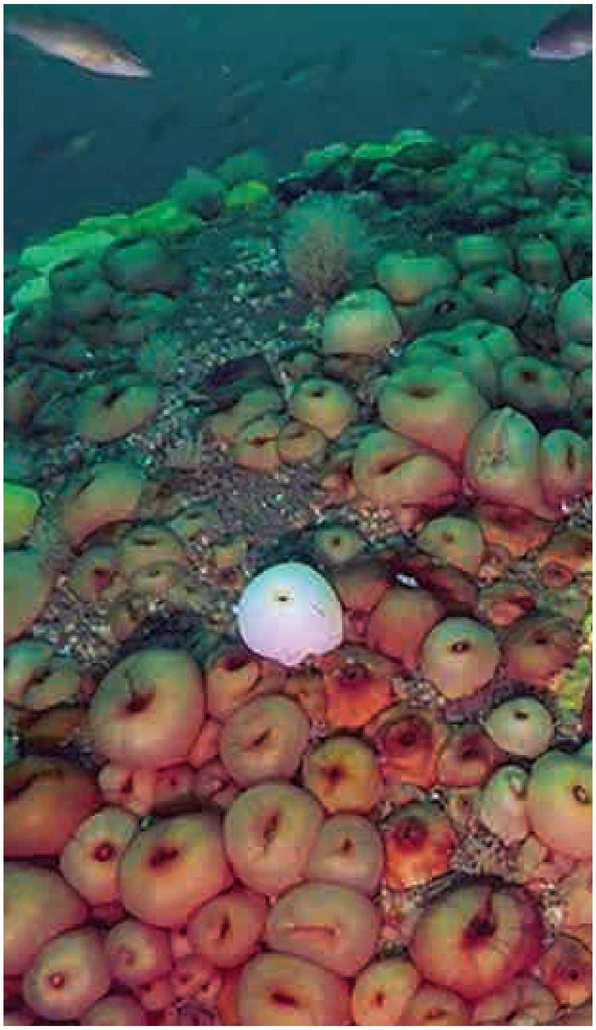

2017 Outfall Monitoring Overview

Massachusetts Water Resources Authority
Environmental Quality Department Report 2018-07

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Cover photo credits clockwise from top left:

Sea anemones and other organisms on an outfall riser in Massachusetts Bay:
Barbara Hecker and Normandeau Associates

Sediment sampling in Boston’s Inner Harbor:
Chris Baker, Normandeau Associates

Winter flounder in eelgrass bed:
Chris Pickerell, (NOAA Fisheries file photo)

2017
Outfall Monitoring Overview

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November 5, 2018

2017 Outfall Monitoring Panel and Committees

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Judy Pederson, Massachusetts Institute of Technology Sea Grant
Michael Shiaris, University of Massachusetts, Boston
James Shine, Harvard School of Public Health
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Inter-Agency Advisory Committee (IAAC)

US Geological Survey
Massachusetts Coastal Zone Management
US Army Corps of Engineers
Stellwagen Bank National Marine Sanctuary
US Environmental Protection Agency
Massachusetts Division of Marine Fisheries
Massachusetts Department of Environmental Protection

Public Interest Advisory Committee (PIAC)

Save the Harbor/Save the Bay
MWRA Wastewater Advisory Committee
Conservation Law Foundation
Massachusetts Audubon Society
MWRA Advisory Board
Association to Preserve Cape Cod
Safer Waters in Massachusetts
The Boston Harbor Association

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Executive Summary

This outfall monitoring overview for 2017 marks the twenty-sixth year of the Massachusetts Water Resources Authority (MWRA) Massachusetts Bay monitoring program and more than seventeen years since effluent discharge was diverted from the shallow, confined waters of Boston Harbor to the deeper, more open waters of Massachusetts Bay.

Deer Island Treatment Plant continued to operate as designed, earning MWRA the National Association of Clean Water Agencies Platinum 11 Peak Performance Award for facilities with 100% compliance with permit conditions over eleven consecutive years. Solids discharges to Massachusetts Bay remained low, with only a fraction of the discharges that had been made to Boston Harbor in the 1990s (Figure i). Discharges of toxic metals and organic compounds were well below what had been anticipated when discharge to Massachusetts Bay was planned.

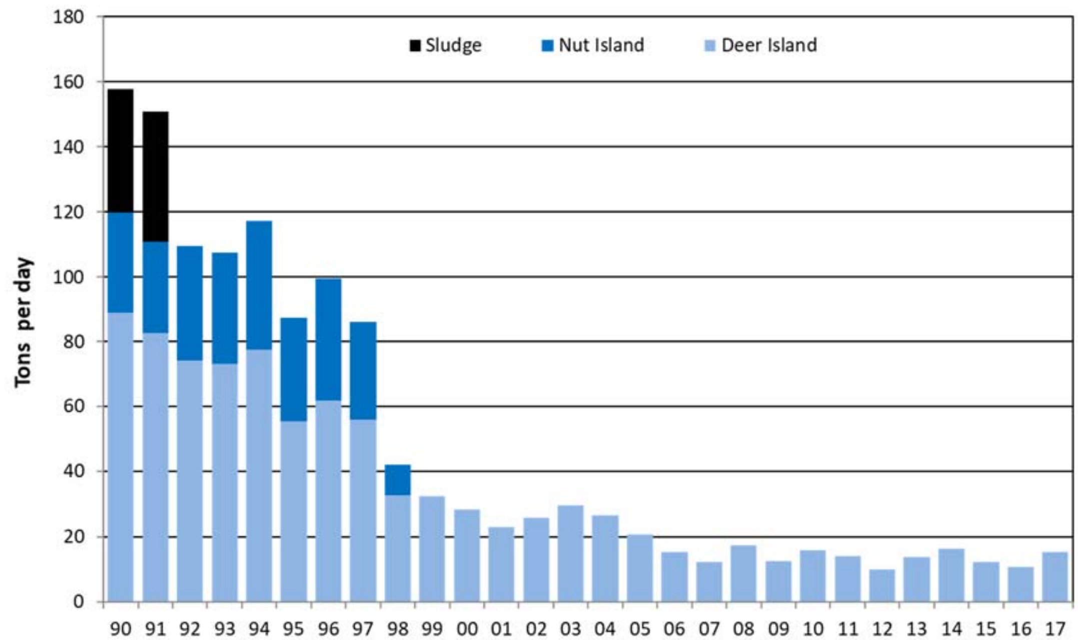

Figure i. Annual solids loads, 1990–2017. Before December 1991, biosolids (sludge) removed during treatment were disinfected and discharged into Boston Harbor. Ending biosolids disposal, ending effluent discharge to the southern portion of the harbor from Nut Island, implementing secondary treatment, 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.

Water-column monitoring in Massachusetts Bay continued to confirm predictions that limited effects of the discharge would be detectable for some parameters but only at stations located in close proximity to the outfall and not at levels that would cause environmental concern. Elevated concentrations of the nutrient ammonium, for example, can be detected close to the outfall, but those increases are limited in comparison to the large decreases in ammonium observed in Boston Harbor (Figure ii). The Massachusetts Bay outfall has not increased harmful phytoplankton blooms or lowered oxygen levels in the bay.

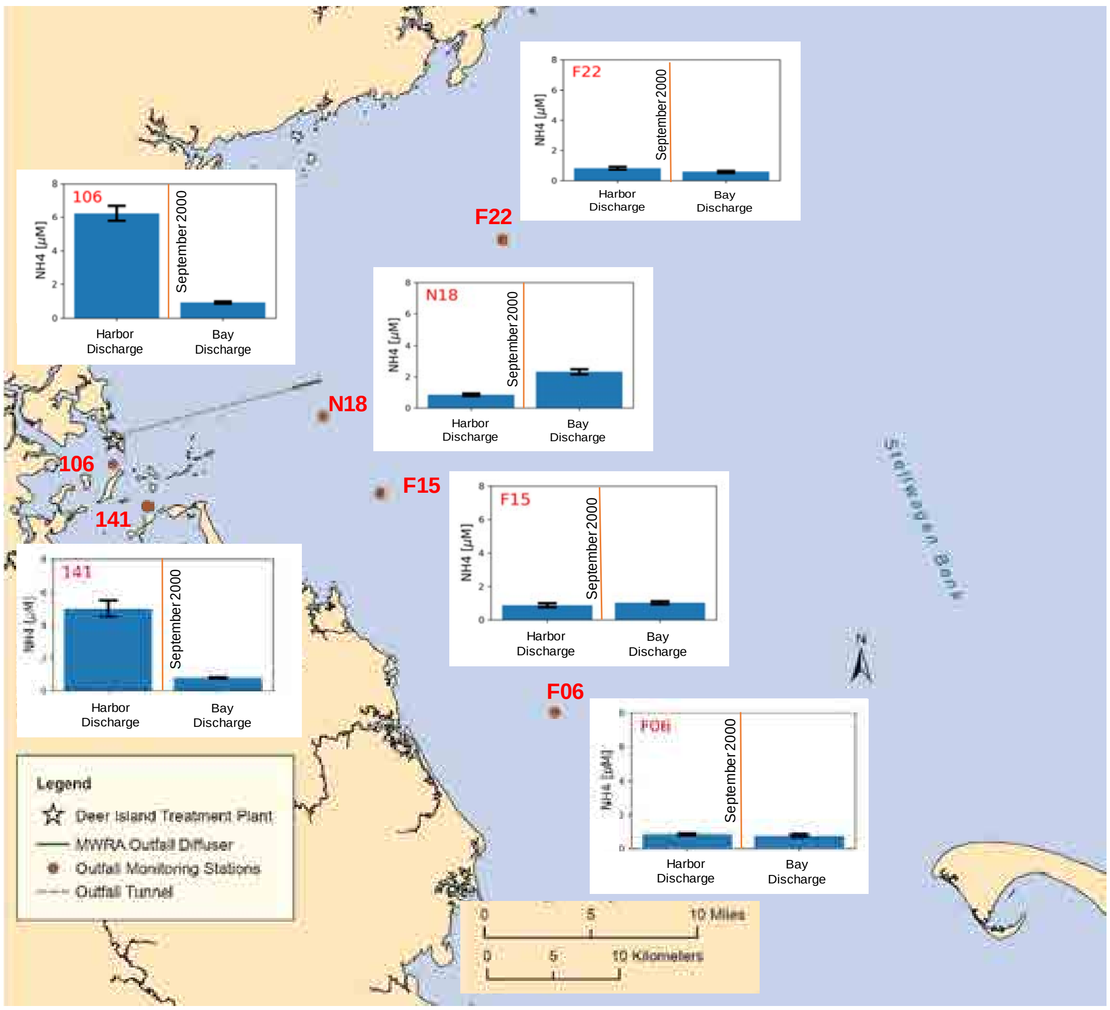

Figure ii. Average ammonium concentrations at selected stations during harbor and bay discharge years.

Healthy benthic communities continue to thrive on the Massachusetts Bay sea floor, where habitats continue to be controlled more by physical factors, such as storm-induced waves and currents, than by outfall discharges. Lush communities of sea anemones and barnacles cover the active outfall diffusers, which are also frequented by fish (Figure iii).

Figure iii. Lush growth of sea anemones and barnacles on an active diffuser head in 2017. Photo credit Barbara Hecker/Normandeau Associates.

Winter flounder remain healthy, without the widespread fin erosion and tumors of the 1980s and 1990s. No tumors have ever been detected in fish taken from near the Massachusetts Bay outfall.

MWRA remains committed to the mission it was given in 1984, to improve conditions in Boston Harbor without damage to Massachusetts Bay. The twenty-six years of Massachusetts Bay monitoring have confirmed predictions made before discharge began and verified continued good effluent treatment and operations at Deer Island Treatment Plant.

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 its 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. Throughout most of its history, MWRA has conducted long-term environmental monitoring in Boston Harbor, where both biosolids and effluent were once discharged, and in Massachusetts Bay, where highly treated wastewater effluent is currently discharged through a deepwater tunnel and diffuser system.

Biosolids discharge 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). An independent Outfall Monitoring Science Advisory Panel (OMSAP) provides technical review to the regulatory agencies.

The NPDES permit requires monitoring of effluent and receiving waters, sediments, and biota 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 study-specific technical reports are available at http://www.mwra.state.ma.us/harbor/enquad/trlist.html, MWRA's technical report list.

This year's outfall monitoring overview presents results from 2017, marking the twenty-sixth year of Massachusetts Bay monitoring and more than seventeen years of discharge from the deepwater outfall. The report presents information relevant to permit and Contingency Plan conditions in the effluent, water column, sea floor, and winter flounder, as well as special studies conducted in response to permit conditions and environmental concerns. This year's special studies section focuses on eutrophication. 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 derived from MWRA's separate monitoring efforts in Boston Harbor.

2. Effluent

2017 Effluent Characterization

Deer Island Treatment Plant continued to operate as designed through 2017, earning MWRA the National Association of Clean Water Agencies (NACWA) Platinum 11 Peak Performance Award. This NACWA award recognizes facilities with 100% compliance with effluent permit limits over eleven consecutive years.

Wastewater influent to Deer Island Treatment Plant includes not only municipal sewage but also groundwater infiltration and stormwater inflow. Consequently, rainfall is an important factor determining wastewater flows and contaminant loads in the MWRA effluent. After two years of drought, the Boston area received 43.3 inches of rain in 2017, equal to the average rainfall for 1990–2017 (Figure 2-1), and suggesting that flows and contaminant loads should be somewhat higher in 2017 than in 2015 or 2016 and about average for the period since the Boston Harbor Project.

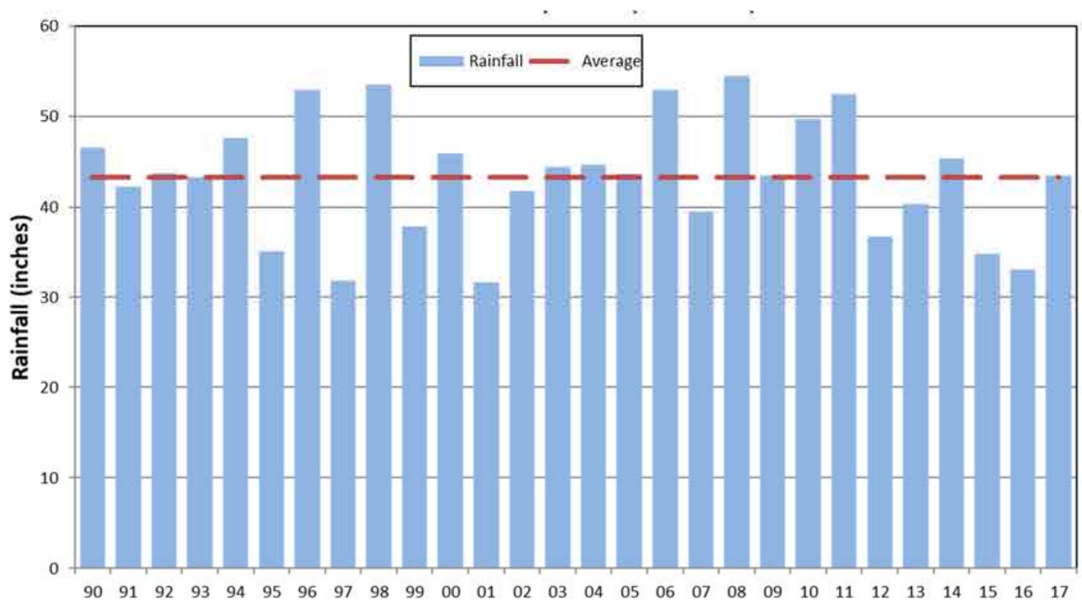

Figure 2-1. Annual rainfall in Boston, 1990–2017.

Effluent flows in 2017 were actually somewhat lower than the 1999–2017 average, about 328 million gallons per day (MGD; Figure 2-2). Almost all the flow, 99%, 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 (Figure 2-3). (During large storms, flow exceeding the 700-MGD secondary capacity of the plant is diverted around the secondary process to prevent washing out the essential microbes that carry out secondary treatment. These diverted flows receive primary treatment and then are combined or "blended" with full secondary-treated flows before disinfection and discharge.)

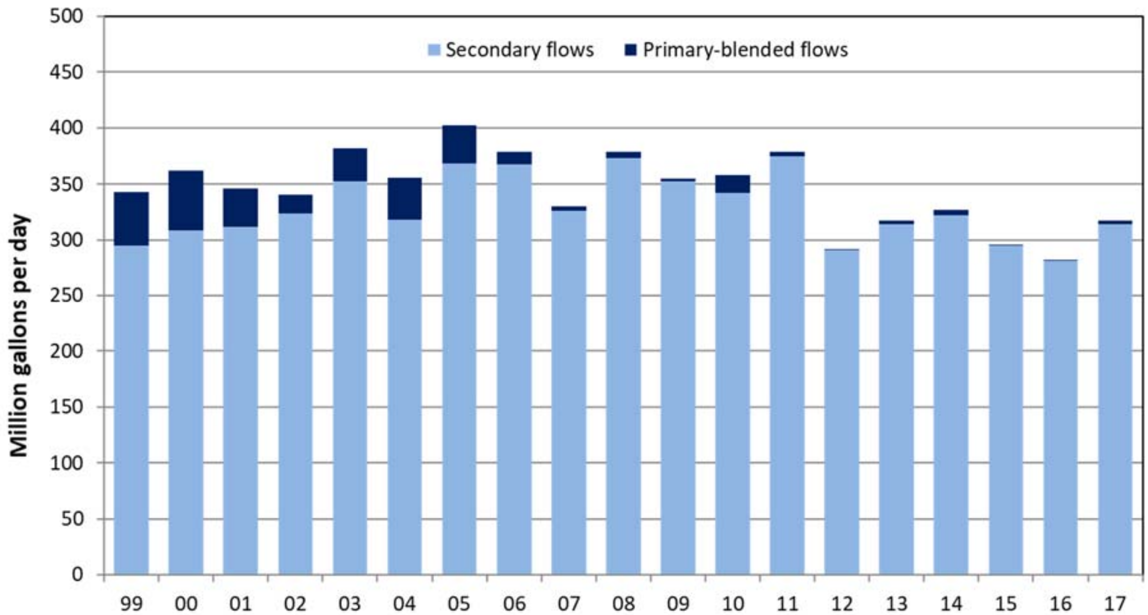

Figure 2-2. Annual primary-blended and full secondary effluent flows, 1999–2017. During large storms, flow exceeding the secondary capacity of the plant is diverted around the secondary process. Primary-treated flows are blended into secondary-treated flows before discharge.

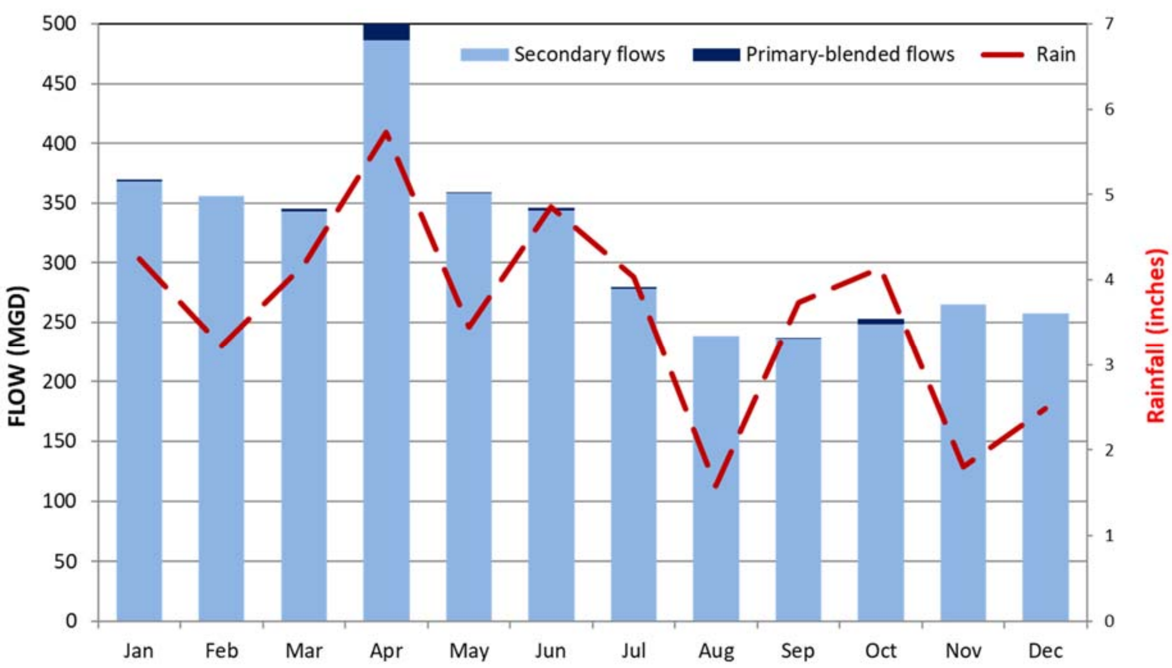

Figure 2-3. Monthly primary-blended and full secondary flows and rainfall during 2017. Highest flows occurred in April, corresponding to heavy rainfall.

