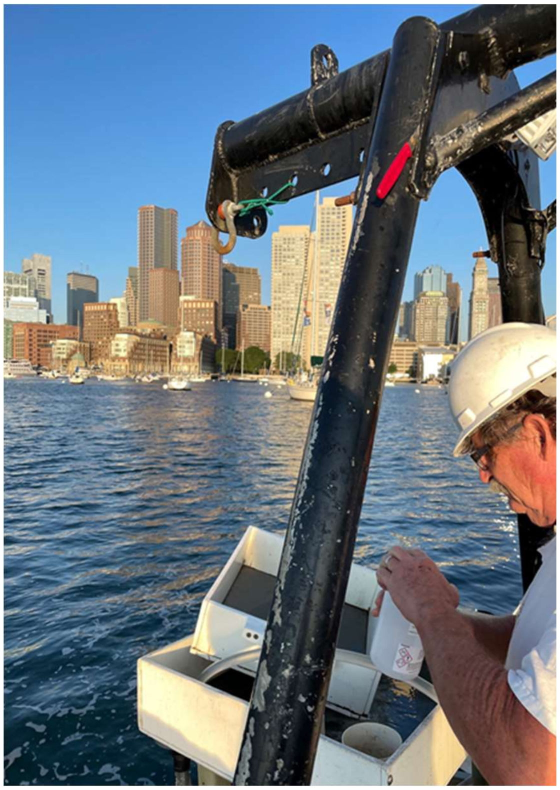

2021 Outfall Monitoring Overview

Massachusetts Water
Resources Authority
Environmental Quality
Department Report 2022-11

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Cover photos:
Top: Humpback whale in Massachusetts Bay, courtesy David Silvia.
Bottom: Seafloor sampling in Boston Harbor, courtesy Eric Nestler, Normandeau Associates, Inc.

2021
Outfall Monitoring Overview

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Massachusetts Bays National Estuary Partnership
Massachusetts Coastal Zone Management
Massachusetts Department of Environmental Protection
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Boston Harbor Now
Cape Cod Commission
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Safer Waters in Massachusetts
Save the Harbor/Save the Bay

Executive Summary

This 2021 Outfall Monitoring Overview summarizes results from the Massachusetts Water Resources Authority (MWRA) monitoring program in Massachusetts Bay and presents highlights from its companion monitoring program in Boston Harbor. MWRA began to monitor the harbor and the bay in 1991 and 1992, respectively, when aging wastewater treatment plants were discharging wastewater effluent to the harbor. In September 2000, those effluent discharges were diverted from the shallow harbor to the deeper and more open waters of Massachusetts Bay.

A National Pollutant Discharge Elimination System (NPDES) permit regulates the MWRA bay discharge. The NPDES permit requires regular monitoring of the effluent and the water column, sea floor, and fish and shellfish in the bay to ensure that any adverse effects will be detected, should they occur. A Contingency Plan attached to the permit mandates responses by MWRA and the regulatory agencies in the event that monitoring detects a potential environmental concern.

The Boston Harbor Project began in 1985, with the goal to clean up the polluted harbor. As part of the project, MWRA constructed improved facilities, including a new treatment plant. Today, wastewater from more than 40 Greater Boston communities receives secondary treatment at Deer Island Treatment Plant.

MWRA also diverted the wastewater effluent discharge from Boston Harbor to Massachusetts Bay, through a long outfall tunnel and a diffuser system. Monitoring has shown that the harbor's health has greatly improved, with only small, anticipated, and localized effects on the bay.

In 2021, MWRA marked its twenty-first year of treated wastewater discharge into Massachusetts Bay, and its Deer Island Treatment Plant earned a National Association of Clean Water Agencies Peak Performance award for no permit violations over 15 consecutive years. Over the past more than two decades, there have been appreciable improvements to the health of Boston Harbor, with no concurrent adverse effects on Massachusetts Bay. Monitoring has shown no unanticipated or meaningful effects on the water, the sea floor, or the fish and shellfish.

Deer Island Treatment Plant produces clean effluent

Producing high-quality wastewater effluent that meets the NPDES permit limits is critical to protecting the health of Massachusetts Bay. Preventing pollutants from entering the wastewater system is the first step of ensuring a clean effluent. MWRA has championed projects to lessen household hazardous waste disposal and minimize mercury discharges from hospitals and dentists. An industrial pretreatment/pollution prevention program works to ensure that many toxic contaminants never reach the treatment plant.

One of the most important measures of effluent quality is the suspended solids load, the total amount of solid material discharged over a year. The 2021 solids load was consistent with other recent years and far lower than loads before the discharge was diverted from the harbor to the bay (Figure i).

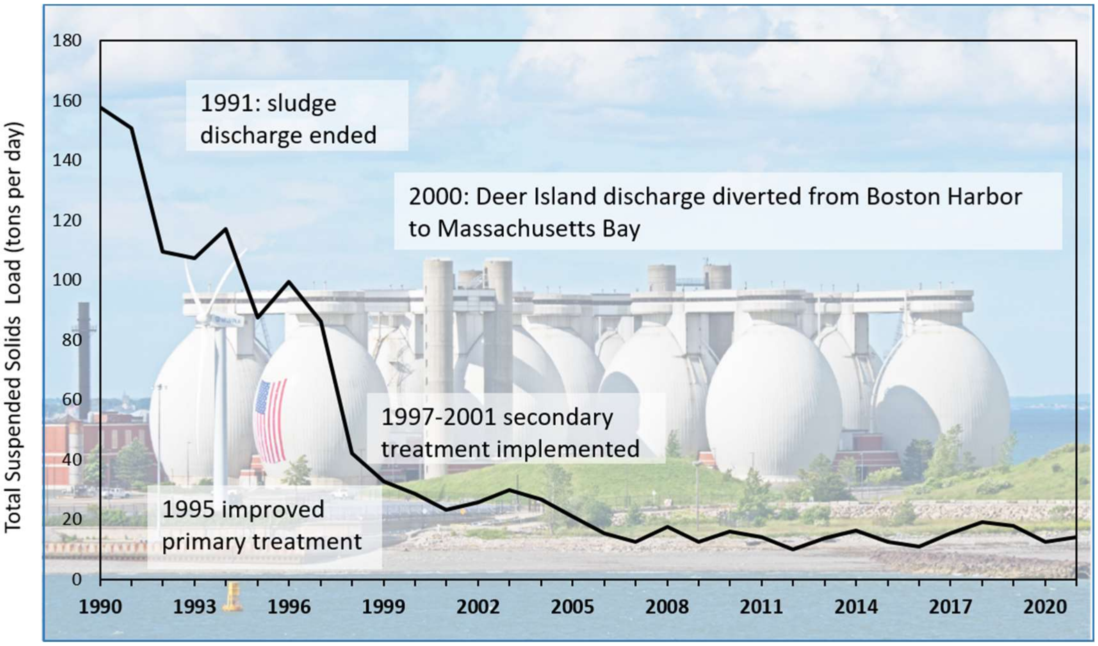


Figure i. Annual solids discharges, 1990–2021. Solids discharges decreased with each step of the Boston Harbor Project and have remained low.

One concern for any wastewater discharge is that high levels of nutrients could promote excess algal growth, a condition called eutrophication, which could result in lower dissolved oxygen levels. Total nitrogen load, a measure of nutrients in the effluent, was well below levels of concern in 2021 (Figure ii). Modeling has suggested that even greater discharges of nitrogen would have no effect on the Massachusetts Bay environment.

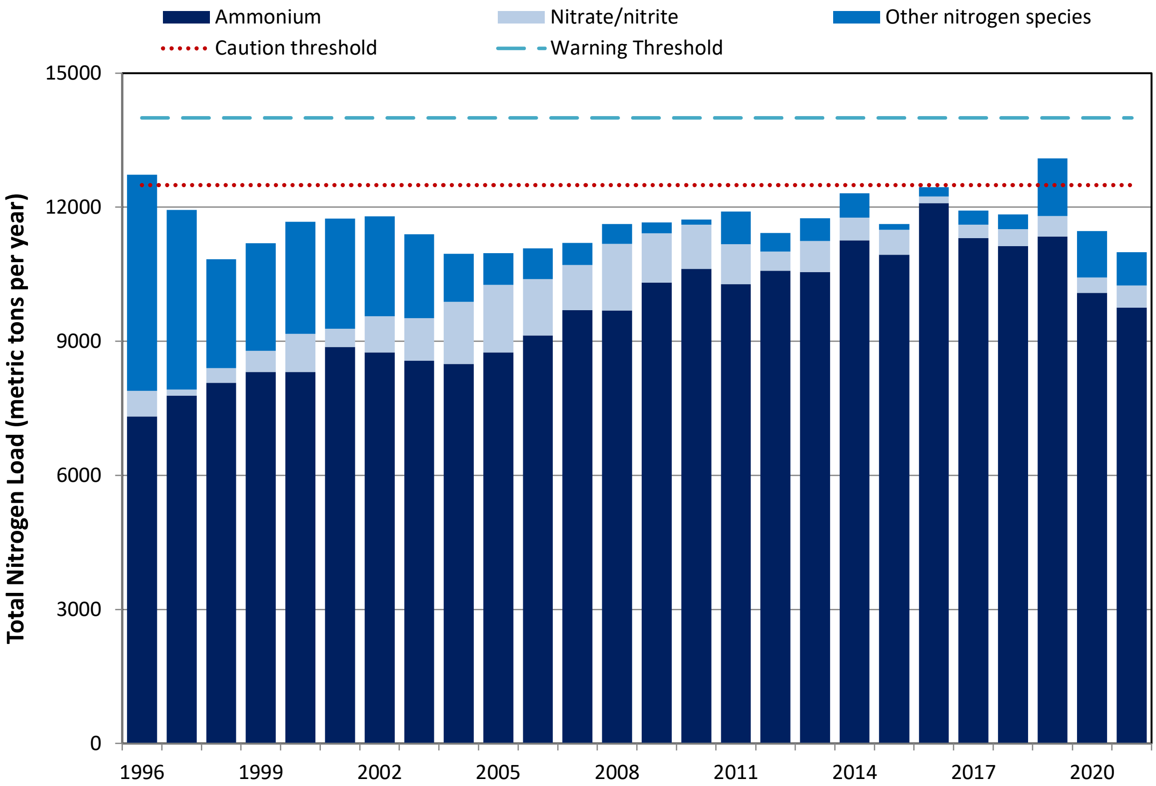


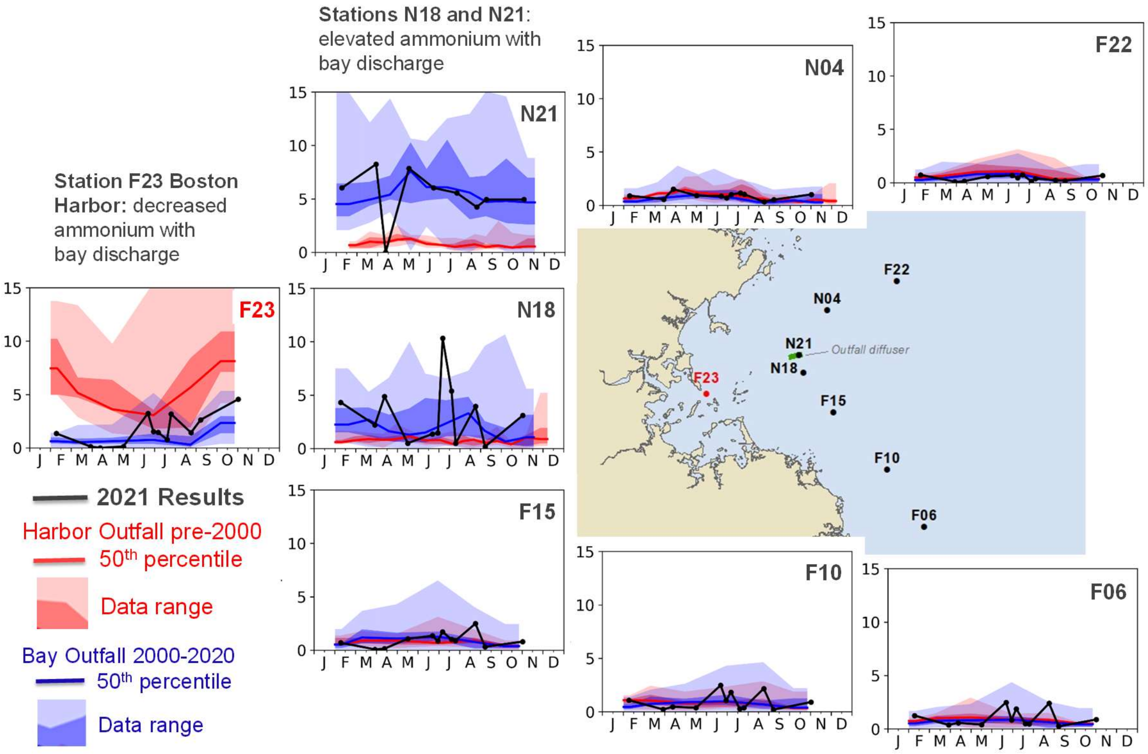
Figure ii. Annual nitrogen discharges, 1996–2021. The warning threshold, 14,000 metric tons per year, was set as the load anticipated for 2020; the caution threshold was set at 90% of the warning threshold. Actual loads have remained lower than anticipated.

Discharges have not changed algal growth or oxygen levels

Ammonium, the nutrient that makes up the largest part of the MWRA nitrogen discharge is a good effluent tracer. As had been expected when the bay outfall began to discharge, increased ammonium levels were frequently detected at stations closest to the outfall (Figure iii). Variability in ammonium measurements also increased, with higher levels measured when sampling happened to occur directly in the effluent plume, which moves with the tides and currents. Intermittent increases are sometimes also detected at greater distances.

Concentrations of ammonium have increased near the outfall but have not changed the growth of phytoplankton, the microscopic algae in the water column, or reduced dissolved oxygen concentrations.

Most importantly, increased nutrient levels have not increased the growth of phytoplankton or reduced dissolved oxygen levels in Massachusetts Bay, partially because the discharge is in deep water. During the summer months, warmer surface waters keep the discharge plume below the depth where most phytoplankton grow.


Stations N18 and N21: elevated ammonium with bay discharge

Station F23 Boston Harbor: decreased ammonium with bay discharge

Figure iii. When the discharge was diverted from Boston Harbor to Massachusetts Bay, ammonium concentrations increased near the outfall but decreased in the harbor. Appreciable increases have been seen at Stations N21 and N18, very near the outfall, while levels at Station F23 at the mouth of Boston Harbor have drastically decreased. The black line shows results from 2021. Red lines and shading show data from 1992-2000, when effluent was discharged to Boston Harbor. Blue lines and shading show data from September 2000, when the Massachusetts Bay outfall began to discharge, through 2020. For the pre-2000 and the 2000–2020 data, lines are the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range.

Seafloor communities are not affected by the outfall

Seafloor communities are influenced by types of sediments and water depth rather than by the outfall discharge.

MWRA's study of the sea floor has also shown little change related to the outfall. Bottom-dwelling animal communities are influenced by the coarseness of seafloor sediments and water depth rather than by the discharge. Concerns that the effluent might increase eutrophication, smother bottom-dwelling life, or increase sediment contaminants have been dispelled. The numbers of animals, numbers of species, and the species makeup of the communities have remained relatively constant, within the ranges of natural variability.

Fish and shellfish are healthy

MWRA tests flounder (Figure iv), lobsters, and mussels for toxic metals and pesticides, and flounder for potential health effects. Levels of toxic contaminants have declined in Boston Harbor and remained low or even declined in fish and shellfish sampled near the Massachusetts Bay outfall. Because there has been no evidence of effects of the discharge, the regulatory agencies have approved several reductions in the timing and geographic extent of monitoring.

The great improvement to flounder health is one of the most notable successes of the Boston Harbor Project. Since 2004, no tumors have been found in fish from the harbor or the bay.

MWRA examines flounder for physical abnormalities, such as fin disease, ulcers, tumor precursors, and cancerous liver tumors. Flounder health has not declined but has even improved near the Massachusetts Bay outfall and has greatly improved near the former outfall in Boston Harbor. In the harbor, better flounder health correlates well with the declines in total solids and organic material discharged.

Figure iv. Abundant flounder catch near the Massachusetts Bay outfall site in 2021. Photo credit Michael Moore, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

Boston Harbor is cleaner and still improving

While monitoring in Massachusetts Bay has shown that the outfall does not degrade the environment, Boston Harbor continues to improve since the effluent discharge was diverted from the harbor to the bay. Monitoring stations that had been subject to effluent discharge before September 2000 now exhibit healthy habitats, including thriving eelgrass, a sign of good seafloor conditions (Figure v).

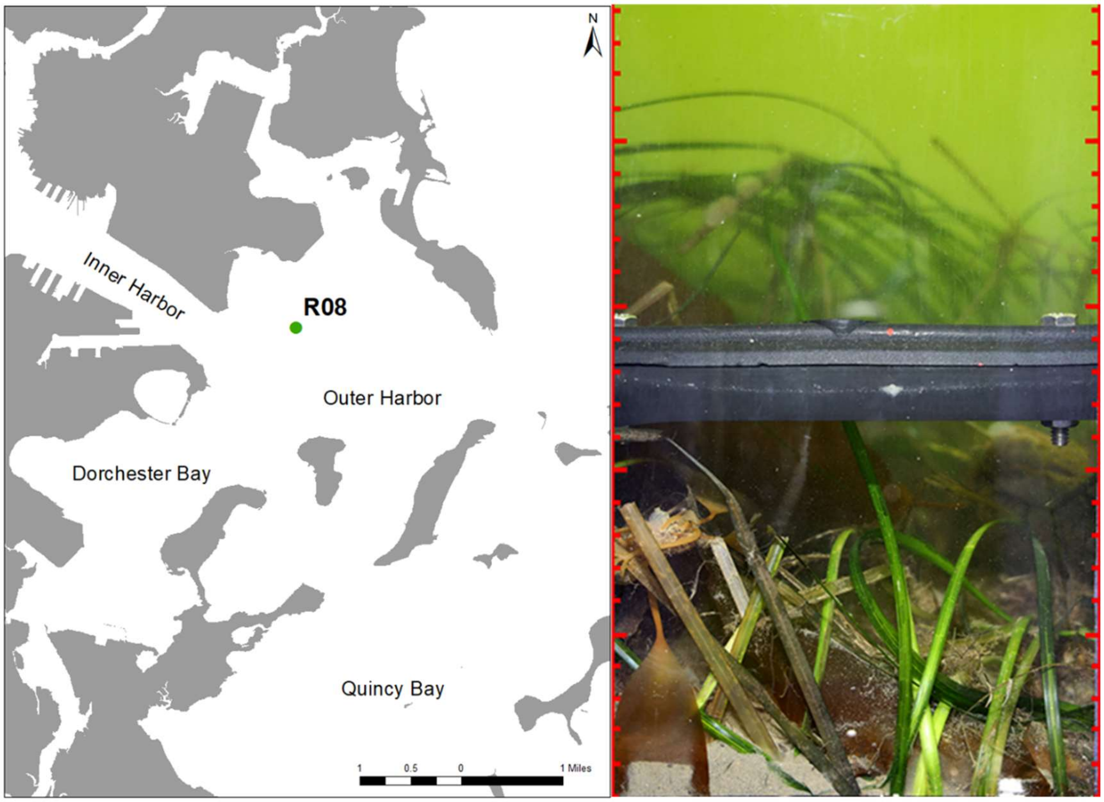


Figure v. An eelgrass bed off Deer Island, where effluent was once discharged into Boston Harbor, continued to thrive in 2021. Green dot on map shows Station R08, the location of the image. The red markings on the photo edges are centimeters.

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1. Introduction

A generation ago, Boston Harbor was known as one of the dirtiest harbors in the nation. Since 1984, the Massachusetts Water Resources Authority (MWRA) has worked to reverse that reputation, minimizing adverse effects of municipal wastewater discharges on the marine environment through a vigorous pretreatment program, a carefully maintained treatment plant, and vigilant effluent and environmental monitoring. One of the most important steps in MWRA's Boston Harbor Project came in September 2000, when the MWRA wastewater effluent discharge was diverted from a shallow-water discharge in Boston Harbor to deeper, more open waters in Massachusetts Bay. The outfall operates under a National Pollutant Discharge Elimination System (NPDES) permit, jointly issued by the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MassDEP). The independent Outfall Monitoring Science Advisory Panel (OMSAP) assists EPA in addressing scientific questions about potential environmental effects of the outfall on Massachusetts Bay.

The NPDES permit ensures that wastewater discharge does not degrade the environment in Massachusetts Bay. It requires MWRA to measure effluent quality before discharge and to monitor the water, sediments, and marine life that could be affected in Massachusetts Bay. A Contingency Plan, which is attached to the permit, requires comparing measured conditions against "caution" and "warning" thresholds. If a caution threshold is exceeded, MWRA must investigate the issue, while a warning threshold is a higher level of concern that could require responsive action. Background information about the monitoring program (Werme et al. 2012), the most current monitoring plan (MWRA 2021) and Contingency Plan (MWRA 2001), past plans and overviews, and study-specific technical reports are available on MWRA's technical report list, http://www.mwra.state.ma.us/harbor/enquad/trlist.html.

This annual Outfall Monitoring Overview report fulfills a requirement of the NPDES permit that MWRA produce an annual summary of monitoring results for Massachusetts Bay. Annual overviews also report on special studies, conducted in response to permit conditions and environmental concerns, often in cooperation with other agencies. In 2021, MWRA documented changing water temperatures in the Gulf of Maine and studied regional dissolved oxygen levels, conditions that are important to understanding the complex harbor and bays system. In addition to studies of possible outfall effects, MWRA continued to monitor the influent for the virus that causes COVID-19 and posted daily results on its website.

This annual overview also reports on results relevant to the Stellwagen Bank National Marine Sanctuary and presents some findings from MWRA's in-house Boston Harbor monitoring program. Harbor monitoring documents the success of the Boston Harbor Project, while Massachusetts Bay monitoring ensures that no new harm occurs offshore.

2. Effluent

Despite the continuing challenges of the COVID-19 pandemic, Deer Island Treatment Plant continued to operate as designed through 2021, earning MWRA the National Association of Clean Water Agencies (NACWA) Platinum 15 Peak Performance Award. This NACWA award recognizes facilities with 100% compliance with effluent permit limits over 15 consecutive years.

2021 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 in determining wastewater flows and contaminant concentrations in the wastewater effluent. The Boston area received 52 inches of rain in 2021, well above the 38 inches of rain in 2020 and also above the 1990–2021 average (Figure 2-1).

MWRA's pretreatment program and secondary sewage treatment minimize contaminants, such as pathogens, organic material, and toxic compounds, that are discharged into Massachusetts Bay.

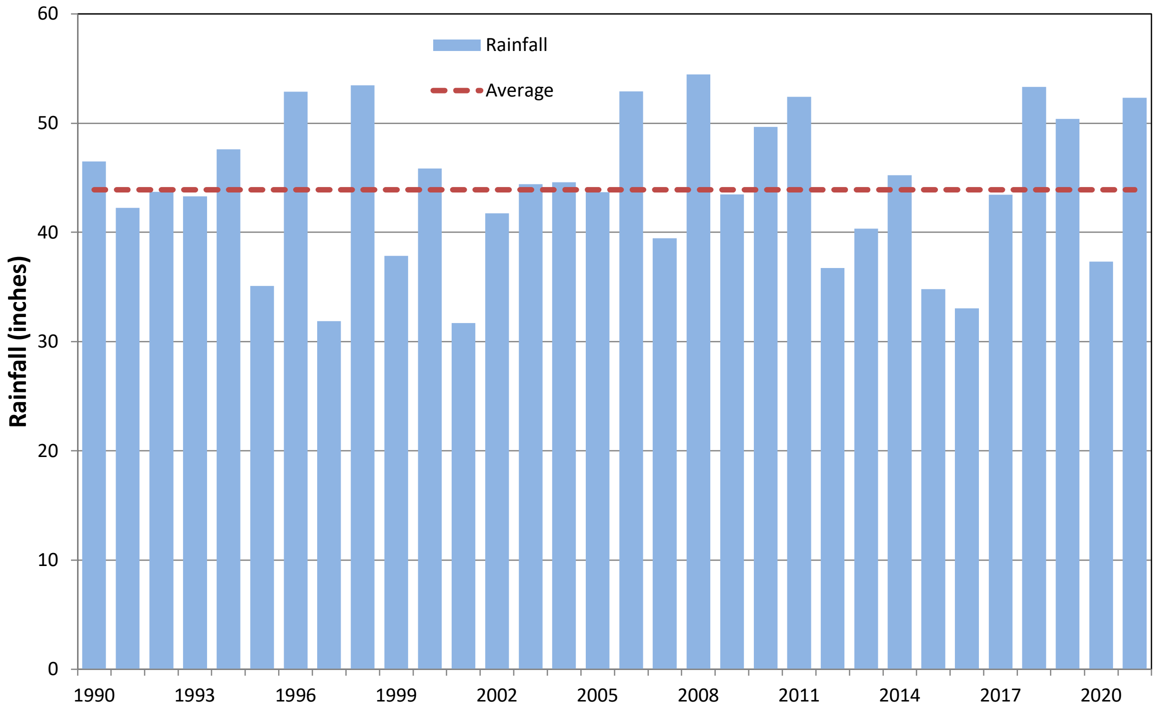


Figure 2-1. Annual and average rainfall in Boston, 1990–2021. Rain data are from the National Weather Service rain gauge at Boston Logan International Airport.

