2014 Outfall monitoring overview

Massachusetts Water Resources Authority
Environmental Quality Department
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2014
Outfall Monitoring Overview

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Save the Harbor/Save the Bay
MWRA Wastewater Advisory Committee
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Massachusetts Audubon Society
MWRA Advisory Board
Association to Preserve Cape Cod
Safer Waters in Massachusetts
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Summary

Each year, the Massachusetts Water Resources Authority (MWRA) prepares an overview of environmental monitoring related to the discharge of municipal wastewater effluent from Deer Island Treatment Plant through an offshore outfall tunnel into Massachusetts Bay. The report presents monitoring results and information relevant to MWRA's permit-required Contingency Plan, including threshold exceedances and permit violations, responses, and, if needed, 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.

This 2014 report marks more than fourteen years of "outfall-discharge" monitoring, covering the years since September 2000, when MWRA ceased discharge of wastewater effluent to the relatively confined waters of Boston Harbor and began to discharge into deeper water in Massachusetts Bay. Before September 2000, MWRA had completed almost nine years of baseline monitoring. This report includes results of effluent analyses; water-column, sea-floor, and fish-and-shellfish monitoring in the outfall nearfield and at reference stations; and results pertinent to Stellwagen Bank and to Boston Harbor. This year's report on special studies focuses on bacterial water quality in Boston Harbor, modeling results, and ongoing Cape Cod Bay studies.

Operations at the Deer Island Treatment Plant continued to be exceptional in 2014, earning MWRA a National Association of Clean Water Agencies (NACWA) Platinum 8 Peak Performance Award. This NACWA award recognizes facilities with 100% permit compliance for eight consecutive years. Nearfield and reference-station monitoring results from 2014 were consistent both with predictions made during the outfall-siting process and with past results, showing no unanticipated effects of the discharge (Tables i through iv). No Contingency Plan "warning-level" exceedances were observed, but "caution-level" exceedances* occurred for one water-column and two soft-bottom sea-floor parameters: summer levels of the nuisance algal species *Phaeocystis pouchetii* and two benthic-community parameters, Shannon-Wiener diversity and Pielou's evenness. The exceedances have been analyzed and are not thought to be related to the outfall. The summer *Phaeocystis* exceedance resulted from a cool spring, which delayed the annual phytoplankton cycles. The benthic community exceedances resulted from normal variability in relative abundances of animal populations.

* MWRA's discharge 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 exceedances were related to the discharge, MWRA might 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 2014 results for effluent monitoring.

Parameter	Baseline	Caution Level	Warning Level	2014 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	Compliance <95% 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
Plant performance = compliance with permit conditions

Table ii. Contingency Plan threshold values and 2014 results for water-column monitoring.

Parameter	Baseline	Caution Level	Warning Level	2014 Results
Dissolved oxygen*				
Nearfield concentration	6.05 mg/L	6.5 mg/L	6.0 mg/L	7.19 mg/L
Nearfield percent saturation	65.3%	80%	75%	81.6%
Stellwagen concentration	6.23 mg/L	6.5 mg/L	6.0 mg/L	6.76 mg/L
Stellwagen percent saturation	67.2%	80	75%	75.0%
Nearfield depletion rate	0.024 mg/L/d	0.037 mg/L/d	0.049 mg/L/d	0.015 mg/L/d
Chlorophyll				
Annual	72 mg/m^2	108 mg/m^2	144 mg/m^2	66 mg/m^2
Winter/spring	50 mg/m^2	199 mg/m^2	None	75 mg/m^2
Summer	51 mg/m^2	89 mg/m^2	None	68 mg/m^2
Autumn	90 mg/m^2	239 mg/m^2	None	50 mg/m^2
Nuisance algae *Phaeocystis pouchetii*				
Winter/spring	622,000 cells/L	2,860,000 cells/L	None	27,800 cells/L
Summer	72 cells/L	357 cells/L	None	395,000 cells/L, caution level exceedance
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	106 cells/L
Summer	14,635 cells/L	43,100 cells/L	None	Absent
Autumn	10,050 cells/L	27,500 cells/L	None	270 cells/L
Nuisance algae nearfield *Alexandrium fundyense*				
Any nearfield sample	Baseline maximum 163 cells/L	100 cells/L	None	20 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 2014 results for sea-floor monitoring.

Parameter	Baseline	Caution Level	Warning Level	2014 Results
Polycylclic aromatic hydrocarbons (PAHs) (ng/g dry weight)				
Acenaphthene	22.7 – 43.5	None	500	28.3
Acenaphylene	30.3 – 43.1	None	640	11.1
Anthracene	101 – 159	None	1,100	77.3
Benzo(a)anthracene	206 – 302	None	1,600	176
Benzo(a)pyrene	204 – 298	None	1,600	182
Chrysene	164 – 296	None	2,800	172
Dibenzo(a,h)anthracene	27.8 – 38.3	None	260	26.7
Fluoranthene	422 – 621	None	5,100	389
Fluorene	35.5 – 66.6	None	540	32.5
Naphthalene	53.6 – 103	None	2,100	31.6
Phenanthrene	273 – 431	None	1,500	247
Pyrene	412 – 579	None	2,600	362
Total HMW PAH	2,790 – 3,850	None	9,600	2,440
Total LMW PAH	1,390 – 1,630	None	3,160	814
Total PAHs	4,180 – 5,400	None	44,792	3,260
Other organic contaminants (ng/g dry weight)				
p,p’-DDE	0.386 – 1.00	None	27	0.37
Total DDTs	2.51 – 5.69	None	46.1	0.79
Total PCBs	10.2 – 20.2	None	180	7.17
Metals (µg/g dry weight)				
Cadmium	0.0727 – 0.185	None	9.6	0.11
Chromium	59.2 – 79.9	None	370	47.6
Copper	19.1 – 25.2	None	270	22.9
Lead	41.1 – 46.3	None	218	32.7
Mercury	0.159 – 0.353	None	0.71	0.12
Nickel	15.7 – 17.2	None	51.6	8.46
Silver	0.335 – 0.485	None	3.7	0.17
Zinc	49.5 – 57.5	None	410	41.5
Sediment parameters				
RPD depth	NA	<1.18 cm	None	4.01 cm
Benthic community parameters				
Species per sample	NA	<42.99 or >81.85	None	62.73
Fisher’s log-series alpha	NA	<9.42 or >15.8	None	13.35
Shannon diversity	NA	<3.37 or >3.99	None	4.03, caution level exceedance
Pielou’s evenness	NA	<0.57 or >0.67	None	0.68, caution level exceedance
% opportunists	NA	>10%	>25%	0.12%

HMW = high molecular weight; LMW = low molecular weight
NA = not applicable; RPD = redox potential discontinuity

Table iv. Contingency Plan threshold values and 2014 result for fish-and-shellfish monitoring.

Parameter	Baseline	Caution Level	Warning Level	2014 Results
Liver disease CHV	24.4%	44.9%	None	10%

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 municipal 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 wastewater-effluent discharge. Throughout MWRA's early years, scientists conducted environmental monitoring in Boston Harbor and also in Massachusetts Bay, at what would become the site of a relocated wastewater-effluent discharge.

By the end of 2000, most of the Boston Harbor Project had been completed, including the relocated outfall, which diverted wastewater 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 wastewater 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 have also included information relevant to the Stellwagen Bank National Marine Sanctuary.

This outfall monitoring overview presents results from 2014, marking the twenty-third year of MWRA's monitoring program, including more than fourteen 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, and additional information from MWRA's in-house Boston Harbor monitoring is included in the water-column, sea-floor, and flounder monitoring sections.

2. Effluent

2014 Characterization

As in past years, DITP continued to operate as designed through 2014, earning MWRA the National Association of Clean Water Agencies (NACWA) Platinum 8 Peak Performance Award. This NACWA award recognizes facilities with 100% permit compliance over eight consecutive years.

The Boston area received about 40.5 inches of rain in 2014, wetter than 2012 or 2013 and slightly rainier than the long-term average (Figure 2-1). Total effluent flow in 2014 was slightly higher than flow in 2012 or 2013, but lower than in all other years since the Massachusetts Bay outfall came on line in 2000 (Figure 2-2). Virtually all the flow received full primary and secondary treatment, with only small discharges of primary-only effluent blended with fully treated effluent prior to discharge, mostly during March and December storms (Figure 2-3).

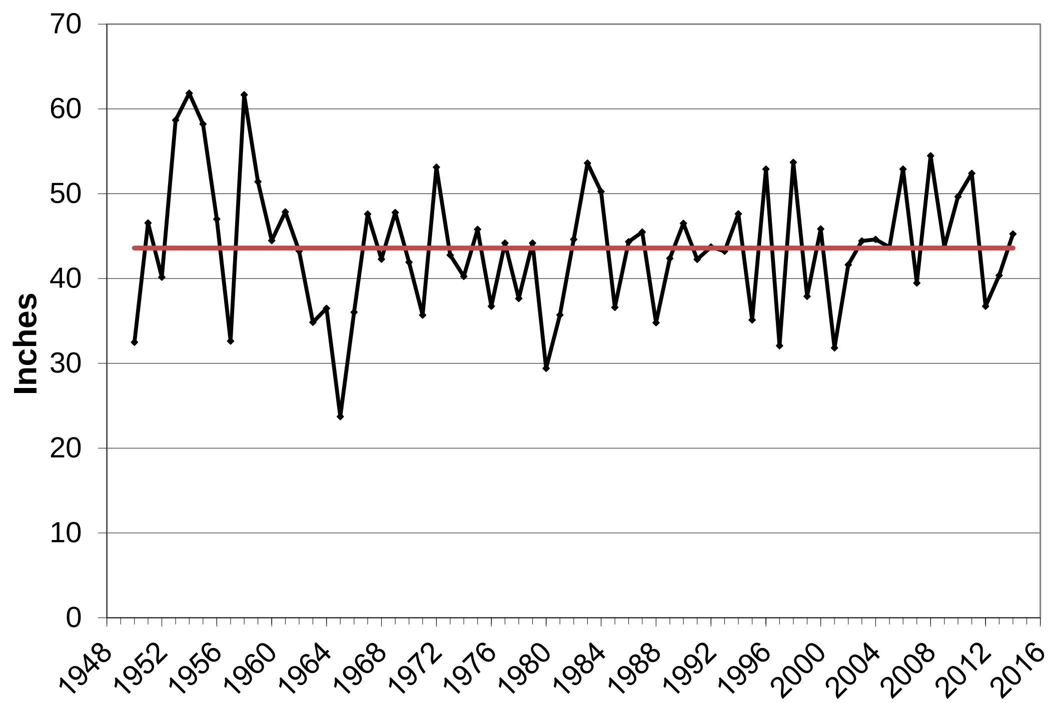

Figure 2-1. Annual rainfall in Boston, 1950–2014.

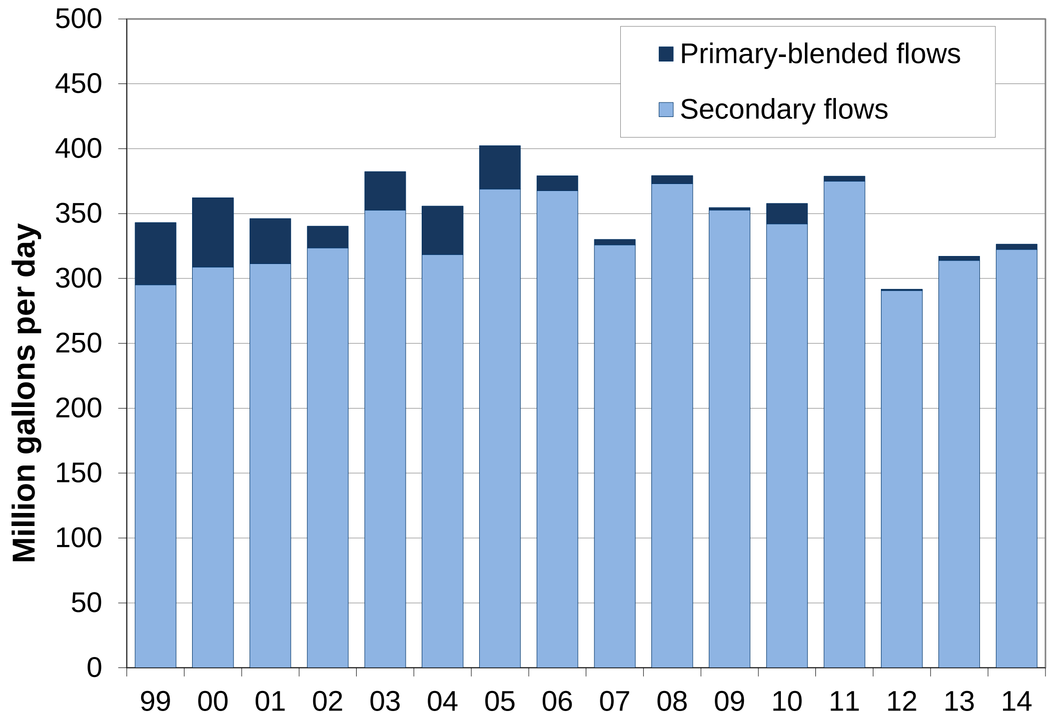

Figure 2-2. Annual primary-blended and full secondary effluent flows, 1999–2014. (During large storms, flow exceeding the secondary capacity of the plant is diverted around the secondary process to prevent washing out the essential microbes that carry out secondary treatment. These primary-treated flows are then combined ("blended") with full secondary flows before disinfection and discharge. All discharges in 2014 met permit limits.)

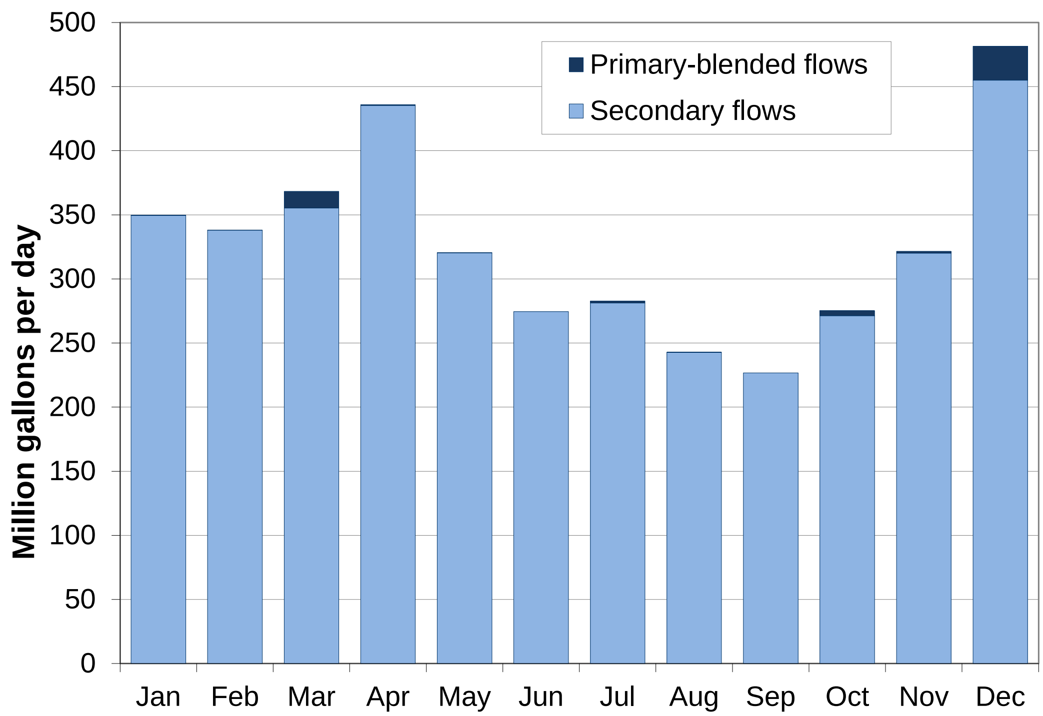

Figure 2-3. Monthly primary-blended and full secondary effluent flows during 2014. Small discharges of primary-blended flow in any month correspond to rainfall, most notably during March and December storms.

The total suspended solids load to Massachusetts Bay remained well below the loads discharged to Boston Harbor before the outfall came on line in 2000 and similar to loads measured since 2006 (Figure 2-4). Carbonaceous biological demand, a measure of the amount of oxygen consumed by microorganisms, also remained low, well below levels that would be expected to affect dissolved oxygen at the discharge (Figure 2-5).

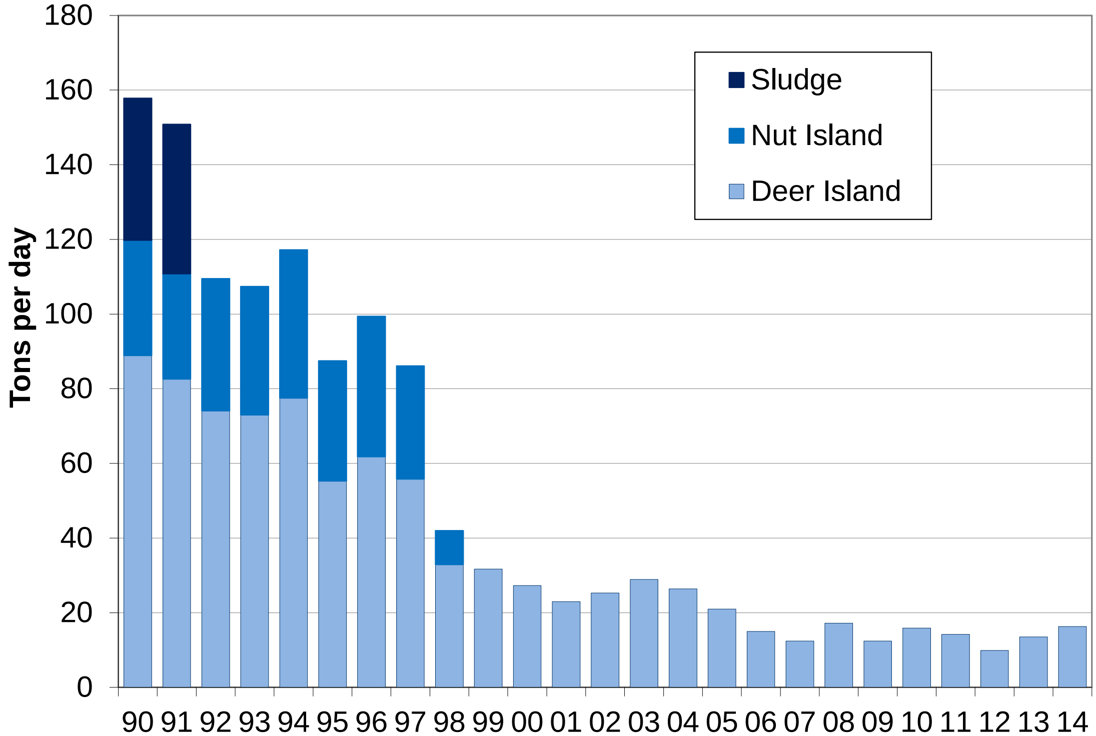

Figure 2-4. Annual solids discharges, 1990–2014. Solids discharges remained low in 2014, less than 20 tons per day. (Ending biosolids (sludge) disposal and effluent discharge to the southern portion of the harbor from Nut Island, and the addition of secondary treatment were important steps in the Boston Harbor Project. All effluent discharge was diverted from Boston Harbor to Massachusetts Bay in September 2000.)

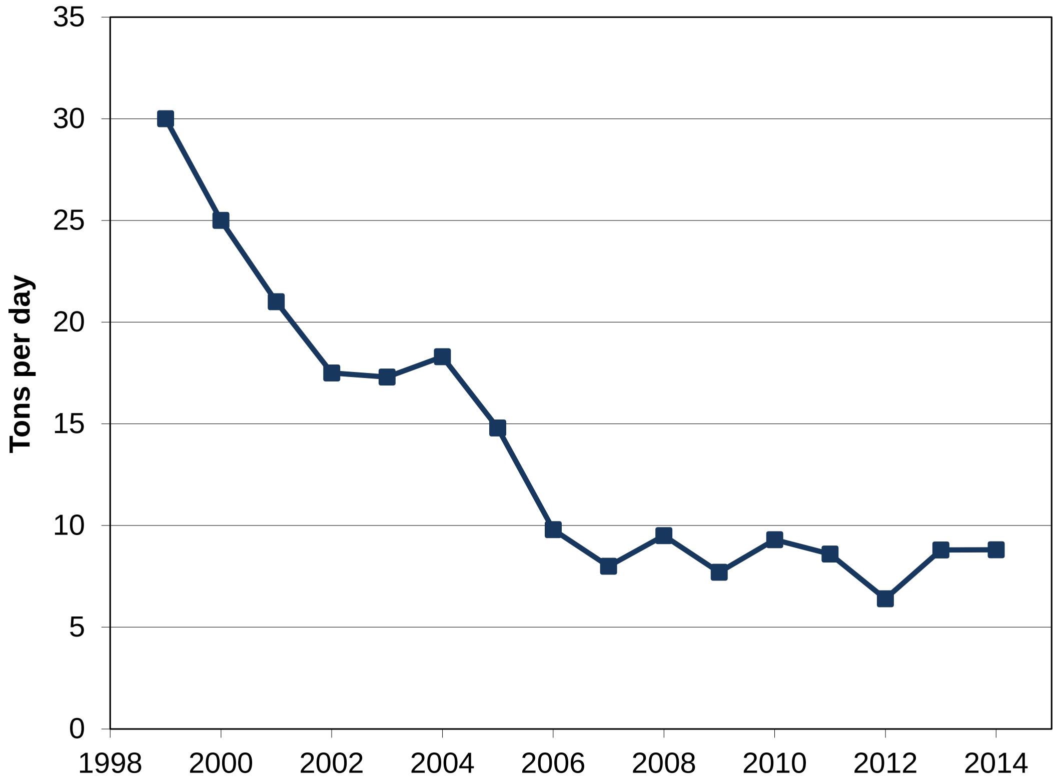

Figure 2-5. Annual carbonaceous biochemical oxygen demand, 1999–2014.

The total nitrogen load also remained below its threshold in 2014 (Figure 2-6). In 1996, during construction, DITP discharged more than 12,700 metric tons of nitrogen, while discharges in 2014 were about 12,200 metric tons. The portion of the load made up of ammonium also increased, as it has since earlier years of the Boston Harbor Project. About 10% of the ammonium in the wastewater 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 to end biosolids discharge to the harbor, are reintroduced to DITP for treatment, adding to the ammonium load. The high total nitrogen and ammonium loads in 2014 may correspond to low flow in the system throughout the summer months. 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. 2015). Because nitrogen loads have remained below the Contingency Plan caution threshold, and there have not been adverse environmental effects due to nitrogen, nitrogen removal has not been required or implemented.

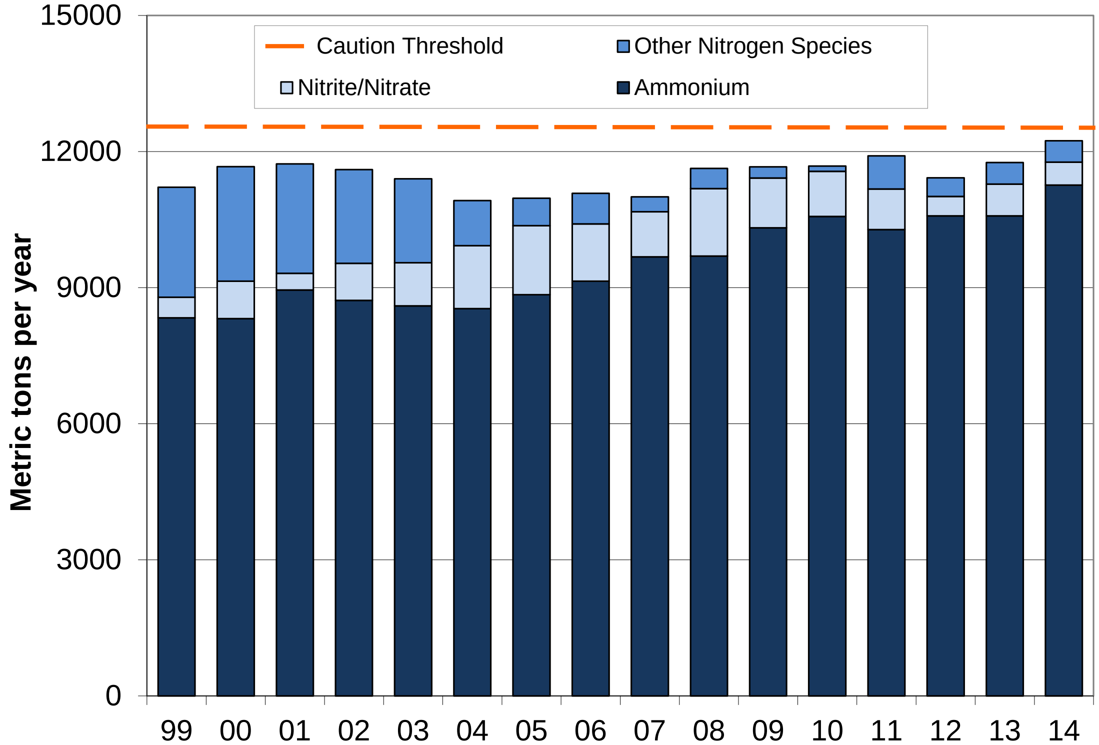

Figure 2-6. Annual nitrogen discharges, 1999–2014. Most of the nitrogen in the effluent is in the form of ammonium.

Metals loads remained low in 2014, 112 pounds per day, but were higher than past years since 2006 (Figure 2-7). Zinc and copper continued to comprise most of the annual discharge. The increase in 2014 could be traced to a storm on December 9–11, which corresponded by chance with effluent-sampling times. Without those wet-weather data points, the calculated loads would have totaled 90 pounds per day, with particularly large differences in the mercury and lead loads. Even with the higher values, metals discharges are now only a small fraction of what they were before the Boston Harbor Project began, 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 in appreciable amounts, a result of removal efficiencies and the change from film to digital photography.

Annual mercury discharges in 2014 were also higher than those in 2012 or 2013, but far below the discharges of the late 1990s (Figure 2-8). Mercury discharges are only a small fraction of what had been anticipated during the outfall-planning process, and most mercury inputs to New England waters come from atmospheric deposition.

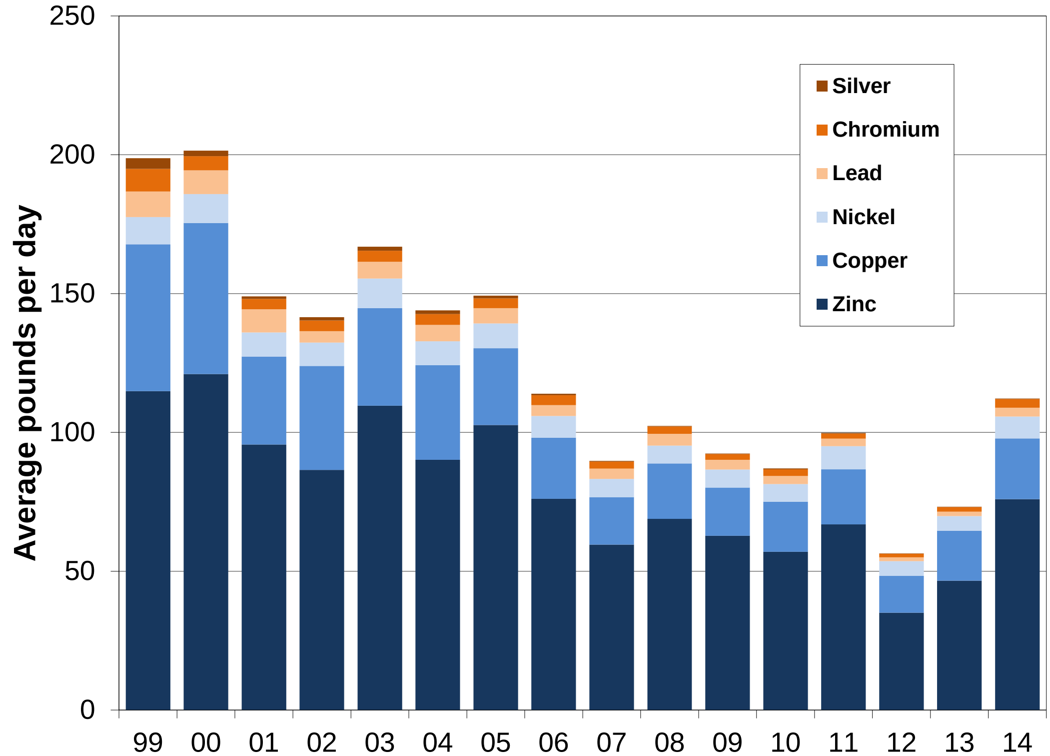

Figure 2-7. Annual metals discharges, 1999–2014. Total metals discharges were higher than in recent years, but remained low.

