2012
Outfall Monitoring Overview

Massachusetts Water Resources Authority

Environmental Quality Department
Report 2013-14

Citation:
Werme C, Keay KE, Hall MP, Leo WS, Mickelson MJ, Taylor DI, Rex AC, Libby, PS. 2013. **2012 outfall monitoring overview**. Boston: Massachusetts Water Resources Authority. Report 2013-14. 68 p.

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Outfall Monitoring Overview

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October 10, 2013

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Summary

Each year, the Massachusetts Water Resources Authority (MWRA) prepares this report, an overview of environmental monitoring related to the discharge of municipal effluent from the Deer Island Treatment Plant through its Massachusetts Bay outfall. The report presents monitoring results and information relevant to the MWRA's permit-required Contingency Plan, including threshold exceedances and permit violations, responses, and corrective actions. The overview also includes monitoring results relevant to the Stellwagen Bank National Marine Sanctuary and information on special studies.

The 2012 report marks the twenty-first year of MWRA's monitoring program, including almost nine years of baseline monitoring and more than twelve years of "outfall-discharge" monitoring, covering the years since MWRA ceased discharge of sewage effluent to the relatively confined waters of Boston Harbor and began to discharge into deeper water in Massachusetts Bay. The monitoring program reports on results from effluent, water-column, sea-floor, and fish-and-shellfish monitoring in the outfall nearfield and at reference stations and on results from special studies.

Operations at the Deer Island Treatment Plant continued to be exceptional in 2012, earning MWRA a second consecutive National Association of Clean Water Agencies (NACWA) Platinum Peak Performance Award. This NACWA award recognizes facilities with 100% permit compliance for five consecutive years.

Ambient monitoring results from 2012 were consistent with predictions and past results. There were exceedances of Contingency Plan "caution level" thresholds[1] (Tables i through iv) for presence of *Phaeocystis pouchetii*, a nuisance algal species that is poor food for zooplankton; *Alexandrium fundyense*, a nuisance algal species that can cause paralytic shellfish poisoning; and for two soft-bottom benthic community parameters, Shannon-Wiener diversity and Pielou's evenness. No "warning level" exceedances were observed in 2012

These exceedances have been reviewed for evidence of whether they were or were not caused or exacerbated by the outfall discharge. Blooms of *Phaeocystis pouchetii* are greatly influenced by temperature patterns and have not been found to be influenced by the outfall. Presence and abundance of *Alexandrium fundyense* is controlled by the presence and extent of seed beds to the northeast of Massachusetts Bay and on

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[1] MWRA's NPDES permit includes Contingency Plan threshold indicators that may indicate a need for action. The thresholds are based on permit limits, state water quality standards, and expert judgment. "Caution level" thresholds generally indicate a need for a closer look at the data to determine the reason for an observed change. "Warning level" thresholds are a higher level of concern, and the permit requires a series of steps to evaluate whether adverse impacts occurred and if so, whether they were related to the discharge. If caused by the discharge, MWRA may need to implement corrective action. Thresholds based on effluent discharge permit limits are only "warning level." Some ambient parameters have both "caution" and "warning" level thresholds, and others have only "caution level" thresholds.

temperature, wind, and current patterns in the spring. The pattern of *Alexandrium* abundance in 2012 was unusual. In 2012 highest cell abundances were observed in Boston Harbor, the western portions of the nearfield, and along the Boston south shore, while counts in northern Massachusetts Bay were consistently much lower (i.e. the bloom did not begin in the north and move south as previous blooms have). Evaluation of the 2012 *Alexandrium* bloom found no evidence effluent nutrients played a major role, and indicates the unusual pattern may have resulted from the mild wind and weak currents that occurred during the bloom. However, the available data do not allow conclusions to be drawn as to the causes of the bloom. The exceedances in the benthic community parameter thresholds, which occurred for a third consecutive year, were indications of a somewhat more diverse community, resulting from normal cycles of relative abundance in the animal populations. Increased diversity is not considered to be environmentally adverse, and the changes are not thought to be related to the outfall.

Table i. Effluent Contingency Plan thresholds and exceedances. ✓ = no exceedance, NA = not applicable, W = warning level exceedance

Effluent Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
pH	W	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fecal coliform bacteria, monthly	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fecal coliform bacteria, weekly	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fecal coliform bacteria, daily	✓	W	✓	✓	W	✓	✓	✓	✓	✓	✓	✓	✓
Fecal coliform bacteria, 3 consecutive days	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Chlorine residual, daily	W	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Chlorine residual, monthly	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total suspended solids, weekly	✓	✓	W	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total suspended solids, monthly	✓	✓	W	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
cBOD, weekly	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
cBOD, monthly	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Acute toxicity, mysid shrimp	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Acute toxicity, fish	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Chronic toxicity, fish	✓	W	✓	✓	✓	✓	W	✓	✓	✓	✓	✓	✓
Chronic toxicity, sea urchin	✓	W	✓	✓	✓	W	✓	✓	✓	✓	✓	✓	✓
PCBs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Plant performance	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Flow	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Total nitrogen load	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Floatables	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Oil and grease	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table ii. Water column Contingency Plan thresholds and exceedances. ✓ = no exceedance, NA = not applicable, C = caution level exceedance

Water Column Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Nearfield bottom water													
Dissolved oxygen concentration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dissolved oxygen saturation	C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dissolved oxygen depletion rate	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Stellwagen Basin bottom water													
Dissolved oxygen concentration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dissolved oxygen saturation	C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nearfield chlorophyll													
Annual	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Winter/spring	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Summer	NA	✓	✓	✓	✓	✓	C	✓	✓	✓	✓	✓	✓
Autumn	C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nearfield nuisance algae *Phaeocystis pouchetii*													
Winter/spring	NA	✓	✓	✓	C	✓	✓	C	✓	✓	✓	✓	✓
Summer	NA	✓	C	C	C	C	C	✓	✓	✓	✓	✓	C
Autumn	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nearfield nuisance algae *Pseudonitzchia*													
Winter/spring	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Summer	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Autumn	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nearfield nuisance algae *Alexandrium*													
Any sample	✓	✓	✓	✓	✓	C	C	✓	C	C	✓	C	C
Farfield shellfish													
PSP toxin extent	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Plume													
Initial dilution	NA	✓	Complete										

Table iii. Sea floor Contingency Plan thresholds and exceedances. ✓ = no exceedance, NA = not applicable, C = caution level exceedance

Sea Floor Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Nearfield sediment													
Acenaphthene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Acenaphylene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Anthracene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Benzo(a)anthracene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Benzo(a)pyrene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Cadmium	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Chromium	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Chrysene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Copper	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Dibenzo(a,h)anthracene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Fluoranthene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Fluorene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Lead	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Mercury	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Naphthalene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Nickel	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
p,p'-DDE	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Phenanthrene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Pyrene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Silver	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Total DDTs	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Total HMW PAH	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Total LMW PAH	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Total PAHs	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Total PCBs	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Zinc	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓	NA
Sediment RPD depth	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nearfield soft-bottom benthic diversity													
Species per sample	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fisher's log-series alpha	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Shannon diversity	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	C	C	C
Pielou's evenness	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	C	C	C
Nearfield soft-bottom species composition													
Percent opportunists	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table iv. Fish and shellfish Contingency Plan thresholds and exceedances. ✓ = no exceedance, NA = not applicable, C = caution level exceedance

Fish and Shellfish	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Nearfield flounder tissue													
Total PCBs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Mercury	NA	✓	✓	✓	✓	NA	✓	NA	NA	✓	NA	NA	✓
Chlordane	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Dieldrin	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Total DDTs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Nearfield flounder disease													
Liver disease (CHV)	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nearfield lobster tissue													
Total PCBs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Mercury	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Chlordane	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Dieldrin	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Total DDTs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Nearfield mussel tissue													
Total PCBs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Lead	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Mercury	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Chlordane	NA	C	C	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Dieldrin	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Total DDTs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Total PAHs	NA	C	C	C	NA	NA	✓	NA	NA	✓	NA	NA	✓

1. Introduction

Since its creation by the Massachusetts state legislature in 1984, the Massachusetts Water Resources Authority (MWRA) has worked to minimize the effects of wastewater discharge on the marine environment. The mission of what became known as MWRA's Boston Harbor Project included reducing inflow of contaminants into the waste stream, ending biosolids discharge, improving wastewater treatment facilities, and providing better dilution of the sewage effluent discharge. Throughout MWRA's early years, scientists conducted environmental monitoring in Boston Harbor and also in Massachusetts Bay, at the (then future) location of a relocated sewage effluent discharge.

In 2000, most of the Boston Harbor Project had been completed, including the relocated effluent outfall, which diverted sewage effluent from Boston Harbor to the deeper, less confined waters of Massachusetts Bay. The outfall operates under a National Pollutant Discharge Elimination System (NPDES) permit for the Deer Island Treatment Plant (DITP) constructed as part of Boston Harbor Project. The permit was issued jointly by the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MADEP).

The NPDES permit includes requirements for ongoing monitoring of the sewage effluent and for ambient monitoring of the receiving waters. Monitoring assesses compliance with specific permit conditions and additional conditions specified by a permit-required Contingency Plan. Background information on the monitoring program can be found in Werme et al. (2012), an updated document that describes monitoring revisions implemented in 2011. The background document, monitoring plans (MWRA 1991, 1997a, 2004, 2010), the Contingency Plan (MWRA 1997b, 2001), and area-specific technical reports are available on the technical report list at MWRA's website, http://www.mwra.state.ma.us/harbor/enquad/trlist.html.

Results from most baseline years and for each year since the outfall began to discharge have been documented in reports such as this one, the annual outfall monitoring overview. Since the Massachusetts Bay outfall came on line in 2000, the reports have included information relevant to permit requirements, including Contingency Plan threshold exceedances, responses, and corrective actions. Reports also include information relevant to the Stellwagen Bank National Marine Sanctuary.

This year's outfall monitoring overview presents results for 2012, marking the twenty-first year of MWRA's monitoring program, including more than twelve years of outfall-discharge monitoring. Measurements include effluent, water-column, sea-floor, and fish-and-shellfish parameters, as well as special studies conducted in response to permit conditions and environmental concerns. Data specifically related to the Stellwagen Bank National Marine Sanctuary are included in the overview's water-column and sea-floor sections.

2. Effluent

2012 Characterization

As in past years, DITP continued to operate as designed through 2012, earning MWRA the National Association of Clean Water Agencies (NACWA) Platinum Peak Performance Award for a second consecutive year. The Platinum Award is NACWA's highest award recognizing compliance with NPDES permit limits and is reserved for facilities that have had no permit violations for five consecutive years.

It was a relatively dry year in the Boston area in comparison to other years since the outfall came on line in 2000, with precipitation about 20% below the long-term average (Figure 2-1). Total effluent flow was lower in 2012 than in any year since the outfall came on line, and virtually all the flow, 99.6%, received full primary and secondary treatment (Figure 2-2). There were no extreme or protracted storms, and consequently, storm-related discharges of primary-only effluent blended with effluent receiving full secondary treatment were relatively small and brief (Figure 2-3).

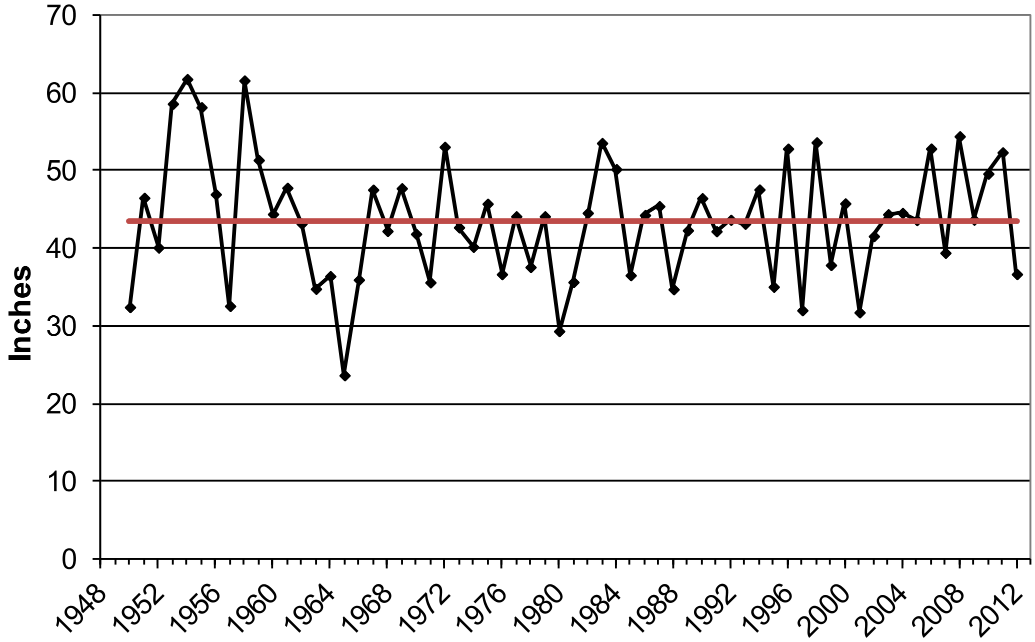


Figure 2-1. Annual rainfall in Boston in 1950–2012 (black line) and mean (red line) for the period. Rainfall in 2012 was about 20% below the long-term average (red line).

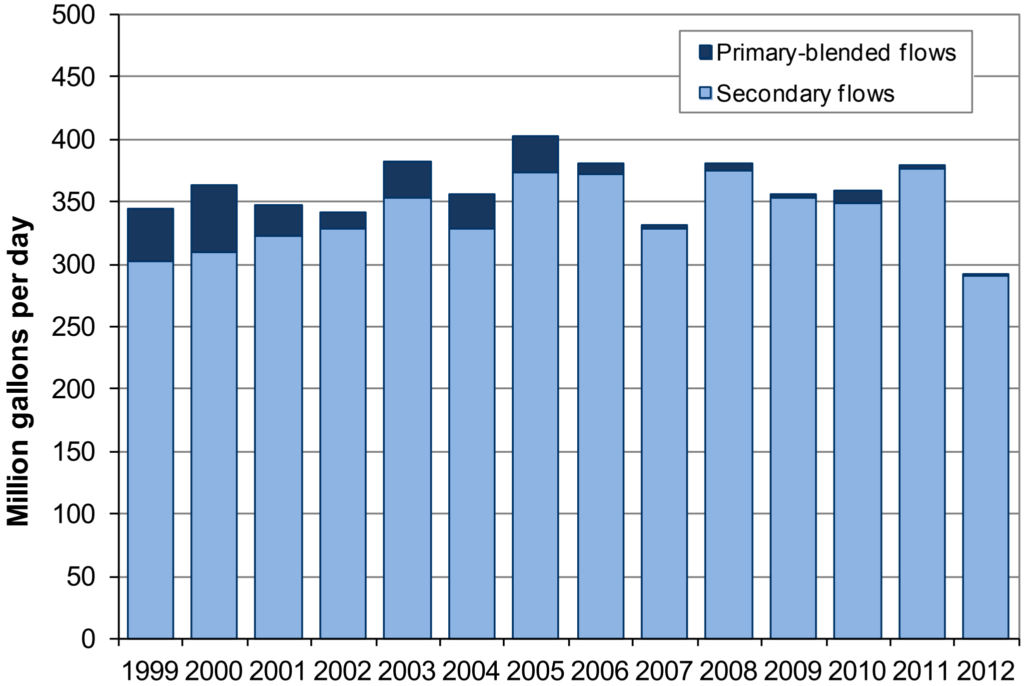


Figure 2-2. Annual primary-blended and full secondary effluent flows. In 2012, 99.6% of effluent flow received full secondary treatment. (During large storms, flow exceeding the secondary capacity of the plant is diverted around the secondary process to prevent washing out the essential microbes that carry out secondary treatment. These diverted flows are combined with full-secondary flows before disinfection; all discharges meet permit limits.)

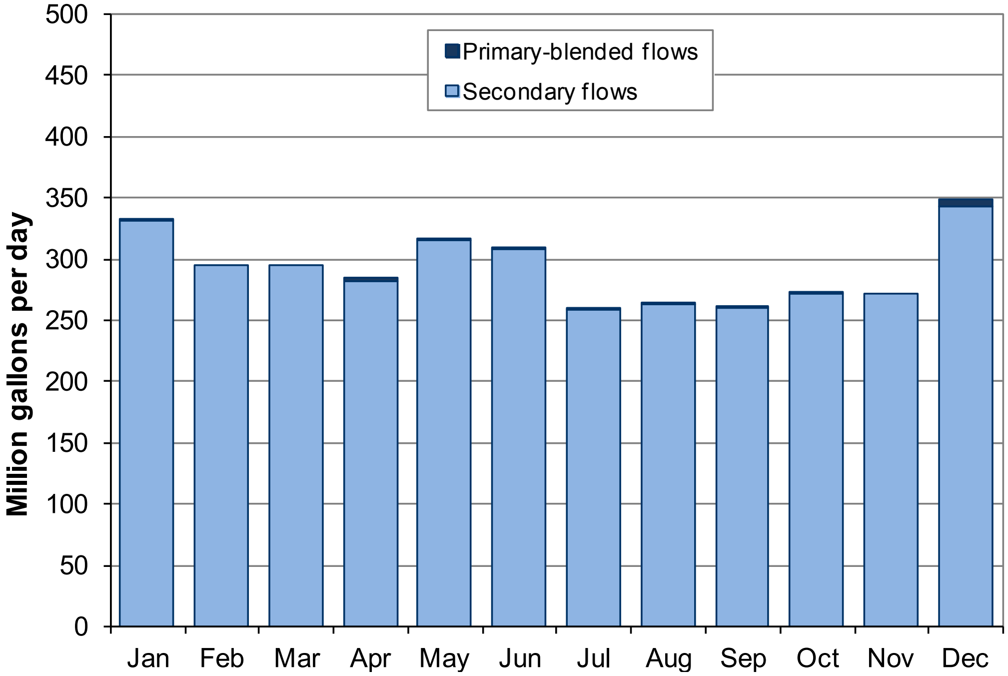


Figure 2-3. Monthly primary-blended and full secondary effluent flows during 2012. Total flow was below average (about 350 million gallons per day) in every month throughout 2012, and there were only small amounts of primary-blended flow.

The total suspended solids load to Massachusetts Bay was just less than 10 tons per day, the lowest level recorded (Figure 2-4). Carbonaceous biochemical oxygen demand (BOD) was also at a record low in 2012, remaining well below levels that might be expected to affect ambient waters at the discharge site (Figure 2-5). Nitrogenous BOD (also shown in Figure 2-5), which is a result of the biological processes in secondary treatment and not a permit limit or Contingency Plan parameter, was lower than any level measured since 2001.

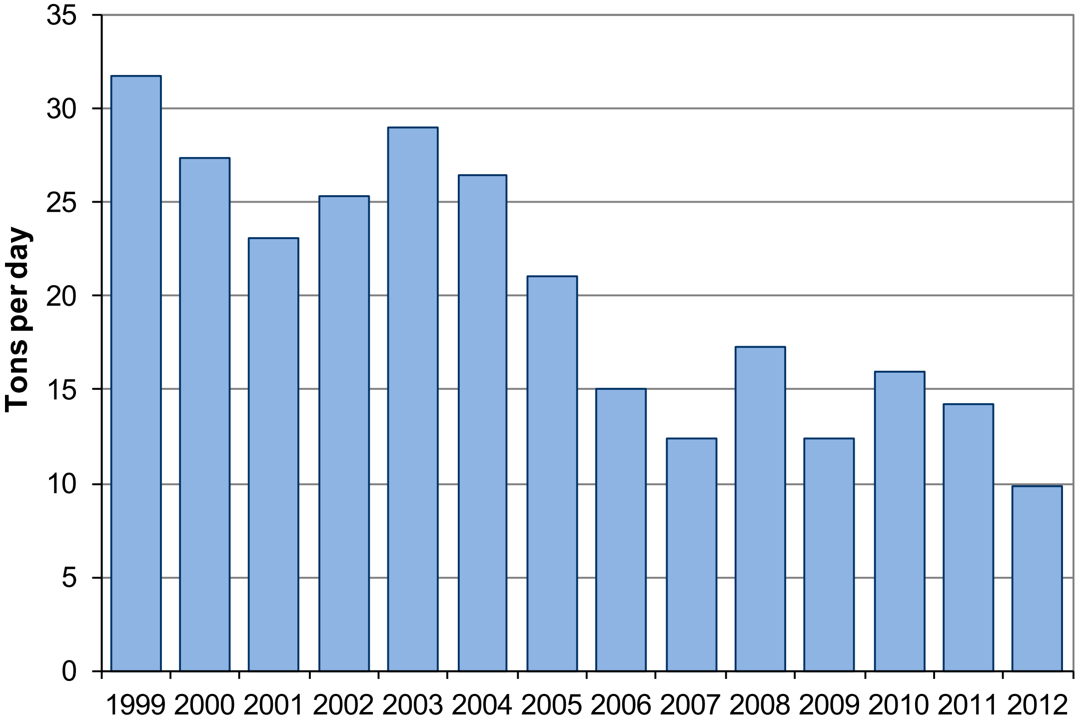


Figure 2-4. Annual solids discharges. Solids discharges reached a record low in 2012.

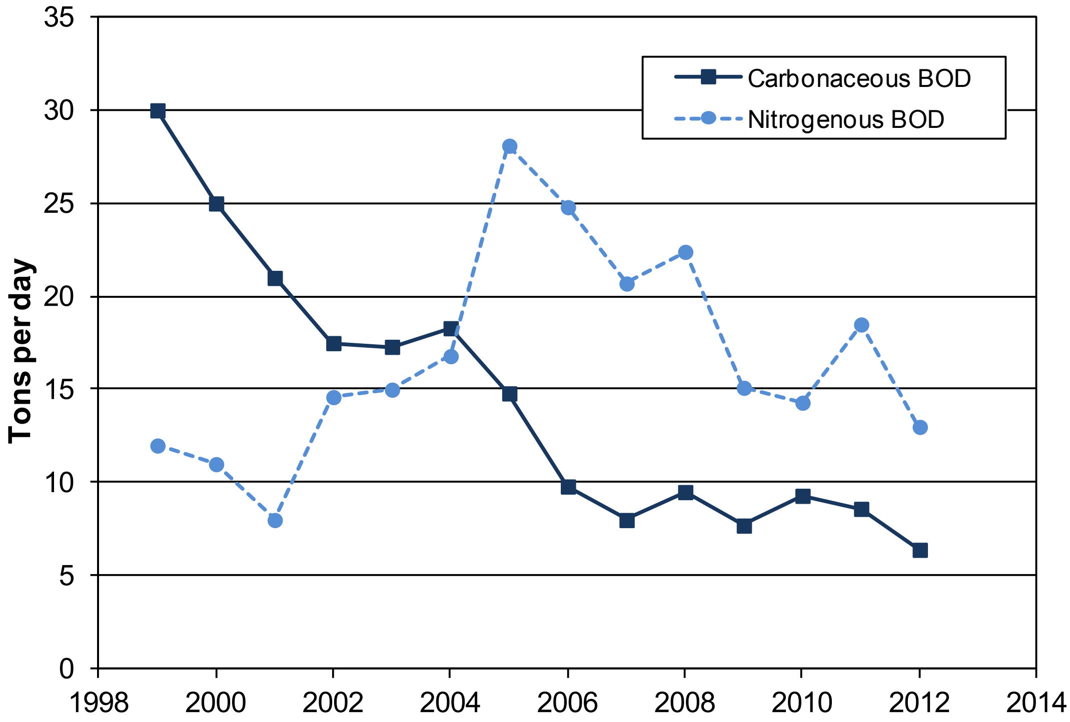


Figure 2-5. Annual biochemical oxygen demand (BOD). MWRA's permit limits carbonaceous BOD, which reached a record low in 2012. Nitrogenous BOD is the result of microbiological breakdown that occurs during secondary treatment and is not regulated by the permit.

Total nitrogen loads were also lower in 2012, remaining below the permit limits (Figure 2-6). The portion of the load made up of ammonium increased slightly. About 10% of the ammonium in the sewage influent is removed by secondary treatment, but the biological treatment process converts some organic forms of nitrogen to ammonium. Also, ammonium-rich liquids from the biosolids pelletizing (fertilizer) plant, built as part of the Boston Harbor Project, are reintroduced to DITP for treatment, adding to the ammonium load. As required by its permit, MWRA continually evaluates nitrogen-removal technologies, so that it could be quickly implemented, should a need arise (Bigornia-Vitale and Wu 2012). Because nitrogen loads have remained below the Contingency Plan caution threshold, and there have not been nitrogen-related adverse environmental impacts, nitrogen removal has not been required or implemented.

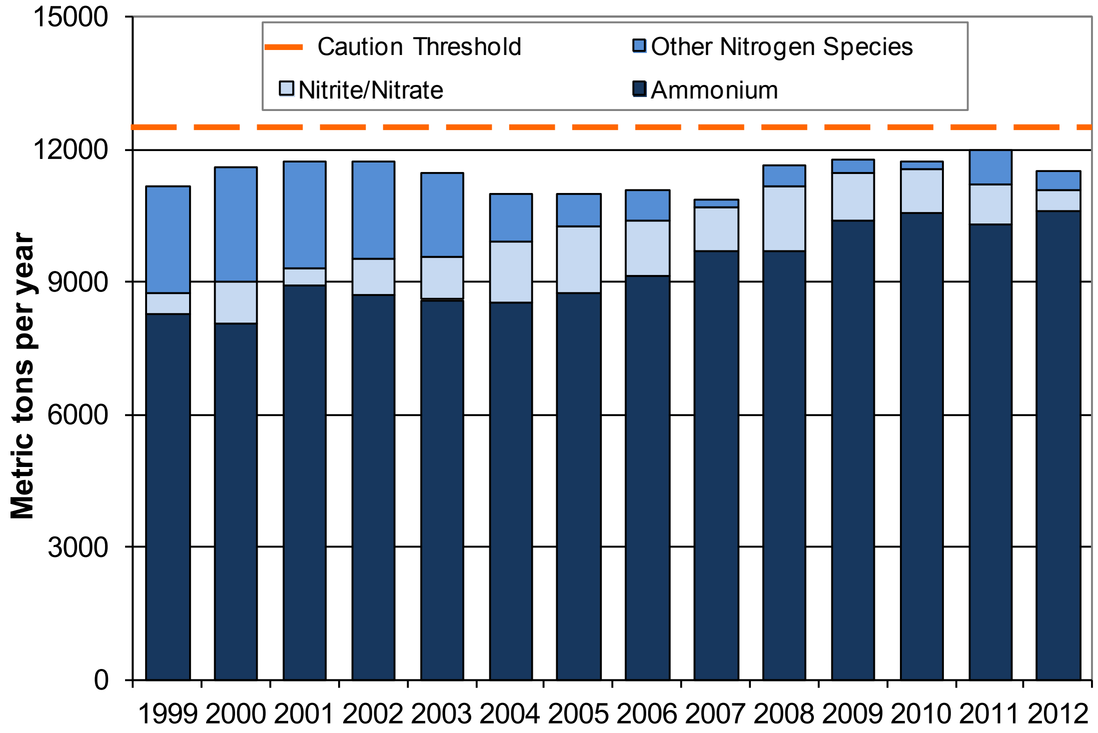


Figure 2-6. Annual nitrogen discharges. Most of the nitrogen in the effluent is in the form of ammonium.

Metals loads also decreased to record low levels in 2012 (Figure 2-7). Metals discharges are now only a small fraction of what they were before the Boston Harbor Project, when more than seven hundred fifty pounds of metals were discharged to Boston Harbor each day. Most metals meet water quality criteria in the effluent itself, while copper meets the criteria after initial dilution at the Massachusetts Bay outfall.

Mercury loads were also low (Figure 2-8). Although sensitive methods have been adopted for mercury analysis, mercury is now only rarely detected in effluent samples, the consequence of efforts on the part of MWRA and the New England states and New York to reduce mercury use, handle workplace spills, and discourage disposal practices that introduce mercury into the sewer system. Most mercury entering New England waters is from atmospheric deposition.

