2013 Water column monitoring results

Massachusetts Water Resources Authority
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Report 2014-17

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Executive Summary

The Massachusetts Water Resources Authority (MWRA), as part of its National Pollutant Discharge Elimination System (NPDES) permit, is required to monitor water quality in Massachusetts and Cape Cod bays. This report documents the results of water column monitoring for 2013. The objectives of the monitoring are to (1) verify compliance with NPDES permit requirements, (2) evaluate whether the impact of the treated sewage effluent discharge on the environment is within the bounds projected by the EPA Supplemental Environmental Impact Statement (EPA 1988), and (3) determine whether change within the system exceeds Contingency Plan thresholds (MWRA 2001).

During 2013 none of the Contingency Plan water column Warning or Caution level thresholds were exceeded. The 2013 water column monitoring again demonstrated that the impacts of the wastewater discharges from the bay outfall were localized and as predicted earlier by calibrated eutrophication-hydrodynamic models. Noteworthy observations made in the bays during 2013 included:

- The winter/spring period was characterized by water temperatures and salinities that were greater than average. Both surface and bottom waters temperatures in the bays during summer were higher than average. Salinity in the surface waters during summer was lower than during most years monitoring has been conducted, which resulted in stronger stratification during summer 2013 than most years.
- One of the defining features of 2013 was the absence of a winter/spring phytoplankton bloom. Typically, a winter/spring bloom is observed in the monitoring data. Timing of the blooms usually start off with an increase in diatom abundance, followed subsequently by increased *Phaeocystis pouchetii* populations.
- Warm conditions may have been conducive to continued production and elevated phytoplankton abundances over the winter (November 2012 to February 2013). This was corroborated by elevated chlorophyll levels in satellite imagery during this period. An extended period of phytoplankton production over the winter could have resulted in the lower nutrient concentrations observed in February 2013. Subsequently, the lower levels of nutrients during the warm, dry winter/spring, may have been responsible for the absence of phytoplankton blooms.
- 2013 was first year since 1999 that *Phaeocystis* has not bloomed in Massachusetts and Cape Cod Bays. Seasonal mean *Phaeocystis pouchetii* and *Pseudo-nitzschia pungens* counts in the nearfield during 2013 were very low and easily met the Contingency Plan thresholds for these nuisance species. *Pseudonitzschia* counts have been low through the entire period the bay outfall has been on line.
- Counts of the toxic dinoflagellate, *Alexandrium fundyense*, the red-tide phytoplankton known to cause PSP, were low in 2013. When *Alexandrium* counts have been elevated in Massachusetts Bay in the past, transport of cells into the bay from the north was responsible for the initial bloom. In 2013, *Alexandrium* counts in the western Gulf of Maine, as in the bay, were low.
- Zooplankton counts during summer of 2013 were high, possibly because water temperatures were relatively high.
- Bottom-water DO concentrations easily met the Contingency Plan threshold. Given the low initial "setup" DO concentrations in May/June, strongly stratified summer conditions and prolonged duration into mid-November, it was surprising that bottom water DO levels were not lower. The late fall DO concentrations fell within the range seen during previous years.

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1 INTRODUCTION

The Massachusetts Water Resources Authority (MWRA) conducts a long-term ambient outfall monitoring program in Massachusetts and Cape Cod Bays. The objectives of the program are to (1) verify compliance with National Pollutant Discharge Elimination System (NPDES) permit requirements, (2) evaluate whether the impact of the treated sewage effluent discharge on the environment is within the bounds projected by the EPA Supplemental Environmental Impact Statement (EPA 1988), and (3) determine whether change within the system exceeds Contingency Plan thresholds (MWRA 2001).

A detailed description of the monitoring and its rationale are provided in the monitoring plans developed for the baseline (MWRA 1991, 1997) and outfall discharge periods (MWRA 2004, 2010). The 2013 data complete thirteen years of monitoring since outfall start-up on September 6, 2000. **Table 1-1** shows the timeline of major upgrades to the MWRA wastewater treatment system.

Table 1-1. Major upgrades to the MWRA treatment system.

Date	Upgrade
December 1991	Sludge discharges ended
January 1995	New primary plant on-line
December 1995	Disinfection facilities completed
August 1997	Secondary treatment begins to be phased in
July 9, 1998	Nut Island discharges ceased: south system flows transferred to Deer Island – almost all flows receive secondary treatment
September 6, 2000	New outfall diffuser system on-line
March 2001	Upgrade from primary to secondary treatment completed
October 2004	Upgrades to secondary facilities (clarifiers, oxygen generation)
April 2005	Biosolids line from Deer Island to Fore River completed and operational
2005	Improved removal of TSS etc. due to more stable process
2010	Major repairs and upgrades to primary and secondary clarifiers

MWRA's Effluent Outfall Ambient Monitoring Plan (AMP) was revised in 2010 (MWRA 2010); 2013 was the third year of monitoring according to the new design. The 2010 AMP revision builds on the scientific understanding gained over the past 20 years—the monitoring is now focused on the nearfield, stations potentially affected by the discharge, and reference stations in Massachusetts Bay. There are nine synoptic one-day surveys per year (**Table 1-2**). The Provincetown Center for Coastal Studies (PCCS) monitors Cape Cod Bay in the same timeframe. This annual report summarizes the 2013 results as seasonal patterns, in the context of the annual cycle of ecological events in Massachusetts and Cape Cod Bays, and with respect to Contingency Plan thresholds (MWRA 2001). Long-term inter-annual patterns are also analyzed.

1.1 DATA SOURCES

The details of field sampling procedures and equipment, sample handling and custody, sample processing and laboratory analysis, instrument performance specifications, and the program's data quality objectives are given in the Quality Assurance Project Plan (Libby *et al.* 2011a). The survey objectives, station locations and tracklines, instrumentation and vessel information, sampling methodologies, and staffing were documented in the survey plan prepared for each survey. A survey report prepared after each survey summarizes the activities accomplished, details on any deviations from the methods described in the QAPP, the actual sequence of events and tracklines, the number and types of samples collected, and a preliminary summary of *in situ* water quality data. This includes the results of a rapid analysis of >20 μm phytoplankton species abundance in one sample, whale watch information, and any deviations from the survey plan. Electronically gathered and laboratory-based analytical results are tabulated in data reports.

1.2 WATER COLUMN MONITORING PROGRAM OVERVIEW

Under the AMP (MWRA 2010) all sampling locations (**Figure 1-1**) are visited during nine surveys annually; 2013 sampling dates are in **Table 1-2**. There are five stations sampled in the nearfield and nine stations in the farfield. All stations in Massachusetts Bay are sampled for a comprehensive suite of water quality parameters, and plankton is sampled at all stations except N21. The 11 stations in Massachusetts Bay were sampled synoptically during one-day surveys; the three Cape Cod Bay stations were sampled by PCCS within a day of the Massachusetts Bay stations.

Table 1-2. Water column surveys for 2013.

Survey	Massachusetts Bay Survey Dates	Cape Cod Bay Survey Dates	Closest Harbor Monitoring survey dates
WN131	February 6	February 5	--
WN132	March 21	March 21	March 25
WN133	April 10	April 10	April 4
WN134	May 17	May 17	--
WN135	June 18	June 20	June 13
WN136	July 24	July 22	July 25
WN137	August 20	August 20	August 15
WN138	September 4	September 4	September 4
WN139	October 22	October 23	October 17

PCCS collected samples at the three MWRA Cape Cod Bay stations (**Figure 1-1**) and has an ongoing water quality monitoring program at eight other stations in Cape Cod Bay.[1] Nutrient data from all the Cape Cod Bay stations are included in this report. MWRA collected samples at 10 stations in Boston Harbor [Boston Harbor Water Quality Monitoring (BHWQM)].[2] The BHWQM data (nutrient, dissolved oxygen, and *Alexandrium*) collected within 6 days of an AMP survey are included in this report. The survey dates are in **Table 1-2**.

In addition to sampling surveys, this report includes MODIS-Aqua satellite imagery provided by NASA, and continuous monitoring data from the NOAA National Data Buoy Center (NDBC) Buoy 44013 and the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) Buoy A. NDBC Buoy 44013 is located ~10 km southeast of the outfall, near station N07; NERACOOS Buoy A is located in the northwestern corner of Stellwagen Bank National Marine Sanctuary and ~5km northeast of MWRA station F22 (**Figure 1-1**). The satellite imagery provides information on regional-scale patterns, while the buoys collect data at high temporal frequency.

The data are grouped by season for calculation of chlorophyll, *Phaeocystis*, and *Pseudo-nitzschia* Contingency Plan thresholds. Seasons are defined as the following 4-month periods: winter/spring is from January through April, summer is from May through August, and fall is from September through December. Comparison of baseline and outfall discharge period data are made for a variety of parameters. The baseline period is February 1992 to September 6, 2000 and the outfall discharge period is September 7, 2000 through December 2013.[3]

[1] PCCS station map available at http://www.coastalstudies.org/what-we-do/cc-bay-watch/stations.htm
[2] BHWQM station map available at http://www.mwra.state.ma.us/harbor/graphic/bostonharbor_850.gif
[3] Year 2000 data are not used for calculating annual means as the year spans both periods, but are included in plots and analyses broken out by survey and season. Specific details on how the 2000 data are treated are included in the captions and text.

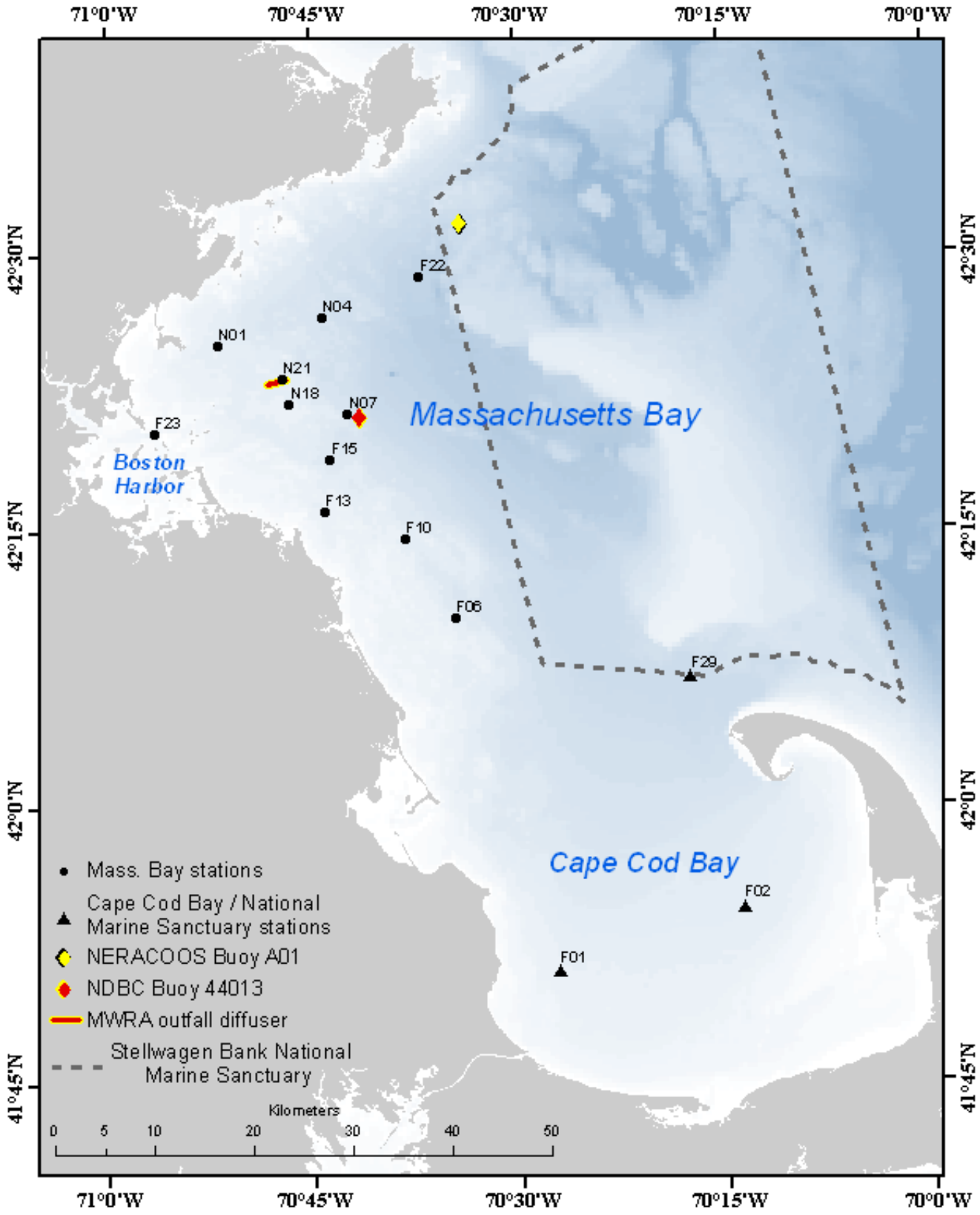

Figure 1-1. Water column monitoring locations.

2 MONITORING RESULTS

The 2013 monitoring data deviated in the winter/spring from what we have typically observed over the seasonal sequence of water quality events in Massachusetts Bay. A winter/spring phytoplankton bloom typically is observed as light becomes more available, temperatures increase, and nutrients are readily available. In recent years, the winter/spring diatom bloom has been followed by a bloom of *Phaeocystis pouchetii* in April. The 2013 data are characterized by the apparent lack of a winter/spring bloom and there was no observed diatom or *Phaeocystis* bloom in February-April 2013. However, elevated phytoplankton abundances may have occurred prior to that survey based on nutrient data and satellite imagery. This was the first year since 1999 that *Phaeocystis* did not bloom in Massachusetts and Cape Cod Bays.

By late spring, the 2013 data were more in line with typical seasonal trends for May through October. Typically by late spring, the water column transitions from well-mixed to stratified conditions, and this was observed. The summer is generally a period of strong stratification, depleted surface water nutrients, and a relatively stable mixed-assemblage phytoplankton community – seen again in the 2013 data. In the fall, as temperatures cool, stratification deteriorates and nutrients are again supplied to surface waters. This transition often contributes to the development of a fall phytoplankton bloom, which was seen in 2013.

Typically the lowest observed dissolved oxygen (DO) concentrations for the year can be found in bottom waters just prior to the complete fall overturn of the water column. In 2013, the return of the system to well-mixed winter conditions occurred after the final survey in October, but DO levels were moderate throughout the bay in comparison to previous years. By late fall or early winter, the water column became well mixed and reset to winter conditions.

The details of the major features observed and differences noted in 2013 relative to the previous 21 years of monitoring are considered below.

2.1 2013 RESULTS

The most notable characteristic of the physical environment was that 2013 was a relatively warm winter/spring and dry year, which was similar to conditions in 2012 (**Figure 2-1**; Libby *et al*. 2013). Warm winter/spring air temperatures resulted in warmer than usual water temperatures at the onset of spring stratification (**Figure 2-2**). There were a few strong storms in February and March 2013, the strongest of which was named winter storm "Nemo", with wave heights reaching 10 meters in the bay. The water column was well mixed at the time so there were no major changes to water column properties, but the storm's waves did result in high suspended sediment loads in the bay that were evident in MODIS satellite images the day after the storm (February 10, 2013). There was also a precipitation event in early June that resulted in an annual maximum in Charles River discharge, but this was not a regional event as the peak in Merrimack River flow at that time was not substantial (**Figure 2-1**). The June storm event did lead to a decrease in surface salinity in Boston Harbor and the nearfield area.

Overall for 2013, the annual average flows in the Merrimack and Charles Rivers were below average. This is the second year in a row with lower than average flow following seven years (2005-2011) of relatively wet conditions. These physical forcing events, or lack thereof, contributed to the trends and events observed in other water quality and biological data.

A chronological synopsis of the 2013 results is provided below.

