Semiannual water column monitoring report

July - December 2003

Massachusetts Water Resources Authority

Environmental Quality Department
Report ENQUAD 2004-03

Citation:

Libby PS, Mansfield AD, Keller AA, Turner JT, Borkman DG, Oviatt CA, Mongin CJ. 2004. **Semiannual water column monitoring report: July – December 2003**. Boston: Massachusetts Water Resources Authority. Report ENQUAD 2004-03. 269p.

SEMIANNUAL WATER COLUMN MONITORING REPORT

July – December 2003

Submitted to

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April 2004

Report No. 2004-03

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 have been designed to evaluate water quality on both a high-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 ten surveys conducted from July to December 2003.

Over the course of the HOM program, a general trend in water quality events has emerged from the data collected in Massachusetts and Cape Cod Bays. The trends are evident even though the timing and year-to-year manifestations of these events are variable. The 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 2003, although the water column remained weakly stratified through November and the fall bloom occurred over a prolonged period from late September into December.

The primary physical characteristic of this period was the delay in the overturn of the water column and the return to winter conditions. Regionally, seasonal stratification had deteriorated at the coastal and Boston Harbor stations and had begun to weaken offshore by the October survey. In the nearfield, stratification was breaking down by late September, but a weak density gradient remained throughout the fall. It was not until December that fully well-mixed conditions were observed over the entire nearfield. This represents a late transition to winter conditions as compared to previous years, although 2003 was similar to data observed in fall/winter 2001. The weak stratification in October and November allowed a steady influx of nutrients to the surface waters, which supported the prolonged late fall bloom.

The general trend in nutrient concentrations during the 2003 July to December period was similar to previous years, although the late breakdown in stratification delayed the development of typical fall nutrient conditions until later in the season. Seasonal stratification led to persistent nutrient depleted conditions in the upper water column due to biological utilization. It also ultimately led to an increase in nutrient concentrations in bottom waters due to increased rates of respiration and remineralization of organic matter. In late fall, nutrient concentrations began to increase with the breakdown of stratification. Although nutrient concentrations were replete throughout the water column by November, persistent weak stratification and the late fall bloom kept nutrients at moderate levels until December. This weak stratification caused a moderate nutrient flux into surface waters, which likely supported the prolonged fall bloom.

One of the distinct features in fall 2003 was the phytoplankton bloom which lasted from late September into December. Even though it was prolonged, the relative magnitude of the bloom was minor in comparison to past fall blooms. Phytoplankton abundance peaked in the nearfield at 2.3 million cells L^{-1} in comparison to a baseline survey mean peak of nearly 4 million cells L^{-1}. Peak productivity was also lower in 2003 compared with prior years. The fall blooms observed at nearfield stations in 1995-2002 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. Chlorophyll and POC concentrations were comparable to previous fall blooms, but the timing of the peak values was later then typically observed. SeaWiFS imagery and fluorescence data from the USGS mooring corroborate both the magnitude and the spatial and temporal extent of elevated chlorophyll concentrations from late September into December

The fall 2003 phytoplankton bloom was a mixed assemblage of centric diatom species typically observed in Massachusetts Bay in the fall. In late September and early October, the assemblage was dominated by *Dactyliosolen fragilissimus* and *Skeletonema costatum*. By late October and into November, the dominant diatom species were *Leptocylindrus danicus* and *L. minimus*. Zooplankton assemblages during the second half of 2003 were comprised of taxa typically recorded for this time of year. Despite the presence of ctenophores throughout most of this period, zooplankton abundances in the second half of 2003 were higher than in 2002. Nonetheless, the zooplankton abundances during the October survey were lower than typically observed, suggesting that increased grazing pressure by ctenophores may have both decreased zooplankton abundance and contributed to the occurrence of the fall bloom. The impact of ctenophore grazing, however, was not as apparent as observed in late summer/early fall 2002.

The delay in destratification in fall 2003 led to a prolonged decline in DO values from July to November. Mean bottom water DO concentrations and %saturation in the nearfield reached minima of 6.5 mgL^{-1} and 69% in November. These minima were relatively high considering the extended period of decline. Dissolved oxygen concentration and %saturation threshold values are based on survey mean minima from June to October. In the nearfield, threshold comparison minima were reached in late October (6.72 mg L^{-1} and 71.8%). The survey mean bottom water minima for Stellwagen Basin stations were higher than in the nearfield. Both the nearfield and Stellwagen DO concentration and %saturation minima were well above established background threshold values and there was no threshold exceedance for dissolved oxygen.

The summer *Phaeocystis pouchetii* threshold value, however, was exceeded. The spring *Phaeocystis* bloom had declined but was still present at low abundance in mid-May. The continued presence of *Phaeocystis* in May, albeit only in one sample and at low abundance (48,400 cells L^{-1}), and the very low summer threshold value resulted in an exceedance. This exceedance is not considered indicative of an impact associated with the outfall. *Alexandrium* spp. were not observed in the nearfield during this reporting period. The *Pseudo-nitzschia "pungens*" threshold was not exceeded, but the abundance of this group of species (non-toxic *P. pungens*, domoic-acid-producing species *P. multiseries* and *Pseudo-nitzschia* unidentified beyond species) peaked during the early October survey with a nearfield mean value of 52,000 cells L^{-1}.

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1.0 INTRODUCTION

1.1 Program Overview

The Massachusetts Water Resources Authority (MWRA) has conducted a long-term Harbor and Outfall Monitoring (HOM) Program for Massachusetts and Cape Cod Bays since 1992. The objective of the HOM Program is to (1) test for compliance with National Pollutant Discharge Elimination System (NPDES) permit requirements; (2) test 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) test whether change within the system exceeds the Contingency Plan thresholds (MWRA 2001). A detailed description of the monitoring and its rationale is provided in the Effluent Outfall Monitoring Plan developed for the baseline period and the post discharge monitoring plan (MWRA 1991 and 1997).

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

Table 1-1. Water Quality Surveys for WF038-WN03H July to December 2003

Survey #	Type of Survey	Survey Dates
WN038	Nearfield	July 12
WN039	Nearfield	July 25
WN03A	Nearfield	August 9
WF03B	Nearfield/Farfield	August 19-22
WN03C	Nearfield	September 19
WN03D	Nearfield	September 25
WF03E	Nearfield/Farfield	October 7, 9, 10, 15
WN03F	Nearfield	November 4
WN03G	Nearfield	November 20
WN03H	Nearfield	December 11

The bay outfall became operational on September 6, 2000. The ten surveys conducted during this semiannual period are the third set of summer surveys and fourth set of fall-winter 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 December 2003. Preliminary comparison against baseline data are discussed and appropriate threshold values presented. A detailed evaluation of 2003 versus the baseline period (1992-2000) will be presented in the 2003 annual water column report.

Initial data summaries, along with specific field information, are available in individual survey reports submitted immediately following each survey. In addition, nutrient data reports (including calibration information, sensor, 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 on an initial compilation of the water column data collected during the reporting period. Integrated physical and biological results are also discussed for key water column events and potential areas for expanded discussion in the annual water column report are recommended. The report first provides a summary of the survey and laboratory methods (Section 2). The bulk of the report, as discussed in further detail below, presents results of water column data from the last ten surveys of 2003 (Sections 3-5). Finally, the major findings of the semiannual period are summarized in Section 6.

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

Sections 4 (Results of Water Column Measurements) and 5 (Productivity, Respiration, and Plankton Results) include preliminary interpretation of the data with selected graphic representations of the horizontal and vertical distribution of water column parameters in both the farfield and nearfield. The horizontal distribution of physical parameters is presented through regional contour plots. The vertical distribution of water column parameters is presented using time-series plots of averaged surface and bottom water column parameters and along vertical transects in the survey area (**Figure** 1-3). The time-series plots utilize average values of the surface water sample (the "A" depth, as described in Section 3), and the bottom water collection depth (the "E" depth). Examining data trends along four farfield transects (Boston-Nearfield, Cohasset, Marshfield and Nearfield-Marshfield), and one nearfield transect, allows three-dimensional presentation of water column conditions during each survey. One offshore transect (Boundary) enables analysis of results in the outer most 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 stratification period (WN038 – WN03C), the gradual breakdown of stratified conditions (WN03D – WN03G), and the eventual return to winter conditions in December (WN03H). Time-series data are commonly provided for the entire semiannual period for clarity and context of the data presentation.

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

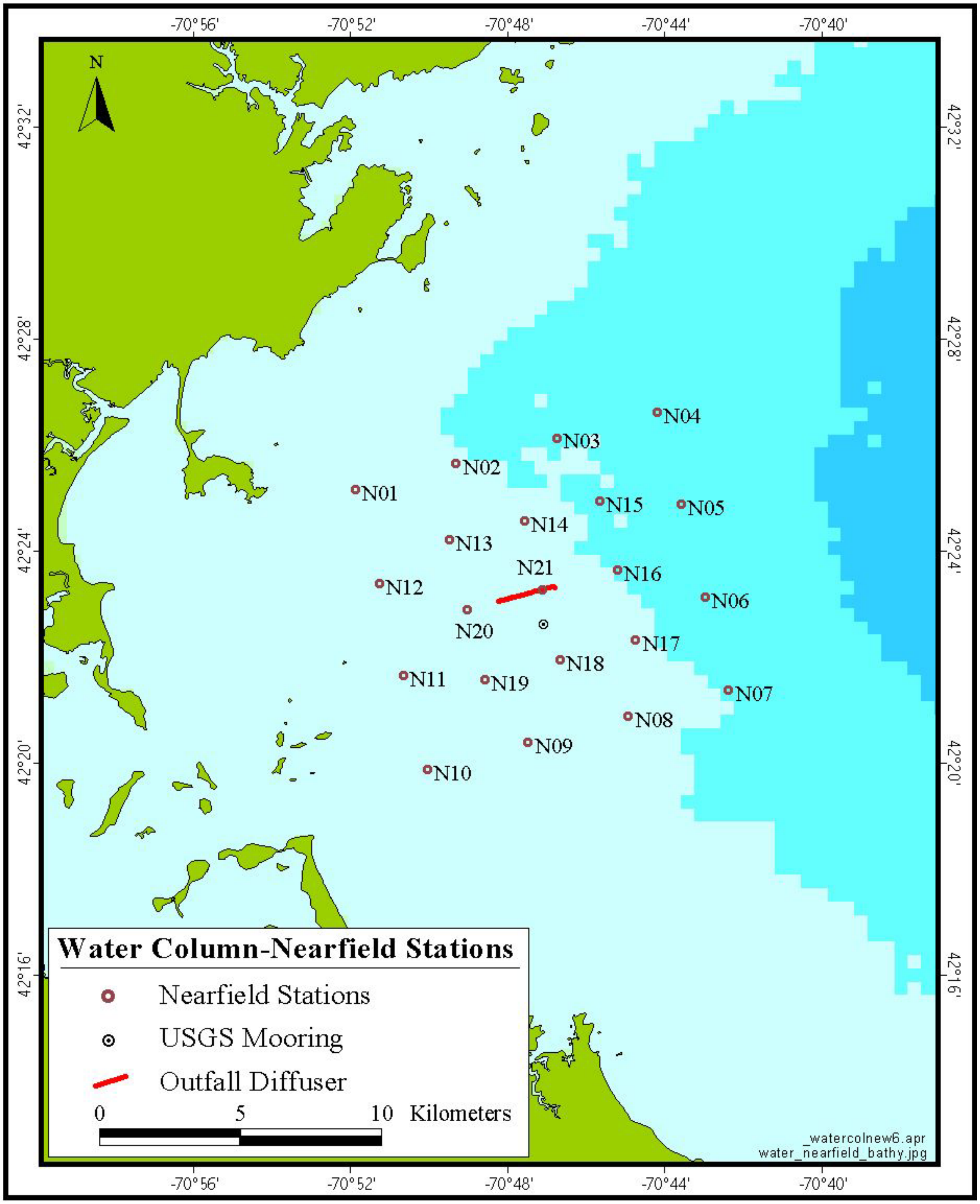


Figure 1-1. Locations of MWRA offshore outfall, nearfield stations and USGS mooring

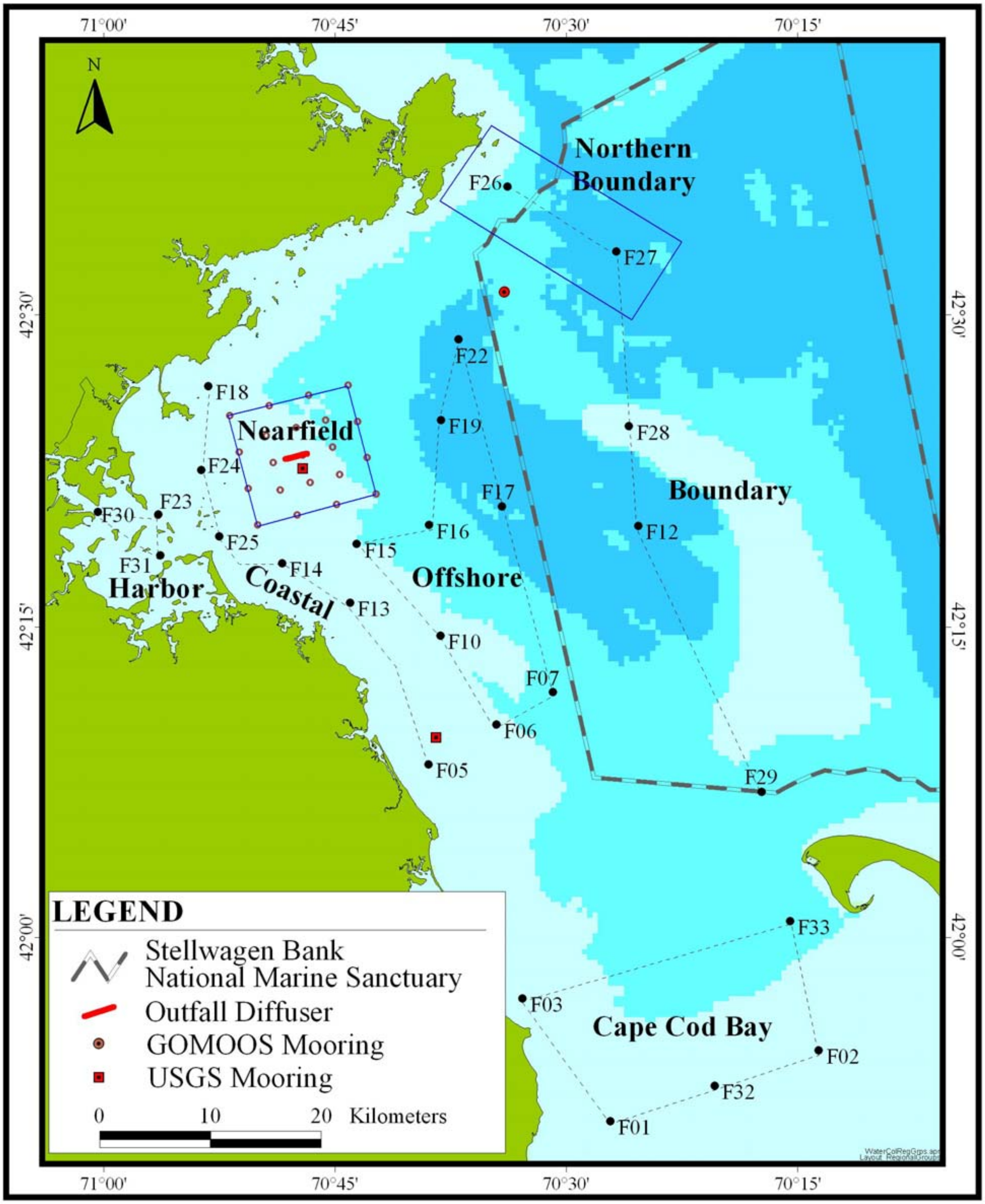


Figure 1-2. Locations of farfield stations and regional station groupings

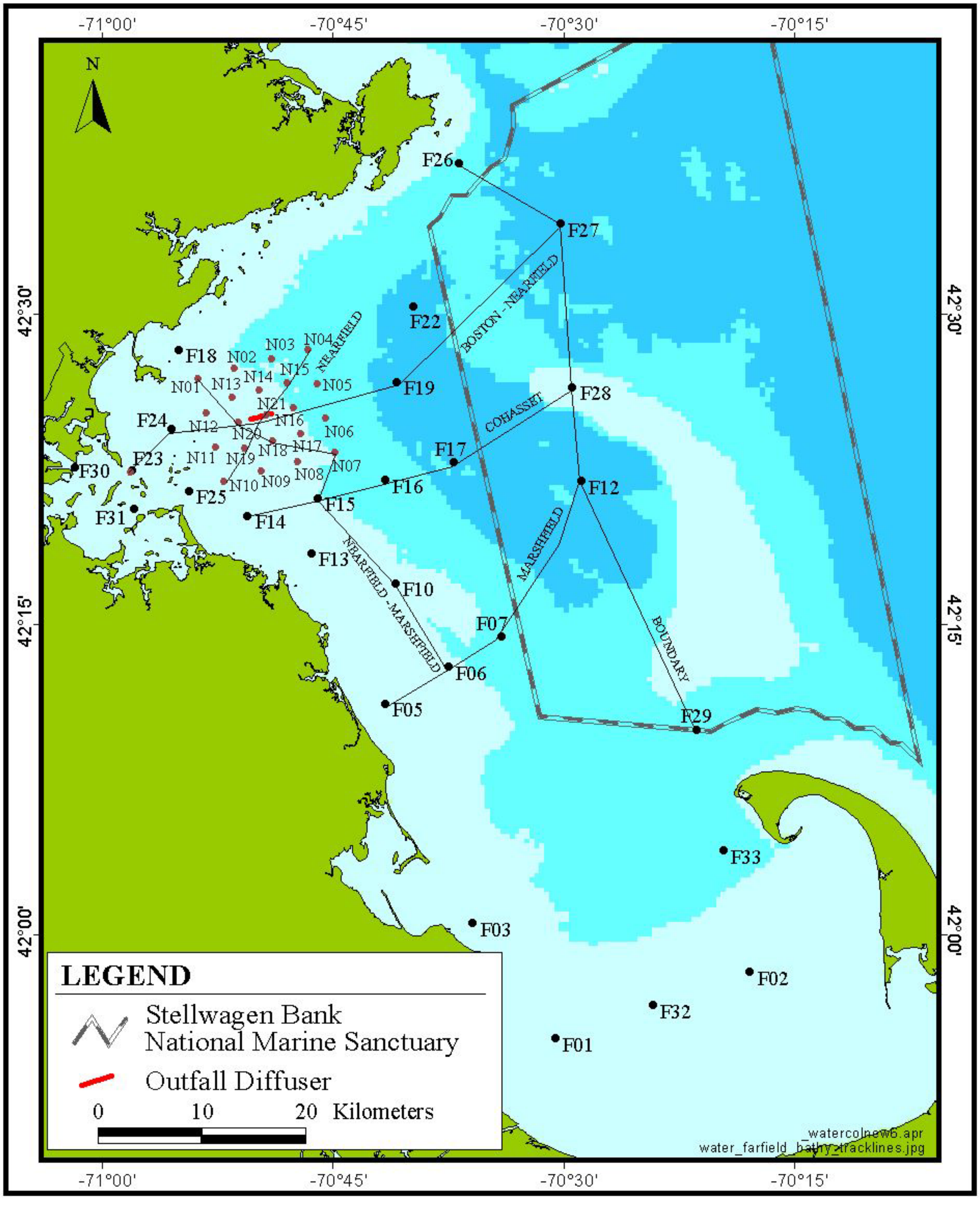


Figure 1-3. Locations of stations and selected transects

2.0 METHODS

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

2.1 Data Collection

The farfield and nearfield water quality surveys for 2003 represent a continuation of the water quality monitoring conducted from 1992 - 2002. 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, and 2003. The data collected during outfall discharge monitoring are evaluated internally and against baseline data. Data collection methods and schema have not changed from the baseline to the outfall discharge water quality monitoring periods.

Water quality data for this report were collected from the sampling 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 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, total suspended solids (TSS), and phytoplankton (screened and rapid assessment) were filtered and preserved immediately after obtaining water from the appropriate Go-Flo bottles. Whole water phytoplankton samples (unfiltered) were obtained directly from the Go-Flo bottles and immediately preserved. Zooplankton samples were obtained by deploying a zooplankton net overboard and making an oblique tow of the upper two-thirds of the water column but with a maximum tow depth of 30 meters. Productivity samples were collected from the Go-Flo bottles, stored on ice and transferred to University of Rhode Island (URI) employees. Incubation was started no more than six hours after initial water collection at URI's laboratory. Respiration samples were collected from the Go-Flo bottles at four stations (F19, F23, N04, and N18). Incubations of the dark bottles were started within 30 minutes of sample collection. The dark bottle samples were maintained at a temperature within 2°C of the collection temperature for five to nine 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 (**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 (designated as type Z) are occupied during the first three farfield surveys of each year and only zooplankton samples and hydrocast data are collected.

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

Station Type	A	D	E	F	G[1]	P	R[4]	Z
Number of Stations	6	10	24	2	2	3	1	2
Analysis Type								
Dissolved inorganic nutrients (NH_4, NO_3, NO_2, PO_4, and SiO_4)	•	•	•	•	•	•		
Other nutrients (DOC, TDN, TDP, PC, PN, PP, Biogenic Si)[1]	•	•			•	•		
Chlorophyll [1]	•	•			•	•		
Total suspended solids [1]	•	•			•	•		
Dissolved oxygen	•	•		•	•	•		
Phytoplankton, urea [2]		•			•	•		
Zooplankton[3]		•			•	•		•
Respiration [1]						•	•	
Productivity, DIC						•		

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

2.3 Operations Summary

Field operations for water column sampling and analysis during the summer/fall 2003 semi-annual period were conducted as described above. Deviations from the CW/QAPP experienced during surveys WN038 to WN03H had no effect on the data or data interpretation. There were, however, concerns with *in situ* dissolved oxygen, beam attenuation, and salinity during a number of surveys during this period.

During the July and August 2003 surveys, there were substantial differences between DO values for the up and downcasts. The difference was most pronounced in the vicinity of the pycnocline and has been observed in previous years, but not to the same magnitude as seen in 2003. Review and evaluation of the data determined that a combination of factors contributed to these large differences. The impact of a >12°C temperature gradient and the slow response time of the old Sea-Bird model 18B DO sensor (especially across large temperature changes) led to poor downcast results. The upcast results, however, were obtained after leaving the instruments at depth until data stabilized and are representative of *in situ* conditions. This problem was most pronounced during the late August combined survey (WF03B) for which all downcast data have been marked suspect. Downcast from surveys WN039 and WN03A were qualified "w" – used with caution. The upcast values that are presented in this report, however, are valid for all of the surveys. Beginning with the September survey WN03C, new DO sensors were deployed. The Sea-Bird SBE Model 43 DO sensor has a faster response time and is less affected by temperature deviations. The switch to using new SBE Model 43 sensors in September 2003 dramatically improved the reproducibility between the up and downcasts reducing the hysteresis.

In late August (WF03B), a large hysteresis was observed in beam attenuation data at a number of stations. Three sensors were evaluated in field during the survey, but the result was similar for all three instruments. The hysteresis was determined to be related to rapid temperature changes of over 12°C from surface to bottom. The sudden change in temperature is beyond the ability of the sensor to compensate for differential strains in the housing and resulted in unsatisfactory data in many instances. This problem was confined to the bottom depths of a limited number of downcasts and the upcast at more than 50% of the stations. The affected data have been deemed not fit for use and are null in the database and "e" qualified. All data reported here and in the appendices are valid.

Higher than normal salinity values were initially observed during the fall 2003 surveys. This prompted a review of the data that indicated the salinity data from WF03C to WN03H are off by ~0.5 to 1 PSU. By comparing survey data at stations in the vicinity of the USGS nearfield mooring and the GoMOOS A mooring (see **Figure** 1-2), an offset was calculated for each of these surveys. Based on these comparisons, all of the conductivity, salinity, density, and DO percent saturation data were revised for surveys WN03C to WN03H. The conductivity and salinity data from these surveys has been qualified as 'w' – use with caution. The magnitude of the data may still be slightly in error, but the vertical and horizontal trends are valid as discussed in this report.

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

Nearfield Water Column Sampling Plan

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

Nearfield Water Column Sampling Plan

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

Nearfield Water Column Sampling Plan

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

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

Farfield Water Column Sampling Plan

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

Farfield Water Column Sampling Plan

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

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
			5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
F26	56	D	3_Mid-Depth	15	2	1	1	1	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1				
			6_Net Tow															1			
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
F27	108	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1				
			6_Net Tow															1			
			1_Bottom	1	1	1															
			2_Mid-Bottom	1	1	1															
F28	33	E	3_Mid-Depth	1	1	1															
			4_Mid-Surface	1	1	1															
			5_Surface	1	1	1									1						
			1_Bottom	2	1	1								1							
			2_Mid-Bottom	2	1	1								1							
F29	66	F	3_Mid-Depth	2	1	1								1							
			4_Mid-Surface	2	1	1								1							
			5_Surface	2	1	1								1	1						
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	3							
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1				
F30	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1				
			6_Net Tow															1			
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	3							
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1				
F31	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1				
			6_Net Tow															1			
F32	30	Z	5_Surface												1						
			6_Net Tow															1			
F33	30	Z	5_Surface												1						
			6_Net Tow															1			
			1_Bottom	8.1	2	1	2	2	2	2	2	1	2	1							
			2_Mid-Bottom	2.5	1	1						1		1							
N16	40	D	3_Mid-Depth	15	2	2	2	2	2	2	2	2	2	1		1	1				
			4_Mid-Surface	2.5	1	1						1		1							
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1				
			6_Net Tow															1			
					otals	132	44	44	84	84	84	80	84	96	28	26	26	15	36	5	6
			Blanks B						1	1	1	1	1								
			Blanks C						1	1	1	1	1								
			Blanks D						1	1	1	1	1								

3.0 DATA SUMMARY PRESENTATION

Data from each survey were compiled from the HOM Program 2003 database and organized to facilitate regional comparisons among surveys, and to allow a quick evaluation of results for evaluating monitoring thresholds (**Table** 3-1 Method Detection Limits; Data **Tables** 3-2 through 3-13). Each table provides summary data for each parameter over the course of the ten surveys. The nearfield data are presented separately and in combination with data from other farfield areas for surveys WF03B and WF03E. 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. Minimum, maximum, and mean values are provided because of the need to assess data in comparison to pre-outfall conditions relative to contingency criteria (MWRA, 2001). Regional mean values for nutrient and biological water column data are calculated by averaging all samples collected at stations within each region. The "All" data summaries provide means based on the survey or regional mean values. Detailed considerations for individual data sets are provided in the sections below.

3.1 Defined Geographic Areas

The primary partitioning of data is between the nearfield and farfield stations (**Figures** 1-1 and 1-2). Farfield data were additionally segmented into five geographic areas: stations in Boston Harbor (F23, F30, and F31), coastal stations (F05, F13, F14, F18, F24, F25), offshore stations (F06, F07, F10, F15, F16, F17, F19, and F22), boundary region stations (F12, F26, F27, F28, F29), and Cape Cod Bay stations (F01, F02, and F03; and F32 and F33 as appropriate). These regions are shown in **Figure** 1-2.

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

3.2 Sensor Data

Six CTD profile parameters provided in the data summary Tables 3-2 to 3-4 include temperature, salinity, density (σ_t), fluorescence (chlorophyll a), transmissivity, and dissolved oxygen (DO) concentration. Statistical parameters (maximum, minimum, and average) were calculated from the sensor readings collected at five depths through the water column (defined as A-E). These depths were sampled on the upcast of the hydrographic profile. The five depth values, rather than the entire set of profile data, were selected to reduce the statistical weighting of deep-water data at the offshore and boundary stations. Generally, the samples were collected in an even depth-distributed pattern. The mid-depth sample (C) was typically located at the subsurface fluorescence (chlorophyll) peak in the water column, depending on the relative depth of the chlorophyll maximum. Details of the collection, calibration, and processing of CTD data are available in the Water Column Monitoring CW/QAPP (Libby *et al.,* 2002), and are summarized in Section 2.

Following standard oceanographic practice, patterns of variability in water density are described using the derived parameter sigma-*t* ($\sigma_{t,}$), which is calculated by subtracting 1,000 kg/m^3 from the recorded density. During this semi-annual period, density varied from 1021.8 to 1026.1, meaning σ_t varied from 21.8 to 26.1.

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

3.4 Biological Water Column Parameters

Four productivity parameters have been presented in the data summary tables. The parameters α [$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$] 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 (surface, mid-depth and bottom) are also presented in **Table** 3-11. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Libby *et al.,* 2002).

3.5 Plankton

Plankton results 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 Nitrex mesh to retain and concentrate larger dinoflagellate species. Zooplankton samples were collected by oblique tows using a 102-μm mesh at all plankton stations. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Libby *et al.,* 2002).

Final plankton values were derived from each station by first averaging analytical replicates, and 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. Results of the nuisance species *Phaeocystis pouchetii* and *Pseudo-nitzschia pungens* in **Table** 3-13 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 sample data were reported.

3.6 Additional Data

Two additional data sources were utilized during interpretation of HOM Program semi-annual water column data. Sea surface temperature and SeaWiFS chlorophyll *a* satellite images collected near survey dates were preliminarily interpreted for evidence of surface water events, including intrusions of surface water masses from the Gulf of Maine, upwelling, and regional blooms (Appendix D). U.S. Geological Service continuous *in situ* temperature and salinity data were collected with a mooring located between nearfield stations N21 and N18 (**Figure** 1-1). Daily averaged temperature and salinity data from mid-surface (6 m), mid-depth (13 m), mid-bottom (20 m) and near-bottom (1 m above bottom, 27 m) are plotted in **Figure** 3-1. Chlorophyll *a* data (as measured by *in situ* fluorescence) from the MWRA WETStar sensor mounted at mid-depth (13 m) on the nearfield USGS mooring are plotted in **Figure** 3-2. Data at comparable depths from station N18 are included in both figures for comparison.

Table 3-1. Method detection limits

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

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

			Temperature (°C)			Salinity (PSU)			Sigma T		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN038	7/9	5.76	17.01	8.98	31.0	32.4	31.8	22.7	25.5	24.6
Nearfield	WN039	7/21	5.92	19.00	10.96	31.0	32.2	31.7	22.0	25.3	24.1
Nearfield	WN03A	8/4	5.84	17.05	9.71	30.9	32.5	31.9	22.5	25.5	24.5
Nearfield	WF03B	8/18	6.17	20.32	12.28	31.1	32.8	32.2	21.8	25.8	24.2
Nearfield	WN03C	9/10	6.97	17.33	13.02	30.9	32.0	31.7	22.6	25.0	23.8
Nearfield	WN03D	9/25	7.72	17.76	13.27	31.5	32.2	31.8	22.8	25.1	23.8
Nearfield	WF03E	10/9	7.72	14.62	11.25	31.9	32.6	32.2	23.8	25.4	24.5
Nearfield	WN03F	10/31	7.93	10.90	9.92	31.8	33.0	32.2	24.4	25.6	24.8
Nearfield	WN03G	11/18	7.97	9.48	8.78	31.9	32.8	32.3	24.7	25.5	25.0
Nearfield	WN03H	12/19	4.76	6.25	5.58	32.0	32.8	32.4	25.2	25.8	25.6
Nearfield	All		4.76	20.32	10.38	30.9	33.0	32.0	21.8	25.8	24.5
Boundary	WF03B	8/18-21	4.84	19.74	10.24	30.8	33.1	32.5	22.1	26.1	24.8
Cape Cod Bay	WF03B	8/18-21	7.07	20.08	13.20	31.7	32.6	32.2	22.4	25.5	24.1
Coastal	WF03B	8/18-21	7.72	20.69	14.07	31.5	32.5	32.0	22.1	25.3	23.8
Harbor	WF03B	8/18-21	11.90	18.20	16.65	30.7	32.2	31.5	22.0	24.4	22.9
Nearfield	WF03B	8/18-21	6.17	20.32	12.28	31.1	32.8	32.2	21.8	25.8	24.2
Offshore	WF03B	8/18-21	5.51	20.84	10.71	31.1	32.9	32.4	21.9	26.0	24.7
All	WF03B	8/18-21	4.84	20.84	12.86	30.7	33.1	32.1	21.8	26.1	24.1
Boundary	WF03E	10/6-9	7.09	14.21	11.18	31.9	32.8	32.3	23.8	25.6	24.6
Cape Cod Bay	WF03E	10/6-9	8.75	15.15	12.76	30.8	33.0	31.8	22.7	25.0	23.9
Coastal	WF03E	10/6-9	9.12	14.13	12.18	31.8	32.3	32.0	23.8	25.0	24.2
Harbor	WF03E	10/6-9	11.23	13.94	12.57	31.2	31.9	31.7	23.3	24.4	23.9
Nearfield	WF03E	10/6-9	7.72	14.62	11.25	31.9	32.6	32.2	23.8	25.4	24.5
Offshore	WF03E	10/6-9	7.41	14.95	11.76	31.9	32.6	32.2	23.6	25.5	24.4
All	WF03E	10/6-9	7.09	15.15	11.95	30.8	33.0	32.0	22.7	25.6	24.3

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

			Beam (m^{-1})			DO (mgL^{-1})			DO % Saturation		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN038	7/9	0.57	2.49	1.18	8.90	12.37	9.91	88.6	154.9	105.8
Nearfield	WN039	7/21	0.55	1.97	1.03	8.13	10.98	9.61	82.6	129.4	106.9
Nearfield	WN03A	8/4	0.55	1.88	0.93	8.12	10.80	9.37	80.8	126.5	101.7
Nearfield	WF03B	8/18	0.81	1.55	1.19	7.91	10.32	9.02	79.5	125.6	103.5
Nearfield	WN03C	9/10	0.57	1.76	0.95	7.32	9.47	8.33	77.0	107.5	96.8
Nearfield	WN03D	9/25	0.59	1.97	0.93	6.75	8.50	7.79	70.8	108.1	91.1
Nearfield	WF03E	10/9	0.63	2.18	1.17	6.51	9.90	7.81	69.4	114.3	87.8
Nearfield	WN03F	10/31	0.72	2.01	1.29	6.29	9.84	8.11	65.5	109.2	88.3
Nearfield	WN03G	11/18	0.75	1.30	0.95	5.67	9.31	8.12	59.5	98.8	86.1
Nearfield	WN03H	12/19	0.79	1.48	1.08	9.11	9.90	9.61	91.3	96.2	94.5
Nearfield	All		0.55	2.49	1.07	5.67	12.37	8.77	59.5	154.9	96.2
Boundary	WF03B	8/18-21	0.56	1.20	0.83	7.65	10.62	9.07	74.2	128.8	100.1
Cape Cod Bay	WF03B	8/18-21				6.91	11.45	9.07	70.5	144.5	106.6
Coastal	WF03B	8/18-21	0.81	1.59	1.15	7.83	10.08	9.03	83.9	126.4	107.3
Harbor	WF03B	8/18-21	1.41	2.92	2.00	8.08	9.35	8.75	93.8	118.5	109.0
Nearfield	WF03B	8/18-21	0.81	1.55	1.19	7.91	10.32	9.02	79.5	125.6	103.5
Offshore	WF03B	8/18-21	0.62	1.26	0.85	7.86	10.57	9.01	77.4	130.6	100.2
All	WF03B	8/18-21	0.56	2.92	1.20	6.91	11.45	8.99	70.5	144.5	104.5
Boundary	WF03E	10/6-9	0.55	1.82	0.92	6.79	9.78	8.04	69.3	112.9	90.2
Cape Cod Bay	WF03E	10/6-9	0.70	1.43	0.89	5.82	8.23	7.59	61.4	98.6	87.8
Coastal	WF03E	10/6-9	0.76	2.16	1.47	6.38	8.95	7.85	68.7	102.1	89.7
Harbor	WF03E	10/6-9	1.86	2.80	2.21	7.06	8.04	7.55	78.8	93.8	86.6
Nearfield	WF03E	10/6-9	0.63	2.18	1.17	6.51	9.90	7.81	69.4	114.3	87.8
Offshore	WF03E	10/6-9	0.56	1.66	0.85	6.97	9.54	7.83	71.7	110.3	88.8
All	WF03E	10/6-9	0.55	2.80	1.25	5.82	9.90	7.78	61.4	114.3	88.5

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

			Fluorescence (μgL^{-1})			Chlorophyll *a* (μgL^{-1})			Phaeophytin (μgL^{-1})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN038	7/9	0.00	17.17	2.01	0.10	12.07	3.37	0.18	3.48	1.11
Nearfield	WN039	7/21	0.00	8.11	1.20	0.06	5.65	1.49	0.02	2.29	0.83
Nearfield	WN03A	8/4	0.15	5.91	1.06	0.11	6.22	1.60	0.13	2.44	0.82
Nearfield	WF03B	8/18	0.17	5.99	1.25	0.19	4.11	1.34	0.02	1.99	0.90
Nearfield	WN03C	9/10	0.15	2.83	0.88	0.11	2.25	1.03	0.24	2.39	0.93
Nearfield	WN03D	9/25	0.02	5.07	1.46	0.09	5.03	1.69	0.14	2.29	0.79
Nearfield	WF03E	10/9	0.00	16.11	3.29	0.10	13.05	5.07	0.29	2.36	1.10
Nearfield	WN03F	10/31	0.70	14.35	4.74	0.18	13.56	5.25	0.45	1.57	1.08
Nearfield	WN03G	11/18	0.02	7.95	3.24	0.26	6.91	3.49	0.36	1.25	0.80
Nearfield	WN03H	12/19	0.46	1.95	1.32	0.63	1.92	1.48	0.23	0.51	0.33
Nearfield	All		0.00	17.17	2.05	0.06	13.56	2.58	0.02	3.48	0.87
Boundary	WF03B	8/18-21	0.11	3.11	0.91	0.08	2.30	1.16	0.13	1.41	0.75
Cape Cod Bay	WF03B	8/18-21	0.30	5.04	1.91	0.46	4.01	1.67	0.27	2.74	1.06
Coastal	WF03B	8/18-21	0.32	4.56	1.51	1.02	3.39	1.87	0.71	2.32	1.47
Harbor	WF03B	8/18-21	0.97	4.42	2.30	1.09	5.34	2.89	1.24	3.27	2.11
Nearfield	WF03B	8/18-21	0.17	5.99	1.25	0.19	4.11	1.34	0.02	1.99	0.90
Offshore	WF03B	8/18-21	0.13	3.15	0.95	0.05	2.59	1.12	0.02	1.95	0.76
All	WF03B	8/18-21	0.11	5.99	1.47	0.05	5.34	1.68	0.02	3.27	1.18
Boundary	WF03E	10/6-9	0.02	13.52	2.09	0.05	13.39	3.91	0.17	2.84	1.13
Cape Cod Bay	WF03E	10/6-9	0.54	3.69	2.07	0.98	3.18	1.99	0.29	0.77	0.48
Coastal	WF03E	10/6-9	0.14	15.57	4.29	0.81	9.50	5.30	0.47	3.80	1.57
Harbor	WF03E	10/6-9	1.84	3.51	2.74	2.87	4.80	3.81	1.16	1.81	1.37
Nearfield	WF03E	10/6-9	0.00	16.11	3.29	0.10	13.05	5.07	0.29	2.36	1.10
Offshore	WF03E	10/6-9	0.00	11.78	1.75	0.05	12.87	4.58	0.23	3.69	1.31
All	WF03E	10/6-9	0.00	16.11	2.70	0.05	13.39	4.11	0.17	3.80	1.16

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

				NH_4 (µM)			NO_2 (µM)			$NO_2 + NO_3$ (µM)	
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN038	7/9	0.01	14.43	3.55	0.01	0.20	0.10	0.08	4.20	1.58
Nearfield	WN039	7/21	0.10	15.09	2.61	0.01	0.32	0.12	0.01	5.11	1.46
Nearfield	WN03A	8/4	0.05	12.19	3.15	0.01	0.59	0.26	0.01	7.95	2.89
Nearfield	WF03B	8/18	0.17	17.35	2.61	0.01	0.63	0.25	0.03	9.52	2.67
Nearfield	WN03C	9/10	0.03	8.20	1.24	0.01	0.34	0.12	0.01	12.02	3.27
Nearfield	WN03D	9/25	0.01	13.13	2.40	0.01	0.62	0.24	0.04	11.17	4.35
Nearfield	WF03E	10/9	0.01	12.00	0.81	0.01	0.58	0.28	0.02	13.73	6.50
Nearfield	WN03F	10/31	0.17	6.58	1.64	0.01	0.61	0.29	0.53	15.34	7.05
Nearfield	WN03G	11/18	0.01	7.36	0.94	0.20	0.48	0.28	3.23	14.17	6.65
Nearfield	WN03H	12/19	0.33	6.95	1.40	0.21	0.47	0.29	9.62	14.00	11.29
Nearfield	All		0.01	17.35	2.04	0.01	0.63	0.22	0.01	15.34	4.77
Boundary	WF03B	8/18-21	0.18	3.85	1.00	0.07	0.42	0.17	0.08	11.01	3.83
Cape Cod Bay	WF03B	8/18-21	0.28	2.88	1.28	0.02	1.08	0.27	0.08	4.30	1.19
Coastal	WF03B	8/18-21	0.01	3.84	1.09	0.02	0.48	0.20	0.06	5.39	1.65
Harbor	WF03B	8/18-21	0.43	2.39	1.21	0.08	0.31	0.17	0.17	2.01	0.96
Nearfield	WF03B	8/18-21	0.17	17.35	2.61	0.01	0.63	0.25	0.03	9.52	2.67
Offshore	WF03B	8/18-21	0.01	2.25	0.71	0.01	0.54	0.21	0.02	13.63	4.66
All	WF03B	8/18-21	0.01	17.35	1.32	0.01	1.08	0.21	0.02	13.63	2.49
Boundary	WF03E	10/6-9	0.01	1.05	0.33	0.04	0.36	0.18	0.06	15.56	5.75
Cape Cod Bay	WF03E	10/6-9	0.01	1.13	0.40	0.01	1.13	0.34	0.04	10.14	3.48
Coastal	WF03E	10/6-9	0.01	2.24	0.67	0.01	0.70	0.33	0.24	11.14	4.76
Harbor	WF03E	10/6-9	0.91	2.75	1.64	0.43	0.69	0.55	4.77	8.10	6.55
Nearfield	WF03E	10/6-9	0.01	12.00	0.81	0.01	0.58	0.28	0.02	13.73	6.50
Offshore	WF03E	10/6-9	0.01	0.32	0.13	0.01	0.42	0.18	0.38	12.58	5.50
All	WF03E	10/6-9	0.01	12.00	0.66	0.01	1.13	0.31	0.02	15.56	5.42

