# 2019 Outfall Monitoring Overview

Massachusetts Water
Resources Authority
Environmental Quality
Department Report 2020-11

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Deer Island Treatment Plant and Boston Harbor Islands
*Wayne Wurtsbaugh, LimnoVision*

Water Column Sampling in Massachusetts Bay, 2020
*Alex Whiffen-Mansfield, Battelle*

# 2019
# Outfall Monitoring Overview

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# 2019 Outfall Monitoring Panel and Committees

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Massachusetts Coastal Zone Management
U.S. Army Corps of Engineers
Stellwagen Bank National Marine Sanctuary
U.S. Environmental Protection Agency
Massachusetts Division of Marine Fisheries
Massachusetts Department of Environmental Protection

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Save the Harbor/Save the Bay
MWRA Wastewater Advisory Committee
Conservation Law Foundation
Massachusetts Audubon Society
MWRA Advisory Board
Association to Preserve Cape Cod
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# Executive Summary

This outfall monitoring overview for 2019 marks the twenty-eighth year of the Massachusetts Water Resources Authority (MWRA) Massachusetts Bay monitoring program, including eight years of baseline studies. Twenty years ago, in September 2000, MWRA took an important step to clean up Boston Harbor, diverting the greater Boston area municipal effluent discharge from the relatively shallow, confined waters of Boston Harbor to the deeper, more open waters of Massachusetts Bay. Since then, the MWRA monitoring program has worked to ensure that the discharge leads to no environmental harm.

Through 2019, Deer Island Treatment Plant continued to operate as designed, earning MWRA the National Association of Clean Water Agencies Platinum 13 Peak Performance Award for facilities with 100% compliance with permit conditions over 13 consecutive years. Annual solids discharges, that portion of the MWRA effluent that contains most of the persistent organic and inorganic contaminants, remained low, only a small fraction of the biosolids (sludge) and effluent discharges to Boston Harbor in the 1990s (Figure i).

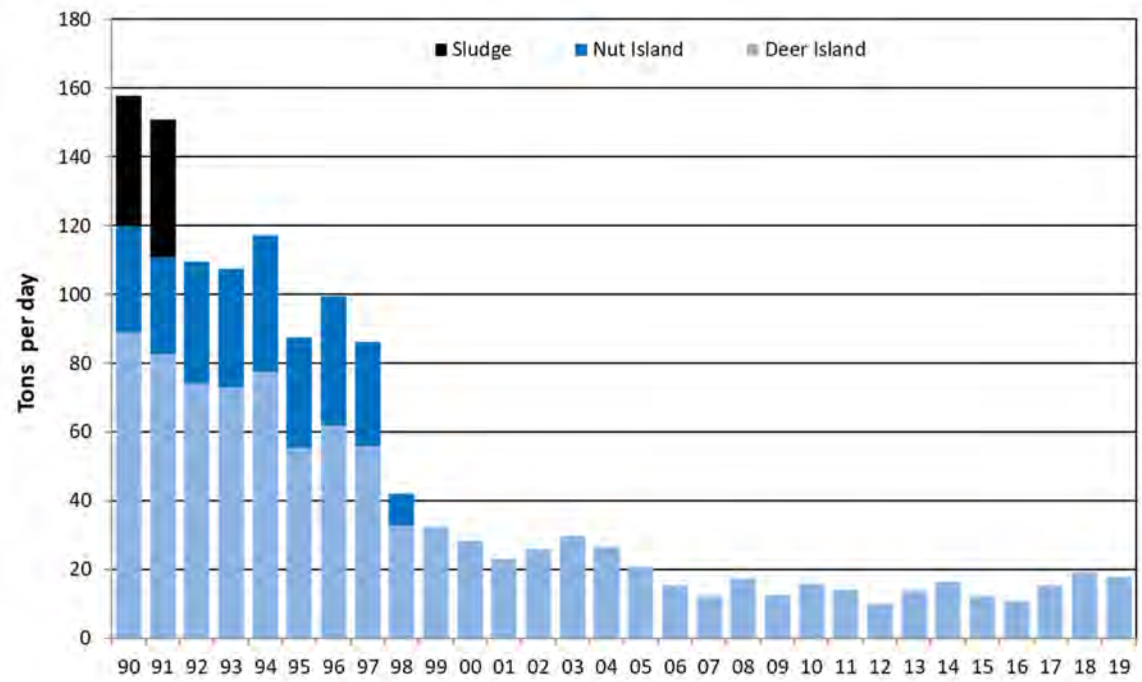

**Figure i. Annual solids discharges, 1990–2019.** Before December 1991, biosolids (sludge) removed during treatment were disinfected and discharged into Boston Harbor. Ending biosolids disposal in 1991, ending effluent discharge to the southern portion of the harbor from Nut Island in 1998, implementing 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 mostly be attributed to variation in flow rather than to variations in treatment.

Total nitrogen discharges in 2019 were 13,217 metric tons, exceeding MWRA's Contingency Plan caution level (12,500 metric tons per year), which is set at approximately 90% of the warning level, 14,000 metric tons per year (Figure ii). The warning level had represented the anticipated nitrogen load for the year 2020, so it was not surprising that the caution level could be exceeded in 2019. In fact, nitrogen removal at Deer Island Treatment plant has been more successful than had initially been predicted, about 30% rather than 10–15%. Total nitrogen discharges track well with population growth in the MWRA service area. Population growth has been about 8% since 2010, while increases in nitrogen discharges have been about 7%.

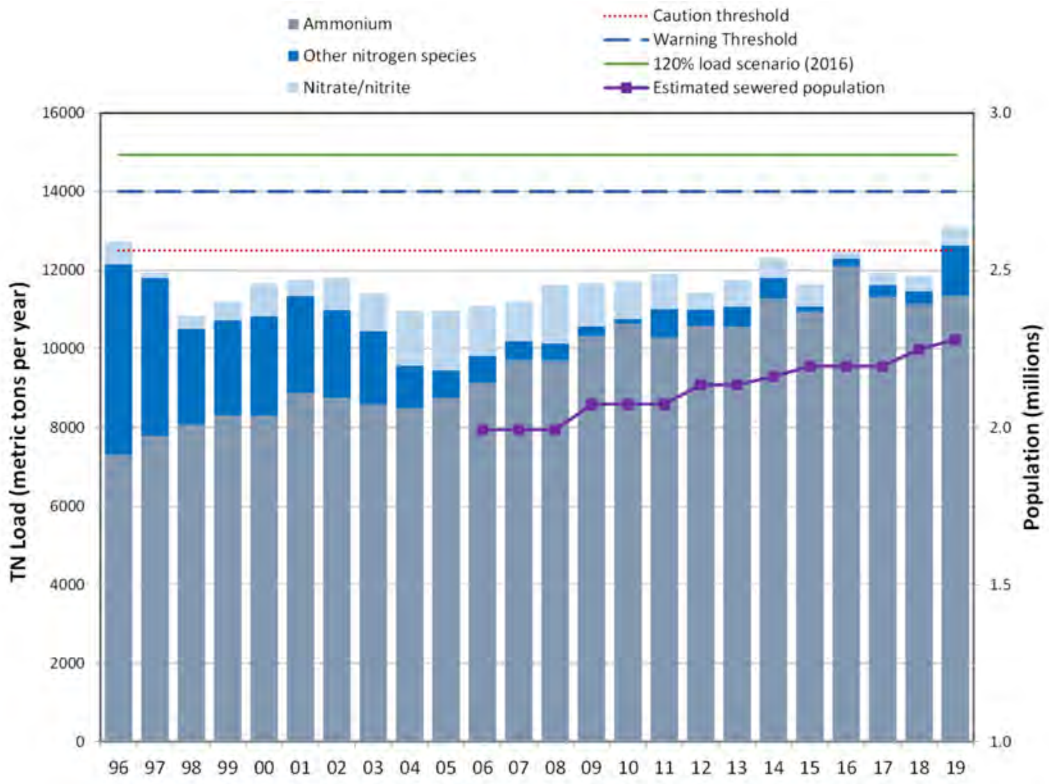

**Figure ii. Annual nitrogen discharges, 1996–2019, and estimated population of the MWRA service area, 2006–2019.** During outfall planning, experts estimated that discharges would total 14,000 metric tons per year by 2020. The warning threshold was set at that level, and the caution level was set at about 90% of that projected load. A water-quality model simulation using 120% of the 2016 discharge (green line) projected negligible environmental effect.

This caution-level exceedance is not considered an environmental concern for Massachusetts Bay or the surrounding region. Water-quality monitoring has detected no increases in nitrogen levels outside the immediate vicinity of the Massachusetts Bay discharge, and there has been no indication of nutrient stimulation of phytoplankton growth, even at stations nearest to the outfall. Water-quality modeling has suggested that even large increases in discharges would not adversely affect the marine environment.

Despite the Contingency Plan caution exceedance for total nitrogen discharge, the change to the nutrient regimes in Boston Harbor and Massachusetts Bay remains one of the great successes of the outfall relocation. Concentrations of ammonium, the form of nitrogen most readily taken up by phytoplankton, plummeted in Boston Harbor immediately following the effluent discharge diversion from the harbor to Massachusetts Bay (Figure iii). Elevated concentrations of ammonium have been detected at stations closest to the outfall, as had been anticipated, but not at stations further away. A recent review of results from the past nine years of data collection has reconfirmed those findings. The deeper water outfall further protects the environment by confining the summer discharge to beneath the pycnocline, below the well-lit depths where most phytoplankton growth occurs.

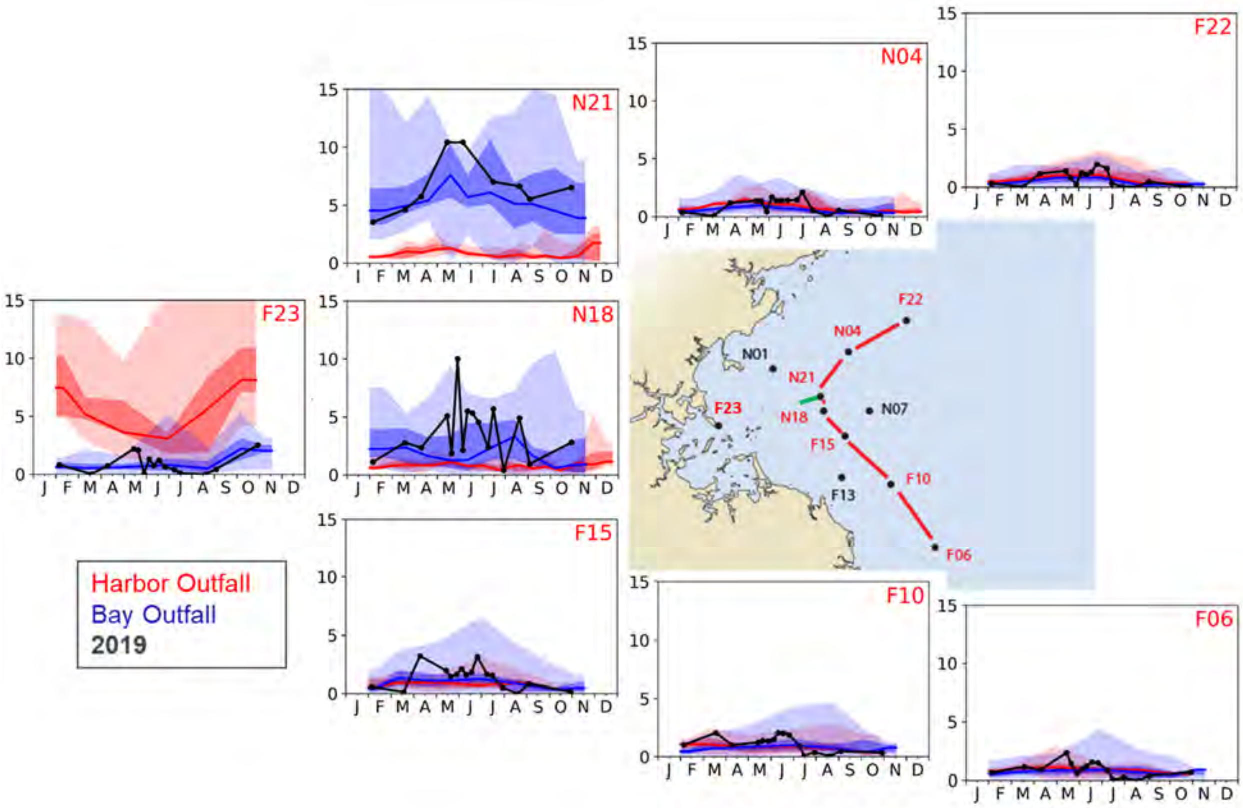

**Figure iii. Station average ammonium concentrations at selected stations in 2019 compared to prior years.** Black points and lines are results from individual surveys in 2019. Red lines and shading show data from Boston Harbor discharge years (1992–September 2000). Results from Massachusetts Bay discharge years (September 2000–2018) are in blue. Line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range.

Massachusetts Bay remains susceptible to periodic spring blooms of the nuisance dinoflagellate species *Alexandrium catenella*, which, at high densities, can cause paralytic shellfish poisoning or PSP, a public health risk. These blooms occur when strong spring winds from the northeast bring *Alexandrium* cells from coastal Gulf of Maine waters into Massachusetts Bay. The 2019 *Alexandrium* bloom was relatively large and prolonged, exceeding the Contingency Plan caution level, but it was otherwise typical of past years, with cells first detected in northern samples (Figure iv). Massachusetts Bay shellfish beds were closed from mid-June until mid-July, when the bloom quickly ended. Neither the timing nor geographic progression of the bloom suggested any influence of the Massachusetts Bay outfall.

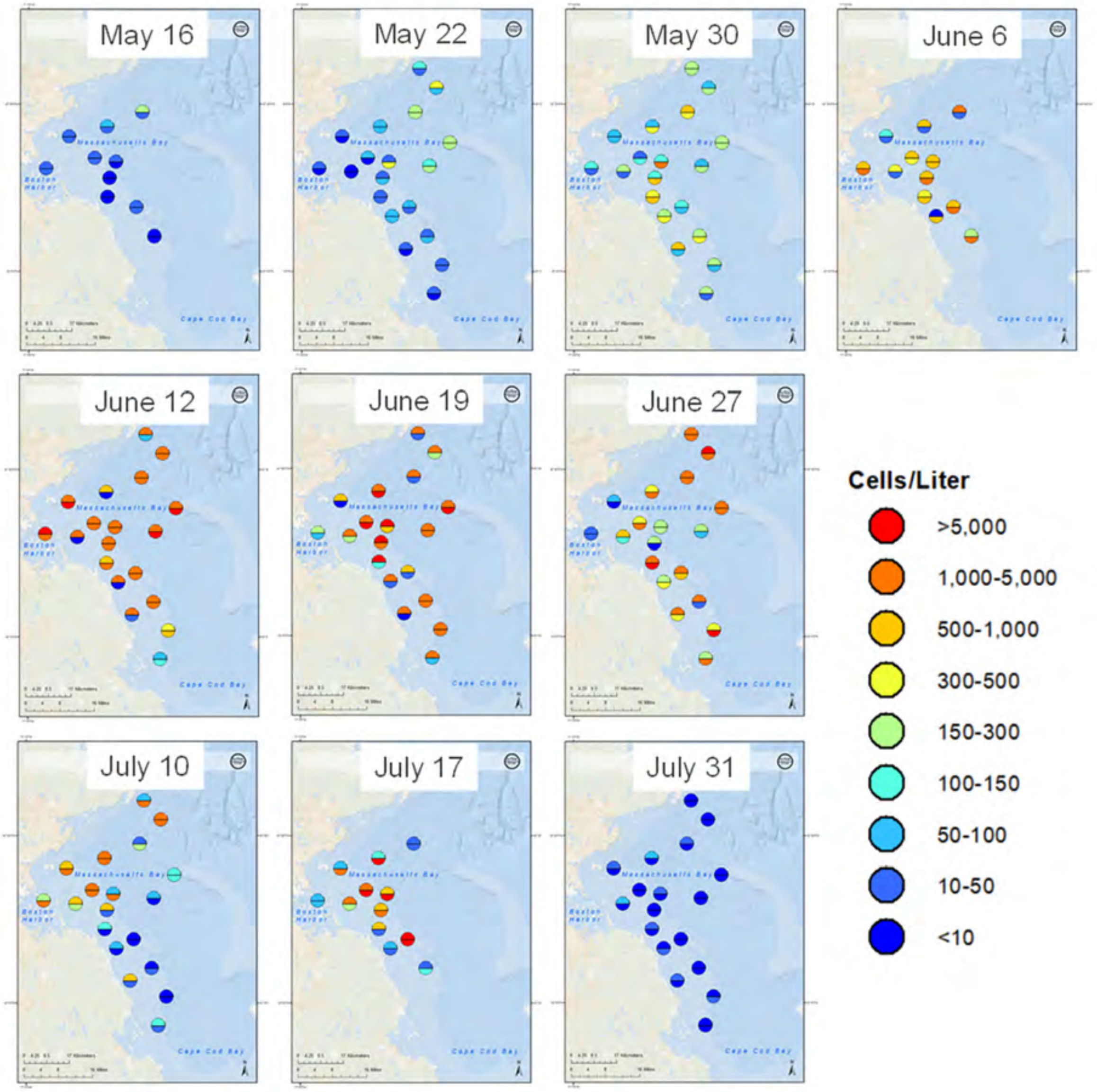

**Figure iv. *Alexandrium* abundance in surface- and mid-depth samples during the 2019 bloom.** The upper half of the symbols indicates abundance in surface waters; the lower half indicates abundance at about 10 meters.

Seafloor communities in Massachusetts Bay have remained unaffected by the relocated outfall. The bacterial effluent tracer *Clostridium perfringens* spores can be detected in sediment samples at stations closest to the outfall, but there has been no evidence of increased organic carbon content. Total abundances, numbers of species, and diversity measurements of the soft-bottom communities have remained within expected ranges over the 28 years of baseline and post-discharge monitoring. Community structures appear to be affected by sediment grain size and water depth rather than by proximity to the outfall.

Sediment-habitat measures, such as the redox potential discontinuity depth, a measure of how deeply oxygen penetrates into sediments, and a related organism sediment index have documented improvements in nearfield conditions over time rather than any adverse effects of the outfall.

Long-term analyses have now shown that weather and climate are the driving forces that shape the seafloor habitats and probably the water column as well (Figure v). Long-term trends in water temperatures and salinities may affect the species making up the seafloor communities. Severe winter storms with winds strong enough to resuspend and transport sediments can affect species compositions in the succeeding years. Severe winter storms have been increasingly common during recent years of the monitoring program, most likely a result of regional oscillations and long-term trends.

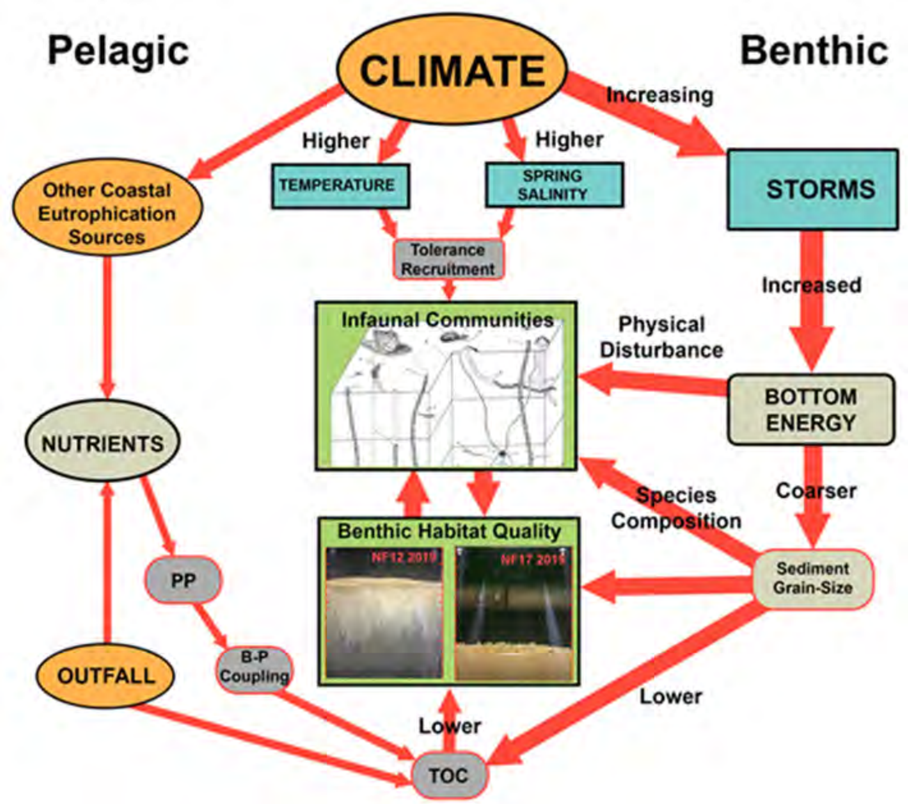

**Figure v. Storms and other climate-related factors continue to have the greatest effects on the habitats and communities in Massachusetts Bay, as indicated by the thickness of the arrows.**

Winter flounder remained healthy, without the widespread tumors and precancerous conditions that occurred in Boston Harbor in the 1980s and 1990s. MWRA monitoring has never detected tumors in fish taken from near the Massachusetts Bay outfall or tumors in fish from any location since 2004. Improvements in Boston Harbor flounder health began in the first years of the Boston Harbor cleanup, and incidence of cancer precursors has also declined at the Massachusetts Bay outfall site (Figure vi). The improvements correlate well with declines in total solids and organic-contaminant discharges. Improving winter flounder health in Boston Harbor without degrading it in Massachusetts Bay has been one of the most notable successes of MWRA's improvements to sewage treatment and relocation of the discharge.

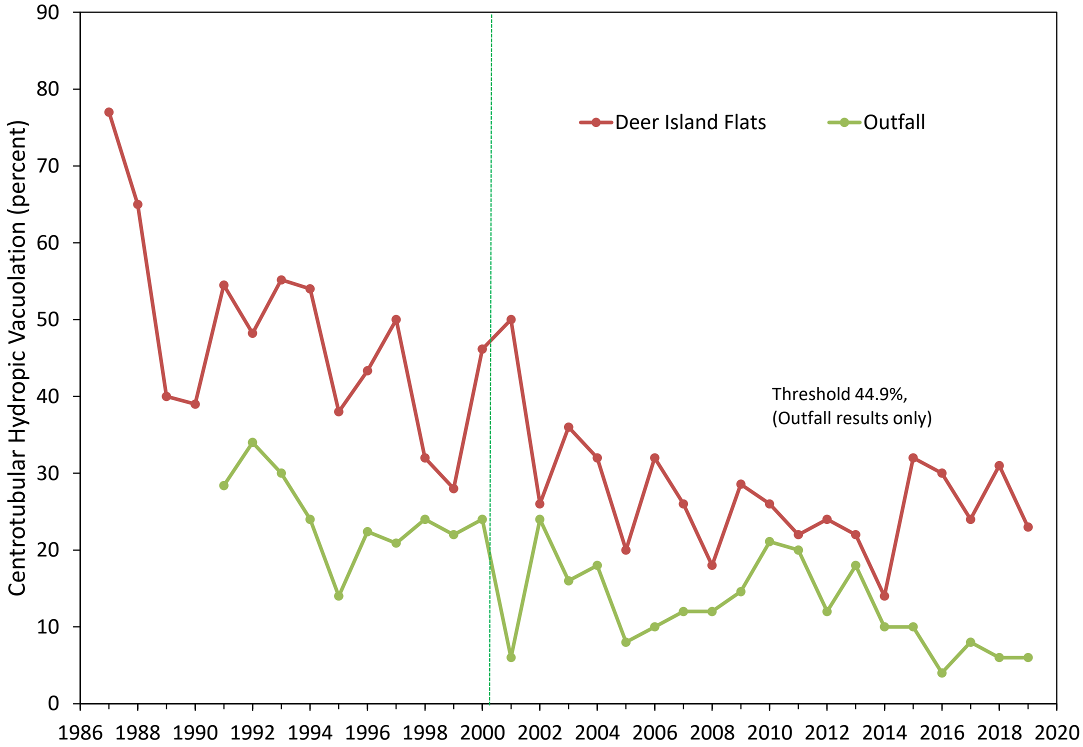

**Figure vi. Incidence of the tumor precursor centrotubular hydropic vacuolation in flounder from Deer Island Flats and the Massachusetts Bay outfall over time**. Incidence at the outfall has remained well below the Contingency Plan caution-level threshold of 44.9%.

Looking ahead, MWRA has worked with its regulators to identify parts of the monitoring program that, based on past results, could be reduced or ended. Some of these changes will be implemented in 2020 and 2021. Possible new additional monitoring questions addressing contaminants of emerging concern are also being considered. Recommendations for approaches to address these new questions will be issued in late 2020 or early 2021.

# 1. Introduction

For more than 35 years, the Massachusetts Water Resources Authority (MWRA) has worked to minimize adverse effects of municipal discharges on the marine environment. When MWRA was established in 1984, Boston Harbor was known as one of the dirtiest in the nation, largely due to discharges of both biosolids (also called sludge) and inadequately treated sewage effluent. MWRA's mission, dubbed the "Boston Harbor Project," was to clean up the harbor without causing new environmental harm. The project included reducing contaminants entering the wastewater through better management practices and pretreatment; ending biosolids discharges; rebuilding aged treatment facilities; and sending highly treated effluent not to the shallow, confined harbor, but to the deeper, more open waters of Massachusetts Bay.

During the 1990s, MWRA ended biosolids discharges, ended effluent discharges to the southern part of the harbor, and upgraded Deer Island Treatment Plant. In September 2000, the highly treated effluent discharge was diverted from the harbor to 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 the effluent before discharge and of the Massachusetts Bay waters, sediments, and marine life that could be affected. Monitoring assesses compliance with permit conditions and with a permit-required Contingency Plan, which was specifically designed to protect the environmental health of the bay. 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 long-term environmental monitoring in both Boston Harbor and Massachusetts Bay has documented the cleanup of the harbor, while ensuring that no environmental harm has come to the bay. This report, the annual outfall monitoring overview, as required by the discharge permit, summarizes annual monitoring results. This year's overview presents results from 2019, marking the twenty-eighth year of Massachusetts Bay monitoring and more than nineteen years of discharge from the deep-water outfall. The report presents information relevant to permit and Contingency Plan requirements in the effluent, water column, sea floor, and fish and shellfish; special studies conducted in response to permit conditions and environmental concerns; and recently approved changes to the monitoring plan.

