Semi-annual water column monitoring report

August – December 1998

Massachusetts Water Resources Authority

Environmental Quality Department
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Semi-Annual Water Column Monitoring Report
August – December 1998

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EXECUTIVE SUMMARY

The Massachusetts Water Resources Authority (MWRA) has collected water quality data in Massachusetts and Cape Cod Bays for the Harbor and Outfall Monitoring (HOM) Program since 1992. This monitoring is in support of the HOM Program mission to assess the 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 surveys) 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 1998.

The summer/fall time period is usually characterized by the overturn of the stratified water column and the return to winter physical, chemical, and biological conditions. In 1998, the breakdown of stratification was delayed. Regionally, seasonal stratification had deteriorated at the coastal stations and had begun to weaken at the offshore stations by the October survey (WF98E). The nearfield survey data indicated the pycnocline broke down in the eastern nearfield by October (WF98E), but the water column at the outer nearfield stations was not mixed until late November (WN98G). In fact, a deep halocline persisted into December at the eastern nearfield and deep offshore stations. Due to the persistence of stratified conditions, bottom water DO concentrations decreased over the entire August to December time period in the nearfield area. The delay in mixing, combined with a pulse of organic material from an atypical winter phytoplankton bloom, led to the annual minimum in bottom water DO concentration (7 mg L^{-1}) observed in December. The high initial bottom water DO concentration that was observed in June (11.2 mg L^{-1}) lessened the effect of the delay in returning to well-mixed winter conditions.

Upwelling events in August brought cooler, more saline and nutrient replete waters into the surface layer at coastal and western nearfield stations. The upwelled and harbor supplied nutrients supported the abundant phytoplankton assemblage that was observed in the nearfield area during the August survey (WF98B). Areal production measured in August was generally low at nearfield stations N04 and N18 (200-500 mg C m^{-3} d^{-1}), but achieved an annual peak at harbor station F23 (750 mg C m^{-3} d^{-1}). High chlorophyll values, however, were measured across the region during the August survey (WF98B) and were coincident with the high phytoplankton abundance.

Chlorophyll, productivity and phytoplankton data indicate that a fall bloom occurred over a one to two month period including the late September to October surveys. The bloom initiated in the shallow western portion of the nearfield and progressed offshore. In late September (WN98D), high chlorophyll concentrations were observed nearshore and they decreased to the east. Concurrent production and phytoplankton abundance data also exhibited an inshore to offshore decrease across the nearfield. By the October survey (WF98E), high chlorophyll concentrations were observed throughout nearfield area and peaks in annual production were measured at stations N04 and N18. Phytoplankton abundance was also high at each of the nearfield stations in October. Carbon-specific respiration and POC data suggest that the October survey was conducted near the conclusion of the fall bloom.

In November and December, anomalously high concentrations of ammonium and phosphate were observed in Boston Harbor and the western nearfield. The source of these nutrients was not determined, but may have been due to the transfer of south system sewage flows from Nut Island to the Deer Island facility, an ecological change in biological utilization of nutrients in the Harbor or other factors. The anomalously high NH_4 and PO_4 concentrations may have contributed to a bloom in chlorophyll and phytoplankton in the nearfield that was observed December. A concurrent bloom in chlorophyll was observed in Cape Cod Bay and throughout much of the western Gulf of Maine, but due to the lack of phytoplankton data in the farfield it is unclear if the nearfield phytoplankton bloom was part of a regional or a localized phenomena.

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[Note: These appendices are not available on-line. To obtain a printed copy, please call the Environmental Quality Department at (617) 788-4700.]

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 objectives of the HOM Program are 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 1998 (Table 1-1).

Table 1-1. Water Quality Surveys for WN98A-WN98H August to December 1998.

Survey #	Type of Survey	Survey Dates
WN98A	Nearfield	August 7
WF98B	Farfield/Nearfield	August 18 – 25
WN98C	Nearfield	September 3
WN98D	Nearfield	September 24
WF98E	Farfield/Nearfield	October 5 – 16
WN98F	Nearfield	November 4
WN98G	Nearfield	November 25
WN98H	Nearfield	December 16

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. 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 1998 (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 including 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. This report describes the horizontal and vertical characterization of the water column during the summer stratification period (WN98A – WN98D) and the subsequent deterioration of stratification and return to winter conditions in the nearshore-nearfield, coastal, and harbor stations (WF98E – WN98H). 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.

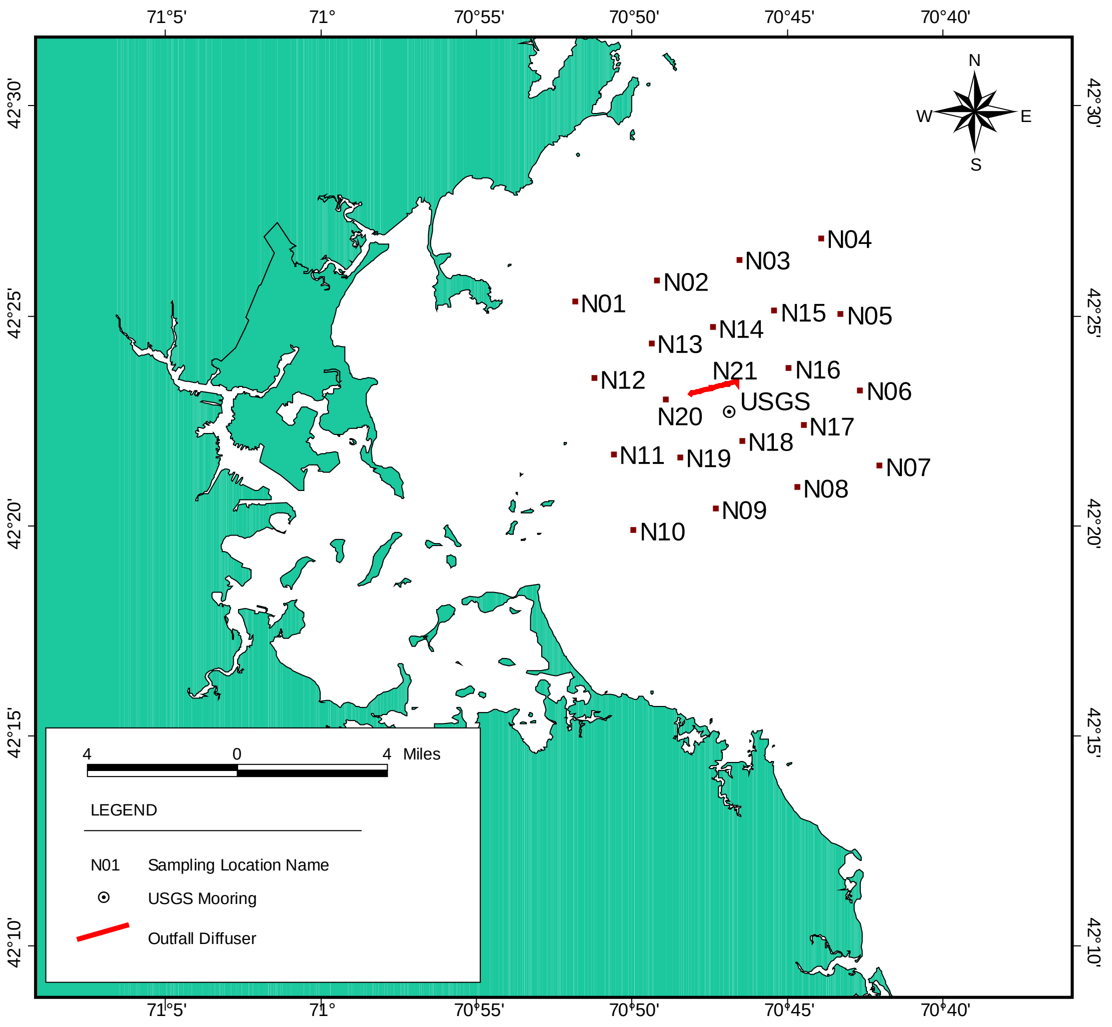


Figure 1-1. Locations of MWRA Offshore Outfall, Nearfield Stations and USGS Mooring.

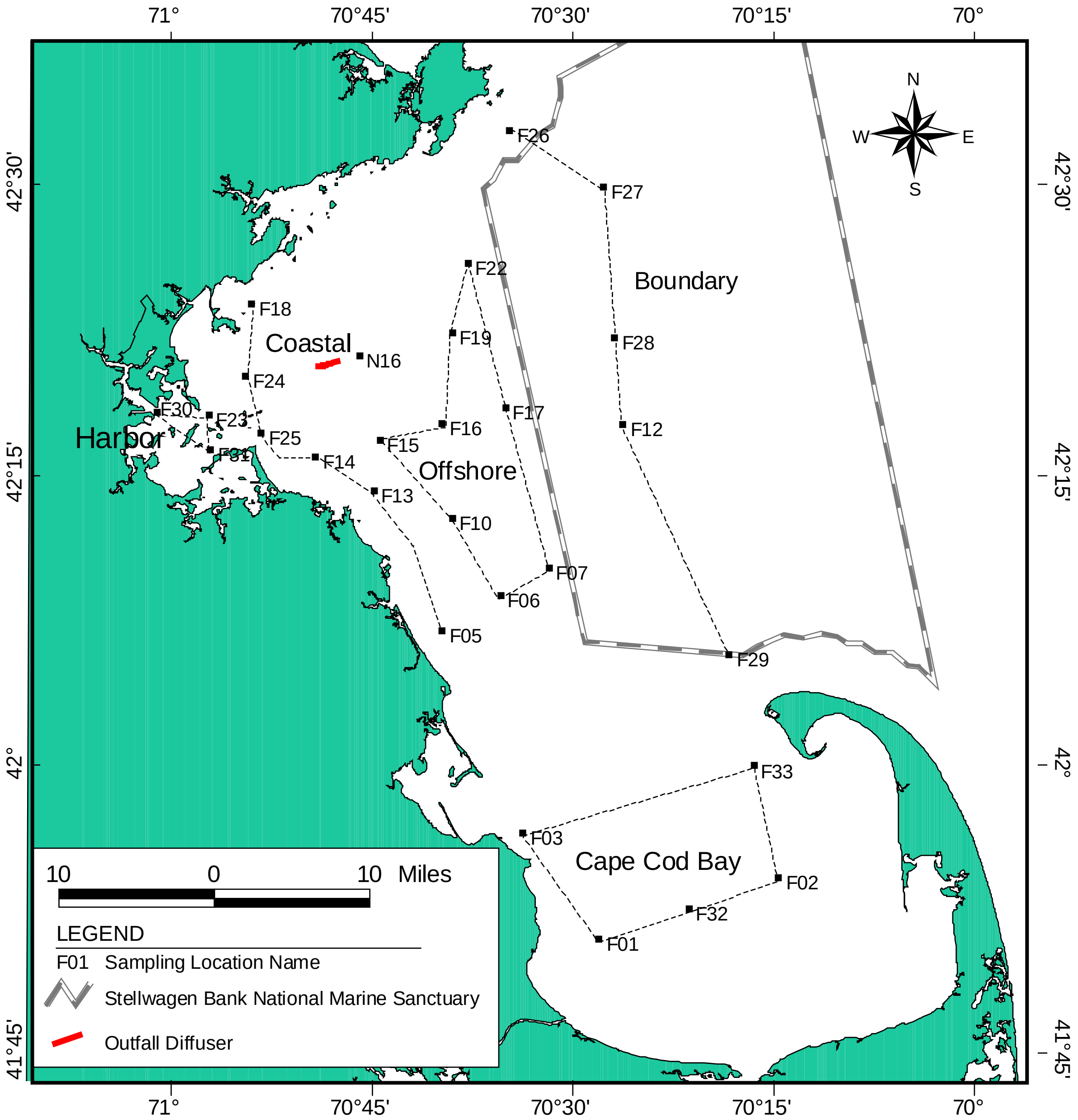


Figure 1-2. Locations of Farfield Stations.

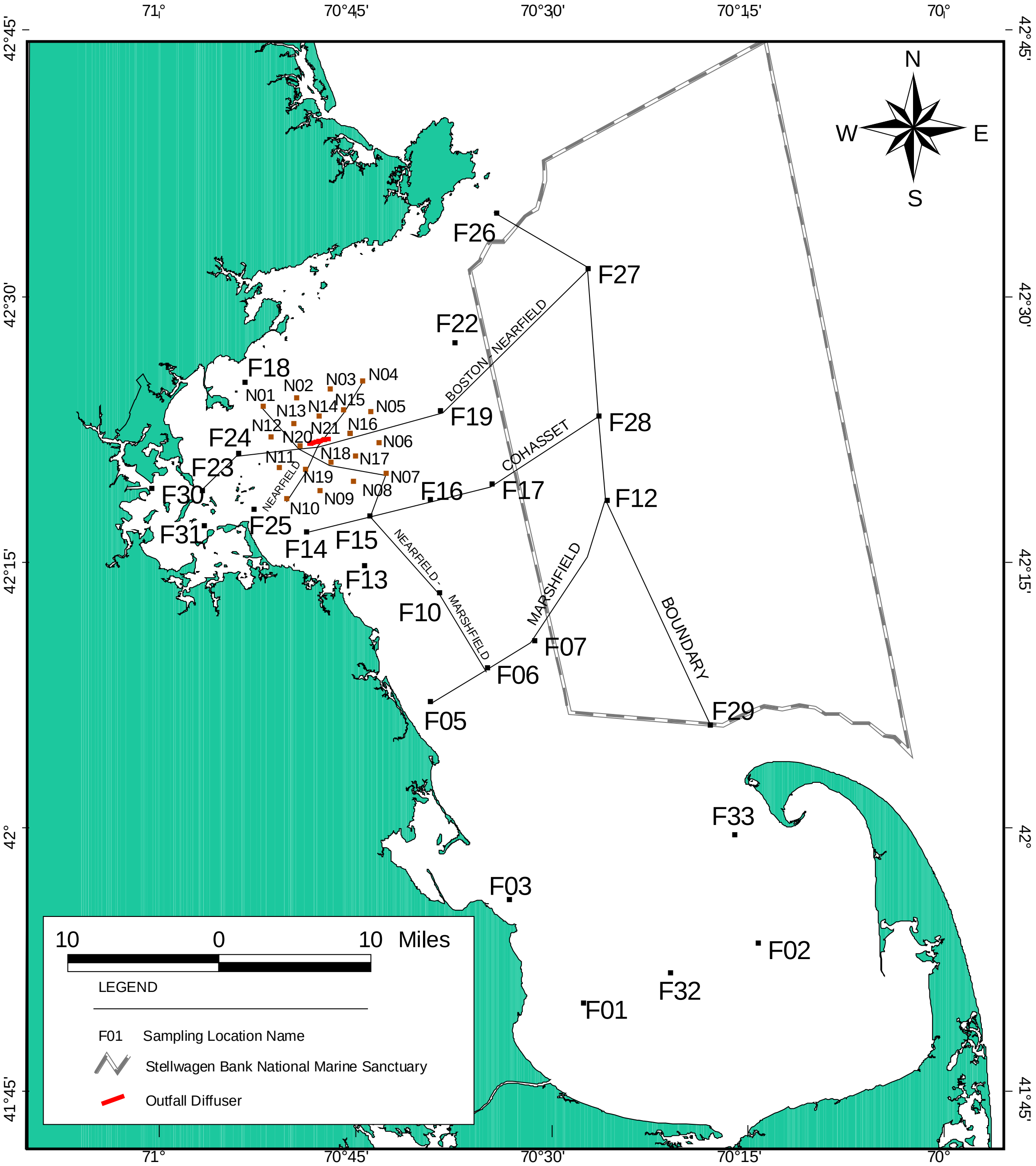


Figure 1-3. Location of Stations Selected for Vertical Transect Graphics Showing Transect Name.

2.0 METHODS

This section describes general methods of data collection and sampling for the last eight water column monitoring surveys of 1998. 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 1998 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 1998 represent a continuation of the baseline water quality monitoring conducted from 1992 – 1997. The monitoring program has been improved over the years as more data have been collected and evaluated.

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. 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 in order 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 were 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 at the five depths from the Go-Flo bottles, stored on ice and transferred to University of Rhode Island (URI) employees. Incubations were started no more that six hours after initial water collection at URI's laboratory. Respiration samples were collected from the Go-Flo bottles at four stations (F19, F23, N04, and N18). Incubation of the dark bottles was started within 30 minutes of sample collection. The dark bottle samples were maintained at a temperature within 2°C of the collection temperature for five to nine days.

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 a type Z).

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

Station Type	**A**	**D**	**E**	**F**	**G**[1]	**P**	**R**	**Z**
Number of Stations	**5**	**8**	**26**	**3**	**2**	**3**	**4**	**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 by oblique tow

2.3 Operations Summary

Field operations for water column sampling and analysis during the second semi-annual period were conducted as described above. Principal deviations from the CW/QAPP plan for each survey and the sampling schema are described below. For additional information about a specific survey, the individual survey reports may be consulted.

Deviations from the CW/QAPP for nearfield surveys WN98A, WN98C, WN98F, WN98G, and WN98H and farfield/nearfield survey WF98E had no effect on the data. During farfield/nearfield survey WF98B, station F23 and 7 Nearfield stations were collected on August 24 while the remaining 14 Nearfield stations were collected on August 25. One deviation from the CW/QAPP occurred during WN98D. Due to problems with the DO titrator, DO titrations were conducted at a land-based laboratory the day after the survey. The problems resulted in all of the samples being titrated 1 to 4 hours beyond the 24-hour holding time limit.

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

Nearfield Water Column Sampling Plan																						
Station ID	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																
			5_Surface	1	1	1																

Nearfield Water Column Sampling Plan

Station ID	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
N09	32	E	1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
			3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
N10	25	A	1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
			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								
N11	32	E	1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
			3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
N12	26	E	1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
			3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
N13	32	E	1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
			3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
N14	34	E	1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
			3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
N15	42	E	1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
			3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
N16	40	A	1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			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								
N17	36	E	1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
			3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																

Nearfield Water Column Sampling Plan

Station ID	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	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

Station ID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	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
F01	27	D	1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
			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				
F02	33	D	1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
			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				
F03	17	E	1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
			3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
F05	18	E	1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
			3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
F06	35	D	1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
			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				
F07	54	E	1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
			3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
F10	30	E	1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
			3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
F12	90	F	1_Bottom	4	1	1								1								
			2_Mid-Bottom	2	1	1								1								
			3_Mid-Depth	2	1	1								1								
			4_Mid-Surface	2	1	1								1								
			5_Surface	4	1	1								1	1							
F13	25	D	1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
			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			

Farfield Water Column Sampling Plan

Station ID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	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
			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														6		
			2_Mid-Bottom	2	1	1								1								
F19	81	F+R	3_Mid-Depth	7	2	1														6		
			4_Mid-Surface	2	1	1								1								
			5_Surface	7	2	1									1					6		
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F22	80	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	18	3	1	1	1	2	2	2	1	2							6	1	1
			2_Mid-Bottom	8.5	1	1						1		1							1	2
F23	25	D+R +P	3_Mid-Depth	24	3	1	1	1	2	2	2	2	2			1	1		1	6	1	1
			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								
			2_Mid-Bottom	2.5	1	1						1		1								

Farfield Water Column Sampling Plan

Station ID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	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**
F25	**15**	**D**	_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			_Mid-Surface	2.5	1	1						1		1								
			_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			_Net Tow															1				
			_Bottom	1	1	1																
			_Mid-Bottom	**1**	**1**	**1**																
F26	**56**	**E**	_Mid-Depth	1	1	1																
			_Mid-Surface	1	1	1																
			_Surface	1	1	1									1							
			_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			_Mid-Bottom	**2.5**	**1**	**1**						**1**		**1**								
F27	**108**	**D**	_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			_Mid-Surface	2.5	1	1						1		1								
			_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			_Net Tow															1				
			_Bottom	1	1	1																
			_Mid-Bottom	**1**	**1**	**1**																
F28	**33**	**E**	_Mid-Depth	1	1	1																
			_Mid-Surface	1	1	1																
			_Surface	1	1	1									1							
			_Bottom	2	1	1								1								
			_Mid-Bottom	**2**	**1**	**1**								**1**								
F29	**66**	**F**	_Mid-Depth	2	1	1								1								
			_Mid-Surface	2	1	1								1								
			_Surface	2	1	1								1	1							
			_Bottom	9.9	2	1	1	1	2	2	2	1	2	3								
			_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
F30	**15**	**G**	_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			_Net Tow															1				
			_Bottom	9.9	2	1	1	1	2	2	2	1	2	3								
			_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
F31	**15**	**G**	_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			_Net Tow															1				
F32	**30**	**Z**	_Surface												1							
			_Net Tow															1				
F33	**30**	**Z**	_Surface												1							
			_Net Tow															1				
			_Bottom	8.1	2	1	2	2	2	2	2	1	2	1								
			_Mid-Bottom	**2.5**	**1**	**1**						**1**		**1**								
N16	**40**	**D**	_Mid-Depth	15	2	2	2	2	2	2	2	2	2	1		1	1		1			
			_Mid-Surface	2.5	1	1						1		1								
			_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			_Net Tow															1				
					otals	**132**	**35**	**35**	**66**	**66**	**66**	**62**	**66**	**76**	**28**	**22**	**22**	**13**	**22**	**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 1998 database and organized to facilitate regional comparisons between surveys, and to allow a quick evaluation of results for evaluating monitoring thresholds (Tables 3-1 through 3-8). 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), beam attenuation, and dissolved oxygen (DO) concentration. Statistical parameters (maximum, minimum, and average) were calculated from the upcast sensor readings collected at five depths through the water column (defined as A-E). 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 1021.4 to 1025.4, meaning σ_t varied from 21.4 to 25.4.

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, beam attenuation 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. Information on the collection, processing, and analysis of nutrient samples can be found in the CW/QAPP (Albro *et al*., 1998).

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}[μEm^{-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 Nitex mesh to retain and concentrate larger dinoflagellate species. Zooplankton samples were collected by oblique tows using a 102-µm mesh at all plankton stations. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (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 3-1 through 3-8).

Results for total phytoplankton and centric diatoms reported in Tables 3-1 through 3-8 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 monitoring data, collected from a mooring located between nearfield stations N21 and N18 (Figure 1-1) were also reviewed. Hourly temperature and salinity data from the mid-depth (~20 m below surface) and near-bottom (1 m above bottom) are plotted in Figure 3-1. Chlorophyll a data from the MWRA Wetlab sensor from the mid-depth (~ 20m below surface) are plotted in Figure 3-2.

Table 3-1. Nearfield Survey WN98A (Aug 98) Data Summary.

Region		Nearfield		
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	5.05	17.9	9.68
Salinity	psu	29.8	31.6	30.9
Sigma_T		21.6	25.0	23.7
Beam Attenuation	m-1	0.57	2.54	1.13
DO Concentration	mg/L	8.86	13.9	11.10
DO Saturation	%	87.3	139.5	107.0
Fluorescence	ug/L	0.0043	13.0	3.10
Chlorophyll a	ug/L	0.38	11.10	3.15
Phaeopigment	ug/L	0.01	0.15	0.08
Nutrients				
NH4	uM	0.18	2.39	0.69
NO2	uM	0.02	0.27	0.14
NO2+NO3	uM	0.07	10.1	3.64
PO4	uM	0.06	1.08	0.58
SIO4	uM	0.01	10.2	4.68
BIOSI	uM	0.7	3.5	1.77
DOC	uM	134.7	272.3	192.5
PART P	uM	0.078	0.81	0.35
POC	uM	8.9	74.2	33.3
PON	uM	1.21	8.79	4.40
TDN	uM	11.3	29.83	15.5
TDP	uM	0.46	1.19	0.80
TSS	mg/L	1.37	10.7	4.82
Urea	uM	0.3	0.6	0.43
Productivity				
Alpha	ALPHA	0.01	0.05	0.03
Pmax	mgCm-3h-1	0.89	5.25	2.68
Areal Production	mgCm-2d-1	457.9	506.5	482.2
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	149.1	161.1	155.1
Respiration [1]	uM/hr	-0.12	0.22	0.05
Plankton				
Total Phytoplankton	E6CELLS/L	1.50	3.43	
Centric diatoms	E6CELLS/L	0.38	1.74	
Alexandrium tamarense	CELLS/L	1.375	1.375	
Phaeocystis pouchettii	CELLS/L	ND	ND	
Pseudo-nitzschia pungens	CELLS/L	1479.22	9811.13	
Total Zooplankton	#/m3	33505.88	58272.67	

ND - Not detected in the sample

[1] - Respiration values reported as negative numbers were determined to be correct

Table 3-2. Combined Farfield/Nearfield Survey WF98B (Aug 98) Data Summary.