The total suspended solids load to Massachusetts Bay was higher than in 2015 or 2016, but also low, well below the loads discharged to Boston Harbor before the relocated outfall began operation in 2000 (Figure 2-4). Carbonaceous biological oxygen 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 concentrations at the discharge (not shown).

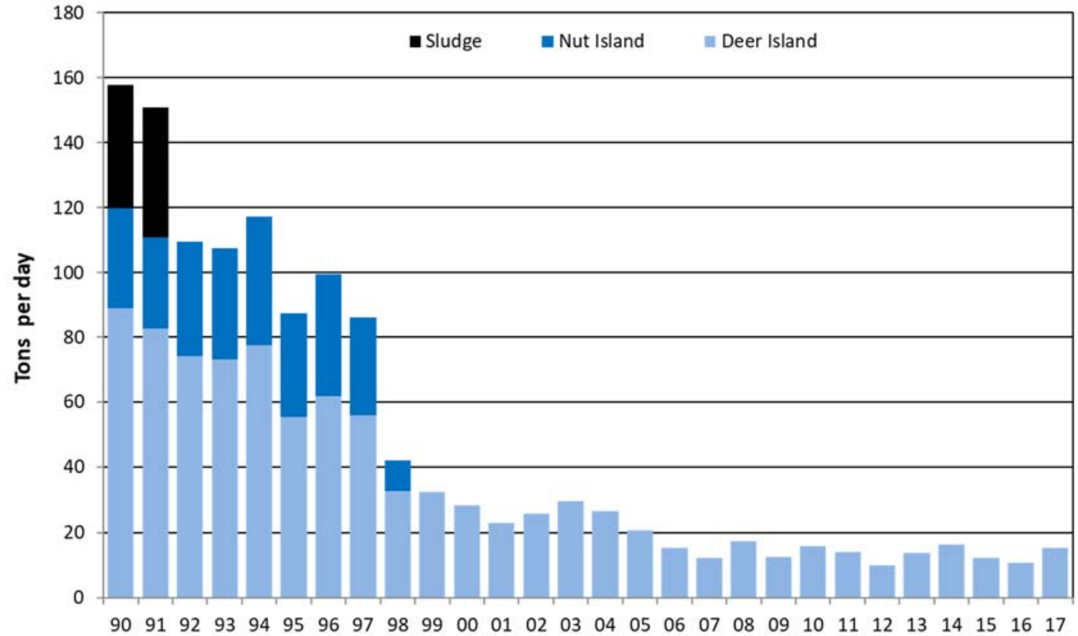

Figure 2-4. Annual solids loads, 1990–2017. Before December 1991, biosolids (sludge) removed during treatment were disinfected and discharged into Boston Harbor. Ending biosolids disposal, ending effluent discharge to the southern portion of the harbor from Nut Island, implementing secondary treatment, 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.

The total nitrogen load was lower than in 2016, remaining just under its caution-level Contingency Plan threshold (Figure 2-5) and well below the warning-level threshold, 14,000 metric tons per year. The caution level was somewhat arbitrarily set as 90% of the of the warning level; the warning level was the projected total nitrogen load for the year 2020. Since discharges to the harbor ended, total nitrogen loads have been lower than were predicted at the start of the Boston Harbor Project.

The portion of the nitrogen load made up of ammonium declined after a record high in 2016. Increased ammonium loads are a consequence of the biological treatment process and addition of ammonium-rich liquids from the biosolids pelletizing plant. Total effluent nitrogen loads reflect variability in nitrogen levels in the influent reaching Deer Island, with about 30% of the nitrogen 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 large increases to the nitrogen discharge would have no adverse effect on the environment. The relatively high nitrogen load measured in 2016 was evaluated during permit-required computer modeling of water quality in Massachusetts Bay. In addition to the model run with actual 2016 effluent nutrient measurements, modelers conducted a projection run, artificially introducing a 20% increase in effluent nitrogen above the 2016 load. Model results indicated that even the projection of 20% increased nitrogen loads over actual 2016 loads would have only negligible effects on the water column (Zhao et al. 2017).

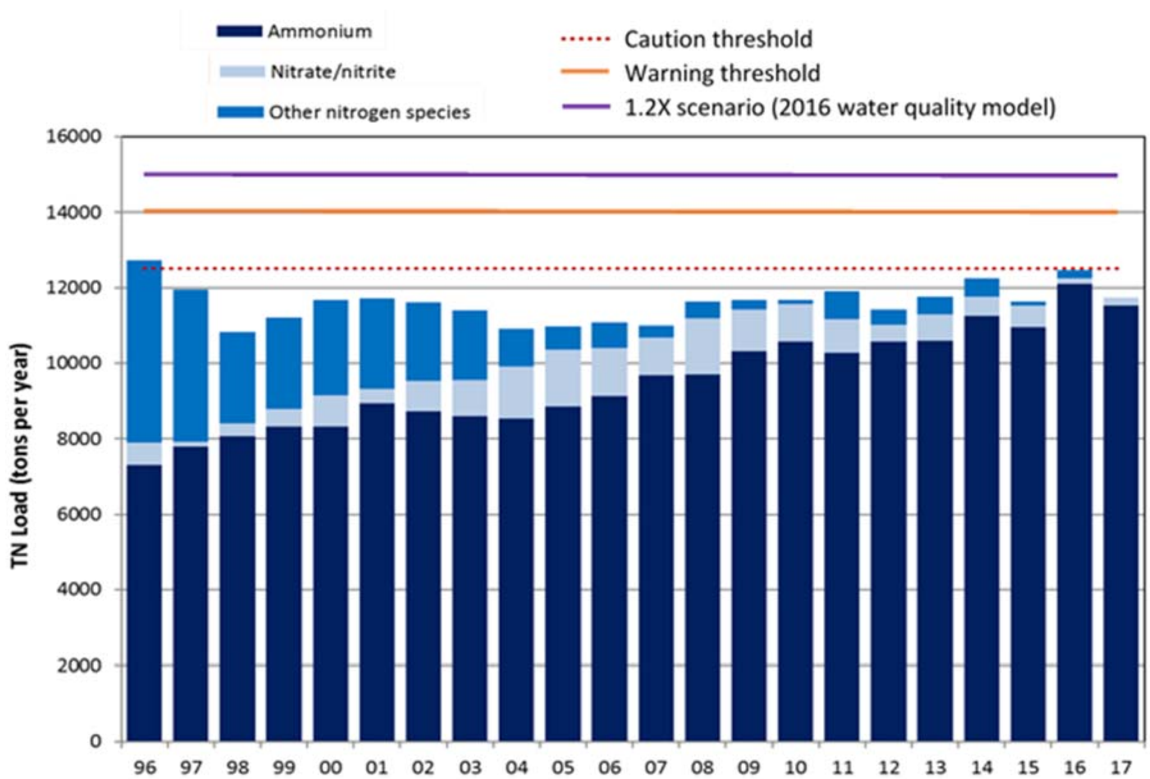

Figure 2-5. Annual nitrogen loads, 1996–2017. During outfall planning, managers and regulators assumed that discharges would total 14,000 tons per year by 2020. TN = total nitrogen, 1.2X scenario = a 20% increase over the actual 2016 load

Metals loads also remained low in 2017, with zinc and copper continuing to comprise most of the annual discharges (Figure 2-6). 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.

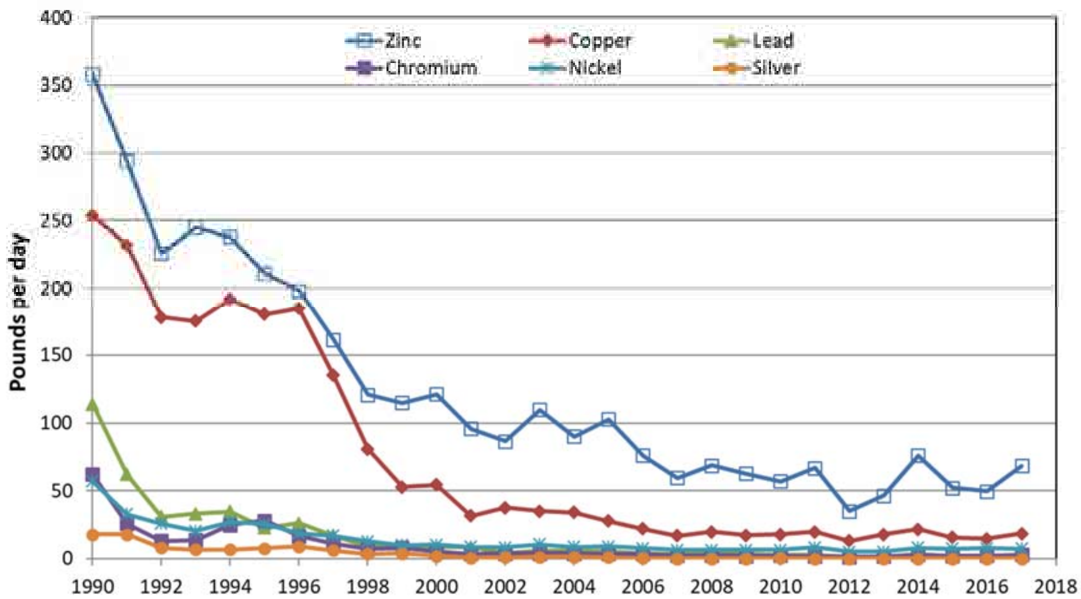

Figure 2-6. Annual metals loads, 1990–2017.

Polycyclic aromatic hydrocarbon and other organic contaminant loads (not shown) 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 remained well below predictions made during the planning and permitting process for the Massachusetts Bay outfall (Table 2-1). Mercury discharges were about 1% of the projected load, while copper discharges were just over one quarter of what had been projected. Loads of total PCBs, and 4-4' DDE (a breakdown product of the banned pesticide DDT) were only about 1% of the loads anticipated in the Supplemental Environmental Impact Statement (SEIS) prepared during planning (EPA 1988).

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 planning and permitting of the Massachusetts Bay outfall.

Parameter	SEIS Projected Load (kg/year)	2017 Load (kg/year)	Percent Projected Load
Chromium	3,517	501	14%
Copper	11,945	3,062	26%
Lead	4,961	456	9.2%
Mercury	216	2.7	1.3%
Nickel	8,926	1,208	14%
Silver	299	27	9.0%
Total PCBs	50	0.52	1.0%
4-4' DDE	28	0.34	1.2%

SEIS = Supplemental Environmental Impact Statement

Contingency Plan Thresholds

There were no permit violations in 2017 and no exceedances of the Contingency Plan effluent thresholds (Table 2-2). Effluent threshold exceedances have been rare throughout the duration of the monitoring program, and none have occurred over the past eleven years.

Table 2-2. Contingency Plan threshold values and 2017 results for effluent monitoring.

Parameter	Baseline	Caution Level	Warning Level	2017 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

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).

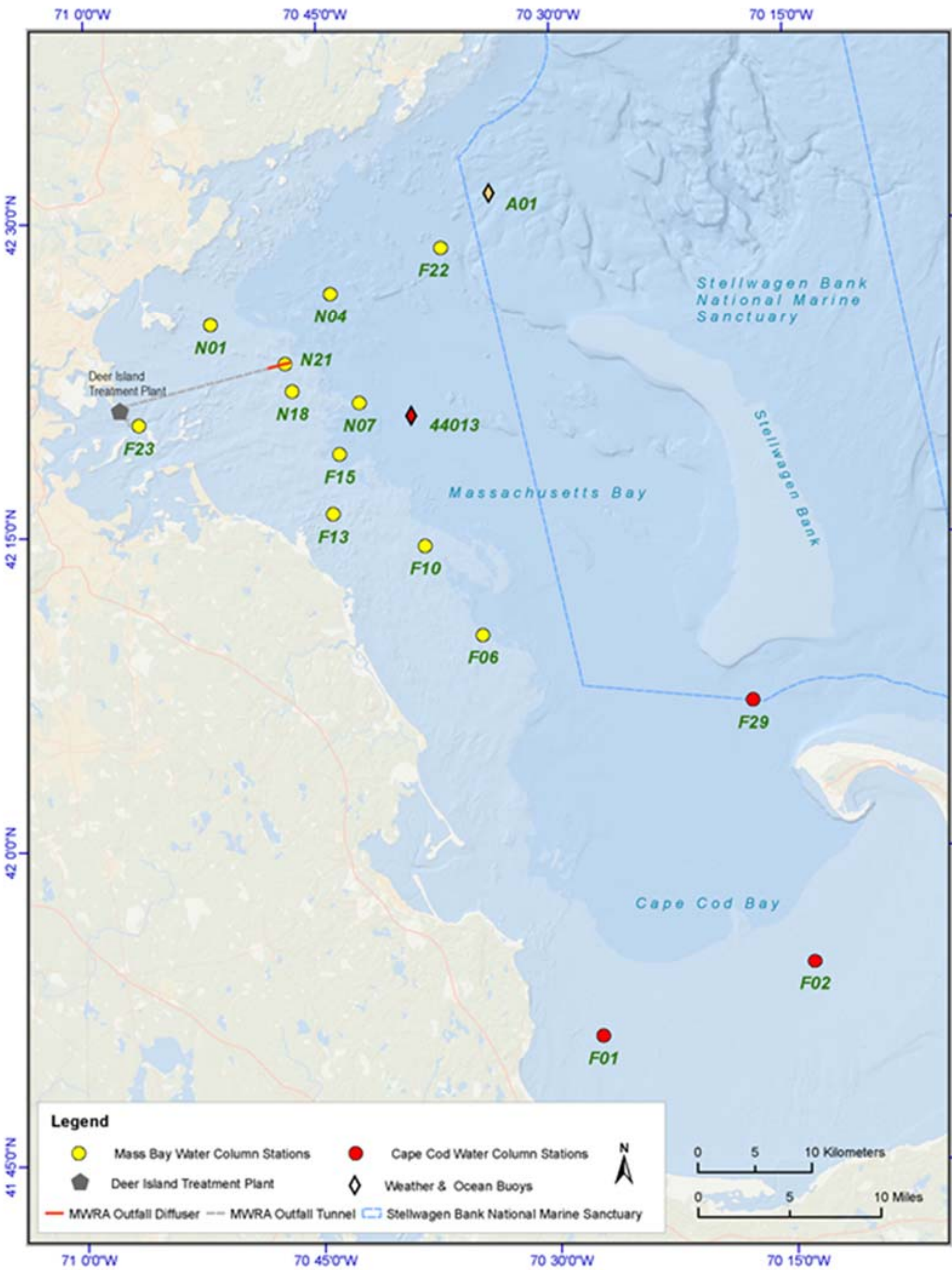

Figure 3-1. Water-column monitoring stations in Massachusetts and Cape Cod bays.

Sampling during nine surveys of fourteen stations in 2017 included vertical profiles of physical, chemical, and biological parameters in the nearfield (the 10 by 12-kilometer area around the outfall where some effects of the effluent were expected and have been observed), and at farfield reference stations, including a station northwest of the outfall and 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. During the June 13 survey, abundance of the toxic dinoflagellate *Alexandrium catenella* (formerly known as *Alexandrium fundyense* and responsible for red tide in New England) exceeded 100 cells per liter (see Figure 3-13, page 21), triggering four *Alexandrium* special surveys, conducted in June and July.

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 and, as part of the MWRA monitoring program, samples the water-column stations in Cape Cod Bay and near 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. Surveys for which sampling cannot occur within 48 hours should be reported in this annual outfall monitoring overview. In 2017, the April Massachusetts Bay survey was delayed by instrument repairs and subsequent engine problems, delaying the survey to ten days after the Cape Cod Bay survey. All other surveys were conducted within 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 higher rainfall in the Boston area in 2017 compared with 2015 and 2016 (see Figure 2-1), discharges from the Merrimack and Charles rivers were also higher than in recent years, and, on an annual basis, close to average for the monitoring program (Figure 3-2). Seasonally, discharge from the Merrimack River was particularly higher than average during the spring, and discharge from the Charles River was especially low in the winter.

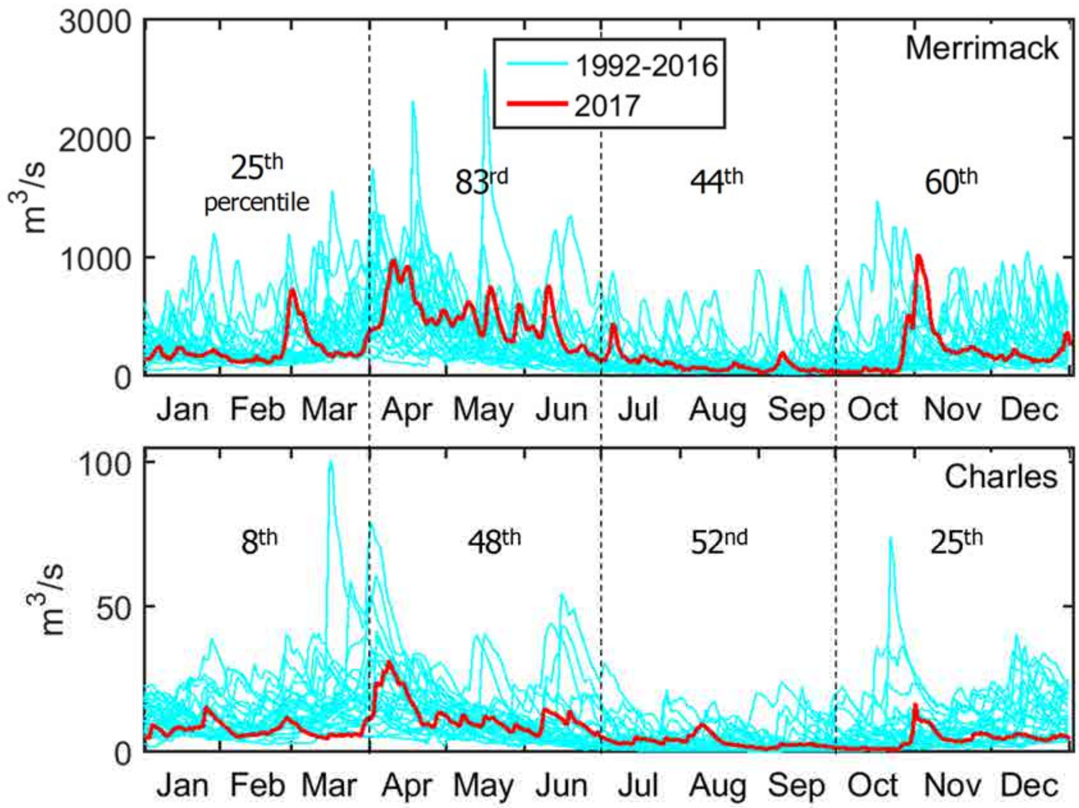

Figure 3-2. Flows of the Merrimack (top) and Charles (bottom) rivers. Dark red lines are 2017 data. Results from 1992–2016 are in light blue. The quarterly percentiles represent the 2017 flows in comparison to the entire 26-year record.

Surface-water temperatures, measured at the NDBC Buoy 44013 (Figure 3-3) and at nearby Station N18 (not shown) were warmer than average at the beginning and end of the year, setting records as the long-term maxima for the monitoring program for January and February (Libby et al. 2018). Surface waters were relatively cool during June, corresponding to a period of strong and consistent upwelling of cool water from depth.

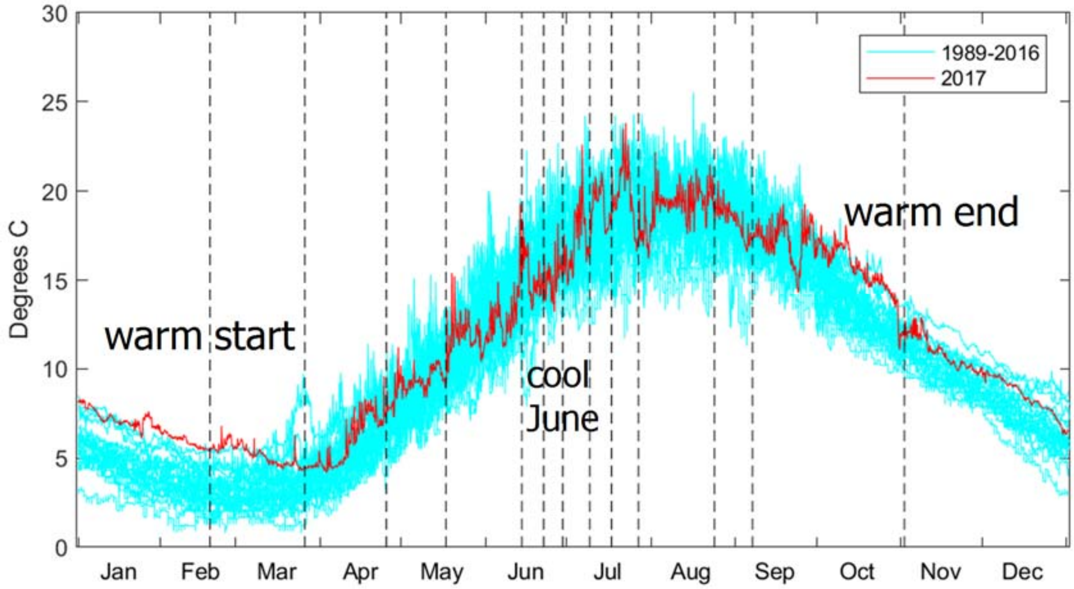

Figure 3-3. Surface-water temperature at NDBC Buoy in 2017 compared to prior years. Vertical dashed lines denote timing of MWRA surveys.

