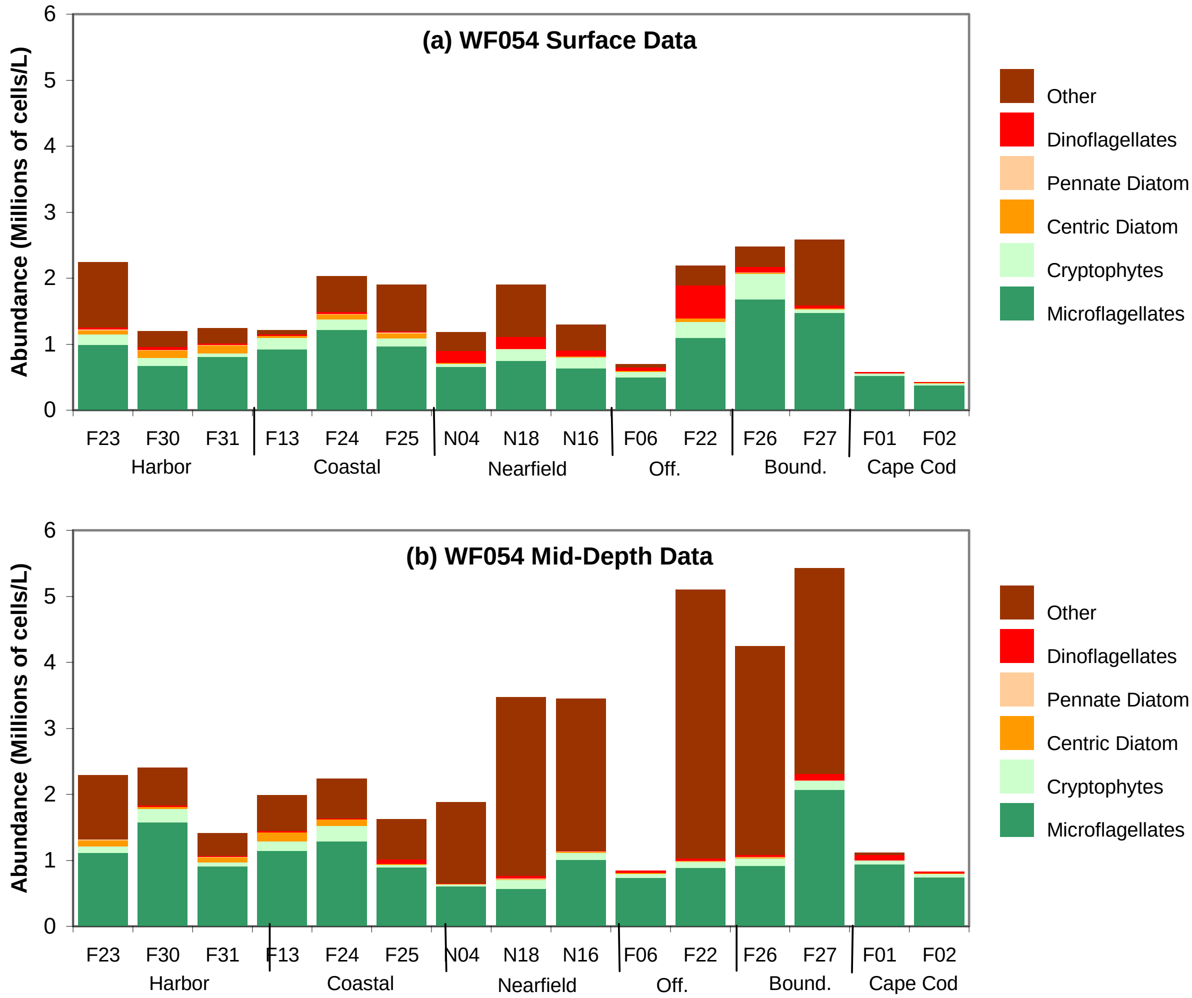


Figure 5-18. Phytoplankton abundance by major taxonomic group – WF054 farfield survey results (April 4 – 7)

