2013 Outfall monitoring overview

Massachusetts Water Resources Authority
Environmental Quality Department
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2013
Outfall Monitoring Overview

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Table of Contents

List of Figures

List of Tables

Summary

Each year, the Massachusetts Water Resources Authority (MWRA) prepares this overview of environmental monitoring related to the discharge of municipal effluent from Deer Island Treatment Plant through an offshore outfall tunnel into Massachusetts Bay. The report presents monitoring results and information relevant to the MWRA's permit-required Contingency Plan, including threshold exceedances and permit violations, responses, and corrective actions. The overview also includes monitoring results relevant to the Stellwagen Bank National Marine Sanctuary and information on special studies conducted in response to specific permit requirements, scientific questions, or public concerns.

The 2013 report marks almost nine years of baseline monitoring and more than thirteen years of "outfall-discharge" monitoring, covering the years since September 2000, when MWRA ceased discharge of sewage effluent to the relatively confined waters of Boston Harbor and began to discharge into deeper water in Massachusetts Bay. It includes results of effluent analyses; water-column, sea-floor, and fish-and-shellfish monitoring in the outfall nearfield and at reference stations; and special studies. This year's report on special studies focuses on improvements in Boston Harbor following the transfer of discharges to offshore waters and on ongoing Cape Cod Bay studies.

Operations at the Deer Island Treatment Plant continued to be exceptional in 2013, earning MWRA a National Association of Clean Water Agencies (NACWA) Platinum 7 Peak Performance Award. This NACWA award recognizes facilities with 100% permit compliance for seven consecutive years.

Nearfield and reference-station monitoring results from 2013 were consistent with predictions made more than 20 years ago and past results, showing no unanticipated effects of the discharge (Tables i through iv). No Contingency Plan "warning level" exceedances were observed in 2013. There were "caution level" Contingency Plan exceedances[*] for two soft-bottom benthic community parameters, Shannon-Wiener diversity and Pielou's evenness. These exceedances, which occurred for a fourth consecutive year, were indications of a somewhat more diverse community, resulting from normal cycles of relative abundance in the animal populations. Increased diversity is not considered to be environmentally adverse, and the changes are not thought to be related to the outfall.

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[*] MWRA's NPDES permit includes Contingency Plan threshold indicators that may indicate a need for action. The thresholds are based on permit limits, state water quality standards, and expert judgment. "Caution level" thresholds generally indicate a need for a closer look at the data to determine the reason for an observed change. "Warning level" thresholds are a higher level of concern, and the permit requires a series of steps to evaluate whether adverse impacts occurred and if so, whether they were related to the discharge. If caused by the discharge, MWRA may need to implement corrective action. All thresholds based on effluent discharge permit limits are "warning level." Some ambient parameters have both "caution" and "warning" level thresholds, and others have only "caution level" thresholds.

Table i. Contingency Plan threshold values and 2013 results for effluent monitoring.

Parameter	Baseline	Caution Level	Warning Level	2013 Results
pH	NA	None	<6 or >9	Not exceeded
Fecal coliform	NA	None	14,000 fecal coliforms/100 mL	Not exceeded
Chlorine, residual	NA	None	631 µg/L daily, 456 µg/L monthly	Not exceeded
Suspended solids	NA	None	45 mg/L weekly 30 mg/L monthly	Not exceeded
cBOD	NA	None	40 mg/L weekly, 25 mg/L monthly	Not exceeded
Acute toxicity	NA	None	LC50 <50%	Not exceeded
Chronic toxicity	NA	None	NOEC <1.5% effluent	Not exceeded
PCBs	NA	Aroclor=0.045 ng/L	None	Not exceeded
Plant performance	NA	5 violations/year	Noncompliance >5% of the time	Not exceeded
Flow	NA	None	>436 MGD average dry days	Not exceeded
Total nitrogen load	NA	12,500 mtons/year	14,000 mtons/year	Not exceeded
Oil and grease	NA	None	15 mg/L weekly	Not exceeded

NA = not applicable
cBOD = carbonaceous biological oxygen demand
LC50 = 50% mortality concentration
NOEC = no observable effect concentration
PCB = polychlorinated biphenyl

Table ii. Contingency Plan threshold values and 2013 results for water-column monitoring.

Parameter	Baseline	Caution Level	Warning Level	2013 Results
Dissolved oxygen*				
Nearfield concentration	6.05 mg/L	6.5 mg/L	6.0 mg/L	6.71 mg/L
Nearfield percent saturation	65.3%	80%	75%	73.6%
Stellwagen concentration	6.23 mg/L	6.5 mg/L	6.0 mg/L	6.97 mg/L
Stellwagen percent saturation	67.2%	80	75%	75.3%
Nearfield depletion rate	0.024 mg/L/d	0.037 mg/L/d	0.049 mg/L/d	0.021 mg/L/d
Chlorophyll				
Annual	72 mg/m^2	108 mg/m^2	144 mg/m^2	61 mg/m^2
Winter/spring	50 mg/m^2	199 mg/m^2	None	53 mg/m^2
Summer	51 mg/m^2	89 mg/m^2	None	65 mg/m^2
Autumn	90 mg/m^2	239 mg/m^2	None	64 mg/m^2
Nuisance algae *Phaeocystis pouchetii*				
Winter/spring	622,000 cells/L	2,860,000 cells/L	None	5,160 cells/L
Summer	72 cells/L	357 cells/L	None	Absent
Autumn	370 cells/L	2,960 cells/L	None	Absent
Nuisance algae nearfield *Pseudo-nitzschia*				
Winter/spring	6,735 cells/L	17,900 cells/L	None	Absent
Summer	14,635 cells/L	43,100 cells/L	None	667 cells/L
Autumn	10,050 cells/L	27,500 cells/L	None	490 cells/L
Nuisance algae nearfield *Alexandrium fundyense*				
Any nearfield sample	Baseline maximum 163 cells/L	100 cells/L	None	23 cells/L
PSP toxin extent	NA	New incidence	None	No new incidence

*Dissolved oxygen caution and warning levels represent numerical criteria, with the caveat “unless background conditions are lower.” Results are therefore compared to the baseline rather than to the caution and warning levels.

PSP = paralytic shellfish poisoning

NA = not applicable

Table iii. Contingency Plan threshold values and 2013 results for sea-floor monitoring.

Parameter	Baseline	Caution Level	Warning Level	2013 Results
Sediment parameters				
RPD depth	NA	<1.18 cm	None	3.76 cm
Benthic community parameters				
Species per sample	NA	<42.99 or >81.85	None	55.55
Fisher's log-series alpha	NA	<9.42 or >15.8	None	13.14
Shannon diversity	NA	<3.37 or >3.99	None	4.08, caution level exceedance
Pielou's evenness	NA	<0.57 or >0.67	None	0.71, caution level exceedance
% opportunists	NA	>10%	>25%	0.47 %

NA = not applicable
RPD = Redox potential discontinuity

Table iv. Contingency Plan threshold values and 2013 result for fish-and-shellfish monitoring.

Parameter	Baseline	Caution Level	Warning Level	2013 Results
Liver disease CHV	24.4%	44.9%	None	18%

CHV = centrotubular hydropic vacuolation

1. Introduction

Since its creation by the Massachusetts state legislature in 1984, the Massachusetts Water Resources Authority (MWRA) has worked to minimize the effects of wastewater discharge on the marine environment. The mission of what became known as MWRA's Boston Harbor Project included reducing inflow of contaminants into the waste stream, ending biosolids discharge, improving wastewater treatment facilities, and providing better dilution of the sewage effluent discharge. Throughout MWRA's early years, scientists conducted environmental monitoring in Boston Harbor and also in Massachusetts Bay, at the (then future) location of a relocated sewage-effluent discharge.

By the end of 2000, most of the Boston Harbor Project had been completed, including the relocated outfall, which diverted sewage effluent from Boston Harbor to the deeper, less confined waters of Massachusetts Bay. The outfall operates under a National Pollutant Discharge Elimination System (NPDES) permit for the Deer Island Treatment Plant (DITP) constructed as part of the Boston Harbor Project. The permit was issued jointly by the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MADEP).

The NPDES permit includes requirements for ongoing monitoring of the sewage effluent and for ambient monitoring of the receiving waters. Monitoring assesses compliance with specific permit conditions and additional conditions specified by a permit-required Contingency Plan. Background information on the monitoring program can be found in Werme et al. (2012). That document, as well as monitoring plans (MWRA 1991, 1997a, 2004, 2010), the Contingency Plan (MWRA 1997b, 2001), and area-specific technical reports are available on the technical report list at MWRA's website, http://www.mwra.state.ma.us/harbor/enquad/trlist.html.

Results from most baseline years and from each year since the outfall began to discharge have been documented in annual outfall monitoring overviews. The reports have included information relevant to permit requirements, including Contingency Plan threshold exceedances, responses, and corrective actions. Reports also include information relevant to the Stellwagen Bank National Marine Sanctuary.

This outfall monitoring overview presents results from 2013, marking the twenty-second year of MWRA's monitoring program, including more than thirteen years of outfall-discharge monitoring. Measurements include effluent, water-column, sea-floor, and fish-and-shellfish parameters, as well as special studies conducted in response to permit conditions and environmental concerns. Data specifically related to the Stellwagen Bank National Marine Sanctuary are included in the overview's water-column and sea-floor sections.

2. Effluent

2013 Characterization

As in past years, DITP continued to operate as designed through 2013, earning MWRA the National Association of Clean Water Agencies (NACWA) Platinum 7 Peak Performance Award. This NACWA award recognizes facilities with 100% permit compliance over seven consecutive years.

The Boston area received about 40 inches of rain in 2013, almost 4 inches more than in 2012, but less than the long-term average (Figure 2-1). These two dry years contrast with mostly wetter years since the outfall came on line in 2000. Consequently, total effluent flow in 2013 was also lower than average, second only to 2012 in low flows (Figure 2-2). Virtually all the flow, 99.2%, received full primary and secondary treatment. Flows were lower than average in every month except June, and autumn flows were especially low, with no storm-related discharges of primary-only effluent blended with effluent receiving full secondary treatment prior to discharge (Figure 2-3).

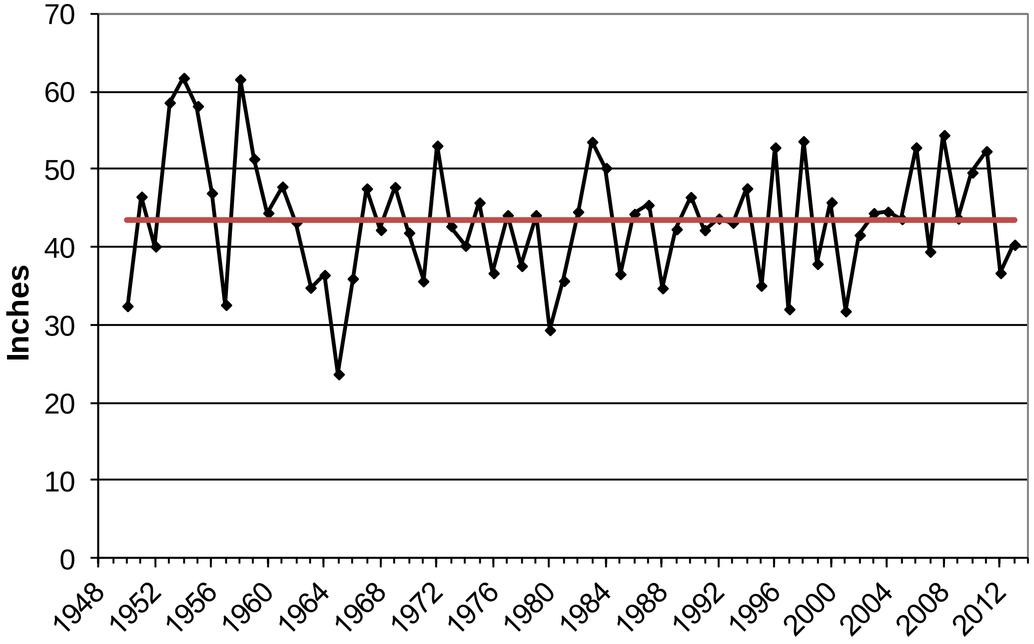

Figure 2-1. Annual rainfall in Boston, 1950–2013. Most years since the Massachusetts Bay outfall came on line have been wet, but rainfalls in 2012 and 2013 were below the long-term average (shown as the red line).

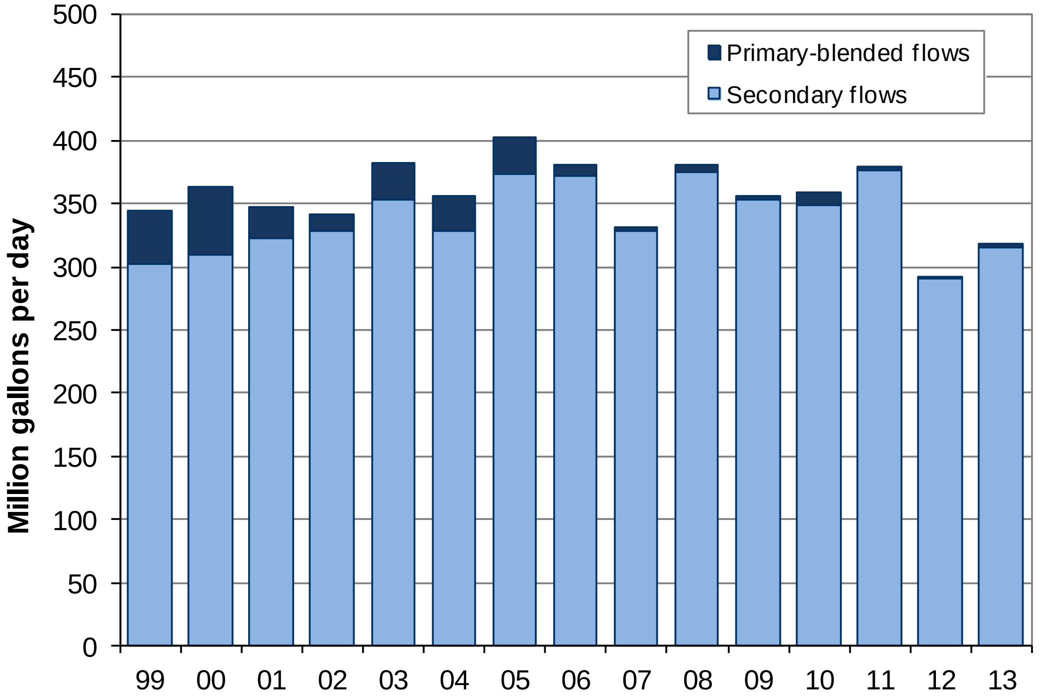

Figure 2-2. Annual primary-blended and full secondary effluent flows, 1999–2013. In 2013, 99.2% of effluent received full secondary treatment. (During large storms, flow exceeding the secondary capacity of the plant is diverted around the secondary process to prevent washing out the essential microbes that carry out secondary treatment. These primary-blended flows are combined with full secondary flows before disinfection and discharge. All discharges meet permit limits.)

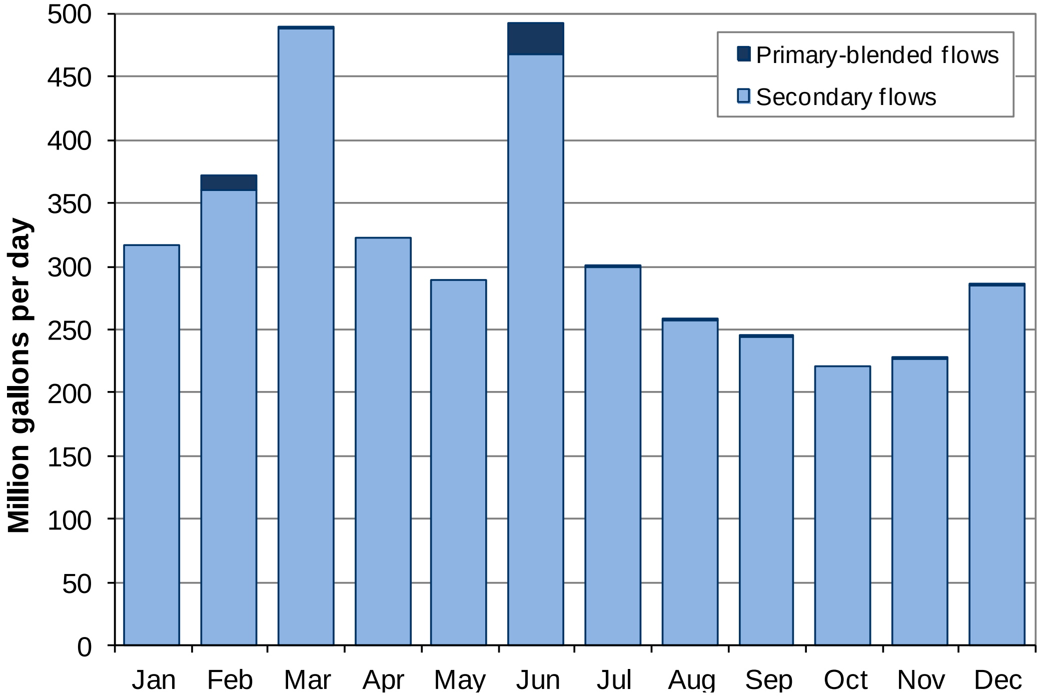

Figure 2-3. Monthly primary-blended and full secondary effluent flows during 2013. Total flow was below average in every month except June, and there were only small amounts of primary-blended flow in any month.

The total suspended solids load to Massachusetts Bay was 13.5 tons per day, well below the loads discharged to Boston Harbor before the outfall came on line in 2000 and also below the average for recent years (Figure 2-4). Carbonaceous biochemical oxygen demand (BOD) was also low, remaining well below levels that might be expected to affect ambient waters at the discharge site (Figure 2-5). Nitrogenous BOD (also shown in Figure 2-5), which is a result of the biological processes in secondary treatment and not a permit limit or Contingency Plan parameter, was lower, except for 2012, than any level measured since 2001.

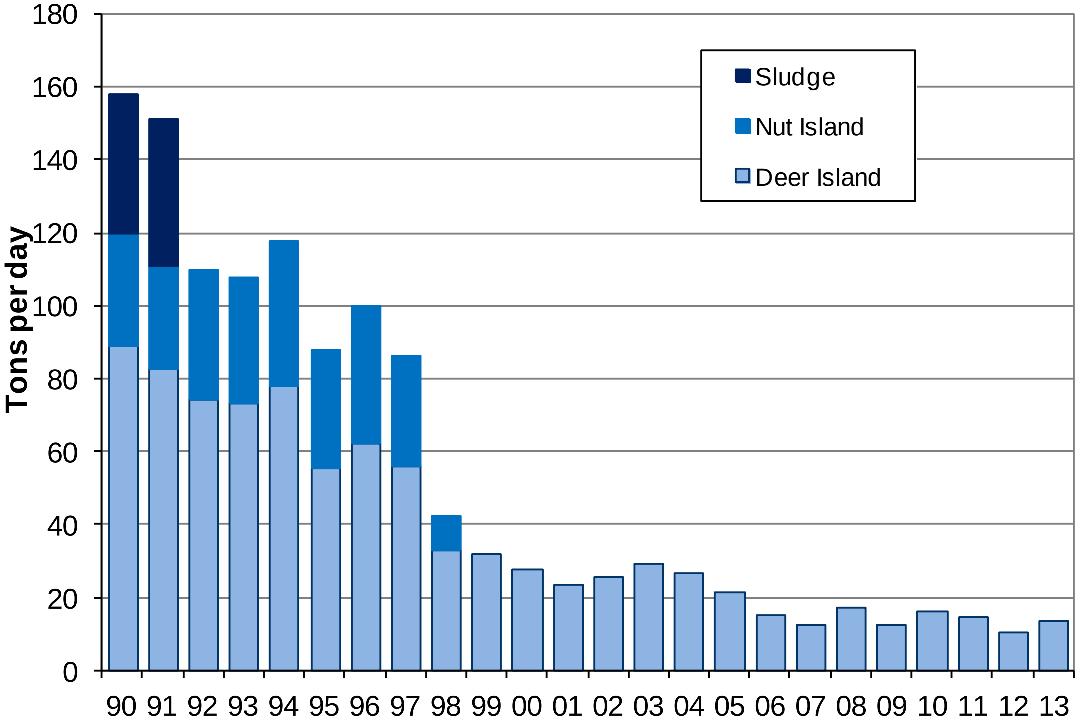

Figure 2-4. Annual solids discharges, 1990–2013. Solids discharges remained low in 2013, 13.5 tons per day.

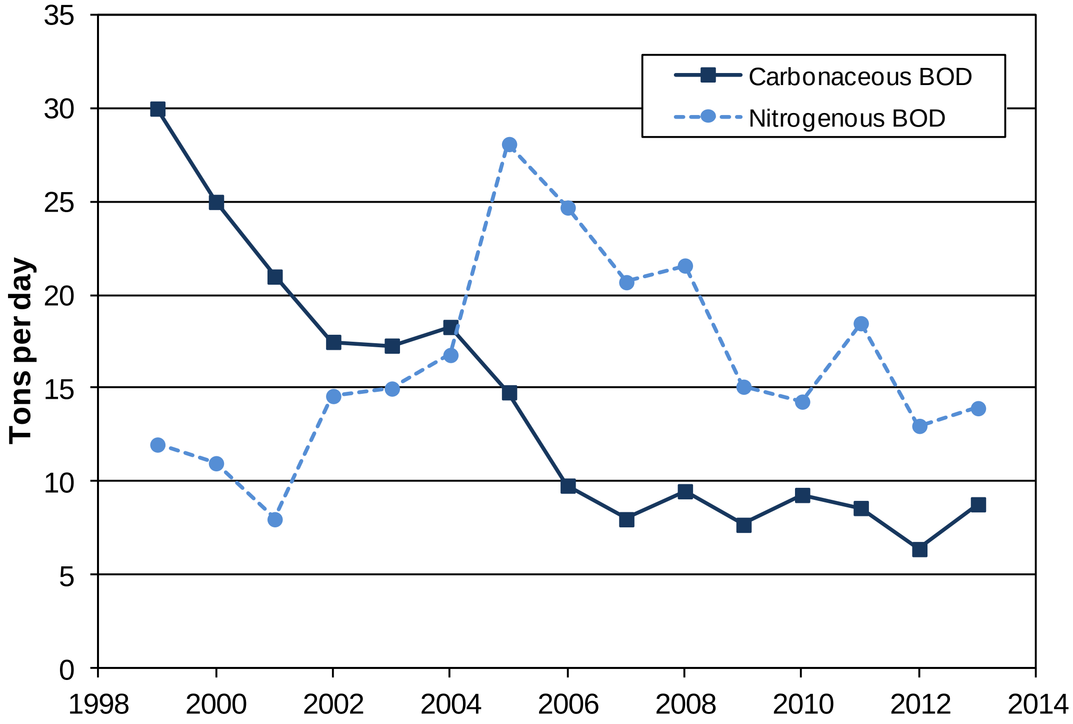

Figure 2-5. Annual biochemical oxygen demand, 1999–2013. MWRA's permit limits carbonaceous BOD. Nitrogenous BOD is the result of microbiological breakdown that occurs as a result of secondary treatment and is not regulated by the permit.

The total nitrogen load also remained below its threshold in 2013 (Figure 2-6). The portion of the load made up of ammonium continued to be higher than in earlier years of the Boston Harbor Project. About 10% of the ammonium in the sewage influent is removed by secondary treatment, but the biological treatment process converts some organic forms of nitrogen to ammonium. Also, ammonium-rich liquids from the biosolids pelletizing (fertilizer) plant, built as part of the Boston Harbor Project, are reintroduced to DITP for treatment, adding to the ammonium load. As required by its permit, MWRA continually evaluates nitrogen-removal technologies, so that removal could be quickly implemented, should a need arise (Smolow et al. 2013). Because nitrogen loads have remained below the Contingency Plan caution threshold, and there have not been nitrogen-related adverse environmental effects, nitrogen removal has not been required or implemented.

