2011
Outfall Monitoring Overview

Environmental Quality Department
Report 2012-11

Massachusetts Water Resources Authority

Citation:
Werme C, Rex AC, Hall MP, Keay KE, Leo WS, Mickelson MJ, Libby, S, Hunt CD. 2012. **2011 outfall monitoring overview**. Boston: Massachusetts Water Resources Authority. Report 2012-11. 62p.

2011
Outfall Monitoring Overview

prepared by

Christine Werme

Independent Consultant
Berkeley, CA 94705

and

Andrea C. Rex, Maury P. Hall, Kenneth E. Keay, Wendy S. Leo,
Michael J. Mickelson

Massachusetts Water Resources Authority
Environmental Quality Department
100 First Avenue
Charlestown Navy Yard
Boston, MA 02129

and

Scott Libby, Carlton D. Hunt

Battelle
397 Washington Street
Duxbury, MA 02332

November 5, 2012

2011 Outfall Monitoring Panel and Committees

Outfall Monitoring Science Advisory Panel (OMSAP)

Andrew Solow (chair), Woods Hole Oceanographic Institution
Robert Beardsley, Woods Hole Oceanographic Institution
Norbert Jaworski, retired (Environmental Protection Agency)
Robert Kenney, University of Rhode Island
Scott Nixon, University of Rhode Island
Judy Pederson, Massachusetts Institute of Technology Sea Grant
Michael Shiaris, University of Massachusetts, Boston
James Shine, Harvard School of Public Health
Juanita Urban-Rich, University of Massachusetts, Boston

Inter-Agency Advisory Committee (IAAC)

US Geological Survey: Michael Bothner
Massachusetts Coastal Zone Management: Todd Callaghan, Jan Smith
US Army Corps of Engineers: Thomas Fredette
Stellwagen Bank National Marine Sanctuary: Ben Haskell
US Environmental Protection Agency: Matthew Liebman
Massachusetts Division of Marine Fisheries: Jack Schwartz
Massachusetts Department of Environmental Protection: Catherine Vakalopoulos

Public Interest Advisory Committee (PIAC)

Save the Harbor/Save the Bay: Patty Foley (chair), Bruce Berman
MWRA Wastewater Advisory Committee: Edward Bretschneider
Conservation Law Foundation: Priscilla Brooks
Massachusetts Audubon Society: Robert Buchsbaum
MWRA Advisory Board: Joseph Favaloro
Association to Preserve Cape Cod: Maggie Geist, Tara Nye
Safer Waters in Massachusetts: Sal Genovese
The Boston Harbor Association: Vivian Li

Table of Contents

2011 Outfall Monitoring Panel and Committees iv
Table of Contents i
List of Figures ii
List of Tables iv
Summary v
1. Introduction 1
2. Effluent 2
2011 Characterization 2
Contingency Plan Thresholds 8
3. Water Column 9
Physical Conditions 10
Water Quality 14
Phytoplankton Communities 22
Zooplankton Communities 24
Stellwagen Bank National Marine Sanctuary 25
Contingency Plan Thresholds 32
4. Sea Floor 34
Sediment Characteristics and Tracers 37
Sediment-profile Imaging 40
Soft-bottom Communities 41
Hard-bottom Communities 42
Stellwagen Bank National Marine Sanctuary 43
Contingency Plan Thresholds 44
5. Flounder Studies 48
Contingency Plan Thresholds 52
6. Special Studies 53
Chlorophyll Measurements 53
Productivity Measurements 54
Boston Harbor Sediment-profile Images 54
Boston Harbor Beach Monitoring 55
Cape Cod Bay Studies 56
Contingency Plan Threshold Recalculations 58
Water Column Thresholds 59
Sea Floor Thresholds 59
References 60
List of Acronyms 62

List of Figures

Figure 2-1. MWRA primary-blended and full secondary effluent flows. 2
Figure 2-2. MWRA primary-blended and full secondary effluent flows during 2011. 3
Figure 2-3. Solids in MWRA treatment plant discharges. 4
Figure 2-4. Biochemical oxygen demand in MWRA discharges.. 4
Figure 2-5. Deer Island Treatment Plant nitrogen discharges.. 5
Figure 2-6. Deer Island Treatment Plant metals discharges.. 6
Figure 2-7. Mercury in Deer Island Treatment Plant discharges. 6
Figure 2-8. PCBs and pesticides in Deer Island Treatment Plant discharges. 7
Figure 3-1. Water-column monitoring stations. 9
Figure 3-2. Flows of the Merrimack (top) and Charles (bottom) rivers 11
Figure 3-3. Stratification near the outfall site in 2011, compared to the previous 19 years of monitoring. 11
Figure 3-4. Bottom water dissolved oxygen concentrations in the nearfield in 2011 compared to the previous years of monitoring. 12
Figure 3-5. Bottom water dissolved oxygen concentration (mg/L) at stations in Massachusetts and Cape Cod bays during the nine surveys conducted in 2011. 13
Figure 3-6. Bottom water dissolved oxygen concentrations at NERACOOS Buoy A01 and nearby MWRA stations F22 and F27. 14
Figure 3-7. Annual mean ammonium concentrations, 1992–2010. 15
Figure 3-8. Mean nutrient concentrations at Station N18 in 2011, compared to prior years. 16
Figure 3-9. Surface water nitrate+nitrite (µM) by station in Massachusetts and Cape Cod bays. 17
Figure 3-10. (Top) Surface and bottom water ammonium on March 15, 2011 at the monitoring stations. (Bottom) Cross-sections of concentrations at other depths along transects connecting selected stations showing well-mixed conditions. 18
Figure 3-11. (Top) Surface and bottom water ammonium on June 16, 2011 at the monitoring stations during stratified conditions. (Bottom) Cross-sections of concentrations at other depths along transects connecting selected stations, showing that the plume is contained at depth. 19
Figure 3-12. Surface water chlorophyll fluorescence by station in Massachusetts and Cape Cod bays. 20
Figure 3-13. Moderate Resolution Imaging Spectroradiometer satellite imagery of surface chlorophyll concentrations in 2011.. 21
Figure 3-14. Winter/spring mean nearfield abundance of *Phaeocystis pouchetii*, 1992–2011. 22
Figure 3-15. Nearfield abundance of *Alexandrium fundyense*, 1992–2011. 23
Figure 3-16. Surface *Alexandrium fundyense* abundance (cells/L) for individual samples during the April to June 2011 surveys. 23
Figure 3-17. Nearfield abundance of total zooplankton in 2011 compared to past years. 24

Figure 3-18. Bottom water dissolved oxygen concentrations in Stellwagen Basin in 2011 compared to the previous years of monitoring. 25
Figure 3-19. Location of east-west transect from Deer Island, across MWRA outfall, through Stellwagen Bank, for modeled water-quality parameters presented in Figures 3-20 through 3-23. 26
Figure 3-20. Modeled dissolved oxygen concentration (mg/L) on the east-west transect across the MWRA outfall and Stellwagen Bank National Marine Sanctuary at the end of each month from January through December 2011. 27
Figure 3-21. Modeled percent dissolved oxygen saturation on the east-west transect across the MWRA outfall and Stellwagen Bank National Marine Sanctuary at the end of each month from January through December in 2011. 28
Figure 3-22. Modeled dissolved inorganic nitrogen concentrations (μM) on the east-west transect across the MWRA outfall and Stellwagen Bank National Marine Sanctuary at the end of each month from January through December in 2011. 29
Figure 3-23. Modeled chlorophyll concentrations (μg/L) on the east-west transect across the MWRA outfall and Stellwagen Bank National Marine Sanctuary at the end of each month from January through December in 2011. 30
Figure 3-24. Surface-water phytoplankton abundance and composition at MWRA Cape Cod Bay stations, including Station F29 near Stellwagen Bank National Marine Sanctuary... 31
Figure 3-25. Zooplankton abundance and composition at MWRA Cape Cod Bay Stations, including Station F29 near Stellwagen Bank National Marine Sanctuary... 32
Figure 4-1. Soft-bottom monitoring stations. 34
Figure 4-2. Sediment-profile imaging stations. 35
Figure 4-3. Hard-bottom stations... 36
Figure 4-4. Concentrations of *Clostridium perfringens* spores, corrected for sediment grain size, in 2011. 38
Figure 4-5. Mean concentrations of *Clostridium perfringens* spores, 1992–2011. 38
Figure 4-6. Mean concentrations of total PCBs at individual stations, 1992–2011.. . 39
Figure 4-7. Annual apparent color RPD for data from nearfield stations.................. 40
Figure 4-8. Mean infaunal abundance per sample in four areas of Massachusetts Bay, 1992–2011.. 41
Figure 4-9. Screen captures from Waypoint T1-3, located north of the diffusers, 1996–2011.. 42
Figure 4-10. Stations superimposed on non-metric multidimensional scaling plots, a multivariate analyses tool.. 44
Figure 4-11. Annual community parameters with nearfield Contingency Plan. 46
Figure 5-1. Flounder sampling sites.. 48
Figure 5-2. External conditions noted during the 2011 field program.. 50
Figure 5-3. Annual prevalence of centrotubular hydropic vacuolation (CHV), corrected for age. 51
Figure 6-1. Boston Harbor sediments and environmental conditions........................ 55
Figure 6-2. Percent of days beaches in South Boston failed swimming standards…..56
Figure 6-3. The Provincetown Center for Coastal Studies monitoring 57
Figure 6-4. Provincetown Center for Coastal Studies whale sightings in 2011. 58

List of Tables

Table i. Effluent Contingency Plan thresholds and exceedances vi
Table ii. Water column Contingency Plan thresholds and exceedances.................... vii
Table iii. Sea-Floor Contingency Plan thresholds and exceedances......................... viii
Table iv. Fish and shellfish Contingency Plan thresholds and exceedances ix
Table 2-1. Contingency Plan threshold values and 2011 results for effluent monitoring 8
Table 3-1. Contingency Plan threshold values and 2011 results for water-column monitoring 33
Table 4-1. Contingency Plan threshold values and 2011 results for sea-floor monitoring 45
Table 5-1. Contingency Plan threshold values and 2011 results for winter flounder monitoring 52

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 special studies.

The 2011 report marks the twentieth year of MWRA's monitoring program, including almost nine years of baseline monitoring and more than eleven years of "outfall-discharge" monitoring, 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, fish and shellfish, and other studies, in the outfall nearfield and reference stations.

The year also marked the inauguration of a revised monitoring plan (MWRA 2010), developed because the original questions posed at the beginning of the program have been answered. The revised design is based on the results of a decade of outfall effects monitoring, focuses more on the area most likely to be affected by the discharge, with sufficient reference stations for comparison. The design was made more consistent and efficient, and some special studies were ended. A background document (Werme et al. 2012), prepared in conjunction with this report, explains the rationale for the monitoring, and describes the revised monitoring design.

