Semiannual water column monitoring report

August – December 2000

Massachusetts Water Resources Authority

Environmental Quality Department

Report ENQUAD 2001-16

Citation:

Libby PS, McLeod LA, Mongin CJ, Keller AA, Oviatt CA, Turner JT. 2001. **Semi-Annual Water Column Monitoring Report: August – December 2000.** Boston: Massachusetts Water Resources Authority. Report ENQUAD 2001-16. 467 p.

SEMIANNUAL WATER COLUMN MONITORING REPORT

August – December 2000

Submitted to

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December 14, 2001

Report No. 2001-16

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 potential environmental effects of the relocation of effluent discharge from Boston Harbor to Massachusetts Bay. The data are being collected to establish baseline water quality conditions and ultimately to provide the means to detect significant departure from that 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 eight surveys conducted from August through December 2000. This period marks the end of the baseline monitoring as the outfall became operational on September 6, 2000. The first three surveys of this time period were conducted prior to September 6.

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 nutrients, and a relatively stable mixed-assemblage phytoplankton community. In the fall, stratification deteriorates and supplies nutrients to surface waters often developing into a fall phytoplankton bloom as it did in 2000. The lowest dissolved oxygen concentrations are usually observed in October prior to the fall overturn of the water column. By late fall or early winter, the water column becomes well mixed and resets to winter conditions. In 2000, the major event was the region wide fall bloom.

The primary physical characteristic of this period was the overturn of the water column and the return to winter conditions. The nearfield survey data indicated the pycnocline had broken down at the inshore stations by early October, but the water column at the offshore stations was not well mixed until late November. In September, there was in influx of cooler, more saline, nutrient-replete waters into the nearfield that likely contributed to the major fall chlorophyll bloom observed in 2000.

The general trend in nutrient concentrations during the 2000 August to December period was similar to previous baseline monitoring years. Nutrients were depleted in the surface waters during the summer due to biological utilization and increased in concentration with the change from a stratified to a well-mixed water column. In September 2000, two sources of additional nutrients were noted for the nearfield area – an influx of nutrient rich waters from offshore and the transfer of MWRA effluent from the harbor to the bay outfall on September 6th. The transfer of discharge to the bay decreased NH_4 concentration in the harbor, coastal waters, and western nearfield, and moved this anthropogenic signal offshore to the center of the nearfield. Although it is not a conservative tracer due to biological utilization, it appears that NH_4 is a clear indicator of the effluent plume in the nearfield now that the outfall is online.

The 2000 fall bloom had started by the September 1st nearfield survey and continued through late October. Survey mean chlorophyll concentrations were high during each of the September and October surveys. The high concentrations combined with the extended duration of the bloom resulted in a fall mean chlorophyll concentration of 5.69 μgL^{-1}. The fall 2000 mean was higher than all baseline values and continued the trend of elevated fall chlorophyll concentrations started in 1999. The fall 2000 mean areal chlorophyll was 205 mg m^{-2} exceeding the caution threshold of 161mg m^{-2}. Fall blooms are typical for the bays and the bloom in 2000 is part of the natural variability of the region.

As in 1999, there was a disconnect in phytoplankton abundance, primary production, and chlorophyll during the fall bloom in 2000. Nearfield phytoplankton abundance peaked in early September and gradually declined through October. Productivity was highest at station N18 during the September surveys and in late October further offshore at station N04. The elevated productivity observed at station N18 is the highest value observed throughout the monitoring period. Chlorophyll concentrations, although steadily increasing in September, did not reach maximum levels until late October. While the availability of NH_4 in the nearfield after September 6, 2000 may have contributed to a localized increase in chlorophyll concentrations and helped to sustain the fall bloom in the nearfield for an extended duration, the 2000 fall bloom in Massachusetts and Cape Cod Bays was part of a large regional bloom that was observed throughout the western Gulf of Maine.

With major spring and fall blooms in 2000 and high chlorophyll concentrations observed throughout much of the year, it was anticipated that exceptionally low DO concentrations might be observed during the fall of 2000. This was not the case as bottom water survey mean minima for both DO concentration and percent saturation were relatively high. The situation was likely mitigated by an influx of less DO depleted waters from offshore. Nearfield and Stellwagen Basin DO percent saturation survey mean minima (78%) were below the threshold caution level of 80%, but were well above the background levels (64.3% for the nearfield and 66.3% for Stellwagen Basin).

The regional fall bloom in 2000 consisted of chain-forming diatoms and may be related to another apparently regional event in 2000 – an anomalously high abundances of ctenophores. The ctenophore *Mnemiopsis leidyi* was abundant in Boston Harbor, coastal, and western nearfield waters during in September and October. The fall 2000 ctenophore "bloom" was unprecedented for the baseline period and caused severe decimation of abundances of copepods. Such overpredation of zooplankton grazers could have also contributed to resultant phytoplankton increases during the fall, particularly in terms of the bloom of large chain-forming diatoms.

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1.0 INTRODUCTION

1.1 Program Overview

The Massachusetts Water Resources Authority (MWRA) has implemented a long-term Harbor and Outfall Monitoring (HOM) Program for Massachusetts and Cape Cod Bays. The objective of the HOM Program is to (1) test for compliance with NPDES permit requirements; (2) test whether the impact of the discharge on the environment is within the bounds projected by the SEIS; and (3) test whether change within the system exceeds the Contingency Plan thresholds. 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, 1997a).

To help establish the present water quality conditions with respect to nutrients, water properties, phytoplankton and zooplankton, and water-column respiration and productivity, the MWRA conducts baseline water quality surveys in Massachusetts and Cape Cod Bays. 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 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 semi-annual report summarizes water column monitoring results for the eight surveys conducted from August through December 2000 (Table 1-1).

Table 1-1. Water Quality Surveys for WN00A-WN00H August to December 2000

Survey #	Type of Survey	Survey Dates
WN00A	Nearfield	August 2
WF00B	Nearfield/Farfield	August 16 – 18, 20
WN00C	Nearfield	September 1
WN00D	Nearfield	September 22
WF00E	Nearfield/Farfield	October 3-5, 12[a]
WN00F	Nearfield	October 24
WN00G	Nearfield	November 29
WN00H	Nearfield	December 21

[a] Due to severe weather, the WF00E survey was completed over the course of two weeks in October – nearfield samples were collected October 5th and farfield samples were collected October 3, 4, and 12.

This period marks the end of the baseline monitoring as the outfall became operational on September 6, 2000. The first three surveys of this time period were conducted prior to September 6, while the other five surveys were conducted after MWRA began discharging secondary effluent from the outfall. The data in this report are evaluated as a whole from August to December 2000 and discussion will focus on characterization of spatial and temporal trends for this time period. Preliminary discussion focused on the data collected following initiation of discharge is also discussed, but detailed comparison of this data with baseline data will be presented in the 2000 Annual Water Column Report.

Initial data summaries, along with specific field information, are available in individual survey reports submitted immediately following each survey. In addition, nutrient data reports (including calibration information, sensor and water chemistry data), plankton data reports, and productivity and respiration data reports are each submitted five 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 Semi-Annual Report

The scope of the semi-annual report is focused primarily towards providing an initial compilation of the water column data collected during the reporting period. Secondarily, integrated physical and biological results are discussed for key water column events and potential areas for expanded discussion in the annual water column report are recommended. The report first provides a summary of the survey and laboratory methods (Section 2). The bulk of the report, as discussed in further detail below, presents results of water column data from the last eight surveys of 2000 (Sections 3-5). Finally, the major findings of the semi-annual period are summarized in Section 6.

Section 3 data are provided in data summary tables. The summary tables include the major numeric results of water column surveys in the semi-annual period by survey. 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, Cohassett, Marshfield and Nearfield-Marshfield), and one nearfield transect, allows three-dimensional analysis 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 semi-annual 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 Site. This report describes the horizontal and vertical characterization of the water column during the summer stratification period (WN00A – WF00E) and the subsequent deterioration of stratification and return to winter conditions (WN00F– WN00H). Time-series data are commonly provided for the entire semi-annual period for clarity and context of the data presentation.

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

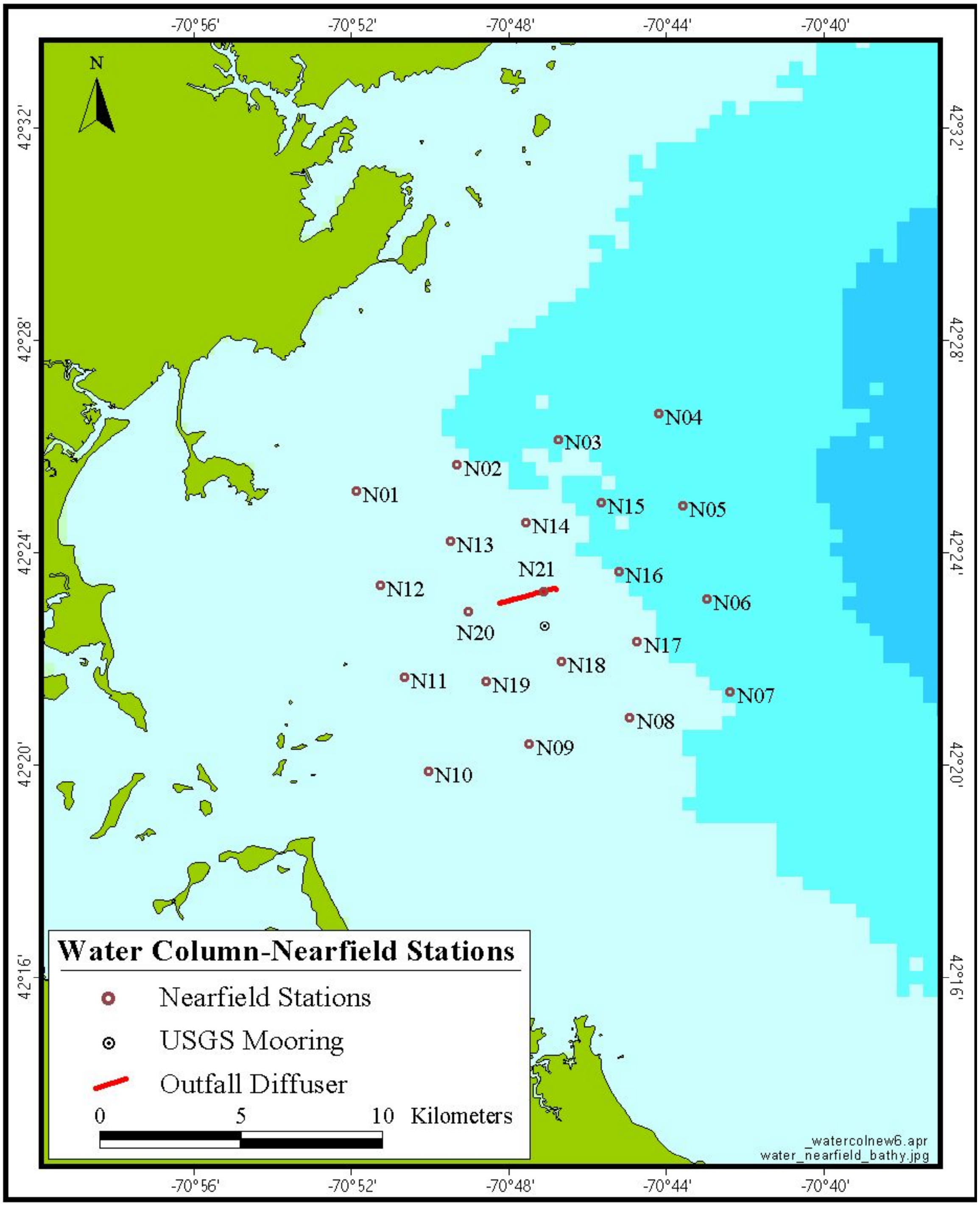


Figure 1-1. Locations of MWRA Outfall Site, Nearfield Stations and USGS Mooring

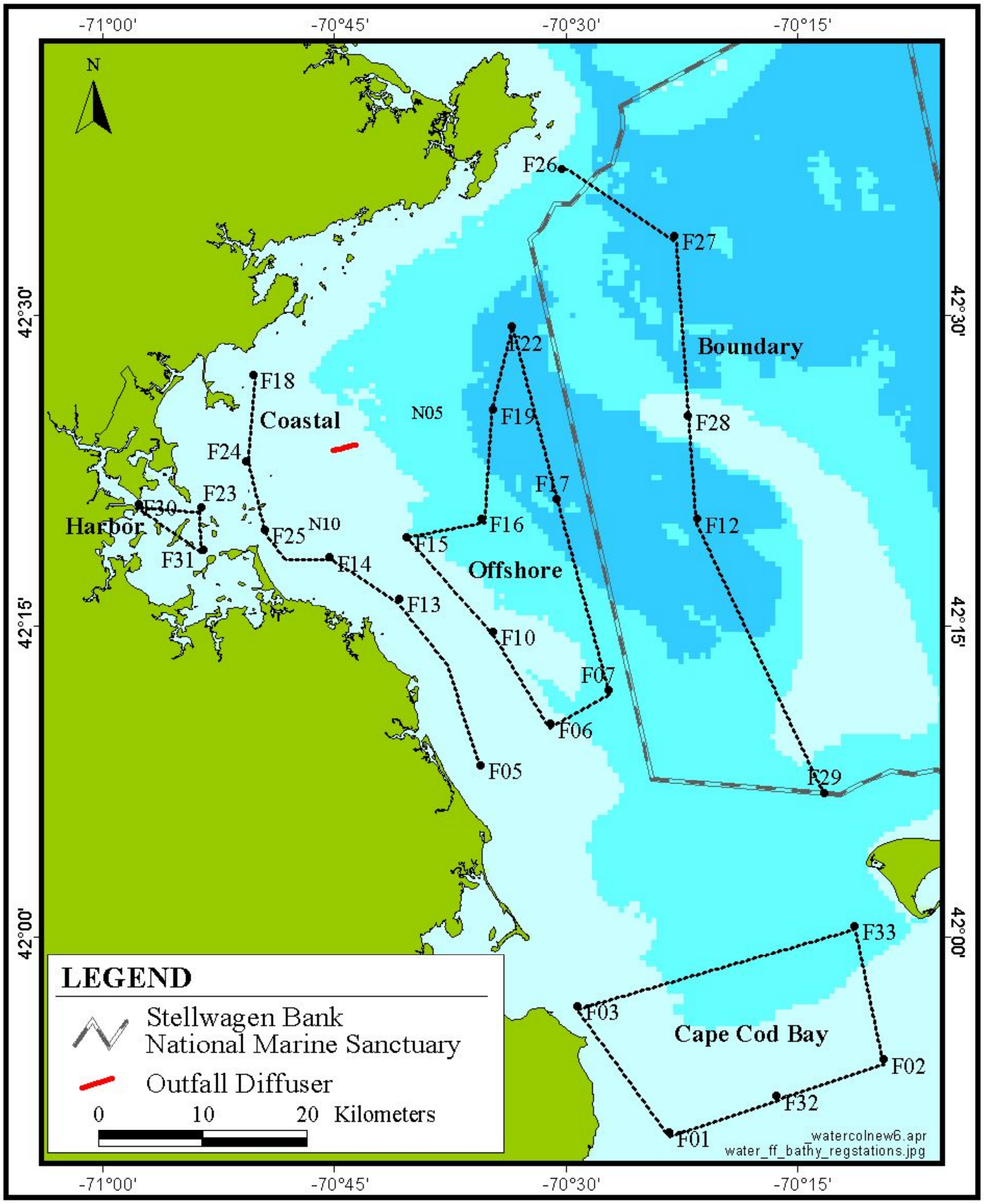


Figure 1-2. Locations of Farfield Stations and Regional Area Groupings

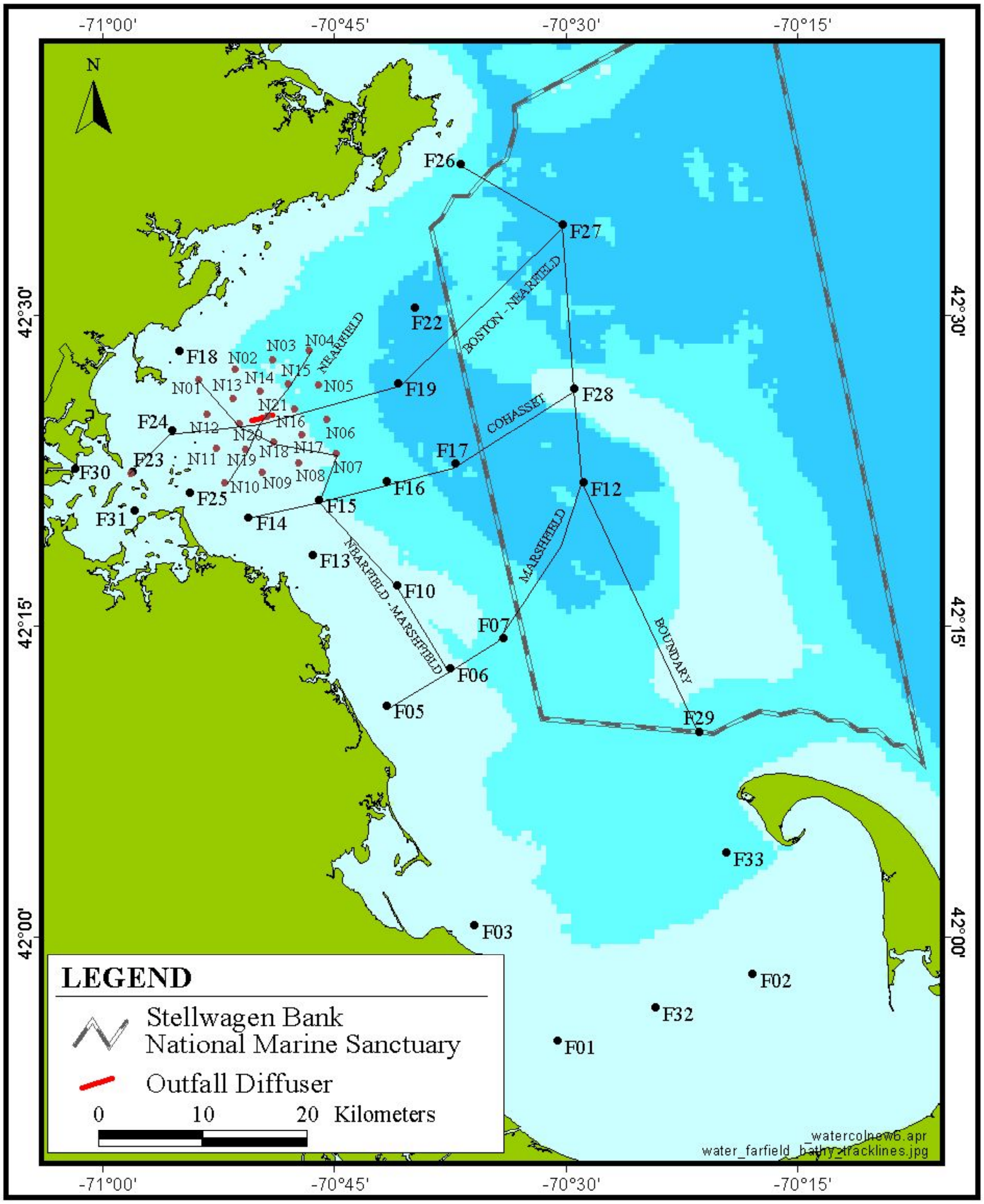


Figure 1-3. Location of Stations and Selected Transects

2.0 METHODS

This section describes general methods of data collection and sampling for the last eight water column monitoring surveys of 2000. 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 second 2000 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 (Albro *et al*. 1998). Details on productivity sampling procedures and analytical methods are also available in Appendix A.

2.1 Data Collection

The farfield and nearfield water quality surveys for 2000 represent a continuation and conclusion of the baseline water quality monitoring conducted from 1992 – 1999. On September 6, 2000, the outfall went online and began discharging effluent. The monitoring program has been improved over the years as more data have been collected and evaluated. In 1998, two Cape Cod Bay stations (F32 and F33) were added to better capture the winter/spring variability in zooplankton abundance and species in these Right whale feeding grounds. During the first three farfield surveys of 2000, these two stations were again sampled for zooplankton and hydrographic (CTD) properties. For the 2000 monitoring, a decision was made to collect more data at stations 'upstream' of the nearfield area (stations F22 and F26). Additional nutrient parameters were measured at these stations starting in February (WF001) and during the April survey (WF004) phytoplankton and zooplankton samples were also added to the list of parameters measured at these stations to better define biological conditions at the northeastern boundary of Massachusetts Bay. These additional parameters continue to be measured at stations F22 and F26 during each farfield survey. Starting with the August combined survey (WF00B), additional nutrient samples were also collected at station F19 to provide ancillary data on dissolved and particulate organic nutrients coincident with respiration measurements.

Water quality data for this report were collected from the sampling platform *R/V Aquamonitor.* Continuous vertical profiles of the water column and discrete water samples were collected using a CTD/Go-Flo Bottle Rosette system. This system includes a deck unit to control the system, display *in situ* data, and store the data, and an underwater unit comprised of several environmental sensors, including conductivity, temperature, depth, dissolved oxygen, transmissometry, irradiance, and fluorescence. These measurements were obtained at each station by deploying the CTD; in general, one cast was made at each station. Water column profile data were collected during the downcast, and water samples were collected during the upcast by closing the Go-Flo bottles at selected depths, as discussed below.

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

Samples from each depth at each station were collected by subsampling from the Go-Flo bottles into the appropriate sample container. Analyses performed on the water samples are summarized in Table 2-1. Samples for dissolved inorganic nutrients (DIN), dissolved organic carbon (DOC), total dissolved nitrogen (TDN) and phosphorus (TDP), particulate organic carbon (POC) and nitrogen (PON), biogenic silica, particulate phosphorus (PP), chlorophyll *a* and phaeopigments, total suspended solids (TSS), urea, and phytoplankton (screened and rapid assessment) were filtered and preserved immediately after obtaining water from the appropriate Go-Flo bottles. Whole water phytoplankton samples (unfiltered) were obtained directly from the Go-Flo bottles and immediately preserved. Zooplankton samples were obtained by deploying a zooplankton net overboard and making an oblique tow of the upper two-thirds of the water column but with a maximum tow depth of 30 meters. Productivity samples were collected from the Go-Flo bottles, stored on ice and transferred to University of Rhode Island (URI) employees. Incubation was started no more 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 seven days until analysis.

2.2 Sampling Schema

A synopsis of the sampling schema for the analyses described above is outlined in Tables 2-1, 2-2, and 2-3. Station designations were assigned according to the type of analyses performed at that station (see Table 2-1). Productivity and respiration analyses were also conducted at certain stations and represented by the letters P and R, respectively. Table 2-1 lists the different analyses performed at each station. Tables 2-2 (nearfield stations) and 2-3 (farfield stations) provide the station name and type, and show the analyses performed at each depth. Station N16 is considered both a nearfield station (where it is designated as type A) and a farfield station (where it is designated a type D). Stations F32 and F33 are occupied during the first three farfield surveys of each year and collect zooplankton samples and hydrocast data only (designated as type Z). During 2000, a decision was made to collect more data at stations F22, F26, and F19. Stations F22 and F26 were sampled as type A stations (additional nutrients) during the first two farfield surveys (WF001 and WF002) and as type D stations (addition of plankton samples) for the remaining farfield surveys of 2000. Additional nutrient samples were also collected at station F19 during the last two farfield surveys of this time period (WF00B and WF00E).

Table 2-1. Station Types and Numbers (Five Depths Collected Unless Otherwise Noted)

Station Type	A	D	E	F	G[1]	P	R[5]	Z
Number of Stations	**6**	**10[4]**	**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, DIN						●		

[1]Samples collected at three depths (bottom, mid-depth, and surface)
[2]Samples collected at two depths (mid-depth and surface)
[3]Samples collected at the surface
[4]Stations F22 and F26 accounted as type D stations in this table
[5]Respiration samples collected at type A station F19 (previously type F station)

2.3 Operations Summary

Field operations for water column sampling and analysis during the second semi-annual period were conducted as described above. Deviations from the CW/QAPP for nearfield surveys WN00A, WN00C, WN00D, WN00F, WN00G, and WN00H had no effect on the data. During survey WF00B (August 2000) the respiration samples were allowed to warm to 30ºC from the correct temperature of 19ºC on two separate occasions and a problem with the DO titrator occurred affecting a number of samples. The principal deviation for survey WF00E (October 2000) was that due to weather and crew scheduling problems, it took 10 days to complete the farfield/nearfield survey. Nearfield samples were collected on October 5, 2000 and farfield samples were collected on October 3, 4, and 12, 2000. Due to the delay, the survey was conducted well beyond the normal 4-day time frame for a farfield survey. Data will be evaluated within this context in this report. For additional information about a specific survey, the individual survey reports may be consulted.

Table 2-2. Nearfield Water Column Sampling Plan (3 Pages)

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.6	0.3	0.5	1	1	4	1	4	1	0.1	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		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		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																

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	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			5_Surface	1	1	1																
			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																
N14	34	E	2_Mid-Bottom	1	1	1																
			3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
N15	42	E	2_Mid-Bottom	1	1	1																
			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								
N16	40	A	2_Mid-Bottom	2.5	1	1						1		1								
			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																

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	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			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
		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		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		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	4	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 Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.3	0.3	0.5	1	1	0	1	4	1	0.1	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		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		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		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		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		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		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		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 Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F14	20	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F15	39	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F16	60	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F17	78	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F18	24	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	7	2	1	1	1	2	2	2	1	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		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		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		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		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		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		1			
			6_Net Tow															1				
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	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 Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			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		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		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		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		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		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		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		1			
F30	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	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		1			
F31	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	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		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		1			
			6_Net Tow															1				
				Totals		132	44	44	84	84	84	80	84	96	28	26	26	15	26	36	5	6
			Blanks B						1	1	1	1	1									
			Blanks C						1	1	1	1	1									
			Blanks D						1	1	1	1	1									

3.0 DATA SUMMARY PRESENTATION

Data from each survey were compiled from the final HOM Program 2000 database and organized to facilitate regional comparisons between surveys, and to allow a quick evaluation of results for evaluating monitoring thresholds (Table 3-1 Method Detection Limits, Survey Data Tables 3-2 through 3-10). Each table provides summary data from one survey. A discussion of which parameters were selected, how the data were grouped and integrated, and the assumptions behind the calculation of statistical values (average, minimum, and maximum), is provided below. Individual data summarized in this report are available from MWRA either in hard copy or electronic format.

The spatial pattern of data summary follows the sample design over major geographic areas of interest in Massachusetts Bay, Cape Cod Bay, and Boston Harbor (Section 3.1). Compilation of data both horizontally by region and vertically over the entire water column was conducted to provide an efficient way of assessing the status of the regions during a particular survey. Maximum and minimum values are provided because of the need to assess extremes of pre-outfall conditions relative to criteria being developed for contingency planning purposes (MWRA, 1997b).

Regional compilations of nutrient and biological water column data were conducted first by averaging individual laboratory replicates, followed by field duplicates, and then by station visit within a survey. Prior to regional compilation of the sensor data, the results were averaged by station visit. Significant figures for average values were selected based on precision of the specific data set. 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 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 (Albro *et al*. 1998), 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 1021.0 to 1026.5, meaning σ_t varied from 21.0 to 26.5.

Fluorescence data were calibrated using concomitant extracted 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 were used for all discussions of chlorophyll in this report. The concentrations of phaeopigments are included in the summary data tables as part of the nutrient parameters.

In addition to DO concentration, the derived percent saturation was also provided. 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).

Finally, the derived beam attenuation coefficient from the transmissometer ("transmittance") was provided on the summary tables. 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}.

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 urea. Total suspended solids (TSS) data are provided as a baseline for total particulate matter in the water column. 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. Areal production, which is determined by integrating the measured productivity over the photic zone, and chlorophyll-specific areal production is included for the productivity stations (F23 representing the Harbor, and N04 and N18, representing the nearfield). Because areal production is already depth-integrated, averages were calculated only among productivity stations for the two regions sampled. The derived parameters α ($gC[gChla]^{-1}h^{-1}[\mu Em^{-2}s^{-1}]^{-1}$) and Pmax ($gC[gChla]^{-1}h^{-1}$) are also included. The productivity parameters are discussed in detail in Appendix A.

Respiration rates were averaged over the respiration stations (the same Harbor and nearfield stations as productivity, and additionally one offshore station [F19]), and over the three water column depths sampled (surface, mid- and bottom). The respiration samples were collected concurrently with the productivity samples. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Albro *et al*. 1998).

3.5 Plankton

Plankton results were extracted from the HOM database and include whole water phytoplankton, screened phytoplankton, and zooplankton. Phytoplankton samples were collected for whole-water and screened measurements during the water column CTD casts at the surface (A) and mid-depth (C) sampling events. As discussed in Section 2.1, when a subsurface chlorophyll maximum is observed, the mid-depth sampling event is associated with this layer. The screened phytoplankton samples were filtered through 20-µm 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 (Albro *et al*. 1998).

Final plankton values were derived from each station by first averaging analytical replicates, then averaging station visits. Regional results were summarized for total phytoplankton, total centric diatoms, nuisance algae (*Alexandrium tamarense, Phaeocystis pouchetii,* and *Pseudo-nitzschia pungens*), and total zooplankton (Tables 3-2 through 3-9).

Results for total phytoplankton and centric diatoms reported in Tables 3-2 through 3-9 are restricted to whole water surface samples. Results of the nuisance species *Phaeocystis pouchetii* and *Pseudo-nitzschia pungens* include the maximum of both whole water and screened analyses, at both the surface and mid-depth. Although the size and shape of both taxa might allow them to pass through the Nitex screen, both have colonial forms that in low densities might be overlooked in the whole-water samples. For *Alexandrium tamarense*, only the screened samples were reported.

3.6 Additional Data

Two additional data sources were utilized during interpretation of HOM Program semi-annual water column data. Temperature and chlorophyll a satellite images collected near survey dates were preliminarily interpreted for evidence of surface water events, including intrusions of surface water masses from the Gulf of Maine and upwelling (Appendix I). U.S. Geological Service continuous temperature and salinity data were collected from a mooring located between nearfield stations N21 and N18 (Figure 1-1). Daily temperature and salinity data from ~20 m below surface and ~1 m above bottom are plotted in Figure 3-1. Chlorophyll *a* data (as measured by *in situ* fluorescence) from the MWRA Wetlab sensor mounted at mid-depth (~13 m below surface) on the nearfield USGS mooring are plotted in Figure 3-2.

3.7 Revised Data

Two sets of data were revised based on analytical and sensor issues that were discovered in early 2001 – chlorophyll and irradiance. The data have been corrected and the new data are presented herein and have been used for all applicable calculations included in this report (i.e. areal production and chlorophyll-specific production).

A quality assurance review found analytical errors in the chlorophyll measurement method used by the MWRA monitoring program during 1998-2000. In the fall of 2000, extracted chlorophyll and draft calibrated fluorescence data exhibited unusually high values relative to other fall data collected under HOM. These high values precipitated a major review of HOM3 chlorophyll and fluorescence data the findings of which are summarized in Hunt 2001. In our evaluation of the fluorescence and bottle chlorophyll data, the project team identified two major technical issues requiring action: correction for chlorophyll standard purity (all HOM3 data) and degradation of the chlorophyll standard (limited number of surveys). Each issue had led to an upward bias in the extracted chlorophyll data and calibrated fluorescence.

The irradiance data was corrected based on problems with the MWRA Deer Island light sensor. The problem was discovered when the sensor was replaced on April 20, 2001 and the old unit subsequently post-calibrated. The new calibration values were different from the initial values (used throughout HOM3) and were the result of damage to the unit during installation (10/96). The revised

Deer Island surface irradiance data were used to recalculate the productivity data presented in this report.

Table 3-1. Method Detection Limits

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

Table 3-2. Nearfield Survey WN00A (Aug 2000) Data Summary

Region		Nearfield		
Parameter		**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	7.41	18.74	14.66
Salinity	PSU	30.5	32.1	31.3
Sigma _T		21.7	25.1	23.2
Beam Attenuation	m^{-1}	0.67	2.40	1.23
DO Concentration	mgL^{-1}	7.58	10.06	8.91
DO Saturation	PCT	84.5	128.0	106.7
Fluorescence	μgL^{-1}	0.01	5.13	1.63
Chlorophyll a	μgL^{-1}	0.04	3.28	1.15
Phaeopigment	μgL^{-1}	0.19	2.80	0.63
Nutrients				
NH4	µM	0.21	6.95	1.70
NO2	µM	0.01	0.42	0.14
NO2+NO3	µM	0.02	6.78	1.54
PO4	µM	0.02	1.17	0.50
SIO4	µM	1.29	13.70	4.50
BIOSI	µM	0.20	2.20	0.87
DOC	µM	154.7	407.5	290.4
PARTP	µM	0.08	0.50	0.26
POC	µM	8.42	65.00	30.04
PON	µM	1.14	9.14	4.67
TDN	µM	10.1	20.8	14.3
TDP	µM	0.20	1.11	0.52
TSS	mgL^{-1}	0.42	1.67	0.91
Urea	µM	0.14	0.34	0.24
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.008	0.242	0.098
Pmax	$mgCm^{-3}h^{-1}$	0.27	18.84	7.80
Areal Production	$mgCm^{-2}d^{-1}$	1092.6	1889.1	1490.9
Depth-averaged Chlorophyll-specific Production	$mgC(mg\ Chla)^{-1}d^{-1}$	22.7	31.8	27.2
Respiration	μMO_2h^{-1}	0.028	0.231	0.132
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	0.600	3.503	
Centric diatoms	10^6Cells L^{-1}	0.003	0.358	
Alexandriium tamarense	Cells L^{-1}	ND	ND	
Phaeocystis pouchettii	10^6Cells L^{-1}	ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND	
Total Zooplankton	Individuals m^{-3}	48,333	84,911	

NA = Data not available due to samples loss
ND = Not detected in the sample.

Table 3-3. Combined Farfield/Nearfield Survey WF00B (Aug 2000) Data Summary

		Farfield								
Region		**Boundary**			**Cape Cod Bay**			**Coastal**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	6.48	19.11	11.79	10.82	19.81	18.12	12.71	19.82	18.85
Salinity	PSU	30.6	32.4	31.8	30.9	31.7	31.1	30.7	31.6	30.9
Sigma _T		21.7	25.4	24.1	21.7	24.2	22.2	21.6	23.8	21.9
Beam Attenuation	m^{-1}	0.49	1.75	0.84	0.78	1.67	1.45	0.88	2.24	1.51
DO Concentration	mgL^{-1}	8.20	10.11	8.93	5.89	8.77	8.20	6.45	8.49	7.39
DO Saturation	PCT	84.8	123.6	101.1	65.0	115.2	105.8	75.1	111.2	95.7
Fluorescence	μgL^{-1}	0.06	6.95	2.29	0.25	7.12	4.35	0.45	5.98	2.27
Chlorophyll a	μgL^{-1}	0.07	4.58	0.86	0.51	6.22	2.67	0.57	3.09	1.96
Phaeopigment	μgL^{-1}	0.15	1.38	0.42	0.16	2.29	1.02	0.68	2.47	1.69
Nutrients										
NH4	µM	0.13	2.10	0.54	0.09	6.05	1.15	0.16	18.50	4.28
NO2	µM	0.02	0.35	0.11	0.01	0.50	0.09	0.01	0.46	0.19
NO2+NO3	µM	0.01	10.47	4.76	0.02	3.88	0.52	0.01	3.16	1.08
PO4	µM	0.12	1.19	0.66	0.06	1.15	0.33	0.16	1.30	0.57
SIO4	µM	0.89	14.74	5.92	1.26	14.23	3.54	1.95	13.26	4.50
BIOSI	µM	0.40	1.40	0.88	0.50	2.40	1.50	1.10	4.40	2.97
DOC	µM	175.2	343.2	232.0	156.6	420.4	252.1	168.1	524.0	254.4
PARTP	µM	0.05	0.19	0.11	0.13	0.38	0.28	0.18	0.36	0.30
POC	µM	5.61	43.60	17.05	15.90	46.20	35.62	16.90	39.80	26.30
PON	µM	1.08	5.65	2.52	2.76	5.92	4.91	2.86	6.07	4.26
TDN	µM	10.2	19.6	15.5	11.4	19.7	14.7	12.7	35.0	22.5
TDP	µM	0.41	1.18	0.86	0.39	1.35	0.68	0.42	1.58	1.05
TSS	mgL^{-1}	0.24	0.67	0.49	1.19	1.62	1.39	0.90	3.65	2.11
Urea	µM	0.18	0.76	0.47	0.05	0.25	0.15	0.25	0.45	0.38
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$									
Pmax	$mgCm^{-3}h^{-1}$									
Areal Production	$mgCm^{-2}d^{-1}$									
Depth-averaged Chlorophyll-specific Production	$mgC(mg\ Chla)^{-1}d^{-1}$									
Respiration	μMO_2h^{-1}									
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.212	1.676		0.579	2.166		0.970	2.230	
Centric diatoms	10^6Cells L^{-1}	0.007	0.132		0.043	0.404		0.070	0.094	
Alexandrum tamarense	Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Total Zooplankton	Individuals m^{-3}	21,723	42,856		22,197	35,938		22,853	111,266	

NA = Data not available due to sample loss.
ND = Not detected in the sample.

Table 3-3. Combined Farfield/Nearfield Survey WF00B (Aug 2000) Data Summary (continued)

		Farfield						Nearfield		
Region		**Harbor**			**Offshore**			**Nearfield**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	19.54	20.11	19.69	6.40	19.63	13.01	8.08	19.90	15.18
Salinity	PSU	30.1	30.7	30.4	30.5	32.3	31.7	30.6	32.1	31.3
Sigma _T		21.0	21.5	21.3	21.6	25.3	23.7	21.6	25.0	23.0
Beam Attenuation	m^{-1}	2.07	3.39	2.65	0.51	1.46	0.90	0.48	1.76	1.11
DO Concentration	mgL^{-1}	6.02	6.67	6.39	7.29	10.44	8.48	6.49	8.96	8.20
DO Saturation	PCT	79.2	87.6	83.7	81.8	120.6	98.3	72.3	116.1	99.3
Fluorescence	μgL^{-1}	1.20	2.94	2.01	0.14	5.75	2.11	0.01	5.83	2.47
Chlorophyll a	μgL^{-1}	0.08	4.58	2.59	0.09	5.38	1.88	0.20	4.74	1.90
Phaeopigment	μgL^{-1}	0.11	5.18	2.53	0.21	2.28	0.80	0.29	6.49	1.18
Nutrients										
NH4	µM	8.54	19.88	14.50	0.06	8.98	1.40	0.05	7.44	1.35
NO2	µM	0.41	0.59	0.49	0.01	0.53	0.16	0.01	0.56	0.27
NO2+NO3	µM	2.24	3.74	2.94	0.01	10.49	3.42	0.01	10.73	2.67
PO4	µM	1.20	1.61	1.44	0.07	1.24	0.58	0.03	1.05	0.45
SIO4	µM	6.07	7.90	6.88	1.24	14.25	5.41	2.09	13.25	5.33
BIOSI	µM	3.40	7.10	4.77	0.60	1.60	1.12	0.50	3.90	1.35
DOC	µM	192.4	444.0	273.6	157.4	369.0	245.3	119.9	652.3	266.6
PARTP	µM	0.42	0.52	0.47	0.07	0.30	0.17	0.07	0.36	0.23
POC	µM	30.10	36.40	32.97	5.79	39.80	23.38	6.91	46.80	25.32
PON	µM	4.99	6.52	5.60	1.24	5.95	3.30	1.18	6.78	3.92
TDN	µM	25.9	36.0	32.3	10.7	22.6	15.0	10.4	42.9	17.8
TDP	µM	1.44	1.96	1.73	0.37	1.17	0.74	0.36	1.21	0.70
TSS	mgL^{-1}	3.11	6.54	5.08	0.50	1.51	0.96	0.49	2.14	1.09
Urea	µM	0.52	0.72	0.60	0.25	0.25	0.25	0.18	1.06	0.50
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.045	0.076	0.056				0.010	0.081	0.044
Pmax	$mgCm^{-3}h^{-1}$	7.54	8.09	7.85				0.38	7.95	3.67
Areal Production	$mgCm^{-2}d^{-1}$			443.4				794.9	1023.0	909.0
Depth-averaged Chlorophyll-specific Production	$mgC(mg\ Chla)^{-1}d^{-1}$			9.9				7.8	13.7	10.7
Respiration	μMO_2h^{-1}	0.181	0.230	0.205	0.110	0.305	0.207	0.018	0.249	0.168
Plankton										
Total Phytoplankton	$10^6 Cells\ L^{-1}$	0.743	1.453		0.902	2.433		0.548	1.424	
Centric diatoms	$10^6 Cells\ L^{-1}$	0.024	0.184		0.059	0.389		0.035	0.319	
Alexandrum tamarense	$Cells\ L^{-1}$	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	$10^6 Cells\ L^{-1}$	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	$10^6 Cells\ L^{-1}$	ND	ND		ND	ND		ND	ND	
Total Zooplankton	$Individuals\ m^{-3}$	65,523	103,600		35,749	95,794		16,253	44,992	

NA = Data not available due to sample loss.
ND = Not detected in the sample.

Table 3-4. Nearfield Survey WN00C (Sep 2000) Data Summary

Region		Nearfield		
Parameter		**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	8.06	19.84	13.15
Salinity	PSU	31.0	32.3	31.7
Sigma _T		22.0	25.1	23.8
Beam Attenuation	m^{-1}	0.62	2.87	1.35
DO Concentration	mgL^{-1}	7.15	11.75	8.59
DO Saturation	PCT	77.8	152.7	100.6
Fluorescence	μgL^{-1}	0.12	18.75	5.87
Chlorophyll a	μgL^{-1}	0.10	21.66	6.16
Phaeopigment	μgL^{-1}	0.13	3.39	1.16
Nutrients				
NH4	µM	0.01	1.78	0.38
NO2	µM	0.01	0.41	0.13
NO2+NO3	µM	0.01	9.59	4.32
PO4	µM	0.10	1.24	0.70
SIO4	µM	0.41	12.40	5.88
BIOSI	µM	0.30	4.90	2.87
DOC	µM	153.6	375.4	218.3
PARTP	µM	0.08	0.79	0.40
POC	µM	2.71	93.30	42.05
PON	µM	0.69	11.10	5.49
TDN	µM	12.8	22.1	16.3
TDP	µM	0.47	1.26	0.83
TSS	mgL^{-1}	0.65	2.18	1.45
Urea	µM	0.040	0.140	0.098
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.005	0.339	0.132
Pmax	$mgCm^{-3}h^{-1}$	0.26	34.68	11.75
Areal Production	$mgCm^{-2}d^{-1}$	1191.5	4151.1	2671.3
Depth-averaged Chlorophyll-specific Production	$mgC(mg\ Chla)^{-1}d^{-1}$	8.1	23.7	15.9
Respiration	μMO_2h^{-1}	0.023	0.370	0.206
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	2.300	3.575	
Centric diatoms	10^6Cells L^{-1}	0.519	1.906	
Alexandrium tamarense	Cells L^{-1}	ND	ND	
Phaeocystis pouchettii	10^6Cells L^{-1}	ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND	
Total Zooplankton	Individuals m^{-3}	27,242	42,432	

NA = Data not available due to sample loss.
ND = Not detected in the sample.

Table 3-5. Nearfield Survey WN00D (Sep 2000) Data Summary

Region		Nearfield		
Parameter		**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	8.66	15.67	12.31
Salinity	PSU	31.7	32.4	32.1
Sigma _T		23.4	25.2	24.2
Beam Attenuation	m^{-1}	0.60	1.89	1.12
DO Concentration	mgL^{-1}	6.88	10.50	8.42
DO Saturation	PCT	75.5	124.5	96.7
Fluorescence	μgL^{-1}	0.07	25.12	9.13
Chlorophyll a	μgL^{-1}	0.53	21.12	9.93
Phaeopigment	μgL^{-1}	0.44	17.76	6.52
Nutrients				
NH4	μM	0.11	8.23	1.36
NO2	μM	0.01	0.46	0.18
NO2+NO3	μM	0.02	9.98	4.40
PO4	μM	0.24	1.27	0.73
SIO4	μM	0.56	11.18	5.46
BIOSI	μM	0.60	6.40	2.92
DOC	μM	164.9	507.5	240.4
PARTP	μM	0.09	0.69	0.40
POC	μM	6.23	80.70	42.91
PON	μM	1.26	10.60	6.09
TDN	μM	11.1	25.8	18.3
TDP	μM	0.57	1.27	0.89
TSS	mgL^{-1}	1.01	2.23	1.49
Urea	μM	0.22	0.46	0.30
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.010	0.410	0.210
Pmax	$mgCm^{-3}h^{-1}$	0.61	50.19	20.82
Areal Production	$mgCm^{-2}d^{-1}$	2390.4	4926.4	3658.4
Depth-averaged Chlorophyll-specific Production	$mgC(mg\ Chla)^{-1}d^{-1}$	6.6	16.1	11.4
Respiration	μMO_2h^{-1}	0.121	0.226	0.157
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	1.793	2.825	
Centric diatoms	10^6Cells L^{-1}	0.747	1.640	
Alexandriium tamarense	Cells L^{-1}	ND	ND	
Phaeocystis pouchettii	10^6Cells L^{-1}	ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	0.009	0.063	
Total Zooplankton	Individuals m^{-3}	9,671	11,156	

ND = Not detected in the sample.

Table 3-6. Combined Farfield/Nearfield Survey WF00E (Oct 2000) Data Summary

		Farfield								
Region		**Boundary**			**Cape Cod Bay**			**Coastal**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	8.87	14.91	11.89	12.60	14.30	13.58	11.26	14.38	13.21
Salinity	PSU	31.4	32.8	32.2	31.3	31.8	31.6	30.7	32.2	31.5
Sigma _T		23.5	25.4	24.4	23.3	23.9	23.6	22.9	24.6	23.6
Beam Attenuation	m^{-1}	0.56	1.38	0.94	0.94	1.64	1.34	0.97	3.03	1.49
DO Concentration	mgL^{-1}	6.83	9.31	7.85	4.80	9.99	8.80	6.55	10.93	9.07
DO Saturation	PCT	74.2	108.6	89.2	55.1	116.8	103.0	73.3	129.7	105.5
Fluorescence	μgL^{-1}	0.19	21.45	9.36	2.26	20.43	12.08	1.46	22.77	12.40
Chlorophyll a	μgL^{-1}	0.25	10.03	3.63	7.17	15.55	12.51	2.68	21.57	12.15
Phaeopigment	μgL^{-1}	0.24	2.46	1.13	2.15	6.29	3.45	1.02	10.09	4.90
Nutrients										
NH4	µM	0.14	1.67	0.71	0.20	1.68	0.44	0.26	3.78	1.42
NO2	µM	0.03	0.20	0.12	0.01	0.21	0.06	0.02	0.41	0.16
NO2+NO3	µM	0.08	11.15	5.19	0.07	4.81	0.62	0.11	6.57	1.87
PO4	µM	0.26	1.17	0.69	0.39	0.96	0.49	0.34	1.07	0.64
SIO4	µM	0.19	13.65	6.29	1.44	15.54	3.76	0.17	10.37	3.19
BIOSI	µM	0.20	2.00	1.22	2.10	3.10	2.68	1.80	5.40	3.58
DOC	µM	119.0	321.3	192.4	192.9	304.5	243.7	177.6	417.8	256.6
PARTP	µM	0.06	0.30	0.15	ND	ND	ND	0.16	0.52	0.35
POC	µM	6.49	43.90	19.73	20.80	43.90	33.28	9.75	65.50	34.31
PON	µM	1.19	5.08	2.79	3.54	5.71	4.73	1.92	7.29	4.87
TDN	µM	12.1	20.7	17.4	14.0	25.8	18.4	14.9	30.7	19.9
TDP	µM	0.49	1.23	0.90	0.67	1.13	0.77	0.56	1.30	0.94
TSS	mgL^{-1}	0.49	0.95	0.65	0.60	1.33	1.02	0.79	3.88	1.94
Urea	µM	0.15	0.19	0.17	0.09	0.22	0.14	0.22	0.42	0.31
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$									
Pmax	$mgCm^{-3}h^{-1}$									
Areal Production	$mgCm^{-2}d^{-1}$									
Depth-averaged Chlorophyll-specific Production	$mgC(mg\ Chla)^{-1}d^{-1}$									
Respiration	μMO_2h^{-1}									
Plankton										
Total Phytoplankton	$10^6 Cells\ L^{-1}$	0.558	1.525		1.020	2.129		1.370	2.544	
Centric diatoms	$10^6 Cells\ L^{-1}$	0.107	0.558		0.239	0.776		0.650	0.933	
Alexandrium tamarense	$Cells\ L^{-1}$	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	$10^6 Cells\ L^{-1}$	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	$10^6 Cells\ L^{-1}$	0.002	0.015		0.009	0.055		0.007	0.027	
Total Zooplankton	$Individuals\ m^{-3}$	14,140	29,660		4,164	30,744		24	4,531	

ND = Not detected in the sample.

Table 3-6. Combined Farfield/Nearfield Survey WF00E (Oct 2000) Data Summary (continued)

Region		Farfield						Nearfield		
		Harbor			Offshore					
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	°C	13.66	14.47	13.95	8.85	15.15	12.17	9.40	15.11	12.84
Salinity	PSU	31.9	32.0	31.9	30.9	32.6	32.0	31.8	32.6	32.1
Sigma _T		23.8	23.9	23.9	23.1	25.2	24.2	23.5	25.1	24.1
Beam Attenuation	m^{-1}	1.81	1.98	1.89	0.65	1.40	1.01	0.63	1.82	1.19
DO Concentration	mgL^{-1}	7.32	8.50	8.12	5.67	9.84	8.15	6.28	10.55	8.41
DO Saturation	PCT	86.0	100.2	95.7	68.7	117.9	93.1	69.7	125.1	97.7
Fluorescence	μgL^{-1}	9.06	17.69	11.96	0.30	16.51	7.53	0.01	22.27	8.76
Chlorophyll a	μgL^{-1}	11.59	15.60	13.52	0.42	12.88	6.55	0.87	15.69	8.47
Phaeopigment	μgL^{-1}	3.01	8.51	6.58	0.59	3.53	2.01	0.78	7.94	2.79
Nutrients										
NH4	μM	1.19	2.38	1.75	0.20	3.50	1.00	0.01	27.84	2.26
NO2	μM	0.19	0.31	0.26	0.02	0.34	0.12	0.01	0.49	0.20
NO2+NO3	μM	1.87	3.02	2.26	0.01	11.03	4.31	0.01	10.06	3.65
PO4	μM	0.55	0.73	0.69	0.25	1.24	0.69	0.19	1.88	0.70
SIO4	μM	1.67	2.94	1.95	0.47	16.90	5.89	0.05	13.03	5.02
BIOSI	μM	3.90	5.40	4.67	1.30	3.00	1.76	1.40	4.10	2.40
DOC	μM	141.7	484.0	285.3	145.6	338.1	226.0	129.4	760.6	265.7
PARTP	μM	0.38	0.46	0.43	0.09	0.28	0.18	0.10	0.35	0.25
POC	μM	31.10	39.90	34.63	7.56	40.40	25.19	8.50	44.00	27.15
PON	μM	5.49	6.69	5.84	1.51	4.98	3.55	1.44	5.14	3.59
TDN	μM	16.6	24.0	18.9	10.1	28.3	18.3	10.9	29.7	17.4
TDP	μM	0.97	1.16	1.06	0.55	1.40	0.86	0.52	1.56	0.91
TSS	mgL^{-1}	2.43	3.45	2.78	0.51	1.78	0.85	0.71	2.17	1.20
Urea	μM	0.22	0.49	0.30	0.09	0.09	0.09	0.22	0.56	0.36
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.177	0.196	0.185				0.006	0.270	0.148
Pmax	$mgCm^{-3}h^{-1}$	24.71	28.90	26.82				0.54	9.61	6.80
Areal Production	$mgCm^{-2}d^{-1}$			1023.2				678.7	1023.2	851.0
Depth-averaged Chlorophyll-specific Production	$mgC(mg\ Chla)^{-1}d^{-1}$			3.0				1.7	5.3	3.5
Respiration	μMO_2h^{-1}	0.139	0.154	0.149	0.012	0.144	0.069	0.051	0.217	0.151
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.419	1.891		0.822	1.873		1.226	2.251	
Centric diatoms	10^6Cells L^{-1}	0.189	0.790		0.192	0.603		0.298	0.540	
Alexandrium tamarense	Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	10^6Cells L^{-1}	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	0.001	0.013		0.002	0.005		0.003	0.011	
Total Zooplankton	Individuals m^{-3}	28	279		22,770	46,109		17,332	30,270	

ND = Not detected in the sample.