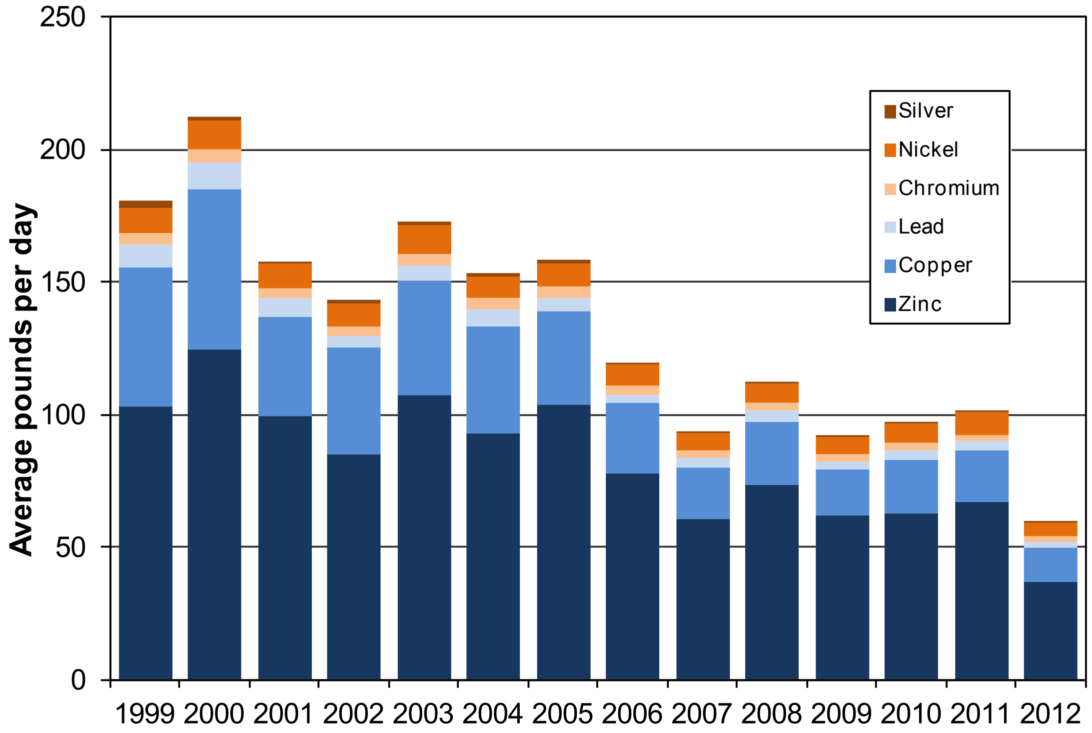


Figure 2-7. Annual metals discharges. Except for copper, the metals meet receiving water quality criteria in the effluent, even without the dilution provided by the outfall.

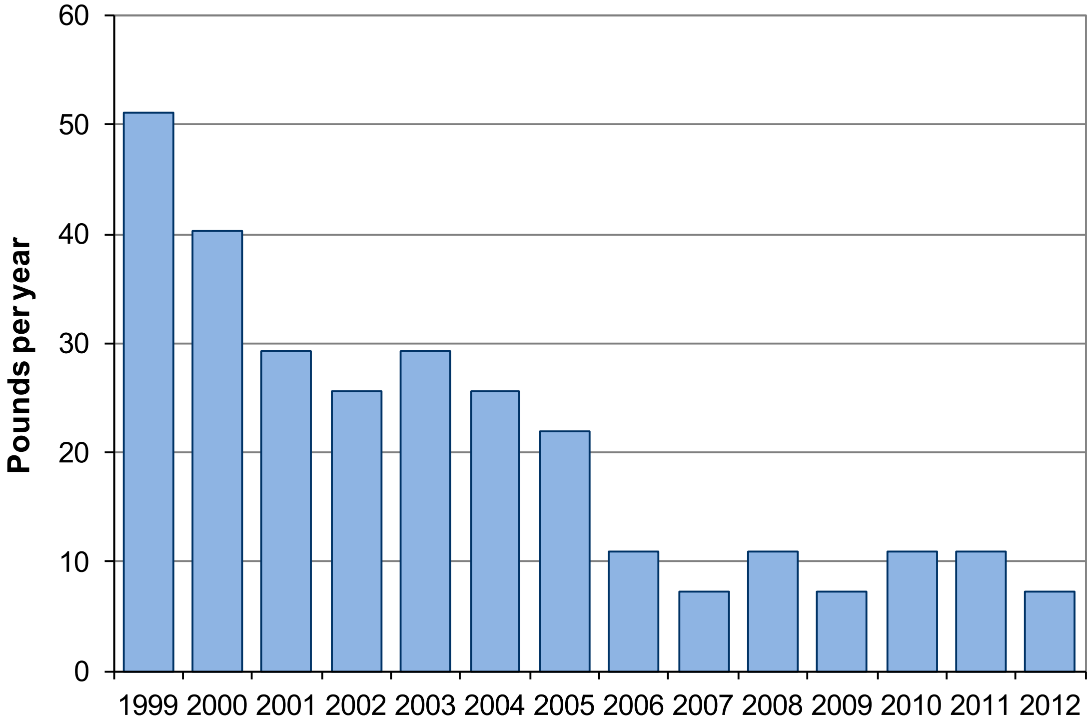


Figure 2-8. Annual mercury discharges. Mercury is only rarely detected in the effluent, and fewer than ten pounds were discharged in 2012. (Note that prior years' outfall monitoring overviews reported loads in pounds per day.)

Polychlorinated biphenyl (PCB) and pesticide loads also decreased in 2012 and were similar to loads discharged in 2007 and 2009 (Figure 2-9). About two pounds of PCBs and two pounds of pesticides were discharged. All contaminant loads remained well below those that had been anticipated during the planning process for the relocated outfall. Those predictions had been that more than 10 pounds of the pesticide DDT and its breakdown products and more than 100 pounds of PCBs would be discharged each year.

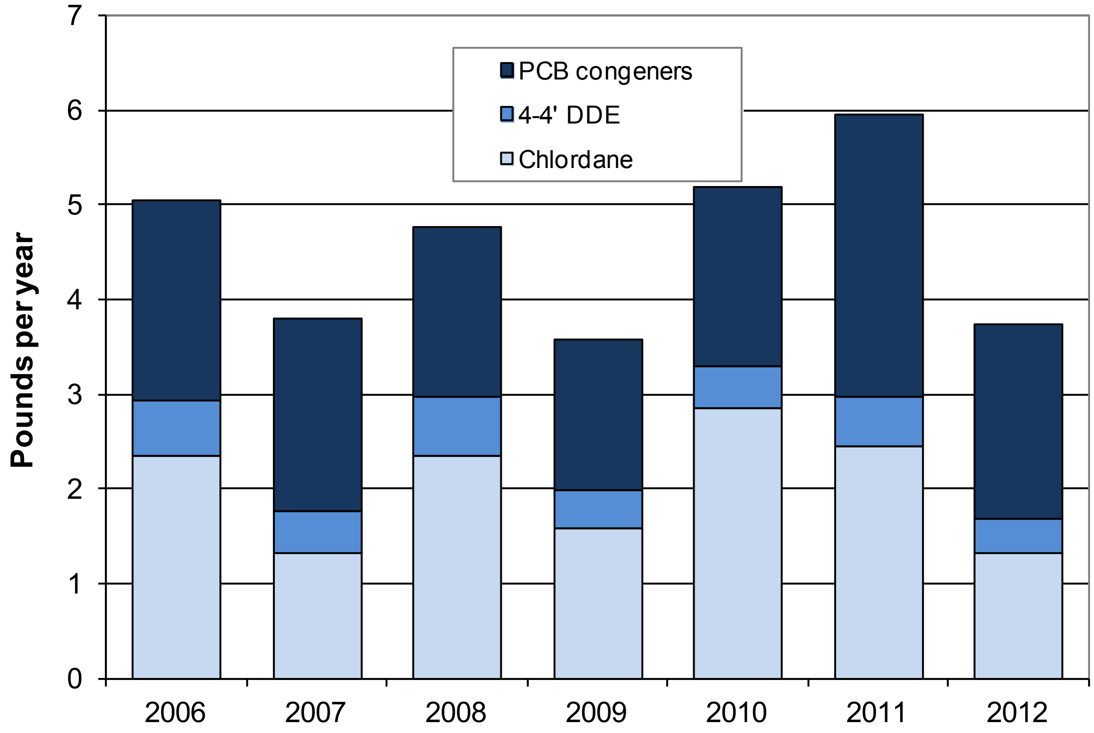


Figure 2-9. Annual PCBs and pesticides discharges. New methods were implemented in 2006 to detect these compounds, which are present at very low levels. PCBs and the pesticides DDT and chlordane were banned in the 1970s and 1980s but persist in the environment (4-4' DDE is a DDT breakdown product and the only form detected in the effluent). (Note that prior years' outfall monitoring overviews reported loads in pounds per day.)

Contingency Plan Thresholds

DITP had no permit violations, and there were no exceedances of the Contingency Plan effluent thresholds in 2012 (Table 2-1). For a second consecutive year, DITP achieved the NACWA Platinum Award for facilities having five consecutive years with 100% permit compliance.

Table 2-1. Contingency Plan threshold values and 2012 results for effluent monitoring. cBOD = carbonaceous biological oxygen demand, NOEC = no observable effect concentration, LC50 = 50% mortality concentration, NA = not applicable

Parameter	Caution Level	Warning Level	2012 Results
pH	None	<6 or >9	Not exceeded
Fecal coliform bacteria	None	14,000 fecal coliforms/100 ml (monthly 90th percentile, weekly geometric mean, maximum daily geometric mean, and minimum of 3 consecutive samples)	Not exceeded
Chlorine, residual	None	631 µg/L daily, 456 µg/L monthly	Not exceeded
Total suspended solids	None	45 mg/L weekly 30 mg/L monthly	Not exceeded
cBOD	None	40 mg/L weekly, 25 mg/L monthly	Not exceeded
Toxicity	None	Acute: effluent LC50<50% for shrimp and fish Chronic: effluent NOEC for fish survival and growth and sea urchin fertilization <1.5% effluent	Not exceeded
PCBs	Aroclor=0.045 ng/L	None	Not exceeded
Plant performance	5 violations/year	Noncompliance >5% of the time	Not exceeded
Flow	None	Flow >436 mgd for annual average of dry days	Not exceeded
Total nitrogen load	12,500 mtons/year	14,000 mtons/year	Not exceeded
Floatables	NA		
Oil and grease	None	15 mg/L weekly	Not exceeded

3. Water Column

The water-column monitoring program measures physical processes and water quality and studies phytoplankton and zooplankton at stations at the mouth of Boston Harbor, in Massachusetts Bay, and in Cape Cod Bay (Figure 3-1).

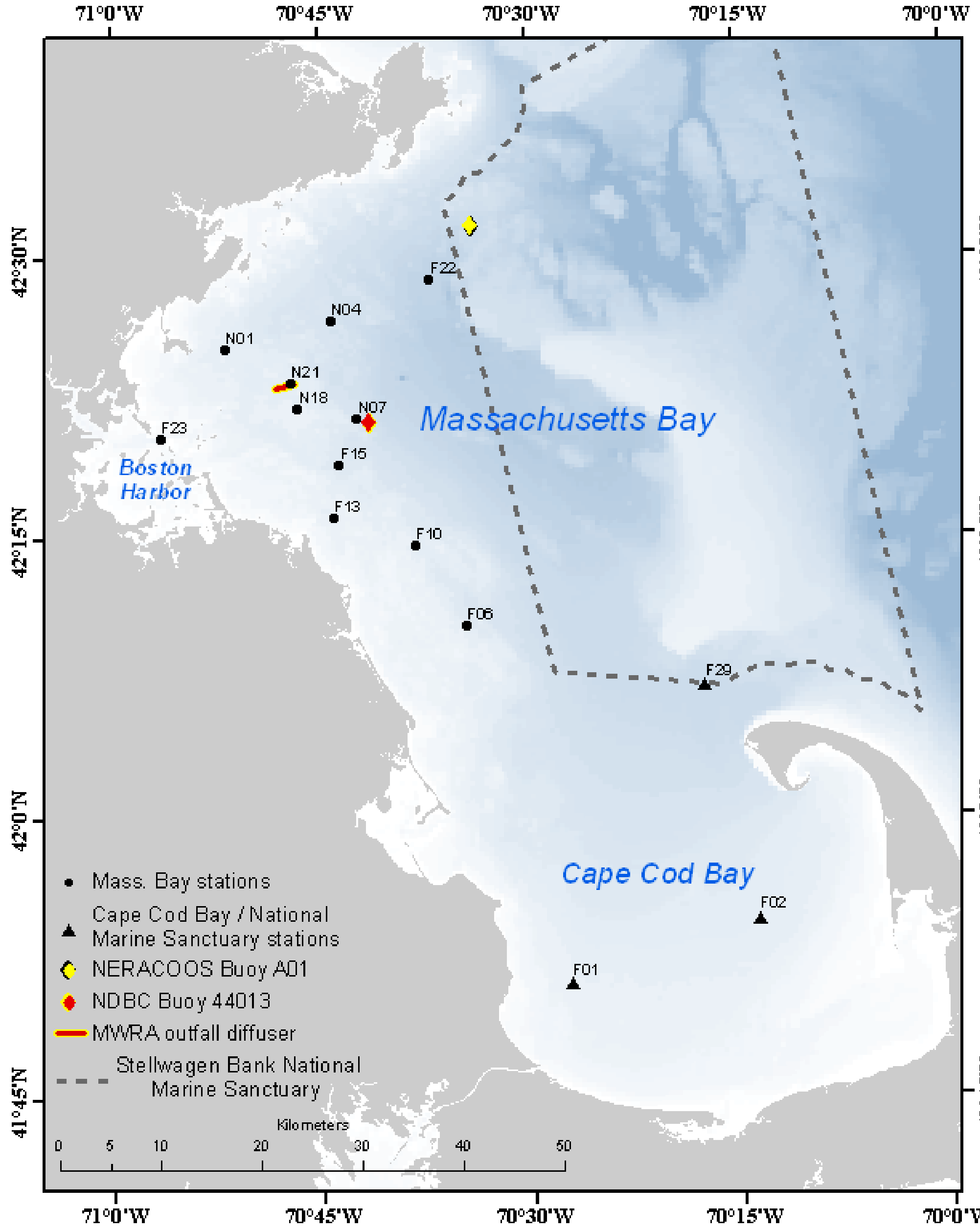


Figure 3-1. Water-column monitoring stations. Also shown are two instrumented buoys, one operated by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the other by the National Data Buoy Center (NDBC); the MWRA outfall diffuser; and the Stellwagen Bank National Marine Sanctuary.

The revised water-column monitoring plan implemented in 2011 (MWRA 2010, Werme et al. 2012) includes nine annual surveys at fourteen stations. Monitoring includes sampling for vertical profiles of physical, chemical, and biological characteristics in the area around the outfall (the nearfield), where some effects of the effluent were expected and have been observed. Similar measurements are carried out at farfield reference stations, including stations in Cape Cod Bay and near the Stellwagen Bank National Marine Sanctuary. Additional surveys are conducted and stations sampled in response to *Alexandrium fundyense* red tide blooms. The field monitoring program is augmented by measurements on two instrumented buoys, the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) Buoy A01 and the National Oceanic and Atmospheric Administration's National Data Buoy Center (NDBC) Buoy 44013, and by satellite imagery.

The program also benefits from collaboration with the Center for Coastal Studies at Provincetown, which conducts a monitoring program in Cape Cod Bay (see Section 6, Special Studies). The Center for Coastal Studies also conducts MWRA's monitoring at stations in Cape Cod Bay and the Stellwagen Bank National Marine Sanctuary. Regulators have set a target that, whenever possible, sampling in Cape Cod Bay should occur within 48 hours of MWRA Massachusetts Bay sampling and that any failure to meet that schedule should be reported in the annual outfall monitoring overview. Except for one survey, in the first two years of sampling under the new monitoring plan, sampling in Cape Cod Bay was completed within 24 hours of sampling in Massachusetts Bay. For that one survey (May 14–20, 2011), inclement weather delayed sampling in Massachusetts Bay until six days after the Cape Cod Bay survey had been completed. All 2012 sampling was completed within the regulatory schedule.

Physical Conditions

Monitoring has shown that the water column in the vicinity of the outfall and throughout Massachusetts and Cape Cod bays is heavily influenced by river inflows, weather, and other physical factors. Information about physical conditions has proven key to interpreting the annual monitoring data.

The year 2012 was notably drier than other recent years (noted in Section 2, Effluent), with an unusually warm winter, a mixing event in June, and Hurricane Sandy in the fall. The relatively dry conditions followed a period of wetter years in the Boston area and resulted in river discharges that were below average compared to 1992–2011 (Libby et al. 2013). Flows from both the Merrimack and Charles rivers were below average in every season and especially lower than average during the spring months (Figure 3-2).

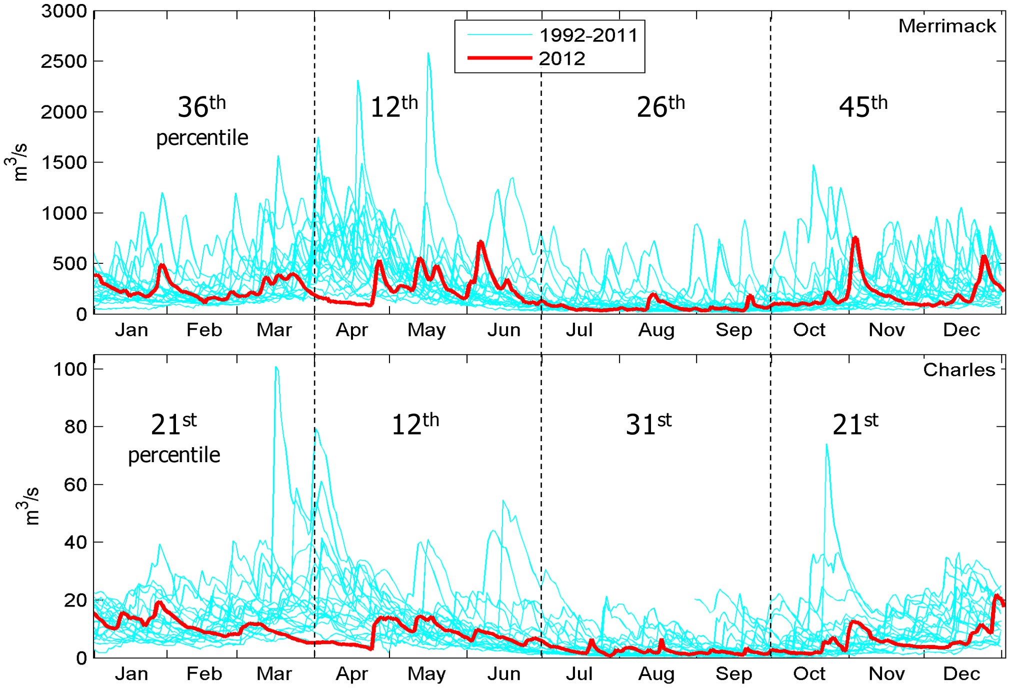


Figure 3-2. Flows of the Merrimack (top) and Charles (bottom) rivers were low throughout much of the year, reflecting the relatively dry year. Flows from both rivers were low, especially during April–June, with flows translating to only the 12th percentile for flows throughout the period. Even lower flows translated to higher percentiles during July–August, because flows are more typically low in the summer.

Wind conditions promoted strong upwelling conditions in May, July, August, and September (Figure 3-3). In early June, a storm with winds from the northeast broke that pattern. Strong downwelling conditions late October and early November were caused by Hurricane Sandy, which reached the region on October 29.

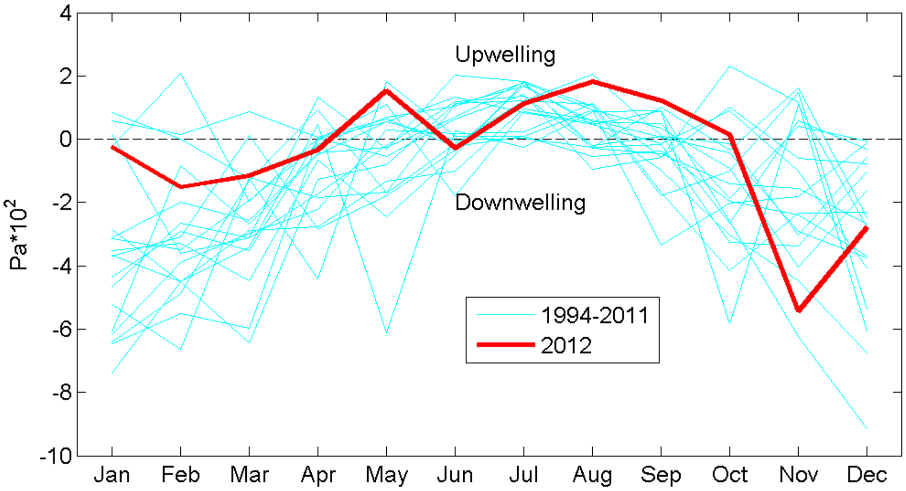


Figure 3-3. Average wind stress at NDBC Buoy 44013. Positive values indicate winds from the south or southwest, which result in upwelling-favorable conditions; negative values indicate winds from the north or northeast, which favor downwelling. The dip in June corresponds to a storm with winds from the northeast, and the strong decline in the fall corresponds to Hurricane Sandy.

Nearfield surface- and bottom-water temperatures were higher than average throughout the late winter and spring, setting record highs for some surveys (Figure 3-4). Warm, calm weather heated surface waters in late May. Then in early June, a storm mixed warm surface waters down to the bottom, causing a strong spike in the temperature of bottom waters. The persistent upwelling following that event kept temperatures lower through the rest of the year, within the range for the monitoring program.

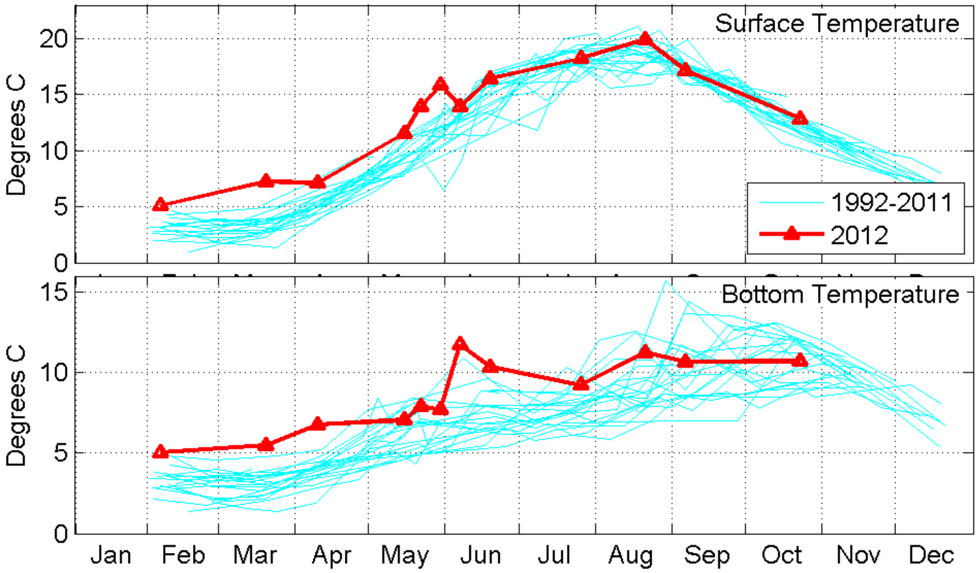


Figure 3-4. Nearfield surface- and bottom-water temperature. Water temperatures were particularly warm, during the early part of the year, reaching record highs for the monitoring program during some surveys**.**

Surface- and bottom-water salinities began the year within normal ranges but, because of the dry conditions, did not show the typical drop during the spring, when runoff usually introduces fresh water to the bays (Figure 3-5). Record high salinities were recorded for May, and relatively high levels persisted throughout the duration of field sampling for the year.

Dissolved oxygen concentrations were lower than normal in the winter, and in May, bottom water dissolved oxygen levels reached record lows for that month (Figure 3-6, 3-7). Upwelling in late May and the mixing event in June may have prevented further drops, and through the rest of the summer and fall, concentrations were low but falling at a typical rate. The time-series data from the NERACOOS A01 buoy located off Cape Ann corresponded well with the survey data and documented the continued decline in bottom-water levels through mid-October (Figure 3-8). For much of Massachusetts Bay, stratification persisted until Hurricane Sandy reached the area on October 29. Another storm, with winds from the northeast, followed the hurricane, and by early November, the water column was well-mixed.

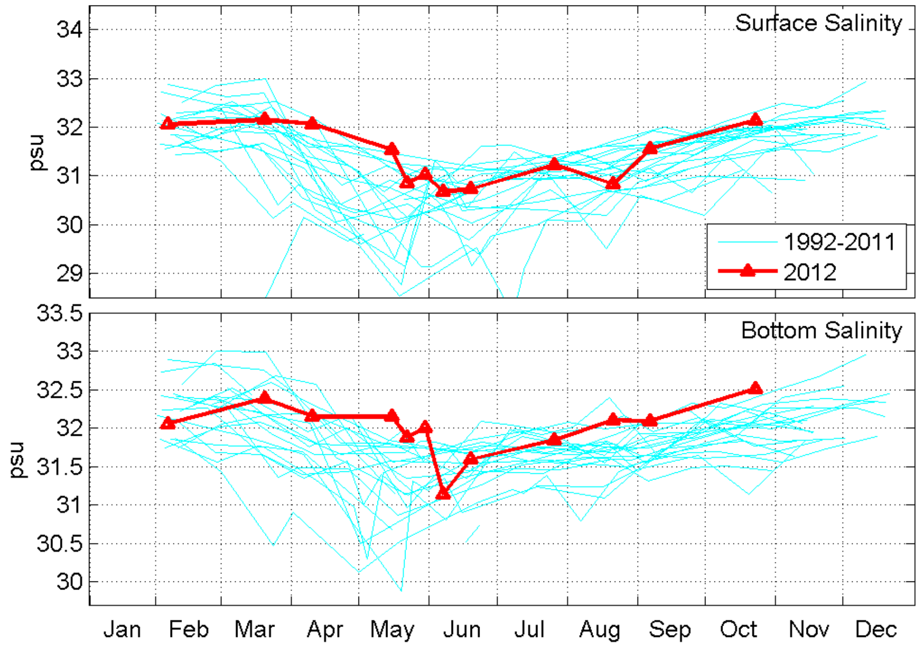


Figure 3-5. Nearfield surface- and bottom-water salinity. Salinity was high due to the relatively dry conditions throughout the year.

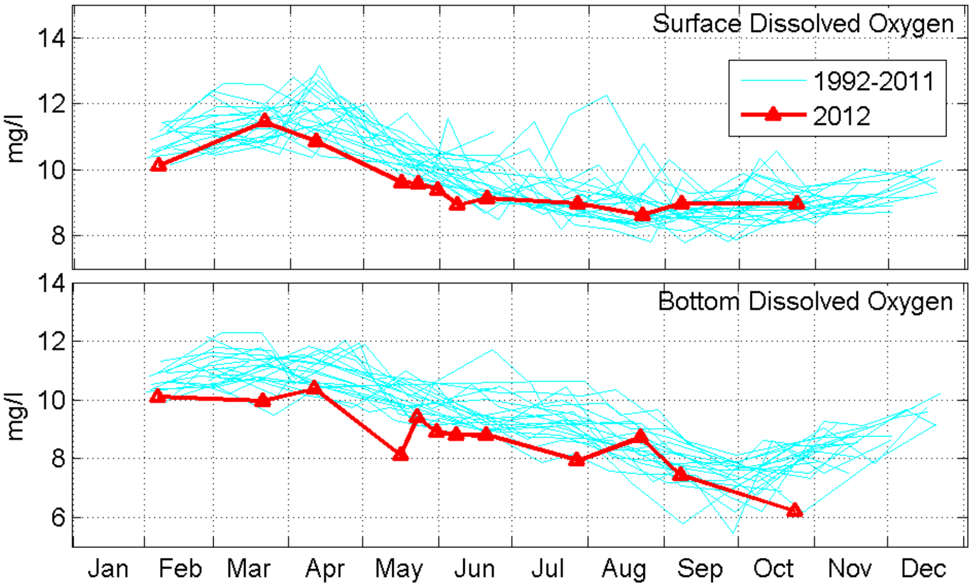


Figure 3-6. Nearfield surface- and bottom-water dissolved oxygen concentrations. Dissolved oxygen concentrations were relatively low, although even lower values would be expected based on the warmer than average bottom temperatures and higher than average bottom salinity measurements.

