2016 Outfall monitoring overview

Massachusetts Water Resources Authority
Environmental Quality Department
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2016
Outfall Monitoring Overview

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2016 Outfall Monitoring Panel and Committees

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MWRA Wastewater Advisory Committee
Conservation Law Foundation
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MWRA Advisory Board
Association to Preserve Cape Cod
Safer Waters in Massachusetts
The Boston Harbor Association

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Summary

Each year, the Massachusetts Water Resources Authority (MWRA) prepares an overview of effluent and environmental monitoring related to the discharge of municipal wastewater effluent from Deer Island Treatment Plant through an offshore outfall tunnel into Massachusetts Bay. This overview presents monitoring results and information relevant to MWRA's permit-required Contingency Plan, including any threshold exceedances or other permit violations, responses, and, should they be 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 report for 2016 marks 25 years of monitoring, including more than 16 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, less confined waters in Massachusetts Bay. This report for 2016 includes results of effluent analyses; water-column, seafloor, and fish-and-shellfish monitoring in the vicinity of the outfall (the "nearfield") and at reference stations; and results pertinent to Stellwagen Bank and to Boston Harbor. Special studies reports included in this year's overview focus on indicator bacteria in sewage effluent, continued recovery of Boston Harbor, and ongoing Cape Cod Bay studies.

Operations at Deer Island Treatment Plant continued to be exceptional in 2016, earning MWRA a National Association of Clean Water Agencies (NACWA) Platinum 10 Peak Performance Award. This NACWA award recognizes facilities with 100% compliance with permit effluent limits for ten consecutive years. Nearfield and reference-station monitoring results from 2016 were consistent both with predictions made during the outfall planning process and with past results, showing no unanticipated effects of the discharge (Tables i through iv). No Contingency Plan "warning-level" exceedances were observed. A "caution-level" exceedance[*] occurred for one water-column parameter, summer levels of the nuisance algal species *Phaeocystis pouchetii*. Overall, *Phaeocystis* abundance was low in 2016. However, as has occurred in other recent years, this exceedance was due to presence of *Phaeocystis* at a low abundance in one sample during the May ("summer") survey. These exceedances have caused no measurable aesthetic or other adverse effects, prompting MWRA regulators to approve discontinuing the summer *Phaeocystis* threshold in future monitoring years. Regulators also approved discontinuing upper bounds for benthic community thresholds, as exceeding those thresholds would not be indicative of environmental degradation.

[*] MWRA's discharge permit includes Contingency Plan thresholds, indicators that may signal a need for action. The thresholds are based on permit limits, state water quality standards, and expert judgment. "Caution-level" thresholds indicate a need for a closer assessment of 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 effects 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 2016 results for effluent monitoring.

Parameter	Baseline	Caution Level	Warning Level	2016 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 2016 results for water-column monitoring.

Parameter	Baseline	Caution Level	Warning Level	2016 Results
Dissolved oxygen*				
Nearfield concentration	6.05 mg/L	<6.5 mg/L	<6.0 mg/L	7.12 mg/L
Nearfield percent saturation	65.3%	<80%	<75%	83.9%
Stellwagen concentration	6.23 mg/L	<6.5 mg/L	<6.0 mg/L	6.33 mg/L
Stellwagen percent saturation	67.2%	<80	<75%	70.5%
Nearfield depletion rate	0.024 mg/L/d	>0.037 mg/L/d	>0.049 mg/L/d	0.013 mg/L/d
Chlorophyll				
Annual	72 mg/m^2	>108 mg/m^2	>144 mg/m^2	87 mg/m^2
Winter/spring	50 mg/m^2	>199 mg/m^2	None	89 mg/m^2
Summer	51 mg/m^2	>89 mg/m^2	None	85 mg/m^2
Autumn	90 mg/m^2	>239 mg/m^2	None	89 mg/m^2
Nuisance algae *Phaeocystis pouchetii*				
Winter/spring	622,000 cells/L	>2,860,000 cells/L	None	6,790 cells/L
Summer	79 cells/L	>357 cells/L	None	1,110 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	Absent
Summer	14,635 cells/L	>43,100 cells/L	None	954 cells/L
Autumn	10,050 cells/L	>27,500 cells/L	None	3,310 cells/L
Nuisance algae nearfield *Alexandrium fundyense*				
Any nearfield sample	Baseline maximum 163 cells/L	>100 cells/L	None	15 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 2016 results for seafloor monitoring.

Parameter	Baseline	Caution Level	Warning Level	2016 Results
Sediment parameters				
RPD depth	NA	<1.18 cm	None	3.89 cm
Benthic community parameters				
Species per sample	NA	<42.99 or >81.85	None	58.5
Fisher's log-series alpha	NA	<9.42 or >15.8	None	12.7
Shannon-Wiener diversity	NA	<3.37 or >3.99	None	3.93
Pielou's evenness	NA	<0.57 or >0.67	None	0.672
% opportunists	NA	>10%	>25%	0.21%

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

Table iv. Contingency Plan threshold value and 2016 results for fish-and-shellfish monitoring.

Parameter	Baseline	Caution Level	Warning Level	2016 Results
Liver disease CHV	24.4%	>44.9%	None	4%

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 (sludge) discharge, improving wastewater-treatment facilities, and providing better dilution of the effluent discharge. MWRA has conducted long-term environmental monitoring in Boston Harbor, where both biosolids and effluent were once discharged, and in Massachusetts Bay, where wastewater effluent is currently discharged through a deepwater tunnel and diffuser system.

Biosolids discharges to Boston Harbor ended in December 1991, all discharges to the southern portion of the harbor ended in 1998, and upgrades to Deer Island Treatment Plant were completed in 1995–2001. A major milestone was reached in September 2000, when all effluent discharge was diverted from Boston Harbor to the deeper, less confined waters of Massachusetts Bay. The relocated outfall operates under a National Pollutant Discharge Elimination System (NPDES) permit, jointly issued by the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MassDEP).

The NPDES permit requires monitoring of effluent and receiving waters to assess compliance with permit conditions and with a permit-required Contingency Plan. Results are presented in annual outfall monitoring overviews, such as this report. Background information about the monitoring program (Werme et al. 2012), the monitoring plan (MWRA 2010), the Contingency Plan (MWRA 2001), past plans and overviews, and area-specific technical reports are available in MWRA's technical report list, http://www.mwra.state.ma.us/harbor/enquad/trlist.html.

This year's outfall monitoring overview presents results from 2016, marking the twenty-fifth year of Massachusetts Bay monitoring and more than sixteen years of outfall discharge from the deepwater outfall. The report presents information relevant to permit and Contingency Plan conditions in the effluent, water column, sea floor, and fish and shellfish, as well as special studies conducted in response to permit conditions and environmental concerns. Data relevant to the Stellwagen Bank National Marine Sanctuary, located offshore from the outfall, are presented in sections covering the water column and the sea floor. The report also includes pertinent information from MWRA's separate monitoring efforts in Boston Harbor.

2. Effluent

2016 Characterization

The Deer Island Treatment Plant continued to operate as designed through 2016, earning MWRA the National Association of Clean Water Agencies (NACWA) Platinum 10 Peak Performance Award. This NACWA award recognizes facilities with 100% compliance with effluent permit limits over ten consecutive years.

The Boston area received about 10 inches less rain than the long-term average in 2016, a second consecutive year of drought and one of the driest years since 1990 (Figure 2-1). Drought conditions persisted until May 2017. Correspondingly, average effluent flow in 2016, 281 million gallons per day, was the lowest measured since the Massachusetts Bay outfall began to discharge in September 2000 (Figure 2-2). Virtually all the flow, 99.8%, received full primary and secondary treatment, with only trace discharges of primary-treated effluent blended with fully treated effluent prior to discharge in any month. (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 or “blended” with full secondary-treated flows before disinfection and discharge.)

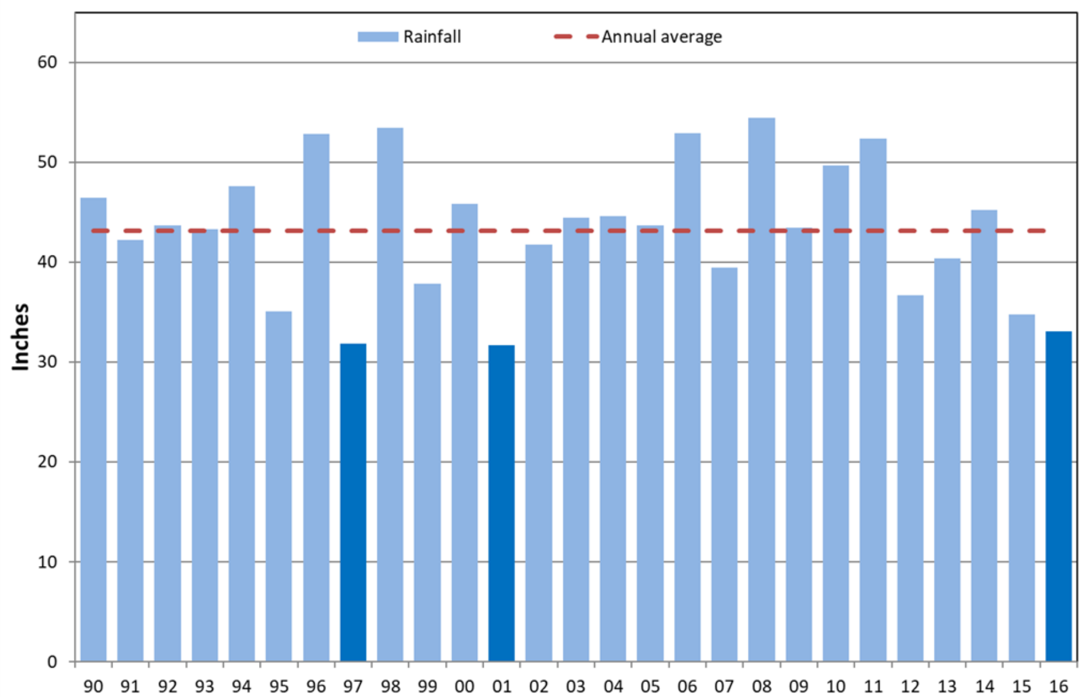

Figure 2-1. Annual rainfall in Boston, 1990–2016. Rainfall in 2016, 33.05 inches, was the third driest of the monitoring program, with only 1997 and 2001 having less rainfall. Those years are shown in darker blue. The dashed line shows the average rainfall for the period, 43.17 inches.

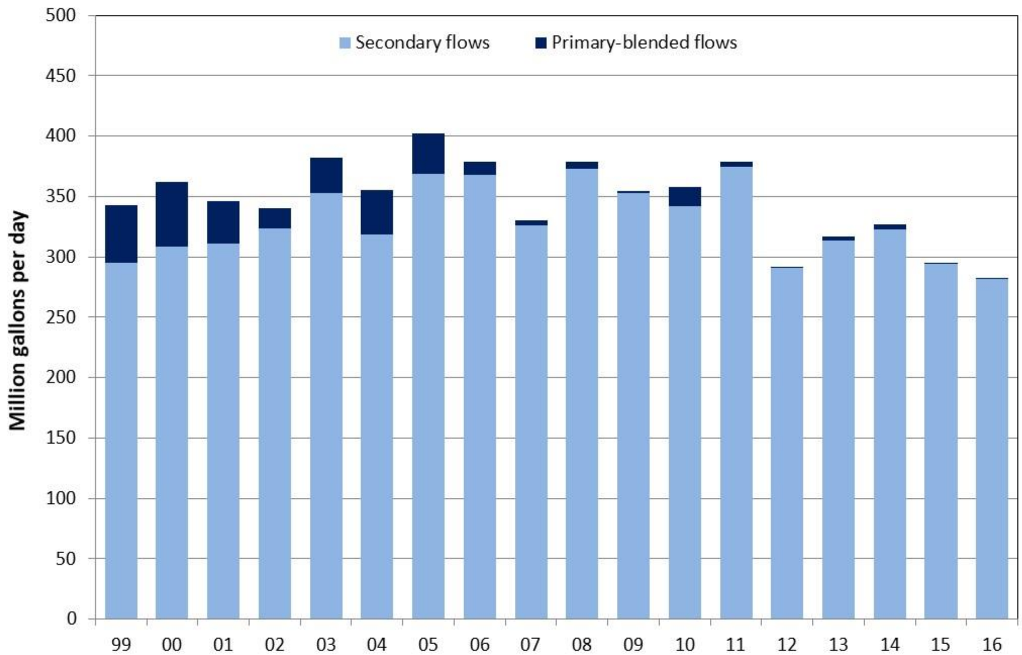

Figure 2-2. Annual primary-blended and full secondary effluent flows, 1999–2016. During large storms, flow exceeding the secondary capacity of the plant is diverted around the secondary process. Primary-treated flows are blended into secondary-treated flows before discharge.

The total suspended solids load to Massachusetts Bay was also low, well below the loads discharged to Boston Harbor before the relocated outfall began operation (Figure 2-3). Carbonaceous biological oxygen demand, a measure of the amount of oxygen consumed by microorganisms, also remained low (not shown), well below levels that would be expected to affect dissolved oxygen concentrations at the discharge.

The total nitrogen load remained just under its caution-level Contingency Plan threshold in 2016 (Figure 2-4), but was well below the warning-level threshold, 14,000 metric tons per year. (The caution level was somewhat arbitrarily set as 90% the of the warning level; the warning level was the projected total nitrogen load for the year 2020.)

The portion of the nitrogen load made up of ammonium reached a record high, continuing a gradual increase since early years of the Boston Harbor Project. Increased ammonium loads are a consequence of the biological treatment process and addition of ammonium-rich liquids from the biosolids (sludge) pelletizing plant. Total effluent nitrogen loads reflect variability in nitrogen levels in the influent reaching Deer Island (although about 30% of the nitrogen is removed during treatment). There have been no observed adverse environmental effects due to nitrogen discharge into Massachusetts Bay, and water-quality modeling has suggested that even doubling the nitrogen discharge would have no adverse effect on the environment.

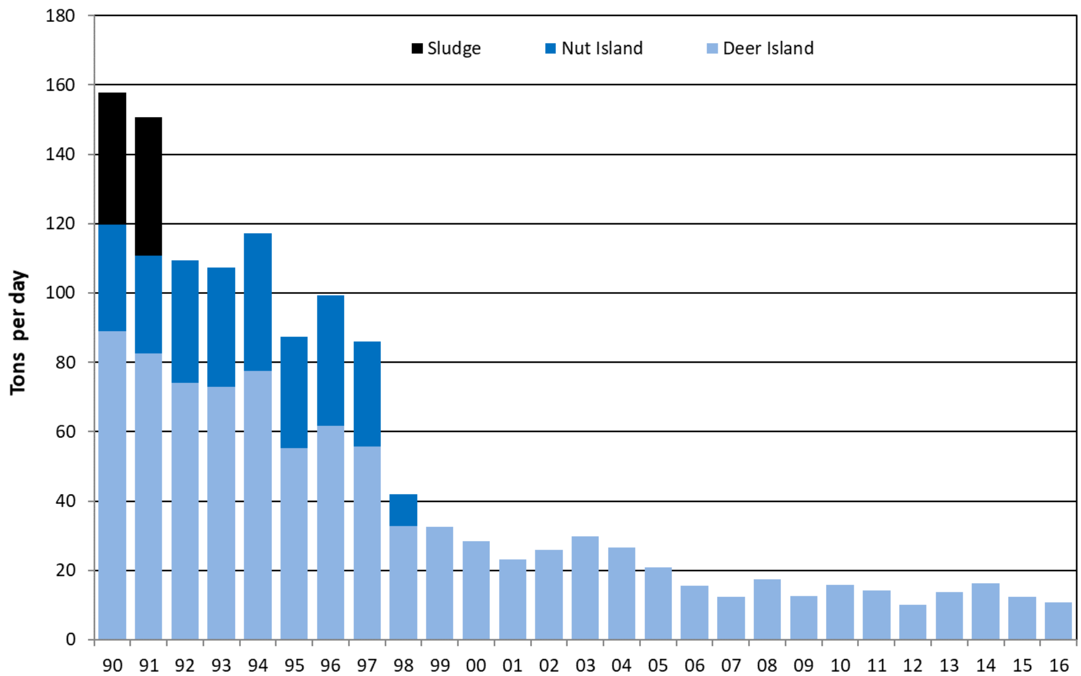

Figure 2-3. Annual solids discharges, 1990–2016. Before December 1991, biosolids (sludge) removed during treatment were disinfected and discharged into Boston Harbor. Ending biosolids disposal, ending effluent discharge to the southern portion of the harbor from Nut Island, implementing secondary treatment, and ending all discharges to the harbor in September 2000 were important steps in the Boston Harbor Project. Since 2006, variability in solids discharges to Massachusetts Bay can be mostly attributed to variation in flow.

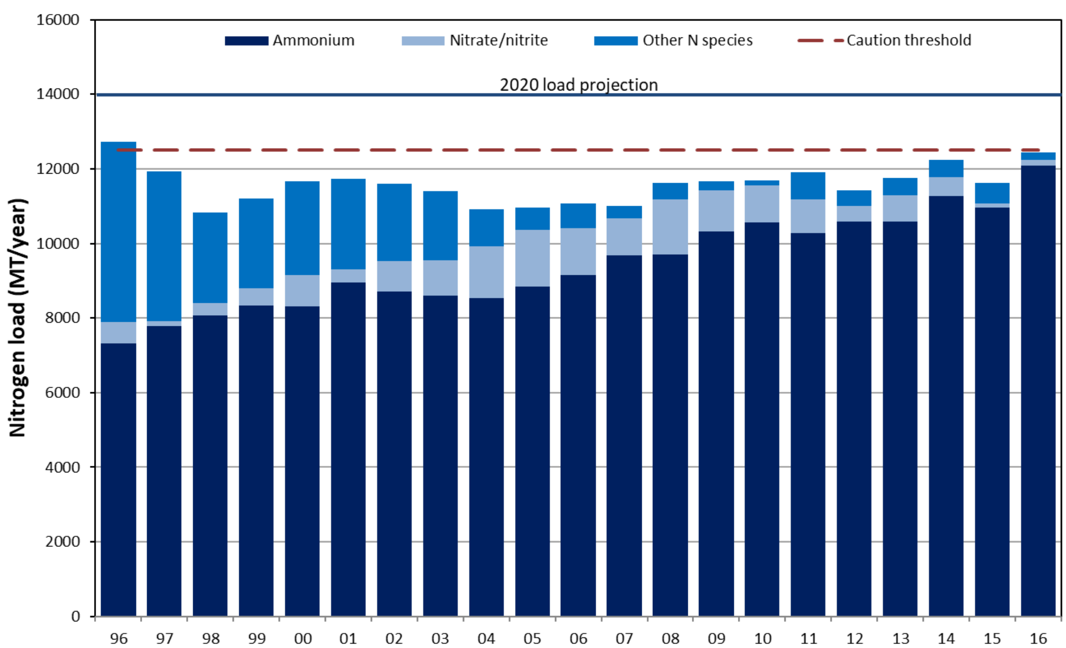

Figure 2-4. Annual nitrogen discharges, 1996–2016. Nitrogen discharges in 2016, 12,447 metric tons, were almost at the Contingency Plan caution threshold of 12,500 metric tons per year. Modeling suggests that even doubling the nitrogen discharge would have no adverse effect on the environment.

Metals loads remained low in 2016, with zinc and copper continuing to comprise most of the annual discharges (Figure 2-5). Metals loads are now mostly a factor of rainfall and flow rates rather than variations in inputs to the waste stream. Except for copper, metals meet water quality standards prior to discharge, while copper meets the standard 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 high removal efficiencies associated with secondary treatment and the change from film to digital photography.

Polycyclic aromatic hydrocarbon (PAH, Figure 2-6) and other organic contaminant loads (Figure 2-7) were low, as they have been throughout the monitoring program. Discharges of organic contaminants have varied slightly from year to year but have been well below levels historically discharged into Boston Harbor.

Total discharges of both metals and organic compounds remain well below predictions made during the planning and permitting process for the Massachusetts Bay outfall (Table 2-1). Metals discharges are well below projected levels, ranging from mercury, with discharges about 1% of the projected load, to copper, with discharges just over 20% of what had been projected. Loads of total PCBs, and 4-4' DDE (a breakdown product of the banned pesticide DDT) are only about 1% of the loads that had been anticipated in the Supplemental Environmental Impact Statement (SEIS) prepared during planning (EPA 1988).