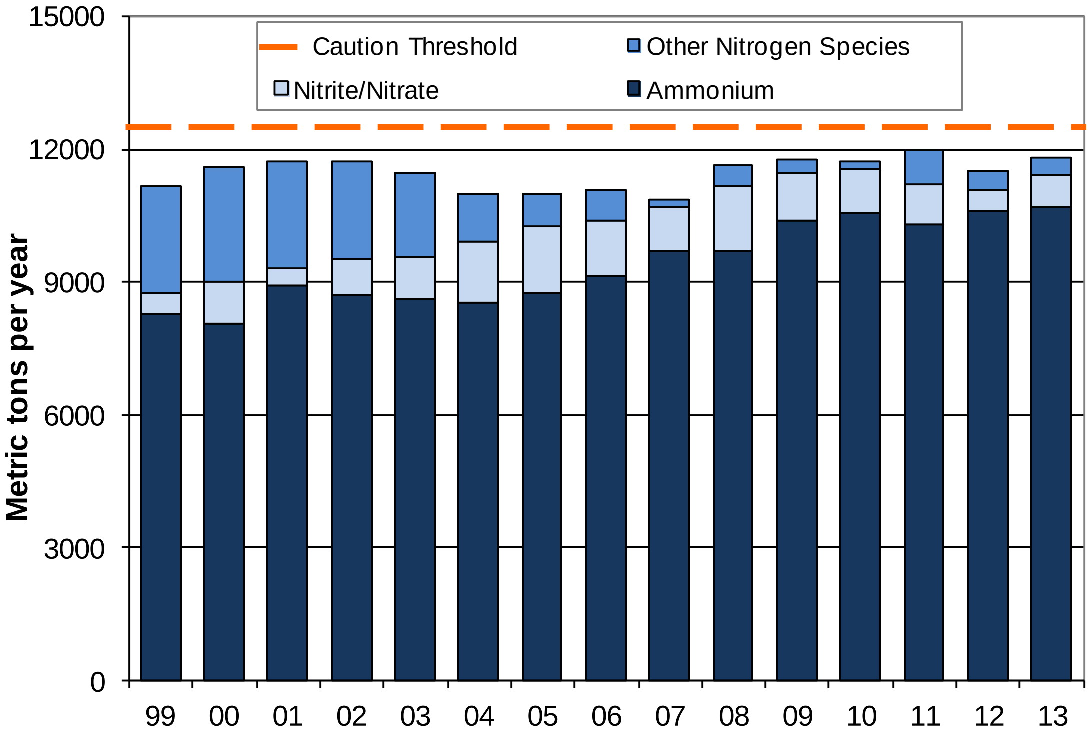

Figure 2-6. Annual nitrogen discharges, 1999–2013. Most of the nitrogen in the effluent is in the form of ammonium.

Metals loads remained low in 2013, with zinc and copper comprising most of the annual discharge (Figure 2-7). Metals discharges are now only a small fraction of what they were before the Boston Harbor Project, when more than 750 pounds of metals were discharged to Boston Harbor each day. Except for copper, metals meet water quality criteria prior to discharge, while copper meets the criteria after initial dilution at the Massachusetts Bay outfall. Once considered a sewage tracer, silver is no longer detected in the effluent, a result of removal efficiencies and the change from film to digital photography.

Mercury loads were also low, with only 3.7 pounds per year discharged in 2012 and 2013, compared to more than 50 pounds per year in 1999 and less than one percent of the amount anticipated during the planning process for the outfall (Figure 2-8). Although sensitive methods have been adopted for mercury analysis, mercury is now only rarely detected in effluent samples, the consequence of efforts on the part of MWRA and the New England states and New York to reduce mercury use, handle workplace spills, and discourage disposal practices that introduce mercury into the sewer system. Most mercury entering New England waters is in atmospheric deposition.

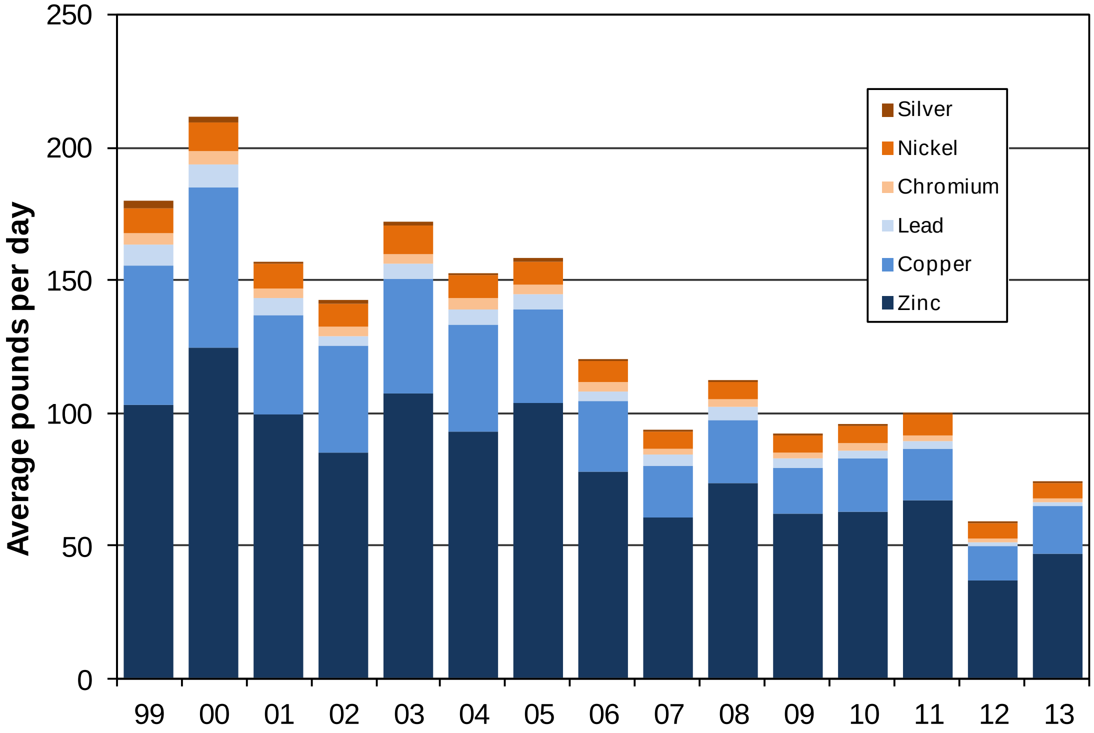

Figure 2-7. Annual metals discharges, 1999–2013. Total metals discharges remained low in 2013, with removal efficiencies greater than 90% for lead, copper, and zinc. Except for copper, the metals meet receiving water quality criteria in the effluent, even without the dilution provided by the outfall.

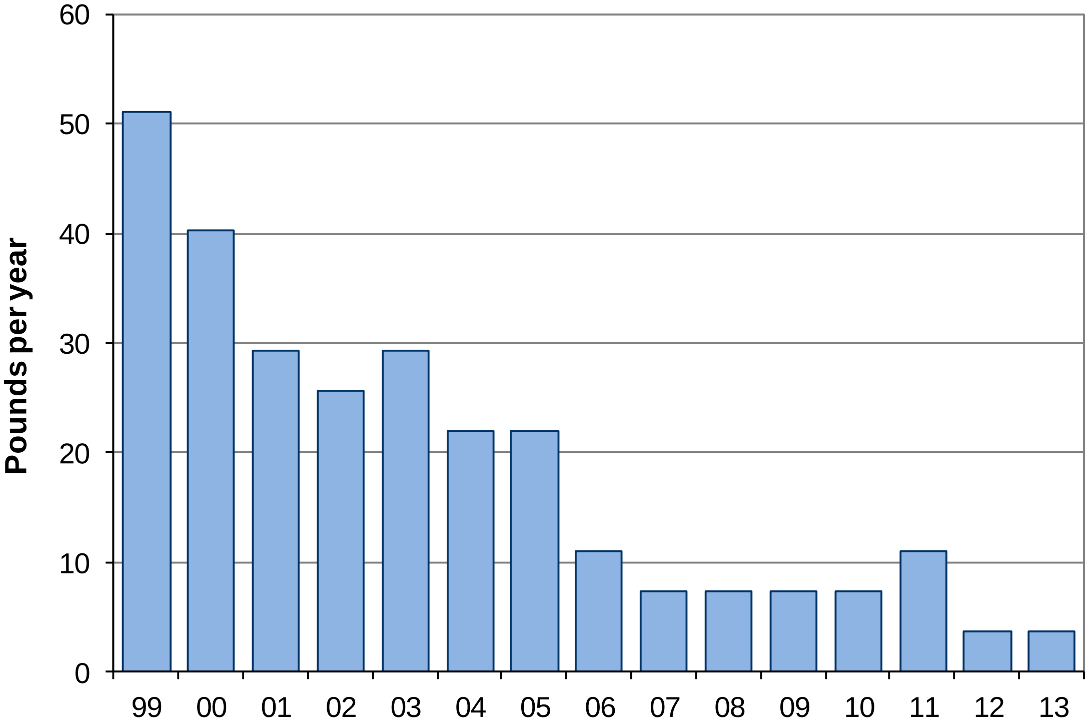

Figure 2-8. Annual mercury discharges, 1999–2013. Mercury discharges are only about 1% of the loads that had been predicted during the outfall-siting process.

Polychlorinated biphenyl (PCB) and pesticide loads decreased to record lows in 2013. About one pound of PCBs and fewer than two pounds of chlorinated pesticides were discharged. All contaminant loads remained well below those that had been anticipated during the planning process for the relocated outfall. Those predictions were that more than 10 pounds of the chlorinated pesticide DDT and its breakdown products and more than 100 pounds of PCBs would be discharged each year.

Solids Processing and Energy Production

On average, DITP removes more than 94% of solids and organic material present in wastewater influent before discharging effluent into Massachusetts Bay, resulting in an average of almost 250 dry tons of biosolids per day. Anaerobic digestion at DITP further removes about 62% of the volatile solids from those biosolids, more than the industry-wide average of 45–50% removal. Almost 190,000 standard cubic feet per hour of digester gas is produced by the process and burned on site, enough to provide 97% of DITP’s heating needs, as well as 27 million kilowatt-hours of energy each year. Overall, the digester gas provides 62% of the energy needs at DITP. In 2013, production and burning of digester gas resulted in $27-million of avoided costs to the operation of the treatment plant.

After digestion, the remaining 106 dry tons of biosolids per day are pumped to MWRA’s pelletizing plant, where they are dewatered, dried, and compressed into small, granular pellets suitable for beneficial re-use, mostly as slow-release organic fertilizers. The fertilizer pellets contain approximately 60% organic matter and have more nutrients than compost. Typical uses include turf farms, parks, and golf courses.

Contingency Plan Thresholds

DITP had no permit violations, and there were no exceedances of the Contingency Plan effluent thresholds in 2013 (Table 2-1).

Table 2-1. Contingency Plan threshold values and 2013 results for effluent monitoring.

Parameter	Caution Level	Warning Level	2013 Results
pH	None	<6 or >9	Not exceeded
Fecal coliform	None	14,000 fecal coliforms/100 mL	Not exceeded
Chlorine, residual	None	631 µg/L daily, 456 µg/L monthly	Not exceeded
Suspended solids	None	45 mg/L weekly 30 mg/L monthly	Not exceeded
cBOD	None	40 mg/L weekly, 25 mg/L monthly	Not exceeded
Acute toxicity	None	LC50<50% for shrimp and fish	Not exceeded
Chronic toxicity	None	NOEC for fish survival and growth and sea urchin fertilization <1.5% effluent	Not exceeded
PCBs	Aroclor=0.045 ng/L	None	Not exceeded
Plant performance	5 violations/year	Noncompliance >5% of the time	Not exceeded
Flow	None	>436 MGD for annual average of dry days	Not exceeded
Total nitrogen load	12,500 mtons/year	14,000 mtons/year	Not exceeded
Oil and grease	None	15 mg/L weekly	Not exceeded

cBOD = carbonaceous biological oxygen demand
LC50 = 50% mortality concentration
NOEC = no observable effect concentration
PCB = polychlorinated biphenyl

3. Water Column

The water-column monitoring program measures relevant physical-oceanographic processes and water quality and evaluates phytoplankton and zooplankton communities at stations in Massachusetts Bay, at the mouth of Boston Harbor, and in Cape Cod Bay (Figure 3-1).

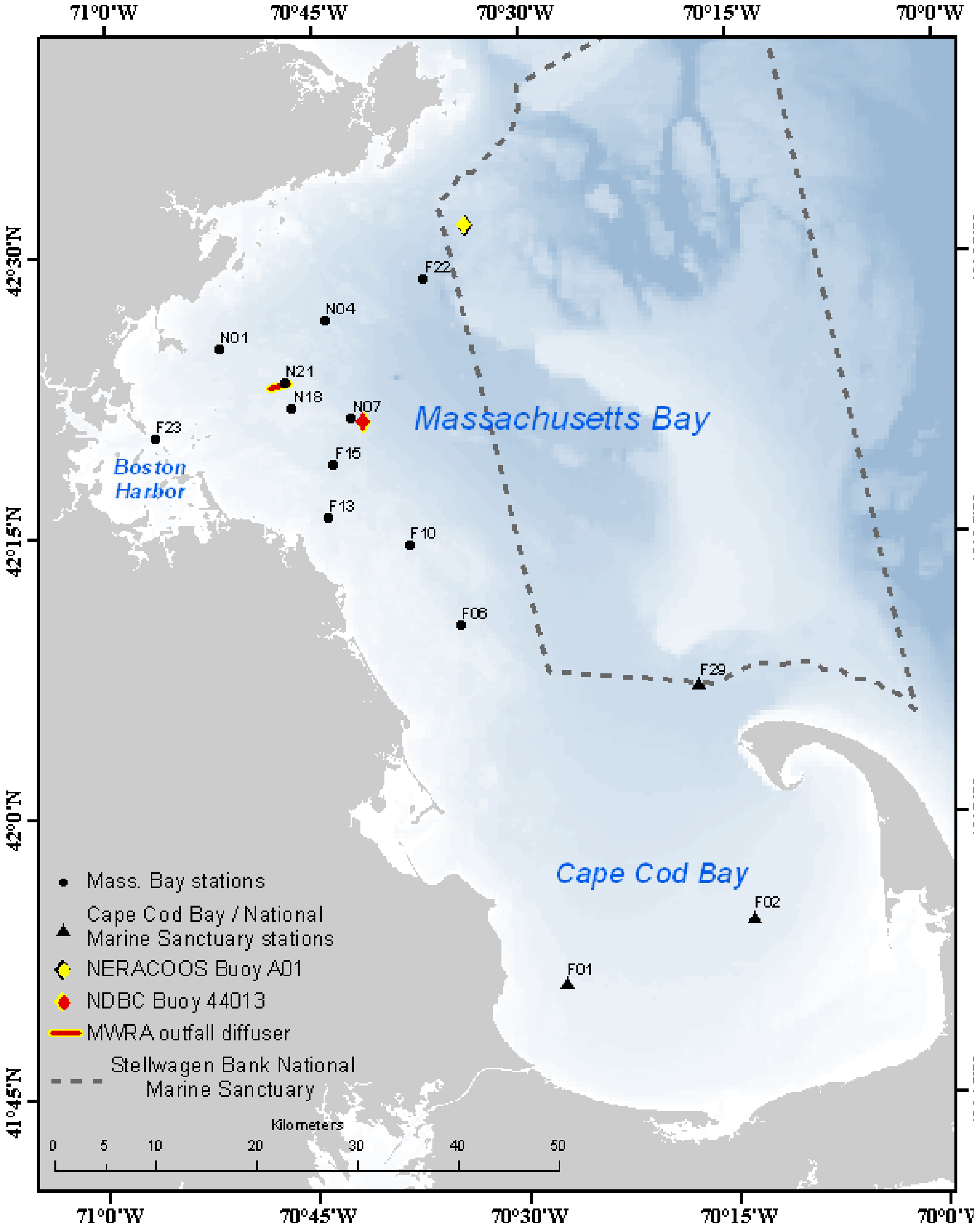

Figure 3-1. Water-column monitoring stations. Also shown are two instrumented buoys, one operated by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the other by the National Data Buoy Center (NDBC); the MWRA outfall diffuser; and the Stellwagen Bank National Marine Sanctuary.

Sampling during nine annual surveys at fourteen stations in 2013 included vertical profiles of physical, chemical, and biological characteristics in the area around the outfall (the nearfield), where some effects of the effluent were expected and have been observed and at farfield reference stations, including stations in Cape Cod Bay and near the Stellwagen Bank National Marine Sanctuary. Analyses included data from ten additional stations, sampled as part of MWRA's Boston Harbor water-quality monitoring program when sampling dates were close (see Boston Harbor Water Quality in Section 6, Special Studies, for some additional results from that program). In some years, special surveys are conducted in response to *Alexandrium fundyense* red tide blooms, but no additional surveys were necessary in 2013.

The program continued to benefit from collaboration with the Center for Coastal Studies at Provincetown, which conducts a monitoring program in Cape Cod Bay. The Center for Coastal Studies samples MWRA's monitoring stations in Cape Cod Bay and the Stellwagen Bank National Marine Sanctuary. Regulators have set a target that, whenever possible, sampling in Cape Cod Bay should occur within 48 hours of MWRA Massachusetts Bay sampling and that any failure to meet that schedule should be reported in the annual outfall monitoring overview. In 2013, all Cape Cod Bay sampling was completed within the required time frame. (See Cape Cod Bay Monitoring in Section 6, Special Studies, for additional results from that program.)

The field monitoring program was augmented by measurements on two instrumented buoys, the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) Buoy A01 and the National Oceanic and Atmospheric Administration's National Data Buoy Center (NDBC) Buoy 44013. The National Aeronautics and Space Administration provided Moderate Resolution Imaging Spectroradiometer (MODIS-Aqua) satellite imagery.

Physical Conditions

Monitoring has shown that the water column in the vicinity of the outfall and throughout Massachusetts and Cape Cod bays is heavily influenced by river inflows, weather, and other physical factors. Information about physical conditions has proven key to interpreting the annual monitoring data.

The year 2013 was slightly drier than other recent years, although not as dry as 2012 (See Figure 2-1 in Section 2, Effluent). It was warmer than average in the winter and spring, with storms in February and March, which produced large waves. The strongest of these winter storms, nicknamed "Nemo," produced 10-meter waves within Massachusetts Bay, sufficient to reach the sea floor and resuspend deposited sediments. Resuspended sediment was evident in satellite imagery from February 10, the day after the storm.

For a second consecutive year, the relatively dry conditions resulted in slightly lower-than-average river discharges in both the Merrimack and Charles rivers (Libby et al. 2014). Flows from both rivers were below average in every season except July through September, when low flows are typical (Figure 3-2).

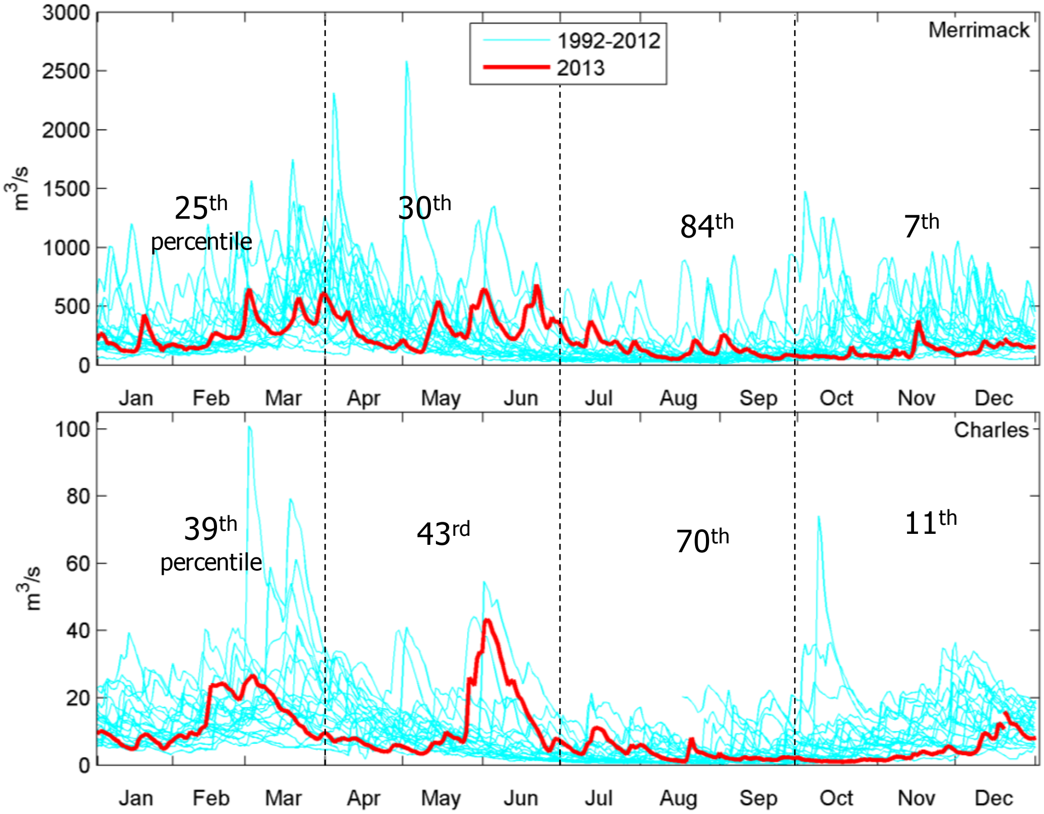

Figure 3-2. Flows of the Merrimack (top) and Charles (bottom) rivers. Flows from both rivers were below average, less than the 50th percentile throughout much of the year, but higher in summer, when low flows are typical.

Warm air temperatures in the late winter and spring led to higher-than-average nearfield surface- and bottom-water temperatures at the onset of spring stratification of the water column. Surface-water temperatures reached a record high for the monitoring program in July (Figure 3-3). For the first half of the year, bottom-water temperatures followed a similar trajectory, but were about average for the monitoring program in August through October.

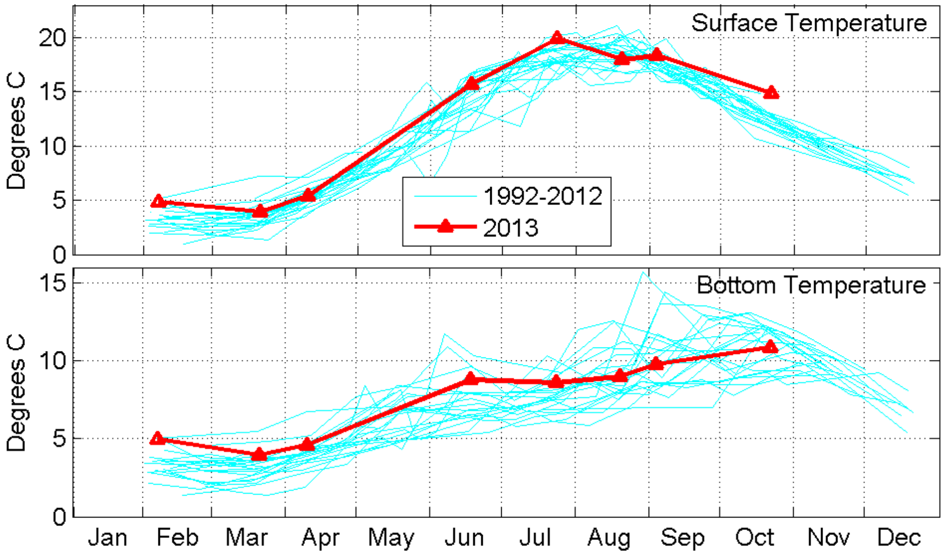

Figure 3-3. Nearfield surface- and bottom-water temperatures. Surface-water temperatures were warmer than average during the early part of the year and reached record high for the monitoring program in July.

Surface- and bottom-water salinities began the year at higher-than-normal levels, due to the dry conditions in 2012. A surge in flow from the Charles River caused a large drop in surface salinity in June. No similar drop was observed in bottom waters, which are affected more by flow from the Merrimack River. High bottom-water salinities persisted throughout the duration of field sampling for the year.

Wind conditions promoted strong downwelling in February and March, a result of the strong winter storms. A downwelling event also occurred in July, and strong upwelling was not observed until August. Summer stratification intensity, estimated by the difference in densities of surface and bottom waters, was among the strongest measured by the monitoring program. Destratification, the re-mixing of the water column that occurs as waters cool in the autumn, occurred later than in most years. Downwelling conditions in November ended summertime stratification.

Water Quality

Water quality measurements for 2013 included quantification of nutrients, phytoplankton biomass (measured as chlorophyll), and dissolved oxygen. Results continued to confirm predictions of measureable outfall influence in some parameters at stations very near the outfall but no unexpected adverse effects (Libby et al. 2014).

Nitrate, silicate, and phosphate concentrations averaged through the water column were lower during February, the first survey of the year, than most years (Figure 3-4), possibly due to continual phytoplankton production over the warm winter or to an early phytoplankton bloom that occurred prior to the start of the sampling season. For the rest of the year, concentrations of the major nutrients important to phytoplankton growth fell into the ranges observed throughout the monitoring program.