# 2. Effluent

Deer Island Treatment Plant continued to operate as designed through 2019, earning MWRA the National Association of Clean Water Agencies (NACWA) Platinum 13 Peak Performance Award. This NACWA award recognizes facilities with 100% compliance with effluent permit limits over 13 consecutive years.

## 2019 Effluent Characterization

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 concentrations in the wastewater effluent. The Boston area received about 50 inches of rain in 2019, marking a second consecutive year with higher than average rainfall (Figure 2-1).

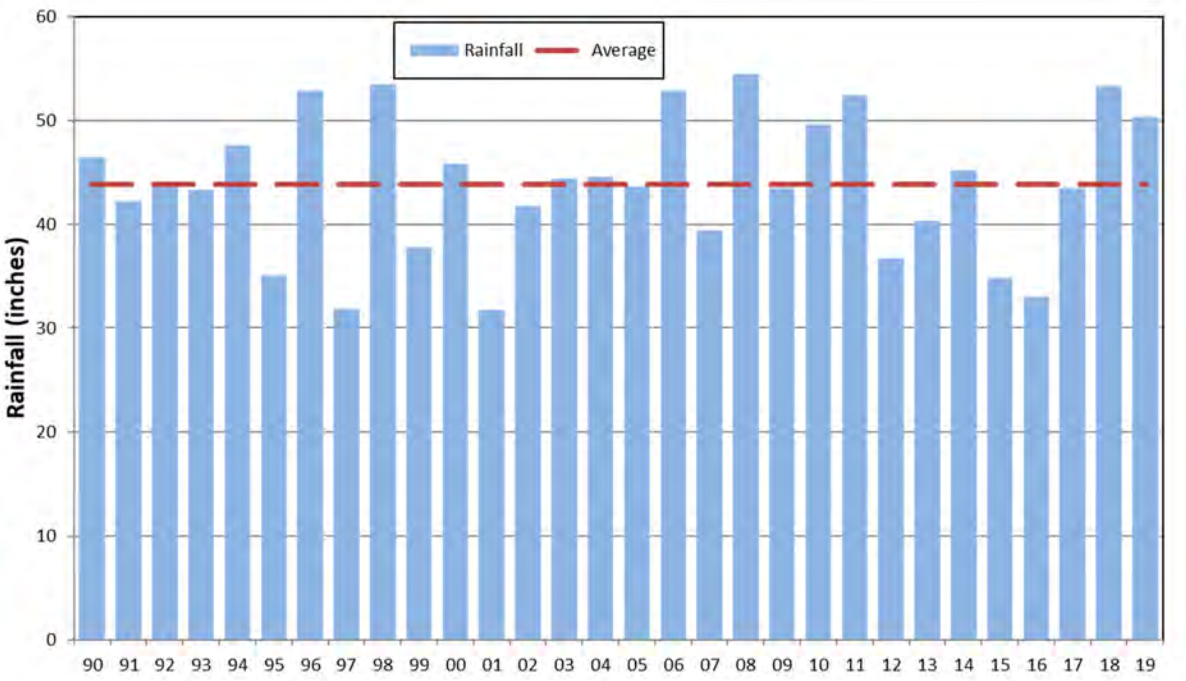

**Figure 2-1. Annual and average rainfall in Boston, 1990–2019.**

Despite the high rainfall, effluent flow in 2019 was slightly less than the 1998–2019 average, those years since all effluent flow was transferred to Deer Island (Figure 2-2). Virtually all the flow received full primary and secondary treatment, with only trace amounts of primary-treated effluent blended with fully treated effluent prior to discharge in months with particularly strong rainstorms (Figure 2-3).

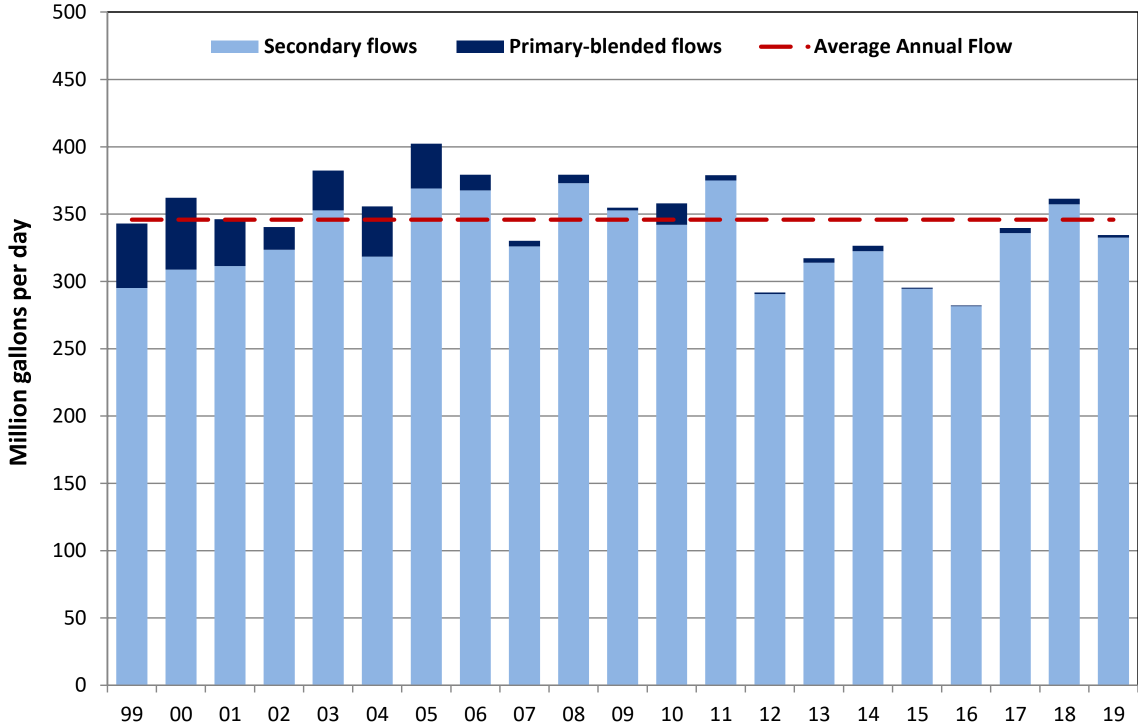

**Figure 2-2. Annual primary-blended and full secondary effluent flows and average annual flow, 1999–2019.** During large storms, flow exceeding the secondary capacity of the plant is diverted around the secondary process. Primary-treated flows are blended into secondary-treated flows before discharge.

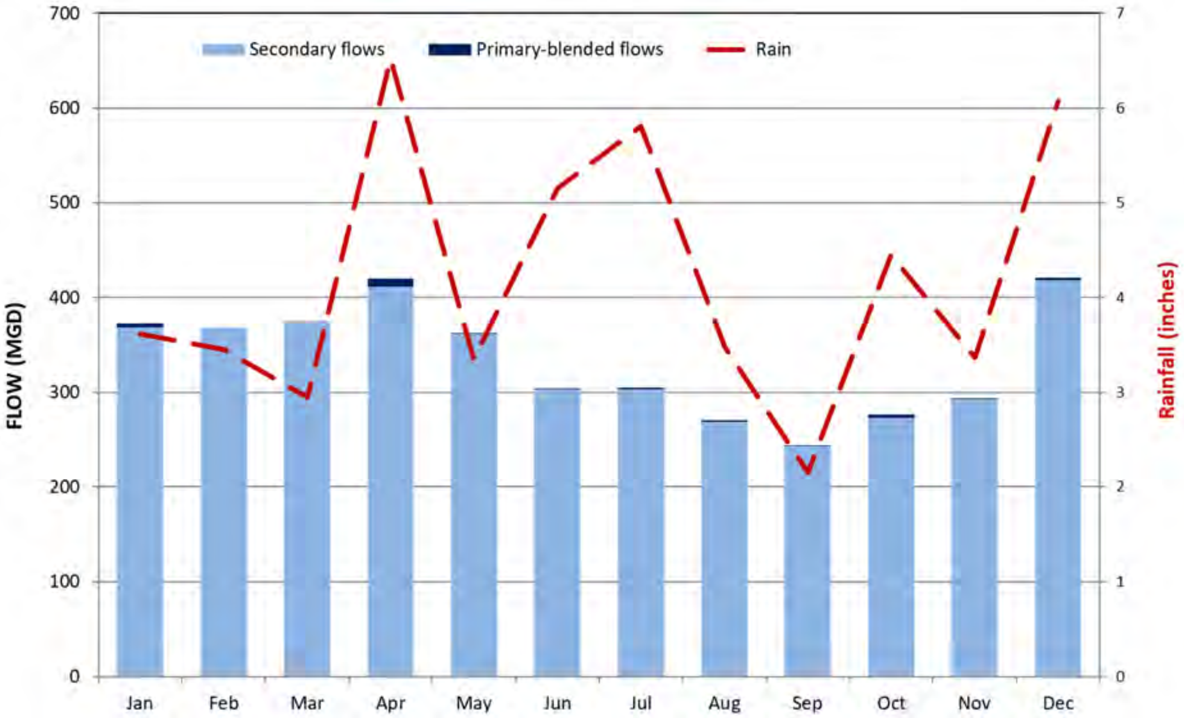

**Figure 2-3. Monthly primary-blended and full secondary flows and rainfall during 2019.**

In 2019, the total suspended solids load to Massachusetts Bay, about 17 tons per day, was similar to recent rainy years and well below the levels discharged into Boston Harbor before the outfall diversion to Massachusetts Bay in 2000 (Figure 2-4). In recent years, variability in the suspended solids load has corresponded to variability in rainfall and effluent flow. Carbonaceous biochemical 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.

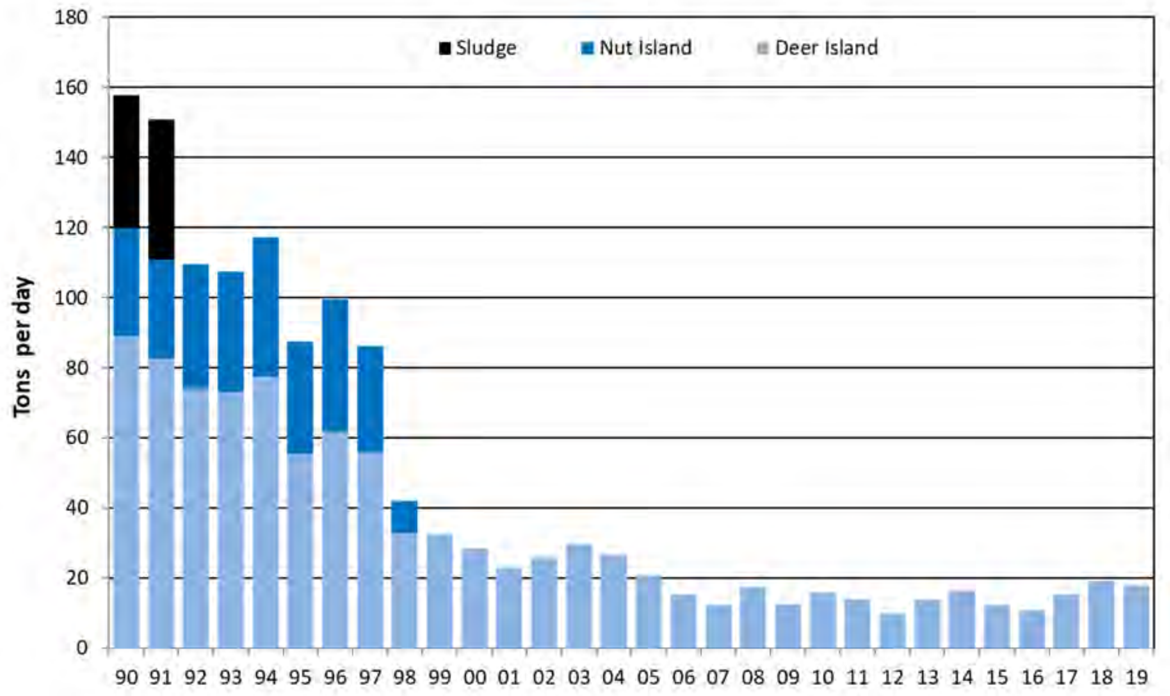

**Figure 2-4. Annual solids discharges, 1990–2019.** Before December 1991, biosolids (sludge) removed during treatment were disinfected and discharged into Boston Harbor. Ending biosolids disposal, ending effluent discharge to the southern portion of the harbor from Nut Island, implementing secondary 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 mostly be attributed to variation in flow.

Metals loads also remained low in 2019, with little evidence of increases associated with higher flow (Figure 2-5). Zinc continued to be the most abundant metal in the annual discharge, followed by copper. Both are present in water pipes and fixtures. Other notable sources of zinc to wastewater include commercial enterprises, such as beauty shops, automobile-repair shops, and hospitals; residential household products, such as shampoos, ointments, and laundry detergent; and street runoff (MWRA unpublished data).

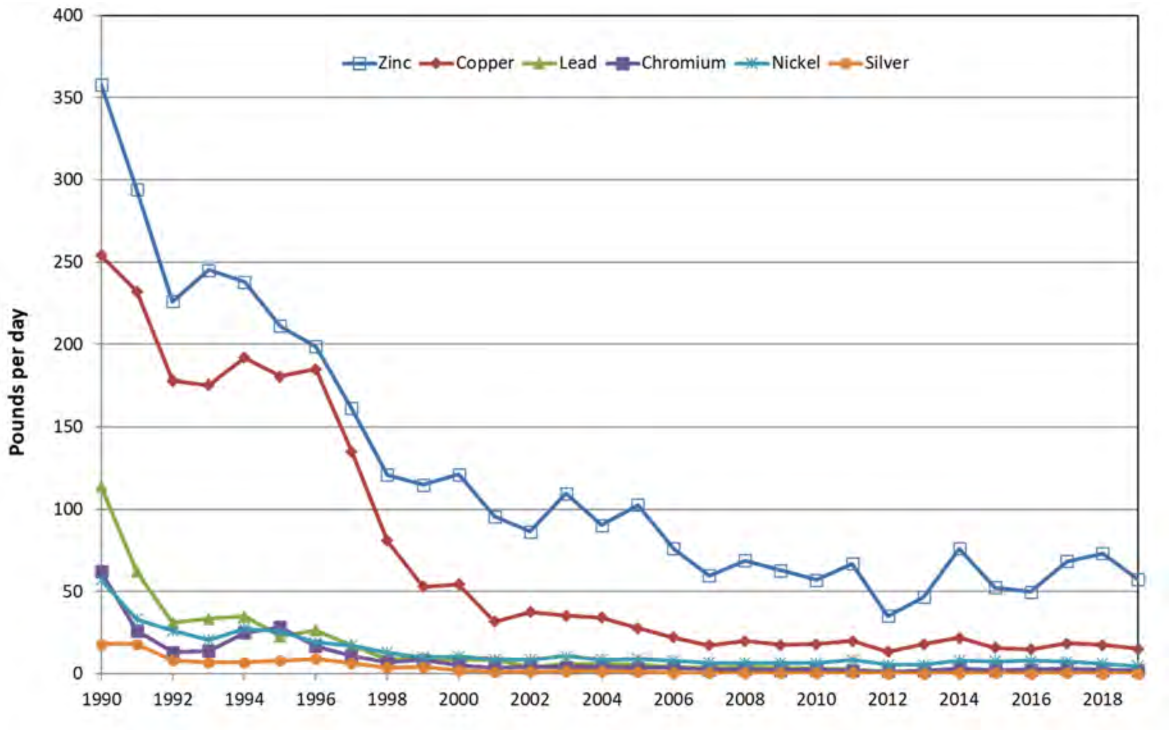

**Figure 2-5. Annual metals discharges, 1990–2019.**

Total loads of all metals remained small percentages of what had been anticipated during planning for the Massachusetts Bay outfall (Table 2-1). Except for copper, metals meet water quality standards prior to discharge, where initial dilution further reduces concentrations. Copper discharges meet the standard after initial dilution and have declined over time, a result of drinking-water corrosion control, which decreases leaching from water pipes, and other source-reduction efforts.

**Table 2-1. Projected and actual loads of metals 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) | 2019 Load (kg/year) | Percent Projected Load |
|---|---|---|---|
| Chromium | 3,517 | 310 | 8.8% |
| Copper | 11,945 | 2,493 | 21% |
| Lead | 4,961 | 267 | 5.4% |
| Mercury | 216 | 2.0 | 9.3% |
| Nickel | 8,926 | 775 | 8.6% |
| Silver | 290 | 20 | 6.9% |

SEIS = Supplemental Environmental Impact Statement (EPA 1988)

Polycyclic aromatic hydrocarbon (PAH) and other organic contaminant loads were also low and only a small fraction of what had been anticipated during planning for the outfall, 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. For some compounds, such as 4,4'-DDE, a breakdown product of the pesticide DDT, there is some evidence of the very slow declines anticipated after those persistent substances were banned (Figure 2-6).

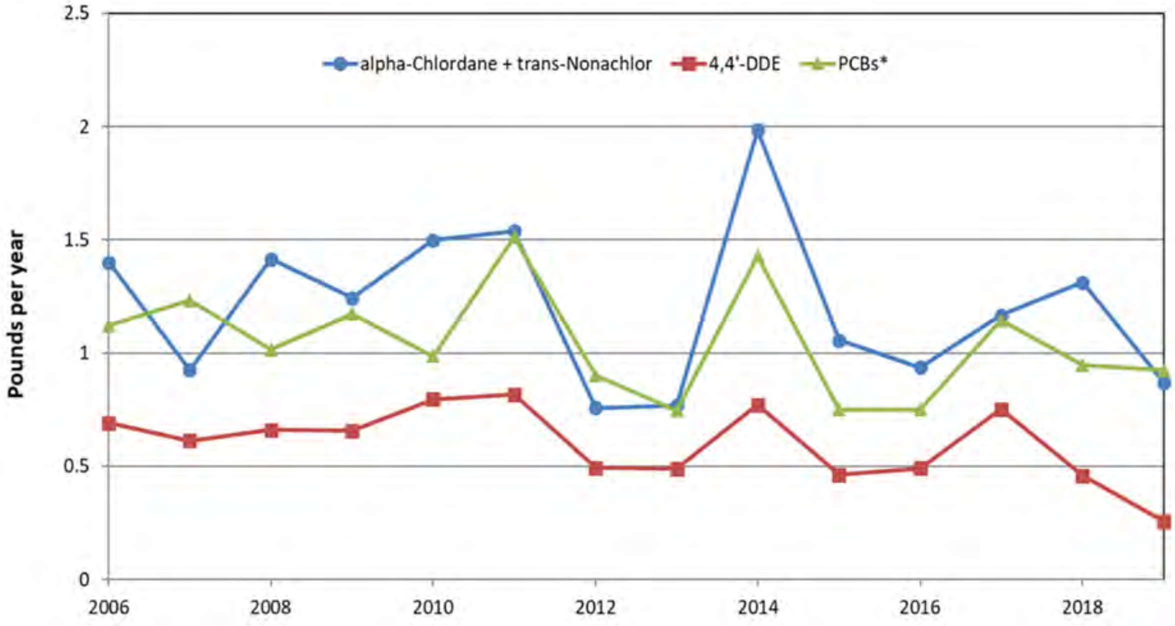

**Figure 2-6. Annual discharges of organochlorine compounds, 2006–2019.**

The total nitrogen load for 2019 was 13,217 metric tons, below the Contingency Plan warning-level threshold, 14,000 metric tons per year, but exceeding the caution-level threshold of 12,500 metric tons, set at about 90% of the warning level.
See Figure 2-7 and further discussion, below.

## Contingency Plan Thresholds

There were no permit violations in 2019, but the 2019 nitrogen load exceeded the Contingency Plan caution-level threshold (Table 2-2). Effluent threshold exceedances based on permit conditions have been rare, and none have occurred in the past 13 years. The Deer Island NPDES permit does not include an effluent limit for nitrogen, so that threshold exceedance did not represent a permit violation.

**Table 2-2. Contingency Plan threshold values and 2019 results for effluent monitoring.**

| Parameter | Baseline | Caution Level | Warning Level | 2019 Results |
|---|---|---|---|---|
| **Permit Conditions Thresholds** | | | | |
| 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,<br>>456 µg/L monthly | Not exceeded |
| Suspended solids | NA | None | >45 mg/L weekly<br>>30 mg/L monthly | Not exceeded |
| cBOD | NA | None | >40 mg/L weekly,<br>>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 |
| Oil and grease | NA | None | >15 mg/L weekly | Not exceeded |
| **Contingency Plan Thresholds** | | | | |
| Total nitrogen load | NA | >12,500 mtons/year | >14,000 mtons/year | 13,217 mtons/year caution level exceedance |

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
MGD = million gallons per day

Total effluent nitrogen loads reflect variability in nitrogen levels in the influent reaching Deer Island, with about 30% of the nitrogen removed during treatment (compared to 10–15% removal predicted at the start of the Boston Harbor Project). Total nitrogen loads have increased modestly since the Massachusetts Bay outfall began to discharge, most likely due to population increases in the MWRA service area (Figure 2-7). MWRA's sewered population in 2019 was about 6% higher than the population projections for 2020 that were used to develop the thresholds.

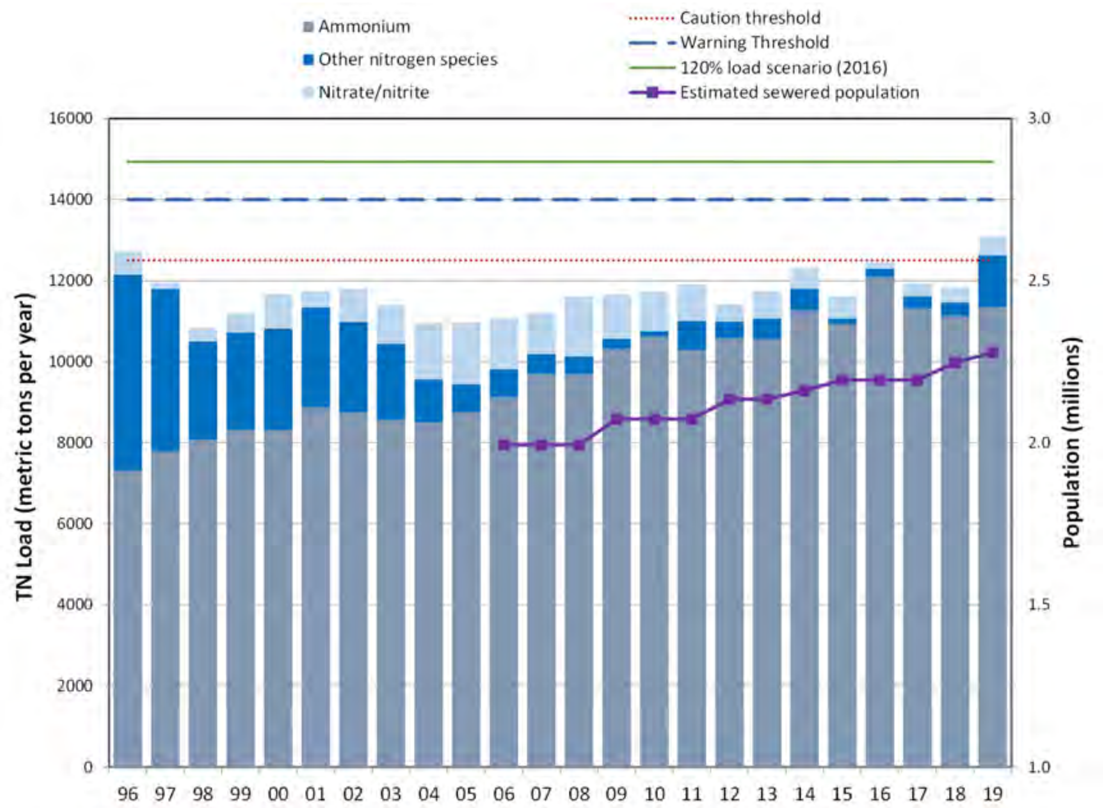

**Figure 2-7. Annual nitrogen discharges, 1996–2019, and estimated population of the MWRA service area, 2006–2019.** During outfall planning, experts estimated that discharges would total 14,000 metric tons per year by 2020. The warning threshold was set at that level, and the caution level was set at about 90% of that projected load. A water-quality model simulation using 120% of the 2016 discharge (green line) projected negligible environmental effect.

Interestingly, much of the nitrogen increase in 2019 was due to an increase in what is known as "other nitrogen species," or organic nitrogen, rather than ammonium and nitrate/nitrite, the forms of nitrogen most readily used by phytoplankton. Evaluation of the 2019 results does not suggest any analytical error or change in treatment processes that would explain the results.

The exceedance did not result in any observed unexpected or adverse environmental effects due to nitrogen discharge into Massachusetts Bay, such as increased phytoplankton biomass or decreased dissolved oxygen levels. Water-quality modeling has suggested that even large increases to the nitrogen discharge would have no adverse effect on the environment.

Each year, MWRA assesses alternatives for nitrogen-removal technologies, should they be required in the future (see, for example Ellis-Hibbett 2020). About 13 acres of land on Deer Island have been identified as potentially available for possible nitrogen-removal facilities, although alternatives to treatment at Deer Island could be employed, such as treating the return flow from the pelletizing plant where biosolids are converted to fertilizer. These returns account for only about 1% of the total flow but about 10% of the total nitrogen load.

# 3. Water Column

Water-column monitoring evaluates relevant physical oceanographic processes, water quality, and phytoplankton and zooplankton communities at stations in Massachusetts Bay, at the mouth of Boston Harbor, and in Cape Cod Bay (Figure 3-1). Ship-based field surveys are augmented by measurements from instrumented buoys and satellite imagery.