Table 3-7. Nearfield Survey WN00F (Oct 2000) Data Summary

Region		Nearfield		
Parameter	**Unit**	**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	9.95	12.97	11.94
Salinity	PSU	31.7	32.4	32.0
Sigma _T		24.0	25.0	24.2
Beam Attenuation	m^{-1}	0.59	1.61	1.01
DO Concentration	mgL^{-1}	6.31	9.98	8.64
DO Saturation	PCT	68.8	114.0	98.0
Fluorescence	μgL^{-1}	0.24	43.64	13.85
Chlorophyll a	μgL^{-1}	1.57	29.50	13.19
Phaeopigment	μgL^{-1}	1.03	5.70	3.19
Nutrients				
NH4	µM	0.13	21.49	2.02
NO2	µM	0.01	0.42	0.20
NO2+NO3	µM	0.18	11.41	3.47
PO4	µM	0.41	1.66	0.74
SIO4	µM	1.83	13.54	4.92
BIOSI	µM	0	3.60	1.98
DOC	µM	131.5	317.5	184.9
PARTP	µM	0.07	0.45	0.29
POC	µM	9.25	65.90	33.62
PON	µM	1.46	8.43	4.88
TDN	µM	12.6	22.4	17.3
TDP	µM	0.69	1.37	0.98
TSS	mgL^{-1}	0.91	1.79	1.34
Urea	µM	0.15	0.49	0.27
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.011	0.279	0.154
Pmax	$mgCm^{-3}h^{-1}$	1.27	29.34	15.57
Areal Production	$mgCm^{-2}d^{-1}$	1915.6	2486.5	2201.1
Depth-averaged Chlorophyll-specific Production	$mgC(mg\ Chla)^{-1}d^{-1}$	2.2	6.3	4.2
Respiration	μMO_2h^{-1}	0.062	0.185	0.142
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	1.202	1.672	
Centric diatoms	10^6Cells L^{-1}	0.319	0.403	
Alexandrium tamarense	Cells L^{-1}	ND	ND	
Phaeocystis pouchettii	10^6Cells L^{-1}	ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	0.005	0.024	
Total Zooplankton	Individuals m^{-3}	4,503	24,723	

ND = Not detected in the sample.

Table 3-8. Nearfield Survey WN00G (Nov 2000) Data Summary

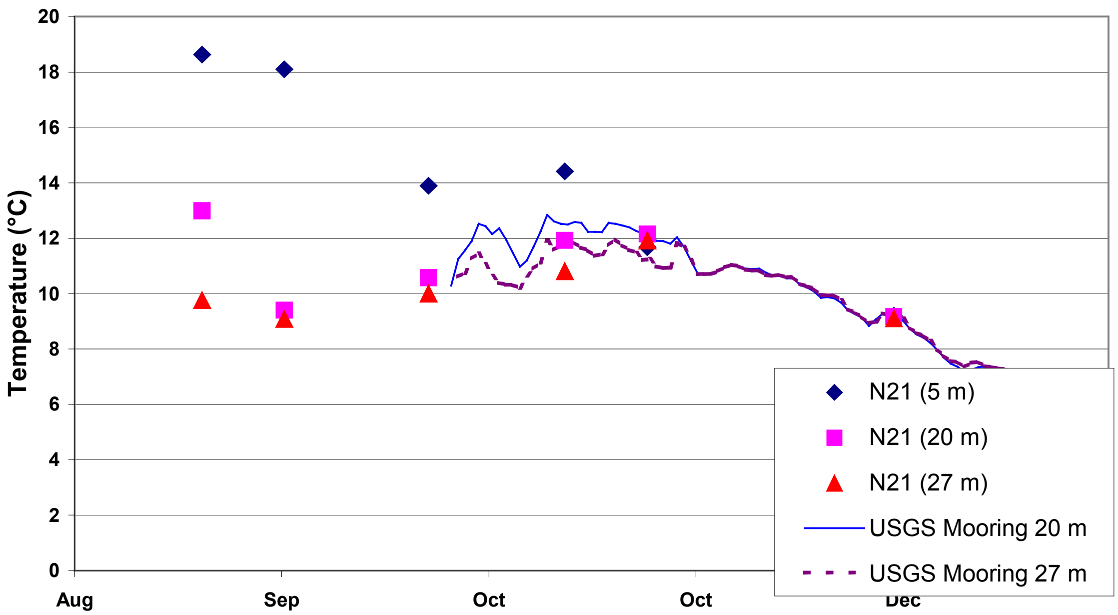
Region		Nearfield		
Parameter		**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	7.58	9.44	8.90
Salinity	PSU	31.7	32.5	32.2
Sigma _T		24.6	25.1	24.9
Beam Attenuation	m^{-1}	0.59	1.15	0.78
DO Concentration	mgL^{-1}	8.89	9.89	9.39
DO Saturation	PCT	94.9	103.0	99.6
Fluorescence	μgL^{-1}	0.42	5.89	3.06
Chlorophyll a	μgL^{-1}	0.80	5.16	3.22
Phaeopigment	μgL^{-1}	0.32	10.15	1.00
Nutrients				
NH4	μM	0.14	10.63	2.33
NO2	μM	0.05	0.37	0.17
NO2+NO3	μM	3.81	7.03	5.58
PO4	μM	0.53	1.16	0.90
SIO4	μM	2.90	11.97	5.10
BIOSI	μM	0.30	2.90	2.03
DOC	μM	128.8	231.6	176.7
PARTP	μM	0.11	0.25	0.19
POC	μM	11.34	29.81	21.24
PON	μM	1.66	3.80	2.72
TDN	μM	14.0	24.2	17.6
TDP	μM	1.00	1.40	1.18
TSS	mgL^{-1}	0.80	2.09	1.18
Urea	μM	0.06	0.31	0.20
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.022	0.082	0.051
Pmax	$mgCm^{-3}h^{-1}$	2.16	6.43	4.63
Areal Production	$mgCm^{-2}d^{-1}$	490.0	647.9	569.0
Depth-averaged Chlorophyll-specific Production	$mgC(mg\ Chla)^{-1}d^{-1}$	3.6	12.1	7.9
Respiration	μMO_2h^{-1}	0.035	0.073	0.058
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	0.609	0.826	
Centric diatoms	10^6Cells L^{-1}	0.081	0.169	
Alexandrium tamarense	Cells L^{-1}	ND	ND	
Phaeocystis pouchettii	10^6Cells L^{-1}	ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	0.001	0.007	
Total Zooplankton	Individuals m^{-3}	18,365	27,438	

ND = Not detected in the sample.

Table 3-9. Nearfield Survey WN00H (Dec 2000) Data Summary

Region		Nearfield		
Parameter		**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	4.81	7.22	6.63
Salinity	PSU	31.4	32.9	32.4
Sigma _T		24.8	25.8	25.4
Beam Attenuation	m^{-1}	0.61	1.14	0.73
DO Concentration	mgL^{-1}	9.60	10.84	10.11
DO Saturation	PCT	98.4	106.1	101.9
Fluorescence	μgL^{-1}	0.24	3.75	1.95
Chlorophyll a	μgL^{-1}	1.21	2.94	2.17
Phaeopigment	μgL^{-1}	0.36	1.22	0.61
Nutrients				
NH4	µM	0.42	14.10	2.17
NO2	µM	0.16	0.48	0.23
NO2+NO3	µM	6.75	7.76	7.18
PO4	µM	0.87	1.12	0.94
SIO4	µM	4.99	12.10	5.92
BIOSI	µM	0.70	2.60	1.87
DOC	µM	122.5	217.2	161.3
PARTP	µM	0.12	0.19	0.15
POC	µM	13.92	22.14	17.02
PON	µM	1.36	3.54	2.57
TDN	µM	16.9	26.3	20.1
TDP	µM	1.04	1.46	1.21
TSS	mgL^{-1}	0.65	1.53	1.01
Urea	µM	0.31	2.64	0.97
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.030	0.047	0.037
Pmax	$mgCm^{-3}h^{-1}$	3.05	6.39	3.84
Areal Production	$mgCm^{-2}d^{-1}$	375.4	468.3	421.9
Depth-averaged Chlorophyll-specific Production	$mgC(mg\ Chla)^{-1}d^{-1}$	4.4	10.4	7.4
Respiration	μMO_2h^{-1}	0.039	0.097	0.072
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	0.417	0.716	
Centric diatoms	10^6Cells L^{-1}	0.048	0.107	
Alexandrium tamarense	Cells L^{-1}	ND	ND	
Phaeocystis pouchettii	10^6Cells L^{-1}	ND	ND	
Psuedo-nitzschia pungens	10^6Cells L^{-1}	0.001	0.001	
Total Zooplankton	Individuals m^{-3}	11,811	27,823	

NA = Data not available due to sample loss.
ND = Not detected in the sample.



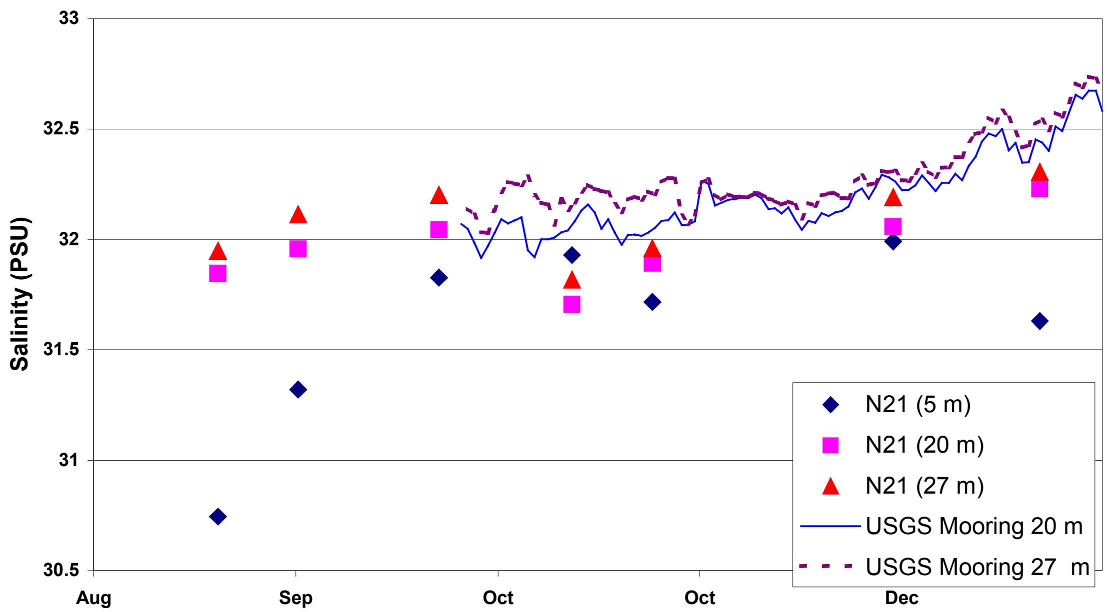


Figure 3-1. USGS Temperature and Salinity Mooring Data Compared with Station N21 Data from Comparable Depths

Note: Mooring instruments failed in early August and were redeployed on September 26, 2000.

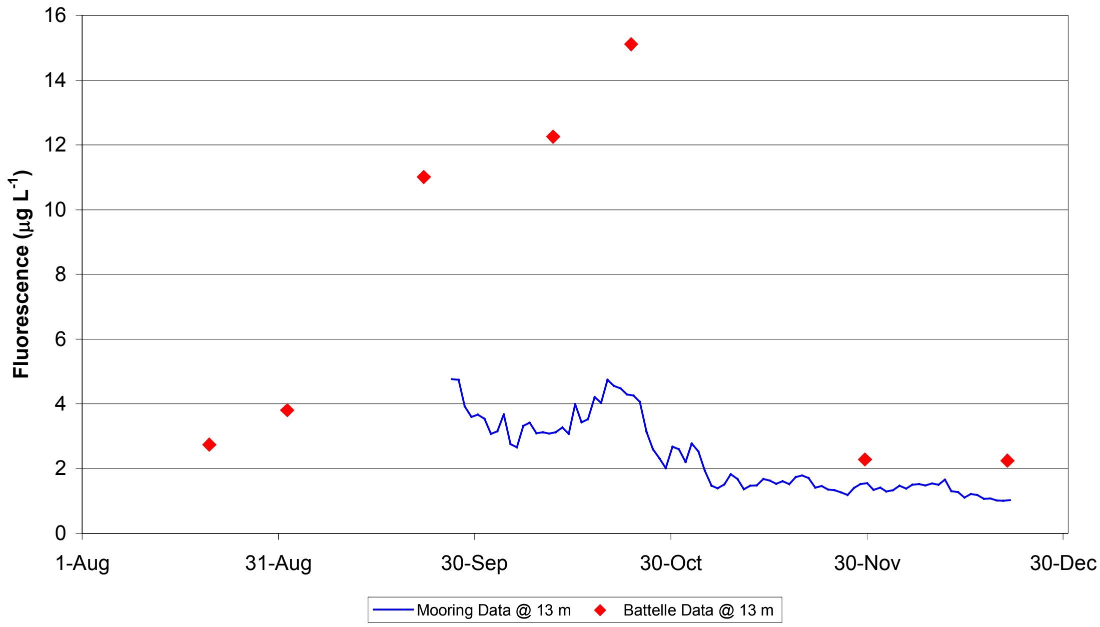


Figure 3-2. MWRA and Battelle *In Situ* Wetstar Fluorescence Data (MWRA Data Acquired at ~13 m on USGS Mooring and Battelle Data Acquired at 12.5 to 13.5 m at Station N21)

Note: Wetstar instrument failed on July 26, 2000 and was redeployed on September 26, 2000.

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. Finally, a summary of the major results for these water column measurements is provided in Section 4.3.

Two of the eight surveys conducted during this semi-annual period were combined farfield/nearfield surveys. In August during the first combined survey of this period (WF00B), seasonal stratification conditions existed throughout the bays. By October (WF00E), the density gradient had weakened at the nearshore nearfield, coastal, and Cape Cod stations while offshore stations maintained a clearly defined pycnocline. Boston Harbor was well mixed during both farfield surveys. The change from stratified to well-mixed conditions in the nearfield is illustrated in Figure 4-1. At the western nearfield stations (N10 and N11), the water column had become well mixed with respect to density by late October while a weak density gradient still existed at the outer nearfield stations. By late November, the water column had returned to well-mixed winter conditions over the entire nearfield.

Data collected during the farfield surveys were evaluated for trends in regional water masses throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay. The variation of regional surface water properties is presented using contour plots of surface water parameters, derived from the surface (depth 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 farfield transects (Boston-Nearfield, Cohassett, and Marshfield) in the survey area, and one transect across the Nearfield (Figure 1-3). 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 destabilization of stratified conditions. In addition to the nearfield vertical transect (Figure 1-3), 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 the surface contour maps, vertical transect plots, and parameter scatter plots is provided in Appendices B, C, and D, 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 (Figure 4-2). This destabilization of the water column significantly affects a number of water quality parameters during this time period. 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 as it did in 2000. 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 late fall/early winter storms increase wind-forced mixing. As mentioned above, the surface and bottom water density data collected during the combined surveys indicated 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 in the inner nearfield region by early October (WF00E), but the water column at the outer nearfield stations was not well mixed until late October (Figure 4-2).

4.1.1.1 Horizontal Distribution

In August (WF00B), surface water temperatures were highest along the coast and exceeded 20°C in Boston Harbor (Figure 4-3). Elevated surface temperatures were also found in Cape Cod Bay. The coolest surface temperatures (<18°C) were measured at boundary stations F27 and F29. Surface water salinity ranged from 30.0 PSU at Boston Harbor station F30 to ~31.5 PSU at station F07 offshore of Marshfield and boundary stations F27, F28 and F29 (Figure 4-4). The slightly higher surface salinity observed at the offshore and boundary stations may be due to an incursion of more saline water from the Gulf of Maine. No clear upwelling signal of cooler more saline waters was observed for the surface data in the coastal waters in August 2000. Local climatological data from the National Weather Service station at Logan Airport indicated wind speeds were below normal for the summer of 2000 and the direction of prevailing winds was inconsistent.

During the nearfield surveys conducted in September (WN00C and WN00D), there was an ~3°C variation in surface temperature across the nearfield area. In early September, surface water temperatures were warmer (>19°C) at the offshore stations and along a band from station N05, which had the warmest (19.8°C) to N13 through the middle of the nearfield. The coolest surface waters were at station N01 (16.8°C), perhaps due to its inshore location (mixing) or time of day (first station sampled). In late September, surface water temperatures ranged from ~13°C at stations N01 and N02 to the northwest to ≥15°C along the southern edge of the nearfield. During both surveys, there was little variation in surface salinity (31 to 31.5 PSU during WN00C and 31.8 to 32.1 for WN00D) with the surface waters at inshore stations slightly less saline than at the offshore stations.

The October survey (WF00E) was conducted over the course of two weeks and the change in surface water temperatures over that time are evident in Figure 4-5. The warmest (15.2°C) and coolest (12.6°C) surface temperatures were observed at neighboring stations F16 and F15, respectively. Although these two stations are about 8 km apart spatially, they were sampled just more than a week apart (October 4th and 12th). Station F15, stations along the Marshfield transect, boundary station F29 and the Cape Cod Bay stations were sampled on October 12th while the rest of the farfield and nearfield stations were sampled a week earlier. During the intervening week, record low air temperatures and relatively strong winds (potential for mixing) served to lower surface water temperatures. A somewhat similar pattern is present in the salinity data (Figure 4-6). Salinities of <31.5 PSU were observed in southern Massachusetts Bay and Cape Cod Bay with the lowest (<31 PSU) occurring along coastal waters south of Boston Harbor. The lower salinity surface waters on October 12th suggests that the changes in surface water temperature were due to meteorological effects of cooler air temperatures rather than mixing/upwelling, which would have led to increased surface salinity.

During the remaining three nearfield surveys, lower temperatures and lower salinity were observed in the surface waters along the western nearfield. The inshore to offshore gradient for each parameter increased from late October to December.

The fall of 2000 was relatively dry. Periodic rainfall events of <1 in occurred from August through October and two events of >1 in were measured in November (Figure 4-7). There were no major precipitation events until December (2.67 in on December 17th). The lack of rain resulted in relatively low flow in both the Charles and Merrimack Rivers from August to December with higher flow only occurring after the December 17th rain event. The rain event and increased runoff was evident in the cooler, fresher water observed at stations N10 and N11, which are influenced by tidal exchange with Boston Harbor. Meteorologically, the fall of 2000 can be characterized as having little freshwater input into the bays (precipitation and riverine) due to the lack of storms, which also resulted in a sunnier than normal period.

4.1.1.2 Vertical Distribution

Farfield. The water column was stratified throughout the bays during the summer of 2000 and, by October, the stratified water column conditions had begun to deteriorate although it did not become well mixed until later in October. As suggested previously, the density gradient ($\Delta\sigma_t$), representing the difference between the bottom and surface water σ_t, can be used as a relative indicator of a mixed or vertically stratified water column. During the August farfield survey (WF00B), the $\Delta\sigma_t$ between surface and bottom waters was >1 throughout the region except at the Boston Harbor stations (Figure 4-8). These stations are shallow and subject to strong tidal mixing. Surface water densities had increased by the October survey across the region and the water column was only well mixed at the harbor stations, but $\Delta\sigma_t$ had decreased to <1 at the coastal and Cape Cod Bay stations. At the offshore and boundary area stations, stratification had weakened, but the density difference between bottom and surface waters was still >1. For the stations in both the offshore and boundary areas, the density difference was driven by the continued gradient in temperature over the water column (Figure 4-9). Temperatures had decreased in the surface waters, but there was still a 4°C gradient at these deeper stations. During both of the combined surveys, there was little variation in salinity over the water column in the harbor, coastal and Cape Cod Bay areas (<0.5 PSU). At the deeper offshore and boundary stations, the salinity gradient was ~1 PSU in August and decreased to ~0.5 PSU by October.

The temporal and spatial variability during the seasonal return to well-mixed winter conditions can also be seen in the vertical contour plots of temperature, salinity, and sigma-T for the Boston-Nearfield, Cohassett, and Marshfield transects (Appendix C). In August, the water column was strongly stratified along each of the transects ($\Delta\sigma_t$ >2; Figure 4-10) and a sharp pycnocline was observed at ~20 m. The gradient was weaker at the inshore stations along each of the transects. The density gradient was driven by temperature, which exhibited a >8°C difference between the surface and bottom layers at all but the nearshore stations along each transect (Figure 4-11). An upwelling signature, which is often observed in western Massachusetts Bay in August, was not evident in the temperature and salinity contours. By October, stratification had weakened throughout the region. As mentioned above, $\Delta\sigma_t$ between surface and bottom waters was <1 at the nearshore stations and it appeared that there was an inshore-offshore destabilization of the pycnocline (Figure 4-12). The decrease in $\Delta\sigma_t$ was driven by changes in surface and bottom water temperatures. Decreasing air temperatures cooled the surface waters, while bottom waters continued to be warmed due to mixing with warmer mid-depth waters. The cooler temperatures at station F15 and along the inner half of the Marshfield transect were due to the weeklong delay in sampling these stations during the October survey (Figure 4-13).

The return to winter conditions can also be seen by examining the temperature-salinity (T-S) relationship for the region. In Figure 4-14, the T-S plots for the August and October surveys are presented. In August (WF00B), the T-S pattern is indicative of the vertical stratification that exists in the bays during the summer season. Surface water temperatures were generally 18-20°C and there was a strong thermal gradient (8-10°C) between surface and bottom water temperatures across the bays. Salinity varied over a relatively wide range (30-32.5 PSU) from the shallow harbor stations to the deeper waters offshore. There was a negative relationship between the parameters as an increase in salinity with depth was coincident with a decrease in temperature. By October (WF00E), the range in temperatures had decreased (8 to 15°C) as temperatures had decreased in the surface waters and increased at depth. The range in salinity remained about the same though salinity had increased by ~0.5 throughout the bays. The T-S pattern at the deeper stations in the offshore, boundary, and nearfield areas continued to exhibit the summer signature of increasing salinity corresponding to decreasing temperature from the surface to the bottom waters. In Boston Harbor, coastal areas and Cape Cod Bay, the T-S pattern was shifting towards the characteristics of a well-mixed winter water column – minimal variation in salinity or temperature.

Nearfield. The breakdown of seasonal stratification and the 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 Figure 4-1, it was evident that the breakdown of stratification proceeded from the shallow inshore stations to the deeper offshore stations. In late October, the inner nearfield stations (N10 and N11) had become well mixed with σ_t = 24 for both the surface and bottom waters. In Broad Sound (N01) and at the outer nearfield stations (N04, N07, N16, and N20), stratification had deteriorated and $\Delta\sigma_t$ decreased to ~0.5. By late November, the entire nearfield area was well mixed and had returned to winter conditions. Figure 4-15 presents σ_t along the nearfield transect (see Figure 1-3) from early September to late October showing the inshore to offshore progression in the destabilization of the water column during the fall of 2000. In early September, stratified conditions were present along the entire nearfield transect and the pycnocline was observed at 10-15 m though it was not as clearly defined as during the August surveys. By late September, the density gradient had decreased, but a relatively strong pycnocline remained at 15-20 m. In early October, the water column had become mixed in the western nearfield, but a density gradient of ~1 was still present at the eastern nearfield stations. By late October, winter physical characteristics were present along the entire nearfield transect, though there was still a small gradient in density between the surface and deep waters.

The vertical gradient in density is predominantly driven by temperature during the fall in Massachusetts and Cape Cod Bays. In early September, there was a very strong temperature gradient (~10°C) between surface and bottom waters along the nearfield transect (Figure 4-16). By late September, surface water temperatures had decreased by ~4°C, which resulted in a decrease in the temperature (and density) gradient. Water temperatures below the pycnocline remained unchanged although there appears to have been a deepening of the thermocline over the course of the month as the surface mixing depth increased bringing cooler waters into the surface layer. By early October, mixing had resulted in a warming of the bottom waters as stratification deteriorated and by the end of the month the water column along the nearfield transect was essentially isothermal except for the deeper waters (>35 m).

Although the data do not indicate any strong upwelling events for 2000, physical oceanographic data indicate there was an influx of denser, saltier, cooler bottom water into the nearfield during the two September surveys – before and following initiation of discharge from the bay outfall (Figure 4-17). There are no USGS mooring data available for this time period with which to corroborate and bracket the actual timeframe of this event (see Figure 3-1). It is likely that the influx is due to advection of deeper bottom waters from further offshore – Stellwagen Basin or the Gulf of Maine. The time series contours of density, salinity and temperature also suggest that this cool, more saline water in September was mixed with the surface waters by October. This influx of bottom water also brought additional nutrients into the nearfield that eventually mixed into the surface waters to support the large fall bloom in 2000. The physical forcing factors that might have physically stimulated fall plankton bloom will be evaluated in the 2000 annual report.

In addition to the harbor, coastal and offshore influences on nearfield physical conditions, the fall of 2000 marked the start of direct discharge of MWRA effluent into the nearfield area. The effluent discharge was transferred from the harbor outfall to the bay outfall on September 6, 2000. The region of rapid initial dilution is tightly constrained to the local area around the diffuser. Even so, the salinity data shows an effluent derived influence albeit at very high dilutions. Figure 4-18 presents salinity data along the nearfield transect following initiation of discharge at the bay outfall. In late September, there was a relatively weak salinity signal at station N21, which is within 100m of the outfall at approximately two thirds of the way along the diffuser. By October, the signal was more pronounced with salinities ~0.5 PSU below background between 15-30 m depth at station N21. Lower salinity water was also present at station N10, which may be due to the effluent plume or tidal exchange with Boston Harbor. In December, low salinity was observed again at both stations N10 and N21, but in this case it is likely that the N10 salinity is due to harbor exchange while the N21 is a surfacing of the effluent plume. A review of farfield data along the Boston-Nearfield transect before and after September 6th also shows the bay outfall plume (Figure 4-19). The plume appears to have extended into surface waters as lower salinity water was observed both in the plume at depth at stations N20 and N21 and in surface waters of stations N16 and F24. Ammonium (NH_4) was also found to be a good tracer of the effluent plume. The distribution of NH_4 in the nearfield and the potential ramifications of the availability of this nutrient as it pertains to the fall bloom are discussed in Sections 4.2.

4.1.2 Transmissometer Results

Water column beam attenuation was measured synoptically with the other *in situ* measurements at all nearfield and farfield stations. The transmissometer determines beam attenuation by measuring the percent transmission of light over a given path length in the water. The beam attenuation coefficient (m^{-1}) is indicative of particulate concentration in the water column. The two primary sources of particles in coastal waters are biogenic material (plankton or detritus) and suspended sediments. Beam attenuation data is often evaluated in conjunction with fluorescence data to ascertain the source of the particulate materials (phytoplankton versus detritus or suspended sediments).

In August (WF00B), surface water beam attenuation ranged from 1.00 m^{-1} at station F28 on Stellwagen Bank to 3.01 m^{-1} at station F30 in Boston Harbor (Figure 4-20). As is normally observed, elevated beam attenuation measurements were found at the harbor stations. An inshore to offshore decrease in beam attenuation was evident. A similar inshore to offshore decrease in surface water beam attenuation was observed during the October farfield survey (Figure 4-21). The highest value was measured at station F23 (1.93 m^{-1}) in Boston Harbor and the lowest value was observed at nearfield station N02 (0.98 m^{-1}). In addition to the high values (>1.5 m^{-1}) measured in the harbor and near-harbor coastal waters, beam attenuation was elevated in Cape Cod Bay (station F03). There was little change in surface water beam attenuation in Massachusetts and Cape Cod Bays from August to October although Boston Harbor and some coastal water values decreased over this time period.

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 4-22 presents beam attenuation data along three of the farfield transects in August (WF00B). These contour plots clearly show the harbor signature of high beam attenuation (station F23) and its influence on nearfield stations. The beam attenuation signal along the Cohassett and Marshfield transects is likely due to both a terrestrial source and phytoplankton as the elevated beam attenuation values are coincident with high chlorophyll concentrations. Along the nearfield transect, the highest beam attenuation values (2.2-3.0 m^{-1}) were observed in the surface waters during the early September survey (Figure 4-23). Beam attenuation values remained elevated in the surface layer (upper 20 m), but tended to decrease in magnitude from early September through October. This is in contrast to the increase in chlorophyll concentrations from early September to late October when they had their highest values (see Figure 4-43). Note that beam attenuation values peaked early in the fall bloom, which might be expected as phytoplankton abundance also peaked at this time for the fall 2000 bloom. The spatial distribution of beam attenuation values along the nearfield transect appears to have become more variable following initiation of discharge at the bay outfall (Figure 4-23). It is unclear if these less cohesive patterns in the data are related to or driven by the effluent plume.

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 (Appendix D). As observed with the physical characteristics, surface water contour maps (Appendix B) and vertical contours of nutrient data from select transects (Appendix C) were also produced to illustrate the spatial variability of these parameters.

The general trend in nutrient concentrations during the 2000 August to December period was similar to previous baseline monitoring years. Seasonal stratification led to the persistent nutrient depleted conditions in the surface and mid-depth waters 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 fall, nutrient concentrations began to increase with the breakdown of stratification, but they remained low in the surface waters and decreased at mid-depth during the fall bloom. In November and December, nutrient concentrations returned to typical winter values as the water column became well mixed.

The most noteworthy observation for this time period was the continued presence of elevated concentrations of ammonium (NH_4) in Boston Harbor and near-harbor coastal waters during August 2000, and the transfer of effluent to the bay outfall and the change in the NH_4 signature in the nearfield. The elevation of NH_4 concentration in the harbor was first observed during the fall/winter period of 1998. The source of NH_4 was determined to be an increase in the discharge of NH_4 from the Deer Island facility (Libby *et al*. 1999). This increase resulted from a combination of increased treated sewage flow from the Deer Island Outfall as all sewage from the MWRA system is now treated at the Deer Island facility and the treatment itself. Secondary treatment, which is now fully on line, leads to the breakdown of organic wastes, but one of the consequences or by-products of the secondary treatment process is higher NH_4 concentrations in the effluent (Hunt *et al*. 2000). Following the diversion of flow from the harbor outfall to the bay outfall on September 6, 2000, the NH_4 signature was reduced in Boston Harbor and relocated in the nearfield. The NH_4 plume signature and potential effects are one of the main focuses of this section.

4.2.1.1 Horizontal Distribution

In August (WF00B), the highest surface nutrient values were found in Boston Harbor [dissolved inorganic nitrogen (DIN) = 21.05 µM, nitrate (NO_3) = 3.16 µM, phosphate (PO_4) = 1.58 µM and silicate (SIO_4) = 7.82 µM at station F30 and ammonium (NH_4) = 18.09 µM at station F23]. Nutrient concentrations generally decreased outside of the harbor and away from the coast as represented by DIN in Figure 4-24. Nitrate and phosphate concentrations were depleted throughout Massachusetts and Cape Cod Bays. Silicate was present in concentrations of >2 µM over most of Massachusetts Bay with lower concentrations observed in the further offshore, in the boundary area, and Cape Cod Bay (Appendix B).

The representation of surface nutrient distribution for the October survey was influenced by a week long delay between the first three and last day of sampling and the export of nutrients from Boston Harbor. The highest surface nutrient concentrations were observed in Boston Harbor (DIN = 4.66 µM and NO_3 = 2.71 µM at station F30 and NH_4 = 2.38 µM at station F23), coastal station F25 that is just offshore of the southern entrance to the harbor (PO_4 = 1.69 µM), and at station F29 off of Provincetown (SiO_4 = 3.62 µM). Along with the higher SiO_4 concentrations at station F29, nutrient concentrations were somewhat elevated at the other stations sampled on October 12th in comparison to the rest of Massachusetts Bay (station F15, stations along the Marshfield transect, and the Cape Cod Bay stations). Changes in surface temperature and salinity suggested meteorological factors (air temperature and perhaps increased runoff to coastal waters) were the cause of the week-to-week variability in parameters at these stations. The increase in nutrient concentrations (especially at stations F29 and F15) suggests that there may have been an advective influx or mixing of more nutrient rich waters. The absolute increase in comparison to stations in the vicinity that were sampled earlier in the week was quite large at station F15, but for the remaining stations the increase was not substantial.

Although the harbor signal continued to be observed in DIN distribution (Figure 4-25), the concentrations were substantially lower than the surface concentrations seen in August 2000 or previous October surveys during preceding years. This is obviously due to the diversion of MWRA effluent from the harbor outfall to the bay outfall. A comparison of the surface and bottom water NH_4 distribution in October 1999 and 2000 is presented in Figures 4-26 and 4-27. During each of these surveys, the water column was weakly stratified undergoing a transition from seasonal stratification to well-mixed winter conditions. Surface water NH_4 concentrations were high in the harbor in 1999 and low in 2000. Bottom water NH_4 concentrations were high in the harbor and low in the bays in 1999, while concentrations were low in the harbor, high in the nearfield in the vicinity of the outfall, and low throughout the rest of Massachusetts and Cape Cod Bays in 2000.

The usefulness of NH_4 as a tracer of the effluent plume can be seen in more detail for the nearfield data. Although it is not a conservative tracer due to biological utilization, NH_4 does provide a potential natural tracer of the effluent plume in the nearfield area especially in low light conditions where biological activity is minimal (i.e. below the pycnocline during stratified conditions and during the winter). The nearfield NH_4 concentrations in early September showed very low concentrations and no clear pattern in the nearfield (Figure 4-28a). By late September, approximately two weeks after the outfall began operations, the distribution of NH_4 concentrations clearly demonstrated that the effluent was present within the nearfield (Figure 4-28b). In late September, water column stratification was beginning to breakdown. Although production rates were high, it appears that the effluent plume NH_4 signal extended into the surface waters. By early October, the data suggest that the plume was trapped below the pycnocline (Figure 4-29a), but physical conditions may have been such that the NH_4 was utilized before reaching the surface waters (slow mixing or transport) or was transported out of the nearfield area before reaching the surface (fast transport). By late October and for the remainder of the year, the effluent plume was clearly observed over the entire water column in the nearfield (Figure 4-29b). Ammonium in the water column has proven to be an excellent tracer of the influence of Boston Harbor on coastal and western nearfield waters over the course of the baseline monitoring program and it appears that it is a clear indicator of the effluent plume in the nearfield now that the outfall is online.

4.2.1.2 Vertical Distribution

Farfield. The vertical distribution of nutrients was evaluated using vertical contours of nutrient data collected along three transects in the farfield: Boston-Nearfield, Cohassett, and Marshfield (Figure 1-3; Appendix C). During the August combined farfield/nearfield survey (WF00B), nutrient concentrations were low in the surface waters and increased with depth. As observed for NO_3 in Figure 4-30, low concentrations were found throughout the surface layer and increased near the pycnocline and closer to Boston Harbor. The vertical pattern for PO_4 and SiO_4 was similar to that of NO_3, but the concentrations were not as depleted in the surface waters. Usually, the summer pattern of depleted nutrients in the surface waters is concomitant with low chlorophyll concentrations at the surface and a sub-surface chlorophyll maximum near the pycnocline. In August 2000, subsurface chlorophyll maxima were observed, but elevated chlorophyll concentrations were found in the surface waters that were nutrient depleted (see Section 4.2.2.2).

In October (WF00E), NO_3 concentrations were still depleted in the surface waters along each of the transects and increased with depth (Figure 4-31). Elevated NO_3 concentrations were again found in surface waters near Boston Harbor and there was a slight increase in concentrations at station F15, which was sampled a week later than the other stations on the Cohassett transect. Similar trends were observed in the PO_4 and SiO_4 data. One clear difference in the PO_4 distribution was the elevated concentrations located above the diffuser at station N21 (Figure 4-32a). This was coincident with very high NH4 concentrations (>16 μM) that were present in the effluent plume (Figure 4-32b). Both of these nutrients are enriched in the effluent in comparison to background concentrations in the nearfield. The plume appears to have been confined below the pycnocline along the Boston-Nearfield transect as it was in the nearfield contour data for October (see Figure 4-29a). A review of concomitant salinity data along the transect, however, suggested that the plume may have extended into surface waters (see Figure 4-19b). Lower salinity water was observed both in the plume at depth at stations N20 and N21 and in surface waters of stations N16 and F24. The lack of an NH_4 signal in these surface waters might suggest that the NH_4 was utilized before reaching the surface waters during the fall bloom. It should be noted again, however, that NH_4 is not a conservative tracer and that given the temporal and spatial scales that NH_4 is measured during these surveys it is difficult to definitively ascribe changes in the distribution of the plume to particular physical or biological factors. A more refined examination of physical current structure, mixing, and loading is needed to allow for better differentiation of physical and biological effects on NH_4 distributions in the nearfield.

Nutrient-salinity plots are useful in distinguishing water mass characteristics and in examining regional linkages between water masses (Appendix D). In August, DIN plotted as a function of salinity exhibits a pattern that is often observed during this time period (Figure 4-33a). There is a decrease in DIN concentration with increasing salinity at harbor and coastal stations. In the other areas, there was an increase in DIN from low or depleted surface concentrations at intermediate salinity to high concentrations in the higher salinity, bottom waters. This pattern is complicated somewhat by elevated DIN concentrations at intermediate salinity for some nearfield stations. These stations are located along the western edge of the nearfield and are influenced by harbor water quality conditions. In general, the decreasing trend in DIN concentration from low to intermediate salinity is indicative of the dilution of harbor DIN with lower-nutrient, higher-salinity water at coastal and western nearfield stations. The depleted DIN at intermediate salinity and the increase in DIN concentrations with increasing salinity is common during stratified conditions. It results from biological utilization of nutrients in the surface waters and the combination of biological decomposition and nutrient regeneration processes at depth.

During the October survey, the main source of nutrients to Boston Harbor had been moved offshore to the bay outfall. This transfer of discharge combined with biological utilization during the fall bloom served to substantially decrease DIN concentrations in the harbor, coastal and western nearfield stations. This results in the removal of the usual harbor dilution signal in the DIN vs. salinity plots (Figure 4-33b). However, the typical stratified condition pattern of increasing DIN concentrations from intermediate to high salinity was observed throughout the rest of the bays.

Notable in the October data are the high DIN concentrations in the nearfield at intermediate salinity. These data are associated with the effluent plume from the bay outfall.

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 until late October (WN00F). The progression from summer to winter conditions is illustrated in the series of nearfield transect plots for NO_3 presented in Figures 4-34 and 4-35. In August (WF00B), NO_3 concentrations were depleted in the surface layer (0-15 m) and increased gradually with depth across the nearfield transect (Figure 4-34). By September 1st (WN00C), NO_3 levels were still depleted in surface waters along the transect, but concentrations had increased substantially in the all but the upper ~10 m of water. The physical oceanographic data suggest that this was due to a combination of an influx of water into the area and a weakening of mixing. A strong gradient in NO_3 concentrations was still associated with the pycnocline at 10-15 m. By late September, biological utilization had reduced nutrient concentrations in the surface waters, but NO_3 was still available at concentrations of 1-5 μM above the pycnocline (15-20 m).

By early October (WF00E), NO_3 concentrations had become depleted throughout most of the surface layer (upper 20 m) and had decreased at depths below the weakening pycnocline (Figure 4-35). The mixing that led to a warming of the bottom waters also served as a source of nutrients into the surface waters and likely contributed to the extended duration of the fall bloom in 2000. In late October, NO_3 concentrations had increased in the surface waters. The additional availability of nutrients was coincident with an increase in productivity at station N04 and N18 (see Section 5.1) and the highest chlorophyll concentrations of the fall bloom. By November, the water column was well mixed and nutrient concentrations had returned to typical winter levels over the entire nearfield transect.

As mentioned previously, upwelling events are often observed in August in Massachusetts Bay (Libby *et al*. 1999). In 2000, the lack of strong southwesterly winds may have lessened the strength of the upwelling signal. Time series contour plots of density, salinity and temperature at nearfield station N18 (see Figure 4-17) suggested that cooler, more saline waters were advected into the nearfield in September. Similar plots were examined to evaluate the effect of this on NO_3, PO_4, and SiO_4 concentrations at station N18 (Figure 4-36). The plots show elevated concentrations of each of these nutrients in bottom waters and at shallower depths in September compared to earlier in August or later in October. These data suggest that even though there may not have been a strong upwelling event in 2000, cooler more nutrient rich waters were being transported into the nearfield supporting elevated primary production in September 2000.

An examination of the nutrient-nutrient plots showed that surface waters were generally depleted in DIN relative to PO_4 and SiO_4 in the nearfield during this semi-annual period (Appendix D).

4.2.2 Chlorophyll A

Chlorophyll concentrations (based on *in situ* fluorescence measurements) reached very high levels during this time period. The 2000 fall bloom had started by the September 1st nearfield survey prior to the new outfall going on line and continued through late October. The peak survey mean chlorophyll concentration in late October was higher than any observed over the baseline period. These high concentrations combined with the extended duration of the bloom resulted in a fall nearfield mean chlorophyll concentration of 5.69 mgL^{-1}. The fall 2000 mean was higher than all baseline values and exceeded the areal chlorophyll threshold. The trends in chlorophyll concentration did not closely parallel phytoplankton abundance and primary production during the fall bloom in

2000. Nearfield phytoplankton abundance peaked in early September and gradually declined through October. Productivity was highest at station N18 during the September surveys and in late October further offshore at station N04. Chlorophyll concentrations, although steadily increasing in September, did not reach maximum levels until late October.

4.2.2.1 Horizontal Distribution

During the August combined survey, elevated surface chlorophyll concentrations > 5 μgL^{-1} were observed in northeastern Massachusetts Bay (stations F22 and F26) and western Cape Cod Bay (station F01 and F03; Figure 4-37). The survey maximum chlorophyll concentration was recorded at station F22 (5.75 $\mu g\ L^{-1}$). The lowest surface chlorophyll concentration was seen at station F07 offshore along the Marshfield transect (0.43 $\mu g\ L^{-1}$). Surface chlorophyll concentrations were relatively high in the western nearfield (3-4 $\mu g\ L^{-1}$). The rest of Massachusetts and Cape Cod Bays had surface chlorophyll concentrations between 1-3 μgL^{-1}. The August 2000 chlorophyll concentrations were substantially lower than those observed in 1999 when a late summer bloom was observed.

In October (WF00E), surface chlorophyll concentrations had increased substantially ranging from 3.18 $\mu g\ L^{-1}$ at station F22 to 18.11 $\mu g\ L^{-1}$ at station N11 (Figure 4-38). There was a gradient of decreasing chlorophyll from inshore to offshore in the surface water. The pattern in surface chlorophyll concentrations in and around the nearfield suggests that the local source of nutrients from the outfall may have had a localized effect during the fall bloom. A similar pattern of elevated surface chlorophyll concentrations in the vicinity of the outfall was seen during September nearfield surveys (Figure 4-39).

There was a substantial increase in surface chlorophyll concentrations from August to early September in the western nearfield (Figure 4-39a). Chlorophyll concentrations had decreased in the eastern half of the nearfield with the minimum surface chlorophyll concentration of 0.02 at station N07 in the southeast corner. The highest surface chlorophyll concentration was found at station N20 (9.00 μgL^{-1}). By late September, nearfield chlorophyll concentrations in the surface waters had more than doubled in the western nearfield and remained relatively low further offshore. This led to a wide range of values (1 to 25 μgL^{-1}) across the nearfield with the low value at station N15 and the highest once again at station N20 just to the east of the diffuser (Figure 4-39b). Surface chlorophyll concentrations were lower at the offshore stations and to the north during both of the September surveys. The patterns exhibited in Figure 4-39 show elevated chlorophyll concentrations at the inshore stations extending out toward the outfall with the highest concentrations at station N20 during each survey. Although it may be suggestive of an outfall effect, the early September survey was conducted five days before the start of the offshore outfall and the trend was likely due to an inshore to offshore development of the fall bloom as has often been the case during the baseline period. An inshore to offshore trend in bloom progression is also suggested in the production data with higher values observed at station N18 in comparison to offshore station N04 during each of the September surveys. The elevated chlorophyll and production were coincident with relatively high abundance of diatoms (~1.5 million cells L^{-1}) that were the basis for the fall bloom.

The surface chlorophyll concentrations increased in the nearfield as the fall bloom continued into October. Surface concentrations were >13 μgL^{-1} in the southern half of the nearfield and ranged from 5 to 13 μgL^{-1} to the north (see Figure 4-38). The minimum concentration was at station N02 and the maximum at station N11 (18.11 μgL^{-1}). The increase in chlorophyll occurred even though production rates decreased from late September to mid October by about 50% at station N04 and 80% at station N18 (see Figure 5-2) and phytoplankton abundance was slightly lower (see Figure 5-16). Chlorophyll concentrations reached a maximum during the late October survey. Surface water concentrations did not change substantially from the previous survey and values ranged from 6.4 μgL^{-1} at N21 to 21.8 μgL^{-1} at station N19. Surface chlorophyll concentrations decreased over the last two surveys of the year.

The nearfield data indicate that the fall 2000 bloom occurred over an extended time period from before September 1st through at least late October. The high surface chlorophyll concentrations observed during the October farfield survey suggests the regional extent of the bloom. Both the magnitude and breadth of the bloom are corroborated by composite SeaWiFS images for September and October (Figure 4-40). Elevated chlorophyll concentrations (5-15μgL^{-1}) were present in coastal waters throughout the region during each of the months and October seems to have somewhat higher concentrations than September. Although the surface data are indicative of a large fall bloom, the highest chlorophyll concentrations were found subsurface and elevated concentrations were present over most of the upper ~20 m of the water column.

4.2.2.2 Vertical Distribution

Farfield. Chlorophyll concentrations over the water column were examined along the three east/west farfield transects (Figure 1-3) to compare the vertical distribution of chlorophyll across the region. In August, elevated chlorophyll concentrations (1-4 μgL^{-1}) were found in the surface waters along each of the transects (Figure 4-41). There were sporadic instances of higher concentrations (4-7 μgL^{-1}) both near the surface and the pycnocline. Elevated surface water chlorophyll was coincident with slightly higher phytoplankton abundance for surface waters versus mid-depth. The phytoplankton assemblage was dominated by microflagellates.

By October (WF00E), production rates had increased and phytoplankton were more abundant and dominated by centric diatoms and microflagellates. Chlorophyll concentrations had increased substantially and high concentrations (>10 $\mu g\ L^{-1}$) were observed over a thick layer extending from the surface to the pycnocline at ~20 m along each of the transects (Figure 4-42). Although high concentrations were observed over the entire surface layer, chlorophyll concentrations reached subsurface chlorophyll maxima of >15 μgL^{-1} at about 10-15 m along each of the transects. The elevated chlorophyll concentrations along these transects were likely sustained by the increased in nutrient availability as discussed in the previous section.

Nearfield. Trends in the nearfield chlorophyll concentrations are summarized in Figure 4-43. 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 for each of the surveys during this time period.

In August, nearfield chlorophyll concentrations were consistently low (Figure 4-43). Mean values were ≤2 μgL^{-1} except at mid-depth in late August (~4 μgL^{-1}). There was a substantial increase in chlorophyll concentrations at mid-depth by the early September survey. Mean chlorophyll concentrations increased slightly in the surface waters to 3 μgL^{-1} with a range of values from 0 to 9 μgL^{-1} with the higher values at the inshore stations (Figure 4-39a). The mean mid-depth concentration increased to >10 μgL^{-1} and the highest values were generally located in near the center of the nearfield. By late September, nearfield mean chlorophyll concentrations had doubled to ~7 μgL^{-1} in the surface waters and increased slightly at mid-depth and a wide range of values (0 to 25 μgL^{-1}) was observed at both surface (Figure 4-39b) and mid-depth. The fall bloom continued into October with mean chlorophyll concentrations increasing to 12.3 μgL^{-1} in the surface waters and 14.6 μgL^{-1} at mid-depth. Surface concentrations were higher in the southern half of the nearfield

(Figure 4-38), while mid-depth concentrations were elevated at both the inshore and southern nearfield stations. These increases in chlorophyll occurred even though production rates decreased from late September to mid October and phytoplankton abundance was slightly lower. Chlorophyll concentrations reached a maximum during the late October survey. Bottom and surface water concentrations did not change substantially from the previous survey, but at mid-depth the mean chlorophyll concentration increased to 23 μgL^{-1} and values ranged from 11.6 to 43.6 μgL^{-1}. The highest values were at stations located near the center of the nearfield (N13, N19 and N20) and further offshore (N05, N06, N07, and N16). This increase from mid to late October was coincident with an increase in production and a slight decrease in phytoplankton abundance. By late November, surface chlorophyll concentrations had returned to lower levels throughout the nearfield and continued to decrease into December.

The progression of chlorophyll concentrations in the nearfield during the fall of 2000 can be more clearly seen through a series of contour plots of fluorescence over time at stations N10, N21, N18, and N07 (Figure 4-44). These stations are representative of inshore (N10), center (N21 and N18), and offshore (N07) nearfield stations. The fall bloom began in early September and elevated chlorophyll concentrations were observed at each of these stations, though they were somewhat lower at station N10. By late September, chlorophyll concentrations had increased substantially at stations N10 and N21 reaching concentrations of >15 μgL^{-1} over the upper 10 to 15 m of the water column. Chlorophyll concentrations increased at stations N18 and N07, but not to the same levels. It is interesting that there was such a difference in chlorophyll concentrations between stations N18 and N21, which are only 2 kilometers apart. It is unclear if the elevated concentrations at N21 are in response to the additional source of nutrients from the outfall or result from local physical factors. The data in Figure 4-39 suggested that this pattern was observed both prior to and after the outfall going online. By late October, chlorophyll concentrations reached a maximum at station N18 and N07. Concentrations of >11 μgL^{-1} were observed from the surface to depths of 20 meters at each of these stations. High chlorophyll concentrations at depth were also found at station N21with a subsurface maximum of > 15 μgL^{-1} at ~20 m. Although still high (9-15 μgL^{-1}), concentrations were slightly lower in the surface waters at station N21 and over the water column at station N10. These time series contours indicate there was inshore to offshore variability in the timing of peak chlorophyll levels during the fall 2000 bloom. More importantly, they show that chlorophyll concentrations were very high for an extended time period and over the entire upper water column.

The vertical distribution of chlorophyll during the fall bloom was examined in more 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 August, chlorophyll concentrations were relatively low in comparison to later surveys and reached a maximum in the subsurface waters at all but harbor-influenced station N10 (3-5 $\mu g\ L^{-1}$; Figure 4-45a). By early September, elevated chlorophyll concentrations were observed across the entire transect with maximum concentrations (>15 $\mu g\ L^{-1}$) found in the subsurface waters between station N19 and N21 (Figure 4-45b). At the inshore nearfield stations, high chlorophyll concentrations were observed from the surface to a depth of 10 m. Chlorophyll concentrations decreased in the surface waters and subsurface chlorophyll maximum to the northeast. These high chlorophyll concentrations were associated with the centric diatom bloom that was observed at stations N04 and N18. By late September, chlorophyll concentrations had increased to >15 μgL^{-1} in the upper 15 m from station N10 to N21 and there was an inshore to offshore decrease in concentration with low surface concentrations at N15 and N04 (Figure 4-45c). The occurrence of a surface chlorophyll maximum inshore and a separate subsurface chlorophyll maximum further offshore has been noted during previous fall blooms, but the presence of very high chlorophyll concentrations over the entire surface layer (0-15 m) in the western nearfield was atypical.

By October, chlorophyll concentrations had decreased slightly at stations N10, N19 and N21, but high concentrations (7 to >15 μgL^{-1}) were observed over the upper 20 m of the water column at these stations (Figure 4-46a). Concentrations again decreased from inshore to offshore, but chlorophyll concentrations had increased at stations N15 and N04 since September and ranged from 7 to 11 μgL^{-1} over the upper 25 m. The highest chlorophyll concentrations of the bloom were observed during the late October survey. The inshore to offshore difference in chlorophyll distribution continued to be present with the highest concentrations (>15 μgL^{-1}) in the upper 10 m at stations N10 and N19, at a subsurface chlorophyll maximum around 20 m at station N21, and over most of the upper 25 m at stations N15 and N04 (Figure 4-46b). Chlorophyll concentrations throughout the upper 30m along the transect were >5 μgL^{-1}. By November, chlorophyll concentrations had decreased to lower levels signaling that the fall bloom had ended earlier in November (Figure 4-46c).

The 2000 fall bloom had started by early September and continued through late October. The extended duration of the bloom and the high concentrations resulted in a fall mean chlorophyll concentration of 5.69 μgL^{-1}, which was higher than the fall mean observed in 1999 (Libby *et al.*, 2000a). As in 1999, phytoplankton abundance, primary production, and chlorophyll did not parallel each other closely during the fall bloom in 2000. Nearfield phytoplankton abundance peaked in early September and gradually declined through October. Productivity was highest at station N18 during the September surveys and in late October at station N04. Chlorophyll concentrations, though steadily increasing in September, did not reach maximum levels until October. The same progression of high phytoplankton abundance, high productivity, and then high chlorophyll concentrations was observed during the 1999 fall bloom. The fall of 2000, however, was the first time period to be compared against baseline by way of threshold values. The fall mean chlorophyll concentration (5.69 μgL^{-1}) was more than double the 1992-1999 fall mean of 2.70 μgL^{-1} and would have exceeded the originally proposed threshold value of 4.96 μgL^{-1} (95th percentile of baseline means). It should be noted that the mean chlorophyll concentration for fall 1999 (5.45 μgL^{-1}) was also higher than this value. A brief summary of threshold values is presented in section 4.3 and a detailed discussion of threshold values will be included in the 2000 annual report.

4.2.3 Dissolved Oxygen

Spatial and temporal trends in the concentration of dissolved oxygen (DO) were evaluated for the entire region (Section 4.2.3.1) and for the nearfield area (Section 4.2.3.2). Due to the importance of identifying low DO conditions, bottom water DO minima were examined for the water sampling events. The minimum bottom water DO concentration was 6.3 mgL^{-1} in the nearfield at station N11 in early October and at station N07 in late October. Regionally, a DO concentration minimum of 4.8 mgL^{-1} was observed in Cape Cod Bay at station F02 in October. The second lowest DO value (5.9 mgL^{-1}) was measured at the same station during the August farfield survey. Not surprisingly, these four bottom water samples also had the lowest %saturation values for the year – 55% at F02 in October, 65% at F02 in August, 69% at N07 in late October, and 70% at N11 in October.

The 2000 nearfield survey mean bottom water DO minimum (7.1 mgL^{-1}) and %saturation minimum (78%) occurred during the mid October survey. These values were comparable to the survey mean bottom water minima for Stellwagen Basin stations – 7.3 mgL^{-1} and 78%. Although all of these survey mean minimum values were relatively high and well within the range observed during baseline monitoring (Libby *et al.*, 2000a), the DO %saturation values were below the caution threshold (80%) for both the nearfield and Stellwagen Basin.