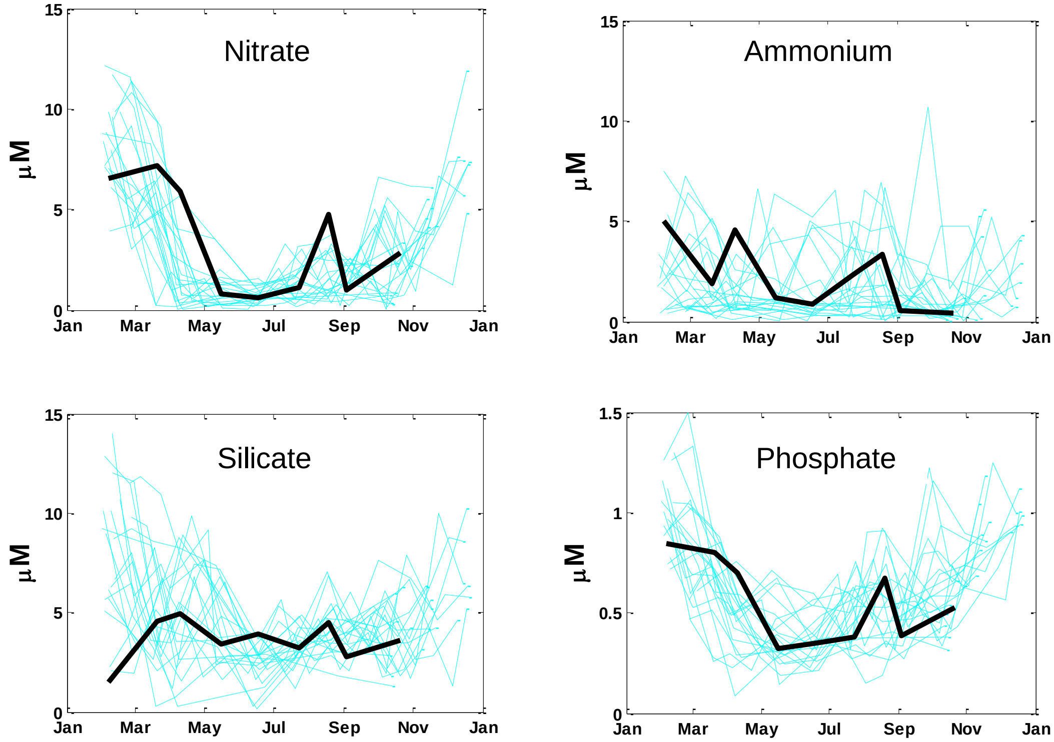

Figure 3-4. Mean depth-averaged nutrient concentrations at nearfield station N18 in 2013, compared to prior years. Spring nutrient concentrations were lower than other years, possibly due to phytoplankton blooms prior to the first MWRA survey in February. (Station N18 is immediately southwest of the outfall.)

Elevated ammonium levels were apparent at the outfall for most surveys (Figure 3-5), consistent with the results from prior years. As has been typical since the offshore outfall began to discharge, the plume was found in surface waters during the winter and spring (Figure 3-6), but was confined beneath the pycnocline during the summer, stratified season (Figure 3-7). This ammonium signature could be detected within 10–20 kilometers of the outfall in both well-mixed and stratified seasons.

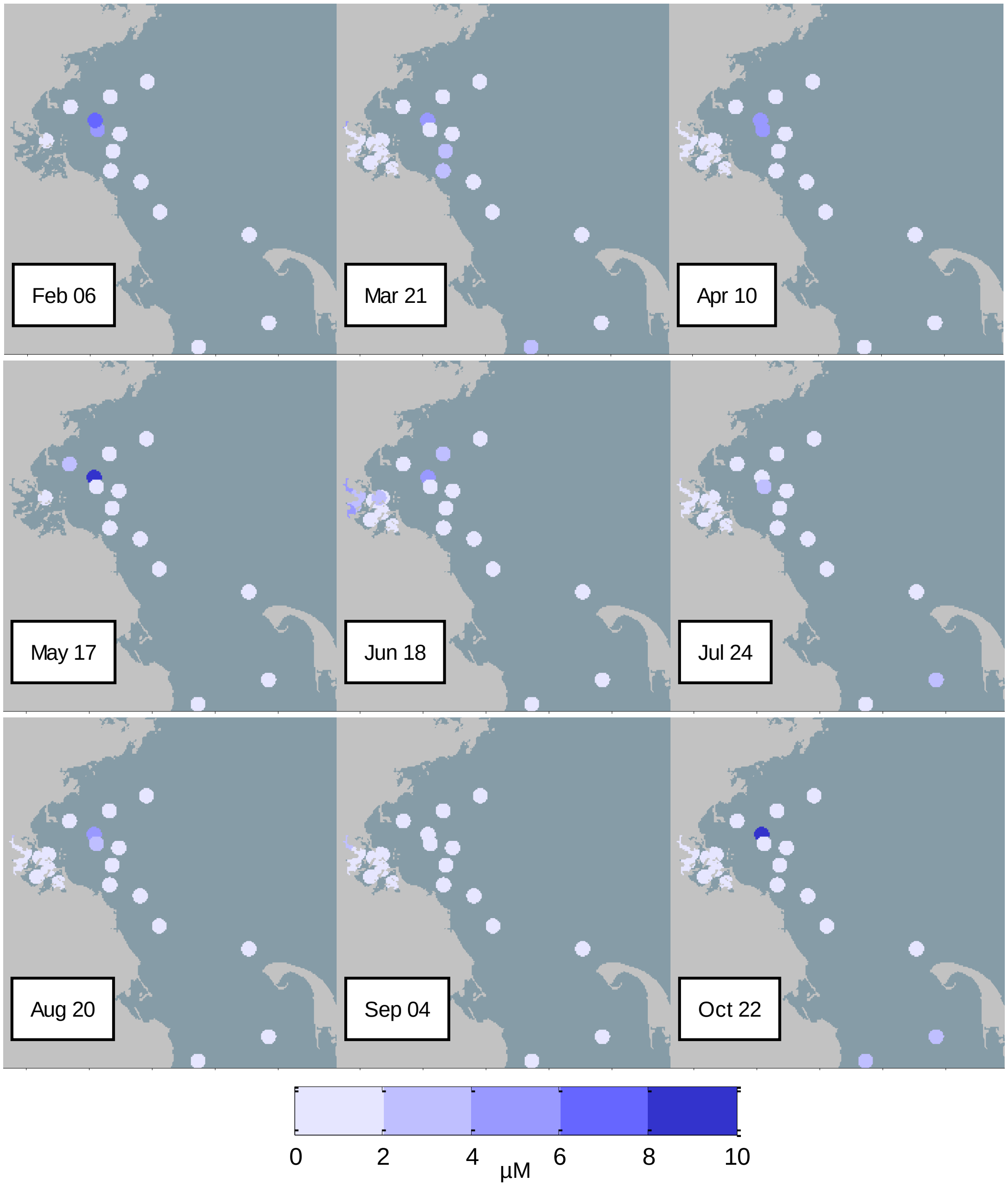

Figure 3-5. Depth-averaged ammonium concentrations by station in Massachusetts and Cape Cod bays. Several panels show additional data from MWRA's in-house Boston Harbor monitoring surveys when those surveys were within a few days of the outfall monitoring surveys. Elevated ammonium levels are detected near the outfall throughout the year.

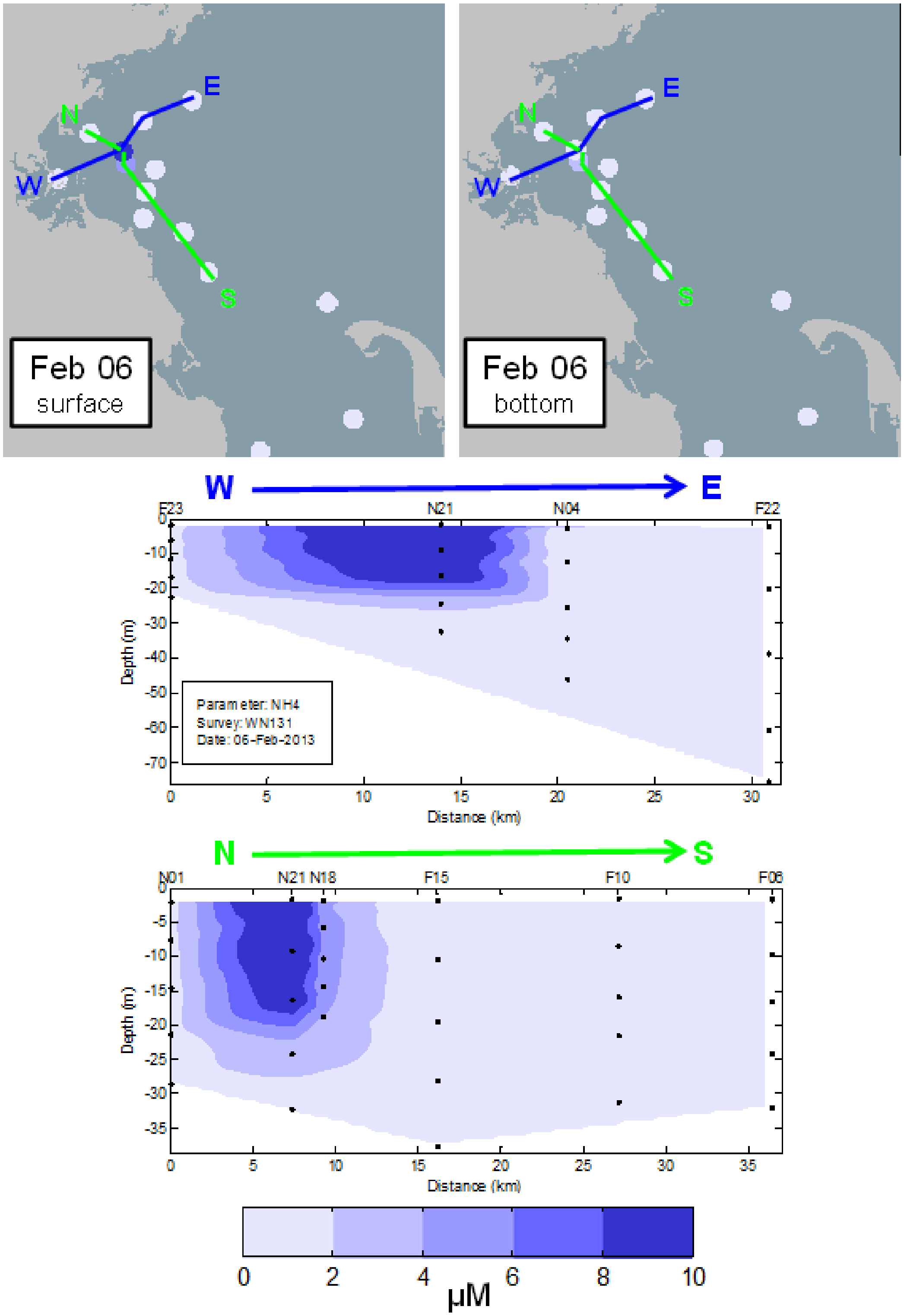

Figure 3-6. (Top) Surface- and bottom-water ammonium concentrations on February 6, 2013, showing monitoring stations during mixed conditions. (Bottom) Cross-sections of concentrations along transects connecting selected stations. The plume reached surface waters during the winter.

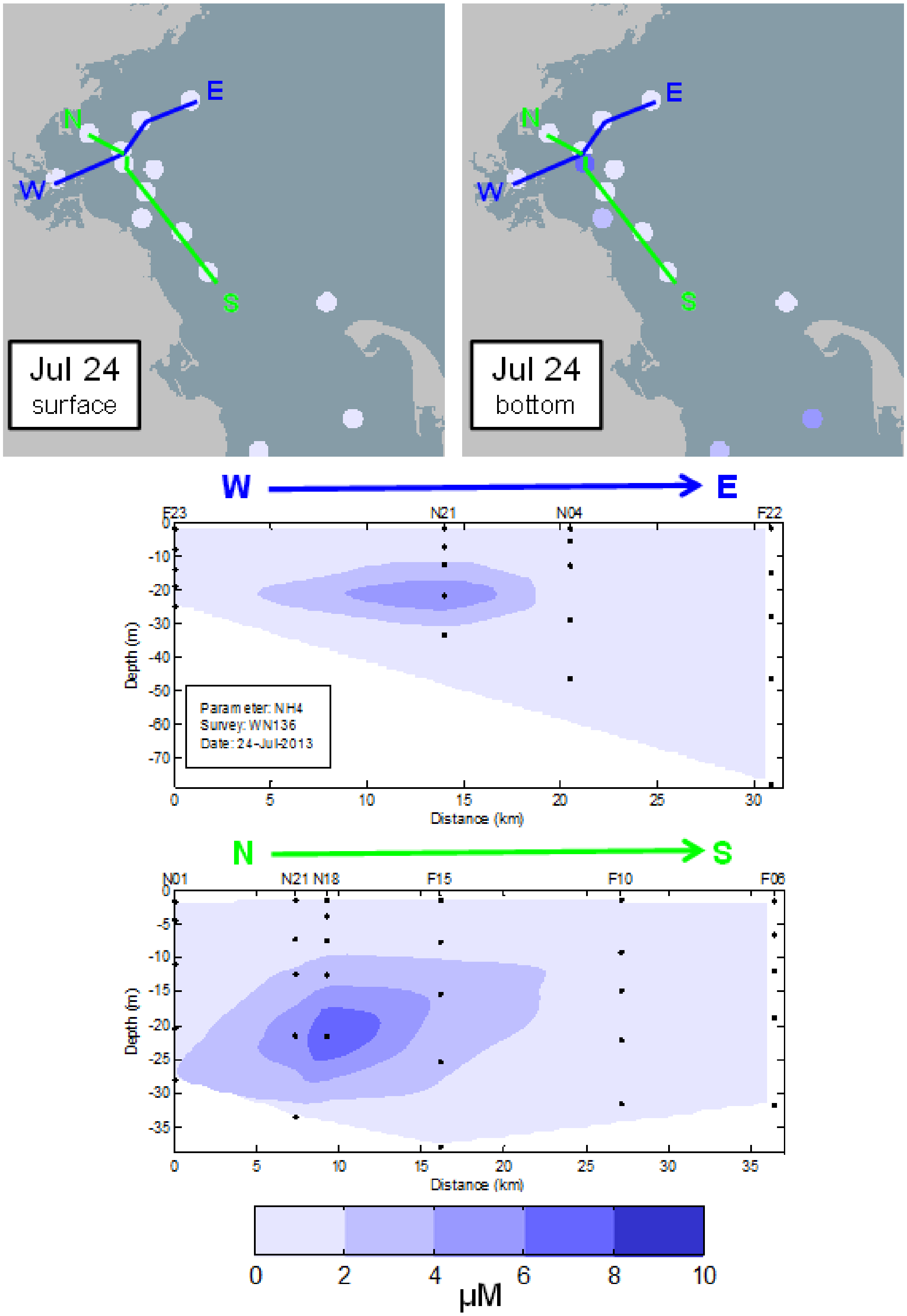

Figure 3-7. (Top) Surface- and bottom-water ammonium concentrations on July 24, 2013 at the monitoring stations during stratified conditions. (Bottom) Cross-sections of concentrations along transects connecting selected stations. The plume remained beneath the pycnocline during the summer.

At many stations, particularly in Boston Harbor and nearby shallow-water stations, peak chlorophyll levels occurred in July (Figure 3-8). Over much of the year, chlorophyll levels were low, often at historic minima for the monitoring program. Satellite imagery (Figure 3-9) suggested that chlorophyll levels were somewhat elevated in January and February, relatively low from late February until July, increasing in later July, and higher throughout the fall.

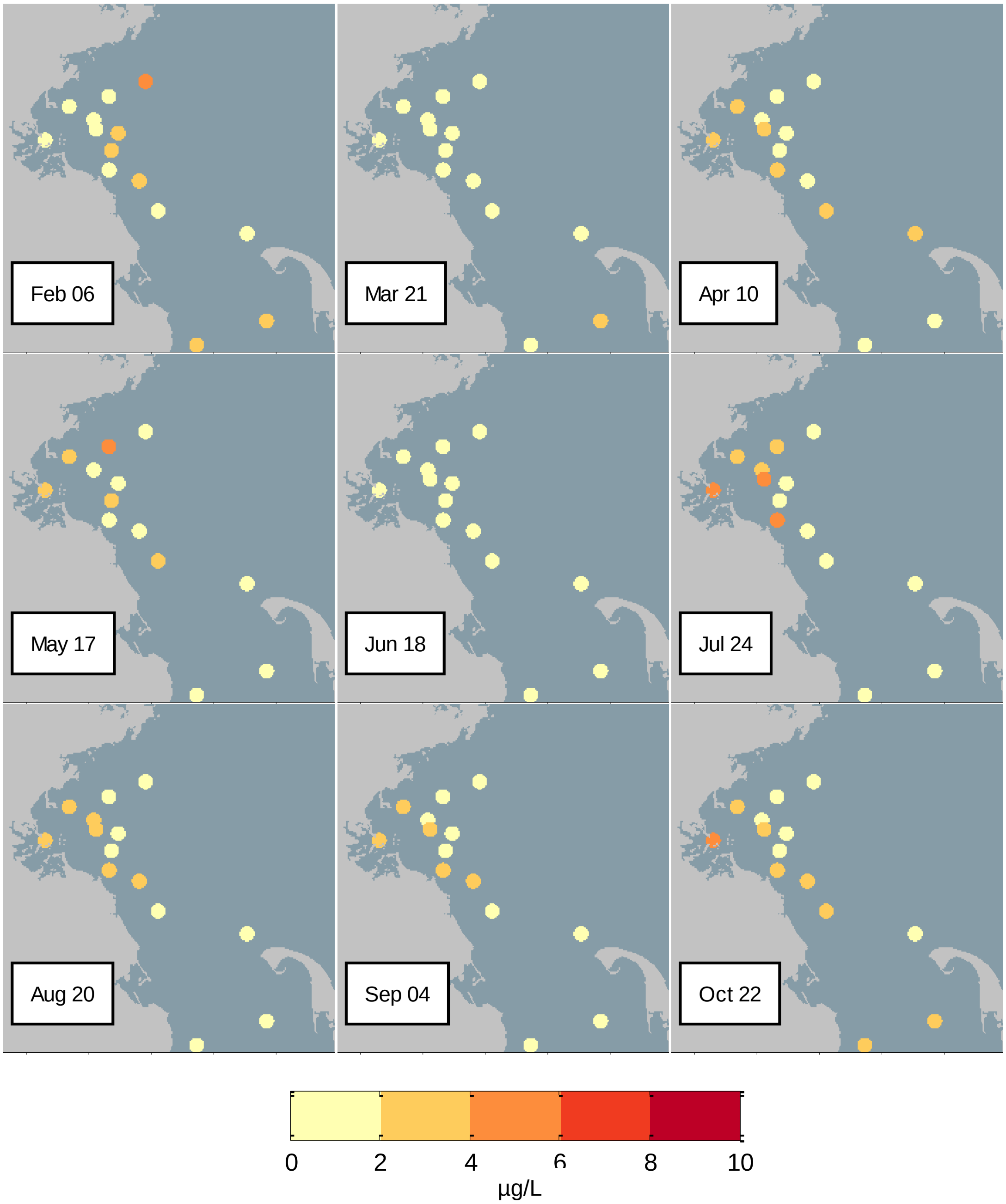

Figure 3-8. Average chlorophyll fluorescence by station in Massachusetts and Cape Cod bays..

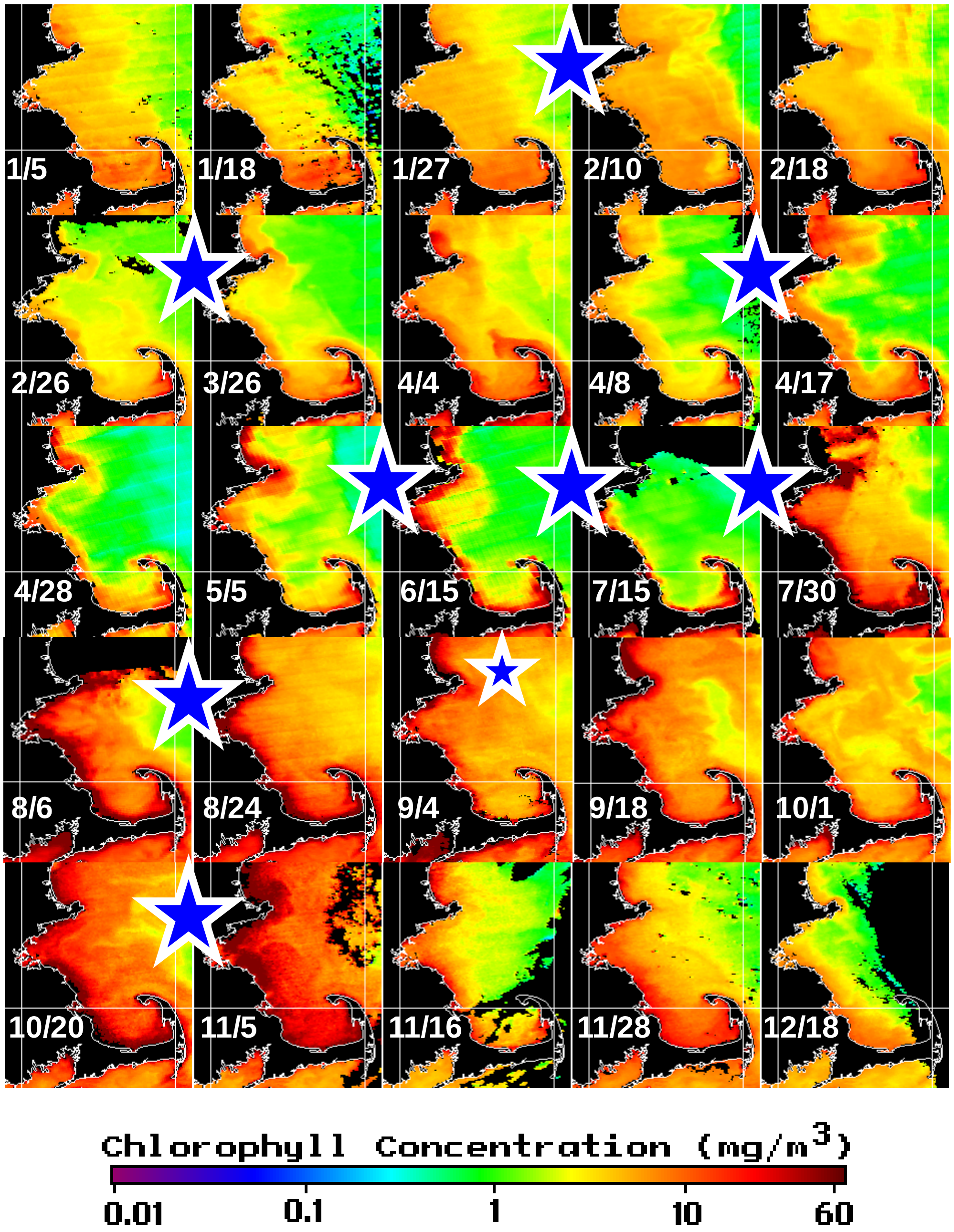

Figure 3-9. Moderate Resolution Imaging Spectroradiometer satellite imagery of surface chlorophyll concentrations in 2013. These images are heavily weather dependent and do not represent consistent intervals of time. The stars show the timing of the nine MWRA surveys. Highlights:

1st row – early elevated chlorophyll levels January – February
2nd & 3rd rows – relatively low from late February into July
4th row – late summer chlorophyll increase, September bloom
5th row – elevated chlorophyll levels into early November

Nearfield bottom-water dissolved oxygen concentrations were relatively low during the first surveys of the year, a result of warm temperatures and high salinity (Figure 3-10). Levels declined at rates typically observed throughout the summer and fall. The fall oxygen minima were moderate in comparison to other years and higher than observed in 2012. With low levels at the onset of the season and strong stratified conditions persisting in October, it was surprising that the minima were not lower than observed. Data from the NERACOOS buoy indicated that levels in the deep bottom waters of Massachusetts Bay remained above 6.5 mg/L throughout the season.