		Farfield								
Region		Boundary			Cape Cod Bay			Coastal		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	4.95	17.8	9.98	5.74	18.3	10.0	7.53	15.7	11.3
Salinity	psu	30.5	32.0	31.3	30.4	31.4	31.1	30.5	31.4	30.9
Sigma_T		22.0	25.3	24.0	22.2	24.8	23.8	22.4	24.5	23.5
Beam Attenuation	m-1	0.56	3.28	1.33	1.01	5.29	2.16	0.88	2.45	1.45
DO Concentration	mg/L	9.51	12.3	10.50	7.08	12.20	10.50	9.04	12.00	10.20
DO Saturation	%	91.8	137.3	113.8	69.5	139.8	112.4	94.6	133.4	113.5
Fluorescence	ug/L	0.01	15.1	3.35	0.55	9.96	4.07	0.83	10.4	5.61
Chloropyll a	ug/L	0.06	4.46	2.20	1.59	9.57	5.42	1.73	8.96	4.57
Phaeopigment	ug/L	0.03	0.08	0.05						
Nutrients										
NH4	uM	0.22	7.23	1.11	0.21	3.03	1.12	0.22	5.61	1.51
NO2	uM	0.01	0.25	0.08	0.02	0.14	0.06	0.03	0.22	0.11
NO2+NO3	uM	0.02	11.66	4.67	0.1	7.98	2.10	0.04	4.54	1.57
PO4	uM	0.1	1.1	0.59	0.23	1.09	0.54	0.24	0.90	0.59
SIO4	uM	0.16	12.0	5.24	0.54	17.0	5.91	0.48	8.55	3.92
BIOSI	uM	1.6	1.8	1.7	2.5	5.4	3.25	1.2	3.6	2.64
DOC	uM	122.2	215.8	171.5	145.8	349.6	252.1	166.2	301.7	209.8
PART P	uM	0.12	0.28	0.23	0.24	0.47	0.35	0.16	0.48	0.36
POC	uM	11	47.5	30.0	26.2	49.4	38.35	16.3	51.1	32.9
PON	uM	1.49	4.3	3.34	3.33	5.5	4.80	2.56	8.71	5.19
TDN	uM	13.1	30.5	21.4	12.7	26.5	17.8	17.5	31.9	22.2
TDP	uM	0.41	1.33	0.86	0.65	1.34	0.96	0.71	1.08	0.95
TSS	mg/L	2.1	8.6	4.34	1.77	5.79	3.36	2.06	7.45	4.05
Urea	uM	0.4	0.4	0.4	0.5	0.7	0.58	0.4	0.8	0.58
Productivity										
Alpha	ALPHA									
Pmax	mgCm-3h-1									
Areal Production	mgCm-2d-1									
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1									
Respiration	uM/hr									
Plankton										
Total Phytoplankton	E6CELLS/L	0.823	2.135		2.136	5.044		2.060	4.865	
Centric diatoms	E6CELLS/L	0.350	1.514		0.775	3.197		0.834	3.117	
Alexandrium tamarense	CELLS/L	ND	ND		ND	ND		2.7	2.7	
Phaeocystis pouchettii	CELLS/L	ND	ND		ND	ND		ND	ND	
Pseudo-nitzschia pungens	CELLS/L	5282.98	38037.43		13086.69	74464.81		8313.90	404534.77	
Total Zooplankton	#/m3	48254.25	48254.25		42217.54	62186.67		30105.60	44701.54	

ND - Not detected in the sample

Table 3-2. Combined Farfield/Nearfield Survey WF98B (Aug 98) Data Summary. (Continued)

		Farfield								
Region		Harbor			Offshore			Nearfield		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	13.3	15.6	14.3	4.95	16.3	9.54	5.60	17.8	10.8
Salinity	psu	29.1	30.7	30.4	30.5	31.9	31.3	30.40	31.7	31.1
Sigma_T		21.4	22.9	22.6	22.3	25.2	24.0	22.1	25.0	23.7
Beam Attenuation	m-1	1.68	2.78	2.04	0.55	1.75	0.99	0.53	2.23	1.04
DO Concentration	mg/L	9.03	10.40	9.76	8.81	12.10	10.20	7.89	11.80	9.48
DO Saturation	%	108.9	120.7	115.0	86.9	135.5	110.2	78.4	139.9	104.8
Fluorescence	ug/L	3.81	7.54	5.34	0.04	11.0	3.09	0.03	15.5	3.10
Chloropyll a	ug/L	2.32	8.50	4.98	1.02	3.41	2.71	0.22	10.67	2.66
Phaeopigment	ug/L	0.09	3.71	1.30	0.15	0.19	0.17	0.03	0.96	0.18
Nutrients										
NH4	uM	2.92	8.04	5.56	0.20	1.89	0.65	0.01	6.23	1.20
NO2	uM	0.14	0.37	0.22	0.01	0.3	0.10	0.02	0.42	0.20
NO2+NO3	uM	1.83	4.30	2.73	0.07	11.43	4.43	0.08	11.0	4.02
PO4	uM	0.62	1.03	0.84	0.11	1.14	0.62	0.07	1.05	0.62
SIO4	uM	4.32	9.03	5.95	0.30	12	5.32	0.01	10.8	5.03
BIOSI	uM	1.9	4.8	3.6	1.4	2.2	1.7	0.2	3.1	1.41
DOC	uM	172.7	418.1	253.2	158.1	204.6	185.8	137.3	413.7	206.8
PART P	uM	0.45	0.70	0.54	0.097	0.35	0.21	0.071	0.57	0.26
POC	uM	29.9	48.6	40.0	14	48.9	29.1	11.1	52.3	27.9
PON	uM	4.96	8.86	6.85	2	5.45	3.66	1.64	7.93	4.09
TDN	uM	20.4	34.9	27.2	20.8	23.3	21.9	15.8	33.5	22.7
TDP	uM	0.97	1.5	1.24	0.64	1.29	1.00	0.46	1.37	0.94
TSS	mg/L	2.63	6.83	4.14	1.24	4.94	2.62	0.37	11.3	3.58
Urea	uM	0.30	0.60	0.53	0.60	0.6	0.6	0.5	1.3	0.78
Productivity										
Alpha	ALPHA	0.06	0.09	0.08				0.0008	0.03	0.01
Pmax	mgCm-3h-1	8.37	12.9	10.5				0.68	3.8	1.7
Areal Production	mgCm-2d-1	751.9	751.9	751.9				187.7	311.8	249.8
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	195.3	195.3	195.3				157.2	161.9	159.6
Respiration	uM/hr	0.15	0.27	0.20	0.07	0.27	0.16	0.01	0.21	0.10
Plankton										
Total Phytoplankton	E6CELLS/L	3.170	5.257		1.155	3.077		0.307	4.035	
Centric diatoms	E6CELLS/L	0.800	1.447		0.642	2.114		0.056	1.973	
Alexandrium tamarense	CELLS/L	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	CELLS/L	ND	ND		ND	ND		ND	ND	
Pseudo-nitzschia pungens	CELLS/L	126794.48	655104.82		8754.65	12624.80		3521.98	123896.32	
Total Zooplankton	#/m3	42086.40	72797.09		27251.61	27251.61		30460.76	64663.70	

ND - Not detected in the sample

Table 3-3. Nearfield Survey WN98C (Sep 98) Data Summary.

Region		Nearfield		
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	5.60	19.0	12.6
Salinity	psu	25.6	31.8	31.1
Sigma_T		20.1	25.1	23.4
Beam Attenuation	m-1	0.50	2.67	0.94
DO Concentration	mg/L	7.14	11.0	9.01
DO Saturation	%	72.7	130.1	103.5
Fluorescence	ug/L	0.10	8.09	1.56
Chlorophyll a	ug/L	0.23	4.90	1.46
Phaeopigment	ug/L	0.00	1.32	0.22
Nutrients				
NH4	uM	0.01	4.25	0.96
NO2	uM	0.005	0.32	0.12
NO2+NO3	uM	0.05	10.8	2.70
PO4	uM	0.005	1	0.39
SIO4	uM	0.55	10.1	4.72
BIOSI	uM	0.3	2.9	1.01
DOC	uM	135.5	348.4	222.3
PART P	uM	0.08	0.53	0.24
POC	uM	7.44	59	22.5
PON	uM	1.28	7.71	3.26
TDN	uM	10.3	27.9	16.4
TDP	uM	0.58	1.17	0.825
TSS	mg/L	0.42	8.32	2.60
Urea	uM	0.3	0.6	0.43
Productivity				
Alpha	ALPHA	0.01	0.04	0.03
Pmax	mgCm-3h-1	0.40	6.36	2.71
Areal Production	mgCm-2d-1	404.3	473.6	439.0
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	355.1	359.1	357.1
Respiration	uM/hr	0.05	0.23	0.13
Plankton				
Total Phytoplankton	E6CELLS/L	0.544	2.203	
Centric diatoms	E6CELLS/L	0.032	0.799	
Alexandrium tamarense	CELLS/L	ND	ND	
Phaeocystis pouchettii	CELLS/L	ND	ND	
Pseudo-nitzschia pungens	CELLS/L	754.84	7694.35	
Total Zooplankton	#/m3	11894.59	13870.72	

ND - Not detected in the sample

Table 3-4. Nearfield Survey WN98D (Sep 98) Data Summary.

Region		Nearfield		
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	6.93	16.3	12.3
Salinity	psu	30.9	31.9	31.3
Sigma_T		22.7	25.0	23.6
Beam Attenuation	m-1	0.54	2.43	1.03
DO Concentration	mg/L	6.75	10.9	8.48
DO Saturation	%	71.2	131.8	96.9
Fluorescence	ug/L	0.002	15.2	4.70
Chlorophyll a	ug/L	0.07	13.72	3.68
Phaeopigment	ug/L	0.02	7.35	1.07
Nutrients				
NH4	uM	0.01	4.66	1.30
NO2	uM	0.005	0.29	0.14
NO2+NO3	uM	0.08	10	3.72
PO4	uM	0.36	1.59	0.86
SIO4	uM	0.3	12.4	5.62
BIOSI	uM	0	5.2	2.15
DOC	uM	137.9	295	195.1
PART P	uM	0.08	0.70	0.25
POC	uM	8.67	60.3	28.0
PON	uM	1.34	7.93	3.89
TDN	uM	14.1	30.8	21.6
TDP	uM	0.67	1.42	1.05
TSS	mg/L	0.35	6.3	3.22
Urea	uM	0.3	0.4	0.325
Productivity				
Alpha	ALPHA	0.003	0.10	0.04
Pmax	mgCm-3h-1	0.29	12.0	3.70
Areal Production	mgCm-2d-1	171.1	985.3	578.2
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	337.7	458.7	398.2
Respiration	uM/hr	0.10	0.33	0.20
Plankton				
Total Phytoplankton	E6CELLS/L	0.547	2.333	
Centric diatoms	E6CELLS/L	0.024	1.111	
Alexandrium tamarense	CELLS/L	1.5	1.5	
Phaeocystis pouchettii	CELLS/L	ND	ND	
Pseudo-nitzschia pugens	CELLS/L	1358.38	6047.41	
Total Zooplankton	#/m3	24939.61	45539.07	

ND - Not detected in the sample

Table 3-5. Combined Farfield/Nearfield Survey WF98E (Oct 98) Data Summary.

		Farfield								
Region		Boundary			Cape Cod Bay			Coastal		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	6.08	13.6	10.7	9.06	15.3	13.1	8.85	13.8	11.8
Salinity	psu	30.8	32.2	31.4	31.0	31.5	31.2	30.6	31.6	31.1
Sigma_T		23.3	25.4	24.0	22.8	24.4	23.4	23.1	24.5	23.6
Beam Attenuation	m-1	0.51	0.93	0.70	0.54	1.31	0.76	0.60	1.85	1.05
DO Concentration	mg/L	7.67	10.0	8.95	6.09	9.15	8.32	7.63	9.70	8.60
DO Saturation	%	76.9	112.2	98.7	64.6	104.9	96.4	84.0	111.9	96.7
Fluorescence	ug/L	0.01	5.76	3.16	0.48	4.61	2.40	0.60	5.90	2.74
Chlorophyll a	ug/L	0.11	1.49	0.91	0.82	2.45	1.57	0.44	5.63	2.60
Phaeopigment	ug/L	0.21	0.99	0.64	0.59	1.63	0.85	0.20	1.78	1.08
Nutrients										
NH4	uM	0.2	2.33	0.66	0.07	4.98	1.27	0.01	17.26	4.73
NO2	uM	0.01	0.21	0.07	0.005	0.21	0.05	0.005	0.46	0.20
NO2+NO3	uM	0.14	13.4	3.41	0.03	6.29	1.53	0.07	8.2	2.97
PO4	uM	0.36	1.32	0.68	0.47	1.19	0.66	0.47	1.57	0.97
SIO4	uM	0.29	14.6	4.13	1.44	19.4	5.04	1.03	9.78	4.13
BIOSI	uM	0.6	1.6	1.17	1.3	6.6	3.1	3	4.5	3.68
DOC	uM	155.9	184.2	171.8	157.1	186	175.1	163.6	285.4	208.5
PART P	uM	0.06	0.14	0.11	0.14	0.27	0.20	0.16	0.39	0.28
POC	uM	8.16	18.2	14.3	17.8	31.3	22.0	11.9	43.1	28.8
PON	uM	1.34	2.85	2.33	2.58	3.89	3.16	1.99	5.62	4.20
TDN	uM	10.7	23.9	15.4	7.6	31.4	19.3	10	28.8	19.0
TDP	uM	0.58	1.23	0.83	0.53	1.79	1.02	0.59	1.53	1.13
TSS1	mg/L	-0.08	1.75	1.03	1.9	7.21	3.64	1	5.68	3.33
Urea	uM	0.23	0.37	0.3	0.1	0.85	0.39	0.3	0.85	0.50
Productivity										
Alpha	ALPHA									
Pmax	mgCm-3h-1									
Areal Production	mgCm-2d-1									
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1									
Respiration	uM/hr									
Plankton										
Total Phytoplankton	E6CELLS/L	0.332	0.512		0.313	1.021		0.208	1.314	
Centric diatoms	E6CELLS/L	0.138	0.138		0.045	0.320		0.105	0.574	
Alexandrium tamarense	CELLS/L	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	CELLS/L	ND	ND		ND	ND		ND	ND	
Pseudo-nitzschia pungens	CELLS/L	1761.29	1847.84		27497.66	63406.37		1660.64	73219.26	
Total Zooplankton	#/m3	26350.73	26350.73		15978.52	17340.46		27700.00	55210.30	

ND - Not detected in the sample

Table 3-5. Combined Farfield/Nearfield Survey WF98E (Oct 98) Data Summary. (Continued)

		Farfield						Nearfield		
Region		Harbor			Offshore					
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	10.0	12.2	11.2	6.00	13.7	10.6	6.41	13.2	10.1
Salinity	psu	30.1	31.3	30.9	31.1	32.0	31.4	31.2	31.9	31.5
Sigma_T		22.8	24.1	23.6	23.3	25.2	24.0	23.5	25.1	24.2
Beam Attenuation	m-1	1.23	3.09	2.02	0.53	1.34	0.73	0.57	1.63	0.98
DO Concentration	mg/L	7.93	8.20	8.11	7.24	9.88	8.65	7.25	11.5	8.80
DO Saturation	%	88.6	92.2	89.7	74.7	112.2	95.4	73.7	129.9	95.9
Fluorescence	ug/L	0.52	3.01	2.22	0.02	5.34	2.90	0.02	14.8	4.95
Chlorophyll a	ug/L	1.10	3.76	2.52	1.15	3.47	2.41	0.28	14.34	5.51
Phaeopigment	ug/L	0.22	2.07	1.48	0.62	1.64	1.34	0.26	4.98	1.59
Nutrients										
NH4	uM	12.7	17.0	14.9	0	2.38	0.42	0.03	4.57	0.81
NO2	uM	0.07	0.64	0.48	0.005	0.24	0.10	0.005	0.61	0.17
NO2+NO3	uM	5.32	9.8	8.09	0.06	12.93	4.18	0.06	13	5.03
PO4	uM	1.43	1.84	1.68	0.29	1.47	0.78	0.44	1.45	0.91
SIO4	uM	6.32	11.9	10.2	0.24	14.77	5.30	0.34	14.41	5.87
BIOSI	uM	3.5	9.1	5.6	2.3	2.5	2.37	0.5	6.4	4.02
DOC	uM	147.5	246	195.6	146.6	175.3	158.8	127.7	277.7	196.9
PART P	uM	0.25	0.49	0.39	0.16	0.23	0.19	0.08	0.81	0.34
POC	uM	5.27	36.1	27.2	18.8	33.8	27.7	5.28	69.4	36.2
PON	uM	3.56	6.04	5.03	2.84	3.86	3.48	0.75	8.79	5.10
TDN	uM	17.3	44.9	30.1	7.6	20.6	15.2	7.1	22.5	14.4
TDP	uM	1.11	1.83	1.60	0.57	0.83	0.68	0.46	1.35	0.88
TSS1	mg/L	3.87	8.33	5.43	1.95	5.58	3.79	1.03	6.87	4.04
Urea	uM	0.03	1.12	0.62	0.3	0.64	0.47	0.03	0.85	0.29
Productivity										
Alpha	ALPHA	0.06	0.07	0.07				0.015	0.34	0.12
Pmax	mgCm-3h-1	6.76	8.63	7.614				1.29	58.0	20.3
Areal Production	mgCm-2d-1	557.6	557.6	557.6				1664.6	1988.5	1826.6
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	185.9	185.9	185.9				492.3	1059.3	775.8
Respiration	uM/hr	0.11	0.13	0.12	0.03	0.25	0.17	0.02	0.19	0.12
Plankton										
Total Phytoplankton	E6CELLS/L	0.517	1.445		0.661	0.855		0.950	2.802	
Centric diatoms	E6CELLS/L	0.089	0.313		0.189	0.281		0.519	1.872	
Alexandrium tamarense	CELLS/L	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	CELLS/L	ND	ND		ND	ND		ND	ND	
Pseudo-nitzschia pungens	CELLS/L	1509.68	4076.12		48762.52	62802.50		20999.59	54348.32	
Total Zooplankton	#/m3	26070.59	83151.88		36184.62	36184.62		35756.75	59200.00	

ND - Not detected in the sample

Table 3-6. Nearfield Survey WN98F (Oct 98) Data Summary.

Region		Nearfield		
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	6.90	10.4	9.51
Salinity	psu	31.1	32.0	31.5
Sigma_T		24.0	25.1	24.3
Beam Attenuation	m-1	0.51	1.59	0.78
DO Concentration	mg/L	6.43	9.27	8.65
DO Saturation	%	66.3	100.8	92.8
Fluorescence	ug/L	-0.69	3.09	1.37
Chlorophyll a	ug/L	0.39	2.64	1.46
Phaeopigment	ug/L	0.04	2.03	0.68
Nutrients				
NH4	uM	0.07	7.77	1.40
NO2	uM	0.005	0.32	0.11
NO2+NO3	uM	0.27	13.3	2.91
PO4	uM	0.005	1.49	0.70
SIO4	uM	0.93	16.1	4.44
BIOSI	uM	1.3	4.6	2.20
DOC	uM	122.9	186.3	141.7
PART P	uM	0.13	0.41	0.24
POC	uM	13.9	33.3	23.1
PON	uM	2.25	5.37	3.57
TDN	uM	8.92	21.2	13.1
TDP	uM	0.74	1.48	0.90
TSS	mg/L	1.05	7.6	3.45
Urea	uM	0.03	0.37	0.20
Productivity				
Alpha	ALPHA	0.02	0.08	0.05
Pmax	mgCm-3h-1	0.91	7.60	5.02
Areal Production	mgCm-2d-1	687.2	775.0	731.1
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	472.3	746.4	609.4
Respiration	uM/hr	0.05	0.13	0.09
Plankton				
Total Phytoplankton	E6CELLS/L	0.665	0.904	
Centric diatoms	E6CELLS/L	0.145	0.193	
Alexandrium tamarense	CELLS/L	ND	ND	
Phaeocystis pouchettii	CELLS/L	ND	ND	
Pseudo-nitzschia pungens	CELLS/L	1154.62	4844.90	
Total Zooplankton	#/m3	39049.09	77615.94	

ND - Not detected in the sample

Table 3-7. Nearfield Survey WN98G (Nov 98) Data Summary.

		Farfield			Nearfield		
Region		Boundary					
Parameter	Unit	Min	Max	Avg	Min	Max	Avg
In Situ							
Temperature	C	7.16	8.89	8.22	7.18	8.71	8.10
Salinity	psu	31.7	32.1	31.8	31.3	32.2	31.6
Sigma_T		24.5	25.1	24.8	24.4	25.2	24.6
Beam Attenuation	m-1	0.53	0.80	0.63	0.55	0.91	0.65
DO Concentration	mg/L	7.07	9.42	8.40	7.02	9.44	8.77
DO Saturation	%	72.1	99.6	87.8	71.9	98.7	91.1
Fluorescence	ug/L	1.60	2.45	2.15	0.01	3.19	1.57
Chlorophyll a	ug/L	0.13	2.15	1.12	0.11	2.70	1.45
Phaeopigment	ug/L	0.15	0.23	0.19	0.02	0.45	0.20
Nutrients							
NH4	uM	1	2.66	1.77	0.74	8.66	3.50
NO2	uM	0.18	0.27	0.21	0.17	0.43	0.27
NO2+NO3	uM	2.96	13.3	7.28	2.91	12.9	6.81
PO4	uM	0.83	1.48	1.10	0.87	1.66	1.19
SIO4	uM	4.82	15.9	9.40	2.5	16.46	9.98
BIOSI	uM	0.4	1	0.63	0	1.3	0.47
DOC	uM	112.3	248.5	164.5	106.8	199	144.3
PART P	uM	0.07	0.12	0.09	0.06	0.18	0.12
POC	uM	0.07	0.20	0.13	0.08	0.23	0.16
PON	uM	0.01	0.03	0.03	0.01	0.05	0.03
TDN	uM	16.6	25.1	19.8	13.7	29.5	20.9
TDP	uM	0.93	1.51	1.16	0.91	1.55	1.25
TSS	mg/L	1.14	3.92	2.15	0.98	4.58	2.29
Urea	uM				0.6	0.9	0.73
Productivity							
Alpha	ALPHA				0.01	0.11	0.05
Pmax	mgCm-3h-1				0.94	8.34	5.22
Areal Production	mgCm-2d-1				643.9	828.4	736.2
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1				417.6	506.1	461.9
Respiration [1]	uM/hr 1				-0.02	0.13	0.08
Plankton							
Total Phytoplankton	E6CELLS/L				0.346	0.703	
Centric diatoms	E6CELLS/L				0.065	0.098	
Alexandrium tamarense	CELLS/L				ND	ND	
Phaeocystis pouchettii	CELLS/L				ND	ND	
Pseudo-nitzschia pungens	CELLS/L				815.22	2667.09	
Total Zooplankton	#/m3				61944.20	66980.83	

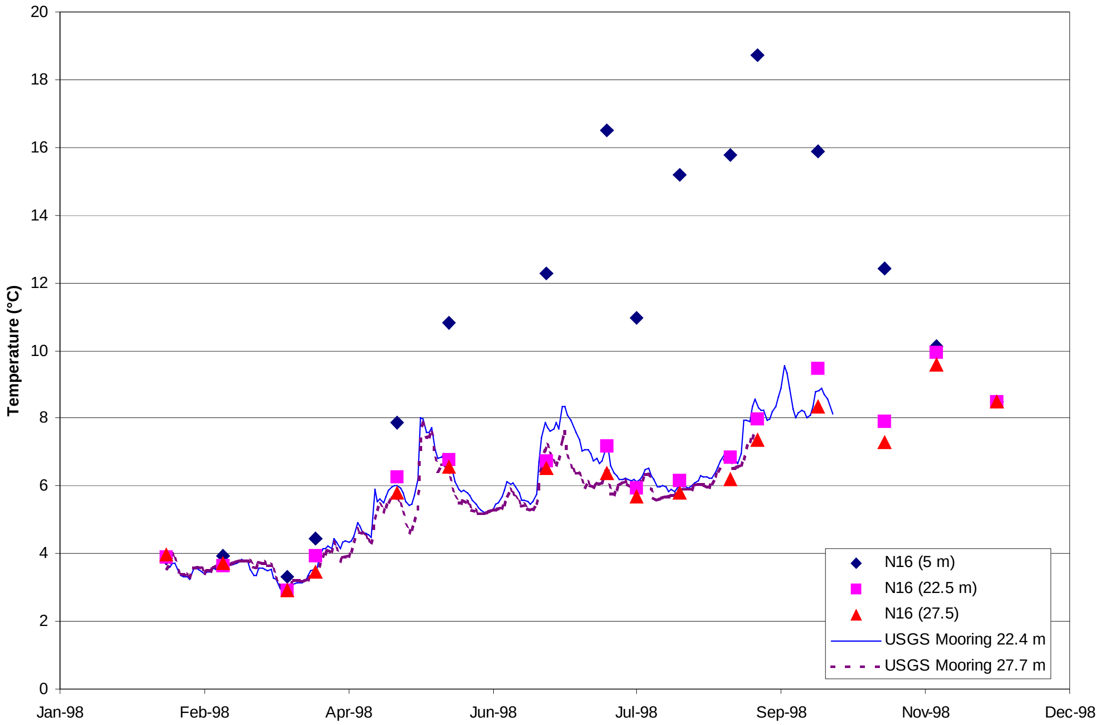
ND - Not detected in the sample

1 - Respiration values reported as negative numbers were determined to be correct

Table 3-8. Nearfield Survey WN98H (Dec 98) Data Summary.

