2012 Water Column
Monitoring Results

Massachusetts Water Resources Authority
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Report 2013-15

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2012 Water Column Monitoring Results

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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 is provided in the monitoring plans developed for the baseline (MWRA 1991, 1997) and outfall discharge periods (MWRA 2004, 2010). The 2012 data complete twelve 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); 2012 was the second 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 2012 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. Appendices A-E provide abstracts and presentations from the March 2013 Annual Technical meeting showing physical, chemical, and biological data in Massachusetts and Cape Cod Bays for 2012.

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

The new AMP (MWRA 2010) requires sampling at 14 locations in Massachusetts and Cape Cod Bays (**Figure 1-1**) during 9 surveys annually. Two boats are used to cover the 14 stations, with the goal of sampling on the same day, or an adjacent day if weather and tide constrain sampling from the smaller boat in Cape Cod Bay. The regularly scheduled *a priori* sampling is described in (Libby *et al.* 2011a and Costa *et al.* 2012). The sampling dates for 2012 are listed in **Table 1-2**.

Table 1-2. Regular (*a priori*) water column surveys for 2012. The stations are shown in Figure 1-1

Survey #	Survey ID	Massachusetts Bay. Eleven stations within 40km of the outfall.	Cape Cod Bay and Sanctuary. Stations F01, F02, and F29
1	WN121	February 6	February 5
2	WN122	March 20	March 20
3	WN123	April 10	April 11
4	WN124	May 15	May 14
5	WN125	June 19	June 18
6	WN126	July 26	July 26
7	WN127	August 21	August 21
8	WN128	September 6	September 6
9	WN129	October 23	October 24

The AMP (MWRA 2010) also references the need for additional *ad hoc* weekly sampling at 19 locations (**Figure 1-2**) during *Alexandrium* red tide events. The red tide sampling is described in Libby (2013). During 2012 MWRA conducted 3 red tide surveys **Table 1-3**

Table 1-3. *Ad hoc* Red Tide surveys for 2012 triggered by decisions related to the presence of *Alexandrium.* The stations are shown in Figure 1-2

Survey ID	Massachusetts Bay. Ten stations within 40km of the outfall, plus nine additional stations
AF121	May 22
AF122	May 30
AF123	June 7

For convenience, the suvey dates in Table 1-2 and Table 1-3 are combined in Table 1 of Appendix E, along with the dates of surveys from two complementary studies:

1) **Internal Harbor Monitoring**. MWRA staff conducted 24 surveys in 2012 in Boston Harbor at 10 stations[1]. Ten of these Harbor surveys were within 6 days of the 9 regular or 3 Red Tide surveys so we were able to group those results, for example, in all but two of the panels in **Figure** 2-2.

2) **Provincetown Center for Coastal Studies**. PCCS not only collects samples at three MWRA stations (F01, F02, F29) but also has an ongoing water quality monitoring program at eight other stations in Cape Cod Bay. The results are discussed in Appendix E and in Costa and Hughes (2012)

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; 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 2012.[2]

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[1] The station map is fig 5A of http://www.mwra.state.ma.us/harbor/enquad/pdf/2013-07.pdf

[2] 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.

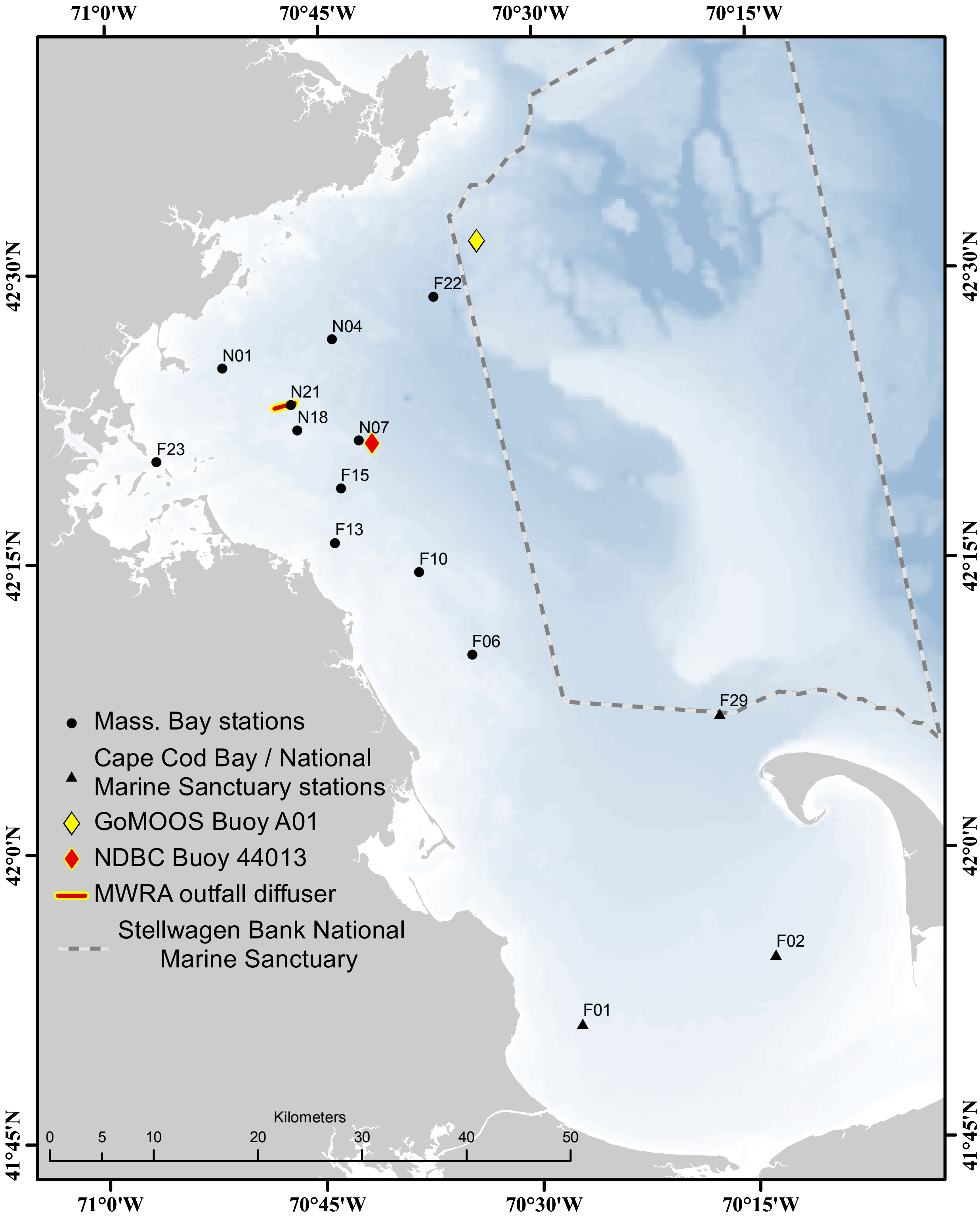

Figure 1-1. **Water column monitoring locations.**
Includes 11 stations within 40km of the outfall, and 3 stations in Cape Cod Bay (F01, F02) and the sanctuary (F29). The station prefix "N" stands for "nearfield"; "F" for "farfield." The survey dates are listed in Table 1-2

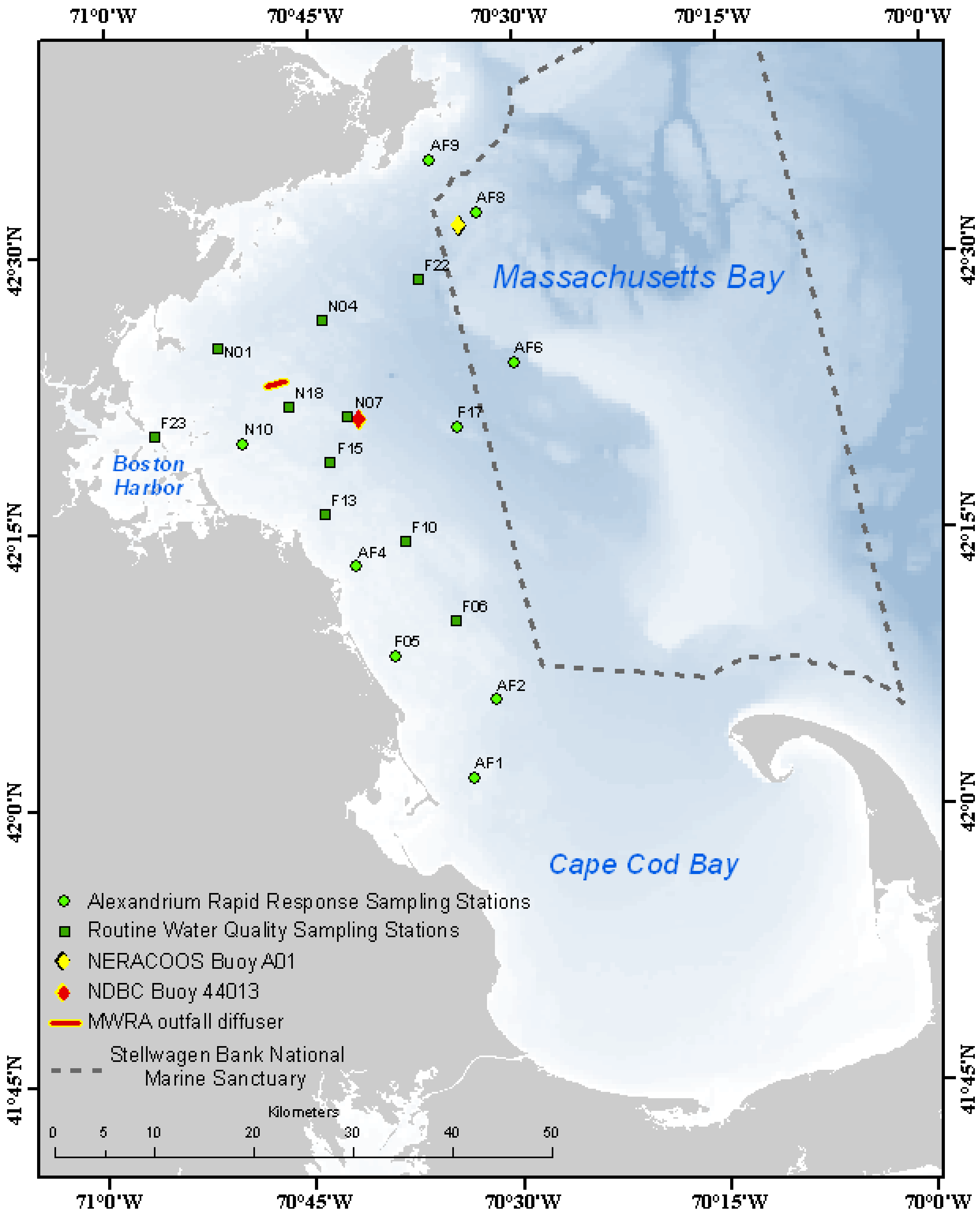

Figure 1-2. **Red Tide survey monitoring locations.**
Includes 10 regular stations plus 9 farther-reaching stations.
The survey dates are listed in Table 1-3

2 MONITORING RESULTS

The 2012 data followed the typical seasonal sequence of water quality events in Massachusetts Bay. A winter/spring phytoplankton bloom occurred as light became more available, temperatures increased, and nutrients were readily available. In recent years, the winter/spring diatom bloom has been followed by a bloom of *Phaeocystis pouchetii* in April. This year's *Phaeocystis* bloom was earlier, peaking in March. The water column transitioned from well-mixed to stratified conditions in the late spring with concomitant cut-off of the nutrient supply to surface waters terminating the spring bloom. The summer period was stratified, with depleted surface water nutrients, and a relatively stable mixed-assemblage phytoplankton community. The normal fall cooling of surface waters, initial vertical mixing and return of the nutrient supply to surface waters was evident as well as the associated development of a fall phytoplankton bloom. Previous observations showed that the lowest observed dissolved oxygen concentrations for the year can be found in bottom waters just prior to the complete fall overturn of the water column. In 2012, the return of the system to well-mixed winter conditions occurred after the final survey in October and bottom water DO levels at that time were low throughout Massachusetts Bay in comparison to previous years. The details of the major features observed and differences noted in 2012 relative to the previous 20 years of monitoring are considered below.

2.1 2012 RESULTS

The physical, water quality, and biological conditions in 2012 followed the seasonal patterns observed from 1992 through 2011. The most notable characteristic of the physical environment was that 2012 was an unusually warm winter/spring and relatively dry year, which was in contrast to wet conditions in 2011 (**Figure 2-1**; Libby *et al*. 2012). Putting the Massachusetts Bay data into a wider context, NOAA reported that 2012 sea surface temperature were the highest for coastal/shelf waters in the Northwest Atlantic in 150 years of shipboard and satellite measurements.[3] Warm winter/spring air temperatures resulted in warmer than usual water temperatures at the onset of spring stratification. There were no major storm events in winter/spring nor did the rivers show a substantial spring freshet. The only storm events of note occurred in late October and early November with the one-two punch of Hurricane Sandy and a subsequent northeasterly storm that led to a short pulse in freshwater flow into the system (**Figure 2-1**). These storm events also mixed the water column ending a prolonged period of stratification. For 2012, the annual average flows in the Merrimack and Charles Rivers were the 2nd and 3rd lowest measured since 1992, respectively (Appendix A slide 7). 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 2012 results is provided below and additional details are presented in Appendices A-E.

Nutrient concentrations were relatively low in Massachusetts Bay in February and March 2012 in comparison to previous years (see Appendix B slides 4, 5, and 6). Surface nitrate + nitrite (NO_3 +NO_2), as well as silicate (SiO_4) and phosphate (PO_4), levels in Cape Cod Bay were less than half those in Massachusetts Bay in February (**Figure 2-2**; note that for the BHWQM program NO_3 +NO_2 are not measured separately, but for this report they are discussed as NO_3 even when both are plotted; NO_2 is a minor component of NO_3 +NO_2). Surface NO_3 and SiO_4 were nearly depleted by March across the bays (**Figure 2-3**). A comparison of nutrient levels at station N18 for 2012 against previous years' data highlights how much lower NO_3 and SiO_4 levels were in February and March 2012 vs. 2011 and earlier years (see **Figure 2-25**). This may be related to the relatively dry winter spring conditions in 2012 with lower inputs of riverine nutrients and high rates of biological utilization given the warmer temperatures. The decrease in nutrients coincided with high chlorophyll concentrations in March and April due to an early, large

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[3] Ecosystem Advisory issued by NOAA's Northeast Fisheries Science Center http://www.nefsc.noaa.gov/ecosys/advisory/current/advisory.html

Phaeocystis pouchetii bloom in 2012 (**Figure 2-4**; Appendix B slide 16). The *Phaeocystis* bloom was the dominant phytoplankton event of the year. Total phytoplankton abundance during this bloom was highest in the northeast, offshore waters (i.e. station F22) with decreasing abundances towards shallow, inshore Massachusetts Bay stations and to the south in Cape Cod Bay (**Figure 2-5**). No *Phaeocystis* were observed by PCCS at the two stations within Cape Cod Bay in March, but the bloom was observed at station F29 off of Provincetown with *Phaeocystis* abundance of ~2 million cells L^{-1} (Appendix E slide 13).

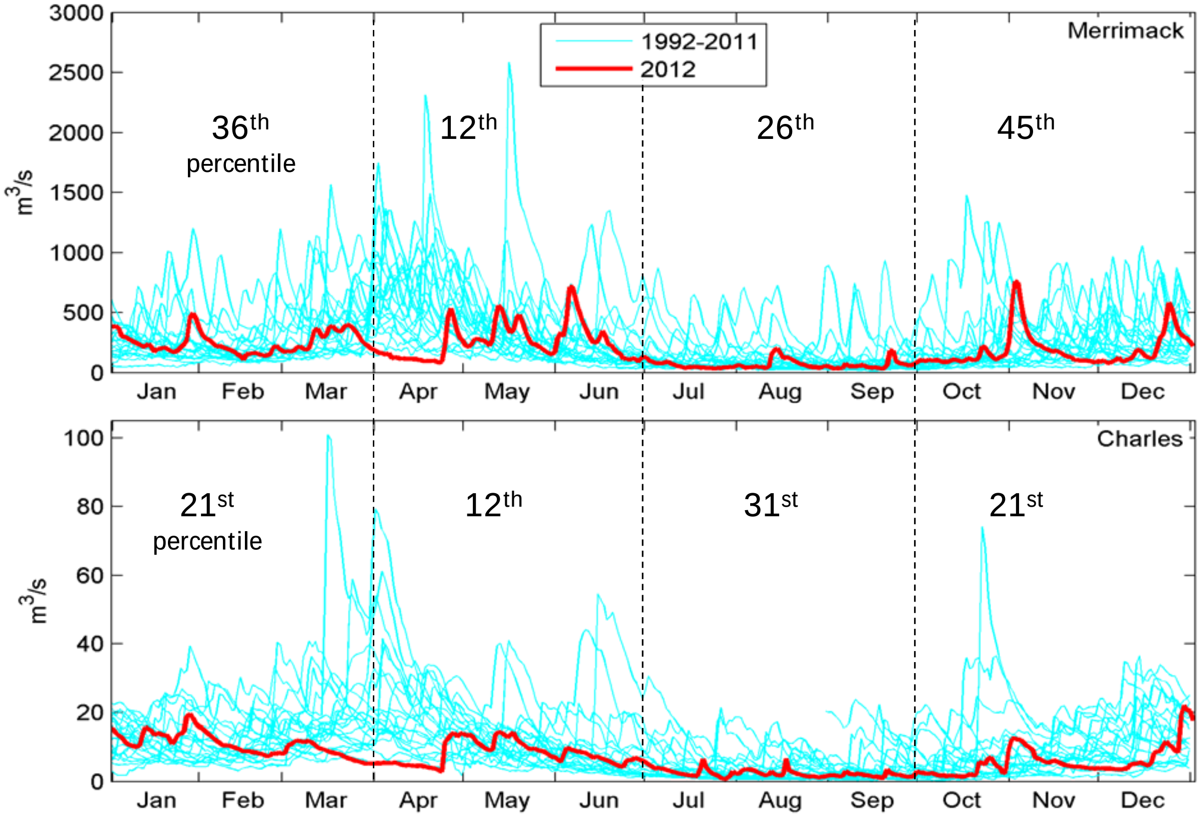

Figure 2-1. Comparison of the 2012 discharge of the Charles and Merrimack Rivers (solid red curve) with 1992-2011 (light blue lines). Percentile of flow in 2012 relative to other years is presented for each river/season.

From March to May, there was a sharp increase in surface water SiO_4 levels throughout Massachusetts Bay, while surface NO_3 concentrations remained depleted at all but harbor station F23 (Appendix B slide 4 and **Figure 2-2**). In April, NO_3 concentrations were low throughout the upper 30 m of the water column (**Figure 2-6**). There was a slight increase in NO_3 concentrations in May below the surface waters likely due to increased mixing – though by June the upper water column was depleted of NO_3 and remained so until the fall. The winter/spring changes in nutrient concentrations (absolute and relative) were coincident with increases in chlorophyll (**Figure 2-4**; Appendix B slide 15) associated with the March/April *Phaeocystis* bloom. The relative decrease in NO_3 vs. SiO_4 is also consistent with a *Phaeocystis* bloom as this phytoplankton species, unlike diatoms, does not utilize SiO_4. Station-average chlorophyll levels peaked during the March survey at 8 µg L^{-1} in the nearfield and a similar peak was seen in the MODIS imagery for early March suggesting that the winter/spring bloom may have started prior to the March 7 image (**Figure 2-7**). Phytoplankton data indicate that the community was dominated by *Phaeocystis* on the March 20 survey, but nutrient data suggest that diatom abundance may have peaked earlier in the month – hence the low SiO_4 concentrations measured in March. Chlorophyll fluorescence data from NERACOOS buoy A01 near station F22 suggests that there may have been two winter/spring peaks in chlorophyll consistent with two different winter/spring blooms (**Figure 2-8**).

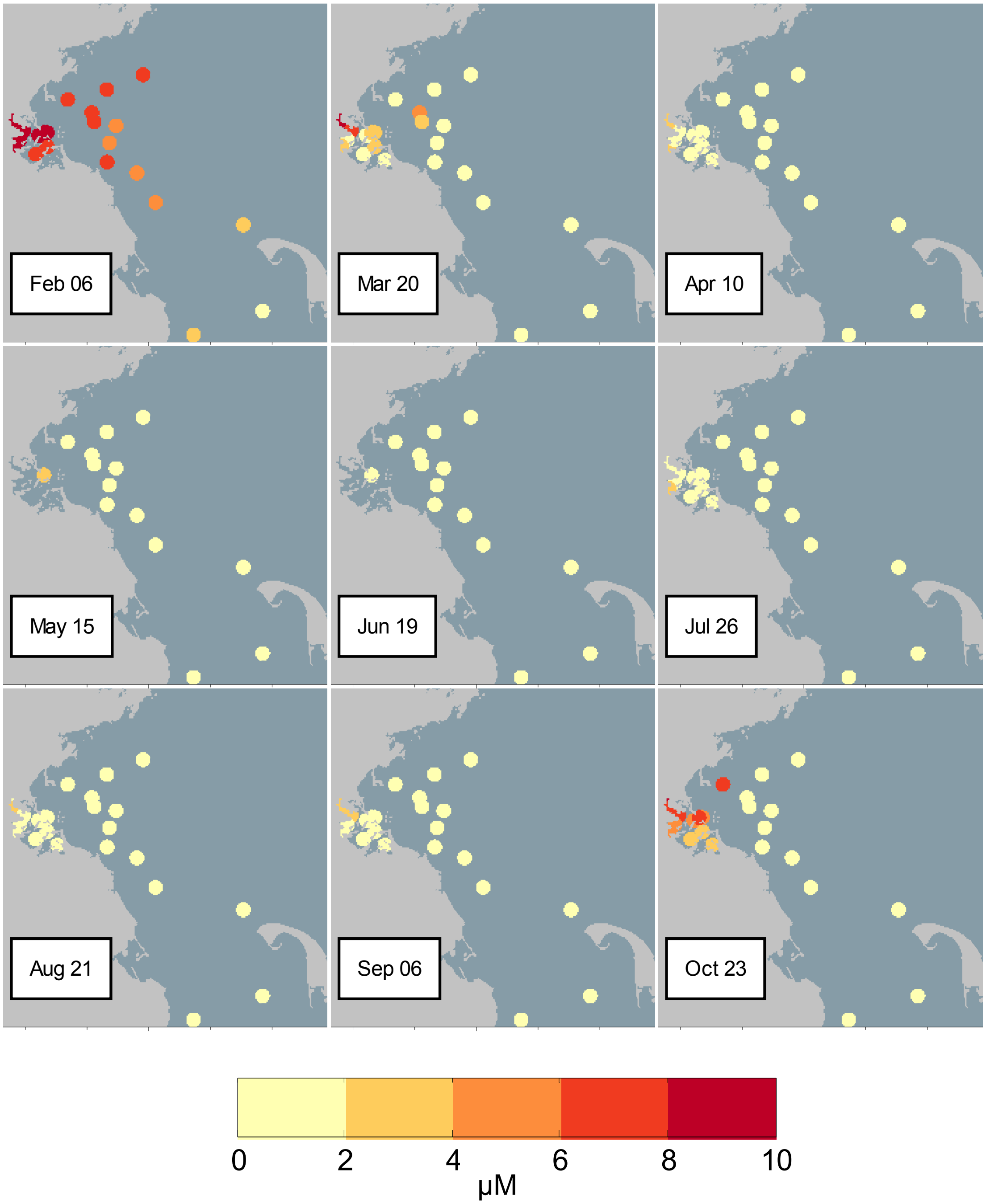

Figure **2-2.** **Surface water $NO_3 + NO_2$ (µM) by station in Massachusetts and Cape Cod Bays.**

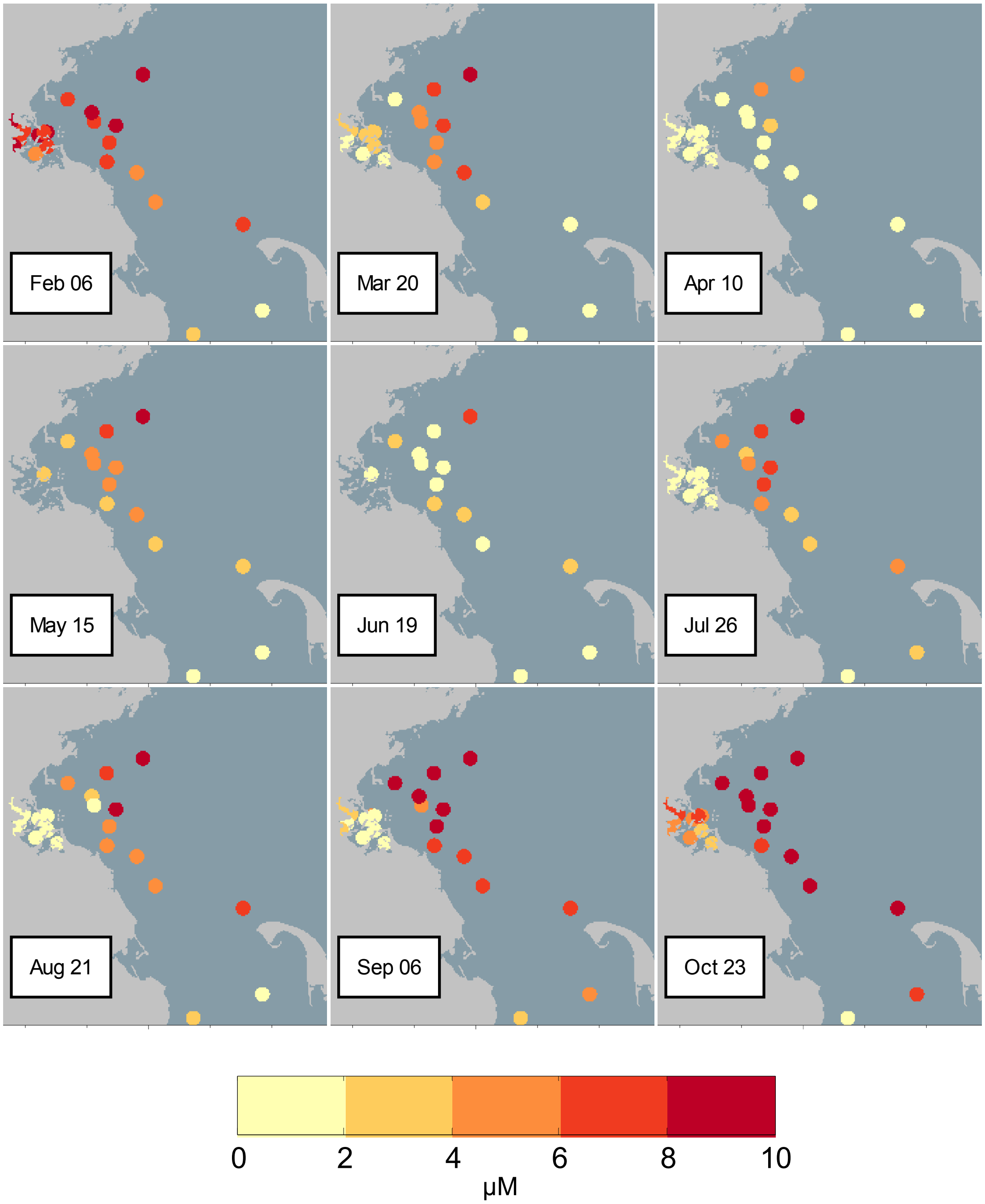

Figure **2-3.** **Bottom water $NO_3 + NO_2$ (µM) by station in Massachusetts and Cape Cod Bays.**

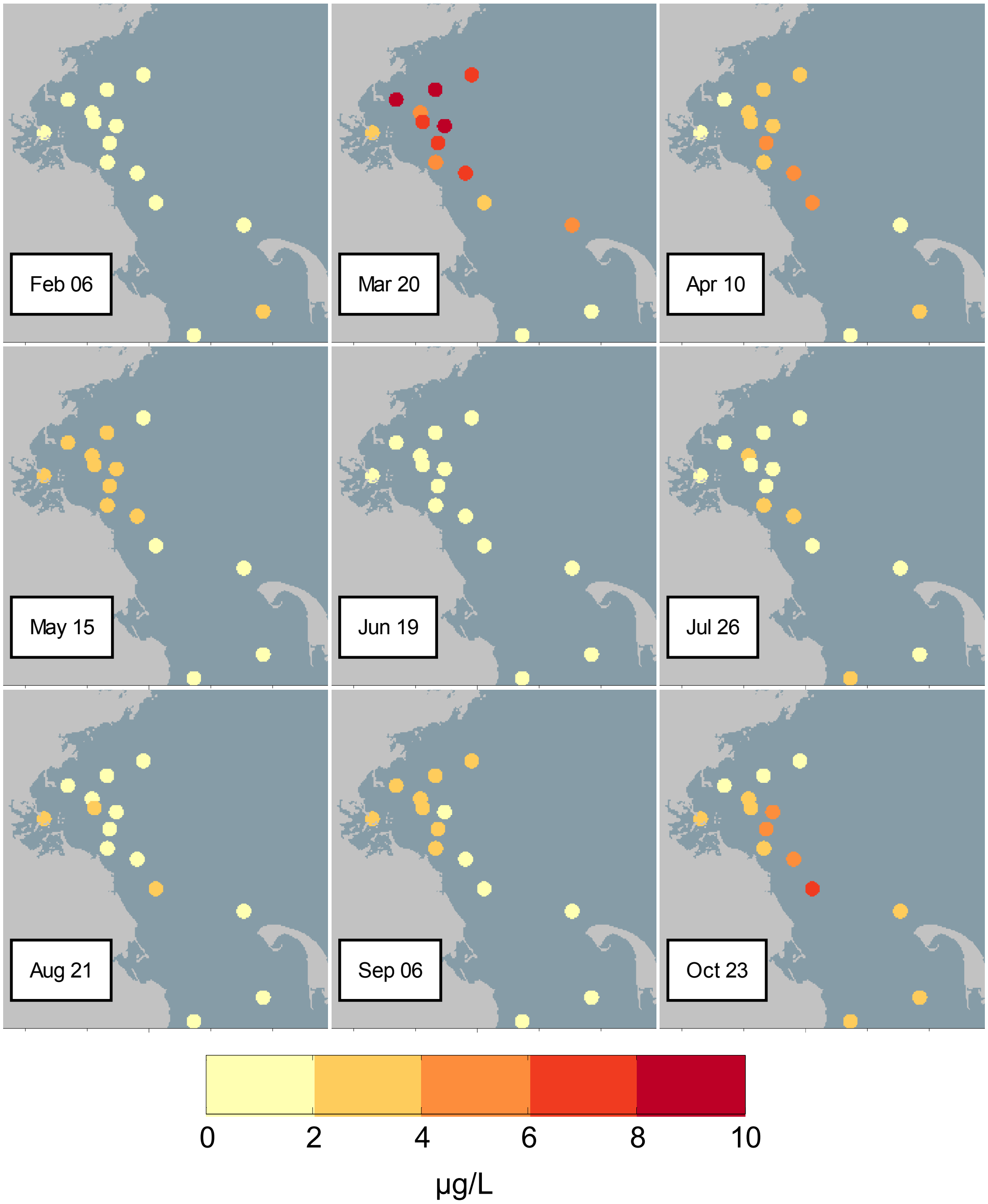

Figure 2-4. Average in situ chlorophyll fluorescence (µg L-1) by station in Massachusetts and Cape Cod Bays.

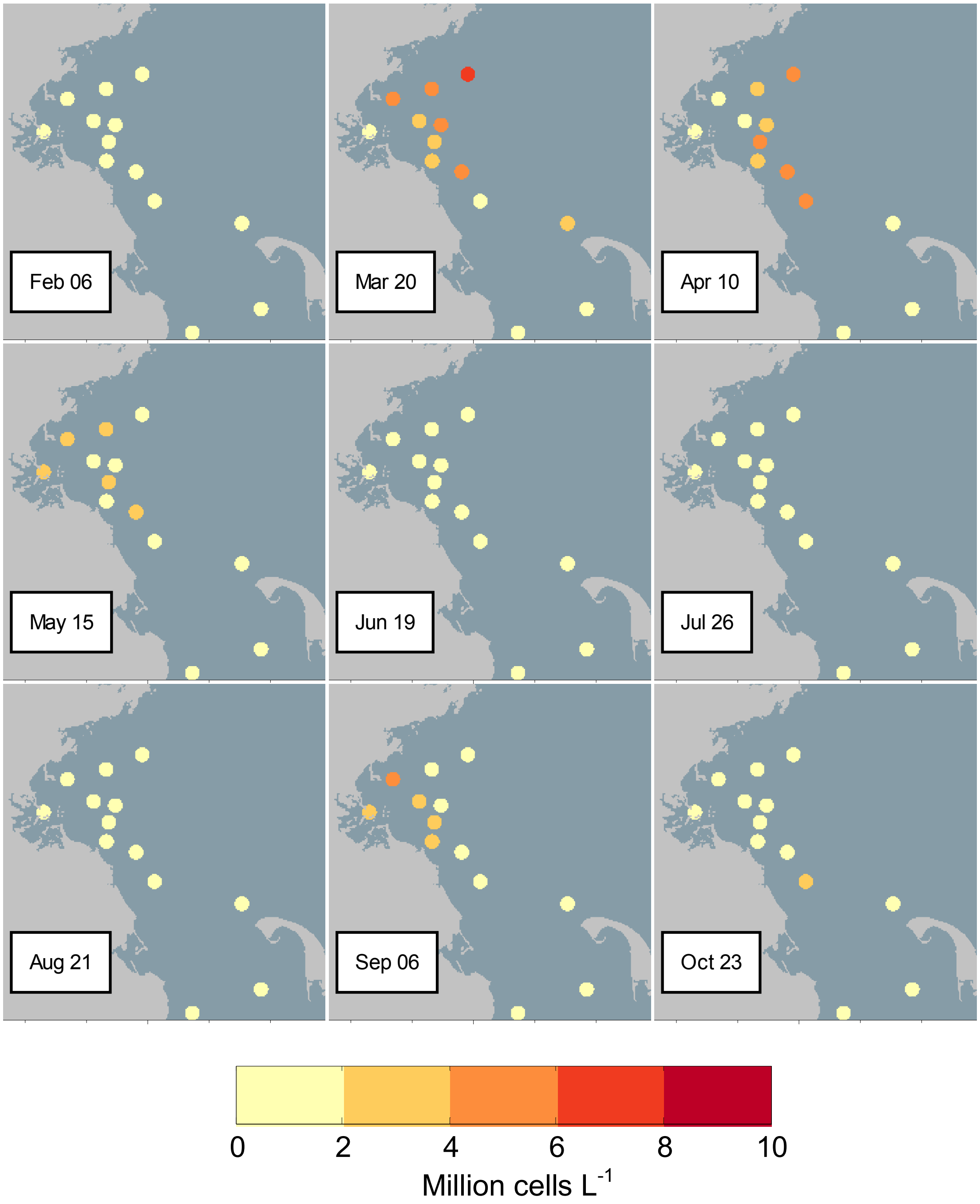

Figure **2-5.** **Average phytoplankton abundance (million cells L^{-1}) by station in Massachusetts and Cape Cod Bays.**

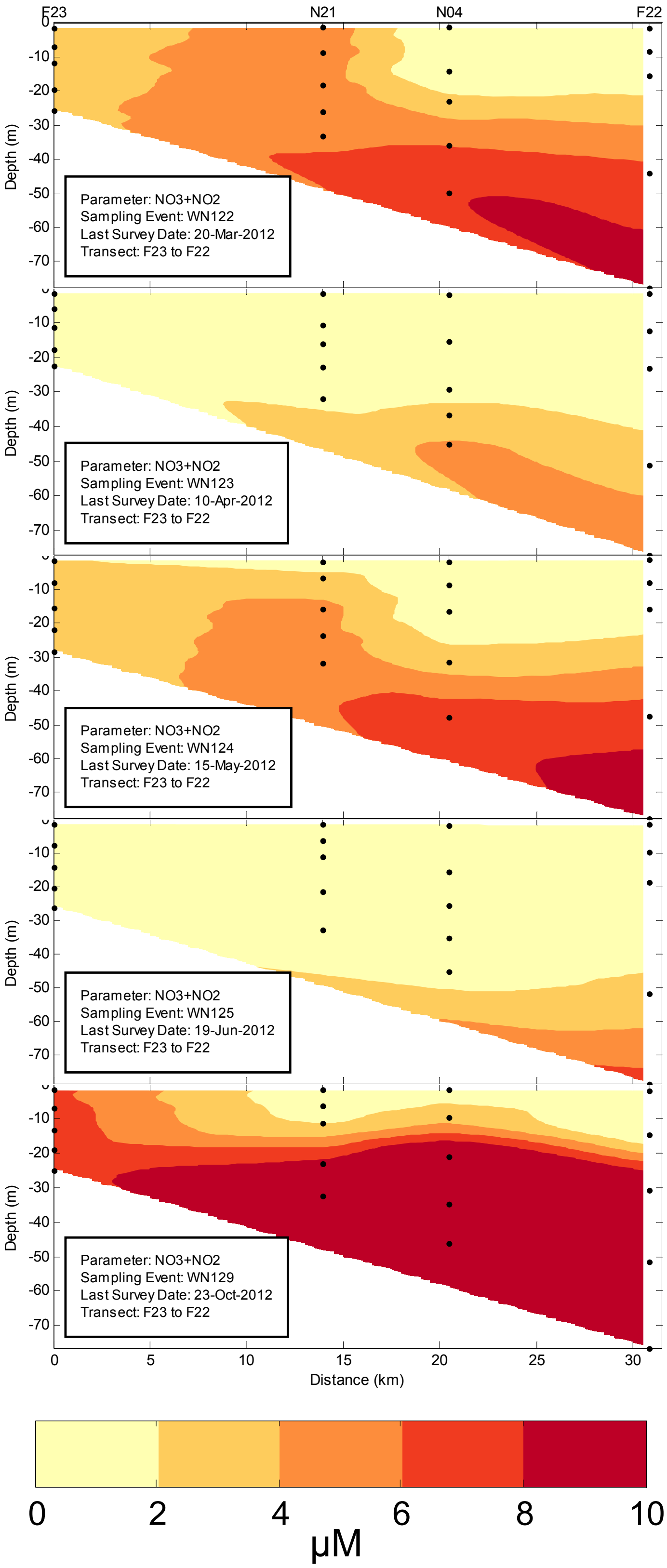

Figure **2-6.** **West to east transect vertical contours of $NO_3 + NO_2$ (µM) from Boston Harbor station F23, through the nearfield (stations N21 and N04), to station F22 south of Cape Ann.**

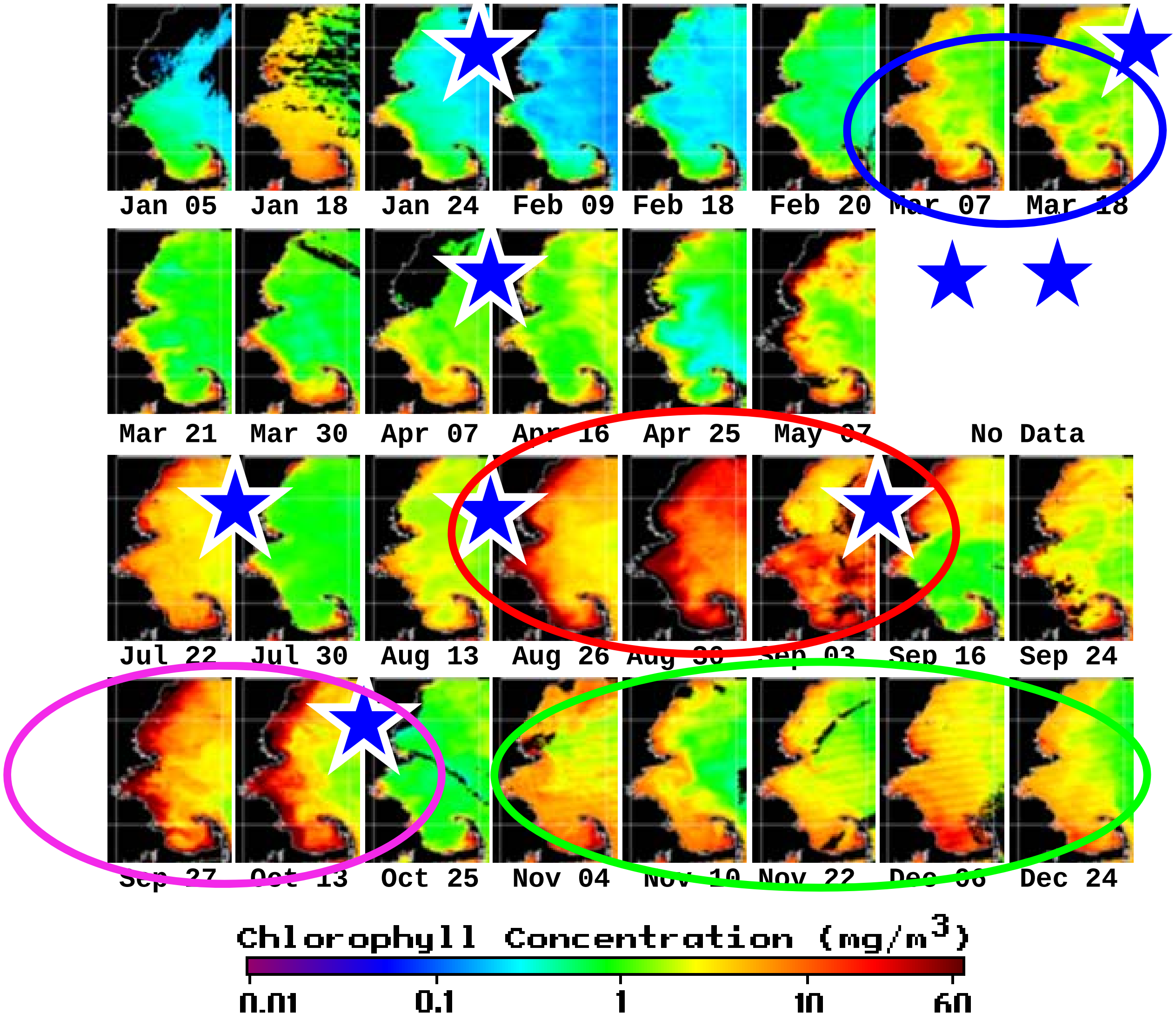

Figure 2-7. MODIS imagery of surface chlorophyll concentrations (mg m^{-3}) in 2012.

The circles highlight specific blooms:
1st row – region-wide *Phaeocystis* bloom in March;
3rd row – late summer bloom dominated by *Skeletonema* spp.;
4th row – late September and early October *Leptocylindrus* spp. bloom and then elevated chlorophyll levels right through the end of 2012.
(Note that these images are heavily weather dependent and do not represent consistent intervals of time; additionally in 2012 there was a greater than two-month period between May 7 and July 22 for which no images were available. The stars on the image correspond to relative timing of the nine MWRA surveys.)

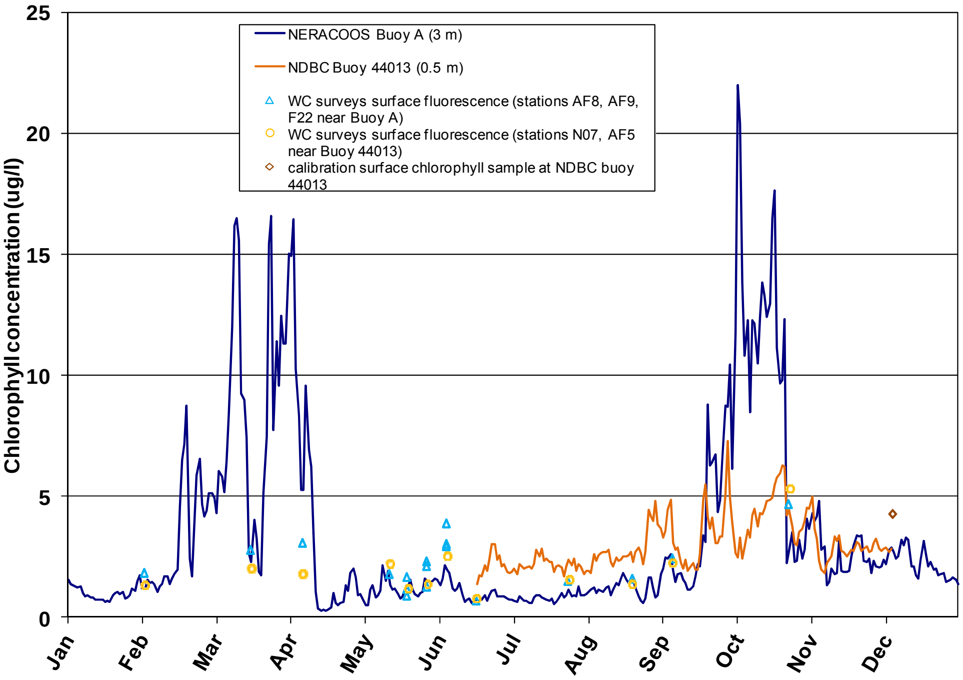

Figure 2-8. **Surface water chlorophyll concentrations (µg L-1) at NERACOOS Buoy A01, NDBC Buoy 44013, and nearby MWRA stations.**

In May, the winds were conducive for strong upwelling conditions in Massachusetts Bay (**Figure 2-9**). The winds were not strong, but they were consistently out of the south and upwelling favorable (**Figure 2-10**). This pushed surface water offshore, which was replaced by deep water drawn in from offshore. That led to higher salinities in the bottom waters and an increase in nutrient concentrations into the upper water column though they remained depleted in the very shallowest surface waters (Appendix A slide 16 and **Figure 2-6**). The effluent plume (as delineated by elevated ammonium (NH_4) concentrations) extended into the surface waters due to the upwelling, but did not surface. Elevated NH_4 concentrations were measured in the nearfield and to the south at station F15 (**Figure 2-11**). High NH_4 levels were observed in the nearfield during all but one (August) of the surveys in 2012 (Appendix B slides 7-12). The plume signature of elevated NH_4 concentrations was generally confined to within 10-20 km of the bay outfall during both well-mixed and stratified conditions. Remnants of the large March/April *Phaeocystis* bloom lingered in Massachusetts Bay in May including a sample from the nearfield, which was enough to trigger the summer *Phaeocystis* threshold exceedance, which is only 357 cells L^{-1} (see **Table 2-1**). This exceedance had no ecological impact, but simply resulted from a few remaining *Phaeocystis* colonies from the bloom being present in the bay in May.

Another nuisance species, *Alexandrium fundyense*, was observed at very low abundances in April, but by May levels had increased with abundances of >100 cells L^{-1} observed in the nearfield (**Figure 2-12**) triggering an *Alexandrium* rapid response study (ARRS) survey. A series of three weekly ARRS surveys were conducted from May 22nd to June 7th. On May 15th, *Alexandrium* peaked for that day in the nearfield at station N01 at 533 cells L^{-1} with higher abundances (>1,000 cells L^{-1}) found in samples collected 10 meters deep at stations along the South Shore. The *Alexandrium* bloom reached peak abundances during the May 22nd survey with ~5,200 cells L^{-1} at station F05 off of Scituate (**Figure 2-12**). *Alexandrium* abundances remained elevated in the nearfield in late May, but by June 7th the bloom was over and only a few *Alexandrium* cells were observed (Appendix B slide 30). This moderate bloom resulted in an exceedance of the MWRA Contingency Plan Threshold for *Alexandrium* and shellfish PSP toxicity sufficient for DMF to close shellfishing beds from Duxbury north to Salem in western Massachusetts Bay. These are discussed in more detail in Section 2.2.

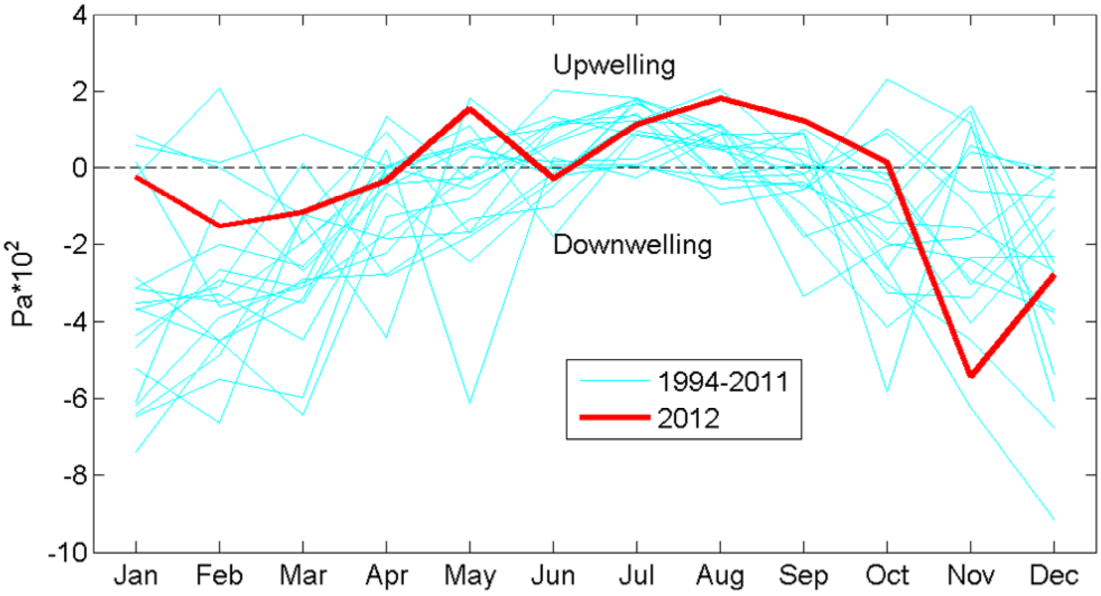

Figure 2-9. Upwelling index in the nearfield in 2012 (red line) and previous 20 years (1992-2011, light blue lines).

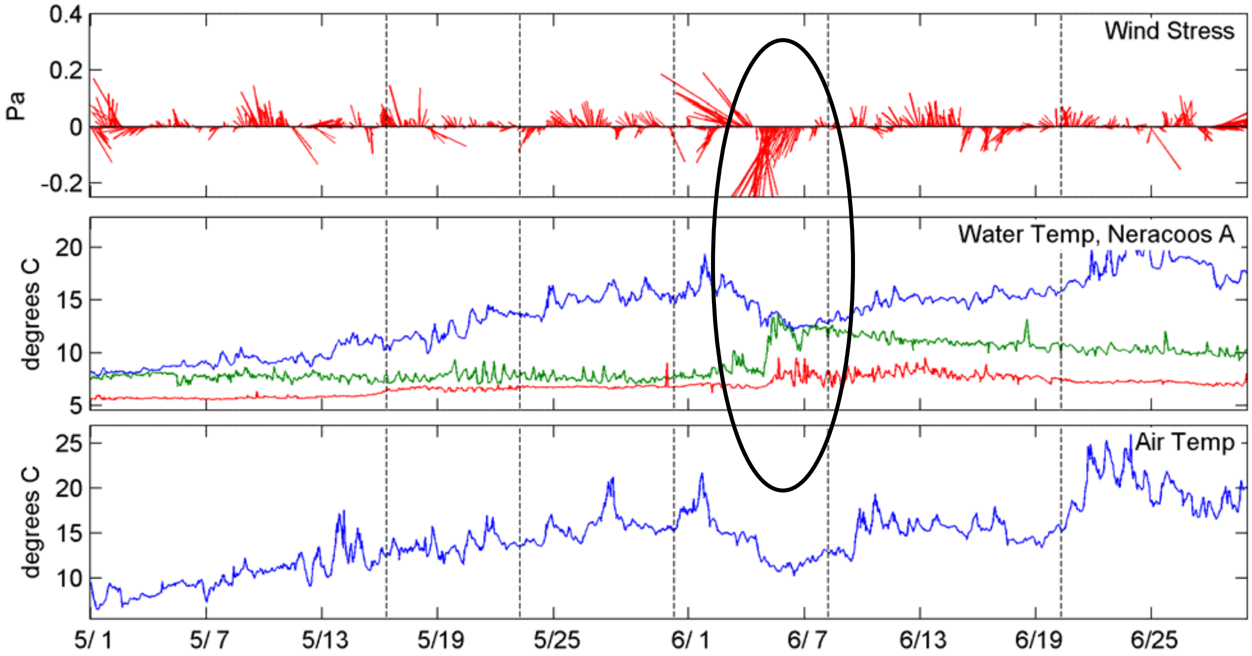

Figure 2-10. May and June 2012 winds and temperature at NERACOOS Buoy A01. Oval highlights northeast wind induced mixing event.

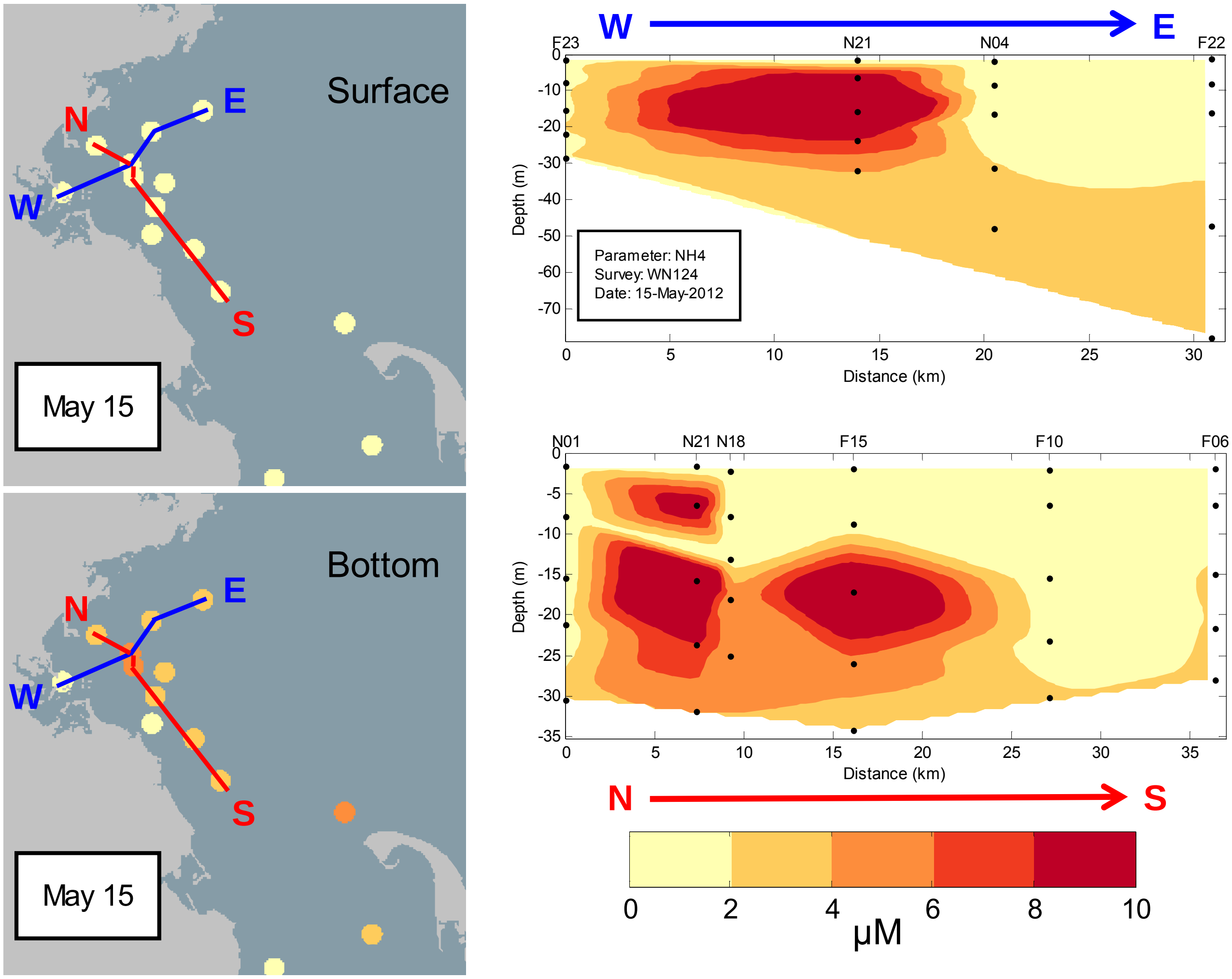

Figure **2-11.** **Surface and bottom water NH_4 (µM) by station and along two vertical transects in Massachusetts and Cape Cod Bays on May 15, 2012.**

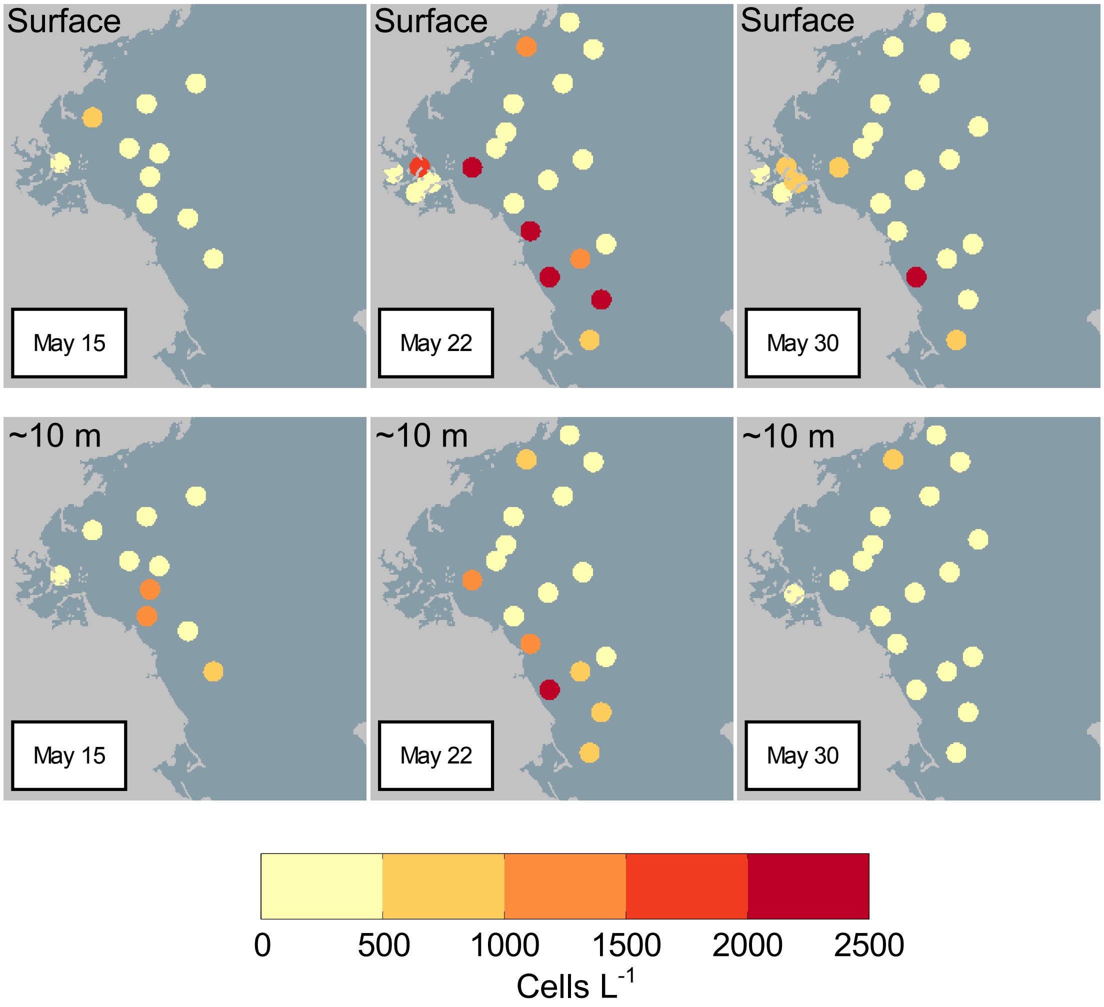

Figure **2-12.** ***Alexandrium*** **abundance (cells L^{-1}) at surface and 10 m during the May 2012 surveys.**

By the June survey, along with the decrease in *Alexandrium*, levels of nutrients, chlorophyll, and POC were low throughout Massachusetts Bay. The water column had become stratified and nutrients (including those associated with the effluent plume) were confined below the pycnocline (Appendix B slide 11). Nutrient and chlorophyll levels remained low over the remainder of the summer surveys (see **Figure 2-2** and **Figure 2-4**). Total phytoplankton abundances were low (**Figure 2-5**) and the summer centric diatom community that often develops in near shore waters featured *Leptocylindrus minimus, Leptocylindrus danicus, Cerataulina pelagica* and *Skeletonema* spp. at low abundance levels from June through early August 2012. Unlike the last few years, we did not observe a near shore bloom of the centric diatom *Dactyliosolen fragilissimus*. No MODIS imagery was received between May 8 and July 21 to compare with the May and June results. However, an image from July 22 suggested elevated chlorophyll throughout the bays. This was not observed during the field measurements on July 26th, which showed low chlorophyll levels that were more comparable to the MODIS image taken on July 30th (**Figure 2-7**). Chlorophyll levels remained low through mid August. Dinoflagellate abundance ranged from tens of thousands of cells per liter in the winter/spring to summer peak abundances of 100,000 to 200,000 cells L^{-1} at many stations in July, August, and September. The dinoflagellate community composition displayed a seasonal shift from relatively small forms (*Heterocapsa triquetra, Heterocapsa rotundata*, small *Gymnodinium* spp.) in the late winter/early spring to large forms dominated by *Ceratium* spp. in the summer. *Ceratium* spp. showed a large increase in 2012 relative to levels seen in the past several years (Appendix C slide 14), with 2012 mean *Ceratium* spp. abundance (2,848 cells

L^{-1}) that was double the long-term mean of 1,427 cells L^{-1}. Large *Ceratium* are slow growing cells that thrive at the seasonal pycnocline and require prolonged periods of stratification to accumulate. The 2012 return of *Ceratium* abundance to levels not seen since 2001 may reflect the increase in water column stability, perhaps related to the warm winter-spring of 2012.

By late August and early September, MODIS imagery indicated that chlorophyll levels had increased throughout the bays. By the time of the September 6th survey, chlorophyll and POC concentrations had increased throughout Massachusetts Bay (**Figure 2-4**; Appendix B slides 15 and 18). This was coincident with a bloom of the centric diatom *Skeletonema*. This bloom was the dominant feature of the 2012 diatom cycle, with *Skeletonema* spp. abundance peaking at 2.5 million cells L^{-1} in the harbor, coastal and nearfield regions in September (Appendix C slides 8, 9, and 11).

MODIS imagery suggests that this early fall bloom may have declined by mid September; a subsequent bloom (indicated by an increase in chlorophyll concentrations) was observed further offshore by late September and into October (**Figure 2-7**). This was also suggested by the chlorophyll readings at both the NDBC and NERACOOS A01 buoys (**Figure 2-8**). In late August and early September, the inshore waters had elevated chlorophyll concentrations as shown by the NDBC vs. NERACOOS data, but by late September there had been a large increase at the offshore NERACOOS buoy. This increase in chlorophyll levels was due to an offshore bloom of *Leptocylindrus danicus*. Chlorophyll concentrations had decreased by the October 23rd survey though remained elevated compared to summer levels (**Figure 2-4** and **Figure 2-8**). Nutrient levels increased somewhat in the fall and clearly supported the diatom bloom, but the water column did not remix and surface waters remained depleted of NO_3 through October except in Boston Harbor (Appendix B slide 4 and **Figure 2-6**).

Bottom water DO concentrations declined sharply from April annual maxima to May (**Figure 2-13**). In early June, a northeast wind-induced mixing event led to a sharp decrease in bottom water salinity and an increase in bottom water temperature and DO levels as surface waters were mixed to depth (**Figure 2-10** and Appendix A slides 10 and 16). This mixing event likely averted even lower DO levels from being reached in fall 2012. From June to October, bottom water DO concentrations gradually decreased across most of Massachusetts Bay. In the shallower waters of Boston Harbor (F23) and Cape Cod Bay (F01), bottom water DO increased in October as seasonal mixing had occurred at these stations (Appendix B slide 21). Dissolved oxygen levels of just under 6 mg L^{-1} were observed at stations N01 and F02, while the annual minima in DO was observed in the near bottom waters at station F06 (5.11 mg L^{-1}; **Figure 2-13**).

Time series data from NERACOOS Buoy A showed bottom water DO levels continuing to decrease into late October dipping close to 6 mg L^{-1} (**Figure 2-14**). The lack of major fall storms until late October delayed destratification of the water column and recovery of bottom water DO concentrations. Hurricane Sandy hit the region on October 29th, soon after the final MWRA survey, and initiated breakdown of seasonal stratification as indicated by the sharp increase in bottom water DO levels at NERACOOS Buoy A01 (**Figure 2-14**). A subsequent strong Northeasterly storm completed the process and by early November the water column was well mixed. The DO regression model predicted even lower DO levels than were observed (Appendix A slide 19), due to warmer than normal bottom temperatures and higher than normal bottom salinity. The fact that DO was not as low as the model prediction may be related in part to the June mixing event. 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 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.

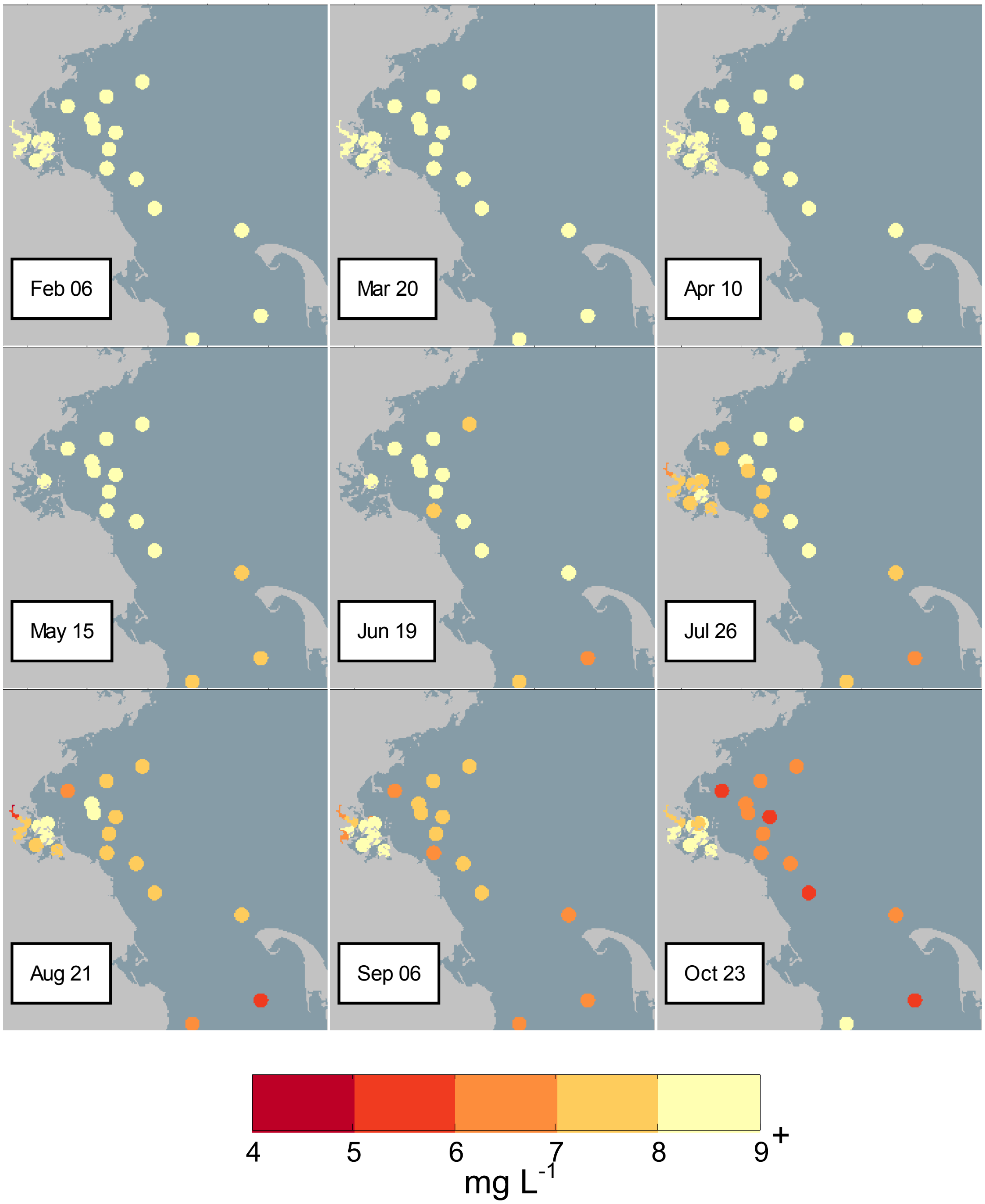

Figure **2-13.** **Bottom water DO concentration (mg L^{-1}) at stations in Massachusetts and Cape Cod Bays in 2012.** The lowest DO measured in 2012 was 5.4 mg L^{-1} at station F06 during the October survey. Only twice during the monitoring program has bottom DO fallen below 5 mg L^{-1}, in October 1994 and 2000.

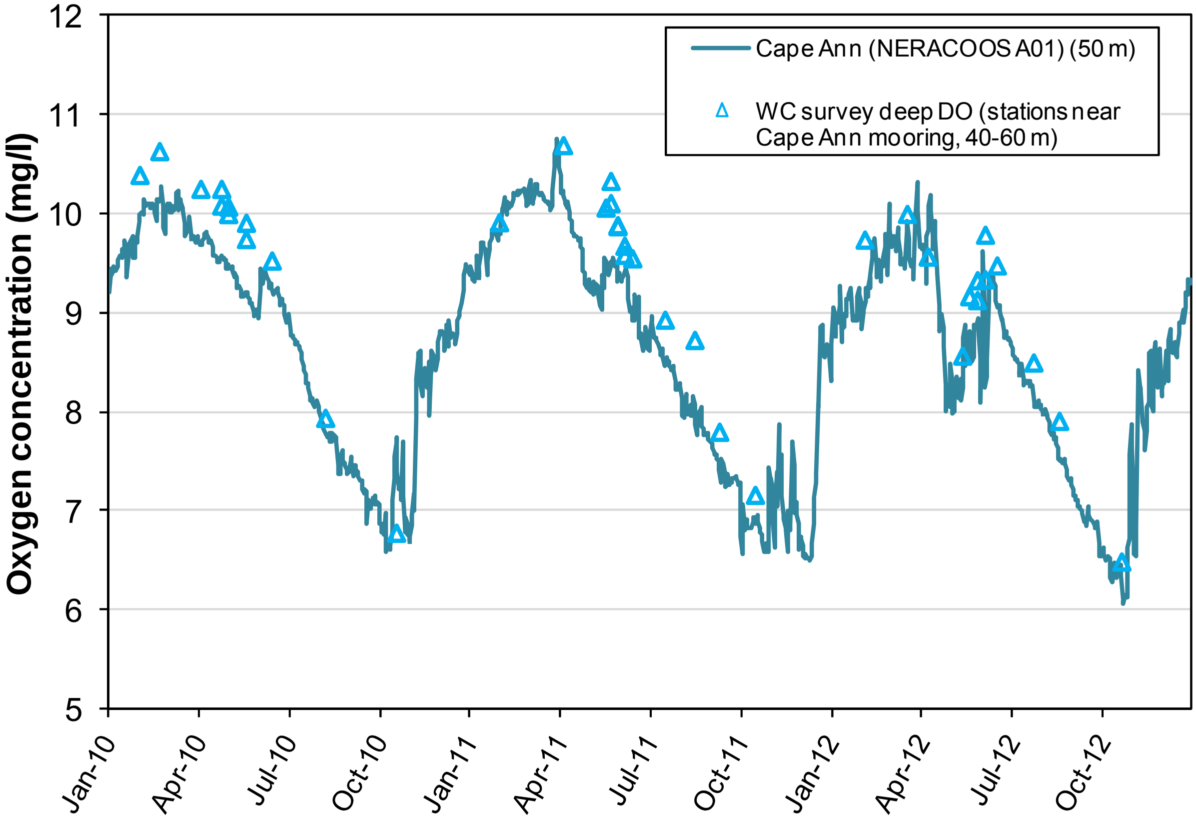

Figure **2-14.** **Bottom-water DO concentrations at NERACOOS Buoy A01 near Cape Ann and nearby MWRA stations, 2010–2012.**

In 2012, the zooplankton community composition, abundance, seasonality, and distributional patterns generally followed typical patterns. This is interesting since winter/spring 2012 was warmer than usual and the timing of phytoplankton blooms seemed earlier especially the *Phaeocystis* bloom that peaked in March, about a month early. Total zooplankton abundance increased from the winter through the spring peaking in the summer, and declined in the fall as usual (**Figure 2-15**). Comparisons against previous years suggest that initial zooplankton abundances (including the dominant groups and species – copepods, copepod nauplii and *Oithona similis*) during the first survey in February 2012 may have been slightly higher than earlier years, but the overall pattern was essentially the same (Appendix D slides 8 and 9). Thus, apart from February, in terms of zooplankton community composition and seasonal patterns, 2012 was a typical year. Total zooplankton abundance was dominated by copepod nauplii and *O. similis* copepodites and adults. As previously found (Kropp *et al*. 2003), there was more temporal variability in abundance than spatial variability in abundance. *O. similis* was ubiquitously abundant everywhere, whereas *Acartia* spp. were abundant only in Boston Harbor (Appendix D slides 6 and 7).