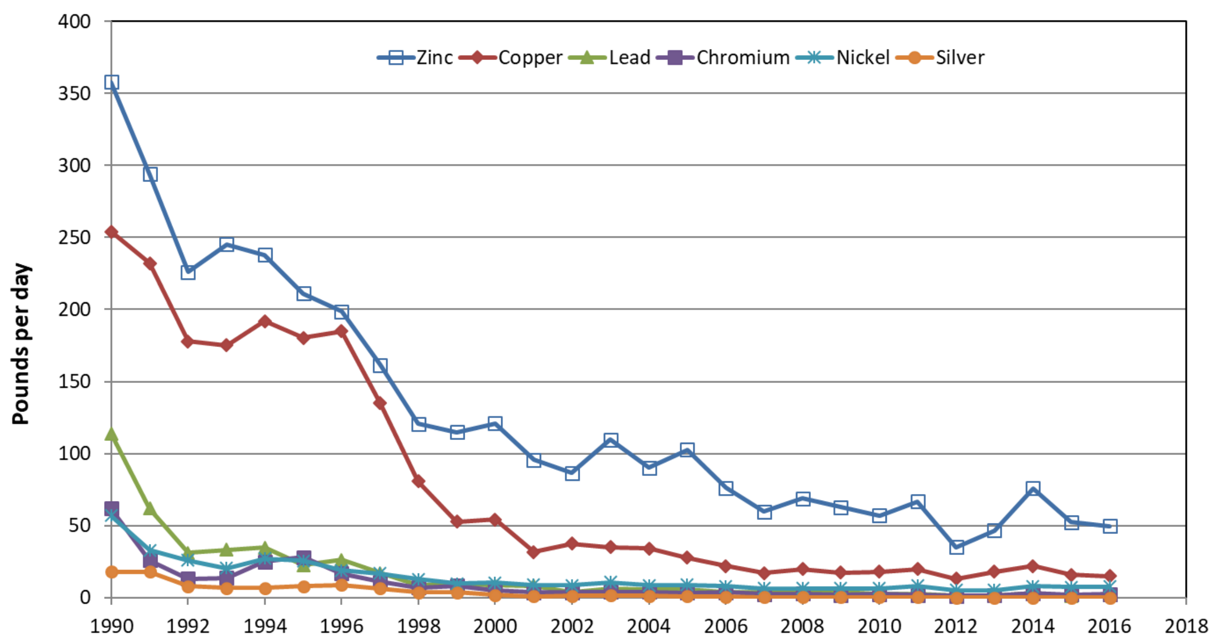

Figure 2-5. Annual metals discharges, 1990–2016.

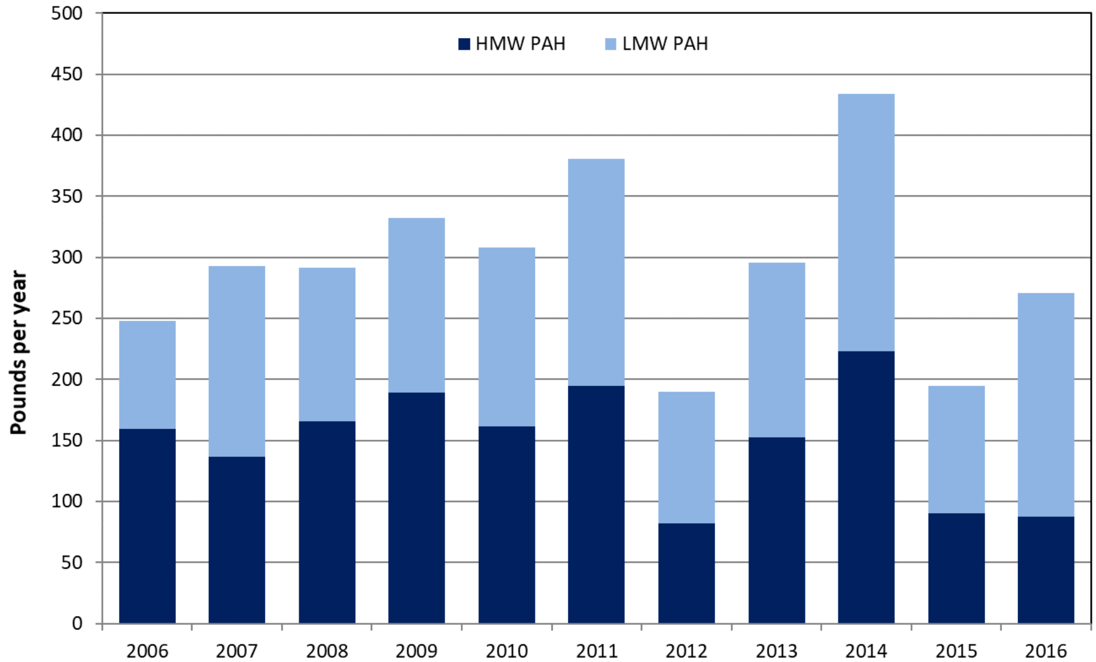

Figure 2-6. Annual polycyclic aromatic hydrocarbon (PAH) discharges, 2006–2016. LMW PAH = lower molecular weight PAH, HMW PAH = high molecular weight PAH

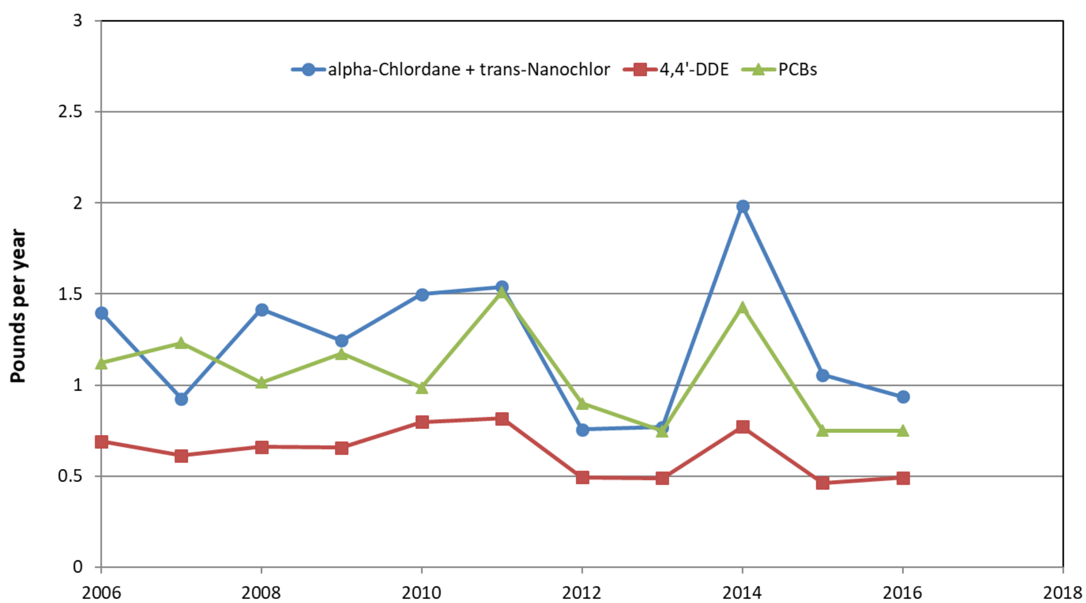

Figure 2-7. Annual discharges of banned organic pesticides and their breakdown products and PCBs, 2006–2016.

Table 2-1. Projected and actual loads of metals and organic contaminants in MWRA effluent. Loads of metals and organic contaminants are far below those projected during the planning and permitting process.

Parameter	SEIS Projected Load (kg/year)	2016 Load (kg/year)	Percent Projected Load
Chromium	3,517	416	12
Copper	11,945	2,460	21
Lead	4,961	279	5.6
Mercury	216	2	0.93
Nickel	8,926	1,271	14
Silver	290	23	7.9
Total PCBs	50	0.52	1.0
4-4' DDE	28	0.31	1.1

SEIS = Supplemental Environmental Impact Statement

Contingency Plan Thresholds

There were no permit violations in 2016 and no exceedances of the Contingency Plan effluent thresholds (Table 2-1). Effluent threshold exceedances have been rare throughout the duration of the monitoring program, and none have occurred over the past ten years.

Table 2-2. Contingency Plan threshold values and 2016 results for effluent monitoring.

Parameter	Caution Level	Warning Level	2016 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

Water-column monitoring evaluates relevant 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).

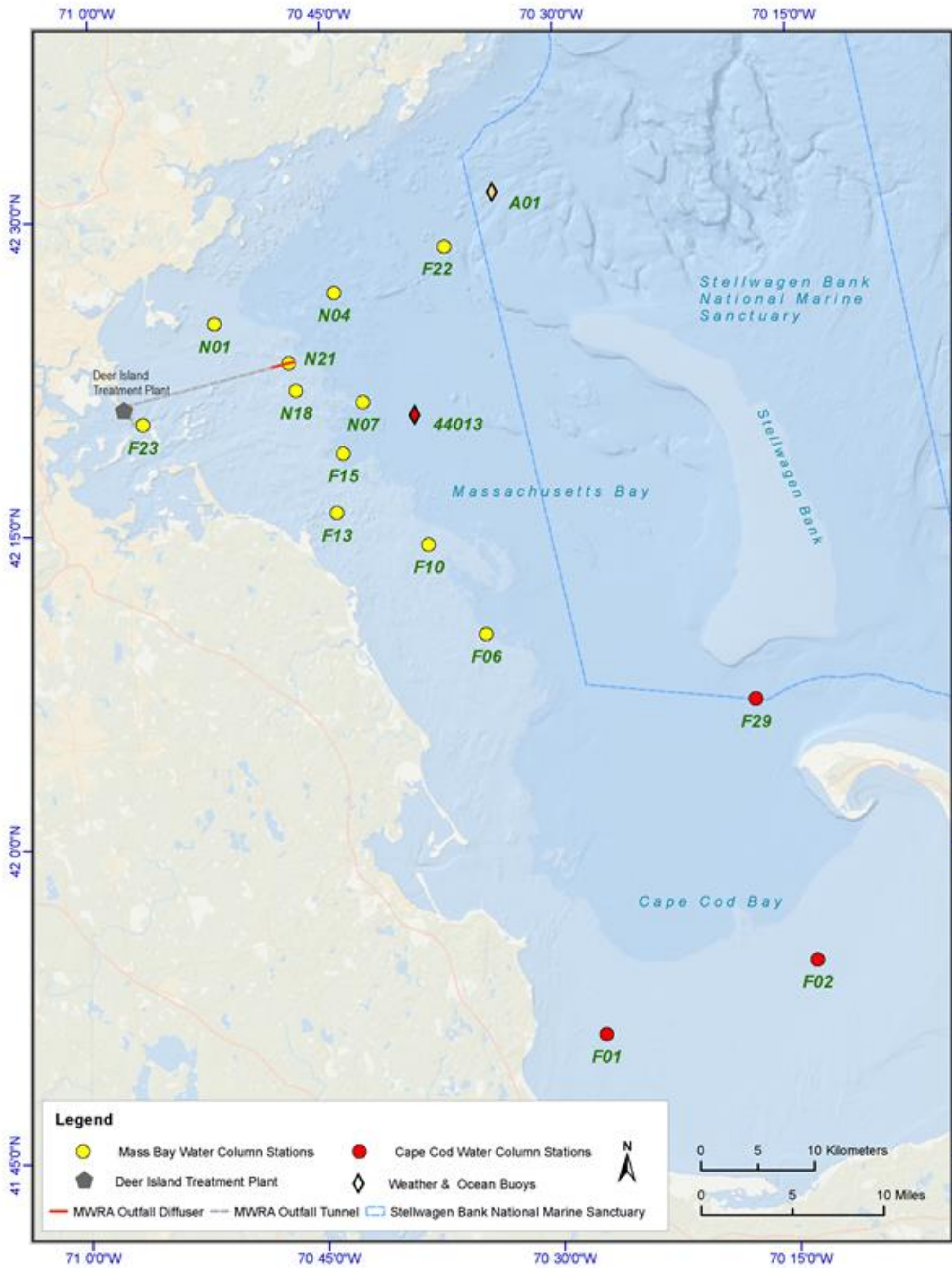

Figure 3-1. Water-column monitoring stations in Massachusetts and Cape Cod bays.

Sampling during nine surveys of fourteen stations in 2016 included vertical profiles of physical, chemical, and biological parameters in the nearfield (the area around the outfall 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 within a few days of the outfall-monitoring surveys. In some years, including 2016, special surveys are conducted in response to *Alexandrium fundyense* red tide blooms. In 2016, *Alexandrium* special surveys were conducted in late May and early June.

The program continued to benefit from collaboration with the Center for Coastal Studies at Provincetown, Massachusetts, which conducts a monitoring program in Cape Cod Bay. As part of the MWRA monitoring program, the Center for Coastal Studies samples water-column 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 on the same day as Massachusetts Bay sampling conducted by MWRA. Surveys for which sampling cannot occur within 48 hours should be reported in this annual outfall monitoring overview. In 2016, engine problems and weather forced one Massachusetts Bay survey to be delayed to seven days after the Cape Cod Bay sampling on September 26. All other survey dates met the 48-hour window.

As in past years, the field monitoring program was augmented by measurements on two instrumented buoys: the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) Buoy A01 and the National Oceanic and Atmospheric Administration's National Data Buoy Center (NDBC) Buoy 44013. The National Aeronautics and Space Administration provided Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery of chlorophyll and 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 weather, river inflows, and other physical factors. Information about physical conditions has proven key to interpreting the annual water-column monitoring data.

Corresponding to the low rainfall in the Boston area in 2016, discharges from the Merrimack and Charles rivers were also low, with Merrimack River discharges higher than average at the beginning of the year, but discharges from both rivers dropping to the lowest flows measured in any year of the monitoring program (Figure 3-2).

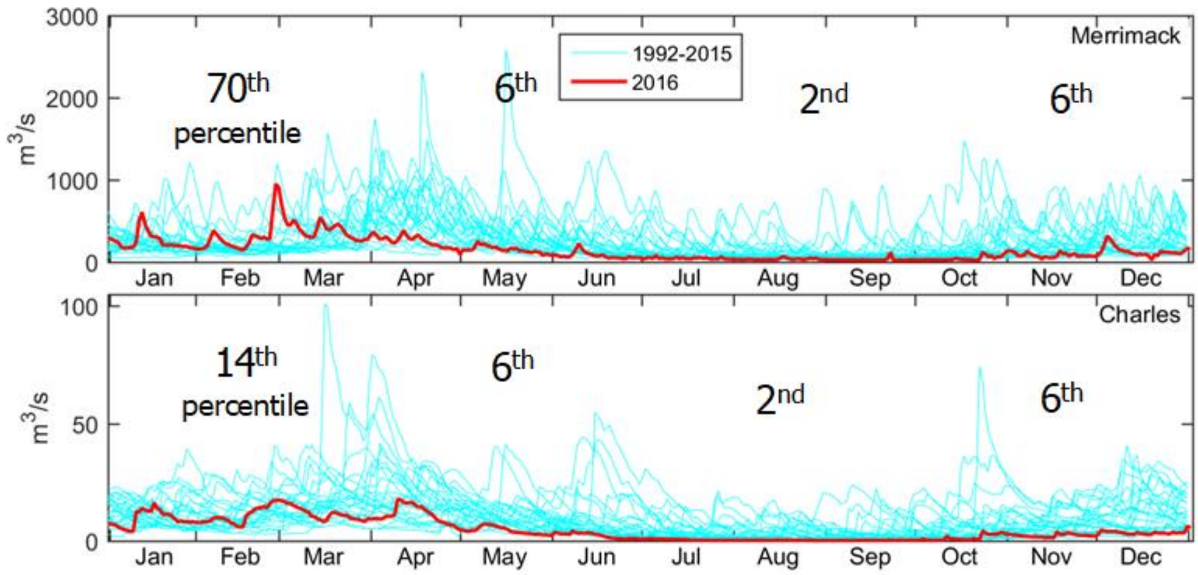

Figure 3-2. Flows of the Merrimack (top) and Charles (bottom) rivers. Flow from the Charles River was the lowest measured in 25 years of monitoring. Dark red lines are 2016 data. Results from 1992–2015 are in light blue. The quarterly percentiles represent the 2016 flows in comparison to the entire 25-year record.

Water temperatures, measured at the NDBC Buoy 44013 (not shown) and at nearby Station N18 (Figure 3-3, top panels), reached the long-term maxima for the monitoring program (Libby et al. 2017). During the first survey of the year, surface water temperature at Station N18 was the highest February temperature measured since monitoring began. Surface temperature again exceeded past measurements in late July and was elevated throughout fall. Bottom water temperatures at Station N18 were also high compared to past years, particularly during the spring and fall.

The low river flows resulted in correspondingly high salinity measurements in surface and bottom waters (Figure 3-3, bottom panels). Surface- and bottom-water salinity measurements at Station N18 were at or above the long-term maxima from June until the last survey date, November 1.

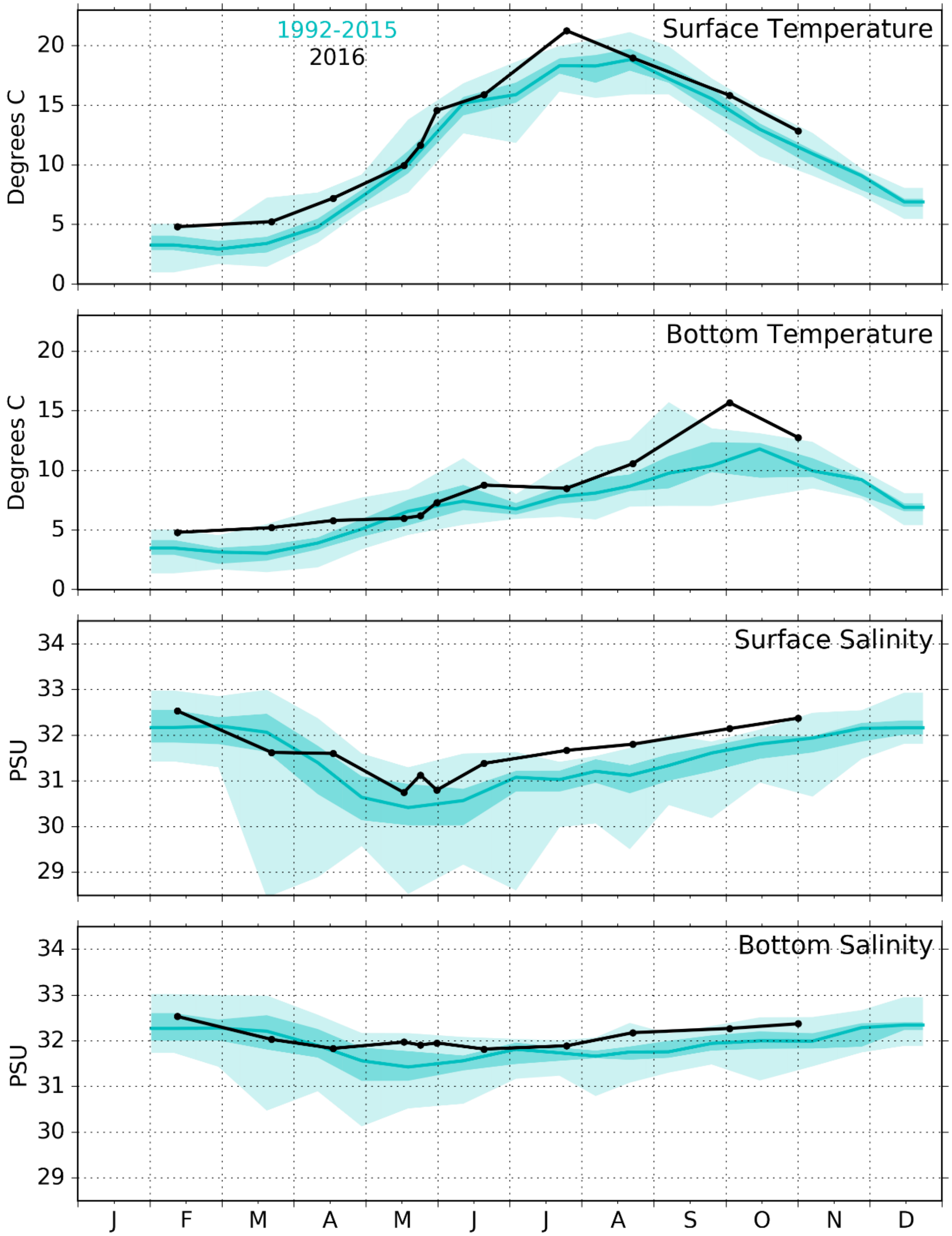

Figure 3-3. Surface- and bottom-water temperature and salinity concentrations at nearfield Station N18 in 2016 compared to prior years. Black points are results from individual surveys in 2016. Results from 1992–2015 are in blue: line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range.