Monitoring results in 2011 were consistent with predictions of no unanticipated effects associated with the outfall discharge. There were exceedances of Contingency Plan thresholds (Tables i through iv) for presence of *Alexandrium fundyense*, a nuisance algae known in the region as causing red tides, and for two soft-bottom benthic community parameters, Shannon-Wiener diversity and Pielou's evenness. These exceedances have been reviewed, and there is no indication that they were caused or exacerbated by the outfall discharge. Presence and abundance of *Alexandrium fundyense* is controlled by the presence and extent of seed beds to the northeast of Massachusetts Bay and on temperature, wind, and current patterns in the spring. Both exceedances in the benthic community parameters thresholds were indications of a somewhat more diverse community, likely resulting from normal cycles of relative abundance in the animal populations.

Table i. Effluent Contingency Plan thresholds and exceedances. [1] ✓ = no exceedance, NA = not applicable, W = warning level exceedance

Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
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
Oil and grease	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

[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 if they were related to the discharge, and 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.

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

Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Nearfield bottom water												
Dissolved oxygen concentration	C	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Dissolved oxygen saturation	C	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Dissolved oxygen depletion rate (June–October)	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Stellwagen Basin bottom water												
Dissolved oxygen concentration	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Dissolved oxygen saturation	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
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	✔	✔	✔	✔	✔
Autumn	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Nearfield nuisance algae *Pseudonitzchia* spp.												
Winter/spring	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Summer	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Autumn	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Nearfield nuisance algae *Alexandrium fundyense*												
Any sample	✔	✔	✔	✔	✔	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

Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Nearfield sediment												
Acenaphthene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Acenaphylene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Anthracene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Benzo(a)anthracene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Benzo(a)pyrene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Cadmium	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Chromium	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Chrysene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Copper	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Dibenzo(a,h)anthracene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Fluoranthene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Fluorene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Lead	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Mercury	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Naphthalene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Nickel	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
p,p'-DDE	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Phenanthrene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Pyrene	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Silver	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Total DDTs	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Total HMW PAH	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Total LMW PAH	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Total PAHs	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Total PCBs	NA	✓	✓	NA	NA	✓	NA	NA	✓	NA	NA	✓
Zinc	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-Wiener diversity	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	C	C
Pielou's evenness	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	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

Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
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. Prior to that time, the Boston metropolitan region discharged both inadequately treated sewage effluent and sewage biosolids into the relatively confined waters of Boston Harbor. The mission of the 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 of most baseline years and for each year since the outfall began to discharge have been documented in reports such as this one, the 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 2011, marking the twentieth year of MWRA's monitoring program, including more than eleven years of outfall-discharge. Measurements included effluent, water-column, sea-floor, and fish-and-shellfish parameters, as well as special studies conducted in response to permit conditions and environmental concerns.

2. Effluent

2011 Characterization

As in past years, DITP continued to operate as designed through 2011, earning the National Association of Clean Water Agencies' Platinum Peak Performance Award. This is their 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 wet year in the Boston area, with total precipitation about 20% higher than the long-term average. Most of the years since the Massachusetts Bay outfall came on line have been wet, generally resulting in relatively high effluent flows. Total flow was slightly higher in 2011 than in 2009 or 2010 and about the same as in 2008 (Figure 2-1), and in 2011, 99% of the flow received full primary and secondary (Figure 2-2) treatment.

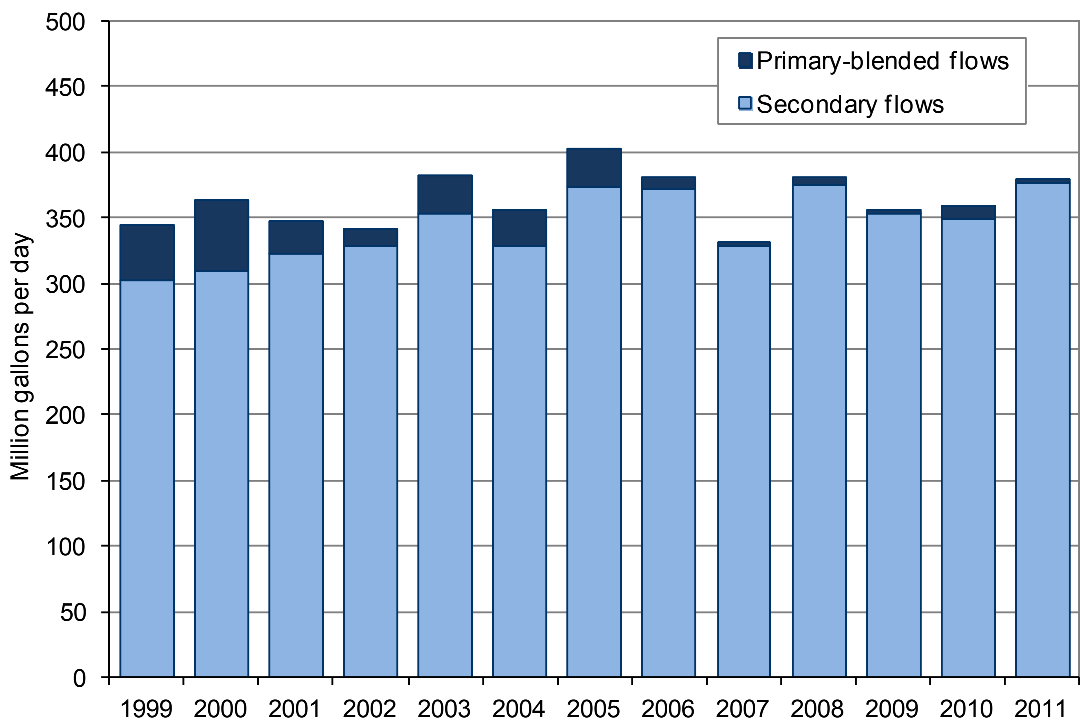

Figure 2-1. MWRA primary-blended and full secondary effluent flows. Almost all the flow from the treatment plant has received full secondary treatment since the completion of the secondary facilities in 2001. During large storms, flow exceeding the secondary capacity of the plant is diverted around the secondary process to prevent washing out the essential microbes that carry out secondary treatment. These primary-blended flows combine with full secondary flows before disinfection and discharge. All final effluent flows meet permit limits.

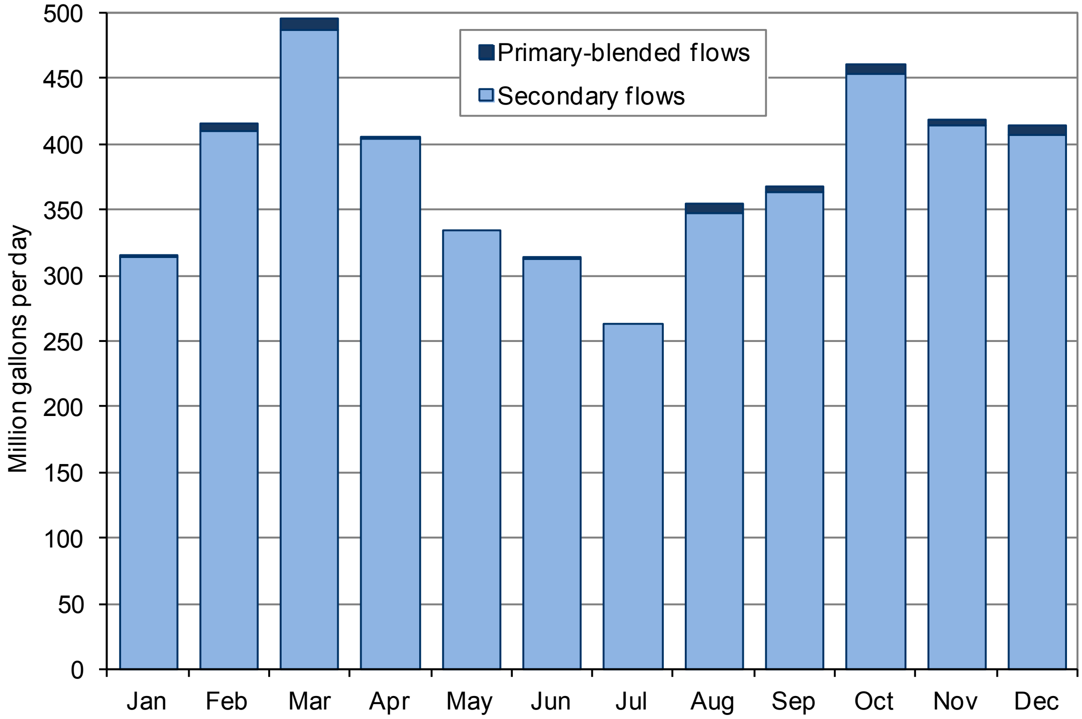

Figure 2-2. MWRA primary-blended and full secondary effluent flows during 2011. Amounts of blended flow were low in every month, despite the relatively wet year.

Although total annual flow was somewhat higher than in 2010, the total suspended solids load to Massachusetts Bay was about 14 tons per day, less than in 2010 and about average for the past five years (Figure 2-3). Carbonaceous biochemical oxygen demand (BOD) was also slightly lower in 2011 than in 2010, remaining well below levels that might be expected to affect ambient waters at the discharge site (Figure 2-4). Nitrogenous BOD (also shown in Figure 2-4), which is a result of the biological processes in secondary treatment and not a permit limit or Contingency Plan parameter, was somewhat higher in 2011 than in 2009 and 2010, but lower than in 2005–2008.

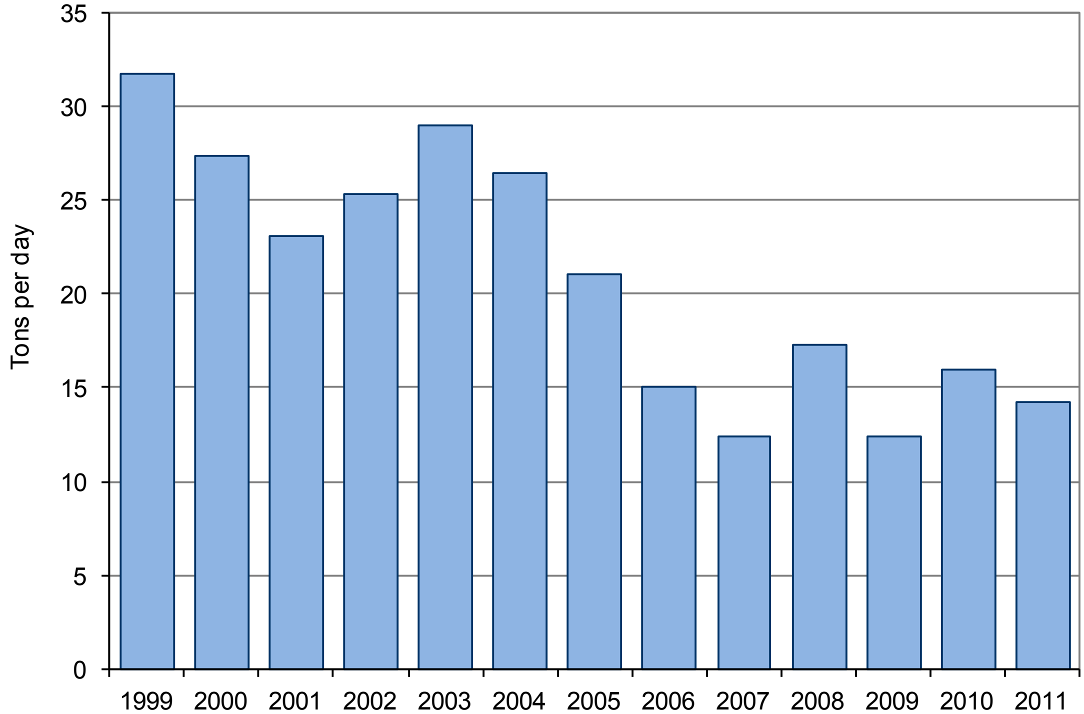

Figure 2-3. Solids in MWRA treatment plant discharges. Solids discharges remained low in 2011.