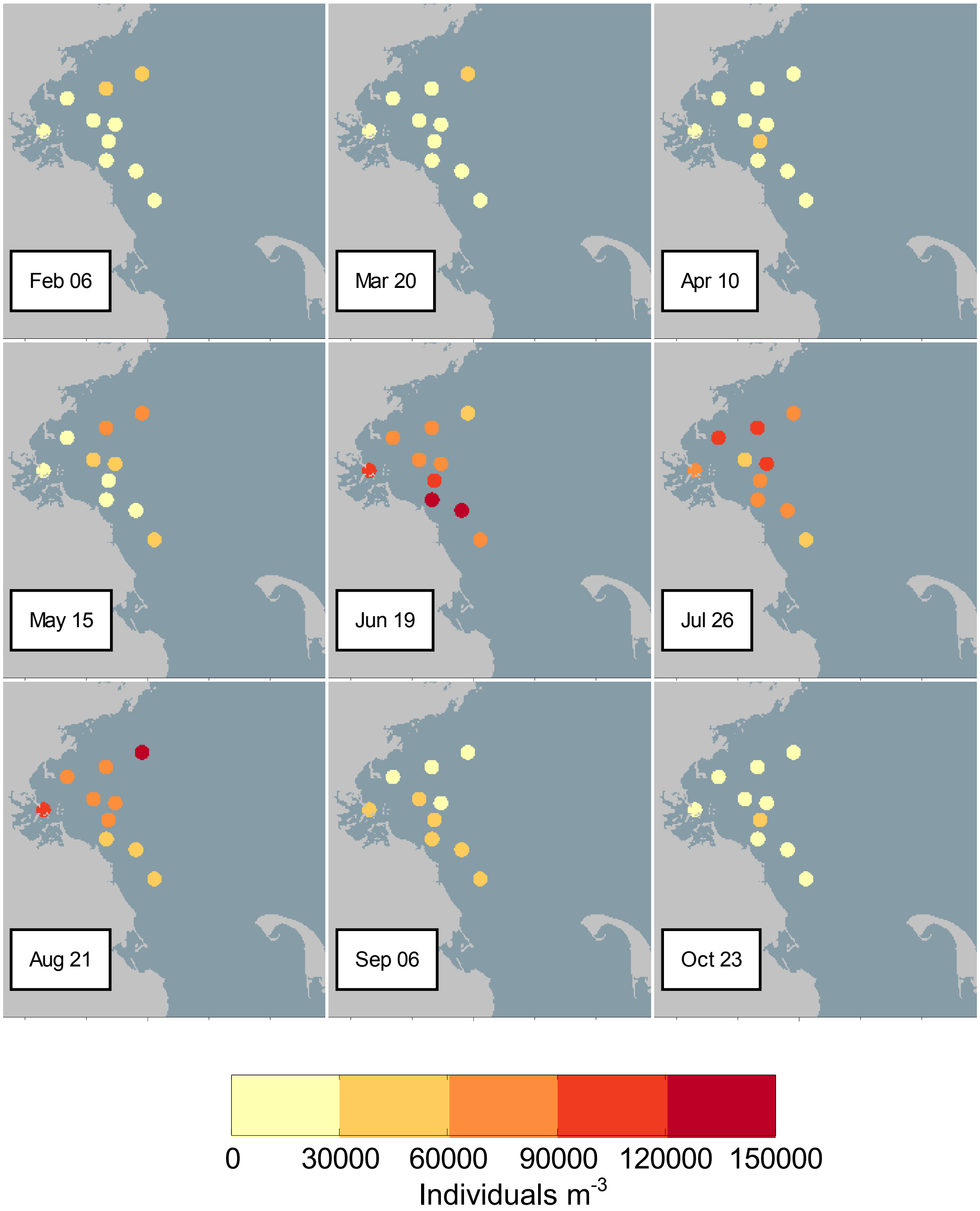

Figure **2-15.** **Total zooplankton abundance (individuals m^{-3}) at each station in Massachusetts Bay.**

2.2 CONTINGENCY PLAN THRESHOLDS FOR 2012

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**). The Contingency Plan provides rationale for the thresolds including those for DO concentration and saturation, which are based on the requirement (MADEP 1996) that dissolved oxygen not fall below 6.0 mg/L or 75% saturation <u>unless background conditions are lower</u>. Our baseline monitoring (1992-2001) showed that background values were indeed lower and thus provide the benchmark for comparison to the present values.

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 both non-toxic *P. pungens* as well as the domoic-acid-producing species *P. multiseries*; these appear identical under a light microscope. Since distinguishing between these two species requires scanning electron microscopy or molecular probes, all *P. pungens* and *Pseudo-nitzschia* unidentified 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}.

There were two water column threshold exceedances in 2012. One was for summer *Phaeocystis* abundance due to a prolonged presence of this species in Massachusetts Bay into May. *Phaeocystis* has been observed in the bay on an annual basis since 2000 and is a regular constituent of the winter/spring bloom in the Gulf of Maine. The other was for *A. fundyense*, which has frequently been present in the bay in May/June since the extraordinary bloom of 2005.

Bottom water DO concentrations in 2012 were consistent with the normal annual pattern: highest in winter, decreasing over the summer stratified period, and reaching the annual minima in October. The value of the bottom water minima, however, were low in comparison to past years with nearfield and Stellwagen basin minima of 6.19 and 6.6 mg L^{-1}, respectively. These DO levels (and their respective percent saturation values) were only slightly above the Contingency Plan threshold values of 6.05 and 6.23 mg L^{-1}, respectively (from Table 2-1 column 2). Comparisons of the bottom water DO concentrations at nearfield station N18 and Stellwagen Basin station F22 in 2012 vs. previous years illustrates how low DO was in 2012 (Figure 2-16). The individual survey concentrations were near or below previous values for each of the stations for most of the year. This was also the case throughout the rest of Massachusetts Bay as shown for stations F13 and F06, where the minima in 2012 were the lowest observed over the monitoring program. These low bottom water DO levels are due to the regional forcing associated with the warmer and drier conditions in 2012 as suggested by bottom water temperature and salinity data presented in Figure 2-17.

Table **2-1.** **Contingency plan threshold values for water column monitoring in 2012.** The highest nearfield value is shown for the *Alexandrium* exceedance.

Water Column Parameter	Baseline	Caution Level	Warning Level	2012 Results
Nearfield bottom water				
Dissolved oxygen concentration	Background 5th percentile 6.05 mg/L	Lower than 6.5 mg/L for any survey (June-October) unless background conditions are lower	Lower than 6.0 mg/L for any survey (June-October) unless background conditions are lower	Lowest survey mean = 6.19 mg/L
Dissolved oxygen saturation	Background 5th percentile 65.3%	Lower than 80% for any survey (June-October) unless background conditions are lower	Lower than 75% for any survey (June-October) unless background conditions are lower	Lowest survey mean = 67.5%
Dissolved oxygen depletion rate (June–October)	0.024 mg/L/d	0.037 mg/L/d	0.049 mg/L/d	0.022 mg/L/d
Stellwagen Basin bottom water				
Dissolved oxygen concentration	Background 5th percentile 6.23 mg/L	*same as for nearfield concentration*	*same as for nearfield concentration*	Lowest survey mean = 6.6 mg/L
Dissolved oxygen saturation	Background 5th percentile 67.2%	*same as for nearfield saturation*	*same as for nearfield saturation*	Lowest survey mean = 70.4%
Nearfield chlorophyll				
Annual	72 mg/m^2	108 mg/m^2	144 mg/m^2	96 mg/m^2
Winter/spring	50 mg/m^2	199 mg/m^2	None	144 mg/m^2
Summer	51 mg/m^2	89 mg/m^2	None	69 mg/m^2
Autumn	90 mg/m^2	239 mg/m^2	None	78 mg/m^2
Nearfield nuisance algae *Phaeocystis pouchetii*				
Winter/spring	622,000 cells/L	2,860,000 cells/L	None	1,690,000 cells/L
Summer	72 cells/L	357 cells/L	None	1,120 cells/L caution level exceedance
Autumn	370 cells/L	2,960 cells/L	None	Absent
Nearfield nuisance algae *Pseudonitzchia*				
Winter/spring	6,735 cells/L	17,900 cells/L	None	526 cells/L
Summer	14,635 cells/L	43,100 cells/L	None	388 cells/L
Autumn	10,050 cells/L	27,500 cells/L	None	2,820 cells/L
Nearfield nuisance algae *Alexandrium*				
Any sample	Baseline maximum = 163 cells/L	100 cells/L	None	3,731 cells/L caution level exceedance
Farfield shellfish				
PSP toxin extent	Not applicable	New incidence	None	No new incidence

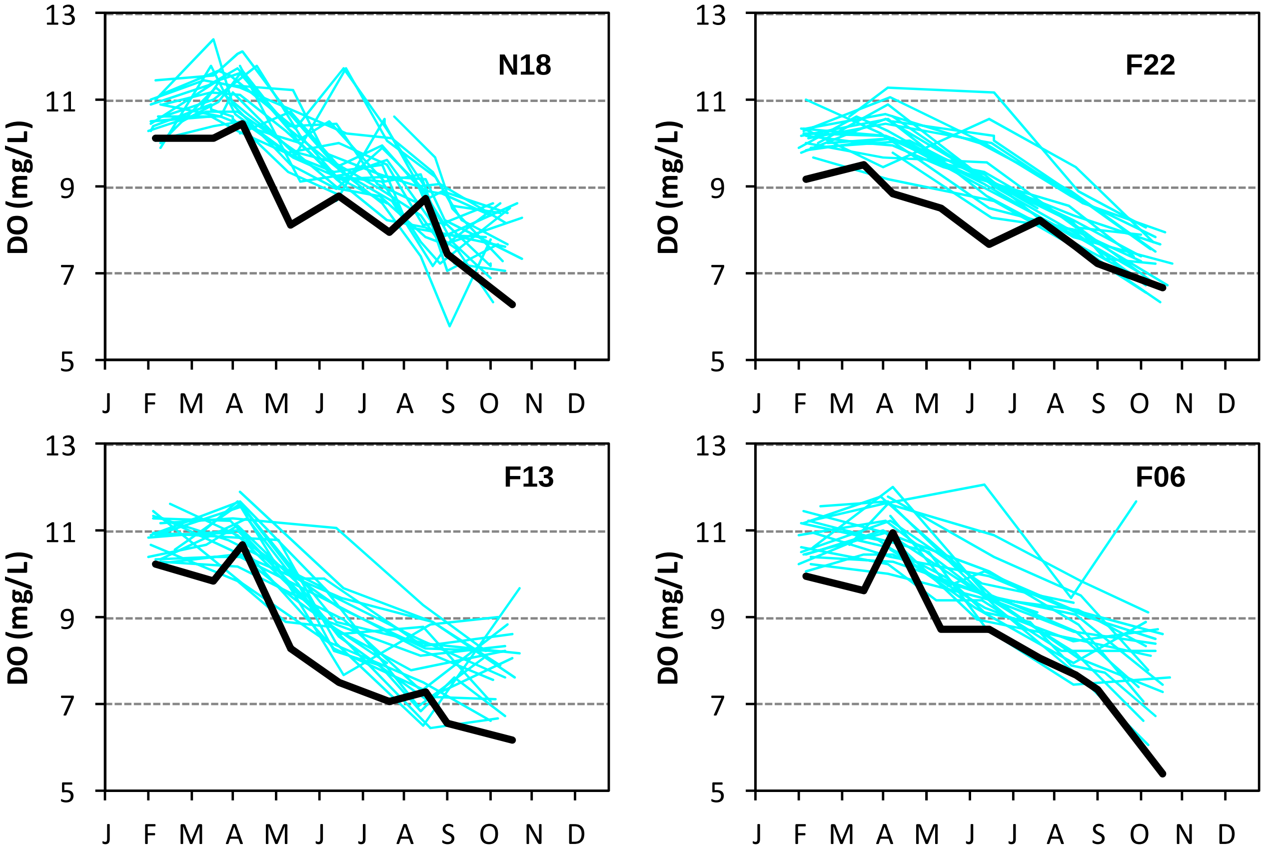

Figure **2-16.** **Time-series of bottom water DO concentration (mg L^{-1}) at stations N18, F22, F13, and F06 for 2012 (black) compared to the previous 20 years of observations (1992-2011; light blue).**

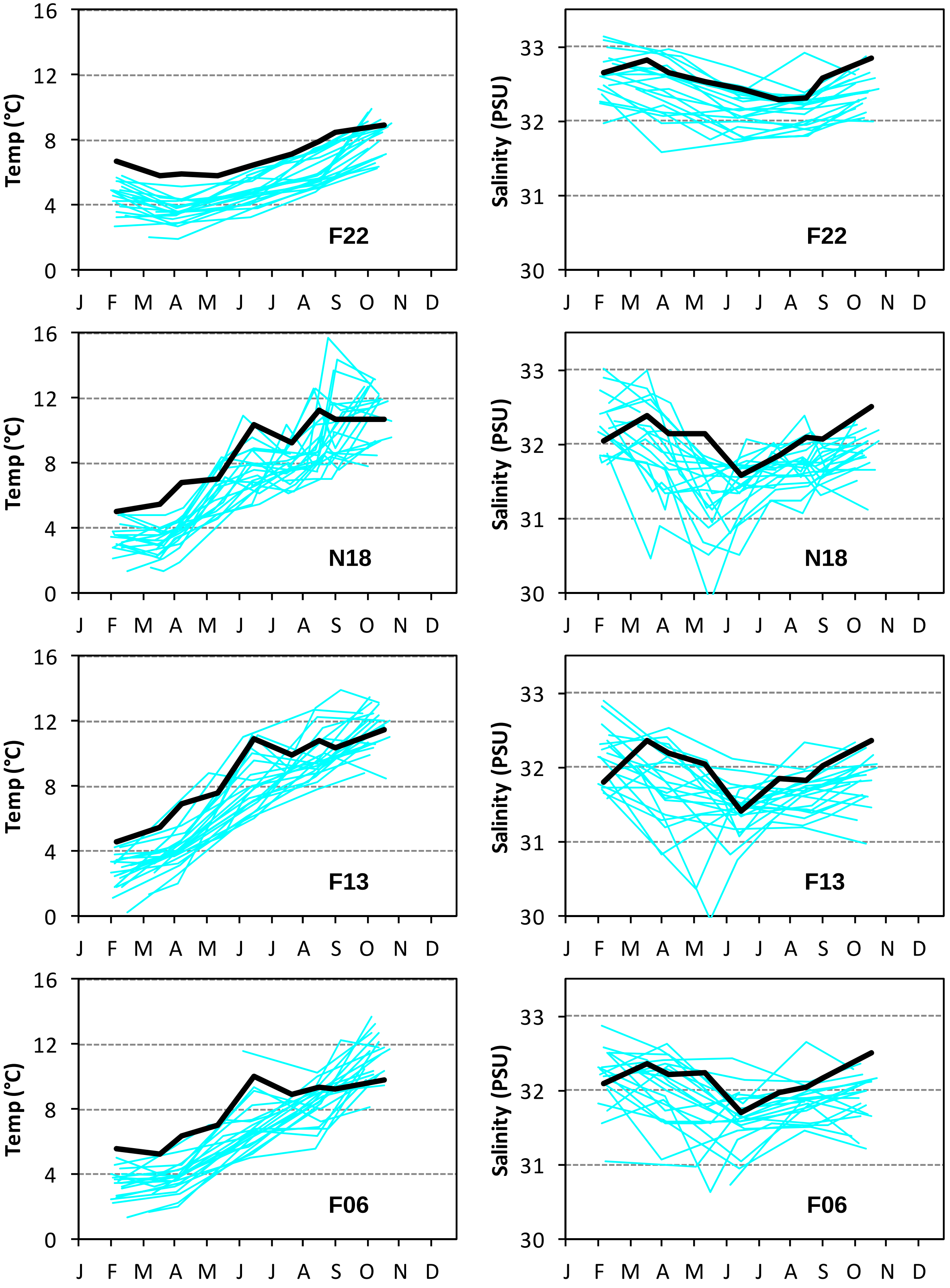

Figure 2-17. **Time-series of bottom water temperature (°C, left) and salinity (PSU; right) at stations N18, F22, F13, and F06 for 2012 (black) compared to the previous 20 years of observations (1992-2011; light blue).**

Bottom water temperatures were elevated compared to previous years from February through August 2012, while salinity remained elevated over most of the year. The cooler bottom water temperatures in September and October are the result of continued stratification into late October (**Figure 2-18**) – no mixing down of warmer surface waters as had occurred during the majority of previous years. The combination of the low initial DO levels, plus the lack of mixing with surface waters until late in the fall led to low bottom water DO and the conditions were likely further exacerbated by the input of organic material associated with the relatively large winter/spring and fall blooms in 2012. Even with the high chlorophyll concentrations and low bottom water DO levels; there were no threshold exceedances for these water quality parameters in 2012. Bottom water DO levels in the bays are primarily driven by regional physical oceanographic processes (Geyer *et al*. 2002) and have been unaffected by the outfall.

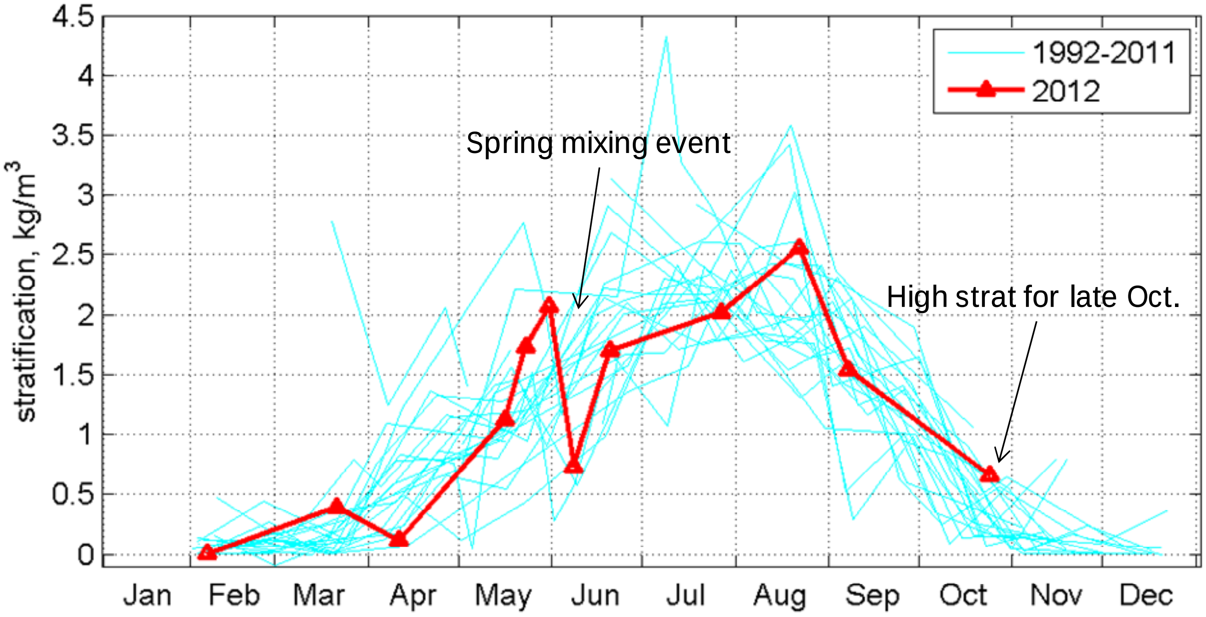

Figure **2-18.** **Strength of stratification near the outfall site (nearfield station N18) for 2012 (red line) compared to the previous 20 years of observations (1992-2011; light blue).** The strength of stratification is estimated as the difference between surface and bottom densities.

The seasonal and annual nearfield mean areal chlorophyll levels for 2012 were above background levels except for autumn, but below Contingency Plan threshold values (**Table 2-1**). The early, large *Phaeocystis* bloom in March combined with the elevated summer dinoflagellate abundances led to elevated chlorophyll concentrations and the winter/spring and summer seasonal means were above baseline means and approached the threshold values (95th percentile of baseline seasonal means). There was a fall diatom bloom in Massachusetts Bay, but the overall chlorophyll concentrations in fall 2012 were relatively low when directly compared to those observed in the past at nearfield station N18 (**Figure 2-19**). The winter/spring peak and generally elevated summer chlorophyll levels in 2012 led to an annual mean of 96 mg m^{-2}, which is higher than the baseline annual mean and the highest annual mean since 2006.

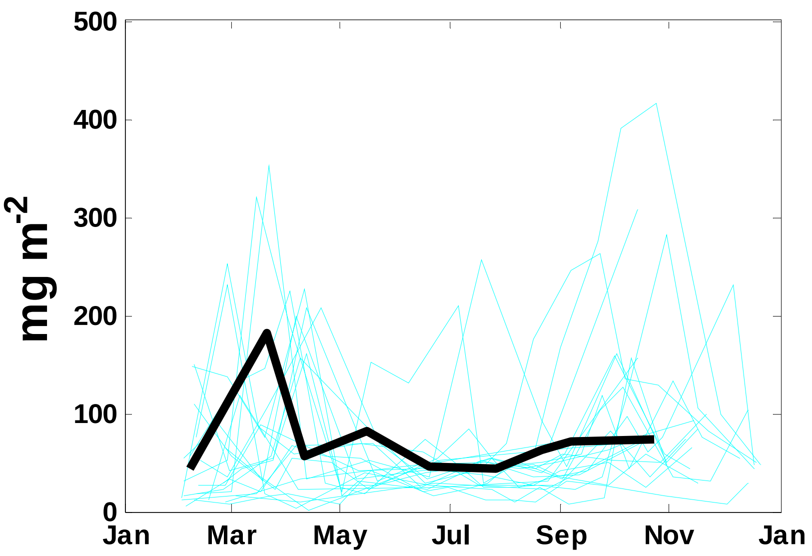

Figure **2-19.** **Areal chlorophyll (mg m^{-2}) near the outfall site (nearfield station N18) for 2012 (black line) compared to the previous 20 years of observations (1992-2011; light blue).**

As mentioned previously, there was a large *Phaeocystis* bloom in the bay in 2012 with abundances reaching ten million cells L^{-1} in March and a few million cells L^{-1} in April. The prolonged bloom, however, did not lead to an exceedance of the winter/spring threshold (1.69 million cells L^{-1} vs. threshold value of 2.86 million cells L^{-1}), rather it was the presence of remnants of the bloom in May (one nearfield sample with 36,000 cells L^{-1}) that led to an exceedance of the summer threshold of 357 cells L^{-1} (**Figure 2-20**) This is the 13th year in a row that a *Phaeocystis* bloom was observed in Massachusetts Bay and during four previous blooms (2003-2006) the summer threshold was exceeded (**Figure 2-21**). We have attributed this to cooler springs with cooler surface waters prolonging the viability of *Phaeocystis* till later in the spring. Given the warm temperatures observed this winter/spring, this did not initially appear to be the case for 2012. However, the 2012 *Phaeocystis* bloom fit the "bloom duration vs. day of year 14 °C relationship" quite well (**Figure 2-22**). This functionality suggests that *Phaeocystis* bloom duration is longer in cold years when the 14 °C threshold is reached late in the spring or early summer. The 2012 bloom started relatively early, so its duration appears relatively long given the May 22nd date when 14 °C was first observed at the NDBC Buoy. However, the observation of *Phaeocystis* in only 3 samples during the May 15th survey suggests that the resulting bloom duration estimate of 55 days may be an overestimate,. Ending the bloom at the previous survey moves the 2012 point closer to the linear regression and improves the significance of the relationship. The potentially toxic, threshold *Pseudo-nitzschia* species were again present in low abundances during each season (**Table 2-1**). This has been the case during the 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.

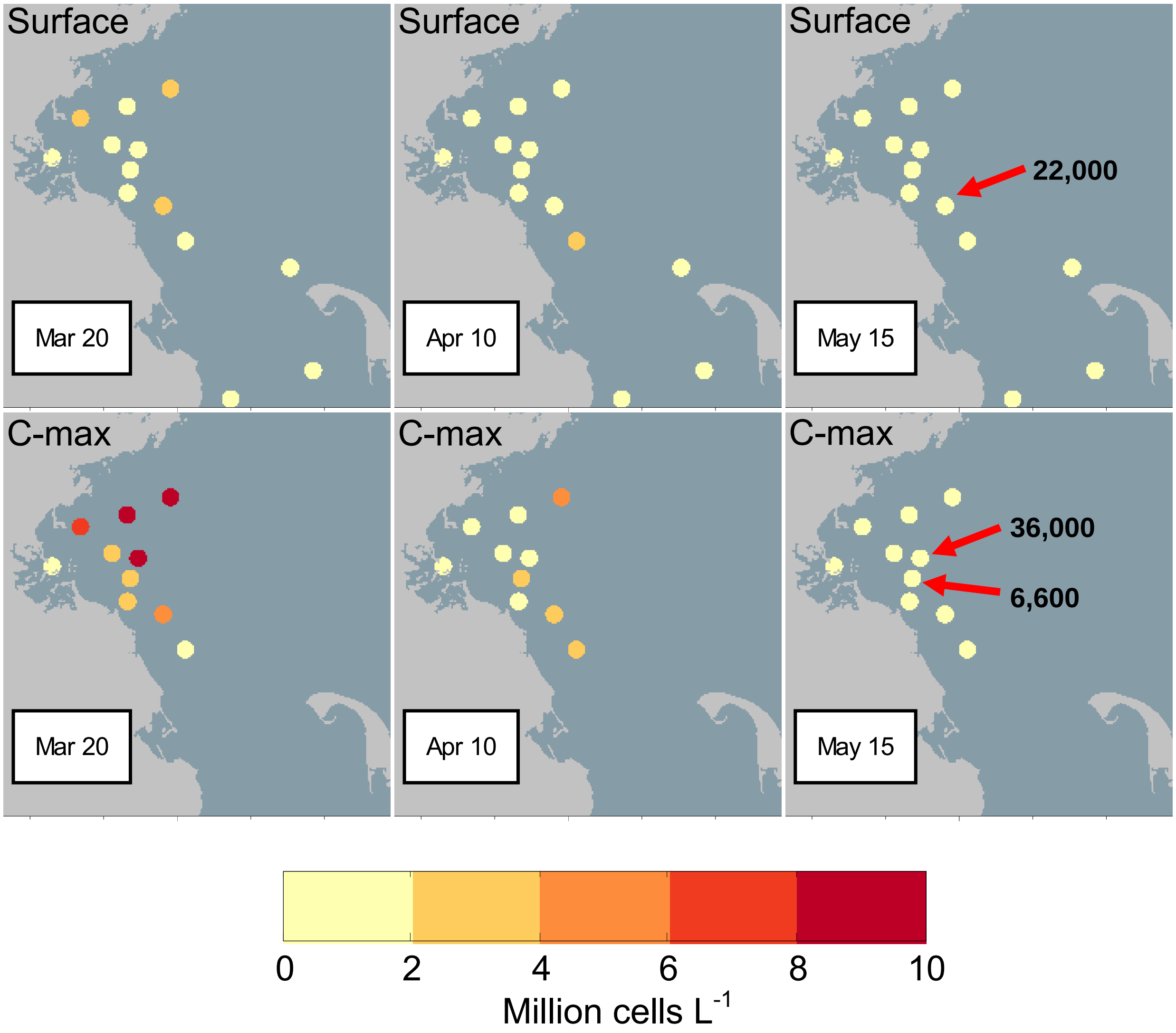

Figure **2-20.** ***Phaeocystis* abundance (million cells L^{-1}) for surface and chlorophyll maximum depths by station in Massachusetts and Cape Cod Bays in March-May 2012.** Only three samples contained Phaeocystis during the May 15 survey as indicated.

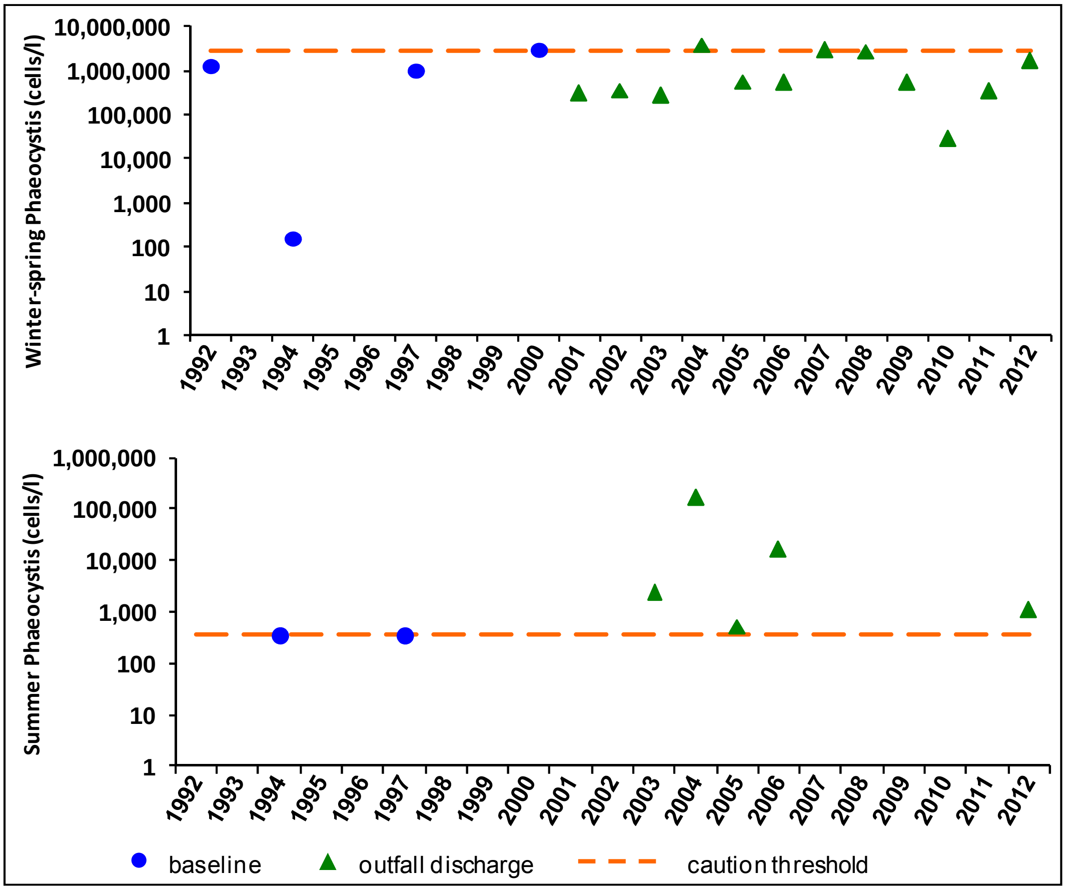

Figure **2-21. Winter/spring and summer seasonal mean nearfield *Phaeocystis* abundance (cells L^{-1}; note log axis) for 1992 to 2012.** Contingency Plan threshold value shown as dashed line.

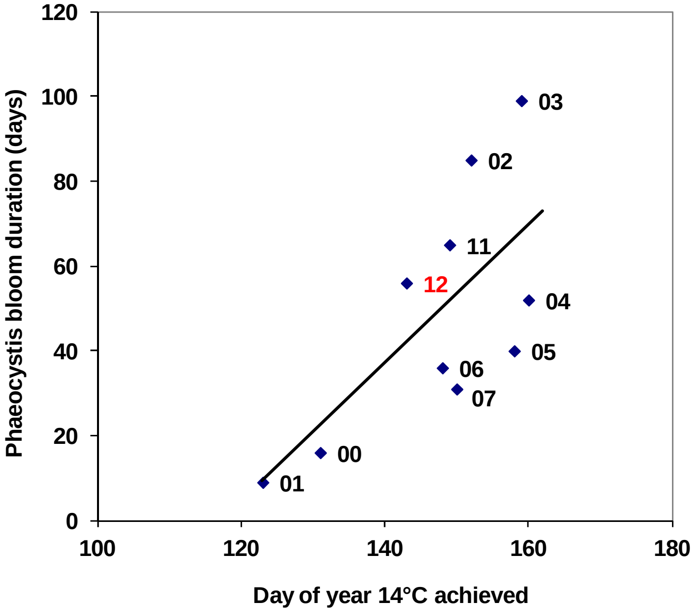

Figure **2-22. *Phaeocystis* bloom duration vs. day of year 14°C reached in surface waters at NDBC Buoy 44013.** (Linear regression $r^2 = 0.47$ and p= 0.0279)

As discussed above, *Alexandrium* abundances reached moderately high levels with a maximum in the nearfield of 3,731 cells L^{-1} (station N10 surface on May 22), well above the 100 cells L^{-1} threshold (**Figure 2-23**). The 2012 *Alexandrium* bloom lasted about a month in Massachusetts Bay and led to shellfishing closures along the western coastline from Salem south to Duxbury, starting on May 25th (Appendix B slide 28). Low cell abundances were present in the bay as early as April.

Elevated concentrations (>100 cells L^{-1}) were observed along coastal New Hampshire and at Isle of Shoals on May 7th (data provided by Candace Dolan at New Hampshire Phytoplankton Monitoring Program[4]). This was coincident with low but measureable PSP toxicity at Isle of Shoals (NH DES, Chris Nash[5]). Offshore counts decreased after May 7th, but abundances at inshore stations remained elevated for most of May. PSP toxicity was not observed by NH DES at its inshore stations, but continued to be measureable at Isle of Shoals and eventually approached the 80 µg/100 mg triggering a shellfish closure along the New Hampshire coast on May 15th.

Researchers from WHOI observed *Alexandrium* cells offshore of Portsmouth, NH, just north and east of the Isle of Shoals from May 3 to May 9, with levels reaching 100-200 cells L^{-1} (Bruce Keafer pers. comm.). These results were reported from analyses made by WHOI's Environmental Sample Processor (ESP; essentially a moored "lab in a can" that collects, processes, and analyzes samples for presence of *Alexandrium* cells[6]). After the ESP's positive identification of *Alexandrium* cells at 200 cells L^{-1} on May 9, the ESP did not report finding any abundance above its ~100 cell L^{-1} detection limit for the rest of May. A WHOI survey in late May observed elevated abundances of *Alexandrium* to the northeast of Casco Bay (Bruce Keafer pers. comm.), but these cells did not appear to make it further south (at least not close to shore) as there were no PSP toxicity closures along the Massachusetts coast north of Cape Ann.

It is likely that the *Alexandrium* cells first observed off of New Hampshire in early May were part of a nearshore water mass that was rapidly transported down the western Maine coast and into Massachusetts Bay. PSP toxicity was first measured at low levels (<60 µg/100 mg) by MA DMF on May 7 at its Ipswich, Essex and Gloucester sites (MADMF 2013). Low PSP levels continued to be measured at these sites through May 14 when comparable PSP toxicity levels were first measured along the south shore sites in Cohasset, Scituate, and Marshfield. On the May 15th MWRA survey, *Alexandrium* abundances had increased to >500 cells L^{-1} in the nearfield and >1,000 cells L^{-1} at stations along the South Shore. On May 21st, MA DMF reported continued low levels of PSP toxicity at the Essex, Gloucester, and South Shore sampling sites. The *Alexandrium* bloom in Massachusetts Bay reached peak abundances during the May 22nd survey with maximum of ~5,200 cells L^{-1} at station F05 off of Scituate (**Figure 2-12**). MA DMF mussel sampling on May 25th resulted in elevated PSP toxicity levels at the South Shore sites and closure of shellfishing from Salem south to Duxbury, while PSP toxicity was no longer detectable at the northern sites near Cape Ann. *Alexandrium* abundances remained elevated in the nearfield and to the south into late May.

In contrast to prior years of high *Alexandrium* abundance (e.g. 2005) when onshore winds drove the offshore *Alexandrium* bloom into Massachusetts Bay (Anderson *et al.* 2005), the 2012 bloom was moderate and relatively short-lived. The strongest northeasterly storm of the season occurred in early June (**Figure 2-10**) resulting in a strong mixing event that greatly reduced water column stratification (**Figure 2-18**). This storm and mixing event occurred just prior to the June 7th survey when *Alexandrium* were found at only 9 of the 23 stations sampled and the highest abundance was 39 cells L^{-1} (Appendix B slide 30). By June 19th, no *Alexandrium* cells were observed in the bay.

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[4] http://nhphyto.blogspot.com/

[5] http://des.nh.gov/organization/divisions/water/wmb/shellfish/index.htm

[6] See http://www.mclanelabs.com/master_page/product-type/samplers/environmental-sample-processor for information

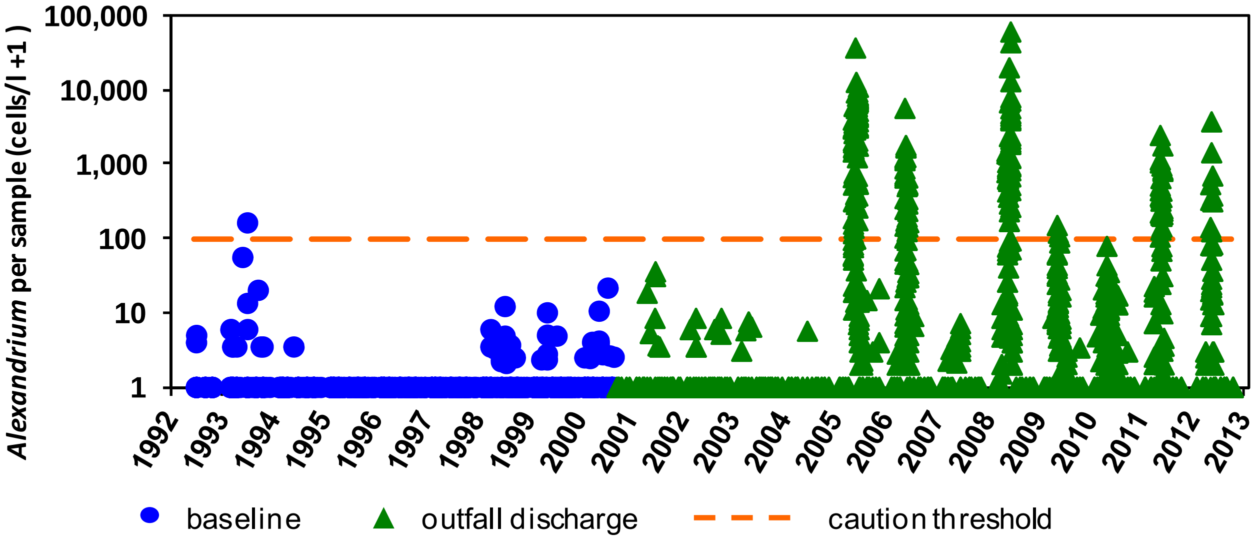

Figure **2-23. Nearfield *Alexandrium* abundance for individual samples (cells L^{-1}; note log axis).** Contingency Plan threshold value shown as dashed line.

The 2012 *Alexandrium* bloom in Massachusetts Bay was primarily an inshore event with high abundances of cells (>1,000 cells L-1) observed during each of the surveys at stations in Boston Harbor, the western nearfield, and along the South Shore. This type of spatial pattern in *Alexandrium* abundance and PSP toxicity was listed as one that could be suggestive of an outfall effect (Libby 2006). This is because toxicity has historically been detected first along the north shore of Massachusetts, and subsequently in a north-south pattern within Massachusetts Bay. Toxicity also tended to decrease from north to south within the bay. In 2012, toxicity was first measured to the north of Cape Ann, but toxicity levels lasted longer and reached higher levels along the South Shore resulting in shellfishing closures from Salem to Duxbury –areas north of Salem never closed.

Unlike previous years when strong northeast winds and associated downwelling were responsible for transporting cells from the Gulf of Maine into the area and then concentrating the cells within near shore waters, in May 2012 meteorological conditions were primarily upwelling favorable (**Figure 2-9**). Overall winds were quite weak and from the south for most of the month (**Figure 2-10**). We believe an early-season population was carried into the Bay (possibly by the Gulf of Maine Coastal Plume – GOMCP; Keafer *et al.* 2005), inoculating the Bay with a small initial population. The lack of strong winds presumably weakened currents within the bay, increasing residence times, and allowing the inoculum of cells to simply grow and move with the currents. Given the weak winds and their upwelling-favorable direction, very few cells were transported along the western Maine coast and into Massachusetts Bay after the early-season pulse shown in **Figure 2-12**. Indeed, north shore stations remained largely toxin free, and none were closed in 2012. On May 15th, when elevated *Alexandrium* abundances were first observed in the bay, the effluent plume as characterized by elevated NH_4 concentrations was observed to the south of the nearfield at station F15 (**Figure 2-11**). This suggests that the general flow was to the south and that these effluent nutrients may have been available to the local phytoplankton community, including *Alexandrium*. During subsequent ARRS surveys, NH_4 concentrations were relatively low in the surface and 10-m waters, but elevated in bottom waters across most of the Massachusetts Bay survey area (**Figure 2-24**).

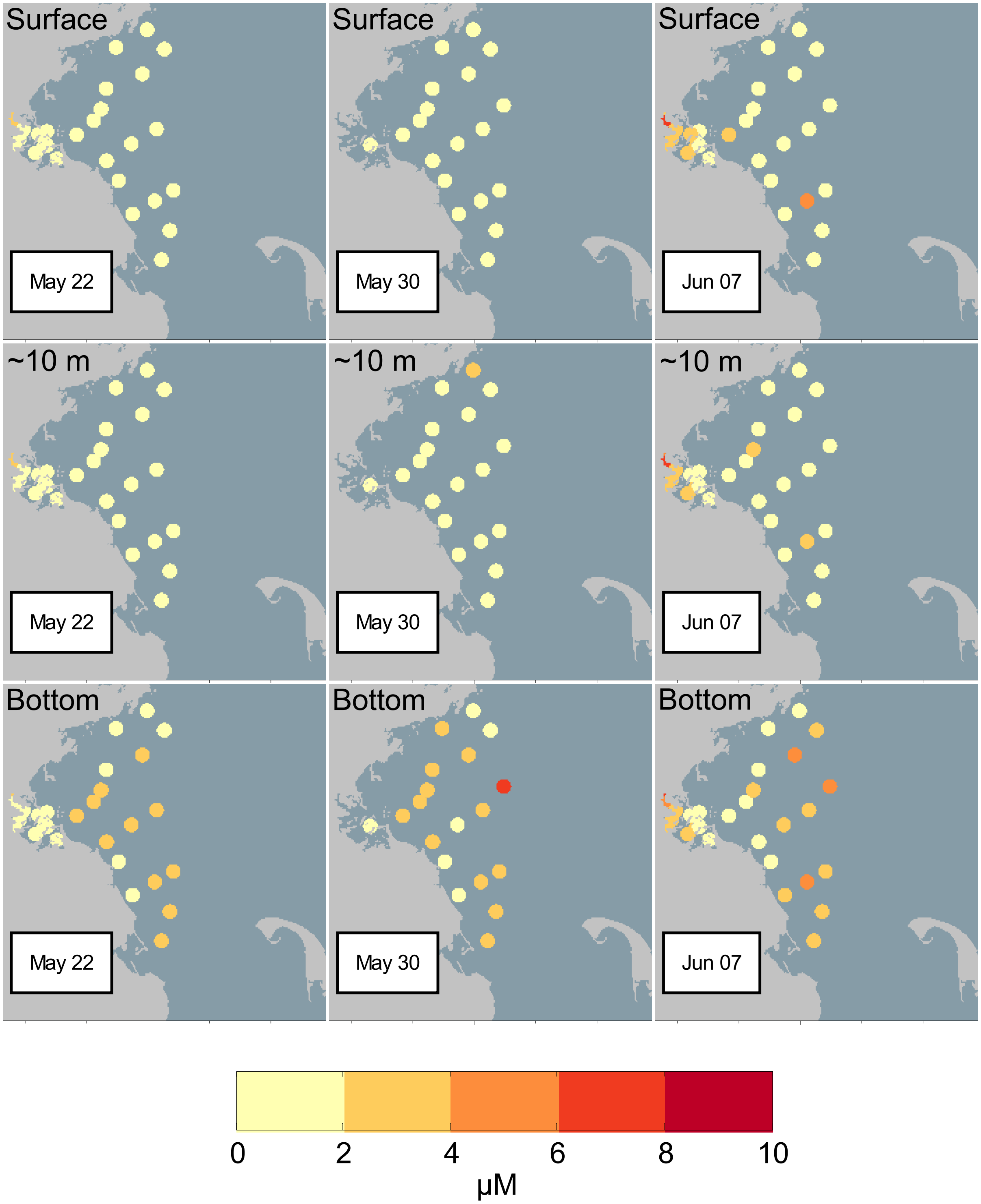

Figure **2-24.** **Ammonium concentrations (µM) at surface, 10 m, and near bottom during the 2012 ARRS surveys.**

Cause-and-effect cannot be attributed based on the monitoring data in hand. The potential effect of the MWRA effluent on the historic 2005 *Alexandrium* bloom was assessed using the measured NH_4 concentrations in Massachusetts Bay within a physical/biological *Alexandrium* population dynamics model of the Gulf of Maine (Stock *et al.* 2005, McGillicuddy *et al.* 2005, Anderson *et al.* 2007). Anderson *et al.* (2007) showed that ambient NH_4 could have caused, at most, an increase of 10-20% in *Alexandrium* levels in the "downstream" area south of the nearfield. A similar modeling effort would be needed to more completely assess the impact or lack thereof of the MWRA effluent on the 2012 *Alexandrium* bloom. Recent model improvements and the development of a new nutrient climatology for the Gulf of Maine (with much better post-outfall coverage of Massachusetts Bay) may allow for a better evaluation of the potential relationship between this nutrient source and local *Alexandrium* blooms.

The WHOI researchers predicted a low to moderate *Alexandrium* bloom for Massachusetts Bay in 2012, based on moderate cyst abundances in coastal sediments in the fall of 2011,[7] which were comparable to those seen in fall 2010, but lower than those measured prior to the major red tides events of 2005 and 2008. The 2012 bloom was in fact moderate, lower than 2005 and 2008 and similar to 2006 and 2011 (**Figure 2-23**). But near real-time model predictions (Ruoying He, North Carolina State University) were not corroborated very well by the MWRA field observations for the 2012 *Alexandrium* bloom (Appendix B slide 31). The model did a good job in capturing the initiation of the bloom, but it missed the high abundances and spatial trends observed in the field data. The best explanation for the poor correspondence between the model and observations is that comparisons at these small scales are unrealistic and beyond what the expectations should be for the model's temporal and spatial resolution. The model has good skill in capturing the general features of the regional bloom (e.g., timing, alongshore and cross-shore extent, etc.), but it is not expected to provide accurate cell abundances at specific locations and times.

2.3 HISTORICAL COMPARISONS

The 2012 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) has demonstrated that the annual cycle for NO_3 and SiO_4 was unaffected by the effluent discharge, which began in late 2000. This can be seen in **Figure 2-25** 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. In contrast, NH_4 and PO_4 concentrations in the nearfield have clearly shown increases since the offshore outfall began discharging. This can be seen in **Figure 2-25** for NH_4 by the spiky lines that show multiple peaks throughout the year (including 2011 and 2012). 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 as seen for both 2011 and 2012.

The low concentrations of NO_3 and SiO_4 observed in February and March 2012 is highlighted when compared to 2011 and previous years. This pattern of low NO_3 and SiO_4 concentrations in early 2012 was observed across the survey area from the shallow Boston Harbor and coastal stations to the offshore stations to the north and south of the nearfield. High survey-to-survey variability is evident for each of the nutrients in 2012 with a series of dips and peaks from April to August. Strong upwelling in May and July may explain those peaks, but upwelling was also strong in August and the data suggest biological utilization was relatively low during that survey so it is unclear why August nutrient levels were so low in 2012. Elevated NH_4 concentrations associated with the effluent plume surfacing in the winter months (February and March 2012) and being confined below the pycnocline under stratified summer conditions (May to July 2012) were

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[7] See http://www.whoi.edu/page.do?pid=83338&tid=3622&cid=96609&c=2 for article

again evident in 2012. August thru October 2012 levels of NH_4 were very low in the nearfield compared to previous years (**Figure 2-25**). Nutrient data at station N18 for 2011 and 2012 was within the range of concentrations observed over the course of the monitoring program.

Although increases in NH_4 and PO_4 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 2012 vs. historic values shows the levels were within the ranges observed during prior years at nearfield station N18 (**Figure 2-26**), but unlike recent years as represented by 2011, the winter/spring and fall blooms were relatively large in comparison to 1992-2011 results. This trend in larger winter/spring and fall blooms was observed across the range of stations sampled (Appendix B slides 16 and 17). 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 quite low in both 2011 and 2012 compared to historic values (**Figure 2-26**). Total phytoplankton as well as the various phytoplankton groups and species present in 2012 were found at relatively high abundances at various times of the year. The winter/spring 2012 total phytoplankton peak was moderate in the nearfield compared to historic data and only about 1 million cells L^{-1} higher than observed in 2011, but it was a historic maximum level for March as most of the larger winter/spring blooms were observed in April (**Figure 2-26**).

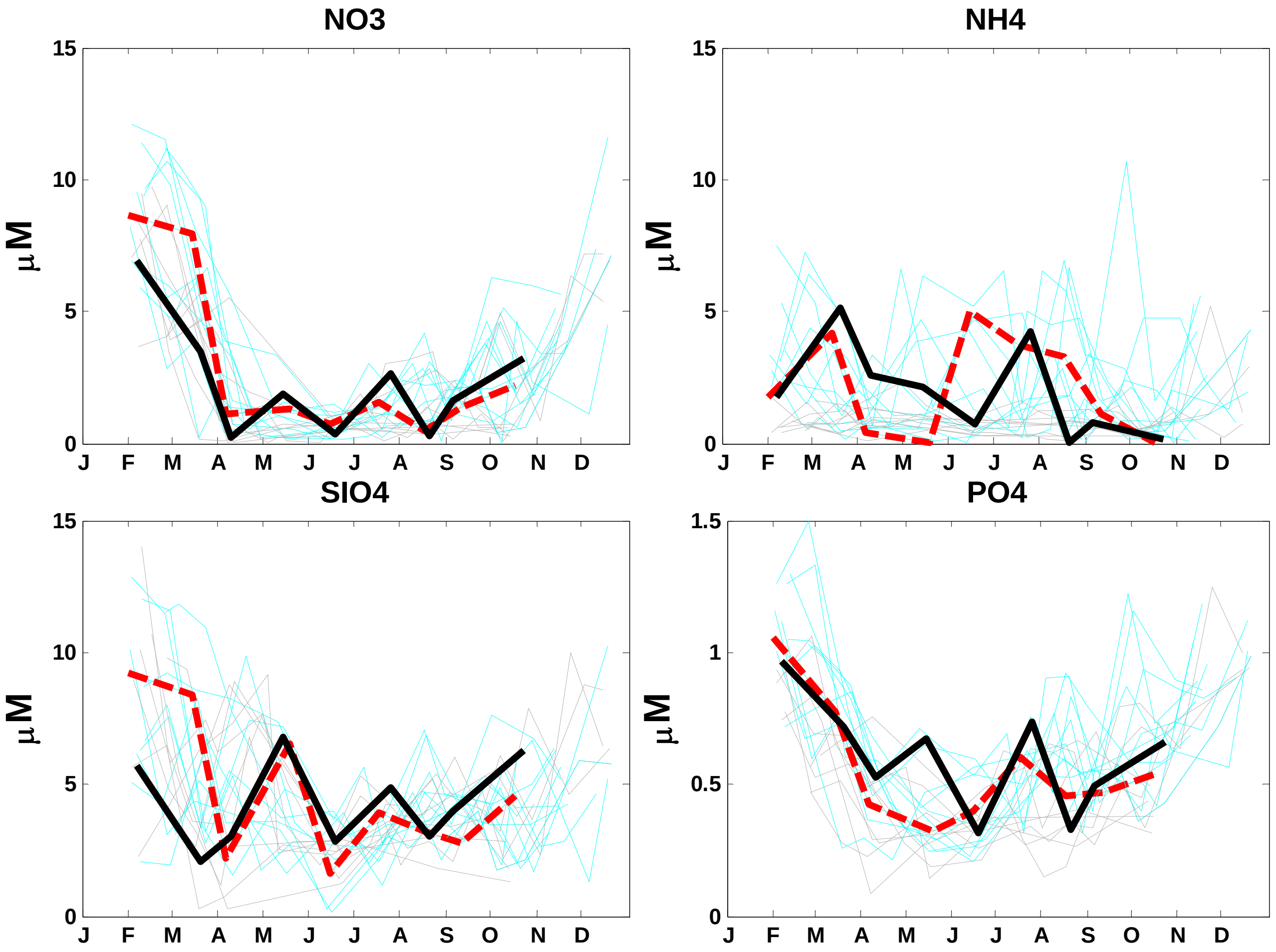

Figure **2-25. Station average nutrient concentrations (µM) near the outfall site (nearfield station N18) for 2011 (red dashed line) and 2012 (black line) compared to the previous 19 years of baseline (1992-August 2000; grey) and post diversion (September 2000-2010; light blue) observations.** Note change in scale for PO_4 plot.

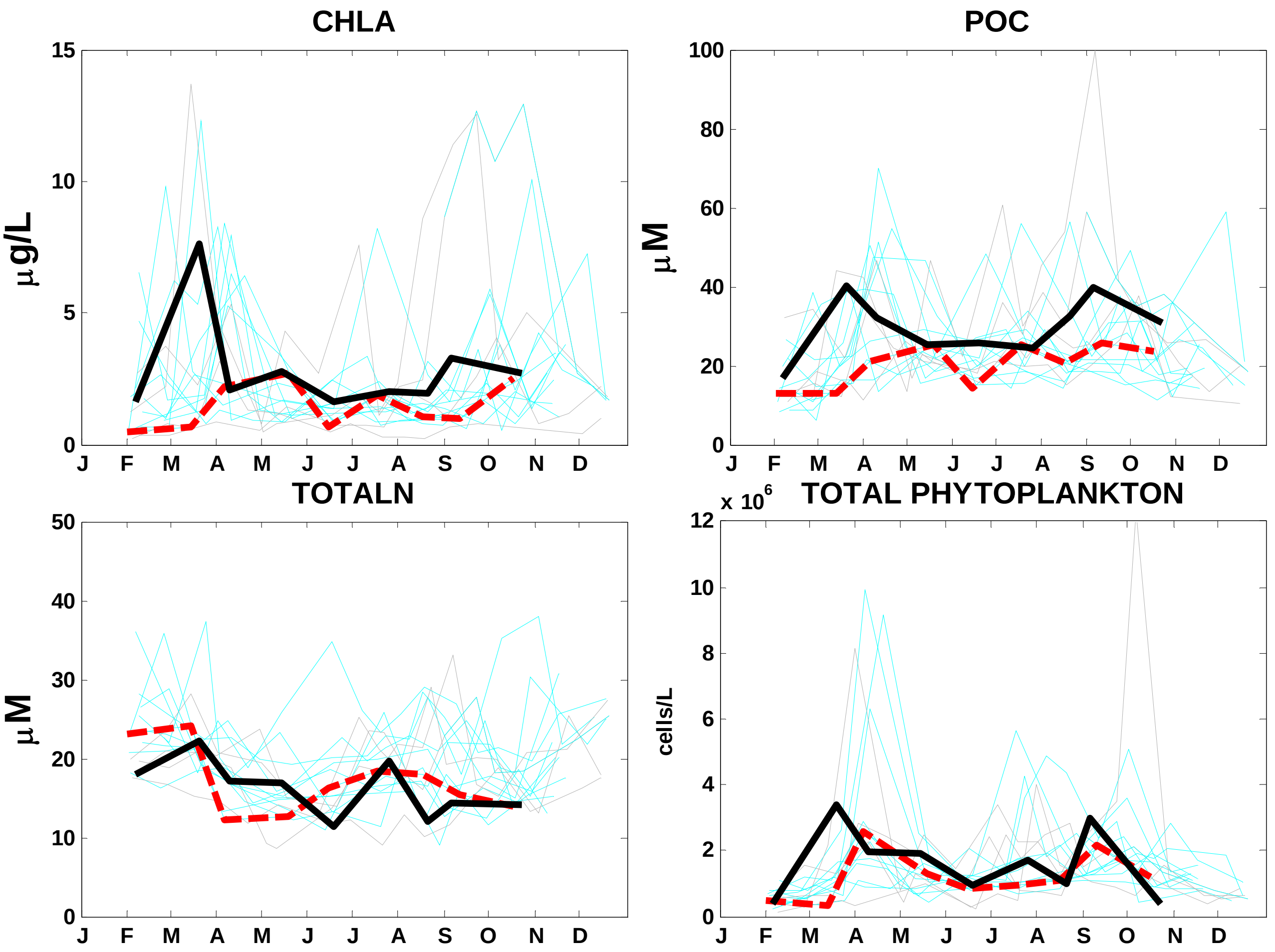

Figure **2-26.** **Station average chlorophyll (µg L^{-1}), POC (µM), total nitrogen (µM), and total phytoplankton (million cells L^{-1}) near the outfall site (nearfield station N18) for 2011 (red dashed line) and 2012 (black line) compared to the previous baseline (1992-August 2000; grey) and post diversion (September 2000-2010; light blue) observations.**

The 2012 abundance of main phytoplankton groups in the nearfield was compared to long-term (1992-2011) levels using a Mann-Whitney test (**Table 2-2**). The annual average of the total phytoplankton abundance in 2012 (1.68 million cells L^{-1}) was not different than the long-term mean level of 1.50 cells million cells L^{-1}. However, analyses of other species and functional groups reveal a pattern of reduced winter/spring and mid-summer diatoms and elevated late summer diatom abundance. *Thalassiosira* spp., commonly a major component of the winter/spring diatom bloom, was present at abundances in 2012 lower than the long-term mean with only about 20% of the average levels. Similarly, *Dactyliosolen fragilissimus*, a centric diatom that is typically most abundant in early to mid-summer and has bloomed during the summer during the last few years was relatively low in 2012 with abundances about <15% of the long-term mean. However, there was a late summer to early fall bloom of *Skeletonema* spp. with abundances two and a half times higher than the long-term mean. Together the reduced winter-spring and elevated late summer diatom abundance pattern resulted in a mean diatom abundance in 2012 (356,875 cells L^{-1}) that was different than the long-term average of 307,132 cells L^{-1}. Annual mean *Phaeocystis pouchetii* abundance in the nearfield in 2012 (455,943 cells L^{-1}) was nearly double the long-term mean level (256,533 cells L^{-1}). In addition, *Phaeocystis* abundance at the sub-surface was elevated relative to the surface in 2012 (**Figure 2-20**). This contributed to

Table 2-2. Comparison of 2012 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	1992-2011	2012	p value	Change?
CENTRIC DIATOM	307,132	356,875	0.2929	
Dactyliosolen fragilissimus	48,873	6,372	0.0347	Decline
Chaetoceros	46,185	28,841	0.1273	
Skeletonema costatum complex	60,510	160,535	0.0001	Increase
Thalassiosira	36,801	6,669	0.0425	Decline
PENNATE DIATOM	48,200	16,902	0.0898	
Pseudonitzschia	11,190	8,245	0.4726	
CRYPTOPHYTES	124,958	67,157	0.0038	Decline
DINOFLAGELLATES	53,371	52,065	0.7959	
Ceratium	1,427	2,848	0.0380	Increase
Phaeocystis pouchetii	256,533	455,943	0.0313	Increase
MICROFLAGELLATES	696,066	720,024	0.5302	
TOTAL PHYTOPLANKTON	1,497,640	1,675,666	0.1275	

the unusual elevated abundance of subsurface phytoplankton relative to surface abundance observed in 2012. *Ceratium* spp. a genus of large dinoflagellates that thrive in the sub-surface pycnocline were elevated in 2012 (2,848 cells L^{-1}) in comparison to the long-term mean of 1,427 cells L^{-1}.
The dominant feature of the 2012 phytoplankton annual cycle was the March-April *Phaeocystis* bloom. Multi-dimensional scaling was used as an exploratory technique to assess the similarity of sampling years in the context of phytoplankton community composition and abundance. Mean annual nearfield averaged abundance of six main phytoplankton functional groups were assessed (centric diatoms, cryptophytes, dinoflagellates, microflagellates, pennate diatoms, and *Phaeocystis pouchetii*) over the 1992-2012 period. A Bray-Curtis similarity index on standardized, non-transformed data was calculated for the phytoplankton data matrix (6 phytoplankton variables by 21 sample years) and a non-metric multidimensional scaling (NMDS) plot was calculated from the similarity matrix using Primer v5.2.9 software. The graphical NMDS representation of a similarity index shows that 2012 was not anomalous with regard to phytoplankton abundance and community composition (**Figure 2-27**). In this graphical representation of monitoring years in multidimensional phytoplankton species/functional group space, proximity of years implies similarity in phytoplankton community composition.

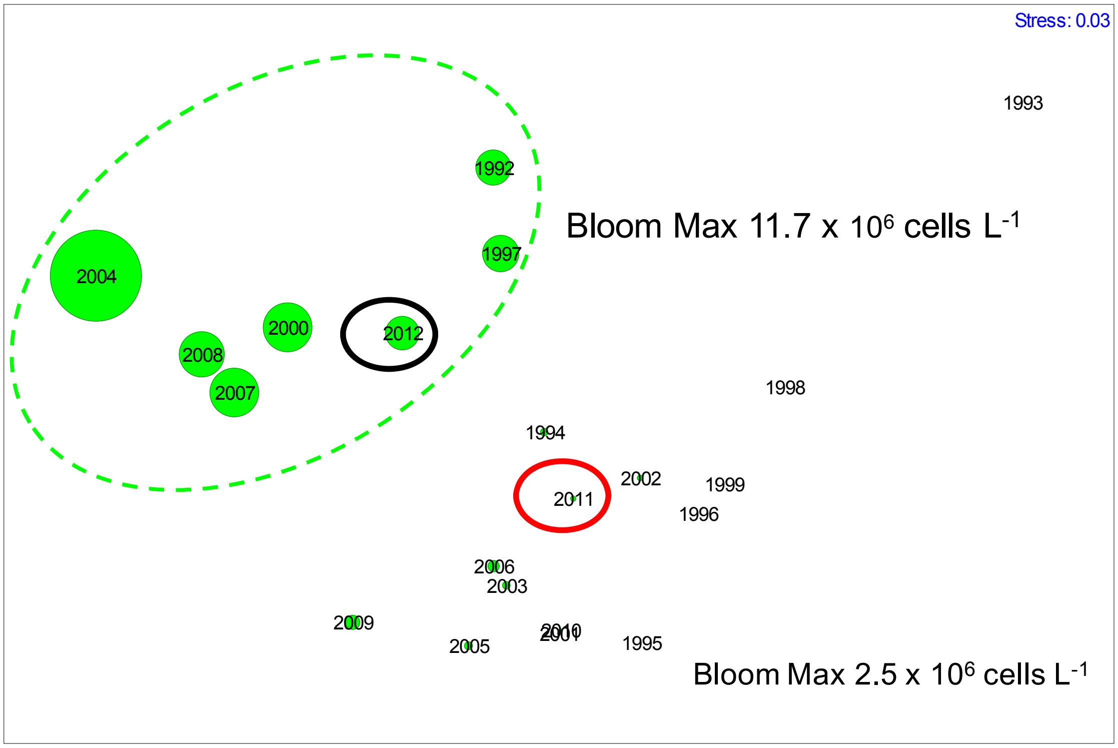

Figure **2-27.** **Non-metric multidimensional scaling plot of 21 years (1992-2012) of MWRA monitoring phytoplankton data in the context of multivariate phytoplankton species space.** Maximum nearfield *Phaeocystis pouchetii* abundance in each year is represented by green bubbles.

To further explore the influence *Phaeocystis* has on the phytoplankton community across years, we coded each of the years by their maximum nearfield *Phaeocystis* abundance (green bubbles in **Figure 2-27**). This effort identifies a group of seven years (1992, 1997, 2000, 2004, 2007, 2008, 2012) that are '*Phaeocystis* years' with maximum bloom concentrations of 2.5 to 11.7 million cells L^{-1}. This contrasts with the other 14 years in which the maximum *Phaeocystis* abundance was <2.5 million cells L^{-1} in the nearfield. It is clear that the presence and abundance of *Phaeocystis* is one of the primary factors in determining the distribution of years in the MDS plot. Further, the analysis indicates a *Phaeocystis* bloom maximum threshold of 2.5 million cell L^{-1} that discriminates between *Phaeocystis* bloom years (*Phaeocystis* abundance of >2.5 million cells L^{-1}) and non-bloom years (<2.5 million cells L^{-1}) based on phytoplankton community composition. Efforts will continue to further differentiate the patterns and determine what other factors play important roles in the development of specific phytoplankton communities each year.

Shifts within the phytoplankton community assemblage associated with long-term, regional trends have been noted previously (Hunt *et al.* 2010). Diatom and *Phaeocystis* abundance tend to vary inversely between years. In 1992-2003, dinoflagellates went through periods of decreasing and increasing abundance sometimes dominated by rarer, but larger species (e.g. C*eratium* spp.) and sometimes by more plentiful, smaller species (e.g. *Heterocapsa rotundatum*, *H. triquetra*, *Gymnodinium* spp., *Prorocentrum micans*). There is no plausible outfall-related link or causality associated with these shifts as they occur over large spatial scales; such long term trends in the phytoplankton community appear instead to be related to regional ecosystem dynamics in the Gulf of Maine.

The 2012 zooplankton abundance and community structure were generally within the envelope of historical ranges and patterns except for slightly elevated numbers during the first two surveys of the year

(**Figure 2-28**). This may be due to the warm, dry conditions in early 2012 combined with a suspected early diatom bloom – providing conditions with both higher metabolism and available food source. Total zooplankton abundance in February and March 2012 was among the highest long-term (1992-2012) levels at the Massachusetts Bay stations including nearfield station N18 and was well above any previous observations at northern offshore station F22 (Appendix D slide 8). The high February zooplankton abundances were driven by high numbers of copepods (primarily *Oithona*), which were above historical maxima in the nearfield in February (**Figure 2-28**). Total zooplankton remained within the historical range for the rest of 2012. There was a peak in both copepod and *Oithona* abundance in June that is relatively early for the annual maxima for both and was well above historical maxima. Again, the earlier timing by about a month or so may be related to the warm, dry conditions in 2012. In 2011, *Calanus finmarchicus* and *Acartia* abundances had high, early peaks in abundance in April and May, respectively (**Figure 2-28**). These 2011 levels were nearly double long-term numbers for those months, and contributed about 20% of total zooplankton abundance during those surveys. In 2012, these two species were essentially absent from the nearfield. The differences observed in these zooplankton species abundances may be directly related to the wet vs. dry years. A similar difference in *C. finmarchicus* was also observed by PCCS in Cape Cod Bay between abundant in spring 2011 and nearly absent in spring 2012 (Appendix E slide 16). Interestingly, PCCS reported high numbers of Right whale sightings for both 2011 and 2012 (Appendix E slides 18 and 20) – perhaps the *C. finmarchicus* were in nearby waters in 2012.

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, which confirms that current levels of zooplankton have been above the long-term mean for the last couple of years (**Figure 2-29**). 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.

The MWRA program is shedding light on a variety of ecosystem interactions. For instance, the overwhelming numerical dominance of *Oithona similis* in the MWRA as well as many other time series raises issues in terms of our understanding of planktonic food webs in coastal waters. The classical paradigm of feeding interactions in lower trophic levels of pelagic food webs has been that of copepods and other zooplankters grazing upon phytoplankton, and in turn being eaten by larger consumers such as larval fish. This paradigm is complicated by the fact that *O. similis* is primarily a microzooplankton predator, feeding mainly upon protozoans such as ciliates and heterotrophic dinoflagellates, rather than grazing upon phytoplankton (Nakamura and Turner 1997; Lonsdale *et al*. 2000; Castellani *et al*. 2005). Thus, the overwhelming numerical dominance of *O. similis* in Massachusetts Bay (Turner *et al*. 2011), as well as globally (Gallienne and Robins 2001), in waters as diverse as the Antarctic (Lonsdale *et al*. 2000) and the northeastern North Atlantic (Castellani *et al*. 2005), fundamentally challenges the classical paradigm of how pelagic marine food webs function. Linkages from the most abundant phytoplankton (namely "microflagellates") to the zooplankton appear to be primarily through protozoans, and not directly through copepods in most areas of the sea. These protozoans are then consumed by copepods such as *O. similis* (Turner 2004), which in turn are consumed by fish larvae (Lough and Mountain 1996).

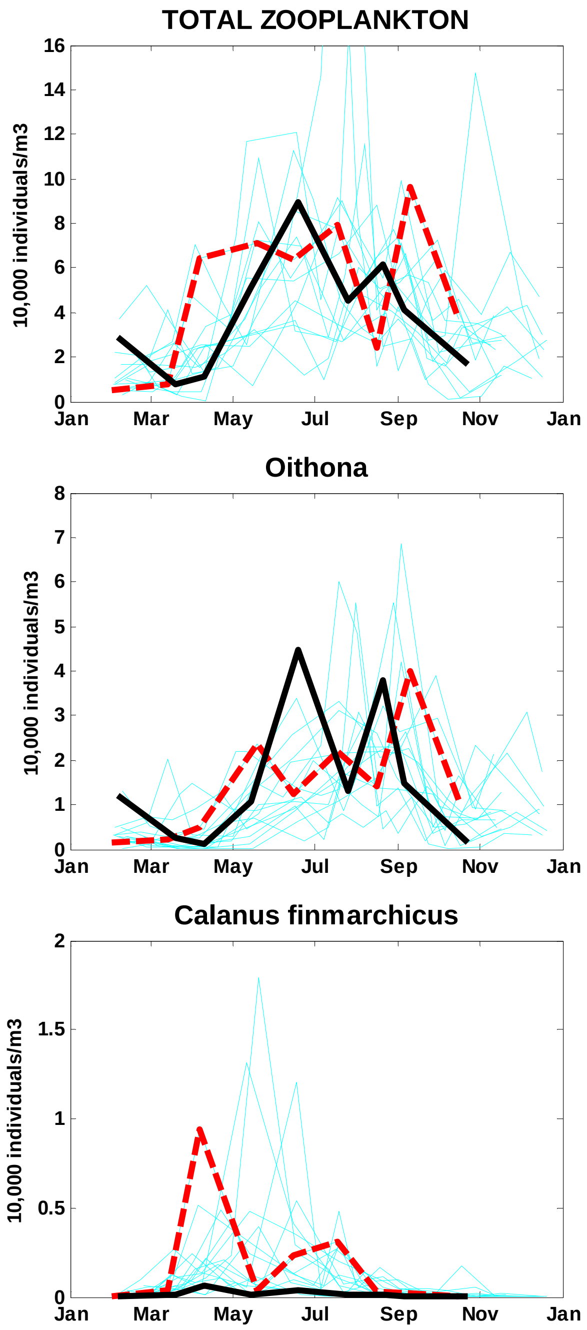

Figure **2-28.** **Abundance (10,000 individuals m^{-3}) of total zooplankton, copepods, *Oithona*, *Pseudocalanus*, *Calanus finmarchicus*, and *Acartia* near the outfall site (station N18) for 2011 (red dashed line) and 2012 (black line) compared to the previous 19 years of observations (1992-2010; light blue).** Note change in scale for each row of plots.

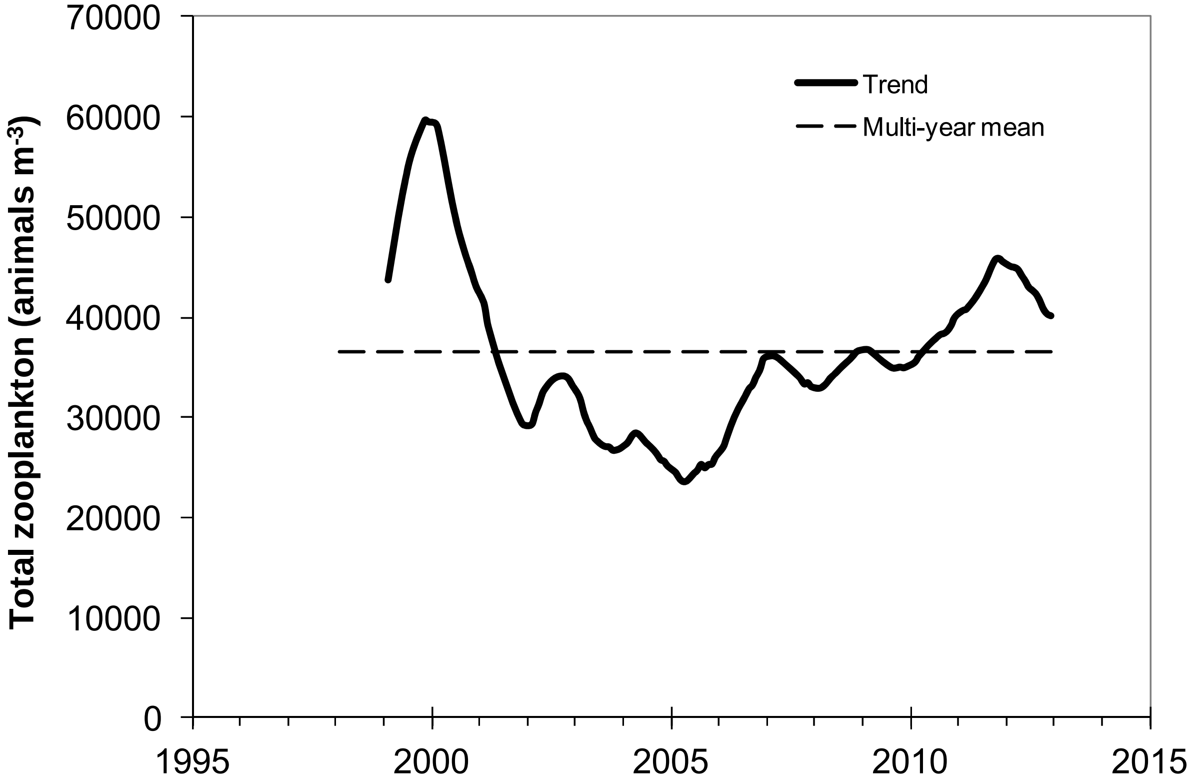

Figure **2-29. Long-term trend (1998 - 2012) in total zooplankton abundance derived from time series analysis.** Long-term mean levels are also shown (dashed line). Data from stations N04 and N18, only.

3 SUMMARY

2012 was the second year of sampling following MWRA's latest revision of its effluent outfall ambient monitoring plan (MWRA 2010). Fourteen stations in Massachusetts and Cape Cod Bays were sampled nine times. The sampling design changes do not appear to have affected our ability to observe the typical seasonal trends seen for a wide variety of parameters nor appreciably decrease our capability to understand potential impacts to the Massachusetts Bay ecosystem. 2011 and 2012 were very different years characterized by wet and cool conditions in 2011 and warm and dry conditions in 2012 yet the observations continued to be consistent with historical data and typical seasonal events. We were able to detect differences in the timing of blooms and changes in conditions were apparent within and between the two bays. The monitoring delineated inshore-to-offshore gradients across Massachusetts Bay for temperature, salinity, DO, chlorophyll, and various nutrients and detected differences between years for these parameters. The phytoplankton blooms and zooplankton species showed clear inshore-to-offshore gradients and long-term changes in various species or groups – even though the typical seasonal sequence of water quality events continued to be observed as it has been over the entire 1992-2012 monitoring program.

The most notable characteristic of the physical environment was that 2012 was an unusually warm winter/spring and relatively dry year, which was in contrast to wetter conditions in 2011. This warm anomaly was observed over a very large region of the northwest Atlantic, extending to the Arctic and as far south as Cape Hatteras. For 2012, the annual average flows in the Merrimack and Charles Rivers were the 2nd and 3rd lowest measured since 1992, respectively. There were no major storm events in the winter/spring nor did the rivers show a substantial spring freshet. The only storms of note occurred in late October and early November with the one-two punch of Hurricane Sandy and a subsequent northeasterly storm that led to the fall overturn of the water column ending a prolonged period of stratification. These physical forcing events, or lack thereof, contributed to the trends and events observed in other water quality and biological data.

The warm conditions seemed to have shifted the biological seasonal cycle forward by about a month. Although we did not observe a winter diatom bloom, the nutrient data and buoy chlorophyll readings suggest that one may have occurred between the February and March surveys. The *Phaeocystis* bloom peaked in March rather than the typical peak observed in April. Zooplankton – primarily copepods (dominated by *Oithona*) – were near or above the monthly maxima in February and March compared to historical levels. Remnants of the *Phaeocystis* bloom remained in the bay into May and observations for one nearfield sample in May (36,000 cells L^{-1}) resulted in an exceedance of the summer *Phaeocystis* threshold. This exceedance had no ecological impact and was merely the result of a few remaining *Phaeocystis* colonies still present in the bay in May

Alexandrium cells appear to have been introduced into the bay by an early season pulse of water from the north - possibly the Gulf of Maine Coastal Plume described by Keafer *et al*. (2005). Once within the bay, the weak winds led to increased residence times that gave the introduced cells the opportunity to grow and cause toxicity levels to rise above closure thresholds. The lack of northeaster storms in late April and May did not prevent *Alexandrium* from reaching moderate bloom abundances, but a strong northeaster in early June was coincident with the end of the bloom. The May bloom of *Alexandrium* exceeded the 100 cell L^{-1} threshold and a series of three weekly ARRS surveys were conducted. The 2012 red tide peaked during the first ARRS survey on May 22nd with maximum cell abundances above 5,000 cells L^{-1} offshore of Scituate and PSP toxicity shellfishing closures were in place by May 25 from Salem to Duxbury Bay. By early June, the bloom had ended in Massachusetts Bay. The 2012 bloom was unusual in that the highest abundances of cells were observed in Boston Harbor, the western portions of the nearfield, and along the Boston south shore, while counts in northern Massachusetts Bay were consistently much lower. Also, while the bloom caused PSP toxicity and closed beds from Salem to Duxbury, there were no closures on the north shore. When MWRA discussed the bloom and the Contingency Plan threshold exceedance with regulators and OMSAP at its April 1, 2013 meeting, Panel members requested MWRA review the available data further to address whether effluent nutrients might have contributed to the unusual spatial pattern of the bloom. As noted previously, 2012 was a dry year, with lower river discharges during the spring than occurs most years. Coupled with the weak and upwelling favorable winds experienced around the time of the *Alexandrium* bloom, this may have slowed circulation and increased residence times of the early season pulse of cells within Massachusetts Bay, allowing time for the small population of cells to grow to bloom levels. These weak winds also prevented transport south of elevated cell abundances seen off the coast of Maine in late May. Unfortunately, the available data do not allow conclusions to be drawn as to the causes of this unusual bloom. It is important to note that even for an organism like *Alexandrium*, which has been extensively studied for decades because of its impacts on the shellfish industry; gaps remain in our understanding of all the factors involved in a bloom. Modeling studies have been suggested as one means of more closely examining the spatial patterns of *Alexandrium* and PSP toxicity during the unusual 2012 bloom.

