Semiannual water column monitoring report

July - December 2004

Massachusetts Water Resources Authority

Environmental Quality Department
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SEMIANNUAL WATER COLUMN MONITORING REPORT

July – December 2004

Submitted to

Massachusetts Water Resources Authority
Environmental Quality Department
100 First Avenue
Charleston Navy Yard
Boston, MA 02129
(617) 242-6000

prepared by

P. Scott Libby[1]
Alex D. Mansfield[1]
Aimee A. Keller[2]
Jeff T. Turner[3]
David G. Borkman[2]
Candace A. Oviatt[2]
Claudia J. Mongin[1]

[1] Battelle Duxbury Operations
Duxbury, MA 02332

[2] University of Rhode Island Graduate School of Oceanography
Narragansett, RI 02882

[3] University of Massachusetts at Dartmouth
North Dartmouth, MA 02747

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EXECUTIVE SUMMARY

The Massachusetts Water Resources Authority (MWRA) has collected water quality data in Massachusetts and Cape Cod Bays for the Harbor and Outfall Monitoring (HOM) Program since 1992. This monitoring is in support of the HOM Program mission to assess the environmental effects of the relocation of effluent discharge from Boston Harbor to Massachusetts Bay. The data from 1992 through September 1, 2000 were collected to establish baseline water quality conditions and to provide the means to detect significant departure from the baseline. The surveys are designed to evaluate water quality on both a moderate-frequency basis for a limited area in the vicinity of the outfall site (nearfield) and a low-frequency basis over an extended area throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (farfield). This semi-annual report summarizes water column monitoring results for the six surveys conducted from July to November 2004.

Over the course of the HOM program, a general trend in water quality events has emerged from the data collected in Massachusetts and Cape Cod Bays. The trends are evident even though the timing and year-to-year manifestations of these events are variable. The summer is generally a period of strong stratification, depleted surface water nutrients, and a relatively stable mixed-assemblage phytoplankton community dominated by microflagellates. In the fall, stratification breaks down supplying nutrients to surface waters and often resulting in the development of a fall phytoplankton bloom. The lowest dissolved oxygen concentrations are usually observed in the nearfield bottom water in October prior to the fall overturn of the water column. By late fall or early winter, the water column is usually well mixed and has returned to winter conditions.

These trends were generally evident in 2004, but the most striking difference was the lack of a fall bloom. Fall blooms are a normal aspect of the seasonal biological cycle in Massachusetts Bay, although the timing of the bloom can vary from late August (2002) to as late as December (2001) and the magnitude can also be highly variable. In fall 2004, however, there was no indication in any of the phytoplankton biomass, abundance, productivity or satellite imagery data that a bloom may have occurred. It was the first year since monitoring began in 1992 not to exhibit any indications of a fall bloom.

The physical oceanographic characteristics of this period followed the typical transition from a stratified summer water column, weakening in October, to a well-mixed water column by November. Regionally, seasonal stratification had deteriorated at the coastal and Boston Harbor stations and had begun to weaken in the nearfield and offshore by October. The boundary and Cape Cod Bay stations were not sampled until November after a series of survey-delaying storms had hit the region and the water column was well mixed throughout the bays. In the nearfield, stratification had begun to weaken by late September, but a weak density gradient remained in October before returning to well mixed conditions by November. The breakdown of stratification appeared to have occurred in typical fashion supplying nutrients to the surface waters. It is unclear if there were physical oceanographic or meteorological conditions (winds, currents, upwelling/downwelling, etc.) that may have played a role in the failure of a fall bloom in 2004.

The general trend in nutrient concentrations during the 2004 July to November period was similar to previous years. Seasonal stratification led to persistent nutrient depleted conditions in the upper water column due to biological utilization and minimal mixing. It also ultimately led to a slight increase in nutrient concentrations in bottom waters. Typically, increased rates of respiration and remineralization of organic matter lead to larger increases in bottom water nutrient concentrations than observed in 2004. Respiration rates, however, were low in 2004 and the lack of a fall bloom may have reduced the organic load to the bottom. Typically, nutrient concentrations begin to increase with the breakdown of stratification. However, even though there was not a fall bloom, nearfield surface water concentrations remained depleted into October. By November, the water column had become well-mixed and nutrient levels had increased in the surface waters. The lack of a fall bloom and the persistence of low nutrient concentrations in the surface waters into October suggest that even with weakening stratification, there was little input of nutrients into the surface waters. The NH_4 plume signature in the outfall area was clearly observed and continued to be confined to within 10-20 km of the outfall. This has been the case ever since the diversion of flow from the harbor outfall to the bay outfall on September 6, 2000.

In past years, there has often been a disconnect between biological parameters associated with the fall bloom with the timing of peak chlorophyll, productivity, and phytoplankton abundance occurring during different surveys. Without a fall bloom in 2004, this was not the case as all of the biological parameters peaked in August at relatively low values and remained low throughout the fall. Chlorophyll concentrations reached a maximum of 7.4 $\mu g\ L^{-1}$ in Boston Harbor in August and never exceeded 4.5 $\mu g\ L^{-1}$ in the nearfield over the July to November time period. These low concentrations in the nearfield resulted in a seasonal mean areal chlorophyll concentration of only 44 $mg\ m^{-2}$, which is only ~20% of the fall threshold value. Areal productivity peaked in the harbor (1387 $mg\ C\ m^{-2}\ d^{-1}$) and nearfield (~1000 $mg\ C\ m^{-2}\ d^{-1}$) in August and declined sharply by October. The peak productivity rates observed in the nearfield during the fall of 2004 were lower than all other years on record (1995 – 2003).

Phytoplankton abundance remained relatively consistent (1.5 to 2 million cells L^{-1}) in the nearfield from August to October and was consistently dominated by microflagellates and cryptomonads with only sporadic elevated abundances of diatoms. SeaWiFS imagery indicates that except for a brief, moderate increase in nearshore chlorophyll levels in early October, chlorophyll concentrations were low across the region from September to December (Appendix D). Thus any suggestion that the change in survey schedule (lengthening the period between the fall surveys) may have missed sampling during the fall bloom is not valid.

Dissolved oxygen concentrations were relatively high during the fall of 2004. This may have been due to a lack of organic material without a fall bloom or due to physical oceanographic conditions. The survey mean bottom water minima for DO concentrations and percent saturations were well above threshold values in the nearfield and Stellwagen Basin.

Zooplankton assemblages during the second half of 2004 were comprised of taxa typically recorded for this time of year. As observed in recent years, there was a sharp decline in zooplankton abundance from July/August to October. In both 2002 and 2003, there were indications that the presence of ctenophores led to increased predation and low zooplankton abundances during the October surveys of those years. The low zooplankton abundances were also cited as factors in the development of the fall blooms during those years. In 2004, there was no clear indication of ctenophore predation. Although ctenophore predation may still have been a factor, the lack of a fall bloom likely exerted some degree of bottom-up control of zooplankton in 2004.

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1.0 INTRODUCTION

1.1 Program Overview

The Massachusetts Water Resources Authority (MWRA) is conducting a long-term Harbor and Outfall Monitoring (HOM) Program for Massachusetts and Cape Cod Bays. The objective of the HOM Program is to (1) verify compliance with National Pollutant Discharge Elimination System (NPDES) permit requirements; (2) evaluate whether the impact of the discharge on the environment is within the bounds projected by the EPA Supplemental Environmental Impact Statement (SEIS; EPA 1988), and (3) determine whether change within the system exceeds the Contingency Plan thresholds (MWRA 2001). A detailed description of the monitoring and its rationale is provided in the Effluent Outfall Monitoring Plan developed for the baseline period and the post discharge period Monitoring Plan (MWRA 1991 and 1997). A comprehensive review of the data to date in June 2003 led to revisions to the Ambient Monitoring Plan (MWRA 2004) that were first implemented in 2004. The changes to the water column monitoring program include reducing the number of nearfield surveys from 17 to 12 and reducing the number of nearfield stations from 21 to 7. These changes were based on both a qualitative and statistical examination of baseline and post-discharge data (MWRA 2003). For the July to December time period, four surveys were dropped: one each in July (WN0X8), August (WN0XA), November (WN0XG), and December (WN0XH).

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 a moderate-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 July through November 2004 (**Table** 1-1).

Table 1-1. Water Quality Surveys for WN049-WF04F July to November 2004

Survey[1]	Type of Survey	Survey Dates
WN049	Nearfield	July 20
WF04B	Nearfield/Farfield	August 17-19
WN04C	Nearfield	September 1
WN04D	Nearfield	September 27
WF04E	Nearfield/Farfield	October 18-19
WF04F[2]	Nearfield/Farfield	November 10-18

[1] Surveys WN048, WN04A, WN04G, and WN04H were dropped based on recommendations made by OMSAP (MWRA 2004).
[2] Weather delays postponed sampling at half of the farfield stations from WF04E until WF04F.

The bay outfall became operational on September 6, 2000. The six surveys conducted during this semiannual period are the fifth set of autumn 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 July to November 2004. Preliminary comparisons against baseline data are discussed and relevant threshold values for this period presented. A detailed evaluation of 2004 versus the baseline period (1992-2000) will be presented in the 2004 annual water column report.

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

1.2 Organization of the Semiannual Report

The scope of the semiannual report is focused primarily towards an initial compilation of the water column data collected during the reporting period. Secondarily, integrated physical and biological results are discussed for key water column events and potential areas for expanded discussion in the annual water column report are recommended. The report first provides a summary of the survey and laboratory methods (Section 2). The bulk of the report presents results of water column data from the last six surveys of 2004 (Sections 3-5). The major findings of the semiannual period are summarized in Section 6.

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

Sections 4 (Results of Water Column Measurements) and 5 (Productivity, Respiration, and Plankton Results) include preliminary interpretation of the data with selected graphic representations of the horizontal and vertical distribution of water column parameters in both the farfield and nearfield. The horizontal distribution of physical parameters is presented through regional contour plots. The vertical distribution of water column parameters is presented using time-series plots of averaged surface and bottom water column parameters and along vertical transects in the survey area (**Figure** 1-2). The time-series plots utilize average values of the surface water sample (the "A" depth, as described in Section 3), and the bottom water collection depth (the "E" depth). Examining data trends along four farfield transects (Boston-Nearfield, Cohasset, Marshfield and Nearfield-Marshfield), and one nearfield transect, allows three-dimensional presentation of water column conditions during each survey. One offshore transect (Boundary) enables analysis of results in the outermost boundary of the survey area during farfield surveys.

Results of water column physical, nutrient, chlorophyll, and dissolved oxygen data are provided in Section 4. Survey results were organized according to the physical characteristics of the water column during the semiannual period. The timing of water column vertical stratification, and the physical and biological status of the water column during stratification, significantly affects the temporal response of the water quality parameters, which provide a major focus for assessing effects of the outfall. This report describes the horizontal and vertical characterization of the water column during the summer stratified period (WN049 – WN04D), the initial deterioration of stratification (WF04E), and the eventual return to well-mixed, winter conditions in November (WF04F). Time-series data are commonly provided for the entire semiannual period for clarity and context of the data presentation.

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

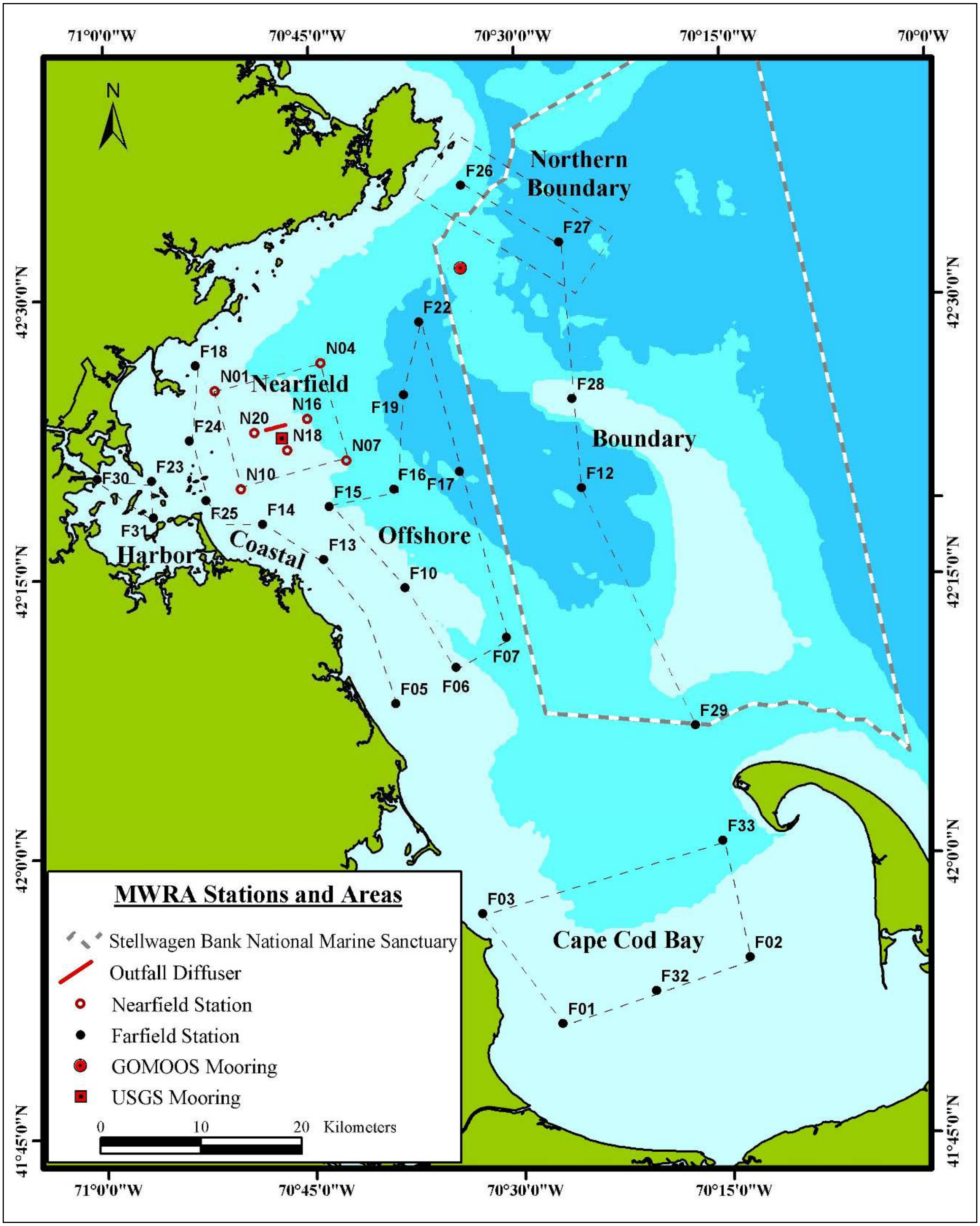


Figure 1-1. Locations of farfield stations and regional station groupings

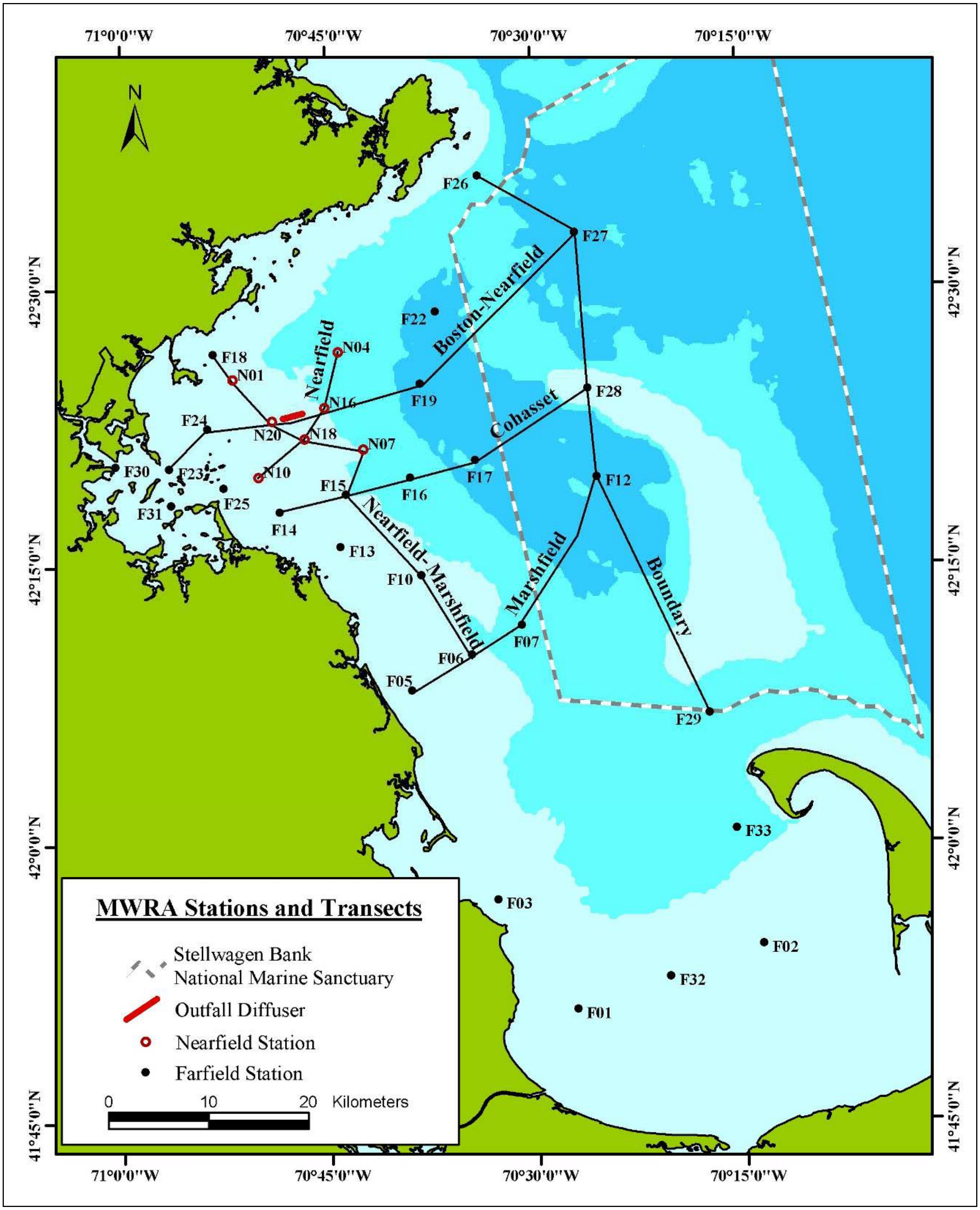


Figure 1-2. Locations of stations and selected transects

2.0 METHODS

This section describes general methods of data collection and sampling for the last six water column monitoring surveys of 2004. Section 2.1 describes data collection methods, including survey dates, sampling platforms, and analyses performed. Section 2.2 describes the sampling schema undertaken, and Section 2.3 details specific operations for this 2004 semiannual period. Specific details of field sampling and analytical procedures, laboratory sample processing and analysis, sample handling and custody, calibration and preventative maintenance, documentation, data evaluation, and data quality procedures are discussed in the Water Quality Monitoring CW/QAPP (Libby *et al.* 2005).

2.1 Data Collection

The farfield and nearfield water quality surveys for 2004 represent a continuation of the water quality monitoring conducted from 1992 - 2004. On September 6, 2000, the offshore outfall went online and began discharging effluent. The baseline monitoring period includes surveys from February 1992 to September 1, 2000. The last five fall 2000 surveys represented the beginning of the outfall discharge monitoring period, which continued in 2001, 2002, 2003 and 2004. The data collected during outfall discharge monitoring are evaluated internally and against baseline data. Data collection methods and schema did not change from the baseline for the first three years after the outfall came online. In 2004, however, the number of nearfield surveys and stations was reduced (MWRA 2004). This change was supported by statistical analysis of baseline and post-discharge data collected from 1992-2002, which indicate that there will be little loss of information or in the ability of the monitoring program to detect changes.

Water quality data for this report were collected from the sampling platform 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 (winter/spring surveys only). 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 respiration bottles were started within 30 minutes of sample collection. The 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 WN049, WF04B, WN04C, and WN04D had no effect on the data or data interpretation. For additional information about a specific survey, the individual survey reports may be consulted. In October, inclement weather led to the delay in sampling at approximately half of the WF04E farfield stations until the November survey. The overall impact of this delay on the interpretations in this report was minimized by geographic breakdown of stations sampled on each survey. The nearfield stations were sampled during both surveys. During WF04E, the farfield stations sampled were primarily located in Boston Harbor (F23, F30, and F31) and the coastal and offshore waters of western Massachusetts Bay (F13, F14, F15, F16, F17, F18, F19, F22, and F24). In November, the remaining farfield stations were sampled along the boundary transect (F26, F27, F28, F12, and F29), in southern Massachusetts Bay (F05, F06, and F07), one coastal station (F25), and the Cape Cod Bay stations (F01, F02, and F03). Thus, the typical regional groupings (see **Figure** 1-1) were sampled during one of the two surveys and are interpreted herein in that manner.

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[2]		●			●	●		
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 Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.6	0.3	0.5	1	1	4	1	4	1	1	1	1
			1_Bottom	8.5	2	1	1	1	2	2	2	1	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	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	RE	AP	IC
			6_Net Tow															1			
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F14	20	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F15	39	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F16	60	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F17	78	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F18	24	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	7	2	1	1	1	2	2	2	1	1						6		
			2_Mid-Bottom	2	1	1						1		1							
F19	81	A	3_Mid-Depth	7	2	1	1	1	2	2	2	2	2						6		
		+R	4_Mid-Surface	2	1	1						1		1							
			5_Surface	7	2	1	1	1	2	2	2	1	1		1				6		
			1_Bottom	7.9	2	1	1	1	2	2	2	1	1	3							
			2_Mid-Bottom	2.5	1	1						1		1							
F22	80	D	3_Mid-Depth	14	2	2	1	1	2	2	2	2	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	18	3	1	1	1	2	2	2	1	1						6	1	1
		D	2_Mid-Bottom	8.5	1	1						1		1						1	2
F23	25	+R	3_Mid-Depth	24	3	1	1	1	2	2	2	2	1			1	1		6	1	1
		+P	4_Mid-Surface	7.5	1	1						1		1						1	1
			5_Surface	23	3	1	1	1	2	2	2	1	1		1	1	1		6	1	1
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	1	3							
			2_Mid-Bottom	2.5	1	1						1		1							
F24	20	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	9.9	2	1	1	1	2	2	2	1	1	1							
			2_Mid-Bottom	2.5	1	1						1		1							

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	RE	AP	IC
F25	15	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	15	2	1	1	1	2	2	2	1	1	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	1	1							
			2_Mid-Bottom	2.5	1	1						1		1							
F26	56	D	3_Mid-Depth	15	2	1	1	1	2	2	2	2	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	1	1	1	1				
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	1	1							
			2_Mid-Bottom	2.5	1	1						1		1							
F27	108	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	1	1	1	1				
			6_Net Tow															1			
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F28	33	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	2	1	1								1							
			2_Mid-Bottom	2	1	1								1							
F29	66	F	3_Mid-Depth	2	1	1								1							
			4_Mid-Surface	2	1	1								1							
			5_Surface	2	1	1								1	1						
			1_Bottom	9.9	2	1	1	1	2	2	2	1	1	3							
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	1	1		1	1				
F30	15	G	5_Surface	15	2	1	1	1	2	2	2	1	1	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	9.9	2	1	1	1	2	2	2	1	1	3							
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	1	1		1	1				
F31	15	G	5_Surface	15	2	1	1	1	2	2	2	1	1	3	1	1	1				
			6_Net Tow															1			
F32	30	Z	5_Surface												1						
			6_Net Tow															1			
F33	30	Z	5_Surface												1						
			6_Net Tow															1			
			1_Bottom	8.1	2	1	1	1	2	2	2	1	1	1							
			2_Mid-Bottom	2.5	1	1						1		1							
N16	40	D	3_Mid-Depth	15	2	2	2	2	2	2	2	2	1	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	1	1	1	1	1				
			6_Net Tow															1			
					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 2004 database and organized to facilitate regional comparisons between surveys and enable quick evaluation of results against the 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 WF04B, WF04E, and WF04F. 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 1021.5 to 1025.6 kg/m^3, meaning σ_t varied from 21.5 to 25.6.

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

Respiration rates measured at the same harbor and nearfield stations as productivity, and additionally at offshore station F19 at three water column depths sampled (surface, mid-depth and bottom) are also presented in **Table** 3-11. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Libby *et al.* 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 vertical/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, Phaeocystis pouchetii,* and *Pseudo-nitzschia pungens*), and total zooplankton (**Tables** 3-12 and 3-13).

Results for total phytoplankton and centric diatoms reported in **Table** 3-12 are restricted to whole water samples (surface and mid-depth. Results of the nuisance species *Phaeocystis pouchetii* and *Pseudo-nitzschia pungens* include the maximum of both whole water and screened analyses, at both the surface and mid-depth. Although the size and shape of both taxa might allow them to pass through the Nitex screen, both have colonial forms that in low densities might be overlooked in the whole-water samples. For *Alexandrium tamarense*, only the screened samples were reported.

3.6 Additional Data

Two additional data sources are utilized during interpretation of HOM Program water column data. Temperature and chlorophyll *a* satellite images collected near survey dates are reviewed for evidence of surface water events, including intrusions of surface water masses from the Gulf of Maine, upwelling, and regional bloom events (Appendix D). U.S. Geological Survey continuous *in situ* temperature and salinity data are 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 collected along with *in situ* fluorescence from the MWRA WETStar sensor mounted at mid-depth (13 m) on the nearfield USGS mooring. At the time of writing, mooring data for this time period were in review and not yet available to include in this semiannual. It is expected that the data will be available for review and interpretation in the 2004 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 & 0.06 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 July - November 2004.

			Temperature (°C)			Salinity (PSU)			Sigma T		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN049	7/20	5.87	18.75	12.92	31.15	32.36	31.80	22.2	25.5	23.9
Nearfield	WF04B	8/17	5.99	18.54	11.22	30.74	31.98	31.53	22.2	25.2	23.9
Nearfield	WN04C	9/1	6.85	18.05	10.84	31.24	32.15	31.81	22.6	25.2	24.3
Nearfield	WN04D	9/27	7.33	16.94	13.26	30.53	32.25	31.67	22.3	25.2	23.7
Nearfield	WF04E	10/18	8.43	13.30	12.12	31.82	32.71	32.21	23.9	25.4	24.4
Nearfield	WF04F	11/17	7.64	9.37	8.87	31.48	32.13	31.87	24.6	24.8	24.7
Nearfield	All		5.87	18.75	11.54	30.53	32.71	31.81	22.2	25.5	24.1
Boundary	WF04B	8/17-8/19	4.13	19.21	11.09	31.28	32.30	31.80	22.1	25.6	24.1
Cape Cod Bay	WF04B	8/17-8/19	7.15	20.23	13.54	31.20	31.90	31.54	21.8	24.9	23.5
Coastal	WF04B	8/17-8/19	8.03	16.90	13.49	30.66	31.78	31.33	22.4	24.7	23.4
Harbor	WF04B	8/17-8/19	15.84	16.94	16.25	29.68	30.94	30.64	21.5	22.6	22.3
Offshore	WF04B	8/17-8/19	4.04	19.33	10.58	31.16	32.28	31.77	22.1	25.6	24.2
Nearfield	WF04B	8/17-8/19	5.99	18.54	11.22	30.74	31.98	31.53	22.2	25.2	23.9
All	WF04B	8/17-8/19	4.04	20.23	12.70	29.68	32.30	31.43	21.5	25.6	23.6
Boundary	WF04E	10/18-10/19									
Cape Cod Bay	WF04E	10/18-10/19									
Coastal	WF04E	10/18-10/19	9.73	13.34	12.53	31.16	32.52	31.91	23.4	25.1	24.1
Harbor	WF04E	10/18-10/19	12.80	13.38	12.97	30.40	31.83	31.53	22.8	24.0	23.7
Offshore	WF04E	10/18-10/19	7.67	13.53	11.60	31.53	32.88	32.26	23.7	25.6	24.5
Nearfield	WF04E	10/18-10/19	8.43	13.30	12.12	31.82	32.71	32.21	23.9	25.4	24.4
All	WF04E	10/18-10/19	7.67	13.53	12.31	30.40	32.88	31.98	22.8	25.6	24.2
Boundary	WF04F	11/10-11/18	8.69	10.23	9.48	31.90	32.50	32.14	24.5	25.2	24.8
Cape Cod Bay	WF04F	11/10-11/18	8.65	9.87	9.39	31.60	31.74	31.64	24.3	24.5	24.4
Coastal	WF04F	11/10-11/18	8.36	9.68	8.81	31.03	31.74	31.54	24.0	24.6	24.4
Harbor	WF04F	11/10-11/18									
Offshore	WF04F	11/10-11/18	8.78	9.90	9.22	31.72	32.12	31.85	24.5	24.8	24.6
Nearfield	WF04F	11/10-11/18	7.64	9.37	8.87	31.48	32.13	31.87	24.6	24.8	24.7
All	WF04F	11/10-11/18	7.64	10.23	9.15	31.03	32.50	31.81	24.0	25.2	24.6

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

			Beam (m^{-1})			DO (mgL^{-1})			DO % Saturation		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN049	7/20	0.58	1.26	0.84	8.59	10.46	9.43	92.8	116.0	108.7
Nearfield	WF04B	8/17	0.54	1.32	0.83	8.39	10.13	8.99	88.2	110.8	99.9
Nearfield	WN04C	9/1	0.62	1.22	0.85	8.54	10.21	9.16	88.5	117.6	101.2
Nearfield	WN04D	9/27	0.55	1.67	0.89	7.10	8.78	8.25	75.6	107.3	96.1
Nearfield	WF04E	10/18	0.66	1.38	0.87	7.28	8.78	8.21	77.9	102.1	93.7
Nearfield	WF04F	11/17	0.65	1.84	1.06	8.16	9.39	9.03	87.2	98.0	95.6
Nearfield	All		0.54	1.84	0.89	7.10	10.46	8.84	75.6	117.6	99.2
Boundary	WF04B	8/17-8/19	0.61	1.21	0.81	8.17	10.78	9.15	82.1	115.0	101.4
Cape Cod Bay	WF04B	8/17-8/19	0.62	1.68	1.09	7.94	9.69	8.80	82.4	111.1	102.6
Coastal	WF04B	8/17-8/19	0.78	1.32	1.08	8.10	9.38	8.71	88.7	113.4	101.6
Harbor	WF04B	8/17-8/19	1.52	2.60	1.90	7.19	8.42	8.01	87.8	104.7	98.4
Offshore	WF04B	8/17-8/19	0.52	1.59	0.80	8.10	10.79	9.30	79.3	120.6	102.0
Nearfield	WF04B	8/17-8/19	0.54	1.32	0.83	8.39	10.13	8.99	88.2	110.8	99.9
All	WF04B	8/17-8/19	0.52	2.60	1.09	7.19	10.79	8.83	79.3	120.6	101.0
Boundary	WF04E	10/18-10/19									
Cape Cod Bay	WF04E	10/18-10/19									
Coastal	WF04E	10/18-10/19	0.84	1.22	1.07	6.99	8.59	8.04	75.7	100.1	92.3
Harbor	WF04E	10/18-10/19	1.22	2.24	1.47	7.72	7.96	7.87	89.3	92.0	90.9
Offshore	WF04E	10/18-10/19	0.60	1.11	0.82	7.55	8.70	8.22	78.2	101.6	92.8
Nearfield	WF04E	10/18-10/19	0.66	1.38	0.87	7.28	8.78	8.21	77.9	102.1	93.7
All	WF04E	10/18-10/19	0.60	2.24	1.06	6.99	8.78	8.08	75.7	102.1	92.4
Boundary	WF04F	11/10-11/18	0.60	1.04	0.76	7.34	9.14	8.76	77.6	98.0	94.1
Cape Cod Bay	WF04F	11/10-11/18	1.07	1.43	1.25	9.05	9.53	9.25	97.9	101.1	98.9
Coastal	WF04F	11/10-11/18	1.05	1.87	1.48	8.94	9.28	9.15	95.6	97.1	96.5
Harbor	WF04F	11/10-11/18									
Offshore	WF04F	11/10-11/18	0.72	1.21	0.98	7.31	9.20	8.81	78.0	97.3	94.0
Nearfield	WF04F	11/10-11/18	0.65	1.84	1.06	8.16	9.39	9.03	87.2	98.0	95.6
All	WF04F	11/10-11/18	0.60	1.87	1.11	7.31	9.53	9.00	77.6	101.1	95.8

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

			Fluorescence (μgL^{-1})			Chlorophyll *a* (μgL^{-1})			Phaeophytin (μgL^{-1})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN049	7/20	0.27	3.68	1.56	0.28	3.70	1.66	0.24	2.02	0.81
Nearfield	WF04B	8/17	0.02	4.21	1.12	0.13	4.26	1.53	0.24	1.37	0.56
Nearfield	WN04C	9/1	0.31	3.36	1.08	0.29	2.74	1.30	0.33	1.67	0.72
Nearfield	WN04D	9/27	0.02	3.89	0.95	0.10	3.33	1.02	0.23	1.33	0.63
Nearfield	WF04E	10/18	0.00	4.30	1.69	0.06	4.27	1.80	0.20	1.94	0.74
Nearfield	WF04F	11/17	0.29	2.04	1.12	0.36	2.10	1.19	0.27	1.03	0.64
Nearfield	All		0.00	4.30	1.25	0.06	4.27	1.42	0.20	2.02	0.68
Boundary	WF04B	8/17-8/19	0.02	6.79	1.24	0.08	3.33	1.29	0.20	1.00	0.62
Cape Cod Bay	WF04B	8/17-8/19	0.14	6.61	2.51	0.47	1.81	1.19	0.21	0.90	0.59
Coastal	WF04B	8/17-8/19	0.23	5.16	2.27	0.80	3.92	2.74	0.60	1.30	0.99
Harbor	WF04B	8/17-8/19	3.03	7.43	4.76	3.45	7.75	4.91	1.41	2.41	1.79
Offshore	WF04B	8/17-8/19	0.02	4.69	1.29	0.14	1.52	0.97	0.19	0.97	0.54
Nearfield	WF04B	8/17-8/19	0.02	4.21	1.12	0.13	4.26	1.53	0.24	1.37	0.56
All	WF04B	8/17-8/19	0.02	7.43	2.20	0.08	7.75	2.10	0.19	2.41	0.85
Boundary	WF04E	10/18-10/19									
Cape Cod Bay	WF04E	10/18-10/19									
Coastal	WF04E	10/18-10/19	0.11	4.32	2.13	0.75	4.16	2.54	0.64	1.94	1.23
Harbor	WF04E	10/18-10/19	1.00	1.81	1.48	1.40	1.81	1.64	0.90	1.54	1.16
Offshore	WF04E	10/18-10/19	0.02	4.49	1.52	0.07	1.82	0.92	0.21	0.98	0.50
Nearfield	WF04E	10/18-10/19	0.00	4.30	1.69	0.06	4.27	1.80	0.20	1.94	0.74
All	WF04E	10/18-10/19	0.00	4.49	1.70	0.06	4.27	1.72	0.20	1.94	0.91
Boundary	WF04F	11/10-11/18	0.02	2.07	1.29	0.08	1.96	1.09	0.25	0.83	0.55
Cape Cod Bay	WF04F	11/10-11/18	1.65	3.57	2.64	2.48	3.33	2.94	1.03	1.59	1.28
Coastal	WF04F	11/10-11/18	1.00	2.22	1.53	1.66	2.16	1.88	0.73	0.83	0.79
Harbor	WF04F	11/10-11/18									
Offshore	WF04F	11/10-11/18	0.31	2.36	1.35	0.72	1.66	1.23	0.52	0.85	0.71
Nearfield	WF04F	11/10-11/18	0.29	2.04	1.12	0.36	2.10	1.19	0.27	1.03	0.64
All	WF04F	11/10-11/18	0.02	3.57	1.59	0.08	3.33	1.67	0.25	1.59	0.79

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

			NH_4 (µM)			NO_2 (µM)			$NO_2 + NO_3$ (µM)		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN049	7/20	0.12	3.00	0.71	0.04	0.21	0.08	0.10	2.66	0.62
Nearfield	WF04B	8/17	0.16	11.00	3.40	0.02	0.50	0.25	0.03	4.56	1.85
Nearfield	WN04C	9/1	0.04	5.53	1.27	0.01	0.41	0.20	0.03	5.63	2.15
Nearfield	WN04D	9/27	0.17	23.60	2.55	0.01	0.50	0.19	0.05	8.14	2.36
Nearfield	WF04E	10/18	0.16	3.02	0.89	0.03	0.40	0.19	0.13	9.07	2.97
Nearfield	WF04F	11/17	0.01	8.00	2.29	0.28	0.53	0.43	3.71	6.31	4.91
Nearfield	All		0.01	23.60	1.85	0.01	0.53	0.22	0.03	9.07	2.48
Boundary	WF04B	8/17-8/19	0.12	1.99	0.52	0.01	0.38	0.14	0.02	9.28	2.98
Cape Cod Bay	WF04B	8/17-8/19	0.12	3.23	0.80	0.02	0.66	0.19	0.03	2.90	0.88
Coastal	WF04B	8/17-8/19	0.10	2.90	1.02	0.04	0.49	0.20	0.06	3.78	1.34
Harbor	WF04B	8/17-8/19	0.41	2.83	1.17	0.02	0.19	0.12	0.23	1.23	0.67
Offshore	WF04B	8/17-8/19	0.06	1.18	0.56	0.03	0.44	0.20	0.04	9.28	2.27
Nearfield	WF04B	8/17-8/19	0.16	11.00	3.40	0.02	0.50	0.25	0.03	4.56	1.85
All	WF04B	8/17-8/19	0.06	11.00	1.25	0.01	0.66	0.18	0.02	9.28	1.67
Boundary	WF04E	10/18-10/19									
Cape Cod Bay	WF04E	10/18-10/19									
Coastal	WF04E	10/18-10/19	0.10	2.26	0.95	0.12	0.50	0.29	0.37	9.00	2.97
Harbor	WF04E	10/18-10/19	1.00	3.07	1.71	0.30	0.47	0.36	2.61	4.21	3.13
Offshore	WF04E	10/18-10/19	0.01	1.06	0.26	0.08	0.38	0.17	0.12	9.78	3.63
Nearfield	WF04E	10/18-10/19	0.16	3.02	0.89	0.03	0.40	0.19	0.13	9.07	2.97
All	WF04E	10/18-10/19	0.01	3.07	0.95	0.03	0.50	0.25	0.12	9.78	3.18
Boundary	WF04F	11/10-11/18	0.01	1.12	0.36	0.02	0.38	0.31	3.82	8.71	5.07
Cape Cod Bay	WF04F	11/10-11/18	0.45	0.86	0.64	0.20	0.40	0.31	0.73	3.49	2.35
Coastal	WF04F	11/10-11/18	1.22	2.92	1.90	0.42	0.48	0.46	4.13	4.87	4.63
Harbor	WF04F	11/10-11/18									
Offshore	WF04F	11/10-11/18	0.18	1.26	0.72	0.32	0.42	0.37	2.89	8.00	4.56
Nearfield	WF04F	11/10-11/18	0.01	8.00	2.29	0.28	0.53	0.43	3.71	6.31	4.91
All	WF04F	11/10-11/18	0.01	8.00	1.18	0.02	0.53	0.38	0.73	8.71	4.30

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

			PO_4 (µM)			SiO_4 (µM)			BioSi (µM)		
Region	Survey	Dates	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Nearfield	WN049	7/20	0.24	0.84	0.46	0.51	7.87	2.10	0.26	2.35	0.86
Nearfield	WF04B	8/17	0.27	1.31	0.74	0.80	8.05	4.19	0.33	2.12	1.01
Nearfield	WN04C	9/1	0.29	1.12	0.68	2.31	7.12	4.67	0.18	1.71	0.69
Nearfield	WN04D	9/27	0.28	1.87	0.70	2.02	11.20	5.18	0.00	2.22	0.85
Nearfield	WF04E	10/18	0.38	1.09	0.63	1.40	9.97	4.03	0.34	2.76	1.43
Nearfield	WF04F	11/17	0.76	1.31	0.96	4.24	6.73	5.49	0.44	2.99	1.49
Nearfield	All		0.24	1.87	0.70	0.51	11.20	4.28	0.00	2.99	1.06
Boundary	WF04B	8/17-8/19	0.24	1.10	0.62	1.09	13.30	4.59	0.15	1.56	0.61
Cape Cod Bay	WF04B	8/17-8/19	0.24	1.03	0.57	1.68	13.70	4.73	0.16	2.54	1.14
Coastal	WF04B	8/17-8/19	0.25	0.94	0.61	0.42	7.48	3.59	1.38	2.68	1.84
Harbor	WF04B	8/17-8/19	0.49	0.88	0.64	2.61	5.13	3.75	2.52	4.52	3.69
Offshore	WF04B	8/17-8/19	0.22	1.16	0.59	0.61	15.40	3.74	0.18	2.13	0.70
Nearfield	WF04B	8/17-8/19	0.27	1.31	0.74	0.80	8.05	4.19	0.33	2.12	1.01
All	WF04B	8/17-8/19	0.22	1.31	0.63	0.42	15.40	4.10	0.15	4.52	1.50
Boundary	WF04E	10/18-10/19									
Cape Cod Bay	WF04E	10/18-10/19									
Coastal	WF04E	10/18-10/19	0.48	1.11	0.70	1.86	10.40	4.43	1.57	2.15	1.88
Harbor	WF04E	10/18-10/19	0.73	0.93	0.80	4.52	9.19	5.58	1.83	3.95	2.87
Offshore	WF04E	10/18-10/19	0.34	1.12	0.64	1.27	10.80	4.34	0.25	2.28	0.92
Nearfield	WF04E	10/18-10/19	0.38	1.09	0.63	1.40	9.97	4.03	0.34	2.76	1.43
All	WF04E	10/18-10/19	0.34	1.12	0.69	1.27	10.80	4.59	0.25	3.95	1.78
Boundary	WF04F	11/10-11/18	0.71	1.05	0.81	3.88	10.30	5.02	0.74	1.48	1.05
Cape Cod Bay	WF04F	11/10-11/18	0.73	0.80	0.76	1.29	4.81	3.45	3.09	5.20	4.12
Coastal	WF04F	11/10-11/18	0.79	0.85	0.82	5.41	6.52	5.80	1.23	1.97	1.65
Harbor	WF04F	11/10-11/18									
Offshore	WF04F	11/10-11/18	0.73	1.02	0.81	3.88	10.70	5.58	1.73	2.41	2.18
Nearfield	WF04F	11/10-11/18	0.76	1.31	0.96	4.24	6.73	5.49	0.44	2.99	1.49
All	WF04F	11/10-11/18	0.71	1.31	0.83	1.29	10.70	5.07	0.44	5.20	2.10