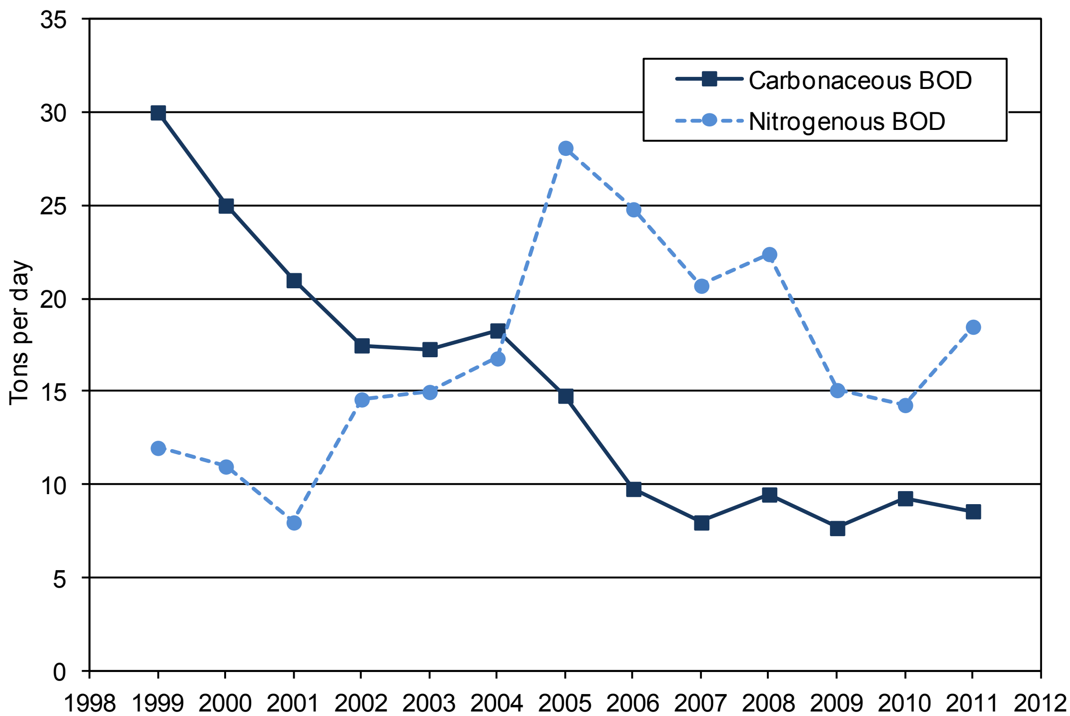

Figure 2-4. Biochemical oxygen demand in MWRA discharges. MWRA's permit limits carbonaceous BOD, which remained low in 2011. Nitrogenous BOD is the result of microbiological breakdown that occurs as a result of secondary treatment.

Total nitrogen loads were slightly higher in 2011, the highest measured by the monitoring program but remaining below the permit limits (Figure 2-5). The portion of the load made up of ammonium decreased 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 are reintroduced to DITP for treatment, adding to the ammonium load. As required by its permit, MWRA continually evaluates nitrogen-removal technologies (Bigornia-Vitale and Wu 2012). Nitrogen loads have remained below the Contingency Plan caution threshold, there have not been nitrogen-related adverse environmental impacts, and nitrogen removal has not been implemented.

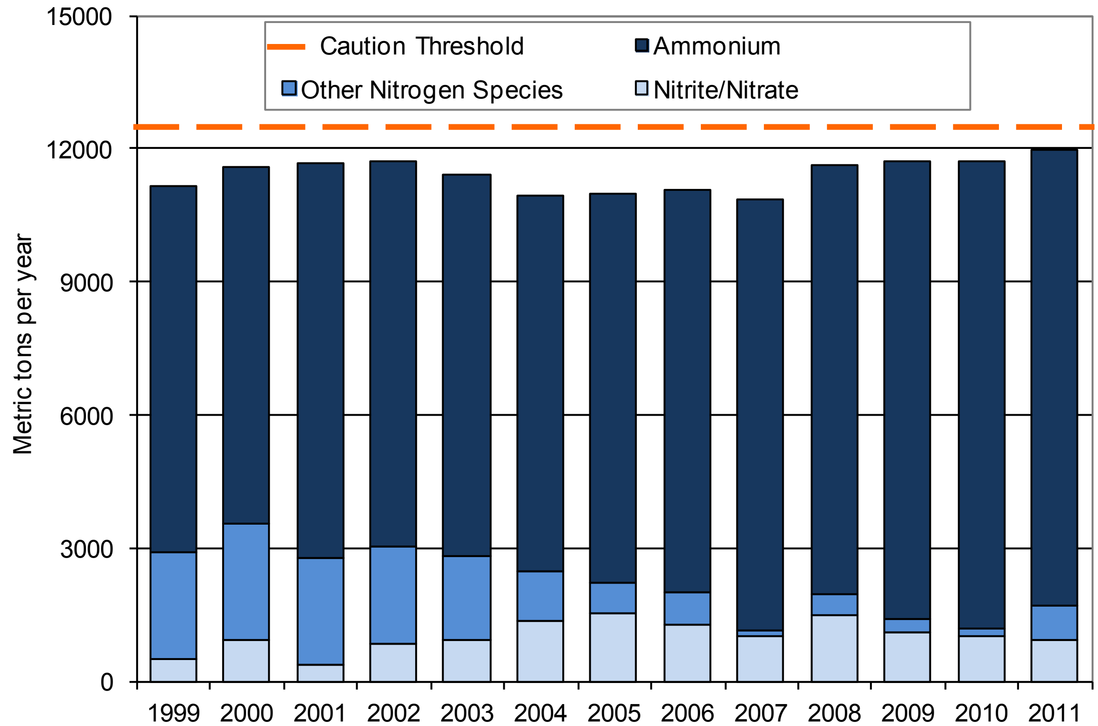

Figure 2-5. Deer Island Treatment Plant nitrogen discharges. Most of the nitrogen in the effluent is in the form of ammonium.

Metals loads increased slightly in comparison to 2010 but remained extremely low (Figure 2-6). A daily average of 100 pounds of metals were discharged, mostly zinc and copper. Silver, which was once thought to be a good effluent tracer, is now only rarely detected. Mercury loads remained about the same in 2011 as in 2010, at extremely low levels (Figure 2-7). 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.

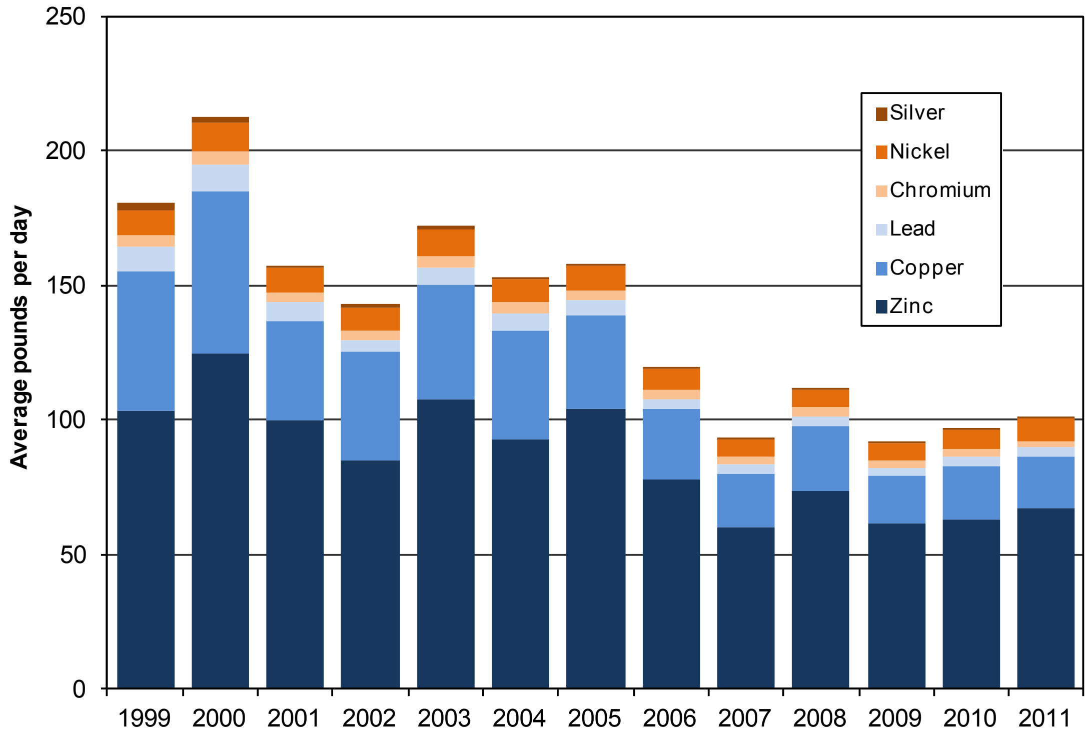

Figure 2-6. Deer Island Treatment Plant metals discharges. Except for copper, the metals meet receiving water quality criteria in the effluent, even without the dilution provided by the outfall.