The bottom waters were warmer than usual when stratification was established and if not for the major mixing event in early June bottom water DO levels may have been much lower as were predicted by the DO regression model based on September/October temperatures and salinity. As it was, the lack of any major storms until late October resulted in some of the lowest bottom water DO levels observed during the monitoring program both in the nearfield and in Stellwagen Basin (6.19 and 6.6 mg L^{-1}, respectively) though they remained well above regulatory thresholds and any levels suspected of causing ecological impacts. The arrival of Hurricane Sandy in late October and a subsequent major northeaster storm mixed the water column and alleviated the low DO conditions as was observed with sharply increasing concentrations at the NERACOOS Buoy A01. These NERACOOS time series data continue to demonstrate that variations in near-bottom DO at the outfall site closely track those observed at 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.

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. Dinoflagellate abundance has also varied: in some years (like 2012) 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*).

The zooplankton community assemblage in the bays is consistently dominated throughout the year by copepod nauplii, *Oithona similis*, and *Pseudocalanus* spp. Subdominant are other copepods such as *Calanus finmarchicus*, *Paracalanus parvus*, *Centropages typicus* and *C. hamatus*. There are also irregular pulses of various meroplankters such as bivalve and gastropod veligers, barnacle nauplii, and polychaete larvae (Libby *et al.* 2007). Seasonal patterns in zooplankton abundance from 1992-2012 generally correlate with temperature, low in winter, rising through spring to maximum in summer, declining in the fall. To highlight this correlation with temperature one needs to look no further than the winter of 2012 when the presence of much warmer water temperatures was coincident with monthly maxima of copepods (specifically *Oithona*) in February that were at or above historic maxima.

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. MWRA's long-term monitoring data are considered one of the most comprehensive datasets on the coastal ocean in existence. Collecting consistent data in the same way in the same locations for 20+ years is allowing new insights into the structure and functioning of marine ecosystems. For example, the overwhelming numerical dominance of *Oithona similis* in the MWRA as well as many other time series raises issues in terms of our understanding of planktonic food webs in coastal waters. The classical paradigm of feeding interactions in lower trophic levels of pelagic food webs has been that of copepods and other zooplankters grazing upon phytoplankton, and in turn being eaten by larger consumers such as larval fish. This paradigm is complicated by the fact that *O. similis* is primarily a microzooplankton predator, feeding mainly upon protozoans such as ciliates and heterotrophic dinoflagellates, rather than grazing upon phytoplankton. Thus, the overwhelming numerical dominance of *O. similis* in Massachusetts Bay (Turner *et al*. 2011), as well as globally (Gallienne and Robins 2001), fundamentally challenges the classical paradigm of how pelagic marine food webs function.

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, Libby *et al.* 2009). Ammonium dramatically decreased in Boston Harbor and nearby coastal waters and has remained low through 2012. The initial increase in nearfield annual mean NH_4 (~1 µM) was much smaller than the decrease in the harbor (~8 µM) due to dilution and transport at the bay outfall (Libby *et al.* 2011b). The NH_4 signature of the effluent plume continues to be detected within 10-20 km of the outfall (see **Figure 2-11** 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, the revised monitoring plan design first implemented in 2011 has been able to adequately describe the seasonal and spatial trends observed for a wide variety of water quality parameters during two years with very different meteorological forcing, thus retaining our capability to understand potential outfall- driven impacts to the Massachusetts Bay ecosystem.

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Physical Processes Influencing Massachusetts Bay, 2012

Rocky Geyer

Overview

The notable conditions in 2012 were 1) drier than normal conditions through the year; 2) an unusually warm winter that produced warmer than usual water temperatures at the time of spring stratification; 3) a major mixing event in June that may have kept dissolved oxygen from getting even lower; and 4) Hurricane Sandy and a strong fall northeasterly resulted in the fall destratification in early November.

Forcing variables

Air temperature (slide 4) was unusually warm from January to March. The rest of the year was normal.

River flow (slide 5) was lower than average for both the Merrimack and Charles throughout the year. Neither river showed a significant spring freshet. The annual average flow (slide 7) in the Merrimack was the 2nd lowest of the monitoring period, and the Charles was the 3rd lowest.

Winds showed strong upwelling in May, July, August and September. This would be expected to result in cooler bottom water temperatures, but the warm winter lead to unusually warm initial bottom water temperatures, so the upwelling effect did not overcome that initial warming. A strong Northeasterly around June 5 (slide 11) provided significant mixing, as did Hurricane Sandy (slides 14 and 15) and a northeasterly around November 7.

Water properties

Surface water temperature (slide 10) was 2 degrees warmer than previously observed in March, due to the warm winter. *Bottom water temperature* was similarly elevated through April. The major June mixing event again brought bottom temperatures to record highs. Persistent upwelling for the rest of the summer kept the temperature from continuing to increase, and it got back into the normal range by August and September.

Salinity (slide 16) started out normal, but it did not exhibit the normal drop due to spring input of fresh water because of the low river discharge conditions. By May, record surface and bottom salinities were observed, and high salinity conditions persisted through the last observations in October.

Stratification (slide 17) showed a big drop due to the strong June mixing event. It rebounded and showed a relatively high value in late October, probably because the fall mixing had not occurred by the time of that survey.

Dissolved oxygen (slide 18) was lower than normal in the winter, and the May observations showed by far the lowest bottom DO values for that time period over the monitoring program. The DO came back up in late May, possibly because of upwelling-favorable winds. The mixing event in June also may have helped keep the DO values from dropping during that period. For the rest of the summer and fall the bottom DO dropped at its normal rate, but because it started relatively low and it was not mixed in late October, it reached an unusually low value of 6.2 mg/l (3rd lowest of the monitoring period).

The DO regression model predicted even lower DO than was observed (slide 19), due to warmer than normal bottom temperatures and higher than normal bottom salinity. The fact that the DO was not as low as the model prediction may be related in part to the persistent upwelling during much of the stratified months.

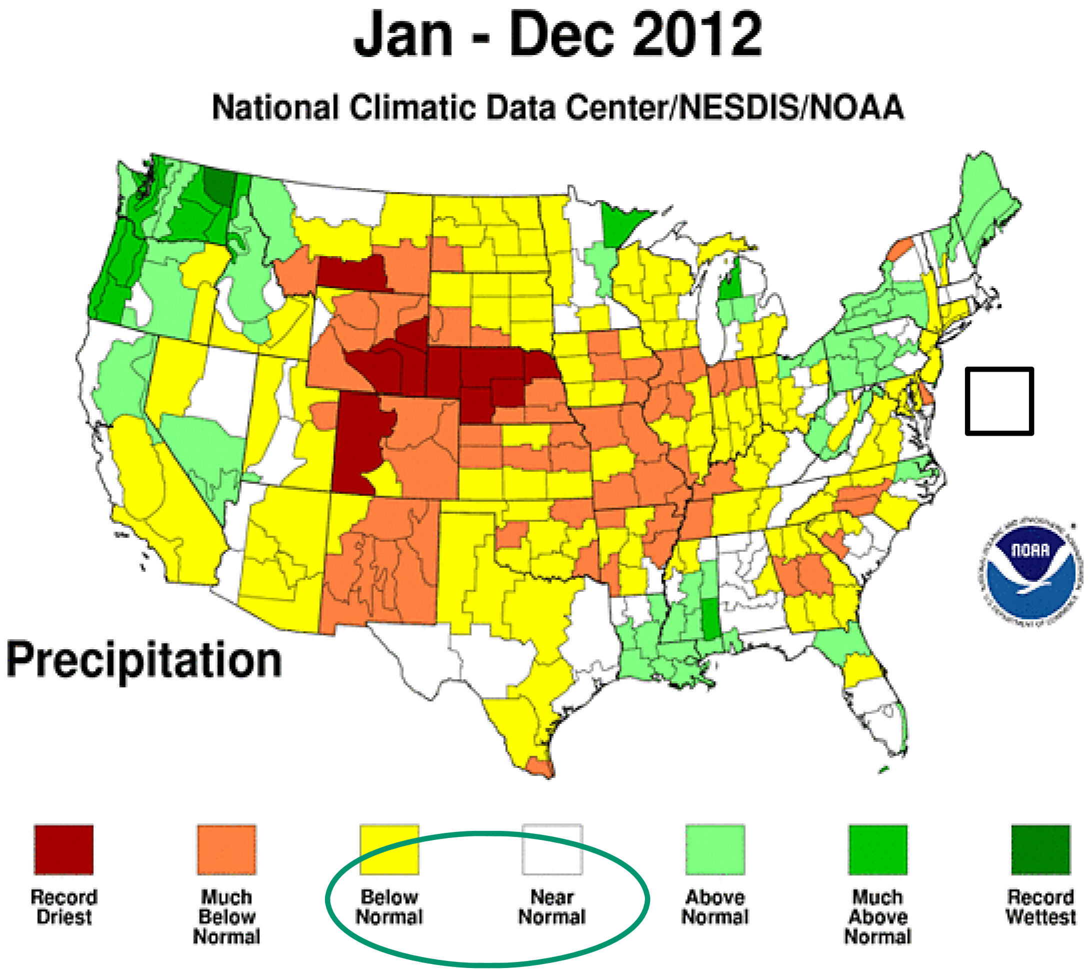
The timeseries data from the NERACOOS A buoy (slide 20) again demonstrate that the variations in DO at the outfall closely track the variations of the near-bottom DO at the outfall site. This indicates that advective processes are very important in determining the interannual variations of DO, and also that interannual variations of DO at the outfall site are more regional than local.

Massachusetts Bay Physics 2012

Rocky Geyer

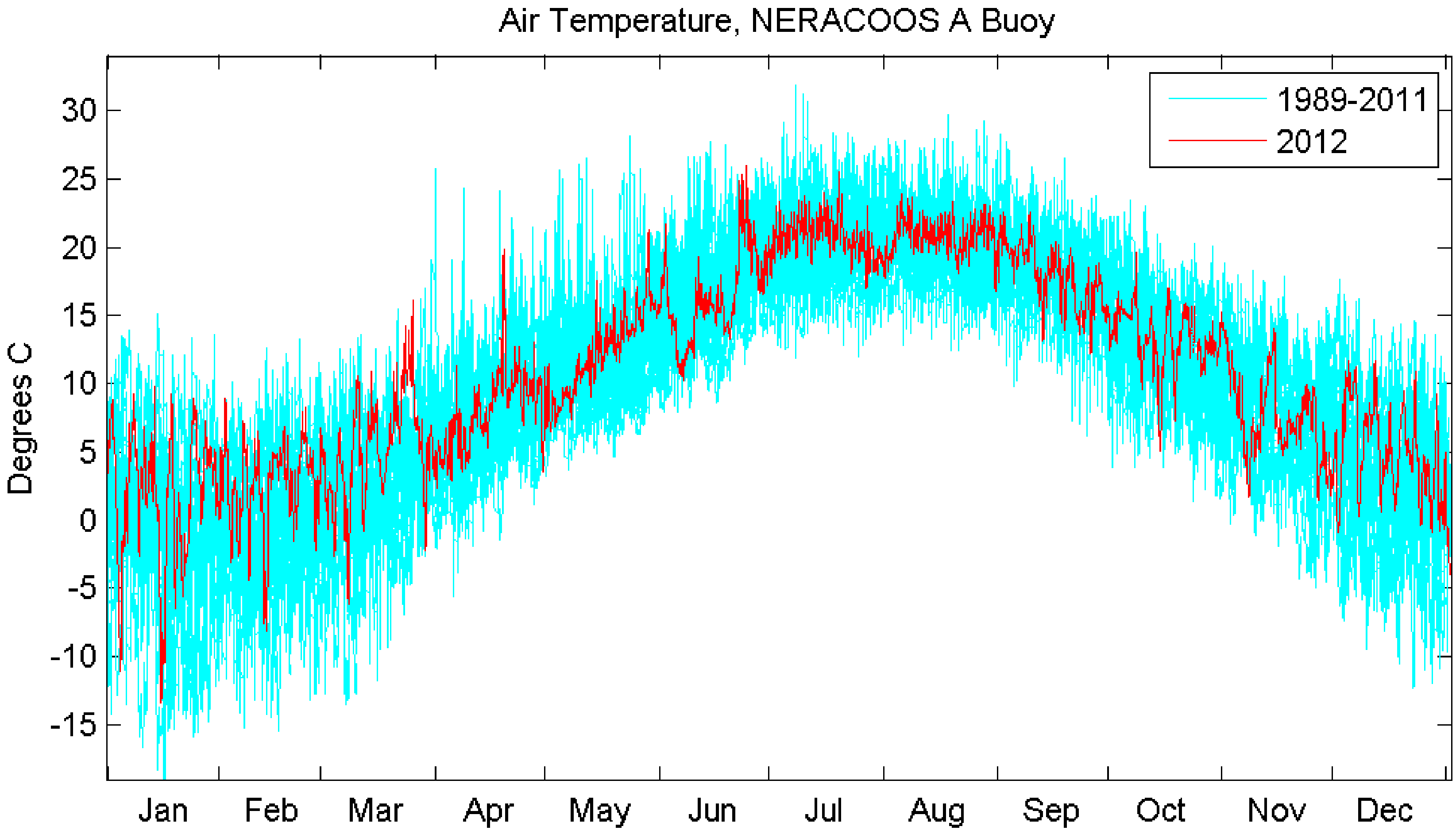
Woods Hole Oceanographic Institution

2012: A dry year in the Northeast

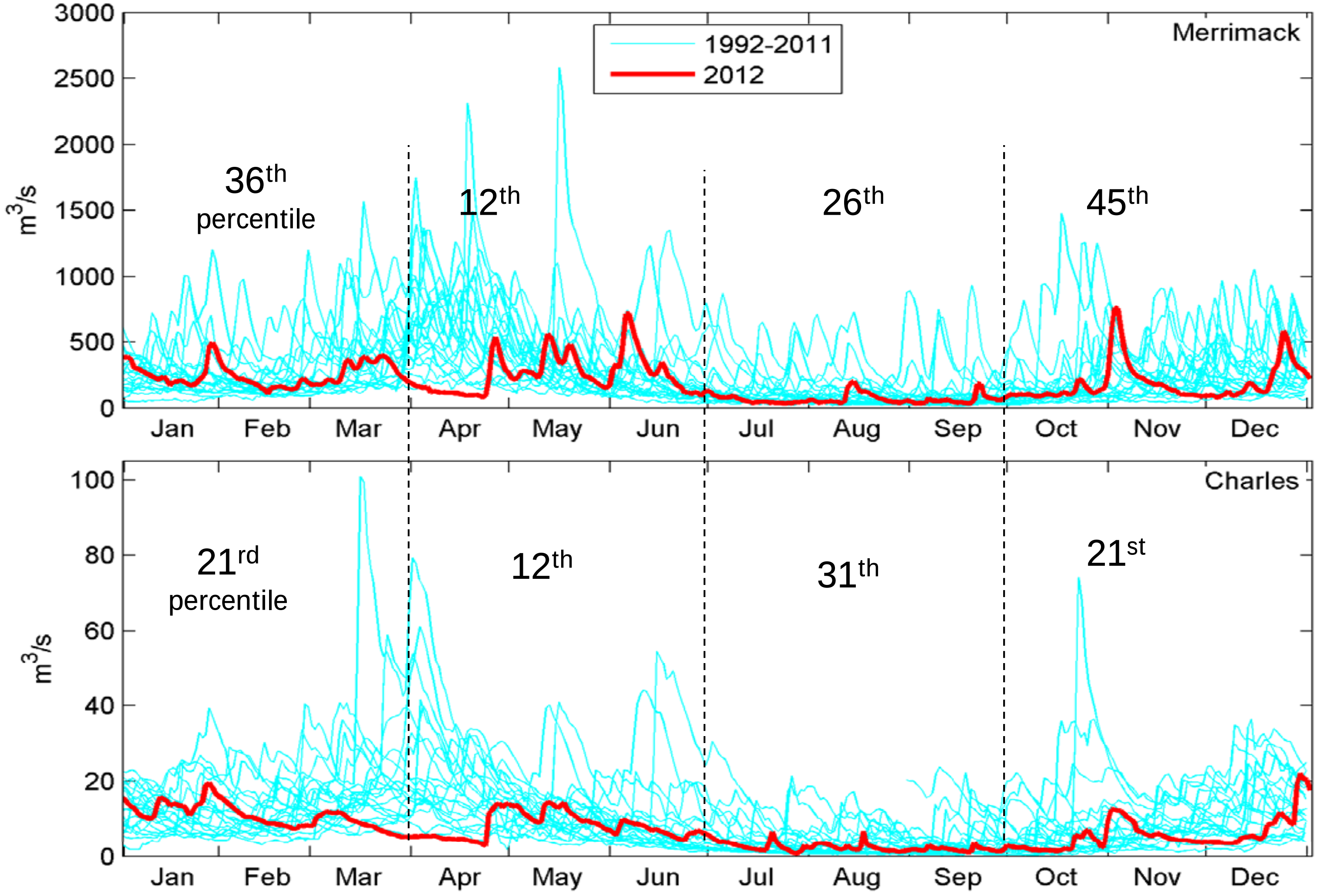


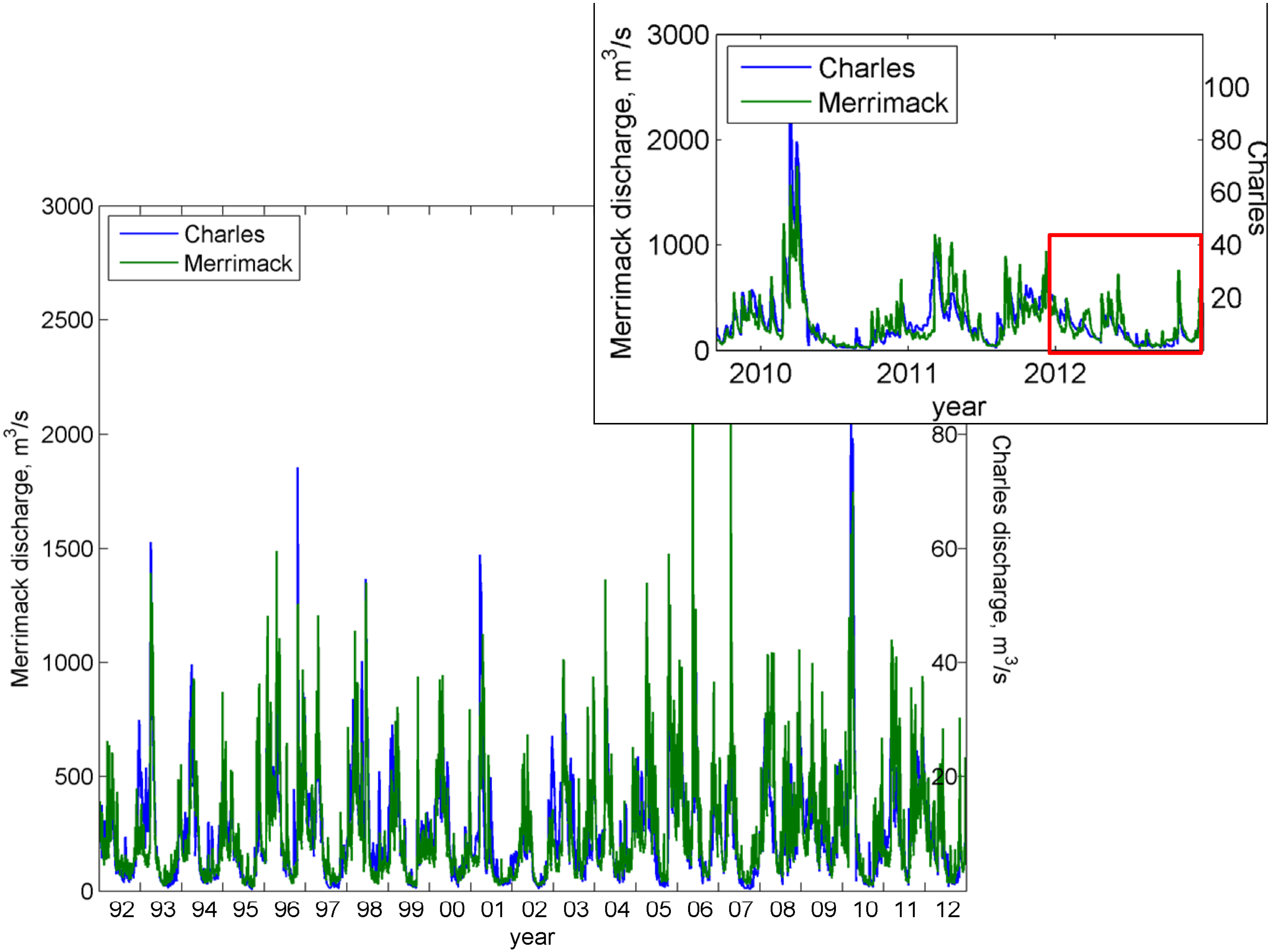
http://www.ncdc.noaa.gov/sotc/service/national/Divisionalprank/201201-201212.gif

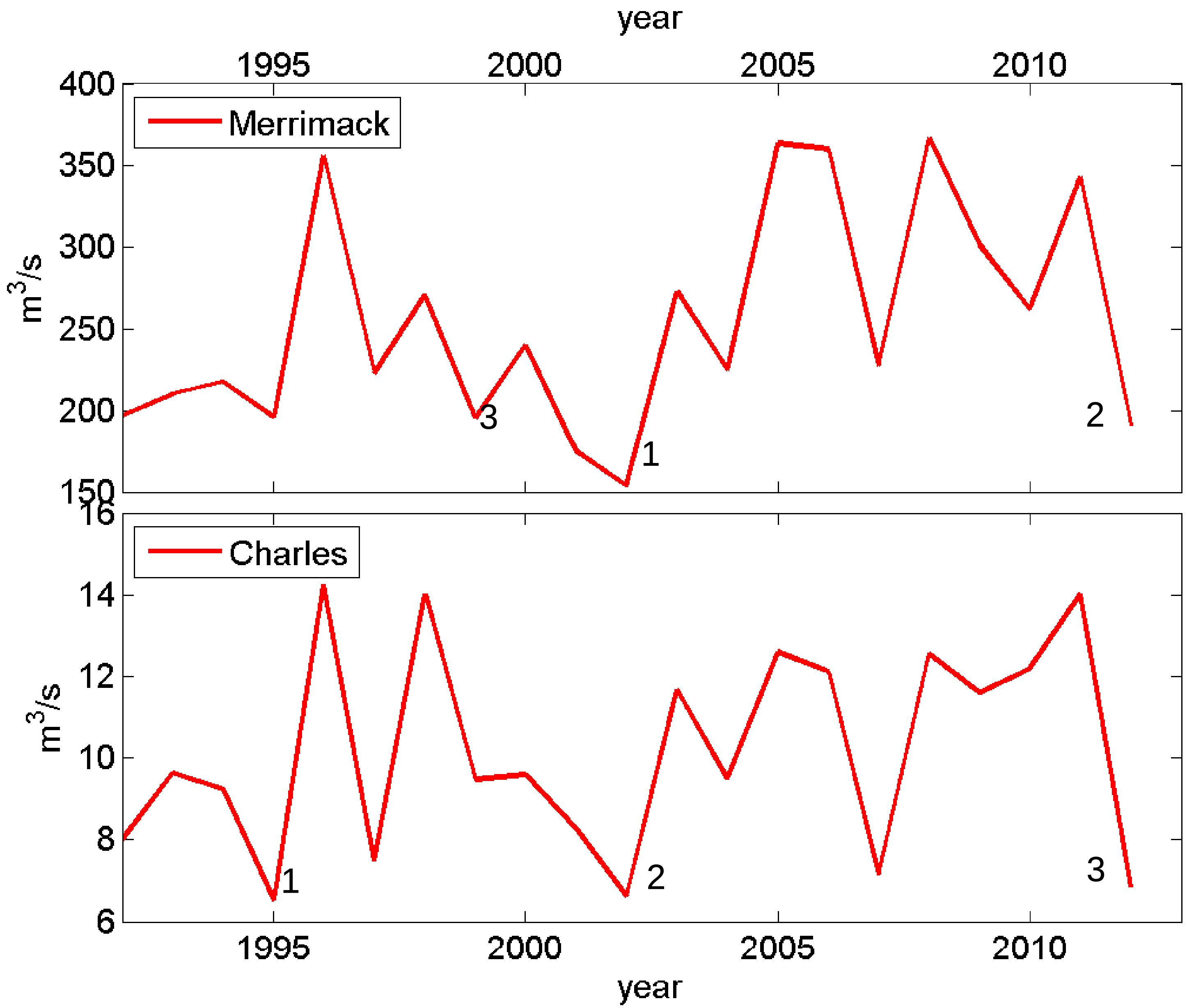
forcing conditions


Air Temperature, NERACOOS A Buoy
1989-2011
2012
Degrees C
30
25
20
15
10
5
0
-5
-10
-15
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

River Discharge, 2012

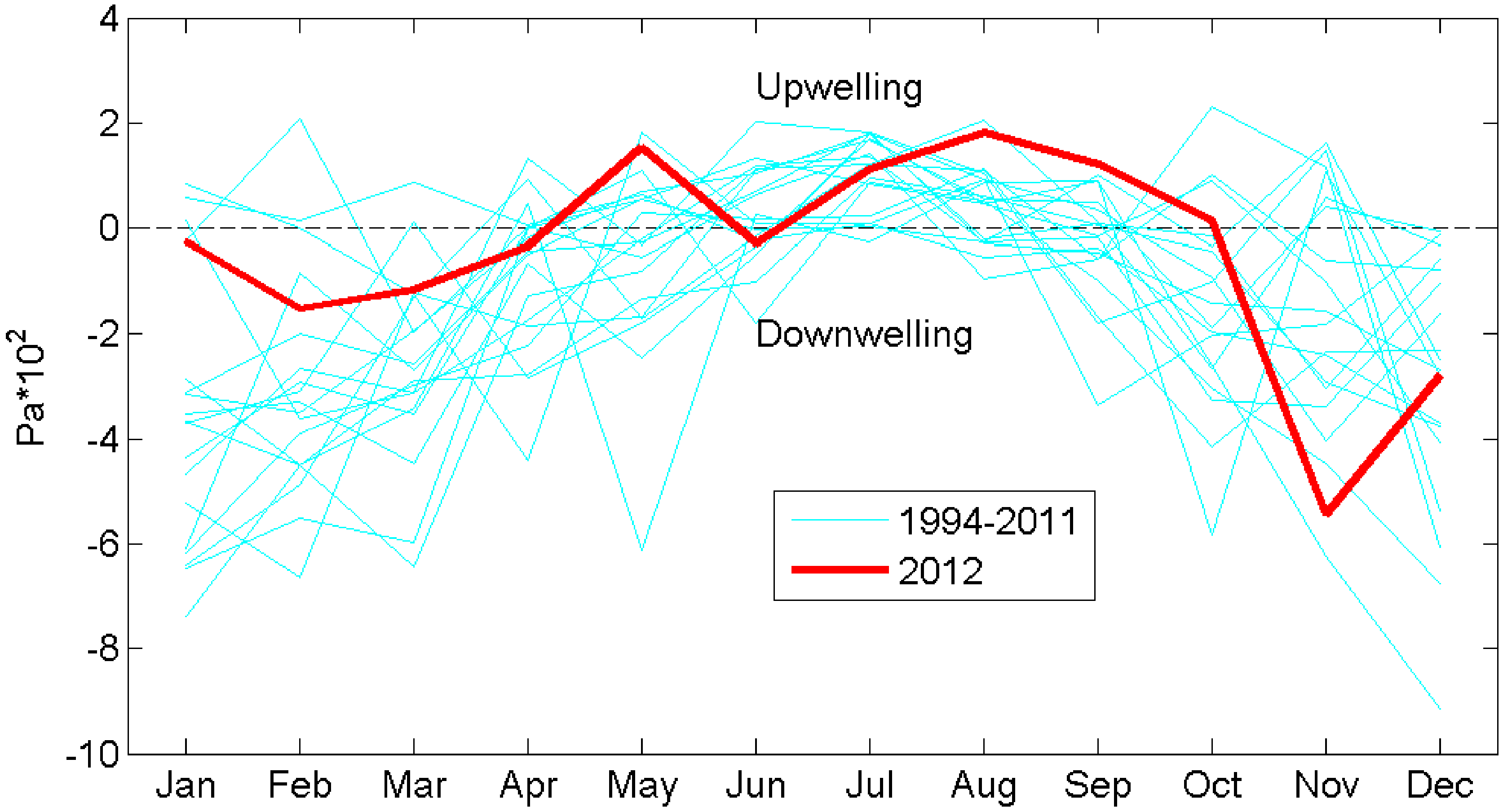



Charles
Merrimack
Merrimack discharge, m^3/s
Charles discharge, m^3/s
3000
2500
2000
1500
1000
500
0
80
60
40
20
92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12
year
Charles
Merrimack
Merrimack discharge, m^3/s
3000
2000
1000
0
100
80
60
40
20
Charles
2010
2011
2012
year


year
1995
2000
2005
2010
400
350
300
250
200
150
m^3/s
Merrimack
3
1
2
16
14
12
10
8
6
m^3/s
Charles
1
2
3
1995
2000
2005
2010
year

Upwelling index, 2012

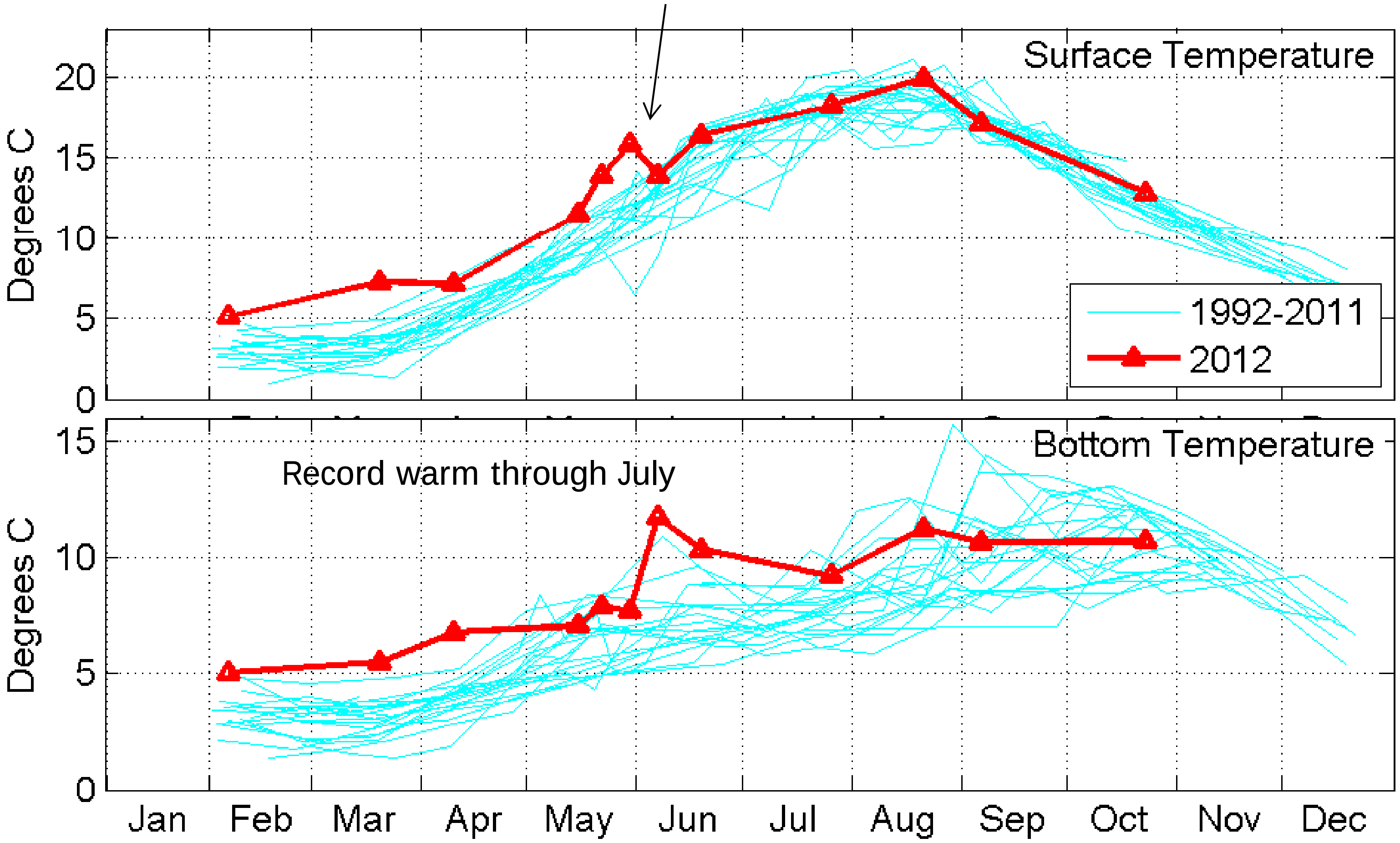
(monthly average N-S wind stress)



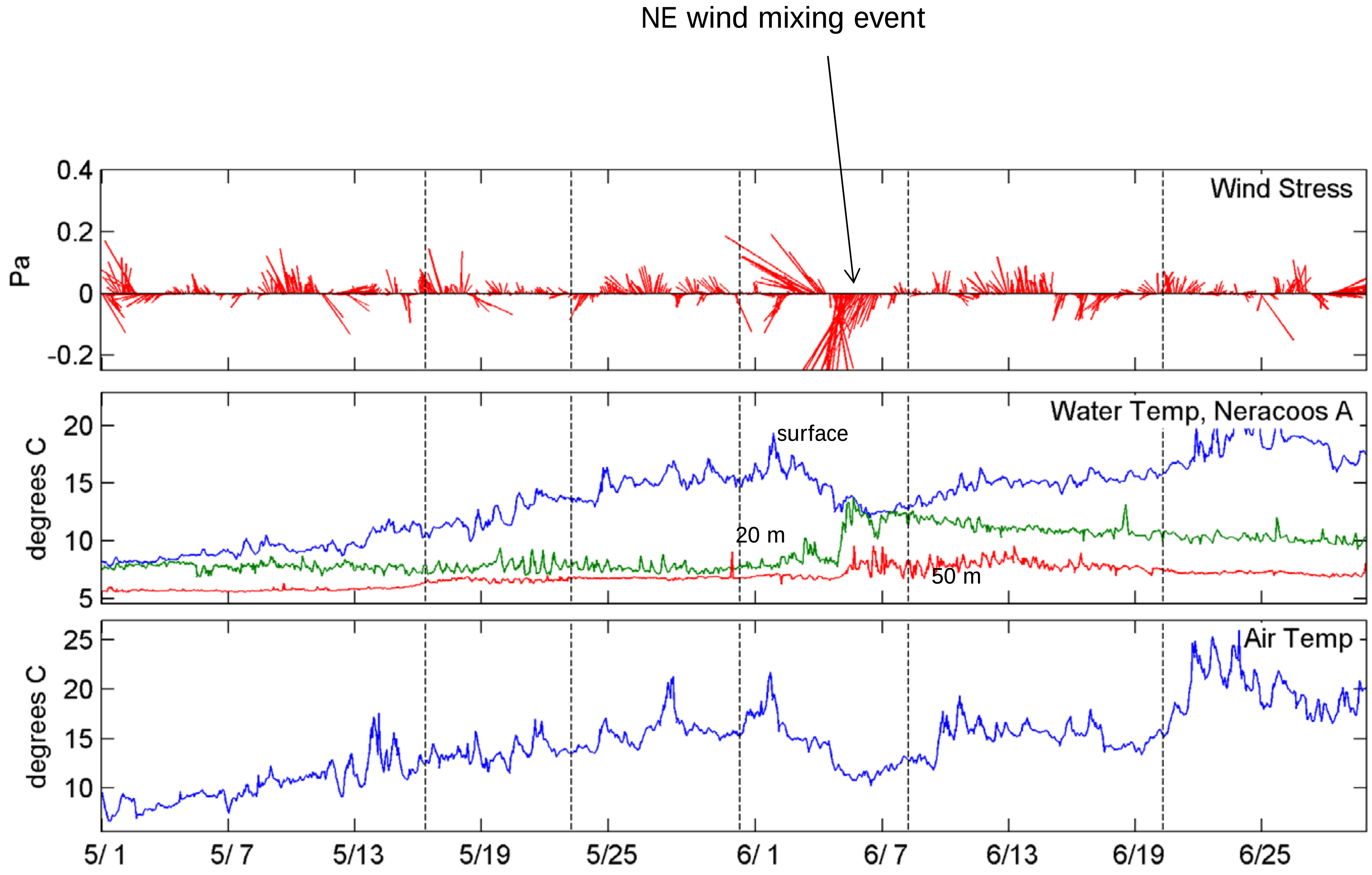
water properties

water temperature

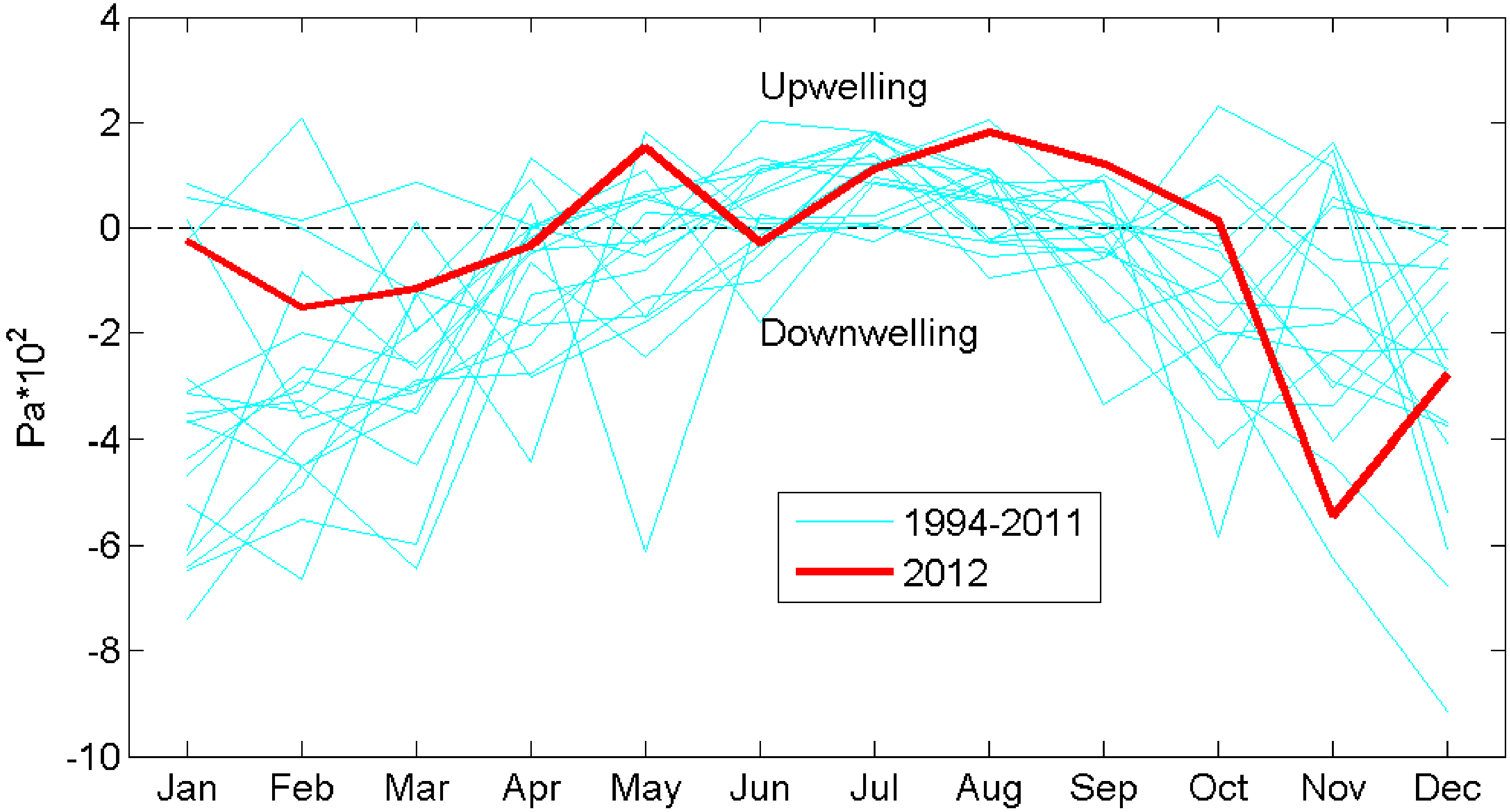
Warm and calm, then mixing event


Record warm through July

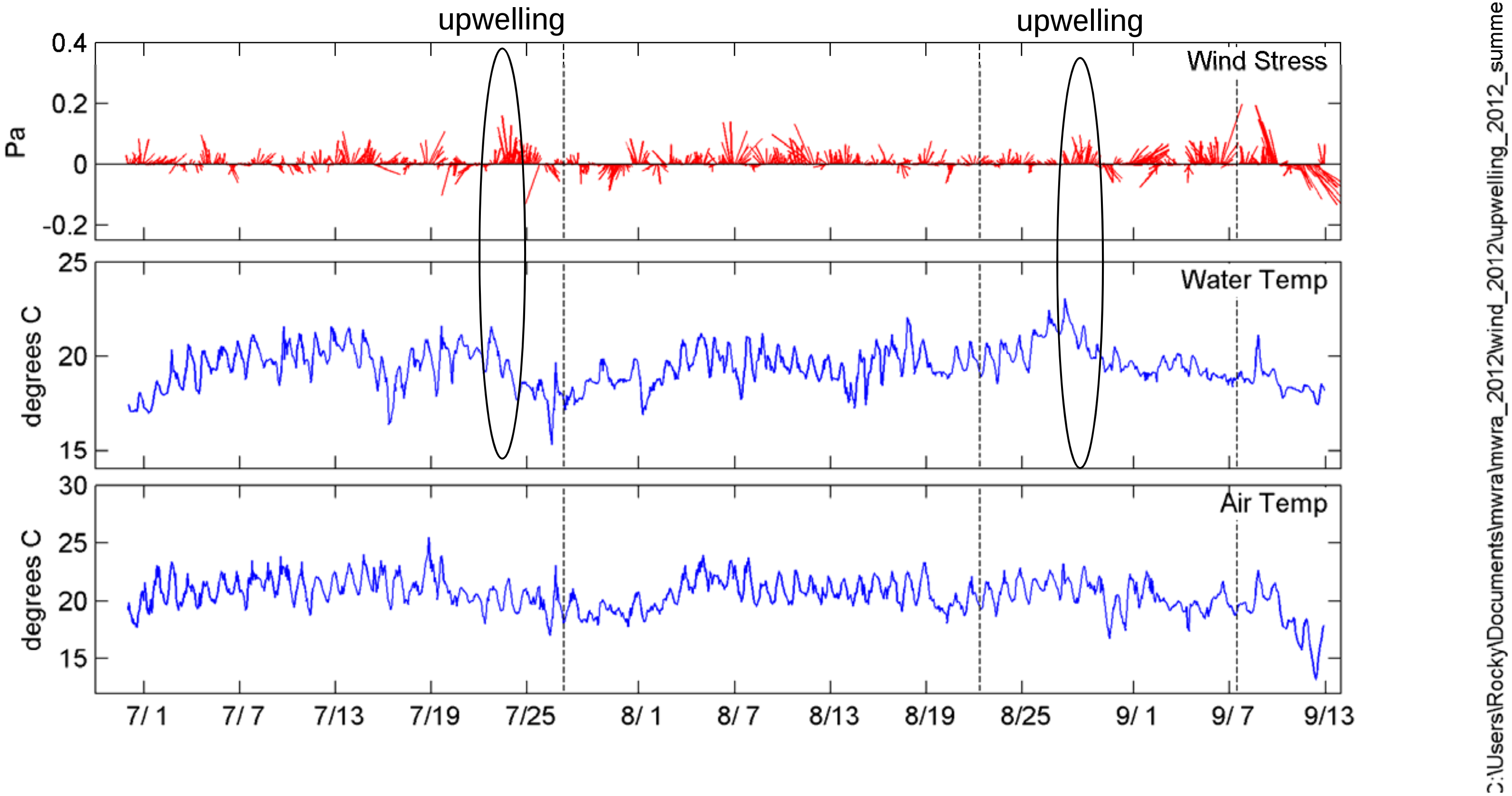
Late spring winds and water temperature



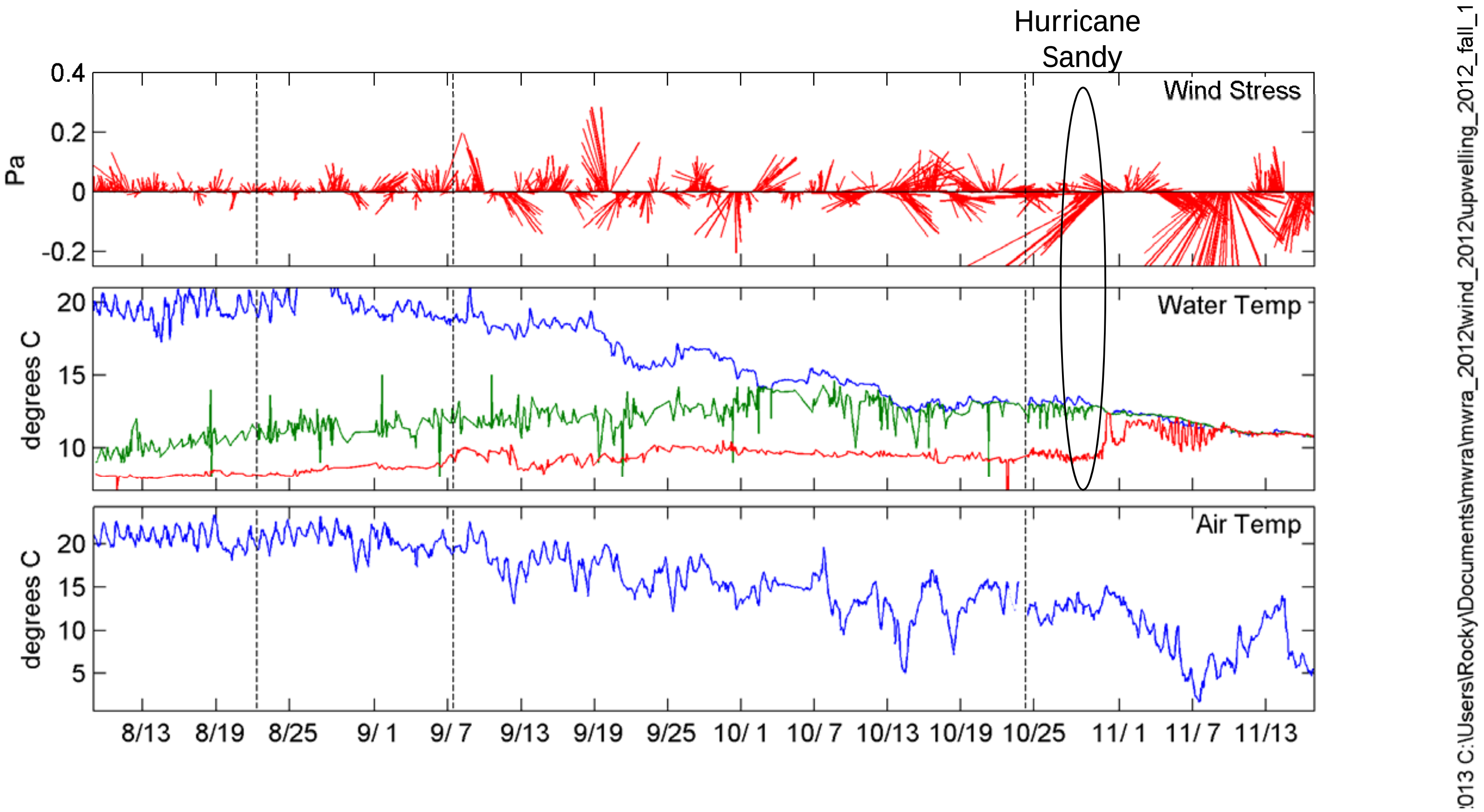
Upwelling index, 2012



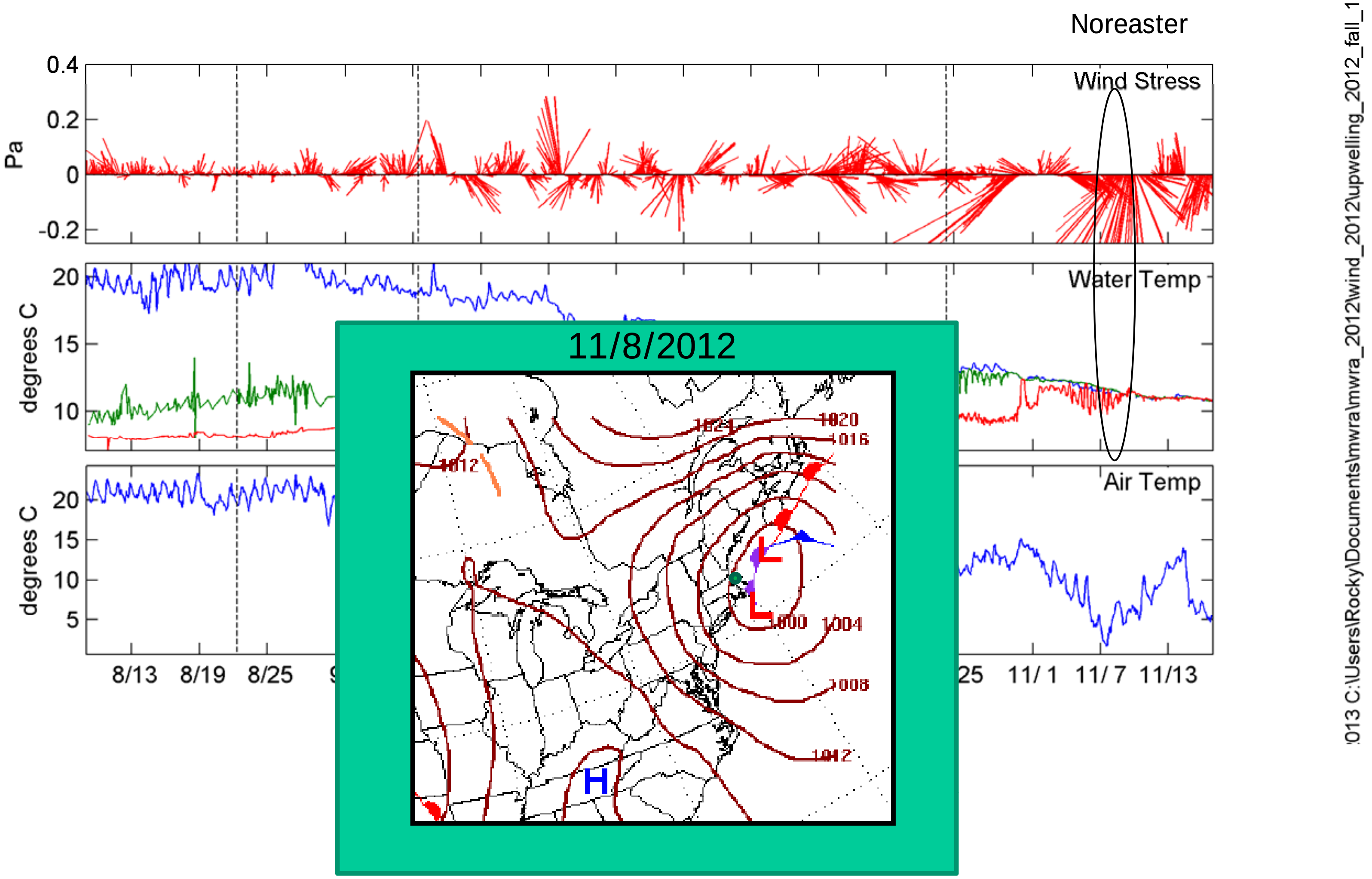
summer winds and water temperature



fall winds and water temperature

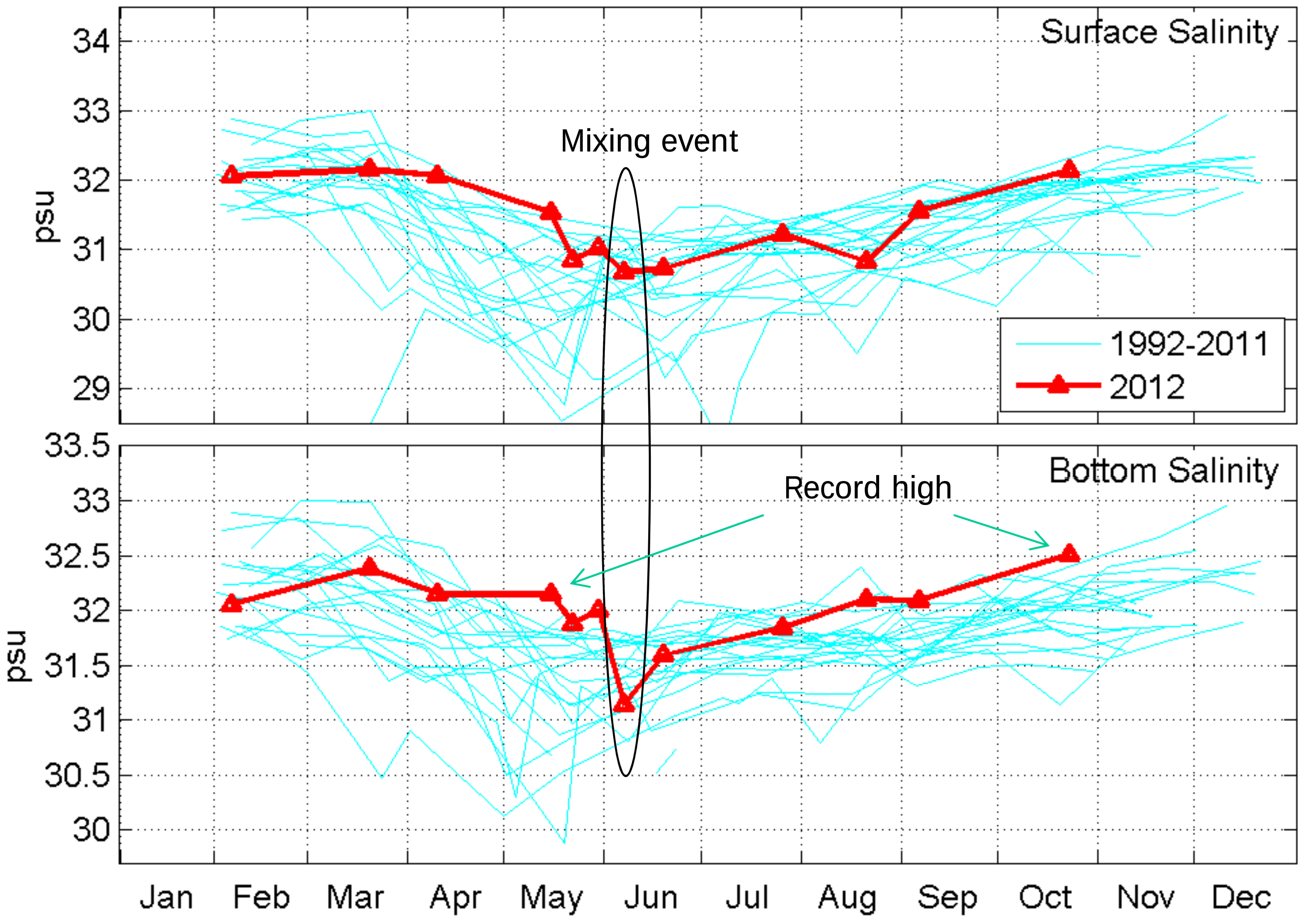


fall winds and water temperature

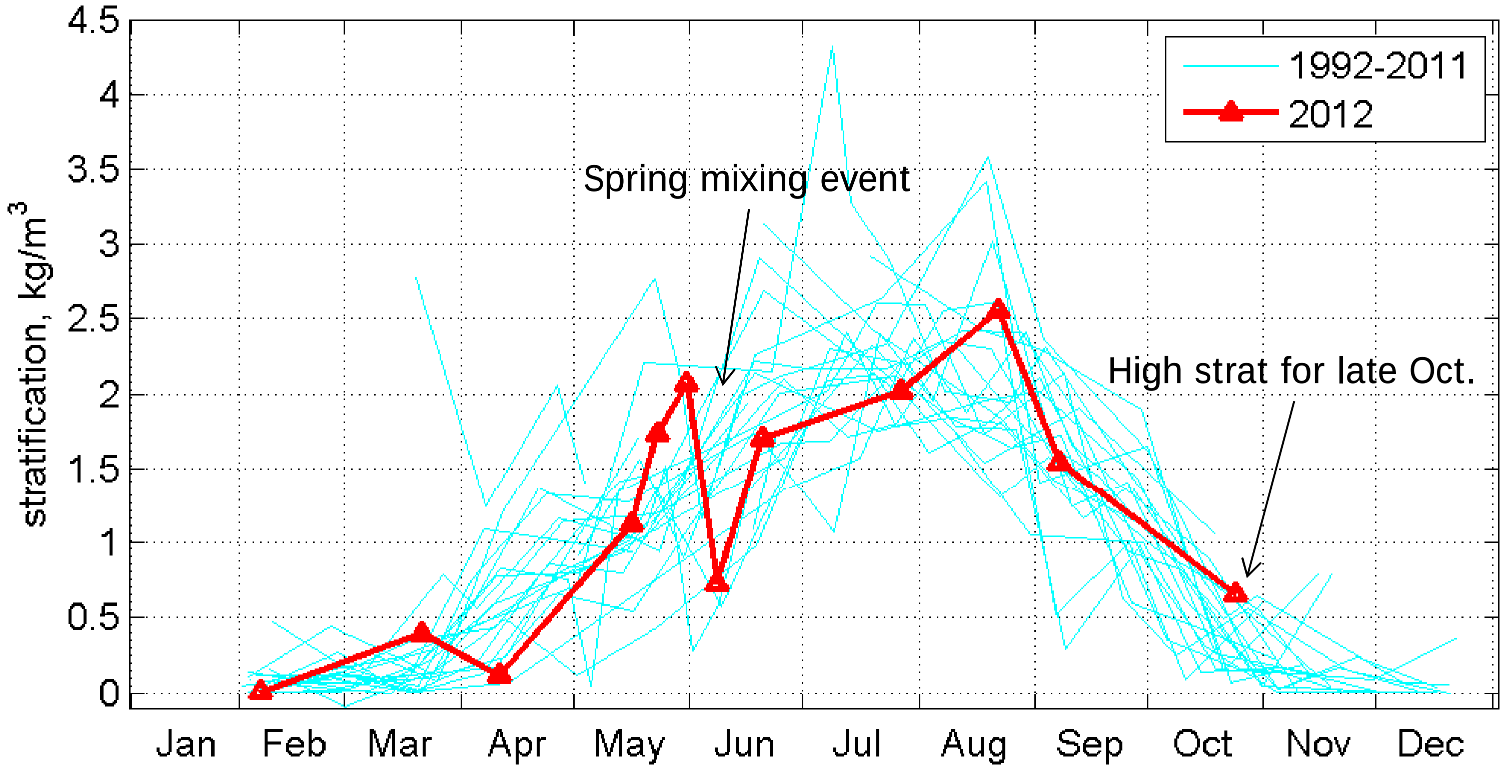


11/8/2012

salinity


Surface Salinity
Bottom Salinity
Mixing event
Record high
1992-2011
2012
psu
psu
34
33
32
31
30
29
33.5
33
32.5
32
31.5
31
30.5
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

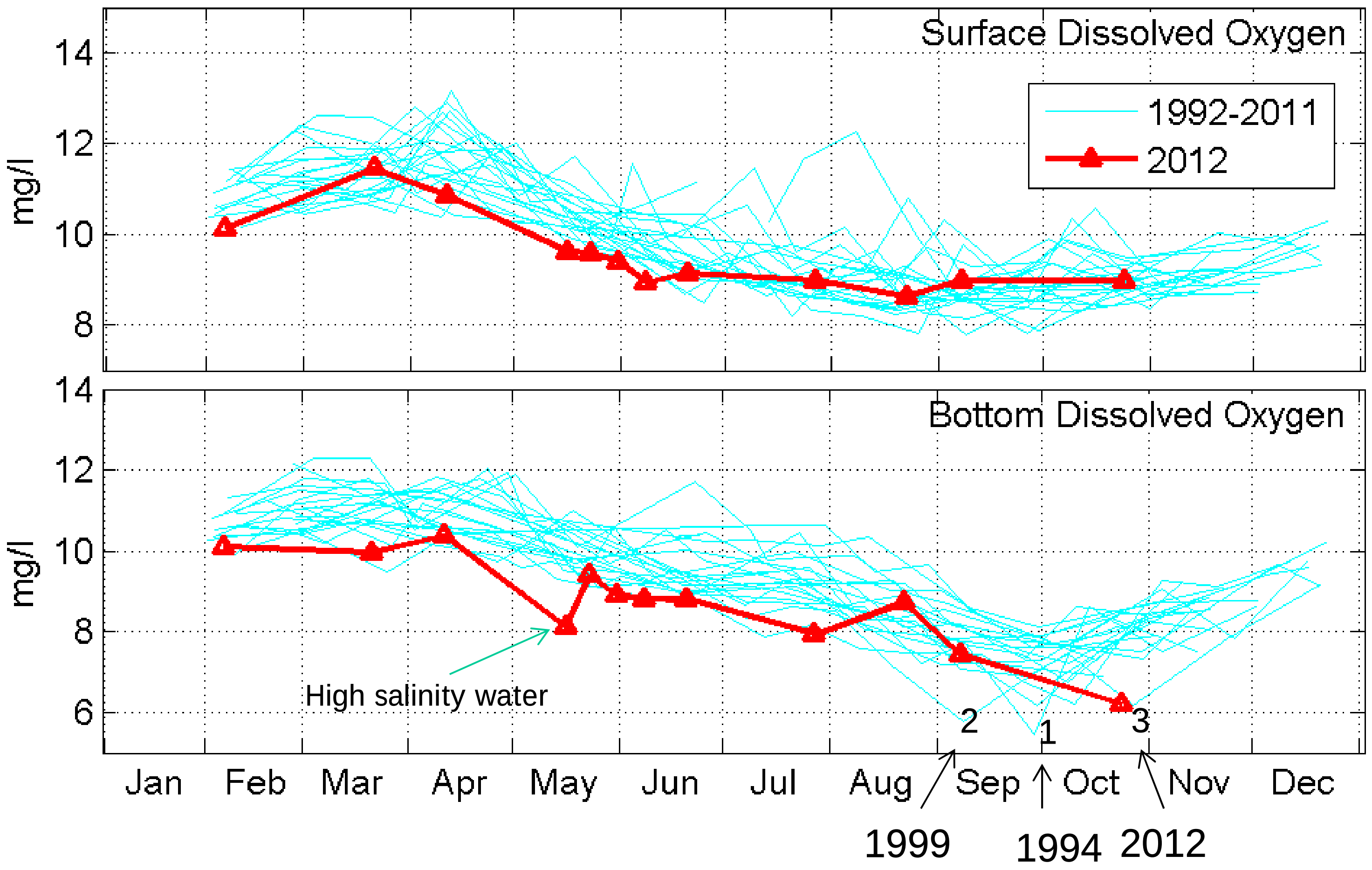
stratification



Spring mixing event

High strat for late Oct.

dissolved oxygen



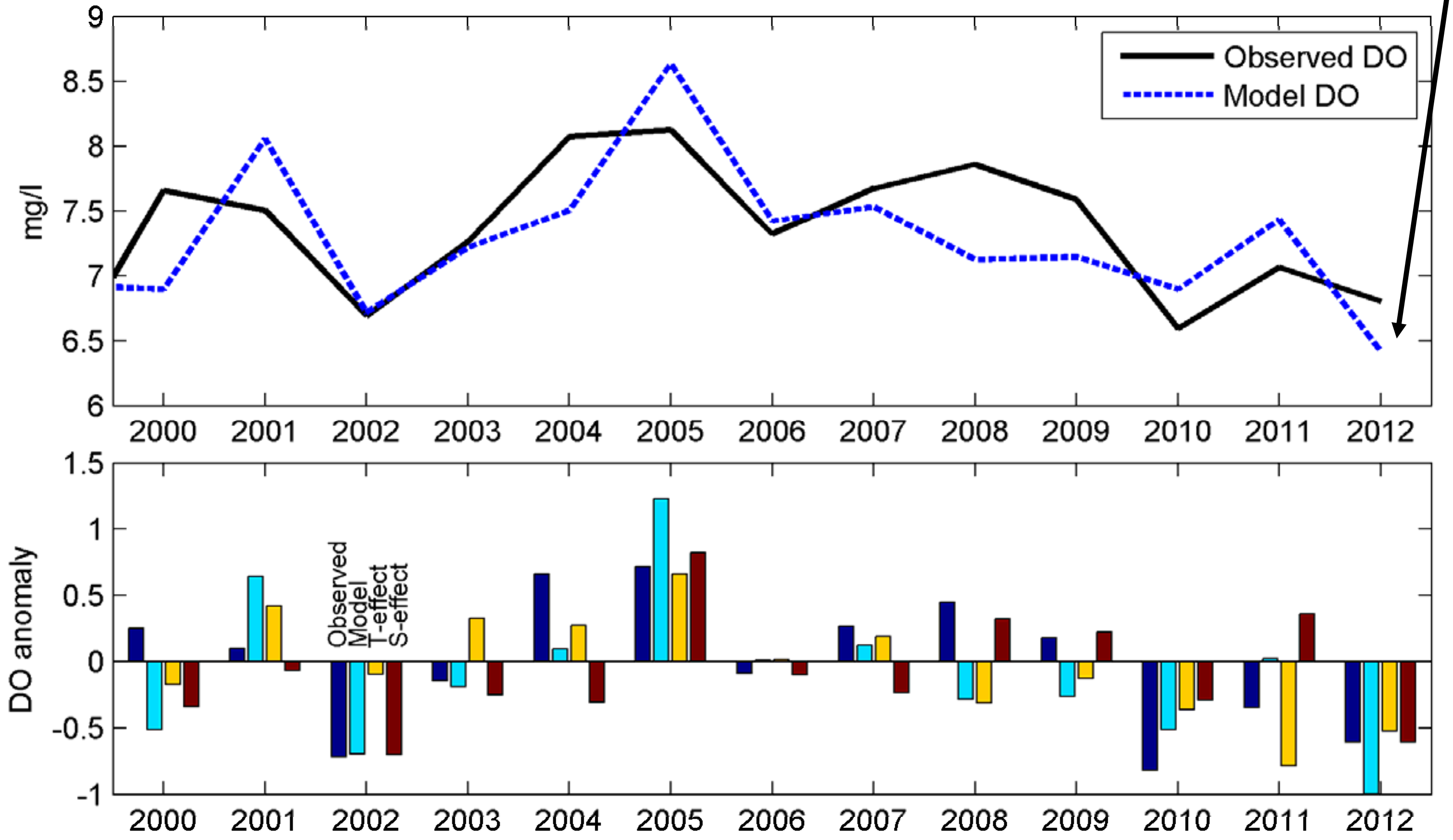
High salinity water

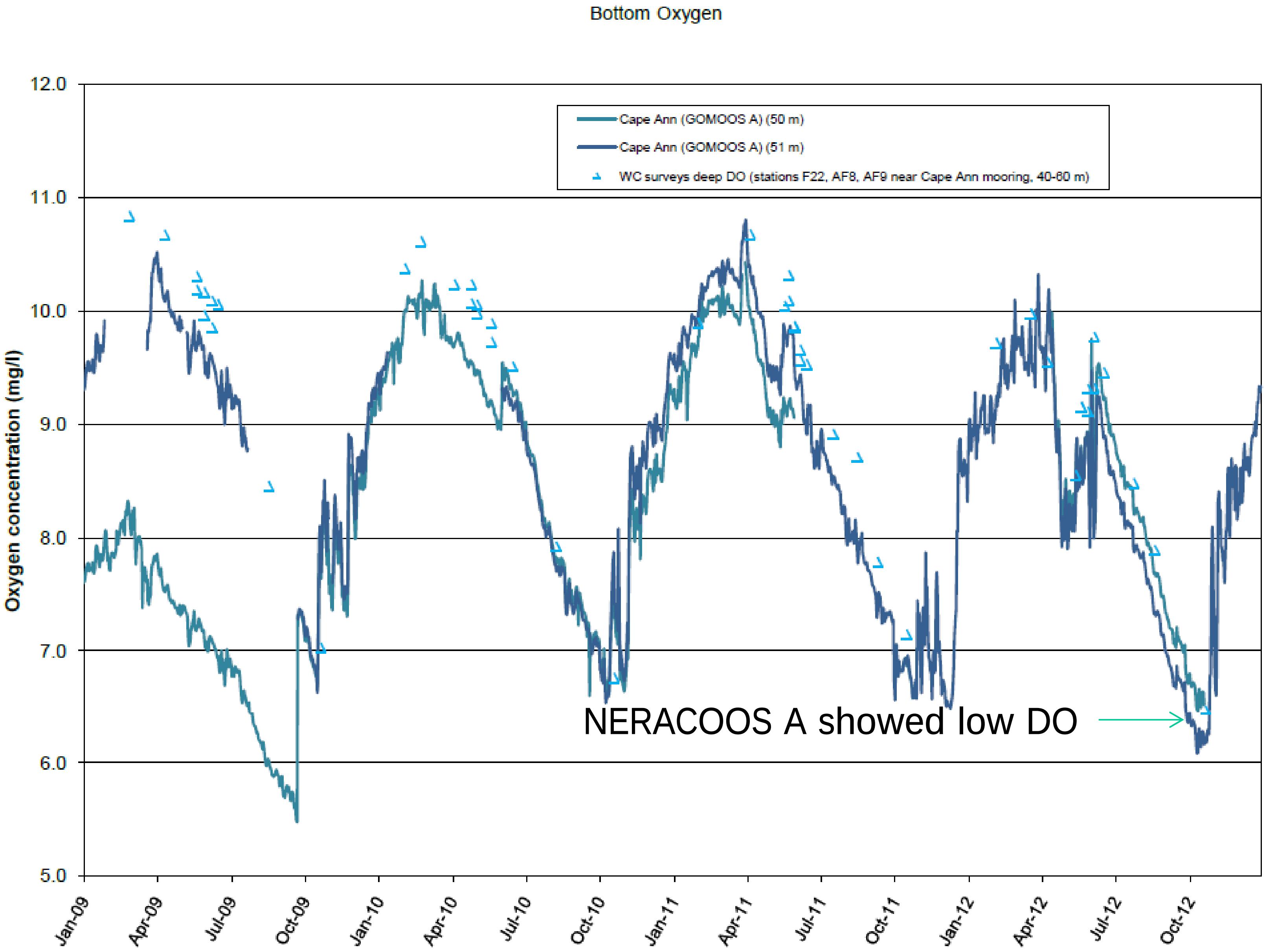
1999

1994

2012

DO model thought it should even be lower





NERACOOS A showed low DO

summary

- Dry year
- Warm winter– lead to early season warm water
- High salinity, low DO
- Mixing event in June, may have kept DO from going too low
- Hurricane Sandy– mixed, but stratification came back
- Nor’easter on Nov. 8 finished the mixing

2012 Water Column Summary

Scott Libby, Battelle

Overview

The 2012 MWRA Harbor and Outfall Monitoring (HOM) program represents the second year of the revised monitoring plan with synoptic sampling being conduct during nine monthly surveys from February to October with sampling at 11 stations in Massachusetts Bay and 3 stations in Cape Cod Bay (slide 3). The three stations in Cape Cod Bay were sampled by Provincetown Center for Coastal Studies (PCCS) and are included in this presentation. As has been observed over the course of the HOM program, the 2012 data follow a seasonal sequence of water quality events in Massachusetts Bay. Typically a winter/spring phytoplankton bloom occurs 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 *Phaeocystis* bloom was earlier in 2012 peaking in March. Late in the spring, the water column transitions from well-mixed to stratified conditions. This cuts off the nutrient supply to surface waters and terminates the spring bloom. The summer is generally a period of strong stratification, depleted surface water nutrients, and a relatively stable mixed-assemblage phytoplankton community. 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. Dissolved oxygen concentrations are lowest in the bottom waters prior to the fall overturn of the water column – usually in October. The October 2012 survey was conducted prior to the fall overturn and the DO levels were low throughout the Bay and in comparison to previous years. By late fall or early winter, the water column becomes well mixed and resets to winter conditions. This sequence has been evident every year of this 21 year dataset (1992-2012). The major features and differences in 2012 are discussed below.

2012 Water Quality Results

Nutrient concentrations were relatively low in Massachusetts Bay in February and March 2012 (slides 4, 5, and 6). Nitrate+nitrite (NO_3+NO_2), silicate (SiO_4), and phosphate (PO_4) levels in Cape Cod Bay were about half those in Massachusetts Bay in February. Surface NO_3+NO_2 and SiO_4 were nearly depleted by March across the bays. A comparison of nutrient levels at station N18 for 2012 against previous years' data highlights how much lower NO_3+NO_2 and SiO_4 levels were in February and March 2012 vs. 2011 and earlier years (slide 5). This may be related to the relatively dry winter spring conditions in 2012 and lower inputs of riverine nutrients (see Geyer summary). Additionally, the decrease in nutrients also coincided with high chlorophyll concentrations in March and April due to an early, large *Phaeocystis* bloom in 2012 (slide 16).

From February to April, the effluent plume (as delineated by elevated ammonium (NH_4) concentrations) was evident in the nearfield surface waters (slides 6 and 9). High NH_4 levels were observed in the nearfield during all but one (August) of the surveys in 2012 (slides 7-12). The furthest south the plume was observed in 2012 was at station F15 in May, while in September and October elevated NH_4 concentrations were measured to the northwest of the outfall at nearfield station N01. 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.