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

			POC (µM)			PON (µM)			PartP (µM)		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN049	7/20	8.13	38.10	20.70	0.96	4.88	2.76	0.06	0.46	0.17
Nearfield	WF04B	8/17	7.44	47.80	22.00	0.83	6.97	2.90	0.06	0.41	0.19
Nearfield	WN04C	9/1	6.63	39.20	19.04	0.77	5.74	2.73	0.06	0.27	0.17
Nearfield	WN04D	9/27	6.48	30.70	15.49	1.01	4.18	2.42	0.07	0.27	0.14
Nearfield	WF04E	10/18	5.25	26.20	15.34	0.74	4.17	2.39	0.05	0.25	0.13
Nearfield	WF04F	11/17	7.32	21.10	13.94	1.00	2.85	1.95	0.06	0.24	0.13
Nearfield	All		5.25	47.80	17.75	0.74	6.97	2.53	0.05	0.46	0.15
Boundary	WF04B	8/17-8/19	9.26	16.60	14.14	0.94	2.60	1.93	0.06	0.16	0.11
Cape Cod Bay	WF04B	8/17-8/19	13.30	25.90	19.68	1.80	3.62	2.60	0.14	0.30	0.20
Coastal	WF04B	8/17-8/19	10.90	34.40	27.58	1.49	5.53	3.93	0.11	0.36	0.25
Harbor	WF04B	8/17-8/19	30.50	40.60	37.06	4.59	6.73	5.87	0.39	0.55	0.46
Offshore	WF04B	8/17-8/19	5.27	26.40	13.94	0.60	3.06	1.84	0.05	0.27	0.14
Nearfield	WF04B	8/17-8/19	7.44	47.80	22.00	0.83	6.97	2.90	0.06	0.41	0.19
All	WF04B	8/17-8/19	5.27	47.80	22.40	0.60	6.97	3.18	0.05	0.55	0.23
Boundary	WF04E	10/18-10/19									
Cape Cod Bay	WF04E	10/18-10/19									
Coastal	WF04E	10/18-10/19	9.44	25.40	17.42	1.60	4.48	2.98	0.11	0.23	0.17
Harbor	WF04E	10/18-10/19	15.00	20.20	17.38	2.19	3.21	2.63	0.17	0.27	0.20
Offshore	WF04E	10/18-10/19	5.68	12.00	9.51	0.89	2.10	1.64	0.07	0.10	0.09
Nearfield	WF04E	10/18-10/19	5.25	26.20	15.34	0.74	4.17	2.39	0.05	0.25	0.13
All	WF04E	10/18-10/19	5.25	26.20	14.91	0.74	4.48	2.41	0.05	0.27	0.15
Boundary	WF04F	11/10-11/18	7.25	14.00	10.80	0.88	2.11	1.57	0.06	0.12	0.08
Cape Cod Bay	WF04F	11/10-11/18	14.90	30.40	22.30	2.26	4.20	3.30	0.17	0.22	0.19
Coastal	WF04F	11/10-11/18	17.40	19.20	18.10	2.26	2.72	2.52	0.15	0.19	0.17
Harbor	WF04F	11/10-11/18									
Offshore	WF04F	11/10-11/18	11.40	13.60	12.50	1.52	2.48	2.06	0.11	0.15	0.13
Nearfield	WF04F	11/10-11/18	7.32	21.10	13.94	1.00	2.85	1.95	0.06	0.24	0.13
All	WF04F	11/10-11/18	7.25	30.40	15.53	0.88	4.20	2.28	0.06	0.24	0.14

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

			DOC (µM)			TDN (µM)			TDP (µM)		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN049	7/20	78.1	120.0	92.1	7.28	19.50	10.89	0.42	1.08	0.65
Nearfield	WF04B	8/17	75.0	135.0	96.2	9.07	40.60	17.33	0.78	1.87	1.24
Nearfield	WN04C	9/1	74.9	161.0	96.2	8.57	24.80	15.23	0.74	1.50	1.10
Nearfield	WN04D	9/27	73.1	145.0	90.5	9.14	24.80	14.81	0.59	1.64	1.03
Nearfield	WF04E	10/18	72.7	101.0	87.4	10.40	21.60	15.03	0.74	1.67	1.10
Nearfield	WF04F	11/17	74.4	107.0	88.9	16.80	35.00	23.46	1.01	1.90	1.34
Nearfield	All		72.7	161.0	91.9	7.28	40.60	16.12	0.42	1.90	1.08
Boundary	WF04B	8/17-8/19	75.9	99.7	85.8	8.71	12.90	10.60	0.70	0.98	0.84
Cape Cod Bay	WF04B	8/17-8/19	75.5	96.7	90.0	9.28	18.20	12.90	0.68	1.61	1.04
Coastal	WF04B	8/17-8/19	83.3	108.0	95.4	10.30	20.80	14.43	0.88	1.57	1.11
Harbor	WF04B	8/17-8/19	102.0	120.0	106.7	11.40	17.40	14.59	1.03	1.46	1.18
Offshore	WF04B	8/17-8/19	70.8	110.0	84.5	9.21	19.30	12.49	0.62	1.46	0.96
Nearfield	WF04B	8/17-8/19	75.0	135.0	96.2	9.07	40.60	17.33	0.78	1.87	1.24
All	WF04B	8/17-8/19	70.8	135.0	93.1	8.71	40.60	13.72	0.62	1.87	1.06
Boundary	WF04E	10/18-10/19									
Cape Cod Bay	WF04E	10/18-10/19									
Coastal	WF04E	10/18-10/19	81.9	95.8	88.4	9.71	18.90	14.40	0.96	1.60	1.20
Harbor	WF04E	10/18-10/19	91.9	121.0	102.1	15.00	22.40	18.01	1.25	1.55	1.39
Offshore	WF04E	10/18-10/19	65.9	88.1	78.9	8.78	18.80	12.78	0.79	1.54	1.09
Nearfield	WF04E	10/18-10/19	72.7	101.0	87.4	10.40	21.60	15.03	0.74	1.67	1.10
All	WF04E	10/18-10/19	65.9	121.0	89.2	8.78	22.40	15.06	0.74	1.67	1.19
Boundary	WF04F	11/10-11/18	78.4	89.9	85.8	16.70	34.80	24.15	1.03	1.62	1.25
Cape Cod Bay	WF04F	11/10-11/18	81.2	91.7	86.1	11.90	18.10	14.60	1.08	1.28	1.15
Coastal	WF04F	11/10-11/18	91.7	154.0	119.6	19.80	41.10	27.77	1.18	1.31	1.24
Harbor	WF04F	11/10-11/18									
Offshore	WF04F	11/10-11/18	80.8	85.6	83.6	17.80	19.30	18.60	1.19	1.32	1.24
Nearfield	WF04F	11/10-11/18	74.4	107.0	88.9	16.80	35.00	23.46	1.01	1.90	1.34
All	WF04F	11/10-11/18	74.4	154.0	92.8	11.90	41.10	21.71	1.01	1.90	1.25

Table 3-9. Summary of total suspended solids data for July - November 2004.

Region	Survey	Dates	TSS (mgL^{-1}) Min	Max	Mean
Nearfield	WN049	7/20	0.24	1.36	0.57
Nearfield	WF04B	8/17	0.33	1.21	0.68
Nearfield	WN04C	9/1	0.12	1.57	0.64
Nearfield	WN04D	9/27	0.27	2.30	0.76
Nearfield	WF04E	10/18	0.12	1.90	0.81
Nearfield	WF04F	11/17	0.34	3.44	1.25
Nearfield	All		0.12	3.44	0.78
Boundary	WF04B	8/17-8/19	0.12	0.93	0.45
Cape Cod Bay	WF04B	8/17-8/19	0.26	2.37	1.14
Coastal	WF04B	8/17-8/19	0.95	1.74	1.32
Harbor	WF04B	8/17-8/19	2.12	4.03	3.19
Offshore	WF04B	8/17-8/19	0.12	1.24	0.40
Nearfield	WF04B	8/17-8/19	0.33	1.21	0.68
All	WF04B	8/17-8/19	0.12	4.03	1.20
Boundary	WF04E	10/18-10/19			
Cape Cod Bay	WF04E	10/18-10/19			
Coastal	WF04E	10/18-10/19	0.59	1.38	1.02
Harbor	WF04E	10/18-10/19	1.56	3.92	2.46
Offshore	WF04E	10/18-10/19	0.12	1.49	0.50
Nearfield	WF04E	10/18-10/19	0.12	1.90	0.81
All	WF04E	10/18-10/19	0.12	3.92	1.20
Boundary	WF04F	11/10-11/18	0.40	0.91	0.59
Cape Cod Bay	WF04F	11/10-11/18	1.21	1.93	1.49
Coastal	WF04F	11/10-11/18	1.46	1.66	1.54
Harbor	WF04F	11/10-11/18			
Offshore	WF04F	11/10-11/18	1.02	1.31	1.17
Nearfield	WF04F	11/10-11/18	0.34	3.44	1.25
All	WF04F	11/10-11/18	0.34	3.44	1.21

Table 3-10. Summary of production parameters alpha and Pmax data for July - November 2004. Production is only measured in nearfield and Boston Harbor (stations N04, N18, and F23).

			Alpha $[mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}]$			Pmax $(mgCm^{-3}h^{-1})$		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN049	7/20	0.003	0.038	0.020	0.40	3.40	1.97
Nearfield	WF04B	8/17	0.004	0.079	0.032	0.16	9.78	2.82
Nearfield	WN04C	9/1	0.005	0.064	0.034	0.17	5.74	2.24
Nearfield	WN04D	9/27	0.004	0.039	0.024	0.14	3.39	1.96
Nearfield	WF04E	10/18	0.005	0.079	0.044	0.27	5.77	3.71
Nearfield	WF04F	11/17	0.008	0.034	0.022	1.06	3.18	1.90
Nearfield	All		0.003	0.079	0.029	0.14	9.78	2.43
Boundary	WF04B	8/17-8/19						
Cape Cod Bay	WF04B	8/17-8/19						
Coastal	WF04B	8/17-8/19						
Harbor	WF04B	8/17-8/19	0.129	0.176	0.154	12.78	19.08	15.05
Offshore	WF04B	8/17-8/19						
Nearfield	WF04B	8/17-8/19	0.004	0.079	0.032	0.16	9.78	2.82
All	WF04B	8/17-8/19	0.004	0.176	0.093	0.16	19.08	8.93
Boundary	WF04E	10/18-10/19						
Cape Cod Bay	WF04E	10/18-10/19						
Coastal	WF04E	10/18-10/19						
Harbor	WF04E	10/18-10/19	0.035	0.058	0.045	5.58	6.42	5.84
Offshore	WF04E	10/18-10/19						
Nearfield	WF04E	10/18-10/19	0.005	0.079	0.044	0.27	5.77	3.71
All	WF04E	10/18-10/19	0.005	0.079	0.045	0.27	6.42	4.77
Boundary	WF04F	11/10-11/18						
Cape Cod Bay	WF04F	11/10-11/18						
Coastal	WF04F	11/10-11/18						
Harbor	WF04F	11/10-11/18						
Offshore	WF04F	11/10-11/18						
Nearfield	WF04F	11/10-11/18	0.008	0.034	0.022	1.06	3.18	1.90
All	WF04F	11/10-11/18						

Table 3-11. Summary of areal production, depth-averaged chlorophyll-specific production, and respiration data for July - November 2004. Production is only measured in nearfield and Boston Harbor (stations N04, N18, and F23). Respiration is measured at the production stations and at offshore station F19.

			Areal Production ($mgCm^{-2}d^{-1}$)			Depth-averaged Chlorophyll- specific Production ($mgCmgChl a^{-1}d^{-1}$)			Respiration (μMO_2h^{-1})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN049	7/20	460.3	460.7	460.5	5.9	14.8	10.4	0.005	0.152	0.075
Nearfield	WF04B	8/17	412.9	907.5	660.2	7.5	22.3	14.9	0.025	0.163	0.105
Nearfield	WN04C	9/1	481.0	536.5	508.8	6.7	13.2	10.0	0.020	0.126	0.053
Nearfield	WN04D	9/27	468.1	605.3	536.7	12.3	20.8	16.6	0.006	0.088	0.049
Nearfield	WF04E	10/18	488.0	629.4	558.7	7.0	12.7	9.9	0.013	0.092	0.047
Nearfield	WF04F	11/17	149.3	215.9	182.6	3.7	4.8	4.2	0.028	0.049	0.036
Nearfield	All		149.3	907.5	484.6	3.7	22.3	11.0	0.005	0.163	0.061
Boundary	WF04B	8/17-8/19									
Cape Cod Bay	WF04B	8/17-8/19									
Coastal	WF04B	8/17-8/19									
Harbor	WF04B	8/17-8/19	1292.5	1292.5	1292.5	11.8	11.8	11.8	0.157	0.179	0.165
Offshore	WF04B	8/17-8/19							0.029	0.161	0.074
Nearfield	WF04B	8/17-8/19	412.9	907.5	660.2	7.5	22.3	14.9	0.025	0.163	0.105
All	WF04B	8/17-8/19	412.9	1292.5	976.4	7.5	22.3	13.3	0.025	0.179	0.115
Boundary	WF04E	10/18-10/19									
Cape Cod Bay	WF04E	10/18-10/19									
Coastal	WF04E	10/18-10/19									
Harbor	WF04E	10/18-10/19	534.6	534.6	534.6	16.9	16.9	16.9	0.060	0.064	0.063
Offshore	WF04E	10/18-10/19							0.011	0.049	0.036
Nearfield	WF04E	10/18-10/19	488.0	629.4	558.7	7.0	12.7	9.9	0.013	0.092	0.047
All	WF04E	10/18-10/19	488.0	629.4	546.7	7.0	16.9	13.4	0.011	0.092	0.049
Boundary	WF04F	11/10-11/18									
Cape Cod Bay	WF04F	11/10-11/18									
Coastal	WF04F	11/10-11/18									
Harbor	WF04F	11/10-11/18									
Offshore	WF04F	11/10-11/18									
Nearfield	WF04F	11/10-11/18	149.3	215.9	182.6	3.7	4.8	4.2	0.028	0.049	0.036
All	WF04F	11/10-11/18									

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

			Total Phytoplankton (10^6 cells L^{-1})			Centric Diatoms (10^6 cells L^{-1})			Total Zooplankton (Individuals m^{-3})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN049	7/20	1.097	1.733	1.384	0.000	0.034	0.020	34276	63790	49033
Nearfield	WF04B	8/17	1.058	2.610	1.850	0.150	0.980	0.462	22354	49737	32775
Nearfield	WN04C	9/1	0.854	4.477	2.184	0.016	0.031	0.022	36930	50459	43694
Nearfield	WN04D	9/27	0.984	1.594	1.253	0.002	0.006	0.003	12438	19873	16155
Nearfield	WF04E	10/18	0.773	2.530	1.688	0.024	0.392	0.125	830	27279	10020
Nearfield	WF04F	11/17	0.662	1.960	1.334	0.009	0.033	0.021	11870	20931	16400
Nearfield	All		0.662	4.477	1.615	0.000	0.980	0.109	830	63790	28013
Boundary	WF04B	8/17-8/19	1.295	1.860	1.522	0.010	0.131	0.061	4399	68694	36546
Cape Cod Bay	WF04B	8/17-8/19	0.663	1.632	1.242	0.002	0.038	0.025	39866	40659	40262
Coastal	WF04B	8/17-8/19	1.879	2.682	2.268	0.677	0.975	0.840	44459	55843	49036
Harbor	WF04B	8/17-8/19	2.259	3.971	2.940	0.743	1.757	1.106	36347	71641	59164
Offshore	WF04B	8/17-8/19	0.994	2.363	1.478	0.010	0.158	0.049	18109	38658	28384
Nearfield	WF04B	8/17-8/19	1.058	2.610	1.850	0.150	0.980	0.462	22354	49737	32775
All	WF04B	8/17-8/19	0.663	3.971	1.883	0.002	1.757	0.424	4399	71641	41028
Boundary	WF04E	10/18-10/19									
Cape Cod Bay	WF04E	10/18-10/19									
Coastal	WF04E	10/18-10/19	1.464	2.131	1.729	0.038	0.206	0.112	28169	54512	41341
Harbor	WF04E	10/18-10/19	1.077	1.657	1.289	0.036	0.057	0.046	19114	30125	24326
Offshore	WF04E	10/18-10/19	0.973	1.228	1.101	0.003	0.021	0.012	6553	6553	6553
Nearfield	WF04E	10/18-10/19	0.773	2.530	1.688	0.024	0.392	0.125	830	27279	10020
All	WF04E	10/18-10/19	0.773	2.530	1.451	0.003	0.392	0.074	830	54512	20560
Boundary	WF04F	11/10-11/18	0.907	1.677	1.273	0.001	0.023	0.009	12359	13199	12779
Cape Cod Bay	WF04F	11/10-11/18	1.198	1.852	1.554	0.055	0.162	0.104	21627	28646	25136
Coastal	WF04F	11/10-11/18	1.243	1.555	1.399	0.021	0.036	0.028	15113	15113	15113
Harbor	WF04F	11/10-11/18									
Offshore	WF04F	11/10-11/18	0.974	1.421	1.197	0.017	0.093	0.055	24520	24520	24520
Nearfield	WF04F	11/10-11/18	0.662	1.960	1.334	0.009	0.033	0.021	11870	20931	16400
All	WF04F	11/10-11/18	0.662	1.960	1.351	0.001	0.162	0.043	11870	28646	18790

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

			***Alexandrium* spp. (cells L^{-1})**			***Phaeocystis pouchetii* (10^6 cells L^{-1})**			***Pseudo-nitzschia pungens* (10^6 cells L^{-1})**		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN049	7/20	0	0	0	0	0	0	0	0	0
Nearfield	WF04B	8/17	0	0	0	0	0	0	0	0.0057	0.0010
Nearfield	WN04C	9/1	0	0	0	0	0	0	0	0.0055	0.0020
Nearfield	WN04D	9/27	0	0	0	0	0	0	0	0	0
Nearfield	WF04E	10/18	0	0	0	0	0	0	0	0.0021	0.0007
Nearfield	WF04F	11/17	0	0	0	0	0	0	0	0	0
Nearfield	All		0	0	0	0	0	0	0	0.0057	0.0006
Boundary	WF04B	8/17-8/19	0	0	0	0	0	0	0	0	0
Cape Cod Bay	WF04B	8/17-8/19	0	0	0	0	0	0	0	0	0
Coastal	WF04B	8/17-8/19	0	0	0	0	0	0	0	0.0014	0.0002
Harbor	WF04B	8/17-8/19	0	0	0	0	0	0	0	0.0326	0.0080
Offshore	WF04B	8/17-8/19	0	0	0	0	0	0	0	0	0
Nearfield	WF04B	8/17-8/19	0	0	0	0	0	0	0	0.0057	0.0010
All	WF04B	8/17-8/19	0	0	0	0	0	0	0	0.0326	0.0015
Boundary	WF04E	10/18-10/19									
Cape Cod Bay	WF04E	10/18-10/19									
Coastal	WF04E	10/18-10/19	0	0	0	0	0	0	0	0	0
Harbor	WF04E	10/18-10/19	0	0	0	0	0	0	0	0.0012	0.0003
Offshore	WF04E	10/18-10/19	0	0	0	0	0	0	0	0	0
Nearfield	WF04E	10/18-10/19	0	0	0	0	0	0	0	0.0021	0.0007
All	WF04E	10/18-10/19	0	0	0	0	0	0	0	0.0021	0.0002
Boundary	WF04F	11/10-11/18	0	0	0	0	0	0	0	0.0005	0.0003
Cape Cod Bay	WF04F	11/10-11/18	0	0	0	0	0	0	0	0	0
Coastal	WF04F	11/10-11/18	0	0	0	0	0	0	0	0	0
Harbor	WF04F	11/10-11/18									
Offshore	WF04F	11/10-11/18	0	0	0	0	0	0	0	0	0
Nearfield	WF04F	11/10-11/18	0	0	0	0	0	0	0	0	0
All	WF04F	11/10-11/18	0	0	0	0	0	0	0	0.0005	0.0001

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 for these water column measurements is provided in Section 4.3.

Three of the six surveys conducted during this semi-annual period were nearfield only surveys. The mid-August survey was a combined farfield/nearfield survey. During the fall, weather disrupted the traditional survey schedule and portions of the farfield were sampled during the October survey (WF04E) and the November survey (WF04F). In August, during the first combined survey of this period (WF04B), summertime stratified conditions existed in the water column throughout all the open bay areas. In contrast, a very limited density gradient was seen in tidally mixed Boston Harbor. By October (WF03E) the density gradient had weakened, although moderate stratification remained in most areas except the harbor and coastal stations. In the nearfield stratification had generally weakened by late September, although fairly strong density gradient remained, and in the inner nearfield warm surface temperatures maintained strong stratification. Weak stratification persisted into October and it was not until the mid-November survey (WF04F) that fully well-mixed winter conditions were observed over the entire nearfield. This was similar timing to the 2003 fall progression.

The variation of regional surface water properties is presented using contour plots of surface 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). Vertical data is also presented across a transect which runs from the southwest corner (N10) to the northeast corner (N04) of the nearfield. Examining data trends along transects provides a three-dimensional perspective of water column conditions during each survey. Nearfield surveys were conducted more frequently than farfield surveys allowing better temporal resolution of the changes in water column parameters and the presence of stratification. In addition to the nearfield vertical transect, vertical variability in nearfield data is examined and presented by comparing surface and bottom water concentrations (A and E depths) and by plotting individual parameters with depth in the water column. A complete set of surface contour maps and vertical transect plots are provided in Appendices A and B respectively.

4.1 Physical Characteristics

4.1.1 Temperature\Salinity\Density

The breakdown of vertical stratification in the fall indicates the change from summer to winter conditions. This destabilization of the water column significantly affects a number of water quality parameters during this time period. Typically, from early September through October, the water column becomes less stratified and nutrients from the bottom waters are available to phytoplankton in the surface and mid-water depths. This often leads to the development of a fall bloom. Phytoplankton production and further mixing of the water column also serve to increase bottom water dissolved oxygen concentrations, which tend to decrease from early June through October.

The pycnocline weakens as surface water temperature declines and storms increase wind-forced mixing. In 2004 the surface and bottom water density data collected during the combined surveys indicates that seasonal stratification had begun to weaken throughout the region by the October survey. Nearfield survey activities provide a more detailed evaluation of the fall/winter overturn of the water column. For the purposes of this report, vertical stratification is defined by the presence of a pycnocline with a density (σ_t) gradient of greater than 1.0 over a relatively narrow depth range (~10 m). Using this definition, the data indicate that the pycnocline began to break down throughout the nearfield by October, but the water column was not fully mixed until the November survey. The change from stratified to well-mixed conditions in the nearfield is illustrated in **Figure** 4-1. The seasonal progression in the water column can also be seen in the contour plots of depth over time at three representative nearfield stations – N10, N18, and N04 (**Figure** 4-2). These stations represent the inshore, center, and offshore of the nearfield "box".

4.1.1.1 Horizontal Distribution

In July, during the first survey of the report period (WN049), surface water temperatures were homogeneous and relatively high (17–19°C) throughout the nearfield area. This same range of temperatures was found throughout the nearfield during the August combined survey (WF04B). The range of farfield temperatures during this survey was somewhat greater, with an upwelling signature of cooler temperatures (<16°C) found along coastal stations and near the mouth of the harbor, and the warmest temperatures (19–20°C) found further offshore and into Cape Cod Bay (see Appendix A). Nearfield surface temperatures in early September (WN04C) were still elevated for the most part (17–18°C), although at the inshore corner station N10 temperatures were reduced to <14°C. At the end of September (WN04D) nearfield surface temperatures had declined, but were homogeneous throughout the area with a range of 16 to 17°C. As expected, surface temperatures continued to decline throughout the remainder of the fall. The range of temperatures in October had had been reduced to 12–13.5°C, and by November the range was 8–10°C. Although comparison of these surveys is limited by the different stations sampled, the general trend was cooler temperatures along the coast increasing towards the offshore areas.

During the July survey a salinity gradient was seen in the surface waters of the nearfield. The western stations were at approximately 31.2 PSU, and the easternmost stations were about 0.5 PSU higher. During the combined survey conducted in August this gradient could be seen more clearly, with the lowest salinities found in the inner harbor (29.7 PSU at F30) and higher salinities found beyond the nearfield at about 31.3 PSU (see Appendix A). Surface salinity patterns during both September surveys were similar, with low values found at inshore station N10 and fairly homogeneous values found throughout the rest of the area. The range was more pronounced in late September survey (30.5–31.5 PSU) than the earlier survey (31.2–31.6 PSU). The harbor to offshore salinity gradient that had been observed on earlier surveys remained throughout the fall, with the highest salinities found in the Northeast corner and lowest salinities found in and around the harbor (Appendix A).

Precipitation and stream flows were normal or above normal for most of the report period and throughout the entire water year (October 2003–September 2004; Massachusetts Department of Environmental Management). The exception was October which had very low precipitation, although stream flow remained in the normal range during this period. Freshwater signatures from stream flow and runoff were not as apparent in the salinity data as in other normal or wet years. This was likely due to the timing of precipitation events and greater spacing in the new sampling schedule. Most of the high flow events did not occur during or near sampling surveys (**Figure** 4-3). In fact the highest stream flows occurred in December, after the final survey of the year had been conducted.

4.1.1.2 Vertical Distribution

Farfield. The temporal and spatial variability during the seasonal return to well-mixed winter conditions can be observed in the vertical contour plots of temperature, salinity, and sigma-*t* provided in Appendix B. Additionally, **Figure** 4-4 shows the mean surface and bottom water densities at each of the five farfield regions during the farfield surveys of this report period (note that the weather issues during the fall farfield resulted in different timing in the sampling of various stations). The water column was stratified throughout the bays during the summer of 2004, but not in Boston Harbor. During the August farfield survey (WF04B), the water column was strongly stratified along each of the transects (although not into the harbor) with a sharp pycnocline present at approximately 10–15 m. The density gradient was driven primarily by temperature, which exhibited approximately a 10°C difference between the surface and bottom layers along all transects except at the harbor stations. The density gradient was somewhat weaker at the inshore stations due to slightly cooler surface water temperatures. Moderate salinity gradients were seen in most areas and appear to have played a limited role in the stratification. The strong freshwater signature that was seen in the surface waters in many areas during the previous summer was not evident. A low salinity signature was seen in the harbor, but this did not extend out into Massachusetts Bay.

By October (WF04E), the density gradient had weakened considerably across the sampled areas. Weak stratification was still evident in the offshore region and along the Nearfield-Marshfield transect. The harbor, which had been fairly well-mixed even in August, showed no stratification. A weak salinity gradient persisted in the coastal and offshore areas which may have helped maintain the slight stratification. Stations in Cape Cod Bay and along the Boundary area were not sampled in October. The water column was well-mixed by the time these stations were sampled in mid-November.

The return to winter conditions and the change in temperature relative to salinity can typically be seen by examining the temperature-salinity (T-S) relationship for the region. In August, the T-S pattern is indicative of the vertical stratification that exists in the bays during the summer season (**Figure** 4-5). Surface water temperatures were generally 16–20°C and bottom waters were generally 4–10°C. Salinity varied over a moderate range throughout the water column (29.7–32.3 PSU). There was a negative relationship between these parameters as an increase in salinity with depth was coincident with a decrease in temperature. This summertime inverse T-S relationship was seen in all of the open bay areas, but was not present in the harbor. In the harbor, salinities ranged from 29.7–30.9 PSU over a very narrow range of water column temperatures (16–17°C). By October, the range in overall water column temperatures had decreased (8–14°C) as surface water temperatures had cooled and bottom water temperatures increased. Salinity had increased somewhat, but the range remained about the same (30.4–32.9 PSU) and the resulting T-S pattern in most regions continued to exhibit the summer signature of increasing salinity corresponding to decreasing temperature from the surface to the bottom waters. It was apparent, however, that summer conditions were breaking down and portions of the nearfield, coastal, and offshore areas no longer displayed a strong negative T-S relationship. Boston Harbor remained well-mixed with minimal variation in temperature across a relatively wide range in salinity. Strong fall storms in October postponed the remainder of the WF04E sampling. By the time sampling resumed for the modified WF04F survey, these storms had contributed to a thoroughly mixed water column in all of the survey areas.

Nearfield. The gradual breakdown of seasonal stratification in 2004 and the eventual return to winter conditions can be observed more clearly from the data collected in the nearfield area. The nearfield surveys are conducted on a more frequent basis and provide a more detailed picture of the physical characteristics of the water column. In July a broad pycnocline was present with a $\Delta\sigma_t$ of ~2.5 across the entire water column. The density change was fairly gradual and from the surface down to 20–30m (**Figure** 4-6). Stratification in the nearfield strengthened as the summer progressed. Although the overall $\Delta\sigma_t$ remained at July levels (~2.5) through the nearfield water column, the pycnocline had compressed somewhat and a sharp density gradient was seen at approximately 10–15m. Stratification remained strong in September throughout most of the nearfield, although cold surface temperatures were found in the inner nearfield (N10) at this time leading to weak stratification in this area. This cold water signature in the southwestern nearfield was most likely associated with tidal exchange with harbor or coastal waters that is often observed at station N10. The harbor signature was not present in the late September survey, and conditions were fairly uniform throughout the nearfield. Moderate stratification was still present in all areas of the nearfield with $\Delta\sigma_t$ at ~2 over the entire water column. Pycnocline structure was breaking down, and this density gradient was found across a broad band from approximately 10–30m (**Figure** 4-7). In the subsequent three weeks, fall storms resulted in considerable mixing especially in the upper portions of the water column. A weak pycnocline ($\Delta\sigma_t$ ~1.1) persisted at approximately 30m in the deeper portions of the nearfield. High winds and waves associated with several fall storms continued through the majority of late October and early November. This resulted in a thoroughly mixed nearfield water column by the last survey of the report period (WF04F).

The vertical density gradient is predominantly driven by temperature during the summer and fall. The 2004 data show this typical response. The seasonal progression of water column temperatures can be seen in the plots of average surface and bottom water temperatures throughout the report period (**Figure** 4-8). In July and August, there was a strong vertical temperature gradient, with bottom temperatures between 6.8 and 9.9°C, and surface temperatures between 17.3 and 18.8°C. The most notable change between July and August was the tightening of the thermocline in August. Although surface and bottom temperatures had not changed, the thermocline became much sharper and was located in a narrow band at about 10–15m. The thermocline had weakened considerably by early September with a decrease in surface temperatures observed throughout the nearfield, but most noticeably in the southwestern corner. By late September surface temperatures in the nearfield (including the inner portion) were at 16°C. Bottom water temperatures were increasing by this survey (8.2–11.1°C). A clear thermocline was still present below 20m, but it had weakened considerably. As the fall progressed, surface water temperatures continued to decrease due to atmospheric cooling and mixing. By the October survey, the shallow area of the inner nearfield (station N10) had become thoroughly mixed. A 4°C temperature differential between surface and bottom temperatures existed throughout the rest of the nearfield with a weak thermocline at about 30m deep. By November, the water column was thoroughly mixed with surface and bottom water temperatures uniform throughout the nearfield.

In addition to the harbor, coastal and offshore influences on nearfield physical conditions, MWRA effluent has been discharging directly into the nearfield area since the transfer from the harbor outfall to the bay outfall on September 6, 2000. Plume tracking studies and monitoring data have indicated that the region of rapid initial dilution is tightly constrained to the local area around the diffuser. Even so, the salinity data often shows an effluent derived influence albeit at very high dilutions. In the second half of 2004, the salinity signal from the discharge could be seen during several of the nearfield surveys (see Appendix B). The salinity signal was not as strong as in previous years where survey activity coincided with periods of elevated precipitation and the associated high effluent flow rates from DITP. As discussed in Section 4.1.1.1, timing of the 2004 fall surveys did not capture many of the high flow periods in the second part of 2004.

4.1.2 Transmissometer Results

Water column beam attenuation was measured synoptically 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 particulate concentration in the water column. The two primary sources of particles in coastal waters are biogenic material (plankton or detritus) and suspended sediments. Beam attenuation data is often evaluated in conjunction with fluorescence data to ascertain the source of the particulate materials (phytoplankton versus detritus or suspended sediments).

In July, the typical trend could be seen, with surface water beam attenuation highest in Boston Harbor (Max = 2.00 m^{-1} at F31) and a gradient of decreasing concentrations towards the offshore stations (Min = 0.71 at F27; Appendix A). This trend in high beam attenuation values was similar to trends in surface fluorescence and phytoplankton abundance which were both high in the harbor at this time. During the October farfield survey, the highest beam attenuation values were again observed in the harbor (2.16 m^{-1} at F30) and decreased to minimum values offshore (0.69 m^{-1} at F17) (boundary and Cape Cod Bay areas were not sampled during this time). Unlike August, this survey showed an uncoupling of beam attenuation from fluorescence and phytoplankton abundance. In the coastal and nearfield regions, phytoplankton abundance and fluorescence were slightly higher than in other areas. This indicates that the harbor beam attenuation signal was likely associated with suspended sediment as opposed to biogenic material. Harbor stations were not sampled during the continuation of the farfield survey in November so it is difficult to compare the beam attenuation trends with earlier in the year. During this survey elevated beam attenuation values (>1 m^{-1}) were found in the western nearfield (Max = 1.74 m^{-1} at N10) and along the coast from Nahant south into Cape Cod Bay, and decreased along a gradient to the offshore areas. This generally corresponded well with fluorescence and phytoplankton abundance which were at peak values in Cape Cod Bay but also were at elevated levels along the coast.

In general, vertical and horizontal trends in beam attenuation are dependent upon the input of particulate material from terrestrial sources and the distribution of chlorophyll/phytoplankton. **Figure 4-9** presents beam attenuation and fluorescence data along the Boston-Nearfield transect in August. These contour plots clearly show the inshore or harbor signature of high beam attenuation and its influence on nearshore stations. By comparing this with fluorescence data along the same transect it is possible to separate the relative contribution of chlorophyll versus particulate material to the beam attenuation signal. Beam attenuation and fluorescence at the eastern (offshore) portion of the transect corresponded well, indicating that the majority of the particulate matter was biogenic in nature. At the western end of the transect, near the harbor, beam attenuation values are higher than expected based strictly on the fluorescence signature, indicating that suspended sediments or other non-biogenic material contributed a large portion of the transmissometer signal in the harbor.

4.2 Biological Characteristics

4.2.1 Nutrients

Nutrient data were analyzed using scatter plots of nutrient depth distribution, nutrient/nutrient relationships, and nutrient/salinity relationships. Surface water contour maps (Appendix A) and vertical contours of nutrient data from select transects (Appendix B) were produced to illustrate the spatial variability of these parameters. Dissolved inorganic nitrogen (DIN), nitrate (NO_3), ammonium (NH_4), phosphate (PO_4), and silicate (SiO_4) are all discussed.

The general trend in nutrient concentrations during the 2004 July to November period followed typical fall patterns. Seasonal stratification led to nutrient depleted conditions in the upper water column and ultimately to a slight increase in nutrient concentrations in bottom waters. Typically increased rates of respiration and remineralization of organic matter associated with the fall bloom typically lead to substantial increases in bottom nutrient concentration. In 2004 no fall phytoplankton bloom occurred, respiration rates were very low as compared to previous years, and as a result only slight nutrient increases were seen in the deeper waters. By October surface nutrient concentrations began to increase in some areas with the weakening of stratification and mixing. However, nutrients remained generally low in surface waters until November when the water column had become fully mixed. This inhibition of nutrient flux into surface waters may have contributed to the lack of a fall bloom in 2004.

Elevated concentrations of ammonium continued to be measured within the nearfield due to the diversion of flow from the harbor outfall to the bay outfall on September 6, 2000. The NH_4 plume signature was clearly observed within 10-20 km of the outfall area.

4.2.1.1 Horizontal Distribution

The horizontal distribution of nutrients is displayed through a series of surface contour plots in Appendix A. In August (WF04B), surface water nutrient concentrations were depleted throughout most of the survey area. The only area of consistently elevated surface nutrients during this time was the inner harbor (station F30; DIN = 3.1 μM, SiO_4 = 4.7 μM, PO_4 = 0.79 μM, and NH_4 = 1.9 μM). DIN was generally <1 μM, although small patches of elevated NH_4 resulted in a few DIN values between 1 and 2.5 μM. Phosphate was <0.8 μM in all areas, and was mostly <0.4 μM. As is often found this time of year, only SiO_4 remained at slightly elevated concentrations in the surface waters (**Figure** 4-10). Summer nutrient concentrations were kept low in the surface waters by strong stratification. Similar to 2003, fluorescence and phytoplankton abundance were low throughout the region in August 2004. Boston Harbor stations showed elevated surface fluorescence (Max = 7.2 μgL^{-1} at F30) and the southwestern portion of Cape Cod Bay was at 2.2 to 3.4 μgL^{-1} but surface waters in most regions were <1 μgL^{-1}. At this time the chlorophyll maximum was located at 10 to 15m deep throughout the area. At this depth, where low level nutrients were available, fluorescence was somewhat higher (3 to 5 μgL^{-1}) in most areas. Phytoplankton abundance in the surface and mid-depth waters was fairly low at 1 to 4 million cells L^{-1} with maximum abundance found in the harbor. Harbor, coastal, and nearfield stations also showed a greater diatom component in the phytoplankton community as compared to other regions, leading to an increased fluorescence signature (see Section 5.3.1).

By October stratification was weakening. In the shallower areas of Boston Harbor and towards the northern coastal stations, surface nutrient concentrations had increased to relatively high levels as seen for NO_3 in **Figure** 4-11. Maximum surface values were still found within the harbor (DIN = 7.3 μM, SiO_4 = 9.2 μM, PO_4 = 0.9 μM, and NH_4 = 3.1 μM at F30). All nutrients also showed high surface concentrations at station F18 near Nahant (DIN = 6.1 μM, SiO_4 = 5.2 μM, PO_4 = 0.9 μM, and NH_4 = 2.1 μM). A similar nutrient signature in this area was seen in June of this year and was attributed to a combination of outfall discharges and upwelling. In October, it appears that upwelling was the primary source of nutrients to surface waters at F18. **Figure** 4-12 shows vertical concentrations of DIN, PO_4, and SiO4 along the nearfield-Marshfield transect, which ends at F18 to the west. Winds were primarily out of the west in the week leading up to this survey which favors upwelling in this area.

Because sampling did not occur further offshore during this survey, no nutrient data is available. However, based on low surface nutrient concentrations in the offshore areas which were sampled and the persistence of stratification in these areas, it can be assumed that the outer stations were nutrient depleted in the upper water column as they have been in previous years under similar conditions. No major fall phytoplankton bloom was observed during this report period. Phytoplankton abundances in October had decreased somewhat from summertime levels, and were ≤2.5 million cells L^{-1} in all areas. In addition to low abundances there was a shift in the community structure away from diatoms, and the community was dominated microflagellates all areas. Fluorescence in surface waters had decreased in the nearfield to ≤2.5 μgL^{-1}, but had increased in the other surveyed areas. Peak fluorescence levels were found at coastal areas off of Hingham and Cohasset (4.3 μgL^{-1} at F13). Fluorescence was generally inversely related to nutrient concentrations, suggesting the areas of lower nutrients in the south coastal area resulted from a combination of limited mixing through the persistent stratification and consumption by the phytoplankton community.

The November survey sampled the nearfield area as well stations which were not sampled in October (boundary, Cape Cod Bay, southern coastal, and offshore). Harbor and northern offshore stations were not sampled. Nutrient concentrations were replete throughout the water column in all areas. The highest surface nutrient concentrations were generally found in the nearfield (DIN = 12.9 and NH_4 = 8.0 µM at N18; PO_4 = 1.3 µM at N20) and were associated with the outfall plume, although SiO_4 was highest just to the southwest of the nearfield (6.4 µM at F25). Phytoplankton abundance had dropped from October levels, and was <2.5 million cells L^{-1} throughout the survey area. Fluorescence had also decreased for the most part, and only well into Cape Cod Bay did values exceed 3 µgL^{-1}.