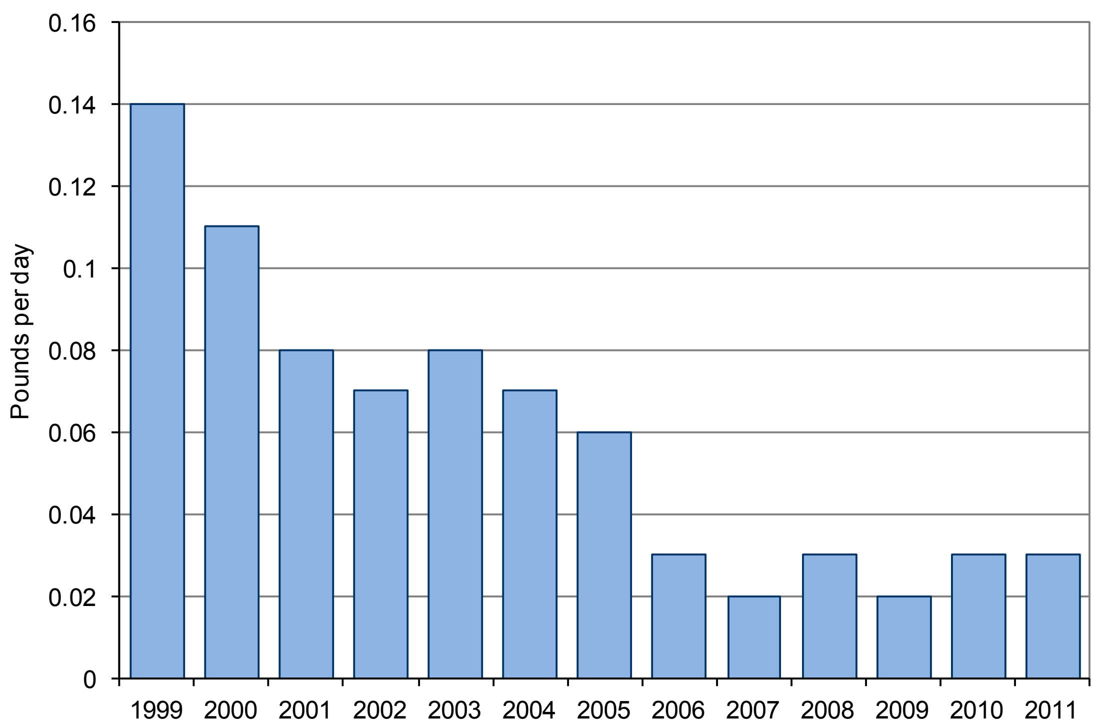

Figure 2-7. Mercury in Deer Island Treatment Plant discharges. Mercury is only rarely detected in the effluent.

Loads of polychlorinated biphenyls (PCBs) and pesticides increased in 2011, likely reflecting the wet-weather inputs through atmospheric deposition and runoff (Figure 2-8). These apparent increases could also be an artifact of a new sampling schedule that was implemented in 2011 (see Werme et al. 2012). The new schedule eliminated sampling on weekends, when loads tended to be lower than average in past years. All contaminant loads remained well below those that had been anticipated during the planning process for the relocated outfall.

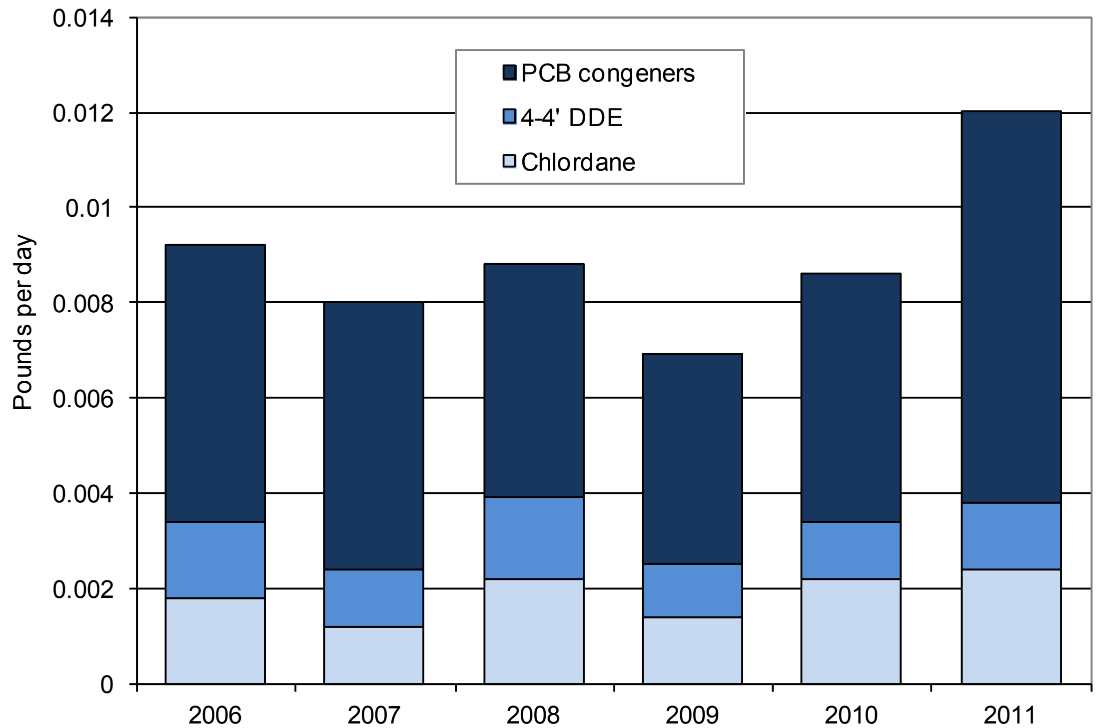

Figure 2-8. PCBs and pesticides in Deer Island Treatment Plant discharges. New methods were implemented in 2006 to detect these compounds, which are present at very low levels. (4-4' DDE is a breakdown product of the pesticide DDT. PCBs, DDT, and the pesticide chlordane were banned in the 1970s and 1980s but they persist in the environment.)

Contingency Plan Thresholds

DITP had no permit violations, there were no exceedances of the Contingency Plan effluent thresholds in 2011 (Table 2-1), and DITP achieved the National Association of Clean Water Agencies' Platinum Award for facilities having five consecutive years with no permit violations.

Table 2-1. Contingency Plan threshold values and 2011 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	2011 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		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 in Boston Harbor, Massachusetts Bay, and Cape Cod Bay (Figure 3-1).

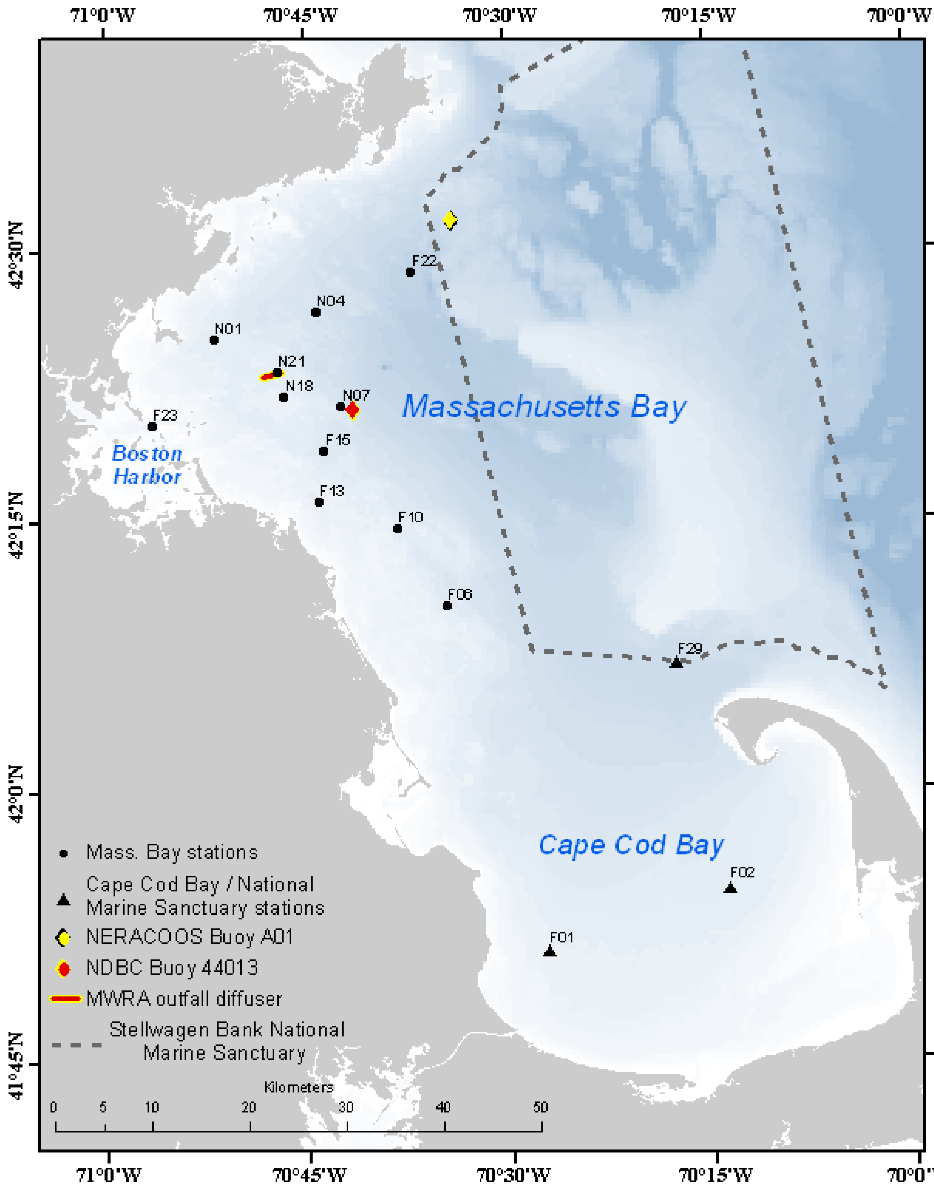

Figure 3-1. Water-column monitoring stations. Also shown are two instrumented buoys, one operated by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the other by the National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC); the MWRA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

A new water-column monitoring plan was implemented in 2011 (MWRA 2010, Werme et al. 2012) to include nine surveys at eleven stations for vertical and horizontal 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, and at reference stations. Measurements at three stations assess the health of Cape Cod Bay and the Stellwagen Bank National Marine Sanctuary. Additional surveys are conducted and stations sampled in response to *Alexandrium fundyense* red tide blooms. The program also benefits from collaboration with the Provincetown Center for Coastal Studies, which conducts a monitoring program in Cape Cod Bay, including sampling at MWRA stations (see Section 6, Special Studies). The field monitoring programs are augmented by measurements on instrumented buoys and from satellite imagery.

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 wet conditions that occurred throughout 2011 in the Boston area resulted in river discharges above average for nearly the whole year, compared to 1992–2010 (Figure 3-2) (Libby et al. 2012). Despite the elevated flows throughout the year, two storms with winds from the northeast in May, and Hurricane Irene in August, there were no major spikes in river discharge as have occurred in some years.

Winds shifts after a late May storm produced a brief period of strong upwelling in late May and early June (Figure 3-3), the period in which more frequent measurements were made in response to an *Alexandrium fundyense* bloom (see Phytoplankton Communities, below). The effects were also seen as dips in surface and bottom temperature and salinity measurements. The intrusion of water from deeper, colder areas caused bottom waters in the monitoring area to cool slightly earlier than surface waters, consistent with upwelling conditions. Salinities were lower than average throughout the year, consistent with the large inputs of freshwater from the rivers.