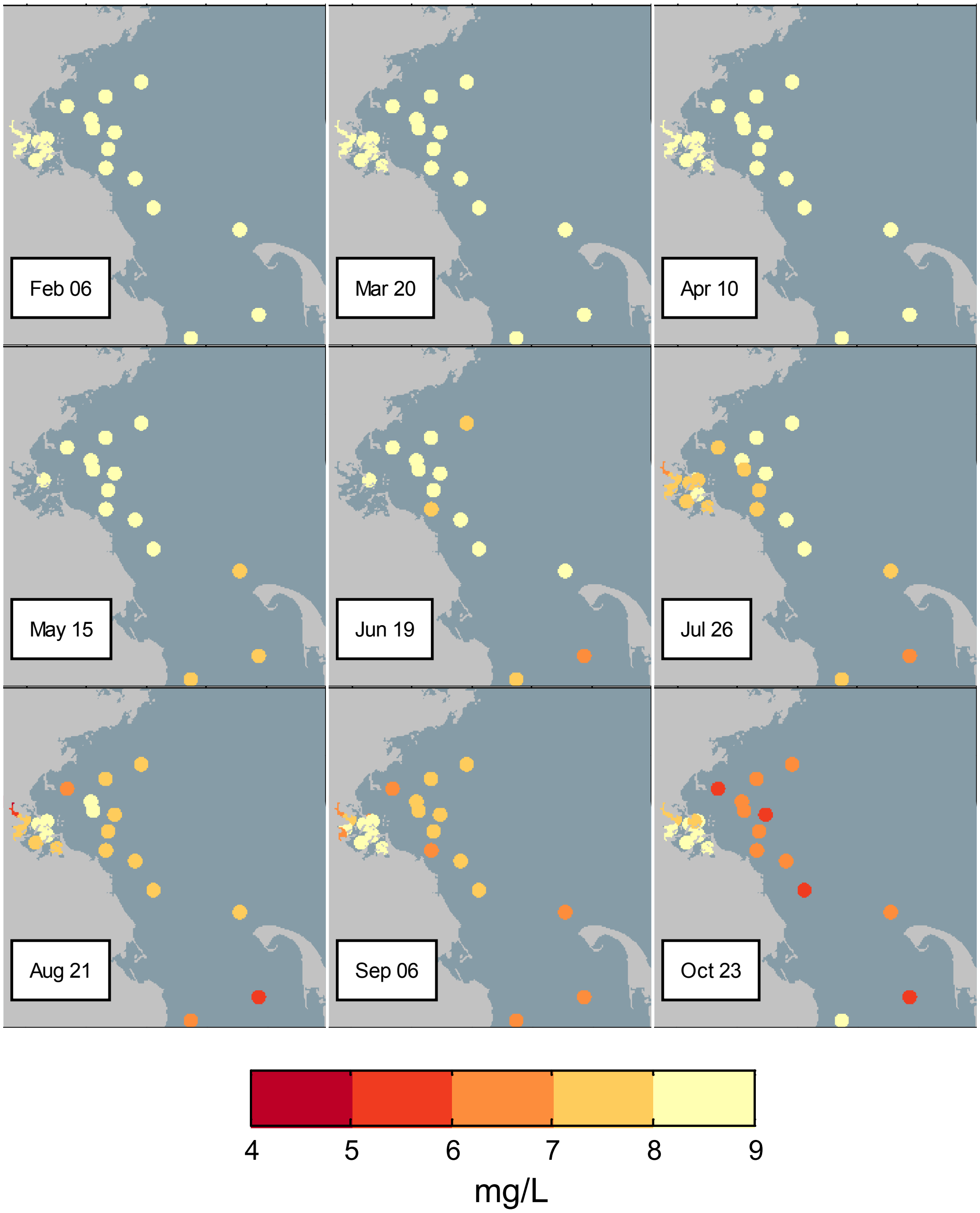


Figure 3-7. Bottom-water dissolved oxygen concentration (mg/L) at stations in Massachusetts and Cape Cod bays during the nine surveys conducted in 2012. Several panels show additional data from MWRA's in-house Boston Harbor monitoring surveys when those surveys were within a few days of the outfall monitoring surveys.

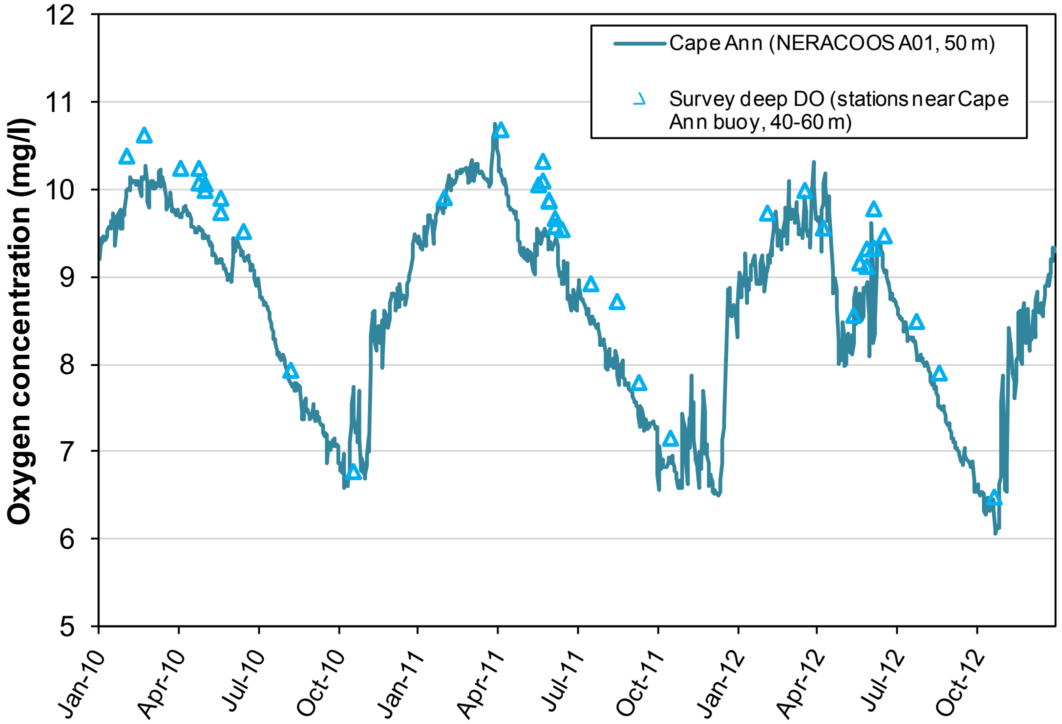


Figure 3-8. Bottom-water dissolved oxygen (DO) concentrations at NERACOOS Buoy A01 near Cape Ann and nearby MWRA stations, 2010–2012. Buoy and survey data were in good agreement during all three years. In 2012, the buoy data showed a continual decline in bottom water dissolved oxygen concentrations until mid-October and a return to mixed conditions by early November.

Water Quality

Water quality measurements for 2012, including quantification of nutrients and phytoplankton biomass (measured as chlorophyll), followed typical annual cycles and continued to confirm predictions that although there would be a measureable increase in levels of some parameters at stations very near the outfall, there would be no unexpected adverse effects (Libby et al. 2013). Nutrient concentrations were somewhat lower than most years during the February and March surveys, possibly due to the dry year with limited runoff, but overall, concentrations of the major nutrients important to phytoplankton growth fell into the ranges observed throughout the monitoring program (Figure 3-9).

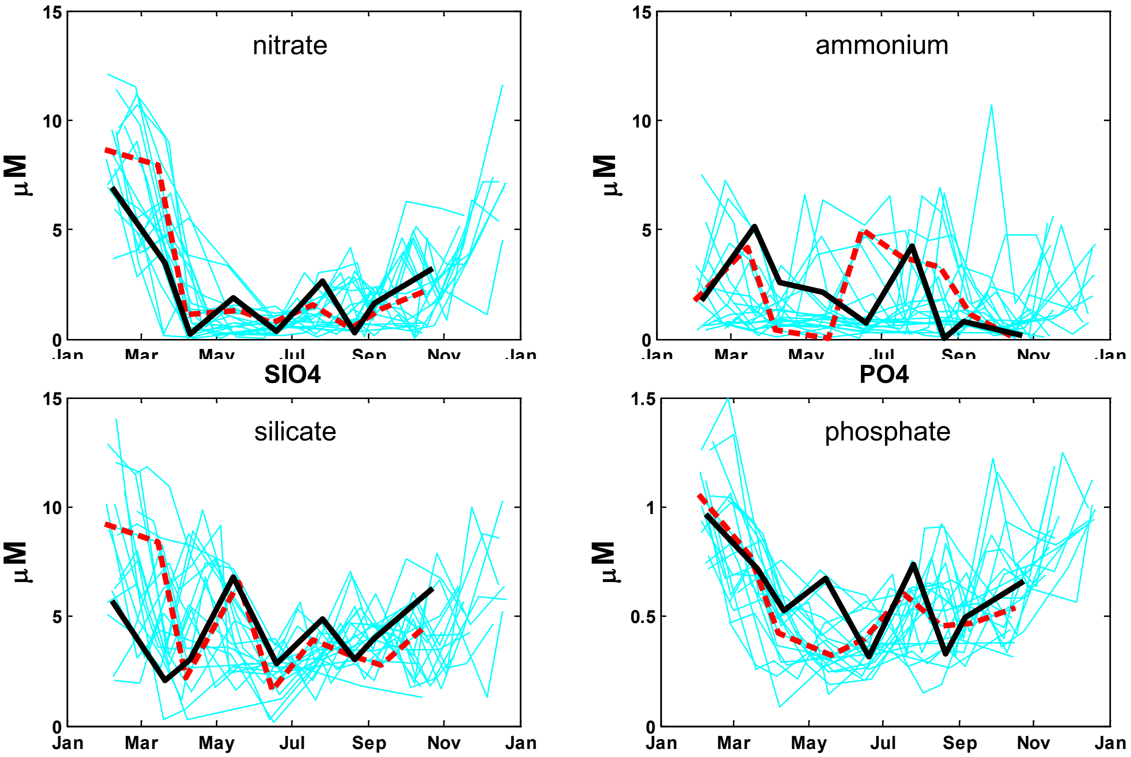


Figure 3-9. Mean nutrient concentrations at Station N18 in 2012 (black), compared to 2011 (red) and other prior years. Spring concentrations of nitrate and silicate were low compared to 2011 and other years, probably largely because it was a much drier year, with low runoff from rivers. and possibly also due to phytoplankton blooms prior to the first MWRA survey in March.

Elevated ammonium levels were apparent at the outfall in most surveys (Figure 3-10), consistent with the results from prior years. The furthest southern extent that plume-related elevated ammonium concentrations were detected was Station F15 in May. Elevated levels were seen at Station N01, to the northwest of the outfall, in September and October.

As has been typical since the outfall began to discharge, the plume was found in surface waters during the winter and spring (Figure 3-11) but was confined beneath the pycnocline during the summer, stratified season (Figure 3-12). The upwelling conditions present in May brought nutrients into the upper portions of the water column, although surface nutrient levels remained low. The detectable ammonium plume did not reach the surface, but it was apparent in the nearfield.

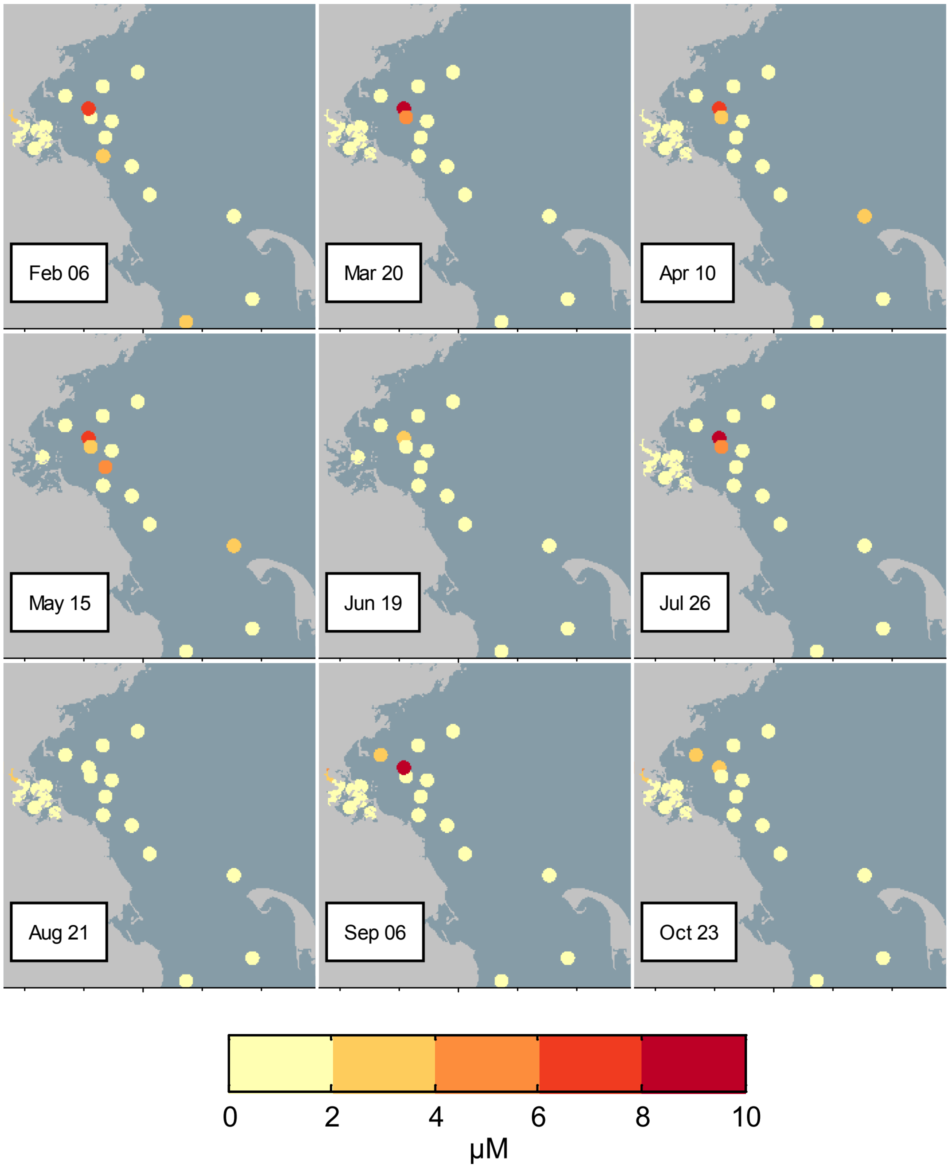


Figure 3-10. Depth-averaged ammonium (µM) by station in Massachusetts and Cape Cod bays. Several panels show additional data from MWRA's in-house Boston Harbor monitoring surveys when those surveys were within a few days of the outfall monitoring surveys.

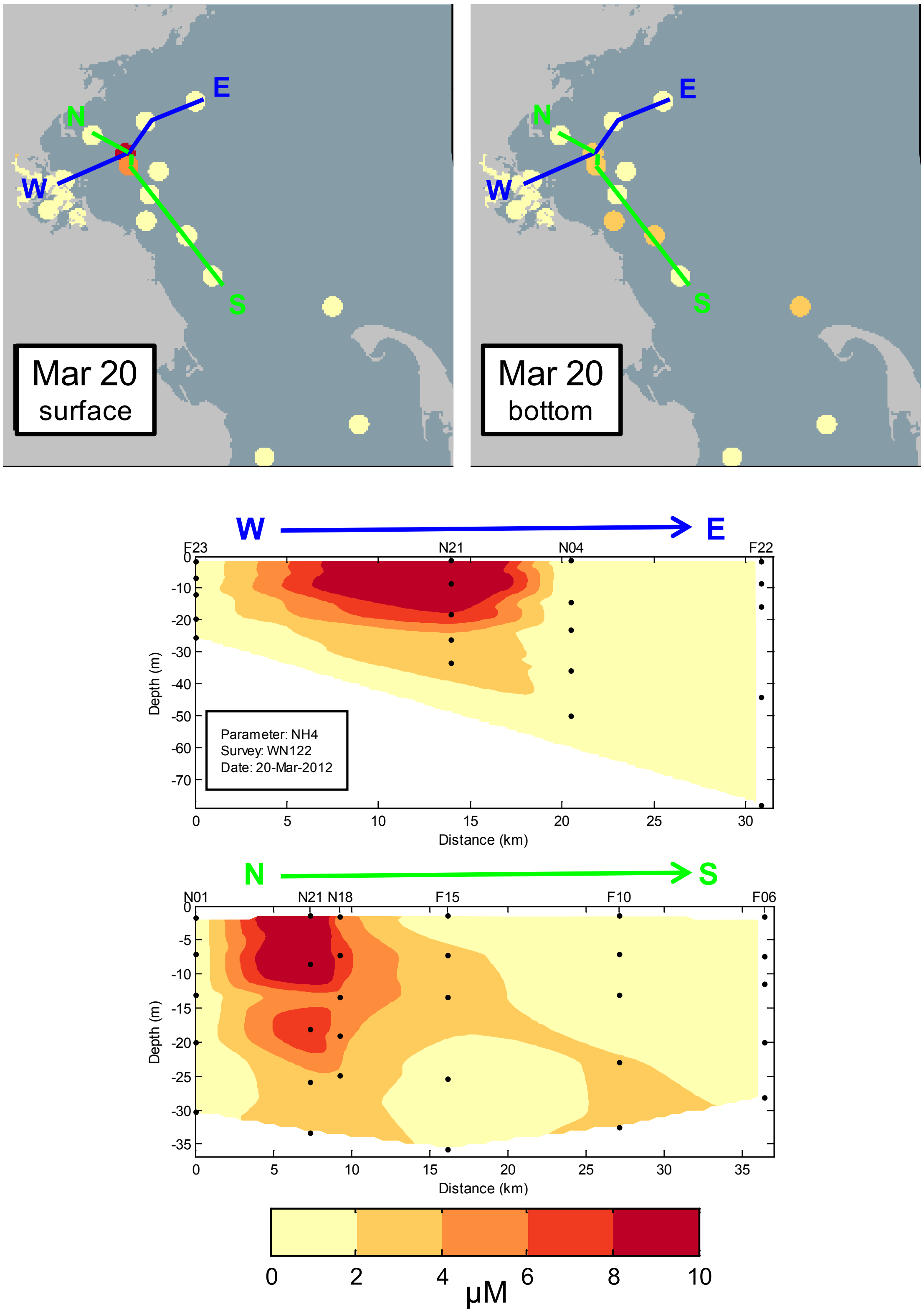


Figure 3-11. (Top) Surface- and bottom-water ammonium on March 20, 2012 at the monitoring stations during mixed conditions. (Bottom) Cross-sections of concentrations at other depths along transects connecting selected stations, showing that the plume reached surface waters.

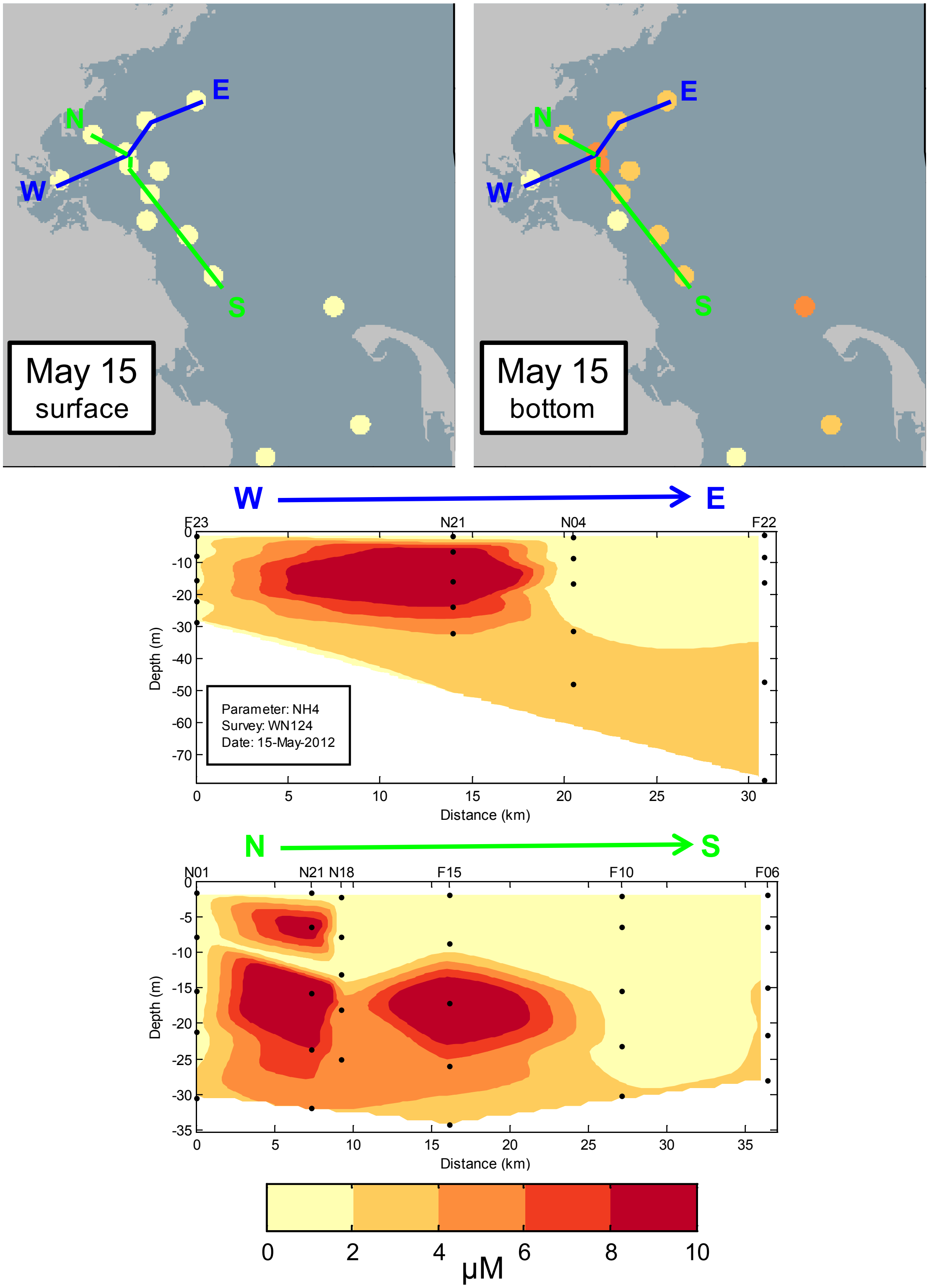


Figure 3-12. (Top) Surface- and bottom-water ammonium on May 15, 2012 at the monitoring stations during stratified conditions. (Bottom) Cross-sections of concentrations at other depths along transects connecting selected stations.

Survey surface-water chlorophyll levels peaked on March 20 (Figure 3-13). High chlorophyll levels were observed two weeks before the survey date in satellite imagery from early March (Figure 3-14), suggesting that a winter-spring bloom began before the March 7 image was made. Chlorophyll fluorescence data from the NERACOOS Buoy A01 near station F22 off Cape Ann suggested that there could have been two early chlorophyll peaks.

Chlorophyll levels were also elevated in the late summer and early fall, consistent with typical fall phytoplankton bloom patterns. The satellite imagery suggests an early fall bloom, which ended by mid September, and a later bloom in late September and October. The imagery also shows high chlorophyll levels later in the year, after the survey season was complete, particularly in the shallow waters of Cape Cod Bay.

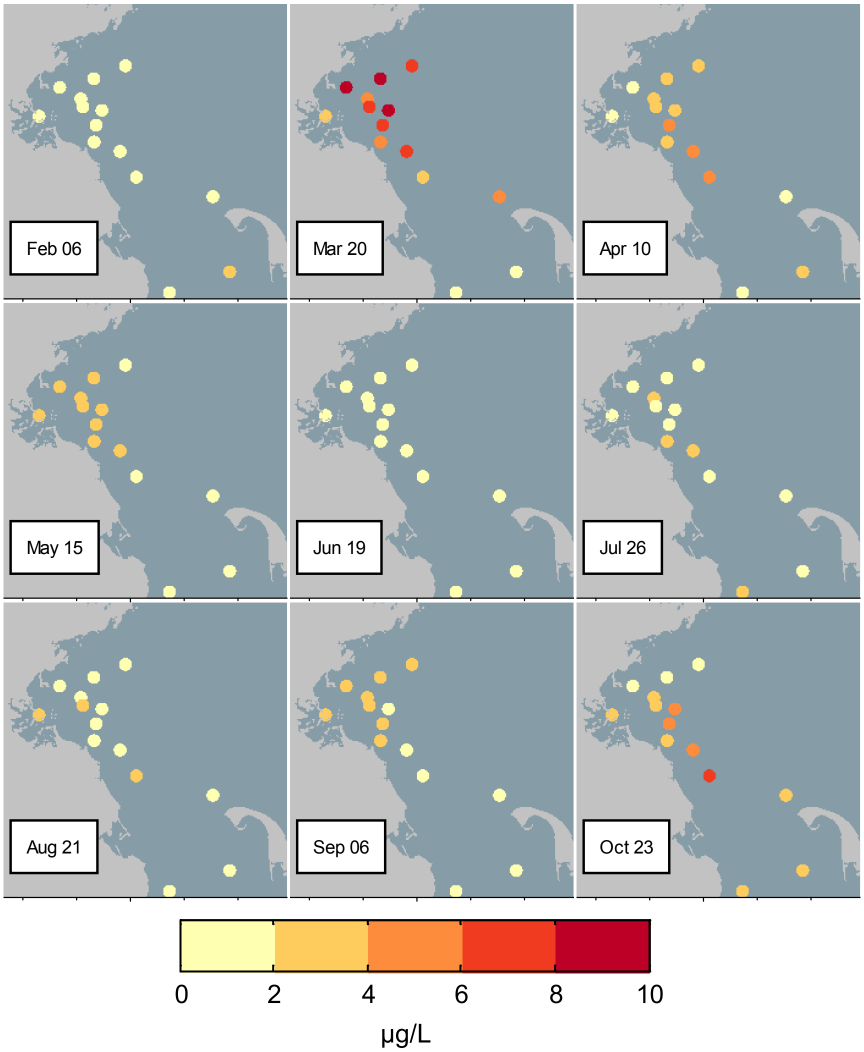


Figure 3-13. Surface-water chlorophyll fluorescence by station in Massachusetts and Cape Cod bays. The highest chlorophyll concentrations were recorded during the March 20, 2012 survey, when concentrations of particulate organic carbon were also high.

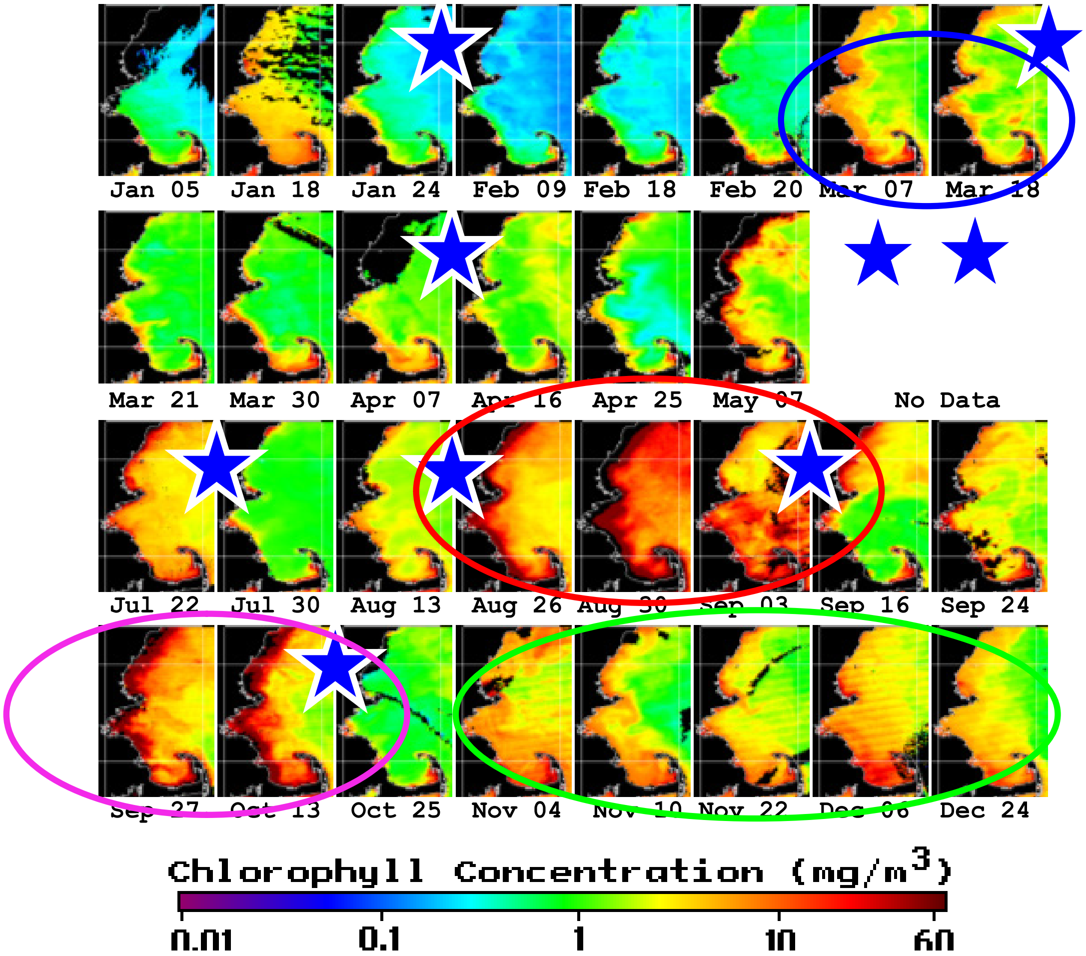


Figure 3-14. Moderate Resolution Imaging Spectroradiometer satellite imagery of surface chlorophyll concentrations in 2012. The stars show the timing of the nine MWRA surveys, and the circles highlight blooms. The imagery shows that the spring bloom detected during the March survey began before March 7. Chlorophyll levels were high throughout the bays in late August and much of the fall. Note that these images are heavily weather dependent and do not represent consistent intervals of time.

Phytoplankton Communities

Total abundance of phytoplankton in 2012 was near the long-term mean for the monitoring program (Libby et al. 2013). The phytoplankton communities followed typical progressions throughout the year, with two notable pulses: a predominantly offshore bloom of *Phaeocystis pouchetii* in March and a coastal pulse of centric diatoms (*Skeletonema* spp.) in September. As in other years, microflagellates comprised the numerically dominant group.

Spring blooms of the colonial flagellate *Phaeocystis pouchetii* have occurred every year in Massachusetts Bay over the past decade, but the 2012 bloom was unique in its early start and early peak abundance, in March rather than in April (Figure 3-15). The bloom persisted, at a low level, into the early summer. Total microflagellate abundance also peaked earlier than usual, and it is possible that both these groups were affected by the unusually warm winter. Overall, *Phaeocystis* abundance was somewhat high in comparison to past years (Figure 3-16).