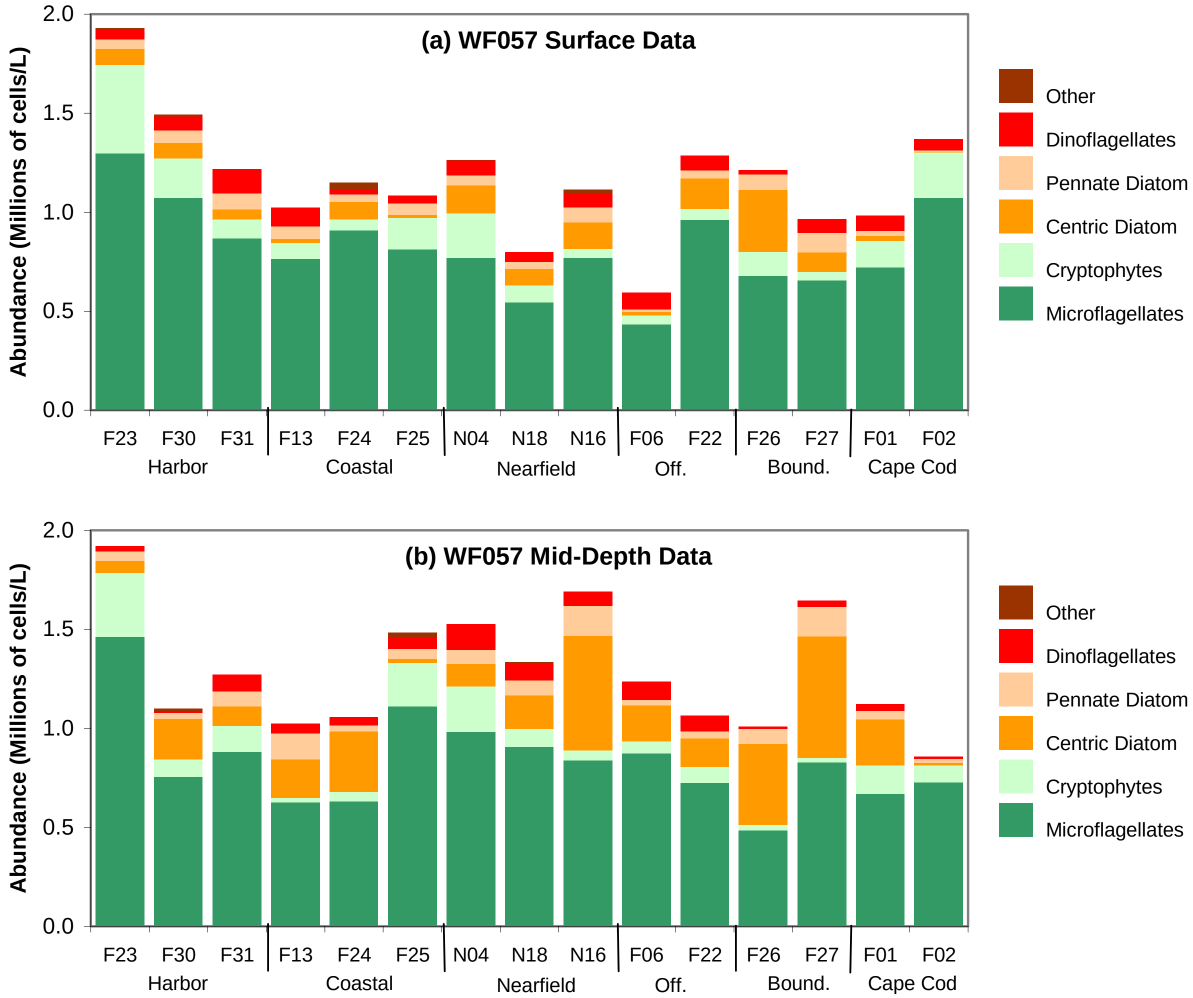


Figure 5-19. Phytoplankton abundance by major taxonomic group – WF057 farfield survey results (June 13 – 18)