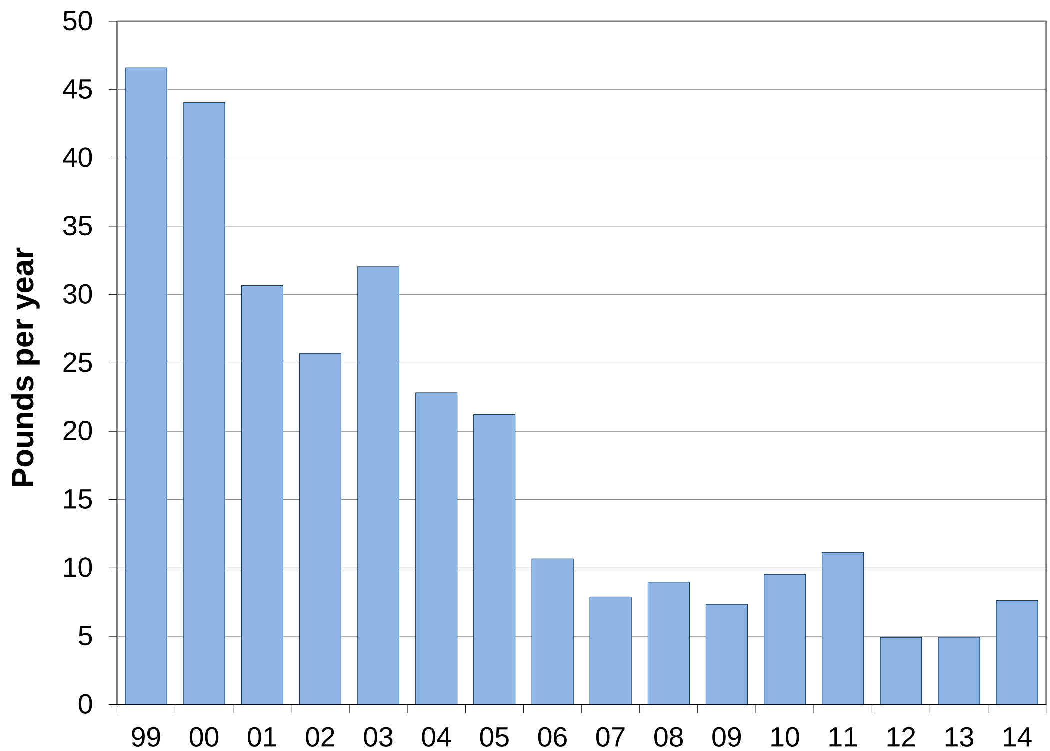

Figure 2-8. Annual mercury discharges, 1999–2014.

Polycyclic aromatic hydrocarbon (PAH) and other organic contaminant loads also increased in 2014 in comparison to 2013 (Figure 2-9), but remained well below levels that had been projected during the outfall-planning process. In 1988, MWRA projected annual discharges of about 3,100 pounds of total PAHs per year with full secondary treatment, while 2014 discharges were less than 15% of that total, approximately 420 pounds.

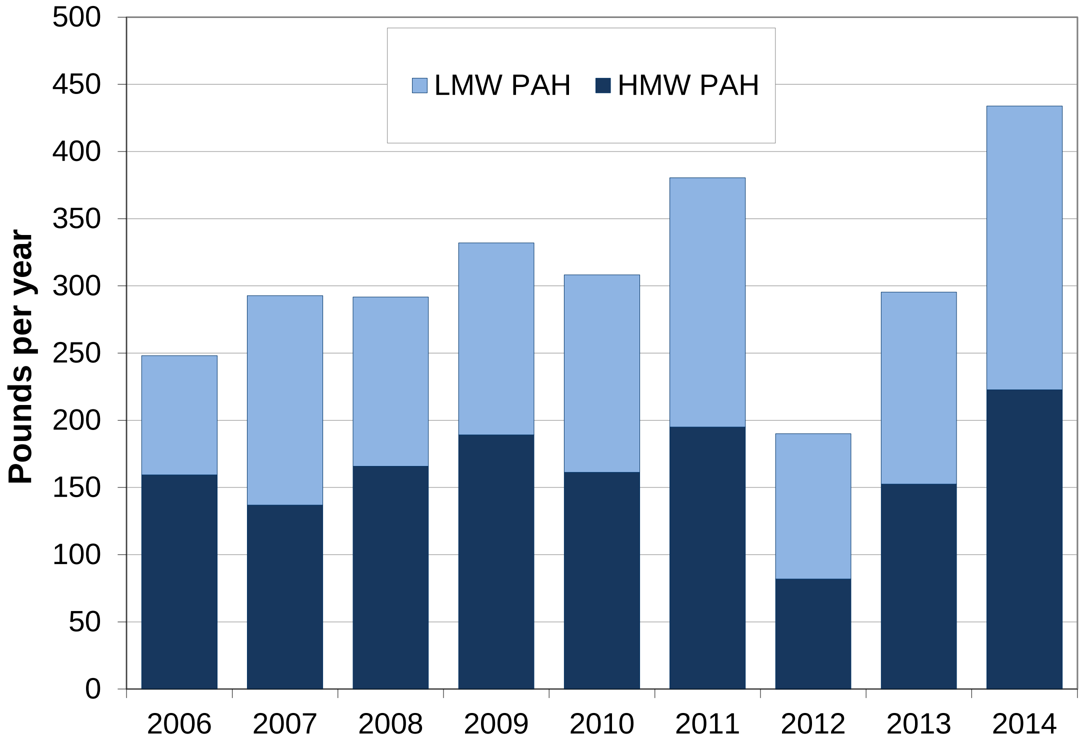

Figure 2-9. Annual PAH discharges, 2006–2014. LMW PAH = low molecular weight PAHs, generally derived from petroleum; HMW PAH = high molecular weight PAHs, generally derived from combustion processes

Contingency Plan Thresholds

DITP had no permit violations, and there were no exceedances of the Contingency Plan effluent thresholds in 2014 (Table 2-1).

Table 2-1. Contingency Plan threshold values and 2014 results for effluent monitoring.

Parameter	Caution Level	Warning Level	2014 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%	Not exceeded
Chronic toxicity	None	NOEC <1.5% effluent	Not exceeded
PCBs	Aroclor=0.045 ng/L	None	Not exceeded
Plant performance	5 violations/year	Compliance <95% of the time	Not exceeded
Flow	None	>436 MGD average 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

NA = not applicable
cBOD = carbonaceous biological oxygen demand
LC50 = 50% mortality concentration
NOEC = no observable effect concentration
PCB = polychlorinated biphenyl
Plant performance = compliance with permit conditions

3. Water Column

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

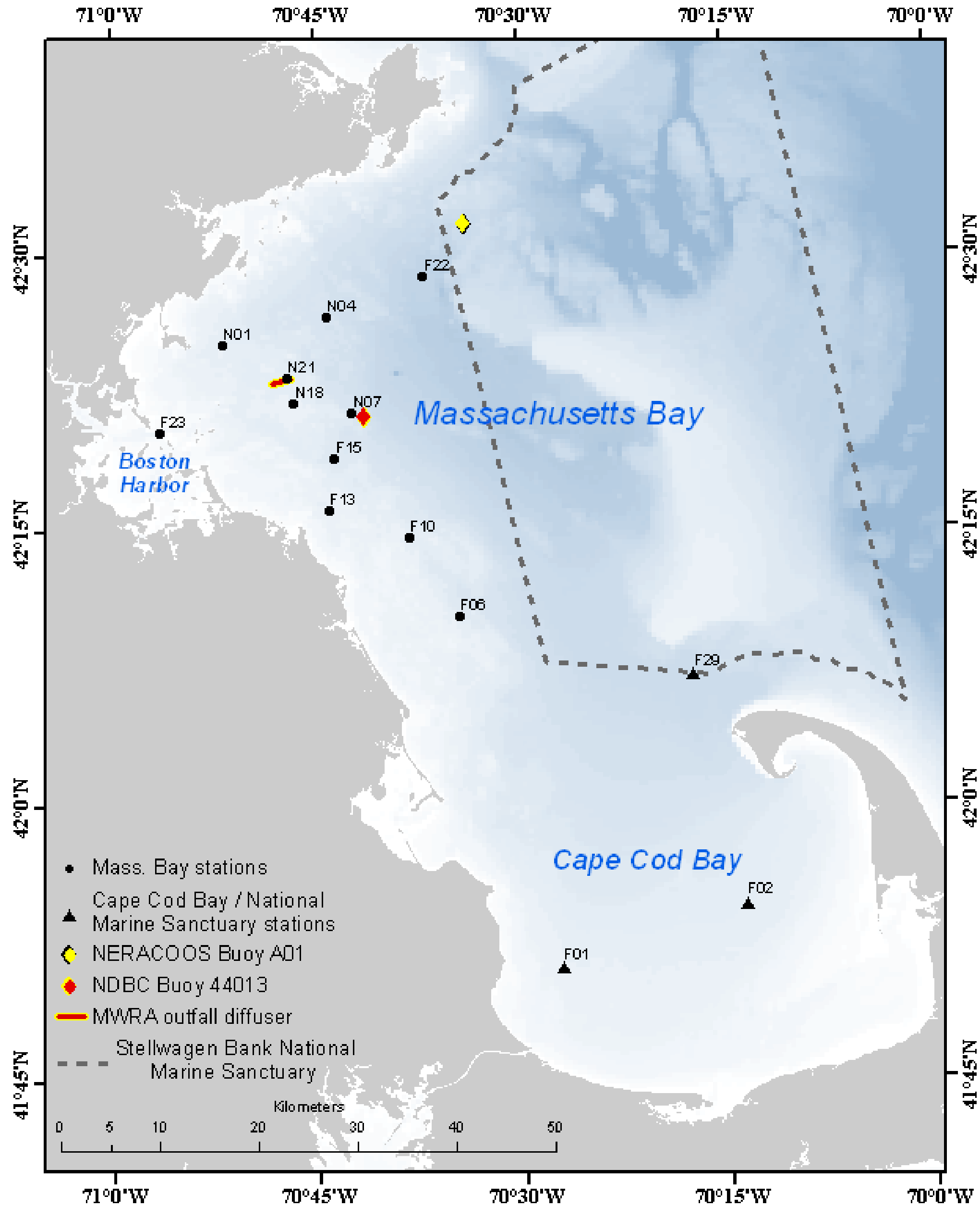

Figure 3-1. Water-column monitoring stations. Also shown are two instrumented buoys, one operated by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the other by the National Data Buoy Center (NDBC); the MWRA outfall diffuser; and the Stellwagen Bank National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

Sampling during nine surveys at fourteen stations in 2014 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. In some years, special surveys are conducted in response to *Alexandrium fundyense* red tide blooms, but no additional surveys were necessary in 2014. However, additional stations were added to the June survey, as a precaution in the event that *Alexandrium* had been transported into the bay. While no bloom was detected in the bay, the additional data collected at those stations were included in analyses.

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 this annual outfall monitoring overview. In 2014, all Cape Cod Bay sampling was completed within the required time frame.

The field monitoring program was augmented by measurements on two instrumented buoys, the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) Mooring 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 for chlorophyll and for sea-surface temperature.

Physical Conditions

Monitoring has shown that the water quality 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 2014 was wetter than 2012 and 2013 (See Figure 2-1 in Section 2, Effluent, for annual rainfall in Boston). River discharges from both the Merrimack and Charles rivers were lower than average in January through March, with no strong spring peaks in runoff (Figure 3-2; Libby et al. 2015). Discharges from the Merrimack River were somewhat higher than average for the remainder of the year. Discharges from the Charles River remained low until the last months of the year, when flows were high following an early December storm.

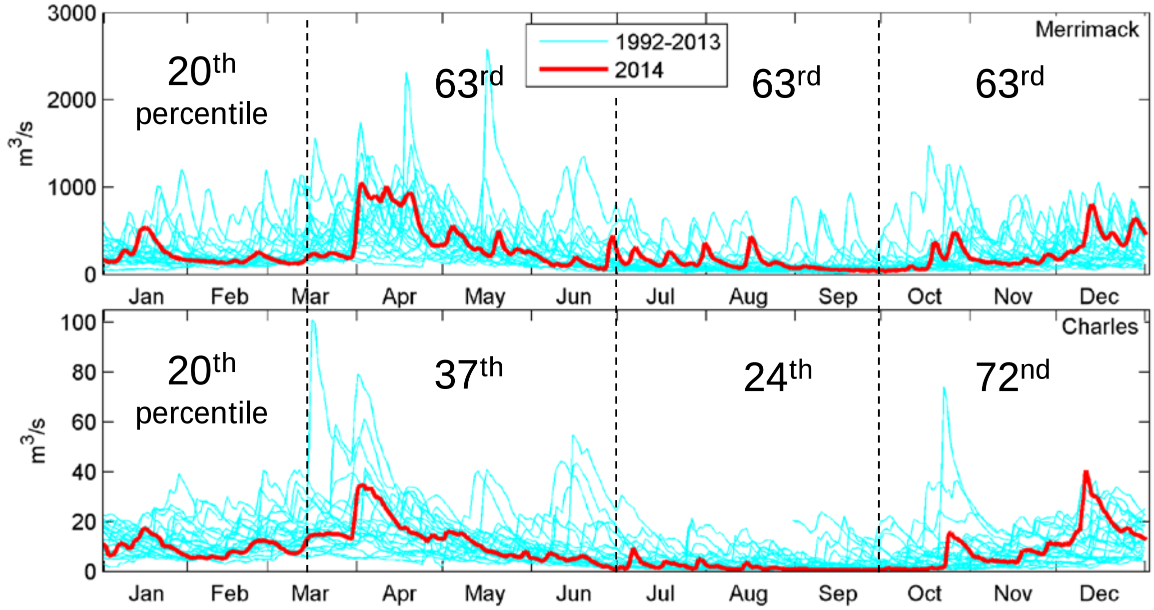

Figure 3-2. Flows of the Merrimack (top) and Charles (bottom) rivers. Flows from both rivers were about average over the year, with no strong spring peaks. Flow from the Charles River was relatively high in the last quarter of the year, translating to the 72nd percentile for all years of the monitoring program.

January surface-water temperatures were close to the long-term average (Figure 3-3). By mid-March, water temperatures had cooled and were close to the minima observed during the monitoring program at the NDBC Buoy 44013 and nearby Station N18. Although there was brief warming at the NDBC Buoy in early April, water temperatures remained cold throughout the region into May, when rapid warming brought them closer to typical levels, where they remained through the summer. Temperatures were warmer than average in the fall.

Wind conditions promoted strong downwelling in February and March (Figure 3-4). Upwelling conditions persisted through the summer and were particularly strong in July. Stratification, the difference in density between surface and bottom waters, developed later than in many years (not shown). Destratification, the re-mixing of the water column that occurs as waters cool in the autumn, was early, with the return to downwelling conditions in the fall.

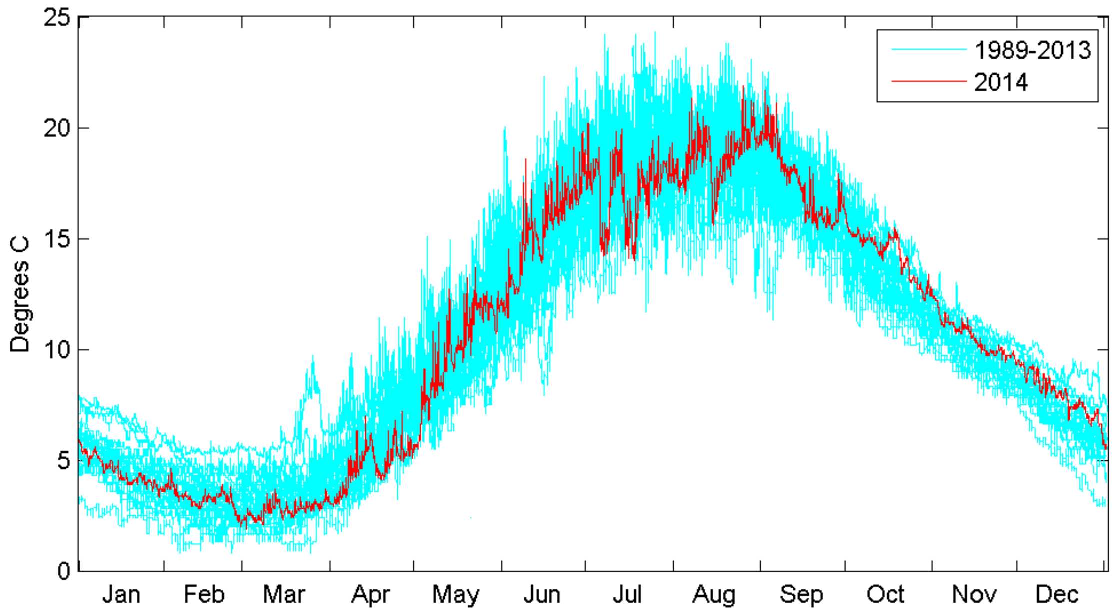

Figure 3-3. Nearfield surface-water temperature at the NDBC Buoy 44013. Surface-water temperatures were relatively cool in March and April and warm during the much of the later months of 2014.

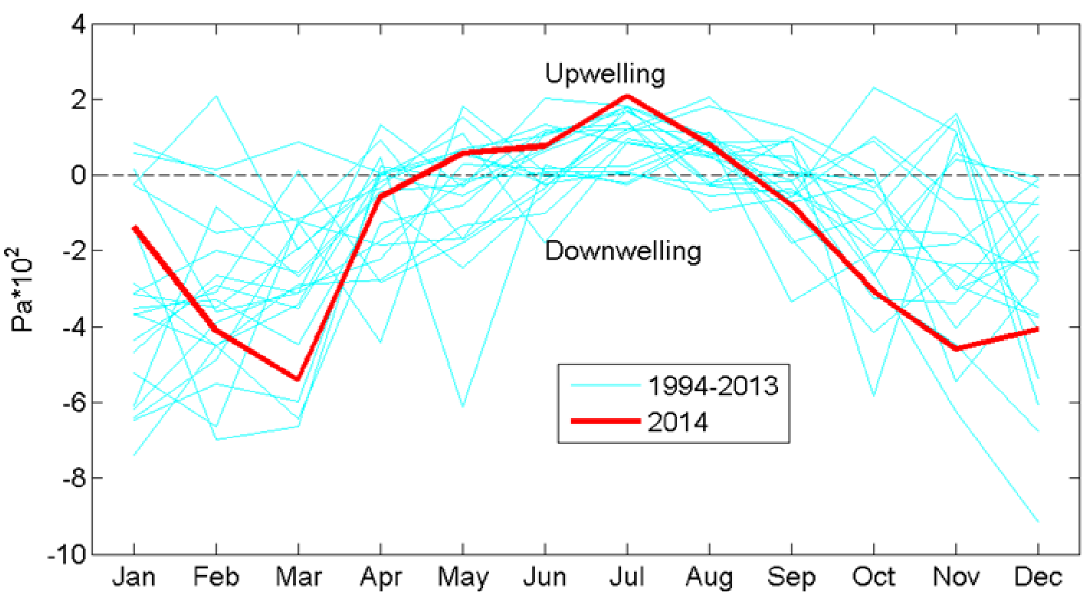

Figure 3-4. Average wind stress at NDBC Buoy 44013. Positive values indicate winds from the south or southwest, which result in upwelling-favorable conditions; negative values indicate winds from the north or northeast, which favor downwelling. The strongest summer upwelling since 1994 was measured in July.

Water Quality

Water quality measurements for 2014 included quantification of nutrients, phytoplankton biomass (measured as chlorophyll and particulate organic carbon), 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. 2015).

Nitrate, ammonium, silicate, and phosphate concentrations at Station N18 near the outfall averaged through the water column were lower than most previous years during the first survey in February (Figure 3-5). Similar low concentrations have been observed since 2012 and may have been caused by continual phytoplankton production over the winter or by early phytoplankton blooms that occurred prior to the start of the sampling season. Ammonium is the largest fraction of the total nitrogen in wastewater and provides a tracer to identify possible effects of the outfall. Throughout the year, depth-averaged ammonium concentrations greater than 4µM were observed only at Station N21 at the outfall and those stations immediately to the south (Figure 3-6).

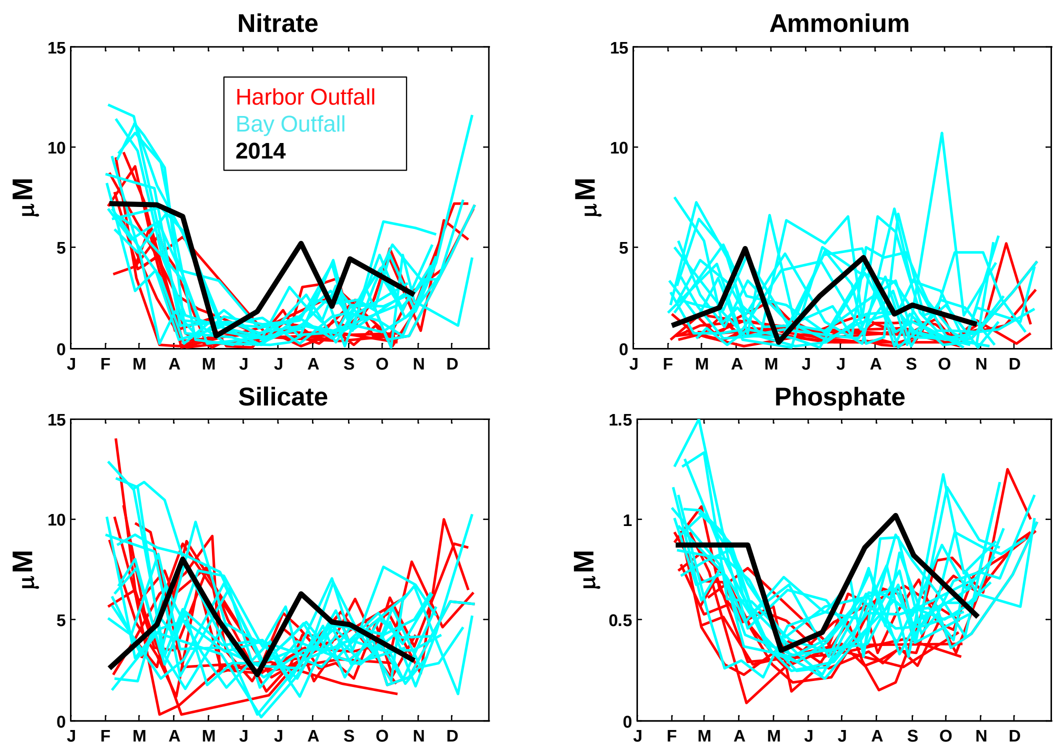

Figure 3-5. Mean depth-averaged nutrient concentrations at nearfield station N18 in 2014, compared to prior years. February nutrient concentrations were lower than other years, possibly due to phytoplankton blooms prior to the first MWRA survey in February. (Station N18 is immediately southwest of the outfall. Note difference in scale for phosphate.)

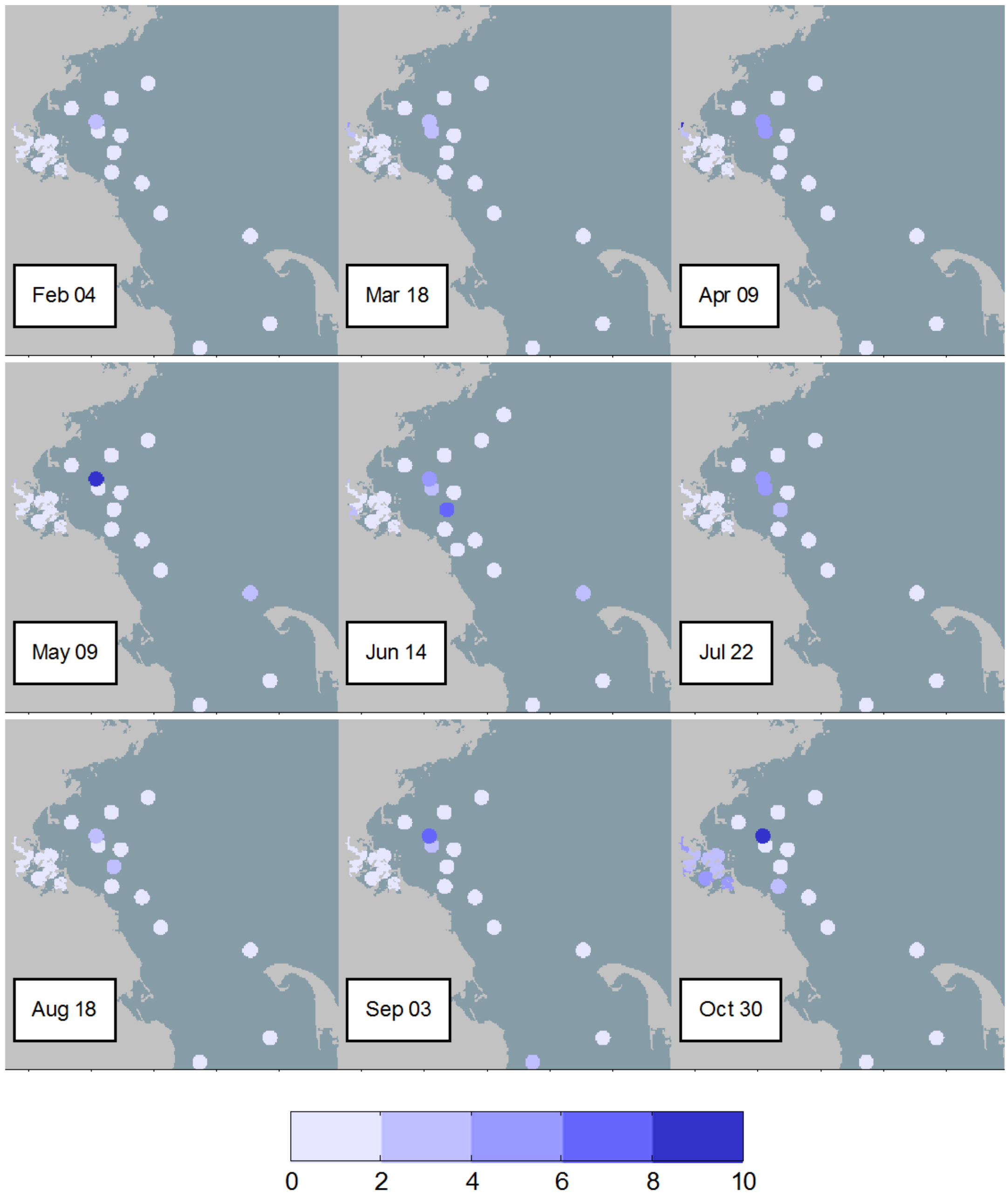

Figure 3-6. Depth-averaged ammonium concentrations (µM) by station in Massachusetts and Cape Cod bays. Several panels show additional data from MWRA's in-house Boston Harbor monitoring surveys when those surveys were within a few days of the outfall-monitoring surveys. Elevated ammonium levels are detected near the outfall throughout the year.

As has been typical since the offshore outfall began to discharge, the ammonium signature of the plume was found in surface waters during the winter and spring (not shown), but was confined beneath the pycnocline during the summer, stratified season (Figure 3-7). The ammonium signature could be detected within 10–20 kilometers of the outfall in both well-mixed and stratified seasons.