With high rainfall, effluent flow in 2021 was also higher than the flows in 2019 and 2020 (Figure 2-2). As in past years, almost all the flow in 2021 received full secondary treatment, with only trace amounts of primary-treated effluent blended with fully treated effluent prior to discharge (Figure 2-3). (Primary treatment is a physical process, which involves removal of solid material through settling; secondary treatment includes bacterial decomposition and removes many more pollutants. All effluent is disinfected before discharge.)

Blending of primary-treated effluent occurs when inflow to the treatment plant exceeds what the secondary treatment process is designed to handle. Excess flow is diverted around the secondary process and blended back into full secondary-treated effluent before disinfection and discharge. This process allows more wastewater to be treated, preventing street flooding and sewage backups into homes and businesses, while also relieving pressure on the secondary treatment system and preventing washout of the beneficial bacteria that are part of that process. Blending occurs only during heavy rain, and blended flows fully meet permit limits. Massachusetts state regulations require MWRA to notify regulators and the public whenever blending occurs.

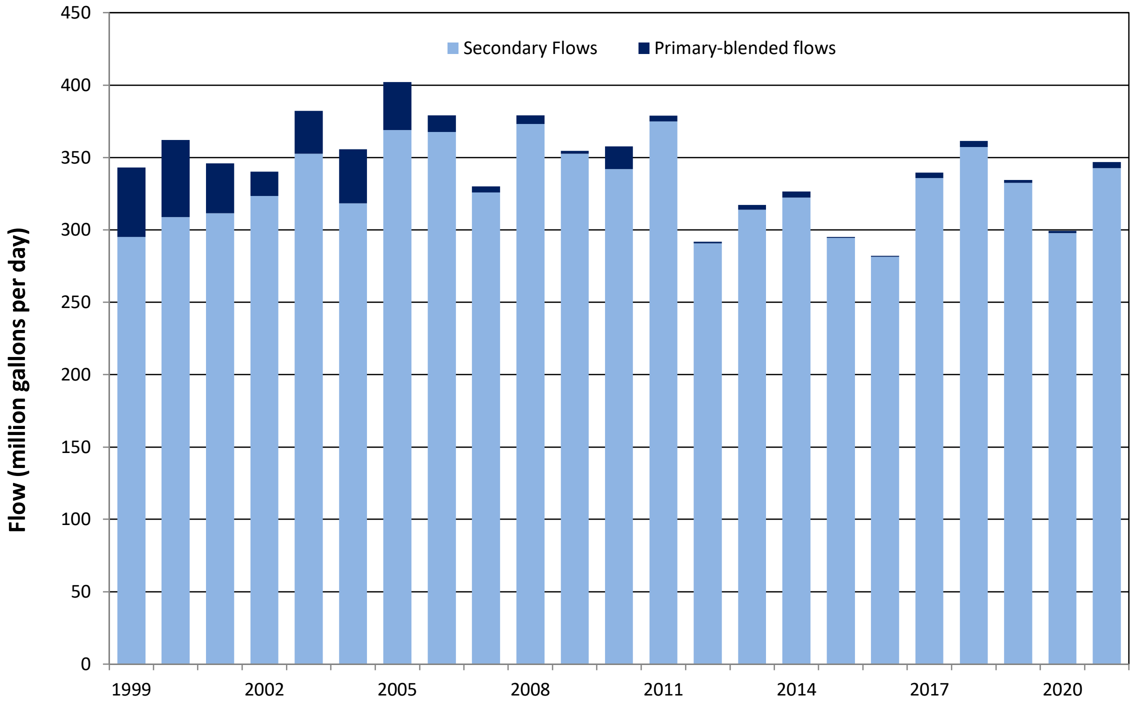


Figure 2-2. Annual full secondary-treated effluent flows and primary-blended flows, 1999–2021. 1999 was the year in which all MWRA flow began to be treated at Deer Island. During large storms, flow exceeding the secondary capacity of the plant is diverted around the secondary process; these primary-treated flows are blended into fully treated flows before disinfection and discharge. Blended flows meet all permit limits.

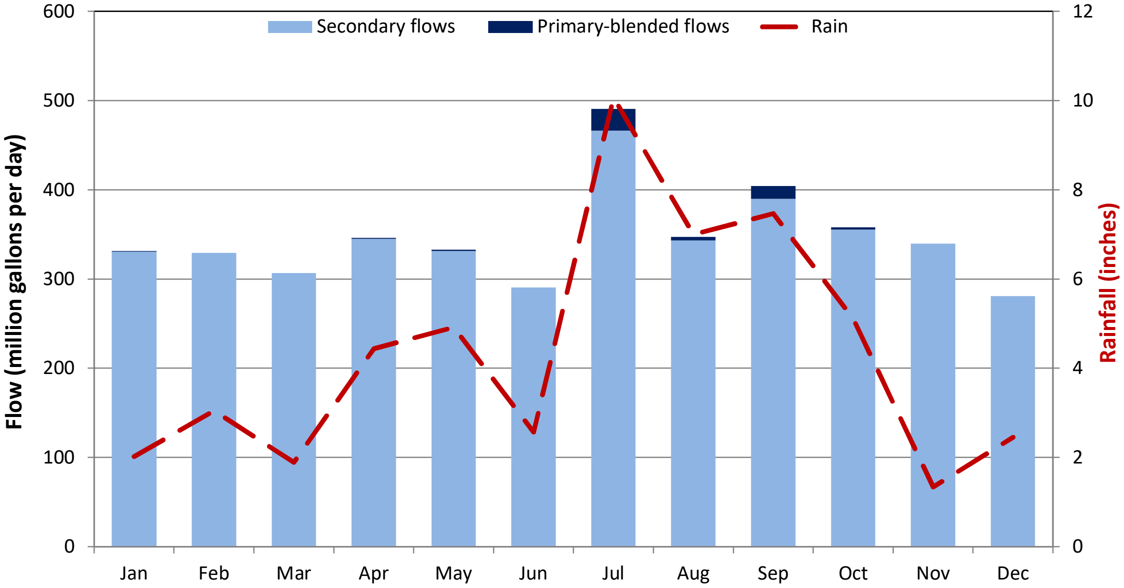


Figure 2-3. Monthly full secondary-treated and primary-blended flows and rainfall during 2021. During large storms, flow exceeding the secondary capacity of the plant is diverted around the secondary process; these primary-treated flows are blended into fully treated flows before discharge.

The total suspended solids load to Massachusetts Bay in 2021 was about 14.1 tons per day, well below the levels discharged into Boston Harbor in the 1990s (Figure 2-4). In recent years, the total solids load has averaged only about 10% of what had been discharged to Boston Harbor in 1990–1991, and variability in the suspended solids load has corresponded to variability in rainfall and, therefore, effluent flow.

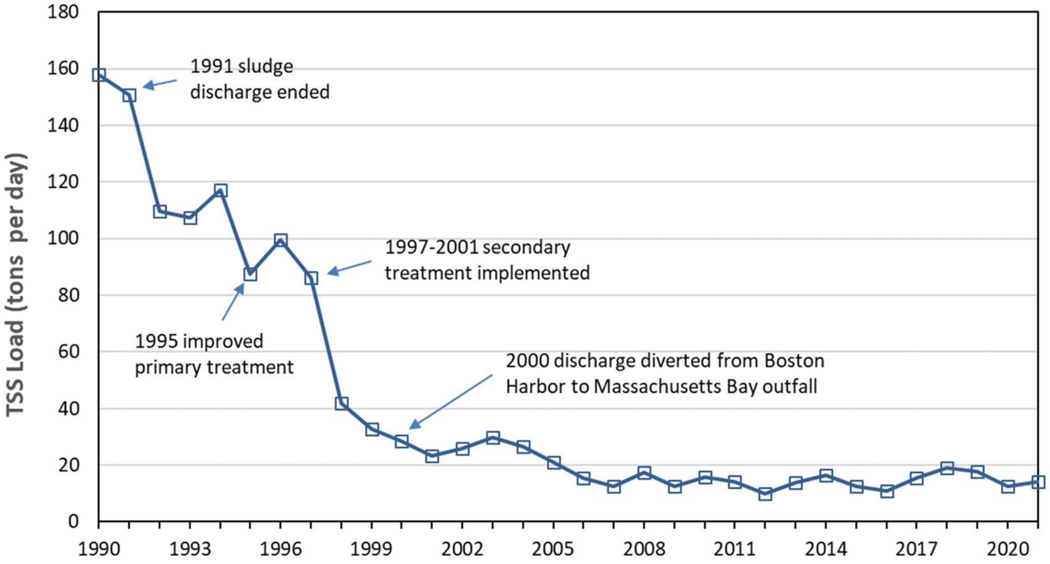


Figure 2-4. Annual solids discharges, 1990–2021. Solids discharges decreased with each accomplishment of the Boston Harbor Project and have remained low.

Biochemical oxygen demand (BOD), the amount of oxygen consumed by microorganisms as they break down organic matter, also remained well below levels that would be expected to affect dissolved oxygen in the environment. MWRA has consistently met its BOD permit limit.

MWRA also monitors the effluent for fecal coliform, a bacterial indicator for pathogens that can make shellfish unhealthy for humans to eat. Levels of fecal coliform in the effluent are well below permit limits (Figure 2-5). MWRA also monitors fecal coliform in Massachusetts Bay, and results at all locations, even those closest to the outfall, meet the stringent shellfishing limits set by the state.

Deer Island Treatment Plant removes almost all the solids from sewage effluent and more than 75% of the biochemical oxygen demand that would deplete dissolved oxygen.

Fecal coliform, a bacterial sewage indicator, remains well below permit limits.

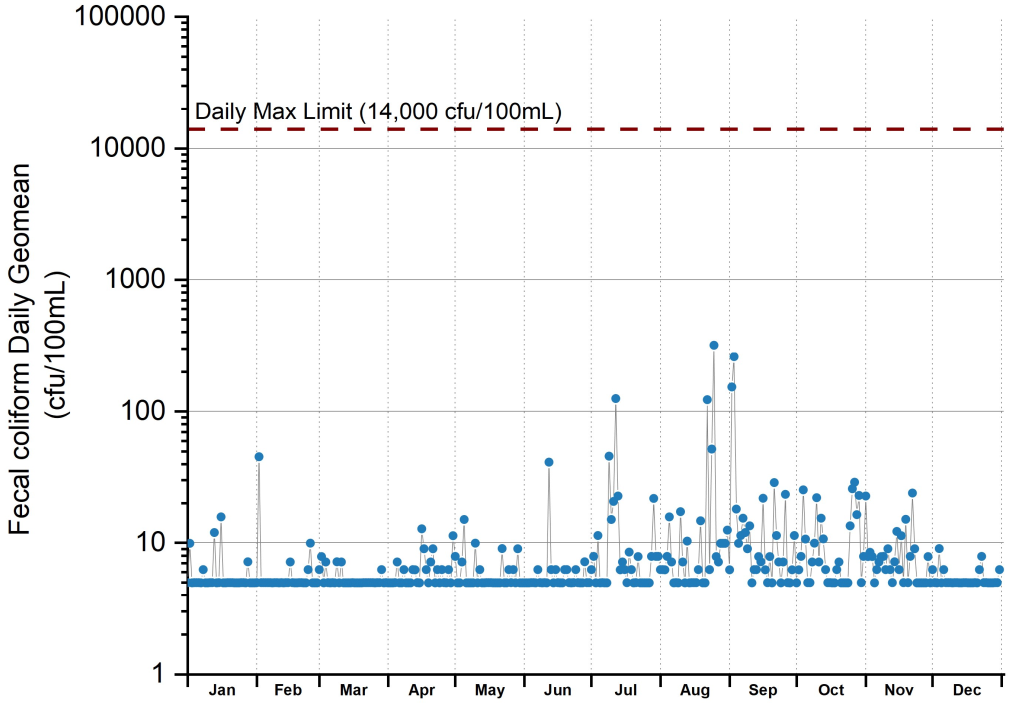


Figure 2-5. Daily geometric mean of fecal coliform counts in Deer Island effluent, 2021. Fecal coliform counts in the effluent were well below the 14,000 colonies per 100 milliliter permit limit throughout the year. The higher counts in the summer were likely due to the extremely high rainfall; at higher flows, disinfection can be less effective. Note the y-axis log scale.

MWRA's permit and monitoring plan include reporting requirements for nutrients and some toxic metals and organic compounds. Nutrient measurements include individual components of total nitrogen (ammonium, nitrate, and nitrite) and other nutrients (for example, total phosphorus and phosphate). Metals include, for example, lead and mercury, and organic compounds include selected pesticides, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs).

The total nitrogen load for 2021 was just under 11,000 metric tons, well below the Contingency Plan caution threshold of 12,500 metric tons (Figure 2-6). The caution threshold was set conservatively at about 90% of the warning threshold, 14,000 metric tons. The caution threshold was exceeded once, in 2019; however, scenario simulations with the Bays Eutrophication Model suggest that even loads up to 24% higher than the higher warning threshold would not have adverse effects (Deltares 2022). MWRA updates its report on potential nitrogen-removal strategies annually (most recently in Ellis-Hibbett and Hunt 2022).

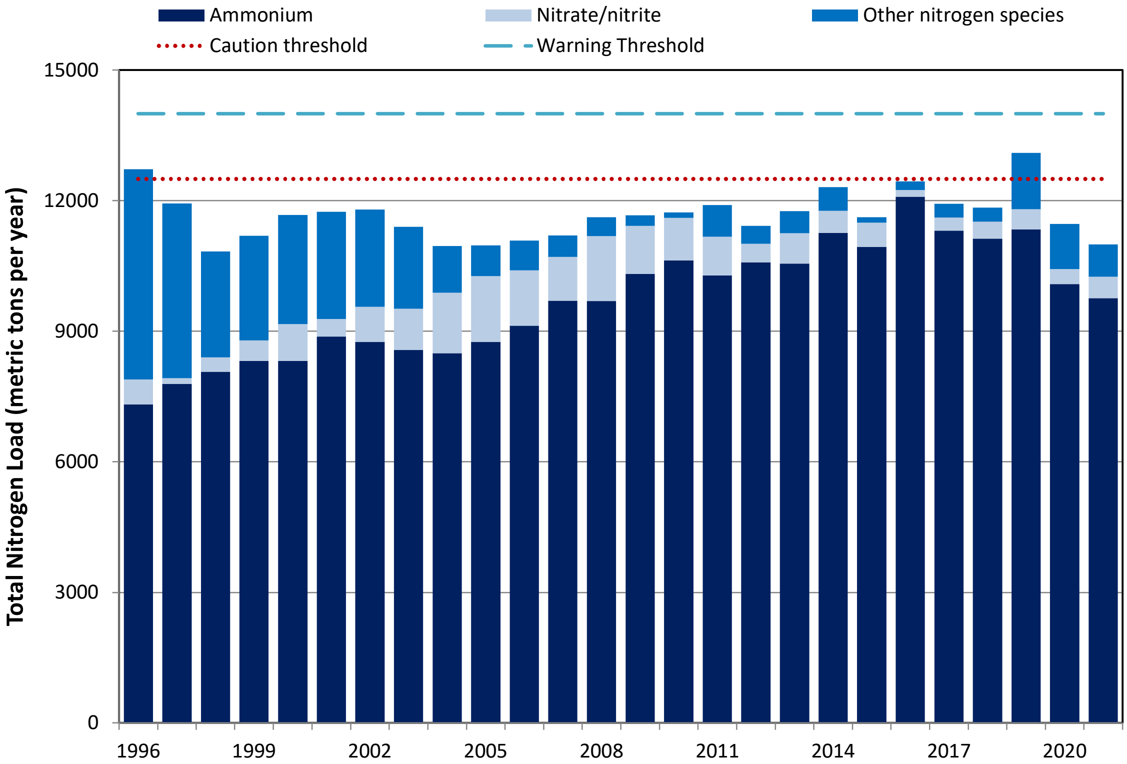


Figure 2-6. Annual nitrogen discharges, 1996–2021. The warning threshold, 14,000 metric tons per year, was set as the load anticipated for 2020; the caution threshold was set at 90% of the warning threshold. Actual loads have remained lower than anticipated.

The portion of the effluent total nitrogen load composed of ammonium, a component readily taken up by phytoplankton, steadily increased over many years of monitoring, but has decreased since 2016. The ammonium load in 2021 was the lowest measured since 2008. The increase had been a result of the treatment processes for both biosolids and effluent; reasons for the recent decreases are not yet clear.

Metals loads remained low in 2021 (Figure 2-7). 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).

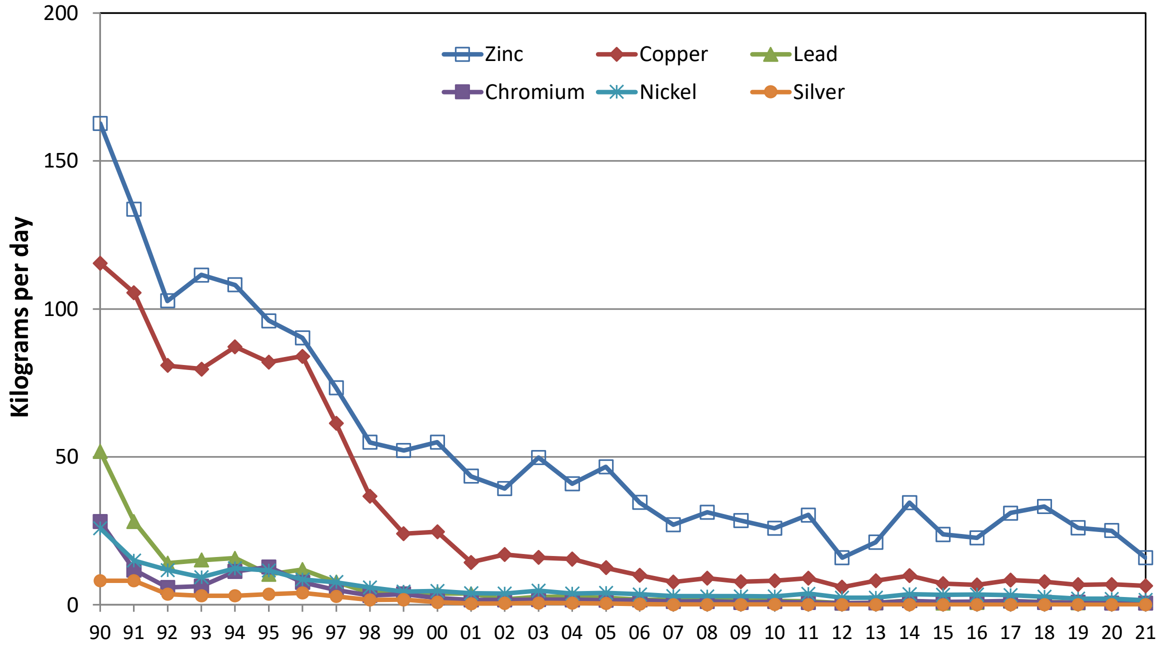


Figure 2-7. Annual metals discharges, 1990–2021. Source reduction, industrial pretreatment, and secondary treatment have dramatically decreased metals loads.

Total loads of all metals remained small percentages of what had been anticipated during planning for the Massachusetts Bay outfall. Except for copper, metals meet water quality standards prior to discharge; on discharge, 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. Silver, once considered a good effluent tracer, is now often at levels below detection limits, a result of the decline in film-based photography, as well as secondary treatment.

Discharges of organic contaminants have varied slightly from year to year but have been well below loads historically discharged into Boston Harbor. Annual PAH loads, for example, remained lower than 100 kilograms, as they have for recent years (Figure 2-8), a strong contrast with the 3,000 kilograms of PAHs that were estimated to be discharged in sewage effluent into Boston Harbor in 1991 (Rex et al. 1992). PAH concentrations now meet water quality standards at discharge, and loads in 2021 were the lowest measured of any monitoring year. For some other organic compounds, such as 4,4'-DDE, one of the most prevalent breakdown products of the pesticide DDT, the effluent data show evidence of the very slow declines anticipated after it was banned along with other persistent substances.

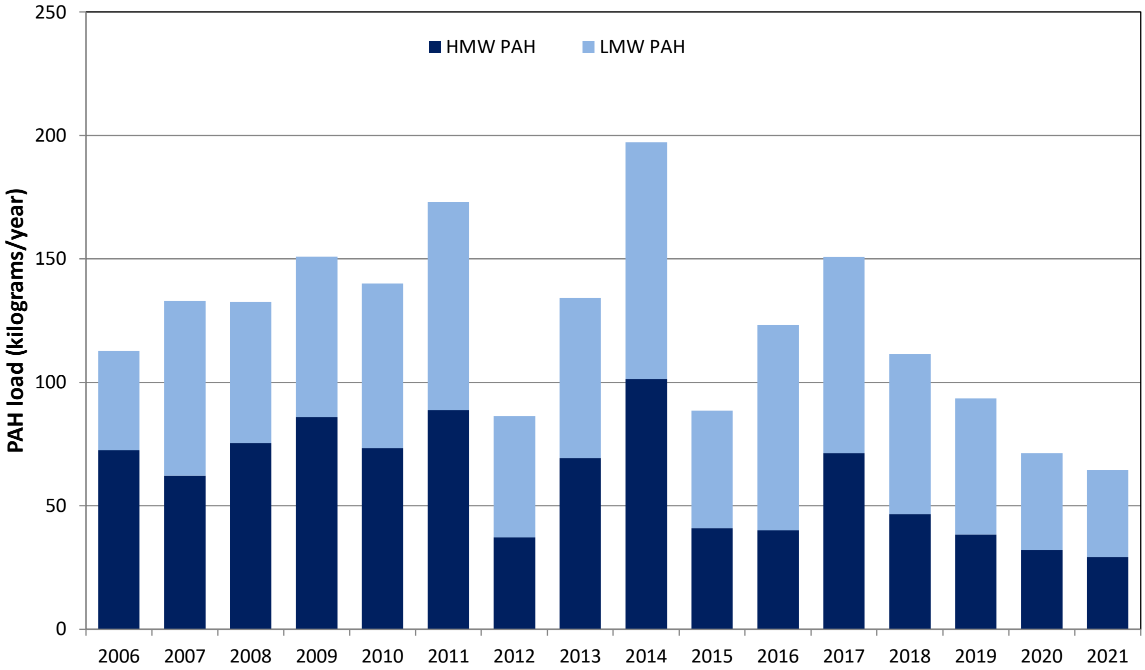


Figure 2-8. High- and low-molecular weight PAH discharges, 2006–2021. (A different analytical method was used before 2006, so those data are not directly comparable to the 2006–2021 results.) High molecular weight PAHs originate primarily from petroleum sources; low molecular weight PAHs are formed during combustion. Discharges have remained lower than those that would cause environmental concern, and loads in 2021 were the lowest measured in any monitoring year.

Contingency Plan Effluent Thresholds

There were no effluent Contingency Plan exceedances in 2021 (Table 2-1). Exceedances of effluent permit conditions have been rare, and none have occurred over the past 15 years. The total nitrogen caution level, which is not a permit condition but set in the Contingency Plan, was exceeded in 2019, but the 2021 load was among the lowest ever measured.

Table 2-1. Contingency Plan threshold values and 2021 results for effluent monitoring.

Parameter	Baseline	Caution Level	Warning Level	2021 Results
Permit Condition and Contingency Plan 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, >456 µg/L monthly	Not exceeded
Suspended solids	NA	None	>45 mg/L weekly >30 mg/L monthly	Not exceeded
cBOD	NA	None	>40 mg/L weekly, >25 mg/L monthly	Not exceeded
Acute toxicity	NA	None	LC50 <50%	Not exceeded
Chronic toxicity	NA	None	NOEC <1.5% effluent	Not exceeded
PCBs	NA	Aroclor>0.045 ng/L	None	Not exceeded
Plant performance	NA	5 violations/year	Compliance <95% of the time	100% compliance
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	10.995 mtons

NA = not applicable
cBOD = carbonaceous biological oxygen demand
LC50 = 50% mortality concentration
NOEC = no observable effect concentration
PCB = polychlorinated biphenyl
mtons – metric tons (1,000 kilograms)
Plant performance = compliance with permit conditions

3. Water Column

Water-column monitoring evaluates physical oceanographic processes (freshwater inflow, temperature, salinity, winds, and ocean currents), water quality (nutrients, phytoplankton biomass, and dissolved oxygen), 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.

Water-column monitoring is primarily designed to protect Massachusetts Bay from eutrophication, a potential result of excess nutrients. Monitoring has focused on nutrients and potential eutrophication, because the effluent loads of other pollutants, such as organic material, pathogens, and toxic contaminants, are too low to expect any potential effects. Eutrophication occurs when phytoplankton growth is overstimulated, which could lead to lower levels of dissolved oxygen or stimulate nuisance or toxic algal blooms. One nuisance phytoplankton species, *Phaeocystis pouchetii*, was a focus in past years but has been shown to vary in response to physical conditions rather than the outfall and is no longer considered a concern. Other potentially toxic species, particularly *Alexandrium catenella* and *Pseudo-nitzschia* spp., continue to be evaluated.

Nine surveys are conducted from February through October of each year. Five stations are in the nearfield (a 12- by 10-kilometer area centered on the outfall, where some effects of the effluent were expected and have been observed), and nine are in the more distant farfield, including the mouth of Boston Harbor, Cape Cod Bay, and near Stellwagen Bank National Marine Sanctuary. Additional surveys may be triggered by elevated abundance of the potentially toxic dinoflagellate *Alexandrium catenella*. These *Alexandrium* Rapid-Response Study surveys (Libby et al. 2013) provide in situ hydrographic data and water samples for measuring nutrients and *Alexandrium* abundance at up to 19 stations.

The water-column monitoring program benefits from collaboration with the Center for Coastal Studies in Provincetown, Massachusetts, which samples the three water-column stations in Cape Cod Bay and near 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.