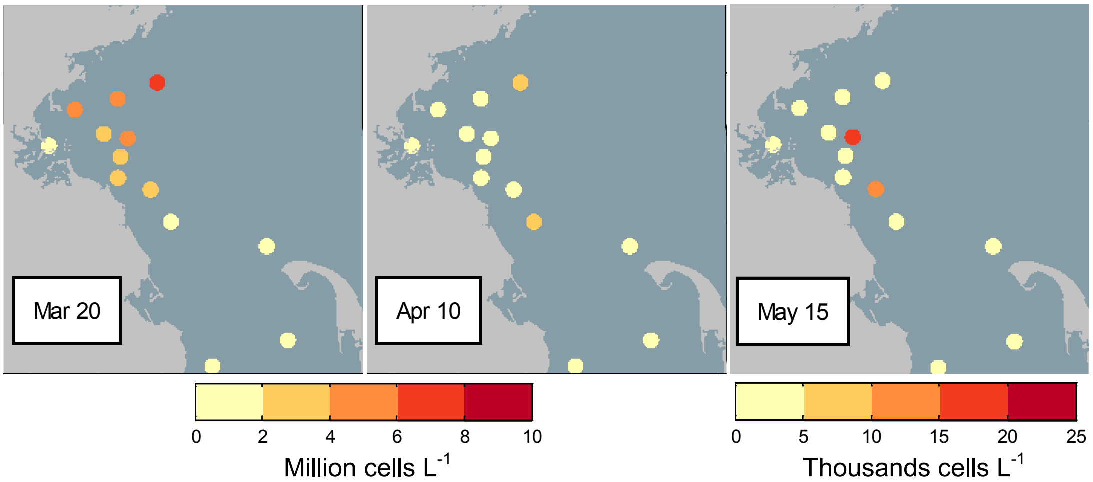


Figure 3-15. *Phaeocystis pouchetii* abundance during the 2012 bloom. The bloom began earlier than in some past years, in March rather than in April, and it persisted into May. Note difference in scale for May survey.

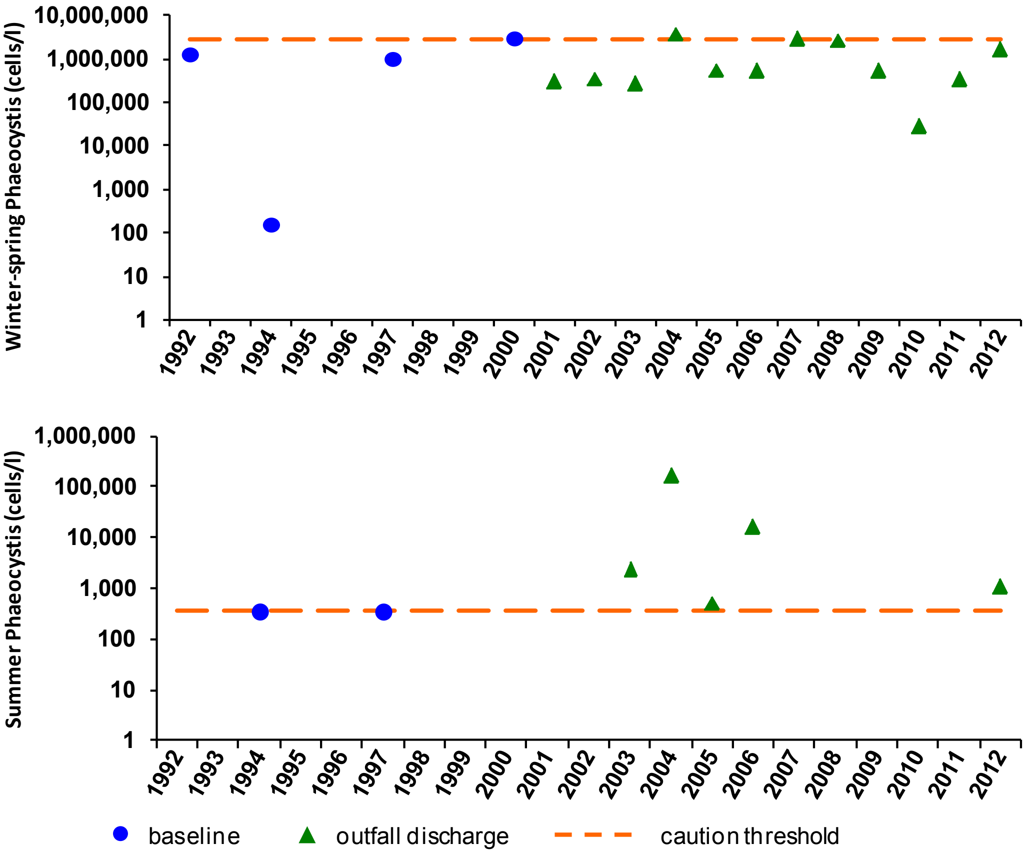


Figure 3-16. Mean nearfield abundance of *Phaeocystis pouchetii*, 1992–2012. (Top) winter-spring. (Bottom) summer.

Centric diatom abundance peaked in September or October in all regions except the northern, offshore stations, where abundance was highest in June. No large winter-spring diatom bloom occurred in any region, but the September bloom, dominated by *Skeletonema* spp., was large enough that annual centric diatom abundance was near the long-term mean. The June bloom in northern waters was dominated by *Thalassiosira* spp. and *Chaetoceros* spp., primarily *Chaetoceros socialis*. That bloom exceeded past *Chaetoceros* abundances in that region.

Dinoflagellate abundances in 2012 were also approximately equal to the long-term mean. The toxic dinoflagellate *Alexandrium fundyense* occurred at low levels in April and June, but bloomed in May (Figure 3-17). *Alexandrium fundyense* blooms have occurred regularly in Massachusetts Bay since 2005 (Figure 3-18). Levels in 2012 reached above the 100 cells/L limit that triggers *Alexandrium* rapid-response surveys.

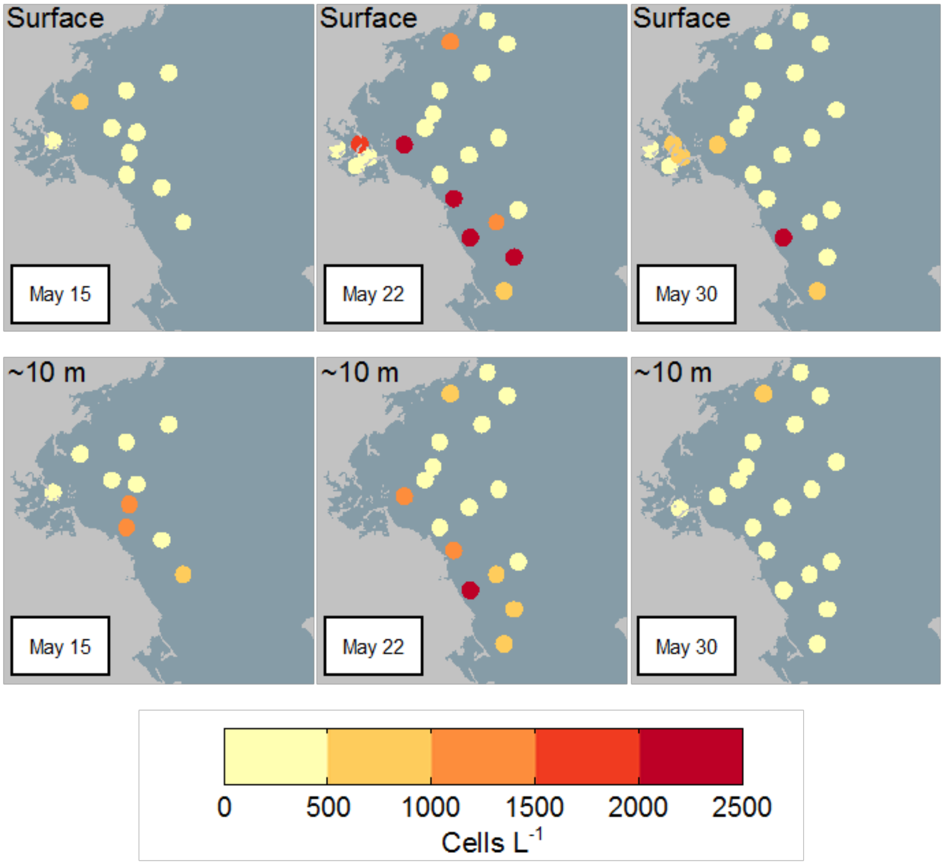


Figure 3-17. ***Alexandrium fundyense*** **bloom in 2012.** The late spring storm ended the bloom rather than bringing cells in from the Gulf of Maine.

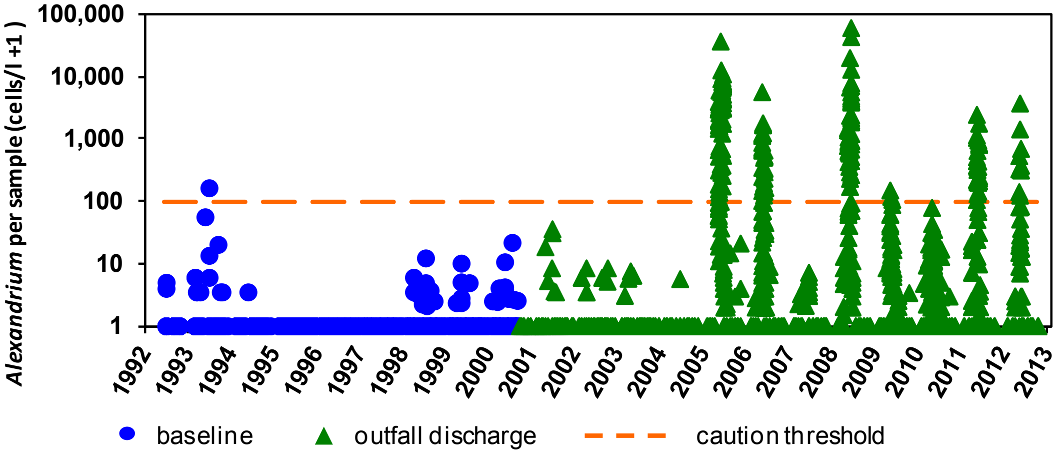


Figure 3-18. Nearfield abundance of *Alexandrium fundyense,* 1992–2012.

While the timing and relatively low magnitude of the 2012 bloom on a New England-wide scale had been forecast by Woods Hole researchers (based on measurements of cyst abundance in the fall of 2011), the spatial pattern in *Alexandrium* abundance and in paralytic shellfish poisoning (PSP) toxicity in Massachusetts Bay was unusual. The normal progression for *Alexandrium* blooms is that they develop in coastal Maine waters when cysts germinate and begin to multiply. The bloom then follows coastal currents south to New Hampshire and Cape Ann. If wind conditions are right, a bloom in those coastal waters can be swept into Massachusetts Bay.

In 2012 the highest cell abundances were observed in Boston Harbor, the western portions of the nearfield, and along the Boston south shore, while counts in northern Massachusetts Bay were consistently much lower (i.e. the bloom did not begin in the north and move south). Also, while the bloom caused PSP toxicity and closed beds from Salem to Duxbury, there were no closures on the north shore.

When MWRA discussed the bloom and the Contingency Plan threshold exceedance with regulators and OMSAP at its April 1, 2013 meeting, Panel members requested MWRA review the available data further to address whether effluent nutrients might have contributed to the unusual spatial pattern of the bloom. That review found no evidence effluent nutrients played a major role in causing the bloom. Effluent nutrient loading before and during the bloom were well within historic ranges for that time of year including the loading of ammonium, the effluent nutrient most immediately available to stimulate phytoplankton growth. The temporal and spatial patterns of nutrients before and during the 2012 *Alexandrium* bloom were well within the ranges observed during previous years, including years in which *Alexandrium* bloomed in Massachusetts Bay and years when it did not. High concentrations of nutrients did not extend further south from the outfall than is normally observed (~10-20 km).

As noted previously, 2012 was a dry year, with lower river discharges during the spring than occurs most years. Coupled with the weak and upwelling favorable winds experienced around the time of the bloom, this may have slowed circulation and increased residence times of the early season pulse of cells within Massachusetts Bay, allowing time for the small population of cells to grow to bloom levels. These weak winds also prevented transportation south of elevated cell abundances seen off the coast of Maine in late May. Unfortunately, the available data do not allow conclusions to be drawn as to the causes of this unusual bloom. It is important to note that even for an organism like *Alexandrium*, which has been extensively studied for decades because of its impacts on the shellfish industry, gaps remain in our understanding of all the factors involved in a bloom.

Zooplankton Communities

The 2012 abundances, species composition, and seasonal progressions of the zooplankton communities fell within the general patterns of past years, with highest abundances in June, July, and August (Figure 3-19) (Libby et al. 2013). Total abundance during the first survey in February was somewhat higher than typical, possibly due to the warm, dry winter and possibly also an end result of an early, undetected diatom bloom (Figure 3-20).

Total zooplankton abundance in February and continuing through the year was dominated by the small copepod *Oithona similis* and by total copepod nauplii, copepodites, and adults. *Oithona* feeds primarily upon microzooplankton, mostly protozoans, rather than on phytoplankton. The dominant abundance of this species in Massachusetts Bay and in other ecosystems around the world has been recognized only recently, because it is too small to be sampled by many conventional protocols.

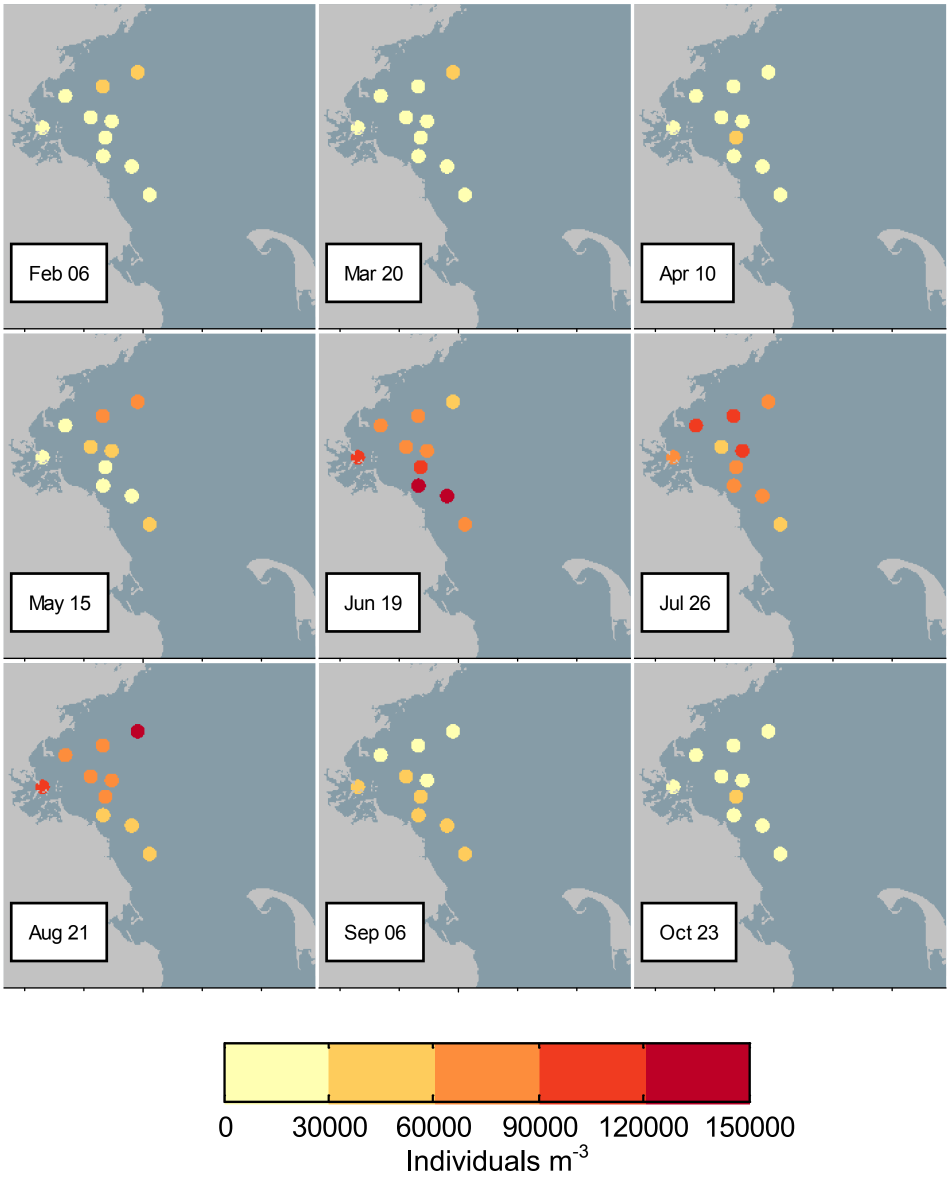
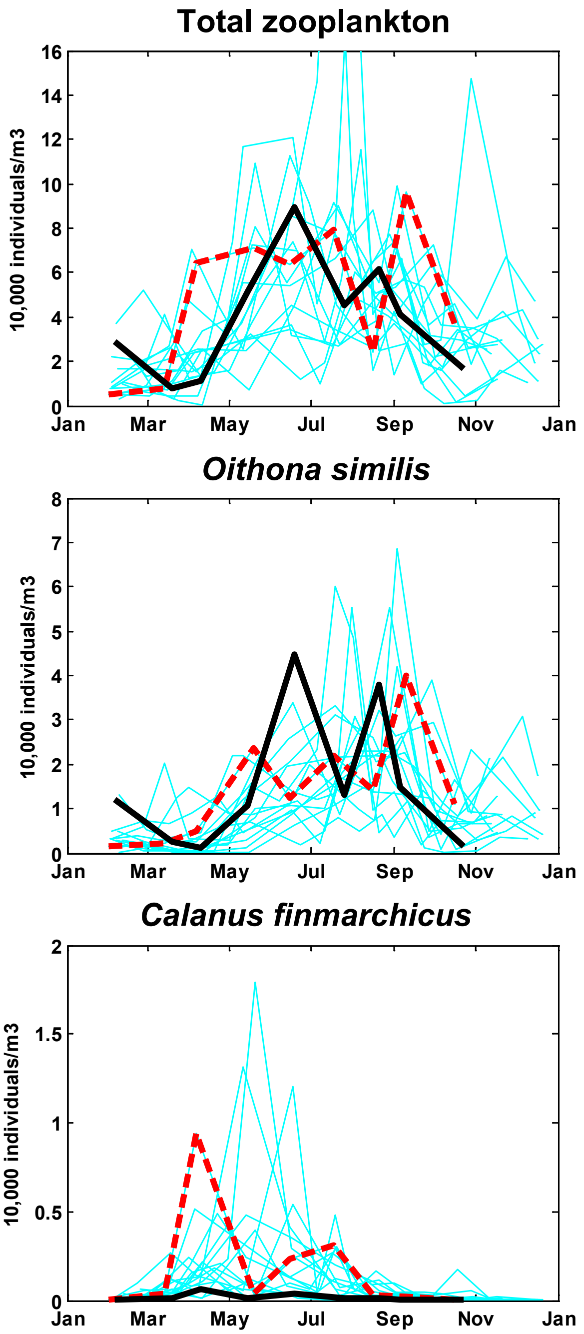


Figure 3-19. Total zooplankton abundance in 2012.


Total zooplankton

Oithona similis

Calanus finmarchicus

Figure 3-20. Nearfield abundance of total zooplankton, *Oithona similis*, and *Calanus finmarchicus* in 2011 (dashed red line) and 2012 (solid black line) compared to past years. Total zooplankton, dominated by *Oithona similis*, were relatively abundant in 2012. *Calanus finmarchicus* was almost absent in 2012, following a relatively abundant year in 2011.

Larger abundant zooplankton taxa typically include *Calanus finmarchicus*, *Acartia* spp., and barnacle nauplii. *Calanus finmarchicus* and *Acartia* spp. were almost absent in the nearfield in 2012, following a year in which they were relatively abundant. *Acartia* spp. were abundant only in Boston Harbor. The dearth of *Calanus finmarchicus*, a known food for right whales, did not appear to affect whale abundance, as sightings by the Center for Coastal Studies remained relatively high (see Section 6, Special Studies).

Time-series analysis of the zooplankton abundance data have shown that there was a decline throughout the bays during 2001–2006, but populations have rebounded since that period (Figure 3-18). Total abundance is now greater than the long-term mean. The 2001–2006 decline in total zooplankton largely reflected lower numbers of copepods during those years. Total copepod abundance has rebounded along with total zooplankton abundance. Reasons for such long-term trends are not well understood but occur on broad regional scales. There is no suggestion that the outfall discharge has affected zooplankton abundance or species composition in Massachusetts Bay.

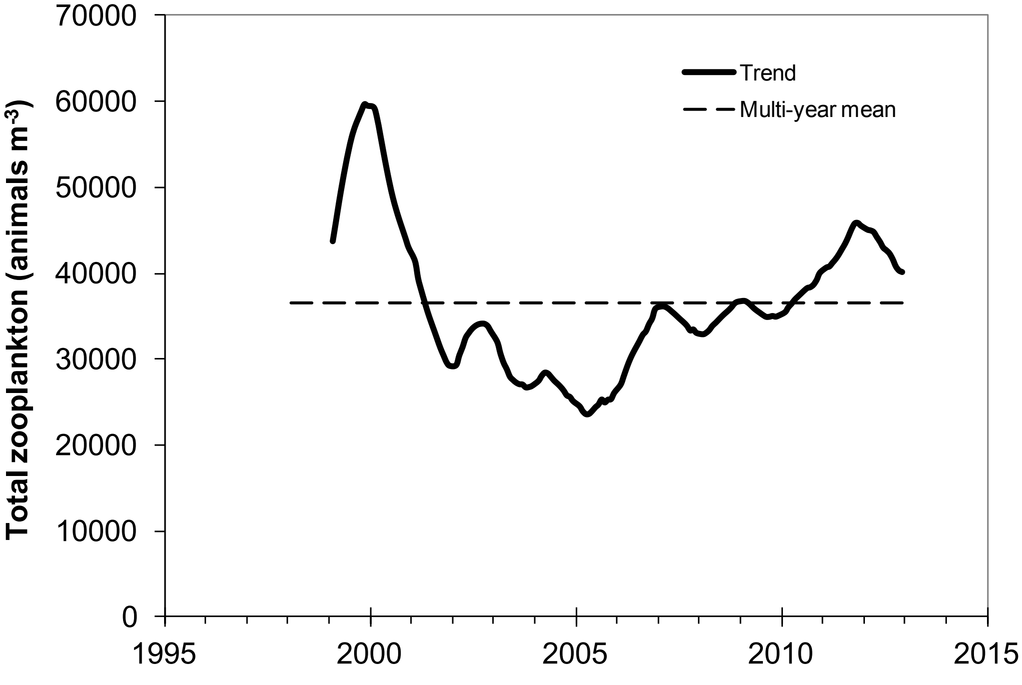


Figure 3-21. Long-term trend in zooplankton abundance and multi-year mean derived from a time-series analysis. Data are from Stations N04 and N18.

Stellwagen Bank National Marine Sanctuary

The NPDES permit to discharge from DITP into Massachusetts Bay requires annual reporting on results that are relevant to the Stellwagen Bank National Marine Sanctuary. Two stations are most relevant to the sanctuary, Station F22 in Stellwagen Basin to the northwest of the sanctuary and Station F29 on the sanctuary's southern boundary.

MWRA monitors dissolved oxygen concentration and saturation in Stellwagen Basin as Contingency Plan requirements. Bottom dissolved oxygen concentrations were low throughout 2012, the lowest measured during the monitoring program in late spring and early summer (Figure 3-22) (Libby et al. 2013). These levels reflected the warm, saline conditions found throughout the region in 2012.

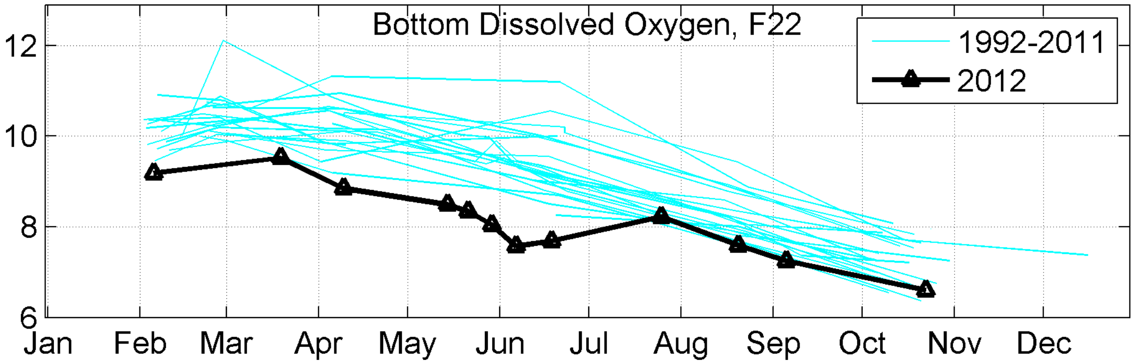


Figure 3-22. Bottom water dissolved oxygen concentrations in Stellwagen Basin in 2012 compared to the previous years of monitoring.

Besides survey data, buoy data and model outputs are useful in determining water quality conditions throughout Massachusetts Bay, including the sanctuary. Data from the deep oxygen sensor on the NERACOOS Buoy A01, within the sanctuary, documented the return to oxygenated conditions with fall mixing (see Figure 3-8 and Section 6, Special Studies).

Figure 3-23 shows the location of a transect running west to east across the Massachusetts Bay outfall and Stellwagen Bank, and Figures 3-24 through 3-27 depict modeled water quality parameters, including dissolved oxygen, dissolved oxygen saturation, dissolved inorganic nitrogen, and chlorophyll, along that transect.

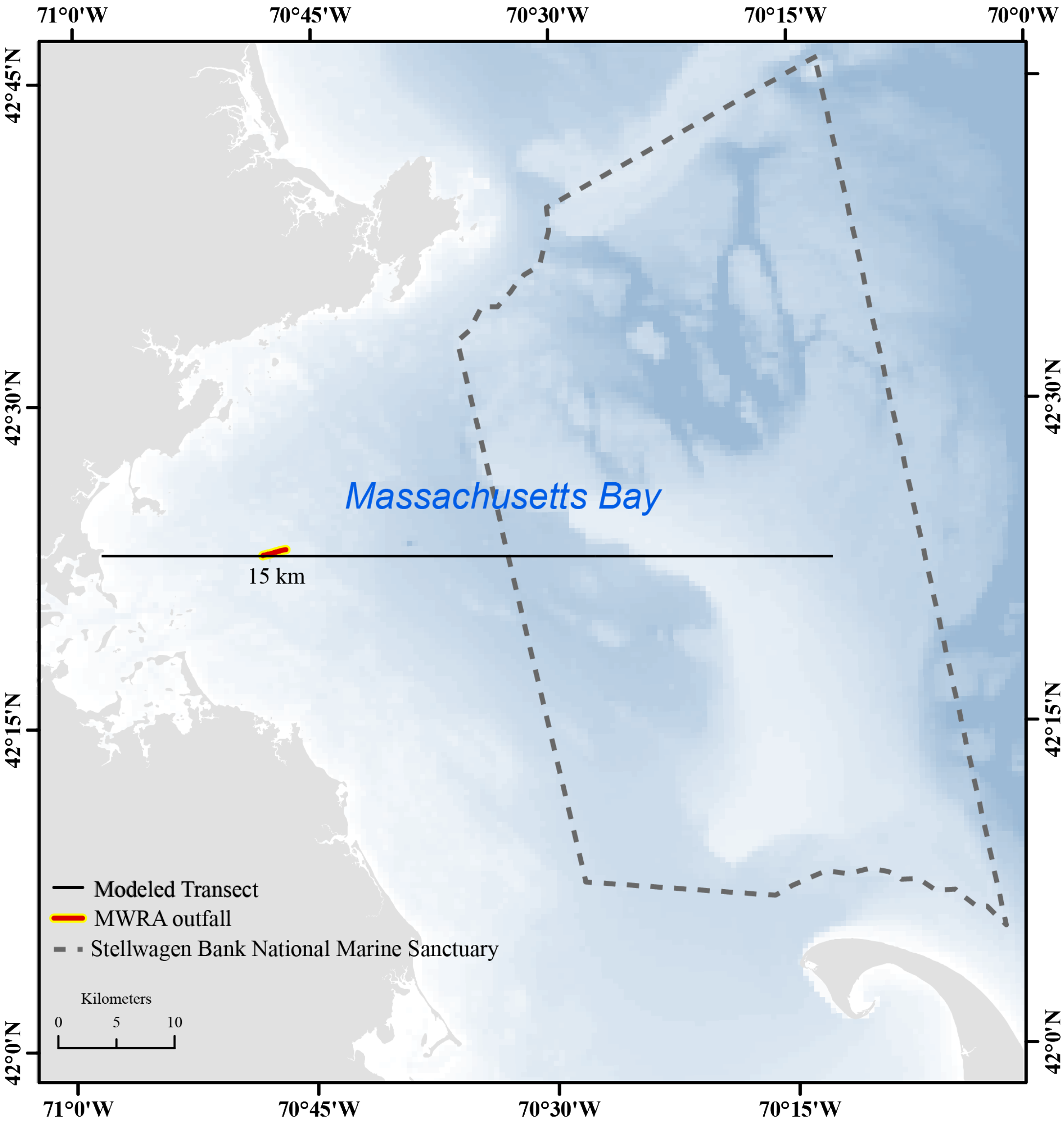


Figure 3-23. Location of west-east transect from Deer Island, across MWRA outfall, through Stellwagen Bank, for modeled water-quality parameters presented in Figures 3-24 through 3-27.