Stratification during the first half of 2016 was much the same as in previous years, but strong during some surveys. Persistent winds in September led to an unusually early breakdown of stratification at Station N18 (Figure 3-4). Data from NERACOOS Buoy A01 also showed destratification to depths of 20 meters in late September and to 50 meters in late October.

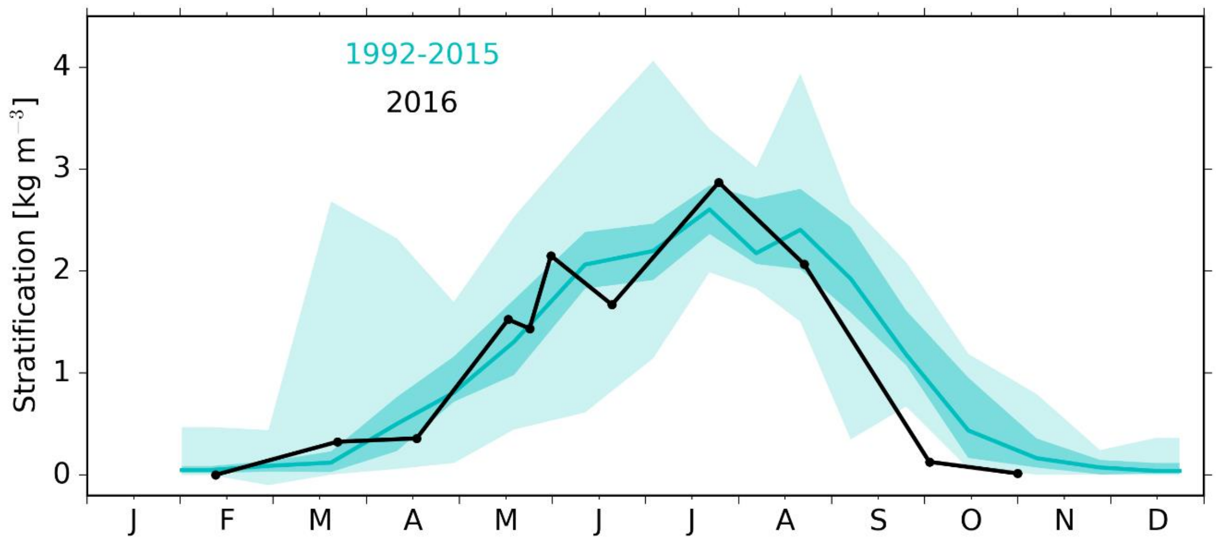

Figure 3-4. Stratification at nearfield Station N18 in 2016 compared to prior years. Black points are results from individual surveys in 2016. Results from 1992–2015 are in blue: line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range.

Water Quality

As in past years, water quality measurements for 2016 included quantification of nutrients, phytoplankton biomass (measured as chlorophyll and particulate organic carbon), and dissolved oxygen. Results continued to confirm predictions of measurable outfall influence in some parameters, but only at stations very near the outfall, and no unexpected adverse effects (Libby et al. 2017).

During 2016, dissolved inorganic nutrient concentrations (nitrate, ammonium, silicate, and phosphate) at nearfield Station N18 one kilometer south of the outfall fell mostly within the ranges seen in previous years (Figure 3-5). Nitrate and phosphate concentrations, which generally follow a similar and strong seasonal pattern at that location, were highest early in 2016, lower during the summer due to phytoplankton uptake, and higher again in the fall. Silicate concentrations were low during the first survey, an indication of a diatom bloom.

Concentrations of ammonium at Station N18, as in most years, varied greatly and did not show a seasonal pattern. Ammonium is the largest fraction of the total nitrogen in wastewater and provides a tracer that could identify possible adverse effects of the outfall, if they were to occur.

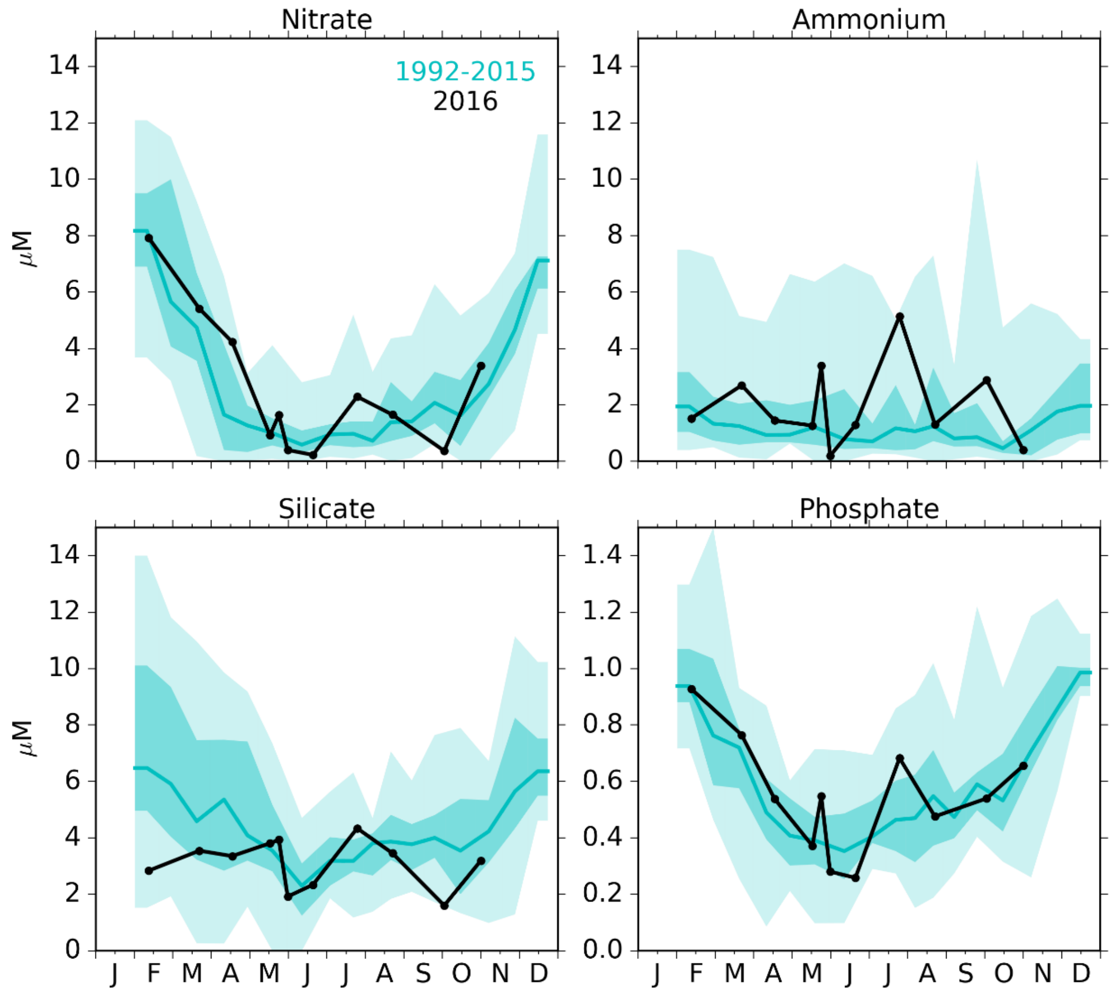

Figure 3-5. Depth-averaged dissolved inorganic nutrient concentrations (micromoles per liter) at nearfield Station N18 in 2016 compared to prior years. Note difference in scale for phosphate. Black points are results from individual surveys in 2016. Results from 1992–2015 are in blue: line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range.

In the immediate vicinity of the outfall, at Station N21, elevated ammonium concentrations have been detected since the discharge began in 2000. In 2016, that signature was especially apparent during some surveys but not others (Figure 3-6). However, despite record-high ammonium discharges from Deer Island Treatment Plant (see Figure 2-4 in Section 2, Effluent), the outfall ammonium signature was not unusual in either magnitude (concentration) or spatial extent in 2016.

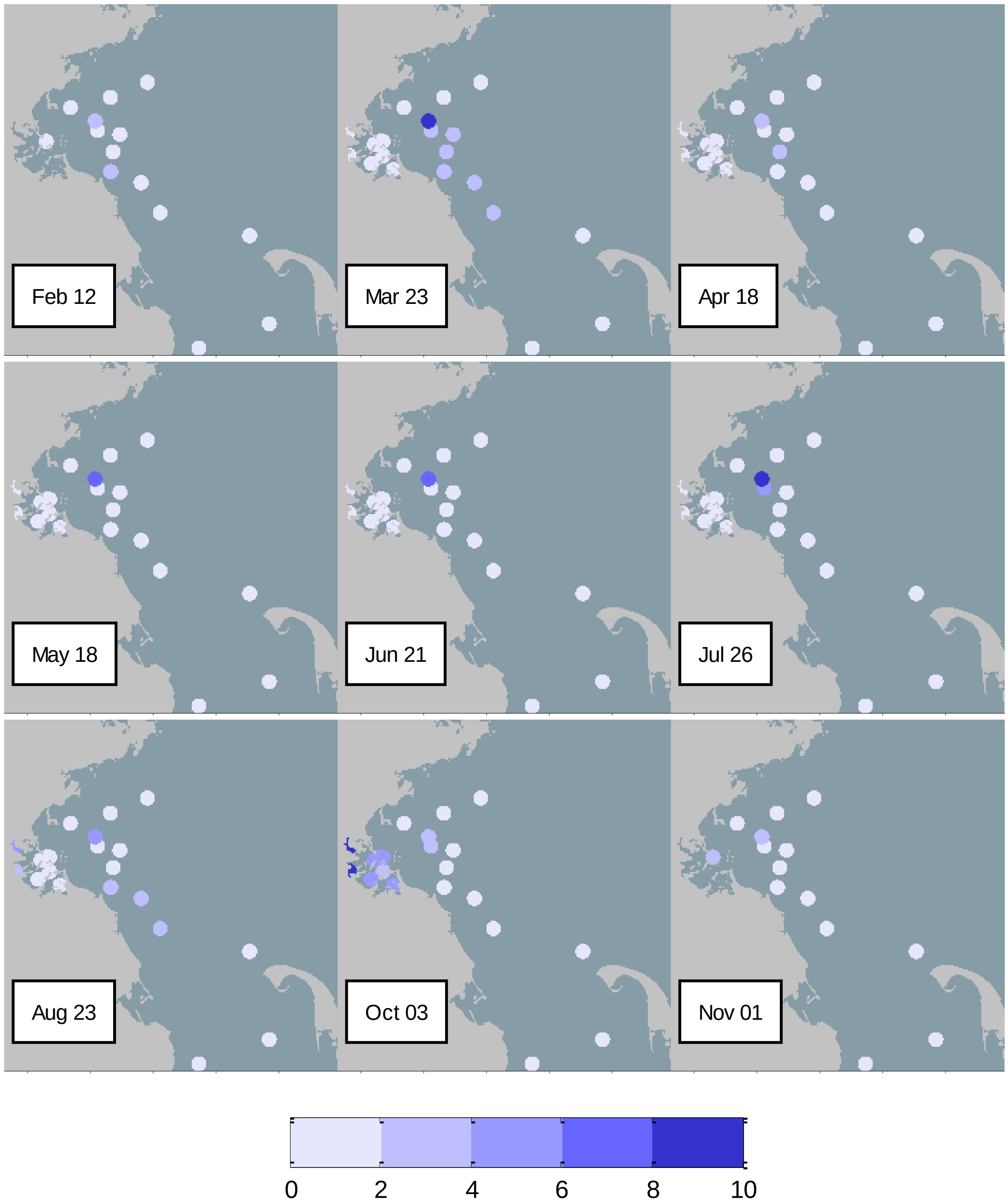

Figure 3-6. Depth-averaged ammonium concentrations (μM) by station in Massachusetts and Cape Cod bays in 2016. Several panels show additional data from MWRA's in-house Boston Harbor monitoring surveys when those surveys were conducted within a few days of the outfall-monitoring surveys.

As in previous years, the plume's ammonium signature was evident in surface waters during the winter and spring (Figure 3-7), but was largely confined beneath the pycnocline during the summer, stratified season (Figure 3-8). The ammonium signature could be detected only within 10 to 20 kilometers of the outfall in both well-mixed and stratified seasons, consistent with predictions made during the outfall planning process.

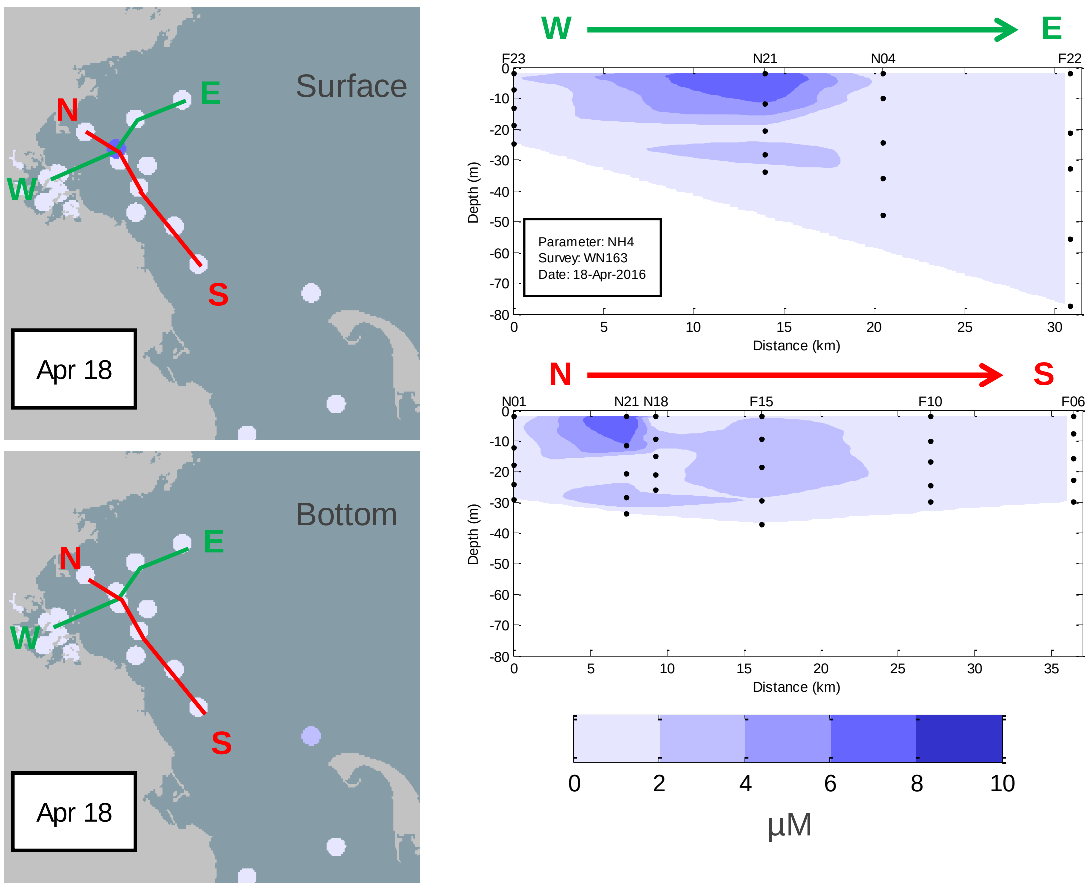

Figure 3-7. (Left) Surface- and bottom-water ammonium on April 18, 2016 at the monitoring stations during mixed conditions. (Right) Cross-sections of concentrations throughout the water column along transects connecting selected stations. Station N21 is directly over the outfall.

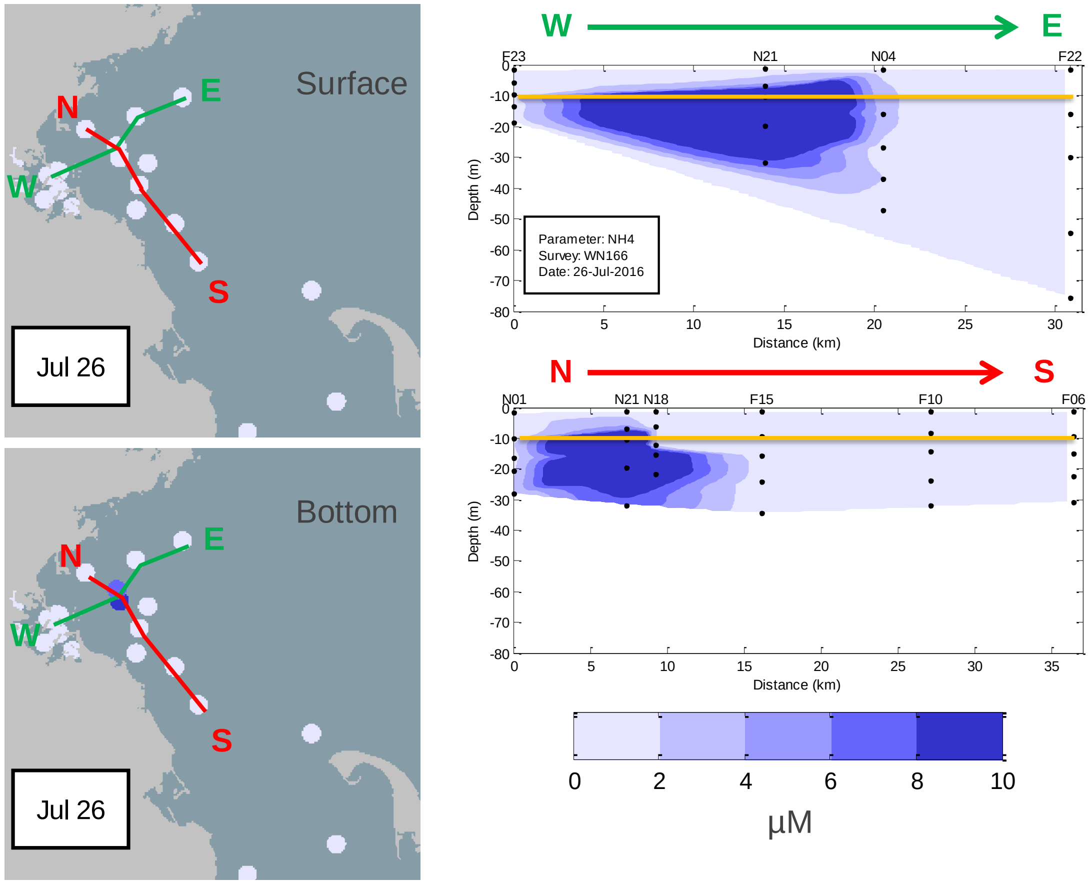

Figure 3-8. (Left) Surface- and bottom-water ammonium on July 26, 2016 at the monitoring stations during stratified conditions. (Right) Cross-sections of concentrations throughout the water column along transects connecting selected stations. The pycnocline (yellow line) was located at approximately 10 meters.

No increase in phytoplankton biomass, measured as chlorophyll or particulate organic carbon, has been evident at the outfall since the discharge began, and none was measured in 2016. The survey data showed elevated chlorophyll levels across much of Massachusetts Bay in February, April, and August surveys and lower levels during other months, particularly March (Figure 3-9). No unusual results were detected by the survey data or by satellite imagery in 2016 (not shown).