Given the unprecedented chlorophyll concentrations during the winter/spring bloom (Libby *et al.*, 2000b) and the relatively high respiration rates achieved during the summer, it is surprising that lower DO concentrations were not observed during the fall of 2000. The influx of nutrient rich, saline waters in September due to physical mixing or horizontal transport may have alleviated detrimental DO conditions as well as been the source of nutrients for the fall bloom. The connection between physical oceanographic conditions and DO concentrations is the focus of ongoing data analysis and modeling to clarify the underlying relationships.

4.2.3.1 Regional Trends of Dissolved Oxygen

Temporal trends in bottom water DO concentrations were limited for the farfield as stations were only sampled twice during this period. Area mean DO concentration reached minimum values (~7.3 mgL^{-1}) in the coastal and Cape Cod Bay areas by the August survey increasing slightly by October. The mean DO %saturation at these two areas was ~90% in August and increased to 92% in coastal waters and decreased to 88% in Cape Cod Bay in October. Boston Harbor survey mean DO concentration and %saturation were lowest in August at 6.4 mgL^{-1} and 83%, and increased to 7.8 mgL^{-1} and 92% by October. At offshore and boundary stations, mean DO concentrations and %saturation decreased from August to October. The October bottom water mean DO concentrations were comparable at each of the five areas ranging from 7.5 to 8 mgL^{-1}. DO %saturation at boundary and Cape Cod stations was ~87% in October while lower DO %saturation was measured for the offshore area (82%). The DO data collected from a subset of boundary and offshore stations in Stellwagen Basin (F12, F17, F19, and F22) have been grouped to evaluate DO trends in these deep waters. The DO concentration and %saturation areal means during the October farfield survey in Stellwagen basin were 7.3 mgL^{-1} and 78%, respectively, which was comparable to the values in the nearfield.

In August (WF00B), bottom water DO concentrations in the bays ranged from a minimum of 5.89 mg L^{-1} at station F02 in Cape Cod Bay to a maximum of 8.86 mg L^{-1} at station F28 on Stellwagen Bank (Figure 4-47). August is relatively early for such low bottom water DO concentrations at station F02. It may have resulted from the large amount of organic material produced during the spring diatom and then *Phaeocystis* blooms that were observed in Cape Cod Bay (Libby *et al*., 2000b). In addition to the low bottom water DO observed in Cape Cod Bay, DO concentrations of 6-7 mg L^{-1} were found in Boston Harbor, coastal station F25, and in the southwest corner of the nearfield at stations N10 and N11. Relatively low DO concentrations of 7-8 mg L^{-1} were observed throughout the western half of the nearfield and at coastal and offshore stations in the vicinity of Boston Harbor and along the south shore. There was a clear inshore to offshore gradient of increasing bottom water DO concentrations.

From August to October, a major change in the pattern of bottom water DO concentrations was observed (Figure 4-48). By October, bottom water DO concentrations had increased to >8 mg L^{-1} at harbor station F23 and along the coast where low DO concentrations had been observed in August. The highest bottom water concentration (9.31 mg L^{-1}) was located at station F05 off of Marshfield. These higher DO concentrations were located at inshore stations that had already become well mixed. The lowest concentration was once again measured at station F02 in Cape Cod Bay. The spatial pattern of bottom water shows the inshore to offshore gradient of decreasing DO concentration. Besides the survey minimum value at station F02 in Cape Cod Bay, lower DO concentrations were generally found in the nearfield area and offshore waters including Stellwagen Basin.

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 4-49). The gradient in DO concentration between the surface and bottom waters ranged from 0 to 2.5 mg L^{-1} over this time period. During the summer, lower production rates and higher respiration rates (see Section 5.2) led to decreases in DO from early to mid August when minima were observed in surface waters. Bottom water DO concentrations decreased from ~8.5 mgL^{-1} to <8 mgL^{-1} in August. DO concentrations increased in the upper water column during the extended fall bloom ranging from 9.5 to 10 mgL^{-1} and remained there through the end of the year. Mean bottom water DO concentrations continued to decrease from August into October. The influx of nutrient rich, saline bottom water into the nearfield in September may have also had higher DO concentrations as the decline in DO concentrations was not as sharp from August through September as it was between the two August surveys. The nearfield bottom water survey mean DO concentration minimum was observed in early October (7.1 mgL^{-1}). Bottom water DO did not increase until after stratification completely broke down following the late October survey.

DO %saturation followed a trend similar to that of DO concentration (Figure 4-49b). Surface water DO %saturation varied by 10-15% from August to October, but remained supersaturated at levels of 110-130%. Average DO %saturation for the bottom waters in early August was 92.5% and decreased to 83.7% by the mid August survey. DO %saturation remained above 80% during the two September surveys. In mid October, the survey mean minimum of 78% saturation was measured, which is below the current caution threshold of 80% for the nearfield. By late October, the mean DO %saturation value had begun to increase (83%). By November, the entire water column had returned to saturation (100%).

Given the unprecedented chlorophyll concentrations during the winter/spring and summer of 2000 and the relatively high respiration rates achieved during the summer, it is surprising that lower DO concentrations were not observed. The influx of nutrient rich, saline waters in late August and September due to physical mixing or horizontal transport may have alleviated detrimental DO conditions as well as been the source of nutrients for the fall bloom. The 2000 DO trends and the current DO thresholds will be discussed in more detail in the 2000 Annual Water Column Report.

4.3 Contingency Plan Thresholds

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. Those parameters include background levels for water quality parameters chlorophyll and dissolved oxygen. Annual and seasonal chlorophyll areal concentration thresholds have been developed for the nearfield area and bottom water dissolved oxygen concentration and percent saturation minima thresholds have been designated for the nearfield and Stellwagen Basin (Table 4-1). The fall of 2000 was the first seasonal time period to be compared against these thresholds. The fall 2000 mean areal chlorophyll was 205 mg m^{-2} exceeding the caution threshold of 161 mg m^{-2} (Table 4-1). As discussed herein, fall blooms are typical for the bays and the bloom in 2000 occurred over the entire Gulf of Maine region and exhibited elevated chlorophyll concentrations from early September through late October. The fall bloom in 2000 is part of the natural variability of the region.

In 1997, the Outfall Monitoring Task Force recommended deleting bottom dissolved oxygen saturation as a threshold parameter, because baseline conditions frequently fell below the thresholds that had been fixed by state standards, both in the nearfield and in Stellwagen Basin. EPA and MADEP declined to accept this recommendation but in 2001 suggested adding the phrase "unless background conditions are lower" to the descriptions of both dissolved oxygen concentration and dissolved oxygen saturation, bringing the threshold into closer conformity with the state standard. During the fall of 2000 the caution level for bottom water dissolved oxygen percent saturation (80%) was exceeded in both the nearfield and Stellwagen Basin (Table 4-1). The DO percent saturation survey mean minima, however, were well within the range of values observed over the baseline period and were not lower than the background conditions of 64.3% saturation in the nearfield and 66.3% saturation in Stellwagen Basin. The chlorophyll and DO thresholds will be discussed in detail in the 2000 Annual Water Column Report.

Table 4-1. Contingency plan threshold values for water quality parameters.

Parameter	Time Period	Caution Level	Warning Level	Background	Fall 2000
Bottom Water DO concentration	Survey Mean in June-October	< 6.5 mg/l (unless background lower)	< 6.0 mg/l (unless background lower)	Nearfield - 5.75 mg/l Stellwagen - 6.2 mg/l	Nearfield – 7.1 mg/l Stellwagen – 7.3 mg/l
Bottom Water DO %saturation	Survey Mean in June-October	< 80% (unless background lower)	< 75% (unless background lower)	Nearfield - 64.3% Stellwagen - 66.3%	Nearfield – 78% Stellwagen – 78%
Chlorophyll	Annual	107 mg/m^2	143 mg/m^2	--	na
	Winter/spring	182 mg/m^2	--	--	na
	Summer	80 mg/m^2	--	--	na
	Autumn	161 mg/m^2	--	--	205 mg/m^2

4.4 Summary of Water Column Results

- Regionally, seasonal stratification had deteriorated at the inshore stations and began to weaken at the offshore stations by the October survey (WF00E).
- In the nearfield area, the data indicate that the pycnocline broke down in the eastern nearfield by early October (WF00E), but the water column at the outer nearfield stations was not well mixed until late November (WN00G).
- There was no indication of strong upwelling events in August, but physical oceanographic data suggests the advection of cooler, more saline, nutrient replete waters into the nearfield in September.
- Ammonium concentrations continued to be high in and near Boston Harbor in August 2000 as observed since 1998. There was a sharp decrease in harbor NH_4 concentrations in October 2000 during the fall bloom and after MWRA transferred effluent discharge from the harbor to the bay outfall on September 6, 2000.
- As expected, the transfer led to a substantial increase in NH_4 concentrations in the nearfield during the fall of 2000.
- Ammonium concentrations appear to be a good tracer, albeit not a conservative tracer, of the effluent plume in the nearfield.
- A substantial fall bloom was observed in the nearfield from early September to late October 2000. There was a disconnect between production, plankton abundance and chlorophyll concentrations with the highest production and plankton abundance occurring in early September and the highest survey mean chlorophyll concentration in late October.
- The magnitude and duration of the region-wide fall bloom resulted in a fall mean chlorophyll concentration in the nearfield of 5.69 μgL^{-1} – the highest recorded for the baseline period though only slightly higher than the fall mean in 1999 (5.45 μgL^{-1}).
- The fall 2000 mean areal chlorophyll was 205 mg m^{-2} exceeding the caution threshold of 161 mg m^{-2}. Had the thresholds been in place, fall chlorophyll concentrations for 1999 would have also exceeded the fall caution threshold. The fall blooms in 2000 and 1999 are part of the natural variability of the region.

- The high chlorophyll values for the fall of 2000 were due to a large region-wide bloom that appears to be part of the natural variability of the region. It remains unclear what localized effect the MWRA outfall, specifically NH_4, may have had on the magnitude or duration of the fall bloom in the nearfield.
- Mean nearfield bottom water DO concentrations in 2000 were relatively high although percent saturation values in October fell just below the caution threshold (<80%) in both the nearfield and Stellwagen Basin (both 78%). The DO percent saturations in both of these areas were well above baseline background levels (64.3 and 66.3 mgL^{-1}, respectively).
- The influx of cool, more saline waters in September likely prevented low DO concentrations from being reached in September and October of 2000.

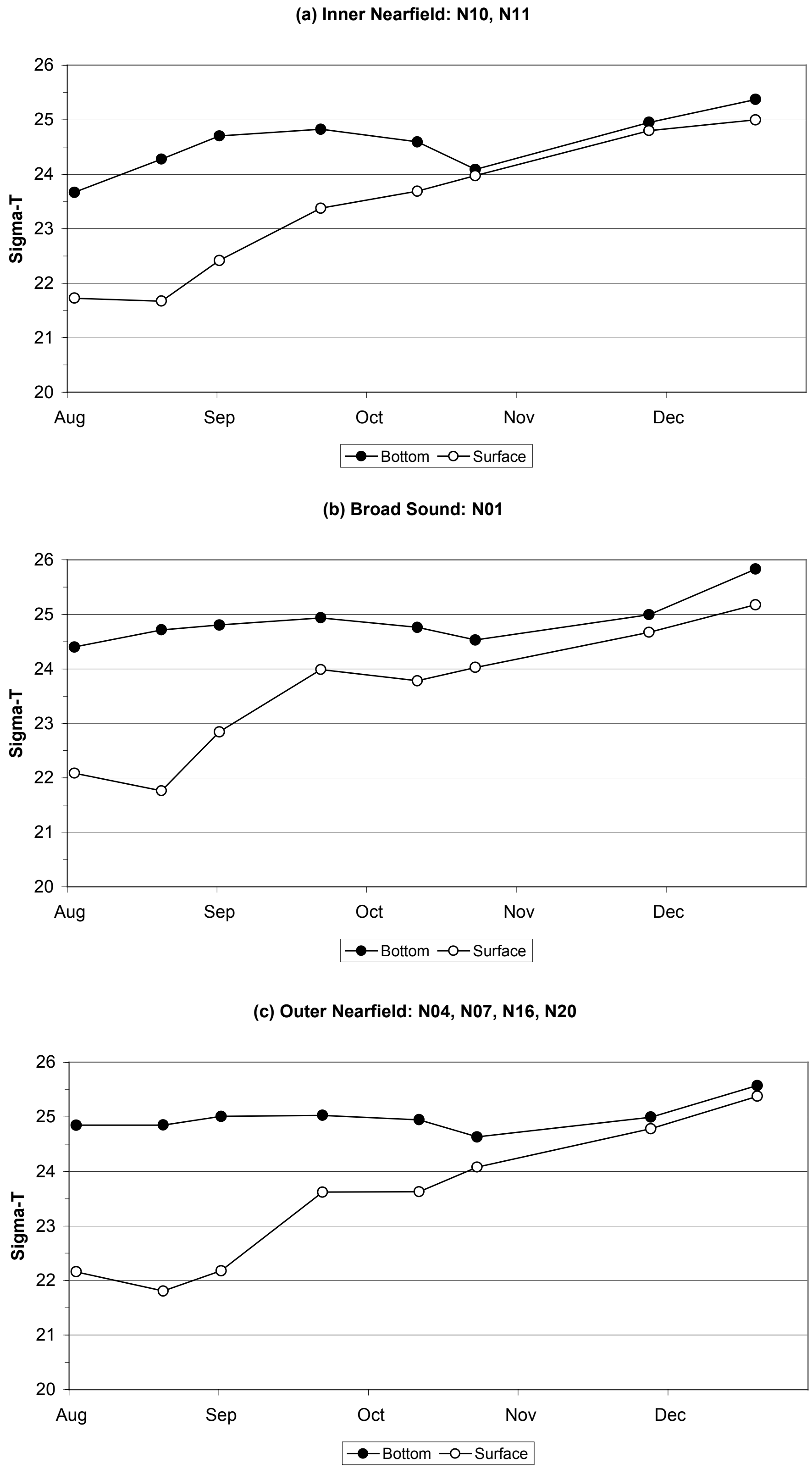


Figure 4-1. Time-Series of Average Surface and Bottom Water Density (σ_T) in the Nearfield

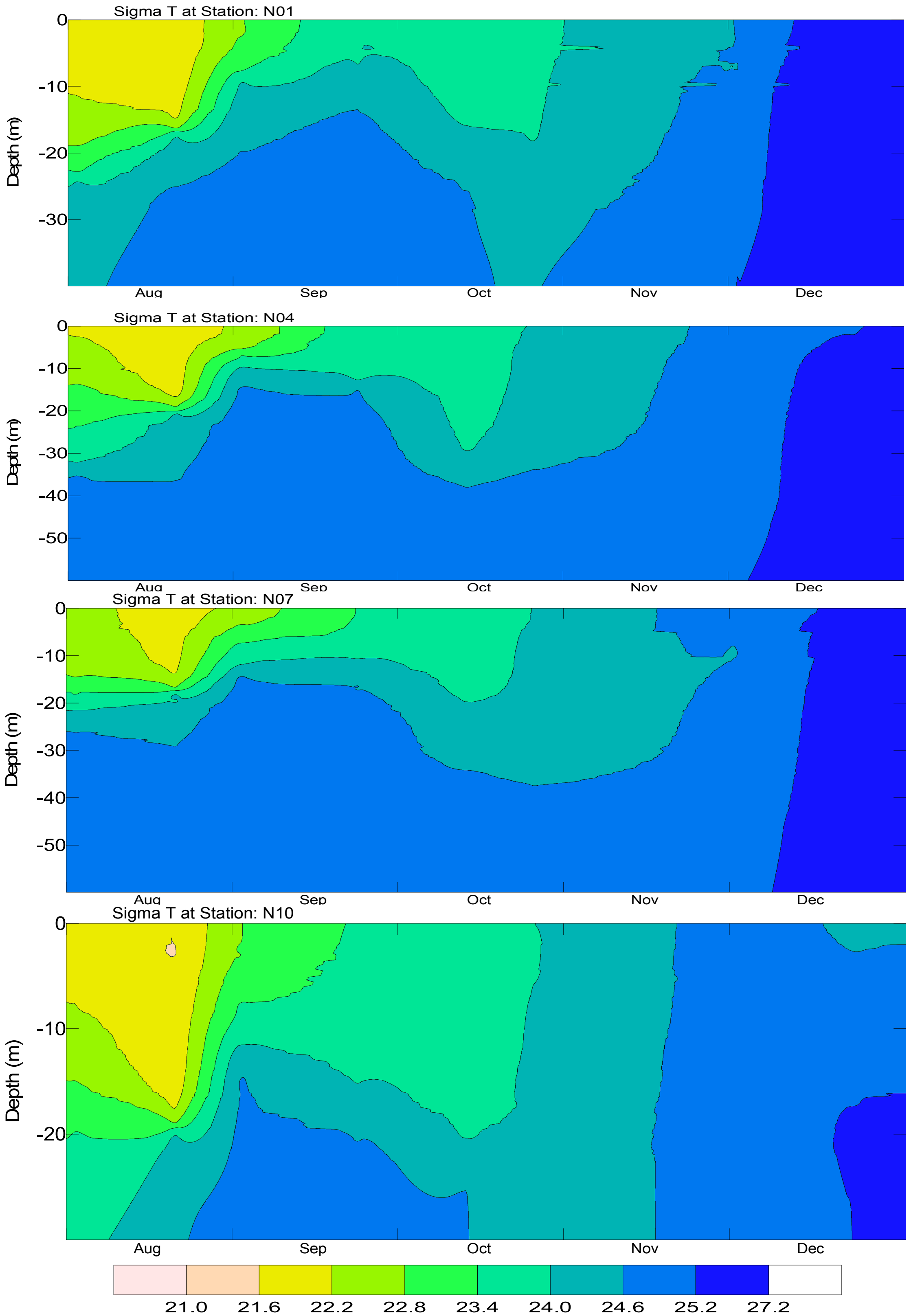


Figure 4-2. Sigma-T Depth vs. Time Contour Profiles for Stations N01, N04, N07, and N10

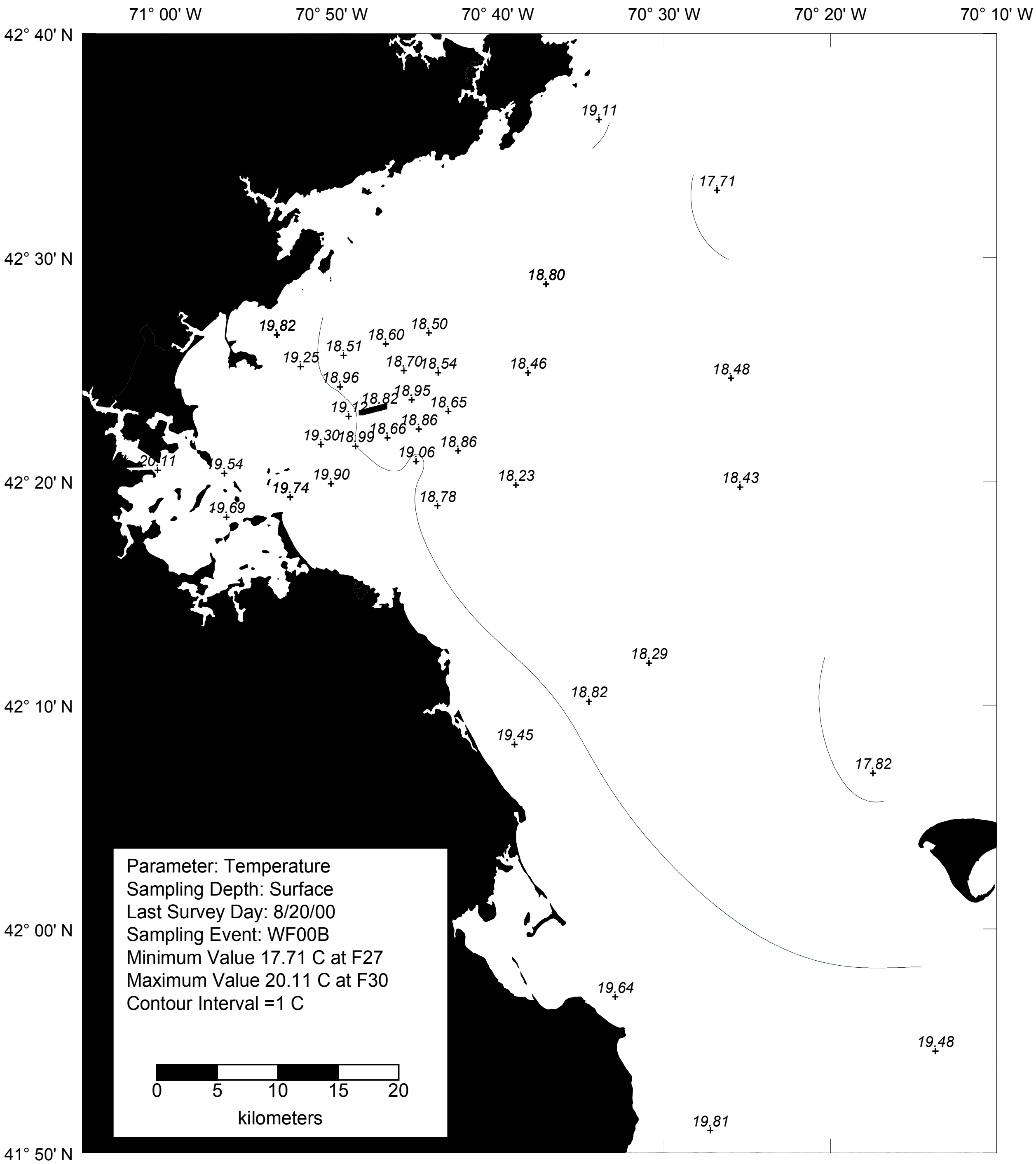


Figure 4-3. Temperature Surface Contour Plot for Farfield Survey WF00B (Aug 00)

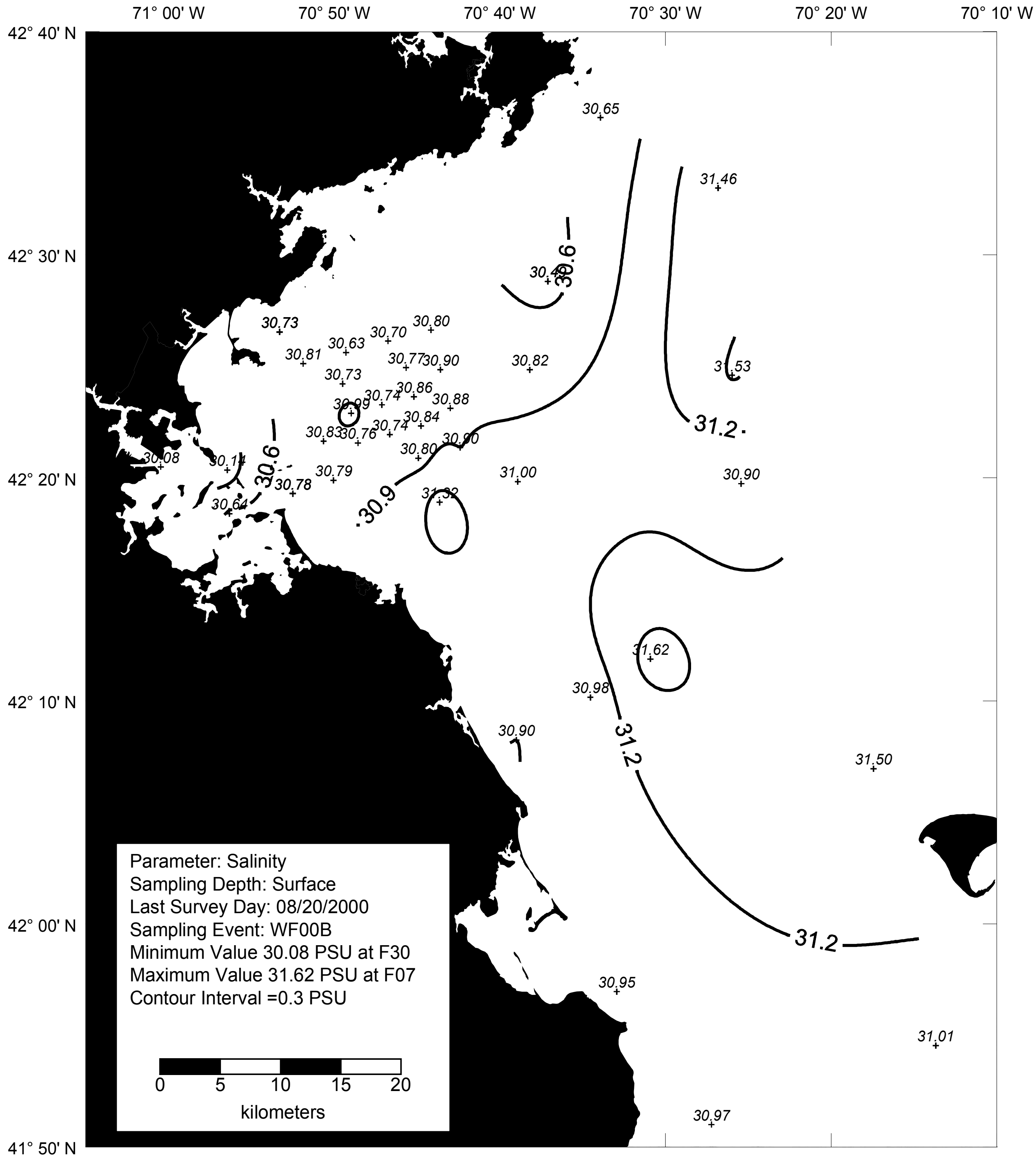


Figure 4-4. Salinity Surface Contour Plot for Farfield Survey WF00B (Aug 00)

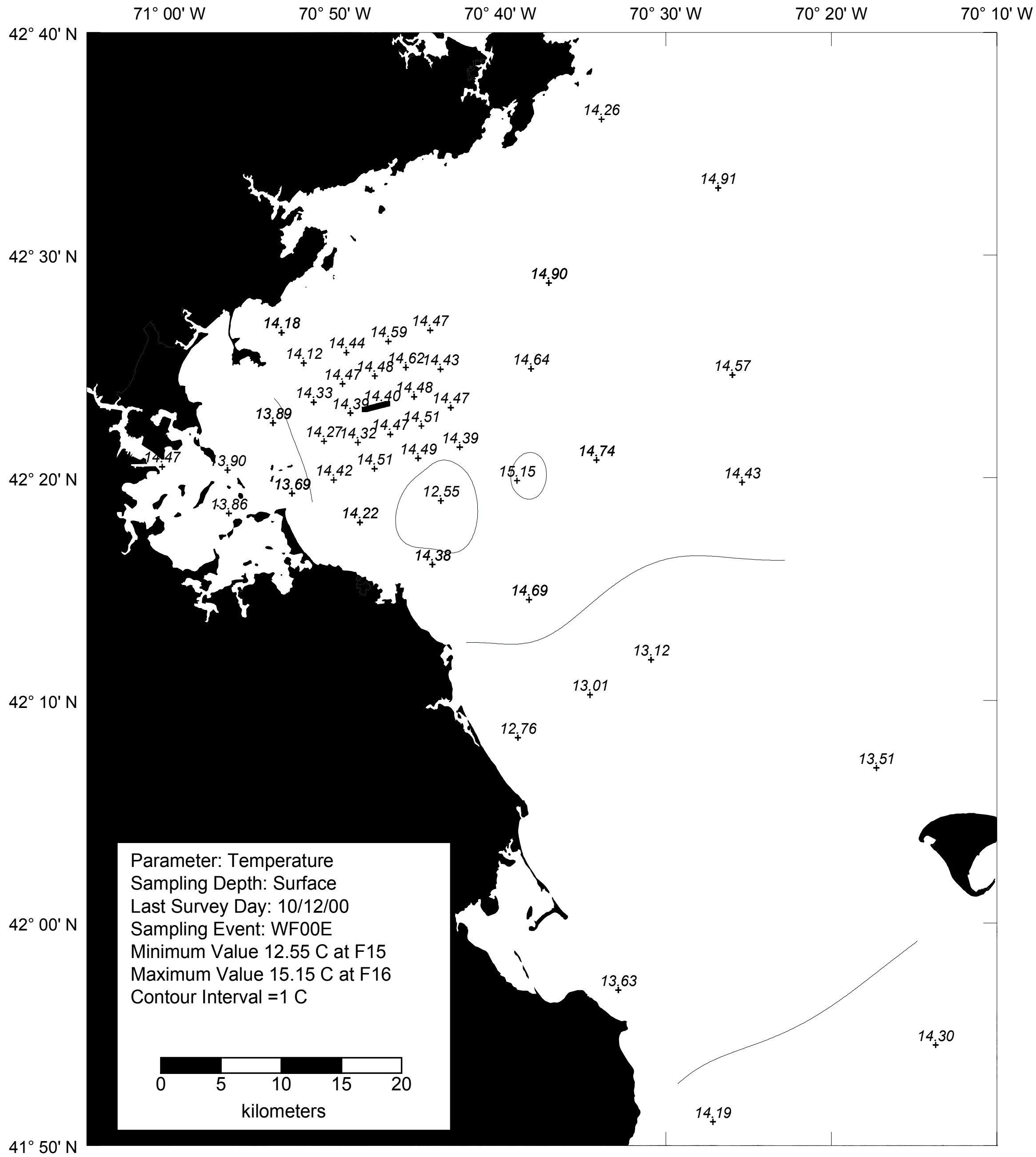


Figure 4-5. Temperature Surface Contour Plot for Farfield Survey WF00E (Oct 00)

Note: All data from the Cape Cod Bay, boundary station F29, and offshore stations F05, F06, F07 and F15 were collect on October 12th one week after the other stations.

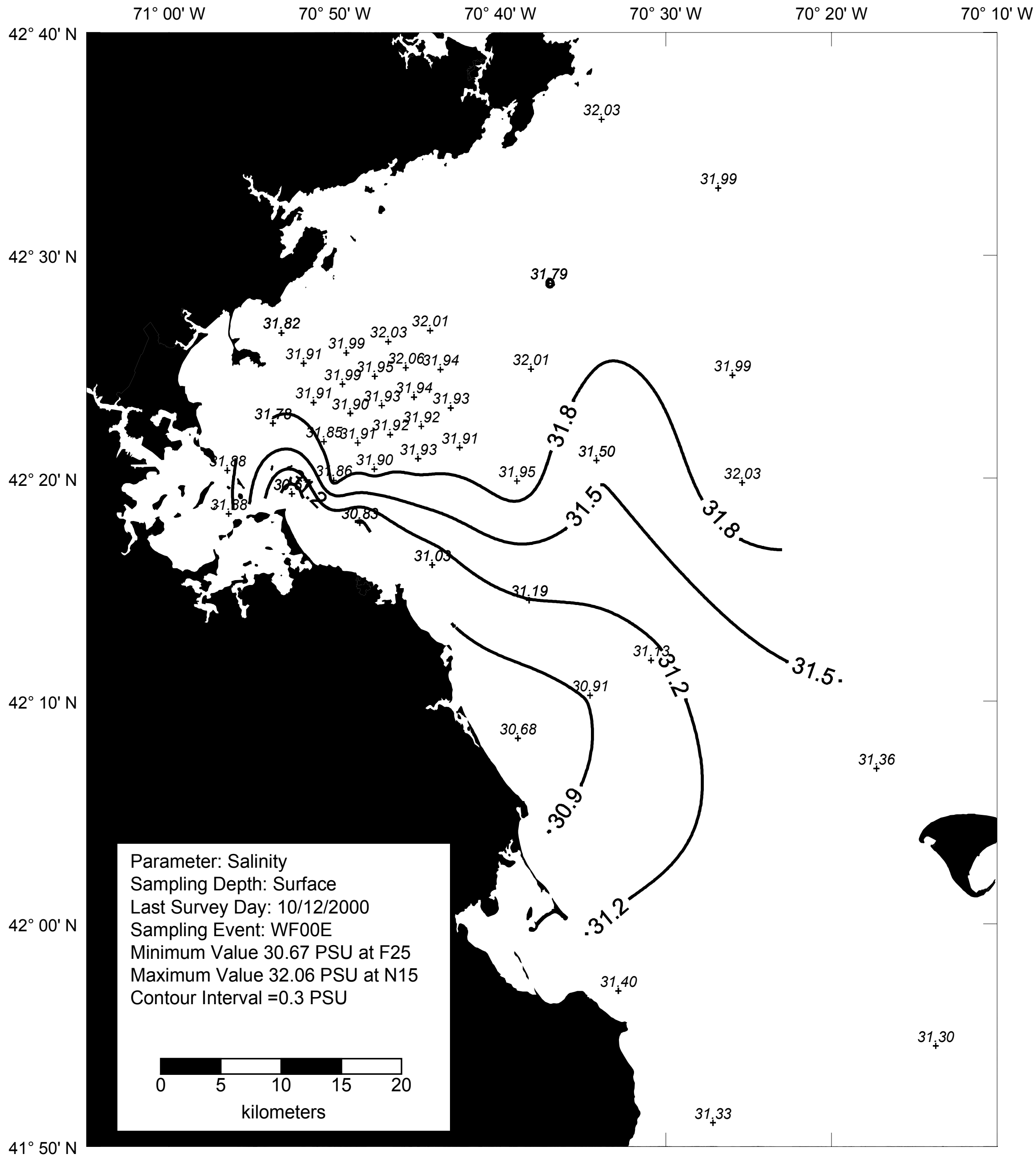


Figure 4-6. Salinity Surface Contour Plot for Farfield Survey WF00E (Oct 00)

Note: See Figure 4-5 caption for sampling dates.

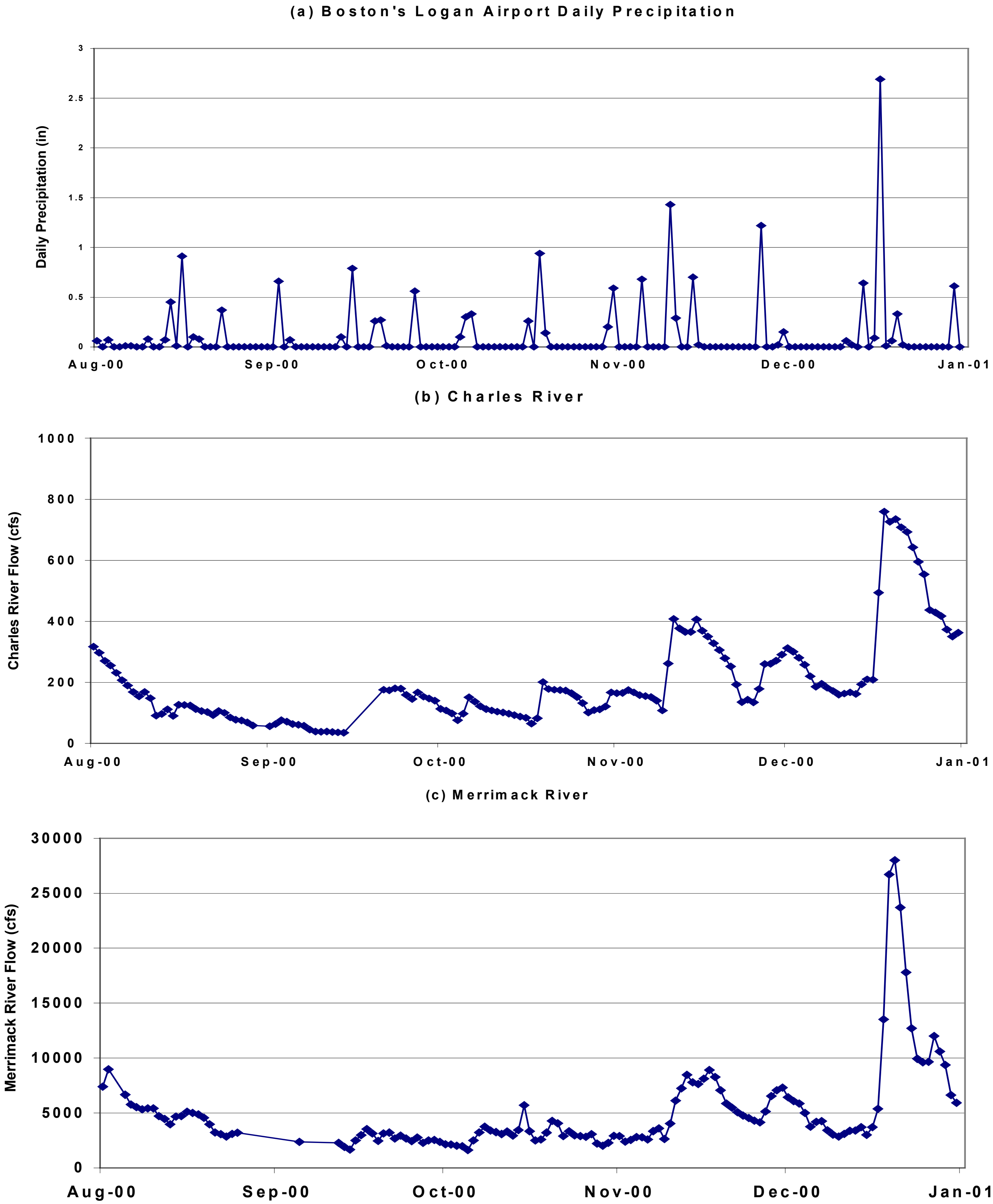


Figure 4-7. Precipitation at Logan Airport and River Discharges for the Charles and Merrimack Rivers

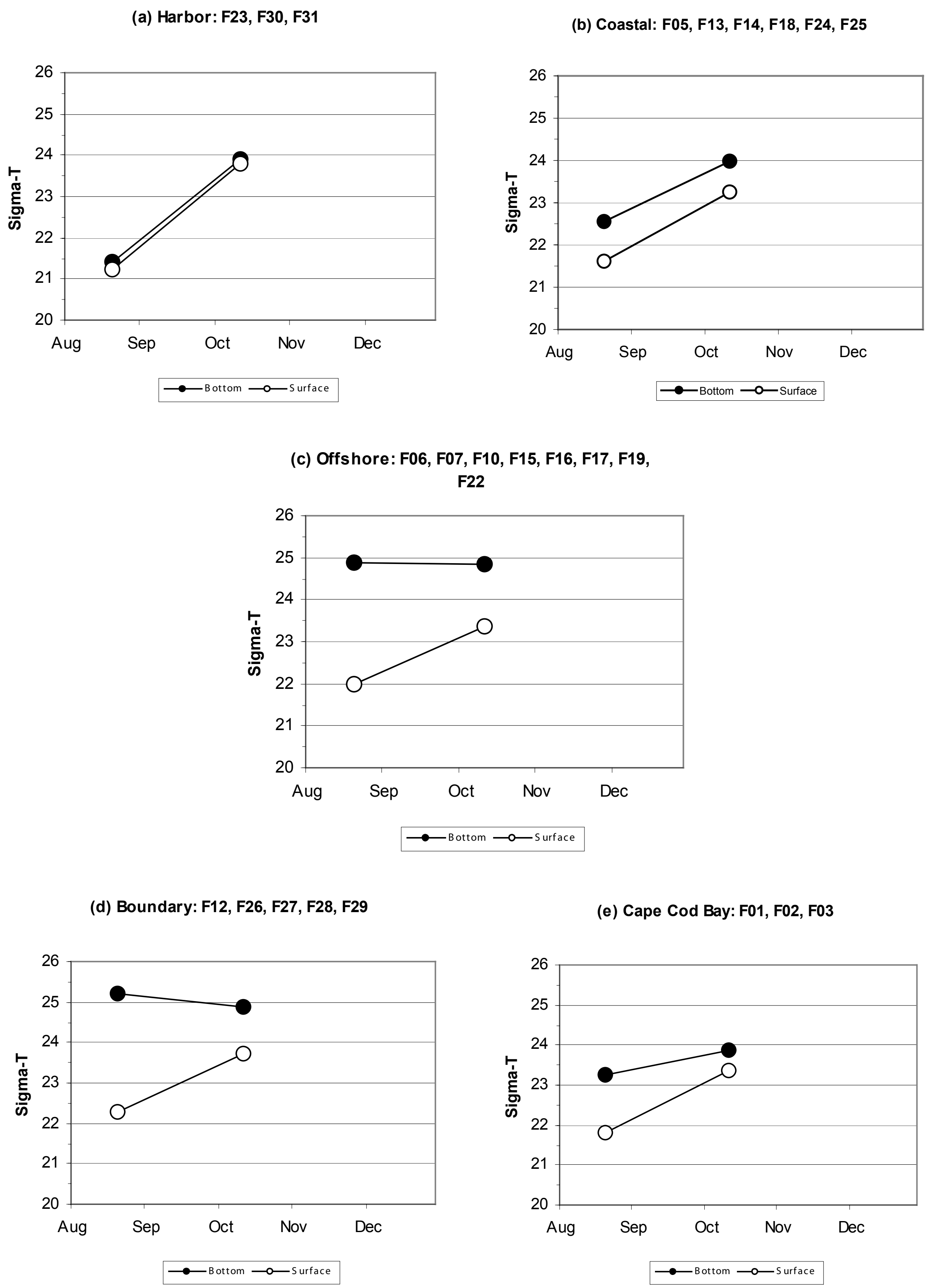


Figure 4-8. Time-Series of Average Surface and Bottom Water Density (σ_T) in the Farfield

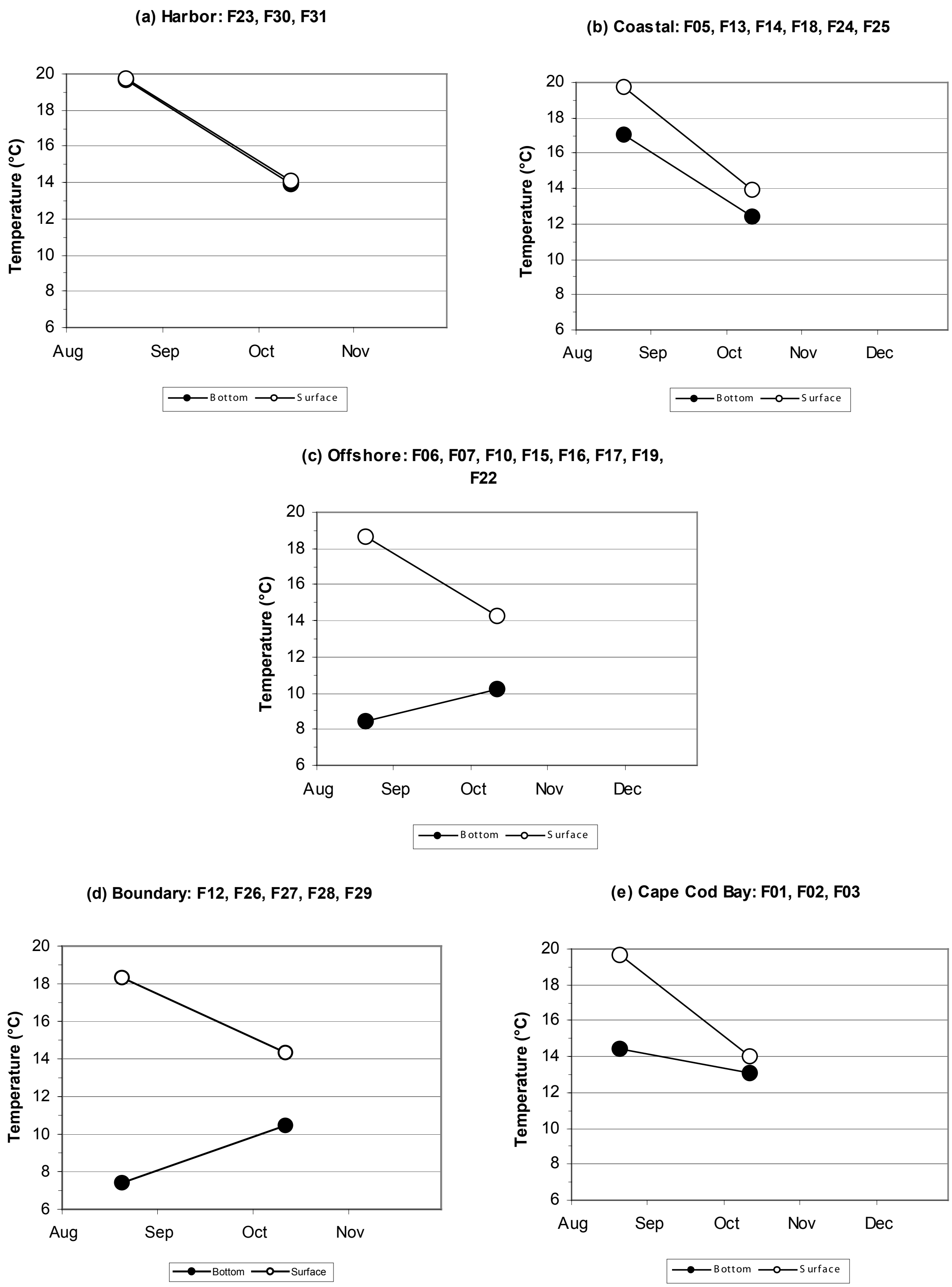


Figure 4-9. Time-Series of Average Surface and Bottom Water Temperature (°C) in the Farfield

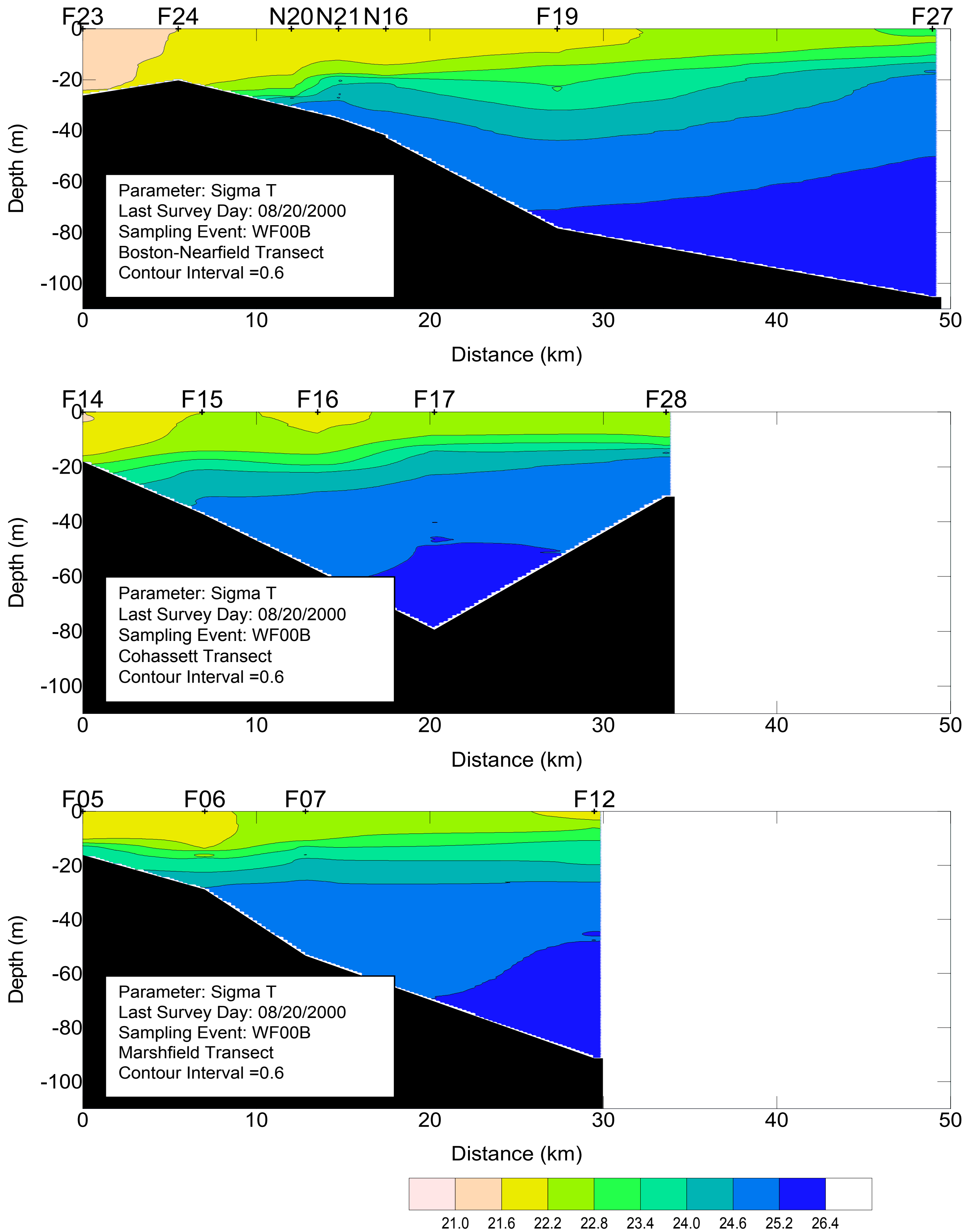


Figure 4-10. Sigma-T Vertical Transects for Farfield Survey WF00B (Aug 00)

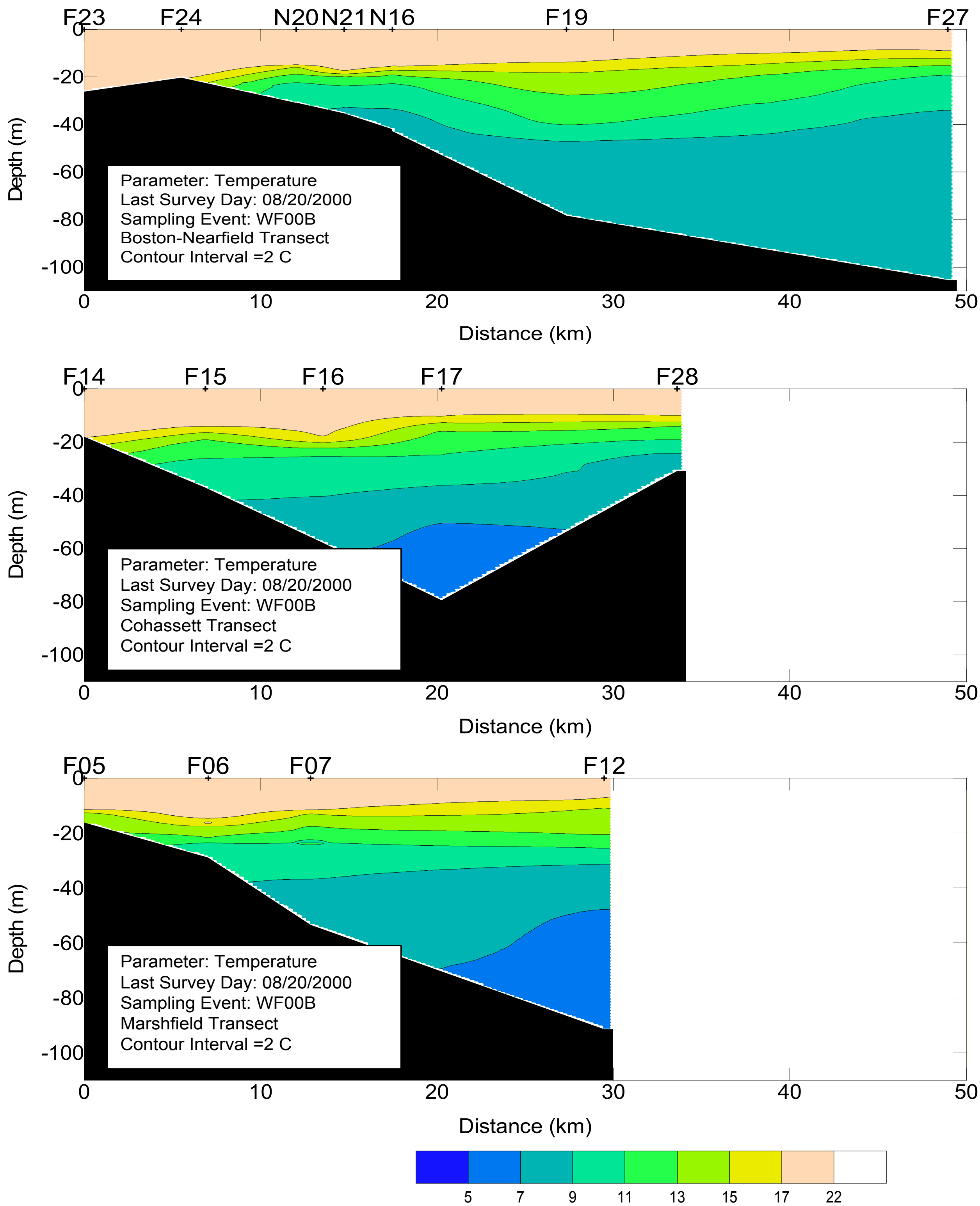


Figure 4-11. Temperature Vertical Transect for Farfield Survey WF00B (Aug 00)

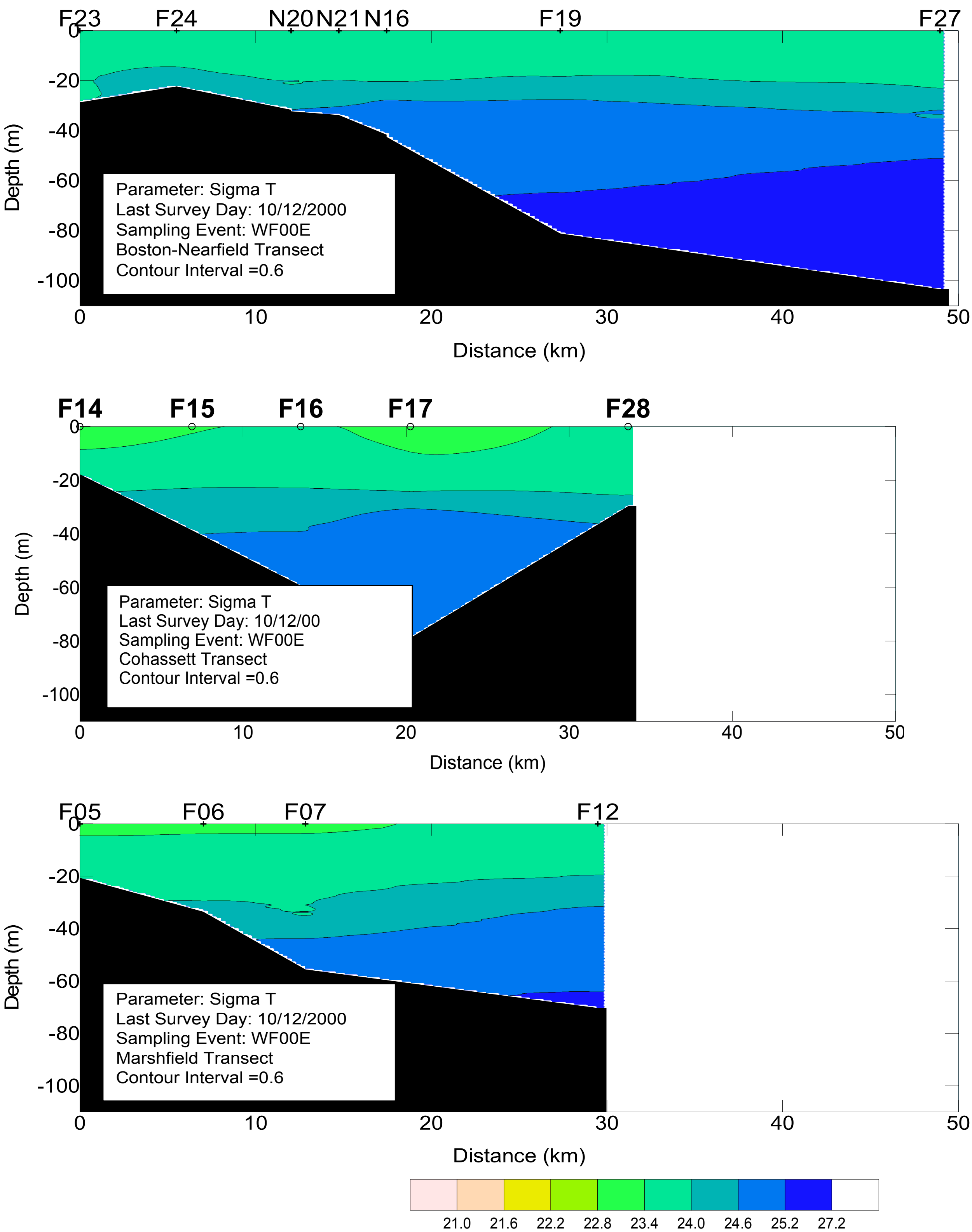


Figure 4-12. Sigma-T Vertical Transect for Farfield Survey WF00E (Oct 00)

Note: See Figure 4-5 caption for sampling dates.

