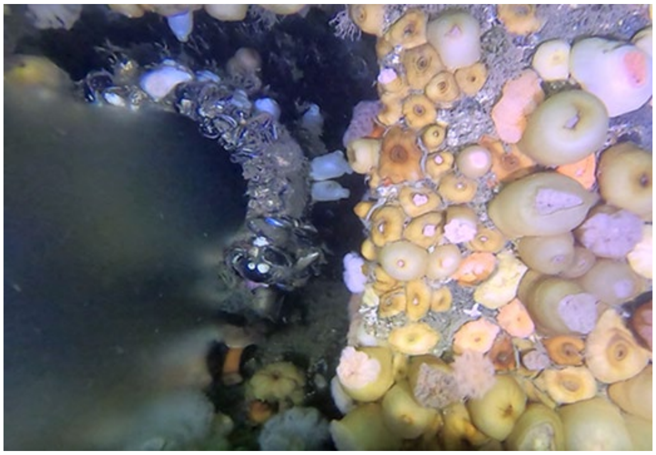


2024 Outfall Monitoring Overview

Massachusetts Water Resources Authority
Environmental Quality Department Report 2025-05

Citation:
Werme C, Libby PS, Carroll SR, Goodwin C. 2025. 2024 outfall monitoring overview. Boston: Massachusetts Water Resources Authority. Report 2025-05. 63 p.

Cover photos:

Top: Researchers recover a rosette used to collect samples and measure parameters like temperature, pH, and dissolved oxygen at station F23 off Deer Island on the September 2024 MWRA survey WN248. Photo credit P. Scott Libby, Battelle, Topsham, Maine.

Bottom: Blue mussels and sea anemones growing on an active outfall diffuser in 2023. Photo credit Hecker Environmental, Falmouth, Massachusetts.

2024
Outfall Monitoring Overview

prepared by

Christine Werme
Independent Consultant

P. Scott Libby
Battelle
72 Main Street
Topsham, ME 04086

Sally R. Carroll and Christopher Goodwin
Massachusetts Water Resources Authority
Environmental Quality Department
Deer Island
33 Tafts Avenue
Boston, MA 02128

November 11, 2025

2024 Outfall Monitoring Panel and Committees

Outfall Monitoring Science Advisory Panel

Judith Pederson, Massachusetts Institute of Technology Sea Grant (chair)
Peter Burn, Suffolk University
Virginia P. Edgcomb, Woods Hole Oceanographic Institution
Loretta Fernandez, Northeastern University
Robert Kenney, University of Rhode Island
Mark Patterson, Northeastern University
Jeff Rosen, Corona Environmental Consulting
Juliet Simpson, Massachusetts Institute of Technology Sea Grant
Juanita Urban-Rich, University of Massachusetts, Boston

Inter-Agency Advisory Committee

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

Public Interest Advisory Committee

Association to Preserve Cape Cod
Boston Harbor Now
Cape Cod Commission
Center for Coastal Studies
Conservation Law Foundation
Massachusetts Audubon Society
Massachusetts Bays National Estuary Partnership
MWRA Advisory Board
MWRA Wastewater Advisory Committee
Safer Waters in Massachusetts
Save the Harbor/Save the Bay

Executive Summary

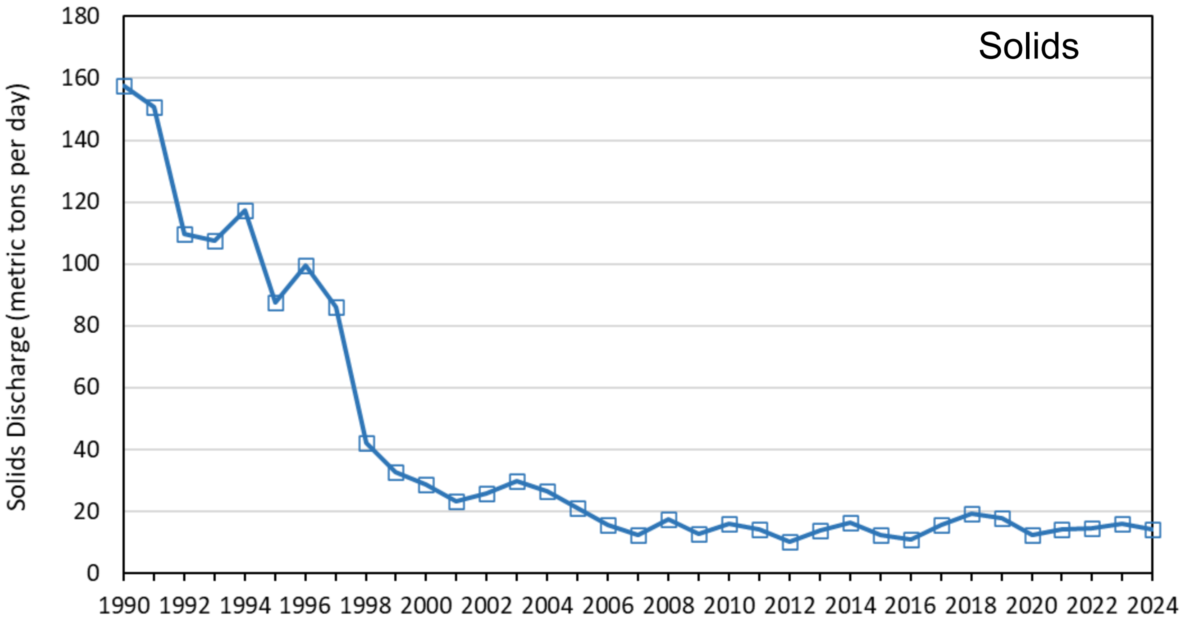
The Massachusetts Water Resources Authority (MWRA) provides water and wastewater services to more than three million people and more than 5,500 businesses in metropolitan Boston. Since its beginnings in 1984, MWRA has strived to minimize any adverse effects of wastewater discharges on the marine environment. MWRA works with industrial dischargers to prevent pollutants from entering the waste stream and provides primary and secondary sewage treatment to remove solid material and ensure that pollutants in the remaining liquid effluent meet permitted limits before discharge. Both the solid material, called sludge, and liquid effluent were once discharged into Boston Harbor. Sludge is now processed into fertilizer for use in gardening and landscaping. Treated effluent is discharged into Massachusetts Bay. The discharge is at depth, below the sunlit portion of the water column where plant growth occurs, preventing nutrients in the effluent from overstimulating algal growth.

MWRA's permit to discharge treated effluent through its Massachusetts Bay outfall requires monitoring the effluent before discharge and monitoring the water column, sea floor, and living communities in Massachusetts Bay. In the more than two decades that MWRA has discharged treated wastewater into Massachusetts Bay, there have been no unanticipated effects or findings of environmental concern.

Deer Island Treatment Plant effluent meets permit conditions

Producing the cleanest possible sewage effluent is the most important way that MWRA strives to protect the marine environment. In 2024, MWRA earned a Platinum Peak Performance Award from the National Association of Clean Water Agencies for 18 consecutive years with no permit-limit exceedances.

One important measure of effluent quality is the suspended solids load, that is, the total amount of solid material discharged each year. Treatment removes most of the solids from sewage as sludge, but small particles remain suspended in the effluent. The 2024 effluent solids discharges remained consistent over the past two decades, measuring far lower than the amounts once discharged into Boston Harbor (Figure i, top). Discharges of potentially toxic metals have followed similar patterns, remaining low for more than 20 years (Figure i, bottom). Discharges of both solids and toxic pollutants have been much less than originally had been anticipated during the planning for the Massachusetts Bay discharge site.



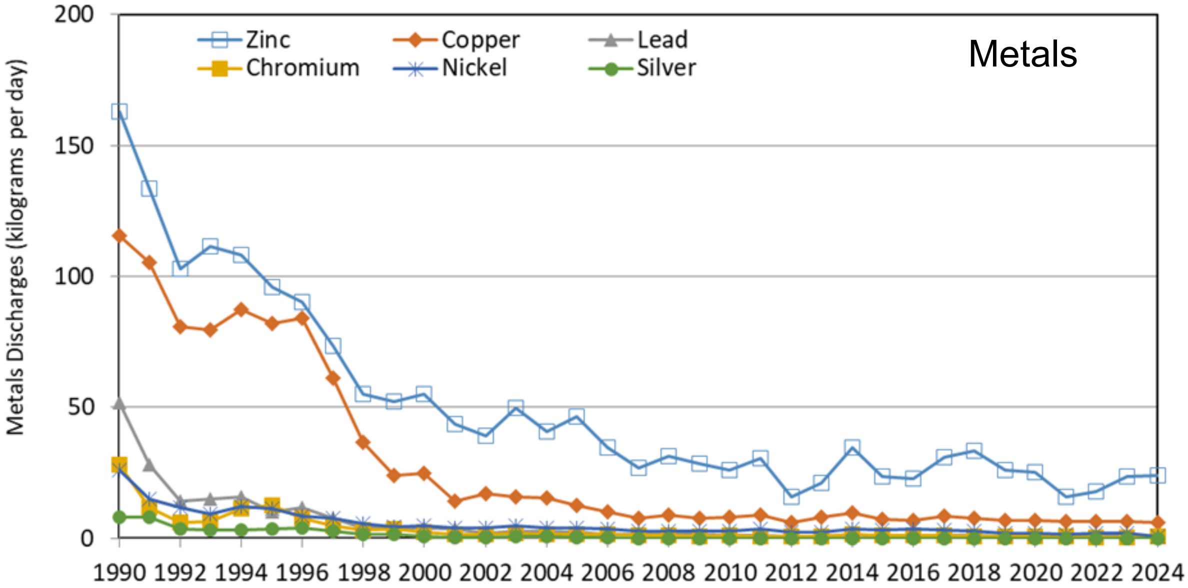


Figure i. Annual discharges of sewage solids (top) and metals (bottom), 1990–2024. Source reduction measures, including industrial pretreatment, ending sludge discharges, and secondary effluent treatment dramatically decreased solids and metals discharges. Those decreases have been sustained for more than 20 years. The effluent discharge was moved from Boston Harbor to Massachusetts Bay in September 2000.

MWRA's discharge has not led to eutrophication

Sewage treatment removes some, but not all, of the nutrients in wastewater, so MWRA water-column monitoring focuses on nutrient inputs and potential eutrophication, the excessive growth and decay of phytoplankton, the microscopic algae that live in the water column (Figure ii).

Eutrophication occurs when nutrients overstimulate phytoplankton growth, leading to lower levels of oxygen when the phytoplankton die and decompose.

Eutrophication can lead to low levels of dissolved oxygen, harming all marine life. It can also stimulate nuisance or toxic algal blooms, which can threaten marine mammal and human health. In 2024, water-quality analyses, including measurements of nutrient concentrations, phytoplankton biomass, and dissolved oxygen concentrations, continued to demonstrate that MWRA's treated effluent discharge has not led to eutrophication in Massachusetts Bay.

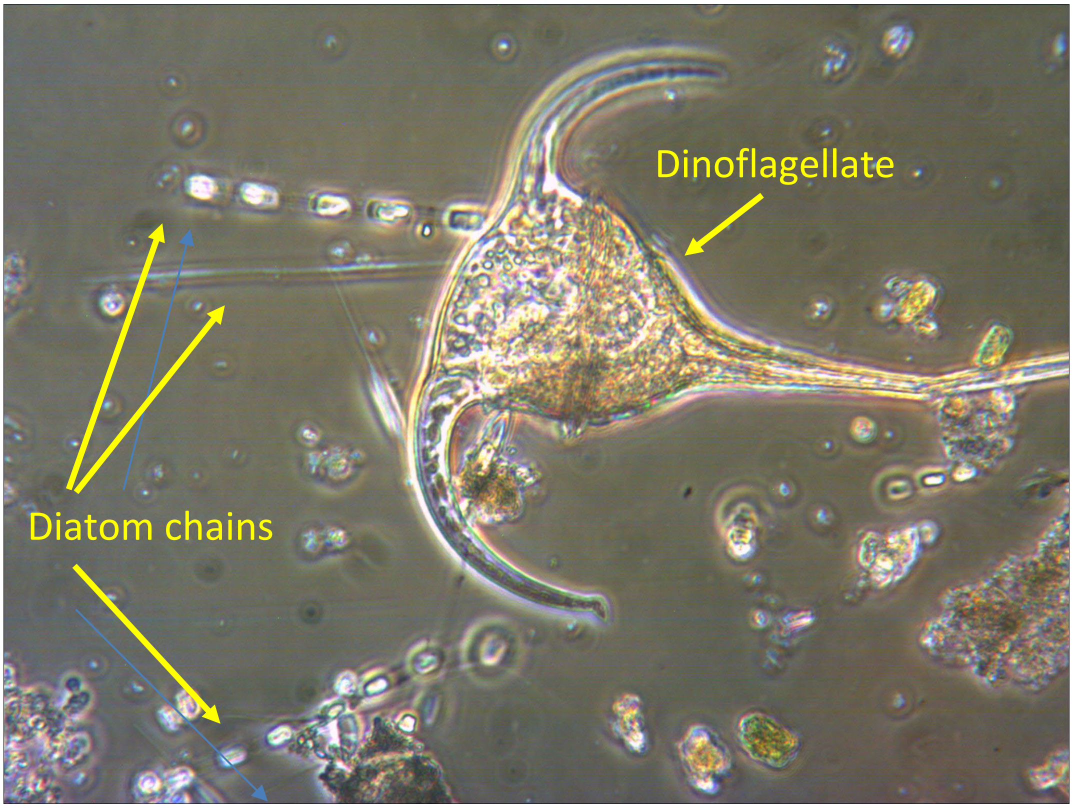


Figure ii. Typical phytoplankton from Massachusetts Bay. Phytoplankton include chains of individual diatoms and larger dinoflagellates. Photo credit David Borkman, Pausacaco Plankton, Saunderstown, Rhode Island.

Seafloor communities are thriving

MWRA's monitoring of the sediments and animals at the sea floor (for example, Figure iii) has shown that bottom-dwelling communities are influenced by sediment types and water depth rather than by the effluent discharge. The total abundance of animals, numbers of species, and the species makeup of bottom-dwelling communities have remained within the ranges of natural variability.

Figure iii. Polychaete worms dominate the soft-bottom habitats in Massachusetts Bay. The image shows a polychaete that is about 2 millimeters long, taken from a former MWRA monitoring station. Polychaetes can range in size from less than a millimeter to several meters; most are very small. This polychaete is in a group sometimes called necklace worms, due to the constricted band depicted in the lower middle part of the photograph. Necklace worms are found in a variety of soft- and hard-bottom habitats. Photo credit Nancy J. Maciolek, Duxbury, Massachusetts.

Pollutant levels in fish and shellfish remain low

MWRA monitors the health of winter flounder, one of the region's popular commercial and recreational fish. Flounder live and feed at the sea floor, where they are susceptible to contaminant-related physical abnormalities and health risks, but no adverse effects have been detected in response to the Massachusetts Bay effluent discharge. Instead, flounder health has improved both near the Massachusetts Bay outfall and at the former sewage effluent outfall in Boston Harbor, a result of pollution prevention and sewage treatment. Cancerous tumors have never been found in fish caught near the Massachusetts Bay outfall.

Every three years, including 2024, MWRA measures pollutant levels in winter flounder, lobsters, and blue mussels. Results show continued low pollutant levels in all three species (for example, Figure iv).

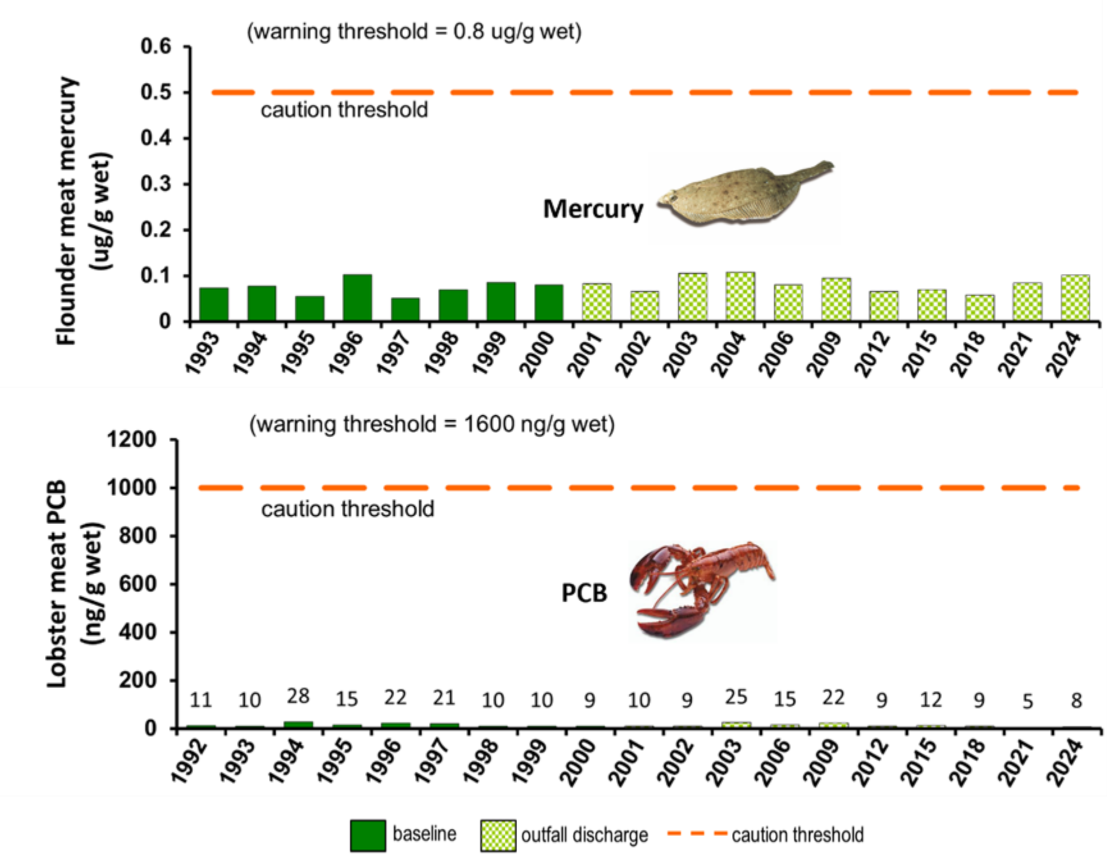


Figure iv. Mercury concentrations in flounder and PCBs in lobsters caught near the Massachusetts Bay outfall have remained low. MWRA has a Contingency Plan, which includes both caution and warning thresholds, designed to alert the regulatory agencies of environmental changes. Only the caution thresholds are shown. "Baseline" is 1992–2000, when effluent was discharged to Boston Harbor; "outfall discharge" is years when the discharge was to Massachusetts Bay; ng/g wet = nanograms per gram wet weight.

Table of Contents

List of Figures

List of Tables

1. Introduction

For more than 40 years, since its creation in 1984, the Massachusetts Water Resources Authority (MWRA) has strived to minimize adverse effects of municipal wastewater on the marine environment. A vigorous pretreatment program, a carefully maintained treatment plant, and vigilant effluent and environmental monitoring have ensured that marine life in Boston Harbor and Massachusetts Bay remain healthy and vibrant. In September 2000, MWRA diverted its Deer Island Treatment Plant wastewater effluent discharge from the shallow, enclosed waters of Boston Harbor to a deeper, more open site in Massachusetts Bay. This milestone was one of the most important components of the "Boston Harbor Project."

MWRA operates the Massachusetts Bay outfall 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. An independent Outfall Monitoring Science Advisory Panel has assisted EPA in addressing scientific questions about potential environmental effects of the outfall discharge.

The NPDES permit requires MWRA to measure effluent quality before discharge and to monitor the water, sea floor, and marine life in Massachusetts Bay. A Contingency Plan attached to the permit requires MWRA to compare measured conditions against "caution" and "warning" thresholds, developed from state standards and baseline monitoring data. If a caution threshold is exceeded, MWRA must investigate the issue. A warning threshold is a higher level of concern and could require both investigation and a responsive action. Threshold exceedances do not imply environmental harm, but rather provide notice of changes from past conditions. 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 Environmental Quality Reports list at www.mwra.com/our-environment/water-quality-reports/technical-reports.

This 2024 Outfall Monitoring Overview fulfills a requirement of the NPDES permit, which stipulates that MWRA produce an annual summary of monitoring results for Massachusetts Bay, including results relevant to Stellwagen Bank National Marine Sanctuary. The sanctuary's closest boundary is about 20 kilometers to the east of the MWRA outfall.

Annual overviews also present special topics selected in response to permit conditions and environmental concerns, often including research completed in cooperation with other agencies and research organizations. Special topics for 2024 focus on key fish-and-shellfish monitoring species and provide an update on the permit-required Bays Eutrophication Model.

2. Effluent

Effective wastewater treatment protects Massachusetts Bay.
MWRA's industrial pretreatment program and its primary and secondary sewage treatment minimize contaminants discharged into Massachusetts Bay. In 2024, the effluent met all permit limits. The total nitrogen discharge exceeded the Contingency Plan caution threshold, as originally had been predicted from projected population data for 2020. That exceedance continues to be reviewed but is not considered an immediate environmental risk.

Deer Island Treatment Plant marked 18 consecutive years of 100% compliance with permit limits in 2024, earning a National Association of Clean Water Agencies Platinum Peak Performance Award.

MWRA's NPDES permit and Contingency Plan set limits on effluent parameters and pollutants. Contaminants of concern include **suspended solids, organic material, pathogens, nutrients, and toxic contaminants**. Because wastewater entering Deer Island Treatment Plant includes not only municipal sewage but also groundwater infiltration and stormwater inflow, rainfall is an important factor in determining annual wastewater flows and contaminant concentrations in the treated effluent. The Boston area received 45 inches of rain in 2024, just above the 1990–2023 average of 44 inches (Figure 2-1). Most of the rainfall occurred in the early part of the year; the summer and early fall were unusually dry.

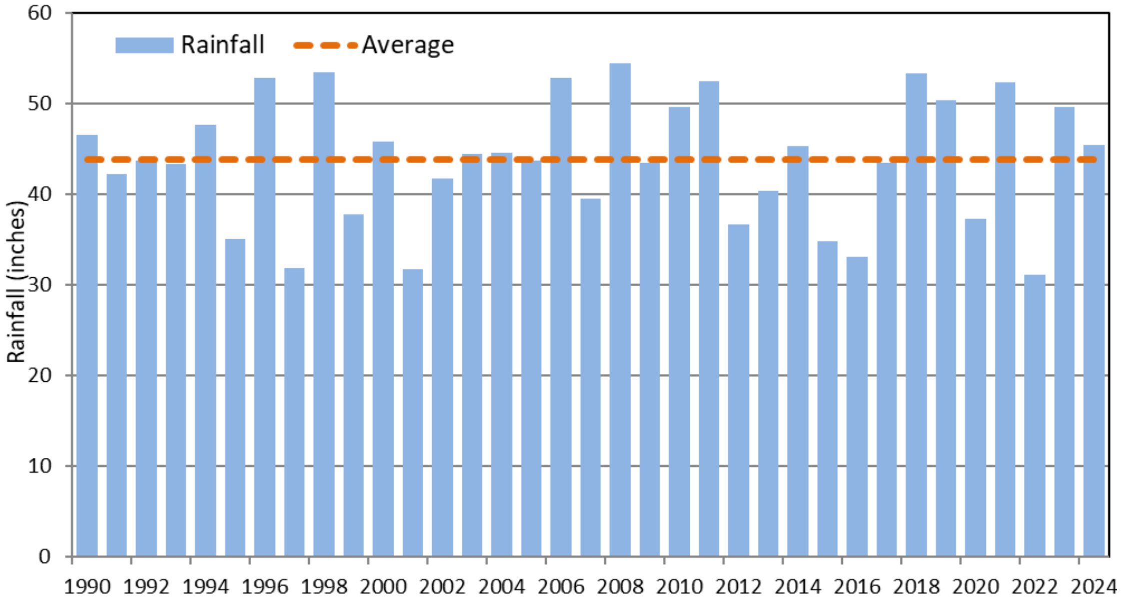


Figure 2-1. Annual and average rainfall in Boston, 1990–2024. Data are from the National Weather Service rain gauge at Boston Logan International Airport.

2024 Effluent Characterization

Flow refers to the rate at which wastewater travels through the treatment plant. It may refer to flow entering the plant (influent), but often refers to outflow from the plant (effluent). Once effluent is released to the environment, it is often called the **discharge**.

Effluent characterization includes measurements of flow, as well as contaminants of concern. In conjunction with contaminant concentration data, flow provides a measure of total discharges to the environment. In 2024, flow averaged 312 million gallons per day, lower than the 327 million gallons per day average for 1999–2023 (Figure 2-2). Almost all effluent in 2024 received full secondary treatment. The 1.6% of the total flow receiving only primary treatment was blended into fully treated effluent prior to disinfection and discharge (Figure 2-3).

Primary treatment uses physical processes to remove solid material through settling. Most organic material and toxic pollutants are removed from the raw sewage through primary treatment. Secondary treatment includes clarifiers to remove particles that do not settle and biological processes to break down organic matter, further reducing pollutants in the effluent. Blending occurs during intense rainfall, when flow to the treatment plant exceeds what the secondary treatment process is designed to handle. Diverting some flow around the secondary treatment process prevents street flooding and sewage backups into homes and businesses. It also protects the secondary treatment system, preventing washout of the beneficial bacteria that provide a critical part of the process. Massachusetts regulations require MWRA to notify regulators and the public whenever a blending event occurs. Historically, blended flows have fully met permit limits, and they continued to meet those limits in 2024.