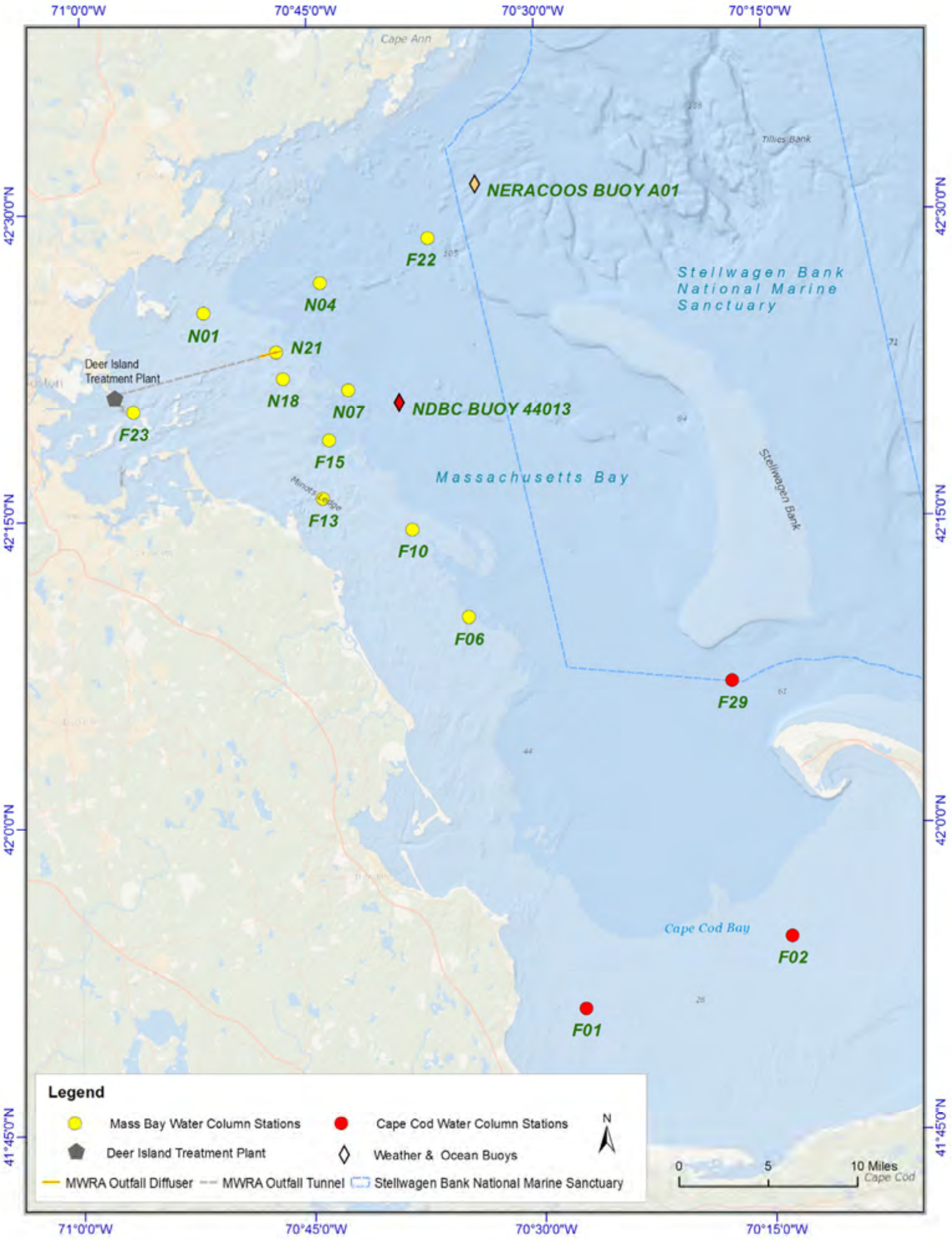

**Figure 3-1. Water-column monitoring stations and instrumented buoys in Massachusetts and Cape Cod bays.**

Nine regular surveys were conducted in February–October 2019.  Five stations are 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 nine are in the farfield, including stations at the mouth of Boston Harbor, in Cape Cod Bay, and near the Stellwagen Bank National Marine Sanctuary.  Seven additional surveys were conducted during May–July, triggered by elevated abundance of the toxic dinoflagellate *Alexandrium catenella*.  These *Alexandrium* Rapid-Response Study surveys (Libby et al. 2013) provided in situ hydrographic data and water samples for measuring dissolved oxygen, inorganic nutrients, and *Alexandrium* abundance from up to 19 stations, including all MWRA water-column stations except Station N21.  Data from another set of ten stations in Boston Harbor, sampled as part of MWRA's harbor water-quality monitoring were included in analyses when sampling dates were within a few days of the outfall-monitoring surveys.

The program continued to benefit from collaboration with the Center for Coastal Studies at Provincetown, Massachusetts, which conducts an independent monitoring program in Cape Cod Bay and, as part of the MWRA 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 within 48 hours of the Massachusetts Bay sampling.  All 2019 surveys were completed within that target.

As in past years, the field monitoring program was supplemented 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 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.

As in 2018, the Boston area experienced heavier than average rainfall in 2019 (see Figure 2-1 in Section 2, Effluent), with higher than average flow from both the Merrimack and Charles rivers during much of the year (Figure 3-2, Libby et al. 2020).  The spring freshet, the high flow during snow melt, from the Merrimack River was especially strong, cresting in April with flows greater than 1,000 cubic meters per second.  As a result, relatively low surface-water salinities were measured in the nearfield throughout the spring and summer, one factor that can contribute to lower bottom-water oxygen levels.

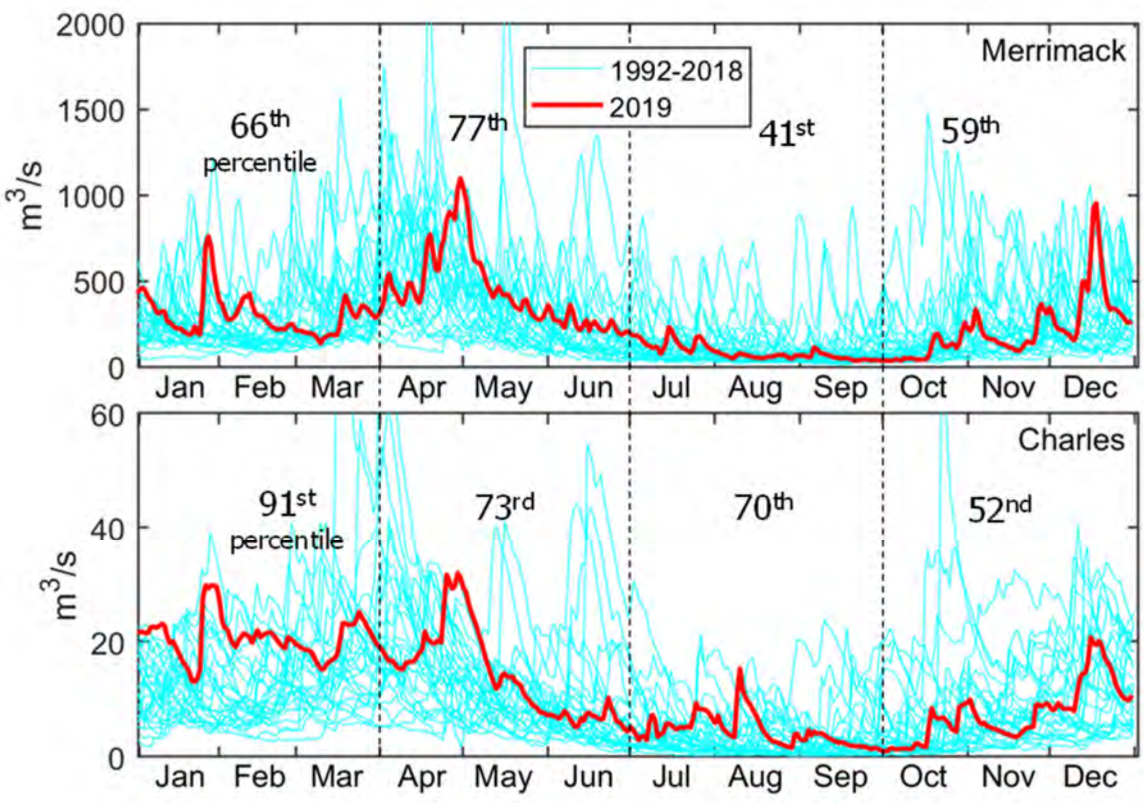

**Figure 3-2. Flows of the Merrimack (top) and Charles (bottom) rivers.** Note differences in scales. Dark red lines are 2019 data. Results from 1992–2018 are in light blue. The quarterly percentiles represent the 2019 flows in comparison to the entire 28-year record.

Warm water temperatures can also contribute to lower dissolved oxygen levels. Surface-water temperatures, important influences on water quality and measured continuously at the NDBC Buoy, were average at the beginning of the year, but especially warm during the summer, reaching a record 22˚ Celsius at the end of July and remaining high through the end of the year (Figure 3-3). Since 1990, both air and surface-water temperatures have increased at the NDBC Buoy, but water temperatures have risen more quickly, suggesting the increases were caused by a change in regional water circulation in the Gulf of Maine (Figure 3-4).

A May 15 storm with winds from the northeast created ideal conditions to transport cells of the nuisance algal species *Alexandrium catenella* from the western Gulf of Maine into Massachusetts Bay (see further discussion below). The autumn was also stormy, with greater than six-meter waves during one storm in early December.

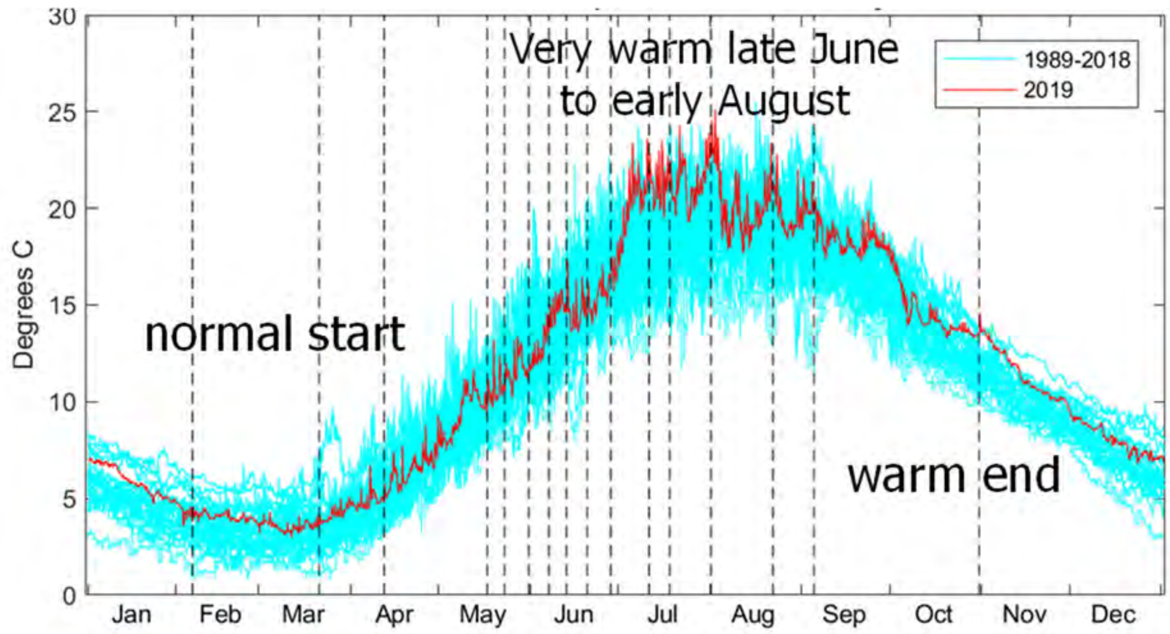

**Figure 3-3. Surface-water temperature at the NDBC Buoy in 2019 compared to prior years**. Vertical dashed lines denote timing of the MWRA surveys.

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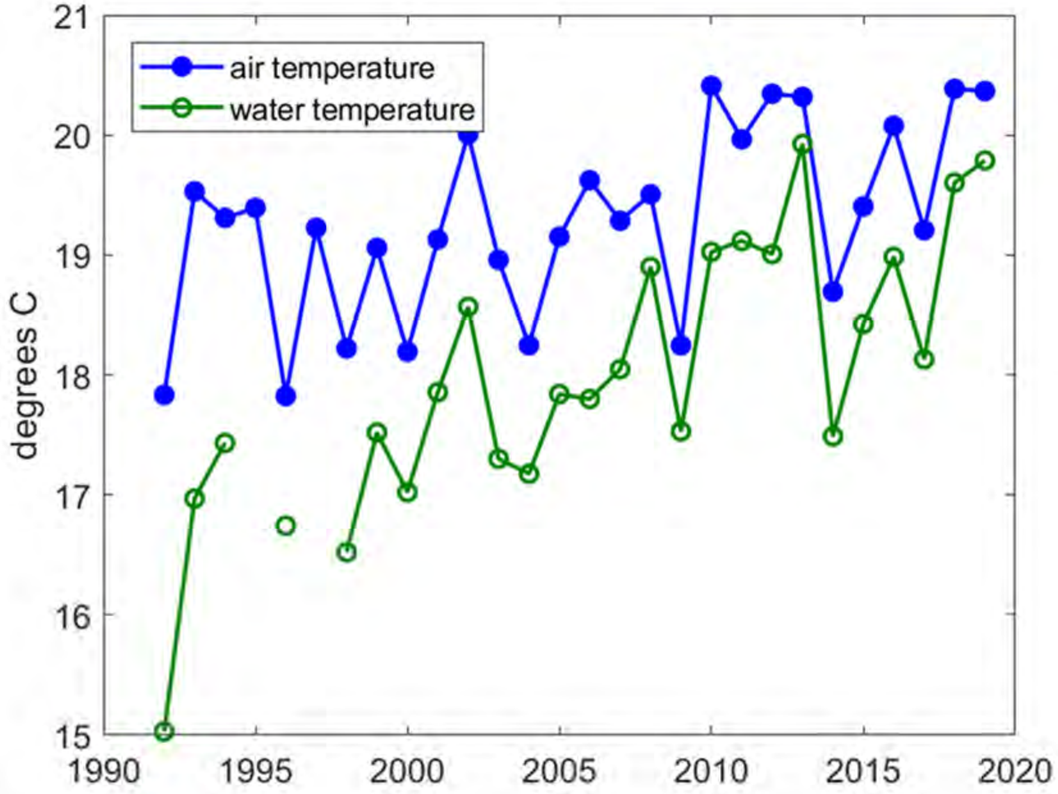

**Figure 3-4. Annual average mid-June through mid-August air and surface-water temperatures at the NDBC Buoy, 1992–2019.** Water temperatures in 1995 were omitted due to data gaps.

Spring and summer stratification of the Massachusetts Bay water column into distinct shallow and deep layers was more intense than average (Figure 3-5). In spring 2019, the high river flows and resulting low surface-water salinity promoted especially strong early stratification. The record warm summer surface-water temperatures contributed to a second peak, which persisted into September. Buoy data (not shown) indicated that the water column did not become well mixed in deeper offshore waters until mid-November.

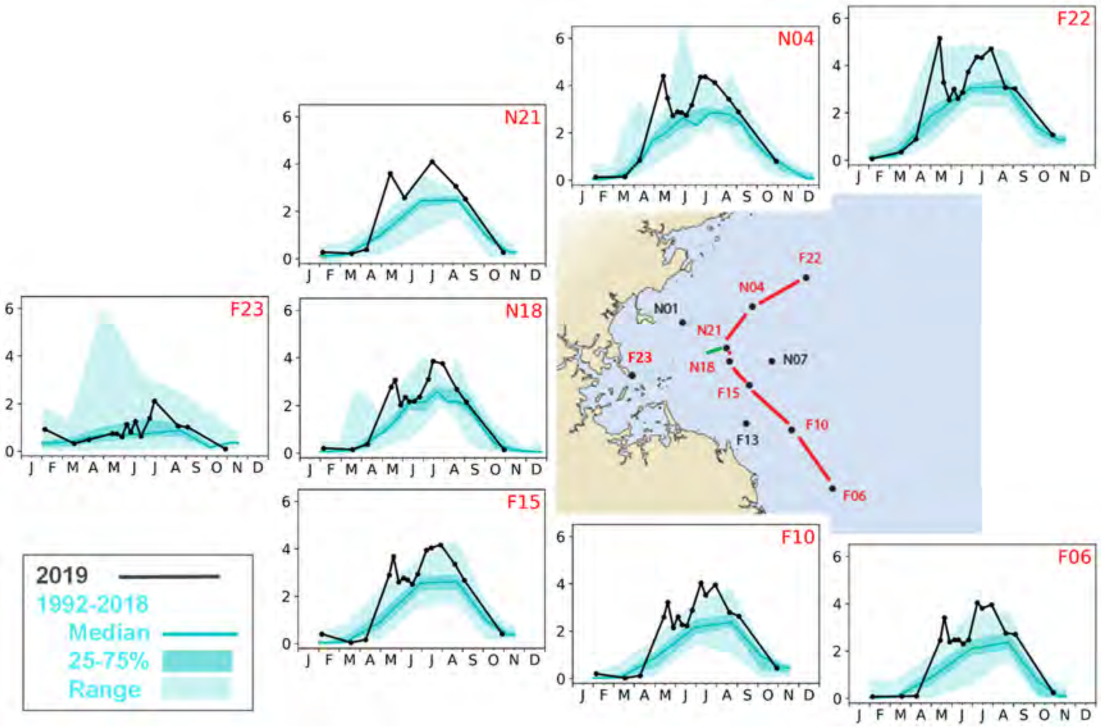

**Figure 3-5. Stratification at selected stations 2019 compared to prior years.** The black points and lines are results from 2019; the blue lines and shading are results from 1992–2018: the line is the 50th percentile, dark shading spans the 25–75th percentiles, and the light shading spans the range.

## Water Quality

Water quality measurements for 2019 included quantification of nutrients, phytoplankton biomass, and dissolved oxygen. Results continued to confirm predictions of measurable outfall influence in some parameters, but only at stations very near the outfall. There were no unexpected or environmentally adverse findings (Libby et al. 2020).

### Nutrients

Dissolved inorganic nutrient concentrations (nitrogen, phosphorus, and silica) in the nearfield stayed mostly within the ranges measured in previous years. Nitrogen is the most important nutrient affecting phytoplankton growth in Massachusetts Bay. Ammonium is the largest fraction of the total nitrogen in wastewater (see Figure 2-6, above), making it a good effluent tracer.

The 2019 outfall ammonium signature was typical of the years since the discharge relocation (Figure 3-6). As in other years since the outfall began to discharge in September 2000, episodic peaks in ammonium concentrations were detected at Station N21, located just 60 meters from the outfall; at Station N18, 2.5 kilometers to the south; and during some surveys, at Station F15, nine kilometers to the southeast. Ammonium concentrations were consistently low at Station F23 at the mouth of Boston Harbor, at other Massachusetts Bay stations, and in Cape Cod Bay. Concentrations at Station F23 remained well below those measured when wastewater was discharged into Boston Harbor.

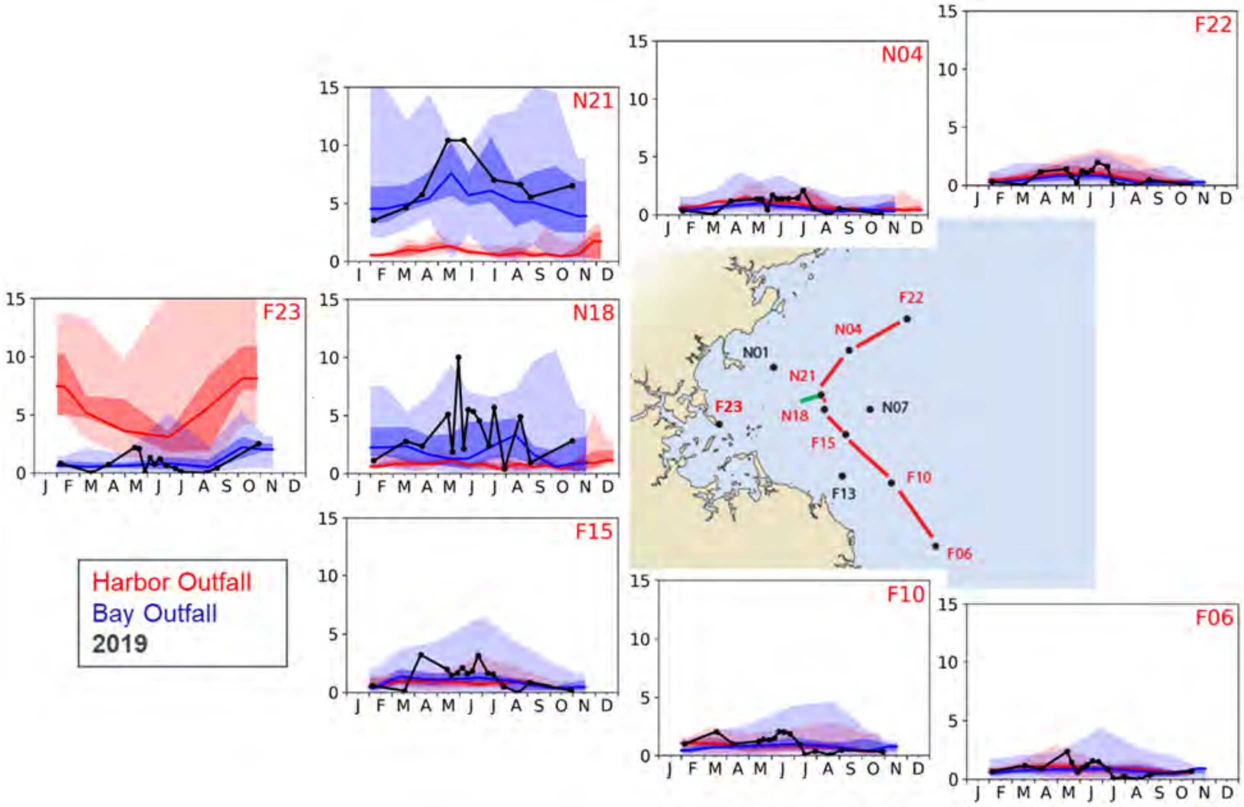

**Figure 3-6. Station average ammonium concentrations at selected stations in 2019 compared to prior years.** Black points and lines are results from individual surveys in 2019. Red lines and shading show data from Boston Harbor discharge years (1992–September 2000). Results from Massachusetts Bay discharge years (September 2000–2018) are in blue. Line is the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range.

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As predicted by numeric model runs in the 1990s and observed each year of monitoring, the effluent plume's ammonium signature was evident in surface waters during the winter and spring when the water column was relatively well-mixed (Figure 3-7). The plume was confined beneath the pycnocline and below depths of maximum phytoplankton growth during the summer, stratified season (Figure 3-8). The distances where the ammonium signature could be detected during both stratified and unstratified seasons remained consistent with predictions made during planning for the outfall. (See Section 6, Special Studies, for additional analysis of nutrient inputs and the detectable signatures during 2011–2019.)

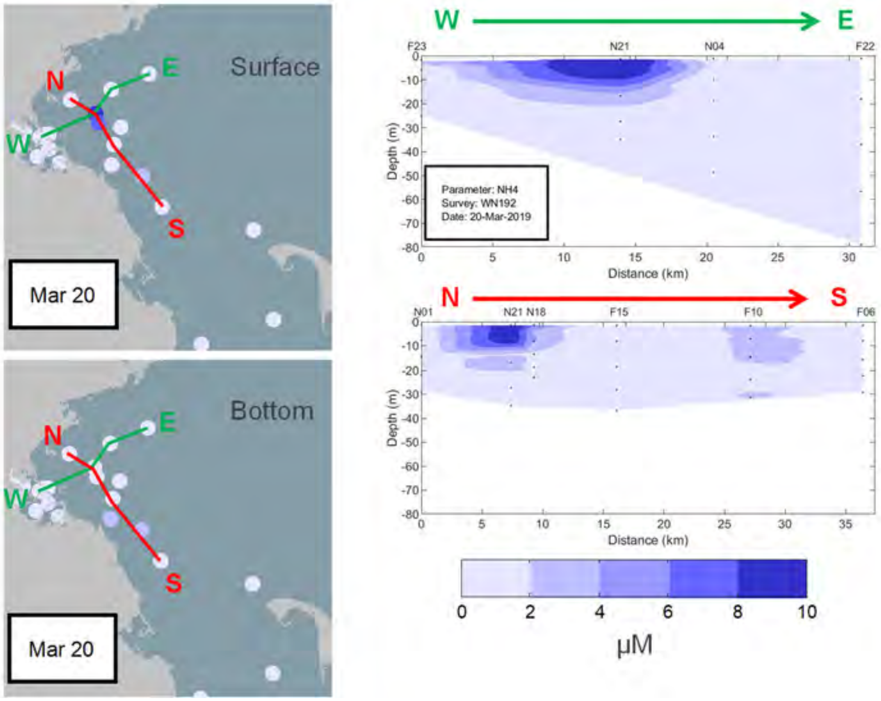

**Figure 3-7. (Left) Surface- and bottom-water ammonium at selected stations on March 20, 2019, during mixed conditions. (Right) Cross-sections of concentrations throughout the water column along transects connecting selected stations.** Station N21 is directly over the outfall.