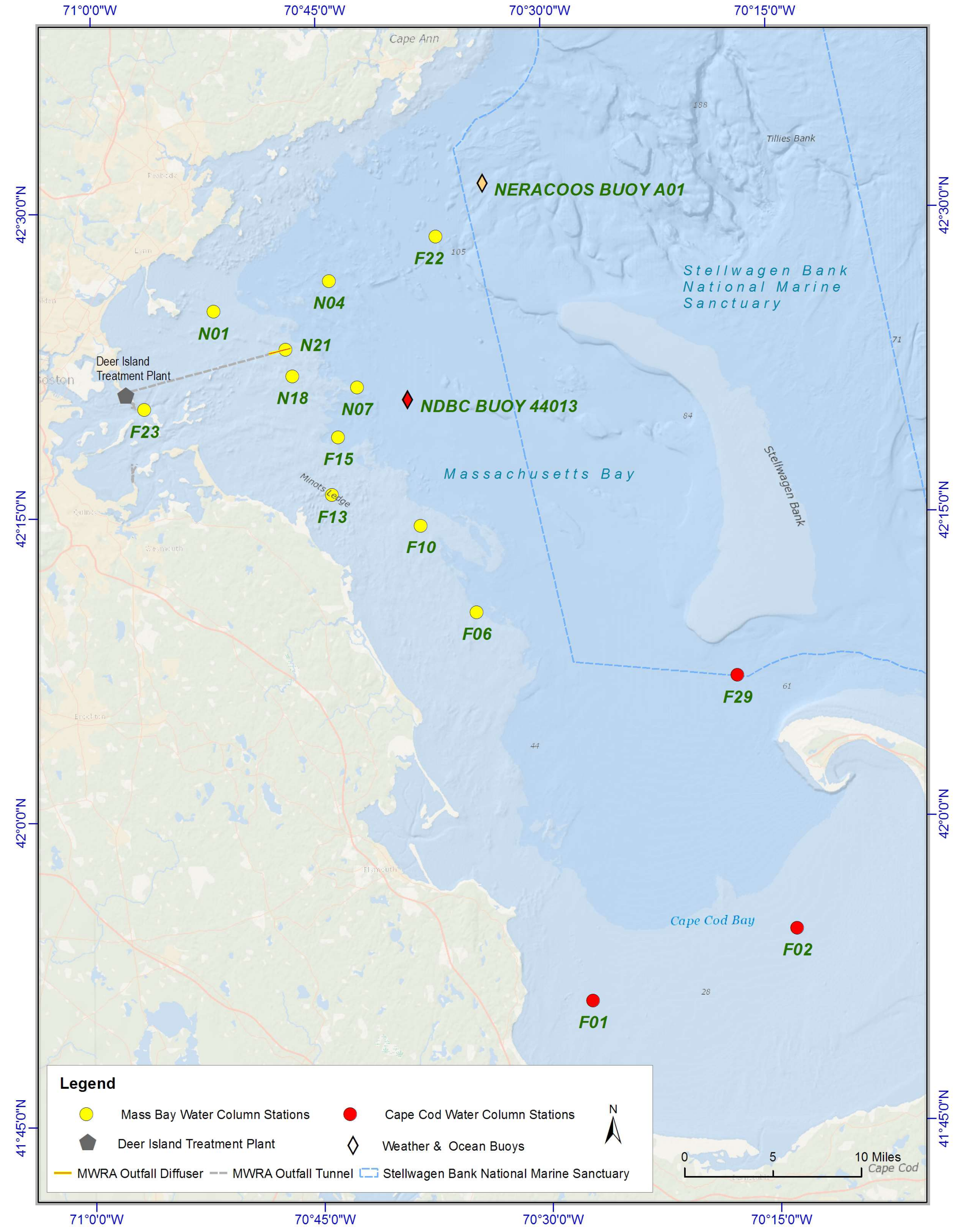


Figure 3-1. Water-column monitoring stations and instrumented buoys in Massachusetts and Cape Cod Bays. Data are obtained from surveys, the NERACOOS A01 and NDBC 44013 buoys, and satellite imagery. Also shown are the outfall and the Stellwagen Bank National Marine Sanctuary.

The surveys are supplemented by measurements on two instrumented buoys: the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) Buoy A01 off Cape Ann, and the National Oceanic and Atmospheric Administration's National Data Buoy Center (NDBC) Buoy 44013 in central Massachusetts Bay. The National Aeronautics and Space Administration provides Moderate Resolution Imaging Spectroradiometer satellite imagery of chlorophyll fluorescence, a measure of phytoplankton biomass.

COVID-19 Pandemic Protocols

As the COVID-19 pandemic continued in 2021, field teams were reduced from six to four during the February, March, and April surveys. These reductions meant that there was no dedicated marine mammal observer, and some nutrient measurements could not be completed. A marine mammal observer was allowed on board the monitoring vessel in May (Figure 3-2), and beginning in June, a full complement of scientists was able to complete all planned sampling and shipboard analyses. None of the reductions affected calculation of Contingency Plan threshold parameters.

Figure 3-2. Humpback whale observed near the outfall in May 2021. Relaxing of COVID-19 protocols allowed for the return of a dedicated marine mammal observer on the monitoring vessel. This whale was first observed from Station N21 at the outfall and again while underway to Station F22 near the Stellwagen Bank National Marine Sanctuary. Photo credit David Silvia, Plymouth, Massachusetts.

Physical Conditions

Physical properties of the water column in Massachusetts Bay, such as temperature and salinity, are driven by river flow and the larger patterns of currents in the Gulf of Maine.

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 throughout the region. Information about physical conditions has proven key to interpreting the annual water-column monitoring data.

After a dry 2020, which continued into early 2021, the summer of 2021 was rainy (see Figure 2-1, page 2), with the highest summer river flows measured in the past 30 years (Figure 3-3; Libby et al. 2022). Year-to-year variability in rainfall and the influx of freshwater in river discharges can exert large effects on conditions in the bay.

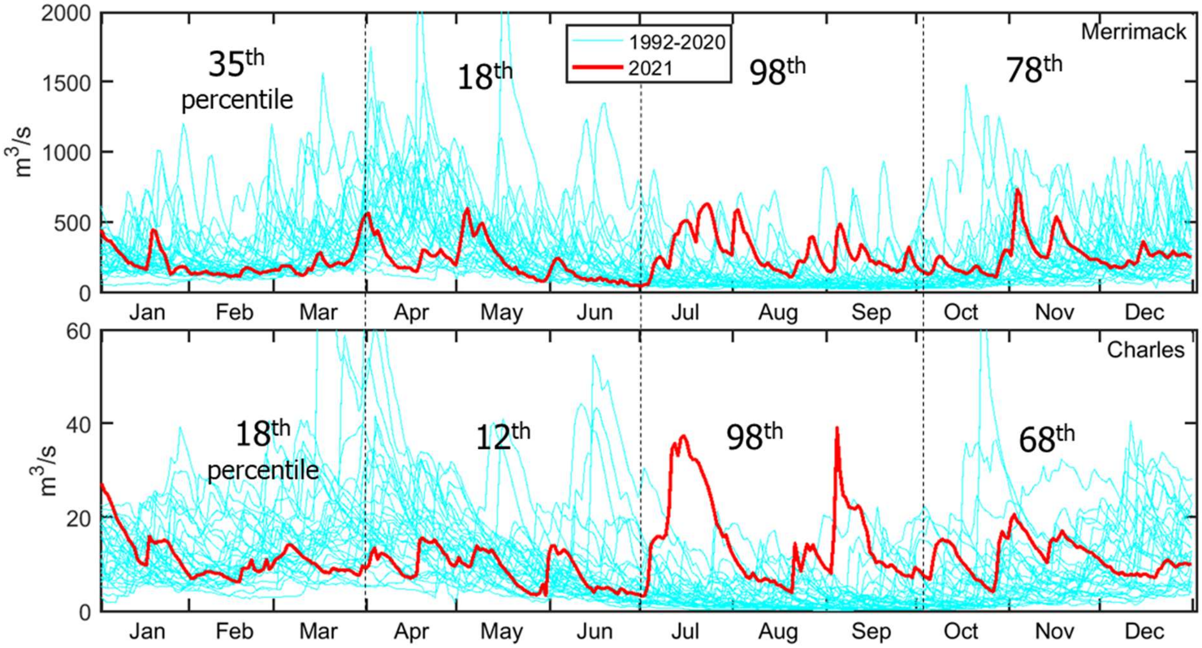


Figure 3-3. Flows of the Merrimack (top) and Charles (bottom) rivers. The Charles River flows into Boston Harbor. The larger Merrimack River flows influence Massachusetts Bay after flowing into the Gulf of Maine just south of the New Hampshire border. Red lines are 2021 data. Results from 1992–2020 are in light blue. The quarterly percentiles represent the 2021 flows in comparison to the entire record.

Average annual air temperature was somewhat cooler than in recent years, but surface- and bottom-water temperatures were warm during most survey months, for example, at Station N18 just south of the outfall (Figure 3-4, top two panels). Surface temperatures at Station F13 off the coast of Boston's South Shore reached 23.3 degrees C, about a half a degree warmer than any past temperature measurement made throughout the monitoring program.

Surface- and bottom-salinity at Station N18 were high during the first half of the survey season, but dropped to below-average levels in July (Figure 3-4, bottom panels). These drops in salinity were directly related to the high summertime river flows, a result of the rainy summer months.

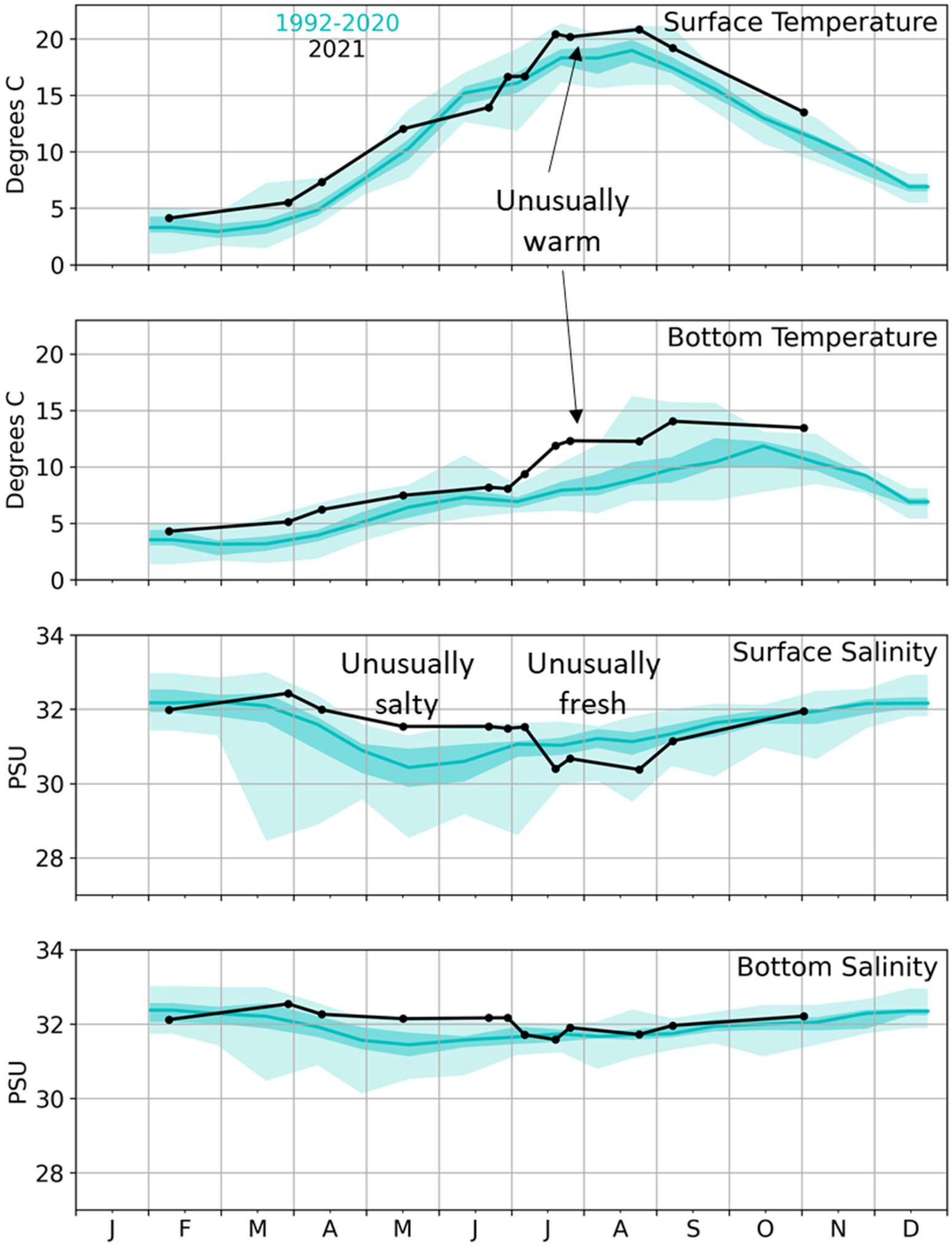


Figure 3-4. Surface- and bottom water temperature and salinity at Station N18 just to the south of the outfall in 2021 compared to prior years. The black points and lines are results from 2021; the blue lines and shading are results from 1992–2020: the line is the 50th percentile, dark shading spans the 25–75th percentiles, and the light shading spans the range. PSU = practical salinity units or parts per thousand.

Wind speeds and directions, which can exert large effects on bay conditions, were largely typical through 2021, with the notable exception of a large storm with winds from the northeast in late October, when significant wave heights reached almost nine meters (Figure 3-5). Several storms in 2021 had winds from the northeast, though not all were what New Englanders often call “Nor’easters.” Instead, these storms were the western-edge remnants of tropical storms. An early September 2021 storm, for example, was a remnant of Hurricane Ida.

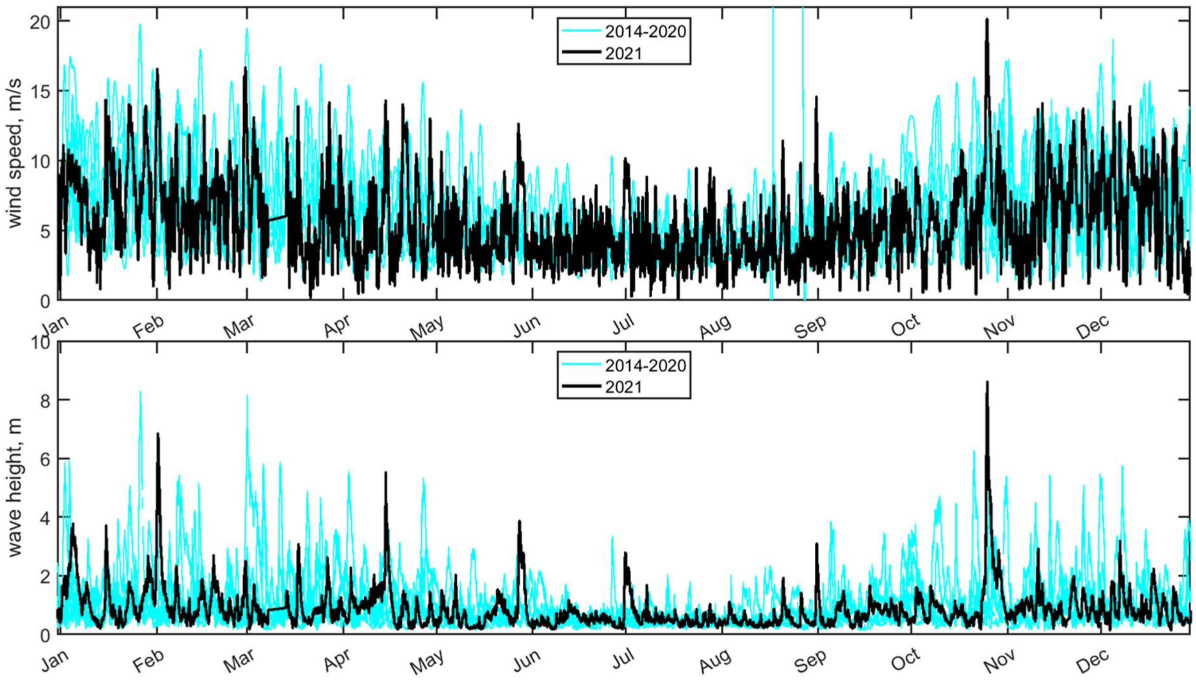


Figure 3-5. Wind speed and significant wave heights at the NDBC Buoy 44013, 1992–2021. Note the large storm in late October 2021, with high wind speeds and wave heights of almost 9 meters. The early September storm was a remnant of Hurricane Ida.

The wind speeds and directions in June promoted upwelling (deep, colder waters rising to the surface), which cools both surface and bottom waters. During July, however, the stormy wind conditions were unusually favorable to downwelling, forcing warmer surface waters deeper. These July downwelling-favorable conditions contributed to the higher-than-average water temperatures observed during the summer. High surface-water temperatures and low surface-water salinities during the summer produced particularly strong water-column stratification. Strong stratification effectively cuts off bottom waters from the surface and can lead to low levels of oxygen at depth.

Water Quality

Water quality measurements include quantification of nutrients, phytoplankton biomass, and dissolved oxygen. Results for 2021 continued to confirm predictions of measurable outfall influence on some parameters at stations near the outfall. There were no unexpected or environmentally adverse findings (Libby et al. 2022).

Nutrients

Dissolved inorganic nutrient concentrations in the nearfield stayed mostly within the ranges measured in previous years, with many measurements at the historic medians. Concentrations of nitrate, phosphate, and silicate continued to show the typical seasonal patterns that were present before the offshore outfall began to discharge. Nutrient levels naturally vary with phytoplankton uptake, exchange with the Gulf of Maine, and inputs from river discharge.

Nitrogen, including the dissolved forms nitrate and ammonium, is the most important nutrient for phytoplankton growth in marine waters. Ammonium is also the largest fraction of the total nitrogen in wastewater (see Figure 2-6, page 6), making it a good effluent tracer. Since the discharge was relocated from the harbor to the bay in late 2000, variable and elevated levels of ammonium have been detected at stations near the outfall, (Figure 3-6). Higher ammonium concentrations at stations closest to the outfall are sometimes a result of a sample being taken directly in the effluent plume, which moves with tides and currents, while particularly low concentrations likely reflect the sample completely missing the plume. Nitrogen concentrations measured at Station F23 at the mouth of the harbor and in MWRA’s Boston Harbor monitoring program have greatly declined since the discharge to the harbor ended in 2000.

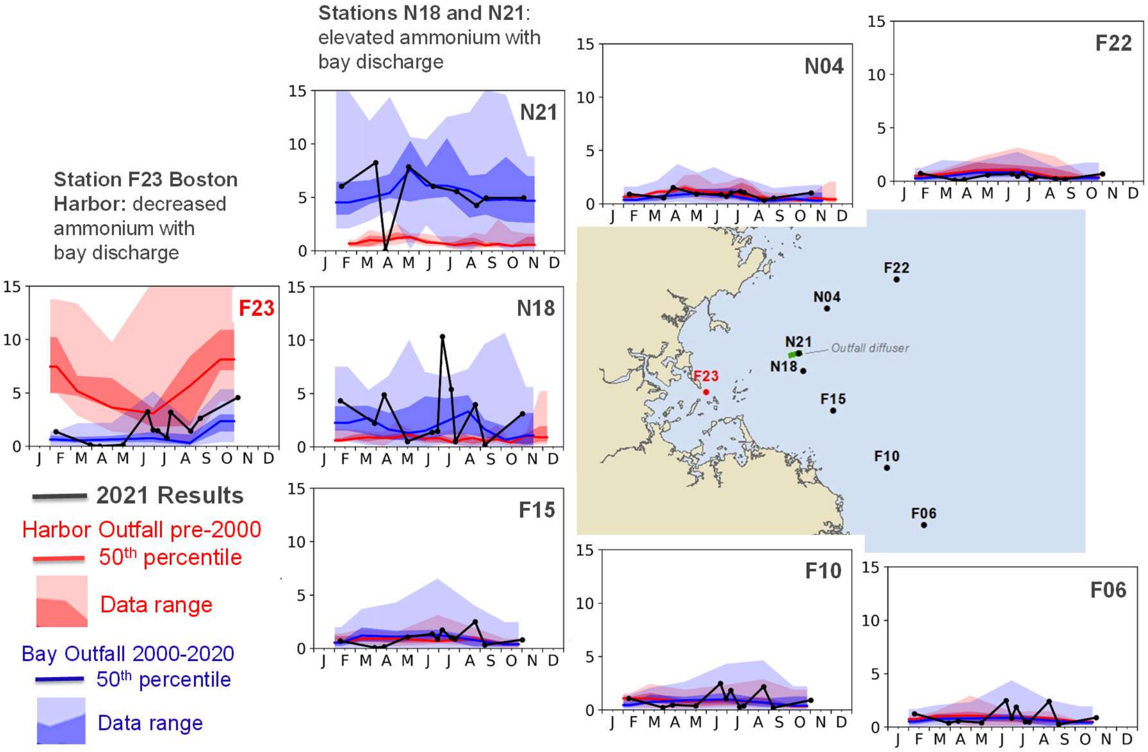


Figure 3-6. Station-average ammonium concentrations at selected stations in 2021 compared to prior years. Black points and line are results from individual surveys in 2021. Red lines and shading show data from 1992-2000, when effluent was discharged to Boston Harbor. Blue lines and shading show data from September 2000, when the Massachusetts Bay began to discharge, through 2020. Red and blue lines are the 50th percentile, dark shading spans the 25th to 75th percentile, and light shading spans the range.

As is typical, the effluent plume's ammonium signature was evident in surface waters at stations closest to the outfall during the winter surveys, when the water column was relatively well-mixed (Figure 3-7). During the August survey, when the water column was stratified, the ammonium signature was detected at greater distance from the outfall, farther than in the February unstratified survey and farther than in most past years (Figure 3-8). However, as in all past years, the plume was confined beneath the pycnocline, below depths where maximum phytoplankton growth occurs.

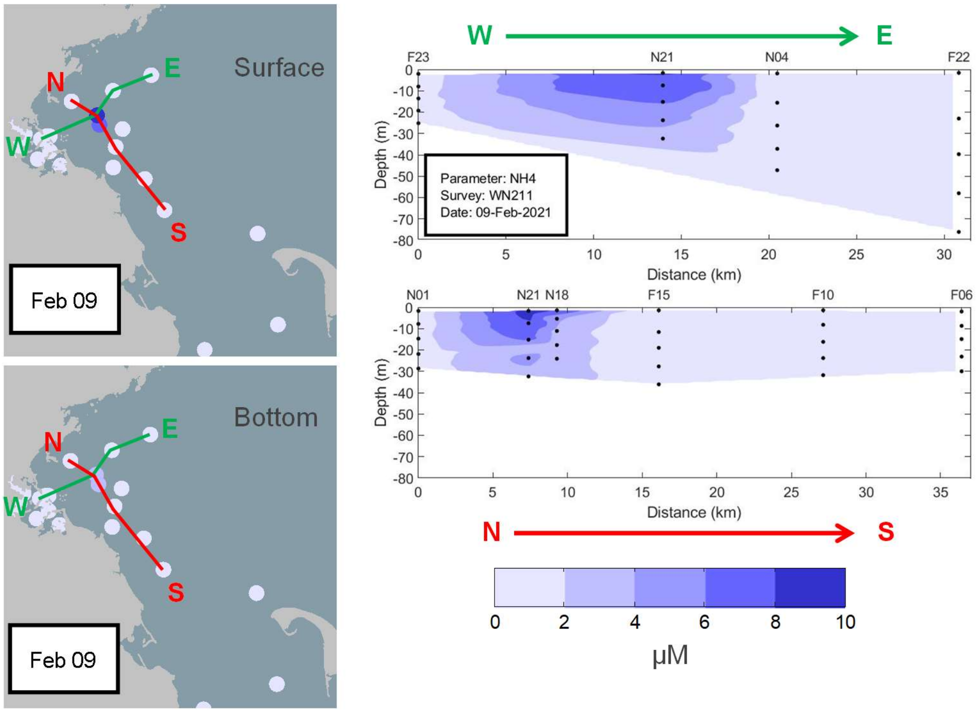


Figure 3-7. (Left) Surface- and bottom-water ammonium on February 9, 2021 at the monitoring stations during mixed (non-stratified) conditions. (Right) Cross-sections of concentrations throughout the water column along transects connecting selected stations. Station N21 is directly over the outfall.

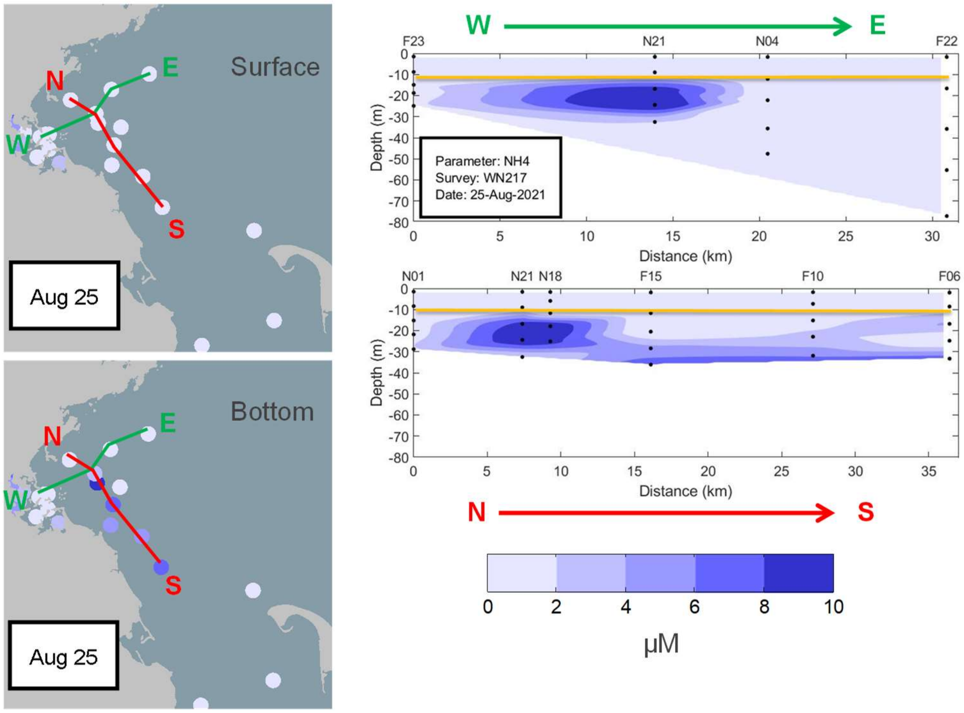


Figure 3-8. (Left) Surface- and bottom-water ammonium on August 25, 2021 at the monitoring stations during stratified conditions. (Right) Cross-sections of concentrations throughout the water column along transects connecting selected stations. The yellow line denotes the pycnocline.