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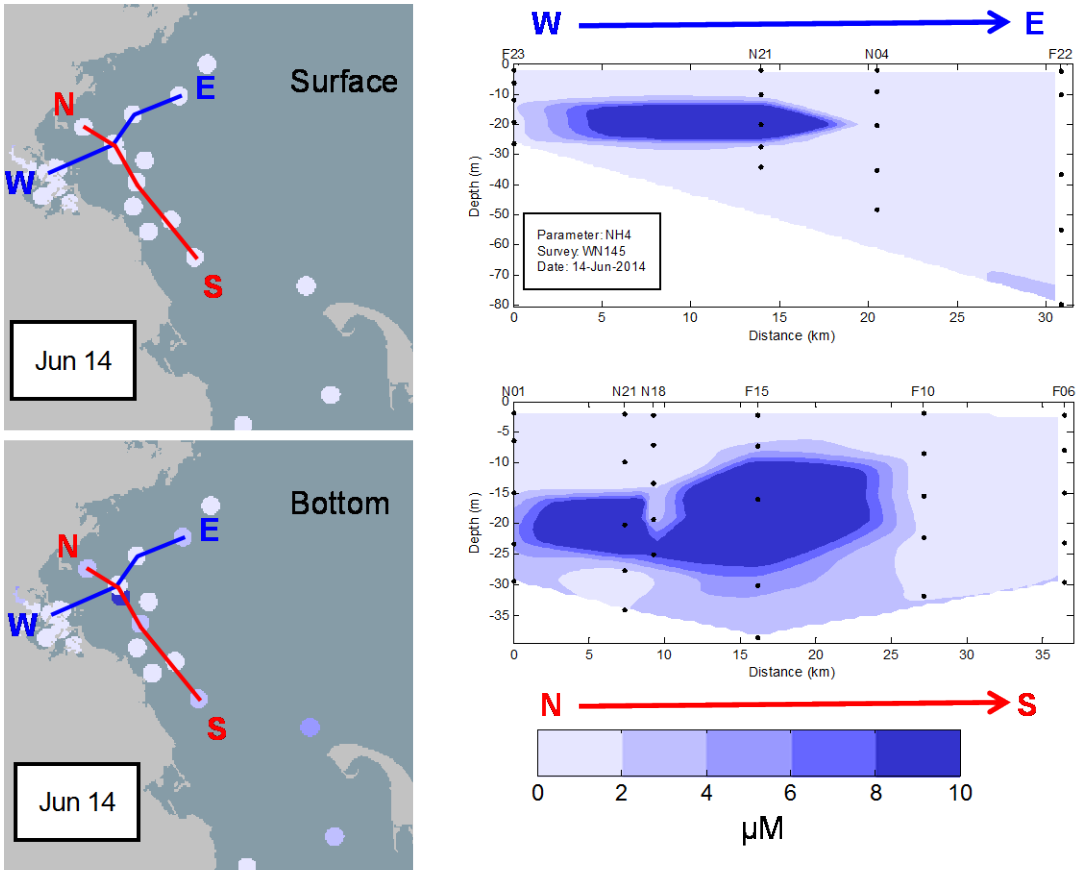

Figure 3-7. (Left) Surface- and bottom-water ammonium (µM) on June 14, 2014 at the monitoring stations during stratified conditions. (Right) Cross-sections of concentrations at the five depths sampled at each station along the two transects. No ammonium signal was detected at Station N04, 7.1 kilometers to the northeast, or Station F10, 20 kilometers to the south of the outfall. Station F10 is the farthest station at which detectable effects of the outfall were anticipated.

Despite the elevated levels of ammonium that have been typical near the outfall, there has been no detectable increase in phytoplankton biomass, measured as chlorophyll or particulate organic carbon. Overall, both chlorophyll and particulate organic carbon levels were low throughout 2014. Even at Station N18 near the outfall, chlorophyll levels were at the low end of the historic range during most surveys. Broadly, survey data showed the possible remnants of a bloom during the February survey, an increase in chlorophyll levels in the north and east in May, and elevated chlorophyll concentrations at the entrance to Boston Harbor and shallower stations in the coastal waters of Massachusetts Bay in July and August (Figure 3-8).

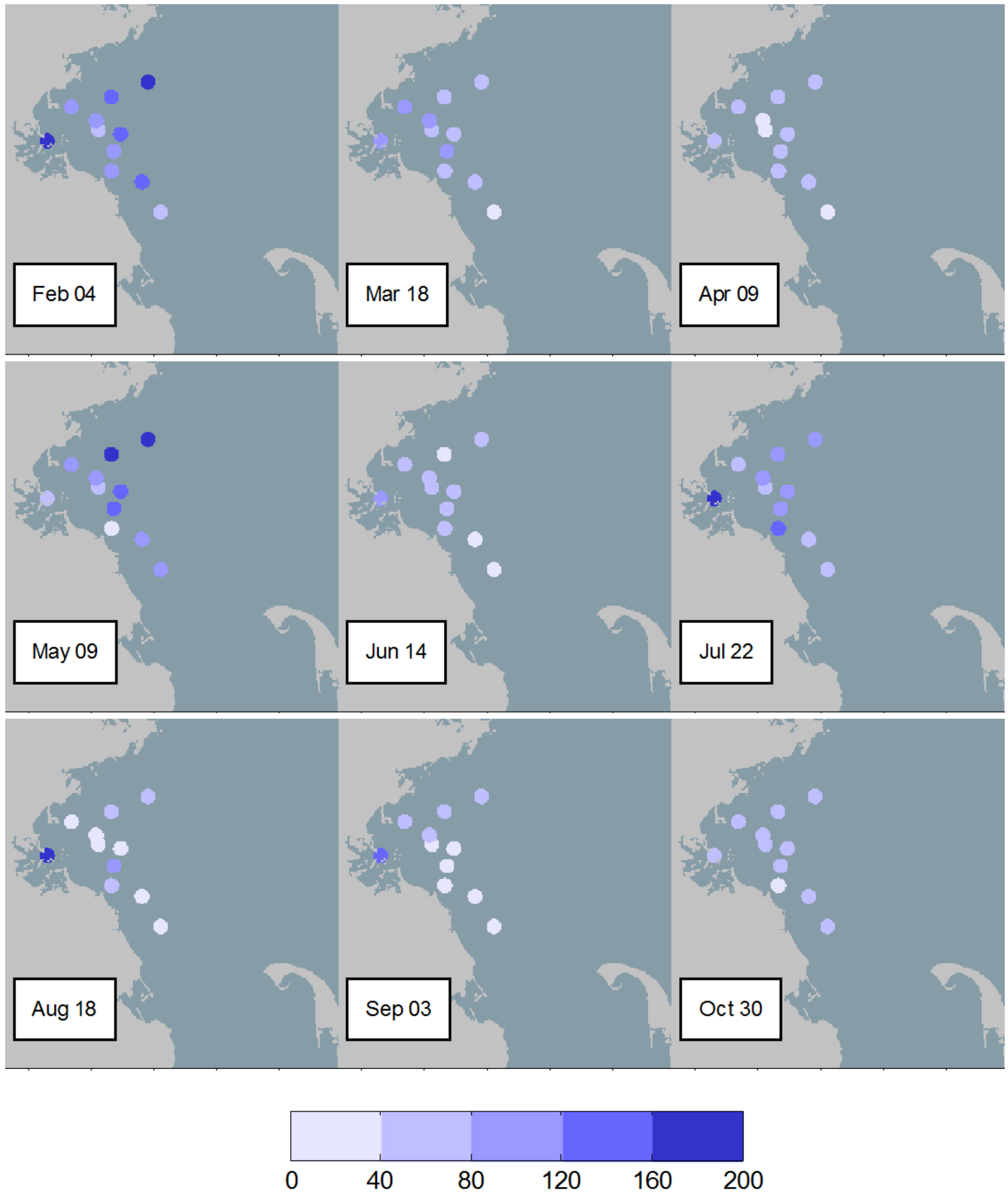

Figure 3-8. Average areal chlorophyll (mg/m^2) by station in Massachusetts Bay, 2014.

Satellite imagery showed that phytoplankton were relatively productive prior to the February 2014 survey, particularly inshore and in Cape Cod Bay (Figure 3-9), as they had been in November and December of 2013. Levels were low in February and into March, then relatively elevated in April and May, corresponding to the *Phaeocystis pouchetii* bloom (discussed in the Phytoplankton Communities section below), and again in the fall, corresponding to a mixed diatom bloom.

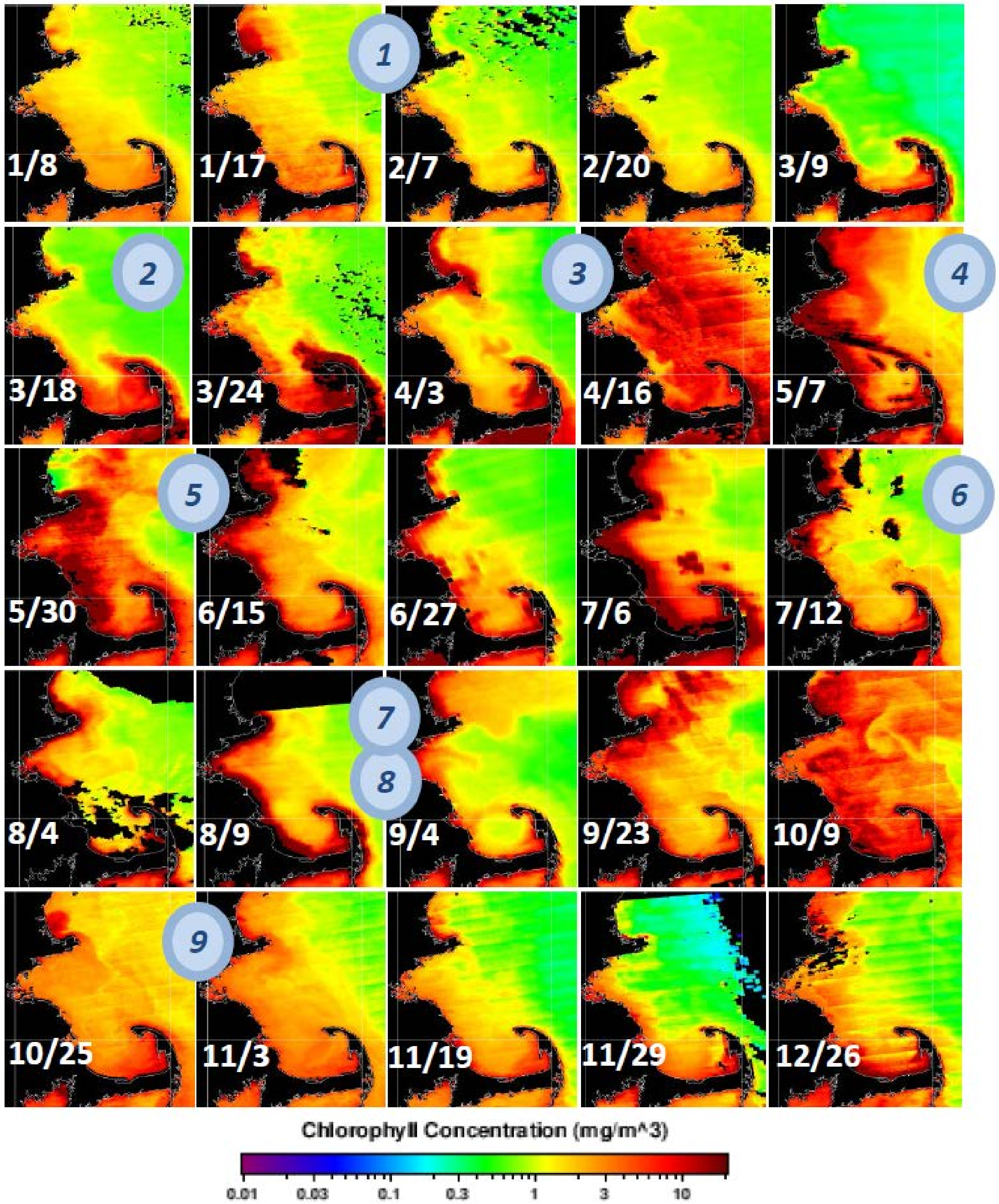

Figure 3-9. Moderate Resolution Imaging Spectroradiometer satellite imagery of surface chlorophyll concentrations in 2014. These images are heavily weather dependent and do not represent consistent intervals of time. The numbers show the timing of the nine MWRA surveys. Survey 2 was on the same day as one image; other surveys occurred between image dates.

Nearfield and farfield bottom-water dissolved oxygen concentrations were in the middle of the historic range in February through May (Figure 3-10). Levels were at the low end of the range in the nearfield during June to September. As is typical, mixing during September and October storms re-oxygenated bottom waters. Fall oxygen minima were moderate in 2014 compared to past years and continued to show no effects of the discharge.

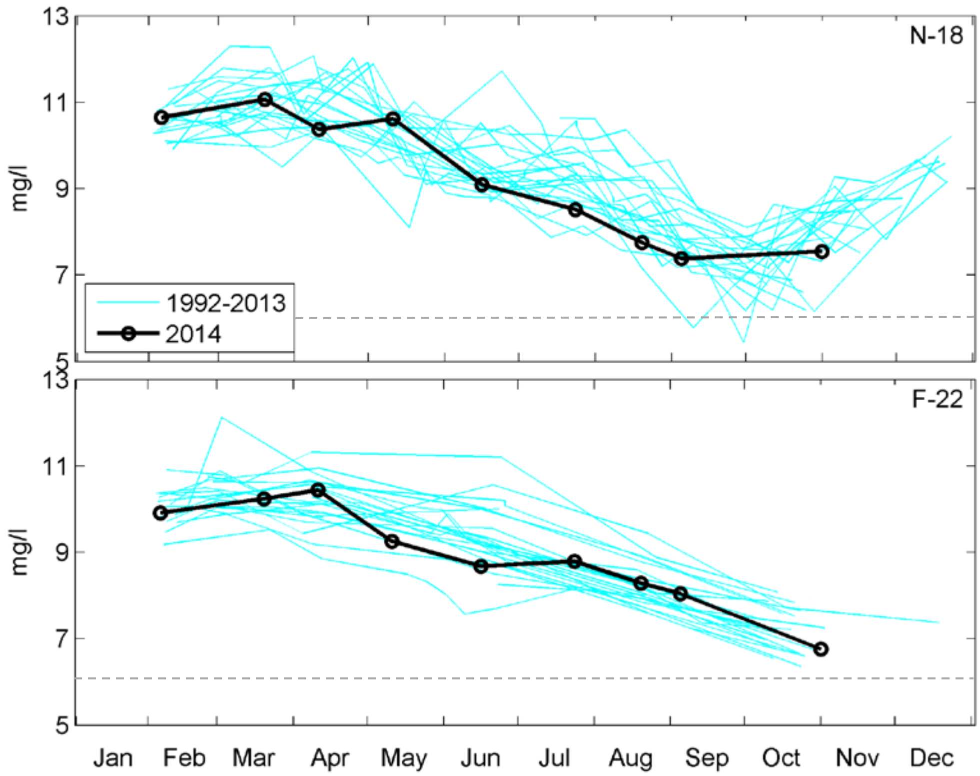

Figure 3-10. Bottom water dissolved oxygen concentrations in the nearfield (Station N18) and offshore (Station F22) in 2014 compared to earlier years. Sampling now ends in October; in earlier years it continued until December. The dashed lines show the 6 mg/L Massachusetts water-quality standard and Contingency Plan warning-level threshold.

Phytoplankton Communities

Total abundance of phytoplankton was low in 2014, ranking lowest of 23 years of monitoring (Figure 3-11, Libby et al. 2015), a result that is thought to be bay-wide and not related to the outfall. The low annual abundance reflected decreases in abundances of all major taxonomic groups, including the centric diatoms, pennate diatoms, dinoflagellates, cryptophytes, and microflagellates. Long-term declines (1992–2014) of centric and pennate diatoms are statistically significant. Abundance of centric diatoms, a major component of the Massachusetts Bay winter/spring flora, was particularly reduced in 2014, with an annual mean abundance in the nearfield the lowest since 2009. Microflagellate, dinoflagellate and cryptophyte abundance showed no linear trends, but long-term mean abundance patterns of those groups suggested there may be cycles in their abundance.

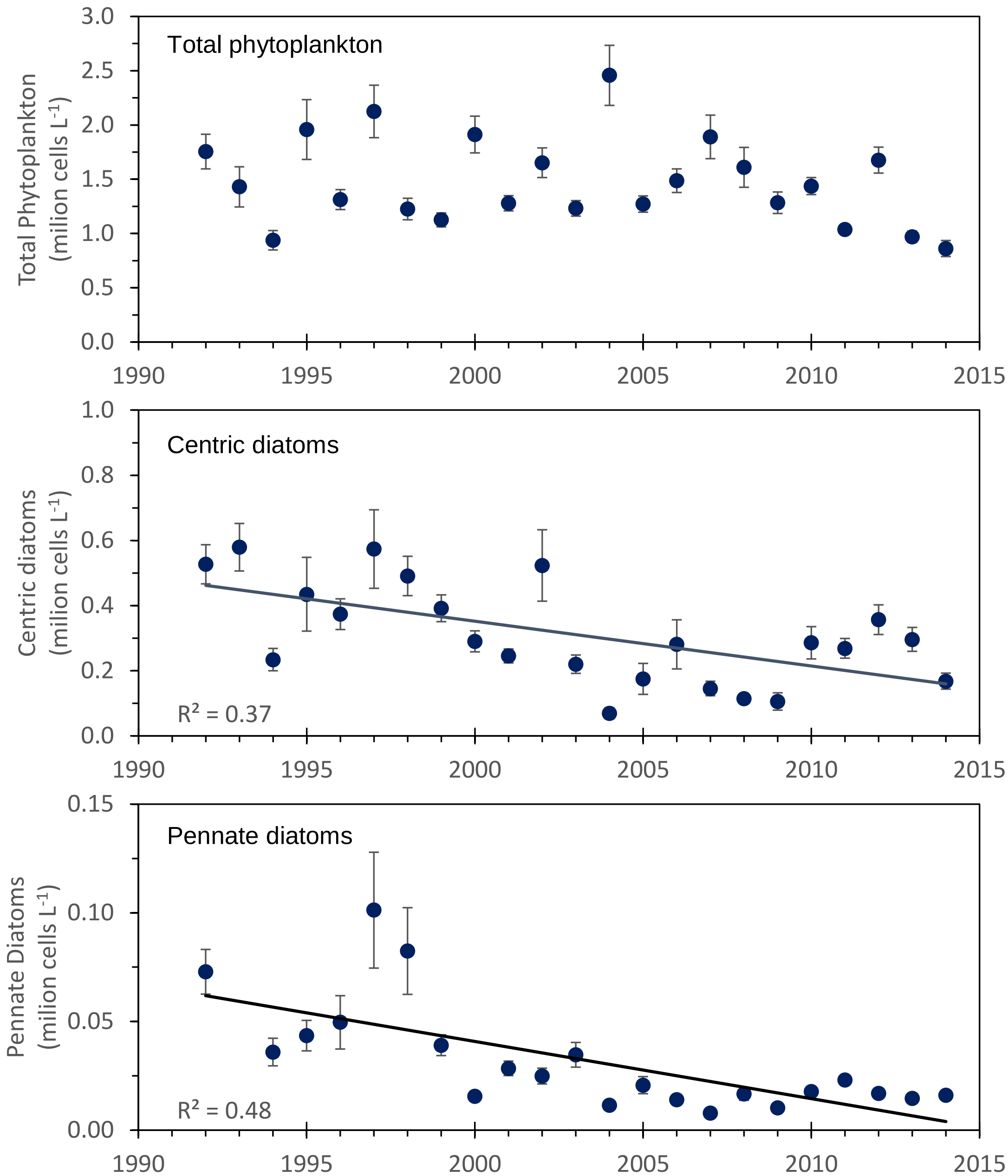

Figure 3-11. Annual mean abundance of total phytoplankton, centric diatoms, and pennate diatoms, 1992–2014. (Data are mean for all samples from all stations ± standard deviation). Declines in centric and pennate diatoms were statistically significant, linear regression lines shown.)

Total phytoplankton abundances were low throughout the year and throughout Massachusetts Bay (Figure 3-12). The survey data did not detect winter/spring blooms. Interestingly, cold-water centric diatoms, *Detonula confervacea, Porosira glacialis* and *Lauderia annulata*, which often comprise the earliest species in the winter/spring, were abundant during March and April 2014. The most abundant of the three species, *D. confervacea*, is typically abundant in cold and boreal waters, with temperatures lower than 5ºC. The delay in springtime warming may have influenced population growth in 2014.

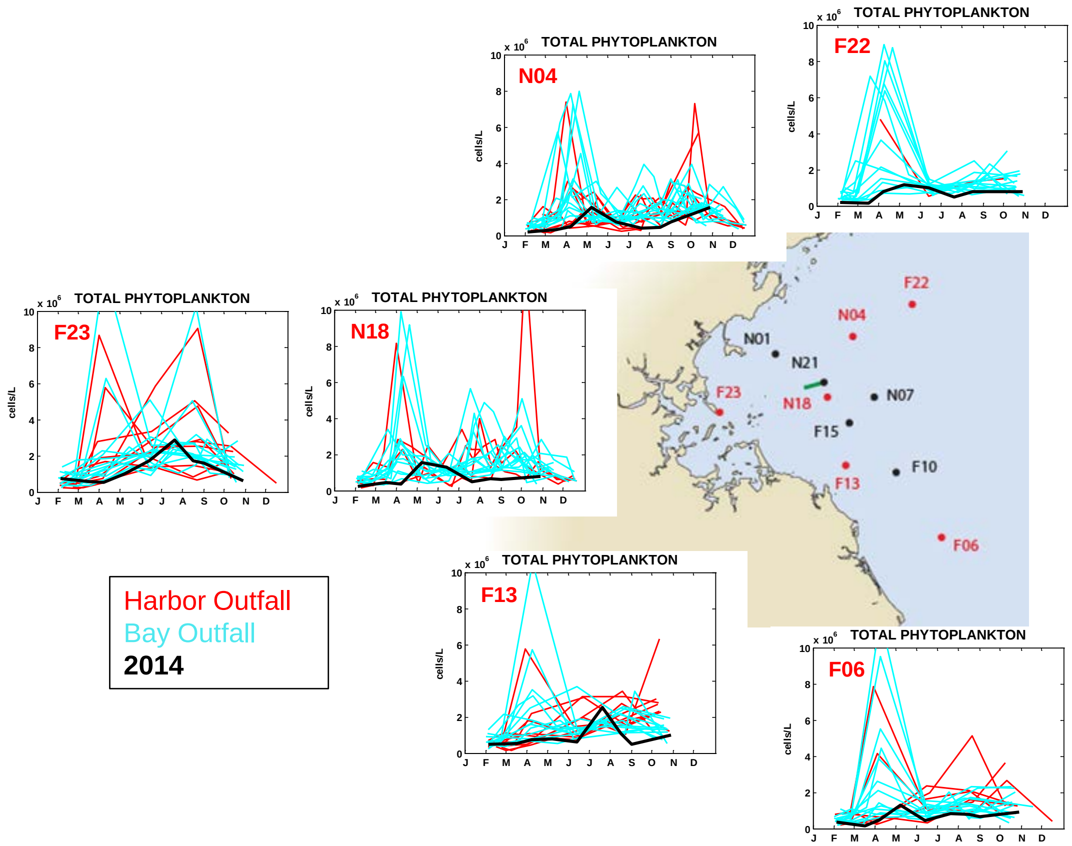

Figure 3-12. Total phytoplankton abundance at selected stations in 2014 compared to baseline (Harbor Outfall) and post-discharge (Bay Outfall) monitoring years.

To some degree, low annual phytoplankton abundance may reflect the timing of the MWRA surveys as well as actual declines. There have been indications of phytoplankton productivity prior to the first surveys of the year in recent years. The satellite imagery in Figure 3-9 above showed, for example, that there was increased chlorophyll between the dates of the April and May surveys.

Even accounting for the artifacts of sampling times, there are indications of region-wide declines, which are unrelated to the outfall. One factor that may have limited phytoplankton abundance in 2014 is grazing by zooplankton. The abundances of total zooplankton and many dominant taxa were at or above maxima for the monitoring program at many of the stations in Massachusetts Bay (see Zooplankton Communities, below).

Abundance of the nuisance species *Phaeocystis pouchetii* was moderate to low in the nearfield in winter/spring 2014, but elevated to above the Contingency Plan caution threshold for the summer (Figure 3-13). Annual abundance was relatively low compared to other years since blooms began to occur regularly just before the outfall came on line in 2000. The cold winter/spring period apparently delayed the onset of the bloom in 2014. The rapid warming in May contributed to rapid senescence, quickly ending the summer bloom. The short-lived bloom was not particularly strong, but because it peaked in May, later than typical for *Phaeocystis* blooms, it fell within the "summer" Contingency Plan threshold season. The summer *Phaeocystis* threshold is extremely low, so the moderate bloom resulted in an exceedance.

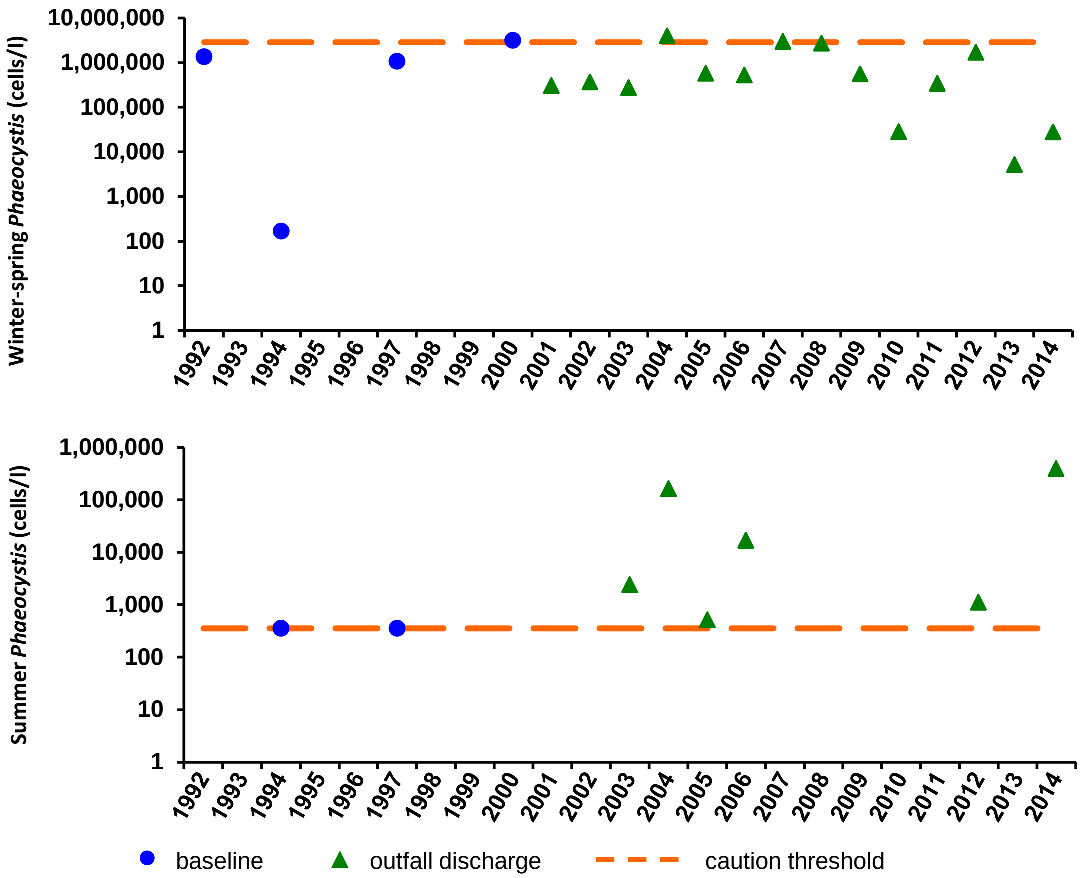

Figure 3-13. Mean nearfield abundance *Phaeocystis pouchetii,* 1992–2014. (Top) Winter/spring. (Bottom) Summer. Note difference in scale for winter/spring and summer. (No *Phaeocystis* were detected in years with no symbol.)

Similar to 2013, abundance of the toxic dinoflagellate *Alexandrium fundyense* in 2014 was lower than it had been in recent years, with only a small bloom (Figure 3-14). Cell counts were at the lowest levels reported since before 2005. The cold winter/spring and a lack of storms with winds from the northeast when waters were warmer in late May and June may have contributed to the modest *Alexandrium* bloom in Massachusetts Bay. Elevated abundances and paralytic shellfish poisoning (PSP) toxicity were observed in the Gulf of Maine in late May and early June, later than the April and early May storms that could have transported cells into Massachusetts Bay. Consequently, 2014 marked a second consecutive year with no shellfishing closures due to PSP toxicity in Massachusetts Bay.