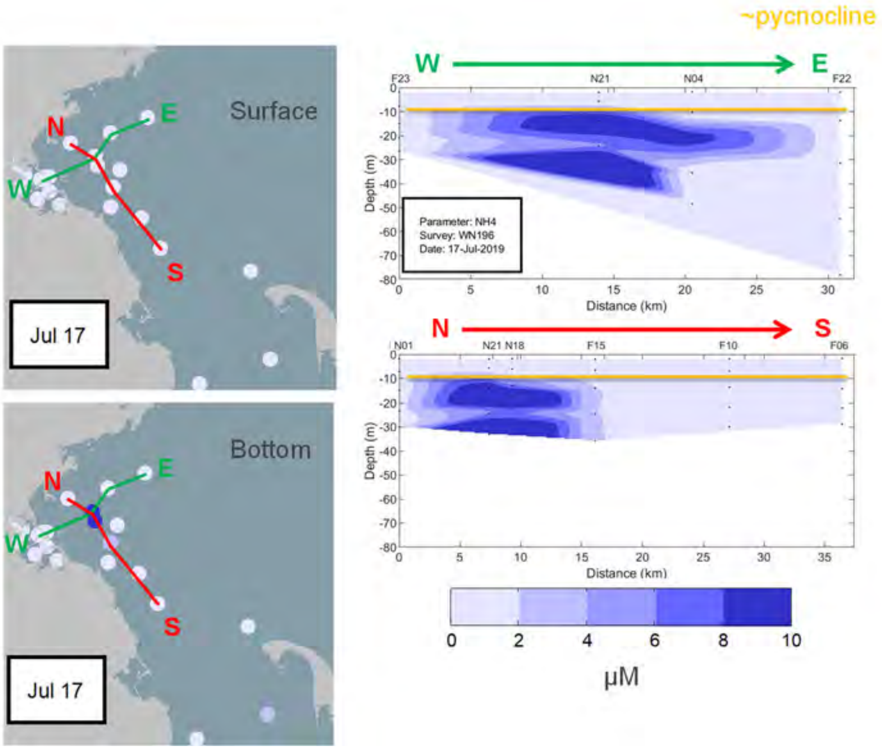

**Figure 3-8. (Left) Surface- and bottom-water ammonium at selected stations on July 17, 2019, during stratified conditions. (Right) Cross-sections of concentrations throughout the water column along transects connecting selected stations.**

## Phytoplankton Biomass

Despite the ammonium concentration increases that have been observed since the outfall began to discharge, no increases in phytoplankton biomass (measured as chlorophyll and particulate organic carbon), have been detected, even at stations closest to the outfall, and none were measured in 2019 (Figure 3-9). Regionally, elevated chlorophyll levels occurred offshore and in Cape Cod Bay in February, followed by an increase in Massachusetts Bay in April and May. As in previous years, diatoms (*Guinardia delicatula* and *Thalassiosira* spp. in 2019) were responsible for the spring blooms. Chlorophyll concentrations were variable during the summer and then increased at all stations in September, with a bloom of the dinoflagellate *Karenia mikimotoi*. The September *Karenia* bloom was especially prominent at Station F23 just offshore from Boston Harbor. (See further discussion of the *Karenia* bloom below.)

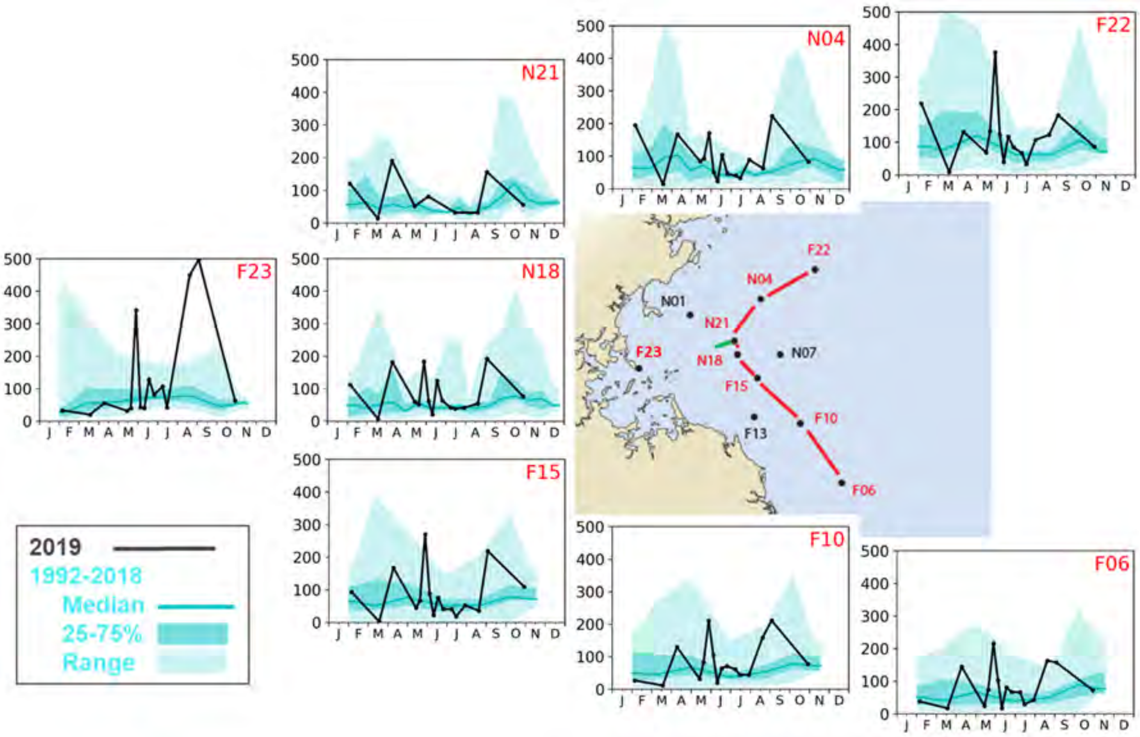

**Figure 3-9. Station average areal chlorophyll concentrations at selected stations in 2019 compared to prior years.** (For some stations, historic data extend later in the year than the current survey schedule.) The black points and lines are results from 2019; the blue lines and shading are results from 1992–2018: the line is the 50th percentile, dark shading spans the 25–75th percentiles, and the light shading spans the range.

## Dissolved Oxygen

Massachusetts Bay bottom-water dissolved oxygen concentrations began the year close to the historic medians for February and March (Figure 3-10). Levels declined and were lower than average in May and June, a result of the strong water-column stratification. Mixing in July re-aerated bottom waters throughout the region, and oxygen concentrations remained typical of the historic record throughout the late summer and early fall. The usual fall overturn and return to oxygenated waters was somewhat delayed in 2019, but measurements from the instrumented buoys indicated that the minima were moderate, typical for the monitoring program. (Data from the NERACOOS buoy are presented in Figure 3-18 on page 26.)

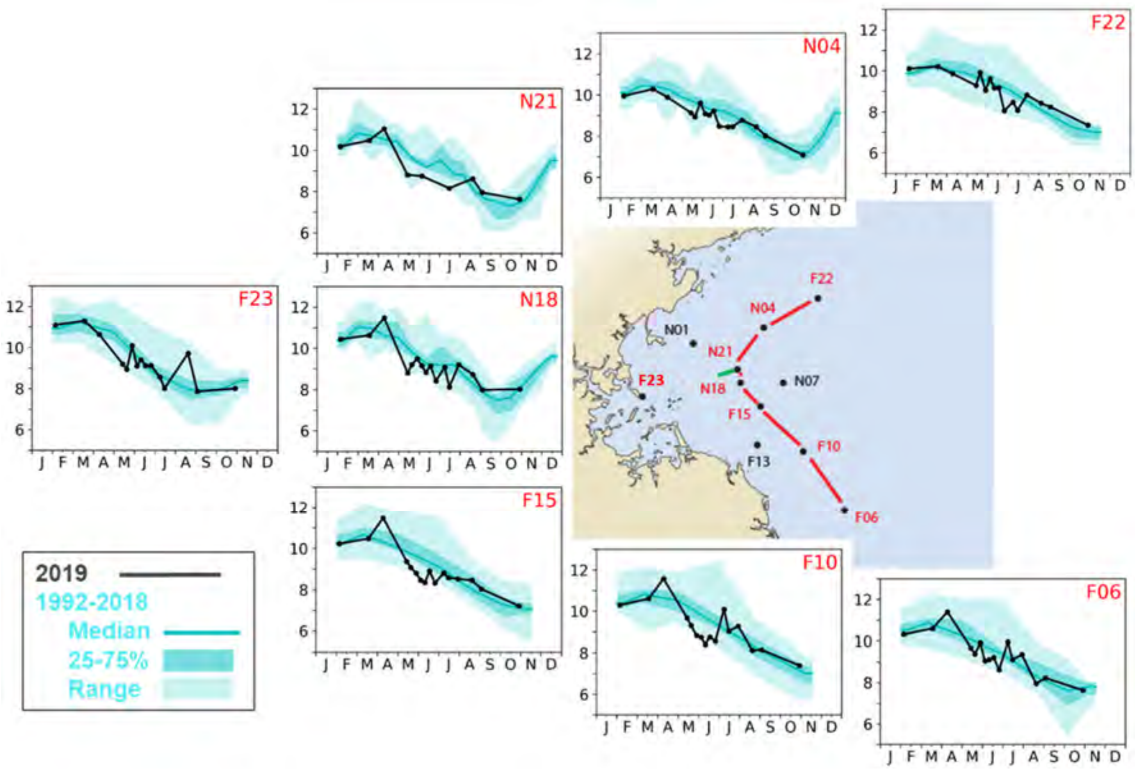

**Figure 3-10. Near-bottom water dissolved oxygen concentrations (milligrams per liter) in 2019 compared to prior years.** (For some stations, historic data extend later in the year than the current survey schedule.) The black points and lines are results from 2019; the blue lines and shading are results from 1992–2018: the line is the 50th percentile, dark shading spans the 25–75th percentiles, and the light shading spans the range.

Cape Cod Bay stations exhibited similar patterns in dissolved oxygen concentrations during most of the year, with an early decline due to strong stratification and then a recovery in July. However, levels fell steeply in late August and early September, reaching 4–5 milligrams per liter at MWRA stations sampled by the Center for Coastal Studies (Figure 3-11). Even lower concentrations were found by other researchers in shallow, southern coastal waters, leading to lobster and crab deaths. This hypoxia event in coastal Cape Cod Bay waters is further discussed in Section 6, Special Studies.

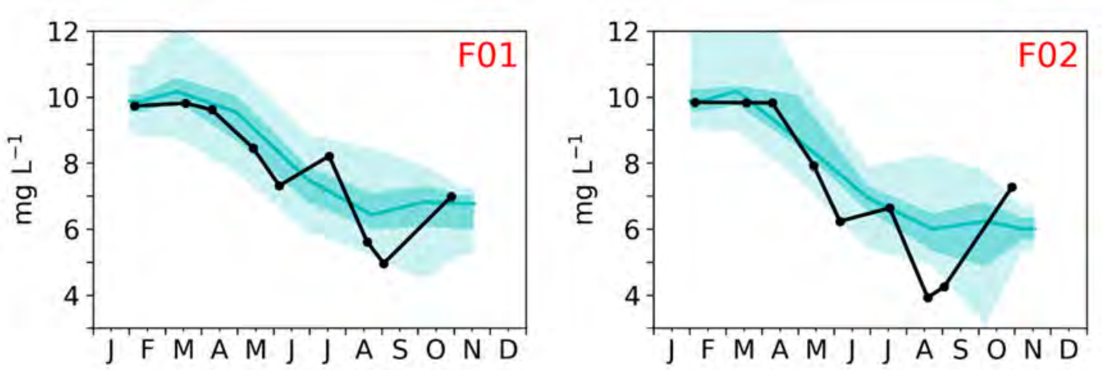

**Figure 3-11. Near-bottom water dissolved oxygen concentrations (milligrams per liter) at Cape Cod Bay stations in 2019 compared to prior years.** The black points and lines are results from 2019; the blue lines and shading are results from 1992–2018: the line is the 50th percentile, dark shading spans the 25–75th percentiles, and the light shading spans the range.

## Phytoplankton Communities

As in recent years, 2019 total phytoplankton abundances remained somewhat low throughout Massachusetts Bay (Figure 3-12, Libby et al. 2020). In the nearfield, overall abundance was 61% of the long-term mean, ranking 23rd out of 28 years of monitoring. The relatively low abundance can be partially explained by a lack of a large winter-spring diatom bloom during the survey season and by the continued absence of a bloom of the nuisance colonial flagellate *Phaeocystis pouchetii* in Massachusetts Bay which has occurred in many years.

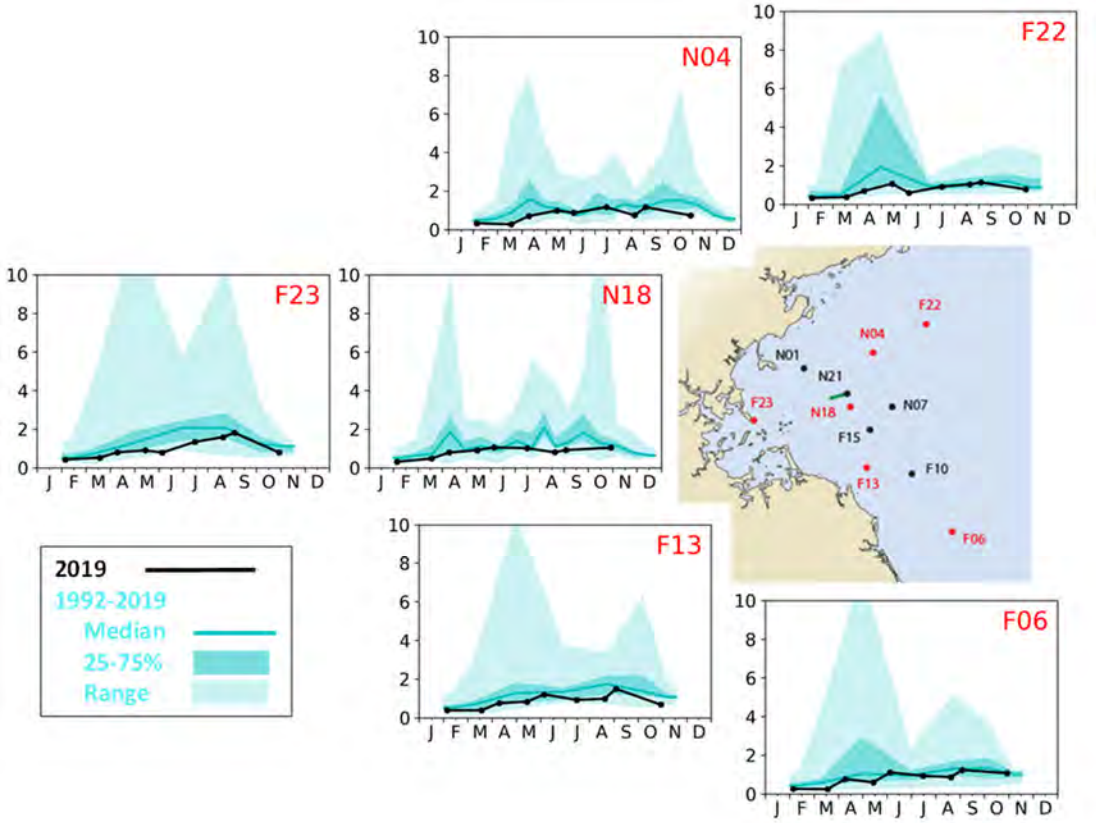

**Figure 3-12. Total phytoplankton abundance (million cells per liter) at selected stations in 2019 compared to prior years**. (For some stations, historic data extend later in the year than the current survey schedule.) The black points and lines are results from 2019; the blue lines and shading are results from 1992–2018: the line is the 50th percentile, dark shading spans the 25–75th percentiles, and the light shading spans the range.

Diatom abundance was low, with centric diatom totals ranking 23rd of 28 years. Centric diatom abundance has been below the long-term mean since 2006. Microflagellates continued to be the most abundant species group, comprising about 60% of the total phytoplankton counts, but were present at only 77% of their long-term average, another factor in the low overall phytoplankton abundance.

Conversely, dinoflagellate abundance increased substantially in comparison to 2018, and 2019 abundance ranked third out of the 28 years of monitoring (Figure 3-13). The late summer and fall bloom of the dinoflagellate *Karenia mikimotoi* was largely responsible for this overall increase. This species has been reported in New England to the Gulf of Saint Lawrence region for many years (Blasco et al. 1996). It was not observed in MWRA samples until 2017, when it had a maximum abundance of about 300,000 cells per liter, and it was present again in 2018, but in lower numbers. In September 2019, *Karenia mikimotoi* abundance reached a maximum of 850,000 cells per liter at Station F23 at the mouth of Boston Harbor and briefly discolored the water within the harbor. Its presence in southern Cape Cod Bay may have contributed to the hypoxia event further discussed in Section 6, Special Studies. Although its toxicity is not well understood, anoxia and benthic mortalities have been associated with this species in other locations.

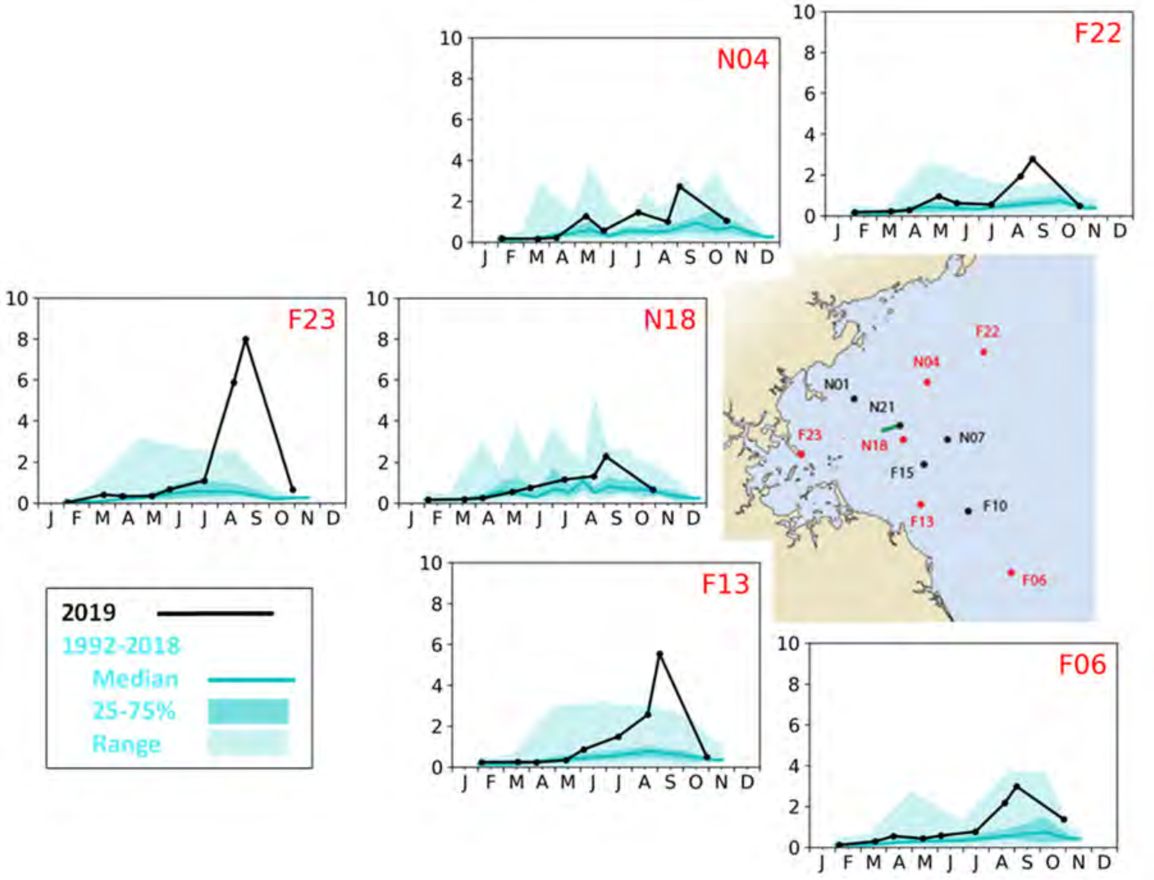

**Figure 3-13. Total dinoflagellate abundance (100,000 cells per liter) at selected stations in 2019 compared to prior years**. (For some stations, historic data extend later in the year than the current survey schedule.) The black points and lines are results from 2019; the blue lines and shading are results from 1992–2018: the line is the 50th percentile, dark shading spans the 25–75th percentiles, and the light shading spans the range.

A large and prolonged bloom of the toxic dinoflagellate *Alexandrium catenella* prompted a series of seven rapid-response surveys over two months in 2019 (Figure 3-14). The 2019 bloom was comparable in magnitude and duration to blooms in 2005 and 2008. Large *Alexandrium catenella* blooms can cause paralytic shellfish poisoning (PSP), a life-threatening condition for marine mammals and humans who consume shellfish. *Alexandrium* blooms in Massachusetts Bay, when they have occurred, have originated from cells from established cyst beds off the coast of Maine. The cells typically enter Massachusetts Bay when winds from the northeast push water masses from coastal Gulf of Maine waters into the bay, conditions that occurred in the spring of 2019.

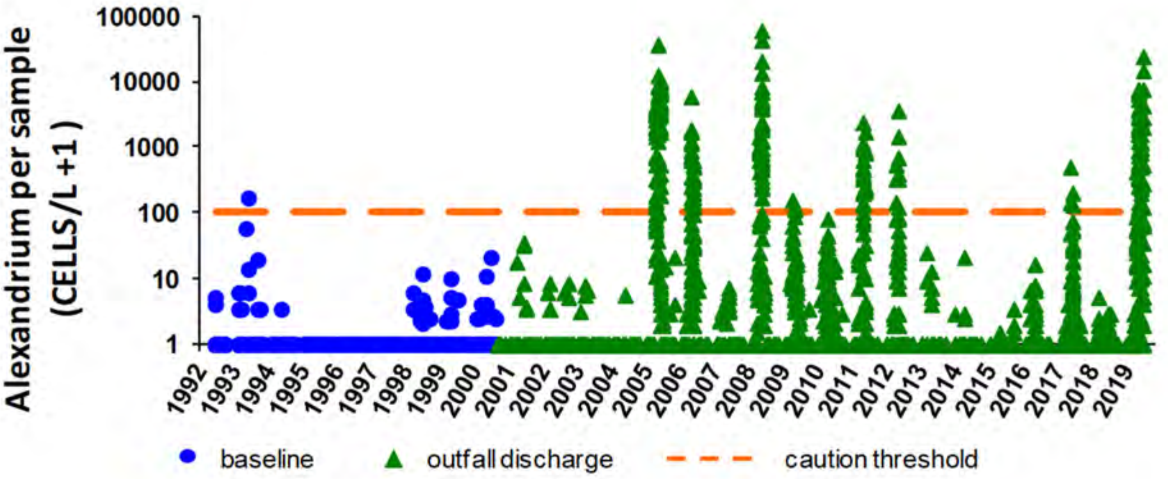

**Figure 3-14. Nearfield abundance of *Alexandrium catenella*, 1992–2019.** Note log scale.

The timing and north-to-south progression of the bloom was typical for Massachusetts Bay (Figure 3-15). Very low abundances were detected during the April MWRA survey, and in early May, there were indications that a bloom was underway in the Gulf of Maine. During the May 16 survey, MWRA detected *Alexandrium* cells at all ten stations sampled, with a maximum level greater than 100 cells per liter at the northeast offshore Station F22, sufficient to trigger weekly rapid-response surveys. From May 30 through July 17, high cell counts, greater than 5,000 and reaching a maximum of 24,000 cells per liter, were observed at the 19 stations sampled. By July 31, counts had decreased to fewer than 100 cells per liter, and the rapid-response surveys were curtailed.

Progression of PSP toxicity associated with the bloom was also typical, appearing first in the north. On May 9, the New Hampshire Department of Environmental Services detected a large increase in PSP toxicity in their state waters. PSP toxicity remained undetected or low in Massachusetts Bay until June 18, when the Massachusetts Department of Fisheries closed shellfishing from Boston to Plymouth. When the peak cell count for the bloom occurred in a July 17 offshore sample, PSP toxicity in the coastal areas had already declined, and the Massachusetts shellfishing closure was lifted on July 19.

Modeling carried out by the federal National Centers for Coastal Ocean Science suggests that the strong stratification in 2019, a result of spring freshwater inflow and warm surface waters, and the region-wide availability of nutrients at the pycnocline were key factors in determining the magnitude and duration of the bloom. In August, the Woods Hole Oceanographic Institution detected *Alexandrium* cysts in Massachusetts Bay, a potential concern for 2020. (A modest *Alexandrium* bloom did occur in 2020 but did not result in shellfishing closures or a Contingency Plan exceedance.)