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

Region	Survey	Dates	PO_4 (µM) Min	PO_4 (µM) Max	PO_4 (µM) Mean	SiO_4 (µM) Min	SiO_4 (µM) Max	SiO_4 (µM) Mean	BioSi (µM) Min	BioSi (µM) Max	BioSi (µM) Mean
Nearfield	WN038	7/9	0.11	1.22	0.56	1.16	9.75	5.32	0.16	5.64	2.06
Nearfield	WN039	7/21	0.04	1.44	0.54	1.46	8.91	4.29	0.34	4.70	1.19
Nearfield	WN03A	8/4	0.15	1.61	0.70	0.81	10.42	4.69	0.16	6.47	1.46
Nearfield	WF03B	8/18	0.12	2.08	0.72	2.53	12.81	5.13	0.16	1.98	0.89
Nearfield	WN03C	9/10	0.11	1.24	0.53	1.74	10.15	5.23	0.16	3.25	1.04
Nearfield	WN03D	9/25	0.25	1.81	0.82	0.39	14.16	5.78	0.42	4.30	1.77
Nearfield	WF03E	10/9	0.30	2.14	0.85	0.40	12.08	6.21	0.64	6.74	3.39
Nearfield	WN03F	10/31	0.52	1.44	0.95	0.44	14.43	5.52	2.33	6.80	5.32
Nearfield	WN03G	11/18	0.62	1.39	0.88	2.79	17.59	7.24	2.24	4.10	3.04
Nearfield	WN03H	12/19	1.01	1.42	1.11	9.96	11.94	10.63	1.82	3.66	2.57
Nearfield	All		0.04	2.14	0.77	0.39	17.59	6.00	0.16	6.80	2.28
Boundary	WF03B	8/18-21	0.24	1.30	0.69	1.36	8.47	4.26	0.16	1.52	0.88
Cape Cod Bay	WF03B	8/18-21	0.35	1.20	0.62	2.79	6.75	4.72	0.35	2.39	0.89
Coastal	WF03B	8/18-21	0.13	0.99	0.58	2.01	8.53	5.80	0.80	3.01	1.72
Harbor	WF03B	8/18-21	0.44	0.74	0.52	4.85	8.74	6.39	2.87	7.27	4.99
Nearfield	WF03B	8/18-21	0.12	2.08	0.72	2.53	12.81	5.13	0.16	1.98	0.89
Offshore	WF03B	8/18-21	0.22	1.21	0.69	2.06	12.45	4.82	0.35	3.46	1.18
All	WF03B	8/18-21	0.12	2.08	0.64	1.36	12.81	5.19	0.16	7.27	1.76
Boundary	WF03E	10/6-9	0.26	1.19	0.68	0.36	12.26	5.16	0.16	6.43	2.73
Cape Cod Bay	WF03E	10/6-9	0.36	1.45	0.69	0.45	17.34	5.46	1.65	4.57	2.99
Coastal	WF03E	10/6-9	0.23	1.20	0.68	0.58	12.00	5.01	1.00	7.08	5.09
Harbor	WF03E	10/6-9	0.87	1.11	1.00	4.65	8.05	6.71	4.37	7.58	5.96
Nearfield	WF03E	10/6-9	0.30	2.14	0.85	0.40	12.08	6.21	0.64	6.74	3.39
Offshore	WF03E	10/6-9	0.10	1.13	0.66	0.13	11.72	5.23	0.36	7.41	3.61
All	WF03E	10/6-9	0.10	2.14	0.76	0.13	17.34	5.63	0.16	7.58	3.96

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

			POC (μM)			PON (μM)			PartP (μM)		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN038	7/9	5.68	88.30	36.94	0.99	12.36	5.45	0.06	0.74	0.29
Nearfield	WN039	7/21	6.80	52.60	25.70	1.07	7.08	3.52	0.06	0.37	0.21
Nearfield	WN03A	8/4	6.37	76.80	23.61	1.24	11.40	3.72	0.06	0.44	0.20
Nearfield	WF03B	8/18	6.86	28.70	17.54	1.49	5.13	3.01	0.06	0.31	0.15
Nearfield	WN03C	9/10	8.42	28.80	17.79	1.64	4.72	3.00	0.07	0.23	0.14
Nearfield	WN03D	9/25	7.89	43.80	23.21	1.24	9.50	3.45	0.08	0.34	0.17
Nearfield	WF03E	10/9	6.73	70.40	29.63	1.22	9.14	4.23	0.06	0.51	0.23
Nearfield	WN03F	10/31	8.18	48.00	27.12	1.16	6.76	4.03	0.07	0.34	0.23
Nearfield	WN03G	11/18	6.27	51.10	24.14	0.95	8.21	3.77	0.12	0.33	0.22
Nearfield	WN03H	12/19	7.84	42.20	14.33	1.31	2.86	2.07	0.07	0.21	0.13
Nearfield	All		5.68	88.30	24.00	0.95	12.36	3.63	0.06	0.74	0.20
Boundary	WF03B	8/18-21	2.64	20.50	13.99	0.84	4.16	2.65	0.02	0.23	0.12
Cape Cod Bay	WF03B	8/18-21	16.30	35.80	25.50	2.69	6.17	4.22	0.13	0.32	0.20
Coastal	WF03B	8/18-21	12.80	26.90	20.80	2.35	4.89	3.81	0.14	0.28	0.21
Harbor	WF03B	8/18-21	27.00	67.40	39.36	5.16	9.71	6.63	0.22	0.56	0.38
Nearfield	WF03B	8/18-21	6.86	28.70	17.54	1.49	5.13	3.01	0.06	0.31	0.15
Offshore	WF03B	8/18-21	5.72	26.50	15.38	1.14	5.61	2.88	0.06	0.19	0.12
All	WF03B	8/18-21	2.64	67.40	22.09	0.84	9.71	3.87	0.02	0.56	0.20
Boundary	WF03E	10/6-9	5.58	54.50	26.88	1.08	8.71	4.34	0.02	0.50	0.23
Cape Cod Bay	WF03E	10/6-9	17.20	27.60	22.43	3.11	4.11	3.63	0.16	0.26	0.21
Coastal	WF03E	10/6-9	13.40	49.50	33.72	2.02	8.14	5.39	0.14	0.47	0.32
Harbor	WF03E	10/6-9	28.70	33.80	31.33	4.41	5.53	4.91	0.28	0.41	0.36
Nearfield	WF03E	10/6-9	6.73	70.40	29.63	1.22	9.14	4.23	0.06	0.51	0.23
Offshore	WF03E	10/6-9	2.64	63.70	30.42	0.93	9.21	4.67	0.04	0.52	0.25
All	WF03E	10/6-9	2.64	70.40	29.07	0.93	9.21	4.53	0.02	0.52	0.27

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

			DOC (μM)			TDN (μM)			TDP (μM)		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN038	7/9	144.30	264.20	184.07	11.84	37.27	19.12	0.38	2.17	0.84
Nearfield	WN039	7/21	153.00	200.00	171.17	11.37	33.99	19.36	0.35	1.19	0.73
Nearfield	WN03A	8/4	134.60	289.50	181.07	11.61	31.57	19.24	0.51	1.50	0.81
Nearfield	WF03B	8/18	138.00	399.50	231.12	10.26	33.90	18.80	0.46	1.43	0.89
Nearfield	WN03C	9/10	126.90	263.60	162.29	12.55	34.73	21.64	0.48	1.51	0.90
Nearfield	WN03D	9/25	118.50	244.90	159.45	11.72	24.26	17.90	0.51	1.39	0.87
Nearfield	WF03E	10/9	124.60	213.70	159.83	12.73	29.84	19.79	0.61	1.39	0.98
Nearfield	WN03F	10/31	98.20	218.30	143.37	9.01	23.77	17.34	0.69	1.49	1.02
Nearfield	WN03G	11/18	103.00	213.20	135.50	16.82	40.26	23.87	0.90	1.63	1.13
Nearfield	WN03H	12/19	99.40	136.00	112.55	20.49	33.44	22.94	1.16	1.43	1.24
Nearfield	All		98.20	399.50	164.04	9.01	40.26	20.00	0.35	2.17	0.94
Boundary	WF03B	8/18-21	196.10	359.50	267.88	14.29	25.58	18.43	0.43	1.23	0.86
Cape Cod Bay	WF03B	8/18-21	135.40	318.40	224.98	15.09	21.48	18.43	0.58	1.36	0.88
Coastal	WF03B	8/18-21	184.90	360.00	248.04	12.08	26.67	18.51	0.60	1.25	0.86
Harbor	WF03B	8/18-21	189.50	456.40	289.98	13.18	22.05	17.44	0.68	1.04	0.79
Nearfield	WF03B	8/18-21	138.00	399.50	231.12	10.26	33.90	18.80	0.46	1.43	0.89
Offshore	WF03B	8/18-21	131.00	549.10	258.74	11.94	29.71	18.56	0.41	1.49	0.88
All	WF03B	8/18-21	131.00	549.10	253.46	10.26	33.90	18.36	0.41	1.49	0.86
Boundary	WF03E	10/6-9	117.20	199.30	156.03	14.09	35.75	21.93	0.60	1.35	0.90
Cape Cod Bay	WF03E	10/6-9	132.60	156.20	142.15	14.65	30.62	23.23	0.72	1.67	1.16
Coastal	WF03E	10/6-9	137.50	170.50	153.10	13.55	26.21	18.74	0.69	1.49	0.98
Harbor	WF03E	10/6-9	136.50	174.40	160.03	23.04	31.01	27.22	1.16	1.51	1.37
Nearfield	WF03E	10/6-9	124.60	213.70	159.83	12.73	29.84	19.79	0.61	1.39	0.98
Offshore	WF03E	10/6-9	126.80	216.00	157.56	14.50	23.51	18.41	0.68	1.29	0.90
All	WF03E	10/6-9	117.20	216.00	154.78	12.73	35.75	21.55	0.60	1.67	1.05

Table 3-9. Summary of total suspended solids data for July - December 2003.

Region	Survey	Dates	TSS (mgL^{-1}) Min	Max	Mean
Nearfield	WN038	7/9	0.50	4.81	1.50
Nearfield	WN039	7/21	0.24	1.55	0.81
Nearfield	WN03A	8/4	0.28	2.32	0.90
Nearfield	WF03B	8/18	0.46	3.96	0.91
Nearfield	WN03C	9/10	0.35	1.83	0.81
Nearfield	WN03D	9/25	0.37	2.64	0.92
Nearfield	WF03E	10/9	0.40	2.71	1.29
Nearfield	WN03F	10/31	1.14	2.46	1.53
Nearfield	WN03G	11/18	0.69	1.82	1.02
Nearfield	WN03H	12/19	0.45	1.35	0.86
Nearfield	All		0.24	4.81	1.05
Boundary	WF03B	8/18-21	0.53	2.39	0.99
Cape Cod Bay	WF03B	8/18-21	0.44	1.02	0.72
Coastal	WF03B	8/18-21	0.72	2.36	1.37
Harbor	WF03B	8/18-21	1.34	5.69	2.77
Nearfield	WF03B	8/18-21	0.46	3.96	0.91
Offshore	WF03B	8/18-21	0.31	2.64	0.93
All	WF03B	8/18-21	0.31	5.69	1.28
Boundary	WF03E	10/6-9	0.31	1.60	0.91
Cape Cod Bay	WF03E	10/6-9	0.47	2.21	1.08
Coastal	WF03E	10/6-9	0.42	6.01	2.68
Harbor	WF03E	10/6-9	2.52	5.57	3.85
Nearfield	WF03E	10/6-9	0.40	2.71	1.29
Offshore	WF03E	10/6-9	0.42	2.00	1.19
All	WF03E	10/6-9	0.31	6.01	1.83

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

			Alpha $[mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}]$			Pmax $(mgCm^{-3}h^{-1})$		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN038	7/9	0.001	0.369	0.069	0.37	15.82	5.14
Nearfield	WN039	7/21	0.002	0.059	0.024	0.18	3.05	1.85
Nearfield	WN03A	8/4	0.002	0.052	0.017	0.35	5.53	1.97
Nearfield	WF03B	8/18	0.004	0.081	0.029	0.40	5.83	2.78
Nearfield	WN03C	9/10	0.002	0.059	0.023	0.18	4.99	2.29
Nearfield	WN03D	9/25	0.004	0.055	0.032	0.46	7.50	3.29
Nearfield	WF03E	10/9	0.010	0.161	0.056	1.13	21.64	6.94
Nearfield	WN03F	10/31	0.005	0.430	0.226	0.56	35.62	19.38
Nearfield	WN03G	11/18	0.024	0.244	0.121	3.19	17.06	10.61
Nearfield	WN03H	12/19	0.018	0.060	0.028	2.08	4.08	2.77
Nearfield	All		0.001	0.430	0.062	0.18	35.62	5.70
Boundary	WF03B	8/18-21						
Cape Cod Bay	WF03B	8/18-21						
Coastal	WF03B	8/18-21						
Harbor	WF03B	8/18-21	0.047	0.135	0.081	3.47	19.50	10.59
Nearfield	WF03B	8/18-21	0.004	0.081	0.029	0.40	5.83	2.78
Offshore	WF03B	8/18-21						
All	WF03B	8/18-21	0.004	0.135	0.055	0.40	19.50	6.68
Boundary	WF03E	10/6-9						
Cape Cod Bay	WF03E	10/6-9						
Coastal	WF03E	10/6-9						
Harbor	WF03E	10/6-9	0.069	0.092	0.082	9.49	14.02	11.54
Nearfield	WF03E	10/6-9	0.010	0.161	0.056	1.13	21.64	6.94
Offshore	WF03E	10/6-9						
All	WF03E	10/6-9	0.010	0.161	0.069	1.13	21.64	9.24

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

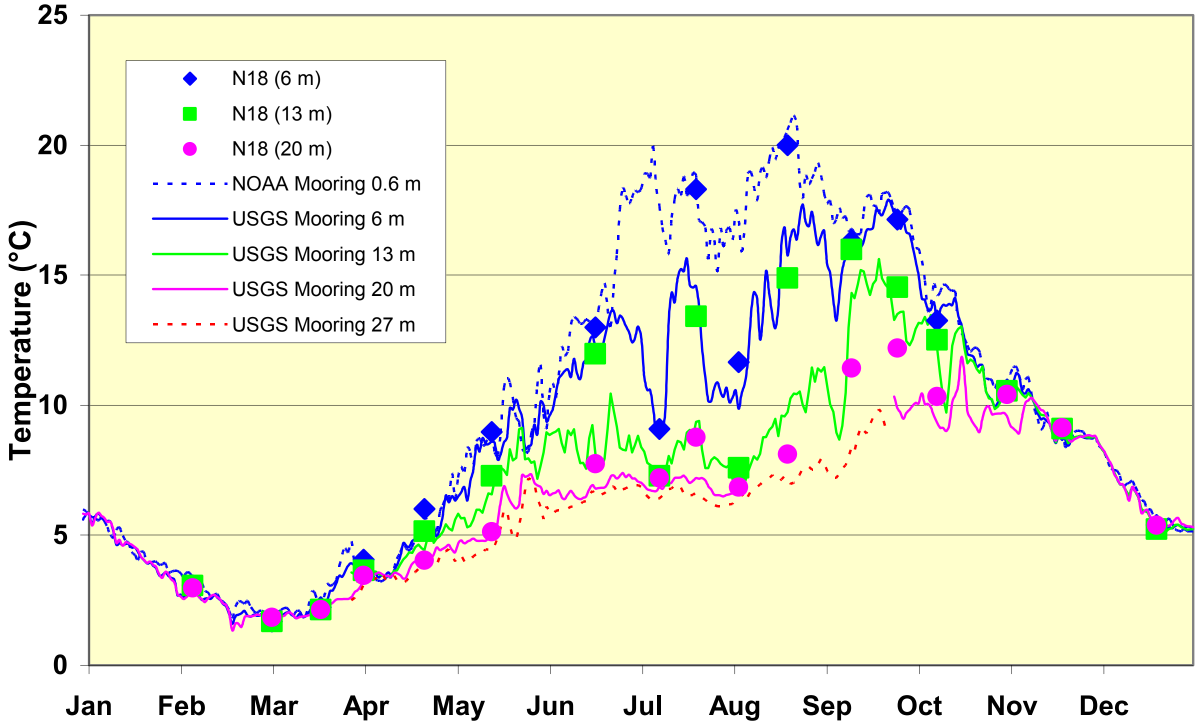
			Areal Production ($mgCm^{-2}d^{-1}$)			Depth-averaged Chlorophyll- specific Production ($mgCmgChla^{-1}d^{-1}$)			Respiration (μMO_2h^{-1})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN038	7/9	774.6	901.3	838.0	15.0	23.7	19.4	0.023	0.214	0.097
Nearfield	WN039	7/21	431.1	678.4	554.8	17.5	26.3	21.9	0.032	0.142	0.104
Nearfield	WN03A	8/4	426.7	569.6	498.2	9.1	15.4	12.3	0.024	0.168	0.089
Nearfield	WF03B	8/18	648.8	959.8	804.3	15.0	29.0	22.0	0.019	0.128	0.067
Nearfield	WN03C	9/10	564.1	628.4	596.3	23.2	27.4	25.3	0.039	0.109	0.081
Nearfield	WN03D	9/25	494.1	779.0	636.6	12.3	18.3	15.3	0.021	0.156	0.109
Nearfield	WF03E	10/9	529.1	1674.6	1101.9	10.0	13.1	11.5	0.022	0.150	0.100
Nearfield	WN03F	10/31	1492.2	2447.0	1969.6	5.8	11.5	8.7	0.013	0.075	0.056
Nearfield	WN03G	11/18	1033.3	1643.9	1338.6	7.4	14.3	10.9	0.009	0.102	0.058
Nearfield	WN03H	12/19	215.3	306.1	260.7	5.0	5.0	5.0	0.006	0.056	0.029
Nearfield	All		215.3	2447.0	859.9	5.0	29.0	15.2	0.006	0.214	0.079
Boundary	WF03B	8/18-21									
Cape Cod Bay	WF03B	8/18-21									
Coastal	WF03B	8/18-21									
Harbor	WF03B	8/18-21	1182.6	1182.6	1182.6	21.0	21.0	21.0	0.085	0.217	0.172
Nearfield	WF03B	8/18-21	648.8	959.8	804.3	15.0	29.0	22.0	0.019	0.128	0.067
Offshore	WF03B	8/18-21							0.049	0.138	0.086
All	WF03B	8/18-21	648.8	1182.6	993.5	15.0	29.0	21.5	0.019	0.217	0.108
Boundary	WF03E	10/6-9									
Cape Cod Bay	WF03E	10/6-9									
Coastal	WF03E	10/6-9									
Harbor	WF03E	10/6-9	705.8	705.8	705.8	6.5	6.5	6.5	0.066	0.081	0.074
Nearfield	WF03E	10/6-9	529.1	1674.6	1101.9	10.0	13.1	11.5	0.022	0.150	0.100
Offshore	WF03E	10/6-9							0.001	0.160	
All	WF03E	10/6-9	705.8	705.8	705.8	6.5	6.5	6.5	0.066	0.081	0.074

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

			Total Phytoplankton (10^6 cells L^{-1})			Centric Diatoms (10^6 cells L^{-1})			Total Zooplankton (Individuals m^{-3})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN038	7/9	0.529	1.454	0.999	0.002	0.033	0.011	10210	10758	10484
Nearfield	WN039	7/21	0.725	1.090	0.926	0.009	0.033	0.021	28890	35877	32383
Nearfield	WN03A	8/4	0.955	1.509	1.244	0.001	0.025	0.013	18957	60356	39657
Nearfield	WF03B	8/18	1.057	1.585	1.315	0.000	0.013	0.004	50814	115528	78931
Nearfield	WN03C	9/10	1.084	1.548	1.344	0.002	0.017	0.008	46674	56554	51614
Nearfield	WN03D	9/25	1.697	2.340	1.947	0.467	1.036	0.769	53157	78623	65890
Nearfield	WF03E	10/9	1.140	1.747	1.386	0.133	0.619	0.456	14675	36703	25468
Nearfield	WN03F	10/31	1.610	3.040	2.295	0.473	2.133	1.169	35286	54458	44872
Nearfield	WN03G	11/18	1.716	2.903	2.218	0.434	1.059	0.744	29207	30044	29626
Nearfield	WN03H	12/19	0.853	1.195	0.954	0.069	0.119	0.093	11254	11944	11599
Nearfield	All		0.529	3.040	1.463	0.000	2.133	0.329	10210	115528	39052
Boundary	WF03B	8/18-21	0.641	1.250	1.012	0.000	0.004	0.003	13880	139778	76829
Cape Cod Bay	WF03B	8/18-21	0.789	1.932	1.378	0.000	0.011	0.005	52249	98932	75591
Coastal	WF03B	8/18-21	1.160	2.525	1.651	0.001	0.032	0.011	80007	117739	103927
Harbor	WF03B	8/18-21	1.772	3.707	2.273	0.012	0.668	0.372	64560	135953	108604
Nearfield	WF03B	8/18-21	1.057	1.585	1.315	0.000	0.013	0.004	50814	115528	78931
Offshore	WF03B	8/18-21	0.780	1.055	0.906	0.000	0.007	0.004	16228	103270	59749
All	WF03B	8/18-21	0.641	3.707	1.422	0.000	0.668	0.066	13880	139778	83938
Boundary	WF03E	10/6-9	0.647	1.590	1.086	0.012	0.698	0.319	12587	39385	25986
Cape Cod Bay	WF03E	10/6-9	0.923	1.767	1.288	0.124	0.229	0.188	32949	88077	60513
Coastal	WF03E	10/6-9	1.128	2.923	2.002	0.113	1.176	0.646	4614	24201	15022
Harbor	WF03E	10/6-9	1.174	1.726	1.533	0.291	0.496	0.386	3698	7892	5633
Nearfield	WF03E	10/6-9	1.140	1.747	1.386	0.133	0.619	0.456	14675	36703	25468
Offshore	WF03E	10/6-9	0.831	3.602	1.940	0.019	1.300	0.585	29598	34592	32095
All	WF03E	10/6-9	0.647	3.602	1.539	0.012	1.300	0.430	3698	88077	27453

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

			Alexandrium spp. (cells L^{-1})			*Phaeocystis* (10^6 cells L^{-1})			*Pseudo-nitzschia pungens* (10^6 cells L^{-1})		
Region	**Survey**	**Dates**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Nearfield	WN038	7/9	0	0	0	0	0	0	0	0	0
Nearfield	WN039	7/21	0	0	0	0	0	0	0	0	0
Nearfield	WN03A	8/4	0	0	0	0	0	0	0	0	0
Nearfield	WF03B	8/18	0	0	0	0	0	0	0.0	0.0001	0
Nearfield	WN03C	9/10	0	0	0	0	0	0	0.0	0	0
Nearfield	WN03D	9/25	0	0	0	0	0	0	0.0	0.0023	0.0006
Nearfield	WF03E	10/9	0	0	0	0	0	0	0.0	0.0047	0.0014
Nearfield	WN03F	10/31	0	0	0	0	0	0	0.0416	0.0717	0.0520
Nearfield	WN03G	11/18	0	0	0	0	0	0	0.0018	0.0046	0.0034
Nearfield	WN03H	12/19	0	0	0	0	0	0	0	0	0
Nearfield	All		0	0	0	0	0	0	0	0.0717	0.0057
Boundary	WF03B	8/18-21	0	0	0	0	0	0	0	0	0
Cape Cod Bay	WF03B	8/18-21	0	0	0	0	0	0	0	0	0
Coastal	WF03B	8/18-21	0	0	0	0	0	0	0	0.0001	0
Harbor	WF03B	8/18-21	0	0	0	0	0	0	0	0.0013	0.0002
Nearfield	WF03B	8/18-21	0	0	0	0	0	0	0	0.0001	0
Offshore	WF03B	8/18-21	0	0	0	0	0	0	0	0	0
All	WF03B	8/18-21	0	0	0	0	0	0	0	0.0013	0
Boundary	WF03E	10/6-9	0	9.20	3.99	0	0	0	0	0.0024	0.0006
Cape Cod Bay	WF03E	10/6-9	0	19.35	5.91	0	0	0	0.0023	0.0398	0.0217
Coastal	WF03E	10/6-9	0	4.80	0.80	0	0	0	0	0.0087	0.0017
Harbor	WF03E	10/6-9	0	6.45	2.08	0	0	0	0	0.0027	0.0004
Nearfield	WF03E	10/6-9	0	0	0	0	0	0	0	0.0047	0.0014
Offshore	WF03E	10/6-9	0	7.50	2.36	0	0	0	0	0.0030	0.0016
All	WF03E	10/6-9	0	19.35	2.52	0	0	0	0	0.0398	0.0046



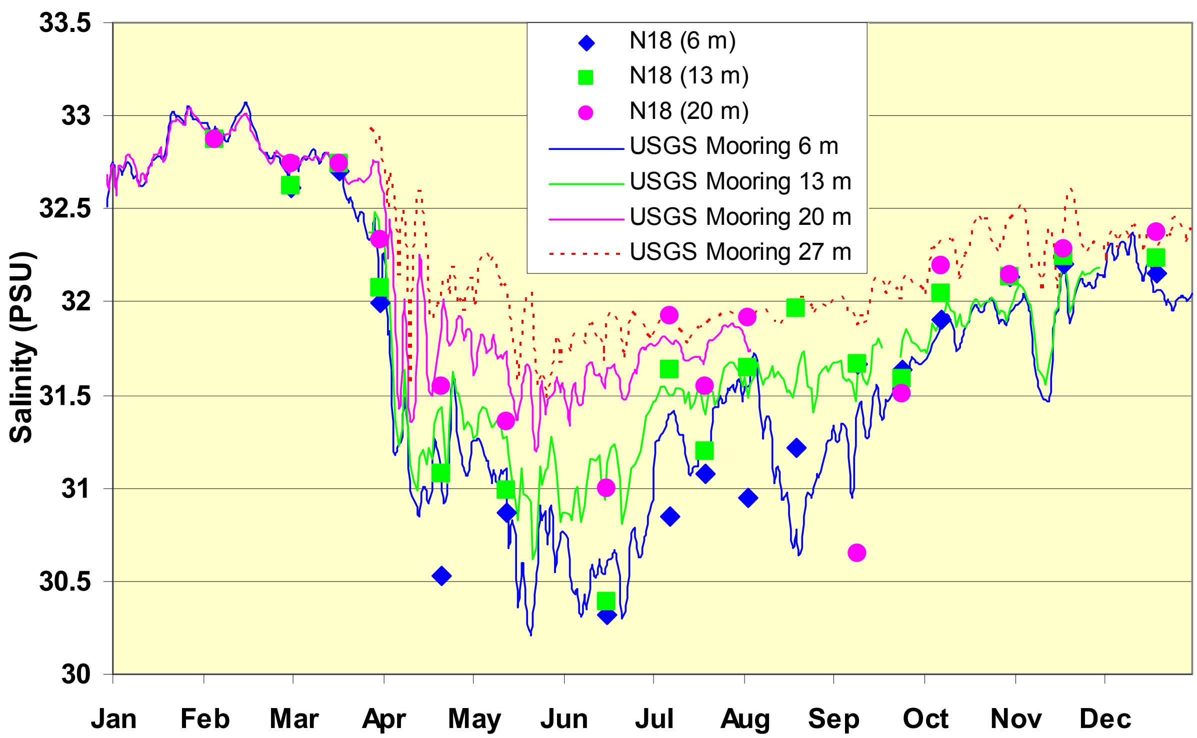


Figure 3-1. USGS Temperature and salinity mooring data compared with station N18 data. (Note: The 20-m conductivity sensor failed during the September 2003 to February 2004 deployment.)

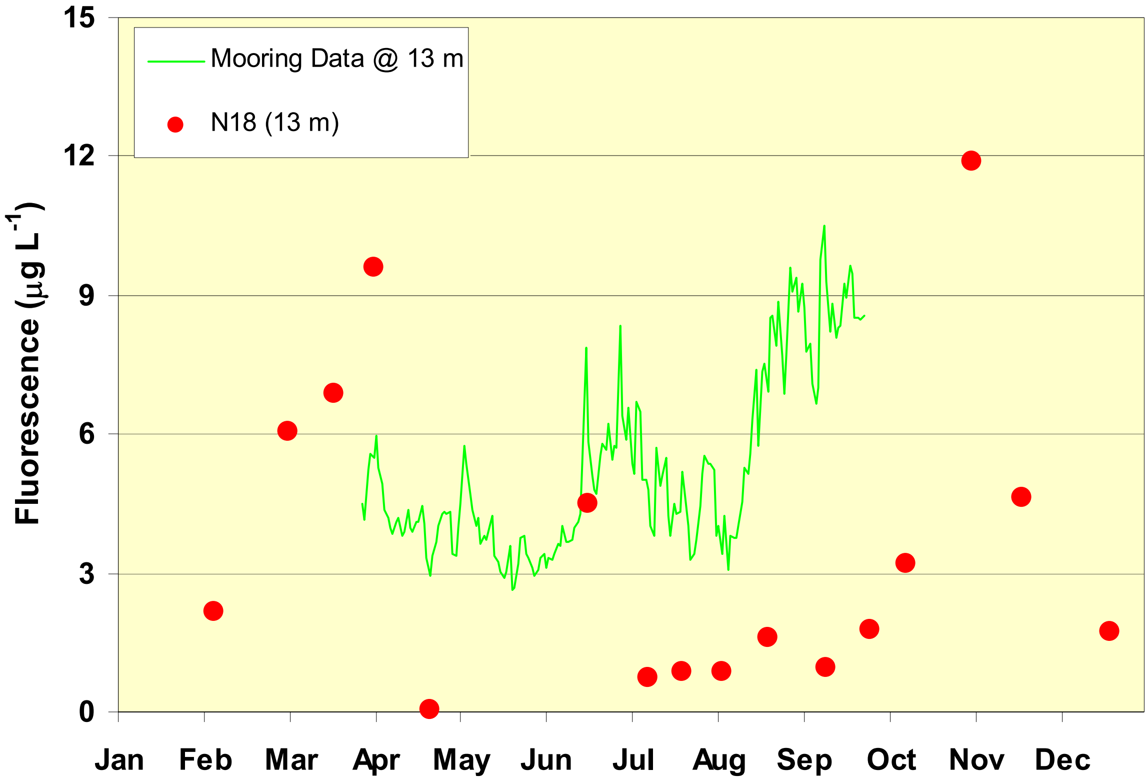


Figure 3-2. MWRA and Battelle *In Situ* WETStar fluorescence data – MWRA data acquired at ~13 m on USGS mooring and Battelle data acquired at 13 m at station N18.

(Note that data from January to April 2003 and from September 2003 to February 2004 were not usable.)

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.

Two of the ten surveys conducted during this semi-annual period were combined farfield/nearfield surveys. In August, during the first combined survey of this period (WF03B), summertime stratified conditions existed in the water column throughout the entire survey area. Compared to the open bays, stratification was less defined in tidally mixed Boston Harbor as typically observed. By October (WF03E), the density gradient had weakened across the bays although moderate stratification remained in most areas except the harbor and coastal stations. In the nearfield, stratification had begun to break down by late September and early October, but a weak density gradient remained throughout the fall and it was not until the December survey (WN03H) that fully well-mixed winter conditions were observed over the entire nearfield. This represents a fairly late transition to winter conditions as compared to previous years, although similar to fall/winter 2001.

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) (**Figure** 1-3). Nearfield vertical data is presented across one transect which runs from the southwest corner (N10) to the northeast corner (N04). 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 2003 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 in October, but the water column was not fully mixed until December. 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". The USGS mooring data collected near station N18 appear to corroborate the trends in the middle of the nearfield (**Figure** 3-1) indicating that the water column at the mooring was relatively well mixed with regards to temperature and salinity by early November.

4.1.1.1 Horizontal Distribution

Over the course of the three nearfield surveys conducted in July and early August (WN038, WN039, and WN03A), there was considerable variability in the surface temperatures throughout the nearfield. In early July the nearfield surface temperatures ranged from <12°C to 17°C. No clear trends were obvious, with patches of different temperature surface waters throughout the area. During the late July survey nearfield surface temperatures ranged from 15.8°C to 19.0°C with a clear trend of warmer water at the outermost stations. This trend remained present in early August, although the gradient was less sharp with a range of only 15.4°C to 17°C. During these three surveys, surface salinity also showed clear trends, although the salinity trends did not correspond well with temperature gradients. In early July the surface salinity range was 31.0 to 31.7 PSU, with the lower salinity waters in the northwest corner as result of fairly high precipitation and river flow (**Figure** 4-3). In late July surface salinities were more evenly distributed with no clear trends (31.0 to 31.4 PSU). In early August the previous trend reemerged with salinities in the northwest corner slightly lower (30.9 PSU) than those in the southeast (31.6 PSU).

In late August (WF03B), surface water temperatures were coolest (<17°C) at stations just outside Boston Harbor in an area where the upwelling signature of cooler water is often observed (**Figure** 4-4). The rest of the survey area showed fairly homogeneous surface temperatures (17.9 to 20.8°C). Surface temperatures in the nearfield were very evenly distributed with a range of only 18.8 to 20.3°C. Surface water salinity was lowest near the harbor (30.7 PSU at F23) and along the north coastline (30.8 PSU at F26) where riverine inputs and runoff have a stronger influence. Surface salinity increased along a gradient to the south and east with maximum values recorded along the boundary stations (32.1 PSU at F27 and F29).

During the first nearfield survey conducted in September (WN03C), surface temperatures had decreased somewhat from the previous survey to a range of 15.7 – 17.3°C with the coolest waters along the northern edge of the nearfield "box". Slightly lower salinities were also identified across these northern nearfield stations with a minimum of 30.9 PSU at N01. Salinities throughout the rest of the nearfield were approximately 31.8 PSU. By late September (WN03D), surface temperatures and salinity were homogeneous throughout the nearfield at 17.0 to 17.8°C and 31.5 to 31.7 PSU.

Surface temperatures continued to decrease as the fall progressed, and by the October farfield survey (WF03E) the temperature range was 11.1 to 15.1°C. This was a decrease from the August survey of approximately 5°C in most areas, although in the coastal waters near Nahant temperatures had dropped by about 9°C. Despite the limited temperature range, a moderate gradient was detected with surface temperatures increasing towards the south where maximum values were found well into Cape Cod Bay (**Figure** 4-5). Surface salinities were also homogeneous throughout most of the farfield area ranging only from 31.8 to 32.3 PSU, except for slightly lower salinity in Cape Cod Bay (minimum 30.8 PSU at F01) and in the inner harbor (31.2 PSU at F30). Surface water salinity was consistent throughout the nearfield at ~32 PSU.

By the end of October (WN03F) surface temperatures in the nearfield had decreased to a narrow range of 10.0 to 10.9°C in nearfield. Surface salinity remained at previous levels throughout the nearfield ranging from 31.8 to 32.1 PSU. During the November and December nearfield surveys (WN03G and WN03H), temperatures continued to decline in all portions of the nearfield. In November temperatures ranged from 8.4 to 9.5°C and by the last survey of the year surface temperatures had diminished to 4.8 - 5.9°C. Surface salinities were stable and homogeneous during these surveys ranging from 31.9 to 32.6 PSU.

Precipitation and stream flows were normal or above normal throughout the report period and throughout the entire water year (October 2002 – September 2003; Massachusetts Department of Environmental Management). A lower salinity signature was apparent during the August farfield survey in the nearshore surface waters (**Figure** 4-6). The August survey was conducted just a few days after local river flows were at some of the highest levels of the summer (**Figure** 4-3; Charles River = 413 cfs, Merrimack River = 17,400 cfs). There was little precipitation and relatively low riverine flow from late August to late October. Thus, there was little variability in surface salinity across the bays during survey WF03E. River flows increased substantially in late fall and winter with peaks flows for the season occurring on December 19 and 20, 2003 (**Figure** 4-3; Charles River = 983 cfs, Merrimack River = 33,500 cfs). No farfield surveys were conducted during this time period so it is difficult to determine the influence of these flows on the Massachusetts Bay water column.

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** 4-7 shows the mean surface and bottom water densities at each of the five farfield regions during the two farfield surveys of this report period. The water column was stratified throughout the bays during the summer of 2003, but weakest in Boston Harbor. During the August farfield survey (WF03B), the water column was strongly stratified along each of the transects with a sharp pycnocline present at approximately 10-15 m. The gradient was weaker at the inshore stations, although even at F23 (just outside the harbor) fairly robust stratification was observed. The density gradient was driven primarily by temperature, which exhibited a >9°C difference between the surface and bottom layers along all transects except at the harbor stations, and >13°C at the deeper offshore and boundary stations. In contrast to 2002, a moderate salinity gradient contributed to the overall stratification. At many stations, particularly in the offshore and boundary areas, salinity varied by more than 1.4 PSU through the water column in August. This salinity gradient was due to the contribution of fresh water into the surface waters of the survey area.

By October (WF03E), the density gradient had weakened somewhat across the bays although clear stratification was still present in most areas. In the harbor and along the coast, the pycnocline had broken down and only a weak density gradient remained between surface and bottom waters. As is typical, the temperature gradient was the primary driver for stratification in the late summer and fall. The density gradient between surface and bottom waters was still >1.3 $\Delta\sigma_t$ at boundary, offshore, and Cape Cod Bay regions. While the density range was <1 $\Delta\sigma_t$ at coastal and harbor stations, the water column was still not fully mixed. By the October farfield survey the salinity gradient had mostly disappeared and the remaining stratification seen in many areas was driven solely by temperature.

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** 4-8). Surface water temperatures were generally 17-20°C and there was a strong thermal gradient (6-14°C) between surface and bottom water temperatures across the bays. Salinity varied over a moderate range (30.7-33.1 PSU). There was a negative relationship between these parameters as an increase in salinity with depth was coincident with a decrease in temperature. By October, the range in temperatures had decreased (7 to 15°C) as surface water temperatures had cooled and bottom water temperatures increased. The range in salinity remained about the same 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. In Boston Harbor, the T-S pattern was shifting towards the characteristics of a well-mixed winter water column – with minimal variation in temperature across a relatively wide range in salinity. This destratification process continued in the nearfield on subsequent surveys (discussed below) and it is expected that similar conditions were present in offshore Massachusetts and Cape Cod Bay waters.

Nearfield. The gradual breakdown of seasonal stratification in 2003 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 later into the winter and thus provide a more detailed picture of the physical characteristics of the water column. In July strong stratification was present throughout the nearfield (**Figure** 4-9). Stratification in the nearfield continued to strengthen as the summer progressed and peaked by the late August survey with $\Delta\sigma_t$ >3 across the nearfield. In early September surface temperatures had dropped leading to a weakening of the density structure. The continuation of this destratification process was observed on subsequent October surveys although it was not until late November that stratification had really broken down (**Figure** 4-10), and not until December that the water column was fully mixed.

The vertical gradient in density is predominantly driven by temperature during the summer and fall. The data from 2003 also show this 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** 4-11). In July and August, there was a strong temperature gradient (6.6 - 9.8°C) between surface and bottom waters with a sharp thermocline at ~10 m along the nearfield transect. By the late August survey, stratification had peaked due to exceptionally high temperatures (~20°C) in the nearfield surface waters. These warm surface waters lead to a temperature differential between surface and bottom waters of as much as 13°C. By mid September, increased mixing of surface and deeper waters led to a decrease in surface water temperatures and increasing temperatures in the deeper waters. By late September, and throughout the remainder of the report period, surface water temperatures continued to decrease due to atmospheric cooling and mixing. By late November, surface and bottom waters were nearly equal and continued to decline together through December. By the last survey of the year, temperatures throughout the water column had declined to <6°C.

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 2003, the salinity signal from the discharge could be seen during nearly all nearfield surveys. Elevated precipitation resulting in relatively high effluent flow rates at DITP contributed to this salinity signature. The most distinct salinity signature from the outfall was seen during the December survey (**Figure** 4-12). This survey was conducted approximately a week after the major snow event of December 5-8. The melt of this snowpack coupled with additional rainfall led to the peak stream flows for the year and DITP flow rates in excess of 580 MGD on December 16th three days before survey WN03H.

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).

Although equipment failures during the August survey resulted in limited beam attenuation data, the typical trend can still be seen, with surface water beam attenuation highest in Boston Harbor (Max = 2.92 m^{-1} at F30) 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 highest in the harbor at this time. During the October farfield survey, the highest beam attenuation values were also observed in the harbor (2.19 m^{-1} at F31) and decreased to minimum values offshore (0.65 m^{-1} at F17). Unlike August, moderately elevated beam attenuation values (~1.5 – 1.9 m^{-1}) were found along the coast of the North Shore (**Figure** 4-13). As in August, the surface beam attenuation trends corresponded well with fluorescence and phytoplankton abundance, although a slight disconnect in the harbor suggests that the highest beam values were related associated with a combination of biogenic material and suspended sediment.

In general, the vertical and horizontal trends in beam attenuation are dependent upon the input of particulate material from terrestrial sources (inshore stations) and the distribution of chlorophyll/phytoplankton (offshore stations). **Figure** 4-14 presents beam attenuation data along the Boston-Nearfield and Nearfield transects in October. These contour plots clearly show the inshore or harbor signature of high beam attenuation and its influence on nearshore stations. By comparing these plots with the transect contour plots for fluorescence (**Figure** 4-15) it is possible to separate the relative contribution of chlorophyll versus particulate material to the beam attenuation signal. Beam attenuation and fluorescence in the nearfield corresponded well, indicating that the majority of the particulate matter was biogenic in nature. In the contrast, the western end of the Boston-Nearfield transect shows a disconnect between beam attenuation and fluorescence. This suggests that suspended sediments contributed a large portion of the transmissometer signal in Boston Harbor. This is not surprising considering the tidal currents and relatively high fresh water flows into the harbor during this period.

4.2 Biological Characteristics

4.2.1 Nutrients

Nutrient data were initially 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.

The general trend in nutrient concentrations during the 2003 July to December period was similar to previous years, although the late breakdown in stratification tended to delay the typical increase of nutrients in the surface waters in the fall until later in the season. Seasonal stratification led to persistent nutrient depleted conditions in the upper water column and ultimately to an increase in nutrient concentrations in bottom waters due to increased rates of respiration (see Section 5.2) and remineralization of organic matter. In the late fall, nutrient concentrations began to increase with the breakdown of stratification. Although concentrations were replete throughout the water column by November, persistent weak stratification in much of the area kept nutrients at moderate levels until December. This inhibition of nutrient flux into surface waters may have contributed to the timing (late) and relatively low (as compared to previous years) phytoplankton abundance observed during the fall phytoplankton bloom in 2003. By December, nutrient concentrations returned to more typical winter values as the water column became well mixed.

Elevated concentrations of ammonium (NH_4) 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 in the outfall area was clearly observed and is one of the main focuses of this section.

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 (WF03B), surface water nutrient concentrations were low throughout most of the survey area. However, areas of slightly elevated nutrients were found in some surface waters. Near the mouth of Boston harbor (F31, F23, F25, N10) DIN values ranged from 1.8 to 3.2 µM, in southern Cape Cod Bay DIN was 3.2 µM, and a maximum DIN value of 4.4 µM was found near Cape Ann at F26 (**Figure** 4-16). Nitrate (NO_3) was low throughout the survey area with concentrations generally less than 0.4 µM except for a slightly elevated area near the harbor entrance (max NO_3 = 0.99 at F23). Like nitrate, phosphate (PO_4) was low throughout both the nearfield and farfield areas (0.12 – 0.51 µM). Surface silicate (SiO_4) concentrations were elevated for this time of year and were quite variable (1.46 to 8.74 µM), although in most areas concentrations were between 3 to 4 µM. The highest SiO_4 concentrations (>5 µM) were found in the harbor and near the harbor entrance (Appendix A). Summer nutrient concentrations were kept low in the surface waters by strong stratification. In contrast to 2002 when a late summer/early fall bloom was observed, fluorescence and phytoplankton abundance was low throughout the region in August 2003. A maximum surface fluorescence of 3.7 μgL^{-1} was found in Boston Harbor, but surface waters in all other regions were <1 μgL^{-1}. At this time the chlorophyll maximum was located at 10-15m throughout the area. Even at this depth, where some low level nutrients were available, fluorescence was fairly low (1.6 to 6 μgL^{-1}) with both the minimum and maximum found in the nearfield and most other areas homogeneous at 2-3 μgL^{-1}. Phytoplankton abundance in the surface and mid-depth waters was fairly low at <2 million cells L^{-1} in all areas except in the harbor where it was somewhat higher reaching 3.7 million cells L^{-1} in the surface at F30 (see Section 5.3.1).