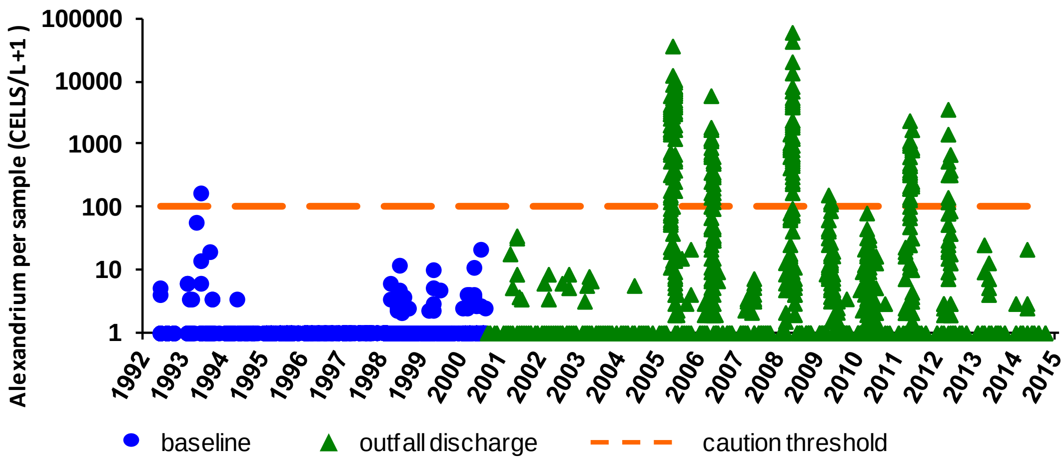

Figure 3-14. Nearfield abundance of *Alexandrium fundyense*, 1992–2014.

Zooplankton Communities

The abundances of total zooplankton and many dominant species groups were relatively high in 2014, continuing a trend of greater abundances since lows in 2005 (Figure 3-15, Libby et al. 2015). Increases in abundances of a wide variety of species, including adults and copepodites of *Pseudocalanus* spp., *Temora longicornis*, *Oithona similis*, and *Calanus finmarchicus*, contributed to the increase in total zooplankton abundance.

The relatively high abundance of total zooplankton was observed throughout Massachusetts Bay (Figure 3-16). Abundances of total zooplankton mostly peaked in June or July, and with levels at or above maxima for the monitoring program at some stations.

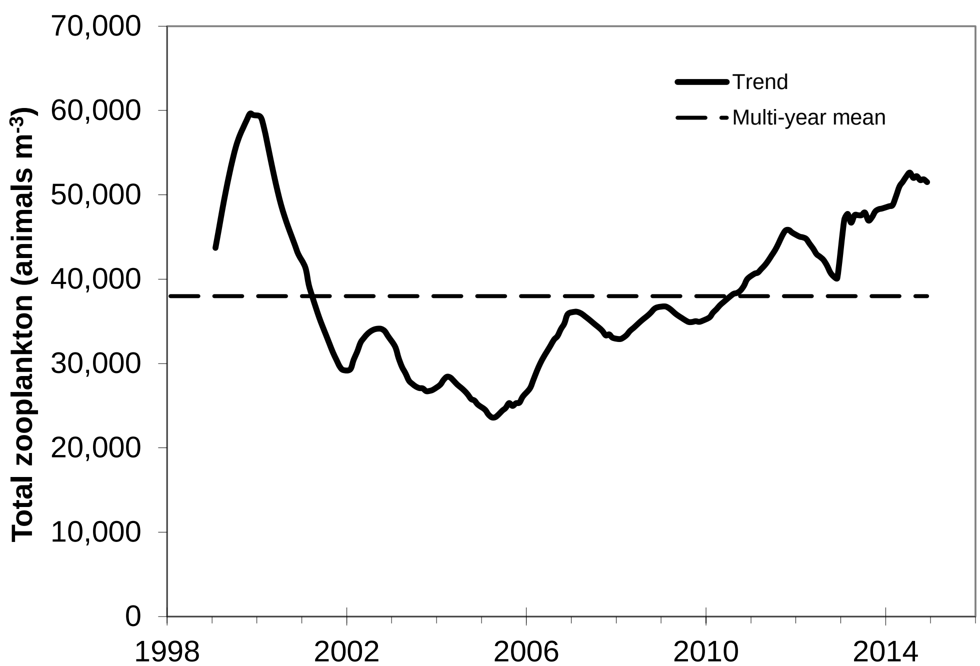

Figure 3-15. Long-term average zooplankton abundance. The graph was derived from a time-series analysis of data from Stations N04 and N18, 1998–2014. The long-term mean, shown as the dashed line, is 38,000 animals per cubic meter.

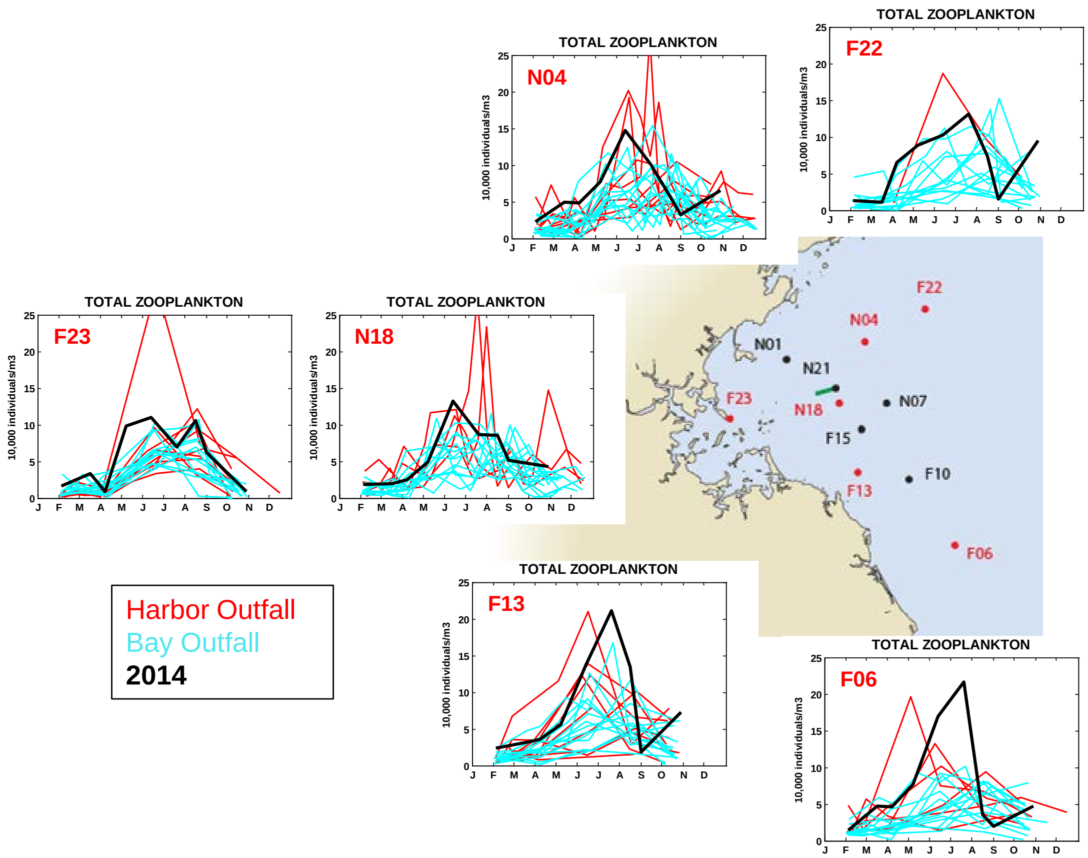

Figure 3-16. Total zooplankton abundance at selected stations in 2014 compared to baseline (Harbor Outfall) and post-discharge (Bay Outfall) monitoring years. Total zooplankton levels were relatively high throughout Massachusetts Bay.

Reasons for the relatively high zooplankton abundances in 2014 and the long-term trends are not well understood, but the increased grazing by zooplankton may have contributed to the long-term decline in phytoplankton abundance described above. Linear-regression analyses suggested that annual mean zooplankton abundance explains 30–40% of the variability in annual mean phytoplankton abundance at nearfield stations (Figure 3-17). Large-scale regional patterns are likely a major factor, but a lack of comparable data across the broader geographic region prevents a direct comparison.

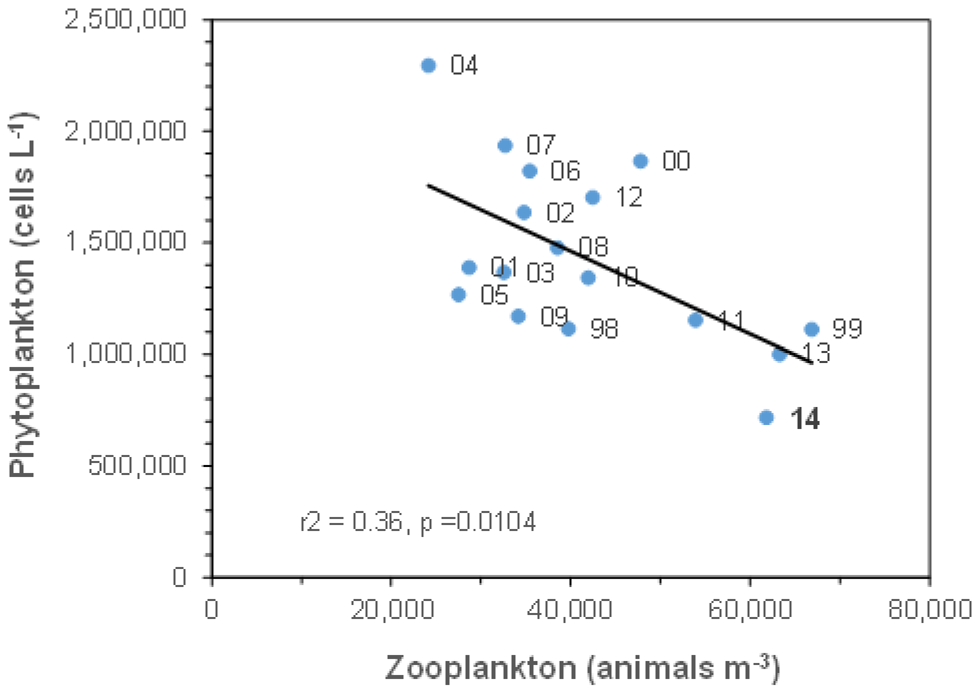

Figure 3-17. Annual total phytoplankton versus total zooplankton at nearfield stations N04 and N18, 1998–2014.

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. Water-column Station F22 is in Stellwagen Basin, to the northwest of the sanctuary and is considered to be representative of northern, offshore conditions.

Ammonium levels have remained low at Station F22 since the outfall began to discharge (see, for example, 2014 results in Figures 3-6 and 3-7, above). Levels have also remained low at Station F06 located to the south and offshore. In contrast, increased ammonium levels have been detected in the nearfield, at Station N18, while decreases have been detected at representative harbor and coastal stations.

Bottom-water dissolved oxygen concentrations at Station F22 were relatively low throughout 2014 (Figure 3-18). These levels reflected the warm, saline conditions found throughout the region. Data from the NERACOOS Mooring A01, located within the sanctuary, documented the return to oxygenated conditions with fall mixing.

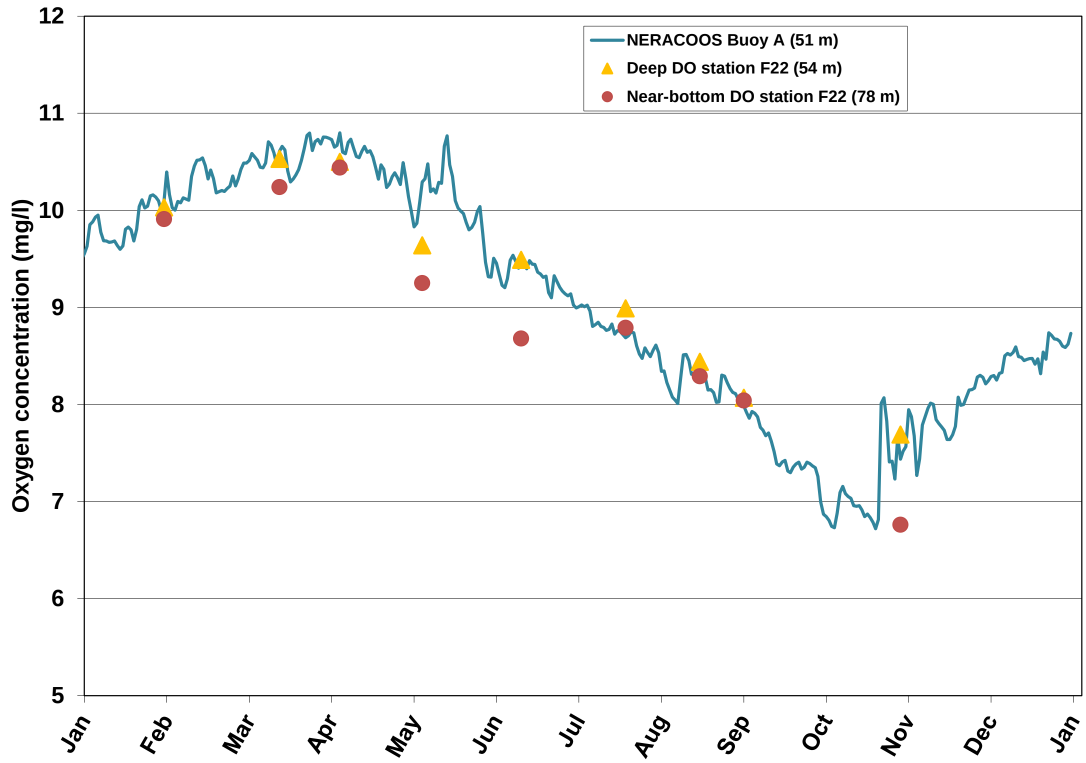

Figure 3-18. Deep and near-bottom water dissolved oxygen concentrations at Station F22 and the NERACOOS Mooring A01, inside Stellwagen Bank Marine Sanctuary. The NERACOOS measurement is at 51 m, the deep Station F22 at 54 m, and the near-bottom Station F22 at 78 m. DO = dissolved oxygen

Potential influences of the MWRA outfall on Stellwagen Bank National Marine Sanctuary were recently assessed using results from the numerical Bays Eutrophication Model, which simulates and predicts the physical and biological conditions in Massachusetts Bay (Zhao et al. 2015). Using 2013 conditions, modelers compared ammonium concentrations along a 60-kilometer east-west transect, passing over the outfall, and across Stellwagen Basin and Stellwagen Bank (Figure 3-19). One model simulation used nutrient concentrations measured in outfall effluent, and a comparison simulation set outfall nutrient inputs to zero.

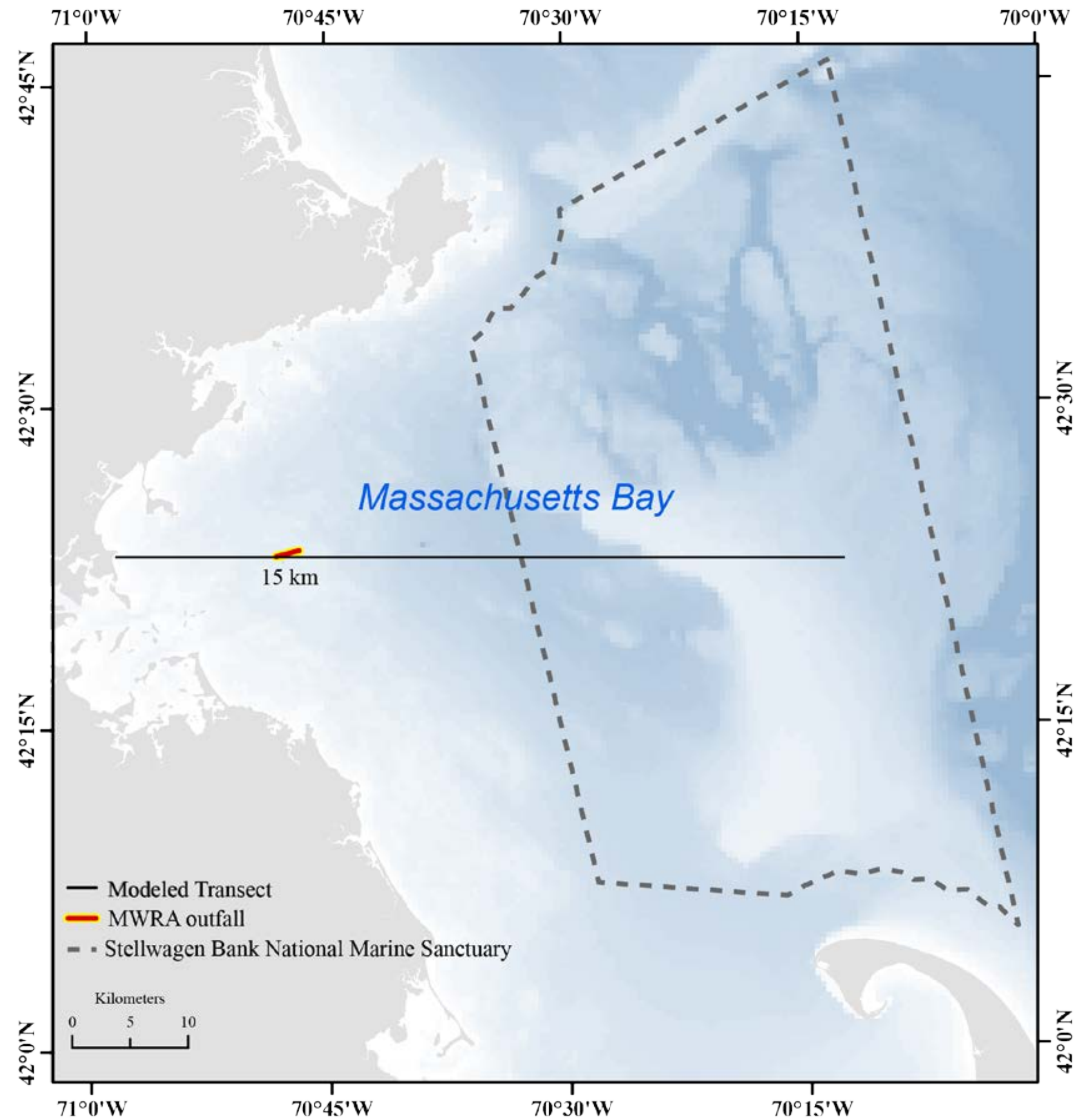

Figure 3-19. Location of an east-west transect from Deer Island, across MWRA outfall, through Stellwagen Bank, for modeled water-quality parameters.

As has also been observed from monitoring data, the model simulations using 2013 effluent data showed that increased ammonium concentrations from the outfall occur mostly within 10 kilometers of the discharge and in the deepest part of the water column (Figure 3-20). The simulations showed small increases (0.5–1.5 µM) in ammonium concentrations extending into waters over Stellwagen Basin in some months (August and October), but no such detectable changes in waters over the Stellwagen Bank.

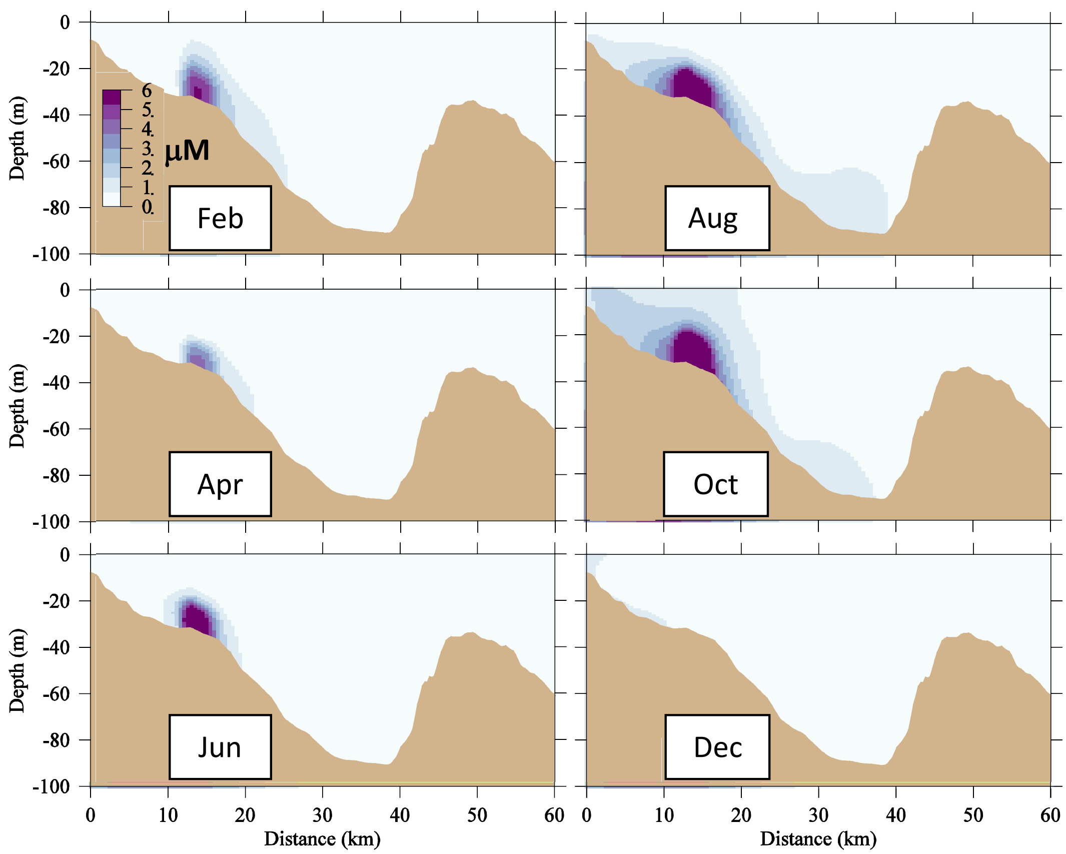

Figure 3-20. Modeled increases in ammonium concentrations (µM) due to MWRA discharge, on the east-west transect across the MWRA outfall and into Stellwagen Bank National Marine Sanctuary for six months in 2013. The model simulations show small increases in ammonium levels in Stellwagen Basin (the deepest waters) in August and October, but no changes on Stellwagen Bank (the offshore shallower area).

Ammonium is, as discussed in the Water Quality section above, the most sensitive indicator of any outfall influence in the bay. Similar model simulations, comparing actual discharge data so a scenario presuming no outfall inputs, showed only negligible differences in chlorophyll and dissolved oxygen levels.

(Additional model results are also presented in Section 6, Special Studies.)

Boston Harbor

Water quality in Boston Harbor has improved throughout the past 20 years, and those improvements continued in 2014 (Taylor 2015). MWRA's in-house Boston Harbor monitoring program confirmed that harbor-wide concentrations of total nitrogen and phosphorus remained low, as they have since discharges to the harbor ended. In 2015, total suspended solids increased and transparency decreased, but those changes could be attributed to shoreline erosion rather than to wastewater inputs. Dissolved oxygen concentrations remained high, as they have been since 2001. Concentrations of the bacterial indicator *Enterococcus* were the lowest since routine monitoring began in 1995. (Additional bacterial water-quality data are presented in Section 6, Special Studies.)

One of the most dramatic improvements in Boston Harbor has been the decrease in ammonium levels (Figure 3-21; Libby et al. 2015). Ammonium concentrations dropped dramatically as soon as effluent discharge was diverted from the harbor to Massachusetts Bay in 2000, and they have remained low. In 2014, ammonium levels at Station F23, at the mouth of Boston Harbor, were near the bottom of the historic range in February through August and about average for the post-diversion years throughout the fall.

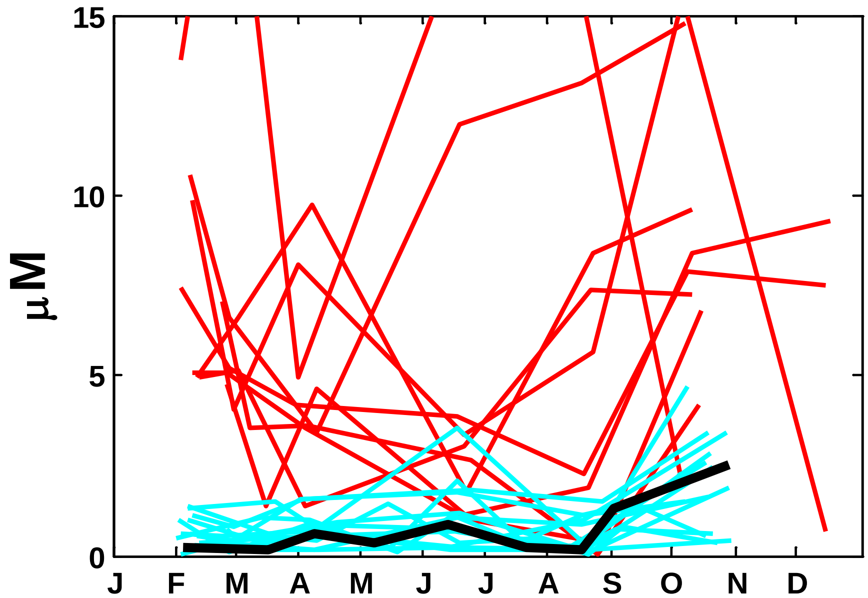

Figure 3-21. Ammonium levels at Station F23 in Boston Harbor. Red lines = Boston Harbor discharge years, Blue lines = Massachusetts Bay discharge years. Black line = 2014

Total phytoplankton biomass, measured as chlorophyll, was slightly higher than during many of the years since the discharges to the harbor ended but lower than when effluent was discharged to the harbor (Taylor 2015). Total phytoplankton abundance by counts was relatively low throughout the year, while total zooplankton abundance was relatively high at Station F23, off Deer Island at the mouth of Boston Harbor (Libby et al. 2015).

While total zooplankton abundance peaked in June and July in Massachusetts Bay, there were two peaks at Station F23, one in June and July and a second one in September. The early peak was largely due to abundances of *Acartia* spp., which are common in the lower-salinity waters found in the harbor (Figure 3-22). The May peak in *Acartia* abundance reflects a long-term shift observed since 2001, which coincided with the transfer of effluent discharge from the harbor to the bay.

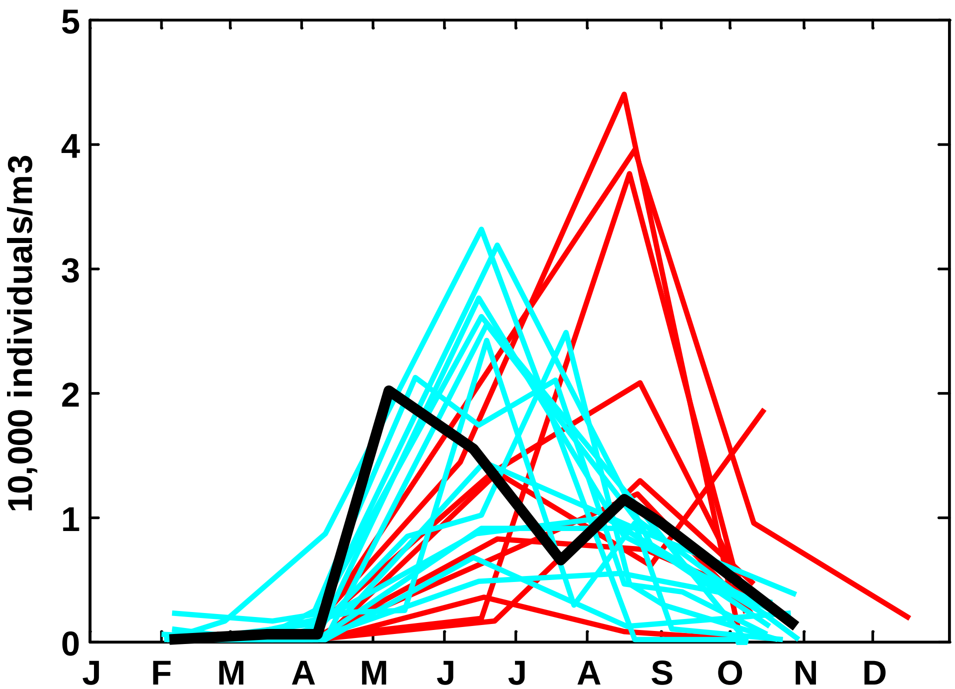

Figure 3-22. *Acartia* spp. abundance at Station F23 in Boston Harbor. Red lines = Boston Harbor discharge years, Blue lines = Massachusetts Bay discharge years. Black line = 2014

The data suggest that the shift has been caused by an earlier peak in *Acartia hudsonica*, which is the dominant of the two *Acartia* species that occur in the harbor. *Acartia hudsonica* populations are typically more abundant in the spring, while populations of the other species present in the harbor, *Acartia tonsa*, peak later in the year (Figure 3-23). It remains unknown whether the increased dominance of *Acartia hudsonica* is a result of the decreased effluent loads to the harbor or whether it is a result of broader regional changes.