The model outputs supported predictions that there would be no indication of any effect of the outfall for most parameters, even in the nearfield, and no evidence of effects on the sanctuary. The model projects no effects of the outfall on dissolved oxygen concentration or saturation in any month. Elevated levels of dissolved inorganic nitrogen can be detected but only in the immediate vicinity of the outfall, with no influence on the sanctuary. Modeled chlorophyll levels show increased levels across the region in March at the time of the *Phaeocystis* bloom but no relation with the outfall. Note that the model tends to show less variation in chlorophyll values (such as a lower peak during the spring bloom and less difference from surface to bottom) than the field observations, but it generally captures the seasonal and geographic patterns.

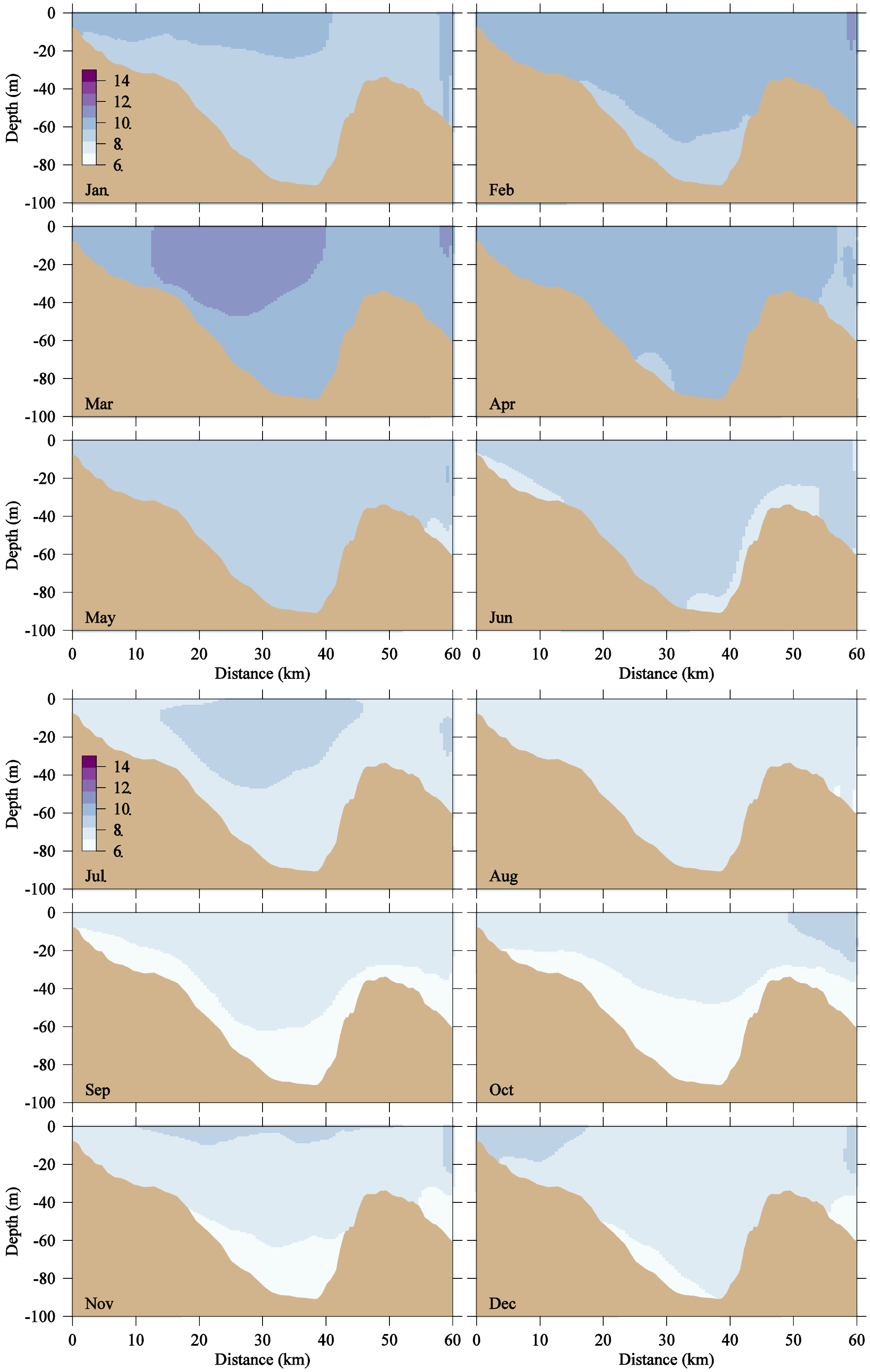


Figure 3-24. Modeled dissolved oxygen concentration (mg/L) on the west-east transect across the MWRA outfall and Stellwagen Bank National Marine Sanctuary at the end of each month from January through December 2012.

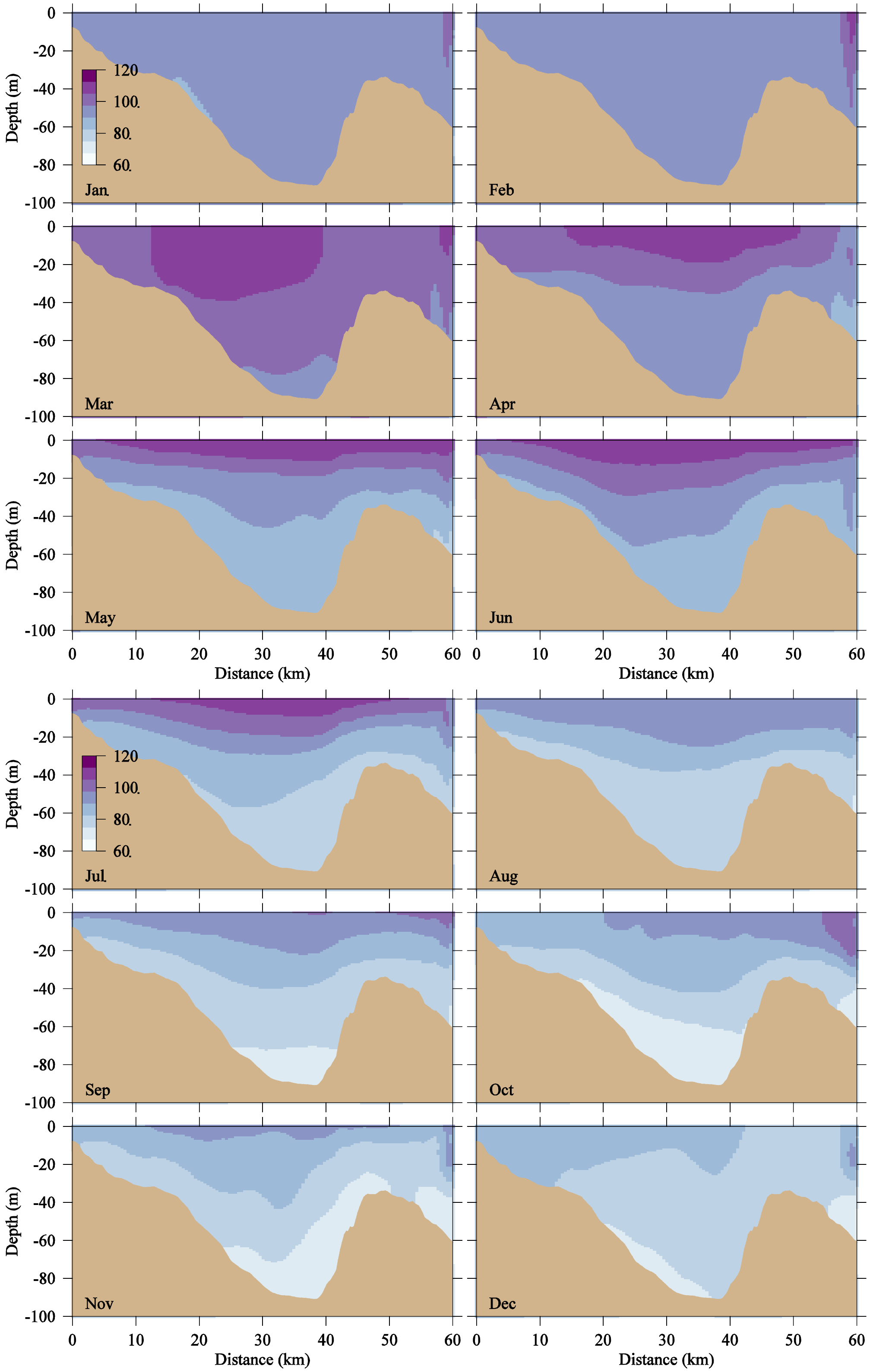


Figure 3-25. Modeled percent dissolved oxygen saturation on the west-east transect across the MWRA outfall and Stellwagen Bank National Marine Sanctuary at the end of each month from January through December in 2012.

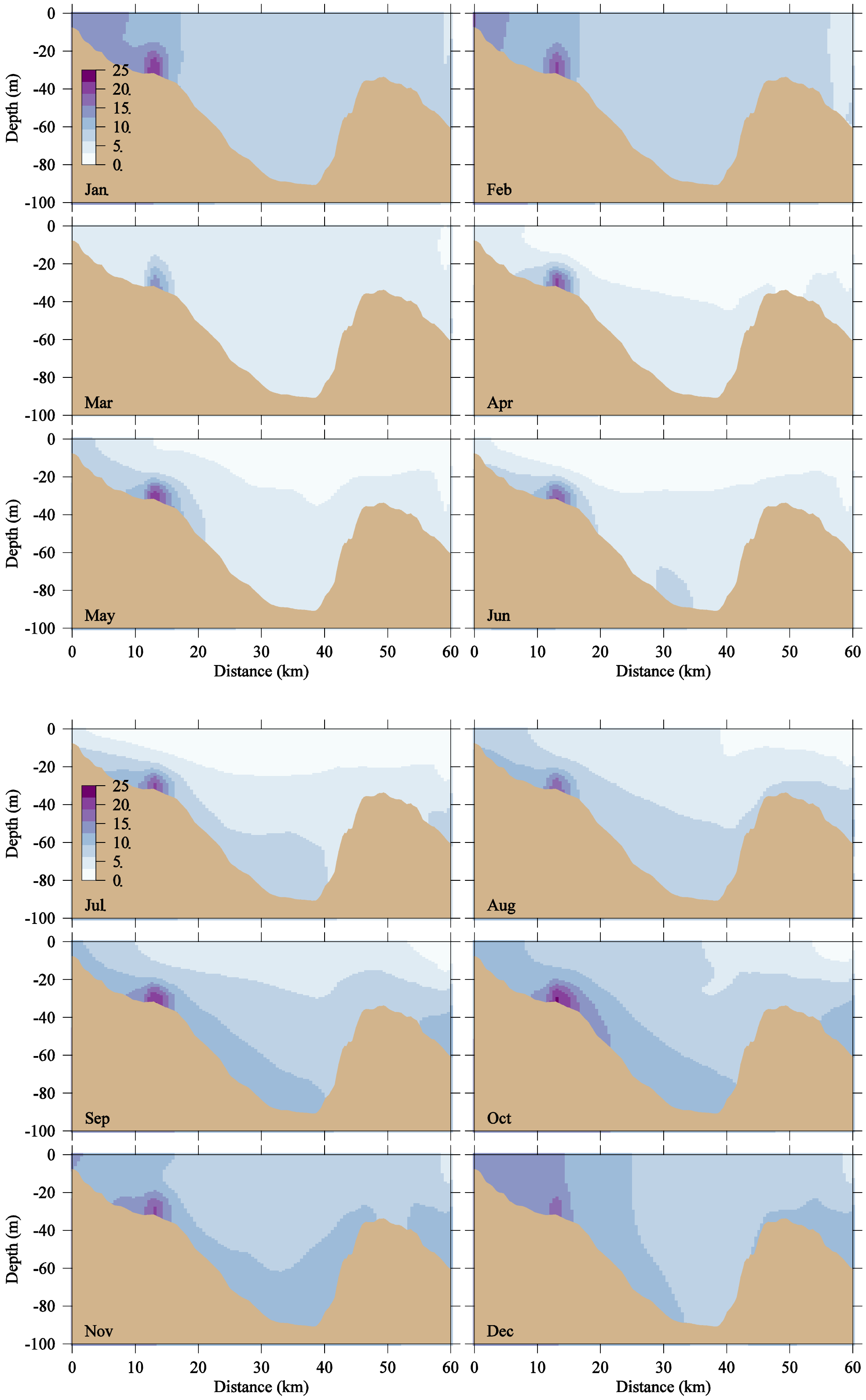


Figure 3-26. Modeled dissolved inorganic nitrogen concentrations (µM) on the west-east transect across the MWRA outfall and Stellwagen Bank National Marine Sanctuary at the end of each month from January through December in 2012.

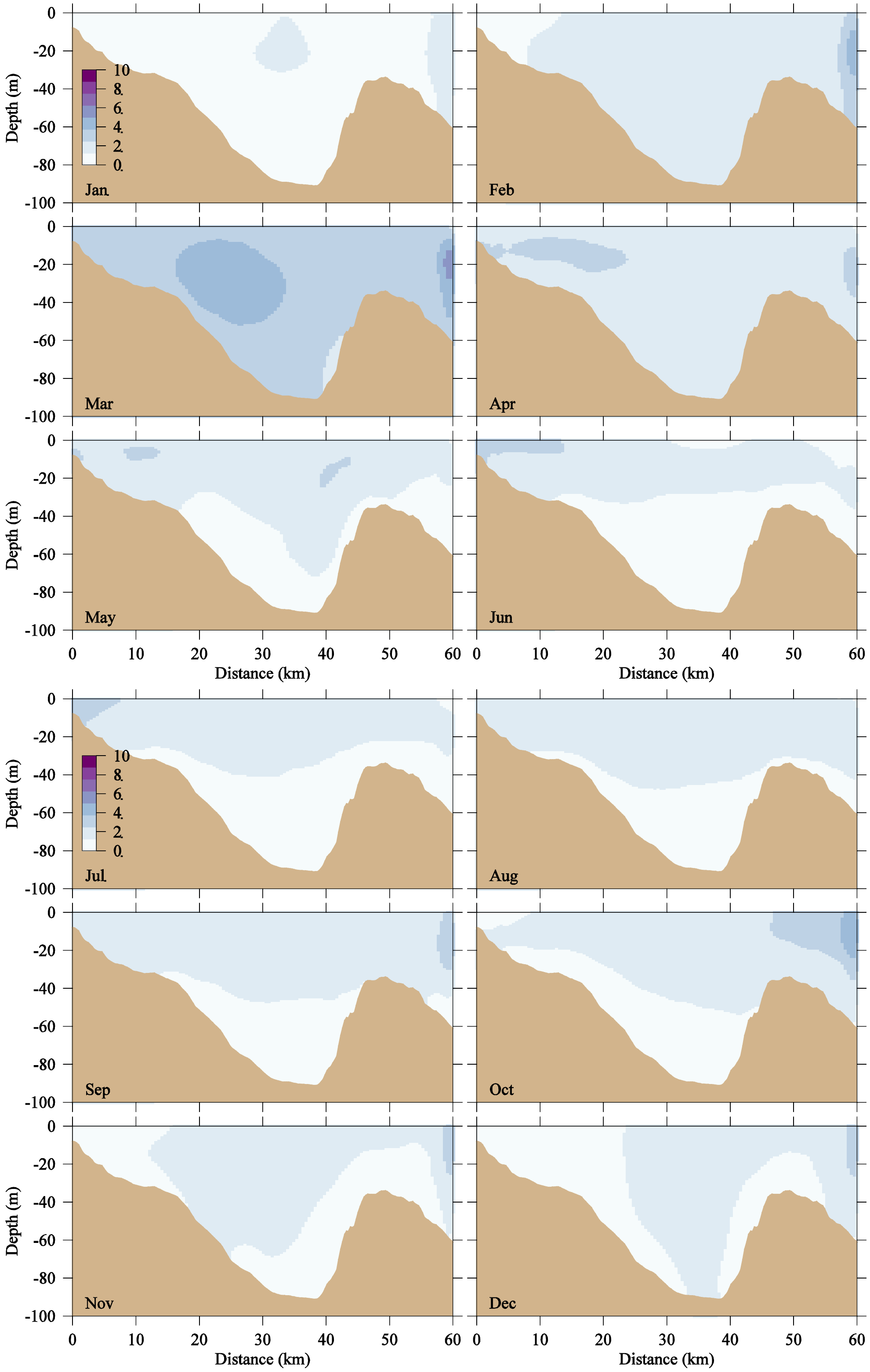


Figure 3-27. Modeled chlorophyll concentrations (µg/L) on the west-east transect across the MWRA outfall and Stellwagen Bank National Marine Sanctuary at the end of each month from January through December in 2012.

The Center for Coastal Studies monitoring program in Cape Cod Bay includes MWRA Station F29, on the southern boundary of the sanctuary as well as MWRA stations F01 and F02 in Cape Cod Bay. Major groups of phytoplankton and zooplankton followed similar abundance patterns at all three stations throughout the year (Figures 3-28 and 3-29). Phytoplankton samples showed dominance of microflagellates at all three stations during much of the year. Samples also confirmed the fall diatom bloom.

Cape Cod Bay zooplankton sampling focuses on larger species than targeted by Massachusetts Bay sampling. The sampling techniques do not capture smaller copepods, such as the *Oithona similis* seen in MWRA's Massachusetts Bay samples, but focuses on larger species, which are favored whale prey. Abundances of several larger species were lower than in 2011. Similar to the MWRA program, the large species *Calanus finmarchicus* was not abundant in any month.

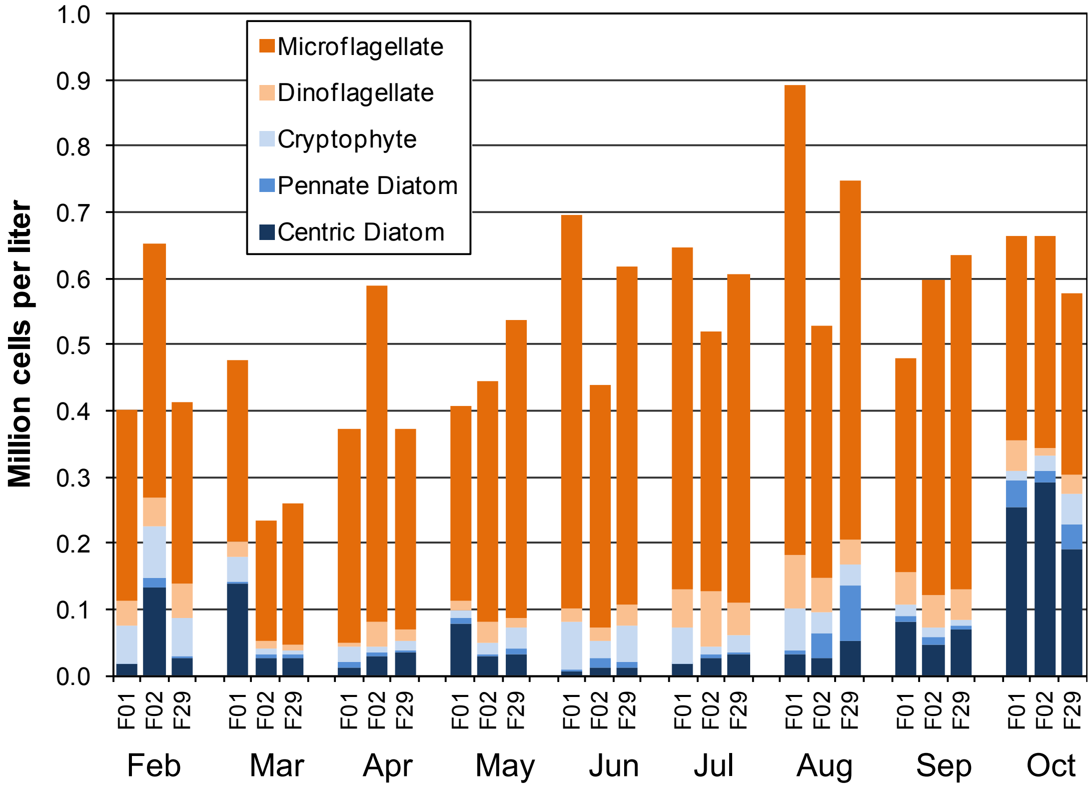


Figure 3-28. Surface-water phytoplankton abundance and composition at MWRA Cape Cod Bay stations, including Station F29 near Stellwagen Bank National Marine Sanctuary. (Data from the Center for Coastal Studies)

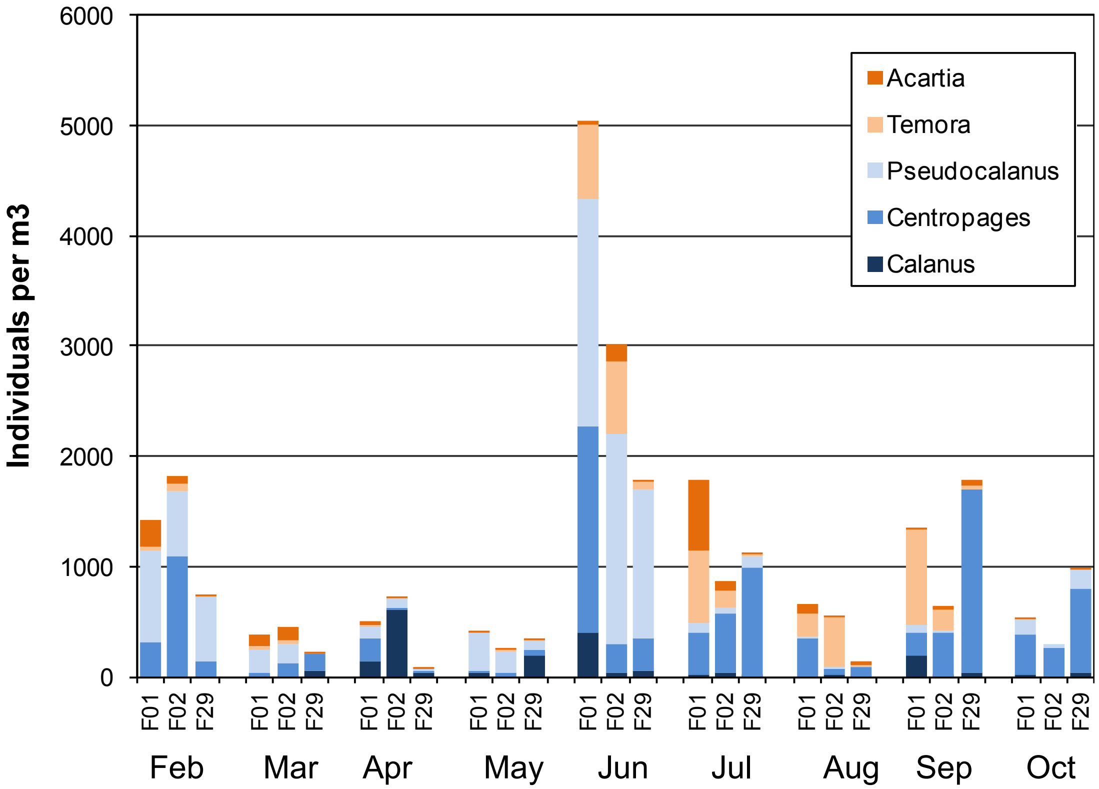


Figure 3-29. Zooplankton abundance and composition at MWRA Cape Cod Bay stations, including Station F29 near Stellwagen Bank National Marine Sanctuary. (Data from the Center for Coastal Studies)

Contingency Plan Thresholds

Most water-quality parameters were within normal ranges throughout 2012. Bottom water dissolved oxygen concentrations were consistent with the normal seasonal pattern but were low in comparison to past years, reaching minima that were only slightly above the Contingency Plan threshold baselines (Table 3-1). The low levels were due to the warm, dry conditions found in 2012 and not affected by the outfall. There were two exceedances of nuisance phytoplankton species thresholds, when samples collected in May exceeded the *Phaeocystis pouchetii* summer and *Alexandrium fundyense* caution levels. The *Phaeocystis* exceedance resulted from the early bloom lingering into May (which is considered summer for threshold calculation). The *Alexandrium* exceedance had been anticipated, based on information on overwintering *Alexandrium* cysts in the sediments off the coast of Maine and spring measurements of *Alexandrium* cells in coastal waters of Maine and New Hampshire. Results from rapid-response surveys indicated that the bloom proceeded in a pattern that was different from historic progressions, but the available data do not allow conclusions to be drawn as to the causes of this unusual bloom.

Table 3-1. Contingency Plan threshold values and 2012 results for water-column monitoring. DO = dissolved oxygen

Location/ Parameter	Specific Parameter	Baseline	Caution Level	Warning Level	2012 Results
Bottom water nearfield	Dissolved oxygen concentration	Background 5th percentile 6.05 mg/L	Lower than 6.5 mg/L for any survey (June-October) unless background conditions are lower	Lower than 6.0 mg/L for any survey (June-October) unless background conditions are lower	Lowest survey mean = 6.19 mg/L
	Dissolved oxygen percent saturation	Background 5th percentile 65.3%	Lower than 80% for any survey (June-October) unless background conditions are lower	Lower than 75% for any survey (June-October) unless background conditions are lower	Lowest survey mean = 67.5%
Bottom water Stellwagen Basin	Dissolved oxygen concentration	Background 5th percentile 6.23 mg/L	6.5 mg/L for any survey (June-October) unless background conditions lower	Lower than 6.0 mg/L for any survey (June-October) unless background conditions are lower	Lowest survey mean = 6.6 mg/L
	Dissolved oxygen percent saturation	Background 5th percentile 67.2%	Lower than 80% for any survey (June-October) unless background conditions	Lower than 75% for any survey (June-October) unless background conditions are lower	Lowest survey mean = 70.4%
Bottom water nearfield	DO depletion rate (June-October)	0.024 mg/L/d	0.037 mg/L/d	0.049 mg/L/d	0.022 mg/L/d
Chlorophyll nearfield	Annual	72 mg/m^2	108 mg/m^2	144 mg/m^2	96 mg/m^2
	Winter/spring	50 mg/m^2	199 mg/m^2	None	144 mg/m^2
	Summer	51 mg/m^2	89 mg/m^2	None	69 mg/m^2
	Autumn	90 mg/m^2	239 mg/m^2	None	78 mg/m^2
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	622,000 cells/L	2,860,000 cells/L	None	1,690,000 cells/L,
	Summer	72 cells/L	357 cells/L	None	1,120 cells/L, caution level exceedance
	Autumn	370 cells/L	2,960 cells/L	None	Absent
Nuisance algae nearfield *Pseudo-nitzschia*	Winter/spring	6,735 cells/L	17,900 cells/L	None	526 cells/L
	Summer	14,635 cells/L	43,100 cells/L	None	388 cells/L
	Autumn	10,050 cells/L	27,500 cells/L	None	2,820 cells/L
Nuisance algae nearfield *Alexandrium fundyense*	Any nearfield sample	Baseline maximum = 163 cells/L	100 cells/L	None	3,731 cells/L, caution level exceedance
Farfield	PSP toxin extent	Not applicable	New incidence	None	No new incidence

4. Sea Floor

Sea-floor monitoring in 2012 included soft-bottom sampling for sediment conditions and infauna at 14 stations and sediment-profile imaging at 23 stations (Figures 4-1 and 4-2).