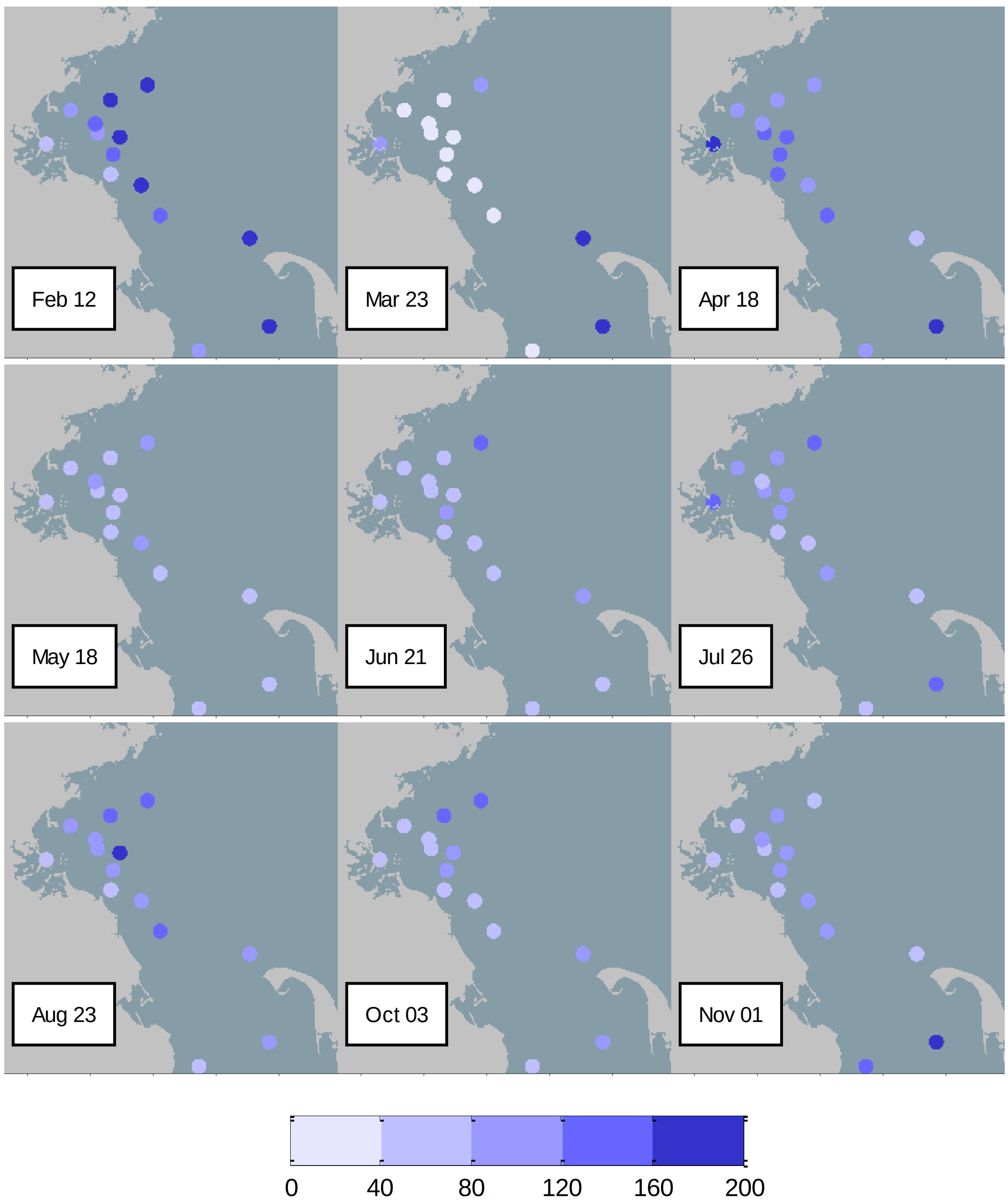

Figure 3-9. Depth-averaged chlorophyll (mg/m^2) by station in Massachusetts Bay in 2016.

Typically, concentrations of dissolved oxygen in bottom waters of Massachusetts Bay fall steadily from highest concentrations in the spring to lowest in the fall, with recovery after the breakdown of stratification in the fall. In 2016, that steady decline was interrupted by a mixing event in June. Early destratification, a result of a late September storm and persistent winds, resulted in relatively high oxygen minima at some stations. Although low oxygen levels were measured in some deep waters in the fall, oxygen minima were higher than would have been expected, considering the warm bottom waters and high salinities in 2016.

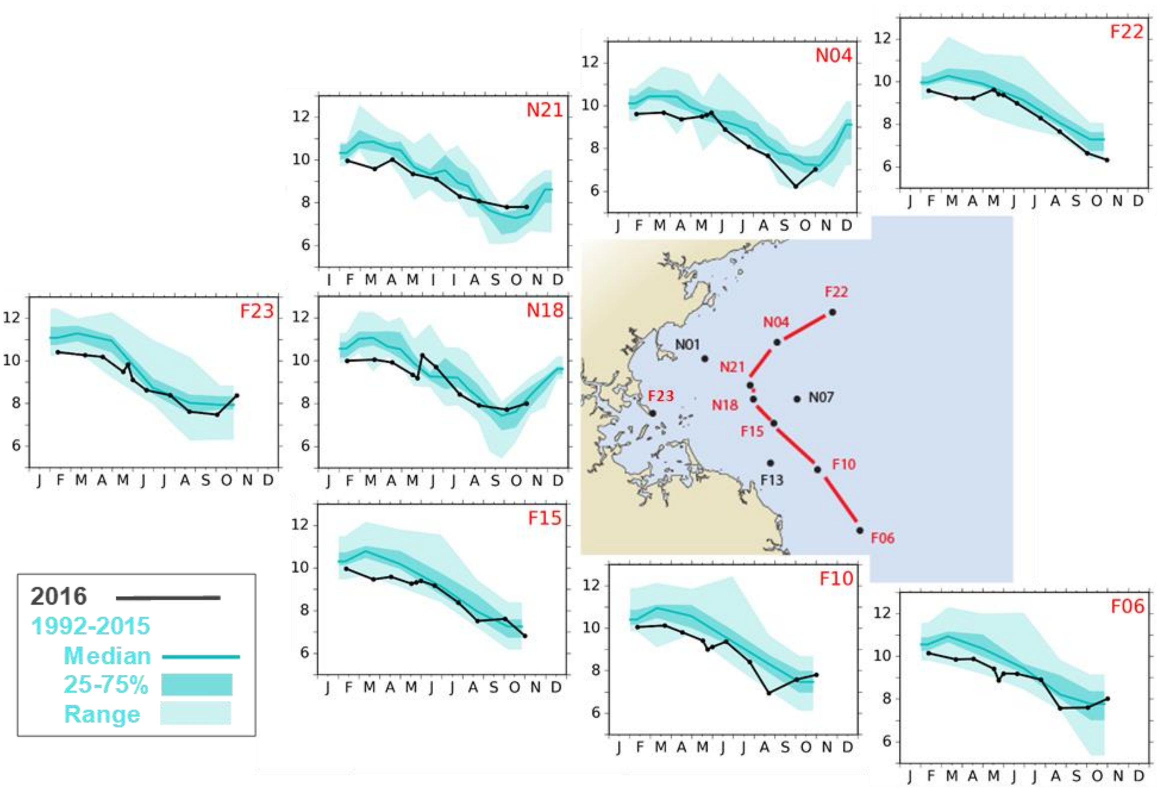

Figure 3-10. Bottom-water dissolved oxygen concentrations at selected stations in 2016 compared to prior years. Black points and line are results from individual surveys in 2016. Results from 1992–2015 are in blue: line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range.

Phytoplankton Communities

As in recent years, total observed phytoplankton abundances were low throughout the year and throughout Massachusetts Bay (Figure 3-11, Libby et al. 2017). Abundances were low during the first survey of the year, even though chlorophyll levels were relatively high. Abundances peaked in April, during a moderate bloom of centric diatoms, with total phytoplankton cell counts highest at Boston Harbor Station F23 and coastal Station F13. The bloom was dominated by *Thalassiosira* spp. and *Skeletonema* spp., which are the generally dominant taxa in the summer in Massachusetts Bay.

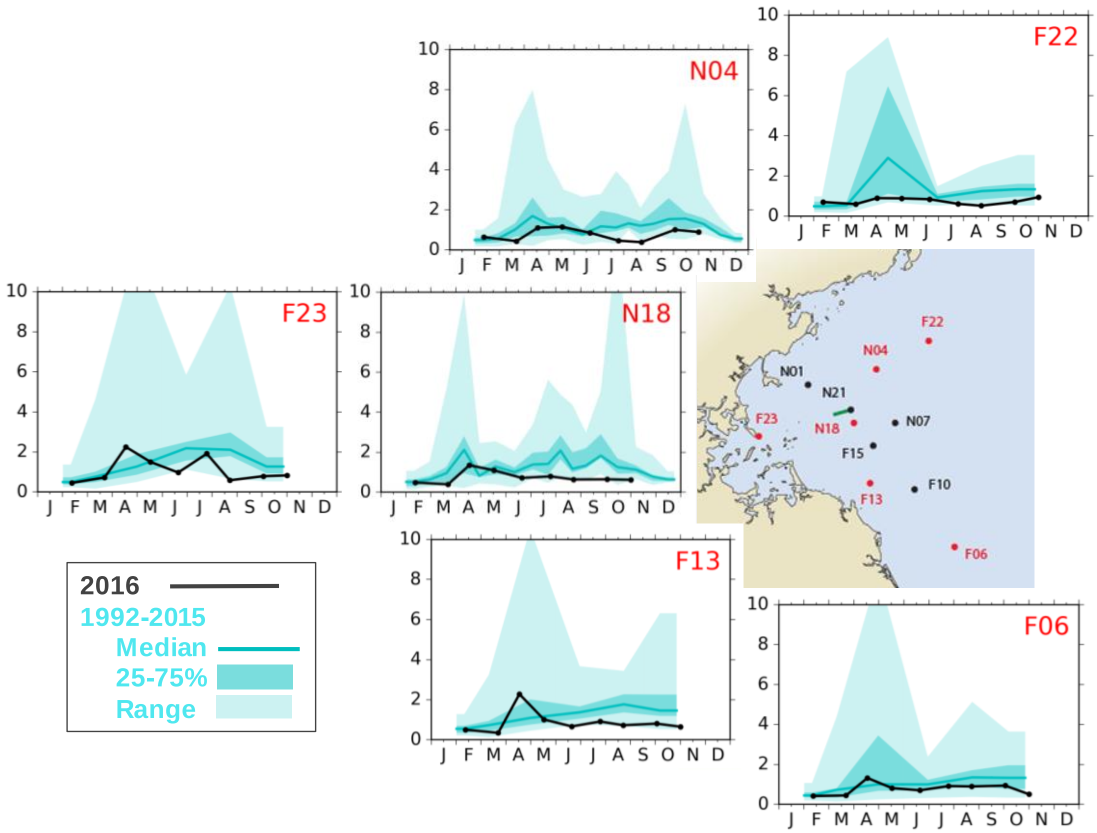

Figure 3-11. Total phytoplankton abundance (million cells per liter) at selected stations in 2016 compared to prior years. Black points and line are results from individual surveys in 2016. Results from 1992–2015 are in blue: line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range.

Since 2000, spring diatom blooms have often been followed by April blooms of the nuisance species *Phaeocystis pouchetii*. Since 2013, *Phaeocystis* abundances have been relatively low, both in the nearfield and throughout Massachusetts Bay, and this trend continued in 2016 (Figure 3-12). However, *Phaeocystis* abundance in one May sample was sufficiently high to exceed the very low summer Contingency Plan threshold (see Contingency Plan Thresholds, below).

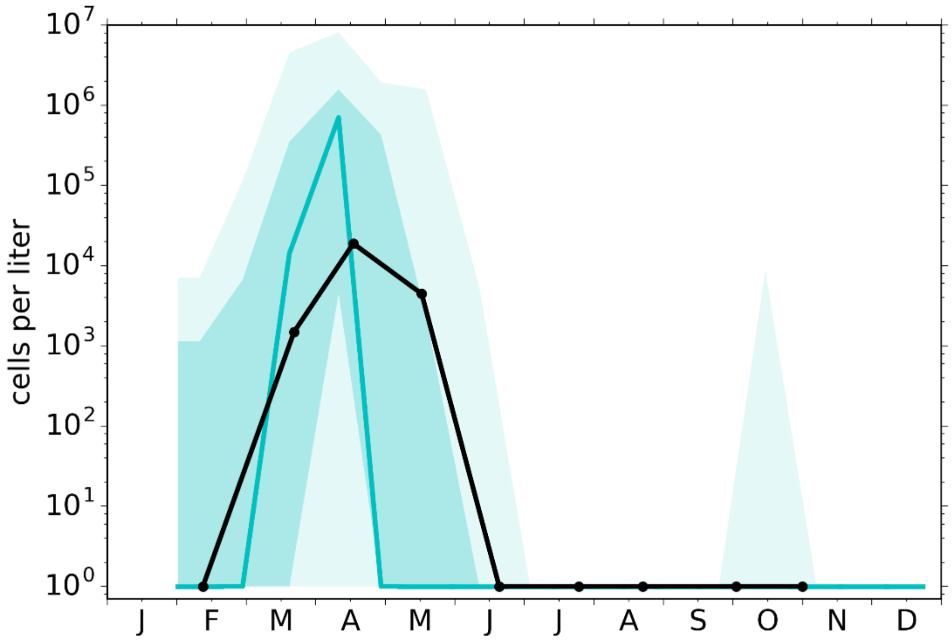

Figure 3-12. Mean nearfield abundance of *Phaeocystis pouchetii in* 2016, compared to 1992–2015. Black points and line are results from individual surveys in 2016. Results from 1992–2015 are in blue: line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range. Note log scale.

Nearfield abundance of the toxic dinoflagellate *Alexandrium fundyense* (responsible for red tide in New England) remained relatively low in 2016 (Figure 3-13). Its presence in one farfield sample during the May survey exceeded 100 cells per liter, triggering *Alexandrium* rapid-response surveys.

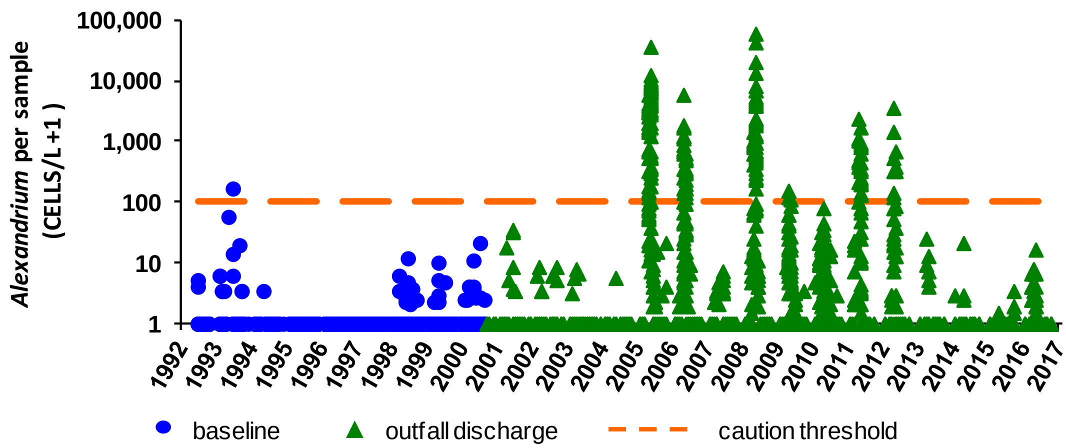

Figure 3-13. Nearfield abundance of *Alexandrium fundyense,* 1992–2016.

In early May, *Alexandrium* cells had been sufficiently abundant in the western Gulf of Maine that paralytic shellfish poisoning (PSP) toxicity was measured in coastal and offshore New Hampshire waters. On May 5–7, a storm with winds from the northeast brought cells into Massachusetts Bay, and during the May 18 survey, cell counts were elevated at the northeast farfield Station F22. On May 25, elevated abundances of *Alexandrium* were detected during the special survey, but only at stations just south of Cape Ann in northeastern Massachusetts Bay. By the June 21 regular survey, no *Alexandrium* cells were detected in any sample from Massachusetts Bay. No PSP toxicity was measured in Massachusetts Bay at any time in 2016.

Zooplankton Communities

Annual peak abundances of total zooplankton did not reach the record highs observed in 2015 (Figure 3-14, Libby et al. 2017). Those 2015 abundances were largely driven by the presence of bivalve veliger larvae in July and August, and those ephemeral taxa were not present in large numbers during the 2016 surveys. However, abundances of total zooplankton and of other dominant taxa were above the maxima for the monitoring program at many stations from February through June. Warm temperatures may have contributed to early increases in zooplankton abundances.

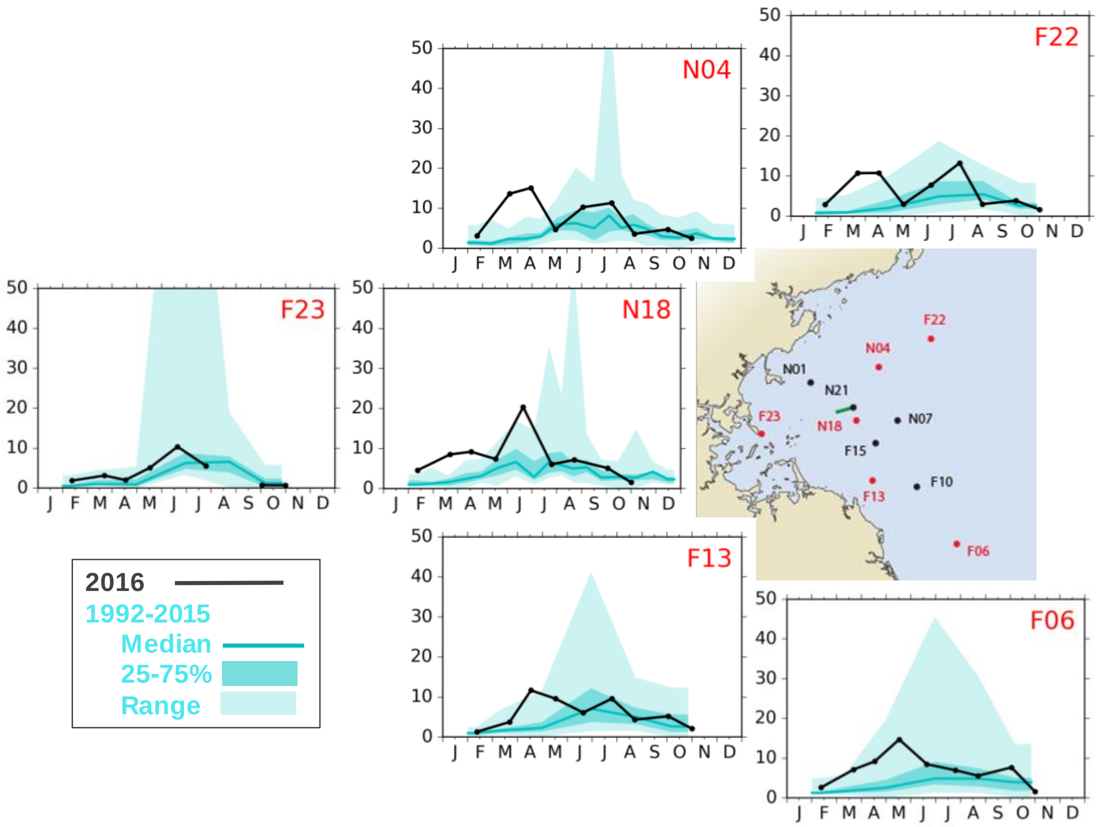

Figure 3-14. Total zooplankton abundance (10,000 animals per square meter) at selected stations in 2016 compared to prior years. Black points and line are results from individual surveys in 2016. Results from 1992–2015 are in blue: line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range.

In general, since 2008, total phytoplankton abundance has declined, while total zooplankton abundance has increased. Regression analyses suggest that phytoplankton abundance may be at least partially controlled by zooplankton grazing.

Stellwagen Bank National Marine Sanctuary

The NPDES permit to discharge from Deer Island Treatment Plant 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, Figure 3-6, above). Levels have also remained low at Station F06, located to the south of the outfall and offshore. In contrast, increased ammonium levels have been detected in the nearfield, while decreases have been detected at representative harbor and coastal stations.

Sampling at Station F22 and data from NERACOOS Buoy A01 (Figure 3-15), as well as satellite imagery (not shown), detected no unusual chlorophyll levels in offshore regions in 2016. No effects on chlorophyll levels in the offshore were predicted, and none have been measured.

Bottom-water dissolved oxygen concentrations at Station F22 were healthy throughout 2016, and both survey observations and data from NERACOOS Buoy A01, located within the sanctuary, showed the typical decline during the stratified season (Figure 3-15). Data from the buoy documented the return to oxygenated conditions as a result of fall mixing events.