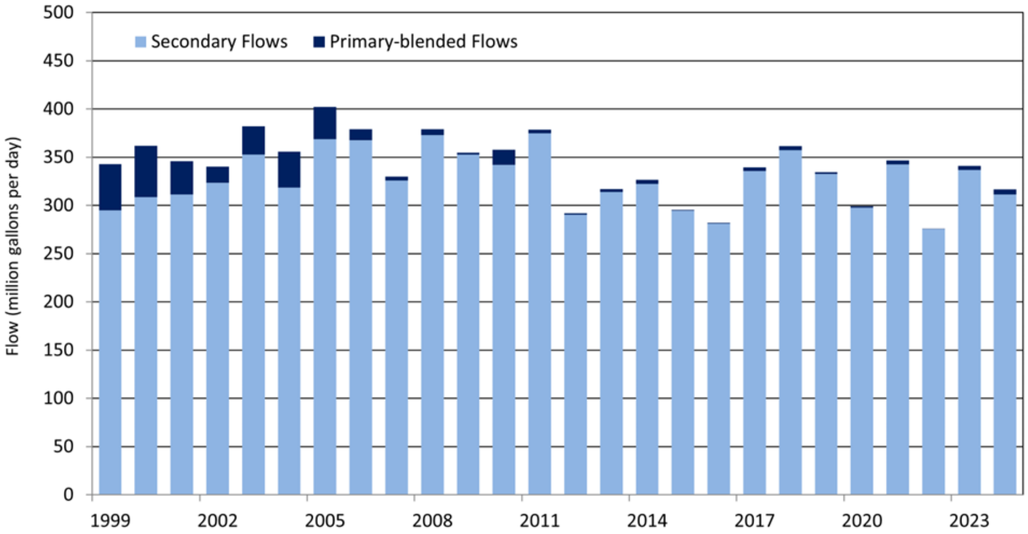


Figure 2-2. Annual full secondary-treated effluent flows and primary-blended flows, 1999–2024. Average flow of 1999–2023 was 327 million gallons per day. During large storms, flow exceeding the secondary capacity of the plant is diverted around the secondary process; this primary-treated flow is blended with the fully treated flow before disinfection and discharge. Historically, blended flows have been minimal and met all permit limits.

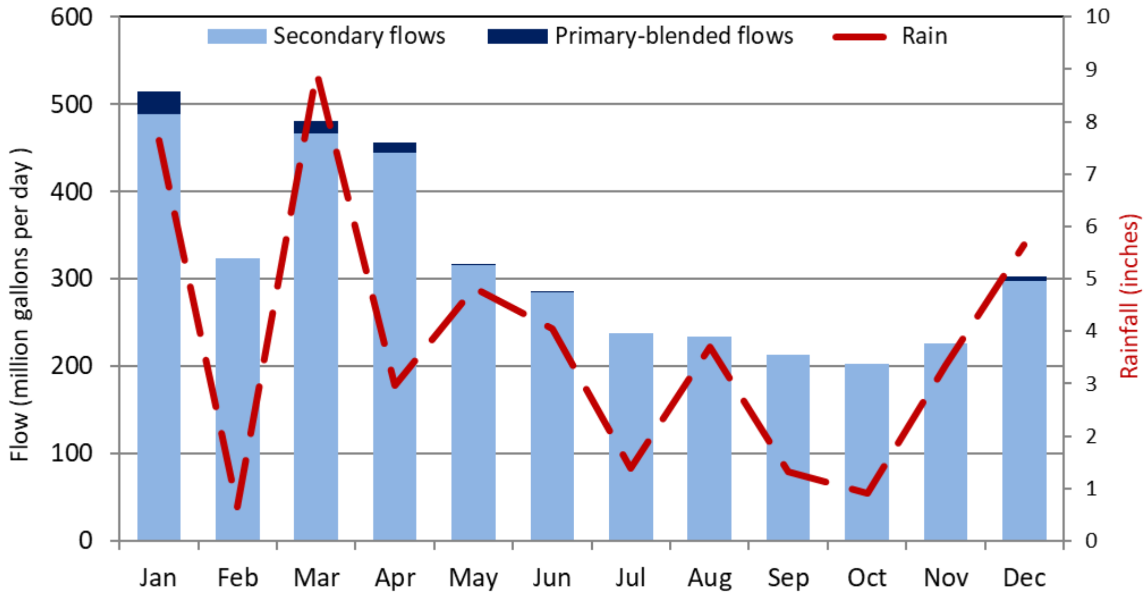


Figure 2-3. Monthly full secondary-treated and primary-blended flows (bars) and rainfall (dashed line) in 2024. Months with primary-blended flows corresponded with months of greater rainfall and snow melt.

Most solid material is removed from sewage influent as sludge, and the remaining particles are called total suspended solids. Solids discharge in 2024 remained consistently low at 14 metric tons per day (Figure 2-4). Over the past two decades, the total solids discharges have been only about 10% of what had been discharged in 1990–1991, when sludge as well as effluent was disposed of in Boston Harbor.

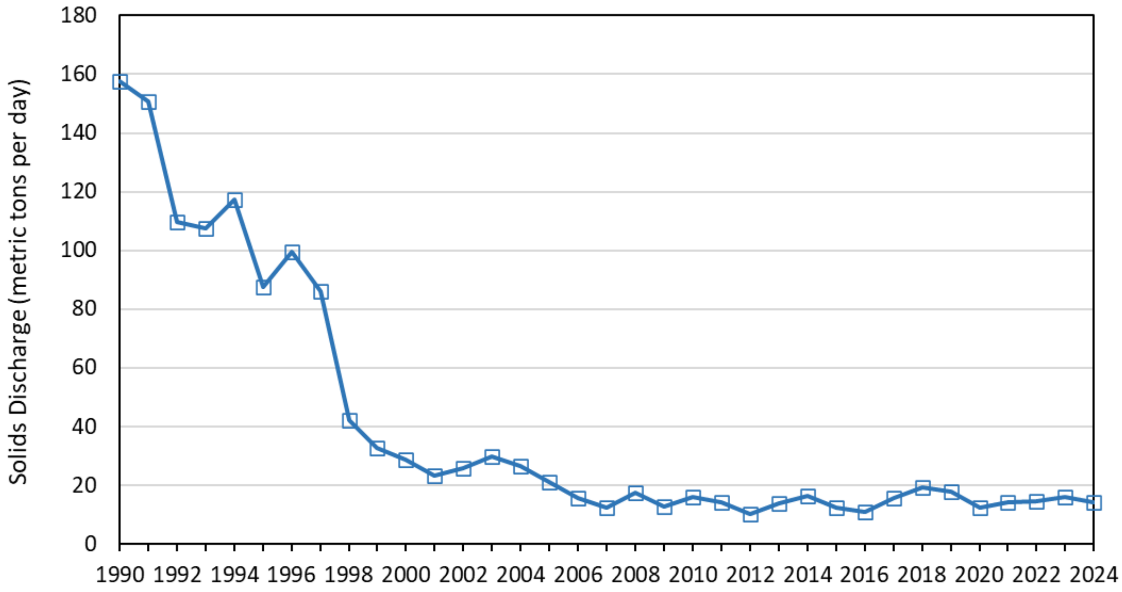


Figure 2-4. Average annual daily discharges of sewage solids, 1990–2024. Solids discharges have remained low.

Organic material, a major constituent of untreated sewage that consumes oxygen as it decays, remains at safe levels.

Organic material in effluent consumes oxygen as it decays. Biochemical oxygen demand (BOD), a measure of the amount of oxygen needed to decompose organic material, remained well below levels that would be expected to affect dissolved oxygen in the environment in 2024. MWRA has consistently met its weekly and monthly BOD permit limits.

Pathogens include disease-causing bacteria, viruses, and protozoans, and are found in human and animal waste. Effluent bacteria levels continue to meet permit limits.

MWRA monitors the effluent for fecal coliform bacteria, one indicator of a variety of pathogens that can make waters unsafe for swimming or shellfish unhealthy for human consumption. Fecal coliform bacteria levels in the effluent have always been well below permit limits. Under a separate program, MWRA monitors fecal coliform bacteria and another bacteria indicator, *Enterococcus*, in Massachusetts Bay. Results at all locations, even those closest to the outfall, meet the stringent shellfishing standards set by the state.

Nutrients control algal growth and, in excess, can lead to lower oxygen concentrations or stimulate nuisance algal blooms.

MWRA's permit has not set limits on effluent nutrients, potentially toxic metals, and organic compounds but requires measurements and reporting. Nutrient measurements include individual components of total nitrogen (ammonium, nitrate, and nitrite). Potentially toxic metals with reporting requirements include zinc, copper, lead, nickel, silver, and mercury. Organic compounds include selected chlorinated pesticides and polychlorinated biphenyls (PCBs), known as legacy pollutants. These contaminants have been banned for use for decades, but break down slowly and persist in low amounts in wastewater and stormwater runoff.

The Contingency Plan attached to MWRA's permit includes thresholds for nitrogen discharges. The total nitrogen load for 2024 was 12,755 metric tons, above the Contingency Plan caution threshold of 12,500 metric tons per year (Figure 2-5). This threshold was set conservatively at about 90% of the warning threshold, 14,000 metric tons, which was the amount expected to be discharged annually by 2020, based on population growth projections for the MWRA service area made in the 1990s. Actual population growth has been somewhat higher than projected, but nitrogen loads have remained below the anticipated discharge, a result of water conservation, better controls on groundwater infiltration, and good removal efficiencies during treatment. The nitrogen caution threshold was exceeded once before, in 2019, when the population size of the MWRA service area was about 6% greater than had been predicted for 2020.

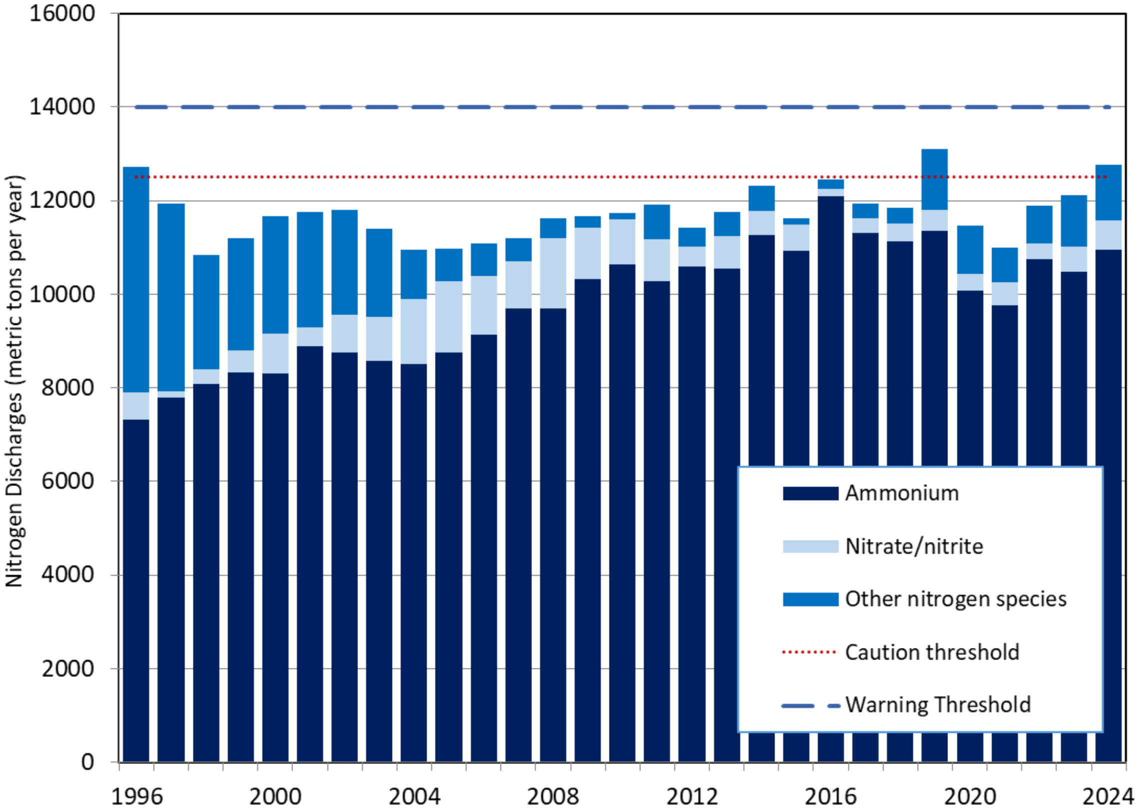


Figure 2-5. Annual nitrogen discharges, 1996–2024. The warning threshold, 14,000 metric tons per year, was set as the load anticipated for 2020; the caution threshold was set at 90% of the warning threshold.

Modeling has suggested that even higher nitrogen loads than the more stringent warning threshold would not harm the environment (Deltares 2022). As required by the permit, MWRA updates a report on potential nitrogen-removal strategies annually (most recently, Davis et al. 2025).

Ammonium is the form of nitrogen most readily taken up by phytoplankton and a good effluent tracer. During the late 1990s and early 2000s, ammonium discharges became a larger component of the total nitrogen discharge, a result of the treatment processes for both sewage effluent and sludge. When sludge, for example, is processed into fertilizer pellets, some ammonium-rich water is returned to the treatment plant. Those increases have plateaued in recent years.

Toxic contaminants in the effluent include heavy metals, such as copper and lead, and organic compounds, including some now-banned pesticides and polychlorinated biphenyls (PCBs).

Metals discharges remained low in 2024 (Figure 2-6). Zinc continued to be the most abundant metal, followed by copper. Both are present in water pipes and fixtures. Other notable sources of zinc to wastewater include hair salons, automobile-repair shops, hospitals, residential household products, and street runoff.

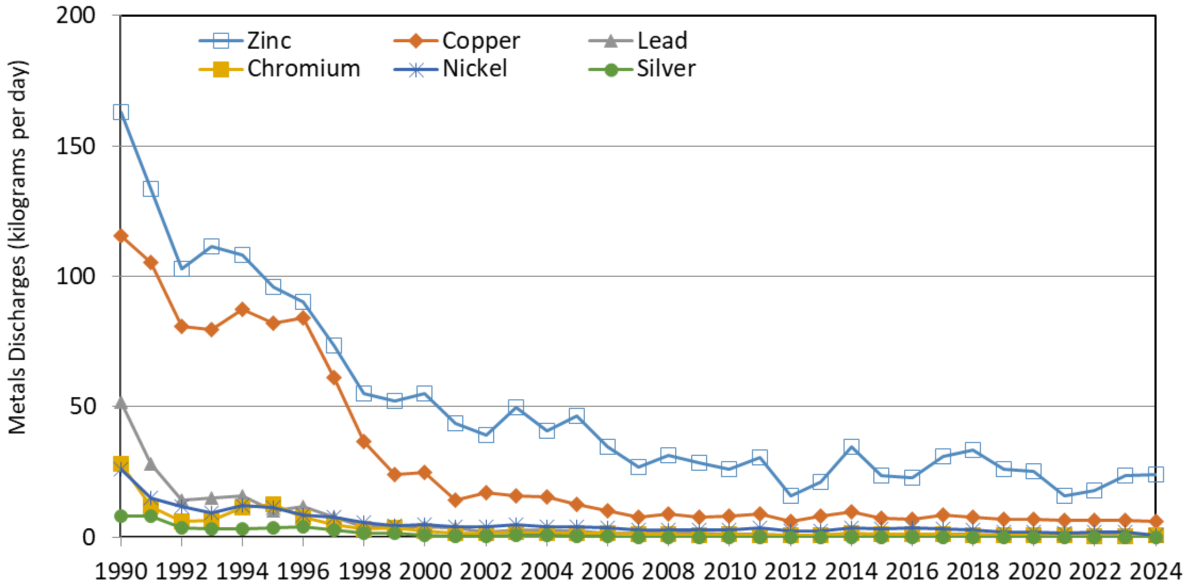


Figure 2-6. Annual metals discharges, 1990–2024. Zinc and copper from water pipes and fixtures remain the most abundant metals. Besides ending sludge discharge in 1991, source reduction, industrial pretreatment, and secondary treatment have dramatically decreased metals loads in the effluent.

Total loads of all metals remained small percentages of what had been anticipated during planning for the Massachusetts Bay outfall (summarized in Werme et al. 2021). Zinc discharges were about one quarter of the amounts predicted for 2020. Copper discharges remained less than 20%, and all other metals discharges were less than 10% of the predictions made in the 1990s. Except for copper, all metals meet water quality standards even prior to discharge. Initial dilution (the amount of mixing within a strictly defined area near the outfall) further reduces concentrations. Copper discharges meet the standard after initial dilution, a result of drinking-water corrosion control, which decreases leaching from water pipes. Removing lead from pipes and service lines has significantly reduced lead levels in the effluent discharge.

Mercury discharges were only 1% of what had been anticipated during planning for the outfall, largely a result of source-reduction efforts in dental and medical facilities. Once considered an effluent tracer, silver is now often at levels below detection limits, due to the decline in film-based photography, as well as efficient removal by 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 polycyclic aromatic hydrocarbon (PAH) discharges, which include compounds produced by combustion processes and are ubiquitous in the environment, now meet water quality standards at discharge. Effluent data for some other organic compounds, such as 4,4’-DDE, one of the most prevalent breakdown products of the chlorinated pesticide DDT, show evidence of the very slow declines anticipated in the 1970s, when chlorinated pesticides were banned. Discharges of PCBs, which were once used in industrial and consumer electrical equipment, also remain well below the historic loads discharged into Boston Harbor.

Effluent Contingency Plan Thresholds

There were no effluent Contingency Plan exceedances based on permit limits in 2024 (Table 2-1). The total nitrogen threshold, set in the Contingency Plan attached to the permit, was exceeded in 2024. MWRA continues to review this exceedance in the context of the historical effluent data, population growth, and sampling patterns, but it is not considered an immediate environmental risk. When planning for the outfall, scientists and regulators projected that the more stringent warning level would be exceeded by 2020. No increased phytoplankton biomass or decreased dissolved oxygen concentrations or saturation resulted from the nitrogen discharge (see Section 3, Water Column).

Table 2-1. Contingency Plan threshold values and 2024 results for effluent monitoring.

Parameter	Baseline	Caution Level	Warning Level	2024 Results
Permit Limits and Contingency Plan Thresholds				
pH	NA	NA	<6 or >9	Not exceeded
Fecal coliform	NA	NA	>14,000 fecal coliforms/100 mL	Not exceeded
Chlorine, residual	NA	NA	>631 µg/L daily, >456 µg/L monthly	Not exceeded
Suspended solids	NA	NA	>45 mg/L weekly >30 mg/L monthly	Not exceeded
cBOD	NA	NA	>40 mg/L weekly, >25 mg/L monthly	Not exceeded
Acute toxicity	NA	NA	LC50 <50%	Not exceeded
Chronic toxicity	NA	NA	NOEC <1.5% effluent	Not exceeded
PCBs	NA	Aroclor>0.045 ng/L	NA	Not exceeded
Plant performance	NA	5 violations/year	Compliance <95% of the time	100% compliance
Flow	NA	NA	>436 MGD average dry days	Not exceeded
Oil and grease	NA	NA	>15 mg/L weekly	Not exceeded
Contingency Plan Thresholds				
Total nitrogen load	NA	>12,500 mtons/year	>14,000 mtons/year	12,755 mtons

NA = not applicable
cBOD = carbonaceous biological oxygen demand
LC50 = 50% mortality concentration
NOEC = no observable effect concentration
PCB = polychlorinated biphenyl
Aroclor = total for a specified suite of PCB compounds (called Aroclors)
Plant performance = compliance with permit conditions
mL = milliliter
µg/L = micrograms per liter
mg/L = milligrams per liter
ng/L = nanograms per liter
MGD = million gallons per day
mtons = metric tons

3. Water Column

Water-column monitoring focuses on eutrophication.
Excess nutrient inputs can lead to low levels of dissolved oxygen or stimulate nuisance or toxic algal blooms, so water-column monitoring evaluates nutrient concentrations, water-quality parameters, and plankton. For most parameters, 2024 was a typical year in the water column, following well-established seasonal patterns. There were no Contingency Plan threshold exceedances for chlorophyll, dissolved oxygen, or nuisance phytoplankton species, confirming that the outfall discharge has not led to eutrophication in Massachusetts Bay.

MWRA’s water-column monitoring program measures and evaluates **physical oceanographic conditions, water quality, and phytoplankton and zooplankton communities** at stations in Massachusetts Bay, at the mouth of Boston Harbor, and in Cape Cod Bay. Ship-based field surveys are augmented by data from instrumented buoys and satellite imagery.

Organic material, pathogens, and toxic contaminants are largely removed in wastewater treatment and are unlikely to have any harmful effects on water quality or plankton communities. Therefore, water-column monitoring focuses mainly on potential effects of excess nutrients, which are less completely removed by treatment.

Excess nutrients can cause eutrophication or promote growth of nuisance or toxic algal blooms. Potentially toxic species include *Alexandrium catenella*, which occurs regularly in Massachusetts Bay, and *Pseudo-nitzschia*, a species group that is often present, but usually in low numbers and in its nontoxic forms. One nuisance, but not toxic, phytoplankton species, *Phaeocystis pouchetii*, was a focus in past years, but its presence and abundance have been shown to vary in response to physical oceanographic conditions rather than the outfall, and it is no longer a focus of the monitoring program.

Each monitoring year includes nine ship-based surveys, completed monthly between February and October. Five stations are in the “nearfield,” a 12×10-kilometer area centered on the outfall, where some effects of the effluent were expected and have been observed. Nine stations are in the more distant “farfield,” including the mouth of Boston Harbor, Cape Cod Bay, and near Stellwagen Bank National Marine Sanctuary (Figure 3-1). Nearfield Station N18, located just to the south of the outfall, is often considered representative of the nearfield, as it has been consistently monitored over time and would be likely to show any effects of the outfall, should they occur.

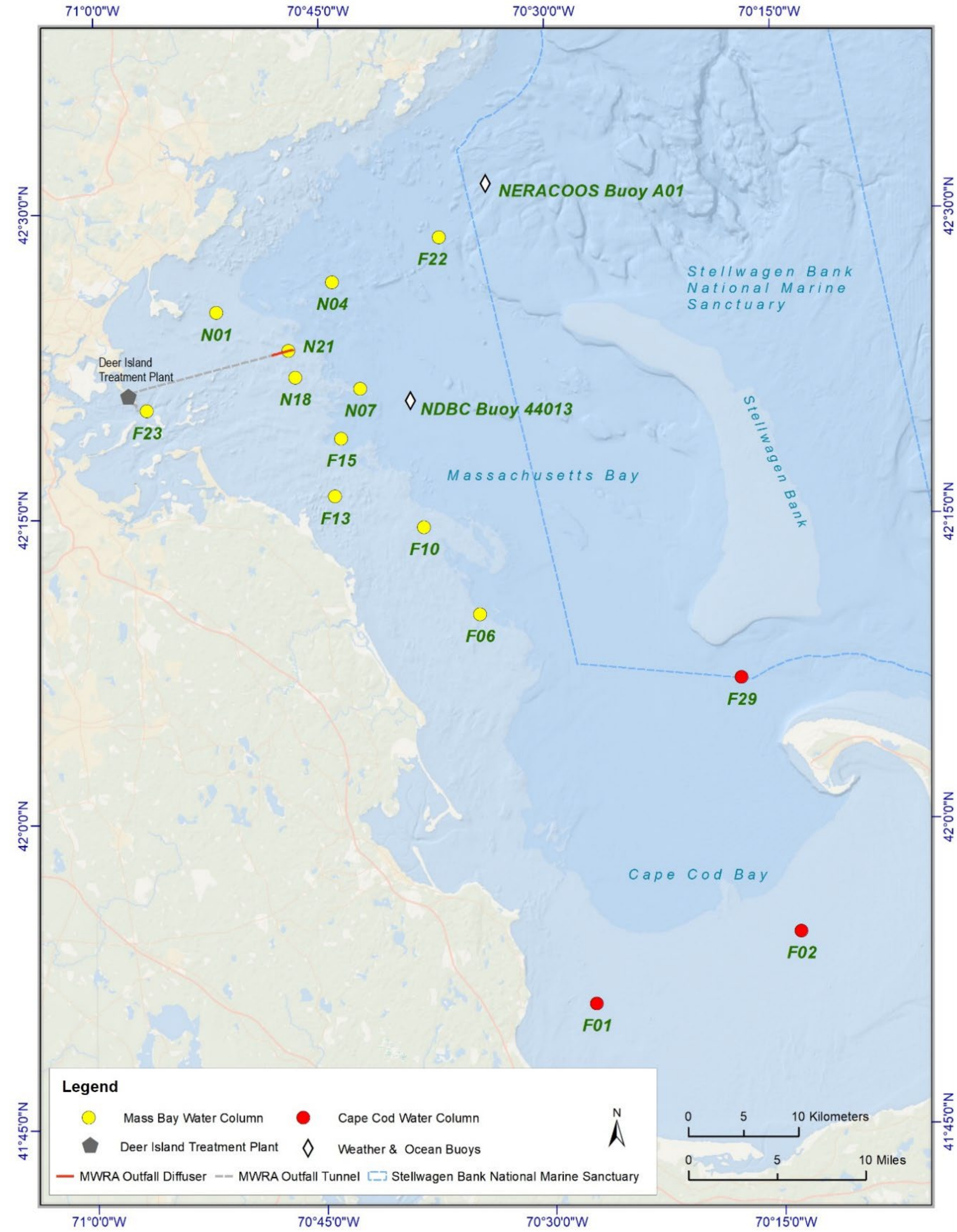


Figure 3-1. Water-column monitoring stations and instrumented buoys in Massachusetts and Cape Cod Bays. Data are obtained from surveys, the NERACOOS A01 and NDBC 44013 buoys, and satellite imagery. Also shown are the outfall and the Stellwagen Bank National Marine Sanctuary. Nearfield station labels begin with N, while farfield stations begin with F. NERACOOS = Northeastern Regional Association of Coastal Ocean Observing Systems; NDBC = National Data Buoy Center.

Additional surveys may be triggered by elevated abundance of the potentially toxic phytoplankton species *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 catenella* abundance at up to 19 stations. No additional surveys were necessary in 2024.

The monitoring program benefits from collaboration with the Center for Coastal Studies in Provincetown, Massachusetts, which samples the three stations in Cape Cod Bay and near Stellwagen Bank National Marine Sanctuary. Due to rough sea conditions, the August and October 2024 sampling in Cape Cod Bay occurred outside a 48-hour target window for completing all sampling in both bays.

Surveys are supplemented by measurements at two instrumented buoys: the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) Buoy A01 off Cape Ann at the northern limit of Massachusetts Bay and the National Oceanic and Atmospheric Administration (NOAA) 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.

Physical Conditions

Circulation and physical properties in Massachusetts Bay are driven by the larger patterns of water flow in the Gulf of Maine. Water typically enters Massachusetts Bay from the north, circulates in a counter-clockwise direction, and exits by Provincetown, at the tip of Cape Cod. Consequently, Station F22, to the north and east of the outfall, is considered a reference station for water entering the bay, while stations to the south of the outfall are more likely to have detectable outfall influences. Water flows vary from week-to-week and depend on the strength of the current and on wind speed and direction. The coastal current is strongest during spring runoff from rivers and streams.

As in other temperate regions, there are seasonal patterns to the physical structure of the water column, extending from the surface to the sea floor. In the winter, the water column is well mixed, and dissolved oxygen levels are uniformly high. Warm water is less dense than cold water, so as surface waters warm, the water column stratifies, effectively separating surface from bottom waters. Bottom waters become isolated from the atmosphere and oxygen production by phytoplankton. This isolation, combined with respiration and decomposition of organic material, leads to lowered bottom-water dissolved oxygen levels in late summer and fall. In the fall, cooling surface waters and strong winds promote mixing, ending the stratified season and re-oxygenating deeper waters.