From March to May, there was a sharp increase in surface water SiO_4 levels throughout Massachusetts Bay, while surface NO_3 concentrations remained depleted at all but harbor station F23 (slide 4). In April, NO_3 concentrations were low throughout the upper 30 m of the water column (slide 13). There was a slight increase in NO_3 concentrations in May below the surface waters likely due to increased mixing – though by June the upper water column was depleted of NO_3 and remained so until the fall (slide 13). The winter/spring changes in nutrient concentrations (absolute and relative) were coincident with increases in chlorophyll and particulate organic carbon (slide 13) associated with the March/April *Phaeocystis* bloom. The relative decrease in NO_3 vs. SiO_4 is also consistent with a *Phaeocystis* bloom as this phytoplankton species does not utilize SiO_4 like diatoms. Surface chlorophyll levels peaked during the March survey at 8 $\mu g\ L^{-1}$ in the nearfield (slide 15) and a similar peak was seen in the MODIS imagery from early March suggesting that the winter/spring bloom may have started prior to March 7 (slide 19). Phytoplankton data indicate that the community was dominated by *Phaeocystis* on March 20 survey, but nutrient data suggest that diatom abundance may have peaked earlier in the month – hence the low SiO_4 concentrations measured during the March survey. Chlorophyll fluorescence data from NERACOOS buoy A01 near station F22 suggests that there may have been two winter/spring peaks in chlorophyll also supporting that there may have been two different winter/spring blooms (slide 20).

The May mixing event (see Geyer presentation) resulted in an increase of nutrient concentrations in the upper water column though they remained depleted in the surface waters. Remnants of the large March/April *Phaeocystis* bloom remained in Massachusetts Bay in May present in three of the 20 samples collected. An abundance of 36,000 cells L^{-1} (well below the >10 million cells L^{-1} observed in samples from March 2012) in a sample from station N07 resulted in an exceedance of the summer *Phaeocystis* threshold of 357 cells L^{-1} (slides 25, 26, and 27). This exceedance has no ecological impact, rather simply resulted from a few remaining Phaeocystis colonies from the bloom being present in the bay in May.

A few *Alexandrium fundyense* cells were observed during the April survey, but by May levels had increased in the nearfield to well above the 100 cells L^{-1} trigger for *Alexandrium* rapid response surveys (ARRS) and a series of three weekly ARRSs were conducted from May 22nd to June 7th (slides 28 and 29). On May 15th, *Alexandrium* peaked in the nearfield at station N01 at 533 cells L^{-1} with higher abundances (>1,000 cells L^{-1}) at stations along the South Shore. The *Alexandrium* bloom reached peak abundances during the May 22nd survey with ~5,200 cells L^{-1} at station F05 off of Scituate (slide 30). *Alexandrium* abundances remained elevated in the nearfield in late May, but by June 7th the bloom was over and only a few *Alexandrium* cells were observed (slides 30). This moderate bloom resulted in an exceedance of the MWRA Contingency Plan Threshold for *Alexandrium* and a PSP toxicity closure of shellfishing beds from Duxbury north to Salem in western Massachusetts Bay (slides 25 and 28).

By the June, along with the decrease in *Alexandrium*, levels of nutrients, chlorophyll and POC were low throughout Massachusetts Bay. The water column had become stratified and nutrients (including those associated with the effluent plume) were confined below the pycnocline (slides 11 and 13). Nutrient and chlorophyll levels remained low over the remainder of the summer surveys. No MODIS imagery was received between May 8 and July 21 to compare with the May and June results. However, an image from July 22 suggested elevated chlorophyll throughout the bays. This was not observed during the field measurements on July 26th, which showed low chlorophyll levels that were comparable to the MODIS image taken on July 30th (slides 18 and 19).

By late August and early September, MODIS imagery chlorophyll levels had increased throughout the bays (slide 19). By the September 6th survey, chlorophyll and POC concentrations had increased throughout Massachusetts Bay (slides 15 and 18). This was coincident with a bloom of the centric diatom *Skeletonema* (see Borkman summary). The fall diatom bloom continued thru September and into October as suggested by the high chlorophyll readings at NERACOOS Buoy A01 (slide 20) and elevated concentrations during the October 23rd survey (slide 18). Nutrient levels had increased somewhat in the fall and clearly supported the diatom bloom, but the water column did not remix and surface waters remained depleted of NO_3 through October except in Boston Harbor (slides 4 and 13).

Bottom water dissolved oxygen (DO) concentrations declined sharply from April annual maxima to May (slide 21). The late May/early June mixing events (see Geyer summary) led to an increase in bottom water DO levels between the May and June surveys and likely averted even lower DO levels from being reached in the fall 2012. From June to October, bottom water DO concentrations decreased across most of the bay. There was a slight increase at nearfield station N18 in August and at the stations in Boston Harbor (F23) and Cape Cod Bay (F01) bottom water DO increased in October suggesting seasonal mixing had occurred at these shallower stations (slide 21). Bottom water minima, however, were low in comparison to past years with nearfield and Stellwagen basin minima of 6.19 and 6.6 mg L^{-1}, respectively. These DO levels (and their respective percent saturation values) were only slightly above the contingency Plan threshold values (slide 14). Comparisons of the bottom water DO concentrations at these stations in 2012 vs. previous years illustrates how low DO was in 2012 (slide 24). The individual survey concentrations were near or below previous values for each of the stations for most of the year. These low bottom water DO levels are due to the regional forcing associated with the drier, warmer conditions in 2012 (see Geyer summary) and they were likely exacerbated by the higher input of organic material associated with the large winter/spring and fall blooms in 2012. Even with the relatively high chlorophyll concentrations and low bottom water DO levels, there were no threshold exceedances for these water quality parameters in 2012.

As mentioned previously, there was a large *Phaeocystis* bloom in the bay in 2012 with abundances reaching ten million cells L^{-1} in March and a few million cells L^{-1} in April. The prolonged bloom, however, did not lead to an exceedance of the winter/spring threshold (1.69 million cells L^{-1} vs. threshold value of 2.86 million cells L^{-1}), rather it was the presence of remnants of the bloom in May (one nearfield sample with 36,000 cells L^{-1}) that led to an exceedance of the summer threshold of 357 cells L^{-1} (slide 25). This is the 13th year in a row that a *Phaeocystis* bloom was observed in Massachusetts Bay and during four previous blooms (2003-2006) the summer threshold was exceeded (slide 26). The primary reason for this had been attributed to cooler springs with surface waters prolonging the viability of *Phaeocystis* till later in the spring. This does not appear to be the case in 2012, but it will be examined in more detail in the summary report. The potentially toxic, threshold *Pseudo-nitzschia* species were again present in low abundances during each season, as has been the case during the post-diversion period (slide 25). As discussed above, *Alexandrium* abundances reached moderately high levels with a maximum in the nearfield of 3,731 cells L^{-1}, well above the 100 cells L^{-1} threshold (slides 25 and 28). The 2012 *Alexandrium* bloom lasted about a month and led to shellfishing closures along the western Massachusetts Bay coastline from Salem south to Duxbury.

Historical Comparisons

Overall, the 2012 data were consistent with the trends and patterns observed during both the baseline (1992-2000) and post-diversion (2001-present) time periods. Trends in nutrients at station N18, just south of the bay outfall, are indicative of those that have been observed for NO_3 and SiO_4 since 1992 and for NH_4 and PO_4 since September 2000 when the outfall came on line and elevated concentrations of these nutrients were became noticeable in the nearfield. Comparisons of biomass (as measured by chlorophyll and POC) in 2012 vs. historic levels shows that biomass levels were within the range of representative stations (slides 16 and 17), but unlike recent years as represented by 2011, the winter/spring and fall blooms were relatively large in comparison to 1992-2011 results (slide 23).

As predicted, there has been an increase in NH_4 in the nearfield relative to the baseline and also relative to the regional background concentrations. The signature levels of NH_4 in the effluent plume are generally confined to an area within 10-20 km of the outfall (slides 7 thru 11). There were exceedances of nuisance phytoplankton species in 2012 and this year represents a continuation of annual blooms of *Phaeocystis* and *Alexandrium* in the bay since 2000 and 2005, respectively. This change from infrequent or minor blooms to frequent, larger blooms continues to be a focus of study both within the MWRA monitoring program and with Gulf of Maine researchers, but the trends appear to be related to larger regional factors or forcing processes rather than localized nutrient inputs.

2012 Water Column Results

MWRA Annual Technical Meeting March 6, 2013

Scott Libby

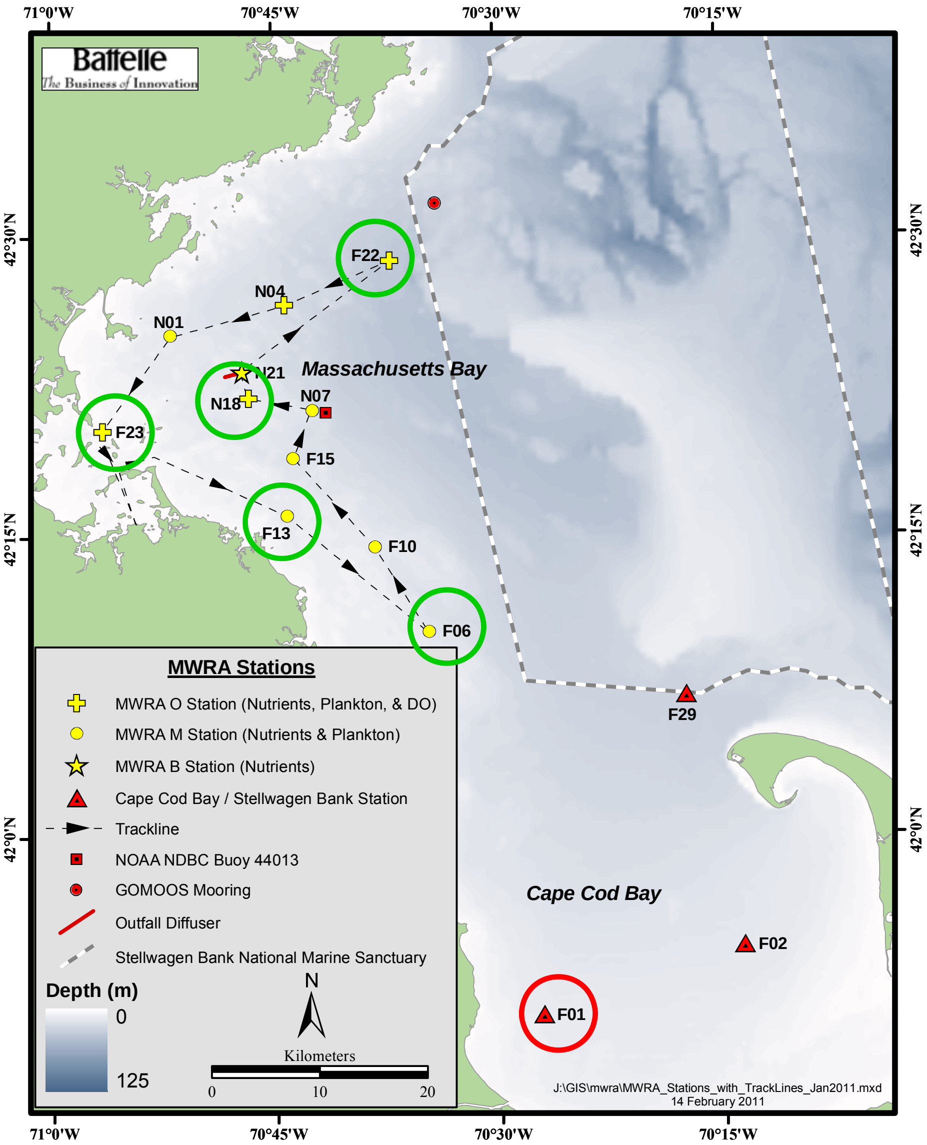
Battelle

Presentation Overview

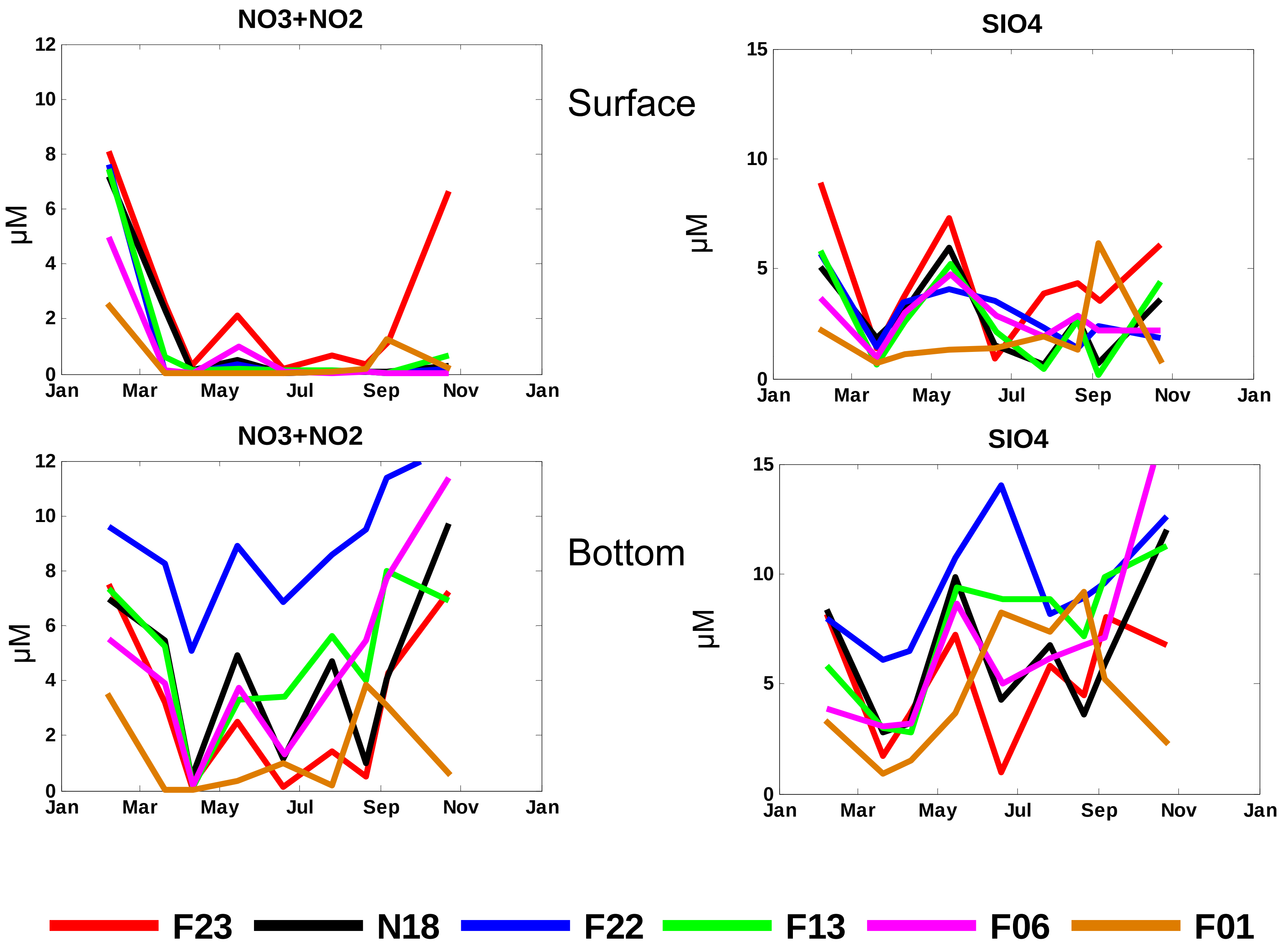
- 2012 nutrient, chlorophyll, and DO results
  - "Typical" seasonal trends generally observed
- 2012 in perspective of 1992-2011 monitoring results
- Contingency Plan threshold results for 2012
  - No chlorophyll or dissolved oxygen exceedances
    - Relatively high chlorophyll levels winter/spring and fall
    - Low bottom water DO
  - *Phaeocystis* bloom – large, early bloom, with summer exceedance
  - *Alexandrium* bloom - moderate bloom exceeded threshold (100 cell/l)

2012 WQ Monitoring Program

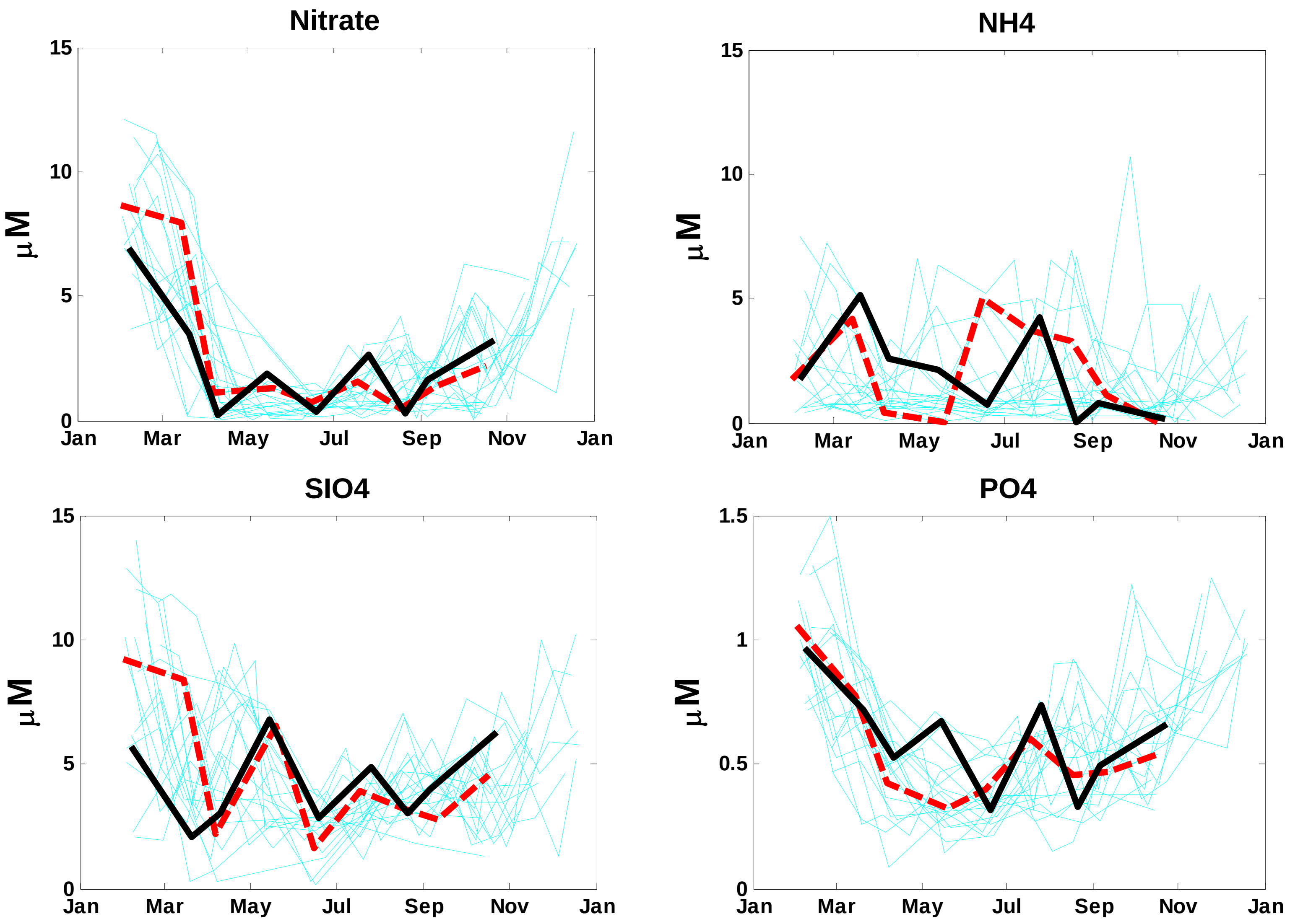
- **9 Surveys**
- **11 Stations (+3 in CCB)**
- **Suite of oceanographic parameters measured at each station**
    - *In situ* hydrographic parameters
    - Nutrients
    - Dissolved oxygen
    - Chlorophyll & particulate organics
    - Phytoplankton & zooplankton community structure (not @ N21)
- **Additional data from –**
    - Other components of the MWRA programs (ARRS, BHWQM, & PCCS)
    - NERACOOS & NOAA buoys
    - MODIS satellite imagery



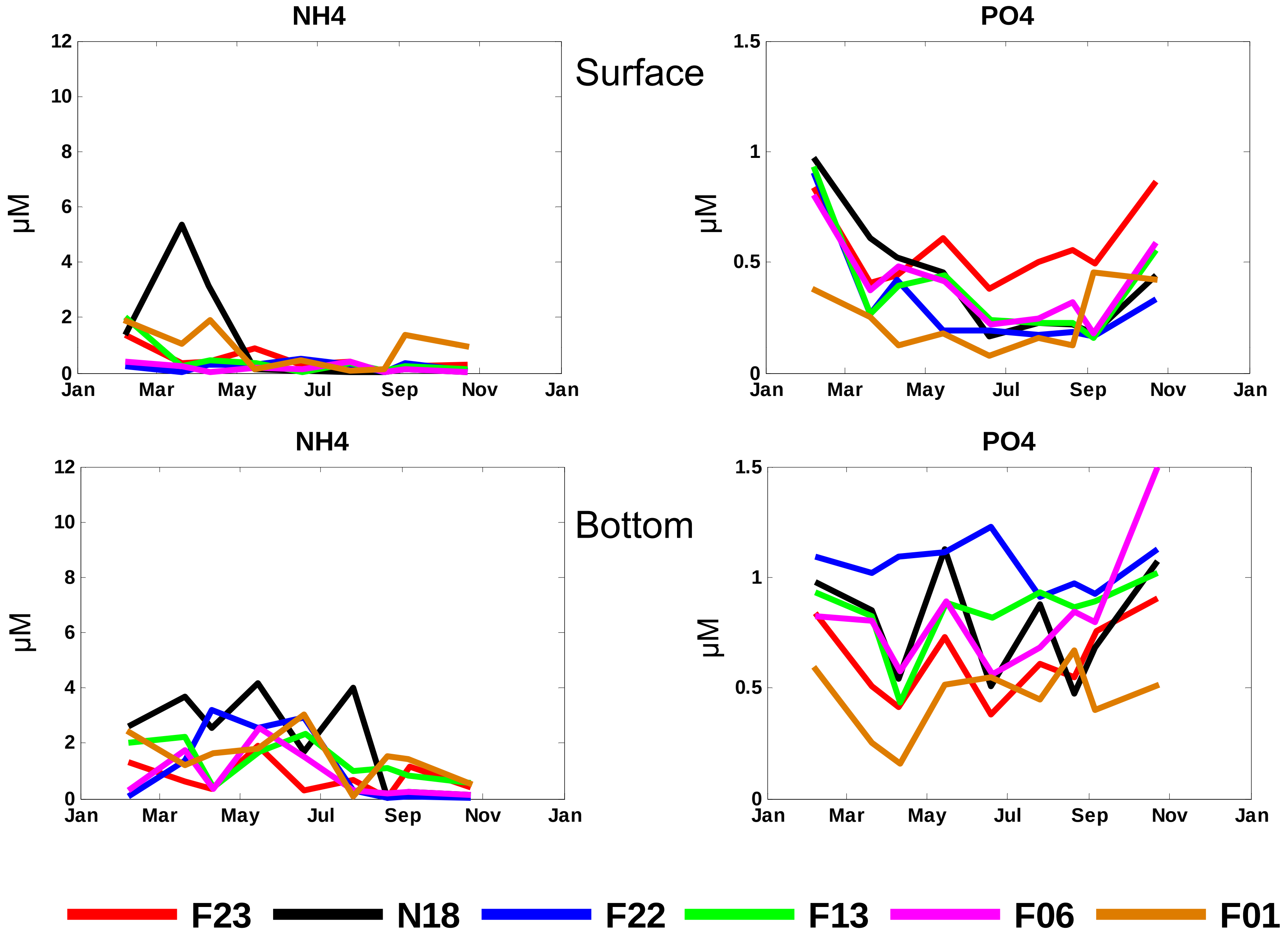
2012 Nutrients – NO_3+NO_2 & SiO_4



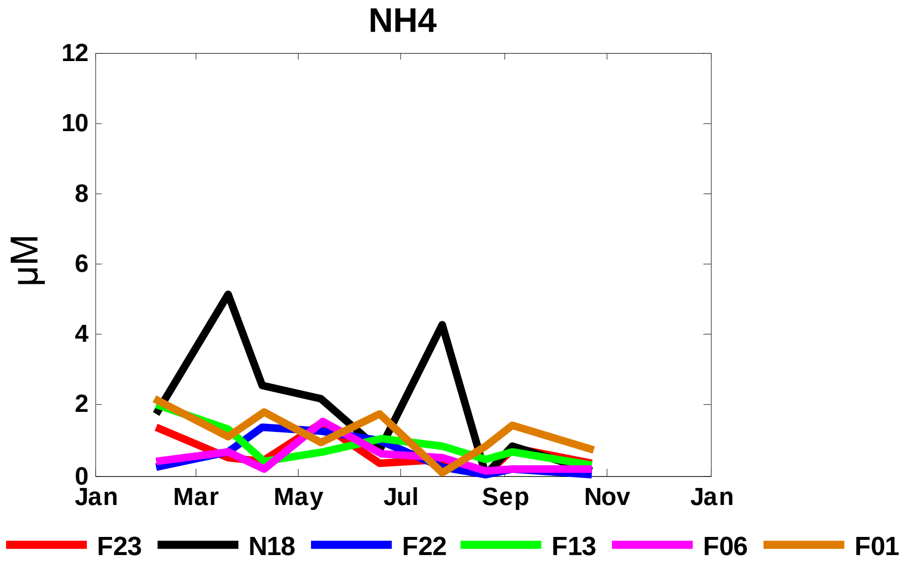
Nearfield – N18 Averages

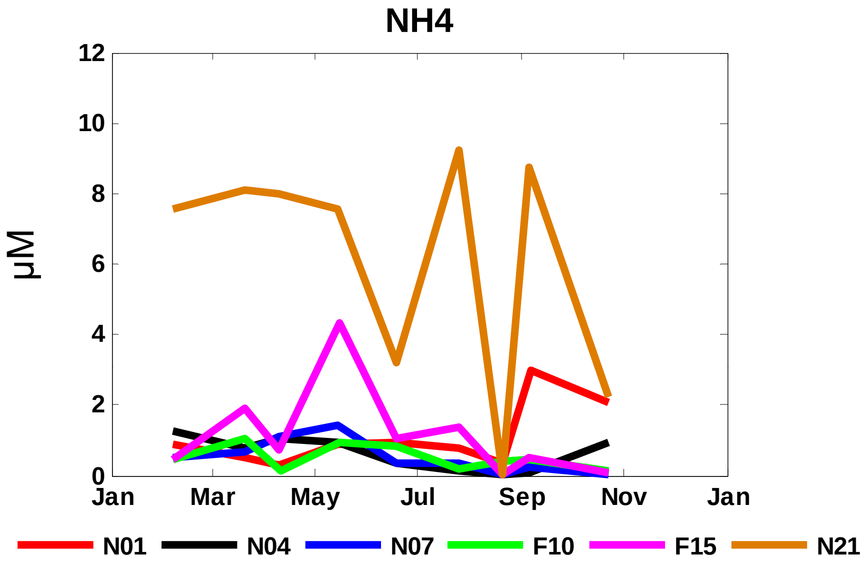


2012 Nutrients – SiO_4 & PO_4

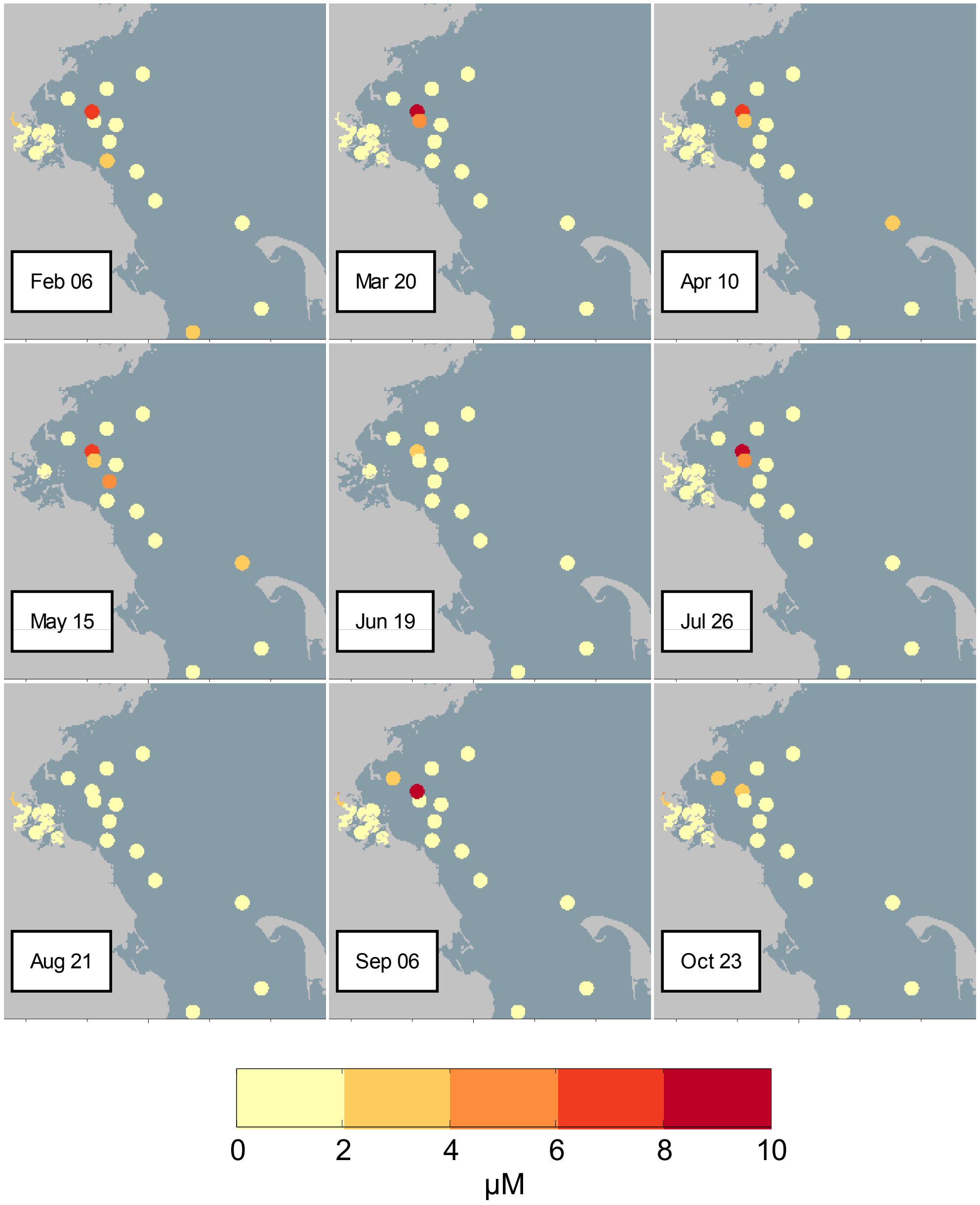


2012 Nutrients – Average NH_4

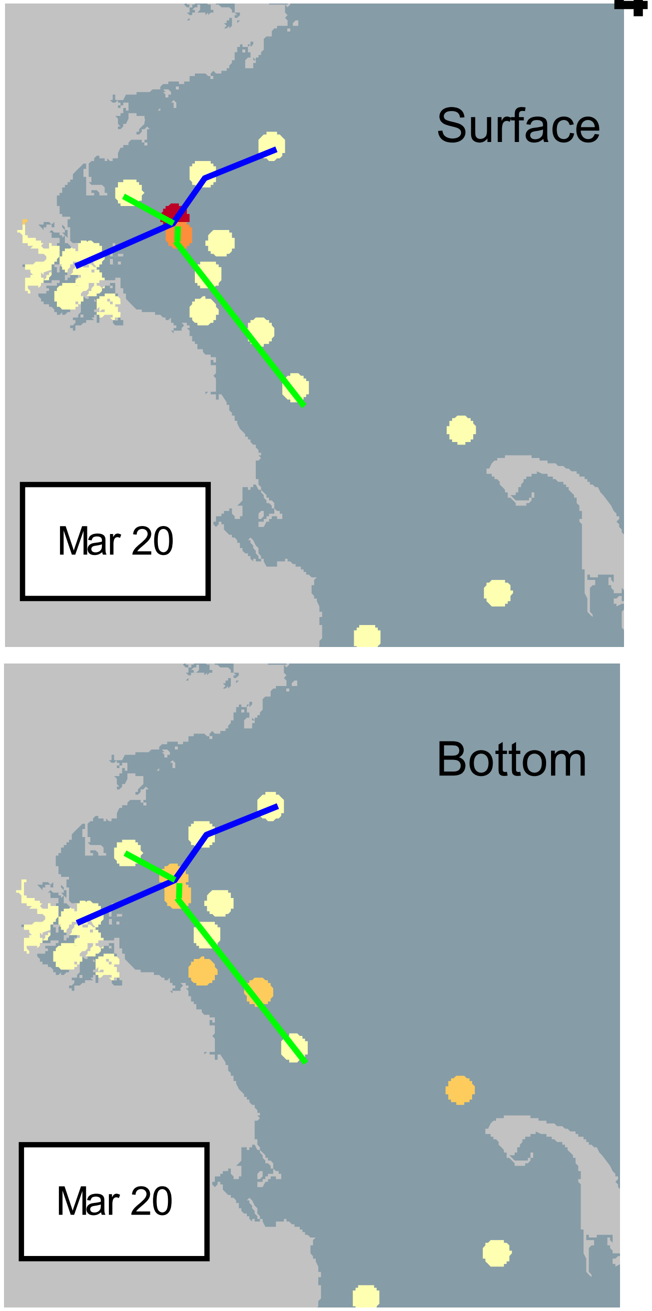


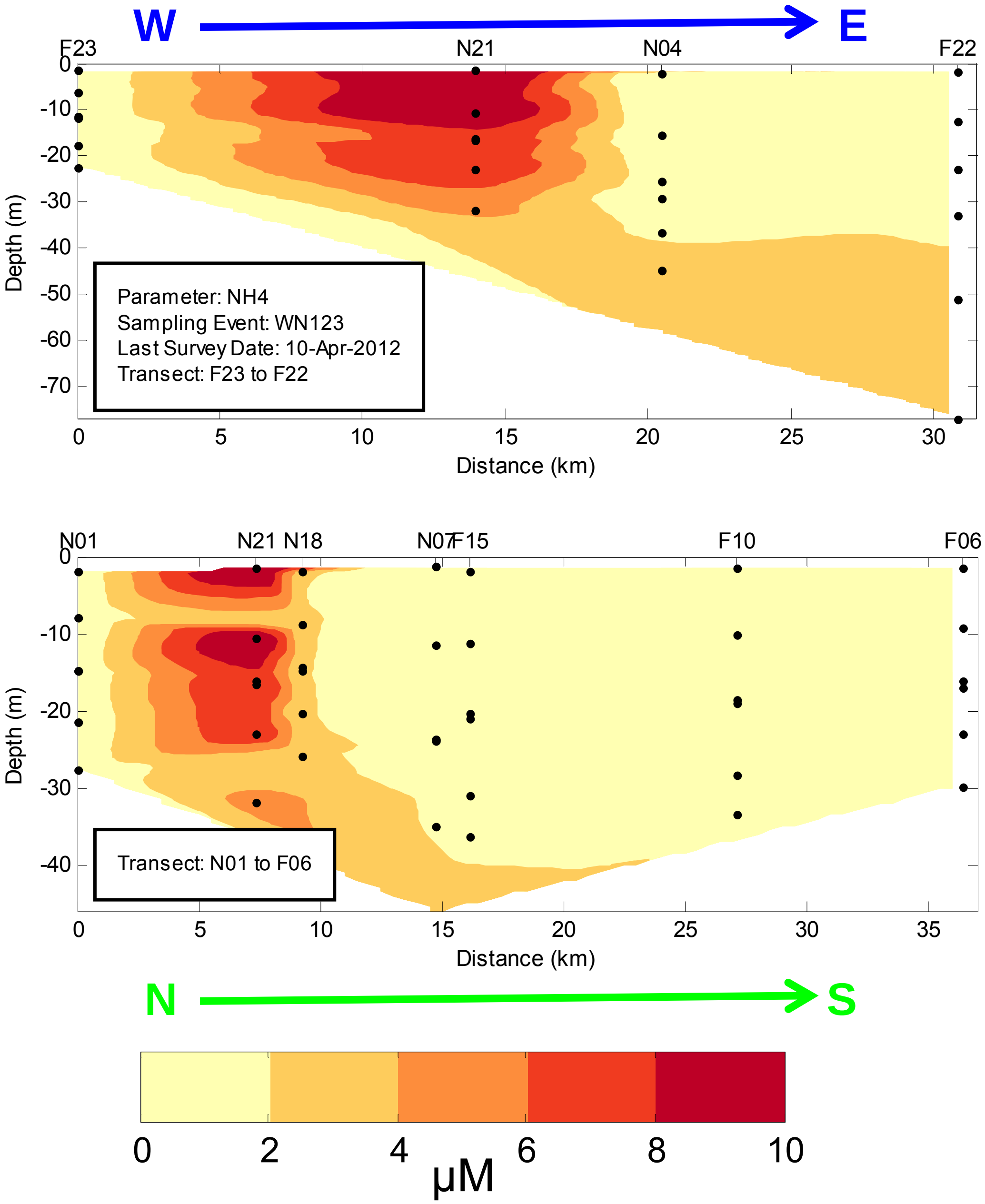


Survey Average NH4



March 2012 - NH_4

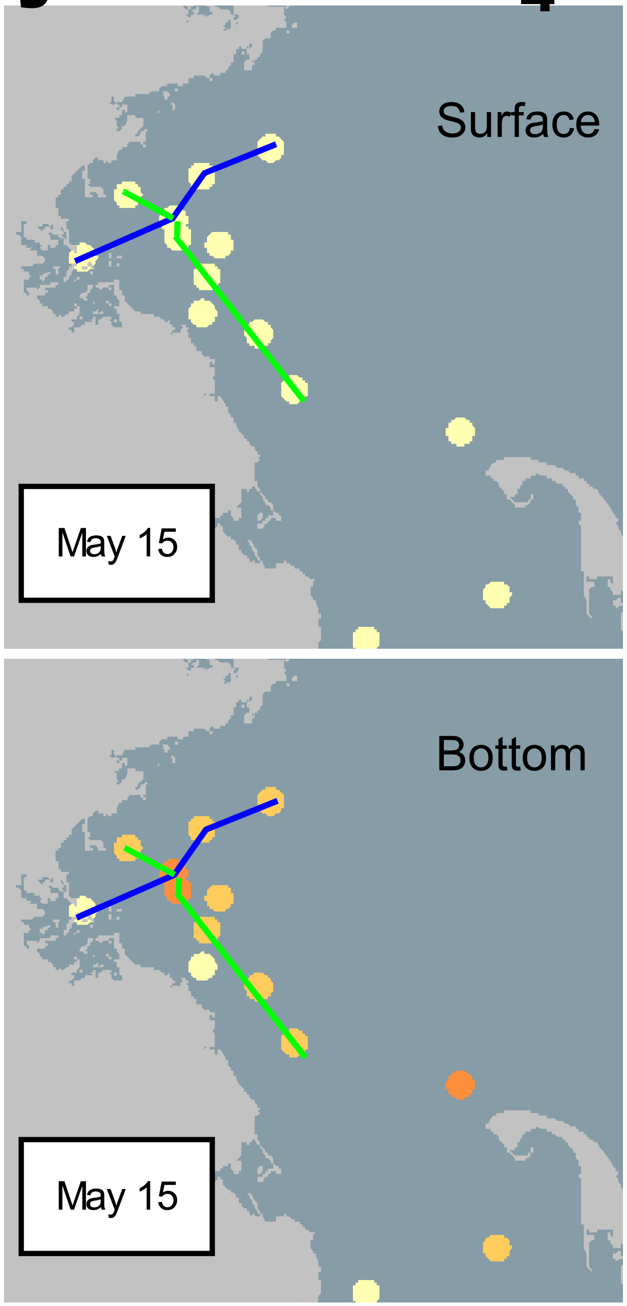


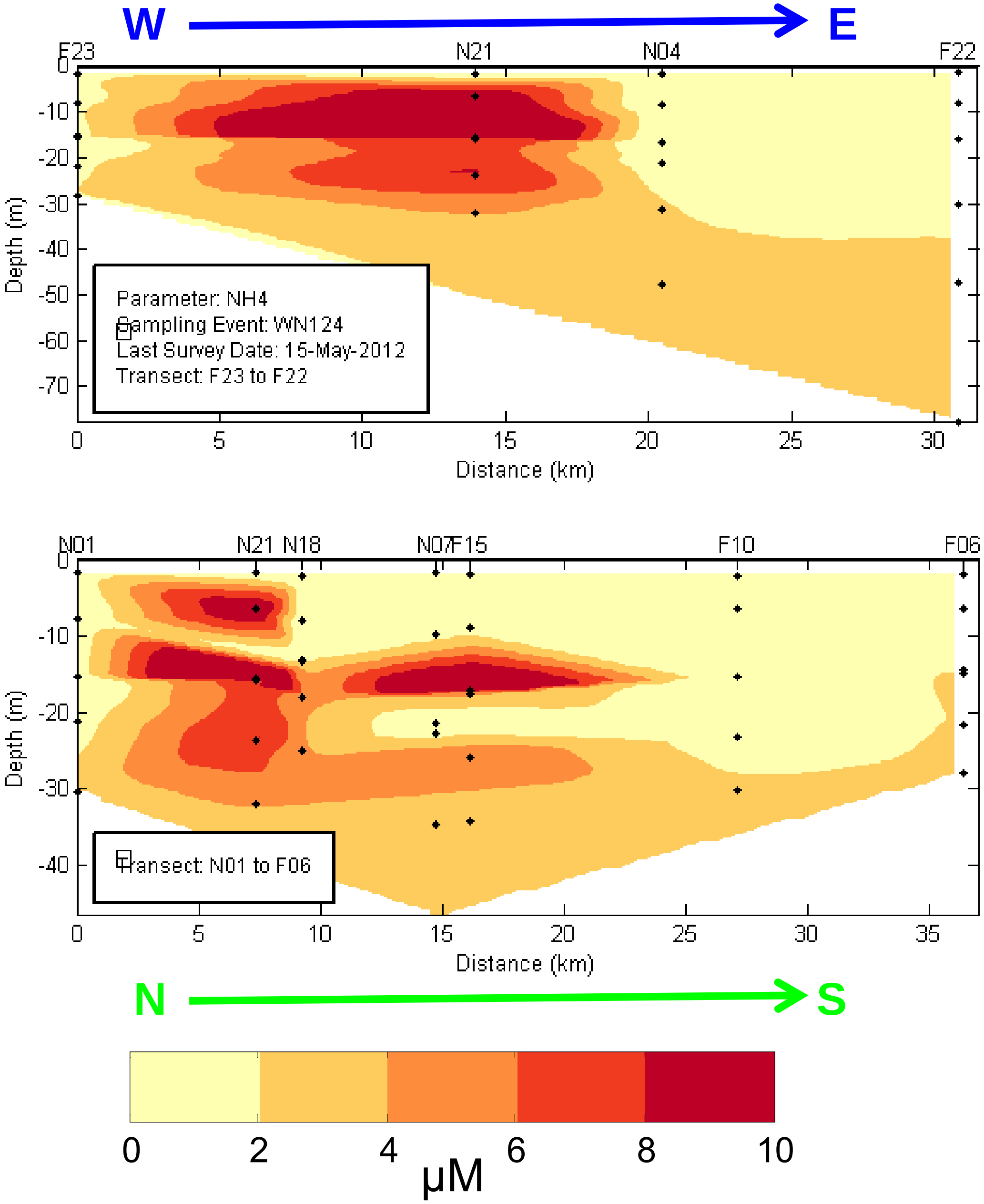


Parameter: NH4
Sampling Event: WN123
Last Survey Date: 10-Apr-2012
Transect: F23 to F22

Transect: N01 to F06

May 2012 - NH_4





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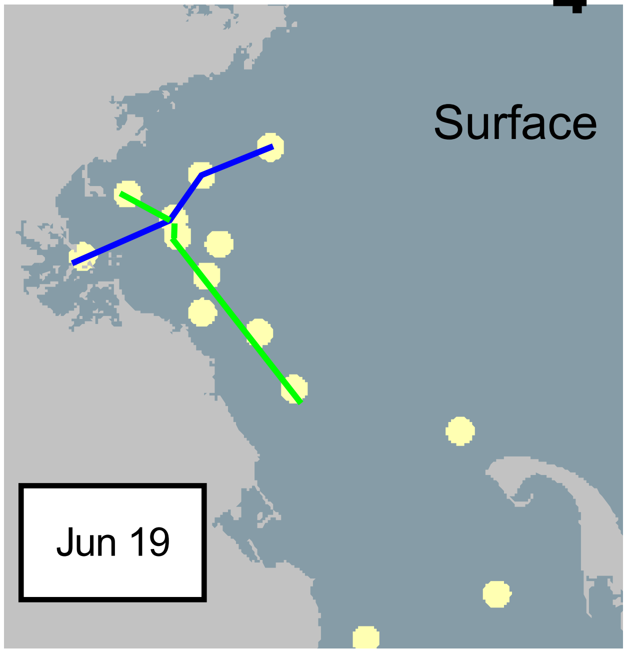
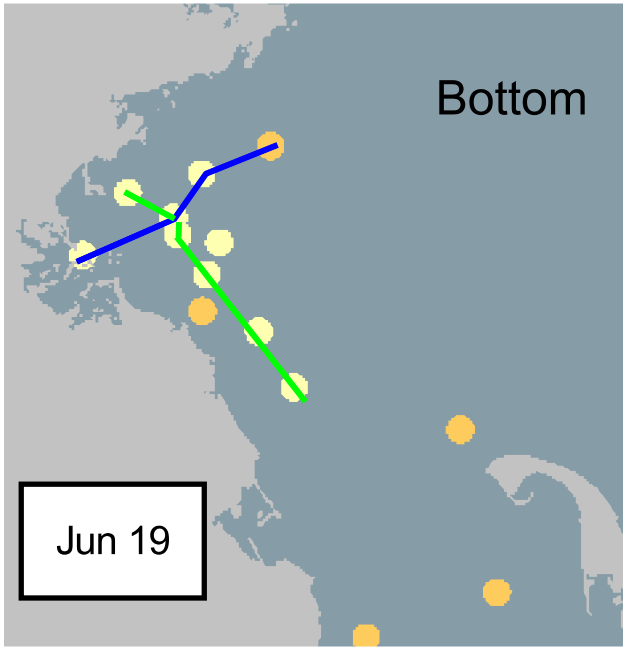
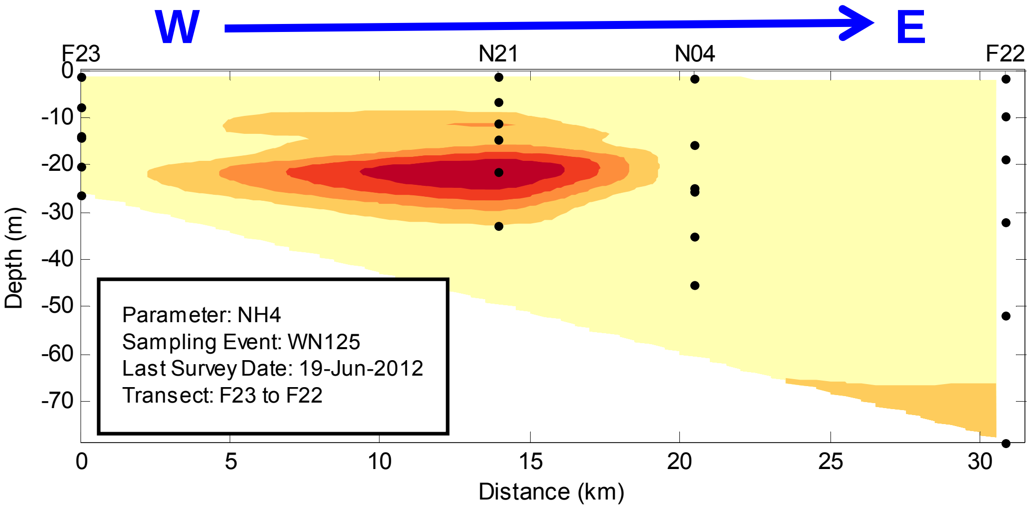
Sampling Event: WN124
Last Survey Date: 15-May-2012
Transect: F23 to F22

Transect: N01 to F06

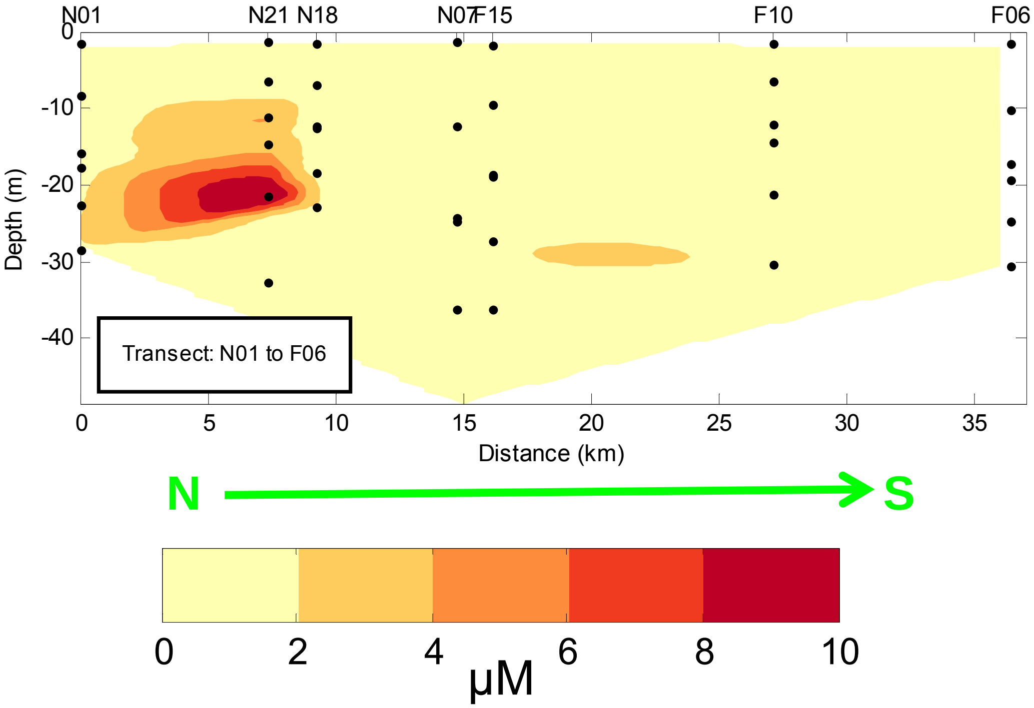
June 2012 - NH_4





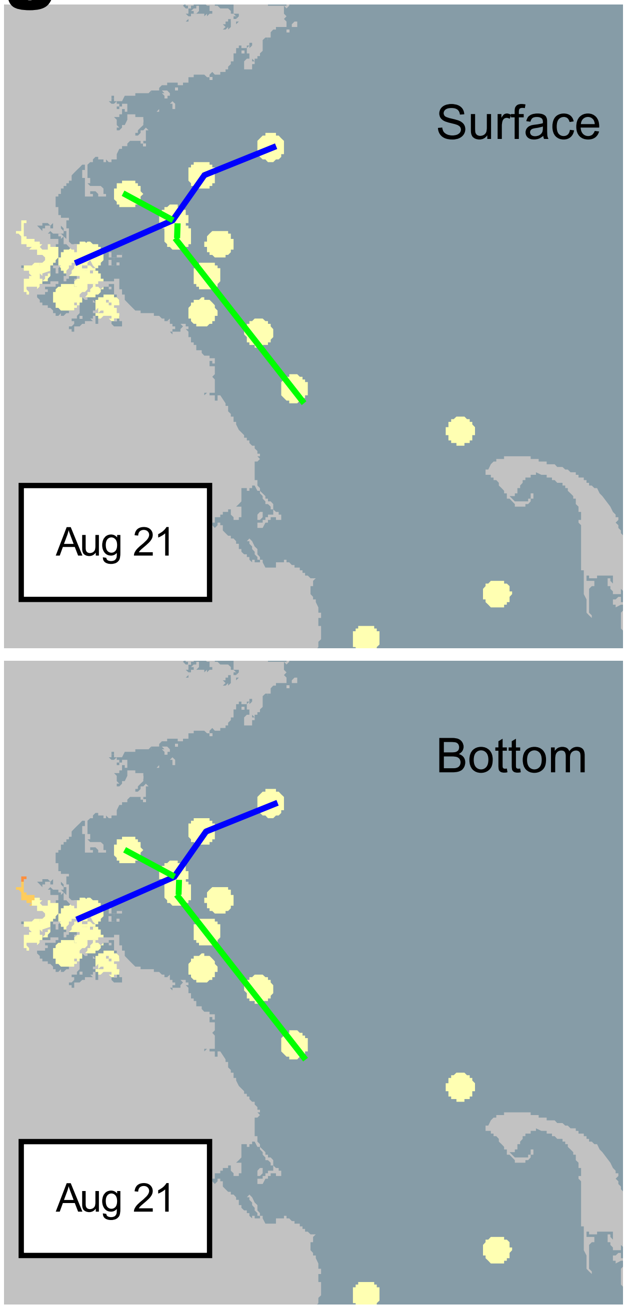


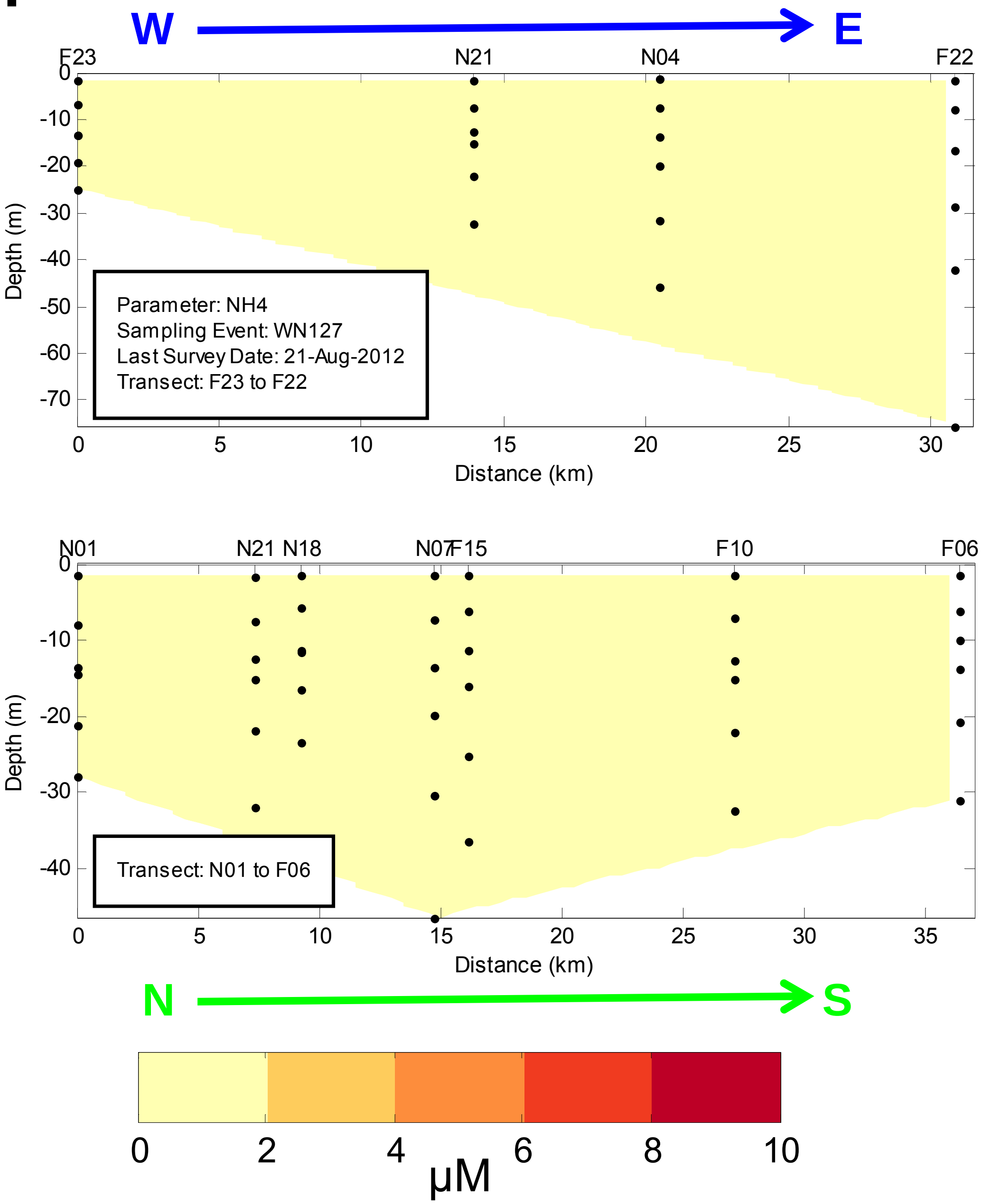
Parameter: NH4
Sampling Event: WN125
Last Survey Date: 19-Jun-2012
Transect: F23 to F22



Transect: N01 to F06

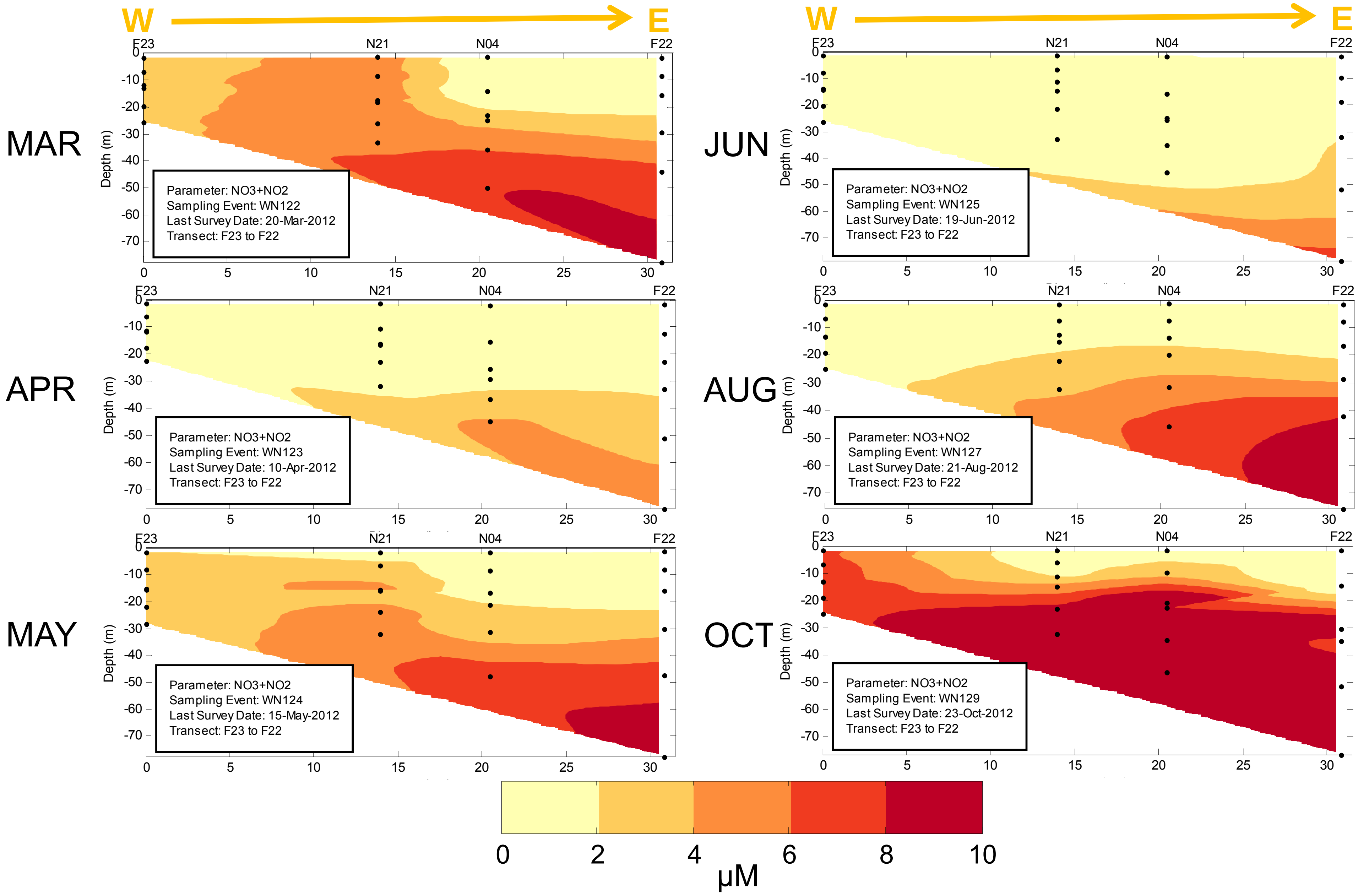
August 2012 - NH_4




Parameter: NH4
Sampling Event: WN127
Last Survey Date: 21-Aug-2012
Transect: F23 to F22

Transect: N01 to F06

2012 NO_3+NO_2 – W to E transect



Parameter: NO3+NO2
Sampling Event: WN122
Last Survey Date: 20-Mar-2012
Transect: F23 to F22

Parameter: NO3+NO2
Sampling Event: WN123
Last Survey Date: 10-Apr-2012
Transect: F23 to F22

Parameter: NO3+NO2
Sampling Event: WN124
Last Survey Date: 15-May-2012
Transect: F23 to F22

Parameter: NO3+NO2
Sampling Event: WN125
Last Survey Date: 19-Jun-2012
Transect: F23 to F22

Parameter: NO3+NO2
Sampling Event: WN127
Last Survey Date: 21-Aug-2012
Transect: F23 to F22

Parameter: NO3+NO2
Sampling Event: WN129
Last Survey Date: 23-Oct-2012
Transect: F23 to F22

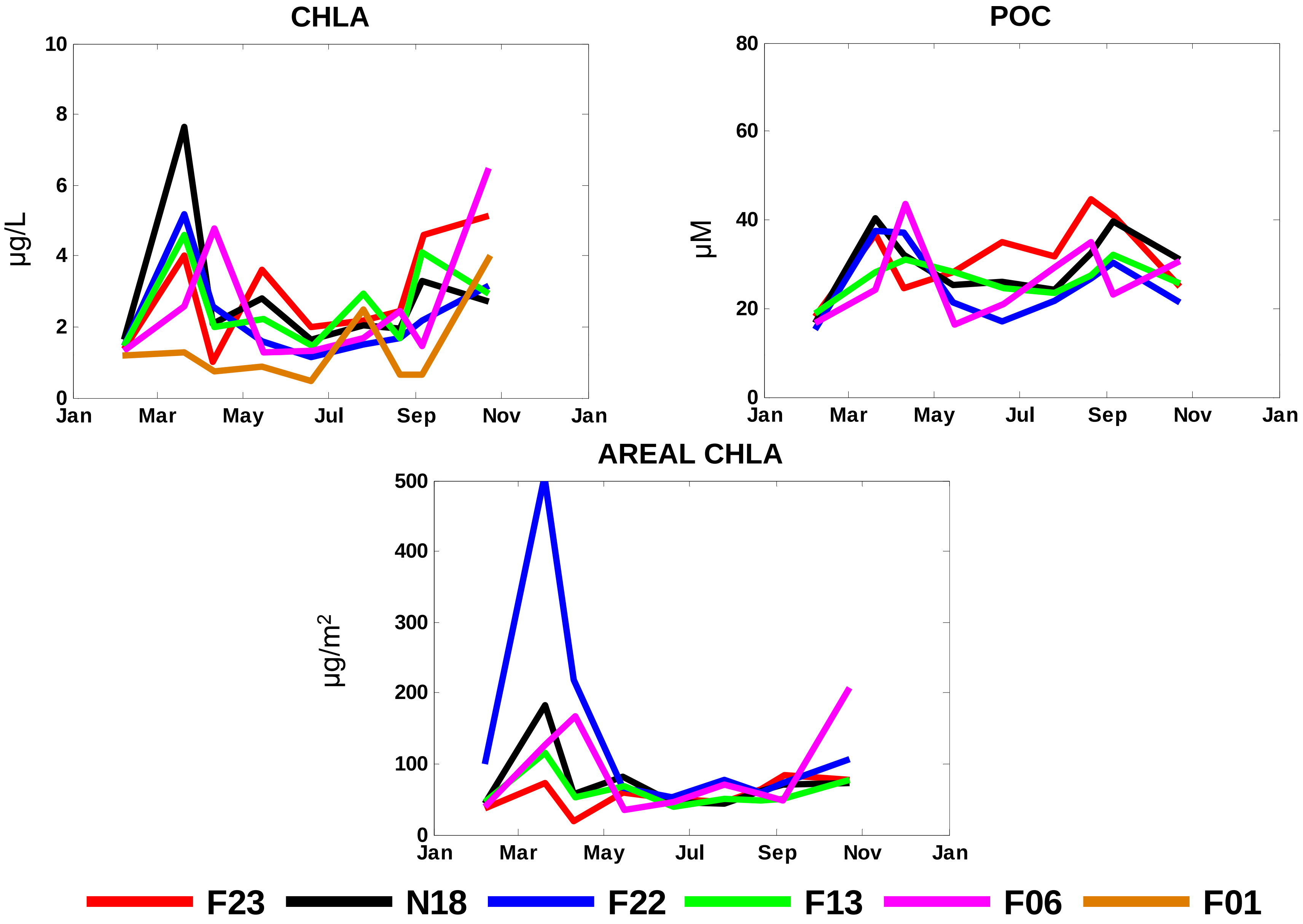
Threshold Values for DO and Chlorophyll

Parameter	Time Period	Caution Level	Warning Level	Background	2012
Chlorophyll	Annual	108 mg/m^2	144 mg/m^2	--	96 mg/m^2
	Winter/spring	199 mg/m^2	--	--	145 mg/m^2
	Summer	89 mg/m^2	--	--	69 mg/m^2
	Autumn	239 mg/m^2	--	--	78 mg/m^2
Bottom Water DO concentration	Survey Mean in June-October	< 6.5 mg/l (unless background lower)	< 6.0 mg/l (unless background lower)	Nearfield 6.05 mg/l Stellwagen 6.23 mg/l	6.19 mg/l 6.6 mg/l
Bottom Water DO %saturation	Survey Mean in June-October	< 80% (unless background lower)	< 75% (unless background lower)	Nearfield - 65.3% Stellwagen - 67.2%	67.5% 70.4%
Bottom Water DO depletion rate	June to October	0.037 mg/l/d	0.049 mg/l/d		0.022 mg/l/d

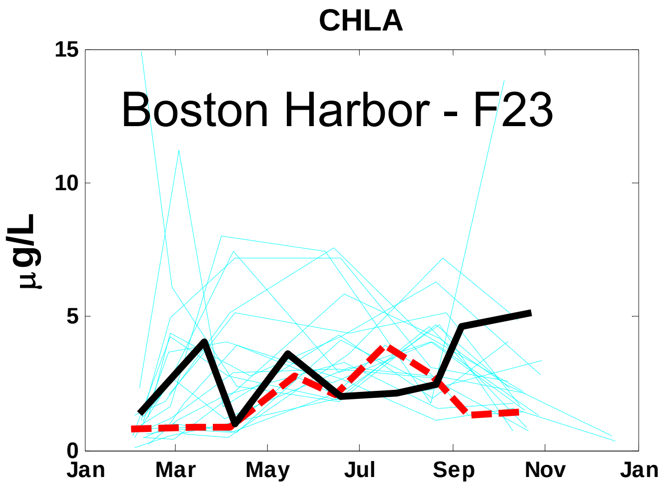
No Chlorophyll or DO threshold exceedances in 2012

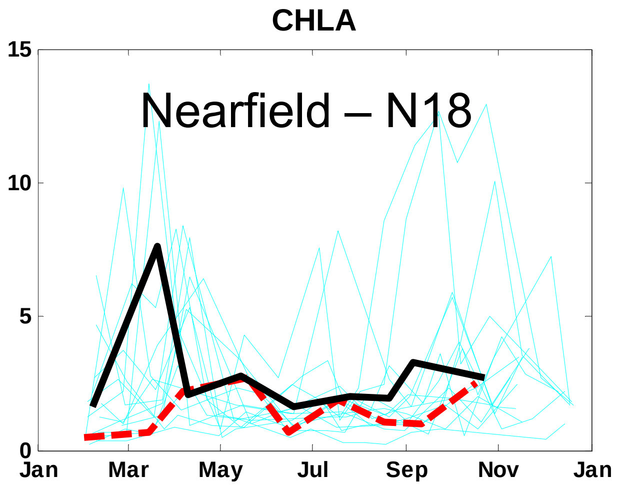
Relatively high chlorophyll levels and low DO

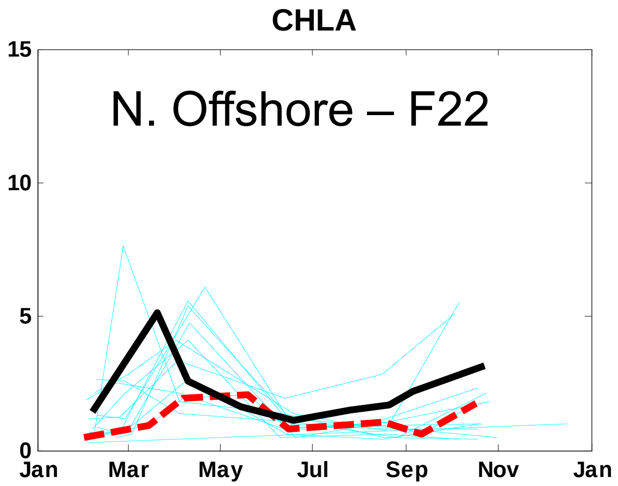
2012 Average Chlorophyll & POC

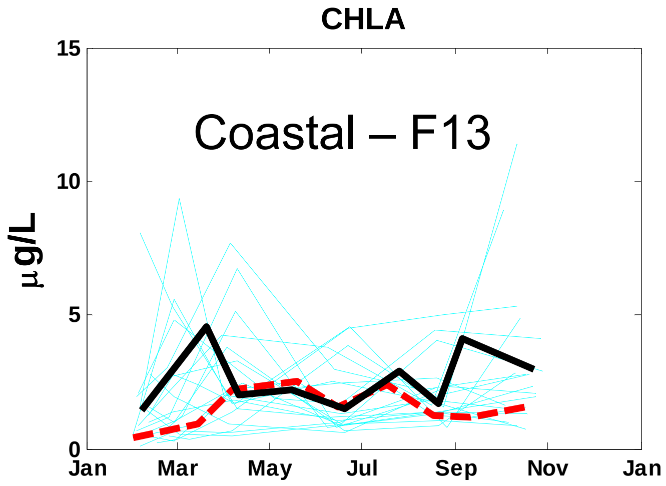


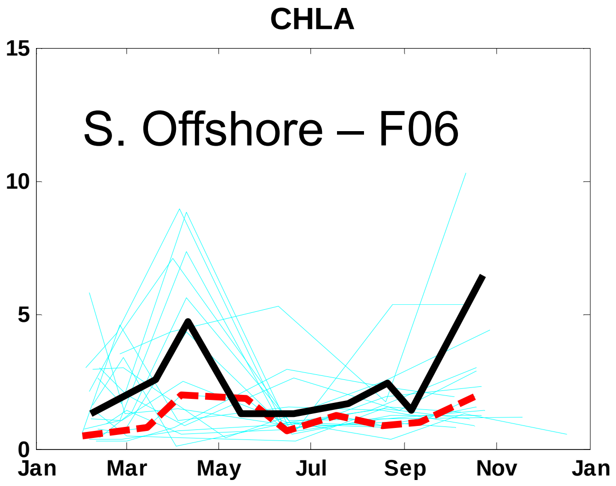
Long term Chlorophyll (µg/l)



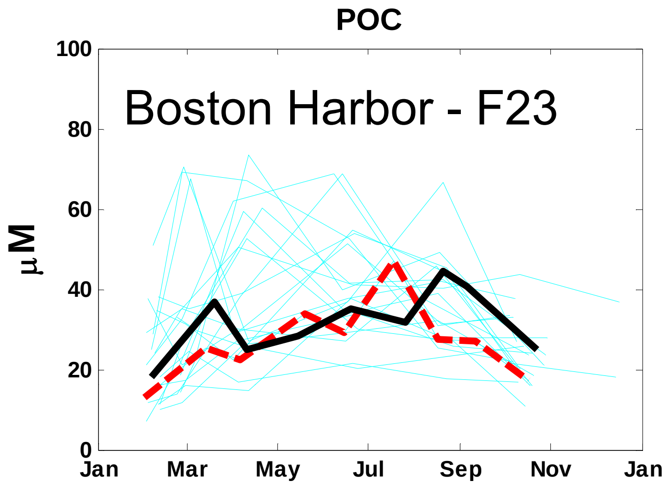


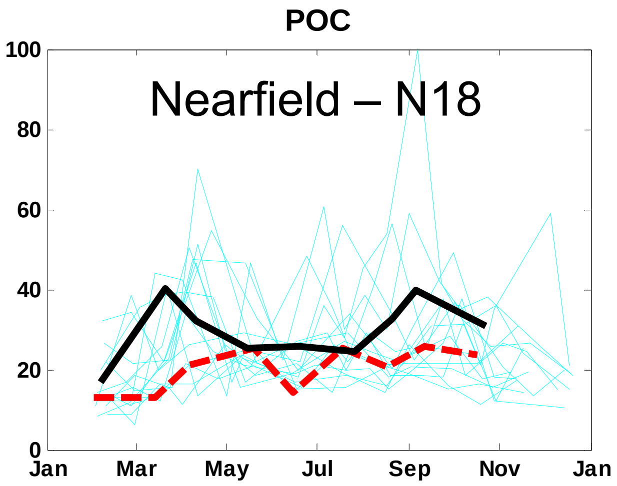


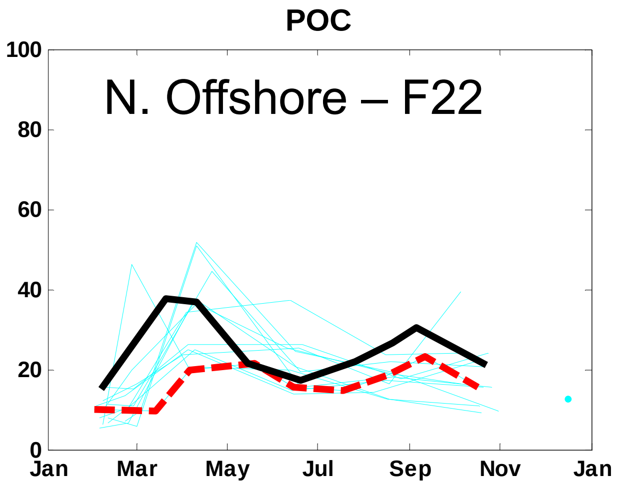


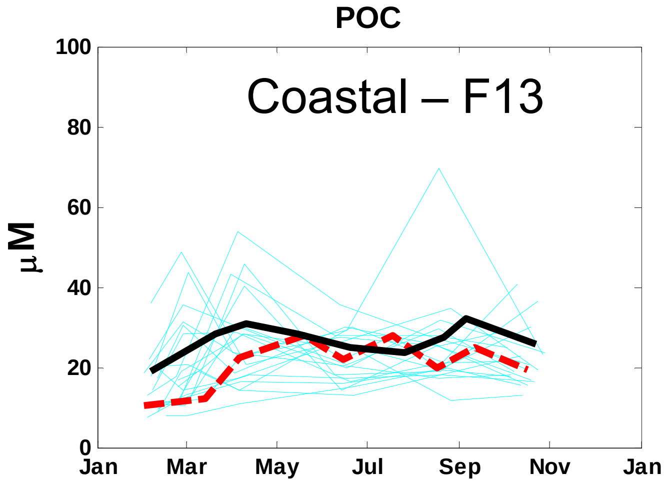


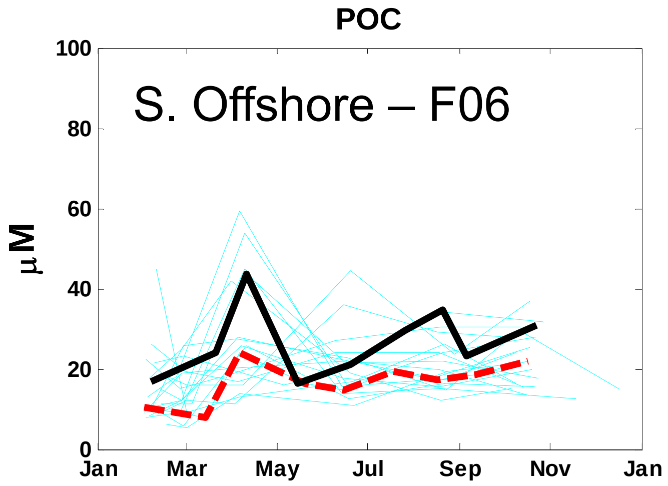
Long term POC (µM)