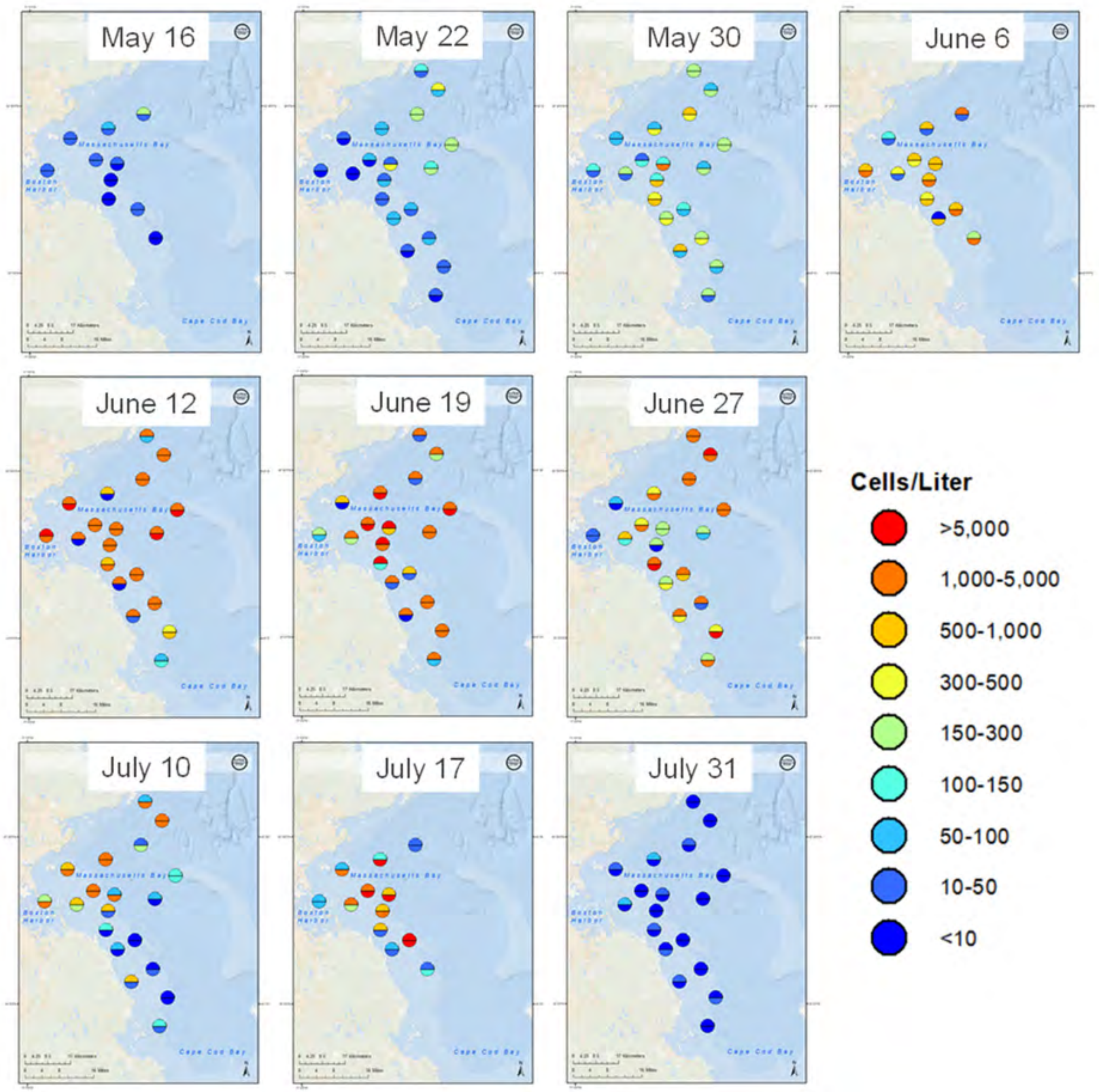

**Figure 3-15. *Alexandrium* abundance in surface- and mid-depth samples during the 2019 bloom.** The upper half of the symbols indicates abundance in surface waters; the lower half indicates abundance at about 10 meters.

The potentially toxic genus of pennate diatoms, *Pseudo-nitzschia*, was also present in somewhat elevated numbers in 2019, although higher abundances occurred in the 1990s. At particularly high abundance, domoic acid produced by some species of *Pseudo-nitzschia* can cause amnesic shellfish poisoning (ASP), a life-threatening illness. *Pseudo-nitzschia delicatissima*, the species that dominated in 2019, does not produce much toxin, and there were no closures due ASP toxicity.

## Zooplankton Communities

Annual peak abundances of total zooplankton were higher than in many years of the monitoring period and within in the 25–75th percentile range at most stations during most surveys (Figure 3-16, Libby et al. 2020). There were no extreme peaks coinciding with survey dates, such as the bivalve veliger larvae that drove total abundance peaks to record highs in July and August of 2015. In 2019, zooplankton communities continued to be dominated by the typical mix of larval, young, and adult copepods and by meroplankton, those animals that are planktonic for only a portion of their lives. The small copepod *Oithona similis* continued to be the most abundant species in most samples, with *Acartia* spp. dominating in Boston Harbor.

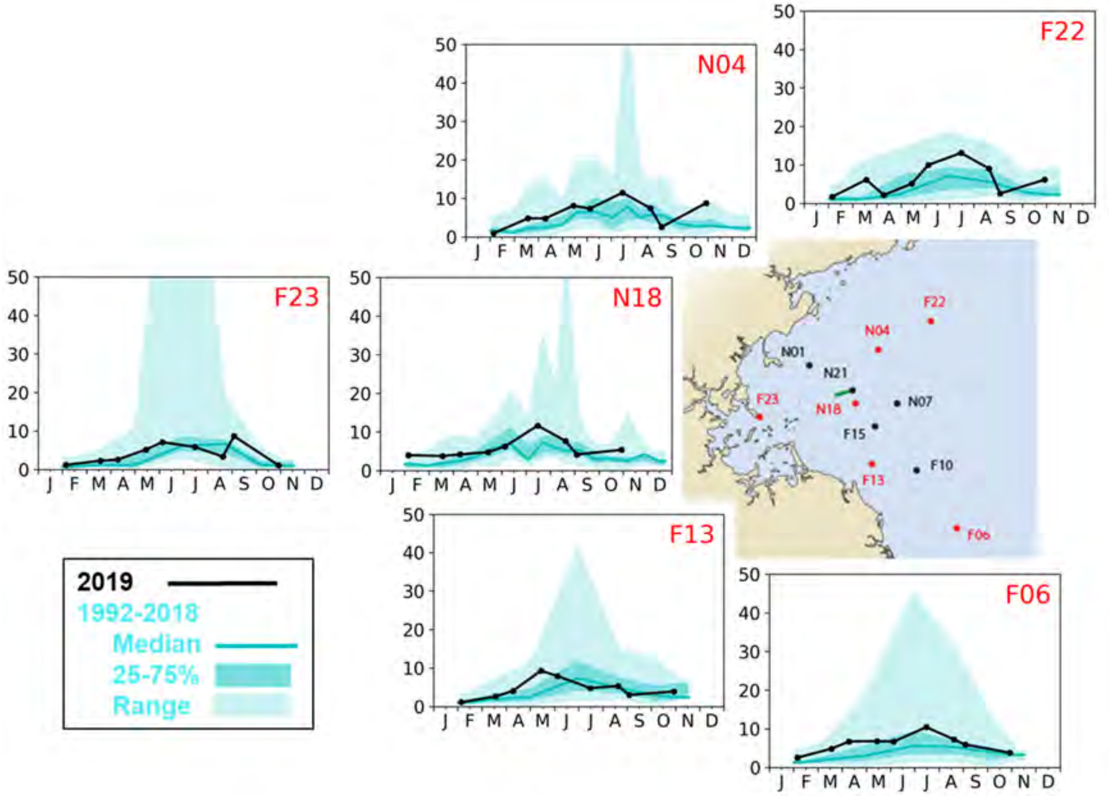

**Figure 3-16. Total zooplankton abundance (10,000 animals per square meter) at selected stations in 2019 compared to prior years.** (For some stations, historic data extend later in the year than the current survey schedule.) The black points and lines are results from 2019; the blue lines and shading are results from 1992–2018: the line is the 50th percentile, dark shading spans the 25–75th percentiles, and the light shading spans the range.

Trend analysis has shown a sustained decrease in total zooplankton abundance during 2000–2006, followed by an increase in 2006–2017, and then a decrease in 2018 and 2019. The trend in phytoplankton abundance mirrors this pattern, suggesting that zooplankton grazing is one factor determining abundances of both phytoplankton and zooplankton populations (Figure 3-17).

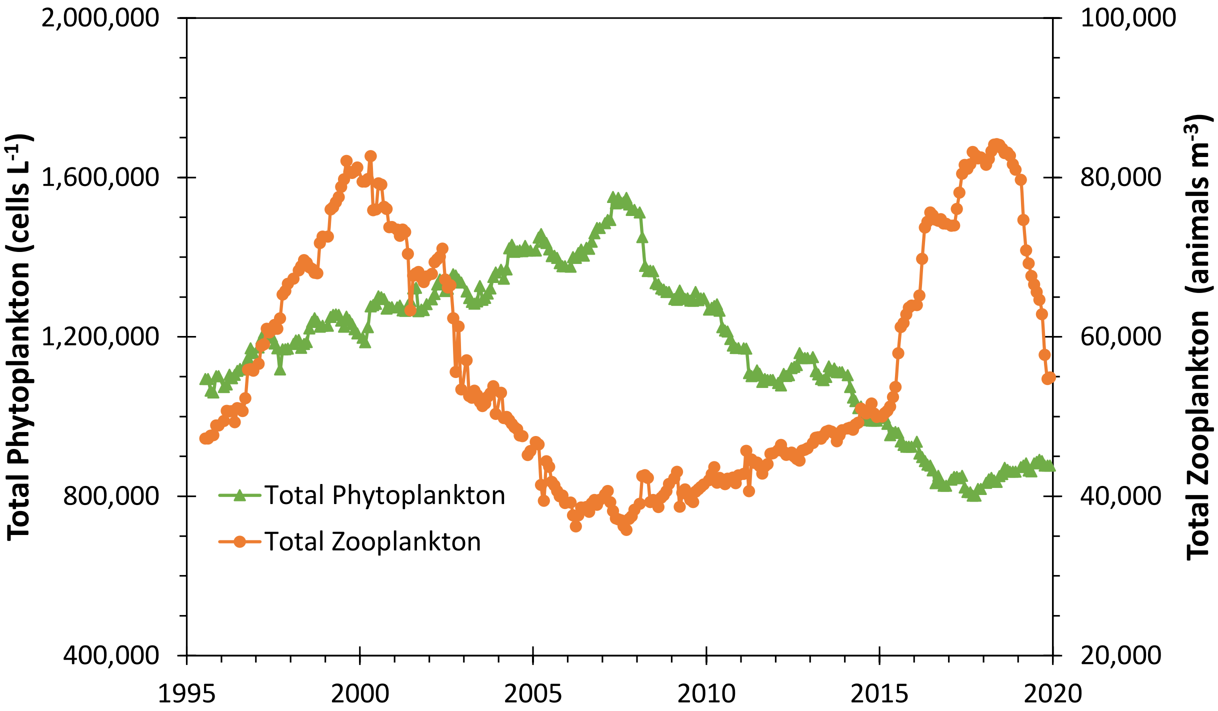

**Figure 3-17. Trends in abundance of total phytoplankton (green triangles) and total zooplankton (orange circles) in the nearfield.** Lines are smoothed using a moving average of about four years.

## 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, just to the west of the sanctuary and is considered to be representative of northern, offshore conditions. The instrumented NERACOOS Buoy is located within the sanctuary.

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 29 kilometers offshore of the outfall and west of the sanctuary.

Sampling at Station F22, as well as data from the NERACOOS Buoy and satellite imagery, detected no unusual chlorophyll levels in offshore regions in 2019. No effects on chlorophyll levels in the offshore, including the sanctuary, were predicted and none have been measured.

Deepwater dissolved oxygen concentrations at Station F22 in Stellwagen Basin were healthy throughout 2019. Both survey observations and data from the NERACOOS Buoy showed the typical decline during the stratified season (Figure 3-18). Data from the buoy documented the rapid return to oxygenated conditions following fall mixing events.

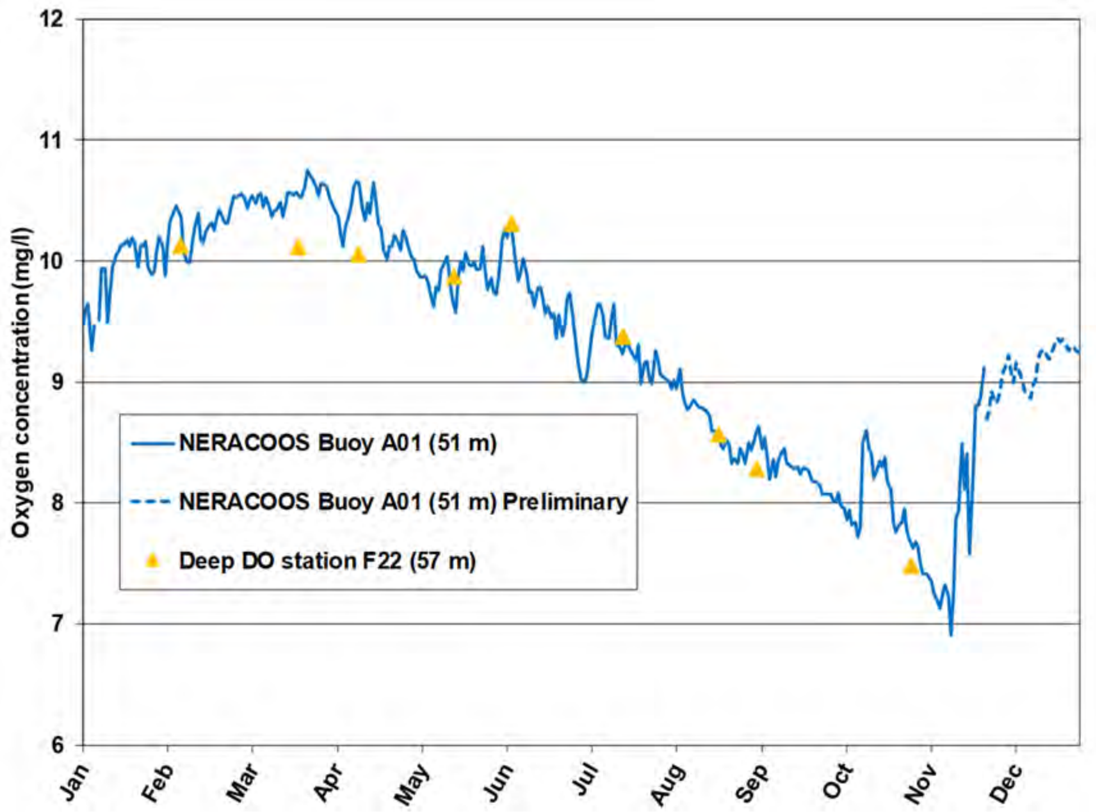

**Figure 3-18. Deepwater dissolved oxygen at the NERACOOS Buoy A01 and Station F22 in Stellwagen Basin.**

## Boston Harbor Water Quality

Water quality in Boston Harbor has greatly improved during the past 20 years, and those improvements were sustained in 2019. 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). Ammonium concentrations dropped precipitously in 2000 when the effluent discharge was diverted from the harbor to the bay and have remained low. The decreases in nutrient inputs have been accompanied by decreases in primary production and phytoplankton biomass, an abatement of the harbor's historic high level of eutrophication, the result of over-stimulation of phytoplankton growth in urban waters (Taylor 2020, and reviewed in the 2017 outfall monitoring overview, Werme et al. 2018).

## Contingency Plan Thresholds

There were no water-column threshold exceedances for dissolved oxygen or chlorophyll parameters in 2019, but there was a caution level exceedance for presence of the nuisance algal species *Alexandrium catenella* (Table 3-1). The *Alexandrium* bloom was region-wide, was first detected at northern stations, and exhibited higher PSP toxicity in the north than at more southern stations. These results were consistent with past blooms and not considered indicative of an outfall effect.

**Table 3-1. Contingency Plan threshold values and 2019 results for water-column monitoring.**

| Parameter | Baseline | Caution Level | Warning Level | 2019 Results |
|---|---|---|---|---|
| **Dissolved oxygen** | | | | |
| Nearfield concentration | 6.05 mg/L | <6.5 mg/L | <6.0 mg/L | 7.18 mg/L |
| Nearfield percent saturation | 65.3% | <80% | <75% | 81.2% |
| Stellwagen concentration | 6.23 mg/L | <6.5 mg/L | <6.0 mg/L | 7.35 mg/L |
| Stellwagen percent saturation | 67.2% | <80% | <75% | 79.0% |
| Nearfield depletion rate | 0.024 mg/L/d | >0.037 mg/L/d | >0.049 mg/L/d | 0.011 mg/L/d |
| **Chlorophyll** | | | | |
| Annual | 72 mg/m$^2$ | >108 mg/m$^2$ | >144 mg/m$^2$ | 92 mg/m$^2$ |
| Winter/spring | 50 mg/m$^2$ | >199 mg/m$^2$ | None | 112 mg/m$^2$ |
| Summer | 51 mg/m$^2$ | >89 mg/m$^2$ | None | 57 mg/m$^2$ |
| Autumn | 90 mg/m$^2$ | >239 mg/m$^2$ | None | 132 mg/m$^2$ |
| **Nuisance algae nearfield *Pseudo-nitzschia*** | | | | |
| Winter/spring | 6,735 cells/L | >17,900 cells/L | None | 18 cells/L |
| Summer | 14,635 cells/L | >43,100 cells/L | None | 598 cells/L |
| Autumn | 10,050 cells/L | >27,500 cells/L | None | 523 cells/L |
| **Nuisance algae nearfield *Alexandrium catenella*** | | | | |
| Any nearfield sample | Baseline maximum 163 cells/L | >100 cells/L | None | 24,342 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. Dissolved oxygen concentrations and percent saturation for the year are the lowest survey means.

*Alexandrium catenella* count is the highest sample abundance for all surveys.

PSP = paralytic shellfish poisoning

NA = not applicable

# 4. Sea Floor

Seafloor monitoring in 2019 included sampling and analysis of soft-bottom sediment conditions, effluent tracers, and infauna at 14 stations and sediment-profile imaging at 23 stations (Figures 4-1 and 4-2). Anthropogenic contaminants analyses and video assessment of 23 hard-bottom stations have occurred at three-year intervals, most recently in 2017.

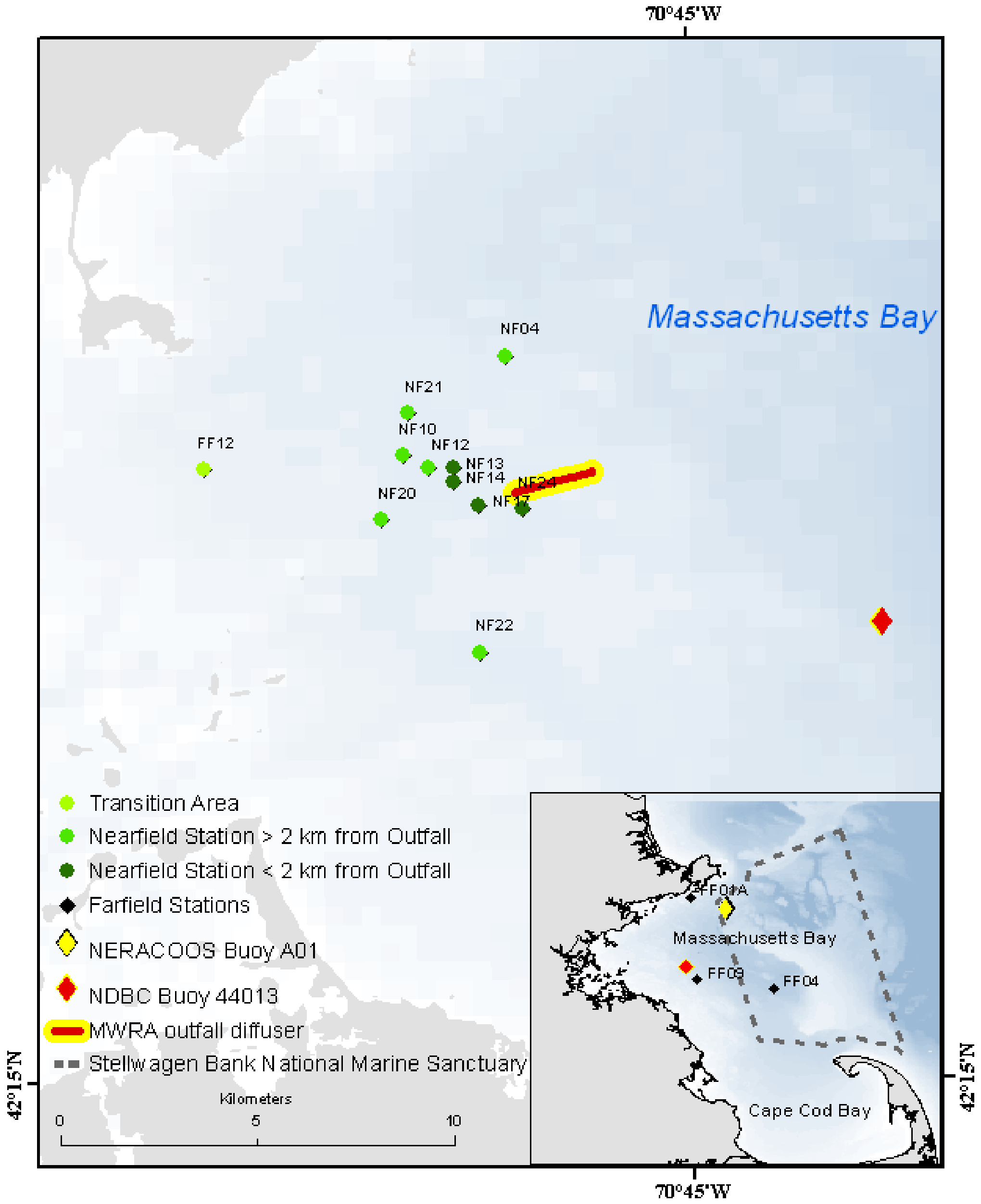

**Figure 4-1. Soft-bottom monitoring stations.** Also shown are the instrumented buoys, the MWRA outfall diffuser, and the Stellwagen Bank National Marine Sanctuary.

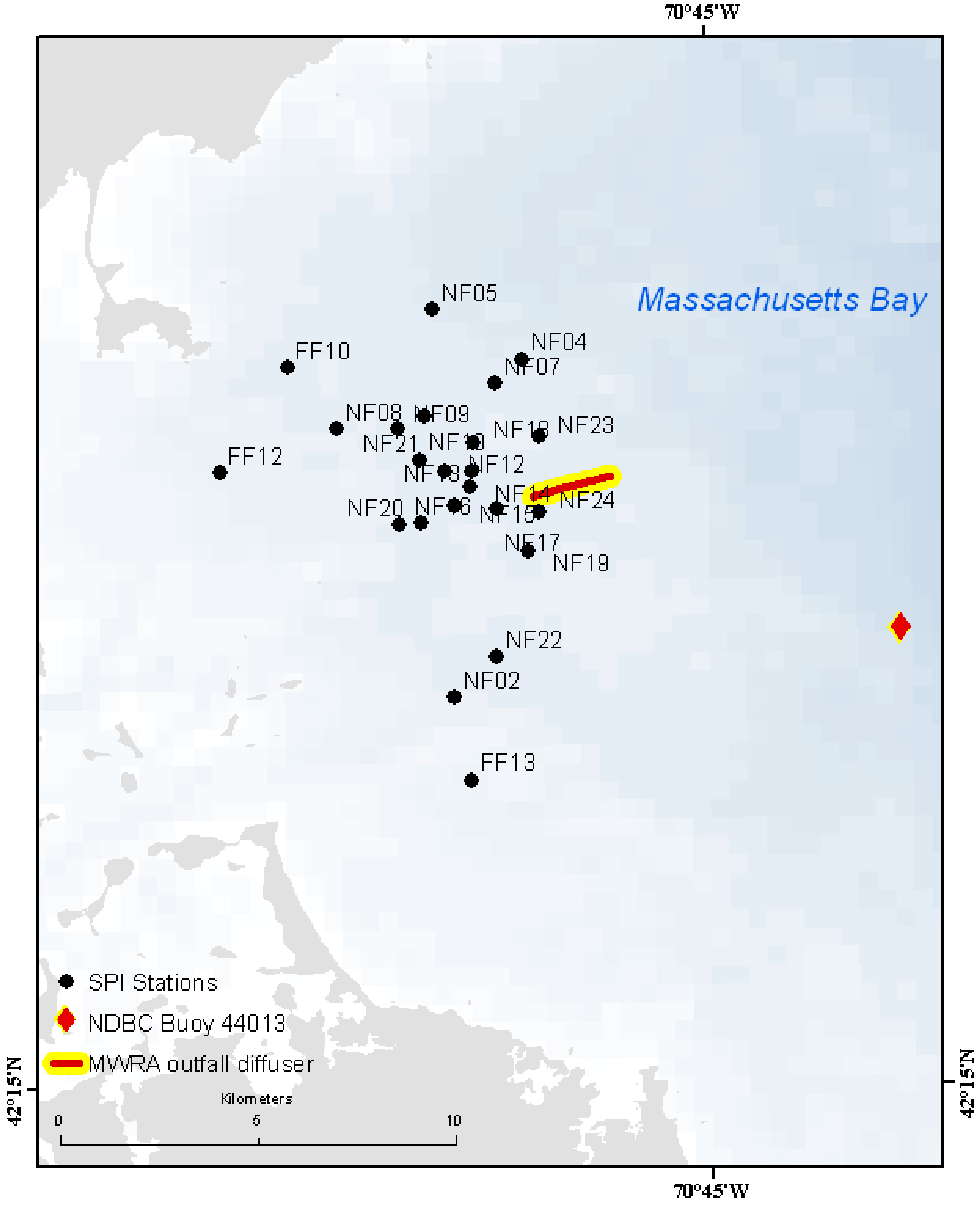

**Figure 4-2. Sediment-profile imaging stations.** Also shown are NDBC Buoy 44013 and the MWRA outfall diffuser. SPI = sediment-profile imaging

Soft-bottom sediment sampling was completed in August 2019, with samples analyzed for grain-size distribution, the effluent tracer *Clostridium perfringens* spores, total organic carbon, and benthic infauna.  The 14 stations included four nearfield stations within two kilometers of the outfall (NF13, NF14, NF17, NF24); six nearfield stations in western Massachusetts Bay but farther from the outfall (NF04, NF10, NF12, NF20, NF21, NF22); one station in the “transition” area between Boston Harbor and the nearfield stations (FF12); and three farfield reference stations in Massachusetts Bay and Cape Cod Bay (FF01A, FF04, and FF09).  For the purposes of threshold testing, “nearfield” included the transition station, as well as both nearfield groups, for a total of eleven stations.

Sediment-profile imaging was also completed in August 2019.  Triplicate images from 23 stations were used to measure the apparent reduction-oxidation (redox) potential discontinuity (RPD) depth, an approximation of the depth that oxygen penetrates the sediments as determined by color changes, and to assess the status of the bottom community.

## Sediment Characteristics and Tracers

As in past years, sediment grain-size distributions in 2019 varied broadly among stations, ranging from silt and clay at some stations (particularly Station FF04 within Stellwagen Basin) to almost entirely sand at others (Nestler et al. 2020).  Sediment grain-size distributions have remained generally consistent at individual stations over the years of the monitoring program.  When changes have occurred, they have been mostly preceded by large storms with wave-driven currents sufficient to resuspend bottom sediments.