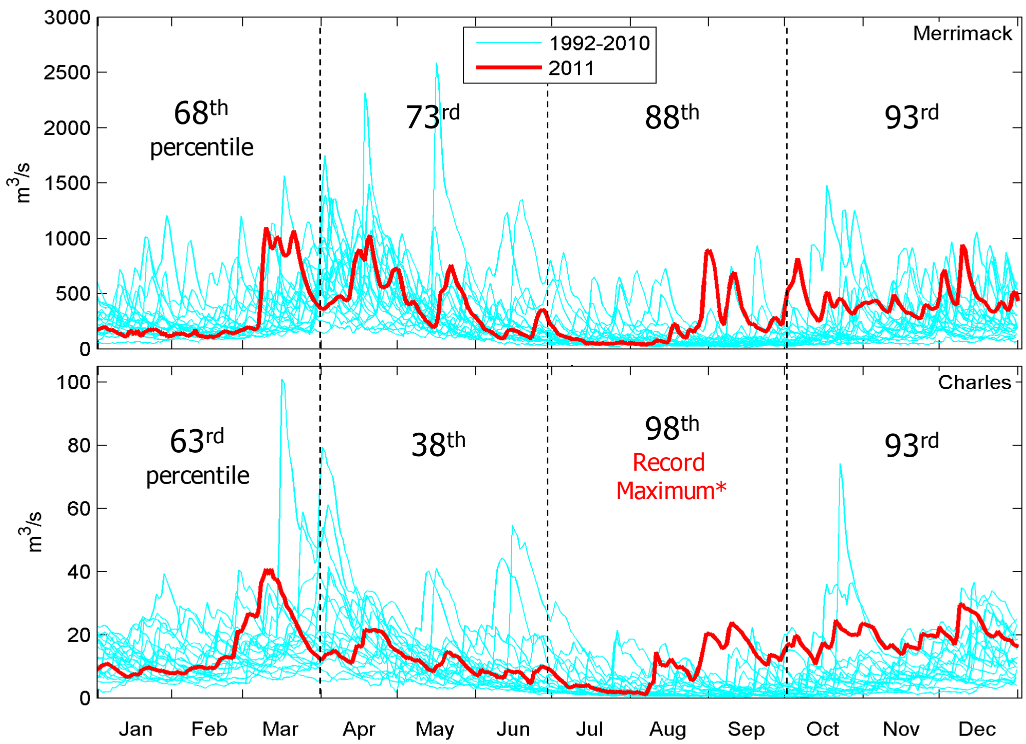

Figure 3-2. Flows of the Merrimack (top) and Charles (bottom) rivers were high throughout much of the year, continuing a wet period in the Boston area. Flows from the Charles set a record during July–September, translating to the 98th percentile. The record flow was due to rainfall during Hurricane Irene in late August.

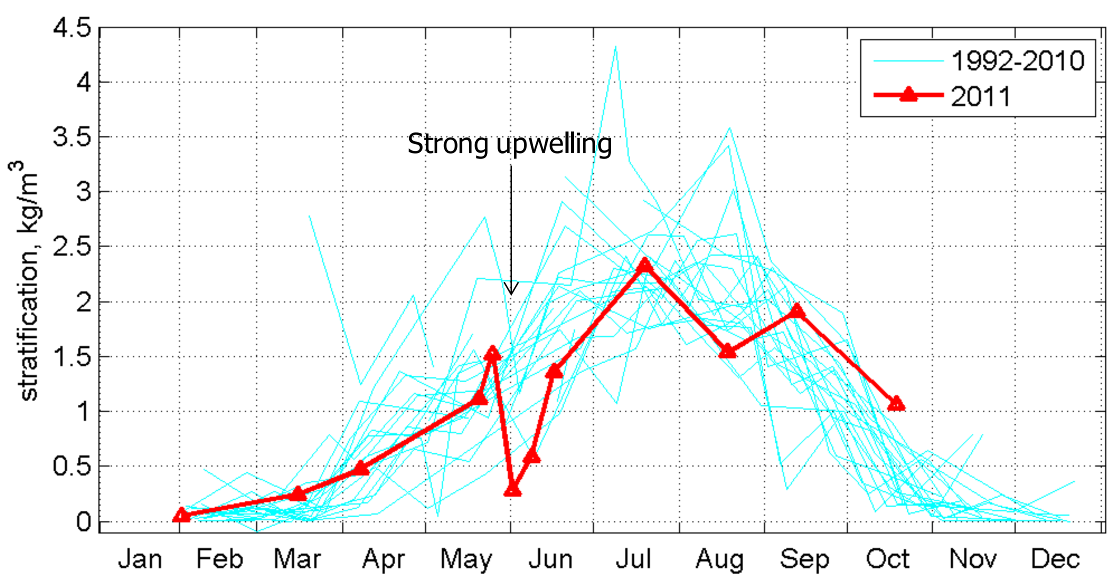

Figure 3-3. Stratification near the outfall site in 2011, compared to the previous 19 years of monitoring. A strong upwelling event in late May and early June promoted mixing in the water column throughout the near-shore area. (Data for 2011 are from Station N18.)

Nearfield bottom-water dissolved oxygen measurements also showed a small dip, in response to the strong upwelling period (Figure 3-4). Dissolved oxygen concentrations were slightly lower than average throughout the region and throughout the year, dropping below 7 mg/L at many stations in the September and October surveys (Figure 3-5). Time-series data from the NERACOOS Buoy A01 indicated that dissolved oxygen concentrations continued to decrease through late October, dipping below 6 mg/L (Figure 3-7). Temperature and unusually strong and persistent winds promoting onshore water flow contributed to the low dissolved oxygen levels. A lack of storms in October, which otherwise would have broken up stratification, contributed to the relatively low oxygen levels late into the year.

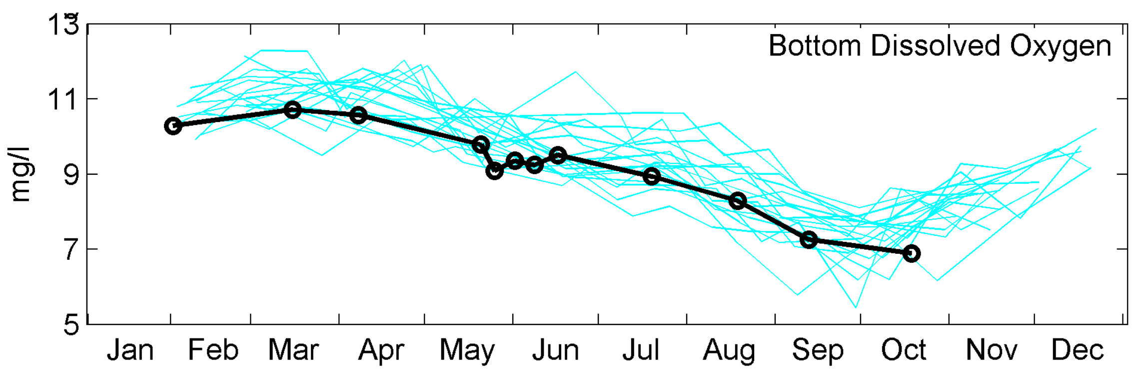

Figure 3-4. Bottom water dissolved oxygen concentrations in the nearfield in 2011 compared to the previous years of monitoring.

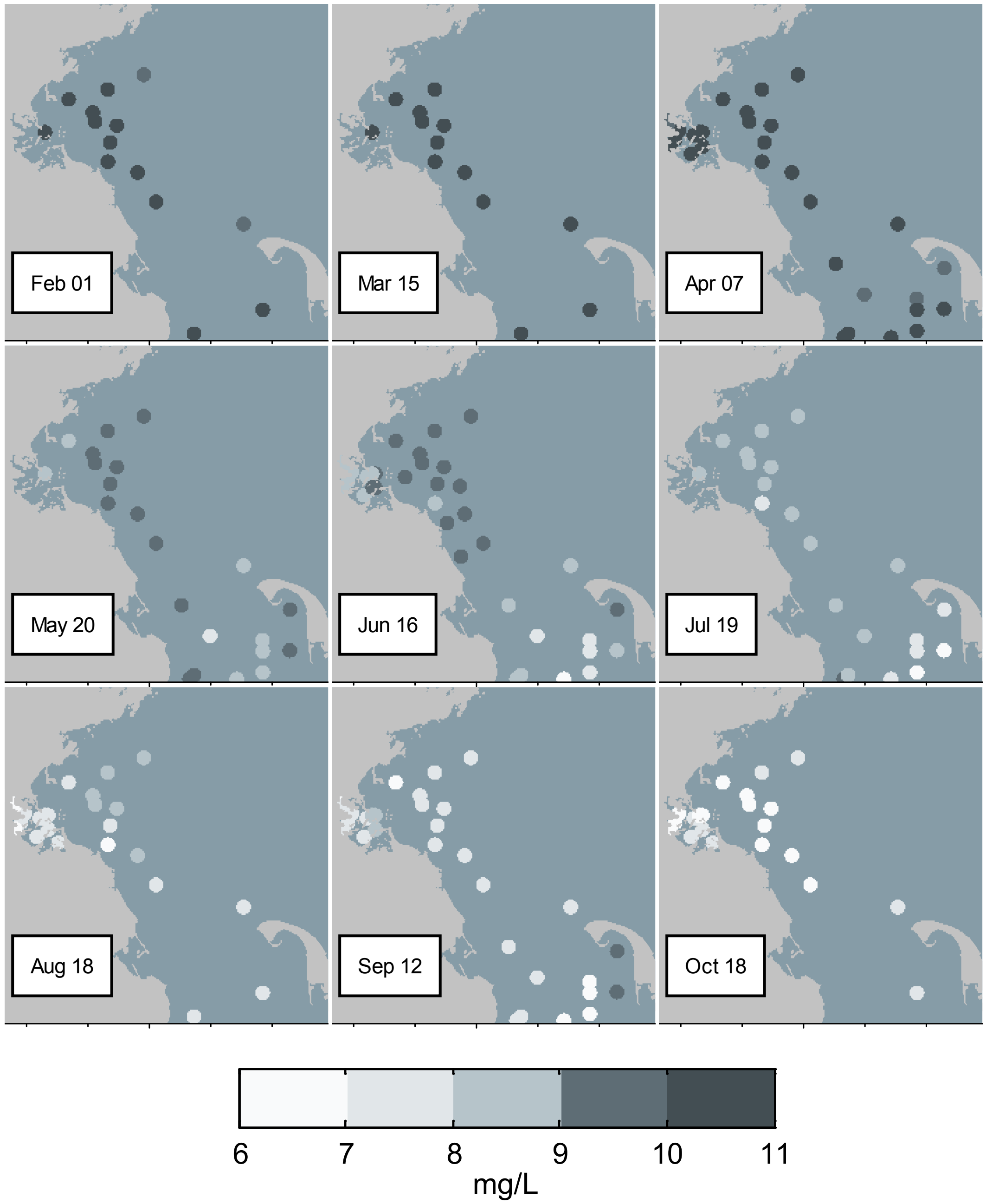

Figure 3-5. Bottom water dissolved oxygen concentration (mg/L) at stations in Massachusetts and Cape Cod bays during the nine surveys conducted in 2011. (Cape Cod Bay stations include those sampled by the Provincetown Center for Coastal Studies.)