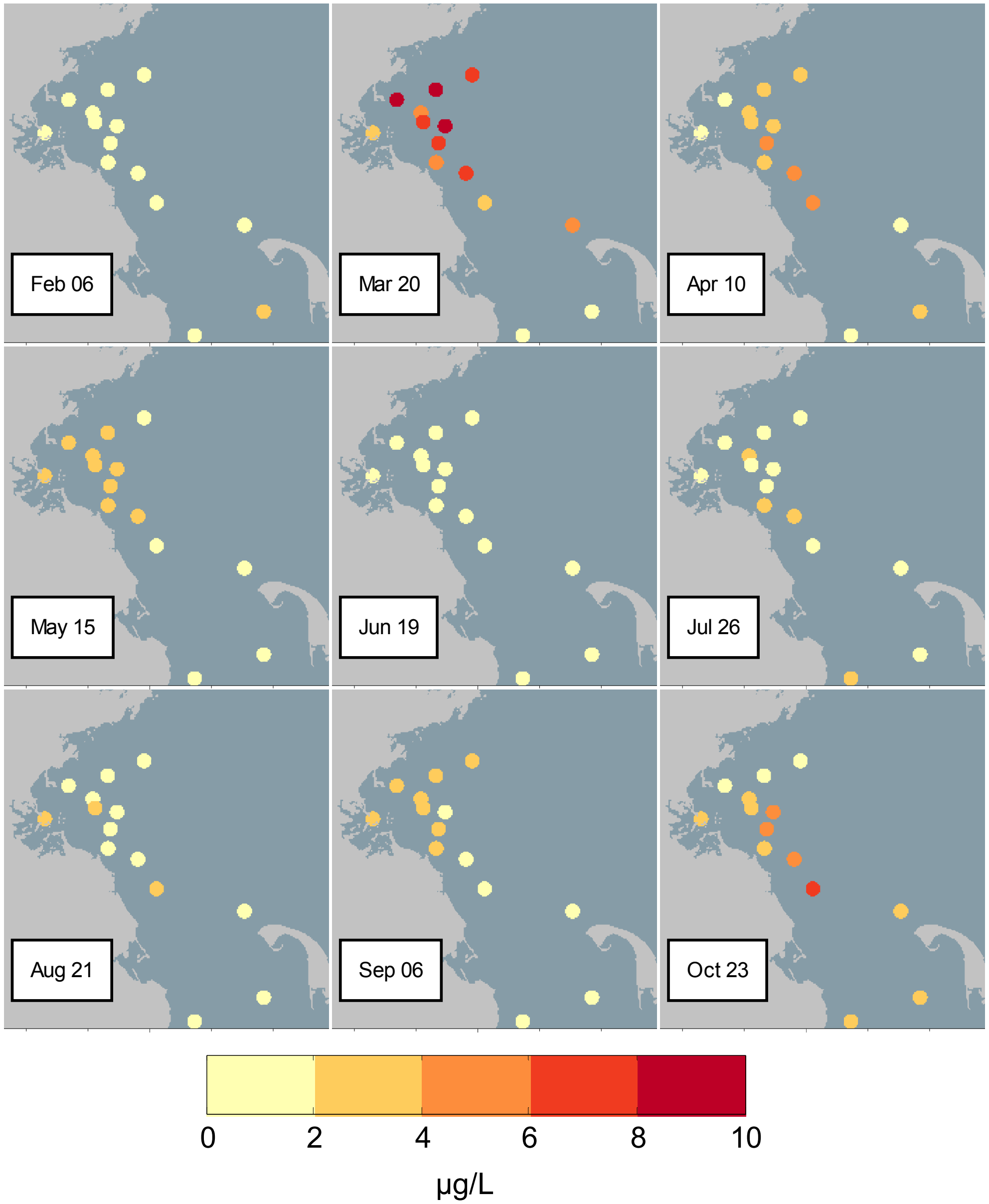




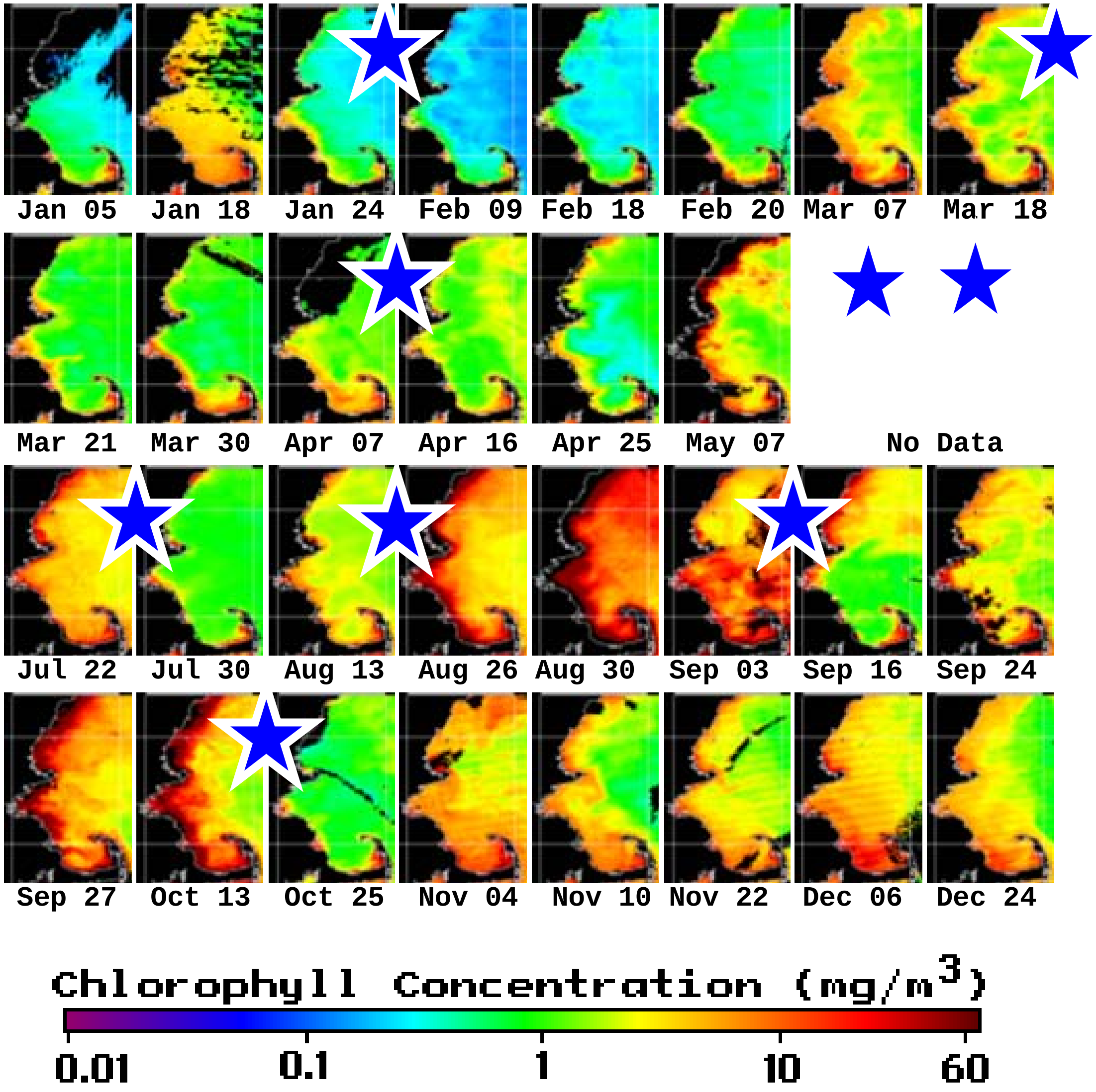




Average Chla Fluorescence (µg/L)

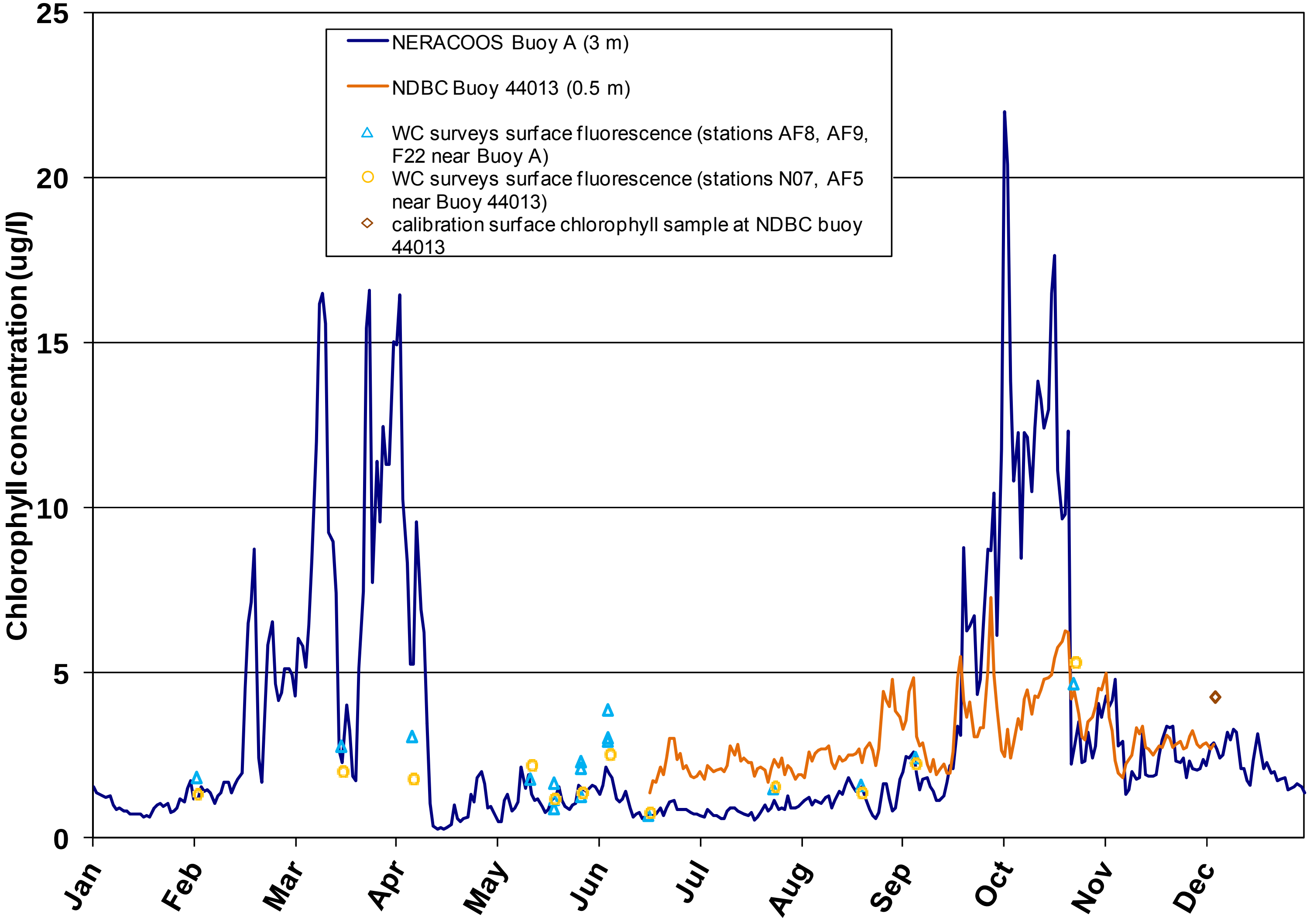


MODIS Chla Fluorescence

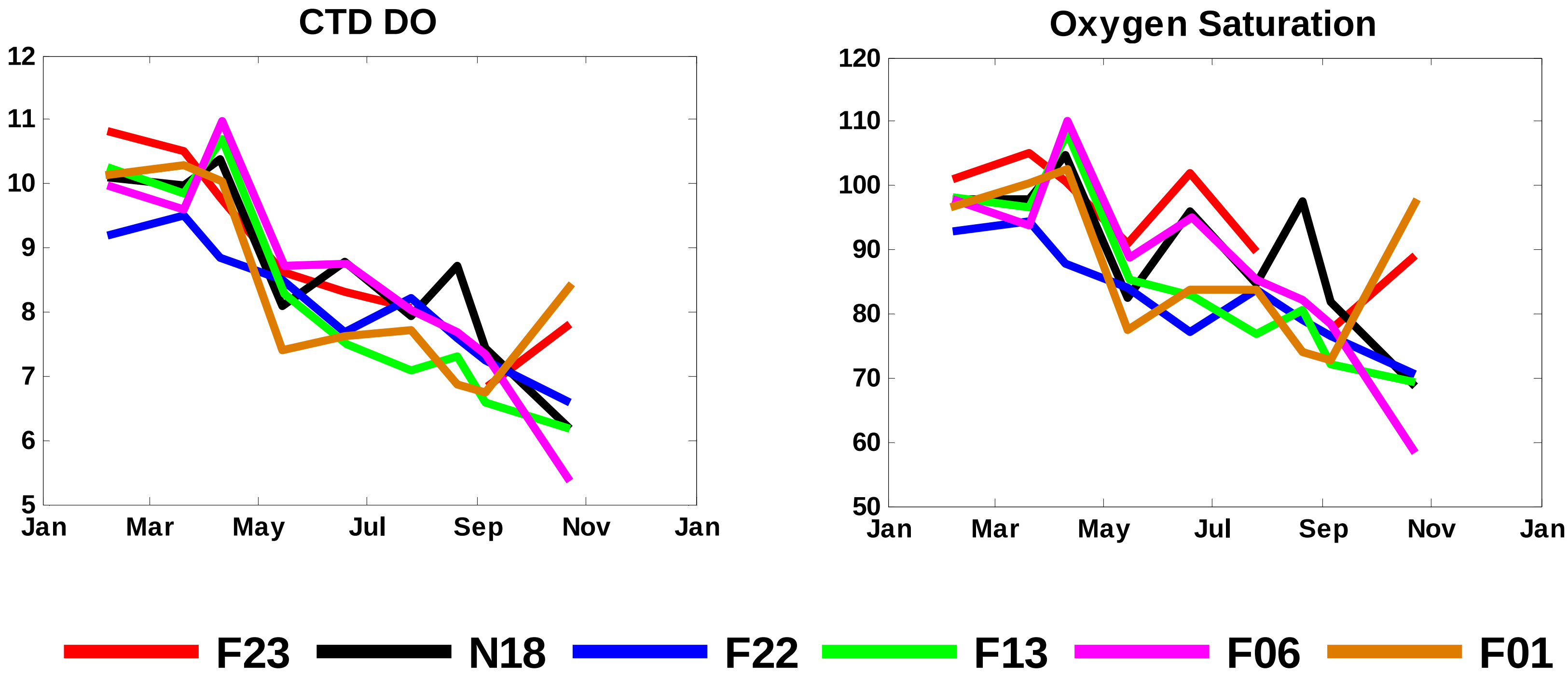


- Increase in early March – by March 20 baywide *Phaeocystis* bloom
- No data from May 8 – July 21
- Late summer chla increase
- September diatom bloom (*Skeletonema* dominated)
- Centric diatoms remain into October
- Elevated chlorophyll levels in November and December

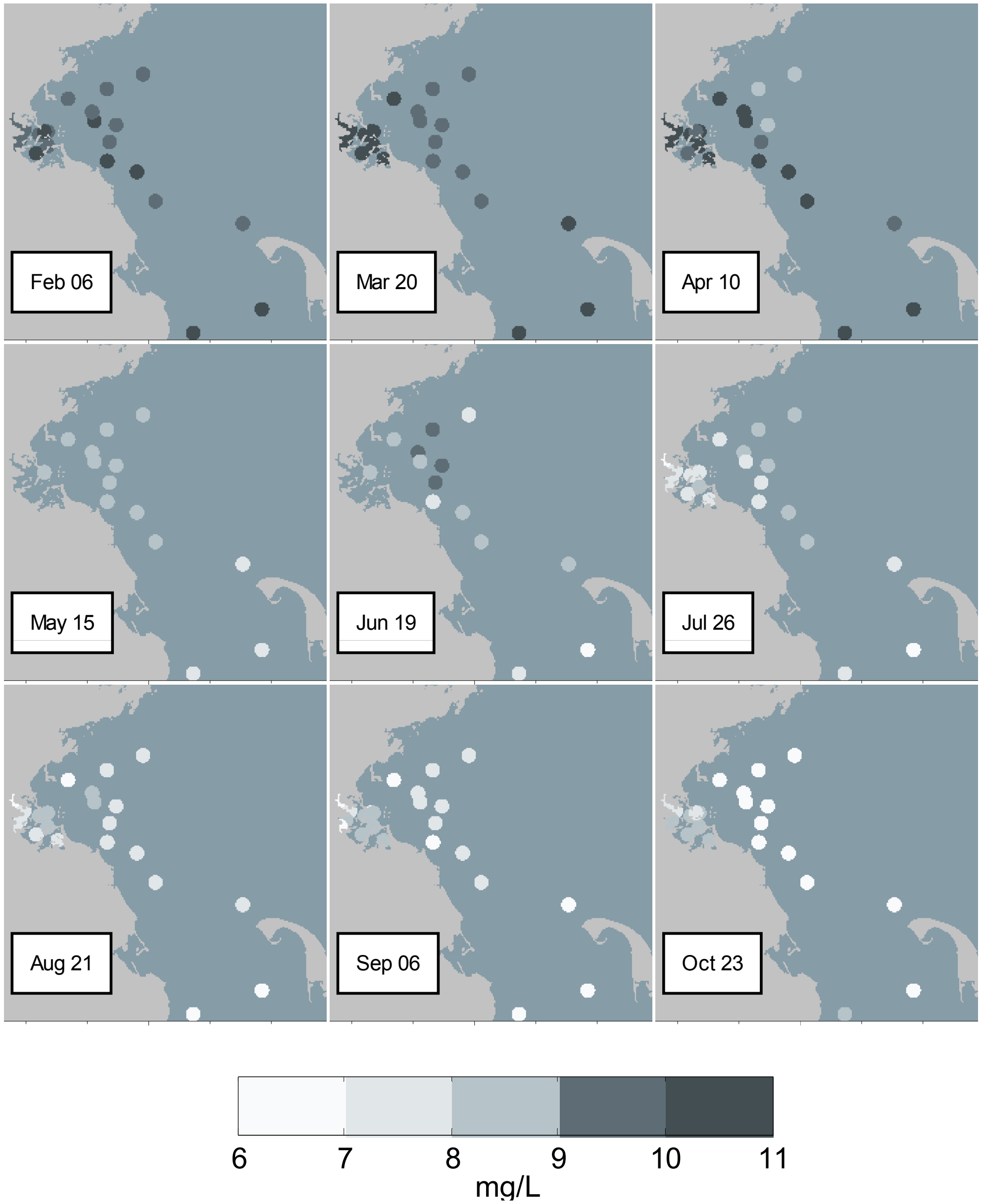
Buoy Surface Chlorophyll 2012



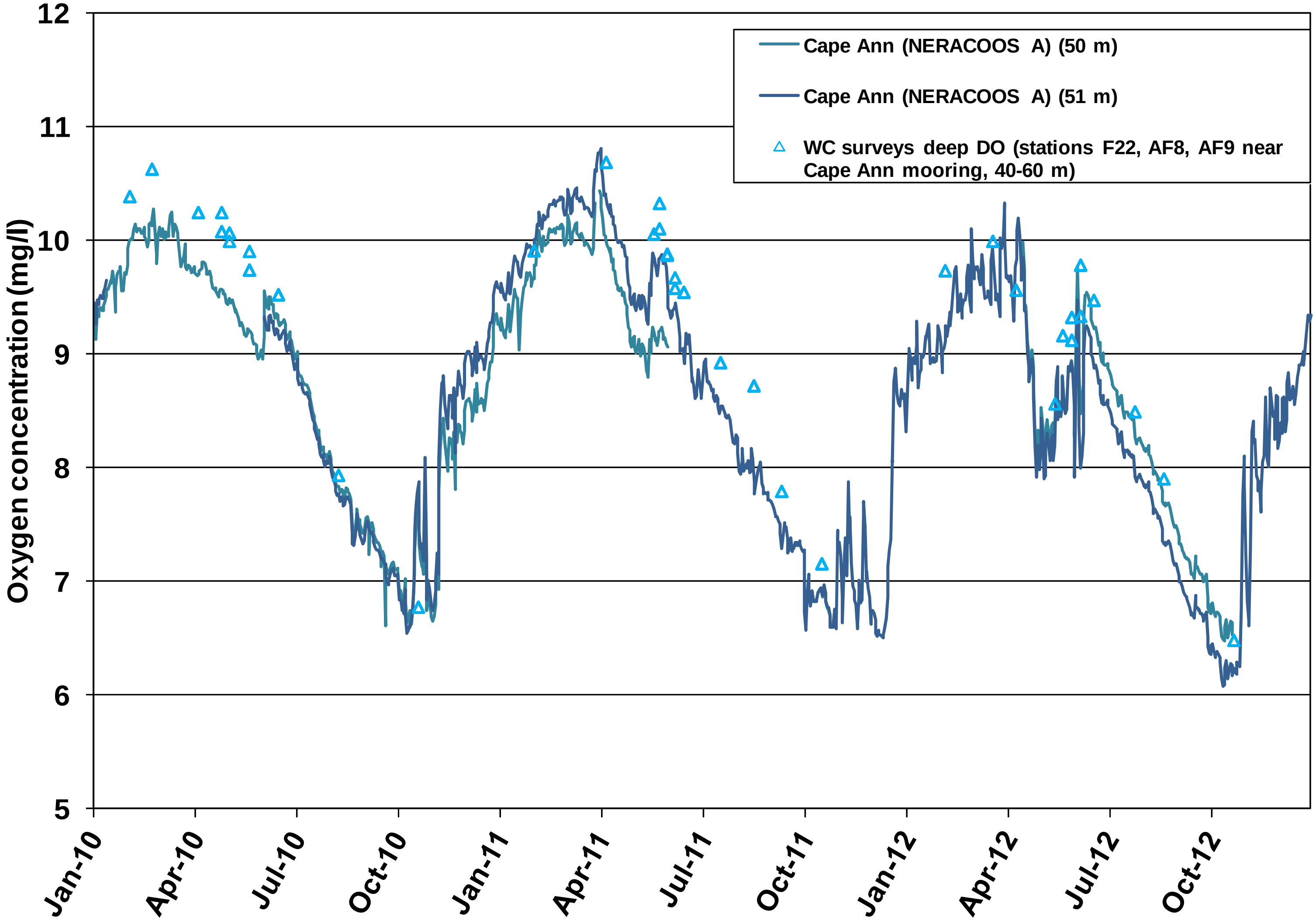
2012 – Bottom Water DO



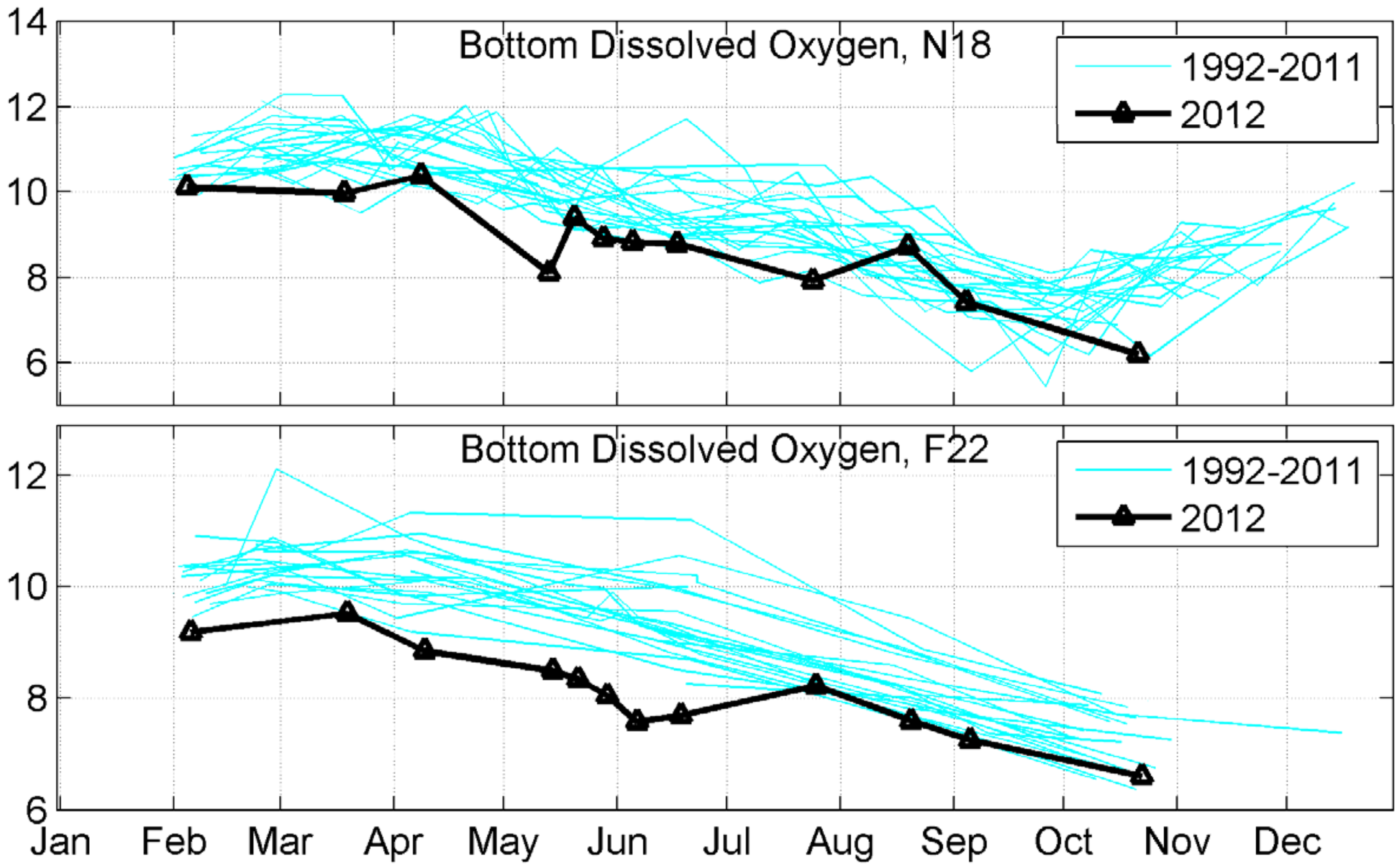
2012 Bottom DO



Cape Ann Buoy A – Bottom DO



Bottom DO Nearfield & Stellwagen


Nearfield
N18

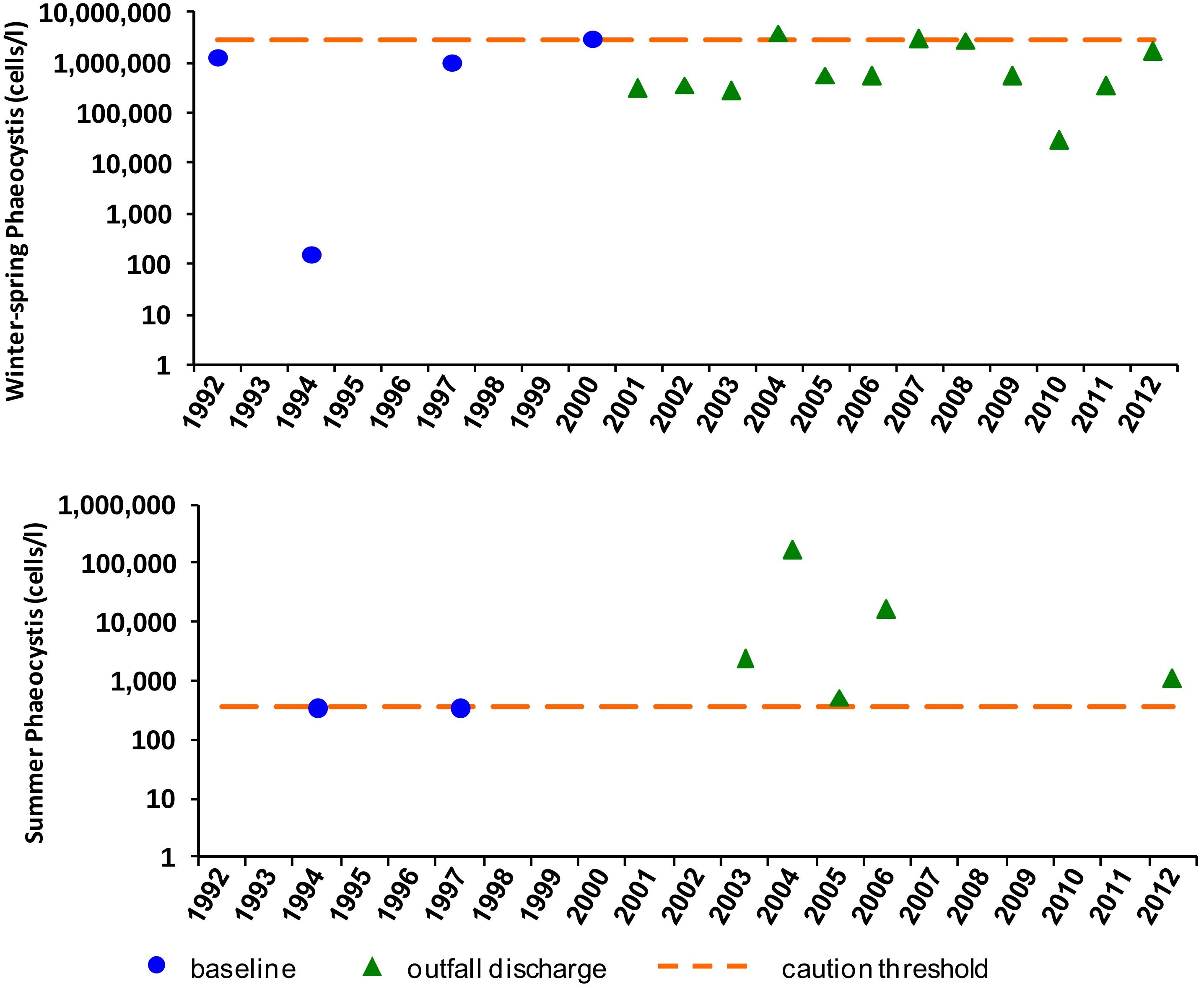
Stellwagen
F22

Threshold Values for Nuisance Species

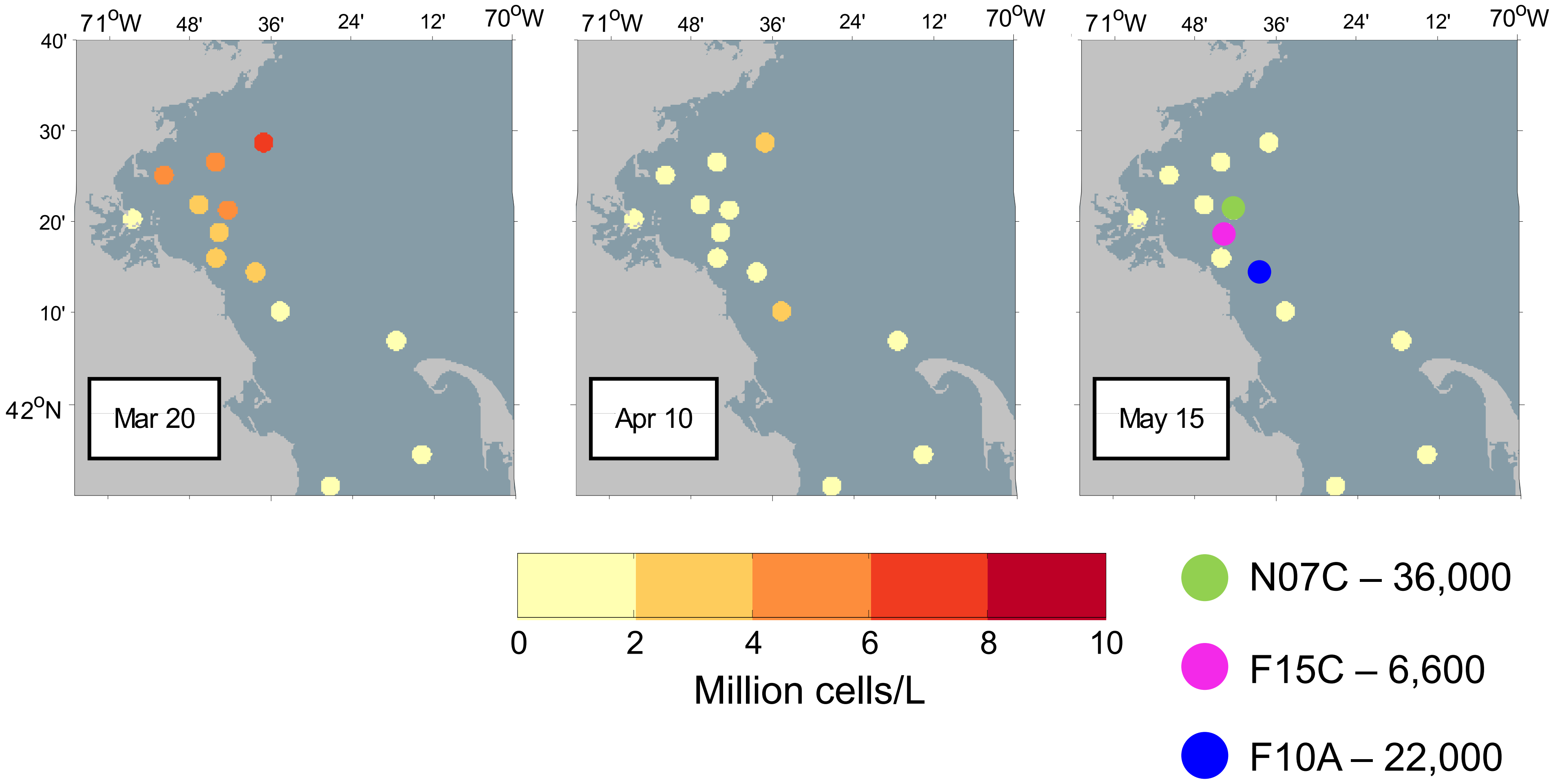
Parameter	Time Period	Caution Level	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Phaeocystis pouchetii (cells L^{-1})	**W**	2,860,000	303,000	366,000	272,000	**3,940,000**	571,000	526,000	**2,960,000**	2,720,000	552,000	28,100	338,000	1,690,000
	S	357	absent	absent	**2,420**	**164,000**	**517**	**16,800**	absent	absent	absent	absent	absent	1,120
	F	2,960	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent	absent
Pseudo-nitzschia (cells L^{-1})	**W**	17,900	8510	1230	149	15.5	202	absent	69	absent	absent	664	absent	526
	S	43,100	163	234	83.5	380	3320	absent	absent	540	absent	53.7	660	388
	F	27,500	3930	3090	833	1190	80.4	absent	absent	309	71.7	522	1,240	2,820
Alexandrium	**Any**	100	35	8	7	5	**36,831**	**5,668**	7.2	**60,430**	**151**	79	**2,454**	3,731

Summer *Phaeocystis* and *Alexandrium* threshold exceedances in 2012

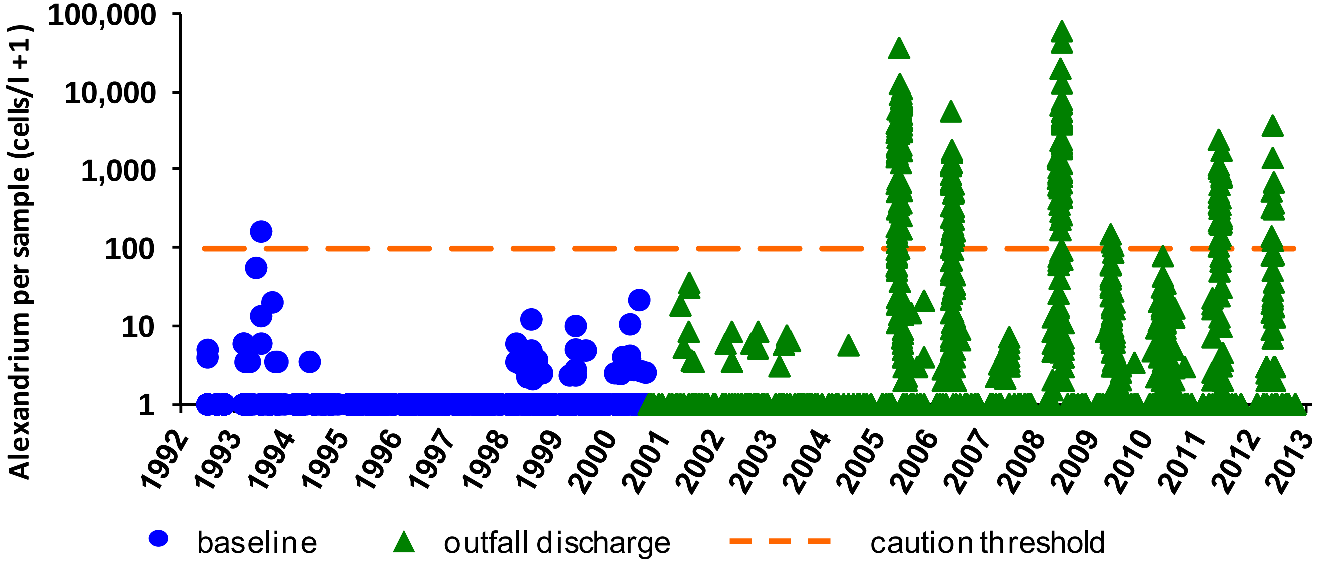
Phaeocystis seasonal means 92-12



Phaeocystis station means 2012



Nearfield *Alexandrium* Abundance



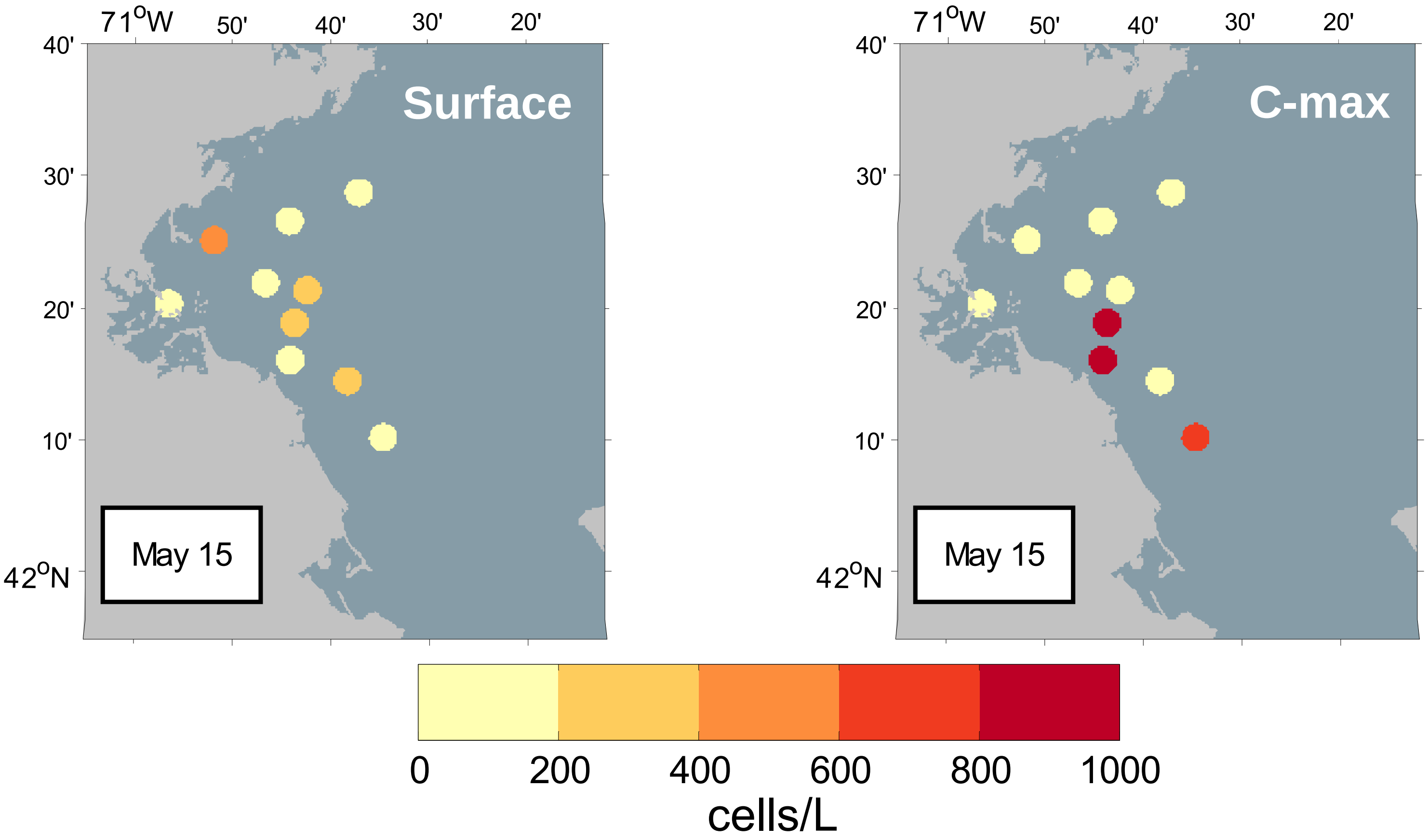
Moderate bloom for 2012 in Massachusetts Bay (as forecast)

Shellfishing closures in Mass Bay (Salem to Duxbury)

No closures in Massachusetts north of Salem

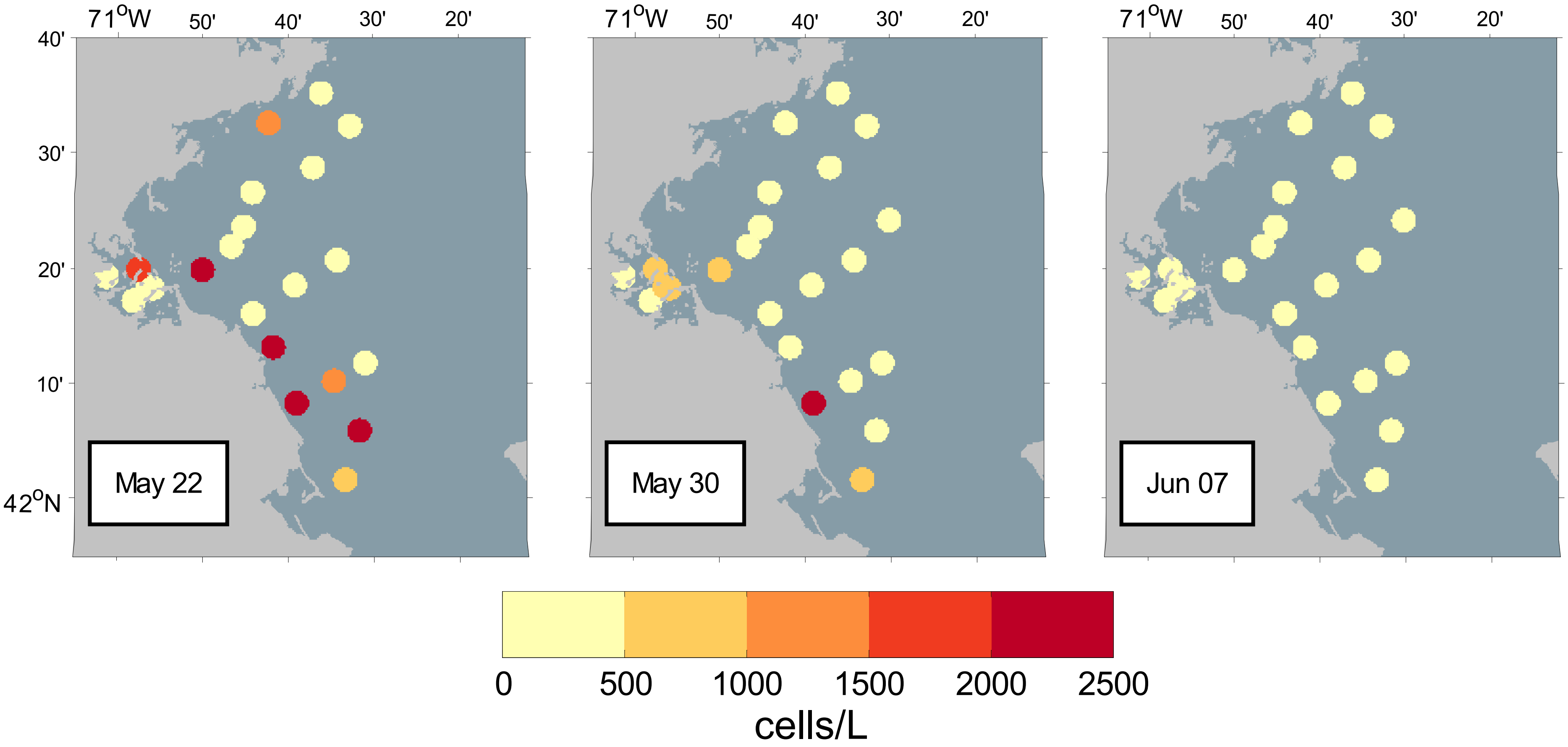
PSP closure map - 2012

2012 *Alexandrium* bloom



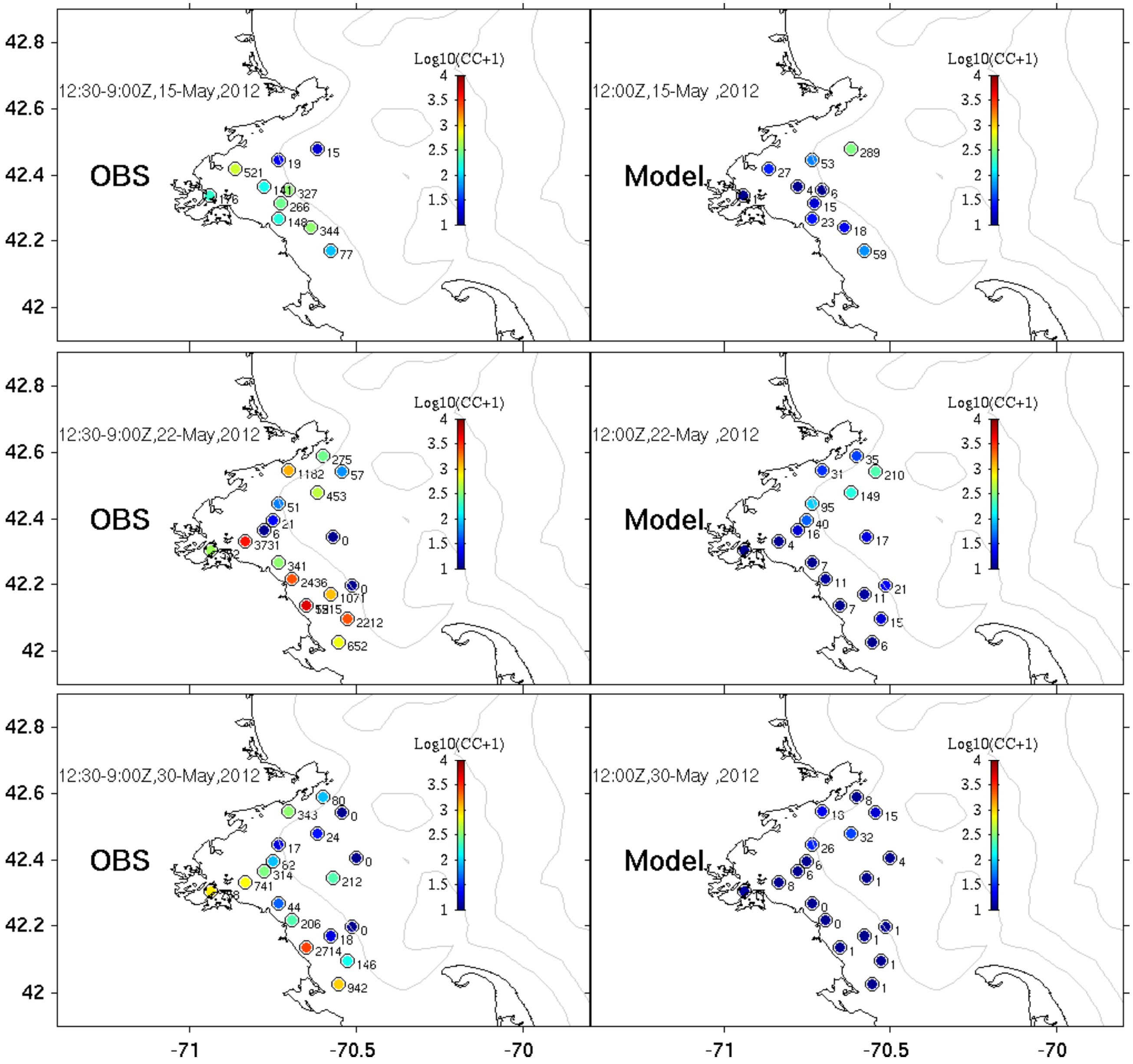
- A few cells present in early April in MB
- By May 15 – elevated abundances in Nearfield and to the south
- Nearfield peak abundance at N01 – 533 cells/L
- Highest values off Cohasset at depth of C-max (1,201 and 1,470 at stations F15 and F13, respectively)

2012 *Alexandrium* bloom



- Nearfield peak abundance May 22 at N10 – 3,731 cells/L
- Overall peak of 5,215 at station F05 off of Scituate on May 22
- Relatively high abundances through late May (2,700 cells/L at F05)
- Bloom over by early June

2012 Observations vs. Model



- Poor comparison between observed data and model
- Model captured initiation of the bloom
- Model missed high abundances and spatial trends in the observed data
- Why – weather?
  Or perhaps unrealistic expectations of model resolution?
- Forecast for moderate bloom was correct

Summary

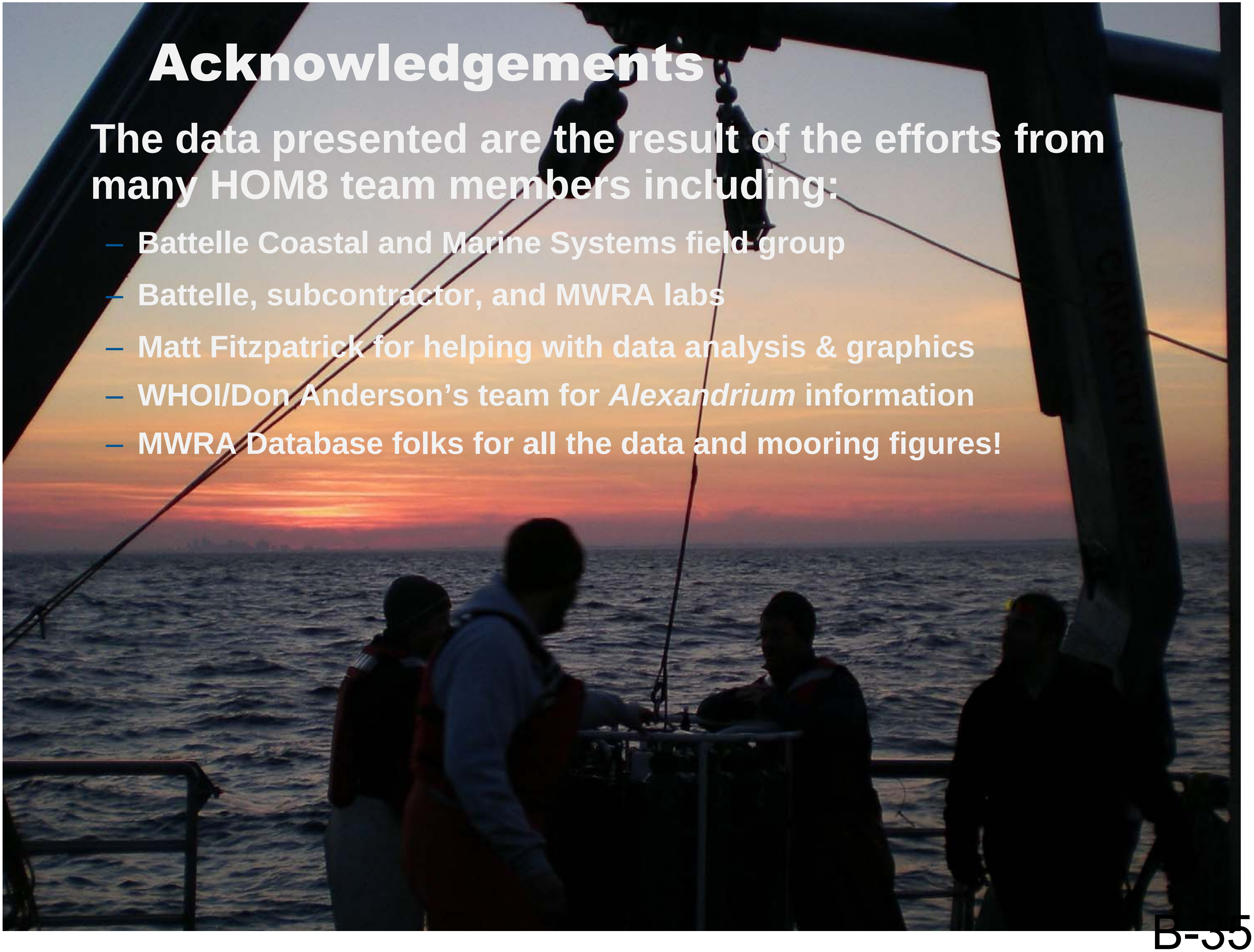
- Nutrients
  - Lower in February 2012 compared to 2011 and previous years
  - Surface NO_3 was depleted over most of the bay by March, there was also a decrease in SiO_4 in March, but SiO_4 increased in April when NO_3 was depleted throughout the bay (mixed diatom/*Phaeocystis* bloom in March and April)
  - Nutrient concentrations increased in May following the remixing of the water column due to a strong Nor'easter
  - Surface nutrients remained low during summer with increasing concentrations and variability into the fall
  - Effluent plume elevated NH_4 signal
    - clearly observed in the surface waters during well mixed conditions
    - elevated subsurface concentrations were seen in the nearfield and to the south (Station F15) during stratified conditions
    - in August no evidence of plume in NH_4 measurements
  - Except for the elevated NH_4 levels in the effluent plume (consistently high since diversion to the bay outfall September 2000) – nutrient levels in 2012 were similar to those observed in 1992-2011 in Massachusetts Bay.

Summary

- Chlorophyll
  - High chlorophyll in March (annual maxima) with early winter/spring bloom of *Phaeocystis* (plus minor *Chaetoceros*) and remained elevated in April
  - Winter/spring chlorophyll (and POC) levels much higher than 2011 and among higher levels observed during the monitoring program
  - MB and BH stations had peaks in chlorophyll and POC in both spring and fall 2012 with comparable levels achieved each season and lower levels during the summer.
  - Increase in chlorophyll in September during a fall diatom bloom and remained elevated in October (centric diatom blooms)
- Dissolved Oxygen
  - Bottom water 2012 levels were low throughout the year across the bays
  - Increase in DO in late May due to a major mixing event
  - Minima in October were only slightly above background minima
  - Related to the warm, dry conditions as suggested by Rocky's model and further exacerbated by higher inputs of organic material (measured as chlorophyll and POC)

Summary

- Contingency Plan Thresholds
  - Winter/spring and fall phytoplankton blooms were moderate to substantial in comparison to past blooms; chlorophyll levels were relatively high resulting in moderate seasonal and annual chlorophyll threshold values
  - DO concentrations and percent saturation were low, only slightly above warning threshold levels, but remained above background levels in in both nearfield and Stellwagen Bank bottom waters
  - *Phaeocystis* present in the bays in March-April at moderate to high abundances; remnants of bloom were present in May resulting in threshold exceedance
  - *Pseudo-nitzschia* abundance continues 10+ year trend of low abundances
  - A moderate *Alexandrium* bloom was observed in MB in 2012
    - Abundances peaked at 3,700 cell/L in the nearfield in late May
    - Shellfishing closures extended across western MB from Salem to Duxbury Bay
    - Continues trend of blooms and PSP toxicity in MB since the 2005 red tide event
    - Disconnect between model and observed data
    - Forecast for moderate bloom was correct



Acknowledgements

The data presented are the result of the efforts from many HOM8 team members including:

- Battelle Coastal and Marine Systems field group
- Battelle, subcontractor, and MWRA labs
- Matt Fitzpatrick for helping with data analysis & graphics
- WHOI/Don Anderson’s team for *Alexandrium* information
- MWRA Database folks for all the data and mooring figures!

2012 MWRA Phytoplankton Monitoring Summary

David Borkman

2012 Phytoplankton Annual Cycles

2012 total phytoplankton abundance (1.68 X 10^6 cells L^{-1}) was near the long-term mean abundance level (1.50 X 10^6 cells L^{-1}). The 2012 phytoplankton cycle featured tow main pulses: a predominantly offshore *Phaeocystis pouchetii*-dominated pulse in March and a predominantly harbor and coastal pulse of the centric diatom *Skeletonema* spp. in September 2012 (slide 3). The magnitude of the March 2012 *Phaeocystis* bloom (maximum of 10.8 X 10^6 cells L^{-1}) at the northern and southern offshore stations dwarfed the magnitude of the September 2012 *Skeletonema* spp. bloom (maximum if 2.5 X 10^6 cells L^{-1}) resulting in a winter-spring dominated annual cycle in the offshore regions (slide 3). In other regions that had lower winter-spring *Phaeocystis* abundance, the total phytoplankton annual cycle featured winter-spring and late summer peaks in abundance that were of similar magnitude (slide 3).

The *Phaeocystis pouchetii* bloom in March and April was the dominant phytoplankton event of 2012 (slide 7). In 2012 *Phaeocystis* abundance was greatest in the northern offshore region, with individual sample *Phaeocystis* observations reaching a maximum of 10.8 X 10^6 cells L^{-1}. The timing of the 2012 *Phaeocystis* bloom differed from previous years in that its peak occurred in March 2012 rather than the usual April *Phaeocystis* bloom peak (slide 7). Overall, 2012 was a '*Phaeocystis* year' with *Phaeocystis* abundance was among the top one-third (2012 was 7th ranked of 21 years) in *Phaeocystis* abundance. Of note was the elevated abundance of *Phaeocystis* at the sub-surface (Cmax) depth. In 2012 subsurface *Phaeocystis* abundance (742,924 cells L^{-1}) was ca. 3-fold that observed at the surface (235,188 cells L^{-1}).

Microflagellates usually dominate Massachusetts Bay phytoplankton numerically and 2012 offered no exception to this. Mean microflagellate abundance in 2012 (720,024 cell L^{-1}) was within 5% of the long-term mean abundance of 696,066 cell L^{-1}. While abundance was near the long-term mean pattern, the 2012 microflagellate annual cycle was unusual in that the annual abundance peak occurred in April or May of 2012 rather than the mid-summer peak usually observed (slide 5). 2012 featured an anomalously warm winter (see Geyer summary), and it is possible that the one-month earlier than usual *Phaeocystis* peak and the earlier than usual peak in microflagellate abundance may be related to the warm winter conditions and subsequent water column habitat changes.

The 2012 centric diatom annual cycle had a summer character. Annual maximum centric diatom abundance was observed in September or October in all regions monitored except the northern offshore stations that had an annual peak in June 2012 (slide 9). A large winter-spring diatom bloom was not observed in any region during 2012 monitoring. *Thalassiosira* spp. and Chaetoceros spp. dominated the winter-spring diatoms. Of note was a *Chaetoceros* spp. (dominated by *C. socialis*) bloom in the northern offshore region that reached ca. 350,000 cells L^{-1} in May 2012 (slide 11). This far exceeded (by >4-fold) previous *Chaetoceros* spp. abundance observations for that region. The summer centric diatom community featured *Leptocylindrus minimus, Leptocylindrus danicus, Cerataulina pelagica* and *Skeletonema* spp. at relatively low abundance levels from June through August 2012. In September 2012 a bloom of *Skeletonema* spp. was observed (slide 10). This *Skeletonema* bloom was the dominant feature of the 2012 centric diatom cycle, with *Skeletonema* spp. abundance peaking at ca. 2.5 X 10^6 cells L^{-1} in the harbor, coastal and nearfield regions during September 2012. The relatively weak winter-spring diatom bloom was offset by this large, coastal and harbor summer *Skeletonema* bloom such that mean 2012 centric diatom abundance (2012 mean = 356,875 cells L^{-1}) was near the long-term mean of 307,132 cells L^{-1}.

Pennate diatom abundance remained relatively low in 2012, continuing the trends of low pennate diatom abundance observed over the past several years. Mean pennate diatom abundance in 2012 (16,902 cells L^{-1}) was ca. one-third of the long-term mean abundance of 48,299 cells L^{-1} (slide 15).

Dinoflagellate abundance during 2012 (mean = 52,065 cells L^{-1}) was near the long-term level of 53,371 cells L^{-1} (slide 13). Dinoflagellate abundance ranged from tens of thousands of cells per liter in February through April and reached a mid-summer peak of ca. 100,000 to 200,000 cells L^{-1} at most stations. The dinoflagellate community composition displayed a seasonal shift from relatively small forms (*Heterocapsa triquetra, Heterocapsa rotundata*, small *Gymnodinium* spp.) in the late winter to early spring to large forms dominated by *Ceratium* spp. in the summer. *Ceratium* spp. showed a large increase in 2012 relative to levels seen in the past several years (slide 14), with 2012 mean *Ceratium* spp. abundance (2,848 cells L^{-1}) that was ca. double the long-term mean *Ceratium* abundance of 1,427 cells L^{-1}. Large *Ceratium* are slow growing cells that thrive at the seasonal pycnocline and require prolonged periods of stratification in order to accumulate. The 2012 return of *Ceratium* abundance to levels not seen since 2001 suggests a change in water column stability, perhaps related to the warm winter-spring of 2012.

Surface vs. Cmax Total Phytoplankton Abundance 2012

In most years there is an approximately 1:1 ratio between the numerical abundance of total phytoplankton at the surface and the Cmax depth (Figure 1). Comparison of 1188 paired surface and Cmax estimates of total phytoplankton show that the slope of a fited line is +1.05, implying that Cmax phytoplankton abundance is 1.05 time that observed at the surface. In 2012 however, the slope of the line fitted to the paired surface-Cmax plot was +1.53, implying that Cmax phytoplankton was 1.5 times that observed at the surface during 2012. A comparison of slopes test showed that the 2012 slope (+1.53) was significantly different than the long-term mean slope of 1.05 (F=9.97; df=1,1188; p=0.0016; Figure 1). In 2012 much of the deviation from the long-term pattern appears to be due to the elevated sub-surface abundance of *Phaeocystis pouchetii* observed in the spring of 2012.

The 2012 phytoplankton annual cycles can be summarized by the following highlights:

- Microflagellate near long-term abundance.
    - Annual peak early (April-May). Emergent pattern? Related to warming?
- *Phaeocystis*
    - A "*Phaeocystis* year"; 7th greatest abundance in 21 years
    - *Phaeocystis* blooms ($>10^6$ L^{-1}) in past 12 years running
    - Sub-surface abundance ca. 3X surface abundance
    - Bloom peak in March instead of April. Related to warming?
- Diatoms
    - Winter-spring bloom reduced or absent
    - September *Skeletonema* bloom was dominant diatom feature
- Dinoflagellates
    - Small cells (*Gymnodinium, Heterocapsa*) in spring 2012
    - Transition to larger forms (*Ceratium)* in summer.
    - *Ceratium spp.* returned to greater than long-term mean abundance levels in 2012

2012 Potentially Harmful Phytoplankton:

2012 featured a large *Phaeocystis pouchetii* bloom in March-April 2012 with a maximum of 10.8 x 10^6 cells L^{-1} in March. There was a moderate *Alexandrium fundyense* bloom (5,215 cells L^{-1} maximum) in April-June of 2012. *Pseudo-nitzschia* spp. abundance remained relatively low in 2012 (mean 8,245 cells L^{-1}) reduced relative to long-term levels (11,190 cells L^{-1}).

2012 Phytoplankton Abundance Relative to Prior Years

The 2012 abundance of main phytoplankton groups was compared to long-term (1992-2011) levels using a Mann-Whitney test (slide 22). Total phytoplankton abundance in 2012 (1.68 X 10^6 cells L^{-1}) was not significantly different than the long-term mean level of 1.50 cells X 10^6 cells L^{-1}. However, analyses of other species and functional groups reveal a pattern of reduced winter-spring and mid-summer diatoms and elevated late summer (*Skeletonema* spp.) diatom abundance. *Thalassiosira* spp., commonly a major component of the winter-spring diatom bloom, abundance in 2012 (6,669 cells L^{-1}) was significantly lower than the long-term mean of 36,801 cells L^{-1}. Similarly, *Dactyliosolen fragilissimus*, a centric diatom that typically is most abundant in early to mid-summer was relatively low in 2012 (6,372 cells L^{-1}) compared to the long-term mean (48,873 cells L^{-1}). The low winter-spring and early summer diatom abundance was offset by increased late summer abundance of *Skeletonema* spp. which was abundant in 2012 (160,535 cells L^{-1}) compared to the long-term mean (60,510 cells L^{-1}). Together the reduced winter-spring and elevated late summer diatom abundance pattern resulted in a mean diatom abundance in 2012 (356,875 cells L^{-1}) that was not significantly different than the long-term average of 307,132 cells L^{-1}.

Mean *Phaeocystis pouchetii* abundance in 2012 (455,943 cells L^{-1}) was significantly greater than the long-term mean level (256,533 cells L^{-1}). In addition, *Phaeocystis* abundance at the sub-surface was elevated relative to the surface in 2012 (slide 22). This contributed to the unusual elevated abundance of subsurface phytoplankton relative to surface abundance observed in 2012 (Figure 1). *Ceratium* spp. a genus of large dinoflagellates that thrive in the sub-surface pycnocline were elevated in 2012 (2,848 cells L^{-1}) in comparison to the long-term mean of 1,427 cells L^{-1}.

2012 featured near mean total phytoplankton abundance. The dominant feature of the 2012 phytoplankton annual cycle was the March-April *Phaeocystis* bloom. Graphical representation of a similarity index shows that 2012 was not anomalous with regard to phytoplankton abundance and community composition (slide 24). In this graphical representation of monitoring years in multidimensional phytoplankton species/functional group space, proximity of years implies similarity in phytoplankton community composition. Further, coding of the years by *Phaeocystis* abundance (green bubbles in slide 24) identifies a group of seven years (1992, 1997, 2000, 2004, 2007, 2008, 2012) that are '*Phaeocystis* years' with bloom concentrations of 2.5 X 10^6 cells L^{-1} to 11.7 X 10^6 cells L^{-1}. This contrasts with the remainder of years in which the maximum *Phaeocystis* abundance was <2.5 X 10^6 cells L^{-1} (slide 24). Overall, 2012 phytoplankton was near long-term mean levels and community composition, with a large *Phaeocystis* bloom in March-April of 2012. The relatively early (March instead of April peak) 2012 *Phaeocystis* and the spring, rather than summer, peak in microflagellate abundance were coincident with an anomalously warm winter of 2012. Ongoing analyses will attempt to statistically link this anomalous warm winter to 2012 phytoplankton patterns in an attempt to infer mechanisms that may be driving the temporal advance of *Phaeocystis* and microflagellate observed in 2012.

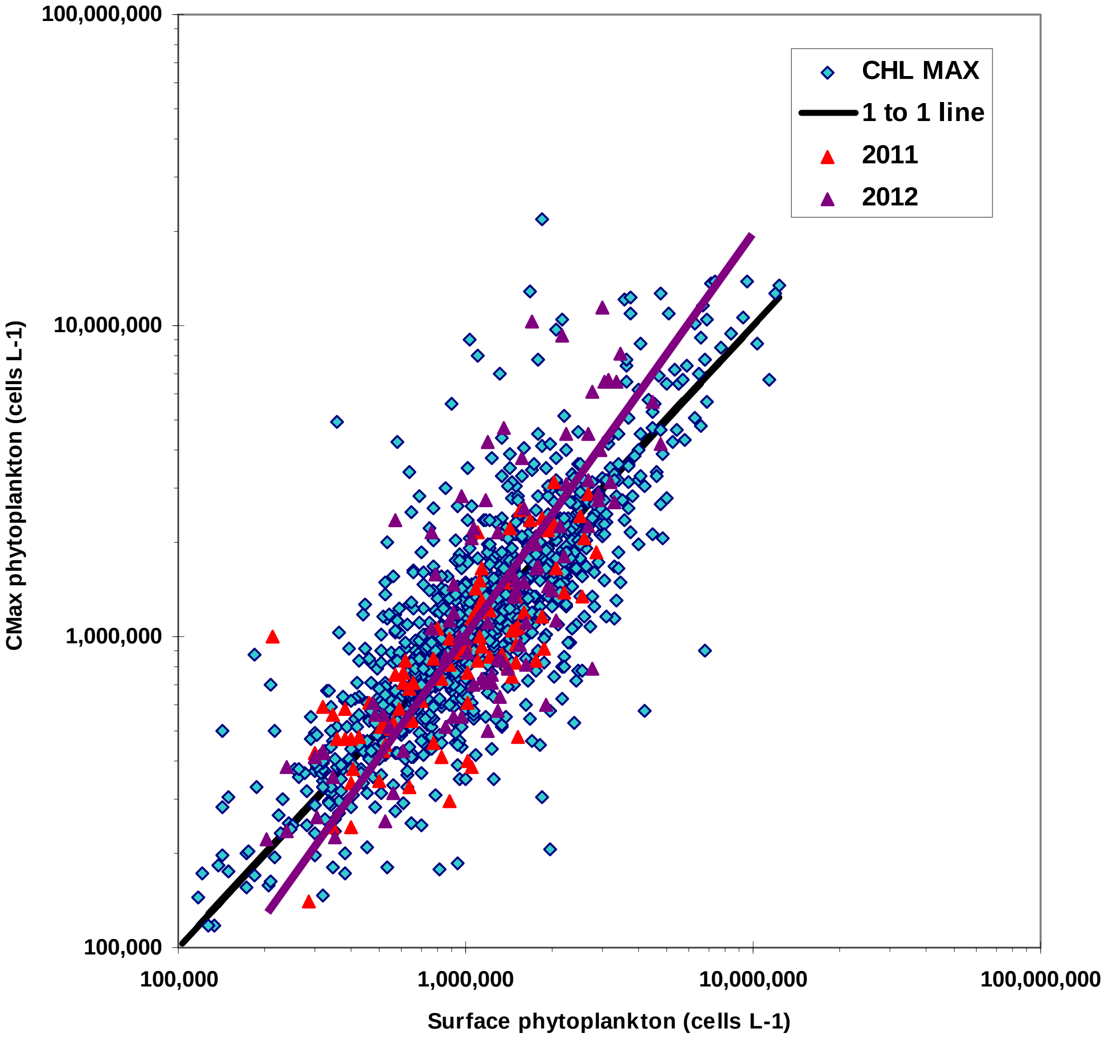


Figure 1: Comparison of paired surface and sub-surface (Cmax) total phytoplankton abundance at MWRA Massachusetts Bay monitoring stations during 1992-2012. Slope of 2012 observations (= 1.53) was significantly different (F = 9.97; df=1, 1188; p=0.0016) than the long-term slope of 1.05 indicating elevated sub-surface phytoplankton abundance during 2012.