Phytoplankton Biomass

The localized ammonium concentration increases have not fueled phytoplankton growth or resulted in increased phytoplankton biomass at any station, even those closest to the outfall (Figure 3-9). Survey phytoplankton biomass is reported as vertically summed (areal) chlorophyll from measurements collected throughout the water column from the surface to the sea floor. Seasonal peaks often occur in the winter or spring and again in the fall, although timing and magnitude varies from year to year. During the 2021 survey season, areal chlorophyll levels peaked during June and July as well as the spring and fall at several stations. None of the 2021 peaks were high compared to observations from previous years.

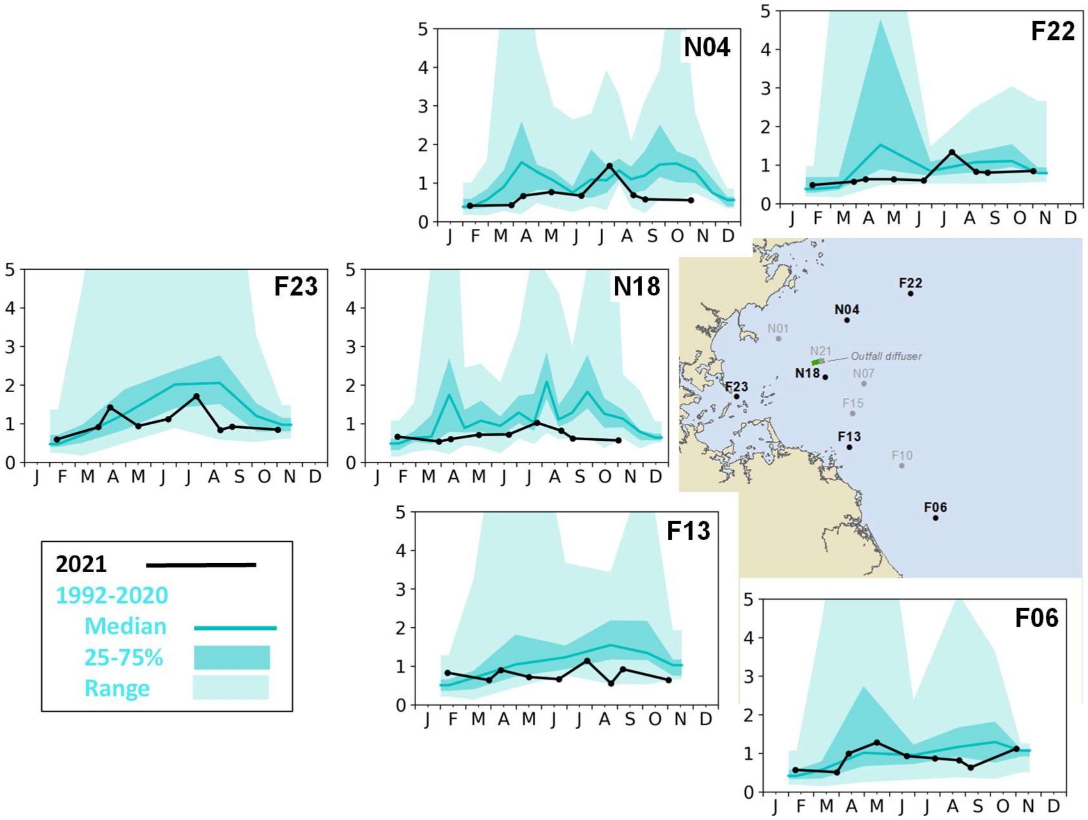


Figure 3-9. Station average areal chlorophyll concentrations at selected stations in 2021 compared to prior years. For some stations, historic data (shaded areas) extend later in the year than the current survey schedule.

Satellite imagery, which helps fill in the gaps between survey dates, showed moderate chlorophyll in January and early February, prior to the start of the survey season (Figure 3-10). Imagery also showed elevated chlorophyll levels in May, variable levels in the summer, and elevated levels in the fall. These patterns are typical of past observations.

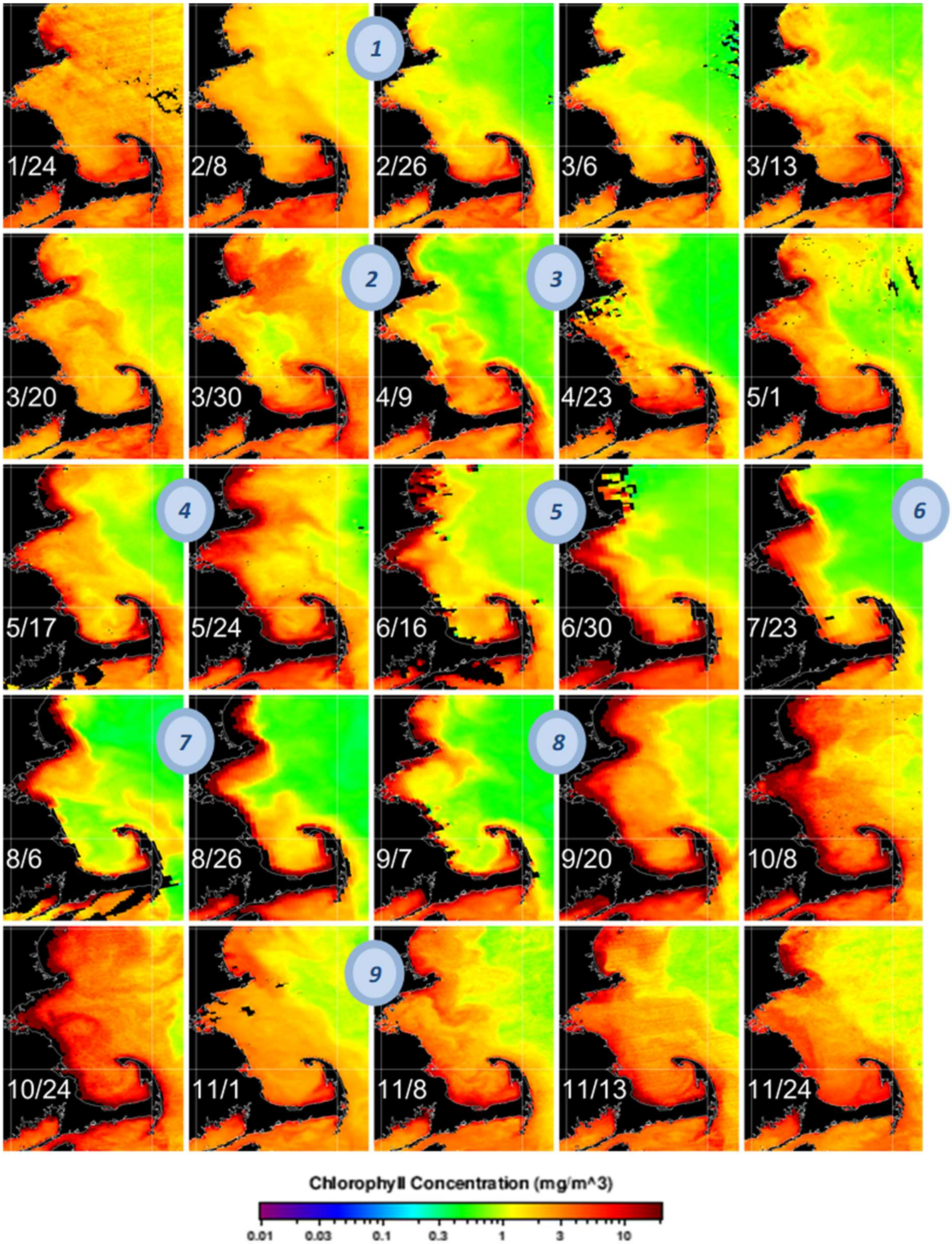


Figure 3-10. Moderate-Resolution Imaging Spectroradiometer satellite imagery of surface chlorophyll concentrations in 2021. The dates (marked in each frame) are highly weather-dependent and do not represent consistent intervals of time. The numbers 1–9 show the timing of the routine MWRA surveys; the imagery helps fill the temporal gaps between the surveys. In 2021, a moderate bloom began in January, before the start of the survey season and a fall bloom persisted after its end in early November.

Dissolved Oxygen

Typically, bottom-water dissolved oxygen levels (concentration and percent saturation) begin the year relatively high and steadily decline throughout the summer, while the water column is stratified. Stratification prevents exchange between the atmosphere and bottom waters, so dissolved oxygen levels naturally decline, a result of biological processes.

Massachusetts Bay bottom-water dissolved oxygen concentrations began the year close to historic medians during the February survey (Figure 3-11). Concentrations decreased throughout the region in the spring, at some stations reaching the lowest levels measured for any May survey. Mixing resulting from storms in June and July temporarily disrupted stratification and re-aerated the bottom waters at many stations. However, an influx of river flow from those storms led to low salinity in surface waters, which, coupled with warm surface waters, created particularly strong stratification in July and August. Bottom-water dissolved oxygen concentrations declined throughout the region, reaching the lowest annual minimum concentrations measured during the monitoring program at several stations. The low percent saturation of dissolved oxygen in Stellwagen Basin failed to meet Contingency Plan thresholds in September and November. The Contingency Plan threshold for low dissolved oxygen concentration in Stellwagen Basin was also not met in November. Those exceedances are discussed on page 31.

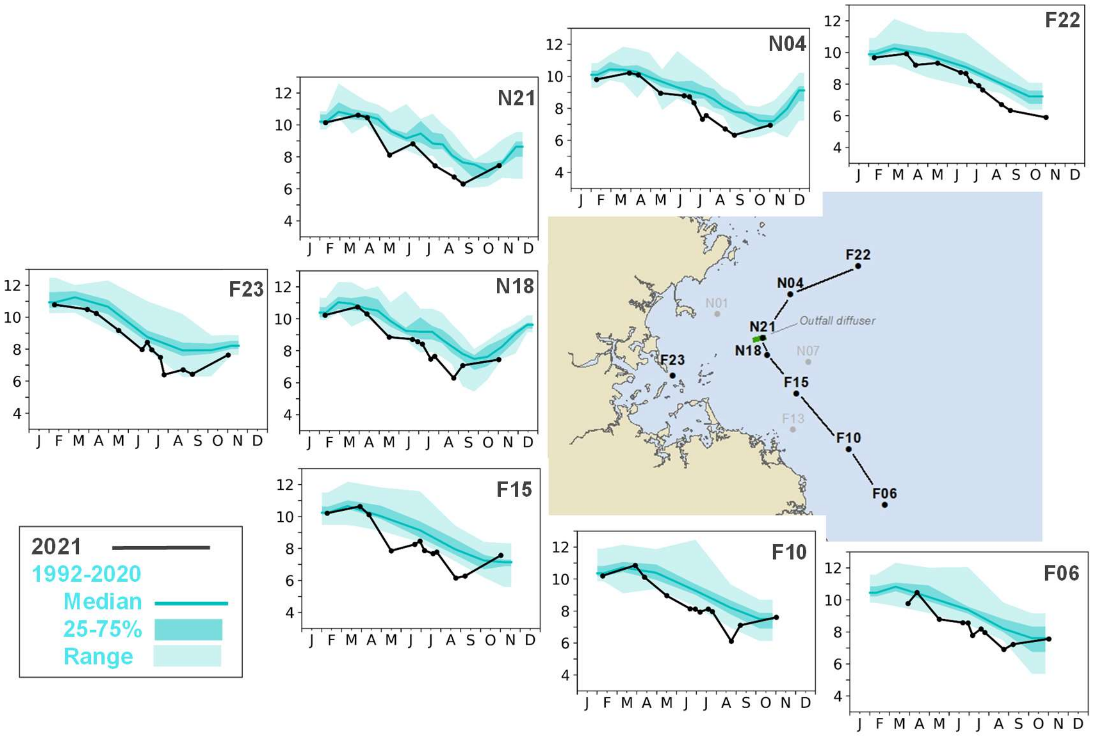


Figure 3-11. Near-bottom water dissolved oxygen concentrations (milligrams per liter) in 2021 compared to prior years. For some stations, historic data (shaded ranges) extend later in the year than the current survey schedule.

Low dissolved oxygen also occurred in Cape Cod Bay. Bottom-water dissolved oxygen at Station F01 in Cape Cod Bay was at historically low levels during May through July. A Massachusetts Division of Marine Fisheries (DMF) study of shallower, more inshore, areas not surveyed by MWRA recorded concentrations lower than 3 milligrams per liter in mid-August (see Figure 3-15 on page 26 and Section 6, Special Studies). Although hypoxia (dissolved oxygen concentrations lower than two milligrams per liter) occurred in these inshore areas in 2019 and 2020, mixing prevented a recurrence in 2021.

Phytoplankton Communities

Total phytoplankton abundances remained relatively low in Massachusetts Bay in 2021, comparable to recent years (Figure 3-12, Libby et al. 2022). The nearfield annual abundance was 691,169 cells per cubic meter, only 52% of the long-term mean and ranking 27th out of 30 years of monitoring.

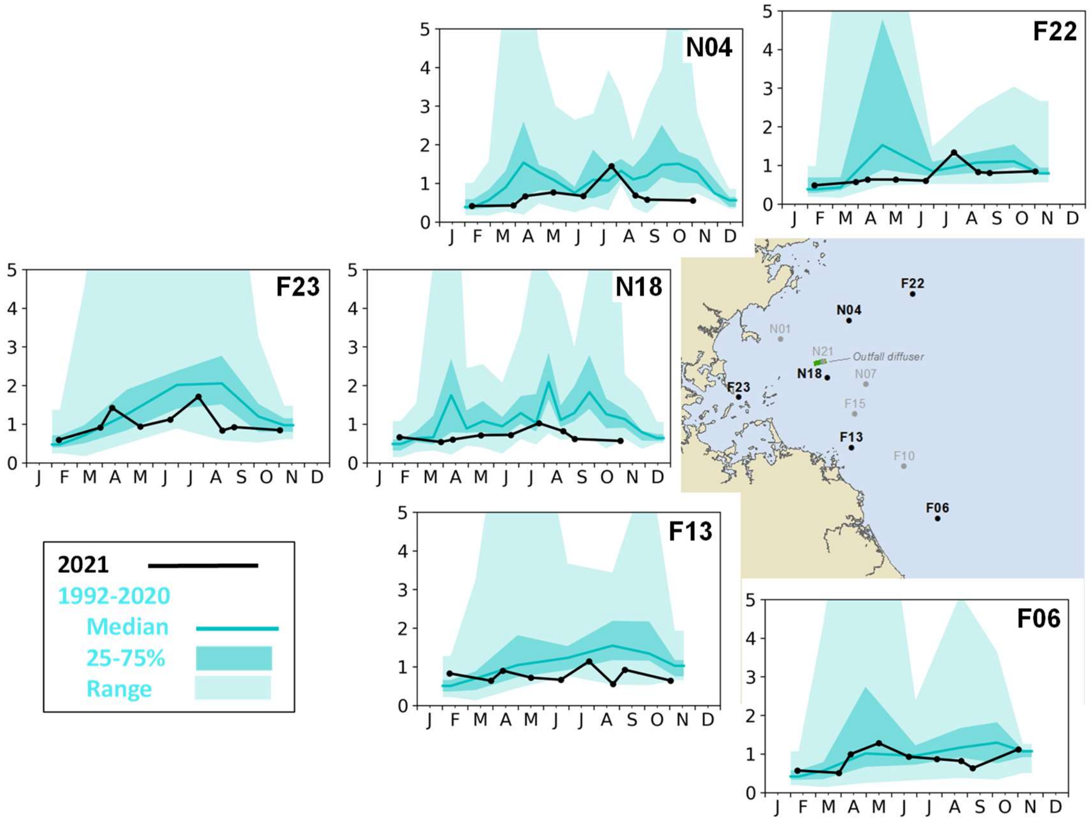


Figure 3-12. Total phytoplankton abundance (million cells per liter) at selected stations in 2021 compared to prior years. For some stations, historic data (shaded ranges) extend later in the year than the current survey schedule.

Species composition was typical of past years (Figure 3-13). The low overall abundances were largely due to the lack of a spring bloom of the sometimes-common nuisance species *Phaeocystis pouchetii* and continuing low abundance of both centric and pennate diatoms, the two major types of silica-rich species common in marine waters.

Pennate diatoms were present at only 17% of the long-term mean, ranking 29th of 30 years, partially due to low abundances of the potentially toxic species group *Pseudo-nitzschia*. At higher abundances, *Pseudo-nitzschia* spp. can produce domoic acid, a neurotoxin that causes amnesic shellfish poisoning (ASP), a life-threatening illness in animals that consume contaminated shellfish. Historically, ASP has not caused shellfish closures in Massachusetts or Cape Cod Bays, and there were no closures in 2021. Other often-common diatoms, such as *Thalassiosira* spp., *Thalassionema* spp., and *Asterionellopsis glacialis* were also present in lower-than-average numbers.

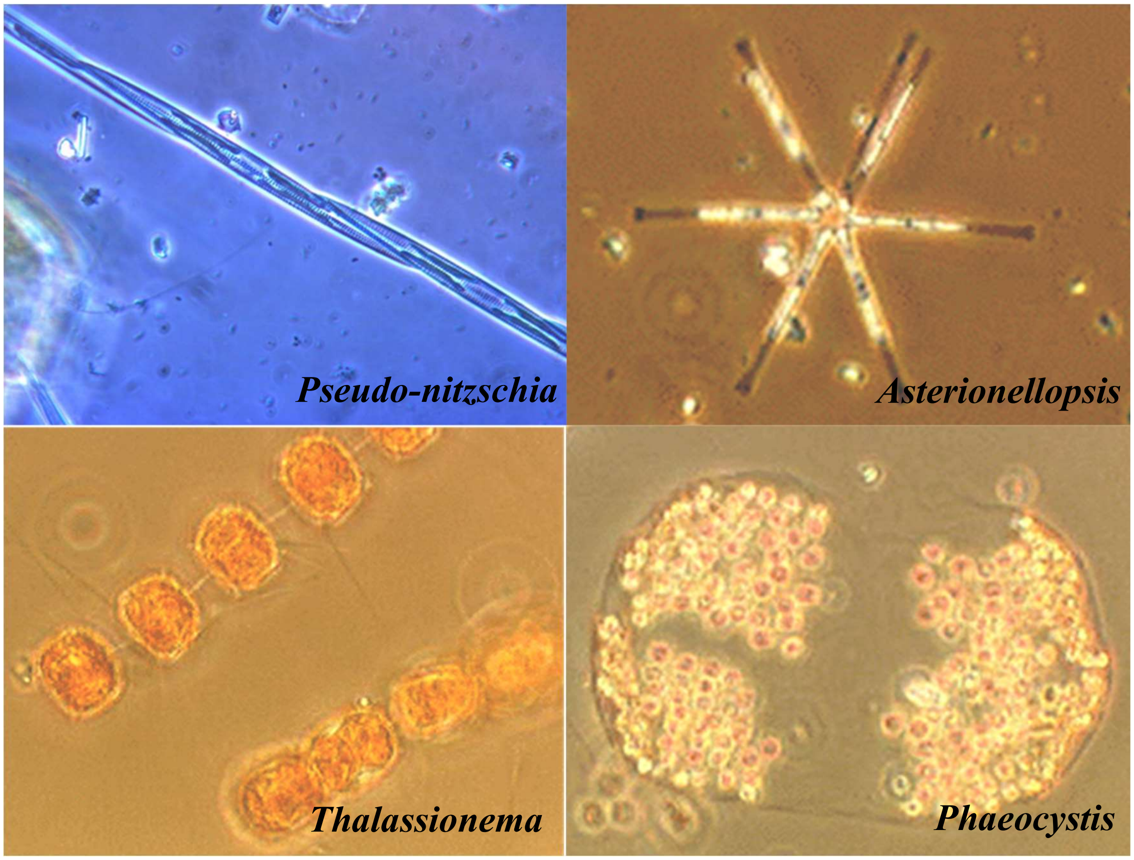


Figure 3-13. Phytoplankton species typical of Massachusetts Bay. Photo credits David Borkman, University of Rhode Island, Narragansett, Rhode Island.

Annual dinoflagellate abundance was somewhat closer to average than other phytoplankton groups, with nearfield abundance at 75% of the long-term mean, ranking 21st of 30 years. Throughout the monitoring program, dinoflagellate abundance has been cyclic, increasing and decreasing on approximately 11-year natural cycles. The spring and early summer 2021 communities were dominated by small species, such as *Prorocentrum minimum.* This species has been known to produce toxins but has not been considered a nuisance species in Massachusetts Bay. August and September were especially dominated by *Prorocentrum* spp. and *Karenia mikimotoi*.

Karenia mikimotoi was present for a fifth consecutive year, but at lower abundance than in 2019 and 2020 (Figure 3-14). Maximum abundance was 36,215 cells per liter, far lower than the 879,087 cells per liter recorded in 2020. *Karenia* has, for the past two years, been present almost year-round. In other geographic locations, it is known for maximizing growth in areas with strong vertical gradients, such as pycnoclines (Li et al. 2019). Targeted sampling in Cape Cod Bay in August 2021 by the Center for Coastal Studies, an MWRA monitoring partner, found more than 1 million *Karenia mikimotoi* cells per liter at the pycnocline. The process of accumulation, senescence, and decay of *Karenia mikimotoi* cells in the bottom waters below the pycnocline appears to be a major factor in the low-oxygen conditions measured in shallow inshore Cape Cod Bay over the past several years.

> Decay of *Karenia mikimotoi* cells in the waters below the pycnocline appears to be a major factor in the low-oxygen conditions measured in shallow inshore Cape Cod Bay in 2019 and 2020.

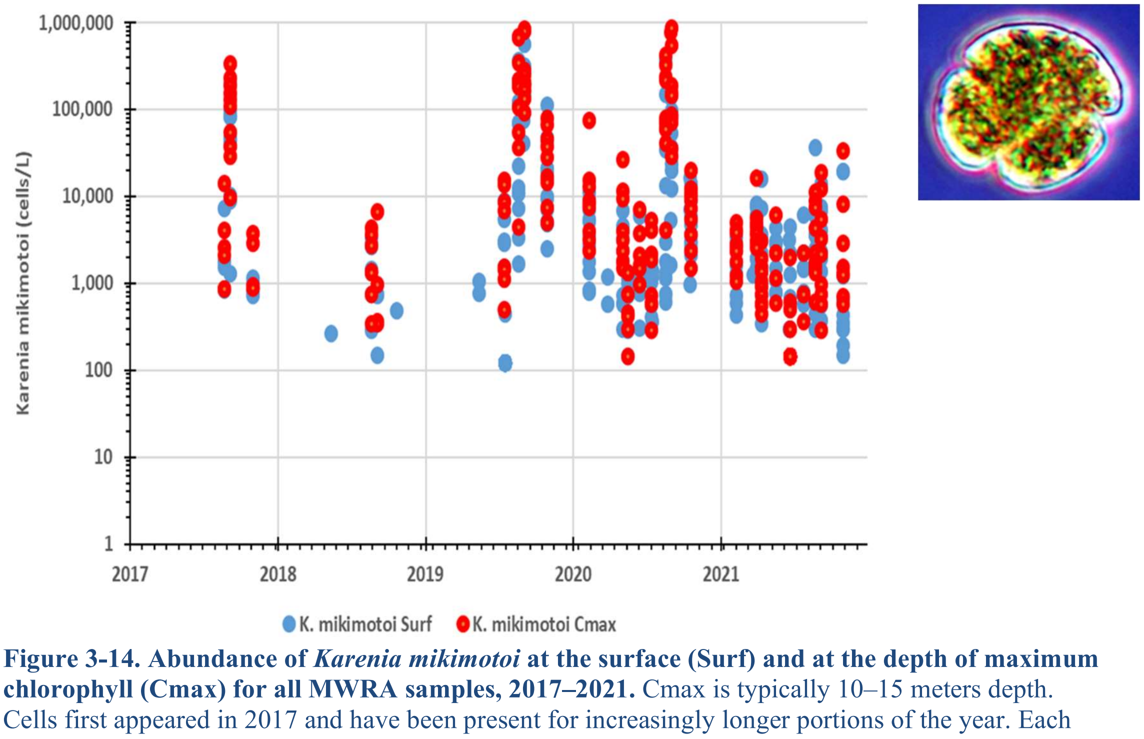


Figure 3-14. Abundance of *Karenia mikimotoi* at the surface (Surf) and at the depth of maximum chlorophyll (Cmax) for all MWRA samples, 2017–2021. Cmax is typically 10–15 meters depth. Cells first appeared in 2017 and have been present for increasingly longer portions of the year. Each dot represents one sample. Note log scale. Figure does not include data from the Center for Coastal Studies. Photo credit David Borkman, University of Rhode Island, Narragansett, Rhode Island.