		Farfield												Nearfield		
Region		Boundary			Cape Cod Bay			Harbor			Offshore					
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ																
Temperature	C	7.30	7.40	7.36	7.52	7.80	7.65	6.25	6.68	6.44				6.90	7.65	7.33
Salinity	psu	32.0	32.2	32.1	31.5	31.8	31.7	31.2	31.5	31.4				31.8	32.3	31.9
Sigma_T		25.0	25.1	25.1	24.6	24.8	24.7	24.5	24.7	24.6				24.9	25.2	25.0
Beam Attenuation	m-1	0.66	0.70	0.68	0.68	0.72	0.70	1.12	1.17	1.14				0.60	0.87	0.70
DO Concentration	mg/L	9.27	10.3	9.78	9.39	9.98	9.75	8.18	9.28	8.80				4.54	10.3	8.97
DO Saturation	%	95.0	105.1	100.1	96.8	102.7	100.2	82.1	92.1	87.7				46.9	104.2	91.6
Fluorescence	ug/L	2.15	15.5	8.24	1.01	8.60	3.50	3.42	6.57	5.47				0.33	13.2	7.65
Chlorophyll a	ug/L	3.56	11.91	8.46	1.35	5.49	4.08	1.69	2.21	1.96	1.77	5.86	4.54	1.31	9.24	5.36
Phaeopigment	ug/L	0.38	1.79	1.17	0.23	1.30	0.81	1.03	1.32	1.20	0.51	1.13	0.73	0.34	1.58	0.91
Nutrients																
NH4	uM	0.37	4.35	1.47	0.38	1.43	0.97	0.12	1.35	0.65	15.4	22.1	17.8	0.19	5.48	1.58
NO2	uM	0.21	0.22	0.21	0.21	0.25	0.24	0.2	0.28	0.26	0.67	0.78	0.72	0.25	0.49	0.33
NO2+NO3	uM	4.37	5.75	4.77	1.28	2.78	2.18	3.14	11.5	6.69	11.7	12.7	12.2	4.67	10.4	6.98
PO4	uM	0.86	0.90	0.88	0.78	0.84	0.82	0.7	1.37	1.01	1.91	2.24	2.07	0.88	1.41	1.08
SIO4	uM	2.96	3.90	3.52	4.11	8.53	6.13	3.03	13.9	7.37	15.4	16.7	16.0	4.65	13.3	8.25
BIOSI	uM	2.40	3.30	2.93	0.80	2.20	1.55	1.7	2.4	2.1	1.4	2.4	1.83	1.1	2.6	1.98
DOC	uM	123.8	147.5	135.0	126.1	261	168.1	140.7	154.4	146.1	145.4	161.5	150.8	123.7	186.3	149.1
PART P	uM	0.16	0.20	0.18	0.11	0.16	0.14	0.08	0.15	0.12	0.2	0.25	0.22	0.09	0.23	0.16
POC	uM	18.2	22.1	20.5	11.6	19.2	15.0	16.3	20	18.2	7.6	16.7	13.0	7.9	21.8	15.5
PON	uM	3.14	3.43	3.24	2.29	3.11	2.56	2.45	2.81	2.64	1.36	2.86	2.15	1.24	3.61	2.55
TDN	uM	14.3	19.5	16.6	8.48	15.5	11.2	33.3	39.2	36.4	19.2	31.0	24.4	12.0	27.7	16.7
TDP	uM	0.84	0.98	0.93	0.8	1.06	0.91	1.88	2.09	1.96	1	1.44	1.15	0.92	1.7	1.14
TSS	mg/L	1.85	6.43	4.01	1.17	4.28	2.18	2.62	4.87	3.52	1.93	6.23	3.48	1.17	4.58	2.40
Urea	uM													0.3	0.5	0.45
Productivity																
Alpha	ALPHA													0.02	0.09	0.07
Pmax	mgCm-3h-1													3.35	12.2	8.1
Areal Production	mgCm-2d-1													643.6	677.1	660.4
Chlorophyll Specific Areal Productio	mgC(mg Chla)-1m-2d-1													89.8	96.8	93.3
Respiration	uM/hr													0.02	0.06	0.04
Plankton																
Total Phytoplankton	E6CELLS/L													0.605	0.936	
Centric diatoms	E6CELLS/L													0.091	0.257	
Alexandrium tamarense	CELLS/L													ND	ND	
Phaeocystis pouchettii	CELLS/L													ND	ND	
Pseudo-nitzschia pungens	CELLS/L													40000.64	81510.74	
Total Zooplankton	#/m3													47407.41	59662.10	

ND - Not detected in the sample



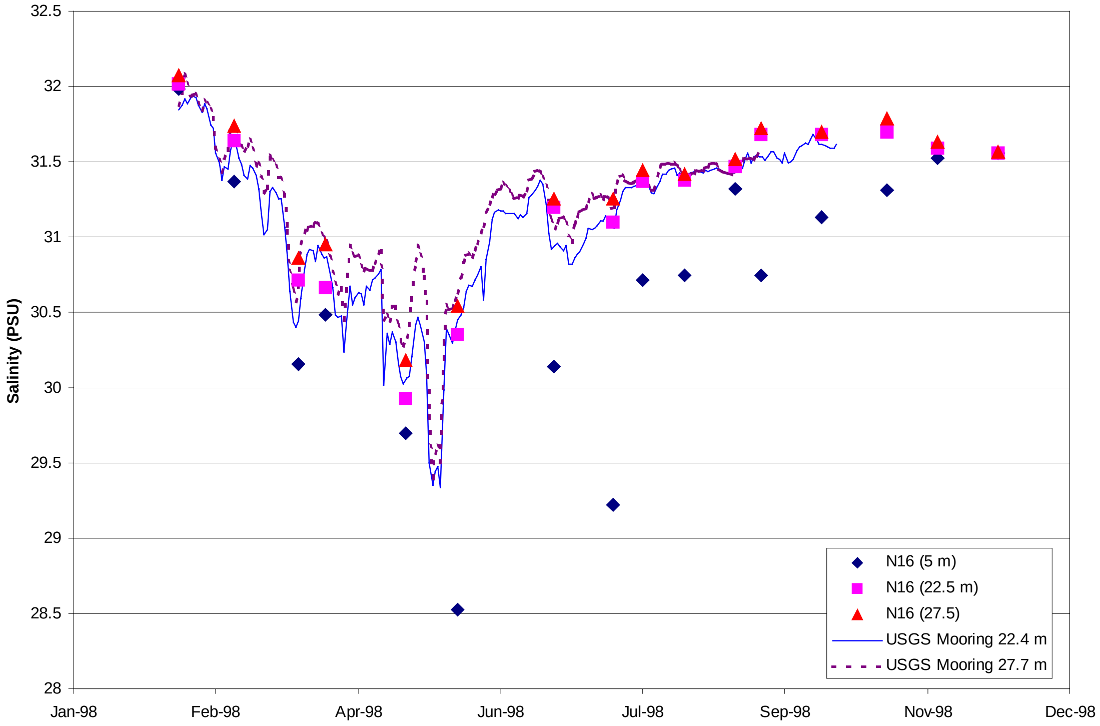


Figure 3-1. USGS Temperature and Salinity Mooring Data.

Mooring data are daily average for comparative purposes.

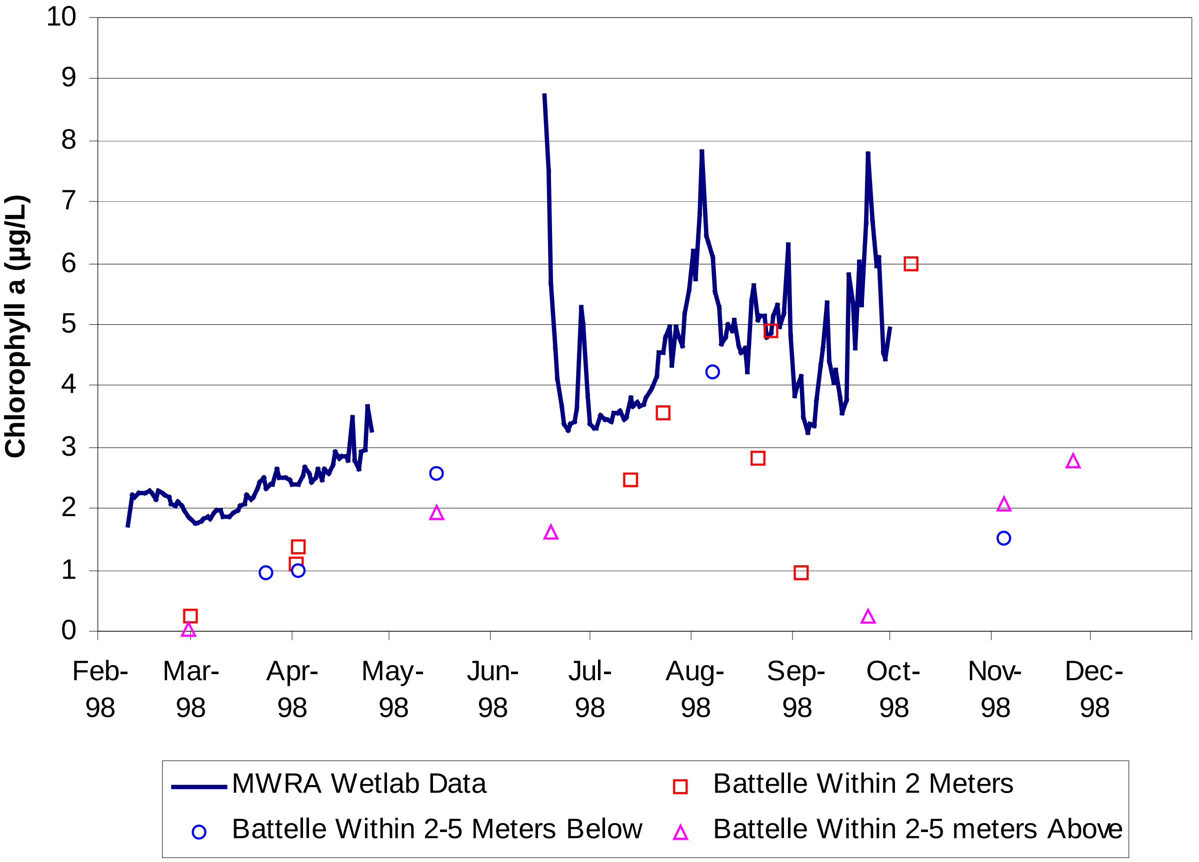


Figure 3-2. MWRA and Battelle Wetlab Chlorophyll a Data.

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 of water column measurements (excepting biological 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 (WF98B), seasonal stratification conditions existed throughout the Bays. By mid-October (WF98E), the density gradient was negligible at the nearshore-nearfield, coastal, and harbor stations while offshore stations maintained a clearly defined pycnocline. The change from stratified to well-mixed conditions in the nearfield is illustrated in Figure 4-1. The inner nearfield stations had become well mixed with respect to density by the mid-October survey while a density gradient of >1.0 still existed at the outer nearfield stations. A density gradient of 0.5 to 1.0 persisted between the surface and bottom waters at these outer nearfield stations through the November surveys.

Data collected during the farfield surveys were evaluated for trends in regional water masses throughout the 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 (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. 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 of 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. This destabilization of the water column significantly affects a number of water quality parameters during this time period. In September to October, the water column begins to become less stratified and nutrients from the bottom waters become available to phytoplankton in the surface and/or mid-water depths. This leads to the development of the fall bloom. The phytoplankton production and further mixing of the water column 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, surface salinity increases, 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 deteriorated at the coastal stations and weakened 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, the water column is stratified when the density gradient between surface and bottom waters is greater than 1.0 sigma-T. Using this definition, the water column stratification had broken down in the inner nearfield region by October (WF98E), but the water column at the outer nearfield stations was not well mixed until late November (Figure 4-2).

4.1.1.1 Horizontal Distribution

In late August (WF98B), surface water temperatures ranged from 11.2 °C at coastal station F05 to 18.3 °C at Cape Cod Bay station F02. In general, cooler surface water temperatures (11-15 °C) were observed in the coastal waters and at the western nearfield stations (Figure 4-3). Warmer surface water temperatures were found at the offshore and eastern nearfield stations (16-18 °C). An incursion of cooler Gulf of Maine water was detected along the northeastern corner of Massachusetts Bay. Diurnal heating of the surface water may have accounted for the variations in temperature that were observed at the nearfield stations. Surface water salinity was fairly uniform throughout the Bays ranging from 29.1 PSU at Boston Harbor station F23 to 31.1 PSU at station F02 in Cape Cod Bay (Figure 4-4). There was a slight increase in surface water salinity across the nearfield from 30.5 inshore to 30.7 offshore. Lower salinity surface water was observed off Cape Ann at station F26. Higher salinity surface water was found at station F05 and was coincident with cooler surface water temperature. This area is relatively shallow and is often the site of strong summer upwelling of bottom waters.

During the nearfield surveys conducted in September (WN98C and WN98D), there was little variation in surface temperature or salinity across the nearfield area. The surface waters at inshore stations continued to be slightly cooler and less saline than at the offshore stations.

By October (WF98E), surface water temperatures were more uniform in Massachusetts Bay ranging from a low of 10.5 °C in the harbor at station F23 to ~13 °C offshore (Figure 4-5). The inshore-offshore gradient in surface water temperature in Massachusetts Bay was equal in magnitude to the north-south gradient between the two Bays. Surface water temperatures were highest (>15 °C) at the southern Cape Cod Bay stations F01 and F02. Surface salinity measurements ranged from 30.1 at station F31 in Boston Harbor to 31.4 at boundary station F27 (Figure 4-6). At station F26 off of Cape Ann, cooler and less saline surface waters were observed on October 16th. This may have been due to increased output from the Merrimack River resulting from an intense rain event October 8-10 (Figure 4-7).

In general during the October survey, lower surface water salinity was observed in the harbor, coastal, and Cape Cod waters and increased with distance from the shoreline. The trend of slightly lower temperatures and lower salinity along the western nearfield was observed in October and continued during the November and December surveys.

4.1.1.2 Vertical Distribution

Farfield. The water column was stratified throughout the region during the summer and early fall of 1998. By late October, the stratified water column conditions had begun to deteriorate and at the shallow, nearshore stations had already become well mixed. 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

(WF98B), 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 late October survey across the region and the water column was well mixed at the harbor and coastal stations. Though stratification had weakened at the Offshore, Boundary, and Cape Cod Bay stations, the $\Delta\sigma_t$ between surface and bottom waters was still >1 and was driven primarily by the continued gradient in temperature over the water column. Temperatures had decreased in the surface waters, but there was still a 4-6°C gradient at these deeper offshore stations (Figure 4-9). A number of farfield stations were visited during the November and December surveys (WN99G and WN99H) and by December the water column at each of these stations had become well mixed.

The temporal and spatial variability during the seasonal return to well-mixed winter conditions was also illustrated 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). A sharp pycnocline was observed at 10-15 m along each of these transects. The pycnocline was shallower at the harbor, coastal, and nearfield stations along the Boston-Nearfield transect and also appeared to shoal at station F05 along the Marshfield transect. The shoaling of the pycnocline may be due to both the Harbor influence (nearfield stations) and upwelling (nearfield and coastal station F05). The upwelling signal was also observed in the vertical contour plots of temperature along these transects (Figure 4-11). Generally, the vertical temperature gradient was >8°C between the surface and bottom layers with a thermocline at 10-15 m. Lower water temperatures were observed in the upper water column at the nearshore nearfield, coastal and harbor stations. Though the cooler harbor temperatures were also associated with lower salinity, the cooler surface layer temperatures at station F05 and to some extent in the nearfield were concomitant with higher salinity (Figure 4-12). This suggests that the cooler, more saline water observed at these stations had been upwelled and may have also served as a source of nutrients to these areas.

By October, stratification had weakened throughout the region. As mentioned above, $\Delta\sigma_t$ was <1 at the nearshore stations and it appeared that there was an inshore-offshore destabilization and deepening of the pycnocline (Figure 4-13). The decrease in the $\Delta\sigma_t$ was driven by changes in surface and bottom water temperatures. While decreasing air temperatures were cooling surface waters, the bottom waters continued to be warmed due to mixing with mid-depth waters. The return to winter conditions can be more clearly 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 (WF98B), the T-S pattern reflects the normal vertical stratification that exists in the Bays during the summer season. Surface water temperatures were generally in the 14-18°C range and throughout the Bays there was a strong thermal gradient (8-10°C) between the surface and bottom water temperatures. Salinity varied over a narrower range (30-32 PSU), but there was a systematic increase in salinity with depth coincident with the decrease in temperature. At the Harbor stations, which were relatively well mixed, the range in both temperature and salinity (except for the low surface salinity at station F23) was narrower compared to the other areas. By the late October survey (WF98E), the range in temperatures had decreased throughout the Bays while the range in salinity remained about the same. The T-S pattern at the deeper stations in the Cape Cod Bay, 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 the harbor and coastal areas, the T-S pattern was shifting towards the characteristics of a well-mixed winter water column.

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 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 October, the inner nearfield stations N10 and N11 had become well mixed with σ_t = 24 for both the surface and bottom waters. At the outer nearfield stations, however, a relatively strong gradient in σ_t existed until December. Figure 4-15 presents σ_t along the nearfield transect (see Figure 1-3) and clearly shows the inshore to offshore progression in the destabilization of the water column during the fall of 1998. In early August (WN98A), stratified conditions were present along the entire nearfield transect and a strong pycnocline was observed at 5-10 m at all stations except station N10. At this harbor-influenced station, tidal forces led to a less defined pycnocline. By the late September survey (WN98D), the pycnocline had deepened to about 15 m, but there was still a sharp gradient in σ_t between the surface and bottom layers. In October, as mentioned previously, the water column had become relatively well mixed in the inner nearfield which includes station N10, but a pycnocline was still present at 15-20 m depth along the rest of the transect. By late November (WN98G), 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 at the offshore stations.

The vertical gradient in temperature was very strong (6-10°C) throughout the nearfield from early August to late September (Figure 4-16). The surface temperatures observed at the inner nearfield stations in August were lower than the temperatures observed earlier in the summer and in September. The data suggest that upwelling events may have brought lower temperature (and nutrient replete) bottom water into the surface layer. This is more clearly shown in time series contours of temperature at stations N01 and N10 (Figure 4-17). In Massachusetts Bay, upwelling events occur regularly during the summer due to prevailing winds that blow from the south and southwest.

The inner nearfield was well mixed with respect to both temperature and salinity by October. The gradient in temperature between surface and bottom waters continued to decline at the outer nearfield stations until December when the water column throughout the region was isothermal. A salinity gradient of ~0.5 PSU was observed at the Broad Sound and outer nearfield stations through December (Figure 4-18). The persistence of this high salinity, deep-water layer apparently led to the annual dissolved oxygen minima for the nearfield region occurring in December. In previous baseline monitoring years, the nearfield DO minima occurred in September or October and DO concentrations increased with the deterioration of stratified conditions. This topic is discussed in more detail in Section 4.2.3.

4.1.2 Transmissometer Results

Water column beam attenuation was measured along with the other *in situ* measurements at all nearfield and farfield stations. The transmissometer determines beam attenuation by measuring the percent transmission of light over a given path length in the water. The beam attenuation coefficient (m^{-1}) is indicative of 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 (WF98B), surface water beam attenuation ranged from 1.01 m^{-1} at station N05 to 5.29 m^{-1} at station F02 (Figure 4-19). The high observation at the Cape Cod Bay station was coincident with elevated phytoplankton counts of ~5 million cells L^{-1} primarily composed of centric diatoms and microflagellates. The fluorescence measurements were not elevated, however, suggesting that the cells had low chlorophyll/cell ratios due to photo bleaching. In Massachusetts Bay, beam attenuation and fluorescence were more closely correlated and elevated levels were observed in the western nearfield and coastal stations in areas of suspected upwelling. As usual, elevated beam attenuation measurements were found at the Harbor stations. Generally, there was an inshore to offshore decrease in beam attenuation that was due to elevated harbor and coastal observations. A similar inshore to offshore decrease in surface water beam attenuation was observed during the October survey (WF98E). The highest value was seen at station F30 (2.71 m^{-1}) in Boston Harbor and the lowest value was observed at station F02 (0.54 m^{-1}) in Cape Cod Bay. In October, the correlation between beam attenuation and chlorophyll fluorescence was stronger with higher values for each being observed at the western nearfield stations and lower values found further offshore and to the south including Cape Cod Bay.

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 phytoplankton (offshore stations). Figure 4-20 presents beam attenuation data along the Boston-Nearfield transect in August (WF98B) and October (WF98E). These contour plots clearly show the harbor signature of high beam attenuation and the harbor influence in the surface water of the western nearfield stations. This figure also illustrates the interaction of harbor and coastal waters in the tidal mixing region between stations F23 and N20.

4.2 Biological Characteristics

4.2.1 Nutrients

Nutrient data were preliminarily analyzed using x/y plots of nutrient depth distribution, nutrient/ nutrient relationships, and nutrient/salinity relationships (Appendix D). As with the physical characteristics, surface water contour maps (Appendix B) and vertical contours from select transects (Appendix C) were also produced from the nutrient data to illustrate the spatial variability of these parameters.

The general trend in nutrient concentrations during the 1998 August to December period was similar to previous baseline monitoring years. Nutrients were depleted in the surface waters during the summer and increased in concentration with the change from a stratified to a well-mixed water column. There were, however, two observations that were noteworthy for this time period. In August, upwelling events supplied nutrients to the surface waters, which supported the maximum phytoplankton populations that were observed in August (Section 5.3). In November and December, elevated concentrations of ammonium and phosphate were observed in the western nearfield that correlated with high concentrations observed in Boston Harbor. The source of these nutrients could not be determined, but may have been due to the transfer of south system sewage flows from Nut Island to the Deer Island facility, or other factors.

4.2.1.1 Horizontal Distribution

During this semi-annual period, the highest nutrient concentrations were consistently measured at the harbor and harbor influenced coastal and nearfield stations. In August (WF98B), dissolved inorganic nutrients were generally depleted in the surface waters at the offshore stations in Massachusetts and Cape Cod Bays. The highest concentrations were observed at the harbor stations and elevated concentrations were seen at the coastal and western nearfield stations due to Harbor discharge and periods of coastal upwelling. By October (WF98E), surface water nutrient concentrations had increased at the harbor and inshore stations while remaining relatively depleted offshore. During the

November and December surveys, extraordinarily high ammonium and phosphate concentrations were observed at the harbor stations and along the western nearfield area.

In August (WF98B), the highest nutrient values were found in Boston Harbor (Ammonia (NH_4) = 7.63 µM, Nitrate (NO_3) = 3.93 µM, and Silicate (SIO_4) = 9.03 µM at station F30; Phosphate (PO_4) = 1.03 µM at station F23). Nutrient concentrations generally decreased outside of the harbor and away from the coast (Figure 4-21). Nitrate and silicate concentrations were depleted at many of the offshore stations (Figures 4-21 and 4-22). The low nutrient concentrations coincided with elevated chlorophyll concentrations and phytoplankton abundance (centric diatoms dominant). The higher nutrient concentrations observed at some of the coastal and western nearfield stations may have been due to input of nutrients into the upper water column by upwelling. This is discussed in more detail in the following section.

By October (WF98E), the nutrient concentrations at the Boston Harbor stations had increased while biological uptake had further depleted the nutrient concentrations in offshore surface waters leading to a strong inshore-offshore gradient (Figure 4-23). The highest nutrient concentrations were observed at the harbor stations F23 (NH_4 = 17.04 µM and PO_4 = 1.84 µM) and F30 (NO_3 = 9.16 µM and SIO_4 = 11.90 µM). Nitrate concentrations were depleted (<0.2 µM) at the offshore stations. The highest productivity rates of the year were measured in the nearfield in October and the increase in production led to a decrease in nutrients in the surface waters. Throughout most of Massachusetts and Cape Cod Bays, NO_3 concentrations had become limiting (>0.2 µM) in the surface waters. Nitrogen limitation may have contributed to the relative increase in surface PO_4 concentrations in October compared to August. Though nutrients were depleted throughout much of the nearfield, nutrient replete conditions were found at the eastern nearfield stations and were coincident with the highest surface fluorescence values of the survey.

The NH_4 and PO_4 concentrations observed in the harbor, coastal and western nearfield waters during the October survey (WF98E) were anomalously high (Figure 4-24). During the November survey (WN98G), high NH_4 and PO_4 concentrations were again observed in the nearfield with highest values on the western side of the nearfield and decreasing concentrations away from the Harbor (Figure 4-25). Nutrient data collected by MWRA for the Boston Harbor monitoring program were also anomalous with NH_4 concentrations 5-10 µM higher than any measurement from 1993-1997 (D. Taylor, personal communication, April 1999). The reason for these high concentrations has not been determined, but it is expected that anthropogenic activities or ecological processes within Boston Harbor led to these atypical conditions.

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 (WF98B), nutrient concentrations were generally low in the surface waters and increased with depth. Low concentrations of NO_3 (Figure 4-26) were found throughout the surface layer and increased near the pycnocline. The elevated nutrient concentrations at the pycnocline were coincident with the subsurface chlorophyll maximum that was observed at the offshore stations during this survey. The typical inshore/offshore gradient of decreasing concentration was observed for each of the dissolved inorganic nutrients along the Boston-Nearfield transect. As mentioned previously, the August survey was conducted during a period of intermittent upwelling conditions. The vertical transect plots for NO_3 suggest that the upwelled bottom waters carried nutrients into the upper water column at the shallow, nearshore stations along the Marshfield transect. Upwelling also brought nutrients into the surface waters of the nearfield area. Due to biological utilization of NO_3, this is not clearly illustrated in Figure 4-26, but transect contours of coincident SiO_4 concentrations suggest that there is an input of nutrients into the nearfield surface layer (Figure 4-27). Time series contour plots of NO_3, PO_4, and SiO_4 at station N01 show the effect of the upwelling events in the nearfield from a temporal perspective (Figure 4-28). It seems that the Harbor and upwelling were significant sources of nutrients to the nearfield surface waters in August.

In October (WF98E), nutrient concentrations were again low and generally depleted in the surface waters at the offshore stations and increased with depth. The harbor signal of higher nutrient concentrations was very strong especially for NH_4, which was high along both the Boston-Nearfield and Cohassett transects (Figure 4-29). Phosphate concentrations were generally higher in October than August and exhibited a strong inshore/offshore gradient of decreasing concentrations across all depths. Silicate and nitrate concentrations in the bottom waters had also increased since the August survey (Figure 4-30). The degradation of summer phytoplankton assemblages and remineralization of the nutrients at depth may have contributed to the increase in bottom water nutrient concentrations.

Nutrient-salinity plots are useful in distinguishing water mass characteristics and in examining regional linkages between water masses (Appendix D). Dissolved inorganic nitrogen (DIN) plotted as a function of salinity exhibits a pattern that is often observed (Figure 4-31): a decrease in DIN concentration with increasing salinity over the lower salinity range, low or depleted DIN at intermediate salinity, and increasing DIN concentration with increasing salinity at higher salinities. The decreasing trend in DIN concentration at lower salinity is indicative of the dilution of Harbor DIN with low-nutrient 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 both surveys, the Harbor was a source of DIN (primarily NH_4 – see Appendix D) to the coastal and western nearfield and summer conditions existed throughout the rest of the Bays.

Nearfield. The nearfield surveys are conducted more frequently and provide a higher resolution look at temporal variation in nutrient concentrations over the semi-annual period. In previous sections, the delay in 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 November (WN98G). The progression from summer to winter conditions is illustrated in the series of nearfield transect plots presented in Figure 4-32. In August (WN98A), NO_3 concentrations were depleted in the surface waters across the nearfield area and low concentrations continued to be present through early November except at the harbor-influenced station N10. By the end of November (WN98G), the water column had become relatively well mixed and relatively high NO_3 concentrations were observed throughout the nearfield. A similar trend was observed for silicate. Phosphate concentrations, however, had begun to increase in surface waters by late September. This apparent increase may have been due to nitrogen limitation of phytoplankton in the nearfield and inability of phytoplankton to utilize the available PO_4. Ammonium concentrations were very low along the nearfield transect during the first three surveys of this period. By late September (WN98D), elevated NH_4 concentrations (>2 μM) were observed in the surface at station N10 and at depth along the nearfield transect (Figure 4-33). In October (WF98E), productivity achieved its maximum rates in the nearfield and NH_4 was once again depleted across most of the region. The elevated concentrations found at depth during this survey were the result of a combination of biological decomposition and nutrient regeneration processes. A strong harbor signal was seen in early November (WN98F) and by late November (WN98G) the anomalously high NH_4 concentrations were observed across the nearfield region. Ammonium concentrations in December had returned to a typical range for winter conditions, but the availability of NH_4 and PO_4 in late

November may have contributed to the anomalously high chlorophyll concentrations that were observed in December.

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). The DIN:PO_4 ratio was less than the Redfield value of 16 during each of the surveys. Nitrogen limiting conditions existed in the surface waters of the nearfield and throughout the Bays during WN98D and WF98E (Figure 4-34).

4.2.2 Chlorophyll A

Chlorophyll concentrations (based on *in situ* fluorescence measurements) were relatively high during this time period. Maximum chlorophyll values were measured across the region during the August survey WF98B coinciding with the highest phytoplankton abundance. High chlorophyll concentrations were also observed in the nearfield area (14.8 μg L^{-1}) during the fall bloom (WF98E). The typical trend of decreasing chlorophyll concentrations after the fall bloom was observed in the nearfield in November, but during the December survey (WN98N) anomalous chlorophyll concentrations were found at stations throughout the Bays. The mean chlorophyll concentrations in December ranged from 3.5μg L^{-1} in Cape Cod Bay to 8.2 μg L^{-1} at boundary station F29 and a mean concentration of 7.5 μg L^{-1} was measured for the nearfield area.