4.2.1.2 Vertical Distribution

Farfield. The vertical distribution of nutrients was evaluated using vertical contours of nutrient data collected along the farfield transects (**Figure** 1-2; Appendix B). In late August, the water column in the open bays was strongly stratified. Consequently, nutrient concentrations were low in the surface waters and increased with depth as observed for NO_3 and PO_4 along the Boston-Nearfield transect (**Figure** 4-13). Silicate concentrations followed similar patterns, although in most areas, especially along the coast, SiO_4 concentrations were moderately elevated throughout the water column. The exception to these trends was the harbor area where stratification was not present and a well-mixed water column kept nutrient levels fairly high at all depths. Ammonium concentrations directly reflect the influence of the outfall in the nearfield (**Figure** 4-13). The effluent plume is clearly observed in both the NH_4 and PO_4 data and is also characterized by slightly higher NO_3 and SiO_4 concentrations. As discussed above, elevated NH_4 is found only in the immediate outfall area. As is typically the case in the summertime, the effluent plume and associated nutrients were constrained to the waters below the pycnocline. The summer pattern of depleted nutrients in the surface waters was concomitant with low surface chlorophyll concentrations. A low level sub-surface chlorophyll maximum was observed near the pycnocline and was associated with available nutrients. Again, the harbor was the exception to these trends with elevated fluorescence associated with fairly high nutrients throughout water column. In the harbor surface waters where both light and nutrients were available, fluorescence was as high as 7 µgL^{-1} (see **Figure** 4-9).

In October, NO_3 concentrations were still low in the surface waters in all areas except for the harbor and north coastal stations. The breakdown of stratification at these nearshore regions allowed water column mixing which resulted in elevated NO_3 concentrations in the surface waters. In the remaining regions NO_3 was low at the surface and increased with depth (see Appendix B). Note again that not all farfield areas were sampled in October so data is unavailable for the stations to the east and south. Phosphate and silicate data exhibited a similar trend decreasing from inshore to offshore in the surface waters and increasing with depth across the weak pycnocline. The effluent plume signal was still evident in the NH_4 and PO_4 data along the Boston-Nearfield transect during this survey.

Typically, as weakening stratification allows some penetration of nutrients into the surface waters fluorescence and productivity increase. This was not the case in 2004. No fall phytoplankton bloom was observed in 2004. In contrast to previous years, phytoplankton abundance had declined from summertime levels to ≤2.5 million cells L^{-1} and was dominated by microflagellates in October. For comparison, the 2003 fall bloom was considered only a modest bloom with a maximum phytoplankton abundance of 3.6 million cells L^{-1} (and diatom dominated). This is discussed in further detail in Section 5.3. Productivity was also extremely low as compared to previous years (see Section 5.2).

Nutrient-salinity plots are often useful in distinguishing water mass characteristics and in examining regional linkages between water masses. Dissolved inorganic nitrogen plotted as a function of salinity has been used in past reports to illustrate the transition from summer to winter conditions and back again. Typically summer conditions in this region are 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. Winter conditions 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. During the August farfield survey the summertime trend was apparent throughout much of the offshore areas. However, in the coastal, nearfield, and harbor areas this trend was less evident (**Figure** 4-14). In the harbor, this was due to weak stratification and a fairly well-mixed water column. In the nearfield, the lack of a positive DIN-salinity relationship was due to the strong NH_4 signal rising with the effluent plume into near surface waters. At the coastal stations, there was considerable variability in both salinity and DIN concentrations resulting in only a weak DIN-salinity relationship. By August, the summertime positive DIN-salinity relationship had actually strengthened in most areas. The harbor had developed a weak negative relationship typical of winter conditions, but the coastal offshore and nearfield areas showed a strong positive relationship (**Figure** 4-14). By the time of the modified farfield survey in November the water column was well-mixed and, for the most part, the DIN-salinity relationship had broken down. Note that a positive DIN-salinity relationship persisted at the deep boundary stations due to the continued presence of relatively high salinity and nutrients in the bottom waters.

Nearfield. The nearfield surveys are conducted more frequently and provide a higher resolution of the temporal variation in nutrient concentrations over the semi-annual period. In previous sections, the transition from summer to winter physical and nutrient characteristics has been discussed. For most of the nearfield, summer conditions of depleted nutrient concentrations in the surface waters existed into October. The progression from summer to winter conditions is illustrated in the series of nearfield transect plots for NO_3 throughout the report period presented in **Figures** 4-15 and 4-16. In July a broad pycnocline constrained nutrients to the deeper waters, and the water column above 20–30 meters was generally nutrient depleted (e.g. NO_3 <1 μM). From July through mid-October concentrations were generally depleted in the surface layer (0–5m) and increased gradually with depth along the nearfield transect. As summer progressed, the pycnocline strengthened and became sharper in the upper water column. Concentrations remained depleted in the surface layer, which allowed nutrients to migrate higher in the water column, just below the pycnocline (as seen in WN04B and WN04C of **Figure** 4-15). Also, throughout this period NO_3 concentrations in the bottom waters were slightly increasing as a result of remineralization. In July nearfield bottom NO_3 concentrations were less than 3 μM. By late September (WN04D) bottom NO_3 concentrations had increased to 7–8 μM but were still depleted in the surface layer. By mid October, bottom concentrations had peaked at approximately 9 μM NO_3 and nutrients began penetrating into portions of the nearfield surface waters as stratification weakened. By November stratification had broken down throughout the nearfield and strong storms had thoroughly mixed nutrients throughout the water column (NO_3 = 4–6 μM). In general, PO_4 and SiO_4 followed the same spatial and temporal trends as NO_3, although during several surveys a PO_4 effluent signature was evident in the immediate outfall area (**Figure** 4-17).

Ammonium followed the same general nutrient trends, but its distribution throughout the nearfield was generally limited to the immediate outfall area. This has been typical of NH_4 distributions in the nearfield since the outfall came on line in September 2000. The rapid dilution and biological utilization of NH_4 generally restricts elevated levels to within 10-20 km of the outfall area. Although PO_4 and SiO_4 concentrations were somewhat elevated and indicative of the outfall plume during most surveys, NH_4 continued to be the best tracer of the effluent plume. As observed since the fall of 2000, the distribution of NH_4 illustrates the influence of the effluent plume in the nearfield both under stratified and well-mixed conditions (**Figure** 4-18). In August (WF04B) under strongly stratified conditions, the plume can be seen rising from the outfall and remaining entrained beneath the pycnocline. It was not until the last survey of the year in November that stratification had fully broken down and NH_4 can be seen rising from the outfall into the surface waters. There was no clear indication that the NH_4 signal or effluent plume extended much further than the immediate nearfield and surrounding (station F18 to the north) area during the July to November 2004 surveys.

An examination of the nutrient-nutrient plots showed that nearfield waters were depleted in DIN relative to PO_4, with the DIN:PO_4 ratio less than the Redfield ratio of 16:1 throughout the entire semi-annual period (**Figure** 4-19). Strong stratification maintained very low DIN:PO_4 ratios (< 4:1) in surface waters from July to the beginning of September. Without a significant fall phytoplankton bloom to rapidly consume nutrients, DIN:PO_4 began to increase in the nearfield by late September. The DIN:PO_4 ratio continued to increase throughout the year with the breakdown of stratification. Although DIN was no longer limiting in nearfield waters by November, the DIN:PO_4 ratio remained below Redfield values throughout the water column. Nearfield waters were also generally low in DIN as compared to SiO_4 (DIN:SiO_4 < 2:1) throughout the report period. As a result there was a wide range of DIN:SiO_4 ratios during most surveys.

The overall transition from winter to summer nutrient regimes in the nearfield can be demonstrated by examining contour plots of NO_3 concentrations over time at three representative nearfield stations – N10, N18, and N04 (**Figure** 4-20). These stations represent the inshore, center, and offshore of the nearfield "box". The progression from stratified summer conditions with low surface NO_3 to winter conditions with a well-mixed, nutrient replete water column can be seen in these plots. These plots also capture other water column features during the fall transition, such as remineralization or an influx of offshore waters into the deep waters of N04. Biological utilization of nutrients can also be seen in the reduction of NO_3 at 10–15m at N18 in October, which was coincident with increased fluorescence. The dynamics associated with destratification and nutrient availability in fall 2004 relative to lack of a significant fall bloom will be examined in more detail in the 2004 annual report.

4.2.2 Chlorophyll *a*

Chlorophyll concentrations (based on *in situ* fluorescence measurements) were low throughout the report period as compared to previous years. Peak fluorescence for the period was 7.4 μgL^{-1} in the harbor in August. Peak nearfield fluorescence levels never exceeded 4.3 μgL^{-1} during this time period. Low fluorescence was consistent with low phytoplankton abundance, particularly diatoms, throughout the entire period.

4.2.2.1 Horizontal Distribution

In July, surface chlorophyll concentrations in the nearfield area were slightly elevated at inshore station N10 (3.2 μgL^{-1}), but were low at all other stations (0.5–1.4 μgL^{-1}). At the mid-depth chlorophyll maxima the trends were the same but the values were somewhat higher (2.1–3.7 μgL^{-1}). By August, nearfield fluorescence values had decreased to very low levels (0.3–0.8 μgL^{-1}) and mid-depth values were similar to July (1.4–4.2 μgL^{-1}). In the farfield surface fluorescence was very low in most areas (<1 μgL^{-1}). A slight fluorescence increase was seen in western Cape Cod Bay (2.2–3.4 μgL^{-1}), but the only area of truly elevated fluorescence was Boston Harbor (4.9–7.2 μgL^{-1}). The farfield fluorescence distribution in the mid-depth waters was somewhat different from the surface. Slightly elevated values were again found the in the harbor (3.7–7.4 μgL^{-1}) and western Cape Cod Bay (3.6–6.7 μgL^{-1}). However, the majority of the farfield had values of approximately 3 to 5 μgL^{-1}. These fluorescence trends were generally consistent with phytoplankton abundance and distribution. Although the phytoplankton assemblage was dominated by microflagellates, the abundance of diatoms in the harbor and coastal waters was relatively high (~1-2 million cells L^{-1}). Both the diatom and total counts observed in these waters in August were the highest farfield values of the report period.

In early September surface fluorescence in the nearfield was still low and continued to show the previous trends with highest surface value (1.6 μgL^{-1}) found at N10, and the rest of the area at lower levels (0.3–0.6 μgL^{-1}). Mid-depth values were only slightly higher but showed the opposite pattern, with a peak value of 3.4 μgL^{-1} in the northeast corner and the remainder of the nearfield somewhat lower and decreasing towards the inshore area (1.6 -2.5 μgL^{-1}). The elevated fluorescence at N04 was coincident with the highest phytoplankton abundance of the report period of 4.5 million cells L^{-1}. However, the community was dominated by microflagellates (85%) and virtually no diatoms were present, leading to only a minor fluorescence increase. Later in September (WN04D) fluorescence values in the nearfield remained at low levels. Surface values were 0.1 to 2.1 μgL^{-1} and mid-depth values were 1.2 to 3.9 μgL^{-1} with the peak value found to the northwest at N01. Nearfield phytoplankton abundances had dropped somewhat, and the community continued to be dominated by microflagellates.

SeaWiFS imagery from the time period between surveys WN04D and WF04E show a moderate increase in chlorophyll along the coastline. While this may represent a period of increased productivity that was not captured by the sampling schedule, this event was short-lived at best as these surveys were only three weeks apart. During the October farfield survey fluorescence continued to be measured at only low to moderate values (**Figure** 4-21 and Appendix A). Surface and mid-depth values were at similar levels and followed similar trends. Peak values of 4.3 μgL^{-1} were found at the coastal stations off Cohasset (F10 mid-depth and F13 surface). Fluorescence generally decreased to the north of these stations, although comparable values were seen at mid-depth in the nearfield. Harbor stations showed low fluorescence during this survey. Stations to the south and east were not sampled during this survey so it is difficult to determine if the gradient of increasing fluorescence towards the south would continue down the coastline or into Cape Cod Bay. Due to cloud cover, no SeaWiFS images are available within a week on either side of this survey. The SeaWiFS image from 10 days prior to the survey indicates that moderate chlorophyll values were present along the coastline and into Cape Cod Bay but decreased rapidly further offshore (Appendix D). SeaWiFS images from 10 days after the survey show low chlorophyll levels in most areas, but Cape Cod Bay is again obscured. The next SeaWiFS image which includes Cape Cod Bay is from November 1 and shows fairly high chlorophyll values in the southern portion. These combined images suggest that had the full farfield area had been sampled during the October survey, elevated fluoresce values and phytoplankton abundance may have been encountered in Cape Cod Bay but it does not appear that elevated levels existed further offshore. This is consistent with results from the November survey. During this survey peak fluorescence values in both the surface and mid-depth were found furthest into Cape Cod Bay (3.2–3.6 μgL^{-1}). Concentrations decreased towards the north and were generally $< 2\mu gL^{-1}$ in both the surface and mid-depth waters north of the Marshfield transect. These low values were consistent with low phytoplankton abundance <2 million cells L^{-1}, and a continued dominance of microflagellates in the community structure. The values observed on the survey are also consistent with SeaWiFS images from that time period.

The fall storms that disrupted the sampling schedule and the cloud cover associated with these storms which also obscured satellite imagery may have played a factor in the lack of initiation of a fall phytoplankton bloom. Heavy cloud cover reduces the available light for phytoplankton growth. In addition, even weak mixing of the upper portions of the water column tends to force phytoplankton deeper in the photic zone where reduced light inhibits growth. These factors will be explored further in the 2004 annual report.

4.2.2.2 Vertical Distribution

Farfield. Chlorophyll concentrations over the water column were examined along the three east/west farfield transects (Appendix B) to compare the vertical distribution of chlorophyll across the region. In August, the typical summer distribution of chlorophyll concentrations was observed along each of the transects with elevated concentrations in the surface waters at the inshore stations and near the pycnocline (15–20 m) further offshore. Only moderately elevated fluorescence was found along these transects with peak values at 4.2 to 7.4 μgL^{-1}. By October, chlorophyll concentrations had decreased noticeably throughout the area with peak values just above 4 μgL^{-1} in all of the sampled areas except the harbor which had decreased the most to <2μgL^{-1}. Typical of the fall season, the fluorescence layer was broader than during the summer and extended from the surface to approximately 20m. The decline in fluorescence continued into November with peak value of 3.6 μgL^{-1} found in Cape Cod Bay, but the majority of readings were <2.5μgL^{-1}. As discussed above, the low fluorescence values found throughout this report period were consistent with the lack of a fall phytoplankton bloom and the limited contribution of diatoms to the phytoplankton community that was present.

Nearfield. Trends in the nearfield chlorophyll concentrations are summarized in **Figure** 4-22. This figure presents the average of the surface, mid-depth, and bottom values for each nearfield survey. Note that when a subsurface chlorophyll maximum was present, the mid-depth sample represents the water quality characteristics associated with the feature. The lack of a fall phytoplankton bloom resulted in fairly consistent nearfield fluorescence over the four month survey period. The nearfield mean for the mid-depth chlorophyll concentrations was higher than the surface and bottom mean values throughout the entire report period. The fluorescence levels throughout the report period were very low for this time of year in the nearfield. Although these mean values do not capture horizontal heterogeneity along the chlorophyll maximum, they are a fairly good indicator of the semi-annual nearfield trends. Mid-depth maximum values were only 0.6 to 1.9 μgL^{-1} greater than the means throughout the period. Mean surface fluorescence was ≤2 μgL^{-1} throughout the period.

The vertical distribution of chlorophyll during the report period was examined in greater detail along a transect extending diagonally through the nearfield from the southwest to the northeast corner (see **Figure** 1-2). The southwest corner, station N10, often exhibits an inshore or harbor chlorophyll signal while an offshore chlorophyll signal is more often observed at the northeast corner, station N04. In July a broad band of slightly elevated fluorescence (~2–3.5 μgL^{-1}) was found from the surface to approximately 20m deep which was consistent with the broad pycnocline during this survey (**Figure** 4-23). In August fluorescence along the nearfield transect showed two distinct signatures. In the inner nearfield (N10) relatively elevated fluorescence (~4 μgL^{-1}) was found just above the pycnocline. Based on the farfield data from this survey it appears that this fluorescence signature was due primarily to harbor influences. In addition to this signal, a weak fluorescence signature could be seen which appeared to be associated with nutrients from the effluent plume. Centered at ~20m deep directly over the outfall was an area of fluorescence which was higher than the ambient waters at ~2–3 μgL^{-1}. During the two September surveys, fluorescence was low along the nearfield transect with only slightly elevated values (~2–3 μgL^{-1}) found in a broad band from the surface to ~20m deep. This broadening of the vertical fluoresce layer continued in October and November. In both months, a weak effluent related fluorescence signature could be seen but values peaked at <3 μgL^{-1} along the transect. In October, the nearfield transect did not capture the peak fluorescence value of 4.3 μgL^{-1} found at station N20, but in general the vertical trends of this transect were representative of the nearfield water column. November fluorescence values were ≤2μgL^{-1} and were fairly well distributed throughout the well-mixed water column.

The progression of chlorophyll concentrations in the nearfield from summer to fall in 2004 can be clearly seen through a series of contour plots of *in situ* fluorescence over time at stations N10, N18, and N04 (**Figure** 4-24). These stations are representative of inshore (N10), center (N18), and offshore (N04) nearfield stations. In contrast to typical years, this progression showed no increase associated with a fall bloom and generally levels were the same or decreasing over this period.

4.2.3 Dissolved Oxygen

Spatial and temporal trends in the concentration of dissolved oxygen (DO) were evaluated for the entire region and the nearfield area. Due to the importance of identifying low DO conditions, bottom water DO minima were examined for the water sampling events. DO values were somewhat atypical for the time of year. The lack of a fall bloom kept DO higher than normal in the bottom waters and generally lower than typical at the surface, although all values were in the range of those previously seen. Bottom concentration declined only slightly and surface concentrations were fairly stable throughout the fall. Percent saturation was fairly high in all areas throughout the entire period.

4.2.3.1 Regional Trends of Dissolved Oxygen

In August, bottom water DO concentrations were relatively high throughout the bays for the time of year. Average bottom values based on survey region were 7.9 to 9.1 mg L^{-1}. The minimum single point value recorded in August was 7.2 mg L^{-1} in Boston Harbor at station F30. Minimum values were ≥8 mg L^{-1} in all other regions and exceeded 9 mg L^{-1} in many areas (**Figure** 4-25). By October, bottom water DO concentrations had decreased slightly and were generally between 7 and 8 mg L^{-1} in all surveyed areas (**Figure** 4-26). This represented the lowest concentrations of 2004 in all regions. During the continuation of farfield sampling in November bottom DO concentrations had rebounded and ranged from 7.3 to 9.3 mg L^{-1} (**Figure** 4-27). During this survey the lowest values were found in the deep waters at the furthest offshore stations and increased closer to the coast.

Percent saturation in the bottom waters followed the same general seasonal trends as DO concentration, although in the harbor during the summer these parameters exhibited seemingly opposite trends. In August, peak DO %saturation values were found in Boston Harbor (104% at F31) where low DO concentration was found. This was driven by warm temperatures throughout the well-mixed harbor water column. Across the other regions, percent saturation was generally between 80 and 90% and fluctuated relative to DO concentration. In October percent saturation was strongly related to DO concentration in all areas. The peak bottom value of 98.7% was found at coastal station F14. This was associated with somewhat elevated fluorescence (~3 μgL^{-1}) throughout a fairly well-mixed water column. Percent saturation values declined across a gradient away from this area, and were at a minimum of 75.7% at the northern coastal station F18. As farfield sampling continued in November, percent saturation in the bottom waters continued to follow trends seen with DO concentration. The lowest values were found in the deep offshore and boundary waters where mixing had had not yet reached (min = 77.6% at F12). In all other areas percent saturation exceeded 90% in the bottom waters.

4.2.3.2 Nearfield Trends of Dissolved Oxygen

Dissolved oxygen concentrations and percent saturation values for both the surface and bottom waters at the nearfield stations were averaged and plotted for each of the nearfield surveys (**Figure** 4-28). Dissolved oxygen values in the nearfield surface waters were 8.9 mgL^{-1} during the first survey of the report period in July. DO concentration is the surface waters was lower than bottom concentrations during the first two surveys of the period (July and August). In years in which a substantial phytoplankton fall bloom occurs, DO and percent saturation often increase in surface waters as a result of production and reach maximum values at the height of the bloom. In 2004 the lack of a fall bloom resulted in very little change in surface water DO levels. Surface DO values were between 8.5 and 9.1 mgL^{-1} during all six surveys, with the peak value occurring in November. As observed in the harbor, percent saturation trends in the surface waters were opposite of those in DO concentration during the summer months and were driven primarily by temperature. Percent saturation was at a peak for the report period in July at 113% and was well higher than the bottom waters. In general percent saturation in the nearfield surface waters declined steadily throughout the period (although August was slightly lower than early September). By November %saturation had declined to 96.7%.

Bottom water DO concentration was higher than in the surface for the first two surveys (9.6 mgL^{-1} in July and 9.0 in August) (**Figure** 4-28). DO in the bottom water continue to decline while surface concentration stayed fairly stable. By the early September concentrations were equal in the bottom and surface (8.8 mgL^{-1}). Bottom waters declined to minimum nearfield mean of 7.6 mgL^{-1} by late September and remained there into mid October. As fall storms mixed the water column in late October and November bottom DO concentrations rose, and by the November survey values returned to 8.8 mgL^{-1}. Percent saturation in the bottom waters followed the same trends and DO concentration, declining from a peak of 99.9% in July to a minimum of 80.4%in late September. Like DO concentration, percent saturation increased in the fall reaching 93.5% by the November survey.

4.3 Summary of Water Column Results

- Regionally, seasonal stratification persisted throughout the summer months and into October. The fall storms that disrupted the October sampling provided the final strong mixing event which resulted in the change over to winter conditions.
- Boston Harbor was well-mixed throughout the report period.
- Although precipitation and streamflows were normal to above normal throughout the period, strong gradients in salinity were not evident in the data. This may have been a function of survey timing.
- Beam attenuation values were somewhat lower than previous years and were frequently coupled primarily to non-biogenic sources. This was a result of low phytoplankton abundance throughout the period.
- Nutrient concentrations followed generally typical trends in the fall of 2004.
- NH_4 concentrations continue to be a good tracer, albeit not a conservative tracer, of the effluent plume both within and extending from the nearfield.
- Chlorophyll concentrations were highest in the summertime and decreased throughout the report period. The lack of a fall bloom, resulted in unusually low fall chlorophyll levels.
- Mean nearfield bottom water DO concentrations in 2004 were somewhat higher than typical and were well above threshold levels. DO concentrations were within the normal range of values measured in the baseline period. The fluctuation of DO from year to year is an indication of the natural variability of waters in this area.
- DO percent saturation values fell just below the caution threshold (<80%) in some areas. However, the DO percent saturation was well above background levels.

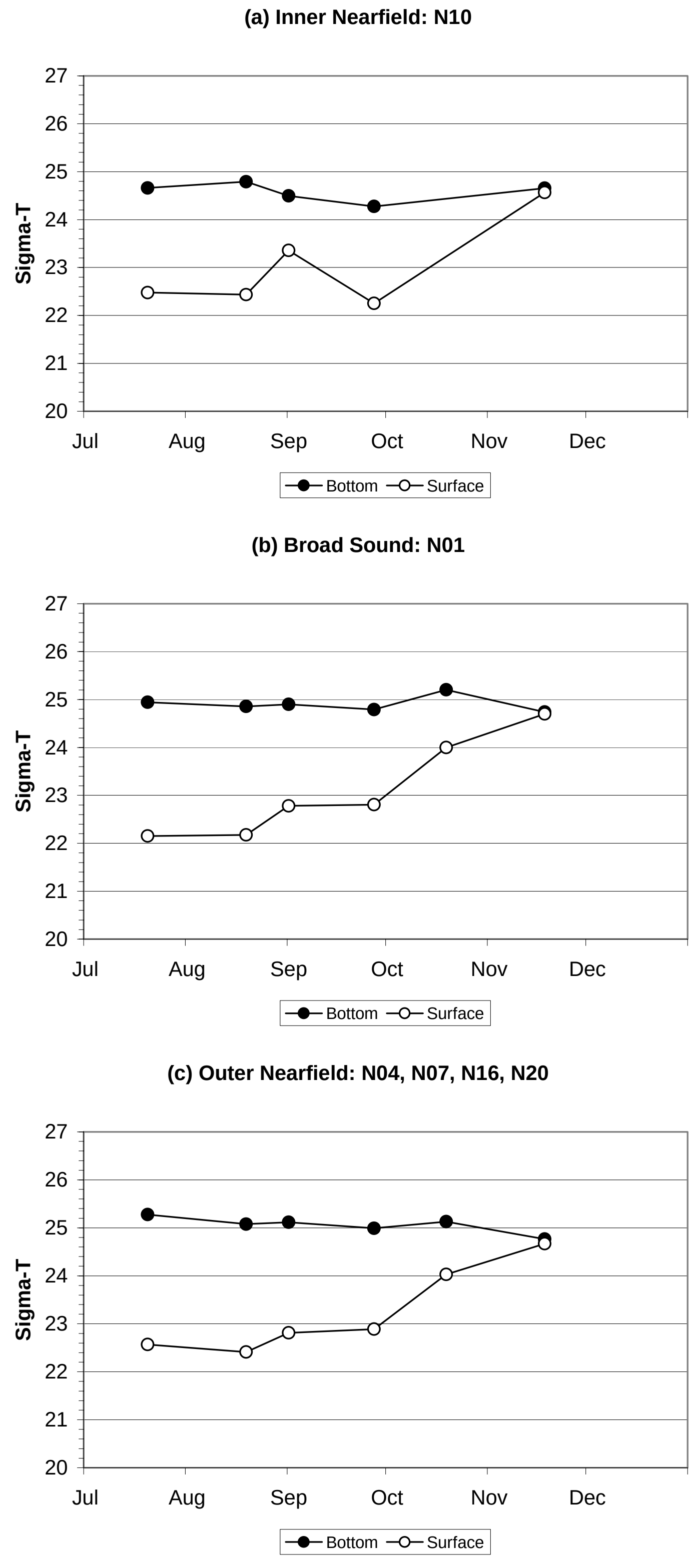


Figure 4-1. Time-series of average surface and bottom water density (σ_T) in the nearfield

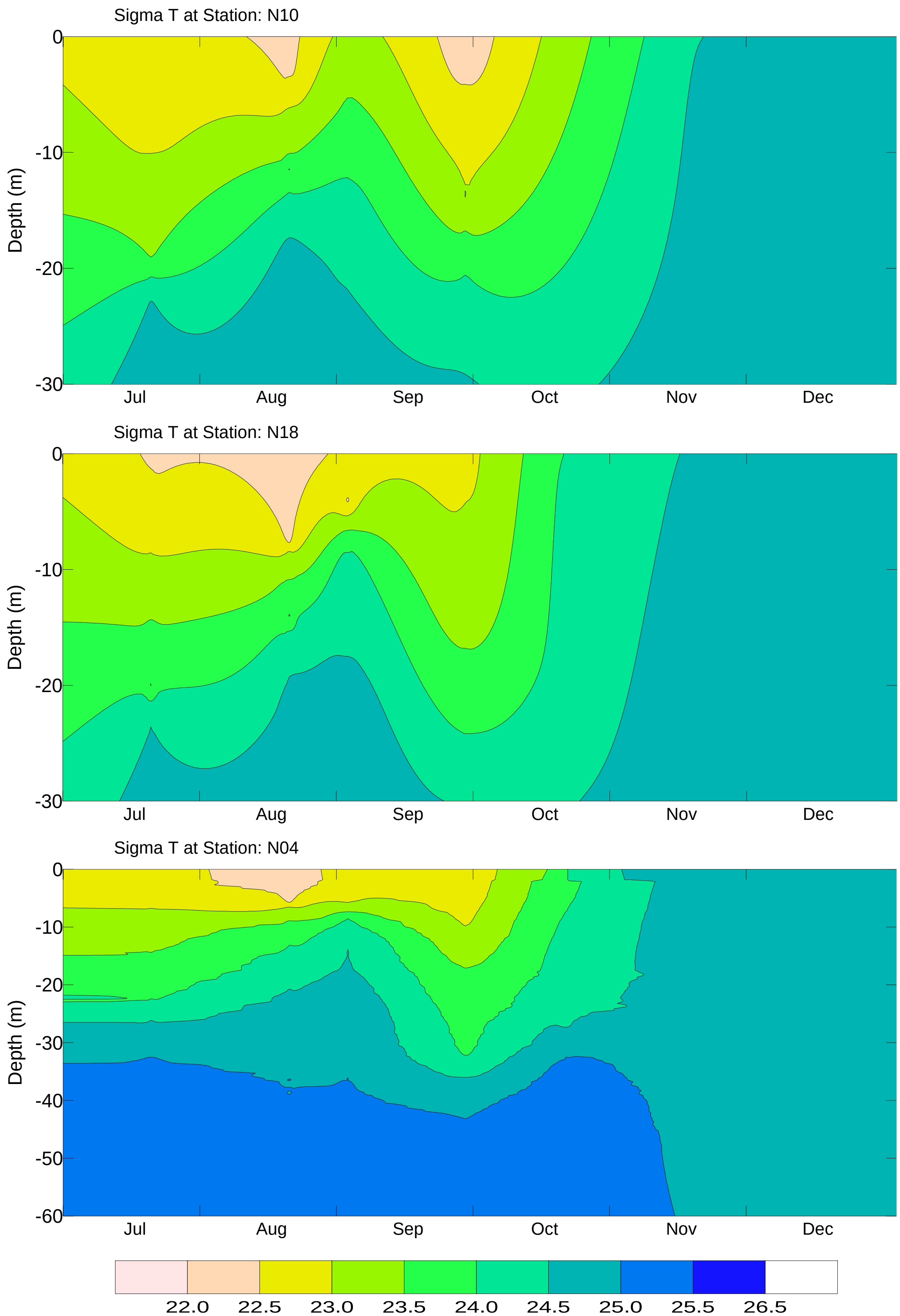


Figure 4-2. Sigma-*t* depth vs. time contour profiles for stations N10, N18, and N04

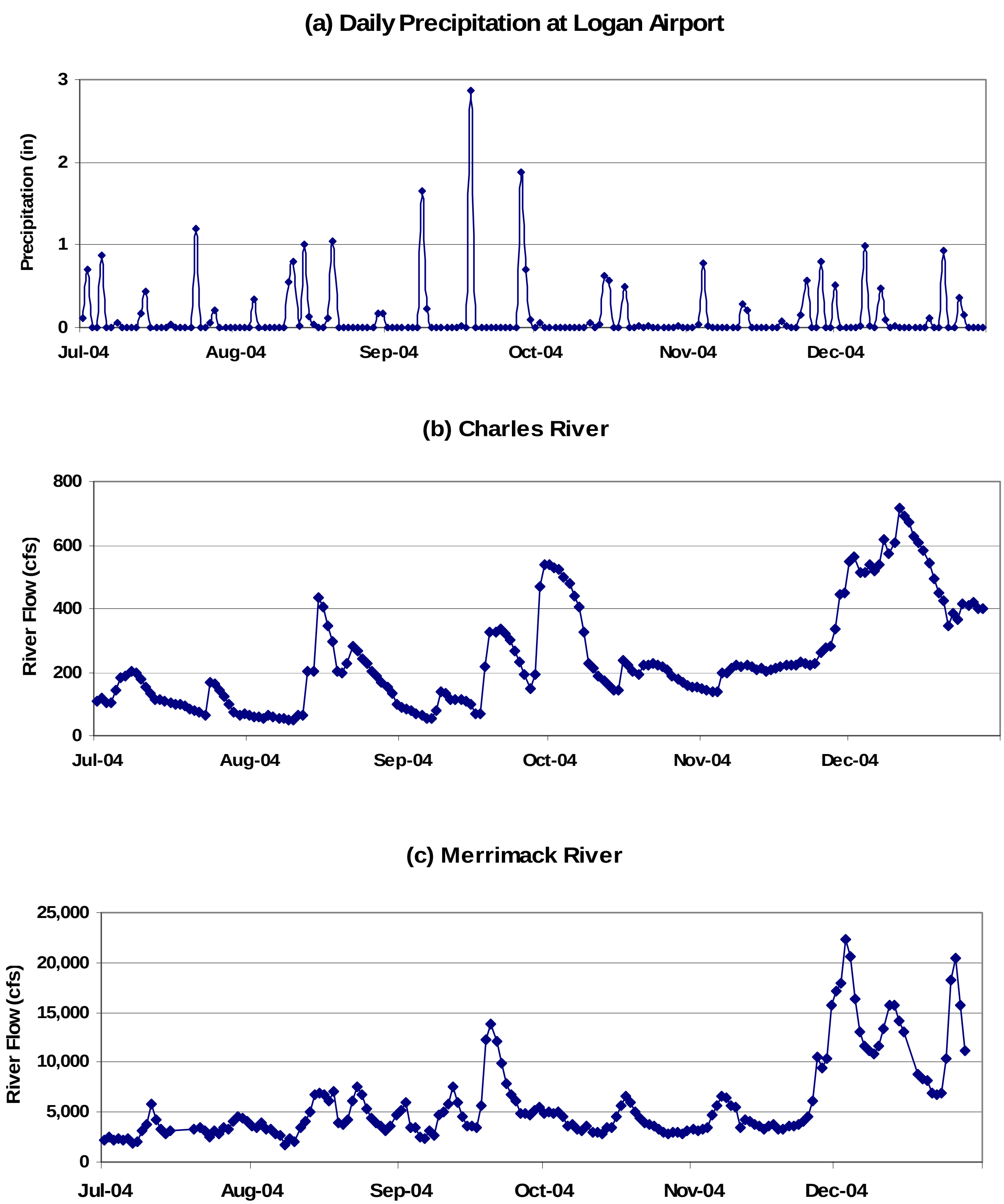


Figure 4-3. Precipitation at Logan Airport and river discharges for the Charles and Merrimack Rivers

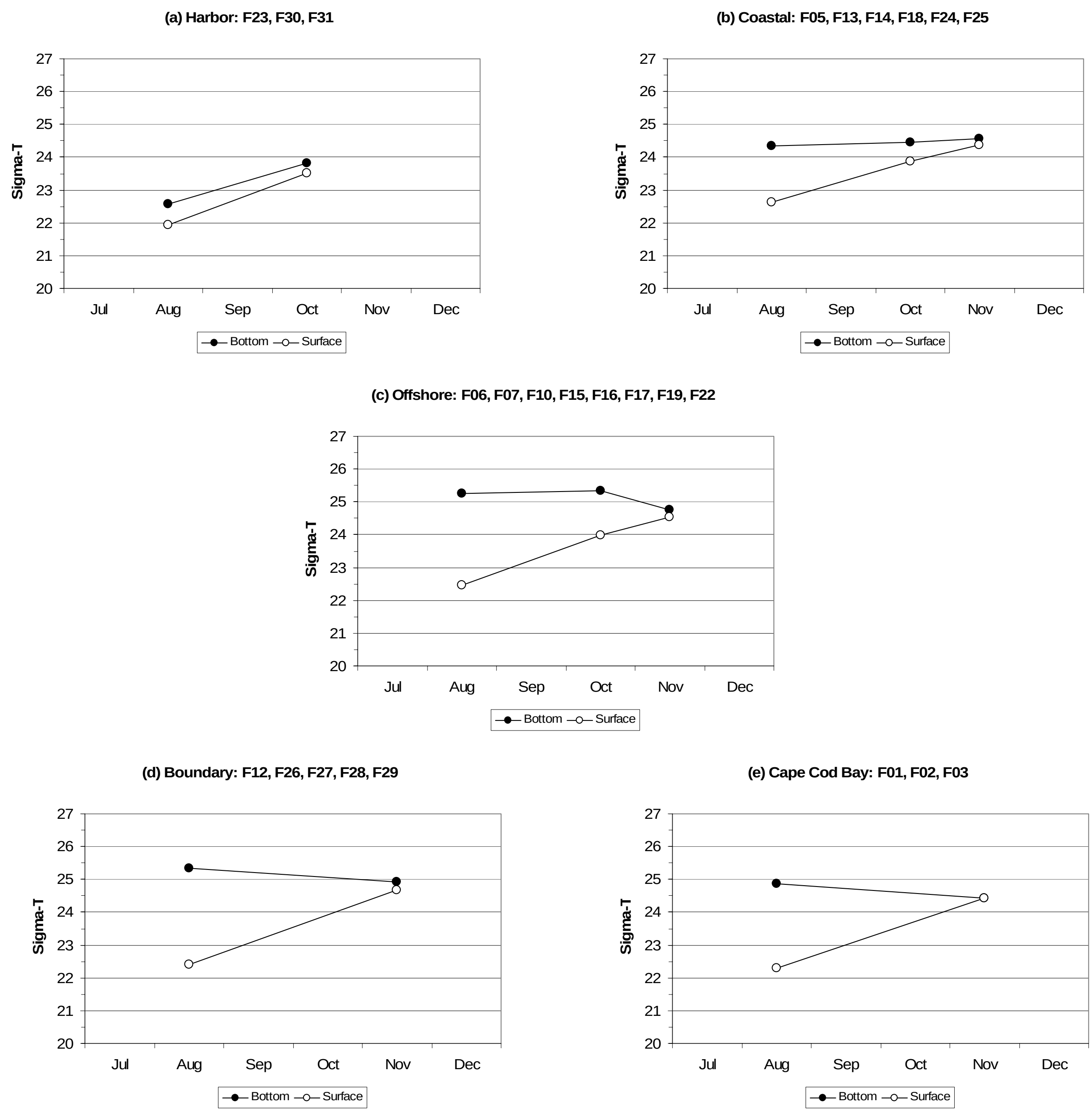


Figure 4-4. Time-series of average of surface and bottom water density (σ_T) in the farfield

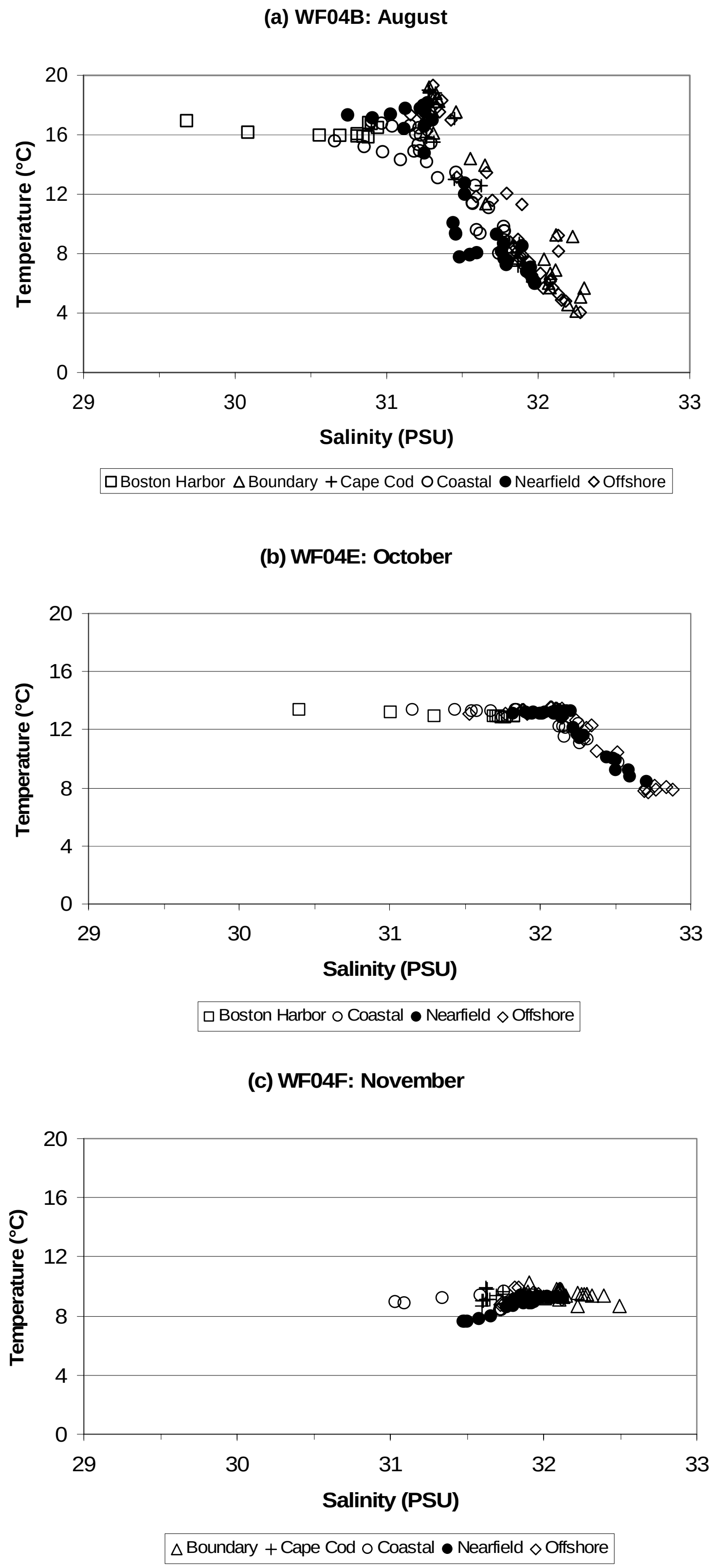


Figure 4-5. Temperature/salinity distribution for all depths during (a) August, (b) October, and (c) November