Abundance of the potentially toxic dinoflagellate *Alexandrium catenella* (informally known in New England as a "red tide" species) was low during February–May, but its toxin, which causes paralytic shellfish poisoning (PSP), was detected in mussels on June 28 by DMF, and MWRA's routine survey, also on June 28, found elevated *Alexandrium* cell counts. The highest counts, 7,386 cells per liter, were found at Station N01 located to the north of the outfall, but counts exceeding the 100 cells per liter Contingency Plan threshold were also found at Station N18 near the outfall and along the South Shore. Abundance was sufficient to exceed the Contingency Plan caution threshold and trigger rapid-response surveys, which characterize *Alexandrium catenella* blooms on a weekly basis. Three special surveys were completed in July, and by July 21, *Alexandrium* abundances had subsided. By the July 27 routine survey, the bloom had ended. Additional information on the Contingency Plan exceedance is presented on page 32.

Although cell counts were high in Massachusetts Bay and in Boston Harbor throughout the bloom, PSP toxicity was not. Toxicity was detected in New Hampshire on July 5, and DMF measured levels of PSP toxin greater than 200 micrograms per 100 grams to the north of Cape Ann on July 12 (the DMF action level is 80 micrograms per 100 grams). Toxicity remained below action levels within Massachusetts Bay, but shellfishing beds were closed from July 12 until July 30. The disconnect between high cell counts and low toxicity may be related to wind patterns and currents, which continue to be analyzed.

Zooplankton Communities

Total zooplankton abundance and seasonal patterns were mostly typical in 2021 (Figure 3-15, Libby et al. 2021). As in past years, copepod adults and younger life stages dominated in every survey. The small species *Oithona similis* continued to dominate the zooplankton community.

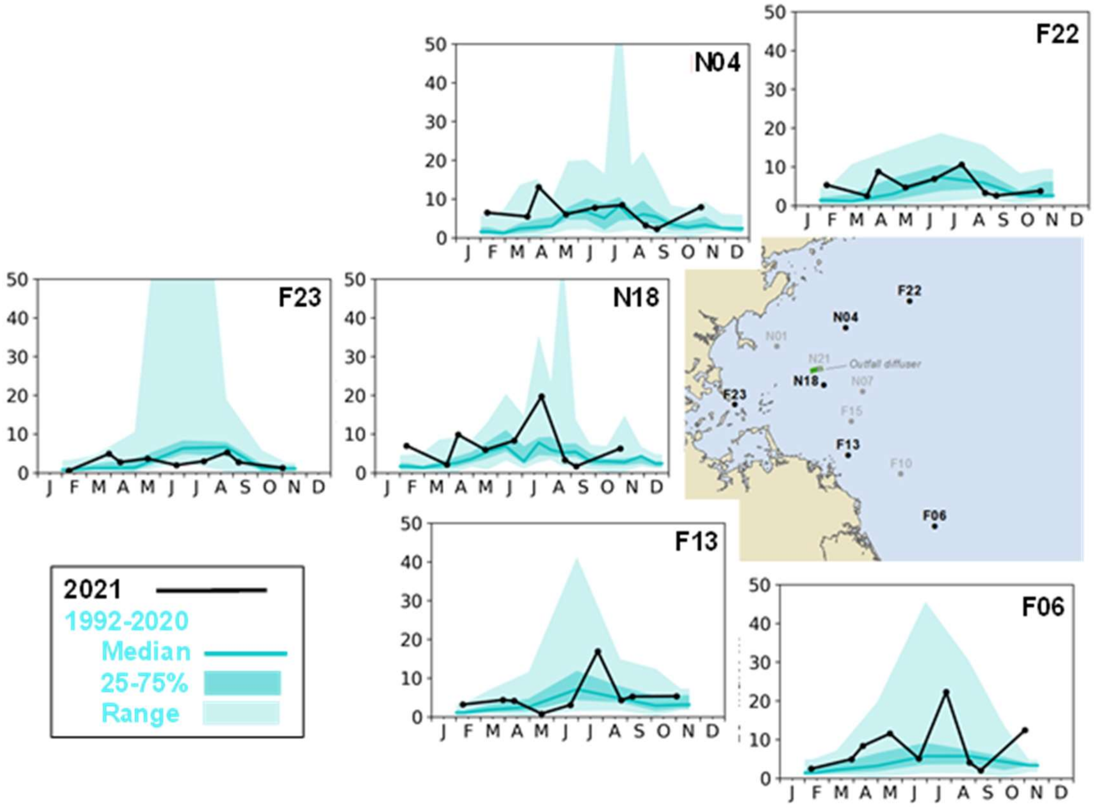


Figure 3-15. Total zooplankton abundance (10,000 individuals per cubic meter) at selected stations in 2021 compared to prior years. For some stations, historic data (shaded regions) extend later in the year than the current survey schedule. The high historic values that extend beyond the y-axis occurred in July 2015, when larval bivalves were present in very large numbers.

The July and November samples included an unprecedented number of radiolarians, single-celled protozoans that build ornate silica exoskeletons (Figure 3-16). Radiolarians were similarly abundant in August and September 2020, but had not been observed in prior years of the monitoring program. Radiolarians are more typically found in offshore waters, and their presence appears to reflect an influx of water masses from the offshore. Changes in regional water movements have also influenced water temperature trends; these shifts are discussed further in Section 6, Special Studies.

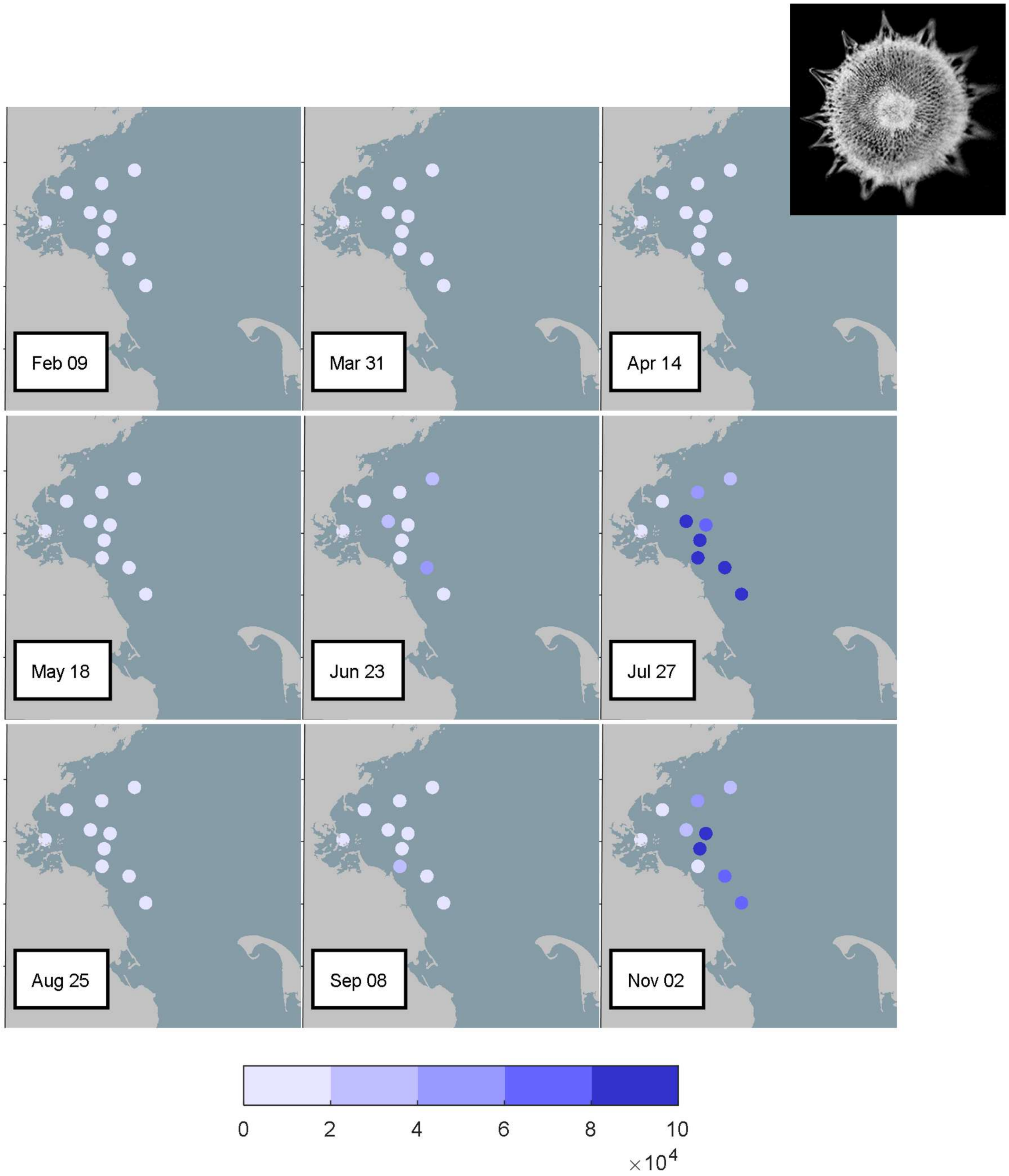


Figure 3-16. Total abundance of non-copepod zooplankton (10,000 organisms per cubic meter) at selected stations in 2021. Radiolarians, which are usually found offshore, dominated samples during July and November. Photo credit Randolf Femmer, USGS, public domain image.

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 Stellwagen Bank National Marine Sanctuary. Water column Station F22 is just north of Stellwagen Basin, to the west of the sanctuary, and is considered to be representative of 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 Figure 3-6, page 17). Sampling at Station F22, data from the NERACOOS Buoy, and satellite imagery detected no unusual chlorophyll levels in offshore regions in 2021. No effects on chlorophyll levels in the offshore areas of Massachusetts Bay, including the sanctuary, were predicted as a result of moving the discharge from Boston Harbor to the bay, and none have been measured.

Dissolved oxygen concentrations and percent saturation at Station F22 in Stellwagen Basin did reach low levels in the fall, failing to meet the Contingency Plan warning thresholds. These exceedances have not been attributed to the outfall and are discussed further on page 31, below. Data from the NERACOOS Buoy (which are not used to calculate Contingency Plan threshold parameters) showed the decline during the stratified season and also documented the rapid return to oxygenated conditions following fall mixing events (Figure 3-17).

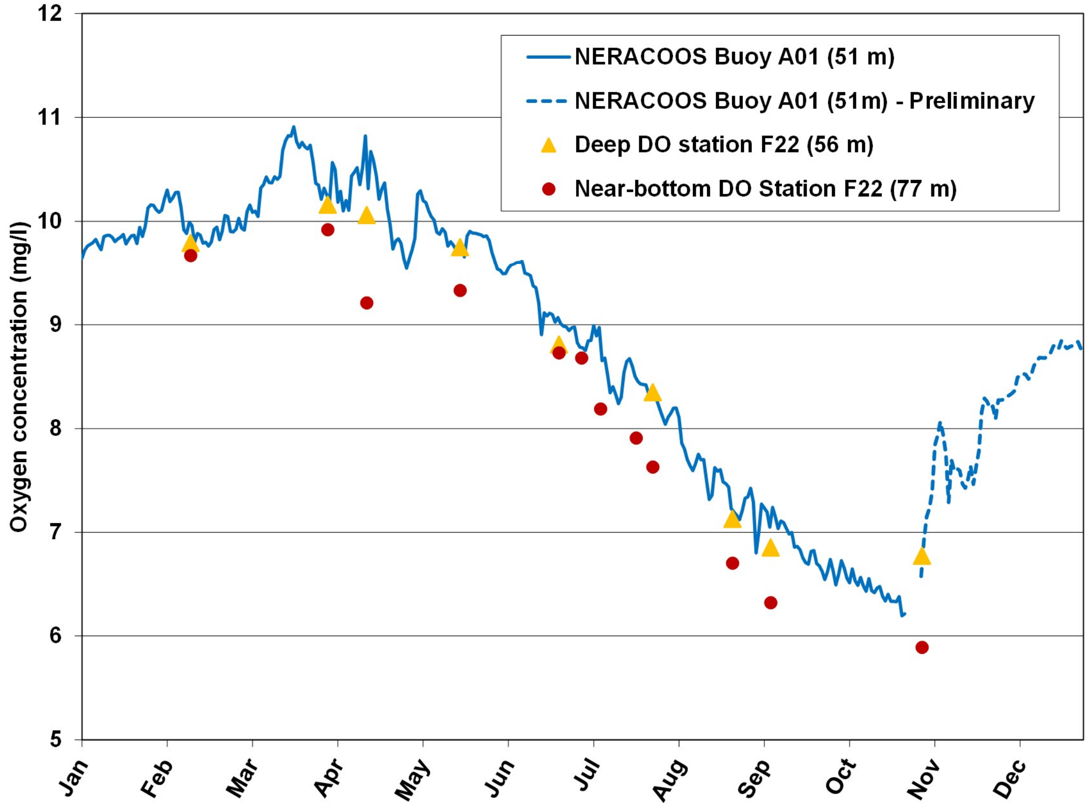


Figure 3-17. Dissolved oxygen concentrations at the NERACOOS Buoy A01 (lines) and at nearby deepwater MWRA survey Station F22 (symbols) in 2021. Note the rapid increase in dissolved oxygen concentration captured by the buoy sensors following the late fall and early winter mixing events, after the final MWRA survey of the year.

Boston Harbor Water Quality

Water quality in Boston Harbor has greatly improved during the decades of the Boston Harbor Project, and those improvements were sustained in 2021.

Perhaps the most dramatic improvement in Boston Harbor was the immediate decrease in ammonium levels. Ammonium concentrations in the harbor 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 (Werme et al. 2018, Taylor et al. 2020).

Contingency Plan Water Column Thresholds

There were four exceedances of three water-column thresholds in 2021: oxygen concentration in Stellwagen Basin in November, oxygen percent saturation in Stellwagen Basin in September and November, and abundance of the nuisance algal species *Alexandrium catenella* in June (Table 3-1).

Table 3-1. Contingency Plan threshold values and 2021 results for water-column monitoring.

Parameter	Baseline	Caution Level	Warning Level	2021 Results
Dissolved oxygen*				
Nearfield concentration	6.05 mg/L	<6.5 mg/L	<6.0 mg/L	6.36 mg/L
Nearfield percent saturation	65.3%	<80%	<75%	71.3%
Stellwagen concentration	6.23 mg/L	<6.5 mg/L	<6.0 mg/L	5.89 mg/L
Stellwagen percent saturation	67.2%	<80%	<75%	65.9 %
Nearfield depletion rate	0.024 mg/L/d	>0.037 mg/L/d	>0.049 mg/L/d	0.012 mg/L/d
Chlorophyll				
Annual	72 mg/m^2	>108 mg/m^2	>144 mg/m^2	49 mg/m^2
Winter/spring	50 mg/m^2	>199 mg/m^2	None	62 mg/m^2
Summer	51 mg/m^2	>89 mg/m^2	None	43 mg/m^2
Autumn	90 mg/m^2	>239 mg/m^2	None	42 mg/m^2
Nuisance algae nearfield *Pseudo-nitzschia*				
Winter/spring	6,735 cells/L	>17,900 cells/L	None	130 cells/L
Summer	14,635 cells/L	>43,100 cells/L	None	3,110 cells/L
Autumn	10,500 cells/L	>27,500 cells/L	None	94 cells/L
Nuisance algae nearfield *Alexandrium catenella*				
Any nearfield sample	Baseline maximum 163 cells/L	>100 cells/L	None	7,386 cells/L
PSP toxin extent	NA	New incidence	None	No new incidence

*Dissolved oxygen caution and warning levels represent numerical criteria, with the caveat "unless background conditions are lower." Exceedances are highlighted in orange.

PSP = paralytic shellfish poisoning

NA = not applicable

Oxygen Concentration and Saturation in Stellwagen Basin

Dissolved oxygen parameters, including concentration, percent saturation, and the rate of depletion throughout the summer months, are compared to baseline minima rather than the specific caution and warning thresholds when the baseline levels were already lower than the thresholds. No exceedances occurred in the nearfield in 2021, but there were exceedances in Stellwagen Basin (Figure 3-18). Compared to a background minimum of 67.2%, saturation at Station F22 was 66.3% during the September survey and 65.9% during the November survey (originally scheduled for October). The oxygen concentration at Stations F22 was 5.89 milligrams per liter on November 2, compared to a background minimum of 6.23 milligrams per liter.

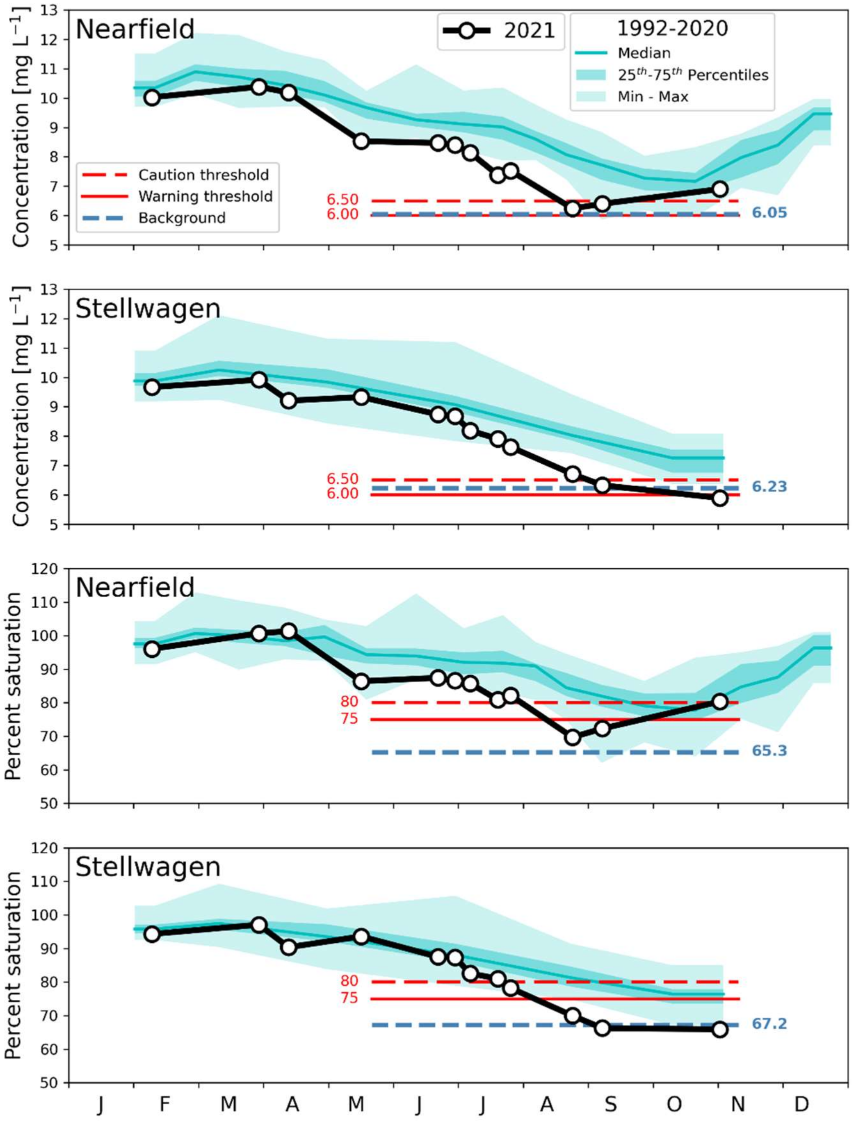


Figure 3-18. Bottom dissolved oxygen concentrations (top) and percent saturation (bottom) in the nearfield and Stellwagen Basin, 2021.

These exceedances have not been attributed to the outfall, but instead appear to be the result of broader, regional physical conditions. There is no evidence that changes in nutrient levels have fueled algal blooms that could result in lower dissolved oxygen measurements. The depth-averaged ammonium concentrations at Station F22 have not changed from baseline levels. One likely driver of lower oxygen levels is the warming temperatures that are being observed throughout the Gulf of Maine. Increased temperatures in the region are discussed further in Section 6, Special Studies.

Alexandrium catenella Abundance

The phytoplankton species *Alexandrium catenella* occurs regularly in Massachusetts Bay, most typically peaking in May and June. *Alexandrium* blooms have been noted in Massachusetts Bay since the early 1970s and were particularly common in the 1970s and 1980s, followed by a lull in the 1990s and early 2000s. When the water-sample threshold for *Alexandrium* abundance was set at 100 cells per liter, OMSAP recognized that blooms were patchy and unpredictable and therefore also endorsed an alternative threshold based on PSP toxin in shellfish. The water-sample cell count caution threshold (there is no warning threshold) was not exceeded in the first five years after the outfall began to discharge to Massachusetts Bay, but it has been exceeded nine times since 2005, including in 2021 (Figure 3-19). The threshold for new incidence of PSP toxin, has never been exceeded.

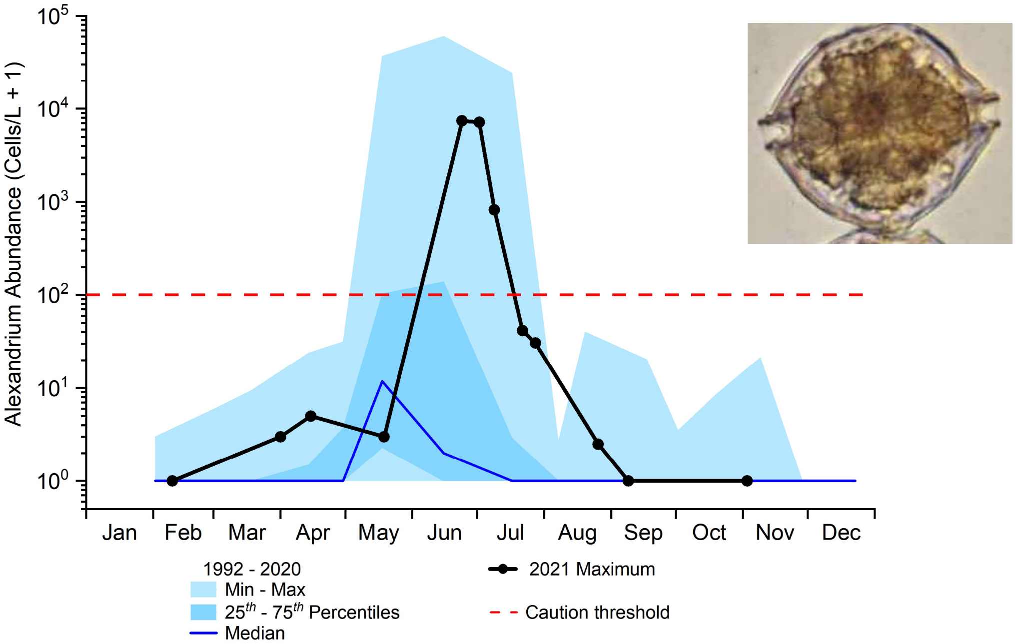


Figure 3-19. Maximum *Alexandrium* nearfield sample counts for 2021 surveys and quartile distributions from all prior nearfield samples. Note log scale. Photo credit Don Anderson, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

In the past, Massachusetts Bay blooms originated from cyst beds to the north of Massachusetts Bay, along the coast of Maine (Anderson et al. 2013). However, a large bloom in 2019 may have resulted in the establishment of a more local cyst bed. Cysts have been detected in Massachusetts Bay, so the possibility exists that blooms may originate from a more local source. This hypothesis is being investigated.

4. Sea Floor

Seafloor monitoring assures continued health of soft- and hard-bottom habitats. Soft-bottom surveys are conducted annually, while photographic and video assessments of hard-bottom habitats occur at three-year intervals, most recently in 2020. A separate seafloor monitoring program, including sediment-profile imagery, is conducted in Boston Harbor.

The initial concerns for the sea floor, such as smothering by discharged solids, low oxygen levels, or accumulation of toxic contaminants in the sediments, have been contradicted by years of monitoring. The good results have allowed some monitoring to be scaled back. Visual analyses by sediment-profile imaging and chemical analyses of sediments are no longer part of the Massachusetts Bay monitoring program. Measurements of sediment characteristics, sewage tracers, and community structures continue.

Massachusetts Bay soft-bottom sediment sampling was completed in August 2021, with samples analyzed for grain-size distribution, the effluent tracer *Clostridium perfringens* spores, total organic carbon, infauna abundance, and species composition. Samples were collected at 14 Massachusetts Bay stations (Figure 4-1). The stations included four nearfield stations located within two kilometers of the outfall; six nearfield stations in western Massachusetts Bay farther from the outfall; one station in the “transition” area between Boston Harbor and the nearfield; and three farfield reference stations in Massachusetts and Cape Cod Bays. For the purposes of threshold testing, “nearfield” includes both nearfield groups and the transition station, for a total of eleven stations.