Stratification separates warm, surface water from colder, denser bottom water. The boundary between layers is called the thermocline or pycnocline.

Stratification is also affected by rainfall and river flow to Massachusetts Bay. Inputs of freshwater, which is lighter than seawater, contribute to stronger stratification. The Merrimack River, which enters the Gulf of Maine just to the north of Massachusetts Bay, is the largest river in the region and plays an important role in freshwater delivery to Massachusetts Bay. Discharge from the smaller Charles River, which flows into Boston Harbor, also influences conditions in the bay.

Physical conditions in 2024 were largely typical of past years (Libby et al. 2025). Over the course of the year, Massachusetts received average rainfall (see Figure 2-1 on page 2), but most of the rain fell in the early months of the year, while later months were unusually dry. Flows from both the Merrimack and Charles Rivers reflected that pattern, with record high river discharges in the early part of the year and near-record low discharges through the summer and fall (Figure 3-2).

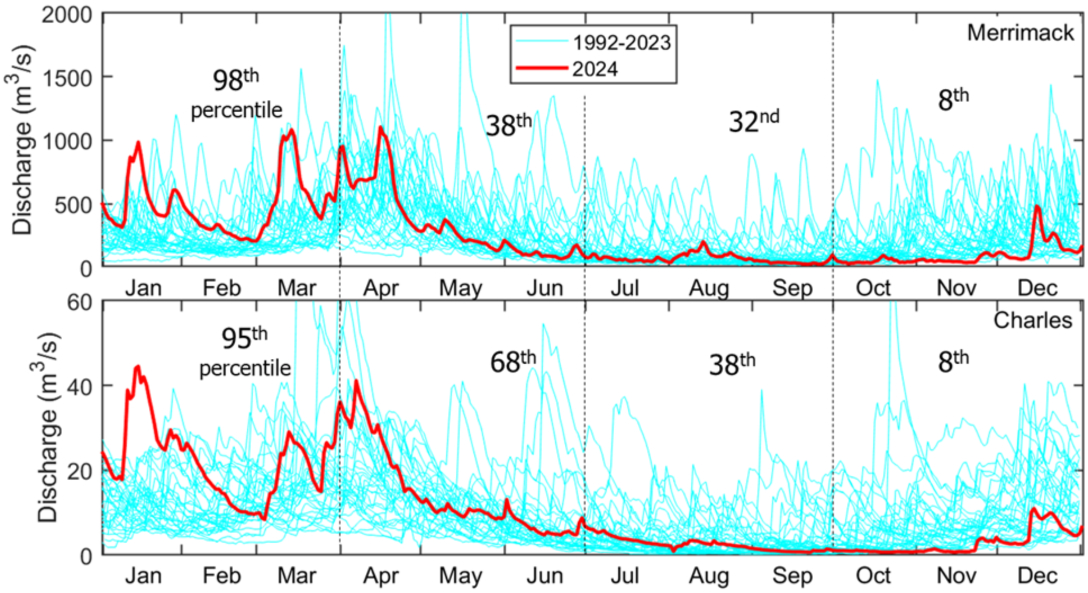


Figure 3-2. Flows of the Merrimack (top) and Charles (bottom) Rivers. The much larger Merrimack River flows into the Gulf of Maine just south of the New Hampshire border and greatly influences the physical conditions in Massachusetts Bay. The Charles River flows into Boston Harbor. Note differences in scale. The quarterly percentiles represent the 2024 discharges in comparison to the entire record. m^3/s = cubic meters per second.

Air temperatures, measured at both the NERACOOS and NDBC buoys, were mostly typical, with slightly higher spring and fall temperatures and lower summertime temperatures than average. Surface- and bottom-water temperatures at Station N18 just south of the outfall showed similar patterns (Figure 3-3, top two panels).

Surface- and bottom-water salinities at Station N18 reflected the high river discharges in early 2024 (Figure 3-3, bottom panels), with record-low salinities recorded during the first survey of the season. The low salinity measurements continued through May.

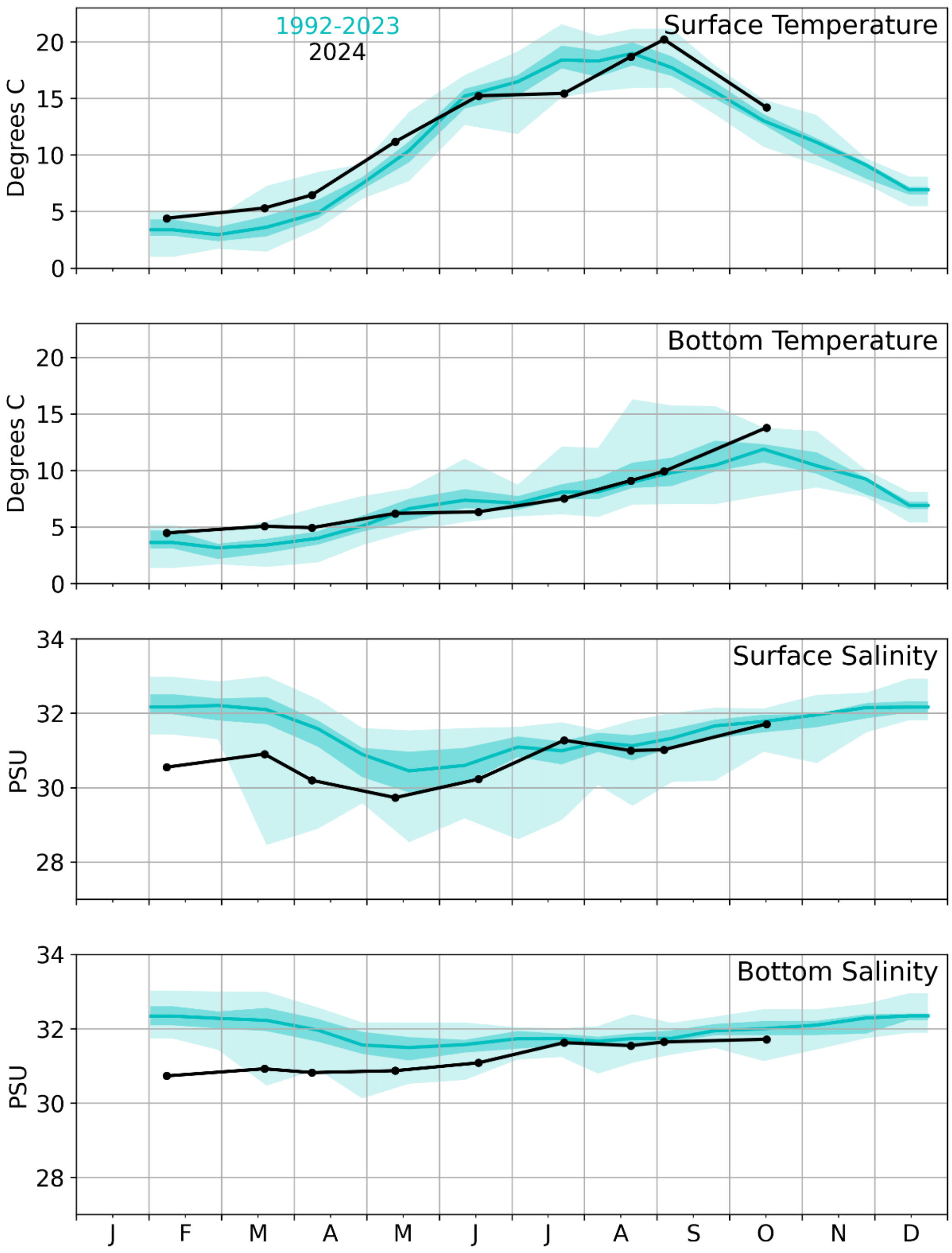


Figure 3-3. Surface- and bottom water temperature and salinity at Station N18 just to the south of the outfall in 2024 compared to prior years. PSU = practical salinity units or parts per thousand.

Wind speeds and directions in 2024 were mostly typical of past years. One large storm with winds from the northeast occurred in early April, producing waves large enough to resuspend and transport bottom sediments. Similar but much smaller storms occurred in May and June. In the past, spring and early summer storms with winds from the northeast have transported cells of the potentially toxic phytoplankton species *Alexandrium catenella* from the Gulf of Maine into Massachusetts Bay.

As is typical, wind directions promoted downwelling conditions in the spring and fall and upwelling in the summer months (Figure 3-4). Downwelling occurs when winds come from the north, bringing water masses in from the Gulf of Maine. Upwelling occurs when wind directions are from the south. Upwelling brings bottom waters to the surface, promoting cooling throughout the water column and alleviating the natural declines in dissolved oxygen concentrations that occur throughout the summer.

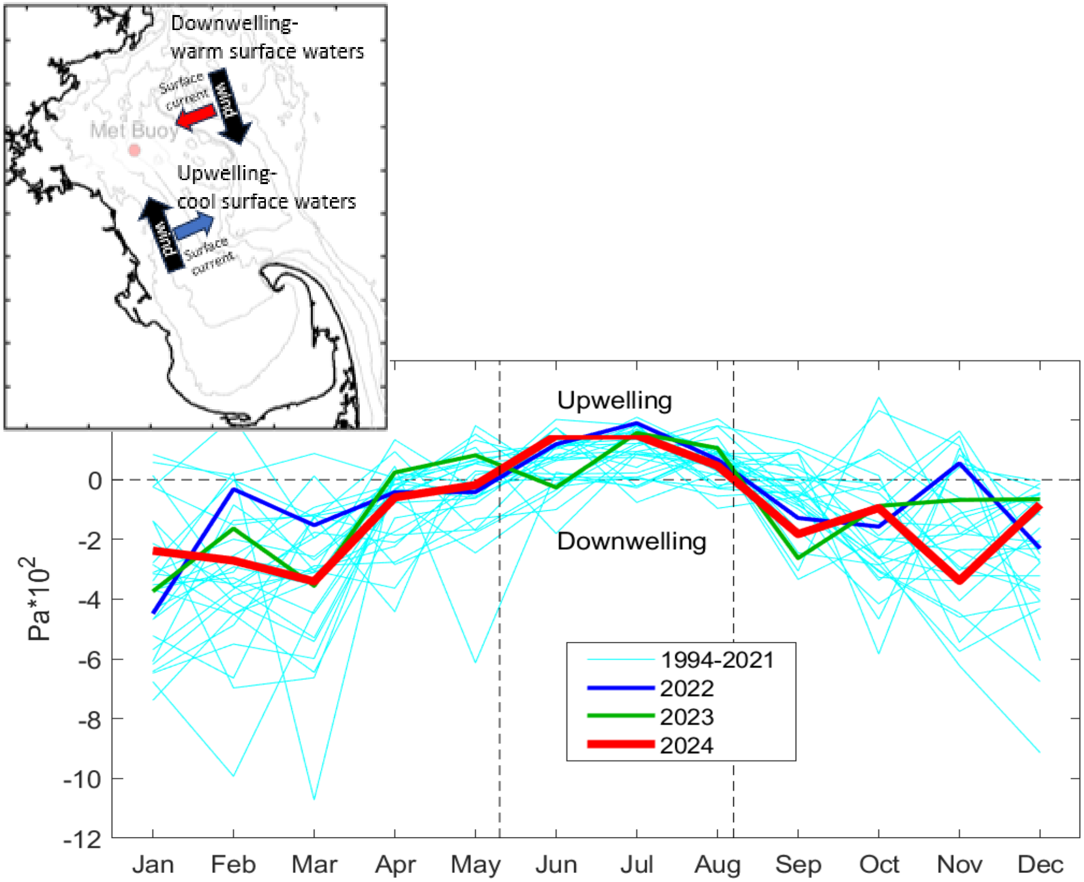


Figure 3-4. Upwelling and downwelling conditions at Station N18 in 2024, compared to prior years. Pa = Pascal, a unit used to quantify wind stress and other pressure-related measurements.

Water Quality

Water quality measurements include quantification of **nutrients** (nitrogen, phosphorus, and silica), **phytoplankton biomass** (chlorophyll and particulate organic carbon), and **dissolved oxygen** (concentration and percent saturation). Results for 2024 continued to confirm measurable outfall influence on some nutrient concentrations at stations near the outfall, but no increases in other nutrients or phytoplankton biomass and no decreases in dissolved oxygen parameters (Libby et al. 2025).

Nutrients

The most important nutrients that fuel phytoplankton growth in Massachusetts Bay are two forms of nitrogen (nitrate and ammonium), phosphate, and silicate. Typical of temperate, coastal waters, nutrient concentrations follow seasonal patterns, naturally varying with phytoplankton uptake, seasonal stratification, river flow, and water exchange with the Gulf of Maine. As anticipated by baseline field studies and modeling, increased concentrations of some nutrients were detected in the immediate vicinity of the outfall in 2024. These increases are usually measured within 10 kilometers of the outfall. Intermittent signals can be detected up to 20 kilometers from the outfall.

Nitrate concentrations remained close to long-term means throughout the survey season, with some variations due to the high river discharges in the spring. MWRA has not detected changes in nitrate concentrations in response to the effluent discharge. Phosphate concentrations were also typical, except for one unusually high measurement at Station N18 near the outfall in June. The high value may have resulted from the sample being taken right in the plume, before it was completely mixed into the surrounding water. Elevated concentrations may also reflect upwelling conditions, which bring deep nutrient-rich water to the surface. Silicate concentrations remained typical, without any detectable outfall signal.

Ammonium concentrations have varied from any typical seasonal pattern at stations nearest the outfall. Ammonium is the largest fraction of the total nitrogen in wastewater (see Figure 2-5, page 6), and ambient concentrations are relatively low for most of the year, making it a good effluent tracer. Since the discharge was relocated from the harbor to the bay in late 2000, MWRA monitoring has detected variable and elevated ammonium concentrations at stations nearest and immediately to the south of the outfall, in the direction of the predominant currents (Figure 3-5).

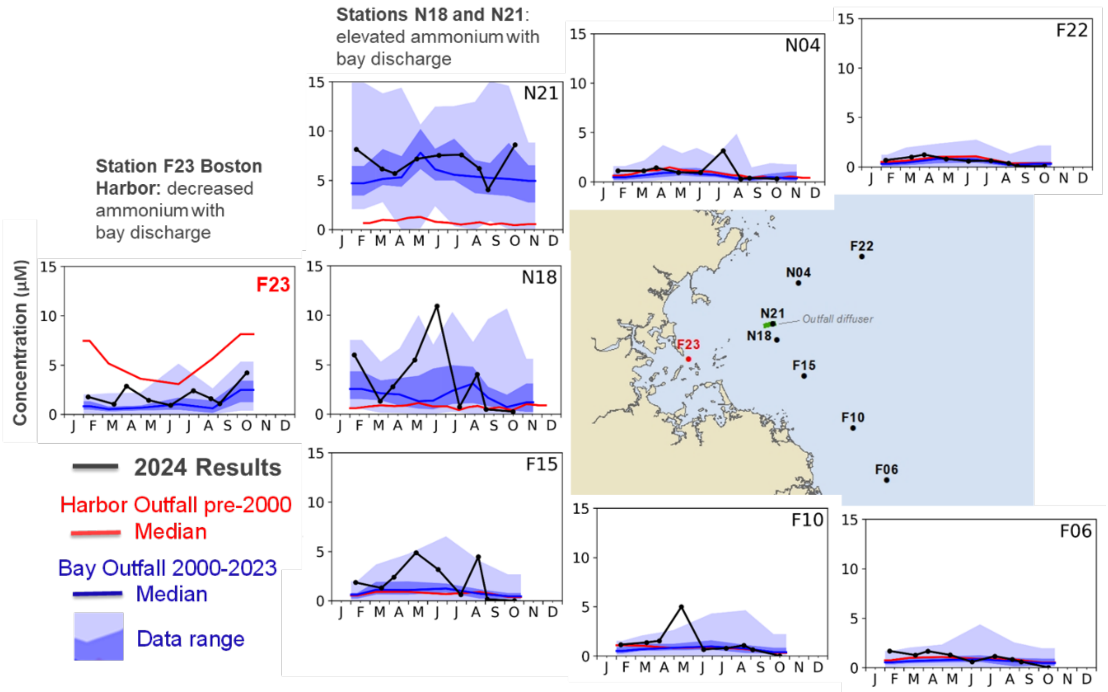


Figure 3-5. Ammonium concentrations at selected stations in 2024 compared to prior years. Increased and more variable concentrations of the sewage tracer ammonium are found at stations closest to the outfall, while stations farther away have maintained concentrations similar to pre-outfall levels. Ammonium concentrations at Station F23 at the mouth of Boston Harbor decreased abruptly when discharge to Boston Harbor ended and have remained low. µM = micromoles.

Especially high ammonium measurements at stations closest to the outfall are sometimes a result of a sample being taken directly in the effluent plume. Similar to phosphate, ammonium concentrations were especially elevated at Station N18 near the outfall during the June survey. As in past years, ammonium levels remained lower than the baseline concentrations at Station F23, at the mouth of Boston Harbor. Ammonium concentrations dropped precipitously at Station F23 and at all stations sampled as part of MWRA's separate Boston Harbor monitoring program as soon as effluent discharge to Boston Harbor ended and the Massachusetts Bay outfall discharge began.

As was anticipated during outfall siting and has occurred every year, the effluent plume's ammonium signature was detected in the surface waters of stations closest to the outfall during the winter surveys, when the water column was relatively well-mixed (Figure 3-6). During the summer, when the water column was stratified, the plume was confined beneath the pycnocline, below depths where maximum phytoplankton growth occurs.

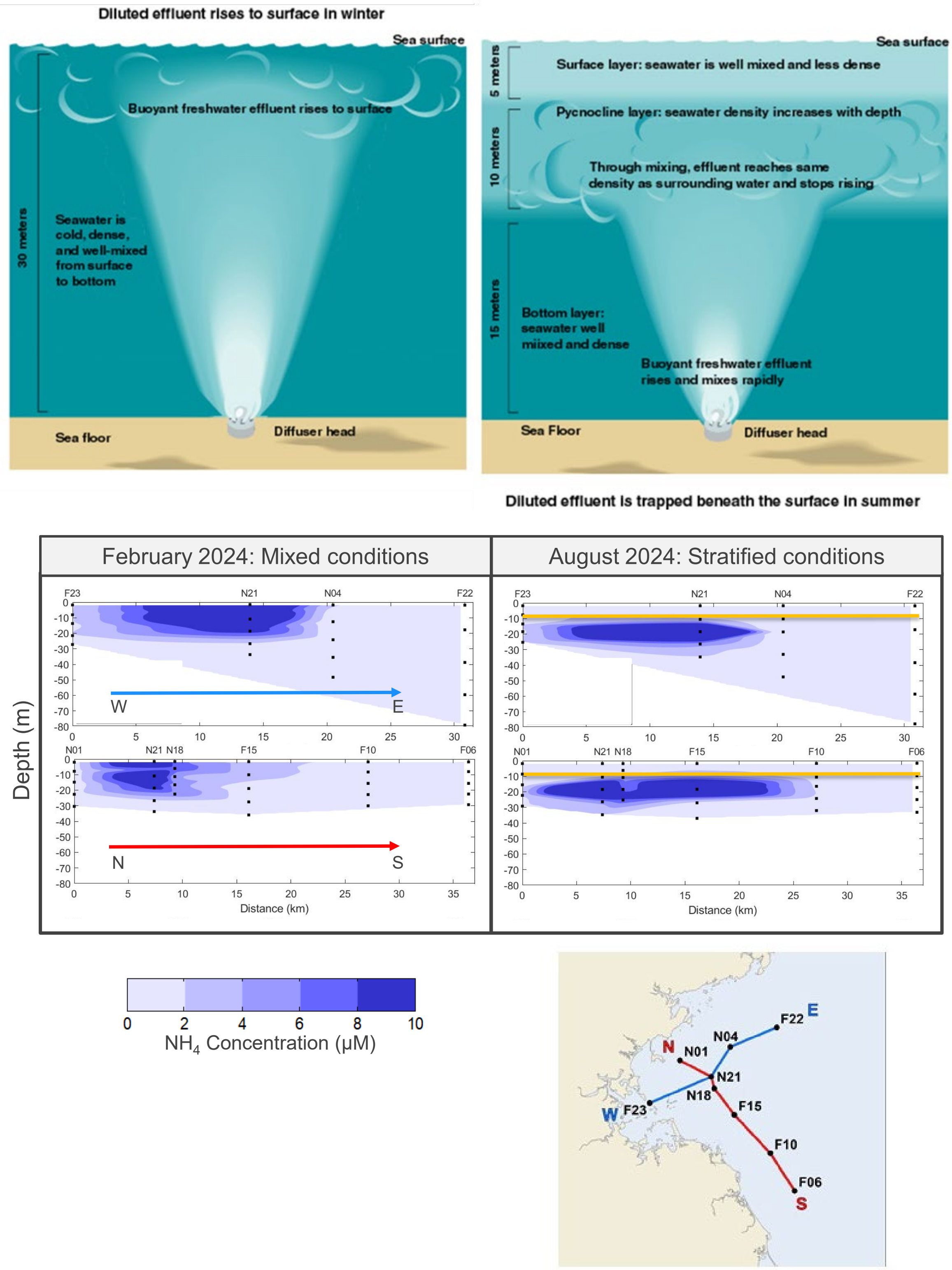


Figure 3-6. Surface- and bottom-water ammonium concentrations during mixed and stratified conditions. During winter, well-mixed conditions, the plume was evident in surface waters. During the summer, the plume was confined below the pycnocline (yellow line) and below the depth of most phytoplankton growth. Station N21 is directly over the outfall; m = meters; NH_4 = ammonium; µM = micromoles.

Phytoplankton Biomass

More than two decades of monitoring have shown that the increases in ammonium concentrations near the outfall have not stimulated phytoplankton growth or resulted in increased phytoplankton biomass at any station. Phytoplankton biomass in the water column is determined from measurements of chlorophyll concentrations and fluorescence and from particulate organic carbon concentrations.

Chlorophyll levels in 2024 remained close to historic means across all stations and throughout the year (Figure 3-7). There was no repeat of the large phytoplankton bloom of 2023, which occurred throughout a broad region, including much of New England's coastal waters.

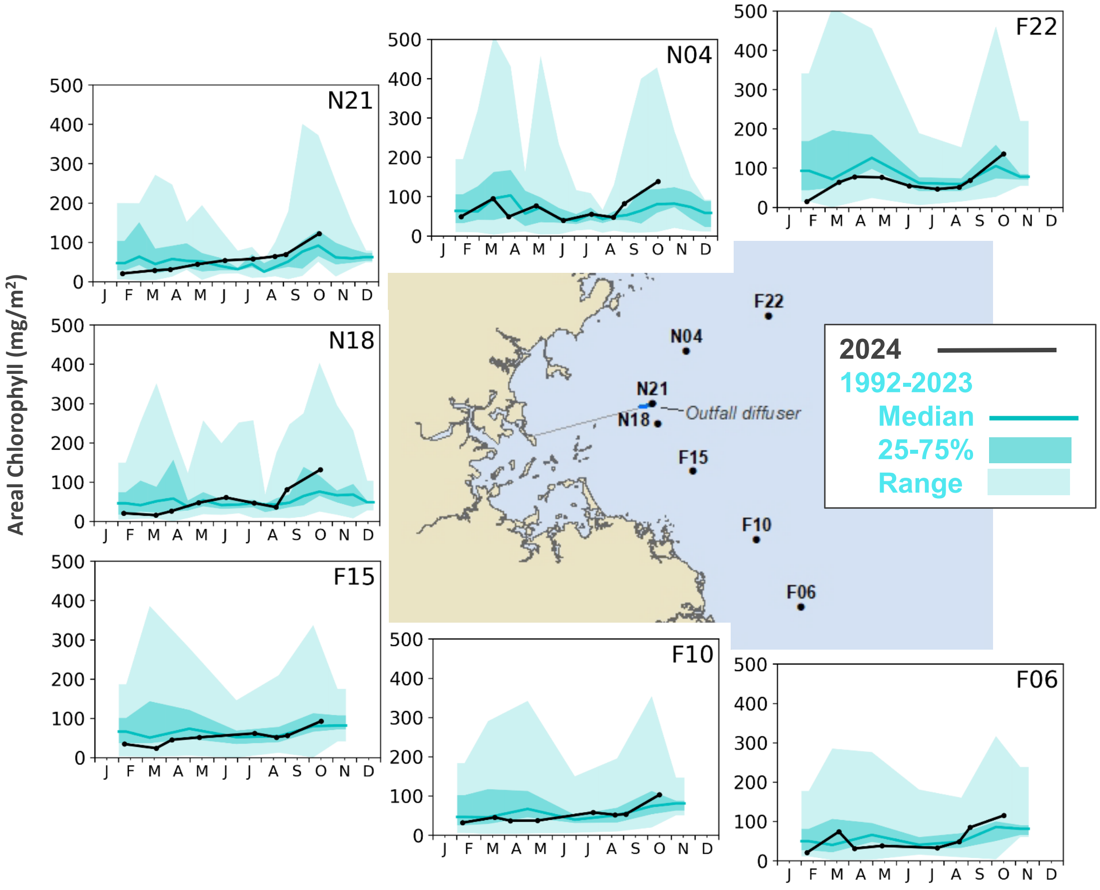


Figure 3-7. Monthly areal chlorophyll concentrations at selected stations in 2024 compared to prior years. Survey phytoplankton biomass is reported as vertically summed (areal) chlorophyll from measurements throughout the water column, from the surface to the sea floor, rather than as an amount within a fixed volume. mg/m^2 = milligrams per square meter summed over depth.

Dissolved Oxygen

Typically, bottom-water dissolved oxygen concentrations and percent saturation begin the year relatively high and steadily decline throughout the summer. Stratification prevents exchange between the atmosphere and bottom waters, so dissolved oxygen levels naturally decline at depth, as animals and microbes respire. That general pattern persisted in 2024 (Figure 3-8).

In May 2024, near-bottom dissolved-oxygen concentrations at most stations in Massachusetts and Cape Cod Bays were unexpectedly lower than historic spring ranges. The unusually early decline was most likely due to regional weather patterns. Storms with winds from the northeast likely transported lower-oxygenated water from the Gulf of Maine to Massachusetts Bay. Upwelling in June and July alleviated those low-oxygen levels, and all measurements remained more typical throughout the rest of the survey season. Annual minimum concentrations were greater than 6.25 milligrams per liter throughout Massachusetts Bay.