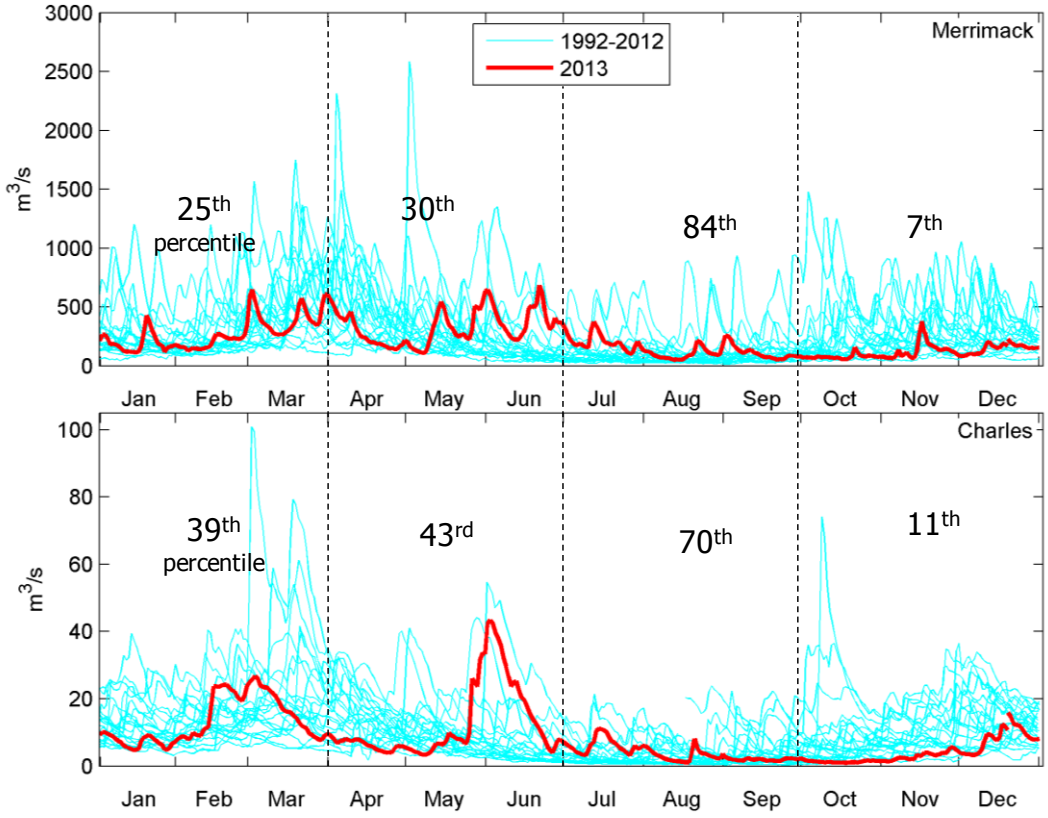

Figure 2-1. **Comparison of the 2013 discharge of the Charles and Merrimack Rivers (solid red curve) with 1992-2012 (light blue lines).** Percentile of flow in 2013 relative to other years is presented for each river/season.

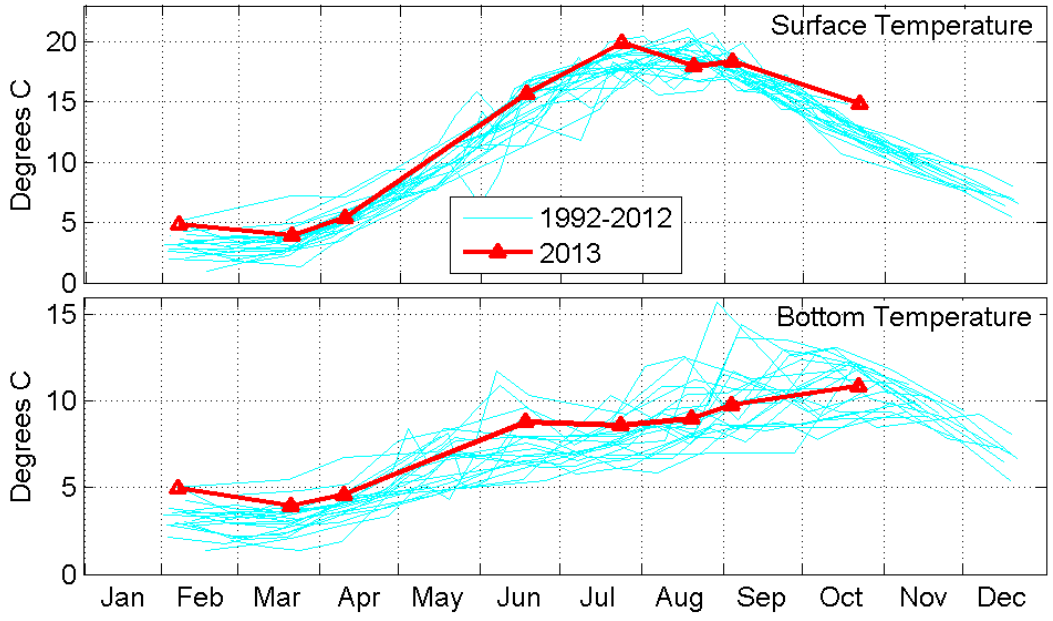

Figure 2-2. **Comparison of 2013 surface and bottom water temperature (°C) at nearfield station N18 (solid red line) with 1992-2012 (light blue lines).**

Nutrient concentrations in Massachusetts and Cape Cod Bays in February 2013 were low compared to previous winter levels. Nitrate+nitrite (NO_3+NO_2) levels in Cape Cod Bay were a third of those in Massachusetts Bay, which were lower than previous years, and silicate (SiO_4) was nearly depleted in both bays in February (**Figure 2-3**). Prolonged presence of elevated diatoms abundances over the warm winter might have been responsible for the low February nutrient levels. There was a large increase in NO_3 and SiO_4 from February to March in Cape Cod Bay. Comparable increases in SiO_4 were observed in Massachusetts Bay, while NO_3 levels remained comparable to February levels. Nitrate levels decreased sharply from March to April and were depleted by May across the bays in all but the deepest bottom waters (i.e. station F22).

A comparison of nutrient levels at station N18 for 2013 against previous years' data highlights how much lower NO_3, SiO_4, and phosphate (PO_4) levels were in February 2013 as well as how high NO_3 and PO_4 were in April (**Figure 2-4**). These trends are likely linked to the presence of a elevated phytoplankton population thru the winter and the lack of a diatom or *Phaeocystis* bloom in February through April. Satellite imagery from November 2012 to early February 2013 is consistent with this speculation as elevated chlorophyll levels were observed throughout the bays (Libby *et al*. 2013; **Figure 2-5**). NERACOOS buoy A temperature readings were relatively high from November 2012 to February 2013 (see: http://neracoos.org) suggesting that conditions may have been conducive to the phytoplankton to remain productive over the winter. Surface water chlorophyll concentrations measured at the buoy were not substantially higher than past winters though, ranging from about 2 to 5 µg L^{-1}.

One of the defining features of the 2013 phytoplankton annual cycle was very low winter-spring phytoplankton abundance (**Figure 2-6**). Abundance of both major components of the Massachusetts Bay winter-spring flora, centric diatoms and *Phaeocystis* was severely reduced in winter-spring 2013. Both nitrate and silicate concentrations were low in February 2013, suggesting that nutrient limitation may have reduced the abundances of phytoplankton typically observed during this winter/spring period. Model and field evidence suggest that reduced nitrate concentration (<6 µM) early in the winter-spring bloom season (February) are sufficient to prevent development of large *Phaeocystis* blooms in Massachusetts Bay (Jiang *et al*. 2014). The simultaneous reduction in early season silicate concentration observed in February 2013 may have also limited development of the winter-spring diatom bloom. In many coastal systems, the serial reduction in different nutrients, first SiO_4 by centric diatoms followed by NO_3 has been proposed as a potential *Phaeocystis* bloom mechanism (Reid *et al*. 1990; Peperzak *et al*. 1998). Therefore, in 2013, the simultaneous reduction in both NO_3 and SiO_4 in Massachusetts Bay may have thwarted development of large winter-spring blooms of both centric diatoms and *Phaeocystis*.

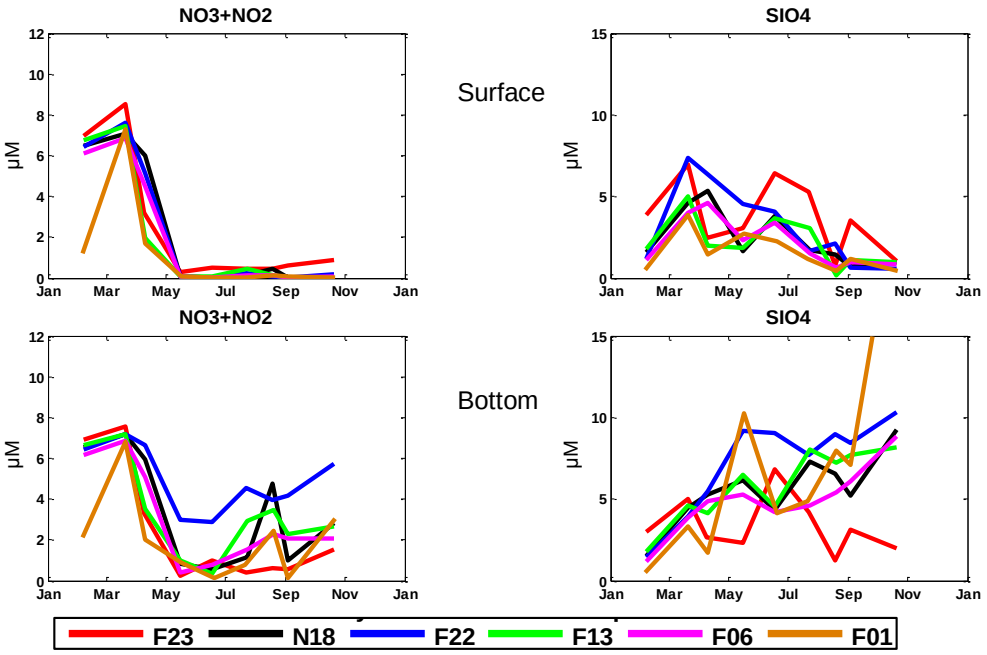

Figure 2-3. **Time-series of surface and bottom mean nutrient concentrations (µM) at representative stations in Massachusetts and Cape Cod Bays.**

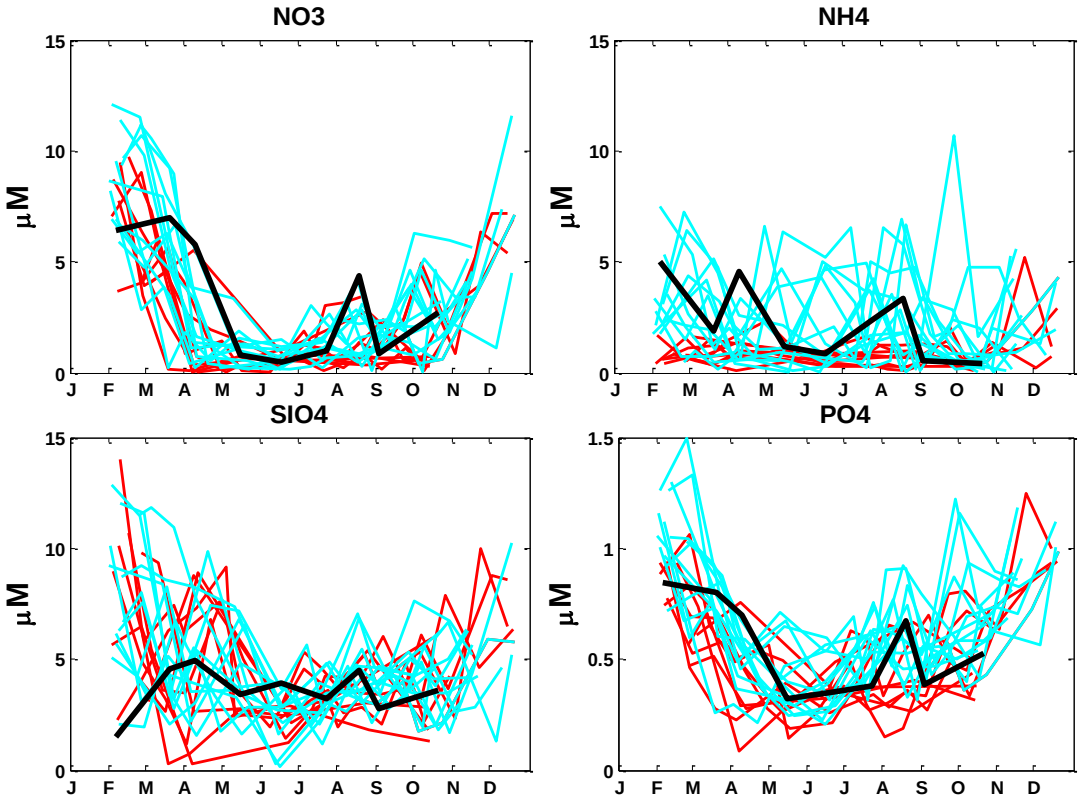

Figure 2-4. **Station average nutrient concentrations (µM) near the outfall site (nearfield station N18) for 2013 (black line) compared to the previous 21 years of baseline (1992-August 2000; red) and post-diversion (September 2000-2012; light blue) observations.** Note change in scale for PO_4 plot.

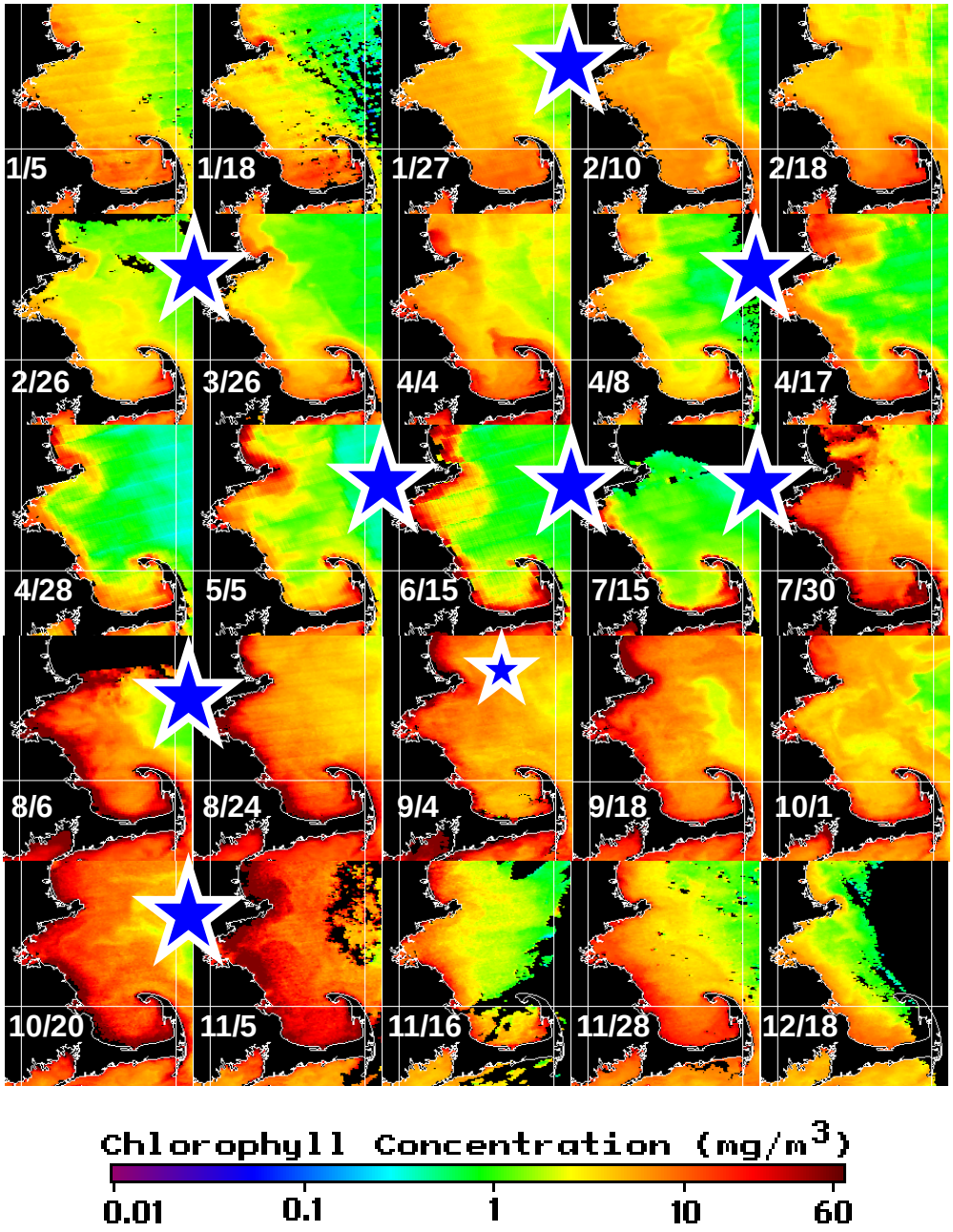

Figure 2-5. Satellite (MODIS) imagery of surface chlorophyll concentrations (mg m^{-3}) in 2013.

Highlights and specific blooms:

1st row – early elevated chlorophyll levels January – February 2013;
2nd & 3rd rows – relatively low from late February into July – no winter/spring diatom or *Phaeocystis* blooms;
4th row – late summer chlorophyll increase - bloom of *Dactyliosolen fragilisima* (and other centric diatoms);
4th row – September diatom bloom (*Skeletonema* dominated);
5th row – elevated chlorophyll levels into early November.

(Note that these images are heavily weather dependent and do not represent consistent intervals of time. The stars on the image correspond to relative timing of the nine MWRA surveys.)