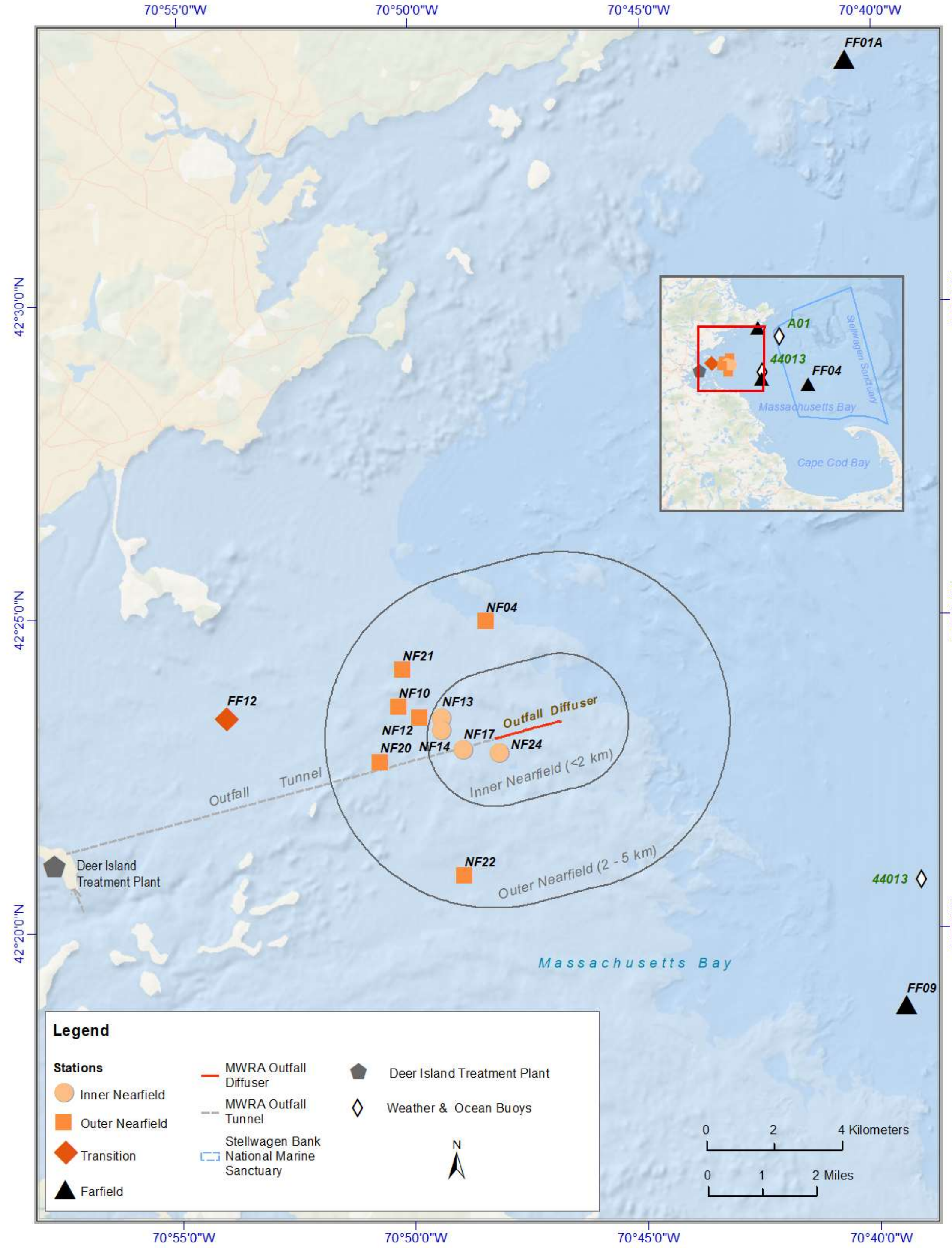


Figure 4-1. Soft-bottom monitoring stations. The inset shows the three farfield stations. Also shown are the instrumented buoys, the MWRA outfall diffuser, and Stellwagen Bank National Marine Sanctuary.

Sediment Characteristics and Tracers

As in past years, sediment grain-size distributions in 2021 varied broadly among stations, ranging from silt and clay at some stations (particularly Station FF04 within Stellwagen Basin in the farfield) to almost entirely sand at others (Nestler et al. 2022). Within individual stations, sediment textures have remained generally stable over the years of the monitoring program, with occasional changes following large storms.

Clostridium perfringens are anaerobic bacteria found in the digestive tracts of humans and other mammals and that form persistent resting spores if they reach oxygen-rich conditions such as those found at the bottom of Massachusetts Bay. These bacteria spores provide a sensitive tracer of sewage effluent. Spore counts are normalized by the percent of the sediments made up of silt and clay ("percent fines"). As in other years since the offshore outfall began to discharge, it was possible to detect elevated levels of *Clostridium* spores at some stations located closest to the outfall in 2021 (Figure 4-2). In most years, *Clostridium* spore concentrations have been elevated at stations located within two kilometers of the outfall. Concentrations at those nearfield stations were lower or about the same in 2021 as in 2020. Across all stations, 2021 *Clostridium* spore concentrations were among the lowest measured throughout the monitoring program.

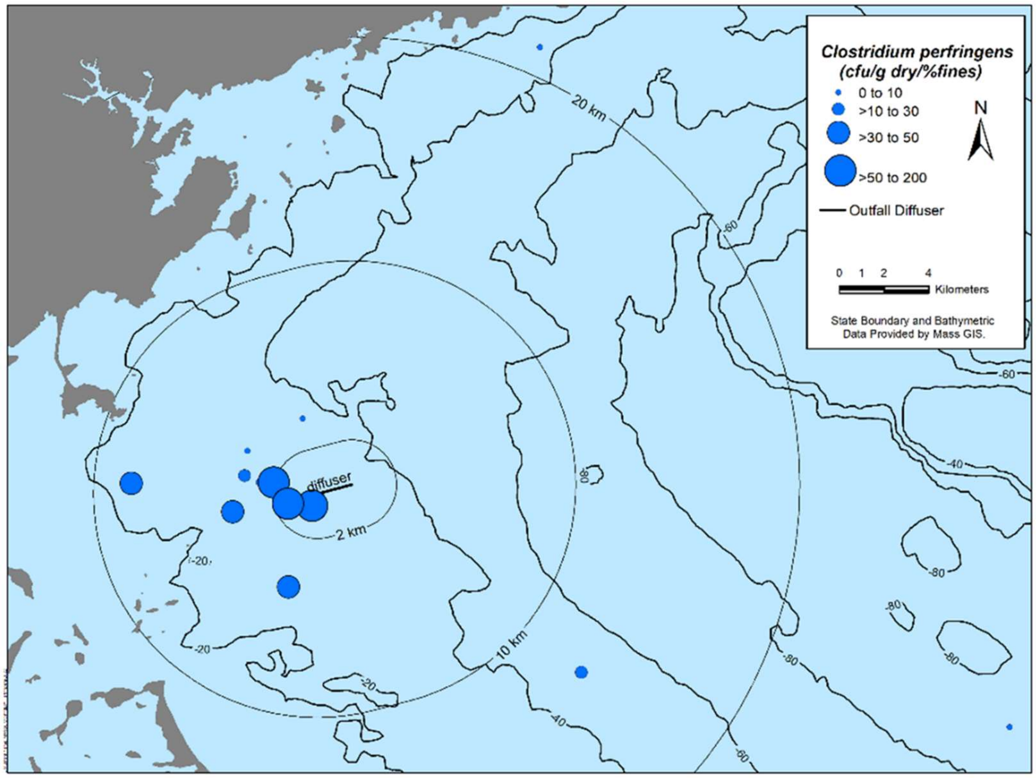


Figure 4-2. Concentrations of *Clostridium perfringens* spores in 2021. Concentrations represent spore counts (cfu, colony forming units) normalized to percent fines. As anticipated during outfall planning, *Clostridium* spores are found in greater concentrations at stations closest to the outfall. These spores are considered a tracer of sewage effluent.

Percent total organic carbon content analyses were consistent with past results, with no increased organic carbon at stations near the outfall or in any other area (Figure 4-3). 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 data continue to show no signs of organic enrichment from the outfall, consistent with predictions made before the outfall began to discharge and also consistent with a detailed special study of sediment metabolism, which was completed in 2010 (Tucker et al. 2010, Tucker et al. 2014).

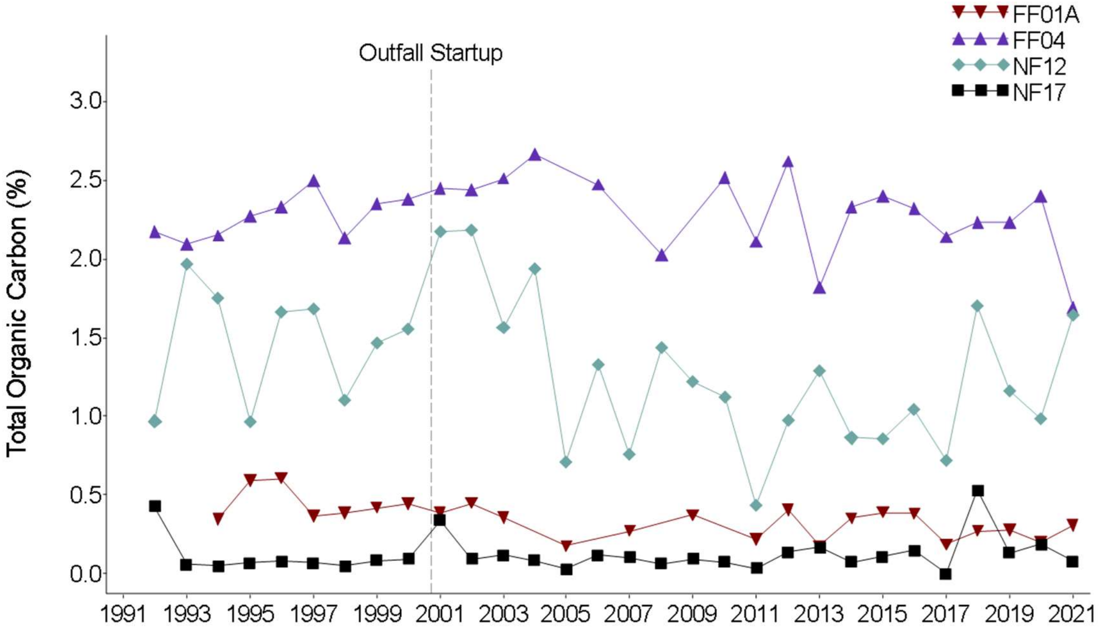


Figure 4-3. Total organic carbon at selected stations, 1992–2021. Station FF01A is the northern reference station; FF04 is within Stellwagen Basin; NF12 is >2km northwest of the outfall; and NF17 is in close proximity and southwest of the outfall, where the effects of the discharge might be expected but have not been found. No effects of the discharge have been observed at any station.

Soft-bottom Communities

The 14 soft-bottom samples collected and analyzed in 2021 yielded 25,086 organisms, classified into 182 species and 20 other discrete taxonomic groups (Nestler et al. 2022). Total abundance of organisms was slightly higher in 2021 than in 2020 in both nearfield station groups and at the one transition station between Boston Harbor and the nearfield (Figure 4-4). Diversity measures were slightly higher than in 2020, but all measurements remained within the ranges measured throughout the monitoring program.

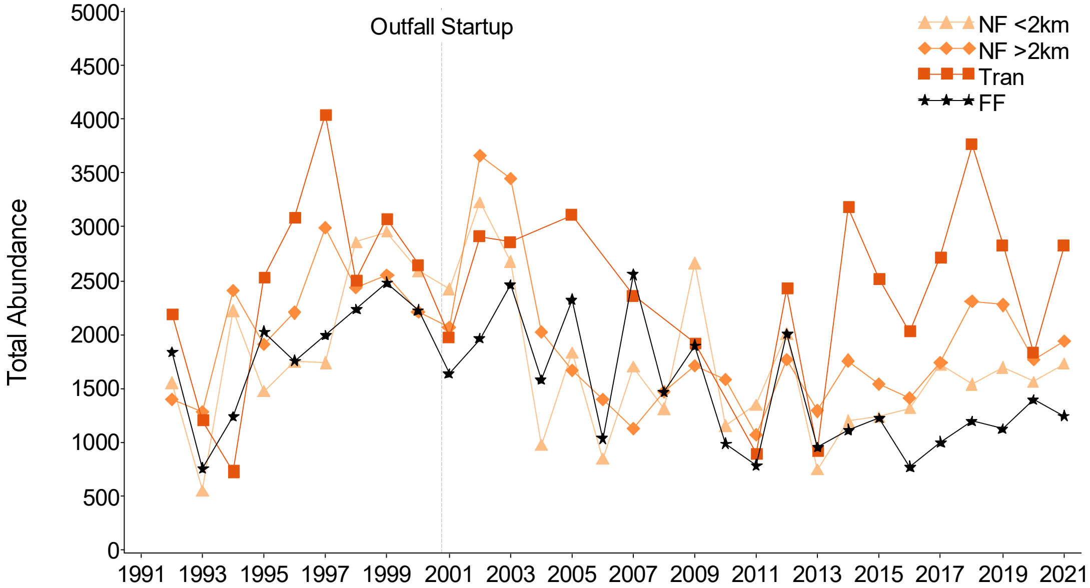


Figure 4-4. Total abundance of soft-bottom organisms by region, 1992–2021. Regions include the nearfield within two kilometers of the outfall, the nearfield farther than two kilometers from the outfall, the transition area between Boston Harbor and the outfall, and the farfield.

Polychaete worms (for example, Figure 4-5), continued to dominate at most stations. These segmented worms are among the most common marine organisms. The spionid polychaete *Prionospio steenstrupi* was slightly less abundant in 2021 than in 2020 but remained the numerically dominant species at nearfield stations. Such minor species changes from year to year are typical of the region. Other common polychaetes, including *Aricidea catherinae* and *Mediomastus californiensis*, were present in numbers comparable to those of other recent years.

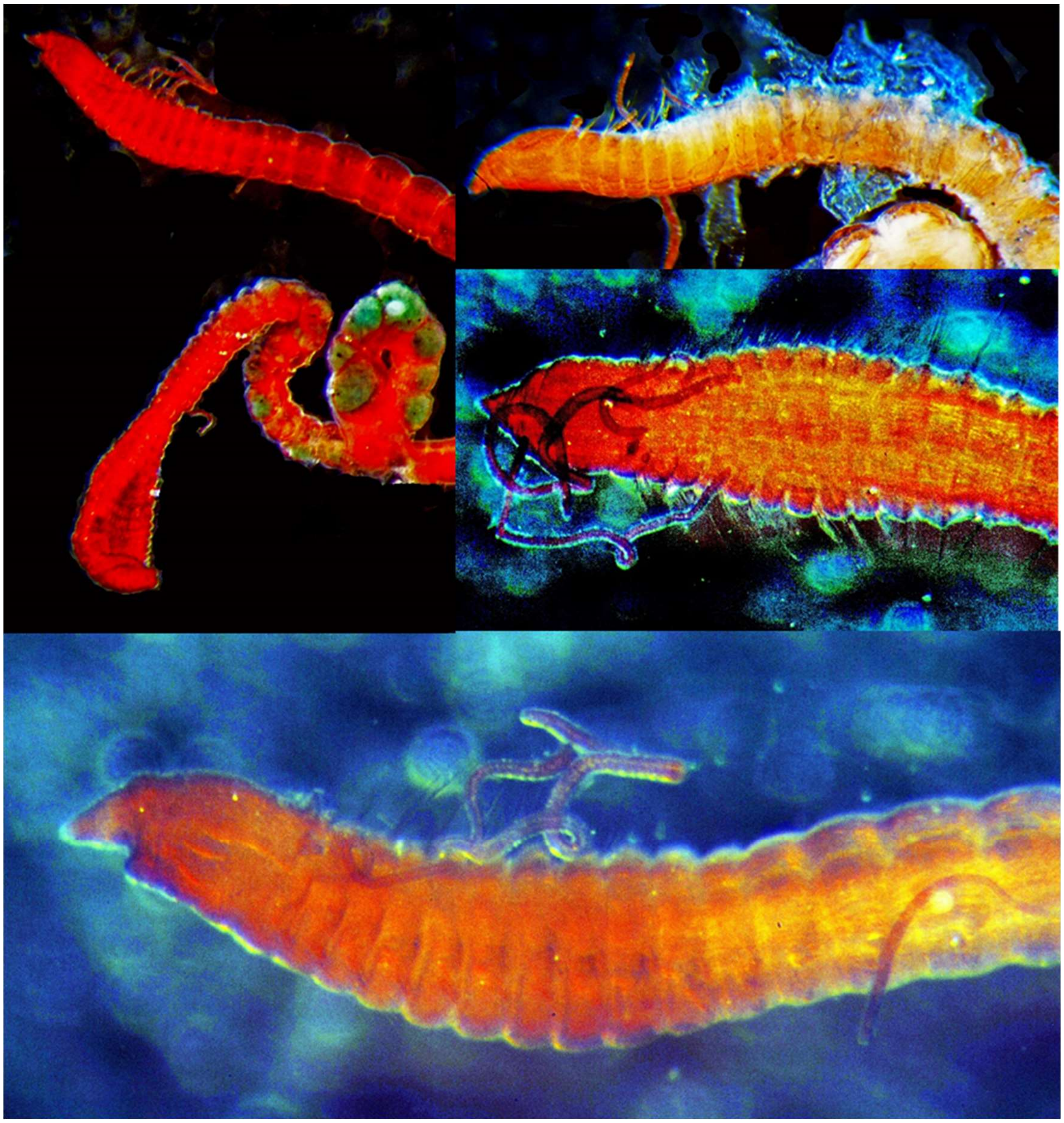


Figure 4-5. Polychaete worms dominate the soft-bottom habitats in Massachusetts Bay. This species, *Kirkegaardia baptistae*, is frequently found in fine-grained, offshore sediments, and MWRA samples were used in its original description. Photo credits James A. Blake, Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts.

Community analyses continued to show no effects of the outfall on relative abundance of animals or community composition. A series of multivariate analyses assessed spatial and temporal patterns in the soft-bottom communities and found no particular species or type of community specifically associated with the outfall.

One type of community analysis, cluster analysis, which groups stations by similarity in species composition and abundance, continued to identify two main infauna assemblage groups and one outlier group. Group I, including two subgroups, was dominated by crustaceans and polychaete worms. Group II, including three subgroups, comprised a greater abundance of polychaetes and also mollusks. The outlier Group III included only the offshore station located within Stellwagen Basin, which has consistently supported a unique polychaete community.

Ordination analysis, an additional analysis determining how closely related the bottom communities within stations are to each other, continued to show no indication of any relation of species composition to proximity to the outfall (Figure 4-6). Groups I and II included stations from both nearfield areas and from the farfield.

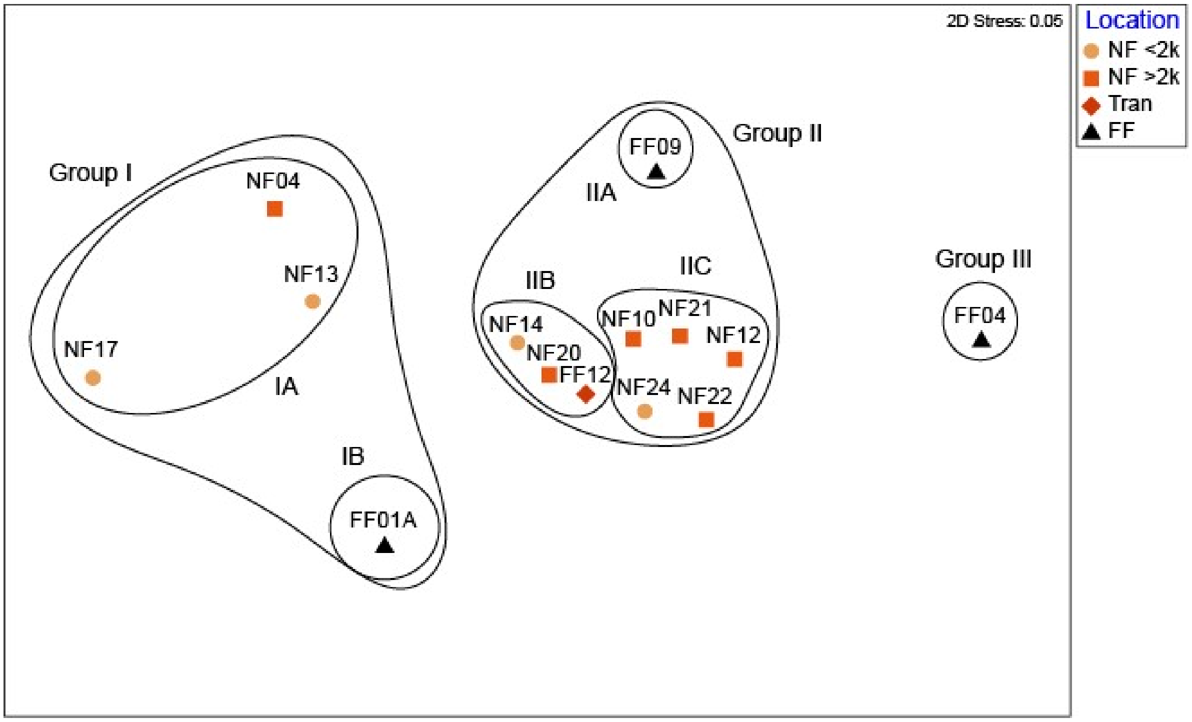


Figure 4-6. Ordination plot of 2021 Massachusetts Bay samples by location. Each point on the plot represents one of 14 stations, and varying colors and shapes depict locations in the nearfield, farfield, and transition area between Boston Harbor and Massachusetts Bay. Placement of the points indicates similarity of the communities—the nearer two points are to each other, the more similar their seafloor communities. (2D Stress noted in the upper right is a measure of good confidence in the analysis.)

As in past years, further assessment of the ordination analysis demonstrated that variations in species distributions largely followed differences in sediment grain size and depth (Figure 4-7). That is, seafloor communities from stations with similar sediment textures or water depths tended to be more closely related, as shown by closer proximity on the ordination plots. These results and past monitoring have confirmed that the Massachusetts Bay sea floor is dominated by physical factors. The strong physical forces, as well as the continued high quality of the effluent discharge, are the principal reasons that soft-bottom habitat quality has remained high.

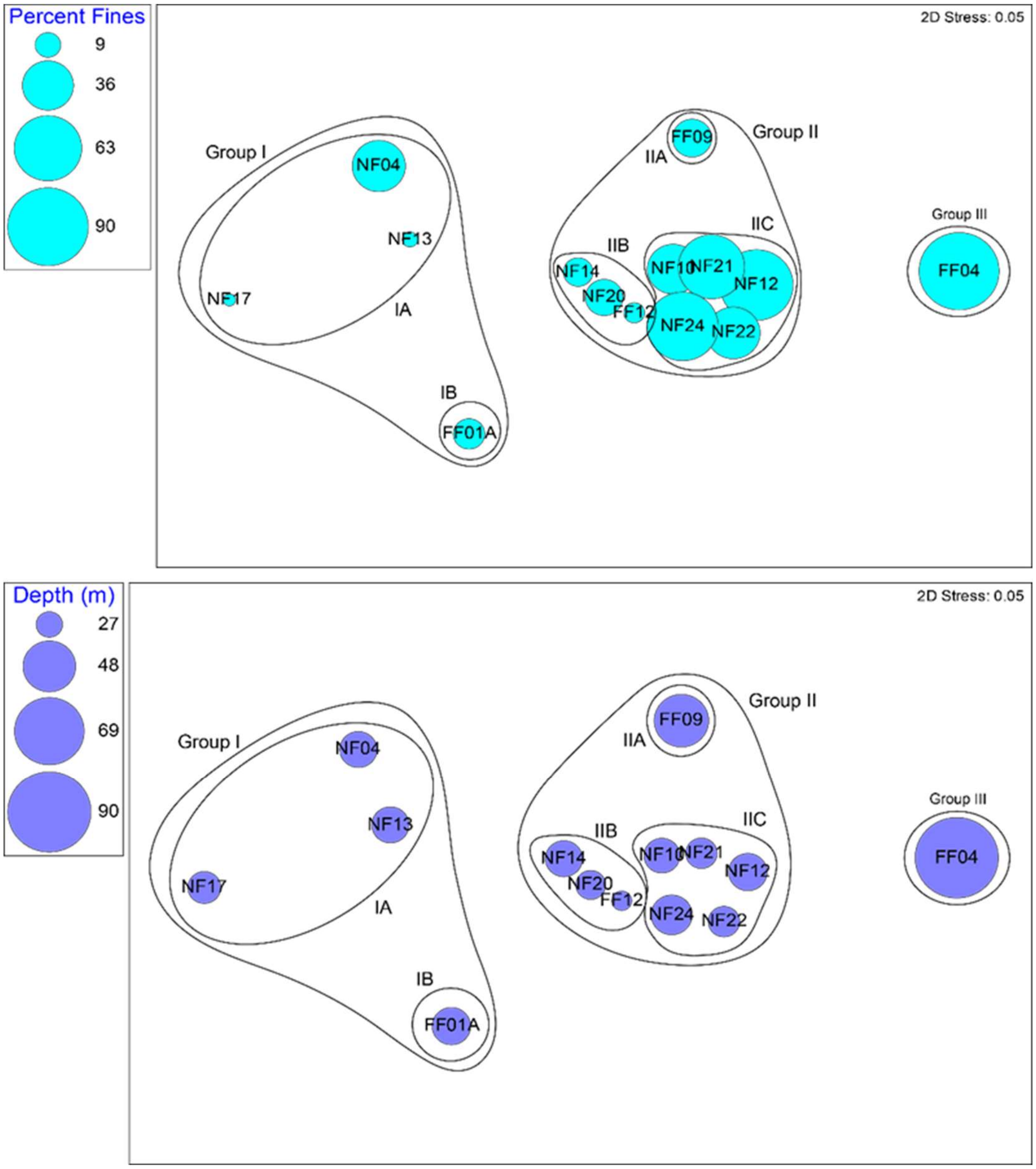


Figure 4-7. Percent fine sediments (top) and depth (bottom) superimposed on the ordination plot of the 2021 samples. Data are shown as in Figure 4-6, with the size of each station marker indicating the percentage of fine sediments (top) or water depth (bottom). Stations with similar sediment textures and/or depths tended to be represented in the same groups. (2D Stress noted in the upper right is a measure of good confidence in the analysis.)