Stratification followed a typical annual pattern in 2017 but was particularly strong in early June, corresponding to freshwater inflow in the surface water, and weaker than usual in late June and July (Figure 3-4). Surface-water salinity measurements (not shown) were also low in June, a result of the high discharge from the Merrimack River during the spring (see Figure 3-2).

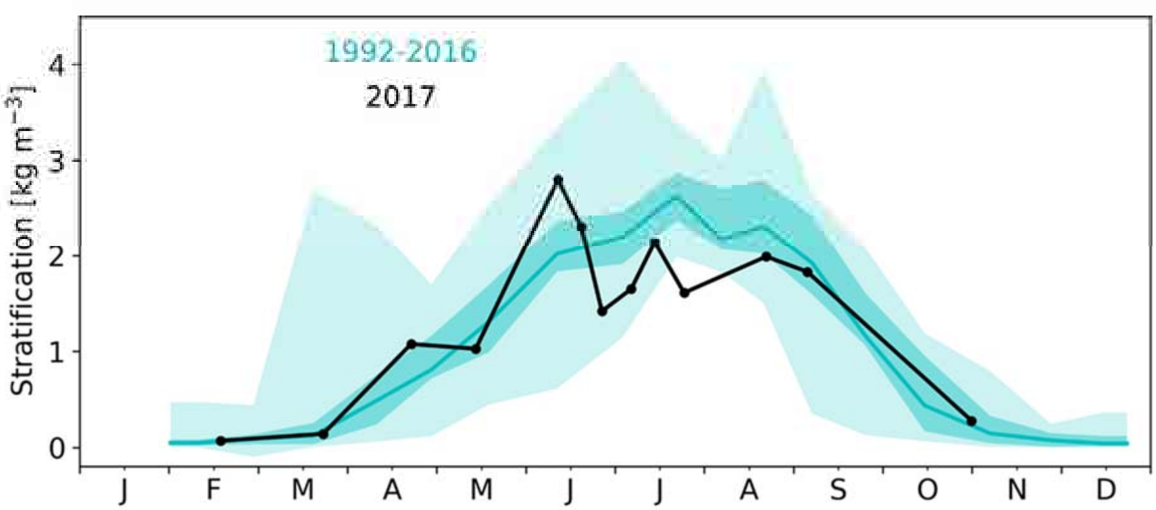

Figure 3-4. Stratification at nearfield Station N18 in 2017 compared to prior years. Black points are results from individual surveys in 2017. Results from 1992–2016 are in blue: line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range. For Station N18, historic data extend later in the year than the current survey schedule.

Water Quality

As in past years, water quality measurements for 2017 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. 2018).

During 2017, dissolved inorganic nutrient concentrations in the nearfield fell mostly within the ranges measured in previous years. As in past years, concentrations of ammonium at nearfield stations very close to the outfall 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.

Elevated ammonium concentrations have been detected at Stations N18 and N21, both in the immediate vicinity of the outfall, since the discharge began in 2000. As noted in Section 2, Effluent, ammonium makes up a large majority of the total nitrogen in the outfall discharge. In 2017, the signature was especially apparent during some surveys but not others, particularly the last survey of the year, when concentrations were low (Figure 3-5). During the late July survey, elevated ammonium concentrations were also detected further south, at Station F10, to the southwest of the outfall. Overall, the ammonium signature of the outfall was typical of the years since the discharge was relocated from Boston Harbor to Massachusetts Bay.

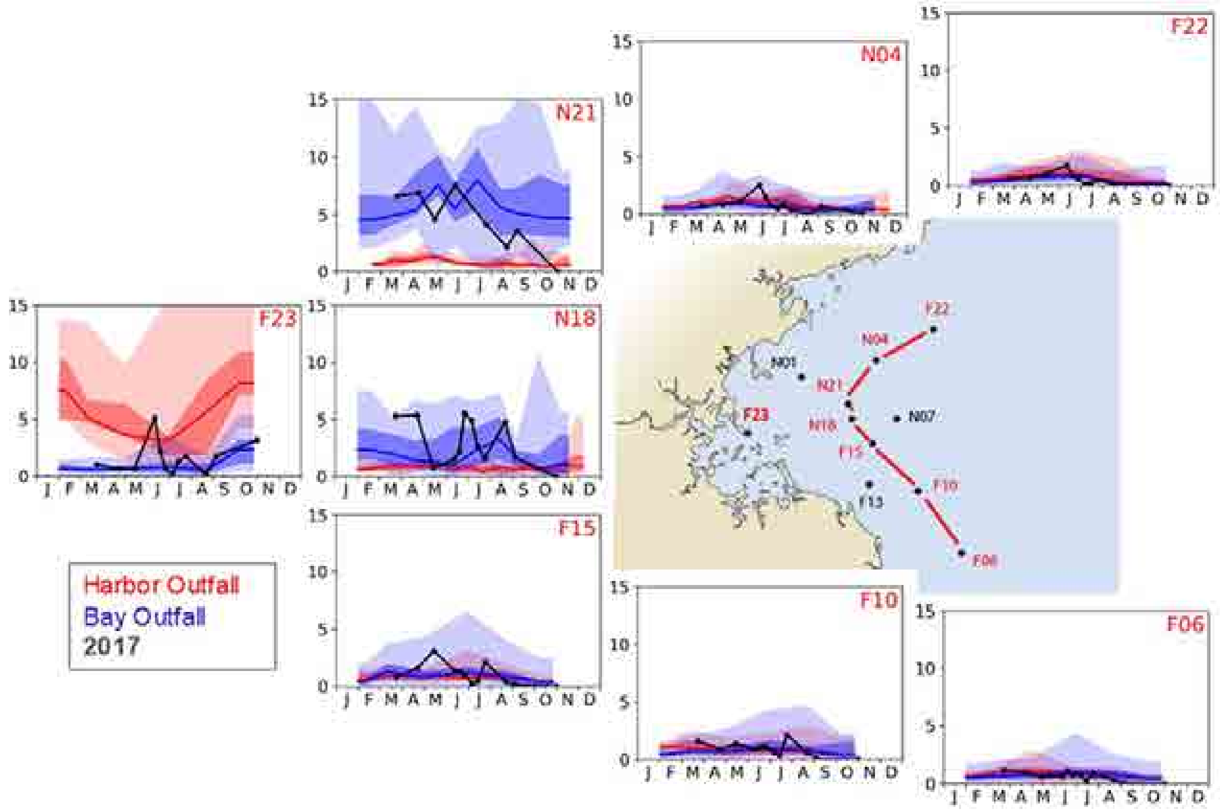

Figure 3-5. Average ammonium concentrations (micromolar) at selected stations in 2017 compared to prior years. Black points and line are results from individual surveys in 2017. Red lines and shading show data from Boston Harbor discharge years. Results from September 2000–2016 are in blue. Line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range. For Stations N04, N18, and N21, historic data extend later in the year than the current survey schedule.

As in previous years, the plume's ammonium signature was evident in surface waters during the winter and spring when the water column was relatively well-mixed (Figure 3-6) but was largely confined beneath the pycnocline during the summer, stratified season (Figure 3-7). 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 planning for the outfall.

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 2017 (see further discussion in Section 6, Special Studies). Satellite imagery (Figure 3-8) showed elevated levels of chlorophyll in January and February, evidence of a winter-spring diatom bloom in process when the sampling season began. Both satellite and survey data (Figure 3-9) showed elevated chlorophyll levels across much of Massachusetts Bay in May and June, during the period that *Alexandrium* cell counts triggered special surveys. Summer chlorophyll levels peaked during the *Alexandrium* special surveys in July, probably due to prolonged upwelling during that time. High chlorophyll levels observed by satellite imagery in November were coincident with a late fall bloom of centric diatoms *Skeletonema* spp.

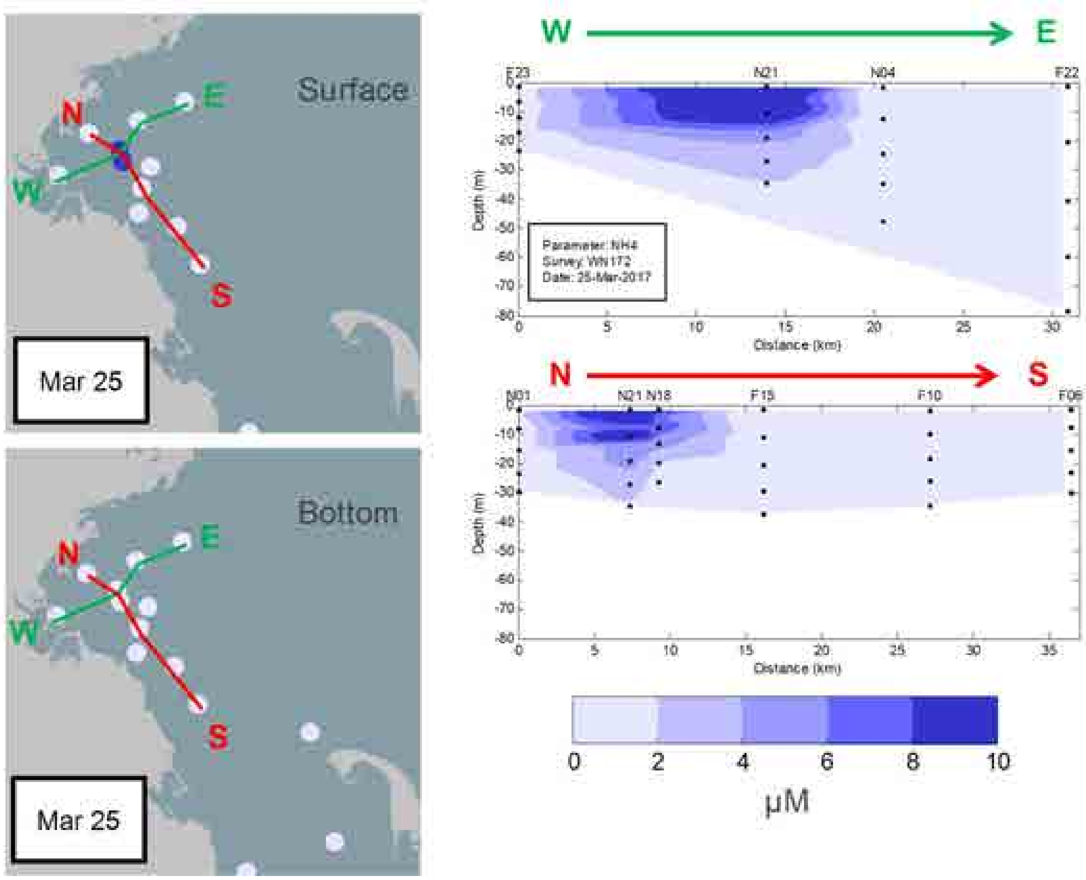

Figure 3-6. (Left) Surface- and bottom-water ammonium on March 25, 2017, during mixed conditions. (Right) Cross-sections of concentrations throughout the water column along transects connecting selected stations. Station N21 is directly over the outfall.

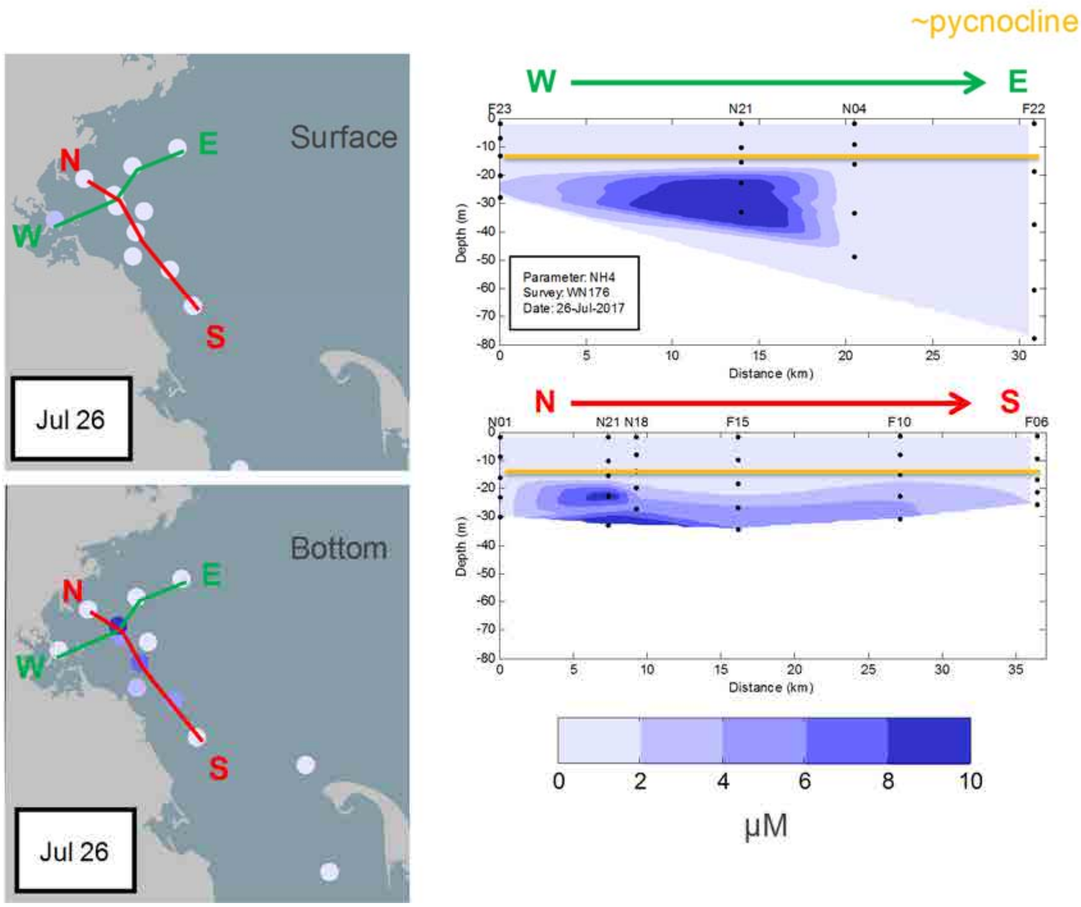

Figure 3-7. (Left) Surface- and bottom-water ammonium on July 26, 2017, during stratified conditions. (Right) Cross-sections of concentrations throughout the water column along transects connecting selected stations. Station N21 is directly over the outfall.

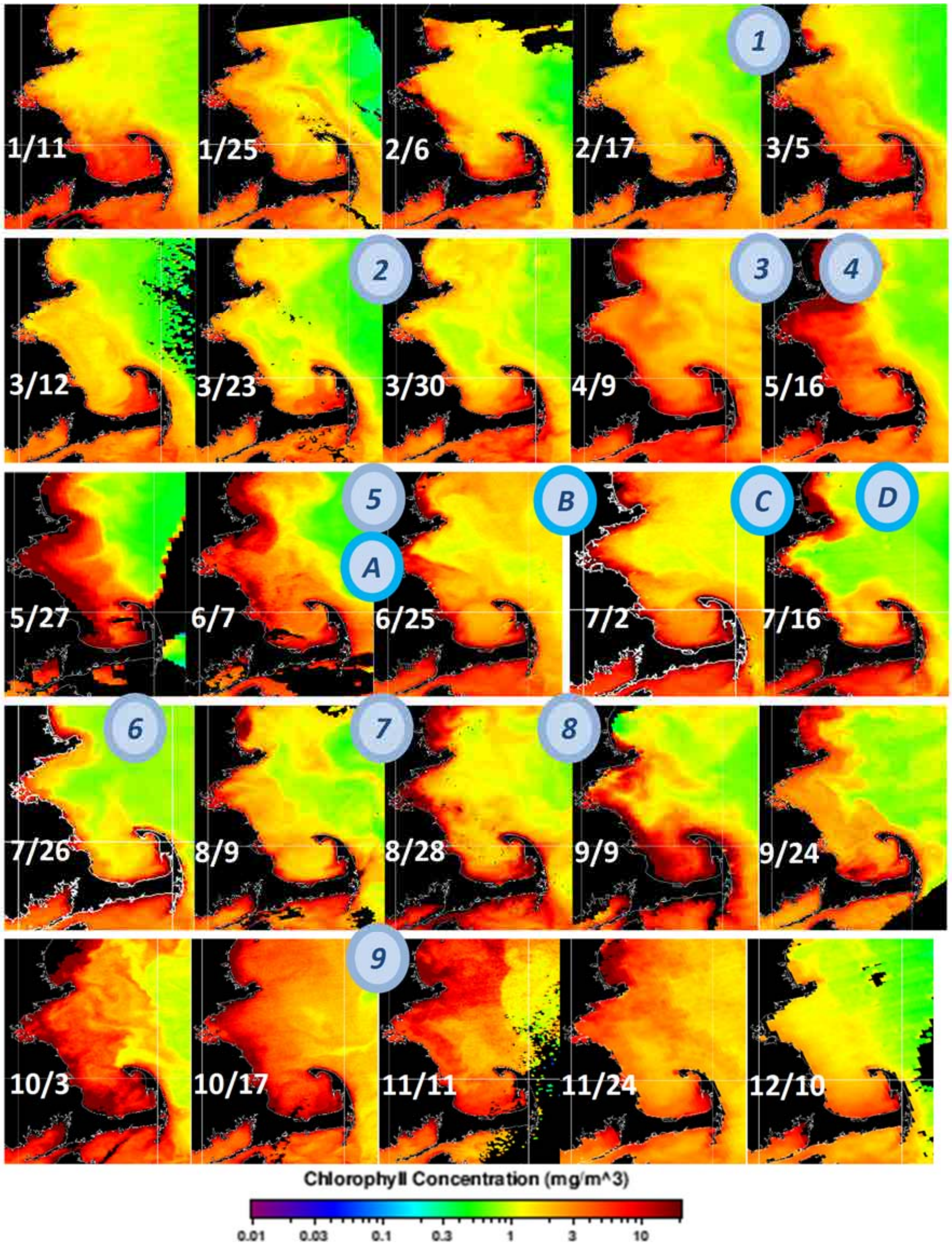

Figure 3-8. Moderate Resolution Imaging Spectroradiometer satellite imagery of surface chlorophyll concentrations in 2017. These images are heavily weather dependent and do not represent consistent intervals of time. The numbers and letters show the timing of the nine regular and four special MWRA surveys.