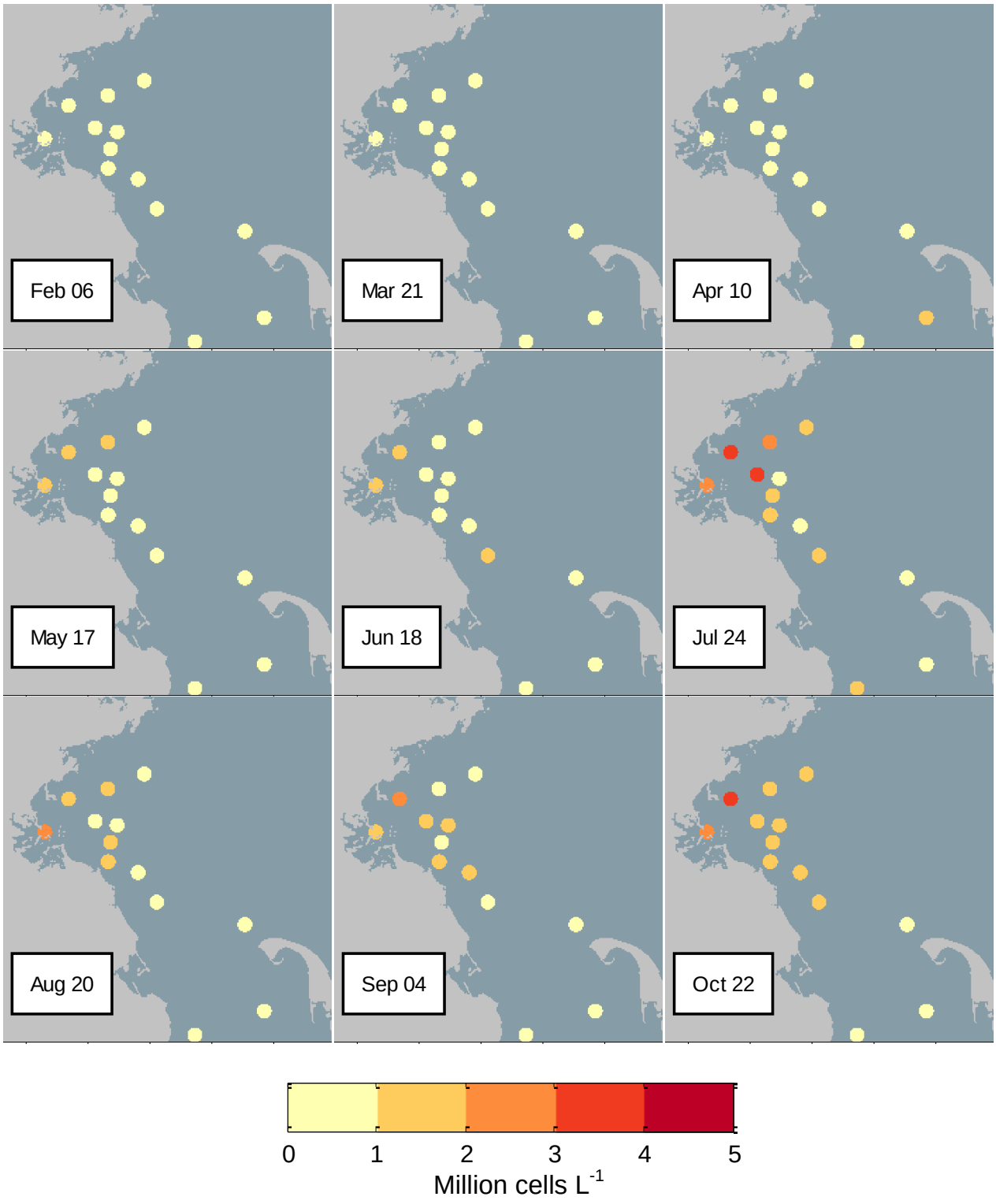

Figure 2-6. **Average phytoplankton abundance (million cells L^{-1}) by station in Massachusetts and Cape Cod Bays.**

Surface water nitrate levels remained relatively low from May through October (**Figure 2-3**). Surface water SiO_4 levels peaked in March/April time period and generally declined over the remainder of the year. The low surface nutrient levels during the summer were likely due to a combination of strong stratification and consistent biological utilization. The relative strength of stratification in June and July 2013, as estimated by the difference in surface and bottom water densities, was amongst the highest levels observed for these months during the monitoring program (**Figure 2-7**) and served to restrict the flux of nutrients from the bottom waters. Elevated chlorophyll concentrations in July suggest that whatever nutrients were making it into the surface layer were rapidly taken up. Annual peak chlorophyll concentrations observed then at the Boston Harbor station F23 and nearby shallow water stations is shown in **Figure 2-8**. Total phytoplankton abundance peaked in July and August at these Boston Harbor and nearfield stations (**Figure 2-6**). Both the harbor and nearfield featured summer diatom blooms that reached cell abundance levels 1.8 (Boston Harbor) and 3.7 (nearfield) times the long-term means for those areas. This summer bloom was two-phased, with dominance by *Dactyliosolen fragilissimus* reaching abundances >2 million cells L^{-1} in July followed by dominance by *Skeletonema* spp. at levels of 2-3 million cells L^{-1} during August.

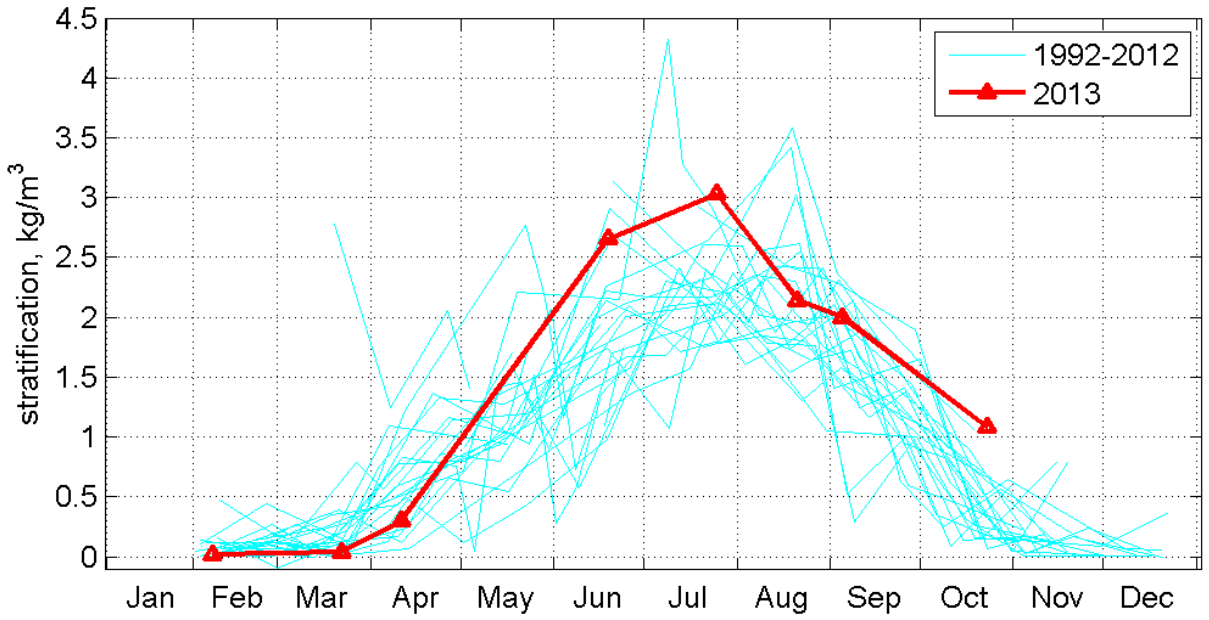

Figure 2-7. Stratification at nearfield station N18 in Massachusetts Bays in 2013 (red line) and previous 21 years (1992-2012, light blue lines).

The *Skeletonema* bloom in August was concomitant with an increase in subsurface nutrient levels that was most notably observed at stations N18 and N21 in the nearfield. This increase in nutrient concentrations in August was probably associated with upwelling that brought nutrient-rich bottom water up into the surface layer as suggested for NO_3 and SiO_4 in **Figure 2-9**. This additional supply of nutrients into the surface layer likely supported the diatom blooms in the late summer and into the fall. Centric diatoms, *Skeletonema* spp. and *Leptocylindrus danicus*, continued to bloom in September and were present at elevated abundances throughout the remainder of the fall. Satellite imagery shows elevated concentrations in the bays from late July to mid-November (**Figure 2-5**). An offshore increase in chlorophyll concentrations was also observed at NERACOOS buoy A with concentrations of 5-15 µg/L from late September to mid-November (**Figure 2-10**). The combination of prolonged utilization and lack of early fall storms led to the depletion nitrate and silicate in surface waters of Massachusetts Bay in September and October 2013 (**Figure 2-3**).

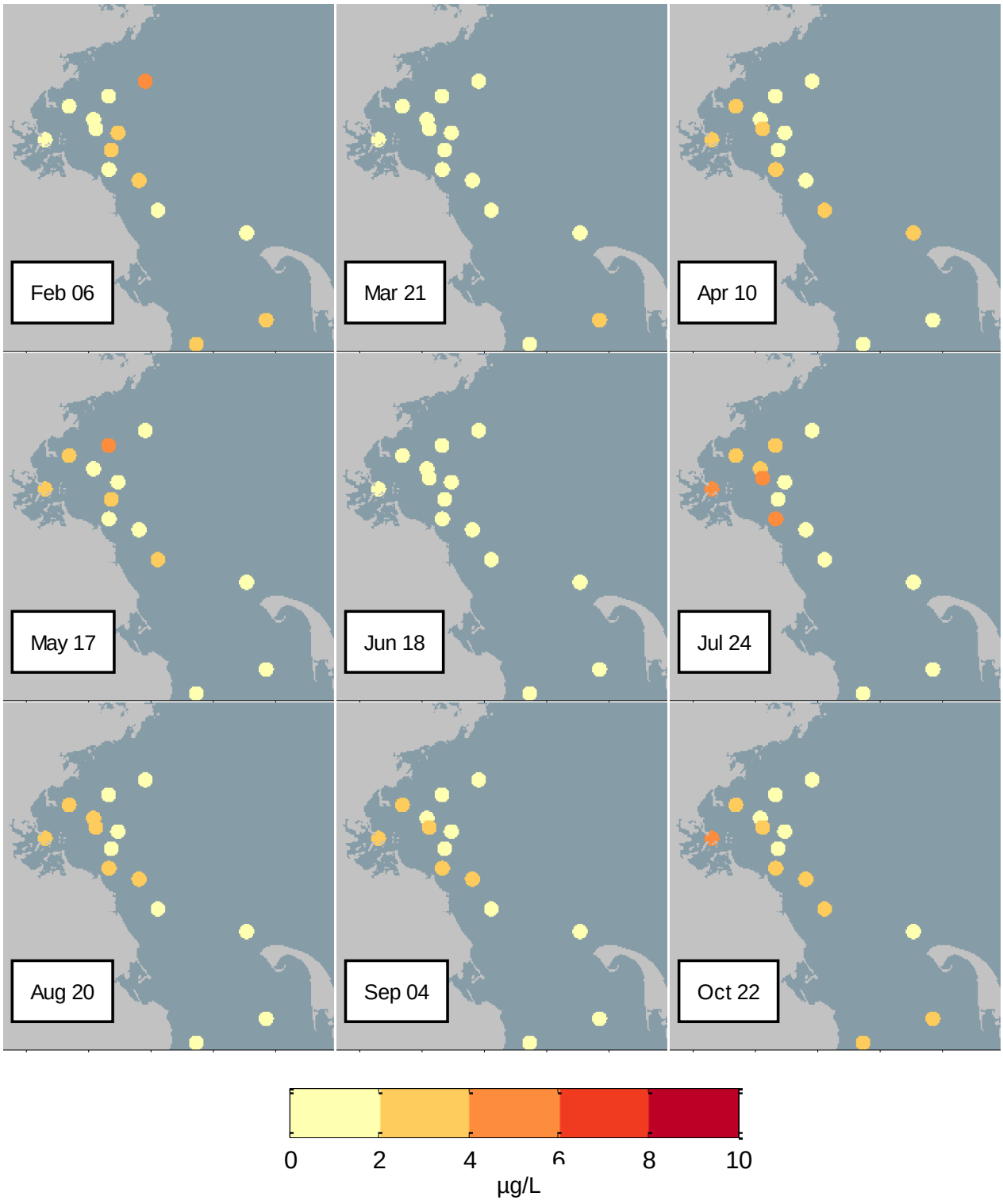

Figure 2-8. **Average *in situ* chlorophyll fluorescence (µg L^{-1}) by station in Massachusetts and Cape Cod Bays.**

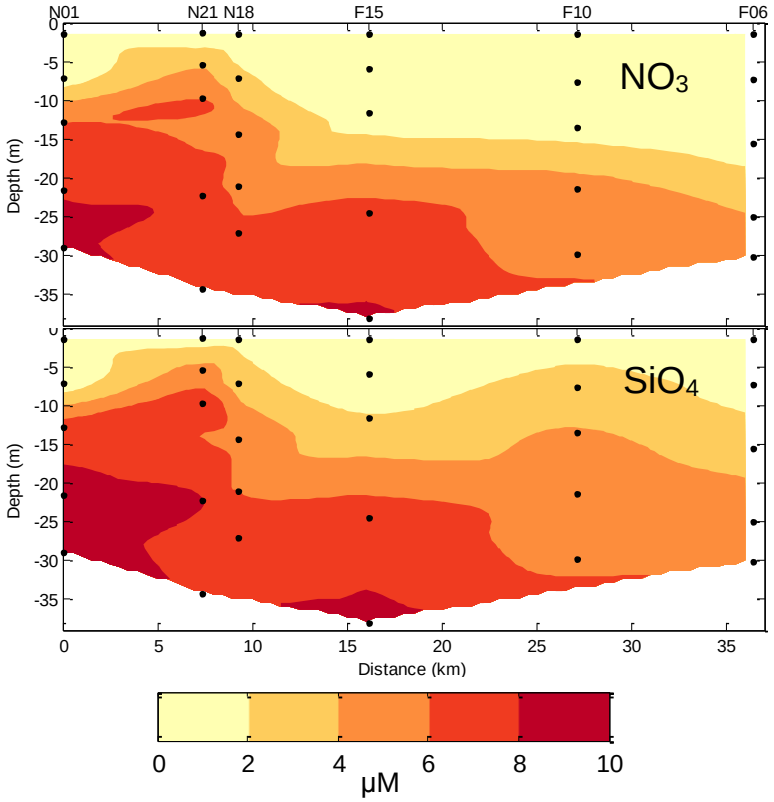

Figure 2-9. **North to South transect vertical contours of NO_3 (top) and SiO_4 (bottom; µM) from Broad Sound, across the nearfield, and to the south to station F06 in August 2013. Same transect as shown in Figure 2-12.**

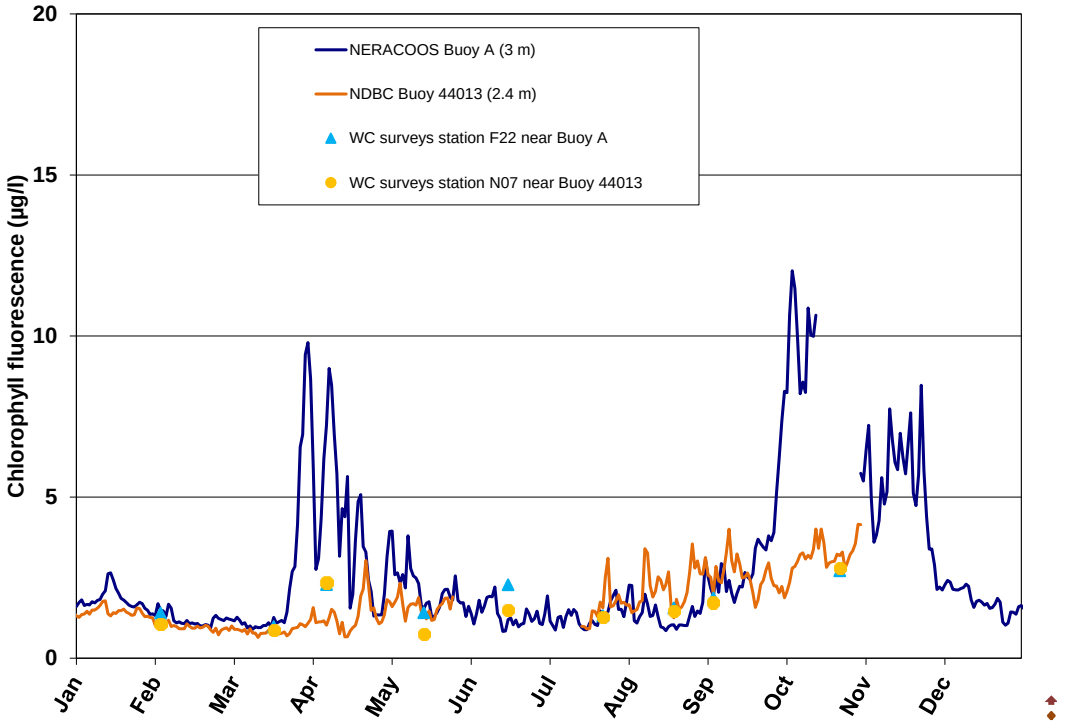

Figure 2-10. **Surface water chlorophyll concentrations (µg L^{-1}) at NERACOOS Buoy A01, NDBC Buoy 44013, and nearby MWRA stations.**

As has been typically observed, the bay outfall effluent plume was detected as elevated ammonium (NH_4) concentrations in the nearfield during all but one (September) of the surveys in 2013 (**Figure 2-11**). The spatial (horizontal and vertical) distribution of the effluent plume in 2013 continued to compare well with model predictions (R. Signell *et al*. 1996). The plume signature of elevated NH_4 concentrations was generally seen within 10-20 km of the bay outfall during both well-mixed and stratified conditions. The furthest south the plume was observed was in mid-depth samples from station F15 in July (**Figure 2-12**).