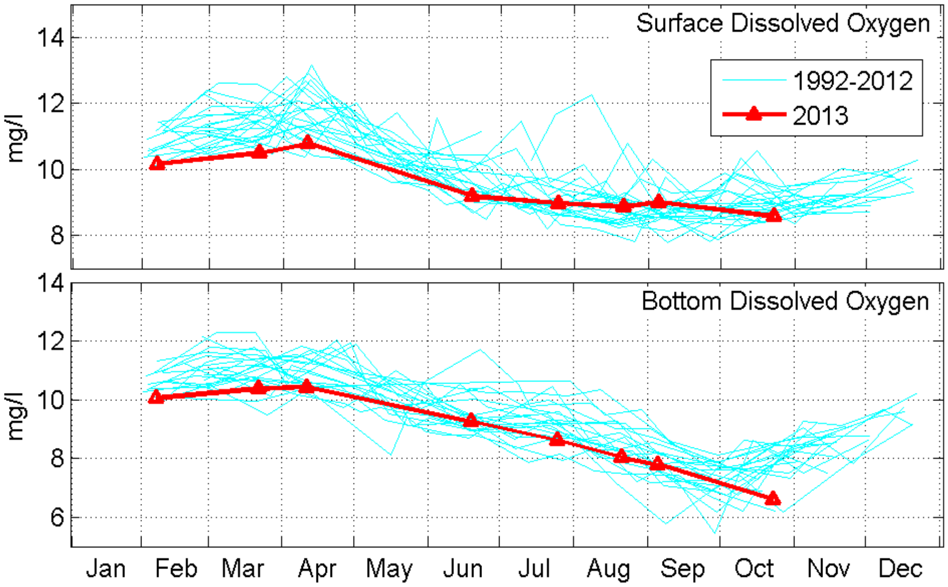

Figure 3-10. Nearfield surface and bottom water dissolved oxygen concentrations..Dissolved oxygen concentrations were low relative to other years of the monitoring program. Even lower values would be expected based on the warmer than average bottom temperatures and higher than average bottom salinity measurements.

The lowest dissolved oxygen concentrations measured in 2013 were at Station F02 in eastern Cape Cod Bay, where levels fell below 5 mg/L during the October survey (Figure 3-11) . During the same survey, bottom-water dissolved oxygen levels in western Cape Cod Bay had increased to more than 8 mg/L, indicating that remixing occurred earlier in that area. High-nutrient, low-oxygen spots have occurred in Cape Cod Bay in some other years, likely a result of southward coastal flow, long residence time, and strong stratification (Jiang et al. 2007).

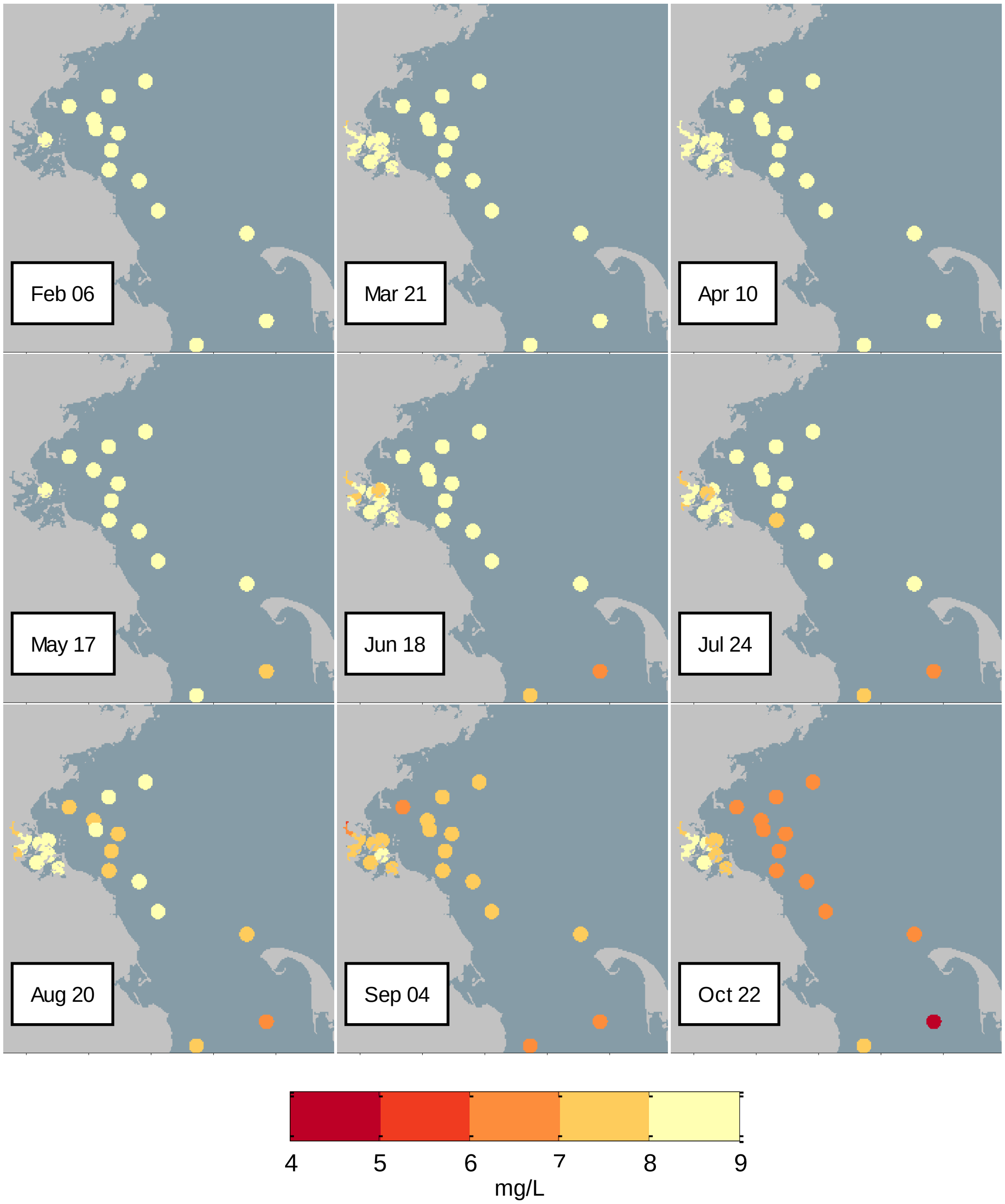

Figure 3-11. Bottom-water dissolved oxygen concentration (mg/L) at stations in Massachusetts and Cape Cod bays during the nine surveys conducted in 2013. The lowest concentration measured in 2013 was at Station F02 in eastern Cape Cod Bay. Levels lower than 5 mg/L have been only rarely measured by the monitoring program. (Several panels show additional data from MWRA's in-house Boston Harbor monitoring surveys when those surveys were within a few days of the outfall monitoring surveys.)

Phytoplankton Communities

Total abundance of phytoplankton was low in 2013, ranking 21st of 22 years of monitoring (Libby et al. 2014). The sampling program detected no winter/spring bloom, although there was a detectable summer bloom, particularly in Boston Harbor and the nearfield (Figure 3-12). Abundances were typical through the fall.

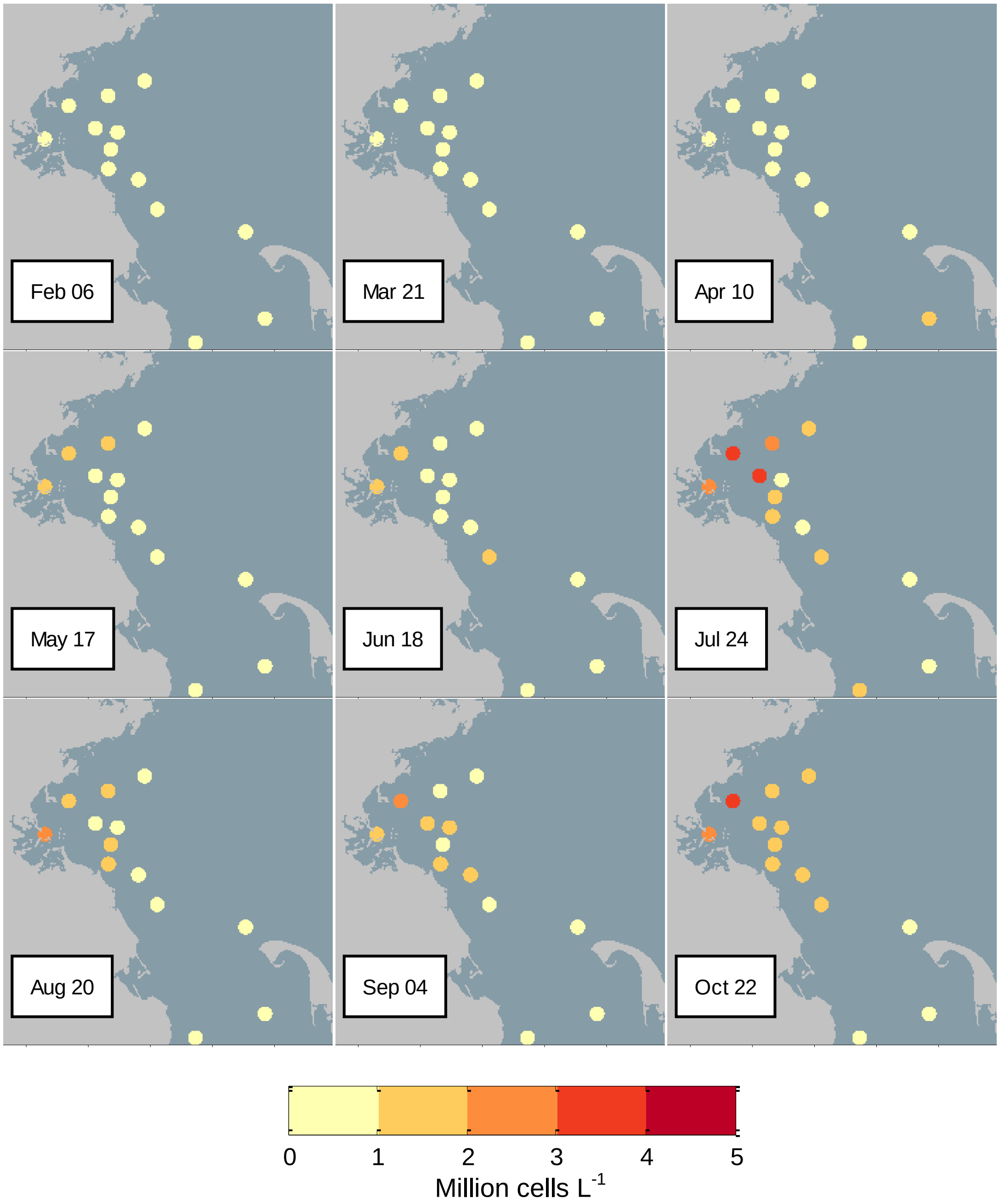

Figure 3-12. Total phytoplankton abundance in 2013. Annual abundance was low, approximately one third the long-term mean.

The lack of an observed winter/spring bloom partially explains the overall low phytoplankton abundances in 2013. Annual abundances of *Chaetoceros* spp., *Skeletonema* spp., and *Thalassiosira* spp., which are usually dominant diatom species in spring blooms, all declined. There were also declines in abundances of the small, often numerous, microflagellates and cryptophytes.

Some species increased in abundance in 2013. Summer blooms of the centric diatom *Dactyliosolen fragilissimus* occurred in Boston Harbor and the nearfield. Abundances of the large flagellates *Ceratium* spp. were elevated, with total abundance for the year ranking 2nd of the 22 years. *Ceratium* are large dinoflagellates with cyclical abundance patterns.

Most noteworthy in 2013, there was no significant bloom of the nuisance species *Phaeocystis pouchetii* (Figure 3-13). The 2013 mean average *Phaeocystis* abundance was only 2,020 cells/L, compared to a long-term average of 272,258 cells/L. Abundances were lower than in any year since annual blooms began to occur regularly just before the outfall came on line in 2000.

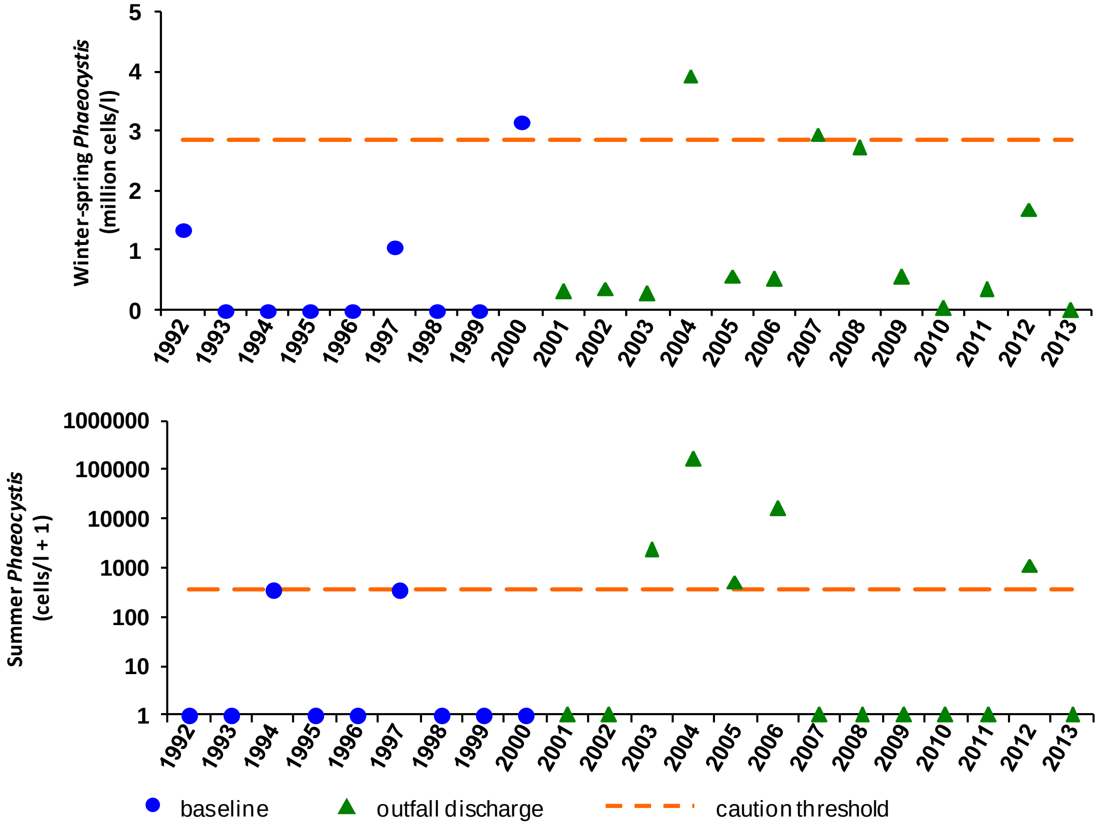

Figure 3-13. Mean nearfield abundance *Phaeocystis pouchetii*, 1992–2013. (Top) Winter/spring. (Bottom) Summer.

Long-term-trend analyses suggest that abundance of *Phaeocystis pouchetii* is inversely correlated with diatom abundance in Massachusetts Bay (Figure 3-14). In 2013, while *Phaeocystis* abundance was low, diatoms abundance was approximately at the long-term mean. Monitoring and modeling have suggested that reduced nitrate levels, such as were observed during the early winter/spring period in 2013, may prevent development of large *Phaeocystis* blooms in Massachusetts Bay (Jiang et al. 2014). The simultaneous low levels of silicate at the beginning of the monitoring season may have prevented diatom growth during the monitoring-program season as well.

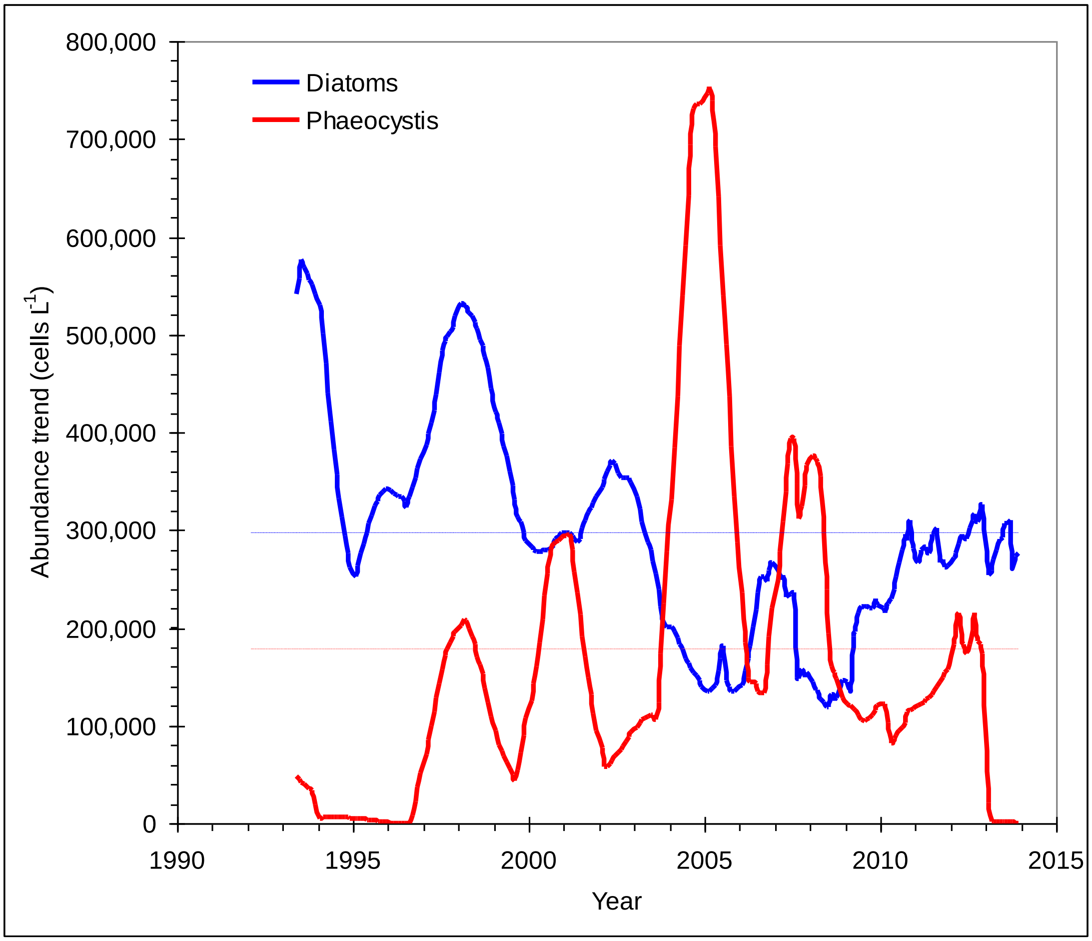

Figure 3-14. Long-term seasonally adjusted average abundance of centric diatoms and *Phaeocystis pouchetii*. Diatom abundance in 2013 was near the long-term mean, while *Phaeocystis* abundance was low.

Abundance of the toxic dinoflagellate *Alexandrium fundyense* was lower than it had been in recent years, with only a small bloom (Figure 3-15). The Woods Hole Oceanographic Institution predicted a larger, moderate bloom, but that did not occur anywhere in the Gulf of Maine. Modeling suggests that low winter/spring nutrient levels throughout the region may have contributed to the lack of a larger bloom.

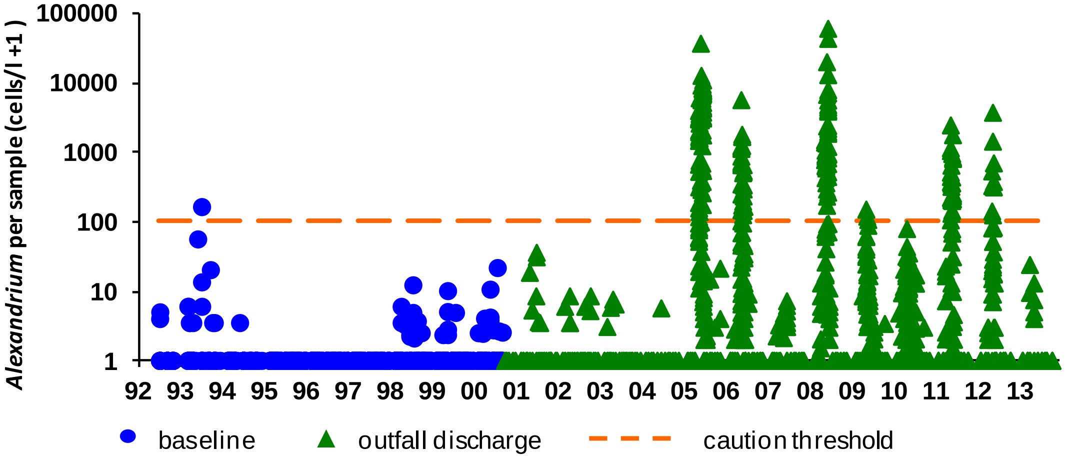

Figure 3-15. Nearfield abundance of *Alexandrium fundyense*, 1992–2013.

Zooplankton Communities

The 2013 zooplankton abundances (Figure 3-16), species composition, and seasonal progressions of the communities fell within the general patterns of past years, although there were atypically high abundances of some species (Libby et al. 2014). Abundances of total zooplankton, total copepod adults and copepodites, *Oithona similis*, *Calanus finmarchicus*, and *Pseudocalanus* spp. were generally higher than in most previous years and, except for *C. finmarchicus*, the highest levels observed since the outfall began to discharge. Several pulses of meroplankton occurred, including barnacle nauplii in March and April and bivalve veligers in July and August.

The relatively high abundances of zooplankton in 2013 may have been influenced by the warm, saline conditions. High abundances were somewhat unexpected in the face of the low winter/spring chlorophyll levels and low total phytoplankton abundances. However, links between phytoplankton and zooplankton abundances can be difficult to discern. In Massachusetts Bay, the dominant zooplankton species *Oithona similis* feeds on small microorganisms rather than on phytoplankton, and there are no abundance data for those microzooplankton species.

Increases in zooplankton abundance have been noted by the monitoring program over the past several years, following declines in abundance in the early 2000s. The reasons for long-term changes are not well understood, but appear to occur on large regional scales. There has been no indication of any effect of the outfall discharge on the zooplankton communities in Massachusetts Bay.

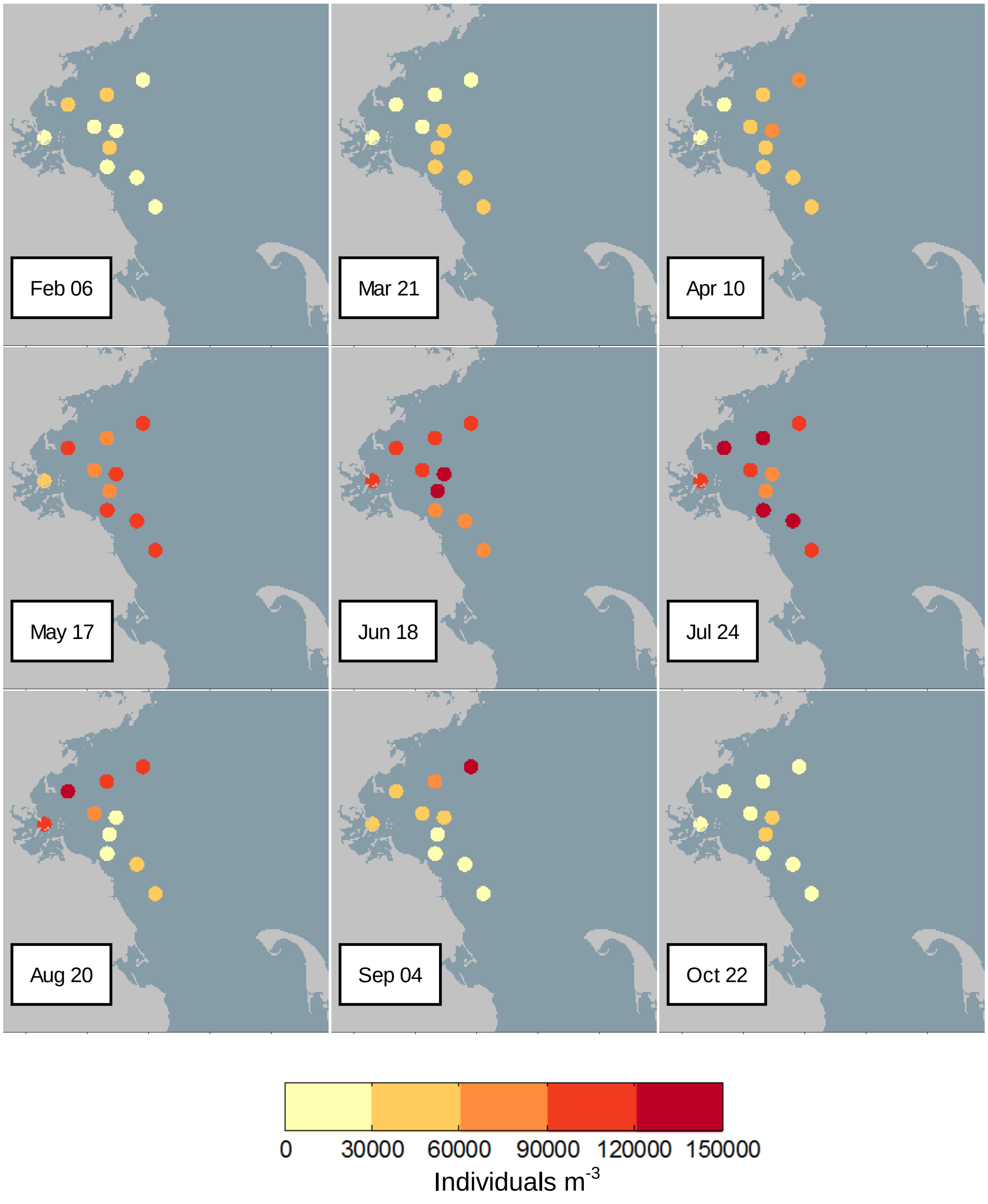

Figure 3-16. Total zooplankton abundance in 2013. Abundance patterns were typical, increasing from the winter through the spring, peaking in the summer, and declining in the fall.