4.2.2.1 Horizontal Distribution

There was a strong inshore/offshore gradient in chlorophyll concentrations during the August survey (Figure 4-35). High chlorophyll concentrations were observed along the western half of the nearfield with the survey maximum recorded at station N11 (13.03 μg L^{-1}). There was a very sharp gradient between the high nearshore concentrations and the surface chlorophyll concentrations observed in the eastern nearfield where the survey minimum was found at station N04 (0.03 μg L^{-1}). Low surface chlorophyll values (<0.5 μg L^{-1}) were seen throughout the northeastern portion of Massachusetts Bay. Surface chlorophyll concentrations were high in Boston Harbor (3.8-7.5 μg L^{-1}) and at the near-harbor coastal stations (6.0 to 9.0 μg L^{-1}). In southern Massachusetts Bay, a band of elevated surface chlorophyll concentrations extended from coastal station F05 to station F29 off Provincetown. Lower chlorophyll concentrations were observed at the Cape Cod Bay stations (0.5 to 1.5 μg L^{-1}). The pattern of surface chlorophyll generally corresponded to spatial variations observed in phytoplankton abundance in Massachusetts Bay, but the low chlorophyll concentration found in Cape Cod Bay were coincident with high phytoplankton abundance (4-5 million cells L^{-1}).

In October (WF98E), surface chlorophyll concentrations ranged from 0.48 μg L^{-1} at station F02 to 11.91 μg L^{-1} at station N20. The range was similar to that seen in August, but elevated chlorophyll concentrations were found throughout Massachusetts Bay during the fall survey (Figure 4-36). The highest concentrations were located in the western nearfield where a sharp gradient had been observed in nitrate concentrations (see Figure 4-23). In the eastern nearfield and offshore Massachusetts Bay, surface chlorophyll concentrations generally decreased with distance from shore though the pattern was irregular with values ranging from 0.5 to 5 μg L^{-1}. The decrease in nutrient availability may have limited phytoplankton production at these offshore stations. Lower chlorophyll concentrations were also observed at the harbor stations, along the south shore and in Cape Cod Bay.

4.2.2.2 Vertical Distribution

Farfield. The 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 (6-9 $\mu g\ L^{-1}$) were found in the surface waters at harbor, coastal and western nearfield stations (Figure 4-37). The high chlorophyll concentrations found in the inshore waters were concomitant with very high phytoplankton abundance (4-5 million cells L^{-1}). The main difference between inshore and offshore phytoplankton assemblages was the high number of pennate diatoms at the nearshore stations (1-2.5 million cells L^{-1}). At the offshore stations along each transect, a sharp subsurface chlorophyll maximum was observed at or just below the pycnocline. This depth was coincident with increasing nutrient concentrations. Though the subsurface chlorophyll maximum extended throughout most of Massachusetts Bay, the eastern nearfield exhibited relatively low chlorophyll concentrations in both surface and deep waters.

By October (WF98E), a fall bloom was occurring in the nearfield area while chlorophyll concentrations had generally decreased across the rest of Massachusetts Bay (Figure 4-38). Along the Boston-Nearfield transect, chlorophyll concentrations were >12 $\mu g\ L^{-1}$ in the subsurface chlorophyll maximum at stations N20 and N21. These high nearfield concentrations were coincident with the highest phytoplankton counts observed during this farfield survey (2-3 million cells L^{-1}) and the highest productivity observed at stations N04 and N18 for the 1998 monitoring year (1500-2000 mg C $m^{-3}\ d^{-1}$). In October, Boston Harbor chlorophyll concentrations were <3 $\mu g\ L^{-1}$ as were surface chlorophyll concentrations along both the Cohassett and Marshfield transects. A broad band of elevated chlorophyll concentrations (3-6 $\mu g\ L^{-1}$) was observed along these transects situated above the weakening pycnocline over a depth of 5 to 25 m.

Five farfield stations were sampled during the December nearfield survey WN98G. During each of the previous baseline monitoring years, chlorophyll concentrations decreased rapidly following the fall bloom and the overturn of the water column. In December 1998, chlorophyll concentrations were high at each of the farfield stations. The highest concentration was observed at station F29 off Provincetown (15.5 $\mu g\ L^{-1}$). In Cape Cod Bay, chlorophyll concentrations ranged from 1.0 to 8.6 $\mu g\ L^{-1}$ and at harbor station F23, chlorophyll values of 3.4 to 6.6 $\mu g\ L^{-1}$ were observed. SeaWiFS images indicated that elevated chlorophyll concentrations were present not only in Massachusetts and Cape Cod Bays but also throughout much of the western Gulf of Maine in early December (Figure 4-39 or see Appendix I).

Nearfield. The mean chlorophyll concentration and range of values observed during each of the surveys conducted during this time period are presented in Figure 4-39. The data are presented for the surface, mid-depth and bottom sampling depths. When a subsurface chlorophyll maximum was present, the mid-depth data was collected within the maximum. In August, the mean chlorophyll concentrations in the surface and mid-depth waters was about 5 $\mu g\ L^{-1}$ during WN98A and WF98B and decreased to 2-3 $\mu g\ L^{-1}$ by early September (WN98C). Chlorophyll concentrations at these depths had increased by late September and into October. During the October survey, the mean chlorophyll concentration at the subsurface chlorophyll maximum was 10 $\mu g\ L^{-1}$ which was the highest survey mean observed during this time period. Chlorophyll concentrations were low (<2 $\mu g\ L^{-1}$) during the two November surveys, but in December an unprecedented winter bloom was observed in the nearfield area with surface chlorophyll concentrations ranging from 3 to 13 $\mu g\ L^{-1}$. The wide range in chlorophyll concentrations that were observed during August, October, and December chlorophyll events is indicative of the inshore/offshore variability that was observed in the nearfield area during this time period.

The vertical distribution of chlorophyll was examined in more detail along a transect from the southwest corner to the northeast corner of the nearfield area (see Figure 1-3). The southwest corner, station N10, often exhibits a harbor chlorophyll signal while an offshore chlorophyll signal is more often observed at the northeast corner, station N04. In early August (WN98A), chlorophyll concentrations were at a maximum in the surface waters at harbor-influenced station N10 (6-9 $\mu g\ L^{-1}$) while a subsurface chlorophyll maximum was observed at each of the other stations along the transect (Figure 4-40). The highest chlorophyll concentrations (>12 $\mu g\ L^{-1}$) were seen at station N19 in a subsurface layer between 5 and 10 m. At the end of August (WF98B), elevated chlorophyll concentrations were only found at stations N10 and N19 and were associated with the nearshore pennate diatom bloom mentioned above. In the eastern nearfield, chlorophyll concentrations were low (<3 $\mu g\ L^{-1}$) throughout the water column and this area seemed to be a transitional zone between the nearshore and offshore water masses. By early September (WN98C), chlorophyll concentrations had decreased at stations N10 and N19 with a subsurface maximum of 6-9 $\mu g\ L^{-1}$ at 5 m

The fall bloom in the nearfield started by late September (WN98D) and continued through October (WF98E). The bloom appears to have been initiated in the shallow western portion of the nearfield and progressed offshore. This is suggested by the chlorophyll data for late September presented in Figure 4-41, which shows elevated concentrations at the nearshore stations N10 (surface) and N19 (subsurface). The highest concentrations (9-12 $\mu g\ L^{-1}$) were observed at station N19 in the subsurface chlorophyll maximum at 10 to 15 m. A subsurface chlorophyll maximum of 6-9 $\mu g\ L^{-1}$ was also observed at stations N21 and N15. In October (WF98E), the fall bloom extended over the entire nearfield area. High surface chlorophyll concentrations were observed inshore, while subsurface maxima were seen at the offshore stations. Chlorophyll concentrations >12 $\mu g\ L^{-1}$ were measured at stations N21 and N04.

The inshore to offshore progression of the fall bloom in the nearfield area was corroborated by the productivity and phytoplankton data. During the late September survey (WN98D), production at station N18 (vicinity of N19 and N21 on the Nearfield transect) was about 1000 mg C $m^{-2}\ d^{-1}$ while at station N04 it was only 200 mg C $m^{-2}\ d^{-1}$. Phytoplankton abundance at station N18 was about four times higher than the abundance at station N04 and the phytoplankton assemblage at N18 was dominated by centric diatoms, which were present in very low numbers at N04. In October, annual peaks in production were measured at both station N18 and station N04. Phytoplankton abundance was high (2-3 million cells L^{-1}) in the mid-depth samples at stations N04, N18 and N16. Centric diatoms (1-2 million cells L^{-1}) dominated the phytoplankton assemblage at these stations. It appears that survey WN98D was conducted during the initiation of the fall bloom and survey WF98E was conducted at or near the peak of the bloom.

By early November (WN98F), the fall bloom had ended and chlorophyll concentrations were <3 $\mu g\ L^{-1}$ throughout the nearfield area (Figure 4-41). During previous baseline monitoring years, low chlorophyll conditions persisted after the collapse of the fall bloom, but in December of 1998, chlorophyll concentrations of 0.3 to 13.2 $\mu g\ L^{-1}$ were observed in the nearfield. The highest concentrations were observed in the surface water of the western nearfield. The anomalously high NH_4 and PO_4 concentrations that were observed in this area during the late November survey (WN98G) might have triggered a localized (Harbor-Nearfield) increase in phytoplankton. There was a 50% to 100% increase in phytoplankton abundance at stations N04 and N18 from late November to December and most of the increase was due to an increase in the abundance of diatoms. The pennate diatom *Pseudo-nitzschia pungens* was dominant at both N04 and N18. This “species” is a grouping of two *Pseudo-nitzschia* species that cannot be distinguished using light microscopy – true *P. pungens* and the domoic acid producing *P. multiseries*.

As mentioned above, high chlorophyll concentrations were also observed in and near Cape Cod Bay (stations F02, F03 and F29) and satellite imagery indicated elevated chlorophyll concentrations in most of the western Gulf of Maine waters. This suggests that the increase in chlorophyll and phytoplankton in the nearfield may have been part of a regional rather than a localized event. The input of NH_4 and PO_4 from Boston Harbor may have contributed to the high chlorophyll concentrations that were observed in the nearfield, but based on the chlorophyll data and SeaWiFS images it appears that the nearfield bloom may have been part of a regional chlorophyll bloom.

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 DO concentration for this semi-annual period was measured in the nearfield during the December survey (4.54 mg L^{-1}). The mean bottom water concentration in December (~7 mg^{-1}) was the lowest survey mean in 1998. Regionally, a DO concentration minimum of 6.09 mg L^{-1} was observed in Cape Cod Bay in October (WF98E). Due to the persistence of stratified conditions, survey mean DO concentrations decreased from August to December in the nearfield bottom waters. The relatively high initial bottom water DO concentrations that were observed in June (nearfield mean = 11.2 mg L^{-1}) kept the survey mean values from reaching the extremely low levels that had been observed during previous years.

4.2.3.1 Regional Trends of Dissolved Oxygen

The DO of bottom waters was compared between areas over the course of the two combined surveys and the last two nearfield surveys. A time series of the average bottom water DO concentration for each area is presented in Figure 4-42a. Average bottom water DO concentrations ranged from 7.0 to 10.0 mg L^{-1}. From August to October, bottom water DO concentrations decreased 1.5-2 mg L^{-1} in each of the areas. In the boundary area, DO concentrations continued to decrease into late November (WN98G) when the lowest average bottom water DO concentration was observed. No other farfield stations were sampled during survey WN98G and it is unclear if DO concentrations continued to decline throughout the region. By December (WN98H), DO concentrations in the boundary area, Boston Harbor and Cape Cod Bay had increased.

The summer/fall decline in bottom water DO concentrations was also observed in the DO %saturation data (Figure 4-42b). In August (WG98B), harbor and coastal bottom waters were supersaturated due to relatively high production rates at these shallow inshore stations. In the other areas, DO %saturation ranged from 90-95%. By October, DO %saturation had decreased to 79-92% regionally. The decreasing trend continued into November in the boundary area where DO %saturation reached a regional annual minimum value of 72%. Boundary and Cape Cod bottom waters were near 100% saturation by December, but Boston Harbor bottom water had decreased since October to 82% saturation.

In August, the spatial distribution of DO was governed by biological and physical processes and a vertical gradient of decreasing DO with depth was observed (Figure 4-43). The stratification of the water column had separated the surface and bottom water layers and disassociated the biological processes of production and respiration. While respiration occurs over the entire water column, it is offset by primary production and aeration in the surface waters and exacerbated by sediment respiration resulting in decreasing DO concentrations. The layers of high DO concentrations (>11 mg L^{-1}) along each of the transects was concomitant with the subsurface chlorophyll maximum.

By October, DO concentrations decreased over the entire water column (Figure 4-44). Surface water DO concentrations exhibited an inshore to offshore increase of ~1 mg L^{-1}. The nearshore stations were generally well mixed with respect to DO. At the offshore stations, DO concentrations decreased with increasing depth and DO concentrations of 7-8 mg L^{-1} were observed in the bottom waters along each of the transects. Station F28, which is on Stellwagen Bank, was well mixed and DO concentrations of 9-10 mg L^{-1} were measured. It is expected that DO concentrations at boundary station F28 remained high during the remainder of the year. The low bottom water DO concentration observed in the boundary area in November was at station F12, which is a deep station (~90 m deep) situated in 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 4-45). The gradient in DO concentration between the surface and bottom waters ranged from 1 to 3 mg L^{-1} over this time period (Figure 4-45a). The trends in surface DO concentration followed changes in biological parameters. The highest DO concentrations were observed in early August when chlorophyll concentrations and phytoplankton abundance were also high. After declining in September, surface DO concentrations increased in October coinciding with the fall bloom. Elevated surface DO concentrations were also seen in December when abnormally high chlorophyll concentrations were observed.

DO concentrations in the nearfield bottom waters decreased from early August to December. The initial decrease from 9.6 mg L^{-1} in early August (WN98A) to 7.8 mg L^{-1} in late September (WN98D) constituted the majority of the seasonal decline. Bottom water DO concentrations remained relatively constant from late September to late November (WN98G). By December (WN98H), bottom water DO had decreased to 7 mg L^{-1}, which was the minimum value for the nearfield during this time period. The persistence of stratified conditions at the eastern nearfield stations resulted in the continual decline in bottom water DO concentrations. Normally, the water column would become well mixed in November and bottom water DO concentration would increase. In 1998, the delay in mixing combined with the atypical winter phytoplankton bloom led to an annual minimum in bottom water DO concentration during the December survey. Although physical and biological conditions in 1998 led to an extended period of DO decline in the nearfield bottom waters, the 1998 nearfield minimum was not the lowest in comparison to previous baseline monitoring years.

DO % saturation followed the same trend as DO concentration in the nearfield surface and bottom waters (Figure 4-45b). The surface waters were supersaturated from August to October and remained near saturation in November and December. Bottom water DO decreased from 94% saturation in August to 80% saturation in late September. DO %saturation remained at 80% until December when it decreased to ~70%.

4.3 Summary of Water Column Results

- The breakdown of stratified conditions was delayed in 1998 relative to other years. In the farfield, seasonal stratification deteriorated at the coastal stations and began to weaken at the offshore stations by the October survey (WF98E).
- In the nearfield area, the data indicate that the pycnocline broke down in the western nearfield by October (WF98E), but the water column at the outer nearfield stations was not well mixed until late November (WN98G).

- Upwelling events in August brought cooler, more saline and nutrient replete waters into the surface layer at coastal and western nearfield stations supporting the high phytoplankton abundance that was observed.
- The highest nutrient concentrations were consistently measured at the harbor and harbor-influenced coastal and nearfield stations.
- In November and December, anomalously high concentrations of ammonium and phosphate were observed in the western nearfield that correlated with high concentrations observed by MWRA in Boston Harbor. The source of these nutrients was not determined, but may have been due to the transfer of south system sewage flows from Nut Island to the Deer Island facility or other factors.
- Maximum chlorophyll values were measured across the region during the August survey (WF98B) coinciding with the highest phytoplankton abundance.
- Chlorophyll, productivity and phytoplankton data suggest that the fall nearfield bloom occurred from September to October. The bloom initiated in the shallow western portion of the nearfield and progressed offshore.
  - September (WN98D): high chlorophyll nearshore decreasing to the east, production and phytoplankton abundance was high at N18 and low at N04;
  - October (WF98E): high chlorophyll throughout nearfield area, peak annual production at N18 and N04, high phytoplankton abundance across nearfield at N18, N04, and N16.
- An unprecedented winter bloom was observed in December in Cape Cod Bay and the nearfield. The nearfield bloom coincided with anomalously high NH_4 and PO_4 concentrations that might have triggered the localized increase in phytoplankton.
- Due to the persistence of stratified conditions, bottom water DO concentrations decreased from August to December in the nearfield.
  - The delay in mixing and the atypical winter phytoplankton bloom led to the annual minimum in bottom water DO concentration (7 mg L^{-1}) observed in December.
  - The relatively high initial bottom water DO concentration (11.2 mg L^{-1}) that was observed in June lessened the effect of the delay in returning to well-mixed winter conditions.

5.0 PRODUCTIVITY, RESPIRATION, AND PLANKTON RESULTS

5.1 Productivity

Production measurements were taken at two nearfield stations (N04, N18) and one farfield station (F23) near the entrance of Boston Harbor during the second half of 1998. All three stations were sampled on August 24, 1998 (WF98B) and October 7, 1998 (WF98E). Stations N04 and N18 were additionally sampled on August 7, (WN98A), September 3, (WN98C), September 24, 1998 (WN98D), November 4, 1998 (WN98F), November 25, 1998 (WN98G), and December 16, 1998 (WN98H). Production was determined by measuring ^{14}C uptake 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 of the productivity samples, they 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 chlorophyll-specific areal production (mg C mg Chl^{-1} d^{-1}) are presented (Figures 5-2 and 5-3). Areal productions are determined by integrating measured productivity (and chlorophyll-specific 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 and 5-5).

5.1.1 Areal Production

Areal production at one of the nearfield stations, N04, fluctuated between 200-500 mg C m^{-2} d^{-1} from August 7, 1998 through September 24, 1998 (Figure 5-2). The peak annual production for 1998 (1665-mg C m^{-3} d^{-1}) was reached on October 7, 1998 (WF98E). Values remained somewhat elevated (~700-800 mg C m^{-3} d^{-1}) compared to August and September throughout the remainder of the annual cycle (WN98F-WN98H) at station N04. A similar pattern was observed at station N18, the second nearfield station (Figure 5-2). Areal production varied around 300-450 mg C m^{-3} d^{-1} during August (WN98A and WN98B) and early September (WN98C) then increased to ~1000 mg C m^{-3} d^{-1} on September 24, 1998 (WN98D) and reached the annual maximum of 1988 mg C m^{-3} d^{-1} on October 7, 1998 (WF98E). Values remained at ~650-700 mg C m^{-3} d^{-1} for the remainder of the year.

At the Boston Harbor productivity/respiration station (F23), areal production was measured only twice from August through December 1998. In August (WF98B) production here was measured as 751.7 mg C m^{-3} d^{-1} and was higher than the nearshore stations. In October (WF98E) production was lower than August and did not display the peak annual levels that were observed at the two nearfield sites (Figure 5-2). The production data are in agreement with the chlorophyll data, which indicated that a phytoplankton bloom occurred during the fall period at stations N04 and N18 (see below) but not at F23.

A well-established fall bloom was observed at station N18 (Figure 5-2). The bloom was initiated in late August, reached its peak on October 7, 1998 and declined by November 4, 1998. The bloom lasted about 10 weeks at this station. A less well-developed fall bloom was observed at station N04. The bloom at this site was established later (late September), reached a lower peak production level and was a shorter duration. Bloom duration at station N04 appeared to be about 3-4 weeks.

Relative to other years, areal production at all three survey stations was low throughout the late summer and fall periods. In general, nearfield stations are characterized by the occurrence of a winter/spring phytoplankton bloom, relatively high production during the summer and a fall bloom. A gradual pattern of increasing areal production from winter through summer is more typical of the harbor (station F23). The fall phytoplankton blooms observed at nearfield stations in 1995-1997 generally reached values of 2000 to 4000 mg C m^{-3} d^{-1}, with blooms typically lasting 1-2 months. The fall phytoplankton bloom during 1998 was generally a lower magnitude bloom than those observed in prior years at station N04 (peak ~1665 mg C m^{-3} d^{-1}). Areal production at station N18 has only been measured during 1997 and 1998. The 1998 peak was about half the value observed in 1997 and the duration was somewhat less. Relative to station N16, a nearby site monitored from 1995-1996, the fall bloom at N18 in 1998 was very similar to prior years.

The productivity cycle at station F23 was also aberrant in August and October 1998. Production values were considerably lower than earlier years and did not display any tendency to increase over the year. During 1995-1997, peak areal productions at station F23 ranged from 2000 to 8000 mg C m^{-2} d^{-1} in the fall. The peak areal production observed at station F23 in August 1998 was 3-10 times lower than peak fall values observed in previous years.

The production values at stations F23, N04 and N18 are consistent with the chlorophyll values observed during the survey period with the exception of the December values. During December, chlorophyll values at station N04 and N18 were elevated while production was not.

Chlorophyll-specific areal production (Figure 5-3) showed a gradual-increasing trend over time at stations N04 and N18 during the fall–winter period. Chlorophyll-specific areal production was relatively low and constant at station F23 throughout the sampling cycle. 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 moderately high in relation to the amount of biomass present at the nearfield stations during the fall bloom. At station N18, chlorophyll-specific production was greater than 700 mg C mg Chl a^{-1} d^{-1} during the early November survey (WN98F). This period of high productivity per unit chlorophyll coincided with the end of the fall bloom. At station N04, the chlorophyll-specific production reached a maximum value of 1059 mg C mg Chl a^{-1} d^{-1} at the same time that production was maximized (October 7, 1998).

5.1.2 Volumetric Production

The spatial and temporal distribution of production and chlorophyll-specific production on a volumetric basis were summarized by contouring production over the sampling period (Figures 5-4 to 5-7). 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.

Daily production was concentrated in the upper 5 m of the water column at station N04 during the fall-winter sampling cycle. A subsurface (5-10 m) productivity maximum was measured at station N18 on October 7, 1998 (WF98E). No subsurface production peaks were observed at station N04 during this sampling cycle. At the two nearfield stations, productions tended to increase during the fall with peak values occurring in October for both stations. For station N04, the highest production value observed (177 mg C m^{-3} d^{-1}) occurred at the surface on October 7, 1998. Peak production values tended to be correlated with the occurrence of the highest chlorophyll *a* measurements. The fall productivity pattern observed in 1998 was similar to that observed in prior years, although peak values continued to be somewhat depressed. Peak fall productions typically occurred in the surface waters at station N04 from 1995-1997. A subsurface production maximum was observed in the fall at station N16 in 1995, but not in 1996 or at station N18 in 1997.

Chlorophyll-specific production at stations N04 and N18 was concentrated in the upper portions of the water column (Figures 5-6 and 5-7). Peak chlorophyll-specific productions occurred during October at station N18 and in early November at station N04. The observed pattern suggests that the efficiency of photosynthesis increased slightly with time up to (or just following) the fall production peak then declined again. When the efficiency of photosynthesis is high but not reflected in higher phytoplankton biomass (measured as total chlorophyll *a*) it suggests that other processes (such as predation by zooplankton) are important in controlling the patterns observed.

5.2 Respiration

Respiration measurements were made at the same nearfield (N04, 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 $\mu MO_2\ hr^{-1}$) and carbon-specific respiration ($\mu MO_2\ \mu MC^{-1}\ hr^{-1}$) rates are presented in the following sections. Carbon-specific respiration was calculated by normalizing respiration rates to the coincident particulate organic carbon (POC) concentrations. Carbon-specific respiration rates provide a relative indication of the biological availability (labile) of the particulate organic material for microbial degradation.

5.2.1 Water Column Respiration

Due to the timing of the surveys, the farfield stations were only sampled twice (August – WF98B and October – WF98E). Evaluations of the temporal trends are therefore focused on the nearfield area where data are available over the whole August to December time period.

High respiration rates had been observed at the end of the previous reporting period ranging from 0.07-0.32 $\mu MO_2\ hr^{-1}$ at the nearfield stations. By early August (WN98A), respiration rates had decreased to 0.05-0.21 $\mu MO_2\ hr^{-1}$ at N18 and <0.15 at N04 (Figure 5-8). At station N18, respiration continued to decline through late August (WF98B) with rates of 0.14 $\mu MO_2\ hr^{-1}$ in the surface waters and <0.02 at the mid and bottom depths. Respiration rates at station N04 had increased to ~ 0.2 $\mu MO_2\ hr^{-1}$ in the surface and mid depth waters by late August, which coincided with an increase in chlorophyll concentrations at this outer nearfield station.

Nearfield respiration rates reached a maximum for this time period during the late September survey (WN98D) with values ranging from 0.16-0.23 $\mu MO_2\ hr^{-1}$ and 0.1-0.33 $\mu MO_2\ hr^{-1}$ at stations N04 and N18, respectively. There was an obvious gradient in rates decreasing from maximum values in surface waters to minimum values in bottom waters.

During the October survey WF98E, high chlorophyll concentrations and production rates were observed at mid depth (subsurface chlorophyll maximum) suggesting the presence of a fall bloom. Respiration rates, however, had decreased from September values. At station N04, rates ranged from ~0.17 μMO_2 hr^{-1} at the surface and mid depths to 0.02 μMO_2 hr^{-1} in the bottom waters and at station N18 respiration rates were 0.15-0.20 μMO_2 hr^{-1} at the surface and mid depths and 0.06 μMO_2 hr^{-1} in the bottom waters. Though rates had decreased, mid depth respiration values had remained relatively high in comparison and were coincident with the elevated levels of production.

Respiration rates continued to decrease with the decreasing water temperatures through November (WN98F and WN98G) and December (WN98H). By December, respiration rates were <0.05 μMO_2 hr^{-1} at each of the depths at stations N04 and N18. The patterns and magnitude of the rates observed in the respiration data for the nearfield stations were similar to previous years for this time period. This is due to the relative consistency of the fall bloom from year to year (Sept-Oct peak in respiration rates) and the decrease in water temperature and increased mixing associated with the fall/winter turnover of the water column (post-bloom decrease in rates).

Given the paucity of data at the farfield stations for this period, it is difficult to clearly characterize the seasonal trends in respiration. At station F23, respiration rates were at a maximum at each of the depths (0.15-0.27 μMO_2 hr^{-1}) during the August survey (WF98B). Unlike the trends observed at the nearfield stations, respiration was highest in the bottom waters at this shallow harbor. By the October survey (WF98E) respiration rates at F23 had decreased to 0.1-0.14 μMO_2 hr^{-1}, which coincided with a decrease in chlorophyll concentrations from August to October. Respiration rates at the Stellwagen Basin station F19 were relatively high in August at the surface (0.28μMO_2 hr^{-1}) and ranged from 0.07-0.14 μMO_2 hr^{-1} at the bottom and mid depths. Respiration rates had decreased slightly in the surface and bottom waters by the October survey, but had increased to 0.25μMO_2 hr^{-1} at mid depth which coincided with a subsurface chlorophyll maximum at station F19.

5.2.2 Carbon-Specific Respiration

Carbon-specific respiration accounts for the effect that 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.