Bottom water dissolved oxygen (DO) concentrations declined at a relatively constant rate in Massachusetts Bay from April annual maxima to October annual minima (**Figure 2-13**). DO levels in the nearfield in February-April 2013 were relatively low in comparison to past years. However, they did not reach abnormally low levels in the fall and were actually moderate in comparison to some past years like 2012 (6.2 mg L^{-1} at station N18 in 2012; Libby *et al*. 2013). Given the low initial "setup" DO concentrations in May/June, the strong stratified conditions in October and prolonged duration into mid-November, it is surprising that bottom water DO levels were not lower. The survey observations ended prior to the overturn of the water column in the fall of 2013, but DO data from NERACOOS buoy A indicate that levels did not get below 6.5 mg L^{-1} in the deeper bottom waters of Massachusetts Bay before the water column became mixed on November 15 during a northeaster storm (**Figure 2-13**). The lowest DO concentrations of 2013 were measured in the bottom water at station F02 in October (4.07 mg L^{-1}; **Figure 2-14**). Low DO levels in Cape Cod Bay are not uncommon (Becker 1992; Jiang *et al*. 2007). Interestingly, bottom water DO at station F01 in Western Cape Cod Bay had increased by October to 8 mg L^{-1} indicating that Western Cape Cod Bay had remixed prior to Eastern Cape Cod Bay.

The 2013 observations of DO were consistent with a regression model developed in previous years (Geyer *et al*. 2002), where low DO is related to warm and/or salty bottom waters. In 2013, high salinity "explained" most of the low DO anomaly (DO level below long-term mean). The time series data from the NERACOOS Buoy A01 continue to demonstrate that variations in near-bottom DO at the outfall site closely track those observed at both the Stellwagen station F22 and the buoy. This indicates that horizontal advective processes are very important in determining the interannual variations of DO, and also that interannual variations of DO at the outfall site are more regional than local.

In 2013, the zooplankton community composition, abundance, seasonality, and distributional patterns generally followed typical patterns except for several atypically high levels of abundance of certain taxa. This is interesting since 2013 marks the second year in a row that was warmer than average and no winter/spring blooms of diatoms or *Phaeocystis* were observed. Total zooplankton abundance increased from the winter through the spring, peaking in July, and declining in the fall as usual (**Figure 2-15**). The zooplankton was usually dominated by copepod nauplii, and copepod adults and copepodites, most of which were *Oithona similis*. *Acartia* spp. were abundant only in Boston Harbor, particularly in August. *Calanus finmarchicus* was most abundant in April, particularly at the most-offshore stations. *Pseudocalanus* spp. were most abundant during May-July, also mainly at nearfield and offshore stations. Abundances of most other taxa were generally similar at most locations during a given sampling period. Seasonal patterns of abundance were similar to previous years. Sampling captured several meroplankton peaks, including barnacle nauplii in March and April, and bivalve veligers in July and particularly August. Total zooplankton, copepod adults and copepodites, *Calanus finmarchicus*, *Pseudocalanus* spp., barnacle nauplii, and other zooplankton (meroplankton) were generally higher than in most previous years, but generally within previously-recorded ranges. Thus, abundances of most taxa were near the high end of normal abundances. In terms of long-term trends (1998-2012), 2013 total zooplankton abundance increased (see **Figure 2-24**).

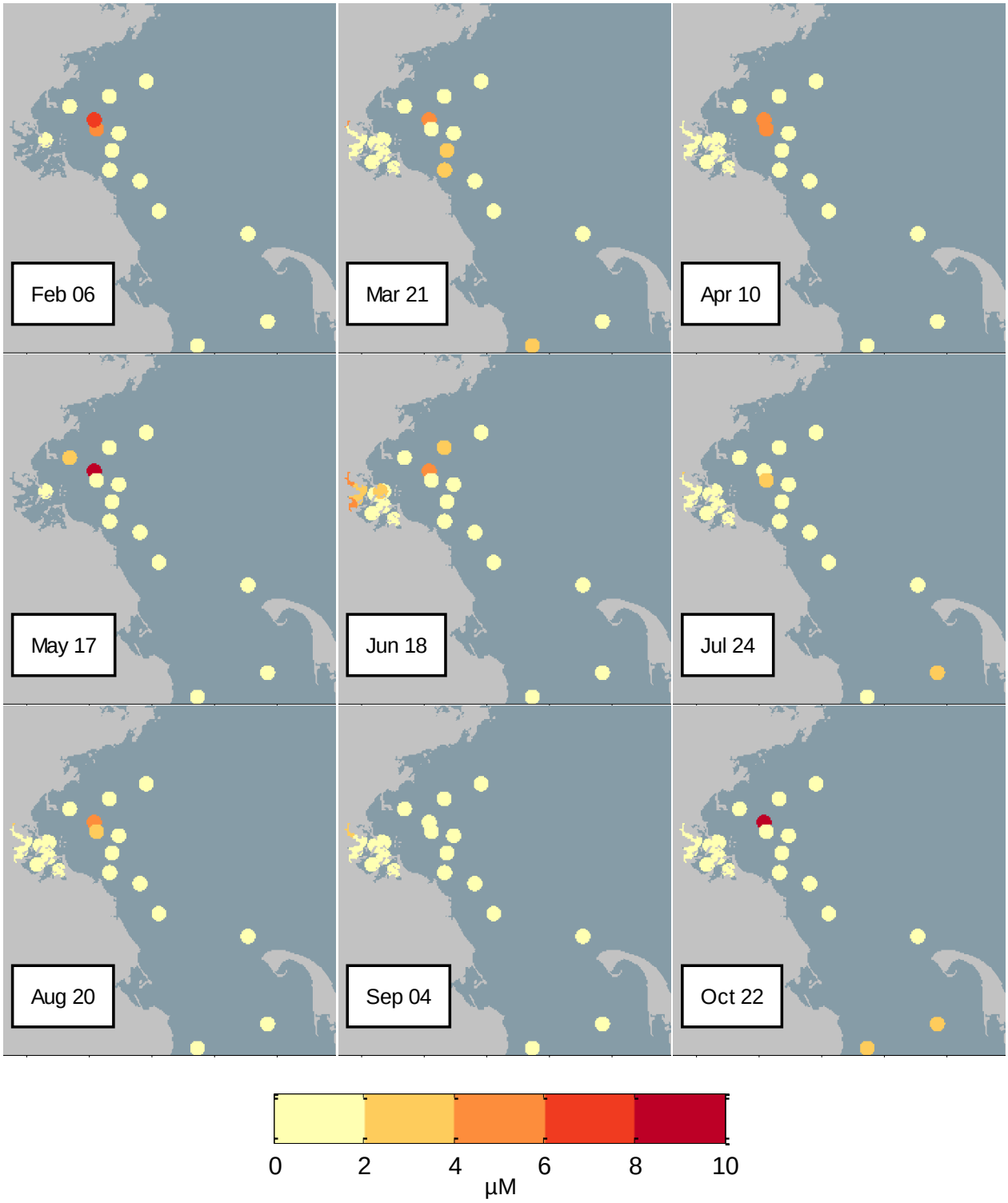

Figure 2-11. Average NH_4 concentrations (µM) by station in Massachusetts and Cape Cod Bays.

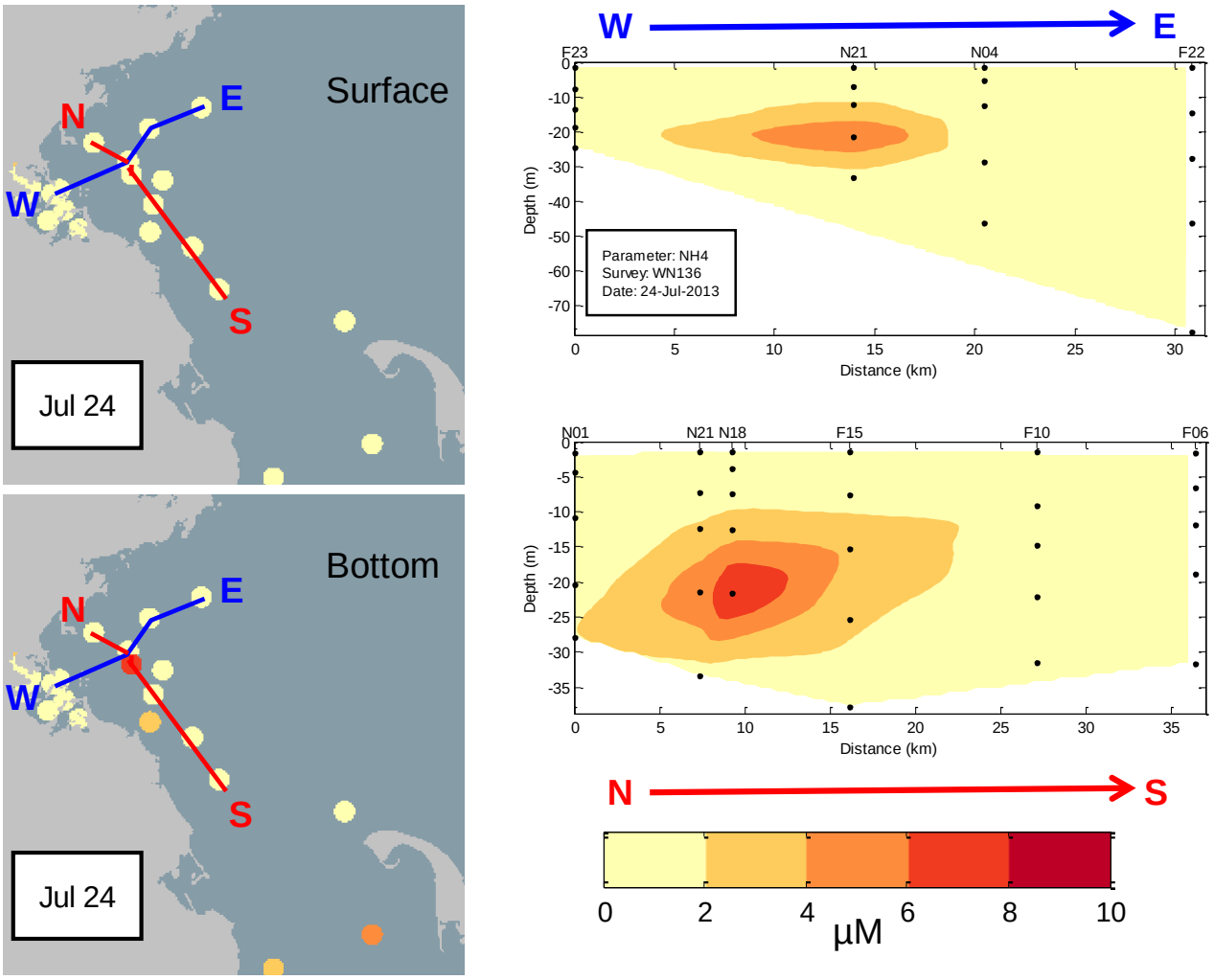

Figure 2-12. Surface and bottom water NH_4 (µM) by station and along two vertical transects in Massachusetts and Cape Cod Bays on July 24, 2013.

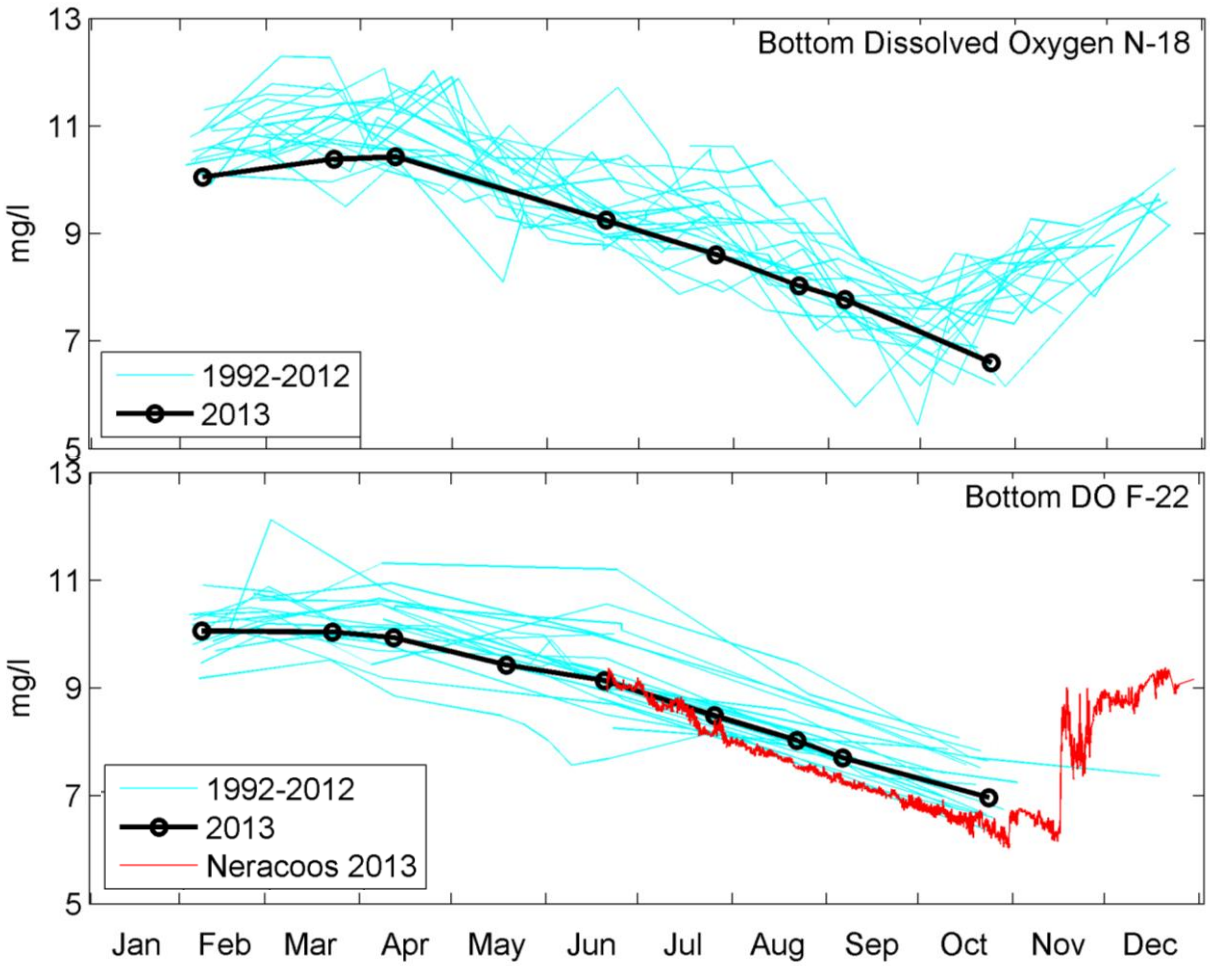

Figure 2-13. Time-series of bottom water DO concentration (mg L^{-1}) at nearfield station N18 (top) and Stellwagen Basin station F22 (bottom) for 2013 (black) compared to the previous 21 years of observations (1992-2012; light blue). NERACOOS buoy A near-bottom water (50 m) DO levels are shown in red.