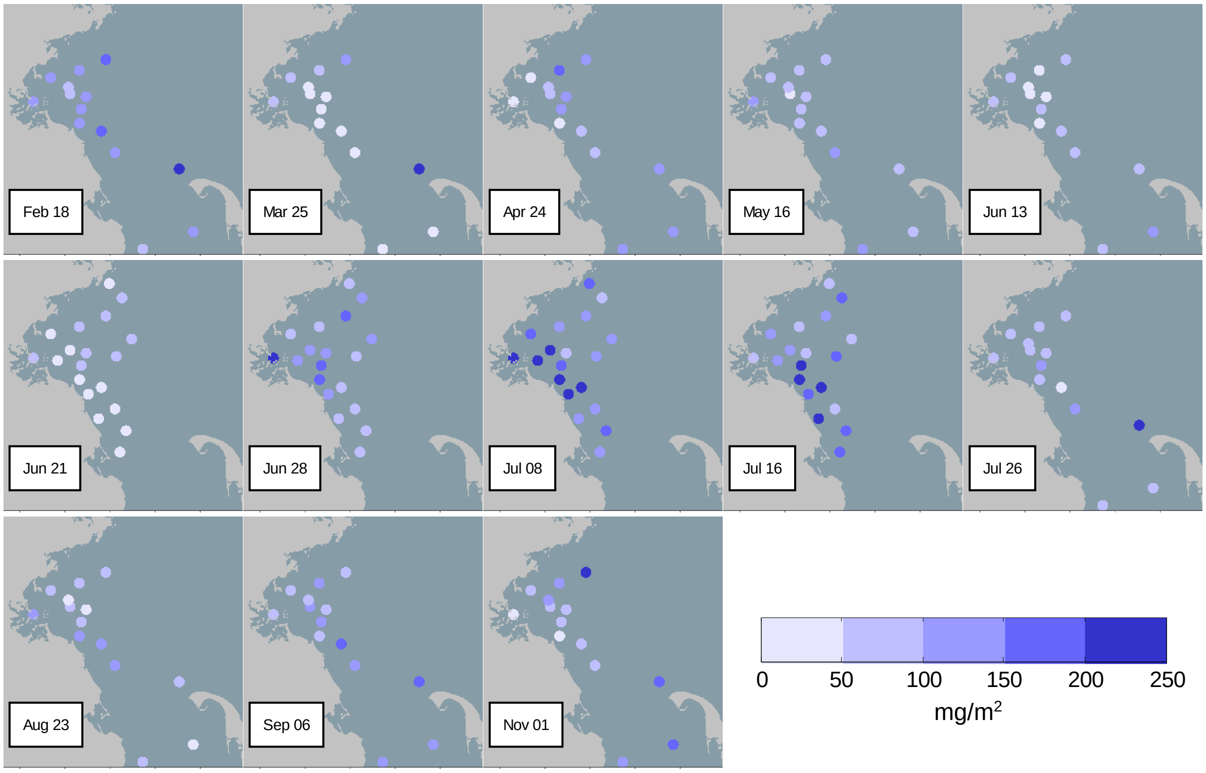

Figure 3-9. Areal chlorophyll by station in Massachusetts Bay in 2017.

Levels of dissolved oxygen in surface and bottom waters were lower than typical during the early months of monitoring in 2017. 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 2017, as in 2016, that steady decline was interrupted by a mixing event in June, which returned concentrations to levels about average for the monitoring program. Typical mixing in the fall, which re-aerates the water column, was delayed until November in 2017, resulting in relatively low dissolved oxygen minima for the year. No measurements fell below the 6 mg per liter water quality standard (Figure 3-10).

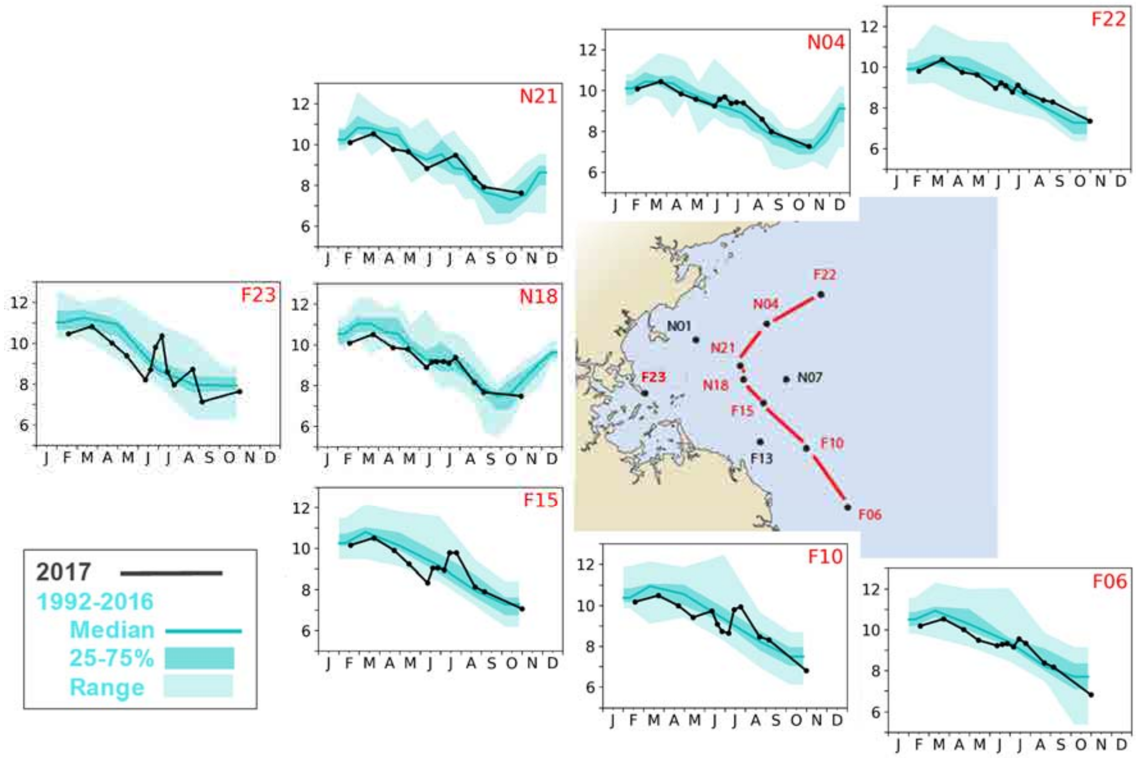

Figure 3-10. Near bottom water dissolved oxygen concentrations (milligrams per liter) at selected stations in 2017 compared to prior years. Black points and line are results from individual surveys in 2017. Results from 1992–2016 are in blue: line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range. For Stations N04, N18, and N21, historic data extend later in the year than the current survey schedule.

Phytoplankton Communities

As in recent years, total observed phytoplankton abundances were somewhat low throughout the year and throughout Massachusetts Bay (Figure 3-11, Libby et al. 2018). In the nearfield, overall abundance was about 65% of the long-term mean. The results can be partially explained by a lack of a winter-spring diatom bloom during the survey season and by absence of a bloom of the nuisance species *Phaeocystis pouchetii*. There were abundance peaks in the late spring and again in late summer or fall throughout Massachusetts Bay. (The July *Alexandrium* special surveys, which measured high levels of phytoplankton biomass, did not include identification and enumeration of other phytoplankton groups.)

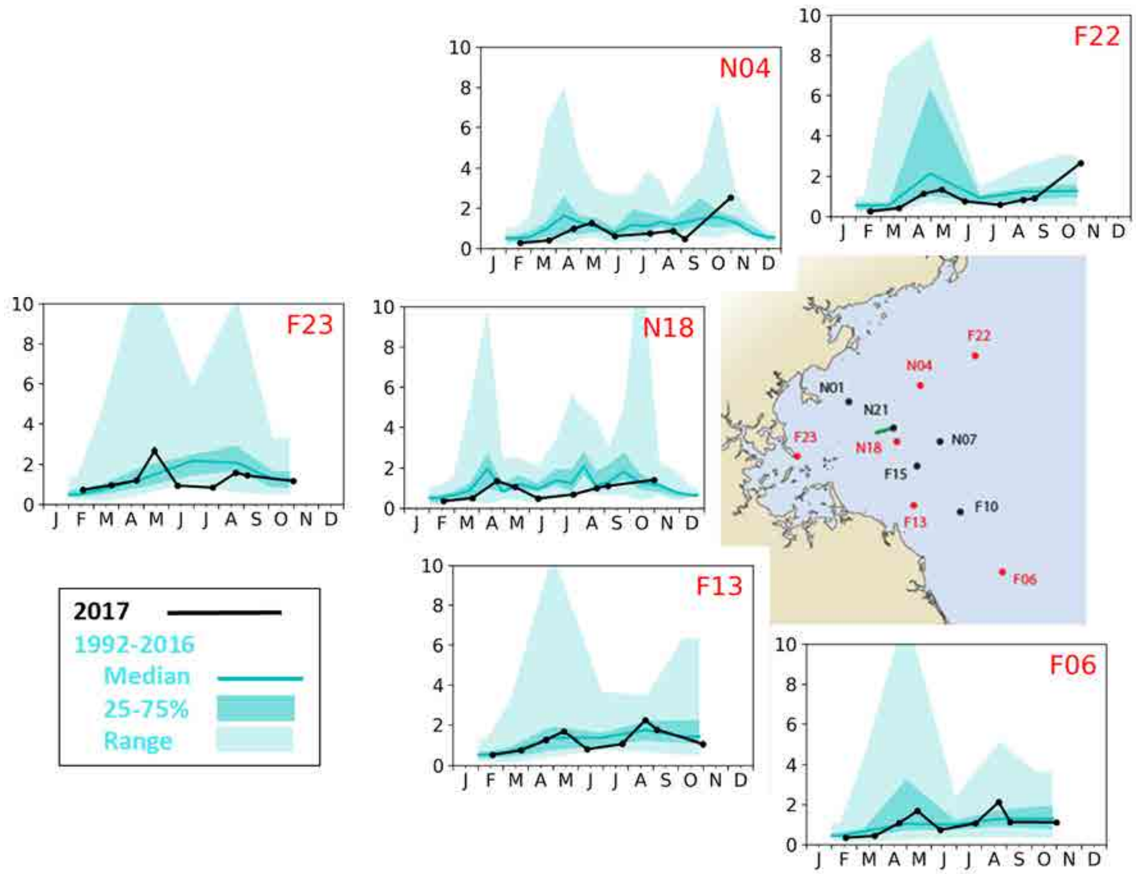

Figure 3-11. Total phytoplankton abundance (million cells per liter) at selected stations in 2017 compared to prior years. Black points and line are results from individual surveys in 2017. Results from 1992–2016 are in blue: line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range. The green line on the map indicates the outfall. For Stations N04 and N18, historic data extend later in the year than the current survey schedule.

During the course of the monitoring program, there have been frequent spring *Phaeocystis* blooms, and after 2000, regional blooms occurred every year. Since 2013, *Phaeocystis* abundances have been relatively low, both in the nearfield and throughout Massachusetts Bay, and this trend continued in 2017 (Figure 3-12). Peak abundances occurred in Cape Cod Bay in April, at levels much lower than in a typical bloom. *Phaeocystis* cells were found only in April and May and in just half the Massachusetts Bay samples.

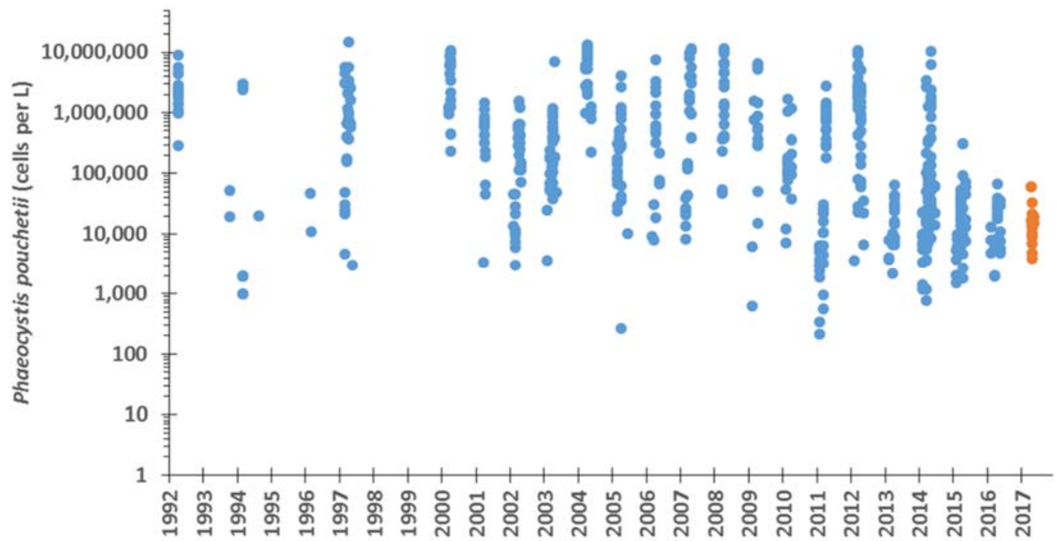

Figure 3-12. Mean nearfield abundance of *Phaeocystis pouchetii* in 1992–2017. Note log scale.

A bloom of the potentially toxic genus of pennate diatoms, *Pseudo-nitzschia*, closed shellfish beds in Maine and Rhode Island in 2017. At abundance, *Pseudo-nitzschia* can cause amnesic shellfish poisoning (ASP). *Pseudo-nitzschia* was detected in Massachusetts Bay in 2017, but at levels well below those that could cause ASP.

As noted above, abundance of the toxic dinoflagellate *Alexandrium catenella* exceeded 100 cells per liter during the June survey and triggered four special surveys. On June 13, *Alexandrium* was detected at all ten stations, in abundances ranging from one to 494 cells per liter (Figure 3-13). During the first special survey, elevated abundances were detected at three northern stations near Cape Ann, with the highest cell counts near the NERACOOS Buoy A01. *Alexandrium* continued to be present in late June and early July, and the bloom ended by late July. The spatial and temporal pattern of the bloom conformed to past understandings of *Alexandrium* bloom dynamics, that is, that cells from established populations off the coast of Maine were carried into Massachusetts Bay. No established *Alexandrium* populations have been found within Massachusetts Bay.

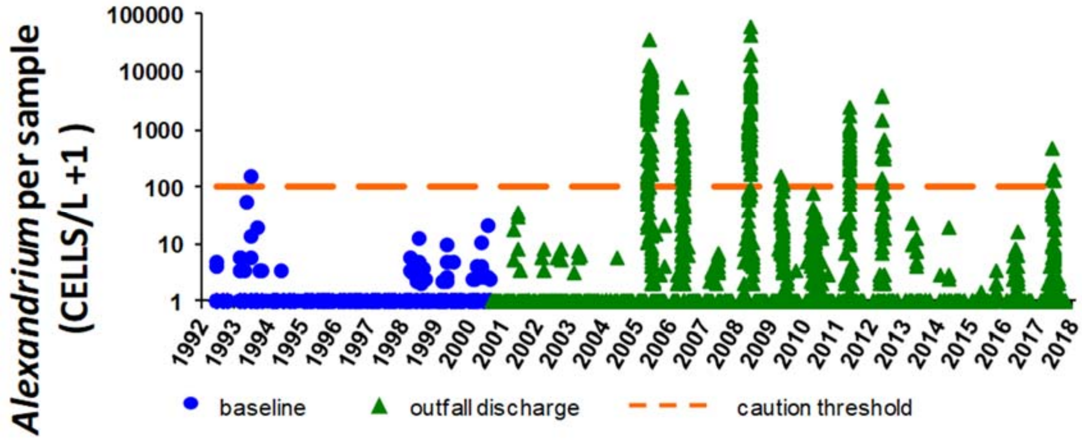

Figure 3-13. Nearfield abundance of *Alexandrium catenella,* 1992–2017. Note log scale.

The 2017 *Alexandrium* bloom caused elevated levels of paralytic shellfish poisoning (PSP) toxicity outside Massachusetts Bay, resulting in closure of shellfish beds in Maine, New Hampshire, and into Massachusetts, as far south as Gloucester. No PSP toxicity was detected in Massachusetts Bay. Winds and water circulation patterns at the time of the bloom were not conducive for transporting *Alexandrium* cells from offshore Massachusetts Bay to coastal shellfish beds.

An unusual bloom of the dinoflagellate *Karenia mikimotoi* was detected in September 2017, with a maximum abundance of 337,800 cells per liter at Station N07, west of the outfall. Overall, abundance was greatest at offshore stations and at the depths of the chlorophyll maxima. *Karenia* had never before been detected by the monitoring program and is not recorded as a member of the regional Gulf of Maine phytoplankton community. A similar species has been found in Woods Hole, Massachusetts, and in coastal Rhode Island, but that species is generally confined to less saline waters. Its presence in 2017 was noted along the coast from Boston north to Portland, Maine. While *Karenia mikimotoi* has been classified as potentially harmful, its toxins have not been well-characterized, and there are no known threats to human health.

Zooplankton Communities

Zooplankton communities continued to be dominated by the typical mix of copepod nauplii, copepodites, and adults and by meroplankton, those animals that live only a portion of their lives in the plankton. The small copepod *Oithona similis* continued to dominate most samples, with *Acartia* spp. dominating in Boston Harbor and the much larger *Calanus finmarchicus* sometimes dominating in offshore samples. Annual peak abundances of total zooplankton were somewhat higher than those in 2016 but did not reach the record highs observed in 2015 (Figure 3-14, Libby et al. 2018). Those 2015 abundances were driven largely by the presence of meroplankton, specifically bivalve veliger larvae, in July and August. Generally, zooplankton abundance peaks in the summer, but somewhat unusually, in 2017, there were two peaks, the first in May and the second in the late summer to early fall. The early abundance peaks may have occurred in response to warm water temperatures.

Trend analysis has shown a sustained increase in total zooplankton abundance from 2006 through 2017, following a steady increase during 1995–2000 and a decrease during 2000–2006. Opposite trends in phytoplankton abundance suggest zooplankton grazing may be an important factor for both phytoplankton and zooplankton communities.

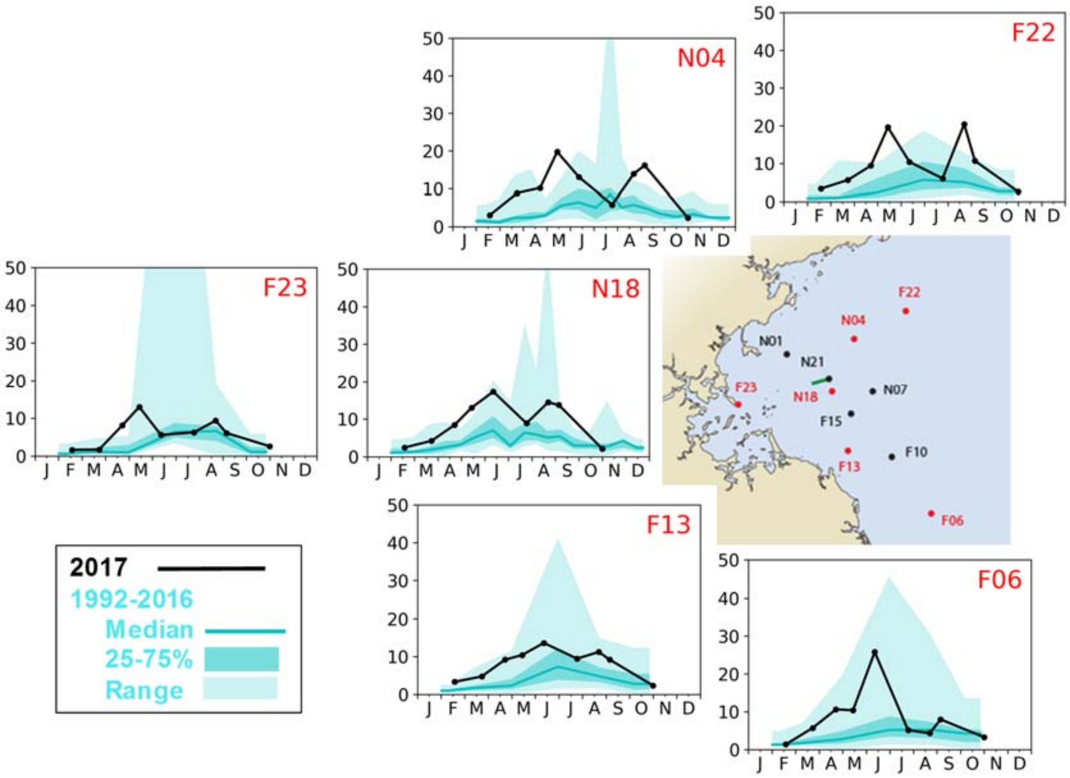

Figure 3-14. Total zooplankton abundance (10,000 animals per square meter) at selected stations in 2017 compared to prior years. Black points and line are results from individual surveys in 2017. Results from 1992–2016 are in blue: line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range. The green line on the map indicates the outfall. For Stations N04 and N18, historic data extend later in the year than the current survey schedule.

Stellwagen Bank National Marine Sanctuary

The NPDES permit to discharge from Deer Island Treatment Plant into Massachusetts Bay requires annual reporting on results 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 3-5, 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, as well as data from NERACOOS Buoy A01 and satellite imagery, detected no unusual chlorophyll levels in offshore regions in 2017. 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 2017, 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 also documented the return to oxygenated conditions as a result of fall mixing events.