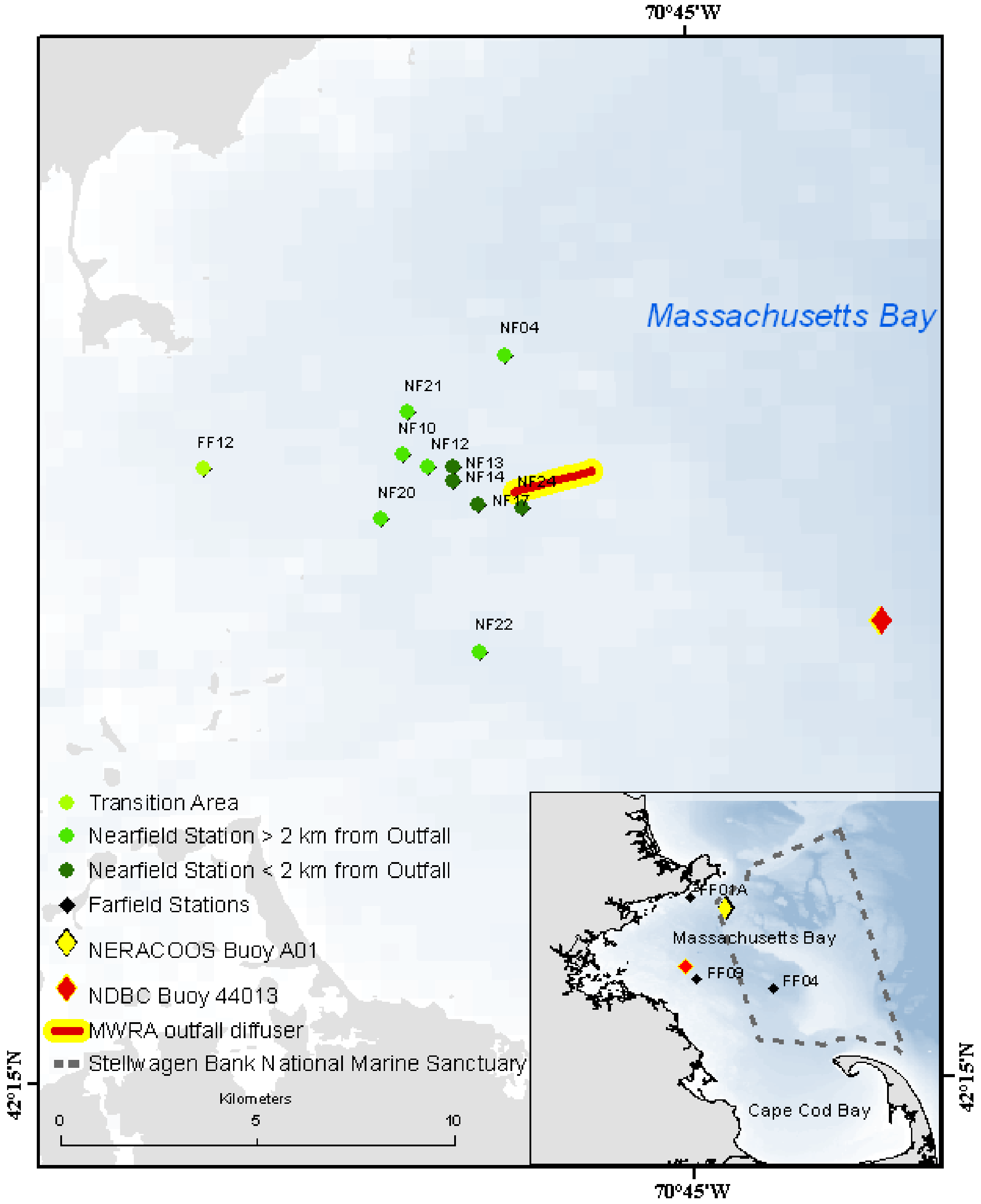


Figure 4-1. Soft-bottom monitoring stations. Fourteen stations were sampled for benthic community parameters and sediment characteristics. Also shown are the instrumented buoys, the MWRA outfall diffuser, and the Stellwagen Bank National Marine Sanctuary.

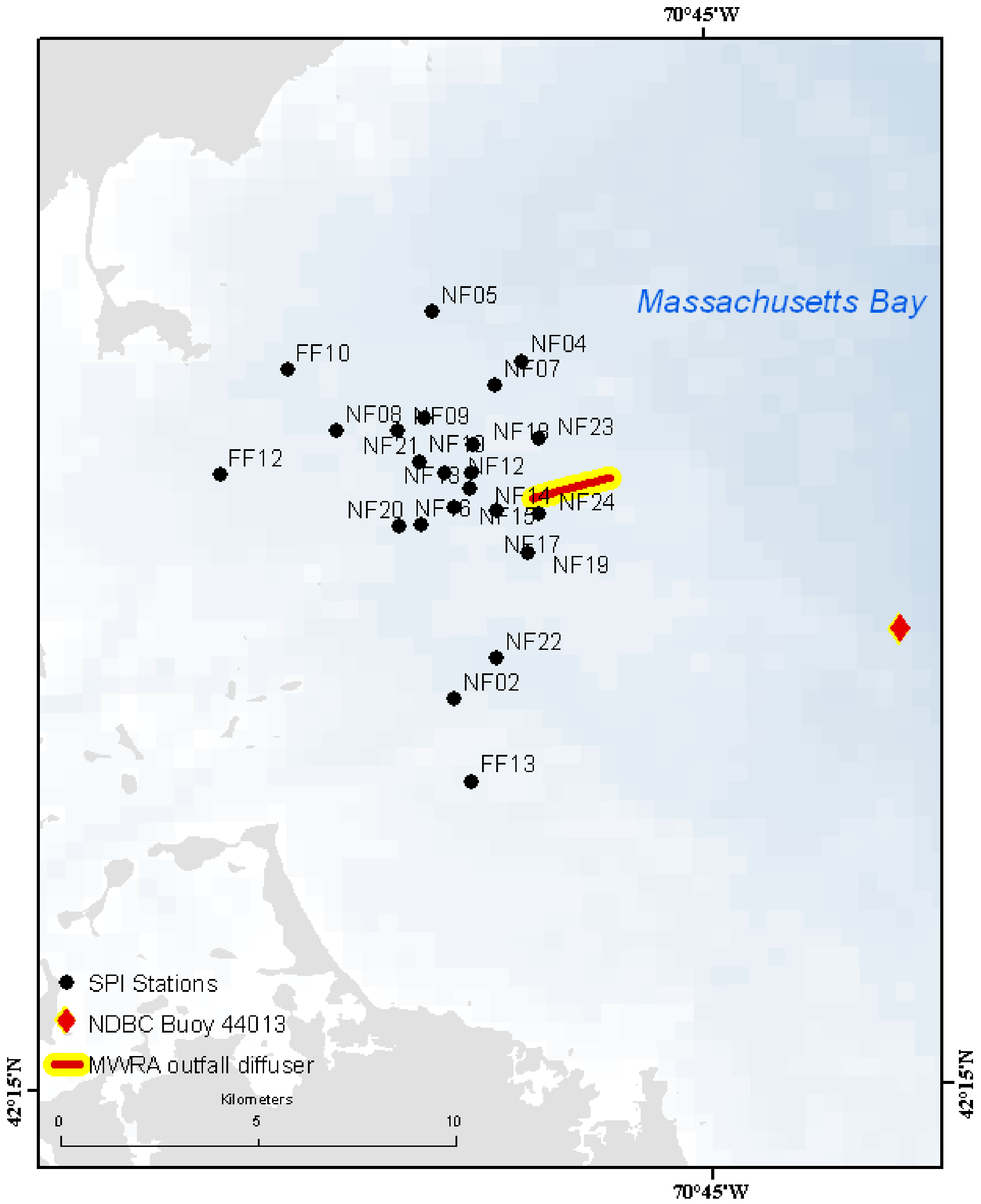


Figure 4-2. Sediment-profile imaging stations. Twenty-three stations are monitored. Also shown are the NDBC buoy and the MWRA outfall diffuser.

Sampling for grain-size composition, total organic carbon, the effluent tracer *Clostridium perfringens* spores, and benthic infauna was completed during August, following the revised monitoring plan implemented in 2011 (MWRA 2010, Werme et al. 2012). Sediment and infauna sampling included one station in the "transition" area, located between Boston Harbor and the nearfield stations (FF12); four nearfield stations located within two kilometers of the outfall (NF13, NF14, NF17, NF24); six nearfield stations located within Massachusetts Bay but farther than two kilometers from the outfall (NF04, NF10, NF12, NF20, NF21, NF22); and three farfield reference stations located in Massachusetts Bay and Cape Cod Bay (FF01A, FF04, and FF09). For the purposes of threshold testing, "nearfield" includes the transition station, as well as both groups of nearfield stations, for a total of eleven stations. The new design provides greater consistency than the one it replaced, in which different sets of soft-bottom stations were sampled in alternate years.

Sediment-profile images were made on August 12. The images were used to measure the apparent reduction-oxidation (redox) potential discontinuity (RPD) depth, apparent successional stage of the community, and an organism sediment index which is derived from the RPD depth and the successional stage.

Sediment Characteristics and Tracers

Grain-size distributions of sediment samples in 2012 remained consistent with results from past years, ranging from silt and clay at some stations to mostly sand at others (Nestler et al. 2013). Percent organic carbon content in the samples was also consistent with past results at most stations, with higher mean total organic carbon concentrations at stations with finer sediments. Total organic carbon concentrations showed no signs of organic enrichment from the effluent discharge, even at stations closest to the outfall.

As in past years since the outfall came on line (except 2006), it was possible to detect elevated levels of the effluent tracer, *Clostridium perfringens* spores, at the stations located closest to the outfall, although even at these stations, concentrations fell within the baseline range (Figures 4-3 and 4-4). Concentrations of *Clostridium perfringens* spores were highest at Stations NF13 and NF24, both located within two kilometers of the outfall. Overall, there has been a large decline in *Clostridium perfringens* spores at the transition station FF12 since the baseline period. A smaller decline may also be apparent in the nearfield samples farther from the outfall, while concentrations at farfield locations have remained stable. A concurrent monitoring program for Boston Harbor has documented declines in *Clostridium* spore counts throughout the Boston Harbor Project, with 2012 spore counts remaining consistently below historic levels (Pembroke et al. 2013).

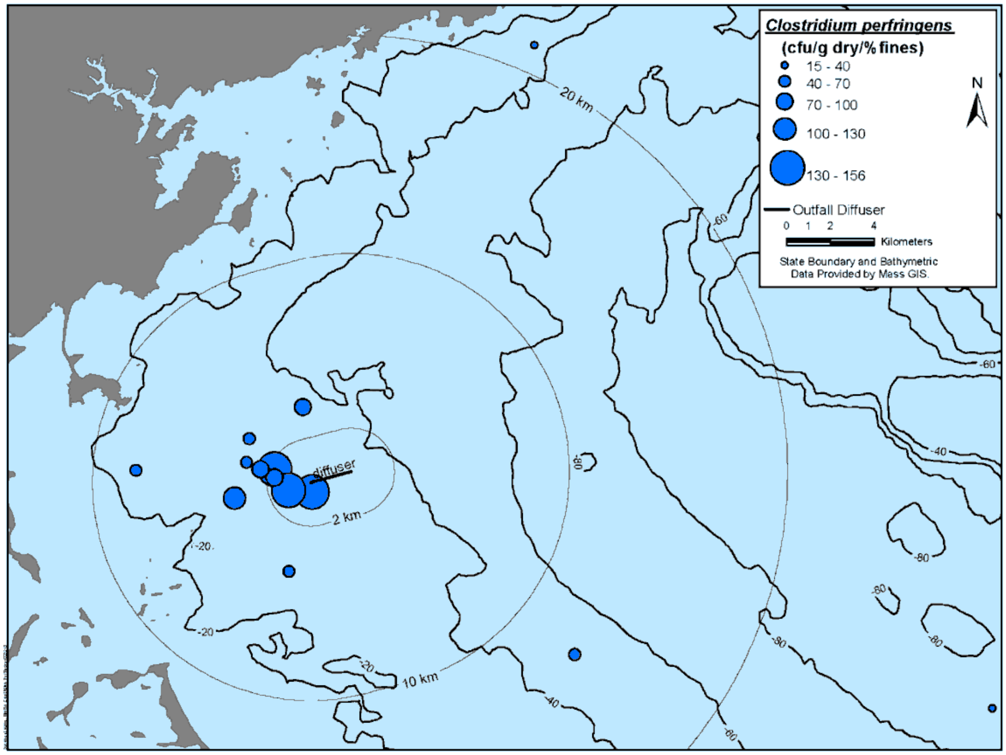


Figure 4-3. Concentrations of *Clostridium perfringens* spores, normalized for sediment grain size, in 2012.

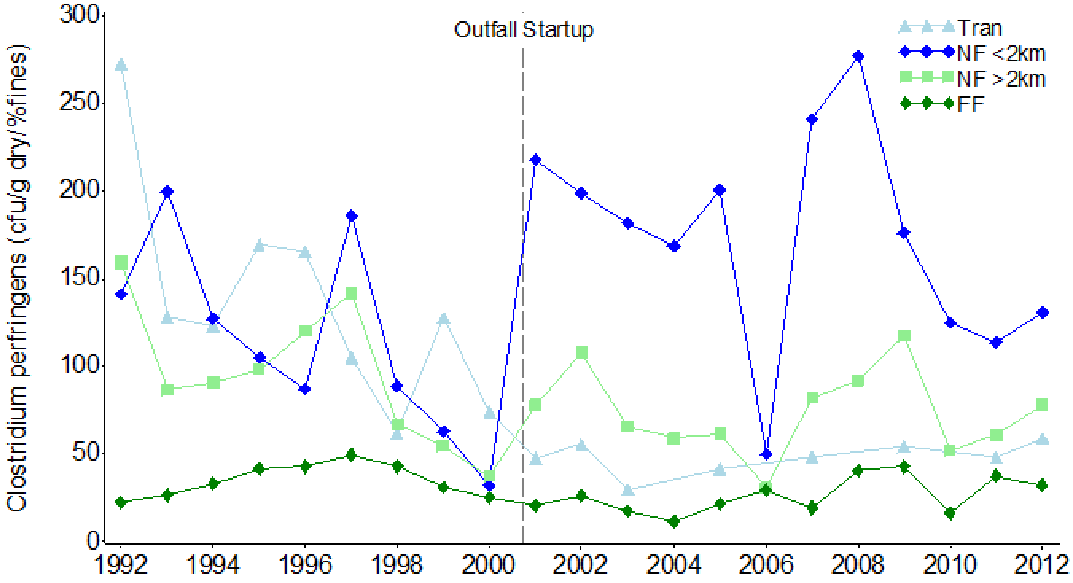


Figure 4-4. Mean concentrations of *Clostridium perfringens* spores during the baseline and outfall-discharge years. Tran = transition area, stations located between Boston Harbor and the nearfield; NF<2km = stations within 2 km of the outfall; NF>2km = nearfield stations greater than 2 km from the outfall;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

Soft-bottom Communities

The soft-bottom communities continued to show no response to the outfall relocation (Nestler et al. 2013). Monitoring has shown that community structure is determined primarily by grain-size distribution of the sediments and by natural fluctuations in populations. Data from 2012 were consistent with past years' results.

Sampling and analysis of the 14 samples taken in 2012 yielded 27,114 organisms, classified into 210 species and 30 other taxonomic groups. The numbers of organisms per sample were higher than found in 2010 and 2011 in all regions and comparable to the historic means (Figure 4-5). Relative abundances of the five dominant species in the samples, those contributing at least 5% to total abundance numbers, were low in 2012, as they has been for several years (Figure 4-6). In particular, the polychaete *Prionospio steenstrupi*, which was the numerically dominant species during much of the 1990s and 2000s, was present in low numbers.

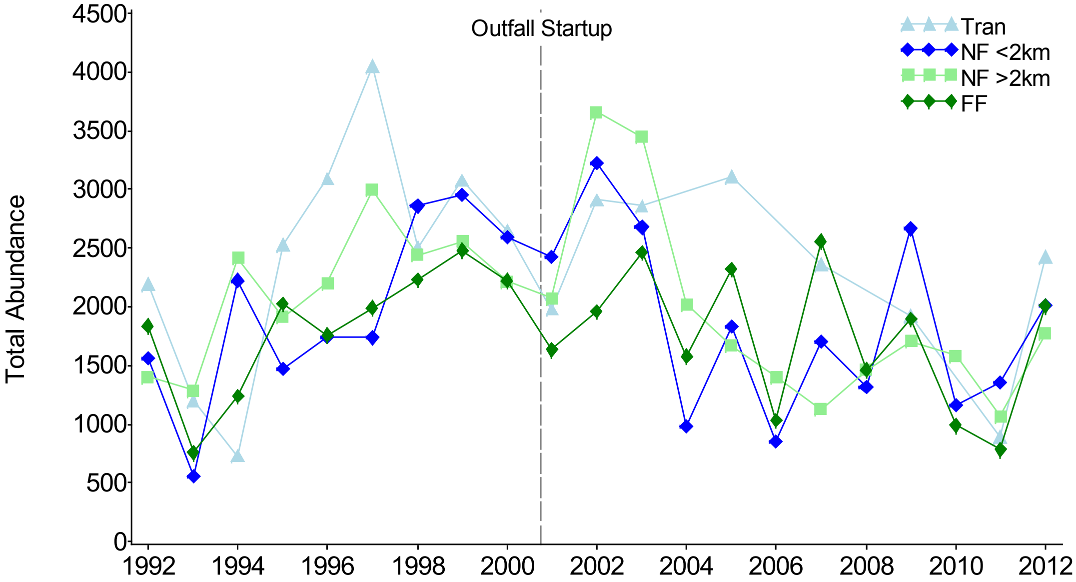


Figure 4-5. Mean infaunal abundance per sample in four areas of Massachusetts Bay, 1992–2012. Tran = transition area, stations located between Boston Harbor and the nearfield; NF<2km = stations within 2 km of the outfall; NF>2km = nearfield stations greater than 2 km from the outfall; FF = farfield stations offshore from the outfall

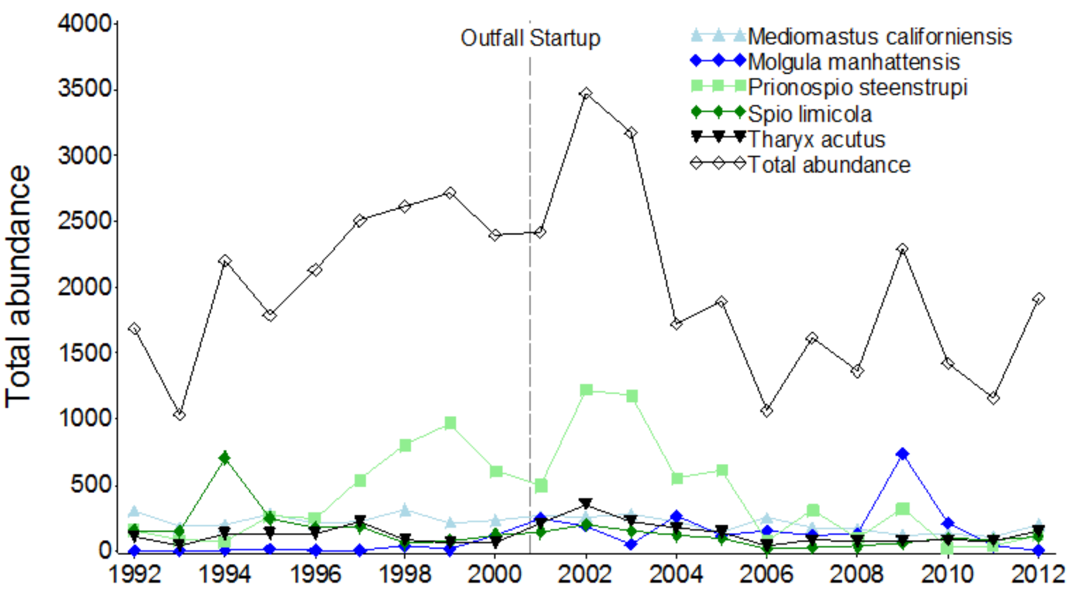


Figure 4-6. Mean abundance per sample of five dominant species and total abundance at nearfield stations, 1992–2012.

A series of multivariate analyses assessed spatial and temporal patterns in the communities and found no particular species or type of community that could be specifically associated with the outfall. A cluster analysis, which identified six separate faunal assemblages in the region, found that three of those species groups occurred at stations within two kilometers of the outfall but also at stations farther away. Species distributions were largely determined by sediment types.

Temporal analyses suggested that species assemblages have varied little since 1992 and that samples were most similar to others collected from the same station over time. These analyses are discussed further under in the subsection addressing Stellwagen Bank National Marine Sanctuary below.

Sediment-profile Imaging

Sediment-profile imaging measurements continued to show no adverse effects of the outfall (Nestler et al. 2013). Monitoring has shown that physical processes, such as storms and storm-induced sediment transport, are the primary stressors on the sea floor. The dominance of physical forces may be considered typical of outfalls that have been located in high-energy areas that promote rapid dispersion of effluent.

The RPD depth (the depth to which oxygen penetrates into sediments as determined by color changes) remained deeper than the baseline mean, as it has been during most outfall-discharge years (Figure 4-7). The environmental concern before the outfall came on line was that the RPD depth would become shallower, so a deeper RPD depth continues to indicate that there has been no adverse effect from the discharge.

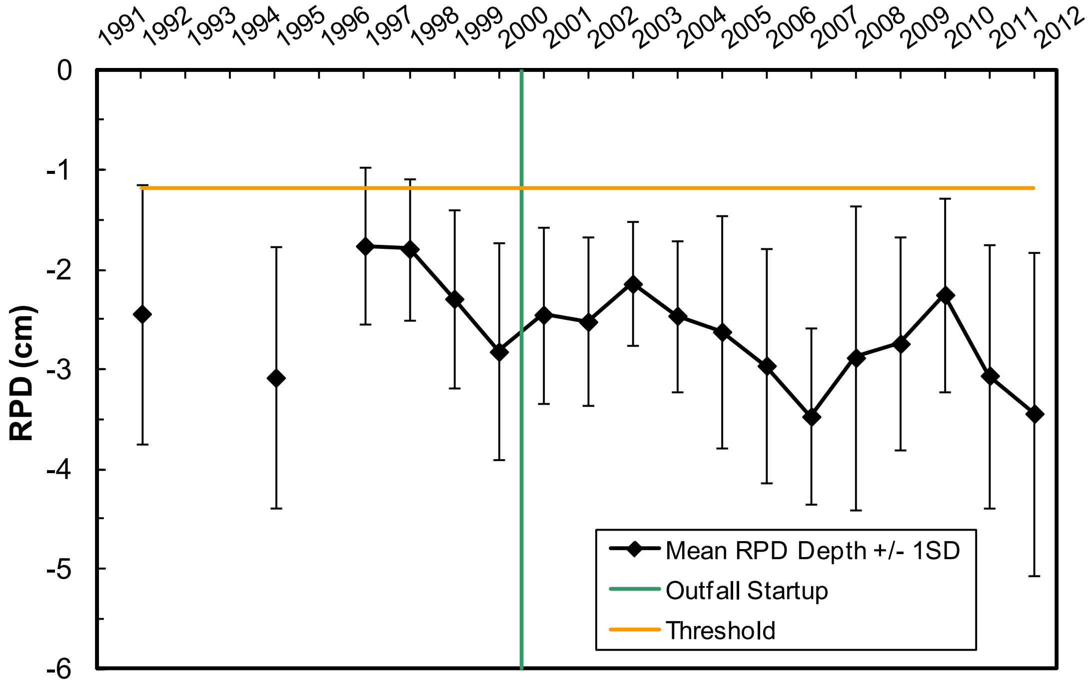


Figure 4-7. Annual apparent color RPD depth for data from nearfield stations. The mean RPD for the outfall-discharge years is slightly deeper than the baseline mean, indicating that there has been no adverse effect from the discharge. SD = standard deviation

The sediment-profile images also found no indications of organic carbon accumulation and no adverse effects on the types of organisms inhabiting the sediments. There is no evidence of organic carbon accumulation, even at stations located close to the outfall (Figure 4-8). If organic carbon concentrations were increasing in the sediments, the images would show increased darkening at the sediment surface, but the images continue to show light-colored, oxygenated surface sediment.

Figure 4-8. Thumbnail images from Station NF24, located within two kilometers of the outfall. There are no indications of increased organic carbon content or other outfall effects. Black hash marks are at five-centimeter intervals in images made prior to 2006 (many are quite faint). Hash marks in recent images are at one-centimeter intervals.

Stellwagen Bank National Marine Sanctuary

The NPDES permit to discharge from DITP into Massachusetts Bay requires annual reports on results that are relevant to the Stellwagen Bank National Marine Sanctuary. One MWRA sea-floor station lies within the sanctuary, in Stellwagen Basin, which is a long-term sediment sink (FF04, see Figure 4-1). Station FF09 is adjacent to the basin, southeast of the outfall diffusers. A third sea-floor station (FF01A) is just northwest of the sanctuary boundary. No large or unexpected changes in bottom-community parameters have been measured within or near the sanctuary since the outfall came on line.

Sediment conditions have not changed at Station FF04, and the deep-water station continued to support infaunal communities typical of the monitoring program (Nestler et al. 2013). As would be expected because of its depth, there are some differences from the shallower communities in the nearfield and elsewhere in Massachusetts Bay. Multivariate analyses of soft-bottom fauna showed that Station FF04 has consistently contained a somewhat distinct infaunal community, in that its samples group together, apart from samples from other stations (Figure 4-9). Community differences at Station FF04 in 2010, 2011, and 2012 compared to earlier years may reflect the decreases in the abundant polychaete *Prionospio steenstrupi*, which has decreased in numbers throughout the region.

The separate grouping reflects Station FF04's deepwater, silty sediment, typical for Stellwagen Basin, whereas many shallower stations are sandier. Monitoring during 1992–2010 showed the faunal community currently found at Station FF04 to be widespread throughout deeper waters, with similar faunal assemblages occurring at all stations with water depths greater than 70 meters.

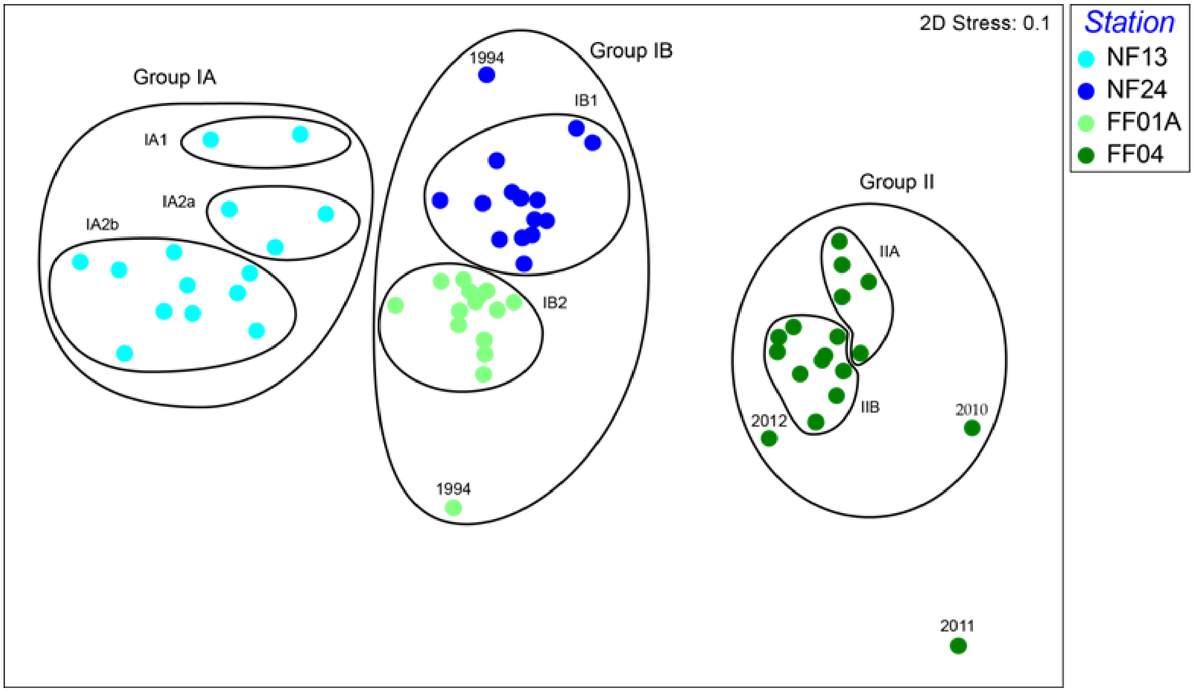


Figure 4-9. Soft-bottom community data superimposed on a non-metric multidimensional scaling plot, a multivariate analyses tool. Each point represents one sample collected during 1992–2012. Similarity of species composition is indicated by proximity of the points on the plot. Station FF04 (located within Stellwagen Basin and almost 30 km southeast of the outfall), has consistently maintained a unique fauna in comparison to sandier stations NF13 (about 2 km north of the outfall), NF24 (less than 2 km south of the outfall), and FF01A (more than 20 km northeast of the outfall).

Contingency Plan Thresholds

RPD depth was more than twice as deep as the caution level, and percent opportunists among the soft-bottom community remained far below caution and warning levels. However, for a third consecutive year, there were Contingency Plan threshold exceedances for sea-floor community parameters (Table 4-1). Values for two threshold parameters, Shannon-Wiener diversity and Pielou's evenness, were higher than the caution-level ranges (Figure 4-10). Two other community threshold parameters, total number of species per sample and Fisher's log-series alpha, were within the caution-level ranges.

Similar exceedances of Shannon-Wiener diversity and Pielou's evenness thresholds were observed in 2010 and 2011 and evaluated in consultation with the Outfall Monitoring Science Advisory Panel (OMSAP). Those evaluations found that the 2010 and 2011 exceedances probably resulted from natural fluctuations in the communities and that they were not related to any outfall effect.

Spatial and temporal analyses showed that the increases in Shannon-Wiener diversity and Pielou's evenness did not result from changes at the stations closest to the outfall. Instead, the threshold exceedances were driven by data from nearfield stations that are farther away, more than two kilometers from the outfall and less likely to be influenced by the discharge. Region-wide declines in the abundance of the numerically dominant species, particularly the spionid polychaete *Prionospio steenstrupi*, are likely important factors in the recent increases.