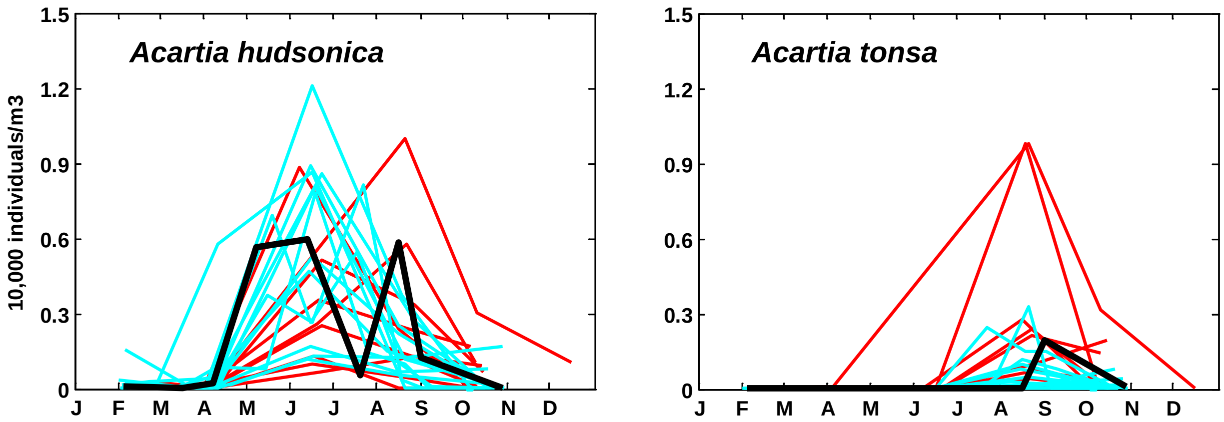

Figure 3-23. *Acartia hudsonica* and *Acartia tonsa* abundance at Station F23 in Boston Harbor. Red lines = Boston Harbor discharge years, Blue lines = Massachusetts Bay discharge years. Black line = 2014

Contingency Plan Thresholds

All water-quality parameters were within normal ranges throughout 2014. There was, however, a Contingency Plan caution-level threshold exceedance for one nuisance algae measure, summer *Phaeocystis pouchetii* (Table 3-1). The exceedance has been analyzed and found to be primarily due to cool temperatures in March and April, which caused a delay in the annual phytoplankton cycle. The overall magnitude of the *Phaeocystis pouchetii* bloom was moderate in 2014, but it peaked in May rather than in March or April, which has been typical. No aesthetic or other adverse effects were observed from the 2014 bloom, and abundance had dropped to much lower levels by mid-June.

Table 3-1. Contingency Plan threshold values and 2014 results for water-column monitoring.

Parameter	Baseline	Caution Level	Warning Level	2014 Results
Dissolved oxygen*				
Nearfield concentration	6.05 mg/L	6.5 mg/L	6.0 mg/L	7.19 mg/L
Nearfield percent saturation	65.3%	80%	75%	81.6%
Stellwagen concentration	6.23 mg/L	6.5 mg/L	6.0 mg/L	6.76 mg/L
Stellwagen percent saturation	67.2%	80	75%	75.0%
Nearfield depletion rate	0.024 mg/L/d	0.037 mg/L/d	0.049 mg/L/d	0.015 mg/L/d
Chlorophyll				
Annual	72 mg/m^2	108 mg/m^2	144 mg/m^2	66 mg/m^2
Winter/spring	50 mg/m^2	199 mg/m^2	None	75 mg/m^2
Summer	51 mg/m^2	89 mg/m^2	None	68 mg/m^2
Autumn	90 mg/m^2	239 mg/m^2	None	50 mg/m^2
Nuisance algae *Phaeocystis pouchetii*				
Winter/spring	622,000 cells/L	2,860,000 cells/L	None	27,800 cells/L
Summer	72 cells/L	357 cells/L	None	395,000 cells/L, caution level exceedance
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	106 cells/L
Summer	14,635 cells/L	43,100 cells/L	None	Absent
Autumn	10,050 cells/L	27,500 cells/L	None	270 cells/L
Nuisance algae nearfield *Alexandrium fundyense*				
Any nearfield sample	Baseline maximum 163 cells/L	100 cells/L	None	20 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

4. Sea Floor

Sea-floor monitoring in 2014 included sampling and analysis of soft-bottom sediment conditions, tracers, contaminants, and infauna at 14 stations; sediment-profile imaging at 23 stations; and video surveys at 23 hard-bottom stations, including one active and one inactive outfall diffuser (Figures 4-1 through 4-3).

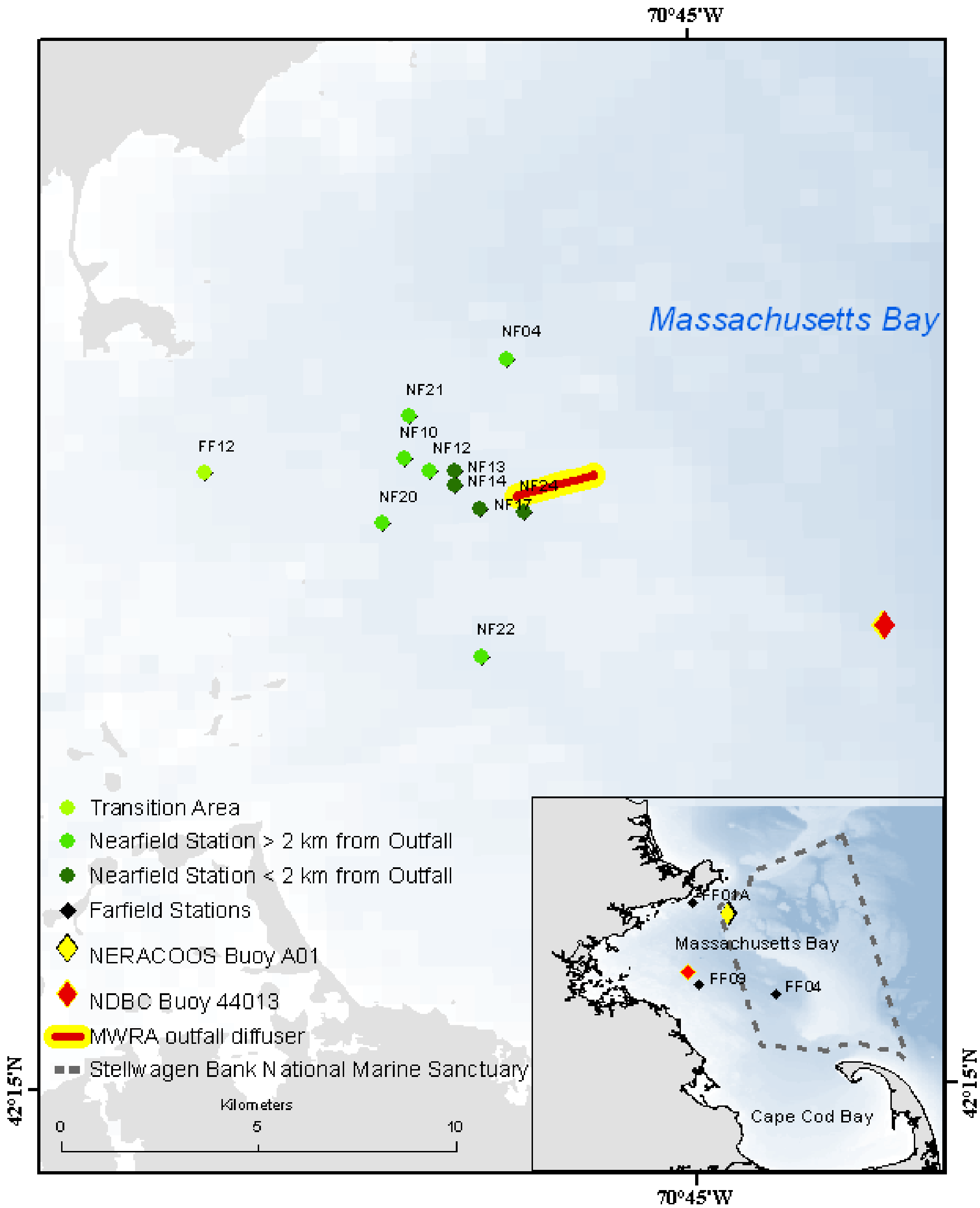

Figure 4-1. Soft-bottom monitoring stations. Fourteen stations were sampled for benthic community parameters and sediment characteristics. Also shown are the instrumented buoys, the MWRA outfall diffuser, and the Stellwagen Bank National Marine Sanctuary.

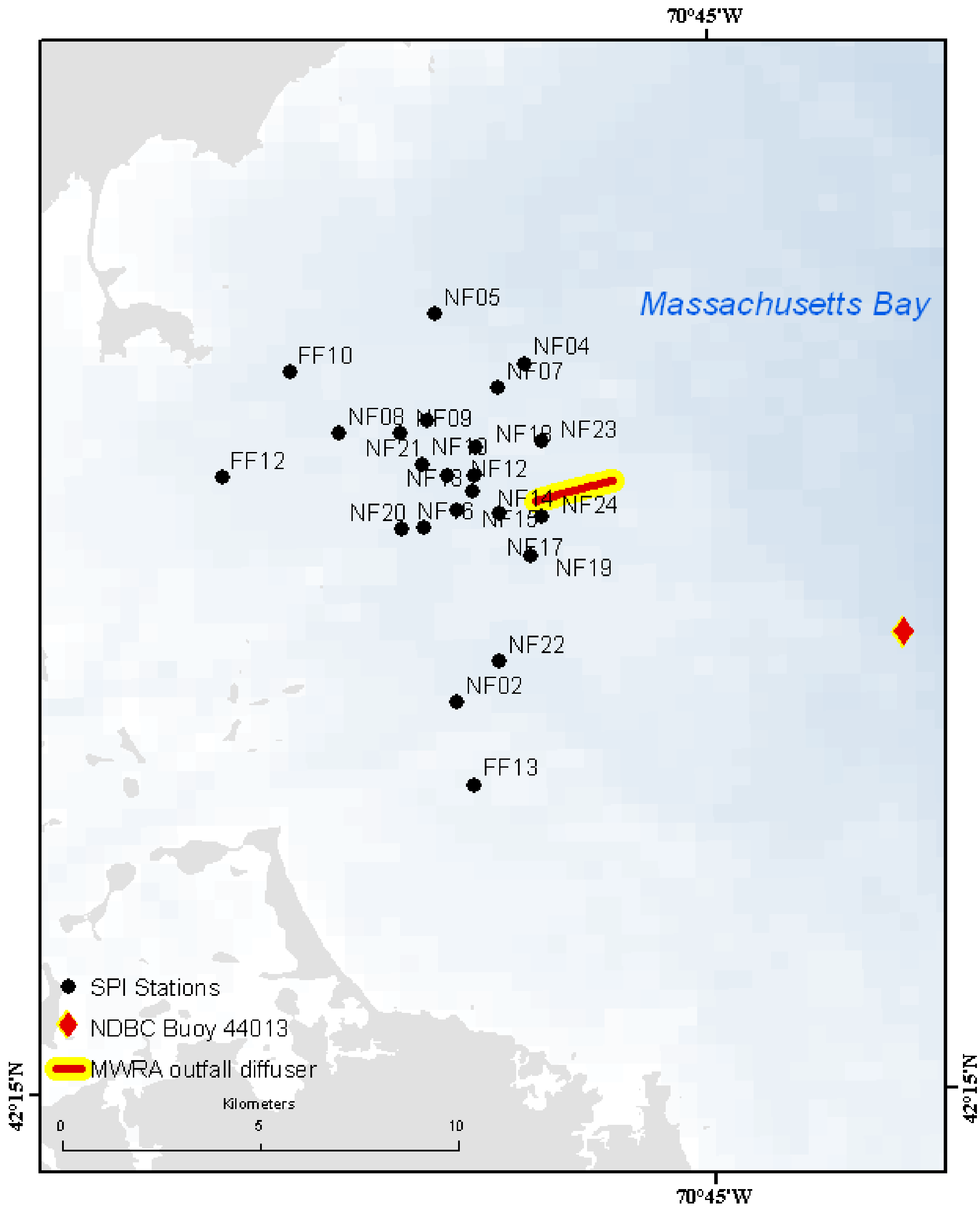

Figure 4-2. Sediment-profile imaging stations. Images are taken at 23 stations and provide rapid assessments of benthic habitats. Also shown are the NDBC buoy and the MWRA outfall diffuser. SPI = sediment-profile imaging

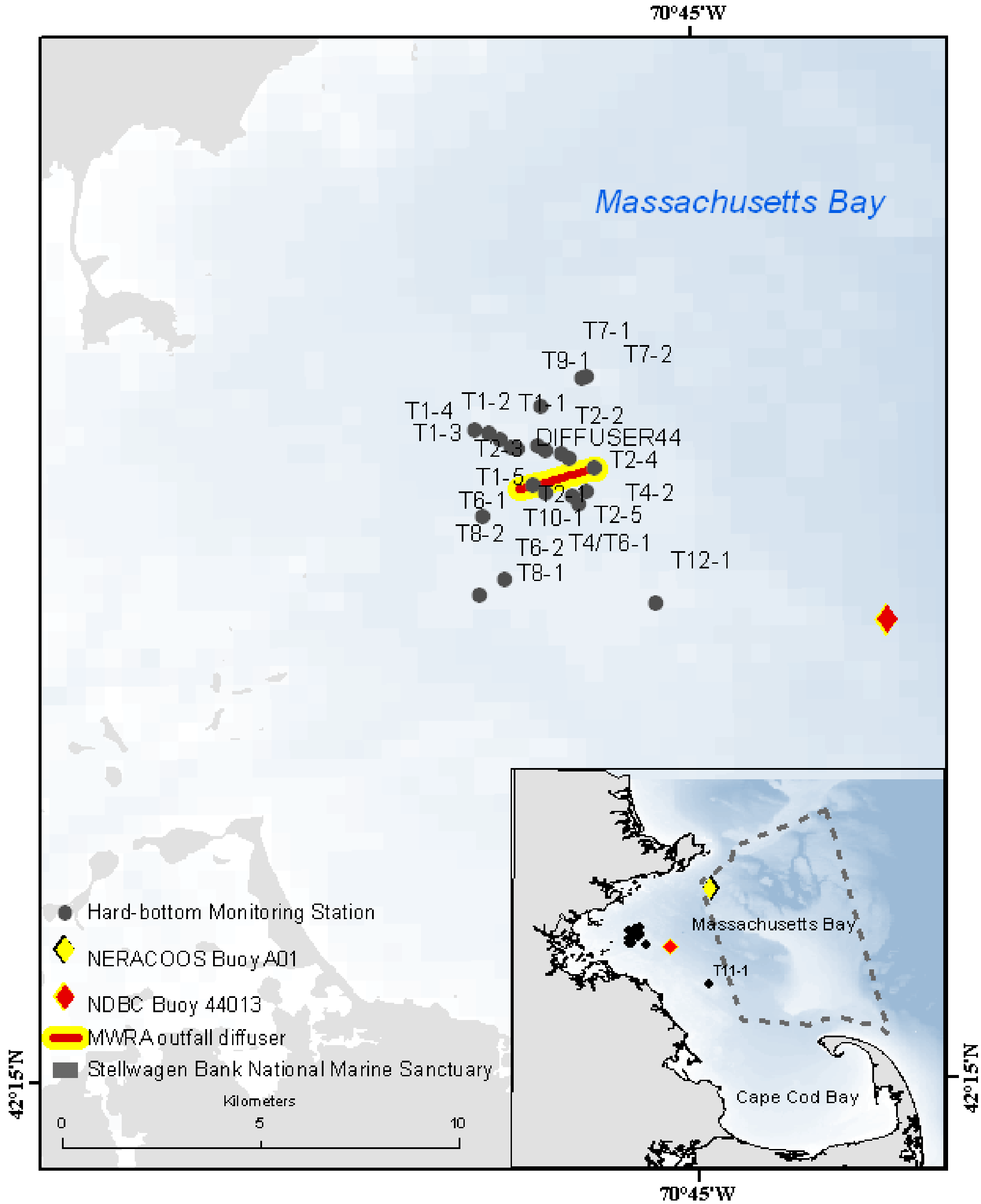

Figure 4-3. Hard-bottom stations. Video and still photographs are collected at 23 stations, including one active diffuser and one inactive diffuser, which has not been opened.

Soft-bottom sediment sampling was completed over two days in early August, with samples analyzed for grain-size distribution, total organic carbon, the effluent tracer *Clostridium perfringens* spores, chemical contaminants, and benthic infauna. The 14 stations 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 nearfield groups, for a total of eleven stations.

Sediment-profile imaging was also completed in August. Triplicate images from 23 stations 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.

Video surveys of hard-bottom areas were performed in June, surveying 23 stations, including an actively discharging diffuser head at the eastern end of the outfall and an unopened diffuser at the western end of the outfall.

Sediment Characteristics and Tracers

Sediment grain-size distributions in 2014 varied broadly among stations, ranging from silt and clay at some stations to mostly sand at others (Nestler et al. 2015). 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 2014. In particular, some stations, which had become coarser following early 2013 storms returned to more typical, siltier conditions. Overall, the percentage of fine particles, silts and clays, making up the sediments was close to the historical average. One exception was at Station NF24, which is located close to the outfall, where percent fine material reached a record high.

Percent organic carbon content, which tracks closely with fine material 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 (Figure 4-4).

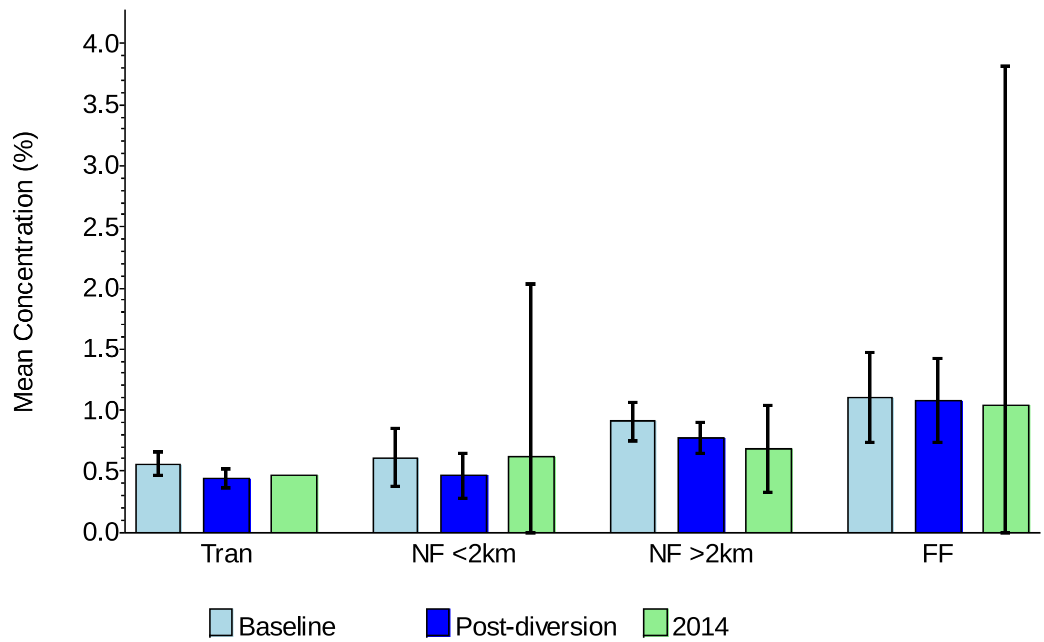

Figure 4-4. Percent total organic carbon by region, during the baseline, other post-diversion years, and 2014. (mean ± standard deviation) There have been no changes from the baseline; variability for the farfield in 2014 resulted from there being only three stations, with widely varying sediment grain size. **(**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.)

As in past years since the offshore outfall began to discharge (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 4-5 and 4-6). Past years' statistical analyses have shown that these increases close to the outfall are statistically significant and consistent with predictions made during the outfall-siting process. In 2014, there was a seemingly large increase in the number of spores normalized to the percentage of fine material at the sites closest to the outfall. This increase resulted in part from changing grain-size distributions at some stations. Some stations, with higher than typical spore counts were especially sandy, so the spore count normalized to percent fine material was especially high. Conversely, the siltiest station, where spore counts are expected to be high, had record low spore counts. Outside the area closest to the outfall, concentrations of *Clostridium perfringens* spores have declined or remained comparable to the baseline throughout the duration of the monitoring program.

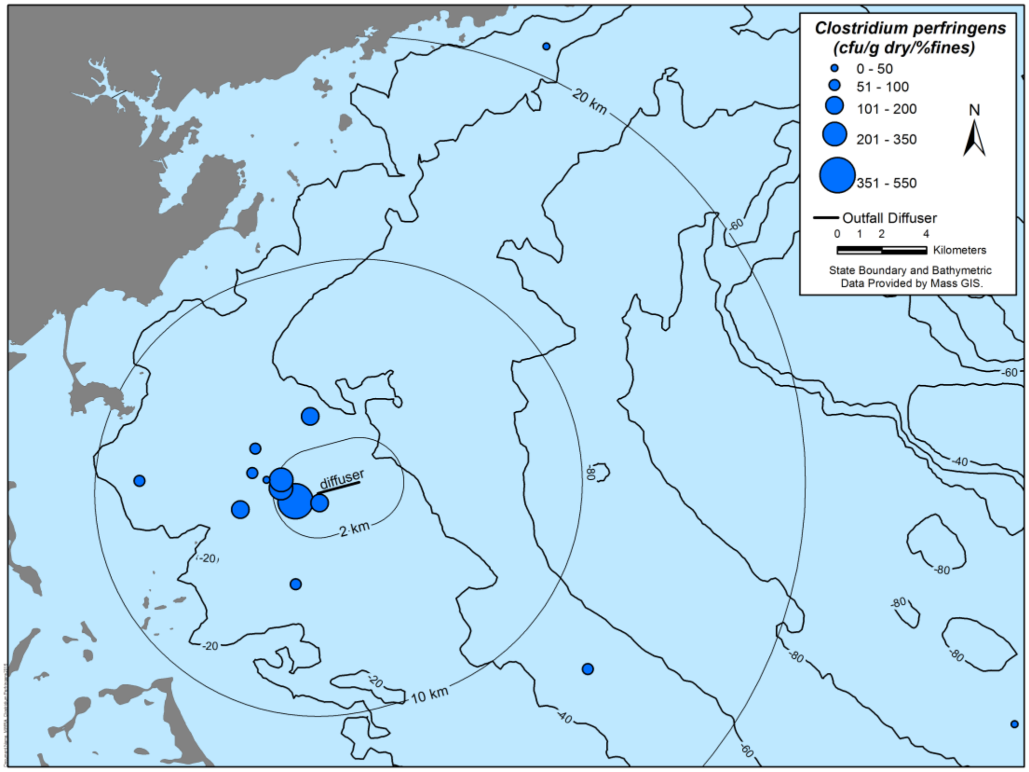

Figure 4-5. Concentrations of *Clostridium perfringens* spores, corrected for sediment grain size, in 2014.

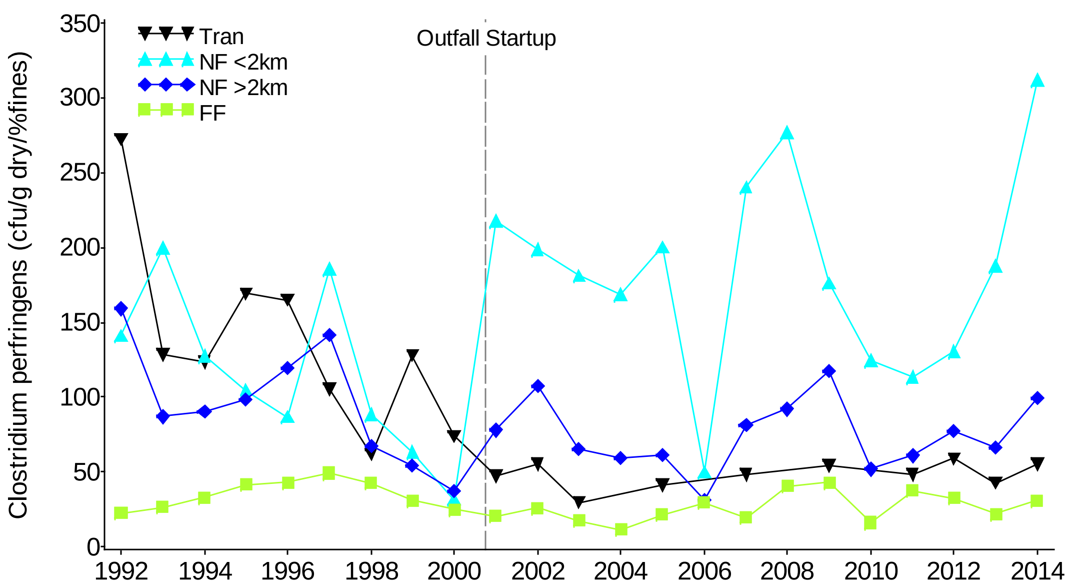

Figure 4-6. Mean concentrations of *Clostridium perfringens* spores during the baseline and outfall-discharge years. (Tran = transition area, stations located between Boston Harbor and the outfall; NF<2km = nearfield stations located within 2 km of the outfall diffusers; NF>2km = nearfield stations located further than 2 km from the diffusers; FF = farfield stations offshore from the outfall.)

Sediment Contaminants

In general, over the course of the monitoring program, concentrations of toxic contaminants in sediments have remained stable or slowly declined. Similar to other measures, concentrations of sediment contaminants tend to be higher in sediments with finer grain-size distributions. That pattern remained evident in 2014, with the finest-grained sediment stations having the highest levels of contaminants. Stations closest to Boston Harbor, the major historic source of contaminants, tend to have higher concentrations than those offshore. Statistical analyses have found no indications of any effects of the outfall on Massachusetts Bay sediments (Nestler et al. 2015).

Concentrations of mercury, for example, showed no indications of any outfall effect (Figure 4-7). Mercury concentrations at the stations closest to the outfall have remained low, lower than baseline levels in most years. Levels at nearfield stations farther from the outfall reached a historic low for the monitoring program in 2014.

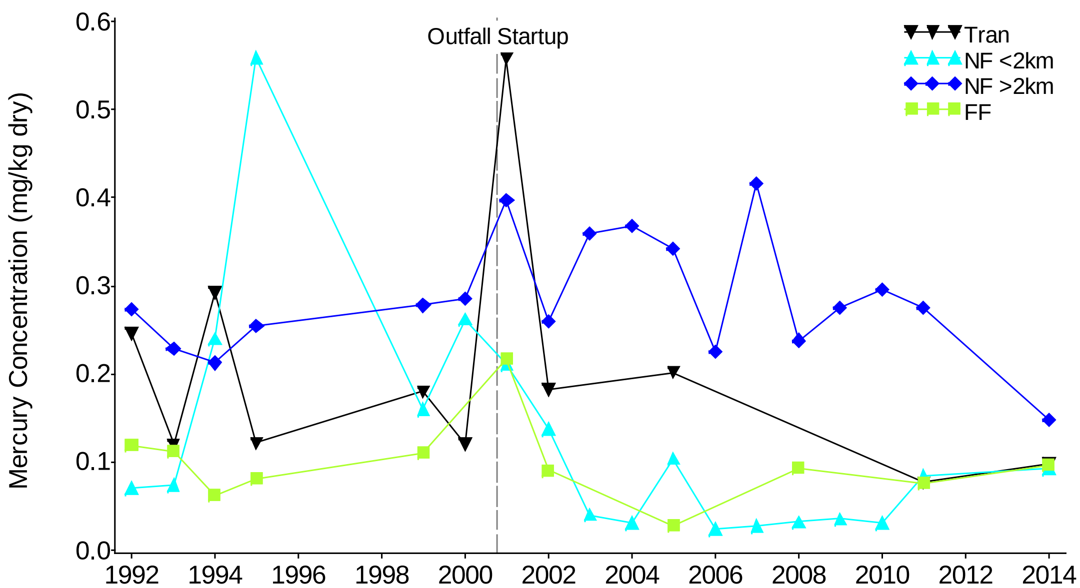

Figure 4-7. Mean concentration of mercury during the baseline and outfall-discharge years. (Tran = transition area, stations located between Boston Harbor and the outfall; NF<2km = nearfield stations located within 2 km of the outfall diffusers; NF>2km = nearfield stations located further than 2 km from the diffusers; FF = farfield stations offshore from the outfall.)