Stellwagen Bank National Marine Sanctuary

The NPDES permit to discharge from DITP into Massachusetts Bay requires annual reporting on results that are relevant to the Stellwagen Bank National Marine Sanctuary. Station F22 is in Stellwagen Basin to the northwest of the sanctuary and is considered to be representative of northern, offshore conditions. Surface-water ammonium levels have not changed, remaining low, at Station F22 since the outfall began to discharge (Figure 3-17). Levels have also remained low at Station F06. located to the south and offshore. Increased ammonium levels can be detected at Station N18 in the nearfield, while dramatic decreases have been detected at representative harbor and coastal stations.

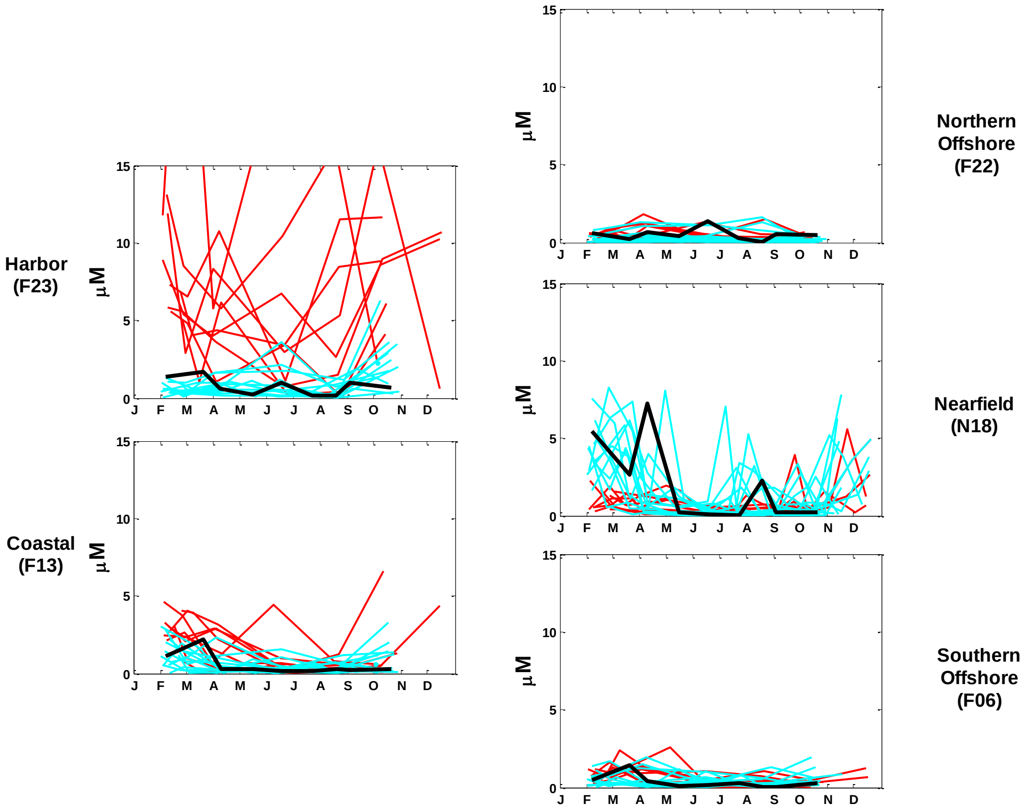

Figure 3-17. Average surface-layer ammonium at representative stations. Black line is 2013, red lines are the baseline (1992–August 2000, and light blue lines are other discharge years (September 2000–2012). Surface-water ammonium levels at Station F22 in Stellwagen Basin (Northern Offshore) have remained low throughout the duration of the monitoring program. See Figure 3-1 for precise locations of all stations.

Bottom-water dissolved oxygen concentrations at Station F22 were relatively low throughout 2013 (Figure 3-18). These levels reflected the warm, saline conditions found throughout the region. Data from the NERACOOS Buoy A01, located within the sanctuary, documented the return to oxygenated conditions with fall mixing.

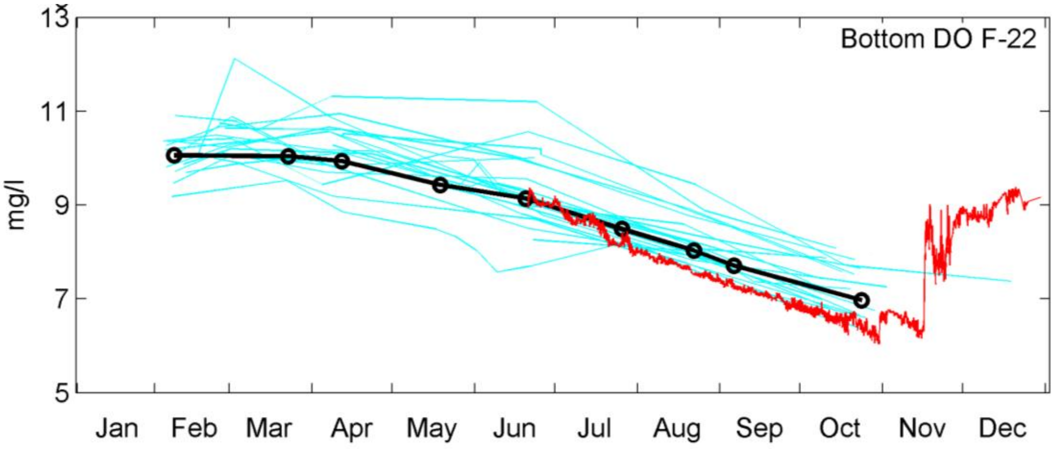

Figure 3-18. Bottom water dissolved oxygen concentrations in Stellwagen Basin in 2013 compared to the previous years of monitoring. Data from the NERACOOS Buoy A01 are shown in red. DO = dissolved oxygen

Contingency Plan Thresholds

All water-quality parameters were within normal ranges throughout 2013, and there were no exceedances of Contingency Plan thresholds (Table 3-1).

Table 3-1. Contingency Plan threshold values and 2013 results for water-column monitoring.

Parameter	Baseline	Caution Level	Warning Level	2013 Results
Dissolved oxygen*				
Nearfield concentration	6.05 mg/L	6.5 mg/L	6.0 mg/L	6.71 mg/L
Nearfield percent saturation	65.3%	80%	75%	73.6%
Stellwagen concentration	6.23 mg/L	6.5 mg/L	6.0 mg/L	6.97 mg/L
Stellwagen percent saturation	67.2%	80	75%	75.3%
Nearfield depletion rate	0.024 mg/L/d	0.037 mg/L/d	0.049 mg/L/d	0.021 mg/L/d
Chlorophyll				
Annual	72 mg/m^2	108 mg/m^2	144 mg/m^2	61 mg/m^2
Winter/spring	50 mg/m^2	199 mg/m^2	None	53 mg/m^2
Summer	51 mg/m^2	89 mg/m^2	None	65 mg/m^2
Autumn	90 mg/m^2	239 mg/m^2	None	64 mg/m^2
Nuisance algae *Phaeocystis pouchetii*				
Winter/spring	622,000 cells/L	2,860,000 cells/L	None	5,160 cells/L
Summer	72 cells/L	357 cells/L	None	Absent
Autumn	370 cells/L	2,960 cells/L	None	Absent
Nuisance algae nearfield *Pseudo-nitzschia* spp.				
Winter/spring	6,735 cells/L	17,900 cells/L	None	Absent
Summer	14,635 cells/L	43,100 cells/L	None	667 cells/L
Autumn	10,050 cells/L	27,500 cells/L	None	490 cells/L
Nuisance algae nearfield *Alexandrium fundyense*				
Any nearfield sample	Baseline maximum 163 cells/L	100 cells/L	None	23 cells/L
PSP toxin extent	NA	New incidence	None	No new incidence

*Dissolved oxygen caution and warning levels represent numerical criteria, with the caveat "unless background conditions are lower." Results are therefore compared to the baseline rather than the caution and warning levels.

NA = not applicable

4. Sea Floor

Sea-floor monitoring in 2013 included sampling for soft-bottom sediment conditions and infauna at 14 stations and sediment-profile imaging at 23 stations (Figures 4-1 and 4-2).

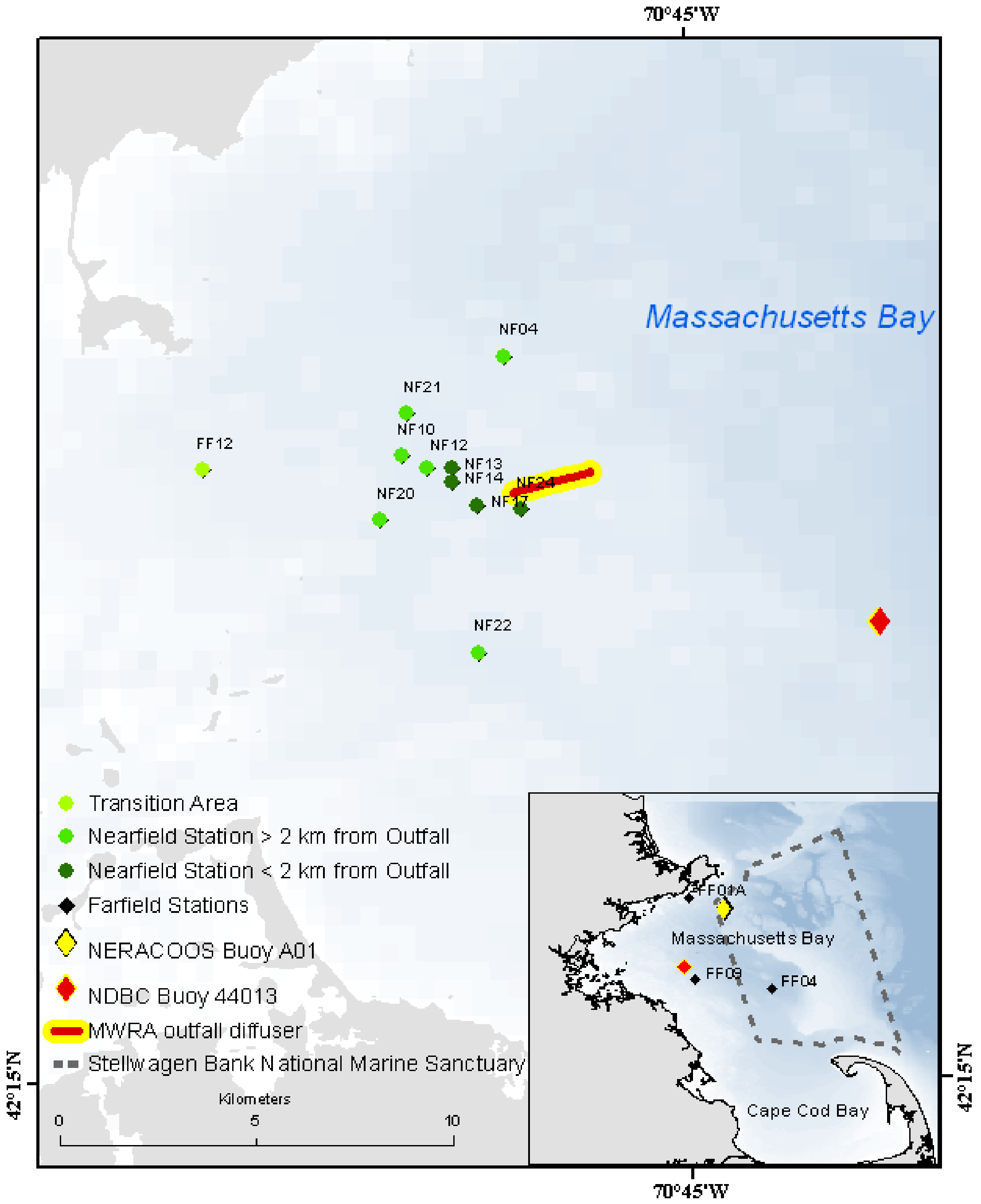

Figure 4-1. Soft-bottom monitoring stations. Fourteen stations were sampled for benthic community parameters and sediment characteristics. Also shown are the instrumented buoys, the MWRA outfall diffuser, and the Stellwagen Bank National Marine Sanctuary.

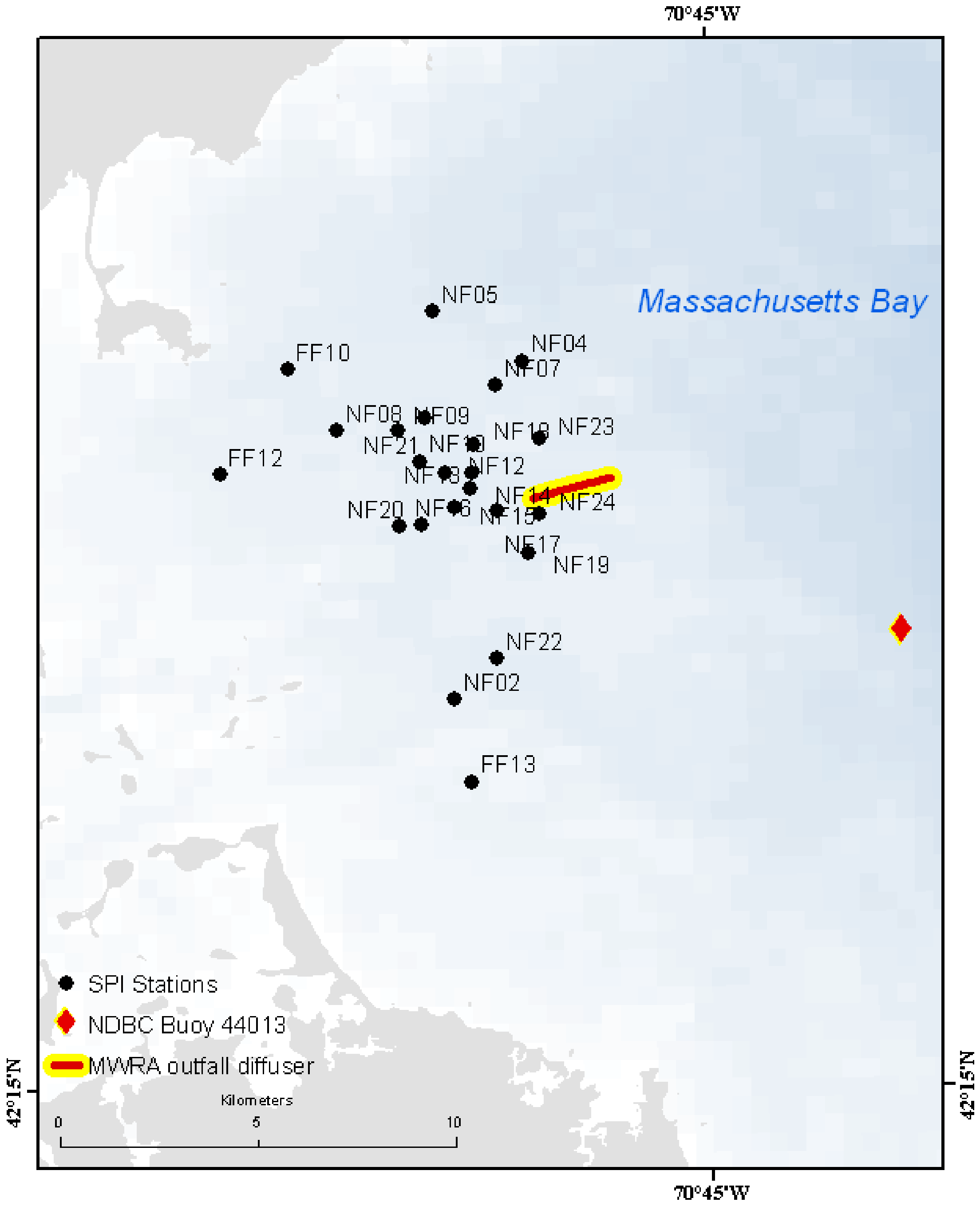

Figure 4-2. Sediment-profile imaging stations. Images are taken at 23 stations and provide rapid assessments of benthic habitats. Also shown are the NDBC buoy and the MWRA outfall diffuser.

Sampling for grain-size distribution, total organic carbon, the effluent tracer *Clostridium perfringens* spores, and benthic infauna was completed during August. Sediment and infauna sampling included one station in the "transition" area, located between Boston Harbor and the nearfield stations (FF12); four nearfield stations located within two kilometers of the outfall (NF13, NF14, NF17, NF24); six nearfield stations located within Massachusetts Bay but farther than two kilometers from the outfall (NF04, NF10, NF12, NF20, NF21, NF22); and three farfield reference stations located in Massachusetts Bay and Cape Cod Bay (FF01A, FF04, and FF09). For the purposes of threshold testing, "nearfield" includes the transition station, as well as both groups of nearfield stations, for a total of eleven stations.

Sediment-profile imaging was also completed in August. The images were used to measure the apparent reduction-oxidation (redox) potential discontinuity (RPD) depth, apparent successional stage of the community, and an organism sediment index which is derived from the RPD depth and the successional stage.

Sediment Characteristics and Tracers

Sediment grain-size distributions in 2013 ranged from silt and clay at some stations to mostly sand at others (Nestler et al. 2014). Although sediment grain-size distributions have remained generally consistent at individual stations over the years of the monitoring program, there were some notable changes in 2013. For example, sediments at Station NF12, just to the northwest of the outfall, became siltier, while those at Station FF01, a sandy station off Cape Ann, were the coarsest ever measured during the monitoring program. These changes are thought to have resulted from sediment transport during the February and March storms. (See Section 3, Water Column; the strongest of these storms produced wave heights of 10 m within Massachusetts Bay.)

Percent organic carbon content in the samples was consistent with past results at most stations, with higher mean total organic carbon concentrations at stations with finer sediments. Total organic carbon concentrations showed no signs of organic enrichment from the effluent discharge, even at stations closest to the outfall.

As in past years since the outfall came on line (except 2006), it was possible to detect elevated levels of the effluent tracer, *Clostridium perfringens* spores, at the stations located closest to the outfall (Figures 4-3 and 4-4). Concentrations of *Clostridium perfringens* spores have declined or remained comparable to the baseline in all other locations.

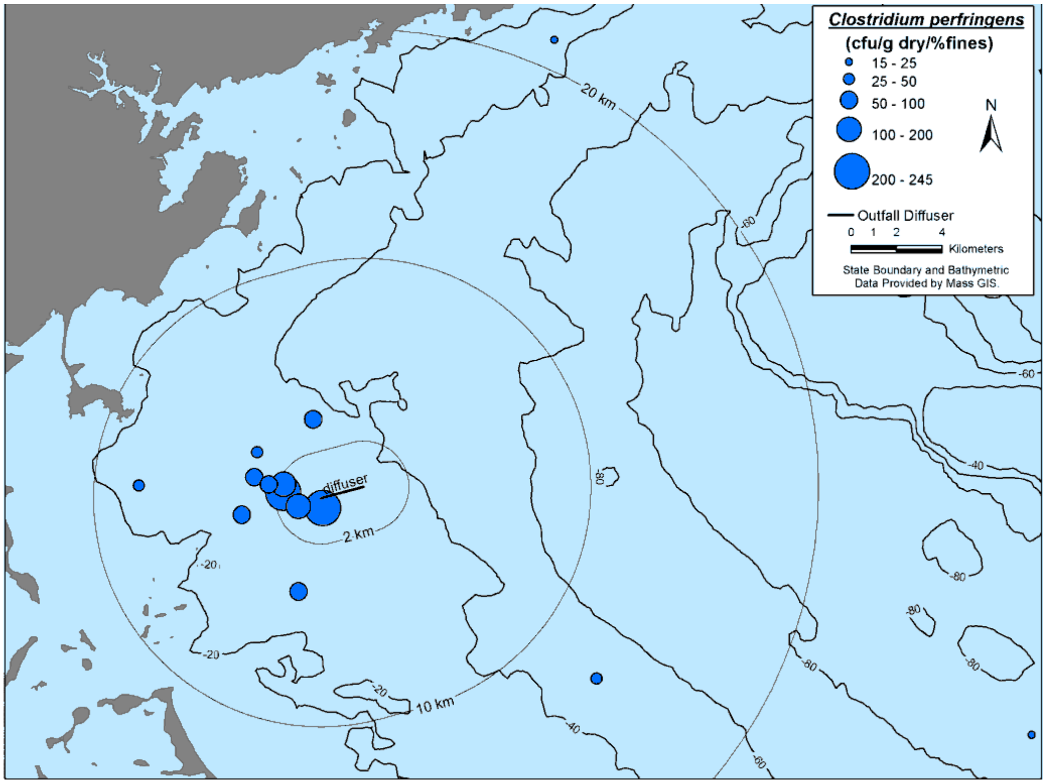

Figure 4-3. Concentrations of *Clostridium perfringens* spores, corrected for sediment grain size, in 2013.

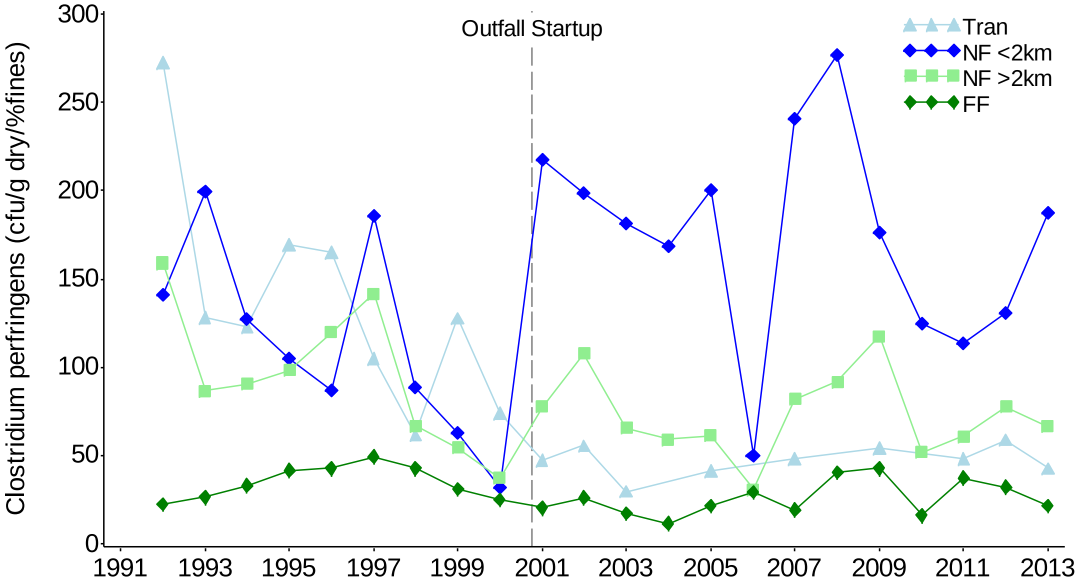

Figure 4-4. Mean concentrations of *Clostridium perfringens* spores during the baseline and outfall-discharge years. (Tran = transition area, stations located between Boston Harbor and the outfall; NF<2km = nearfield stations located within 2 km of the outfall diffusers; NF>2km = nearfield stations located further than 2 km from the diffusers; FF = farfield stations offshore from the outfall.)

Soft-bottom Communities

The 14 soft-bottom samples collected and analyzed in 2013 yielded 14,522 organisms, classified into 183 species and 24 other discrete taxonomic groups (Nestler et al. 2014). Infaunal abundance was within the range observed over the monitoring program, but generally low, comparable to abundances in the 1993 baseline year (Figure 4-5). The low abundances in 2013 were observed in all areas sampled. Relative abundances of the five dominant species in the samples, those contributing at least 5% to total abundances, were low in 2013, as observed for several years (Figure 4-6). In particular, the polychaete *Prionospio steenstrupi*, which was the numerically dominant species during much of the 1990s and 2000s, was present in relatively low numbers.