Increases in Shannon-Wiener diversity and Pielou's evenness can be a signal of improvements rather than degradation in environmental conditions. However, the Contingency Plan community measures thresholds were selected to be triggered by any results that would indicate a change from baseline conditions, and consequently, they have upper as well as lower bounds.

Table 4-1. Contingency Plan threshold values and 2012 results for sea-floor monitoring.

Location/ Parameter Type	Parameter	Caution Level	Warning Level	2012 Results
Nearfield	RPD depth	<1.18 cm	None	3.441 cm
Even years, benthic diversity, nearfield	Species per sample	442.99 or >81.85	None	73.45
	Fisher's log-series alpha	<9.42 or >15.8	None	15.68
	Shannon-Wiener diversity	<3.37 or >3.99	None	4.36, caution level exceedance
	Pielou's evenness	<0.57 or >0.67	None	0.70, caution level exceedance
Benthic opportunists	% opportunists	>10%	>25%	0.16 %

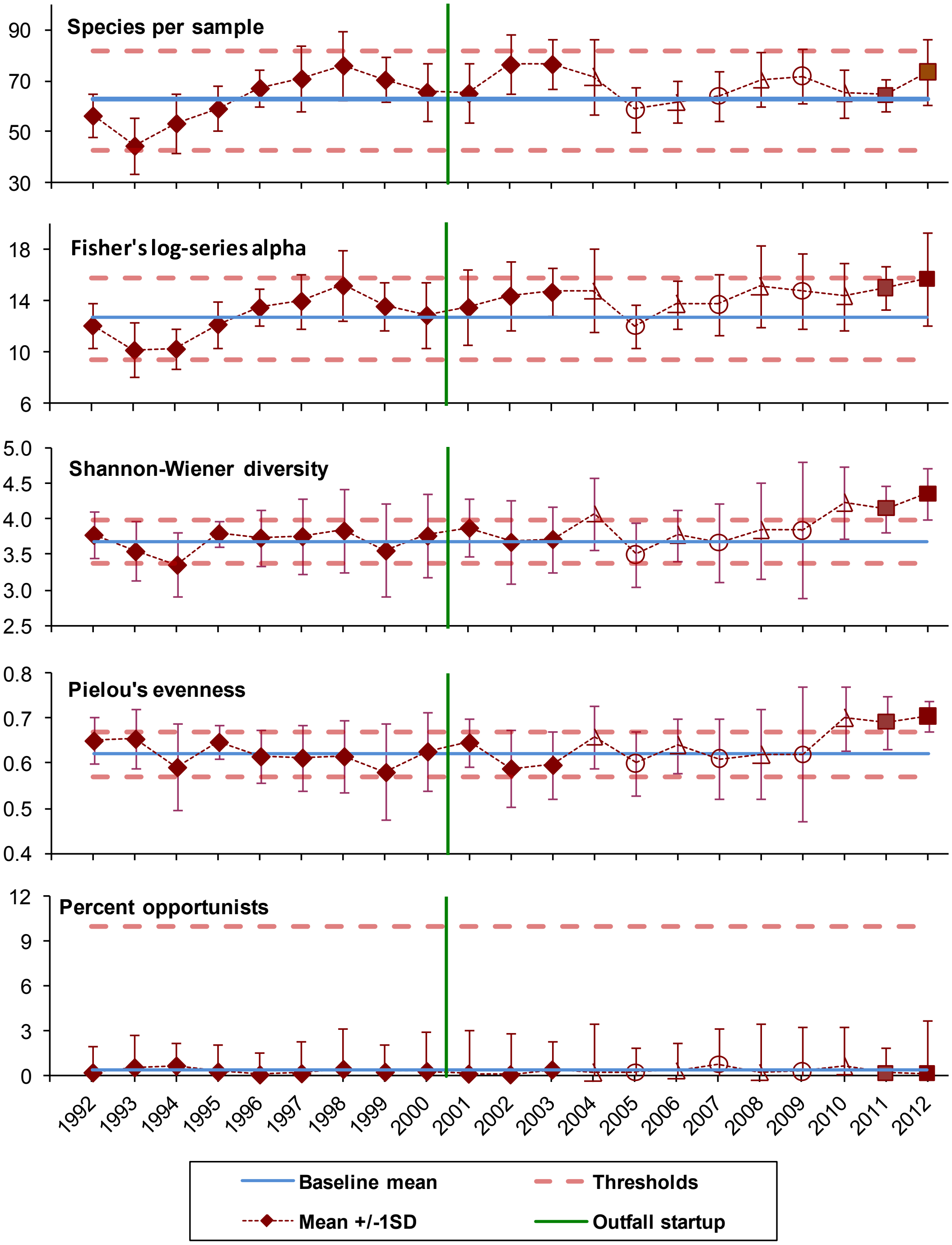


Figure 4-10. Annual community parameters with nearfield Contingency Plan thresholds. The varied symbols represent differences in the stations sampled over the years of the program. Results were tested against thresholds calculated for each sampling design, but only the current threshold values are shown. Except for the percent opportunists threshold, which is based on levels in Boston Harbor, thresholds have both upper and lower bounds show potentially meaningful changes from the baseline. SD = standard deviation

5. Fish and Shellfish

Each year MWRA monitors the health of winter flounder from Deer Island Flats in Boston Harbor, off Nantasket Beach just outside the harbor, the Massachusetts Bay outfall site, and eastern Cape Cod Bay. Every three years, including 2012, monitoring includes chemistry measurements in flounder fillets and liver, lobster meat and hepatopancreas, and blue mussel tissue. Lobsters are sampled from Deer Island Flats, the outfall site, and Cape Cod Bay. Mussels are deployed at two sites near the outfall, at Deer Island Light, and in Boston's inner harbor (Figure 5-1).

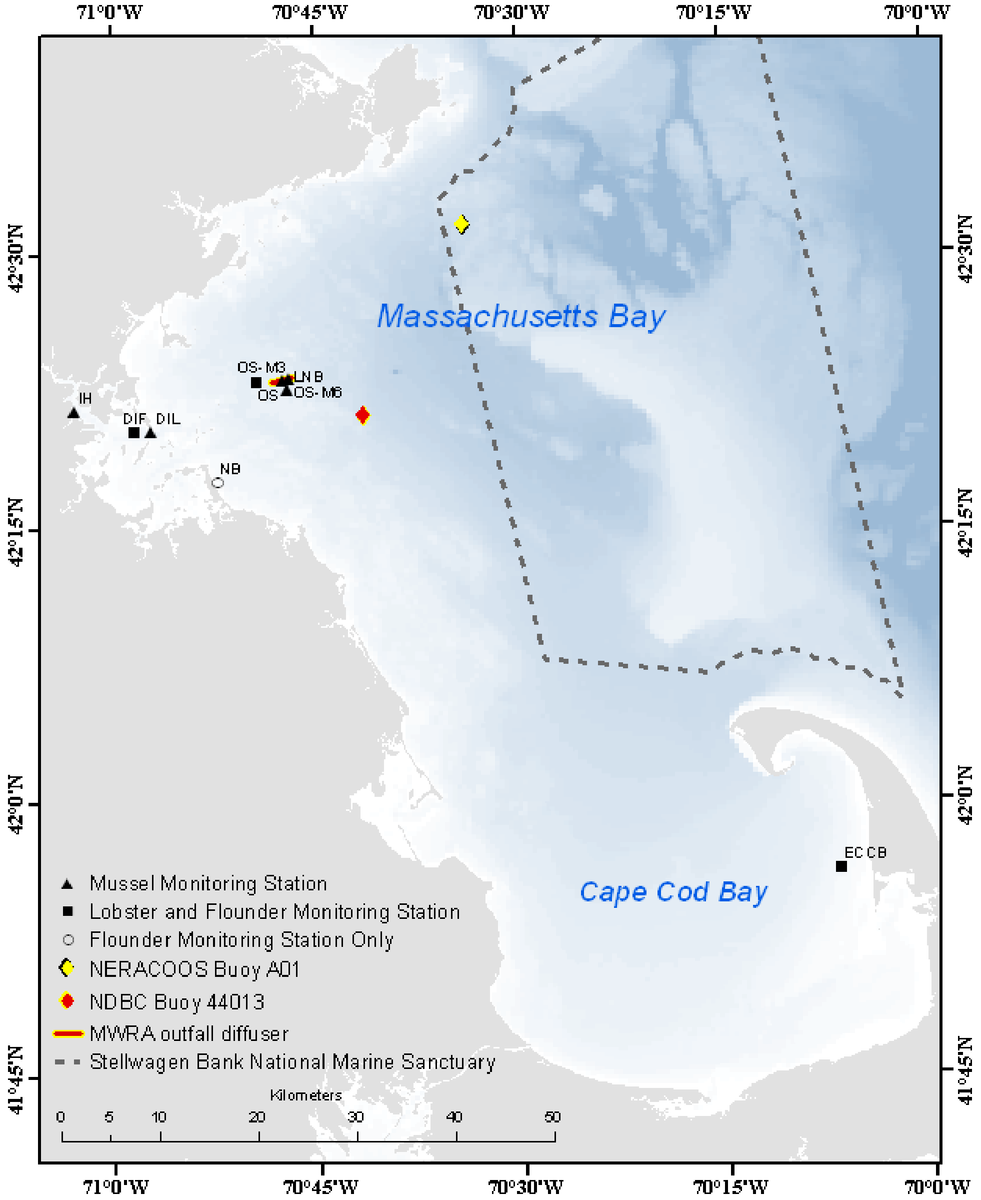


Figure 5-1. Fish-and-shellfish monitoring stations. Also shown are the two instrumented buoys, the MWRA outfall diffuser, and the boundaries of the Stellwagen Bank National Marine Sanctuary.

Flounder Health

Annual flounder monitoring focuses on the presence of early liver disease and liver neoplasms (tumors). Other indications of health are also documented. In April 2012, 50 sexually mature flounder were collected from each site (Moore et al. 2012). Catch per unit effort remained low near the outfall and off Nantasket Beach, as has been typical, and there was a small decrease in eastern Cape Cod Bay, although the catches there remained the highest of the regions. Catch per unit effort increased at Deer Island Flats to the highest levels observed since 2005. Abandoned fishing gear continued to interfere with catches at the outfall site and Deer Island Flats.

Average ages, lengths, and weights of the winter flounder collected from near the outfall site in 2012 were lower than in most years. Average age fell at all locations except Deer Island Flats, but remained within the historic range for the monitoring program. As they have been throughout most of the monitoring program, the catches continued to be dominated by females. The percent females increased at all sites, to more than 95% at Nantasket Beach and eastern Cape Cod Bay.

External condition measures also fell within historic ranges. Prevalence of fin erosion, a condition that can be indicative of elevated concentrations of ammonium and other pollutants, was highest at Deer Island Flats and within the historic range of the monitoring program, continuing to be much lower than had been observed in other studies during the 1980s. The greatest percentage of another common condition, bent fin ray, also occurred at Deer Island Flats. Incidence of blind-side ulcers, which were first noted in 2003, decreased substantially from 2011 and were present only at Nantasket Beach and the outfall site.

No neoplasms were observed in any fish from any site. Incidence of neoplasia has been rare throughout the area since routine monitoring started in 1991, although levels were as high as 12% in flounder taken from Boston Harbor for studies during the 1980s. Neoplasia has never been observed in a fish taken from the outfall site.

The incidence of centrotubular hydropic vacuolation (CHV), a mild condition associated with exposure to contaminants, remained lower than the baseline observations. Incidence of CHV, corrected for age, continued to drop in fish taken near the outfall site after a gradual increase observed during 2005–2010 (Figure 5-2). CHV incidence in fish from Deer Island Flats remained lower than the relatively high baseline levels and about the same as was measured in 2011. Average severity of CHV also remained lower than baseline levels.

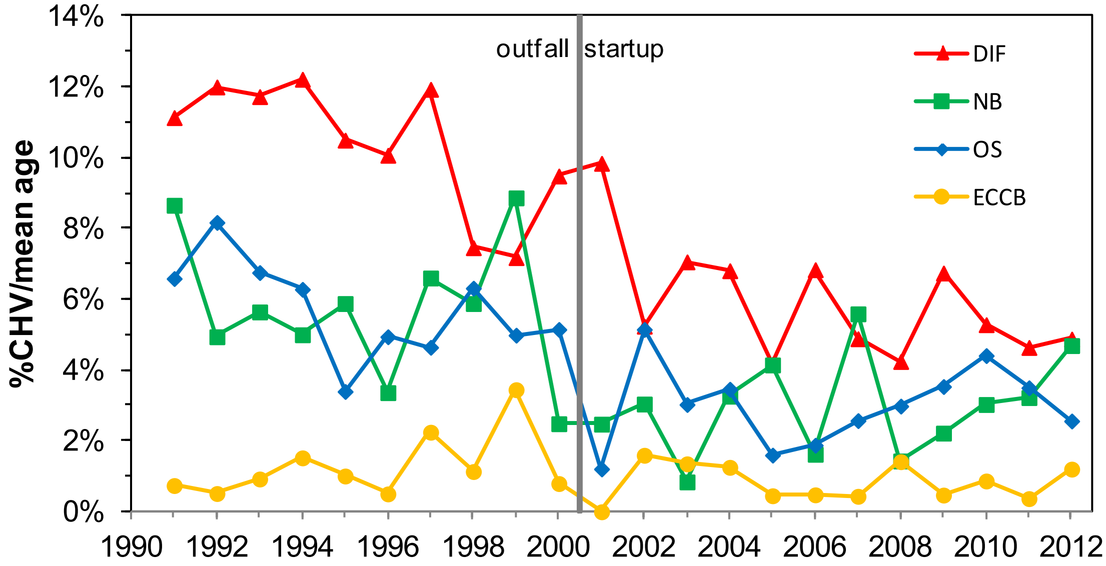


Figure 5-2. Annual prevalence of centrotubular hydropic vacuolation (CHV), corrected for age. DIF = Deer Island Flats, NB = Nantasket Beach, OS = Outfall site, ECCB = Eastern Cape Cod Bay

Fish and Shellfish Chemistry

Samples for chemical analyses of winter flounder tissues were taken from the same April collections made for the health assessments (Hall et al. 2013). Three replicates of winter flounder fillets and livers, each composed of tissue from five fish, were analyzed for PCBs, pesticides, and mercury. Liver samples were also analyzed for selected metals and polycyclic aromatic hydrocarbons (PAHs).

Lobsters were collected by local lobstermen in August and October. Three replicates of lobster meat and hepatopancreas were composed of tissues from seven lobsters from each site and were analyzed for PCBs, pesticides, and mercury. Hepatopancreas samples were also analyzed for metals and PAHs.

Mussels were collected in June from a reference location at Pemaquid Point, Maine, and deployed in cages for 60 days, ending in late August. Mussel tissues were analyzed for PCBs, pesticides, PAHs, mercury, and lead.

Concentrations of organic compounds in flounder fillets and livers remained low, as they have been throughout the monitoring program. Concentrations of the banned organochlorine pesticides, DDT and chlordane, and their breakdown products continued to show long, slow, region-wide declines in most samples. Concentrations of PCBs in fillet samples from Deer Island Flats, Nantasket Beach, and the outfall site were higher than in most past years, but within the range for the monitoring program (Figure 5-3). PCB levels also increased in liver samples but were lower than those measured in 1995 at all sites (Figure 5-4).

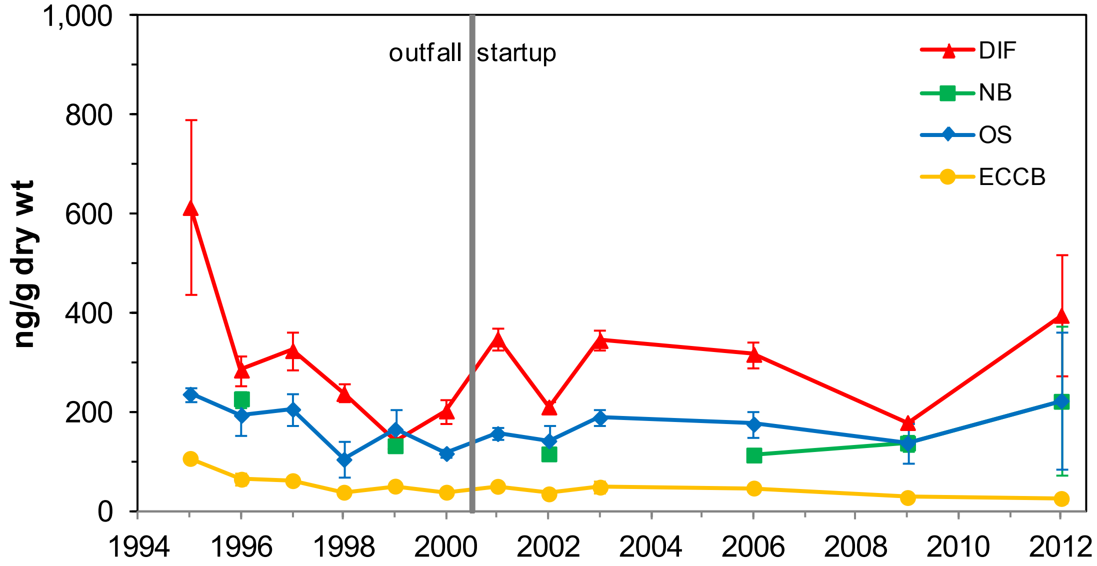


Figure 5-3. PCBs in flounder fillets, 1995–2012. DIF = Deer Island Flats, NB = Nantasket Beach, OS = Outfall site, ECCB = Eastern Cape Cod Bay

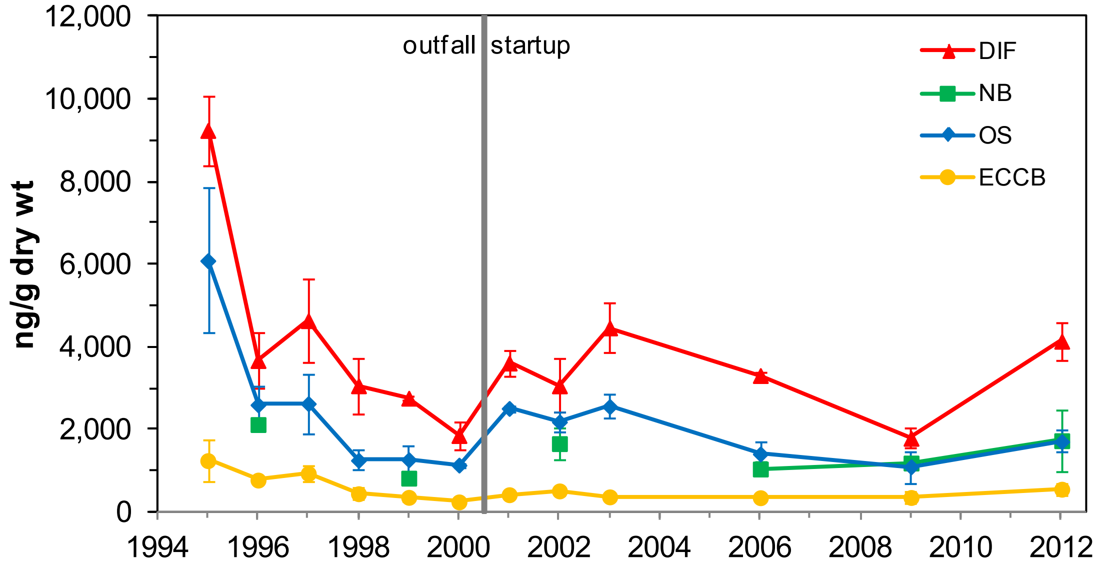


Figure 5-4. PCBs in flounder livers, 1995–2012. DIF = Deer Island Flats, NB = Nantasket Beach, OS = Outfall site, ECCB = Eastern Cape Cod Bay

In contrast, PCB levels in lobster tissues were among the lowest measured throughout the monitoring program. PCB concentrations in lobster meat samples were low at all three sites (Figure 5-5). Concentrations in hepatopancreas samples were similarly low. Concentrations of other organic contaminants in lobster samples were also very low, continuing to reflect long, slow declines, while metals levels continued to have less predictable spatial and temporal patterns.

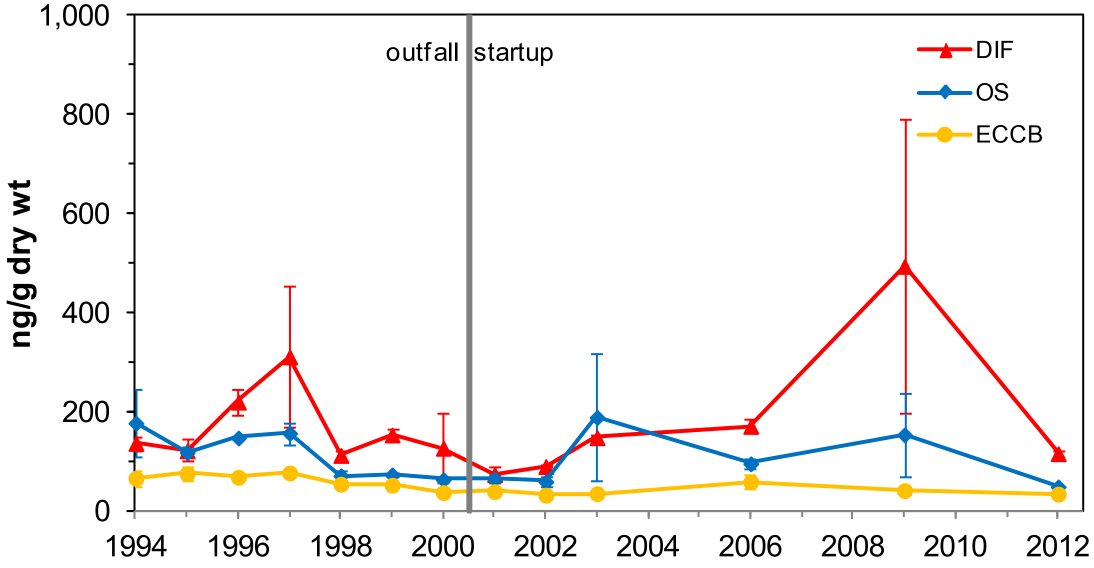


Figure 5-5. PCBs in lobster meat, 1994–2012. DIF = Deer Island Flats, OS = Outfall site, ECCB = Eastern Cape Cod Bay

Deployed mussels also showed historically low levels of PCBs (Figure 5-6). Concentrations of other organic compounds were also low. Total chlordane, which was not detected in the source mussels, bioaccumulated at all sites, but to similarly low levels except the Boston inner harbor. Mussels from the inner harbor also accumulated higher levels of DDT, PAHs, mercury, and lead. Lead levels at all sites except the inner harbor were very low, even lower than detected in the source mussels (Figure 5-7).

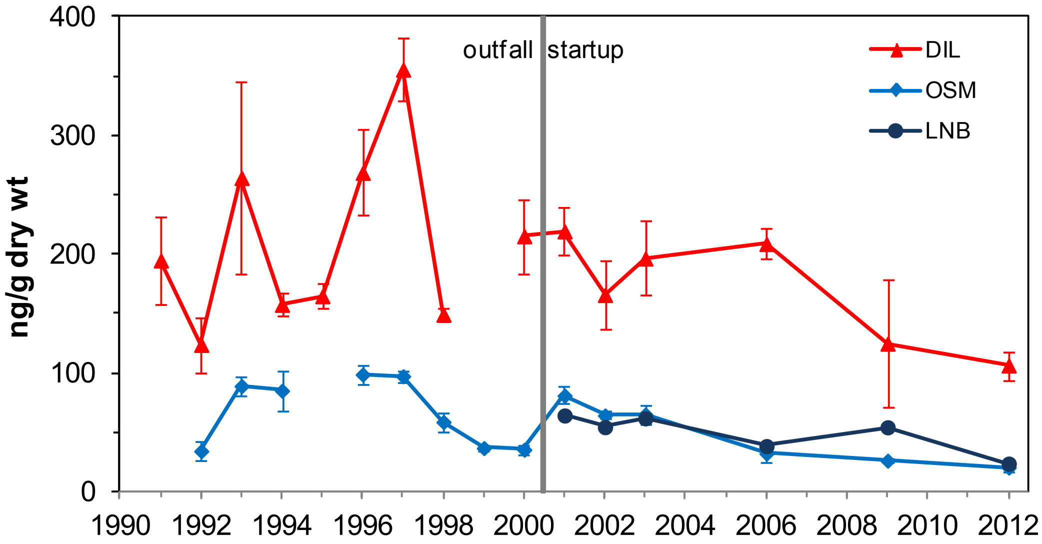


Figure 5-6. PCBs in deployed mussels, 1991–2012. DIL = Deer Island Light; OSM = Outfall site, four locations just south of the diffuser heads; LNB = Buoy B, one kilometer south of the outfall

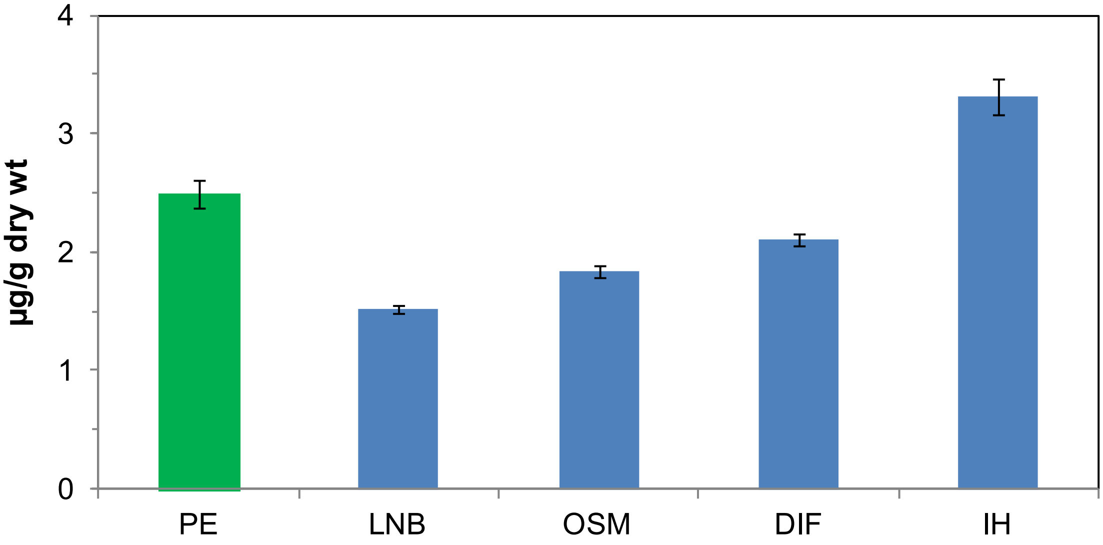


Figure 5-7. Lead in deployed mussels, 2012. Levels at the outfall site were lower than those found at the reference site. PE = reference site at Pemaquid Point, Maine; LNB = Buoy B, one kilometer south of the outfall; OSM = Outfall site, four locations at the edge of the mixing zone; DIF = Deer Island Flats; IH = Boston inner harbor

Contingency Plan Thresholds

There were no Contingency Plan threshold exceedances for fish and shellfish in 2012 (Table 5-1). Incidence of CHV, the most common indicator of liver disease in the winter flounder of the region, was 12% in fish taken from the vicinity of the outfall site, lower than the caution threshold and less than half the baseline average. Chemistry threshold parameters values were lower than the thresholds for every parameter and also lower than baseline averages for every parameter except for PCBs in flounder fillets.

Table 5-1. Contingency Plan threshold values and 2012 results for fish-and-shellfish monitoring.

Parameter Type/ Nearfield	Parameter	Baseline	Caution Level	Warning Level	2012 Results
Flounder disease	Liver disease (CHV)	24.4%	44.9%	None	12%
Flounder meat	PCB	0.033 ppm	1 ppm wet weight	1.6 ppm wet weight	0.0413 ppm
	Mercury	0.074 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.0646 ppm
Flounder liver lipid normalized	Chlordane	242 ppb	484 ppb	None	73.6 ppb
	Dieldrin	63.7 ppb	127 ppb	None	0 ppb
	DDT	775.9 ppb	1552 ppb	None	369 ppb
Lobster meat	PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight	0.0086 ppm
	Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.115 ppm
Lobster hepatopancreas lipid normalized	Chlordane	75 ppb	150 ppb	None	0 ppb
	Dieldrin	161 ppb	322 ppb	None	0 ppb
	DDT	341.3 ppb	683 ppb	None	45.1 ppb
Mussel tissue	PCB	0.011 ppm	1 ppm wet weight	1.6 ppm wet weight	0.0024 ppm
	Lead	0.415 ppm	2 ppm wet weight	3 ppm wet weight	0.216 ppm
	Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.0161 ppm
Mussel tissue lipid normalized	Chlordane	102.3 ppb	205 ppb	None	40.5 ppb
	Dieldrin	25 ppb	50 ppb	None	0 ppb
	DDT	241.7 ppb	483 ppb	None	33 ppb
	PAH	1080 ppb	2160 ppb	None	1020 ppb

6. Special Studies

Besides monitoring the effluent and the water column, sea floor, and fish and shellfish in Massachusetts Bay and the surrounding area, MWRA conducts special studies in response to specific permit requirements, scientific questions, and public concerns. Special studies in 2012 included evaluation of marine debris observations at the outfall site in 2000–2012; continuous monitoring results from instrumented buoys; evaluation of primary productivity models; Center for Coastal Studies monitoring in Cape Cod Bay; and changes in eutrophication indicators in Boston Harbor.