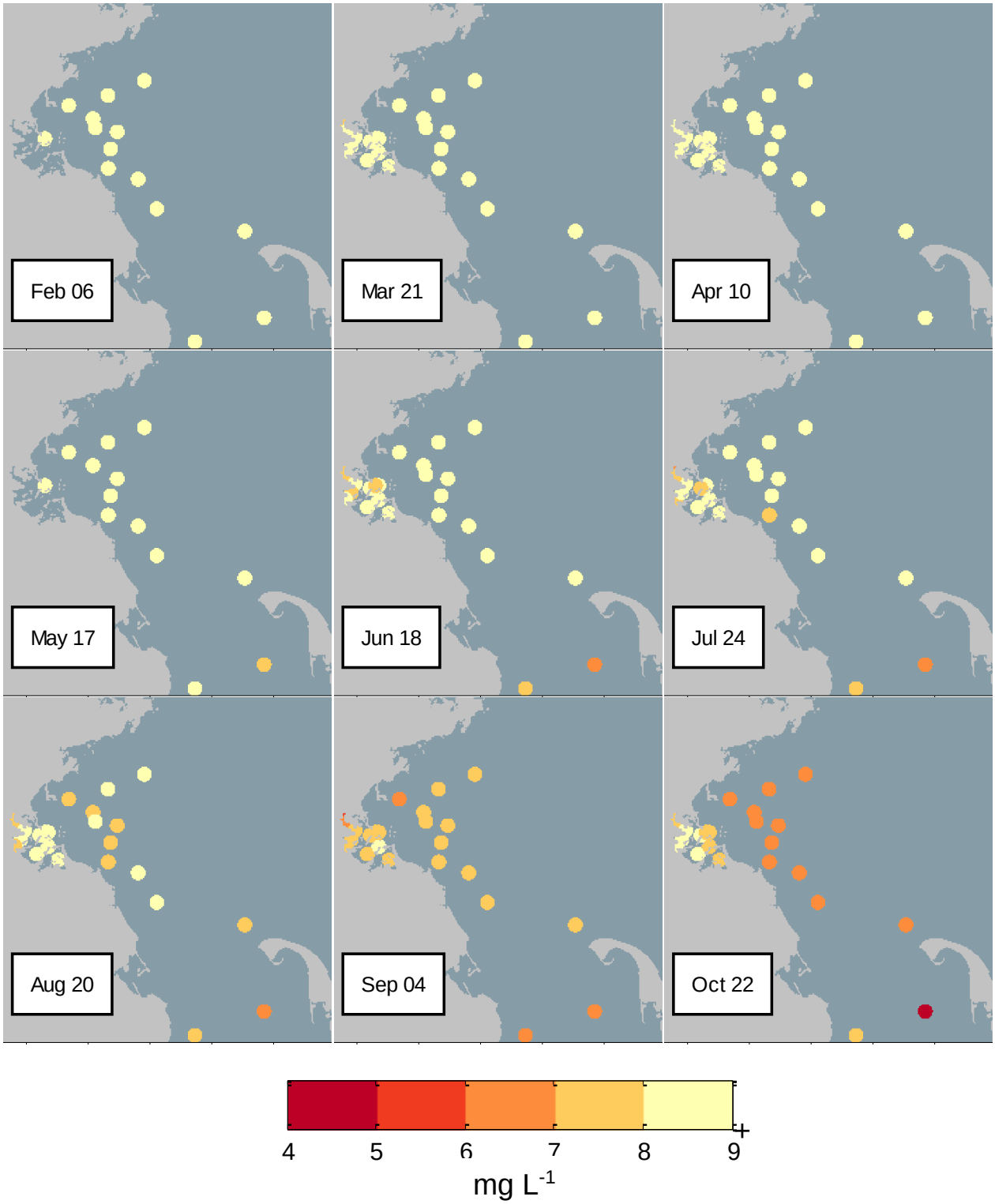

Figure 2-14. Bottom water DO concentration (mg L^{-1}) at stations in Massachusetts and Cape Cod Bays in 2013. The lowest DO measured in 2013 was 4.07 mg L^{-1} at station F02 during the October survey. Only three times during the monitoring program has bottom DO fallen below 5 mg L^{-1}, in October 1994, 2000, and 2012.

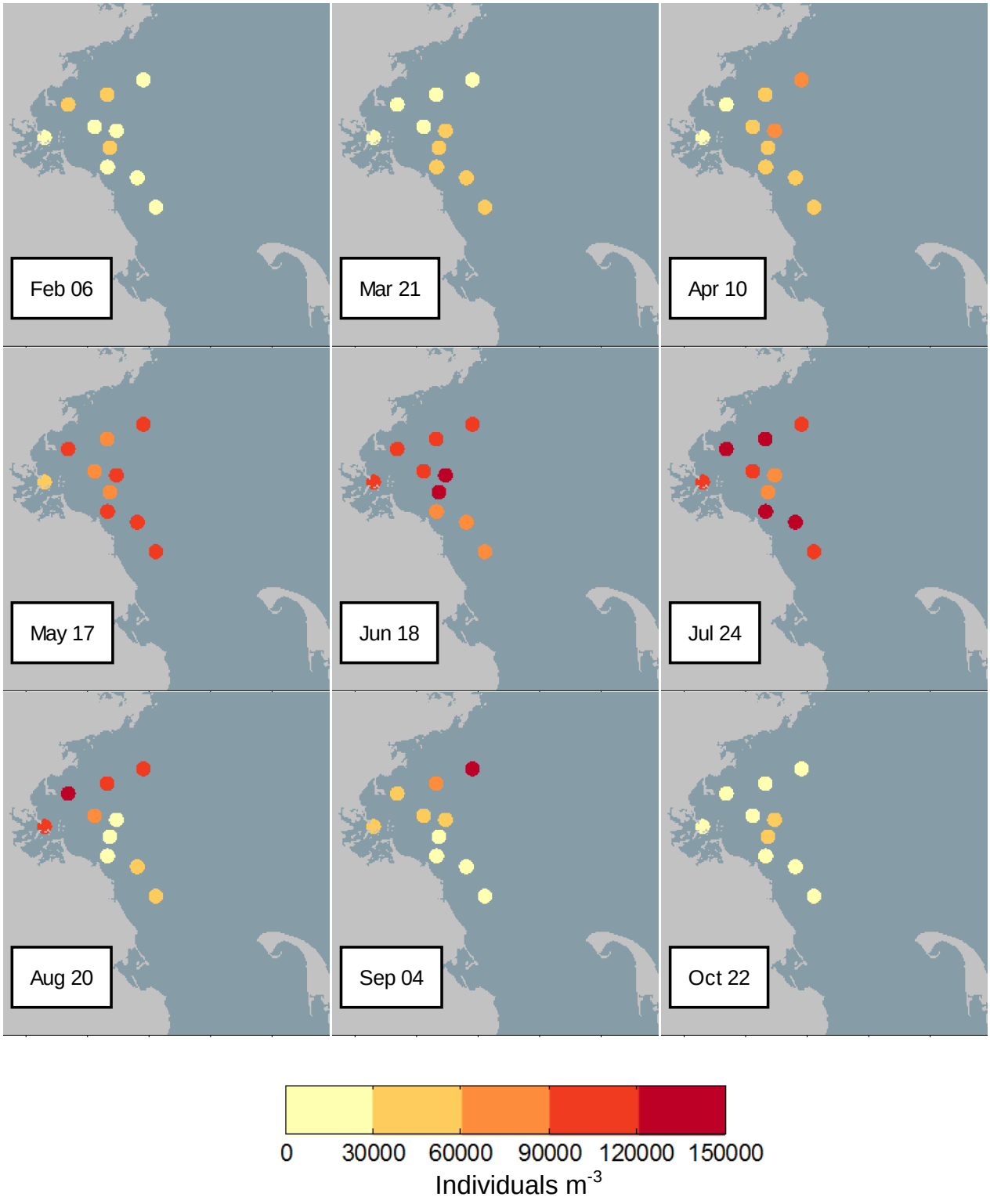

Figure 2-15. Total zooplankton abundance (individuals m^{-3}) at each station in Massachusetts Bay.

2.1 CONTINGENCY PLAN THRESHOLDS FOR 2013

Contingency Plan Threshold water quality parameters include 1) DO concentrations and percent saturation in bottom waters of the nearfield and Stellwagen Basin, 2) rate of decline of DO from June to October in the nearfield, 3) annual and seasonal chlorophyll levels in the nearfield, 4) seasonal means of the nuisance algae *Phaeocystis pouchetii* and *Pseudo-nitzschia pungens* in the nearfield, and 5) individual sample counts of *Alexandrium fundyense* in the nearfield (**Table 2-1**).

Table 2-1. Contingency plan threshold values for water column monitoring in 2013.

Parameter[a]	Time Period	Caution Level	Warning Level	Baseline/ Background	2013
Bottom Water DO concentration (mg L^{-1})	Survey Mean June-October	<6.5 (unless background lower)	<6.0 (unless background lower)	Nearfield: 6.05 SW Basin: 6.23	Nearfield min: 6.71 SW Basin min: 6.97
Bottom Water DO percent saturation (%)	Survey Mean June-October	<80% (unless background lower)	<75% (unless background lower)	Nearfield: 65.3% SW Basin: 67.2%	Nearfield min: 73.6% SW Basin min: 75.3%
Bottom Water DO rate of decline (mgL^{-1} d^{-1})	Seasonal June-October	0.037	0.049	0.024	0.021
Chlorophyll (nearfield mean, mg m^{-2})	Annual	108	144	72	61
	Winter/spring	199	--	50	53
	Summer	89	--	51	65
	Autumn	239	--	90	64
Phaeocystis pouchetii (nearfield mean, cells L^{-1})	Winter/spring	2,860,000	--	622,000	5,160
	Summer	357	--	79	Absent
	Autumn	2,960	--	370	Absent
Pseudo-nitzschia pungens (nearfield mean, cells L^{-1})	Winter/spring	17,900	--	6,735	Absent
	Summer	43,100	--	14,635	667
	Autumn	27,500	--	10,500	490
Alexandrium fundyense (nearfield, cells L^{-1})	Any nearfield sample	100	--	Baseline Max 163	23

[a] The DO values compared against thresholds are calculated based on the survey means of bottom water values for surveys conducted June through October. The nearfield bottom water mean is an average of the five nearfield stations: N01, N04, N07, N18, and N21. The Stellwagen Basin DO value is from station F22. The seasonal rate of nearfield bottom water DO decline is calculated from June to October. The chlorophyll values are calculated as nearfield survey means of areal chlorophyll (mg m^{-2}) and then averaged over seasonal or annual time periods. The *Phaeocystis* and *Pseudo-nitzschia* seasonal values are calculated as the mean of the nearfield station means (each station is sampled surface and mid-depth). The *Pseudo-nitzschia* "*pungens*" threshold designation includes non-toxic *P. pungens*, as well as the domoic-acid-producing *P. multiseries* and six other *Pseudo-nitzschia* species recently shown to occur in the region and to be toxic (Fernandes *et al.* 2014). Distinguishing among *P. pungens*, *P. multiseries*, and the other *Pseudo-nitzschia* species requires scanning electron microscopy, molecular probes, or high-magnification light microscopy, none of which are possible in this program. Therefore, all *Pseudo-nitzschia* species identified within the genus are included in the threshold. For *A. fundyense*, each individual nearfield sample value is compared against the threshold of 100 cells L^{-1}. Although there are several *Alexandrium* species that might occur in the study area, the counts for *A. fundyense* are definitive because species-specific molecular probes are used.

There were no water column threshold exceedances in 2013. Bottom water DO minima in the nearfield and Stellwagen Basin were higher than the thresholds and the low levels observed in 2012. Seasonal and annual chlorophyll levels were low – especially in winter/spring with the lack of a major bloom. There was no *Phaeocystis* bloom and thus no winter/spring or summer issues with that nuisance species. Abundances were low (well below thresholds) for both of the toxic, *A. fundyense* and *Pseudonitzschia spp.* in 2013.

Bottom water DO concentrations in 2013 were consistent with the normal annual pattern: highest in winter, decreasing over the summer stratified period, and reaching the annual minima in late fall. The values of the bottom water minima in 2013 were a bit higher (close to 7 mg L^{-1}) than might have been expected given the low initial set up concentrations in the nearfield and the prolonged, strong stratification in the fall (see **Figure 2-13** and **Figure 2-7**, respectively). The DO minima levels (and their respective percent saturation values) in the nearfield and Stellwagen Basin were above the Contingency Plan threshold values (**Table 2-1**). Comparisons of the bottom water DO concentrations at nearfield station N18 and Stellwagen Basin station F22 in 2013 vs. previous years illustrates relatively low DO at station N18 for much of 2013, while levels at station F22 were close to the long-term mean (**Figure 2-13**). The lowest DO concentrations of 2013 were measured in the bottom water at station F02 in October (4.07 mg/L; **Figure 2-14**). Interestingly, bottom water DO at station F01 in Western Cape Cod Bay had increased by October to nearly 8 mg/L suggesting that Western Cape Cod Bay had remixed prior to Eastern Cape Cod Bay.

The seasonal and annual nearfield mean areal chlorophyll levels for 2013 were low and well below Contingency Plan threshold values (**Table 2-1**). The lack of a winter/spring diatom or *Phaeocystis* bloom resulted in very low winter/spring chlorophyll levels compared to those observed in the past at nearfield station N18 (**Figure 2-16**). The summer blooms of *Dactyliosolen fragilissimus* (July) and *Skeletonema* spp. (August) led to an annual maxima in chlorophyll levels in the nearfield and the shallow coastal and Boston Harbor stations. Fall chlorophyll levels remained low in the nearfield and at offshore stations, but did show a peak in October in Boston Harbor and at coastal stations (**Figure 2-16**). This was due to a late fall bloom (reaching a 1-2 million cells L^{-1}) dominated by *Skeletonema* spp. and *Leptocylindrus danicus*.

As mentioned previously, there was no *Phaeocystis* bloom in the Massachusetts and Cape Cod Bays in 2013. This marks the first year since 1999 without a bloom of this nuisance species in the bays (**Figure 2-17**)[4]. The potentially toxic, threshold *Pseudo-nitzschia* species were also present in very low abundances during each season (**Table 2-1**). This has been the case for this group during the entire post-diversion period, continuing the trend since 2000 of very low abundances that are well below the Contingency Plan threshold and below levels that would cause amnesic shellfish poisoning.

[4] *Phaeocystis* abundance was low in the nearfield in 2010 as shown in **Figure** 2-17, but achieved bloom abundances of >1 million cells L^{-1} in Cape Cod Bay.

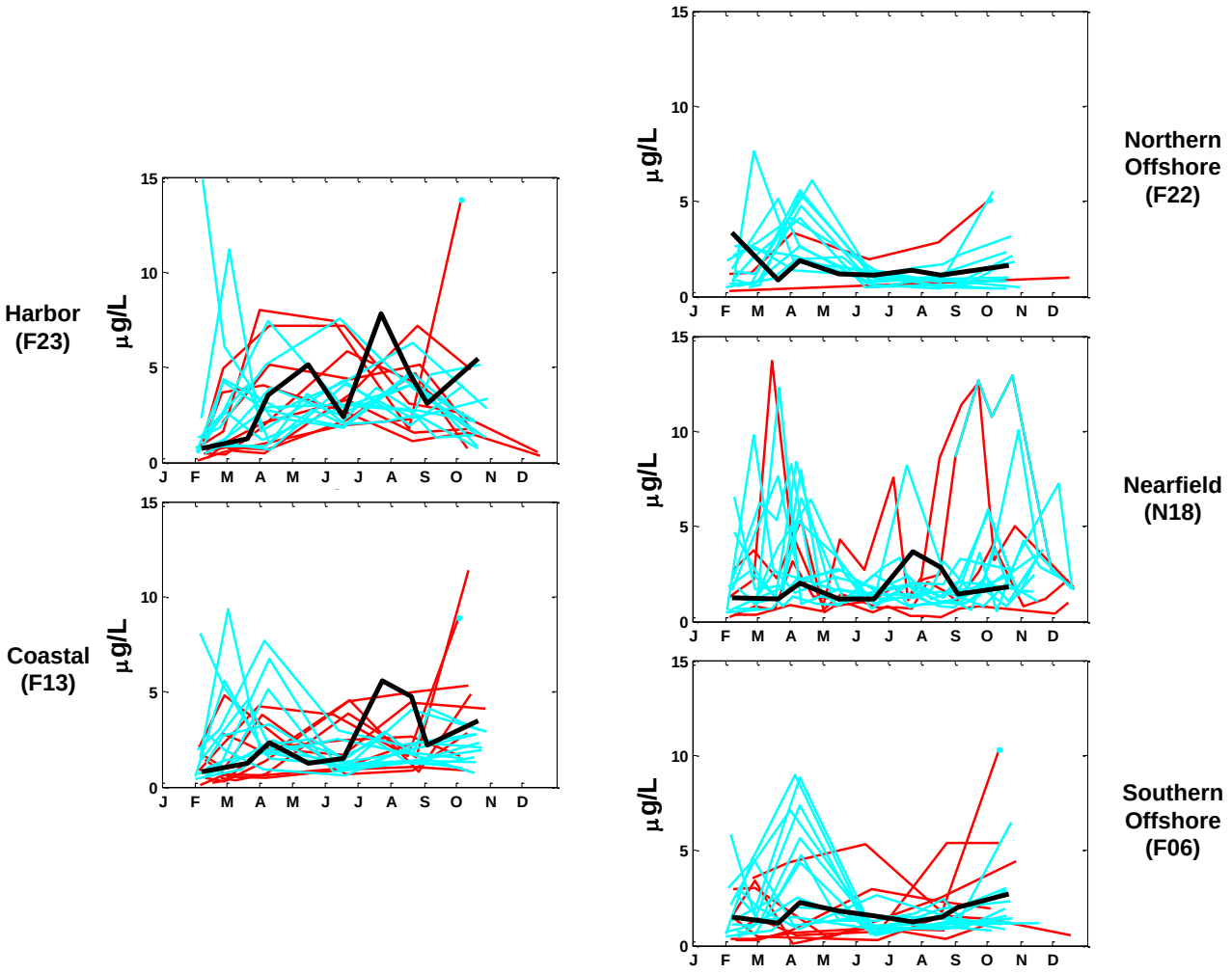

Figure 2-16. Average chlorophyll (µg L^{-1}) at representative stations in Massachusetts Bay for 2013 (black line) compared to the previous 21 years of baseline (1992-August 2000; red) and post-diversion (September 2000-2012; light blue) observations.