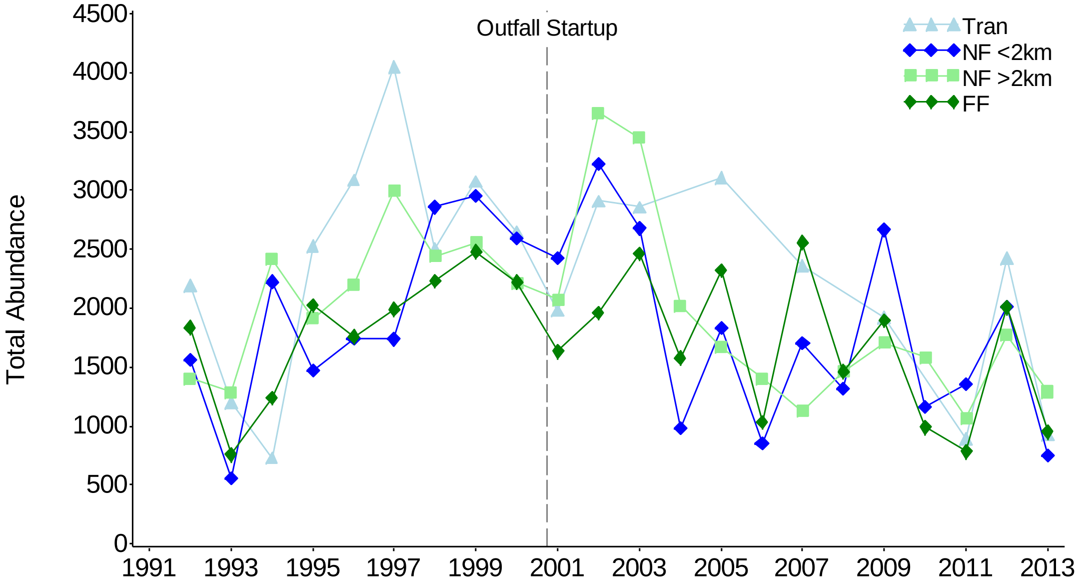

Figure 4-5. Mean infaunal abundance per sample in four areas of Massachusetts Bay, 1992–2013. Tran = transition area, stations located between Boston Harbor and Massachusetts Bay; NF<2km = stations within 2 km of the outfall; NF>2km = nearfield stations greater than 2 km from the outfall; FF = farfield stations offshore from the outfall

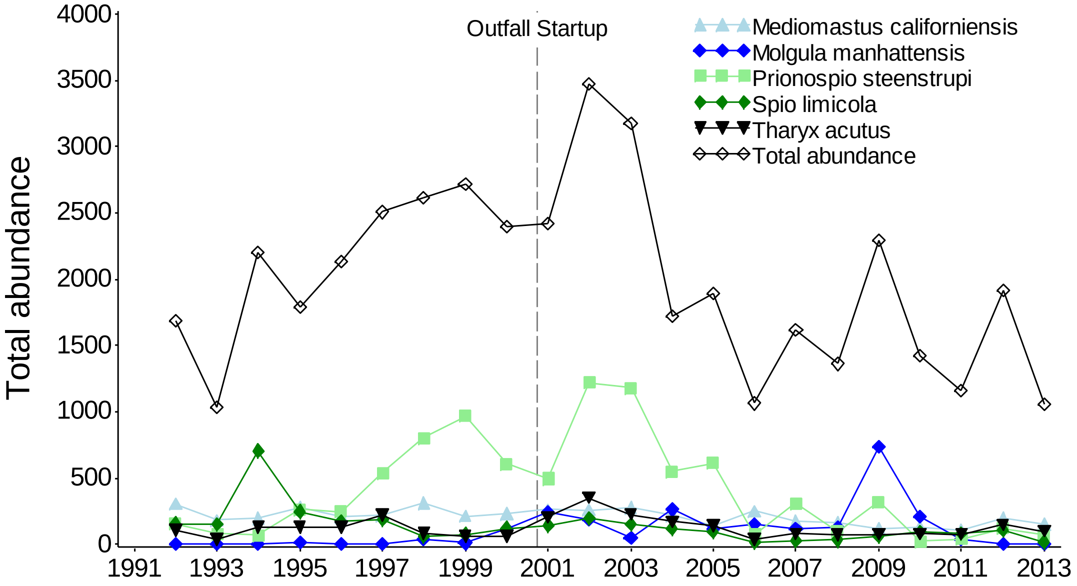

Figure 4-6. Mean total abundance per sample and abundance of five dominant species at nearfield stations, 1992–2013. *Molgula manhattensis* is a tunicate; the other four species are polychaetes.

A series of multivariate analyses assessed spatial and temporal patterns in the soft-bottom benthic communities and found no particular species or type of community that could be specifically associated with the outfall. A cluster analysis identified two main infaunal assemblages, with an outlier at Station FF04, which is offshore in Stellwagen Basin and has consistently had a distinct community. An ordination analysis demonstrated that species distributions were largely determined by sediment type rather than by proximity to the outfall. (See Figure 4-8 in the section on Stellwagen Bank National Marine Sanctuary, below.)

Sediment-profile Imaging

Sediment-profile images continued to show no adverse effects of the outfall (Nestler et al. 2014). Monitoring has shown that physical processes, such as storms and storm-induced sediment transport, are the primary stressors on the sea floor. The dominance of physical forces may be considered typical of outfalls that have been located in high-energy areas that promote rapid dispersion of effluent.

The average RPD depth (the depth to which oxygen penetrates into sediments as determined by color changes) was the deepest ever measured during the monitoring program (Figure 4-7). These deep RPD depths were measured despite a decline in overall depth of penetration by the wedge-shaped prism onto which the sediment-profile-image camera is mounted. In 2013, RPD depths at 13 of the 23 stations were deeper than could be measured, so with better prism penetration, RPD measurements for 2013 would have been even deeper. Prism penetration is typically hampered by coarse-grained sediments and shell fragments, and even small changes in those conditions can affect average RPD measurements. The environmental concern before the outfall came on line was that the RPD depth would become shallower, so a deeper RPD depth continues to indicate that there has been no adverse effect from the discharge.

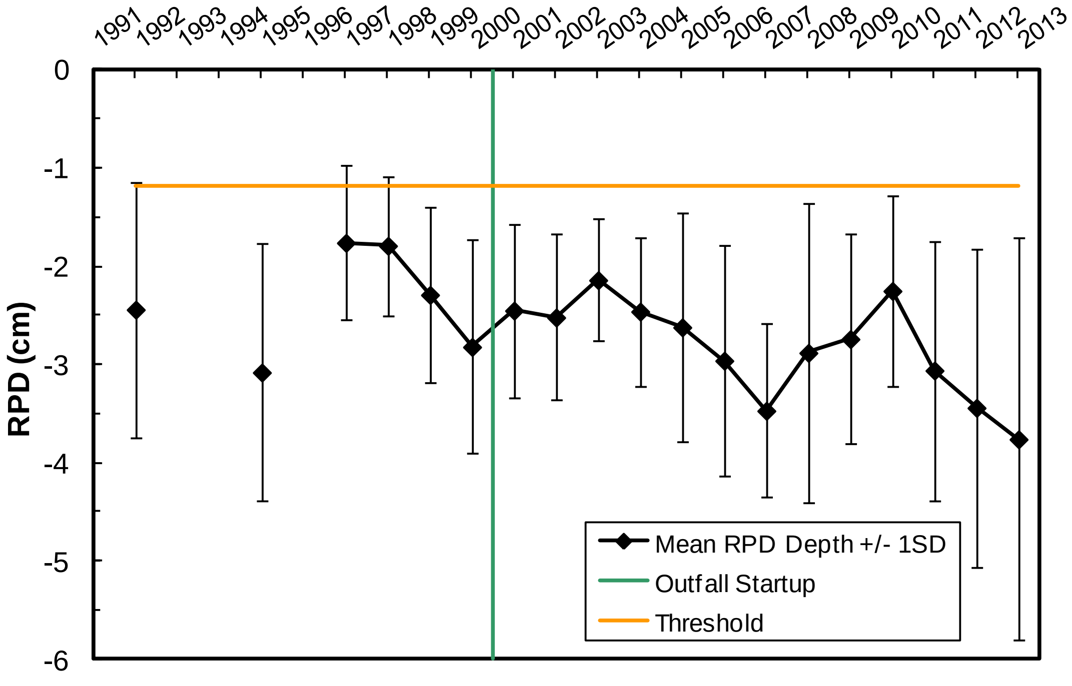

Figure 4-7. Annual apparent color RPD depth for data from nearfield stations. The average RPD discharge-period mean has been deeper than the baseline mean, continuing to indicate that there has been no adverse effect from the discharge.

The sediment-profile images also found no indications of organic carbon accumulation and no adverse effects on the types of organisms inhabiting the sediments. Even at stations located closest to the outfall, there was no evidence of organic carbon accumulation, observations supported by organic carbon measurements made at the stations shown in Figure 4-1.

If organic carbon concentrations were increasing in the sediments, the images would have shown increased darkening at the sediment surface, but instead, they continued to show light-colored, oxygenated surface sediments. The generally light color of the sediments suggested that the true RPD depths, if measured by electrode rather than color discontinuity, would be deeper than the prism penetration at all stations. The color shifts in the apparent RPD are likely indicative of shifts from oxic to suboxic rather than to anoxic conditions.

Stellwagen Bank National Marine Sanctuary

The NPDES permit to discharge from DITP into Massachusetts Bay requires annual reports on results that are relevant to the Stellwagen Bank National Marine Sanctuary. MWRA's deepwater reference station FF04 lies within the sanctuary, in Stellwagen Basin, which is considered a long-term sediment sink.

Multivariate analyses of soft-bottom data from 2013 (Figure 4-8) showed that, as in previous years, fauna from Station FF04 were distinct, grouping separately from other stations. The separate grouping reflects Station FF04's deep water and silty sediment, typical for Stellwagen Basin.

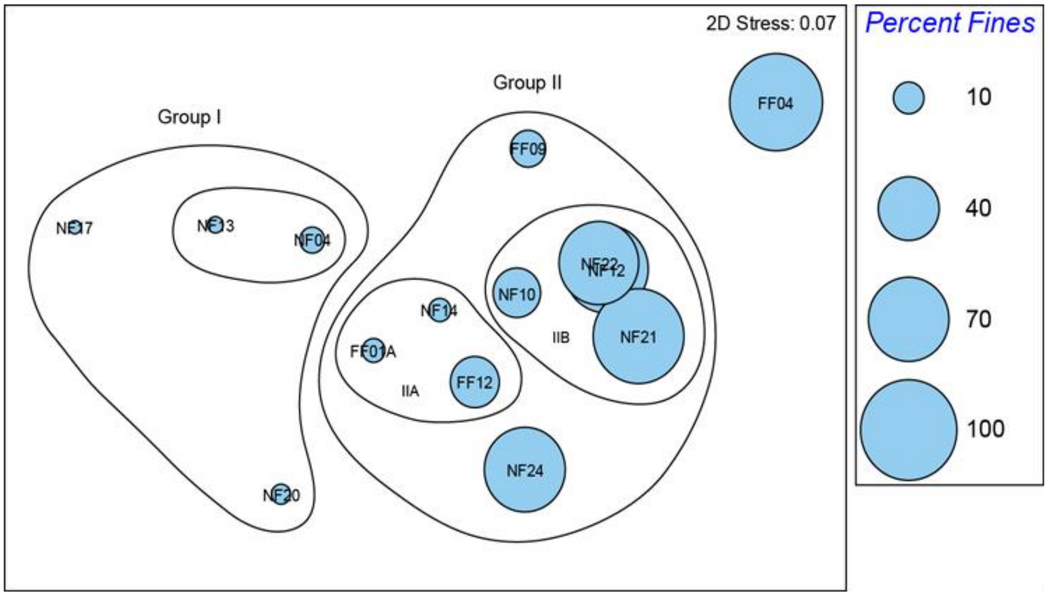

Figure 4-8. Percent fine sediments superimposed on a non-metric multidimensional scaling ordination plot of the 2013 infauna samples. Each point represents the sample from each of the 14 stations. The size of the dot corresponds to the percent fine sediments. The groupings represent the similarity in faunal assemblages, as determined by a cluster analysis. As in previous years, Station FF04, located within Stellwagen Basin, has a unique, deepwater faunal community.

As in past years, the Stellwagen Basin community was dominated by polychaetes. The most abundant species in 2013—*Levinsenia gracilis*, *Chaetozone anasimus*, *Cossura longocirrata*, *Anobothrus gracilis and Aricidea quadrilobata*—have been among the ten most abundant species since 2009, usually comprising the five most abundant taxa. Monitoring during 1992–2010, which included more stations than are currently sampled, showed the faunal community currently found at Station FF04 to be widespread throughout deeper waters, with similar faunal assemblages occurring at all stations with water depths greater than 50 meters.

The decline in abundance of the once-dominant polychaete *Prionospio steenstrupi*, which has been noted in nearfield samples, has occurred at Station FF04 as well. *Prionospio* was not found in samples from FF04 in 2013.

Contingency Plan Thresholds

RPD depth was more than three times the caution-level depth. However, for a fourth consecutive year, there were Contingency Plan threshold exceedances for two sea-floor community parameters (Table 4-1). Values for Shannon-Wiener diversity and Pielou's evenness, both diversity measures, were higher than the caution-level ranges (Figure 4-9). Two other community threshold parameters, total number of species per sample and Fisher's log-series alpha, another diversity measure, were within the caution-level ranges. Percent opportunists among the soft-bottom community remained far below caution and warning levels.

Table 4-1. Contingency Plan threshold values and 2013 results for sea-floor monitoring.

Parameter	Caution Level	Warning Level	2013 Results
Sediment parameters			
Nearfield RPD depth	<1.18 cm	None	3.76 cm
Nearfield benthic community parameters			
Species per sample	<42.99 or >81.85	None	55.55
Fisher's log-series alpha	<9.42 or >15.8	None	13.14
Shannon-Wiener diversity	<3.37 or >3.99	None	4.08, caution level exceedance
Pielou's evenness	<0.57 or >0.67	None	0.71, caution level exceedance
% opportunists	>10%	>25%	0.47 %

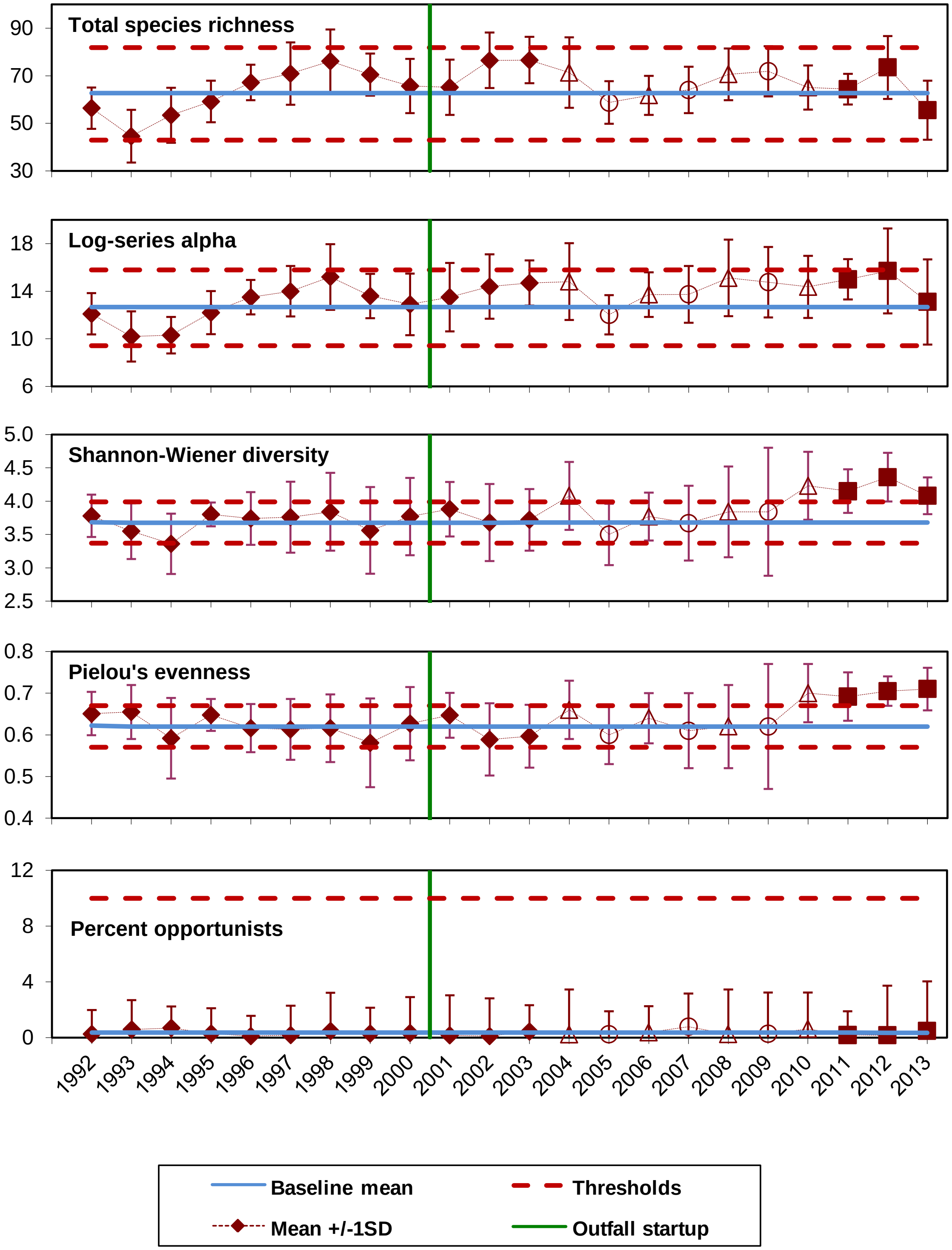

Figure 4-9. Annual community parameters with nearfield Contingency Plan thresholds. The varied symbols represent differences in the stations sampled over the years of the program. Results were tested against thresholds calculated for each sampling design, but only the current threshold values are shown. Except for the percent opportunists threshold, which is based on levels in Boston Harbor, thresholds have both upper and lower bounds to show potentially meaningful changes from the baseline. SD = standard deviation

Similar exceedances of the two indices were observed in 2010–2012, prompting analysis of data from all four years of exceedances. The investigations focused on the species that arithmetically contributed the most in the calculations of the higher values and on possible geographic and temporal patterns that might suggest an effect of the outfall discharge.

The analyses showed that exceedances resulted from changes in the degree to which samples are dominated by a few species (Nestler et al. 2014). The decreases in populations of the formerly most dominant taxon, the polychaete *Prionospio steenstrupi*, and other dominant polychaetes, such as *Spio limicola* and *Mediomastus californiensis*, had the greatest mathematical effect on both the diversity measures.

One analysis, the Schwartz Dominance Index, which represents the minimum number of species it takes to comprise 75% of animals in a sample, demonstrated the changes between the baseline and years since the outfall came on line (Figure 4-10). Both the diversity measures that exceeded thresholds are affected by dominance, while the other two diversity measures, total number of species and log-series alpha, which uses different parameters in its calculation, are not.

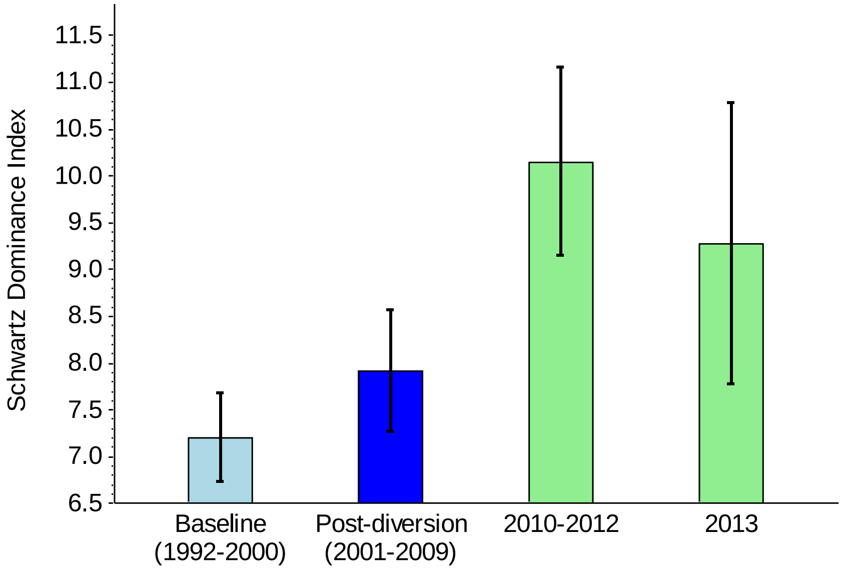

Figure 4-10. Mean Schwartz Dominance Index per sample at nearfield stations in Massachusetts Bay during the baseline and early post-diversion, 2010– 2012, and 2013. The Schwartz Dominance Index is the minimum number of species it takes to make up 75% of the total abundance within a sample. (Samples with a greater Schwartz Dominance Index values are more evenly distributed; samples with low index values are dominated fewer species.)

As in other years, the analyses found no patterns suggesting any effect of the outfall. Spatial patterns have been consistent throughout the duration of the monitoring program, and while species assemblages have changed somewhat over time, the degree and pace of change have been similar throughout the region.

5. Fish and Shellfish

Each year MWRA monitors the health of winter flounder from the Massachusetts Bay outfall site, Deer Island Flats in Boston Harbor, off Nantasket Beach just outside the harbor, and eastern Cape Cod Bay (Figure 5-1). Every three years, most recently in 2012, monitoring includes chemistry measurements in flounder fillets and liver, lobster meat and hepatopancreas, and blue mussel tissue. Sampling in 2013 was limited to winter flounder.

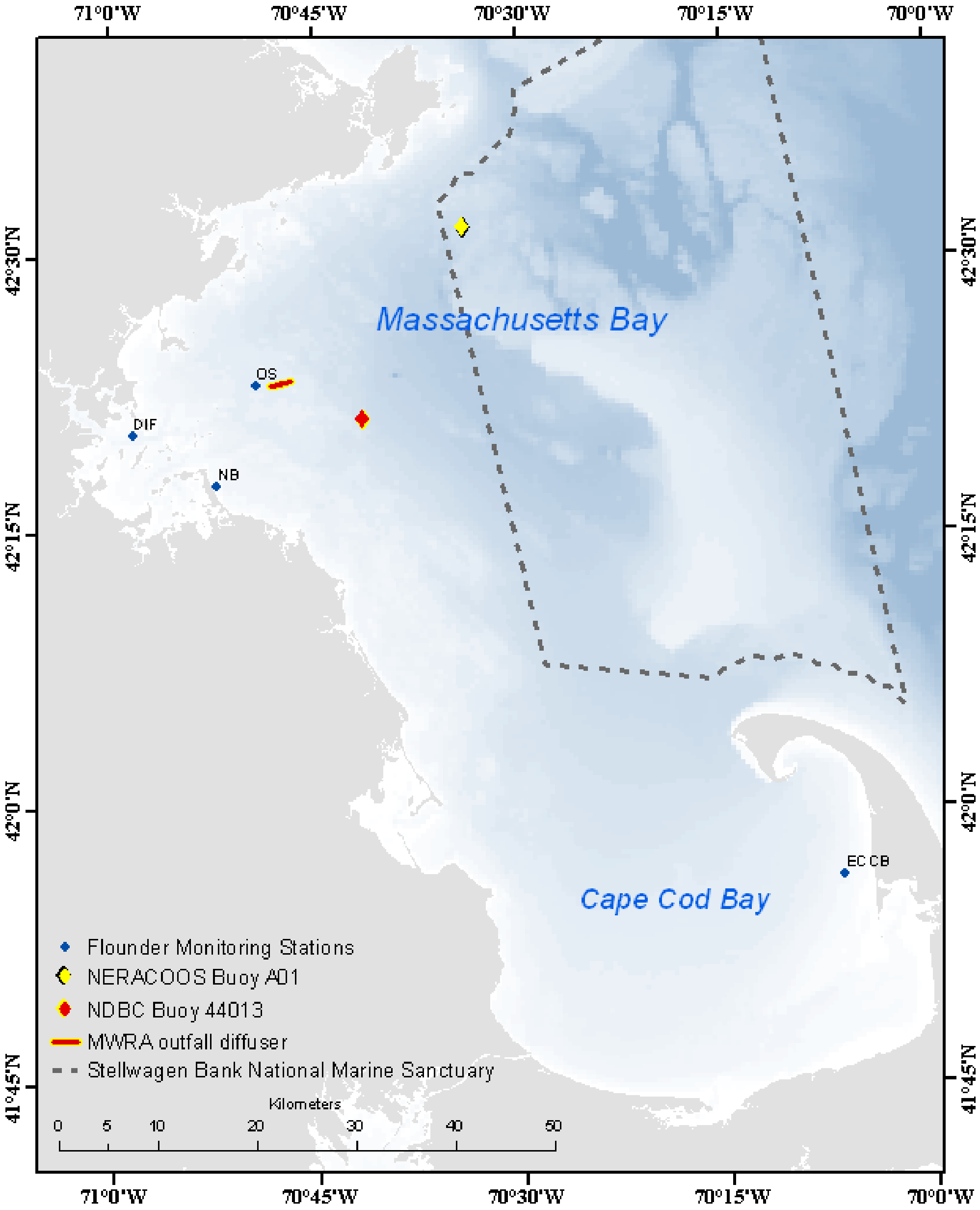

Figure 5-1. Flounder sampling sites. Also shown are the two instrumented buoys, the MWRA outfall diffuser, and the boundaries of the Stellwagen Bank National Marine Sanctuary. OS=outfall site; DIF=Deer Island Flats; NB=Nantasket Beach

Flounder Health

Annual flounder monitoring focuses on the presence of early liver disease and liver neoplasms (tumors). Other indications of health are also documented. In April 2013, 50 sexually mature flounder were collected from each site (Moore et al. 2013). Catch per unit effort, which has varied through time, was moderate near the outfall, approximately at the median for the monitoring program. Abandoned fishing gear continued to interfere with catches, particularly in muddy depressions at the outfall and at Deer Island Flats.