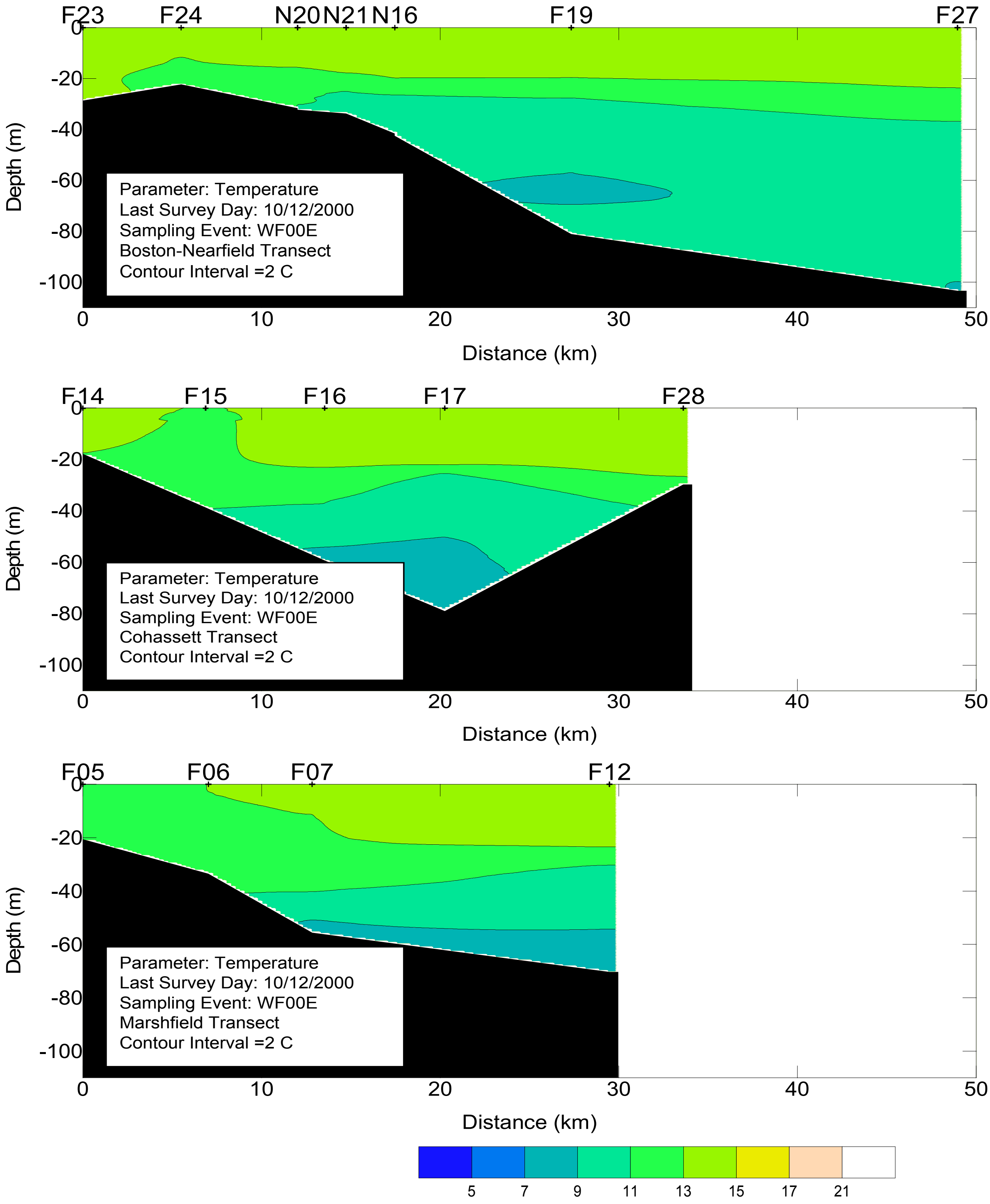


Figure 4-13. Temperature Vertical Transect for Farfield Survey WF00E (Oct 00)

Note: See Figure 4-5 caption for sampling dates.

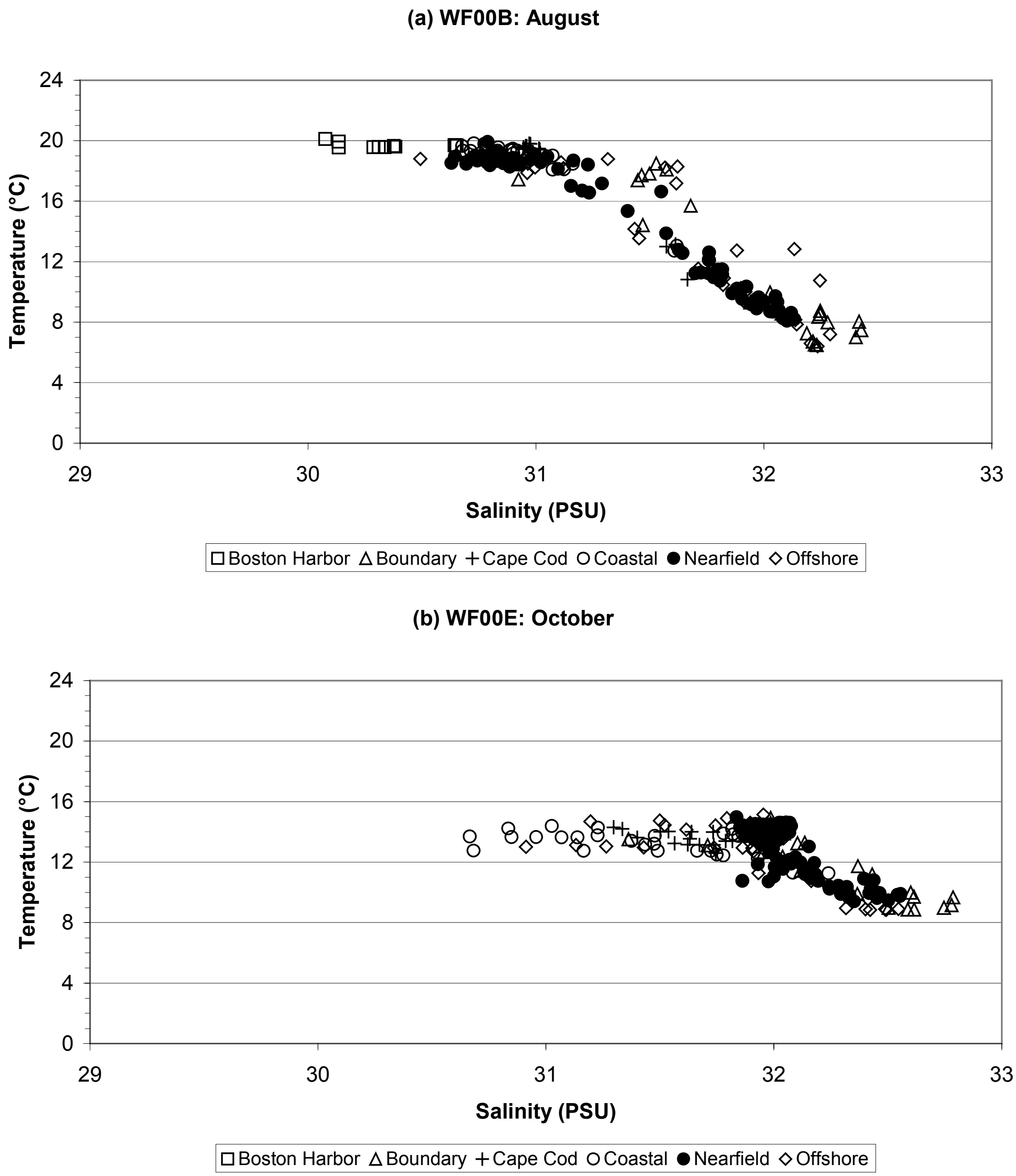


Figure 4-14. Temperature/Salinity Distribution for All Depths during (a) August and (b) October

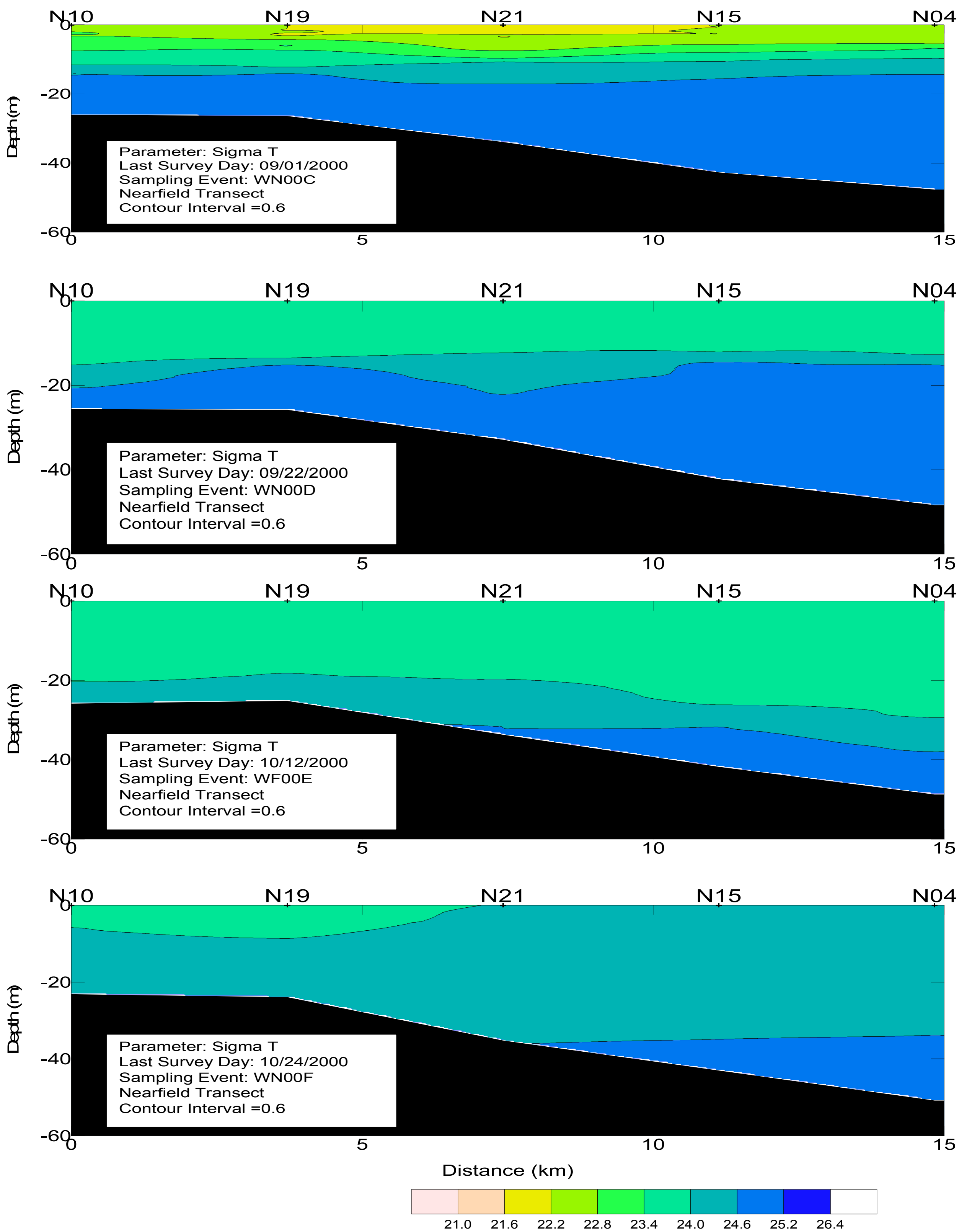


Figure 4-15. Sigma-T Vertical Nearfield Transect for Surveys WN00C, WN00D, WF00E, and WN00F

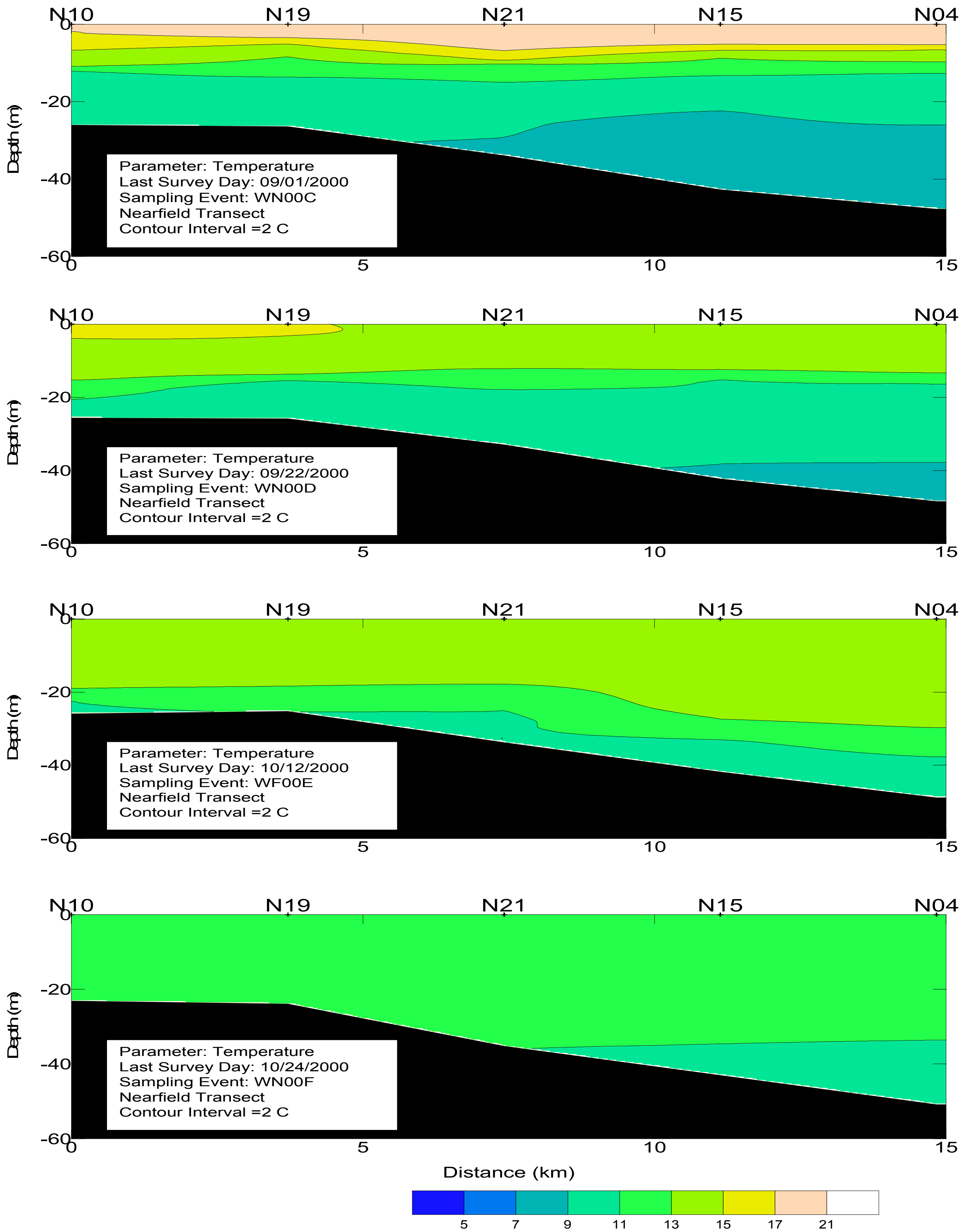


Figure 4-16. Temperature Vertical Nearfield Transect for Surveys WN00C, WN00D, WF00E, and WN00F

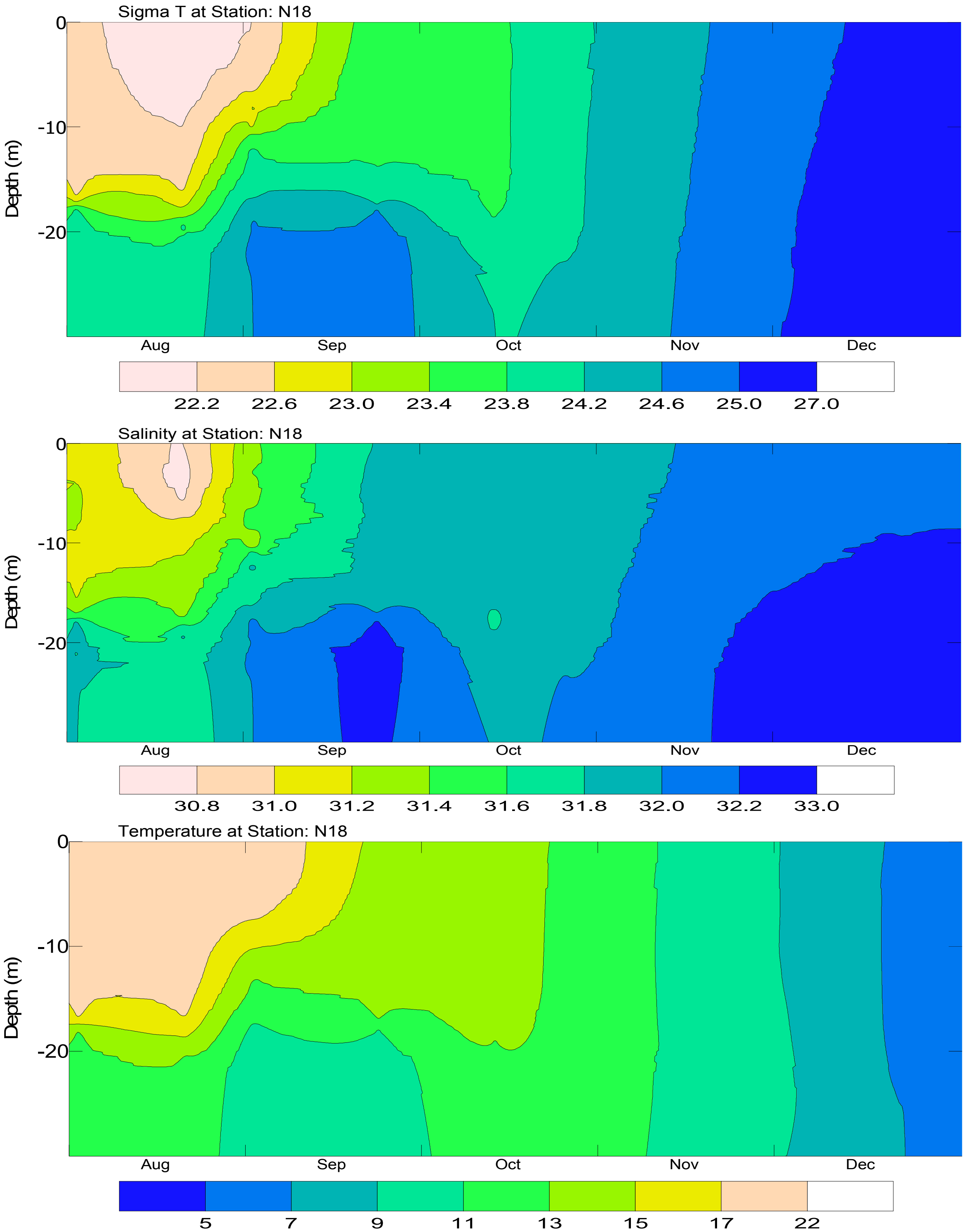


Figure 4-17. Sigma-T, Salinity and Temperature Depth vs. Time Contour Profiles for Station N18

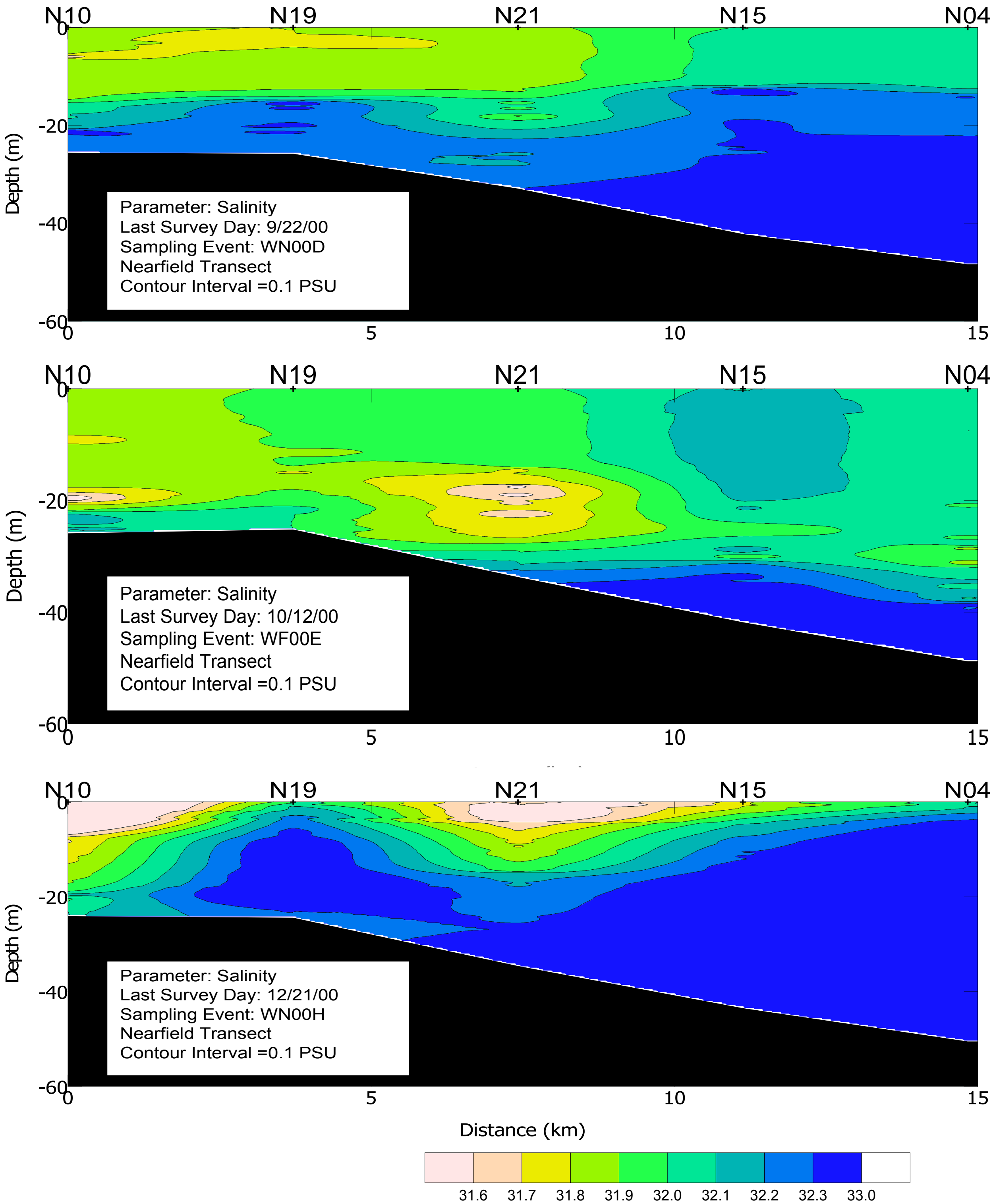


Figure 4-18. Salinity Vertical Nearfield Transect for Surveys WN00D, WF00E, and WN00H

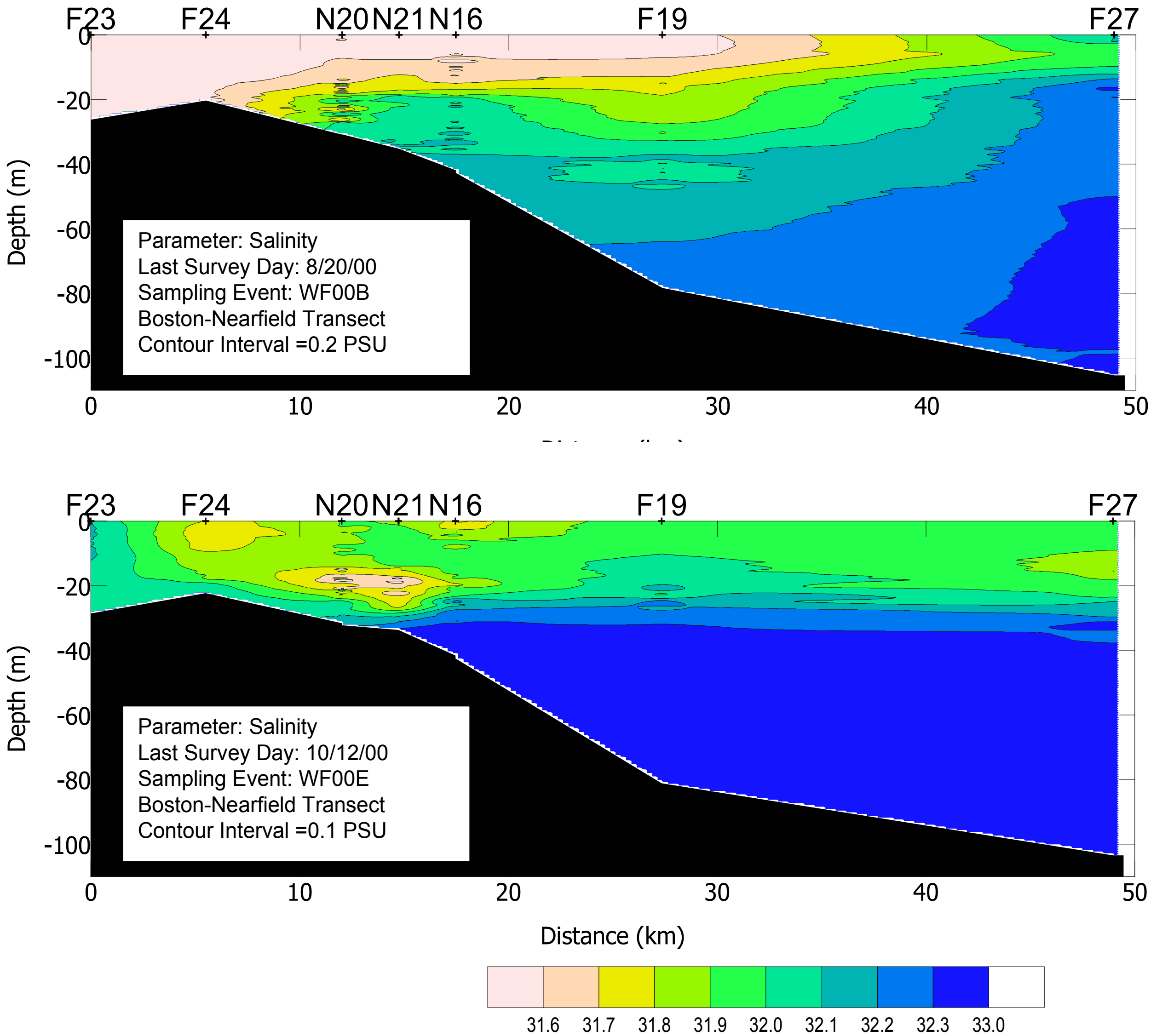


Figure 4-19. Salinity Vertical Boston-Nearfield Transect for Surveys WF00B and WF00E

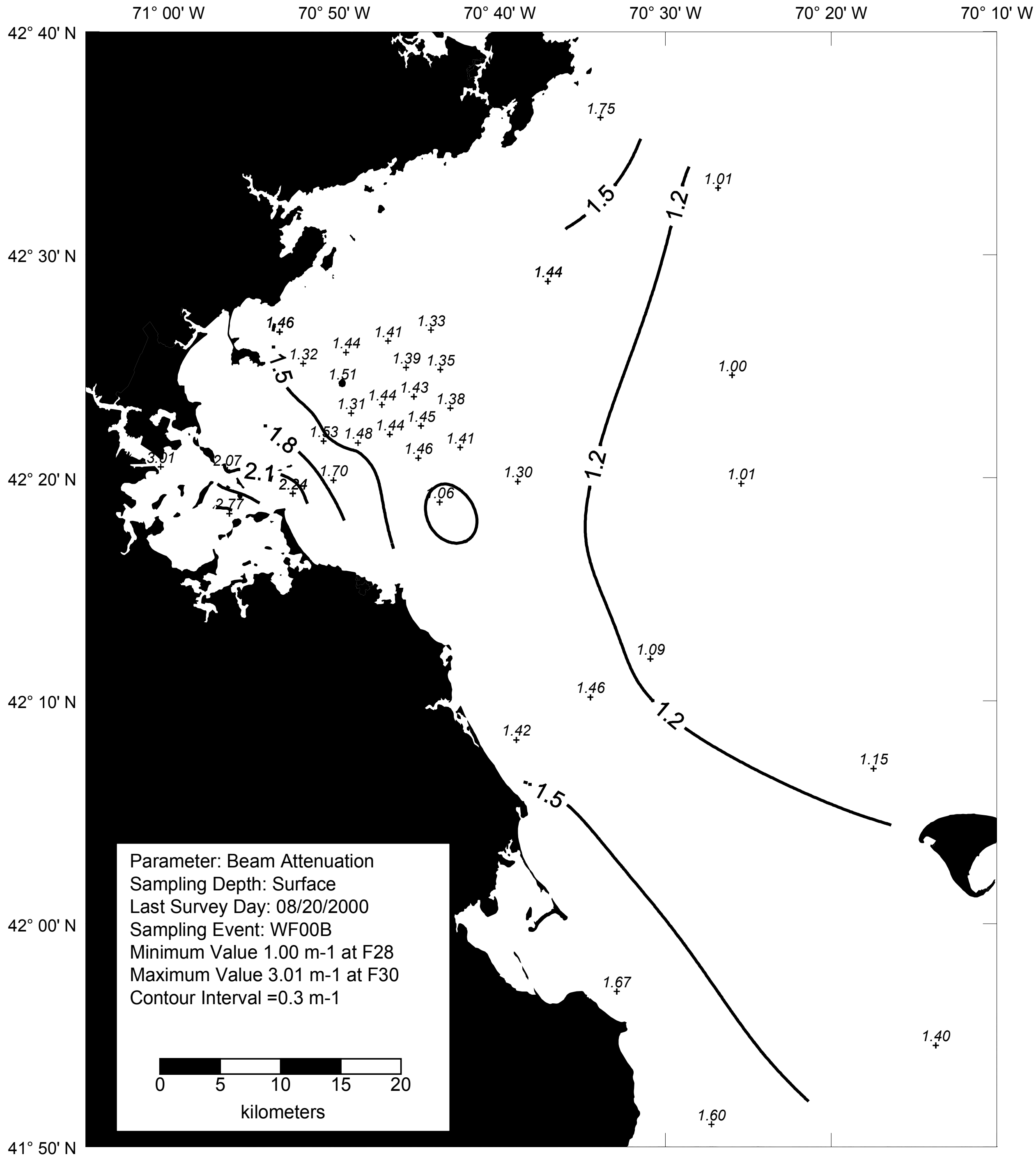


Figure 4-20. Beam Attenuation Surface Contour Plot for Farfield Survey WF00B (Aug 00)

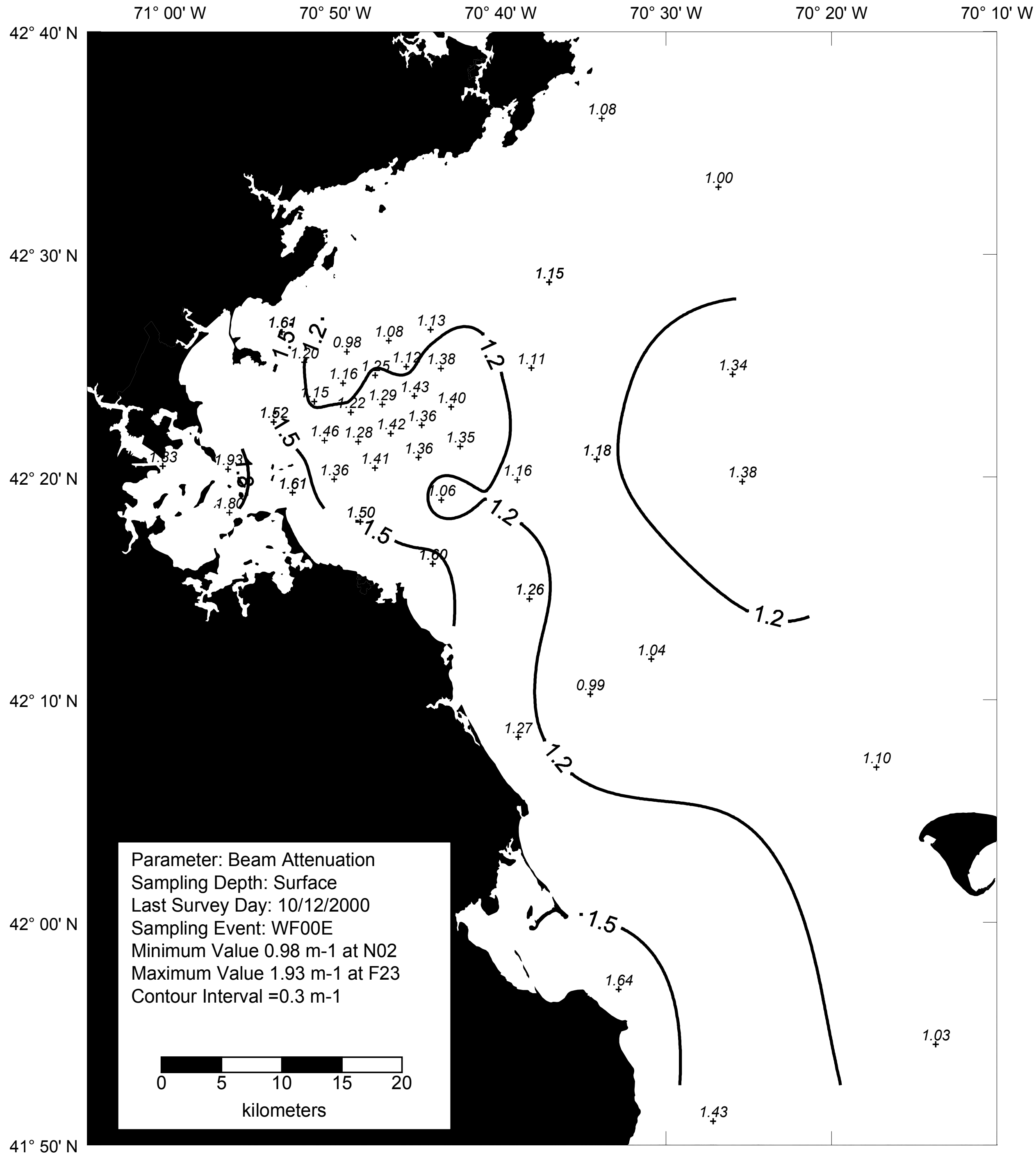


Figure 4-21. Beam Attenuation Surface Contour Plot for Farfield Survey WF00E (Oct 00)

Note: See Figure 4-5 caption for sampling dates.

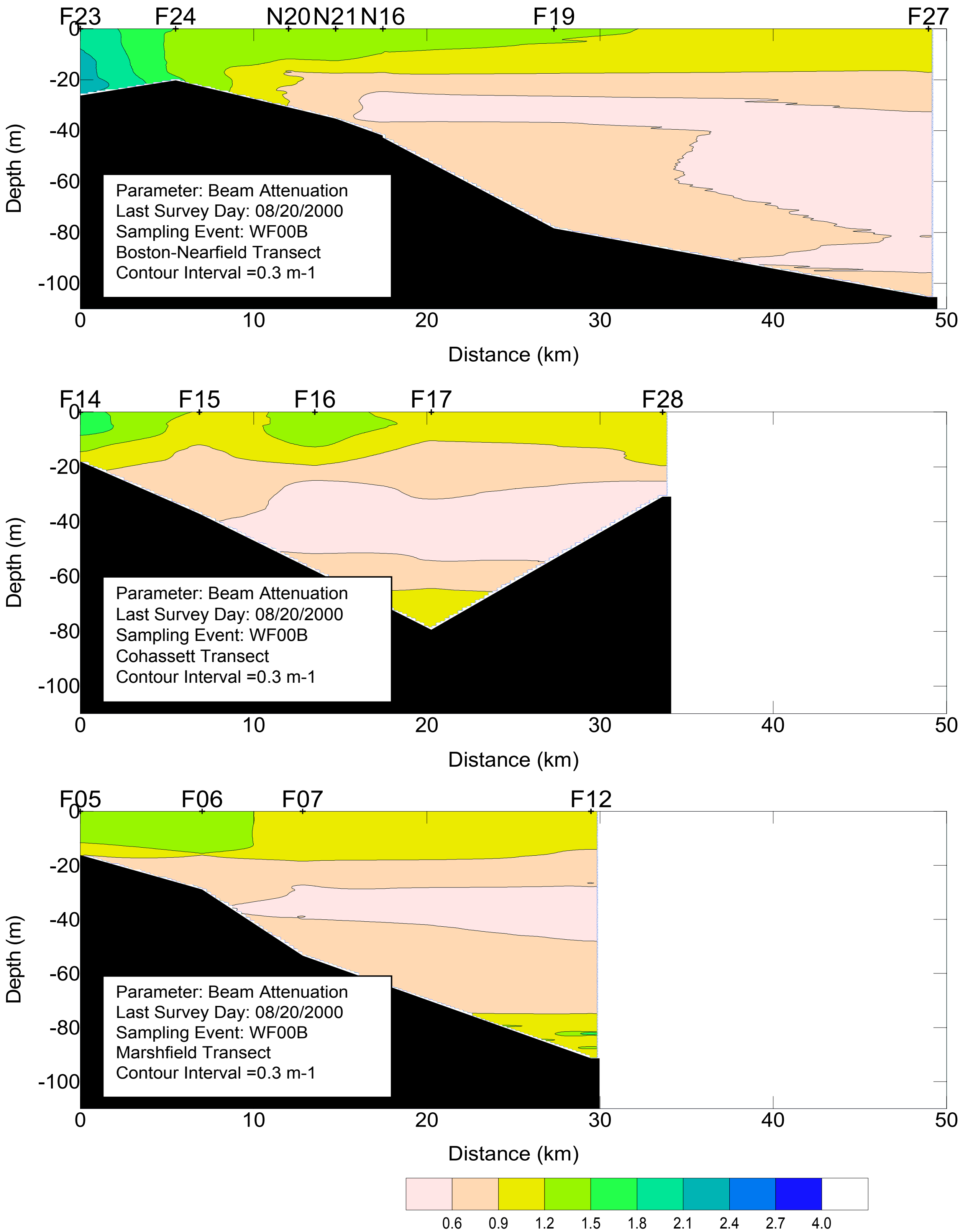


Figure 4-22. Beam Attenuation Vertical Transects for Farfield Survey WF00B (Aug 00)

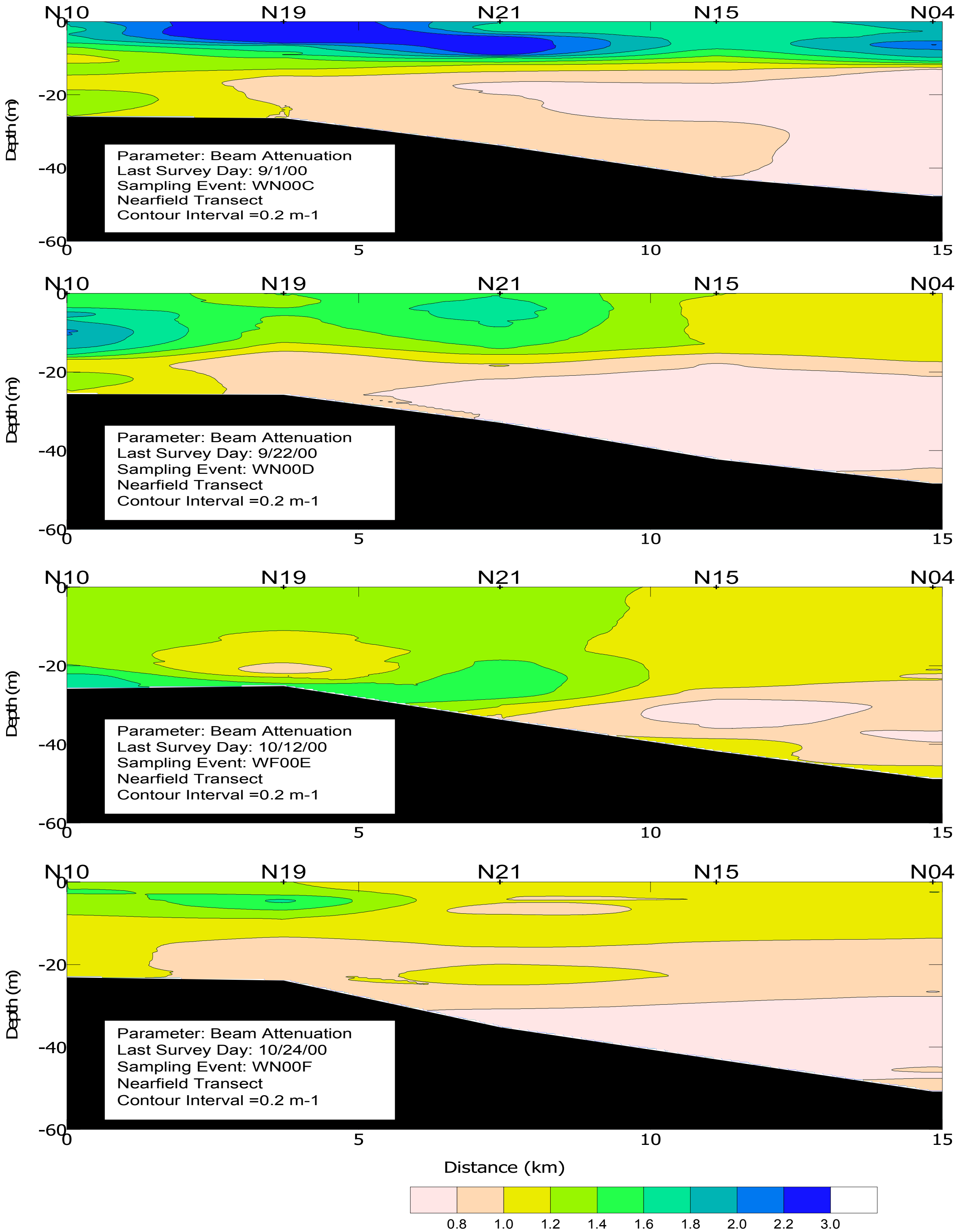


Figure 4-23. Beam Attenuation Vertical Nearfield Transect for Surveys WN00C, WN00D, WF00E, and WN00F

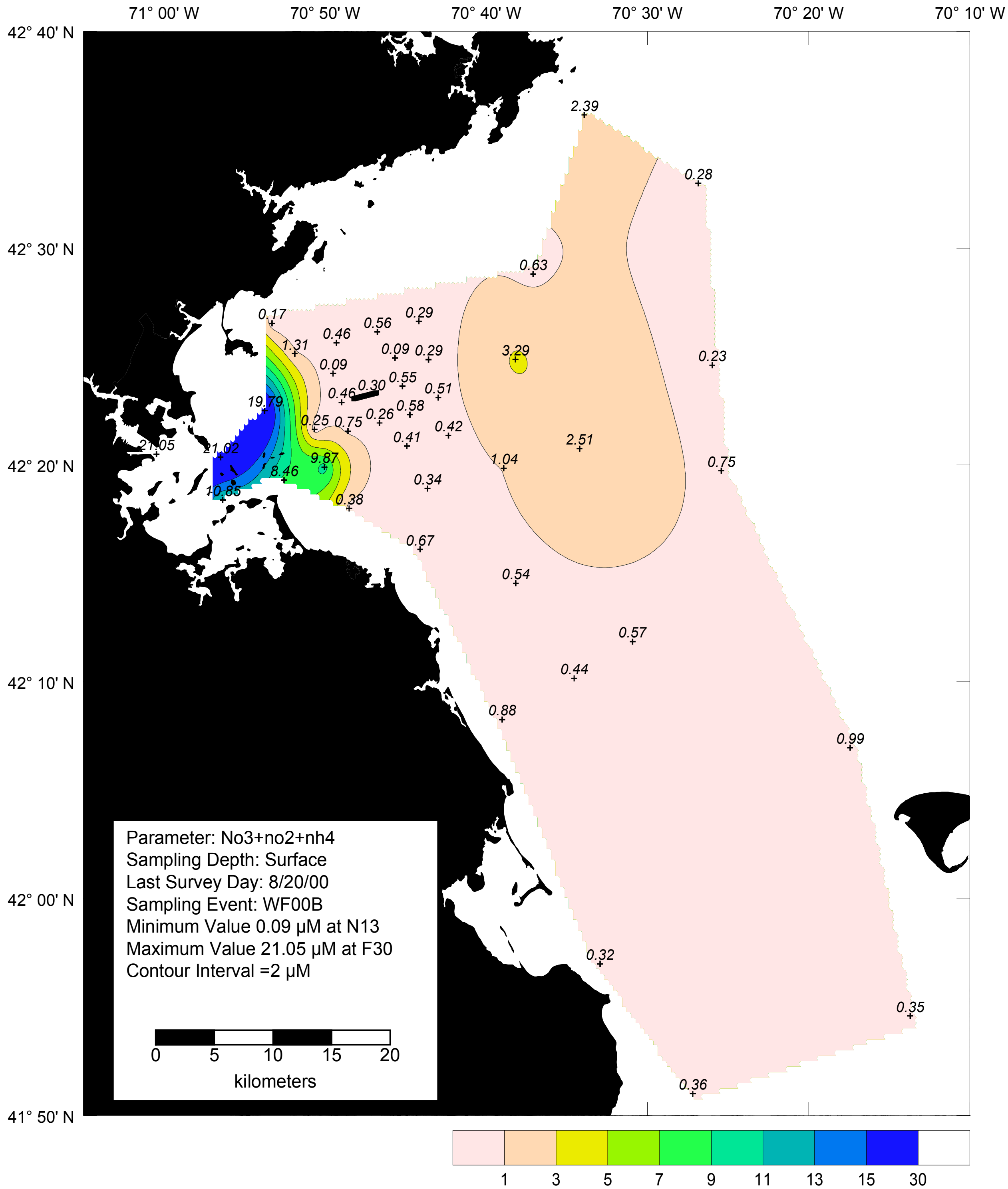


Figure 4-24. DIN Surface Contour Plot for Farfield Survey WF00B (Aug 00)

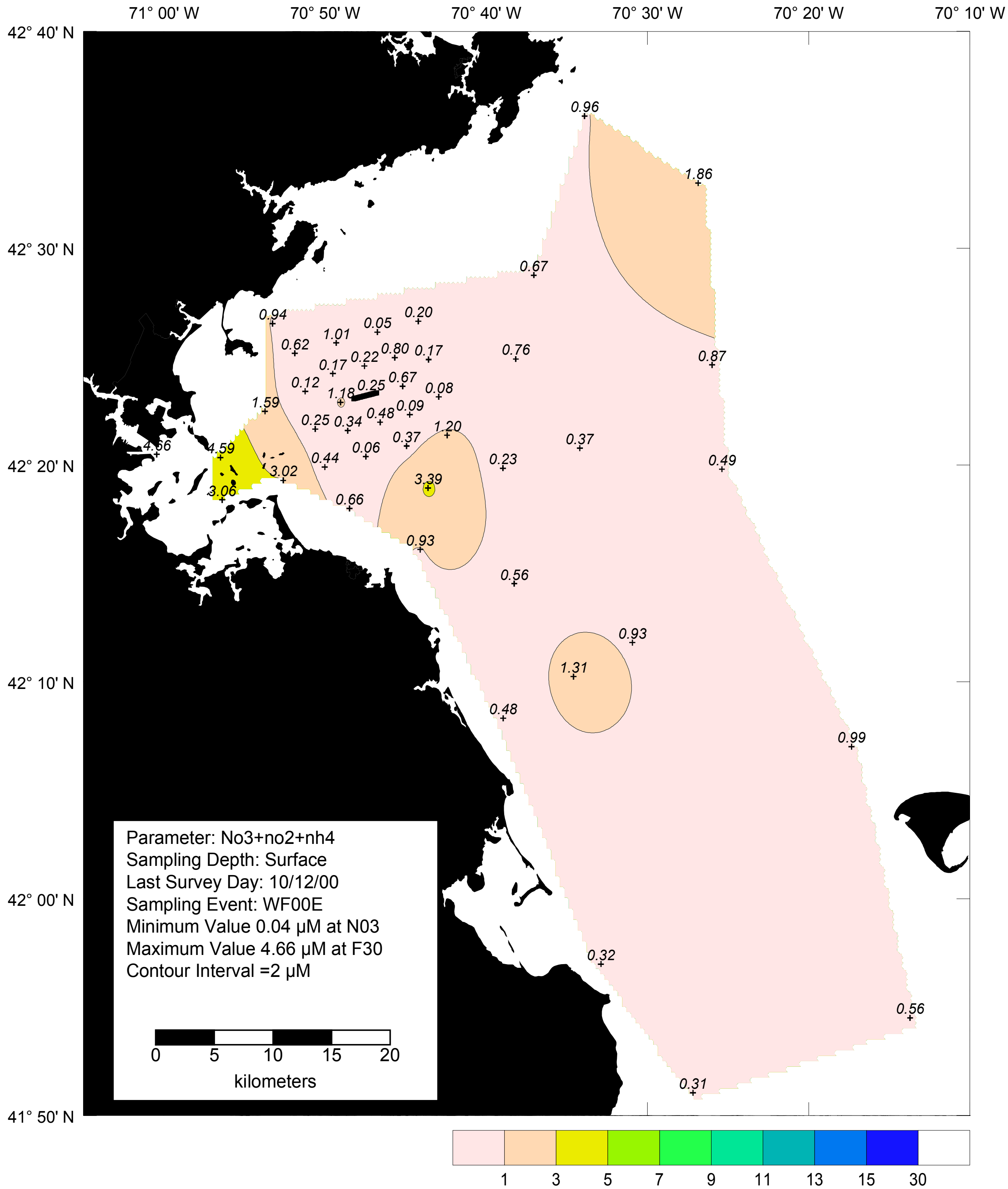
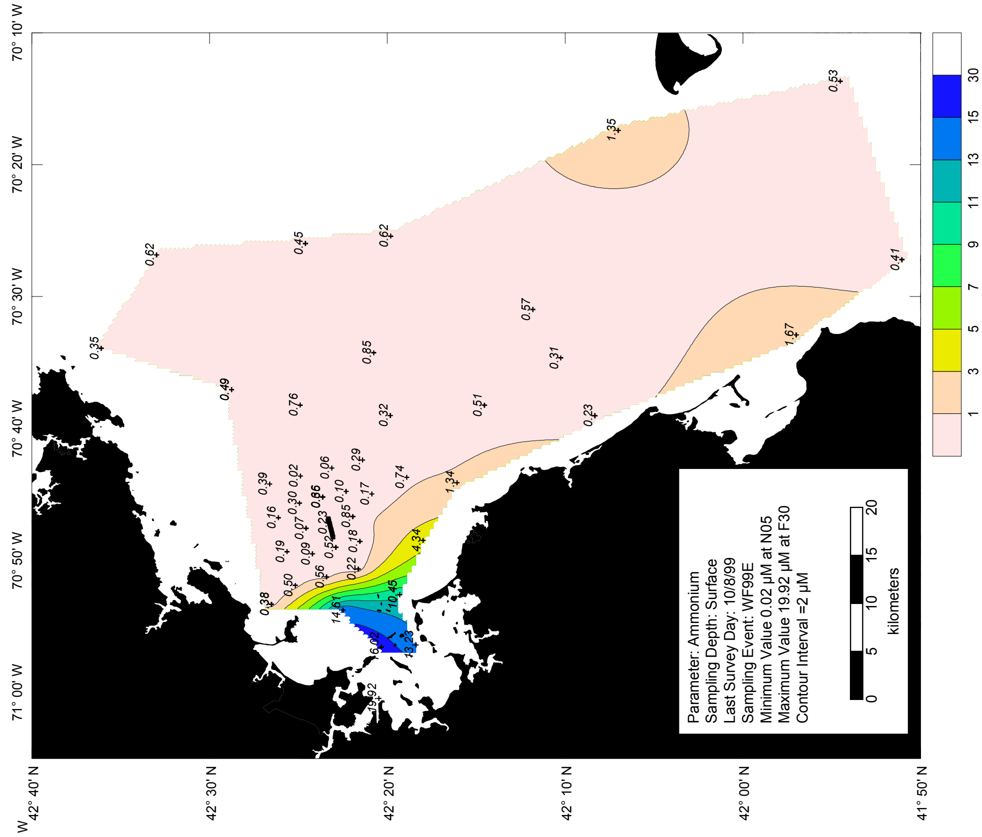


Figure 4-25. DIN Surface Contour Plot for Farfield Survey WF00E (Oct 00)

Note: See Figure 4-5 caption for sampling dates.