As in other years since the offshore outfall began to discharge, it was possible to detect elevated levels of the effluent tracer *Clostridium perfringens* spores at some stations located closest to the outfall (Figures 4-3).  *Clostridium* are anaerobic bacteria that are found in mammalian (including human) digestive tracts and that form persistent spores in oxygen-rich conditions.  In 2019, the average *Clostridium* abundance at stations located within two kilometers of the outfall remained elevated, but only at stations closest to the outfall.  *Clostridium* abundance has declined over time or remained similar to the baseline at stations further from the outfall.

Percent organic carbon content analyses were also consistent with past results, with no increased organic carbon in any area, even the station group closest to the outfall (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 outfall.

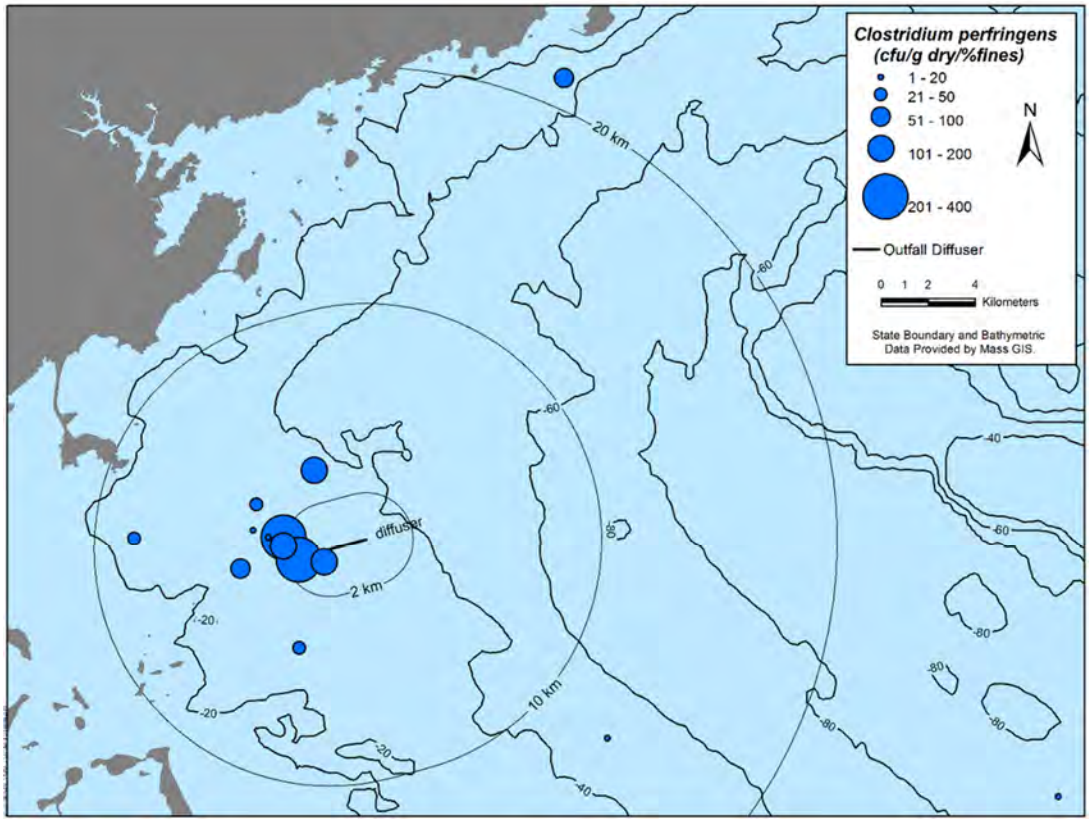

**Figure 4-3. Concentrations of *Clostridium perfringens* spores corrected for sediment grain size, in 2019.**

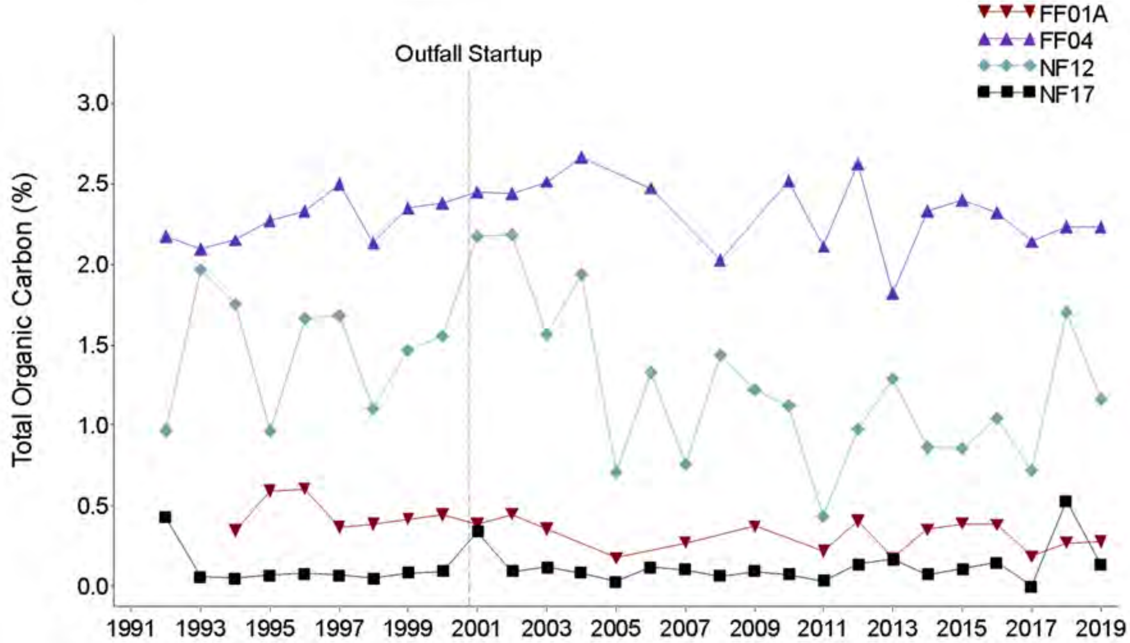

**Figure 4-4. Total organic carbon at selected stations, 1992–2019.** Station FF01A is the northern reference station; FF04 is within Stellwagen Basin; NF12 is >2km northwest of the outfall; and NF17 is in close proximity and southwest of the outfall, where the effects of the discharge might be expected.

## Soft-bottom Communities

The 14 soft-bottom samples collected and analyzed in 2019 yielded 26,614 organisms, classified into 185 species and 28 other discrete taxonomic groups (Nestler et al. 2020). Total abundance of organisms was lower in 2019 than in 2018 across all regions except for the nearfield stations within two kilometers of the outfall, where numbers were slightly higher, about the same as 2017 (Figure 4-5). The numbers of species per sample and diversity measures were slightly higher than in 2018, but remained within the ranges measured throughout the monitoring program. Polychaete worms continued to dominate at most stations, and the spionid polychaete *Prionospio steenstrupi* remained the numerically dominant species at several nearfield stations; it has accounted for 25% of the total number of organisms sampled over the course of the monitoring program. The tube-building amphipod *Crassicorophium crassicorne*, which prefers sandy sediments, was the most abundant species at Station N17, very close to the outfall.

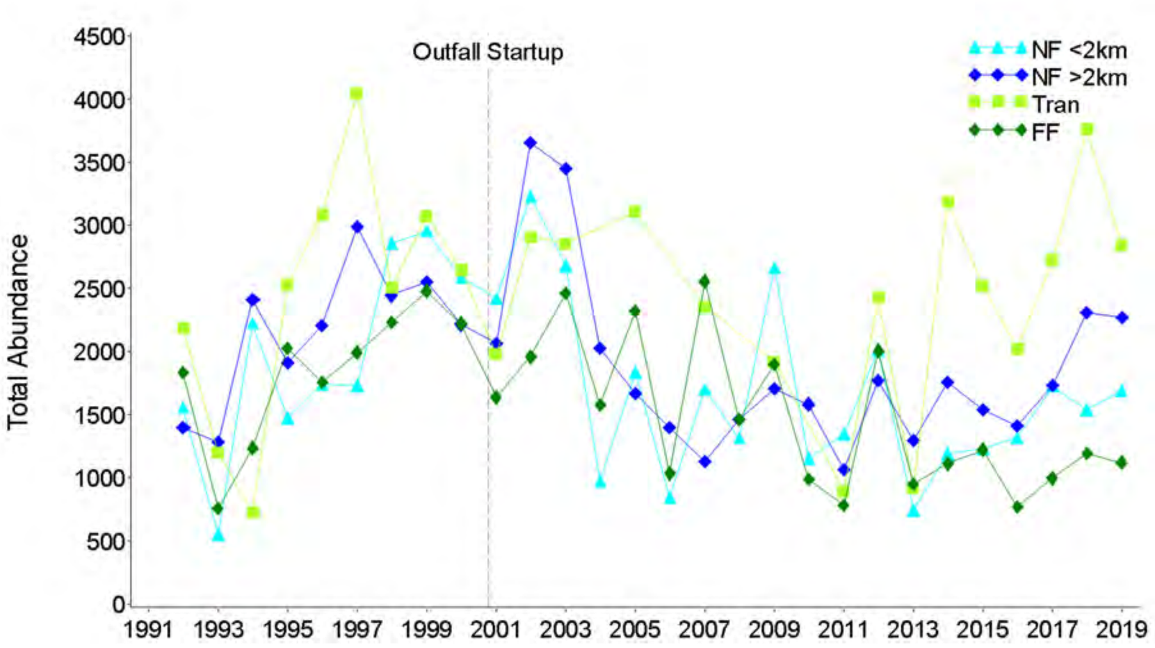

**Figure 4-5. Total abundance by region, 1992–2019**. Regions include the nearfield within two kilometers of the outfall, the nearfield farther than two kilometers from the outfall, the transition area between Boston Harbor and the outfall, and the farfield.

Community analyses continued to show 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.

A cluster analysis identified two main infauna assemblages and one outlier group: Group I dominated by amphipods and polychaete worms, Group II dominated by polychaetes, and the outlier Group III, representing the station located within Stellwagen Basin, which has consistently supported a unique community. Ordination analysis continued to show no indication of any relation of species composition to proximity to the outfall, with stations closest to the outfall represented in the two larger main assemblages (Figure 4-6). Analyses further continued to demonstrate that variations in species distributions largely followed differences in sediment grain size and depth (Figure 4-7).

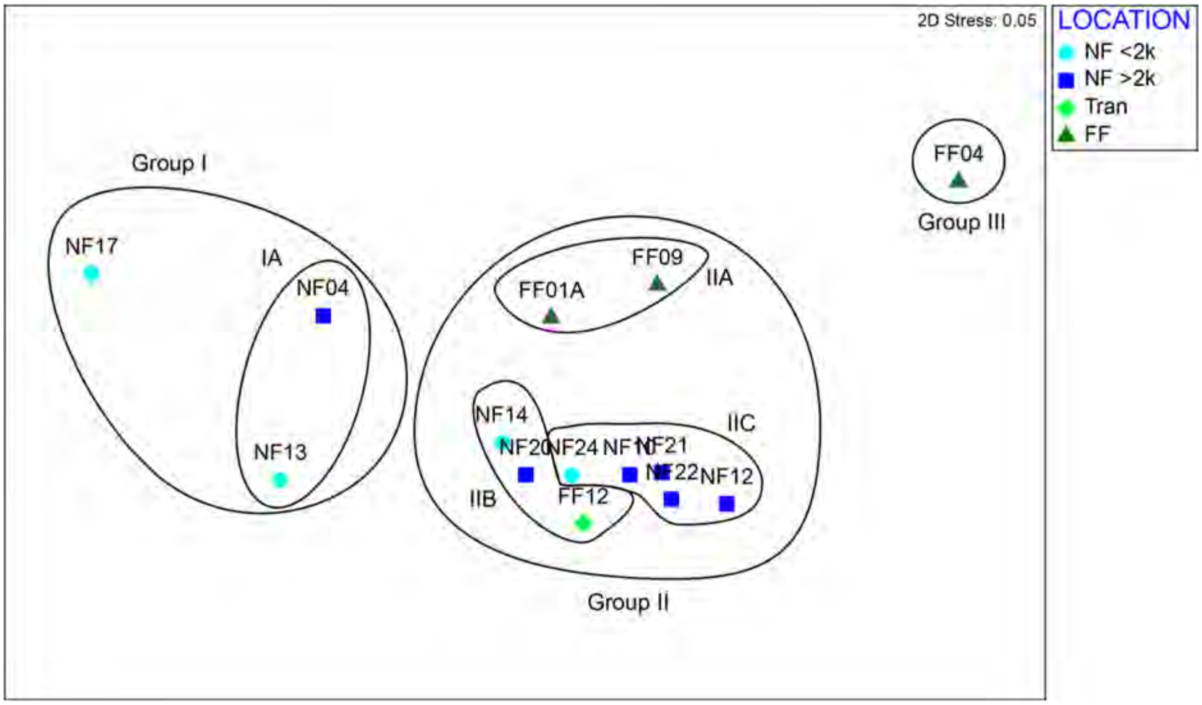

**Figure 4-6. Ordination plot of 2019 Massachusetts Bay samples by location.** Each point on the plot represents one of the 14 stations; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-III, and sub-groups) identified by cluster analysis are circled on the plot. Locations include the nearfield within two kilometers of the outfall, the nearfield farther than two kilometers from the outfall, the transition area between Boston Harbor and the outfall, and the farfield. Stress is a measure of how well the ordination results represent the raw data; a stress of 0.05 indicates excellent representation.

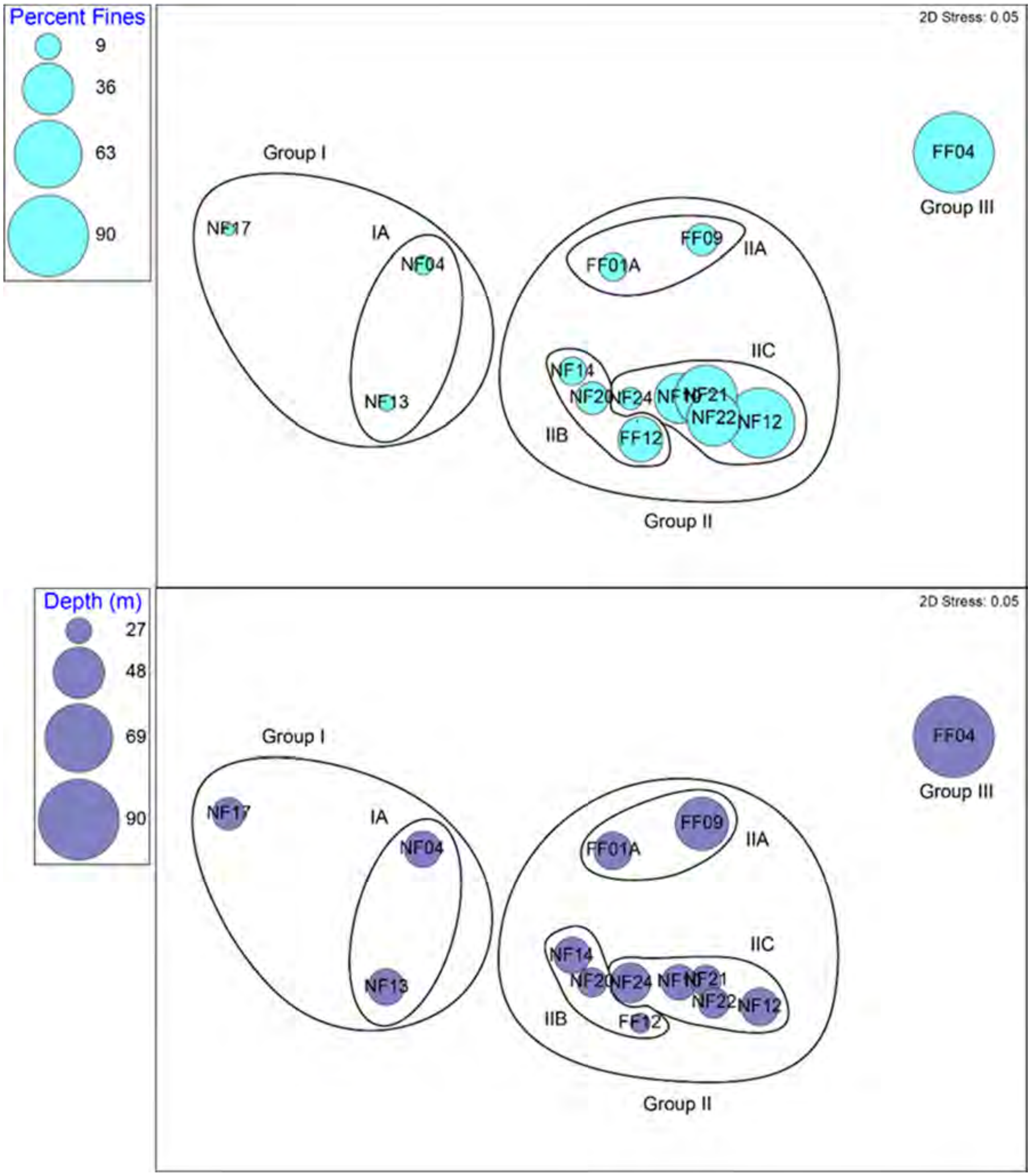

**Figure 4-7. Percent fine sediments (top) and depth (bottom) superimposed on the ordination plot of the 2019 infauna samples.** Each point on the plot represents one of the 14 stations; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and sub-groups) identified by cluster analysis are circled on the plot. Stress is a measure of how well the ordination results represent the raw data; a stress of 0.05 indicates excellent representation.

## Sediment-profile Imaging

Sediment-profile images continued to show no adverse effects of the outfall (Nestler et al. 2020). Rough topography and physical processes in the nearfield remained the more important factors in determining benthic habitat quality.

As in past years, the 2019 average RPD was deeper than the average measured during the baseline period (Figure 4-8), with a mean depth of 4.8 cm for all stations where RPDs could be measured. At eight 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 organic matter causing stress on sensitive sediment-dwelling organisms. The deep RPD in 2019 continued to indicate there has been no adverse effect from the discharge.

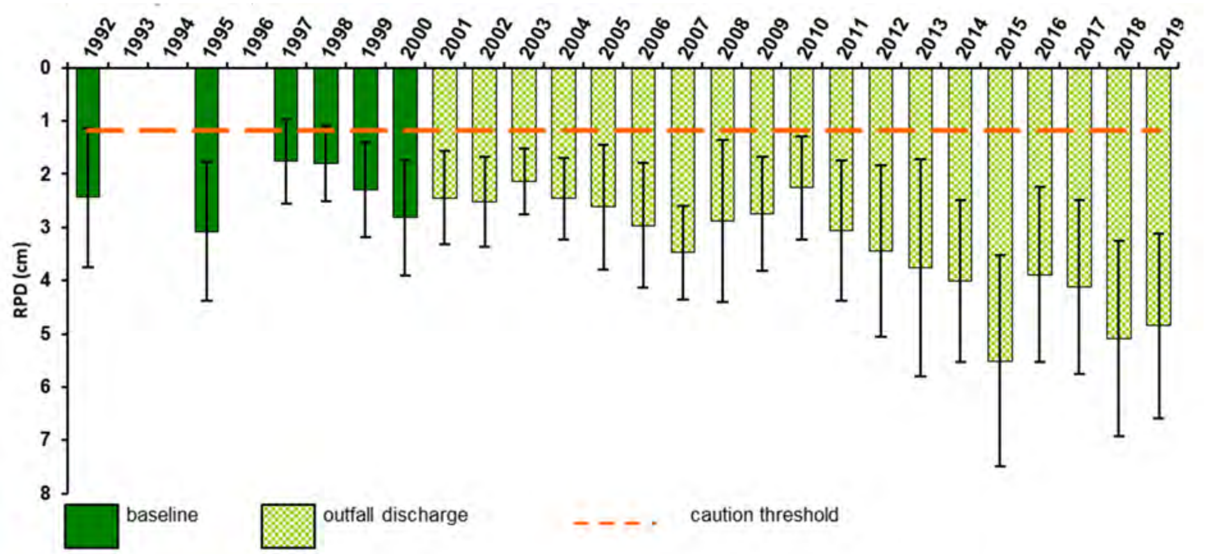

**Figure 4-8. Annual apparent color RPD depth (± standard deviation) for nearfield stations.** The mean RPD has been deeper than in baseline years, a strong indication of no adverse effect from the discharge.

Along with the deepening RPD, nearfield stations have shown an increase in the organism sediment index (OSI; Figure 4-9), a measure that integrates RPD depth with the successional stage of the infauna community. This general increase in OSI has documented increasingly good habitat quality throughout the nearfield. Another measure of biological activity, the number of biogenic structures, such as burrows and voids, has decreased. This decline appears to be related to the number of winter storms occurring within the year rather than to any outfall effect.

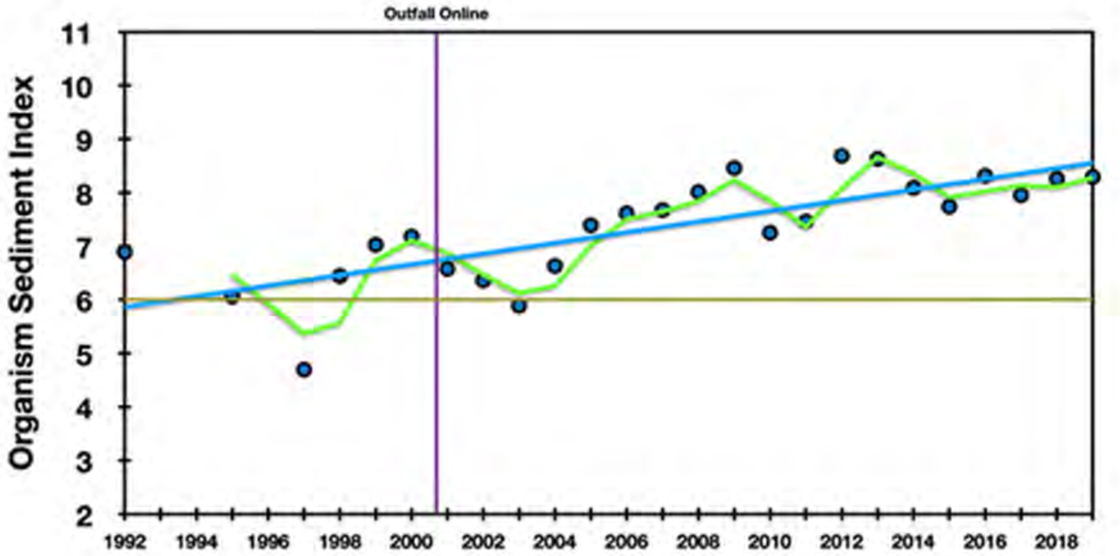

**Figure 4-9. Trend in the Massachusetts Bay organism sediment index over time.** Points are averages for all 23 nearfield stations. Green line is a two-year moving average. Blue line is a linear regression line, $R^2 = 0.60$, $p = <0.001$. An OSI > 6 is considered to represent good benthic habitat.

In general, 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, lessening the chances of any effects of the Massachusetts Bay outfall. At Station FF13 to the southwest of the outfall, for example, biological processes were evident in 1997 and 1998, prior to outfall startup, while physical processes have been particularly evident in recent, stormier years. Section 6, Special Studies, presents further analysis of sediment habitat quality, and Section 7, Monitoring Plan Revisions, provides rationale for ending sediment-profile imaging studies, as well as sediment-contaminant analyses, in Massachusetts Bay.

## 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 deep-water reference Station FF04 lies within the depositional part of the sanctuary, 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 infauna community typical of what had been found at the larger suite of deep-water stations. The deep-water 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 2019 infauna samples continued to show these natural differences (see Figure 4-7, above).

## Boston Harbor Seafloor Monitoring

While the chemistry and biology of the Massachusetts Bay sea floor have not been adversely 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 4-10), and sediment-profile imaging is conducted at 61 stations throughout the inner and outer harbor.