By October, stratification was weakening. In the shallower areas of Boston Harbor and along the coast, surface nutrient concentrations had increased to relatively high levels as seen for NO_3 in **Figure** 4-17. However, surface nutrient levels remained low in most other areas as a moderate density gradient persisted. In addition to persistent stratification, moderate phytoplankton abundances and a shift in the community structure towards diatoms contributed to low surface nutrient concentrations. Fluorescence in surface waters had increased from the low August values to approximately 4-10 μgL^{-1} in the nearfield, coastal, and northern offshore and boundary areas. While overall phytoplankton abundance had not increased greatly since August and was still <2.5 million cells L^{-1} in most areas, diatoms represented a much larger portion of the community structure resulting in increased fluorescence and nutrient uptake. The highest surface nutrient concentrations were mostly observed at the inner Boston Harbor station F30 (DIN = 9.01 µM, NH_4 = 2.74 µM and SiO_4 = 7.87 µM at F30). Nutrient concentrations were also high near the harbor entrance, along the north coast, and in the western nearfield (max NO_3 = 7.56 µM at N01).

Ammonium concentrations close to the outfall (~1 km) have exceeded 20 µM, but the NH_4 is rapidly diluted and utilized on relatively short spatial scales. Elevated concentrations are typically confined to within 10-20 km of the outfall and only rarely have concentrations of ≥5 μM been observed to have advected outside of the nearfield area.

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** 1-3; Appendix B). In late August, the water column was strongly stratified. Consequently, nutrient concentrations were low in the surface waters and increased with depth as observed for NO_3 along the Boston-Nearfield transect (**Figure** 4-18). The vertical pattern for PO_4 was similar to that of NO_3, but the concentrations were not as depleted in the surface layer at the nearshore stations. Silicate concentrations followed similar patterns although in many areas, especially along the coast, SiO_4 concentrations were moderately elevated throughout the water column. Ammonium concentrations directly reflect the influence of the outfall in the nearfield (**Figure** 4-18). The effluent plume is clearly observed in 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 and in the summer time is constrained to the deeper waters below the pycnocline. The summer pattern of depleted nutrients in the surface waters was concomitant with low surface chlorophyll concentrations consistent with previous observations. A low level sub-surface chlorophyll maximum was observed near the pycnocline and associated with available nutrients.

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). 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.

As weakening stratification allowed some penetration of nutrients into the surface waters, fluorescence and productivity increased. However, this increase in fluorescence was coupled with a minor increase in overall phytoplankton abundance and a shift in a community structure from microflagellates to diatoms. Based on nearfield surveys conducted in the fall and winter of 2003, it appears that the fall phytoplankton bloom did not initiate until late September and did not reach maximum levels until late October to mid-November. Even at peak abundances this was only a modest bloom as compared to previous years (max phytoplankton abundance = 3.6 million cells L^{-1}). This is discussed in further detail in Section 5.3.

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 two farfield surveys conducted in this report period only the summer time trends were apparent, with no clear changeover to winter conditions. During August (WF03B), the summertime positive DIN-salinity relationship was observed throughout all farfield regions (**Figure** 4-19). In October, this positive DIN-salinity relationship had diminished but still persisted in all regions except for the harbor. In Boston Harbor high nutrient levels were associated with lower salinity as a result of the strong runoff signature described previously. Portions of the nearfield were also beginning the transition from summer to winter conditions. The nearfield is discussed in more detail below.

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 representative nearfield transect plots for NO_3 presented in **Figure** 4-20 and in the time series average plots of bottom and surface NO_3 concentrations in the nearfield throughout the report period (**Figure** 4-21).

From July through mid-October NO_3 concentrations were generally depleted (<1 µM) in the surface layer (0-5 m) and increased gradually with depth along the nearfield transect. Throughout this period NO_3 concentrations in the bottom waters were steadily increasing as a result of remineralization. In July nearfield bottom NO_3 concentrations were less 5 µM. By late September (WN03D) bottom NO_3 concentrations had increased to 6-10 µM but were still depleted in the surface layer. By late October, bottom concentrations had peaked at approximately 10-15 µM NO_3 and surface concentrations had increased dramatically (1-7 µM) as stratification had weakened in the nearfield. For the remainder of the year water column mixing continued resulting in increasing surface concentrations and decreasing bottom concentrations. By the end of the report period the nearfield water column had fairly homogeneous NO_3 concentrations (~9-11 µM), except were they exceeded 13 µM directly over the outfall at station N21. In general, PO_4 and SiO_4 followed the same spatial and temporal trends as NO_3 although silicate tended to be most depleted in the surface waters during the late fall bloom (**Figure** 4-22).

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 the immediate source 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 (**Figures** 4-23 and 4-24). In August (WF03B) 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 December that stratification had fully broken down and NH_4 can be seen rising from the outfall all the way into surface waters. There was no clear indication that the NH_4 signal or effluent plume extended much further than the immediate nearfield area during the July to December 2003 surveys.

An examination of the nutrient-nutrient plots showed that nearfield waters were generally depleted in DIN relative to PO_4 during this semi-annual period (**Figure** 4-25). Throughout the entire period the DIN:PO_4 ratio was less than the Redfield ratio of 16:1. Strong stratification coupled with a modest phytoplankton bloom in the late fall maintained very low DIN:PO_4 (< 4:1) ratios in surface waters from July through the end of October. It was not until the last two surveys of the year when stratification had weakened enough that DIN was no longer limiting in nearfield surface waters. However, even during this time the DIN:PO_4 ratio remained below Redfield values throughout the nearfield water column. Nearfield waters were also generally low in DIN as compared to SiO_4 (DIN:SiO_4 < 2:1) throughout the report period. However, SiO_4 values were highly variable in the nearfield and 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** 4-26). 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. The progression from summer to winter conditions was interrupted in late October and November as the water column remained slightly stratified and nutrients were utilized during the late fall bloom. This was coincident with phytoplankton biomass (chlorophyll and POC) and productivity. The dynamics associated with destratification and nutrient availability in fall 2003 relative to the late, weak fall bloom (production and phytoplankton abundance) will be examined in more detail in the 2003 annual report.

4.2.2 Chlorophyll A

Chlorophyll concentrations (based on *in situ* fluorescence measurements) were high in early July then dropped to fairly low levels until the onset of the fall bloom in early October. This low-level bloom was short lived and fluorescence values dropped off again by mid November. Fluorescence values were coupled to diatom abundance throughout the fall bloom period.

4.2.2.1 Horizontal Distribution

In early July, surface chlorophyll concentrations were highly variable throughout the nearfield area. Surface concentrations were low (<3 μgL^{-1}) in most areas, but isolated areas of somewhat elevated fluorescence were also found. This variability was even more pronounced at the mid-depth chlorophyll maxima. At mid-depth, areas of low (<3 μgL^{-1}) fluorescence were still observed, but many areas were fairly high (>7 μgL^{-1}) and reached a maximum of 17.2 μgL^{-1} at N07. By late July, chlorophyll concentrations had decreased considerably and surface values were <1 μgL^{-1}, except in the southwest were concentrations ranged from 1.5 to 3.8 μgL^{-1}. The mid-depth range had decreased to 1.2 - 8.1 μgL^{-1} with most areas less than 5 μgL^{-1}. Nearfield fluorescence continued to decline into early August. During WN03A surface concentrations were ≤1 μgL^{-1}, and the mid-depth range was 0.65 – 5.9 μgL^{-1} with most areas <3 μgL^{-1}. In general the SeaWiFS satellite imagery corresponds well with these measurements, although an area of elevated fluorescence (>10 mg m^{-3}) appears in the SeaWiFS image for July 27 which may have been missed between the late July (7/21/03) and early August (8/4/03) surveys (Appendix D).

During the August farfield survey, chlorophyll was low throughout the entire farfield over all depths (**Table** 3-4). Surface values ranged from 0.26 to 3.7 μgL^{-1} with readings greater than 1 μgL^{-1} found only in and near Boston Harbor. Mid-depth values were also low during this farfield survey ranging only from 1.6 to 6.0 μgL^{-1}. The highest concentrations (>3 μgL^{-1}) were found at western nearfield and coastal stations. These low fluorescence values correspond very well with phytoplankton abundance, productivity, and SeaWiFS images during this time (see Section 5 and Appendix D). Phytoplankton abundance was generally low (<2 million cells L^{-1}) and dominated by microflagellates throughout the area with a moderate increase only at the surface of station F30 (3.7 million cells L^{-1}) which was consistent with peak surface fluorescence values found at this station. The elevated phytoplankton abundance in the harbor was due to an increase in the centric diatom *Skeletonema costatum*. The SeaWiFS image from August 18th showed very low surface values throughout the region (Appendix D).

Nearfield fluorescence remained low but began to increase throughout September. During the first September survey chlorophyll values were very low (<1 μgL^{-1}) at the surface and <3 μgL^{-1} at mid-depth. While fluorescence remained fairly low later in September, some higher values were seen at the edges of the nearfield suggesting that fluorescence was starting to increase in the region. Surface values ranged from 0.56 – 4.8 μgL^{-1} with the most elevated concentrations found in the western portion of the nearfield (maximum at N01). Mid-depth fluorescence followed the same trend with a range of 1.3 to 5.1 μgL^{-1} and maximum values along the western edge of the nearfield (maximum at N10). This increase and heterogeneity in the fluorescence values corresponds well with phytoplankton abundance and SeaWiFS images and suggests that a moderate fall bloom was just beginning during this period. Phytoplankton abundance had increased in both the surface and mid-depth waters at stations N04 and N18. In addition to this increase in overall abundance, there was a shift in species community structure with diatoms representing an increasing portion of the total. Phytoplankton sampling during this nearfield survey likely failed to capture the full extent of the emerging bloom as only samples from the central (N18) and eastern (N04) nearfield are enumerated. The fluorescence readings suggest that greater phytoplankton abundance may have been present in the western nearfield. Phytoplankton abundance, community structure, and bloom dynamics are discussed in greater detail in Section 5. No SeaWiFS image is available for the day of the survey (9/25/03) but images from before (9/20/03) and after (10/2/03) the survey clearly show increasing fluorescence inshore during this time (Appendix D).

By the October farfield survey, fluorescence had increased considerably in many parts of the survey area. The highest fluorescence concentrations were found along northern Massachusetts Bay from the harbor out to Cape Ann (**Figure** 4-27). Surface values reached a maximum of 10.8 μgL^{-1} at station F25 just outside the harbor. Elevated surface fluorescence extended into the western nearfield (nearfield maximum = 8.2 μgL^{-1} at N10) and to the northeast where 7.5 μgL^{-1} was recorded in the surface waters at station F26 off Cape Ann. Fluorescence dropped off dramatically to the south and east. Southern coastal, offshore, and boundary stations, as well as Cape Cod Bay stations were generally <1 μgL^{-1}, except for a minor peak off of Plymouth (station F03 = 2.5 μgL^{-1}). Fluorescence also dropped off considerably in the harbor. While maximum values were found just outside the harbor, the three harbor stations ranged only from 1.8 to 3.5 μgL^{-1} with the lowest reading found at inner harbor station F30. Sub-surface chlorophyll fluorescence followed similar patterns although at slightly higher concentrations. Northern stations, including portions of the nearfield, had the highest fluorescence while southern and harbor stations were substantially lower. The area of high fluorescence extended from just outside the harbor (9.5 μgL^{-1} at F25), through the western nearfield (survey maximum of 16.1 μgL^{-1}at N13), and up to the northern boundary (13.5 μgL^{-1}at F26). As in the surface waters, mid-depth fluorescence dropped of dramatically to the south with stations along the Cohasset transect and to the south generally between 1.5 and 3.5 μgL^{-1}.

The SeaWiFS image from October 8th clearly shows similar values and trends as those measured during survey WF03E (**Figure** 4-28). This increase in fluorescence was coincident with a shift in phytoplankton community structure as opposed to an increase in total phytoplankton abundance. Total abundance remained below 2.5 million cells L^{-1} in most areas, with only two mid-depth samples exceeding this level (F24 = 2.9 million cells L^{-1}, F22 = 3.6 million cells L^{-1}). However, diatoms represented approximately 35% of the total phytoplankton population during this survey while they had represented <5% in August. Phytoplankton abundance and community structure is discussed further in Section 5.3.

During the late October nearfield survey, fluorescence values were similar to those seen in the nearfield earlier in the month with a surface range of 0.62 – 8.2 μgL^{-1} and a mid-depth range of 3.4 – 16.1 μgL^{-1}. However, the distribution of these values had changed somewhat from the previous survey. The highest fluorescence values now tended to be located towards the southeast corner of the nearfield whereas they had previously been found in the western portions. This corresponds well to production and phytoplankton abundance during the survey. Production values increased at both nearfield stations and reached the fall bloom peak value of 2,500 mg C m^{-2} d^{-1} at station N18. Phytoplankton abundance at stations N04 and N18 was increased and diatoms were reaching peak contribution to the phytoplankton assemblage during this time. For example, the highest nearfield phytoplankton abundance (3.04 million cells L^{-1}) for this report period was observed in the mid-depth at station N18 during this survey and diatoms made up nearly 75% of the total community. The SeaWiFS image agrees well with the recorded fluorescence values, but shows generally low fluorescence throughout the rest of the larger region.

By mid November, fluorescence had declined from the previous surveys. Surface values ranged from 0.76 to 6.4 μgL^{-1} and the mid-depth values ranged from 3.3 to 8.0 μgL^{-1}. Overall phytoplankton abundance in the nearfield was similar to levels found during the previous survey. However, there was shift in phytoplankton distribution. Abundance had increased at the outside edge of the nearfield (N04) and decreased near the center (N18). This was consistent with the changes in production at these two stations as productivity reached a seasonal maximum of 1,700 mg C m^{-2} d^{-1} at station N04 and had decreased by more that 50% at station N18 (1,100 mg C m^{-2} d^{-1}). The SeaWiFS image corresponds well with the nearfield chlorophyll values, and also shows increased fluorescence along the south coast and into Cape Cod Bay suggesting elevated bloom concentrations that were not captured in the nearfield sampling.

By the last survey of the year in mid December, fluorescence was very low throughout the nearfield. Surface and mid-depth values did not exceed 2 μgL^{-1}. Production and phytoplankton abundance had also dropped down to some of the lowest levels of the year. The SeaWiFS image corroborates these low values, showing elevated surface fluorescence only in Cape Cod Bay. While no further surveys were conducted in 2003, the SeaWiFS images from the rest of the year describe a bloom developing in Cape Cod Bay and expanding into more northern portions of the area by very late in the year (Appendix D).

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. However, the magnitude of concentrations over these transects was low with peak concentrations <5 μgL^{-1}. By October, chlorophyll concentrations had increased substantially throughout the area. Patches of elevated chlorophyll (>9 μgL^{-1}) existed at the northern Boundary station F26, at some northern offshore stations, and at several nearfield stations. These patches were broad layers of elevated chlorophyll extending from near the surface down to ~15m. Chlorophyll concentrations and distribution in October were coincident with phytoplankton abundance patterns. As discussed above, it appears that this increase in fluorescence occurred during a shift in phytoplankton community structure towards the diatom dominated assemblage of the fall bloom.

Nearfield. Trends in the nearfield chlorophyll concentrations are summarized in **Figure** 4-29. 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 nearfield mean for the mid-depth chlorophyll concentrations was higher than the surface and bottom mean values throughout the entire report period. Fairly high mid-depth fluorescence was found early in the report period. As discussed above this was not a homogeneous distribution of fluorescence, but rather a very patchy distribution with both low values (1 μgL^{-1}) and very high values (17 μgL^{-1}). Surface fluorescence was generally low during this time (average = 2.1 μgL^{-1}), although it would continue to diminish even further as the summer progressed.

Although there was some variation, fluorescence in the nearfield declined throughout the summer and into mid September (WN03C). By this survey, mid-depth values averaged <2 μgL^{-1} and surface waters were extremely low at an average of <0.4 μgL^{-1}. As phytoplankton abundance began to increase in late September, and community structure began to favor diatoms, fluorescence increased in both surface and mid-depth waters. By the early October survey, mid-depth concentrations had reached a maximum for the report period at an average of 9.6 μgL^{-1}. Surface water values were also increasing during this period reaching a maximum for the period of 3.7 μgL^{-1} by the late October survey. These fluorescence trends were consistent with the distribution patterns of phytoplankton and productivity measurements in the nearfield. As the fall progressed phytoplankton abundance decreased and community structure again shifted away from a strong diatom presence. This was coupled with a general decrease in nearfield fluorescence. By mid-December, mid-depth values had dropped to a low for the report period of 1.5 μgL^{-1}. Surface values had also declined considerably and were <1 μgL^{-1} by this time. While fluorescence as a whole was declining through the late fall and into winter, bottom fluorescence had increased somewhat. As the moderate bloom settled through the water column and weakening stratification allowed for greater mixing, fluorescence in the bottom waters climbed to a high of 1.5 μgL^{-1} in late October and stayed slightly elevated (~1 μgL^{-1}) through mid December.

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** 1-3). 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 early July patchy fluorescence was seen in the nearfield. From late July to mid September, chlorophyll concentrations were generally low in the nearfield waters although a slight increase was emerging along the pycnocline during the late September survey (**Figure** 4-30). By early October nearfield fluorescence had increased dramatically. The highest concentrations (>9 μgL^{-1}) were found along the weak pycnocline (~15m) in the center of the nearfield at N21. Towards the western side of the nearfield the broad band of elevated fluorescence reached from surface waters down to nearly 20m. In the eastern nearfield fluorescence was also elevated although peak concentrations reached only about 7μgL^{-1}. Here fluorescence was highest at the mid-depth, dropping of sharply below 15m to <1 μgL^{-1}.

In late October, concentrations were high in portions of the nearfield with a broad fluorescence band extending from the surface down to 20m or more (**Figure** 4-30). For the shallow western nearfield this meant elevated fluorescence extending to near the bottom. By mid-November fluorescence had diminished considerably throughout the nearfield water column. The broad band of elevated values seen on the previous survey was still present but concentrations were generally down to between 3 to 7 μgL^{-1}. While this drop in fluorescence was coincident with a decline in production and phytoplankton abundance at station N18, chlorophyll concentrations remained relatively stable at station N04 and production and phytoplankton abundance had actually increased from late October to November. By the last survey of the year, fluorescence was very low throughout the water column. Concentrations were <3 μgL^{-1} along the entire nearfield transect. This was coupled with a major decline in production and phytoplankton abundance.

The progression of chlorophyll concentrations in the nearfield from summer to fall in 2003 can be clearly seen through a series of contour plots of *in vitro* chlorophyll *a* samples over time at stations N10, N18, and N04 (**Figure** 4-31). These stations are representative of inshore (N10), center (N18), and offshore (N04) nearfield stations. The moderate bloom from late September through November is apparent at each station. This progression corresponds well with the SeaWiFS imagery from this period. The seasonal change in nearfield fluorescence can also be seen in the USGS mooring data (see **Figure** 3-2). The mooring fluorescence data (13 m depth) was elevated and variable during the moderate fall bloom from early October and into November with peak concentrations >20 μgL^{-1} measured in early November. The fluorescence signal at the mooring dropped off sharply as November progressed and had dropped to <1 μgL^{-1} by early December. [Note that the mooring fluorescence data for September to December is currently under review and may be revised by USGS.]

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 fairly typical for the time of year although the relatively late fall bloom may have kept bottom values slightly higher than other years, while surface DO values tended to decline throughout the report period.

4.2.3.1 Regional Trends of Dissolved Oxygen

In August, bottom water DO concentrations were relatively high throughout the bays, ranging from 6.9-8.9 mg L^{-1}. Concentrations were mostly homogeneous throughout the nearfield and most of the farfield at approximately 8.2 mg L^{-1}, only dropping below 7.5 mg L^{-1} in southeastern Cape Cod Bay (**Figure** 4-32). By October, bottom water DO concentrations had decreased by ~1 mg L^{-1} across all farfield regions. Values ranged from 5.8 to 8.2 mg L^{-1} but were generally homogeneous at about 7 mg L^{-1}, with only Cape Cod Bay station F02 dropping below 6 mg L^{-1} (**Figure** 4-33). Bottom water DO concentrations in the nearfield were lowest to the southwest (6.5 mg L^{-1} at N11) and highest in the northeast (7.2 mg L^{-1} at N04).

Percent saturation in the bottom waters followed the same general trends as DO concentration. In August, peak DO %saturation values were found in Boston Harbor (110% at F30) with values decreasing offshore down to a minimum of 70% in Cape Cod Bay at station F02. As with DO concentration, DO %saturation had decreased from August to October in all areas. The maximum DO %saturation in October was located at station F25 just outside the harbor (94.3%) and the minimum DO %saturation of 61.8% was again found in Cape Cod Bay at F02.

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** 4-34). Dissolved oxygen values in the nearfield surface waters were at a maximum (12.4 mgL^{-1} and 155%) during the first survey of the report period in early July. 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 2003 the late fall bloom produced only moderate levels of phytoplankton biomass resulting in little change in surface water DO levels. Surface DO values declined from July into the fall reaching a nearfield minimum in late September of 8.3 mgL^{-1}. While percent saturation continued to decline through November (with declining temperatures), surface DO values began to rebound somewhat as the moderate fall bloom emerged late in the season. By the end of the year, surface DO values were up to 9.7 mgL^{-1} and percent saturation values had leveled off at ~96%.

Relative to surface water, the bottom water DO in the nearfield was lower and declined throughout the report period until December when the water column was thoroughly mixed (**Figure** 4-34). The gradient in mean DO concentration between the surface and bottom waters ranged from ~0.75 to 2.3 mgL^{-1} over this time period (except December). In July, bottom water DO concentrations and %saturation were relatively high (~9 mgL^{-1} and 90%). The delay in destratification in fall 2003 led to a prolonged decline in DO values from July to November. Mean bottom water DO concentrations and %saturation in the nearfield reached minima of 6.5 mgL^{-1} and 69% in November. These minima were relatively high considering the extended period of decline. The minimum sample DO value for the report period of 5.67 mgL^{-1} was recorded during this survey. This was the only nearfield DO value <6 mgL^{-1} for the entire period. It was not until December, as stratification eventually broke down, that bottom and surface waters were well mixed and stable DO values were found throughout the water column (~9.5 mgL^{-1} and 95%).

4.3 Summary of Water Column Results

- Regionally, seasonal stratification persisted somewhat later into the year than is typical. Strong stratification was observed throughout the summer months, only beginning to weaken by mid October.
- Weak stratification persisted in the offshore areas through November. It was not until the last survey of the year that the water column was well mixed throughout the entire survey area.
- Nutrient concentrations followed typical trends in the fall of 2003 although the timing was somewhat delayed as stratification persisted late into the year. This typical trend is characterized by depleted concentrations in the surface waters during summer stratified conditions, increasing concentrations with the breakdown of stratification and increased mixing, and finally a return to typical winter levels.
- 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 elevated in early July then dropped to very low levels until the onset of the fall phytoplankton bloom in late September.
- Peak concentrations (early October) preceded peak production and phytoplankton abundance (late October and November) and declined rapidly at the end of the year as the bloom crashed.
- Mean nearfield bottom water DO concentrations in 2003 were moderate 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 in October fell just below the caution threshold (<80%) in both the nearfield and Stellwagen Basin. However the DO percent saturation in both of these areas was well above baseline background levels.

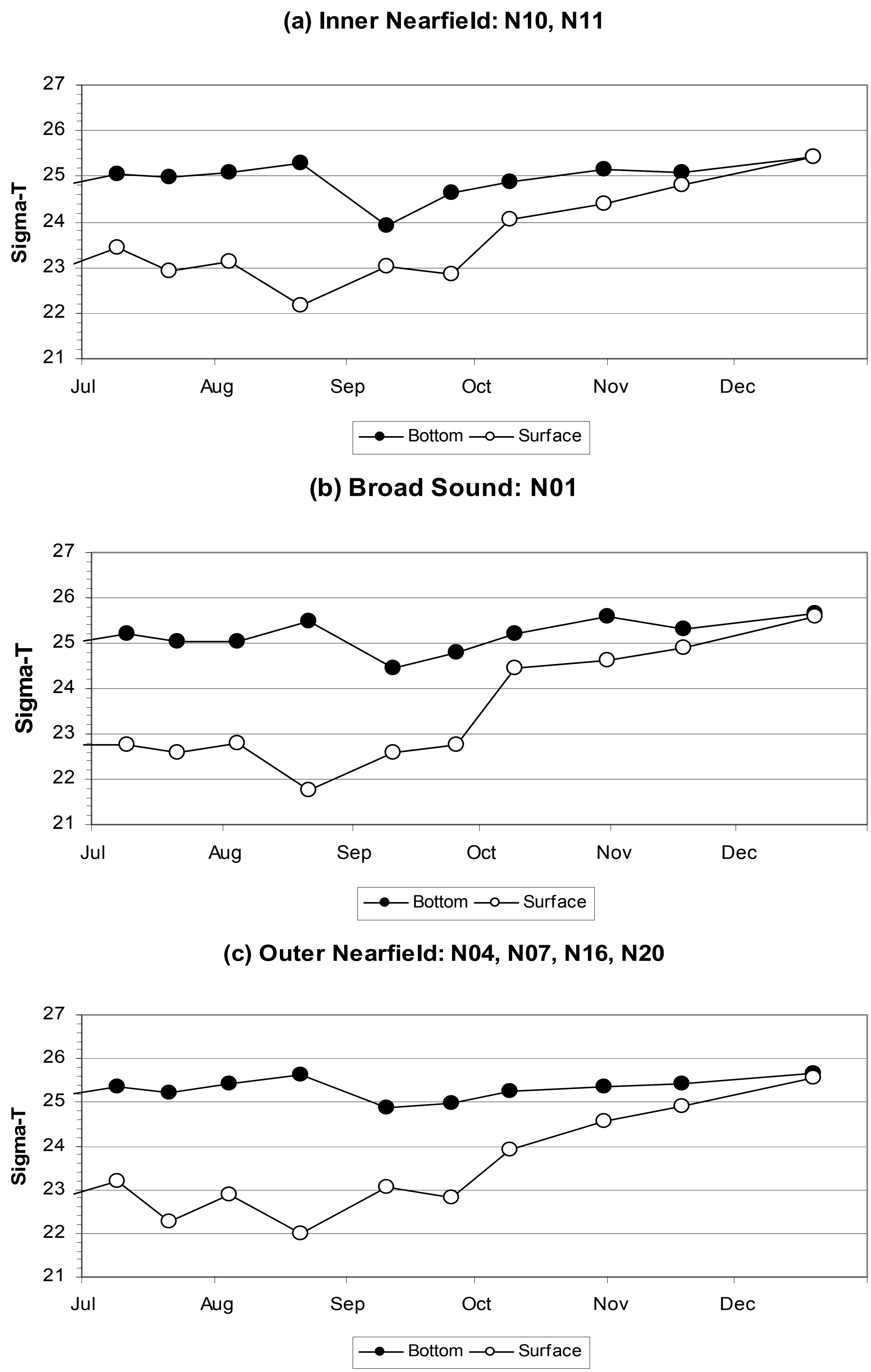


Figure 4-1. Time-series of average surface and bottom water density (σ_T) in the nearfield

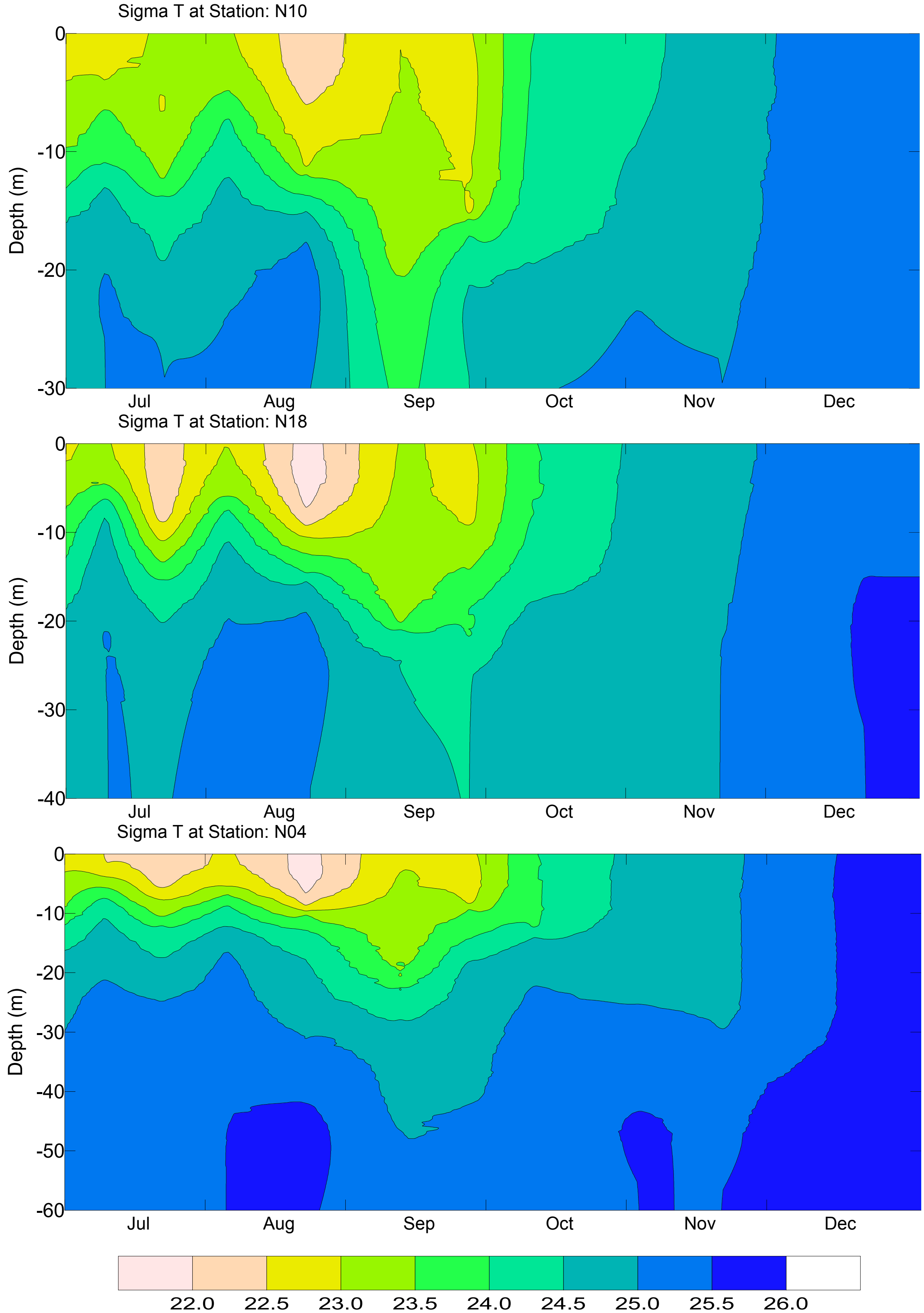


Figure 4-2. Sigma-*t* depth vs. time contour profiles for stations N10, N18, and N04

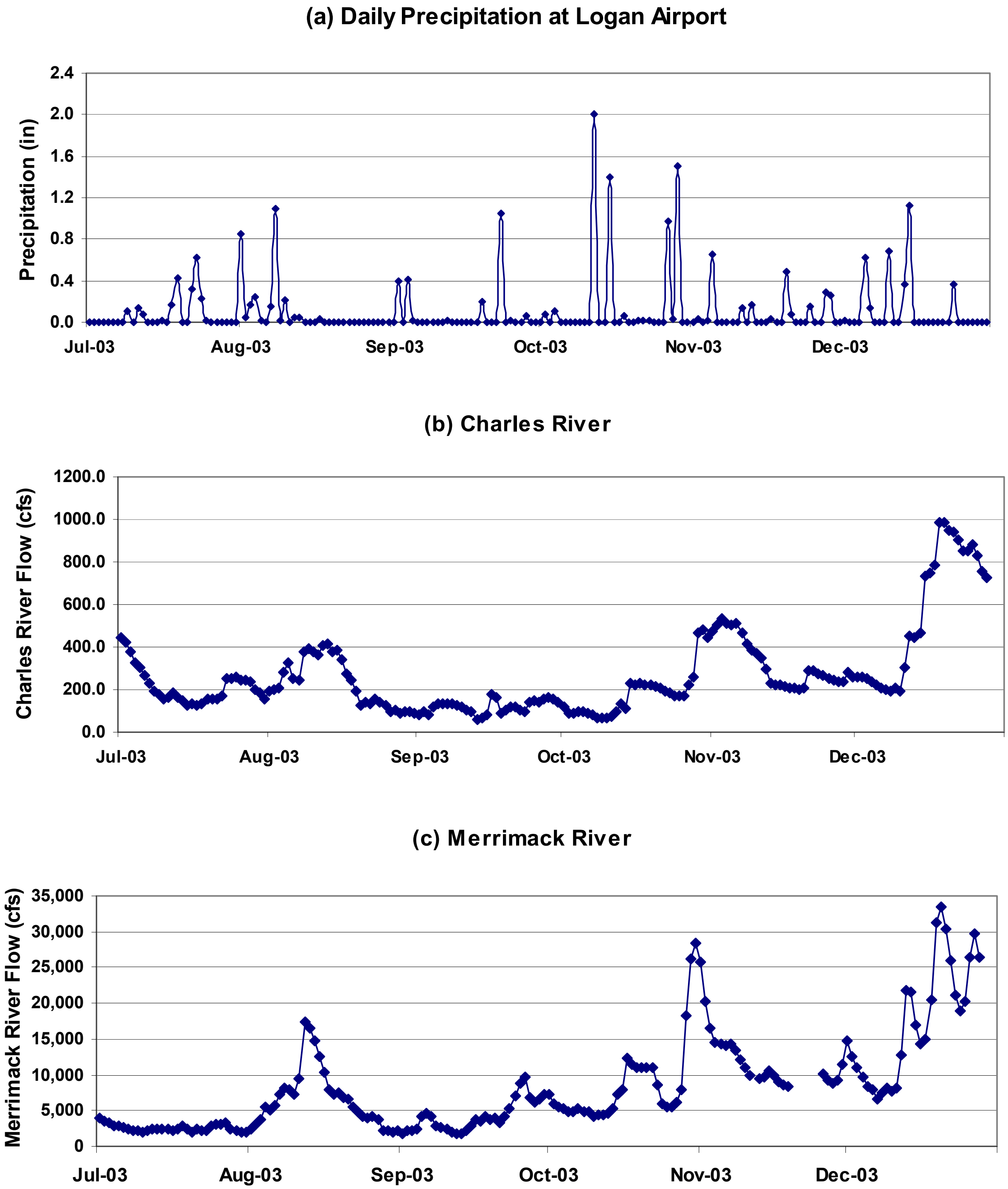


Figure 4-3. Precipitation at Logan Airport and river discharges for the Charles and Merrimack Rivers

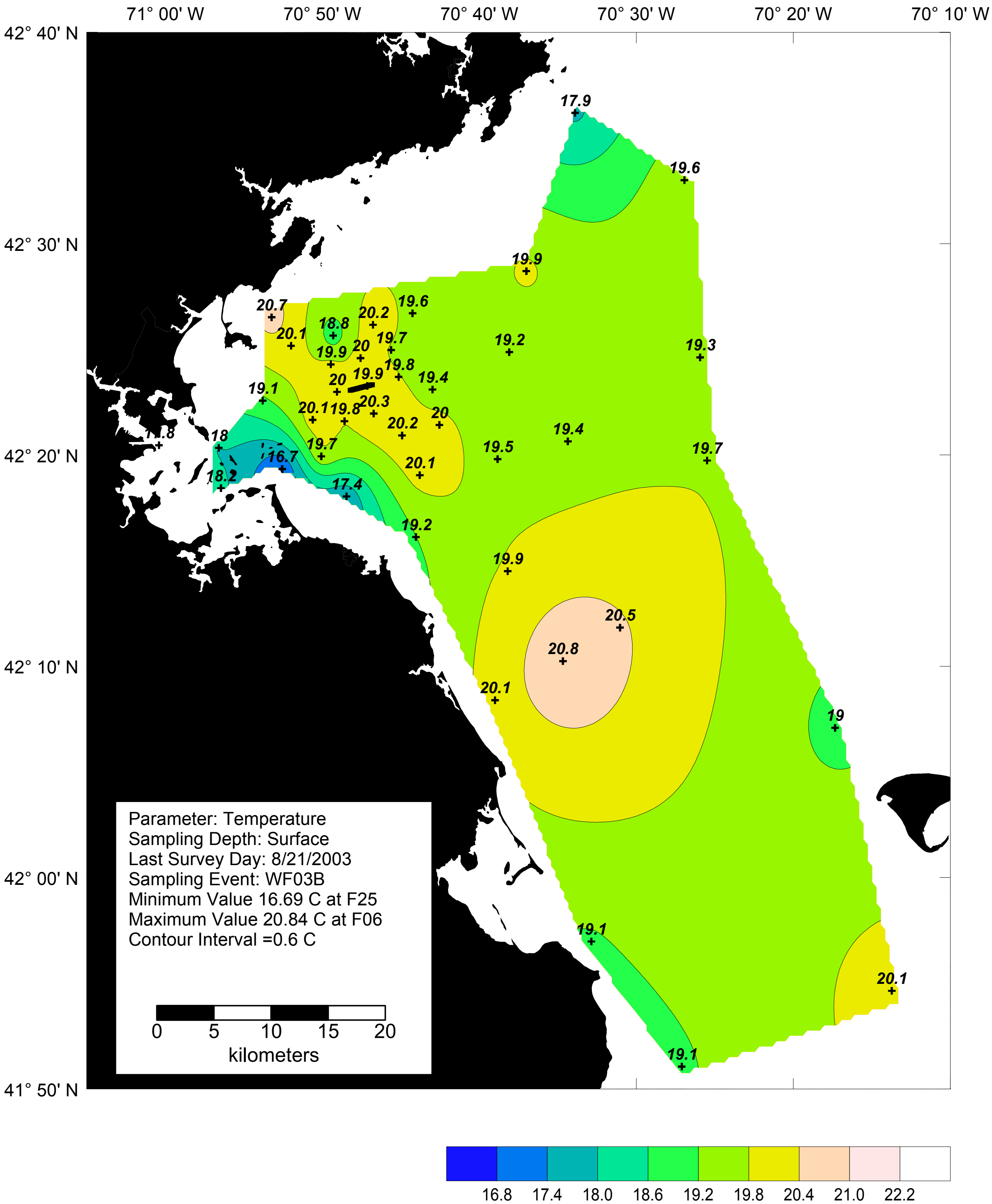


Figure 4-4. Temperature surface contour plot for farfield survey WF03B (Aug 03)

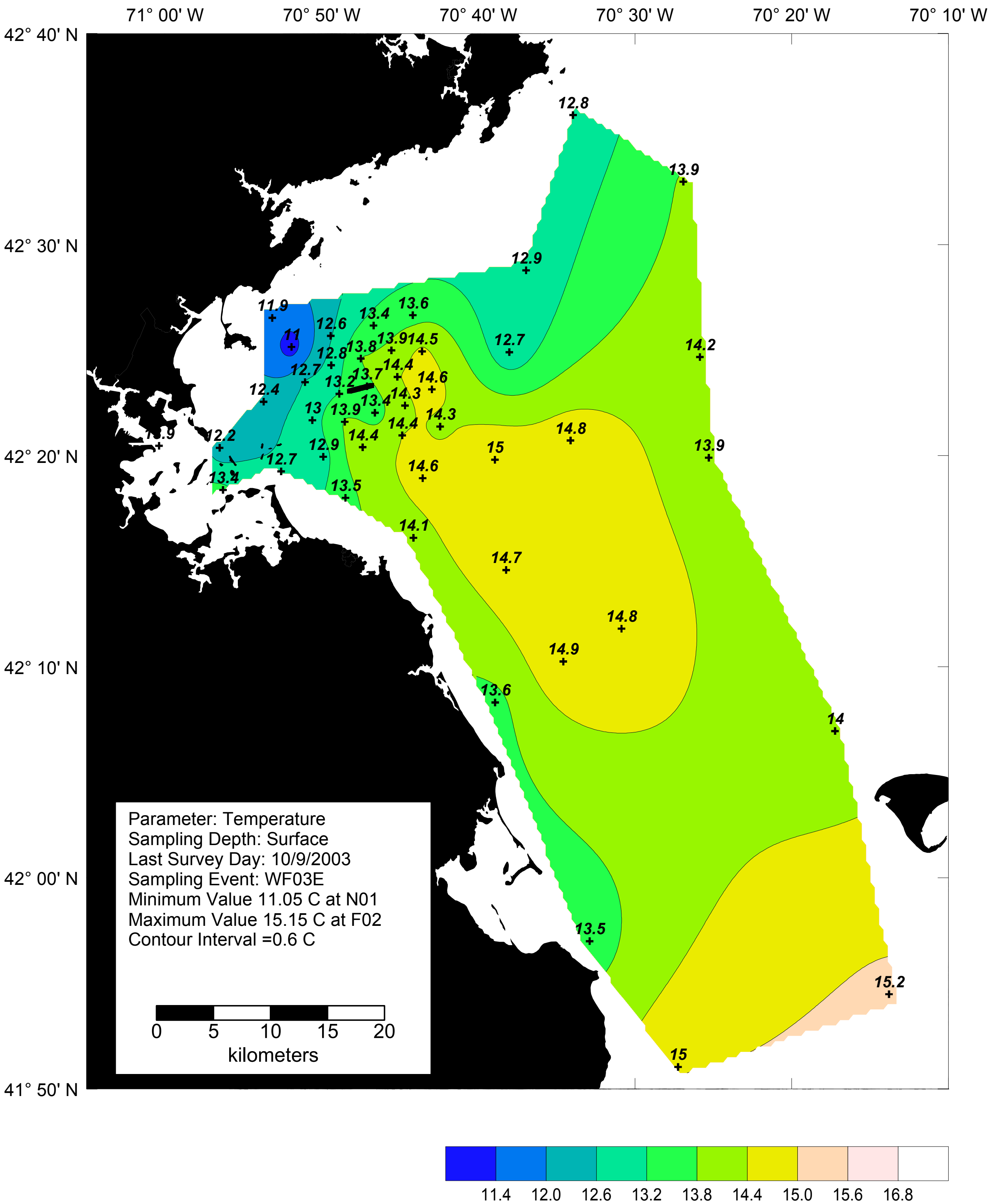


Figure 4-5. Temperature surface contour plot for farfield survey WF03E (Oct 03)