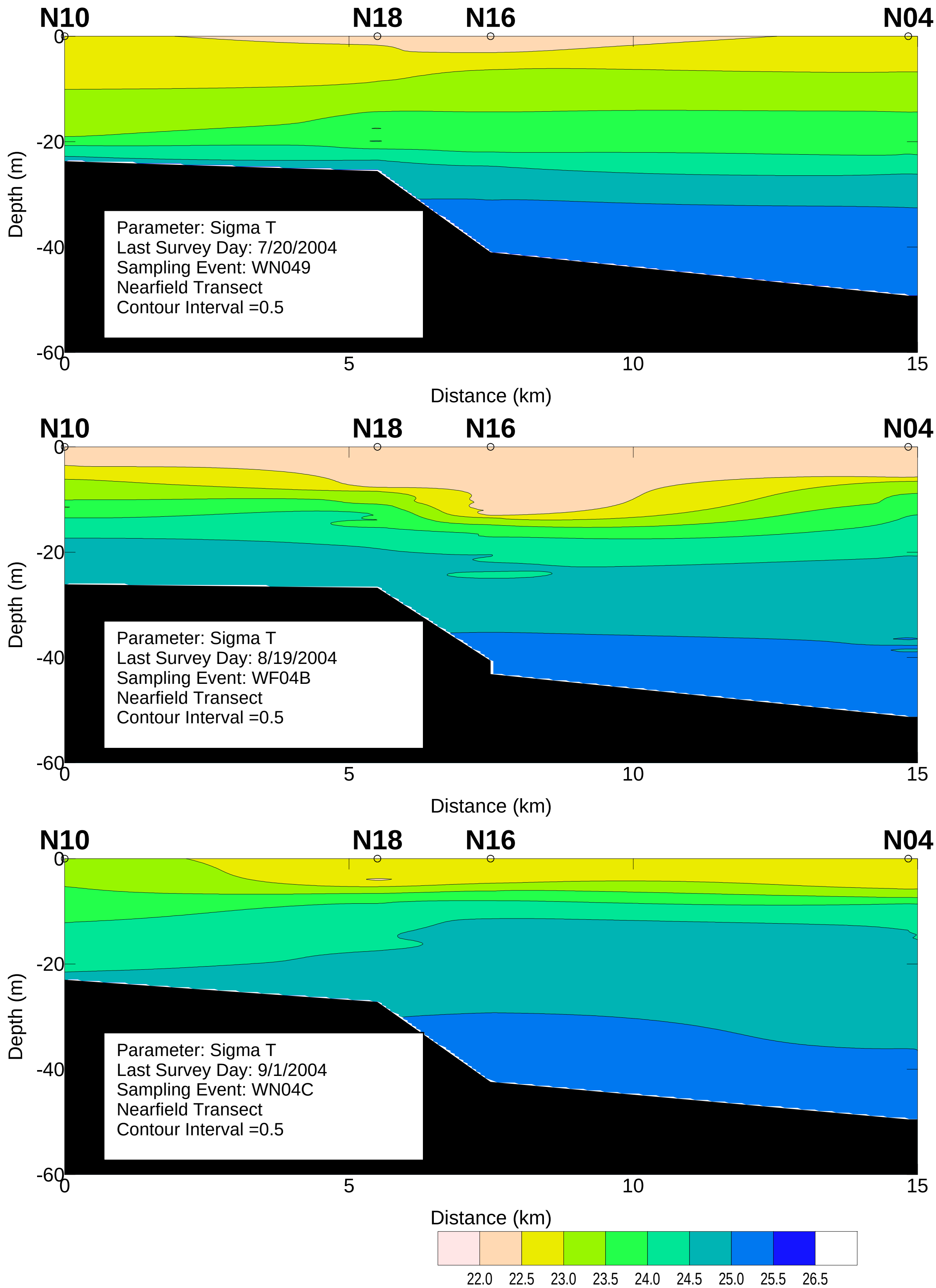


Figure 4-6. Sigma-*t* vertical nearfield transect for surveys WN049, WF04B, and WN04C

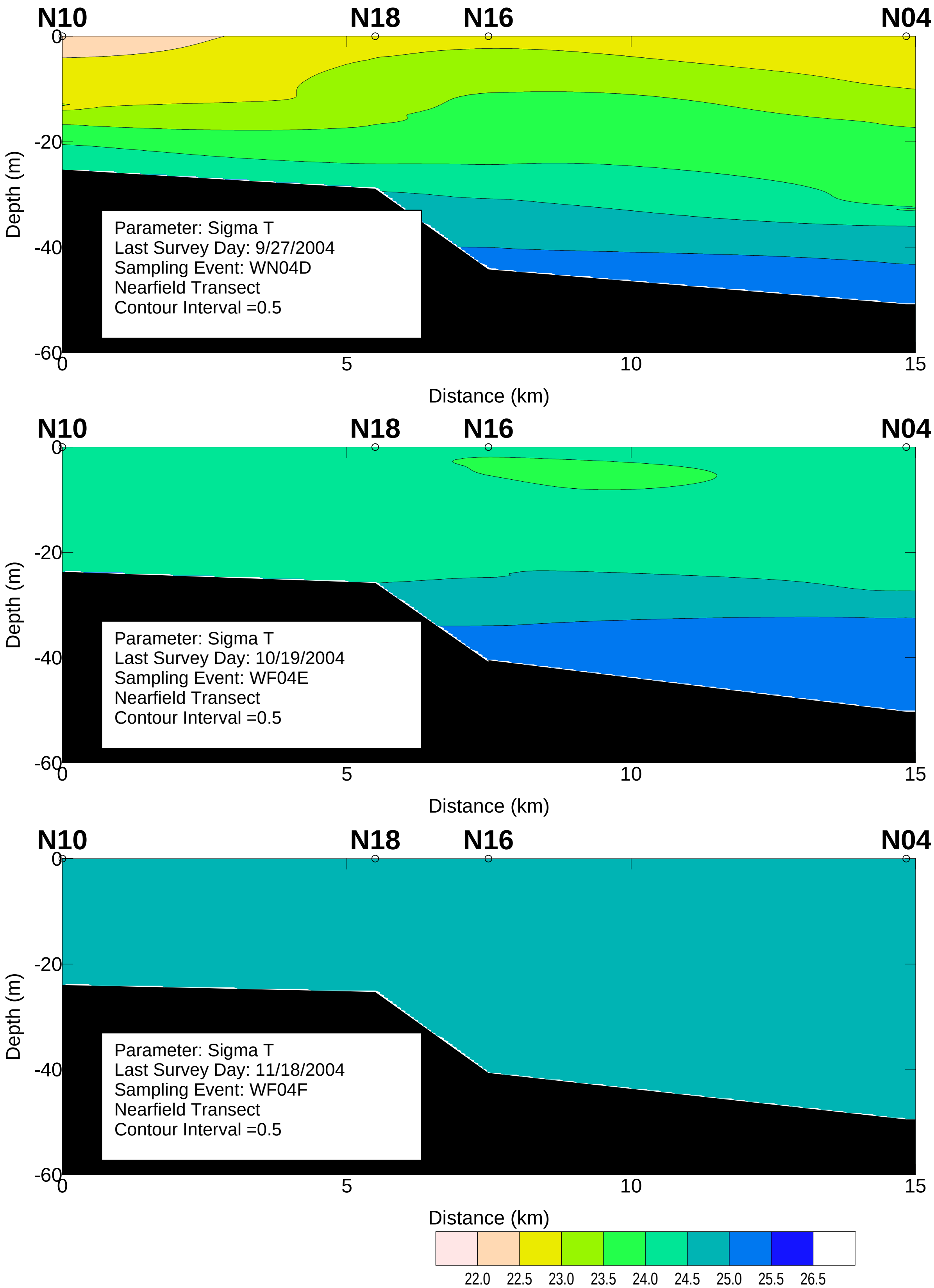


Figure 4-7. Sigma-*t* nearfield transect for survey WN04D, WF04E, and WF04F

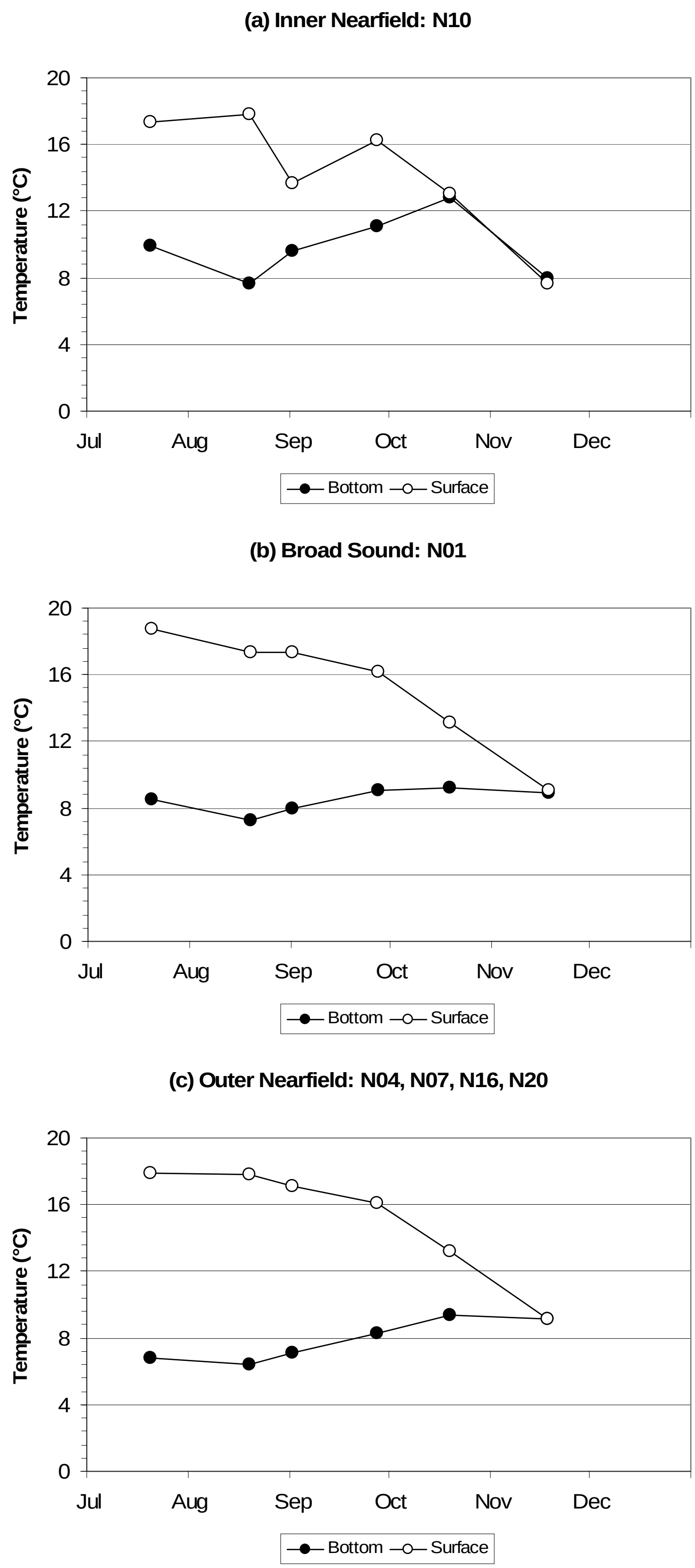


Figure 4-8. Time-series of average surface and bottom water temperature in the nearfield

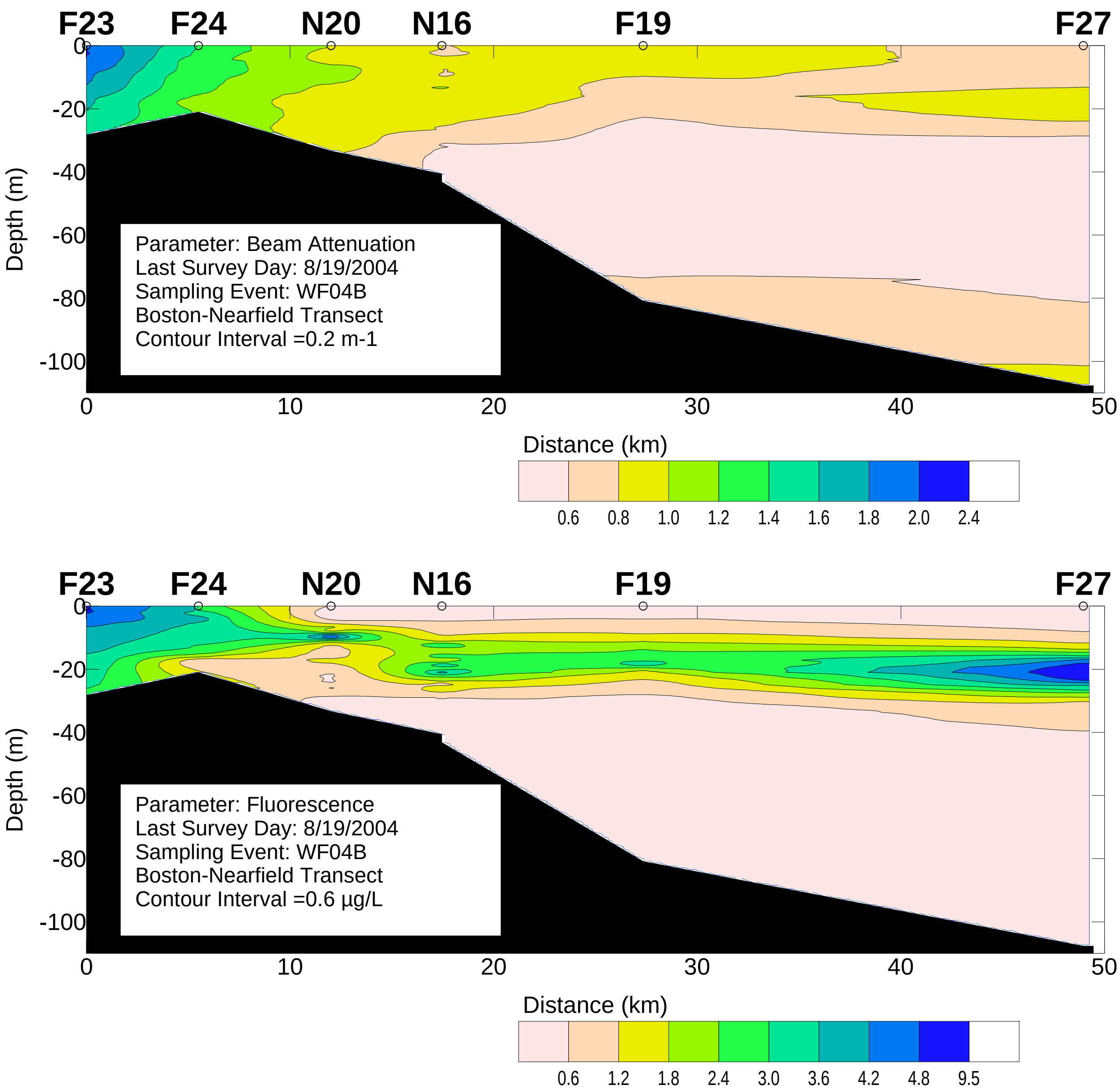


Figure 4-9. (a) Beam attenuation and (b) fluorescence vertical plots along the Boston-Nearfield transect for survey WF04B (Aug 04)

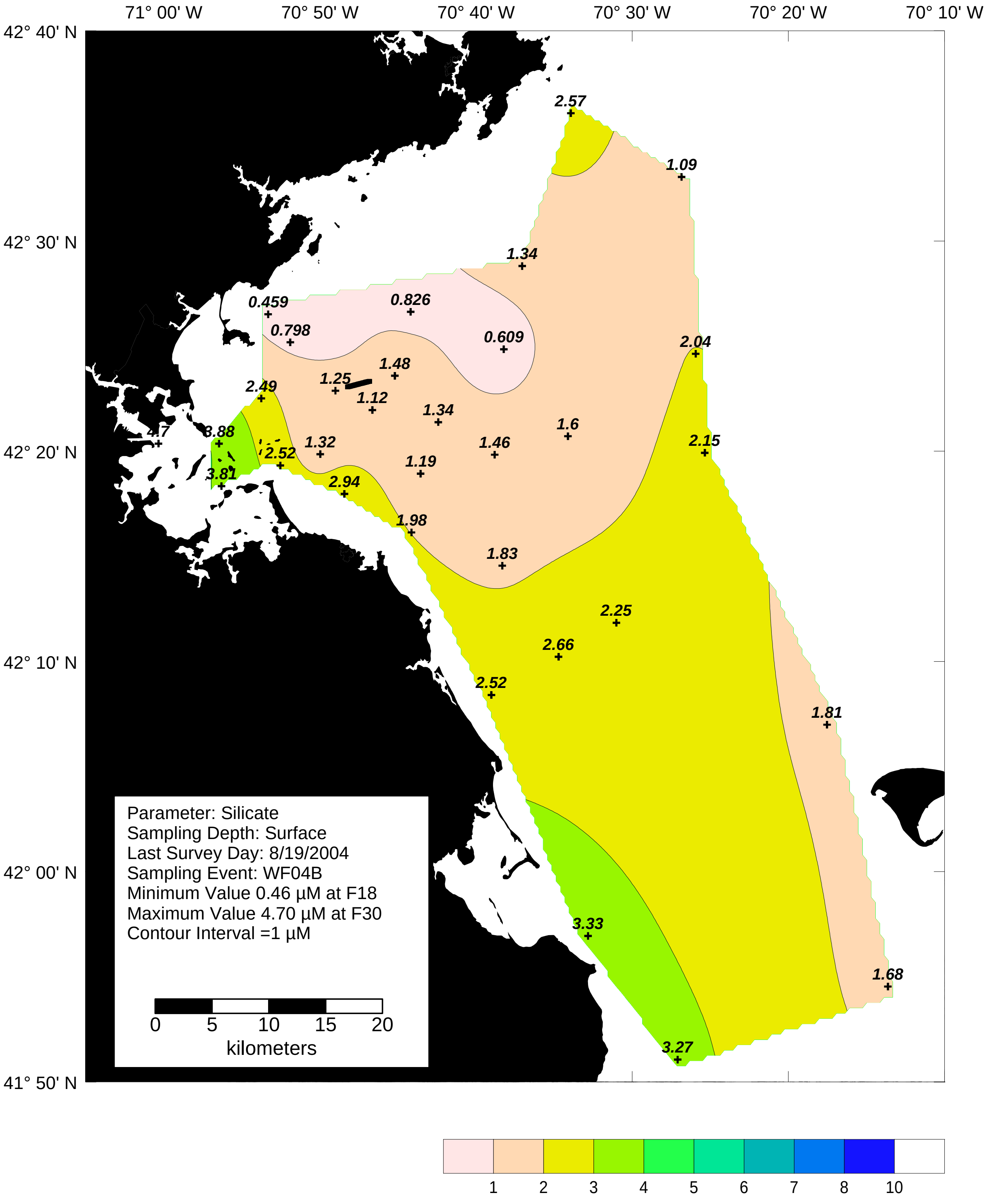


Figure 4-10. Silicate surface contour plot for farfield survey WF04B (Aug 04)

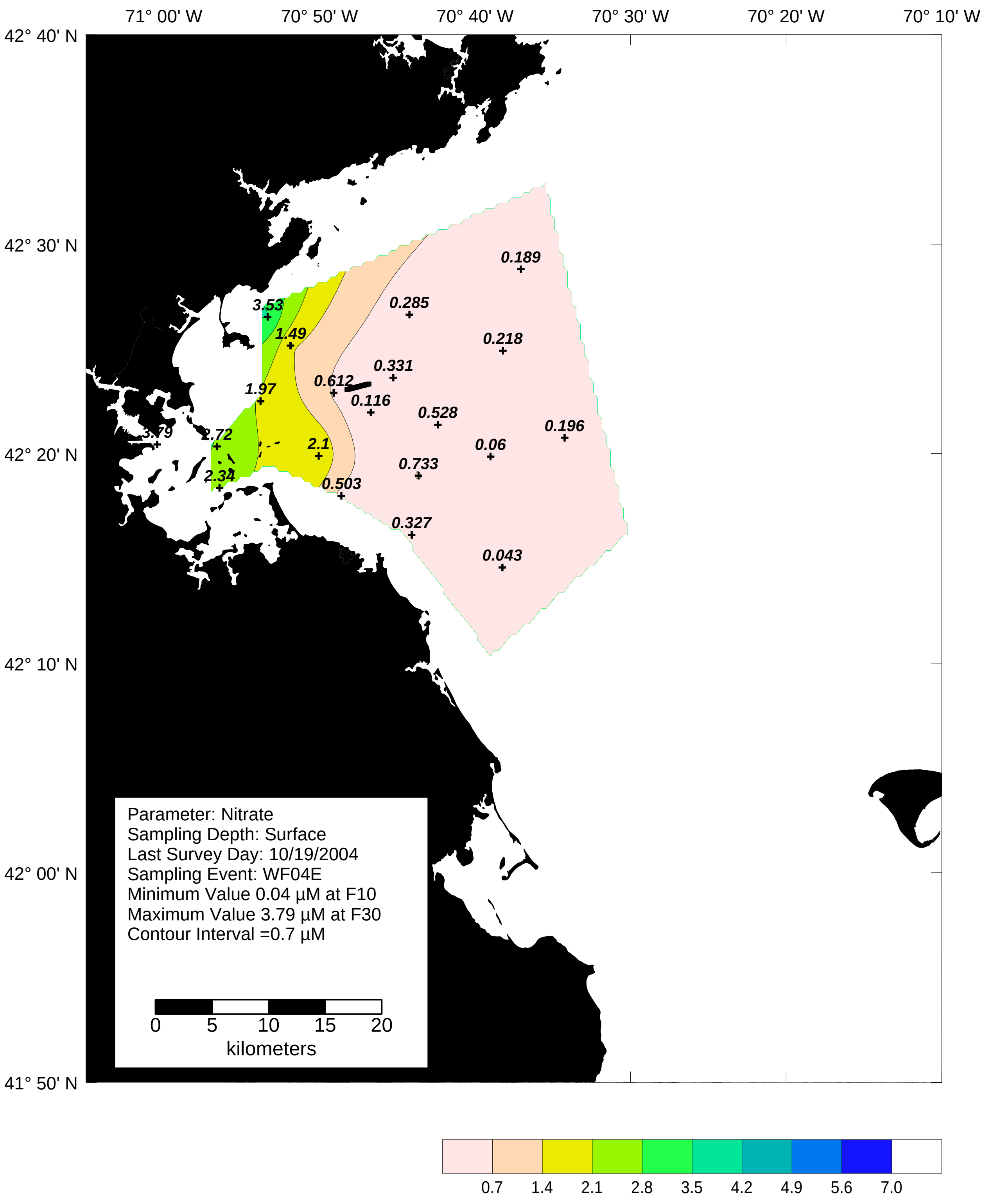


Figure 4-11. Nitrate surface contour plot for farfield survey WF04E (Oct 04)

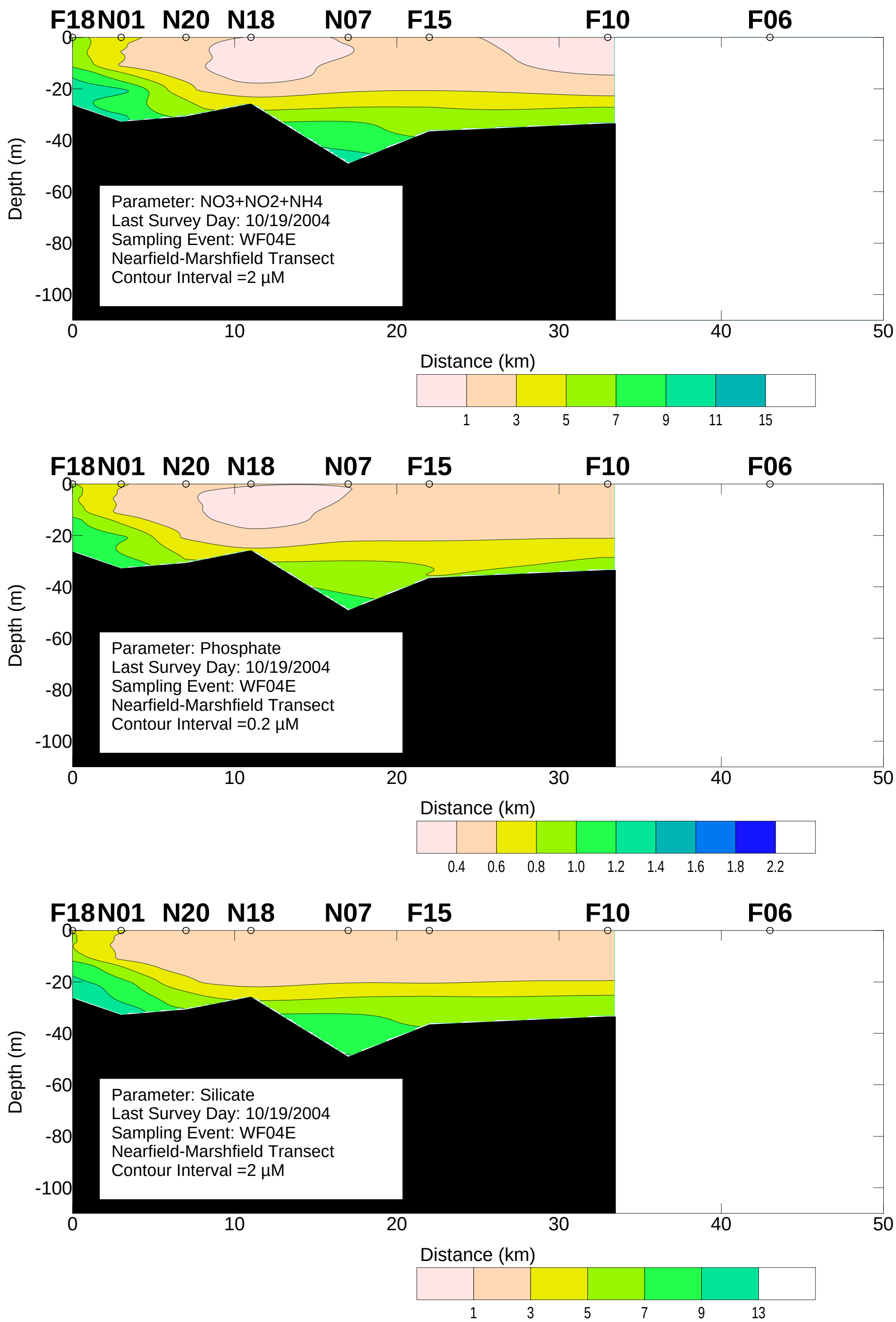


Figure 4-12. DIN, phosphate, and silicate vertical plots along the Nearfield-Marshfield transect for survey WF04E (Oct 04)

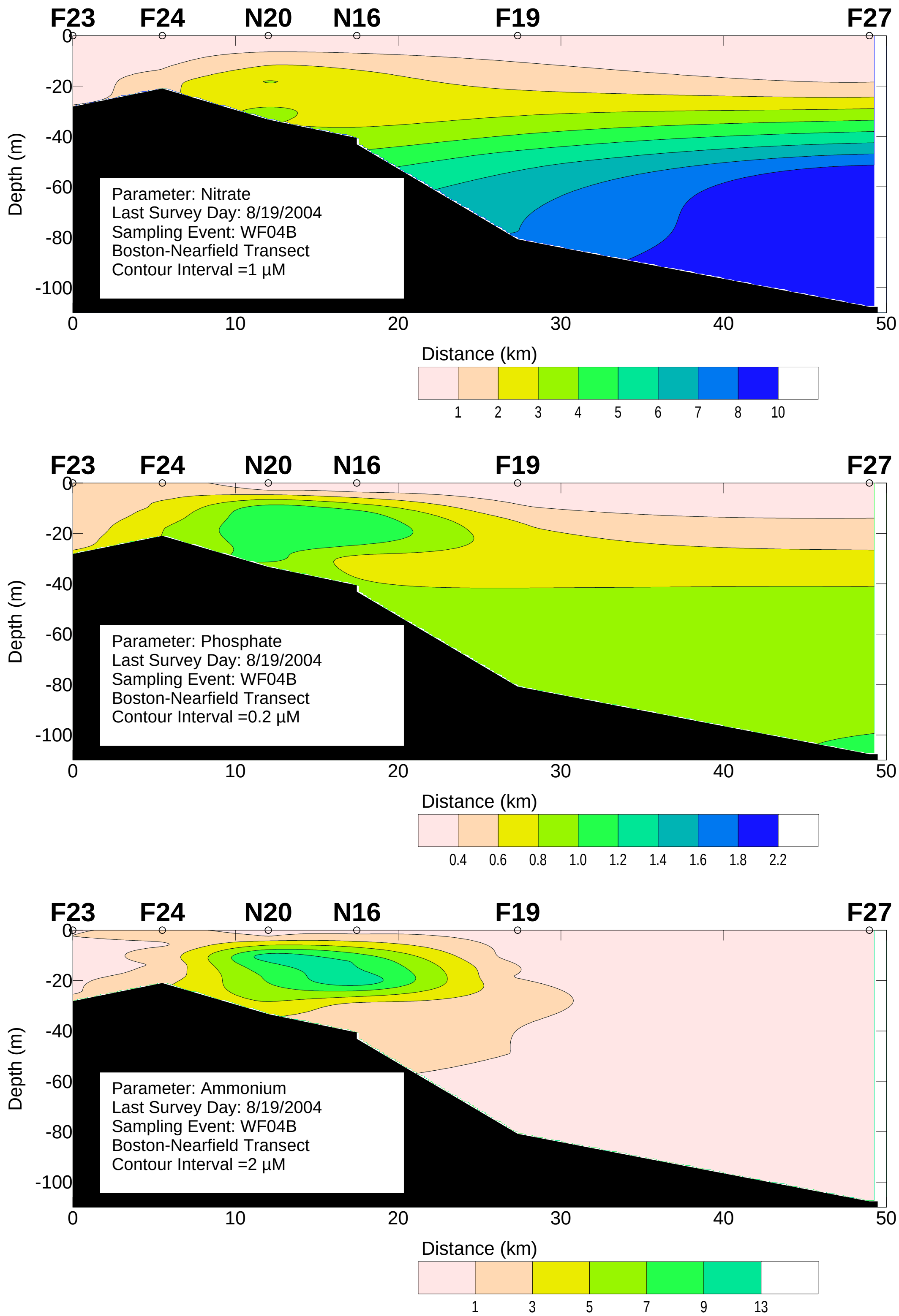


Figure 4-13. Nitrate, phosphate, and Ammonium vertical plots along Boston-Nearfield transects for survey WF04B (Aug 04)

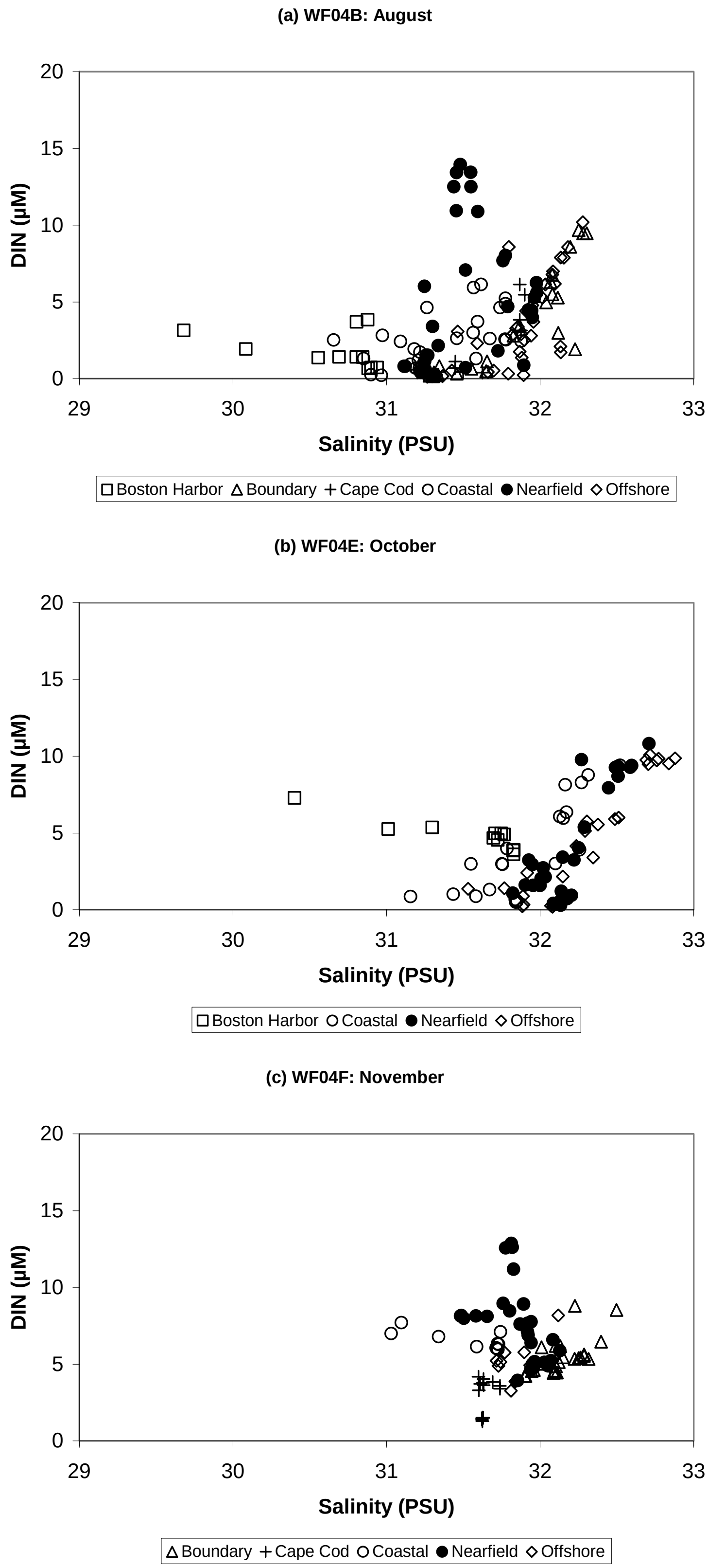


Figure 4-14. DIN versus salinity for distribution for all depths during (a) August, (b) October, and (c) November farfield surveys

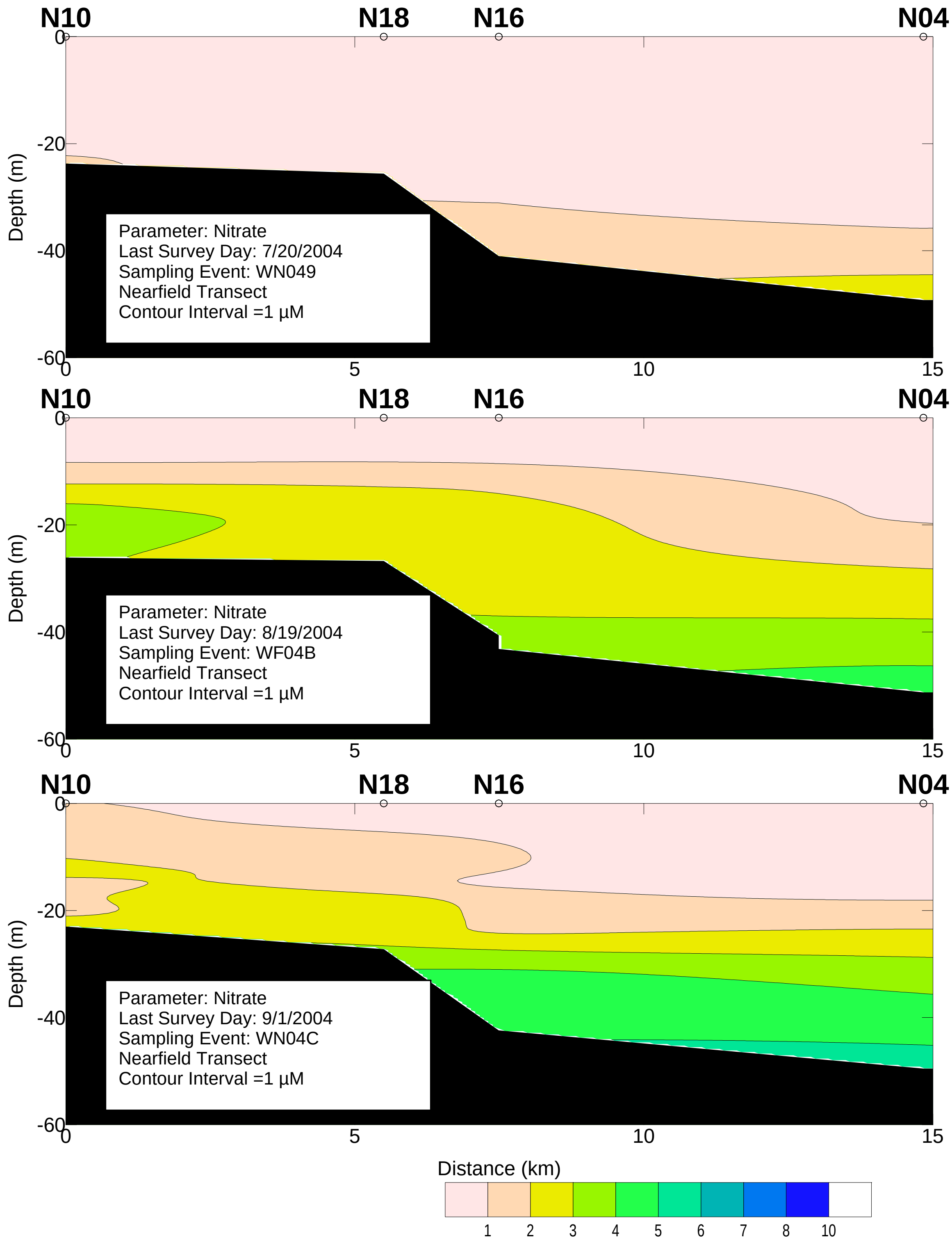


Figure 4-15. Nitrate vertical nearfield transect for surveys WN049, WF04B, and WN04C

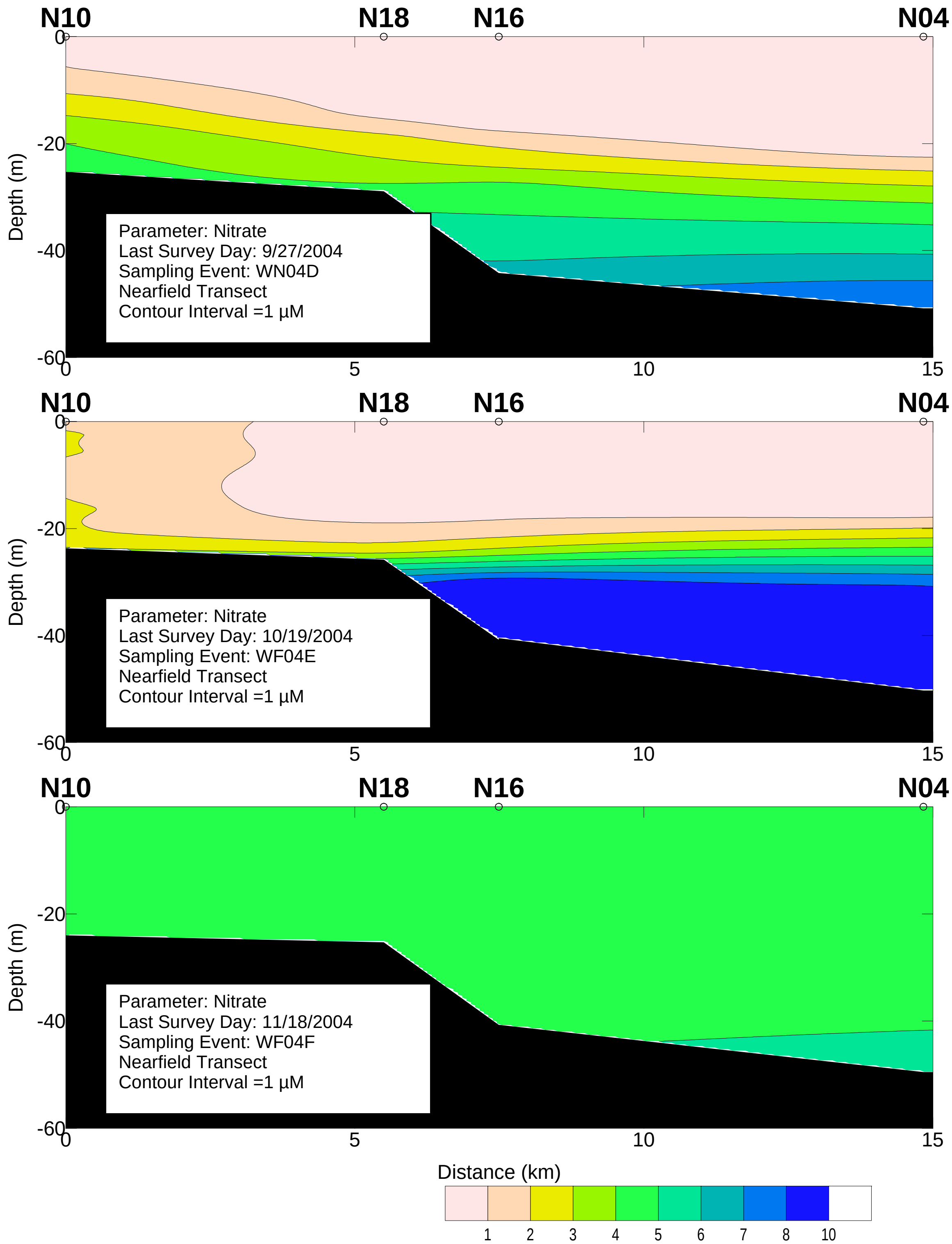


Figure 4-16. Nitrate vertical nearfield transect for surveys WN04D, WF04E, and WF04F