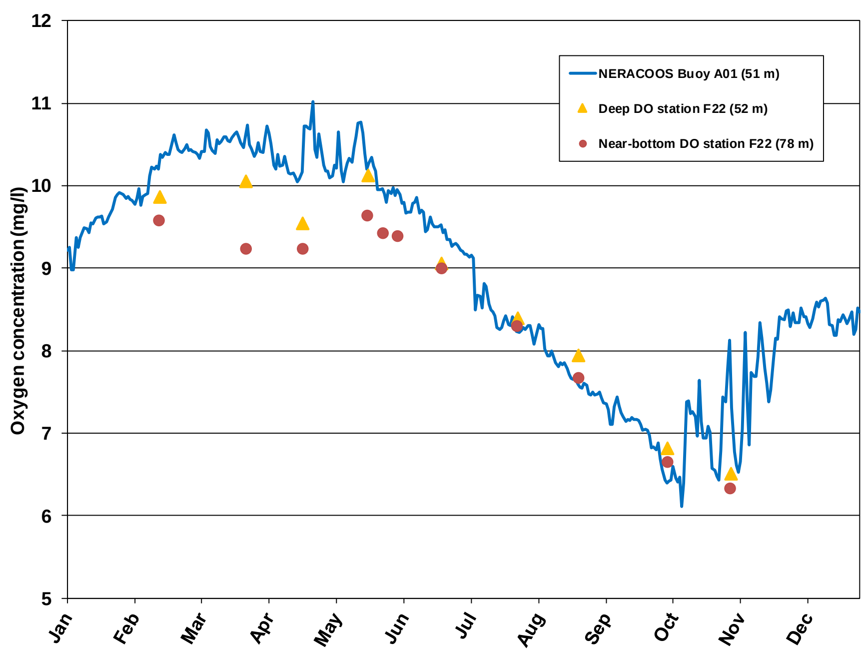

Figure 3-15. Bottom water dissolved oxygen concentrations at NERACOOS Buoy A01, inside the Stellwagen Bank National Marine Sanctuary, and at nearby Station F22. The NERACOOS measurement (blue) is at 51 m, the deep Station F22 (yellow) at 52 m, and the near-bottom Station F22 (red) at 78 m. DO = dissolved oxygen

Boston Harbor

Water quality in Boston Harbor has improved during the past 20 years, and those improvements were sustained in 2016. MWRA's in-house Boston Harbor monitoring program confirmed that harbor-wide concentrations of total nitrogen and phosphorus remained low, as they have since effluent discharges to the harbor ended.

Perhaps the most dramatic improvement in Boston Harbor has been the decrease in ammonium levels (Figure 3-16, Libby et al. 2017). Ammonium concentrations dropped precipitously when the effluent discharge was diverted from the harbor to Massachusetts Bay in 2000 and have remained low. In 2016, ammonium levels at Station F23, at the harbor mouth, were typical for the post-diversion years. In contrast, ammonium levels have increased at stations closest to the Massachusetts Bay outfall, such as Station N18. However, because of increased dilution at the offshore outfall, those increases have been substantially smaller than the concurrent decreases in ammonium concentrations in the harbor. Levels remain unchanged at stations farther from the outfall.

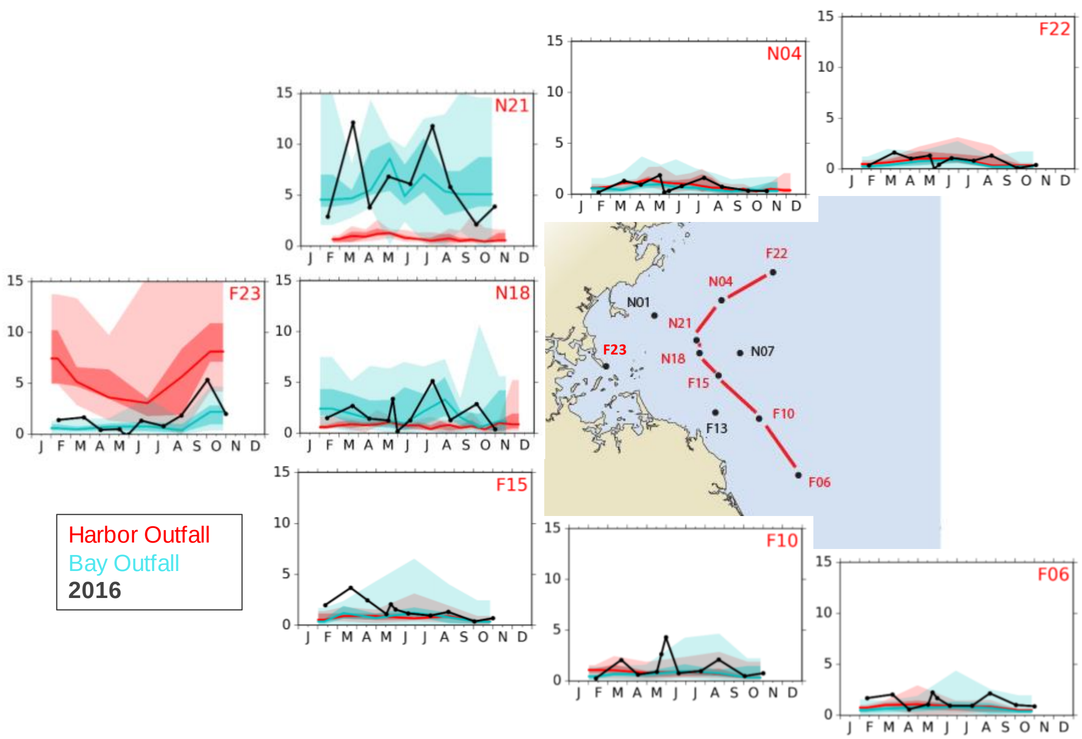

Figure 3-16. Depth-averaged ammonium levels (µM) at selected stations in 2016. Black points and line show 2016 results. Red line and shading show data from Boston Harbor discharge years. Blue line and shading show data from Massachusetts Bay discharge years. Lines are the 50th percentile; dark shading spans the 25th to 75th percentile; light shading spans the range.

Contingency Plan Thresholds

All water-quality parameters were within normal ranges during 2016. There was one Contingency Plan caution-level threshold exceedance for a nuisance algae measure, summer *Phaeocystis pouchetii* abundance (Table 3-1).

Table 3-1. Contingency Plan threshold values and 2016 results for water-column monitoring.

Parameter	Baseline	Caution Level	Warning Level	2016 Results
Dissolved oxygen*				
Nearfield concentration	6.05 mg/L	<6.5 mg/L	<6.0 mg/L	7.12 mg/L
Nearfield percent saturation	65.3%	<80%	<75%	83.9%
Stellwagen concentration	6.23 mg/L	<6.5 mg/L	<6.0 mg/L	6.33 mg/L
Stellwagen percent saturation	67.2%	<80	<75%	70.5%
Nearfield depletion rate	0.024 mg/L/d	>0.037 mg/L/d	>0.049 mg/L/d	0.01 mg/L/d
Chlorophyll				
Annual	72 mg/m^2	>108 mg/m^2	>144 mg/m^2	87 mg/m^2
Winter/spring	50 mg/m^2	>199 mg/m^2	None	89 mg/m^2
Summer	51 mg/m^2	>89 mg/m^2	None	85 mg/m^2
Autumn	90 mg/m^2	>239 mg/m^2	None	89 mg/m^2
Nuisance algae *Phaeocystis pouchetii*				
Winter/spring	622,000 cells/L	>2,860,000 cells/L	None	6,790 cells/L
Summer	79 cells/L	>357 cells/L	None	1,110 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	Absent
Summer	14,635 cells/L	>43,100 cells/L	None	954 cells/L
Autumn	10,050 cells/L	>27,500 cells/L	None	3,310 cells/L
Nuisance algae nearfield *Alexandrium fundyense*				
Any nearfield sample	Baseline maximum 163 cells/L	>100 cells/L	None	15 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

While winter-spring abundances of *Phaeocystis pouchetii* have been low in recent years (Figure 3-17, top) exceedances of the very low summer *Phaeocystis* threshold have occurred in several years (Figure 3-17, bottom). In May 2016, for example, *Phaeocystis* was detected in just one nearfield sample, but its presence, even at the low abundance of 36,000 cells per liter, was sufficient to exceed the summer Contingency Plan caution threshold. These exceedances have been evaluated and discussed with OMSAP, EPA, and MassDEP and have been determined to have caused no measurable aesthetic or other adverse effects. While the threshold remained in effect in 2016, OMSAP and the regulators have agreed to discontinue its use in future years.

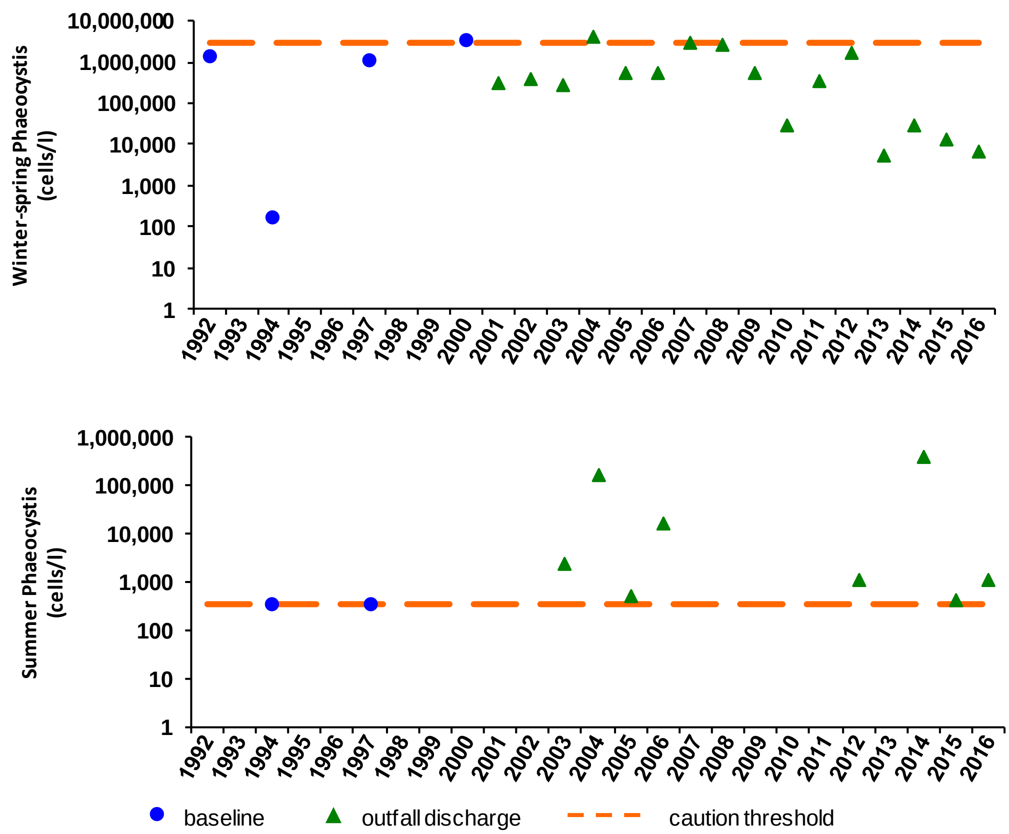

Figure 3-17. Mean nearfield abundance of *Phaeocystis pouchetii,* 1992–2016. (Top) Winter-spring. (Bottom) Summer. (No *Phaeocystis* were detected in years with no symbol.) Note the difference in scales for winter-spring (caution-level threshold of 2.86 million cells per liter) and summer (caution threshold of 357 cells per liter).

4. Sea Floor

Seafloor monitoring in 2016 included sampling and analysis of soft-bottom sediment conditions, tracers, and infauna at 14 stations and sediment-profile imaging at 23 stations (Figures 4-1, 4-2). Every three years, most recently in 2014, monitoring includes analysis of chemical contaminants in sediments and an assessment of hard-bottom habitats.

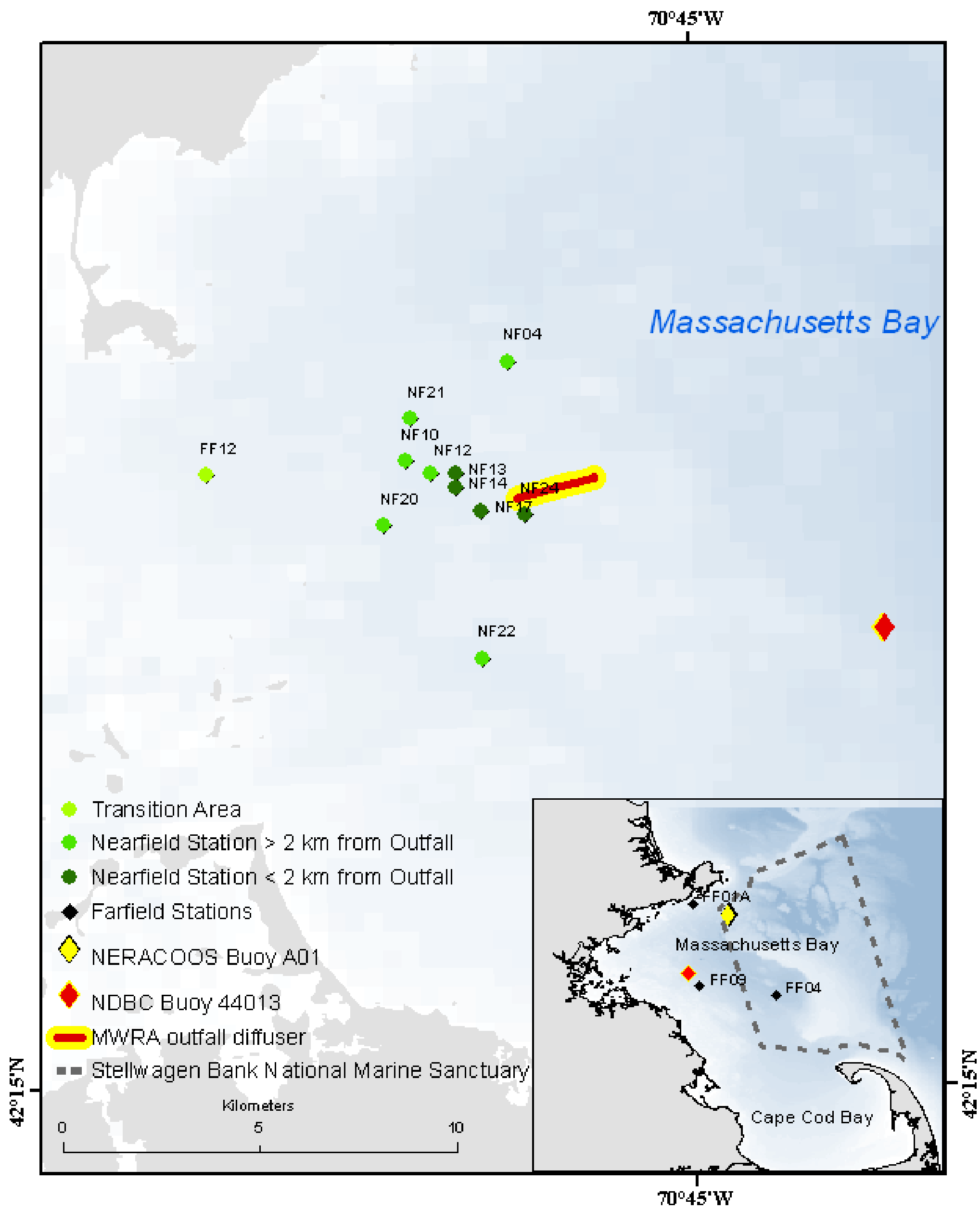

Figure 4-1. Soft-bottom monitoring stations. Benthic community parameters and sediment characteristics are measured in samples from 14 stations. Also shown are the instrumented buoys, the MWRA outfall diffuser, and the Stellwagen Bank National Marine Sanctuary.

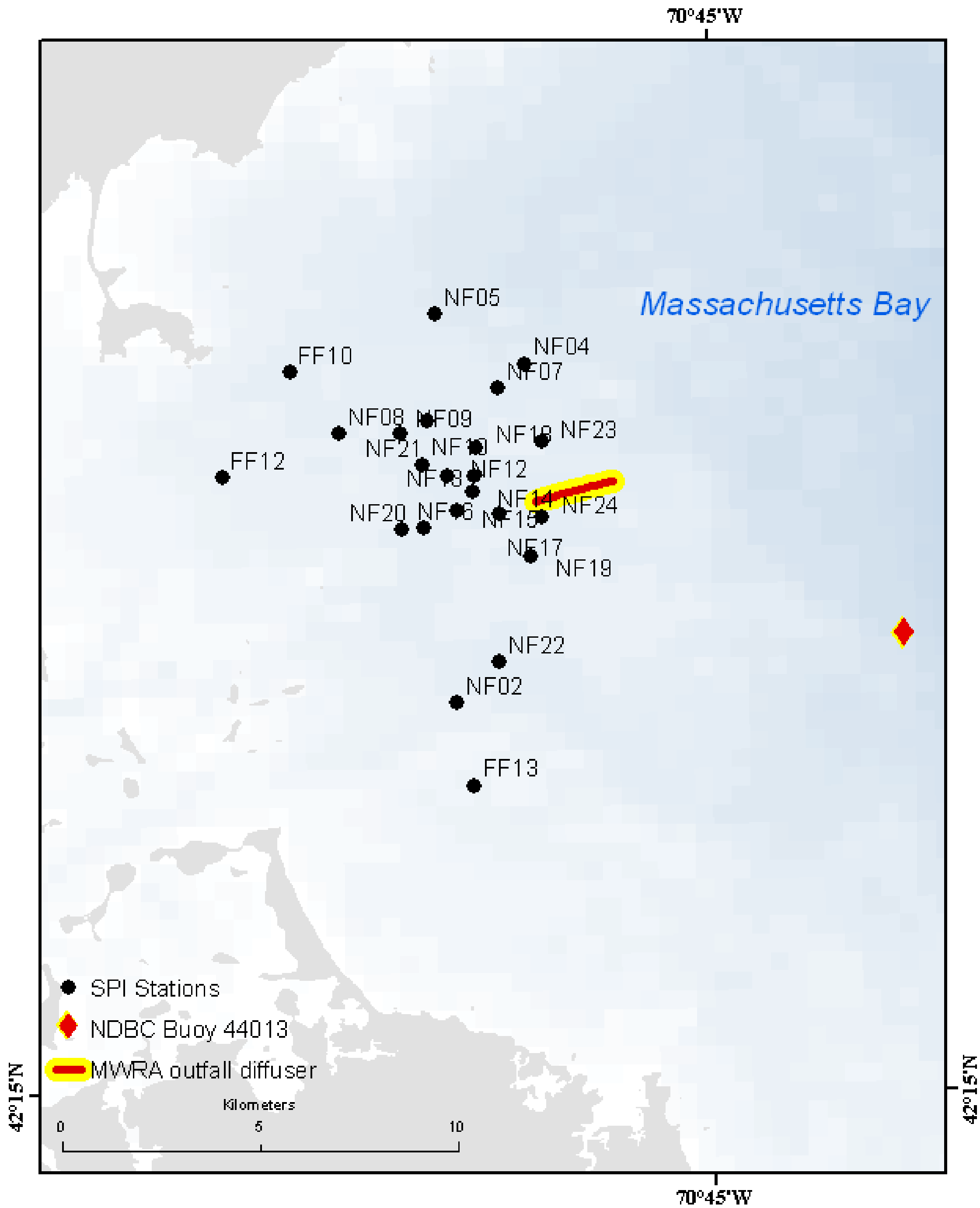

Figure 4-2. Sediment-profile imaging stations. Images are taken at 23 stations and provide rapid assessments of benthic habitats. Also shown are the NDBC buoy and the MWRA outfall diffuser. SPI = sediment-profile imaging

Soft-bottom sediment sampling was completed in August 2016, with samples analyzed for grain-size distribution, total organic carbon, the effluent tracer *Clostridium perfringens* spores, 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 2016. Triplicate images from 23 stations were used to measure the apparent reduction-oxidation (redox) potential discontinuity (RPD) depth, an approximation of the depth of oxygen penetration into the sediments; the apparent successional stage, often indicative of the health of the benthic community; and an organism-sediment index which is derived from the RPD depth and the successional stage.

Sediment Characteristics and Tracers

As in past years, sediment grain-size distributions in 2016 varied broadly among stations, ranging from silt and clay at some stations to mostly sand at others (Nestler et al. 2017). Sediment grain-size distributions have remained generally consistent at individual stations over the years of the monitoring program. Changes that have occurred have been mostly associated with large storms, having wave-driven currents sufficient to re-suspend bottom sediments.

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.

As in past years since the offshore outfall began to discharge, it was possible to detect elevated levels of *Clostridium perfringens* spores at the stations located closest to the outfall (Figures 4-3 and 4-4). Past years’ statistical analyses have shown that these increases close to the outfall are consistent with predictions made during the outfall planning process.