Average ages, lengths, and weights of the winter flounder collected from near the outfall in 2013 were greater than in 2012, but remained within historic ranges, as they did at all sites. As has been common throughout the duration of the monitoring program, the catches were dominated by females, ranging from 66% females at Deer Island Flats to 98% in flounder from eastern Cape Cod Bay. Factors affecting flounder sex ratios are complex and poorly understood, but there are no indications of any effect of the Massachusetts Bay effluent discharge. The already high proportion of the catches made up of females increased at all sites during the 1991–1999 baseline period, and in the eight of thirteen years since the outfall came on line, catches from eastern Cape Cod Bay, 75 km from the outfall, have had the highest proportion of females.

External condition measures also fell within historic ranges. Prevalence of fin erosion, a condition that can be indicative of elevated concentrations of ammonium and other pollutants, ranged from a low of 8% at the outfall to a high of 26% at Deer Island Flats.

Blind-side ulcers, which were first noted in 2003, were absent in 2013. Elevated occurrence of ulcers occurred in 2003–2006 and again 2011. Preliminary results indicate that they were also rare in 2014. The pathology of the ulcers has been studied but is not understood.

No neoplasms (liver tumors) were observed in any fish from any site. Incidence of neoplasia has been rare throughout the area since MWRA monitoring started in 1991, although levels were higher in flounder taken from Boston Harbor for studies during the 1980s (see Boston Harbor Fish and Shellfish in Section 6, Special Studies, for more information). Neoplasia has never been observed in a fish taken from near the outfall.

The incidence of centrotubular hydropic vacuolation (CHV), a mild condition associated with exposure to contaminants and a neoplasia precursor, remained lower than the baseline observations. Incidence of CHV, corrected for age, was slightly higher at the outfall than in 2012 (Figure 5-2). During 2005–2010, there was a slow increase in age-corrected CHV in fish from near the outfall, followed by declines in 2011 and 2012. CHV incidence in fish from Deer Island Flats remained well below the relatively high baseline levels and about the same as was measured in 2011 and 2012. Average severity of CHV also remained lower than baseline levels.

Over the course of the monitoring program, there has been no indication of adverse effects near the outfall, while there have been major improvements in flounder health in Boston Harbor. These improvements are further discussed in Section 6, Special Studies.

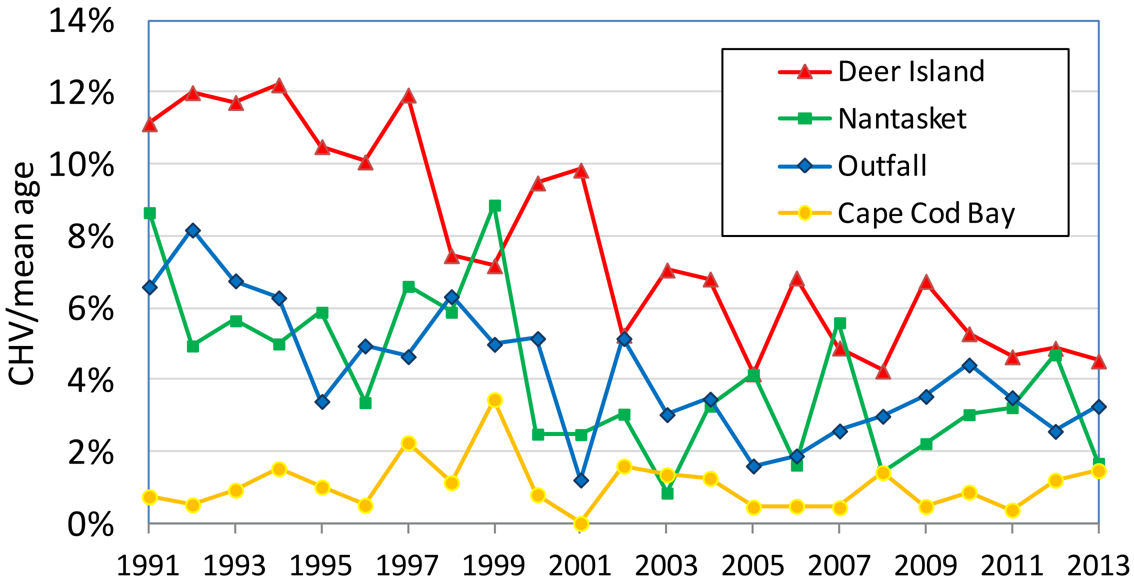

Figure 5-2. Annual prevalence of centrotubular hydropic vacuolation (CHV), corrected for age.

Contingency Plan Thresholds

There was no exceedance of the only Contingency Plan threshold for fish and shellfish in 2013 (Table 5-1). Incidence of CHV, the most common indicator of liver disease in the winter flounder of the region, was 18% in fish taken from the vicinity of the outfall, lower than the caution threshold and the baseline average. CHV incidence in flounder was the only threshold parameter calculated for 2013; chemistry parameters in flounder, lobster, and mussels are measured every three years.

Table 5-1. Contingency Plan threshold values and 2013 results for fish-and-shellfish monitoring.

Parameter	Baseline	Caution Level	Warning Level	2013 Results
Liver disease CHV	24.4%	44.9%	None	18%

CHV = centrotubular hydropic vacuolation

6. Special Studies

Besides monitoring the effluent and the water column, sea floor, and fish and shellfish in Massachusetts Bay and the surrounding area, MWRA conducts special studies in response to specific permit requirements, scientific questions, and public concerns. This year's outfall monitoring overview reports on ongoing monitoring in Boston Harbor and Cape Cod Bay.

Boston Harbor Beaches

MWRA provides technical support to the Massachusetts Department of Conservation and Recreation for its Boston Harbor beach-monitoring program, which allows daily monitoring of beach water quality during the swimming season for urban beaches in Boston Harbor and throughout the MWRA service area (Figure 6-1). Monitoring results are used to post swimmers' advisories throughout the swimming season. Daily monitoring results are also used to assist beach managers in developing and updating rainfall thresholds for precautionary beach postings following wet-weather events.

Figure 6-1. Map of Boston Harbor beaches and bacteria-sampling sites.

Most harbor beaches generally comply with bacteria swimming standards, with most beaches meeting the single-sample *Enterococcus* limit, 104 colony-forming units/100 mL, more than 90% of the time in 2013 (Table 6-1). Compliance was 100% at City Point Beach in South Boston. Wollaston and Tenean beaches, within Boston Harbor, and Kings Beach, outside the harbor in Lynn, were exceptions, with compliance rates below 90%.

The cleanest beaches in Boston Harbor in 2013 were posted with swimmers' advisories due to elevated bacteria counts only one or two days or not at all, while those with poorer water quality were posted more than 15 days out of a 79-day season. (At beaches with multiple sampling locations, daily postings are triggered if two or more locations on a beach exceed the *Enterococcus* limit, so the percent of samples meeting standards does not necessarily correspond directly with the total days posted.)

Table 6-1. Compliance with swimming standards at Boston Harbor beaches in 2013. Percent samples meeting the *Enterococcus* standard in 2013 and the five-year average and total 2013 swimmers' advisory postings due to bacteria levels over a 79-day season.

City or Town/ Harbor Beach		Percent samples meeting standards in 2013 (2009–2013 average)	Total daily postings due to high bacteria
South Boston	Carson Beach	99% (92%)	2 days
	M Street Beach	99% (97%)	1 day
	City Point Beach	100% (98%)	0 days
	Pleasure Bay Beach	96% (96%)	0 days
Dorchester	Tenean Beach	79% (84%)	16 days
Quincy	Wollaston Beach	88% (86%)	12 days
East Boston	Constitution Beach	97% (92%)	1 day
Winthrop	Winthrop Beach*	94% (97%)	1 day
	Short Beach*	94% (96%)	1 day
Revere	Revere Beach*	92% (96%)	1 day
Lynn	Kings Beach*	75% (61%)	17 days

*Beaches located outside Boston Harbor.

Wet-weather discharges due to urban runoff, stormwater, and combined sewer overflows (CSOs) can present challenges to maintaining good water quality at swimming beaches. In South Boston, the North Dorchester Bay CSO storage tunnel came on line in May 2011, eliminating stormwater discharges in up to 5-year storms and CSO discharges in up to 25-year storms. This project resulted in reductions in bacteria levels following wet-weather events at South Boston beaches (Figure 6-2). The discharges had been the primary causes of elevated bacteria levels at those beaches.

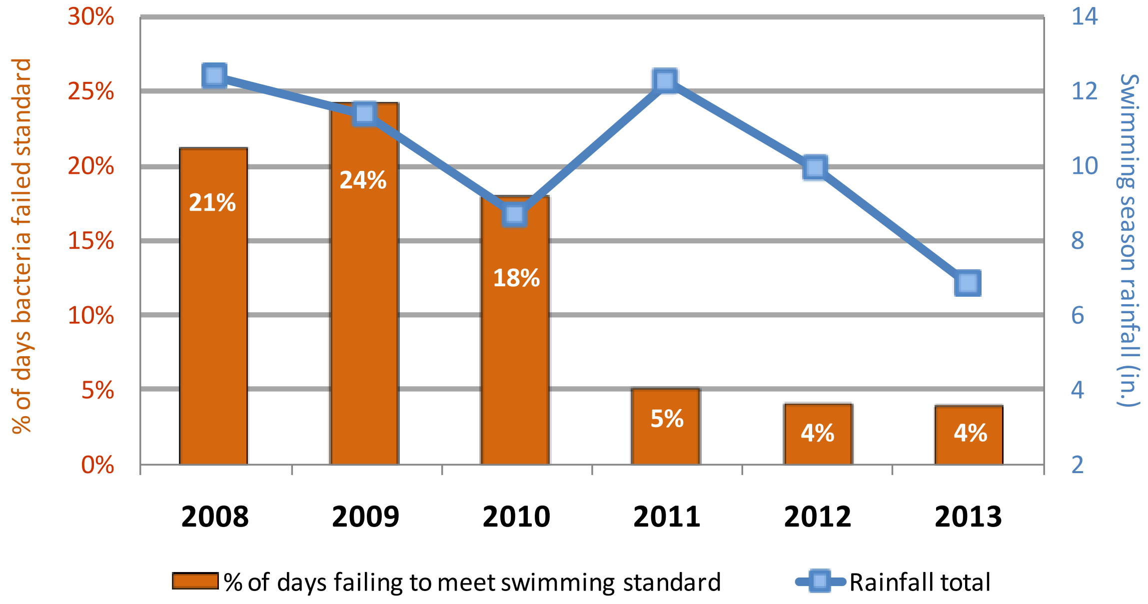

Figure 6-2. Percentage of days that South Boston beaches failed swimming standards before and after the CSO storage tunnel came on line in 2011. The blue line shows summer rainfall during those same years.

Boston Harbor Water Column

In addition to bacterial water quality monitoring (which includes the beach monitoring discussed above), MWRA tracks water quality in Boston Harbor for nutrients, algal biomass (chlorophyll) and dissolved oxygen. Water-column monitoring in Boston Harbor includes 13 stations throughout the harbor (Figure 6-3). The program has documented harbor-wide changes in nutrient concentrations, chlorophyll, and dissolved oxygen throughout each phase of the Boston Harbor Project, including the diversion of sewage effluent offshore in September 2000 (Figure 6-4).

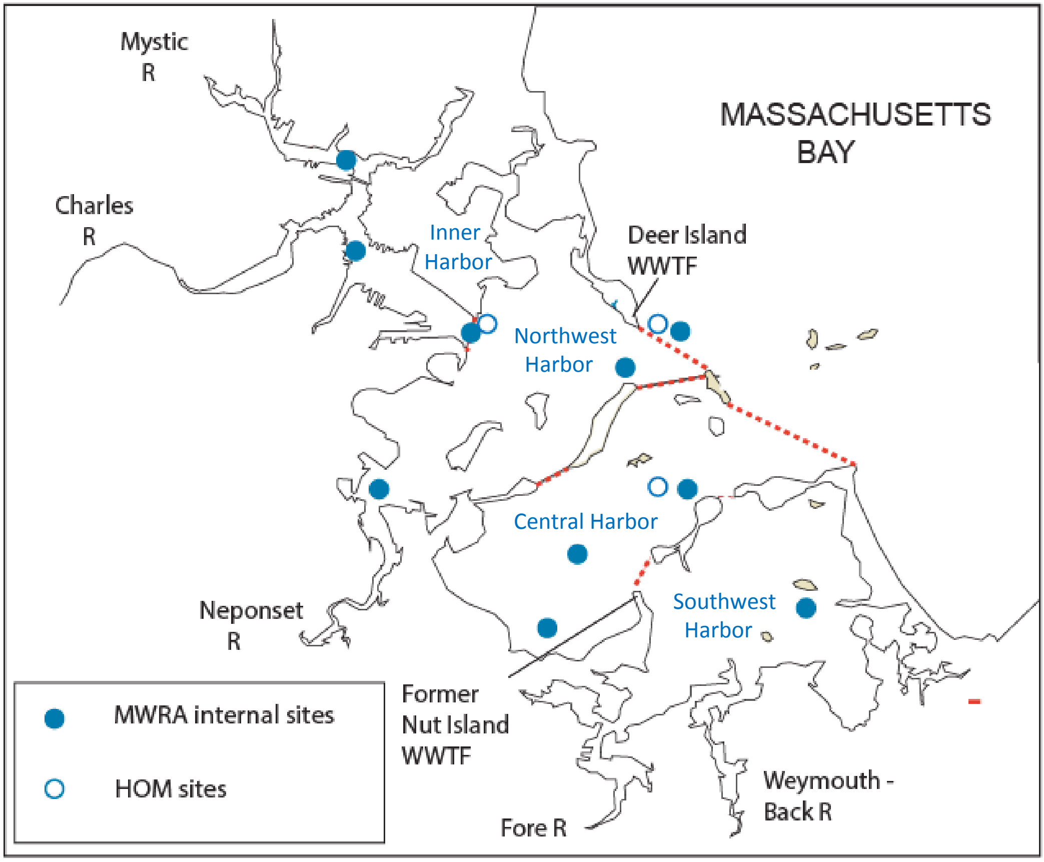

Figure 6-3. Water-column sampling locations in Boston Harbor. Stations include MWRA internal sites, as well as some sites that are also sampled as part of the harbor-and-outfall-monitoring (HOM) program. Dotted red lines depict the regional divisions between the inner, northwest, central, and southeast regions. R = river, WWTF = wastewater treatment facility

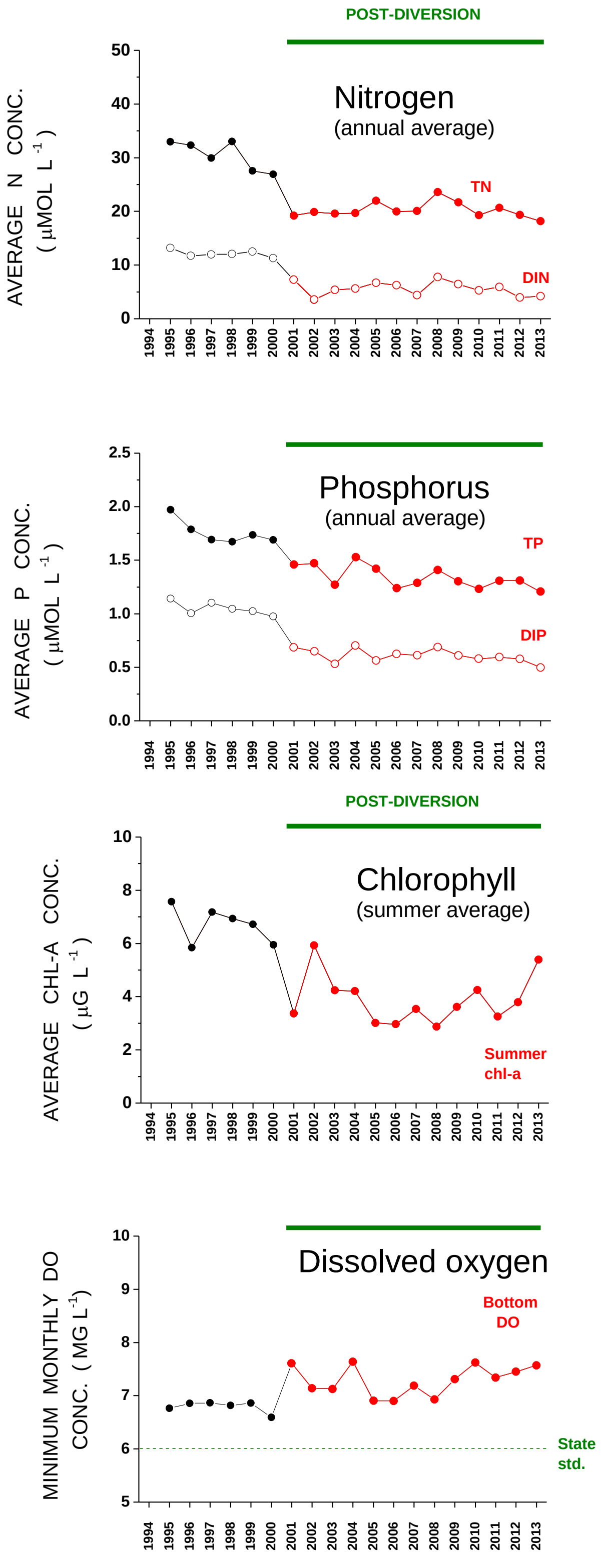

Figure 6-4. Water quality measurements in Boston Harbor, 1995–2013. The green line and change from black to red on the data lines show the diversion of effluent from the harbor to Massachusetts Bay. N=nitrogen, TN=total nitrogen, DIN=dissolved inorganic nitrogen, P=phosphorus, TP=total phosphorus, DIP=dissolved inorganic phosphorus, CHL-A=chlorophyll, DO=dissolved oxygen

In 2013, concentrations of the nutrients total nitrogen and total phosphorus were the lowest recorded by the monitoring program, marking continued recovery of the harbor after years of eutrophic conditions. Summer chlorophyll levels were the second highest recorded since the effluent diversion from the harbor, but remained lower than those of the pre-diversion period. Concentrations of dissolved oxygen in bottom waters were high, also reflecting the sustained recovery from eutrophication.

In addition to monitoring harbor-wide trends in water quality, MWRA evaluates changes in four geographic regions: the inner, northwest, central, and southwest harbor. The large declines in ammonium concentrations, which were observed immediately after the outfall diversion to Massachusetts Bay, continued in all regions of the harbor (Figure 6-5). Ammonium comprises the largest portion of the nitrogen in wastewater (see Section 2, Effluent).

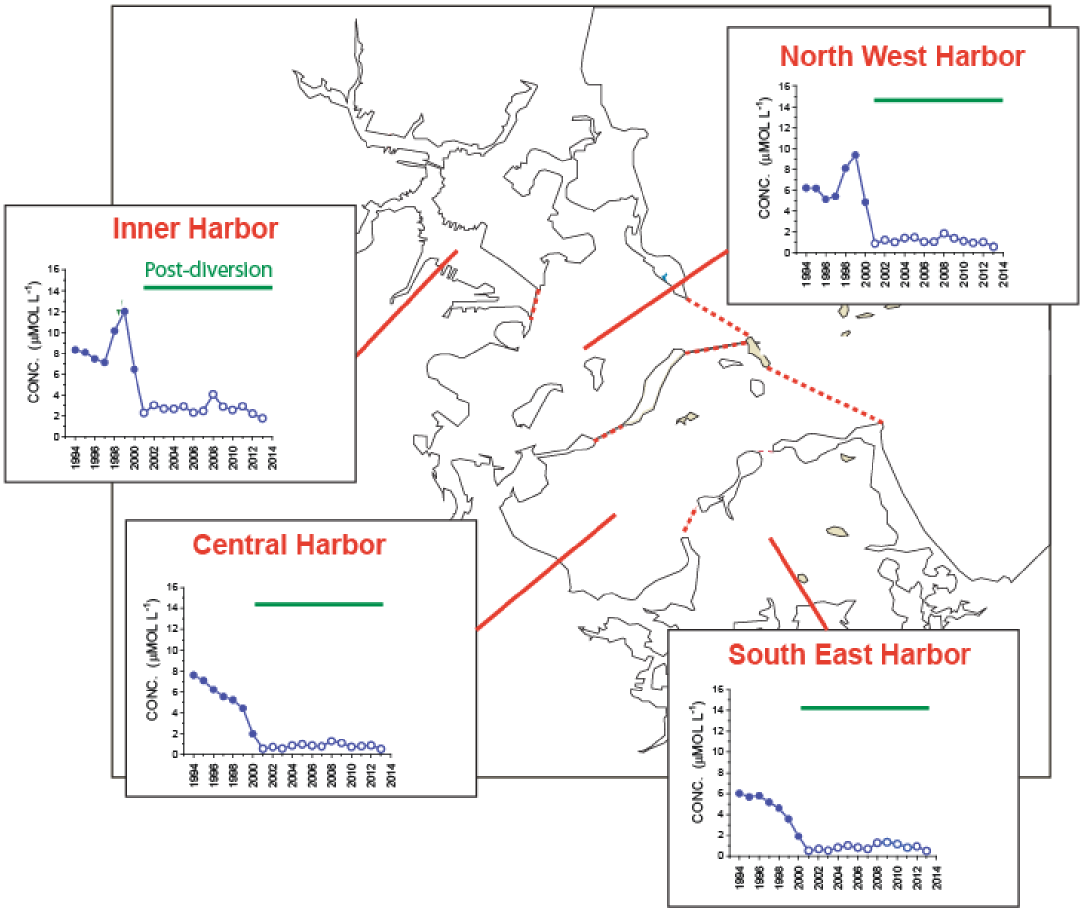

Figure 6-5. Annual average ammonium concentrations in four geographic regions of Boston Harbor.

Boston Harbor Sea Floor

Prior to the Boston Harbor Project, the harbor sediments were polluted with toxic metals, pesticides, oil, and other compounds, and in many places, no oxygen penetrated the surface. The resulting seafloor was called black mayonnaise," and most scientists anticipated that recovery would be slow. MWRA has conducted ongoing sea-floor monitoring in Boston Harbor since 1991. Annual sediment and infauna samples are taken from nine stations (Figure 6-6).