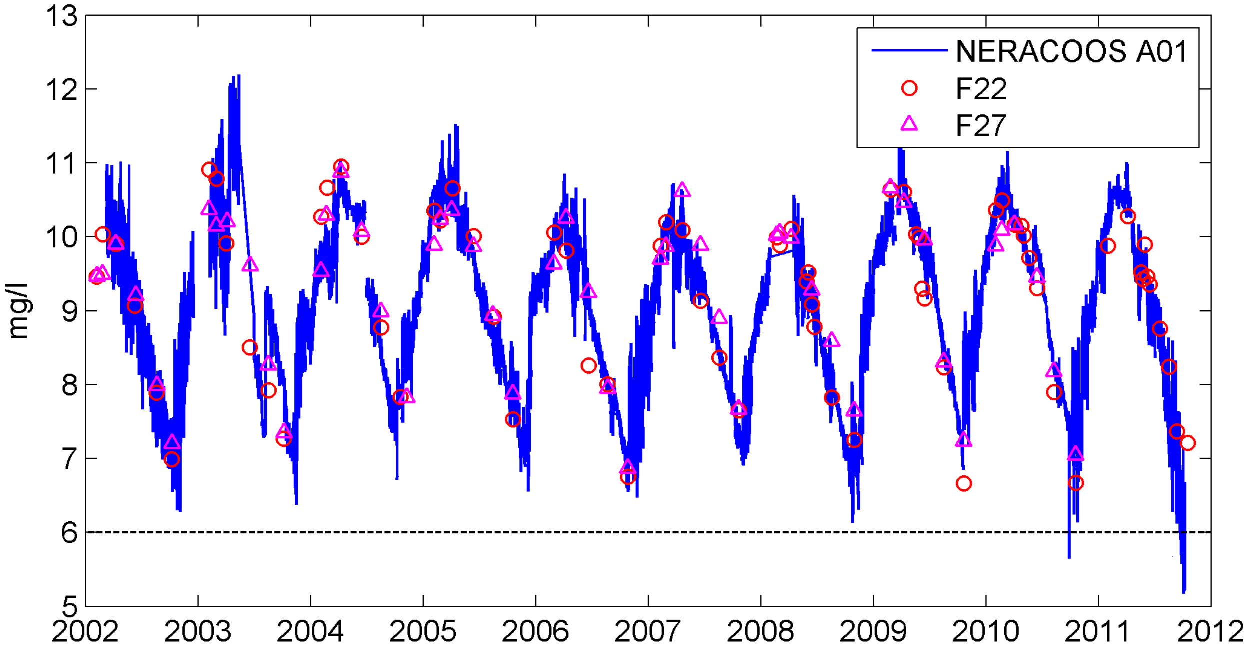

Figure 3-6. Bottom water dissolved oxygen concentrations at NERACOOS Buoy A01 and nearby MWRA stations F22 and F27. The NERACOOS A01 buoy data were calibrated against the MWRA results to account for differences across multiple buoy deployments. The dashed line at 6 mg/L indicates the state standard for dissolved oxygen, unless background conditions are lower; background condition near the outfall is 6.05 mg/L (Station F27 was deleted from the monitoring program in 2011.)

Water Quality

Water quality measurements for 2011, including measurements 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 near the outfall, there would be no detectable adverse effects (Libby et al. 2012). Reflecting the relatively enriched level of ammonium in the effluent, data from 1992–2010 had shown that ammonium concentrations in the nearfield increased to about one micromole/L above background when the outfall came on line and that those concentrations remained at the elevated level. Decreases in background ammonium concentrations (measured at the northern boundary) since 2005 have meant that the measured nearfield concentrations are at levels typical of baseline years despite the inputs from the discharge (Figure 3-7). The dramatic decrease in annual ammonium levels in Boston Harbor following the relocation of the effluent discharge from the harbor to the bay have persisted.

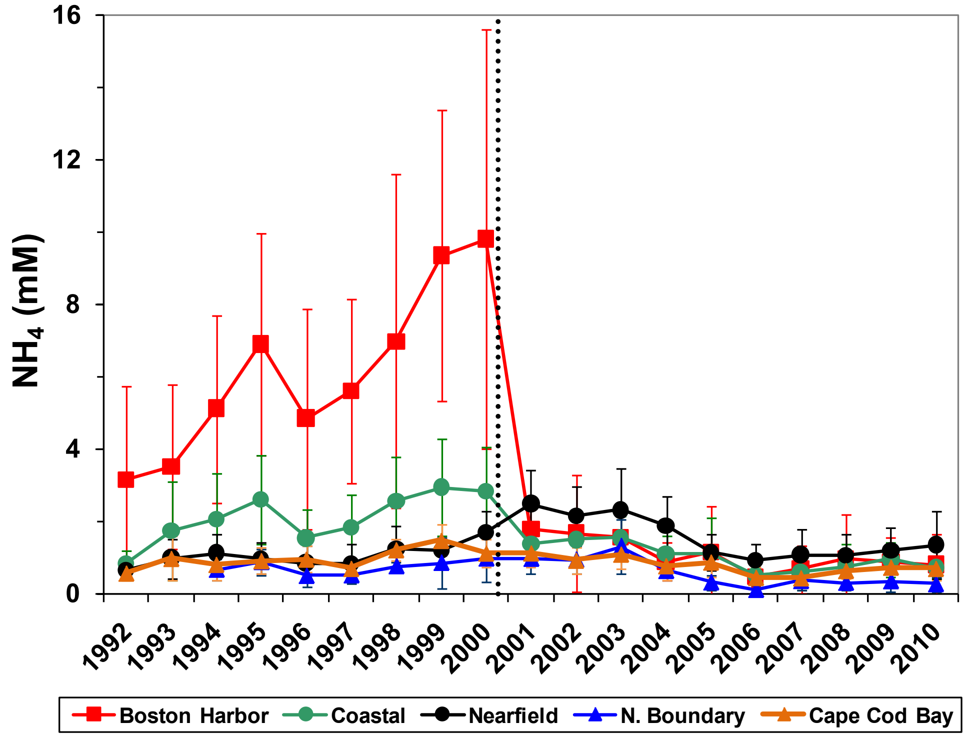

Figure 3-7. Annual mean ammonium concentrations, 1992–2010. This graph shows the historical pattern of ammonium levels in different monitoring areas. Ammonium significantly decreased in Boston Harbor and also decreased in coastal stations, after the outfall diversion to Massachusetts Bay, but did not greatly increase in the nearfield or other regions. Monitoring design changes implemented in 2011 mean the 2011 data are not directly comparable to 1992-2010. (Dotted vertical line shows the start-up Massachusetts Bay outfall. Error bars represent ±1 standard deviation.)

In 2011, nutrient concentrations near the outfall remained within the historic ranges and followed typical seasonal patterns (Figure 3-8). Nitrate and silicate concentrations were typical of the entire duration of the monitoring program, including the baseline period. As is usual, nitrate (plus nitrite) concentrations throughout Massachusetts Bay were higher than those in Cape Cod Bay in the late winter and early spring (Figure 3-9). By late April, nitrate levels were low throughout the region except in and near Boston Harbor.

Ammonium (and also phosphate) concentrations followed a (changed) pattern that has been observed since the outfall came on-line. Elevated subsurface ammonium concentrations near the outfall were apparent during winter months, when the plume reached the surface (Figure 3-10) and in the summer when it was confined below the pycnocline (Figure 3-11). The elevated ammonium concentrations at nearfield stations N18 and N21 persisted from June through September, as seasonal stratification confined the plume to the bottom waters, a consistent pattern in the nearfield. A summer increase in phosphate concentrations was also observed in 2011 and was also associated with the outfall plume.

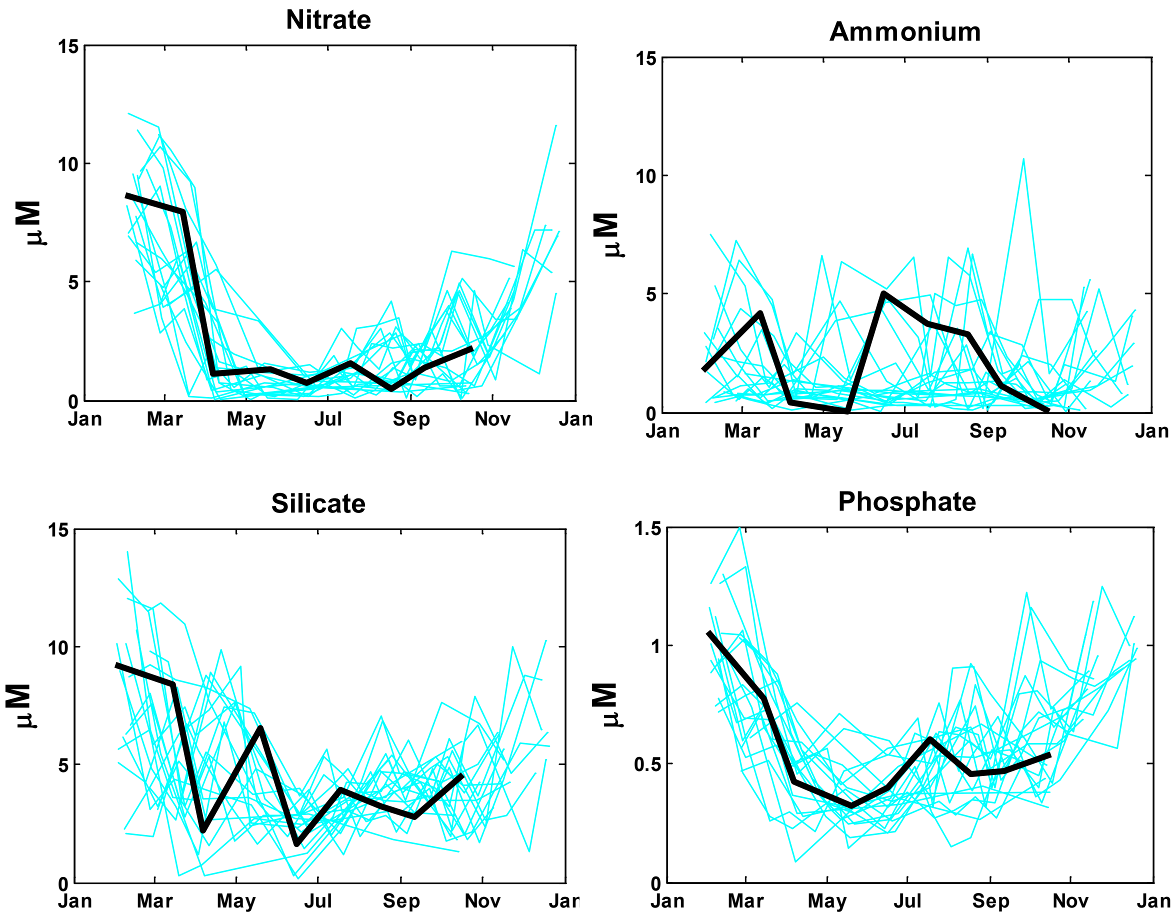

Figure 3-8. Mean nutrient concentrations at Station N18 in 2011, compared to prior years.