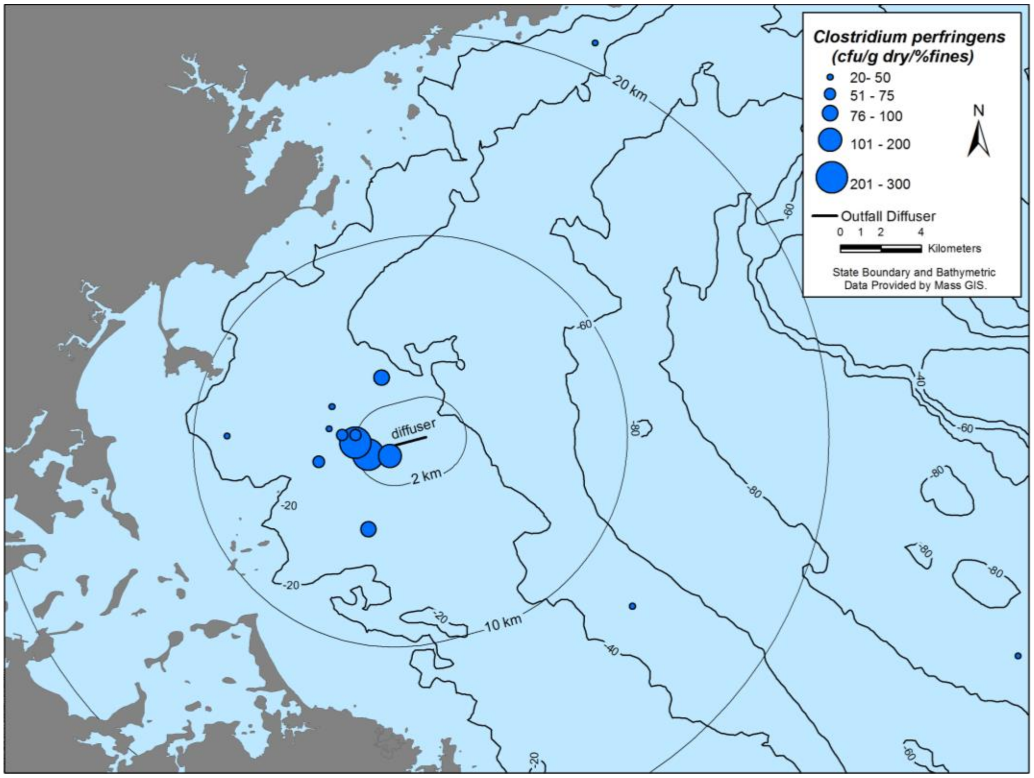

Figure 4-3. Concentrations of *Clostridium perfringens* spores, corrected for sediment grain size, in 2016.

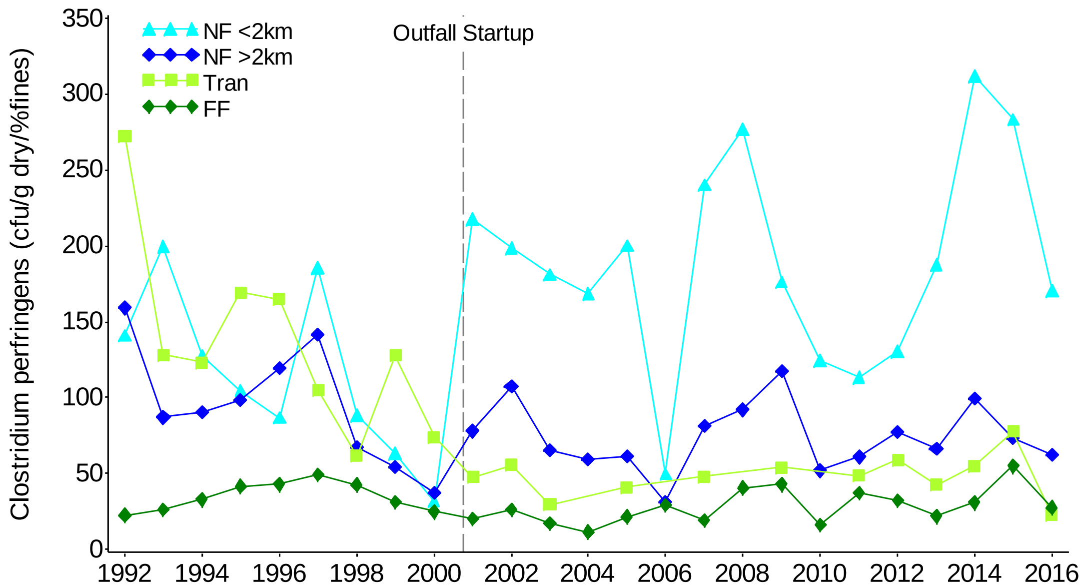

Figure 4-4. Mean concentrations of *Clostridium perfringens* spores during the baseline and outfall discharge years. Tran = transition area, stations located between Boston Harbor and the outfall; NF<2km = nearfield stations located within 2 km of the outfall diffusers; NF>2km = nearfield stations located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

Soft-bottom Communities

The 14 soft-bottom samples collected and analyzed in 2016 yielded 18,077 organisms, classified into 175 species and 21 other discrete taxonomic groups (Nestler et al. 2017). Total abundance of organisms was comparable to recent years and within the ranges of the monitoring program (Figure 4-5). Abundances by station (not shown) were also similar to the past. As in 2014 and 2015, total abundance was highest at stations within the transition area located between the harbor and the nearfield. It remained at the low end for the monitoring program at farfield stations. The mean numbers of species per sample were typical for the monitoring program in all areas.

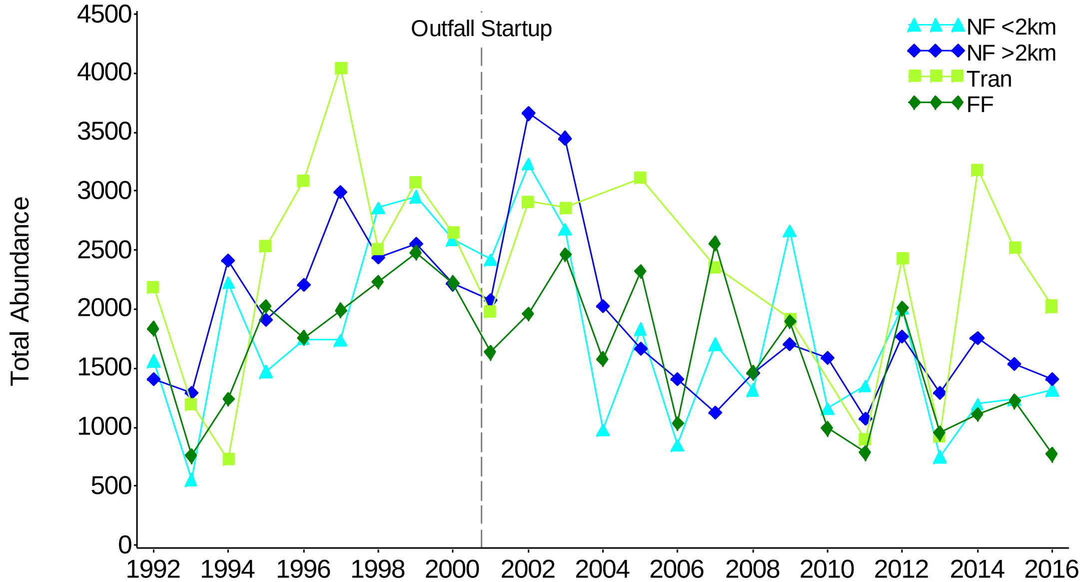

Figure 4-5. Mean infaunal abundance per sample during the baseline and outfall-discharge years. Tran = transition area, stations located between Boston Harbor and Massachusetts Bay; NF<2km = stations within 2 km of the outfall; NF>2km = nearfield stations greater than 2 km from the outfall; FF = farfield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

Community analyses continued to show that sediment grain size, rather than proximity to the outfall, is a major determinant of community composition and relative abundance. (Depth is also a major determinant; see the section on the Stellwagen Bank Marine Sanctuary, p. 34.) 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.

As in past years, a cluster analysis identified two main infaunal assemblages, with an outlier at Station FF04, which is offshore in the deeper waters of Stellwagen Basin and has consistently had a distinct community. Ordination analysis demonstrated that variations in species distributions largely followed differences in sediment type (Figure 4-6). The multivariate analyses have shown no indication of any relation of species composition to proximity to the outfall.

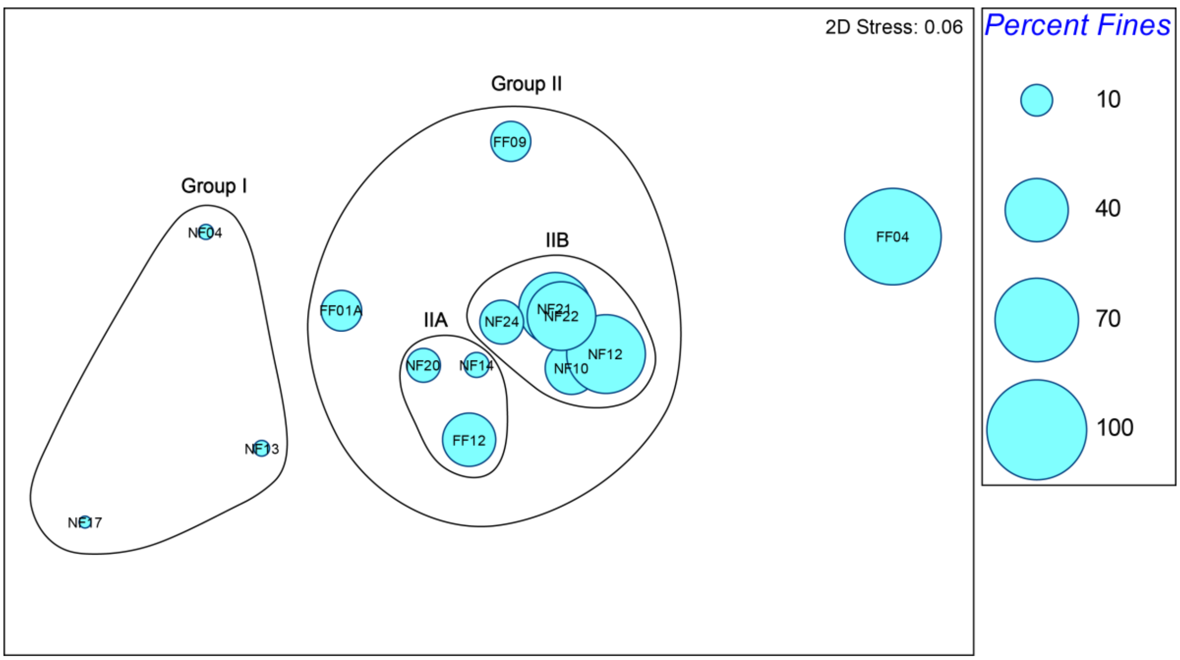

Figure 4-6. Percent fine sediments superimposed on the ordination plot of the 2016 infauna samples. Each point on the plot represents one of the 14 stations; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and sub-groups) identified 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. 2017). Rough topography and physical processes in the nearfield remain the more important factors in determining benthic habitat quality.

As in past years, the average RPD depth (the depth to which oxygen penetrates into sediments as determined by color changes) was deeper than average RPD depths measured during the baseline period (Figure 4-7). At 16 of the 23 stations, the RPD was deeper than the bottom of the images. The environmental concern before the outfall began to discharge was that the RPD depth would become shallower, due to increases in sediment organic matter causing stress on sensitive sediment-dwelling organisms. A deeper RPD continued to indicate that there has been no adverse effect from the discharge.

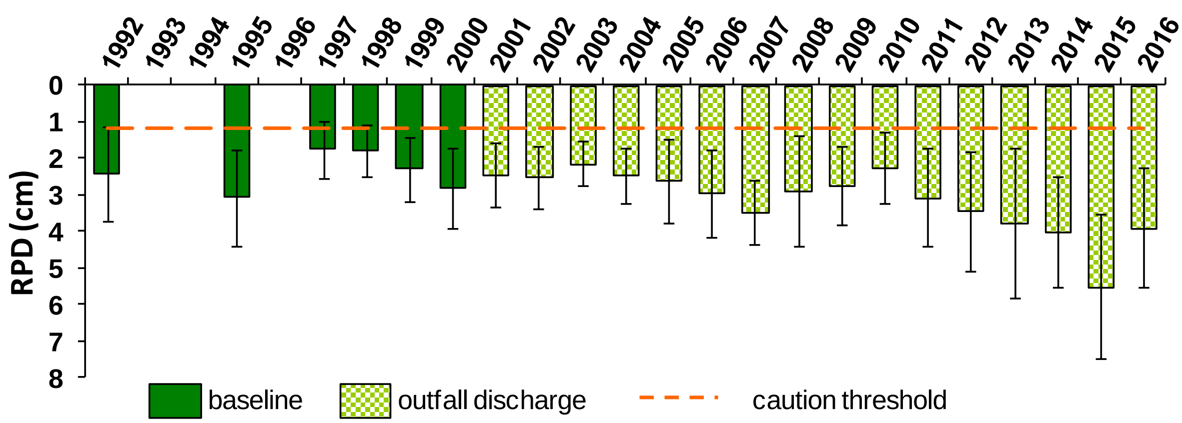

Figure 4-7. Annual apparent color RPD depth for data from nearfield stations. The average RPD discharge-period mean has been deeper than the baseline mean, continuing to indicate that there has been no adverse effect from the discharge.

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 is typical of outfalls that have been located in high-energy areas that promote rapid dispersion of effluent discharges. Physical forces that mix water into the sediments or transport coarser sediments to the sea floor may result in deepening of the RPD depths.

Stellwagen Bank National Marine Sanctuary

The NPDES permit to discharge from Deer Island Treatment Plant 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, where long-term accumulation of pollutants and their effects could be detected if they were to occur.

Station FF04 is typical of the deep waters offshore from the outfall, representative of a number of stations monitored in earlier years of the program, and it continues to support an infaunal community 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, and their distance from shore. Superimposing depth on the ordination plot for 2016 infauna samples continued to show these differences (Figure 4-8; see also Figure 4-6, which superimposed percent fine sediments on the ordination plot).

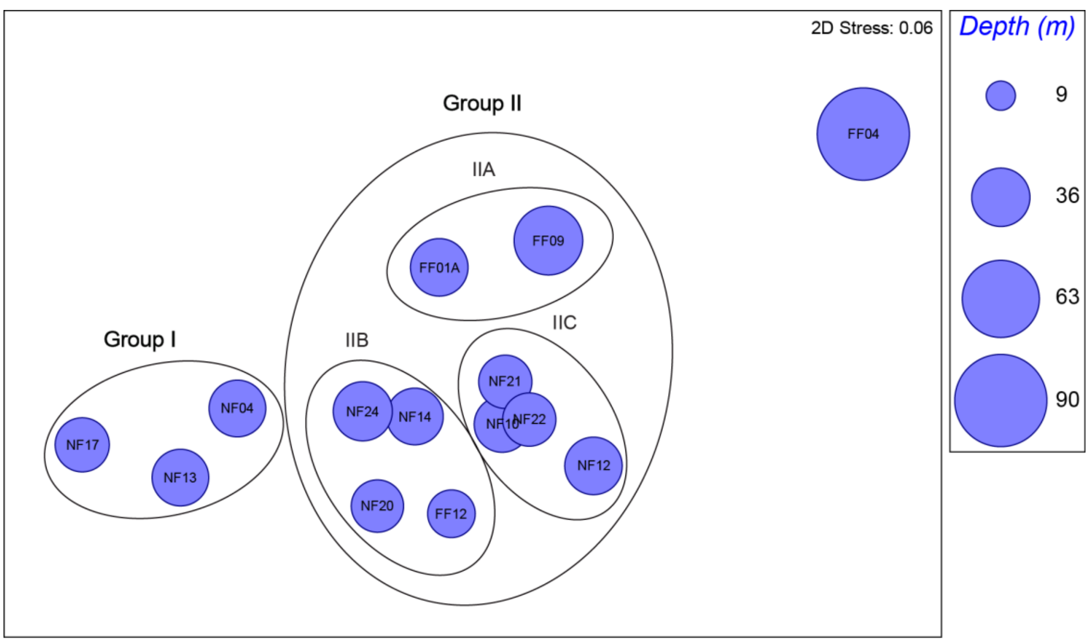

Figure 4-8. Depth superimposed on the ordination plot of the 2016 infauna samples. Each point on the plot represents one of the 14 stations; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and sub-groups) identified by cluster analysis are circled on the plot.

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, a result of the Boston Harbor Project and more recent enhancements to treatment and remediation of combined sewer overflows. MWRA has conducted ongoing seafloor monitoring in Boston Harbor since 1991. Annual sediment and infauna samples are taken from nine stations (Figure 4-9).

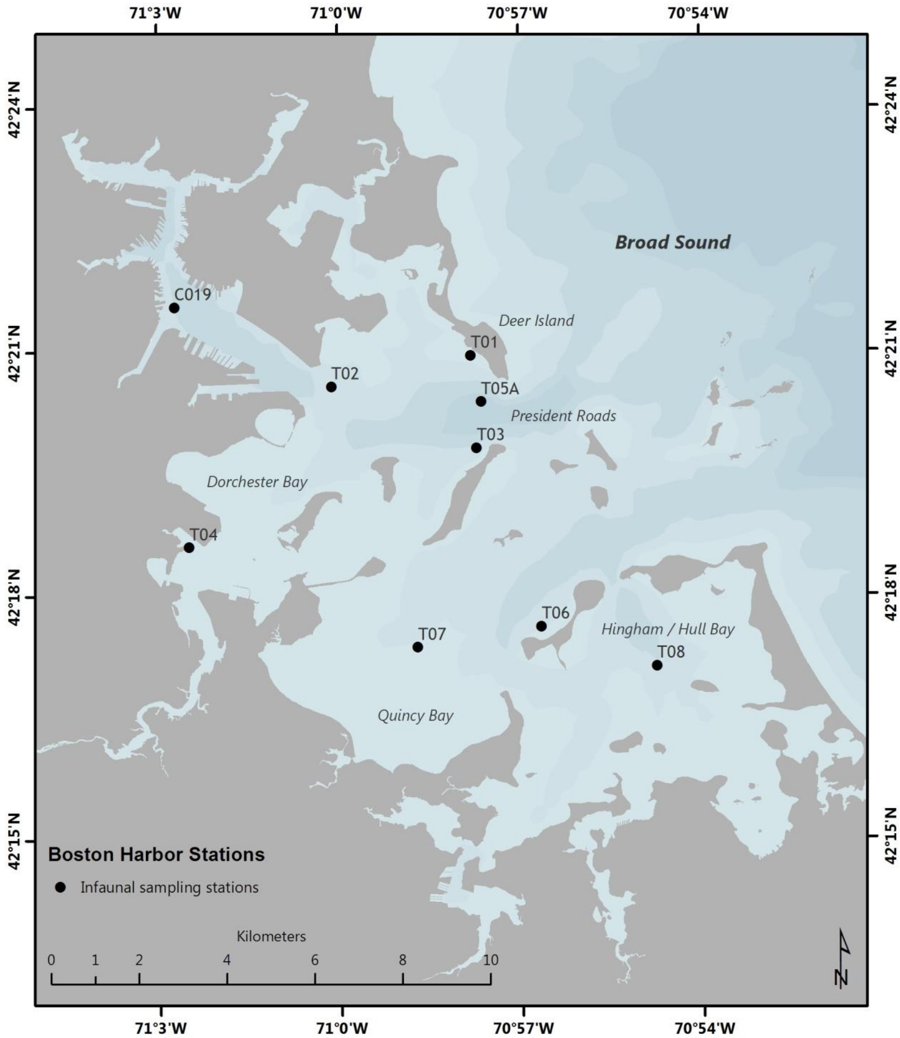

Figure 4-9. Soft-bottom sampling stations in Boston Harbor. Nine stations are sampled each year for sediment characteristics and infauna analyses.

Concentrations of total organic carbon (not shown) and *Clostridium perfringens* spores (Figure 4-10) have declined over time. Infaunal diversity has increased, reflecting continued improvement in habitat conditions. An ordination plot of Boston Harbor infaunal samples shows a separate community in stations in the outer harbor and a most unique fauna at Station T04 at the mouth of Savin Hill Cove, a location recognized as one of the most polluted sites in the harbor (Figure 4-11). Sediment-profile imaging (not shown) also confirmed an inner- to outer-harbor gradient.