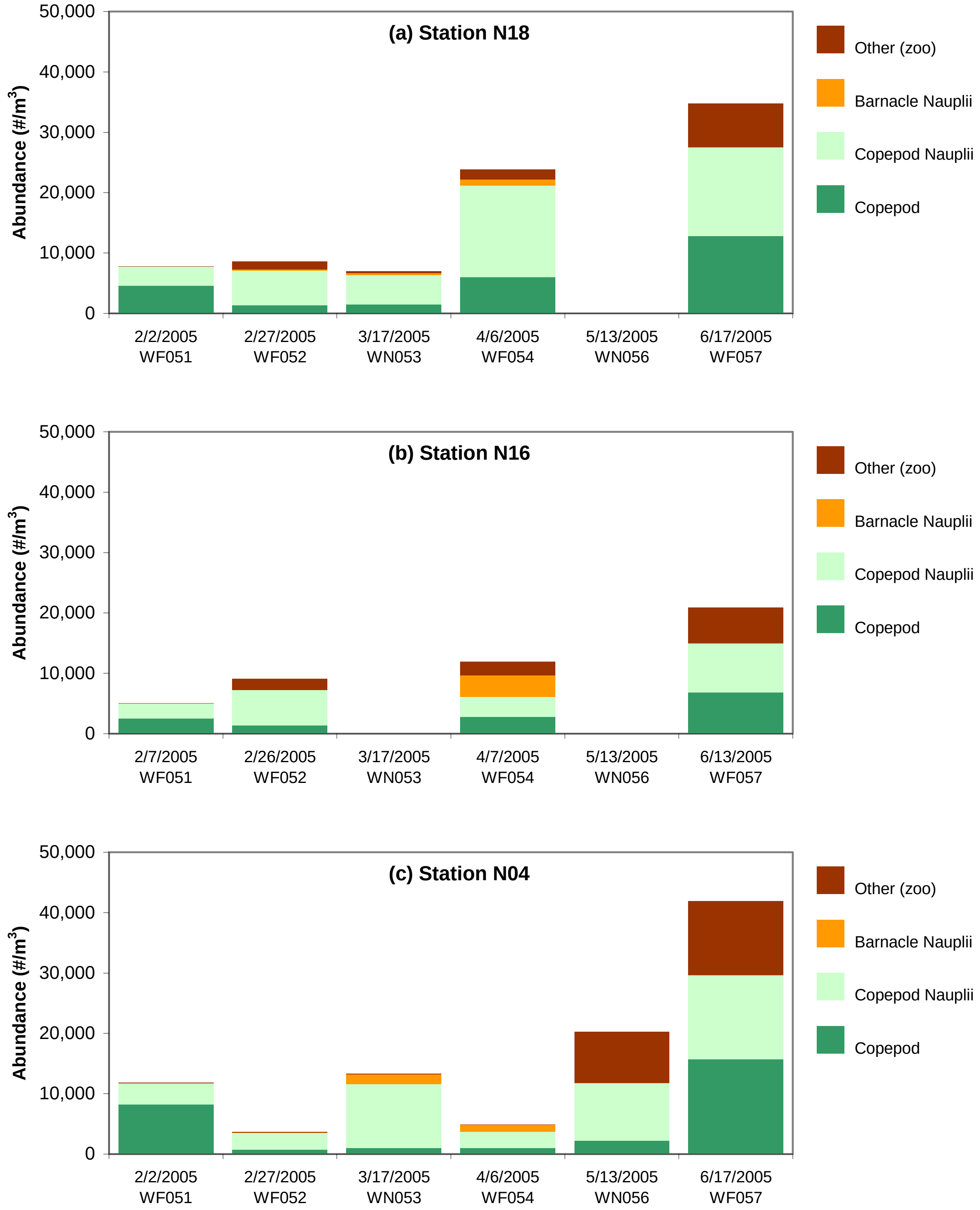


Figure 5-20. Zooplankton abundance by major taxonomic group at stations N18, N16 and N04.