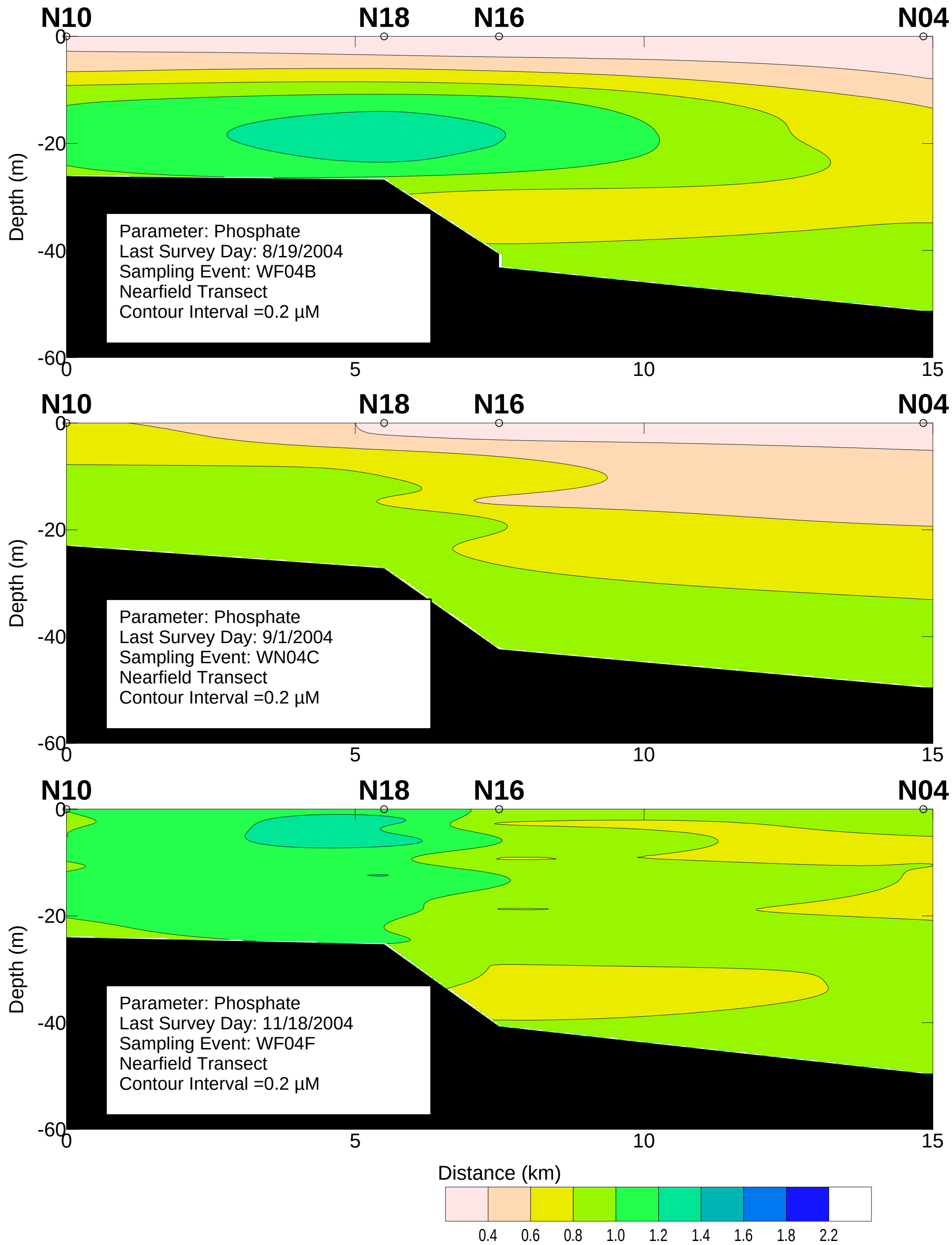


Figure 4-17. Phosphate vertical nearfield transect for surveys WF04B, WN04C, and WF04F

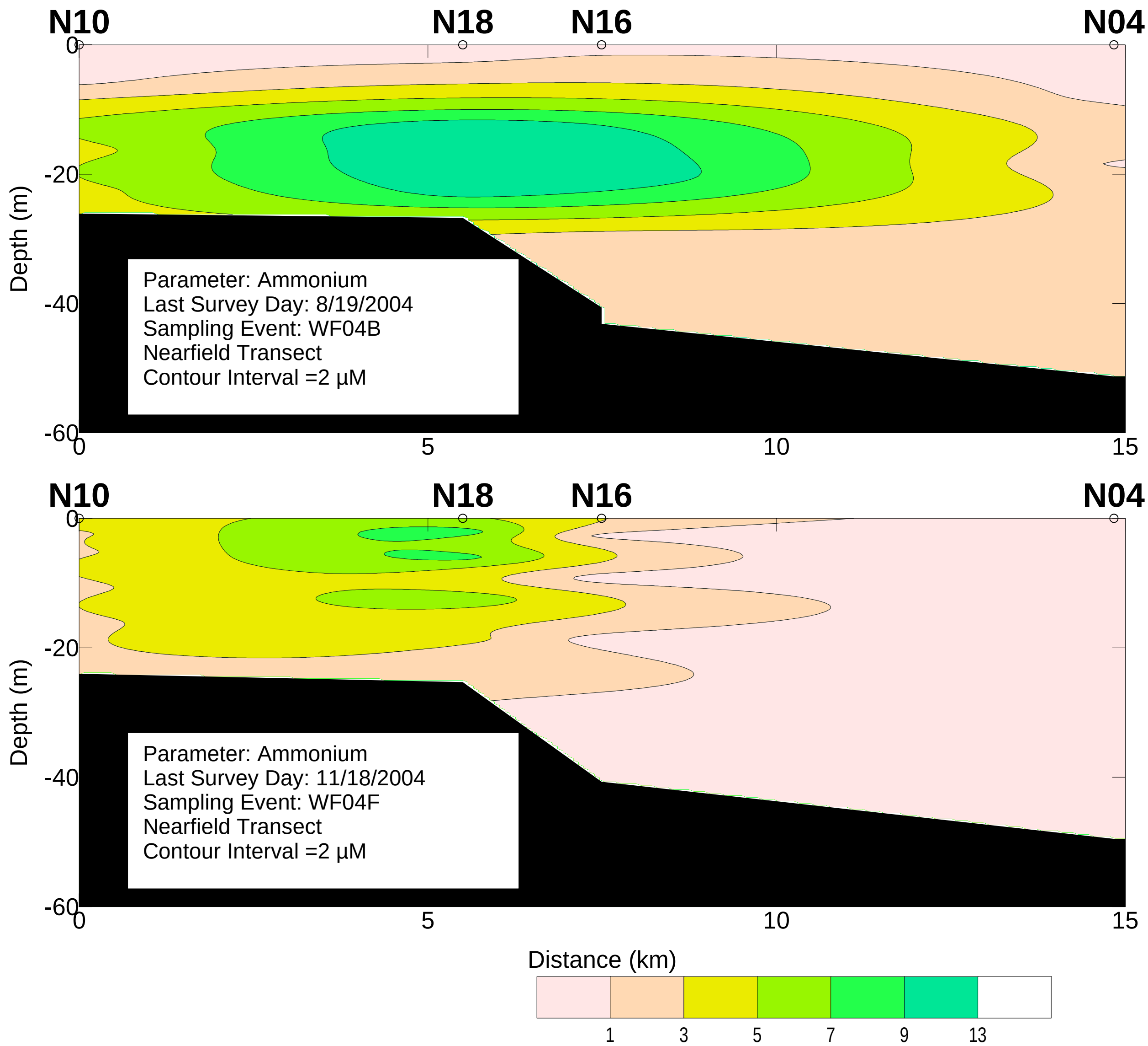


Figure 4-18. Ammonium vertical nearfield transect for surveys WF04B and WF04F

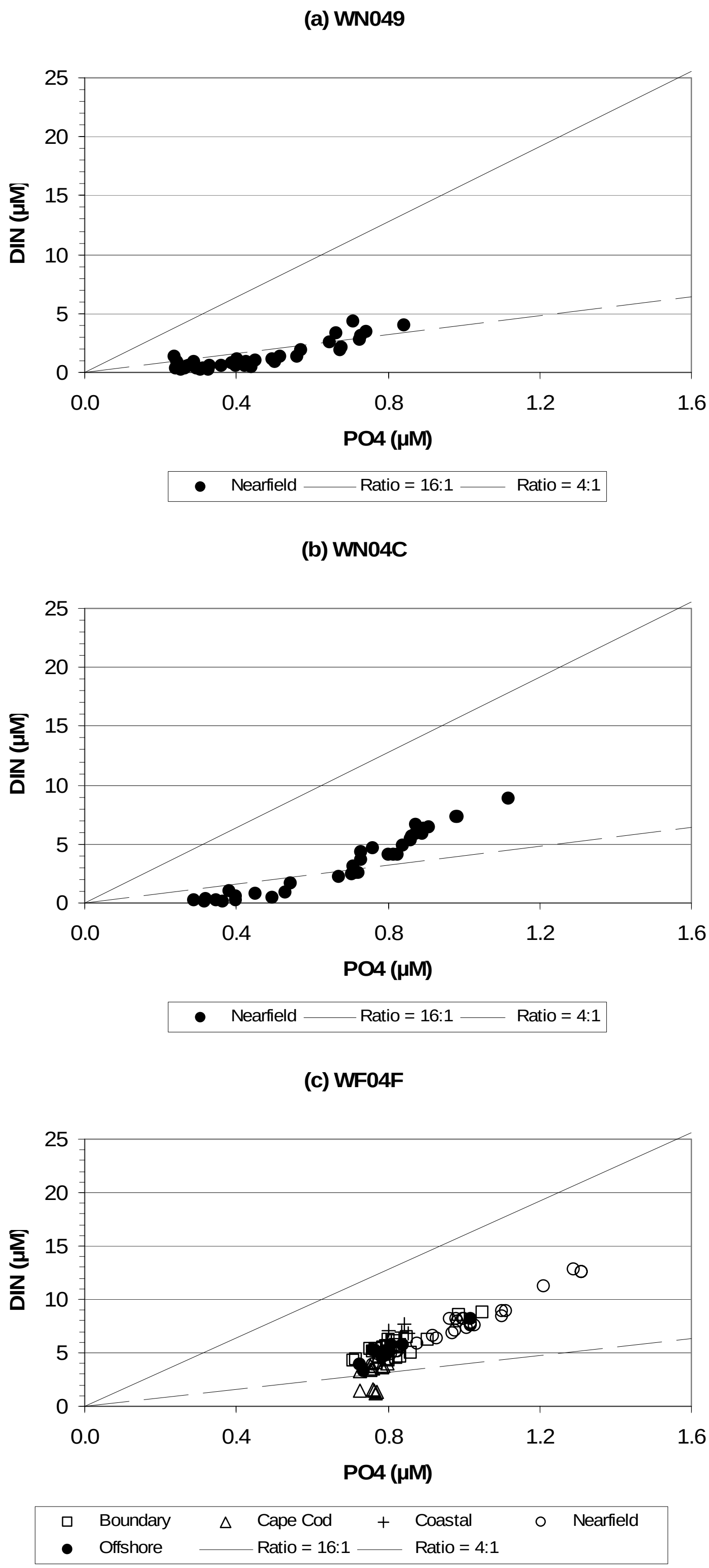


Figure 4-19. DIN versus PO_4 for nearfield surveys WN049, WN04C, and WF04F

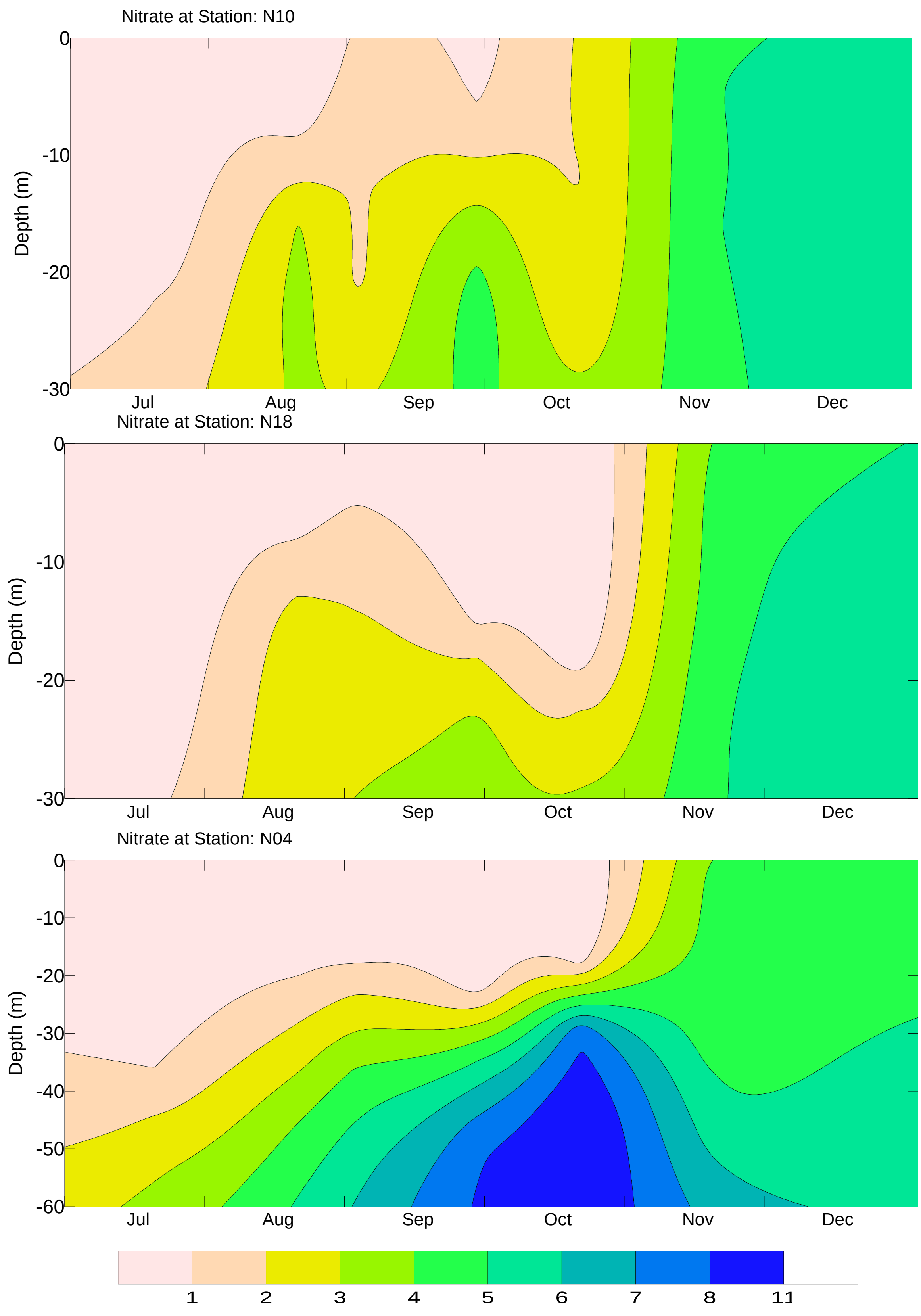


Figure 4-20. Time series of NO_3 at three representative nearfield stations during the summer-winter 2004

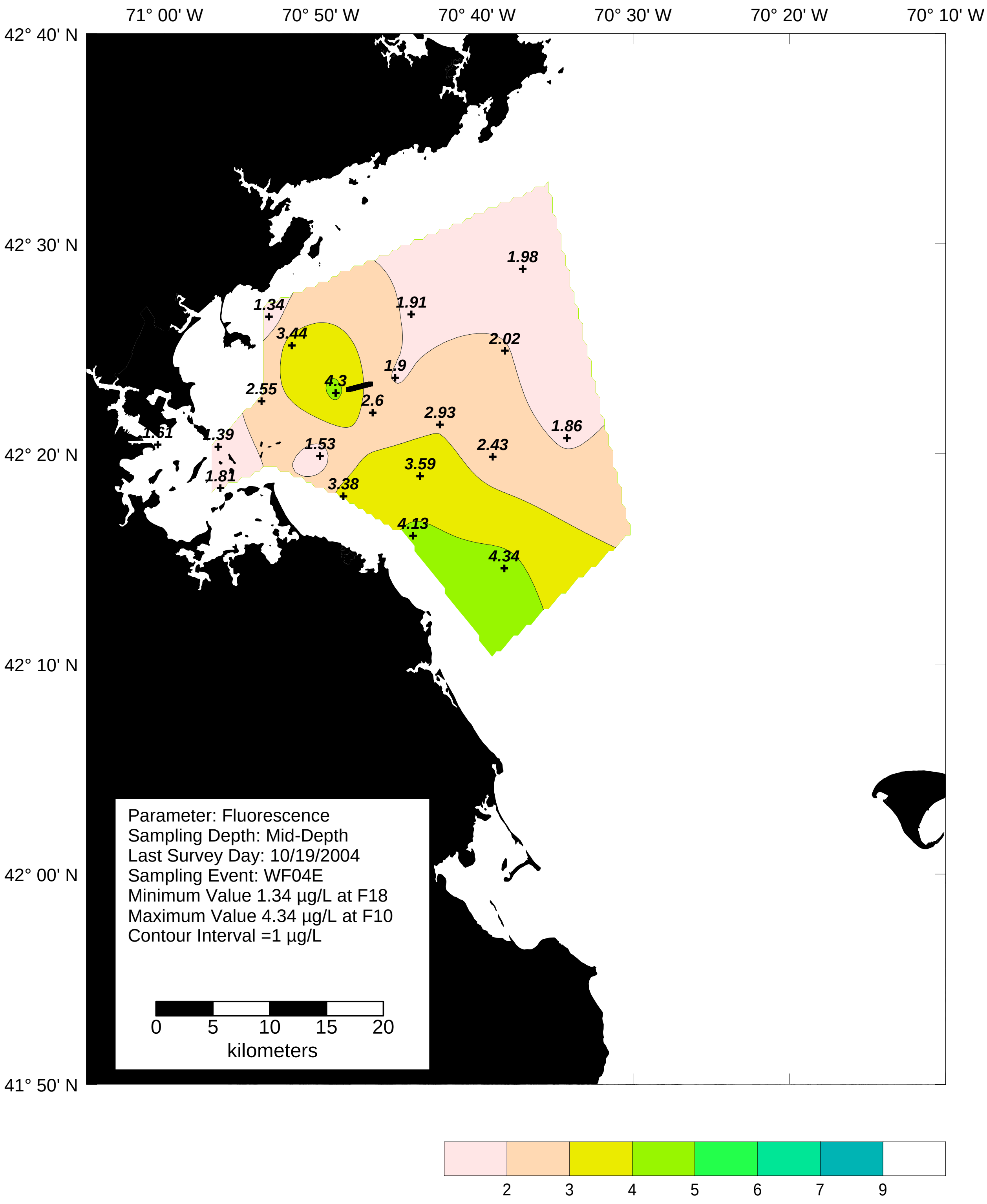


Figure 4-21. Fluorescence mid-depth contour plots for farfield survey WF04E (Oct 04)

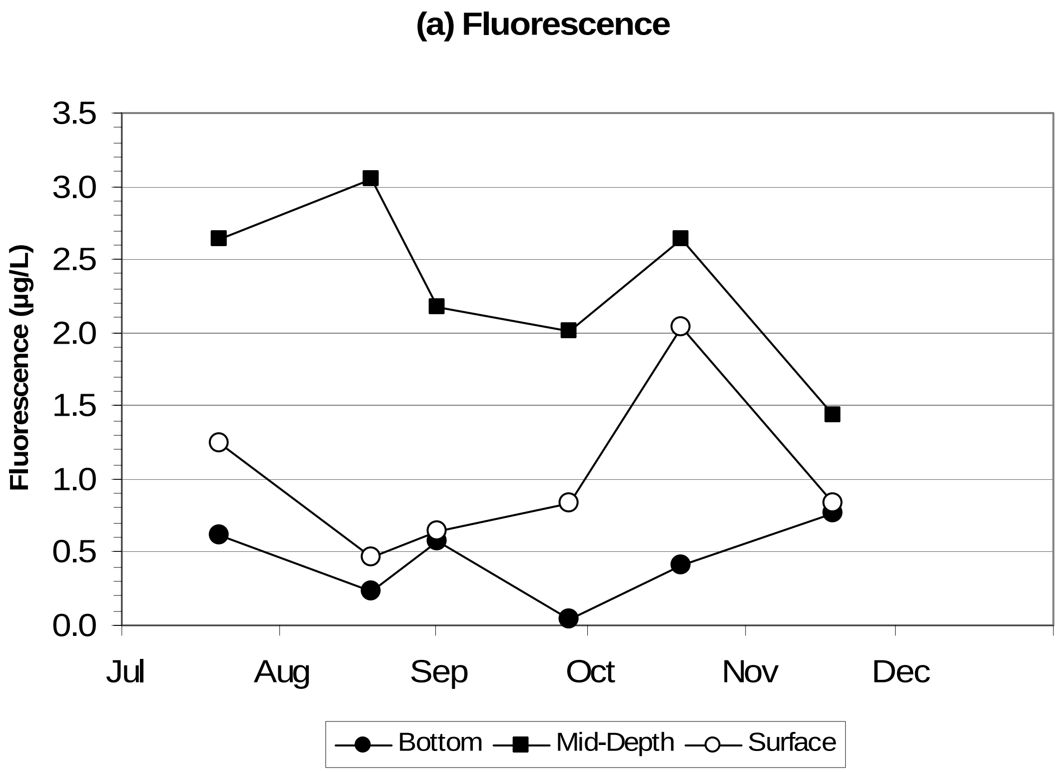


Figure 4-22. Time series of average fluorescence in the nearfield – surface, mid-depth, and bottom depth

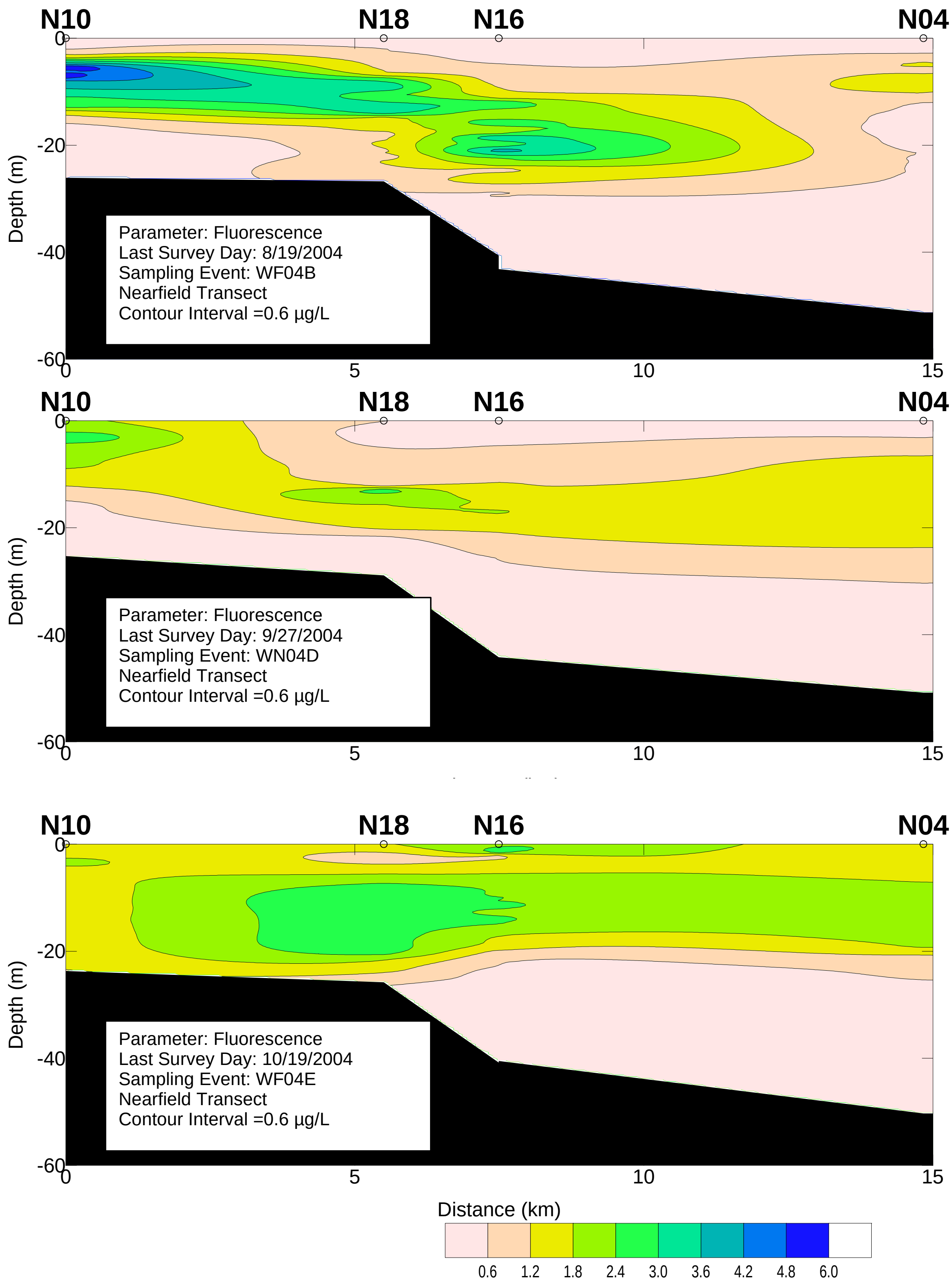


Figure 4-23. Fluorescence vertical nearfield transect plots for surveys (a) WF04B, (b) WN04D, and (c) WF04E

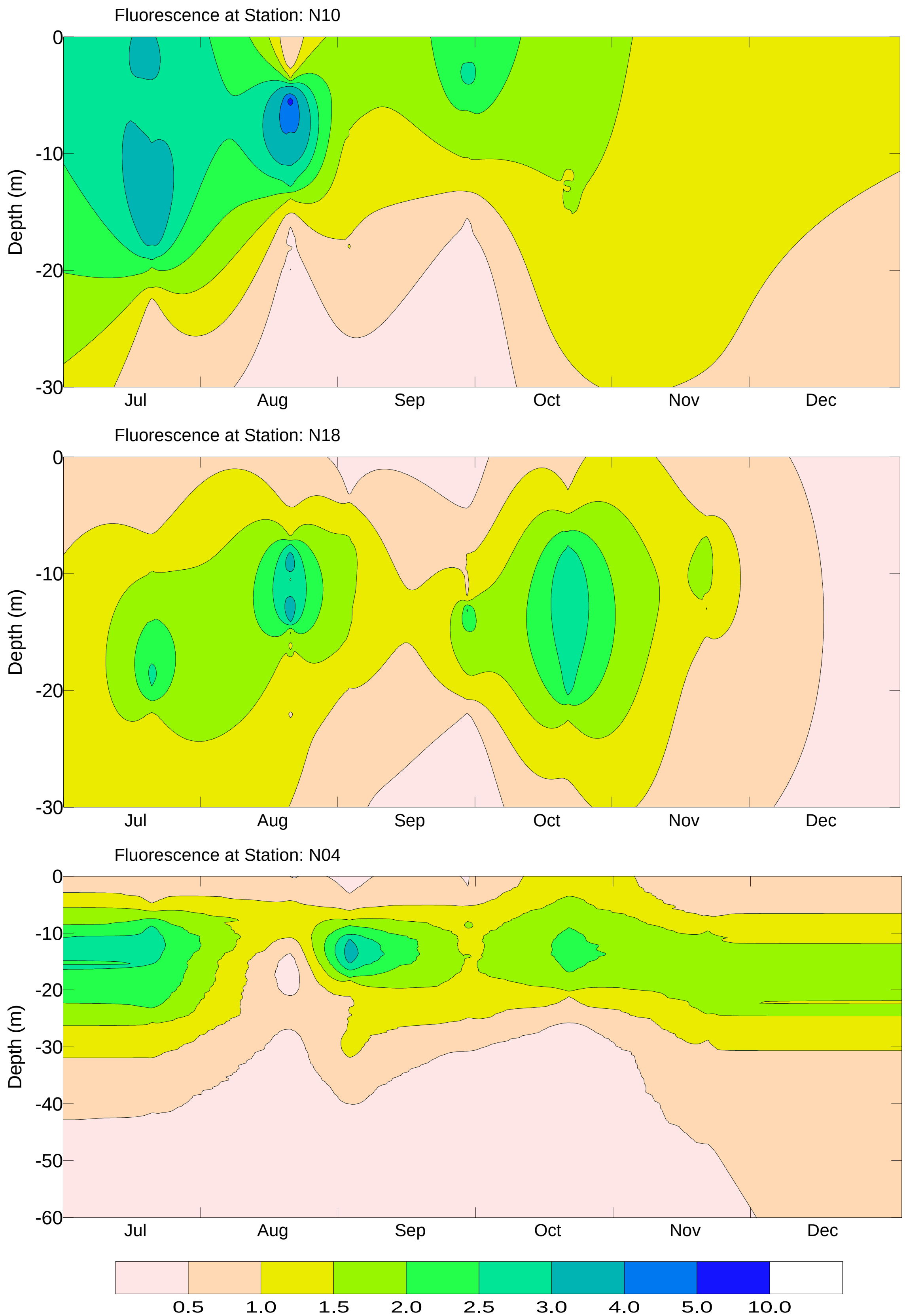


Figure 4-24. Time series of fluorescence at three representative nearfield stations during the summer-winter 2004

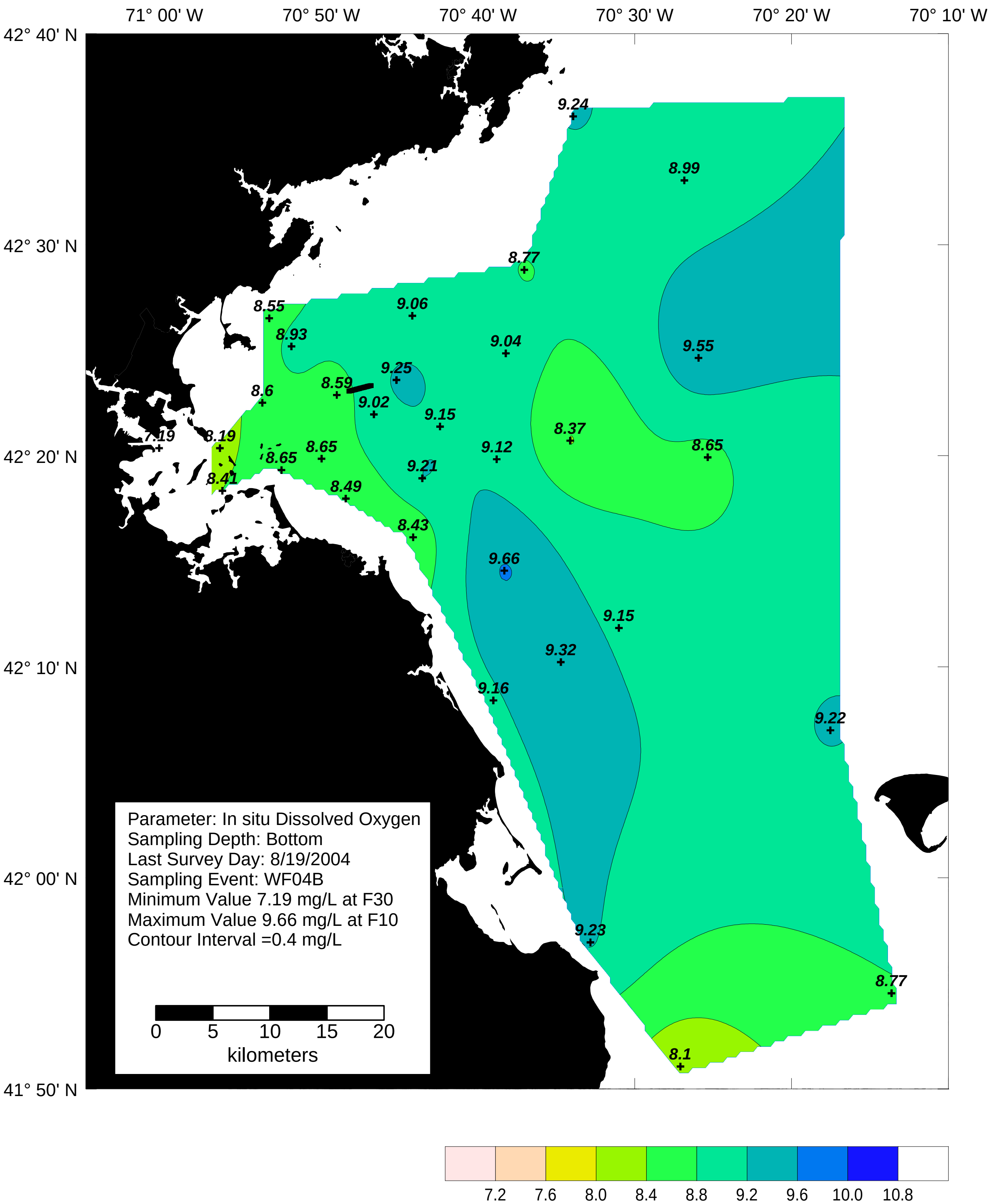


Figure 4-25. Dissolved oxygen bottom contour in the farfield survey WF04B (Aug 04)

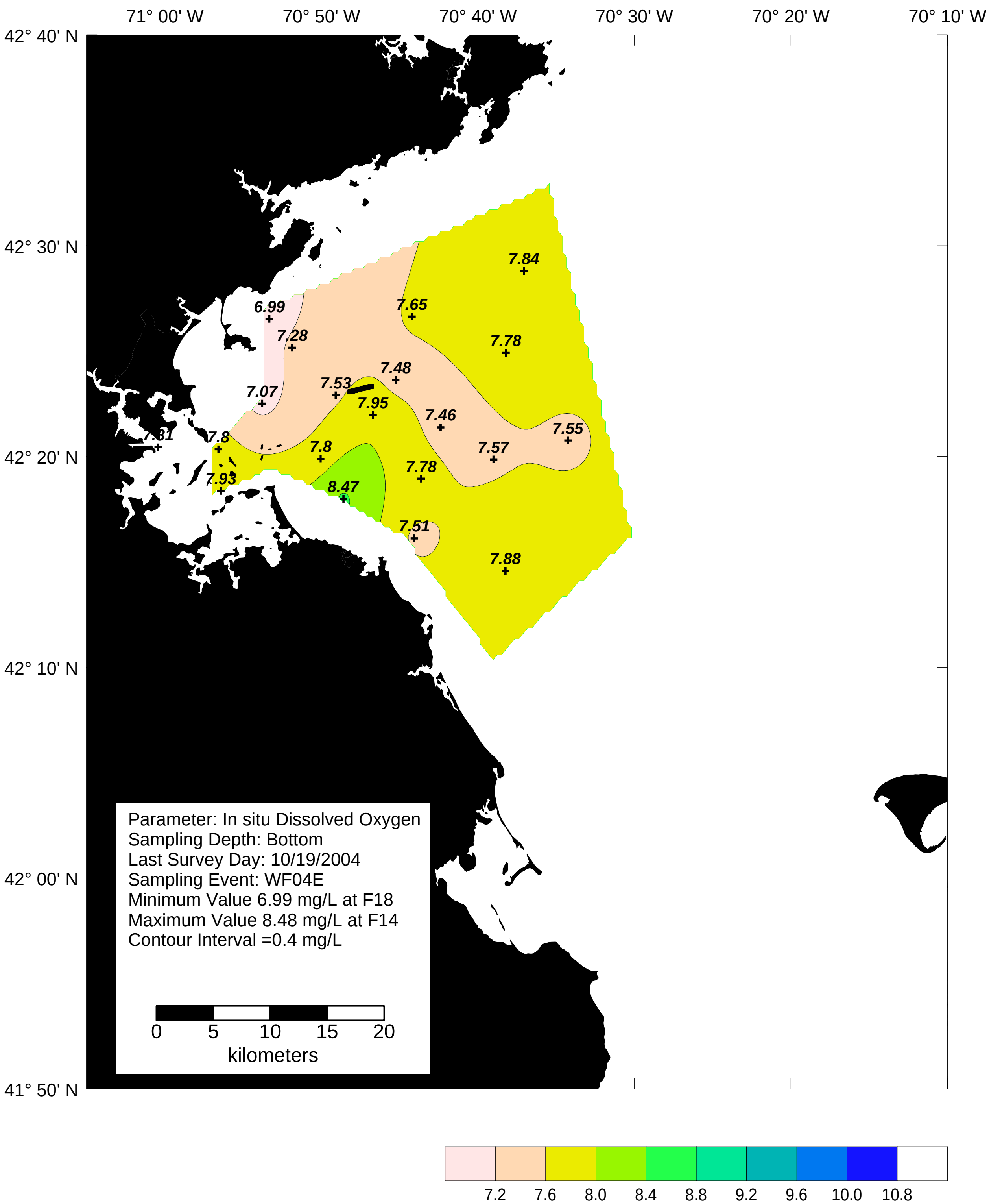


Figure 4-26. Dissolved oxygen bottom contour in the farfield survey WF04E (Oct 04)

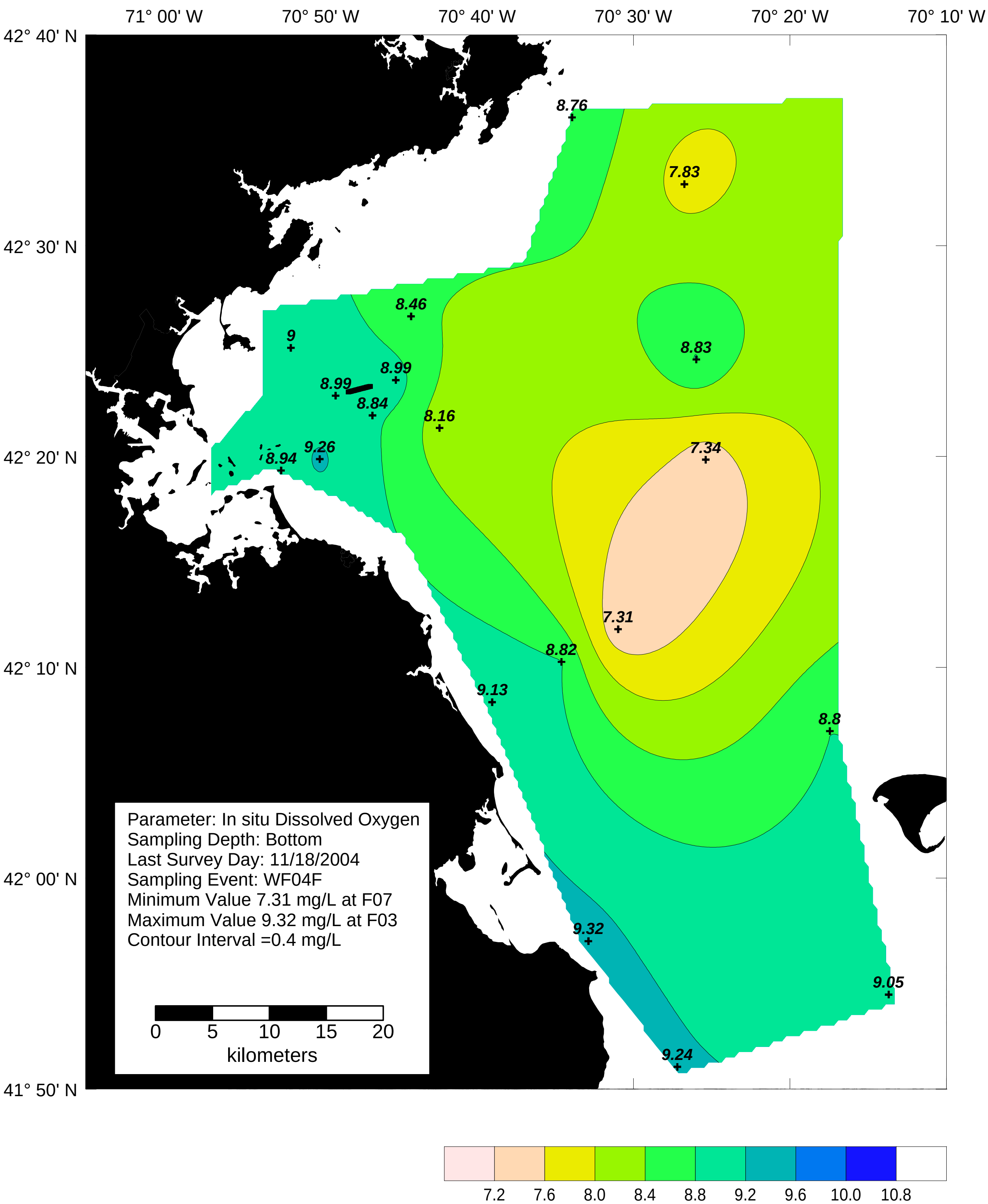


Figure 4-27. Dissolved oxygen bottom contour in the farfield survey WF04F (Nov 04)

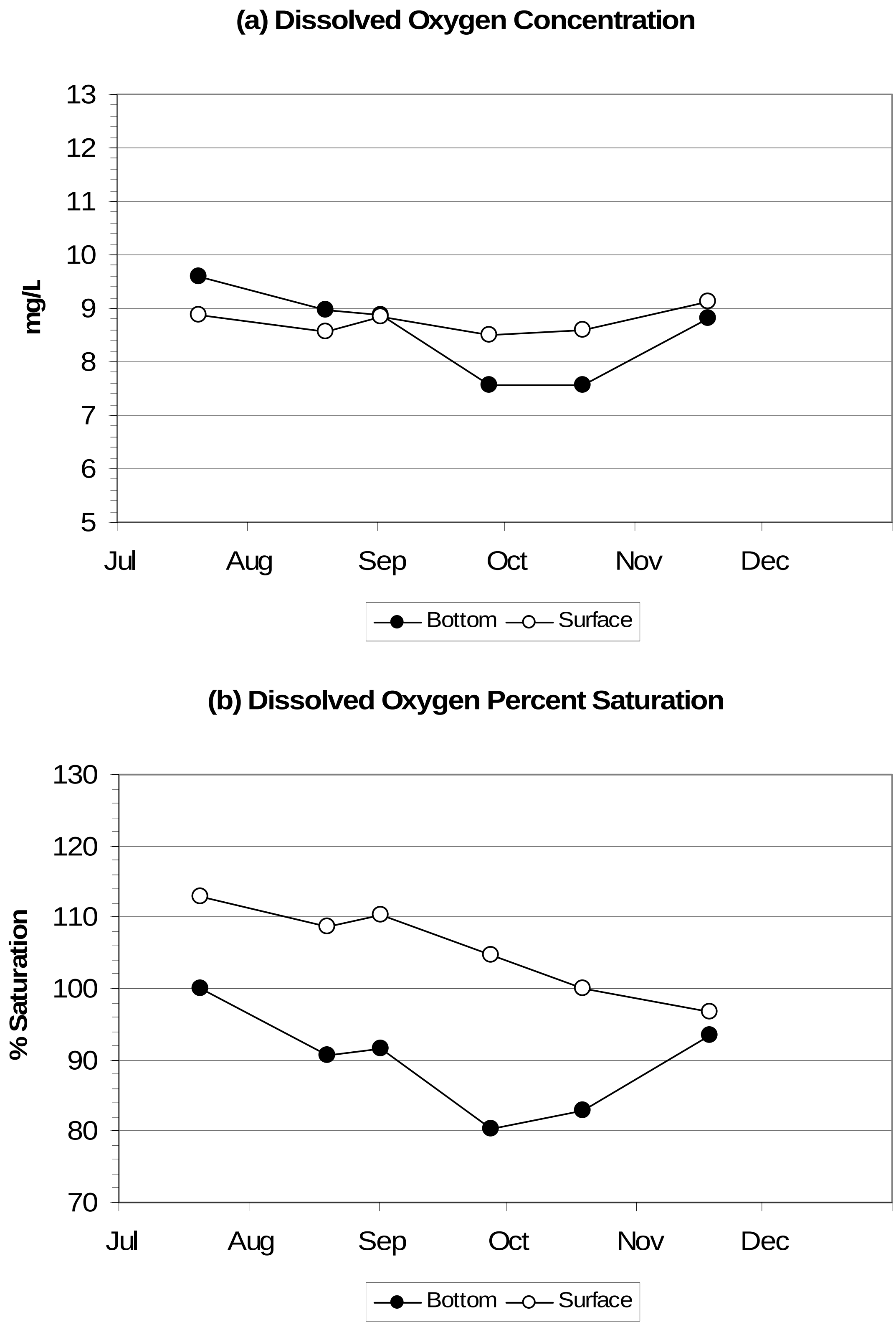


Figure 4-28. Average dissolved oxygen concentrations and percent saturation in nearfield surface and bottom water

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 August 17 (WF04B) and October 18 (WF04E). Stations N04 and N18 were additionally sampled on July 20 (WN049), September 1 (WN04C), September 27 (WN04D), and November 17 (WF04F). 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 semi-annual report, potential areal production (mg C m^{-2} d^{-1}) and depth averaged chlorophyll-specific potential production (mg C mg Chla^{-1} d^{-1}) are presented (**Figures** 5-2 and 5-3). Potential 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 *in vitro* chlorophyll *a*. Potential productivity, *in vitro* chlorophyll *a*, and chlorophyll-specific potential productivity for each depth are also presented as contour plots at station N04 and N18 (**Figures** 5-4, 5-5 and 5-6). Station F23 was only sampled twice during this reporting period hence the data are not presented as contour plots, but the results are discussed. References to production in the text that follows are specifically to potential production, but the term 'potential' has been dropped in the text for brevity.