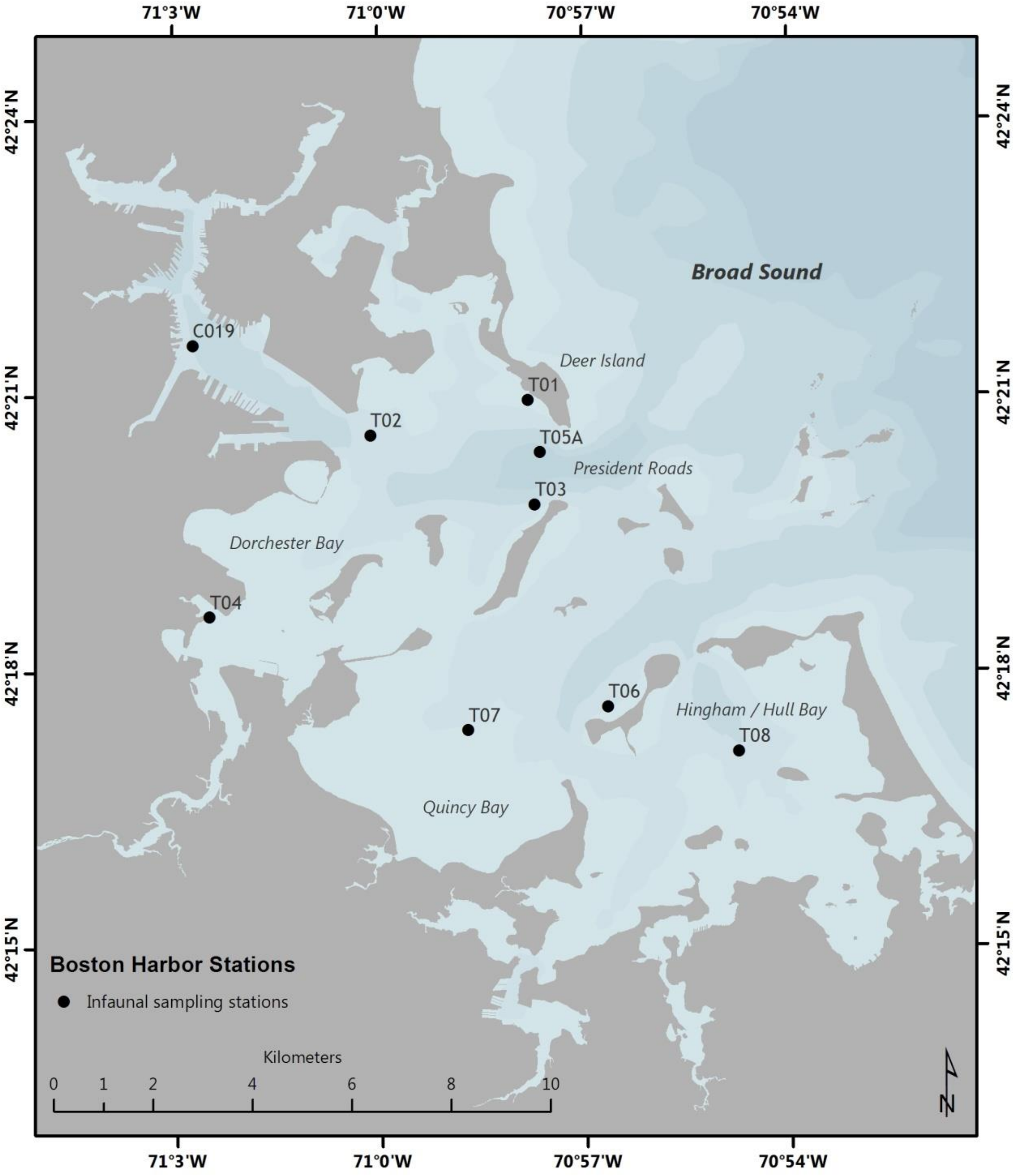

Figure 6-6. Soft-bottom sampling stations in Boston Harbor. Nine stations are sampled each year for sediment characteristics and infauna analyses.

Data from Boston Harbor are frequently presented according to four time periods: Period I, when the harbor received effluent discharges to both the northern and southern harbor, as well as biosolids (sludge) discharges, ending with the cessation of biosolids discharge; Period II, marking the completion of a new primary treatment plant at Deer Island and the beginning of upgrades to secondary treatment; Period III, following the end of effluent discharges to the southern harbor; and Period IV, following the end of all effluent discharge to the harbor. Benthic data analyses offset the time periods by one year to allow for a lag in response.

Annual average concentrations of the sewage tracer *Clostridium perfringens* spores and total organic carbon (Figure 6-7) document the improvements in the harbor in response to each step of the Boston Harbor Project (Pembroke et al. 2014). Particulate organic carbon concentrations have steadily declined throughout the course of facilities upgrades. Abundance of *Clostridium perfringens* spores particularly responded to the upgrade to secondary treatment than occurred in periods II and III, as well as the ending of sewage discharge to the southern harbor.

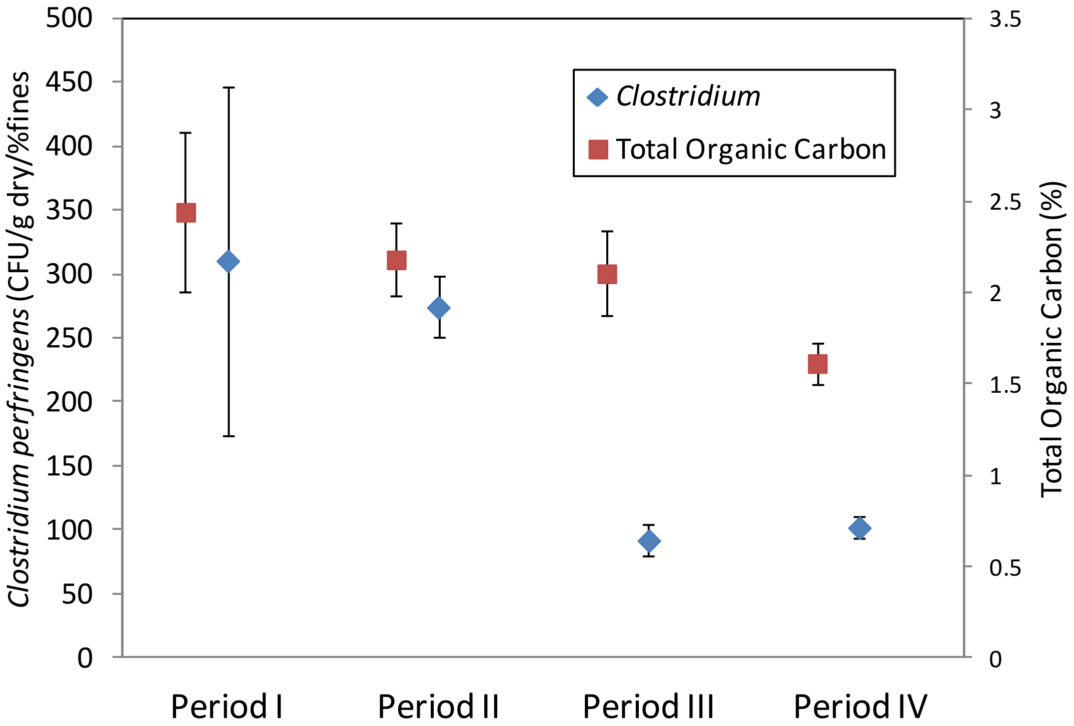

Figure 6-7. *Clostridium perfringens* spores and total organic carbon in Boston Harbor sediments during four time periods marking changes in sewage loadings. (Data are ± one standard error. Data from 1991 were excluded as being variable and anomalously high in comparison with later years.)

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Benthic-community parameters have also changed in response to the changes in sewage loadings to the harbor. Mean total abundance of organisms has not changed greatly, trending downward in periods III and IV, but there have been steady increases in the number of species per sample and diversity indices, such as log-series alpha, throughout the four periods (Figure 6-8). The other diversity indices, Shannon-Wiener diversity and Pielou's evenness, have shown similar increases throughout the course of monitoring.

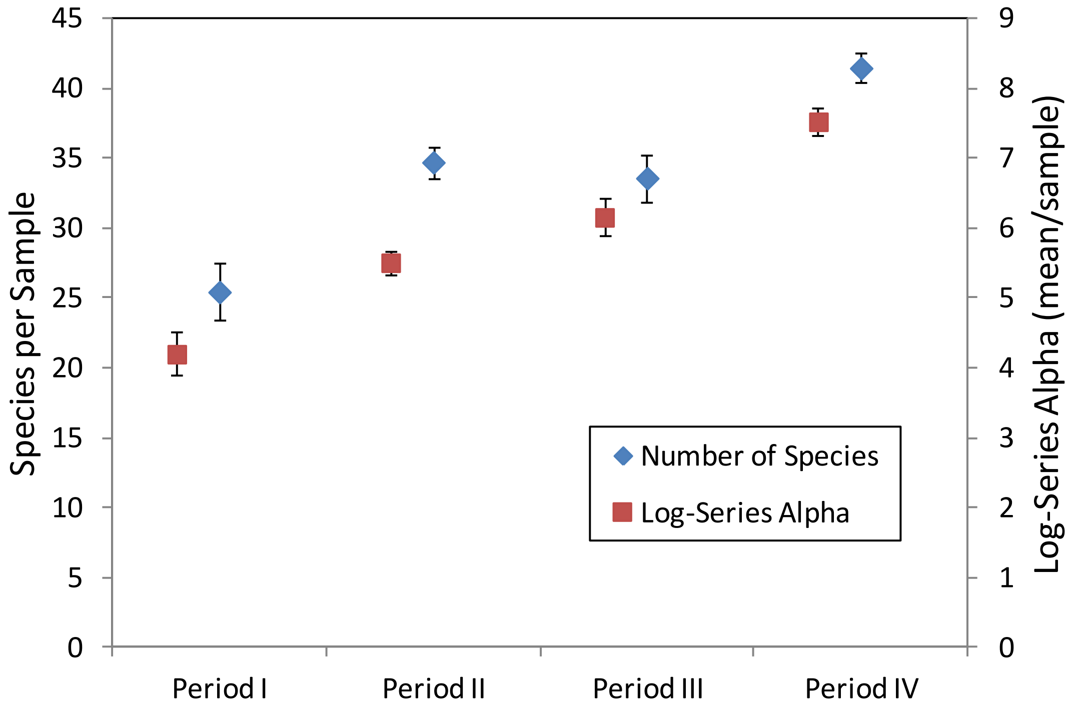

Figure 6-8. Number of species per sample and log-series alpha in Boston Harbor infauna samples during four time periods marking changes in sewage loadings. (Data are ± one standard error.)

The decreases in total abundance of organisms resulted from decreases in the numbers of opportunistic species, such as the polychaete *Capitella capitata*, which is a common indicator of disturbed habitats. Dominance patterns have varied through the years, with some species, such as tube-building amphipods dominant in some years, but not in others. In 2013, two species of oligochaetes and five polychaetes dominated the samples.

The changes in community-diversity parameters and the individual taxa found each year all point to continued improving benthic conditions. The community analyses, along with additional evidence from sediment-profile imagery, suggest that the harbor is now more affected by physical stresses, such as storms, than by the organic enrichment, eutrophication, and contaminant stress associated with sewage discharges.

Boston Harbor Fish and Shellfish

During the 1970s and 1980s, pollutant-related external abnormalities and liver disease were common in winter flounder taken from Boston Harbor. Catches made by MWRA's predecessor, the Metropolitan District Commission, in 1979, found that almost half of the fish had fin erosion. Incidence of fin erosion continues to be variable and greater in fish from Deer Island Flats, near the former Boston Harbor outfall, than it is in fish from near the Massachusetts Bay outfall or from Nantasket Beach, outside the harbor (see Section 5, Flounder Studies).

Studies by the National Marine Fisheries Service in 1984 and 1985 found that flounder from Deer Island Flats had a variety of cancerous tumors and pre-cancerous conditions, with tumors present in 15% of the fish (Murchelano and Wolke 1991). Routine sampling and analysis for liver disease in fish from Deer Island Flats began in 1987 and found that more than half the fish had pre-cancerous liver conditions. That sampling program, adopted by MWRA, has continued, documenting substantial declines in tumors and tumor precursors (Figure 6-9). Liver tumors were present in 12% of the flounder caught in 1988 but have not been seen since 2004. Incidence of the most common tumor precursor, centrotubular hydropic vacuolation (CHV, see Section 5, Flounder Studies), has dropped by more than half.

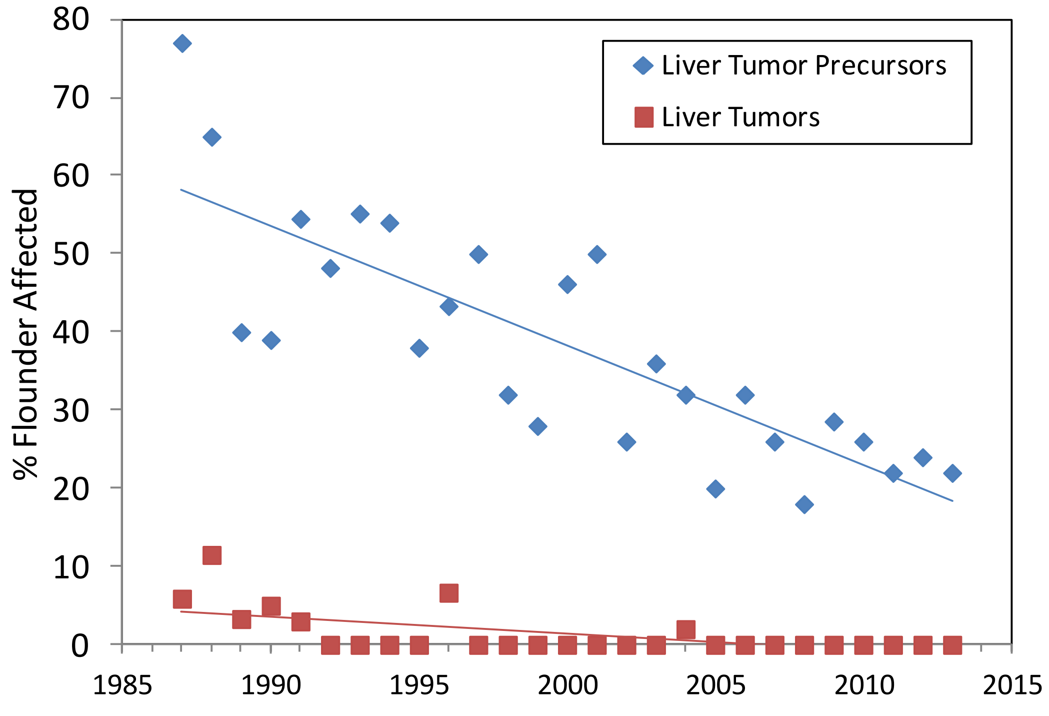

Figure 6-9. Incidence of liver tumor precursors and liver tumors in winter flounder from Deer Island Flats in Boston Harbor, 1987–2013. Incidence of tumor precursors has fallen, and tumors are now rare.

Fish liver disease has been associated with organic contaminants, such as PCBs and chlorinated pesticides, substances that have been banned since the 1970s and 1980s. Slow declines in these persistent compounds, as well as the MWRA efforts to limit their release in sewage effluent, have contributed to the improvements to flounder health within Boston Harbor, without corresponding increases in liver disease in fish taken from Massachusetts Bay.

In conjunction with its Massachusetts Bay outfall-monitoring program, MWRA measures contaminants in flounder and lobster taken from Boston Harbor, and in mussels that are collected from clean, coastal sites and deployed in cages at Deer Island Light near the former harbor outfall. MWRA has documented decreases since the early 1990s in some contaminants in both flounder and lobster tissues (Hall et al. 2013).

Since flounder and lobster can move between Boston Harbor and Massachusetts Bay over the course of the year, mussels provide the best documentation of changes within the harbor. For example, there have been substantial declines in concentrations of high molecular weight polycyclic aromatic hydrocarbons (PAHs) in mussels deployed for 60 days at Deer Island Light (Figure 6-10). At the same time, mussels deployed with the mixing zone of the Massachusetts Bay outfall showed modest increases in PAHs during the early years of the discharge (2001–2003). Since 2006, levels at the outfall have been similar to those at a reference location (Buoy “B”) located a kilometer away from the outfall.

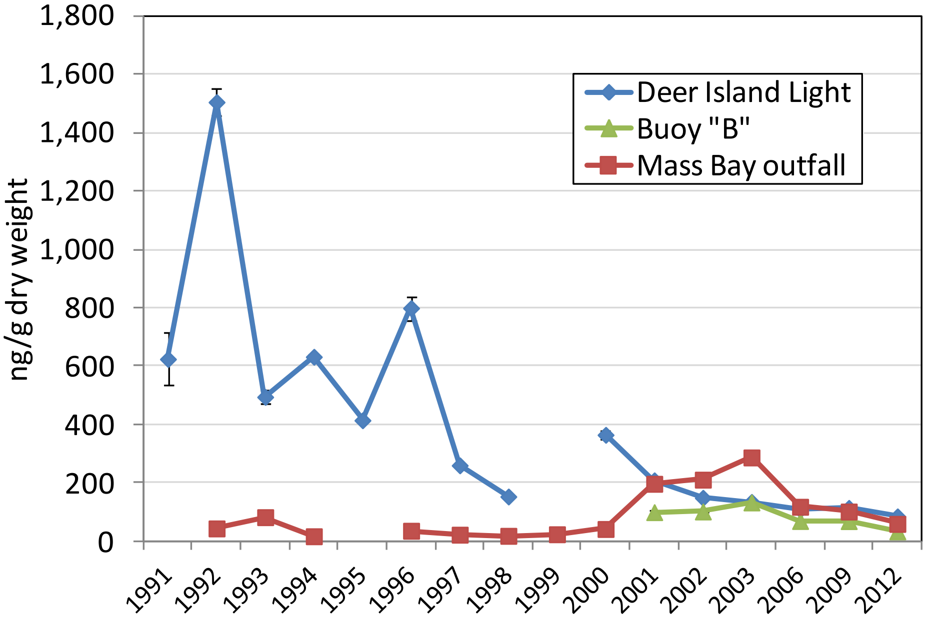

Figure 6-10. High molecular weight PAHs in mussels deployed in Boston Harbor and Massachusetts Bay, 1991–2012. (Mass Bay outfall data are from mussels deployed within the mixing zone; Buoy “B” data are from mussels deployed one kilometer from the Massachusetts Bay outfall. Note change in study frequency from annual to every three years after 2003.)

High molecular weight PAHs are byproducts of hydrocarbon combustion, and many are known carcinogens. They are targets of MWRA's toxics-reduction program. MWRA's secondary sewage treatment removes about 80–90% of PAHs before discharge.

Cape Cod Bay Studies

For many years, the Center for Coastal Studies has conducted a monitoring program in Cape Cod Bay, and since 2011, MWRA has collaborated on a portion of the program. The Center for Coastal Studies monitoring program includes MWRA Station F29, on the southern boundary of Stellwagen Bank National Marine Sanctuary, MWRA stations F01 and F02 in Cape Cod Bay, and eight additional stations (Figure 6-11).

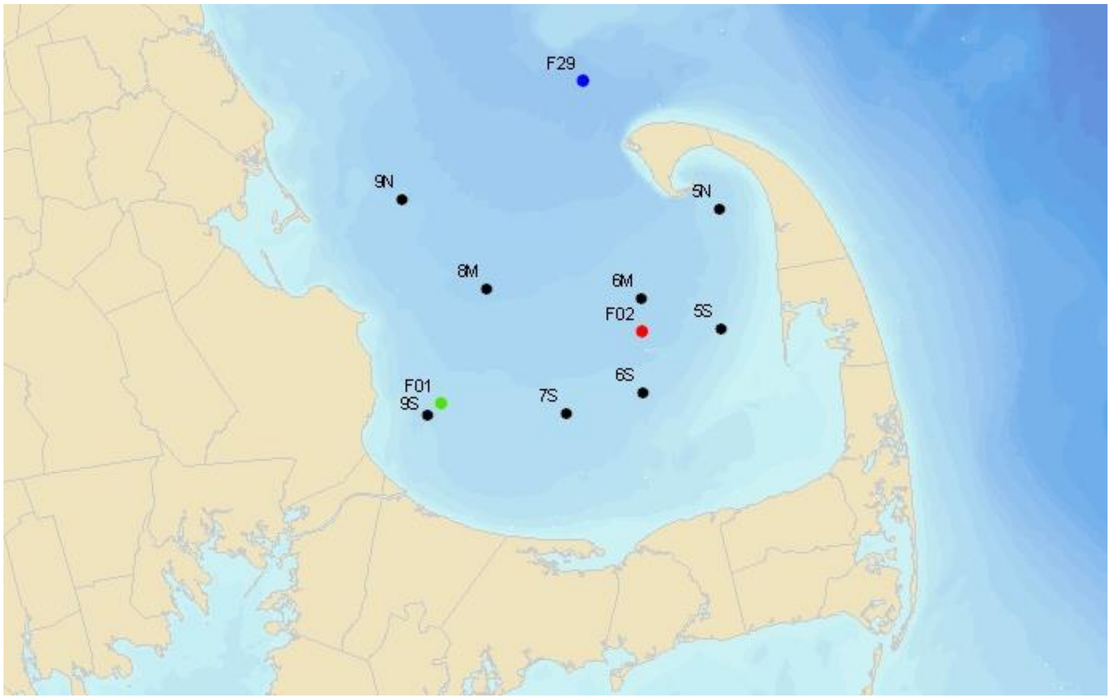

Figure 6-11. The Center for Coastal Studies monitors its own eight stations and three MWRA stations (F01, F02, and F29) in and near Cape Cod Bay. (Figure from the Center for Coastal Studies)

The zooplankton portion of the program focuses on larger species than the MWRA sampling, specifically targeting species that may be prey for right whales. These methods better characterize the abundance of larger species present in lower abundances than many in MWRA's sampling, such as the oil-rich copepod *Calanus finmarchicus*, as well as *Pseudocalanus* spp. These species are favored whale prey. In 2013, abundances of those species were higher than recorded in 2012, and right whale sightings were high (Figure 6-12).

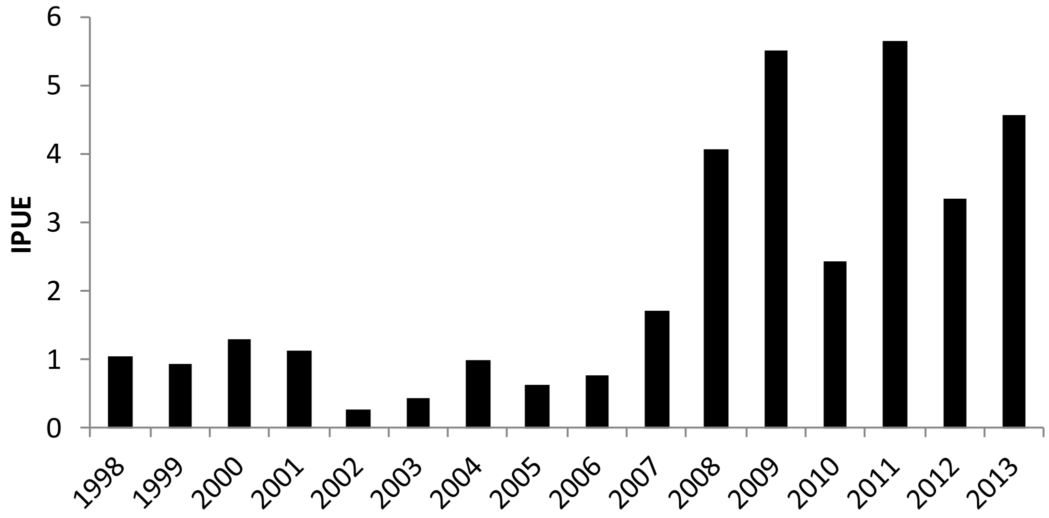

Figure 6-12. Right whale sightings in Cape Cod Bay, 1998–2013. (Figure from the Center for Coastal Studies.)

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List of Acronyms

BOD	Biochemical oxygen demand
cBOD	Carbonaceous biochemical oxygen demand
CHL-A	Chlorophyll
CHV	Centrotubular hydropic vacuolation
CSO	Combined sewer overflow
DDT	Dichlorodiphenyltrichloroethane
DIF	Deer Island Flats
DIN	Dissolved inorganic nitrogen
DITP	Deer Island Treatment Plant
DO	Dissolved oxygen
EPA	U.S. Environmental Protection Agency
FF	Farfield
HOM	Harbor and outfall monitoring program
IAAC	Inter-Agency Advisory Committee
LC50	50% mortality concentration
MADEP	Massachusetts Department of Environmental Protection
MODIS	Moderate Resolution Imaging Spectroradiometer
MWRA	Massachusetts Water Resources Authority
N	Nitrogen
NA	Not analyzed/not applicable
NACWA	National Association of Clean Water Agencies
NB	Nantasket Beach
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
NDBC	National Data Buoy Center
NF	Nearfield
NOEC	No observed effects concentration
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OS	Outfall site
P	Phosphorus
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
PSP	Paralytic shellfish poisoning
R	River
RPD	Redox potential discontinuity
TN	Total nitrogen
TP	Total phosphorus
WWTF	Wastewater treatment facility

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