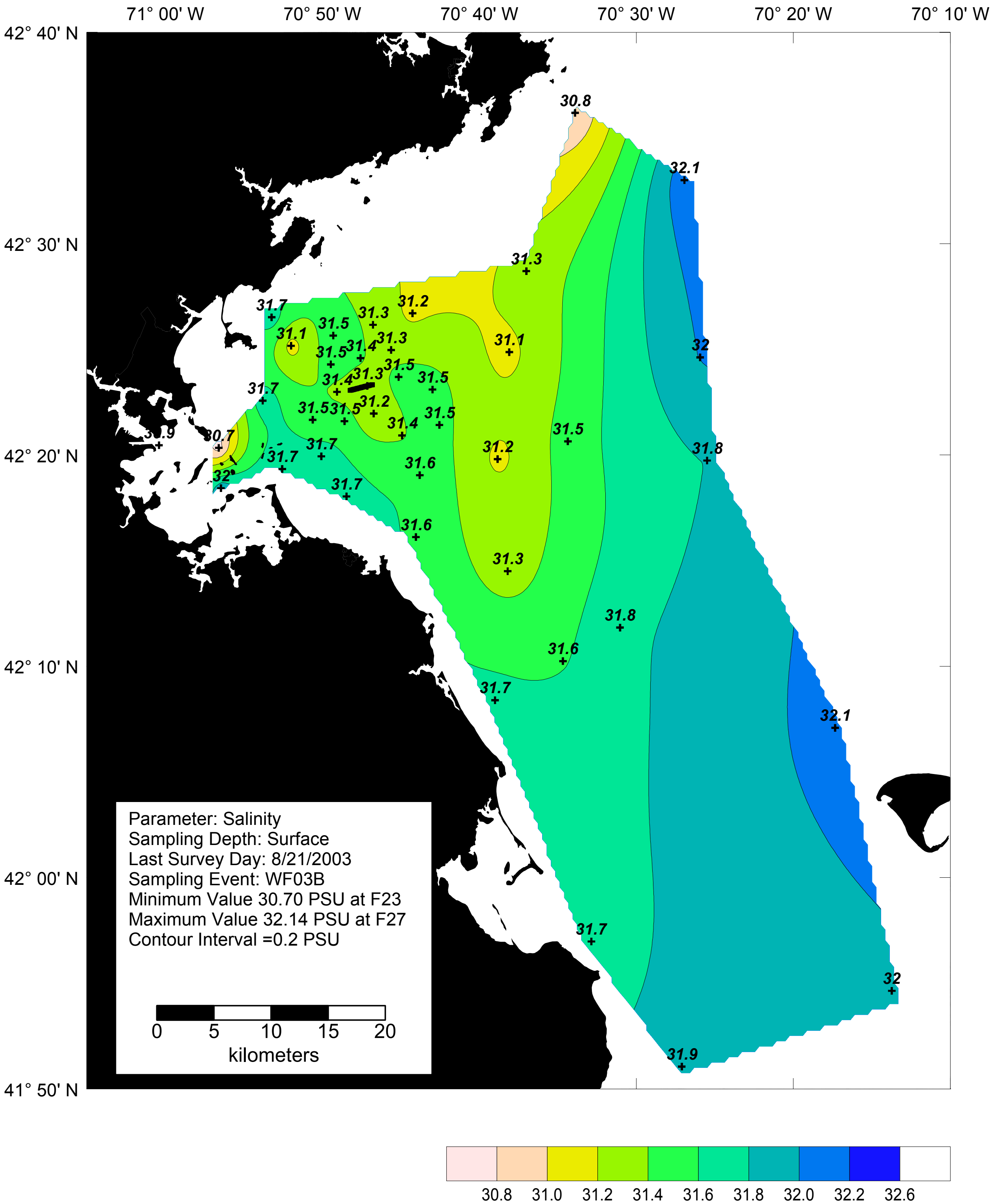


Figure 4-6. Salinity surface contour plot for farfield survey WF03B (Aug 03)

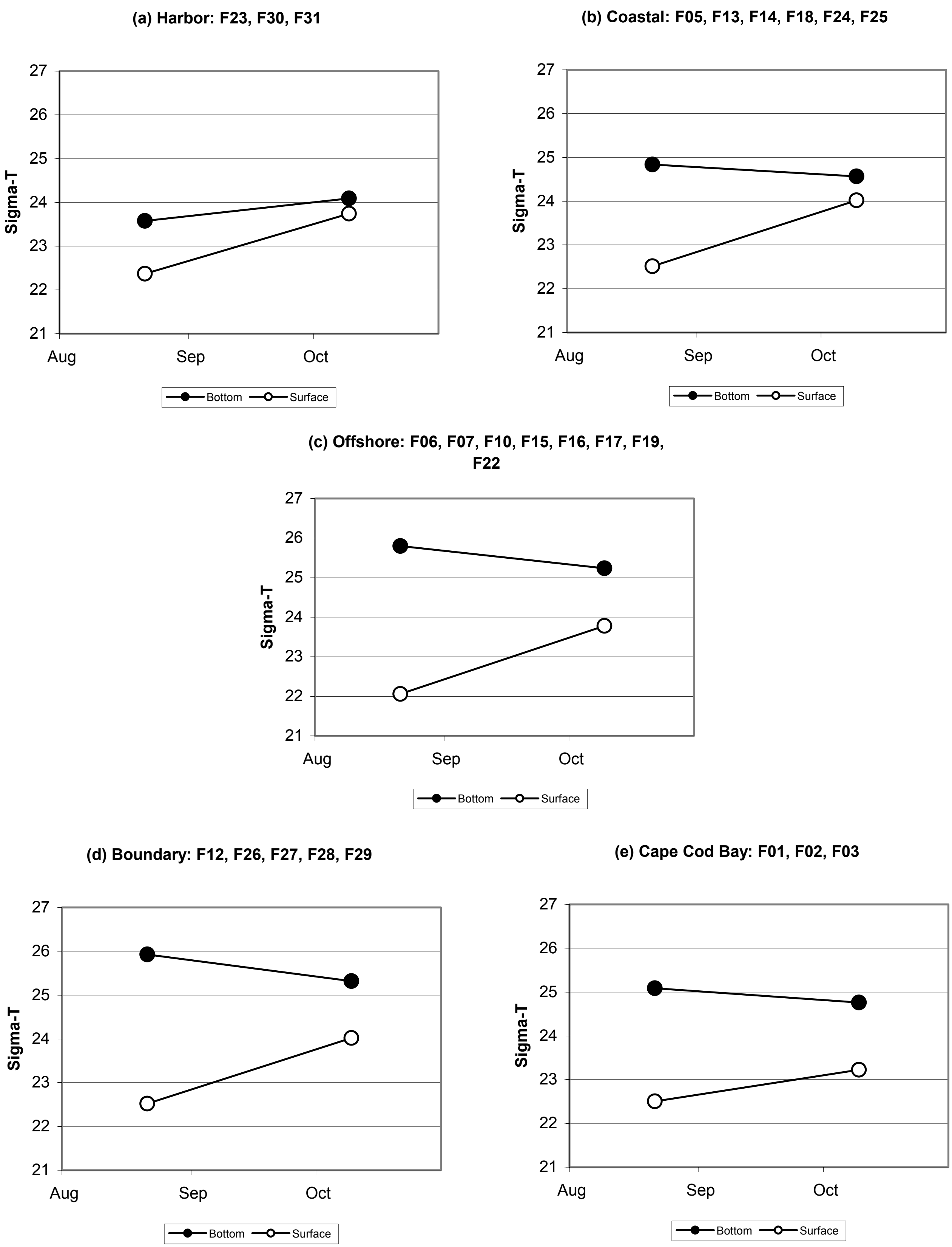
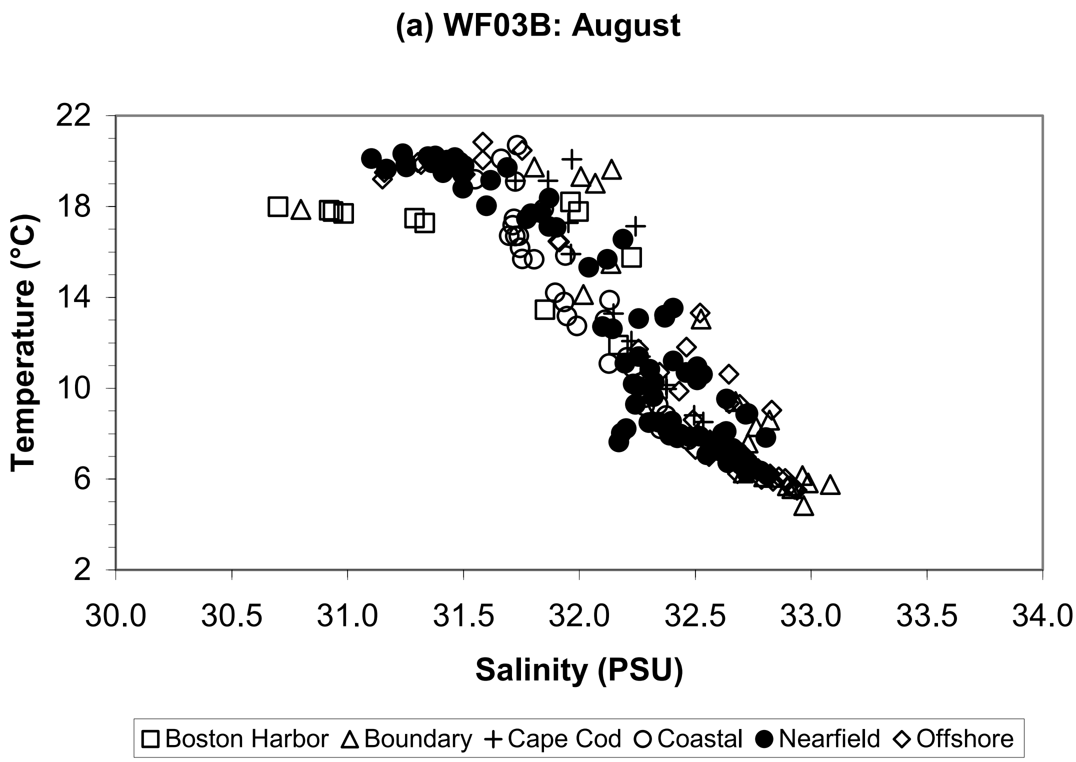


Figure 4-7. Time-series of average of surface and bottom water density (σ_T) in the farfield



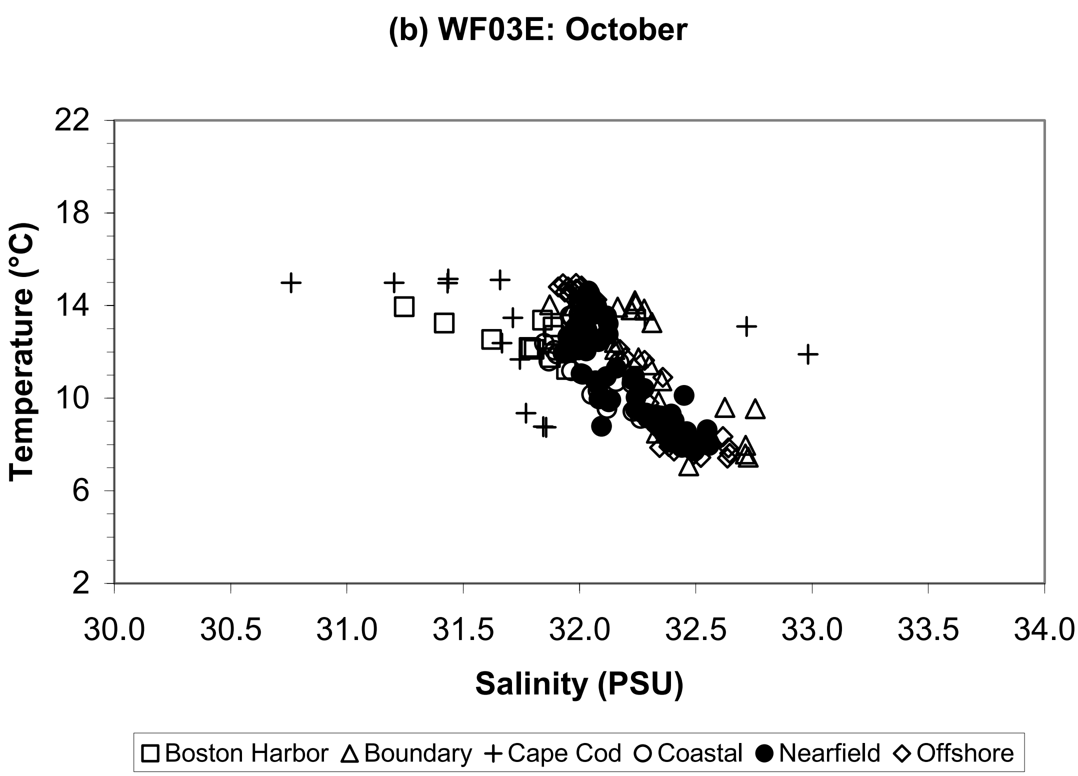


Figure 4-8. Temperature/salinity distribution for all depths during (a) August and (b) October

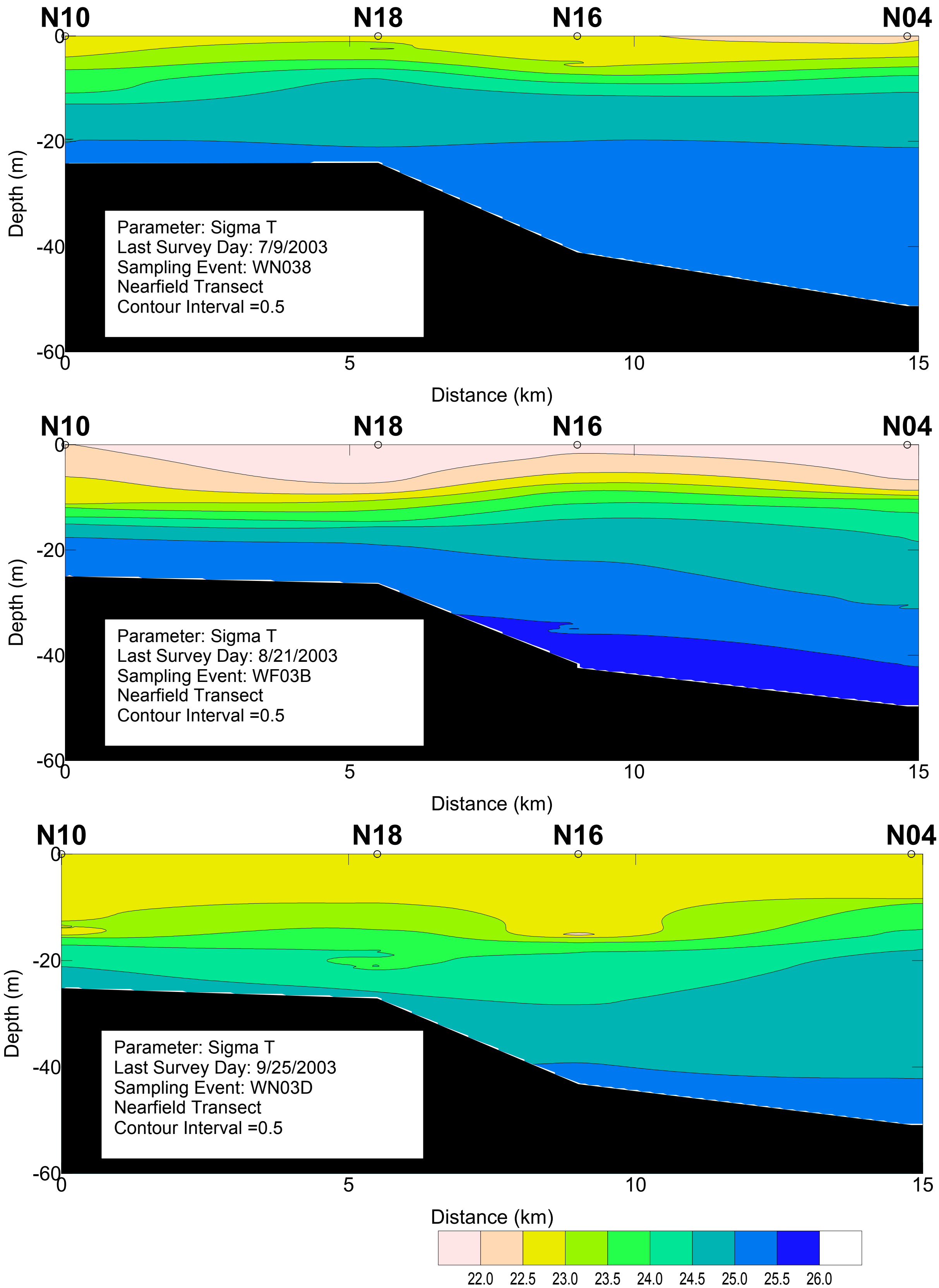


Figure 4-9. Sigma-*t* vertical nearfield transect for surveys WN038, WF03B, and WN03D

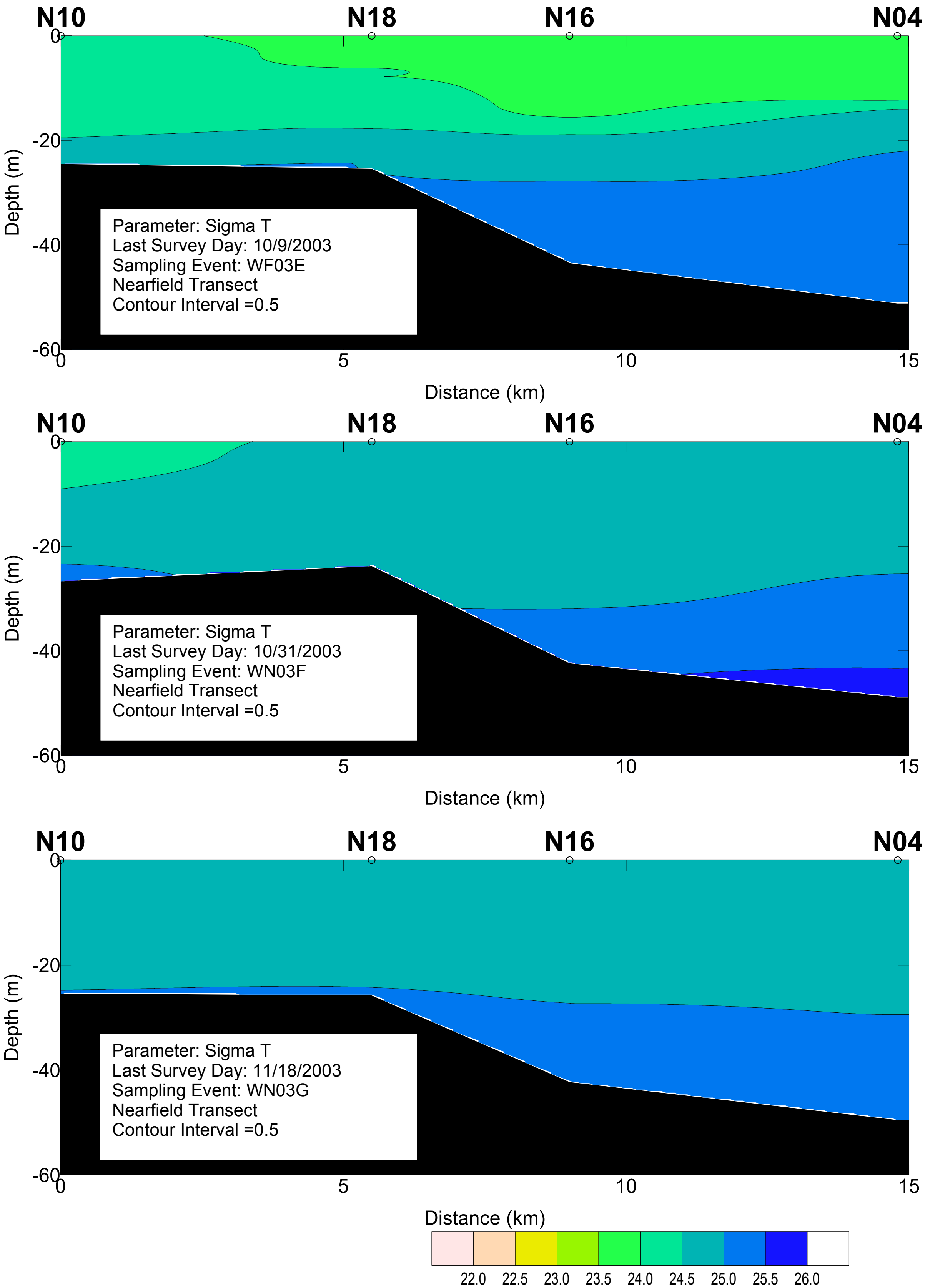


Figure 4-10. Sigma-*t* nearfield transect for survey WF03E, WN03F and WN03G

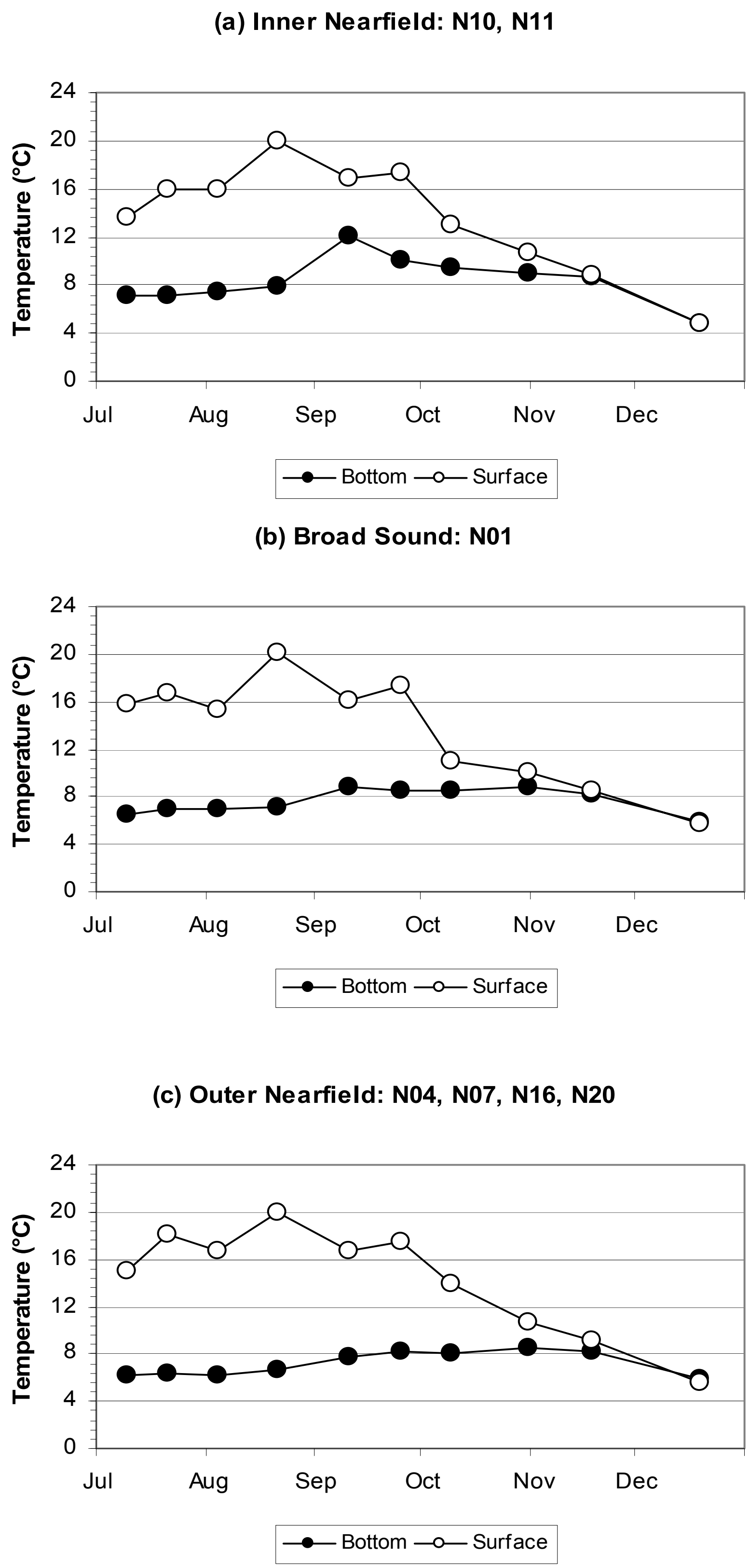


Figure 4-11. Time-series of average surface and bottom water temperature in the nearfield

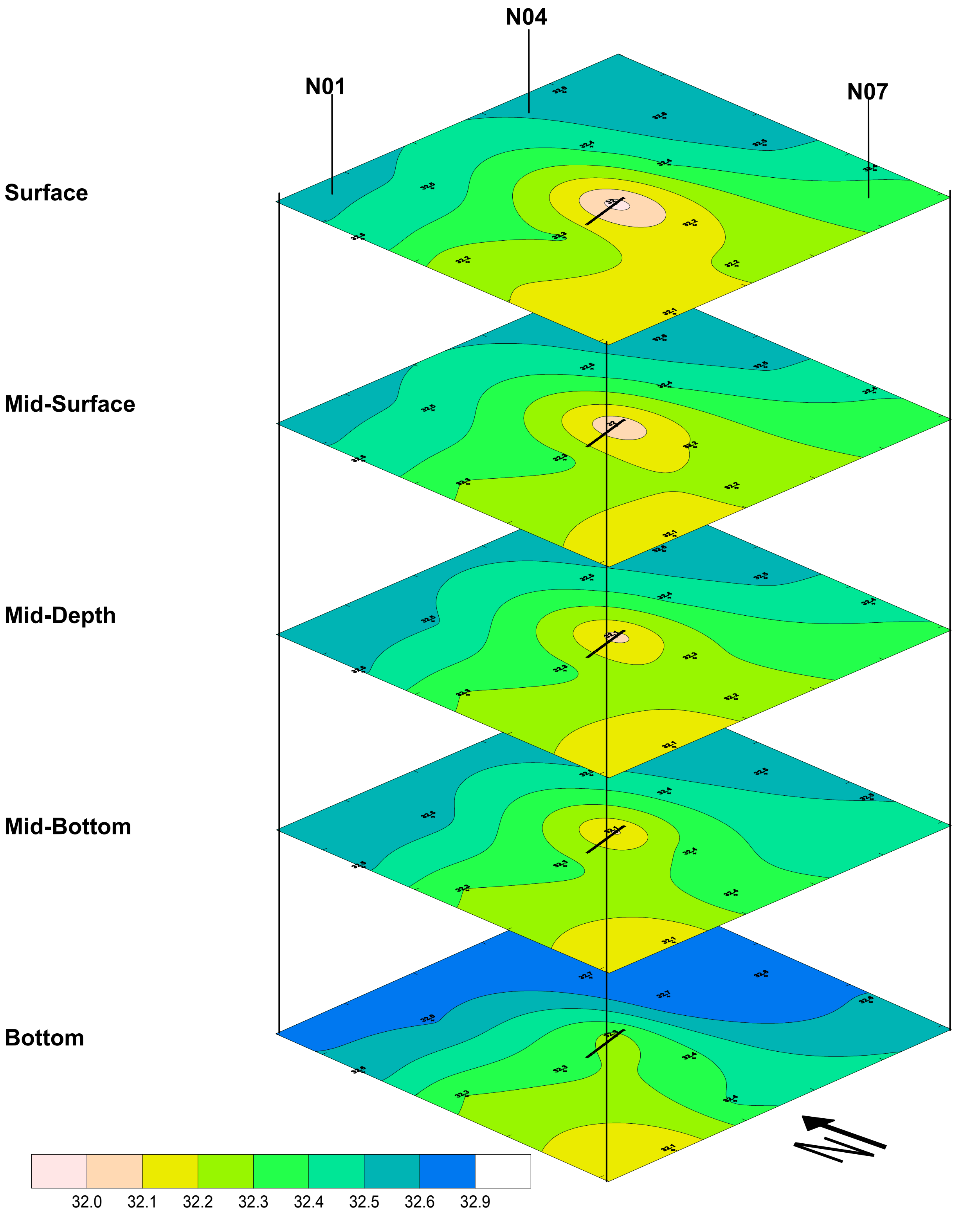


Figure 4-12. Salinity at each of the five sampling depths for the nearfield during WN03H (Dec 03)

[Note: displayed depths are a representation: actual sampling depths vary by station]

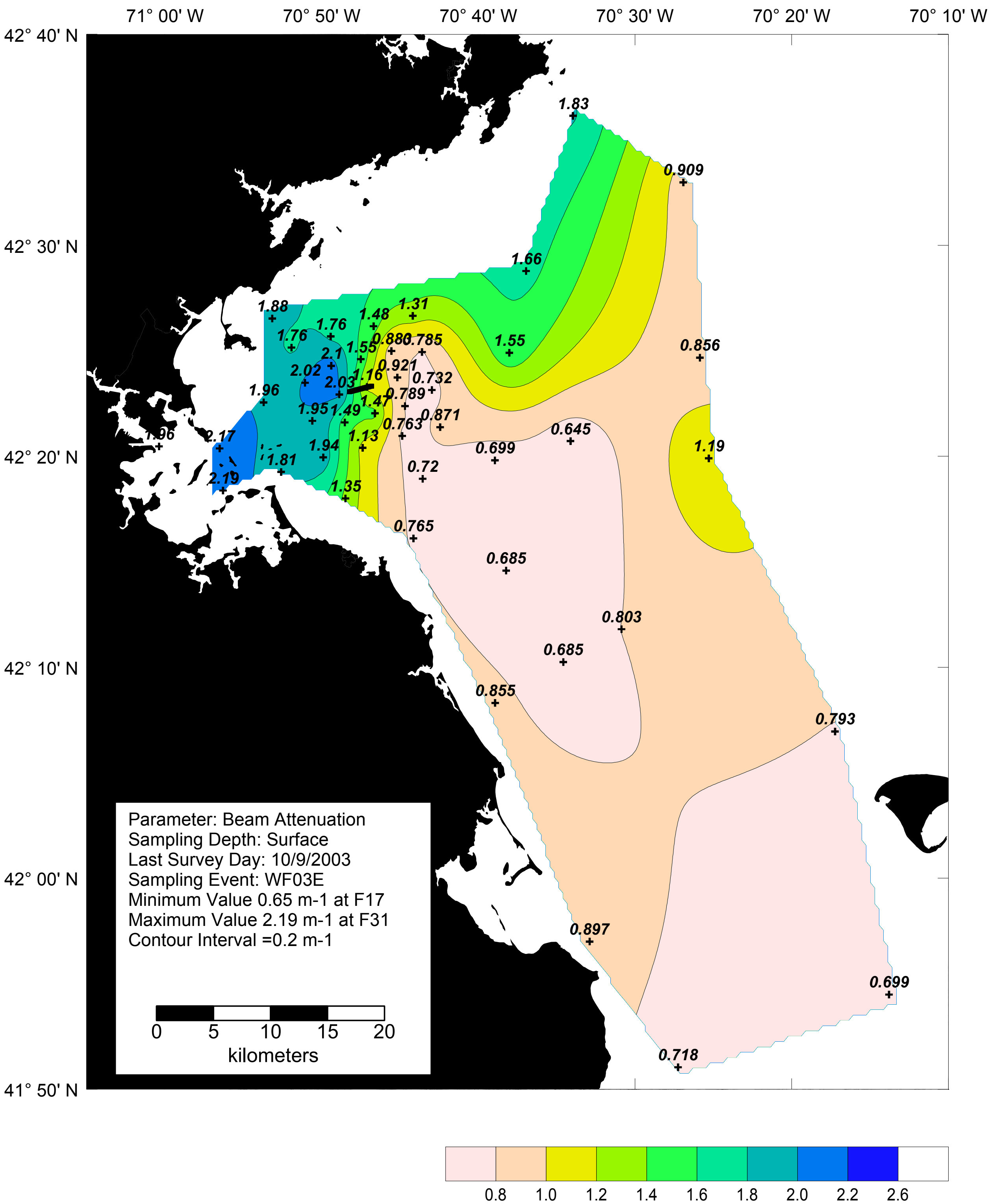


Figure 4-13. Beam attenuation surface contour plot for farfield survey WF03E (Oct 03)

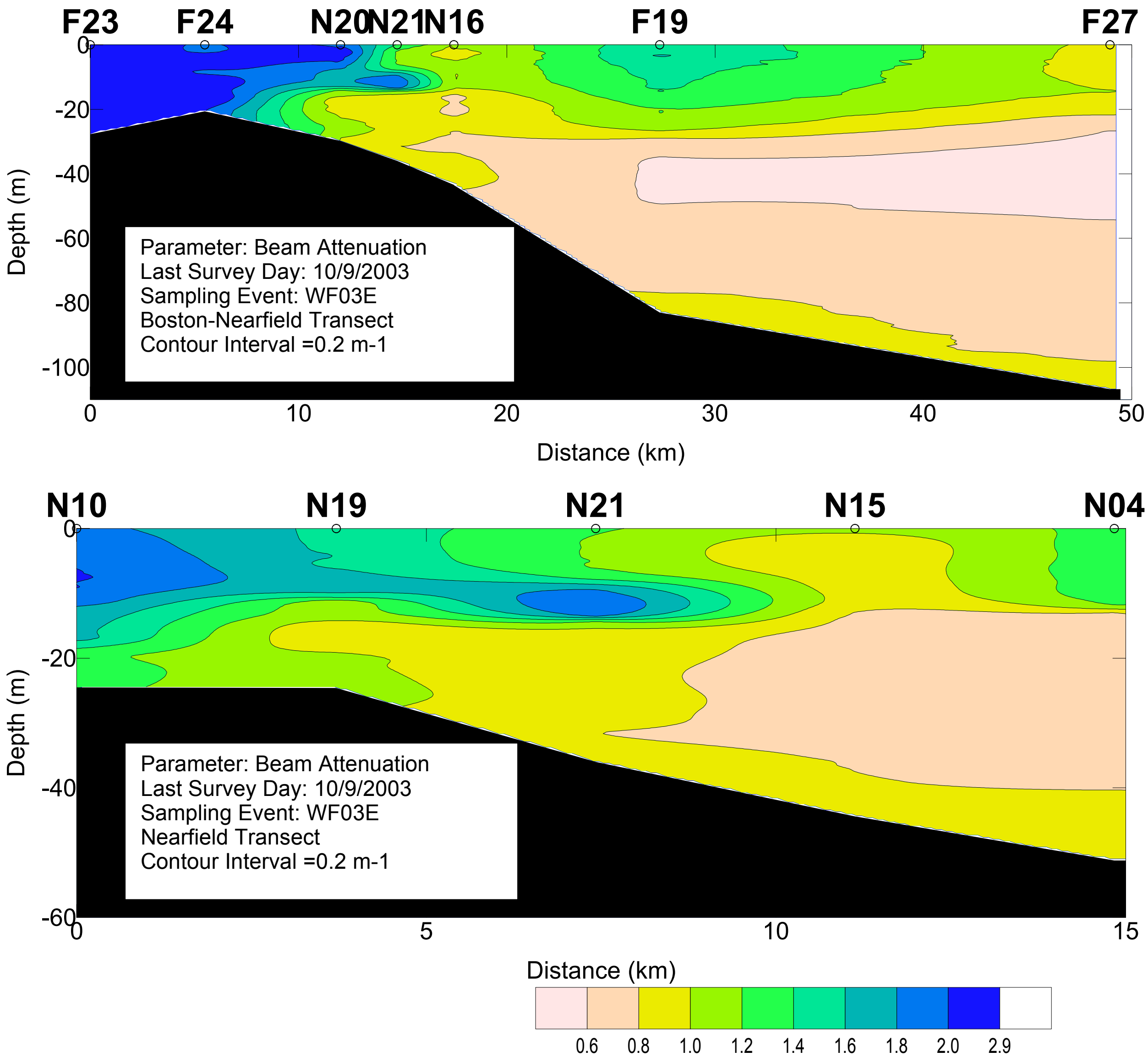


Figure 4-14. Beam attenuation vertical plots along (a) Boston-Nearfield and (b) Nearfield transects for survey WF03E (Oct 03)

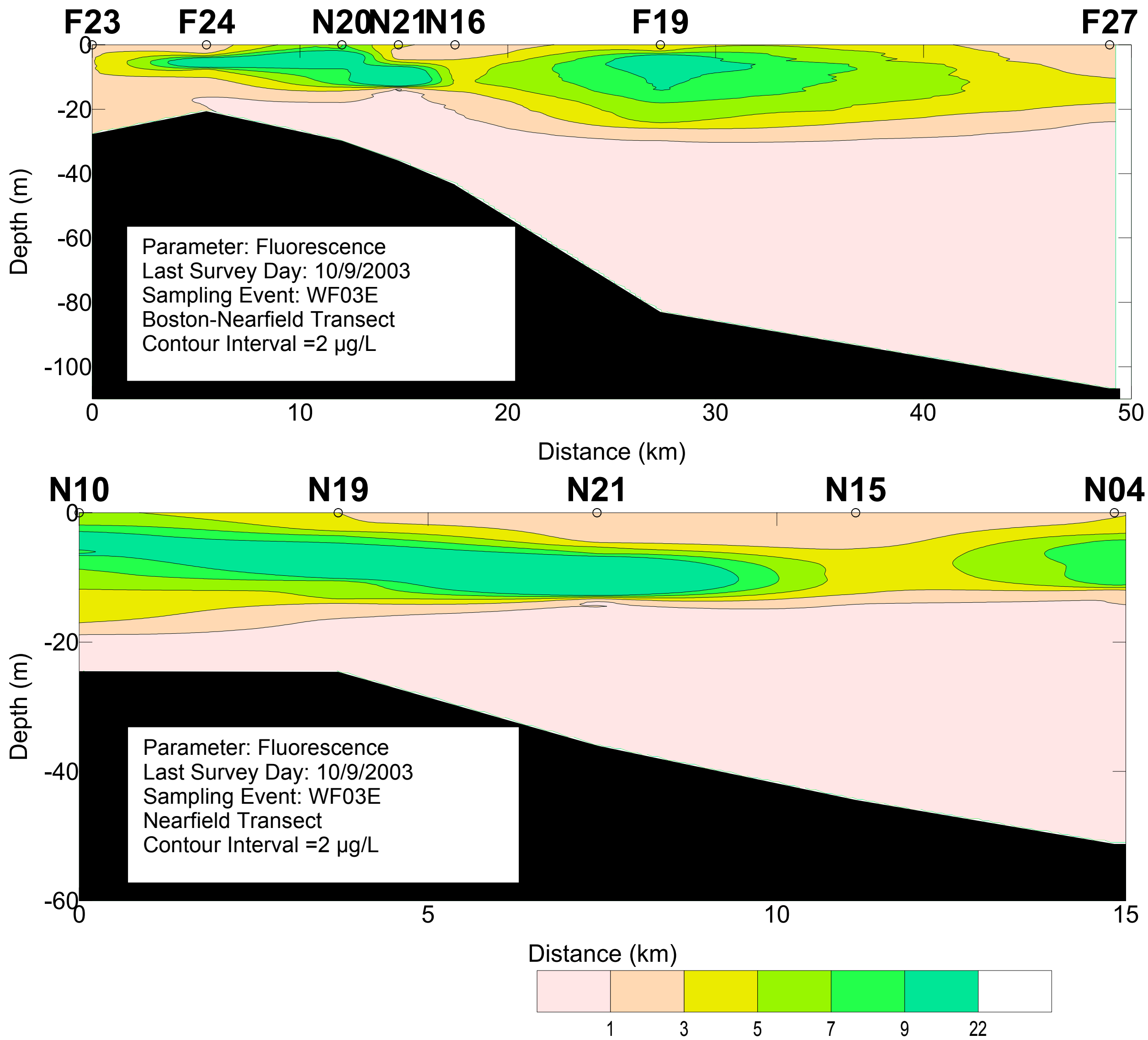


Figure 4-15 Fluorescence vertical plots along (a) Boston-Nearfield and (b) Nearfield transects for survey WF03E (Oct 03)

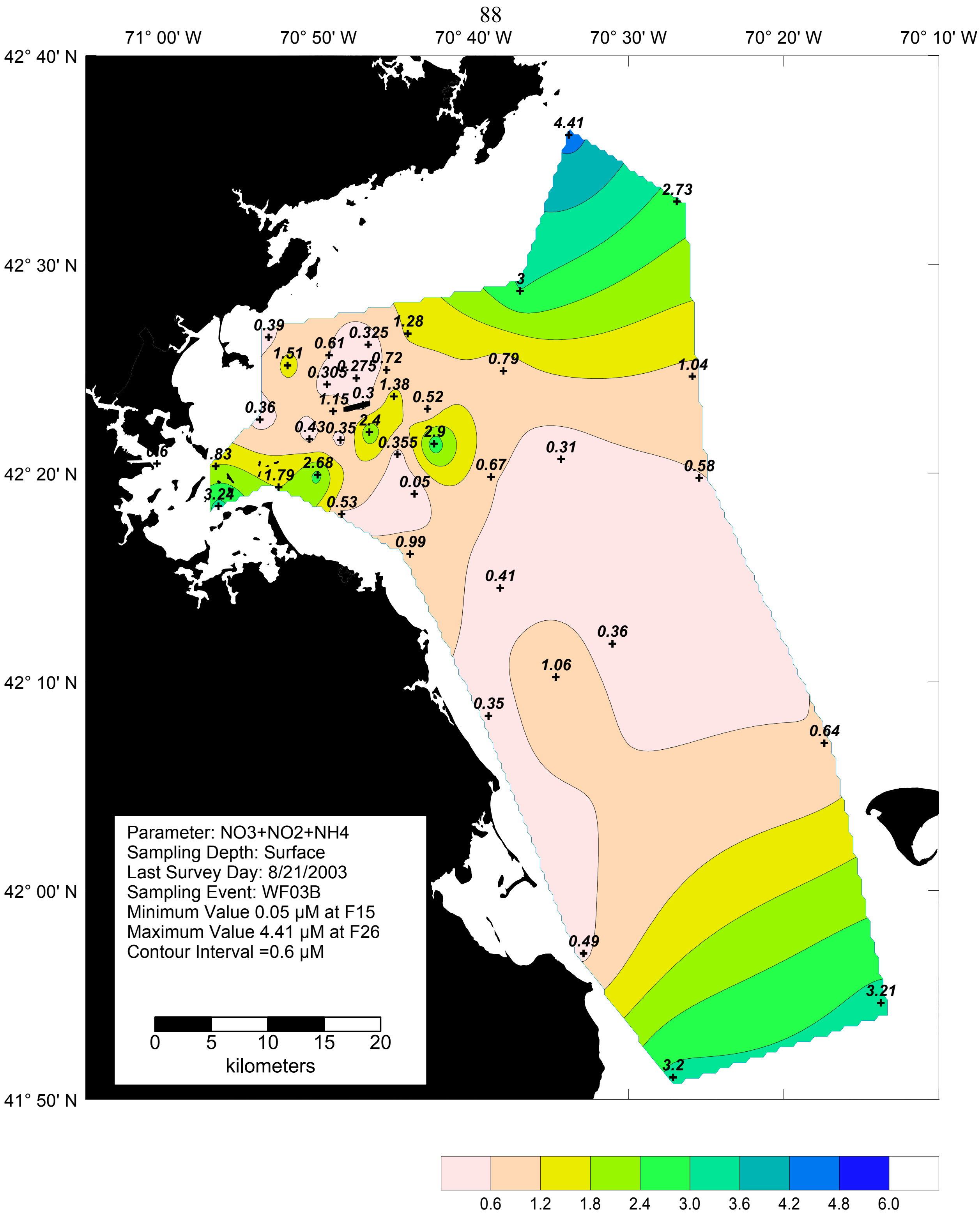


Figure 4-16. DIN surface contour plot for farfield survey WF03B (Aug 03)