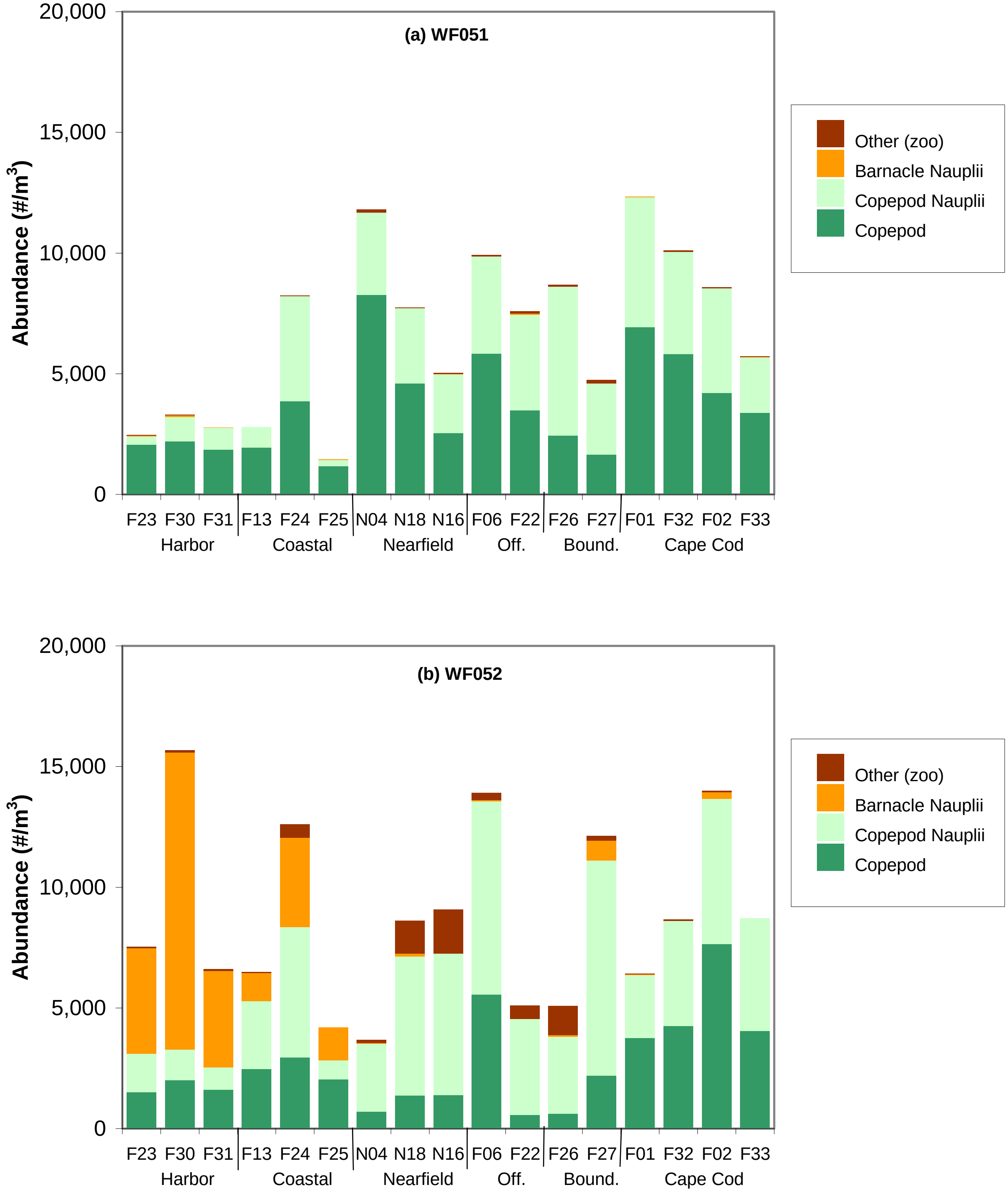


Figure 5-21. Zooplankton abundance by major taxonomic group during (a) WF051 (February 1-7) and (b) WF052 (February 23 – 27) farfield surveys