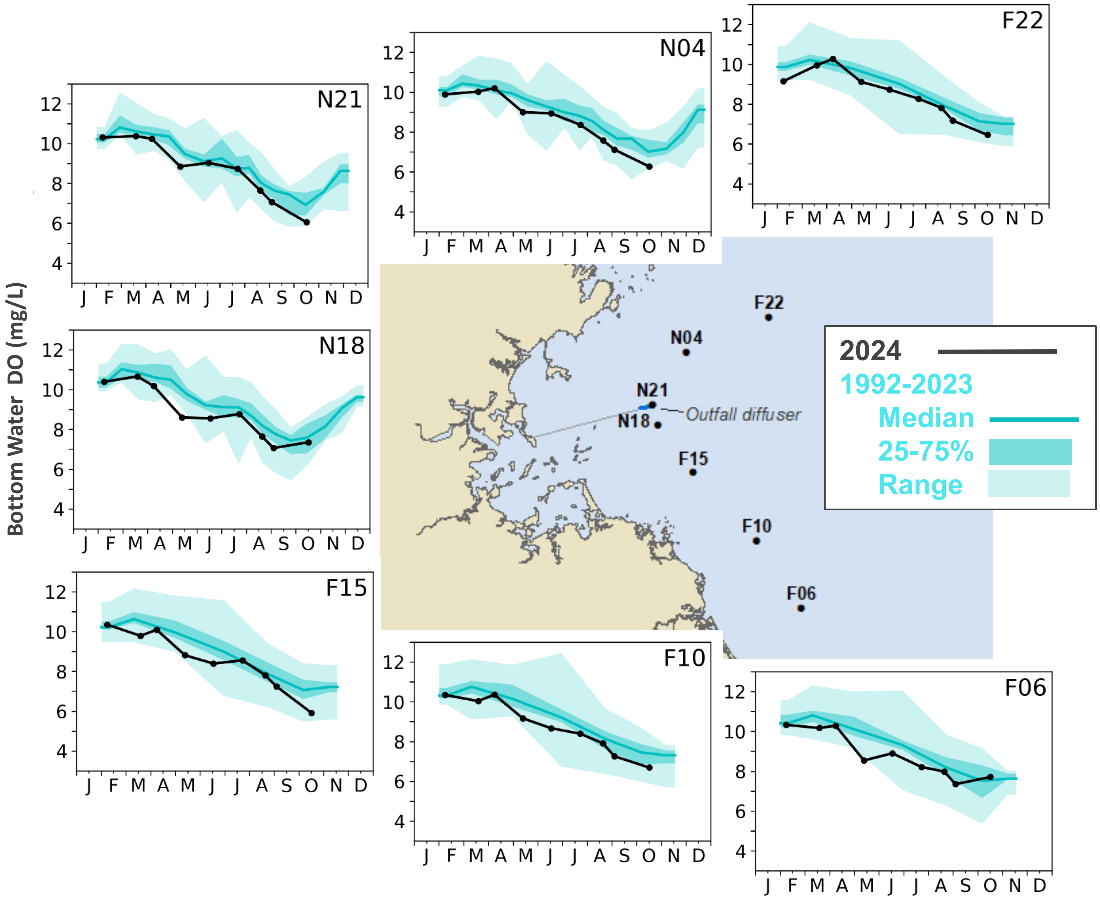


Figure 3-8. Near-bottom water dissolved oxygen concentrations in 2024 compared to prior years. DO = dissolved oxygen; mg/L = milligrams per liter.

Plankton Communities

Marine plankton includes plants and animals that move with winds, tides, and currents, having limited or no ability to move on their own. MWRA monitors **phytoplankton and zooplankton abundance and species composition** to detect any changes that might be associated with the outfall discharge (Cibik et al. 1998). A focus on potentially toxic or nuisance phytoplankton species addresses concerns for marine mammal and human health.

Massachusetts Bay phytoplankton includes small algae and other plant-like organisms, such as microflagellates, centric (rounded) and pennate (elongated) diatoms, and dinoflagellates (Figure 3-9). Microflagellates are microscopically small and are typically the most abundant phytoplankton type in Massachusetts Bay. Centric and pennate diatoms have silica-rich cell walls and often dominate spring blooms. Dinoflagellates have two perpendicular whip-like flagella, which propel them up and down in the water column. Dinoflagellates are classified as phytoplankton, because many species photosynthesize like plants.

One common dinoflagellate, *Alexandrium catenella*, often blooms in Massachusetts Bay and the wider Gulf of Maine region. It is the species known in New England for causing “red tide.” Other geographic areas designate different species, usually other dinoflagellates, as the cause for their local red tides. Many types of phytoplankton can, when abundant, color the water column red or brown.

Zooplankton communities in Massachusetts Bay include animal species that live their entire lives as plankton, including abundant shrimp-like copepods, and species that live in the plankton for only a part of their life cycles, such as barnacle and clam larvae. Most species are small, but larger animals, including jellyfish, are also part of the zooplankton community. Zooplankton provide food for many animals, including other zooplankton, fish, sea turtles, and the endangered North Atlantic right whale. Zooplankton abundance and species composition are highly variable through the seasons and between years.

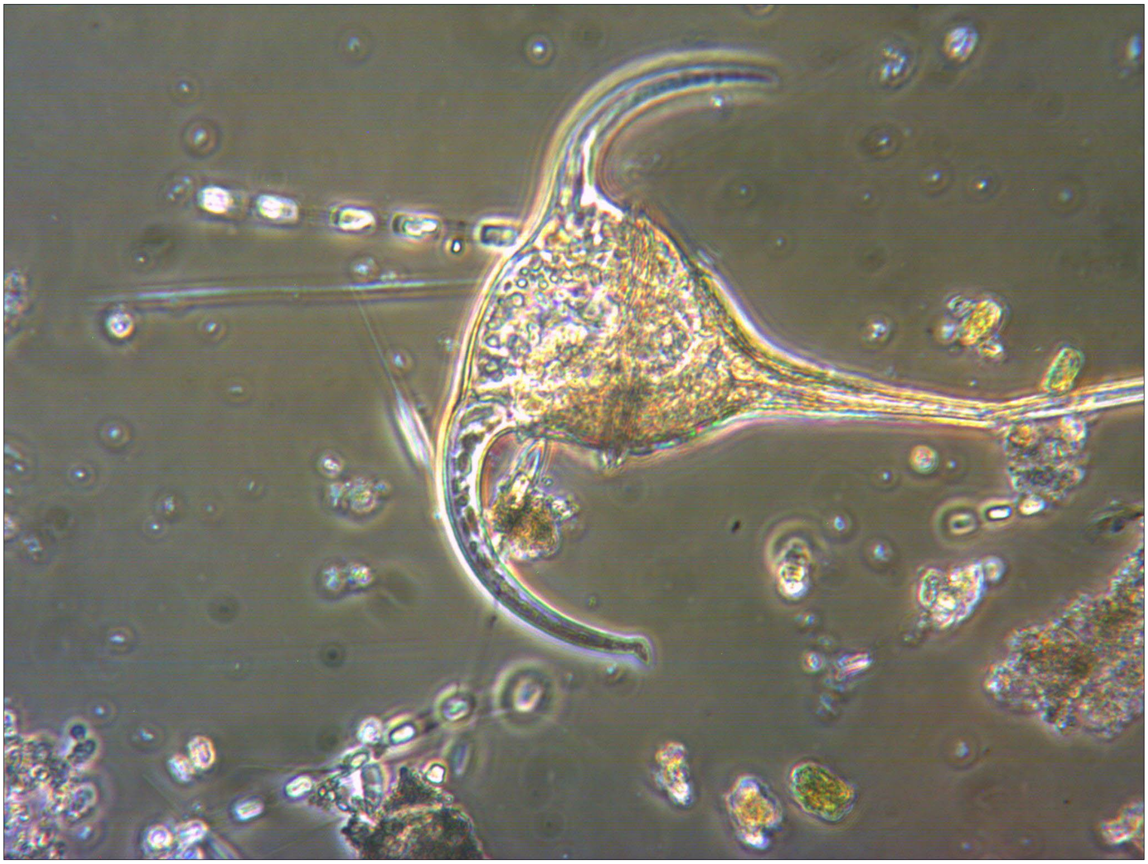


Figure 3-9. Typical phytoplankton from Massachusetts Bay. The large, hooked organism is the dinoflagellate *Tripos muelleri*. The box-like chains are centric diatoms in the genus *Skeletonema*, and the very thin chain is a species of the pennate diatom genus *Pseudo-nitzschia*. *Tripos muelle*ri typically ranges from 200 to 400 micrometers in length. Photo credit David Borkman, Pausacaco Plankton, Saunderstown, Rhode Island.

Phytoplankton Communities

Total phytoplankton abundance was at or near the long-term means at most stations and during most surveys in 2024 (Figure 3-10; Libby et al. 2025). Average overall abundance was about 1.1 million cells per liter, and there were no large blooms of any single species.

Microflagellates, which have consistently remained the most numerically abundant plankton group, were particularly abundant in May and June. Numerically, microflagellates made up 69% of the total phytoplankton community in 2024. Centric diatoms were more abundant than in recent years, particularly in June and July. In June, nearfield centric diatom abundance was three times greater than the historic mean. Pennate diatoms were most abundant in May. Dinoflagellate abundance was relatively low throughout 2024, a contrast to 2023, when a large bloom of the dinoflagellate *Tripos muelleri* dominated the region from April through July.

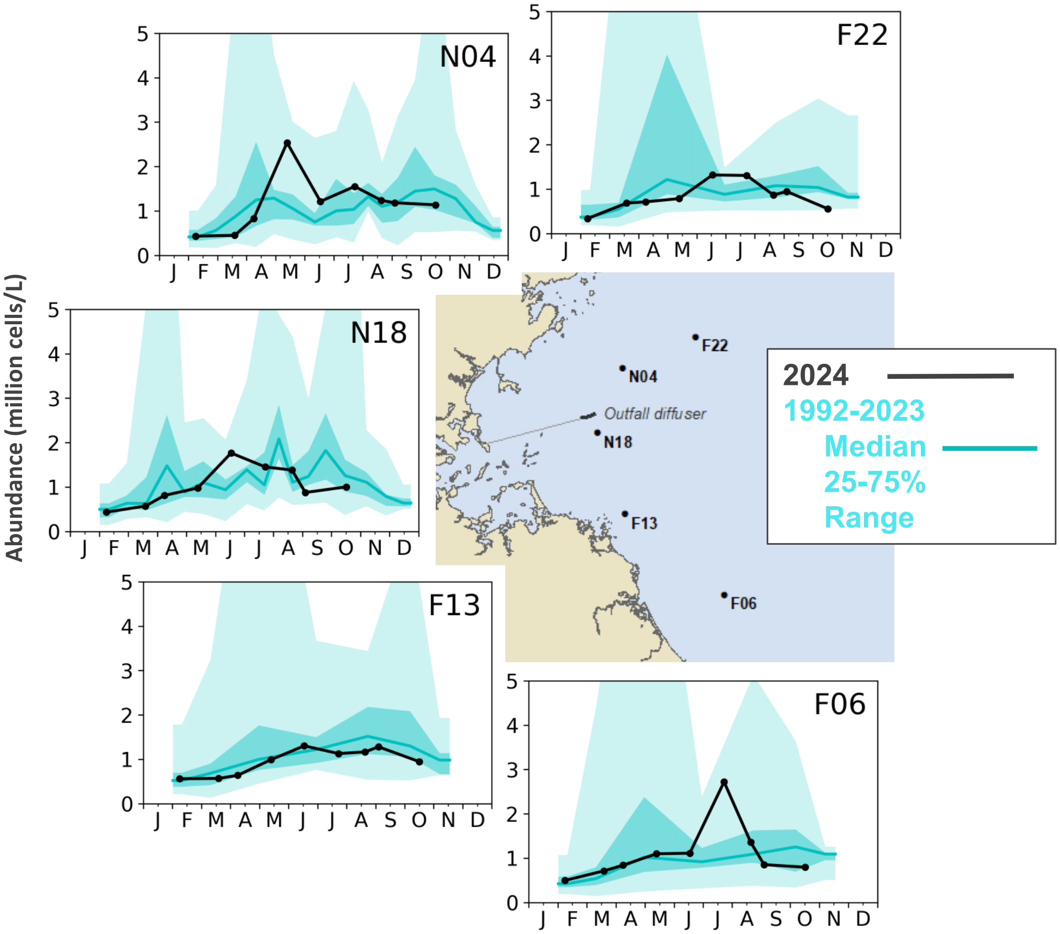


Figure 3-10. Total phytoplankton abundance at selected stations in 2024 compared to prior years. cells/L = cells per liter

A small regional bloom of the pennate diatom genus *Pseudo-nitzschia* occurred in May, with maximum abundance of more than 230,000 cells per liter. Some *Pseudo-nitzschia* species produce domoic acid, a neurotoxin that causes amnesic shellfish poisoning (ASP), a life-threatening condition in seabirds, marine mammals, and humans that consume contaminated shellfish. Most of the cells observed were small, indicative of the low-toxicity species *Pseudo-nitzschia delicatissima*. No toxin was detected in state shellfish monitoring. Historically, ASP has not caused shellfish closures in Massachusetts or Cape Cod Bays.

Abundance of the potentially toxic dinoflagellate *Alexandrium catenella* remained low in 2024, peaking later in the year than usual (Figure 3-11). A maximum abundance of 96 cells per liter was observed at Station N01, northwest of the outfall, in July. Abundances remained just below the Contingency Plan threshold and also below the threshold for conducting *Alexandrium* Rapid-Response Study surveys. The toxin produced by *Alexandrium catenella* causes paralytic shellfish poisoning (PSP), a potentially deadly condition for people and marine mammals that consume shellfish. No PSP toxicity was detected in Massachusetts Bay in 2024.

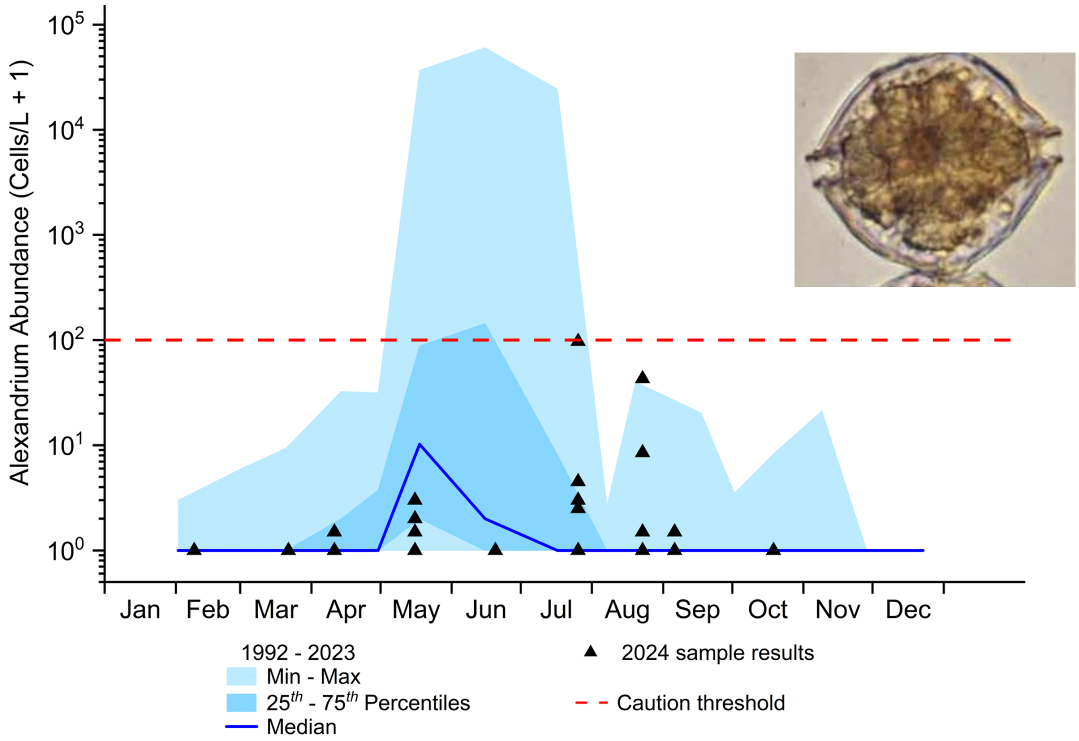


Figure 3-11. A*lexandrium catenella* abundance in 2024 compared to 1992–2023. The highest abundance in 2024 was 96 cells per liter, just below the caution threshold of 100 cells per liter. *Alexandrium catenella* typically ranges from 20 to 80 micrometers in diameter. Photo credit Donald M. Anderson, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. Cells/L + 1 = cells per liter plus 1, a convention that allows abundances of zero to be displayed on this scale.

Zooplankton Communities

Total annual zooplankton abundance was largely typical in 2024, although there were some atypical seasonal patterns (Figure 3-12). Increased abundance from usual winter lows through the spring and summer were only modest, and at some stations, there were substantial increases in abundance in October.

As in past years, copepod adults and younger life stages dominated throughout the year. Numerically, the small copepod species *Oithona similis* continued to be the most abundant species in the zooplankton community, as it has been since the beginning of the monitoring program. Early life stages of barnacles occurred sporadically, particularly in February and March. The planktonic tunicate *Oikopleura dioica*, which can be found in surface waters around the world, was abundant in May.

The unusual October peaks observed at some stations reflected high numbers of radiolarians, single-celled protozoans that build ornate silica-rich exoskeletons. Radiolarians are more typically found in offshore waters, and their presence each year since 2020 may reflect annual influxes of warm water masses from offshore.

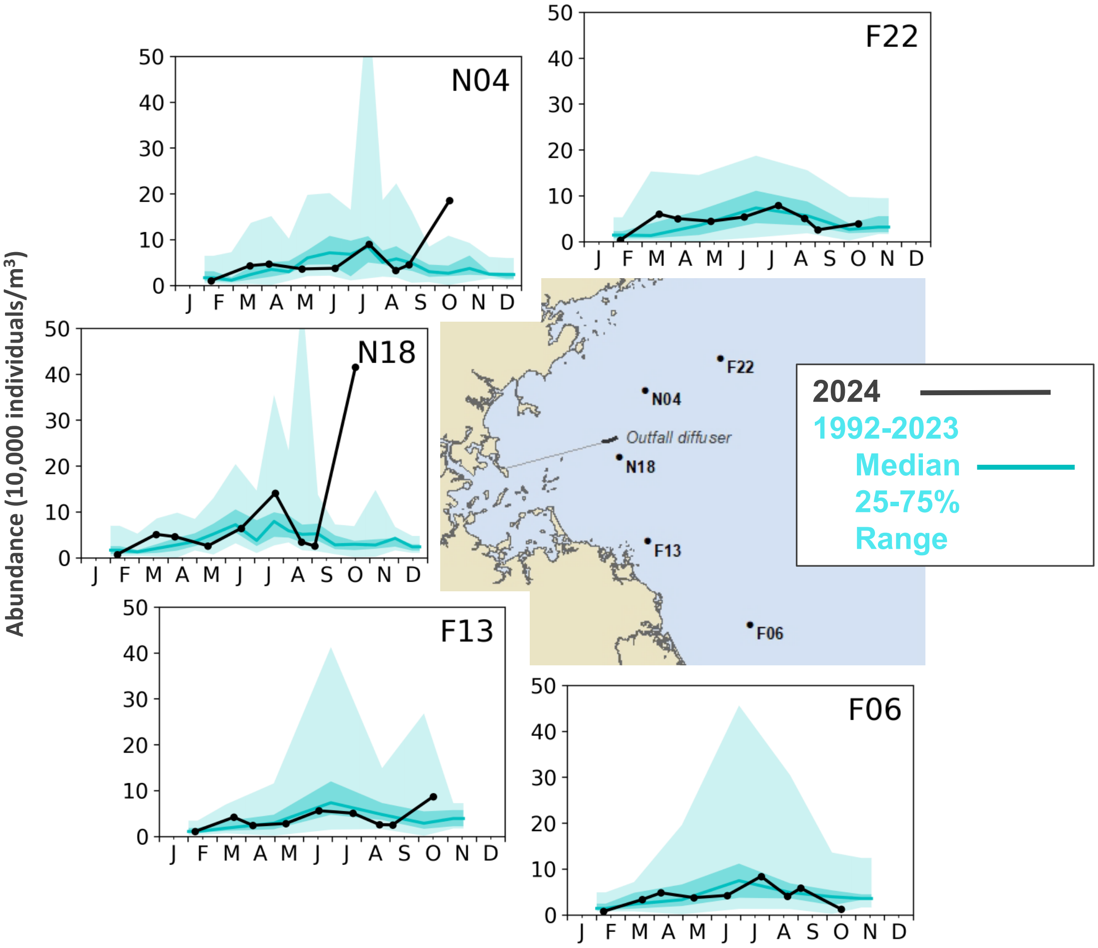


Figure 3-12. Total zooplankton abundance at selected stations in 2024 compared to prior years. The high historical values in July occurred in 2015, when sampling took place just after a major bivalve spawning event. The increases at some stations in October 2024 compared to other years were due to early life stages of copepods and to radiolarians, which are usually found in more offshore waters. individuals/m^3 = individuals per cubic meter.

Stellwagen Bank National Marine Sanctuary

The NPDES permit requires MWRA to report 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 representative of offshore conditions. The instrumented NERACOOS Buoy A01 is located in the northwest corner of the sanctuary. Ammonium concentrations have not increased at Station F22 in the years since the outfall began to discharge (see Figure 3-5, page 17), and there have been no observed effects on phytoplankton biomass or dissolved oxygen levels. Dissolved oxygen concentrations remained above state standards in 2024 (Figure 3-13).

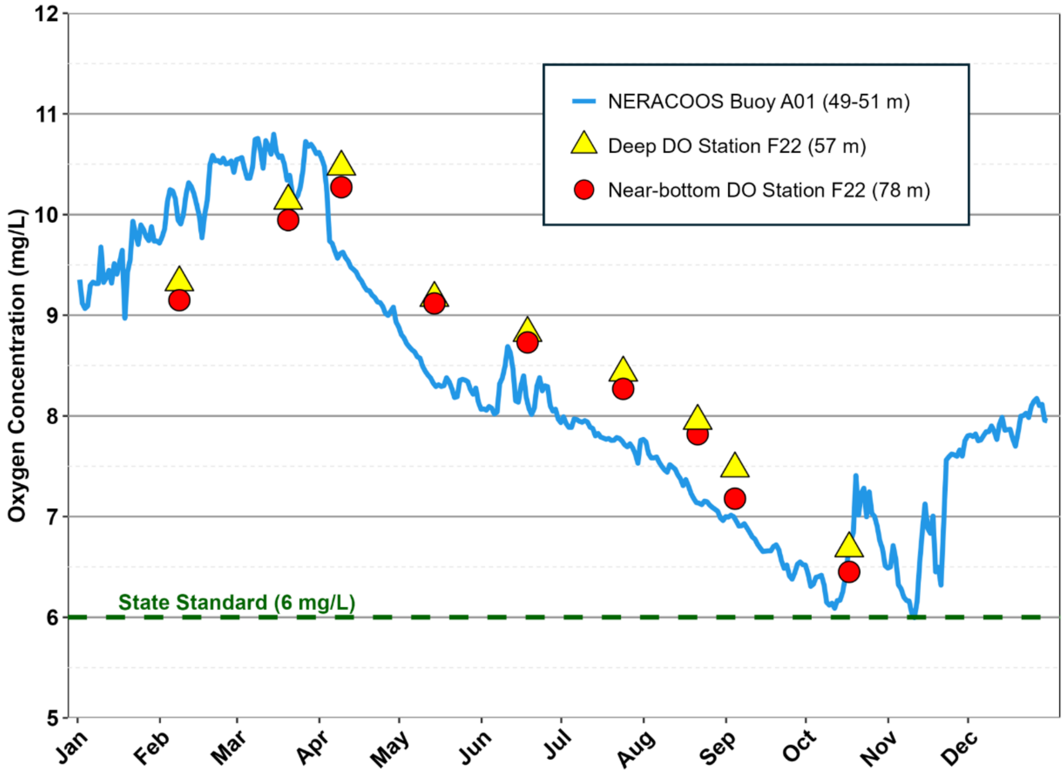


Figure 3-13. Dissolved oxygen concentrations at the NERACOOS Buoy A01 and at nearby deepwater MWRA survey Station F22 in 2024. Buoy values are daily means. The state water quality standard for dissolved oxygen is a minimum of 6 milligrams per liter. mg/L = milligrams per liter.

The sanctuary's most recent condition report rated water quality within its borders as "good," and its most recent management plan agreed with MWRA's assessment that the outfall is not adversely affecting its waters (NOAA Office of Marine Sanctuaries 2020, 2023).

Boston Harbor Water Quality

Water quality in Boston Harbor greatly improved during the Boston Harbor Project, and those advances remained evident in 2024. Perhaps the most dramatic improvement in Boston Harbor was the decrease in ammonium concentrations, which have remained low after dropping precipitously in 2000, when the effluent discharge was diverted from the harbor to Massachusetts Bay. The reduction in nutrient inputs has been accompanied by decreases in previously over-stimulated primary production and phytoplankton biomass, an abatement of the harbor's historically high level of eutrophication (Werme et al. 2018, Taylor et al. 2020).

Water-Column Contingency Plan Thresholds

There were no exceedances of water-column thresholds in 2024 (Table 3-1). Overall, the year was typical, with water-quality parameters close to the long-term means, moderate dissolved-oxygen levels, and no nuisance algal blooms.

Table 3-1. Contingency Plan threshold values and 2024 results for water-column monitoring.