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 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 would be expected if they were to occur.

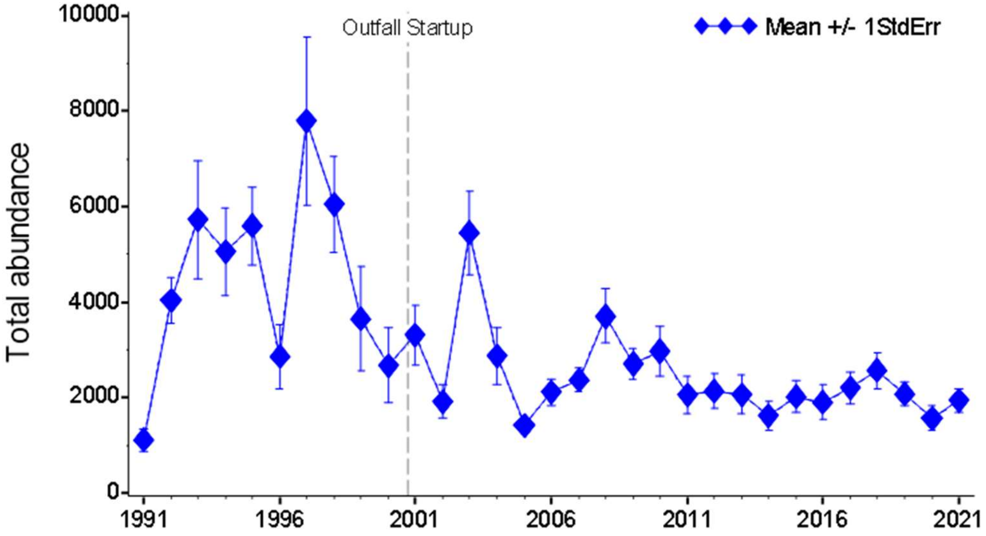
Station FF04 is typical of the deep waters offshore from the outfall, representative of a larger group of stations that were monitored in earlier years of the program, and it continues to support a soft-bottom community typical of what had been found at the larger suite of deep-water stations. Communities at those stations have always shown distinct differences from those found at shallower stations, probably due to their distance from shore, as well as their depth and their fine-grained sediments. Superimposing percent grain size and depth on the ordination plot for 2021 samples continued to show these natural differences (Figure 4-7).

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 are much better and continue to improve in Boston Harbor. MWRA has conducted ongoing seafloor monitoring in Boston Harbor since 1991. Annual sediment samples are taken from nine stations, and sediment-profile imaging is carried out at 61 stations throughout the harbor.

Sediment textures within the harbor have been generally stable over time, ranging from mostly sand at some stations to silt and clay at others. Concentrations of total organic carbon in harbor sediments have declined over time, reflecting the lowered inputs of organic carbon associated with each milestone throughout the Boston Harbor Project.

Over the past decade, the total abundance of organisms and species per sample have stabilized (Figure 4-8), responses to continued and sustained improvement in seafloor habitat conditions. In 2021, 18 samples yielded 31,349 specimens, classified into 132 species and 17 other discrete taxonomic groups. As in past years, the communities varied along an outer- to inner-harbor gradient, reflecting the greater tidal flushing at the outer harbor stations. Sediment-profile imaging has also confirmed an outer- to inner-harbor gradient and clearly documented improvements to habitat conditions throughout the duration of the Boston Harbor Project.



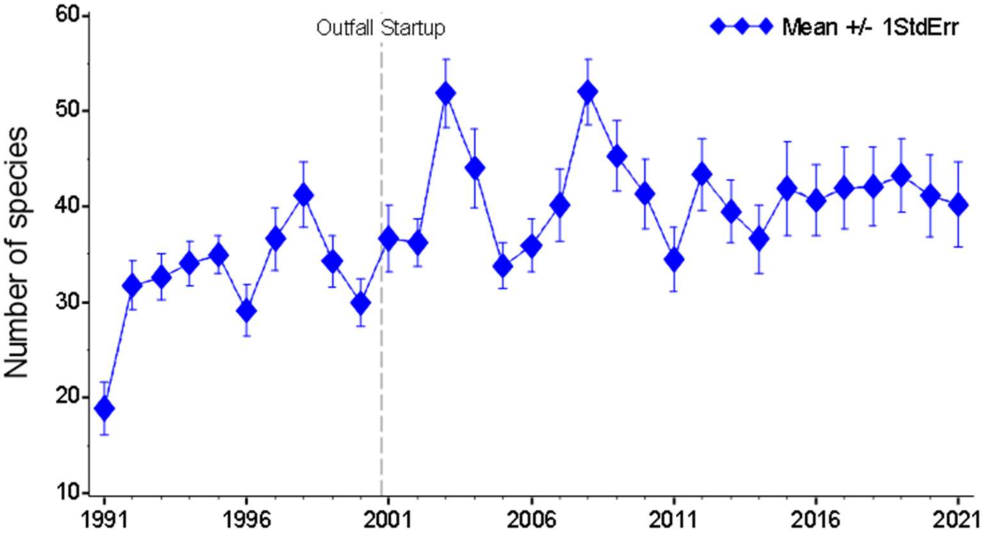


Figure 4-8. Total abundance of soft-bottom animals (top) and species (bottom) per sample in Boston Harbor samples, 1991–2021. Data are from eight harbor stations that have been consistently monitored.

Sediment-profile images depicted the continuing good conditions in 2021. One primary indicator of habitat quality, the organism-sediment index, was higher in 2021 than in 2020, continuing to show improvements to seafloor habitat. Eelgrass continues to be present at Station R08 in Deer Island Flats in 2021 (Figure 4-9).

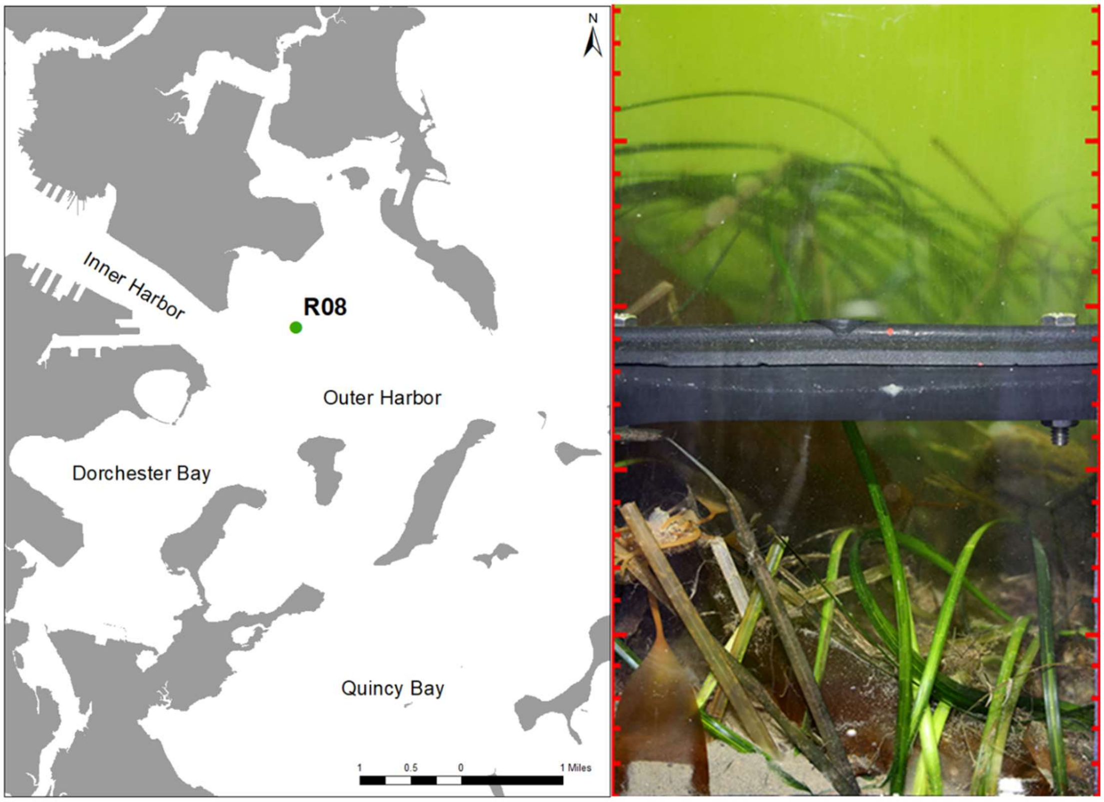


Figure 4-9. An eelgrass bed off Deer Island, where effluent was once discharged into Boston Harbor, continued to thrive in 2021. Green dot on map shows Station R08, the location of the image. The red markings on the photo edges are centimeters.

Contingency Plan Seafloor Thresholds

There were no threshold exceedances for the seafloor Contingency Plan parameters in 2021 (Table 4-1). All seafloor threshold values are calculated for the nearfield; for the purposes of threshold testing, "nearfield" includes all nearfield stations (both nearer and farther than two kilometers from the outfall) and the station in the transition area between Boston Harbor and the Massachusetts Bay outfall.

Number of species per sample and the diversity and evenness indices remained higher than Contingency Plan limits, while the percent opportunistic species remained far below any level of concern, less than 1% compared to a caution level of 10%. All threshold parameters continued to confirm that Massachusetts Bay maintains persistently healthy seafloor habitats, unaffected by the outfall discharge.

Table 4-1. Contingency Plan threshold values and 2021 results for seafloor monitoring.

Parameter	Baseline	Caution Level	Warning Level	2021 Results
Species per sample	NA	<42.99	None	64.9
Fisher's log-series alpha	NA	<9.42	None	13.2
Shannon diversity	NA	<3.37	None	4.11
Pielou's evenness	NA	<0.57	None	0.68
% opportunists	NA	>10%	>25%	0.53%

NA = not applicable There were no exceedances in 2021.

5. Fish and Shellfish

Flounder and lobster, which feed on the sea floor, and mussels, which filter large volumes of seawater, have potential exposure to contaminated particles suspended in water or settled on the ocean floor.

Fish and shellfish monitoring preserves healthy stocks and safe seafood. Fish and shellfish can be good indicators of overall environmental health, and monitoring protects the public health of seafood consumers. This monitoring includes external and internal assessments of winter flounder health and analysis of toxic contaminant levels in winter flounder, lobsters, and cage-deployed blue mussels.

MWRA monitors winter flounder health each year and conducts chemical contaminant analyses of flounder, lobster, and cage-deployed mussel tissues every three years, including 2021. Sampling and deployment sites vary by species (Figure 5-1). Annual flounder monitoring focuses on external condition and the presence of liver disease, precancerous conditions, and tumors. Contaminant monitoring focuses on toxic metals and organic pollutants.

In April 2021, flounder were collected from the Massachusetts Bay outfall site, Deer Island Flats (near the former Boston Harbor outfall), and eastern Cape Cod Bay, a clean, coastal reference area. Monitoring of the eastern Cape Cod Bay site was to have been discontinued after 2020, as contaminant levels have been consistently low, but the location was sampled as part of a separate pilot project. Only health assessments were made of those fish.

A full complement of 50 fish were collected from the outfall site and eastern Cape Cod Bay (Figure 5-2). However, despite three hours of trawling, the time limit designated in the work plan, only 33 fish were taken from Deer Island Flats. Catches have been relatively low throughout the region for the past three years. Southern New England winter flounder populations have declined since the 1980s, possibly a result of overfishing (for example, Frisk et al. 2018). MWRA survey trawls have also been compromised by abandoned lobstering gear and benthic algal growth clogging the trawl net, and both those conditions hampered the 2021 Deer Island Flats catches.

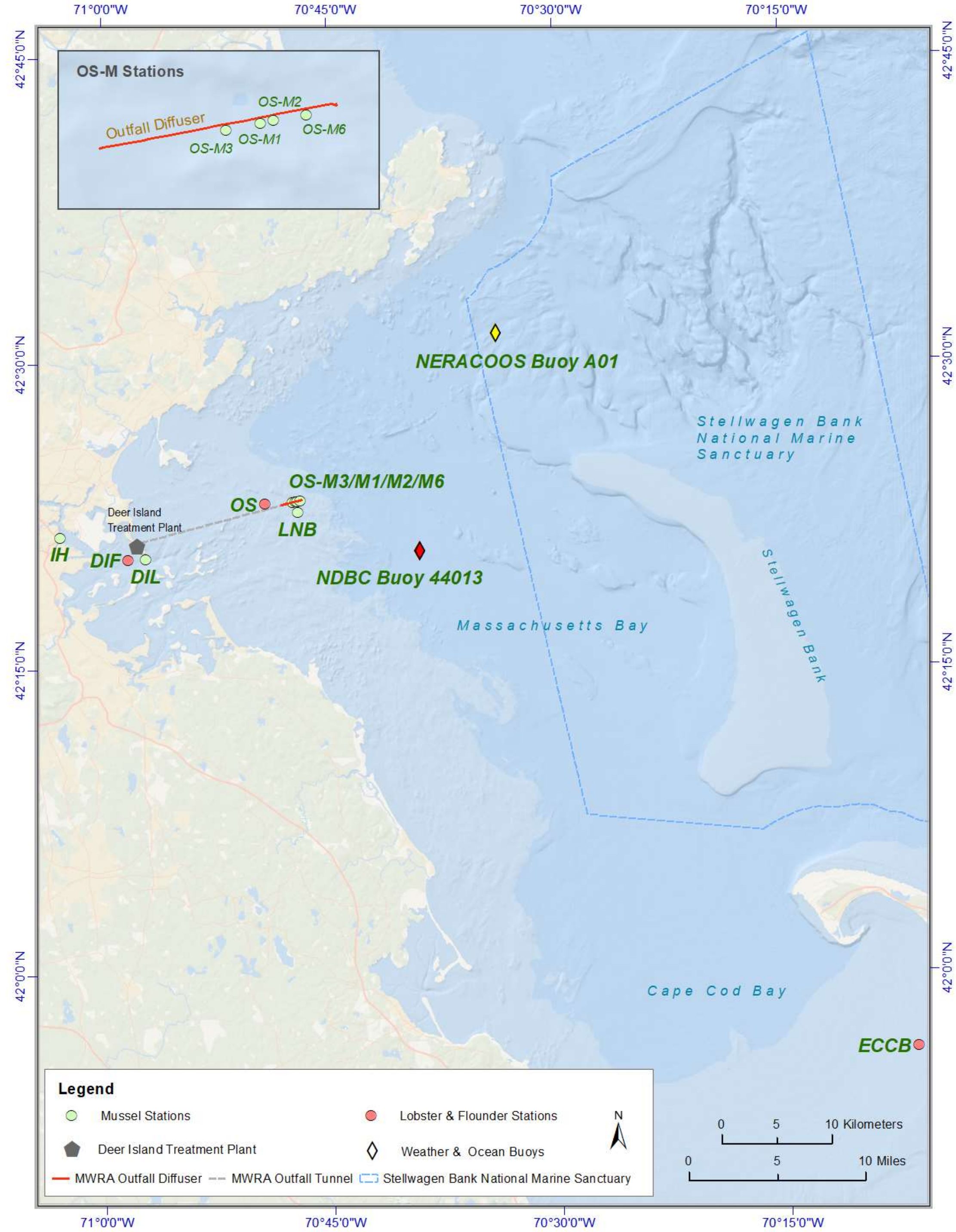


Figure 5-1. Fish-and-shellfish monitoring stations. IH = Inner Harbor; DIF = Deer Island Flats; DIL = Deer Island Light; OS = Outfall Site; OS-M = Outfall Site, Mussels; LNB = Large Navigation Buoy (buoy south of the outfall); ECCB = Eastern Cape Cod Bay. Also shown are the outfall, the instrumented buoys, and the Stellwagen Bank Marine Sanctuary.

Figure 5-2. Abundant flounder catch near the Massachusetts Bay outfall site in 2021. However, over the past three years, catches at Deer Island Flats have been low, as abandoned lobster gear interferes with trawling. Photo credit Michael Moore, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

Lobsters were collected by commercial fishermen from the same locations as the flounder: the Massachusetts Bay outfall site, near Deer Island, and eastern Cape Cod Bay. All lobster collections were completed during a one-week period in July.

Researchers acquired mussels from the Northeastern Massachusetts Aquaculture Center, located at Cat Cove Marine Laboratory, a part of Salem State College in Salem, Massachusetts. Caged mussels were placed at three locations for 30- and 60-day deployments: near the diffusers at the Massachusetts Bay outfall, within Boston Inner Harbor, and at Deer Island Light. Survival of the deployed mussels was high, almost 100%.

Flounder Health

While at sea, scientists complete external health assessments and preserve livers for laboratory analysis (Moore et al. 2022; Figure 5-3). Across all sites, mean age of fish ranged from 4.8 to 5.5 years, and standard length (length from the tip of the head to the base of the tail fin) ranged from 333 to 377 millimeters, somewhat older and longer than the 2020 catches, but within the ranges observed in recent years. As in past years and as is common throughout northeast coastal populations (Moore et al. 2016), the catches were dominated by females, with the highest proportion of females taken from eastern Cape Cod Bay.

Figure 5-3. A scientist examines a flounder at sea.
Photo credit Eric Rydbeck, Normandeau Associates, Bedford, New Hampshire.

Measures of external condition, such as bent fin rays and occurrence and severity of fin erosion, continued to suggest improved conditions since the 1980s and 1990s. Incidence of fin erosion at Deer Island Flats was the lowest ever measured in fish from near the former Boston Harbor outfall site. Blind-side ulcers, which remain poorly understood but are observed in some years, were not present in 2021.

The incidence of centrotubular hydropic vacuolation (CHV), a tumor precursor and mild liver condition associated with exposure to contaminants, remained lower than the baseline observations at all sites (Figure 5-4). CHV incidence was the lowest measured in any year at the outfall site and at Deer Island Flats. Total CHV incidence at Deer Island Flats decreased from more than 75% in 1988 to 20% or less in recent years and only 9% in 2021. CHV incidence has been lower across all age groups in both the harbor and the bay, alleviating any concerns for increased liver disease in Massachusetts Bay.

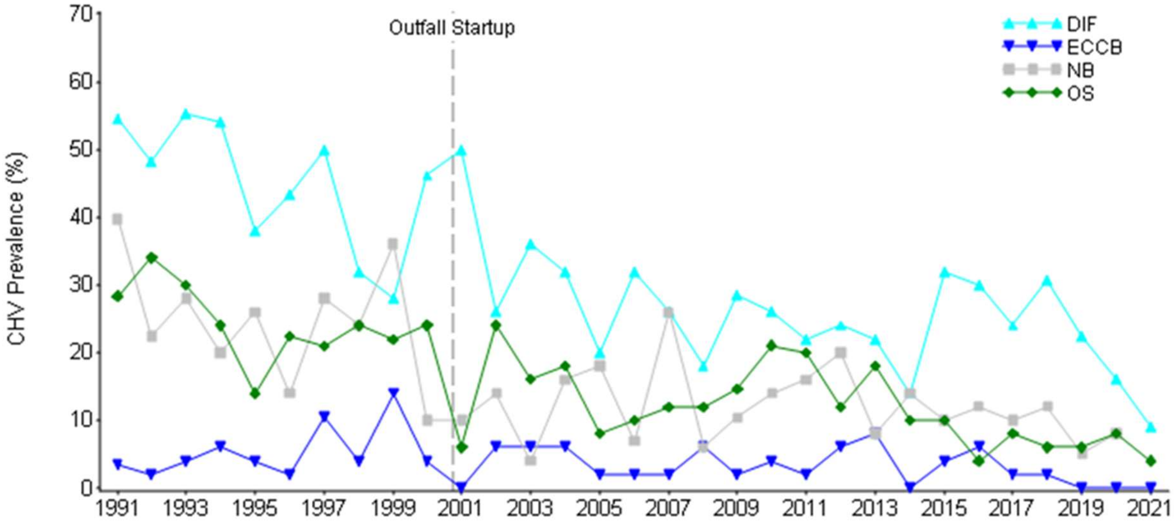


Figure 5-4. Annual prevalence of the tumor precursor centrotubular hydropic vacuolation (CHV) in winter flounder, 1991–2021. DIF = Deer Island Flats, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach (sampled until 2020), OS = Outfall Site

Liver tumors (neoplasia), which were present in up to 10% of fish in the 1980s, have not been observed by the monitoring program since 2004 and have never been found in fish taken from the Massachusetts Bay outfall site (Figure 5-5; see also Moore et al. 2018).

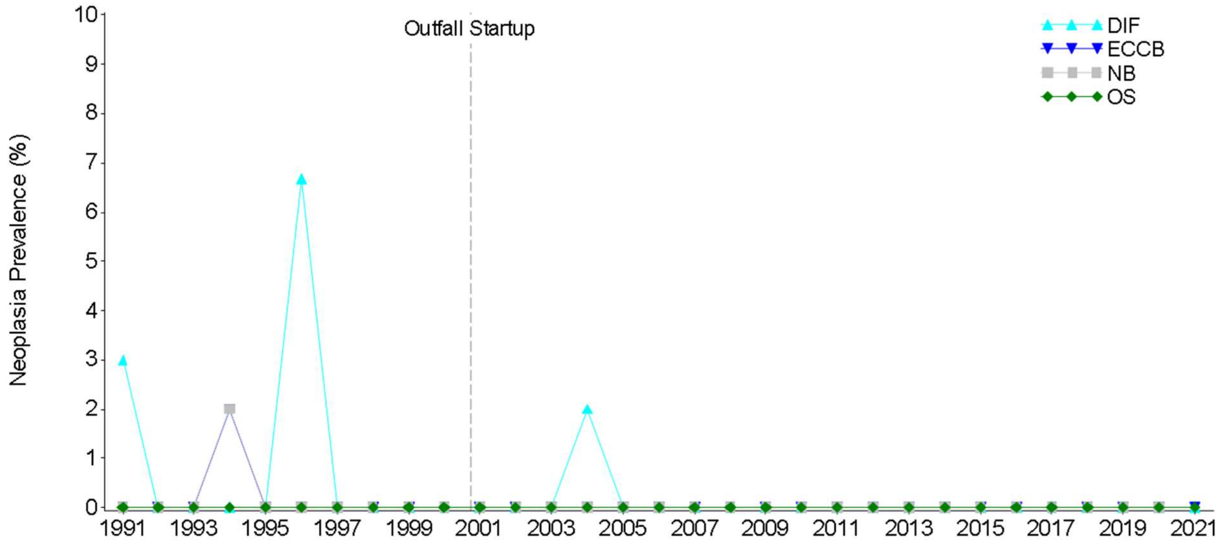


Figure 5-5. Annual prevalence of neoplasia (liver tumors) in winter flounder, 1991–2021. DIF = Deer Island Flats, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach (sampled until 2020), OS = Outfall Site.

Fish and Shellfish Tissue Chemistry

Samples for chemical analyses were taken from the same winter flounder collections made for health assessments at the Massachusetts Bay outfall and Deer Island Flats. Samples of winter flounder fillet were analyzed for PCBs, pesticides, and mercury. Liver samples from the same fish were analyzed for PCBs, pesticides, PAHs, and selected metals.

Contaminants in flounder, lobster, and mussels have not increased since the Massachusetts Bay discharge began in 2000. Levels of many contaminants have declined, particularly near the former Deer Island outfall in Boston Harbor.

Samples of lobster meat collected in July from those same two locations plus eastern Cape Cod Bay were analyzed for PCBs, pesticides, and mercury. Digestive gland (the hepatopancreas, often called tomalley) samples from the same animals were analyzed for PCBs, pesticides, PAHs, and selected metals.

Mussels, deployed in cages in Boston Inner Harbor, Deer Island Flats, and near the outfall, were analyzed for PCBs, pesticides, PAHs, lipids, mercury, and lead. Concentrations following the 30- and 60-day deployments were compared to concentrations in the reference mussels prior to deployment.

Overall, concentrations of metals and banned organochlorine pesticides and PCBs remained low in flounder, lobster and mussel tissues, with the highest concentrations measured in flounder and lobster tissues from near Deer Island and lowest in samples from Cape Cod Bay. Slow declines in banned pesticides and PCBs from the 1990s to present continued across all flounder and lobster tissue types and locations and were particularly evident in samples from the fish caught near Deer Island.

For example, slow declines in concentrations of the banned pesticide chlordane in flounder fillets (Figure 5-6) have persisted throughout the monitoring program. Similarly, long-term declines in concentrations of the banned pesticide DDT and its breakdown products have been observed in lobster meat, even in lobsters from the relatively pristine sampling area in eastern Cape Cod Bay (Figure 5-7).