5.1.1 Areal Production

Areal production at the nearfield stations N04 and N18 was similar throughout much of the semiannual sampling period but diverged during August (**Figure** 5-2). Areal production at the two sites was moderate (~560 – 586 mg C m^{-2} d^{-1}) during the initial survey in July. Values increased at N18 to ~1000 mg C m^{-2} d^{-1} by mid-August, but decreased to ~ 440 mg C m^{-2} d^{-1} at N04. Productivity remained similar at both sites from early September through mid-October, ranging from 477 to 609 mg C m^{-2} d^{-1}. Productivity then decreased to ~300 mg C m^{-2} d^{-1} in mid-November at both stations. The productivity at station N18 was elevated only twice relative to station N04 during this semi-annual reporting period. These results are in agreement with chlorophyll values which were also elevated at station N18 relative to N04 on the same occasions.

At the Boston Harbor productivity/respiration station F23, areal production (1387 mg C m^{-2} d^{-1}) during the August survey was the highest productivity observed at the three monitoring stations for the sampling period. Areal production at station F23 decreased to 573 mg C m^{-2} d^{-1} by October 18 and was similar to the measured production at stations N18 and N04 (**Figure** 5-2). The production data at station F23 are in agreement with the chlorophyll data. In August, chlorophyll values were high and productivity was high. Lower chlorophyll concentrations in October were associated with decreased productivity levels.

Areal production in 2004 did not follow the patterns typically observed in prior years (**Figure** 5-2). A moderate bloom was observed at station N18 in mid-August but no fall bloom was observed at station N04 during the sampling period. In prior years, nearfield stations are characterized by the occurrence of a fall bloom in October, although occasionally the peak has occurred earlier as it did in 2002 or later as at station N04 in 2003. At station N18, the fall bloom occurred consistently in October from 1995 to 1998, while at N04 the fall peak occurred in October from 1996 through 2000. More recently, the timing of the fall bloom at N18 has varied, occurring in September in 2000, December in 2001 and August in 2002 and October in 2003. At station N04, the fall bloom occurred during December in 2001 and August in 2002 and November in 2003. It has been noted that alterations in the timing of the fall productivity peak in recent years may reflect changes in nutrient availability at the nearfield sites related to the outfall (Libby *et al.* 2004a). Decreased sampling frequency in 2004 could have resulted in the fall bloom being missed, but SeaWiFS imagery for the time period did not show any indications that this was the case (see Section 4.2.2). The fall peak observed at station N18 was lower than all other years on record (1995 – 2003) and the failure to observe a fall bloom at station N04 has not been noted in prior years.

Prior to the diversion of effluent offshore, Boston Harbor station F23 exhibited a gradual pattern of increasing areal production from winter through summer rather than the distinct winter/spring peaks observed at the nearfield sites. During 1995-2001, peak areal productions at station F23 ranged from 1000 to 5000 mg C m^{-2} d^{-1} in June-July. Peak areal production observed in 2002 and 2003 reached similar magnitudes (1300 - 3200 mg C m^{-2} d^{-1}) but occurred in February or early March. In 2004, areal production was elevated during August and reduced in October (**Figure** 5-2). The seasonal cycle in 2004 at station F23 is similar to the pattern observed in 1995 – 2001, although the magnitude of the production was reduced relative to these pre-diversion years.

Peak productivity during the fall bloom period was lower in 2004 compared with prior years. The fall blooms observed at nearfield stations in 1995-2003 generally reached values of 2500 to 5000 mg C m^{-2} d^{-1}, at station N18 and 2000 – 3500 mg C m^{-2} d^{-1} at station N04. In 2004, peak fall productivity was 991 mg C m^{-2} d^{-1} at station N18 and 609 mg C m^{-2} d^{-1} at station N04, less than 50% of the peak values observed in former years. The failure of the fall bloom to develop in 2004 will be examined in more detail in the 2004 annual report.

5.1.2 Chlorophyll-Specific Production

Depth-averaged chlorophyll-specific production was elevated at station N18 compared to station N04 during this semi-annual reporting period (**Figure** 5-3). Values were initially low at station N18 (~17 mg C mg Chl a^{-1} d^{-1}), increased in mid-August to 24 mg C mg Chl a^{-1} d^{-1} then decreased to ~13 mg C mg Chl a^{-1} d^{-1} on September 1. Throughout the same period, chlorophyll-specific production at station N04 was less than station N18, varying only slightly from 6.7 to 8.0 mg C mg Chl a^{-1} d^{-1} from July to the beginning of September. Values increased at both nearfield sites in late September then decreased from late September through November. The seasonal minimum was reached at both sites in November. At station N04 the observed minimum was lower (5.2 mg C mg Chl a^{-1} d^{-1}) then the minimum observed at station N18 (7.7 mg C mg Chl a^{-1} d^{-1}). The seasonal maximum at N04 occurred in late September and was lower (12.4 mg C mg Chl a^{-1} d^{-1}) in comparison with the maximum at N18 (24 mg C mg Chl a^{-1} d^{-1}) observed in mid-August. By comparison depth-averaged chlorophyll-specific rates at harbor station F23 were mid-way in magnitude between stations N18 and N04 during August but greater than the nearfield sites in October. Depth-averaged chlorophyll-specific production at F23 did not exceed 18.1 mg C mg Chl a^{-1} d^{-1} over the reporting period (**Figure** 5-3).

5.1.3 Production at Specified Depths

The spatial and temporal distribution of production, chlorophyll and chlorophyll-specific production on a volumetric basis were summarized by showing contoured values over the sampling period (**Figure**s 5-4 to 5-6). Chlorophyll-specific productions (daily potential production normalized to chlorophyll concentration at each depth) were calculated to compare production with chlorophyll concentrations. Chlorophyll-specific production can be used as an indicator of the optimal conditions necessary for photosynthesis.

Peak productivity values (34 – 37 mg C m^{-3} d^{-1}) were observed at mid-surface depth (~11 m) at station N04 and mid-water depths (~12 m) at station N18 during July (**Figure** 5-4). At both nearfield stations productivity tended to increase in mid-August with the seasonal maxima occurring in the surface water (1.9 m) at station N04 and at the mid-surface depth (5.1 m) at station N18. The maximum at station N18 (116 mg C m^{-3} d^{-1}) was considerably higher than that observed at station N04 (41 mg C m^{-3} d^{-1}). The areal productivity peaks reported throughout the seasonal period at stations N04 and N18 were concentrated in the upper 12 m of the water column. At station N04, production was highest in the surface depths from early September through November, with an unusual absence of sub-surface productivity maxima. Sub-surface productivity maxima occurred through late September at station N18. Both stations exhibited a decline in productivity throughout the water column as the season progressed. The depth-specific productivity values at station F23 were highest (219 mg C m^{-3} d^{-1}) in the surface waters in August and decreased from surface through bottom depths.

The productivity pattern at specified depths observed in 2004 appeared more concentrated in the upper water column than in prior years at the nearfield sites. As in most years, elevated productivity (>100 mg C m^{-3} d^{-1}) in the harbor was generally restricted to the upper 10 m of the water column.

Elevated production values tended to be correlated with the occurrence of the highest chlorophyll *a* measurements at the nearfield stations (**Figure** 5-5) and the harbor station. The elevated production at station N18 during August occurred in the surface and mid-surface waters where concentrations of chlorophyll *a* were also high. In August productivity was elevated in the surface water at station F23 while chlorophyll *a* was relatively uniform throughout the water column.

Chlorophyll-specific production at depth followed similar patterns at stations N04 and N18 (**Figure** 5-6). At both sites, chlorophyll-specific production tended to be concentrated in the upper portions of the water column. Values tended to decrease with depth and as the season progressed. The peak depth-specific production per unit chlorophyll *a* observed at mid-surface depths during August at station N18 was greater than levels observed throughout the sampling period at station N04 or later in the season at N18. The elevated chlorophyll-specific production observed in August at N18 was associated with increased phytoplankton biomass as measured by in vitro chlorophyll *a*. However, similar levels of chlorophyll a at station N04 in July did not correspond with elevated chlorophyll-specific production. These results suggest that other processes (such as predation by zooplankton) are important in controlling the patterns observed. Chlorophyll-specific production is an approximate measure for the efficiency of production and frequently reflects nutrient conditions at the sampling sites. The distribution of chlorophyll-specific production indicates that the efficiency of production was higher at the outfall site over the sampling period, perhaps reflecting an additional source of nutrients at this location.

At station F23, chlorophyll-specific production decreased with depth, with peak values occurring in surface waters in August and somewhat deeper in both surface and mid-surface waters in October. The August peak at F23 was associated with elevated chlorophyll *a* at surface depths; however similar levels of chlorophyll-specific productivity in October were associated with even lower levels of chlorophyll *a* distributed throughout the water column.

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 the WF04B and WF04E combined farfield/nearfield surveys and stations N04 and N18 were also sampled during the three nearfield surveys and the modified farfield nearfield survey WF04F in November. 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 $\mu M\ O_2\ hr^{-1}$) and carbon-specific respiration ($\mu M\ O_2\ \mu M\ C^{-1}\ hr^{-1}$) waters 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

Due to the timing of the surveys, the farfield stations were only sampled twice (WF04B and WF04E) in this reporting period. Evaluation of the temporal trends is therefore focused on the nearfield area where data are available over the entire July to November time period. Respiration rates were low in July – November 2004 in comparison to previous years. In 2004, nearfield rates reached a maximum for this time period in August with a rate of 0.16 $\mu M\ O_2\ hr^{-1}$ in the surface waters at station N04 surface waters (**Figure** 5-7). Similar rates were measured in the surface waters at station F19 and throughout the water column at station F23 during the August survey (**Figure** 5-8). The highest rate measured was 0.18 $\mu M\ O_2\ hr^{-1}$ in the surface waters at station F23. Respiration rates were slightly lower at station N18, but peak rates were also measured in August at this station. These rates are slightly lower than in 2003 (Libby *et al.* 2004b) and they are about half the maximum rates of >0.4 $\mu M\ O_2 hr^{-1}$ measured in surface waters at stations N18 and F23 in August 2002 (Libby *et al.* 2003).

Respiration rates decreased sharply at the farfield stations from August maxima to October levels that were approximately one third of the summer values (**Figure** 5-8). A similar decline was seen at station N04 with mid-depth values decreasing from 0.15 to 0.06 $\mu M\ O_2\ hr^{-1}$ from August to early September. Surface water respiration rates at station N04 decreased to ~0.06 by late September and October. Bottom water respiration rates were very low (≤0.03 $\mu M\ O_2\ hr^{-1}$) throughout this period at station N04. At station N18, surface water rates were relatively consistent and low from July to October (~0.10 $\mu M\ O_2\ hr^{-1}$). Mid-depth and bottom water respiration rates were lower and more variable over this time period (**Figure** 5-7). By November, the water column had become cooler and well mixed and respiration rates were low (≤0.05 $\mu M\ O_2\ hr^{-1}$). Overall, respiration rates were very low at both the nearfield and farfield stations.

The rate of respiration is dependent upon a number of factors including the availability of organic carbon and the effect of temperature on metabolic processes. The lack of a fall bloom in 2004 may have contributed to the low respiration rates that were observed as there was less organic carbon available. POC concentrations were low relative to previous years at all four respiration stations during this time period (**Figures** 5-9 and 5-10). At station N18, POC concentrations were low in July (<20 µM), reached a maximum of only 25 µM in early September at mid-depth, and decreased to 10-20 µM by late September and for the remainder of the year. At station N04, POC concentrations were higher with concentrations of 20-30 µM in the surface and mid-depth waters from July to early September (**Figure** 5-9). These elevated POC concentrations in comparison to those at station N18 were consistent with the slightly higher respiration rates observed at station N04. By late September, however, POC concentrations in the surface and mid-depth waters had decreased to lower levels comparable to station N18. The highest POC concentrations (~40 µM) for these four respiration stations were measured in Boston Harbor in August (**Figure** 5-10). By October, the harbor POC levels had decreased by 50% to <20 µM comparable to the nearfield values. At station F19, surface water POC concentrations were slightly elevated in August (27 µM), but were low (≤11 µM) at the other depths and in October. Overall, POC concentrations were quite low in July – November 2004 with nearfield values peaking at <30 µM and a maximum concentration of only 40 µm measured at station F23 in August. This is the second year in a row with low fall respiration rates and the rates in 2004 were 50% lower than those observed in 2003.

As found during previous years, both POC and temperature were correlated with respiration rate even when all data from the four stations were grouped for comparison (**Figure** 5-11). In 2002, POC was more highly correlated with respiration (R^2 = 0.72) than temperature (R^2 = 0.52; Libby *et al*. 2003), but in 2003 the opposite was true with temperature more highly correlated with respiration (R^2 = 0.57 and 0.40; Libby *et al*. 2004b). In 2002 an early fall bloom likely provided ample newly produced POC that fueled elevated rates of respiration. In July – November 2004 as in 2003, respiration rates were low, but unlike 2003, the 2004 respiration rates were more highly correlated with POC than temperature (**Figure** 5-11). It is unclear why this was the case, but in 2004 with no fall bloom, POC and respiration rates (though low) both peaked in the summer along with temperatures. The relationships between respiration and both temperature and POC in 2004 are significant ($P<0.001$).

5.2.2 Carbon-Specific Respiration

Normalizing respiration rates against POC concentrations attempts to account for the effect variations in the size of the 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.

Overall, carbon-specific respiration rates were low during the July – December 2004 period. Higher rates (>0.005 µM O_2 µM C^{-1} hr^{-1}) were observed in the nearfield surface waters from July through September (**Figure** 5-12). Peak rates reached ~0.006 µM O_2 µM C^{-1} hr^{-1} in surface waters at station N18 in July and August and at station N04 from July to early September. Similar rates were found at mid-depth at station N04 in July and August. The values tended to decline throughout the water column at both nearfield stations from September to November. This decrease is coincident with declining POC and respiration rates presumably caused by the lack of a fall bloom and onset of cooler water temperatures. At station F19, carbon-specific respiration rates were also low and followed a similar pattern declining from maxima of 0.006 µM O_2 µM C^{-1} hr^{-1} in August to ≤0.004 µM O_2 µM C^{-1} hr^{-1} in October. At station F23, carbon-specific respiration rates were low (<0.005 µM O_2 µM C^{-1} hr^{-1}) in both August and October and did not vary with depth. The low carbon-specific respiration rates are not surprising given the lack of a fall bloom and the associated low biomass levels.

5.3 Plankton Results

Plankton samples were collected on each of the six surveys conducted from July to November 2004. Phytoplankton and zooplankton samples were collected at two stations (N04 and N18) during each nearfield survey and at 13 farfield plus the two nearfield stations (total = 15) during the farfield surveys. Due to weather conditions, the October farfield survey had to be split into two surveys, with 9 stations (F23, F30, F31, F13, F24, N04, N18, N16, and F22) sampled during survey WF04E (18-19 October) and 8 stations (F25, N04, N18, F06, F26, F27, F01, F02) sampled during survey WF04F (11-18 November). Phytoplankton samples included both whole-water and 20-µm mesh screened samples collected from the surface and mid-depth. The mid-depth sample corresponded to the subsurface chlorophyll maximum, if one was present. 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 abundance 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 abundances and relative proportions of all dominant plankton species (>5% abundance): whole water phytoplankton, 20-µm screened phytoplankton, and zooplankton.

5.3.1 Phytoplankton

5.3.1.1 Seasonal Trends in Total Phytoplankton Abundance

Total phytoplankton abundance (**Table** 5-1) in nearfield whole water samples (surface and mid-depth) ranged from 1.06 – 2.61 x 10^6 cells L^{-1} in July and August, increasing somewhat to 0.85 - 4.48 x 10^6 cells L^{-1} in September. Phytoplankton abundance through October and November ranged from 0.66 – 2.53 x 10^6 cells L^{-1}. Although diatoms were somewhat abundant in August, there was a notable absence of a major fall diatom bloom such as has been seen in several previous years (**Figures** 5-13 and 5-14).

Total phytoplankton abundance in farfield whole water samples (**Table** 5-1) in August ranged from 0.66 – 3.97 x 10^6 cells L^{-1}. This declined in October-November to 0.91 – 2.13 x 10^6 cells L^{-1}. Diatoms were a larger component of the phytoplankton in August at harbor, coastal and nearfield locations than elsewhere (**Figure** 5-15), but diatoms were eclipsed by microflagellates in abundance in October and November throughout the farfield (**Figures** 5-16 and 5-17).

Total abundances of dinoflagellates in 20-µm 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 more rare cells. Screened dinoflagellate abundance fluctuated within the same order-of-magnitude (125 – 2,650 cells L^{-1}) from July through November and was similar to past years (**Table** 5-2). These values do not include non-dinoflagellate taxa, which were counted from these samples, such as silicoflagellates, tintinnid ciliates and aloricate ciliates.

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

Survey	Dates (2004)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WN049	7/20	1.38	1.10-1.73	--	--
WF04B	8/17-19	1.85	1.06-2.61	2.01	0.66-3.97
WN04C	9/01	2.18	0.85-4.48	--	--
WN04D	9/27	1.25	0.98-1.59	--	--
WF04E	10/18-19	1.69	0.77-2.53	1.4	0.97-2.13
WF04F	11/10-18	1.33	0.66-1.96	1.37	0.91-1.85

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

Survey	Dates (2004)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WN049	7/20	292	251-342	--	--
WF04B	8/17-19	283	229-349	266	144-542
WN04C	9/01	1343	380-2650	--	--
WN04D	9/27	255	176-357	--	--
WF04E	10/18-19	373	249-483	244	125-421
WF04F	11/10-18	456	370-518	322	239-444

5.3.1.2 Nearfield Phytoplankton Community Structure

Whole-Water Phytoplankton – Nearfield phytoplankton assemblages (**Figures** 5-13 and 5-14) were similar in composition to previous years. In late July, the nearfield whole-water phytoplankton assemblages at both sampling depths were dominated by unidentified microflagellates <10 μm in diameter (81 - 94% of cells), with cryptomonads (up to 15%) comprising most of the remainder. In August microflagellates continued to dominate nearfield cell abundance, comprising 48 - 75%, with the diatom *Dactyliosolen fragilissimus* comprising 11-36% and cryptomonads up to 10%. During the September surveys, microflagellates comprised 64-86% of abundance, cryptomonads comprised 7-17%, and diatoms were very sparse during a time period when they are typically numerous to dominant. In October, dominance by microflagellates (61-94%) and cryptomonads (up to 17%) was shared only with the diatom *Skeletonema costatum* (up to only 16%). The elevated abundance of *Skeletonema* in October was found only at station N16, which was sampled a day after the other nearfield stations. By November, diatoms were again sparse and the phytoplankton community was once again dominated by microflagellates (75-82%) and cryptomonads (9-19%).

Screened Phytoplankton and Ciliates – Unlike some previous years, in late summer and fall of 2004 the dinoflagellates *Ceratium tripos*, *C. fusus, C. longipes* and other members of this genus were not the overwhelming dominants in most nearfield screened phytoplankton samples. Instead, species of the genus *Ceratium* were part of a diverse assemblage of dinoflagellates and other protists.

In July, members of the genus *Ceratium* including *C. tripos*, *C. lineatum,* and *C. longipes*, were consistently present but not overwhelmingly dominant. Screened water samples were dominated by the dinoflagellates *Ceratium longipes* (12 – 26%) and *Dinophysis norvegica* (12 - 24%), with lesser contributions (< 18% each) by the dinoflagellates *C. tripos, C. lineatum, D. acuminata, Prorocentrum* *minimum, Protoperidinium divergens, Protoperidinium* sp., unidentified thecate and athecate dinoflagellates, the silicoflagellate *Distephanus speculum*, tintinnids and aloricate ciliates.

In August, *C. longipes* (7 - 14%), *D. norvegica* (up to 22%), and *Amalax triacantha* (up to 33%) shared dominance with various other dinoflagellates (< 14% each) including *C. fusus, Ceratium sp., C. tripos, D. acuminata, Gymnodinium sp., P. minimum, Protoperidinium depressum, Protoperidinium* sp., and unidentified athecate and thecate dinoflagellates, and *D. speculum*. Aloricate ciliates (up to 18%) and tintinnids (up to 9%) were also present.

During the early September survey, there was a mixed community dominated by *C. longipes* (14-39%), unidentified athecate dinoflagellates (13-14%), other dinoflagellates (< 11% each) including *C. lineatum, C. fusus, Ceratium* sp., *Gymnodinium* sp., *P. depressum, Protoperidinium* sp., *D. norvegica*, *Scrippsiella trochoidea*, and unidentified thecate dinoflagellates. Aloricate ciliates (up to 12%) and tintinnids (6-9%) were also present. By late September, the mixed assemblage of dinoflagellates was comprised of various species none of which were > 15% of total cells including *C. fusus, C. longipes, D. norvegica,* and *Protoperidinium* sp. Unidentified athecate and thecate dinoflagellates, aloricate ciliates, tintinnids, and *D. speculum* made up the remainder of the assemblage.

In October, the dinoflagellate community was dominated by a mixture of *C. fusus* (up to 17%), *C. longipes* (up to 21%), and *Scrippsiella trochoidea* (8-23%) with lesser contributions (< 12%) by *C. tripos, Gonyaulax* sp., *Gymnodinium* sp., *P. depressum, Protoperidinium* sp., and unidentified athecate and thecate dinoflagellates. The silicoflagellates *D. speculum* and *D. fibula* each comprised up to 9% and 13% of the community, respectively. Aloricate ciliates and tintinnids were also present. In November, screened assemblages were dominated by *C. fusus* (36-62%), with lesser contributions (< 11% each) by *C. longipes, C. tripos, Ceratium* sp., *D. norvegica, Protoperidinium* sp., unidentified thecate and athecate dinoflagellates, *D. speculum*, and aloricate ciliates. Tintinnids comprised 5-15% of assemblages.

5.3.1.3 Farfield Phytoplankton Assemblages

Whole-Water Phytoplankton – Farfield phytoplankton assemblages (**Figures** 5-15 to 5-17) were generally similar in composition to those of the nearfield. During survey WF04B in August, microflagellates dominated at both depths at most farfield stations (38 – 89% of total abundance, except at two stations in Boston Harbor (F30 and F31) where microflagellates comprised only 34-50% of cells. Cryptomonads comprised up to 20% of cells counted. Three diatom taxa were sporadically abundant, with *Dactyliosolen fragilissimus* comprising up to 43%, *Leptocylindrus minimus* up to 8% and *Skeletonema costatum* up to 11% of cell abundance. The diatoms were most abundant in Boston Harbor with slightly lower numbers observed at the coastal and nearfield stations. Diatom abundance was low at the offshore, boundary and Cape Cod Bay stations. Athecate dinoflagellates of the genus *Gymnodinium* comprised 6% of cells at station F01.

By October, as in the nearfield, most farfield stations were dominated by unidentified microflagellates (65 – 87%) and cryptomonads comprised up to 18% at some stations. *S. costatum* and *Gymnodinium* sp. comprised up to 7% and 6% (maxima at station N16), respectively. In November, microflagellates were 69-85% of abundance, with small cryptomonads (< 10 µm) and large cryptomonads (> 10 µm) comprising 9-22% and up to 5%, respectively, of abundance. Small centric diatoms (< 10 µm) were up to 7% of abundance at some stations offshore and in Cape Cod Bay.

Screened Phytoplankton and Ciliates – In August, 20-µm screened phytoplankton samples at most stations from the farfield were similar to nearfield assemblages, comprised of a mixture of *Ceratium longipes* (up to 27%), *C. fusus* (up to 17%), *Dinophysis norvegica* (up to 20%), various unidentified thecate (up to 16%) and athecate (up to 22%) dinoflagellates, the silicoflagellate *Distephanus* *speculum* (up to 13%), aloricate ciliates (up to 23%), and tintinnid ciliates (up to 78%). Other dinoflagellates, individually comprising < 15% at any given station, included *Ceratium tripos*, *Ceratium* sp., *Dinophysis acuminata*, *Gymnodinium* sp., *Prorocentrum micans*, *P. minimum*, *Protoperidinium depressum*, *P. divergens*, *Protoperidinium* sp., and *Scrippsiella trochoideum*.

In October, the screened phytoplankton samples from the farfield continued to be similar to nearfield assemblages. They were comprised of a mixture of the dinoflagellates *Ceratium fusus* (up to 18%), *C. longipes* (up to 21%), *C. tripos* (up to 17%), *Scrippsiella trochoideum* (up to 46%). Other taxa individually comprising < 20% of the assemblage at a given station, included the dinoflagellates *Ceratium lineatum, Ceratium* sp., *Gonyaulax* sp., *Prorocentrum minimum*, *Protoperidinium depressum*, and *Protoperidinium* sp., various other unidentified thecate and athecate dinoflagellates, and the silicoflagellate *Distephanus speculum*. Aloricate ciliates (up to 20%) and tintinnid ciliates (up to 28%) comprised the remainder of assemblages.

Similarly, in November, farfield screened phytoplankton assemblages were comprised of *Ceratium fusus* (up to 25%), *C. lineatum* (up to 13%), *Dinophysis norvegica* (up to 13%), unidentified thecate (up to 16%), athecate (5-18%) dinoflagellates, and various other dinoflagellates (each < 10%) including *Ceratium longipes*, *C. tripos*, *Ceratium* sp., *Prorocentrum micans*, *Protoperidinium depressum*, and *Protoperidinium* sp. Other sporadically abundant protists included the silicoflagellates *Dictyocha fibula*, *Distephanus speculum*, aloricate ciliates (up to 17%), tintinnid ciliates (9-30%), and the photosynthetic ciliate *Mesodinium rubrum* (up to 7%).

5.3.1.4 Nuisance Algae

There were no confirmed blooms of harmful or nuisance phytoplankton species in Boston Harbor, Massachusetts and Cape Cod Bays during July – December 2004. *Phaeocystis pouchetii,* which bloomed in spring, was unrecorded during this period. *Alexandrium* spp. was recorded only once as a single cell in the whole-water sample at station N04 during survey WN04C.

Potentially-toxic species of the diatom genus *Pseudo-nitzschia* were present at many stations from July through December, but usually in low abundances. Cells of the *Pseudo-nitzschia pseudodelicatissima* complex were present in 23 of 68 whole-water phytoplankton samples (33.8%) at abundance levels of 0.1 – 19.7 x 10^3 cells l^{-1} (mean = 2.1 x 10^3 cells l^{-1}). Although *Pseudo-nitzschia pseudodelicatissima* has been associated with domoic acid toxicity in the sea (Hasle and Syvertsen, 1997), it is not included in the *Pseudo-nitzschia "pungens*" threshold. This threshold was established to assess the incidence of the domoic-acid-producing species *P. multiseries*. Nominal *Pseudo-nitzschia pungens* were recorded throughout the July-December period. There were 10 records (14.7% of samples) for *P. pungens*, at abundance levels of 0.3 – 32.6 x 10^3 cells l^{-1} (mean = 6.3 x 10^3 cells l^{-1}).

5.3.2 Zooplankton

5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Total zooplankton abundance at nearfield stations (**Table** 5-3) was maximal (34.3 – 63.8 x 10^3 animals m^{-3}) in late July, declining to levels of 22.4 – 49.7 x 10^3 animals m^{-3} in August and 36.9 – 50.5 x 10^3 animals m^{-3} in early September. By late September, the fall decline in abundance was well underway with levels of 12.4 – 19.9 x 10^3 animals m^{-3}, decreasing further in October and November (0.8 – 27.3 x 10^3 and 11.9 – 20.9 x 10^3 animals m^{-3}, respectively; **Table** 5-3; **Figure** 5-18).

Farfield sampling had wider variability than levels in the nearfield (**Table** 5-3). During August, zooplankton abundance (4.4 – 71.6 x 10^3 animals m^{-3}) was variable (**Figure** 5-19), with a range both lower and higher than the nearfield range. Levels at most stations did not reflect the substantial ctenophore predation seen in 2000 and 2002. However, the zooplankton abundance was lower throughout most of the farfield in October (6.6 – 54.5 x 10^3 animals m^{-3}) and November (12.4 – 28.6 x 10^3 animals m^{-3}) (**Figure** 5-20).

Zooplankton abundance in Boston Harbor reached unprecedented low levels during October 2000 due to decimation of zooplankton populations by ctenophore predation. No ctenophores were noted in fall 2001, but a summer-fall increase of ctenophores occurred in both 2002 and 2003, as disintegrated tissue of the ctenophore *Mnemiopsis leidyi* was either present in, or screened out from many zooplankton samples. In 2002, this resulted in low zooplankton abundance during the July-December semiannual period (Libby *et al.* 2003). In 2003 and 2004, however, the relative number of ctenophores was apparently lower and did not result in a substantial decline in zooplankton abundance in comparison to previous years. Although the lower abundance in October 2004 could reflect some ctenophore predation, it is more likely that it resulted from the lack of a fall bloom and a decrease in available food resources.

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

Survey	Dates (2004)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WN049	7/20	49.0	34.3-63.8	--	--
WF04B	8/17-19	32.8	22.4-49.7	44.6	4.4-71.6
WN04C	9/01	43.7	36.9-50.5	--	--
WN04D	9/27	16.2	12.4-19.9	--	--
WF04E	10/18-19	10.0	0.8-27.3	27.0	6.6-54.5
WF04F	11/10-18	16.4	11.9-20.9	19.2	12.4-28.6

5.3.2.2 Nearfield Zooplankton Community Structure

Zooplankton assemblages during nearfield surveys (**Figure** 5-18) in July were dominated by copepod nauplii (31 - 39%), *Oithona similis* copepodites (39% at both stations) and females (5-10%), with subdominant contributions by copepodites of the genus *Pseudocalanus* (up to 6%), which could include members of two species that are distinguished only with difficulty, *P. newmani* and *P. moultoni*. Copepodites of *Calanus finmarchicus* made up most of the remainder (up to 6%). During August, zooplankton assemblages were dominated by copepod nauplii (16 - 26%), *Oithona similis* copepodites (28-42%) and females (7-10%), with subdominant contributions by *Pseudocalanus* copepodites (10-19%) and bivalve veligers (7-16%).

From early September through late September, the nearfield zooplankton assemblages continued to be dominated by copepod nauplii (11-38%) and *Oithona similis* copepodites (20-48%) and females (5-33%), and *Pseudocalanus* sp. copepodites (up to 28%). At nearfield stations in October, copepod nauplii (14-37%) and *Oithona similis* copepodites (27-52%) and females (6-18%) shared dominance with bivalve veligers (up to 19%). There were variable contributions by *Pseudocalanus* spp. copepodites (up to 14%), and the copepod *Microsetella norvegica* (up to 6%).

5.3.2.3 Farfield Zooplankton Assemblages

At farfield stations in August copepod nauplii (9 - 32%), *Oithona similis* copepodites (up to 45%) and females (up to 17%) were dominants (**Figure** 5-19). Additional sporadically-abundant taxa included *Pseudocalanus* spp. copepodites (up to 30%), and *Temora longicornis* copepodites (up to 8%).

Acartia spp. copepodites comprised 8-19% of abundance at stations F23, F30 and F31 in Boston Harbor, but < 5% elsewhere. Similarly, *Eurytemora herdmani* copepodites comprised 10-17% of abundance at stations F23 and F30 in Boston Harbor, but were <5% elsewhere. *Calanus finmarchicus* copepodites comprised 36% of abundance at boundary station F27, but only up to 7% elsewhere. Other sporadically abundant taxa included *Centropages* spp. copepodites (up to 10%), gastropod veligers (up to 6%) and bivalve veligers (up to 21%).

At farfield stations in October and November (**Figure** 5-20), copepod nauplii comprised up to 38% of animals counted and *Oithona similis* copepodites were up to 43%. Other frequently-recorded taxa throughout most of the farfield included *O. similis* females (up to 12%), *Pseudocalanus* spp. copepodites (up to 10%), *Temora longicornis* copepodites (up to 10%), *Centropages* spp. copepodites (up to 34%), *Microsetella norvegica* (up to 12%), *Paracalanus parvus* copepodites (up to 20%), *Paracalanus crassirostris* females (up to 6%), and *Calanus finmarchicus* copepodites (up to 5% at F27 but were <5% elsewhere). As in the previous farfield survey *Acartia* spp. copepodites (up to 16%) and *Eurytemora herdmani* (up to 7%) were observed at Boston Harbor stations, but not at any station outside of the harbor.

In summary, zooplankton assemblages during the second half of 2004 were comprised of taxa normally recorded for this time of year in previous MWRA monitoring data.

5.4 Summary of Water Column Biological Results

- Nearfield peak productivity rates during fall 2004 were lower in magnitude than values observed during prior years (1995 to 2003)
- Productivity at station F23 was characterized by elevated summer productivity and decreased fall levels in 2004
- The productivity pattern observed at F23 in 2004 was similar to the pattern at this site in the years preceding effluent diversion offshore, although the rate was reduced
- Chlorophyll-specific potential production generally reached higher levels at station N18 compared with N04
- Respiration rates were low ($\leq$0.18 μM O_2 hr^{-1}) in July – November 2004.
- Nearfield respiration rates for this time period were highest in August (0.16 μM O_2 hr^{-1}) in the surface waters at station N04 and decreased sharply after the August survey at station N04 and the farfield stations (F19 and F23). Respiration rates were relatively low throughout this period at station N18. The lack of a fall bloom in 2004 likely kept respiration rates low in September – October 2004.
- Maximum POC concentrations were reached in August – 27 μM in the nearfield (N04) and ~40 in the farfield (F23). With no fall bloom observed, POC concentrations declined from August to November. Overall POC concentrations were low during July – November 2004.
- Respiration was significantly ($P<0.001$) correlated with both temperature and POC concentration.
- Carbon-specific respiration rates reached a maximum of just ~0.006 μM O_2 μM C^{-1} hr^{-1} in nearfield and farfield waters in August and early September. Rates declined and remained low during the fall as biomass concentrations were low and the lack of organic material and cooler temperatures led to low respiration rates.

- There was no fall diatom bloom in the sampling area as typically observed during previous years.
- The whole water phytoplankton assemblage was dominated by unidentified microflagellates and cryptomonads with only sporadic elevated abundances of diatoms.
- The >20-µm screened dinoflagellate assemblage from July through October included a mixed assemblage of dinoflagellates and other protists.
- There were no confirmed blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during July – November 2004, although the potentially-toxic diatom *Pseudo-nitzschia pungens* was present throughout much of the area over this period.
- Zooplankton abundance decreased from maximum levels in August, through the fall into November. The rate of decline, particularly in early October, may have been due in part to ctenophore predation, but apparently not to the extent as in some previous fall periods.
- The reduction in zooplankton abundance uncharacteristically did not seem to contribute to a fall phytoplankton diatom bloom through decreased grazing pressure by copepods and other grazers.
- Zooplankton abundance was, as usual, dominated by copepod nauplii and adults and copepodites of the small copepods *Oithona similis*, and copepodites of *Pseudocalanus* and *Centropages* sp., with lesser contributions, at some stations, by meroplankters such as bivalve veligers and, in Boston Harbor, *Acartia* spp. and *Eurytemora herdmani* copepodites and adults.