Parameter	Baseline	Caution Level	Warning Level	2024 Results
Chlorophyll				
Annual	72 mg/m^2	>108 mg/m^2	>144 mg/m^2	61 mg/m^2
Winter/spring	50 mg/m^2	>199 mg/m^2	None	40 mg/m^2
Summer	51 mg/m^2	>89 mg/m^2	None	56 mg/m^2
Autumn	90 mg/m^2	>239 mg/m^2	None	102 mg/m^2
Dissolved oxygen*				
Nearfield concentration	6.05 mg/L	<6.5 mg/L	<6.0 mg/L	6.24 mg/L
Nearfield percent saturation	65.3%	<80%	<75%	69.2%
Stellwagen concentration	6.23 mg/L	<6.5 mg/L	<6.0 mg/L	6.45 mg/L
Stellwagen percent saturation	67.2%	<80%	<75%	68.7 %
Nearfield depletion rate	0.024 mg/L/d	>0.037 mg/L/d	>0.049 mg/L/d	0.023 mg/L/d
Nuisance algae nearfield *Pseudo-nitzschia*				
Winter/spring	6,735 cells/L	>17,900 cells/L	None	73 cells/L
Summer	14,635 cells/L	>43,100 cells/L	None	28,200 cells/L
Autumn	10,050 cells/L	>27,500 cells/L	None	727 cells/L
Nuisance algae nearfield *Alexandrium catenella*				
Any nearfield sample	Baseline maximum 163 cells/L	>100 cells/L	None	96 cells/L
PSP toxin extent	NA	New incidence	None	No new incidence

"Nearfield" refers to the five stations closest to the outfall, where effects might be detected, if they were to occur. Red shading shows a warning-level exceedance; orange shading shows a caution-level exceedance. For dissolved oxygen parameters, "exceedances" refer to values less than the threshold.
*Dissolved oxygen caution and warning levels represent numerical criteria, with the caveat "unless background conditions are lower." Results are therefore compared to the baseline as well as the caution and warning levels.
PSP = paralytic shellfish poisoning
NA = not applicable
mg/m^2 = milligrams per square meter
mg/L = milligrams per liter
mg/L/d = milligrams per liter per day
cells/L = cells per liter

4. Sea Floor

Seafloor monitoring assesses the health of habitats and communities. MWRA measures sediment characteristics and assesses animal communities living in soft-bottom and rocky, hard-bottom habitats. No effects of the outfall have been detected. Seafloor animal communities vary within typical natural cycles, and are mostly influenced by sediment types and water depths.

The sea floor of Massachusetts Bay was shaped by glaciers, which scoured the bottom and created Stellwagen Basin to the east of the outfall, deposited rocky debris in elongated hills called drumlins, and left the sand-and-gravel ridge that forms Stellwagen Bank. Tides and currents continue to shape the bay, particularly during major storms with waves large enough to resuspend and transport sediments. Seafloor habitats range from mud in soft-bottom depositional areas to rocky cobbles and boulders on the hard-bottom tops and flanks of the drumlins.

Seafloor monitoring assesses potential effects of the outfall on the health of both the soft-bottom areas made up of sand, silt, and clay, and the rocky hard-bottom drumlins. Most seafloor-monitoring studies focus solely on soft-bottom sediments, but such depositional sites are somewhat rare in the immediate vicinity of the outfall. MWRA conducts annual soft-bottom sampling surveys, while photographic and video assessments of the hard-bottom areas occur every three years, most recently in 2023. A separate monitoring program in Boston Harbor includes annual soft-bottom sampling and analysis, as well as photographic sediment-profile imagery.

In August 2024, MWRA sampled 14 Massachusetts Bay soft-bottom stations for analysis of sediment grain-size distribution, the wastewater tracer *Clostridium perfringens* spores, percent total organic carbon, and animal abundance and species composition (Figure 4-1). The stations included four “inner nearfield” stations located within two kilometers of the outfall; six “outer nearfield” stations in western Massachusetts Bay but somewhat 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 testing Contingency Plan thresholds for the sea floor, “nearfield” includes both nearfield groups and the transition station, for a total of 11 stations. The transition area is included in the calculations, because early modeling suggested that it would continue to be a depositional site, where elevated concentrations of particulate organic carbon might be detected (Kropp et al. 2000). Some scientific analyses do not include the transition station when comparing results from the nearfield to those from the farfield, as it is near to and remains affected by historic and continued inputs from Boston Harbor and other coastal sources.

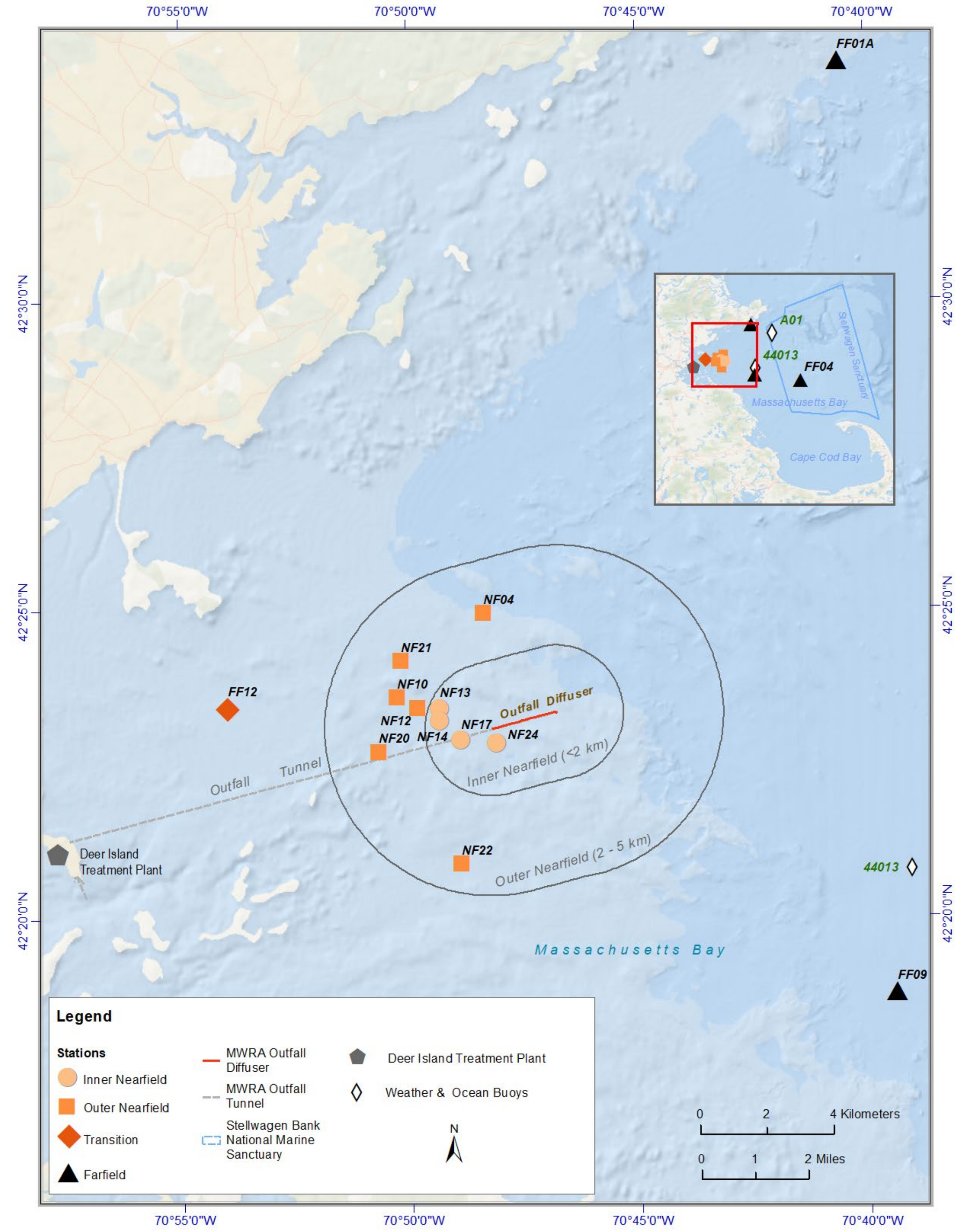


Figure 4-1. Soft-bottom monitoring stations. Also shown are the instrumented buoys, the MWRA outfall diffuser, and Stellwagen Bank National Marine Sanctuary. Nearfield station labels begin with NF, while farfield stations and the transition station begin with FF. The transition station FF12 is included with the nearfield stations to calculate Contingency Plan threshold parameters.

Sediment Characteristics and Tracers

As in past years, sediment grain-size distributions varied broadly in 2024, ranging from silt and clay at some stations (for example, Station NF12 just northwest of the outfall and Station FF04 within Stellwagen Basin) to almost entirely sand at others, including several stations near the outfall (Nestler et al. 2025).

Within individual stations, sediment textures have remained stable over the years of monitoring, with occasional changes following large storms. An April storm with eight-meter waves, capable of resuspending and transporting sediments in Massachusetts Bay, may have caused some changes in 2024 sediment samples. Increased percentages of fine silts and clays, were found at several stations, including Station NF17, a generally sandy station near the outfall, and farfield reference Station FF01A.

Clostridium perfringens is a species of anaerobic bacteria, found in the digestive tracts of humans and other mammals and not completely removed by wastewater treatment. It forms resting spores, which provide a sensitive tracer of sewage effluent in sediments. Since spores can persist for decades, they do not reflect immediate deposition onto the sea floor; instead, they can provide evidence of wastewater discharges over years.

In 2024, as in most other years, MWRA monitoring detected elevated abundance of *Clostridium* spores at some stations closest to the outfall (Figure 4-2). Highest spore counts were found at Stations NF24 and NF14, located within two kilometers of the outfall, and at Station NF22, just to the southwest of the outfall in the direction of most frequent transport of the effluent plume.

Percent total organic carbon content in the sediments was consistent with past results, with no increased organic carbon concentrations at stations near the outfall (Figure 4-3) or at the transition station. In general, there are higher concentrations of total organic carbon at stations with finer sediments, such as Station FF04 in Stellwagen Basin, and lower concentrations at stations with coarser sediments such as NF17 near the outfall. Overall, the total organic carbon data continued to show no signs of organic enrichment from wastewater effluent, consistent with predictions made before the outfall began to discharge and also consistent with an MWRA special study of sediment metabolism, which was completed in 2010 (Tucker et al. 2010, Tucker et al. 2014).

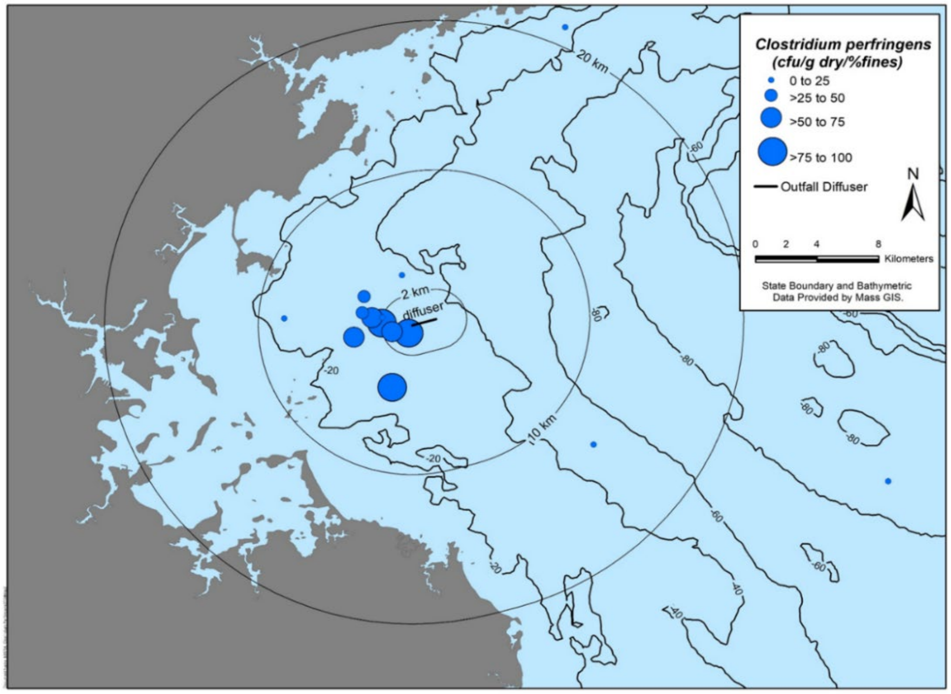


Figure 4-2. Concentrations of the effluent tracer *Clostridium perfringens* spores in 2024. Concentrations represent spore counts normalized to the percent of the sediment made up of fine silts and clays, removing any effect of grain size from the analysis. As anticipated during outfall planning, *Clostridium* spore concentrations are elevated at stations closest and to the southwest the outfall, in the most prevalent current direction. cfu = colony forming units, the measure used in spore counts.

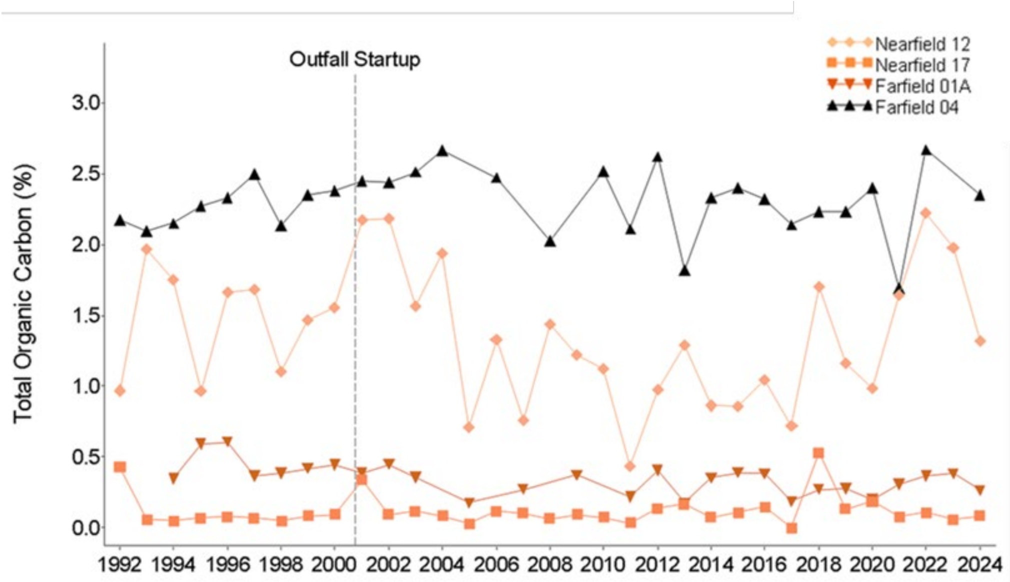


Figure 4-3. T**otal organic carbon at selected stations, 1992–2024.** No effects of the discharge have been observed at any station. NF17 is in closer proximity and southwest of the outfall, where the effects of the discharge might be expected but have not been found. FF01A is the northern reference station, and FF04 is in Stellwagen Basin; both farfield stations are farther than 20 kilometers from the outfall.

Soft-bottom Communities

A variety of small animals live in the sediments, including segmented polychaete worms, mollusks, and crustaceans. MWRA monitors abundance and species composition of animals living within soft-bottom communities to document any changes that might be associated with the outfall discharge, such as decreased biodiversity or increased presence of the opportunistic species typically found in disturbed habitats.

The 14 soft-bottom samples collected and analyzed in 2024 contained 19,606 organisms, classified into 154 species and 21 other discrete taxonomic groups of animals that could not be identified to the species level (Nestler et al. 2025). Both the total number of organisms and the number of species were somewhat lower in 2024 than in 2023 across the regional groups, but both tallies remained within historic ranges (Figures 4-4, 4-5). The several community diversity measures calculated for nearfield samples remained at levels typical of past years.

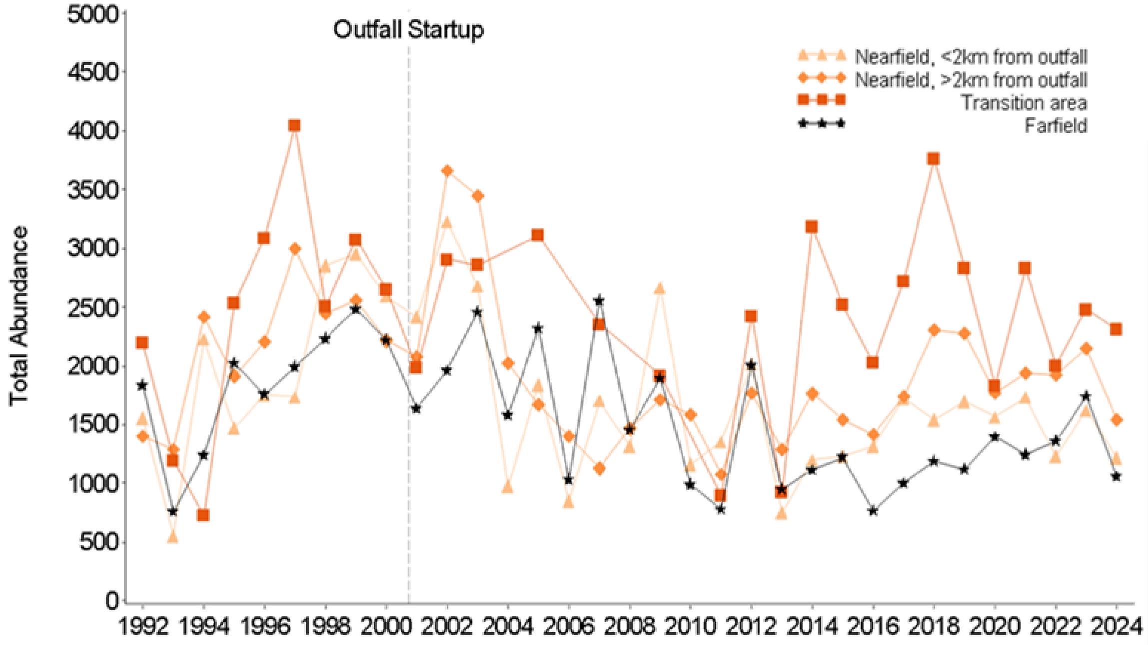


Figure 4-4. Total abundance of soft-bottom organisms by region, 1992–2024. Regions include the nearfield within two kilometers of the outfall, the outer nearfield farther than two kilometers from the outfall, the transition area between Boston Harbor and the outfall, and the farfield.

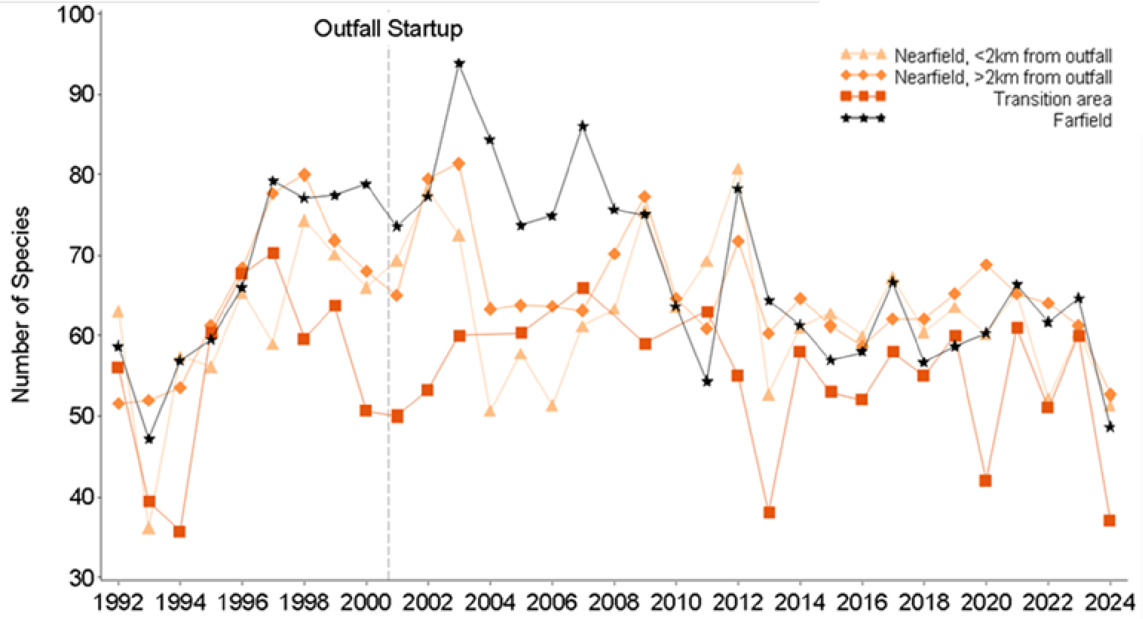


Figure 4-5. Total abundance of species by region, 1992–2024. Regions include the nearfield within two kilometers of the outfall, the outer nearfield farther than two kilometers from the outfall, the transition area between Boston Harbor and the outfall, and the farfield.

Small polychaete worms, sometimes known as bristle worms (Figure 4-6), dominated the samples at most stations, as they have for the duration of the monitoring program. These segmented worms are among the most common marine organisms. The polychaete *Prionospio steenstrupi*, which is found in many places around the world, was the numerically dominant species in 1997–2005. It has declined in abundance over recent years, but remains among a group of dominant species. Other common polychaetes included *Aricidea catherinae* and *Mediomastus californiensis*, which also have wide geographic distributions, and were present in numbers comparable to other recent years.

Figure 4-6. Polychaete worms dominate the soft-bottom habitats in Massachusetts Bay. The image shows the anterior end of a 2-millimeter-long syllid polychaete taken from a former MWRA farfield station. Polychaetes can range in size from less than a millimeter to several meters; most are very small. Syllid polychaetes are sometimes called necklace worms, due to the constricted band depicted in the lower middle part of the photograph. They are found in a variety of soft- and hard-bottom habitats. Photo credit Nancy J. Maciolek, Duxbury, Massachusetts.

Analyses of the seafloor communities by location continued to show no effects of the outfall on total abundance of animals, relative abundance of species, or community composition. A series of analyses assessed patterns in the soft-bottom communities over space and time and found no particular species or type of community specifically associated with the outfall.

One type of community analysis, called cluster analysis, groups stations by similarity in species composition and abundance. Cluster analysis of the 2024 samples identified two main groups (I and II). Group I was dominated by crustaceans and polychaete worms. Group II included a greater abundance of polychaetes and mollusks than Group I.

Some of the stations within Group II could be separated into more specific subgroups, based on slight differences in species composition and abundance. Group II also included two outlier stations, FF09 and FF04. Offshore Station FF09, located to the southeast of the outfall had the largest number of mollusks of any station, including small bivalves and a small snail. *Frigidoalvania carinata*. Station FF04, the offshore station located within Stellwagen Basin, has consistently supported a unique polychaete community, typical of the other deepwater, offshore stations that were sampled in the past. *Chaetozone anasimus*, a moderate-sized polychaete first identified in MWRA samples, dominated in 2024. In some past years, Station FF04 has been placed into a separate Group III.

Further analysis, called ordination analysis, provides a picture of how closely the groups identified in the cluster analysis relate to each other. The 2024 ordination analysis continued to show no indication of any relation between community composition and proximity to the outfall (Figure 4-7). Both main Groups I and II included stations located at various distances and directions from the outfall. Group II included stations from both nearfield station groups, the transition station between the harbor and the outfall, and farfield stations to the northeast and southeast of the outfall. These results were consistent with prior years.

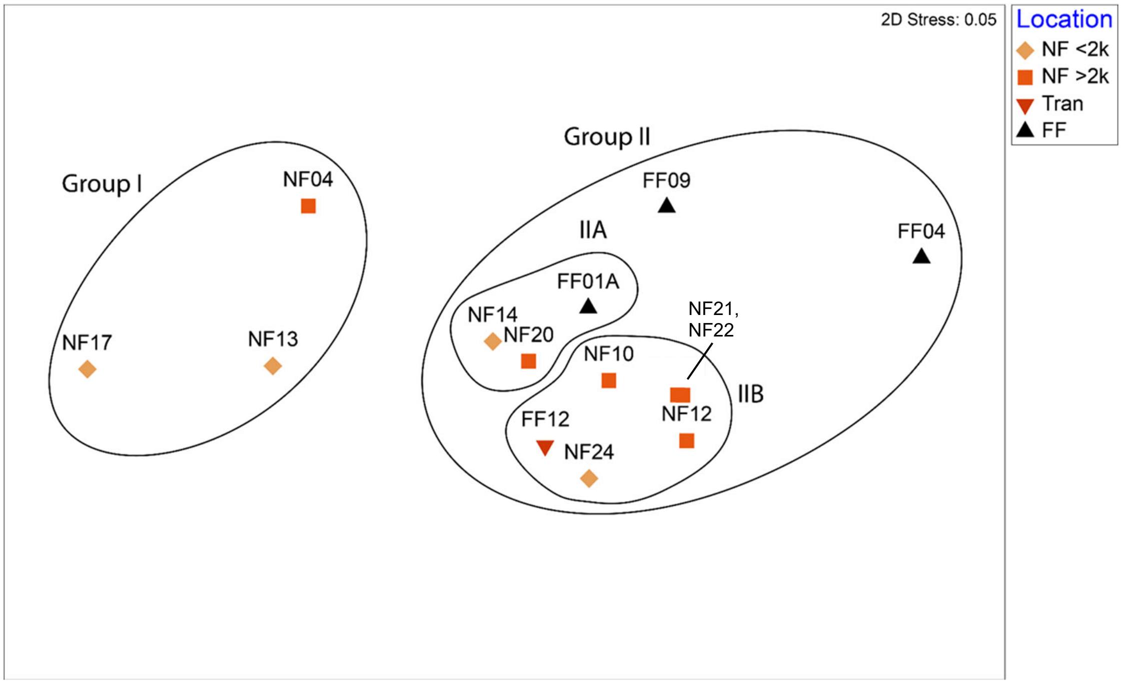


Figure 4-7. Ordination plot of 2024 Massachusetts Bay samples by location. The ordination analysis shows that the distance from the outfall does not correspond with bottom community composition. Each point on the plot represents one of 14 stations, and varying colors and shapes depict locations. The closer two points are to each other in the figure, the more similar their seafloor communities. NF<2k = stations within two kilometers of the outfall; NF >2k = stations near but more than two kilometers from the outfall; Tran = the one transition station between Boston Harbor and the outfall; FF = stations far from the outfall. (The 2D Stress value of 0.05 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 water depth (Figure 4-8). Seafloor animal communities at 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 continued to validate past findings that the Massachusetts Bay seafloor communities are driven by physical factors rather than by the effluent discharge. The strong physical forces in the bay, as well as the low pollutant levels in the discharge, have helped to maintain healthy soft-bottom habitats throughout Massachusetts Bay.