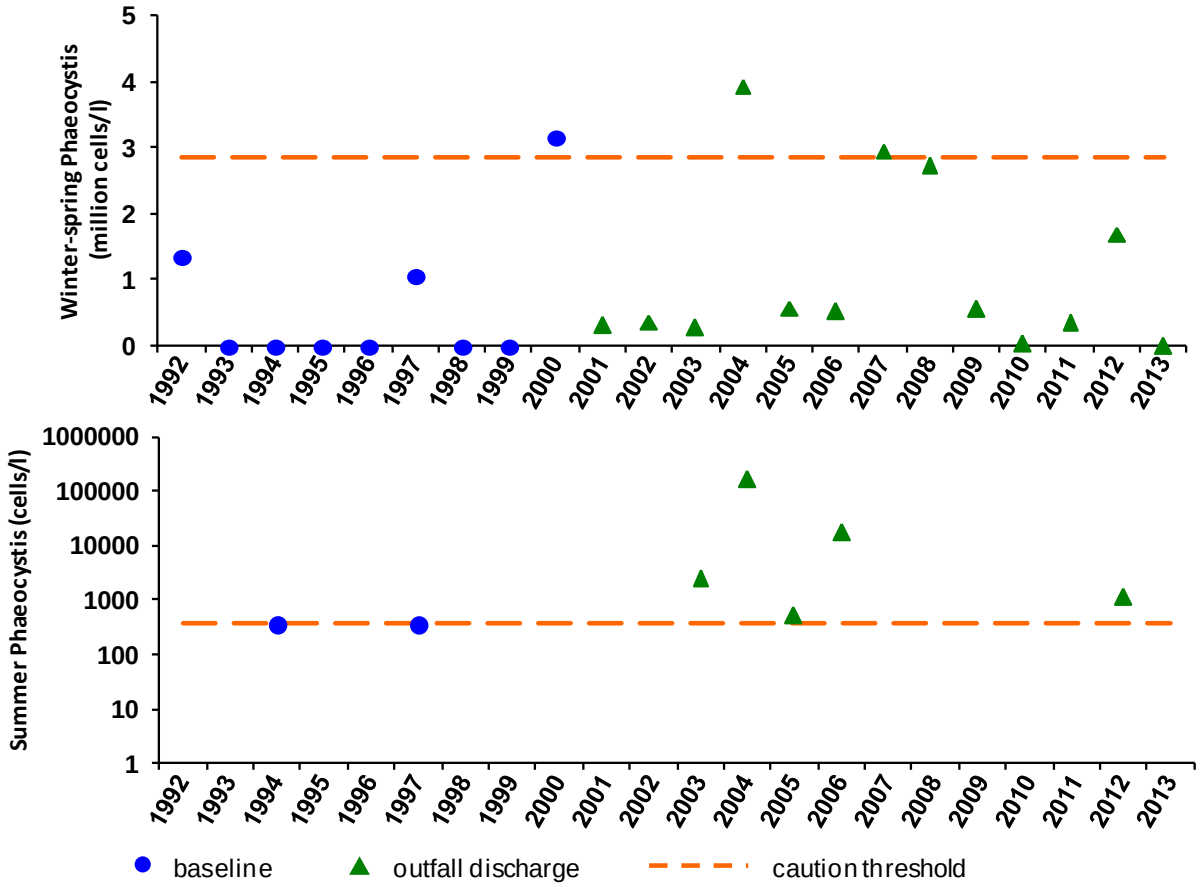

Figure 2-17. Winter/spring (million cells L^{-1}) and summer (cells L^{-1}) seasonal mean nearfield *Phaeocystis* abundance for 1992 to 2013 (note log axis for summer; zeros not plotted). Contingency Plan threshold value shown as dashed line.

The 2013 *Alexandrium* abundances were very low in Massachusetts Bay – peaking at 36 cells L^{-1} in the surface waters at station F10 on April 10, 2013. One nearfield sample had 23 cells L^{-1} during the April survey and in May *Alexandrium* abundances of 2-12 cells L^{-1} were seen in half of the 20 samples collected all well below caution threshold levels (**Figure 2-18**). There were no shellfishing closures for PSP toxicity in Massachusetts Bay (nor NH coastal waters) in 2013, and levels in western Maine were low as well.

The low 2013 abundances observed differed from a WHOI forecast for a moderate *Alexandrium* bloom in the Gulf of Maine for spring 2013.[5] The model forecast is based on cyst abundances in coastal sediments during the previous fall (He *et al*. 2008, Li *et al*. 2009, McGillicuddy *et al*. 2011). In fall 2012, cysts abundances observed were comparable to those seen in fall 2010 and 2011, but lower than those measured prior to the major red tides events of 2005 and 2008. A similar forecast had been made for the 2012 bloom and a moderate bloom was observed in both the western Gulf of Maine and Massachusetts Bay (Libby *et al*. 2013).

[5] See http://www.whoi.edu/main/news-releases?tid=3622&cid=162529 for article.

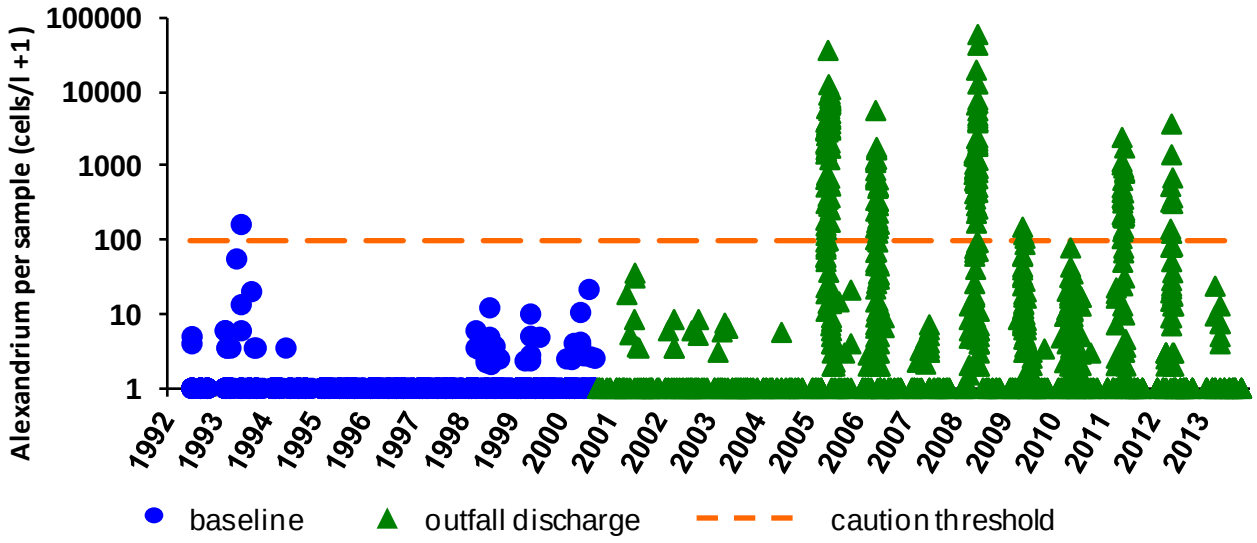

Figure 2-18. Nearfield *Alexandrium* abundance for individual samples (cells L^{-1}; note log axis). Contingency Plan threshold value shown as dashed line.

The lack of a moderate bloom in Massachusetts Bay in 2013 is not surprising. According to WHOI researchers, during years that a moderate bloom has occurred in the Gulf of Maine (17 out of 34 for which records are available) PSP shellfishing closures have only occurred 47% of the time in Massachusetts Bay (D. Anderson pers. comm.). Note also that the definition of "moderate" has recently been quantified, along with two other categories used to describe the extent of PSP toxicity in the Gulf of Maine region (Kleindinst *et al*. 2014). In that study, three levels of PSP outbreak impact were defined: limited (0-200 km of coastline closed); moderate (200-400 km closed); and extensive (400-600 km closed). Thus, even though a moderate bloom may occur in the Gulf of Maine, it does not always extend into Massachusetts Bay. What made 2013 interesting is that there was essentially no *Alexandrium* bloom in the Gulf of Maine that year – based on very low toxicity scores in shellfish tested along the coast, low cell counts detected by an automated Environmental Sample Processor (ESP) on a mooring located near the NERACOOS B buoy, and low counts in all samples collected during ground-truth surveys for the ESP (D. Anderson pers. comm.). Initial investigations indicate that overall water mass conditions were different in the Gulf during 2013 compared to the conditions in 2004-2012 that are used to run the forecast model. Part of the difference may have been a change in the nutrient regime to lower nutrient levels in the Gulf of Maine.

As might be expected given the model based forecast and lack of a bloom, comparisons of near real-time model predictions (Ruoying He, North Carolina State University) and MWRA field observations were not very good. For April, the model did a good job in capturing the low abundances that were seen during the MWRA survey on April 10, 2013, but by May the model projected abundances of >100 cells L^{-1} that were not observed (**Figure 2-19**). In general, the model has been good at capturing the general features of the regional bloom (e.g., timing, alongshore and cross-shore extent, etc.) given the model's temporal and spatial resolution, but it is unrealistic to expect the model to provide accurate cell counts at specific locations and times. As noted above, different water masses and nutrient regimes have been enlisted as possible reasons for the discrepancies between the model and observations. Model sensitivity tests using reduced nutrient levels suggest that this may be part of the reason. When run using nutrient levels 70% lower than the climatology used to typically run the model (Rebuck and Townsend 2014), the predicted *Alexandrium* abundances in Massachusetts Bay for 2013 were more comparable to those observed during the May 2013 survey (**Figure 2-19**; Model RN graphic). This suggests nutrient levels in the Gulf of Maine may have played a role in the lack of a bloom in 2013, which continues to be a focus of investigation by WHOI researchers and others.

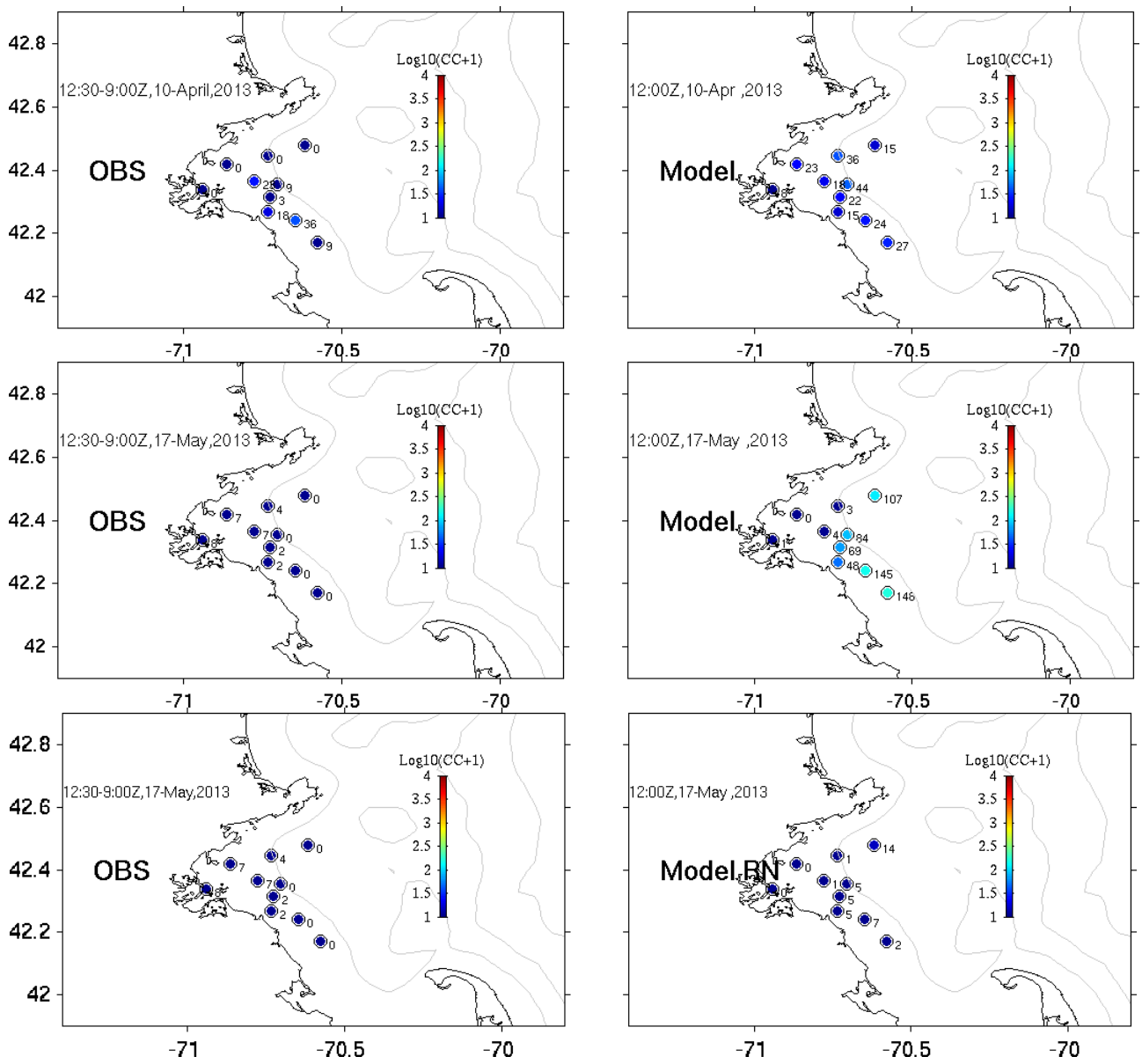

Figure 2-19. Comparison of MWRA survey observations (left) and modeling results (right) for surface *Alexandrium* abundance in April and May 2013. The bottom right panel shows the modeling results for May 2013 with a 70% reduction in the climatological nutrient concentrations. Plots provided by He, Anderson and McGillicuddy.

2.2 HISTORICAL COMPARISONS

The 2013 data were consistent with the general trends and patterns observed during both the baseline (1992-2000) and outfall discharge (2001-present) time periods. Previous monitoring (Libby *et al*. 2007) demonstrated that the annual cycle for nitrate and silicate was unaffected by the effluent discharge, which began in late 2000. This can be seen in **Figure 2-4** in which the NO_3 data from 1992-2012 show a very consistent seasonal pattern, while the SiO_4 data have been highly variable seasonally from the start of the monitoring. As noted previously, both NO_3 and SiO_4 concentrations were low in February 2013 - SiO_4 levels were lower than any previous February survey and all four nutrients show a clear spike in concentrations in August 2013 associated with upwelling favorable conditions. In contrast, ammonium and phosphate concentrations in the nearfield have clearly shown increases since the offshore outfall began discharging. This can be seen in **Figure 2-4** for NH_4 by the spiky lines that show multiple peaks throughout the year (including 2013). Baseline years showed much less month-month variability, and are clustered near the bottom of the plot. For PO_4, the change from baseline to discharge is less pronounced, but has resulted in an upward shift of about 0.5 µM over the course of the year and increased variability with intermittent peaks from survey-to-survey within each year.

By segregating the data into surface layer and bottom layer sampling depths, the change in ammonium concentrations from baseline to post-diversion can be seen spatially (harbor, coastal and nearfield stations) and seasonally (nearfield). The surface water NH_4 has decreased in Boston Harbor and in nearby coastal waters while increasing in the nearfield (**Figure 2-20**). The increases in surface water NH_4 in the nearfield are predominantly in the winter/spring and fall – when the water column is well mixed. There were also a few spikes in concentrations during the summer coincident with upwelling or other mixing events.

The changes in bottom water ammonium concentrations have been equally dramatic at the well-mixed Boston Harbor station while there has been little change along the South Shore coastal stations. In the nearfield, NH_4 concentrations are generally higher in the bottom waters year round, but the increase is most pronounced during the summer and early fall months when the water column is stratified and the effluent plume is confined below the pycnocline (**Figure 2-21**). There has been little change in surface or bottom water NH_4 concentrations at the representative northern and southern offshore stations (**Figure 2-20** and **Figure 2-21**).

The change in ammonium concentrations observed is consistent with model simulations which predicted that the transfer of effluent from Boston Harbor to Massachusetts Bay would greatly reduce nutrients in the harbor and increase them locally in the nearfield (Signell *et al*. 1996). The model also predicted that there would be seasonal differences in how the increased NH_4 load to the nearfield would be distributed – reaching the surface during well mixed winter conditions and confined below the pycnocline under seasonally stratified conditions. This change was predicted to have little impact on concentrations in the rest of Massachusetts and Cape Cod Bays. The spatial patterns in NH_4 concentrations in the harbor, nearfield and bays since the diversion in September 2000 have consistently confirmed this (Taylor 2006; Libby *et al*. 2007).