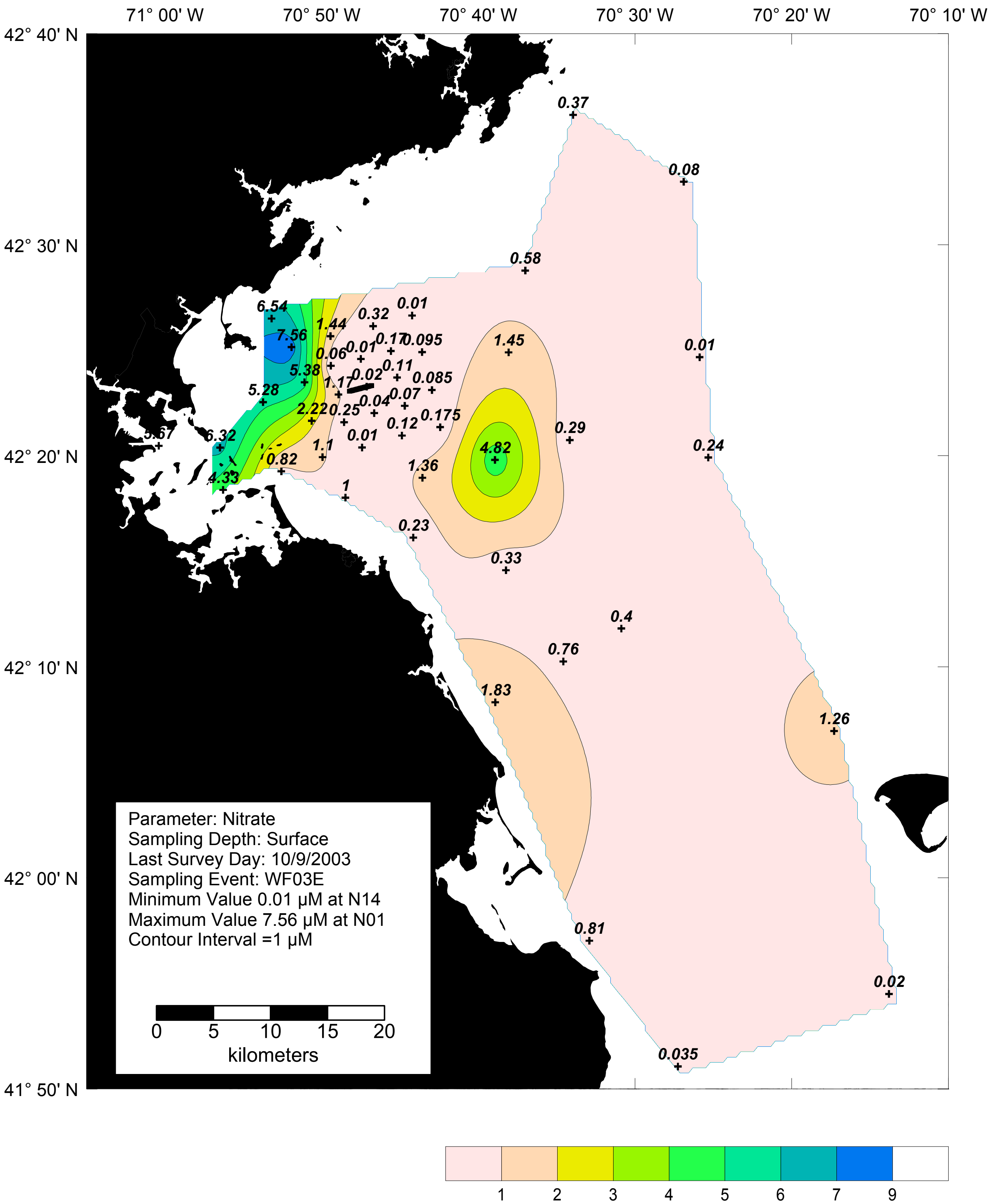


Figure 4-17. Nitrate surface contour plot for farfield survey WF03E (Oct 03)

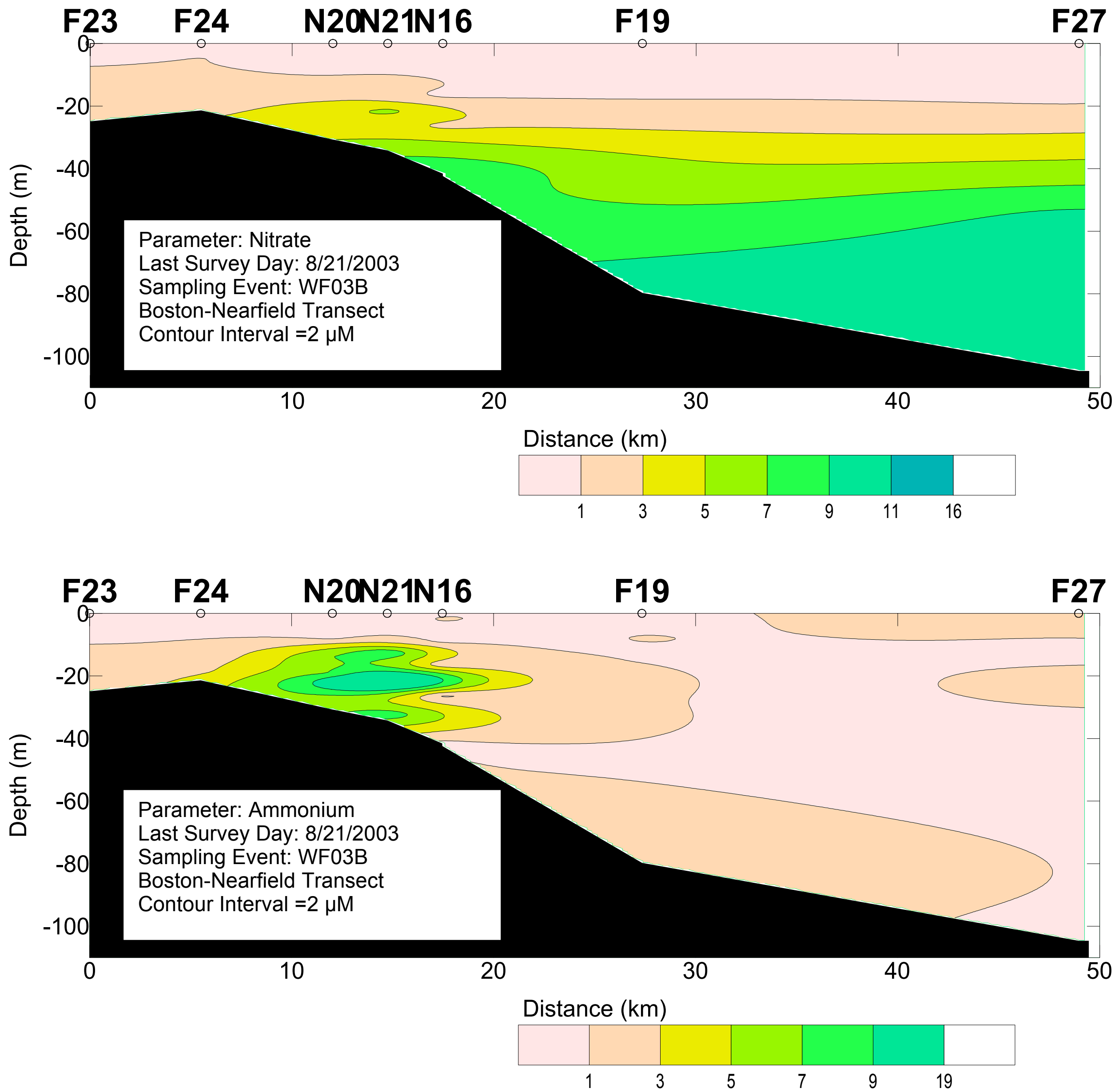


Figure 4-18. Nitrate and Ammonium vertical plots along Boston-Nearfield transects for survey WF03B (Aug 03)

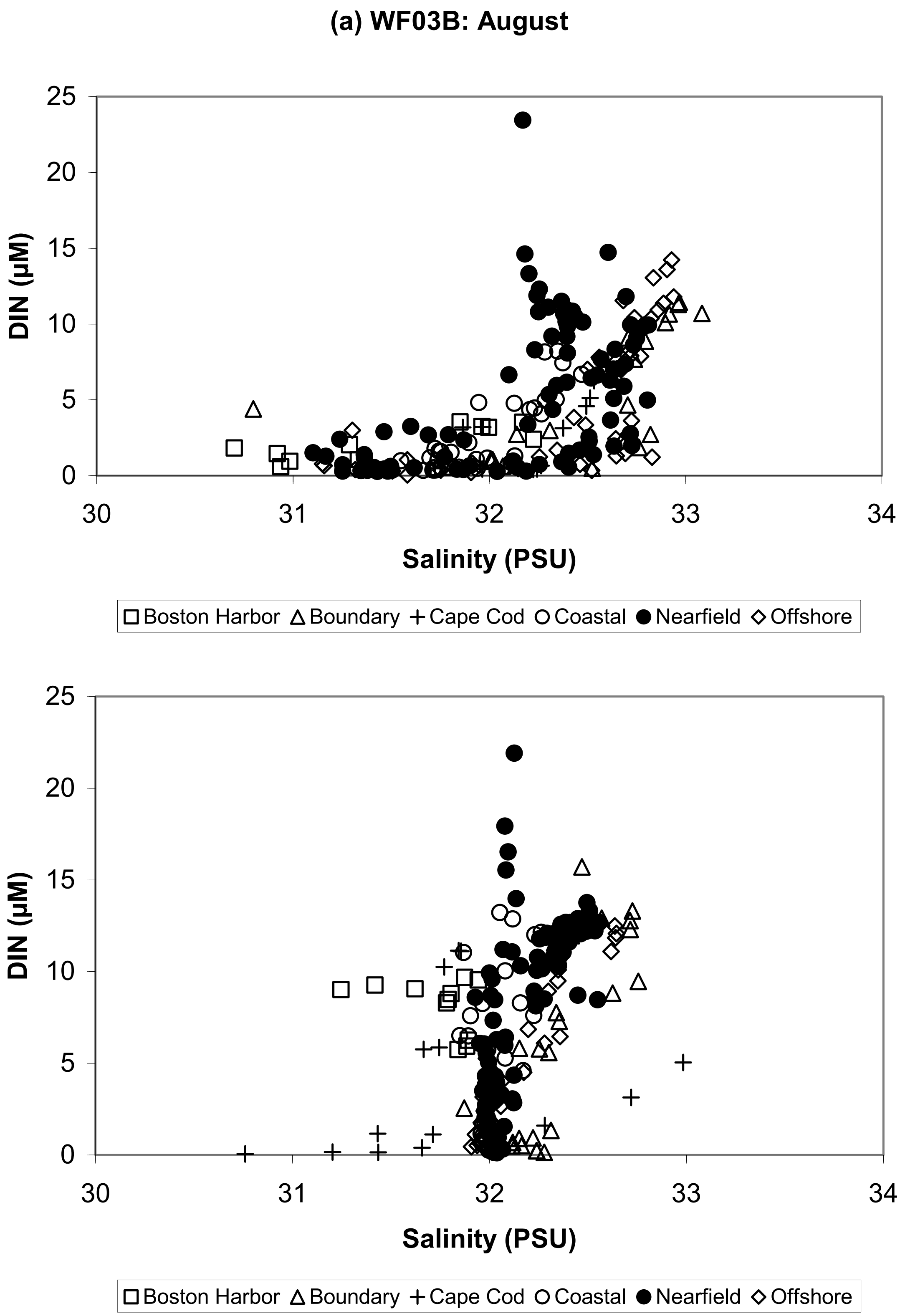


Figure 4-19. DIN versus salinity for farfield surveys WF03B and WF03E

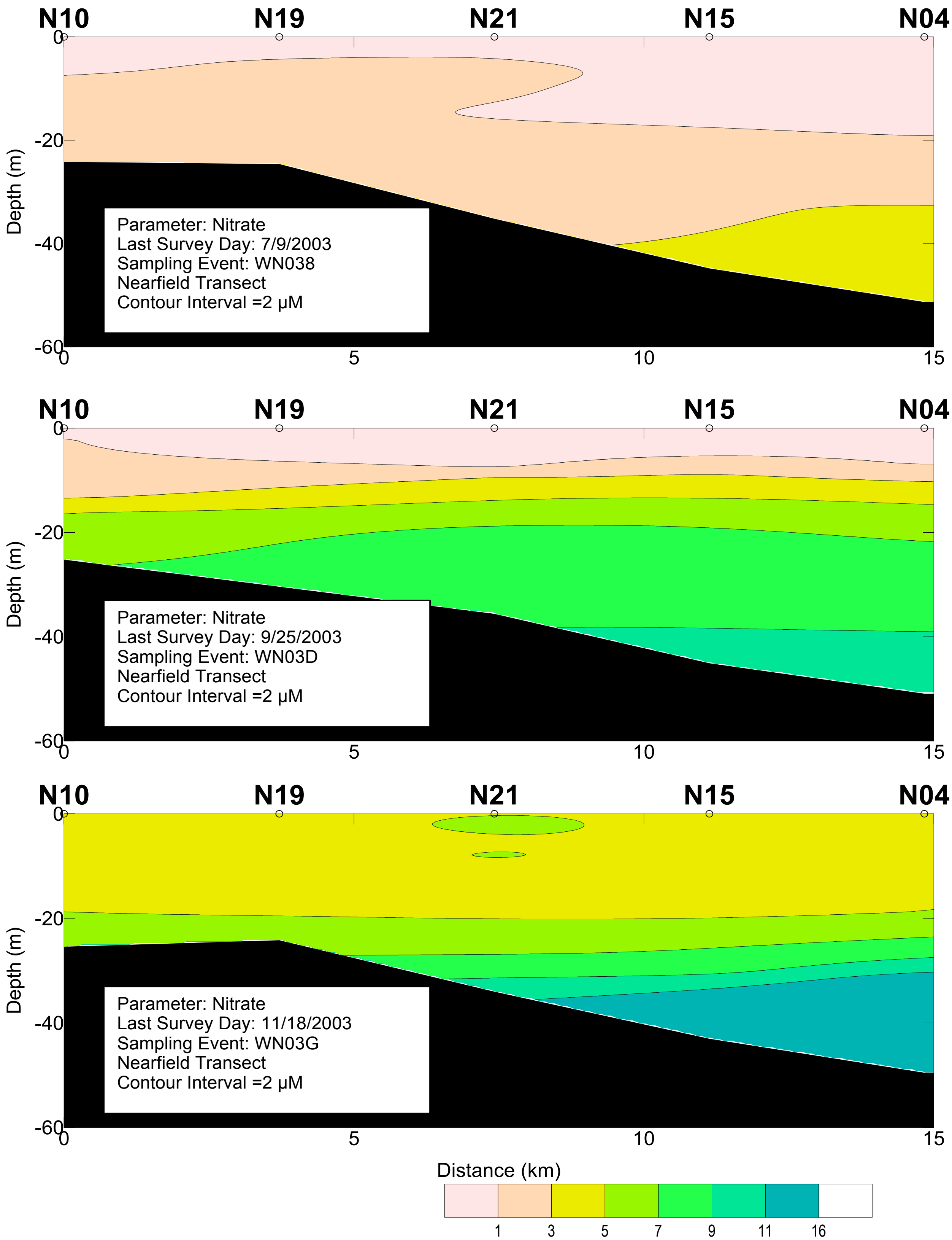


Figure 4-20. Nitrate vertical nearfield transect for surveys WN038, WN03D, and WN03G

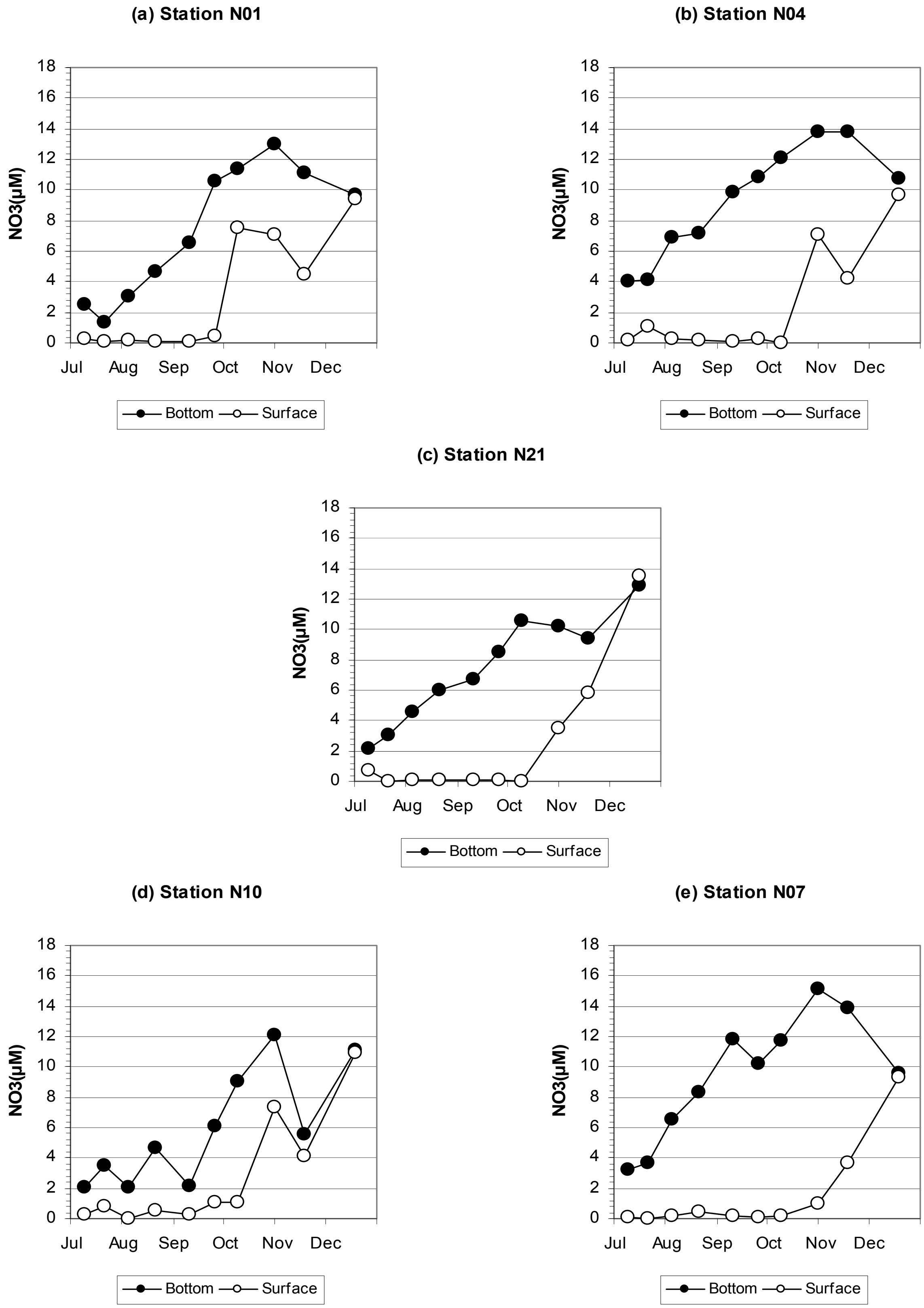


Figure 4-21. Time-series of average surface and bottom water NO_3 concentrations in the nearfield

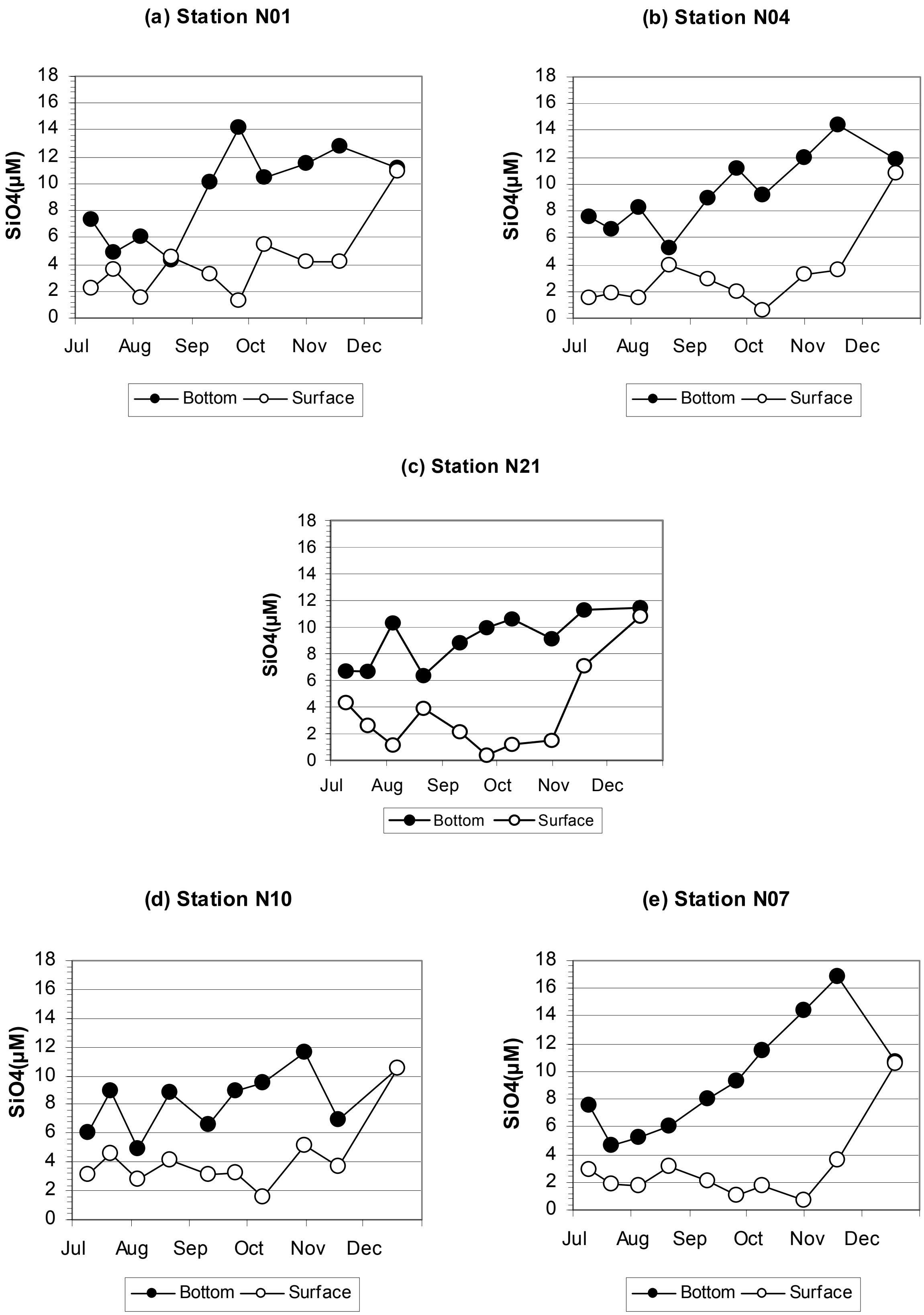


Figure 4-22. Time-series of average surface and bottom water SiO_4 concentrations in the nearfield

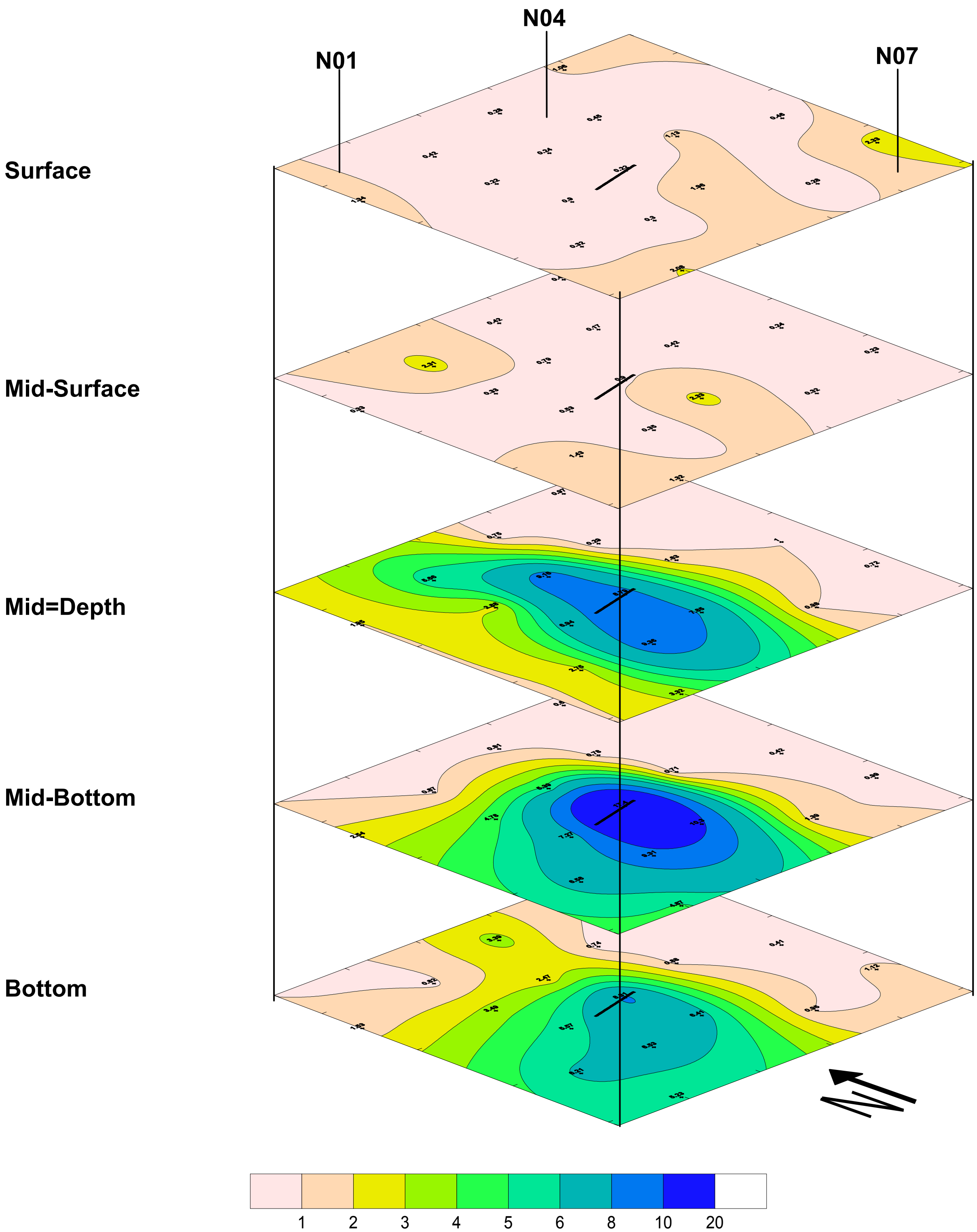


Figure 4-23. Ammonium concentrations at each of the five sampling depths for entire nearfield during WF03B (Aug 03)

[Note: displayed depths are a representation: actual sampling depths vary by station]

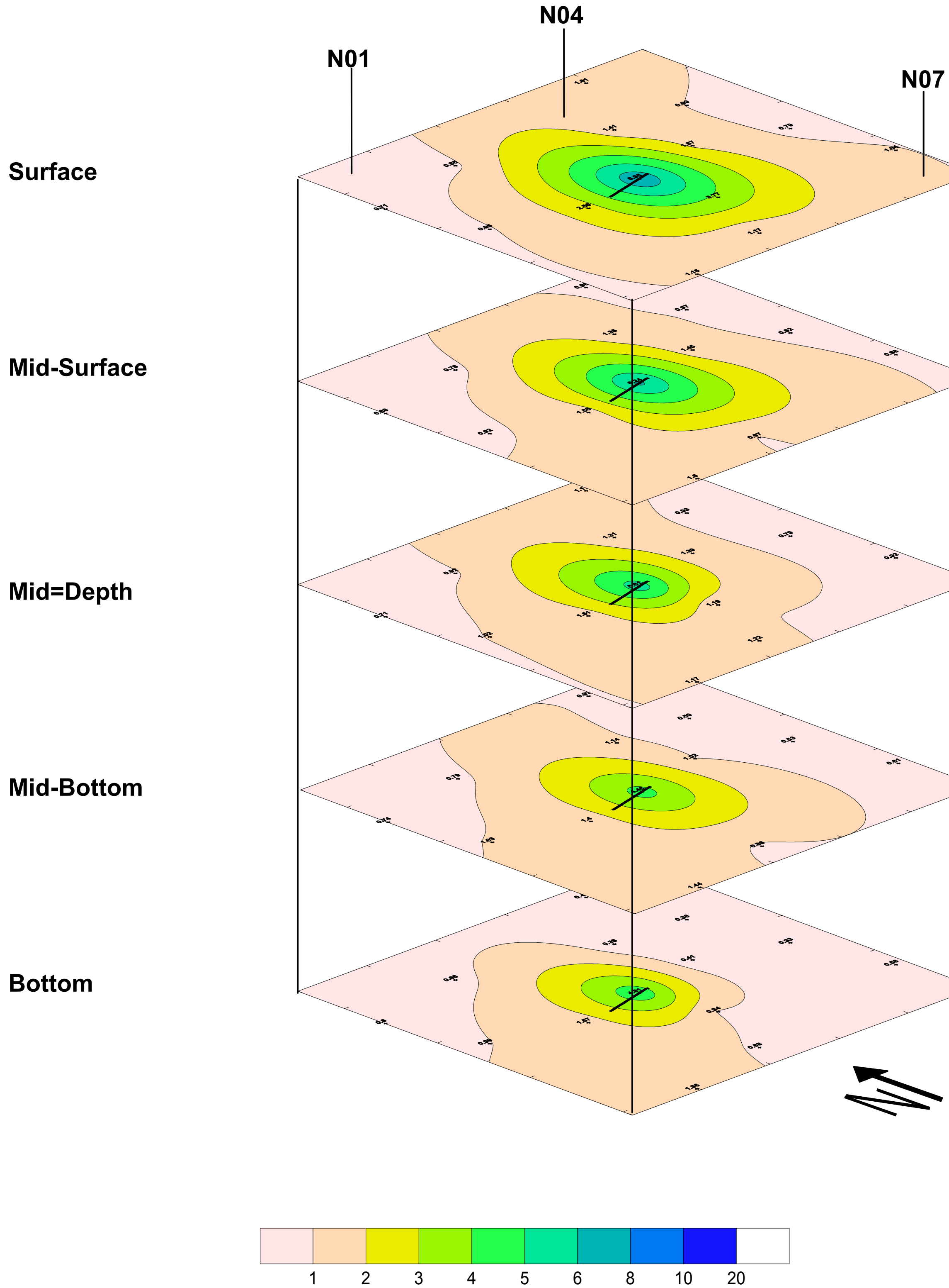


Figure 4-24. Ammonium concentrations at each of the five sampling depths for entire nearfield during WN03H (Dec 03)

[Note: displayed depths are a representation: actual sampling depths vary by station]

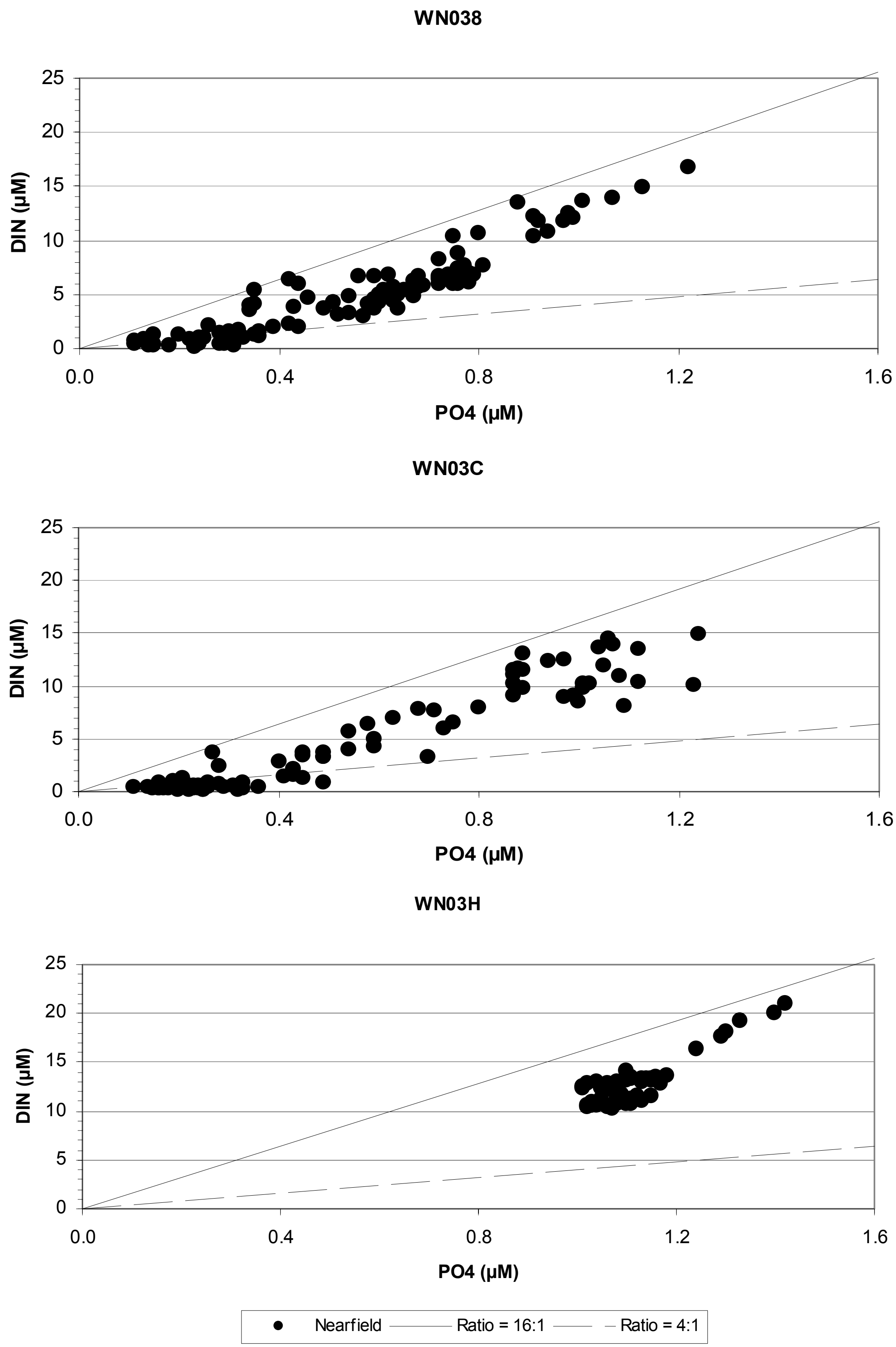


Figure 4-25. DIN versus PO_4 for nearfield surveys WN038, WN03C, and WN03H

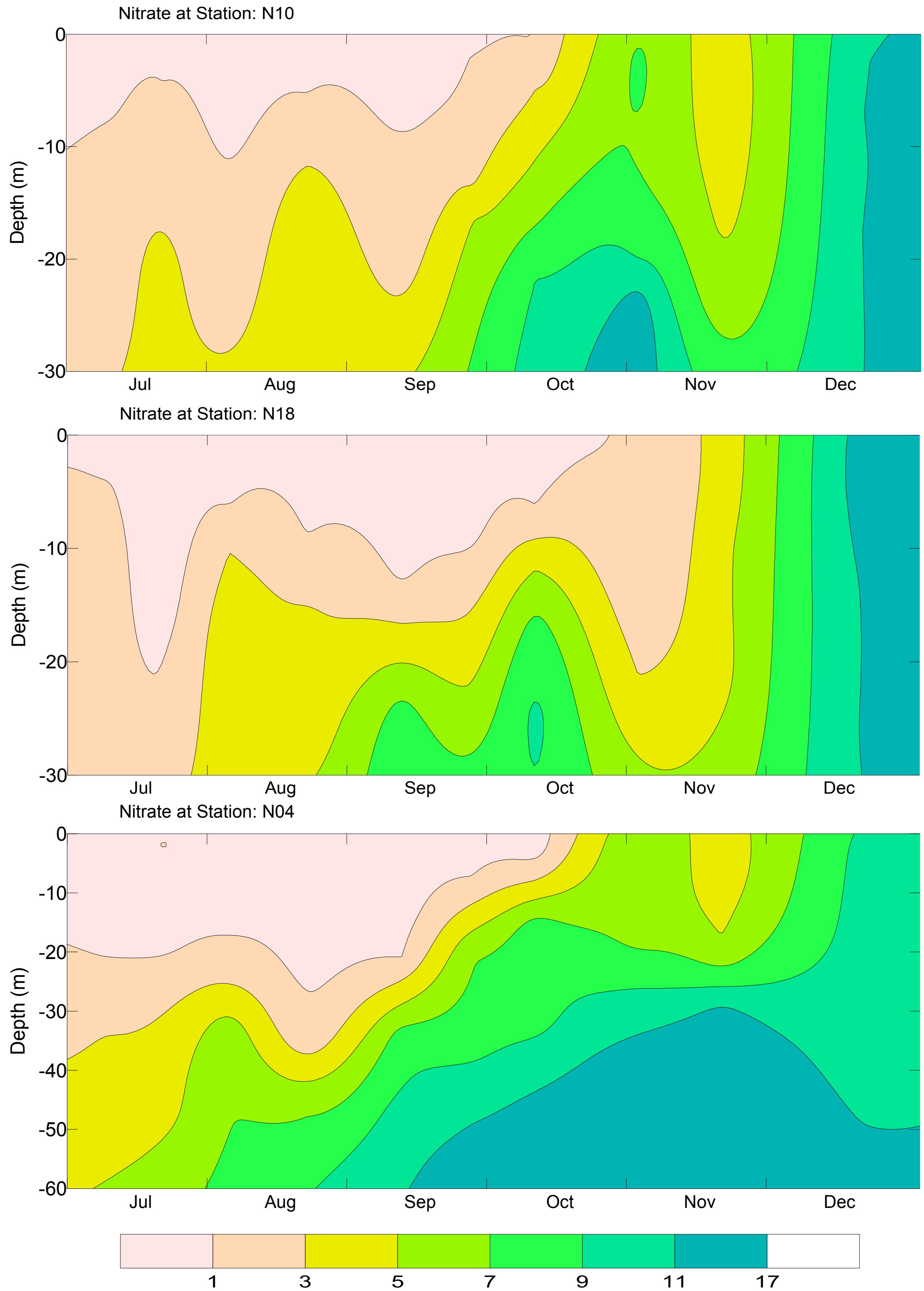


Figure 4-26. Time series of NO_3 at three representative nearfield stations during the summer-winter 2003

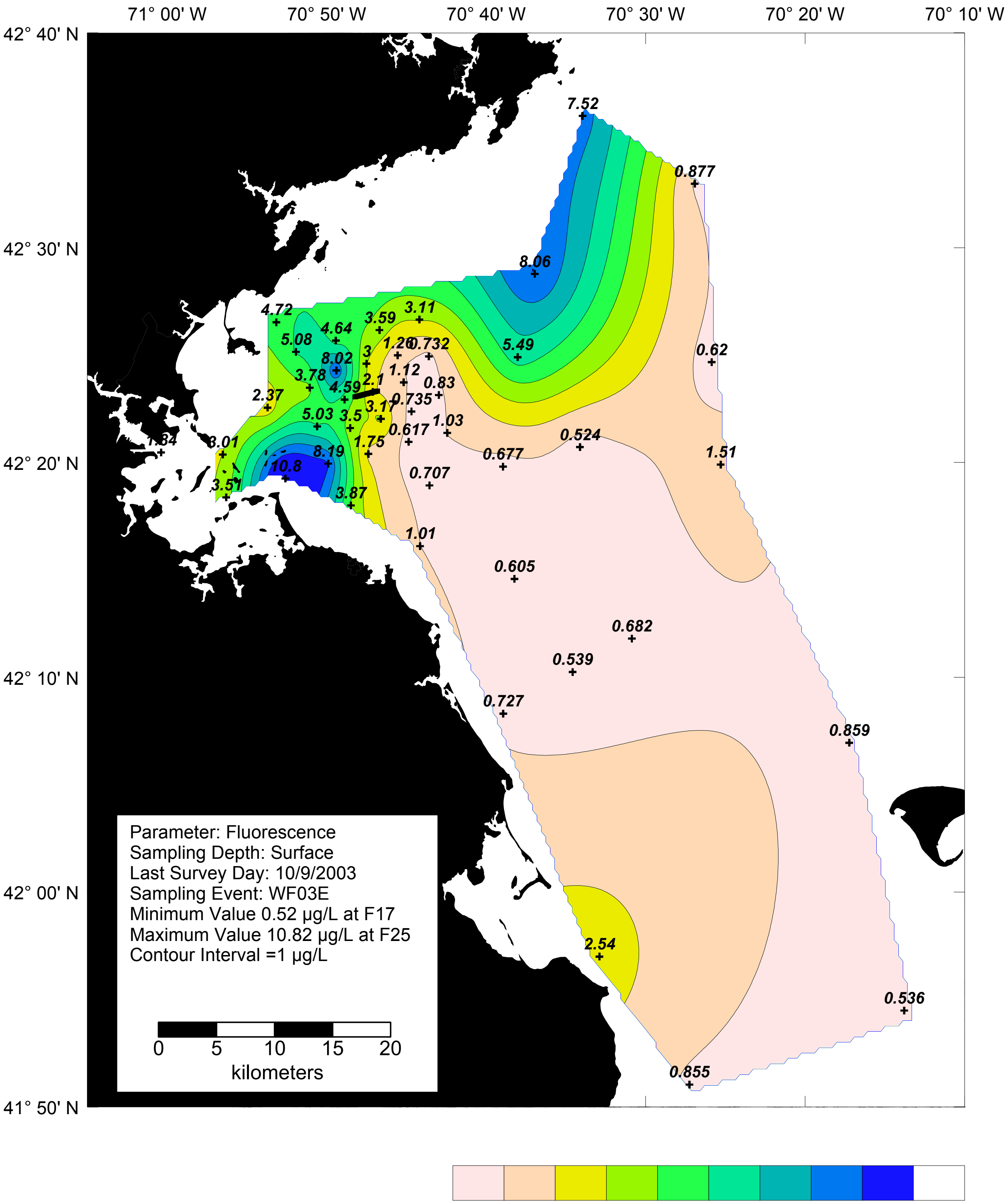


Figure 4-27. Fluorescence surface contour plots for farfield survey WF03E (Oct 03)