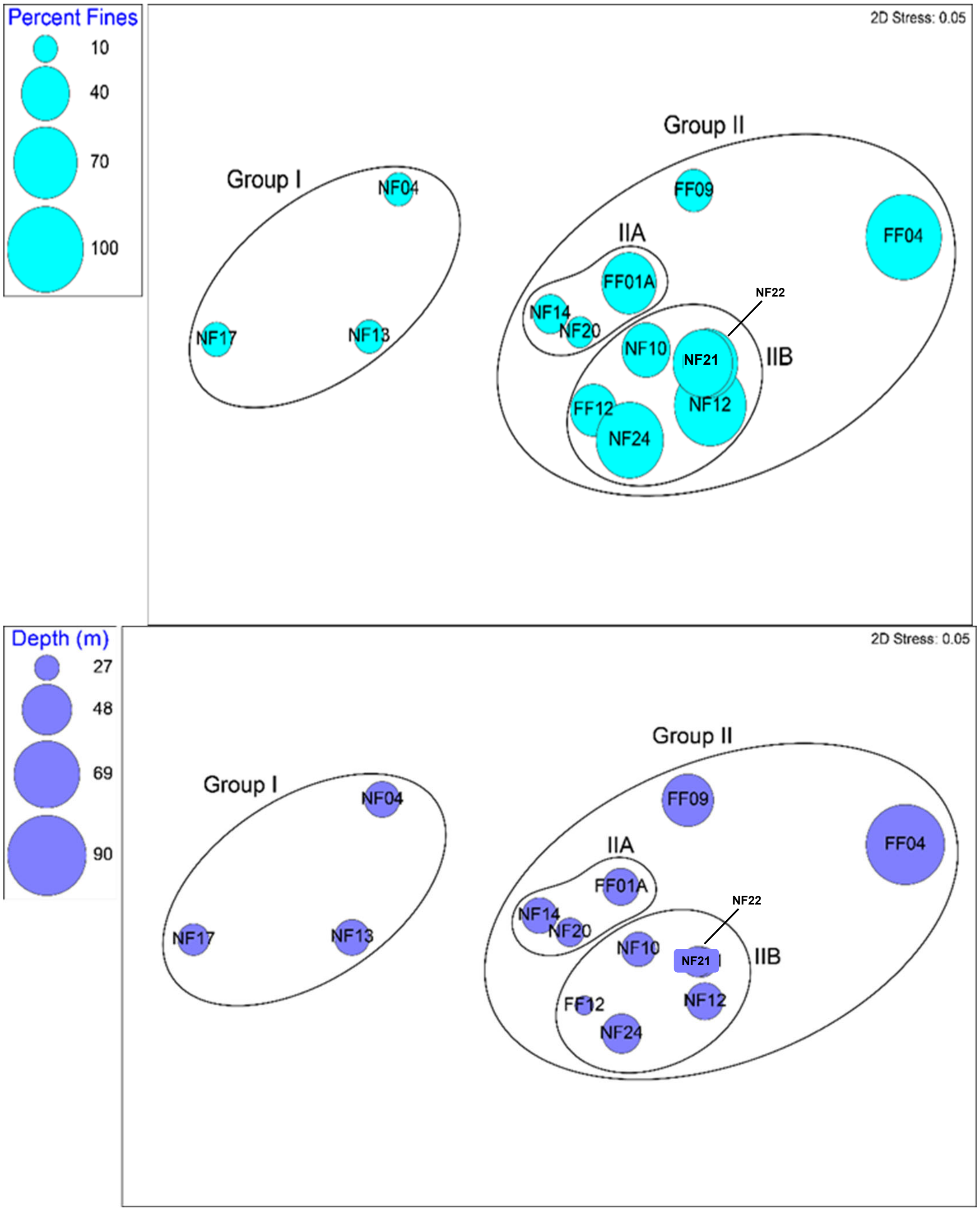


Figure 4-8. Percent fine sediments (top) and water depth (bottom) superimposed on the ordination plot of the 2024 samples. Combining the ordination analysis with sediment grain-size and water-depth data shows that sediment texture and depth are likely strong drivers of community composition. (The 2D Stress values noted in the upper right of each figure are 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 deepwater seafloor reference Station FF04 lies within the depositional part of the sanctuary, Stellwagen Basin, where long-term accumulation of pollutants could feasibly occur.

Station FF04 is typical of deepwater, offshore habitats and is representative of a larger group of stations that MWRA monitored in earlier years of the program. It continues to support a soft-bottom community typical of what had been found at the larger suite of deepwater stations. Communities at those stations have always shown distinct differences from those found in shallower areas, probably due to the distance from shore, as well as greater depth and fine-grained sediments (Figure 4-8, above). Analysis of data from 1992–2024 has demonstrated the temporal consistency of the seafloor community at that station.

The most recent management plan for the sanctuary (NOAA Office of Marine Sanctuaries 2023) includes an action plan to assess all the major habitats within its borders, including sand, boulder, gravel, mud, rocky areas, and shipwrecks. Their most recent environmental assessment (NOAA Office of Marine Sanctuaries 2020) found that changes to seafloor habitats and animal communities came mostly from fishing. Fishing gear physically scrapes the sea floor, and fishing pressures can change the species makeup of both seafloor and fish communities.

Boston Harbor Seafloor Monitoring

Seafloor conditions are much better in Boston Harbor than they were in the 1970s and 1980s, when both sewage sludge and effluent were discharged into its shallow, confined waters. MWRA has conducted ongoing seafloor monitoring in Boston Harbor since 1991, the year that sludge discharges ended. Each year, sediment samples are taken from nine stations, and sediment-profile images are made at 61 locations throughout the harbor (Madray et al. 2025).

Sediment textures vary throughout the harbor, ranging from mostly sand at some stations, particularly in the outer harbor, to silt and clay at others. Percent total organic carbon in harbor sediments has declined over time, reflecting the end of sludge and effluent discharges.

Over the past decade, the total abundances of organisms and number of species per sample have stabilized (Figure 4-9), a sign of sustained improvement in seafloor habitat conditions. In 2024, samples contained 29,013 specimens, classified into 122 species and 13 other discrete taxonomic groups. The predominant species have also changed since the early years of monitoring, when samples were dominated by the opportunistic species often found in disturbed habitats.

As in past years, the communities in 2024 varied along an inner-to-outer harbor gradient, reflecting the greater stream and river inputs to the inner harbor and greater tidal flushing at the outer-harbor stations. Sediment-profile imaging has confirmed the gradient and clearly documented sustained improvements to habitat conditions throughout the harbor over time. Sediment-profile images from 2024 (Figure 4-10) depicted the healthy conditions, including animals and physical structures.

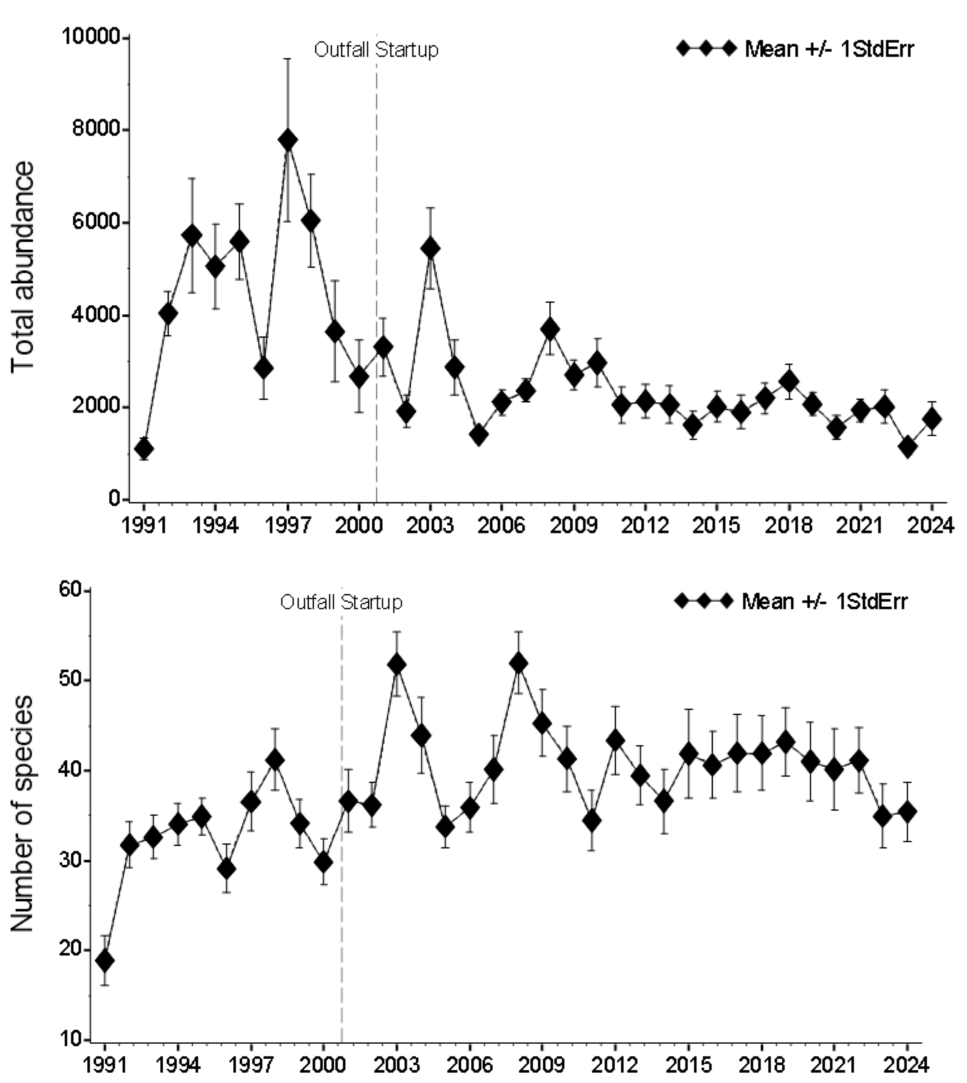


Figure 4-9. Total abundance of soft-bottom animals (top) and number of species (bottom) per sample from Boston Harbor, 1991–2024. The numbers of organisms and species have stabilized as the harbor has recovered from past sludge and effluent discharges. Data are from eight harbor stations that have been consistently monitored since 1991. “Outfall startup” refers to the beginning of discharge through the Massachusetts Bay outfall and the end of discharge to the harbor. Mean +/- 1StdErr = the mean of all measurements, plus or minus one standard error, a measure of variation among individual samples.

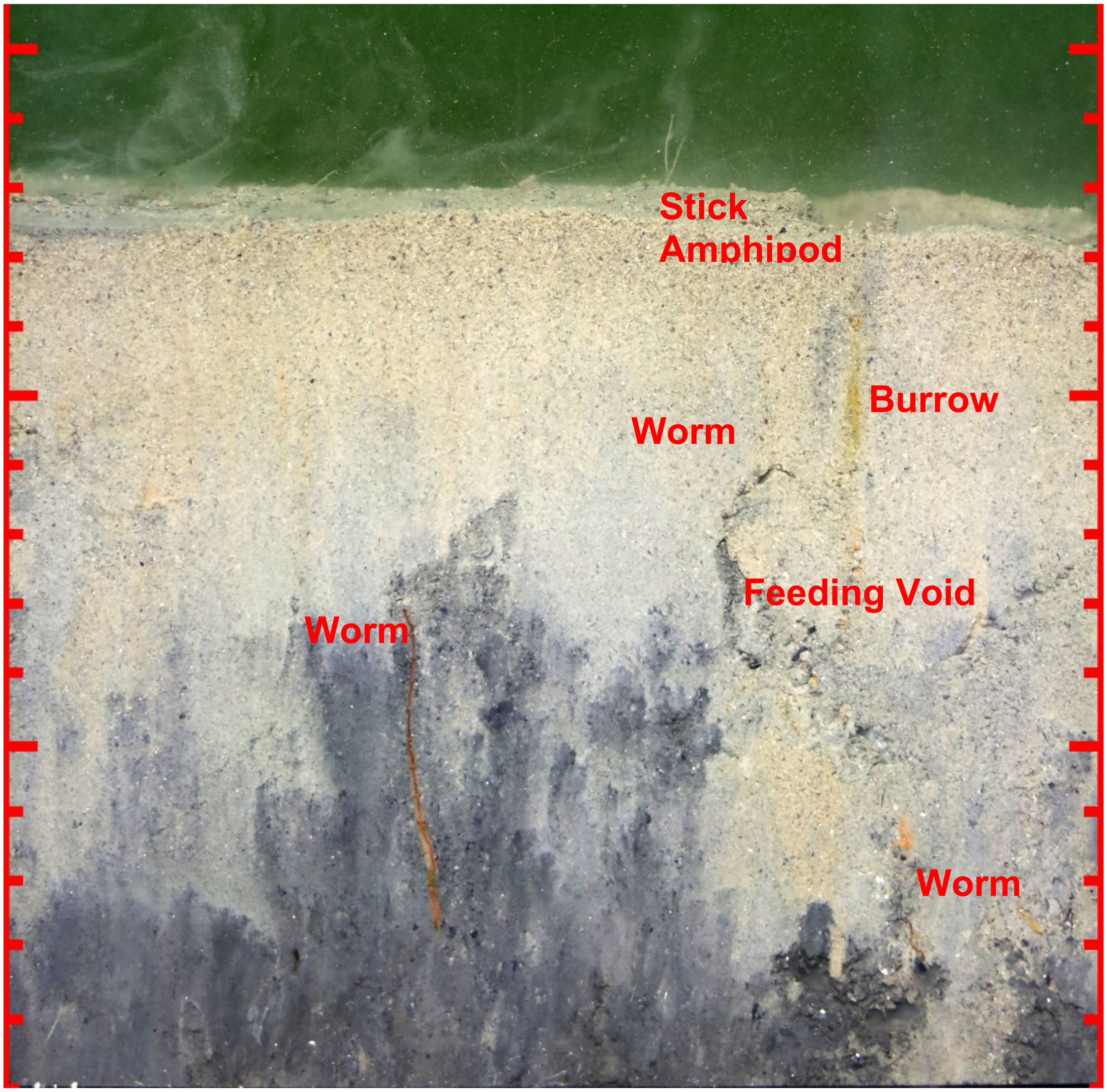


Figure 4-10. Example of a sediment-profile image taken in 2024 south of Deer Island and the north channel into the harbor. The change from light to dark color shows the transition from oxygenated to unoxygenated sediment; this transition zone has deepened in response to improved conditions. Presence of organisms and feeding structures indicate a healthy environment. Scales at the sides of the image are in centimeters. Photo credit RJ Diaz and Daughters, Ware Neck, Virginia.

Seafloor Contingency Plan Thresholds

There were no exceedances of the seafloor Contingency Plan thresholds in 2024 (Table 4-1). For the purposes of threshold testing, “nearfield” includes stations from both nearfield groups (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.

All threshold parameters continued to confirm that Massachusetts Bay maintains healthy seafloor habitats, unaffected by the wastewater discharge. Number of species per sample and the several diversity and evenness indices used to evaluate community structure remained higher than Contingency Plan limits, while the percent opportunistic species, an indicator of disturbed or polluted habitats, was less than 3%, far lower than the caution and warning thresholds of 10% and 25%.

Table 4-1. Contingency Plan threshold values and 2024 results for seafloor monitoring.*

Parameter	Baseline	Caution Level	Warning Level	2024 Results
Species per sample	NA	<42.99	NA	50.7
Fisher’s log-series alpha	NA	<9.42	NA	11.0
Shannon diversity	NA	<3.37	NA	3.80
Pielou’s evenness	NA	<0.57	NA	0.67
% opportunists	NA	>10%	>25%	2.17%

NA = not applicable

* Number of species per sample is often referred to as species richness. Fisher’s log-series alpha and Shannon diversity are indicators of diversity, calculated from both numbers of species and numbers of individuals per species. Pielou’s evenness assesses how evenly numbers of individuals are distributed among the species in the sample. Percent opportunists is the percentage of the total number of animals that are indicators of disturbed habitat. The percent opportunist threshold is a maximum; all other thresholds are minimum values.

5. Fish and Shellfish

Fish and shellfish are healthy, and pollutant levels remain low.
MWRA monitors winter flounder health and quantifies chemical pollutants that occur in wastewater effluent in flounder, lobster, and mussel tissues. Over time, flounder health has improved, and contaminant concentrations have declined or remained low in fish and shellfish from Boston Harbor and Massachusetts Bay.

Fish and shellfish are important to the regional identity and economy of Massachusetts and can be good indicators of overall environmental health. The monitoring program focuses on winter flounder, lobster, and cage-deployed blue mussels. Flounder and lobster are important commercial and recreational species that live on the sea floor, where they come into direct contact with sediments and feed on bottom-dwelling animals, both likely sources for contaminant exposure. The blue mussel is commercially and recreationally harvested and is a frequent biomonitoring organism. Mussels filter large volumes of water and can concentrate metals and organic compounds in their tissues.

Sampling and deployment locations vary by species (Figure 5-1). Sampling locations for winter flounder and lobster were selected to be far enough away from each other to maximize the likelihood of sampling separate populations. Winter flounder are unlikely to range farther than about two kilometers in areas with ample food. Lobster migration is less well understood, although they are known to move from shallower Boston Harbor to deeper water in Massachusetts Bay in the fall. Timing and parameters measured vary by species. MWRA monitors winter flounder health each year and conducts chemical contaminant analyses of flounder, lobster, and mussel tissues every three years, including 2024.

In 2024, flounder were collected two locations, at the Massachusetts Bay outfall site and at Deer Island Flats, near the location where wastewater effluent was once discharged into Boston Harbor. Lobsters were sampled near the outfall, at Deer Island Flats, and at eastern Cape Cod Bay, a relatively pristine area that was once also sampled for winter flounder. Commercially farmed mussels were deployed in cages at several locations near the diffusers of the Massachusetts Bay outfall, within Boston Inner Harbor, and at Deer Island Light at the mouth of Boston Harbor.

Flounder sampling occurred over two days in April and May, and lobsters were collected in July. Mussels were deployed for 40 and 60 days during the summer months. Neither flounder nor lobster catches met their full target numbers at every sampling site. A number of factors have affected catch success over time, and wild mussel populations have also changed over the course of the monitoring program. These changes are discussed in Section 6, Special Topics.

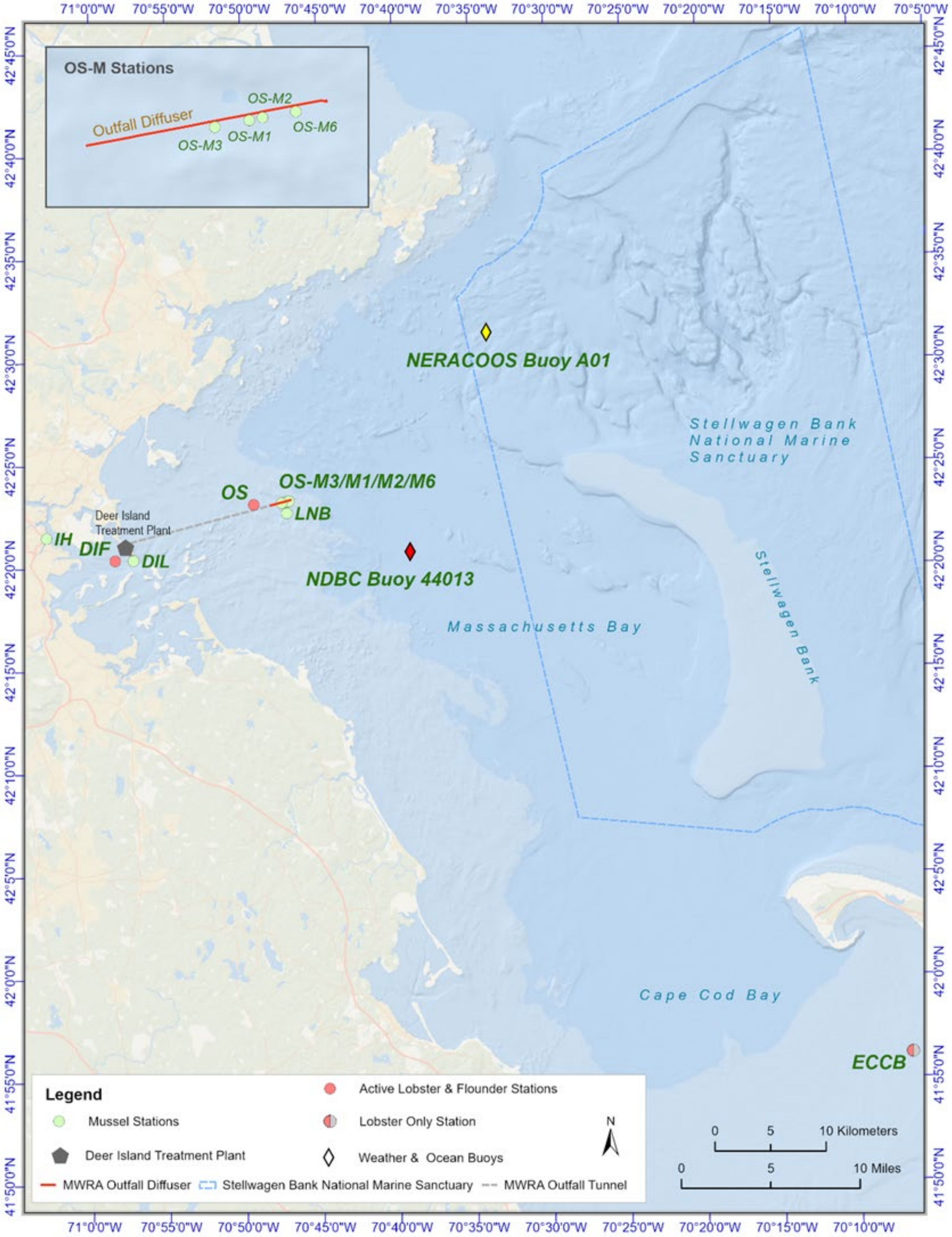


Figure 5-1. Fish-and-shellfish monitoring stations. IH = Inner Harbor; DIF = Deer Island Flats; DIL = Deer Island Light; OS = Outfall Site; OS-M = Outfall Site, Mussels; LNB = Large Navigation Buoy (buoy south of the outfall); ECCB = Eastern Cape Cod Bay. Also shown are the outfall, the instrumented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

Flounder Condition and Health

Flounder sampling included trawls by a commercial fishing boat in April and a backup catch at Deer Island Flats by the Massachusetts Division of Marine Fisheries in May (Moore et al. 2024). The first survey yielded only 34 fish from near the outfall and 20 from Deer Island Flats. The backup collection brought the Deer Island catch to the full complement of 50 fish. Challenges with meeting catch targets are discussed further and given geographic and historic context in Section 6, Special Topics.

Mean ages, lengths, and weights were somewhat lower than in 2024 than in 2023 but remained within the ranges for the monitoring program. The percentage of the catch made up of females also declined slightly, but remained female-dominated, as is common throughout northeast coastal populations (Moore et al. 2016).

Measures of external condition, such as bent fin rays and occurrence and severity of fin erosion, remained variable, but continued to reflect improved conditions since the 1980s and 1990s. Incidence of fin erosion, which has been associated with excess ammonium and other pollutants, remained low at both the Massachusetts Bay outfall site and Deer Island Flats. Ulcers, which are observed on the bottom or “blind side” of the fish in some years, were found on one fish from Deer Island Flats.

Incidence of centrotubular hydropic vacuolation (CHV), a key tumor precursor and mild liver condition (Figure 5-2) associated with exposure to contaminants, was only 8.8% at the Massachusetts Bay outfall and 10% at Deer Island Flats (Figure 5-3), continuing to document a major environmental success story. More than 75% of Boston Harbor flounder livers in the late 1980s showed at least some level of CHV. Incidence has decreased across all age groups in both the harbor and the bay, alleviating the concern prior to the Massachusetts Bay outfall startup that there could be increased liver disease in the bay. In the few fish where CHV has been found, severity of the condition has also declined over time.

Cancerous liver tumors, also called neoplasia, which were present in up to 10% of flounder from Boston Harbor in the 1980s, remained absent, as they have since 2004. Tumors have never been found in a fish taken from near the Massachusetts Bay outfall site (Figure 5-4; see also Moore et al. 2018).

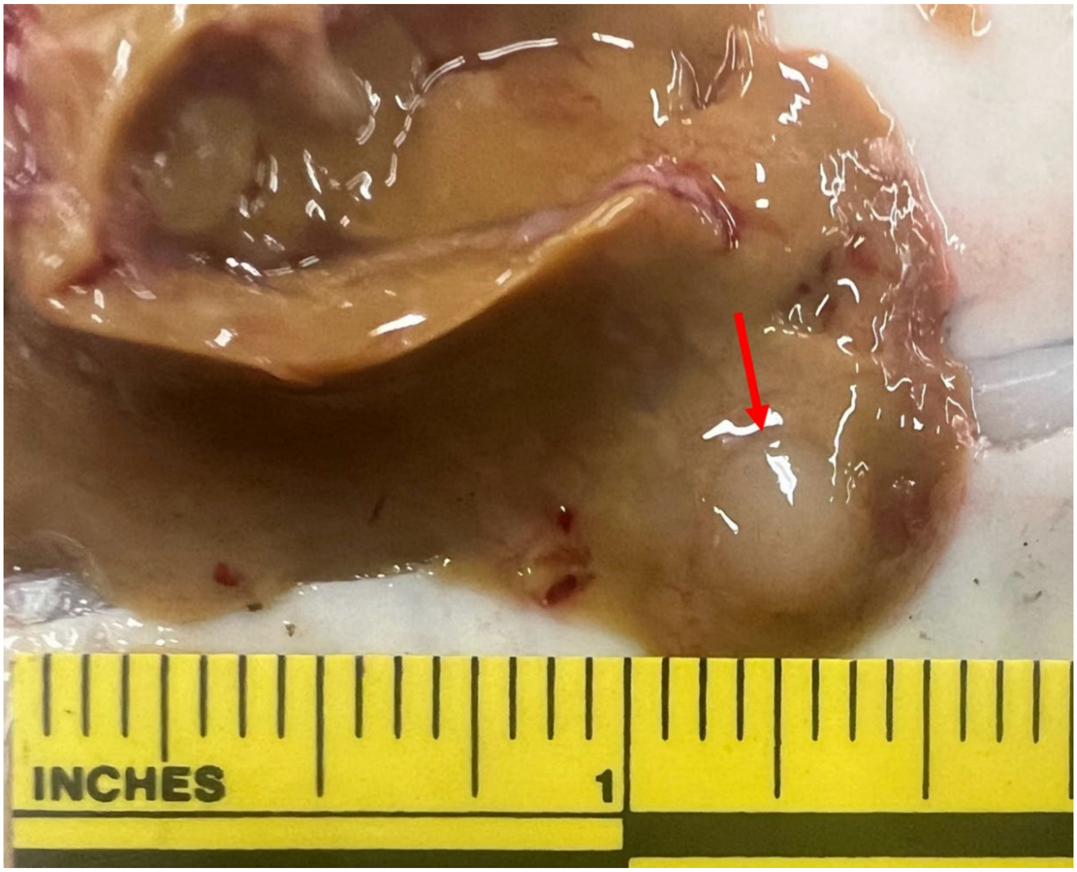


Figure 5-2. Centrotubular hydropic vacuolation (CHV) in flounder liver, 2024. In the 1980s and 1990s, Boston Harbor winter flounder were riddled with similar nodules. Now they are rare. Photo credit Michael Moore, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

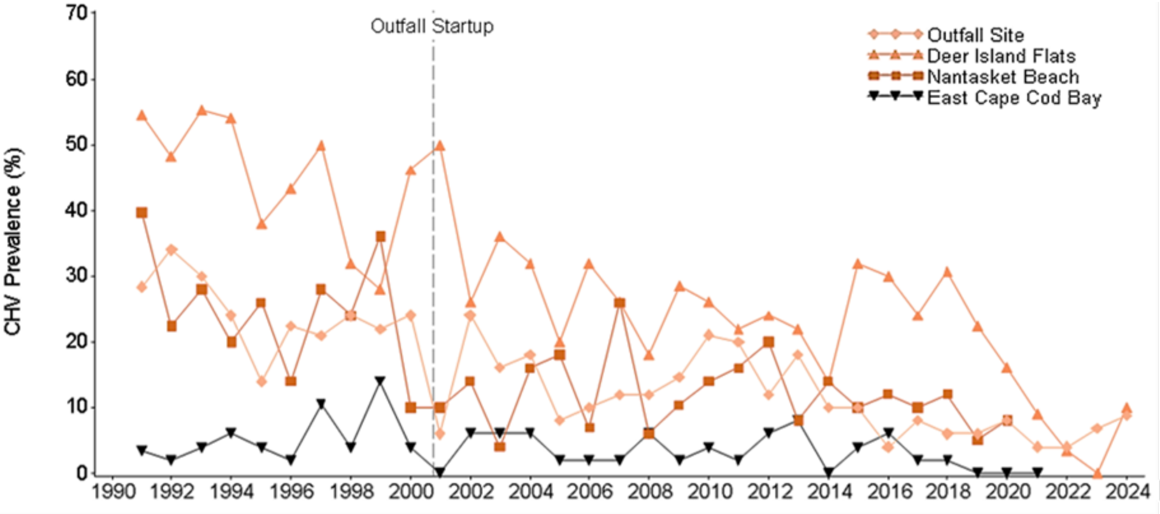


Figure 5-3. Annual prevalence of the tumor precursor CHV in winter flounder, 1991–2024. Nantasket Beach and East Cape Cod Bay are no longer sampled. CHV incidence and severity have declined throughout the region. In 2024, sampling was limited to the outfall site and Deer Island Flats.