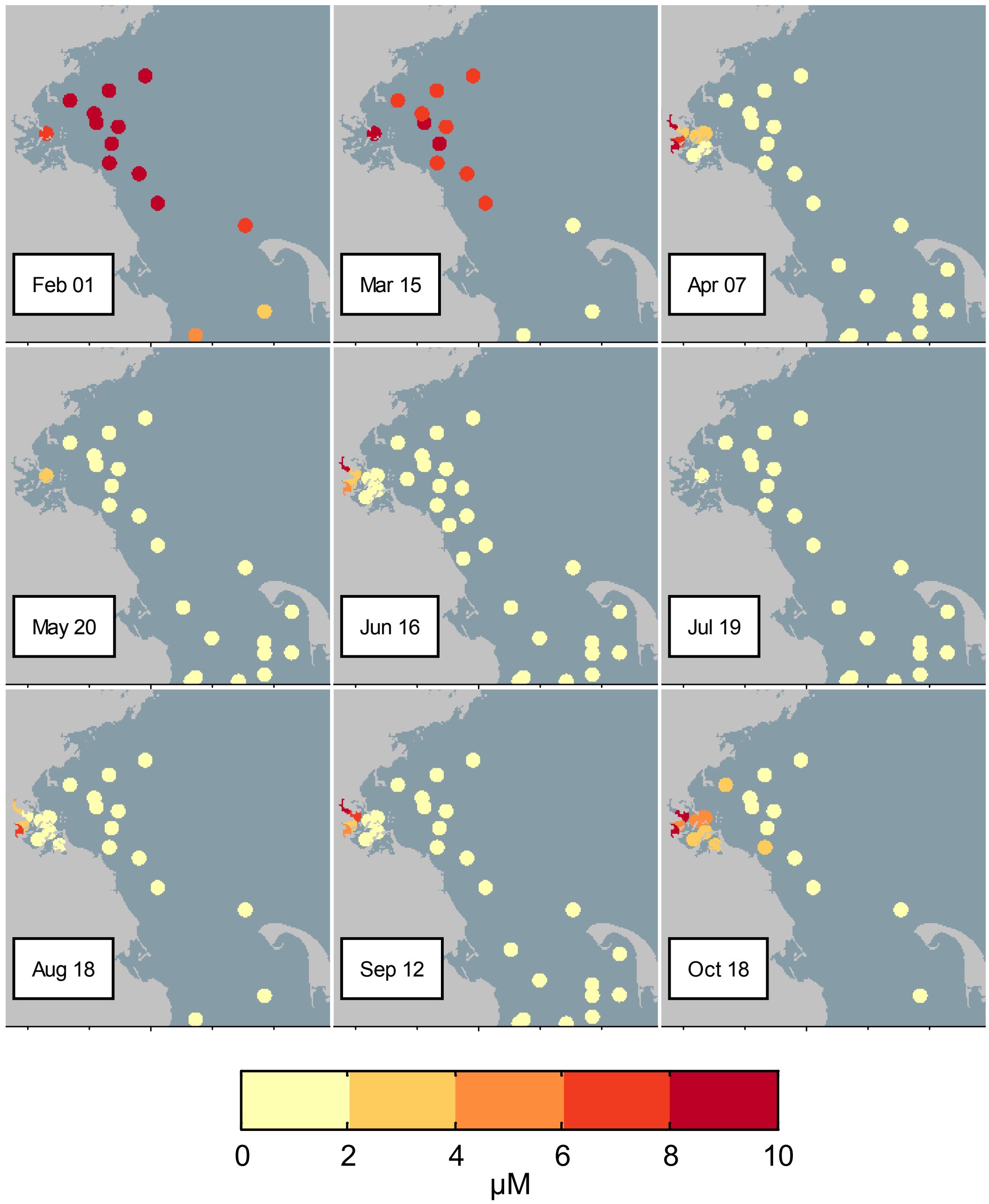

Figure 3-9. Surface water nitrate+nitrite (µM) by station in Massachusetts and Cape Cod bays. Several panels show additional data in Cape Cod Bay provided by the Provincetown Center for Coastal Studies and data from MWRA's in-house Boston Harbor monitoring surveys when those surveys were within a few days of the outfall monitoring surveys.

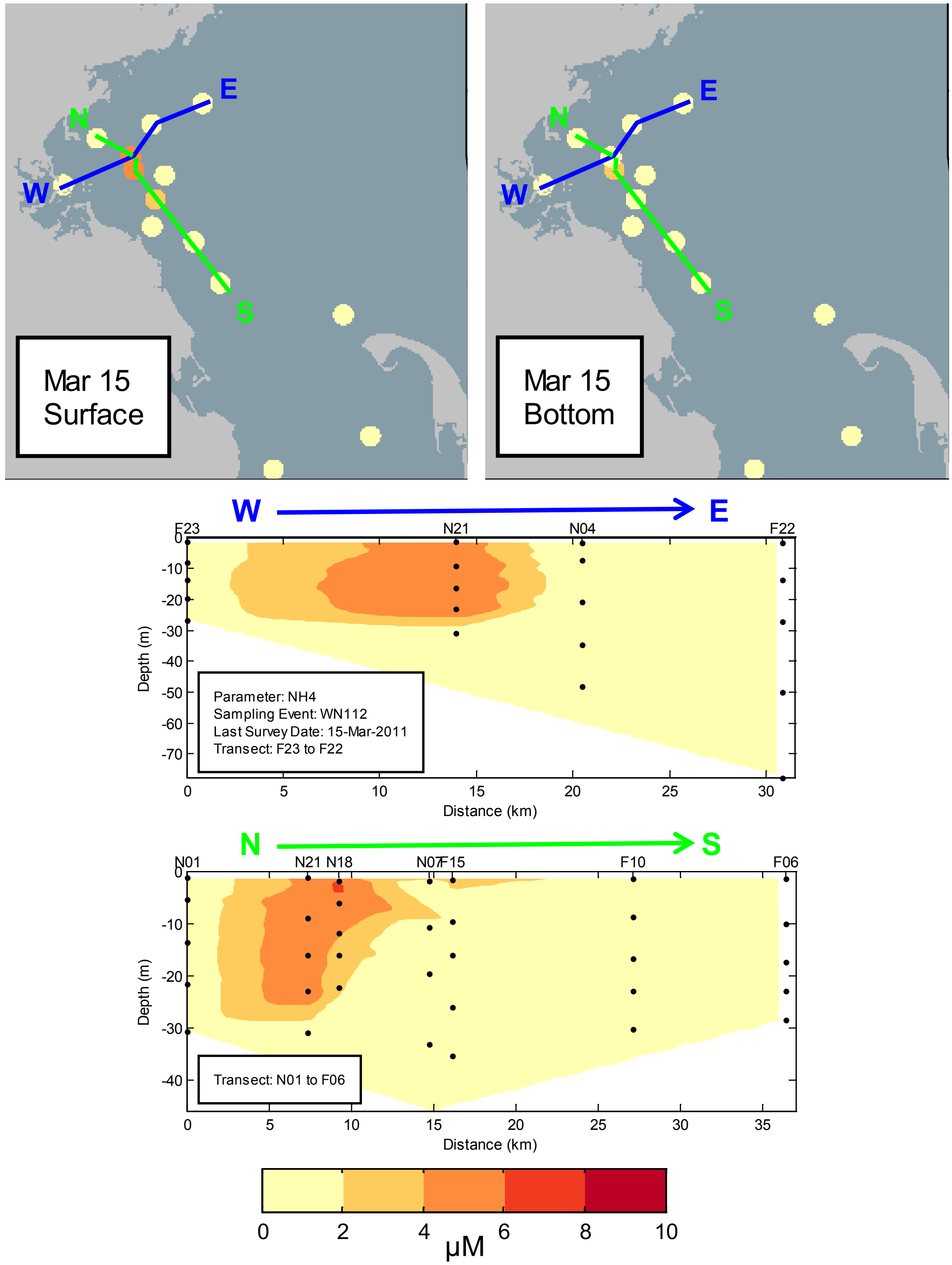

Figure 3-10. (Top) Surface and bottom water ammonium on March 15, 2011 at the monitoring stations. (Bottom) Cross-sections of concentrations at other depths along transects connecting selected stations showing well-mixed conditions.

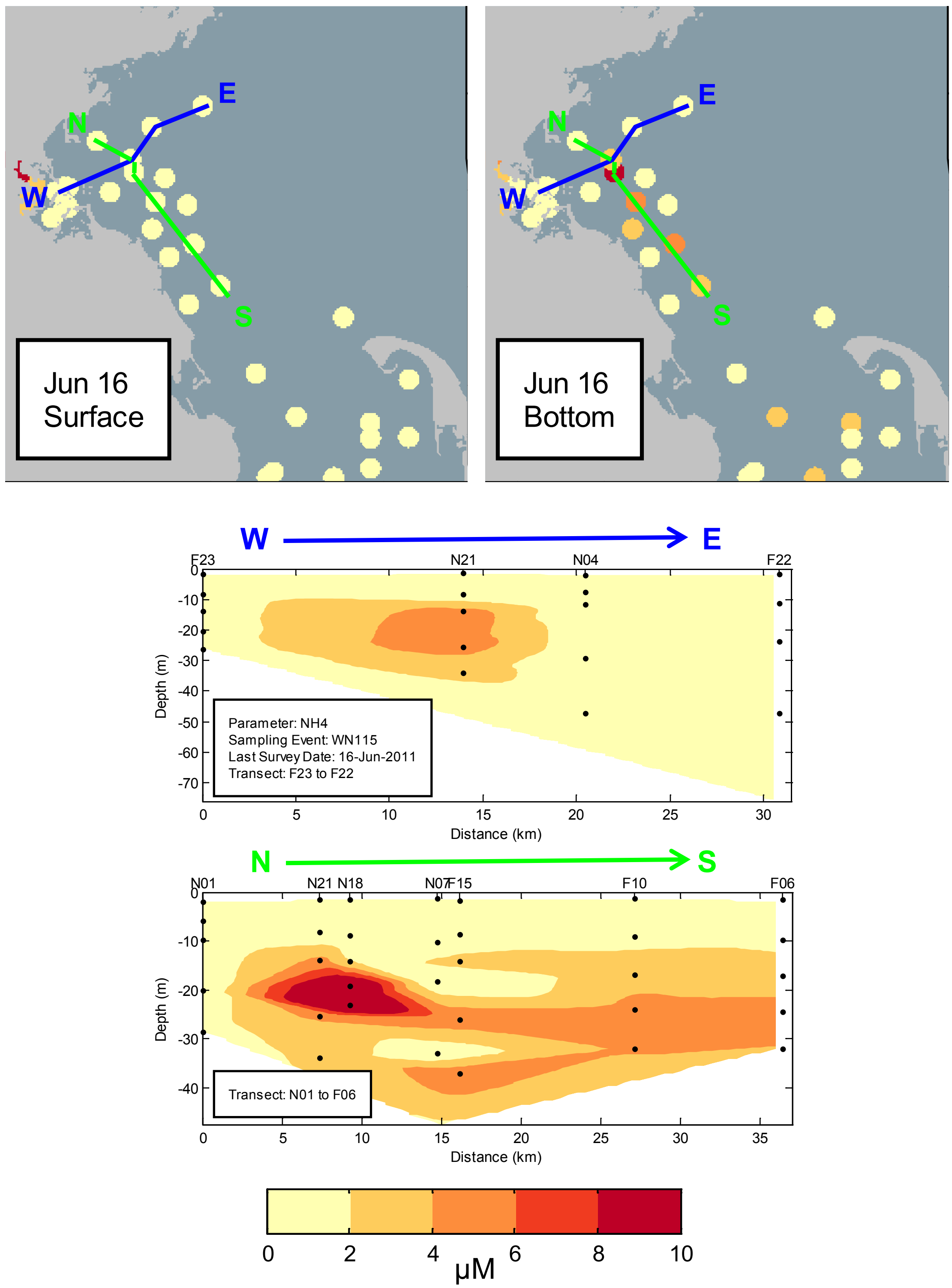

Figure 3-11. (Top) Surface and bottom water ammonium on June 16, 2011 at the monitoring stations during stratified conditions. (Bottom) Cross-sections of concentrations at other depths along transects connecting selected stations, showing that the plume is contained at depth. Additional data from Cape Cod Bay were provided by the Provincetown Center for Coastal Studies.