Concentrations of total polychlorinated biphenyls (PCBs) provided the best indication of the long, slow declines in levels of organic contaminants following bans in their manufacture and use (Figure 4-8). Although the data are variable, there have been some indications of declines in PCB concentrations throughout Massachusetts Bay.

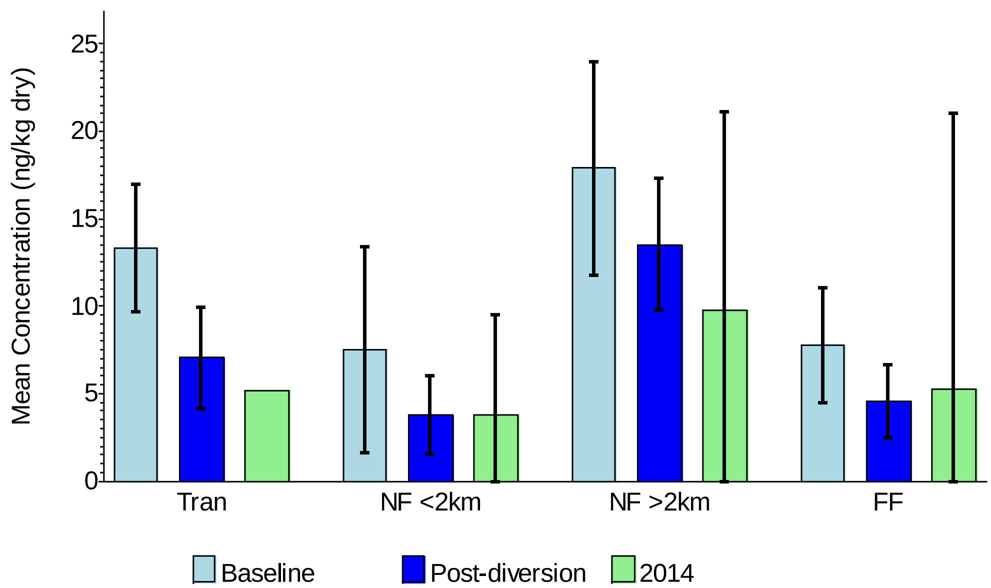

Figure 4-8. Mean PCB concentration by region, during the baseline, other post-diversion years, and 2014. (Tran = transition area, stations located between Boston Harbor and the outfall; NF<2km = nearfield stations located within 2 km of the outfall diffusers; NF>2km = nearfield stations located further 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 2014 yielded 21,863 organisms, classified into 183 species and 24 other discrete taxonomic groups (Nestler et al. 2015). Infaunal abundance was within the range observed over the monitoring program, but was appreciably higher than in 2013 in all regions except the farfield (Figure 4-9). Relative abundances of the five dominant species in the samples, those contributing at least 5% to total abundances, were low in 2014, as has been observed for several years (Figure 4-10). In particular, the polychaete *Prionospio steenstrupi*, which was the numerically dominant species during much of the 1990s and 2000s, continued to be present in relatively low numbers.

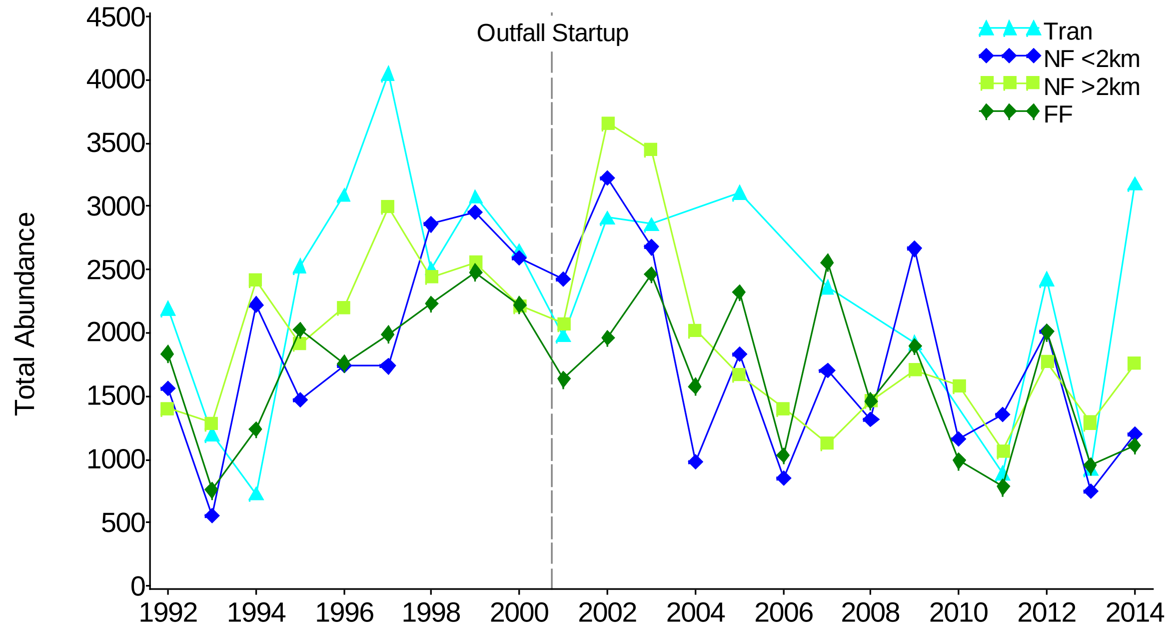

Figure 4-9. Mean infaunal abundance per sample in four areas of Massachusetts Bay, 1992–2014. (Tran = transition area, stations located between Boston Harbor and Massachusetts Bay; NF<2km = stations within 2 km of the outfall; NF>2km = nearfield stations greater than 2 km from the outfall; FF = farfield stations offshore from the outfall)

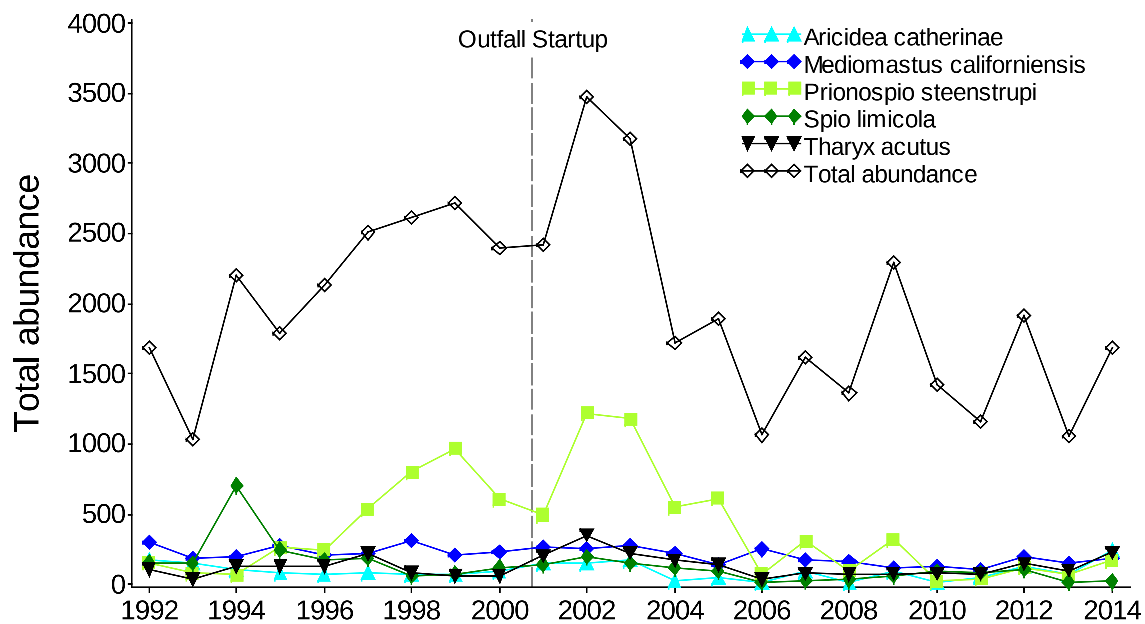

Figure 4-10. Mean abundance per sample of five dominant species compared to total abundance at nearfield stations, 1992–2014.

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 (Figure 4-11).

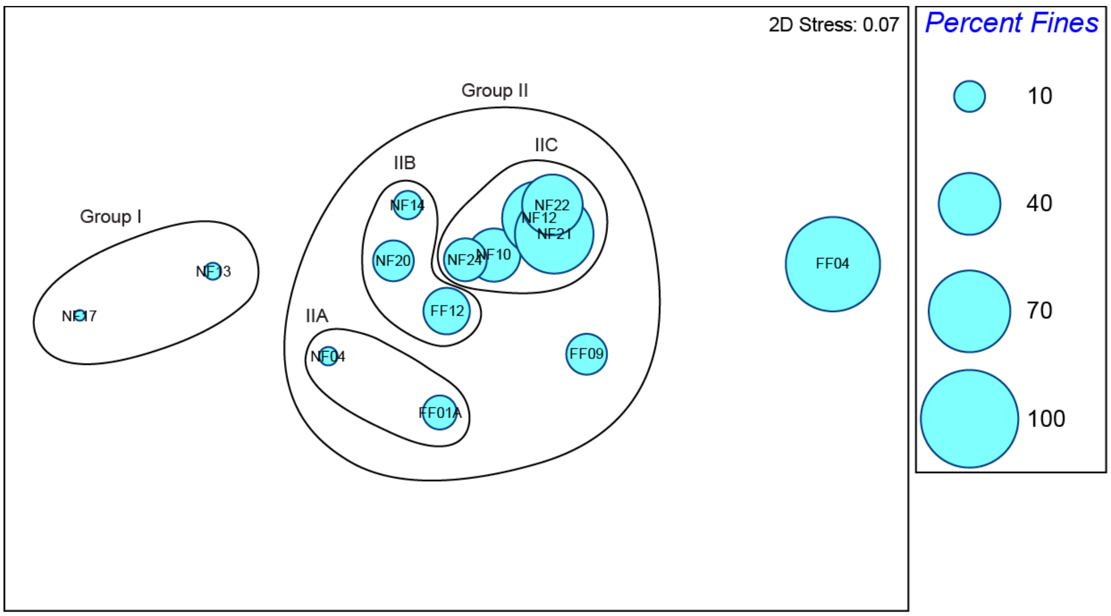

Figure 4-11. Percent fine sediments superimposed on ordination plot of the 2014 infauna samples. Each point on the plot represents one of the 14 samples; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I, II, and sub-groups) identified by cluster analysis are circled on the plot.

Sediment-profile Imaging

Sediment-profile images continued to show no adverse effects of the outfall (Nestler et al. 2015). Secondary treatment effectively reduces contaminants that might affect the sediments, and monitoring has shown that physical processes, such as storms and storm-induced sediment transport, are the primary stressors on the Massachusetts Bay 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 the effluent discharge.

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 4-12). The environmental concern before the outfall came on line was that the RPD depth would become shallower, causing stress on sensitive sediment-dwelling organisms, so a deeper RPD depth continued to indicate that there has been no adverse effect from the discharge.

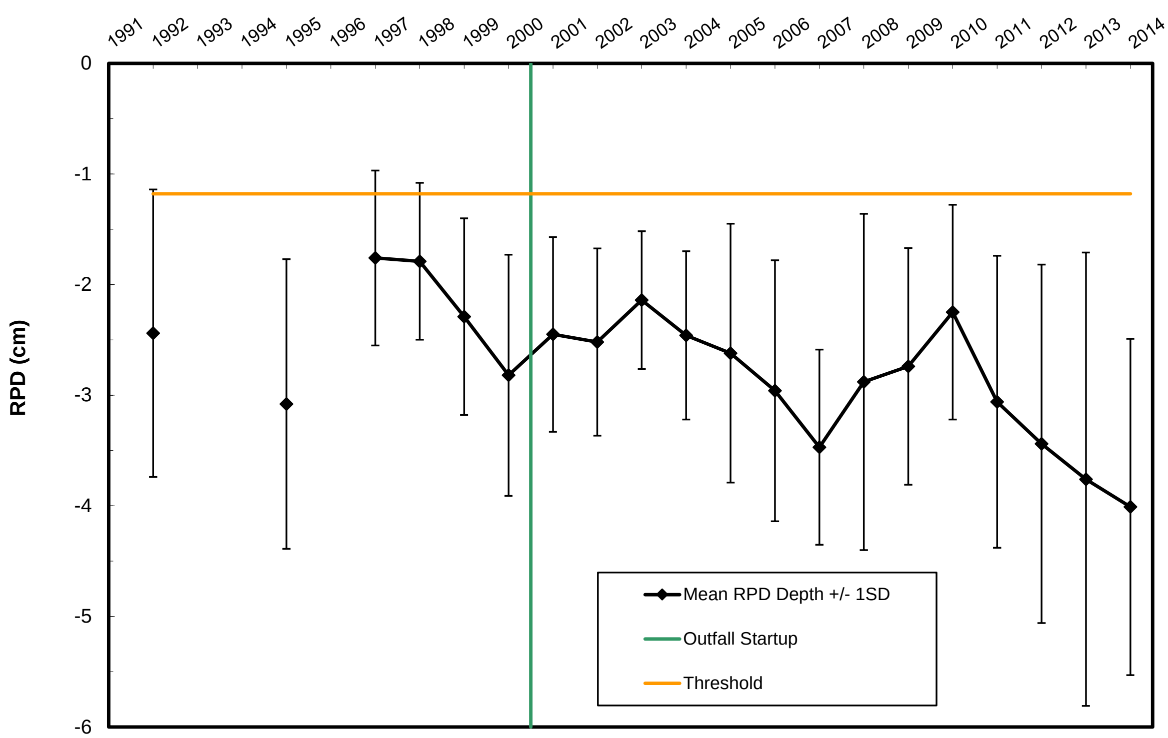

Figure 4-12. Annual apparent color RPD depth for data from nearfield stations. (mean ± standard deviation) The average RPD discharge-period mean has been deeper than the baseline mean, continuing to indicate that there has been no adverse effect from the discharge.

Counter intuitively, the camera images detected a trend beginning in 2013 towards increased numbers of “pioneering” or “Stage I” organisms. This finding would be unexpected where there are deepening RPD depths. It was also not anticipated from the infaunal organism analyses presented above, either from the identification of individual animals or from the diversity and other community-parameter measurements. The change appears to be related to a slight coarsening of sediment grain-size and a resulting decline in visible biogenic structures in the sediment-profile images, a factor in determining succession stage.

Hard-bottom Communities

Photographic coverage of the hard-bottom habitat in the vicinity of the outfall in 2014 included 13–28 minutes of video footage at each station. A total of 488 minutes of video were viewed and analyzed. The footage was generally similar to that taken in 2011, the last time that hard-bottom communities were surveyed (Nestler et al. 2015). The species and the number of species have remained relatively constant over the course of the monitoring program. The distribution of the species has also remained relatively constant. Coralline algae continued to be the most common and widespread component of the hard-bottom benthic communities, being found at 18 of the 23 stations. Lush growth continued to be found on the open diffuser head, included as one of the stations (Figure 4-13).

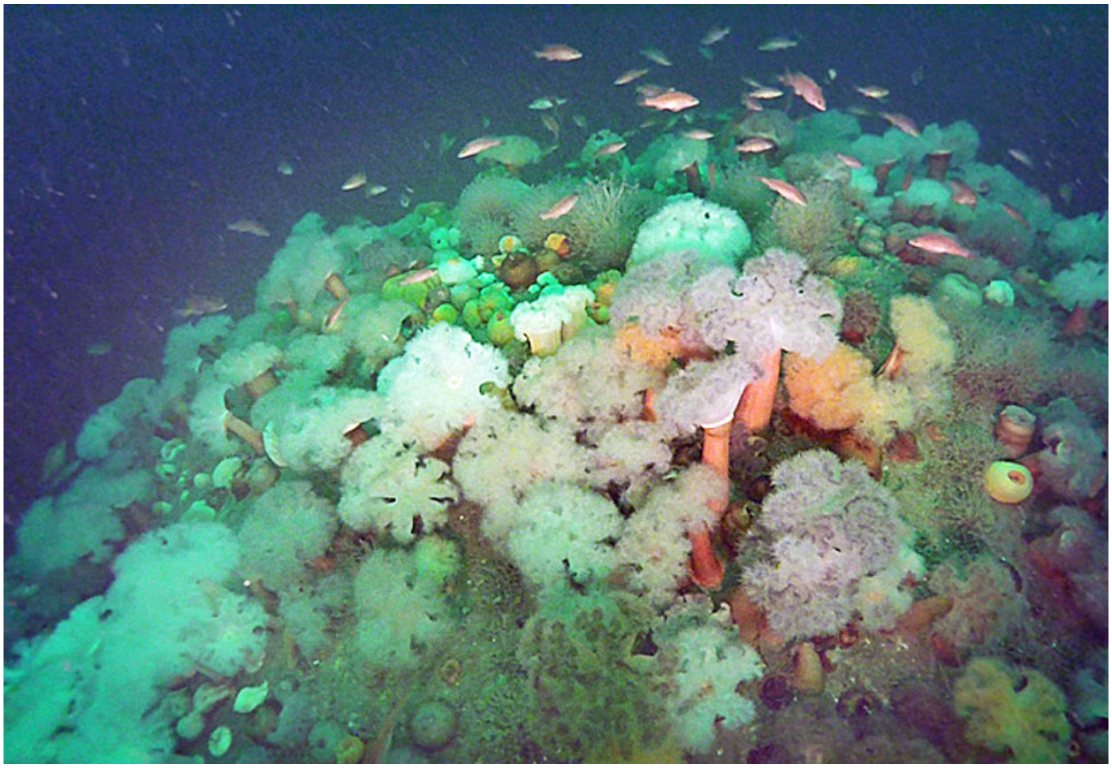

Figure 4-13. Lush growth on active diffuser in 2014.

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 depositional part of the sanctuary, in Stellwagen Basin, which is considered a long-term sediment sink.

Sediment chemistry has not changed at Station FF04, where, because of its depositional environment, some accumulation of contaminants might be expected to occur. For example, mercury and PCB levels at Station FF04 have remained constant throughout the duration of monitoring (Figures 4-14 and 4-15).

Station FF04 is considered typical of the deep waters offshore from the outfall, representative of a number of stations monitored in earlier years of the monitoring program, and it continues to support infaunal communities typical of what was found at the larger suite of deepwater stations. The deepwater stations, including Station FF04, have always shown distinct differences from those found at shallower stations, probably due to their depth, their fine-grained sediments (see Figure 4-11, above), and their distance from shore.

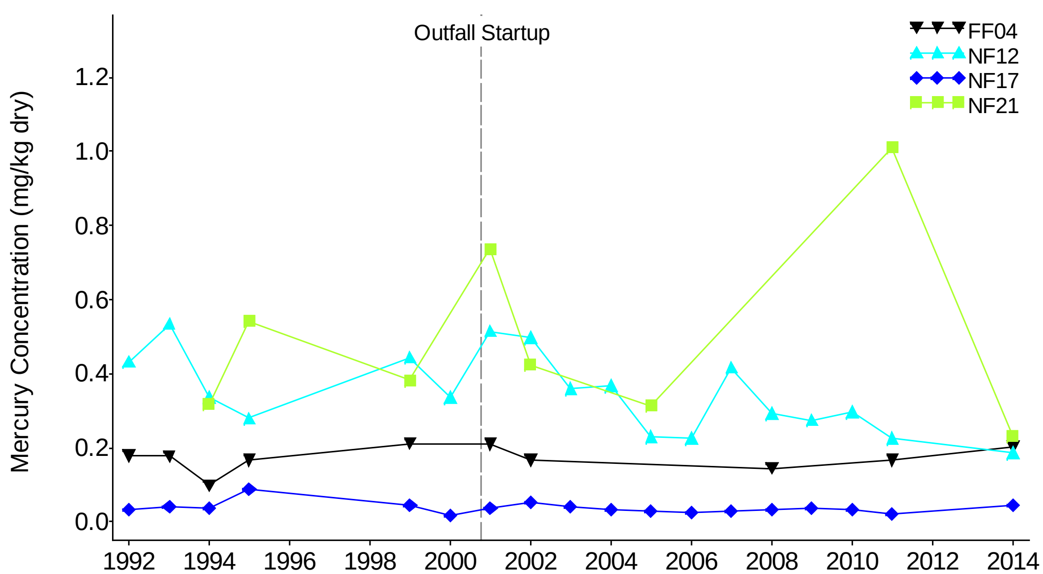

Figure 4-14. Mean concentrations of mercury at selected stations, 1992–2014. Station FF04 is within Stellwagen Basin, a long-term sediment sink.

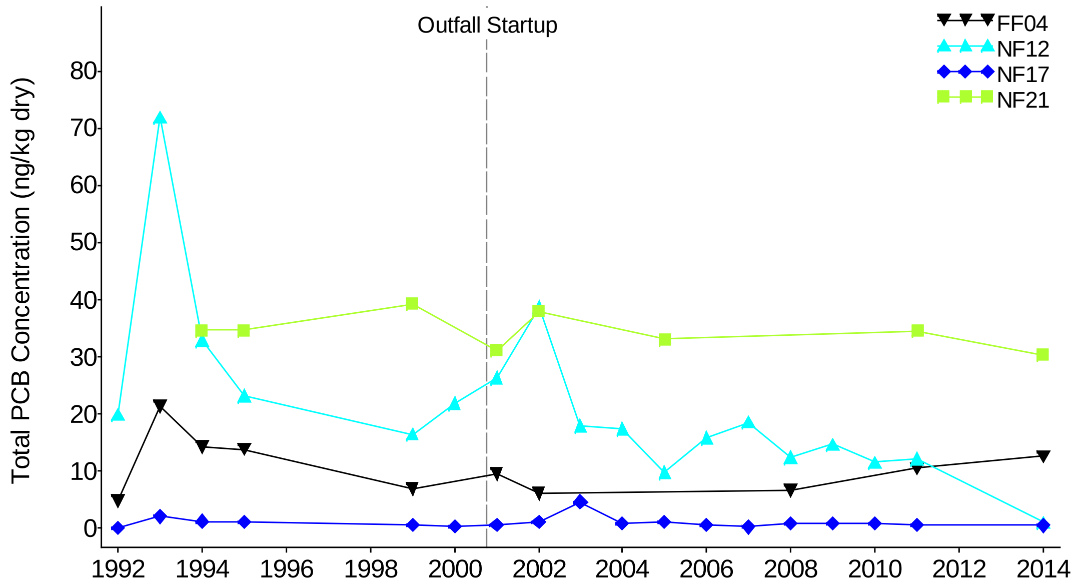

Figure 4-15. Mean concentrations of total PCBs at selected stations, 1992–2014. Station FF04 is within Stellwagen Basin, a long-term sediment sink.

Boston Harbor

While the chemistry and biology of the Massachusetts Bay sea floor have not been affected by the relocated outfall, conditions have greatly improved and continue to improve in Boston Harbor as a result of the Boston Harbor Project and more recent improvements, including enhancements to treatment and remediation of combined sewer overflows. MWRA has conducted ongoing sea-floor monitoring in Boston Harbor since 1991. Annual sediment and infauna samples are taken from nine stations (Figure 4-16).

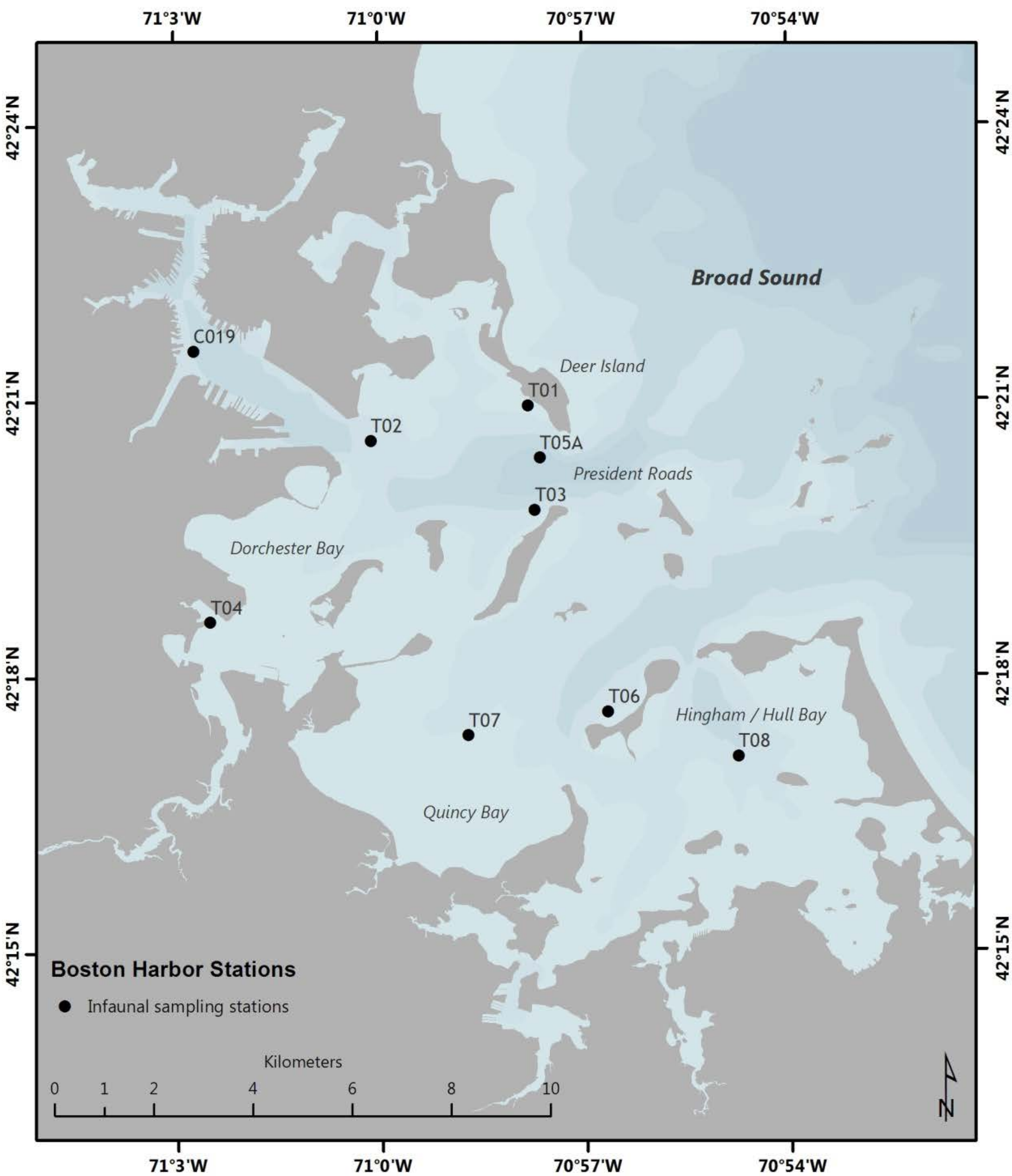

Figure 4-16. Soft-bottom sampling stations in Boston Harbor. Nine stations are sampled each year for sediment characteristics and infauna analyses.

Concentrations of total organic carbon and *Clostridium perfringens* spores have declined over time, and infaunal diversity has increased. Multivariate analyses have found two main faunal assemblages, one found throughout the harbor and a second found in slightly more organically enriched sediments in the inner harbor and in Quincy Bay (Figure 4-17). The station most different from others is T04, at the mouth of Savin Hill Cove in Dorchester Bay. The infaunal assemblages likely reflect a gradient in tidal flushing as well as differences in inputs of organic matter, nutrients, and other possible contaminants.