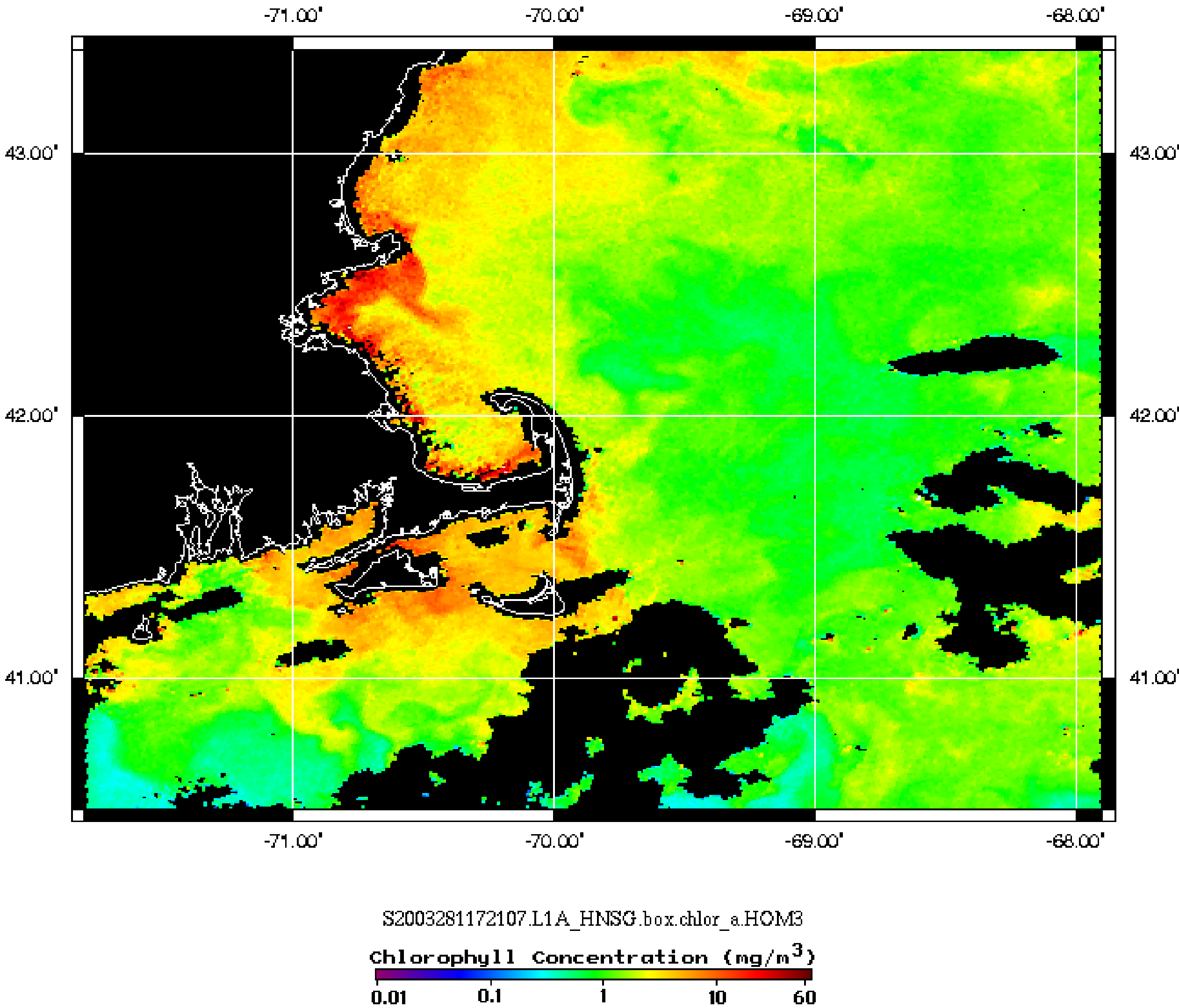


Figure 4-28. SeaWiFS image from October 8, 2003

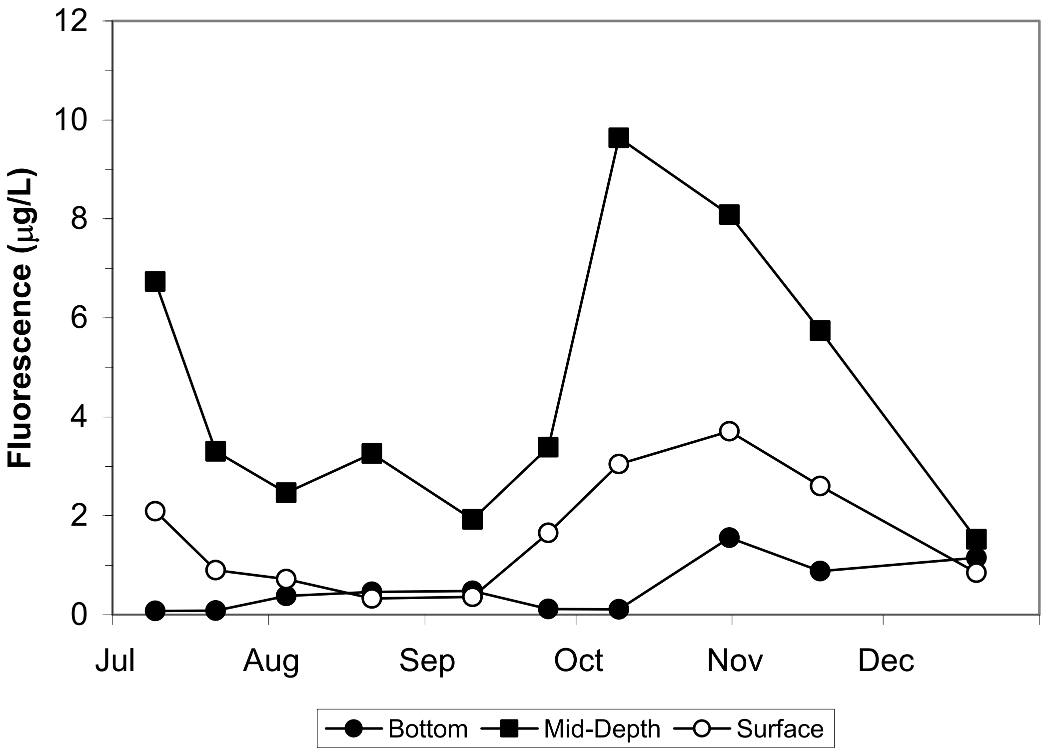


Figure 4-29. Time series of average fluorescence in the nearfield – surface, mid-depth, and bottom depth

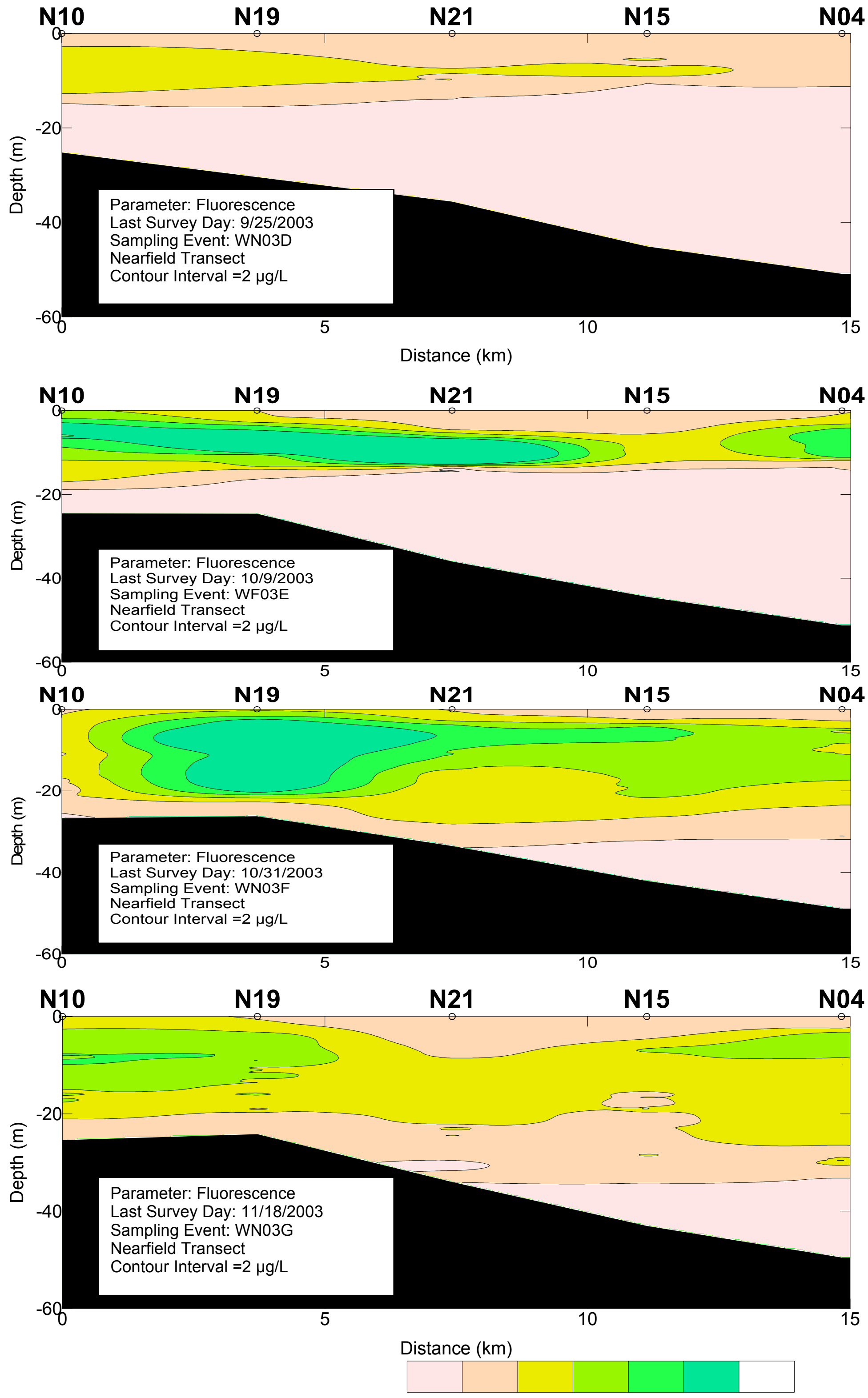


Figure 4-30. Fluorescence vertical nearfield transect plots for surveys (a) WN03D, (b) WF03E, (c) WN03F, and (d) WN03G

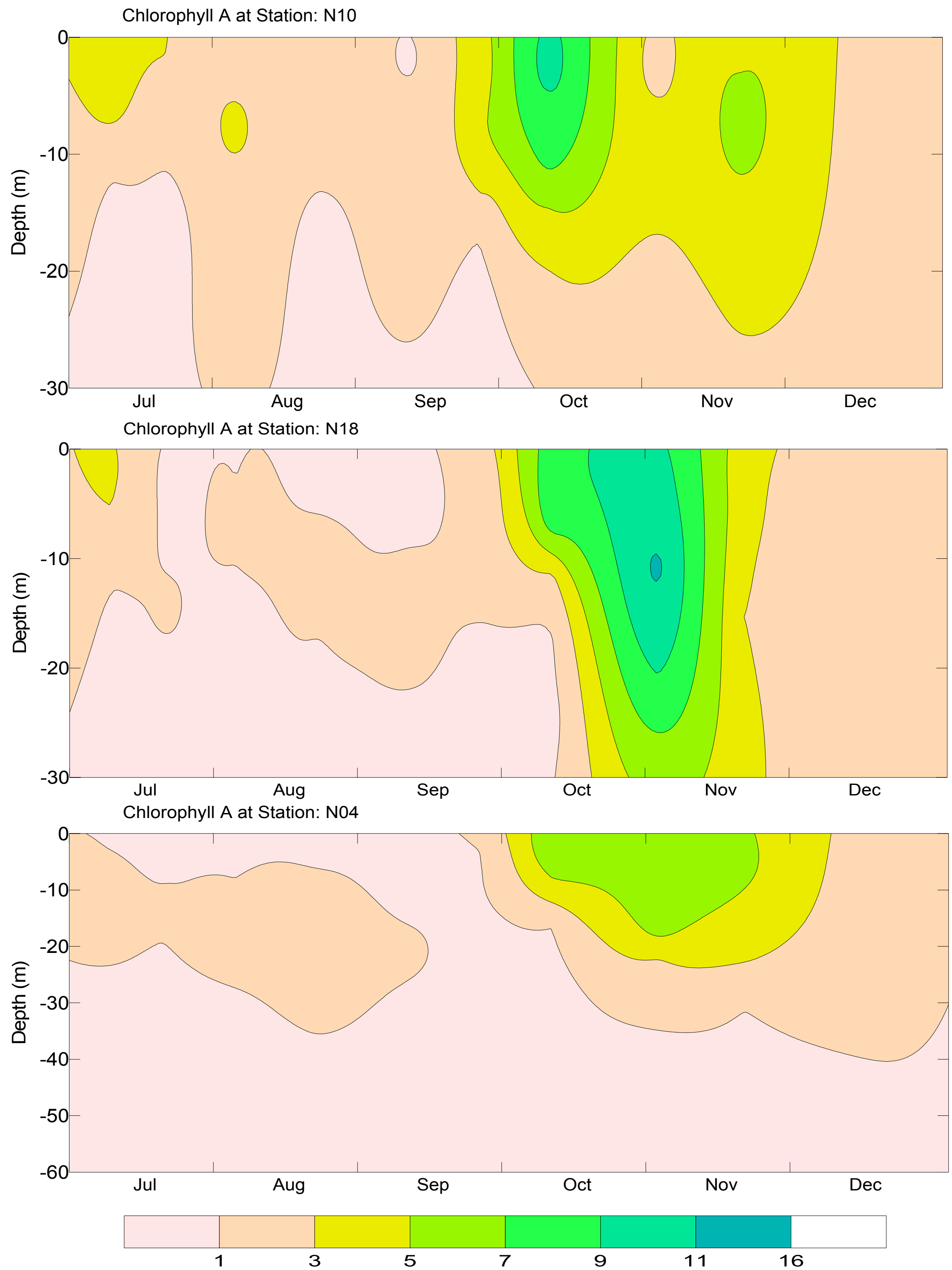


Figure 4-31. Time series of *in vitro* chlorophyll at three representative nearfield stations during the summer-winter 2003

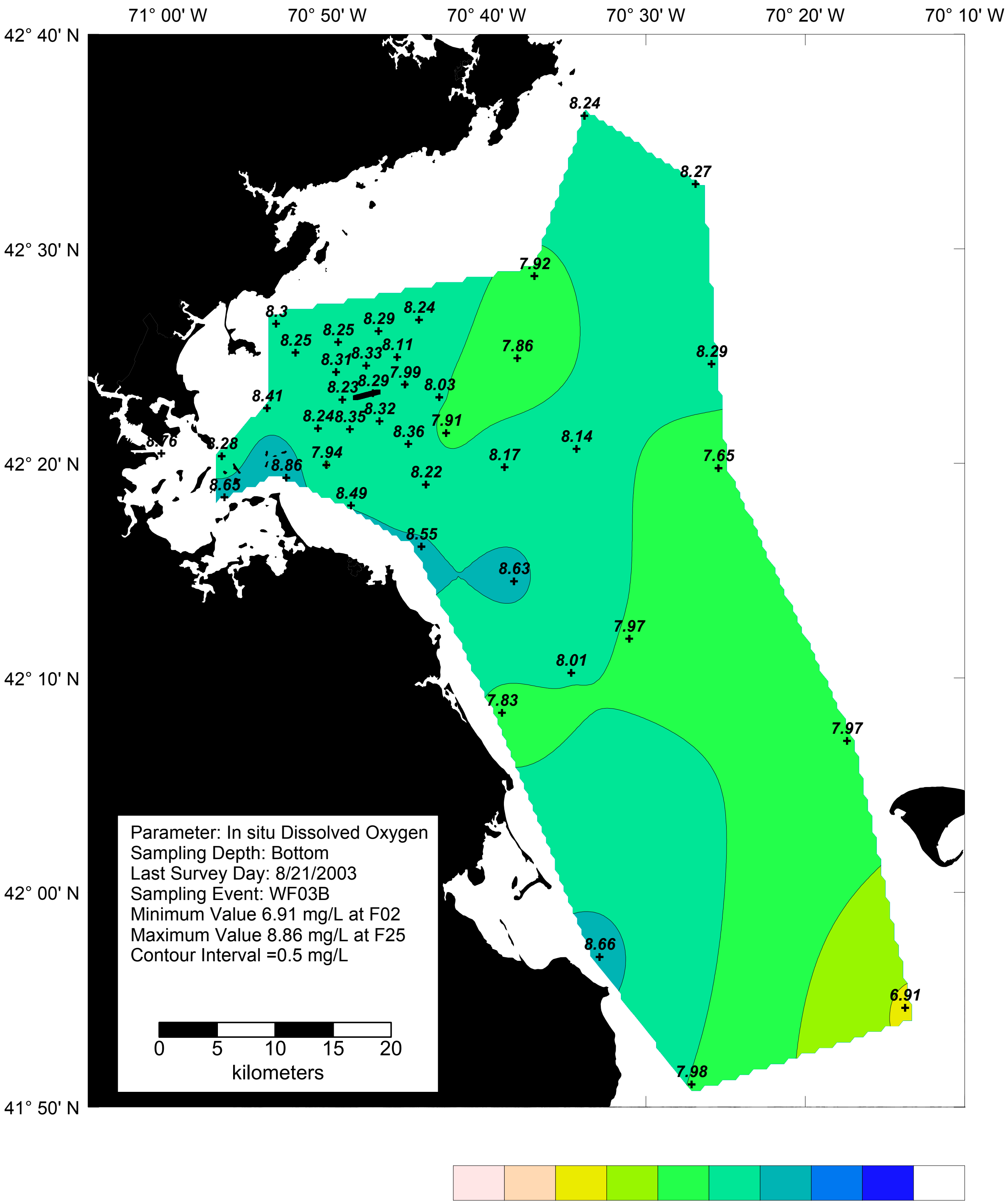


Figure 4-32. Dissolved oxygen bottom contour in the farfield survey WF03B (Aug 03)

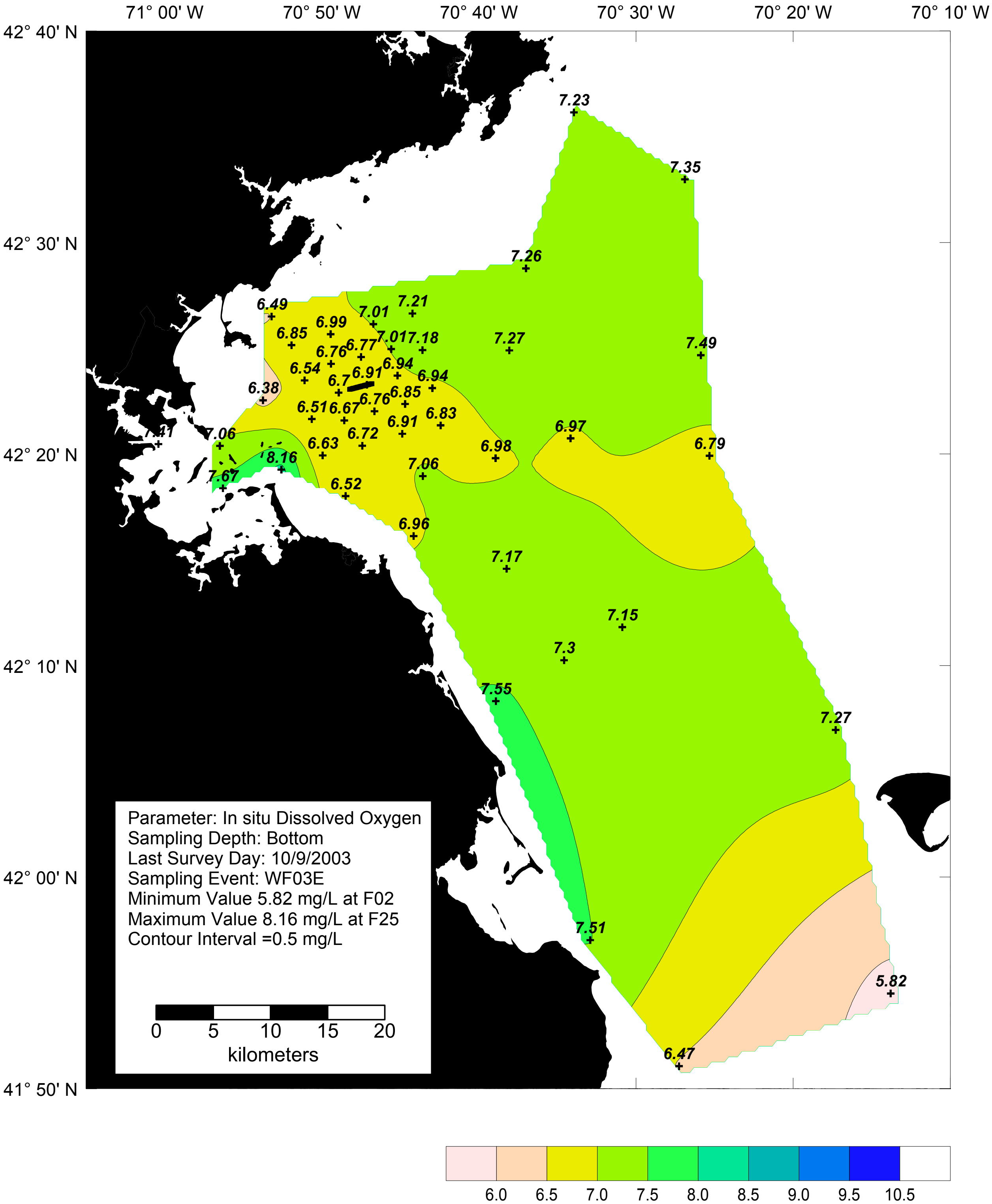


Figure 4-33. Dissolved oxygen bottom contour in the farfield survey WF03E (Oct 03)

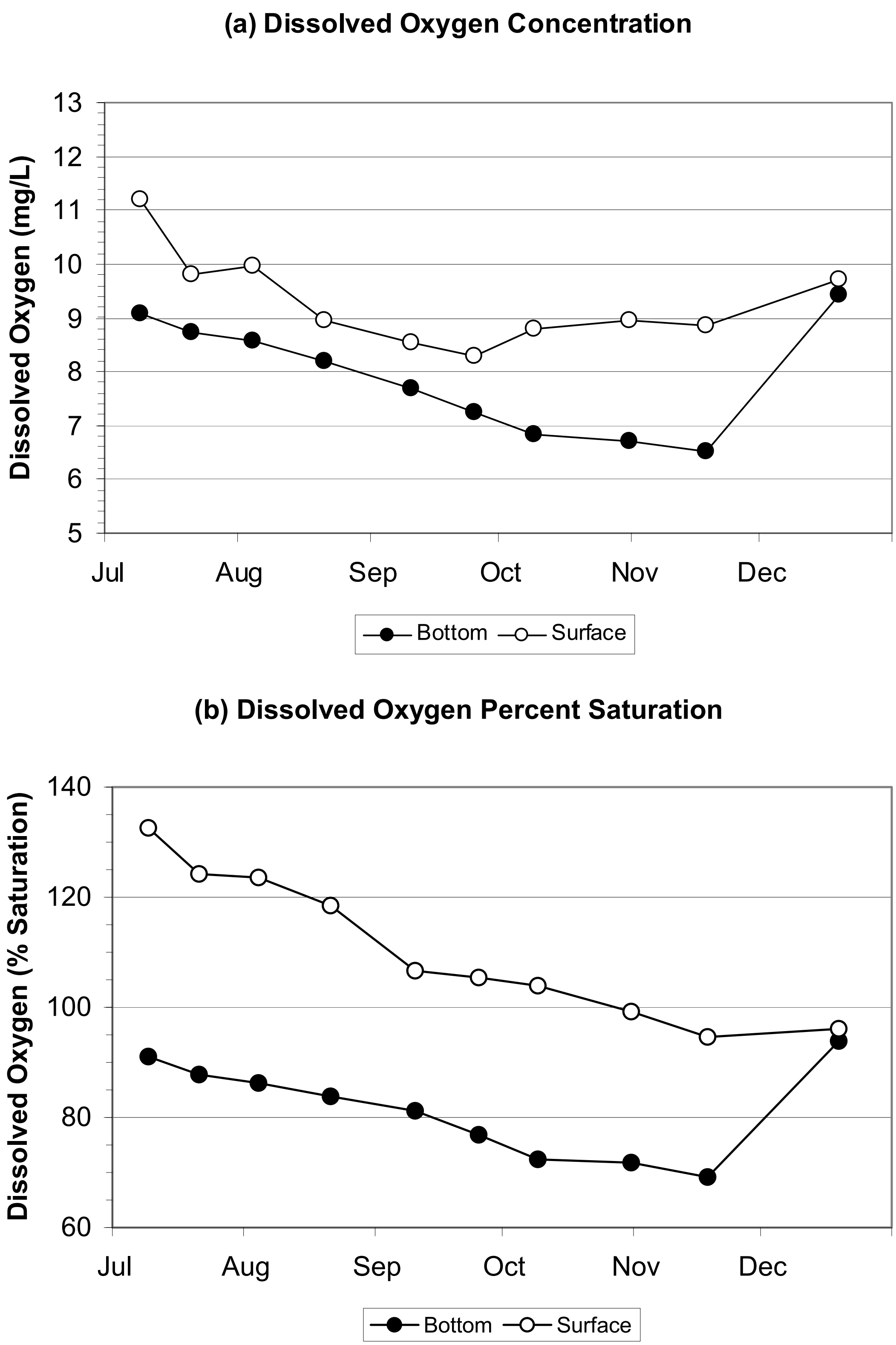


Figure 4-34. Average dissolved oxygen concentrations and percent saturation in nearfield surface and bottom water

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 20 (WF03B) and October 8 (WF03E). Stations N04 and N18 were additionally sampled on July 9 (WN038), July 21 (WN039), August 4 (WN03A), September 10 (WN03C), September 25 (WN03D), October 31 (WN03F), November 18 (WN03G), and December 19 (WN03H). Samples were collected at five depths throughout the euphotic zone. Production was determined by measuring ^{14}C at varying light intensities as summarized below and in Libby *et al*., 2002.

In addition to samples collected from the water column, productivity calculations also utilized light attenuation data from a CTD-mounted 4π sensor, and incident light time-series data from a 2π irradiance sensor located on Deer Island, MA. After collection, productivity samples were returned to the Marine Ecosystems Research Laboratory (MERL) in Rhode Island and incubated in temperature controlled incubators. The resulting photosynthesis versus light intensity (P-I) curves (**Figure** 5-1 and comprehensively in Appendix C) were used, in combination with light attenuation and incident light information, to determine hourly production at 15-min intervals throughout the day for each sampling depth. By selecting irradiance data from a sunny day close in time to the monitoring cruise and substituting these values in the productivity calculations, potential production was determined (under maximum light for that time of year) for each sample day. As the actual production is reduced by clouds, potential production is a better estimate of physiological condition than the values calculated using day of sampling light fields and is the focus of this report.

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 and chlorophyll-specific potential productivity for each depth are also presented as contour plots at station N04 and N18 (**Figures** 5-4 and 5-5). *In vitro* chlorophyll *a* at station N04 and N18 was presented in **Figure** 4-31. 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) displayed a similar pattern throughout the semi-annual sampling period (**Figure** 5-2). Areal production at the two sites was >1200 mg C m^{-2} d^{-1} during the early July survey (WN038). Production at station N04 was somewhat higher at this time (~1500 mg C m^{-2} d^{-1}) compared with station N18 (~ 1200 mg C m^{-2} d^{-1}). Values at both stations decreased by late July (WN039) to 738 mg C m^{-2} d^{-1} at N04 and 471 mg C m^{-2} d^{-1} at N18. Throughout the August sampling period (WN03A and WF02B) production at the nearfield sites fluctuated between 499 and 999 mg C m^{-2} d^{-1} with station N04 remaining somewhat elevated relative to station N18. Moderate rates of productivity continued throughout September (WN03C and WN03D), however, production at station N18 (628 – 771 mg C m^{-2} d^{-1}) was now greater than the levels observed at station N04 (481 – 564 mg C m^{-2} d^{-1}).

Following the mid- to late summer period of low to moderate productivity, production increased in October to 1675 mg C m^{-2} d^{-1} during WN03E and reached a major fall productivity peak of 2515 mg C m^{-2} d^{-1} by the end of the month (WN03F) at station N18. Productivity at station N04 (529 –1534 mg C m^{-2} d^{-1}) was less than station N18 during this fall period. By mid-November (WN03G) productivity declined at station N18 (1098 mg C m^{-2} d^{-1}) while levels continued to increase to peak bloom values (1738 mg C m^{-2} d^{-1}) at station N04. Productivity at station N18 is generally greater than that observed at station N04. However, the fall peak in productivity observed at station N18 was also greater than the productivity recorded at station F23, at the outer edge of Boston Harbor, and continues a trend originally noted in 1997. In 1995 and 1996 the highest areal productivity values were recorded at station F23. Beginning in 1997, the highest areal productivity measurements over the annual cycle were recorded in the central nearfield region (station N18) rather than Boston Harbor.

Productivity at both stations decreased to levels <310 mg C m^{-2} d^{-1} in December (WF03H). At both stations the timing of the fall productivity bloom was similar; however the bloom was initiated earlier at station N18 and reached higher levels (~1.5 fold greater than N04). The peak productivity at station N04 during this semi-annual period occurred November 11 (WN03G) with a production of 1738 mg C m^{-2} d^{-1}. Station N18 reached its maximum value (2515 mg C m^{-2} d^{-1}) during this semi-annual period on October 31, but was also characterized by elevated production (1675 mg C m^{-2} d^{-1}) in early October. Production minima for this reporting period were observed at station N04 (306 mg C m^{-2} d^{-1}) and station N18 (215 C m^{-2} d^{-1}) on December 19, the final survey of the year.

At the Boston Harbor productivity/respiration station F23, areal production (1222 mg C m^{-2} d^{-1}) during the August survey was the highest productivity observed at the three productivity monitoring stations for the sampling period. Areal production at F23 decreased somewhat to 706 mg C m^{-2} d^{-1} by October and was similar to the measured production at the station N04. The production data at station F23 are in agreement with the chlorophyll data. During WF03B, chlorophyll values were high and productivity was high. Lower chlorophyll concentrations during WF03E were associated with decreased productivity levels in the harbor.

Peak productivity during the fall bloom period was somewhat lower in 2003 compared with prior years. The fall blooms observed at nearfield stations in 1995-2002 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.

Areal production in 2003 followed patterns typically observed in prior years (**Figure** 5-2). In general, 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 this year. 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. At station N04, the fall bloom occurred during December in 2001 and August 2002. As in 2001, the delay in peak fall production in 2003 was likely related to the prolonged period of weak stratification that was observed through November. The elevated production during October and November 2003 was coincident with elevated chlorophyll measured during the surveys and observed by SeaWiFS (Appendix D). It has also 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.,* 2003a). This and the timing of the fall bloom will be examined in more detail in the 2003 annual report.

5.1.2 Chlorophyll-Specific Production

Depth-averaged chlorophyll-specific production was elevated at station N18 compared to station N04 during the semi-annual reporting period (**Figure** 5-3). Values were initially high at station N18 (~47 mg C mg Chla^{-1} d^{-1}) in early July then gradually decreased from 27 mg C mg Chla^{-1} d^{-1} in late July to 18.5 mg C mg Chla^{-1} d^{-1} in early August. Throughout the same period, chlorophyll-specific production at station N04 was less than N18 and gradually decreased from 25 to 10 mg C mg Chla^{-1} d^{-1} from early July to early August. Values increased at the nearfield sites in late August with chlorophyll-specific production remaining somewhat elevated through early September. Values decreased at both sites from late September through early October and remained at moderately low levels (3.7 - 11.8 mg C mg Chla^{-1} d^{-1}) for the remainder of the seasonal cycle. The seasonal minimum was reached at station N04 in early October (3.7 mg C mg Chla^{-1} d^{-1}). At station N18 the seasonal minimum (5.0 mg C mg Chla^{-1} d^{-1}) was observed in December. By comparison depth-averaged chlorophyll-specific rates at harbor station F23 were mid-way in magnitude between stations N18 and N04 during August and October. Depth-averaged chlorophyll-specific production at station F23 did not exceed 22 mg C mg Chla^{-1} d^{-1} throughout the reporting period (**Figure** 5-3).

5.1.3 Production at Specified Depths

The spatial and temporal distribution of production and chlorophyll-specific production on a volumetric basis were summarized by showing contoured values over the sampling period (**Figure**s 5-4 and 5-5). 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 summer productivity values (110 – 145 mg C m^{-3} d^{-1}) were observed at mid-surface depth (~9 m) at station N04 and mid-bottom depths (~15 m) at station N18 during July (**Figure** 5-4). At both nearfield stations productivity tended to decrease over the summer following these peak values. The areal productivity peaks reported during October and November 2003 at stations N04 and N18 were concentrated in the upper 10 m of the water column. At station N04, fall production was highest (136 mg C m^{-3} d^{-1}) in the surface depths in late October while a mid-surface productivity maximum (136 mg C m^{-3} d^{-1}) was observed in November. Peak production (250 mg C m^{-3} d^{-1}) at station N18 occurred at the mid-surface depth in late October with elevated levels observed at surface (231 mg C m^{-3} d^{-1}) and mid- depths (130 mg C m^{-3} d^{-1}). There was a decrease in productivity throughout the water column at both sites in December. The depth-specific productivity values at station F23 were highest in the surface and mid-surface waters (213 –229 mg C m^{-3} d^{-1}) in August but decreased from surface through bottom depths in October. The depth-specific productivity values further emphasize that productivity was elevated at station N18, closest to the outfall, relative to both stations N04 and F23 (**Figure** 5-4).

The productivity pattern at specified depths observed in 2003 was similar to that observed in prior years. At station N04, productivity as high as 32 mg C m^{-3} d^{-1} occurred to depths of 16 m. At station N18, productivity as high as 110 mg C m^{-3} d^{-1} was observed at depths of 15 m. As is most prior 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 during the fall bloom period at the nearfield stations (see **Figure** 4-31). The summer period of high productivity at both stations occurred during a period of lower chlorophyll *a* concentrations suggesting an increase in the efficiency of production at this time. The elevated production at F23 during August occurred in the surface and mid-surface waters where concentrations of chlorophyll *a* were also high. In October productivity was elevated in the surface water while chlorophyll *a* was relatively uniform throughout the water column.

Chlorophyll-specific production at depth followed similar seasonal patterns at stations N04 and N18 (**Figure** 5-5). 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-bottom depths during July 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 July was not associated with increased phytoplankton biomass as measured by in vitro chlorophyll *a*. When the efficiency of photosynthesis is high but not reflected in higher phytoplankton biomass (measured as *in vitro* chlorophyll *a*) it suggests that other processes (such as predation by zooplankton) are important in controlling the patterns observed. However, the increased chlorophyll-specific production observed at stations N04 and N18 in October did lead to somewhat elevated phytoplankton biomass (see **Figures** 4-31 and 5-8). It is likely that the combination of relatively low grazing pressure as suggested by low zooplankton abundances (see Section 5.3.2) and mixing led to the increase in phytoplankton biomass at subsurface depths. 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. This will be examined in more detail in the 2003 annual report.

At station F23, chlorophyll-specific production decreased over the sampling season, with peak values occurring in surface and mid-surface waters in August. The August peak at station F23 was associated with elevated chlorophyll *a* at surface and mid-surface depths; however the decrease in chlorophyll-specific productivity in October was associated with even higher 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 each of the combined farfield/nearfield surveys and stations N04 and N18 were also sampled during the eight nearfield surveys. Respiration samples were collected from three depths (surface, mid-depth, and bottom) and were incubated in the dark at *in situ* temperatures for 7±2 days.

Both respiration (in units of $\mu M\ O_2\ hr^{-1}$) 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 (WF03B and WF03E) 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 December time period. Respiration rates were relatively low in July – December 2003 in comparison to previous years. In 2003, nearfield rates reached a maximum for this time period in early July with rates of ~0.21 $\mu M\ O_2\ hr^{-1}$ in station N18 surface waters and similar rates were measured at station F23 in late August (**Figure** 5-6). In comparison to 2002, these were 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.*, 2003b).

Nearfield respiration rates were relatively low during the second semiannual period of 2003. At station N18, rates peaked at 0.21μM O_2 hr^{-1} in the surface waters in early July, remained at ~0.15 μM O_2 hr^{-1} in surface and mid-depth waters in late July and early August before decreasing to ≤0.10 μM O_2 hr^{-1} in late August and early September. Respiration rates for surface and mid-depth waters at station N04 generally ranged from 0.10 to 0.15 μM O_2 hr^{-1} from July to early September. There was a slight increase in rates in late September and early October that coincided with the fall diatom bloom (**Figure** 5-6). By late October, respiration rates at the nearfield stations decreased over the entire water column to ≤0.1 μM O_2 hr^{-1} and remained low for the rest of 2003. In Boston Harbor, respiration rates peaked in surface and mid-depth waters (~0.2 μM O_2 hr^{-1}) in August and decreased to ~0.07 μM O_2 hr^{-1} in October (**Figure** 5-7). Rates at offshore station F19 were comparable to station N04 with a slight increase from August to October. 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 higher respiration rates occurred early in the summer and during the fall bloom and were often coincident with trends observed in POC concentrations (**Figures** 5-8 and 5-9). At station N18, POC concentrations were elevated in early July in the surface water, reached a maximum in late August at mid-depth (50 μM), and elevated concentrations were observed during the fall bloom. Similar trends were observed at station N04 and F19, between respiration rates and POC concentrations. In Boston Harbor, there was little change in POC concentration (~30 μM) between the two surveys, but respiration rates decreased by more than 50% in the surface and mid-depth waters. This was likely due to the sharp decrease in temperatures from 18°C to 12°C over this period. Overall, POC concentrations were relatively low in July – December 2003 with nearfield values peaking at 50 μM and a maximum concentration of only 57 μm measured at station F19 in October.

As might be expected, both POC and temperature were correlated with respiration rate even when all data from the four stations were grouped for comparison (**Figure** 5-10). In 2002, POC was more highly correlated with respiration (R^2 = 0.72) than temperature (R^2 = 0.52; Libby *et al*., 2003b). The early fall bloom in 2002 provided ample newly produced POC, which likely fueled elevated rates of respiration. In July – December 2003, respiration was more highly correlated with temperature than POC. This was likely due to the lower POC concentrations in 2003 leading to relatively low respiration rates, especially during the warmer summer months. The relationships between respiration and both temperature and POC in 2003 are significant ($P<0.001$). As in 2002, there was no significant relationship between dissolved organic carbon and respiration during July – December 2003.

5.2.2 Carbon-Specific Respiration

Normalizing respiration by carbon 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 relatively low during the July – December 2003 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** 5-11). Peak rates reached 0.007 µM O_2 µM C^{-1} hr^{-1} in surface waters at station N18 early July and 0.008 µM O_2 µM C^{-1} hr^{-1} in surface waters at station N04 in late August. The values over the water column were variable in magnitude but tended to follow similar trends at both nearfield stations from July through October. At station N18, similar peaks in carbon specific rates were observed over each depth in late July and late September. At station N04, rates increased over most of the water column from July to late August. Surface and bottom water values began to decline in September, while mid-depth rates peaked in late September. As POC and production increased in October and November, carbon-specific respiration rates declined and remained low (<0.005 µM O_2 µM C^{-1} hr^{-1}) through December. Rather than coincident trends between carbon-specific respiration rates and POC, production and respiration as seen in 2002, these parameters diverged. The timing of elevated biomass and production rates during the late fall bloom was such that cooler temperatures led to lower respiration rates. At stations F19 and F23, carbon-specific respiration rates followed a similar pattern declining from maxima of ≤0.008 µM O_2 µM C^{-1} hr^{-1} in August to ≤0.003 µM O_2 µM C^{-1} hr^{-1} in October during the fall bloom

5.3 Plankton Results

Plankton samples were collected on each of the ten surveys conducted from July to December 2003. 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. Phytoplankton samples included both whole-water and 20-µm mesh screened samples, 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*. (2002).

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 across 0.53 – 1.58 x 10^6 cells L^{-1} in July and August, increasing somewhat to 1.70 - 2.35 x 10^6 cells L^{-1} in September. Phytoplankton abundance increased through October and November to 1.14 – 3.04 x 10^6 cells L^{-1} before declining to 0.85 – 1.20 x 10^6 cells L^{-1} in December. The increase observed from late September through November was primarily due to increased diatom abundance (**Figures** 5-12 and 5-13).

Total phytoplankton abundance in farfield whole water samples (**Table** 5-1) was similar in August (0.64 – 3.71 x 10^6 cells L^{-1}) and October (0.65 – 3.60 x 10^6 cells L^{-1}). The microflagellate dominance found in the nearfield in August was observed throughout the farfield (**Figure** 5-14), and the diatom bloom recorded for the nearfield in late September, October and November was also seen throughout the farfield in October (**Figure** 5-15).

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 (128 – 963 cells L^{-1}) from July through December and was relatively low in comparison 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 (2003)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WN038	7/9	1.00	0.53-1.45	--	--
WN039	7/21	0.93	0.72-1.09	--	--
WN03A	8/4	1.24	0.95-1.51	--	--
WF03B	8/18-21	1.31	1.06-1.58	1.53	0.64-3.71
WN03C	9/10	1.34	1.08-1.55	--	--
WN03D	9/25	1.95	1.70-2.34	--	--
WF03E	10/6-9	1.39	1.14-1.75	1.60	0.65-3.60
WN03F	10/31	2.30	1.61-3.04	--	--
WN03G	11/18	2.22	1.72-2.90	--	--
WN03H	12/19	0.95	0.85-1.20	--	--

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

Survey	Dates (2003)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WN038	7/9	480	411-536	--	--
WN039	7/21	355	264-480	--	--
WN03A	8/4	260	132-365	--	--
WF03B	8/18-21	172	128-205	370	158-963
WN03C	9/10	249	207-361	--	--
WN03D	9/25	277	232-313	--	--
WF03E	10/6-9	334	302-355	337	171-621
WN03F	10/31	397	248-452	--	--
WN03G	11/18	336	296-393	--	--
WN03H	12/19	269	208-319	--	--

5.3.1.2 Nearfield Phytoplankton Community Structure

Whole-Water Phytoplankton – In early July (WN038), nearfield whole-water phytoplankton assemblages from both depths were dominated by unidentified microflagellates <10 µm in diameter (64 - 76% of cells). Cryptomonads (up to 17%) and the dinoflagellates *Prorocentrum minimum* (up to 17%) and *Gymnodinium* sp. (up to 6%) comprised most of the remainder. Throughout the remainder of July, August and early September, microflagellates dominated nearfield cell abundance, comprising 74 - 94% during these surveys. During these same surveys, cryptomonads were consistently the second most dominant species comprising up to 18% of nearfield cell abundance.

Beginning in late September (WN03D), microflagellates (37 - 60%) and cryptomonads (up to 6%) continued to be dominants, but there was a shift towards increasing diatom abundance (**Figures** 5-12 and 5-13). This increase was dominated by an increase in diatoms *Dactyliosolen fragilissimus* (20 - 46% of total abundance) and *Skeletonema costatum* (up to 20%), as the fall diatom bloom was beginning. This bloom continued into early October (WF03E) with microflagellate dominance (39 - 71%) shared by diatoms *Dactyliosolen fragilissimus* (9 - 27%), *Skeletonema costatum* (up to 12%), *Asterionellopsis glacialis* (up to 8%) and cryptomonads (up to 15%). At the end of October (WN03F), microflagellate dominance (24 - 59%) was shared by the diatoms *Leptocylindrus danicus* (21 - 65%), *L. minimus* (up to 28%), *A. glacialis* (up to 7%) and cryptomonads (up to 5%). In November (WN03G) abundance was spread between microflagellates (45 - 58%), cryptomonads (6 - 18%), *L. danicus* (13 - 22%), and *L. minimus* (7 - 21%). In December (WN03H), the fall diatom bloom was over, and re-established microflagellate dominance (73 - 83%) was shared with cryptomonads (up to 18%), and the diatom *Guinardia delicatula* (up to only 8%).

Screened Phytoplankton and Ciliates – As in 2002, the abundance of dinoflagellates was lower than during typical summer and fall seasons. The decrease was in large part due to lower numbers of the dinoflagellates *Ceratium tripos*, *Ceratium fusus, Ceratium longipes* and other members of this genus, which atypically were not the overwhelming dominants in nearfield screened phytoplankton samples. This will be examined in more detail in the 2003 annual report.

In July and August, the members of the genus *Ceratium* including *C. tripos*, *C. lineatum, C. longipes*, and *C. fusus* were consistently present but not overwhelmingly dominant. In early July, screened water samples were dominated by the dinoflagellates *Ceratium longipes* (22.6 – 60.8%) and *Dinophysis norvegica* (9.2 - 36.0%), with lesser contributions by *Gonyaulax* sp., unidentified thecate and athecate dinoflagellates, and aloricate ciliates. *D. norvegica* (18.9 - 31.8%) continued to be dominant in later July along with members of the genus *Ceratium* including *C. tripos* (up to 28.2%), *C. longipes* (up to 27.7%), and *C. fusus* (up to 11.0%). Other dinoflagellates, none of which comprised > 12.2%, included a mixture of *Prorocentrum minimum*, *Gonyaulax* sp. *Protoperidinium* sp. *Gymnodinium* sp., unidentified thecate and athecate dinoflagellates. Protozoans were also recorded, including aloricate ciliates and tintinnid ciliates.