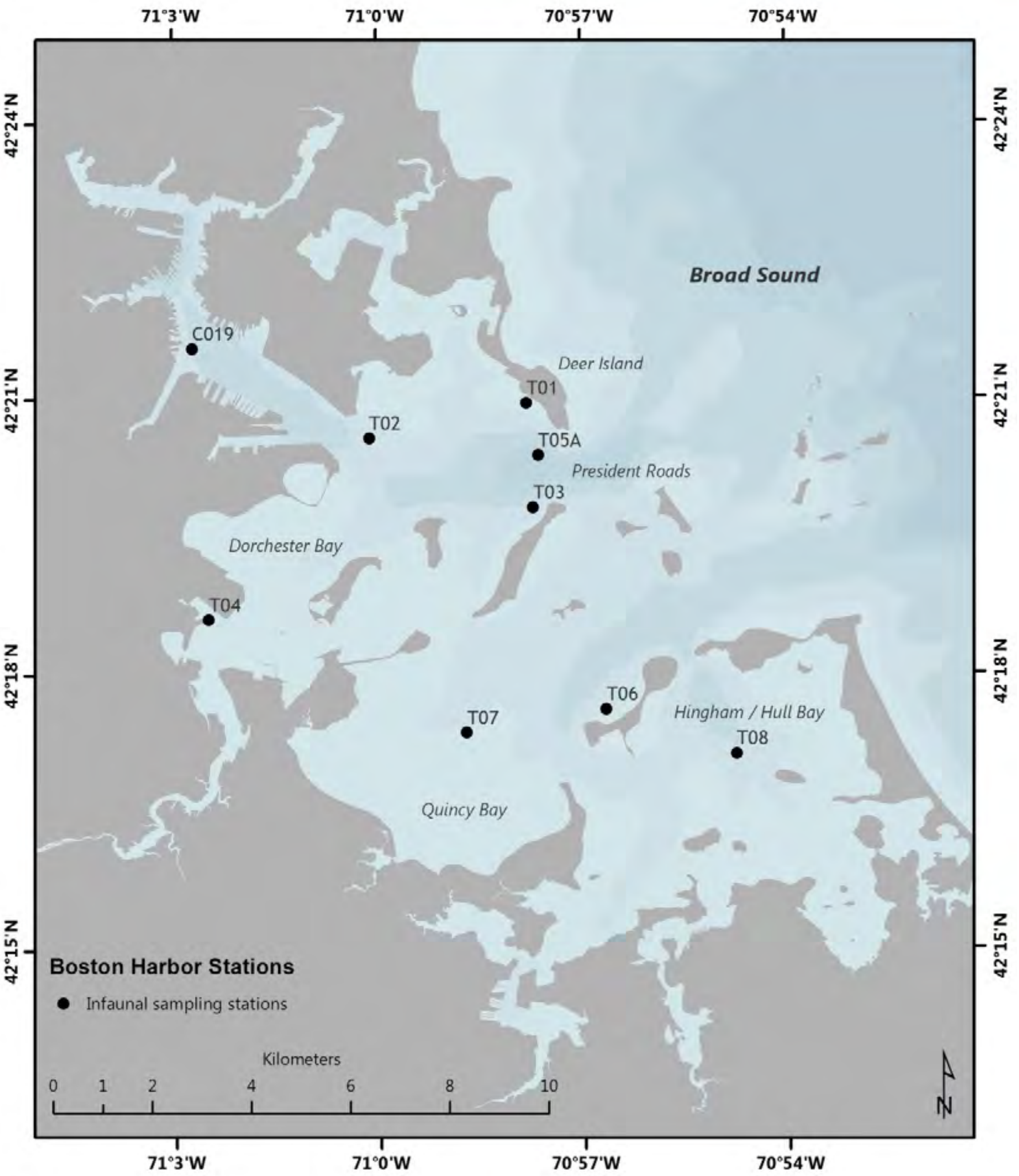

**Figure 4-10. Soft-bottom sampling stations in Boston Harbor.** Nine stations are sampled each year for sediment characteristics and infauna analyses. Sediment-profile images are taken from 61 stations throughout the harbor.

Concentrations of total organic carbon and *Clostridium perfringens* spores in harbor sediments have declined over time, reflecting the improvements made throughout the Boston Harbor Project. During the same time, number of species per sample (Figure 4-11, Rutecki et al. 2020) and infauna diversity measures (not shown) have increased, a response to continued improvement in benthic habitat conditions. As in past years, the samples showed differences between stations in the sandier stations of the outer harbor, finer sediments of the inner harbor and Quincy Bay, and a persistently a unique fauna at the most polluted location, Station T04, at the mouth of Savin Hill Cove.

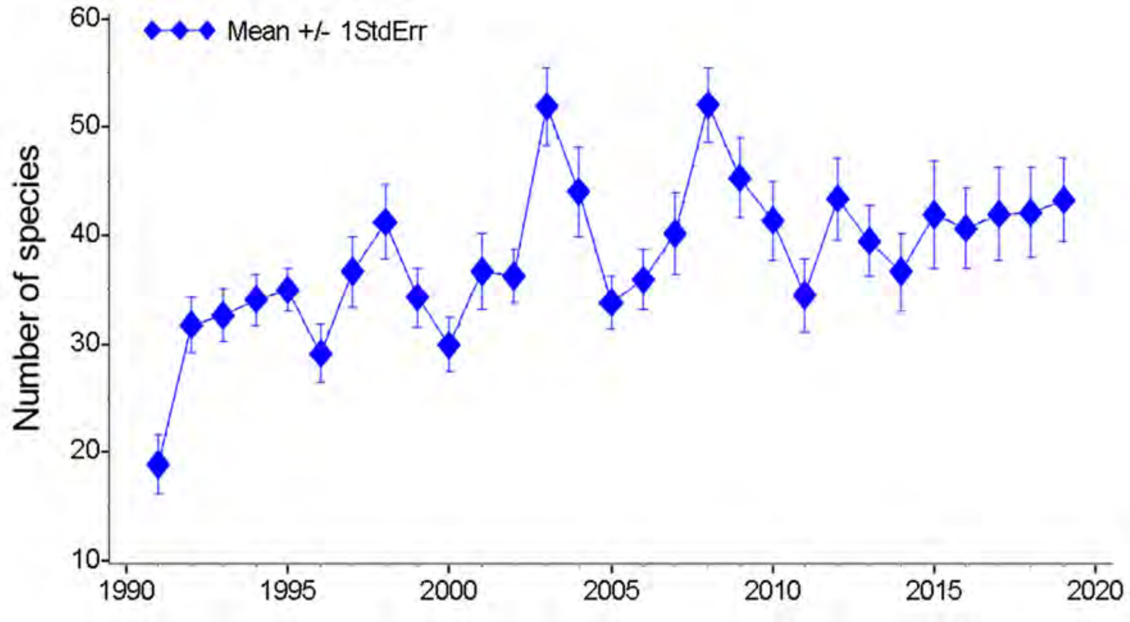

**Figure 4-11. Mean number of species per sample in Boston Harbor, 1991–2019.** Eight stations, T01–T08, were included in the analysis.

Sediment-profile imaging has also confirmed an inner- to outer-harbor gradient and clearly documented improvements to habitat conditions throughout the Boston Harbor Project. The harbor-wide OSI has improved since the early days of the monitoring program, remaining higher than 6, considered indicative of good habitat quality, for the past 17 years (Figure 4-12).

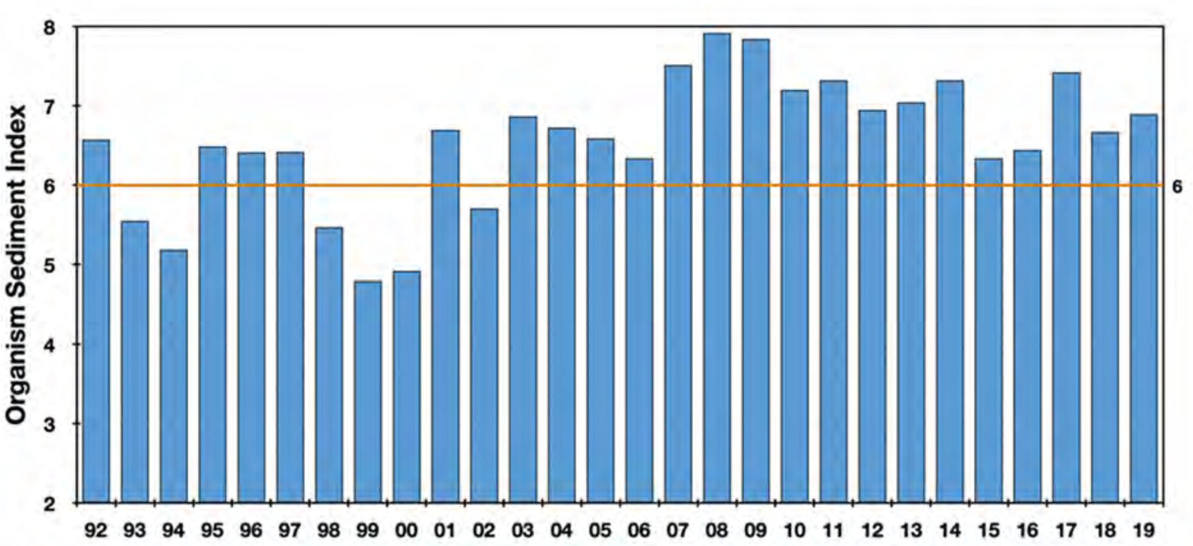

**Figure 4-12. Organism sediment index at 61 sediment-profile stations in Boston Harbor, 1992-2019**. An OSI > 6 is considered to represent good benthic habitat.

Sediment-profile imaging has also documented continued presence of eelgrass at Deer Island Flats, another sign of recovery of the harbor following the outfall diversion. An eelgrass bed was first detected in 2008 and persisted in the 2019 images.

The 2018 and 2019 images showed evidence of dredging, part of a channel-deepening project by the U.S. Army Corps of Engineers. Dredging was underway at the time of the 2018 survey, and because this disturbance completely removed parts of the seafloor community, the OSI at Deer Island Flats, located within the dredged area, was far lower than in 2017. Dredging continued in the area after the 2018 MWRA survey concluded. Effects were still visible in 2019, although there were indications of recolonization and recovery at some stations.

## Contingency Plan Thresholds

There were no Contingency Plan threshold exceedances for seafloor parameters in 2019 (Table 4-1). The average RPD remained deeper than the thresholds and also deeper than baseline values. Diversity and other benthic community parameters were higher than Contingency Plan limits, and the percent opportunistic species remained far below any level of concern, all signs of continued healthy seafloor habitat.

**Table 4-1. Contingency Plan threshold values and 2019 results for sea-floor monitoring.**

| Parameter | Baseline | Caution Level | Warning Level | 2019 Results |
|---|---|---|---|---|
| **Sediment parameters** | | | | |
| RPD depth | NA | <1.18 cm | None | 4.85 cm |
| **Benthic community parameters** | | | | |
| Species per sample | NA | <42.99 | None | 64.1 |
| Fisher's log-series alpha | NA | <9.42 | None | 12.9 |
| Shannon diversity | NA | <3.37 | None | 3.88 |
| Pielou's evenness | NA | <0.57 | None | 0.65 |
| % opportunists | NA | >10% | >25% | 0.28% |

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

# 5. Fish and Shellfish

MWRA monitors winter flounder health each year and conducts chemical contaminant analyses of flounder and lobster meat tissues and cage-deployed blue mussels every three years, most recently in 2018. Sampling and deployment sites vary by species (Figure 5-1). Annual flounder monitoring, the only fish and shellfish study conducted in 2019, focuses on external condition and the presence of liver disease and tumors (neoplasia) in fish collected from near the former Boston Harbor outfall at Deer Island Flats, off Nantasket Beach, the Massachusetts Bay outfall site, and eastern Cape Cod Bay.

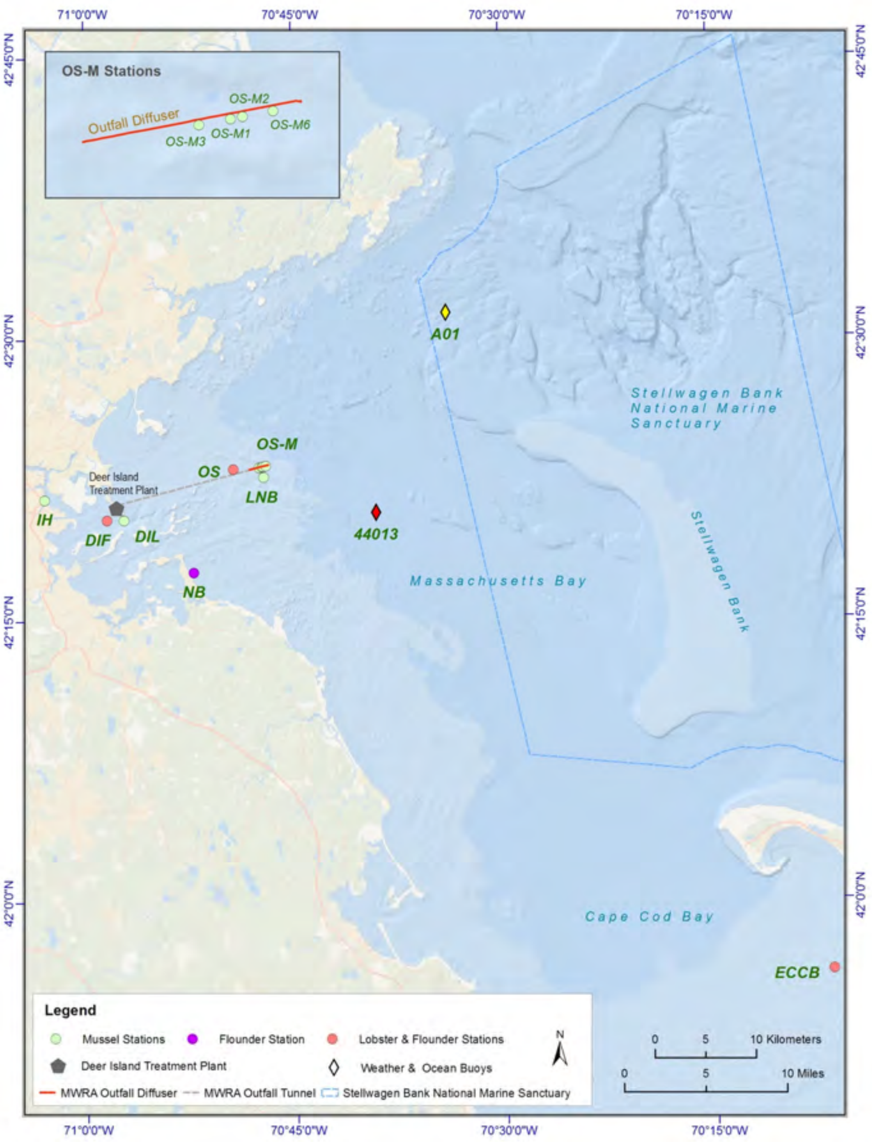

**Figure 5-1. Fish-and-shellfish monitoring stations.** Only flounder were sampled in 2019. Also shown are the two instrumented buoys, the MWRA outfall diffuser, and the boundaries of the Stellwagen Bank National Marine Sanctuary.

## Flounder Health

Annual flounder monitoring for external condition and the presence of liver disease and tumors was hampered in April and May 2019 by a barge laying a new cable to Deer Island, weed clogging, and abandoned lobster gear, which can require cutting the flounder net (Figure 5-2). Only 40 fish were taken at Deer Island Flats and only 20 off Nantasket Beach, with the full complement, 50 fish, taken at the outfall site and eastern Cape Cod Bay.

**Figure 5-2. Lobster gear in flounder net trawl.** Photo credit Michael Moore, Woods Hole Oceanographic Institution

Across the sites, mean age of fish ranged from 4.0 to 4.8 years, and standard length ranged from 276 to 303 millimeters, within the ranges observed in recent years (Moore et al. 2020). As in past years and as is common throughout northeast coastal populations, the catches were dominated by females (reviewed in Moore et al. 2016).

Measures of external condition (such as occurrence and severity of fin erosion) continued to suggest improved conditions since 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 found in fish taken from the outfall site. Incidence of fin erosion, often an indicator of excess ammonium and other pollutants, continued to be highest in fish from Deer Island Flats (32.5%) and was lowest in fish from eastern Cape Cod Bay and off Nantasket Beach (10%). Incidence of fin erosion has been highly variable at all sites, with no obvious long-term trend and no correlation with liver conditions. Blind-side ulcers, a condition that remains poorly understood, were present in small numbers of fish from Deer Island Flats, off Nantasket Beach, and the outfall site.

The incidence of centrotubular hydropic vacuolation (CHV), a mild condition associated with exposure to contaminants and a tumor precursor, remained lower than the baseline observations at all sites (Figure 5-3). CHV incidence remained lower than in any baseline year at the outfall site and somewhat elevated in comparison to some recent years at Deer Island Flats, although also lower than levels found prior to the Boston Harbor Project. Average severity of CHV also remained highest at Deer Island Flats but at lower than levels seen in the early 1990s. Section 7, Monitoring Plan Revisions, provides rationale for reducing future flounder-health monitoring.

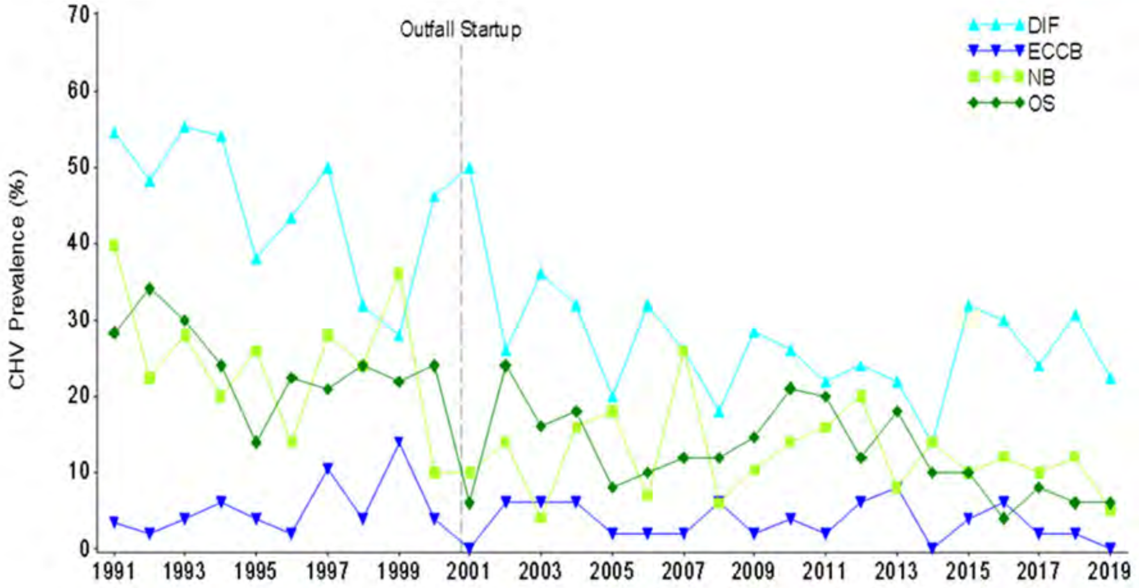

**Figure 5-3. Annual prevalence of centrotubular hydropic vacuolation (CHV), 1991–2018.**
DIF = Deer Island Flats, ECCB = eastern Cape Cod Bay, NB = Nantasket Beach, OS = outfall site

## Contingency Plan Thresholds

There was no Contingency Plan threshold exceedance for the only threshold parameter measured in 2019 (Table 5-1). Incidence of CHV, the most common indicator of liver disease in winter flounder of the region, was 6% in fish taken from the vicinity of the outfall, much lower than the 44.9% caution threshold and the 24.4% baseline average.

**Table 5-1. Contingency Plan threshold values and 2019 result for fish-and-shellfish monitoring.**

| Parameter | Baseline | Caution Level | Warning Level | 2019 Results |
|---|---|---|---|---|
| **Flounder disease** | | | | |
| Liver disease (CHV) | 24.4% | >44.9% | None | *6%* |

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 report on special studies focuses on long-term analyses of nutrient discharges into Massachusetts Bay, sediment-habitat structure in Boston Harbor and Massachusetts Bay, and the summer 2019 hypoxia event in southern Cape Cod Bay.

## Nutrient Discharges into Massachusetts Bay

MWRA recently completed an updated assessment of nutrient inputs and nutrient and phytoplankton biomass gradients in Massachusetts Bay (Libby et al. 2020). The assessment focused on 2011–2019, years when water samples from each of eleven stations were analyzed for full suite of parameters nine times per year. (Before 2011, some stations included only a partial list of parameters, and some stations were sampled just six times per year.) The study confirmed earlier studies that had first predicted and then confirmed that the nutrient signature of the outfall would remain localized and there would be no effect on phytoplankton biomass (for example, Libby et al. 2009). Increased phytoplankton biomass in response to the discharge, were it to occur, could contribute to eutrophication and result in low dissolved oxygen levels.

The new assessment found that total nitrogen, dissolved inorganic nitrogen (ammonium, nitrate, and nitrite), and ammonium levels were each highest at Station N21, located directly over the outfall (Figure 6-1). The proportions of total and dissolved inorganic nitrogen made up of ammonium were also highest at Station N21, as expected, because ammonium makes up the major part of the nitrogen discharge. Concentrations of ammonium, as well as total and dissolved inorganic nitrogen, fell precipitously with distance from the outfall, declining to background levels within 7.5 to 10 kilometers.

Concentrations of total and dissolved inorganic phosphorus (not shown) were similarly highest at Station N21, declining even more quickly with distance from the outfall. Dissolved inorganic silica (silicate) concentrations (also not shown) did not vary with distance from the outfall. Phytoplankton biomass, measured as chlorophyll (Figure 6-2) and particulate organic carbon, varied throughout the year and did not vary with distance from the outfall.

It was not surprising that the study confirmed past predictions and analysis, showing increased ammonium in the immediate vicinity of the outfall but not within greater Massachusetts Bay or Cape Cod Bay and no detectable effect on phytoplankton growth or biomass. While the MWRA effluent is considered nutrient-rich, exchange with offshore waters provides about 15 times more total nitrogen to Massachusetts Bay than the outfall discharge.

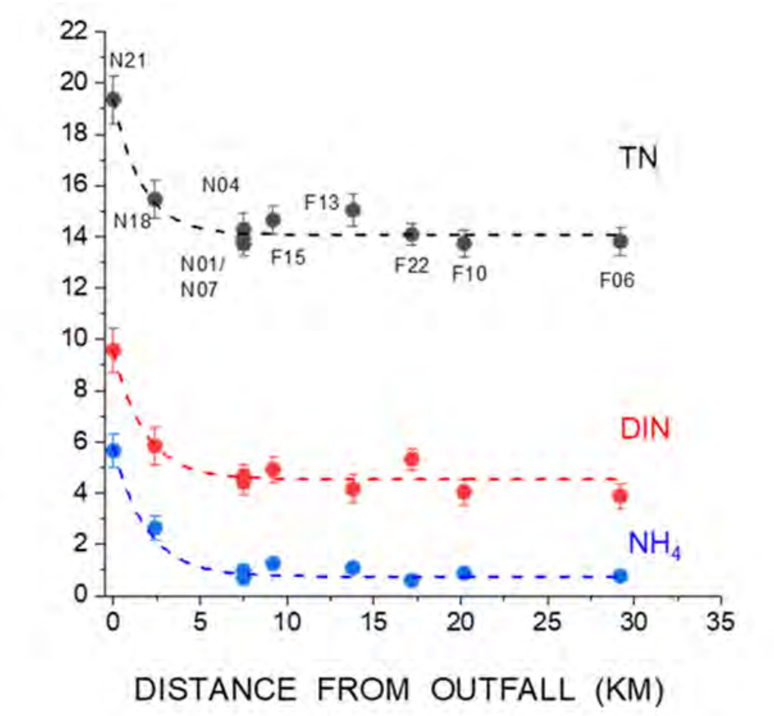

**Figure 6-1. Depth-averaged nitrogen concentrations (µM) and declines with distance from the Massachusetts Bay outfall**. Data are from 2011–2019. Station numbers are in black. TN = total nitrogen DIN = dissolved inorganic nitrogen $NH_4$ = ammonium. Error bars are 95% confidence limits.

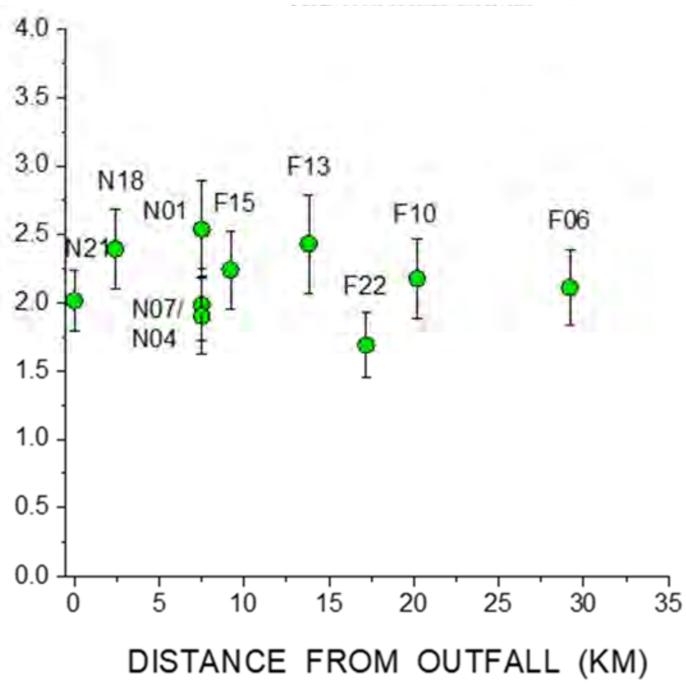

**Figure 6-2. Depth-averaged chlorophyll concentrations (µM per liter as fluorescence) and distance from the Massachusetts Bay outfall**. Data are from 2011–2019. Station numbers are in black. Error bars are 95% confidence limits.

## Sediment-Habitat Structures

The almost 30 years of monitoring sediment-habitat structures in Boston Harbor and Massachusetts Bay has documented improvements in the harbor but identified no adverse effects from effluent discharge in the bay (see Section 4, Sea Floor, above). This long monitoring period has further allowed for an analysis of long-term trends not associated with the MWRA outfall.  Weather and climate may prove to be the most important forces driving future changes in both the harbor and the bay.

Prior to the Boston Harbor Project, organic and nutrient loads were major factors in determining sediment quality in Boston Harbor, dominant enough to obscure analysis of climate-driven stresses.  The harbor's complex geomorphology further made interpreting effects of storms difficult, sometimes dampening and sometimes amplifying the predicted effects.

Declines in organic-matter loading to the harbor began in 1991, with the ending of biosolids discharges and facility upgrades, starting a shift from anaerobic to aerobic conditions and resulting in continually improving habitat quality.  The outfall diversion from the harbor further reduced the organic-matter load, allowing burrowing amphipods to flourish, which accelerated the transition to aerobic conditions.

With recovery of the harbor, effects of weather and climate have become more apparent (Figure 6-3).  For example, an increase in spring salinity levels during 1991–2019 was likely sufficient to favor a new dominant tube-building amphipod species. Around 2014, *Ampelisca vadorum*, a more coastal species that builds shorter and wider tubes, replaced the earlier dominant, *Ampelisca abdita*.  During the same general period, the extent of amphipod tube mats became more obviously associated with occurrence or absence of winter storms.  Eight of the windiest winter storms occurred during 2006–2019, leading to fewer amphipod mats than had been present during earlier recovery stages of the Boston Harbor Project.