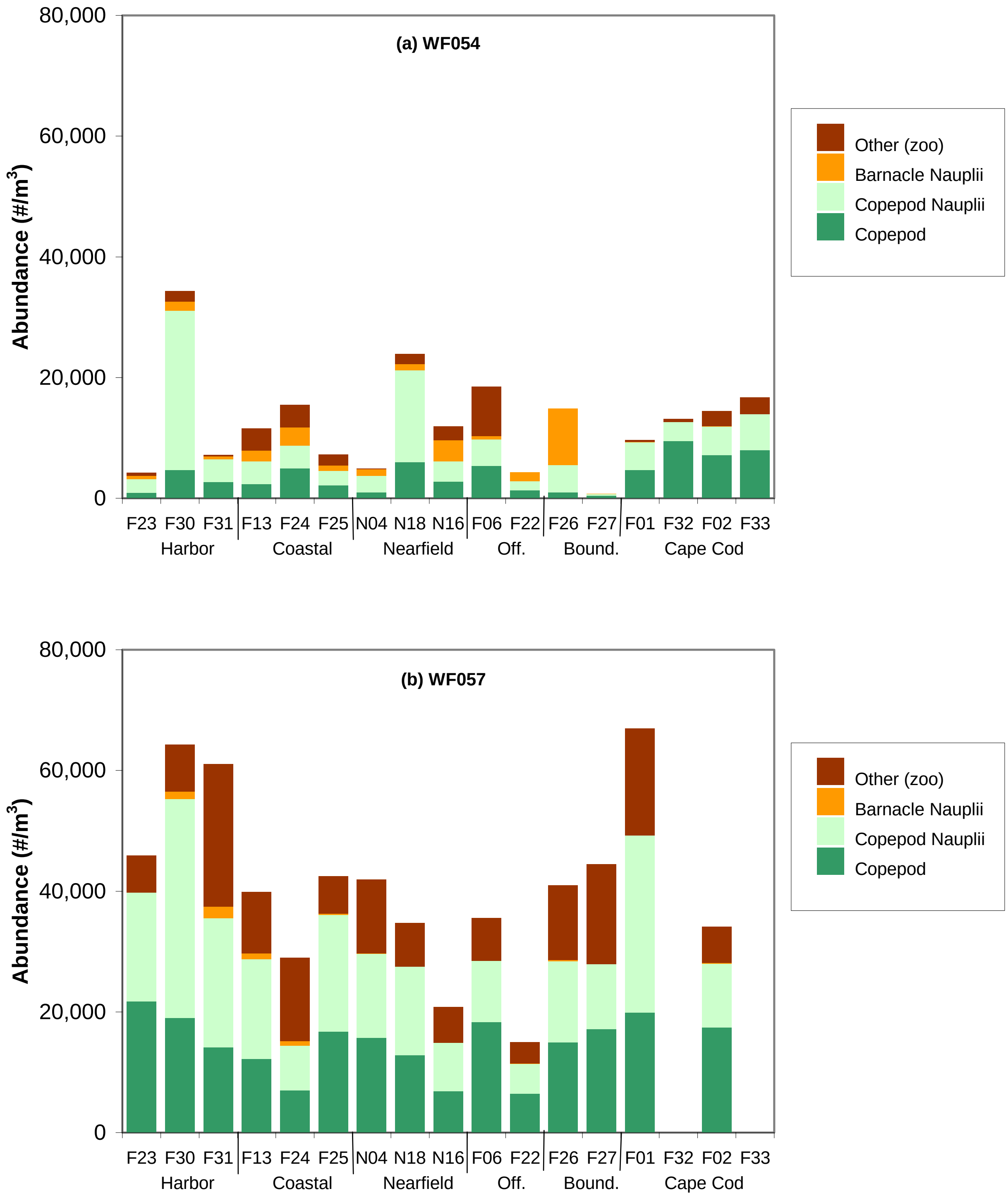


Figure 5-22. Zooplankton abundance by major taxonomic group during (a) WF054 (April 4 – 7) and (b) WF057 (June 13 – 18) farfield surveys