WN049 **Station N18**

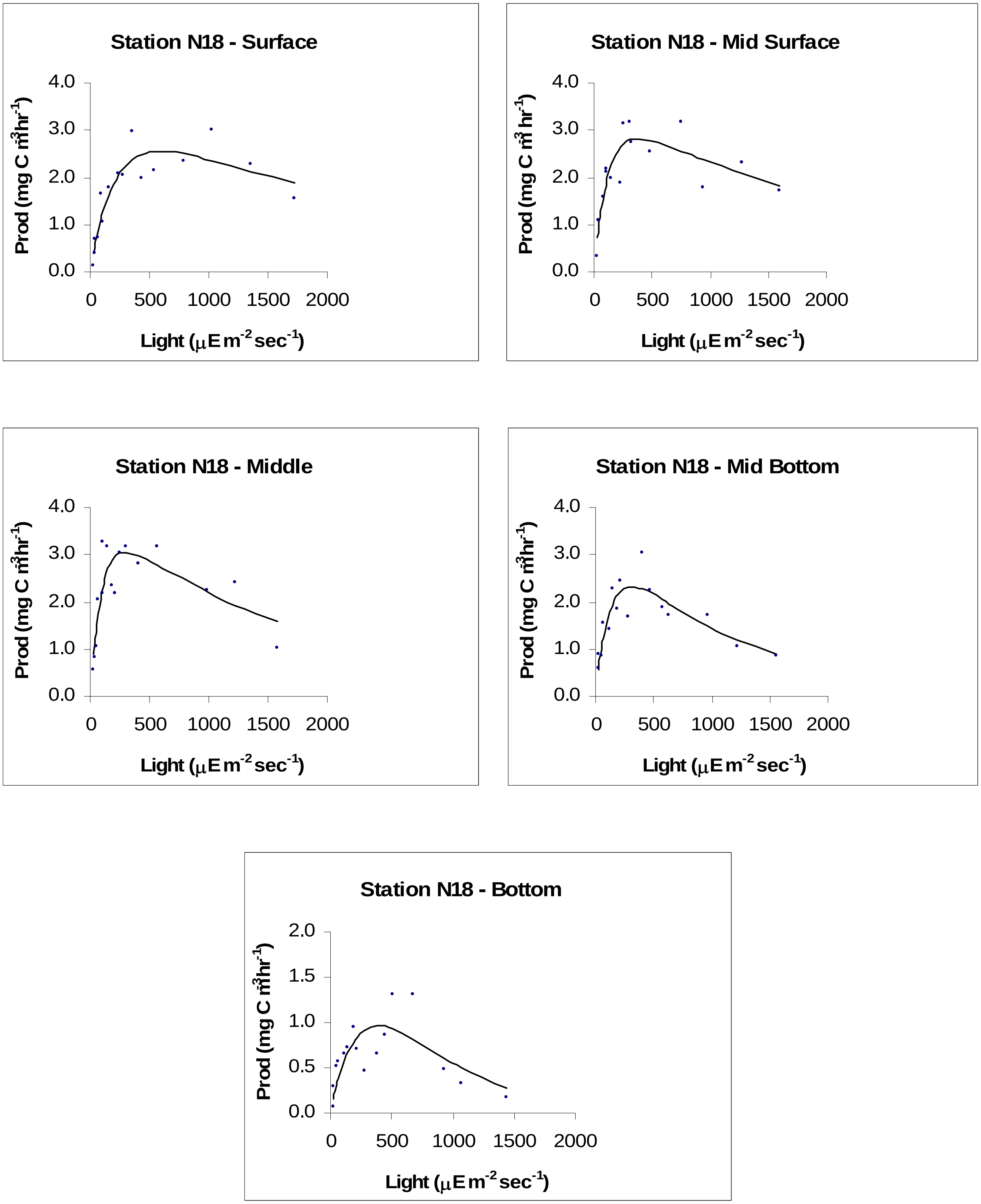


Figure 5-1. An example photosynthesis-irradiance curve from station N18 collected in July 2004

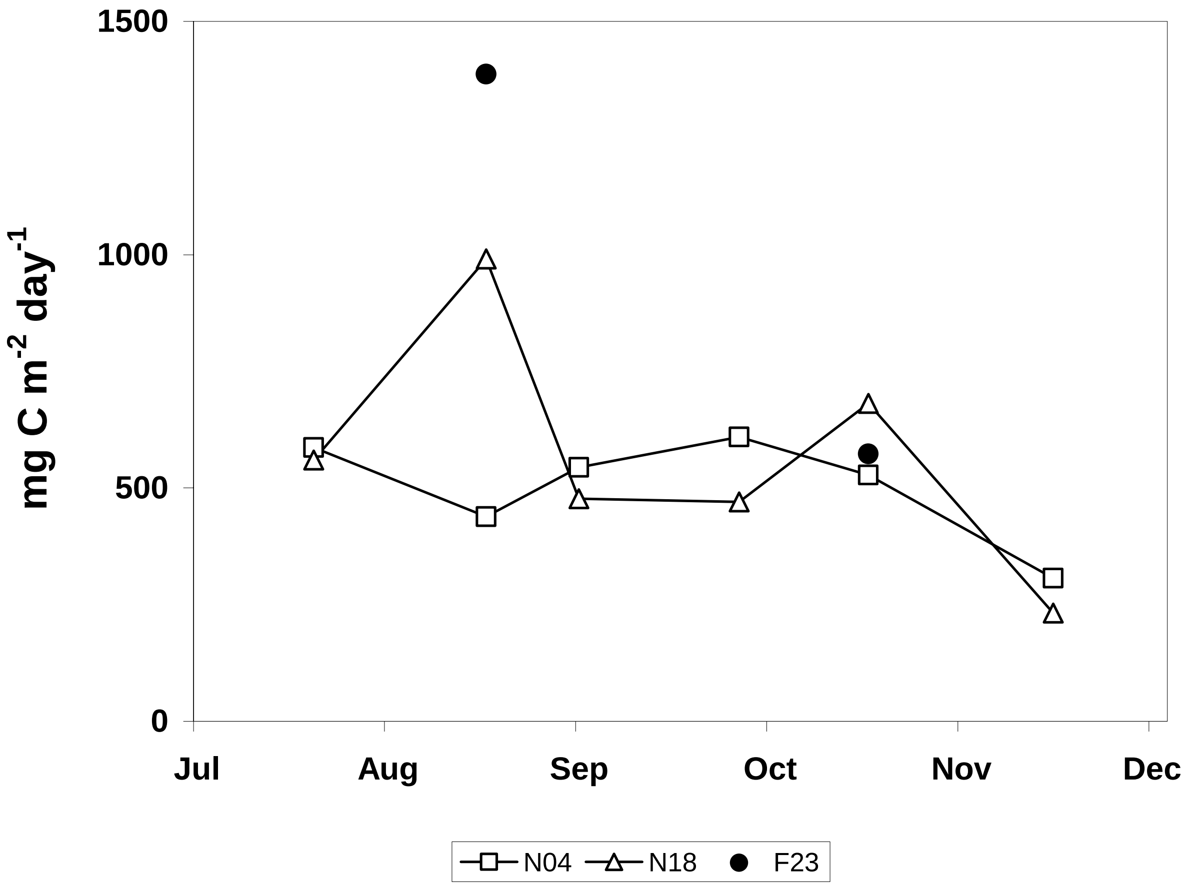


Figure 5-2. Time-series of potential areal production ($mgCm^{-2}d^{-1}$) for stations N04, N18 and F23

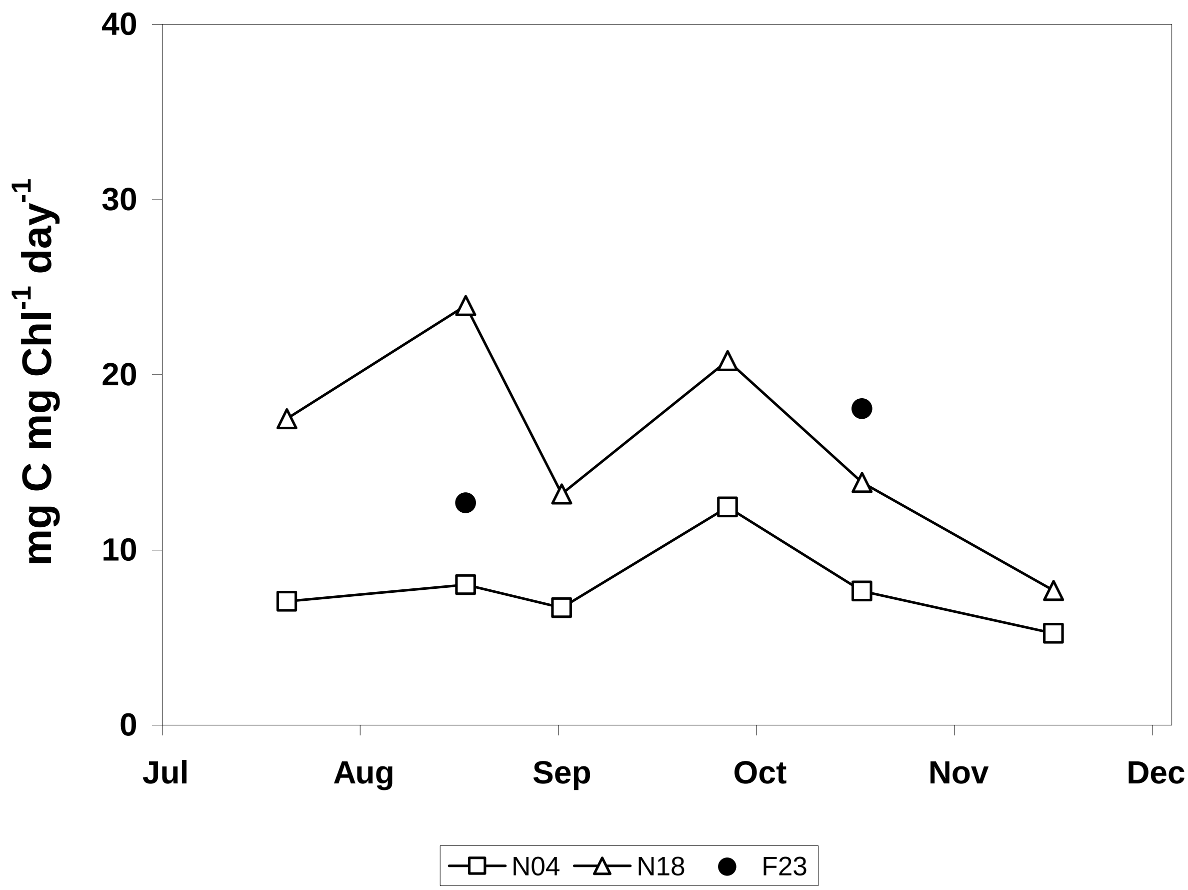


Figure 5-3. Time-series of depth-averaged chlorophyll-specific potential production ($mgCmgChl^{-1}d^{-1}$) for stations N04, N18 and F23

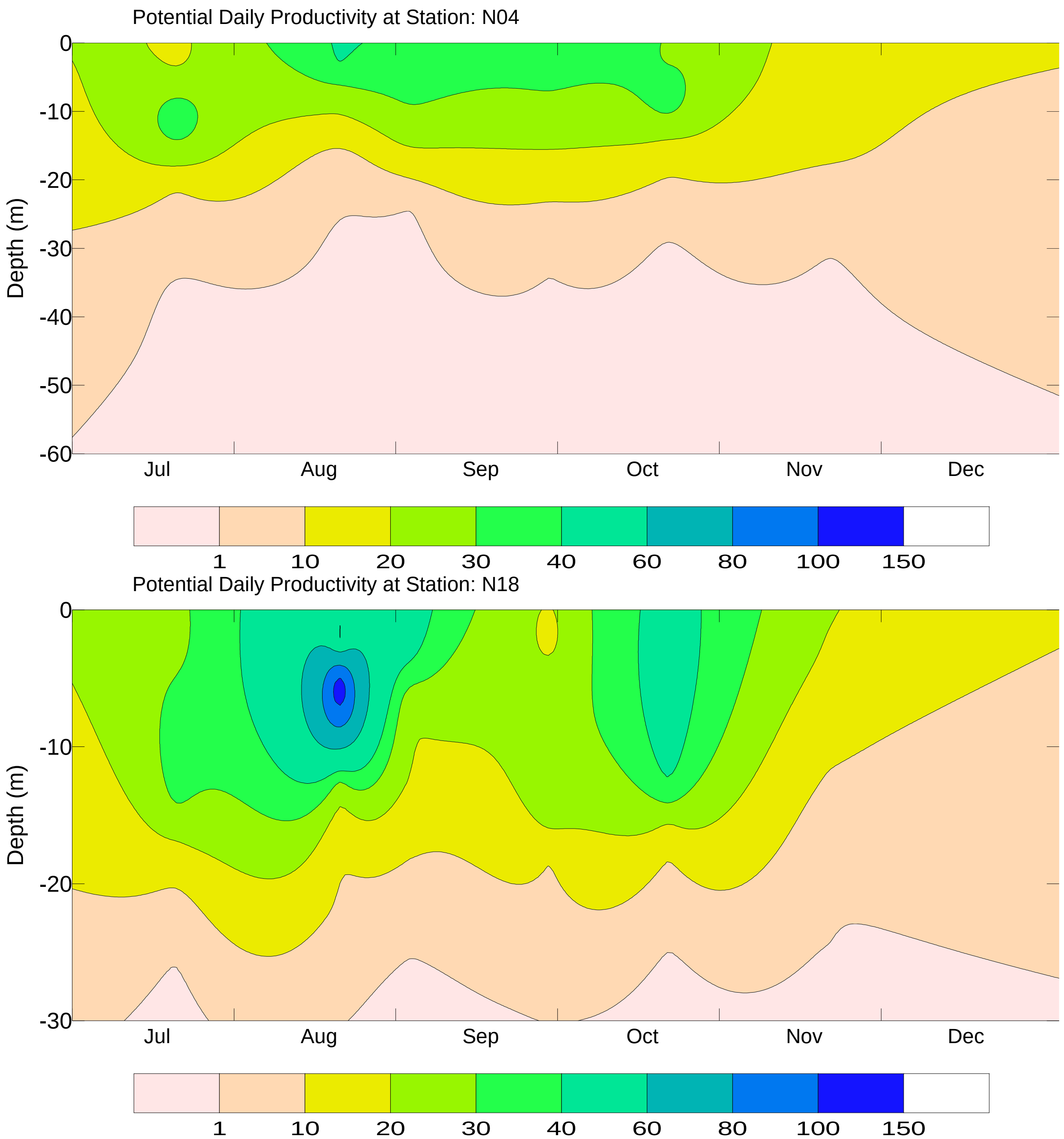


Figure 5-4. Time-series of contoured daily potential production ($mgCm^{-3}d^{-1}$) over depth at stations N04 and N18

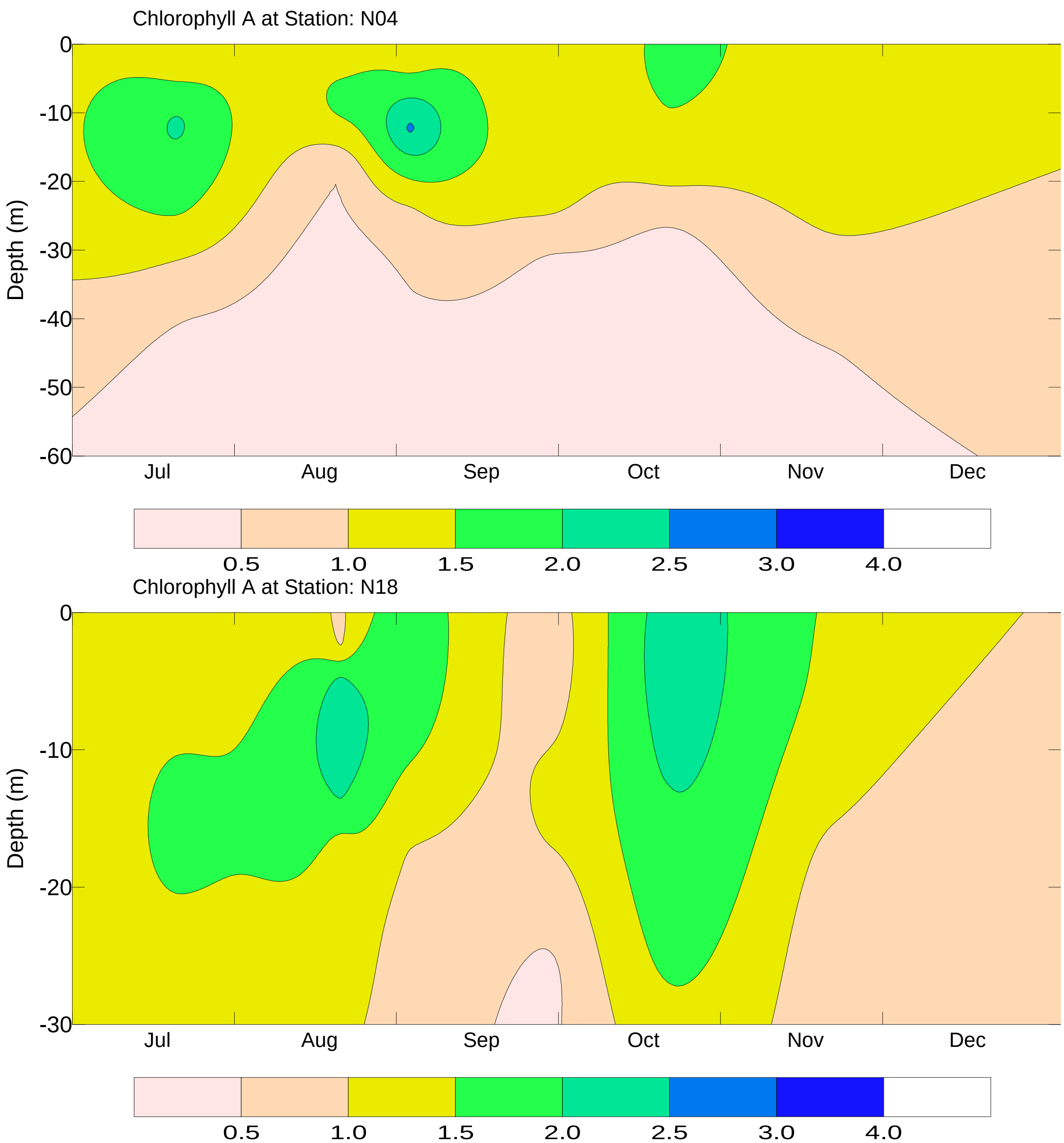


Figure 5-5. Time-series of contoured *in vitro* chlorophyll *a* (µg l^{-1}) over depth at station N04 and N18

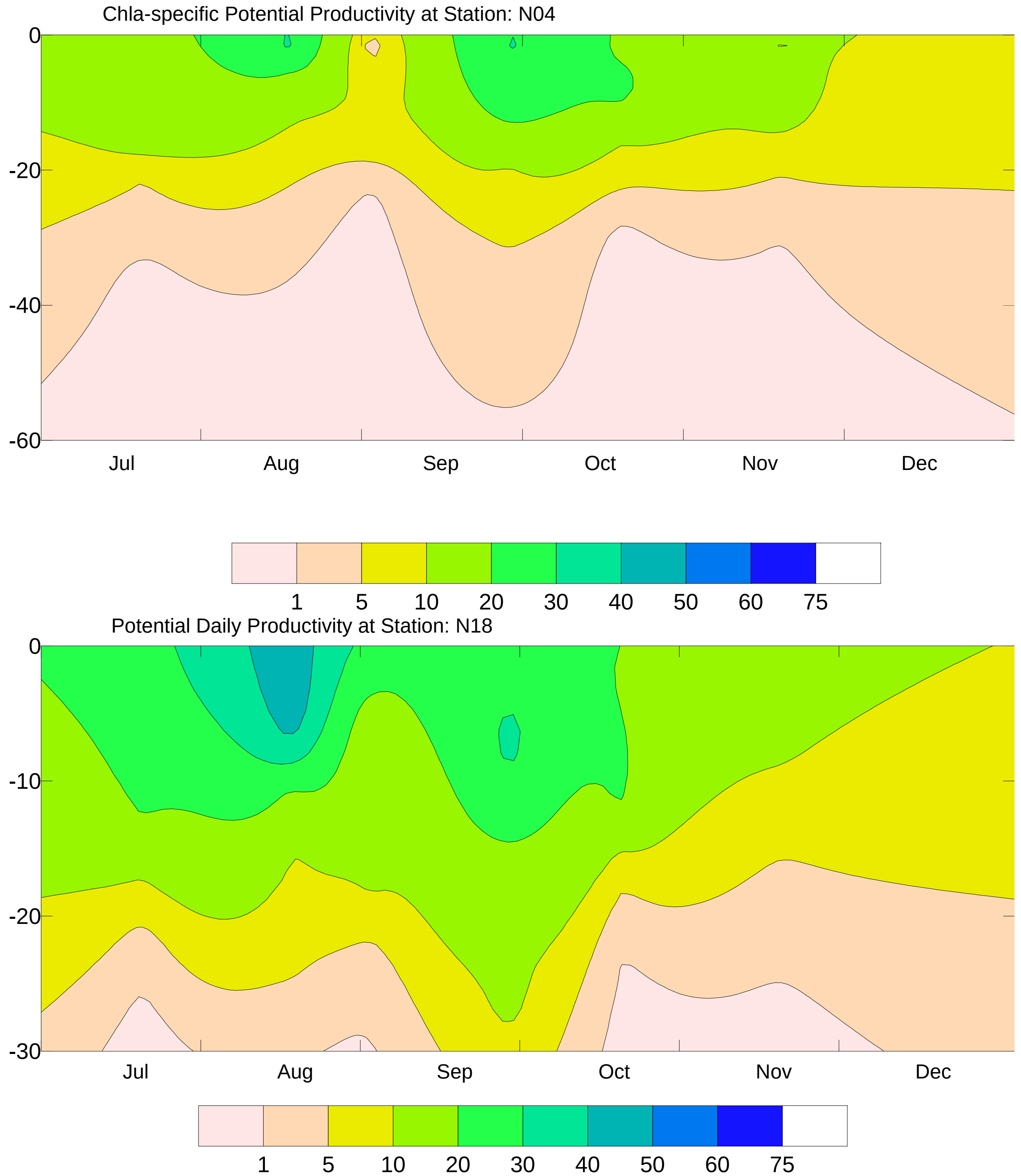
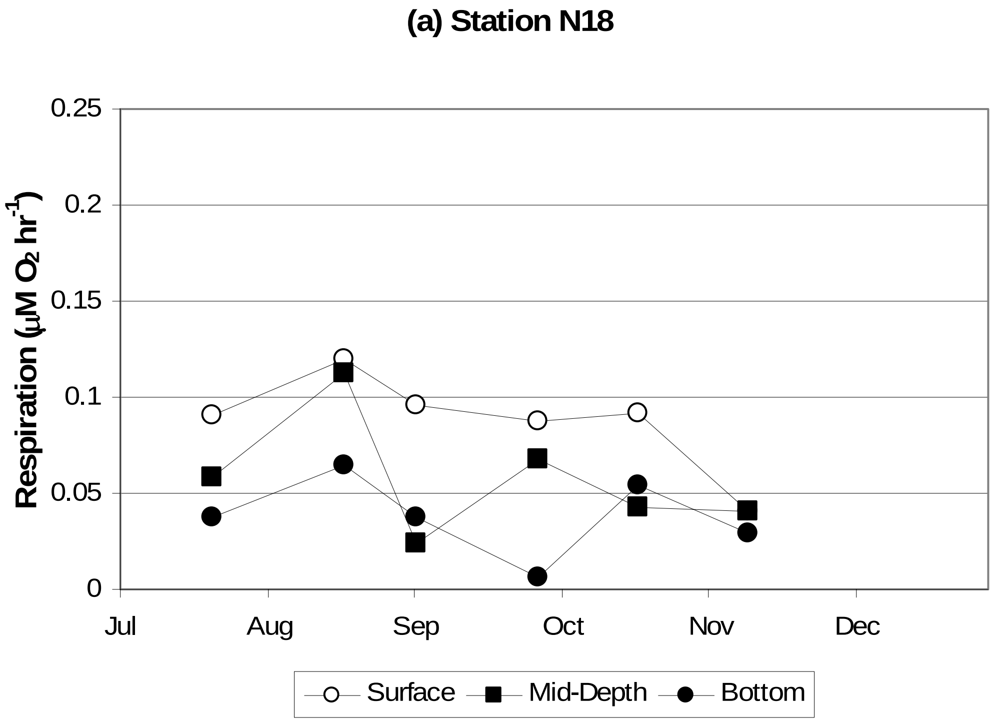


Figure 5-6. Time-series of contoured chlorophyll-specific potential production ($mgCmgChla^{-1}d^{-1}$) over depth at station N04 and N18



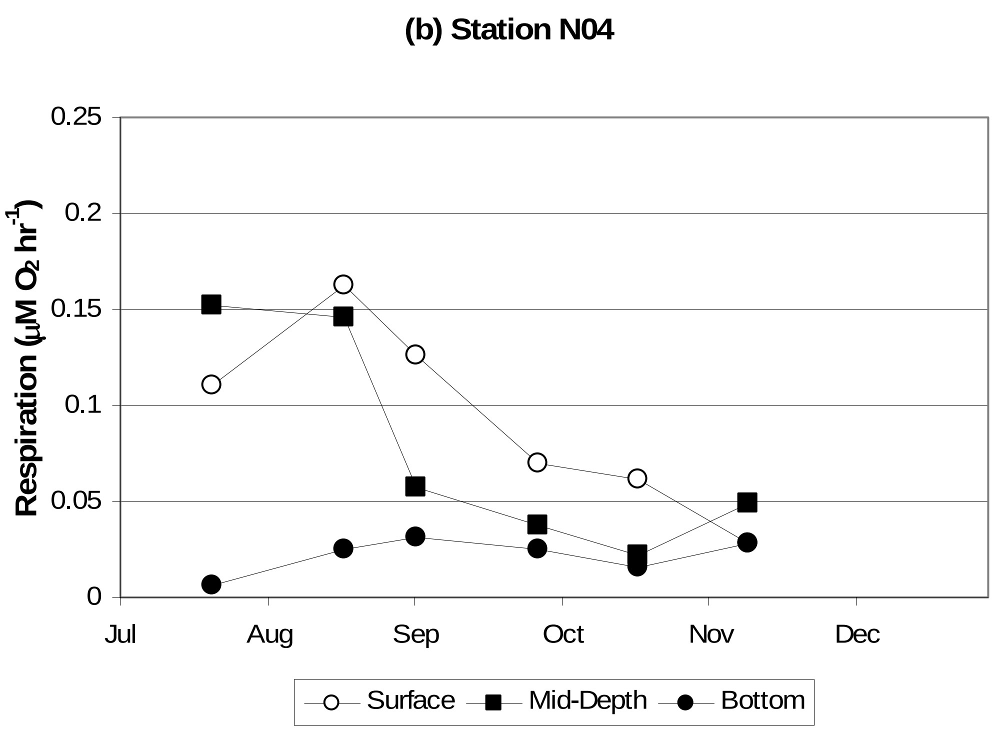
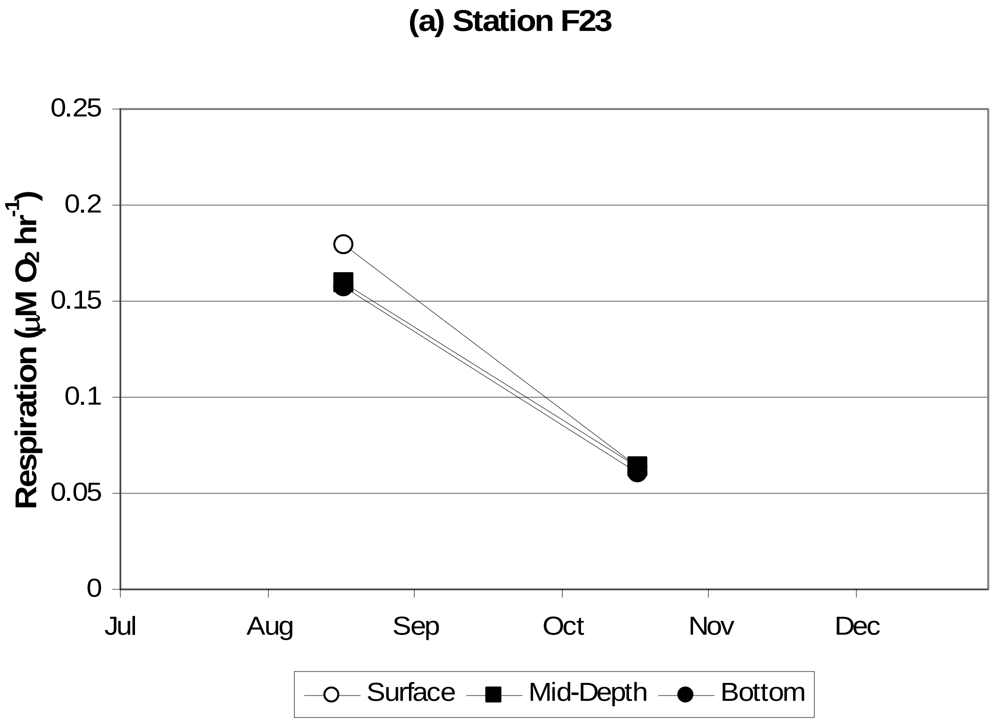


Figure 5-7. Time series plots of respiration (μMO_2hr^{-1}) at stations N18 and N04



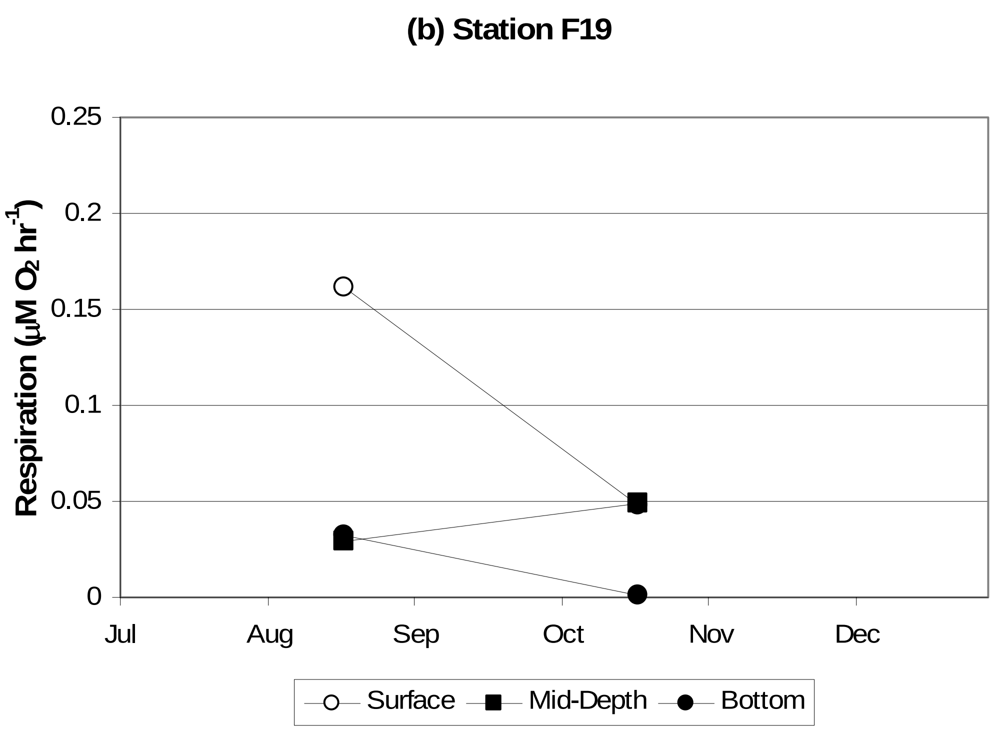
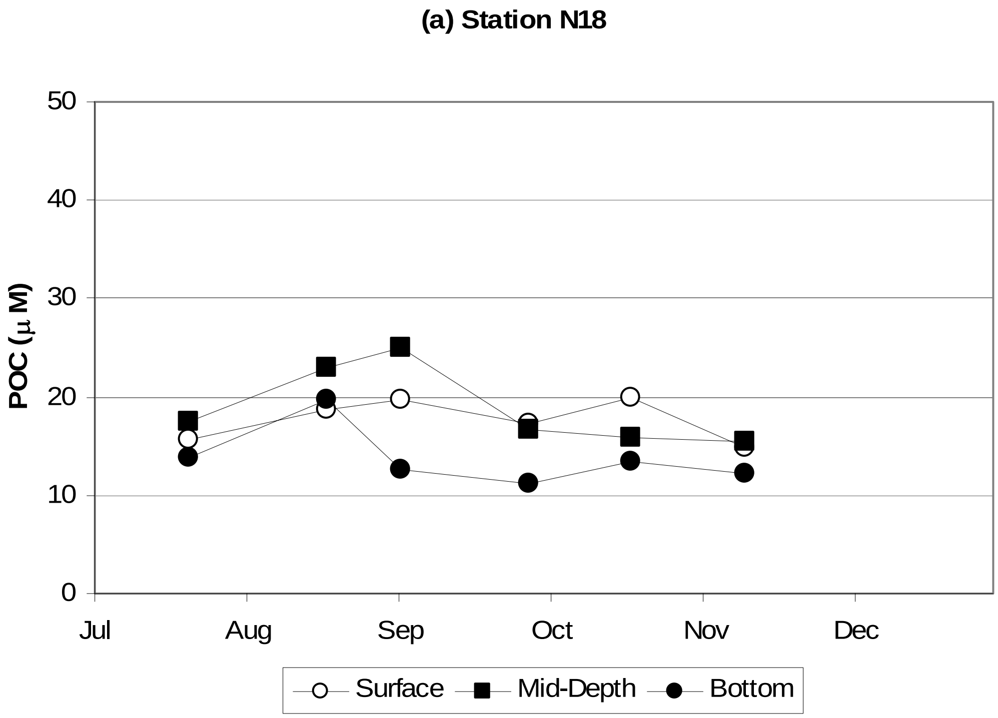


Figure 5-8. Time series plots of respiration (μMO_2hr^{-1}) at stations F23 and F19



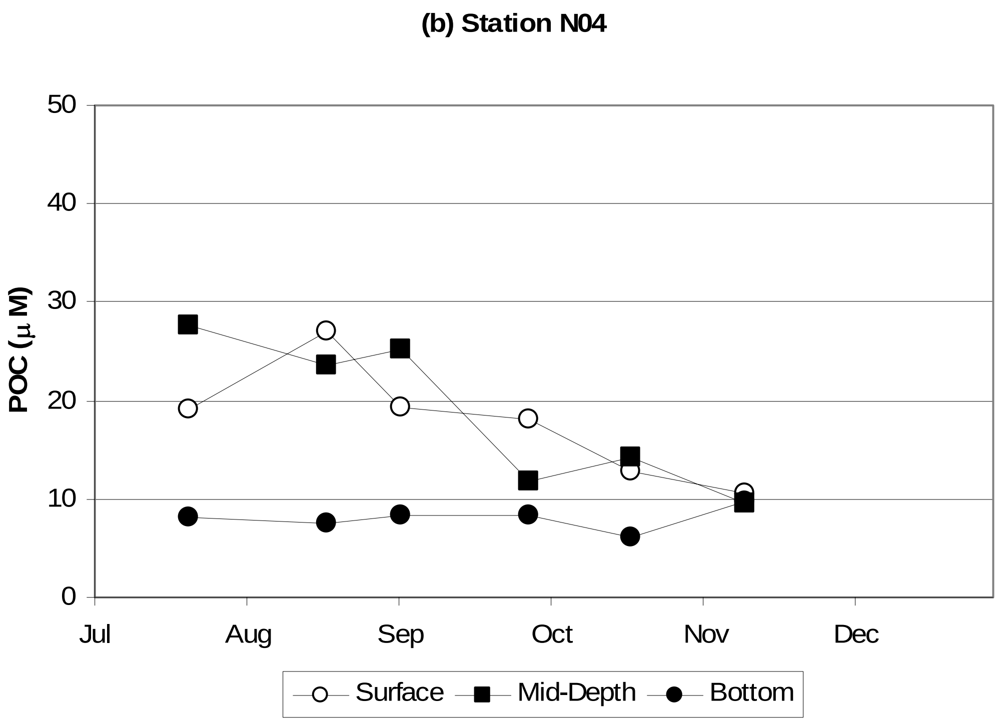
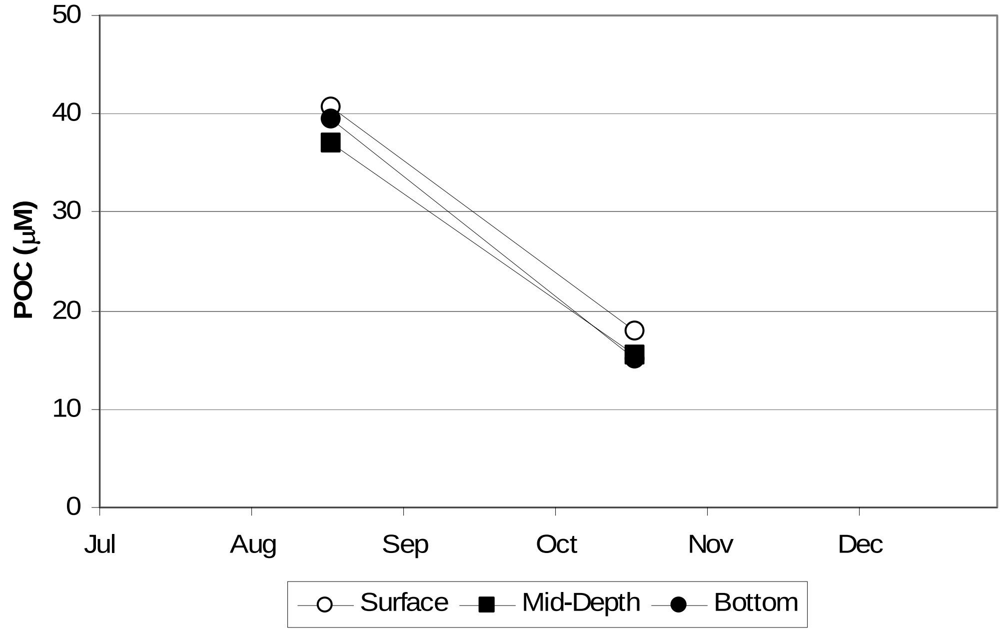


Figure 5-9. Time series plots of POC (μMC) at stations N18 and N04

(a) Station F23



(b) Station F19

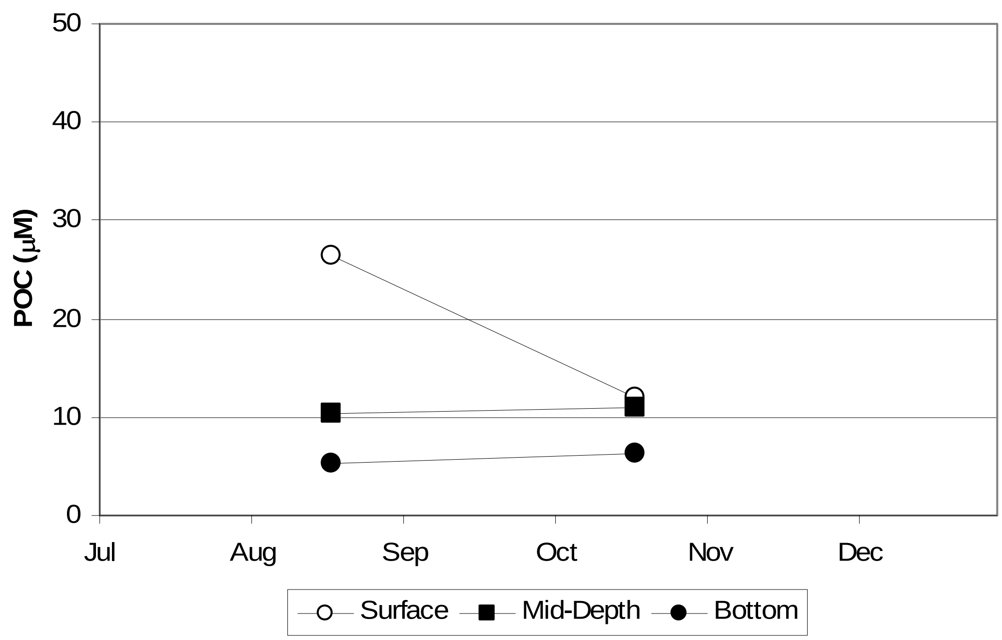
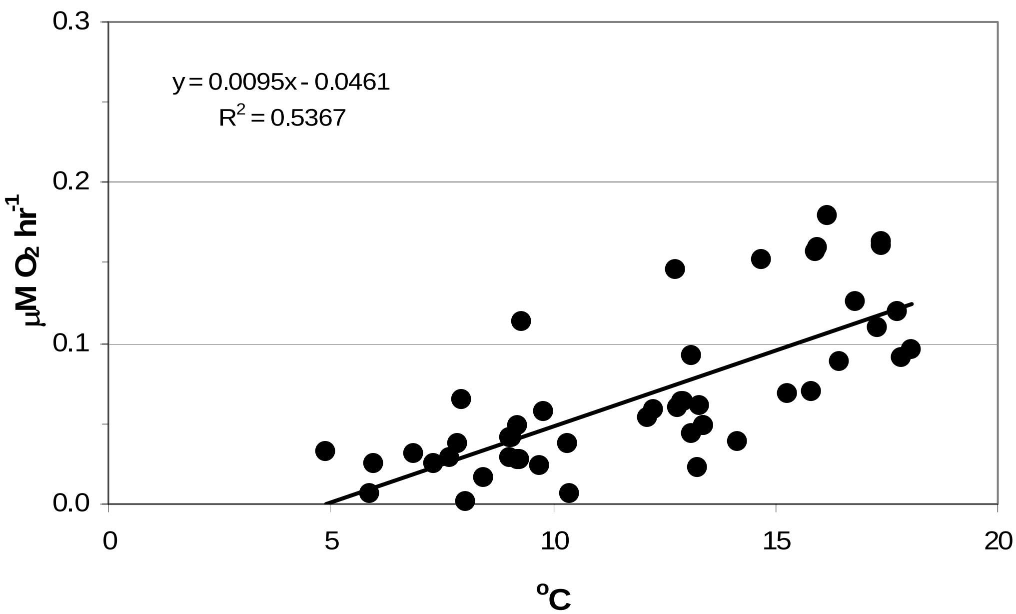