There was a general decrease in POC concentrations from early August to early September (station N18) and late September (station N04). POC concentrations then increased reaching maximum values at both stations in October (Figure 5-9). This pattern was consistent with the trends observed in chlorophyll over this time period. POC concentrations were similar in the surface and mid depth waters at station N04 from August to December decreasing from ~35 µM in early August to 15-20 µM in September then reaching a maximum of 45-50 µM in October. The bottom water POC concentration at station N04 remained relatively constant (10 µM) from August to October and then increase to 25 µM in early November (WN98F). This increase was probably due to the settling out of the fall bloom. At station 18, the POC concentrations in the surface and mid depth waters were not comparable until late September when subsurface chlorophyll concentrations had begun to increase and POC concentrations were at a maximum in both the surface (45 µM) and mid depth (42 µM) waters. POC concentrations had decreased slightly at the surface and mid depths by the October survey, but had reached the maximum value in the bottom waters (29 µM). This pattern was similar to that seen at station N04 except it suggests the fall bloom may have senesced and begun sinking from the water column earlier at N18. At station F23, POC concentrations decreased from 40-50µM in August to 15-20µM in December.

At station N04, the decrease in POC concentrations from August to late September was coincident with increasing respiration rates. This resulted in a substantial increase in the carbon-specific respiration rate indicating that even though the total POC was decreasing that the POC that was present was labile or that another pool of labile organic carbon was present (Figure 5-10). The DOC concentrations at station N04 were higher in September than during previous or subsequent months. The increase in carbon-specific respiration may have resulted from a combination of increased phytoplankton productivity (which increased in September reaching a maximum in October) and increased grazing pressure on the phytoplankton. In October, production and chlorophyll concentrations reach maximum levels and high POC concentrations were measured. Carbon-specific respiration rates, however, were low at stations N04 and N18 ranging from 0.002-0.005 $\mu MO_2/\mu MPOC^{-1}hr^{-1}$ suggesting that the October survey was conducted near the conclusion of the fall bloom. At station N18, carbon-specific respiration rates remained relatively low and constant at station N18 throughout this time period.

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 11 farfield plus the two nearfield stations (total = 13) during the farfield surveys. Phytoplankton samples included both whole-water and 20 µm-mesh screened samples, from the surface and mid-depth. 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 abundances in nearfield whole water samples (surface and mid-depth) remained high (> $0.5X10^6$ cells L^1) from August through early October (Table 5-1; Figures 5-11 and 5-12). These continued a phytoplankton bloom, which had shown a sustained increase from February through July. In late October, however, phytoplankton abundance declined to levels generally half or less of the summer levels, remaining low through December.

Total phytoplankton abundance in farfield whole water samples (surface and mid-depth) showed similar high abundances in August, with lower levels in October (Table 5-1).

Total abundances 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. Nonetheless, similar seasonal trends, though of different taxa, were recorded. Screened phytoplankton abundance fluctuated, but overall decreased from August through December (Table 5-2). These decreases in screened phytoplankton abundance largely reflected a decline in the sustained bloom of the dinoflagellates *Ceratium fusus, Ceratium tripos,* and other species of this genus which had increased from February through July.

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

Survey	Dates (1998)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WN98A	8/7	2.266	1.501-3.432	NA	NA
WF98B	8/18-25	1.938	0.307-4.035	3.533	0.823-5.257
WN98C	9/3	1.312	0.544-2.203	NA	NA
WN98D	9/24	1.376	0.547-2.333	NA	NA
WF98E	10/5-16	1.904	0.950-2.802	0.843	0.208-1.445
WN98F	11/4	0.781	0.665-0.904	NA	NA
WN98G	11/25	0.446	0.346-0.702	NA	NA
WN98H	12/16	0.724	0.605-0.936	NA	NA

NA- Data not available because the farfield stations were not sampled during this survey.

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

Survey	Dates (1998)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WN98A	8/7	4200	2183-6733	NA	NA
WF98B	8/18-25	1516	566-2735	2452	283-8992
WN98C	9/3	809	369-1682	NA	NA
WN98D	9/24	488	135-852	NA	NA
WF98E	10/5-16	744	452-1086	633	62-1940
WN98F	11/4	1670	1366-2075	NA	NA
WN98G	11/25	1556	621-2939	NA	NA
WN98H	12/16	3533	2469-4813	NA	NA

NA- Data not available because the farfield stations were not sampled during this survey.

5.3.1.2 Nearfield Phytoplankton Community Structure

Whole-Water Phytoplankton - During August (WN98A and WF98B), nearfield whole-water phytoplankton assemblages from both depths were dominated by unidentified microflagellates and the diatom *Leptocylindrus danicus* (Figures 5-13 and 5-14). Other diatoms, including *Leptocylindrus minimus, Skeletonema costatum* and *Pseudo-nitzschia delicatissima* made lesser contributions.

During early September (WN98C), the dominance of < 10 µm microflagellates and cryptomonads continued in the nearfield, with *L. minimus* and the dinoflagellate *Gymnodinium* sp. as subdominants (Figure 5-15). By late September (WN98D) microflagellate dominance was overwhelming at station N04, but was shared at station N18 with various diatoms, including *Chaetoceros didymus, L. danicus, L. minimus, S. costatum*, and a small centric < 10 µm in longest dimension (Figure 5-16).

During early October (WF98E) microflagellate dominance was shared with chain-forming diatoms such as *Chaetoceros compressus, Eucampia zodiacus*, and *Skeletonema costatum* (Figure 5-17). Diatoms characterized as *Pseudo-nitzschia "pungens"* (which could include the non-toxic *P. pungens* or the domoic-acid-producing *P. multiseries*, because these cannot be reliably distinguished using light microscopy) was present, comprising 5.7% of cells counted.

In late October (WN98F) microflagellate dominance was shared with cryptomonads, *E. zodiacus*, and an unidentified species of the dinoflagellate genus *Gymnodinium* (Figure 5-18).

By late November (WN98G) microflagellate and cryptomonad abundance was shared only with the diatom *Rhizosolenia delicatula* (Figure 5-19).

The December (WN98H) assemblage was dominated by microflagellates (Figure 5-20), with lesser contributions by *Chaetoceros compressus*, another unidentified species of this genus, a centric diatom < 10 µm in longest dimension and (nominally) two species of *Pseudo-nitzschia* (*delicatissima* and "*pungens*"). These can be distinguished by criteria visible with standard light microscopy, so effectively the designation of "*delicatissima*" means "not *pungens* or *multiseries*." The latter comprised 5-13% of total cells counted in nearfield samples, with abundances of up to 82,000 cells L^{-1}

Screened Phytoplankton – In August during WN98A and WF98B nearfield screened samples were dominated by the thecate dinoflagellates *Ceratium tripos* and *C. fusus*, and secondarily by the dinoflagellates *Dinophysis norvegica, Protoperidinium* spp., and the silicoflagellate *Distephanus speculum*.

By September (WN98C and WN98D), various species of the dinoflagellate genus *Ceratium* (*C. fusus, C. longipes* and *C. tripos*) were dominant with several other species of dinoflagellates present.

From October through December (WF98E, WN98F, WN98G, WN98H) *C. fusus* and *C. tripos* were dominant in the nearfield, with lesser contributions by *Protoperidinium* spp., *Prorocentrum micans*, and *C. macroceros.*

5.3.1.3 Farfield Phytoplankton Assemblages

Whole-Water Phytoplankton - During WF98B in late August, most farfield station assemblages were dominated at both depths by unidentified microflagellates and cryptomonads < 10 µm in cell size, and the diatoms *Leptocylindrus danicus* and *L. minimus* (Figure 5-14). The diatoms *Pseudo-nitzschia delicatissima* and *P. pungens* were subdominants at most stations.

During WF98E in early October, most farfield stations were dominated by unidentified microflagellates and cryptomonads < 10 µm in size, but chain-forming diatoms were also present in subdominant abundance (Figure 5-17). Particularly, these included *Leptocylindrus danicus, Eucampia zodiacus, Skeletonema costatum, Chaetoceros compressus* and *Pseudo-nitzschia pungens*.

There were also unidentified centric diatoms of the genus *Thalassiosira* < 20 µm in individual cell diameter at several other stations.

Screened Phytoplankton – During both WF98B and WF98E, 20-µm screened surface phytoplankton samples were dominated by the dinoflagellates *Ceratium fusus*, and *C. tripos*, and to a lesser extent several other dinoflagellates. These included *Ceratium lineatus, Protoperidinium* spp., *Scrippsiella trochoidea*, *Prorocentrum micans* and several other taxa.

5.3.1.4 Nuisance Algae

There were no confirmed blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during August – December, 1998. 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* (Fanuko, 1989) and *Ceratium tripos*(/*longipes*) (Malone, 1978; Falkowski *et al*. 1980) were routinely present, but not at abundances approaching those previously associated with anoxia. However, potentially-toxic species of the diatom genus *Pseudo-nitzschia* were present, in some cases, in moderately high numbers. A discussion of *Pseudo-nitzschia* spp. is presented below.

There are potentially four species of the genus *Pseudo-nitzschia* that could occur in the MWRA sampling area: *P. pungens, P. multiseries, P. delicatissima*, and *P. pseudodelicatissima*. Although there are reports of all four of these species producing domoic acid, either in field collections, or in culture (see Table 1 of Bates et al. 1998), the primary species that has been associated with domoic acid shellfish toxicity episodes in the North Atlantic is *P. multi-series*. The reports of domoic acid toxicity in the field for *P. pseudodelicatissima* and *P. delicatissima* are based upon only single occurrences, in either the Bay of Fundy or at Prince Edward Island, Canada, respectively. The only published report of domoic acid toxicity in the field attributed to *P. pungens* was from New Zealand, although there have apparently been recent unpublished reports (summarized by Bates et al., 1998) from California and Washington (state). Several other species of the genus, which may or may not produce domoic acid all occur in the Pacific. Based upon criteria given in the Hasle and Syvertsen (1997) chapter of a manual edited by Tomas (1997) entitled "Identifying Marine Phytoplankton," it is possible to distinguish these four species using microscopy, but in some cases only scanning electron microscopy (SEM) can reliably distinguish between species. Criteria are given below.

Members of the genus *Pseudo-nitzschia* form end-to-end chains, with adjacent cells overlapping. Individual cells vary in both length ("apical axis") and width ("transapical axis"). *P. pungens* and *P. multiseries* are not reliably distinguished by light microscopy because they are both of approximately the same length (74-142 µm for *P. pungens* and 68-140 µm for *P. multiseries*), the same width (3.0-4.5 µm for *P. pungens* and 4-5 µm for *P. multiseries*), with adjacent cells overlapping by one-third or more of cell length. The primary accepted way for distinguishing *P. pungens* from *P. multiseries* is to count intercostal poroids, which are small holes that occur in rows between the ribs ("costae") on the inner surfaces of diatom thecae ("valves") that have been separated by treatment with acid or bleach. Since the diameters of these poroids are considerably less than 1 µm, the only reliable method of observation to count them is with SEM. If poroids occur in pairs in rows, then the species is *P. pungens*. If, however, there are multiple poroids (3-4) in a row, then the species is *P. multiseries*. Effectively the designation of "*Pseudo-nitzschia pungens*" in our data (obtained thus far with light microscopy only) means either *P. pungens* or *multiseries* (but we do not know which), but not *P. delicatissima* or *P. pseudodelicatissima*. The reason is that the latter two species are distinguished from *P. pungens/multiseries* by their more narrow cells (1.5-2.5 µm), compared to widths of 3-5 µm for *P. pungens/multiseries*, and by overlapping of adjacent cells in chains in *P. delicatissima* or *P. pseudodelicatissima* by only about one-ninth of cell length, compared to by one-third or more of cell length with *P. pungens/multiseries*. The differentiation of *P. delicatissima* from *P. pseudodelicatissima* is facilitated by differences in length, in that *P. delicatissima* cells are much shorter (40-76 µm length) than those of *P. pseudodelicatissima* (59-140 µm length).

5.3.2 Zooplankton

5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Total zooplankton abundance at nearfield stations fluctuated, but generally remained at similar levels from August through December (Table 5-3).

Total zooplankton abundance at farfield stations was somewhat lower at most stations in October than in August, but there were no consistent trends of higher values in either survey for all stations in a given area compared to others (Figures 5-21 and 5-22). Maximum abundances in both periods occurred in Boston Harbor, but these were nearly matched by levels at other stations in the nearfield or in Cape Cod Bay in August.

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

Survey	Dates (1998)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WN98A	8/7	45.9	33.5-58.3	NA	NA
WF98B	8/18-25	45.0	30.5-64.7	45.8	27.3-72.8
WN98C	9/3	12.9	11.9-13.9	NA	NA
WF98D	9/24	35.2	24.9-45.5	NA	NA
WF98E	10/5-16	44.9	35.8-59.2	35.0	15.9-83.2
WN98F	11/4	58.3	39.0-77.6	NA	NA
WF98G	11/25	64.5	61.9-66.9	NA	NA
WN98H	12/16	53.5	47.4-59.7	NA	NA

NA- Data not available because the farfield stations were not sampled during this survey.

5.3.2.2 Nearfield Zooplankton Community Structure

From early August through early October (WN98A, WF98B, WN98C, WN98D, WF98E) the nearfield zooplankton assemblages were dominated by copepod nauplii, and females and copepodites of *Oithona similis*. Subdominants included copepodites of *Pseudocalanus* sp., *Temora longicornis*, and to a lesser extent bivalve and gastropod veligers, the marine cladoceran *Evadne nordmani* and the tunicate *Oikopleura dioica*. The copepod *Microsetella norvegica* and copepodites of the genus *Centropages* were subdominants in late September (WN98D).

By late October (WN98F) and continuing through late November (WN98F), the dominance of copepod nauplii and *Oithona similis* was being supplanted by bivalve veligers, and to a lesser extent gastropod veligers. This was likely due to a combination of the seasonal decline in copepod abundance in the fall, along with a seasonal reproductive pulse by benthic bivalves and gastropods.

5.3.2.3 Farfield Zooplankton Assemblages

At farfield stations during survey WF98B, copepod nauplii were dominants, with subdominant contributions at various stations by adults and copepodites of copepods such as *Oithona similis, Pseudocalanus* sp., *Temora longicornis* and *Microsetella norvegica*. Non-copepod subdominants at most stations included *Evadne nordmani*, *Oikopleura dioica*, and meroplankters such as bivalve and gastropod veligers. At stations in Boston Harbor (F23 and F30), dominants were the adults and copepodites *of Acartia tonsa* and polychaete larvae. Interestingly, there were sporadic occurrences of adults of *Acartia hudsonica* at Boston Harbor stations (F23, F30, and F31). *A. hudsonica* is generally thought to be a cold-season species, but careful examination confirmed that it does co-occur in Boston Harbor during the summer with its warm-season congener *A. tonsa*, although in lower abundances.

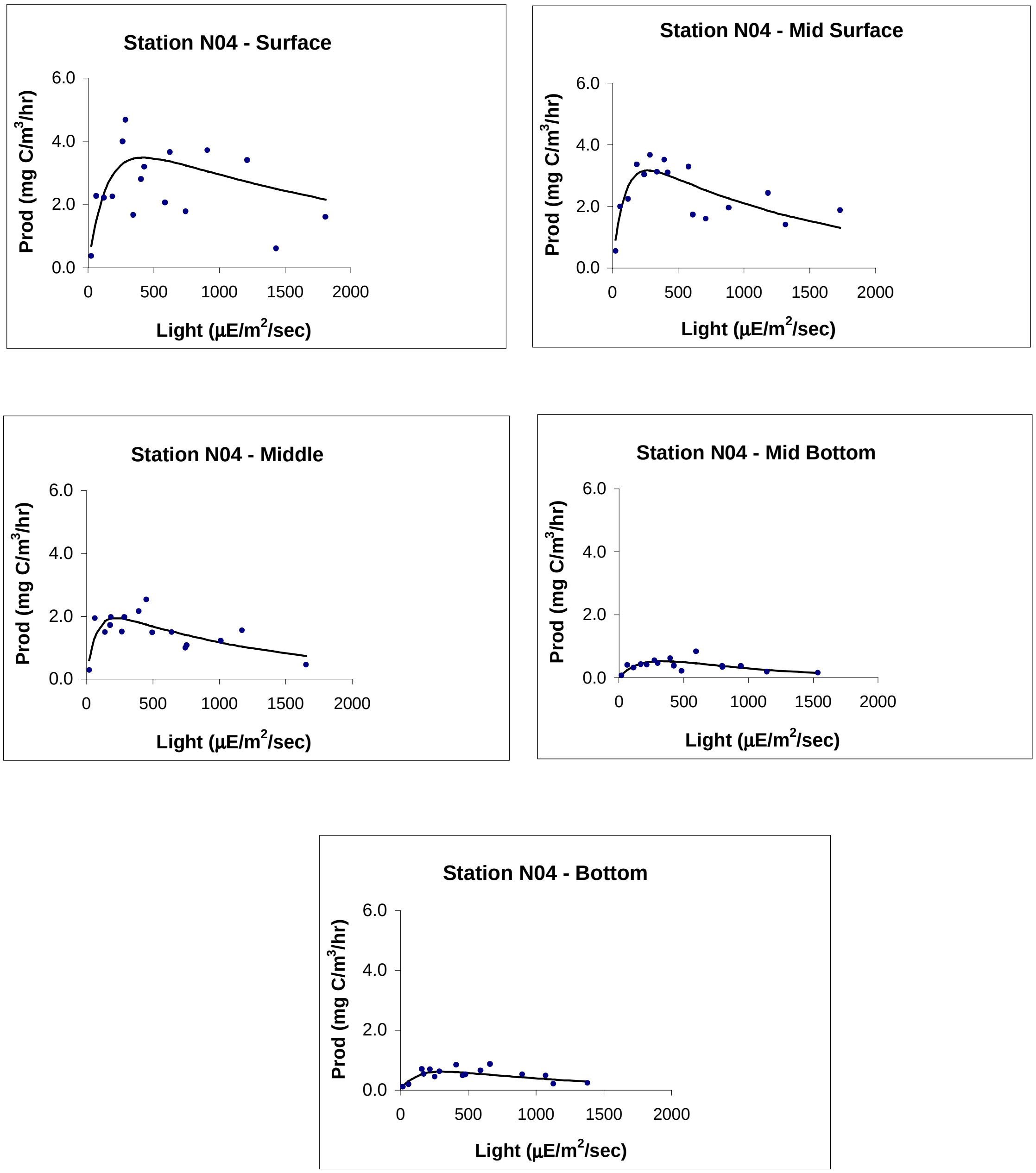
During WF98E, copepod nauplii and *Oithona similis* copepodites were again dominant at farfield stations, but bivalve veligers, *O. dioica*, and copepodites of *Pseudocalanus* sp. and *Temora longicornis* were subdominants at most stations. *Acartia hudsonica* were again abundant at stations F23 and F30 in Boston Harbor. Salps were conspicuous subdominants at several stations in the southern portion of the farfield (F01, F02, and F06).

5.4 Summary of Water Column Biological Events

- The peak annual production values for the nearfield stations were observed during the October survey (WF98E) – 1665 and 1188 mg C m^{-3} d^{-1} for stations N04 and N18, respectively.
- The pattern in areal production for August to December 1998 was generally low production in August/September (200-500 mg C m^{-3} d^{-1}), peak production in October, and then somewhat elevated values for the remainder of the year (600-800 mg C m^{-3} d^{-1})
- Areal production at the Boston Harbor station was higher than the nearfield stations during the August survey (750 mg C m^{-3} d^{-1}), but did not have the peak annual levels that occurred at the nearfield stations.
- A well-established fall bloom was observed at N18 lasting about 10 weeks while a less developed bloom was observed at N04 lasting only 4 weeks.
- Relative to previous years of baseline monitoring, areal production was low at all three stations throughout the late summer and fall period. The difference was most notable at station F23 where during 1995 to 1997 peak areal production ranged from 2000-8000 mg C m^{-3} d^{-1} in the fall compared to the 750 mg C m^{-3} d^{-1} measured in August 1998.
- Although the peak production values were lower, the general pattern of production at the nearfield stations was similar to previous years.
- Production values were consistent with chlorophyll concentrations for each of the surveys except the December survey when elevated chlorophyll concentrations were observed.
- Chlorophyll-specific production indicated that the efficiency of production was moderately high in relation to the amount of biomass present at the nearfield stations during the fall bloom.
- Nearfield respiration rates reached a maximum for this time period in late September with values ranging from 0.16-0.23 μMO_2/hr and 0.1-0.33 μMO_2/hr at stations N04 and N18, respectively. At stations F23 and F19, respiration rates were at a maximum in August.

- During the fall bloom, chlorophyll concentrations and production rates reached their peak during the October survey, but respiration rates had decreased from September values. Though rates had decreased, mid depth respiration values had remained relatively high in comparison and were coincident with the elevated levels of production.
- At the nearfield stations, POC concentrations generally decreased from early August to September and increased reaching maximum values in October. This pattern was consistent with the trends observed in chlorophyll over this time period.
- There was a lag between peak POC concentrations in the surface and mid depth waters and peak concentrations in bottom waters at both nearfield stations that is indicative of the settling out of the fall bloom.
- Carbon-specific respiration rates were highest at station N04 in late September during the initiation of the fall bloom.
- In October, carbon-specific respiration rates were relatively low at stations N04 and N18 suggesting that the October survey was conducted near the conclusion of the fall bloom.
- Total phytoplankton abundances in the whole water samples remained high in the nearfield from August through October continuing the sustained increase observed from February to July. Farfield total phytoplankton abundance peaked in August and lower levels were observed in October.
- *Pseudo-nitzschia "pungens"* were present in noteworthy numbers in October (5.7% of cells counted) and December (5-13% of cells counted). This grouping includes both the non-toxic *P. pungens* and the domoic-acid-producing *P. multiseries* that cannot be distinguished using light microscopy.
- In August, the whole water phytoplankton assemblage was dominated by unidentified microlagellates and the diatom *Leptocylindrus danicus*. From September to December, the assemblage was dominated by microflagellates while various diatoms were present in significant numbers.
- The abundance of >20-µm screened dinoflagellates was high in August, low during September and October, and then increased again in November and December. The >20-µm screened samples were dominated by *Ceratium tripos* and *C. fusus* for the entire period.
- There were no confirmed blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during August – December 1998.

WN98A **Station N04**


Station N04 - Surface

Station N04 - Mid Surface

Station N04 - Middle

Station N04 - Mid Bottom

Station N04 - Bottom

Figure 5-1. An Example Photosynthesis-Irradiance Curve From Station N04 Collected in August 1998.

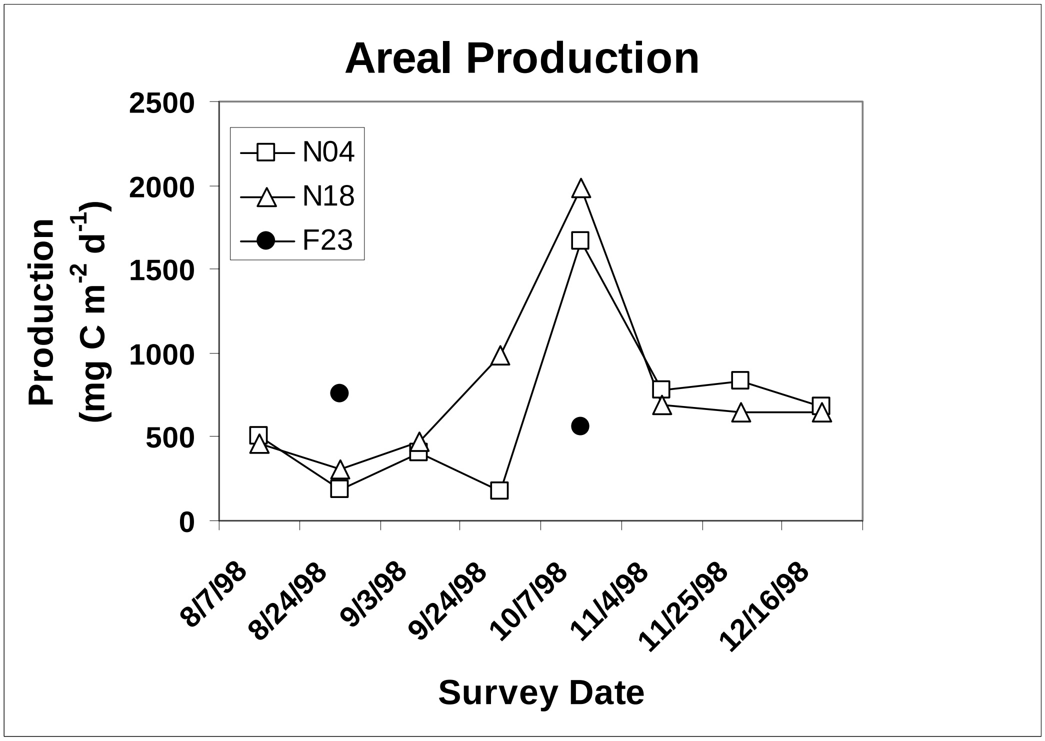


Figure 5-2. Time-Series of Areal Production (Mg C $M^{-2}d^{-1}$) for Productivity Stations.

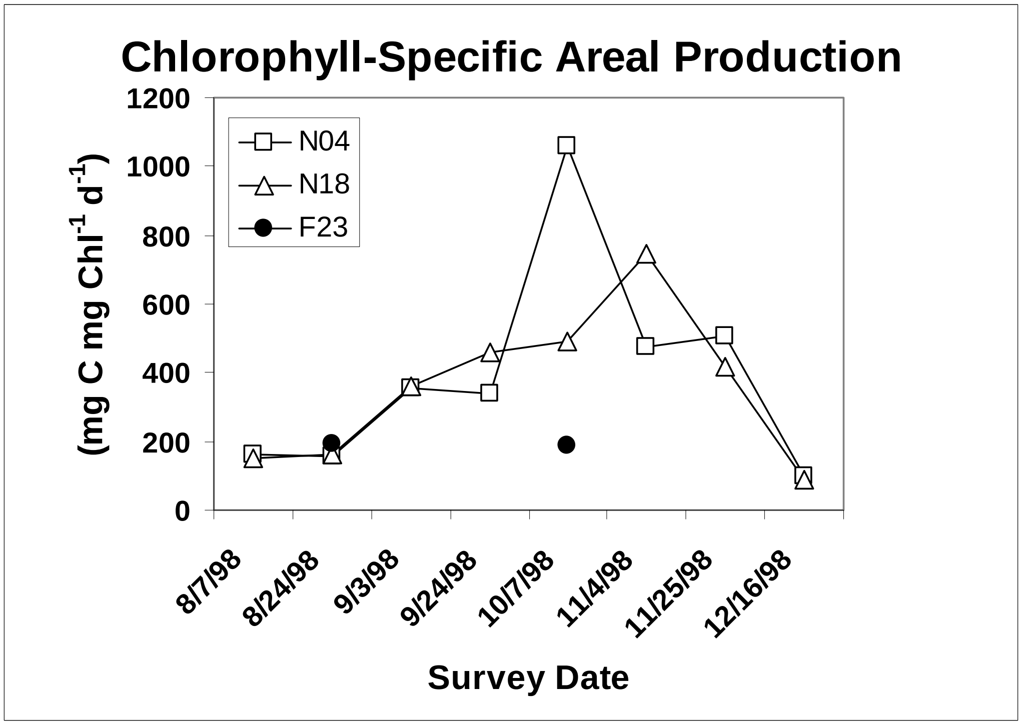


Figure 5-3. Time-Series of Chlorophyll-Specific Areal Production (mg C mg $Chl^{-1}d^{-1}$) for Productivity Stations.