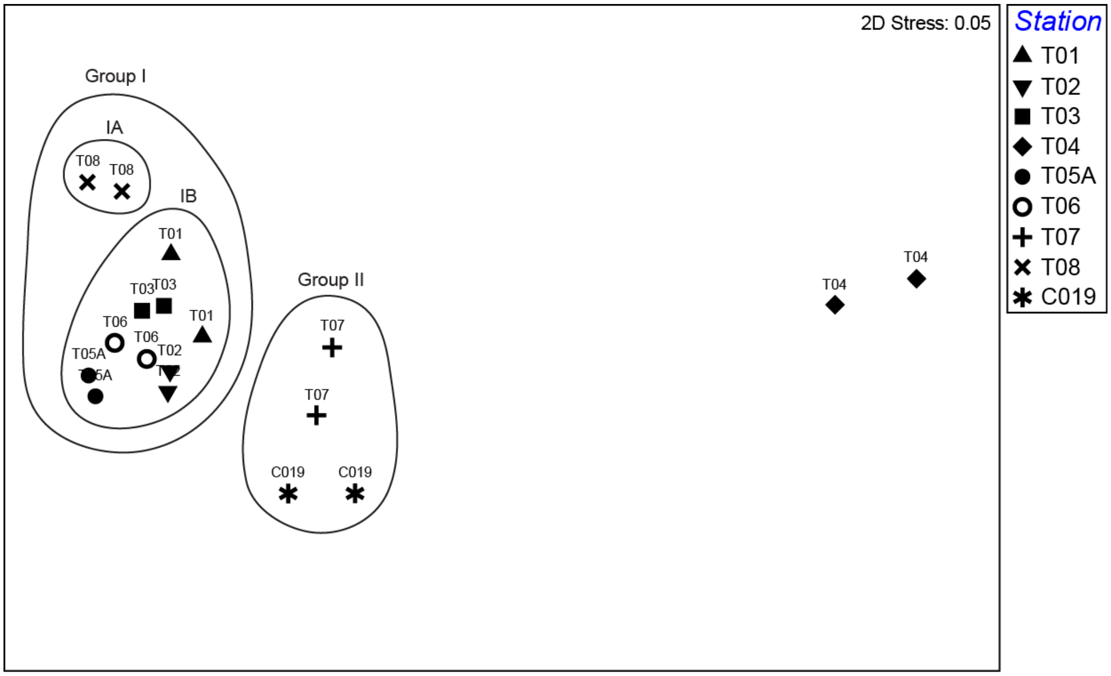

Figure 4-17. Ordination plot of 2014 Boston Harbor infauna samples (2 samples/station). Group I comprises stations from the outer harbor; Group II includes Station C019 in the inner harbor and Station T07 in Quincy Bay. The assemblage most different from others was found at Station T04, at the mouth of Savin Hill Cove, in Dorchester Bay.

Sediment-profile images have also documented improvements in Boston Harbor sediments. An eelgrass bed has persisted at Deer Island Flats since 2008. Improvements continued to be observed in 2014; for example, the RPD has deepened at Station T02, in President Roads near Deer Island Flats (Figure 4-18). Tucker et al. (2014) found that in the early 1990s, sediment oxygen demand and nutrient fluxes at this station increased when macrofauna, particularly tube-building amphipods, colonized the sediments. As reductions to loading to the harbor progressed, mean rates of oxygen uptake and release of ammonium, nitrate, and phosphate decreased. Higher sediment redox potential resulted in the deepening RPD.

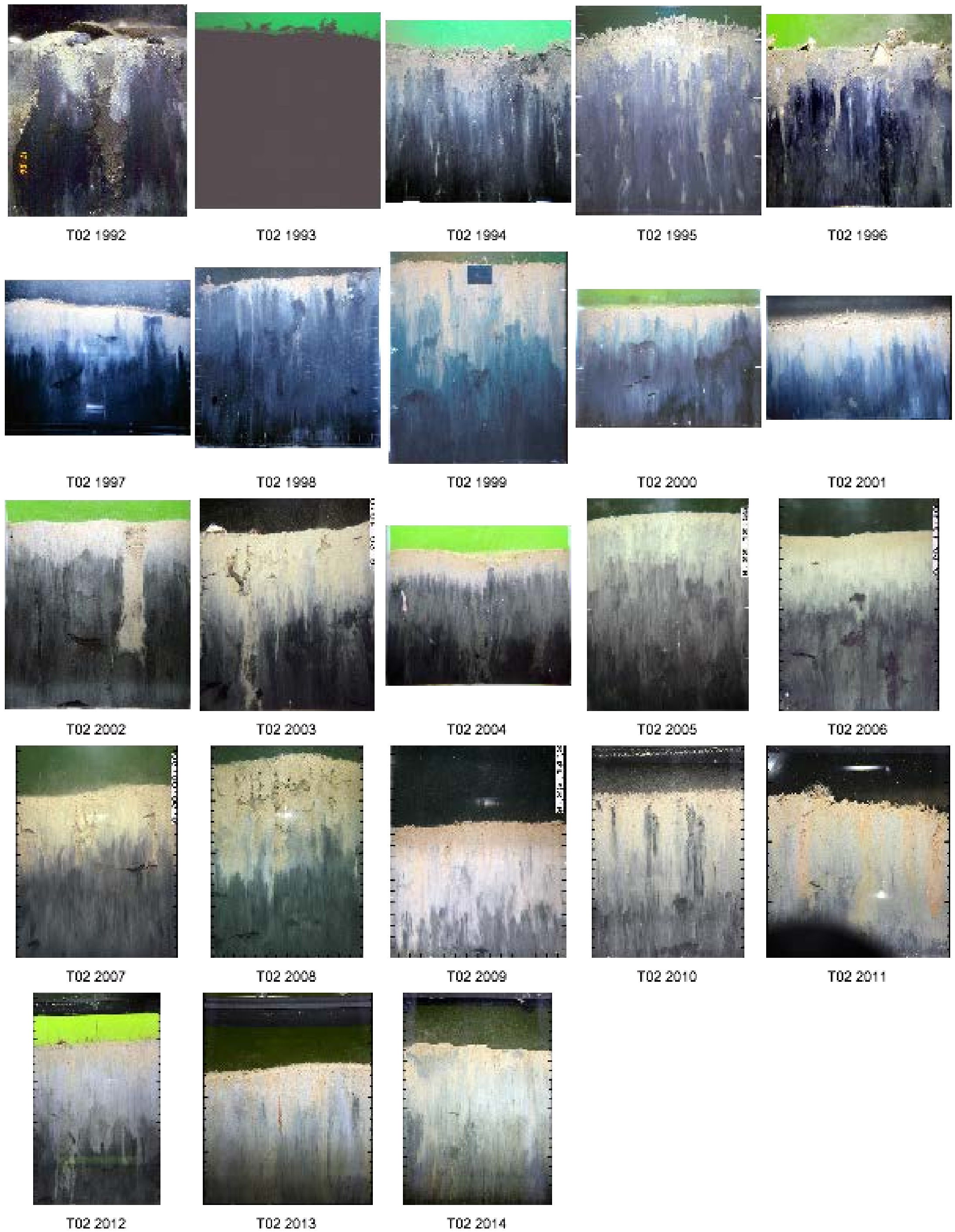

Figure 4-18. Sediment profiles from Station T02, in President Roads, near Deer Island Flats, 1992–2014. Improvements in habitat quality occurred from the 1990s to the late 2000s and persisted in 2014. Scales along the sides of each image are in cm.

Contingency Plan Thresholds

All sediment-contaminant concentrations remained well below Contingency Plan thresholds in 2014, and RPD depth remained more than three times deeper than the caution level. However, for a fifth 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 upper caution-level ranges (Figure 4-19). Two other community threshold parameters, total number of species per sample (species richness) 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.

The exceedances of Shannon-Wiener diversity and Pielou's evenness have been shown to be driven by changes in abundances of a few dominant species (Nestler et al. 2015). Analyses have 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.

Table 4-1. Contingency Plan threshold values and 2014 results for sea-floor monitoring.

Parameter	Baseline	Caution Level	Warning Level	2014 Results
Polycylclic aromatic hydrocarbons (PAHs) (ng/g dry weight)				
Acenaphthene	22.7 – 43.5	None	500	28.3
Acenaphylene	30.3 – 43.1	None	640	11.1
Anthracene	101 – 159	None	1,100	77.3
Benzo(a)anthracene	206 – 302	None	1,600	176
Benzo(a)pyrene	204 – 298	None	1,600	182
Chrysene	164 – 296	None	2,800	172
Dibenzo(a,h)anthracene	27.8 – 38.3	None	260	26.7
Fluoranthene	422 – 621	None	5,100	389
Fluorene	35.5 – 66.6	None	540	32.5
Naphthalene	53.6 – 103	None	2,100	31.6
Phenanthrene	273 – 431	None	1,500	247
Pyrene	412 – 579	None	2,600	362
Total HMW PAH	2,790 – 3,850	None	9,600	2,440
Total LMW PAH	1,390 – 1,630	None	3,160	814
Total PAHs	4,180 – 5,400	None	44,792	3,260
Other organic contaminants (ng/g dry weight)				
p,p'-DDE	0.386 – 1.00	None	27	0.37
Total DDTs	2.51 – 5.69	None	46.1	0.79
Total PCBs	10.2 – 20.2	None	180	7.17
Metals (µg/g dry weight)				
Cadmium	0.0727 – 0.185	None	9.6	0.11
Chromium	59.2 – 79.9	None	370	47.6
Copper	19.1 – 25.2	None	270	22.9
Lead	41.1 – 46.3	None	218	32.7
Mercury	0.159 – 0.353	None	0.71	0.12
Nickel	15.7 – 17.2	None	51.6	8.46
Silver	0.335 – 0.485	None	3.7	0.17
Zinc	49.5 – 57.5	None	410	41.5
Sediment parameters				
RPD depth	NA	<1.18 cm	None	4.01 cm
Benthic community parameters				
Species per sample	NA	<42.99 or >81.85	None	62.73
Fisher's log-series alpha	NA	<9.42 or >15.8	None	13.35
Shannon diversity	NA	<3.37 or >3.99	None	4.03, caution level exceedance
Pielou's evenness	NA	<0.57 or >0.67	None	0.68, caution level exceedance
% opportunists	NA	>10%	>25%	0.12%

HMW = high molecular weight; LMW = low molecular weight
NA = not applicable; RPD = redox potential discontinuity

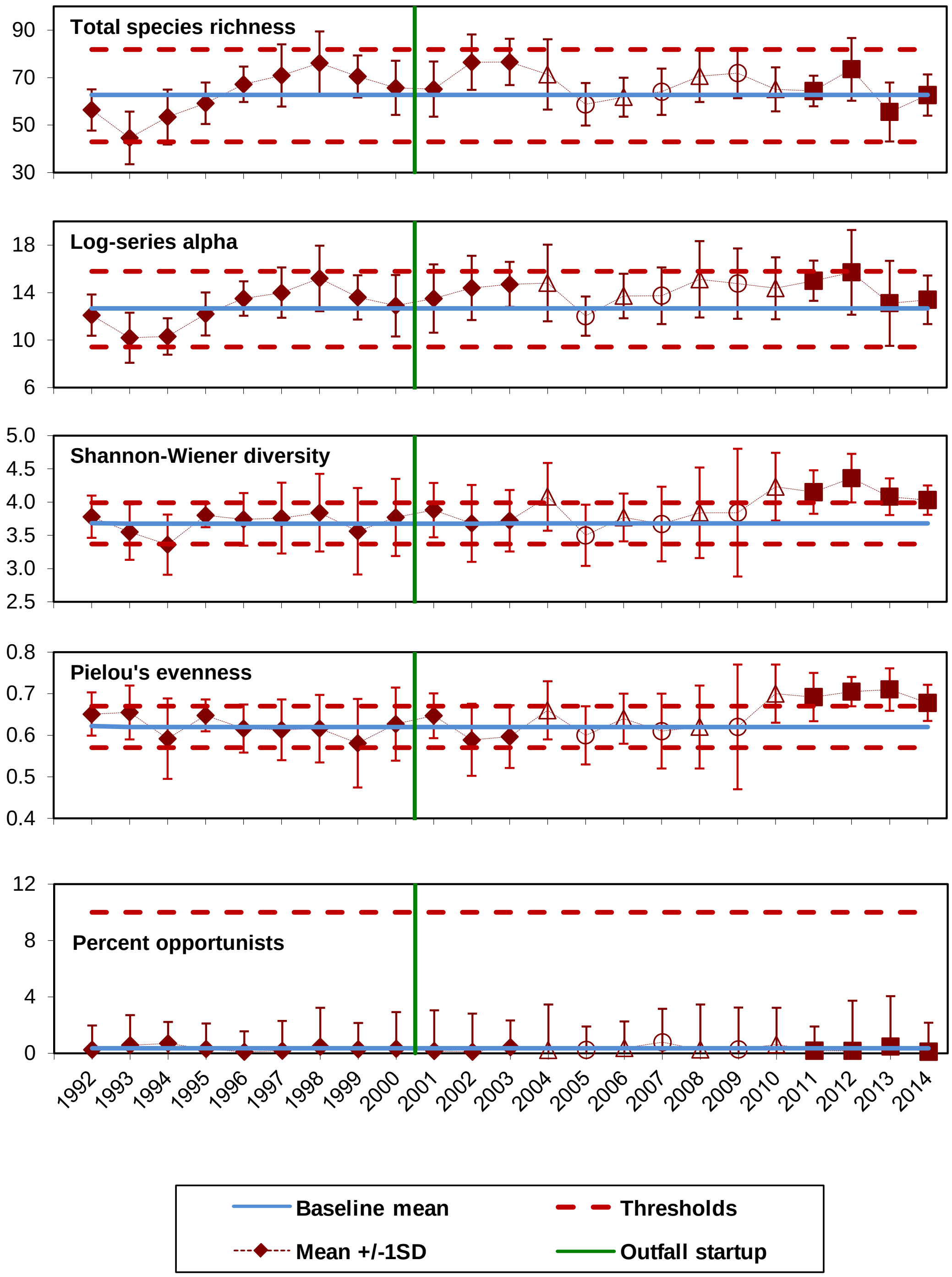

Figure 4-19. Annual community parameters with nearfield Contingency Plan thresholds. (mean ± standard deviation) The varied symbols represent differences in the stations sampled over the years of the program. Results were tested against thresholds calculated for each sampling design, but only the current 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.

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 cage-deployed blue mussels. Sampling and analysis in 2014 was limited to winter flounder health.

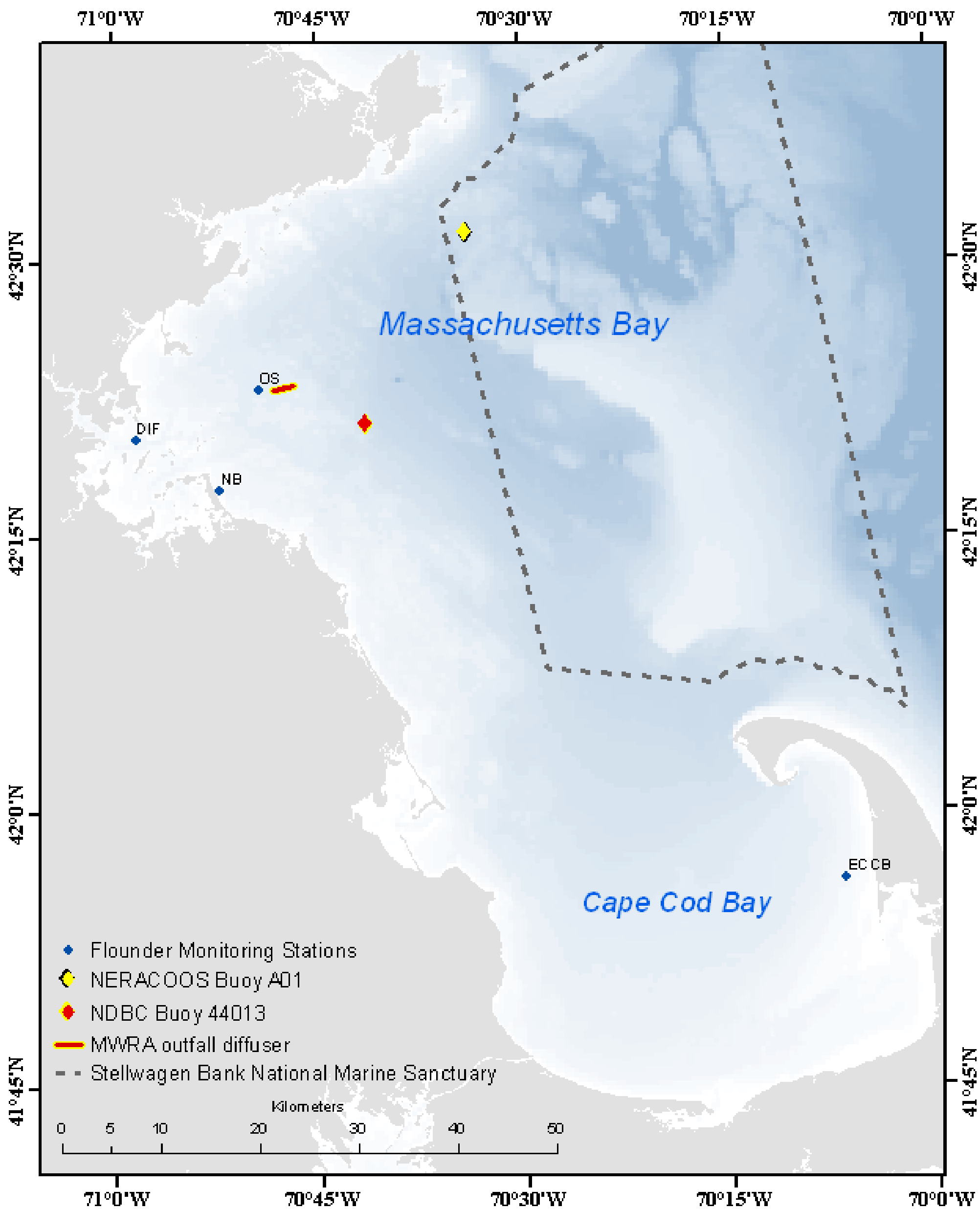

Figure 5-1. Flounder sampling sites. Also shown are the two instrumented buoys, the MWRA outfall diffuser, and the boundaries of the Stellwagen Bank National Marine Sanctuary. OS=outfall site; DIF=Deer Island Flats; NB=Nantasket Beach

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 2014, 50 sexually mature flounder were collected from each site (Moore et al. 2014). 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, sometimes referred to as "ghost gear," continued to interfere with catches, particularly in muddy depressions at the outfall and at Deer Island Flats (Figure 5-2).

Figure 5-2. "Ghost" lobster gear brought up in a flounder trawl.

Average ages of fish were relatively high in 2014. Lengths and weights were somewhat lower than typically observed but remained within historic ranges at all sites. As has been common throughout the duration of the monitoring program, the catches were dominated by females. Skewed sex ratios are common in winter flounder populations, possibly related to temperature, self-segregation by age and sex, and different growth rates of males and females. There are no indications of any effect of the Massachusetts Bay effluent discharge on sex ratios. Catches from eastern Cape Cod Bay, the station farthest (75 km) from the outfall, have in many years had the highest proportion of females.

Measures of external condition, such as fin erosion and blind-side ulcers, 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 rare in 2014. Elevated occurrence of ulcers occurred in 2003–2006 and again 2011. The pathology of the ulcers has been studied but is not well understood.

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 lower at the outfall than in 2013 (Figure 5-3). CHV incidence in fish from Deer Island Flats reached a record low, remaining well below the relatively high baseline levels. Average severity of CHV (not shown) also remained lower than baseline levels.

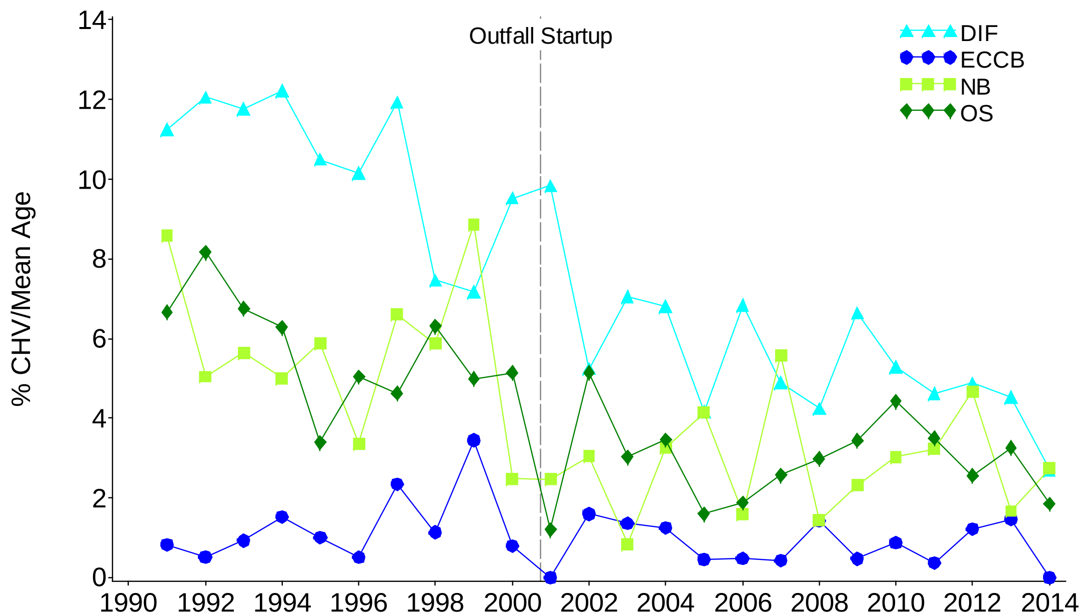

Figure 5-3. Annual prevalence of centrotubular hydropic vacuolation (CHV), corrected for age. (DIF=Deer Island Flats, ECCB=Eastern Cape Cod Bay, NB=Nantasket Beach, OS=outfall site)

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 below). Neoplasia has never been observed in a fish taken from the vicinity of the outfall.

Boston Harbor

While there have been no indications of adverse effects near the outfall, there have been major improvements in flounder health in Boston Harbor. 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 off Nantasket Beach, outside the harbor.

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, such as CHV, 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 5-4). 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, CHV, has dropped by more than half, reaching a new low in 2014.

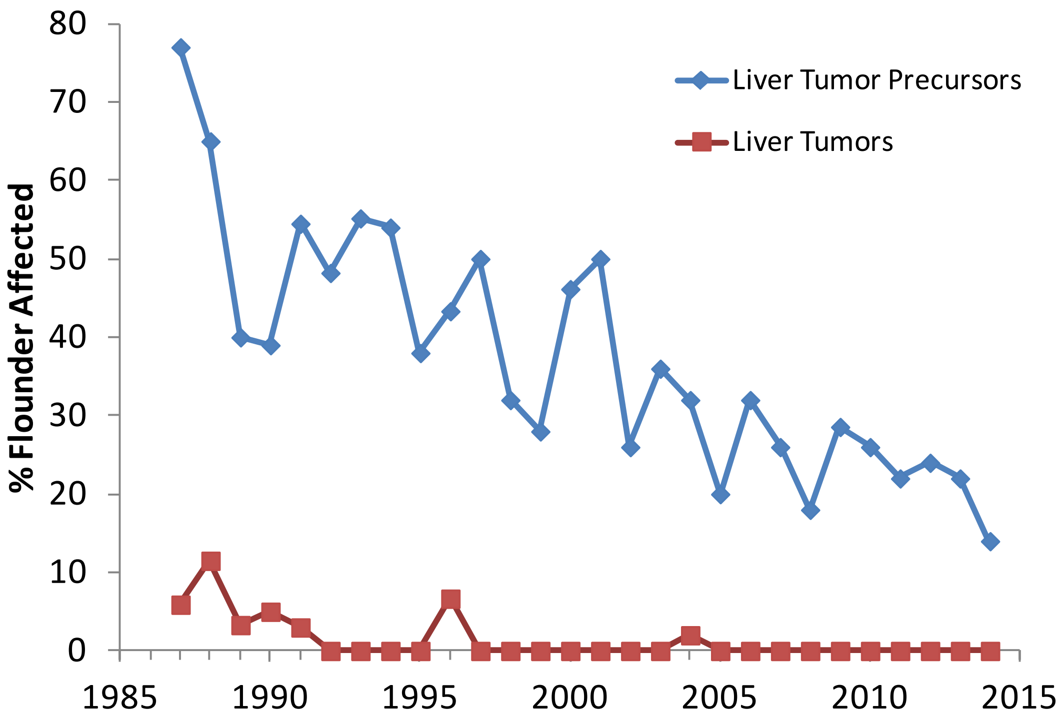

Figure 5-4. Incidence of liver tumor precursors and liver tumors in winter flounder from Deer Island Flats in Boston Harbor, 1987–2014. Incidence of the tumor precursor CHV has fallen, reaching a new low in 2014, and tumors are now rare.

Contingency Plan Thresholds

There was no exceedance of the one Contingency Plan threshold for fish and shellfish in 2014 (Table 5-1). Incidence of CHV, the most common indicator of liver disease in the winter flounder of the region, was 10% in fish taken from the vicinity of the outfall, lower than the 44.9% caution threshold and the baseline average. CHV incidence in flounder was the only threshold parameter calculated for 2014; chemistry parameters in flounder, lobster, and mussels are measured every three years and will be reported next in 2015.

Table 5-1. Contingency Plan threshold values and 2014 result for fish-and-shellfish monitoring.

Parameter	Baseline	Caution Level	Warning Level	2014 Results
Liver disease CHV	24.4%	44.9%	None	10%

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 overview focuses on bacterial water quality in Boston Harbor; water-quality modeling; and ongoing monitoring by the Center for Coastal Studies in Cape Cod Bay.

Boston Harbor Bacterial Water Quality

Before the Boston Harbor Project, bacterial pollution from untreated combined sewer overflows (CSOs), incompletely treated primary wastewater effluent, and daily discharge of digested sewage sludge (biosolids) resulted in widespread beach closures and violations of bacterial water-quality standards throughout the harbor. Degraded water quality from bacterial pollution was one of the main drivers behind the creation of MWRA and the court-ordered Boston Harbor Project.

Before 1991, wet-weather exceedances of water-quality standards were common and severe, with many parts of Boston Harbor exceeding the *Enterococcus* bacteria swimming standard (35 colonies/100 ml), sometimes by a factor of five or more (Figure 6-1, left). Since 2007, after the completion of DITP and most CSO projects, water quality in most of Boston Harbor and its tributaries meets the *Enterococcus* standard, even in wet weather (Figure 6-1, right). Remaining wet-weather *Enterococcus* exceedances occur in smaller areas and are less severe.

The improvements in Boston Harbor have not been accompanied by any degradation to Massachusetts Bay. MWRA conducts bacterial monitoring in the vicinity of the Massachusetts Bay outfall in support of the Massachusetts Division of Marine Fisheries shellfish sanitation programs. Results from that monitoring since the offshore outfall came on line in 2000 have shown that bacterial water quality meets the most sensitive standards, even in wet weather. A report on those results is currently in preparation.

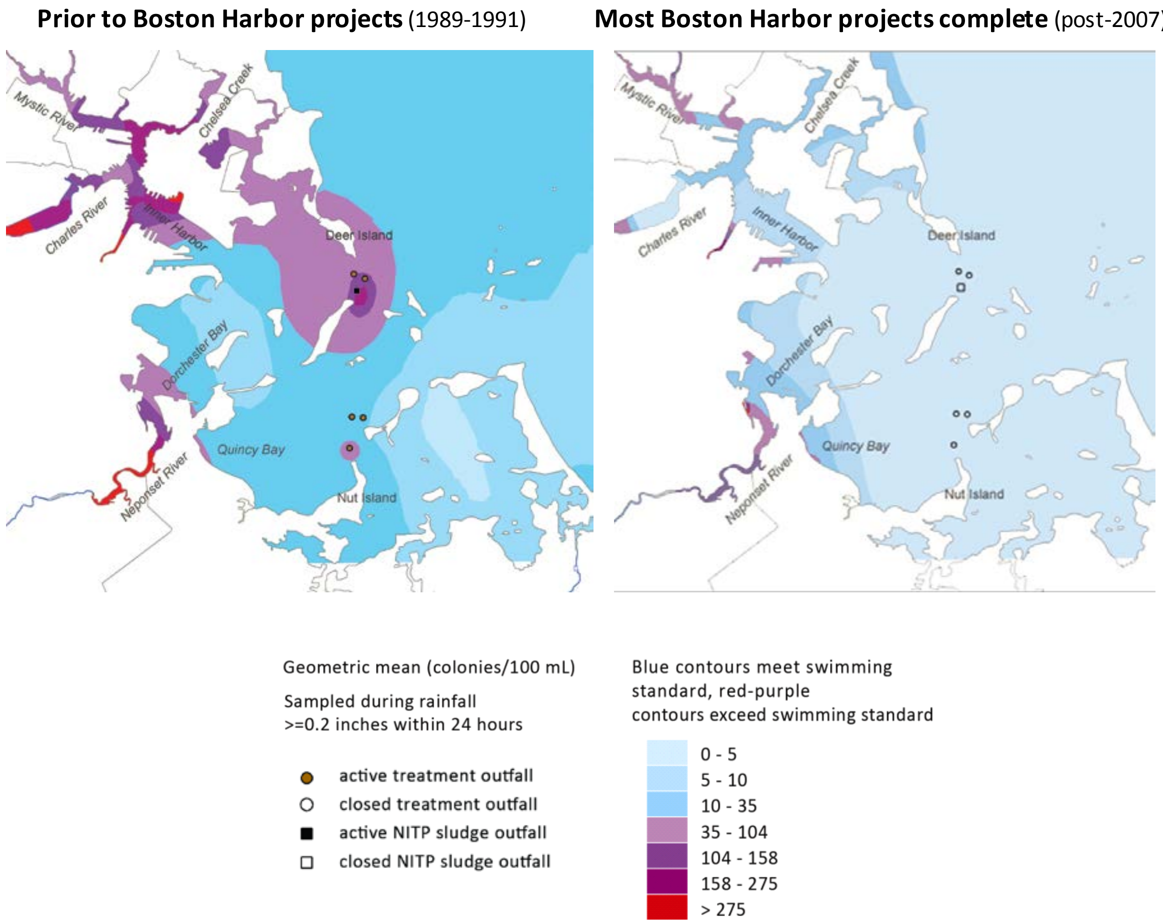

Figure 6-1. Bacterial water quality prior to the Boston Harbor Project and after completion of the treatment plant and most CSO projects.