1999



2000

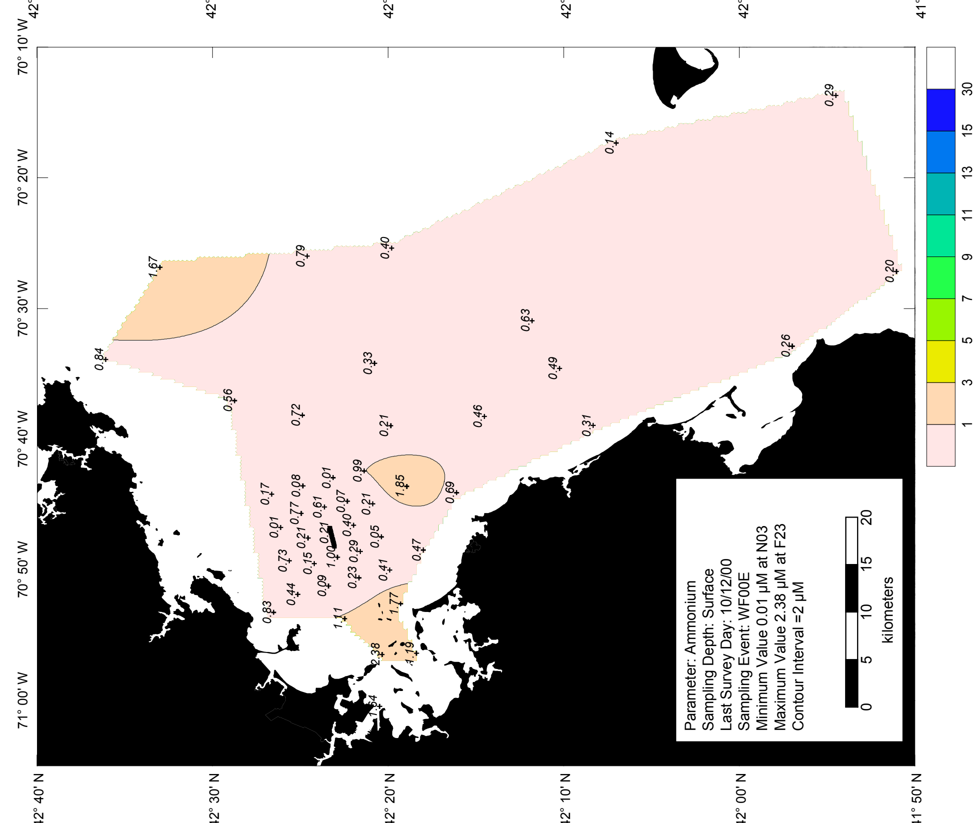


Figure 4-26. Ammonium Surface Contour Plot for Farfield Surveys WF99E (Oct 99) and WF00E (Oct 00)

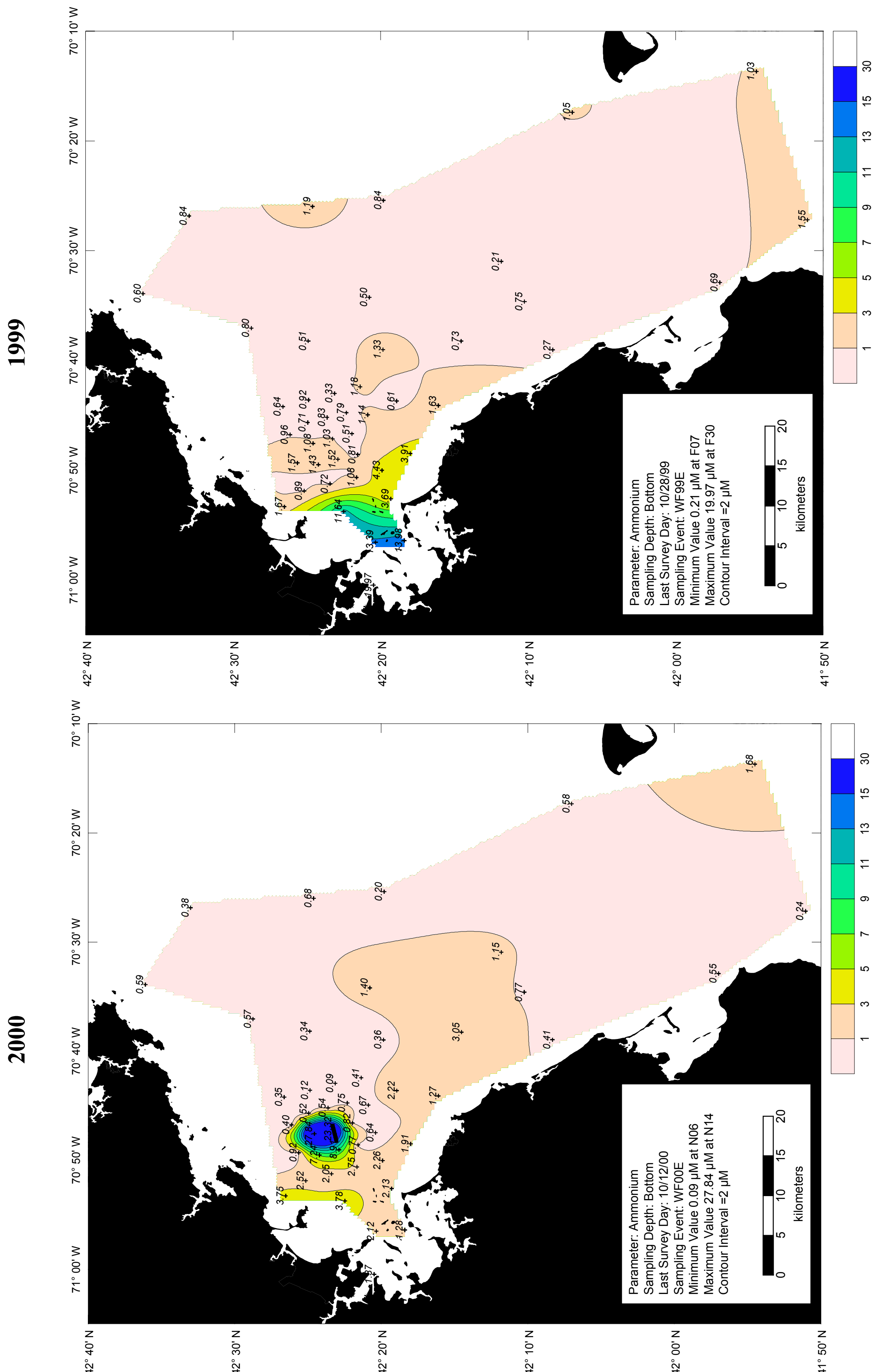


Figure 4-27. Ammonium Bottom Contour Plot for Farfield Surveys WF99E (Oct 99) and WF00E (Oct 00)

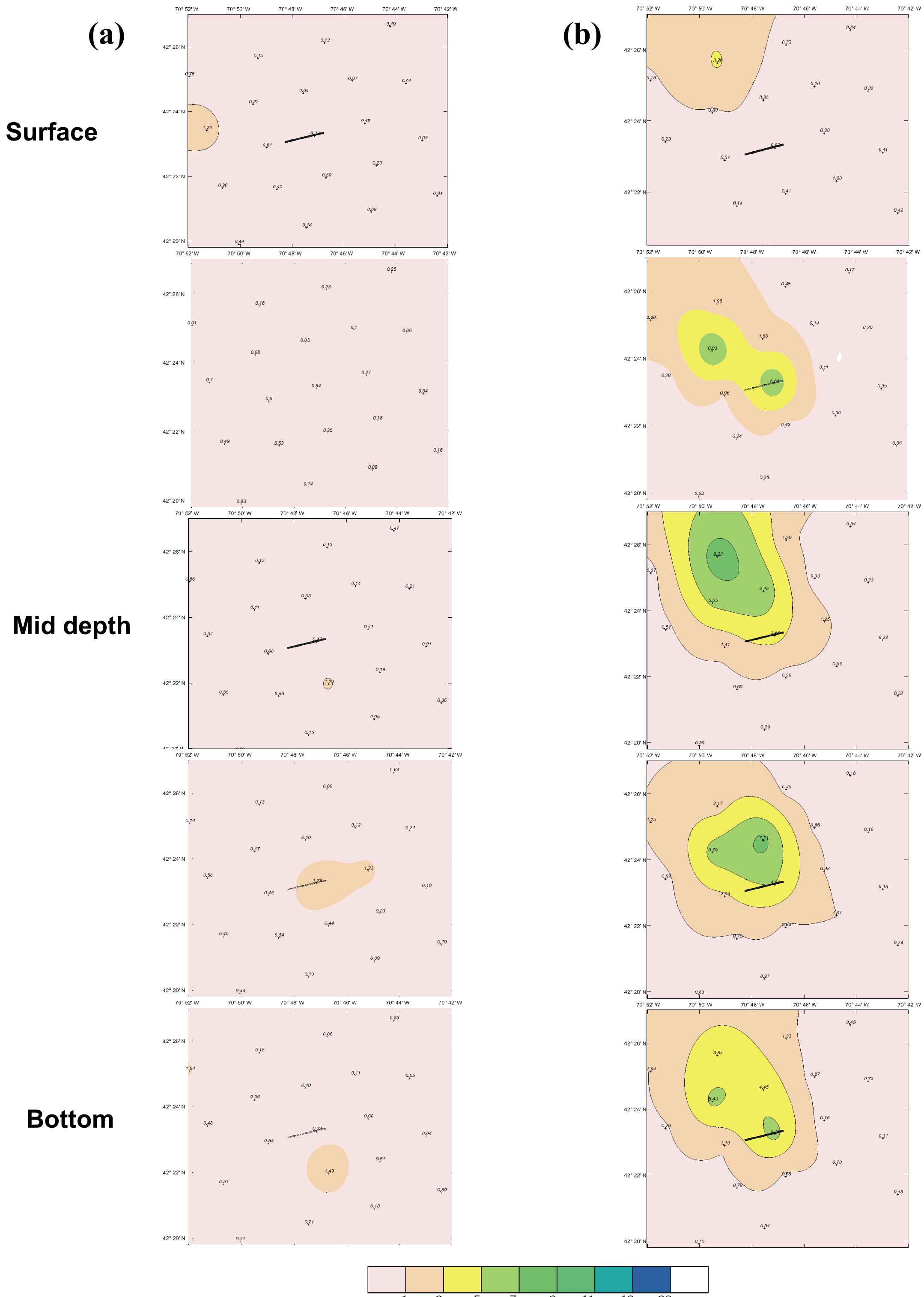


Figure 4-28. Ammonium Contour Plots at All Depths for Nearfield Surveys WN00C and WN00D (Sep 00)

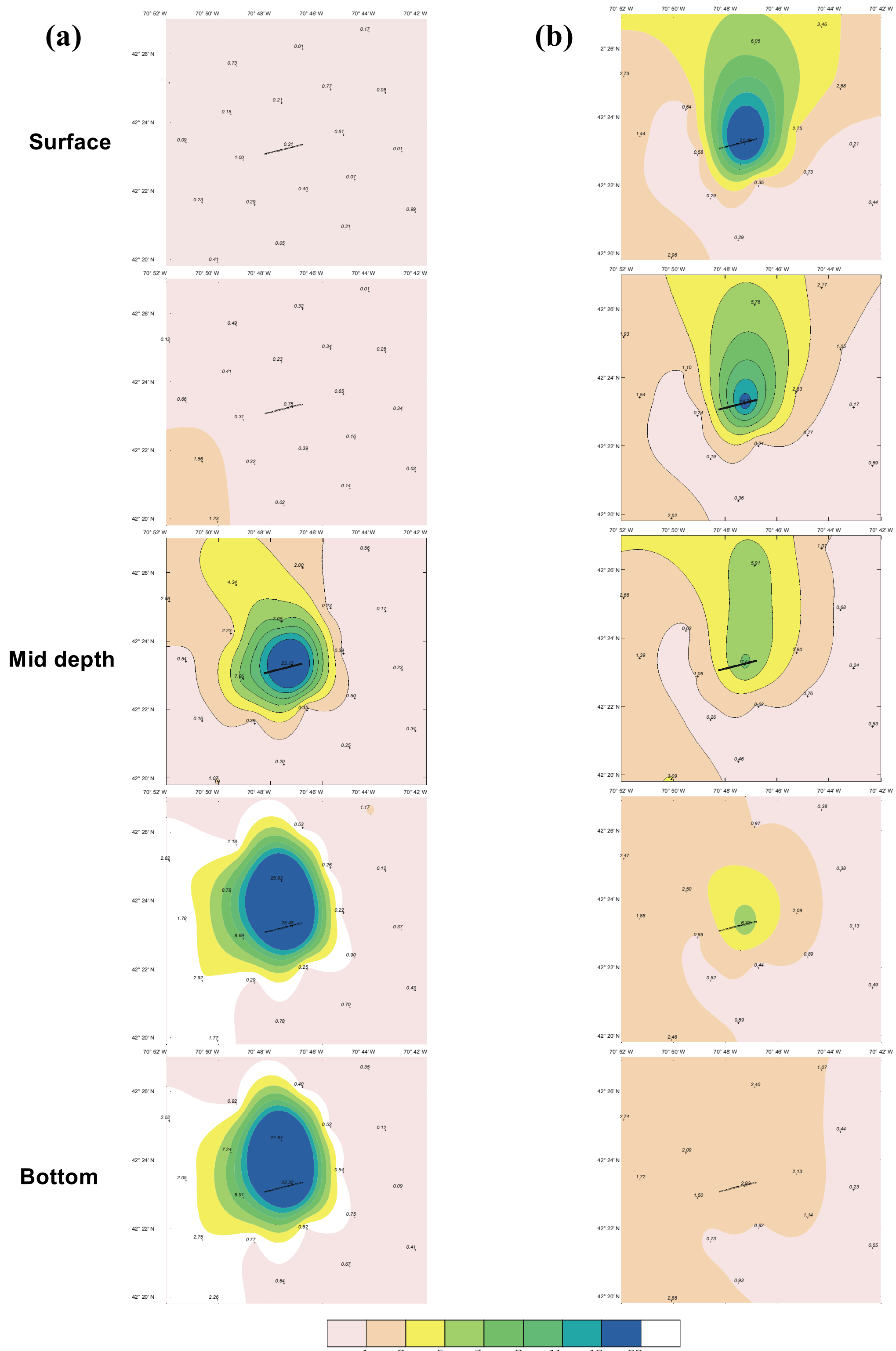


Figure 4-29. Ammonium Contour Plots at All Depths for Nearfield Surveys WF00E and WN00F (Oct 00)

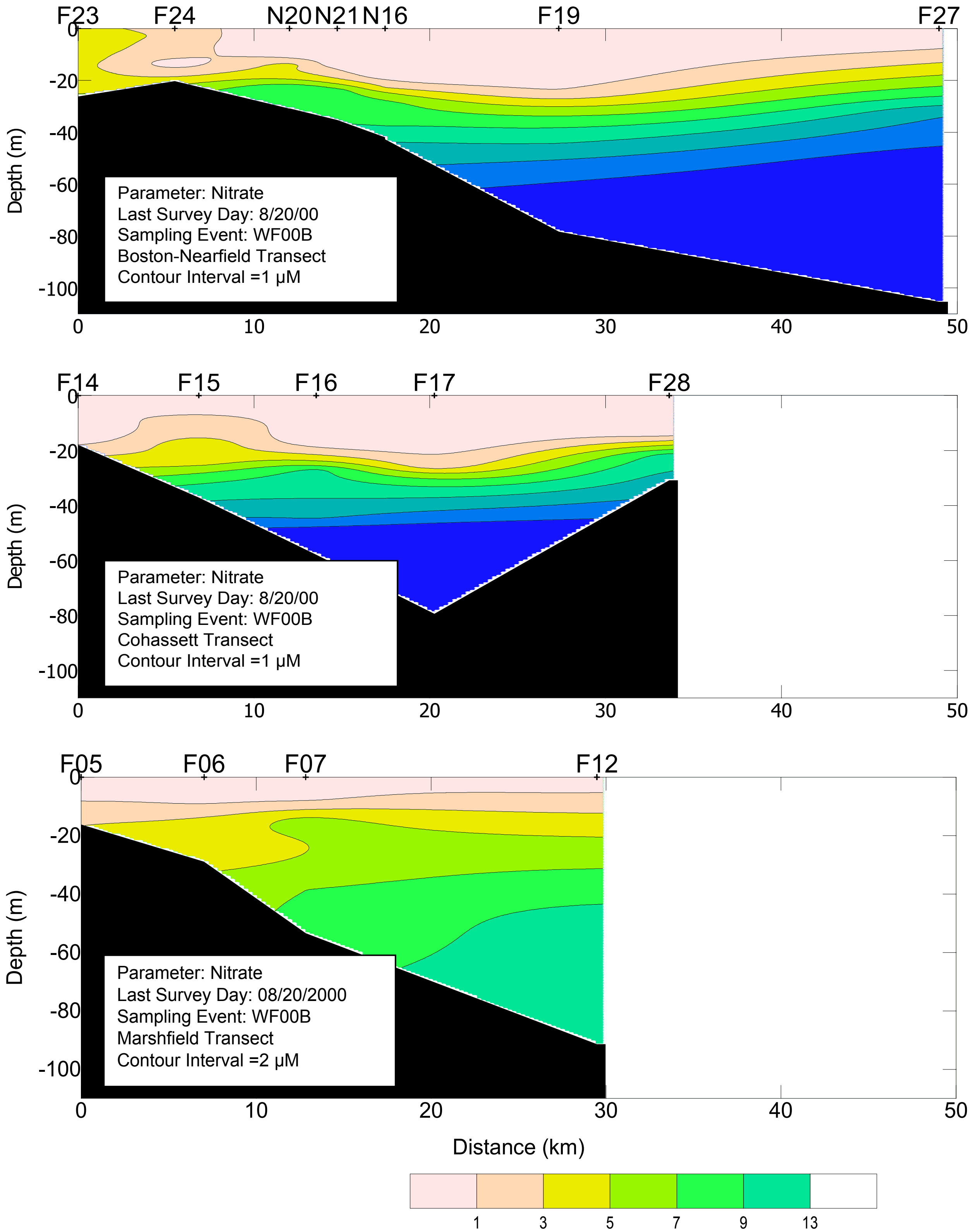


Figure 4-30. Nitrate Vertical Transect Plots for Farfield Survey WF00B (Aug 00)

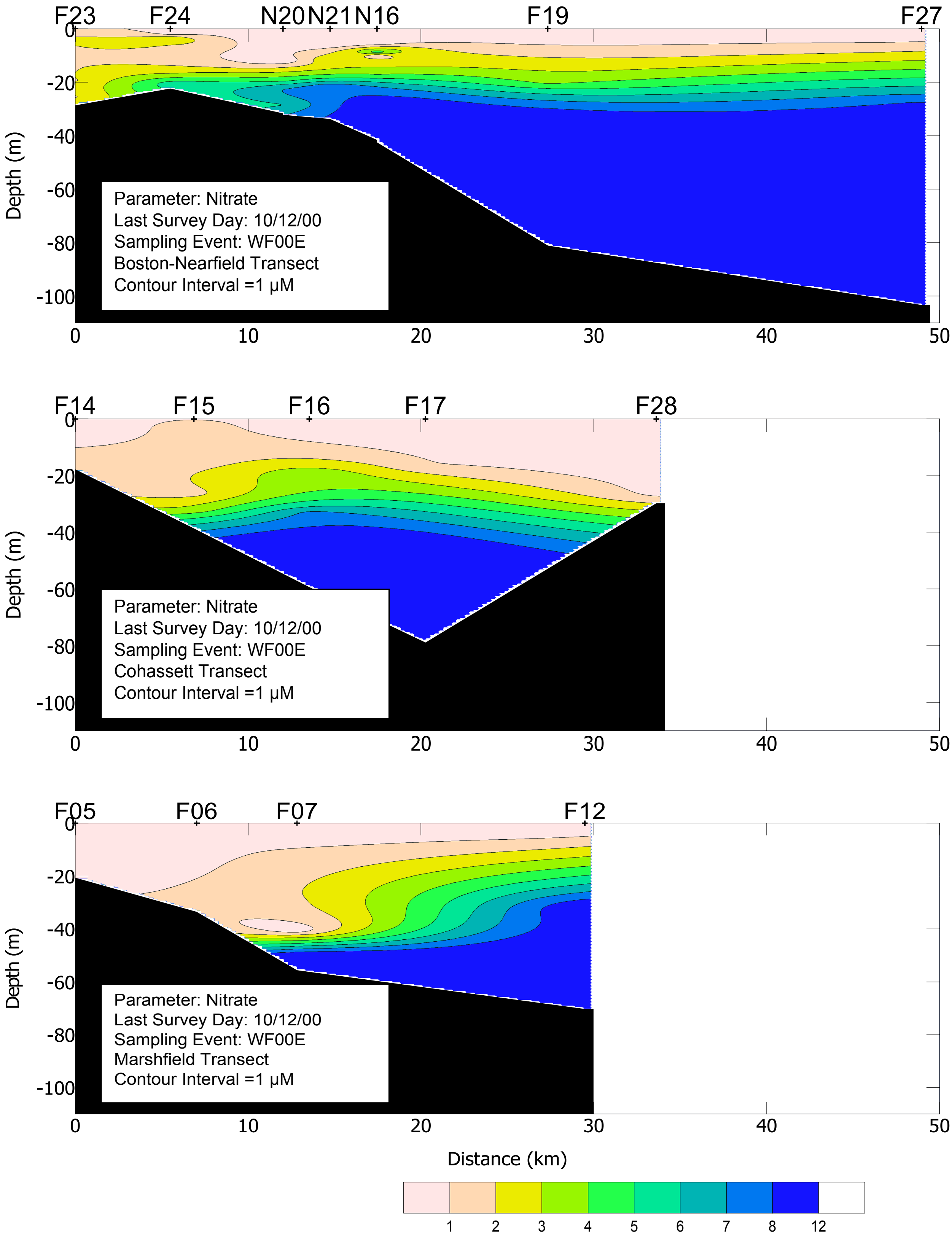
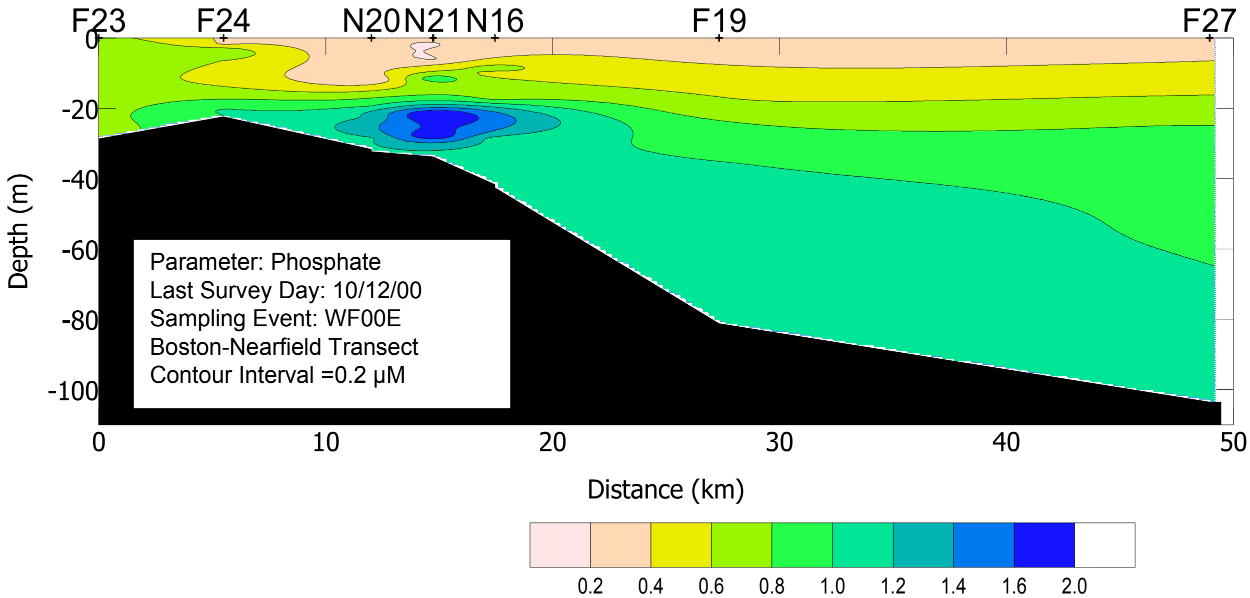


Figure 4-31. Nitrate Vertical Transect Plots for Farfield Survey WF00E (Oct 00)



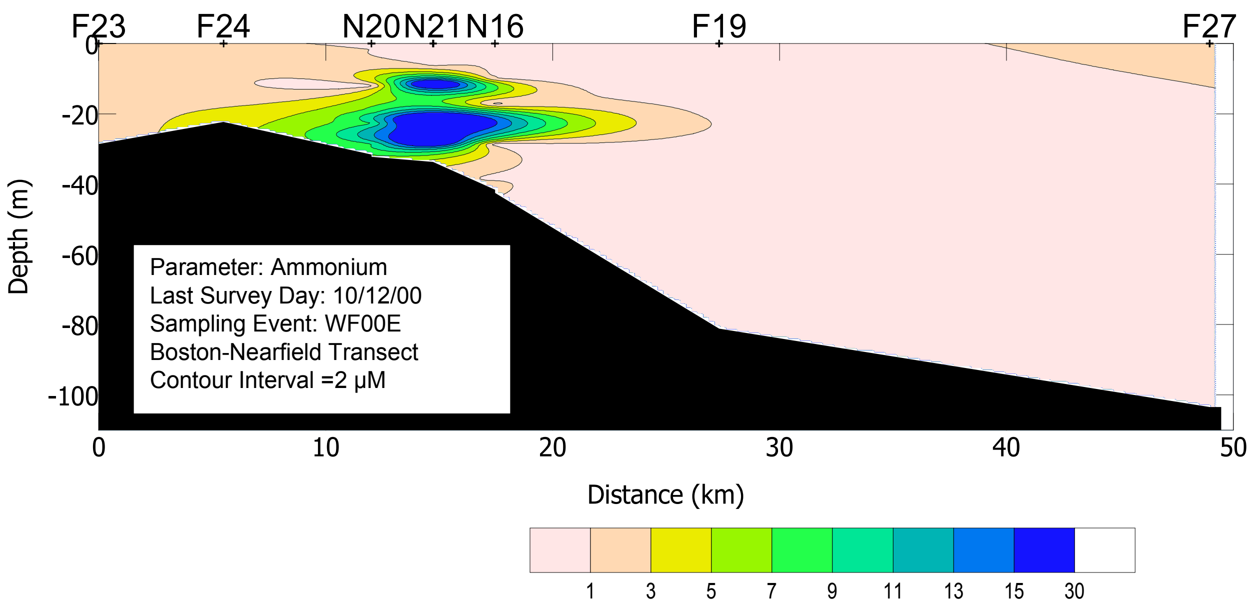
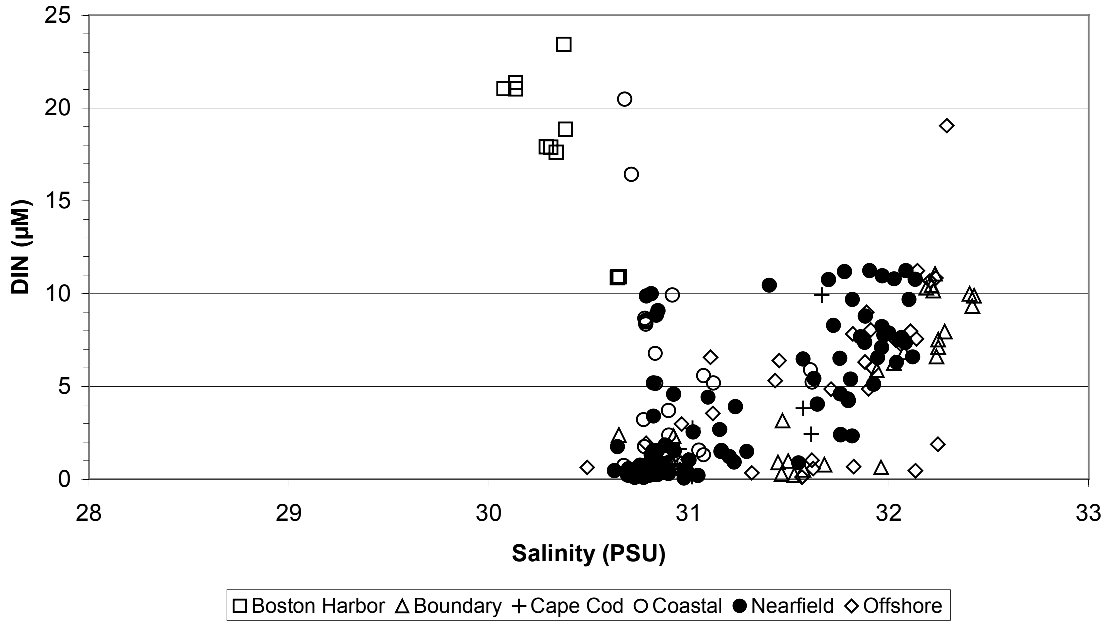


Figure 4-32. Phosphate and Ammonium Vertical Boston-Nearfield Transect Plots for Farfield Survey WF00E (Oct 00)

a) August



b) October

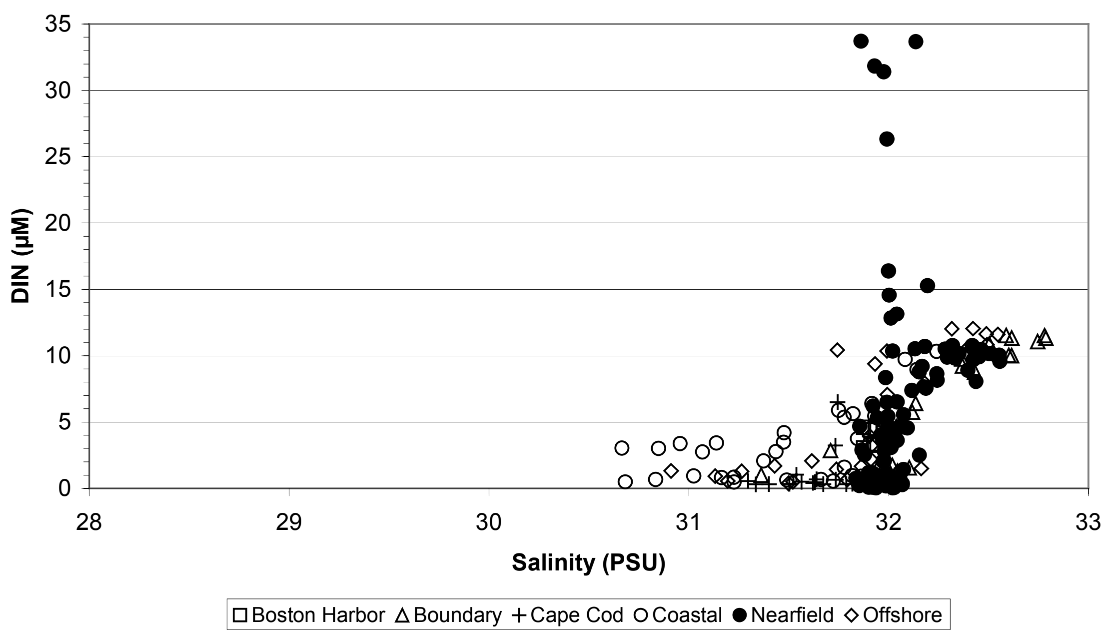


Figure 4-33. DIN vs. Salinity Plots for All Depths during Surveys (a) WF00B (Aug 00) and (b) WF00E (Oct 00)

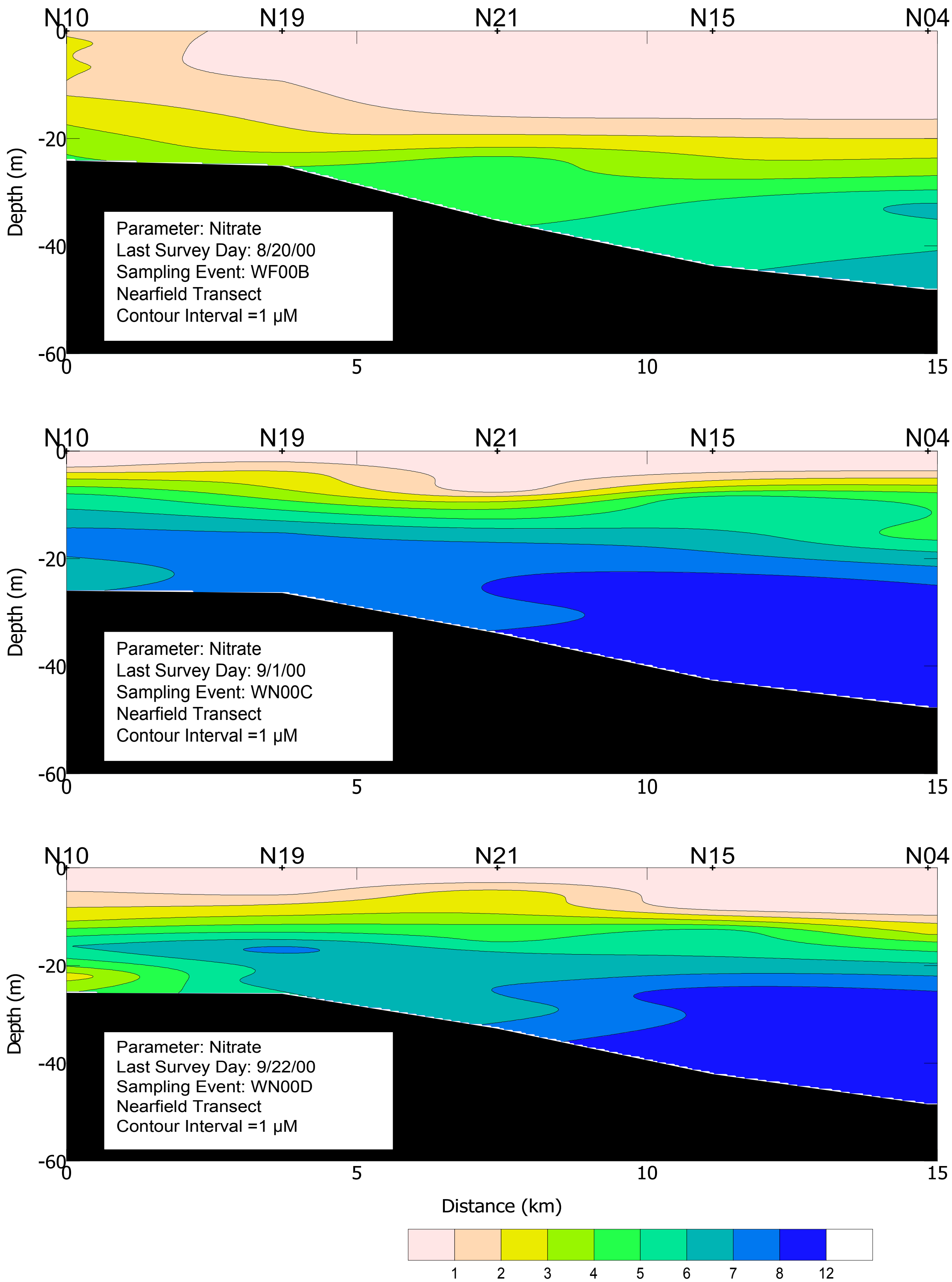
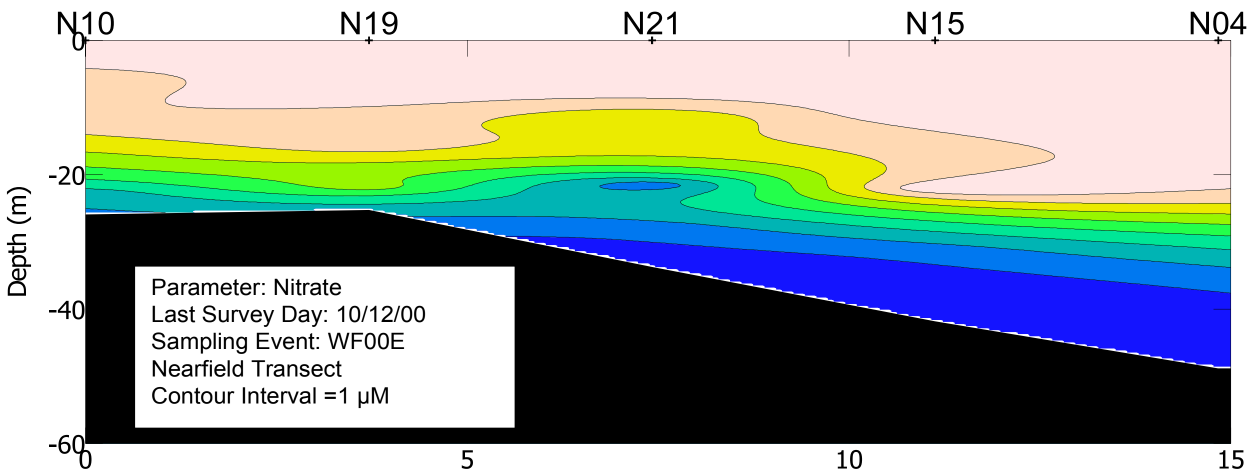
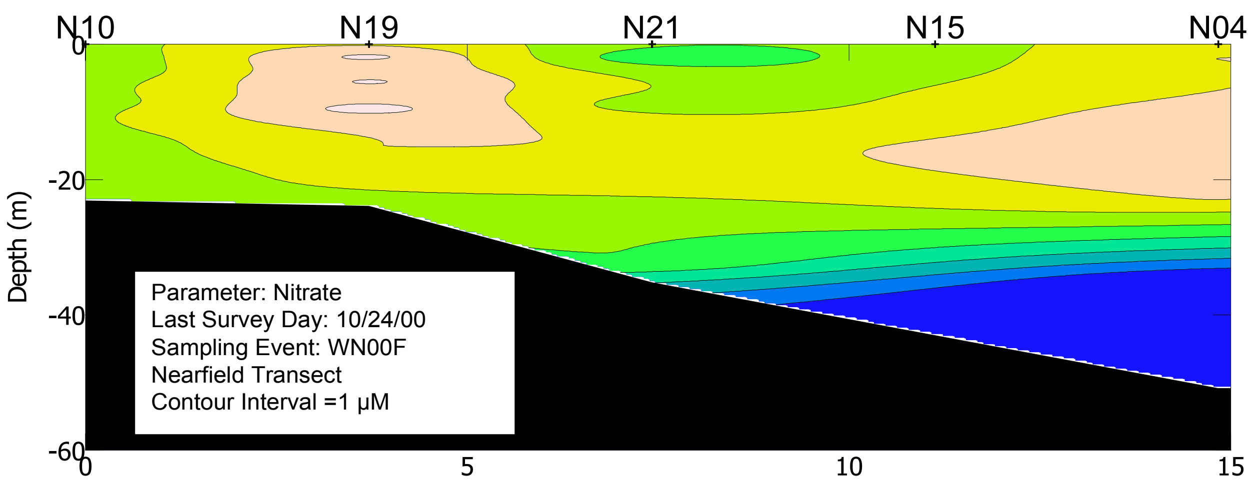


Figure 4-34. Nitrate Vertical Nearfield Transects for Surveys WF00B, WN00C, and WN00D


N10
N19
N21
N15
N04
Depth (m)
0
-20
-40
-60
0
5
10
15
Parameter: Nitrate
Last Survey Day: 10/12/00
Sampling Event: WF00E
Nearfield Transect
Contour Interval =1 µM


N10
N19
N21
N15
N04
Depth (m)
0
-20
-40
-60
0
5
10
15
Parameter: Nitrate
Last Survey Day: 10/24/00
Sampling Event: WN00F
Nearfield Transect
Contour Interval =1 µM

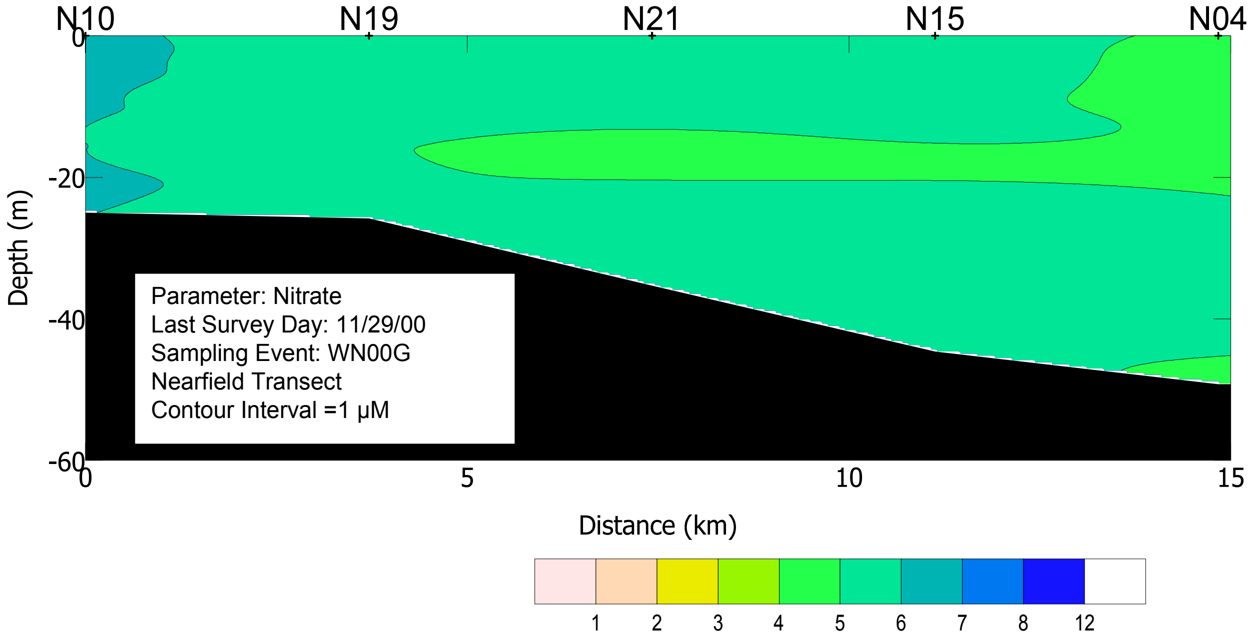


Figure 4-35. Nitrate Vertical Nearfield Transects for Surveys WF00E, WN00F, and WN00G

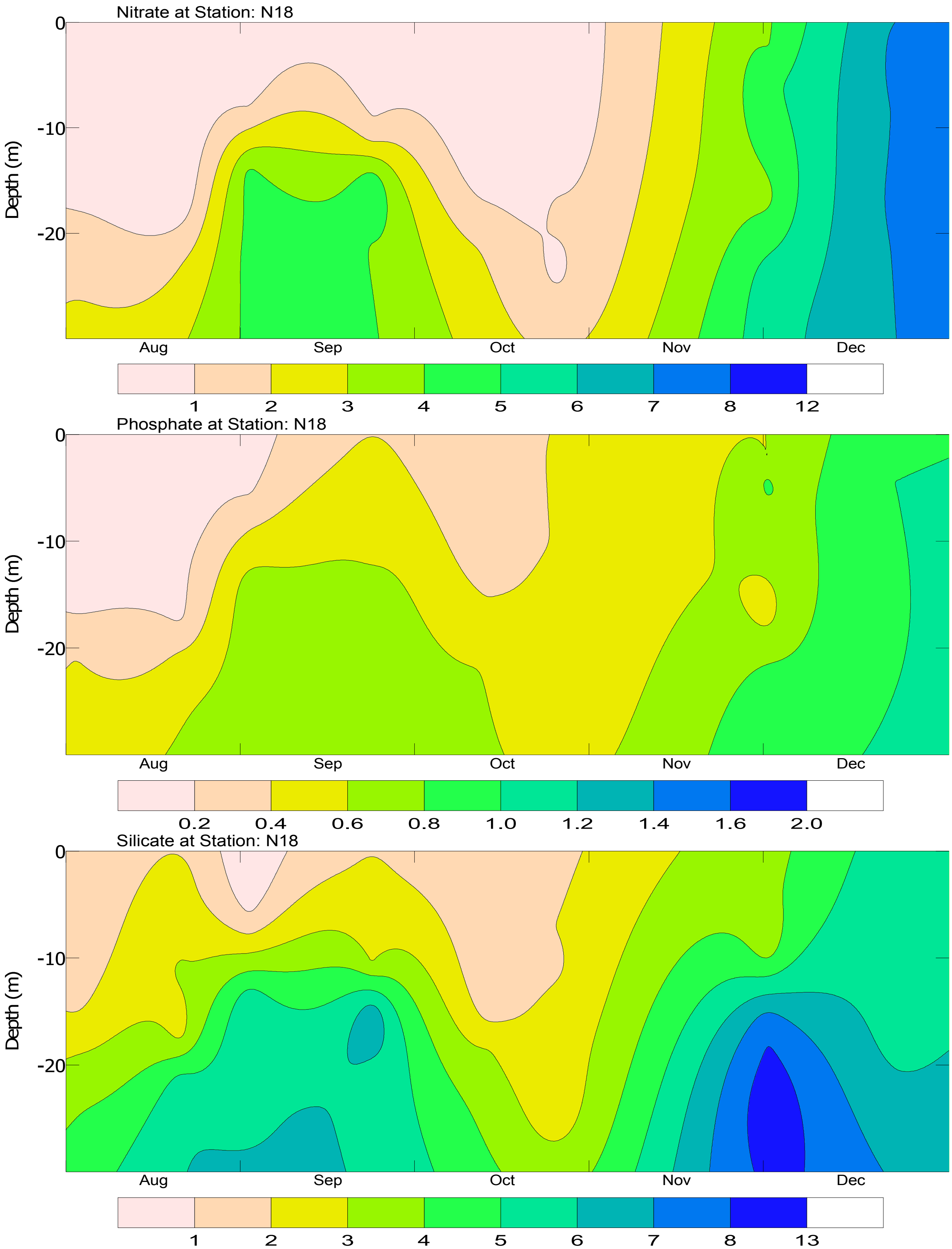


Figure 4-36. Nitrate, Phosphate, and Silicate Depth vs. Time Plots for Station N18

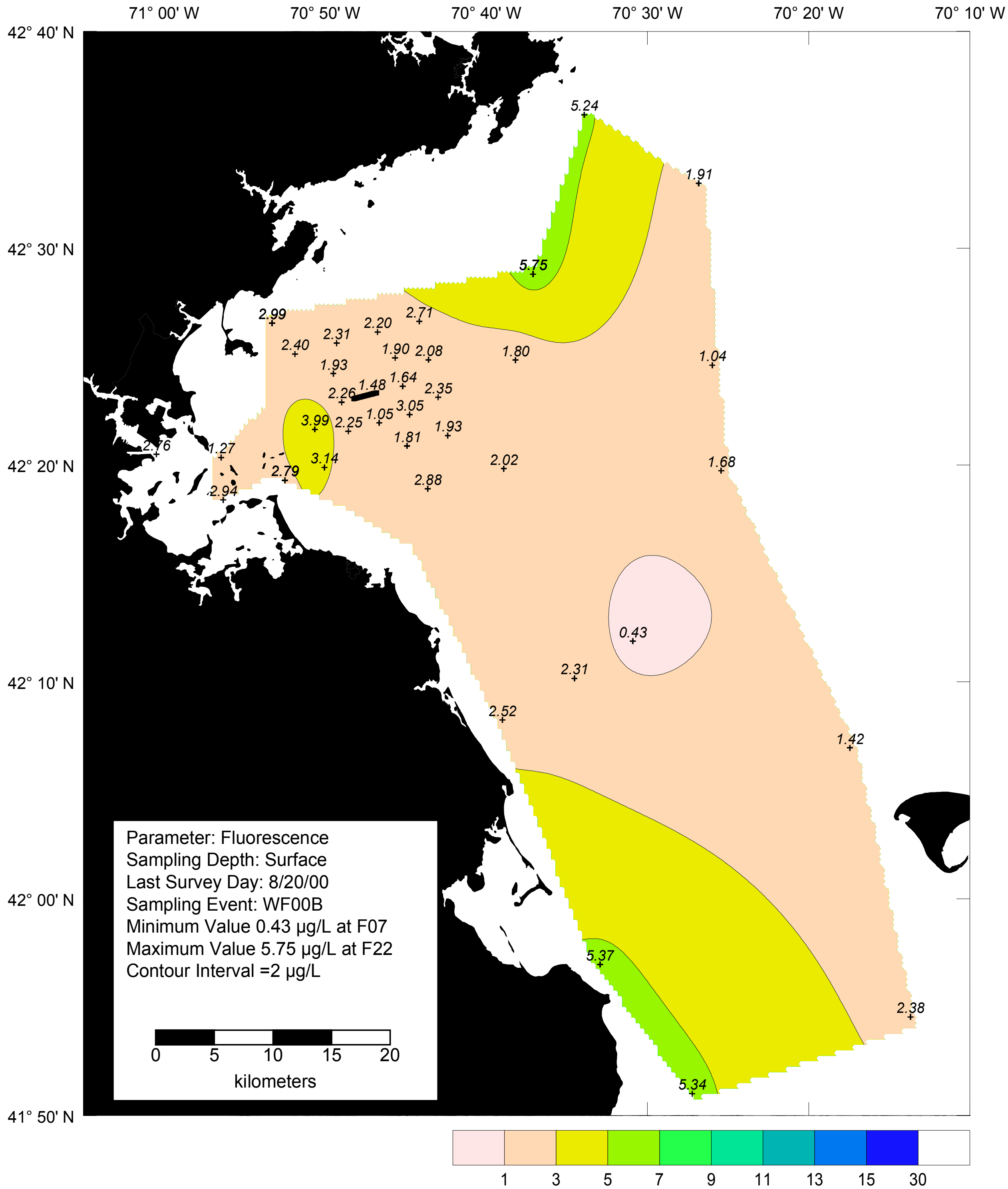


Figure 4-37. Fluorescence Surface Contour Plot for Farfield Survey WF00B (Aug 00)

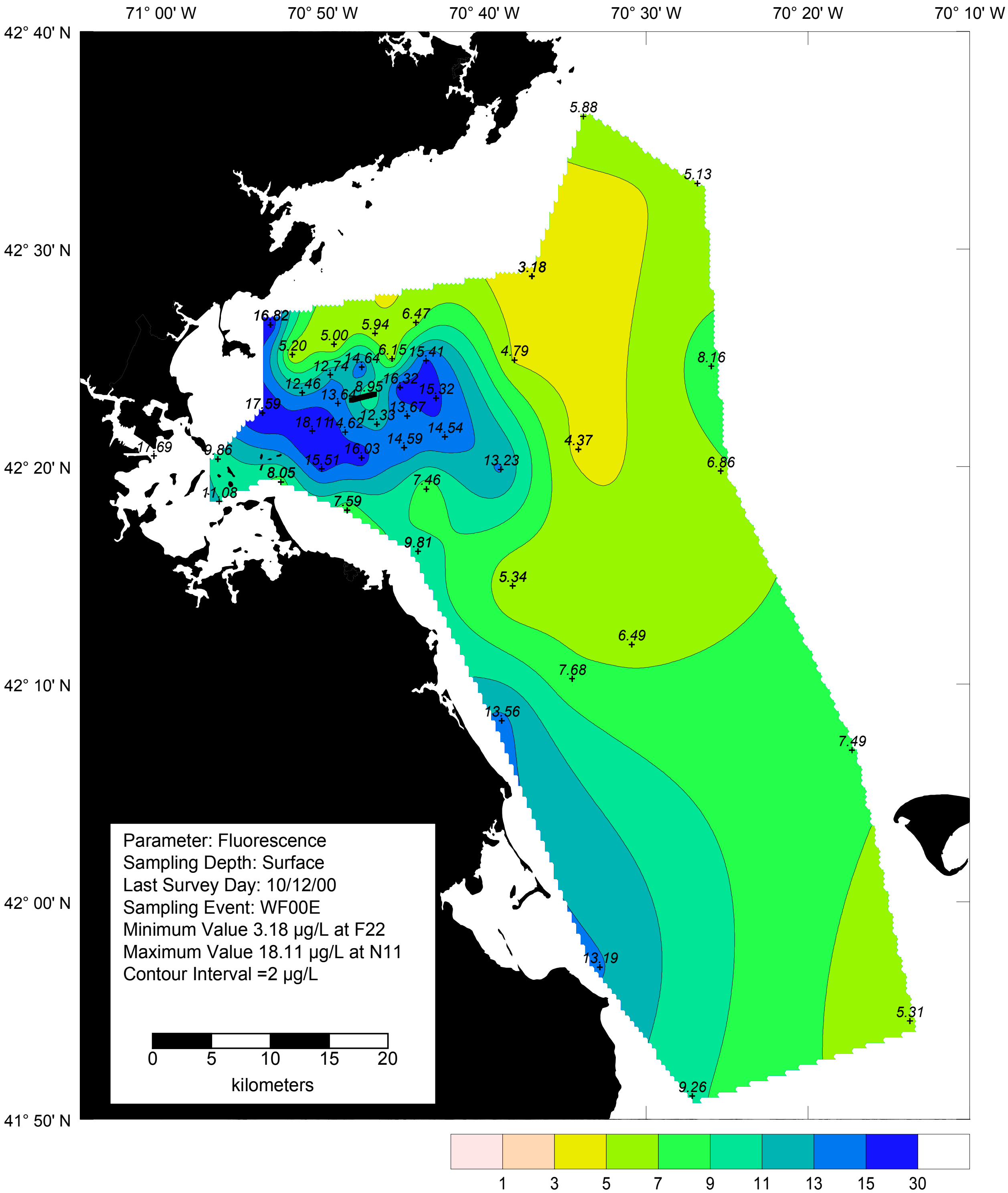


Figure 4-38. Fluorescence Surface Contour Plot for Farfield Survey WF00E (Oct 00)

Note: See Figure 4-5 caption for sampling dates.