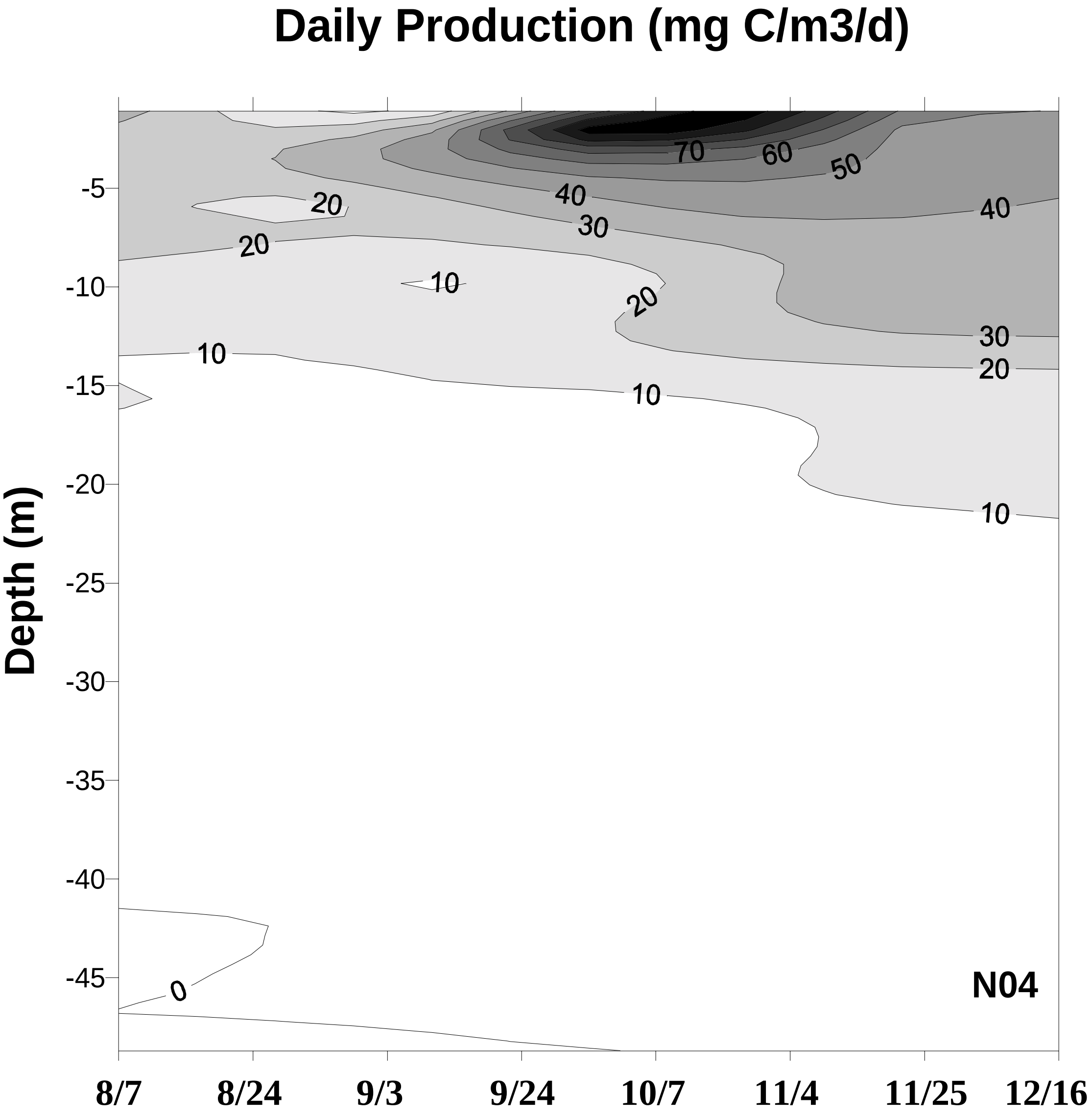


Figure 5-4. Time Series of Contoured Daily Production (mg Cm^{-3}d^{-1}) Over Depth at Station N04.

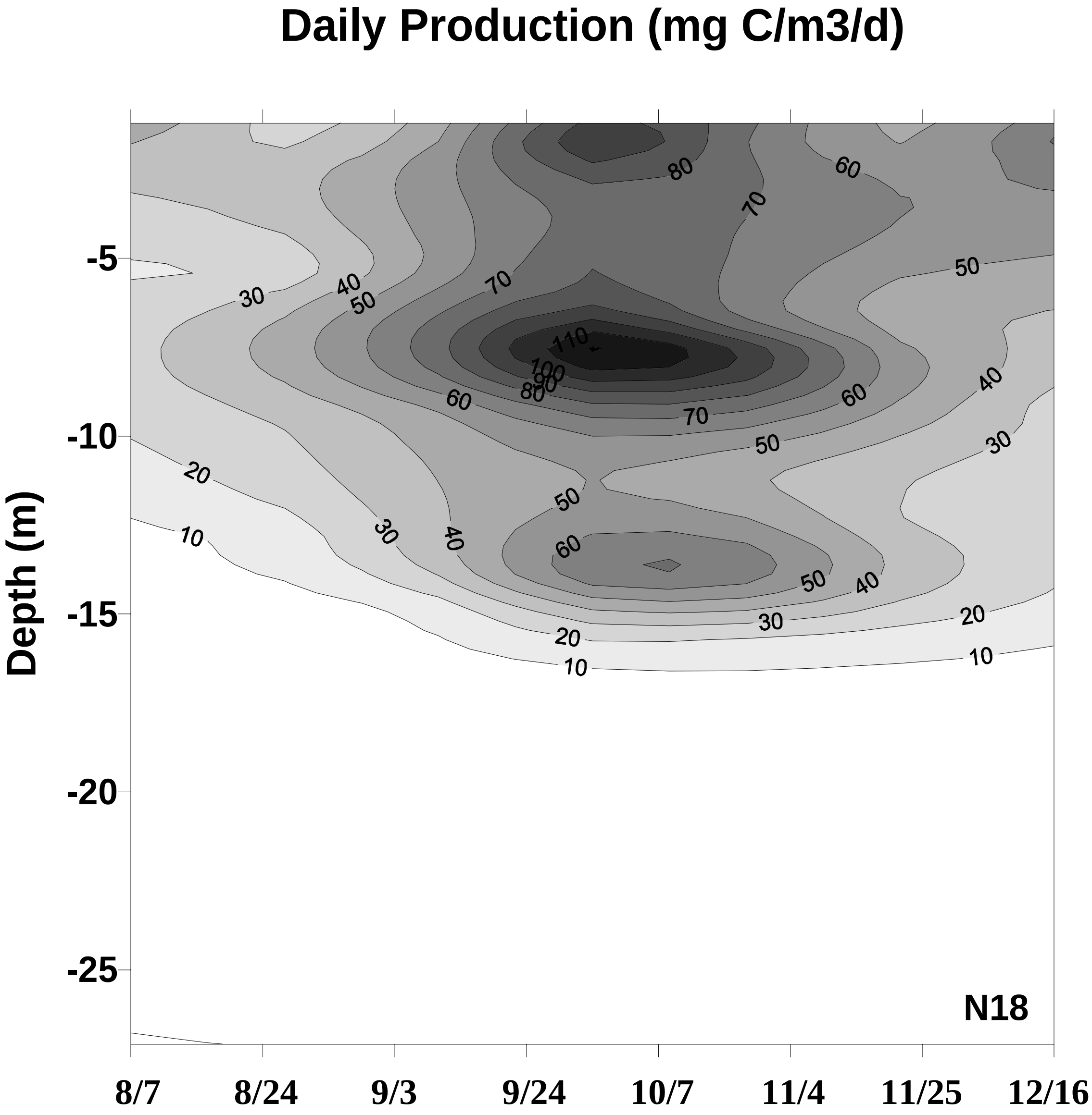


Figure 5-5. Time Series of Contoured Daily Production (mg Cm^{-3}d^{-1}) Over Depth at Station N18.

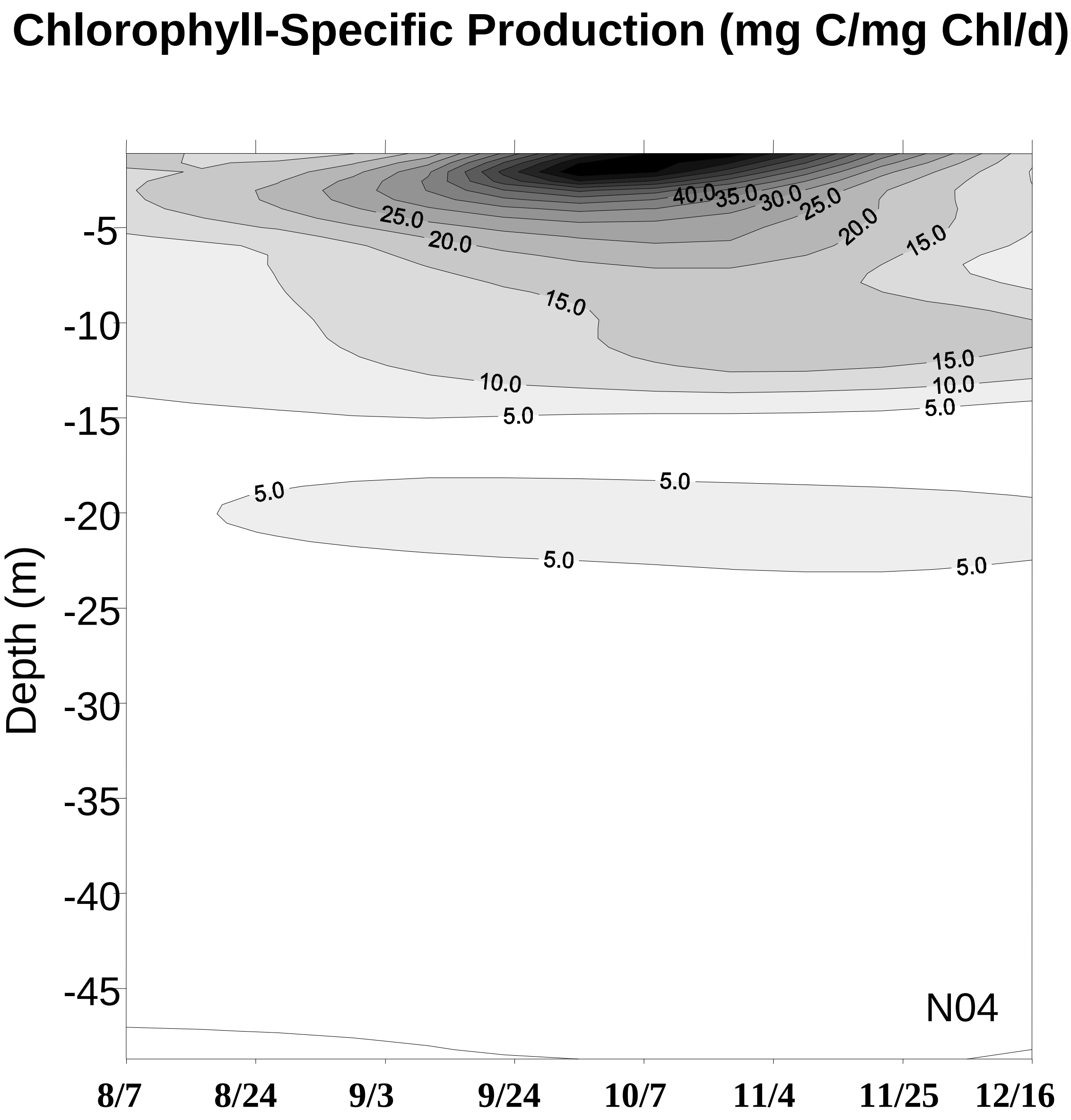


Figure 5-6. Time Series of Contoured Chlorophyll-Specific Production (mg Cmg Chl^{-1}d^{-1}) at Station N04.

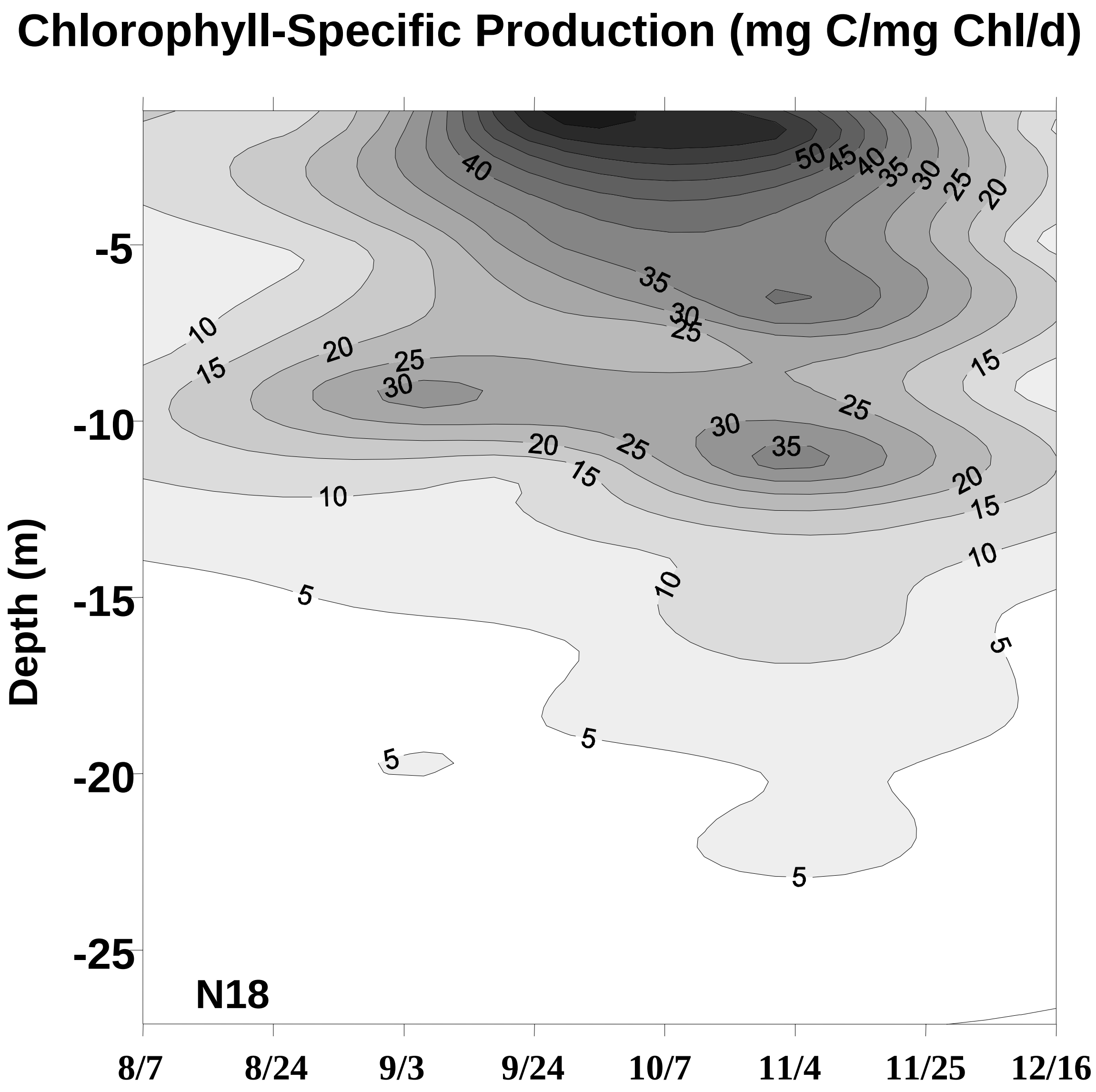
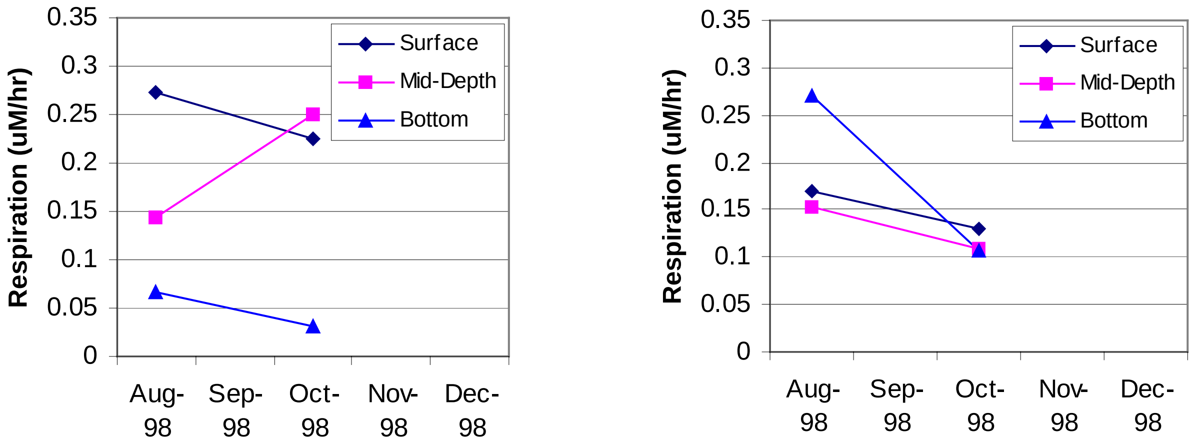
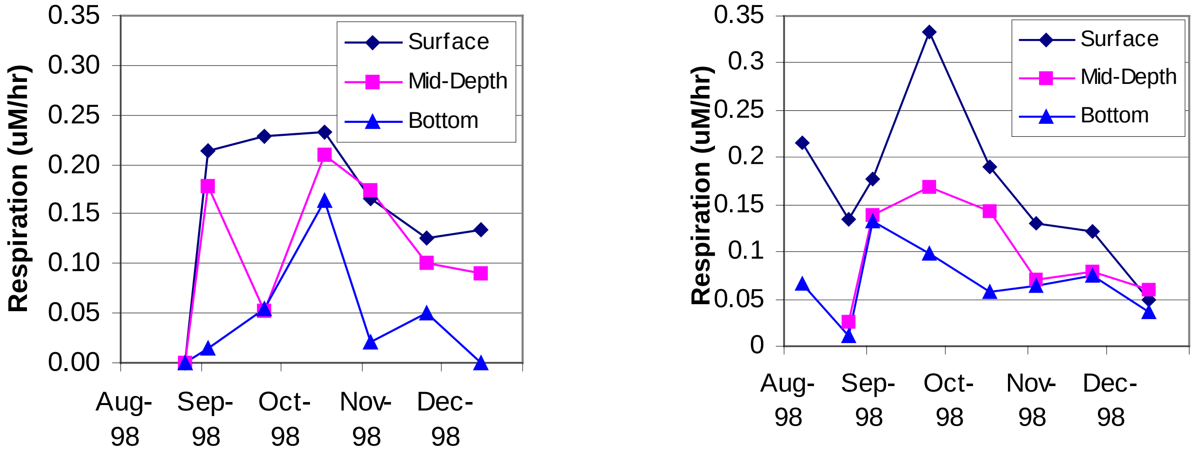


Figure 5-7. Time Series of Contoured Chlorophyll-Specific Production (mg Cmg $Chl^{-1}d^{-1}$) at Station N18.


(a) Station F19

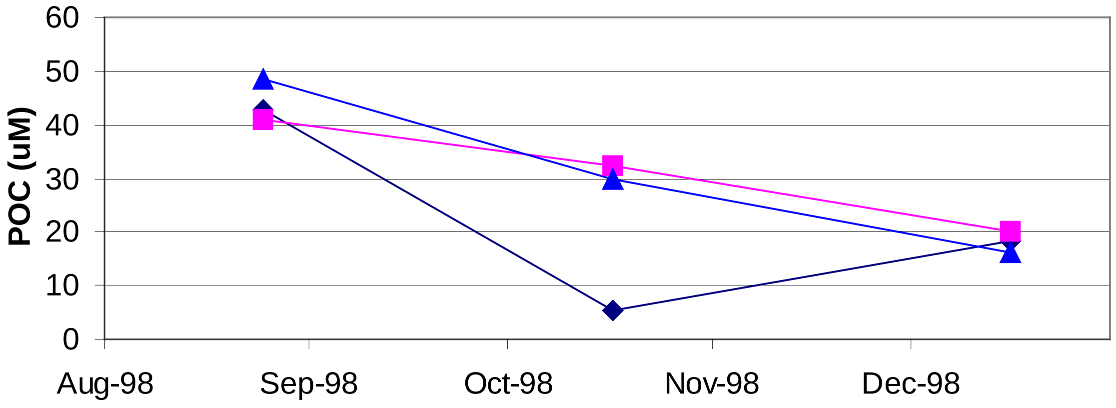
(b) Station F23


(c) Station N04

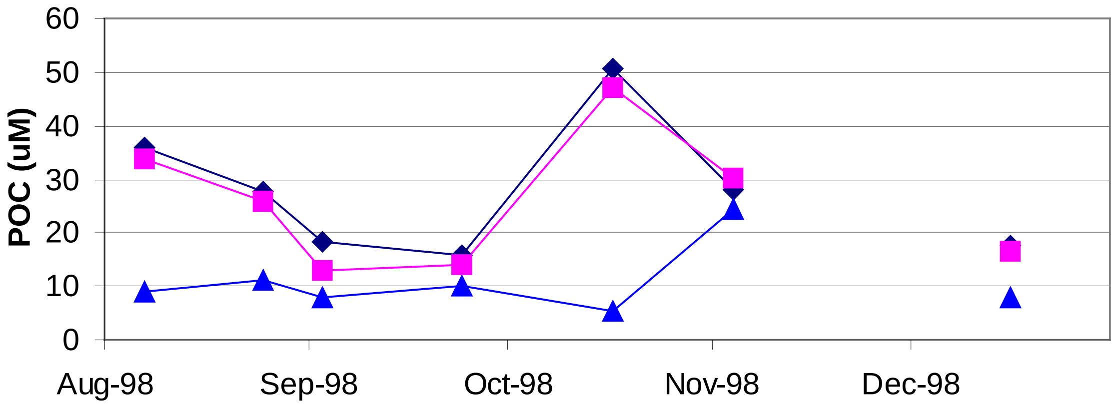
(d) Station N18

Figure 5-8. Time Series Plots of Respiration Stations F19, F23, N04, and N18.

(a) Station F23



(b) Station N04



(c) Station N18

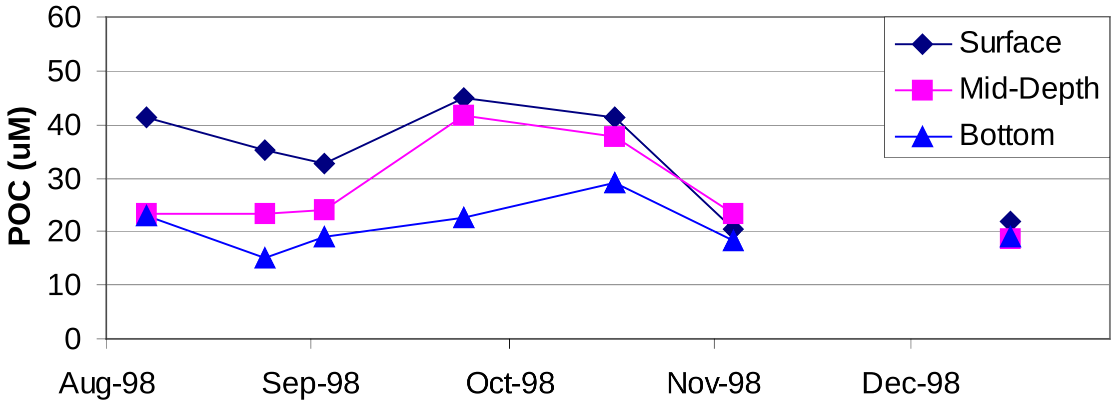
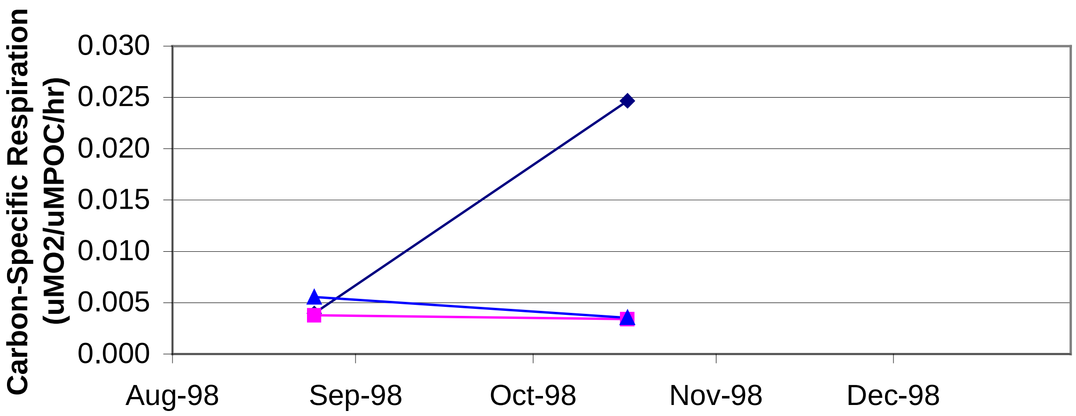
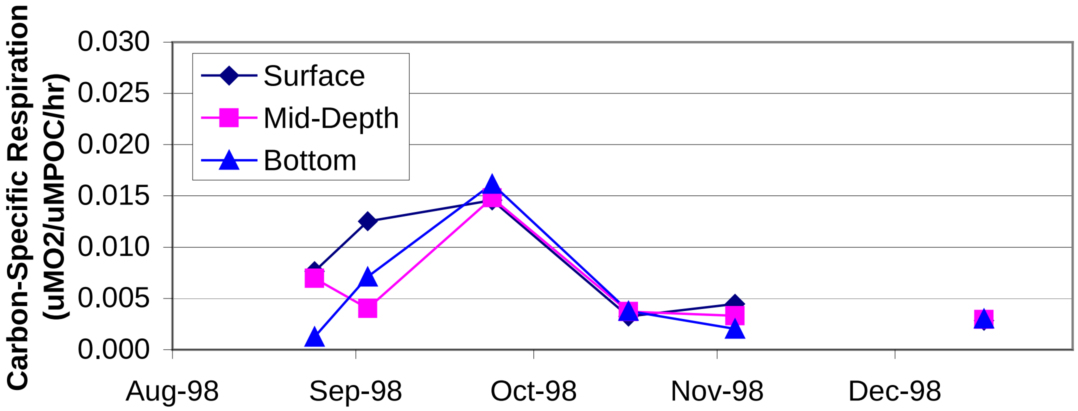


Figure 5-9. Time Series Plots of POC at Stations F23, N04, and N18.