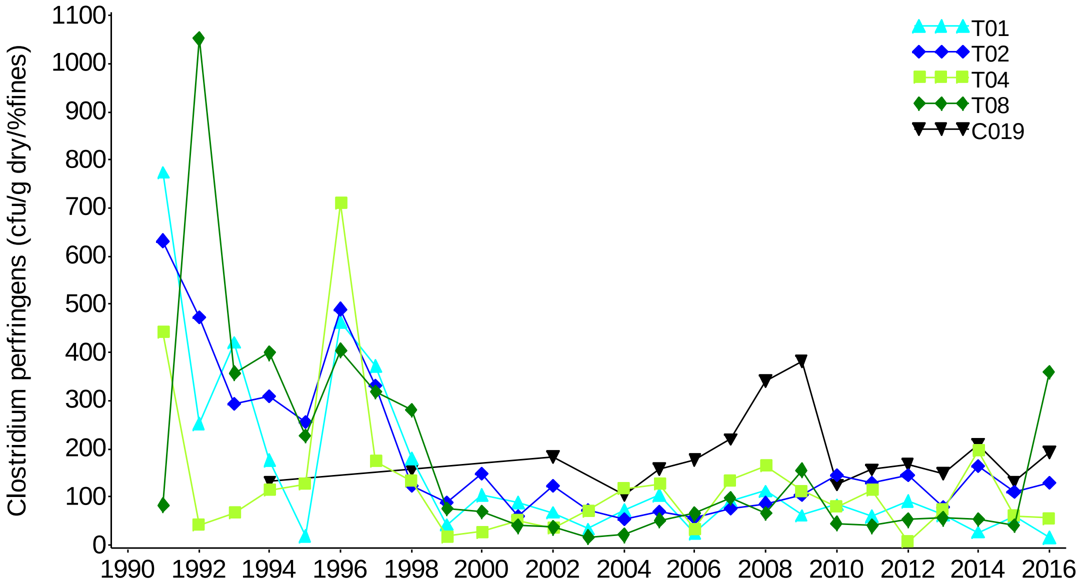

Figure 4-10. Mean concentrations of *Clostridium perfringens* spores at selected harbor stations, 1991–2016.

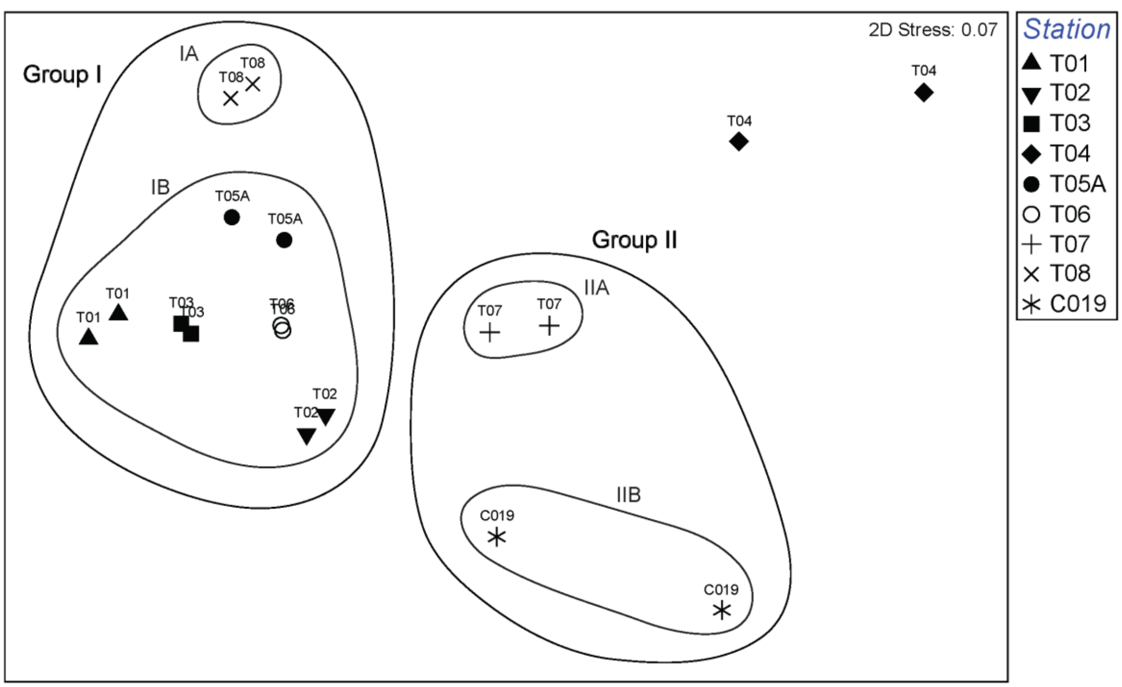

Figure 4-11. Ordination plot of 2016 Boston Harbor infauna samples. Two samples are collected per station. Group I comprises stations from the outer harbor; Group II includes Station C019 in the inner harbor and Station T07 in Quincy Bay. The assemblage most different from others was found at Station T04, at the mouth of Savin Hill Cove, in Dorchester Bay.

Contingency Plan Thresholds

There were no seafloor Contingency Plan threshold exceedances in 2016 (Table 4-1). Values for Shannon-Wiener diversity and Pielou's evenness, both diversity measures that triggered exceedances in 2010–2014, remained high but were within the upper caution-level ranges (Figure 4-12). Two other community threshold parameters, total number of species per sample (species richness) and Fisher's log-series alpha, another diversity measure, were also within the caution-level ranges. Percent opportunists among the soft-bottom community remained far below caution and warning levels.

There has been no indication, even when diversity levels exceeded the upper bounds of the caution-level thresholds, that environmental conditions have worsened or that there has been any effect of the outfall. Indeed, increased diversity is typically considered a good outcome in benthic habitats. The 2010–2014 exceedances, when reviewed, were found to be natural fluctuations in the environment, with no indication of any effect of the outfall. Therefore, OMSAP, with concurrence of EPA and MassDEP, has agreed to discontinue the upper bounds as Contingency Plan thresholds for future monitoring years.

Table 4-1. Contingency Plan threshold values and 2016 results for seafloor monitoring.

Parameter	Baseline	Caution Level	Warning Level	2016 Results
Sediment parameters				
RPD depth	NA	<1.18 cm	None	3.89 cm
Benthic community parameters				
Species per sample	NA	<42.99 or >81.85	None	58.5
Fisher's log-series alpha	NA	<9.42 or >15.8	None	12.7
Shannon-Wiener diversity	NA	<3.37 or >3.99	None	3.93
Pielou's evenness	NA	<0.57 or >0.67	None	0.672
% opportunists	NA	>10%	>25%	0.21%

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

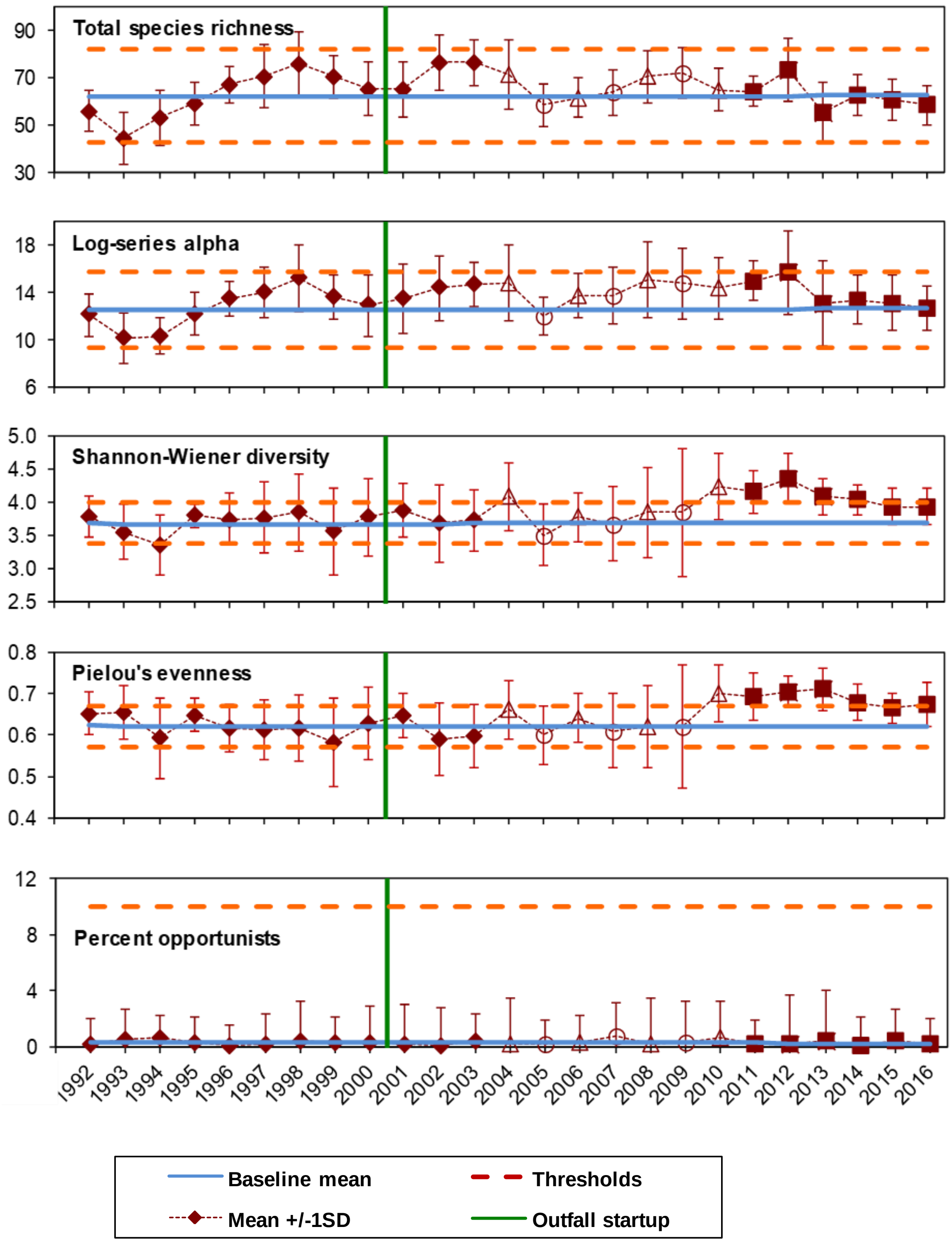

Figure 4-12. Annual community parameters with nearfield Contingency Plan thresholds. The varied symbols represent differences in the stations sampled over the years of the program. Results were tested against thresholds calculated for each sampling design, but only the current threshold values are shown. Except for the percent opportunists threshold, which is based on levels in Boston Harbor, thresholds have both upper and lower bounds to show potentially meaningful changes from the baseline. Upper level threshold will be discontinued in 2017. SD = standard deviation

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 2015, monitoring includes chemical analyses of flounder fillets and liver, lobster meat and hepatopancreas, and cage-deployed blue mussels. Sampling and analysis in 2016 were limited to winter flounder health assessments.

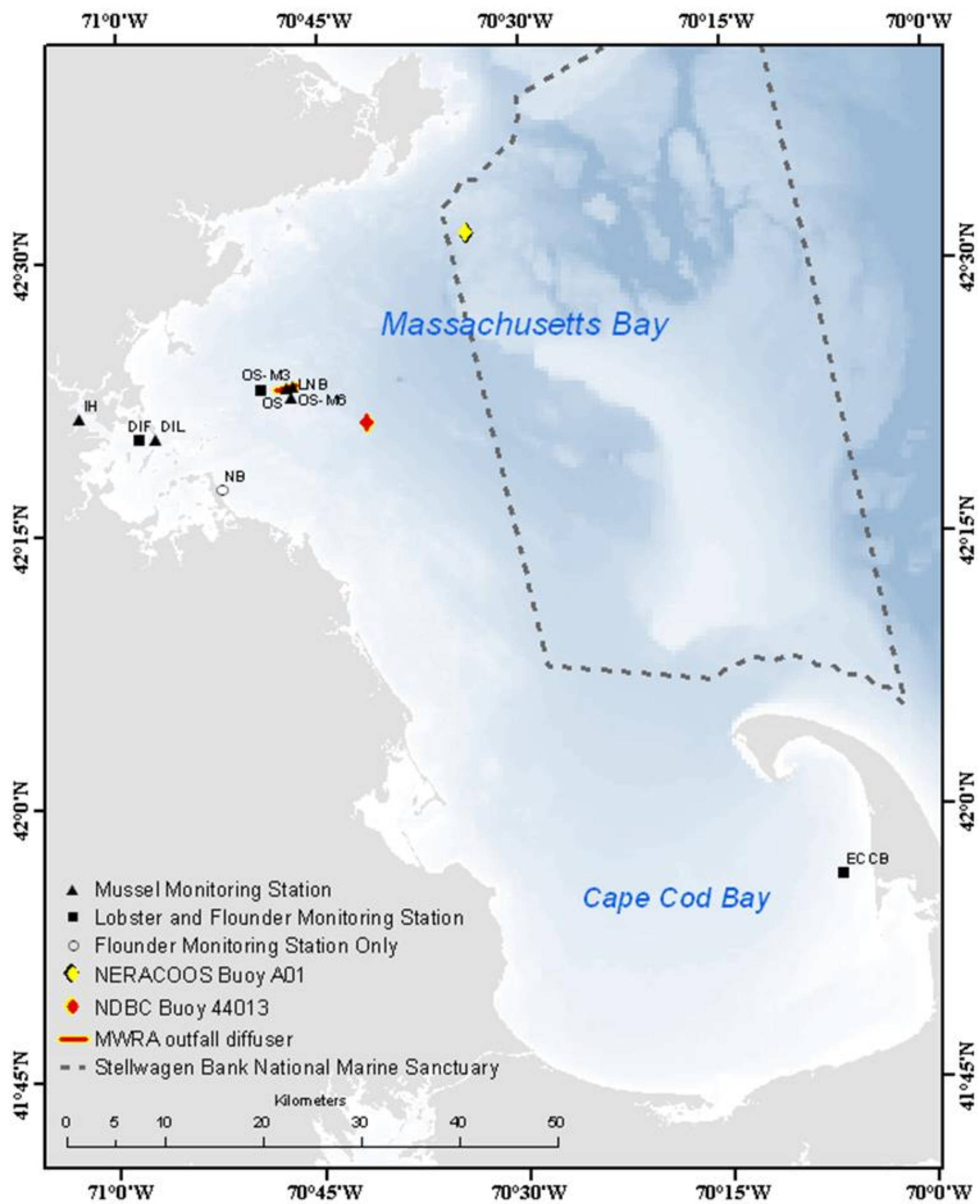

Figure 5-1. Fish-and-shellfish monitoring stations. Also shown are the two instrumented buoys, the MWRA outfall diffuser, and the boundaries of the Stellwagen Bank National Marine Sanctuary.

Flounder Health

Annual flounder monitoring focuses on external condition and the presence of early liver disease and tumors (neoplasia). In April 2016, 50 sexually mature flounder were collected from each of the four sites: Deer Island Flats, off Nantasket Beach, the outfall site, and eastern Cape Cod Bay. Catch per unit effort, which has varied through time, was highest at eastern Cape Cod Bay. 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.

Across the sites, mean age of fish ranged from 4.0 to 4.7 years, and standard length ranged from 278 to 323 millimeters, within the ranges for the monitoring program. As is common throughout northeast coastal populations, the catches were dominated by females (see Moore et al. 2016 for analysis of MWRA and other northeast flounder studies).

Measures of external condition continued to suggest improved conditions in comparison to the 1980s and 1990s, and there continued to be no evidence of neoplasia. Tumors have not been observed by the monitoring program since 2004 and have never been observed in fish taken from the outfall site.

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 (Figure 5-2). Incidence of CHV at the outfall was the lowest measured since MWRA monitoring began in 1991. At Deer Island Flats, near the location of the former Boston Harbor outfall, there was an increase in incidence to about 30% in 2015 and 2016, but even in those years, levels remained lower than observed levels before discharge was diverted to Massachusetts Bay. Average severity of CHV (not shown) also remained lower than baseline levels, and reasons for the two years of increased CHV prevalence were unclear. (In 2017, data not shown, CHV incidence in fish from Deer Island Flats returned to levels similar to what was observed in 2010–2013, about 24%.)

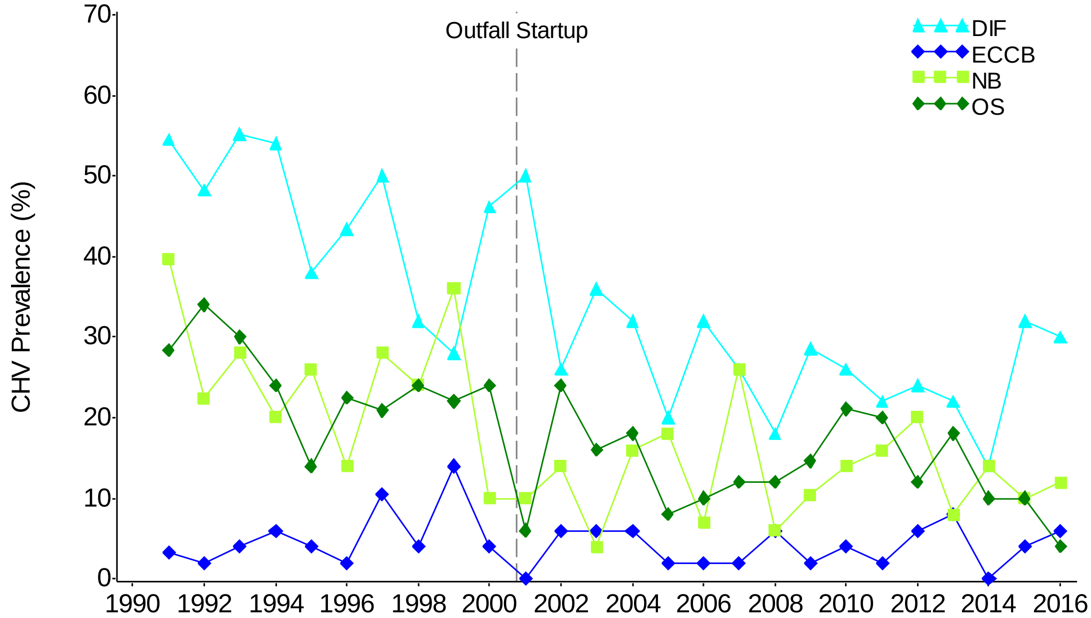

Figure 5-2. Annual prevalence of centrotubular hydropic vacuolation (CHV), 1991–2016. DIF = Deer Island Flats, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, OS = Outfall Site

Contingency Plan Thresholds

There was no Contingency Plan threshold exceedance for the only parameter measured for 2016 (Table 5-1). Incidence of CHV, the most common indicator of liver disease in winter flounder of the region, was 4% in fish taken from the vicinity of the outfall, the lowest recorded during the monitoring program, far lower than the 44.9% caution threshold or 24.4% baseline average.

Table 5-1. Contingency Plan threshold value and 2016 results for fish-and-shellfish monitoring.

Parameter	Baseline	Caution Level	Warning Level	2016 Results
Flounder disease				
Liver disease (CHV)	24.4%	>44.9%	None	4%

CHV = centrotubular hydropic vacuolation

6. Special Studies

Besides monitoring the effluent and the water column, sea floor, and fish and shellfish in Massachusetts Bay, MWRA conducts special studies in response to specific permit requirements, scientific questions, and public concerns. This year's overview focuses on special studies of indicator bacteria in sewage effluent, continued recovery in Boston Harbor, and ongoing monitoring by the Center for Coastal Studies in Cape Cod Bay.

Indicator Bacteria in Sewage Effluent

MWRA's NPDES permit to discharge effluent at the Massachusetts Bay outfall specifies that daily counts of sewage-indicator fecal coliform bacteria not exceed 14,000 coliforms per 100 milliliters at the point of dechlorination, just prior to discharge. Except for one event in 2001 and another in 2004, this daily permit limit has been met throughout the duration of monitoring. Since 2008, almost half of all samples have had no detectable fecal coliform bacteria, and the maximum count was only 501 fecal coliforms per 100 milliliters (Figure 6-1).