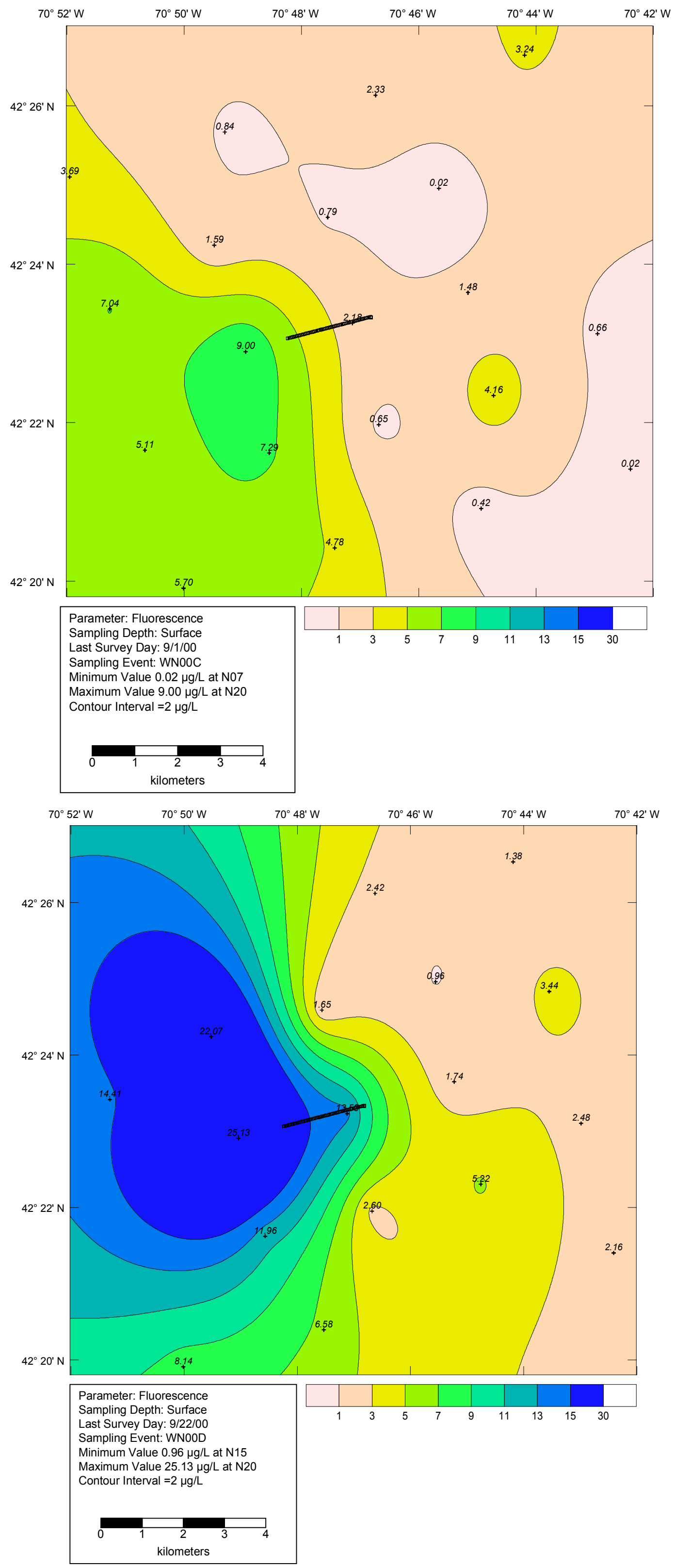


Figure 4-39. Fluorescence Surface Contour Plot for Nearfield Surveys (a) WN00C and (b) WN00D (Sep 00)

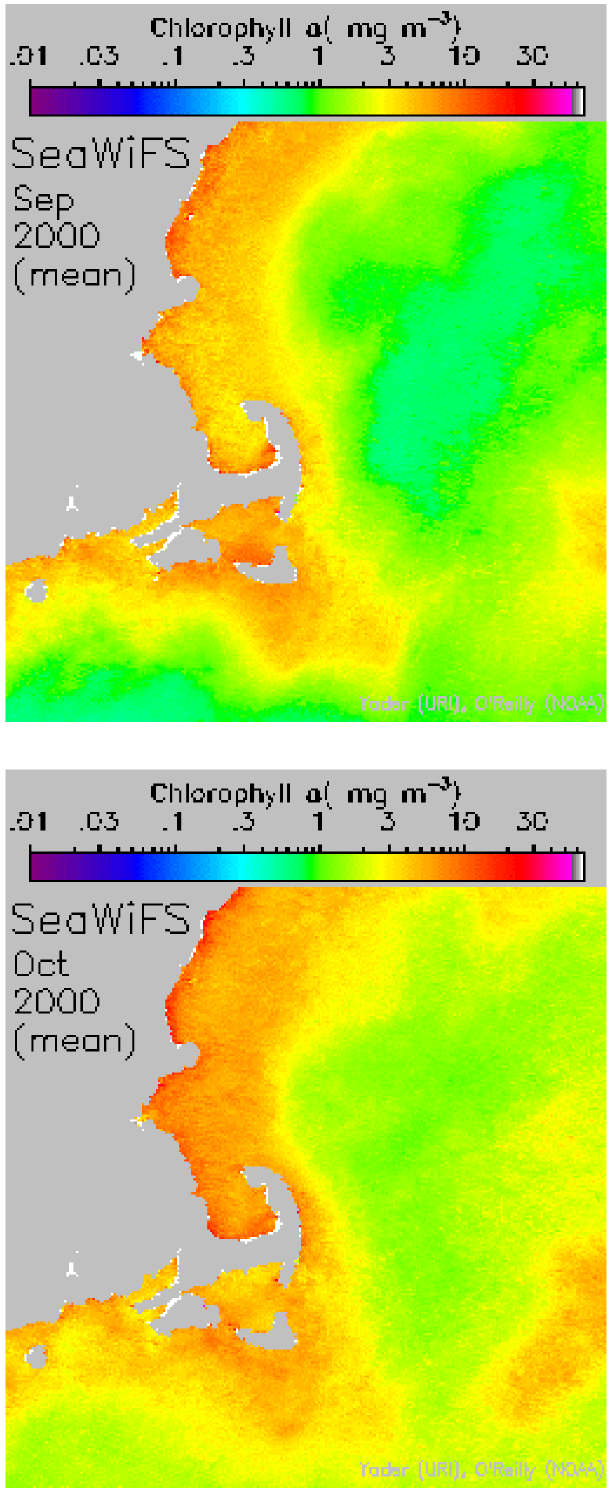


Figure 4-40. Monthly Composite of SeaWiFS Chlorophyll Images for the Southwestern Gulf of Maine for September and October 2000 [J. Yoder (URI) and J. O'Reilly (NOAA)]

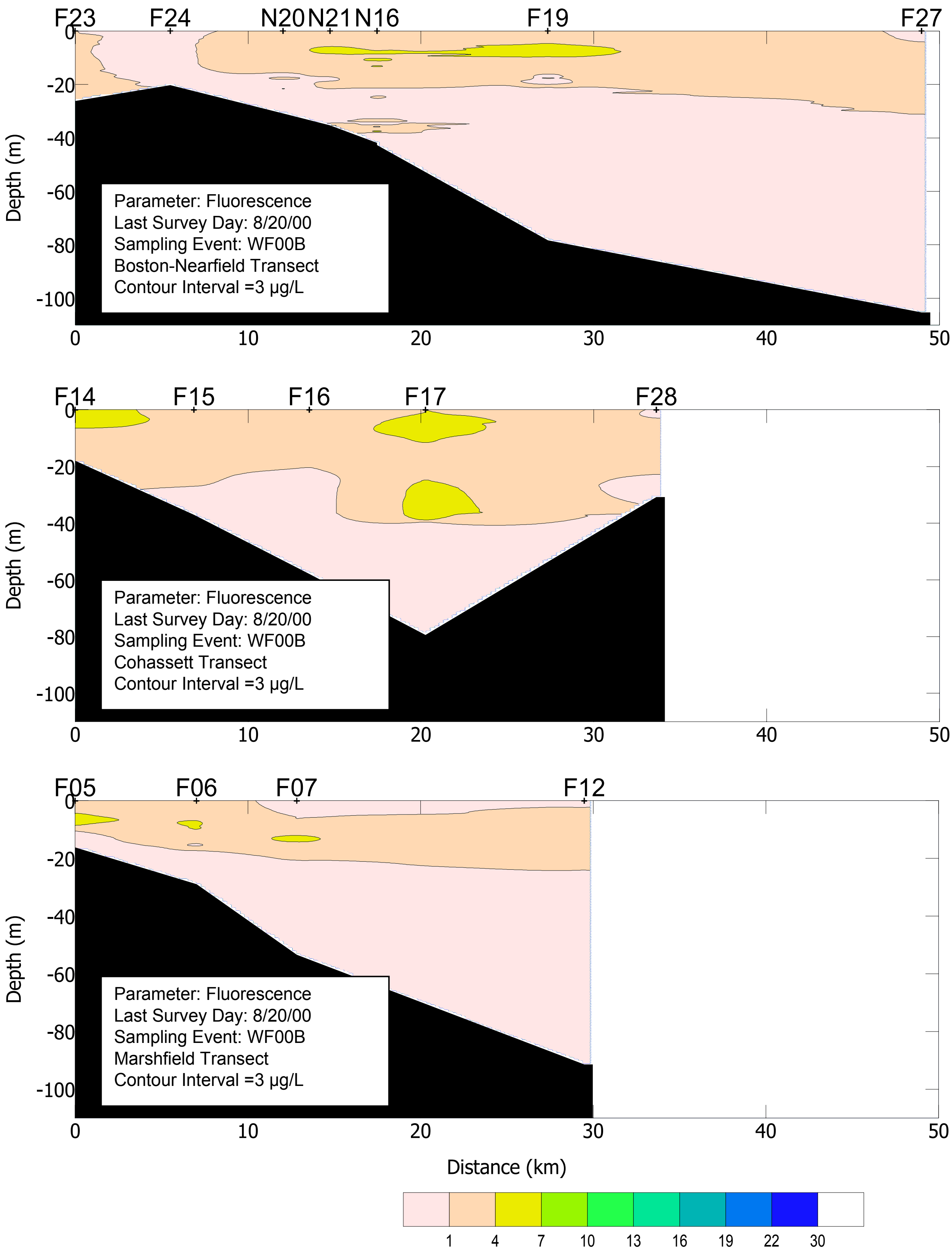


Figure 4-41. Fluorescence Vertical Transect Plots for Farfield Survey WF00B (Aug 00)

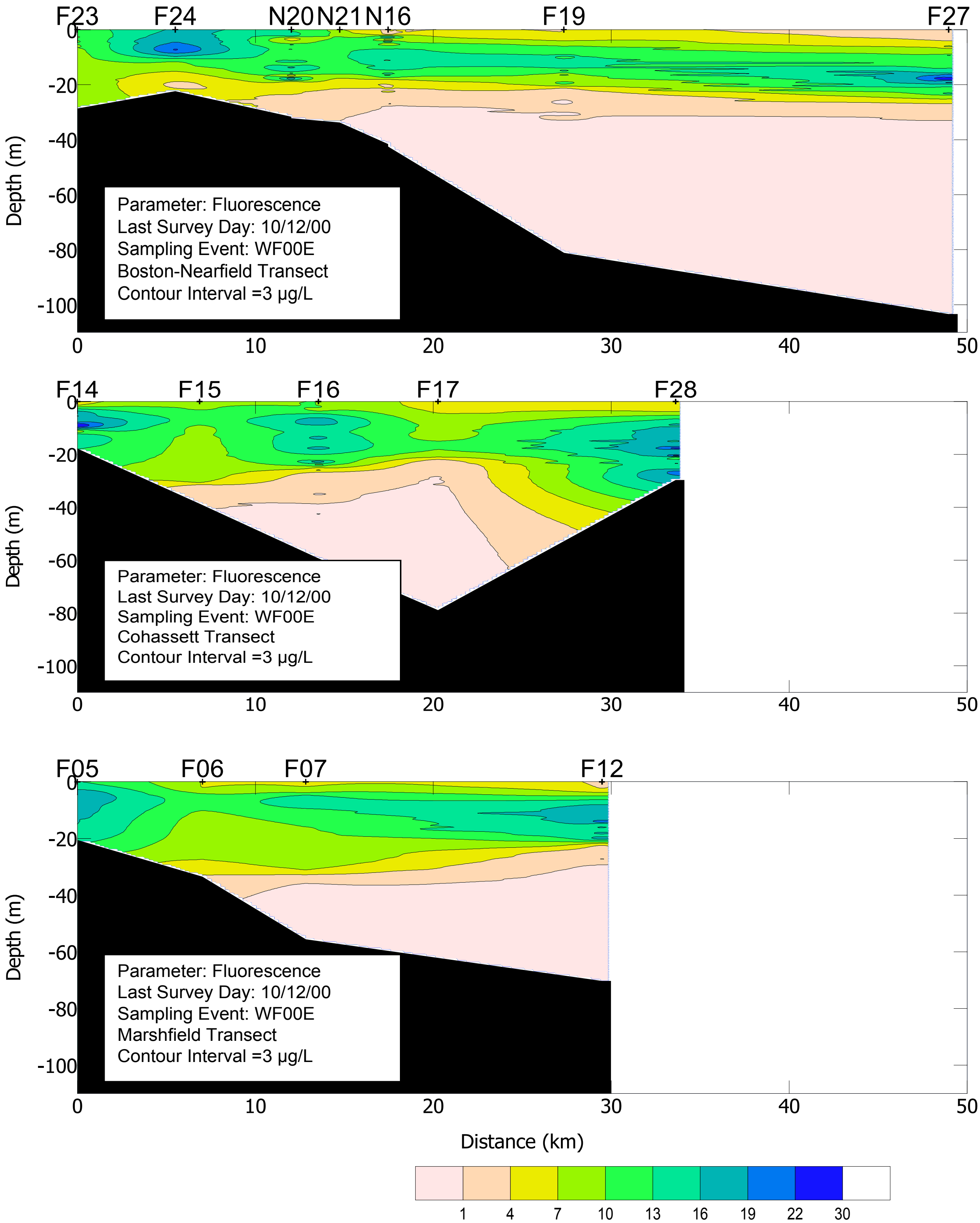


Figure 4-42. Fluorescence Vertical Transect Plots for Farfield Survey WF00E (Oct 00)

Note: See Figure 4-5 caption for sampling dates.

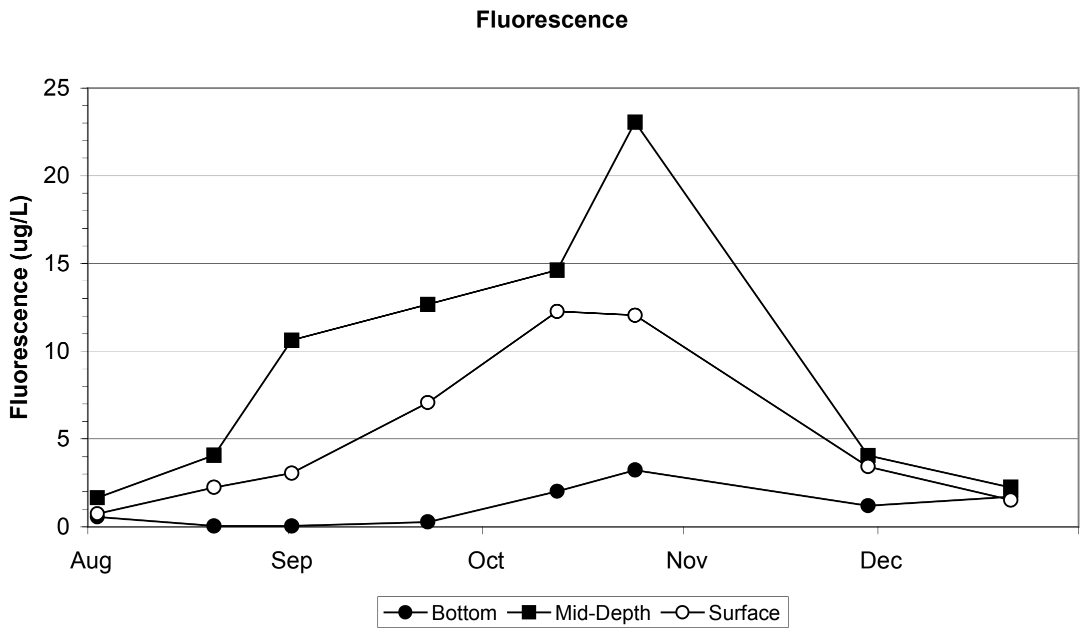


Figure 4-43. Time Series of Average Fluorescence in the Nearfield – Surface, Mid-Depth, and Bottom Depth

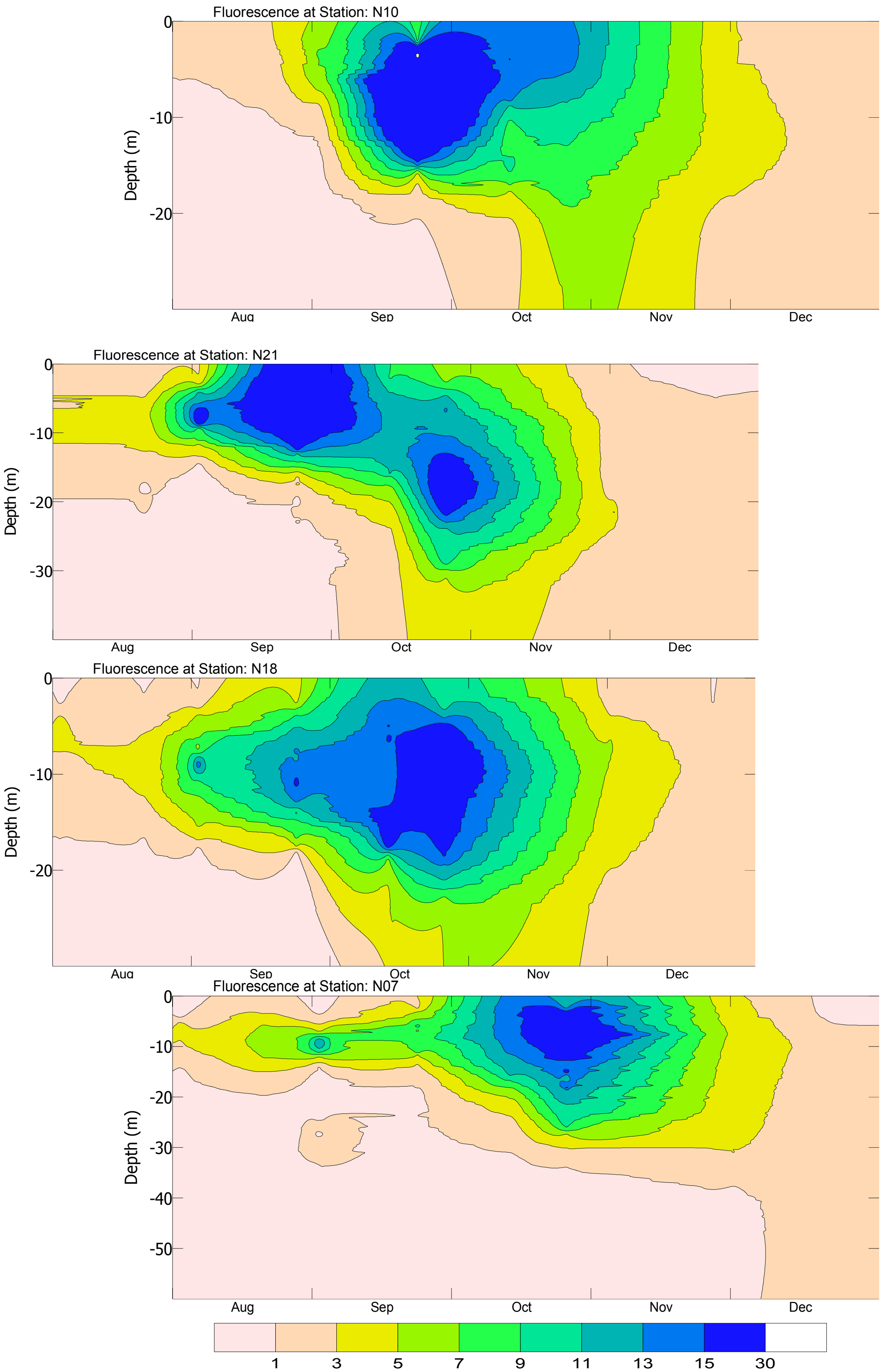


Figure 4-44. Fluorescence Depth vs. Time Contour Profiles for Stations N10, N21, N18, and N07

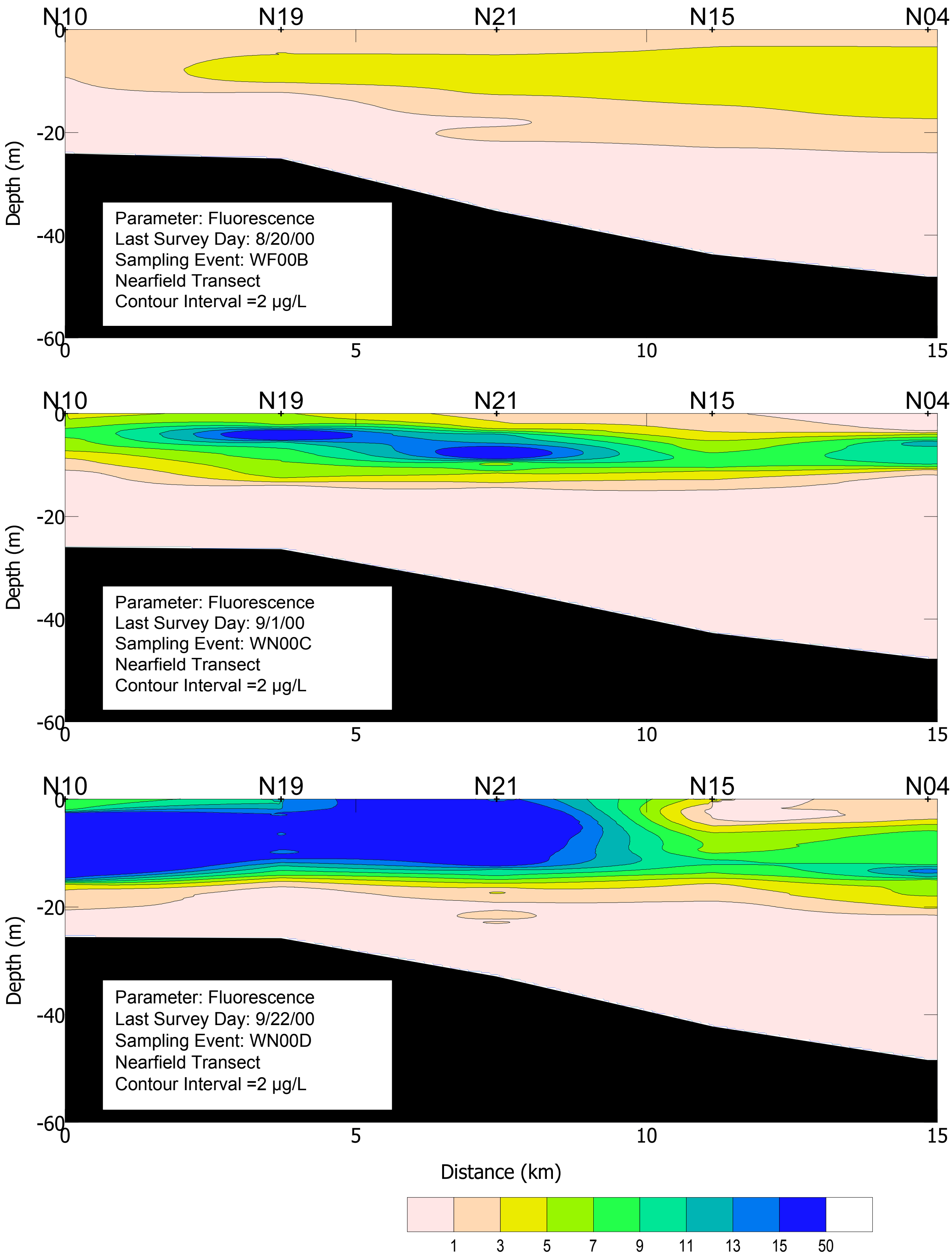


Figure 4-45. Fluorescence Vertical Nearfield Transect Plots for Surveys (a) WF00B, (b) WN00C, and (c) WN00D

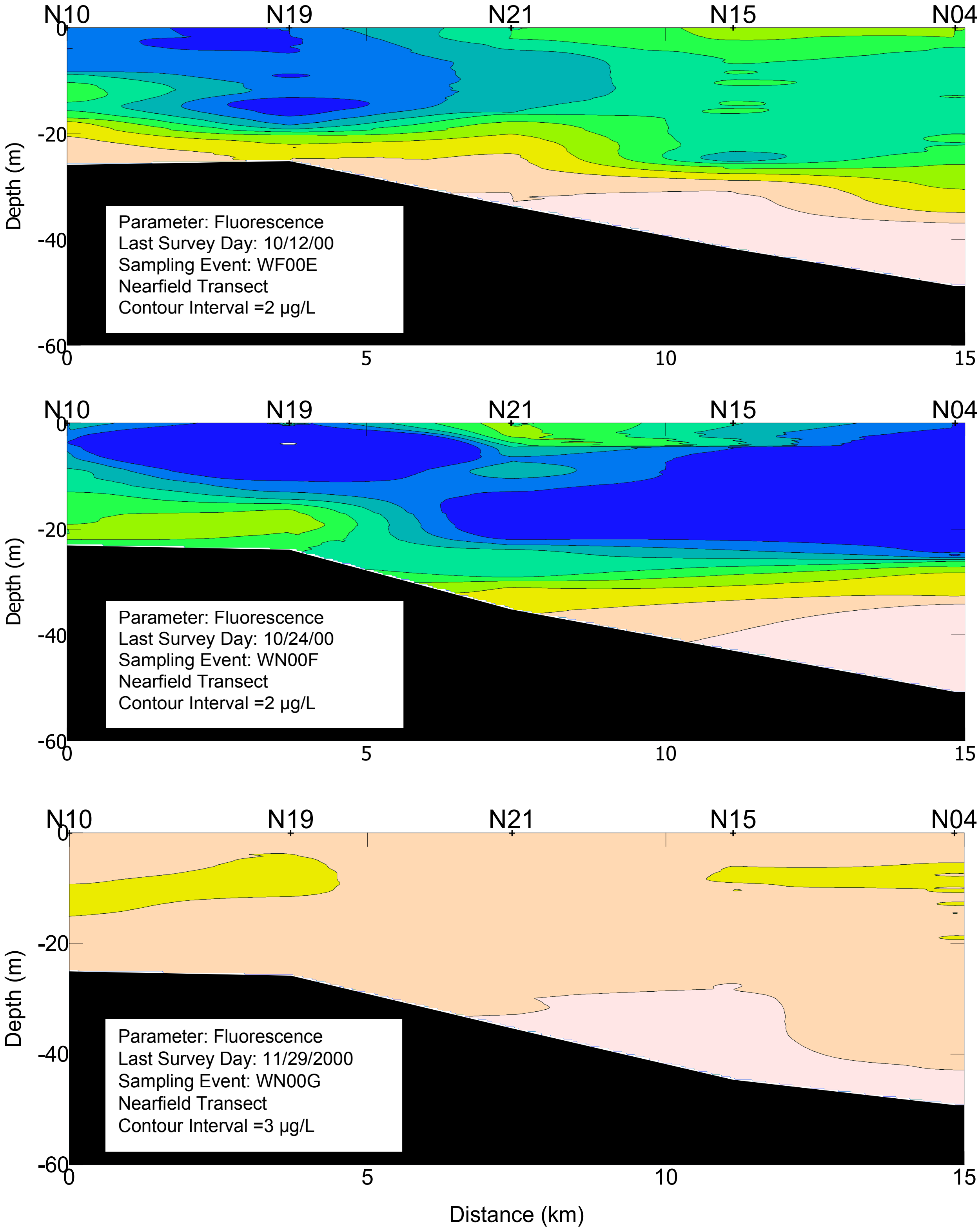


Figure 4-46. Fluorescence Vertical Nearfield Transect Plots for Surveys (a) WF00E, (b) WN00F), and (c) WN00G

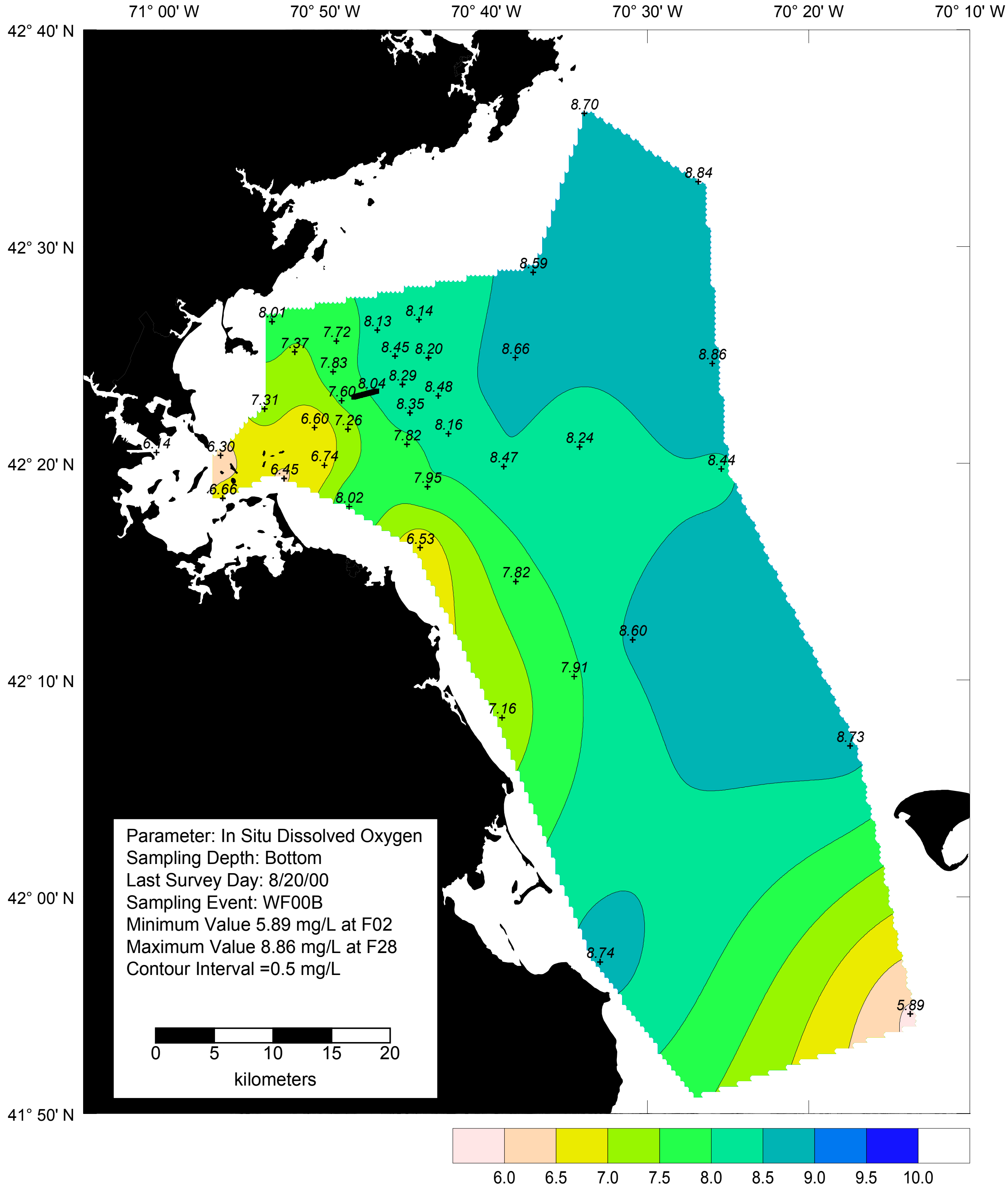


Figure 4-47. Dissolved Oxygen Bottom Contour in the Farfield Survey WF00B (Aug 00)

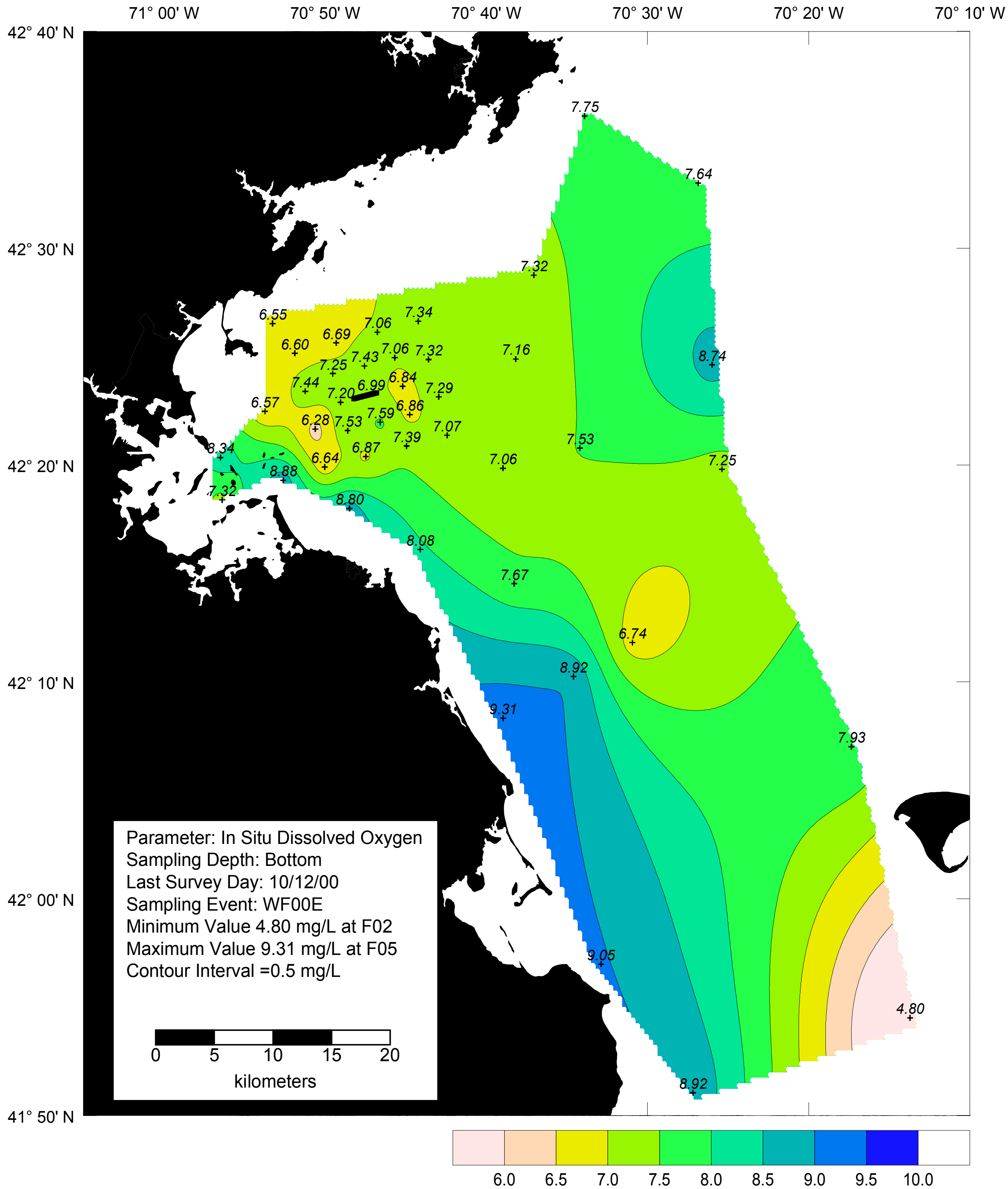
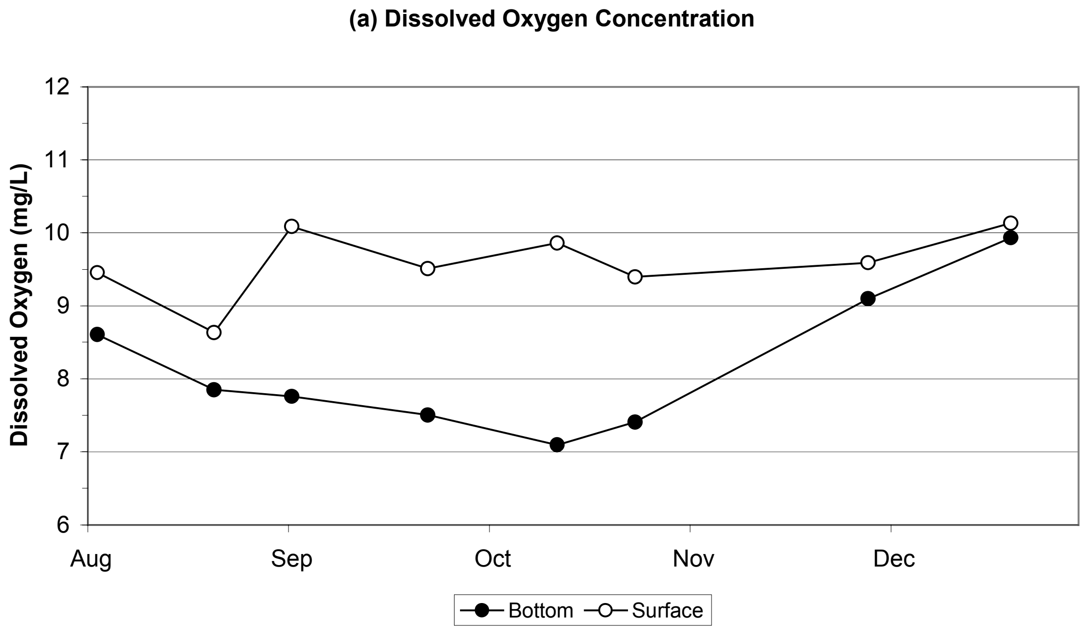


Figure 4-48. Dissolved Oxygen Bottom Contour in the Farfield Survey WF00E (Oct 00)

Note: See Figure 4-5 caption for sampling dates.



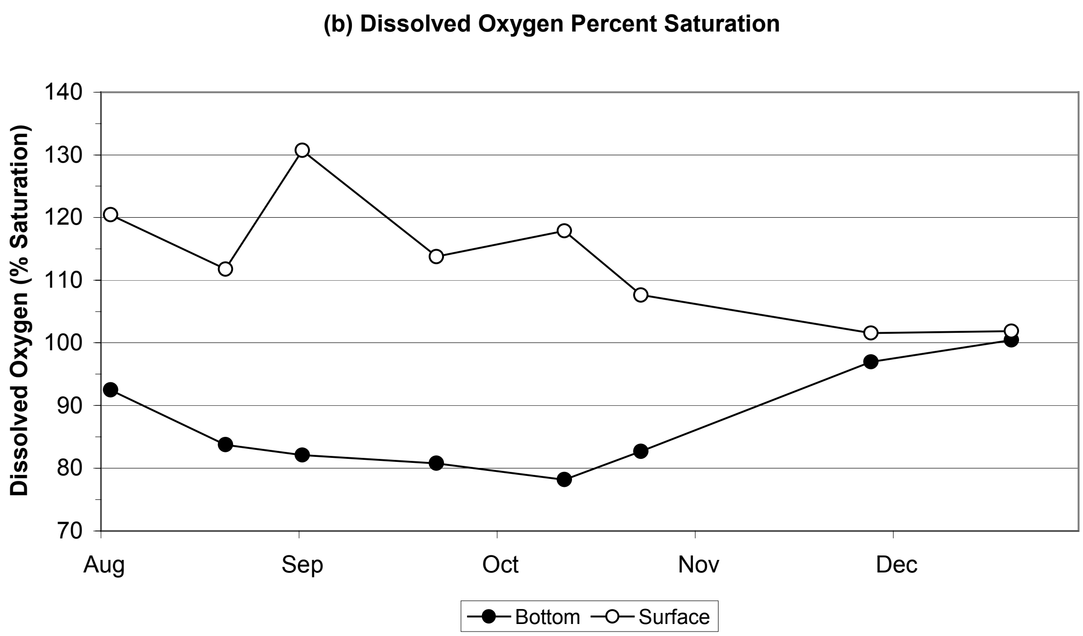


Figure 4-49. Time Series of Average Surface and Bottom (a) DO Concentration and (b) Percentage Saturation in the Nearfield

5.0 PRODUCTIVITY, RESPIRATION, AND PLANKTON RESULTS

5.1 Productivity

Production measurements were taken at two nearfield stations (N04 and N18) and one farfield station (F23) near the entrance of Boston Harbor. All three stations were sampled on August 17 (WF00B) and October 5 (WF00E). Stations N04 and N18 were also sampled during the nearfield surveys conducted on August 2 (WN00A), September 1 (WN00C), September 22 (WN00D), October 24 (WN00F), November 29 (WN00G), and December 21 (WN00H). 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 Appendix A.

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 E) 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.

For this semi-annual report, areal production (mg C m^{-2} d^{-1}) and depth-averaged chlorophyll-specific production (mg C mg Chl^{-1} d^{-1}) are presented (Figures 5-2 and 5-3). Areal productions are determined by integrating measured productivity over the depth interval. Chlorophyll-specific productivity for each depth was first determined by normalizing productivity by measured chlorophyll *a*. Productivity and chlorophyll-specific productivity for each depth are also presented as contour plots (Figures 5-4 to 5-9).

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 > 1000 mg C m^{-2} d^{-1} during the initial cruise on August 2 (WN00A). Production at station N18 was somewhat higher at this time (~1700 mg C m^{-2} d^{-1}) compared with station N04 (~ 1100 mg C m^{-2} d^{-1}). Values at both stations decreased by mid-August (WF00B) to 735 mg C m^{-2} d^{-1} at N18 and 940 mg C m^{-2} d^{-1} at N04. Following this decline, production increased to a major productivity peak on September 1 (WN00C), particularly at station N18, and remained at elevated levels during the September 22 survey (WN00D). Productivity at station N04 (1220 – 2169 mg C m^{-2} d^{-1}) was less than station N18 (4120 - 4553 mg C m^{-2} d^{-1}) during this early fall bloom period. Productivity at station N18 (and N16) 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 <950 mg C m^{-2} d^{-1} by October 5 (WF00E) then increased again to a second peak on October 24 (WN00F). This secondary increase in production on October 24 occurred simultaneously at both stations. At both stations the timing of the early and late fall blooms in production were similar, however productivity was greater (2 – 3.5 fold) at station N18 during the initial bloom and greater (~1.3 fold) at station N04 during the second bloom. The peak productivity at station N04 during this semi-annual period occurred October 24 (WN00F) with a production of 2389 mg C m^{-2} d^{-1}. Station N18 reached its maximum value (4553 C m^{-2} d^{-1}) during this semi-annual period somewhat earlier on September 22 but was also characterized by elevated production (1787 mg C m^{-2} d^{-1}) on October 24. Areal production declined at both stations in November (WN00G) and remained low during December (WN00H). Production minima for this reporting period were observed at station N04 (429 mg C m^{-2} d^{-1}) and station N18 (350 C m^{-2} d^{-1}) on December 21, the final survey of the year.

At the Boston Harbor productivity/respiration station (F23), areal production (406 mg C m^{-2} d^{-1}) during the August 17 survey (WF00B) was the lowest productivity observed at the three monitoring stations for the sampling period. Areal production at F23 increased somewhat to 914 mg C m^{-2} d^{-1} by October 5 (WF00E) and was similar to the measured production at the nearfield stations. The production data at station F23 are in agreement with the chlorophyll data. During WF00B, chlorophyll values were low and productivity was low. Elevated chlorophyll values during WF00E were associated with increased productivity levels.

Areal production in 2000 followed patterns typically observed in prior years. Distinct fall phytoplankton blooms were observed as increases in production at both nearfield stations during the sampling period (Figure 5-2). In general, nearfield stations are characterized by the occurrence of a fall bloom. The fall blooms observed at nearfield stations in 1995-1999 generally reached values of 1600 to 4200 mg C m^{-2} d^{-1}, with blooms typically lasting 3-4 weeks. The bloom in 2000 reached peak values of >2300 mg C m^{-2} d^{-1} at station N04 and > 4500 mg C m^{-2} d^{-1} at station N18 and occurred from September 1 through 22, with a secondary bloom in late October.

The elevated productivity observed at station N18 on September 22 is the highest value observed throughout the monitoring period (1997 – 2000) at this station. This elevated productivity was recorded during the first survey following the September 6 start-up of the sewage outfall and was the cause of some initial concern. Station N18 is the productivity station closest to the outfall and any effects from sewage-derived nutrients would be detected here first. However, the increase in productivity was minor relative to some years and productivity at N18 was lower than N04 on subsequent dates. The patterns observed at the nearfield sites were consistent with those observed during prior years although the timing of events varied.

5.1.2 Chlorophyll-Specific Production

Depth-averaged chlorophyll-specific production showed similar trends at both nearfield sites (N04 and N18) over time, but was consistently higher at station N18 (Figure 5-3). Depth-averaged chlorophyll-specific production was relatively high at the start of the reporting period. Seasonal maxima were reached during WN00A with recorded values greater than 20 – 30 mg C mg Chl a^{-1} d^{-1}. These values are comparable to the seasonal maxima measured during the same period in 1999. Values decreased to ~ 8 – 14 mg C mg Chl a^{-1} d^{-1} at the nearfield sites in mid August then increased to ~8 – 24 mg C mg Chl a^{-1} d^{-1} by early September. Following this increase, depth-averaged chlorophyll-specific production gradually decreased at both stations until the seasonal minima (2-5 mg C mg Chl a^{-1} d^{-1}) were reached during the early October survey. Depth-averaged chlorophyll-specific production then gradually climbed to values between ~2 – 12 mg C mg Chl a^{-1} d^{-1} for the remainder of the sampling period. Depth-averaged chlorophyll-specific rates at harbor station F23 also closely matched the values reported for the nearfield sites (Figure 5-3).

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 high relative to the amount of biomass present at the nearfield stations on August 2. At both stations N04 and N18 the peak chlorophyll-specific production occurred during the summer rather than during the fall phytoplankton bloom. The peaks observed at both station during this semiannual period were somewhat lower than the annual maxima observed in July 2000.

5.1.3 Production at Specified Depths

The spatial and temporal distribution of production, chlorophyll and chlorophyll-specific production on a volumetric basis were summarized by showing contoured values over the sampling period (Figures 5-4 to 5-9). Chlorophyll-specific productions (daily 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.

The volumetric data reveal that the fall peaks in areal productivity (September 22 and October 24) reported during WN00D and WN00F at station N04 were concentrated in the upper 8 m of the water column (Figure 5-4). Areal productivity at station N18 reached bloom values earlier on September 1 (WN00C), with high values observed in the surface, mid-surface and mid-depth samples, also at depths less than 8 m (Figure 5-5). At station N18, the annual productivity peak occurred on September 22 (WN00D) and was distributed throughout the upper 10 m of the water column with values from the surface to mid-depth samples ranging from ~160 - 570 mg C m^{-3} d^{-1} (Figure 5-5). At the two nearfield stations, surface productions tended to decrease following the early fall peak values but increased again on October 24 (WN00F). For station N04, the highest production value observed (~270 mg C m^{-3} d^{-1}) occurred at the surface (1.79 m) on October 24. For station N18, the highest production value observed (~570 mg C m^{-3} d^{-1}) occurred on September 21 and was also recorded at the surface (1.71 m). Peak production values tended to be correlated with the occurrence of the highest chlorophyll *a* measurements (Figures 5-6 and 5-7).

A subsurface (4.52 - 7.75 m) productivity maximum measured at station N18 on September 1 (WN00C) was a major component of the elevated areal productivity recorded here. Station N04 did not exhibit a subsurface elevation in productivity during WN00C thus accounting for the wide difference in areal production between the nearfield sites during the early September survey. A subsurface productivity maximum was recorded at station N04 on September 22 at a depth of 7.57 m. No other subsurface productivity maxima were observed at the nearfield sites during this semiannual sampling period. The productivity pattern at specified depths observed in 2000 was similar to that observed in prior years. At station N04 productivity >20 mg m^{-3} d^{-1} was rarely observed at depths >15 m. At station N18 productivity as high as 27 mg C m^{-3} d^{-1} was recorded from depths of 20 m with values > 6 mg C m^{-3} d^{-1} frequently observed here. Productivity in the harbor was largely restricted to the upper 10 m of the water column.

Chlorophyll-specific production (mg C mg Chl^{-1} d^{-1}) at N04 and N18 exhibited a much more uniform behavior (Figures 5-8 and 5-9) compared to depth-specific daily productivity. Elevated chlorophyll-specific production was primarily concentrated in the upper portions of the water column at both nearfield sites. Peak chlorophyll-specific productions occurred during the August surveys (WN00A and WF00B) at station N04 and station N18. In general, the efficiency of photosynthesis decreased both with depth and as the season progressed. Chlorophyll-specific production did not increase at either station in late October indicating that the late fall production peak reflects higher phytoplankton biomass (measured as total chlorophyll *a*) at this time.

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 six 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 8±1 days.

Both respiration (in units of μMO_2/hr) and carbon-specific respiration (μMO_2/μMC/hr) 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. This semiannual period marks the first time that POC data were collected at the Stellwagen Basin station.

5.2.1 Water Column Respiration

Due to the timing of the surveys, the farfield stations were only sampled twice (August – WF00B and October – WF00E). Evaluation of the temporal trends is therefore focused on the nearfield area where data are available over the whole August to December time period.

Respiration rates were relatively high in the surface and mid-depth waters (>0.2 μMO_2hr^{-1}) at station N18 in early August (WN00A; Figure 5-10). Lower rates were observed in the surface and mid-depth waters at station N04, ~0.13 and 0.07 μMO_2hr^{-1}, respectively. Respiration rates were low (<0.05 μMO_2hr^{-1}) in the bottom waters at both stations in early August. By mid-August (WF00B), respiration rates had increase to almost 0.2 μMO_2hr^{-1} in the surface and mid-depth waters at station N04. At station N18, the rates remained relatively constant over the entire water column. Nearfield respiration rates reached a maximum for this time period during the early September survey (WN00C) with rates reaching ~0.37 μMO_2hr^{-1} in the surface waters at stations N04 and N18. This was coincident with elevated chlorophyll concentrations and very high production at these stations. Respiration rates at mid-depth remained at ~0.2 μMO_2hr^{-1} at station N18 and decreased to <0.1 μMO_2hr^{-1} at station N04. Bottom water rates remained <0.05 μMO_2hr^{-1} at both stations.

In late September (WN00D), the high surface water respiration rates had decreased slightly at station N18 to 0.26 μMO_2hr^{-1} and decreased to 0.15 μMO_2hr^{-1} at station N04, which was comparable to the mid-depth rate at this station. At station N18, there was a large increase in bottom water respiration rate from early to late September and this trend of elevated bottom water rates (~0.12 μMO_2hr^{-1}) continued at N18 through October. During the two October surveys (WF00E and WN00F), the bottom water respiration rates at station N18 were only slightly lower than the surface and mid-depth rates. This convergence suggests a relatively constant rate of metabolism over an increasingly well-mixed water column. There was a slight increase in surface, mid-depth and bottom water respiration rates at station N04 from late September through the late October survey. Though unlike station N18, bottom water rates at N04 remained low (≤0.06 μMO_2hr^{-1}) in October. By late November (WN00G), respiration rates were <0.1 μMO_2hr^{-1} at each of the depths at stations N04 and N18 and remained low in December (WN00H). The magnitude and trends in the respiration rate data for the nearfield stations were similar to previous years for this time period.