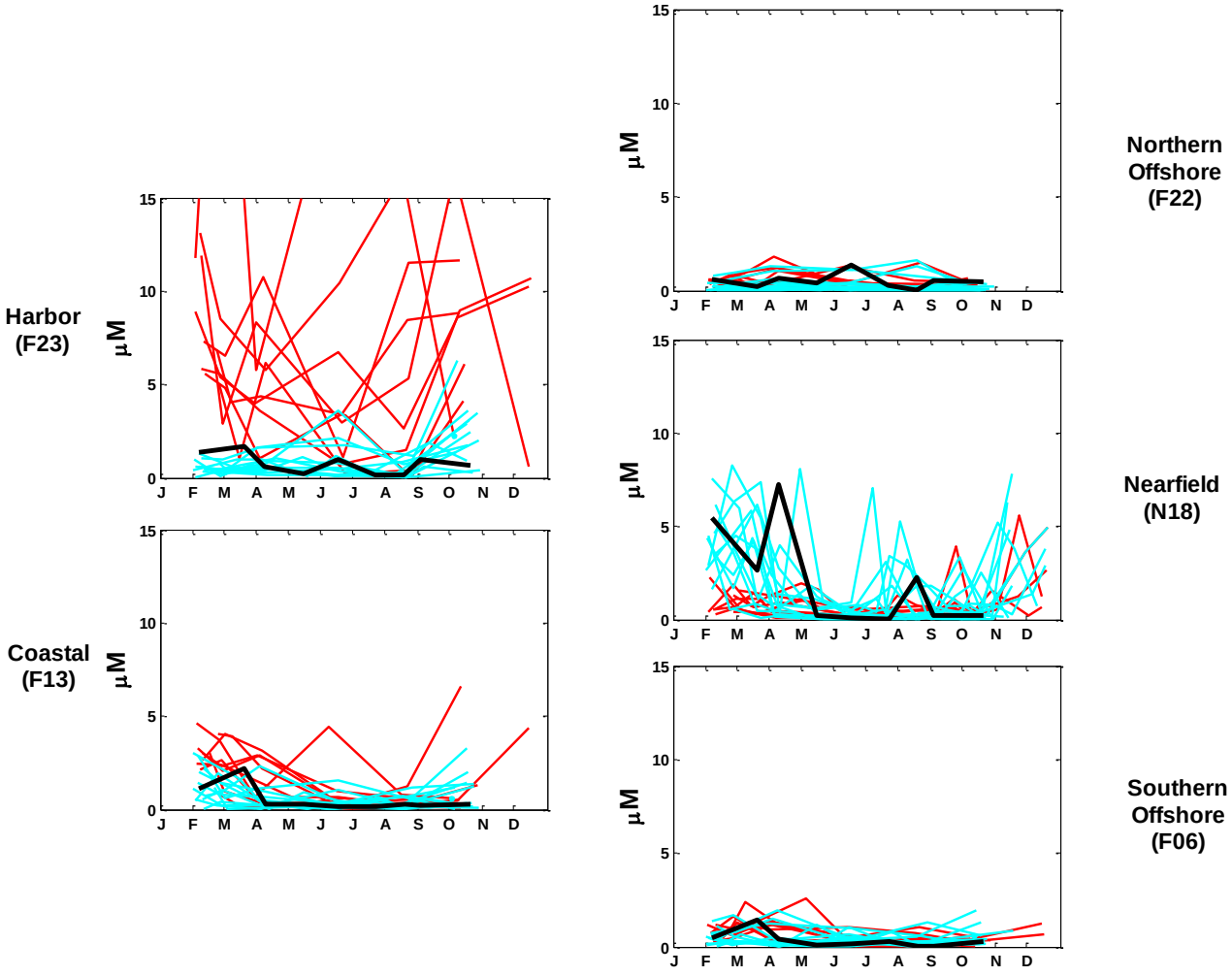

Figure 2-20. **Average NH_4 concentration (µM) in the surface layer (A and B sampling depths) at representative stations in Massachusetts Bay for 2013 (black line) compared to the previous 21 years of baseline (1992-August 2000; red) and post-diversion (September 2000-2012; light blue) observations.**

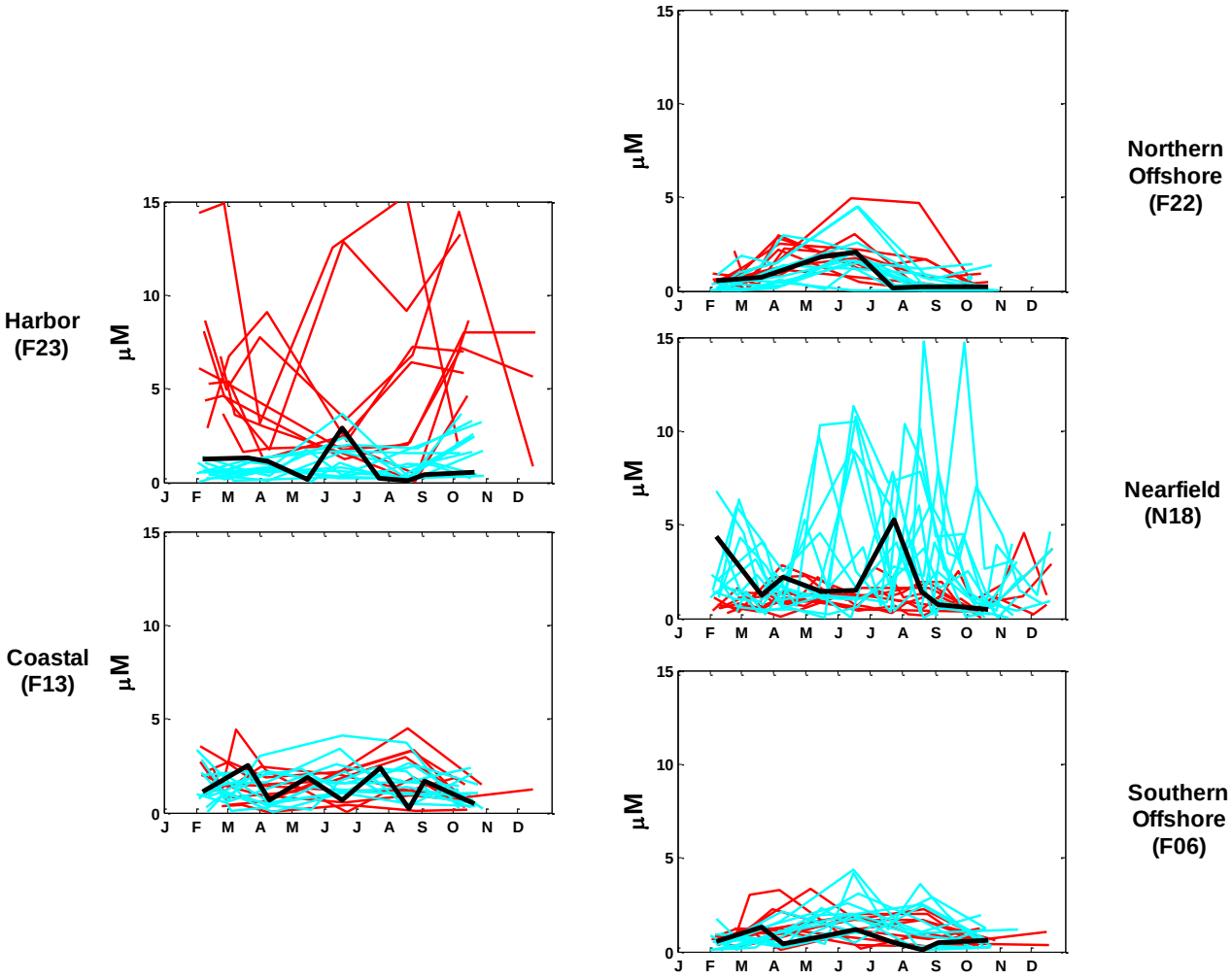

Figure 2-21. Average NH_4 concentration (µM) in the bottom layer (D and E sampling depths) at representative stations in Massachusetts Bay for 2013 (black line) compared to the previous 21 years of baseline (1992-August 2000; red) and post-diversion (September 2000-2012; light blue) observations.

Although increases in ammonium associated with the effluent plume have been observed in the nearfield, no related changes or increases in phytoplankton biomass in this region have been observed. Biomass (as measured by chlorophyll and POC) and total nitrogen in 2013 vs. historic values shows the levels were within the ranges observed during prior years at nearfield station N18 (**Figure 2-22**), but tended to be on the lower end of the range especially for the first half of the year. The lack of winter/spring and fall blooms in the 2013 monitoring data is clearly shown in the plot of total phytoplankton, which was at or near the minimum for each month except for the summer peak in July 2013 (**Figure 2-22**). Total nitrogen includes NH_4, which as mentioned above is enriched in the nearfield by effluent discharge. Despite this, total nitrogen at station N18 was very low (at minima of range) in 2013 compared to historic values (**Figure 2-22**). Overall, biomass and total phytoplankton were low in 2013 often at historic minima compared to baseline and post-diversion levels.

The 2013 abundance of main phytoplankton groups in the nearfield was compared to long-term (1992-2012) levels using a Mann-Whitney test (**Table 2-2**). The annual average of the total phytoplankton abundance in

2013 (0.97 million cells L^{-1}) was very low in comparison to the long-term mean total phytoplankton abundance level of 1.50 million cells L^{-1}. By rank order, mean total phytoplankton abundance in 2013 was the 21st of 22 ranked order years (1 = greatest, 22 = least mean abundance). The 2013 phytoplankton annual cycle was marked by reduced winter-spring phytoplankton abundance. Abundance of both major components of the MA Bay winter-spring flora, centric diatoms and *Phaeocystis pouchetii* was severely reduced in winter-spring 2013.

The 2013 mean annual average *Phaeocystis* abundance was only 2,020 cells L^{-1} compared to a long-term mean annual average of 272,258 cells L^{-1} (**Table 2-2**). These are severely reduced levels when compared to those observed over the 2000-2012 period of '*Phaeocystis* years'. In fact, 2013 was the 17th of 22 years when ranked by *Phaeocystis* abundance (1 = greatest, 22 = least mean abundance) all of the lower ranked (reduced *Phaeocystis* abundance) years occurred before 2000, suggesting that 2013 may mark an end of the string of '*Phaeocystis* years' observed during 2000-2012. Along with the reduction in *Phaeocystis*, there was also a decrease in the small, ubiquitous and often numerous microflagellates and cryptophytes in 2013.

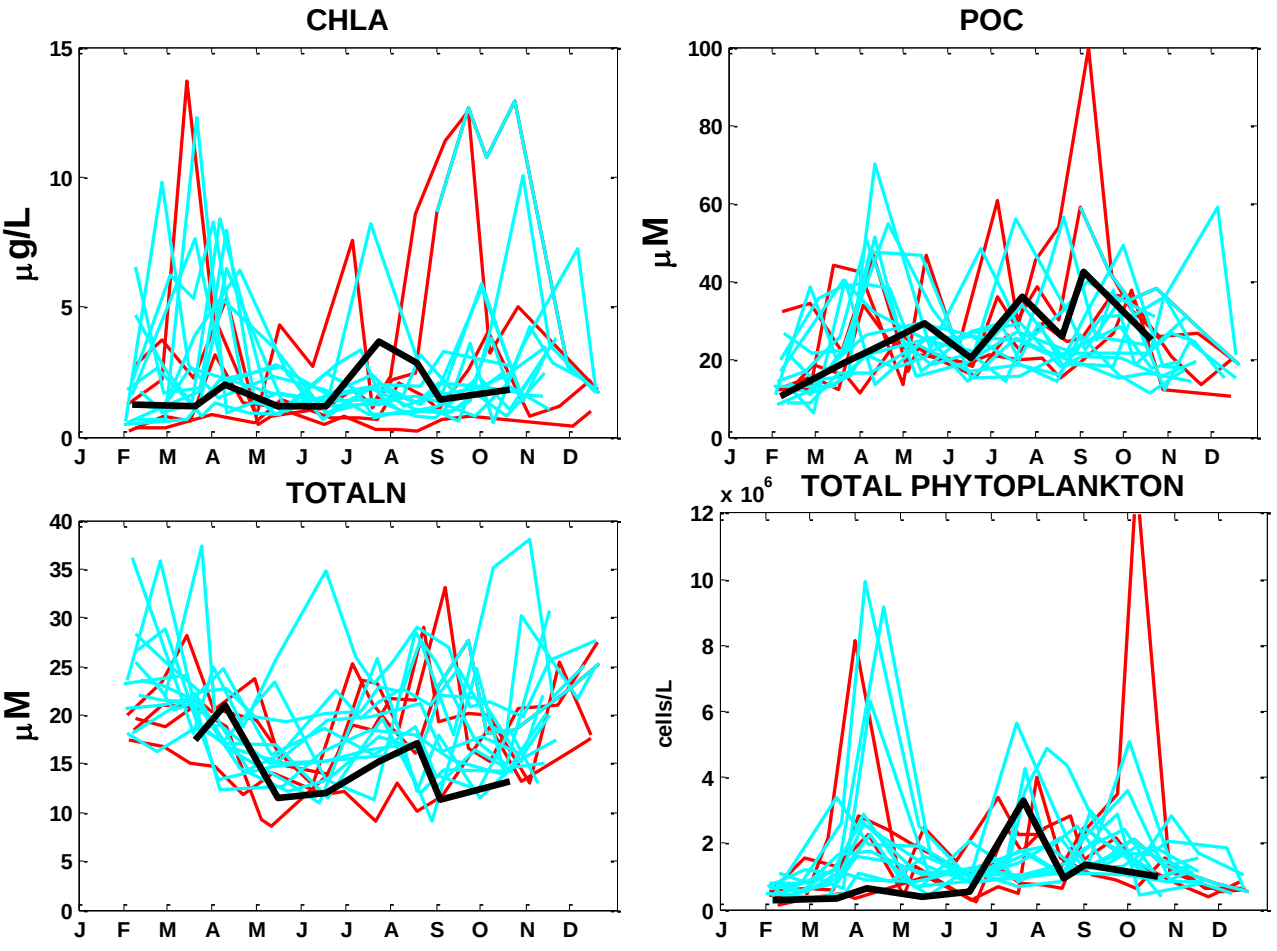

Figure 2-22. Station average chlorophyll (µg L^{-1}), POC (µM), total nitrogen (µM), and total phytoplankton (million cells L^{-1}) near the outfall site (nearfield station N18) for 2013 (black line) compared to the previous baseline (1992-August 2000; red) and post-diversion (September 2000-2012; light blue) observations.

Table 2-2. Comparison of 2013 annual mean phytoplankton abundance in the nearfield (cells L^{-1}) to long-term observations for major groups and species. Note that these are exploratory analyses involving multiple comparisons. The determination of significant changes is complicated by multiple comparison issues and corrections for the associated errors are beyond the intent of the analyses. Differences between values were assessed using the Mann-Whitney non-parametric statistical hypothesis test – p values of ≤0.05 are highlighted as noteworthy.

Group	1992-2012	2013	Rank (out of 22)	p value	Significant Change
CENTRIC DIATOM	311,055	296,377	10th	0.7519	
Dactyliosolen fragilissimus	45,552	110,524	4th	0.0016	Increase
Chaetoceros	44,817	3,303	20th	0.0001	Decline
Skeletonema costatum complex	68,398	45,428	10th	0.3466	
Thalassiosira	34,424	6,834	19th	0.0532	
PENNATE DIATOM	45,733	14,565	18th	0.0787	
Pseudonitzschia	10,958	4,590	14th	0.1088	
CRYPTOPHYTES	120,400	82,518	18th	0.0001	Decline
DINOFLAGELLATES	53,268	54,384	9th	0.8229	
Ceratium	1,539	4,811	2nd	0.0001	Increase
Phaeocystis pouchetii	272,258	2,020	17th	0.0024	Decline
MICROFLAGELLATES	697,955	510,196	18th	0.0001	Decline
TOTAL PHYTOPLANKTON	1,511,679	970,219	21st	0.0001	Decline

In addition to the lack of *Phaeocystis* in the winter/spring, there was also a significant decline in *Chaetoceros*, one of the usually dominant winter/spring diatoms. There was no change in annual centric diatoms as the decreases in the typical winter/spring centric diatom species (*Chaetoceros*, *Skeletonema*, and *Thalassiosira*) was offset by an increase in *Dactyliosolen fragilissimus*, which was relatively abundant in 2013 due to a large summer bloom in the harbor and nearfield regions. The 2013 *D. fragilissimus* abundance was approximately 2.5 times that of its long-term mean (**Table 2-2**). *Ceratium* spp. were also significantly elevated during 2013; consistent with an upswing in the apparent cyclical abundance of this genus of large dinoflagellates.

The summer increase in total phytoplankton abundance was region wide, but the greatest relative summer increase was observed in the Harbor and Nearfield regions (**Figure 2-23**). Following the summer pulse, phytoplankton declined and remained at near long-term mean levels until October 2013. The October 2013 observations indicated an increase in total phytoplankton to relative to long-term mean levels in the harbor, northern offshore and southern offshore regions (**Figure 2-23**). The relative increase in late season phytoplankton abundance, as observed in October 2013, has been observed the past several years and may be indicative of a trend towards persistent, elevated phytoplankton abundances over the winter (November – January) in the MWRA monitoring area, which in turn, could reduce nutrient concentration during the months of February-April that have historically featured winter/spring bloom initiation and peak abundance. This may have been the mechanism leading to the low nutrient and phytoplankton levels observed in February 2013.