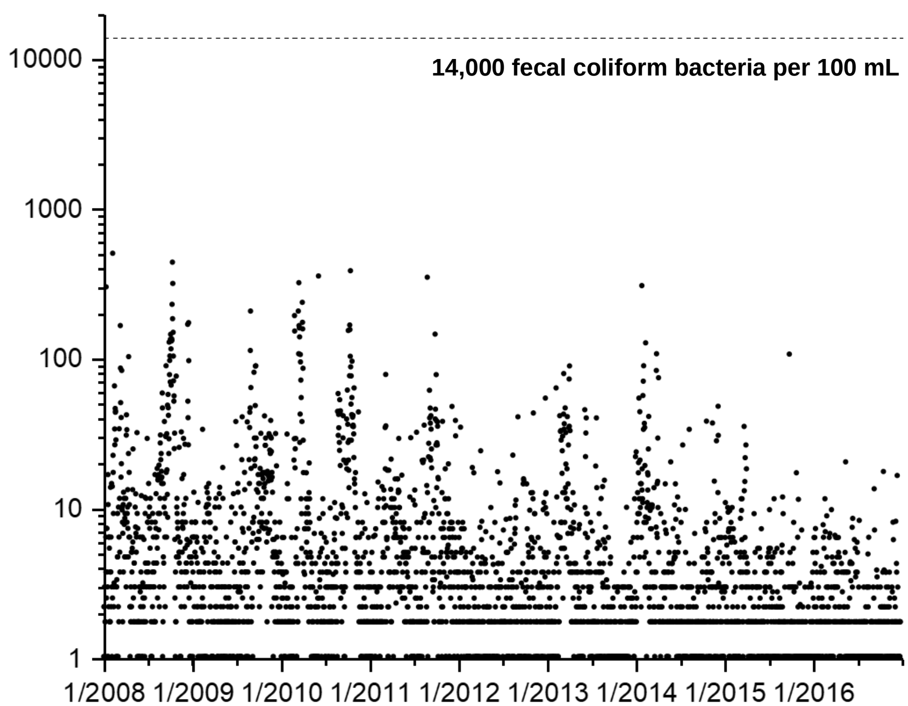

Figure 6-1. Daily geometric mean fecal coliform bacteria in Deer Island effluent, 2008–2016, in comparison to the permit limit, 14,000 fecal coliforms per 100 milliliters. Note log scale.

Future permits may include a limit for another indicator bacteria species group, *Enterococcus*. Meeting an *Enterococcus* effluent limit could be more difficult than meeting the fecal coliform bacteria limit, potentially requiring greater levels of chlorination and subsequent dechlorination prior to discharge.

MWRA already monitors *Enterococcus* in both the effluent and in the vicinity of the Massachusetts Bay outfall (Figure 6-2). Those samples show that under current levels of disinfection, *Enterococcus* counts in the effluent vary strongly by season, with peak counts during the late winter. Despite this variation in the effluent, levels in the receiving water are relatively constant throughout the year and have met the state water quality standard, 35 *Enterococcus* per 100 milliliters, in more than 99.9% of all samples. The vast majority of samples taken from Massachusetts Bay have had undetectable levels of either fecal coliform or *Enterococcus* indicator bacteria.

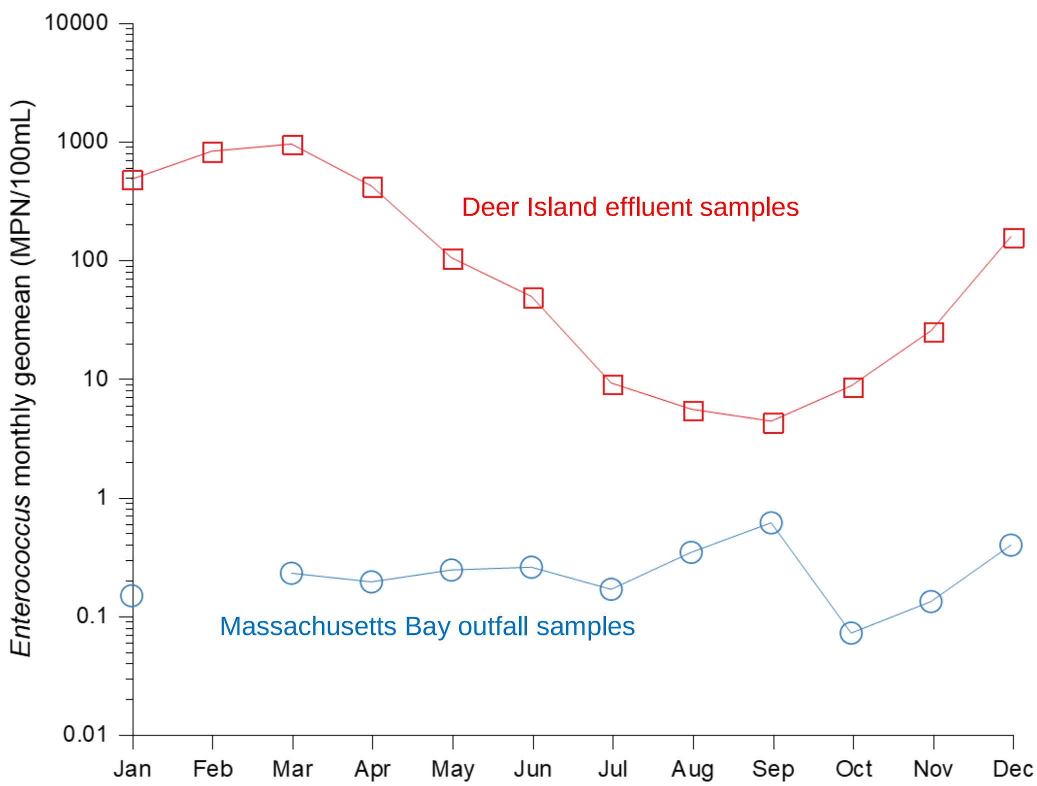

Figure 6-2. Monthly geometric mean *Enterococcus* bacteria in Deer Island effluent, 2008–2016, in comparison to monthly geometric mean *Enterococcus* in surface and bottom samples from two stations near the outfall. Note log scale. *Enterococcus* have not been detected in any February sample from the outfall.

Recovery in Boston Harbor

In 1990, when MWRA discharged both biosolids (sludge) and inadequately treated municipal effluent into Boston Harbor, the harbor was known as one of the dirtiest in the nation. One major problem was eutrophication, that is, an excess of organic matter, which can lead to low levels of dissolved oxygen in the water column and the bottom sediments. In addition to organic matter, the Boston Harbor outfalls discharged nutrients that fueled excessive phytoplankton growth. When the phytoplankton died and decomposed, bacteria removed oxygen from the water. Decomposing phytoplankton also sank to the sea floor, where excess organic matter enhanced benthic respiration and nutrient fluxes, also contributing to lower oxygen levels. However, because tidal mixing in Boston Harbor is strong, oxygen concentrations were not reduced to the unhealthiest conditions, hypoxia or anoxia.

With the end of biosolids discharge in 1991 and the end of effluent discharge in 2000, nutrient inputs have declined, and those decreases have resulted in changes in the water column and the sea floor. Nitrogen inputs are now about 20% of what they were in 1990, and phosphorus inputs are about 5% (Figure 6-3, top). Organic carbon inputs (not shown), have fallen to less than half of what they were in the past.

With the decreases in nutrient inputs, annual primary production (growth of phytoplankton or algae) in the water column has also decreased, changing the classification of the harbor from an unhealthy, hyper-eutrophic water body to a much more favorable condition, borderline eutrophic or mesotrophic (Figure 6-3, middle). In 1990, there had been predictions that primary production might increase despite declines in nutrient inputs, because increased water clarity could also stimulate phytoplankton blooms. In fact, blooms in 2002 and 2007 were not associated with any change in nutrient inputs and may have been storm-induced. Through the overall course of the program, however, phytoplankton production has declined. Phytoplankton biomass (not shown) has also declined over the same period.

Sediment metabolism, the rates of processes such as sediment respiration and regeneration of nutrients by bacteria in the sediments, have also decreased in Boston Harbor (Figure 6-3, bottom). The changes in these measures have been smaller and more variable than the changes observed among the water column parameters. The effects of the 2002 and 2007 phytoplankton blooms were apparent, with increases in benthic fluxes during the immediately following years. The pattern demonstrates a strong coupling between the water column and the sediments.

Numbers of benthic organisms (not shown) have also declined in response to the decreases in nutrients and organic matter. Organism density and extent of dense amphipod mats reached minima about five to eight years after the end of effluent discharge to the harbor, corresponding well to the changes in phytoplankton production and nutrient fluxes.

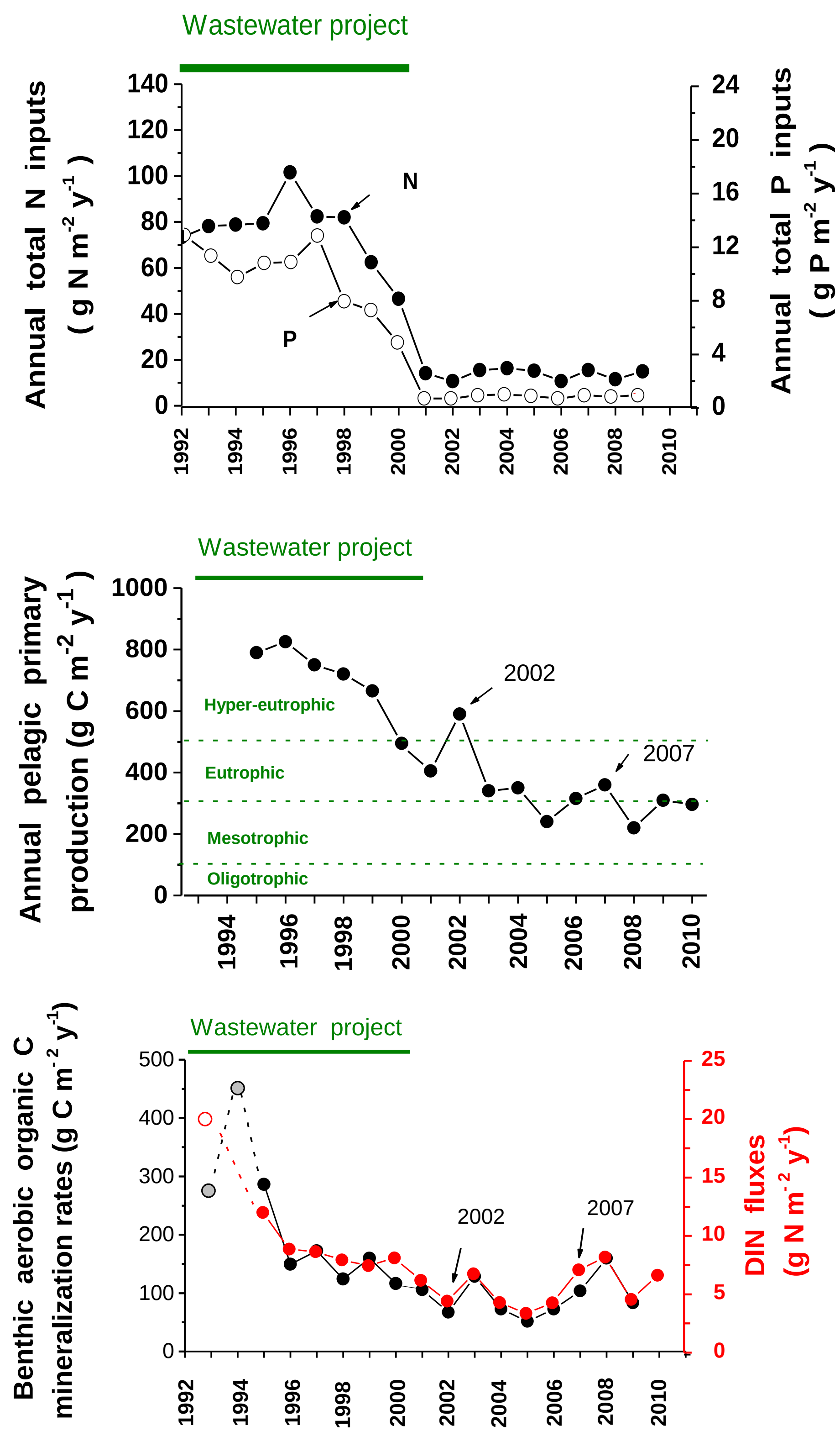

Figure 6-3. Annual nutrient inputs, pelagic community production, and benthic fluxes in Boston Harbor. N=nitrogen, P=phosphorus, C=carbon, DIN=dissolved inorganic nitrogen

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). Recent years' studies have documented conditions ranging from one of the coldest winter sampling dates in early 2015 to the second warmest of winters in early 2016 (Costa et al. 2017). Similar to other MWRA analyses, the studies have found that, in general, nutrient levels and phytoplankton abundances have been somewhat lower than average in recent years, while zooplankton abundances have been higher.

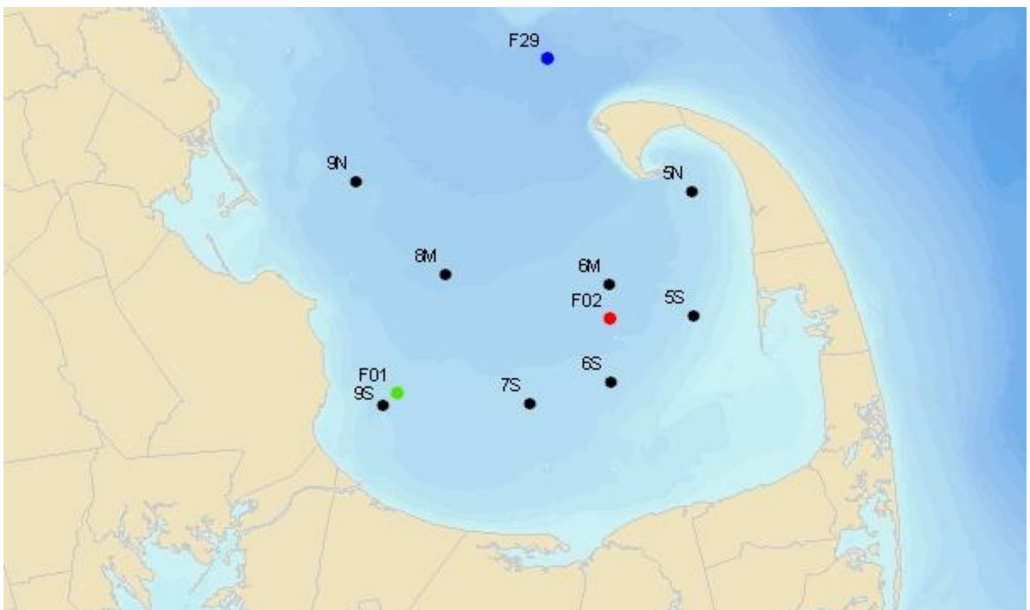

Figure 6-4. The Center for Coastal Studies monitors its own eight stations (black) and three MWRA stations (F01, F02, and F29) in and near Cape Cod Bay. (Figure from the Center for Coastal Studies)

The Center for Coastal Studies also monitors North Atlantic right whales, which are protected under the U.S. Endangered Species and Marine Mammal Protection acts, with Massachusetts and Cape Cod bays considered to be key habitat. Aerial surveys flown along a series of east-west tracks over Cape Cod Bay record presence, dive times, and whale behaviors. Right whales typically occur in Cape Cod Bay during January through May, entering when nutrient and chlorophyll levels are high, and the large zooplankton species favored as food are abundant. In 2016, peak numbers of whales were sighted in March and April. Unlike some years, March sightings did not correspond to zooplankton density (Figure 6-5), although the correspondence was better in April (not shown). Direct observations of deep-diving behaviors suggested that whales may have been feeding more deeply than in other years.

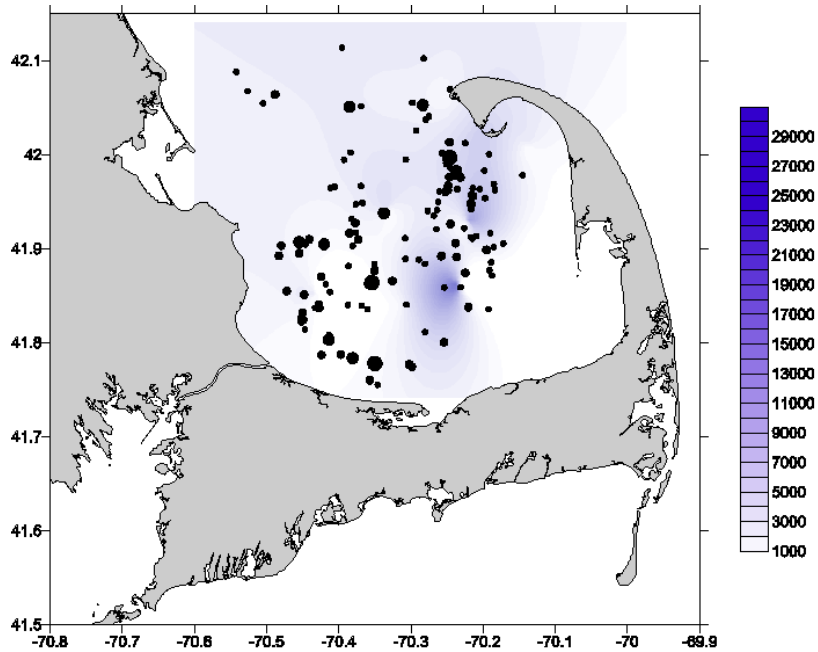

Figure 6-5. Whale sightings (black dots) and zooplankton density (purple shading) in Cape Cod Bay in March 2016. (Figure from the Center for Coastal Studies.)

Overall, there were 178 identified whales observed throughout the season (Figure 6-6), approximately one third of the known North Atlantic right whale population. Total sightings were more numerous than in 2015, when frigid winter conditions delayed the arrival of whales into Cape Cod Bay, but fewer than in 2011–2014.

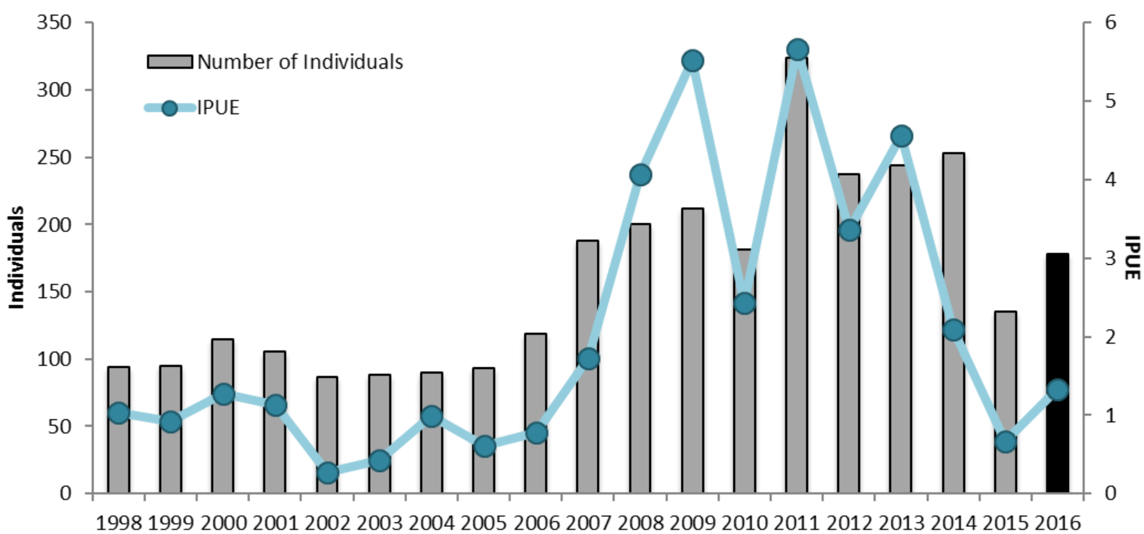

Figure 6-6. Total individual right whale sightings and sightings per unit effort (IPUE) in Cape Cod Bay in 1998–2016. (Figure from the Center for Coastal Studies.)

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List of Acronyms

C	Carbon
cBOD	Carbonaceous biochemical oxygen demand
CHV	Centrotubular hydropic vacuolation
DDT	Dichlorodiphenyltrichloroethane
DIF	Deer Island Flats
DIN	Dissolved inorganic carbon
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
MassDEP	Massachusetts Department of Environmental Protection
MODIS	Moderate Resolution Imaging Spectroradiometer
MWRA	Massachusetts Water Resources Authority
N	Nitrogen
NA	Not analyzed/not applicable
NACWA	National Association of Clean Water Agencies
NB	Nantasket Beach
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
NF	Nearfield
NDBC	National Data Buoy Center
NOEC	No observed effects concentration
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OS	Outfall site
P	Phosphorus
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
PSP	Paralytic shellfish poisoning
RPD	Redox potential discontinuity
SD	Standard deviation
SEIS	Supplemental environmental impact statement
SPI	Sediment-profile imagery

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