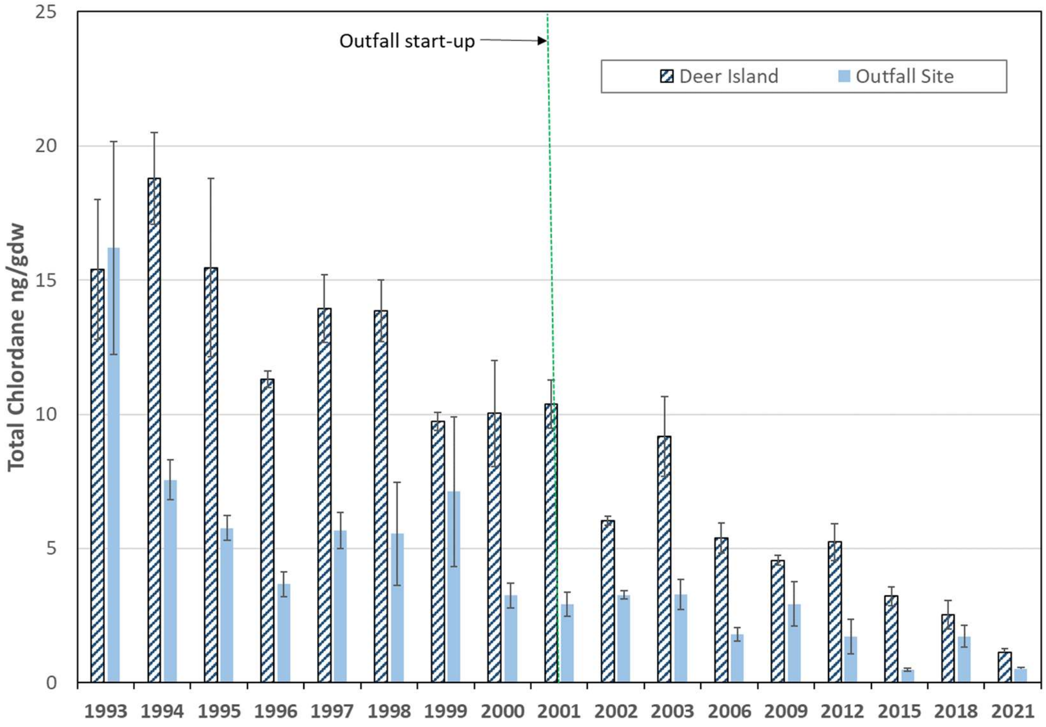


Figure 5-6. Total chlordanes in flounder fillets, 1993–2021. Since 2003, sampling has occurred at three-year intervals. Flounder were also collected from eastern Cape Cod Bay but not analyzed for chemical contaminants.

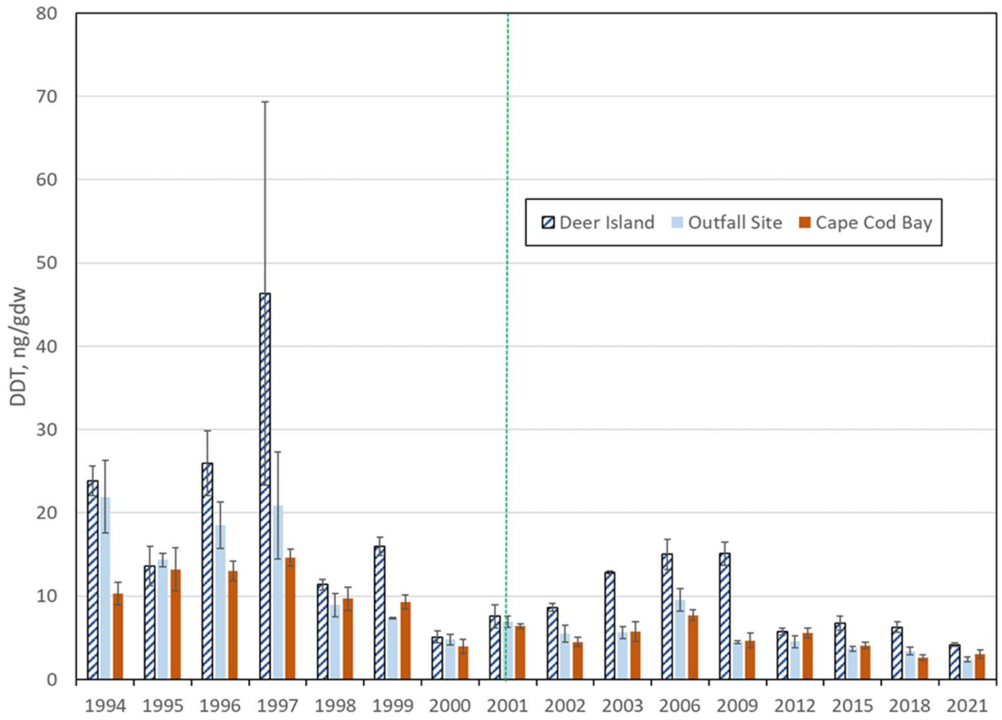


Figure 5-7. DDT in lobster meat, 1994–2021. (Since 2003, sampling has occurred at three-year intervals.)

Pesticide concentrations in deployed mussels have also declined over time, a result not only of pesticide bans, but also due to improved treatment at Deer Island Treatment Plant and the outfall relocation. Results from 2021 demonstrated that contamination remains greatest in Boston Inner Harbor which has a legacy of inputs other than wastewater discharges. For example, consistent with past years, total PCB accumulation was greatest in mussels deployed in Boston Inner Harbor, intermediate in mussels near Deer Island, and lowest in mussels at the Massachusetts Bay outfall (Figure 5-8). Concentrations of PCBs in mussels deployed at the outfall were indistinguishable from the pre-deployment reference mussels from the Northeastern Massachusetts Aquaculture Center. Other contaminants showed similar patterns.

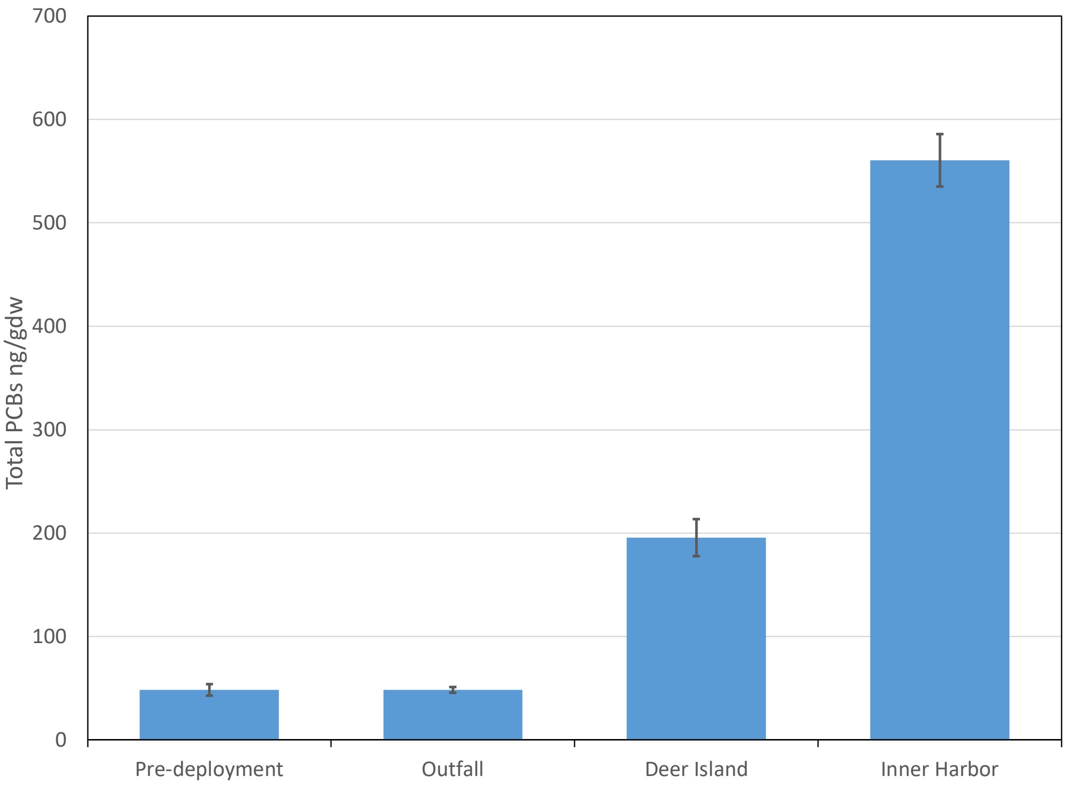


Figure 5-8. Total PCBs in pre-deployment and deployed mussels, 2021. PCB levels show a clear gradient of highest concentrations in the Inner Harbor and lowest at the Massachusetts Bay outfall. Mussels placed at the outfall are indistinguishable from mussels tested for PCBs prior to deployment.

Contingency Plan Fish and Shellfish Thresholds

There were no fish or shellfish Contingency Plan threshold exceedances in 2021 (Table 5-1). Flounder liver disease levels (measured as CHV) were less than 10% of the caution threshold and also well below baseline measurements. Except for mercury in mussel tissue, contaminant levels also remained below the baseline, and those mussel mercury levels were only 3–4% of the caution and warning thresholds.

Table 5-1. Contingency Plan threshold values and 2021 result for fish-and-shellfish monitoring.*

Parameter	Baseline	Caution Level	Warning Level	2021 Results
Flounder disease				
Liver disease (CHV)	24.4%	44.9%	None	4%
Flounder fillet				
PCB	0.033 ppm	1 ppm wet weight	1.6 ppm wet weight	0.009 ppm
Mercury	0.074 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.083 ppm
Flounder fillet, lipid normalized				
Chlordane	242 ppb	484 ppb	None	16 ppb
Dieldrin	63.7 ppb	127 ppb	None	0 ppb
DDT	775.9 ppb	1552 ppb	None	89.7 ppb
Lobster meat				
PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight	0.005 ppm
Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.128 ppm
Lobster meat, lipid normalized				
Chlordane	75 ppb	150 ppb	None	2 ppb
Dieldrin	161 ppb	322 ppb	None	12 ppb
DDT	341.3 ppb	683 ppb	None	37 ppb
Mussel tissue				
PCB	0.011 ppm	1 ppm wet weight	1.6 ppm wet weight	0.007 ppm
Lead	0.415 ppm	2 ppm wet weight	3 ppm wet weight	0.139 ppm
Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.022 ppm
Mussel tissue, lipid normalized				
Chlordane	102.3 ppb	205 ppb	None	31.7 ppb
Dieldrin	25 ppb	50 ppb	None	0 ppb
DDT	241.7 ppb	483 ppb	None	30.7 ppb
PAH	1080 ppb	2160 ppb	None	992 ppb

* Exceedances are all values greater than caution or warning thresholds. There were no exceedances in 2021
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 COVID-19 monitoring in MWRA influent, OMSAP evaluations of contaminants of emerging concern, dissolved oxygen investigations in Cape Cod Bay, and changing temperatures in the Gulf of Maine.

COVID-19 Influent Monitoring

MWRA was one of the first wastewater agencies to monitor the viral RNA in SARS-CoV-2, the virus that causes COVID-19, in its wastewater influent before treatment. Measurements began as a pilot project for MWRA's Department of Laboratory Services, with Biobot Analytics. MWRA routinely posts these data at www.mwra.com (Figure 6-1) and also provides data to the state COVID-19 Command Center.

There have been no known cases of a person contracting COVID-19 from untreated or treated wastewater, and its presence in MWRA influent is not considered a risk to public health or the environment.

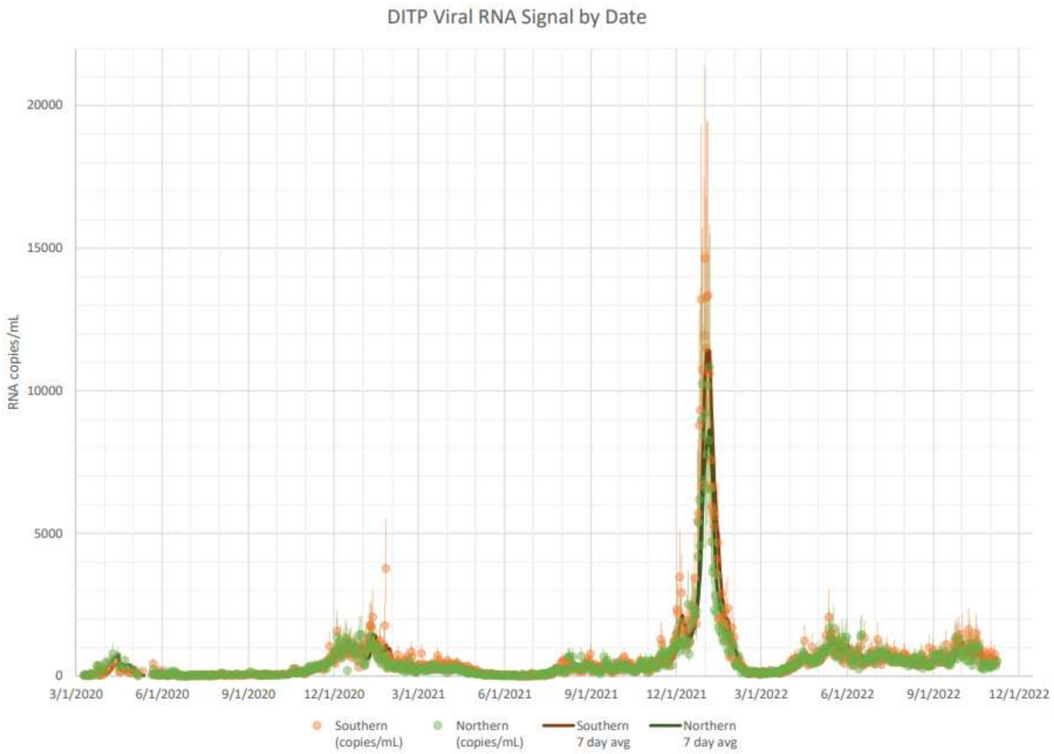


Figure 6-1. Viral RNA in MWRA untreated wastewater influent, March 2020 through November 9, 2022.

Monitoring the virus in wastewater is proving invaluable around the world, and wastewater monitoring is becoming a key tool for tracking other diseases as well. The Centers for Disease Control and Prevention has recognized the value of wastewater monitoring during the COVID-19 pandemic by launching the National Wastewater Surveillance System to coordinate wastewater tracking on a national level. Wastewater monitoring allows for the detection of a disease across the broad population, regardless of whether a person has symptoms or has received a diagnostic test. It can provide early indications of surges and declines and can track new variants as they emerge.

There have been no known cases of a person contracting COVID-19 from untreated or treated wastewater, and its presence in MWRA influent is not considered a risk to public health or the environment.

Contaminants of Emerging Concern

In the summer of 2022, the advisory group that oversees the monitoring program, OMSAP, issued a general framework for approaching questions about monitoring contaminants of emerging concern in Massachusetts Bay. The framework included white papers focusing on three specific contaminant groups: pharmaceuticals and personal care products; per- and poly-fluoroalkyl substances (PFAS); and microplastics (OMSAP 2022).

MWRA is participating in a number of projects to assess the presence of these contaminants in both the effluent and in Massachusetts Bay. For each of the contaminant groups, a number of compounds are widespread in the environment. Public health concerns are not well known, and there are no regulations, limits, or monitoring requirements, with the exception of PFAS, which is now being added to NPDES permits. Projects receiving MWRA support are:

- A pilot study sponsored by EPA detected low levels of some pharmaceutical and personal care products and PFAS in MWRA effluent and in Massachusetts Bay. MWRA provided effluent samples and technical assistance to this pilot study.

- Scientists from the Woods Hole Oceanographic Institution are measuring microplastics at Deer Island Treatment Plant, in Massachusetts Bay, and in Buzzards Bay, with MWRA providing ship time on consultant and MWRA vessels. Their preliminary results found more particles and a greater diversity of plastics in Buzzards Bay than in Massachusetts Bay.

- MWRA is participating in two Water Research Foundation projects. One examines PFAS occurrence in wastewater treatment facilities in the United States, and the other, the potential release of PFAS from biosolids. Biosolids are produced from sludge, those solids removed during the treatment process that are often used as fertilizer. Search for Projects 5031 and 5042 at https://www.waterrf.org/search?type=project for more details.

Dissolved Oxygen in Cape Cod Bay

In recent years, low dissolved oxygen conditions have been detected in the shallow nearshore waters of Cape Cod Bay in the late summer, low enough that fish and lobster mortalities were reported in 2019. These hypoxic conditions were not caused or aggravated by nutrient inputs from the Massachusetts Bay outfall. However, since the hypoxia in 2019, MWRA, its monitoring team members from the Center for Coastal Studies and Woods Hole Oceanographic Institution, and other researchers have participated in research to understand the causes of hypoxia (for example, Scully et al. 2022) and better protect the fish and lobster resources.

In collaboration with DMF, the Massachusetts Lobster Foundation has sponsored a group of local lobstermen to aid in these studies, the Cape Cod Bay Study Fleet. In 2021, DMF provided oxygen probes to local lobstermen for placement on the gear they deploy on the sea floor. The probes provide near real-time measurements of bottom-water dissolved oxygen conditions.

In August 2021, the Cape Cod Bay Study Fleet probes detected declining dissolved oxygen concentrations at numerous sites. Dissolved oxygen levels reached as low as 2.3 milligrams per liter in one lobster trap in eastern Cape Cod Bay (Figure 6-2), well below the state standard of 6 milligrams per liter. An advisory notified lobstermen to check their traps regularly and consider moving some gear; both precautions could prevent trapping lobsters in hypoxic conditions for extended periods of time. Fortunately, conditions did not further decline, as a late August storm mixed and re-aerated the bottom waters. No fish or shellfish mortalities were recorded in 2021.

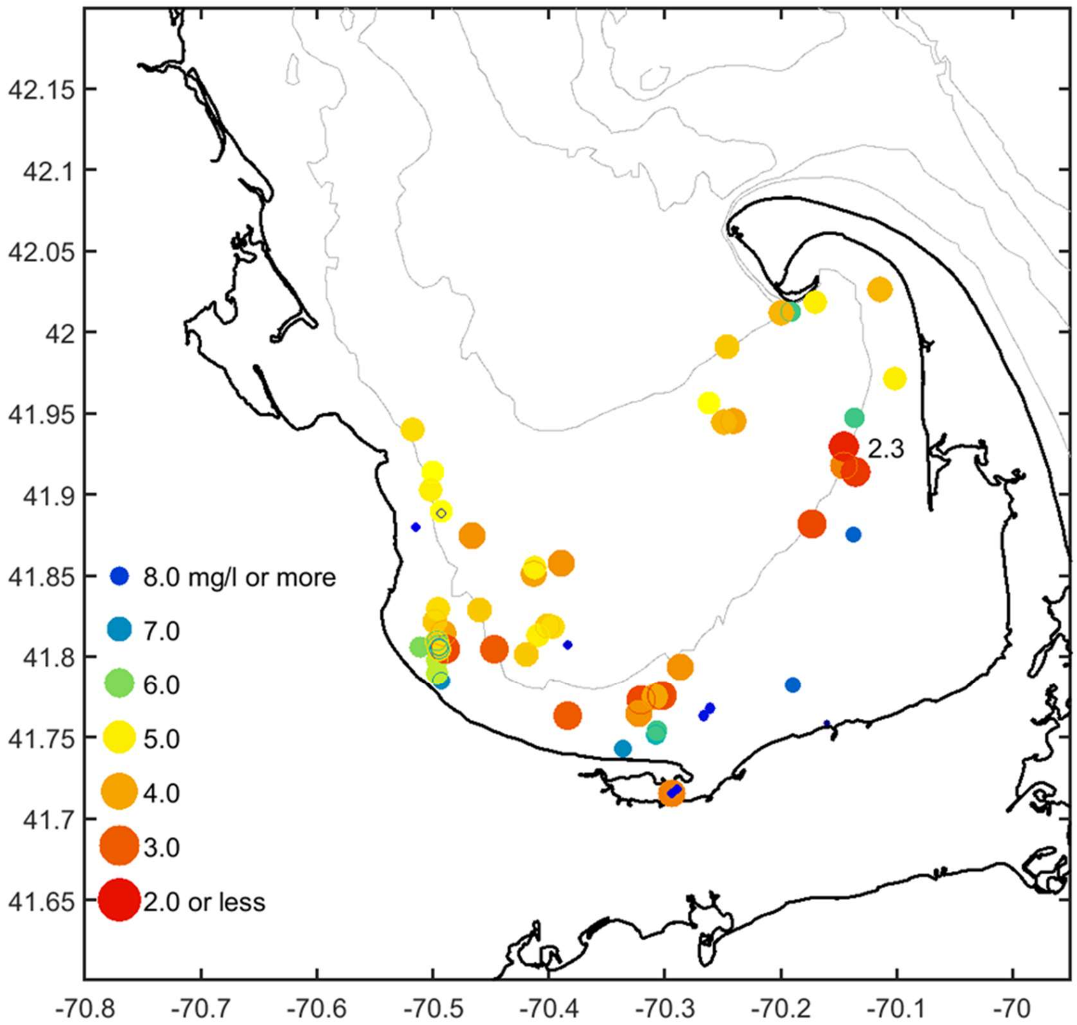


Figure 6-2. Dissolved oxygen levels recorded on sensors deployed on lobster traps in 2021. The lowest value, 2.3 milligrams per liter, was recorded in eastern Cape Cod Bay in mid-August. The state water quality standard is 6 milligrams per liter.

Occurrence of hypoxia in Cape Cod Bay appears to be exacerbated by the presence of *Karenia mikimotoi*, the dinoflagellate that first appeared in the region in 2017 (see Section 3, Water Column and Scully et al. 2022). *Karenia mikimotoi* is well-suited to exploit shallow waters with sharp and relatively deep pycnoclines, conditions found in the Cape Cod Bay lobstering grounds.

Temperature Changes in the Gulf of Maine

Over the course of more than two decades of monitoring, MWRA has documented increasing air and water temperatures. Water temperatures (Figure 6-3) have increased at a faster rate than air temperatures, suggesting that they result from a change in regional water circulation. Some 2020 and 2021 zooplankton samples were dominated by radiolarians, possible further evidence of regional changes in water flows, because radiolarians were previously observed only offshore in the Gulf of Maine.

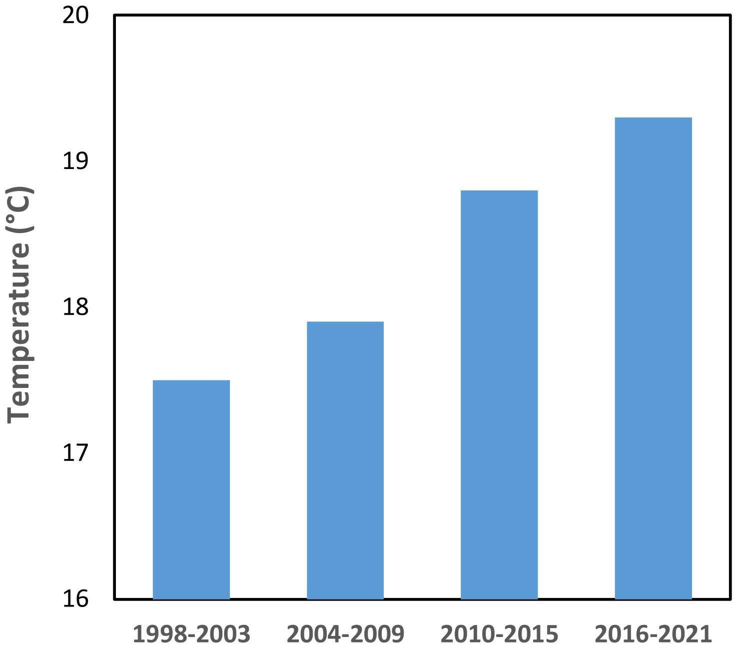


Figure 6-3. Average summer surface-water temperatures in Massachusetts Bay over four six-year periods, 1998–2021. Water temperatures have risen more quickly than air temperatures at the NDBC Buoy 44013 (location shown on Figure 3-1 on page 11).

High water temperatures can lead to lower levels of dissolved oxygen, and in 2021, there were Contingency Plan exceedances for some Stellwagen Basin dissolved oxygen parameters (see Section 3, Water Column). While the outfall discharge was not a factor in these exceedances, MWRA monitoring observations show the general trends of warming waters and declining dissolved oxygen levels in Massachusetts Bay.

Changing wind patterns may also be a factor in higher temperatures. In recent years, winds have come less frequently from the south and southwest (Scully et al. 2022). This shift has reduced upwelling, which brings cool bottom waters to the surface.

The MWRA measurements showing increasing water temperatures mesh with findings from other groups in the broader region. For example, publications from researchers at the Gulf of Maine Research Institute (GMRI) in Portland, Maine, show that Gulf of Maine waters warmed faster than 99% of the world's oceans from 2004 to 2013 (Pershing et al. 2015). The GMRI website suggests that the increases in the past decade could be tied to "marine heat waves," periods when five or more consecutive days reach temperatures in the 90th percentile compared to the average.

Scientists studying right whale populations see these temperature shifts as a driver to pushing the North Atlantic right whale towards extinction. Their hypothesis is that a physical shift has occurred, bringing warmer waters into the region. Beginning in 2010, scientists noted depressed calving success in the Gulf of Maine. By mid-decade, right whales had moved their summer and fall foraging grounds northward from the Gulf of Maine to the Scotian Shelf and the Gulf of Saint Lawrence. Since 2017, there has been evidence that this shift is resulting in greater mortality in Canadian waters, both by entanglement in fishing gear and other marine hardware and by ship strikes in the Gulf of Saint Lawrence (for example, Meyer-Gutbrod et al. 2021).

During the permitting process for the MWRA outfall, concern for the right whale was a primary driver of the permit conditions. Concerns included the possibility that whales could be threatened by infectious bacteria, viruses, or protozoans in the effluent; that toxic metals or PCBs could affect whale health; or that increased nutrient inputs might alter the types of available food (Rex et al. 1997). MWRA scientists firmly believed during the planning for the outfall that those concerns would not be realized, and the more than 20 years of data since the Massachusetts Bay outfall began to discharge have supported their view. Because of its long data set, the MWRA monitoring team is documenting changes that are unrelated to the outfall but which may have much greater effects on this highly endangered species and on the condition of the wider regional environment.

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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
DMF	Massachusetts Division of Marine Fisheries
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
GMRA	Gulf of Maine Research Institute
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
NOEC	No observed effects concentration
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OS	Outfall site
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PFAS	Per- and polyfluoroalkyl substance
PIAC	Public Interest Advisory Committee
PSP	Paralytic shellfish poisoning
PSU	Practical salinity units
RNA	Ribonucleic acid

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