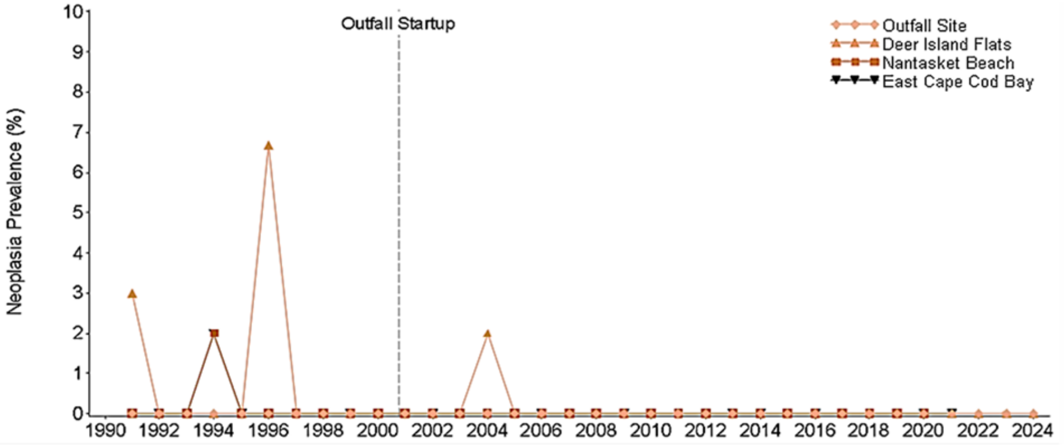


Figure 5-4. Annual prevalence of liver tumors in winter flounder, 1991–2024. No tumors have ever been found in fish taken from near the Massachusetts Bay outfall. In 2024, sampling was limited to the outfall site and Deer Island Flats.

Fish and Shellfish Tissue Chemistry

Flounder, lobster, and mussel tissues were analyzed for metals and organic compounds known for their potential toxicity to marine life and human health. Organic compounds included known carcinogens, such the banned organochlorine pesticides DDT and chlordane; PCBs, which were used in electrical equipment and other products; and PAHs, which derive from natural, domestic, and industrial sources, such as coal, oil, and forest fires. PAHs enter the marine environment through road runoff, sewage, and atmospheric deposition.

Flounder tissues were taken from the same 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.

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, obtained from commercial grower Hollander and De Konig Mussel Farms beds in Mount Desert Narrows, Maine, were 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 40- and 60-day deployments were compared to concentrations in the reference mussels prior to deployment.

Concentrations of all contaminants remained low in flounder, lobster and mussel tissues. Slow declines in concentrations of banned pesticides and PCBs continued across all flounder and lobster tissue types and locations. These declines have been particularly evident in samples from the fish caught near Deer Island.

For example, despite small average increases in 2024, slow declines in concentrations of the pesticide chlordane in flounder fillets have persisted throughout the monitoring program (Figure 5-5). Smaller long-term declines in concentrations of PCBs have been observed in lobster meat, including those taken from the relatively pristine sampling area in eastern Cape Cod Bay (Figure 5-6).

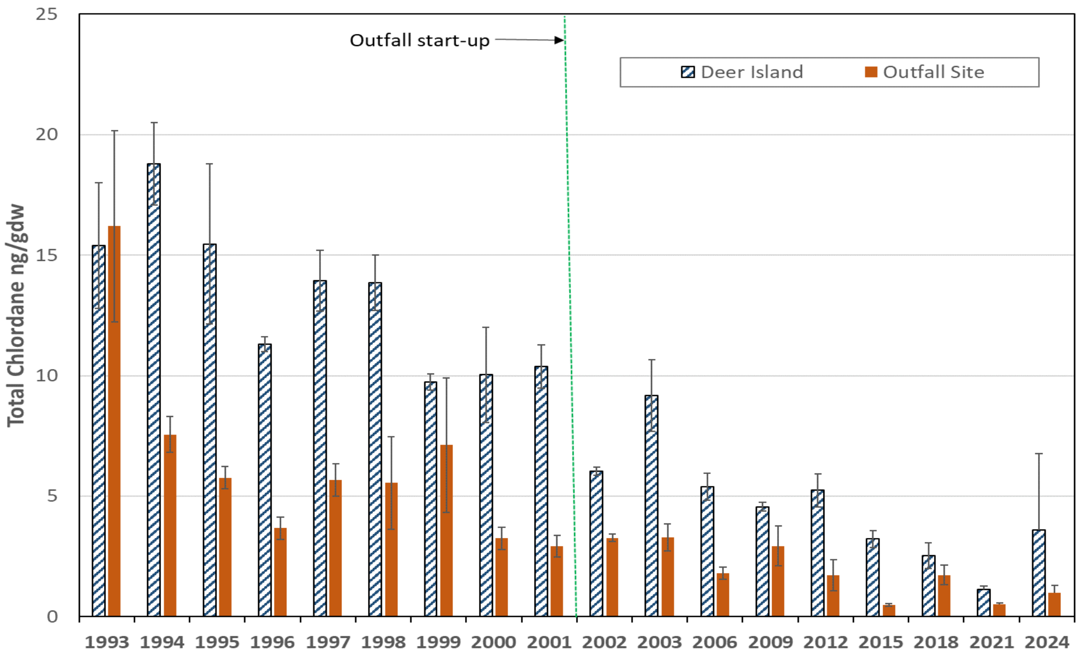


Figure 5-5. Chlordane in flounder fillets, 1993–2024. Since 2003, sampling has occurred at three-year intervals. Chlordane was widely used in agriculture and homes before its ban in the US in 1988.

Pesticide concentrations in deployed mussels have also declined over time, a result not only of pesticide bans, but also due to improved treatment and the outfall relocation to Massachusetts Bay. Results from 2024 showed that contamination remained greatest in Boston Inner Harbor, which has a legacy of inputs from sources other than wastewater discharges. For example, accumulation of the banned pesticide chlordane and its breakdown products was greatest in mussels deployed in Boston Inner Harbor, intermediate in mussels near Deer Island, and lowest in mussels deployed at locations near the Massachusetts Bay outfall (Figure 5-7). Other contaminants showed similar patterns.

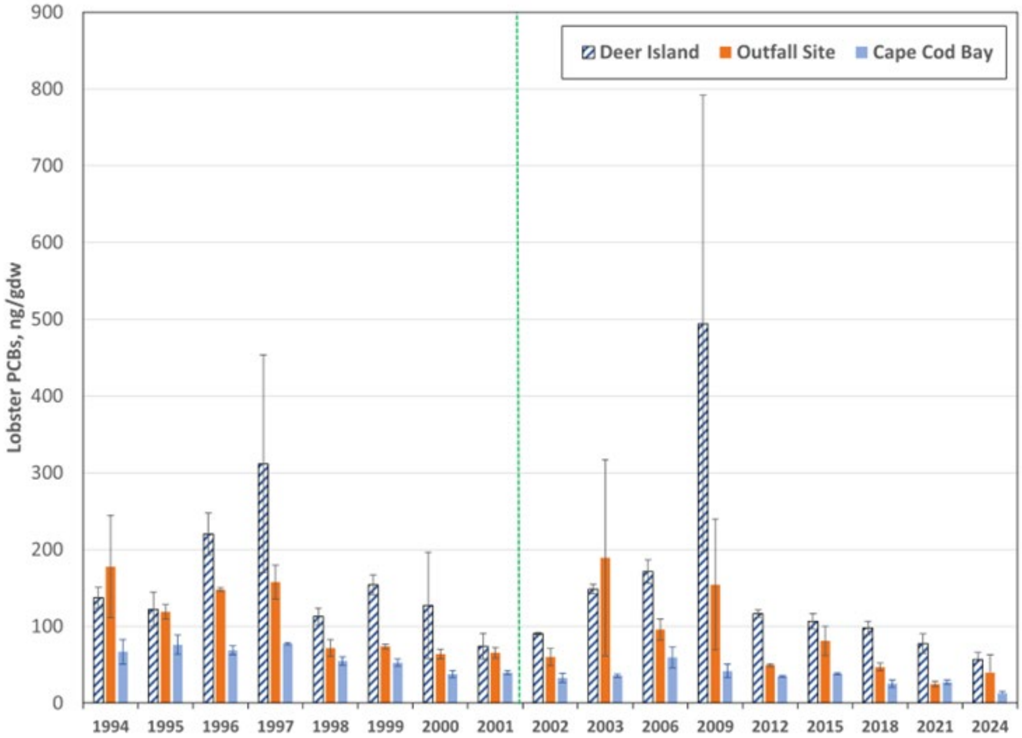


Figure 5-6. PCBs in lobster meat, 1994–2024. Since 2003, sampling has occurred at three-year intervals. PCB use was banned in 1979.

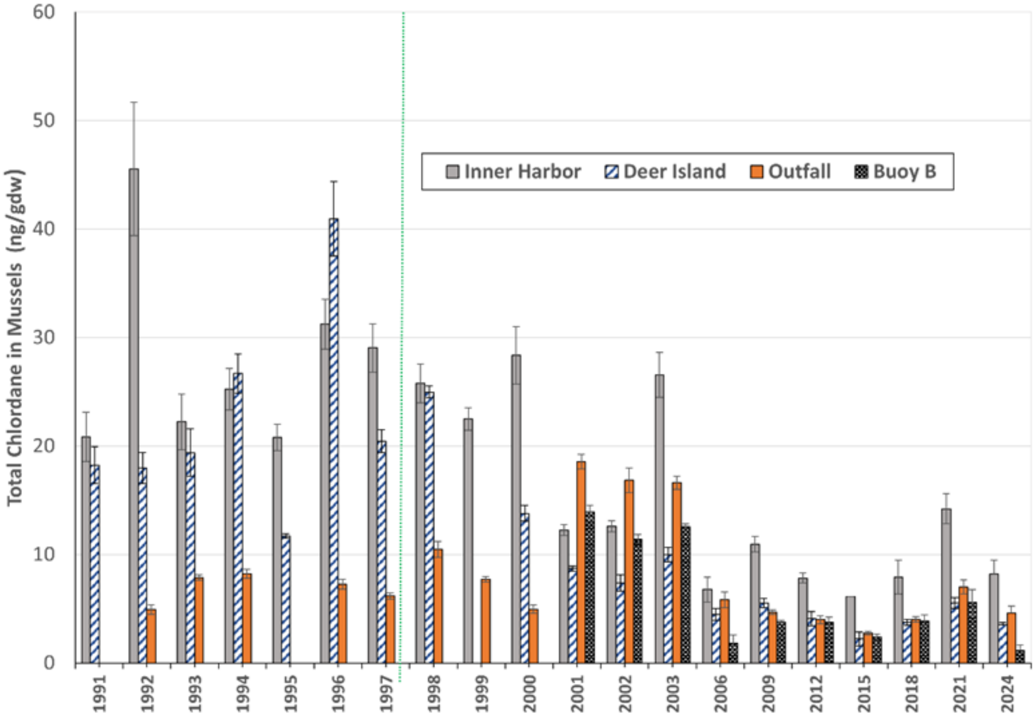


Figure 5-7. Chlordane in mussel tissues, 1993–2024. Since 2003, sampling has occurred at three-year intervals**.** Buoy B is the large navigation buoy located just south of the outfall.

Fish and Shellfish Contingency Plan Thresholds

There were no Contingency Plan threshold exceedances for fish-and-shellfish parameters in 2024 (Table 5-1). The only flounder-health parameter, CHV, occurred in 6.8% of the fish collected near the outfall, compared to the 24.4% baseline and a caution threshold of 44.9%.

Table 5-1. Contingency Plan threshold values and 2024 results for fish-and-shellfish monitoring.*

Parameter	Baseline	Caution Level	Warning Level	2024 Results
Flounder disease				
Liver disease (CHV)	24.4%	44.9%	None	8.8%
Flounder fillet				
PCB	0.033 ppm	1 ppm wet weight	1.6 ppm wet weight	0.008 ppm
Mercury	0.074 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.101 ppm
Flounder fillet, lipid normalized				
Chlordane	242 ppb	484 ppb	None	71 ppb
Dieldrin	63.7 ppb	127 ppb	None	0 ppb
DDT	775.9 ppb	1552 ppb	None	257 ppb
Lobster meat				
PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight	0.008 ppm
Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.152 ppm
Lobster meat, lipid normalized				
Chlordane	75 ppb	150 ppb	None	5 ppb
Dieldrin	161 ppb	322 ppb	None	0 ppb
DDT	341.3 ppb	683 ppb	None	39 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	0.208 ppm
Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.012 ppm
Mussel tissue, lipid normalized				
Chlordane	102.3 ppb	205 ppb	None	19.9 ppb
Dieldrin	25 ppb	50 ppb	None	0 ppb
DDT	241.7 ppb	483 ppb	None	16.8 ppb
PAH	1080 ppb	2160 ppb	None	632 ppb

* Exceedances are all values greater than caution or warning thresholds. There were no exceedances in 2024
CHV = centrotubular hydropic vacuolation

Tissue sample results remained well below baseline measurements, as well as below caution and warning thresholds. For example, concentrations of mercury in flounder meat and PCBs in lobster meat remained at small fractions of the thresholds (Figure 5-8). Most caution-level exceedances were set at 50% of U.S. Food and Drug Administration action levels for seafood consumption; most warning levels were set at 80% of those standards.

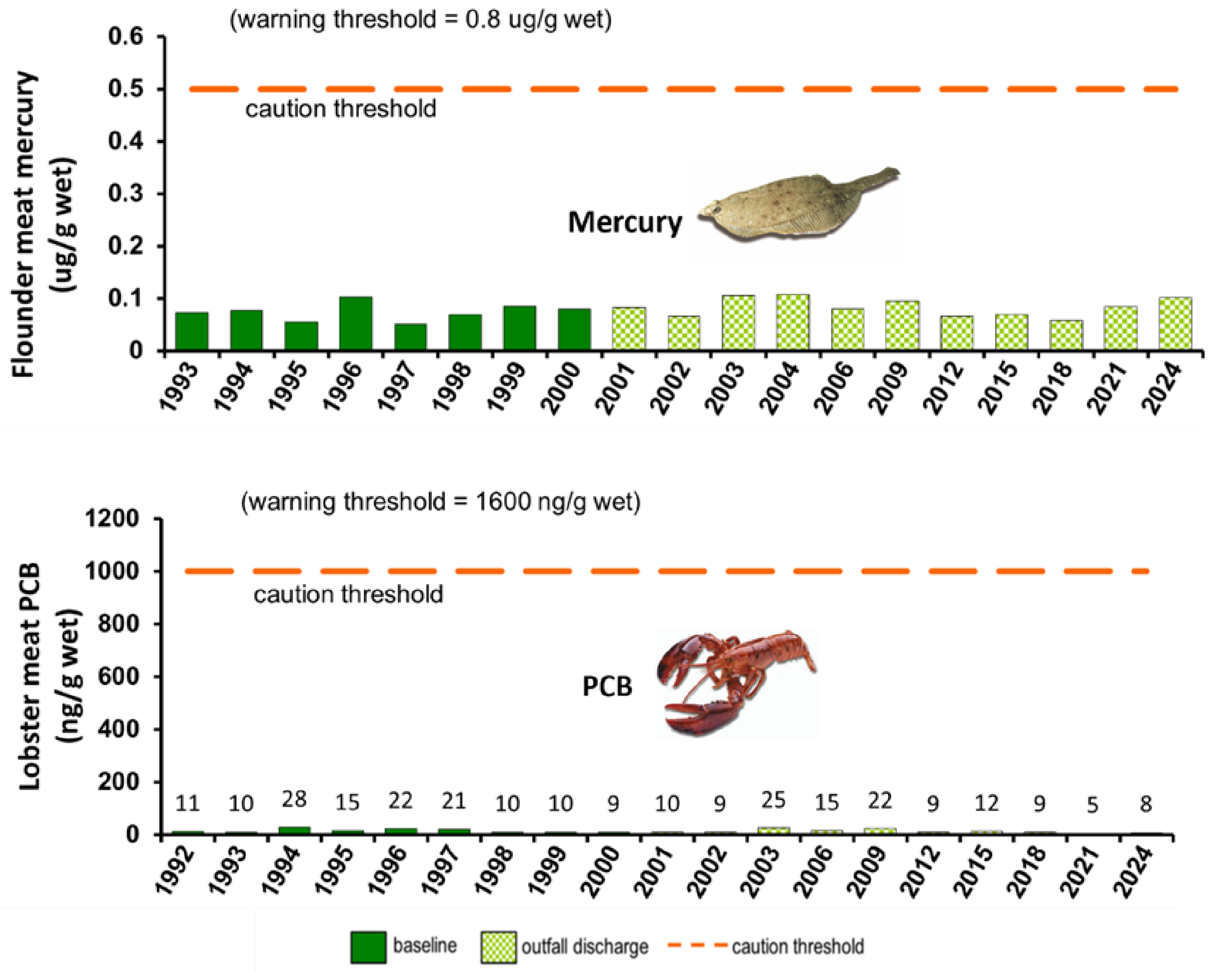


Figure 5-8. Mercury concentrations in flounder and PCBs in lobster meat compared to Contingency Plan thresholds over time. baseline = 1992–2000, when effluent was discharged to Boston Harbor; outfall discharge = years when the discharge was to Massachusetts Bay; ng/g wet = nanograms per gram wet weight. Note that warning thresholds are not shown.

6. Special Topics

In addition to the permit-required monitoring of the effluent and the water column, sea floor, and fish and shellfish in Massachusetts Bay, MWRA also initiates or collaborates on studies of Massachusetts Bay and the wider Gulf of Maine. These studies meet specific permit conditions or better inform interpretations of MWRA monitoring results. This year's report focuses on the three fish-and-shellfish species that have been key to the monitoring program: winter flounder (*Pseudopleuronectes americanus*), American lobster (*Homarus americanus*), and blue mussel (*Mytilus edulis*). It also includes an update on the Bays Eutrophication Model. MWRA's NPDES permit to discharge effluent to Massachusetts Bay requires annual model runs, and this year's report reviews the model run for 2023.

Fish-and-Shellfish Monitoring Species

When MWRA began monitoring in the early 1990s, winter flounder supported a popular recreational and commercial fishery in the region. They lived and fed on the sea floor where they could be exposed to pollutants. Flounder caught in Boston Harbor were known to have a variety of pollutant-related conditions, such as fin erosion and tumors. Lobsters were the region's most valuable fishery and were also bottom-dwellers. Mussels, harvested from relatively pristine areas and deployed in cages, were a frequent biomonitoring tool, as they filter large volumes of suspended material in seawater and can concentrate pollutants in their tissues.

The major concerns for fish-and-shellfish monitoring were that contaminants discharged to Massachusetts Bay would compromise animal health or render them unfit to eat. Some scientists and members of the interested public agreed that ending sludge discharges and moving the effluent outfall farther offshore would improve fish-and-shellfish health in the harbor but were concerned that population sizes in the harbor might decline. They speculated that the high nutrient inputs from sewage supported large, if unhealthy, prey populations. An opinion piece in the New York Times described finding cracks in sewage pipes by following fishing boats (Wald 1987), and unpublished data from MWRA's predecessor agency, the Metropolitan District Commission, suggested that flounder and lobster were more numerous at sites near to their outfalls than farther away.

However, flounder and mussel populations have declined, and there is concern that the lobster population may decrease in the future. The changes are region-wide, so are likely driven by changing environmental conditions, such as the increasing temperature in the Gulf of Maine (Figure 6-1), rather than by changes in sewage inputs. On the other hand, the decades of MWRA monitoring (see Section 5, above) have shown that there has been no adverse effect of the outfall on flounder health, and that instead, fish from both Boston Harbor and Massachusetts Bay are healthier than in the past. There has also been no increase in contaminant levels in any of the three species at any location.

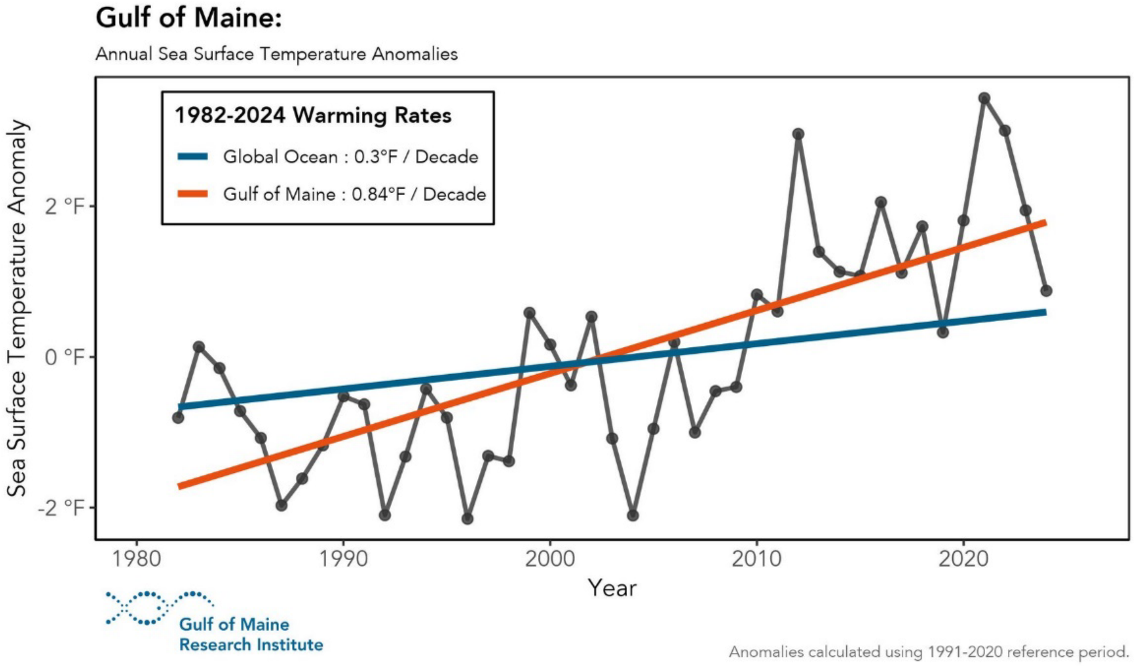


Figure 6-1. The Gulf of Maine has been warming faster than the global ocean. Figure courtesy of the Gulf of Maine Research Institute, Portland, Maine. 2024 Gulf of Maine Warming Update. https://gmri.org/stories/warming-24

Winter Flounder

Prior to the Boston Harbor Project, winter flounder supported popular recreational and commercial fisheries in Boston Harbor and the surrounding region. Tagging studies showed that, while the fish move on- and off-shore, populations north of Cape Cod had very small home ranges (Howe and Coates 1975), making them an ideal tool for comparing the water quality of Boston Harbor, the Massachusetts Bay outfall site, and other nearshore coastal areas.

In the early days of monitoring, flounder were abundant throughout Boston Harbor Massachusetts Bay, and Cape Cod Bay, and the monitoring program easily reached the target catches of 50 fish per location within a prescribed trawling time. In recent years, it has proved more difficult to catch fish, and 2018 was the last year that all 50 fish were taken from each site sampled. In 2023 and 2024, MWRA supplemented samples with fish caught by the Massachusetts Division of Marine Fisheries. Declines in recreational and commercial landings (the number of fish brought to shore and recorded or sold) throughout New England have also made it more difficult to engage the commercial fishing vessels that have been a part of the program.

One reason that sampling has been more difficult is the large amount of entangled lobster traps and other fishing gear resting on the sea floor (Figure 6-2). However, even accounting for entanglements and torn nets due to this "ghost gear," winter flounder landings have been declining throughout southern New England and the Mid-Atlantic since the 1980s. At first, these declines were blamed on overfishing rather than warmer waters or pollution (Frisk et al. 2018). However, subtle changes in temperature regimes may also be a factor (Jeffries and Johnson 1974, Jefferies and Terceiro 1985).

Figure 6-2. Lost lobster traps and other "ghost" fishing gear interfere with flounder collection. Photo credit Michael Moore, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

A recent assessment (Atlantic States Marine Fisheries Commission 2025) showed region-wide declines in commercial and recreational landings across the Gulf of Maine (north of Cape Cod, including Boston Harbor and Massachusetts Bay), Southern New England/Mid-Atlantic, and Georges Bank stocks through 2023 (Figure 6-3). Massachusetts had by far the largest proportion of landings in 2023, making up 97% of the commercial landings and 77% of the reported recreational catch. Commercial and recreational landings peaked in the early 1980s and then declined steadily though the 1990s and 2000s. Declines were partially due to management actions, particularly catch limits, which are designed to decrease landings. The commission has not been able to complete a population-size assessment for fish from the Gulf of Maine stock, which would provide better information than landings data. However, management actions alone could not have caused the large declines in landings, and both commercial fishermen and recreational anglers have noted increased difficulty in locating and catching fish.