In Massachusetts Bay, weather and climate appear to be the driving forces, not only for seafloor communities, but probably also in the water column (Figure 6-4).  Storms and climate change are likely important factors in observed increases in water temperature and salinity over time.  Storms with forces great enough to resuspend and transport sediments affect species composition and overall habitat quality.  Intense winter storms can decrease the total number of infaunal organisms in the following year or change abundance patterns among the most frequently occurring species.  The increasing storminess that has been documented over the last years of the monitoring program is likely related to both regional variability and to long-term trends.

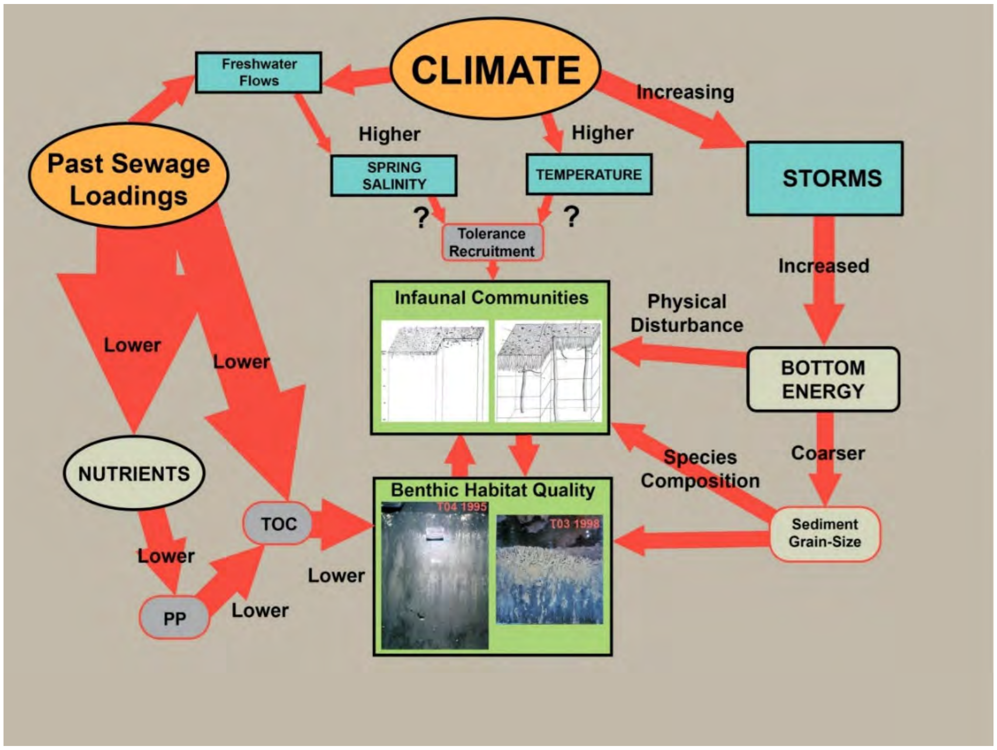

**Figure 6-3. Reducing past sewage loadings, a result of the Boston Harbor Project, has led to recovery of benthic habitat and communities in Boston Harbor.**

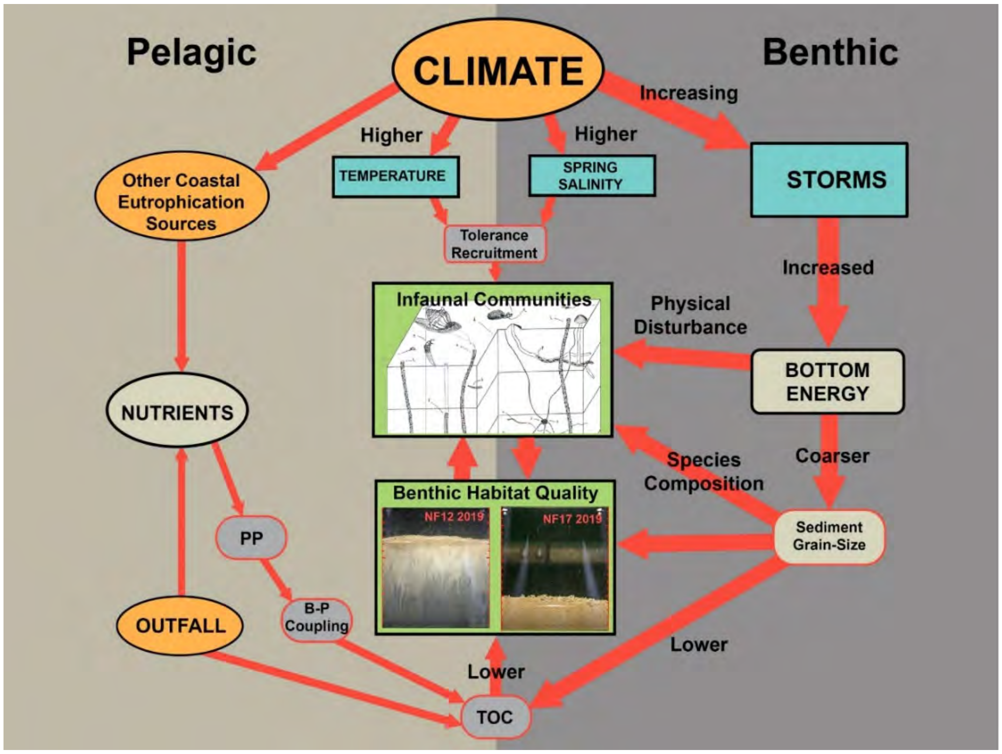

**Figure 6-4. Storms and other climate-related factors continue to have the greatest effects on the habitats and communities in Massachusetts Bay.**

## Hypoxia in Cape Cod Bay

Typically, dissolved oxygen concentrations in coastal bottom waters are high in the winter and early spring, fall steadily through the summer season when the water column is stratified, and return to winter conditions during the fall. This general pattern occurred throughout MWRA's Massachusetts and Cape Cod bays stations in 2019 (see Figures 3-10 and 3-11, above), however the oxygen minima at the Cape Cod Bay stations reached unusually low levels, four to five milligrams per liter.

Monitoring by the Massachusetts Division of Marine Fisheries, using sensors at shallow locations south of the MWRA stations, showed hypoxic and anoxic conditions in early October (Figure 6-5), which led to fish and lobster mortality in traps set in the immediate vicinity of the sensors. The hypoxic event came to an end on October 5, when strong winds from the north mixed and re-oxygenated the water column to the bottom at the most southern sensor locations.

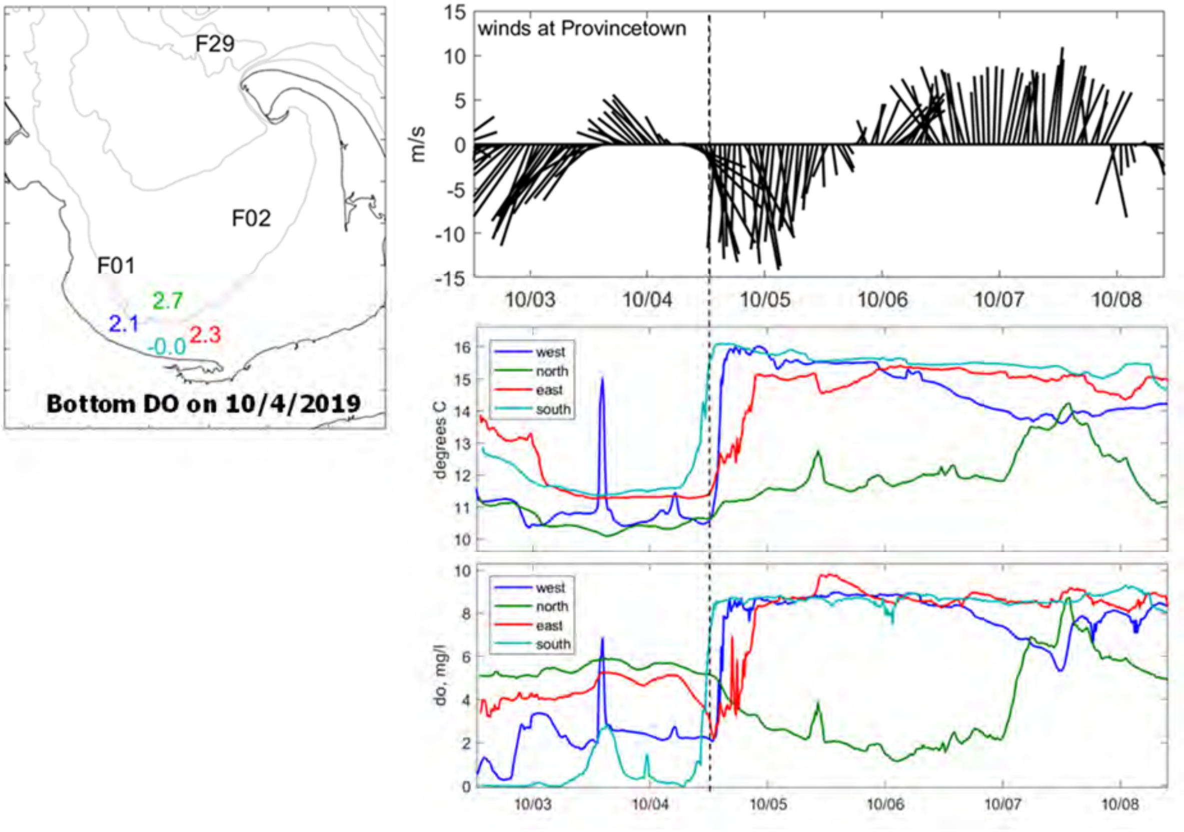

**Figure 6-5. The hypoxia and anoxia dissolved oxygen event in southern Cape Cod Bay, 2019.** (Top left) Map showing MWRA stations in black and bottom dissolved oxygen concentrations at the Department of Marine Fisheries hypoxic/anoxic site sensors on October 4; (Top right) Wind direction and intensity at Provincetown, showing strong winds from the north on October 5; (Middle) Bottom temperature at the site sensors; (Bottom) Bottom-water dissolved oxygen concentrations at the site sensors. Color coding of the lines matches site locations on the station map. DO = dissolved oxygen

This unusual hypoxia event was driven by the large August and September dinoflagellate bloom, likely *Karenia mikimotoi* (see discussion in Section 3, Water Column, above), coupled with strong and prolonged stratification in the shallow waters. Decomposition of dying dinoflagellate cells rapidly depleted oxygen levels in bottom waters. *Karenia mikimotoi* is a relative newcomer to the region, and has been known to cause fish kills in other geographic areas.

Similar strong stratification, coupled with southward coastal flow and long water resident times, have led to localized low-oxygen areas in Cape Cod Bay in the past (Jiang et al. 2007). In the fall of 2013, strong and persistent stratification resulted in relatively low dissolved oxygen levels at MWRA’s Cape Cod Bay stations, with October levels declining to less than five milligrams per liter at Station F02, similar to what occurred in 2019. Unlike 2019, the bottom waters at Station F01 during the same 2013 survey had already recovered to winter oxygenated conditions.

The effects on the fish and lobster resource in 2019 were unprecedented, leaving questions about whether changing oceanographic conditions could lead to recurring hypoxia in future years. As shown above, the Massachusetts Bay discharge has no detectable effect on nutrient levels or phytoplankton biomass at locations as far away as the shallow fish and lobster grounds. However, MWRA will continue to support its partner, the Center for Coastal Studies, as well as the Department of Marine Fisheries and the local lobstermen working in Cape Cod Bay as this issue continues to be studied.

# 7. Monitoring Plan Revisions

The MWRA permit to discharge into Massachusetts Bay includes a process for modifying the monitoring plan in response to changing conditions and past monitoring results. The monitoring plan was intended to be a “living document,” incorporating new scientific information and improved understandings from data analyses into the most appropriate continued measurements. Since the permit went into effect in September 2000, two changes to the monitoring plan have been approved, the first in 2004 and the second in 2010. Both revisions were developed in coordination with EPA, MassDEP, and OMSAP.

Plans for a third set of revisions began in 2018, when OMSAP hosted a large group of scientists, regulators, public interest groups, and interested citizens to review past monitoring results and the ongoing monitoring program. This workshop, “2300 Days at Sea: Monitoring the Impacts of the Outfall on Massachusetts Bay,” also began to identify new issues of environmental and public concern, such as microplastic debris and chemical contaminants of emerging concern.

Following the workshop, OMSAP and a series of subcommittees met throughout 2019 to develop a framework for revising the monitoring plan. With participation from OMSAP members, regulators, and the public, this framework identified and evaluated monitoring studies that could end or be reduced, based on strong evidence that the original monitoring questions had been answered and that there were no indications of environmental harm.

Following the OMSAP and subcommittee findings, MWRA proposed a series of changes to the existing monitoring plan: (1) ending monitoring of the existing suite of chemical contaminants in sediments; (2) ending monitoring of the sediment RPD, a visual assessment of the depth of the sediment-oxygenated layer, and (3) eliminating two sampling areas (off Nantasket Beach and eastern Cape Cod Bay) from monitoring of contaminant-associated liver conditions in winter flounder. These changes are expected to be approved and incorporated into a revised monitoring plan in 2020. The changes in sediment monitoring were implemented in 2020, and the changes to flounder monitoring will take place in 2021.

OMSAP is continuing to evaluate issues related to contaminants of emerging concern. Recommendations for approaches to address these concerns are expected to be issued in late 2020 or early 2021.

## Sediment Contaminants

Sediment-contaminant monitoring was included in the original monitoring plan, and since 2002, sediment contaminants have been measured every third year, in conjunction with the annual benthic infauna sampling and analyses. Contaminants measured have included toxic metals, PAHs, banned organochlorine pesticides, and PCBs. These studies have detected no increases in sediment-contaminant concentrations in response to the MWRA discharge. Instead, contaminant concentrations have slowly decreased over time. For example, since 2005, PCB concentrations in the nearfield have been consistently lower than in any earlier years of monitoring (Figure 7-1).

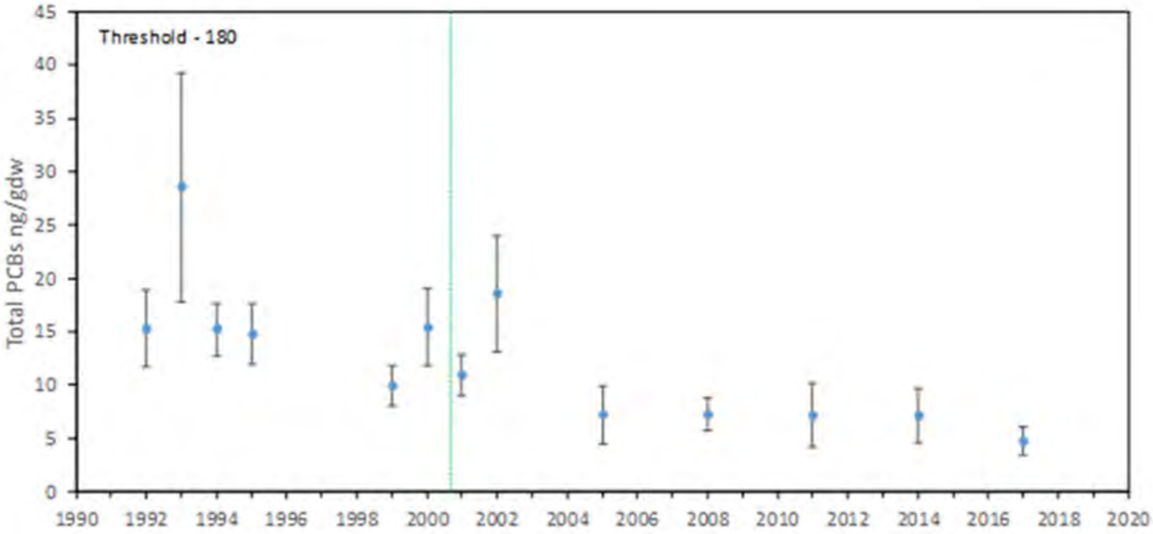

**Figure 7-1. Average total PCB concentrations in nearfield sediments, 1992–2017**. Error bars are ± one standard deviation. Dotted green line marks the outfall startup.

MWRA believes that the sediment-contaminant monitoring can end, and OMSAP has concurred. Going forward, MWRA will continue to monitor the same suite of contaminants in its effluent. These analyses use low detection limits, designed to be protective of the marine environment, and the results of these analyses are reported in the annual outfall monitoring overviews. A technical report further documenting contaminant concentrations in effluent was recently completed (Charlestra et al. 2020).

## Sediment-profile Imaging

Each August, MWRA has used a sharp-edged prism and camera at 23 stations in Massachusetts Bay to provide a rapid assessment of RPD depth and other physical and biological parameters. (See Section 4, Sea Floor, for 2019 results.) The concern during outfall planning and siting was that inputs of organic matter could lead to eutrophication and a shallower RPD.

In contrast to that concern, the nearfield RPD has become steadily deeper over the course of the MWRA monitoring program, and bottom habitats have remained healthy (Figure 7-2 and see Figure 4-8, above). The deeper RPD and good habitat quality have been strong indications that there has been no adverse effect of the discharge on the health of the bottom communities of Massachusetts Bay.

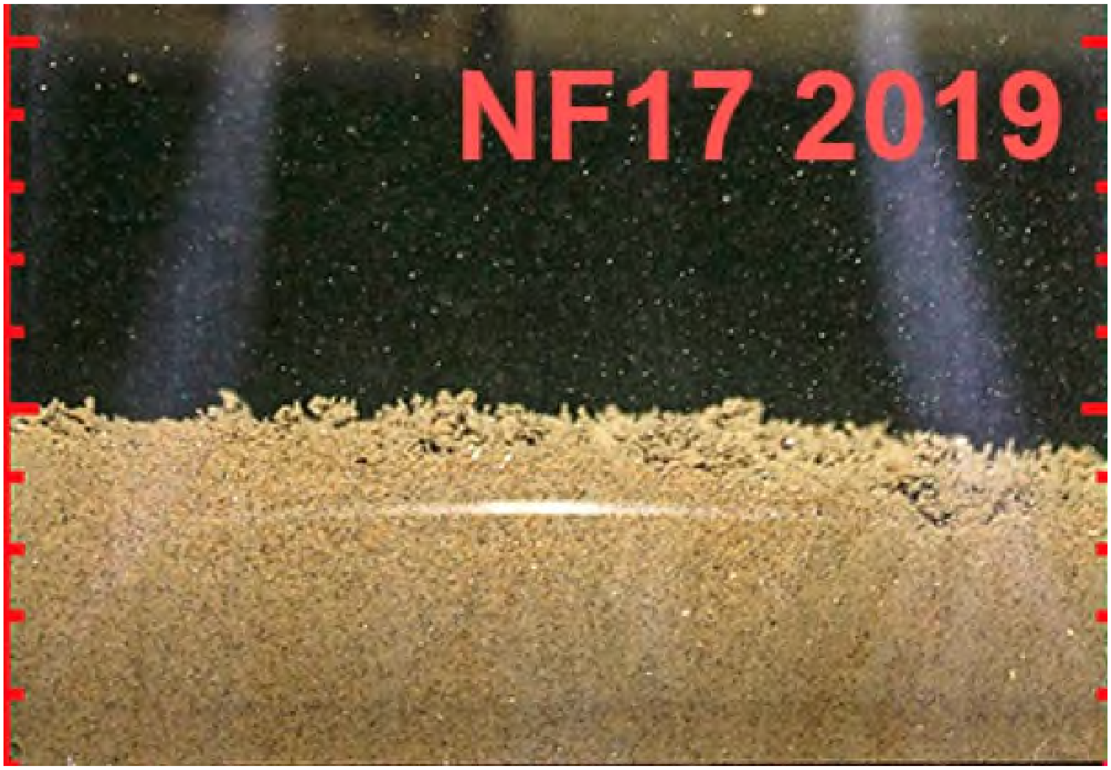

**Figure 7-2. Sediment-profile image from Station NF17, just south of the outfall, with healthy amphipod tubes in 2019.** Light-colored, oxygenated sediments extended deeper than the bottom of this image. Tick marks are one centimeter.

MWRA believes that the sediment-profile imagery measurements in Massachusetts Bay can end, and OMSAP has concurred. However, MWRA will continue to qualitatively document sediment conditions in its infauna grab samples, as has been routine but little reported. Going forward, relevant observations will be included in annual technical reports and the outfall monitoring overview.

## Winter Flounder Health

Each spring, MWRA has collected winter flounder, a popular sport fish, from Deer Island Flats in Boston Harbor, off Nantasket Beach and at the outfall site in Massachusetts Bay, and in eastern Cape Cod Bay and examined them for external health and contaminant-related liver conditions, including tumor precursors and tumors. (See Section 5, Fish and Shellfish, for 2019 results.) Prior to the 2004 monitoring plan revisions, fish were also taken from Broad Sound, just to the north of Boston Harbor in western Massachusetts Bay.

During the 1970s and 1980s, precancerous conditions and tumors were so prevalent in Boston Harbor winter flounder that flounder health became a driving impetus for the Boston Harbor Project. (See the 2018 outfall monitoring overview, Werme et al. 2019, for a discussion of the improved health of Boston Harbor winter flounder, one of the environmental success stories of the Boston Harbor Project.) The concern during the outfall planning and siting was that liver conditions observed in Boston Harbor would increase in Massachusetts Bay.

Liver tumors and tumor precursors have not increased in Massachusetts Bay. Tumors have never been observed in fish taken from the outfall site, and the incidence of CHV, the most common tumor precursor, has decreased in those fish, as well as in fish taken from Deer Island Flats, near the former MWRA Boston Harbor outfall (Figure 7-3).

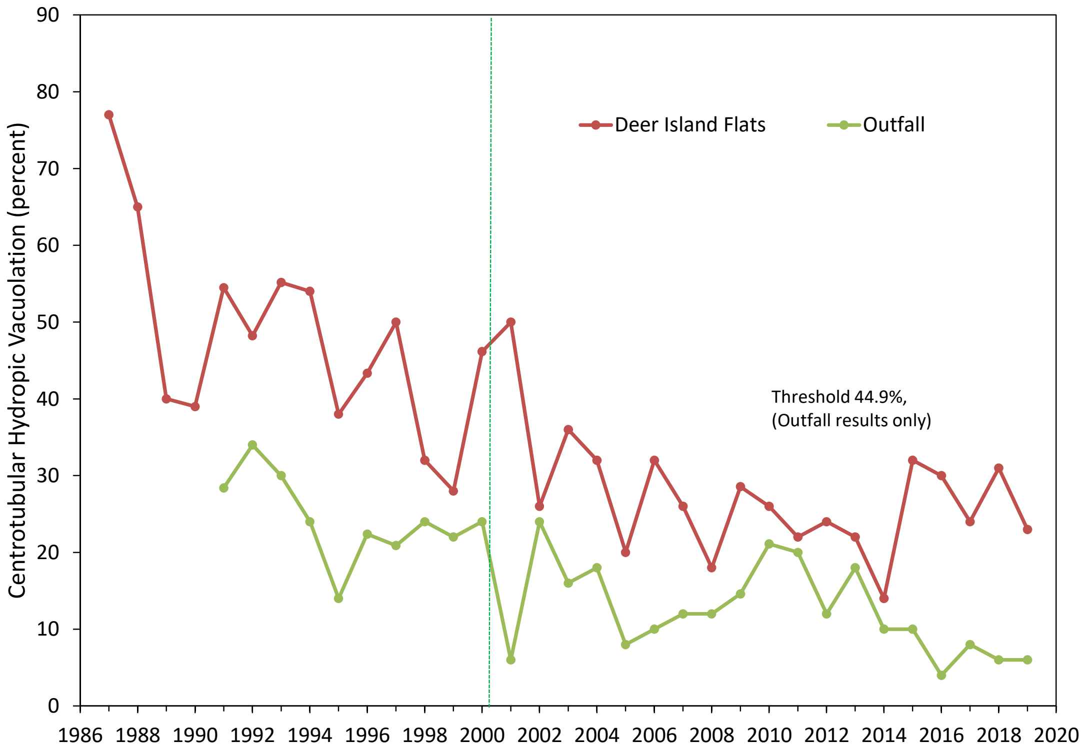

**Figure 7-3. Centrotubular hydropic vacuolation (CHV) incidence at Deer Island Flats and the Massachusetts Bay outfall over time**. Incidence at the outfall has remained well below the Contingency Plan caution-level threshold of 44.9%.

MWRA proposed ending all winter flounder health assessments, but OMSAP members felt that, because moderate levels of liver impairment persist in Boston Harbor, some continued study was warranted. They agreed instead to end monitoring of fish from off Nantasket Beach, which is just outside and to the south of Boston Harbor, and from eastern Cape Cod Bay. Incidence of CHV has slowly declined over time in fish from Nantasket Beach and has remained low throughout the course of the monitoring program in fish from eastern Cape Cod Bay (see Figure 5-3 in Section 5, Fish and Shellfish).

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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 |
| DIN | Dissolved inorganic nitrogen |
| DO | Dissolved oxygen |
| ECCB | Eastern Cape Cod Bay |
| EPA | U.S. Environmental Protection Agency |
| FF | Farfield |
| IAAC | Inter-Agency Advisory Committee |
| LC50 | 50% mortality concentration |
| MassDEP | Massachusetts Department of Environmental Protection |
| MGD | Million gallons per day |
| MWRA | Massachusetts Water Resources Authority |
| NA | Not analyzed/not applicable |
| NACWA | National Association of Clean Water Agencies |
| NB | Nantasket Beach |
| NDBC | National Data Buoy Center |
| NERACOOS | Northeastern Regional Association of Coastal and Ocean Observing Systems |
| NF | Nearfield |
| NOEC | No observed effects concentration |
| NPDES | National Pollutant Discharge Elimination System |
| OMSAP | Outfall Monitoring Science Advisory Panel |
| OS | Outfall site |
| OSI | Organism sediment index |
| PAH | Polycyclic aromatic hydrocarbon |
| PCB | Polychlorinated biphenyl |
| PIAC | Public Interest Advisory Committee |
| PSP | Paralytic shellfish poisoning |
| RPD | Redox potential discontinuity |
| SEIS | Supplemental environmental impact statement |
| SPI | Sediment-profile imagery |
| TN | Total nitrogen |

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