(a) Station F23



(b) Station N04



(c) Station N18

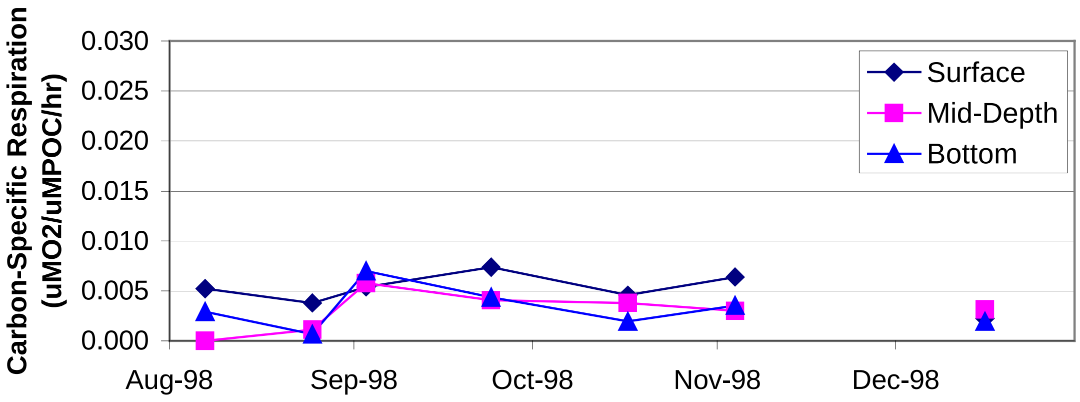


Figure 5-10. Time Series Plots of Carbon-Specific Respiration at Stations F23, N04, and N18.

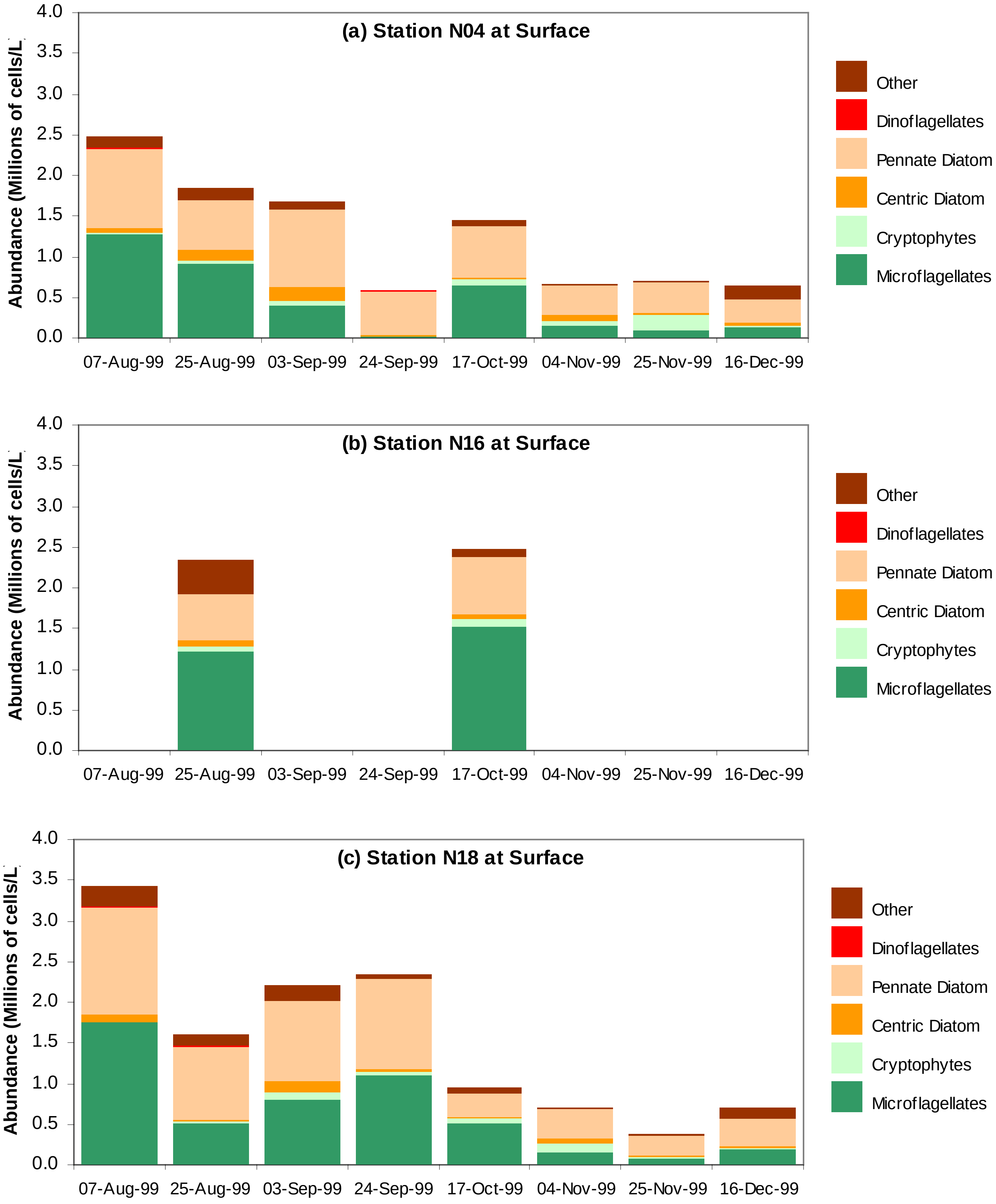


Figure 5-11. Phytoplankton Abundance by Major Taxonomic Group, Nearfield Surface Samples.

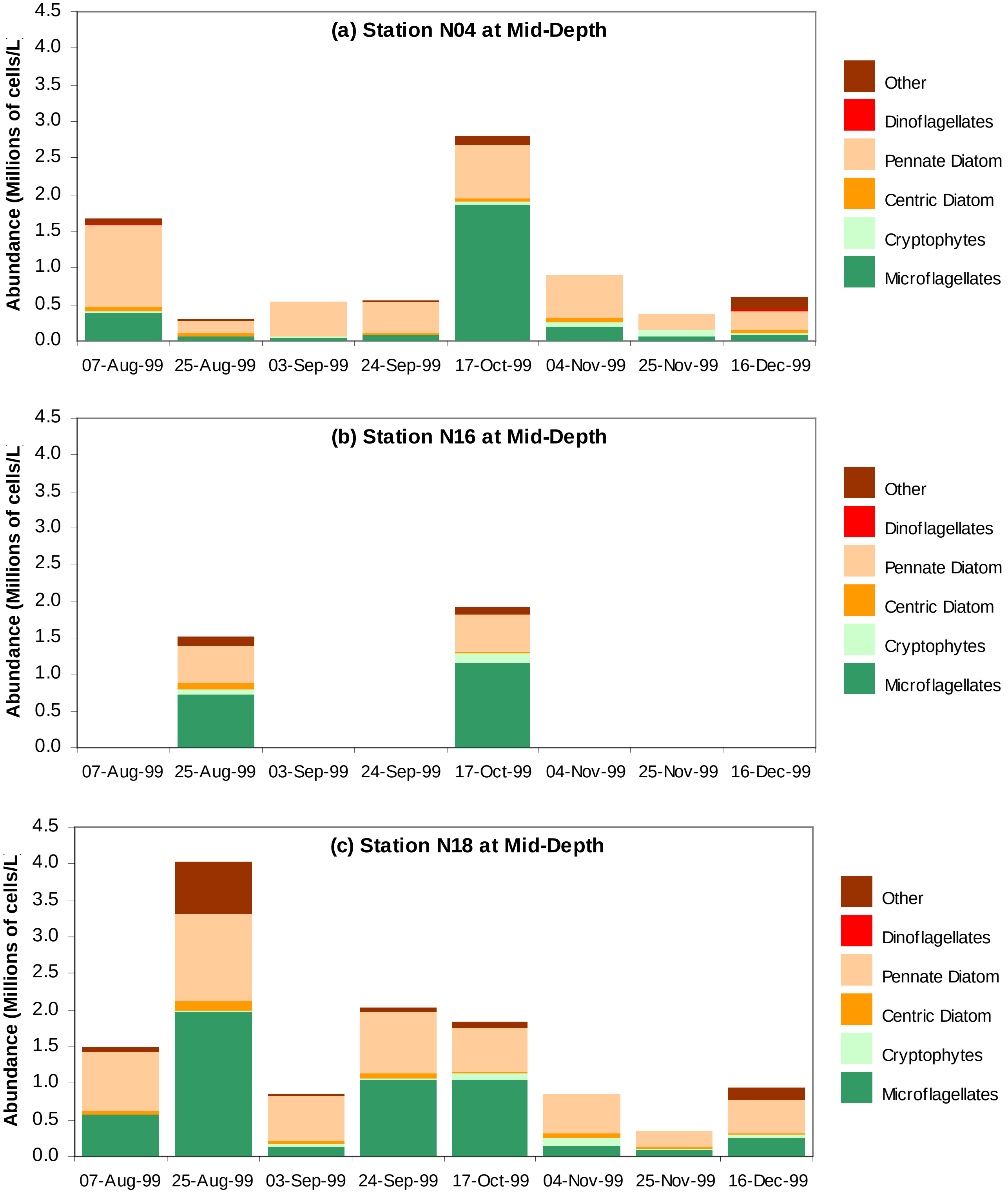


Figure 5-12. Phytoplankton Abundance by Major Taxonomic Group, Nearfield Mid-Depth Samples.

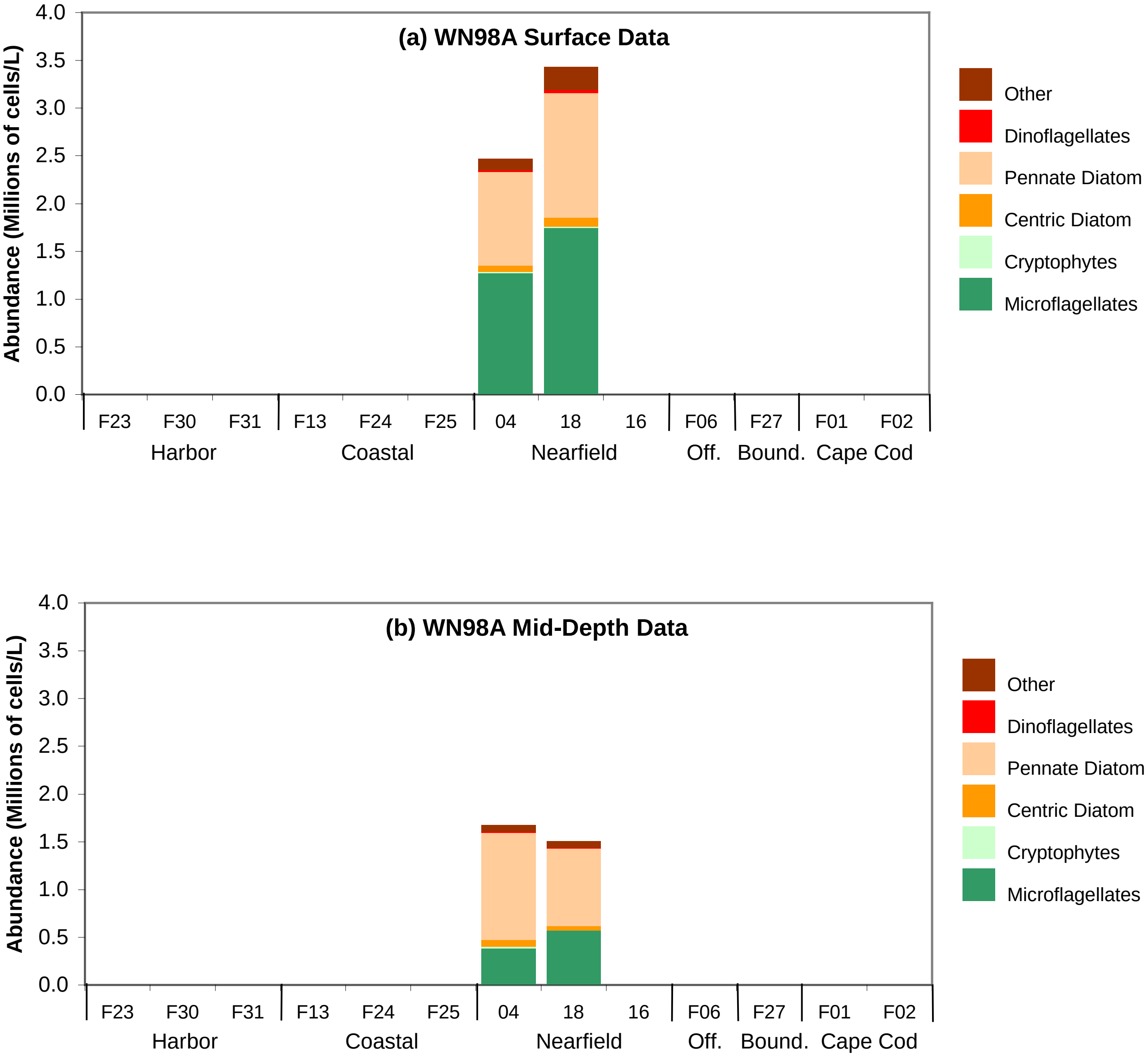
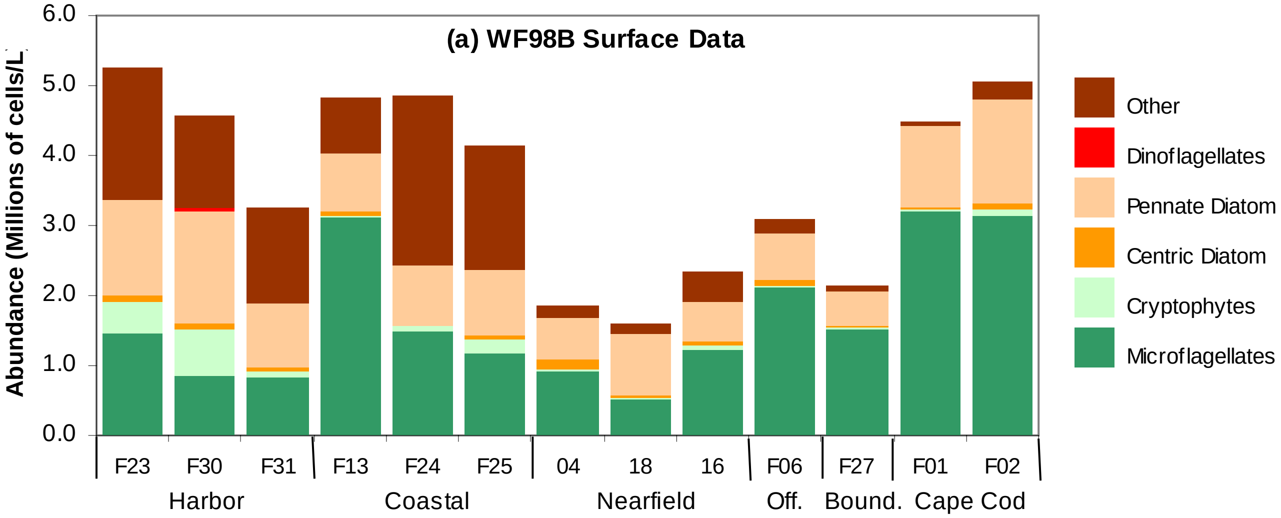


Figure 5-13. Phytoplankton Abundance by Major Taxonomic Group – WN98A Nearfield Survey Results August 7, 1998.

Note: Station N04 is shown as 04, Station N18 is shown as 18, and Station N16 is shown as 16 in the above figures.



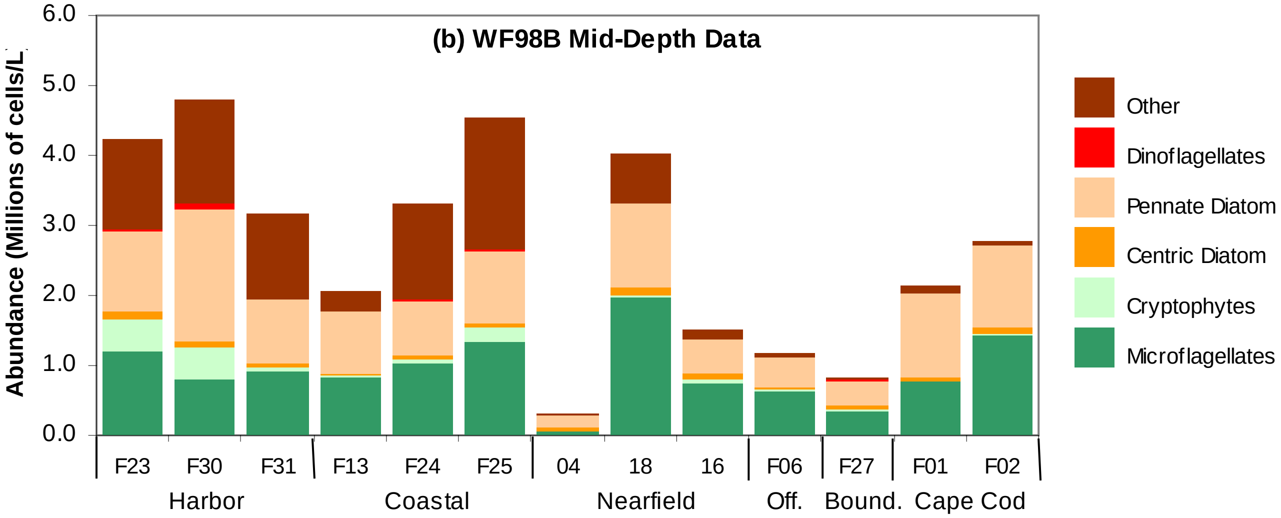
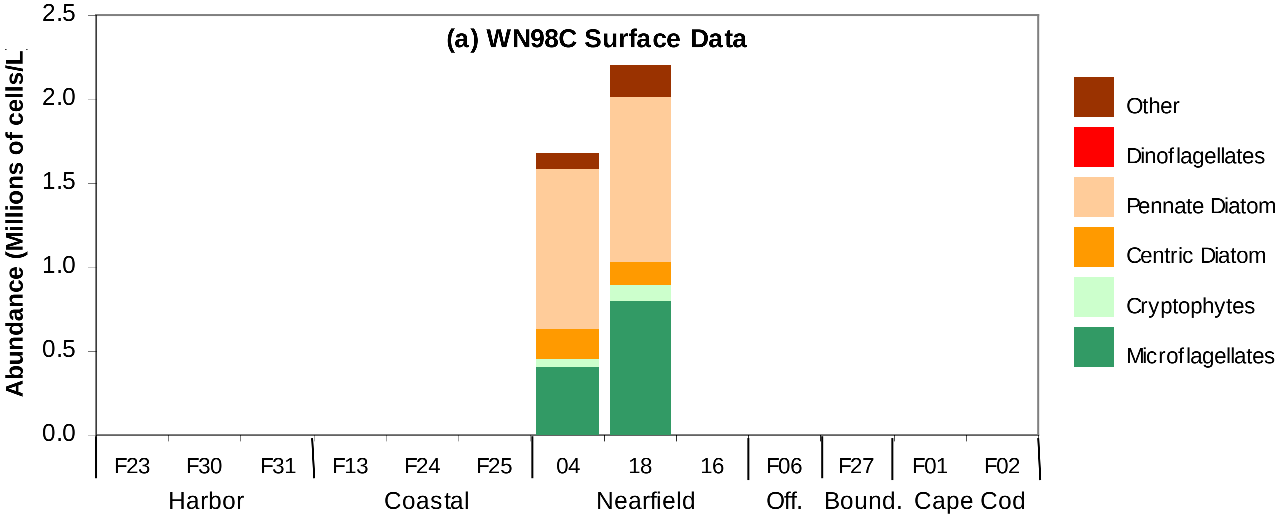


Figure 5-14. Phytoplankton Abundance by Major Taxonomic Group – WF98B Farfield Survey Results August 18 –25, 1998.

Note: Station N04 is shown as 04, Station N18 is shown as 18, and Station N16 is shown as 16 in the above figures.



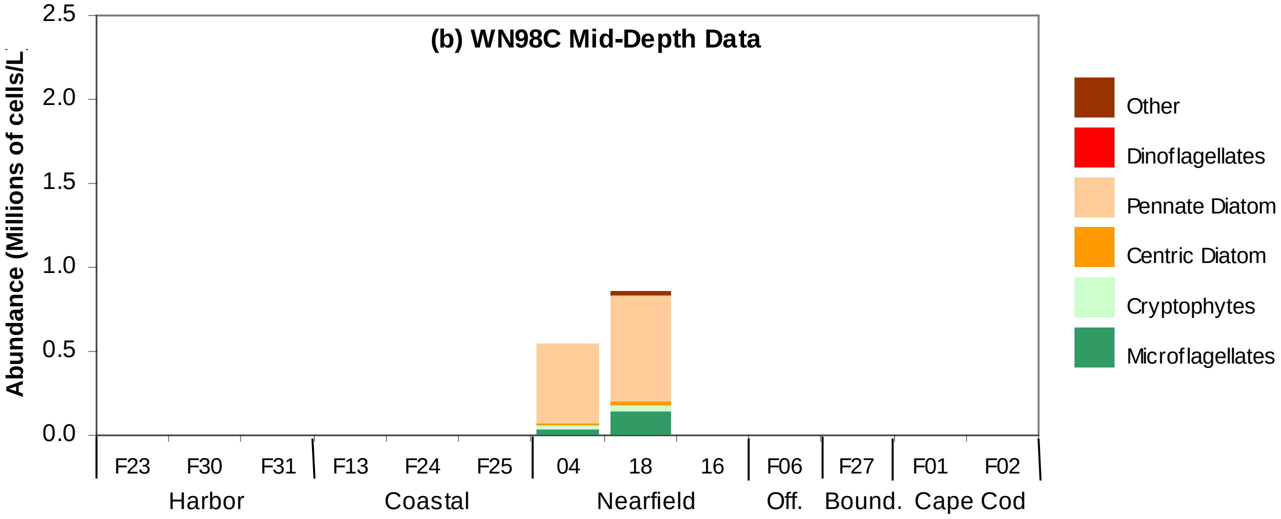


Figure 5-15. Phytoplankton Abundance by Major Taxonomic Group – WN98C Nearfield Survey Results September 3, 1998.

Note: Station N04 is shown as 04, Station N18 is shown as 18, and Station N16 is shown as 16 in the above figures.

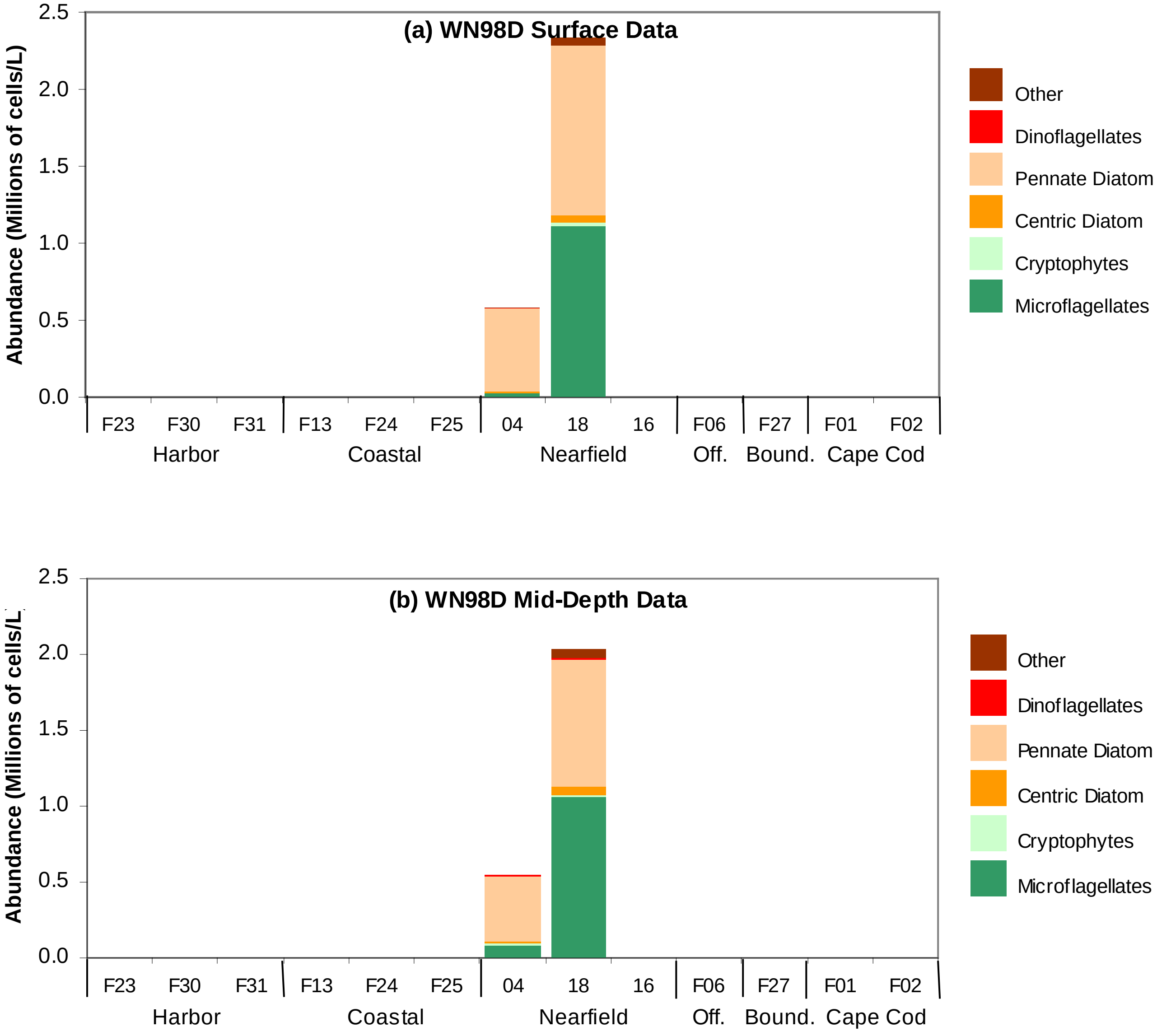


Figure 5-16. Phytoplankton Abundance by Major Taxonomic Group – WN98D Nearfield Survey Results September 24, 1998.