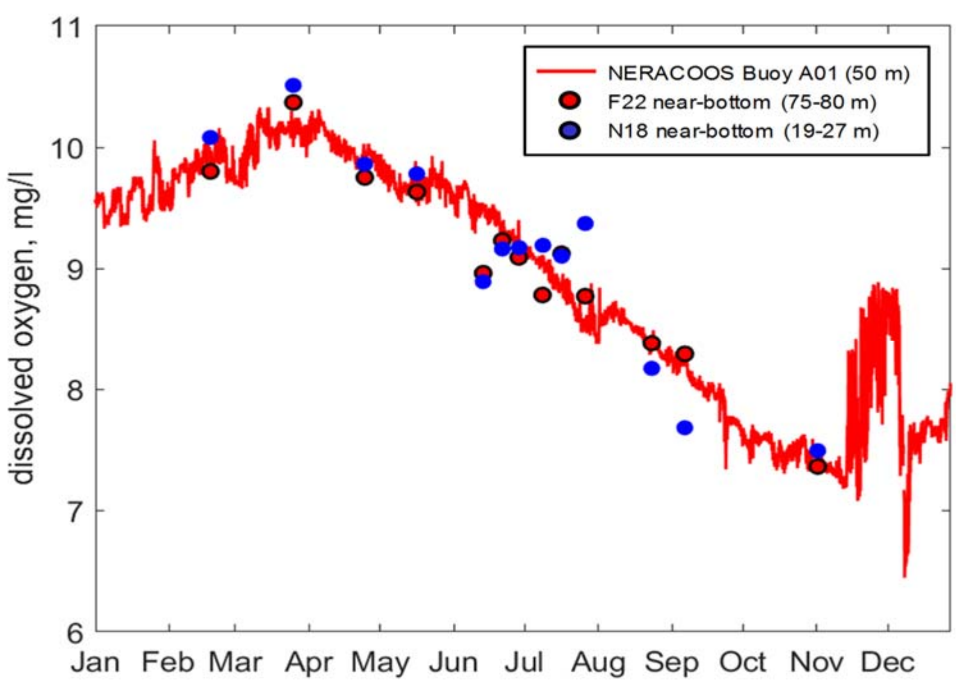

Figure 3-15. Dissolved oxygen at the NERACOOS Buoy A01 and the deepwater measurements at Station F22 in Stellwagen Basin, and at Station N18 in the nearfield. The buoy values are daily means.

Boston Harbor

Water quality in Boston Harbor has improved during the past 20 years, and those improvements were sustained in 2017. 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 (see Figure 3-6, above, and Section 6, Special Studies). Ammonium concentrations dropped precipitously when the effluent discharge was diverted from the harbor to Massachusetts Bay in 2000 and have remained low. In contrast, ammonium levels have increased only at stations closest to the Massachusetts Bay outfall, such as Station N18. However, because of increased dilution at the offshore outfall, those increases in Massachusetts Bay have been substantially less than the concurrent decreases in ammonium concentrations in the harbor. Levels remain unchanged at stations farther from the outfall.

Peak abundance of *Acartia* spp., the dominant zooplankton species in Boston Harbor, occurred earlier in 2017 than had been observed in the 1990s. Since the diversion of sewage effluent from the harbor, *Acartia* abundances have peaked earlier, and warm temperatures also may have contributed to the earlier growth in 2017.

Contingency Plan Thresholds

All water-quality parameters were within normal ranges during 2017. There was one Contingency Plan caution-level threshold exceedance for a nuisance algae measure, *Alexandrium catenella* abundance (Table 3-1), which has been reviewed and is not thought to have been caused or exacerbated by the outfall. In 2017, EPA and MassDEP approved MWRA's proposal, endorsed by OMSAP, to discontinue the seasonal thresholds for *Phaeocystis pouchetii*.

Table 3-1. Contingency Plan threshold values and 2017 results for water-column monitoring.

Parameter	Baseline	Caution Level	Warning Level	2017 Results
Dissolved oxygen*				
Nearfield concentration	6.05 mg/L	<6.5 mg/L	<6.0 mg/L	7.33 mg/L
Nearfield percent saturation	65.3%	<80%	<75%	78.9%
Stellwagen concentration	6.23 mg/L	<6.5 mg/L	<6.0 mg/L	7.36 mg/L
Stellwagen percent saturation	67.2%	<80	<75%	77.2%
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	77 mg/m^2
Winter/spring	50 mg/m^2	>199 mg/m^2	None	88 mg/m^2
Summer	51 mg/m^2	>89 mg/m^2	None	58 mg/m^2
Autumn	90 mg/m^2	>239 mg/m^2	None	99 mg/m^2
Nuisance algae nearfield *Pseudo-nitzschia*				
Winter/spring	6,735 cells/L	>17,900 cells/L	None	68 cells/L
Summer	14,635 cells/L	>43,100 cells/L	None	273 cells/L
Autumn	10,050 cells/L	>27,500 cells/L	None	1,780 cells/L
Nuisance algae nearfield *Alexandrium catenella*				
Any nearfield sample	Baseline maximum 163 cells/L	>100 cells/L	None	494 cells/L caution-level exceedance
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

Seafloor monitoring in 2017 included sampling and analysis of soft-bottom sediment conditions, effluent tracers, chemical contaminants, and infauna at 14 stations, sediment-profile imaging at 23 stations, and video assessment of 23 hard-bottom stations (Figures 4-1 to 4-3). Anthropogenic contaminants analyses and assessment of hard-bottom habitats occur at three-year intervals, including 2017.

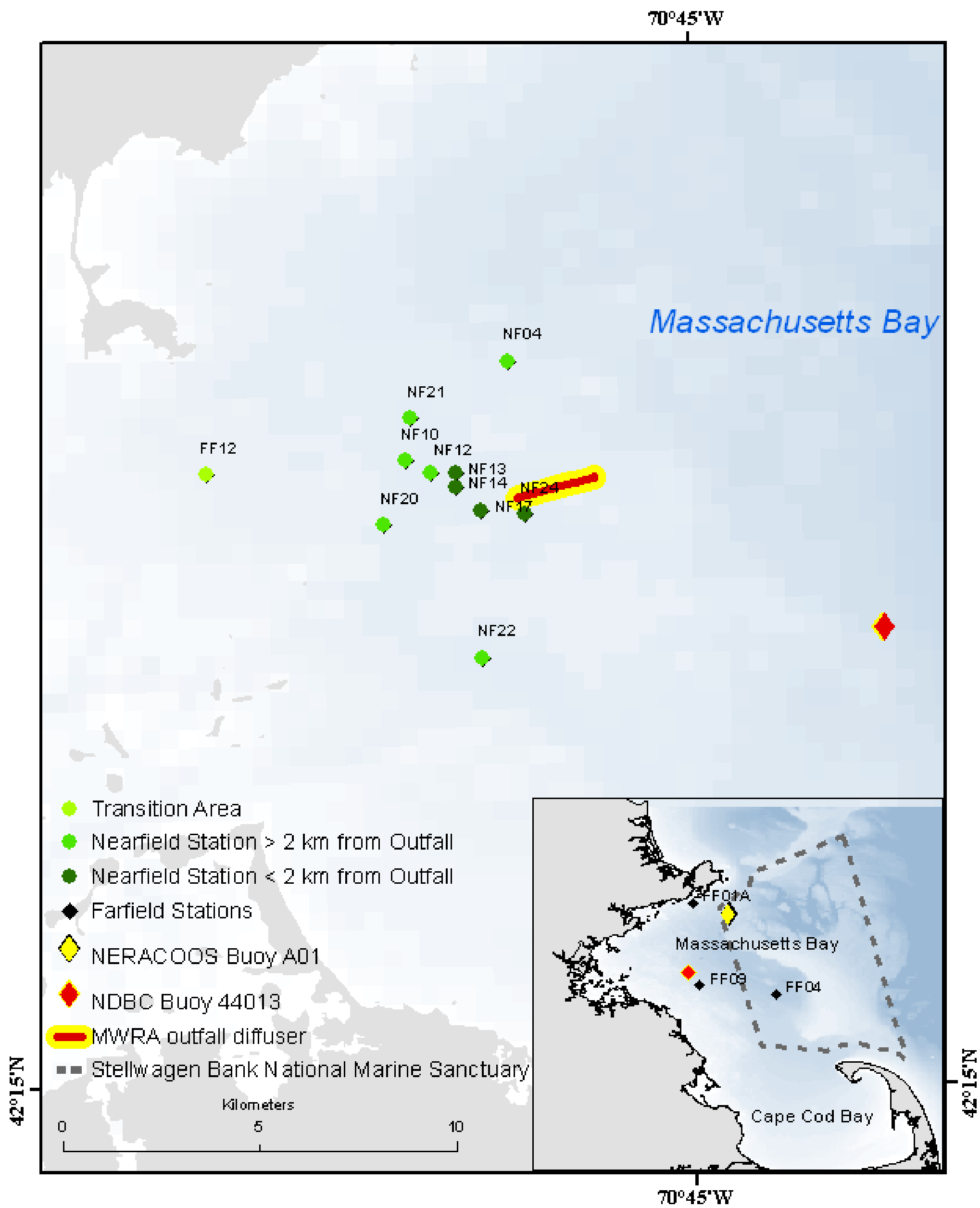

Figure 4-1. Soft-bottom monitoring stations. Also shown are the instrumented buoys, the MWRA outfall diffuser, and the Stellwagen Bank National Marine Sanctuary.

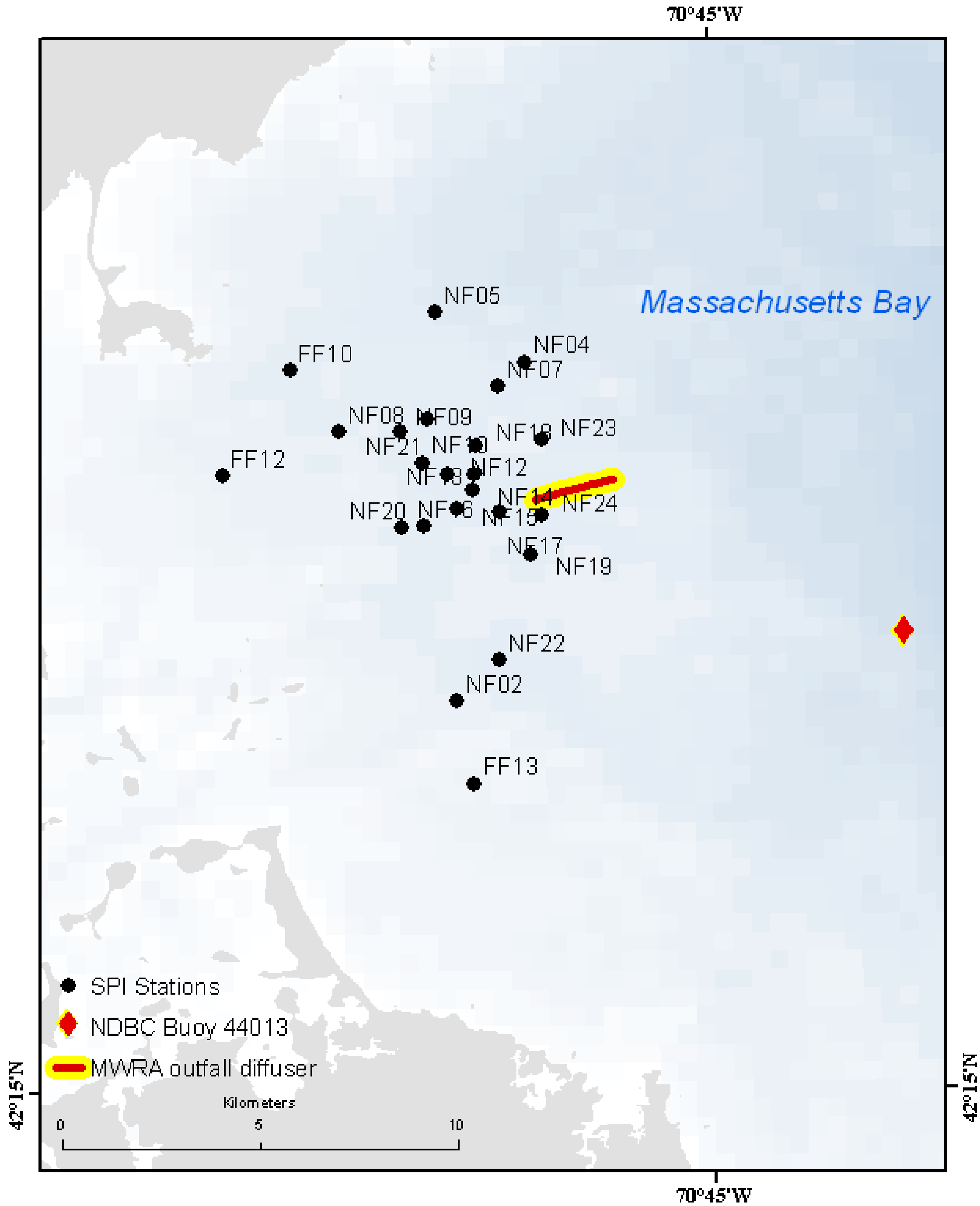

Figure 4-2. Sediment-profile imaging stations. Also shown are the NDBC buoy and the MWRA outfall diffuser. SPI = sediment-profile imaging

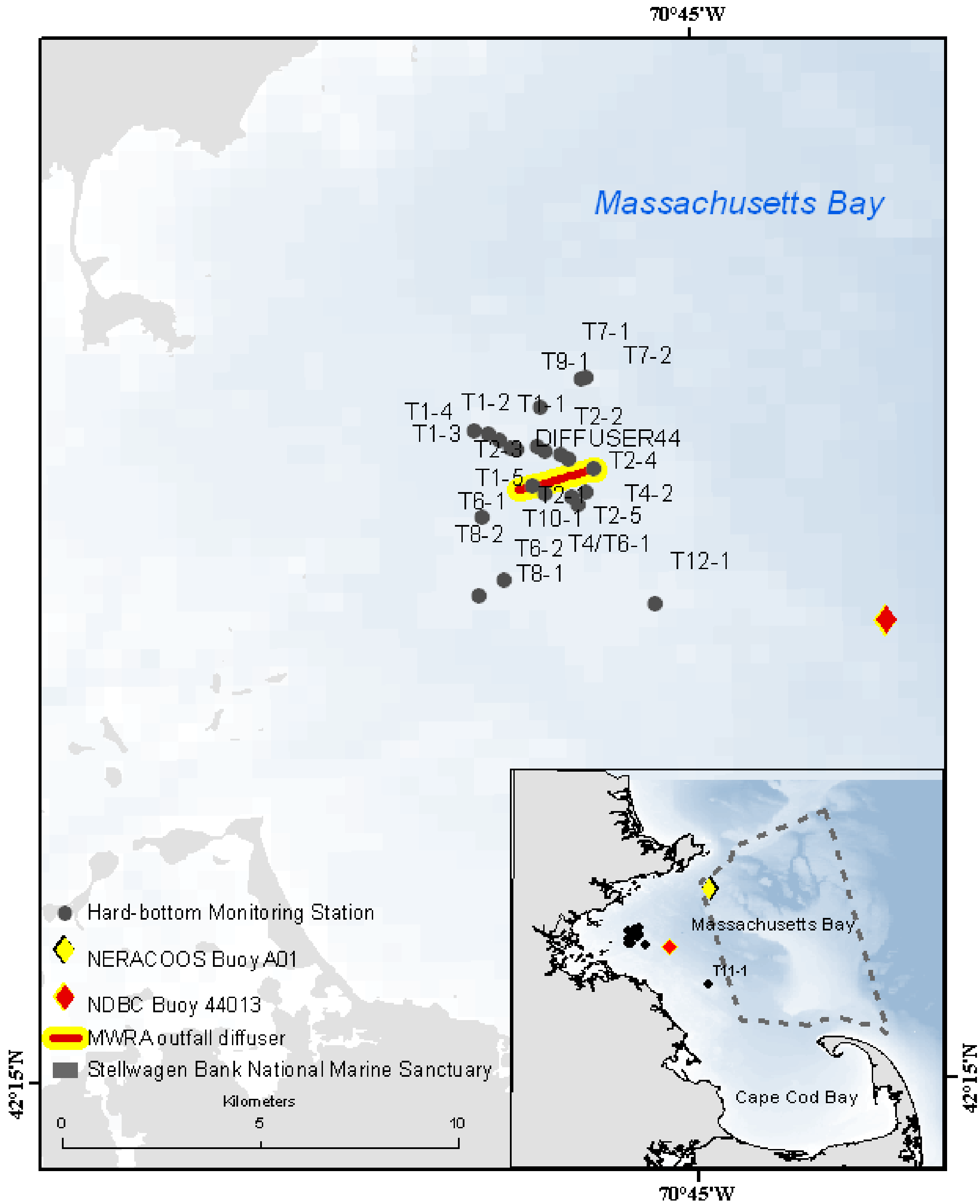

Figure 4-3. Hard-bottom stations. Also shown are the instrumented buoys, the MWRA outfall diffuser, and the Stellwagen Bank National Marine Sanctuary.

Soft-bottom sediment sampling was completed in August 2017, with samples analyzed for grain-size distribution, total organic carbon, the effluent tracer *Clostridium perfringens* spores, metal and organic 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 2017. 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.

Hard-bottom surveys were completed in late June 2017, including 480 minutes of analog video and GoPro, Inc. HD video with simultaneous still photographs. The remotely operated vehicle, a Benthos, Inc. Mini Rover, was somewhat noisier but more reliable than equipment used in the past, conceivably affecting sightings of fish and other mobile animals.

Sediment Characteristics and Tracers

As in past years, sediment grain-size distributions in 2017 varied broadly among stations, ranging from silt and clay at some stations to almost entirely sand at others (Nestler et al. 2018). Sediment grain-size distributions have remained generally consistent at individual stations over the years of the monitoring program. Changes have been mostly associated with large storms with wave-driven currents sufficient to re-suspend bottom sediments.

As in past years since the offshore outfall began to discharge, it was possible to detect elevated levels of effluent tracer *Clostridium perfringens* spores at the stations located closest to the outfall (Figure 4-4). *Clostridium* are anaerobic bacteria found in mammalian (including human) digestive tracts and that form persistent spores in oxygen-rich conditions. Statistical analyses have shown that the increases close to the discharge are consistent with predictions made during planning for the outfall.

Percent organic carbon content analyses were also consistent with past results (Figure 4-5). In general, stations with finer sediments, such as Station FF04 within Stellwagen Basin, have higher mean total organic carbon concentrations, while stations with coarser sediments, such as Station NF17 just to the south of the outfall, have lower concentrations. Total organic carbon concentrations continue to show no signs of organic enrichment from the effluent discharge, even at stations closest to the outfall.

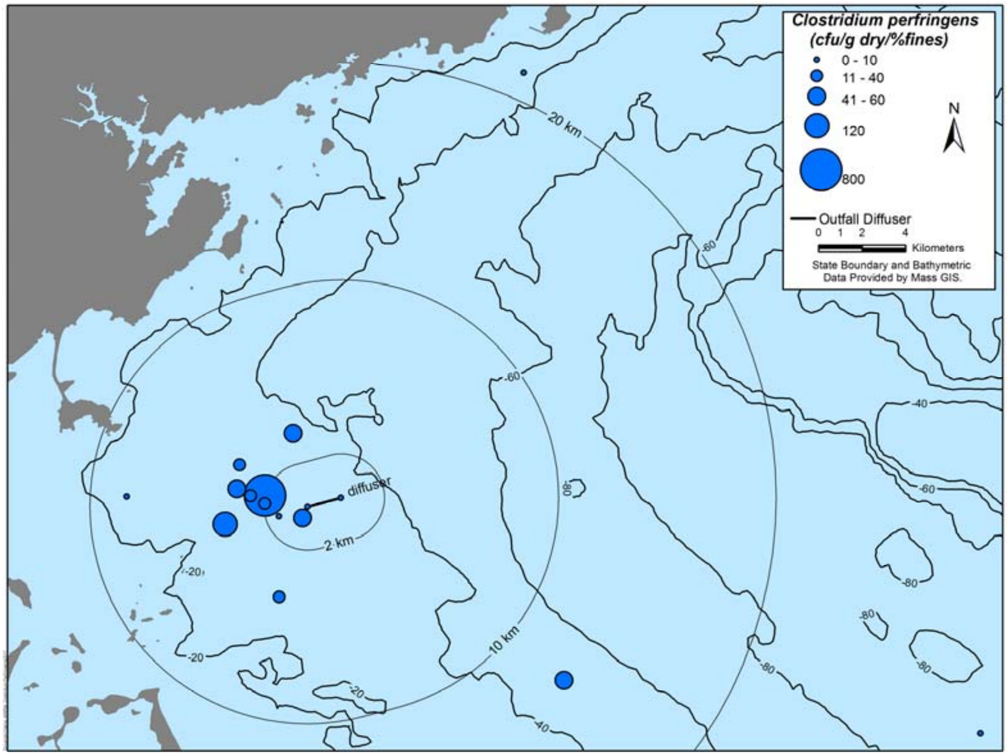

Figure 4-4. Concentrations of *Clostridium perfringens* spores, corrected for sediment grain size, in 2017.