6.0 SUMMARY OF MAJOR WATER COLUMN EVENTS

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 2005. The most significant event in winter/spring 2005 was an unprecedented *Alexandrium* bloom that reached extraordinarily high abundances (>10,000 cells/l) throughout Massachusetts and Cape Cod Bays in May and June. This bloom triggered the *Alexandrium* Rapid Response plan and an additional eight surveys were conducted from early May to early July 2005. The data collected during these special surveys will be discussed in detail in the *Alexandrium* Bloom Interpretive Report and are not presented here. The *Alexandrium* data from the WN056 and WF057 surveys, however, represent the highest abundances ever observed during the HOM program and the first *Alexandrium* bloom of any consequence in the bays since 1993. Although the *Alexandrium* bloom was a significant event, the bloom level abundances were still a minor portion of the overall phytoplankton assemblage and had little impact on trends observed in other water quality parameters such as chlorophyll and nutrient concentrations, production, and overall phytoplankton abundance.

The winter/spring of 2005 was marked by high levels of precipitation in April and May and the occurrence of atypically late Nor'easter storms in May. The water column had begun to stratify by April as surface waters had warmed somewhat and the spring freshet decreased surface salinities further contributing to the stratification in many of the regions. In early May (5/7-5/9), a Nor'easter passed through the area with sustained winds of ~30 MPH and wave heights of 2-5m. In late May (5/24-5/26), a second Nor'easter imparted similar wind and wave conditions in the bays. This extended period of stormy weather, accented by two substantial storms, mixed the water column and broke down the developing stratification. Along with the strong mixing energy, these storms brought heavy precipitation which increased river flows and introduced large pulses of freshwater to the system. The influx of freshwater and associated nutrients have been implicated as contributing factors to an atypical late spring diatom bloom in Massachusetts Bay. Coincident with this bloom, the persistent northeast winds likely transported *Alexandrium* cells into Massachusetts Bay from the Gulf of Maine and resulted in the extraordinary *Alexandrium* bloom that occurred in the bays in May and June 2005. The early May Nor'easter has been cited as bringing the cells into the bays and the later storm with concentrating the cells to unprecedented levels along the shorelines of southern Massachusetts Bay and Cape Cod Bay (Anderson *et al.* 2005). The high precipitation and river flow in April and May 2005 led to a relatively strong salinity gradient, yet the mixing due to the Nor'easter storms in May weakened developing stratification. As a result, a strong pycnocline was not observed in the nearfield and throughout the bays until June.

The nutrient data for February to June 2005 generally followed the typical progression of seasonal events in Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. By late February there was substantial decrease in surface nutrient concentrations as diatom and *Phaeocystis* populations were increasing. There was little change in nearfield nutrient concentrations from late February to March. Stratification had not set up yet so nutrients were generally available, and the total phytoplankton abundance had changed very little. By April, surface water nutrient concentrations had decreased substantially in most areas as the *Phaeocystis* bloom reached peak measured values. Strong mixing events in mid April and early May weakened the developing stratification and likely supplied nutrients to the surface waters. By mid-May, however, surface water nutrients were relatively depleted and there was a significant reduction in nutrient concentrations (<3µM) down to nearly 30m. This widespread nutrient reduction was likely due to the rapid nutrient utilization of an increasing diatom population. By June, nutrient concentrations were generally depleted in the surface waters throughout the entire study area.

In general, chlorophyll fluorescence followed trends typically observed in the bays during the winter/spring. Low fluorescence values were seen in early February, but by late February chlorophyll fluorescence reached peak concentrations in association with the winter/spring diatom bloom and emerging *Phaeocystis* bloom. Fluorescence throughout the nearfield decreased considerably from late February to mid March. By April, the *Phaeocystis* and total phytoplankton abundance was at its peak. However, fluorescence values had decreased in the surface and mid depth waters across the bays. An April increase in bottom water fluorescence values was associated with an increase in phaeophytin as a percentage of total pigments, which is indicative of senescent cells. Although *Phaeocystis* bloom abundance peaked in April, it appears that the bloom may have already begun to senesce and settle out of the water column.