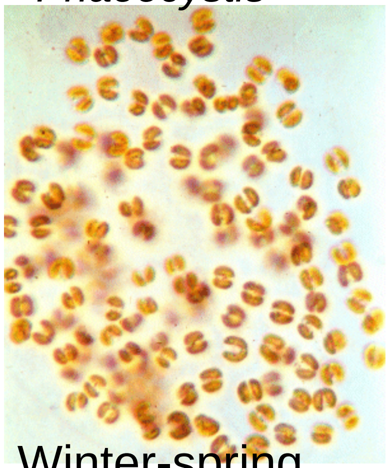
2012 Phytoplankton Summary

David Borkman

URI Graduate School of Oceanography

- Phytoplankton regional distribution patterns
- Annual cycles: 2012 vs. prior years
- Abundance: 2012 relative to prior years

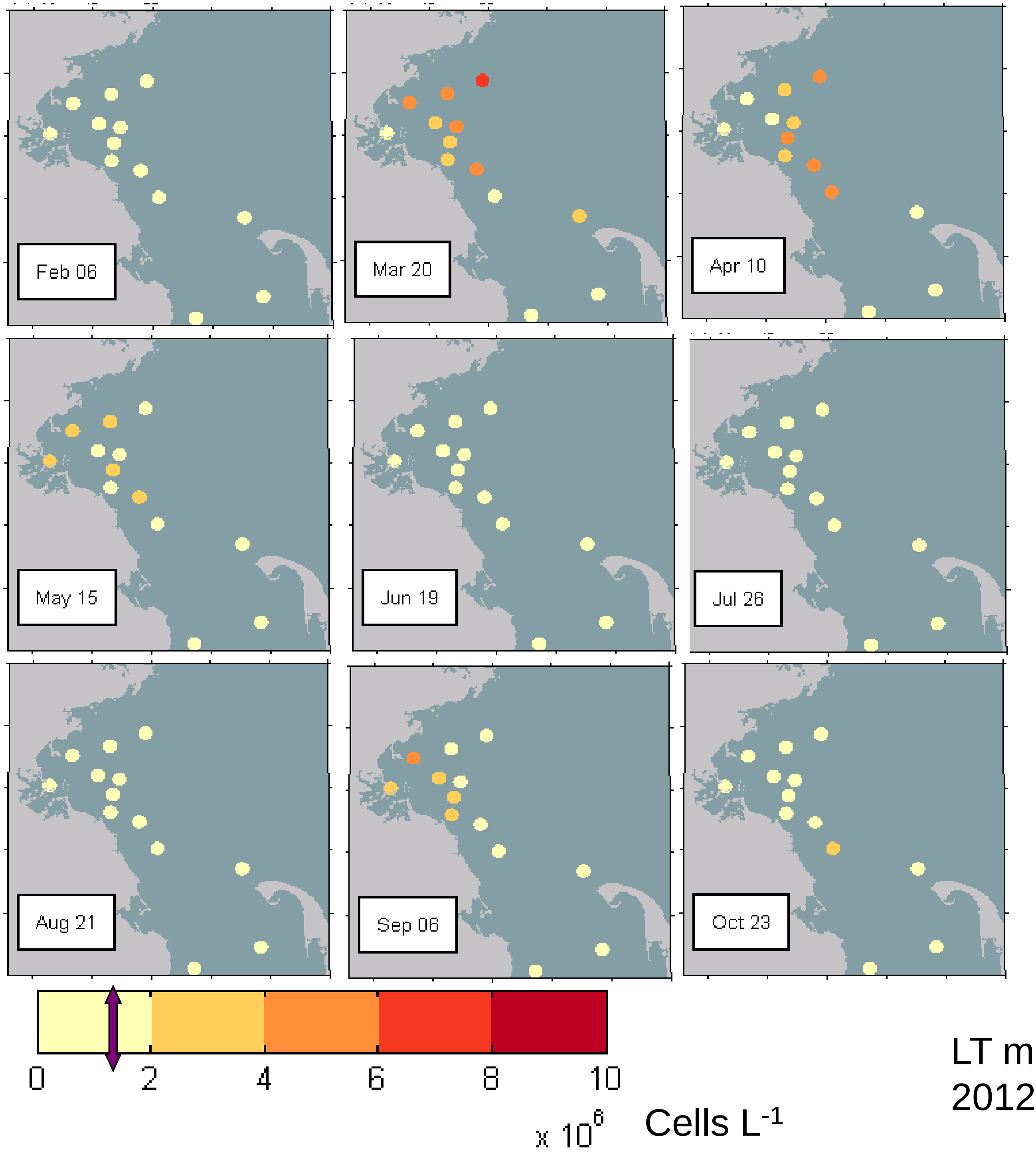
Phaeocystis



Winter-spring

Skeletonema

Late summer



Total Phytoplankton 2012

Regional Patterns

2 pulses:

W-S bloom
- *Phaeocystis*, centric diatoms; to the north, offshore

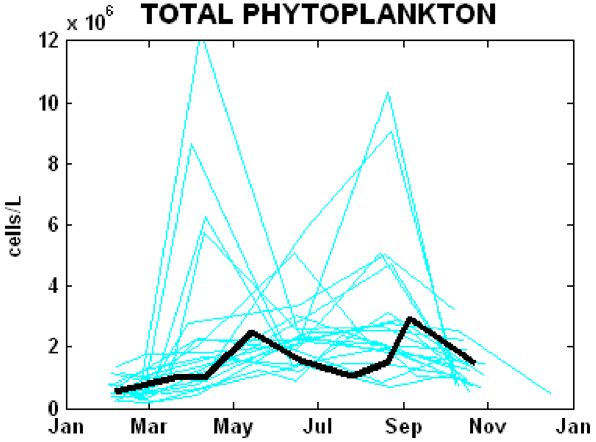
Late summer
- *Skeletonema* bloom; harbor and near shore

LT mean = 1.50×10^6 cells L^{-1}

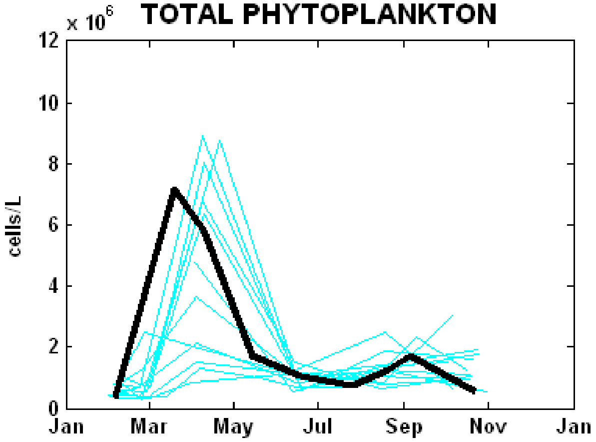
2012 mean = 1.68×10^6 cells L^{-1}

2012 Total Phytoplankton Annual Cycle

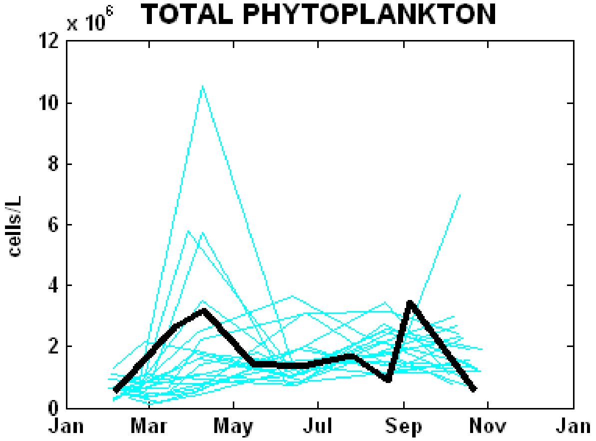
Harbor (F23)


TOTAL PHYTOPLANKTON

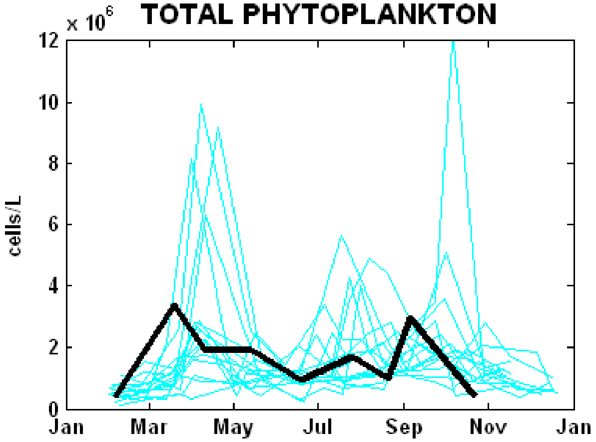
Northern Offshore (F22)


TOTAL PHYTOPLANKTON

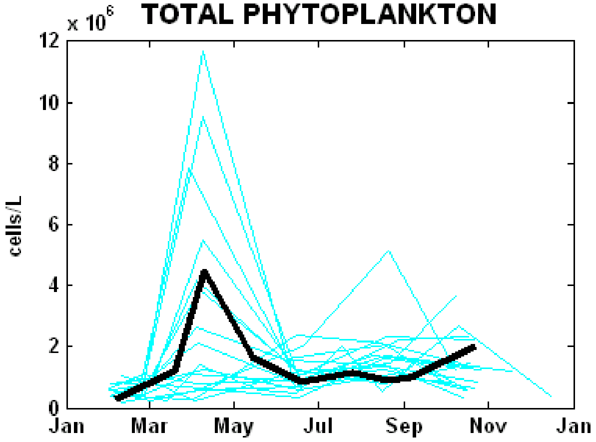
Coastal (F13)


TOTAL PHYTOPLANKTON

Nearfield (N18)

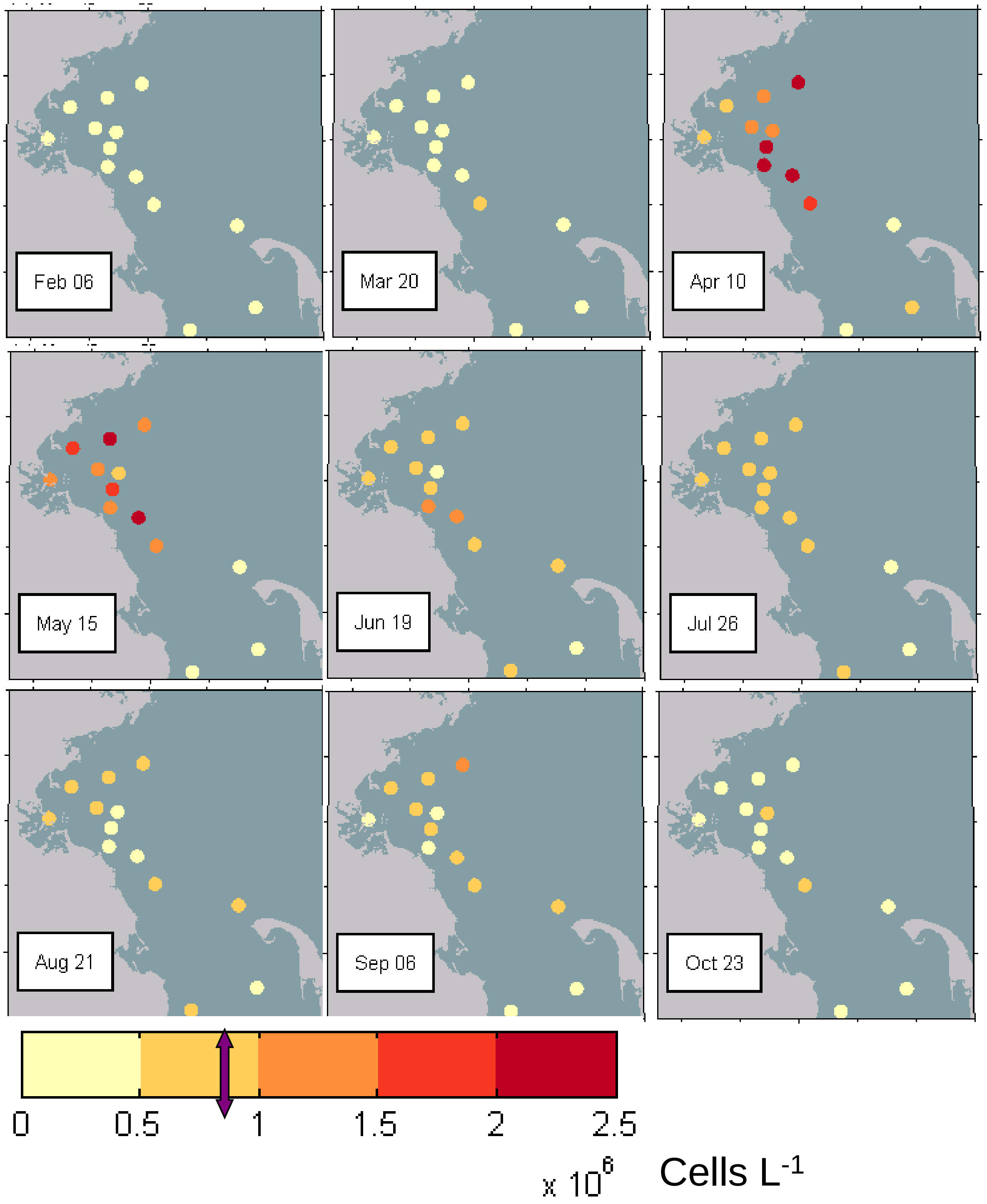

TOTAL PHYTOPLANKTON

Southern Offshore (F06)


TOTAL PHYTOPLANKTON

2012 total phytoplankton

- -Near LT mean abundance
- -(but see N. Offshore & Nearfield, early peak)
- - Bi-modal (spring, fall) pattern



Microflagellates 2011

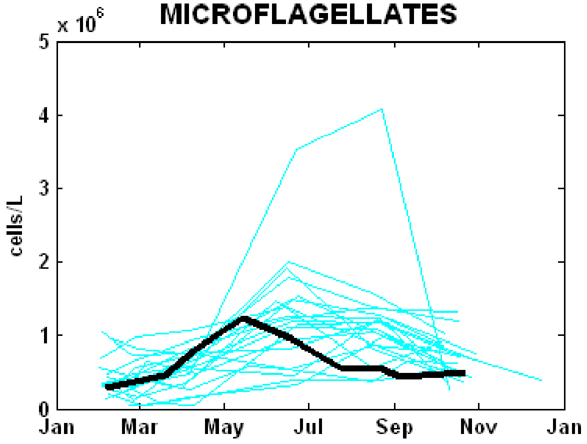
- Mainly regionally uniform

- Annual peak earlier (April, May) than usual?

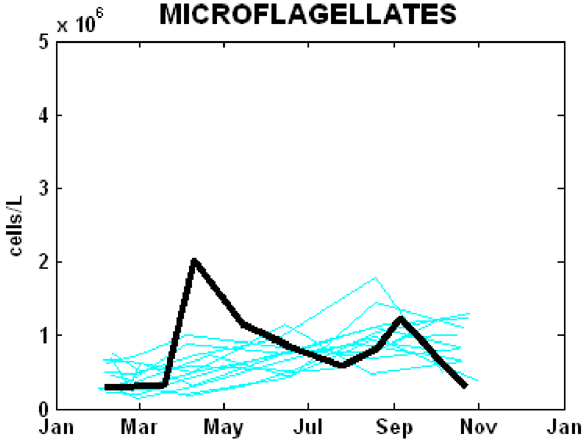
LT mean = 696,066 cells L^{-1}
2012 mean = 720,024 cells L^{-1}

2012 Microflagellate Annual Cycle

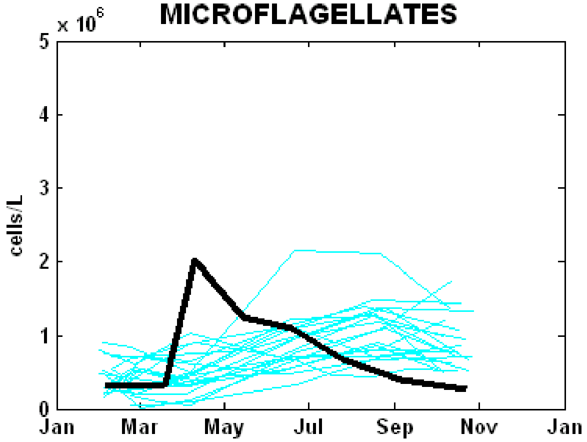
Harbor (F23)



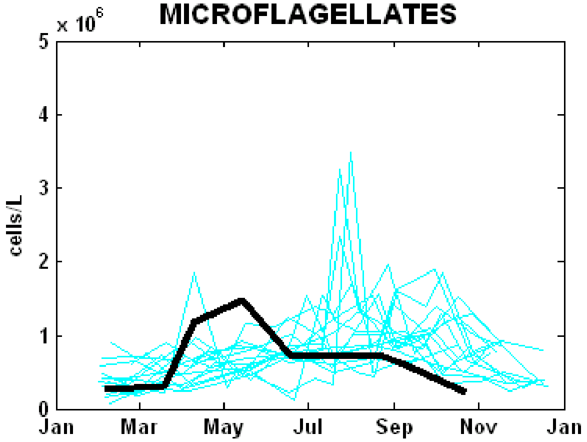
Northern Offshore (F22)



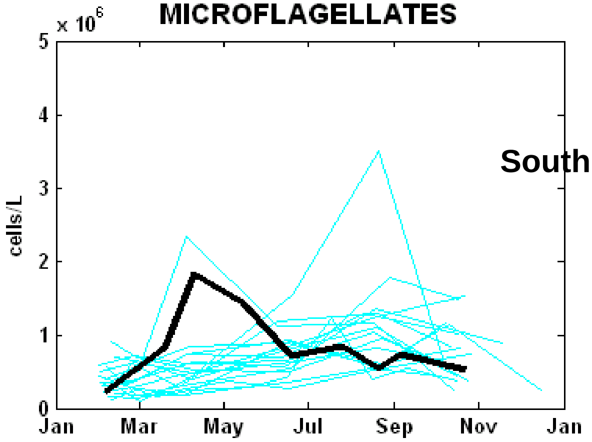
Coastal (F13)



Nearfield (N18)



Southern Offshore (F06)

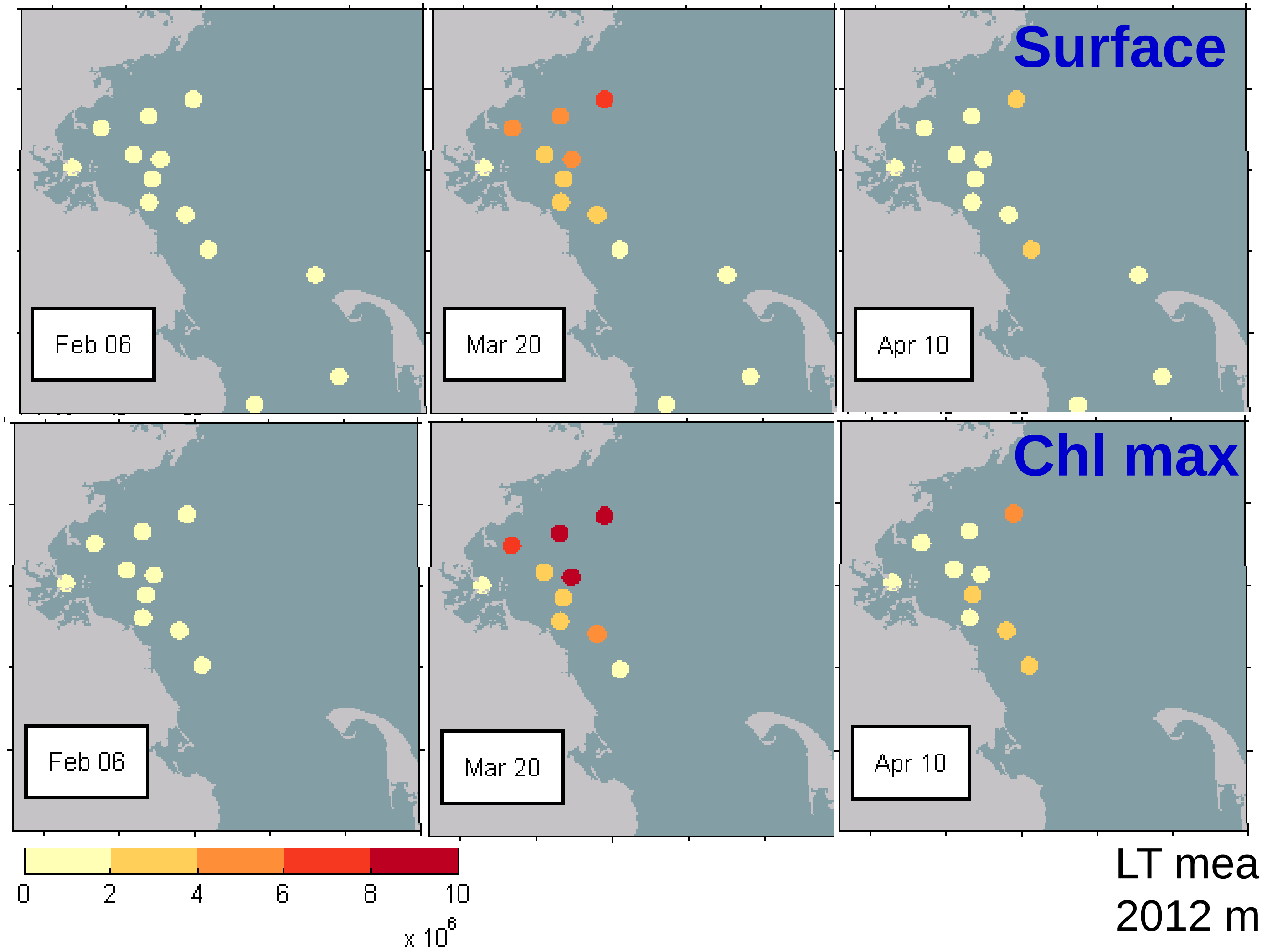


2012 microflagellates

- Elevated spring abundance

- Annual peak advancing ?

Phaeocystis pouchetii 2012



Surface mean = 235,188 cells L^{-1}

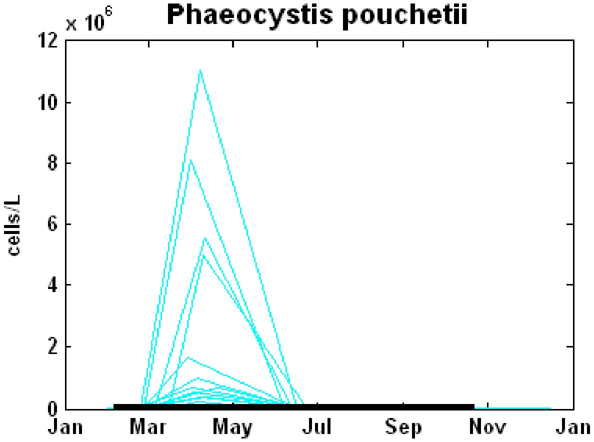
Surface mean = 742,924 cells L^{-1}

LT mean = 256,533 cells L^{-1}
2012 mean = 455,943 cells L^{-1}

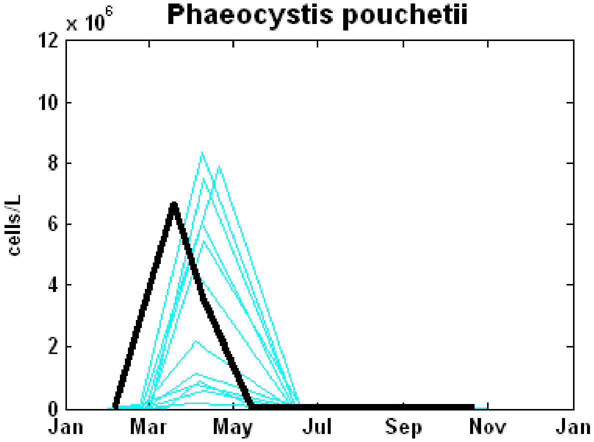
2012 *Phaeocystis*
-*Phaeocystis* bloom year, dominated 2012 phytoplankton cycle
-Maximum of 10.8 million cells L^{-1}
-Cmax abundance significantly > surface (3-fold greater)

2012 *Phaeocystis* Annual Cycle

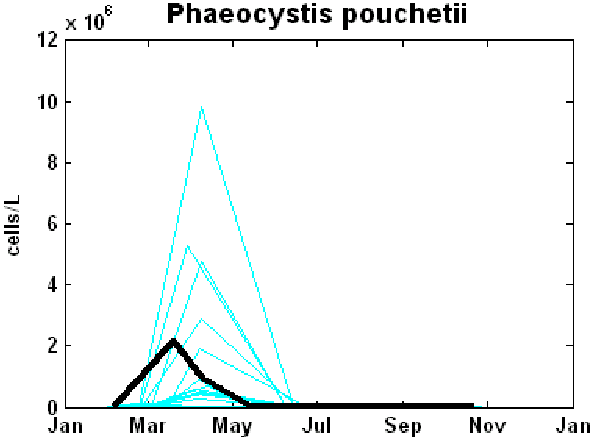
Harbor (F23)



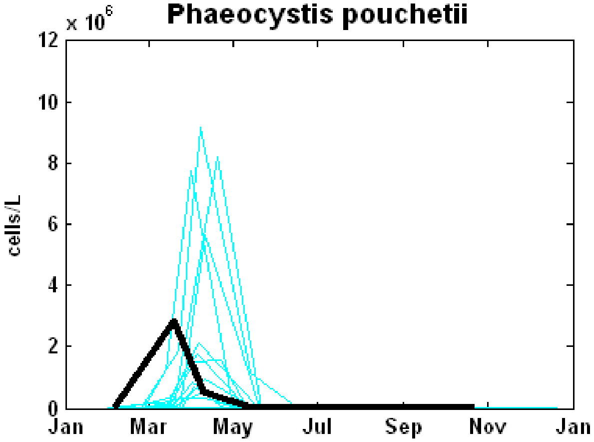
Northern Offshore (F22)



Coastal (F13)



Nearfield (N18)



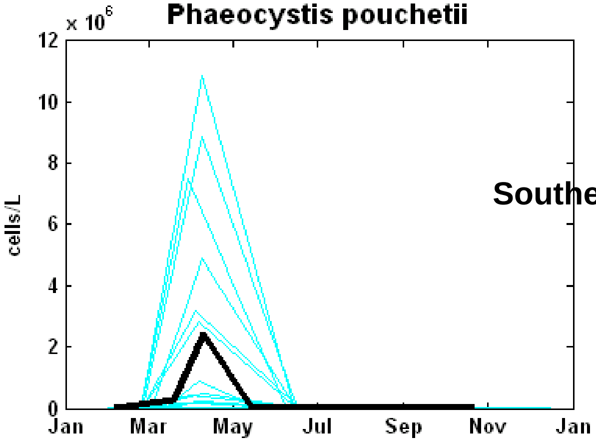
2012 *Phaeocystis*

- Phaeocystis year (7th rank of 21)

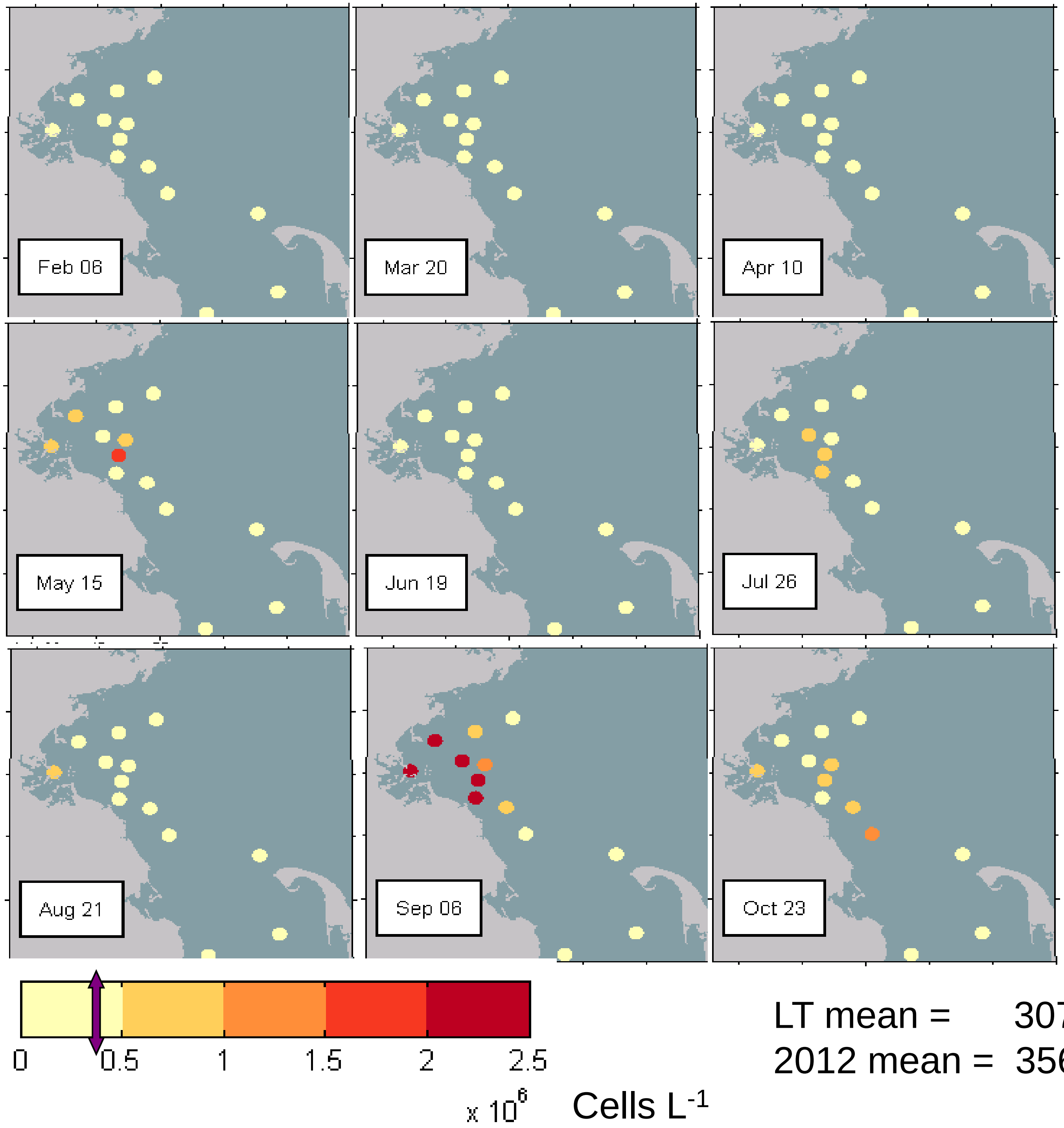
-Northern offshore event

-Earlier bloom peak

Southern Offshore (F06)



Centric Diatoms 2012



-Summer - early autumn dominated annual cycle

-Winter: *Thalassiosira, Chaetoceros, Guinardia, Skeletonema*

-Spring
Leptocylindrus minimus

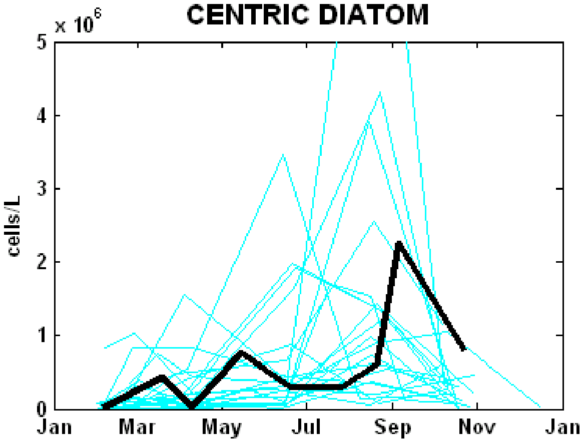
-Summer
Leptocylindrus danicus, Cerataulina, Skeletonema

-Autumn: *Skeletonema* harbor and near shore, *Leptocylindrus* offshore

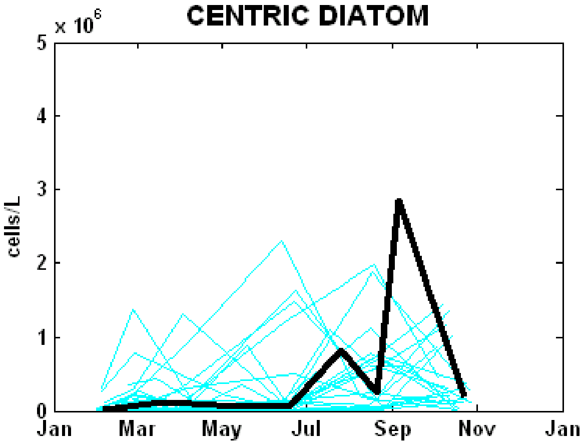
LT mean = 307,132 cells L^{-1}
2012 mean = 356,875 cells L^{-1}

2012 Centric Diatom Annual Cycle

Harbor (F23)

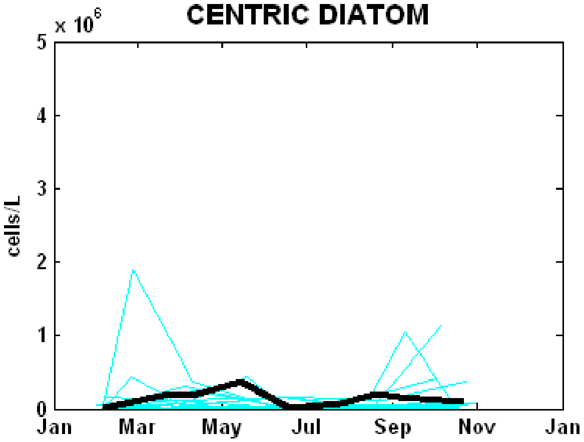


Coastal (F13)

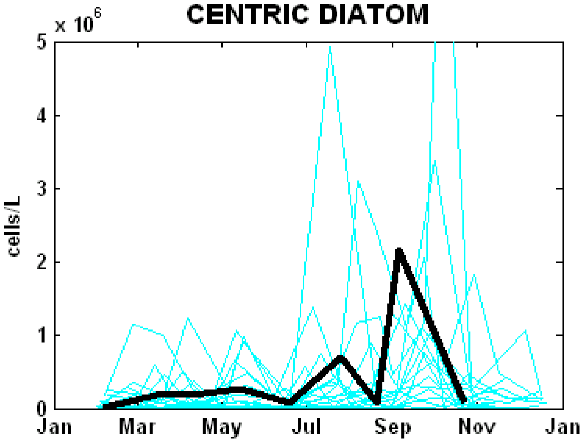


2012 Centric Diatoms:

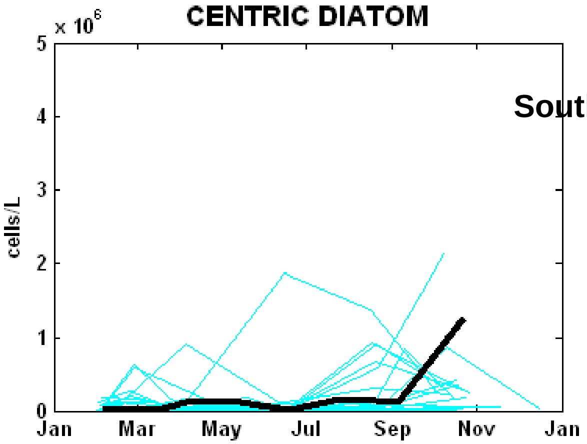
- near mean abundance
- late summer to autumn dominated pattern



Northern Offshore (F22)

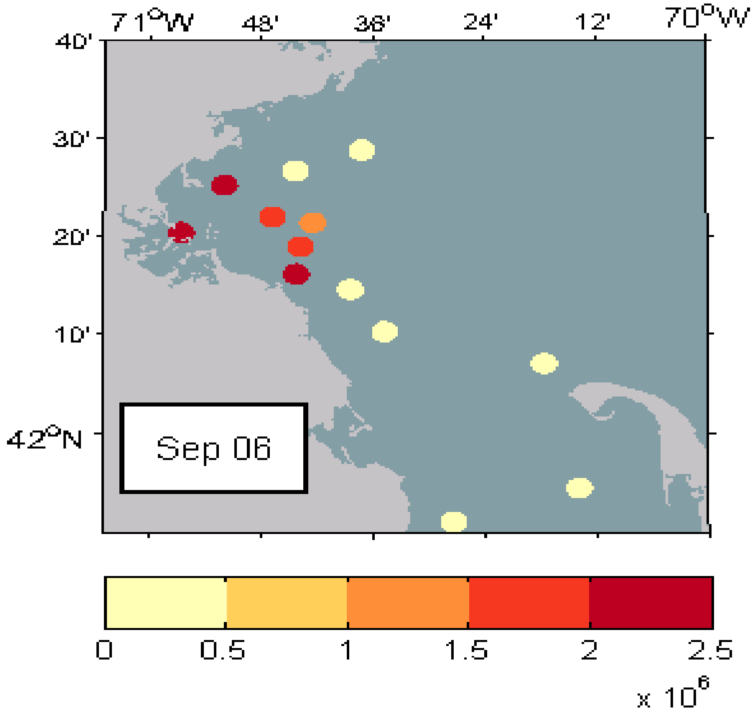


Nearfield (N18)



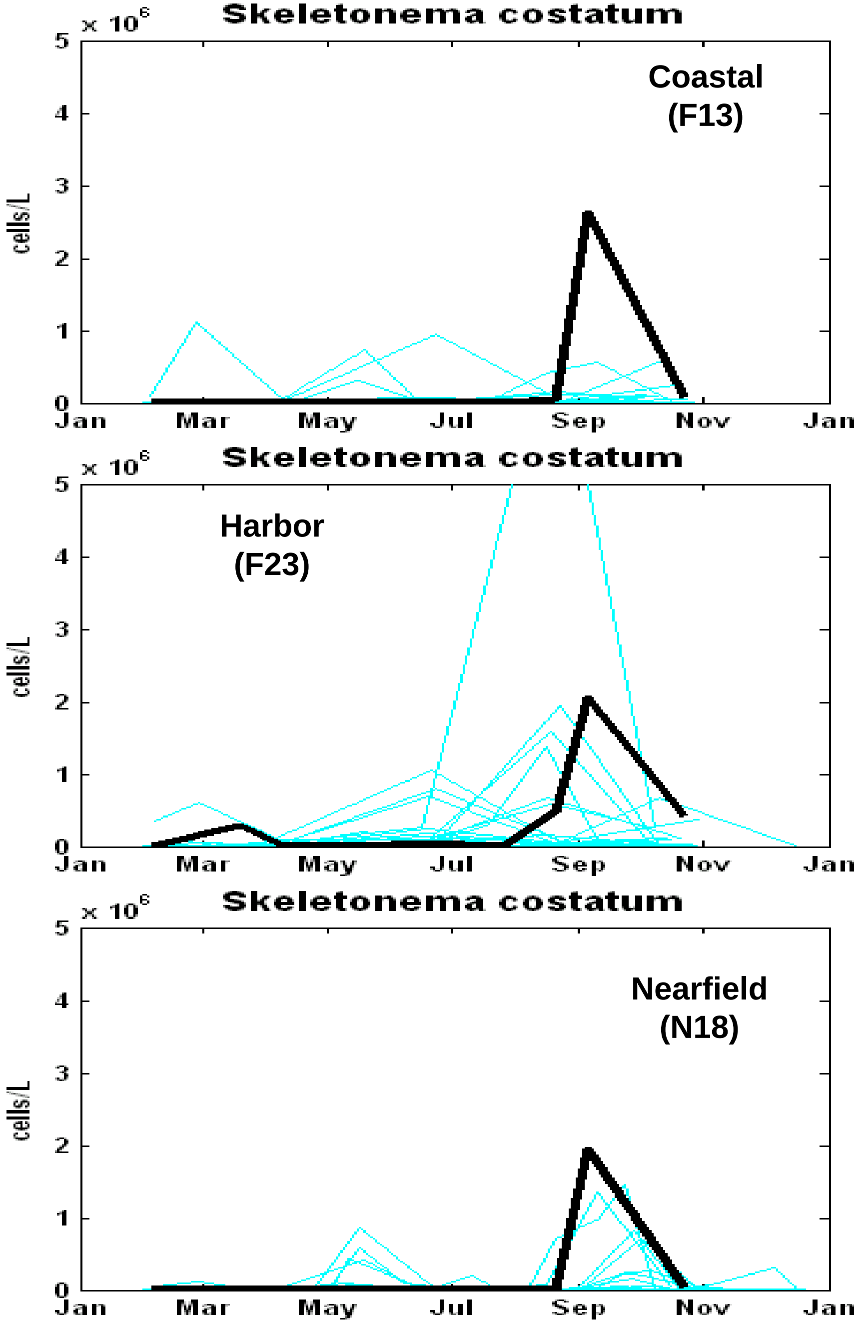
Southern Offshore (F06)

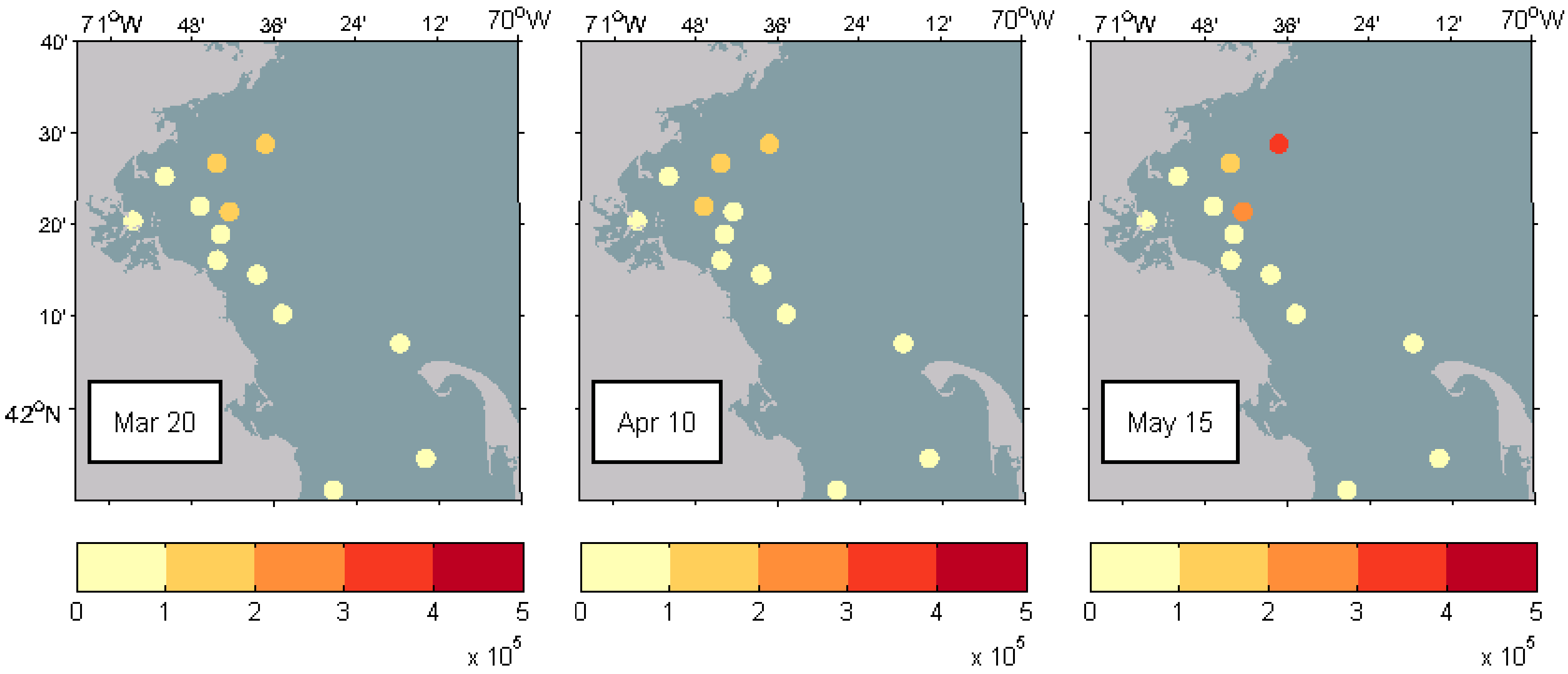
Late summer *Skeletonema* spp. bloom



September *Skeletonema* bloom

- Harbor & nearfield
- 2.5 X 10^6 cell L^{-1} maximum



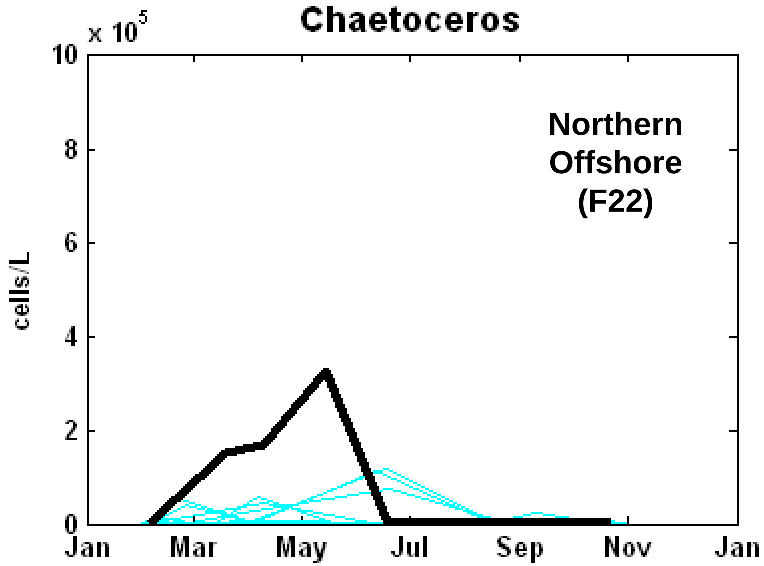


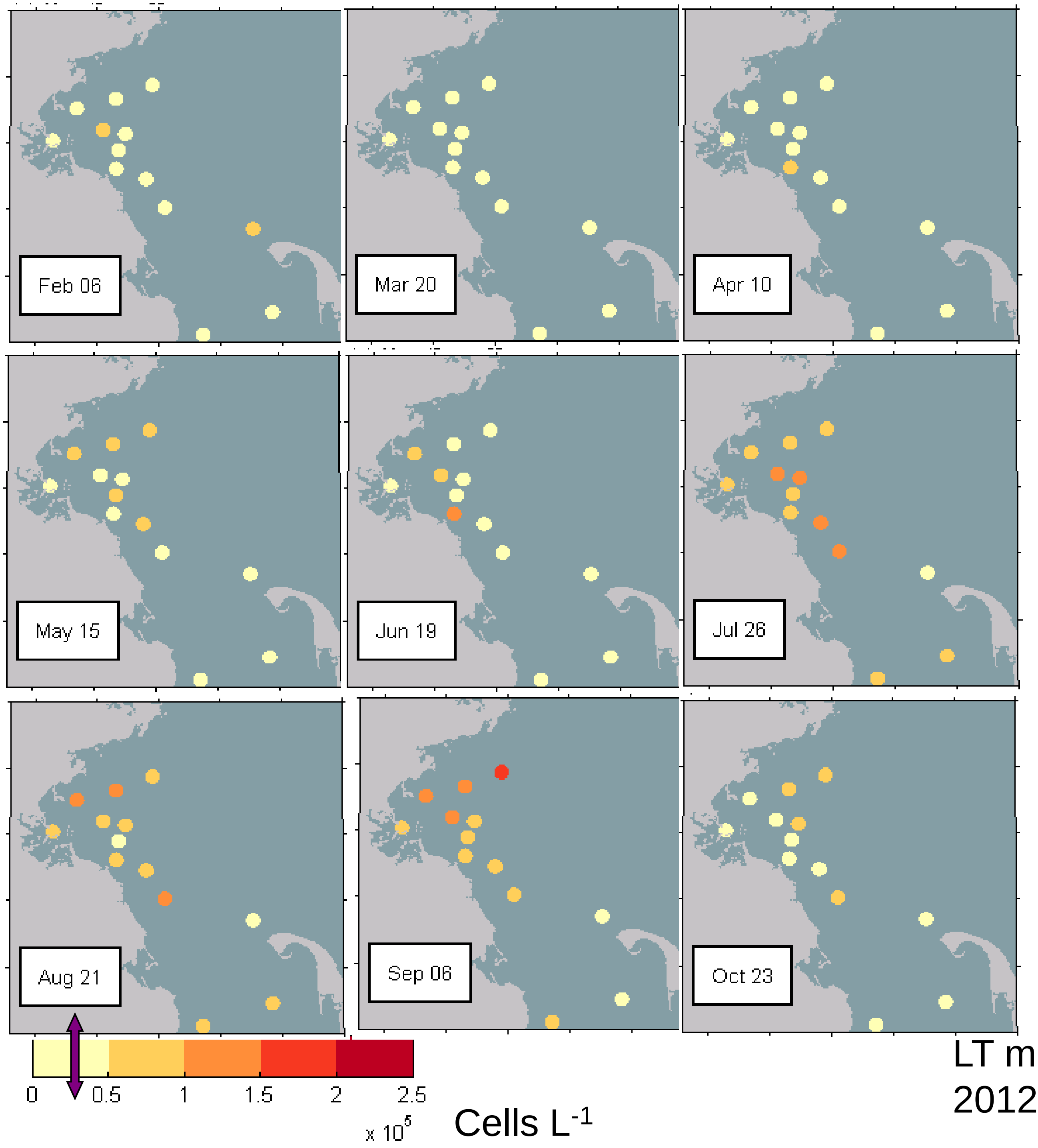
Winter-spring *Chaetoceros* spp.

-abundance was elevated in the northern offshore region

-Especially *C. socialis*

-Ca. 350,000 cells L^{-1}, about 3X LT mean





Dinoflagellates 2012

May

Small dinoflagellates

Gymnodinium spp.

Heterocapsa triquetra

Heterocapsa rotundata

Prorocentrum minimum

Summer

Large dinoflagellates

Ceratium spp.

2X Long-term mean

September-October

Gymnodinum spp.

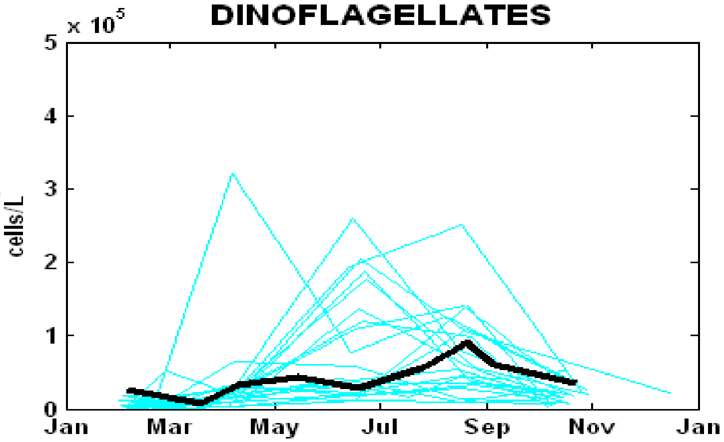
offshore,

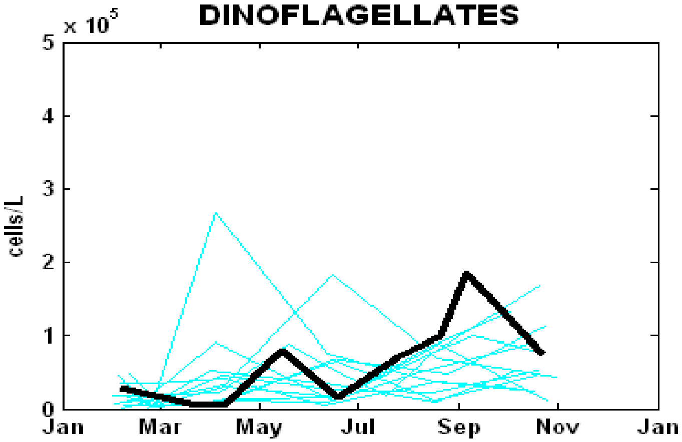
LT mean = 53,371 cells L^{-1}

2012 mean = 52,065 cells L^{-1}

2012 Dinoflagellate Annual Cycle

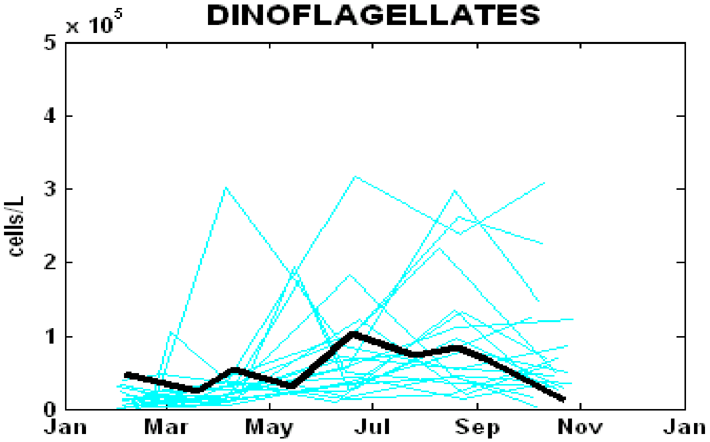
Harbor (F23)

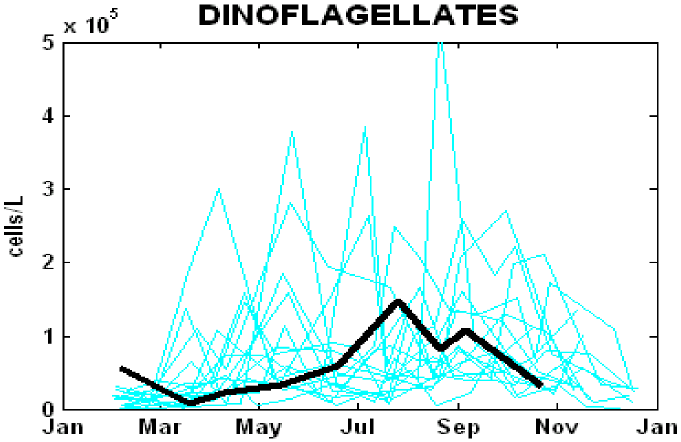




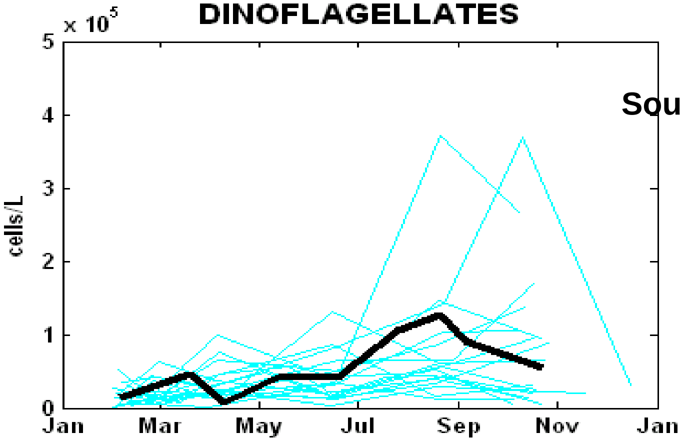
Northern Offshore (F22)

Coastal (F13)





Nearfield (N18)



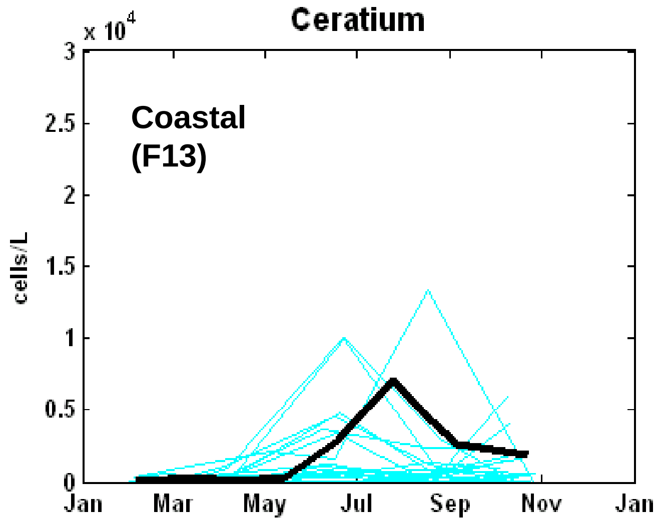
Southern Offshore (F06)

2012 dinoflagellates:

-Spring: small forms

-Summer: *Ceratium*

- Autumn peak N. Offshore



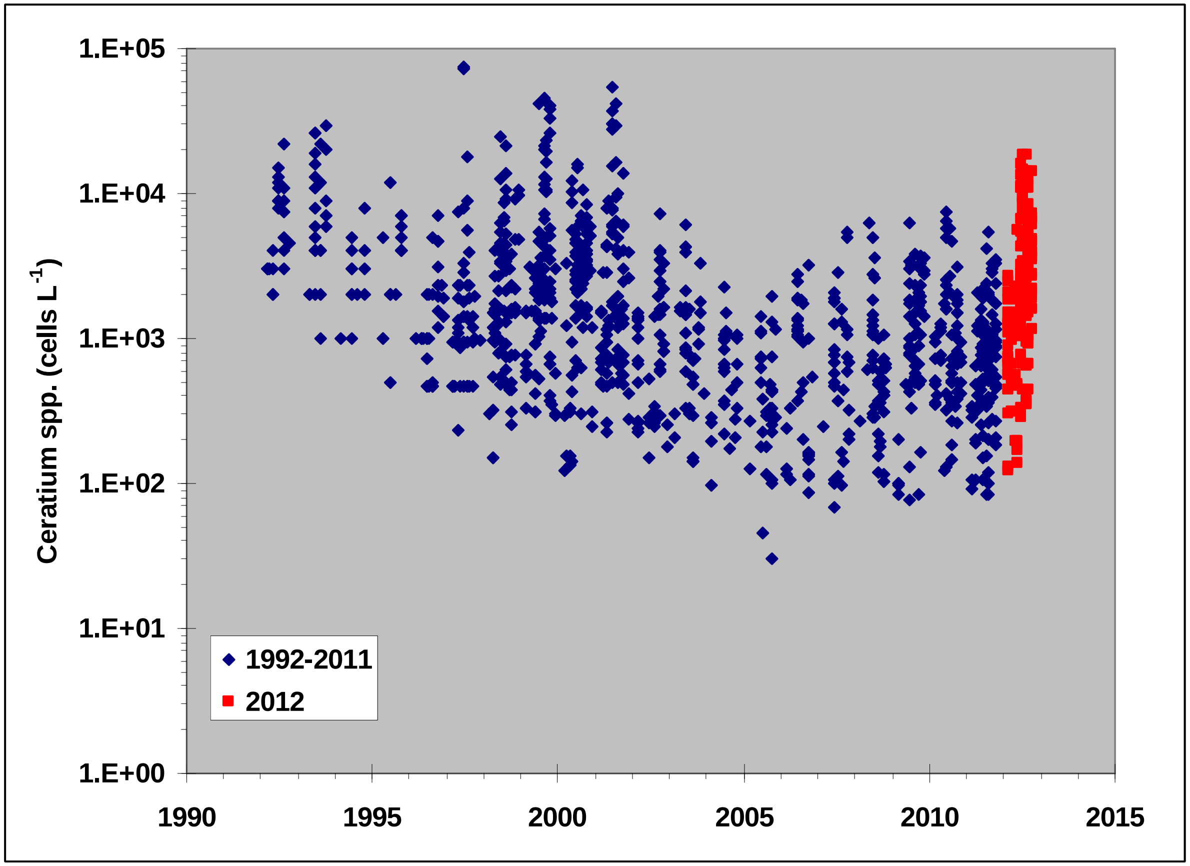
Ceratium spp. 2012

-*Ceratium* returned in summer 2012

-2012 level was 2X LT abundance

-Summer peak most stations

-Elevated abundance extended into autumn offshore

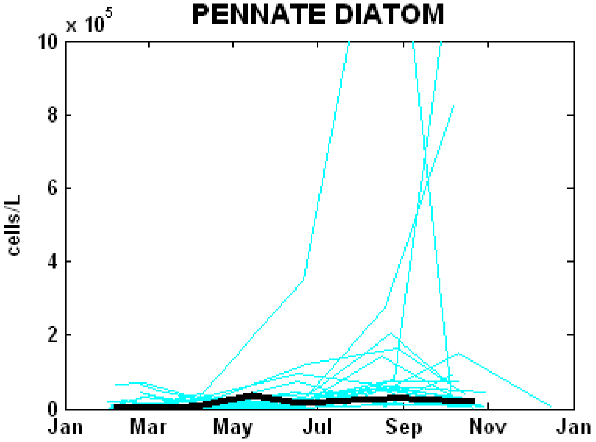


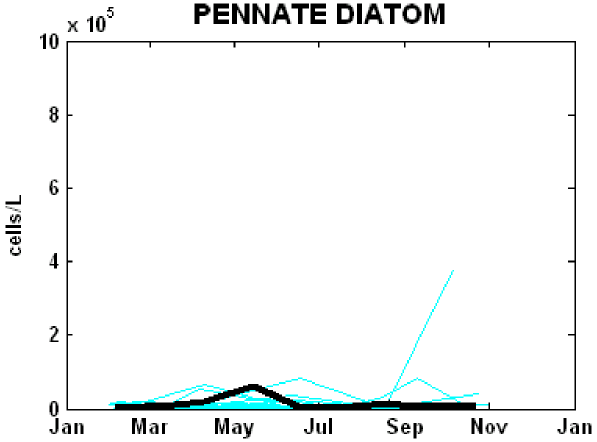
LT mean = 1,427 cells L^{-1}

2012 mean = 2,848 cells L^{-1}

2012 Pennate Diatom Annual Cycle

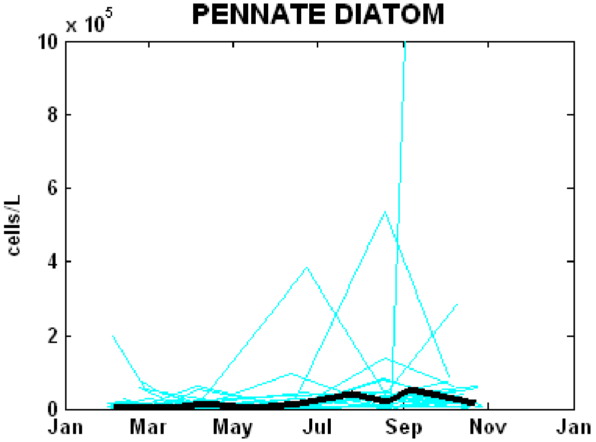
Harbor (F23)

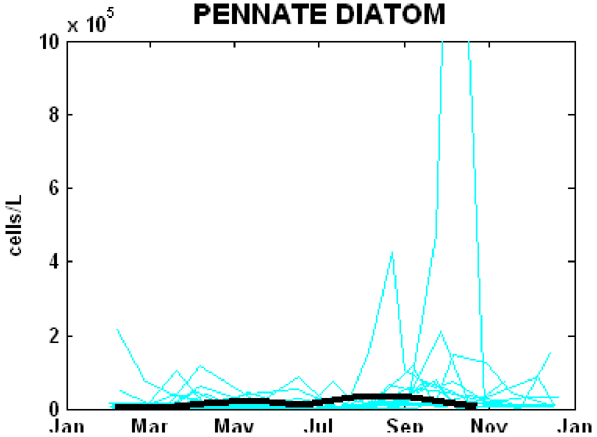




Northern Offshore (F22)

Coastal (F13)





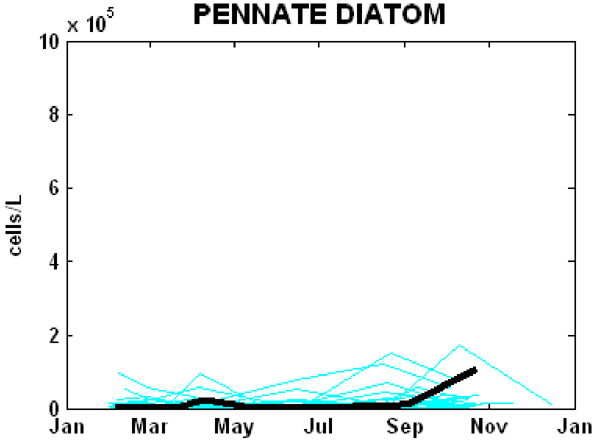
Nearfield (N18)

LT mean = 48,299 cells L^{-1}

2012 mean = 16,902 cells L^{-1}

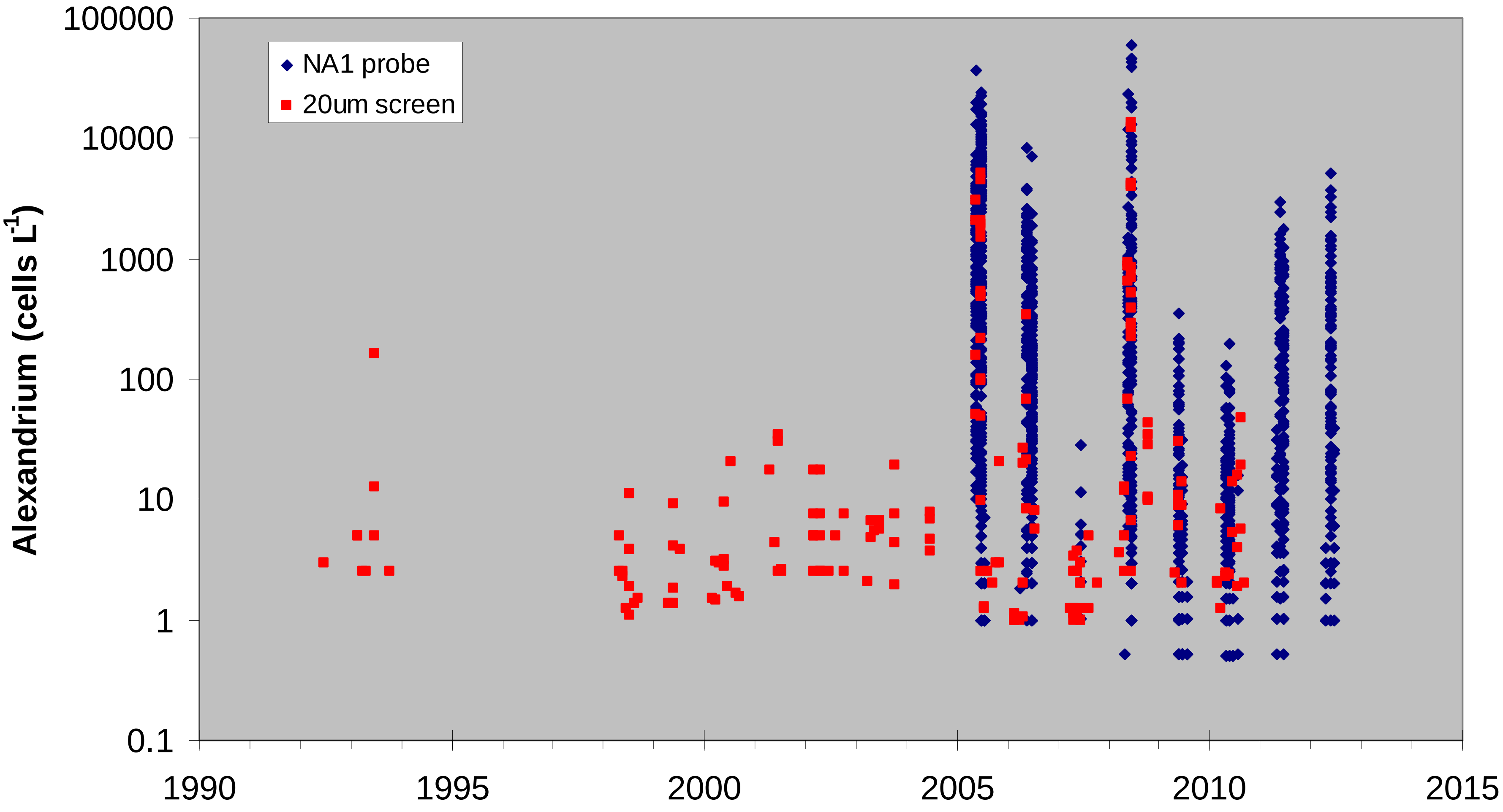
2012 pennate diatoms:

- Low abundance
- Spring and autumn pulses offshore



Offshore (F06)

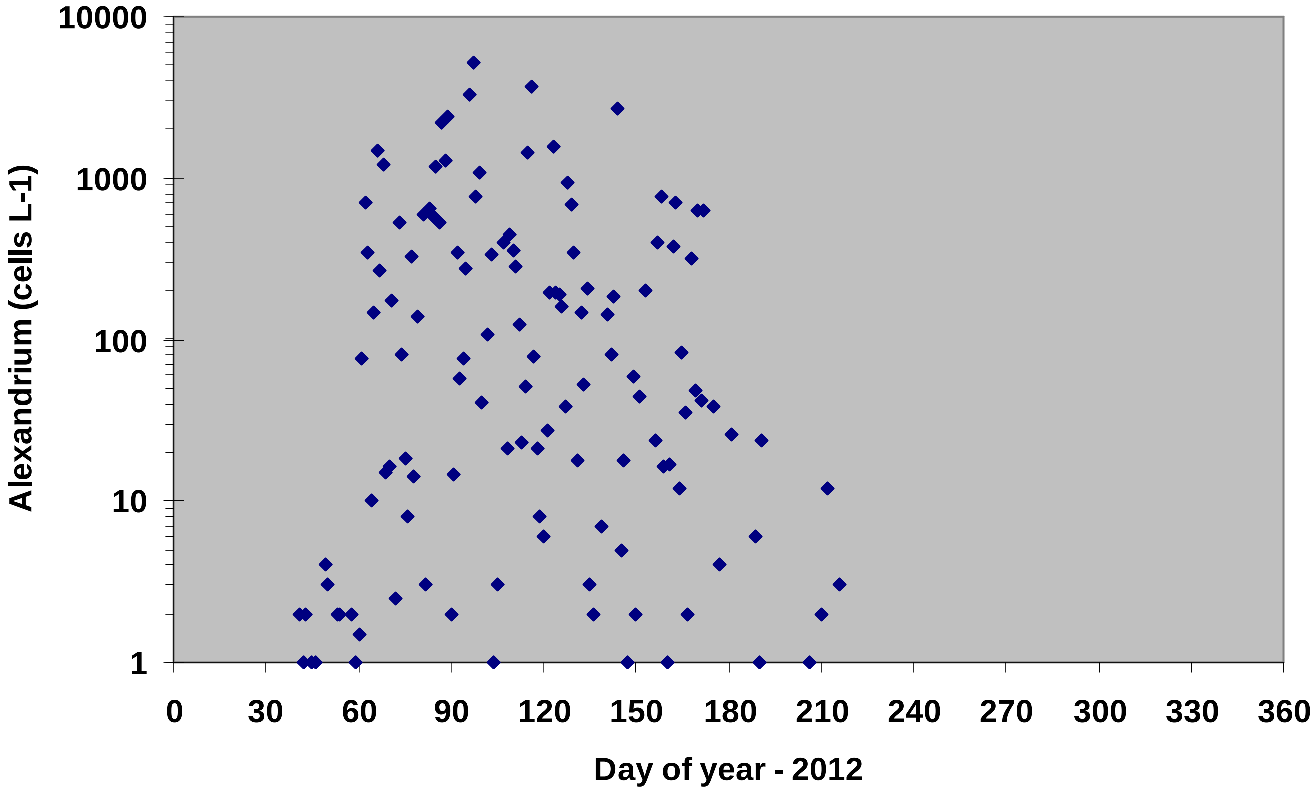
HAB Species - *Alexandrium*



2012 *Alexandrium*

- Maximum of 5,215 cells L^{-1}
- 5th greatest abundance overall

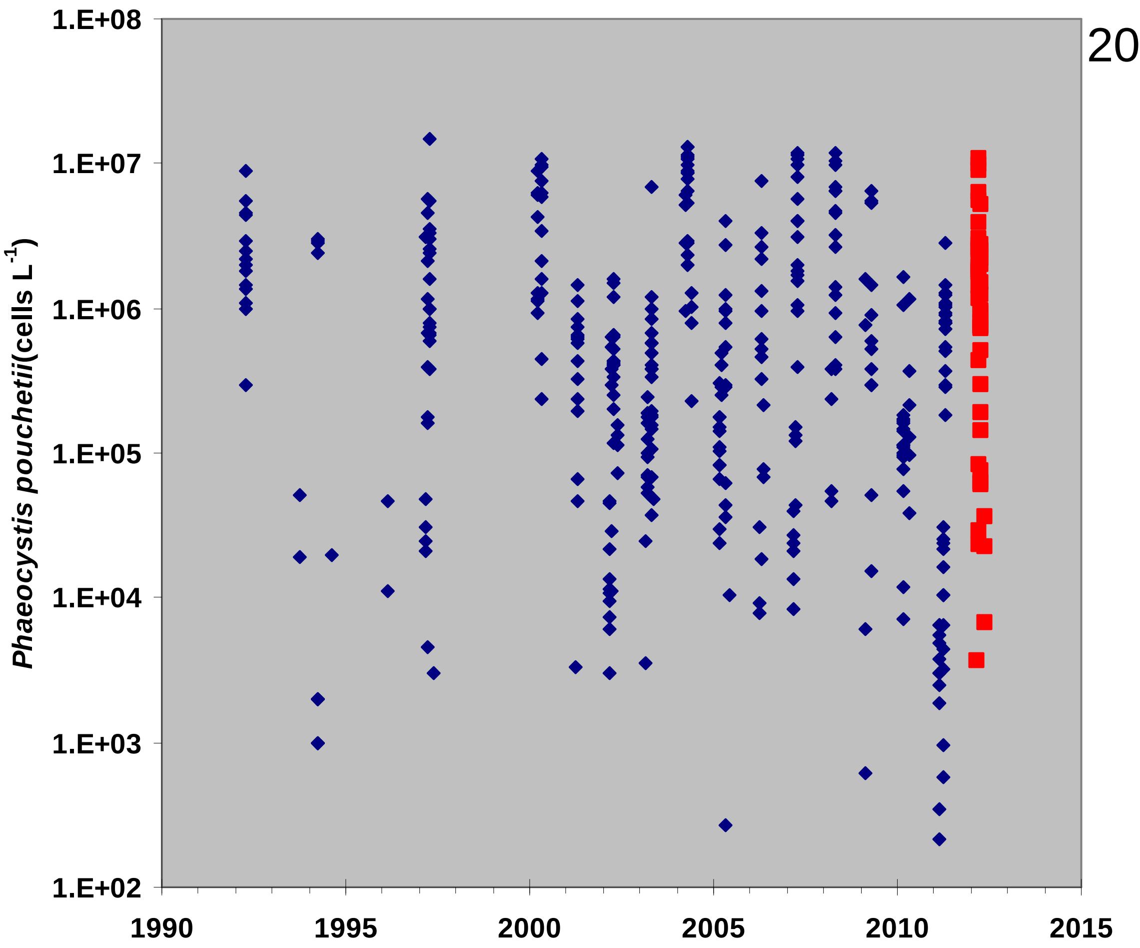
HAB Species - *Alexandrium*



2012 *Alexandrium*

-Note that *Alexandrium* was present February – July 2012

HAB Species - *Phaeocystis*



2012 *Phaeocystis*

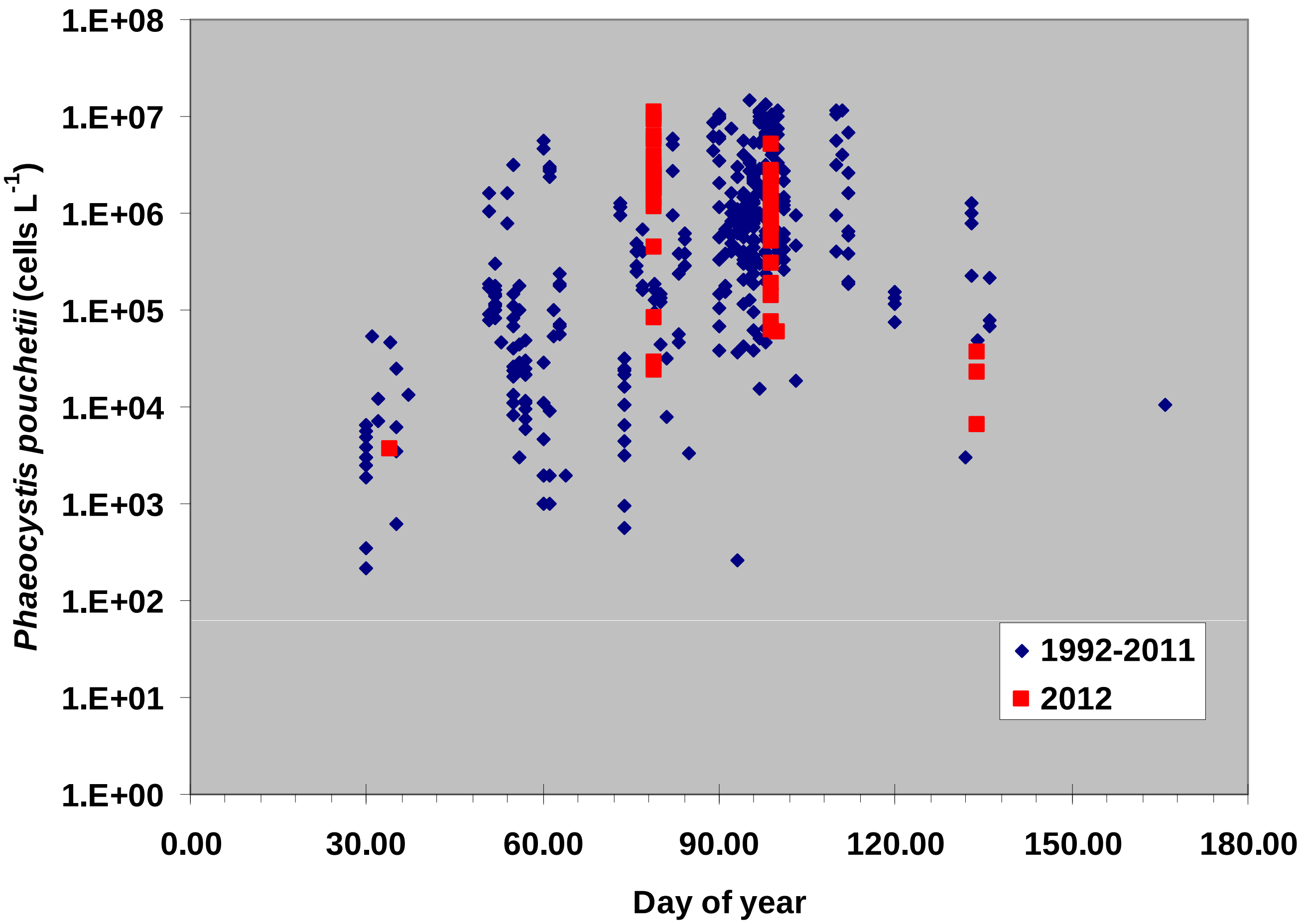
Phaeocystis bloom year

Maximum of 10.8 million cell L^{-1}

Top 1/3rd in abundance

(7th rank of 21 years)

HAB Species - *Phaeocystis*

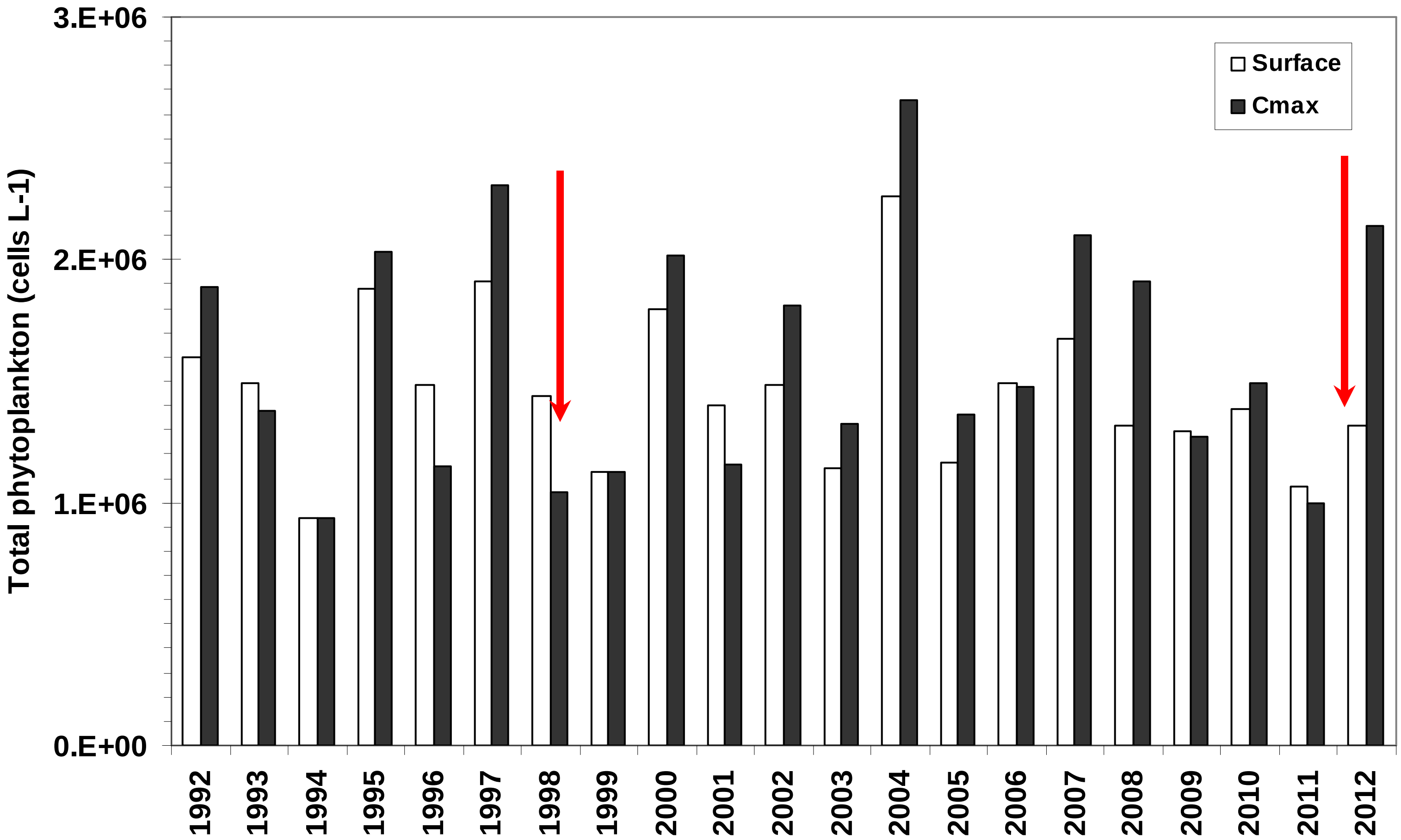


2012 *Phaeocystis* bloom timing

- bloom peak early (March, not April)
- greatest March *Phaeocystis* observations
- earlier bloom in 2012?