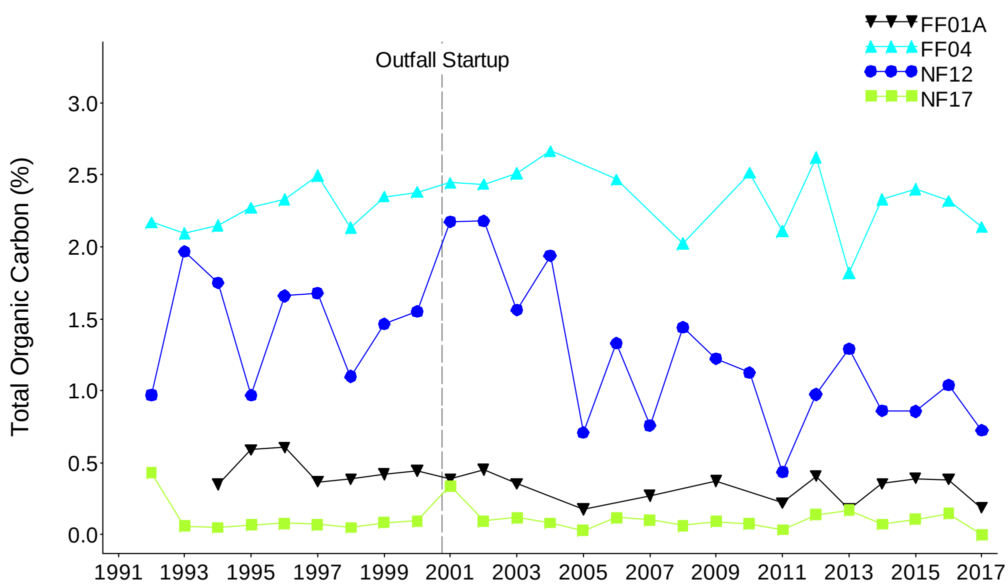

Figure 4-5. Total organic carbon at selected stations, 1992–2017. FF01A is the northern reference station; FF04 is within Stellwagen Basin; NF12 is >2km northwest of the outfall; NF17 is in close proximity and southwest of the outfall, where effects of the discharge might be expected.

Sediment Contaminants

Sediment samples analyzed for toxic metals and organic contaminants continued to provide no evidence of any effect of the Massachusetts Bay outfall. Higher levels of contaminants were associated with fine-grained sediments and with proximity to Boston Harbor, which is the historic contaminant source. No sample from any station located within two kilometers of the outfall had contaminant levels exceeding conservative federal benchmarks that define toxicity in marine sediments. Those benchmarks, known as "effects range low" or ER-L, represent concentrations below which toxicity has rarely been observed.

Concentrations of most sediment contaminants in 2017 were lower than those in earlier years, and in 22 of the 26 sediment contaminants for which there are Contingency Plan thresholds, the average 2017 nearfield concentrations were lower than the lowest annual averages measured during baseline monitoring in 1992–2000. For some contaminants, including the toxic metals chromium and lead (not shown), concentrations in sediments from near the outfall were the lowest measured through the duration of the monitoring program. Concentrations of organic contaminants also remained low. For some organic contaminants, such as PCBs (Figure 4-6), the results have shown continued long, slow declines, as was predicted when those products were banned in the 1970s.

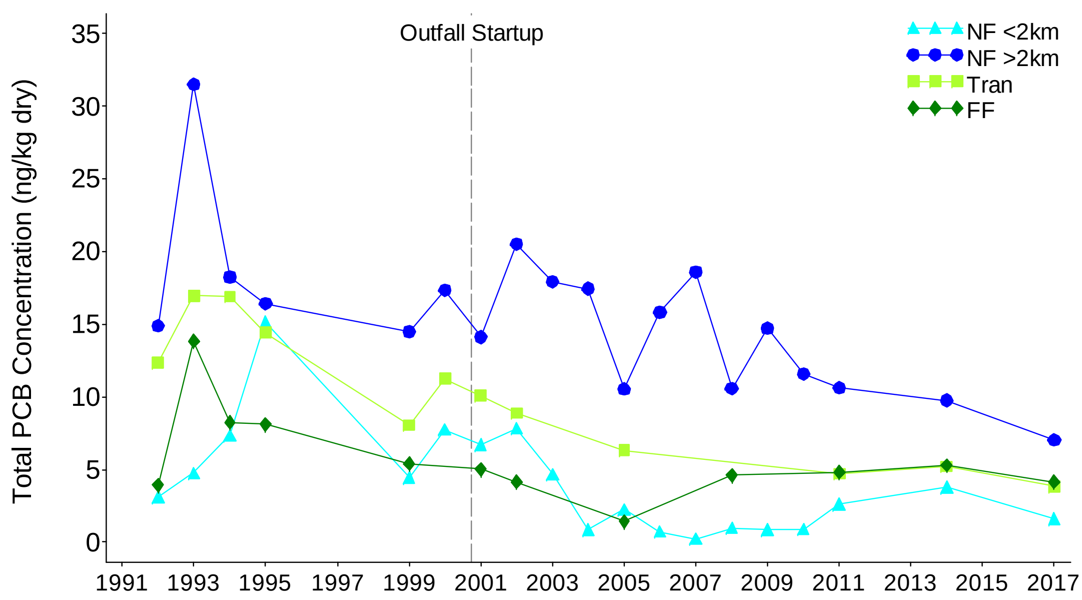

Figure 4-6. Mean concentrations of total PCBs at four areas in Massachusetts Bay, 1992–2017. NF = nearfield, Tran = transition zone, FF = farfield

Soft-bottom Communities

The 14 soft-bottom samples collected and analyzed in 2017 yielded 23,038 organisms, classified into 188 species and 26 other discrete taxonomic groups (Nestler et al. 2018). Total abundances of organisms were higher in 2017 than in 2016 throughout the region, and as in recent years, total abundance was highest at the only station within the transition area located between the harbor and the nearfield. The mean numbers of species per sample were also higher in 2017 than in 2016.

Community analyses showed no effects of the outfall on relative abundance or community composition. 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 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 continued to show no indication of any relation of species composition to proximity to the outfall, with nearfield and farfield stations represented in both major assemblages (Figure 4-7). Analyses further continued to demonstrate that variations in species distributions largely followed differences in sediment type and depth (Figure 4-8).

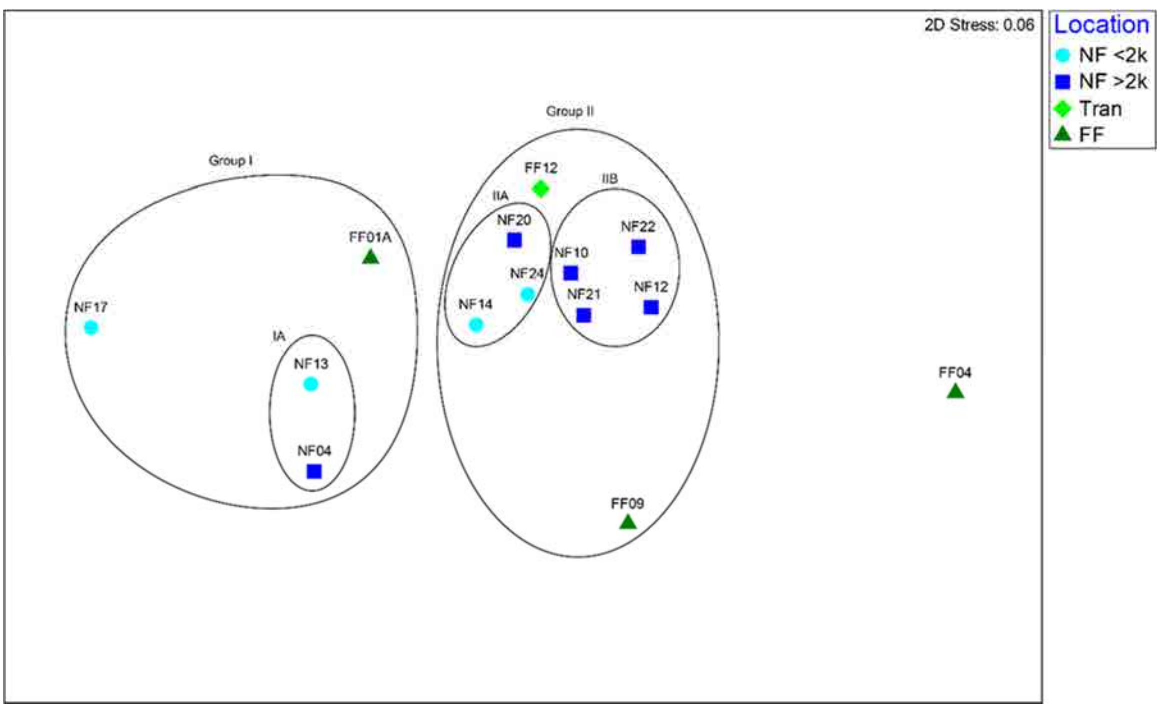

Figure 4-7. Ordination plot of 2017 Massachusetts Bay samples by location. Each point on the plot represents one of the 14 stations; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and sub-groups) identified by cluster analysis are circled on the plot. NF = nearfield, Tran = transition zone, FF = farfield

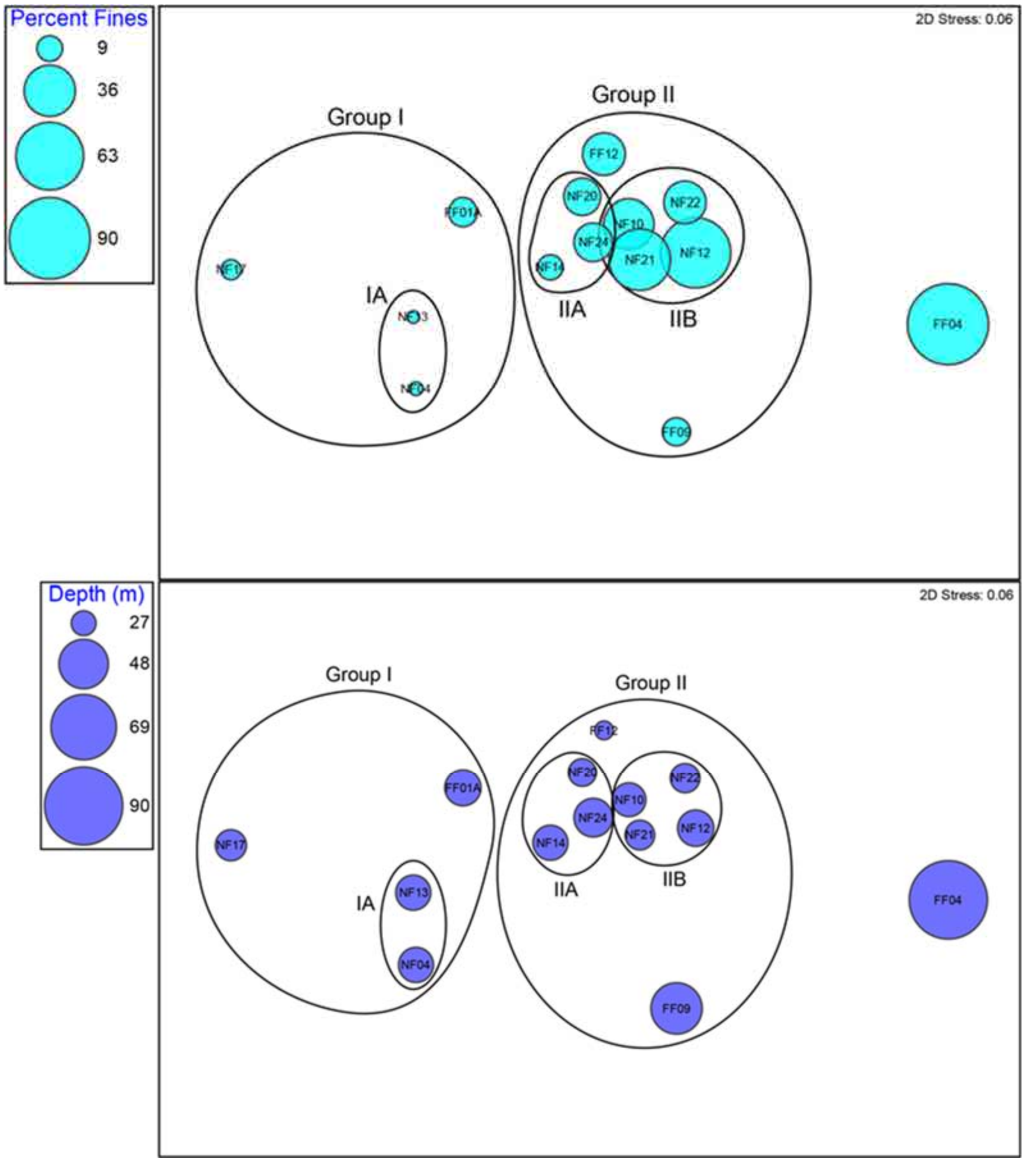

Figure 4-8. Percent fine sediments (top) and depth (bottom) superimposed on the ordination plot of the 2017 infauna samples. Each point on the plot represents one of the 14 stations; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and 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. 2018). 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 4-9), with a mean depth of 4.4 cm for all stations where RPDs could be measured. At nine of the 23 stations, the RPD was deeper than the bottom of the images, either because of sandy sediments or sediment compaction. The environmental concern before the outfall began to discharge was that the RPD would become shallower, due to increases in sediment organic matter causing stress on sensitive sediment-dwelling organisms. A deeper RPD continued to indicate there have been no adverse effects from the discharge.

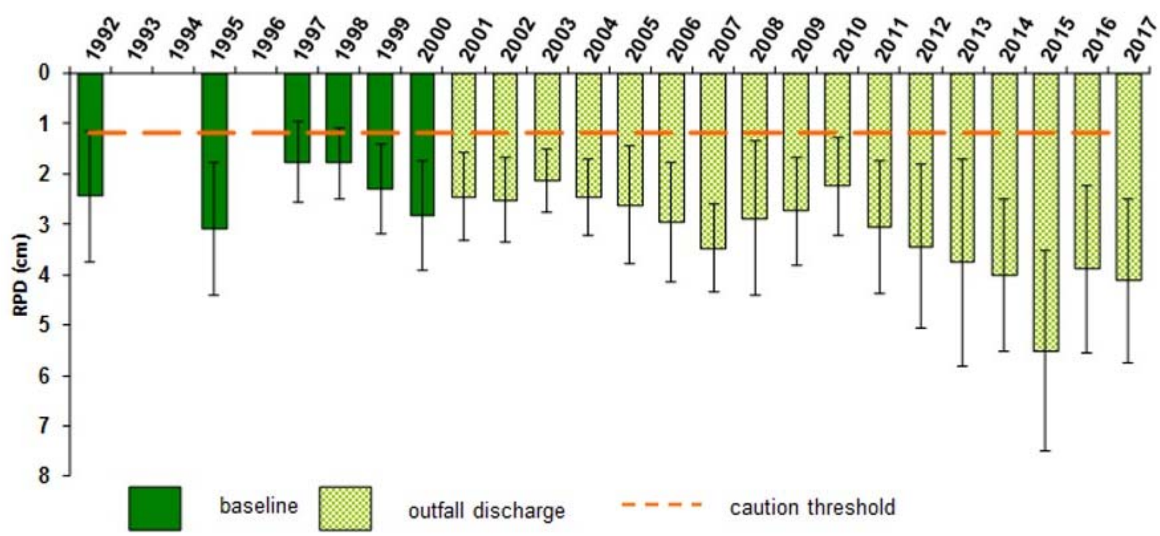

Figure 4-9. Annual apparent color RPD depth for data from nearfield stations. The mean RPD has been deeper than in baseline years, continuing to indicate that there has been no adverse effect from the discharge.

Monitoring has shown that physical rather than biological processes, such as storms and storm-induced sediment transport, can be primary stressors on the Massachusetts Bay sea floor. Physical processes were particularly evident in the first years of sediment-profile monitoring in Massachusetts Bay, as large storms occurred in October 1991 and December 1992. Strong storms in the spring of 2001, just after the Massachusetts Bay outfall startup, also diminished the role of biological processes in structuring the sediments. While biological processes are evident in some years, the active hydrodynamic conditions in Massachusetts Bay have promoted rapid effluent dispersion and prevented the accumulation of organic matter, which could have led to environmental degradation.

Hard-bottom Communities

As in past years, the video surveys of the hard-bottom habitats in the vicinity of the outfall showed that the communities are spatially diverse, but have remained relatively constant through time. Coraline algae, the most abundant taxonomic group, has decreased in abundance, first in northern stations, and now throughout the region. Abundance of upright algae, which were common but patchily distributed, particularly at the northern reference stations, has also declined over time. During 2014 and 2017, wide areas of both living and dead barnacles covered some surfaces.

The active and unopened diffuser heads included in the monitoring program have continued to support healthy and relatively stable communities (Nestler et al. 2018). In 2017, the active diffuser was almost entirely covered by a dense stand of the frilled anemone *Metridium senile*, barnacles, and mussels (Figure 4-10). The inactive diffuser head was similarly covered by anemones, barnacles, and also the sea peach tunicate *Halocynthia pyriformis*.

Figure 4-10. Lush growth of sea anemones and barnacles on an active diffuser head in 2017. Photo credit Barbara Hecker/Normandeau Associates**.**

Since 2007, the hard-bottom surveys have documented severe disturbance caused by deep-draft tankers anchoring at the northern reference site, Station T7-1, and evidence of disturbance was found again in 2017 (Figure 4-11). The disturbance includes overturned boulders and anchor scars.

Figure 4-11. Overturned boulder at a northern reference station, where deep-draft tankers have been observed to anchor. Photo credit Barbara Hecker/Normandeau Associates.

Stellwagen Bank National Marine Sanctuary

The NPDES permit to discharge from Deer Island Treatment Plant into Massachusetts Bay requires annual reports on results 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 had been 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 percent grain size and depth on the ordination plot for 2017 infauna samples continued to show these differences (see Figure 4-8, above).

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, 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 4-12).

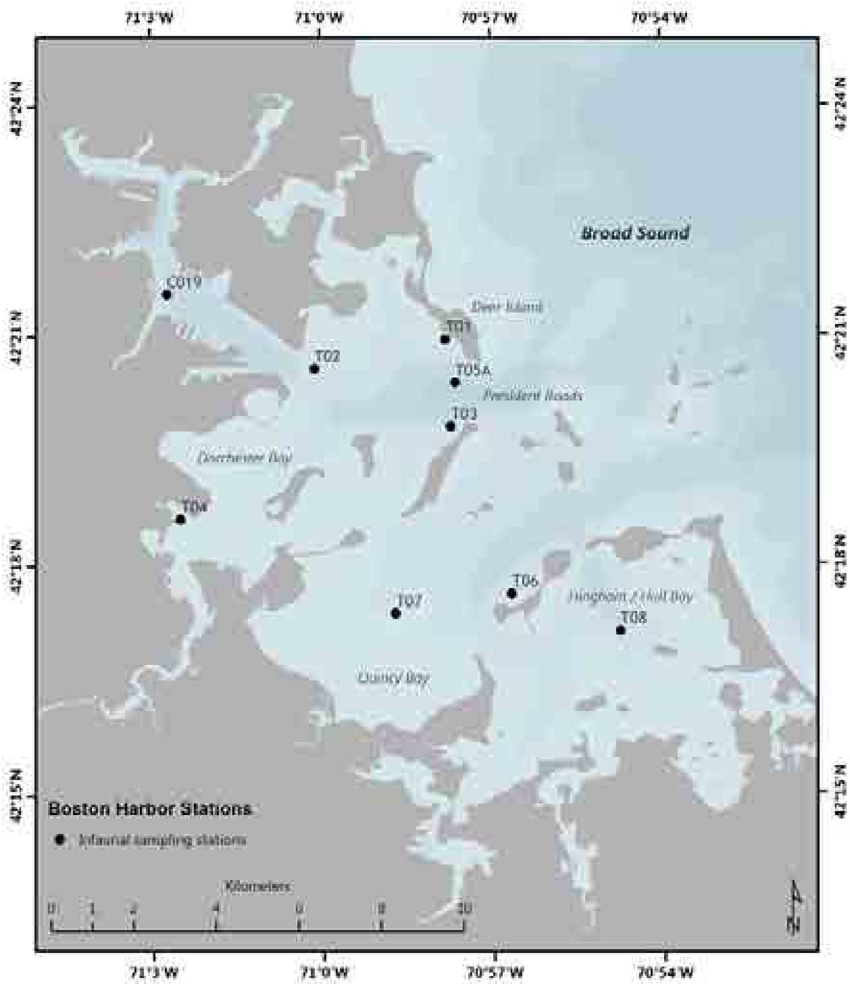

Figure 4-12. Soft-bottom sampling stations in Boston Harbor. Nine stations are sampled each year for sediment characteristics and infauna analyses.

Concentrations of total organic carbon (not shown) and *Clostridium perfringens* spores (Figure 4-13) 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 sheltered cove that tends to accumulate pollutants more than surrounding areas (Figure 4-14). Sediment-profile imaging (not shown) has also confirmed an inner- to outer-harbor gradient.