There was little change in nearfield chlorophyll levels from April to May even though phytoplankton abundance had decreased by 50% as a result of the major decline in the *Phaeocystis* population. This was due to an atypical late spring increase in diatom abundance. By June, chlorophyll fluorescence across the bays was either at a peak for the report period or was similar to the elevated values measured in late February. In contrast to the broad band of fluorescence seen in late February, the areas of elevated fluorescence were now a narrow subsurface band at approximately 15 to 20m. These waters exhibited elevated counts of diatoms in comparison to the April samples. Strong winds quickly mixed the water column in mid June resulting in a sharp decrease in chlorophyll concentrations between the June 14 and June 17 as represented by the data from the two sampling events at station N16 (June 13 17).

Areal production in 2005 followed patterns typically observed in prior years. Distinct winter-spring phytoplankton blooms were observed at both nearfield stations during the sampling period. In general, nearfield stations are characterized by the occurrence of a winter-spring bloom. The winter-spring blooms observed at nearfield stations in 1995-2004 generally reached values of 1200 to 4500 mg C m^{-2} d^{-1}, with bimodal peaks often occurring in February - April. The bloom in 2005 reached maximum values at the nearfield sites of ~1500 mg C m^{-2} d^{-1} with peaks observed in February, March and May. The late February and March peaks were similar to the patterns observed in the past and were representative of the early diatom bloom and the *Phaeocystis* bloom. However, the *Phaeocystis* bloom peaked in abundance in April. The difference in production rates and abundance suggests that the April survey was conducted on the tail end of this bloom (also suggested by the pigment and MODIS data). The productivity peak in the nearfield in May was atypical and the result of the additional nutrients supporting a late spring diatom bloom. Overall, the winter-spring bloom peaks at both nearfield sites in 2005 were somewhat lower than values observed during the winter-spring period in 2004 but within the range observed in earlier years (1999 to 2003).

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 typically ranged from 2000 to 5000 mg C m^{-2} d^{-1} in June-July. Peak areal production values observed in 2001 - 2004 tended to be lower (1100 - 3200 mg C m^{-2} d^{-1}) and to occur earlier in the season. The peak productivity level observed in Boston Harbor thus far in 2005 (574 mg C m^{-2} d^{-1}) is lower than those seen in all other years. 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 2005 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 remained relatively constant from February to April before decreasing to minimum levels for this time period in June. Percent saturation levels were relatively high throughout this period becoming only slightly undersaturated in June. This was likely due to the combination of multiple blooms (diatoms, *Phaeocystis* and then diatoms again) and strong mixing events in both May and June. Overall, the mean bottom water DO concentrations in June 2005 were relatively high and uniform across the survey area.

Whole-water phytoplankton assemblages during the first half of 2005 were dominated by unidentified microflagellates and *Phaeocystis pouchetii*. The main deviations from the typical assemblage were the secondary diatom and *Alexandrium* blooms in Massachusetts Bay in May and June. A minor winter/spring diatom bloom was observed in late February along with the beginning of the *Phaeocystis* bloom. *Phaeocystis* abundance increased in March and by April a nearfield maximum in *Phaeocystis* abundance of 2.7×10^6 cells L^{-1} was observed at station N18 in the mid-depth waters. Higher abundances (>3×10^6 cells L^{-1}) were measured in the mid-depth waters at offshore station F22 and northern boundary stations F26 and F27 off of Cape Ann. As observed during the previous blooms, the 2005 *Phaeocystis* bloom was a regional event with elevated abundances measured throughout the bays. The continued occurrence of spring *Phaeocystis* blooms in six consecutive years (2000 to 2005) 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). In May and into June, storm events led to increased river flow and increased mixing both of which supplied nutrients to the surface waters which led to an atypical late spring increase in diatoms.