HAB Species – Other *spp.*

- Low pennate diatom abundance, including *Pseudo-nitzschia* spp. (ASP)
- Low *Dinophysis* spp. abundance (DSP)



What about depth?

1998, Surface 38% greater

(surf, 1.44 X 10^6 cells L^{-1} > Cmax, 1.04 X 10^6 cells L^{-1})

2012, Cmax 60% greater

- (Cmax, 2.14 X 10^6 cells L^{-1} > surf, 1.32 X 10^6 cells L^{-1})

- in 2012, greater *Phaeocystis* at Cmax & *Ceratium* up

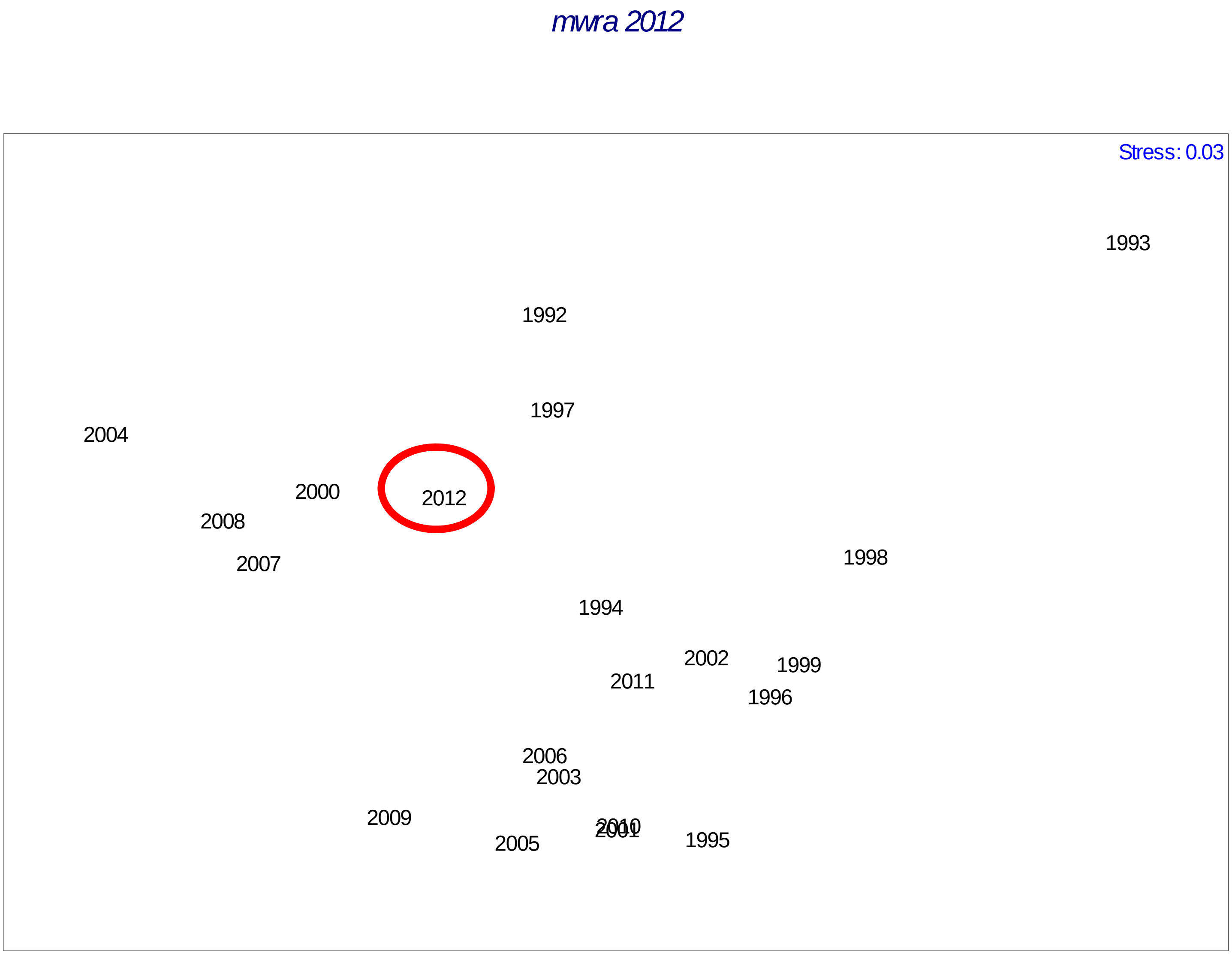
– effects of warm, dry year??

2012 Phytoplankton Groups – Changes?

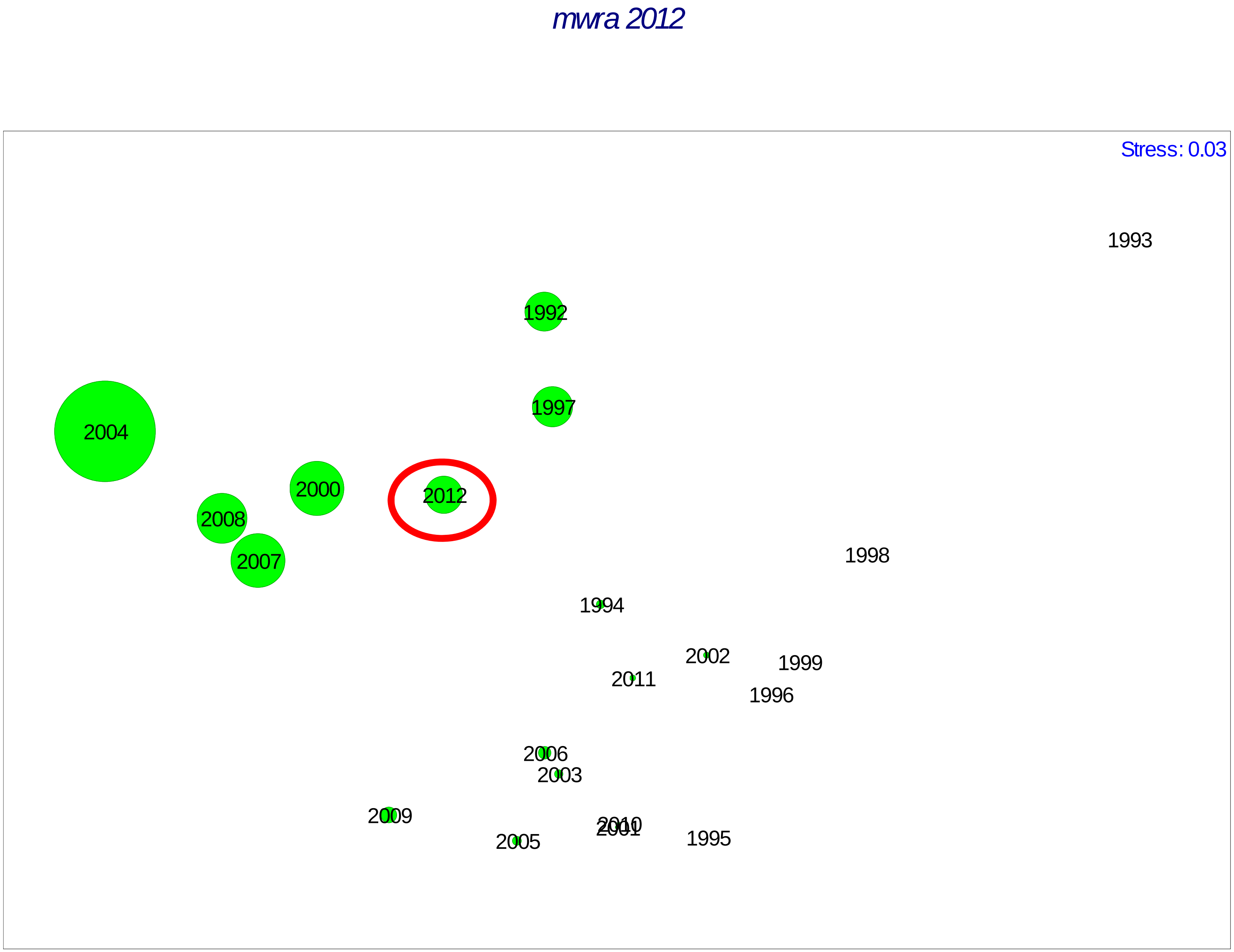
Table 1: Summary of 2012 phytoplankton abundance (cells L-1) compared to corresponding 1992-2011 levels. Comparisons made using Mann-Whitney test.

Group	*Mean 1992 -2011 (cells L^{-1})*	*Mean 2012 (cells L^{-1})*	*P value*	Change?
Centric diatoms	307,132	356,875	0.2929	
Dactyliosolen fragilissimus	48,873	6,372	0.0347	**Decline**
Chaetoceros spp.	46,185	28,841	0.1273	
Skeletonema spp.	60,510	160,535	0.0001	**Increase**
Thalassiosira spp.	36,801	6,669	0.0425	**Decline**
Pennate diatoms	48,200	16,902	0.0898	
Pseudo-nitzschia spp.	11,190	8,245	0.4726	
Cryptomonads	124,958	67,157	0.0038	**Decline**
Dinoflagellates	53,371	52,065	0.7959	
Ceratium spp.	1,427	2,848	0.038	**Increase**
Phaeocystis	256,533	455,943	0.0313	**Increase**
Microflagellates	696,066	720,024	0.5302	
Total phytoplankton	1,497,640	1,675,666	0.1275	

Overall summary: A near mean year …….



Overall summary: A near mean year with *Phaeocystis* bloom



2012 Phytoplankton Summary

- 2012 near LT mean phytoplankton abundance
- Microflagellate annual peak ~1 month early
- *Phaeocystis* year, March & April bloom
  - (>10 million L^{-1} max), north & offshore event, early (1 month) bloom.
- Centric diatoms near mean, but WS diatom bloom reduced
- Late summer diatom bloom *(Skeletonema*)
- HAB spp.: 2012 continues the post-2004 *Alexandrium* era
- 2012, warm winter-spring. Responses?
  - Microflagellate peak earlier
  - *Phaeocystis* peak earlier
  - Phytoplankton abundance different at Surface & Cmax
    - *Phaeocystis*, stratification and return of *Ceratium*?

2012 MWRA Zooplankton Monitoring Summary

Jefferson Turner, UMD

Overview

Zooplankton abundance and community composition was monitored during 2012 as part of the MWRA's comprehensive outfall monitoring program. The zooplankton community was assessed *via* vertical oblique net hauls (102 µm-mesh). In 2012, the second year of the revised monitoring program, zooplankton samples were collected at ten stations across Massachusetts Bay during nine monthly surveys from February to October 2012.

The MWRA time series has consistently shown that zooplankton abundance is numerically dominated by copepod nauplii, and copepodites and adults of small copepod taxa such as *O. similis*, *Pseudocalanus* spp., and in Boston Harbor, *Acartia* spp.. Larger copepod taxa such as *Calanus finmarchicus* which dominate abundance in some other zooplankton time series in temperate waters have been shown to be a relatively minor component of zooplankton abundance in the MWRA time series. There are also sporadic ephemeral pulses of meroplanktonic larvae of benthic animals such as barnacle nauplii, gastropod and bivalve veligers, and larval polychaete worms. A consistent seasonal pattern during all years of the time series has been low zooplankton abundance in the winter, increasing through the spring to maximum levels of abundance during mid- to late-summer and early-fall periods, declining through the late fall and early winter.

Zooplankton monitoring for the MWRA program has produced a unique long-term dataset for seasonal fluctuations of marine zooplankton in a highly seasonal environment. Due to the use of 102 µm-mesh nets, this time-series differs from most others in that the most abundant taxa recorded are copepod nauplii and tiny copepods of the species *Oithona similis*. These small zooplankters have been severely under sampled or missed by most other zooplankton time-series which used nets with meshes of 200 µm or greater. Also, unlike most other long-term zooplankton time series, all samples in the MWRA time series since 1998 have been analyzed by the same experienced analyst, thereby avoiding discrepancies due to different taxonomic decisions by different analysts. Thus, comparisons between the MWRA time series and other zooplankton time series in the Gulf of Maine/Georges Bank area (Pershing *et al.* 2005, Kane 2007, Mountain & Kane 2010) are complicated by the fact that other such time series used nets with meshes that missed the most abundant zooplankton (Turner *et al.* 2011).

2012 Zooplankton Annual Cycle

In terms of zooplankton community composition and seasonal patterns, 2012 was a typical year. Total zooplankton abundance was dominated by copepod nauplii and *Oithona similis* copepodites and adults. Total zooplankton abundance increased from the winter through the spring to peak in the summer, and declined in the fall (slide 4). There was more temporal variability in abundance than spatial variability in abundance. Total zooplankton abundance (comprised primarily by copepods (adults + copepodites), copepod nauplii and *Oithona*) all had similar seasonal increases through winter and spring into summer with declines in the fall (slide 5). *Oithona similis* was ubiquitously abundant everywhere (slide 6), whereas *Acartia* spp. were abundant only in Boston Harbor (slide 7). There were similarities between stations F23, N18, F06, and F13 (slide 5) for seasonal trends and abundances of total zooplankton, but the pattern for station F22 was somewhat different from the others. Patterns for seasonal trends and abundances of total zooplankton at stations N01, N04, N07, F10, and F15 were quite similar to each other (slide 5). Patterns abundance of copepod adults plus copepodites (which dominate total zooplankton), and *Oithona* (which dominates copepods) at stations F22, F23, N18, F06, and F13 were generally similar to each other (slide 6), as were patterns for copepod nauplii at all stations except for F22. Patterns of abundance for total zooplankton at representative stations in all locations (slide 8), and for nearfield abundances of copepod adults plus copepodites, copepod nauplii, *Oithona* spp., and *Pseudocalanus* spp. (slide 9) and nearfield abundances of *Acartia* spp., *Calanus finmarchicus*, barnacle nauplii and other zooplankton (slide 10) revealed that 2012 was comparable to most historic levels of abundance and seasonal patterns with values within the envelope-of-variability established for previous years.

Summary

The overwhelming numerical dominance of *Oithona similis* in the MWRA time series raises issues in terms of our understanding of planktonic food webs in coastal waters. The classical paradigm of feeding interactions in lower trophic levels of pelagic food webs has been that of copepods and other zooplankters grazing upon phytoplankton, and in turn being eaten by larger consumers such as larval fish. This paradigm is complicated by the fact that *Oithona similis* is primarily a microzooplankton predator, feeding mainly upon protozoans such as ciliates and heterotrophic dinoflagellates, rather than grazing upon phytoplankton (Nakamura & Turner 1997; Lonsdale *et al*. 2000; Castellani *et al*. 2005). Thus, the overwhelming numerical dominance of *Oithona similis* in Massachusetts Bay (Turner *et al*. 2011), as well as globally (Gallienne & Robins 2001), in waters as diverse as the Antarctic (Lonsdale *et al*. 2000) and the northeastern North Atlantic (Castellani *et al*. 2005), fundamentally challenges the classical paradigm of how pelagic marine food webs function. Linkages from the most abundant phytoplankton (namely “microflagellates”) to the zooplankton appear to be primarily through protozoans, and not directly through copepods in most areas of the sea. These protozoans are then consumed by copepods such as *Oithona similis* (Turner 2004), which in turn are consumed by fish larvae (Lough & Mountain 1996).

Overall, 2012 was a fairly typical year in terms of zooplankton community composition, abundance, seasonality, and distributional patterns. This is interesting since 2012 was an extremely atypical year in other respects, with warmer temperatures, earlier *Phaeocystis* blooms, and other differences from most previous years.

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2012 Zooplankton Results

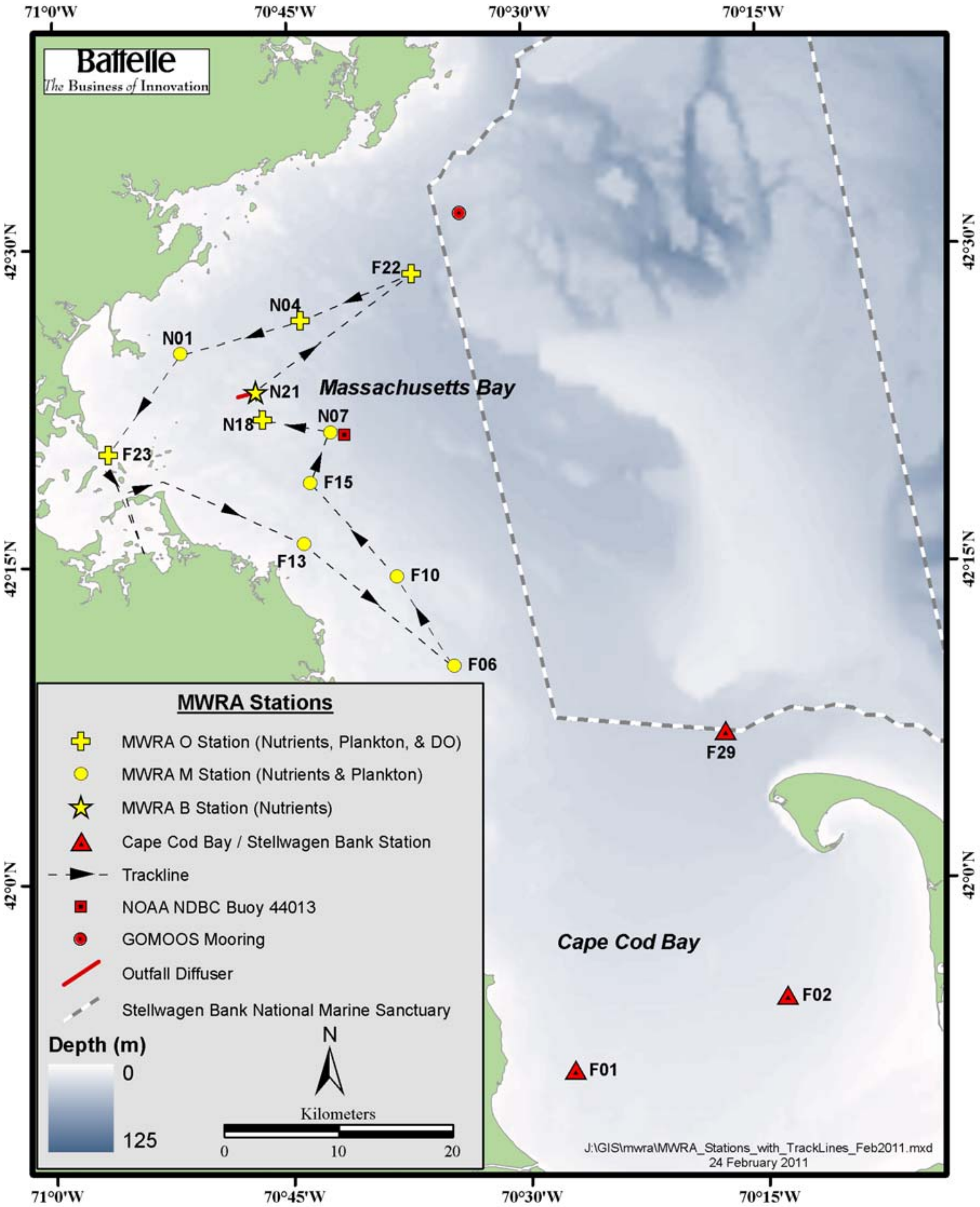
MWRA Harbor Outfall Monitoring Program

Jefferson T. Turner
School for Marine Science & Technology
University of Massachusetts Dartmouth

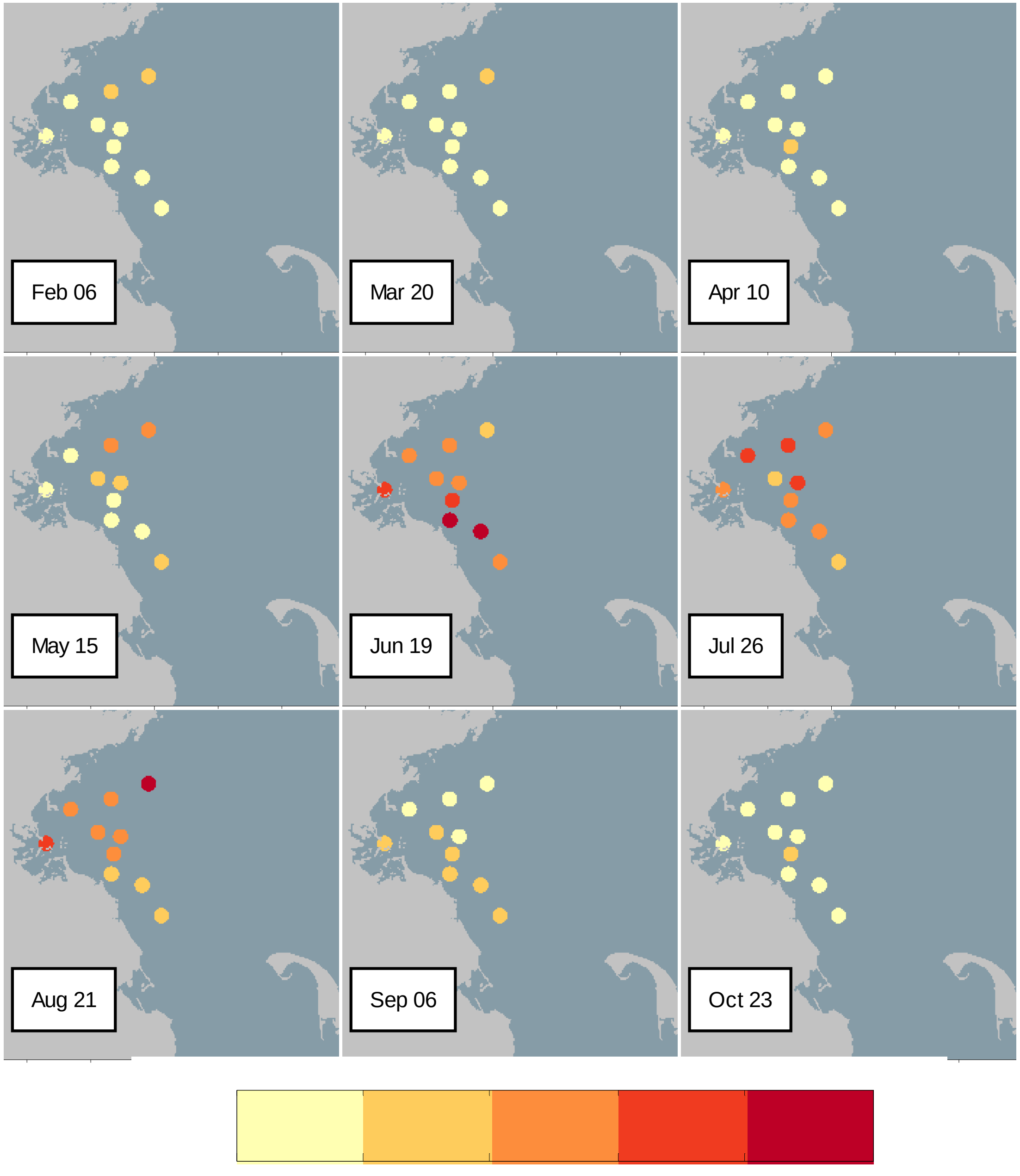
Battelle Annual Science Meeting
Duxbury, Massachusetts
March 6, 2013

2012 Zooplankton - Overview

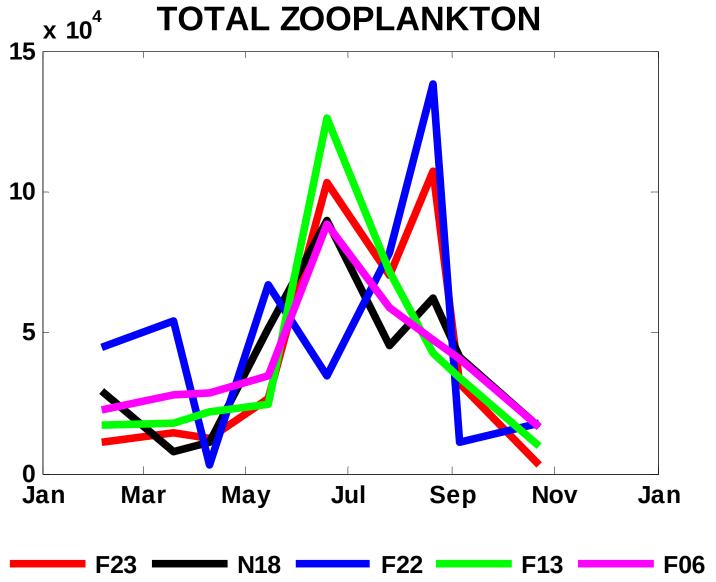
- Patterns of zooplankton abundance and composition in 2012 were similar to previous years.
- Total zooplankton abundance increased through the spring to maximum levels in summer, declining in the fall.
- Zooplankton composition was dominated by copepod nauplii, adults and copepodites of *Oithona similis*.
- *Acartia* spp. Adults and copepodites were abundant only in Boston Harbor.
- Total zooplankton abundance in 2012 was generally within the envelope of variability for previous years of the survey.

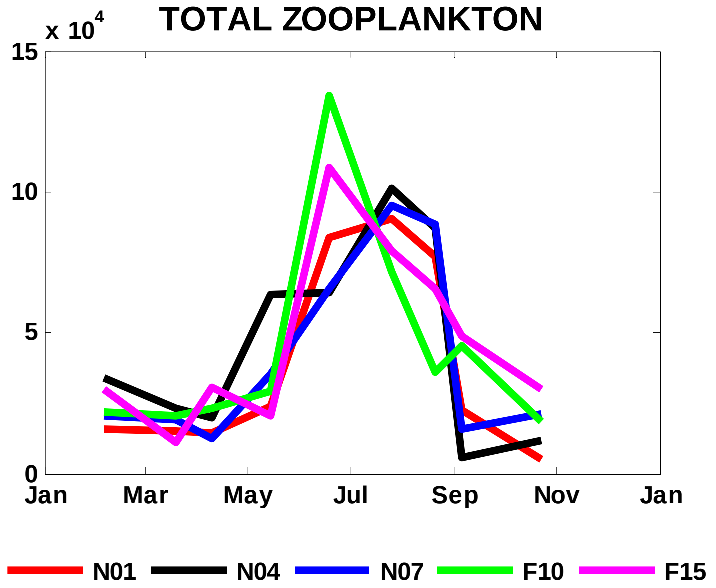

71°0'W
70°45'W
70°30'W
70°15'W
42°30'N
42°15'N
42°0'N
Battelle
The Business of Innovation
F22
N04
N01
N21
Massachusetts Bay
N07
N18
F23
F15
F13
F10
F06
F29
Cape Cod Bay
F02
F01
MWRA Stations
MWRA O Station (Nutrients, Plankton, & DO)
MWRA M Station (Nutrients & Plankton)
MWRA B Station (Nutrients)
Cape Cod Bay / Stellwagen Bank Station
Trackline
NOAA NDBC Buoy 44013
GOMOOS Mooring
Outfall Diffuser
Stellwagen Bank National Marine Sanctuary
Depth (m)
0
125
N
Kilometers
0
10
20
J:\GIS\mwra\MWRA_Stations_with_TrackLines_Feb2011.mxd
24 February 2011

2012 Total Zooplankton

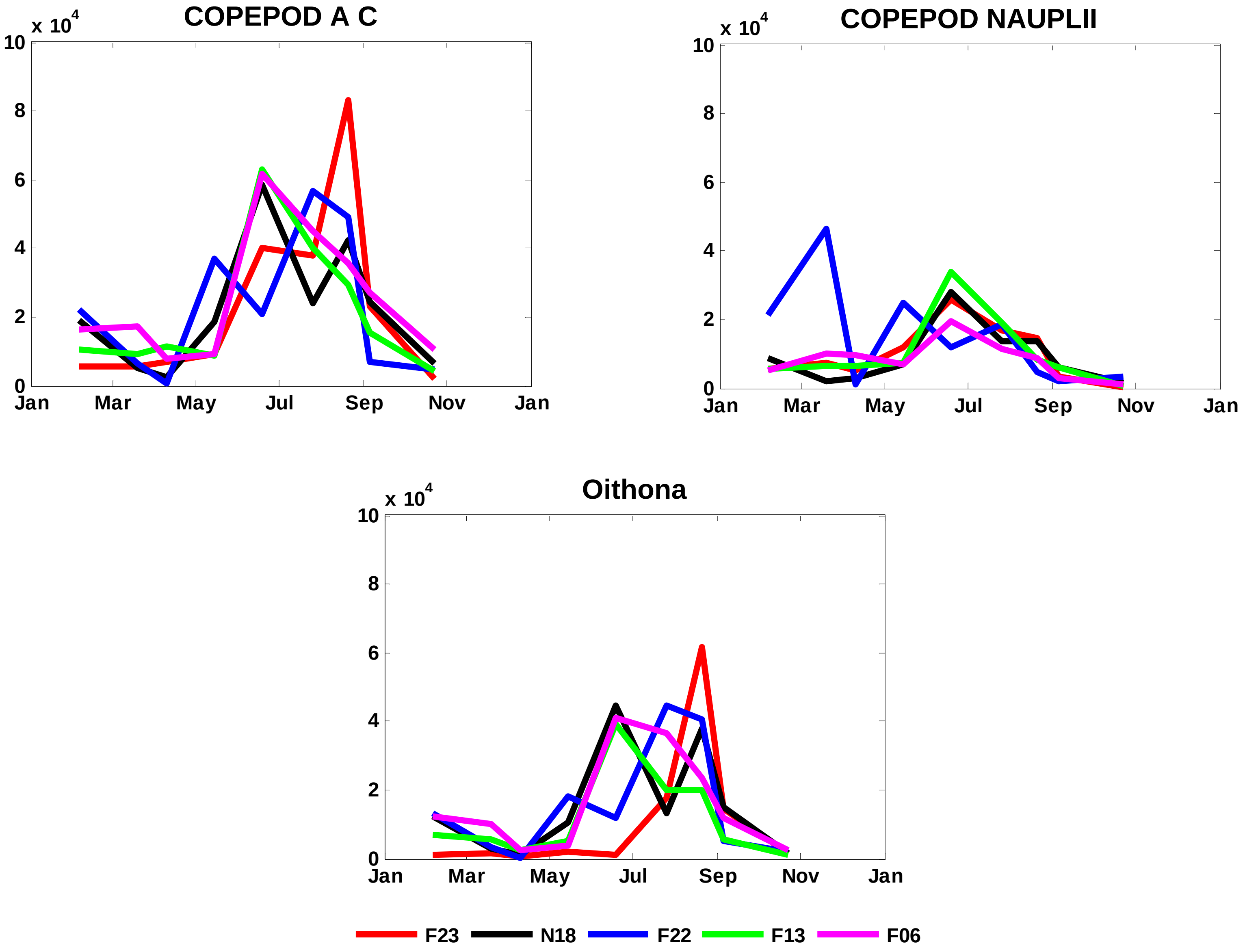


2012 Total Zooplankton

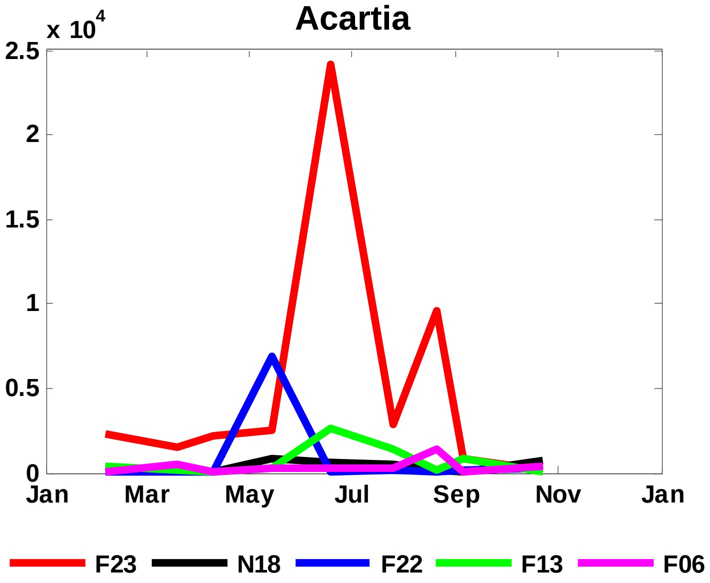


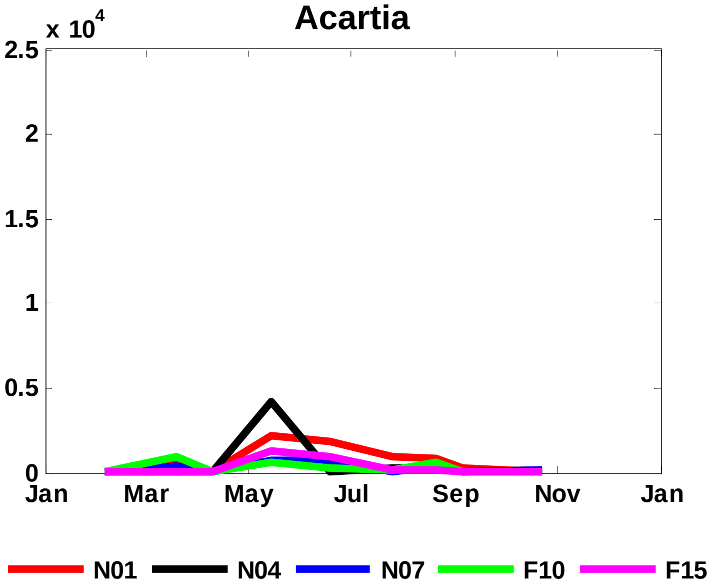


2012 Zooplankton



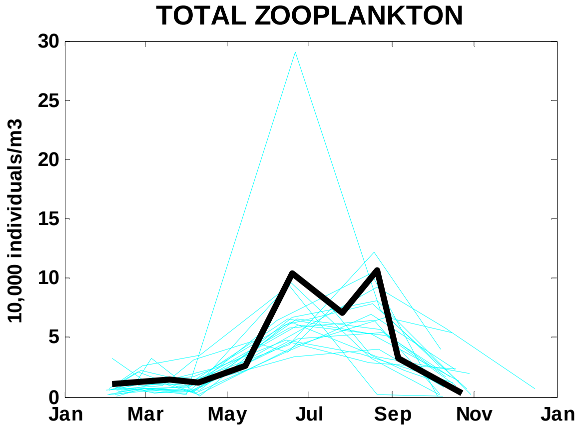
2012 Zooplankton



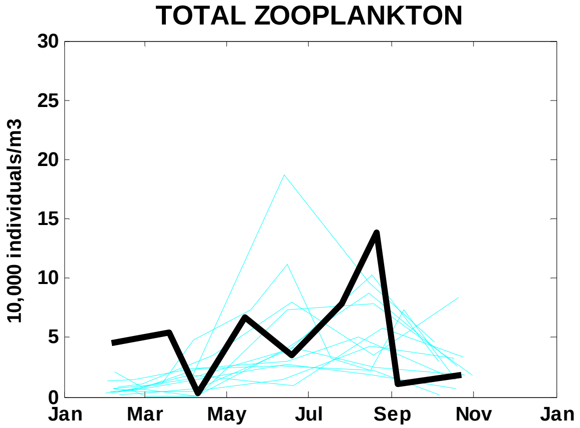


Total Zooplankton Annual Comparisons

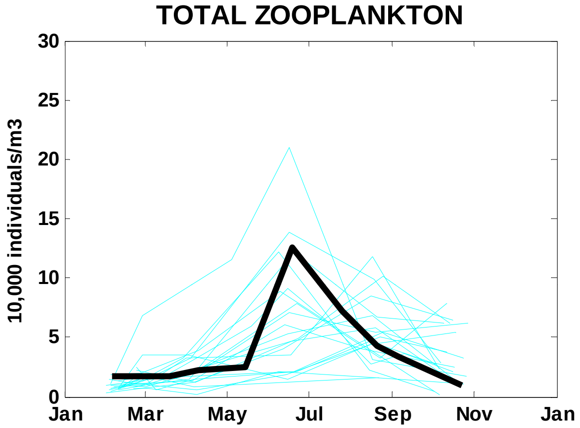
Harbor (F23)



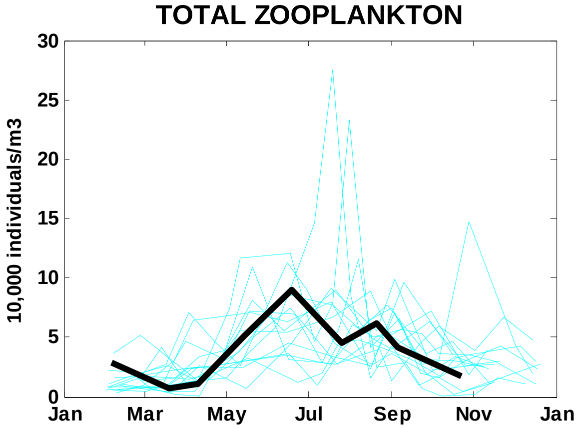
Northern Offshore (F22)

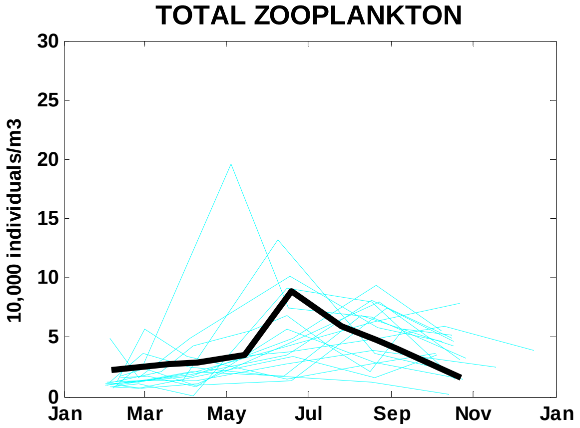


Coastal (F13)



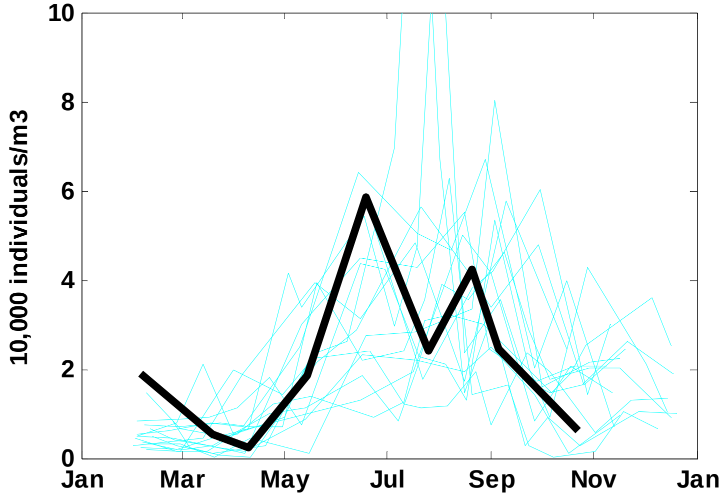
Nearfield (N18)

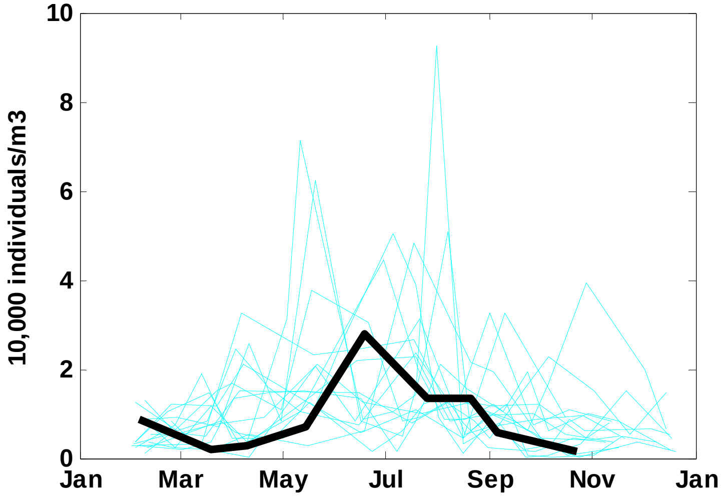


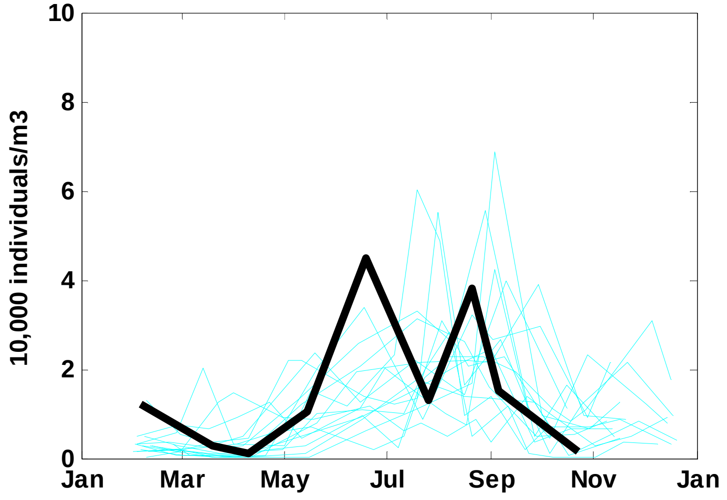


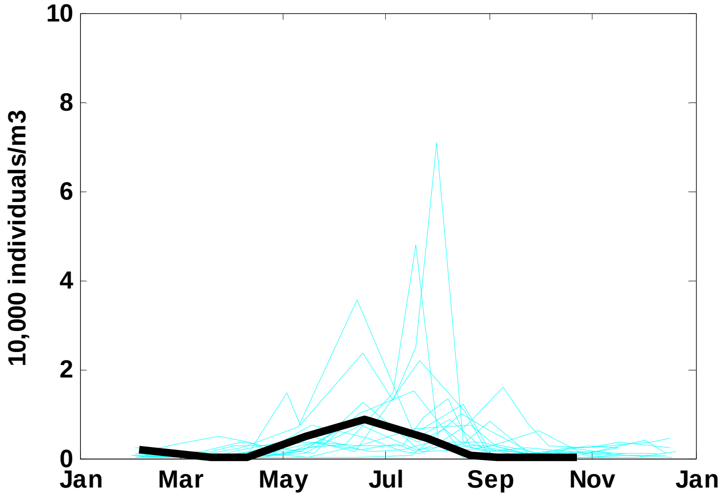
Southern Offshore (F06)

Nearfield Zooplankton

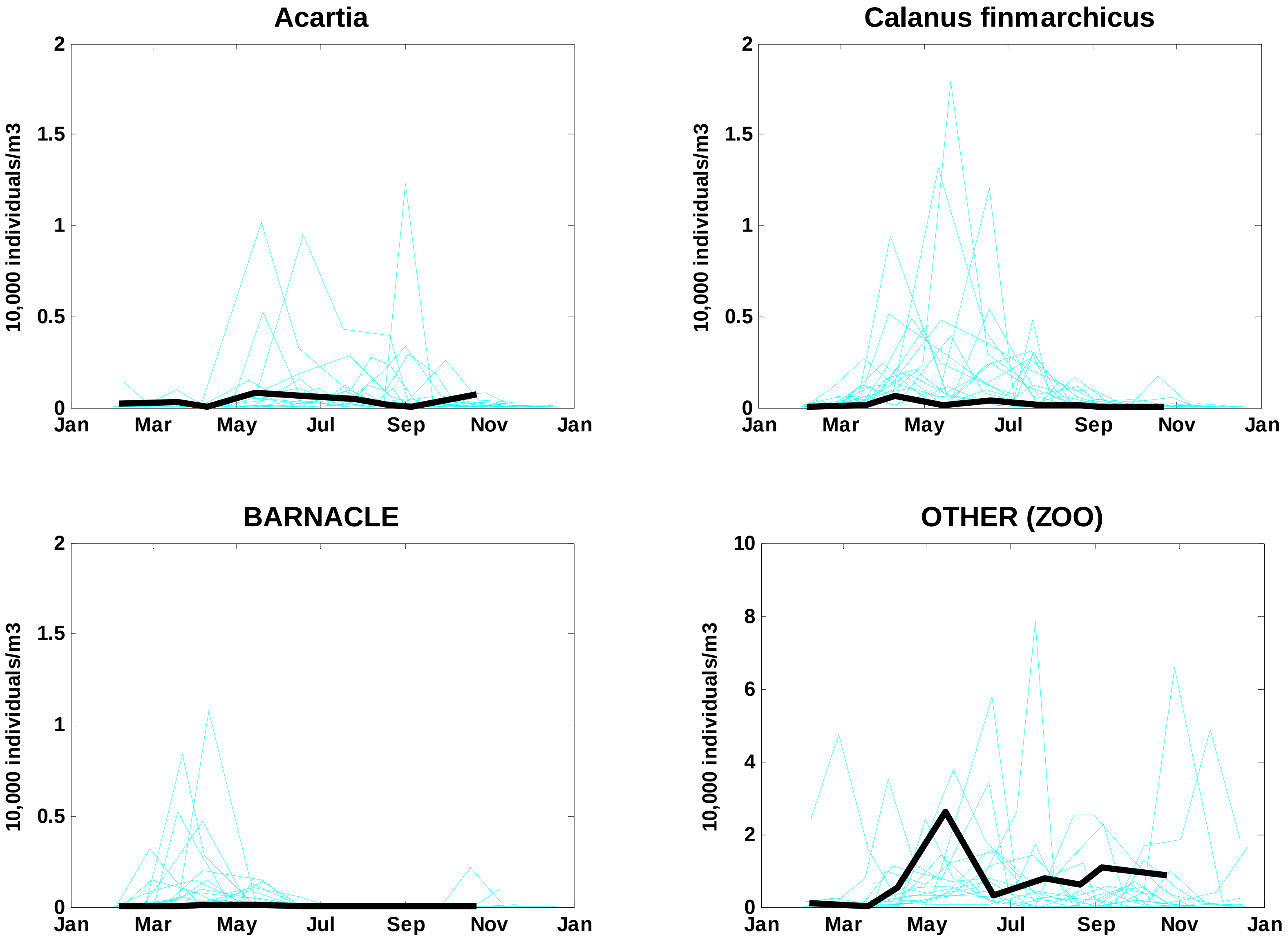

COPEPOD A C


COPEPOD NAUPLII


Oithona


Pseudocalanus

Nearfield Zooplankton



2012 Zooplankton Summary

- Patterns of zooplankton abundance and composition in 2012 were similar to previous years.
- Total zooplankton abundance increased through the spring to maximum levels in summer, declining in the fall.
- Zooplankton composition was dominated by copepod nauplii, adults and copepodites of *Oithona similis*.
- *Acartia* spp. Adults and copepodites were abundant only in Boston Harbor.
- Total zooplankton abundance in 2012 was generally within the envelope of variability for previous years of the survey.

Appendix E

2012 Cape Cod Bay Monitoring

Amy Costa, Provincetown Center for Coastal Studies

In 2012, the Provincetown Center for Coastal Studies (PCCS) completed 15 surveys to conduct water column monitoring in Cape Cod Bay and the southwestern corner of Stellwagen Bank (Figure 1, Table 1). Nine of these surveys focused on monitoring 3 of MWRA's farfield stations. When time and weather permitted, 8 additional PCCS stations were monitored in Cape Cod Bay during these surveys. Otherwise, the 8 PCCS stations were monitored as closely as possible to the targeted survey date for study BWQM. Coincident monitoring of all 11 stations occurred during the surveys in February, May, July, August, September and October. Only PCCS stations were monitored in January, November and December.

This report presents the data collected at the 3 MWRA-PCCS stations (F01, F02, F29) in 2012 and puts these data in the context of data from the 8 CCB stations (Figure 1).

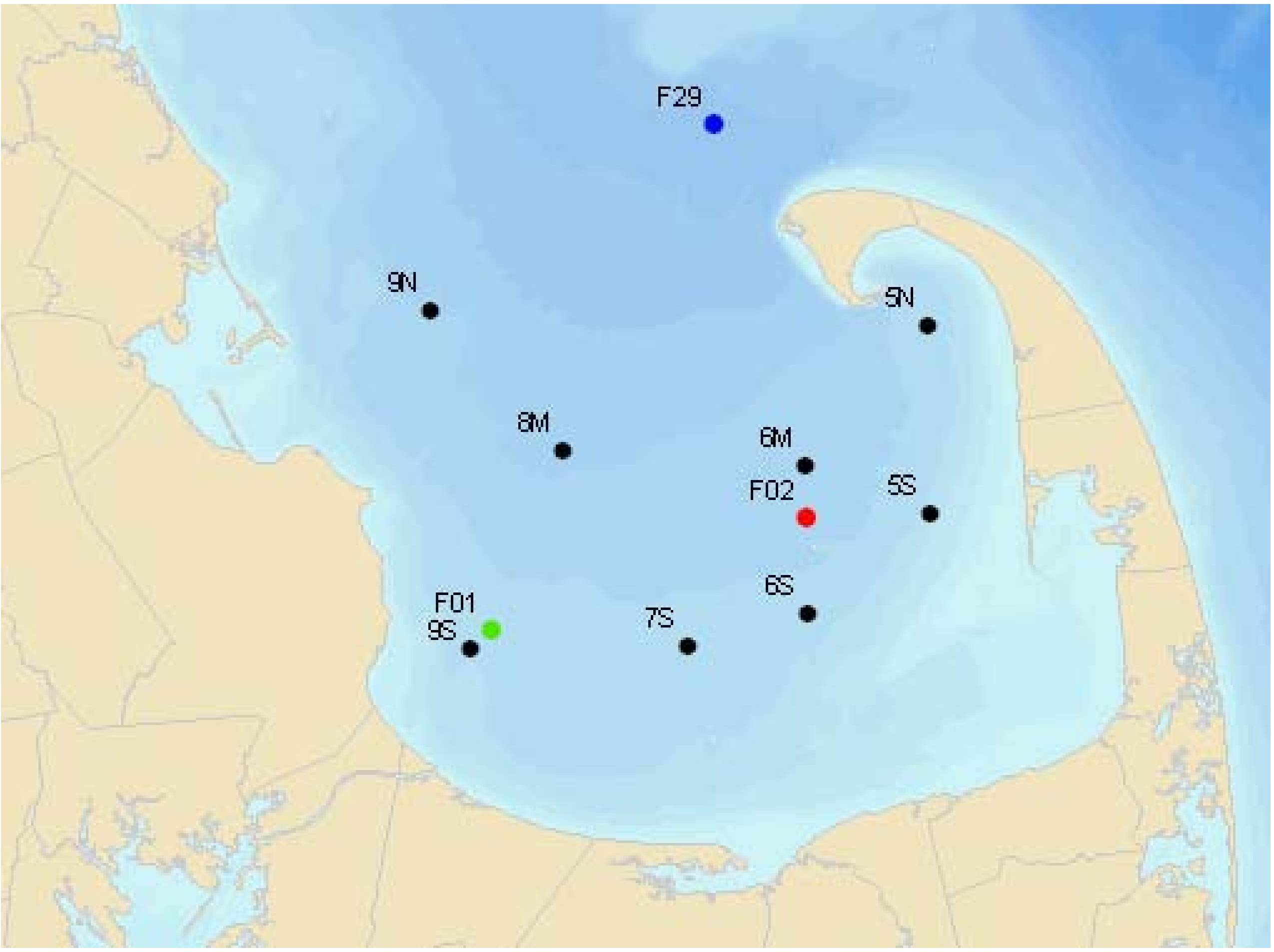


Figure 1. Locations of stations sampled in Cape Cod Bay and Stellwagen Bank. The colors of the symbols correspond to the data from these stations in the following figures.

Table 1. Surveys conducted by PCCS, Battelle, and MWRA during 2012. Data from the MWRA-PCCS and CCB studies are the focus of this report. Data from the Right Whale Habitat study are presented in Figure 8.

Conducted by:	Provincetown Center for Coastal Studies			Battelle		MWRA DLS
Date \ Study:	**MWRA-PCCS**	**CCB**	**Right Whale Habitat**	**BWQM**	**ARRS**	**BHWQM**
01/05/12						01/05/12
01/11/12			SW843			
01/19/12						01/19/12
01/21/12		SW844	SW844			
01/26/12			SW845			
02/02/12						02/02/12
02/05/12	WN121-PCCS	SW846	SW846			
02/06/12				WN121		
02/15/12			SW848			
02/16/12						02/16/12
02/27/12			SW849			
02/29/12			SW850			
03/07/12						03/07/12
03/12/12			SW851			
03/16/12		SW852	SW852			
03/19/12			SW853			03/19/12
03/20/12	WN122-PCCS			WN122		
03/23/12			SW855			
04/01/12			SW856			
04/04/12			SW857			04/04/12
04/10/12				WN123		
04/11/12	WN123-PCCS					
04/13/12		SW860	SW860			
04/17/12			SW861			
04/19/12						04/19/12
05/01/12						05/01/12
05/04/12			SW862			
05/14/12	WN124-PCCS	SW863	SW863			
05/15/12				WN124		
05/17/12			SW864			
05/22/12					AF121	
05/24/12						05/24/12
05/30/12					AF122	
06/07/12					AF123	06/07/12
06/18/12	WN125-PCCS					
06/19/12				WN125		
06/26/12		CCB				
06/27/12						06/27/12
07/05/12						07/05/12
07/26/12	WN126-PCCS	CCB		WN126		07/26/12
08/01/12						08/01/12
08/21/12	WN127-PCCS	CCB		WN127		08/21/12
09/06/12	WN128-PCCS	CCB		WN128		
09/10/12						09/10/12
09/25/12						09/25/12

Conducted by:	Provincetown Center for Coastal Studies			Battelle		MWRA DLS
Date \ Study:	**MWRA-PCCS**	**CCB**	**Right Whale Habitat**	**BWQM**	**ARRS**	**BHWQM**
10/18/12						10/18/12
10/23/12				WN129		
10/24/12	WN129-PCCS	CCB				
10/25/12						10/25/12
11/05/12						11/05/12
11/11/12		CCB				
11/20/12						11/20/12
12/03/12						12/03/12
12/20/12						12/20/12
12/29/12		CCB				

<u>Hydrography:</u> Hydrographic data collected during 2012 followed similar patterns as observed in previous years. The most notable difference was the warmer than average surface water temperatures observed during the winter (Jan-Mar). Surface water temperatures remained slightly above average through June (Figure 2).

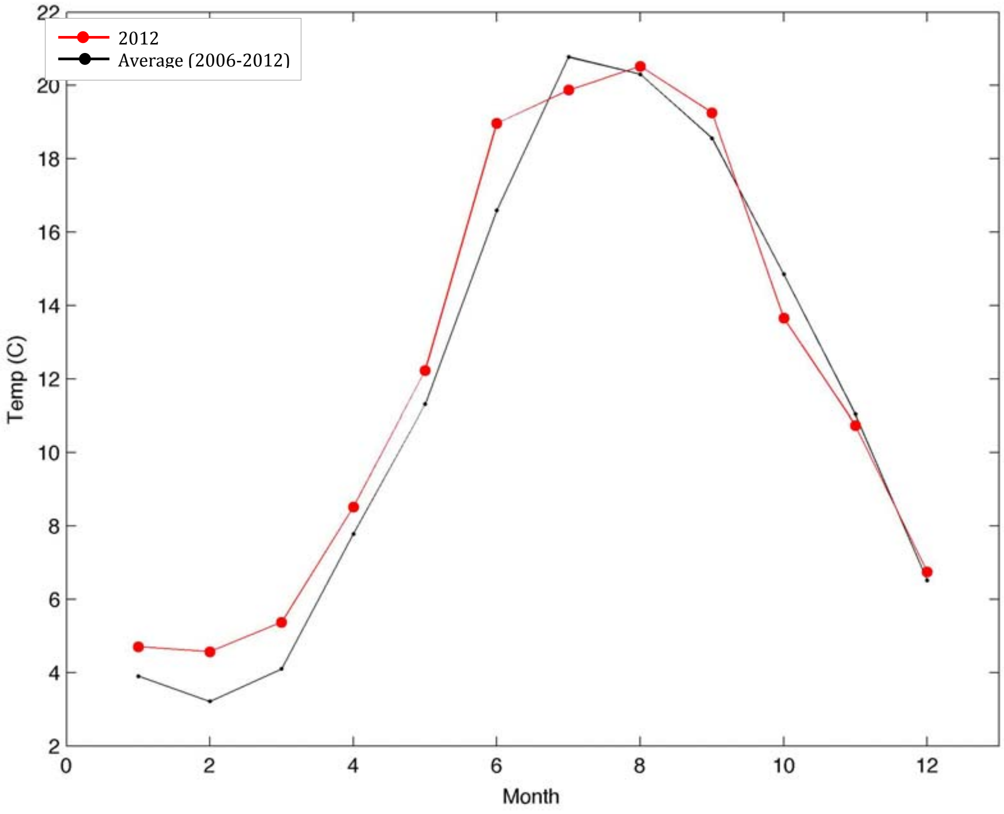
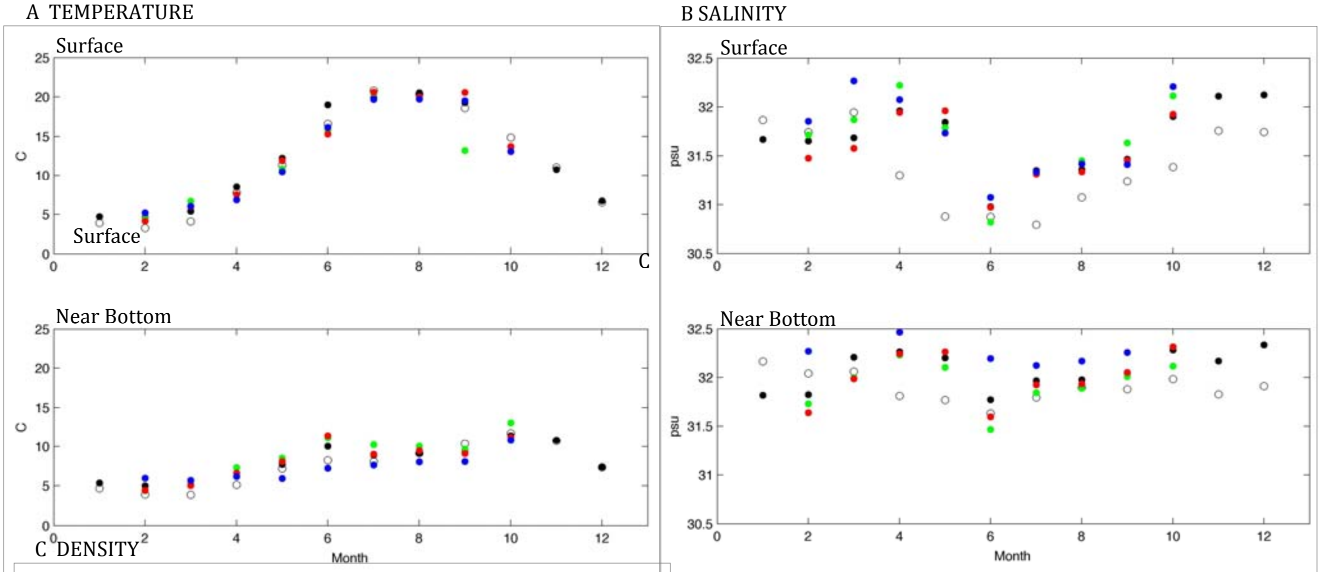


Figure 2. A comparison of surface water temperatures measured in 2012 to the average surface water temperatures measured from 2006-2012 in Cape Cod Bay.

Despite these warmer winter/early spring water temperatures, similar patterns were observed in 2012 as seen in previous years (Figure 3). Surface water temperatures were coldest in February. All stations were well-mixed through the spring. A thermocline began to form in June, strengthening over the course of the summer. In October, cooling temperatures and wind events began to break down the water column stratification. Surface salinities were higher in the spring than typically observed and remained slightly higher than the average surface salinities measured in the bay (2006-2012). Patterns were the same though, with lowest salinities during the spring (June). Density, being driven by changes in temperature and salinity, reflected these seasonal changes.



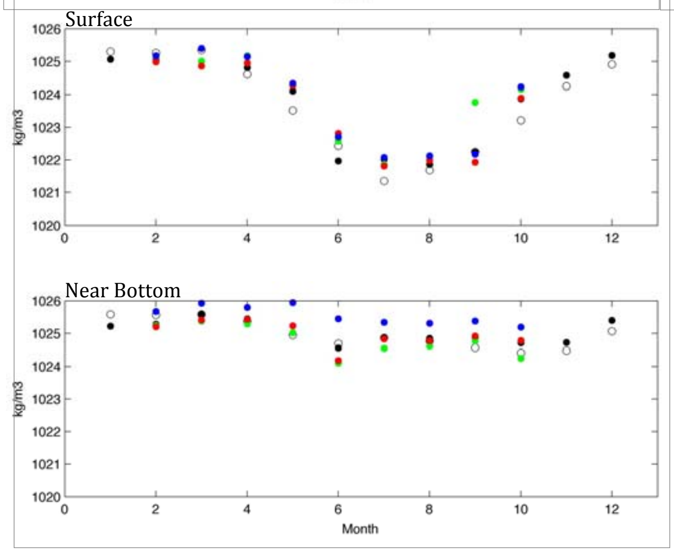


Figure 3. Hydrographic conditions measured at the 3 MWRA stations and the 8 PCCS stations. A) temperature, B) salinity, and C) density. MWRA stations are indicated by color. Average values for CCB stations for 2012 are indicated with a filled black circle. Average values for all stations, 2006-2012, are indicated with an open circle.

○ Average
● CCB Stns
● F01
● F02
● F29

Water Chemistry: As with hydrography, water chemistry followed patterns typical of this area. Dissolved nutrients were highest in the surface waters when the water column was well mixed (Figure 4). This precipitated the seasonal blooms in phytoplankton (winter/spring and fall) as evidenced by the peaks in chlorophyll levels (Figure 5). Bottom waters tended to show an increase in dissolved nutrients when the water column was strongly stratified (Figure 4).

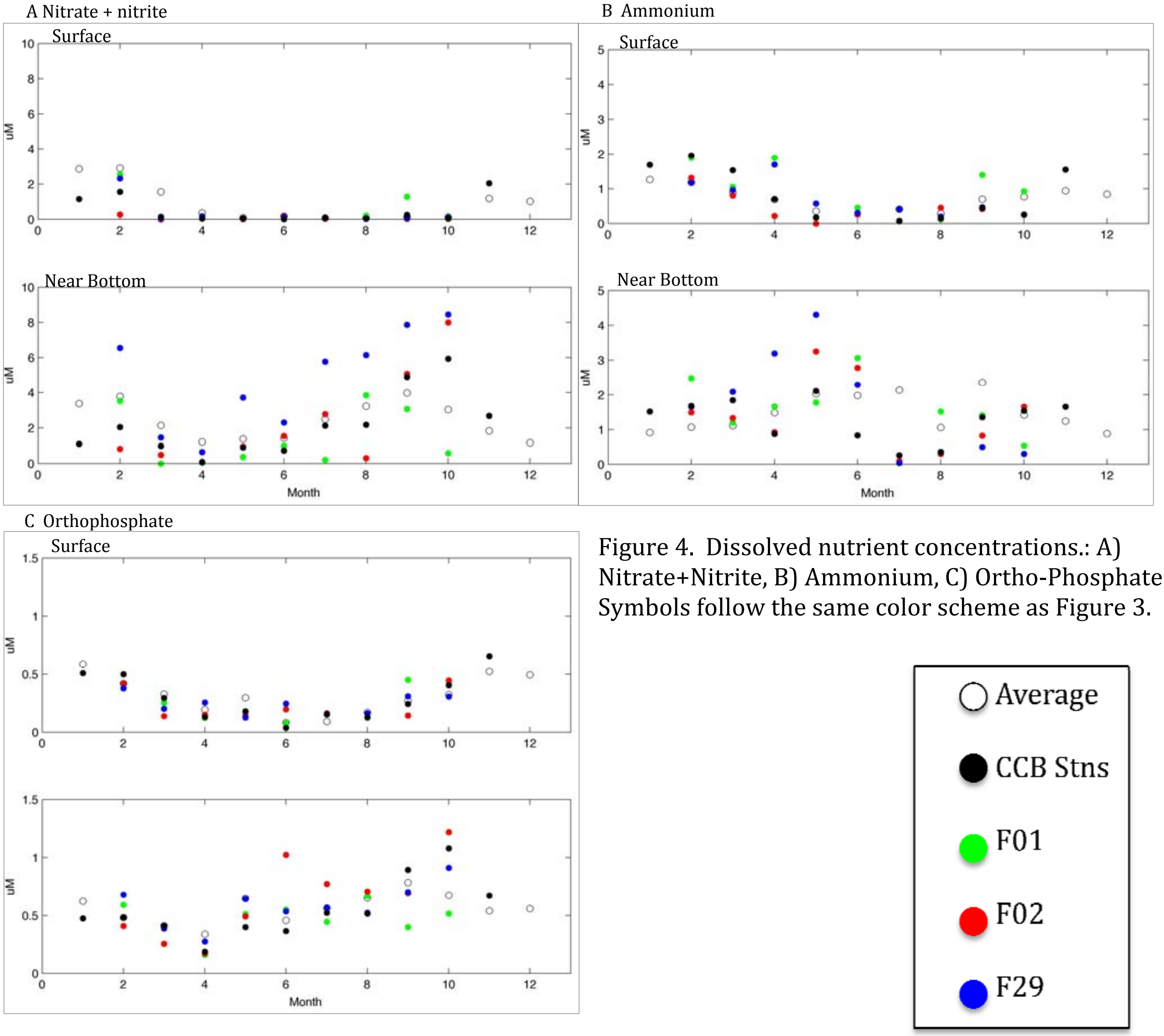


Figure 4. Dissolved nutrient concentrations.: A) Nitrate+Nitrite, B) Ammonium, C) Ortho-Phosphate. Symbols follow the same color scheme as Figure 3.

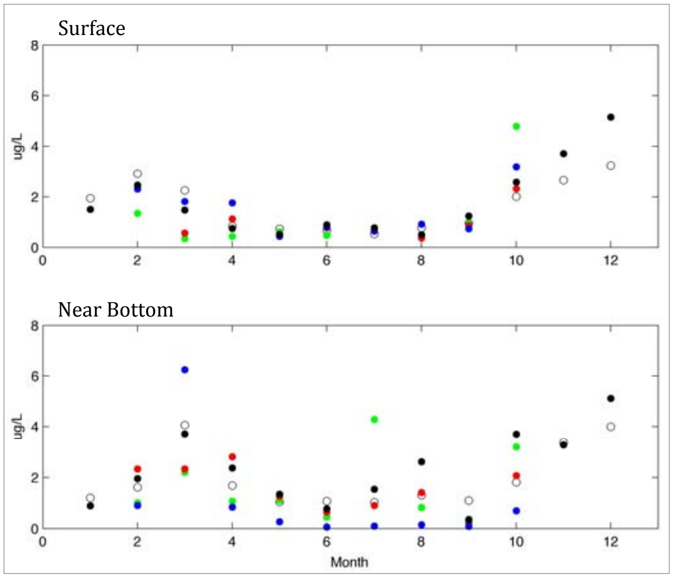


Figure 5. Chlorophyll concentrations. Symbols follow the same color scheme as Figures 3 and 4.

<u>Plankton:</u> The phytoplankton assemblage was typically dominated by flagellates (Figure 6). There was a noticeable absence of diatoms during the spring, although they did contribute to a large part of the fall phytoplankton composition. During March there was a moderate bloom in *Phaeocystis* at station F29.

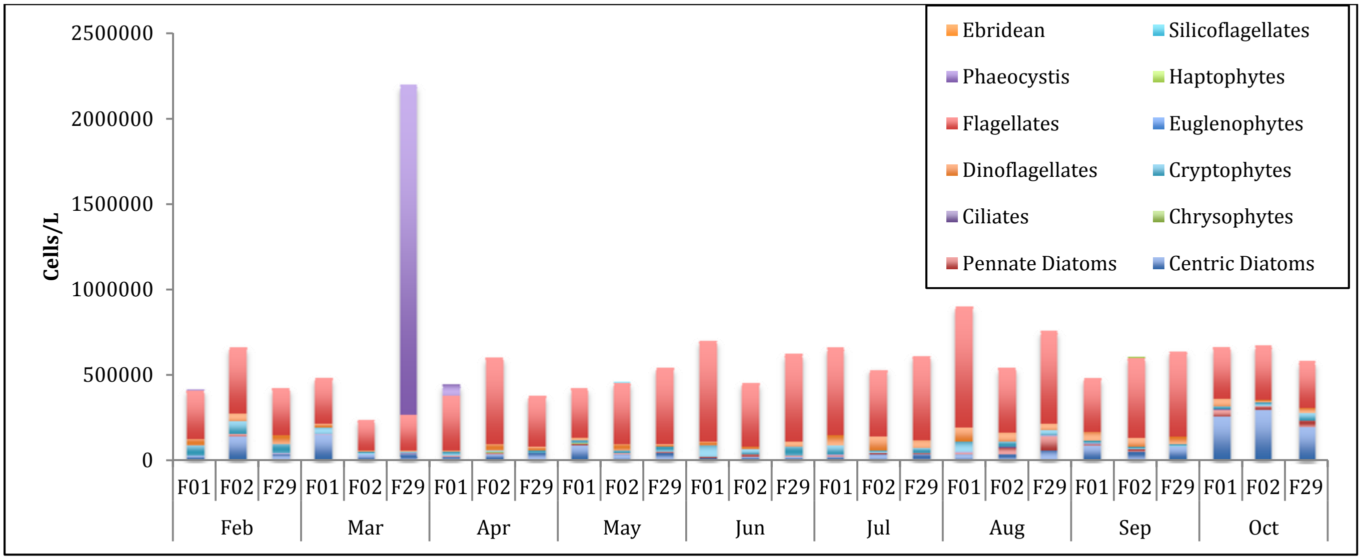


Figure 6. Phytoplankton abundance and composition observed at the 3 MWRA stations.

Zooplankton was dominated by *Centropages* spp. and *Pseudocalanus* spp. during most of the year. Cladocerans and *Temora longicornis* were abundant during the summer and fall. Of note was the lack of *Calanus finmarchicus* which is typically one of the dominant species during the spring (Figure 7).