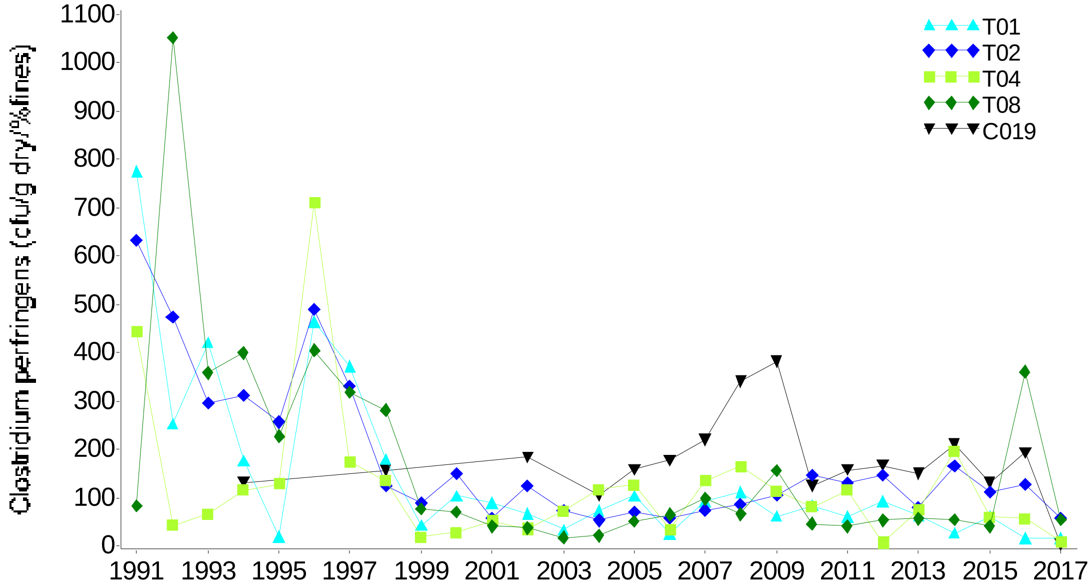

Figure 4-13. Mean concentrations of *Clostridium perfringens* spores at selected harbor stations, 1991–2017.

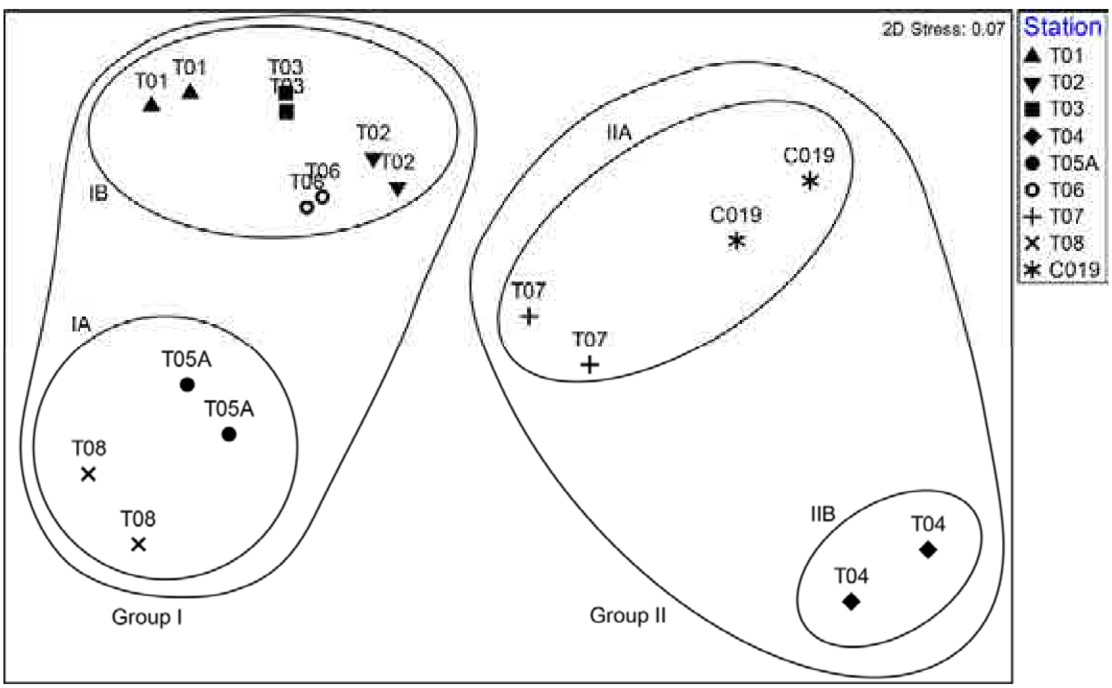

Figure 4-14. Ordination plot of 2017 Boston Harbor infauna samples. Two samples are collected per station. Group I comprises stations from the outer harbor; Group II includes Station C019 in the inner harbor and Station T07 in Quincy Bay. The assemblage most different from others was found at Station T04, at the mouth of Savin Hill Cove, in Dorchester Bay.

Contingency Plan Thresholds

There were no seafloor Contingency Plan threshold exceedances in 2017 (Table 4-1). Levels of PAHs, other organic contaminants, and metals remained well below thresholds. Average RPD depth was deeper than the thresholds and also deeper than baseline values.

Diversity and other benthic community parameters were also within Contingency Plan limits. Until 2017, the community-parameter thresholds had upper as well as lower bounds. In 2017, EPA and MassDEP approved MWRA's proposal, endorsed by OMSAP, to discontinue the upper bounds as Contingency Plan thresholds. In past years, even when diversity levels exceeded the upper bounds of the caution-level thresholds, there were no indications that environmental conditions had worsened or that there had been any effect of the outfall. Increased diversity is typically considered a good outcome in benthic habitats.

Table 4-1. Contingency Plan threshold values and 2017 results for sea-floor monitoring.

Parameter	Baseline	Caution Level	Warning Level	2017 Results
Polycyclic aromatic hydrocarbons (PAHs) (ng/g dry weight)				
Acenaphthene	22.7 – 43.5	None	500	24.8
Acenaphylene	30.3 – 43.1	None	640	24.5
Anthracene	101 – 159	None	1,100	86.2
Benzo(a)anthracene	206 – 302	None	1,600	230
Benzo(a)pyrene	204 – 298	None	1,600	145
Chrysene	164 – 296	None	2,800	191
Dibenzo(a,h)anthracene	27.8 – 38.3	None	260	34.1
Fluoranthene	422 – 621	None	5,100	308
Fluorene	35.5 – 66.6	None	540	29.1
Naphthalene	53.6 – 103	None	2,100	36.4
Phenanthrene	273 – 431	None	1,500	220
Pyrene	412 – 579	None	2,600	281
Total HMW PAH	2,790 – 3,850	None	9,600	2,450
Total LMW PAH	1,390 – 1,630	None	3,160	870
Total PAHs	4,180 – 5,400	None	44,792	3,320
Other organic contaminants (ng/g dry weight)				
p,p’-DDE	0.386 – 1.00	None	27	0.2
Total DDTs	2.51 – 5.69	None	46.1	0.3
Total PCBs	10.2 – 20.2	None	180	4.8
Metals (µg/g dry weight)				
Cadmium	0.0727 – 0.185	None	9.6	0.1
Chromium	59.2 – 79.9	None	370	27
Copper	19.1 – 25.2	None	270	11
Lead	41.1 – 46.3	None	218	23
Mercury	0.159 – 0.353	None	0.71	0.2
Nickel	15.7 – 17.2	None	51.6	9.4
Silver	0.335 – 0.485	None	3.7	0.1
Zinc	49.5 – 57.5	None	410	33
Sediment parameters				
RPD depth	NA	<1.18 cm	None	4.12 cm
Benthic community parameters				
Species per sample	NA	<42.99	None	63.5
Fisher’s log-series alpha	NA	<9.42	None	13.2
Shannon diversity	NA	<3.37	None	3.93
Pielou’s evenness	NA	<0.57	None	0.658
% opportunists	NA	>10%	>25%	1.23%

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

5. Fish and Shellfish

Each year, MWRA monitors the health of winter flounder from the Massachusetts Bay outfall site, Deer Island Flats near the former Boston Harbor outfall, 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 2017 were limited to winter flounder health assessments.

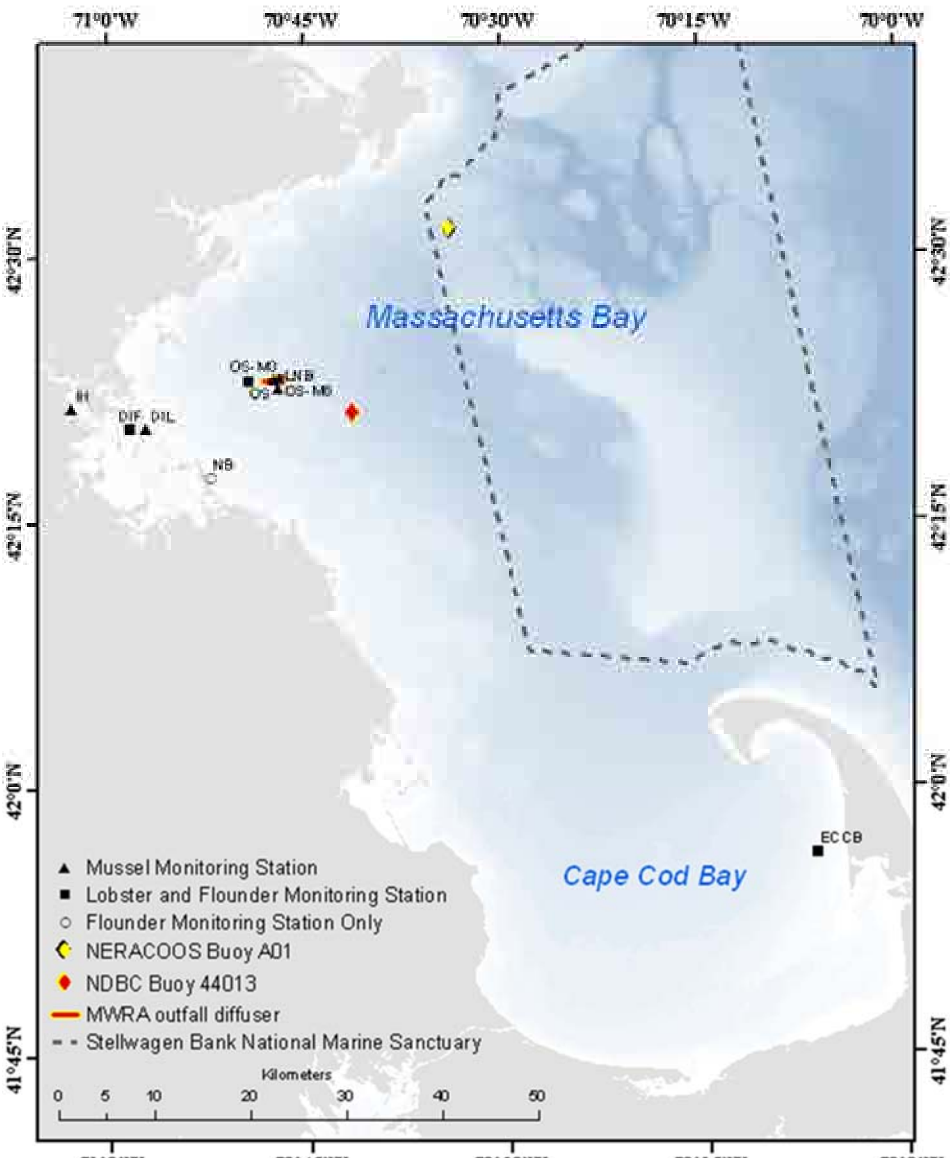

Figure 5-1. Fish-and-shellfish monitoring stations. Also shown are the two instrumented buoys, the MWRA outfall diffuser, and the boundaries of the Stellwagen Bank National Marine Sanctuary. Winter flounder stations are DIF = Deer Island Flats, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, OS = Outfall Site

Flounder Health

Annual flounder monitoring focuses on external condition and the presence of early liver disease and tumors (neoplasia). In April 2017, 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 (Moore et al. 2017). Catch per unit effort 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 (Figure 5-2).

Figure 5-2. "Ghost" lobstering gear brought up in MWRA flounder trawls can make collection difficult, especially at Deer Island Flats and near the outfall site.

Across the sites, mean age of fish ranged from 4.1 to 5.7 years, and standard length ranged from 272 to 316 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 sex ratios in MWRA and other northeast flounder studies).

Measures of external condition continued to suggest improved conditions in comparison to studies from the 1980s and 1990s, and there continued to be no evidence of neoplasia. No fish had blind-side ulcers. Incidence of fin erosion, an indicator of ammonium and other pollutants, was highest in fish from Deer Island Flats and lowest in fish from near the outfall. 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 5-3). Incidence of CHV remained low in fish from the outfall site and fell in fish from Deer Island Flats, after an increase in 2015 and 2106. Average severity of CHV (not shown) also remained lower than baseline levels. Severity of CHV in fish from Deer Island Flats has greatly fallen since 1991; levels of severity have been relatively constant throughout the program since 2005.

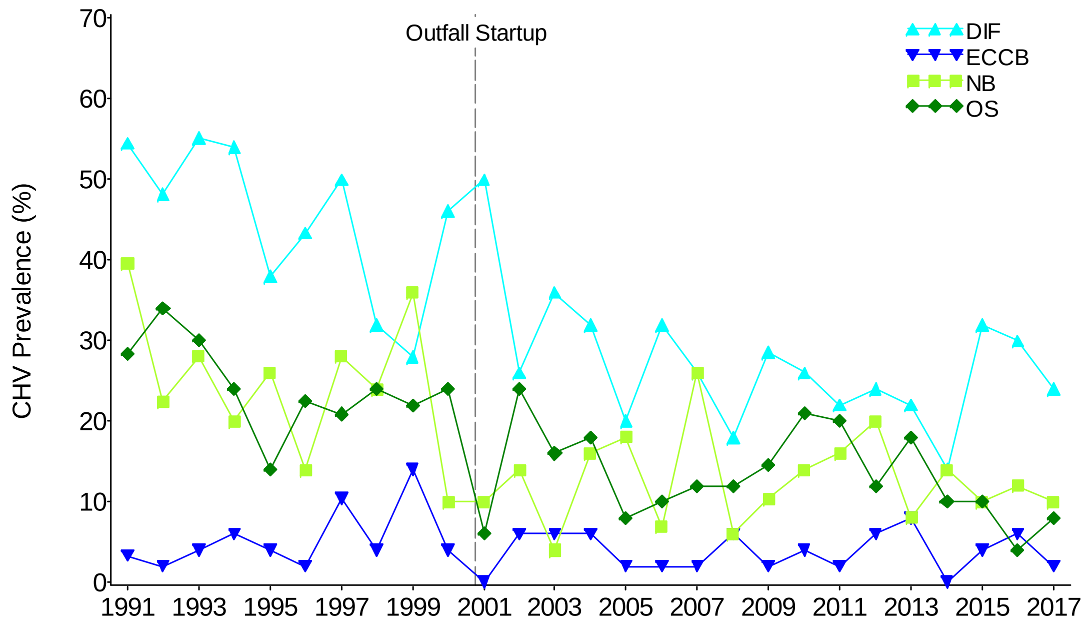

Figure 5-3. Annual prevalence of centrotubular hydropic vacuolation (CHV), 1991–2017.
DIF = Deer Island Flats, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, OS = Outfall Site

Contingency Plan Thresholds

There was no Contingency Plan threshold exceedance for the only parameter measured for 2017 (Table 5-1). Incidence of CHV, the most common indicator of liver disease in winter flounder of the region, was 8% in fish taken from the vicinity of the outfall, far lower than the 44.9% caution threshold or 24.4% baseline average.

Table 5-1. Contingency Plan threshold value and 2017 results for fish-and-shellfish monitoring.

Parameter	Baseline	Caution Level	Warning Level	2017 Results
Flounder disease				
Liver disease (CHV)	24.4%	>44.9%	None	8%

CHV = centrotubular hydropic vacuolation

6. Special Studies

Spotlight on Eutrophication

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 report's special studies section focuses on eutrophication, which was one of the largest concerns when the outfall was planned and sited.

Nutrients, especially nitrogen and phosphorus, are essential for the growth of all plants, including marine phytoplankton and seagrasses. In excess, nutrients, particularly nitrogen, can overstimulate marine phytoplankton growth, and when those algal cells die, they sink to the bottom, using up oxygen as they decompose. Excess phytoplankton growth and depressed levels of dissolved oxygen are the major attributes of eutrophication.

Prior to the Boston Harbor Project, Boston Harbor suffered from very eutrophic conditions. Alleviating eutrophication in the harbor without initiating eutrophic conditions in Massachusetts Bay was a primary goal of the wastewater treatment improvements and outfall relocation.

Scientists and modelers were confident conditions would improve in Boston Harbor without causing harm to Massachusetts Bay. Along with the greater dilution at the Massachusetts Bay outfall, discharging into deeper waters would trap the effluent below the summer pycnocline, in darker waters where less phytoplankton growth can occur. Managers and regulators, however, recognized there would be ongoing questions and concerns about whether Massachusetts Bay could assimilate the thousands of tons of nitrogen that would be discharged each year. Those concerns were recognized in MWRA's monitoring and contingency plans, and there are now 26 years of baseline and monitoring results to confirm the predictions made during outfall siting and design. All results to date confirm that the Boston Harbor Project dramatically decreased eutrophication in Boston Harbor without causing eutrophication in Massachusetts Bay.

Nitrogen Inputs

One reason for concerns that excess nitrogen in MWRA effluent might cause eutrophication in the bay was that nutrient inputs to the treatment plant were expected to increase over time. Also, the dissolved forms of nutrients taken up by phytoplankton were the only components of sewage entering the treatment plant that were not expected to be reduced substantially by secondary treatment. In fact, inputs to the plant have not increased as much as anticipated (see Figure 2-5), and the plant has performed better than expected, removing approximately 30% of the nitrogen from influent rather than the 10% that had been projected.

Monitoring has also shown that overall total nitrogen inputs to Massachusetts Bay have not increased in response to the Boston Harbor Project. Monitoring in the 1990s, prior to the outfall relocation, showed almost all the effluent nitrogen entering Boston Harbor eventually reached the bay. Studies have also found more than 90% of the nitrogen entering Massachusetts Bay originates from the wider water mass of the Gulf of Maine; only about 3% of the total nitrogen inputs to the bay could be attributed to the outfall discharge.

Nitrogen Concentrations in the Water Column

At the onset of the Boston Harbor Project, concentrations of ammonium, the form of nitrogen most available to phytoplankton, were expected to fall in Boston Harbor and increase in the immediate vicinity of the outfall. Those predictions were correct—ammonium concentrations in Boston Harbor plummeted when the outfall was relocated to Massachusetts Bay, while increased concentrations were measured in the immediate vicinity of the outfall (Figure 6-1). Those increases in ammonium concentrations resulting from the Massachusetts Bay discharge have been limited in both magnitude and geographic extent. Larger increases have been confined to areas within a kilometer of the discharge, and detectable increases have been observed only within 10 to 20 kilometers of the outfall.