The May Nor'easter storms were also implicated in bringing a Gulf of Maine bloom of the toxic dinoflagellate *Alexandrium fundyense* into Massachusetts and Cape Cod Bays. The 2005 *Alexandrium* bloom produced the largest red tide in New England since 1972. The bloom extended from Maine to south of Martha's Vineyard, and prompted shellfish closures throughout the region. Typical concentrations of *A. fundyense* in most years are < 100 cells L^{-1}, but in 2005, many samples collected during the WN056 and WF057 surveys had counts of >1,000 cells L^{-1}. Additional samples collected during the *Alexandrium* Rapid Response surveys were analyzed by Don Anderson's group at WHOI and had counts of > 10,000 cells L^{-1}, with maxima in Cape Cod Bay of > 40,000 cells L^{-1}. The various environmental factors contributing to the inception, development and occurrence of this extraordinary red tide event will be examined in detail in an upcoming *Alexandrium* Interpretive Report.

Total zooplankton abundance generally increased from February through June as usual and zooplankton assemblages during the first half of 2005 were comprised of taxa recorded for the same time of year in previous years.

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

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

Parameter	Time Period	Caution Level	Warning Level	Background	2005
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 – 9.61 mg/l Stellwagen - 9.88 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 – 98.3% Stellwagen – 97.0%
Chlorophyll	Annual	118 mg/m^2	158 mg/m^2	--	--
	Winter/spring	238 mg/m^2	--	--	133 mg/m^2
	Summer	93 mg/m^2	--	--	--
	Autumn	212 mg/m^2	--	--	--
Phaeocystis pouchetii	Winter/spring	2,020,000 cells l^{-1}	--	--	438,481 cells l^{-1}
	Summer	357 cells l^{-1}	--	--	--
	Autumn	2,540 cells l^{-1}	--	--	--
Pseudo-nitzschia pungens	Winter/spring	21,000 cells l^{-1}	--	--	147 cells l^{-1}
	Summer	43,100 cells l^{-1}	--	--	--
	Autumn	24,700 cells l^{-1}	--	--	--
Alexandrium tamarense	Any nearfield sample	100 cells l^{-1}	--	--	5,162 cells l^{-1}

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 2005 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 2005 was moderate and well below the threshold. The multiple diatom blooms and the high abundances of *Phaeocystis* did not manifest as correspondingly high chlorophyll biomass nor did they lead to elevated seasonal mean values. The winter/spring mean areal chlorophyll in 2005 was comparable to those measured in 1992-1998 and 2001-2002, and 2004 and well below those for 1999, 2000, and 2003.

The elevated *Phaeocystis* counts in the nearfield in April did not lead to an exceedance of the winter/spring threshold for this species in 2005. However, the occurrence of *Phaeocystis* in a single sample from station N18 in June will lead to a possible exceedance of the low summer threshold value of 357 cells L^{-1}. The mid-depth sample from N18 was the only sample from the WF057 survey with *Phaeocystis* present and indications are that the cells were in poor condition. The summer exceedance should be considered a technical/statistical phenomenon rather than an ecologically significant one. *Pseudo-nitzschia* was observed intermittently during the first half of 2005, but at very low abundance.

The most notable event was the unprecedented *Alexandrium tamarense/fundyense* bloom in Massachusetts and Cape Cod Bays in 2005 that was part of the largest red tide in New England since 1972. Nearfield samples exceeded the threshold value of 100 cells L^{-1} during both the WN056 and WF057 surveys. In May, *Alexandrium* spp. were present in screened water samples at concentrations of 2,059-3,078 cells L^{-1} in both surface nearfield samples and at levels of 51-156 cells L^{-1} in the chlorophyll maximum samples. Cells identified as *Alexandrium fundyense* in June were present in screened water samples at levels of 376 to 5,162 cells L^{-1} in the six nearfield samples analyzed. The *Alexandrium* bloom and threshold exceedances have already been the focus of a briefing to OMSAP (August 11, 2005) and will be examined in detail in an interpretive report focused on the 2005 red tide event.

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LINK TO APPENDICES

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