Given the paucity of data at the farfield stations for this period, it is difficult to characterize the seasonal trends in respiration. At station F23, respiration rates were at a maximum for surface samples (0.23 μMO_2hr^{-1}) during the August survey and decreased to ~0.15 μMO_2hr^{-1} by October (Figure 5-11). Mid-depth and bottom water respiration at station F23 decreased from ~0.18 to 0.15 μMO_2hr^{-1} over this time period. Respiration rates at the Stellwagen Basin station F19 exhibited a similar pattern with rates decreasing from August to October, but surface respiration rates were much higher then those in the harbor. The surface respiration rate at F19 decreased from a maximum of 0.3 μMO_2hr^{-1} in August to 0.15 μMO_2hr^{-1}, in October. Mid-depth and bottom water respiration rates at station F19 dropped from 0.15 and 0.1 μMO_2hr^{-1}, respectively, in August to < 0.05 μMO_2hr^{-1}.

5.2.2 Carbon-Specific Respiration

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

POC concentrations were relatively high in the surface and mid-depth waters at station N18 in early August with concentrations of 44 and 53 µM, respectively, and the bottom water had a concentration of 19 µM. (Figure 5-12a). By mid-August (WF00B), surface and mid-depth concentrations had decreased, while bottom water concentration increased to 31 µM. At station N04, POC concentrations were relatively consistent over the two August surveys in the surface and bottom waters (~35 and 11 µM, respectively), while POC increased sharply from 15 to 35 µM from early to mid-August at mid-depth (Figure 5-12b). By early September, POC concentrations in the surface waters reached a maximum at both N04 (83 µM) and N18 (93 µM). Mid-depth and bottom water POC concentrations were relatively low at station N04 (21 and 9 µM), but were high at station N18 with a concentration of 52 µM at mid-depth and 32 µM in the bottom waters. This increase in POC concentrations was coincident with the productivity maxima observed at both stations and the substantial increase in chlorophyll concentrations during this survey. By late September, POC concentrations had decreased to 40 to 50 µM in the surface and mid-depth waters at stations N04 and N18. Concentrations remained in this range at station N18 through October and bottom water concentrations remained relatively high (30 to 40 µM) at station N18 over this time period. Surface and mid-depth POC concentrations at station N04 decreased in early October to ~ 25 µM and then increase to 30 to 40 µM by the late October survey. Bottom water concentrations remained low at station N04 in October. By late November, POC concentrations were relatively low and uniform at stations N04 and N18 and this continued into December. At station F23, POC concentrations were relatively constant at 30 to 34 µM in August and October (Figure 5-13a). Similarly consistent values were observed in the surface waters at station F19 with a concentration of 37 µM in August and 32 µM in October (Figure 5-13b). POC concentrations in the bottom water remained low (<10 µM) during these two surveys, but there was an increase in the mid-depth waters at station F19 from 6 µM in August to 23 µM in October.

Carbon-specific respiration rates reached a maximum in the nearfield at station N18 in late August with a rate of 0.009 $\mu MO_2 \mu MC^{-1} hr^{-1}$ at mid-depth (Figure 5-14). Otherwise carbon-specific respiration rates were low (≤0.005 $\mu MO_2 \mu MC^{-1} hr^{-1}$) and relatively constant over the entire August to December time period. Given the high chlorophyll concentrations and production rates at stations N04 and N18 and the increase in POC concentrations by early September that resulted, it was expected that carbon-specific respiration would increase with the increased availability of newly produced, labile organic carbon. Interestingly, there was an increase in bottom water carbon-specific respiration at station N18 from early September to early October that may have been related to the increased availability of labile carbon in bottom waters due to senescence of the fall bloom. At station F23, carbon-specific respiration rates remained relatively low and constant throughout this time period with a slight decrease from August to October (Figure 5-15). At the Stellwagen Basin station F19, carbon-specific respiration rates were high in the mid-depth and bottom waters in August

(0.025 and 0.019 $\mu MO_2 \mu MC^{-1} hr^{-1}$, respectively) and decrease sharply by October over the entire water column (<0.005 $\mu MO_2 \mu MC^{-1} hr^{-1}$).

5.3 Plankton Results

Plankton samples were collected on each of the eight surveys conducted during this reporting period. 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 corresponds to the subsurface chlorophyll maximum if one is present. Zooplankton samples were collected by vertical/oblique tows with 102 µm-mesh nets. Methods of sample collection and analyses are detailed in Albro *et al*. (1998).

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 group are presented for each phytoplankton and zooplankton community. Tables in the appendices provide data on cell densities and relative abundance for all dominant plankton species (>5% abundance): Appendix F – whole water phytoplankton, Appendix G – 20-µm screened phytoplankton, and Appendix H – zooplankton.

5.3.1 Phytoplankton

5.3.1.1 Seasonal Trends in Total Phytoplankton Abundance

Total phytoplankton abundance in nearfield whole water samples (surface and mid-depth) varied from 0.55 - 3.50 x 10^6 cells L^{-1} in August and increased to 2.30-3.57 x 10^6 cells L^{-1} by early September (Table 5-1). There was only one sample during the two August surveys with a high abundance (N18 mid depth WN00A) and it was primarily composed of microflagellates (~2.7 million) and cryptomonads (~0.7 million). The September increase was primarily due to a bloom of centric diatoms (Figures 5-16 and 5-17). Phytoplankton abundance decreased slightly by late September (1.79 – 2.82 x 10^6 cells L^{-1}) and into October (1.20 – 2.25 x 10^6 cells L^{-1}), but diatoms remained a dominant component from early September to late October. Phytoplankton abundance declined to low levels in November and December (0.42 – 0.83 x 10^6 cells L^{-1}). The decrease in phytoplankton abundance from early fall through to winter is typical for this time of year.

Total phytoplankton abundance in farfield whole water samples was similar for August (0.21 – 2.43 x 10^6 cells L^{-1}) and October (0.42 – 2.54 x 10^6 cells L^{-1}). As in the nearfield, however, there was a sharp increase in the number of centric diatoms from August to October (Figures 5-18 and 5-19). Across both Massachusetts and Cape Cod Bays there was an increase in the abundance of centric diatoms but, because of the timing of the farfield surveys, the peak in the fall diatom bloom was likely between these surveys.

Total abundance of dinoflagellates and silicoflagellates in 20 µm-mesh-screened water samples were considerably lower than those recorded for total phytoplankton in whole-water samples, due to the screening technique which selects for larger, albeit rarer cells. Screened phytoplankton abundance fluctuated, but overall remained high (means of 2,308 – 17,820 cells L^{-1}) from August through December (Table 5-2). The highest abundance was observed in late November (WN00G).

Table 5-1. Nearfield and Farfield Averages and Ranges of Total Abundance (10^6 Cells L^{-1}) of Whole-Water Phytoplankton

Survey	Dates (2000)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WN00A	8/2	1.69	0.60-3.50	—	—
WF00B	8/16-18, 8/20	1.07	0.55-1.42	1.30	0.21-2.43
WN00C	9/1	2.73	2.30-3.57	—	—
WN00D	9/22	2.28	1.79-2.82	—	—
WF00E	10/3-5, 10/12	1.69	1.23-2.25	1.52	0.42-2.54
WN00F	10/24	1.47	1.20-1.67	—	—
WN00G	11/29	0.75	0.61-.83	—	—
WN00H	12/21	0.55	0.42-.72	—	—

Table 5-2. Nearfield and Farfield Average and Ranges of Total Abundance (Cells L^{-1}) for >20 µM-Screened Dinoflagellates

Survey	Dates (2000)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WN00A	8/2	2308	918-4122	—	—
WF00B	8/16-18, 8/20	1919	77-4348	1534	41-6324
WN00C	9/1	2773	2077-3278	—	—
WN00D	9/22	4129	585-7637	—	—
WF00E	10/3-5, 10/12	2986	1133-5254	1909	423-4565
WN00F	10/24	3414	2310-3989	—	—
WN00G	11/29	17820	13815-19950	—	—
WN00H	12/21	5319	4185-6570	—	—

5.3.1.2 Nearfield Phytoplankton Community Structure

Whole-Water Phytoplankton – In early August (WN00A), nearfield whole-water phytoplankton assemblages from both depths (Figures 5-16 and 5-17) were dominated by unidentified microflagellates. Cryptomonads and centric diatoms of the genus *Thalassiosira* were subdominants (20% of total cells in a surface sample from Station N04). By mid August (WF00B), the dominance of microflagellates and cryptomonads continued, with subdominant contributions (5-7%) from the chain-forming diatoms *Bellerochea malleus* and *Dactyliosolen fragillissimus*.

In September the dominance of <10 µm microflagellates and cryptomonads continued in the nearfield, but there was a minor bloom of diatoms as subdominants. In early September (WN00C), these included the chain-forming diatom *Leptocylindrus danicus* (34.5-39.2% of total cells at the surface, and 12.3-38.0% of total cells at chlorophyll maximum layers), *Thalassionema nitzschoides* (5.1% of total cells at the chlorophyll maximum depth at N04), and small centric diatoms <10 µm in longest dimension (5.4-8.4% of total cells). By late September (WN00D), small centric diatoms <10 µm in longest dimension comprised 5.7-10.8% and *L. danicus* comprised 11.7-44.8% of total cells counted at both depths of both nearfield stations, and the diatoms *Chaetoceros debilis* and *Eucampia cornuta* comprised 5.4-6.6% and 6.3-7.3%, respectively of total cells at both depths at Station N18.

During early October (WF00E), microflagellate dominance was shared with cryptomonads, although small centric diatoms < 10 µm in diameter and *Leptocylindrus danicus* were still abundant. The dominance by microflagellates, cryptomonads and small centric diatoms continued during late

October (WN00F), with larger diatoms such as *Dactyliosolen fragillissimus* and *Rhizosolenia setigera* still abundant, as well as the dinoflagellates *Heterocapsa triquetra* and *Prorocentrum minimum*. By late November (WN00G) microflagellate and cryptomonad abundance was shared with small centric diatoms <10 µm in longest dimension, and at the chlorophyll maximum depth at N04, a small species of the diatom genus *Thalassiosira* with cells 10-20 µm in longest dimension. By late December (WN00H) dominance by microflagellates, cryptomonads and small centric diatoms <10 µm in longest dimension was shared at chlorophyll maximum depths with the diatom *Thalassionema nitzschoides* (5-6% of total cells).

Screened Phytoplankton – The dinoflagellates *Ceratium tripos*, *Ceratium fusus,* and *Ceratium longipes* were the overwhelming dominants in nearfield screened phytoplankton samples in August and September. In October (WF00E and WN00F), dominance by *C. tripos* and *C. fusus* was shared with other dinoflagellates such as *Prorocentrum micans, Gyrodinium* sp. and other athecate dinoflagellates, and the silicoflagellate *Dictyocha fibula*. In November (WN00G), *C. tripos* and *P. micans* dominance was shared by the silicoflagellates *D. fibula* and *Distephanus speculum*. At the chlorophyll maximum depth at station N04, the dinoflagellate *Protoperidinium depressum* comprised 48% of total cells.

The high chlorophyll levels in fall of 2000 may be related to the abundant large chain-forming diatoms such as *Leptocylindrus danicus, Rhizosolenia setigera, Guinardia delicatula, Chaetoceros debilis, Pseudo-nitzschia pungens*, *Pseudo-nitzschia delicatissima,* and others that were recorded for 20-µm screened rapid analysis samples for WN00D, WF00E, and WN00F.

5.3.1.3 Farfield Phytoplankton Assemblages

Whole-Water Phytoplankton - During WF00B in August, most farfield station assemblages were dominated at both depths by unidentified microflagellates, with lesser contributions by cryptomonads and centric diatoms <10 µm in cell size (Figure 5-18). During WF00E in October, most farfield stations were dominated by unidentified microflagellates and cryptomonads <10 µm in size, with small centric diatoms <10µm in size present in subdominant abundance (Figure 5-19). Subdominant contributions at various stations came from the diatoms *Chaetoceros debilis, Leptocylindrus danicus*, and *Skeletonema costatum*, and dinoflagellates of the genus *Gymnodinium*.

Screened Phytoplankton – During both WF00B and WF00E, 20-µm screened phytoplankton samples from the farfield were similar to nearfield assemblages, dominated by the dinoflagellates *Ceratium. tripos* and *C. fusus* with lesser contributions at most stations by the dinoflagellate *Prorocentrum micans* and the silicoflagellate *Dictyocha fibula*, with trace abundances of other dinoflagellates.

Nuisance Algae

There were no confirmed blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during August – December 2000. Some species that have caused harmful blooms in different seasons in previous years, such as *Phaeocystis pouchetii* (early spring), or *Alexandrium tamarense* (late spring and summer), were unrecorded during this period. Other non-toxic species whose blooms have caused anoxic events elsewhere, such as *Distephanus speculum* and *Ceratium tripos* (*longipes*) were routinely present, but not at abundances approaching those previously associated with anoxia. Potentially toxic species of the diatom genus *Pseudo-nitzschia* were present at a few stations in August but in extremely low abundances. *Pseudo-nitzschia pungens* and/or *delicatissima* were present at most stations in October, but at low abundances.

Although the dinoflagellate *Prorocentrum micans* was recorded in 33 screened samples from August through October, all but two of these records were for < 1,000 cells L^{-1}. Abundances increased in November and December to levels of 2,380 – 8,720 cells L^{-1}. Although other species of this genus have been associated with diarrheic shellfish poisoning (DSP), in particular *P. lima* (Maranda *et al*. 1999), *P. micans* has not been associated with DSP.

5.3.2 Zooplankton

5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Total zooplankton abundance at nearfield stations declined from normal seasonal high levels in early August (mean of 66.6 x 10^3 animals m^{-3}) to relatively low levels in mid-August (mean of 28.4 x 10^3 animals m^{-3}; Table 5-3). Zooplankton abundance increased by early September only to decrease in late September and remain low through December (Figure 5-20). These fluctuating levels were generally about a half to a third lower than the early August abundances (Table 5-3). At station N18, the sharp drop off in abundance from early August to late August is clearly shown (Figure 5-20a), but it is also clear that there were very low abundances during the late September and October surveys (WN00D to WN00F). By October, total zooplankton abundance at farfield stations had generally decreased to half or less of the levels observed in August at most stations (compare axes in Figures 5-21 and 5-22).

Zooplankton abundance in Boston Harbor reached unprecedented low levels during WF00E due to decimation of zooplankton populations by ctenophore predation. Disintegrated tissue of the ctenophore *Mnemiopsis leidyi* was abundant in samples from Boston Harbor and coastal stations F30, F23, F25, F31, and F24, and total zooplankton abundances at those stations were 38, 28, 24, 280, and 119 animals m^{-3}, respectively. There was some ctenophore tissue in the sample from station F01 in Cape Cod Bay, but not nearly as much as in the harbor and coastal stations, and zooplankton abundance at F01 was 4,166 animals m^{-3}. This value and the low values in the harbor and coastal stations compare with total abundances during this survey that ranged from 4,530 - 46,105 animals m^{-3} at all other stations.

Although ctenophore tissue was not found in the nearfield samples in early October (WF00E), it was observed in the samples starting in early September through late September. Anecdotal evidence also suggests that ctenophores were present in high abundance in the nearfield during the late September and late October surveys. During each of these surveys, the marine debris tow had to be stopped prior to the usual 10 minutes due to the net clogging with 'jellyfish'. It is likely that these were the ctenophore *Mnemiopsis leidyi* rather than a species of jellyfish. As at the Boston Harbor and coastal stations, ctenophore predation may have led to the very low zooplankton abundances found at station N18 in late September to late October (with especially low copepod counts; Figure 5-20a).

Table 5-3. Nearfield and Farfield Average and Ranges of Total Abundance (10^3 Animals m^{-3}) for Zooplankton

Survey	Dates (2000)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WN00A	8/2	66.6	48.3-84.9	—	—
WF00B	8/16-18, 8/20	28.4	16.3-45.0	61.0	21.7-111.3
WN00C	9/1	34.8	27.2-42.4	—	—
WN00D	9/22	10.4	9.7-11.2	—	—
WF00E	10/3-5, 10/12	23.9	17.3-30.3	13.7	0.02-46.1
WN00F	10/24	14.6	4.5-24.7	—	—
WN00G	11/29	22.9	18.4-27.4	—	—
WN00H	12/21	19.8	11.8-27.8	—	—

5.3.2.2 Nearfield Zooplankton Community Structure

In August (WN00A and WF00B), the nearfield zooplankton assemblages were dominated by copepod nauplii, and females and copepodites of *Oithona similis* with lesser contributions by copepodites of *Temora, Centropages* and *Pseudocalanus* sp.. On 1 September (WN00C), as well as on 22 September (WN00D), nearfield assemblages were primarily composed of copepod nauplii, copepodites of *Acartia* and *Oithona* sp, and the tunicate *Oikopleura dioica*. From October through December, the dominance of copepod nauplii and *Oithona similis* was being shared with bivalve veligers, and to a lesser and copepodites of the genus *Centropages*.

5.3.2.3 Farfield Zooplankton Assemblages

At farfield stations during survey WF00B in mid-August, copepod nauplii were dominants, with subdominant contributions at various stations outside Boston Harbor by adults and copepodites of copepods such as *Oithona similis,* and other species recorded for the nearfield. Adults and copepodites of *Acartia tonsa* were dominant components of the assemblage in Boston Harbor (37-42%) and at Stations F24 and F25 in the coastal region (32-37%). During WF00E in October, copepod nauplii were dominant everywhere, and outside the harbor *Oithona similis*, *Centropages* sp. copepodites and bivalve veligers were abundant at most farfield stations. *A. tonsa* were again dominant in Boston Harbor and adjacent coastal waters.

In summary, zooplankton assemblages during the second half of 2000 were comprised of taxa recorded for this time of year in previous baseline monitoring years. The major exception to the normal pattern was the high abundance of ctenophores in Boston Harbor, whose predation caused unprecedented declines in abundance of other zooplankton.

5.4 Summary of Water Column Biological Results

- Productivity reached maximum values during the September surveys at station N18 (4120 and 4553 mg C m^{-2} d^{-1}) during this early fall bloom period. Productivity was lower at station N04 (1220 and 2169 mg C m^{-2} d^{-1}) for these surveys and did not peak until late October with a production of 2389 mg C m^{-2} d^{-1}.
- Areal production in 2000 followed patterns typically observed in prior years. Distinct fall phytoplankton blooms were observed as increases in production at both nearfield stations during the sampling period. In general, nearfield stations are characterized by the occurrence of a fall bloom.
- Fall blooms observed at nearfield stations in 1995-1999 typically lasted 3-4 weeks and reached production values of 1600 to 4200 mg C m^{-2} d^{-1}. The bloom in 2000 reached a peak value of > 4500 mg C m^{-2} d^{-1} at station N18 and occurred from September 1 through 22, with a secondary bloom in late October. The elevated productivity observed at station N18 is the highest value observed throughout the monitoring period (1997 – 2000) at this station.
- At the Boston Harbor station F23, productivity increased from August (406 mg C m^{-2} d^{-1}) to October (914 mg C m^{-2} d^{-1}). This is a departure from the normal trend for the harbor - decreasing areal production from summer through fall, and may have been related to the increase in phytoplankton and chlorophyll with the fall bloom.
- Depth-averaged chlorophyll-specific production maxima were reached in early August (23-32 mg C mg Chl a^{-1} d^{-1}) rather than during the fall bloom. Chlorophyll-specific rates in Boston Harbor closely matched the values reported for the nearfield sites.
- Nearfield respiration rates reached a maximum for this time period during the early September survey with rates reaching ~0.37 $\mu MO_2 hr^{-1}$ in the surface waters at stations N04 and N18. This

was coincident with elevated chlorophyll concentrations and very high production at these stations.

- At station N18, there was a large increase in bottom water respiration rate from early to late September and this trend of elevated bottom water rates (~0.12 μMO_2hr^{-1}) continued at N18 through October.
- During the two October surveys, the bottom water respiration rates at station N18 were only slightly lower than the surface and mid-depth rates. This convergence suggests a relatively constant rate of metabolism over an increasingly well-mixed water column.
- POC concentrations reached a maximum at both N04 (83 µM) and N18 (93 µM) in early September. The increase in POC concentrations was coincident with the increase in productivity and chlorophyll concentrations during this survey.
- Carbon-specific respiration rates reached a maximum in late August in the nearfield at station N18 with a rate of 0.009 $\mu MO_2\mu MC^{-1}hr^{-1}$ at mid-depth and in the farfield at the Stellwagen Basin station F19 in the mid-depth and bottom waters (0.025 and 0.019 $\mu MO_2\mu MC^{-1}hr^{-1}$, respectively).
- Total phytoplankton abundances in the whole water samples were high in September, decreased somewhat into October, and declined to low levels in November and December.
- The whole water phytoplankton assemblage was dominated by unidentified microflagellates and cryptomonads, the diatom *Leptocylindrus danicus*, and other centric diatoms.
- There were no apparent unusual shifts in phytoplankton abundance or community composition associated with the outfall coming on line on September 6, 2000, although chlorophyll levels for this period were unusually high.
- The high chlorophyll levels in fall of 2000 may relate to abundant large chain-forming diatoms such as *Leptocylindrus danicus, Rhizosolenia setigera, Guinardia delicatula, Chaetoceros debilis, Pseudo-nitzschia pungens*, *Pseudo-nitzschia delicatissima,*and others that were recorded for 20-µm screened rapid analysis samples for WF00E and WN00F.
- The abundance of >20-µm screened dinoflagellates remained high from August through December due to a sustained bloom of *Ceratium tripos, C. longipes* and *C. fusus* for most of August through November.
- There were no confirmed high levels of abundance of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during August – December 2000.
- Zooplankton abundance declined as usual from high levels in early August to progressively lower levels through September and October, into November and December.
- The precipitous decline in zooplankton abundance due to ctenophore predation in October was unprecedented throughout the baseline. The ctenophore "bloom" was recorded for stations primarily in Boston Harbor and the adjacent coastal region, with trace amounts of ctenophore tissue in the sample from station F01 in Cape Cod Bay. September data and anecdotal evidence suggests that ctenophore numbers were also elevated in the nearfield during this time period.
- 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 tonsa* adults and *Acartia* sp. copepodites.

WN00A **Station N04**

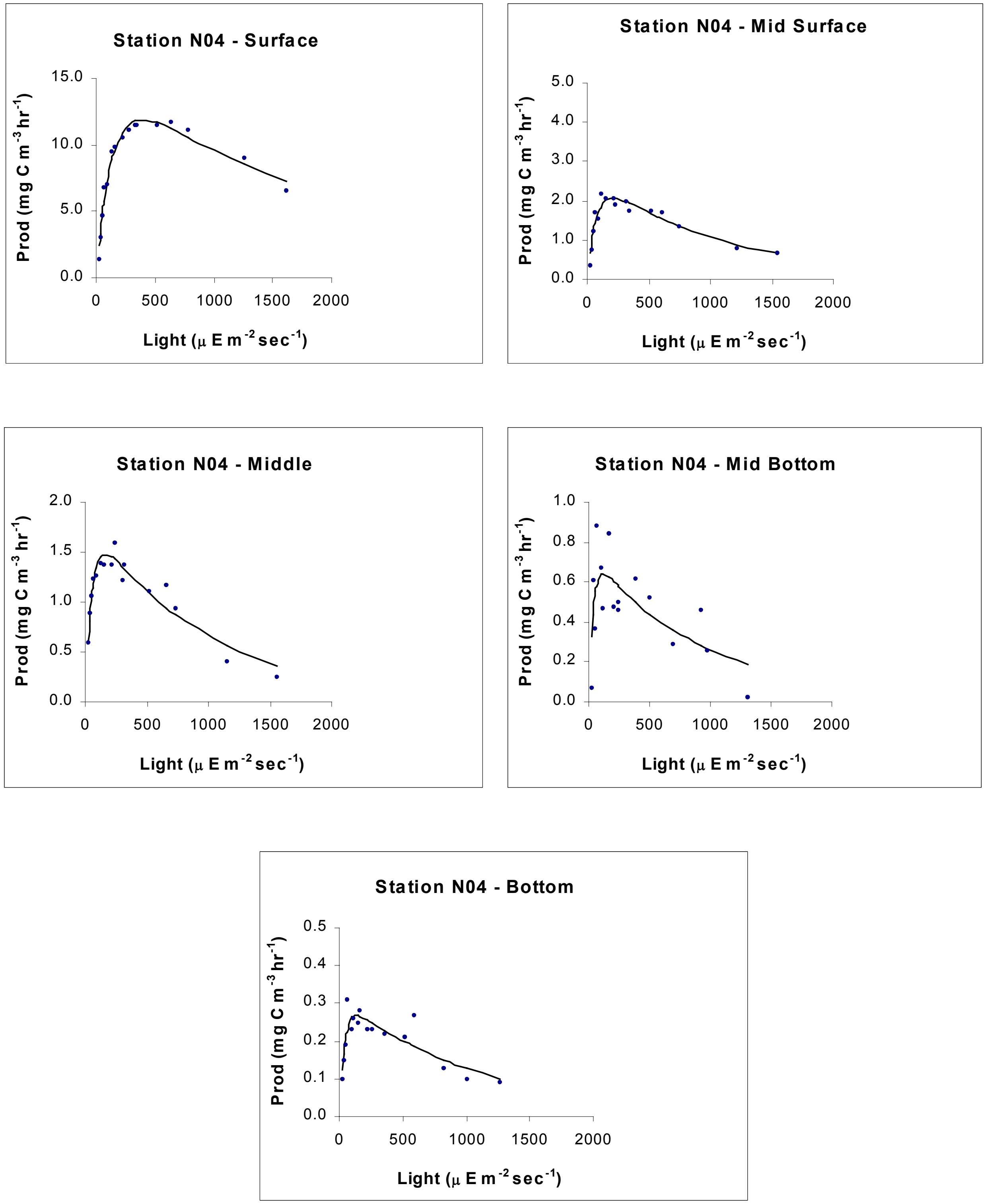


Figure 5-1. An Example Photosynthesis-Irradiance Curve From Station N04 Collected in August 2000

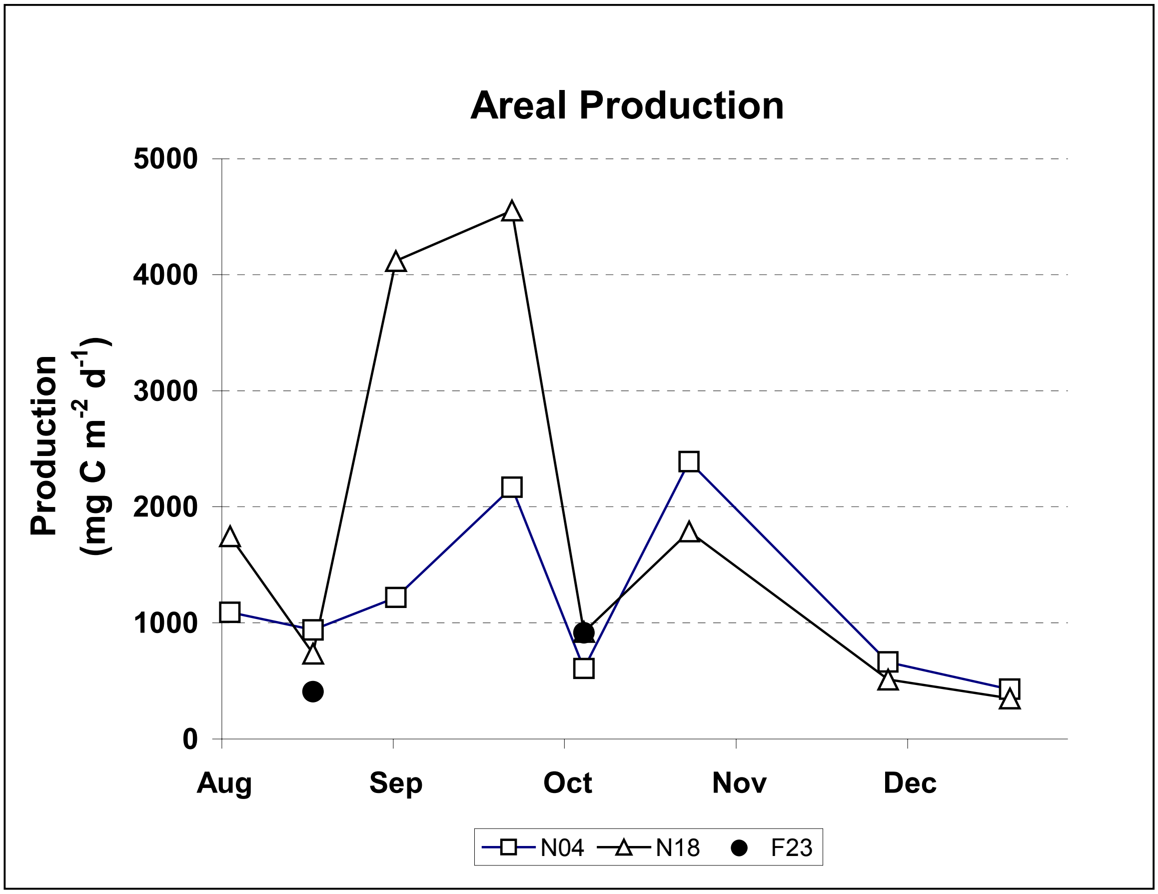


Figure 5-2. Time-Series of Areal Production (mg C m^{-2} d^{-1}) for Productivity Stations

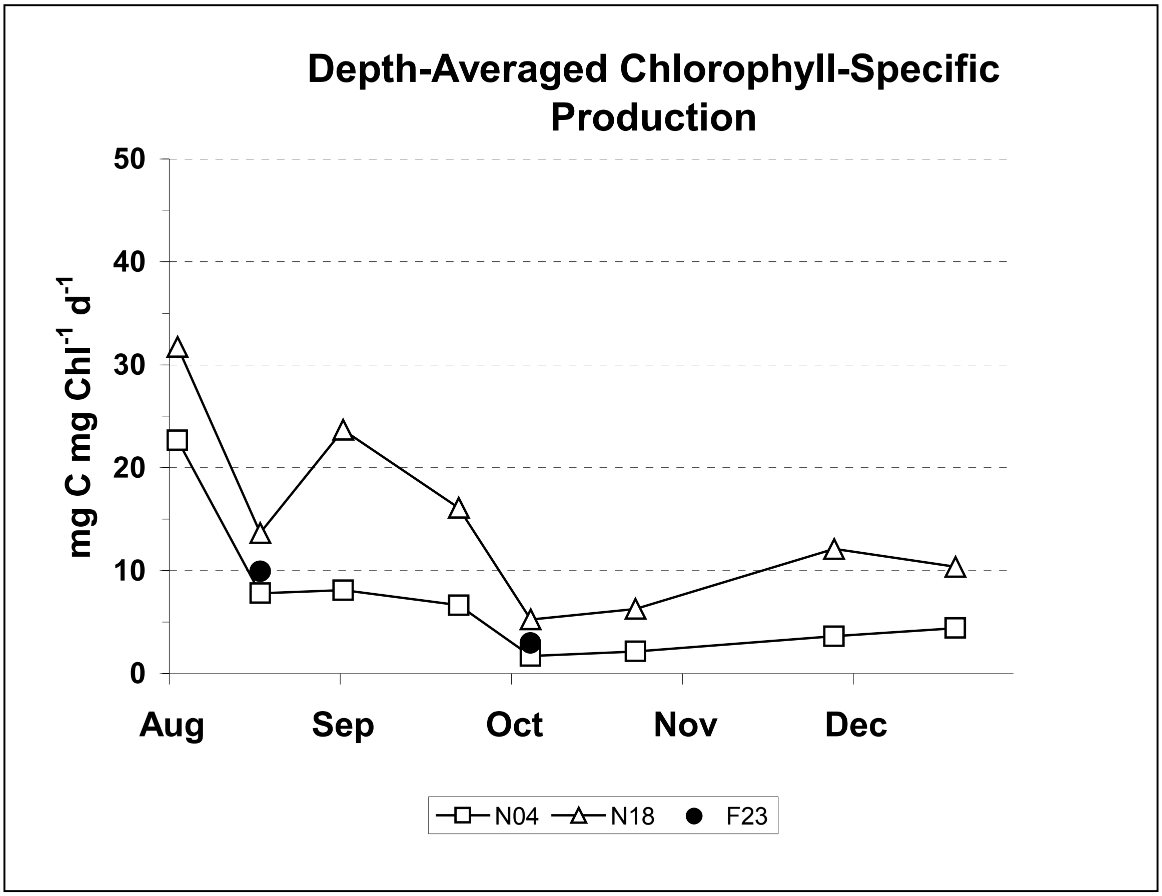


Figure 5-3. Time-Series of Depth-averaged Chlorophyll-Specific Production (mg C mg Chl^{-1} d^{-1}) for Productivity Stations

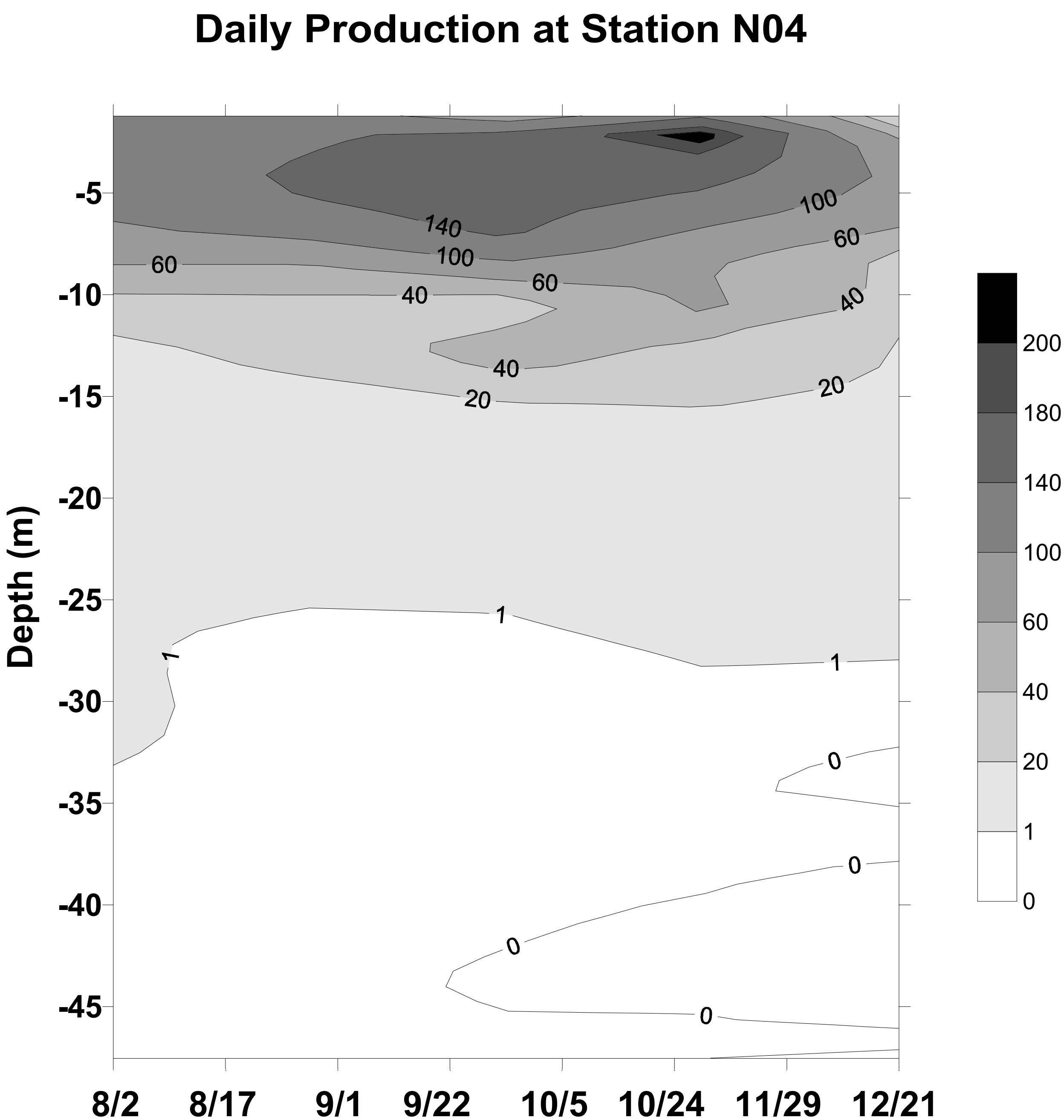


Figure 5-4. Time Series of Contoured Daily Production ($mgCm^{-3}d^{-1}$) Over Depth at Station N04

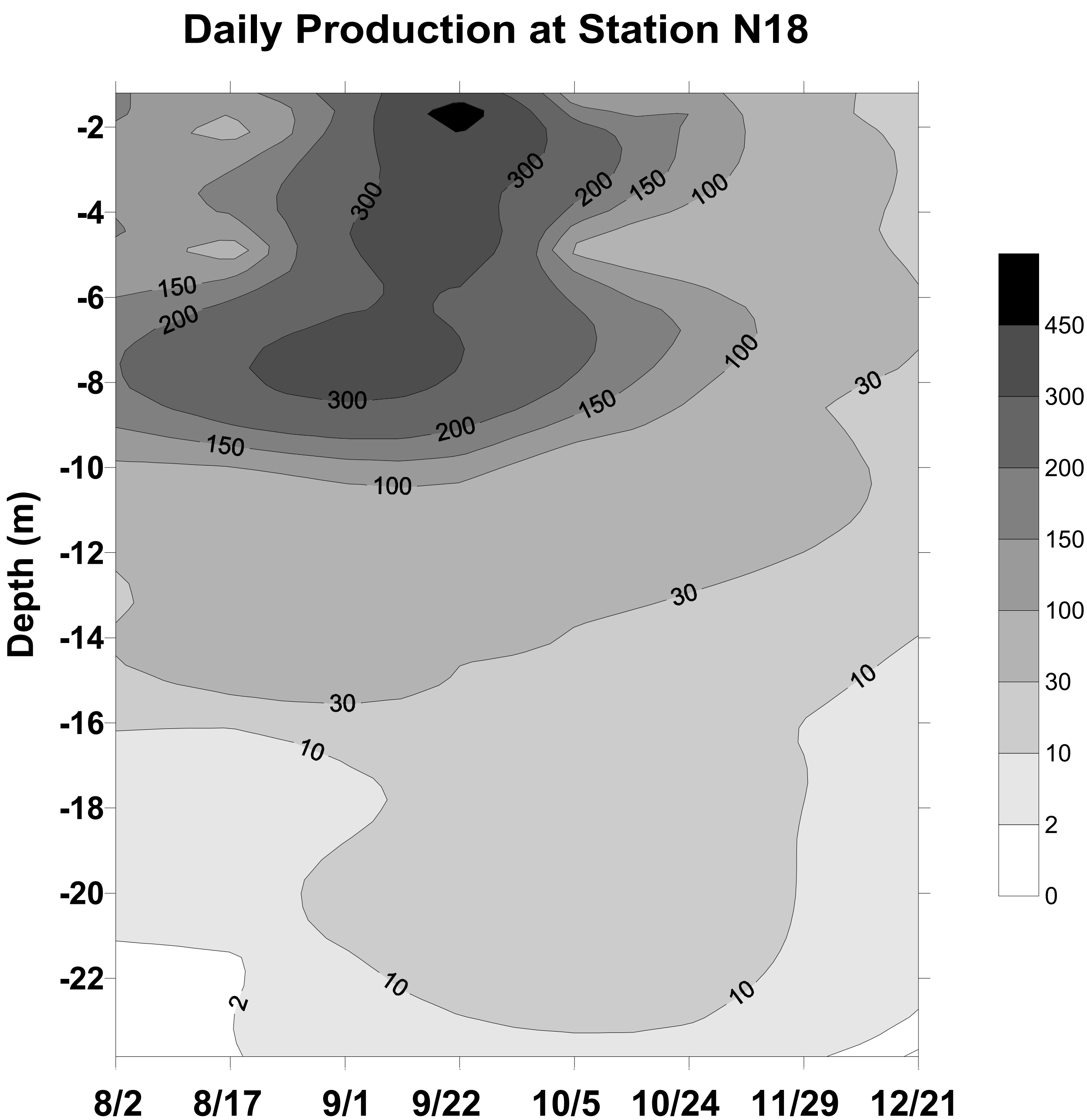


Figure 5-5. Time Series of Contoured Daily Production ($mgCm^{-3}d^{-1}$) Over Depth at Station N18

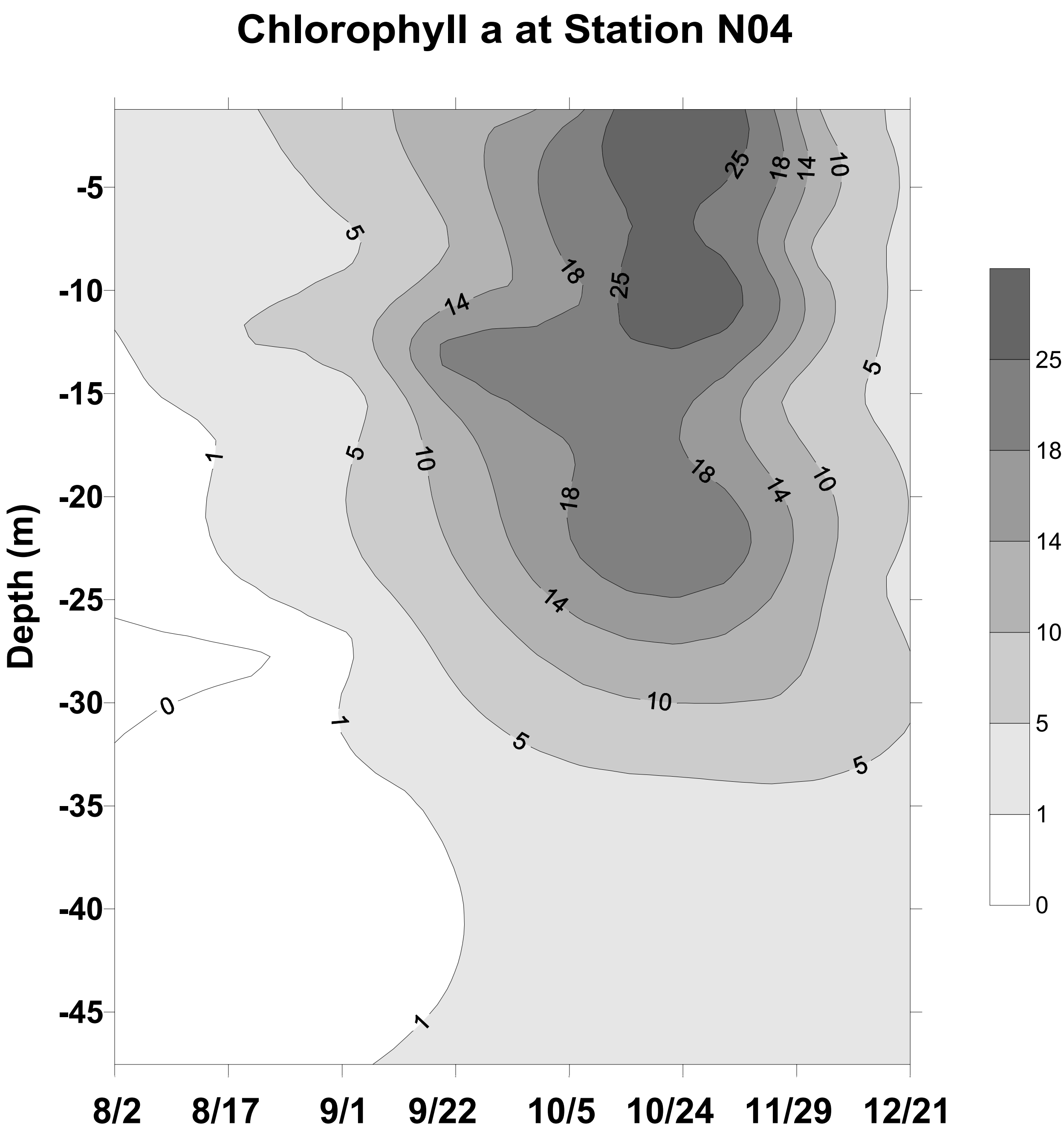


Figure 5-6. Time Series of Contoured Chlorophyll Concentration (μg L^{-1}) at Station N04

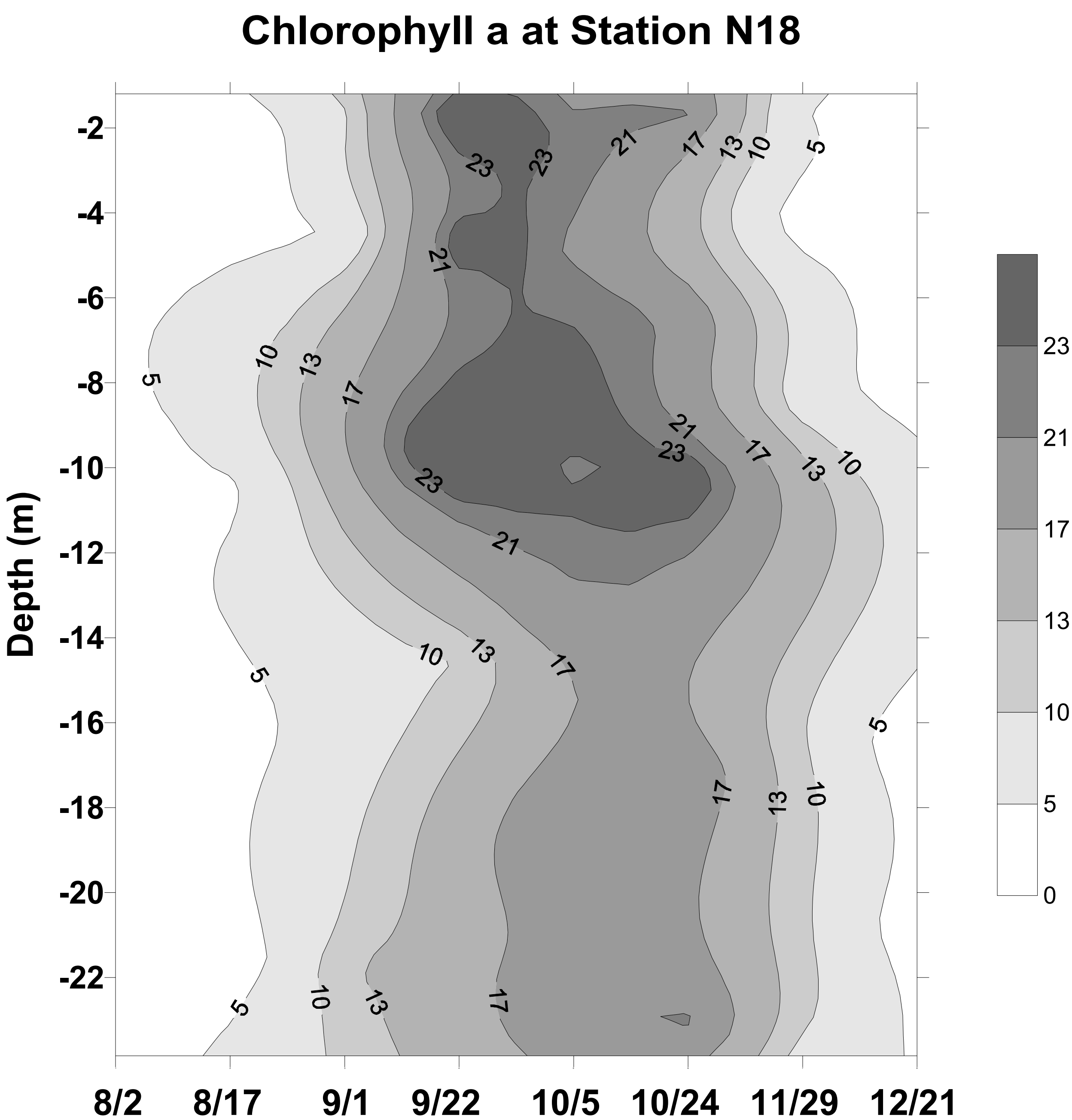


Figure 5-7. Time Series of Contoured Chlorophyll Concentration (μg L^{-1}) at Station N18

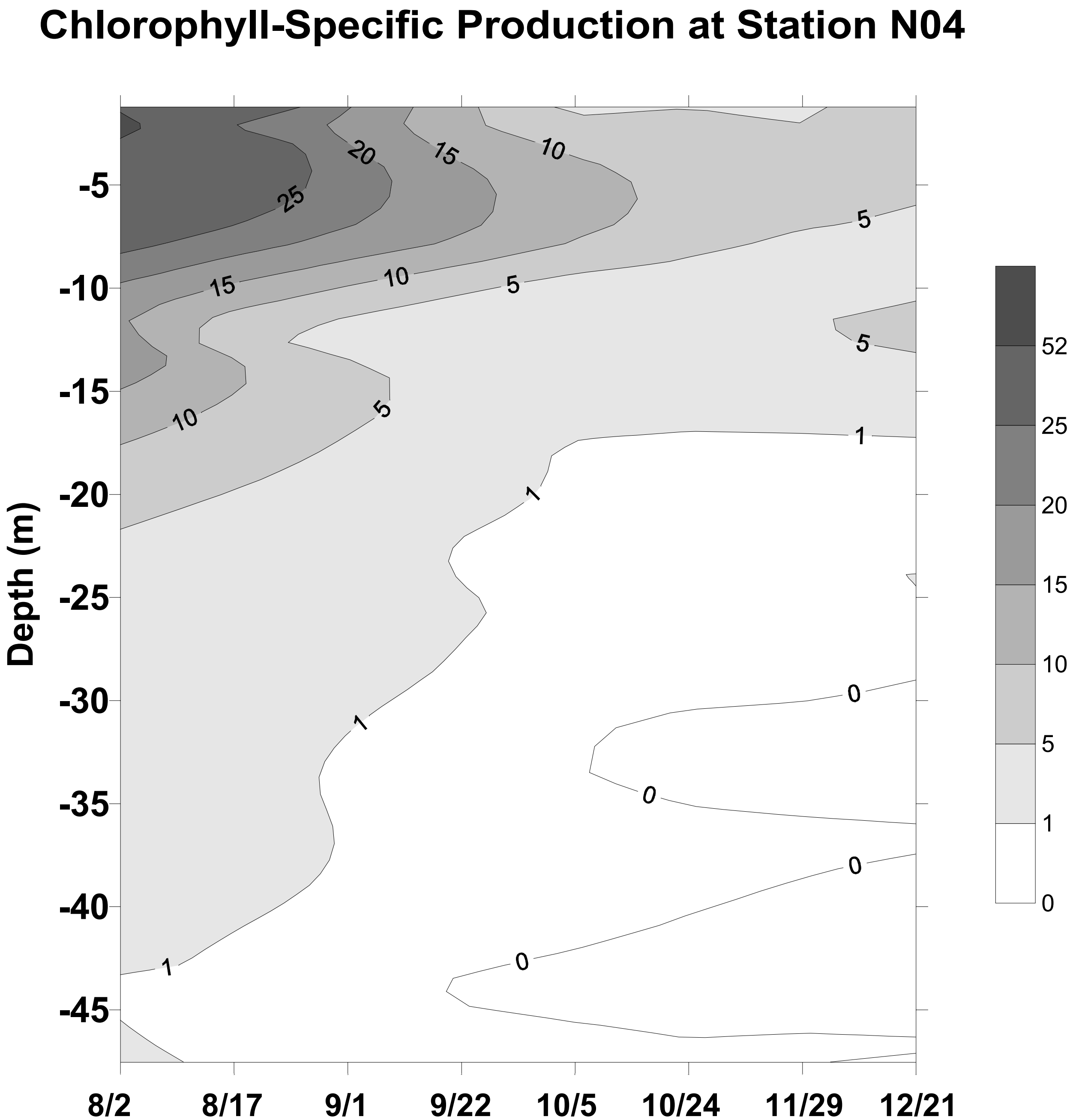


Figure 5-8. Time Series of Contoured Chlorophyll-Specific Production (mg Cmg $Chl^{-1}d^{-1}$) at Station N04