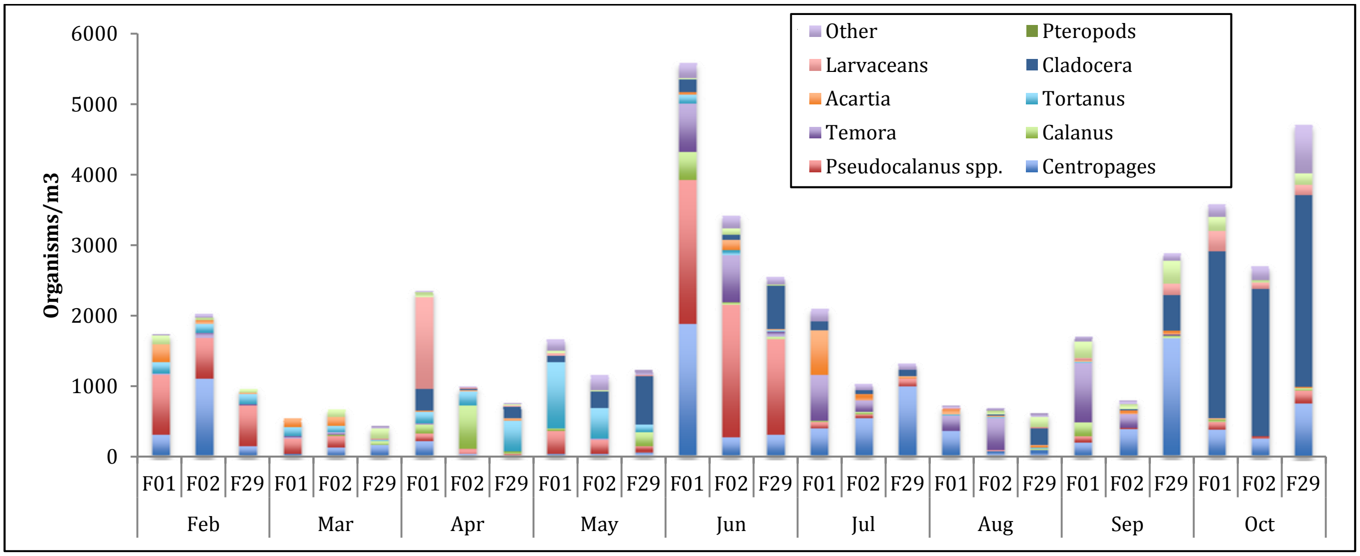


Figure 7. Zooplankton abundance and composition observed at the 3 MWRA stations.

During the winter and spring (January – May), much of the sampling effort for zooplankton in Cape Cod Bay is focused around right whales. During 2012, both zooplankton and whale abundances declined from what was seen during 2011 (Figure 8).

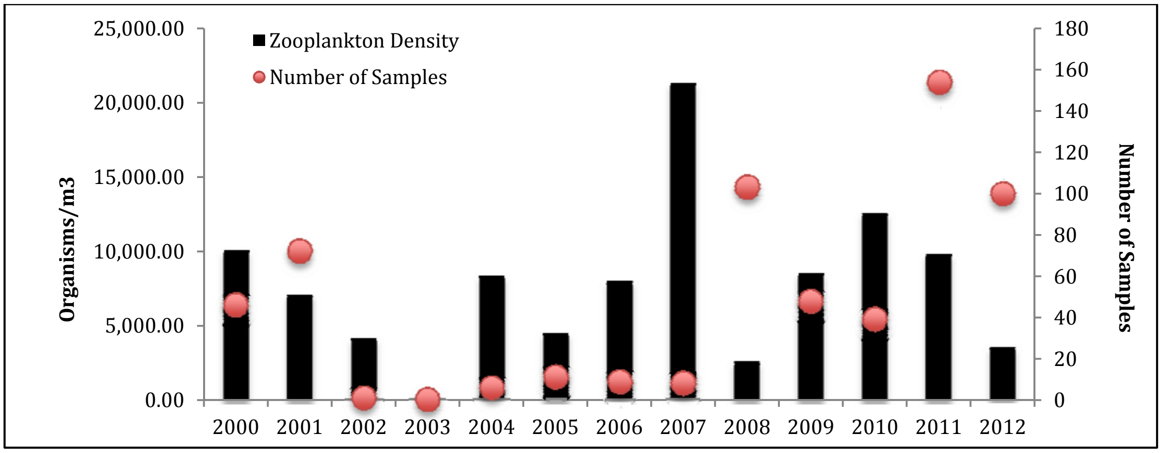
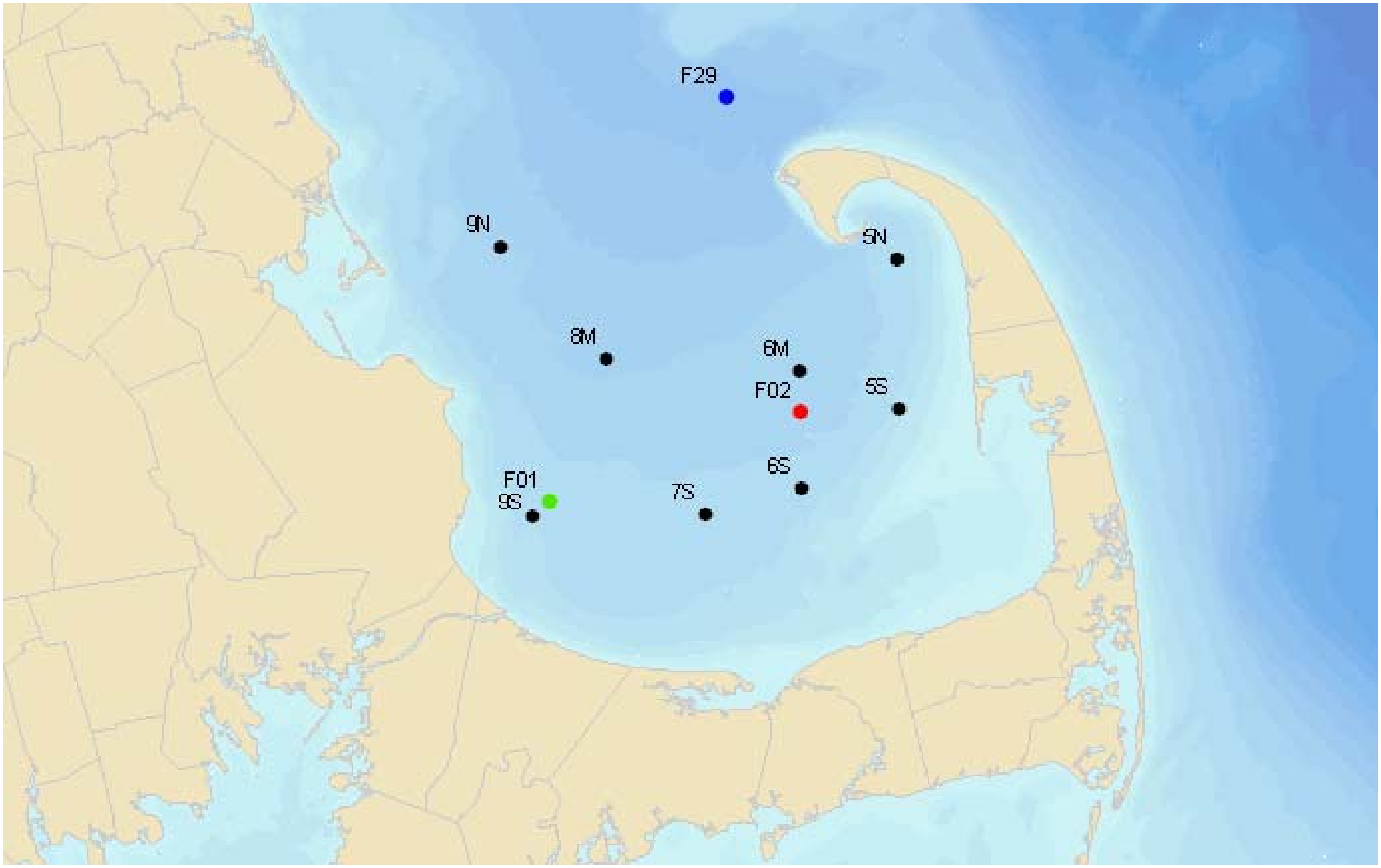


Figure 8. Average abundance of whales and zooplankton observed in Cape Cod Bay.

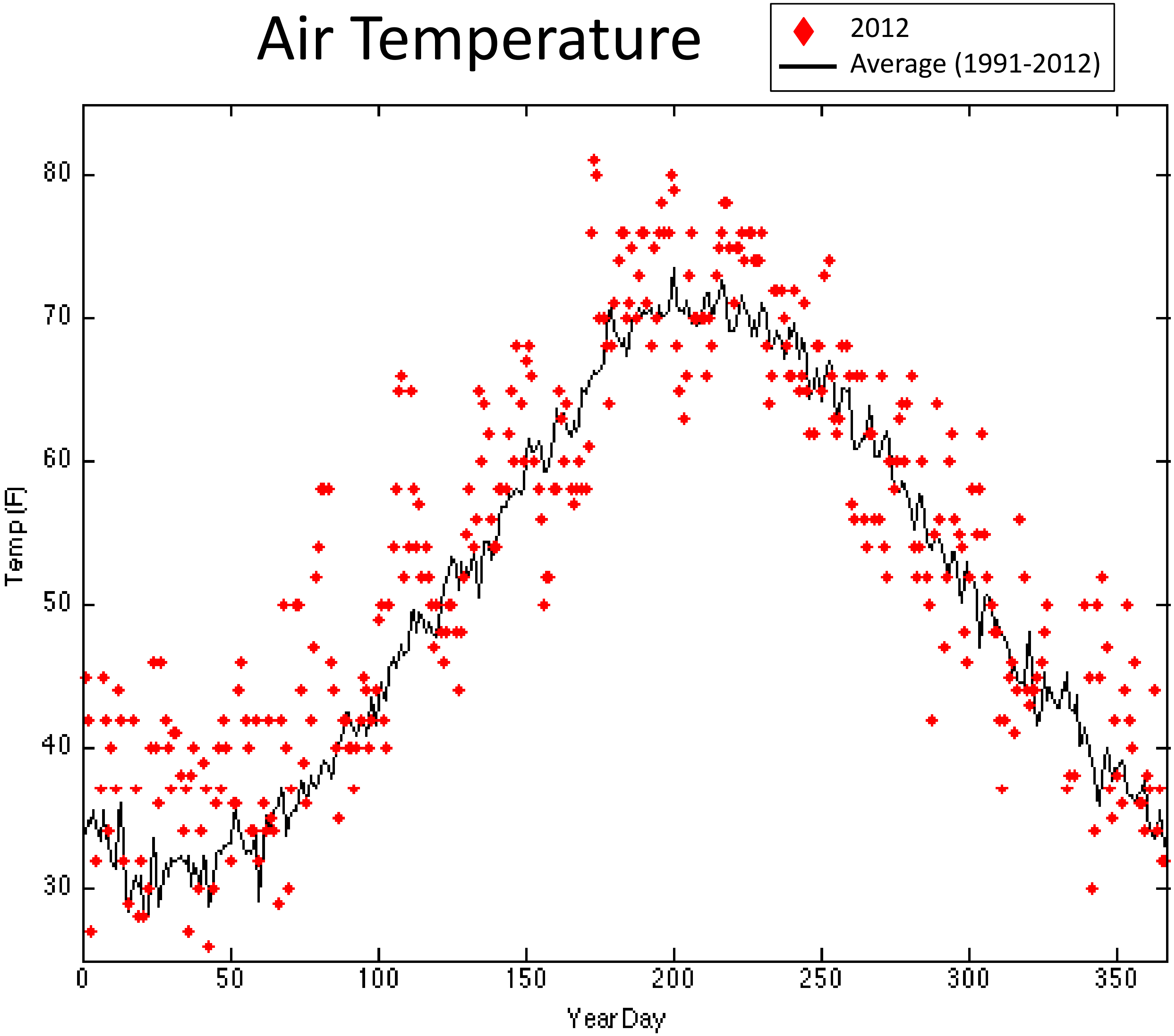
Cape Cod Bay Monitoring
2012

Provincetown Center for Coastal Studies


F29
9N
5N
8M
6M
F02
5S
6S
F01
9S
7S

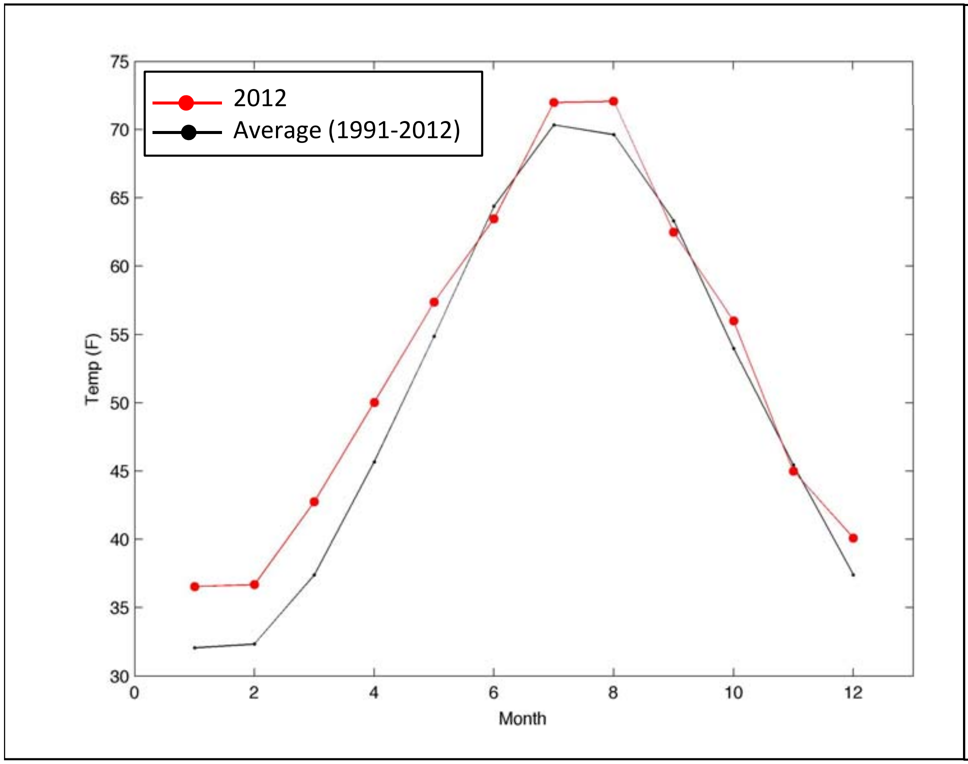
Type of Measurement	Depth	Parameter
Hydro profile	From near surface (approximately 0.5-1.5 m) to near-bottom (3-5 m from bottom). Profiling at 0.5 m intervals	Temperature Salinity Dissolved oxygen Depth of sensor Chlorophyll fluorescence Underwater irradiance Surface Irradiance
Water Chemistry	Two depths: Near- surface Near- bottom	Nitrate + nitrite Ammonia Ortho-phosphate Silicate Total nitrogen Total phosphorus Extracted chlorophyll
Phytoplankton	Near-surface	Enumeration + identification
Zooplankton	Oblique net tow	Enumeration + identification

Air Temperature

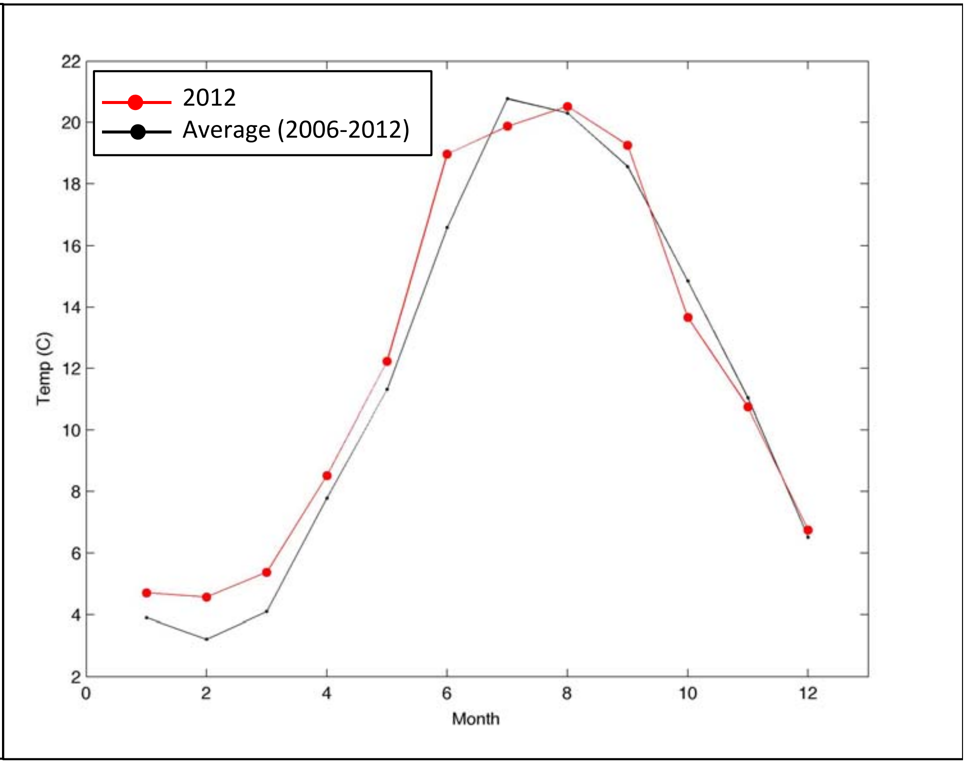


Weather Underground: Provincetown

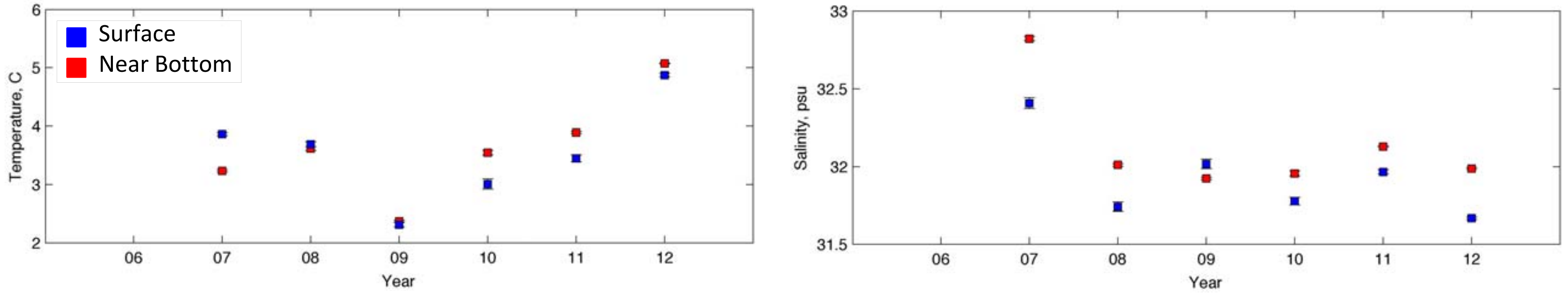
Air Temperatures



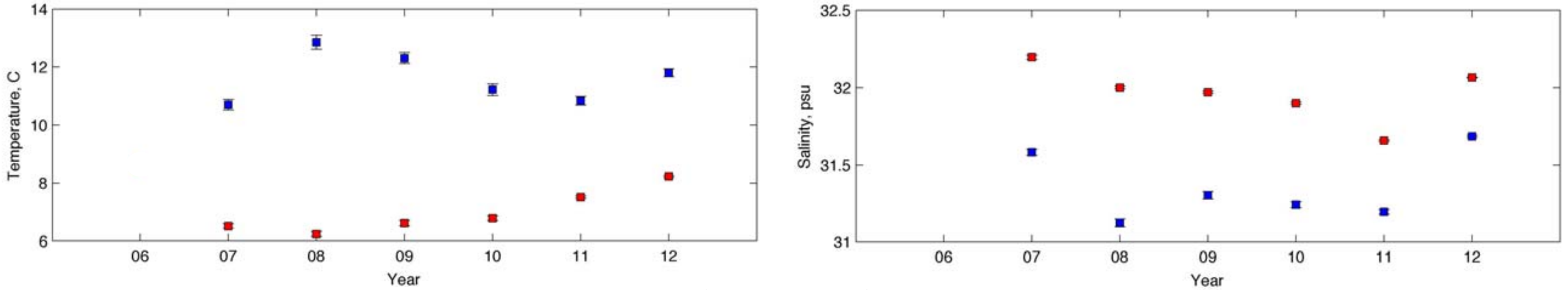
Surface Water Temperatures



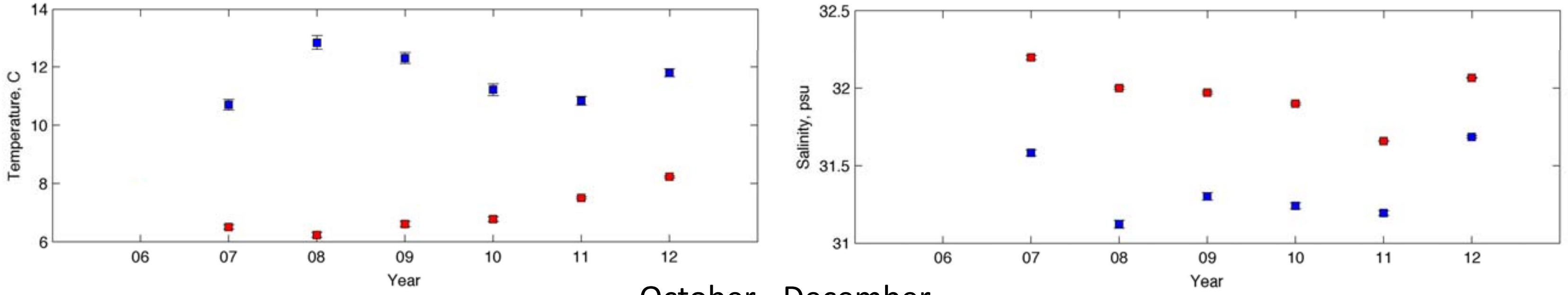
January - March



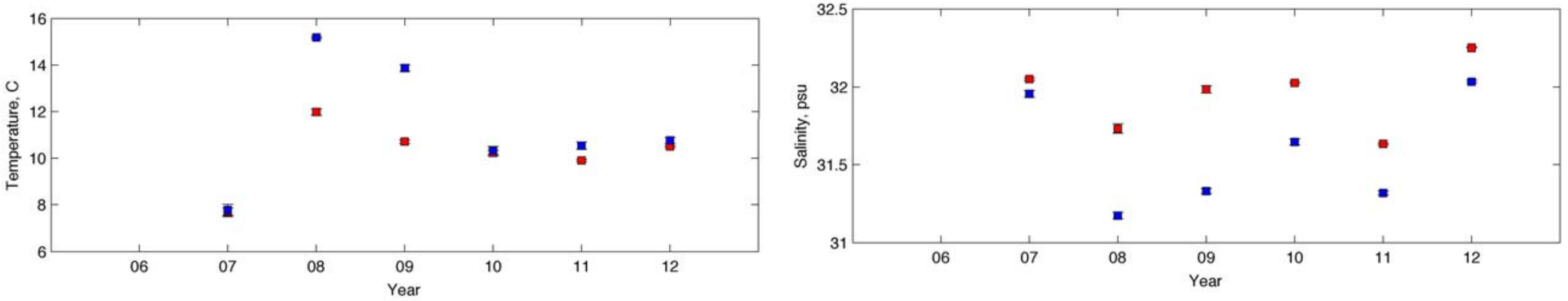
April - June



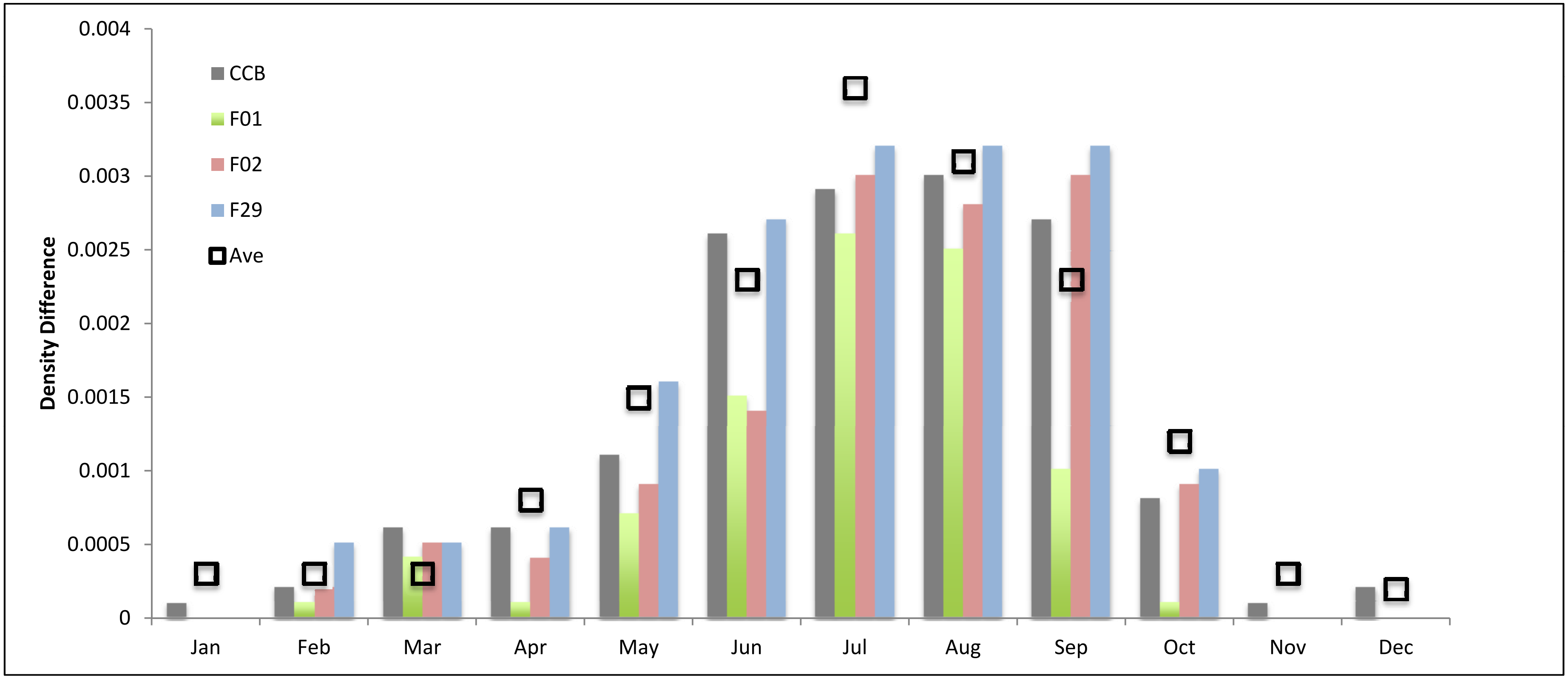
July - September

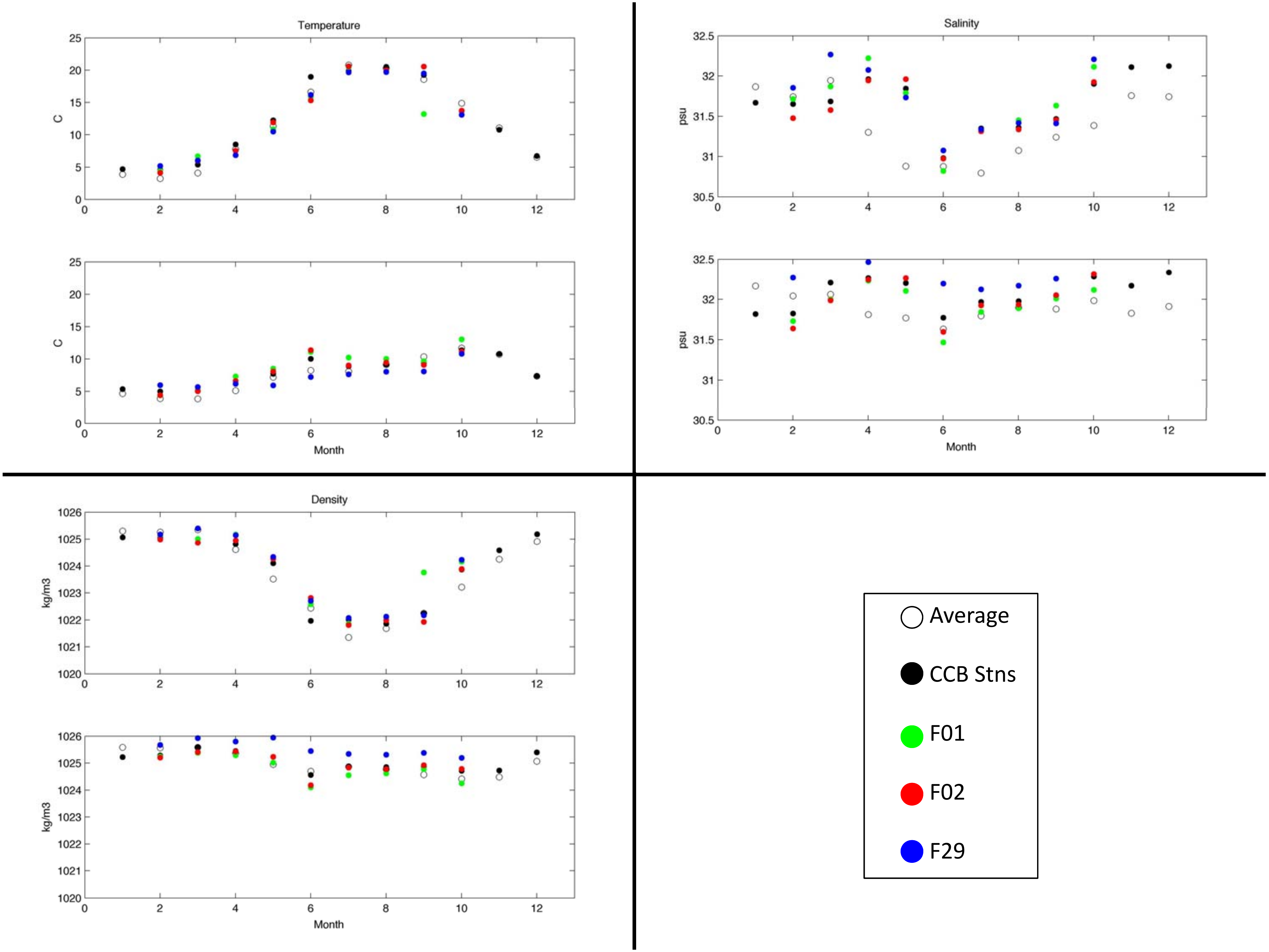


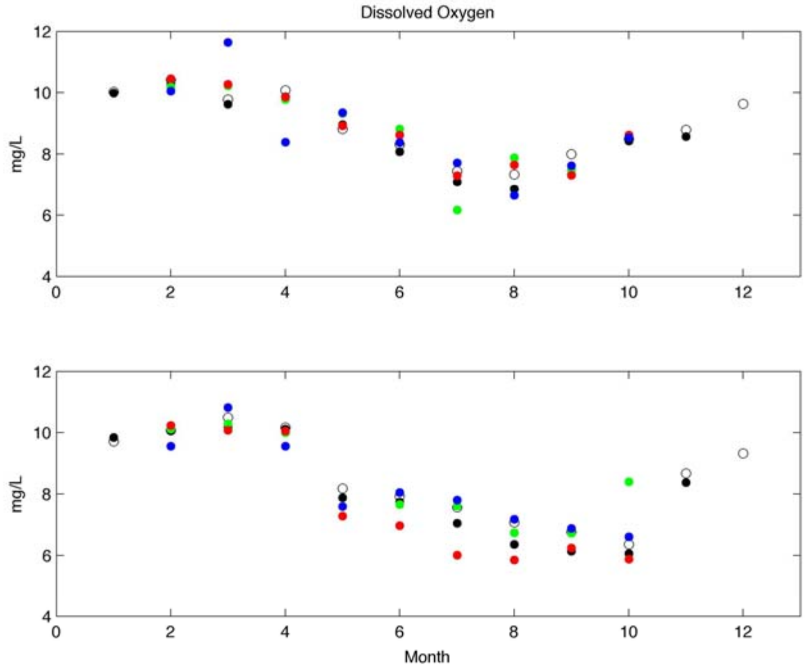
October - December



Stratification




Temperature
C
25
20
15
10
5
0
Month
0
2
4
6
8
10
12
Salinity
psu
32.5
32
31.5
31
30.5
Density
kg/m3
1026
1025
1024
1023
1022
1021
1020
○ Average
● CCB Stns
● F01
● F02
● F29



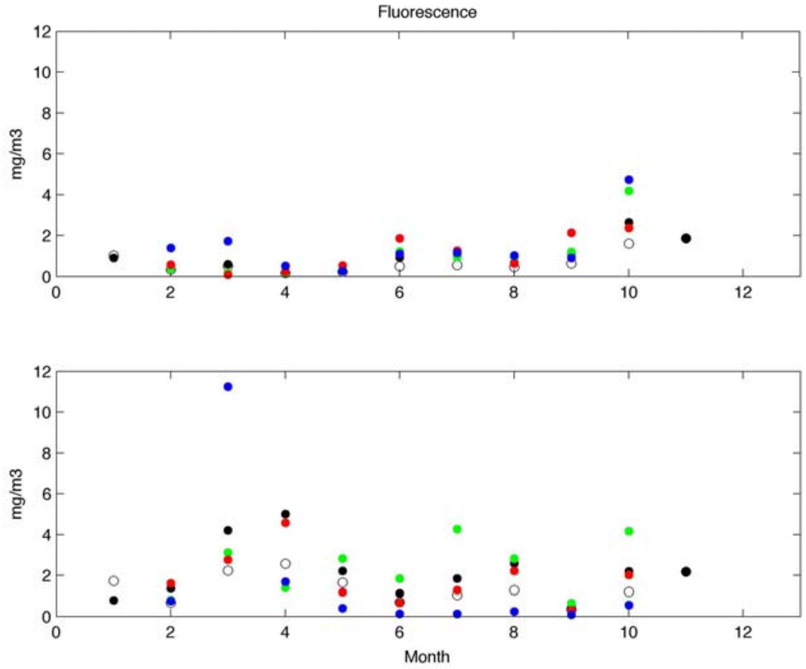
○ Average

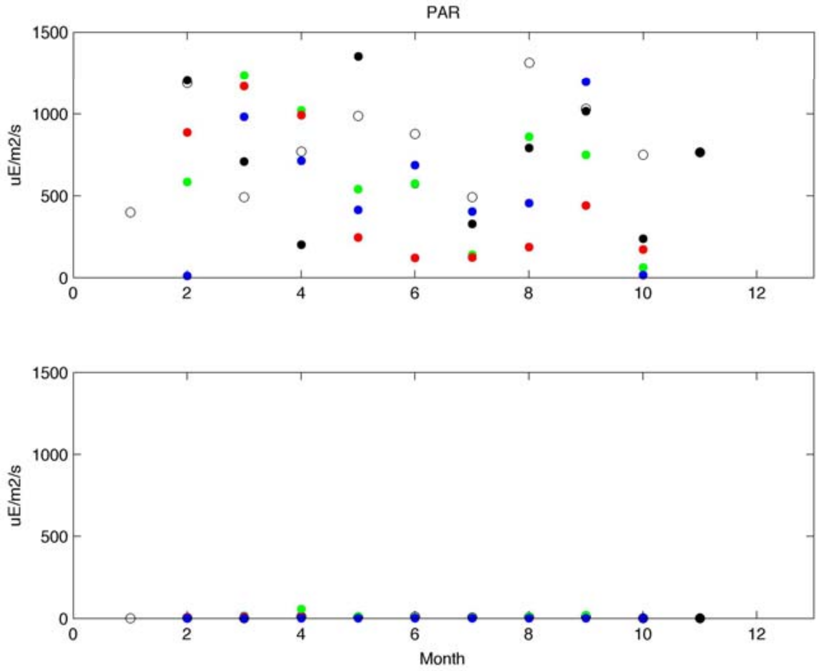
● CCB Stns

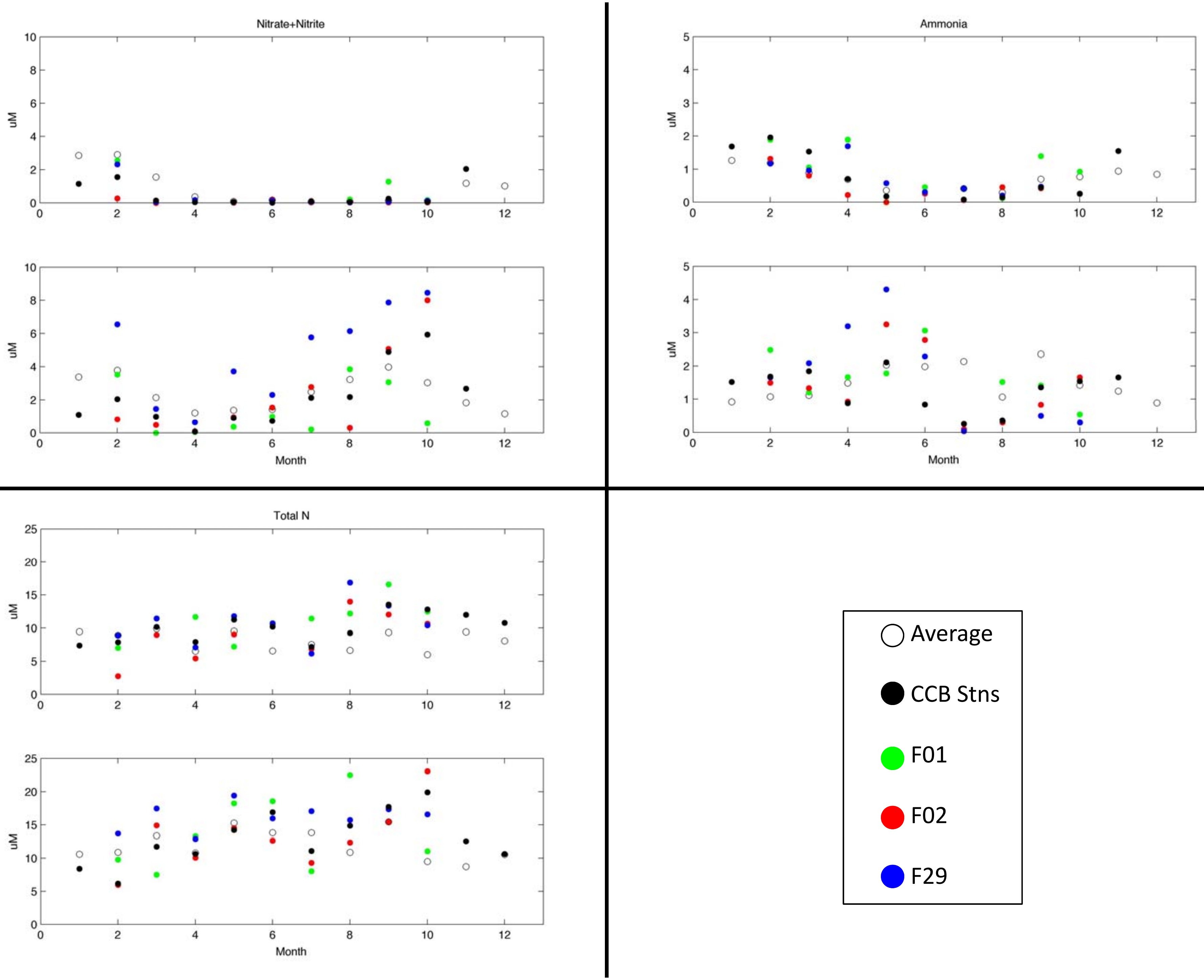
🟢 F01

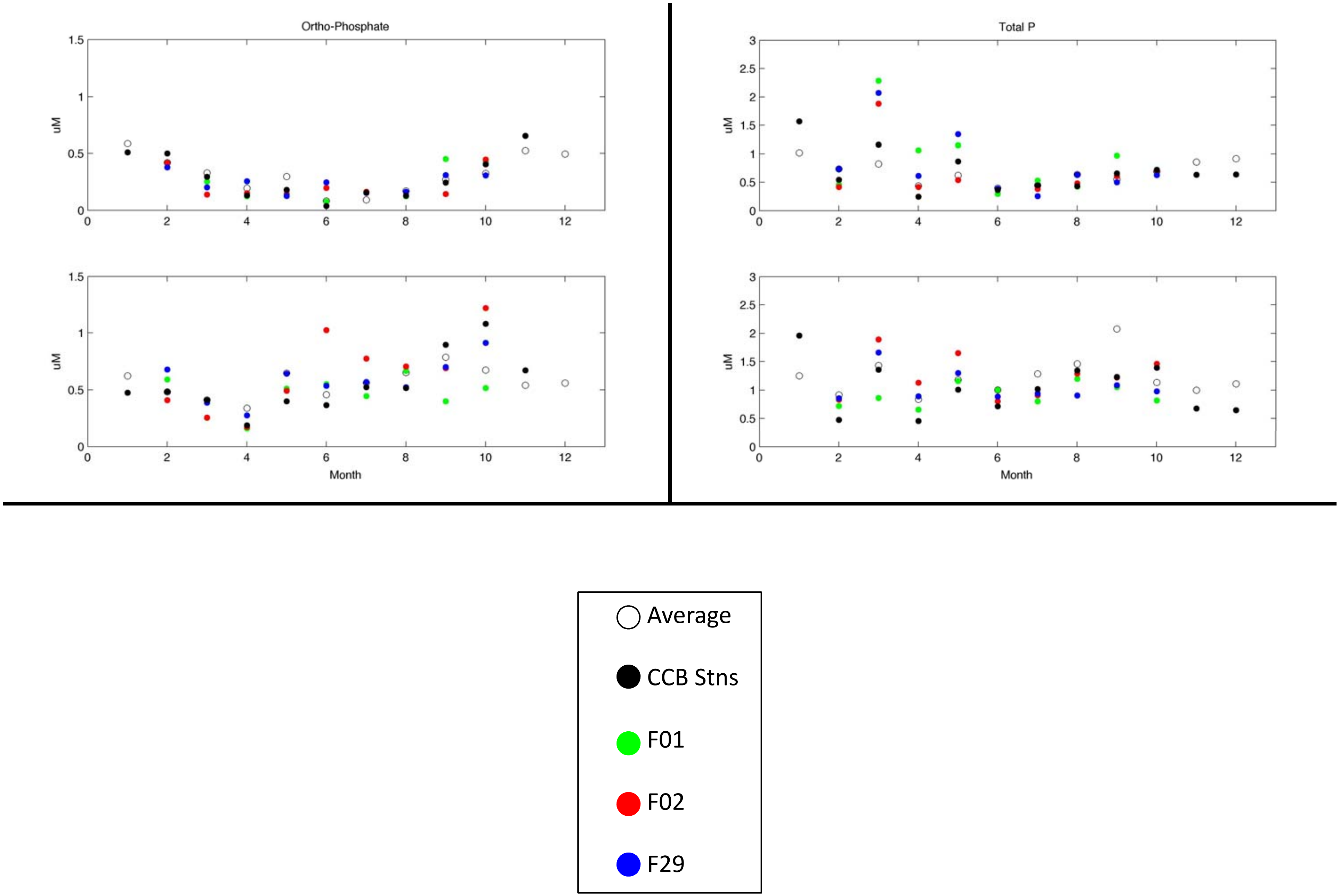
🔴 F02

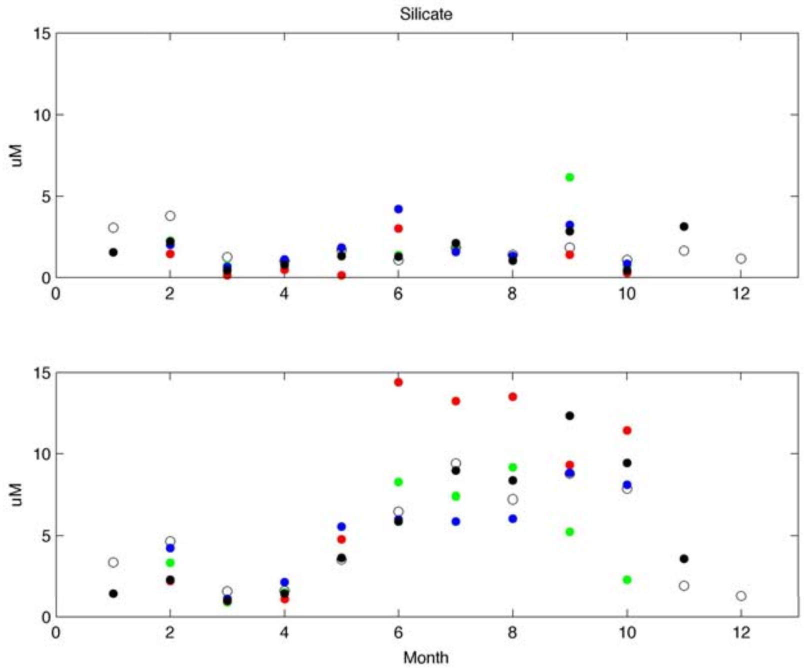
🔵 F29

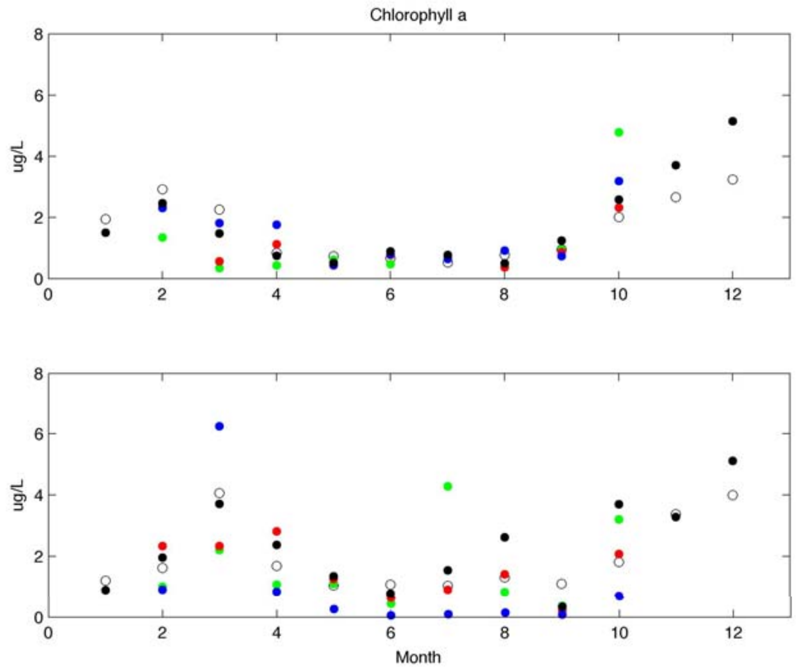





Nitrate+Nitrite
Ammonia
Total N
uM
Month
0
2
4
6
8
10
12
0
1
2
3
4
5
0
2
4
6
8
10
0
5
10
15
20
25
○ Average
● CCB Stns
● F01
● F02
● F29


Ortho-Phosphate
Total P
uM
Month
0
0.5
1
1.5
2
2.5
3
2
4
6
8
10
12
Average
CCB Stns
F01
F02
F29





○ Average

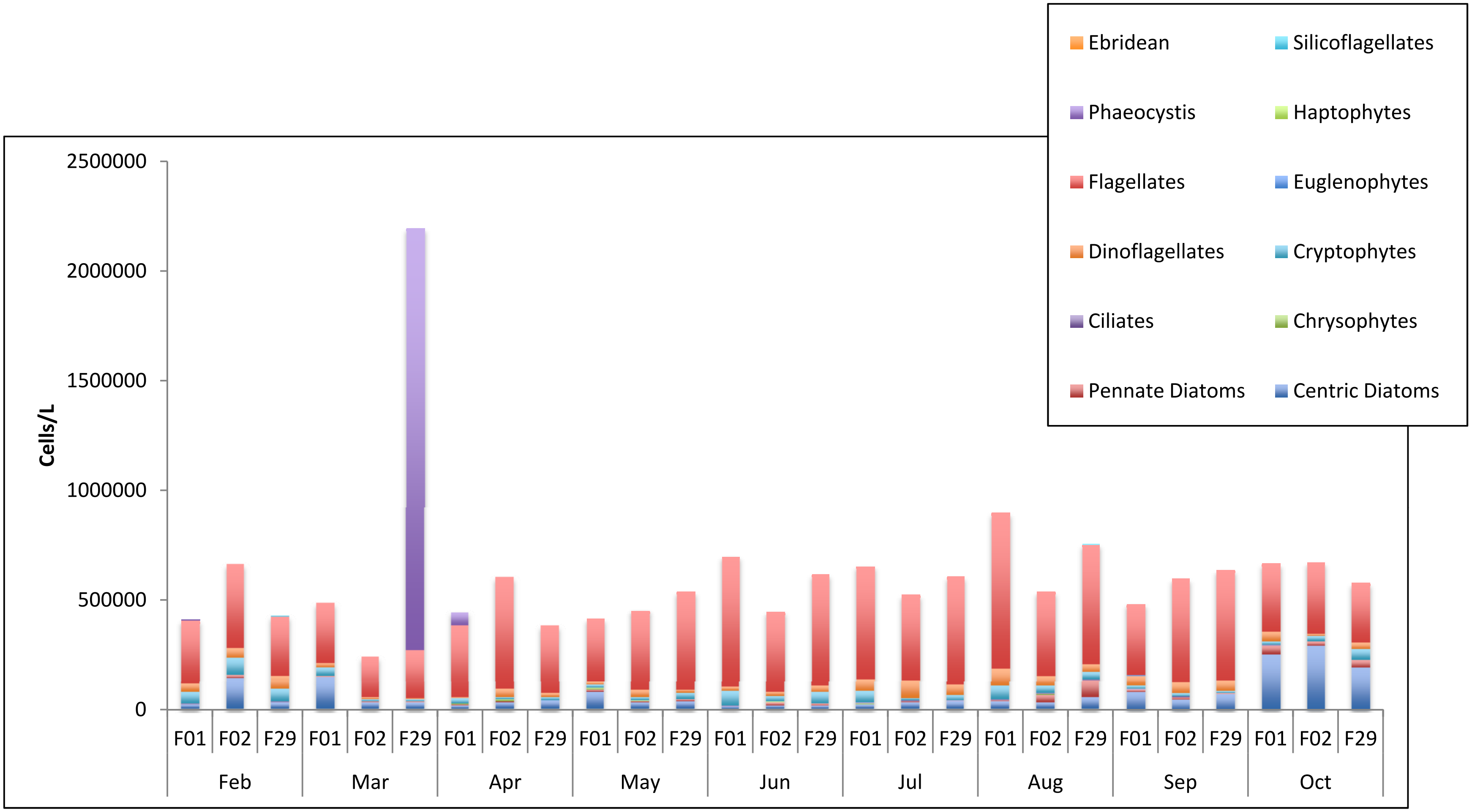
● CCB Stns

🟢 F01

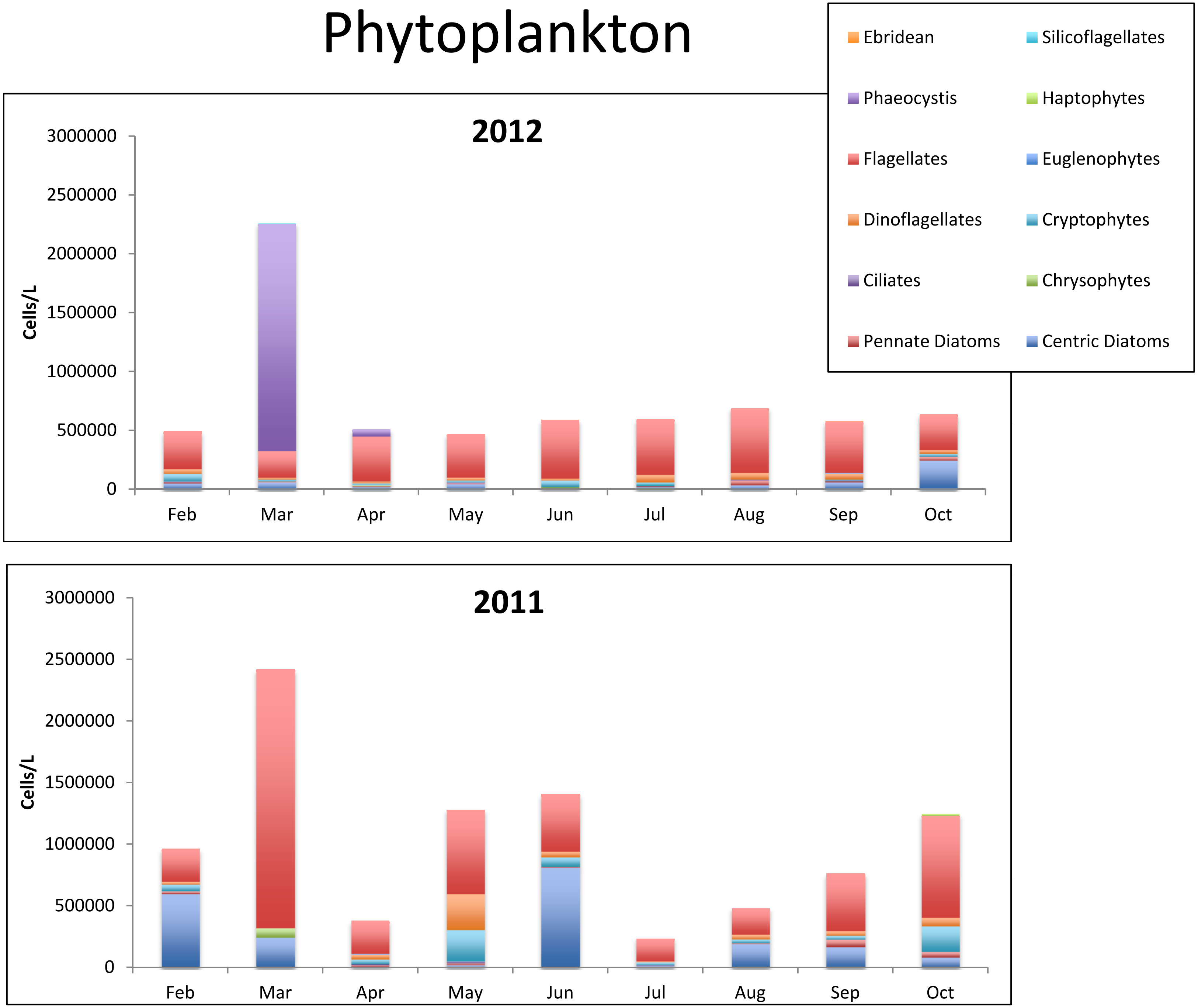
🔴 F02

🔵 F29

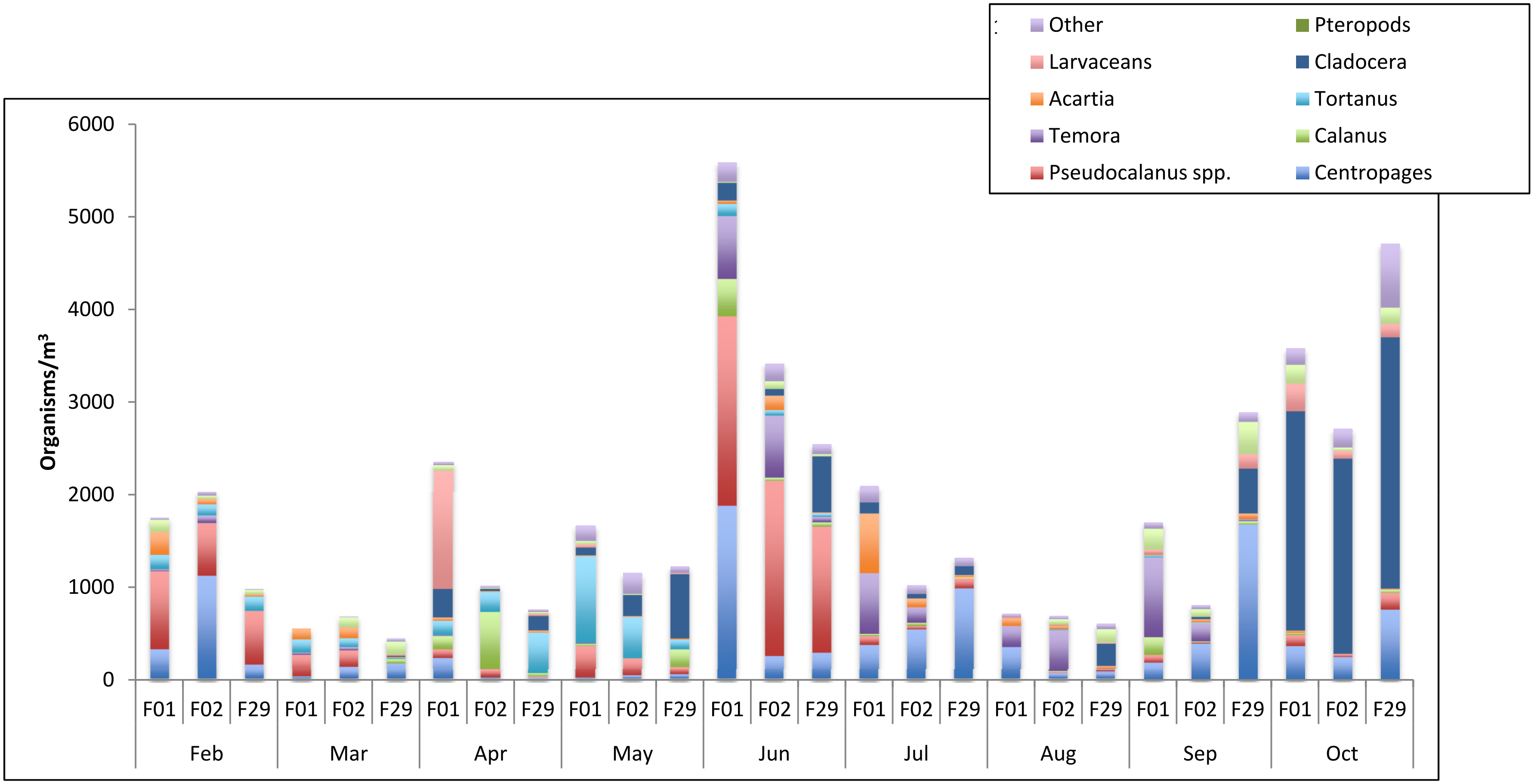
Phytoplankton

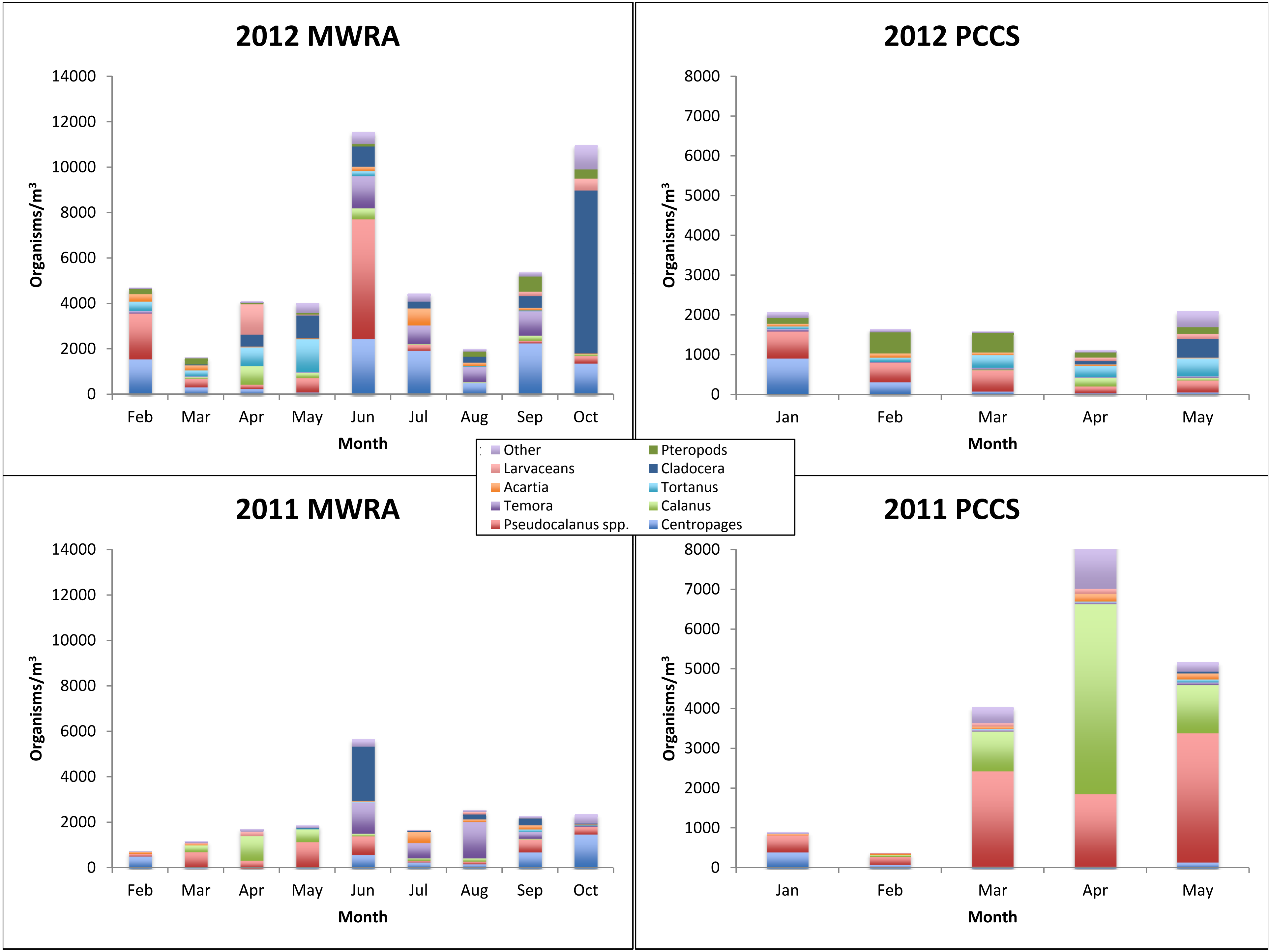


Phytoplankton

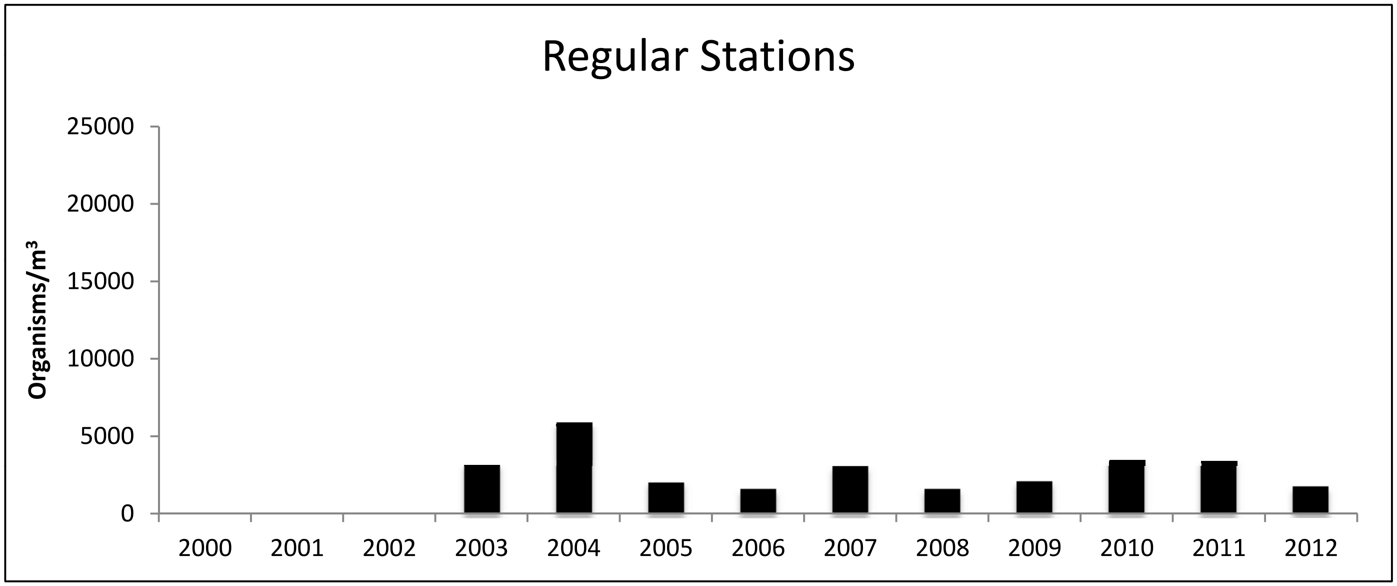


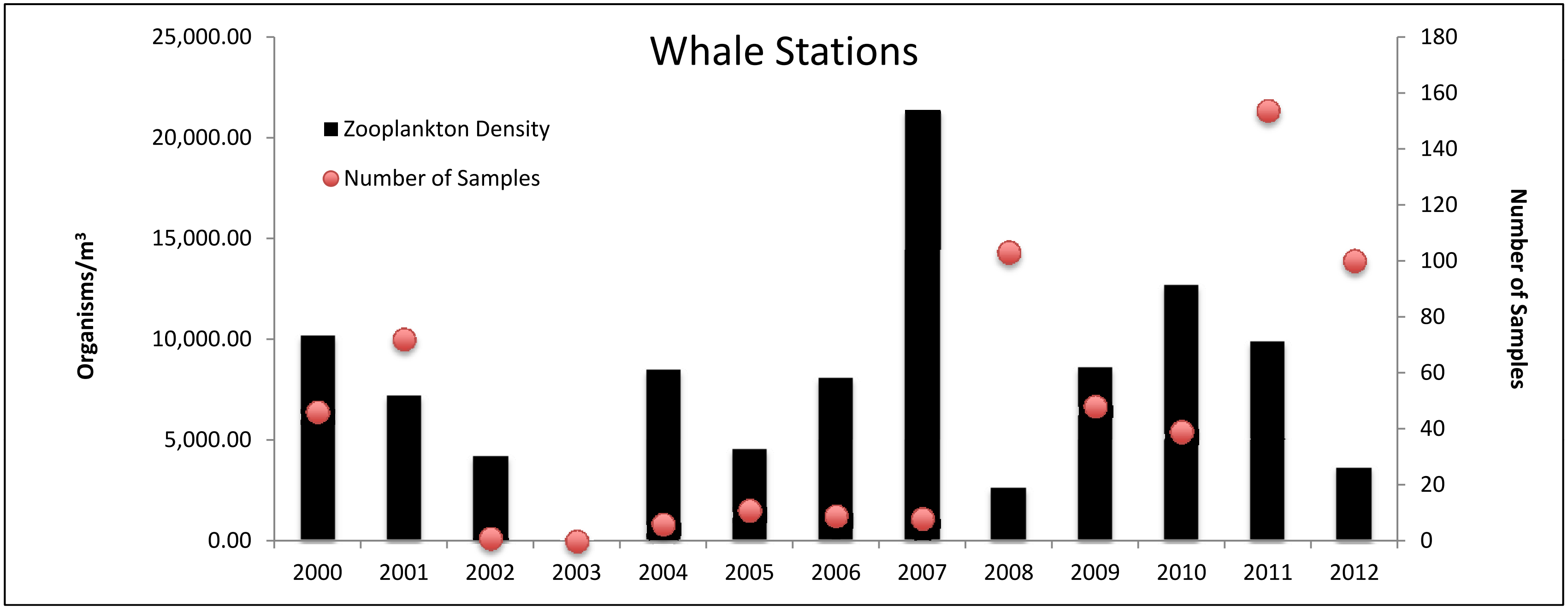
Zooplankton




2012 MWRA
14000
12000
10000
8000
6000
4000
2000
0
Organisms/m³
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Month
2012 PCCS
8000
7000
6000
5000
4000
3000
2000
1000
0
Organisms/m³
Jan
Feb
Mar
Apr
May
Month
Other
Pteropods
Larvaceans
Cladocera
Acartia
Tortanus
Temora
Calanus
Pseudocalanus spp.
Centropages
2011 MWRA
14000
12000
10000
8000
6000
4000
2000
0
Organisms/m³
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Month
2011 PCCS
8000
7000
6000
5000
4000
3000
2000
1000
0
Organisms/m³
Jan
Feb
Mar
Apr
May
Month

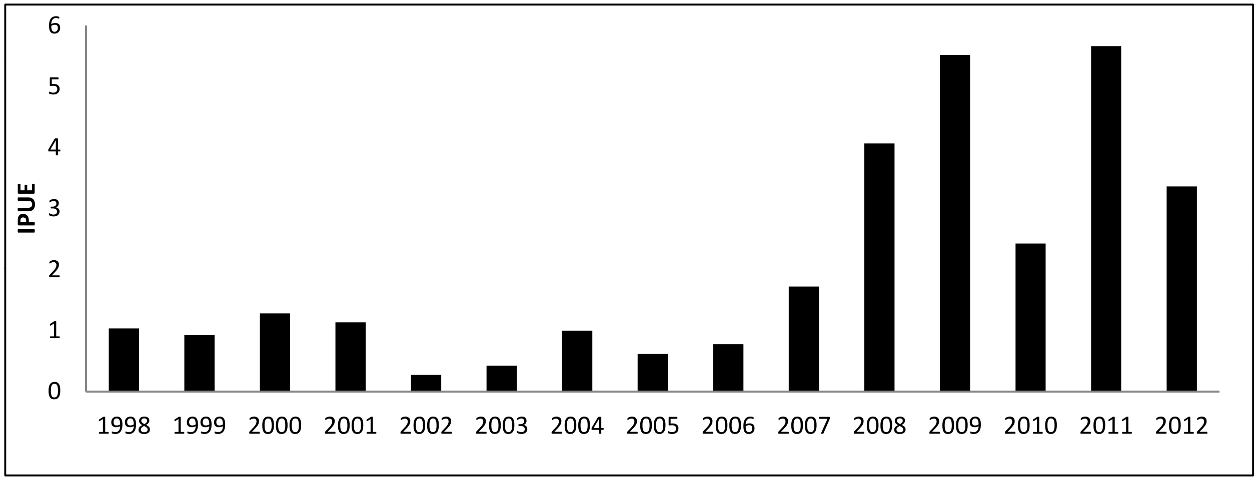
Total Zooplankton



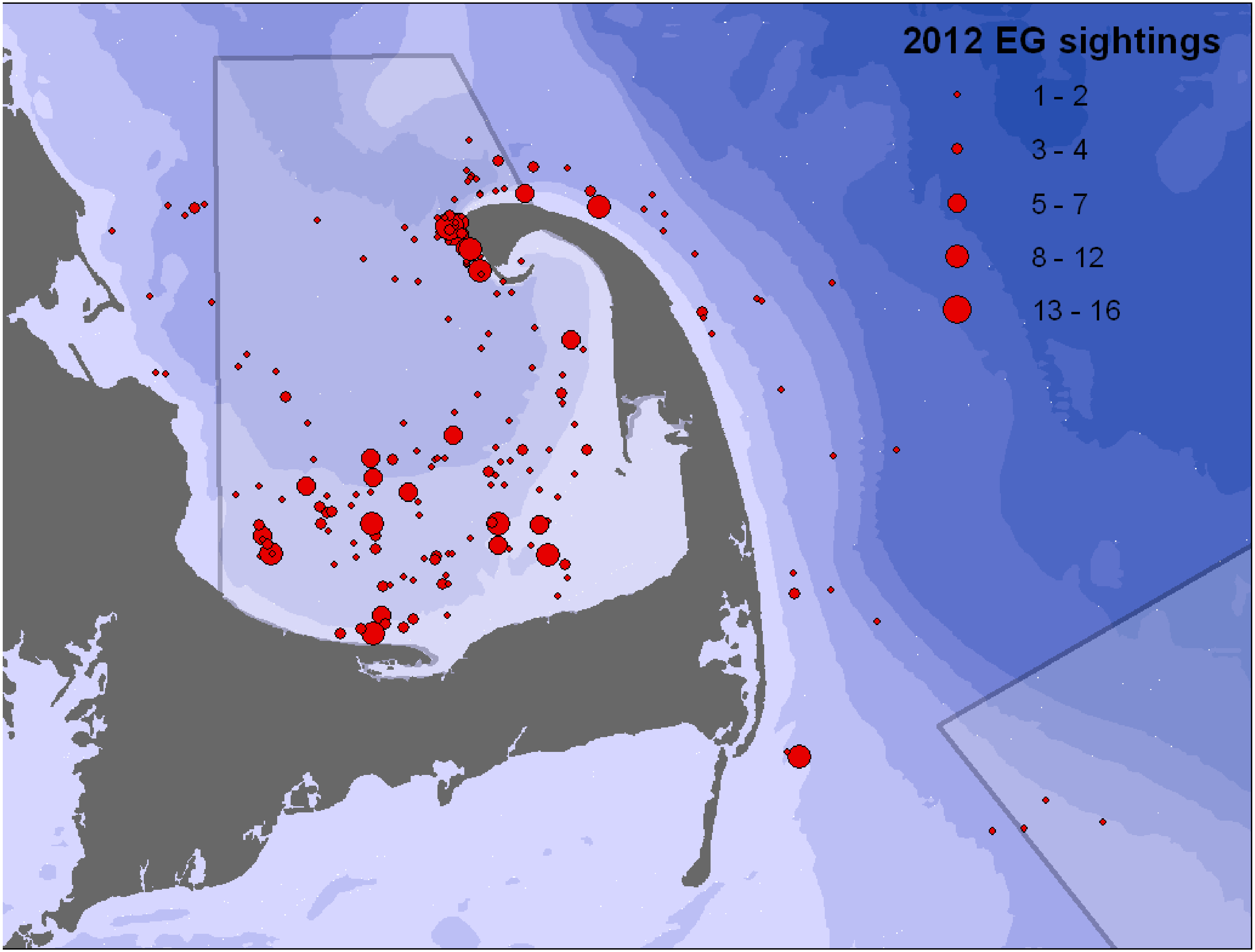


Right Whale Sightings

Cape Cod Bay 1998 - 2012



Year	Number of Individuals
1998	77
1999	78
2000	92
2001	69
2002	15
2003	23
2004	52
2005	45
2006	49
2007	105
2008	167
2009	192
2010	125
2011	245
2012	156


2012 EG sightings
1 - 2
3 - 4
5 - 7
8 - 12
13 - 16

PROVINCETOWN — An unexpectedly high number of North Atlantic right whales have taken up early residence off the coast this winter, part of a set of unusual environmental events that appear to reflect a fundamental shift in the ecology of Cape Cod Bay, scientists said this week.

Those unusual circumstances include a wintertime surface water temperature that's about 2 degrees Celsius higher than what has been typical in the last 13 years, said Charles "Stormy" Mayo, senior scientist at the Provincetown Center for Coastal Studies (Cape Cod Times, Feb 24, 2012).

For the first time in recorded history, a bowhead whale which typically lives in the northern reaches of the Atlantic, Pacific, and Arctic Oceans was spotted off Cape Cod.

The bowhead whale was spotted in the waters east of Orleans by researchers during an aerial survey in March 2012.

The whale, a juvenile approximately 43 feet long, was engaged in social behavior with a group of mostly young North Atlantic right whales.

Not only is this the southern-most record of a bowhead whale in the North Atlantic, but it is also the first documented interaction between bowhead whales and right whales (Fox 25, Aug 28, 2012).

Provincetown Center for Coastal Studies
NOAA Fisheries permit 14603

Thank you…

Cape Cod Bay Monitoring
- Marc Costa
- Jenny Burkhardt

Right Whale Habitat
- Stormy Mayo
- Beth Larson
- Christy Hudak

Right Whale Aerial Survey
- Laura Gangley
- Corey Accardo
- Heather Nicotri

Phytoplankton
- David Borkman

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