Massachusetts Bay Water-Quality Modeling

MWRA uses the numerical Bays Eutrophication Model to simulate and predict the physical and biological conditions in Massachusetts Bay. The model includes a hydrodynamic (ocean circulation) and a water quality model. It has been continuously updated to incorporate new research methods and to improve agreement of model results with monitoring observations.

The most recent modeling efforts included simulations to examine the sensitivity of water quality to hypothetical changes in nutrient loads from the Massachusetts Bay outfall (Zhou et al. 2015). One impetus for the model runs was that a new program for co-digestion of engineered food wastes at DITP is under consideration. Initial estimates suggest that the additional input could increase nutrient concentrations in the effluent by up to 5%. Model runs used 2013 conditions and included hypothetical 10% and 100% nutrient increases, as well as a no-increase control. All other conditions were kept the same. Projections for concentrations of nutrients, chlorophyll, and dissolved oxygen were compared between model runs.

Past modeling and data analyses had shown that the outfall has little effect on the function of Massachusetts Bay, and the new simulations using 2013 conditions largely confirmed those results (Figures 6-2, 6-3). With a 10% increase in nutrient loads, concentrations of dissolved inorganic nitrogen increased only in the immediate vicinity of the outfall, primarily near the sea floor. With a 100% nutrient increase, dissolved inorganic nitrogen levels were substantially higher, about 53% near the seafloor in the vicinity of the outfall. A 10% increase resulted in almost imperceptible effects on chlorophyll and dissolved oxygen (not shown), while a 100% increase resulted in model projections showing modest changes, up to a 7% increase in chlorophyll concentrations and less than a 0.5% decrease in dissolved oxygen levels.

The 2013 nutrient loads used in the hypothetical runs were considered to be representative of typical conditions, as interannual variation in nutrient loads has been small throughout the duration of the program. Results suggested that even a 10% increase, a level that would exceed the effluent Contingency Plan threshold for nitrogen, would exert little effect on the ecological health of Massachusetts Bay.

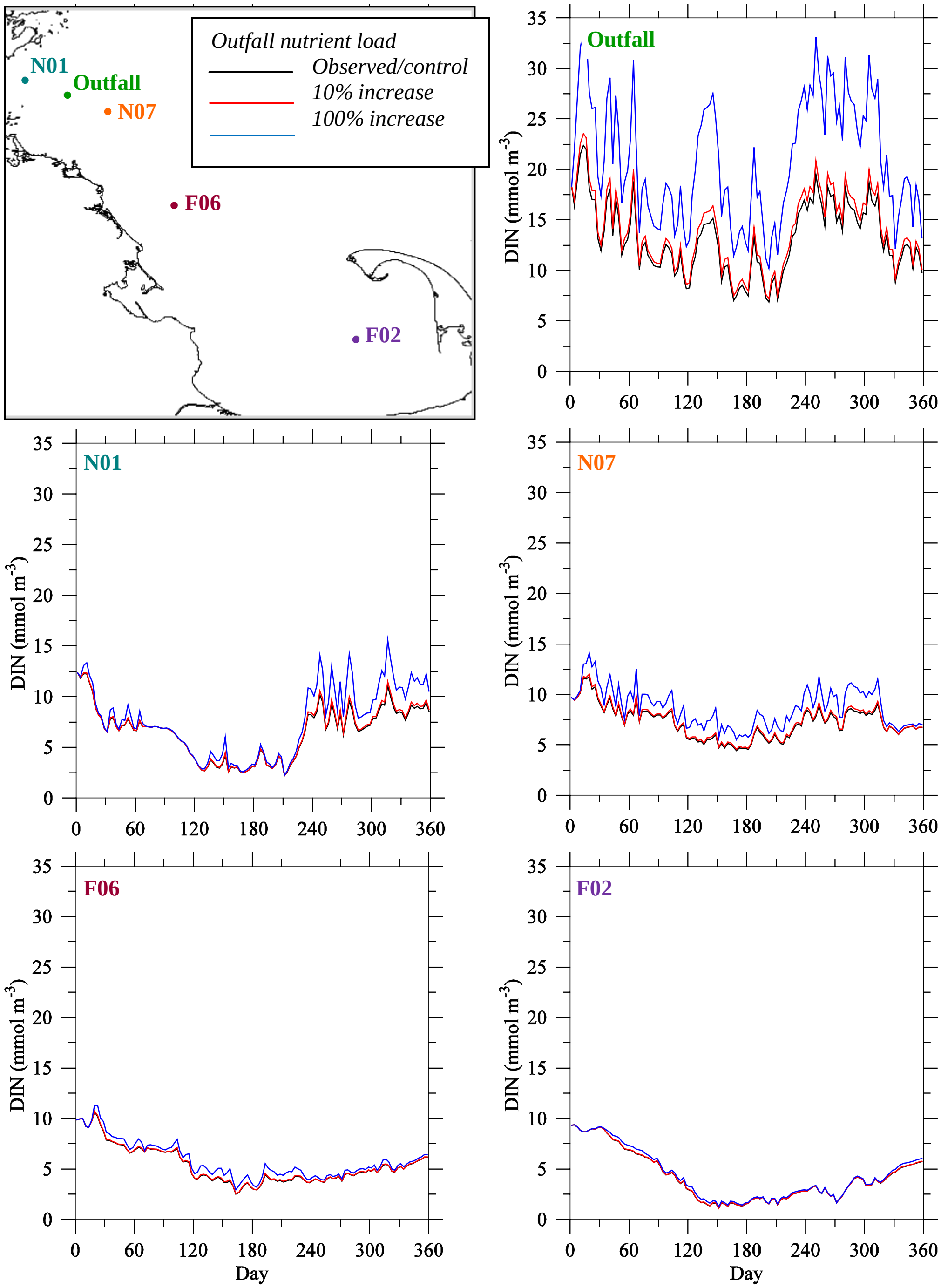

Figure 6-2. Modeled dissolved inorganic nitrogen concentrations in bottom waters at selected stations. Model runs based on 2013 conditions. Black lines = control; red = 10% increase in nutrient load; blue = 100% increase. Where the three traces overlie each other, only the blue trace appears; where red and black traces overlie each other but differ from blue, only the red trace appears.

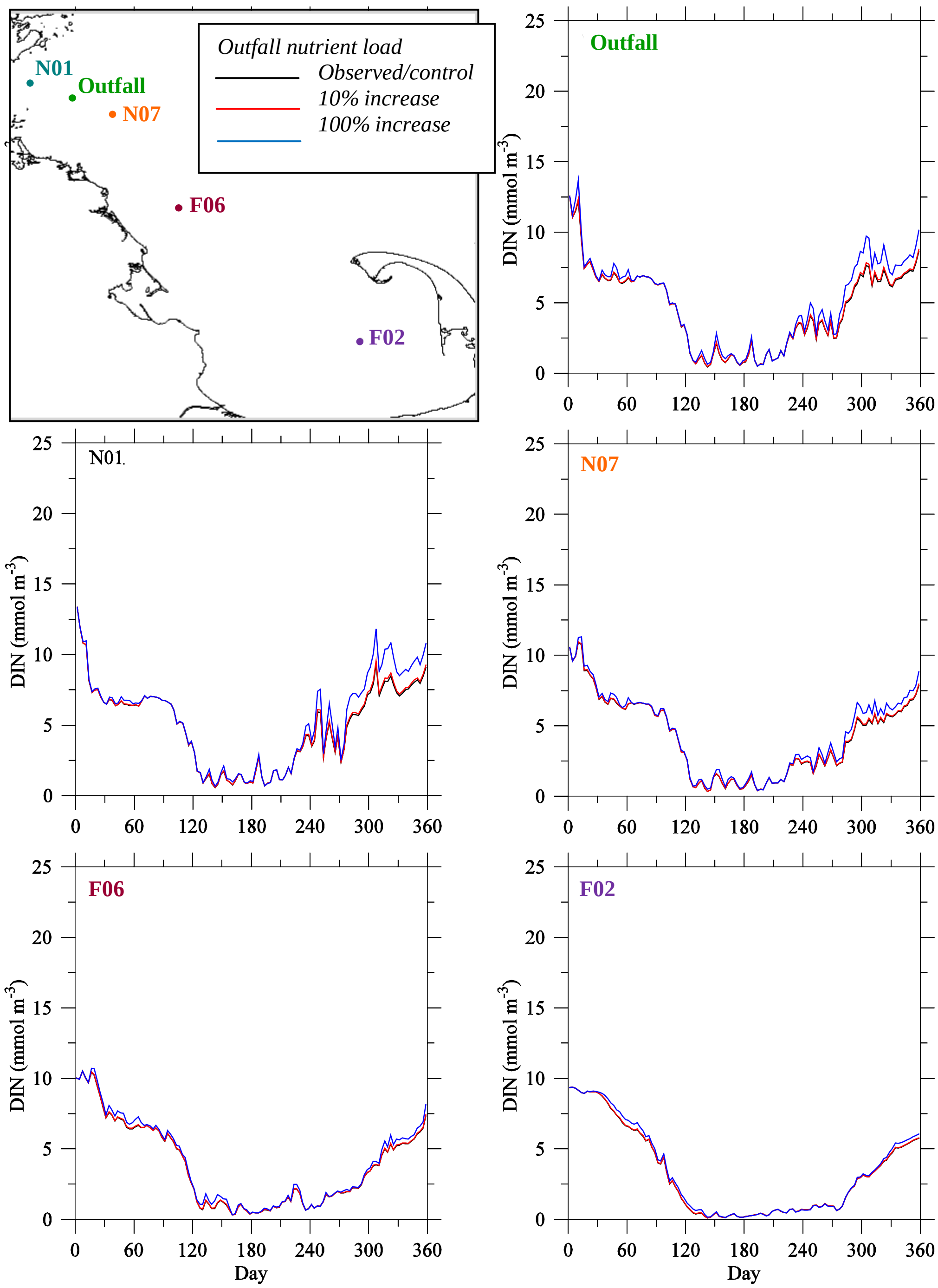

Figure 6-3. Modeled dissolved inorganic nitrogen concentrations in surface waters at selected stations. Model runs based on 2013 conditions. Black lines = control; red = 10% increase in nutrient load; blue = 100% increase. Where the three traces overlie each other, only the blue trace appears; where red and black traces overlie each other but differ from blue, only the red trace appears.

Cape Cod Bay Studies

The Center for Coastal Studies has conducted a monitoring program in Cape Cod Bay for many years, and since 2011, MWRA has collaborated on a portion of the program. The Center for Coastal Studies monitoring program includes MWRA water-column 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 6-4).

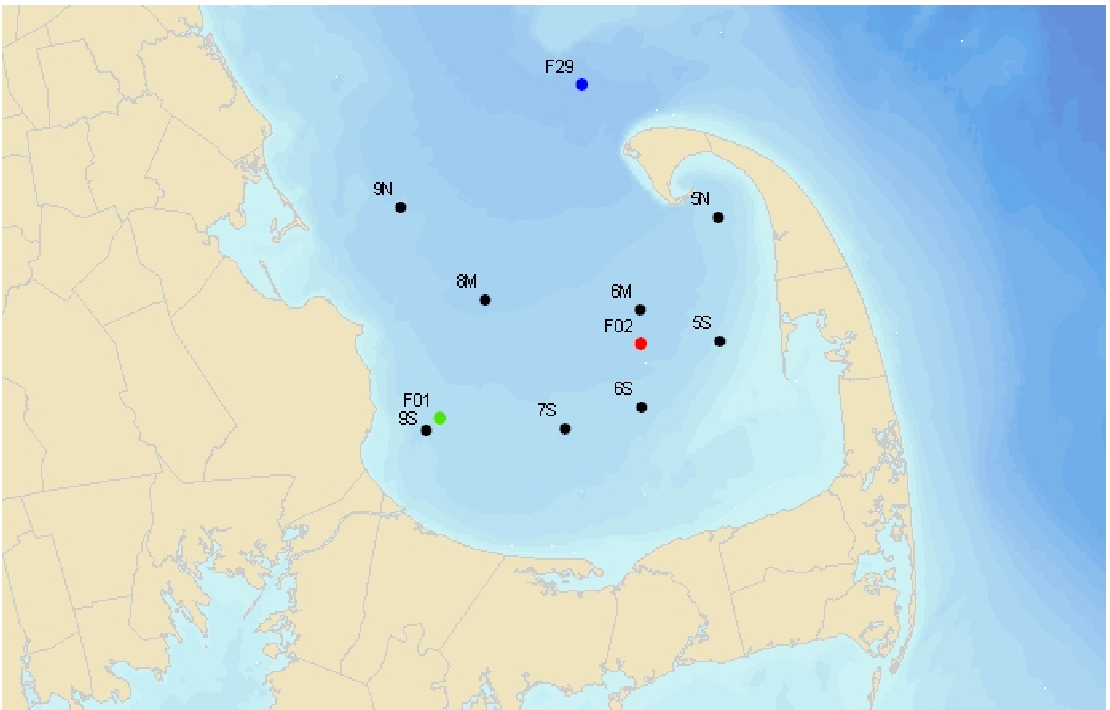

Figure 6-4. The Center for Coastal Studies monitors its own eight stations and three MWRA stations (F01, F02, and F29) in and near Cape Cod Bay. (Figure from the Center for Coastal Studies)

The Center for Coastal Studies also monitors North Atlantic right whales, with aerial surveys flown along a series of east-west tracks over Cape Cod Bay. The surveys record presence, dive times, and whale behaviors. Right whales typically occur in Cape Cod Bay during January through May, entering when nutrients and chlorophyll levels are high, temperatures are low, and food is abundant. Water quality and plankton abundance followed typical patterns in 2014 (Figure 6-5). Whales typically remain in Cape Cod Bay to feed until June, when summer stratification of the water column begins and zooplankton populations diminish. In 2014, whales were present from February through May.

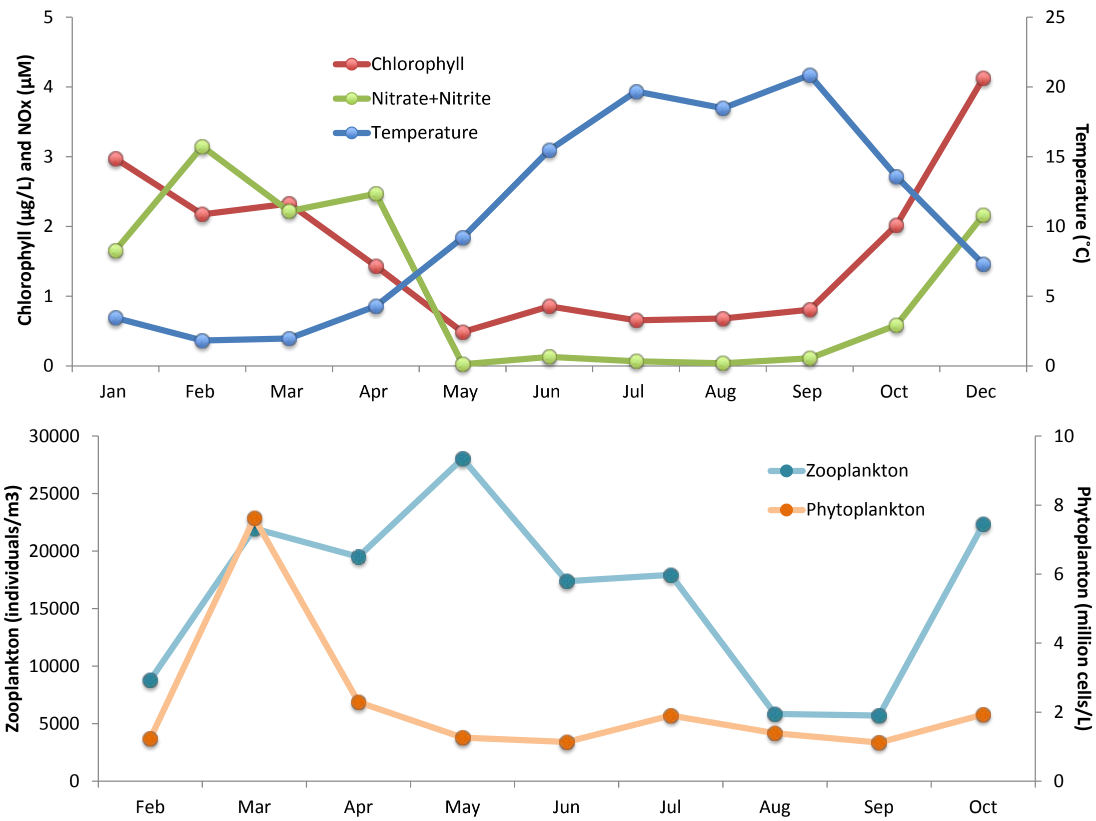

Figure 6-5. Water quality measurements and zooplankton and phytoplankton abundance in Cape Cod Bay in 2014. Whales were present in Cape Cod Bay from February through May. (Figures from the Center for Coastal Studies.)

Early whale sightings, in February 2014, appeared to follow temperature patterns, with most sightings occurring in waters with temperatures 0.2–2.2ºC. Whale distribution within Cape Cod Bay in 2014 was also associated with zooplankton abundance, particularly in April, when 500 whales were sighted during nine aerial reconnaissance flights (Figure 6-6).

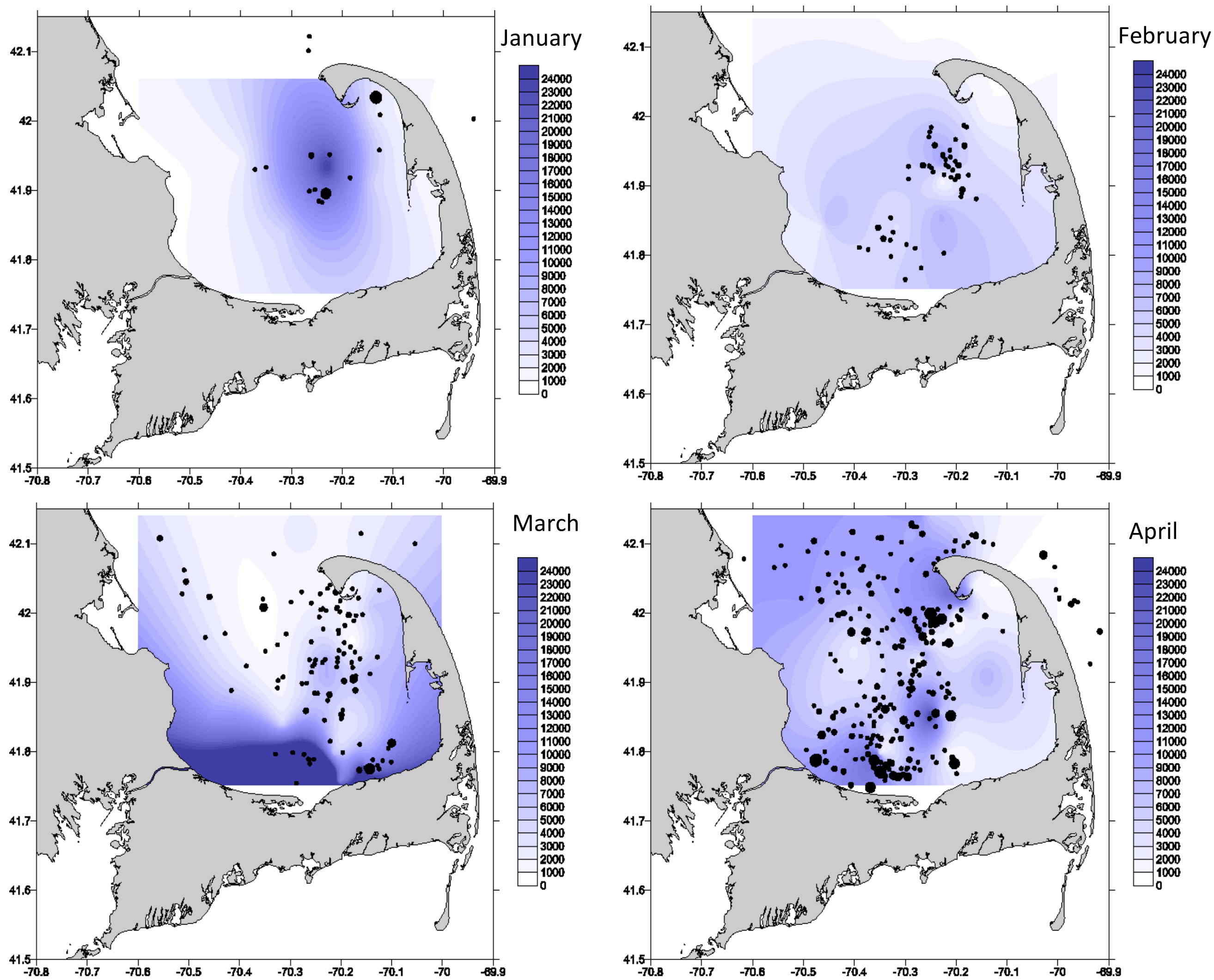

Figure 6-6. Zooplankton abundance (individuals per square meter, blue scale) and whale sightings (black dots) in Cape Cod Bay, January – April 2014. Whale sightings, particularly in April, were associated with zooplankton abundance. (Figures from the Center for Coastal Studies.)

Aerial surveys in 2014 recorded the fourth highest abundance of total right whales since 1998. The surveys sighted the second highest total of known, individual whales, representing about half the total known right whales in the North Atlantic population. Annual whale sightings have been relatively high in recent years, compared to the late 1990s and early 2000s (Figure 6-7). The North Atlantic right whale remains protected under the U.S. Endangered Species and Marine Mammal Protection acts, with Massachusetts and Cape Cod bays considered to be key habitat for the western North Atlantic population.

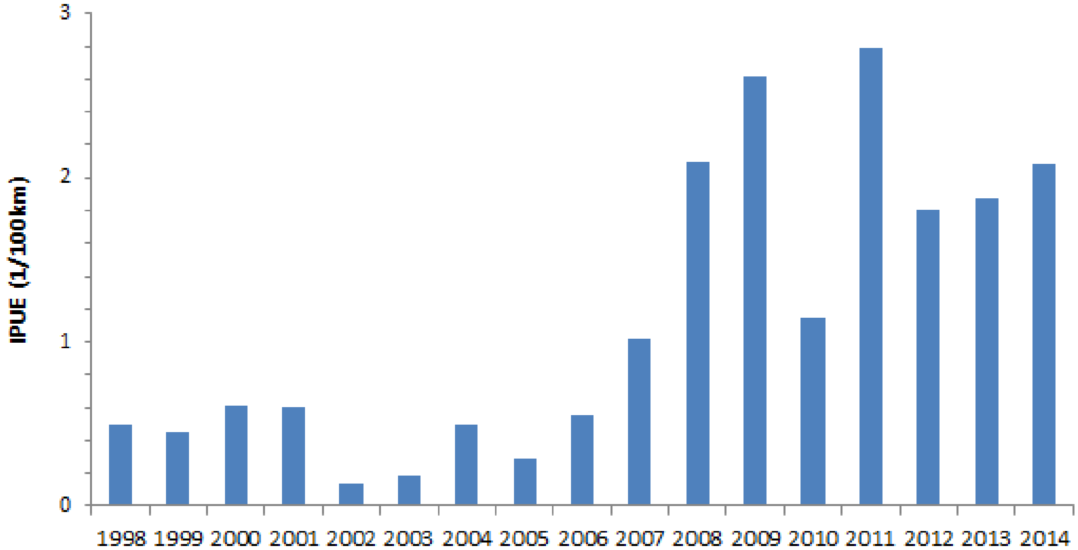

Figure 6-7. Right whale sightings in Cape Cod Bay, 1998–2014. (Figure from the Center for Coastal Studies.) IPUE = individuals per unit effort

References

Libby PS, Borkman DG, Geyer WR, Turner JT, Costa AS. 2015. 2014 water column monitoring results. Boston: Massachusetts Water Resources Authority. Report 2014-09. 42 p.

MWRA. 1991. Massachusetts Water Resources Authority effluent outfall monitoring plan: Phase I baseline studies. Boston: Massachusetts Water Resources Authority. Report 1991-ms-02. 95 p.

MWRA. 1997a. Massachusetts Water Resources Authority effluent outfall monitoring plan: Phase II post discharge monitoring. Boston: Massachusetts Water Resources Authority. Report 1997-ms-44. 61 p.

MWRA. 1997b. Massachusetts Water Resources Authority Contingency Plan. Boston: Massachusetts Water Resources Authority. Report 1997-ms-069. 41 p.

MWRA. 2001. Massachusetts Water Resources Authority Contingency Plan revision 1. Boston: Massachusetts Water Resources Authority. Report 2001-ms-071. 47 p.

MWRA. 2004. Massachusetts Water Resources Authority effluent outfall ambient monitoring plan Revision 1, March 2004. Boston: Massachusetts Water Resources Authority. Report 2004-ms-092. 65 p.

MWRA. 2010. Ambient monitoring plan for the Massachusetts Water Resources Authority effluent outfall Revision 2, July 2010. Boston: Massachusetts Water Resources Authority. Report 2010-04. 107 p.

Moore MJ, Nestler EC, Pembroke AE. 2014. Flounder monitoring report: 2014 results. Boston: Massachusetts Water Resources Authority. Report 2014-16. 18 p.

Murchelano RA, Wolke RE. 1991. Neoplasms and nonneoplastic liver lesions in winter flounder, *Pseudopleuronectes americanus*, from Boston Harbor, Massachusetts. Environmental Health Perspectives 90:17–26.

Nestler EC, Diaz RJ, Hecker B, Pembroke AE, Keay KE. 2015. Outfall benthic monitoring report: 2014 results. Boston: Massachusetts Water Resources Authority. Report 2015-08. 42 p.

Smolow M. 2015. Technical survey of nitrogen removal alternatives of the Deer Island Treatment Plant. Boston: Massachusetts Water Resources Authority. Report 2015-01. 37 p.

Taylor DI. 2015. Boston Harbor water quality, 1994–2014. Boston: Massachusetts Water Resources Authority. Report 2015-05. 11 p.

Tucker J, Giblin AE, Hopkinson CS, Kelsey SW, Howes, BL. 2014. Response of benthic metabolism and nutrient cycling to reductions in wastewater loading to Boston Harbor, USA. Estuarine, Coastal and Shelf Science 151:54–68.

Werme C, Rex AC, Hunt, C. 2012. Outfall monitoring overview background: 2012 update. Boston: Massachusetts Water Resources Authority. Report 2012-02. 59 p.

Zhou L, Chen C, Beardsley RC, Codiga DL, Leo WS, Mickelson MJ. 2015. Modeling 2013 in Massachusetts Bay using the unstructured-grid Bays Eutrophication Model. Boston: Massachusetts Water Resources Authority. Report 2015-03. 102 p.

List of Acronyms

BOD	Biochemical oxygen demand
cBOD	Carbonaceous biochemical oxygen demand
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
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
FF	Farfield
HMW	High molecular weight
IAAC	Inter-Agency Advisory Committee
IPUE	Individuals per unit effort
LC50	50% mortality concentration
LMW	Low molecular weight
MADEP	Massachusetts Department of Environmental Protection
MODIS	Moderate Resolution Imaging Spectroradiometer
MWRA	Massachusetts Water Resources Authority
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
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
PSP	Paralytic shellfish poisoning
RPD	Redox potential discontinuity
SPI	Sediment-profile imaging

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