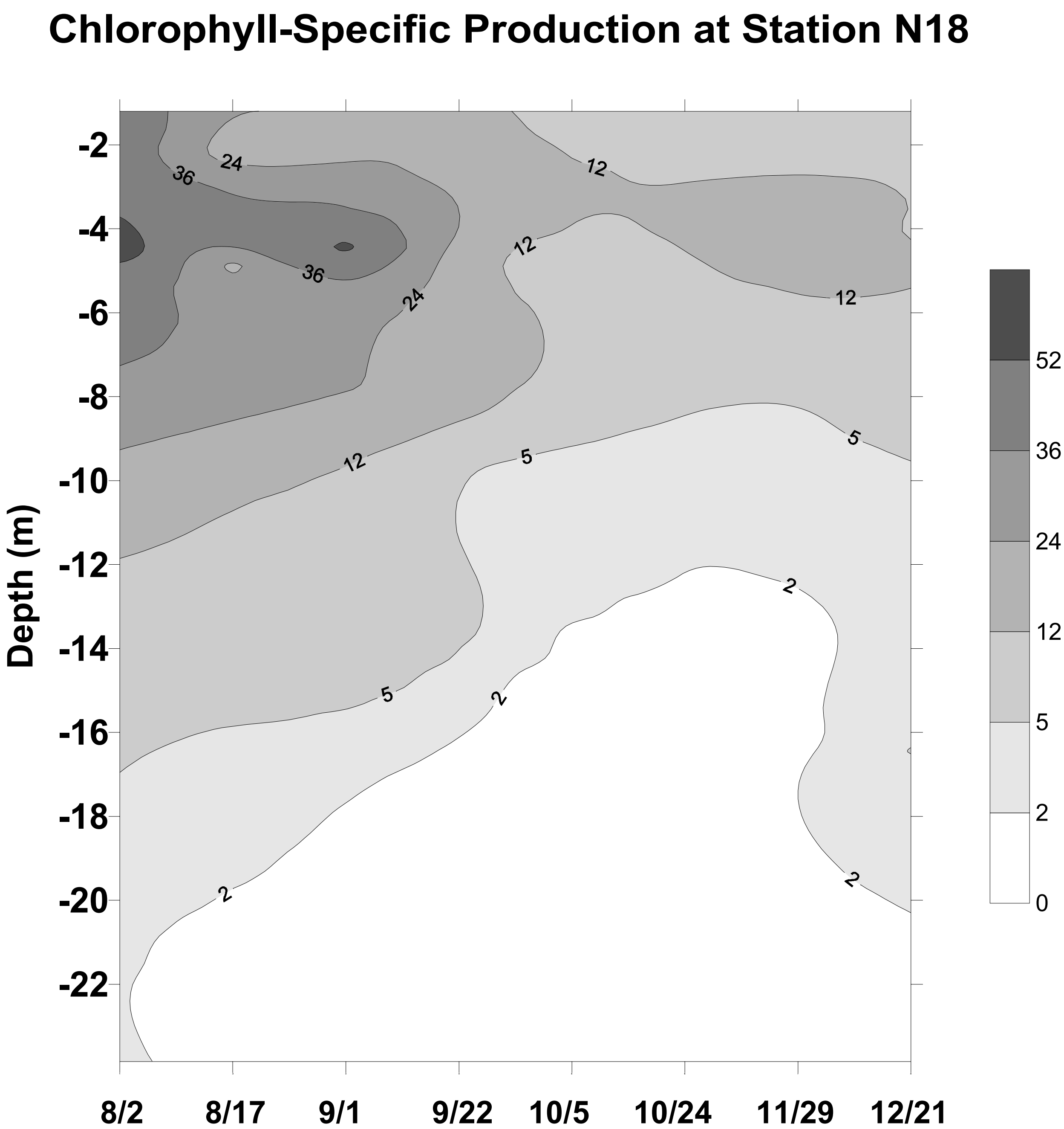


Figure 5-9. Time Series of Contoured Chlorophyll-Specific Production (mg Cmg $Chl^{-1}d^{-1}$) at Station N18

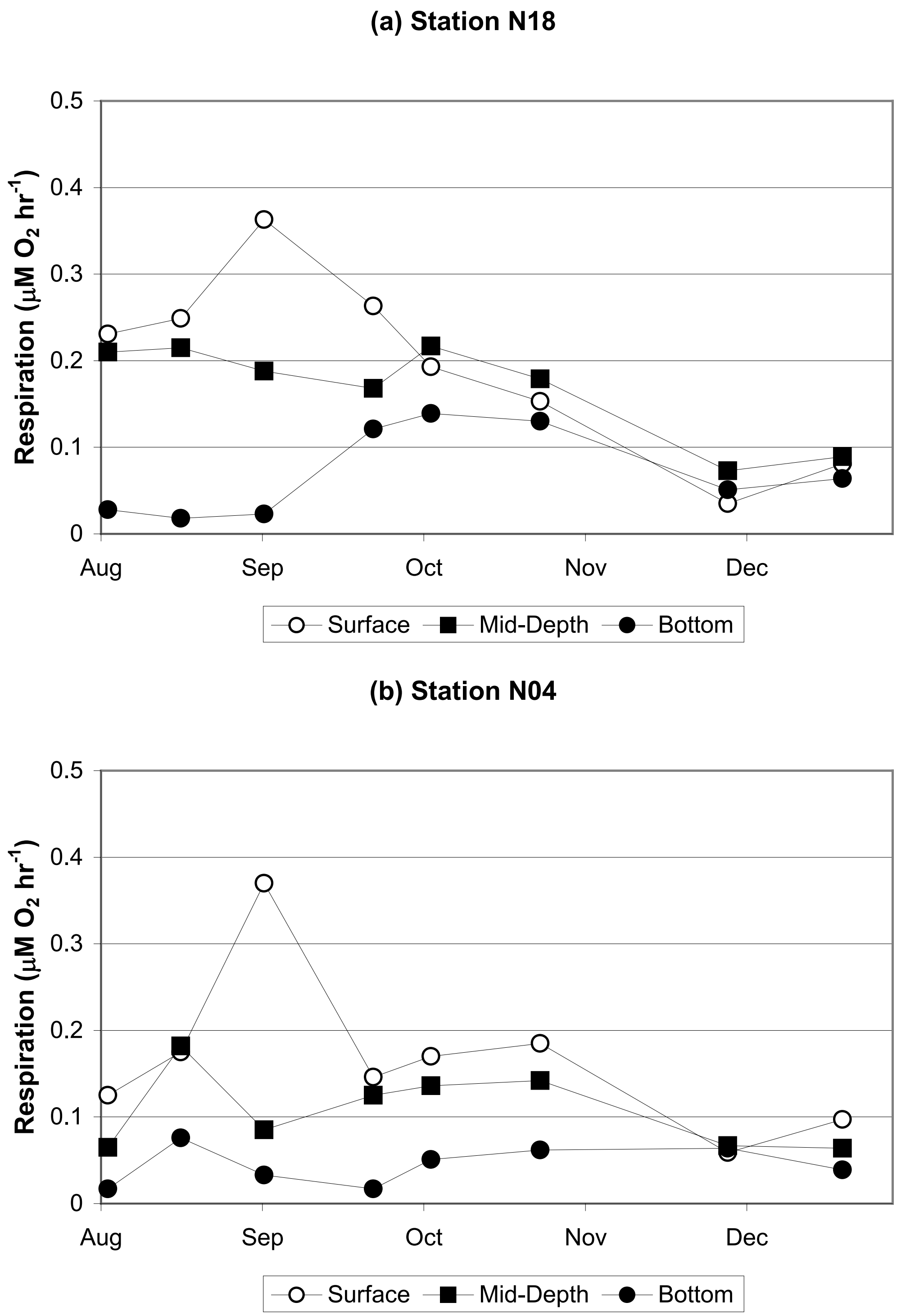


Figure 5-10. Time Series Plots of Respiration at Stations N18 and N04

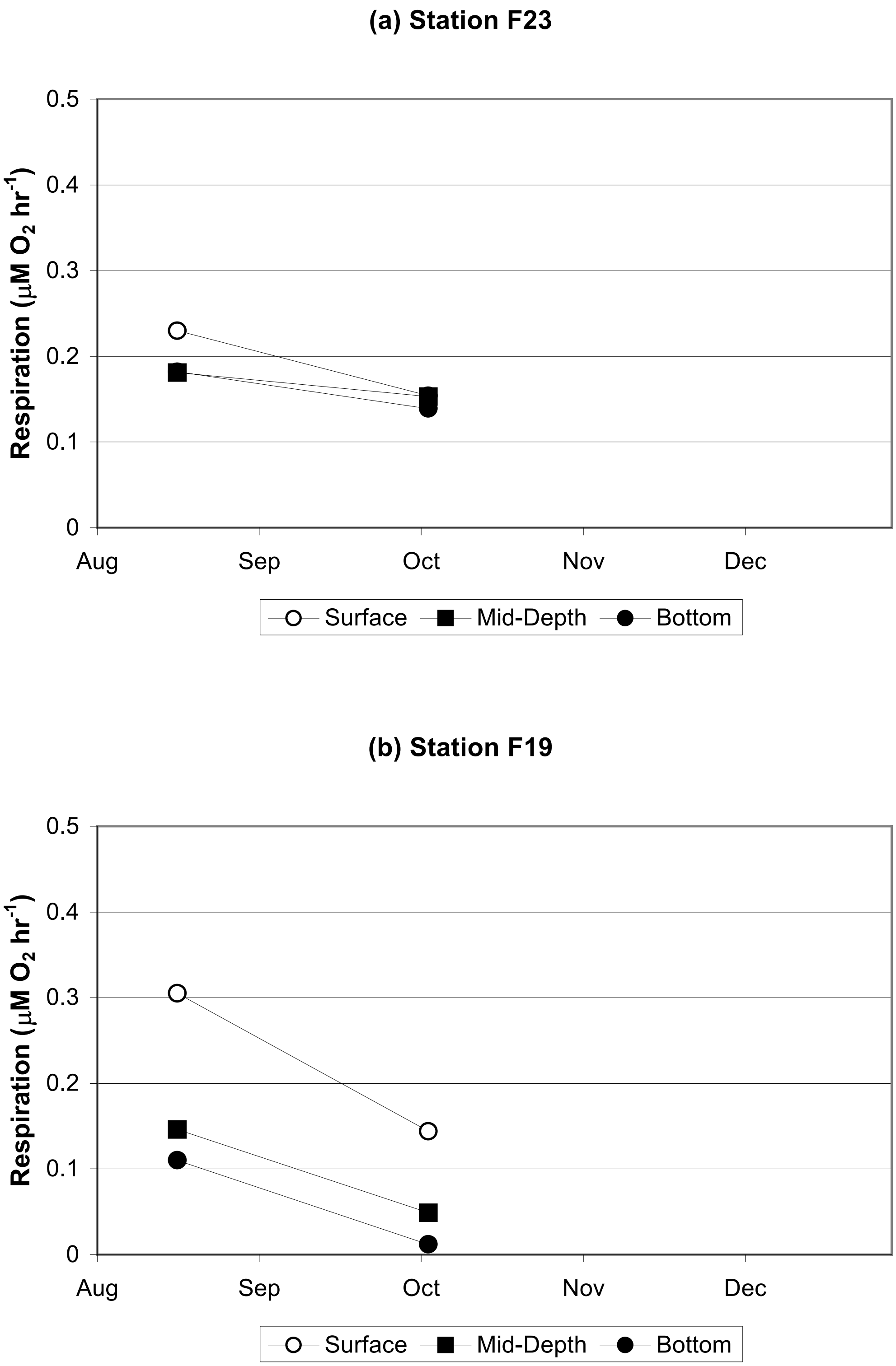
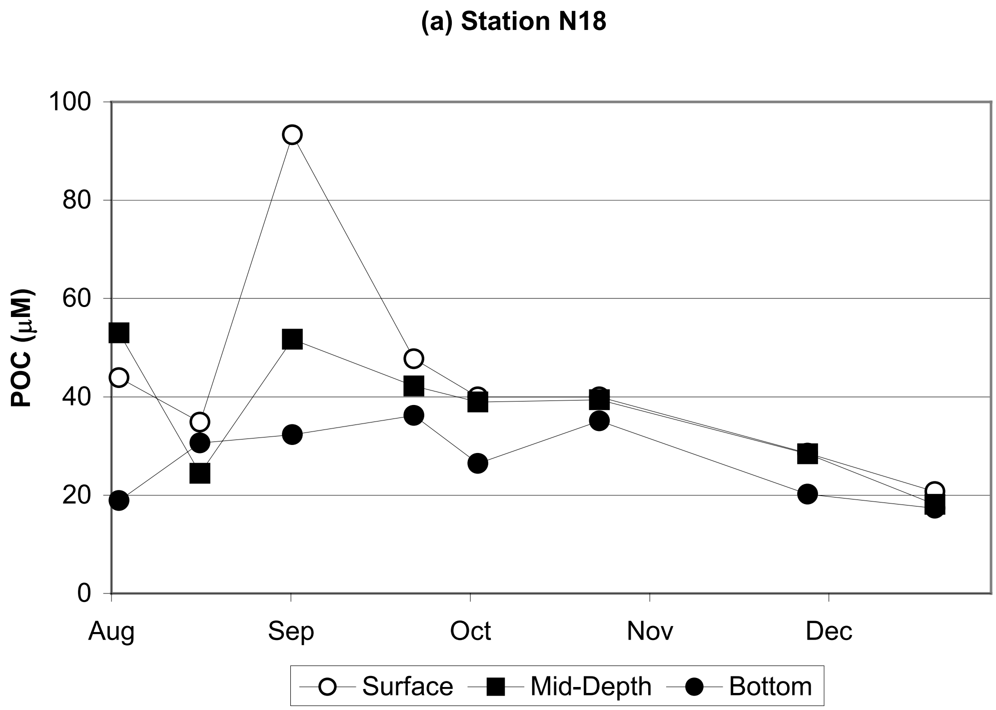


Figure 5-11. Time Series Plots of Respiration at Stations F23 and F19



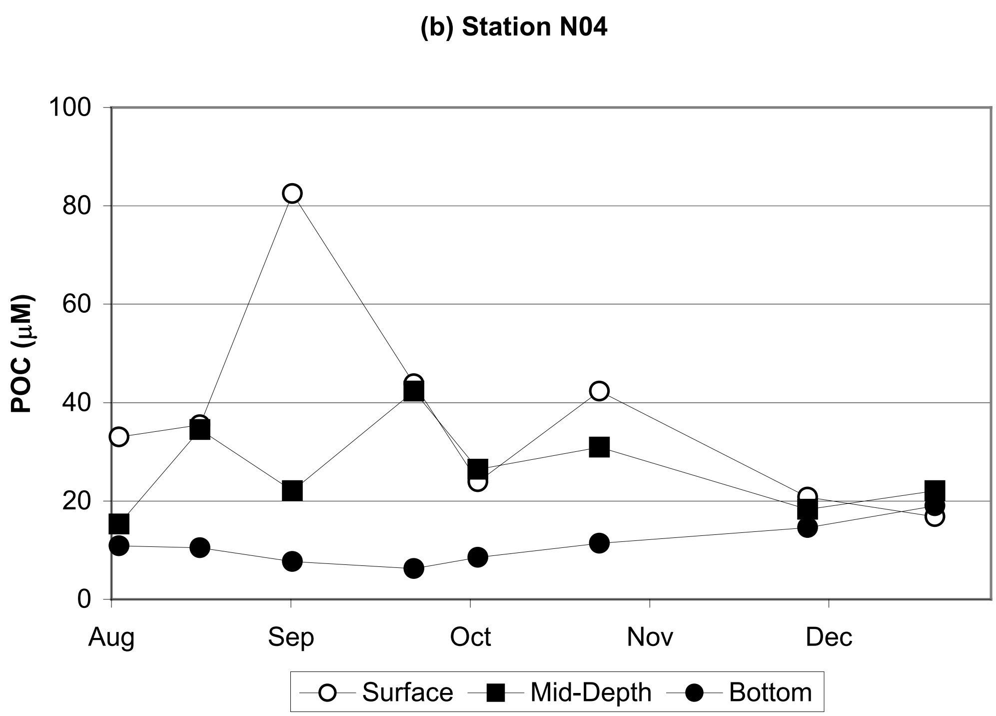
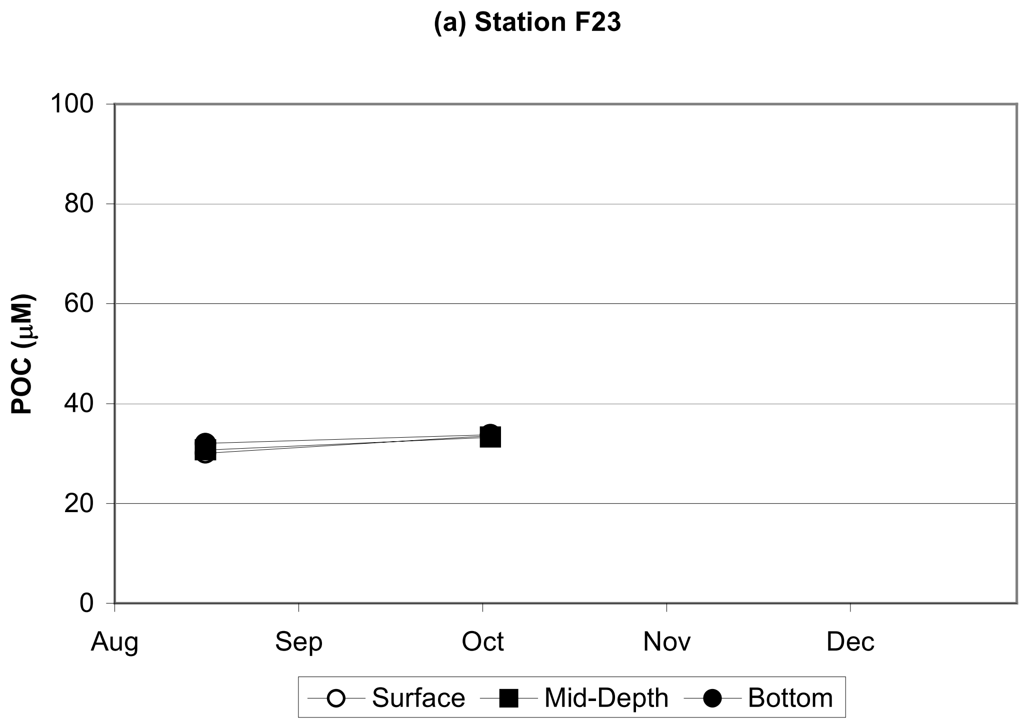


Figure 5-12. Time Series Plots of POC at Stations N18 and N04



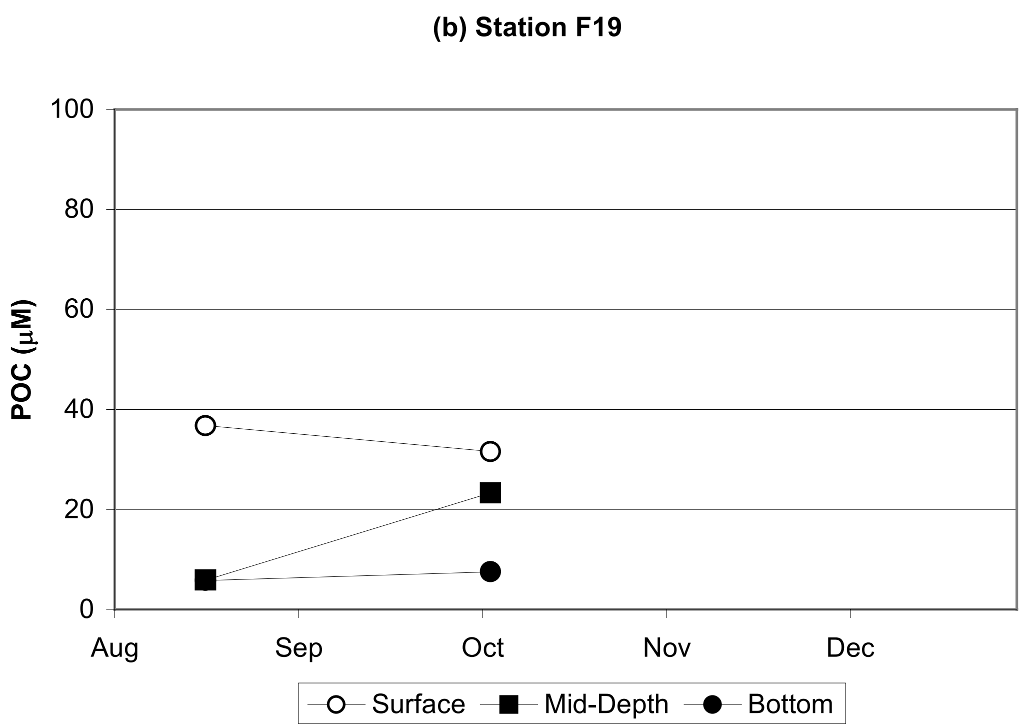
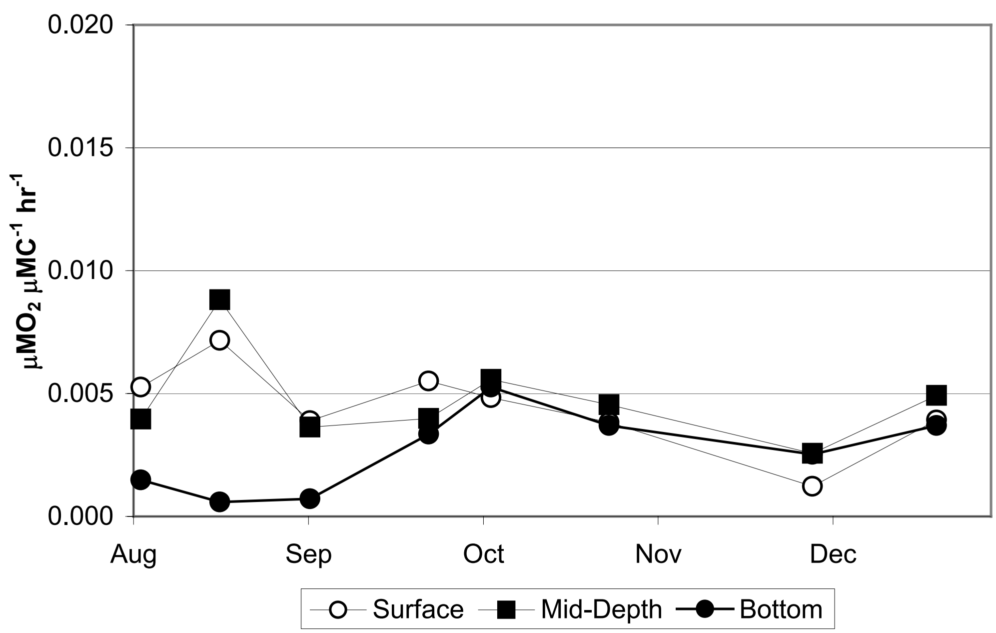


Figure 5-13. Time Series Plots of POC at Stations F23 and F19

(a) Station N18



(b) Station N04

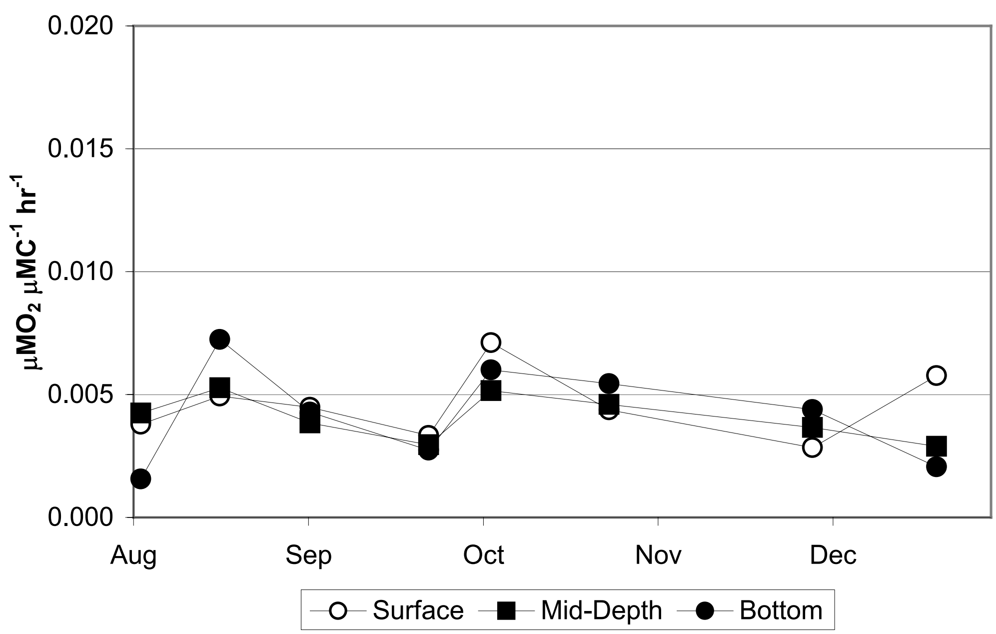


Figure 5-14. Time Series Plots of Carbon-Specific Respiration at Stations N18 and N04

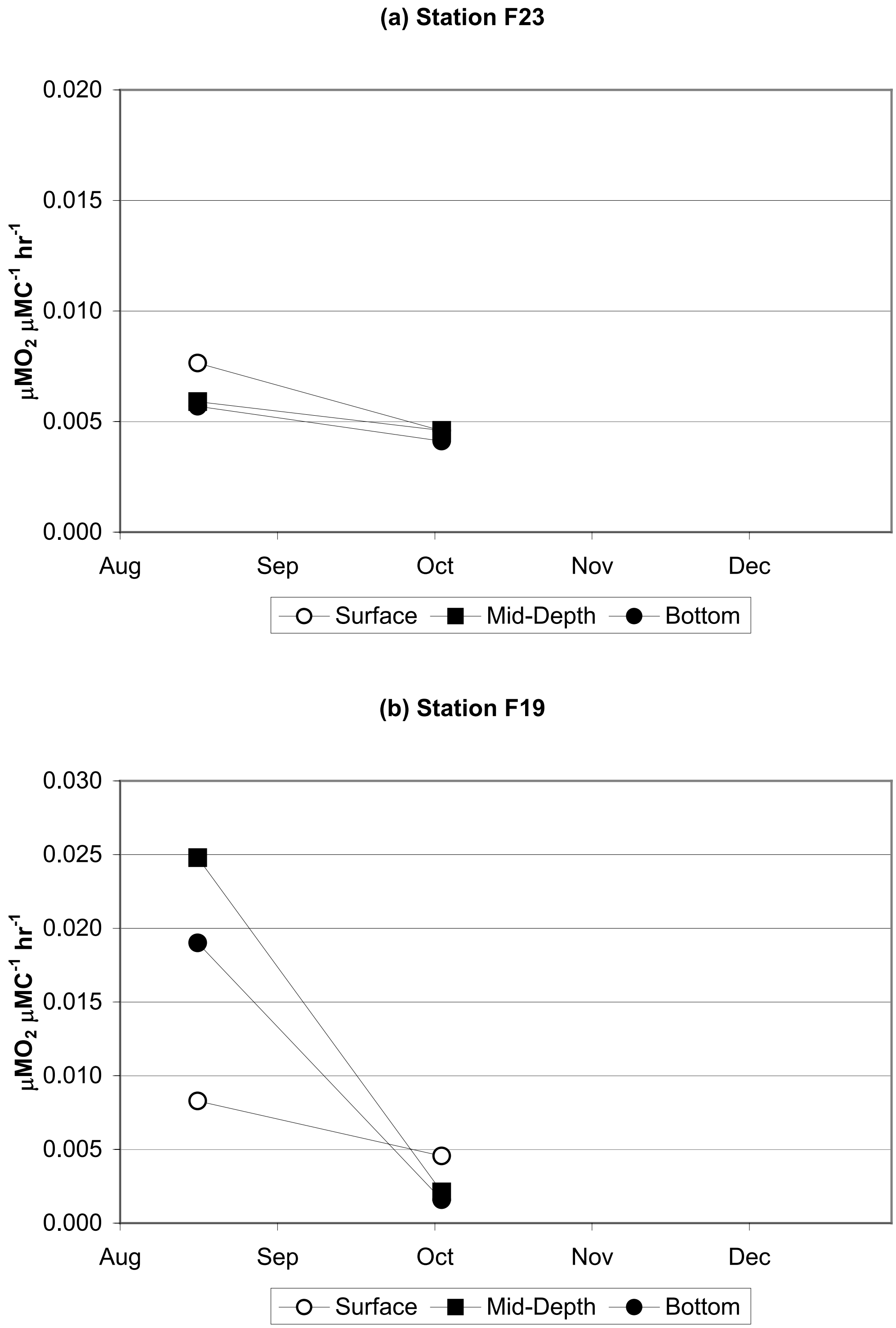


Figure 5-15. Time Series Plots of Carbon-Specific Respiration at Stations F23 and F19

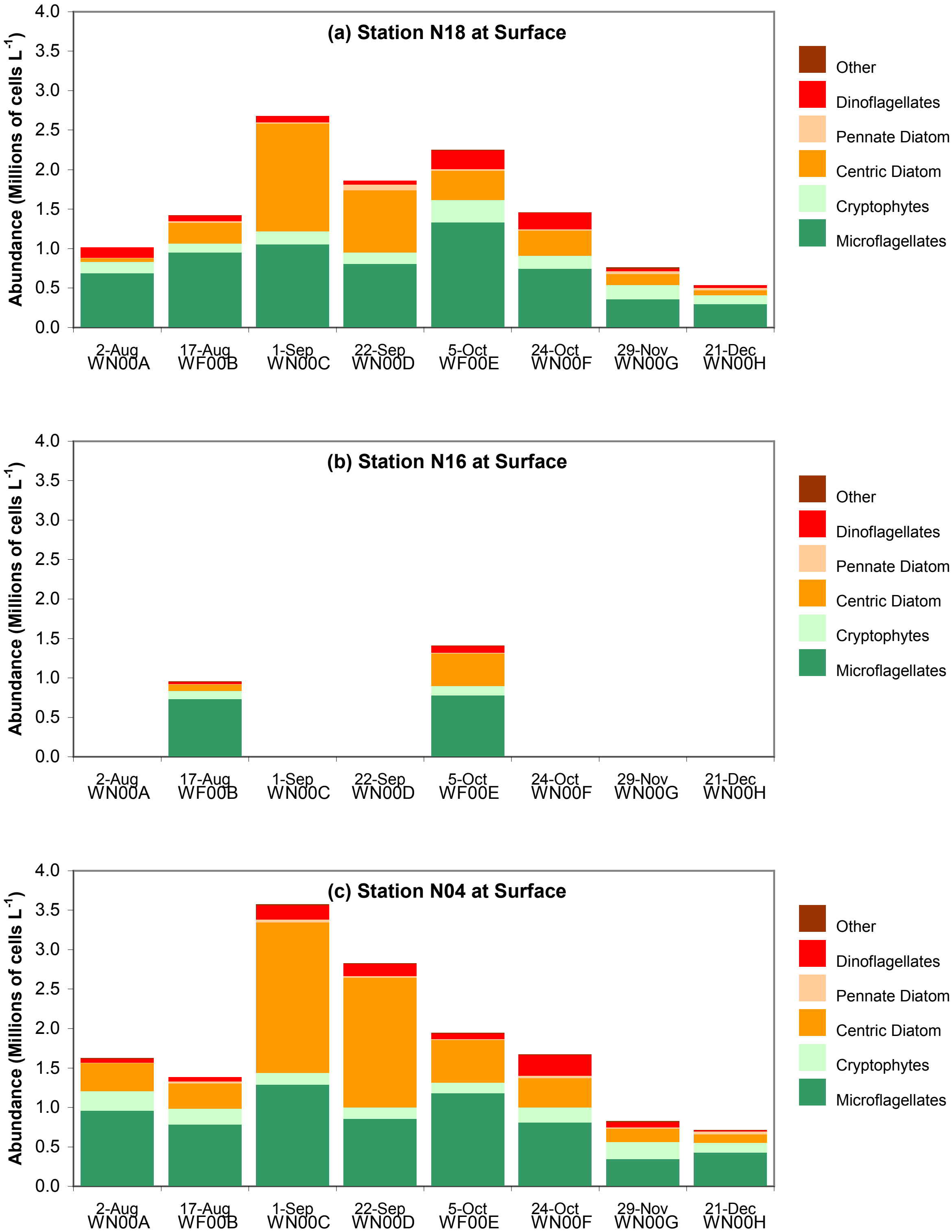


Figure 5-16. Phytoplankton Abundance by Major Taxonomic Group, Nearfield Surface Samples

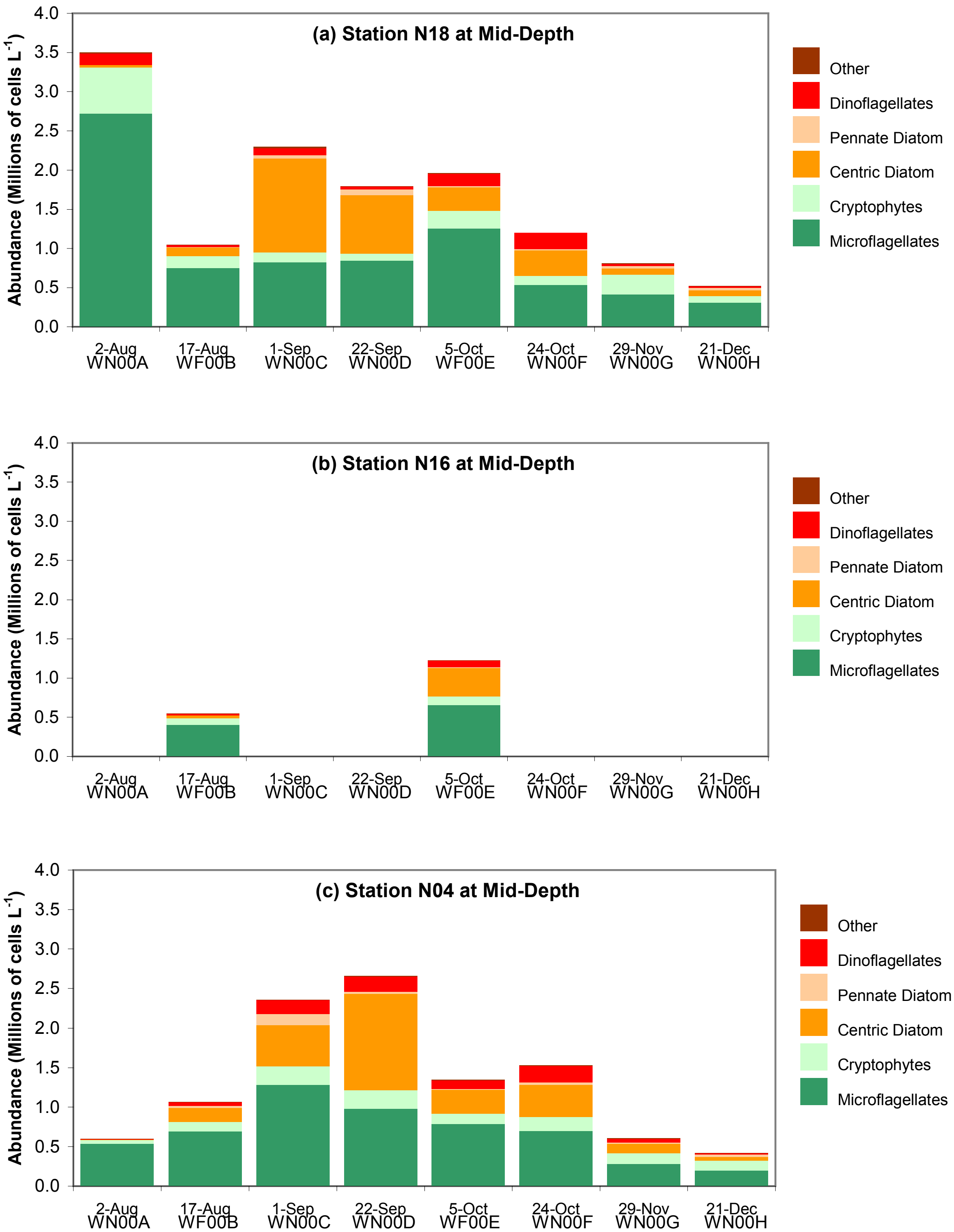


Figure 5-17. Phytoplankton Abundance by Major Taxonomic Group, Nearfield Mid-Depth Samples

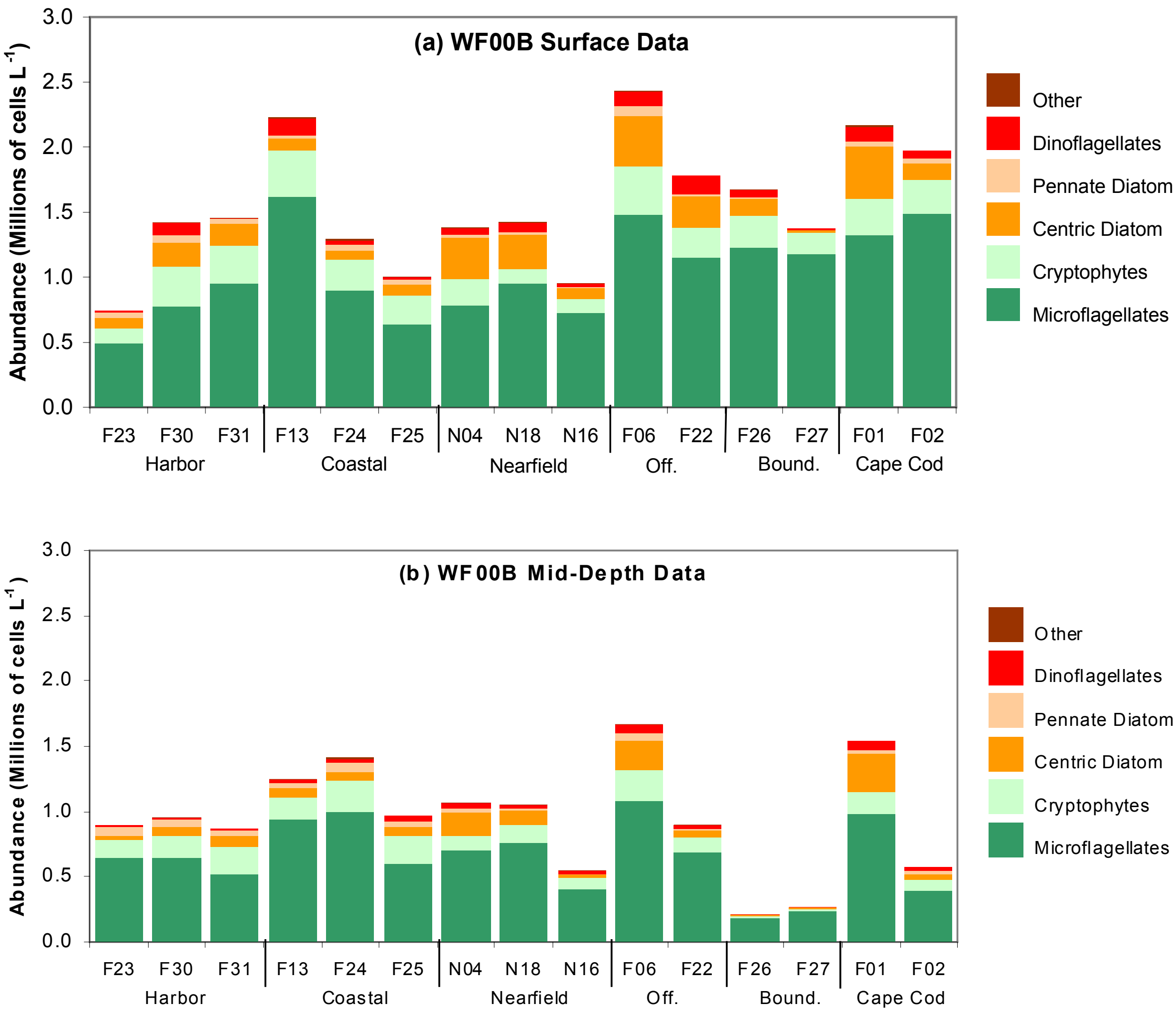


Figure 5-18. Phytoplankton Abundance by Major Taxonomic Group, WF00B Farfield Survey

Figure 5-19. Phytoplankton Abundance by Major Taxonomic Group, WF00E Farfield Survey

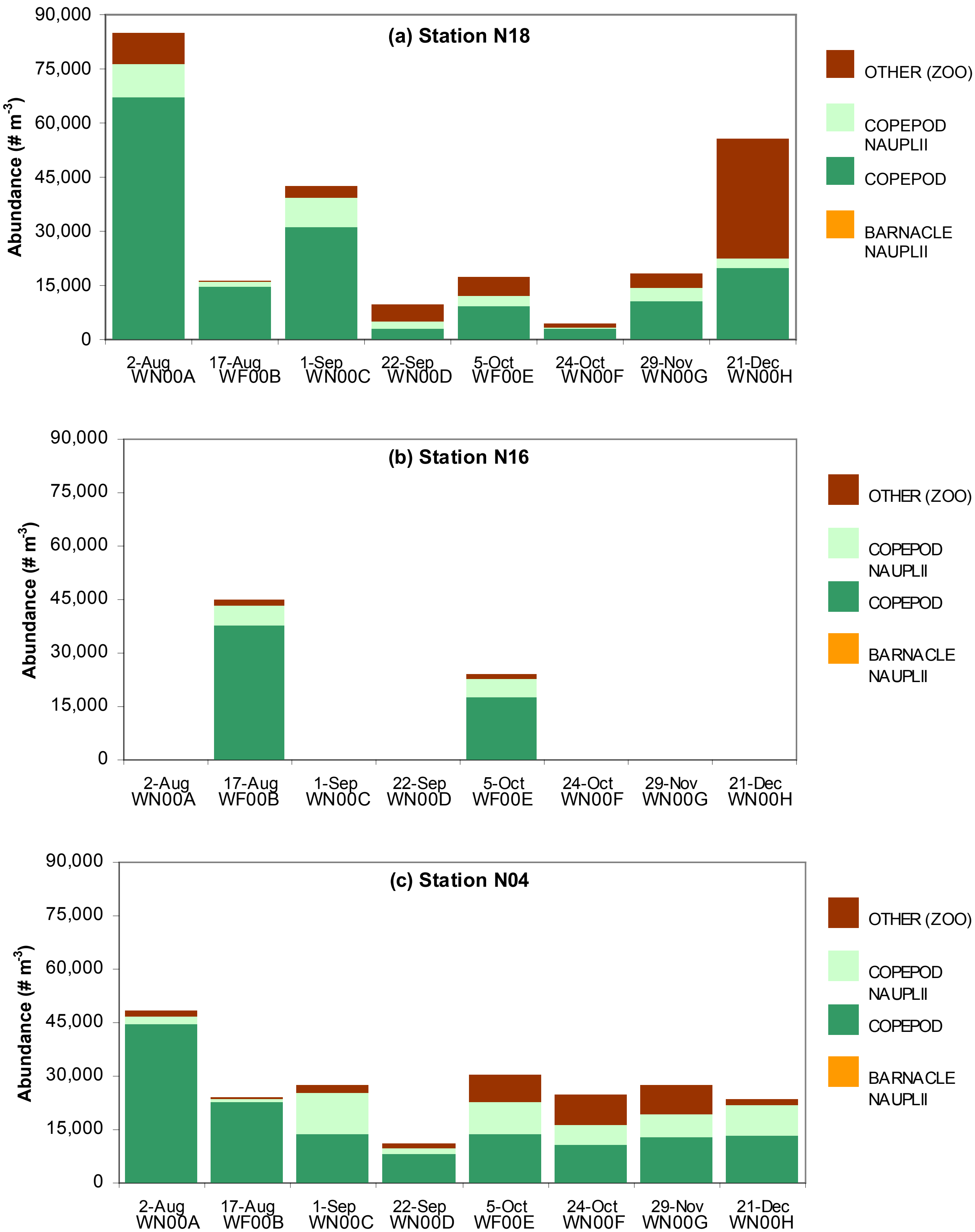


Figure 5-20. Zooplankton Abundance by Major Taxonomic Group, Nearfield Samples

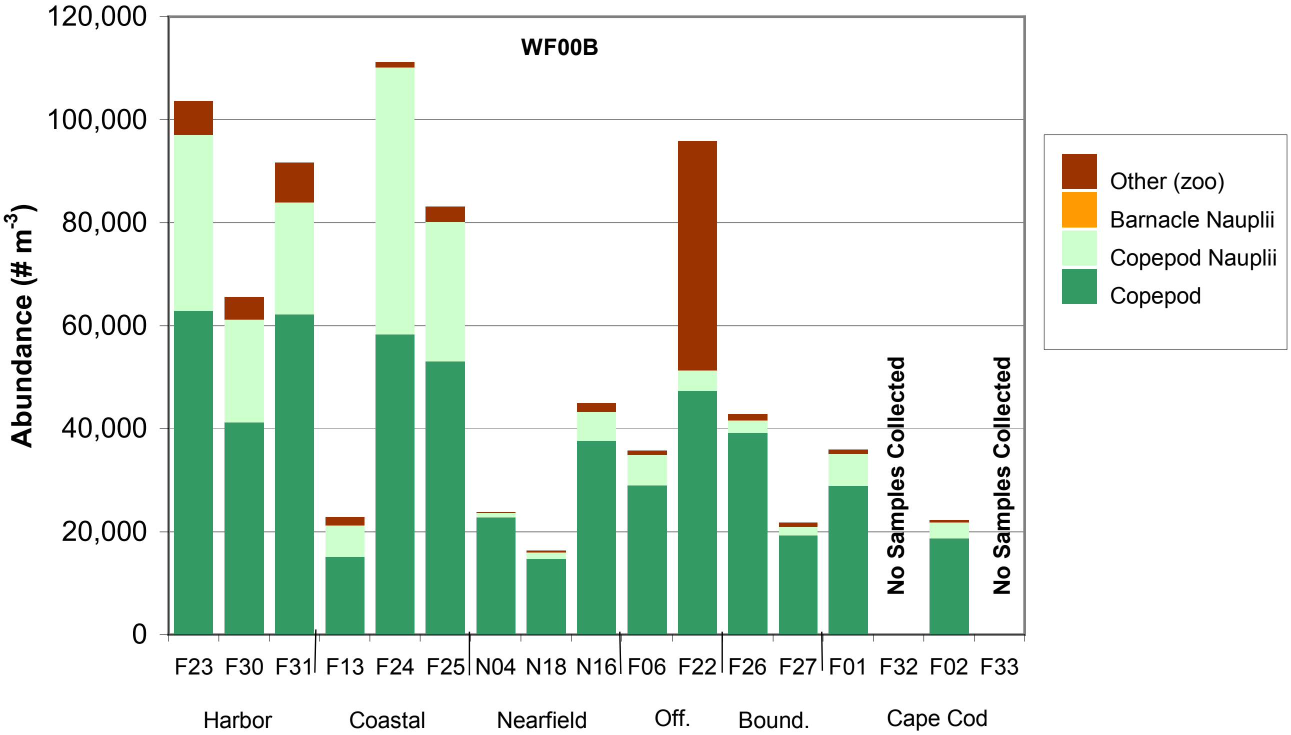


Figure 5-21. Zooplankton Abundance by Major Taxonomic Group, WF00B Farfield Survey

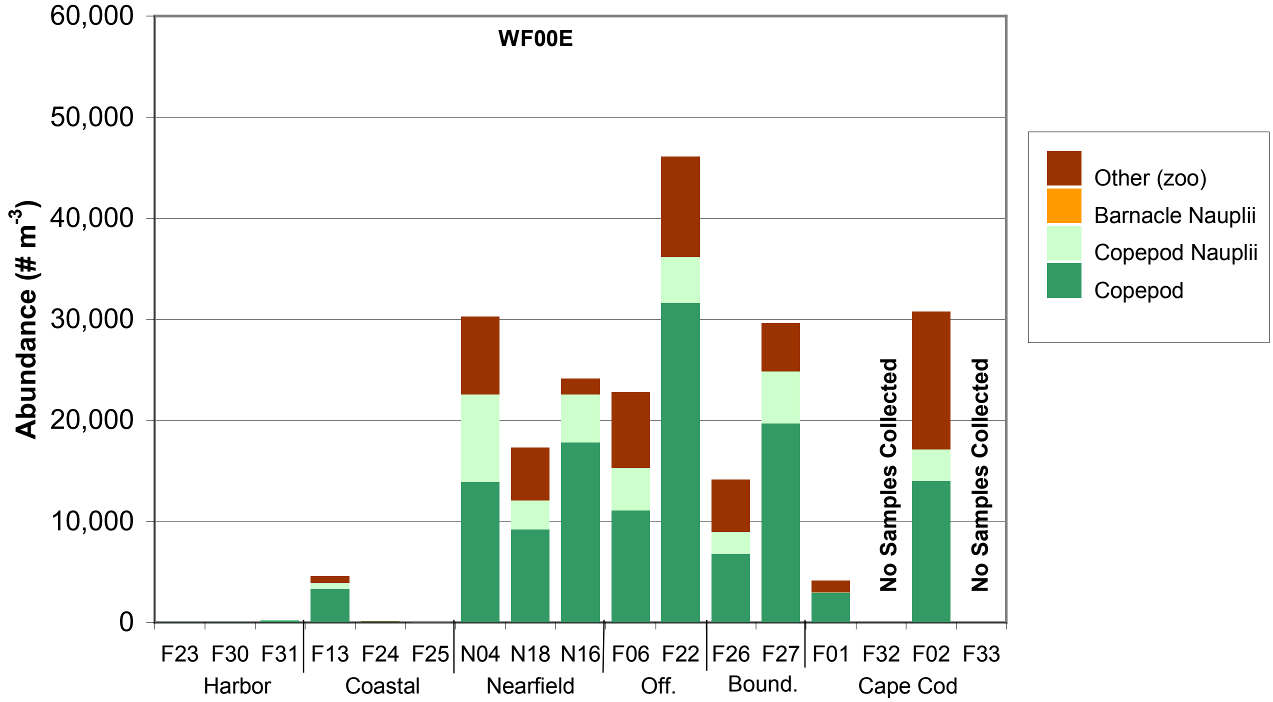


Figure 5-22. Zooplankton Abundance by Major Taxonomic Group, WF00E Farfield Survey

6.0 SUMMARY OF MAJOR WATER COLUMN EVENTS

The primary physical characteristic of this period was the overturn of the water column and the return to winter conditions. Regionally, seasonal stratification had deteriorated at the coastal stations and had begun to weaken at the offshore stations by the October survey (WF00E). The nearfield survey data indicated the pycnocline had broken down in the eastern nearfield by early October (WF00E), but the water column at the outer nearfield stations had not well mixed until late November (WN00G). In September, there was in influx of cooler, more saline, nutrient-replete waters into the nearfield that likely contributed to the fall bloom.

The general trend in nutrient concentrations during the 2000 August to December period was similar to previous baseline monitoring years. Nutrients were depleted in the surface waters during the summer due to biological utilization and increased in concentration with the change from a stratified to a well-mixed water column. In September 2000, two sources of additional nutrients were noted for the nearfield area – an influx of nutrient rich waters from offshore and the transfer of MWRA effluent from the harbor to the bay outfall on September 6th. The transfer of discharge to the bay decreased NH_4 concentrations in the harbor, coastal waters, and western nearfield, and moved this anthropogenic signal offshore to the center of the nearfield. Although it is not a conservative tracer due to biological utilization, it appears that it is a clear indicator of the effluent plume in the nearfield now that the outfall is online. The availability of NH_4 in the nearfield after September 6, 2000 may have contributed to a localized increase in chlorophyll concentrations and helped to sustain the fall bloom in the nearfield for an extended duration.

The 2000 fall bloom had started by the September 1st nearfield survey and continued through late October. Survey mean chlorophyll concentrations were high during each of the September and October surveys. The high concentrations combined with the extended duration of the bloom resulted in a fall mean chlorophyll concentration of 5.69 μgL^{-1}. The fall 2000 mean was higher than all baseline values and continued the trend of elevated fall chlorophyll concentrations started in 1999. As in 1999, phytoplankton abundance, primary production, and chlorophyll did not parallel each other closely during the fall bloom in 2000. Nearfield phytoplankton abundance peaked in early September and gradually declined through October. Productivity was highest at station N18 during the September surveys and in late October further offshore at station N04. Chlorophyll concentrations, although steadily increasing in September, did not reach maximum levels until late October. The fall bloom in Massachusetts and Cape Cod Bays was part of a substantial regional bloom observed in satellite imagery throughout the western Gulf of Maine.

Areal production in 2000 followed patterns typically observed in prior years. Distinct fall phytoplankton blooms were observed as increases in production at both nearfield stations during the sampling period and in general, the nearfield is characterized by the occurrence of a fall bloom. In 1995-1999, fall blooms observed at nearfield stations typically lasted 3-4 weeks and reached production values of 1600 to 4200 mg C m^{-2} d^{-1}. The bloom in 2000 reached a peak value of > 4500 mg C m^{-2} d^{-1} at station N18 and occurred from early September to late October. The elevated productivity observed at station N18 is the highest value observed throughout the monitoring period (1997 – 2000) at this station. At the Boston Harbor station F23, productivity increased from August to October. This is a departure from the normal trend for the harbor - decreasing areal production from summer through fall, and may have been related to the increase in phytoplankton and chlorophyll with the fall bloom.

The regional fall bloom in 2000 consisted of chain-forming diatoms and may be related to another apparently regional event in 2000 – an anomalously high abundances of ctenophores. The ctenophore *Mnemiopsis leidyi* was abundant in Boston Harbor, coastal, and western nearfield waters during in

September and October. The fall 2000 ctenophore "bloom" was unprecedented for the baseline period and caused severe decimation of abundances of copepods. Such overpredation of zooplankton grazers could have also contributed to resultant phytoplankton increases during the fall, particularly in terms of the bloom of large chain-forming diatoms.

The major *Phaeocystis* bloom and high chlorophyll concentrations observed in spring and fall of 2000 imply that there was a substantial amount of organic material produced in the nearfield. It was anticipated that the flux of this organic material into the bottom waters might lead to exceptionally low DO concentrations during the fall of 2000 as it had in 1999 (Libby *et al*., 2000b). The situation was perhaps mitigated by an influx of less DO depleted waters from offshore. The influx of cooler, more saline waters in September may have alleviated detrimental DO conditions as well as been the source of nutrients for the fall bloom.

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. Those parameters include background levels for 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 fall of 2000 was the first seasonal time period to be compared against these thresholds. The fall mean areal chlorophyll caution threshold (161 mg m^{-2}) was exceeded. Note however, that had the outfall been online, fall chlorophyll concentrations for 1999 would have also exceeded the fall caution threshold. Nearfield and Stellwagen Basin DO percent saturation survey mean minima (78%) were below the caution threshold of 80%, but were well above the background levels (64.3% for the nearfield and 66.3% for Stellwagen Basin). None of the nuisance algae thresholds were exceeded for fall 2000. The fall seasonal chlorophyll and DO percent saturation threshold exceedences will be examined in more detail in the 2000 annual water column report.

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