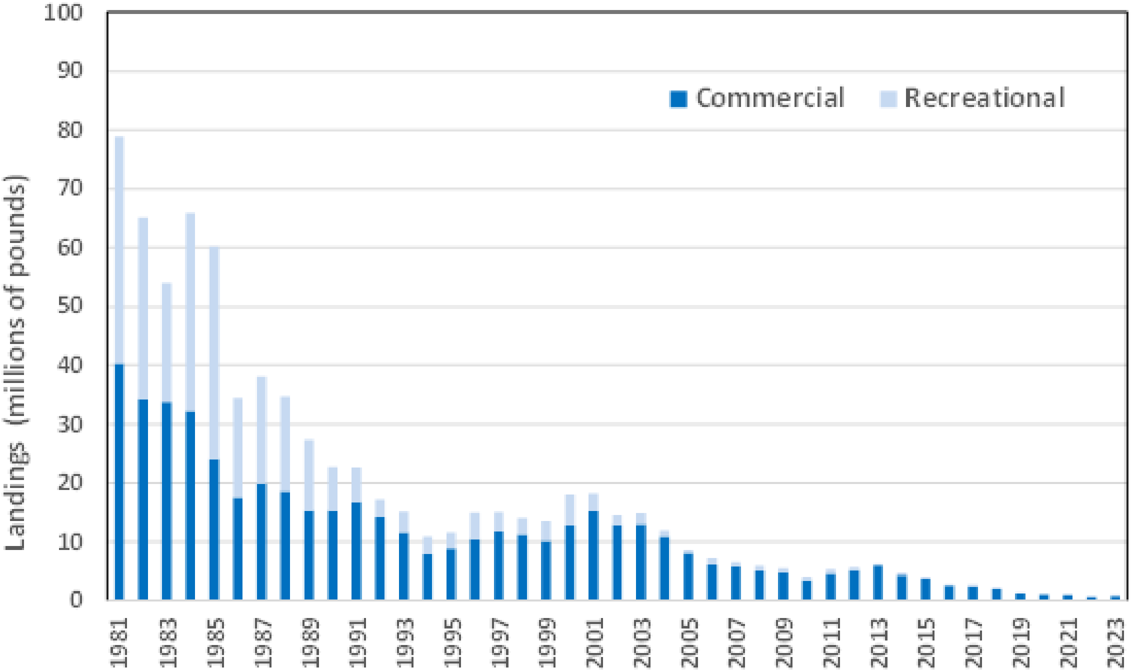


Figure 6-3. Commercial and recreational winter flounder landings throughout its range, 1981–2023. Data compiled by the Atlantic States Marine Fisheries Commission from state compliance reports, the Atlantic Coastal Cooperative Statistics Program, and the Marine Recreational Information Program.

American Lobster

The lobster is the most iconic and valuable of New England seafood. Landings in Massachusetts are second only to Maine, and Boston is considered the major location for processing and shipping lobster to regions outside New England. Some scientists were reluctant to include lobsters as part of the fish-and-shellfish monitoring program, because they move on- and off-shore, and their home ranges are poorly understood. Further, an MWRA review of risks to lobster larvae and juveniles found that dilution and plume dynamics within the water column would protect sensitive life stages from acute or chronic effects (Mitchell et al. 1998). However, lobsters were included in the program in recognition of their importance to the identity and economy of the region.

One complication in assessing lobster catches in Massachusetts is that, for management purposes, catches from north of Cape Cod are included as Gulf of Maine stock, while those south of the Cape are included within the Southern New England stock. The Southern New England population has declined over time, with temperature thought to be the major factor (Le Bris et al. 2018). There are conflicting opinions about current or near-future declines in the Gulf of Maine stock. However, Massachusetts has included all its catches, both north and south of Cape Cod, in new minimum-size rules set forth in guidelines from the Atlantic States marine Fisheries Commission to protect stocks. New Hampshire and Maine have rejected adopting new rules. In its 2024 sampling program, MWRA trapped only 20 lobsters near the Massachusetts Bay outfall, one short of a full complement of 21 lobsters. Full complements were taken near Deer Island and in eastern Cape Cod Bay.

Blue Mussel

MWRA uses cage-deployed blue mussels to assess bioaccumulation of toxic pollutants at sites in Boston Harbor and Massachusetts Bay (Figure 6-4). Mussels harvested from relatively pristine sites are deployed at several sites near the outfall and in Boston Harbor, and MWRA compares pollutant levels in the deployed mussels to levels in a “reference” or “control” group of mussels taken from the same collections but not deployed. In the early days of the monitoring program, natural populations in relatively pristine habitats were widely available for collection and deployment. Over time wild mussel beds declined, and MWRA now purchases mussels for deployment from commercial growers.

Mussel deployments occurred annually from 1991 through 2003 and have continued every three years through 2024 (Figure 6-5). In the first years of monitoring, 1991–1994, all the reference mussels were harvested from Hodkins Cove in Gloucester, Massachusetts. In 1995, concern for possible mercury and lead pollution in Gloucester prompted MWRA to use a second source, in Sandwich, Massachusetts, as the reference site for metals measurements. In 2000, MWRA identified a new source, in Rockport, Massachusetts, in with low levels of metals and organic pollutants, and all collections were made from that site. Over time, the mussel populations decreased in all the previously used sites, and in 2002, the collections moved northeast to Stover’s Point, just northeast of Portland, Maine. In 2012, the collection site was moved further northeast again, to Pemaquid Point, near Boothbay Harbor, Maine.

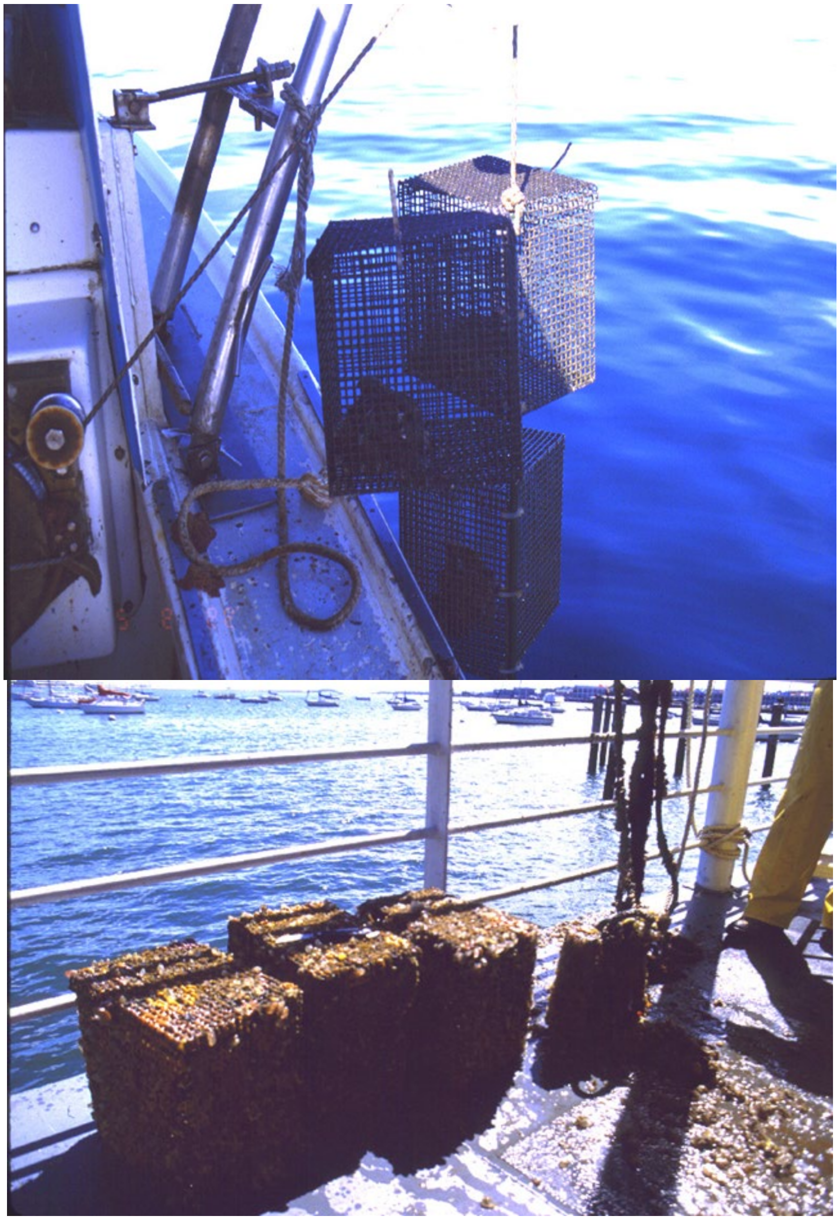


Figure 6-4. Pre- and post-deployment mussel cages. Mussels are collected from relatively pristine sites and deployed for periods of 40 and 60 days. Photo credit Battelle, Norwell, Massachusetts.

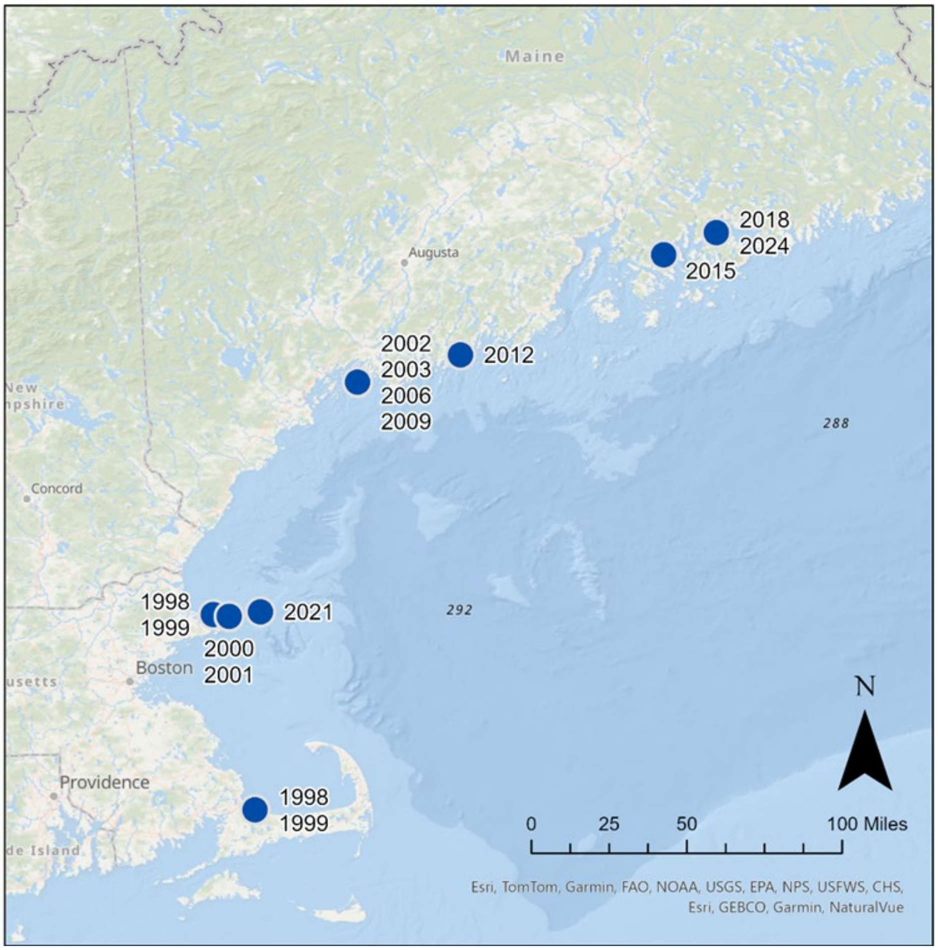


Figure 6-5. Mussel collection sites, 1998–2024. Mussel collection sites have steadily moved to the northeast, with the exception of 2021, when they came from Salem State University’s deepwater Northeastern Massachusetts Aquaculture Center site.

The winter of 2014-2015 began late, but was unusually long and harsh. Boston had almost no snow before January 1, 2015, but quickly exceeded 110 inches for the season, thanks to almost 95 inches in just four storms in January and February. When no wild mussel beds could be found for the 2015 cage deployments, some MWRA team members speculated that the ice that scraped the mussels from intertidal zones that year. Similar ice scouring events have been documented in the Gulf of Maine and in Europe.

The natural mussel beds did not recover, and since then, all mussels used in the monitoring program have been farmed. In 2015, the mussels obtained from Tightrope SeaFarms in Blue Hill Bay, Maine, were cultured on ropes and had thin shells, resulting in great mortality during deployment. In 2021, mussels were obtained from Salem State University’s offshore mussel farm. In 2018 and 2024, MWRA purchased mussels from Hollander and de Koning Mussel Farms beds in Mount Desert Narrows, Frenchman Bay, near Bar Harbor, Maine (Hollander and de Koning, personal communication). The mussels in these beds are grown directly on the sea floor rather than on ropes, and survival rates have been good.

Reasons for the declines in natural mussel beds in the region are not well understood. Predation by non-native green crabs may be one factor. Warming temperatures are almost certainly a factor, as MWRA's mussel sources have moved steadily northward throughout the monitoring period. Warming temperatures may also be leading to blue mussels being found at increasing depths. Once thought of as an intertidal and shallow-water species, they were first detected on an MWRA outfall diffuser head in 2005 and appear to be increasing in numbers both on the diffuser head monitored by MWRA and on nearby large boulders (Figure 6-6; Goode et al. 2024).

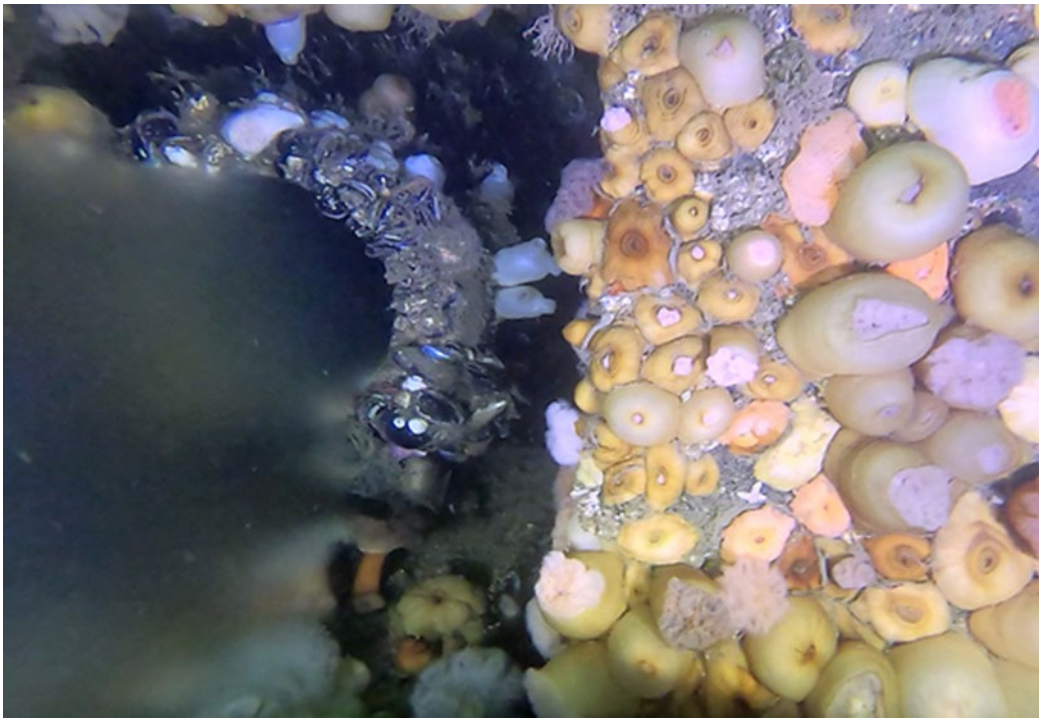


Figure 6-6. Blue mussels and sea anemones growing on an active outfall diffuser in 2023. Photo credit Hecker Environmental, Falmouth, Massachusetts.

All three fish-and-shellfish species monitored by MWRA have provided valuable information, confirming predictions that the Massachusetts Bay discharge would not impair fish health or render fish and shellfish unfit for consumption. However, regional environmental changes may affect the species now or in the future. MWRA's long-term monitoring and studies by other agencies and scientists have documented increased temperatures and salinities and decreased dissolved oxygen concentrations over time (Codiga et al. 2025). Ongoing changes in physical conditions can be expected to continue to affect the region's biological populations and communities.

Bays Eutrophication Model Update

The Deer Island NPDES permit to discharge treated wastewater effluent to Massachusetts Bay requires MWRA to maintain and annually run the Bays Eutrophication Model. This combined circulation and water-quality model simulates the parameters and processes that could lead to eutrophication and subsequent low dissolved oxygen levels in Massachusetts Bay, Boston Harbor, and Cape Cod Bay. Parameters include water temperature, salinity, circulation, nutrient concentrations, and phytoplankton biomass. Annual model runs complement MWRA's monitoring program. Annual simulations have continually confirmed the early predictions that nutrient inputs from the outfall will not lead to eutrophication.

The most recent model simulation, for the year 2023, successfully reproduced many, but not all, of the seasonal and geographic patterns measured during the shipboard surveys (Deltares 2025). The model simulation successfully captured a stratification peak during July and August, which was consistent with observed conditions. The model also continued to show a signature of the effluent discharge, including an expected decrease in total dissolved inorganic nitrogen concentrations with increased distance from the outfall.

Modeled chlorophyll concentrations continued to support the conclusion that the discharge does not significantly influence nearshore phytoplankton biomass. However, the model was unable to replicate the unusual regional bloom of the dinoflagellate *Tripos muelleri*, which occurred across the Gulf of Maine from April through July 2023. The model does not simulate individual species and therefore predicted a more typical spring and summer pattern for generic dinoflagellates. Consequently, the model simulation underestimated actual chlorophyll and particulate organic carbon concentrations during the bloom period.

The model captured the overall seasonal pattern of dissolved oxygen for 2023, with higher concentrations in winter and declines through summer and fall. However, it overestimated bottom water dissolved oxygen concentrations during summer and fall, especially at stations where observed levels dropped below historic lows. This overprediction is consistent with past model runs and may have been affected by underestimation of oxygen consumption and failure to capture the effects of decay of *Tripos muelleri* at the end of the bloom.

Overall, the 2023 model run continued to confirm that nutrient inputs from the outfall did not cause eutrophication in Massachusetts Bay.

References

Atlantic States Marine Fisheries Commission. 2025. Review of the interstate management plan for winter flounder (*Pseudopleuronectes americanus*), 2023 fishing year. Prepared by the Plan Review Team, approved April 2025. 23 p.

Cibik SJ, Lemieux KB, Davis CS, Anderson DM. 1998. Massachusetts Bay plankton communities: characterization and discussion of issues relative to MWRA's outfall relocation. Boston: Massachusetts Water Resources Authority. Report 1998-08. 140 p.

Codiga DL, Keay KE, Libby PS. 2025. Thirty-one years of warming and oxygen decline in Massachusetts Bay, a well-flushed non-eutrophic temperate coastal waterbody. Journal of Geophysical Research: Oceans, 130, e2024JC021589.

Davis S, Hunt C, Wladkowski J. 2025. 2024 technical survey of nitrogen removal alternatives for the Deer Island Treatment Plant. Boston: Massachusetts Water Resources Authority. Report 2025-04. 58 p.

Deltares. 2022. Massachusetts Bay outfall treated effluent discharge plume characteristics from the EPA-supported near-field mixing model. Boston: Massachusetts Water Resources Authority. Report 2022-03. 24 p.

Deltares. 2024. Simulations of 2023 hydrodynamics and water quality in the Massachusetts Bay system using the Bays Eutrophication Model. Boston: Massachusetts Water Resources Authority. Report 2025-03. 81 p.

Frisk MG, Dolan TE, McElroy AE, Zacharias JP, Xu H, Hice LA. 2018. Assessing the drivers of the collapse of winter flounder: implications of management and recovery. Journal of Sea Research 141:1–13.

Goode KL, Hecker B, Madray ME, Rutecki DA. 2024, 2023 outfall benthic monitoring results. Boston: Massachusetts Water Resources Authority. Report 2024-08. 50 p.

Howe AB, Coates PG. 1975. Winter flounder movements, growth, and mortality off Massachusetts. Transactions of the American Fisheries Society 104:13–29.

Jeffries HP, Johnson WC. 1974 Seasonal distributions in the bottom fishes of the Narragansett Bay area: seven-year variations in the abundances of winter flounder (*Pseudopleuronectes americanus*) Journal of the Fisheries Research Board of Canada 31:1057–1066

Jeffries HP, Terceiro M. 1985. Cycle of changing abundances in the fishes of the Narragansett Bay area. Marine Ecology Progress Series 25:239–244.

Kropp RK, Diaz RJ, Hecker B, Dahlen D, Boyle, JD, Keay KE, Hunt CD. 2000. 1999 outfall benthic report. Boston: Massachusetts Water Resources Authority. Report 2000-15.

Le Bris A, Mills KE, Wahle RA, Pershing AJ. 2018. Climate vulnerability and resilience in the most valuable North American fishery. Proceedings of the National Academy of Sciences. 115:1831–1836.

Libby PS, Rex AC, Keay KE, Mickelson MJ. 2013. *Alexandrium* Rapid Response Study survey plan. Revision 1. Boston: Massachusetts Water Resources Authority. Report 2013-06. 13 p.

Libby PS, Borkman DG, Geyer WR, Turner JT, Costa AS, Goodwin C, Wang J. 2025. 2024 water column monitoring results. Boston: Massachusetts Water Resources Authority. Report 2025-DRAFT.

Madray ME, Diaz RJ, Rutecki DA. 2025. 2024 Boston Harbor benthic monitoring report. Massachusetts Water Resources Authority. Report 2025-DRAFT. .

MWRA. 2001. Massachusetts Water Resources Authority Contingency Plan, Revision 1. Boston: Massachusetts Water Resources Authority. Report 2001-ms-71. 47 p.

MWRA. 2021. Ambient monitoring plan for the Massachusetts Water Resources Authority effluent outfall, Revision 2.1, August 2021. Boston: Massachusetts Water Resources Authority. Report 2021-08. 107 p.

Mitchell DF, Maciolek NJ, Hopkins KM, Wandland KD. 1998. Massachusetts Bay monitoring program toxics issue report on biology of the lobster in Massachusetts Bay. Boston: Massachusetts Water Resources Authority. Report 1998-13. 83 p.

Moore MJ, McElroy AE, Geoghegan P, Siskey MR, Pembroke A. 2016. Flounder monitoring report: 2015 results. Boston: Massachusetts Water Resources Authority. Report 2016-05. 40 p.

Moore, M, Pembroke A, Nestler E, Hall M, Lefkovitz L, Lambert M, Keay K. 2018. Toxics source reduction and sewage upgrades eliminated winter flounder liver neoplasia (1984–2017) from Boston Harbor, MA, USA. Diseases of Aquatic Organisms. 131:239-24.

Moore MJ, Madray ME, Rutecki DA. 2024. Flounder monitoring report: 2024 results. Boston: Massachusetts Water Resources Authority. Report 2024-13. 22 p.

Nestler E, Goode K, Madray ME. 2025. 2024 outfall benthic monitoring results. Boston: Massachusetts Water Resources Authority. Report 2025-DRAFT.

NOAA Office of National Marine Sanctuaries. 2020. 2020 condition report: findings of status and trends for 2007–2018. Silver Spring, MD. 263 p.

NOAA Office of National Marine Sanctuaries. 2023. Stellwagen Bank National Marine Sanctuary Final management plan and environmental assessment. Silver Spring, MD. 216 p.

Taylor DI, Oviatt CA, Giblin AE, Tucker J, Diaz RJ, Keay K. 2020. Wastewater input reductions reverse historic hypereutrophication of Boston Harbor, USA. Ambio 49:187–196.

Tucker J, Kelsey S, and Giblin A. 2010. 2009 Benthic nutrient flux annual report. Boston: Massachusetts Water Resources Authority. Report 2010-10. 27 p.

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

Wald ML. 1987 On the verge of a cleanup, Boston takes a close look at harbor, sludge and all. New York Times, January 4, 1987.

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

Werme C, Keay KE, Libby PS, Codiga DL, Taylor DI, Charlestra L, Carroll SR. 2018. 2017 outfall monitoring overview. Boston: Massachusetts Water Resources Authority Report 2018-07. 53 p.

Werme C, Codiga D, Libby PS, Carroll SR. 2021. 2020 Outfall monitoring overview. Boston: Massachusetts Water Resources Authority Report 2021-10. 55 p.

List of Acronyms

ASP	Amnesic shellfish poisoning
BOD	Biochemical oxygen demand
cBOD	Carbonaceous biochemical oxygen demand
cells/L	Cells per liter
cfu	Colony forming units
CHV	Centrotubular hydropic vacuolation
DDT	Dichlorodiphenyltrichloroethane
DIF	Deer Island Flats
DO	Dissolved oxygen
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
kg/m^3	Kilograms per cubic meter
LC50	50% mortality concentration
LNB	Large navigation buoy
m	Meters
m^3/s	Cubic meters per second
mg/L	Milligrams per liter
mg/L/d	Milligrams per liter per day
mg/m^2	Milligrams per square meter
mg/m^3	Milligrams per cubic meter
mL	Milliliters
MGD	Million gallons per day
mtons	Metric tons
MWRA	Massachusetts Water Resources Authority
µg/L	Micrograms per liter
µm	Micrometer
µM	Micromoles
ng/g wet	Nanograms per gram wet weight
NA	Not analyzed/not applicable
NDBC	National Data Buoy Center
NERACOOS	Northeastern Regional Association of Coastal and Ocean Observing Systems
ng/L	Nanograms per liter
NOAA	National Oceanic and Atmospheric Administration
NOEC	No observed effects concentration
NPDES	National Pollutant Discharge Elimination System
OS	Outfall site
Pa	Pascal
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PSP	Paralytic shellfish poisoning
PSU	Practical salinity units
TN	Total nitrogen
TSS	Total suspended solids

Massachusetts Water Resources Authority
Deer Island
33 Tafts Avenue • Boston, MA 02128
617-242-6000