In early August, *C. longipes* (15.9 - 22.0%), *D. norvegica* (< 5% at the surface, but 8.0 - 31.2% at the chlorophyll maximum depth), unidentified athecate (5.6 - 18.2%) and thecate (7.4 - 12.9%) dinoflagellates continued to dominate the screened water assemblages. A mixture of other dinoflagellates, none of which comprised > 10.6%, were present including *Gonyaulax* sp., *Protoperidinium* sp., *Protoperidinium depressum*, *Prorocentrum minimum*, *Gyrodinium* sp., *Polykrikos* sp.. Aloricate ciliates and tintinnids were also present. By late August, the nearfield screened water samples were dominated by a combination of unidentified thecate (6.6 - 22.5%) and athecate (up to 19.1%) dinoflagellates and various *Ceratium* species. *Dinophysis norvegica* was less dominant and part of a mixture of other dinoflagellates, none of which comprised > 11.3%, that included *Gonyaulax* sp., *Gymnodinium* sp., *Gyrodinium* sp, *Prorocentrum minimum*, *Protoperidinium* sp.. Also recorded were the silicoflagellate *Distephanus speculum*, aloricate ciliates, and tintinnids.

In early September, there was a mixed community including aloricate ciliates, tintinnid ciliates, *Ceratium* species (*C. longipes and C. tripos*), *Dinophysis norvegica*, *Prorocentrum minimum*, and unidentified thecate and athecate dinoflagellates. By late September, the assemblage was dominated by *Ceratium fusus*, *C. longipes*, *Dinophysis norvegica*, *Gymnodinium* spp., and unidentified athecate and thecate dinoflagellates. Other dinoflagellates, which never comprised > 10%, included *Prorocentrum micans* and *Protoperidinium* spp.. Tintinnids accounted for up to 17.6% of cells counted. The nearfield dinoflagellate community continued to be dominated by *Ceratium fusus*, *C. longipes*, *Dinophysis norvegica*, and unidentified thecate and athecate dinoflagellates in early October. *Protoperidinium* spp. (up to 19.5%) was also dominant during this survey. Other dinoflagellates that never comprised > 10% included *C. tripos, Dinophysis* sp., *Gonyaulax spinifera*, *Gymnodinium* sp., and *Prorocentrum micans*. Aloricate ciliates comprised up to 8.5% and tintinnids comprised up to 14.2% of cells counted.

In late October, the dinoflagellate community at the chlorophyll maximum depth was dominated by *Ceratium fusus* (23.6 – 34.7%) and unidentified athecate dinoflagellates (14.9 – 16.8%). Both of these taxa comprised < 5% of cells at the surface. Other dinoflagellates that never comprised > 14.0% at either depth included *Ceratium longipes*, *Dinophysis caudata*, *D. norvegica*, *Gonyaulax* sp. *Gyrodinium* sp., *Protoperidinium depressum*, *Protoperidinium* spp., and unidentified thecate dinoflagellates. Aloricate ciliates comprised 5.9 – 7.4% and tintinnids comprised up to 16.0% of cells counted. The dinoflagellate community continued to be dominated by *Ceratium fusus* (30.4 - 47.8%) and athecate dinoflagellates (8.0 – 16.0%) in November. Other dinoflagellates, which never comprised > 9.1%, included *Ceratium lineatum*, *C. longipes*, *Dinophysis caudata*, *D. norvegica*, *Gyrodinium* sp., *Protoperidinium* sp. and unidentified thecate dinoflagellates. Aloricate ciliates and tintinnids accounted for up to 19.2% and 12.6%, respectively. In December, the dinoflagellate assemblage was dominated by *Ceratium fusus* (29.5 – 37.1%), with subdominants (< 15%) including *C. longipes*, *C. tripos*, *Ceratium* spp., *Dinophysis norvegica*, and unidentified thecate and athecate dinoflagellates. Tintinnids comprised 12.5 – 17.6% of cells counted.

5.3.1.3 Farfield Phytoplankton Assemblages

Whole-Water Phytoplankton - During survey WF03B in late August, microflagellates dominated at both depths at most farfield stations (70.3 – 96.3% of total abundance; **Figure** 5-14). Two stations in Boston Harbor (F23 & F30) were dominated by microflagellates (48.9 – 54.1%), but also had elevated abundances *Skeletonema costatum*, which comprised 8.1 – 28.3% of cells. Cryptomonads made up the remainder of counts at most stations, comprising up to 36.9% of cells counted.

By early October, as in the nearfield, most farfield stations were dominated by unidentified microflagellates (28.8 – 82.0%), but diatoms were also a major component of the assemblages at most stations (**Figure** 5-15). Abundant diatoms included *Dactyliosolen fragilissimus* (up to 27.2%), *Skeletonema costatum* (up to 30.5%), *Asterionellopsis glacialis* (up to 17.5%), and members of the *Pseudo-nitzschia delicatissima* complex (up to 7.5% at station F02 only). This latter category included members of the genus *Pseudo-nitzschia* that were thin in width (2-5 µm), mostly *P. delicatissima* and *P. pseudodelicatissima*, that are distinguishable from the wider *P. pungens*, which are > 10 µm in width, while all three taxa are within the same broad range of cell length (30-100 µm). The remainder of cells at most stations consisted of cryptomonads.

Screened Phytoplankton and Ciliates – In late August, 20-µm screened phytoplankton samples at most stations from the farfield were similar to nearfield assemblages, comprised of a mixture of *Ceratium longipes,* various unidentified thecate and athecate dinoflagellates, aloricate ciliates, and tintinnid ciliates. 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, C. longipes, Dinophysis norvegica*, and *Protoperidinium* sp., various other unidentified thecate and athecate dinoflagellates, and aloricate and tintinnid ciliates.

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 2003. *Phaeocystis pouchetii,* which bloomed in spring, was unrecorded during this period. *Alexandrium* spp. and *A. tamarense* were recorded only 9 and 2 times, respectively, in screened water samples in October. All records were collected at farfield stations and had abundances of < 10 cells l^{-1}, except for a single value of 19.4 cells l^{-1} at station F02 at mid-depth during survey WF02E in October. All of these values were well below the threshold limit for *Alexandrium*, which is 100 cells l^{-1} for any single nearfield screened-water sample. A single cell of *A. tamarense* was also recorded for a whole-water sample from the chlorophyll maximum depth at station N16 during this survey, for a calculated abundance level of 0.0013 x 10^6 cells l^{-1}. Other non-toxic species whose blooms have caused anoxic events elsewhere, such as *Ceratium tripos* were routinely present, but at very low abundances never approaching levels previously associated with anoxia.

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 63 of 92 whole-water phytoplankton samples (68.5%) at abundance levels of 0.1 – 203.9 x 10^3 cells l^{-1} (mean = 16.7 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 26 records (28.3% of samples) for *P. pungens*, at abundance levels of 0.1 – 71.7 x 10^3 cells l^{-1} (mean = 13.2 x 10^3 cells l^{-1}). The nearfield autumn mean value for *P. pungens* (17.9 x 10^3 cells l^{-1}) approached the autumn threshold value (24.6 x 10^3 cells l^{-1}). This will be examined in more detail in the 2003 annual report.

5.3.2 Zooplankton

5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Total zooplankton abundance at nearfield stations (**Table** 5-3) increased from 10.5 x 10^3 animals m^{-3} in early July to higher levels of 28.9 – 35.9 x 10^3 animals m^{-3} in late July and 19.0 – 60.4 x 10^3 animals m^{-3} early August. The seasonal maxima of 50.8 – 115.5 x 10^3 animals m^{-3} occurred in late August. Values declined in September with survey mean abundances of 51.6 and 65.9 x 10^3 animals m^{-3} during WN03C and WN03D, respectively. Lower abundance was evident in early October (14.7 – 36.7 x 10^3 animals m^{-3}) and then a slight increase to levels of 35.3 – 54.5 x 10^3 animals m^{-3} in late October. During the final two surveys of 2003, the normal seasonal decline was evident with levels of 30.0 x 10^3 animals m^{-3} in November and < 12.0 x 10^3 animals m^{-3} in December (**Table** 5-3, **Figure** 5-16).

Farfield sampling generally reflected levels in the nearfield. During late August, zooplankton abundance (13.9 – 139.8 x 10^3 animals m^{-3}) was variable (**Figure** 5-17a), with a range slightly 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, with most values <25 x 10^3 animals m^{-3} (**Figure** 5-17b).

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.*, 2003b). In 2003, however, the relative number of ctenophores was lower and did not result in a substantial decline in zooplankton abundance in comparison to previous years, although the lower abundance in October could reflect increased ctenophore predation.

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

Survey	Dates (2003)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WN038	7/9	10.5	10.2-10.8	--	--
WN039	7/21	32.4	28.9-35.9	--	--
WN03A	8/4	39.7	19.0-60.4	--	--
WF03B	8/18-21	78.9	50.8-115.5	88.5	13.9-139.8
WN03C	9/10	51.6	46.7-56.6	--	--
WN03D	9/25	65.9	53.2-78.6	--	--
WF03E	10/6-9	25.5	14.7-36.7	24.9	3.7-88.1
WN03F	10/31	44.9	35.3-54.5	--	--
WN03G	11/18	29.6	29.2-30.0	--	--
WN03H	12/19	11.6	11.3-11.9	--	--

5.3.2.2 Nearfield Zooplankton Community Structure

In early July, nearfield zooplankton assemblages were dominated by copepod nauplii (15 - 28%), *Oithona similis* copepodites (18 – 25%) and females (up to 9%), with subdominant contributions by copepodites and females of the genus *Pseudocalanus*, which could include members of two species that are distinguished only with difficulty, *P. newmani* and *P. moultoni*. Copepodites of *Temora longicornis* and *Calanus finmarchicus* made up most of the remainder. In late July, there was similar dominance by copepod nauplii (29 - 33%), *Oithona similis* copepodites (32 – 43%) and females (up to 7%), with subdominant contributions by copepodites of *Temora longicornis* and *Calanus finmarchicus*.

From early August to early September, the nearfield zooplankton assemblages continued to be dominated by copepod nauplii and *Oithona similis* copepodites and females, with lesser contributions by copepodites of *Pseudocalanus* sp. and *Temora longicornis*. By late September, copepod nauplii and *Oithona similis* copepodites and females were somewhat less dominant and subdominants included *Pseudocalanus* sp. copepodites and *Oikopleura dioica*. At nearfield stations in early October, copepod nauplii and *Oithona similis* copepodites and females shared dominance with bivalve veligers (9 - 32%). There were variable contributions by *Pseudocalanus* spp. copepodites, *Centropages* spp. copepodites, *Paracalanus crassirostris* copepodites, and echinoderm plutei.

In late October, nearfield dominance by copepod nauplii and *Oithona similis* copepodites was shared with *Centropages* spp. copepodites, *Pseudocalanus* spp. copepodites and bivalve veligers. Similar assemblages were observed in November and December, comprised mainly of copepod nauplii, *Oithona similis* copepodites and females, *Centropages* spp. copepodites, *Pseudocalanus* spp. copepodites and *Paracalanus parvus* copepodites. *Microsetella norvegica* was a subdominant species in the December samples.

5.3.2.3 Farfield Zooplankton Assemblages

At farfield stations in late August, copepod nauplii were dominants (29 - 58%), followed by *Oithona similis* copepodites (5 - 36%) and females (up to 9%). Additional sporadically-abundant taxa included *Pseudocalanus* spp. copepodites (8 - 29% everywhere except for station F30 in Boston Harbor), *Temora longicornis* copepodites (8% at station F01 in Cape Cod Bay and 16% at station F31 in Boston Harbor, but < 5% elsewhere), *Calanus finmarchicus* copepodites (19% at boundary station F27, but < 5% elsewhere), and *Acartia* spp. copepodites (12% at station F23 and 29% at station F30 in Boston Harbor, but < 5% elsewhere).

At farfield stations in October, copepod nauplii comprised 5 - 44% of animals counted and *Oithona similis* copepodites were 9 - 42% everywhere except for station F30 in Boston Harbor. Other sporadically-recorded taxa were *O. similis* females, *Pseudocalanus* spp. copepodites, *Temora longicornis* copepodites, *Centropages* spp. copepodites, and *Microsetella norvegica*. *Acartia tonsa* females and *Acartia* spp. copepodites were observed at Boston Harbor stations, but not at any station outside of the harbor. Meroplankton were sporadically abundant at some stations. Bivalve veligers were 10 - 45% of animals recorded at stations F01 and F02 in Cape Cod Bay, at offshore station F06, at coastal stations F24 and F25, and stations F23 and F31 in Boston Harbor. Echinoderm plutei comprised up to 19% at some stations, and polychaete larvae were 18% of animals recorded at station F30 in Boston Harbor.

In summary, zooplankton assemblages during the second half of 2003 were comprised of taxa normally recorded for this time of year in previous MWRA monitoring data. Despite the widespread and long-lasting presence of ctenophores throughout most of this period, zooplankton abundances in the second half of 2003 were much higher than in 2002.

5.4 Summary of Water Column Biological Results

- Areal production in the later half of 2003 at the nearfield sites was similar to patterns typically observed in prior years with a major bloom occurring during the fall period.
- Productivity at station N04 was elevated relative to station N18 from July through late September but the fall bloom peak was initiated earlier and reached higher levels at station N18.
- The fall bloom peaks at both nearfield sites in 2003 were lower than peak fall bloom values observed during the post outfall period but within the range of values observed from 1995 to 1999.
- Chlorophyll-specific production reached higher levels at station N18 compared with N04.
- Respiration rates were relatively low ($\leq$0.22 µM O_2 hr^{-1}) in July – December 2003.
- Nearfield respiration rates reached a maximum for this time period in early July (0.22 µM O_2 hr^{-1}) in the surface waters at station N18 and peaked again in late September and early October at the initiation of the fall bloom. Respiration rates were relatively low in late October and November when production rates peaked.
- Maximum nearfield POC concentrations were reached in July and August – ~50 µM. Secondary peaks were coincident with the October and November fall bloom. Overall POC concentrations were relatively low.
- Respiration was significantly ($P<0.001$) correlated with both temperature and POC concentration.
- Carbon-specific respiration rates reached a maximum of 0.008 µM O_2 µM C^{-1} hr^{-1} in nearfield and farfield surface waters in August. Rates were low during the late fall bloom as biomass concentrations were relatively high and cooler temperatures led to lower respiration rates.
- There was a fall diatom bloom throughout the sampling area that began in late September and continued through October and into November.
- The whole water phytoplankton assemblage was dominated by unidentified microflagellates except during the fall bloom when the chain-forming centric diatoms were abundant. These included *Dactyliosolen fragilissimus*, *Skeletonema costatum*, and *Asterionellopsis glacialis*.

- The >20-µm screened dinoflagellate assemblage from July through October included primarily members of the genus *Ceratium,* as in previous years, but they were not as dominant and occurred at abundance levels generally below the baseline range.
- There were no confirmed blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during July – December 2003, although the potentially-toxic diatom *Pseudo-nitzschia pungens* was present throughout much of the area from July through December. The autumn nearfield mean abundance (17.9 x 10^3 cells l^{-1}) for this species approached the *Pseudo-nitzschia "pungens"* threshold value (24.6 x 10^3 cells l^{-1})
- Trace levels (< 20 cells l^{-1}) of *Alexandrium* spp. were recorded for a few samples in October.
- Zooplankton abundance decreased from maximum levels in August, through the fall into December. The rate of decline, particularly in early October, may have been due in part to ctenophore predation.
- The reduction in zooplankton abundance possibly contributed to the 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. copepodites and adults.

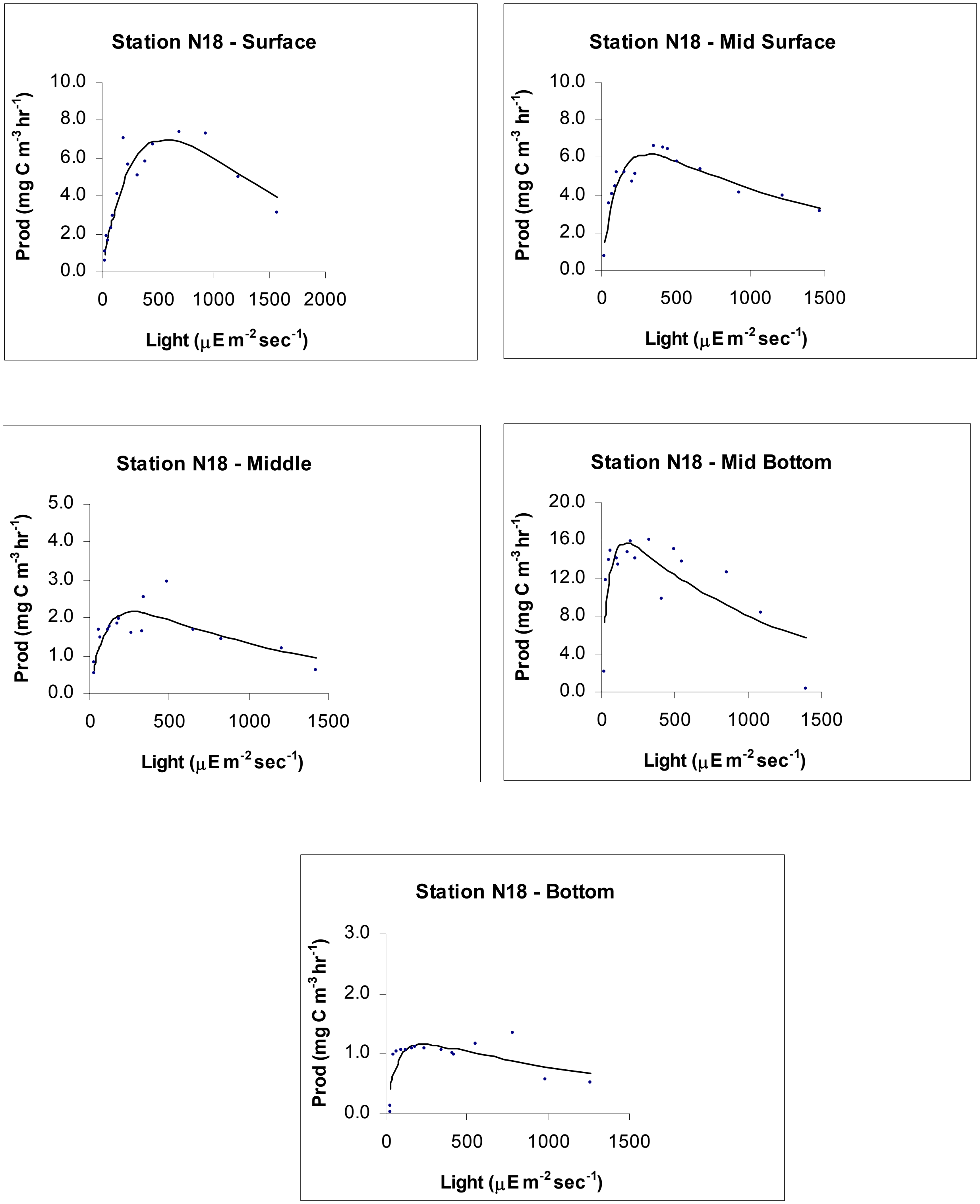


Figure 5-1. An example photosynthesis-irradiance curve from station N18 collected in July 2003

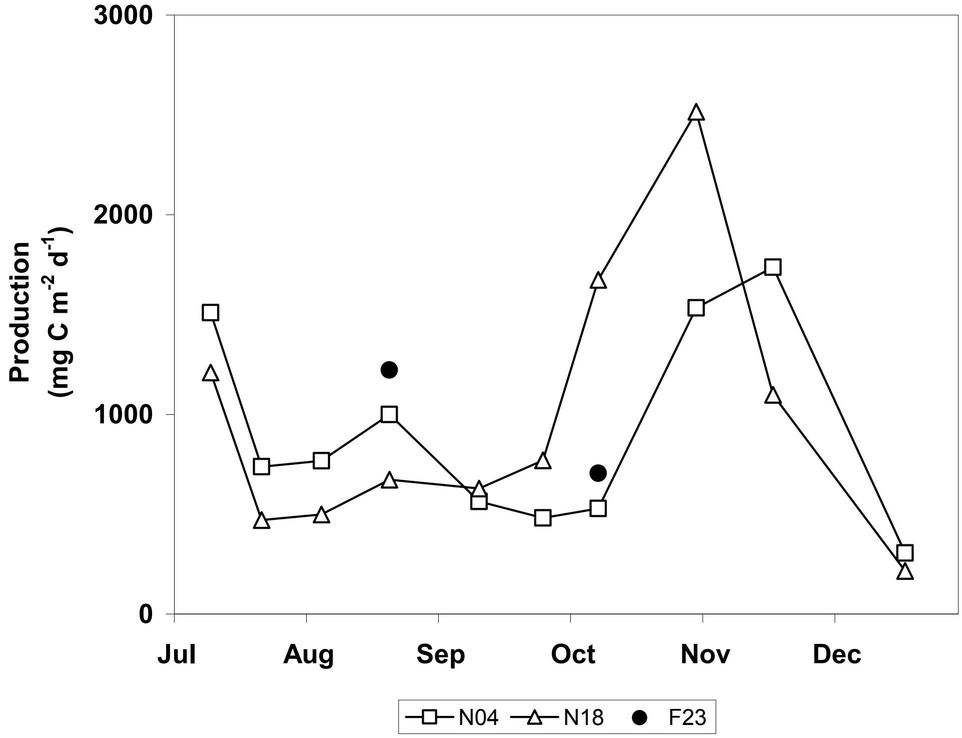


Figure 5-2. Time-series of potential areal production ($mgCm^{-2}d^{-1}$) for stations N04, N18 and F23

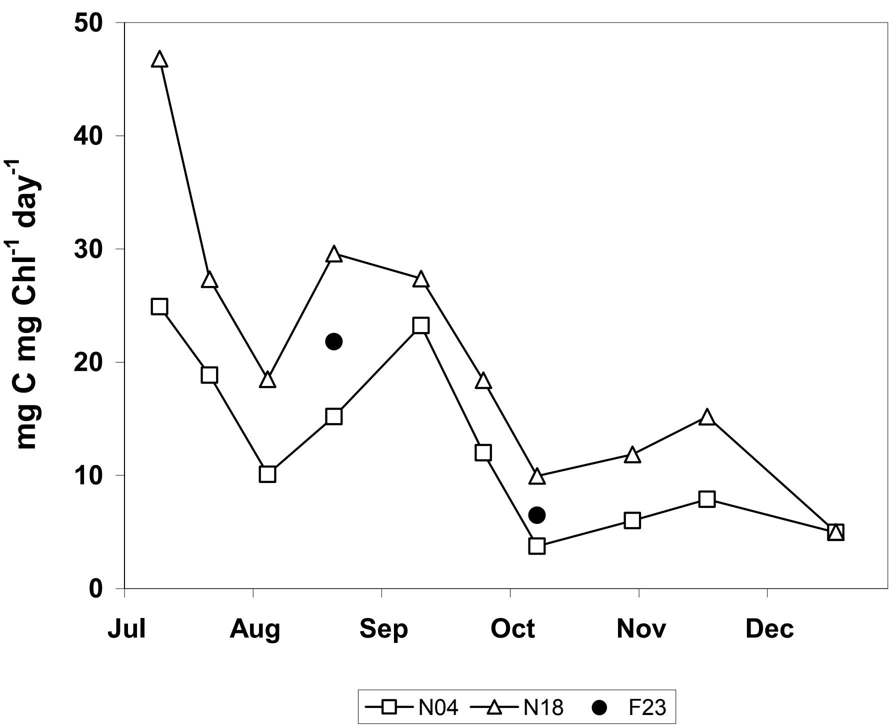


Figure 5-3. Time-series of depth-averaged chlorophyll-specific potential production ($mgCmgChl^{-1}d^{-1}$) for stations N04, N18 and F23

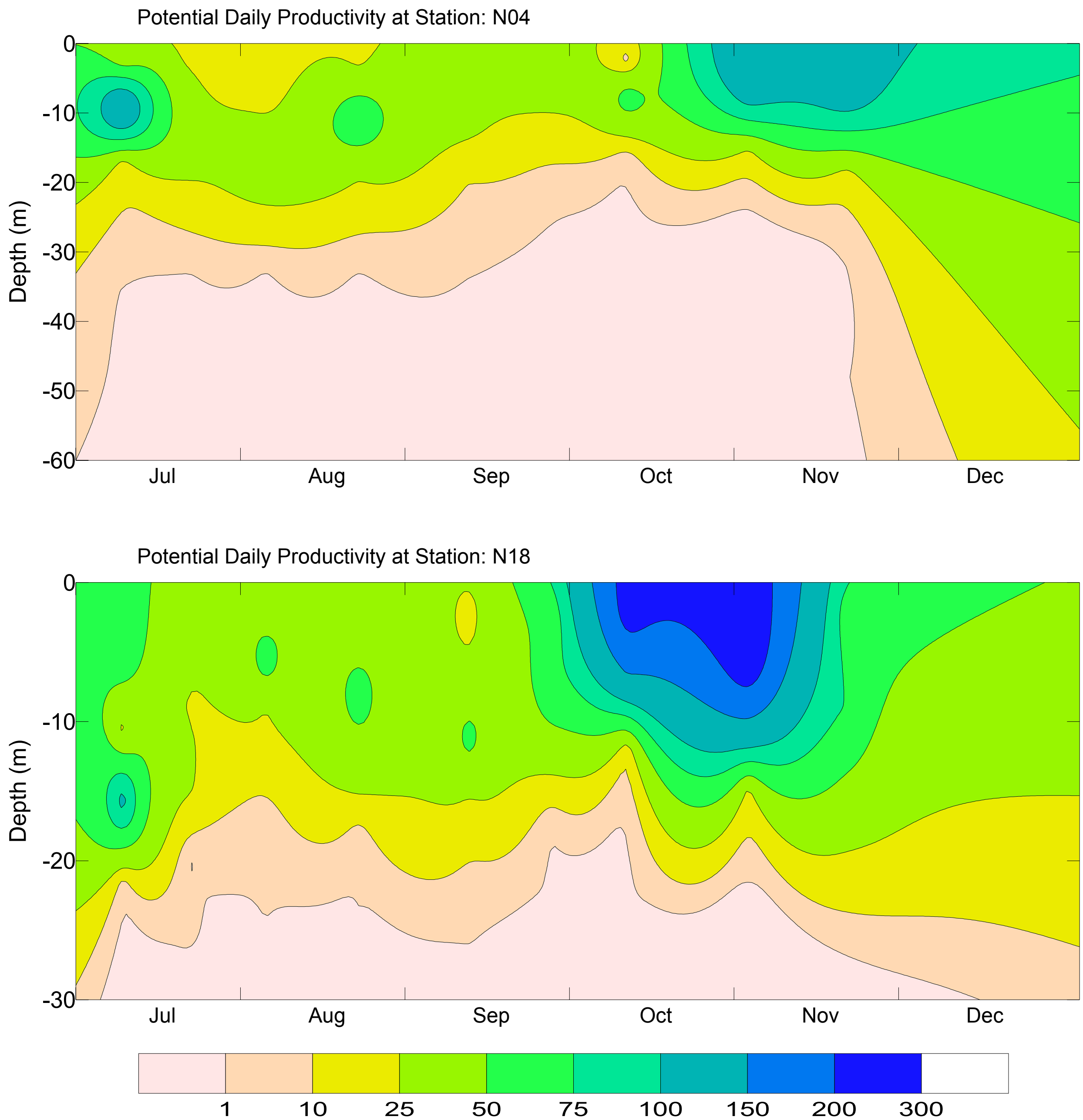


Figure 5-4. Time-series of contoured daily potential production ($mgCm^{-3}d^{-1}$) over depth at stations N04 and N18

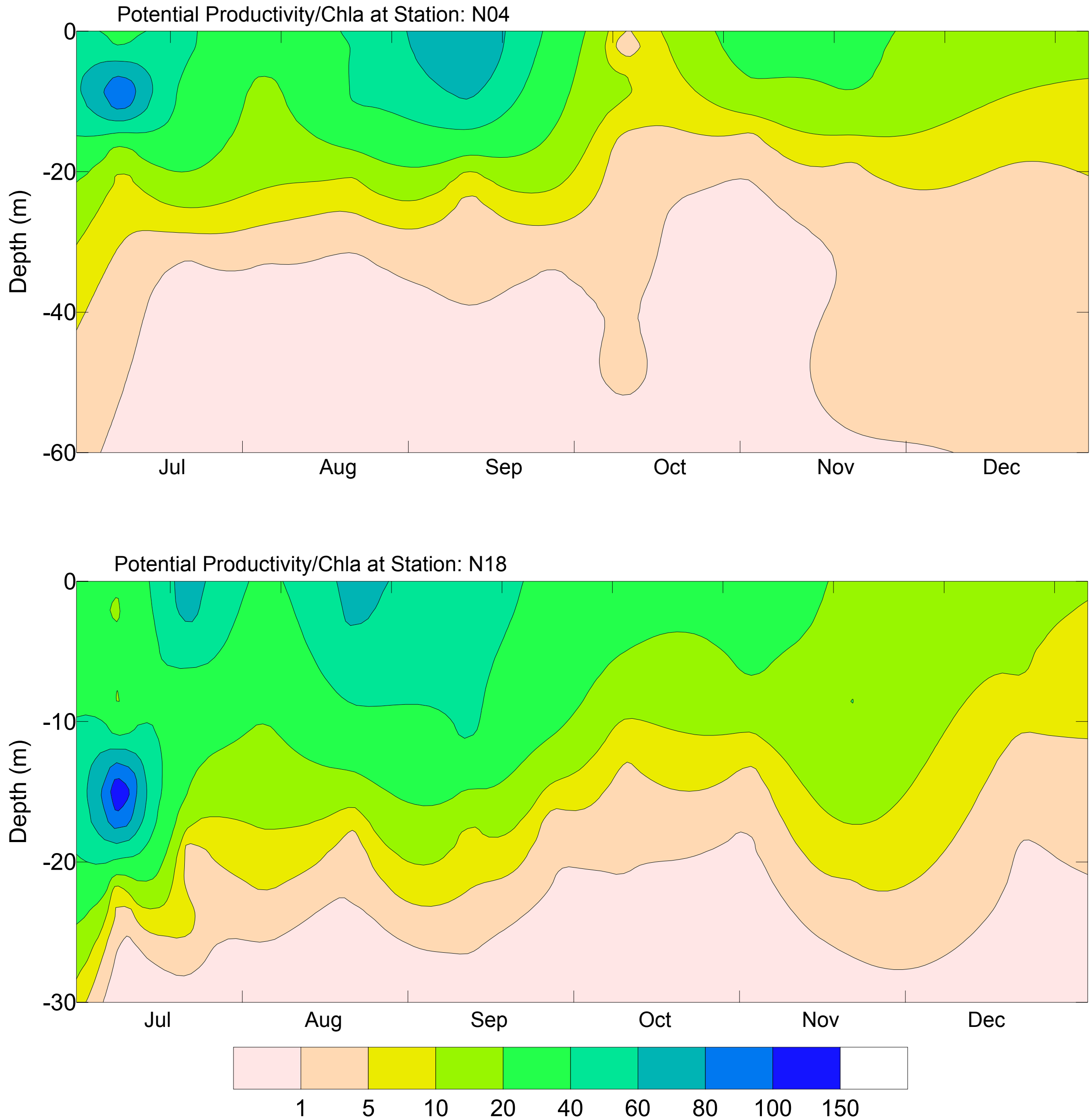
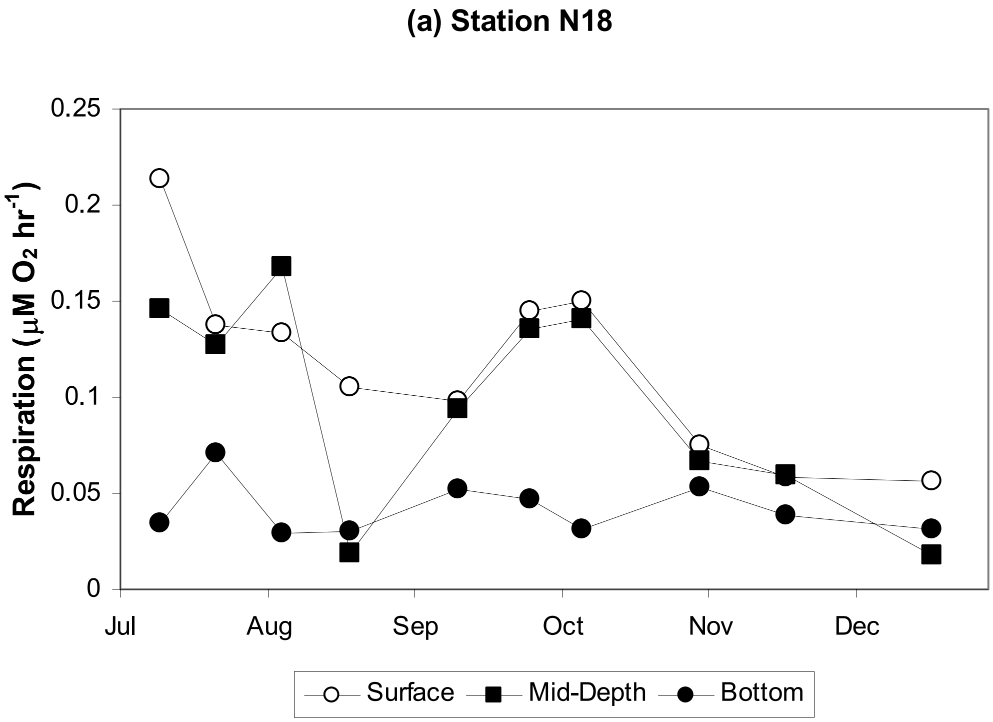


Figure 5-5. Time-series of contoured chlorophyll-specific potential production ($mgCmgChla^{-1}d^{-1}$) over depth at station N04 and N18



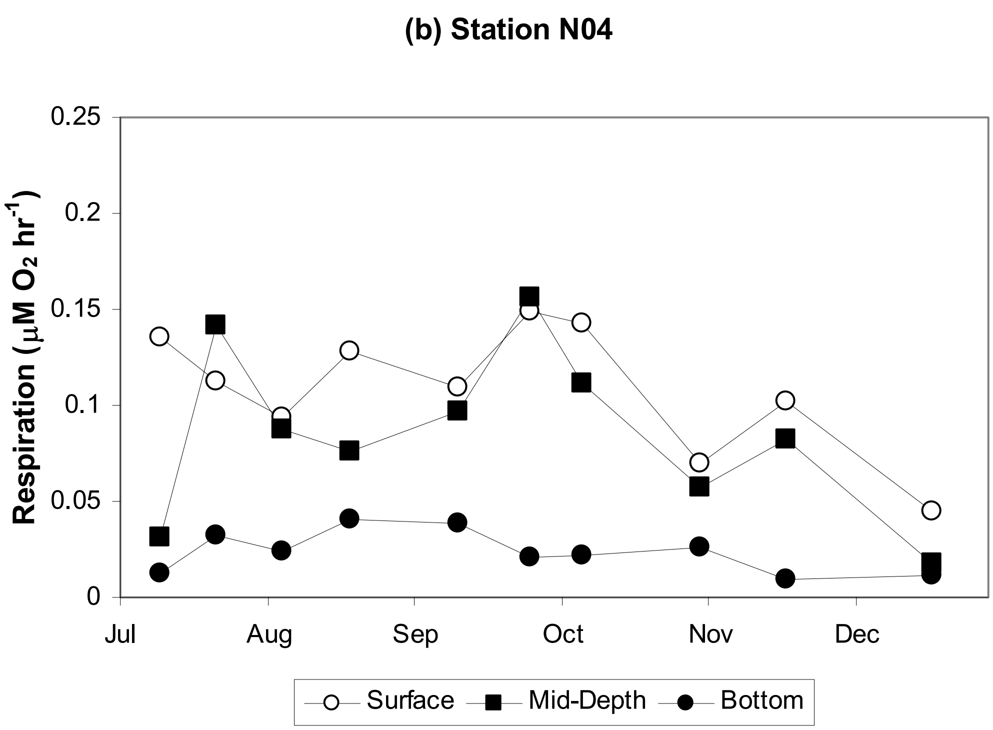
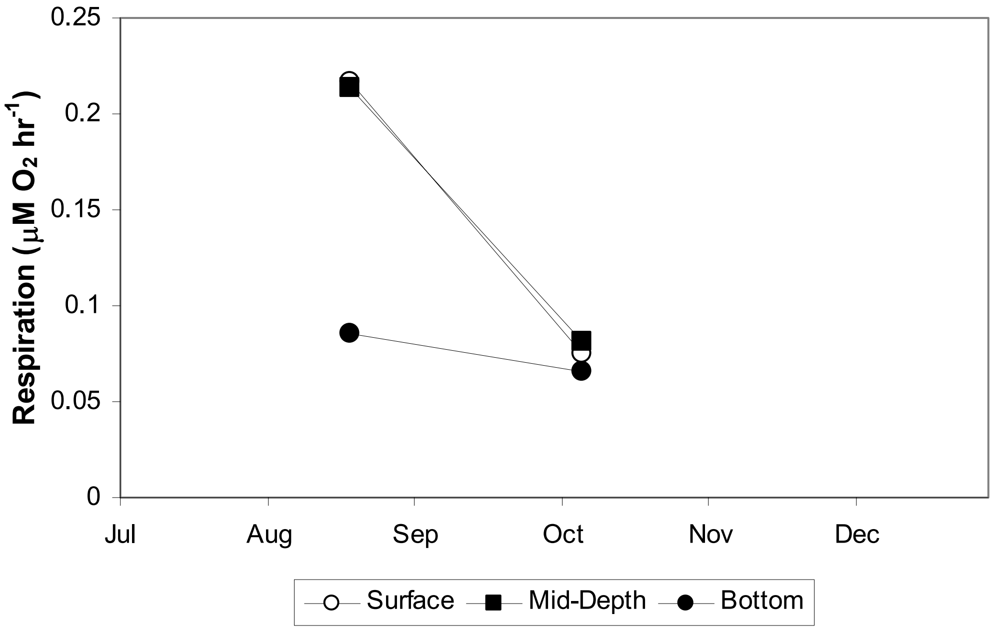


Figure 5-6. Time series plots of respiration (μM$O_2$$hr^{-1}$) at stations N18 and N04

(a) Station F23



(b) Station F19

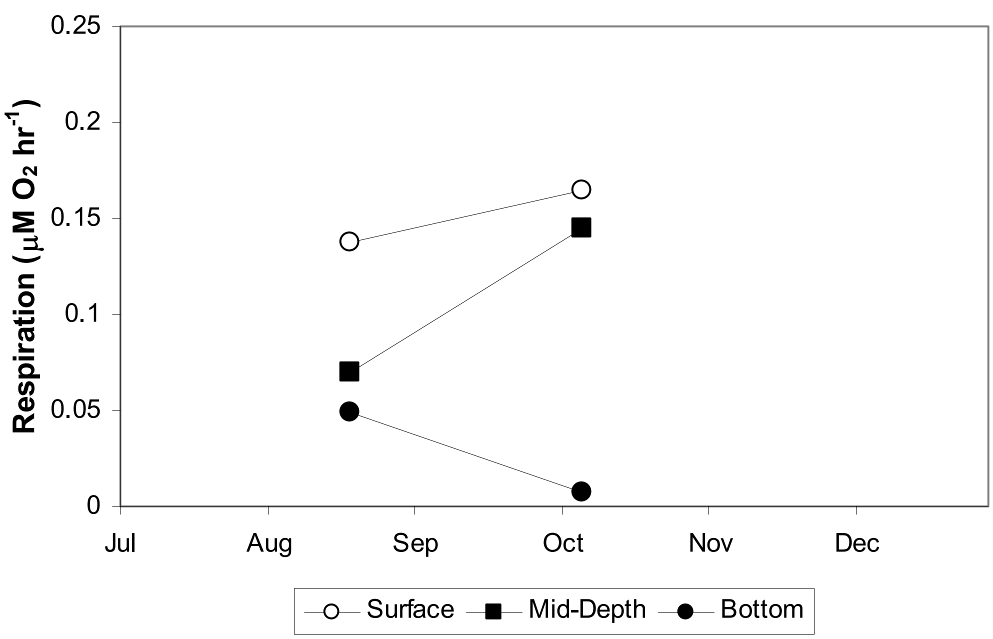
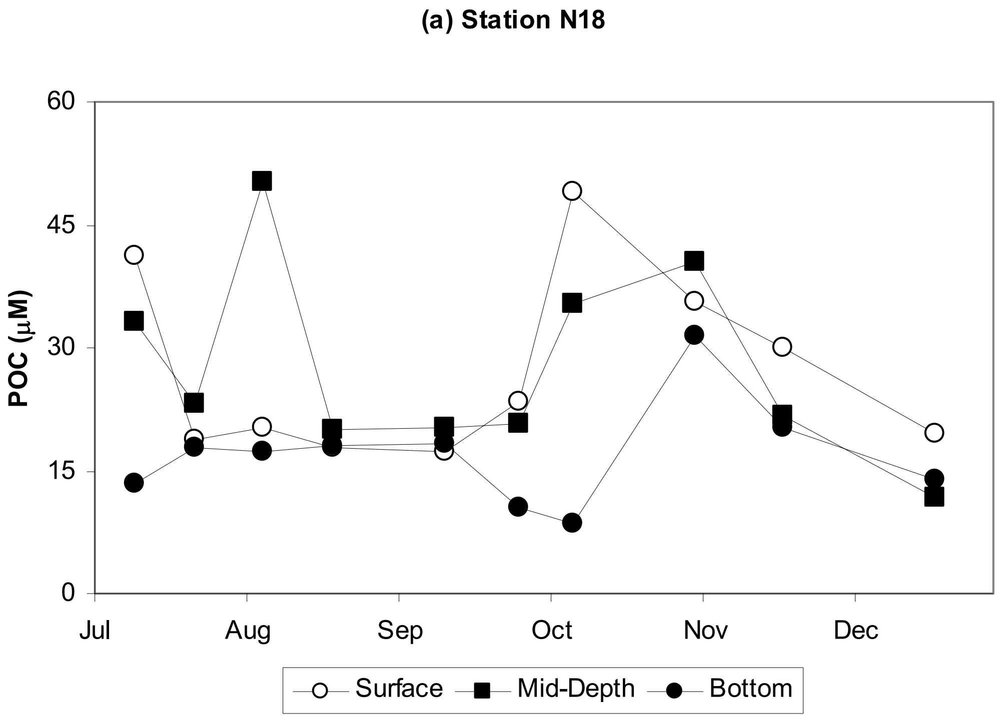


Figure 5-7. Time series plots of respiration (μMO_2hr^{-1}) at stations F23 and F19