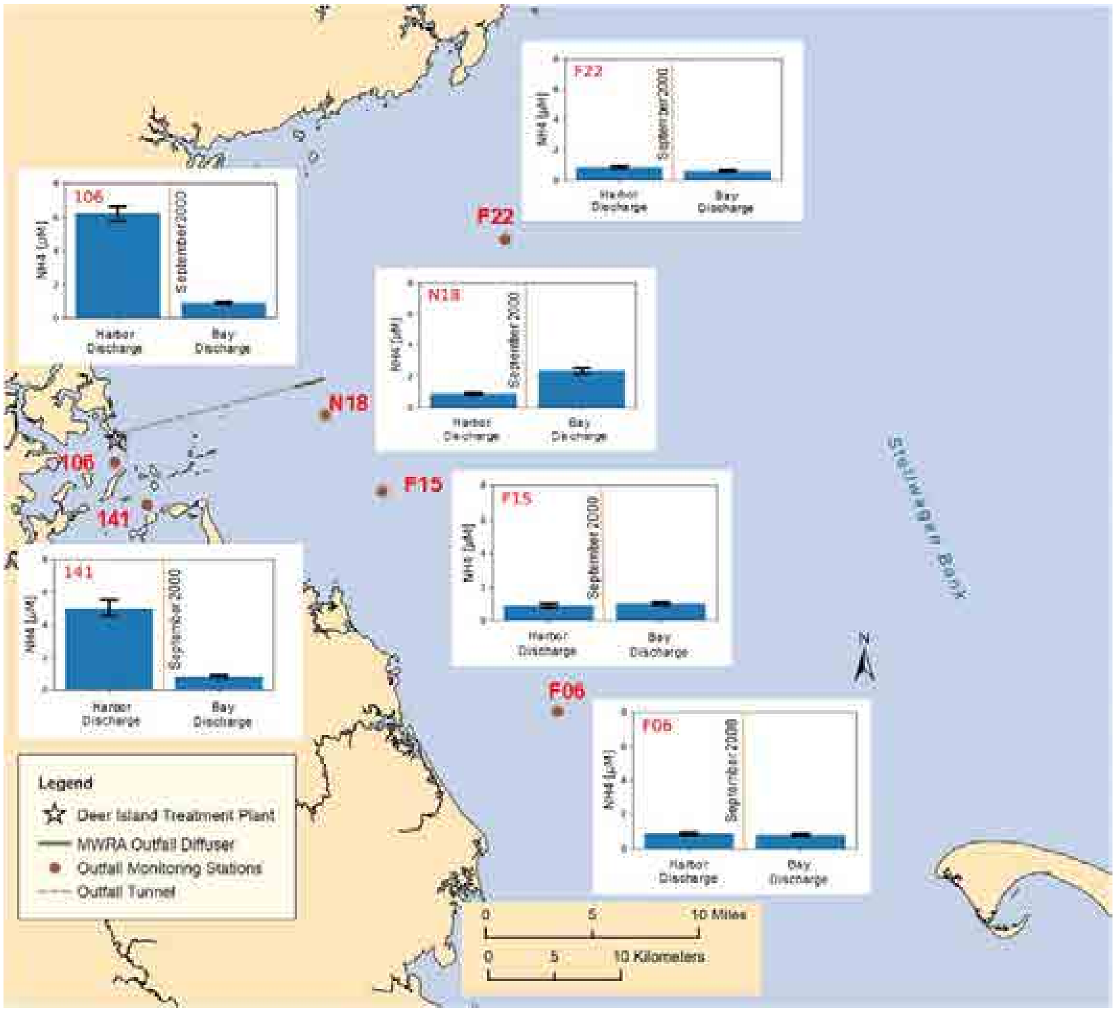

Figure 6-1. Ammonium concentrations at selected stations in Boston Harbor and Massachusetts Bay during harbor discharge and bay discharge years.

Phytoplankton Biomass

Decreasing phytoplankton biomass in Boston Harbor is major evidence for decreased eutrophication. Through the 1990s, when effluent discharge was to Boston Harbor, one symptom of eutrophication was seen in strong summertime algal blooms, which often discolored the water and persisted for weeks. Summertime concentrations of chlorophyll, a measure of algal biomass, decreased in Boston Harbor after the discharge moved offshore (Figure 6-2). No changes in summertime chlorophyll levels have been seen in Massachusetts Bay, where summer chlorophyll levels are naturally lower than in the shallower waters of Boston Harbor. There have also been no indications of phytoplankton species changes in the bay, and no blooms of toxic or noxious species have been attributed to or exacerbated by the offshore outfall.

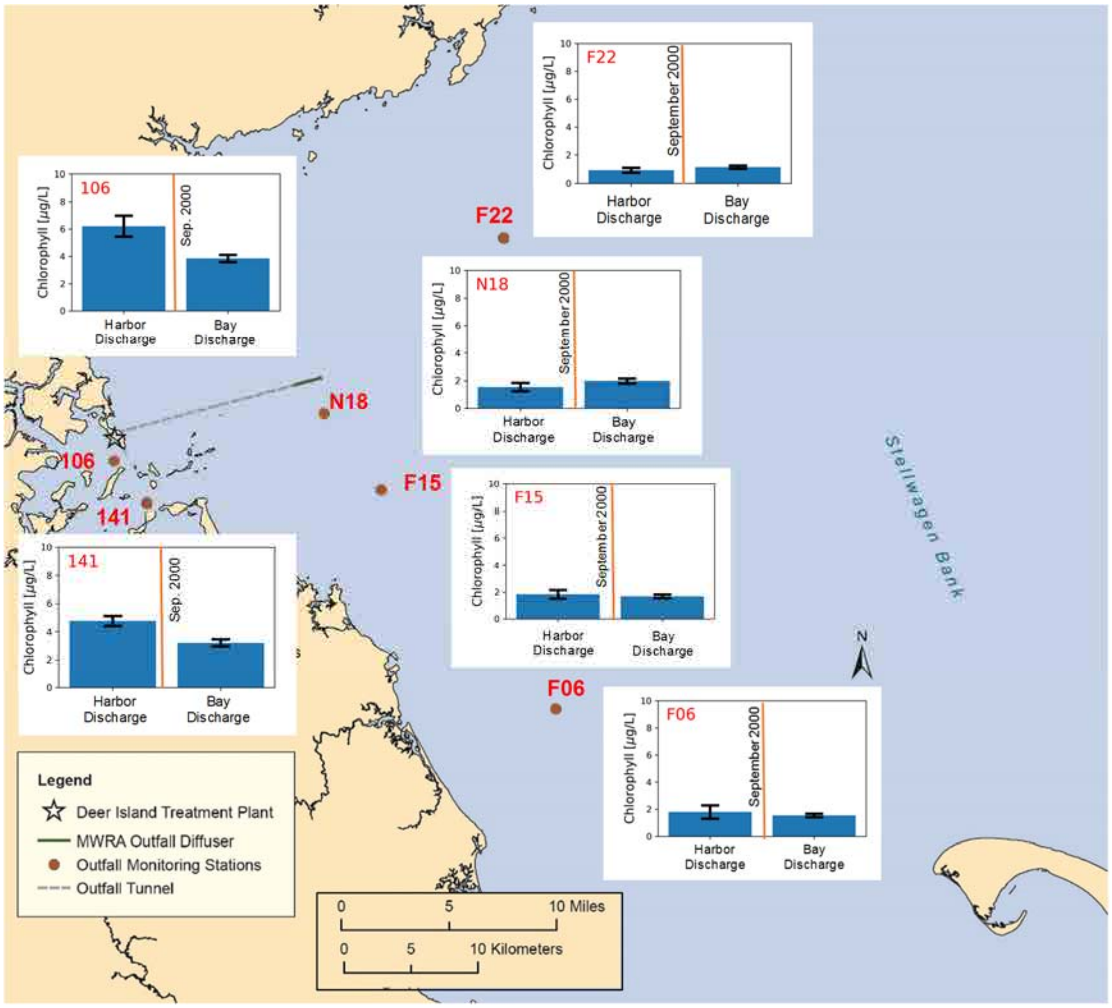

Figure 6-2. Chlorophyll concentrations at selected stations in Boston Harbor and Massachusetts Bay during harbor discharge and bay discharge years.

Dissolved Oxygen

One of the biggest public concerns about the Massachusetts Bay outfall was that it would result in harmfully low levels of dissolved oxygen in bay bottom waters in the summer. Low levels of dissolved oxygen can be found even in relatively pristine waterbodies. However, while dissolved oxygen levels have improved in Boston Harbor, they have remained unchanged in Massachusetts Bay (Figure 6-3). Instead, monitoring has shown the dissolved oxygen concentrations and saturation in Massachusetts Bay are controlled by physical factors, such as temperature, salinity, and the timing of the fall breakdown of stratification of the water column.

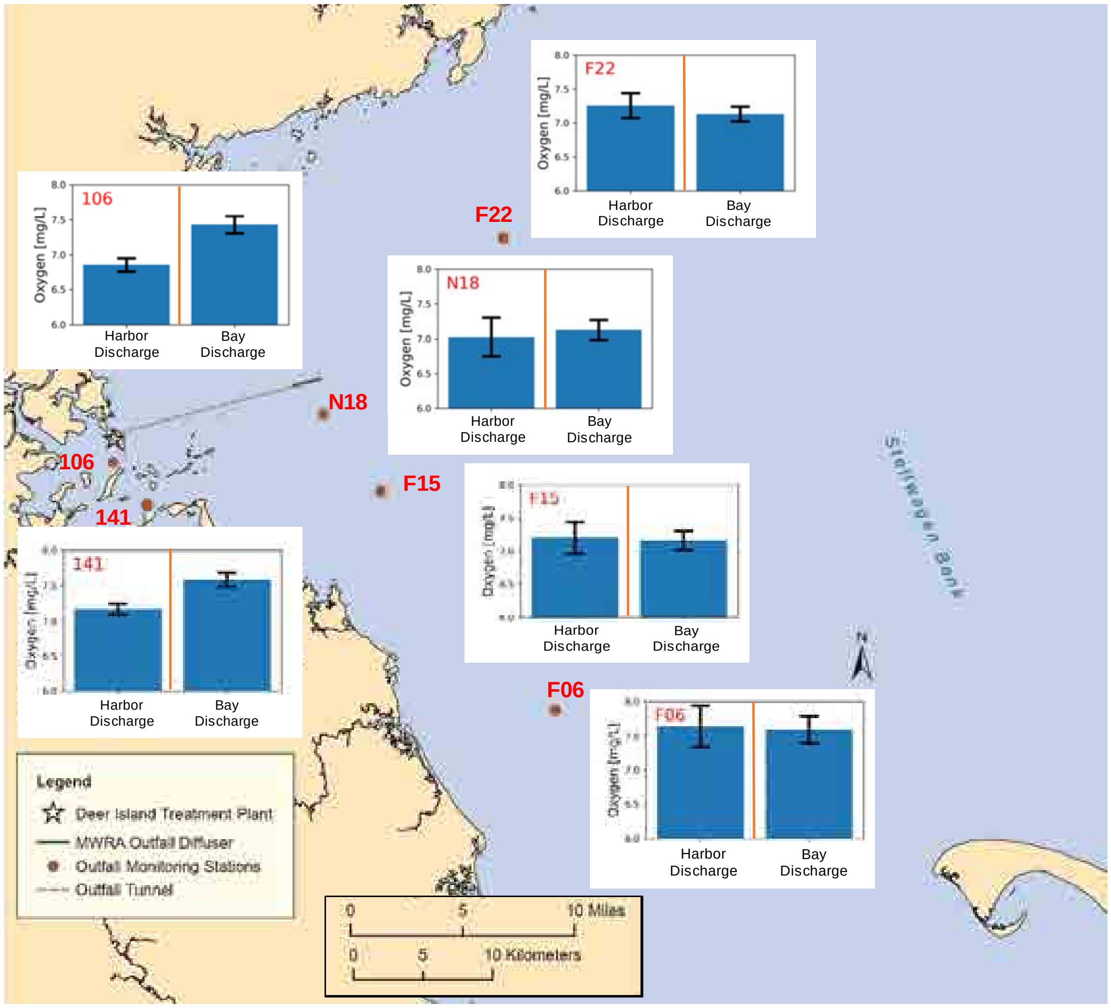

Figure 6-3. Annual minimum dissolved oxygen concentrations at selected stations in Boston Harbor and Massachusetts Bay during harbor discharge and bay discharge years.

Sea Floor Communities

Monitoring has also shown improvements to the bottom habitats of Boston Harbor without any measures of harm to Massachusetts Bay. At muddy stations within Boston Harbor, where changes would be most likely to be detected, total organic carbon concentrations have decreased (Figure 6-4) and species richness (number of species per sample) has increased (Figure 6-5). Because bottom-dwelling organisms have responded to other factors besides eutrophic conditions, and some improvements occurred prior to relocation of the outfall, increases in the harbor in species richness since the beginning of the monitoring have been larger than shown in Figure 6-5. No increases total organic carbon concentrations or decreases in species richness at muddy stations in Massachusetts Bay have occurred, even at Station NF24, the station closest to the Massachusetts Bay outfall.

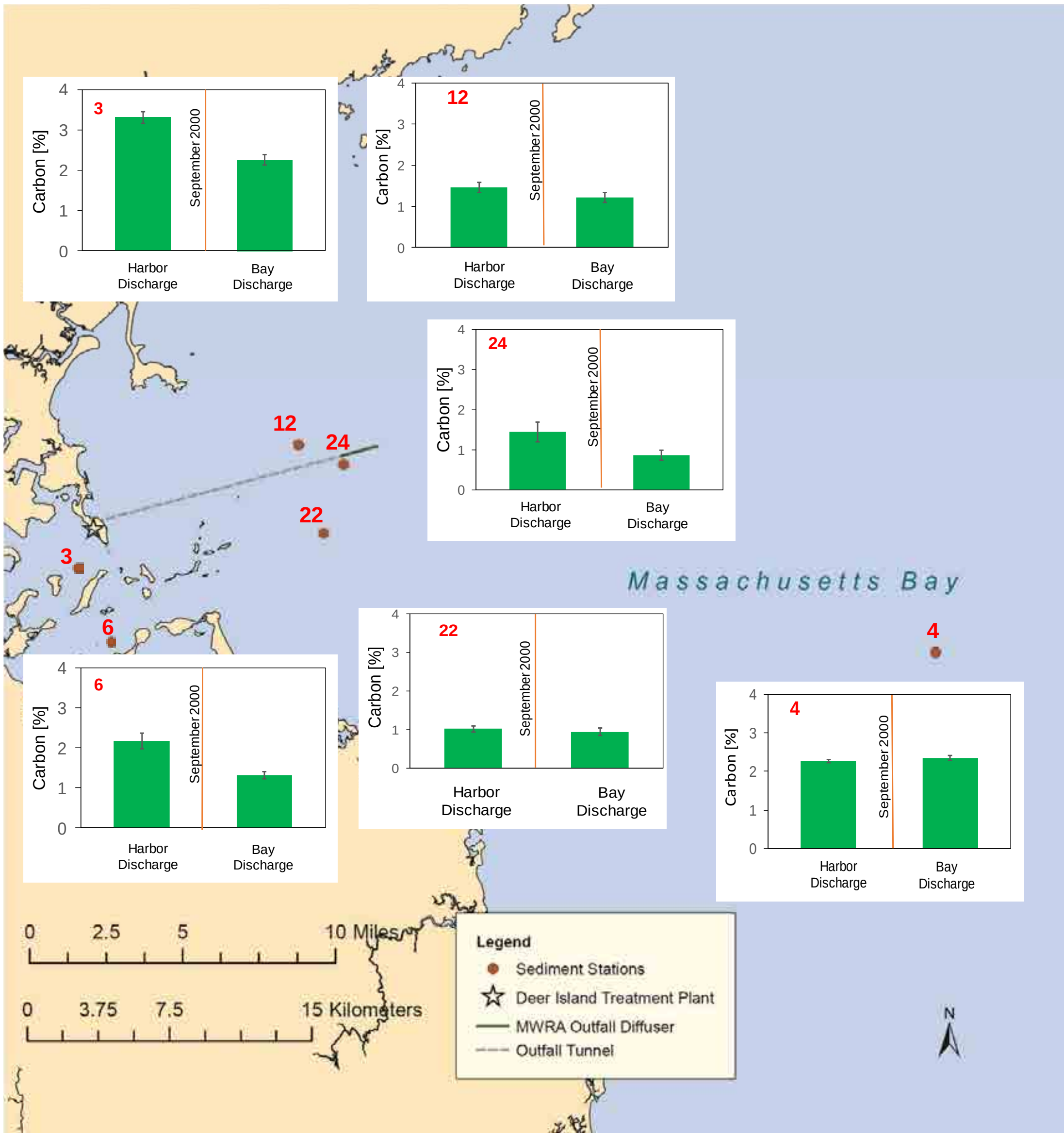

Figure 6-4. Total organic carbon (TOC) concentrations at muddy stations in Boston Harbor and Massachusetts Bay during harbor discharge and bay discharge years. Station labels have been shortened for clarity on the map: 3 = T03, 4 = FF04, 6 = T06, 12 = NF12, 22 = NF22, 24 = NF24

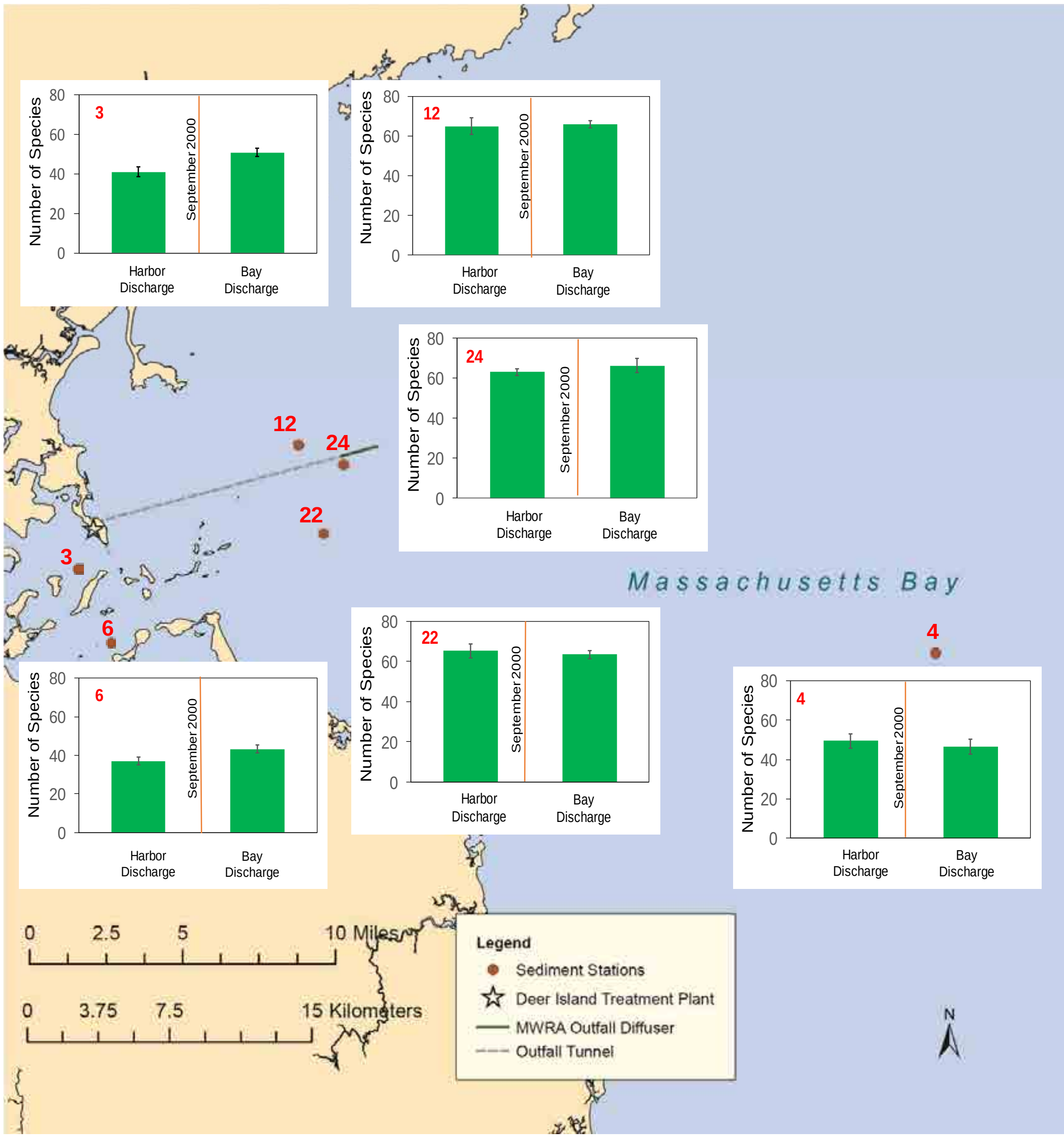

Figure 6-5. Species richness at muddy stations in Boston Harbor and Massachusetts Bay during harbor discharge and bay discharge years. Station labels have been shortened for clarity on the map: 3 = T03, 4 = FF04, 6 = T06, 12 = NF12, 22 = NF22, 24 = NF24

Another indication of decreased eutrophication and habitat enrichment, eelgrass beds, which provide a healthy habitat for fish and shellfish, have begun to grow in parts of Boston Harbor where seagrasses had not previously been seen (Figure 6-6). No concurrent habitat degradation has occurred in Massachusetts Bay, where monitoring has shown that physical processes, such as storms and storm-induced sediment transport, are the primary stressors on the environment. Bottom-dwelling animal communities have remained healthy and diverse, with no indication of eutrophic effects.

Figure 6-6. Eelgrass in Boston Harbor is thriving in areas where it was not previously seen, providing habitat for flounder and other fish and shellfish. Photo credit Phil Colarusso, EPA.

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List of Acronyms

ASP	Amnesic shellfish poisoning
cBOD	Carbonaceous biochemical oxygen demand
CHV	Centrotubular hydropic vacuolation
DDT	Dichlorodiphenyltrichloroethane
DIF	Deer Island Flats
DO	Dissolved oxygen
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
ER-L	Effects range low
FF	Farfield
HMW	High molecular weight
IAAC	Inter-Agency Advisory Committee
LC50	50% mortality concentration
LMW	Low molecular weight
MassDEP	Massachusetts Department of Environmental Protection
MGD	Million gallons per day
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
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
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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