Figure 5-10. Time series plots of POC (μMC) at stations F23 and F19

(a) Respiration vs. Temperature



(b) Respiration vs. POC

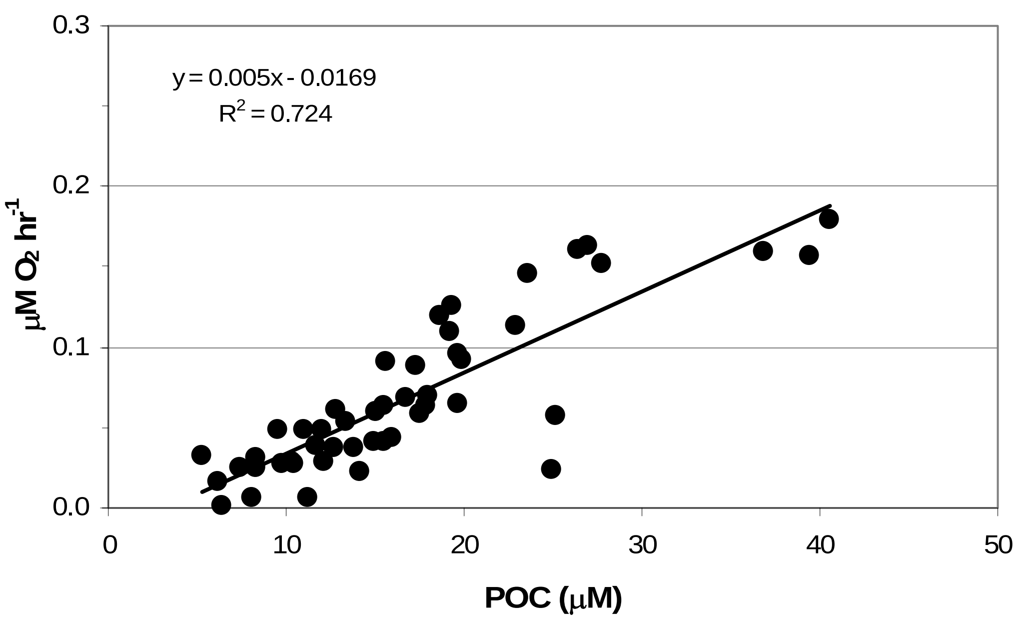
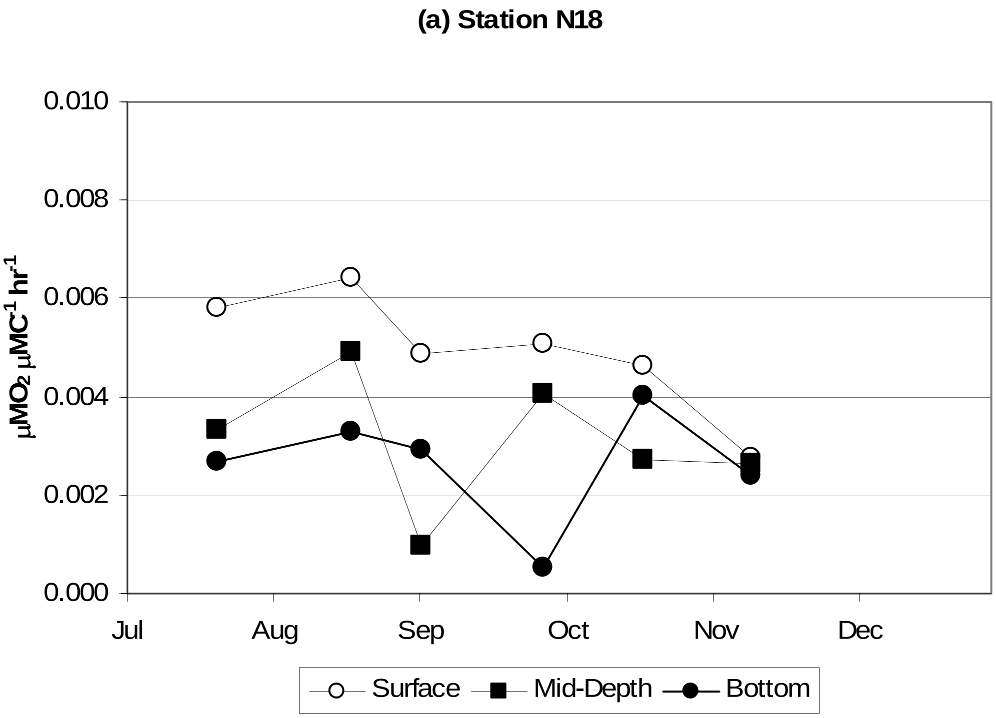


Figure 5-11. Comparison of respiration rate versus a) POC concentration and b) temperature for data collected at stations N04, N18, F19 and F23 in July – November 2004



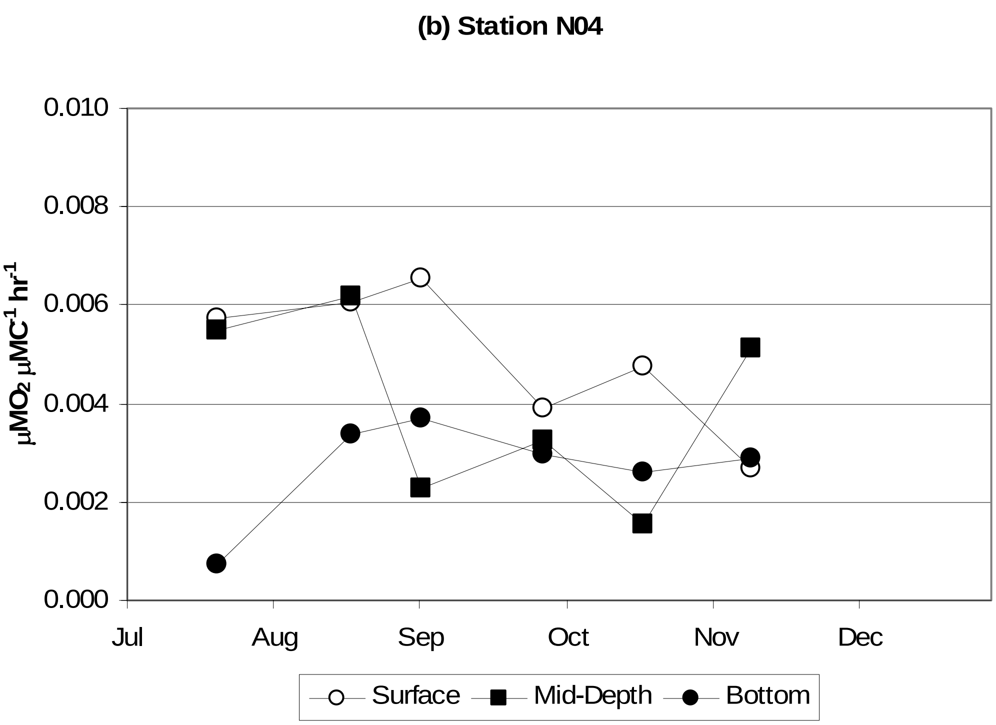


Figure 5-12. Time series plots of carbon-specific respiration ($\mu MO_2 \mu MC^{-1} hr^{-1}$) at stations N18 and N04

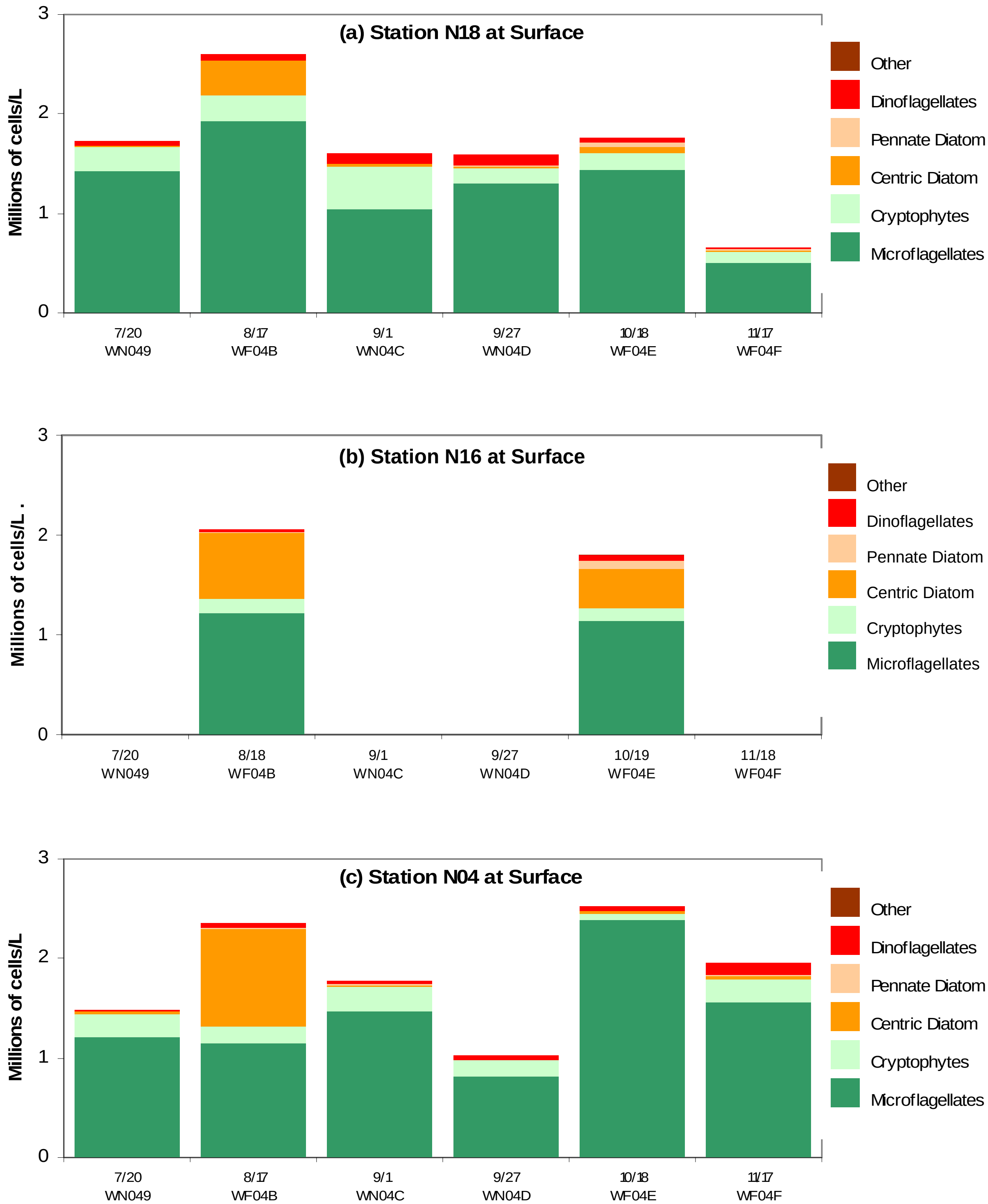


Figure 5-13. Phytoplankton abundance by major taxonomic group, nearfield surface samples

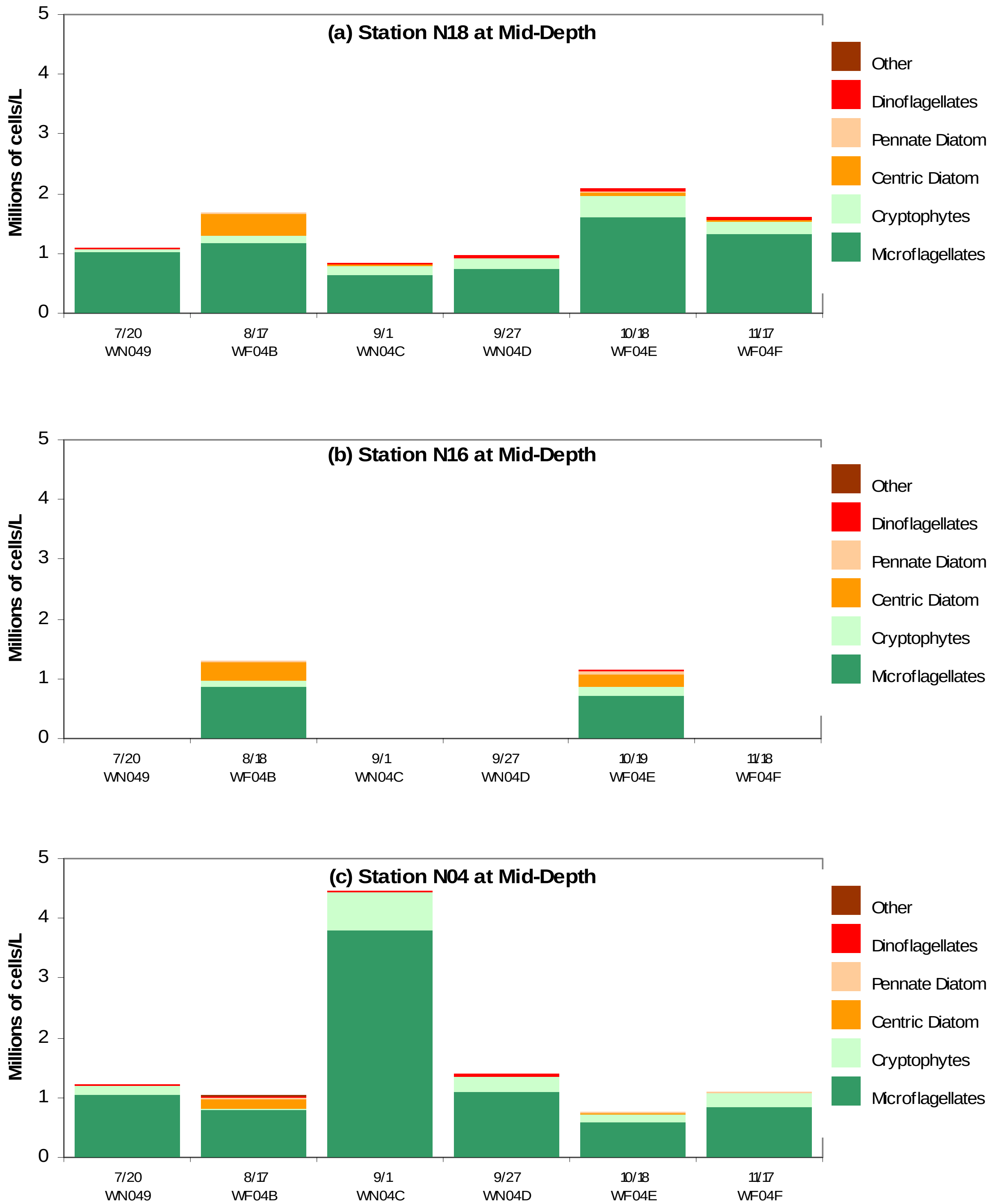
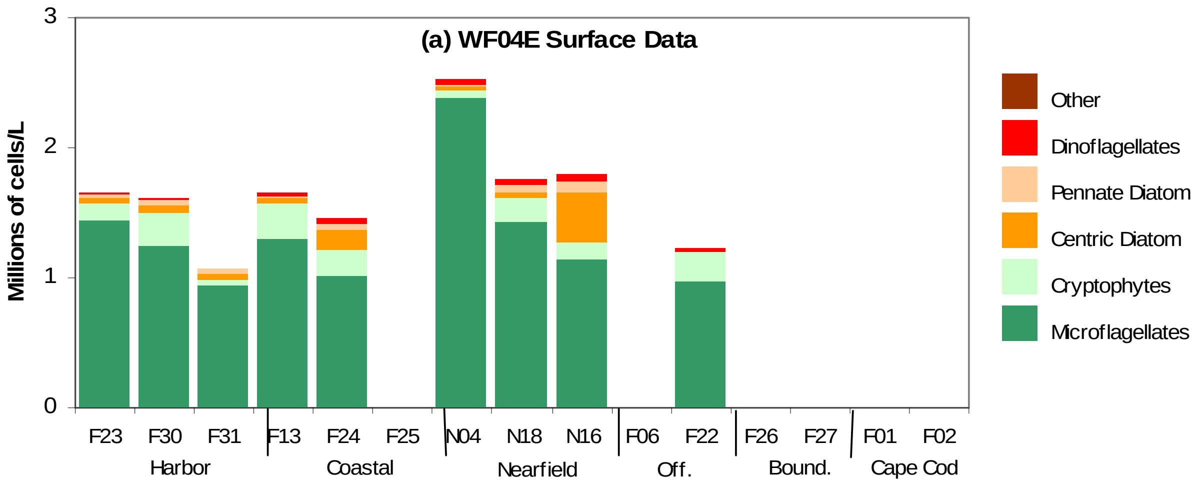


Figure 5-14. Phytoplankton abundance by major taxonomic group, nearfield mid-depth samples

Figure 5-15. Phytoplankton abundance by major taxonomic group, WF04B farfield survey (August 17-19)



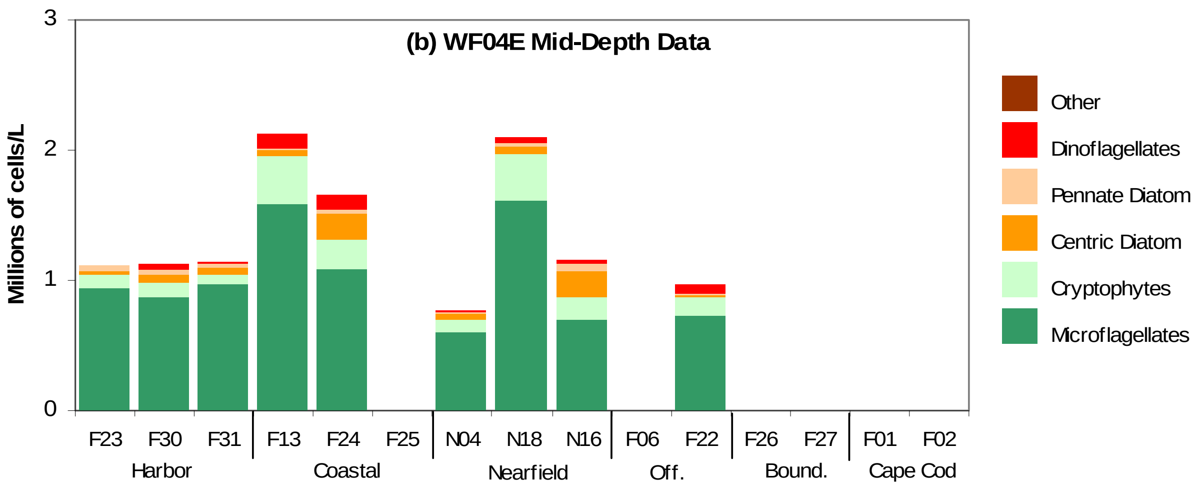


Figure 5-16. Phytoplankton abundance by major taxonomic group, WF04E farfield survey (October 18-19)

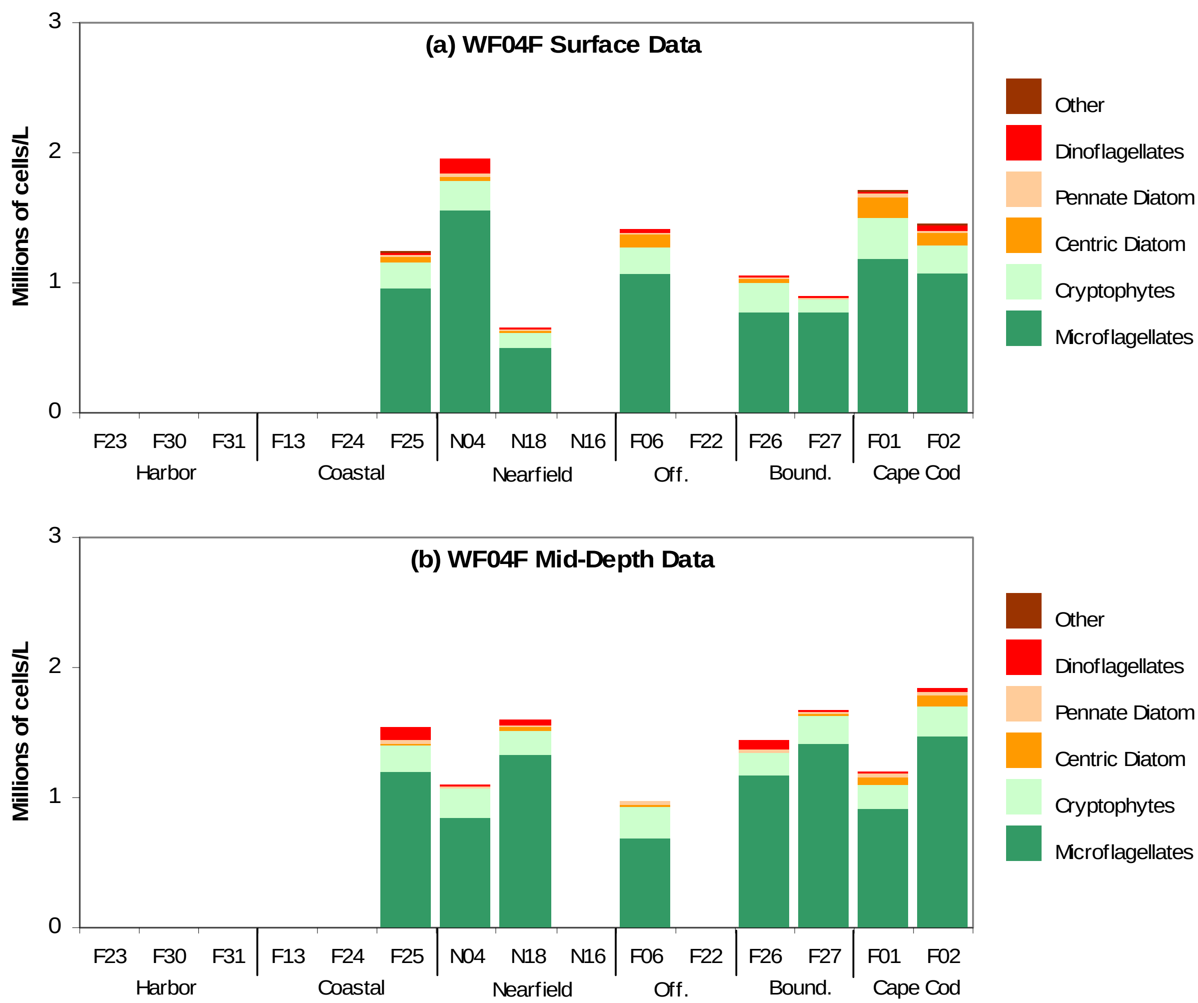


Figure 5-17. Phytoplankton abundance by major taxonomic group, WF04F farfield survey (November 10-18)

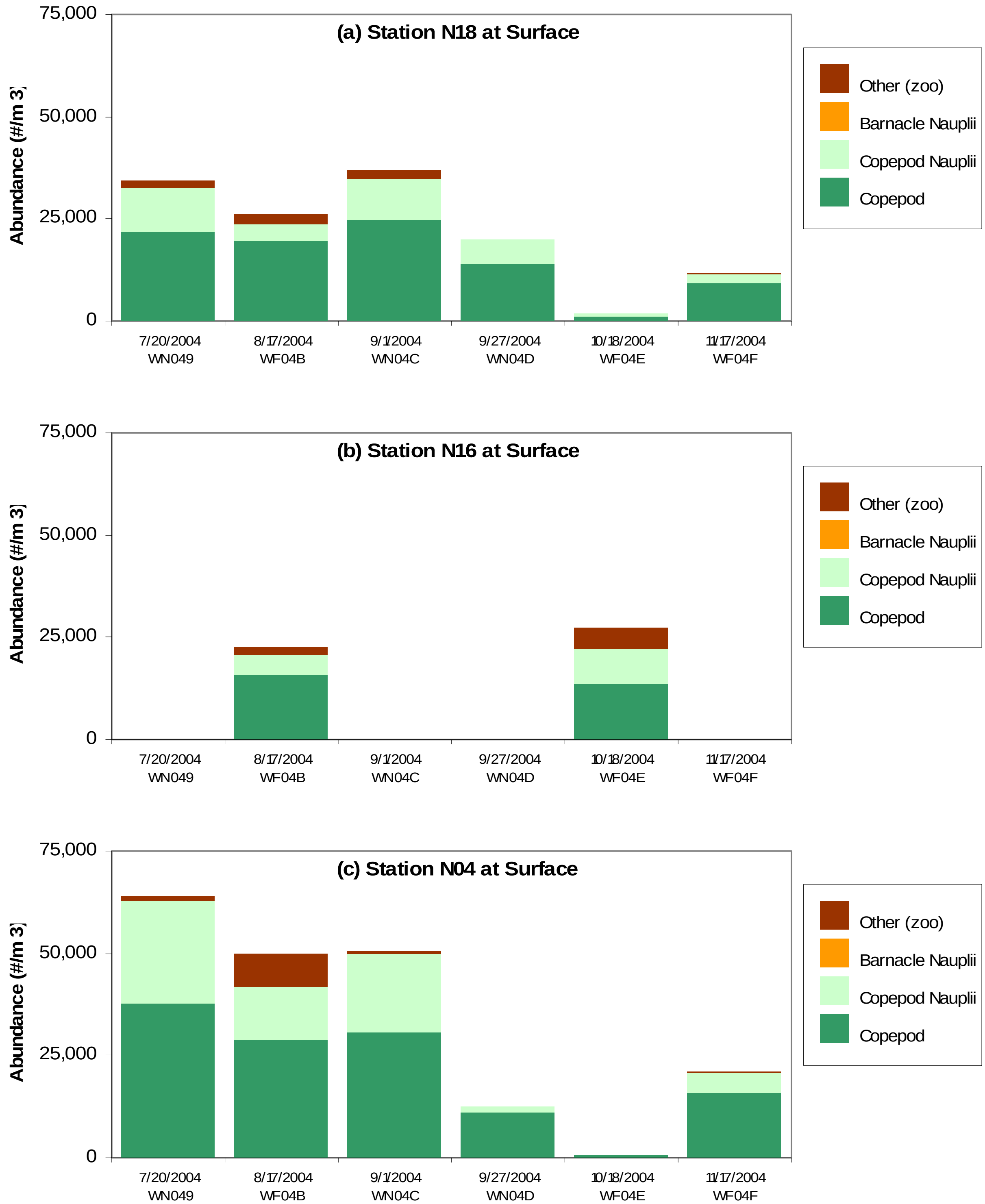


Figure 5-18. Zooplankton abundance by major taxonomic group, nearfield samples

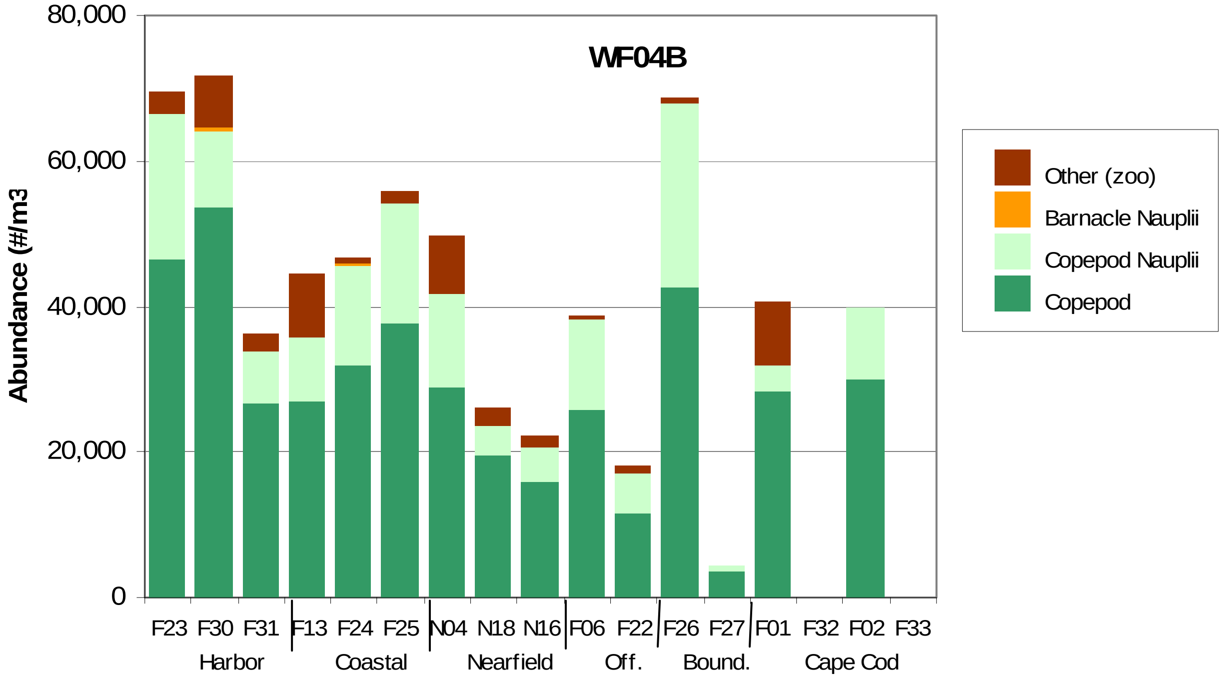


Figure 5-19. Zooplankton abundance by major taxonomic group, WF04B farfield survey (August)

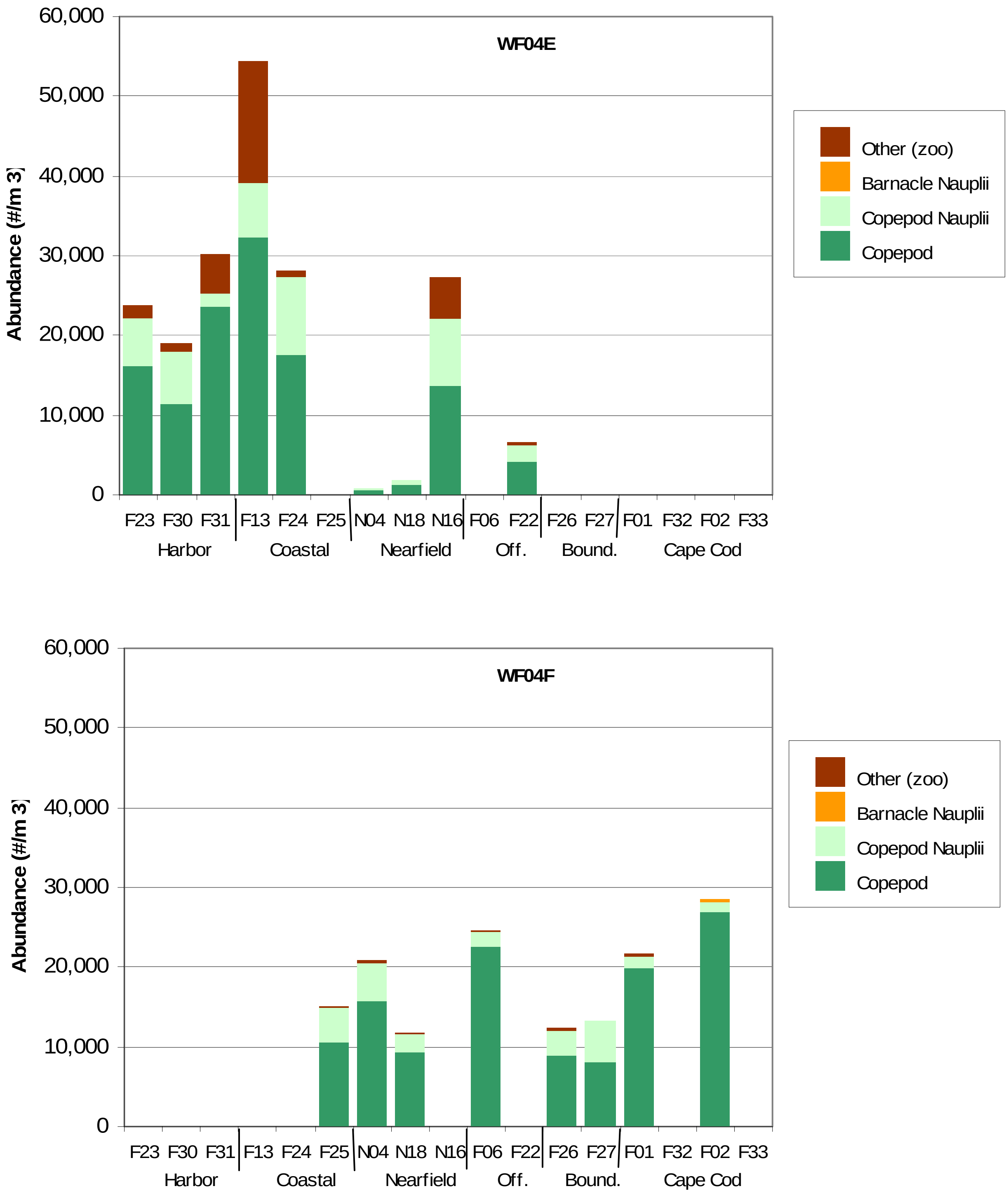


Figure 5-20. Zooplankton abundance by major taxonomic group (a) WF04E farfield survey (October) and (b) WF04F farfield survey (November)

6.0 SUMMARY OF MAJOR WATER COLUMN EVENTS

The summer to winter transition in Massachusetts and Cape Cod Bays is characterized by a series of physical, biological, and chemical events. The summer is generally a period of strong stratification, depleted surface water nutrients, and a relatively stable mixed-assemblage phytoplankton community dominated by microflagellates. In the fall, stratification breaks down supplying nutrients to surface waters and often resulting in the development of a fall phytoplankton bloom. The breakdown is usually complete by late October, but can extend into December (as in fall 2001) depending on weather and storm intensity. The lowest dissolved oxygen concentrations are typically observed in the nearfield bottom water in October prior to the overturn of the water column. By early winter, the water column is typically well mixed and has returned to winter conditions. These trends were generally evident in 2004.

A major deviation from prior years was the lack of a fall bloom. Fall blooms are a normal aspect of the seasonal biological cycle in Massachusetts Bay, although the timing of the bloom can vary from late August (2002) to as late as December (2001) and the magnitude can also be highly variable. However, in fall 2004, there was no indication in any of the phytoplankton biomass, abundance, productivity or satellite imagery data that a bloom may have occurred. It was the first year since monitoring began in 1992 not to exhibit any indications of a fall bloom across all indicators.

The physical oceanographic characteristics of this period followed the typical transition from a stratified summer water column, weakening in October, to a well-mixed water column by November. Regionally, seasonal stratification had deteriorated at the coastal and Boston Harbor stations and had begun to weaken in the nearfield and offshore by October. The boundary and Cape Cod Bay stations were not sampled until November after a series of survey-delaying storms had hit the region and the water column was well mixed throughout the bays. In the nearfield, stratification had begun to weaken by late September, but a weak density gradient remained in October before returning to well mixed conditions by November. The breakdown of stratification appeared to have occurred in typical fashion supplying nutrients to the surface waters. It is unclear if there were physical oceanographic or meteorological conditions (winds, currents, upwelling/downwelling, etc.) that may have played a role in the failure of a fall bloom in 2004. This will be examined in more detail in the 2004 annual water column report.

The general trend in nutrient concentrations during the 2004 July to November period was similar to previous years. Seasonal stratification led to persistent nutrient depleted conditions in the upper water column due to biological utilization and minimal mixing. It also ultimately led to a slight increase in nutrient concentrations in bottom waters. Typically, increased rates of respiration and remineralization of organic matter lead to larger increases in bottom water nutrient concentrations. In 2004, however, respiration rates were low and the lack of a fall bloom likely reduced the organic load to the bottom waters. In the fall, nutrient concentrations usually begin to increase with the breakdown of stratification. However, 2004 was different in that nearfield surface water concentrations remained depleted into October even without the occurrence of a fall bloom. By November, the water column had become well-mixed and nutrient levels had increased in the surface waters. The lack of a fall bloom and the persistence of low nutrient concentrations in the surface waters into October suggest that even though stratification was weakening there was little input of nutrients into the surface waters.

The NH_4 plume signature in the outfall area was clearly observed and continued to be confined to within 10-20 km of the outfall. This has been the case ever since the diversion of flow from the harbor outfall to the bay outfall on September 6, 2000.

In past years, there has often been a disconnect between biological parameters associated with the fall bloom with timing of peak chlorophyll, productivity, and phytoplankton abundance occurring during different surveys. Without a fall bloom in 2004, this was not the case as all of the biological parameters peaked in August at relatively low values and remain low throughout the fall. Chlorophyll concentrations reached a maximum of 7.4 µg L^{-1} in Boston Harbor in August and never exceeded 4.5 µg L^{-1} in the nearfield over the July to November time period. These low concentrations in the nearfield resulted in a seasonal mean areal chlorophyll concentration of only 44 mg m^{-2}, which is only ~20% of the fall threshold value. Areal productivity peaked in the harbor (1387 mg C m^{-2} d^{-1}) and nearfield (~1000 mg C m^{-2} d^{-1}) in August and declined sharply by October. The peak productivity rates observed in the nearfield during the fall of 2004 were lower than all other years on record (1995 – 2003).

Phytoplankton abundance remained relatively consistent (1.5 to 2 million cells L^{-1}) in the nearfield from August to October and was consistently dominated by microflagellates and cryptomonads with only sporadic elevated abundances of diatoms. SeaWiFS imagery indicates that except for a brief, moderate increase in nearshore chlorophyll levels in early October, chlorophyll concentrations were low across the region from September to December (Appendix D). Thus any suggestion that the change in survey schedule (lengthening the period between the fall surveys) may have missed sampling during the fall bloom in not valid.

Zooplankton assemblages during the second half of 2004 were comprised of taxa typically recorded for this time of year. As in recent years there was a sharp decline in zooplankton abundance from July/August to October. In both 2002 and 2003, there were indications that the presence of ctenophores led to increased predation and low zooplankton abundances during the October surveys of those years. The low zooplankton abundances were also cited as factors in the development of the fall blooms during those years (Libby *et al*. 2003 and 2004b). In 2004, there was no clear indication of ctenophore predation and as discussed no fall bloom. Although ctenophore predation may still have been a factor, the lack of a fall bloom likely exerted bottom-up control of zooplankton in 2004. This will be examined in more detail in the 2004 annual water column report.

September 6, 2000 marked the end of the baseline period, completing the data set for MWRA to calculate the threshold values used to compare monitoring results to baseline conditions (**Table** 6-1). The water quality parameters included as thresholds are annual and seasonal chlorophyll levels in the nearfield, dissolved oxygen concentrations and percent saturation in bottom waters of the nearfield and Stellwagen Basin, and nuisance algae (*Alexandrium*, *Phaeocystis*, and *Pseudo-nitzschia*).

The summer and fall 2003 nearfield areal chlorophyll means were 61 and 44 mg m^{-2} respectively, which are approximately 66% and 20% of the caution threshold values. These seasonal values in combination with a relatively low winter/spring 2004 mean resulted in a low annual areal chlorophyll mean of 69 mg m^{-2}. The 2004 annual mean value is comparable to that measured in 2001 (67 mg m^{-2}) and lower than 2002 and 2003 annual means (82 and 99 mg m^{-2}, respectively). All four of the post discharge year's annual means has been below the caution threshold of 107 mg m^{-2} (**Table** 6-1).

Dissolved oxygen concentrations were relatively high during the fall of 2004. This may have been due to a lack of organic material loading without a fall bloom or due to physical oceanographic conditions. The influence of physical oceanographic and meteorological conditions on dissolved oxygen levels will be examined in more detail in the 2004 annual water column report. The nearfield survey mean bottom water minima for DO concentration (7.55 mg L^{-1}) and percent saturation (80.4%) were well above the background and threshold values. Similar results were observed at the Stellwagen Basin stations with both DO concentration (7.72 mg L^{-1}) and percent saturation (80.4%) above threshold values.

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

Parameter	Time Period	Caution Level	Warning Level	Background	2004
Bottom Water DO concentration	Survey Mean in June-October	< 6.5 mg/l (unless background lower)	< 6.0 mg/l (unless background lower)	Nearfield - 5.75 mg/l Stellwagen - 6.2 mg/l	Nearfield – 7.55 mg/l Stellwagen - 7.72 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%	Nearfield – 80.4% Stellwagen – 80.4%
Chlorophyll	Annual	118 mg/m^2	158 mg/m^2	--	69 mg/m^2
	Winter/spring	238 mg/m^2	--	--	101 mg/m^2
	Summer	93 mg/m^2	--	--	61 mg/m^2
	Autumn	212 mg/m^2	--	--	44 mg/m^2
Phaeocystis pouchetii	Winter/spring	2,020,000 cells l^{-1}	--	--	2,870,000 cells l^{-1}
	Summer	357 cells l^{-1}	--	--	164,400 cells l^{-1}
	Autumn	2,540 cells l^{-1}	--	--	0 cells l^{-1}
Pseudo-nitzschia pungens	Winter/spring	21,000 cells l^{-1}	--	--	11 cells l^{-1}
	Summer	43,100 cells l^{-1}	--	--	3,375 cells l^{-1}
	Autumn	24,700 cells l^{-1}	--	--	660 cells l^{-1}
Alexandrium tamarense	Any nearfield sample	100 cells l^{-1}	--	--	0 cells l^{-1}

There were no confirmed blooms of harmful or nuisance phytoplankton in Massachusetts and Cape Cod Bays for July – November 2004. *Alexandrium* spp. were not observed in the nearfield or farfield screened samples during this reporting period. The *Pseudo-nitzschia "pungens"* threshold grouping was observed during many of the surveys from July to November 2004 but at relatively low abundances. *Phaeocystis pouchetii*, which often blooms during the spring and was observed in March-May 2004, was not recorded during this reporting period. The summer *Phaeocystis* threshold value, however, was exceeded as the spring *Phaeocystis* bloom was declining, but still present during the May survey. Data suggest that the *Phaeocystis* colonies observed in mid-May were remnants of a senescent bloom (chlorophyll:phaeophytin of 2:1 to 1:1 and colonies appeared to be senescent with 'empty' *Phaeocystis* cells, lower density of cells, and many fragmented/broken colonies). No *Phaeocystis* were observed in samples collected over the rest of the summer. Although this was the third consecutive year that the summer Phaeocystis threshold has been exceeded, it is not considered indicative of an impact associated with the outfall, but rather a change in the cycle of these events. The 2004 *Phaeocystis* bloom will be a major topic in the annual report.

A number of topics were called out in this report that will be discussed in greater detail in the 2004 annual water column report including the following:

- Assess the influence of physical oceanographic and meteorological conditions and nutrient availability as factors in the failure of the fall bloom 2004

- Examine the possibility of bottom up control of zooplankton in fall 2004 given the lack of a fall bloom and the very low zooplankton abundance in October.

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Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Boston, MA 02129
(617) 242-6000
http://www.mwra.state.ma.us