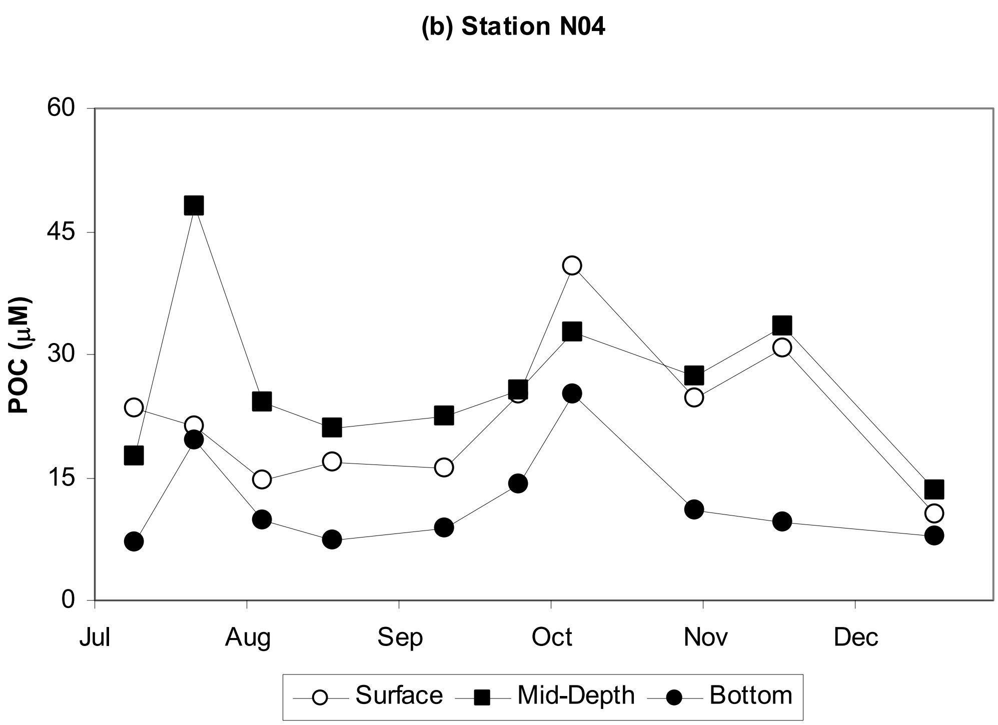
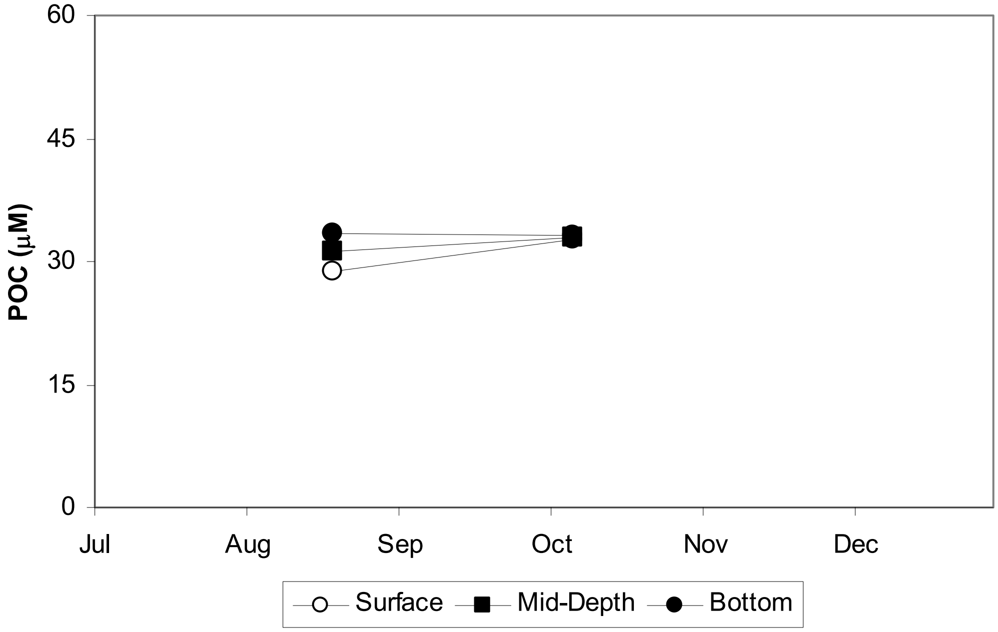


Figure 5-8. Time series plots of POC (μMC) at stations N18 and N04

(a) Station F23



(b) Station F19

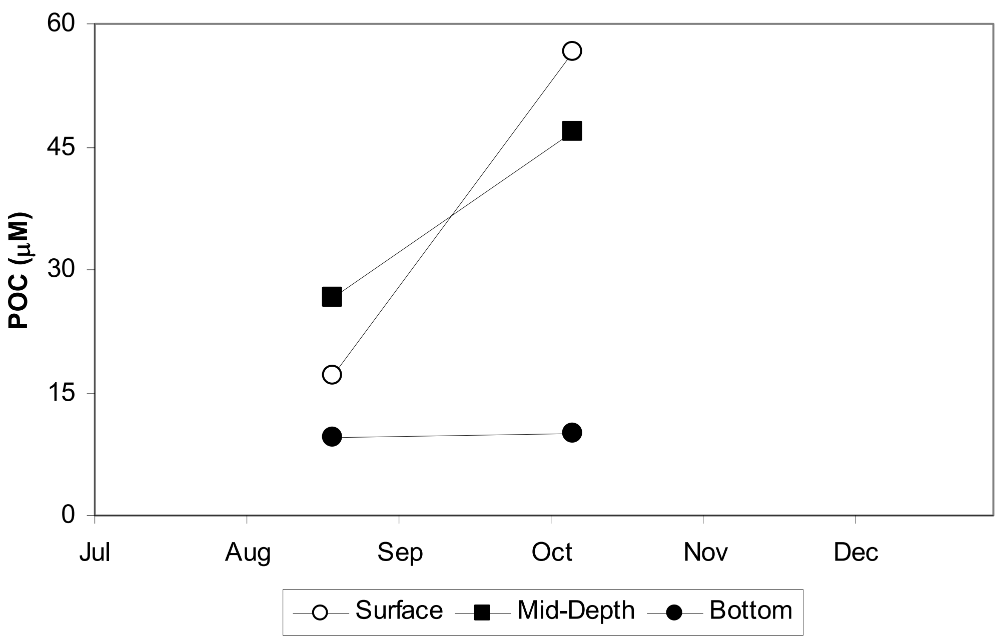
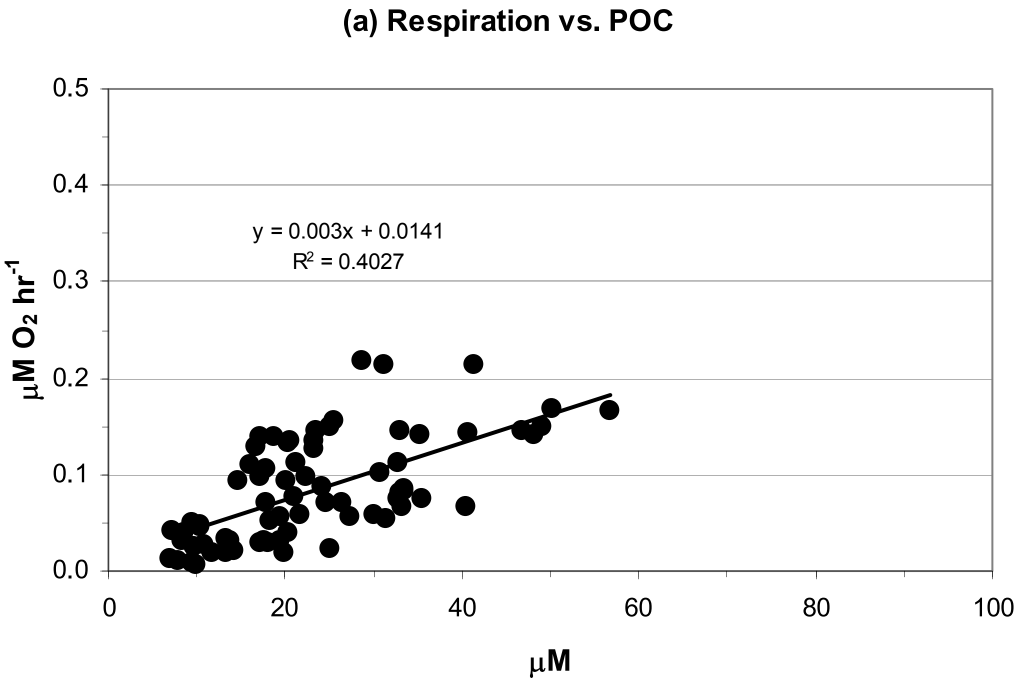


Figure 5-9. Time series plots of POC (μMC) at stations F23 and F19



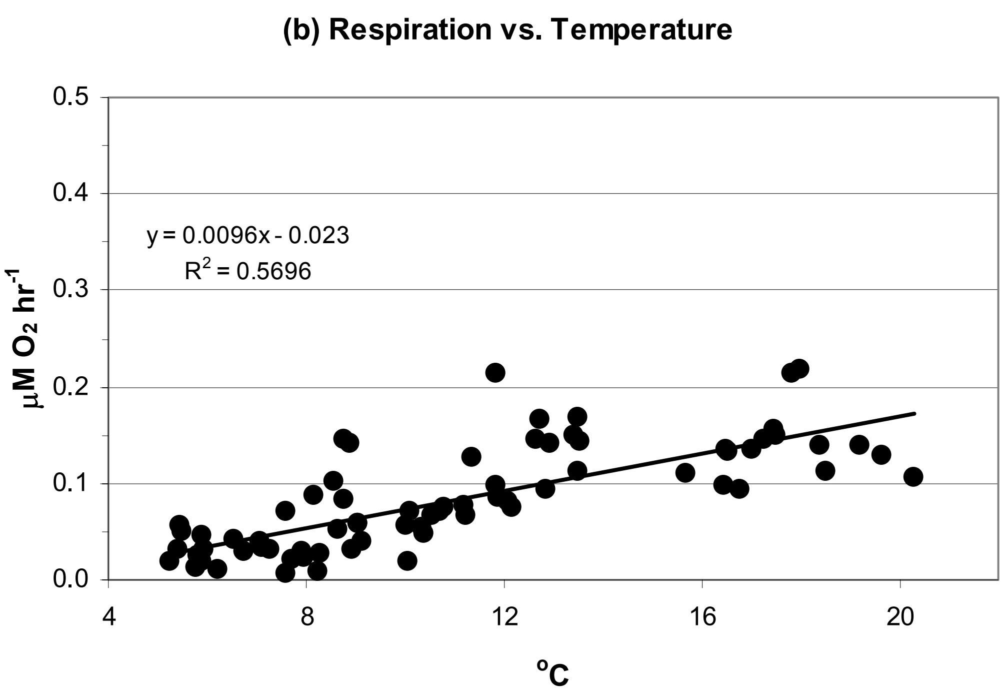
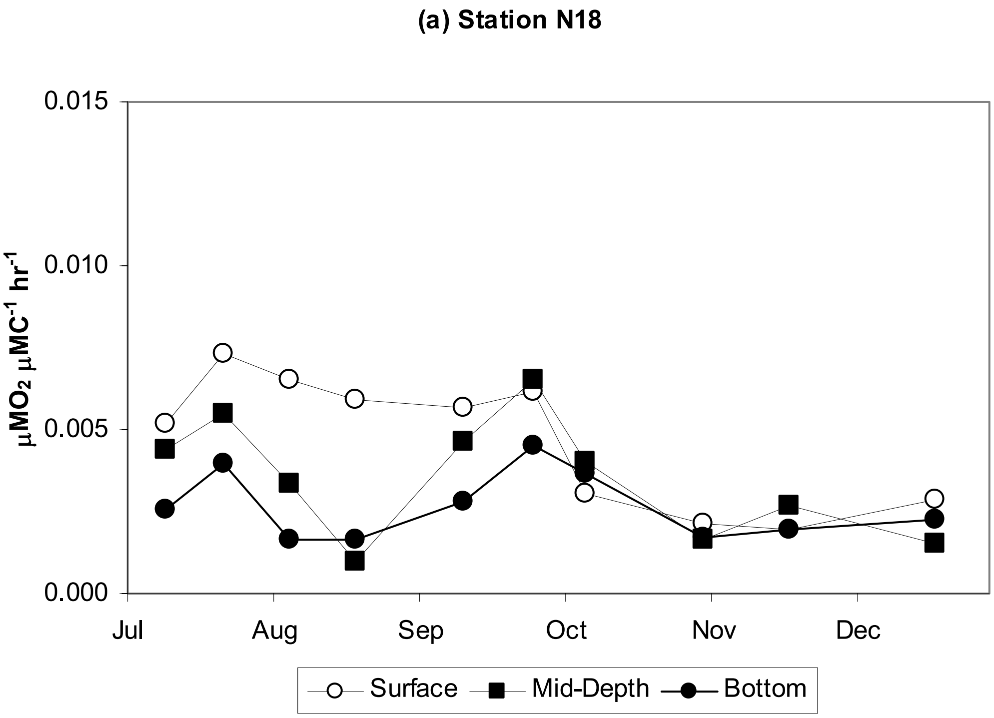


Figure 5-10. Comparison of respiration rate versus a) POC concentration and b) temperature for data collected at stations N04, N18, F19 and F23 in July – December 2003.



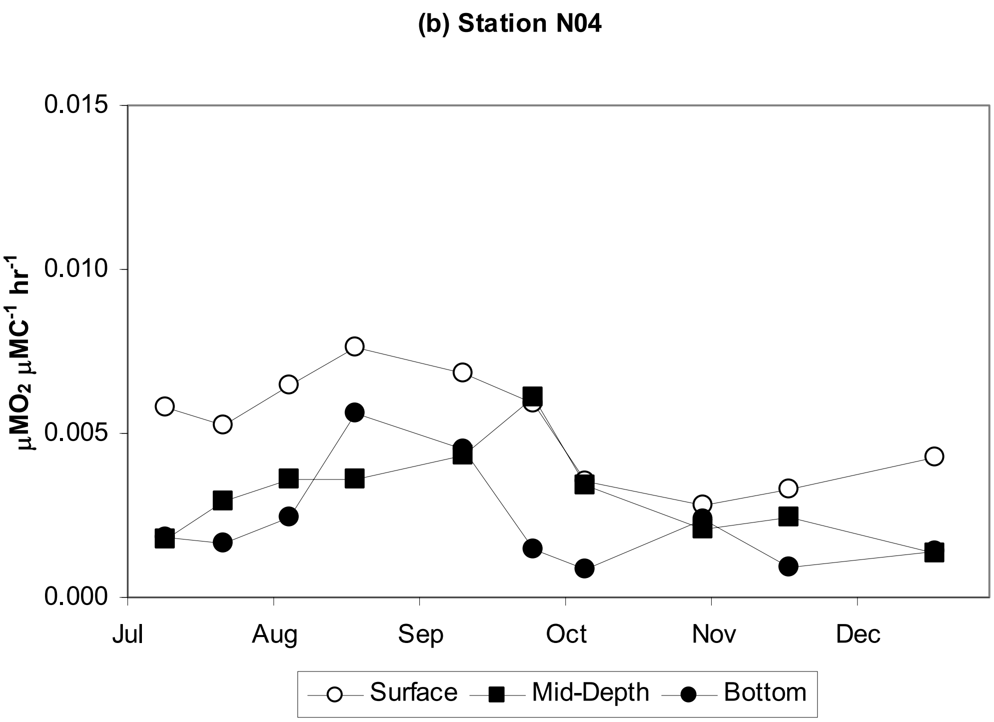


Figure 5-11. Time series plots of carbon-specific respiration ($\mu MO_2 \mu MC^{-1}hr^{-1}$) at stations N18 and N04

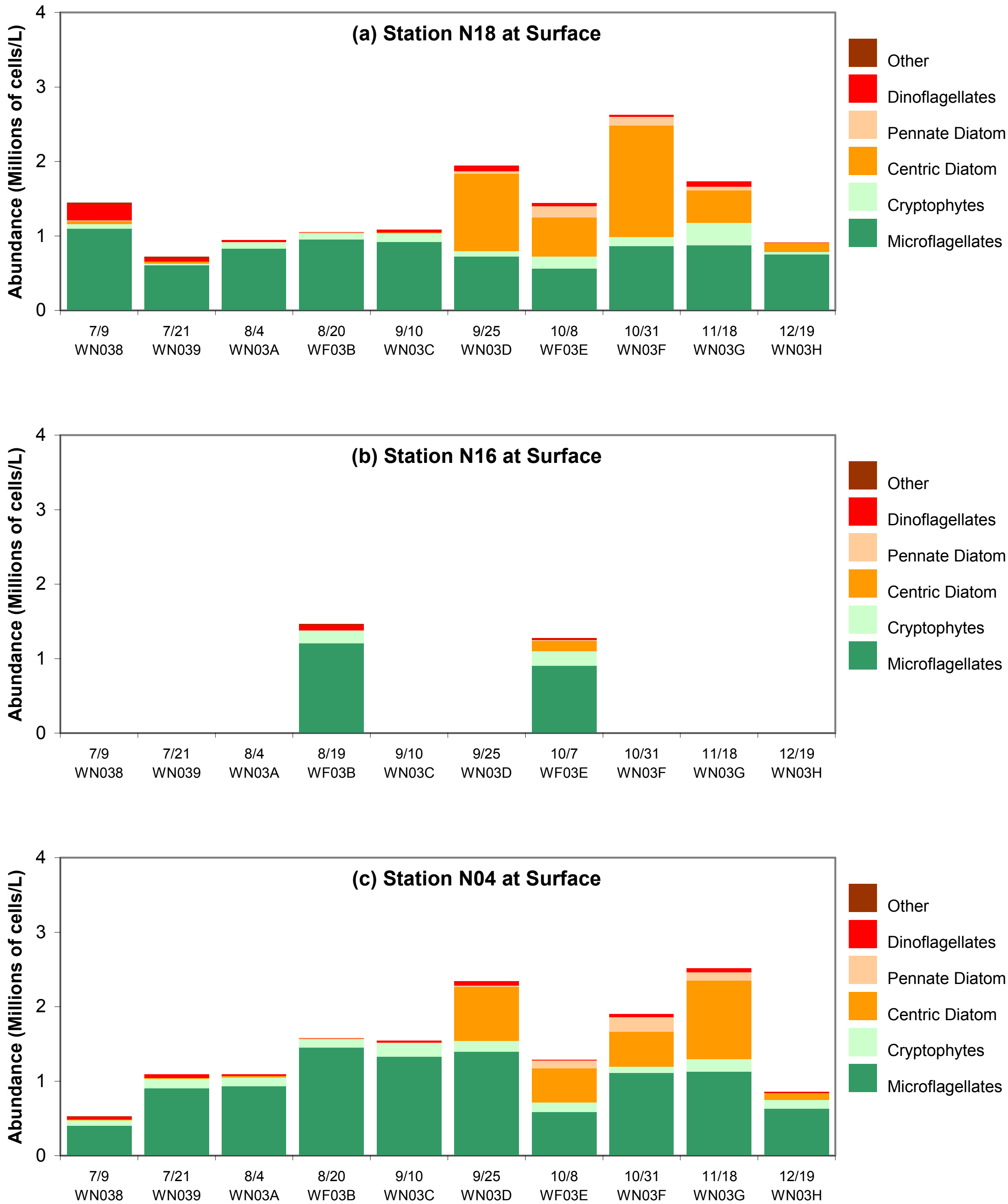


Figure 5-12. Phytoplankton abundance by major taxonomic group, nearfield surface samples

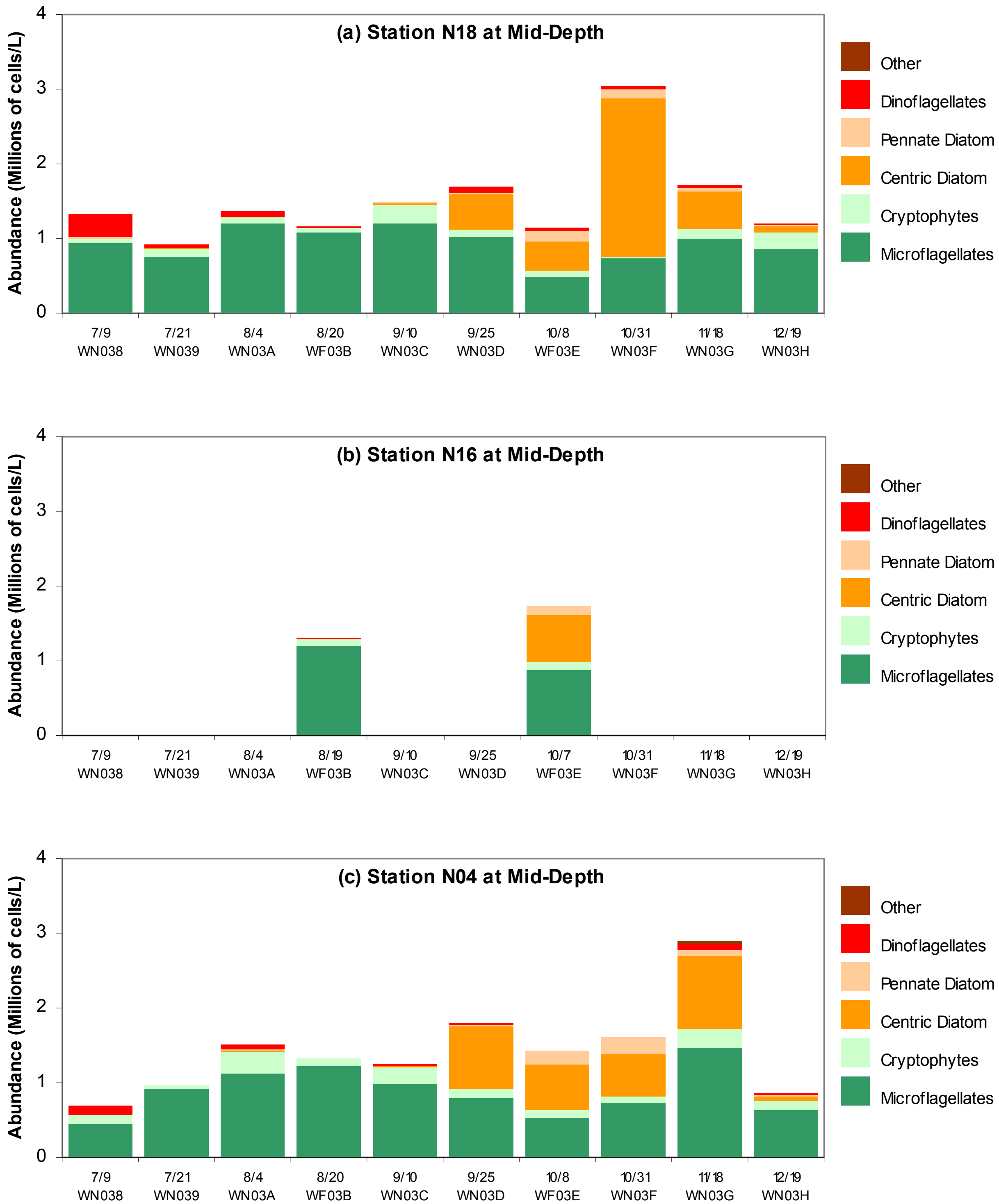


Figure 5-13. Phytoplankton abundance by major taxonomic group, nearfield mid-depth samples

Figure 5-14. Phytoplankton abundance by major taxonomic group, WF03B farfield survey (August 19-22)

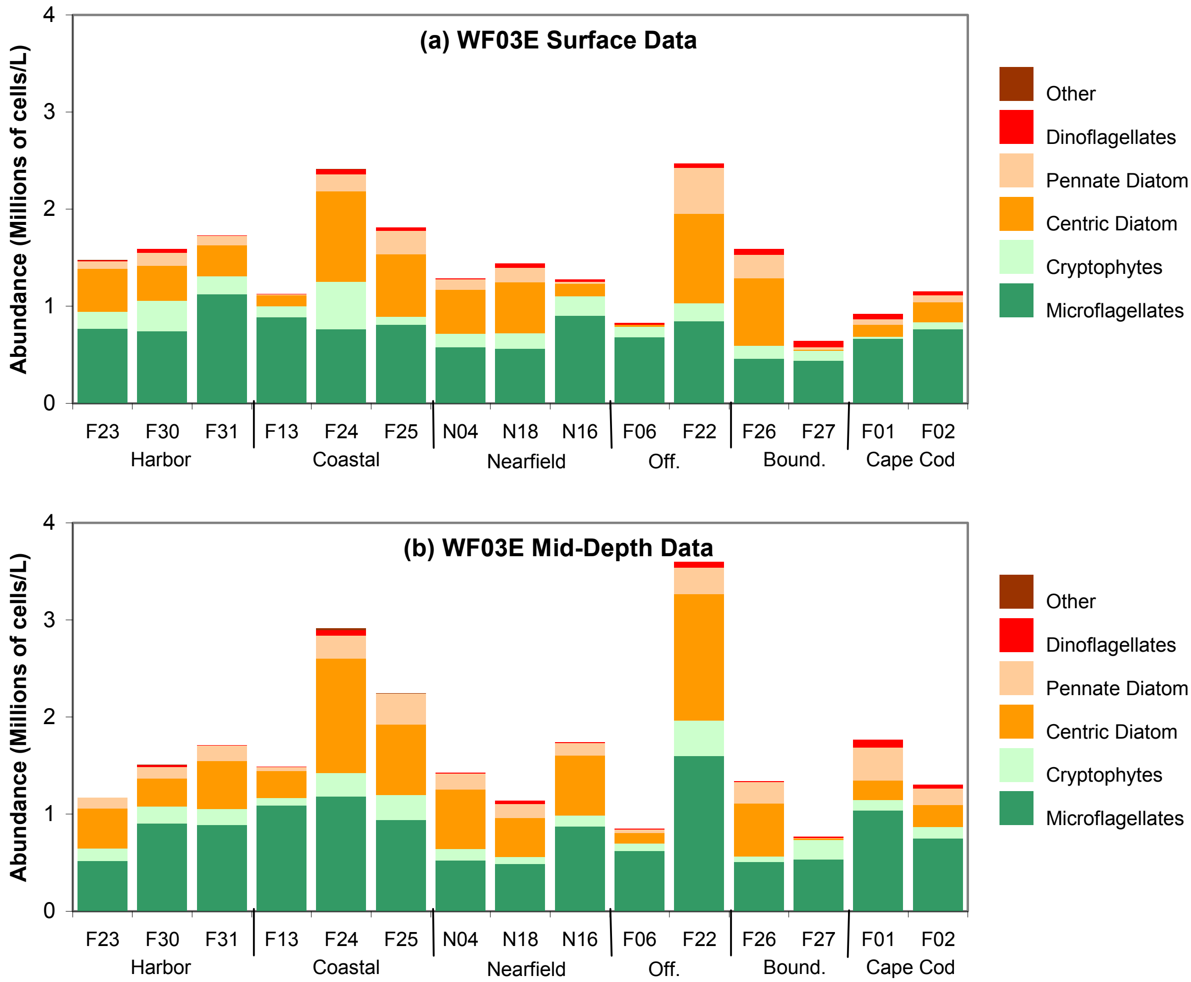


Figure 5-15. Phytoplankton abundance by major taxonomic group, WF03E farfield survey (October 7, 9, 10, 15)

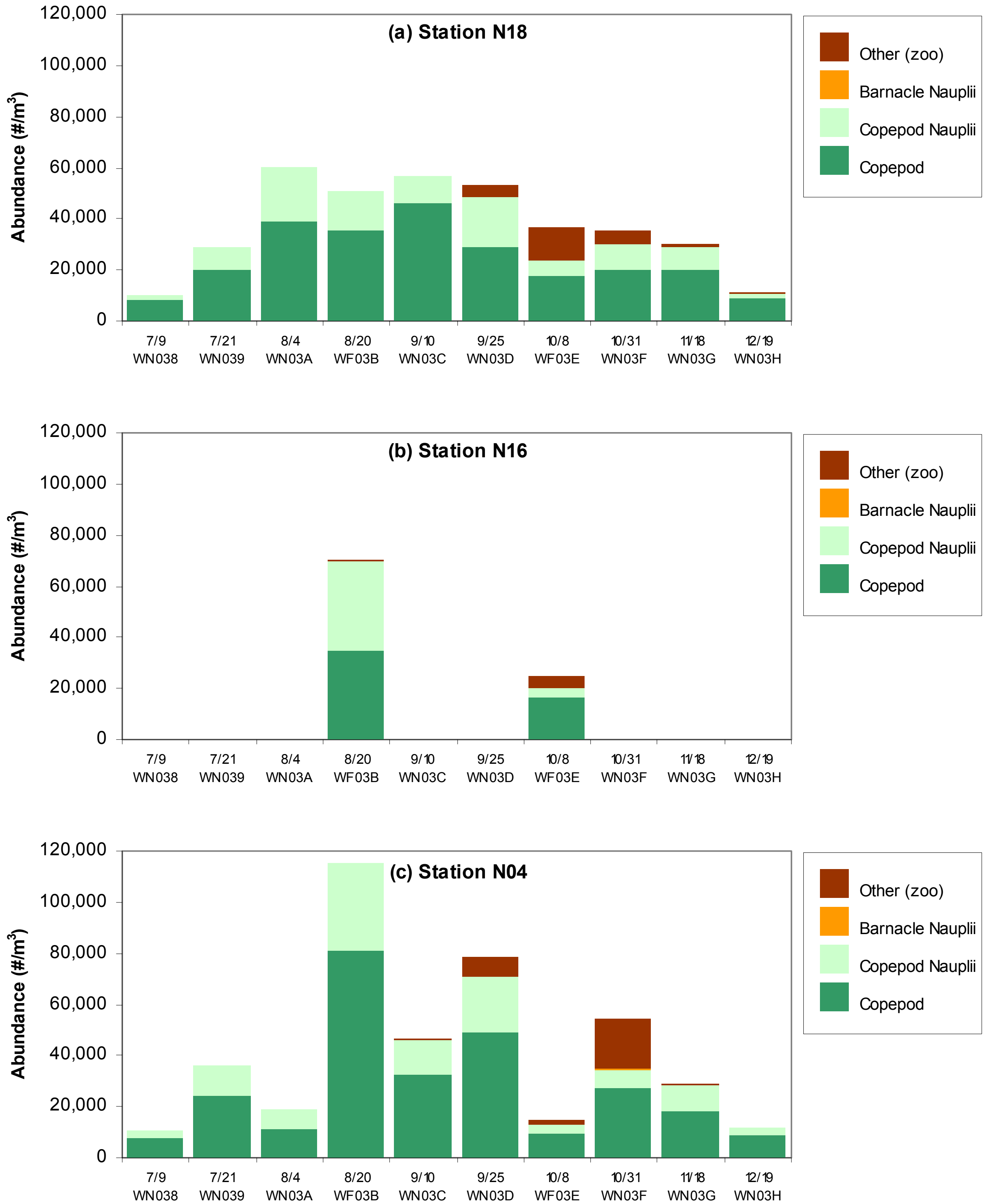


Figure 5-16. Zooplankton abundance by major taxonomic group, nearfield samples

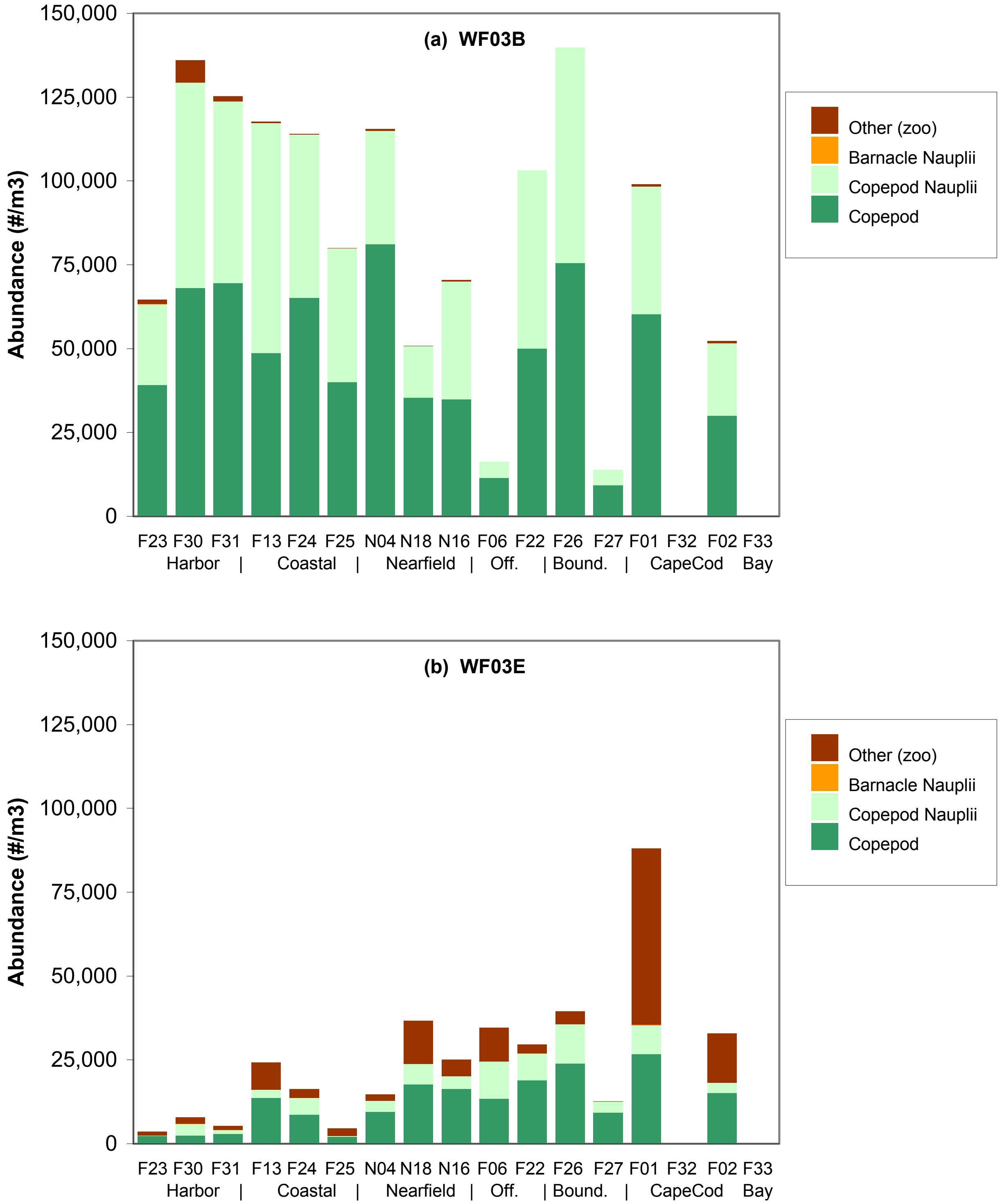


Figure 5-17. Zooplankton abundance by major taxonomic group (a) WF03B farfield survey (August) and (b) WF03E farfield survey (October)

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 2003, although the water column remained weakly stratified through November and the fall bloom occurred over a prolonged period from late September into December.

The primary physical characteristic of this period was the delay in the overturn of the water column and the return to winter conditions. Regionally, seasonal stratification had deteriorated at the coastal and Boston Harbor stations and had begun to weaken offshore by the October survey. In the nearfield, stratification was breaking down by late September, but a weak density gradient remained throughout the fall. It was not until December that fully well-mixed conditions were observed over the entire nearfield. This represents a late transition to winter conditions as compared to previous years, although 2003 was similar to data observed in fall/winter 2001. The weak stratification in October and November allowed a steady influx of nutrients to the surface waters, which supported the prolonged late fall bloom.

The general trend in nutrient concentrations during the 2003 July to December period was similar to previous years, although the late breakdown in stratification delayed the development of typical fall nutrient conditions until later in the season. Seasonal stratification led to persistent nutrient depleted conditions in the upper water column due to biological utilization. It also ultimately led to an increase in nutrient concentrations in bottom waters due to increased rates of respiration and remineralization of organic matter. In late fall, nutrient concentrations began to increase with the breakdown of stratification. Although nutrient concentrations were replete throughout the water column by November, persistent weak stratification and the late fall bloom kept nutrients at moderate levels until December. This weak stratification caused a moderate nutrient flux into surface waters, which likely supported the prolonged fall bloom. By December, nutrient concentrations returned to more typical winter values as the water column became well mixed. 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.

The patterns observed in biological parameters were coupled in July-December 2003. Each of the biological parameters peaked during the prolonged fall diatom bloom observed from late September through November. Centric diatoms were increasing in abundance by late September concomitant with increasing biomass. Nearfield POC and chlorophyll concentrations peaked in early October (40 μM and 10 $\mu g/L^{-1}$, respectively). Areal production doubled at station N18 from September to early October and reached a seasonal maximum of 2,400 mg C m^{-2} d^{-1} at this station in late October. Production at station N04 increased from early to late October and peaked at 1,700 mg C m^{-2} d^{-1} in November. These peaks in production were concomitant with phytoplankton abundance maxima with station N18 peaking in late October and station N04 in November. POC and chlorophyll concentrations remained elevated in October and November, but not at the peak concentrations observed in early October. SeaWiFS imagery and the fluorescence data from the USGS mooring corroborate both the magnitude and the spatial and temporal extent of elevated chlorophyll concentrations from late September into December (image on December 12, 2003 with concentrations of 5-10 $\mu g/L^{-1}$; Appendix D). By mid-December, the late fall bloom had ended and production, phytoplankton abundance and biomass all were at or close to the minima observed for the July – December 2003 period.

One of the distinct features in fall 2003 was the bloom which lasted from late September into December. Even though it was prolonged, the relative magnitude of the bloom was minor in comparison to past fall blooms. Phytoplankton abundance peaked in the nearfield at 2.3 million cells L^{-1} in comparison to a baseline survey mean peak of nearly 4 million cells L^{-1}. Peak productivity was also lower in 2003 compared with prior years. The fall blooms observed at nearfield stations in 1995-2002 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. Chlorophyll and POC concentrations were comparable to previous fall blooms, but the timing of the peak values was later then typically observed.

The fall 2003 phytoplankton bloom was a mixed assemblage of centric diatom species typically observed in Massachusetts Bay in the fall. In late September and early October, the assemblage was dominated by *Dactyliosolen fragilissimus* and *Skeletonema costatum*. By late October and into November, the dominant diatom species were *Leptocylindrus danicus* and *L. minimus*. *Asterionellopsis glacialis* was a subdominant species during the two October surveys.

Zooplankton assemblages during the second half of 2003 were comprised of taxa typically recorded for this time of year. Despite the presence of ctenophores throughout most of this period, zooplankton abundances in the second half of 2003 were higher than in 2002. Tissue from the ctenophore *Mnemiopsis leidyi* were observed in zooplankton samples, but not to the degree observed in 2002. The field team only had to pre-screen the zooplankton sampled during the October farfield survey and the volume of ctenophores removed were less than 10% of those from 2002. Nonetheless, the zooplankton abundances during the October survey were lower than typically observed, suggesting that increased grazing pressure by ctenophores may have both decreased zooplankton abundance and contributed to the occurrence of the fall bloom. The impact of ctenophore grazing, however, was not as apparent as observed in late summer/early fall 2002.

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 45 and 87 mg m^{-2} respectively, which is approximately 50% of the caution threshold value. These seasonal values in combination with the high winter/spring 2003 mean resulted in an annual areal chlorophyll mean of 99 mg m^{-2}. Although this value is considerably higher than the 2001 and 2002 annual means (67 and 82 mg m^{-2}, respectively), it is still well below the caution threshold of 107 mg m^{-2} (**Table** 6-1).

The 2003 nearfield survey mean bottom water minima for DO concentration (6.72 mg L^{-1}) was well above the background and threshold values. The nearfield DO percent saturation minimum of 71.8% was below the nominal warning threshold value, but above the background value of 64.31%. The survey mean bottom water minima for Stellwagen Basin stations was higher than in the nearfield, but as in the nearfield the minima DO %saturation (73.2%) was below the nominal warning threshold value of 75%. As the nearfield and Stellwagen DO %saturation minima were above established background threshold values, there was no threshold exceedance for dissolved oxygen.

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

Parameter	Time Period	Caution Level	Warning Level	Background	2003
Bottom Water DO concentration	Survey Mean in June-October	< 6.5 mg/l (unless background lower)	< 6.0 mg/l (unless background lower)	Nearfield - 5.75 mg/l Stellwagen - 6.2 mg/l	Nearfield – 6.72 mg/l (WN03F) Stellwagen – 7.07mg/l (WF03E)
Bottom Water DO %saturation	Survey Mean in June-October	< 80% (unless background lower)	< 75% (unless background lower)	Nearfield - 64.3% Stellwagen - 66.3%	Nearfield – 71.8% (WN03F) Stellwagen – 73.2% (WF03E)
Chlorophyll	Annual	107 mg/m^2	143 mg/m^2	--	99 mg/m^2
	Winter/spring	182 mg/m^2	--	--	178 mg/m^2
	Summer	80 mg/m^2	--	--	45 mg/m^2
	Autumn	161 mg/m^2	--	--	87 mg/m^2
Phaeocystis pouchetii	Winter/spring	2,020,000 cells l^{-1}	--	--	482,000 cells l^{-1}
	Summer	334 cells l^{-1}	--	--	3,500 cells l^{-1}
	Autumn	2,370 cells l^{-1}	--	--	None
Pseudo-nitzschia pungens	Winter/spring	21,000 cells l^{-1}	--	--	200 cells l^{-1}
	Summer	38,000 cells l^{-1}	--	--	100 cells l^{-1}
	Autumn	24,600 cells l^{-1}	--	--	17,900 cells l^{-1}
Alexandrium tamarense	Any nearfield sample	100 cells l^{-1}	--	--	None

There were no confirmed blooms of harmful or nuisance phytoplankton in Massachusetts and Cape Cod Bays for July – December 2003. *Phaeocystis pouchetii*, which often blooms during the spring and was observed in March/April 2003, 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 at low abundance on May 15, 2003. The continued presence of *Phaeocystis* in May, albeit only in one sample and at low abundance (48,400 cells L^{-1}), and the very low summer threshold value resulted in an exceedance. This exceedance was not considered indicative of an impact associated with the outfall. *Alexandrium* spp. were not observed in the nearfield during this reporting period. Low abundances were seen during the early October survey, but only at farfield stations and at a maximum abundance of <20 cells L^{-1}. The *Pseudo-nitzschia "pungens"* threshold designation can include both non-toxic *P. pungens* as well as the identical-appearing (at least with light microscopy) domoic-acid-producing species *P. multiseries* and since resolving the species identifications of these two species requires scanning electron microscopy all *P. pungens* and *Pseudo-nitzschia* unidentified beyond species were included in the threshold. This grouping of *Pseudo-nitzschia* was observed during many of the surveys from July to December 2003. Abundance peaked for *Pseudo-nitzschia* during the early October survey with a nearfield mean value of 52,000 cells L^{-1}. The autumn mean abundance in 2003, however, was below the threshold value.

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

- Assess the dynamics associated with destratification and nutrient availability in fall 2003 relative to the prolonged fall bloom and the relatively low production and phytoplankton abundance observed.

- Examine the timing of the fall productivity peak in recent years, to evaluate whether changes in nutrient availability at the nearfield sites are related to the outfall and expressed in the timing and duration of the fall bloom. The distribution of chlorophyll-specific production in 2003 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.

- Assess the lower abundance of dinoflagellates in 2003 given the lower than typical levels observed in the summer and fall seasons. The low abundance was in large part due to lower numbers of the dinoflagellates *Ceratium tripos*, *Ceratium fusus, Ceratium longipes* and other members of this genus, which typically are overwhelming dominants in nearfield screened phytoplankton samples in the summer/fall period. In the 2002 annual report (Libby *et al*., 2003a), this was attributed in part to the relatively weak stratification observed over the summer and fall of that year. This hypothesis will be revisited in light of the 2003 results.

- Continue to assess the role of ctenophore predation on zooplankton and secondarily in reducing grazing pressure on phytoplankton.

- Examine the elevated abundance of *Pseudo-nitzschia* during the early October survey in light of the humpback whale deaths in Stellwagen Bank National Marine Sanctuary (SBNMS) that were associated with domoic acid poisoning. Utilize additional phytoplankton data available from coincident SBNMS monitoring.

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