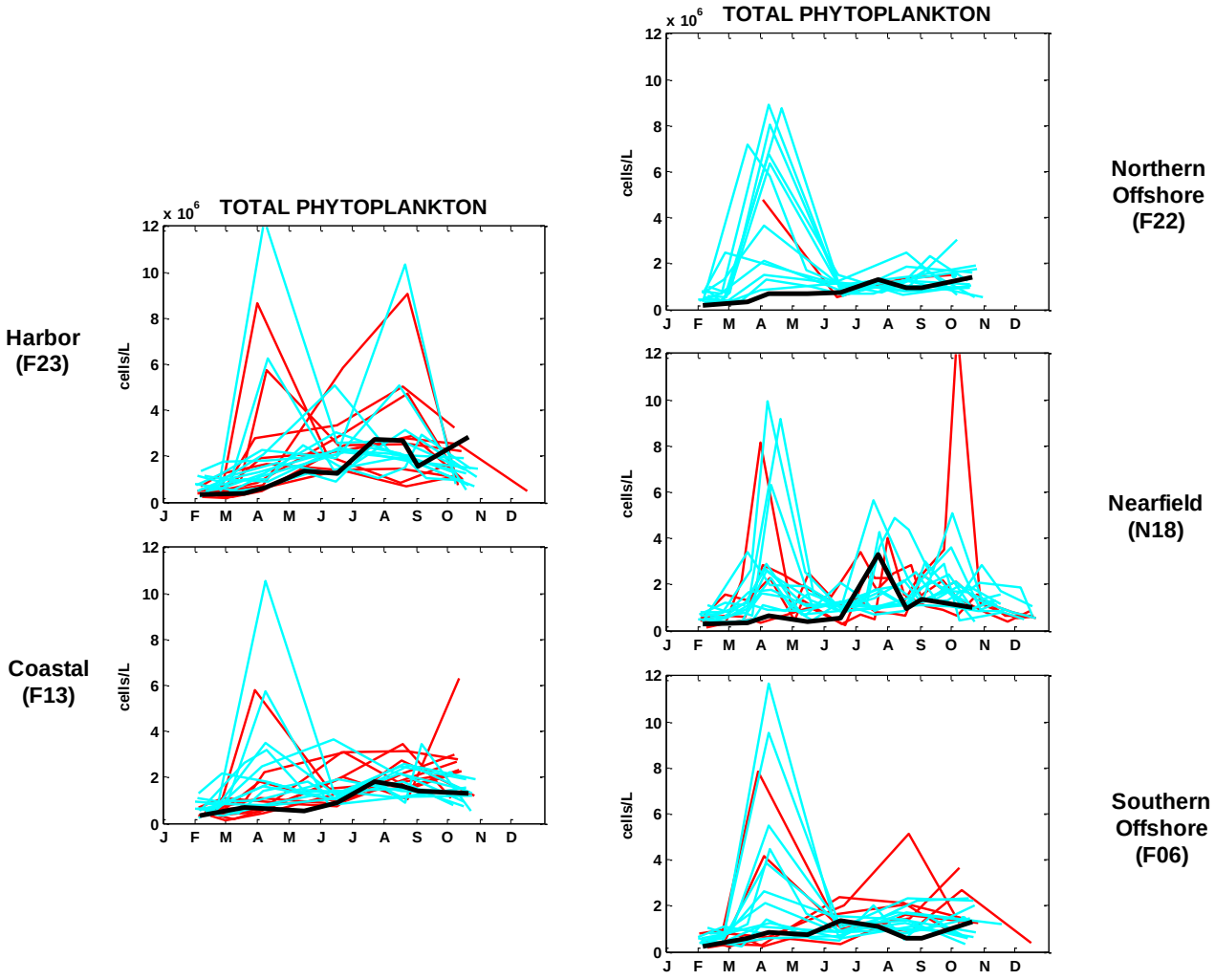

Figure 2-23. Total phytoplankton abundance (million cells L^{-1}) at representative stations in Massachusetts Bay for 2013 (black line) compared to the previous 21 years of baseline (1992-August 2000; red) and post-diversion (September 2000-2012; light blue) observations.

The 2013 zooplankton abundance and community structure were generally within the envelope of historical ranges and patterns except for several atypically-high levels of abundance of certain taxa. Sampling captured several meroplankton peaks, including barnacle nauplii in March and April, and bivalve veligers in July and particularly August. Overall, total zooplankton, copepod adults and copepodites, *Oithona*, *Calanus finmarchicus*, *Pseudocalanus* spp., and other zooplankton (meroplankton) were generally higher than in most previous years and except for *C. finmarchicus* were the highest levels observed since outfall diversion, but generally within baseline ranges (**Figure 2-24**).

The relatively high zooplankton abundances in summer of 2013 compared to most previous years may have been due to the somewhat warmer and more saline conditions in 2013 compared to previous years. This trend in higher zooplankton abundance in 2013 is seemingly at odds with the observations of low chlorophyll and phytoplankton abundance levels in the winter/spring. However, summer levels of phytoplankton were relatively high and may have supported additional zooplankton grazing. Speculation as to the bottom-up or top -down ecosystem relationships is complicated by the fact that the dominant copepod in our samples, *O.*

similis, has been shown to feed primarily as a predator on protistan microzooplankton rather than as a grazer on phytoplankton (Nakamura and Turner 1997). There is an emerging consensus within the oceanographic community that most grazing of phytoplankton is done by protistan microzooplankton, rather than mesozooplankton such as copepods (Miller 2004). We cannot relate phytoplankton fluctuations within the MWRA data to protistan microzooplankton grazing due to the lack of any appreciable data on that class of grazers. In conclusion, 2013 was a generally "typical" year in terms of zooplankton abundance, composition and temporal patterns, with several "atypical" aspects, such as the comparatively large abundances of meroplanktonic barnacle nauplii and bivalve veligers, and generally higher abundances of total zooplankton than in most previous post-diversion years.

The last few years have been characterized by an apparent increase in zooplankton abundance from lower numbers observed during the early 2000s. Time series analysis indicated that there had been a substantial long-term decline in the total zooplankton abundance in the nearfield from 2001-2006 due to a long-term decline in total copepods (Libby *et al.* 2009). Given the recent rebound in total zooplankton and copepod abundances, the time series analyses were revisited using nearfield total zooplankton data through 2012 (Libby *et al*. 2013), which confirmed that current levels of zooplankton have been above the long-term mean for the last couple of years. The data from 2013 suggest that this trend is continuing. The reasons for these long-term changes in zooplankton are not well known and are an active area of study by many researchers. At this point, however, the influences appear to be on a regional scale and unrelated to localized effects associated with the effluent plume discharging into the nearfield.

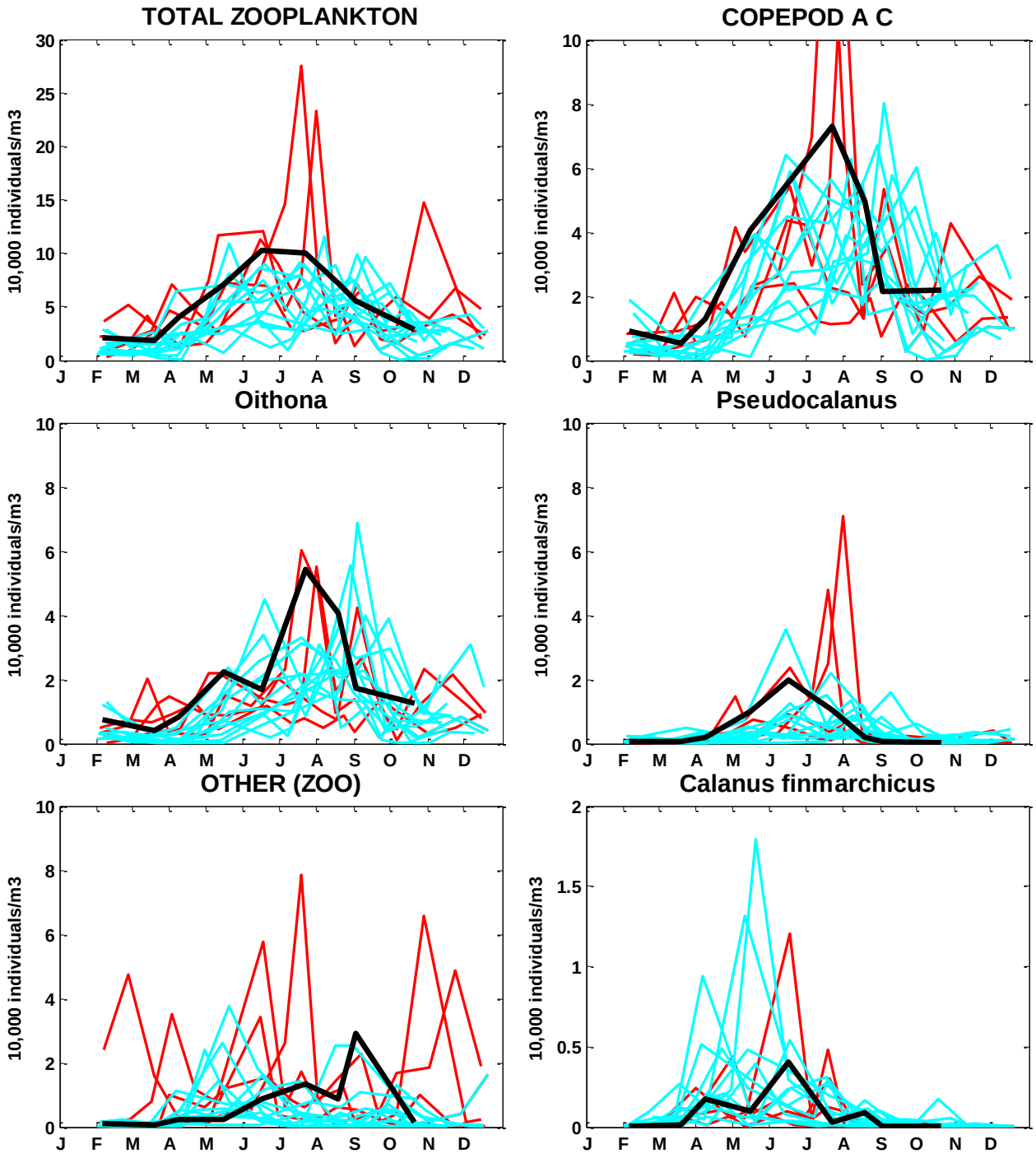

Figure 2-24. Abundance (10,000 individuals m^{-3}) of total zooplankton, copepods, *Oithona*, *Pseudocalanus*, Other Zoo (meroplankton), and *Calanus finmarchicus* near the outfall site (station N18) for 2013 (black line) compared to the previous 21 years of baseline (1992-August 2000; red) and post-diversion (September 2000-2012; light blue) observations. Note change in scale of plots.

3 SUMMARY

The most notable characteristic of the physical environment was that 2013 was another relatively warm winter/spring and dry year, which was similar to warm, dry conditions in 2012. Warm winter/spring air temperatures resulted in warmer than usual water temperatures at the onset of spring stratification. There were a few strong storms in February and March 2013; the strongest of which named winter storm "Nemo" had wave heights reaching 10 meters in the bay. The water column was well mixed at the time so there were no major changes to water column properties, but the storm's waves did produce substantial resuspension of sediments in the bay that were evident in MODIS satellite images the day after the storm. There was also a precipitation event in early June that resulted in an annual maximum in Charles River discharge, but regionally it did not appear to be significant, as the peak in Merrimack River flow at that time was not substantial. Overall for 2013, the annual average flows in the Merrimack and Charles Rivers were below average. This is the second year in a row with lower than average flow following a 7-year period of relatively wet conditions. These physical forcing events, or lack thereof, contributed to the trends and events observed in other water quality and biological data.

The continued warm temperatures from November 2012 through February 2013 may have contributed to elevated chlorophyll concentrations over the winter. The winter satellite imagery and February 2013 nutrient data suggest that elevated diatom levels may have occurred prior to the February 2013 survey. The lack of a major chlorophyll peak in buoy data suggests that the system may have just remained biologically productive through the winter, and therefore there was no winter/spring "bloom" above those elevated levels. Thus, the 2013 monitoring data are characterized by the lack of a winter/spring bloom – *i.e*., no observed diatom or *Phaeocystis* bloom in February-April 2013. This is the first year since 1999 that *Phaeocystis* were not present in elevated numbers in Massachusetts and Cape Cod Bays. Unlike 2012, the warm conditions did not seem to have an impact on the secondary producers. In 2012, zooplankton were near or above the monthly maxima in February and March compared to historical levels. The diminished availability of food (no winter/spring diatom or *Phaeocystis* bloom in February-April 2013) may have offset the effect of the warm winter/spring water temperatures in 2013.

DO levels in the nearfield in February-April 2013 were relatively low in comparison to past years. However, they did not reach abnormally low levels in the fall and were actually moderate in comparison to past years. Given the low initial "setup" DO concentrations in May/June, strong stratified conditions through the summer, and prolonged duration into mid-November, it is surprising that bottom water DO levels were not lower. The survey observations ended prior to the overturn of the water column in the fall of 2013, but DO data from NERACOOS buoy A indicate that levels remained above 6.5 mg L^{-1} in the deeper bottom waters of Massachusetts Bay until increasing when the water column became mixed in mid-November. The DO regression model was consistent with the observations for the fall 2013 near-bottom DO level. The relatively low DO over the course of the year is explained by warmer temperatures and higher salinity, and according to the model, the above-average salinity explains most of the DO anomaly (DO level below long-term mean). The time series data from the NERACOOS Buoy A01 continue to demonstrate that the cycle of near-bottom DO at the outfall site closely track those observed at both the Stellwagen station F22 and the NERACOOS buoy. This indicates that horizontal advective processes are very important in determining the interannual variations of DO, and also that interannual variations of DO at the outfall site are more regional than local.

The phytoplankton community assemblage in the nearfield and most of Massachusetts Bay has varied over more than twenty years of monitoring, reflecting large-scale regional trends in phytoplankton bloom dynamics. For example, diatom and *Phaeocystis* abundance has fluctuated in an inverse pattern over multiple years. However in 2013, as mentioned previously, there was no winter/spring diatom or *Phaeocystis* bloom in the bay. Dinoflagellate abundance has also varied: in some years (like 2012 and 2013)

fewer, larger species (e.g. C*eratium* spp.) dominate, and during other years there are more plentiful, smaller species (e.g. *Heterocapsa rotundatum, H. triquetra, Gymnodinium* spp., *Prorocentrum micans*).

In 2013, the WHOI forecast was for a moderate *Alexandrium* bloom in the Gulf of Maine. A similar forecast had been made for the 2012 bloom, which was moderate in both the western Gulf of Maine and Massachusetts Bay. However, 2013 *Alexandrium* abundances were very low in Massachusetts Bay and there were no shellfishing closures for PSP toxicity in Massachusetts Bay (nor NH coastal waters) in 2013. This was the only the second year (2007 and 2013) since the major *Alexandrium* bloom in 2005 that there were no PSP closures in Massachusetts Bay.

The lack of an *Alexandrium* bloom in Massachusetts Bay in 2013 is not surprising since during years with a "moderate" bloom in the Gulf of Maine PSP shellfishing closures have only occurred about half the time in Massachusetts Bay. Thus, even though a moderate bloom may occur in the Gulf of Maine, it does not always make its way into Massachusetts Bay. What made 2013 interesting is that there was no bloom in the Gulf of Maine either. Initial investigations indicate that overall water mass conditions were different in the Gulf during 2013 compared to the conditions in 2004-2012 that have been used to run the forecast model and part of that difference may have been due to a change in the nutrient regime.

The zooplankton community assemblage in the bays is consistently dominated throughout the year by copepod nauplii, and copepod adults and copepodites, most of which are *Oithona similis*. Subdominant are other copepods such as *Pseudocalanus* spp., *Calanus finmarchicus, Paracalanus parvus, Centropages typicus* and *C. hamatus* (Libby *et al.* 2011b). There are also irregular pulses of various meroplankters such as bivalve and gastropod veligers, and barnacle nauplii that were abundant in the bay in 2013. Seasonal patterns in zooplankton abundance from 1992-2013 generally correlate with temperature, low in winter, rising through spring to maximum in summer, declining in the fall. The most apparent change over the twenty-plus-year monitoring period have been the oscillations in total zooplankton abundances from decreased numbers in 2001-2006 to subsequent increases since 2007. During the last few years, total zooplankton abundance has been higher than the long-term mean value. There is no plausible outfall-related link or causality associated with these shifts in phytoplankton or zooplankton as they occur over large spatial scales; such broad patterns appear instead to be related to regional ecosystem dynamics in the Gulf of Maine.

Nitrogen levels in Massachusetts Bay (including the nearfield) vary considerably over space and time and are governed by regional factors including different loadings to the system, changes in seasonal biological patterns, and circulation shifts related to larger-scale processes such as meteorological events. Observed changes in the nutrient regimes since the new outfall went on-line remain consistent with model predictions (Signell *et al.* 1996). Ammonium dramatically decreased in Boston Harbor and nearby coastal waters and has remained low through 2013. The NH_4 signature of the effluent plume continues to be detected within 10-20 km of the outfall (see **Figure 2-12** for example). The observed increase in NH_4 concentrations in the nearfield has not caused any detectable adverse effects either near or distant from the relocated MWRA outfall. In contrast, the corresponding decrease in nutrient loading to Boston Harbor has resulted in significant improvements in water quality (Taylor 2006). Finally, 2013 marks the third year of monitoring under the revised monitoring plan design and we continue to be able to describe the seasonal and spatial trends observed for a wide variety of water quality parameters during years with very different meteorological forcing and biological responses, thus retaining our capability to understand potential outfall-driven impacts to the Massachusetts Bay ecosystem.

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