Note: Station N04 is shown as 04, Station N18 is shown as 18, and Station N16 is shown as 16 in the above figures.

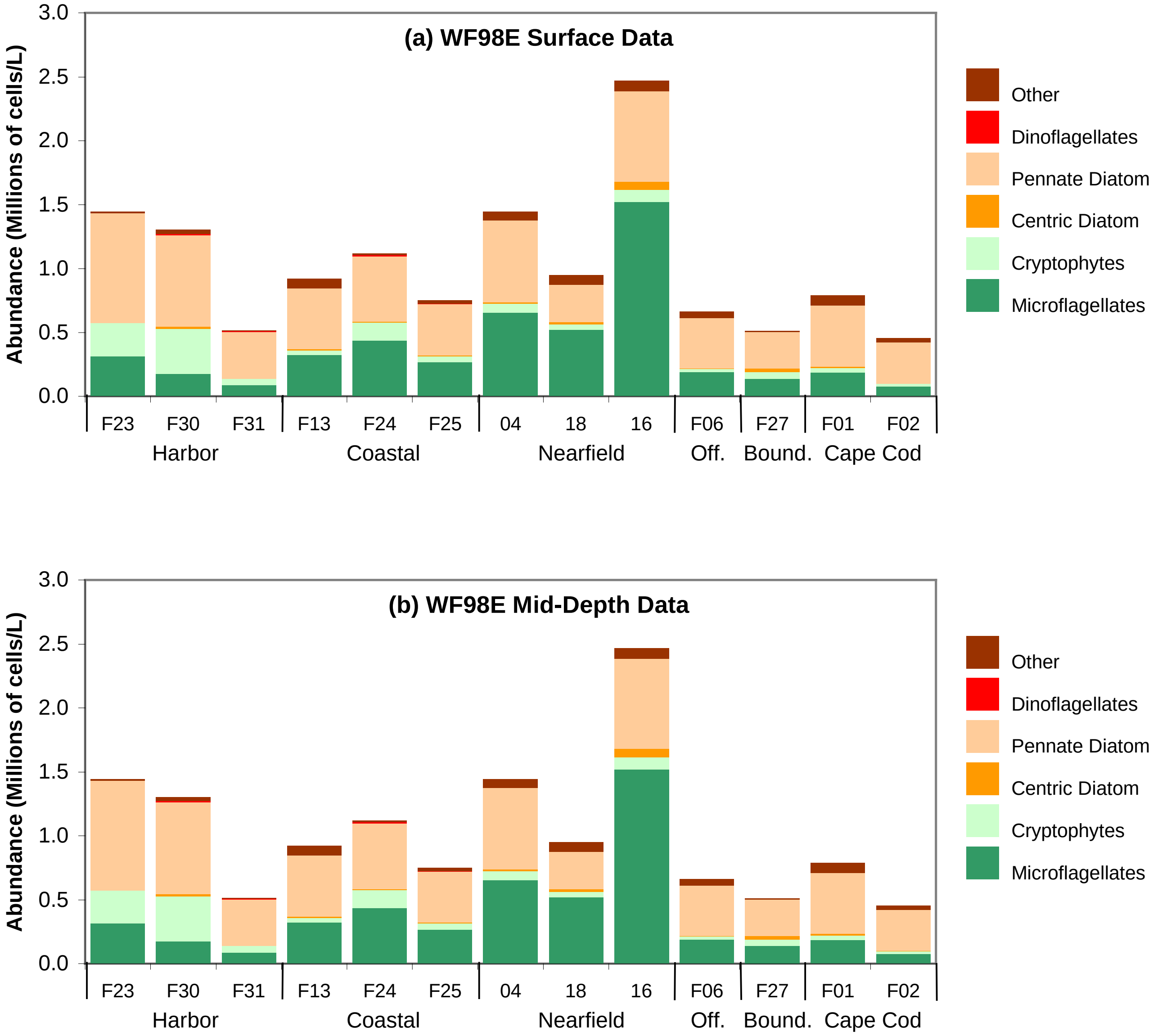


Figure 5-17. Phytoplankton Abundance by Major Taxonomic Group – WF98E Farfield Survey Results October 5 – 16, 1998.

Note: Station N04 is shown as 04, Station N18 is shown as 18, and Station N16 is shown as 16 in the above figures.

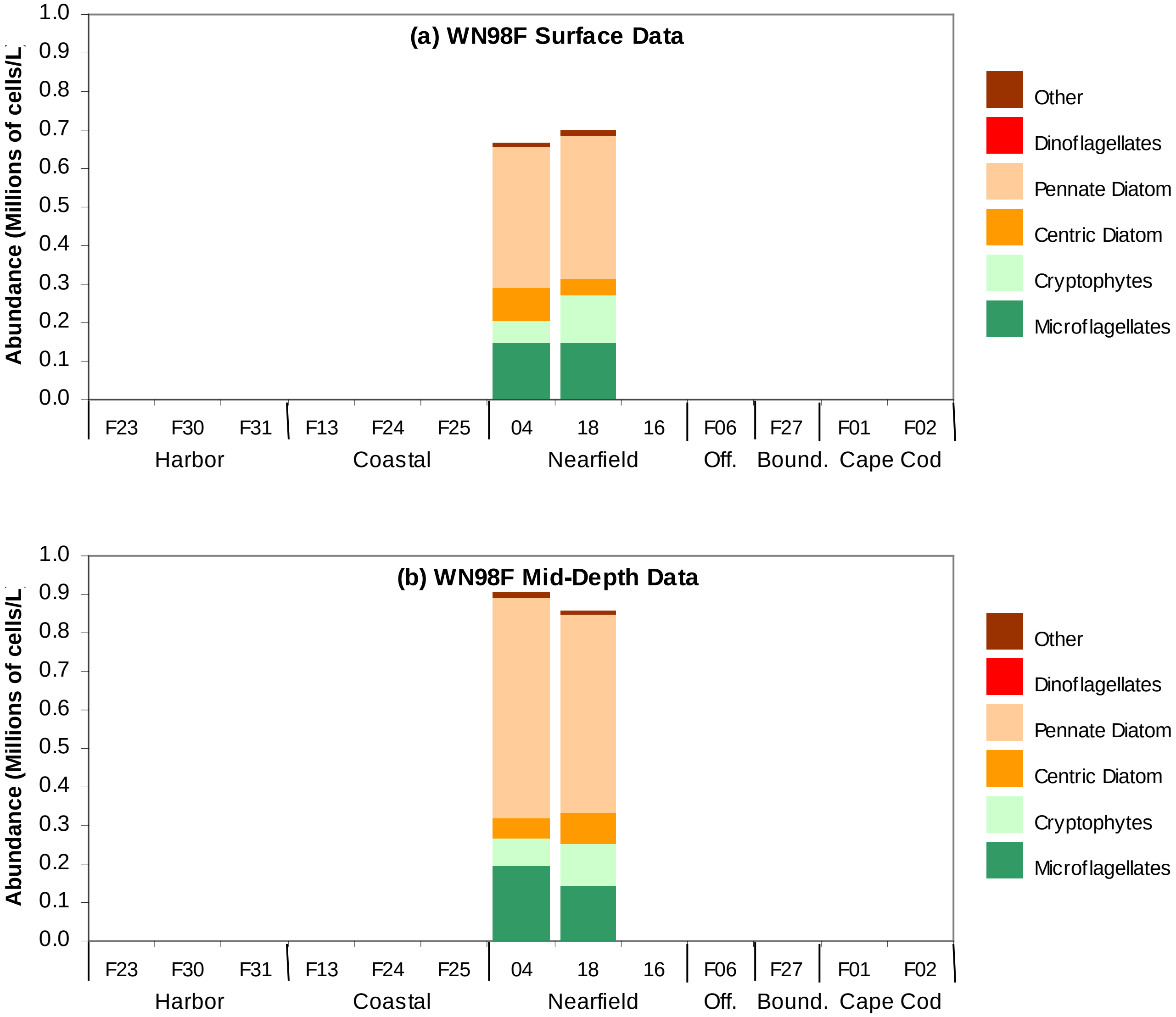
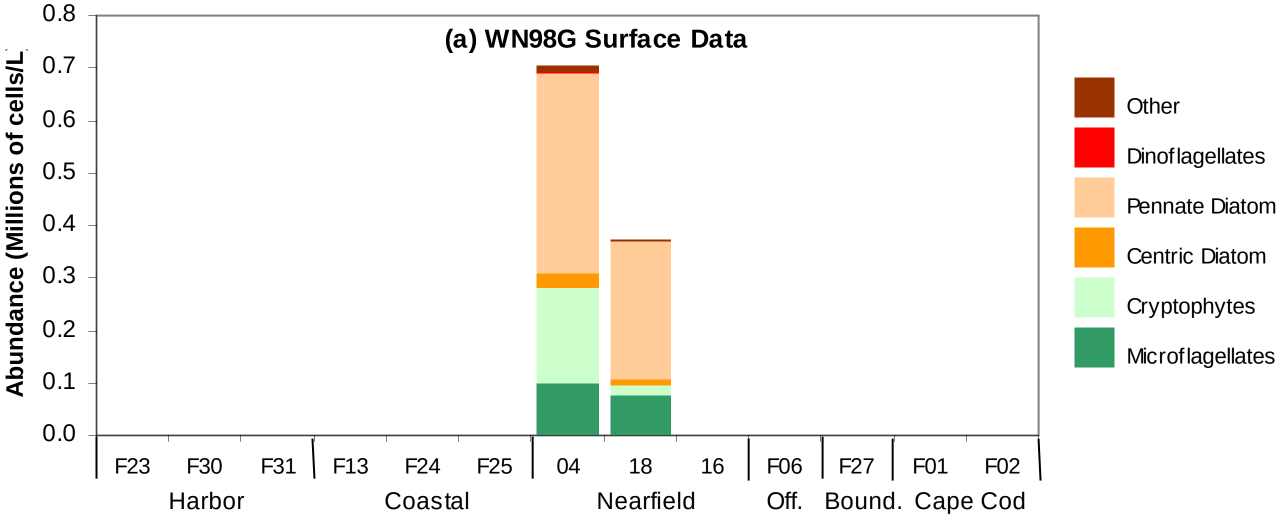


Figure 5-18. Phytoplankton Abundance by Major Taxonomic Group – WN98F Nearfield Survey Results November 4, 1998.

Note: Station N04 is shown as 04, Station N18 is shown as 18, and Station N16 is shown as 16 in the above figures.



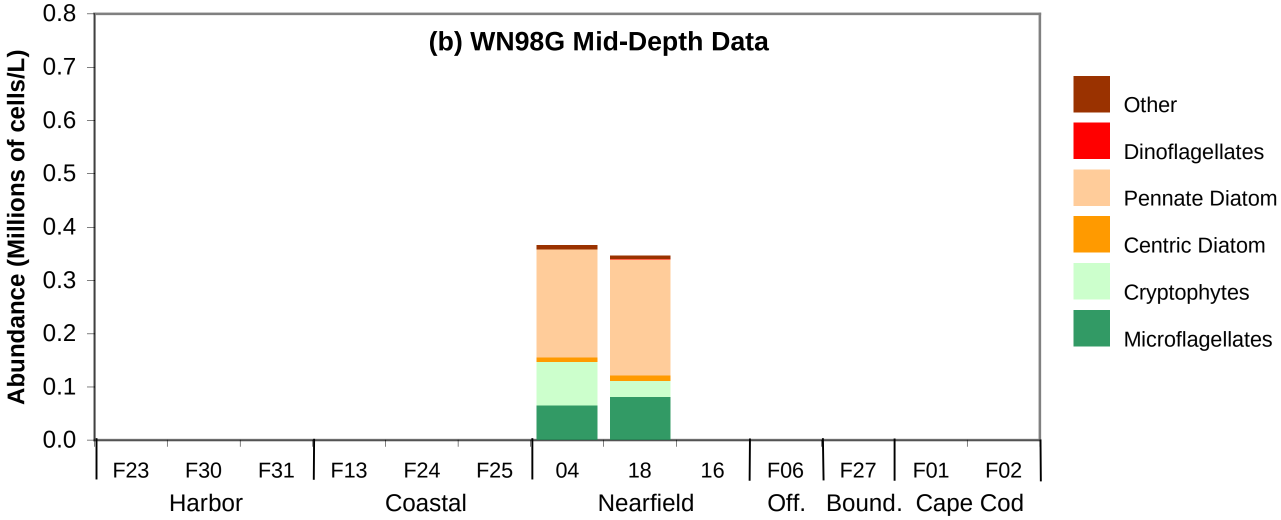


Figure 5-19. Phytoplankton Abundance by Major Taxonomic Group – WN98G Nearfield Survey Results November 25, 1998.

Note: Station N04 is shown as 04, Station N18 is shown as 18, and Station N16 is shown as 16 in the above figures.

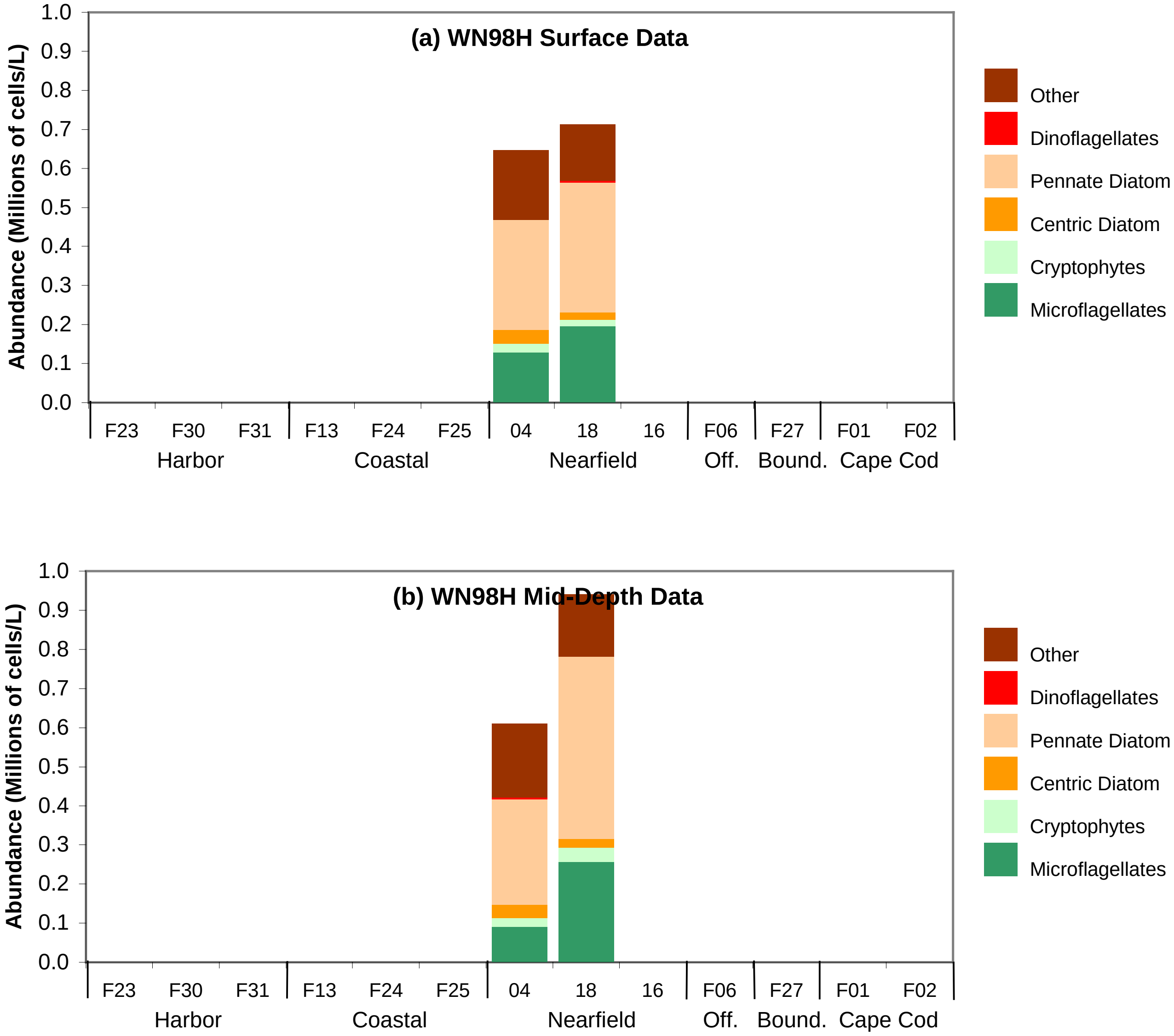


Figure 5-20. Phytoplankton Abundance by Major Taxonomic Group – WN98H Nearfield Survey Results December 16, 1998.

Note: Station N04 is shown as 04, Station N18 is shown as 18, and Station N16 is shown as 16 in the above figures.

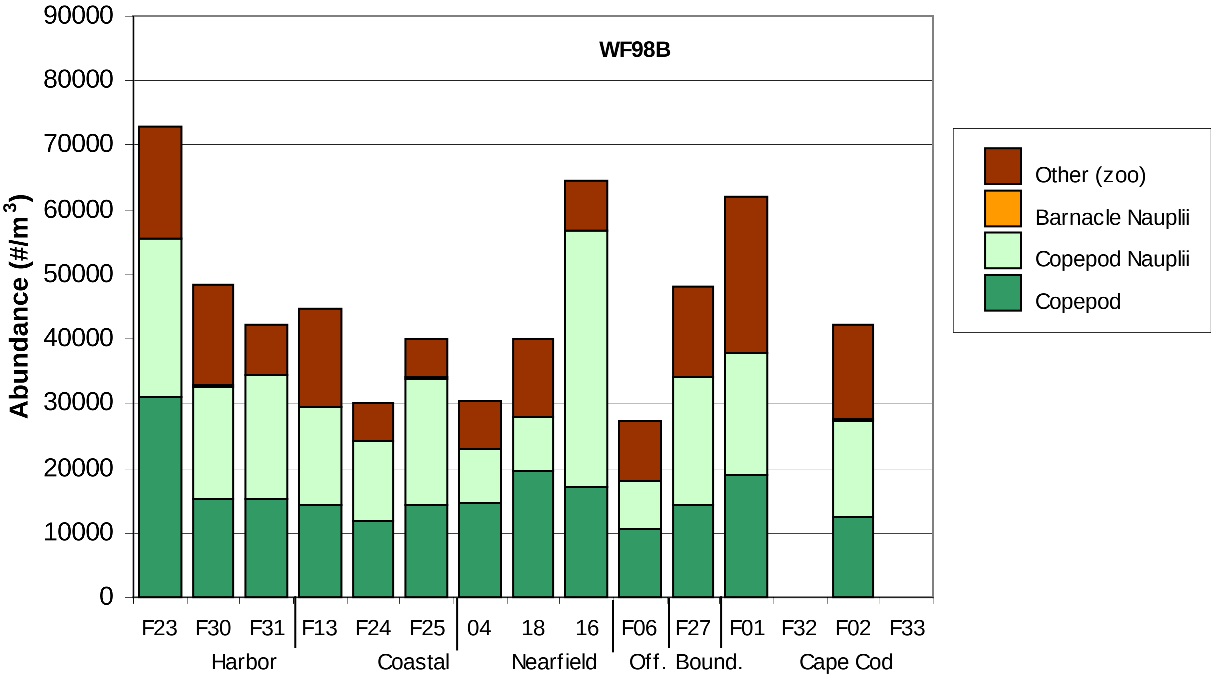


Figure 5-21. Zooplankton Abundance by Major Taxonomic Group – WF98B Farfield Survey Results August 18 – 25, 1998.

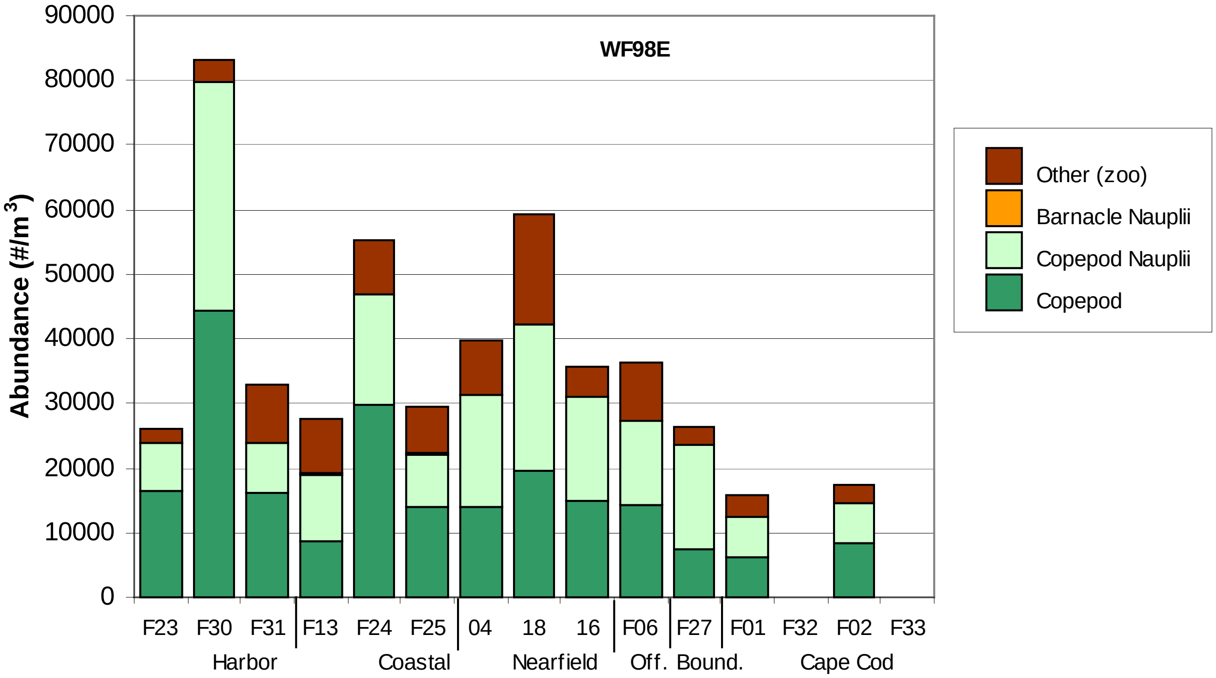


Figure 5-22. Zooplankton Abundance by Major Taxonomic Group – WF98E Farfield Survey Results October 5 – 16, 1998.

6.0 SUMMARY OF MAJOR WATER COLUMN EVENTS

The primary physical characteristic of this period was the delay in the overturn of the water column and the return to winter conditions 1998. Regionally, seasonal stratification had deteriorated at the coastal stations and had begun to weaken at the offshore stations by the October survey (WF98E). The nearfield survey data indicated the pycnocline broke down in the eastern nearfield by October (WF98E), but the water column at the outer nearfield stations was not mixed until late November (WN98G). In fact, a deep halocline persisted into December at the western nearfield and deep offshore stations. Due to the persistence of stratified conditions, survey mean bottom water DO concentrations decreased over the entire August to December time period in the nearfield area. The delay in mixing, combined with a pulse of organic material from the atypical winter phytoplankton bloom, led to the annual minimum in bottom water DO concentration (7 mg L^{-1}) observed in December. The high initial bottom water DO concentration that was observed in June (11.2 mg L^{-1}) lessened the effect of the delay in returning to well-mixed winter conditions.

Upwelling events in August brought cooler, more saline and nutrient replete waters into the surface layer at coastal and western nearfield stations. The upwelled and harbor supplied nutrients supported the abundant phytoplankton assemblage that was observed in the nearfield area during the August survey (WF98B). Areal production measured in August was generally low at nearfield stations N04 and N18 (200-500 mg C m^{-3} d^{-1}), but achieved an annual peak at harbor station F23 (750 mgC $m^{-3}d^{-1}$). High chlorophyll values, however, were measured across the region during the August survey (WF98B) and were coincident with the high phytoplankton abundance.

Chlorophyll, productivity and phytoplankton data suggest that the fall nearfield bloom occurred from September to October. The bloom initiated in the shallow western portion of the nearfield and progressed offshore. In late September (WN98D), high chlorophyll concentrations were observed nearshore and they decreased to the east. Concurrent production and phytoplankton abundance data also exhibited an inshore to offshore decrease across the nearfield. Carbon-specific respiration rates were highest at station N04 in late September during the initiation of the fall bloom at this station. Production was high at station N18 (1000 mg C m^{-3} d^{-1}) and low at N04 (200 mg C m^{-3} d^{-1}) and phytoplankton abundance was 4 times higher at N18 than N04. By the October survey (WF98E), high chlorophyll concentrations were observed throughout nearfield area and peaks in annual production were measured at stations N04 and N18 (1665 and 1988 mg C m^{-3} d^{-1}, respectively). Phytoplankton abundance was also high at each of the nearfield stations (N04, N18, and N16). Carbon-specific respiration rates, however, were relatively low at stations N04 and N18 suggesting that the October survey was conducted near the conclusion of the fall bloom.

Even though a fall bloom was observed in the nearfield, areal production in 1998 was low throughout the late summer and fall period relative to previous baseline monitoring years. This was a continuation of a trend in low production that was observed during the first half of 1998 (Libby et al., 1999).

In November and December, anomalously high concentrations of ammonium and phosphate were observed in the western nearfield that correlated with high concentrations observed by the MWRA in Boston Harbor. The source of these nutrients was not determined, but may have been due to the transfer of south system sewage flows from Nut Island to the Deer Island facility, an ecological change in biological utilization of nutrients in the Harbor, or other factors.

In December, an unprecedented winter bloom was observed in the nearfield area with chlorophyll concentrations of up to 13.2 μg L^{-1}. Phytoplankton abundance had also increased and was 50 to 100% higher at stations N04 and N18 in December in comparison to late November. It is suspected that the anomalously high NH_4 and PO_4 concentrations observed in late November and December contributed to the bloom in the nearfield. The bloom was dominated by microflagellates, but numerous centric and pennate diatoms were present including *Pseudo-nitzschia pungens* which made up 5 to 13% of all cells counted in December.

During the December survey (WN98H), high chlorophyll concentrations were also observed in and near Cape Cod Bay and satellite imagery indicated elevated chlorophyll concentrations in the western Gulf of Maine. This suggests that the elevated chlorophyll concentrations in the nearfield area were part of a regional rather than a localized event. Unfortunately, there were no samples collected for phytoplankton analyses in the farfield and a comparison of Cape Cod Bay and nearfield phytoplankton assemblages was not possible. Data may be available from outside sources and an attempt will be made to access this data in order to determine whether the nearfield phytoplankton bloom resulted from a pulse of NH_4 and PO_4 from Boston Harbor or was part of a regional phytoplankton event. Nevertheless, it appears that physical and/or chemical oceanographic conditions in the Bays were conducive for an atypical regional chlorophyll bloom in December.

7.0 REFERENCES

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APPENDICES

[Note: These appendices are not available on-line. To obtain a printed copy, please call the Environmental Quality Department at (617) 788-4700.]