Marine Debris Observations

One environmental concern for the outfall was aesthetics, specifically that the outfall would discharge unsightly, floating debris. After the outfall came on line in September 2000 and through 2010, MWRA conducted visual observations and sampled debris at the outfall and a reference site during all water-column surveys. Sampling was made by net tows (Figure 6-1).

Figure 6-1. Net used for sampling floatable marine debris. The net measures 1 x 2 meters, with 500-µm mesh.

Routine sampling by nets ended with revisions to the monitoring plan in 2010. The revised plan called for net tows following events in which some primary-only treated effluent is blended with effluent that received full primary and secondary treatment before discharge. The new plan also called for analyzing debris captured by the net for organochlorine pesticides, PCBs, PAHs, and mercury. Four tows were conducted in response to blending events in March 2011 and May and July 2012.

From September 2000 through July 2012, MWRA conducted 136 marine debris surveys, collecting 135 samples at a reference site and 134 samples at the outfall (Rex and Delaney 2013). Debris was found at both the reference site and the outfall but was detected in more samples from the outfall (Figure 6-2). In particular, fat particles were more frequently detected at the outfall, with 49% of the samples from the outfall having fat particles compared to only 5% at the reference site. Other types of debris were found in more similar numbers in both the outfall and the reference tows. Sightings of sewage-related floatable debris, such as tampon applicators and condoms, were rare.

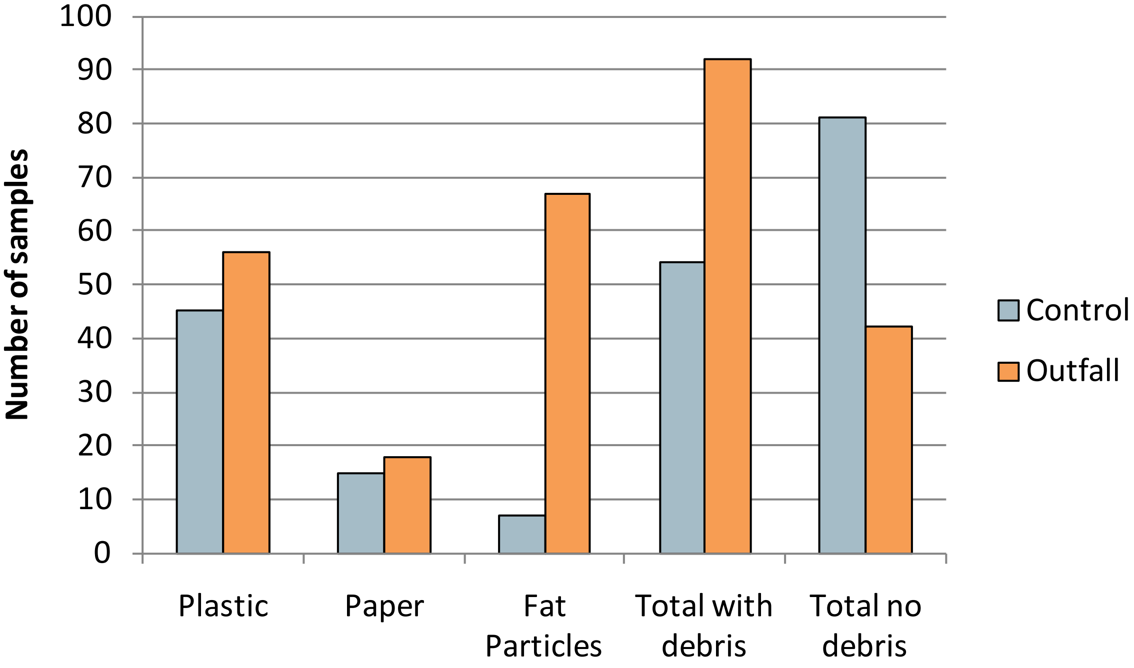


Figure 6-2. Marine debris in net tow samples, 2000–2012. Different types of debris were sometimes present in the same sample. “Plastic” includes plastic and latex-like material; “Paper” includes paper, cellophane, string, and fabric.

Chemical analyses of the fat particles did not detect significant quantities of pesticides, PCBs, PAHs, or mercury. Even using conservative assumptions and calculations, MWRA estimated that only small fractions of the already low total effluent loadings of these contaminants to the bay could have come from the fat particles.

Based on the results from these studies, EPA and MADEP agreed to end net tows and chemical analyses. Visual observations of floating debris continue.

Continuous Monitoring Data

In 2007, MWRA partnered with the National Data Buoy Center (NDBC) to add water quality and oceanographic sensors to the NDBC Buoy 44013, a weather buoy located seven kilometers southeast of the outfall, just east of MWRA's water-column station N07 (see Figure 3-1 in Section 3, Water Column). MWRA's regulators, EPA and MADEP, wanted continuous data from moored sensors communicated or "telemetered" back to shore in real time as a method of "filling the gaps" between surveys.

The active shipping lanes into Boston Harbor pass right over the outfall, making ship strikes a possibility for the surface buoy and antenna required for telemetered data. However, the weather buoy is in a protected traffic-separation corridor and well-known to ship operators. At the time of partnering with MWRA, NDBC was already conducting a pilot study to add water quality and oceanographic sensors to selected buoys nationwide, so adding sensors to Buoy 44013 met needs of both groups.

Deployment of new sensors was completed in June 2009. During the spring through fall months of 2009–2012, hourly temperature, salinity, water clarity, dissolved oxygen, and chlorophyll fluorescence data were telemetered to NDBC. The water quality sensors were not designed to survive freezing temperatures and were removed in the winter. A subset of parameters was measured through the winter using submerged sensors, but those data were not telemetered to shore. Despite its protected location, a ship strike disabled NDBC Buoy 44013 for much of 2012.

Comparisons of data from the NDBC Buoy 44013, from the other instrumented buoy in the region (NERACOOS Buoy A01 off Cape Ann), and from surveys generally showed good correspondence. Temperature (Figure 6-3, top) and salinity (not shown) data from the buoys corresponded well with survey data. Dissolved oxygen measurements from the NDBC buoy through 2011 tended to be slightly lower than the shipboard survey data but showed the typical seasonal cycle (Figure 6-3, bottom). Correspondence between the NERACOOS Buoy A01, which added dissolved oxygen sensors at the end of 2011, and the survey data was relatively good. The limited available 2012 data from both buoys compared relatively well with survey data.

Except for their collaboration with MWRA, NDBC's pilot study for adding instruments to weather buoys ended in 2009. Their support for the MWRA partnership ended in December 2012. MWRA, its regulators, and OMSAP are determining the need for continuous monitoring data closer to the outfall. Meanwhile, measurements at the NERACOOS Buoy A01 continue.

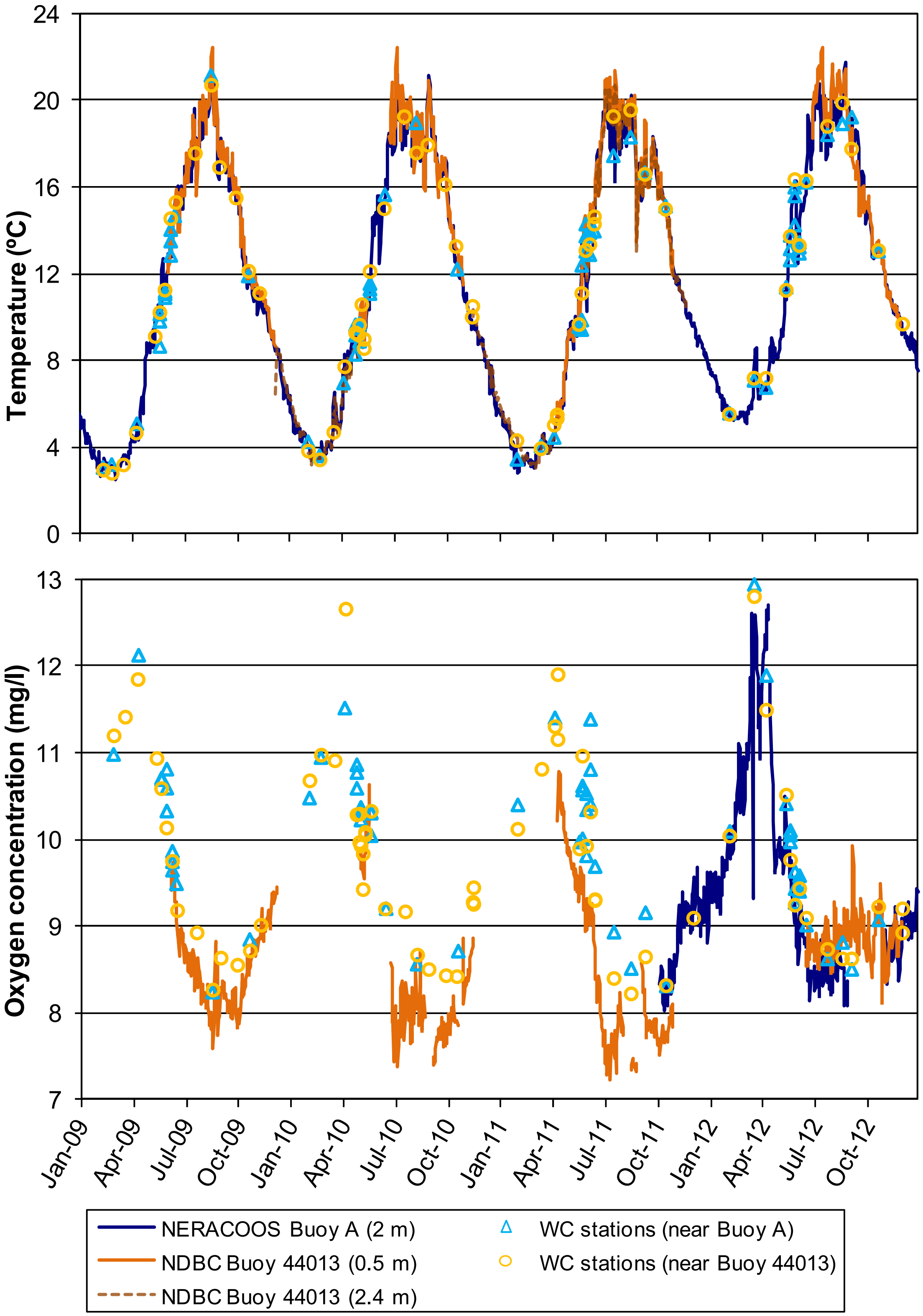


Figure 6-3. Temperature (top) and dissolved oxygen (bottom) at the NERACOOS Buoy A01, NDBC Buoy 44013, and during water quality surveys, June 2009 – December 2012. WC = water column

Primary Productivity Model Evaluations

Through 2010, MWRA measured primary productivity at three stations, one at the mouth of Boston Harbor (F23), one several kilometers to the northeast of the outfall (N04), and one a kilometer to the south of the outfall (N18). (See Figure 3-1 in Section 3, Water Column, for station locations.) In 2009, MWRA proposed ending that special study, because the measurements were costly and results had found that the relocated discharge did not result in detectable increased productivity near the outfall. Regulators and their science advisory panel (OMSAP) concurred, but requested that MWRA evaluate other, less costly approaches to assessing primary productivity in marine waters.

One alternative approach was to use a simple light-biomass model, known as BZ_pI_0, which had been developed for estuaries. BZ_pI_0 multiplies the chlorophyll biomass present in the photic zone (the BZ_p term) by the intensity of the sunlight hitting the ocean surface (the I_0 term). BZ_pI_0 has been found to be a suitable replacement for direct productivity measurements in many well-mixed coastal systems where the amount of available light limits algal growth.

Comparisons between BZ_pI_0 and productivity measurements had already been included in MWRA reports for 1992–2000. Those results were mixed, with good correlations for some stations in some years but poor correlations for other stations and years.

A new evaluation of data from 2001–2010 found similar mixed results (Keay et al. 2013). Comparison of annual results found that some years showed a good correlation between BZ_pI_0 and field measurements, but others did not. Spatially, the correlation was better for data from the station at the mouth of Boston Harbor than it was for the offshore stations (Figure 6-4). Spring and fall data correlated better than summer data (Figure 6-5).

Overall, BZ_pI_0 did not reflect the measured primary productivity well enough to consider its use as a replacement for direct measurements. The variability in results was not surprising, because BZ_pI_0 is a simple model with assumptions that are sometimes not met in Boston Harbor or Massachusetts Bay.

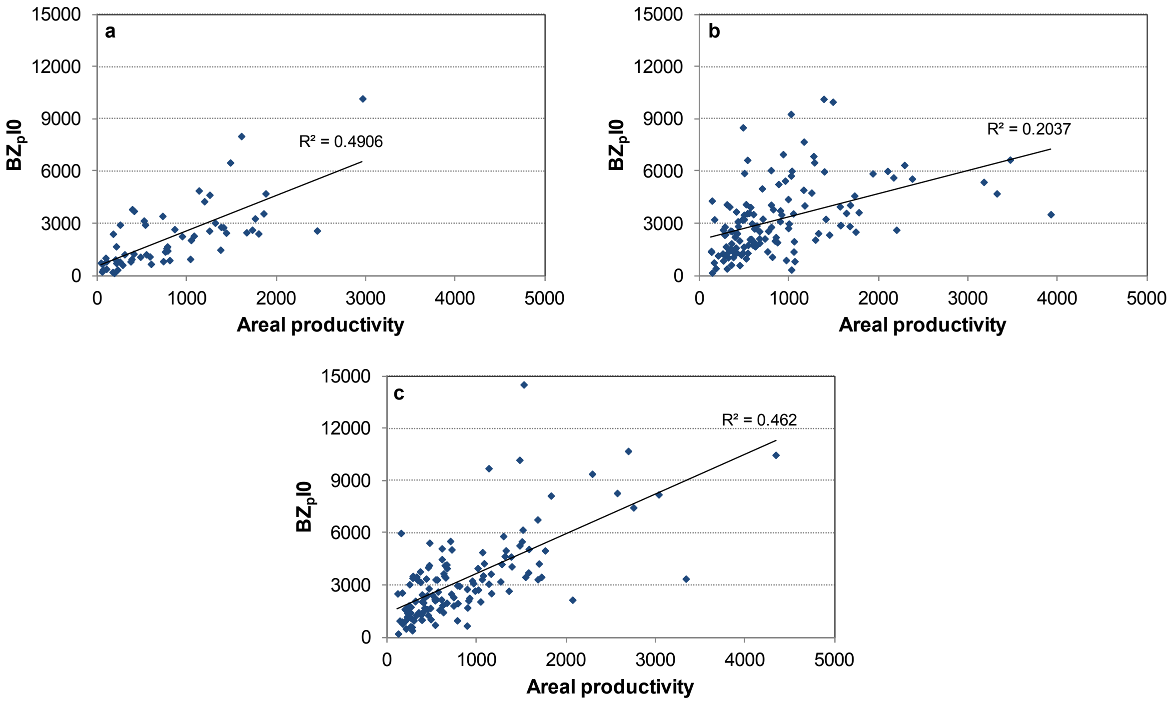


Figure 6-4. Areal productivity and BZ_pI_0 for individual stations. (a) F23, (b) N04, (c) N18

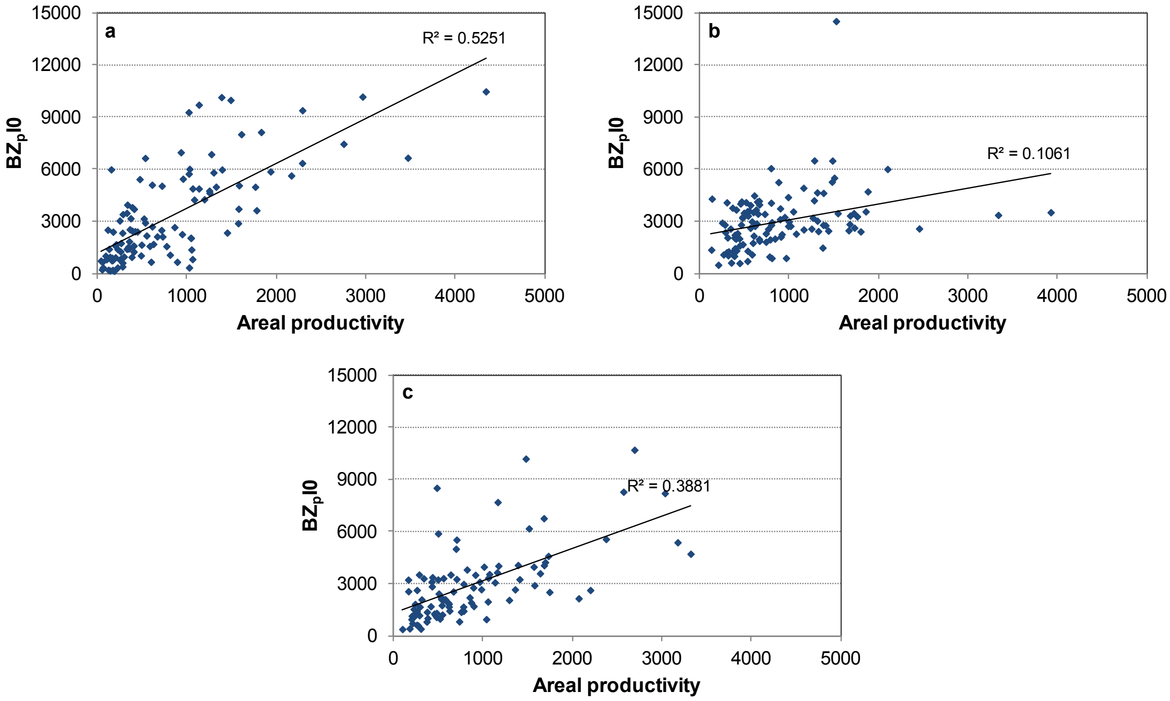


Figure 6-5. Areal productivity and BZ_pI_0 for monitoring seasons. (a) Winter-spring: February – April, (b) Summer: May – August, (c) Autumn: September – December

Cape Cod Bay Studies

Since 2011, MWRA has collaborated with the Center for Coastal Studies at Provincetown, which has had an extensive program to monitor Cape Cod Bay and its shorelines since 2006. MWRA's focus is on the portion of the program that provides offshore water quality and plankton measurements. The Center for Coastal Studies also has an inshore measurement component, which employs citizen volunteers to monitor areas not accessible by boat. Overall, the program provides additional detail for the region, with a focus on information relevant to the whale populations that visit the area each year. The Center for Coastal Studies also makes observations of whales in the region, including aerial surveys and shipboard observations. Some of the Cape Cod Bay program results have been reported on in Section 3, Water Column.

In 2012, the Center for Coastal Studies completed 16 surveys of eleven stations in Cape Cod Bay and the southwestern corner of Stellwagen Bank, including three MWRA stations (F01, F02, F29) (Figure 6-6). Those surveys found typical hydrographic and water quality patterns. Phytoplankton communities were dominated by microflagellates. The zooplankton community was somewhat different from past years, including unusual free-swimming gastropods (pteropods), possibly due to intrusion of water from offshore.

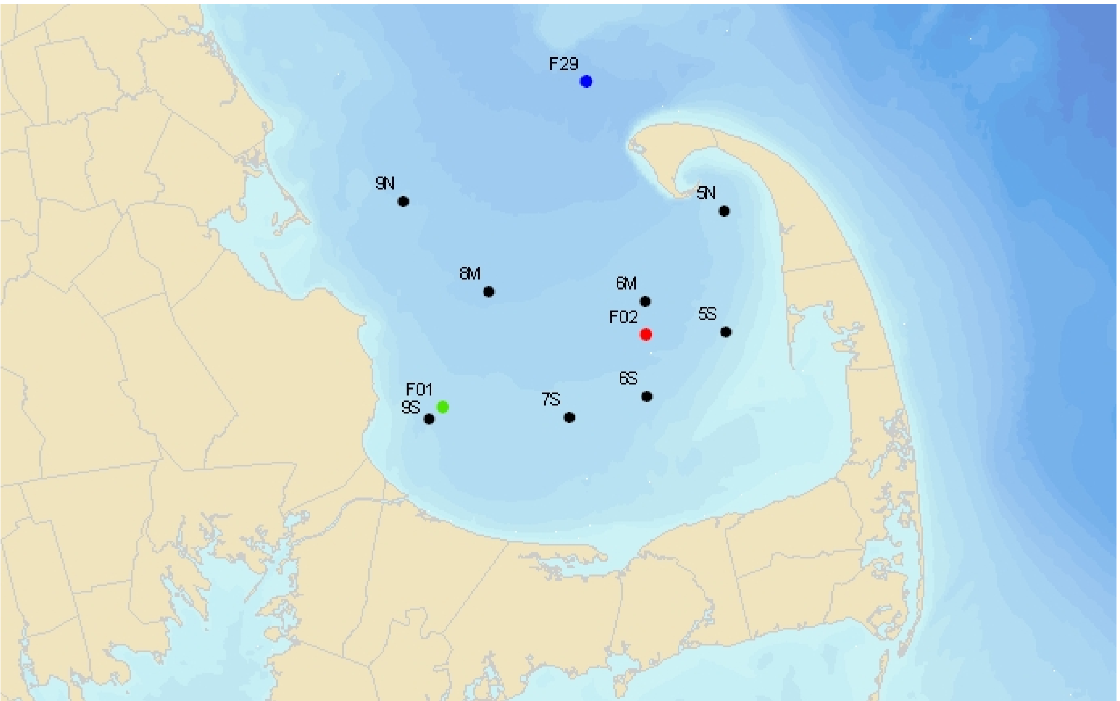


Figure 6-6. The Center for Coastal Studies monitors its own eight stations and three MWRA stations (F01, F02, and F29) in and near Cape Cod Bay. (Figure from the Center for Coastal Studies)

Numbers of Center for Coastal Studies whale sightings have been relatively high since 2007, with 2012 numbers lower than 2011 but greater than 2010 (Figure 6-7). In 2012, whales entered the bay and reached peak abundance earlier than is typical of most years, with the last whales sighted in April. The early arrival may have been related to warm water temperatures.

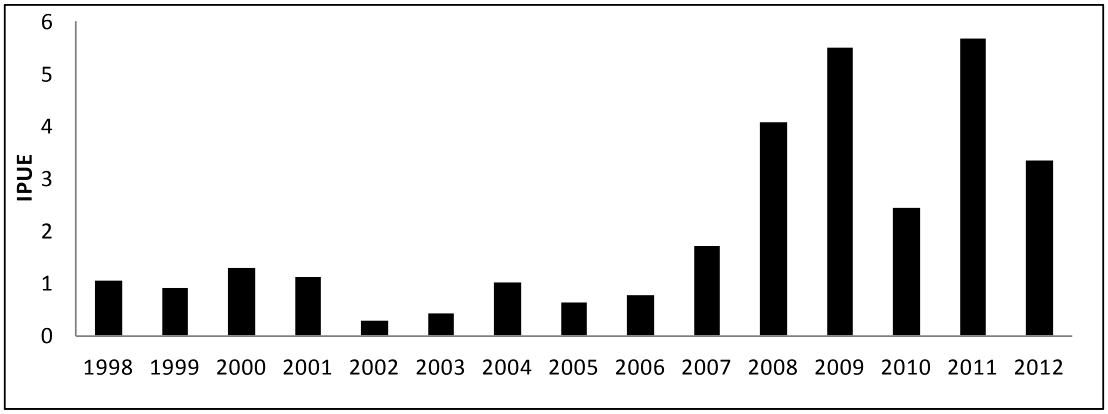


Figure 6-7. Right whale sightings in Cape Cod Bay, 1998–2012. IPUE = individuals per unit effort (Figure from the Center for Coastal Studies)

In March 2012, a bowhead whale was sighted off Cape Cod, the first such recorded sighting. Bowhead whales typically live farther north in the Atlantic, Pacific, and Arctic oceans and had never been sighted so far south.

Eutrophication Studies in Boston Harbor

While studies in Massachusetts Bay have confirmed predictions that any outfall-related changes would be minor and localized, comparable measurements in Boston Harbor have documented improvements resulting from the Boston Harbor Project (Figure 6-8). Average 2012 summer and winter levels of dissolved inorganic nitrogen, chlorophyll, and transparency (measured as a light-attenuation coefficient), were similar to those in 2011, continuing conditions observed in recent years. Minimum dissolved oxygen concentrations in the inner and outer regions of the harbor were also similar to previous years.

Over the course of the Boston Harbor Project, inputs of nitrogen, phosphorus, and organic carbon declined by 65–90%, most of which was due to the ending of sewage effluent discharge to the harbor. A recent report (Taylor 2013) documents the improvements through 2009, changes that reversed the historic eutrophic conditions. These improvements have been maintained since the diversion of discharge to Massachusetts Bay.

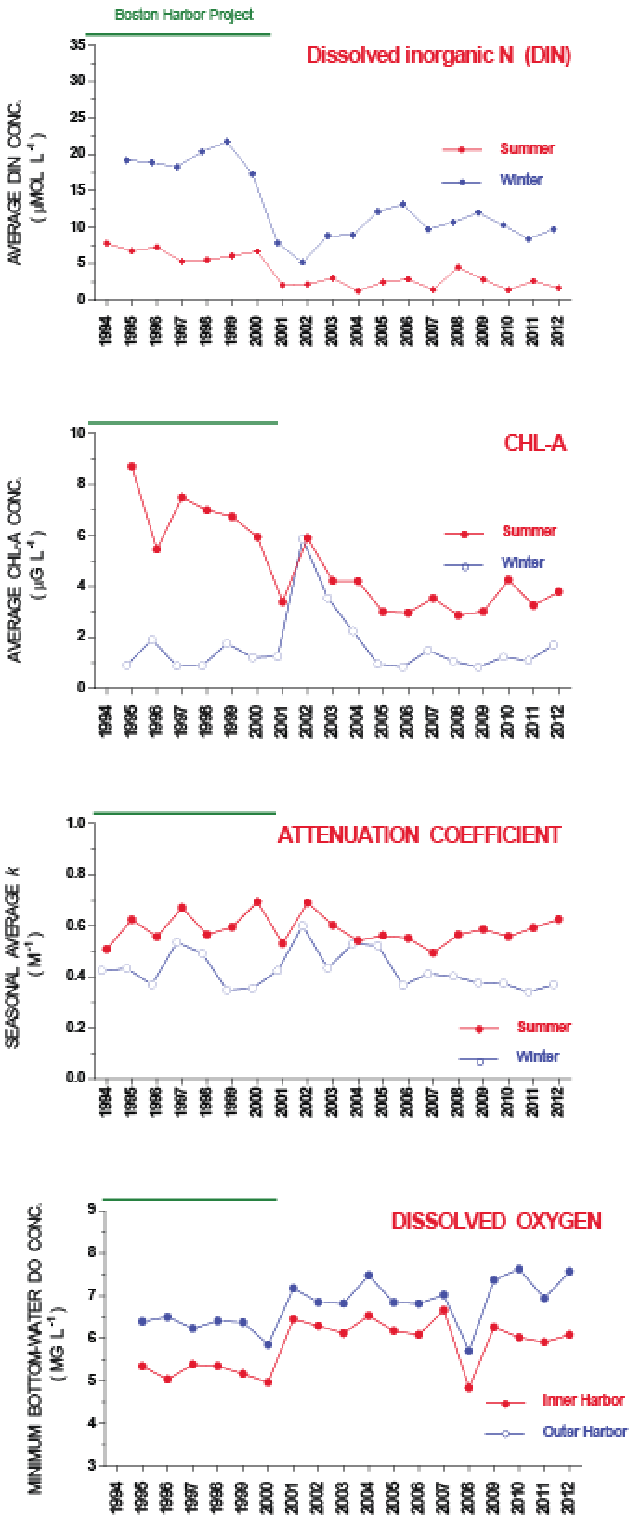


Figure 6-8. Time series plots of Boston Harbor water quality, 1994–2012. DIN=dissolved inorganic nitrogen, CHL-A=chlorophyll

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List of Acronyms

BOD	Biochemical oxygen demand
cBOD	Carbonaceous biochemical oxygen demand
CHL-A	Chlorophyll
CHV	Centrotubular hydropic vacuolation
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DIF	Deer Island Flats
DIN	Dissolved inorganic nitrogen
DITP	Deer Island Treatment Plant
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
FF	Farfield
HMW	High molecular weight
IAAC	Inter-Agency Advisory Committee
IH	Inner Harbor
IPUE	Individuals per unit effort
LC50	50% mortality concentration
LMW	Low molecular weight
LNB	Outfall site B
MADEP	Massachusetts Department of Environmental Protection
MWRA	Massachusetts Water Resources Authority
NA	Not analyzed/not applicable
NACWA	National Association of Clean Water Agencies
NB	Nantasket Beach
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
NDBC	National Data Buoy Center
NF	Nearfield
NOEC	No observed effects concentration
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OS	Outfall site
OSM	Outfall site
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PE	Pemaquid Point, Maine
PIAC	Public Interest Advisory Committee
PSP	Paralytic shellfish poisoning
RPD	Redox potential discontinuity
T	Temperature
WC	Water column

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