Surface water chlorophyll concentrations also followed typical patterns in space and time (Figure 3-12). Early spring blooms were apparent in Cape Cod Bay in the late winter and early spring. Chlorophyll levels rose in Massachusetts Bay in April and May and then again in the fall, although spring concentrations were only moderately high compared with some past years. Silicate in the riverine inputs apparently stimulated diatom growth in May. There was a summer bloom in Boston Harbor, the third year in a row that diatom blooms have occurred in shallow harbor and coastal waters.

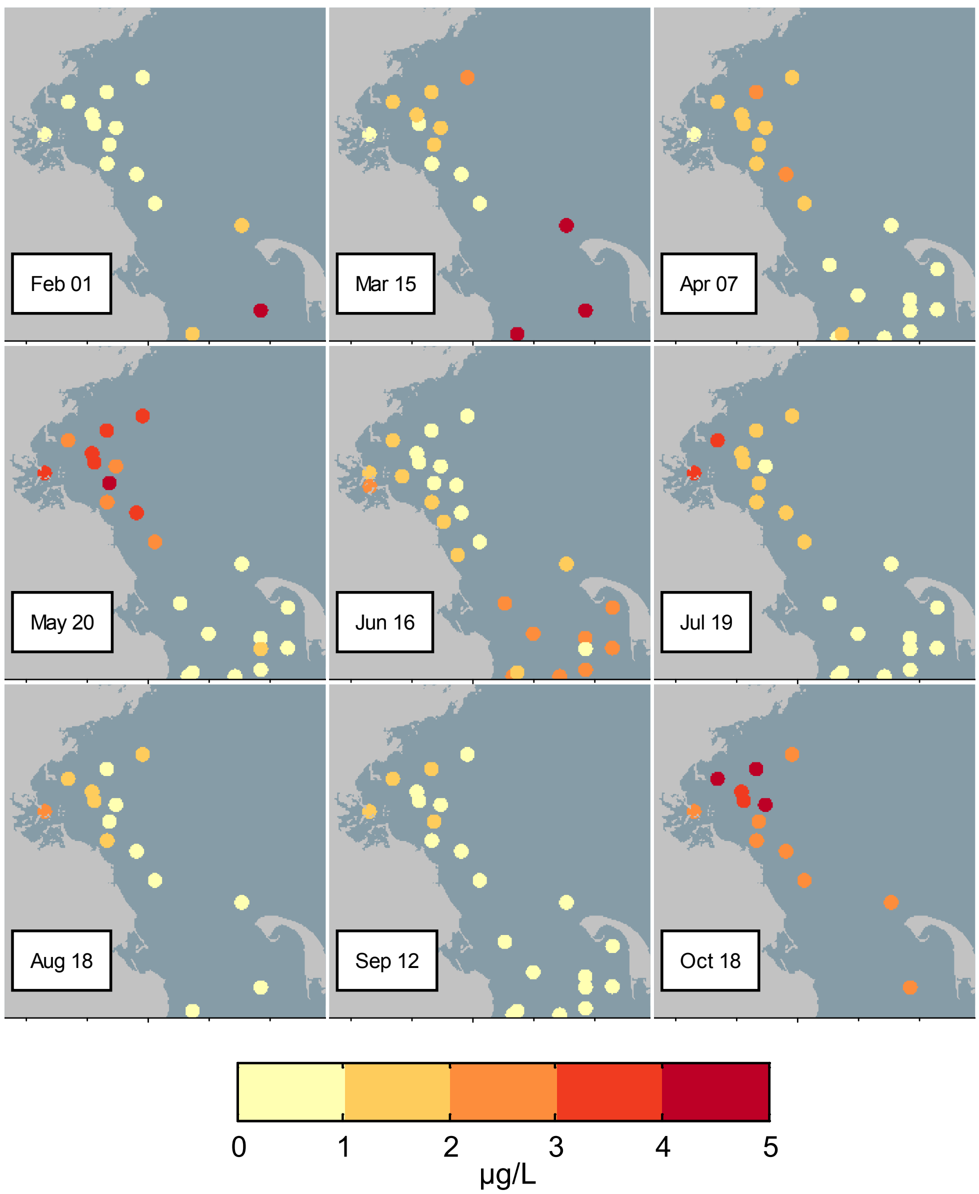

Figure 3-12. Surface water chlorophyll fluorescence by station in Massachusetts and Cape Cod bays. Additional data in Cape Cod Bay were provided by the Provincetown Center for Coastal Studies.

Satellite imagery (Figure 3-13) showed that the spring bloom in Massachusetts Bay may have peaked, in terms of chlorophyll concentrations, in late March, between the March and April survey dates. Cloudy skies prevented obtaining chlorophyll imagery in May.

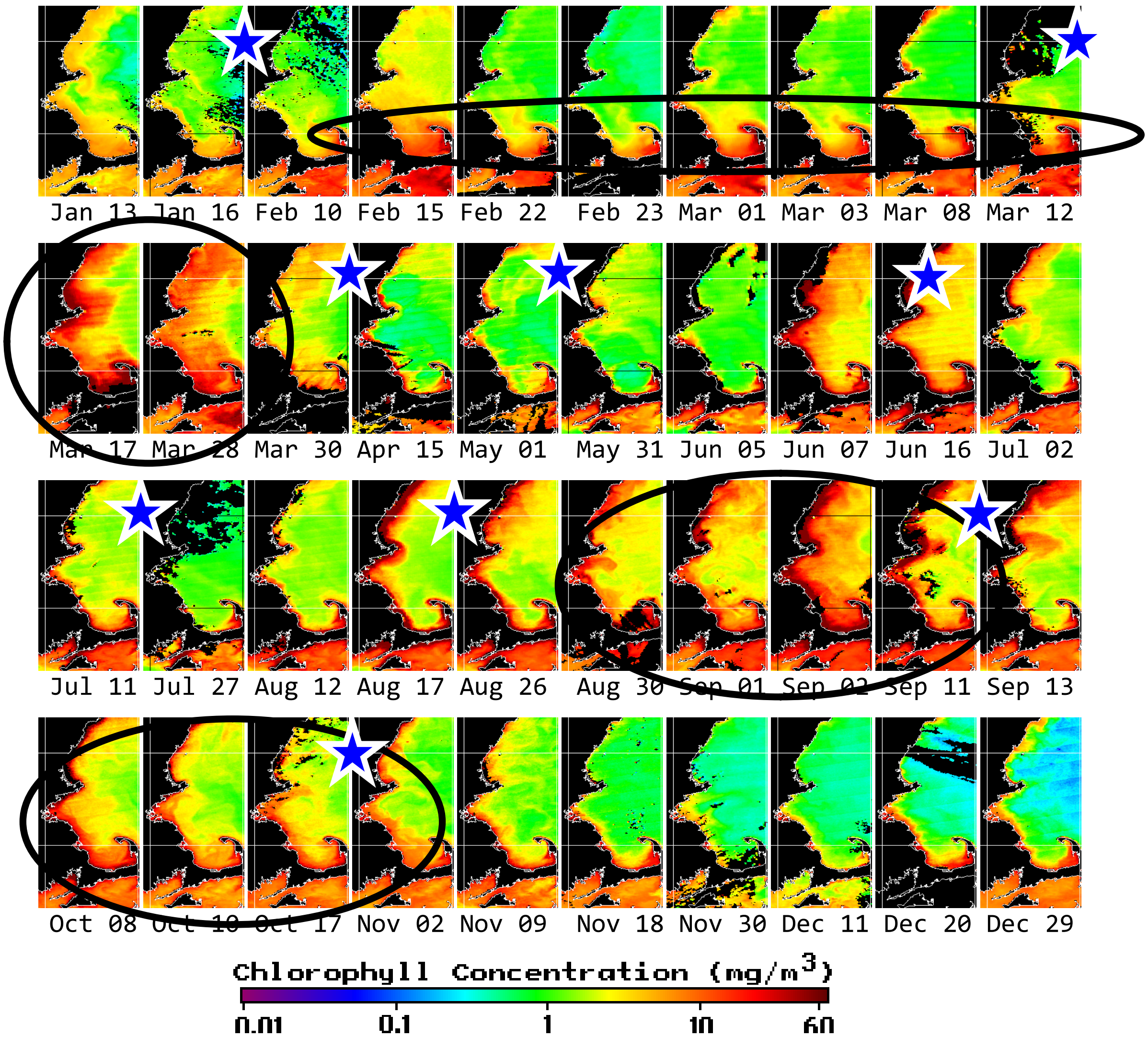

Figure 3-13. Moderate Resolution Imaging Spectroradiometer satellite imagery of surface chlorophyll concentrations in 2011. The circles highlight specific blooms: 1st row- early spring bloom in Cape Cod Bay; 2nd row – region-wide *Phaeocystis* bloom in March; 3rd row – post Hurricane Irene *Skeletonema* and microflagellate blooms in late August and early September; and 4th row – microflagellate and *Prorocentrum* blooms in October. These images are heavily weather dependent and do not represent consistent intervals of time; for example, only two images were available over the two-month period between March 30 and May 31. The stars show the timing of the nine MWRA surveys.

Phytoplankton Communities

The phytoplankton communities followed typical progressions throughout the year, although annual abundances were low compared to some years. The late winter/early spring bloom in Cape Cod Bay was dominated by diatoms and microflagellates. As has been typical, the increased chlorophyll levels in Massachusetts Bay in the spring corresponded with a region-wide bloom of *Phaeocystis pouchetii*, a colonial species that is not toxic but is considered to be an aesthetic nuisance and poor food for zooplankton. The 2011 *Phaeocystis pouchetii* bloom was relatively modest, with average counts similar to other recent years (Figure 3-14). Somewhat elevated abundances of another nuisance species, the pennate diatom *Pseudo-nitzschia delicatissima*, were also observed in April with most cells associated with, observed on, or embedded in *Phaeocystis pouchetii* colonies. *Pseudo-nitzschia* spp. have been present at only very low concentrations throughout the monitoring program.

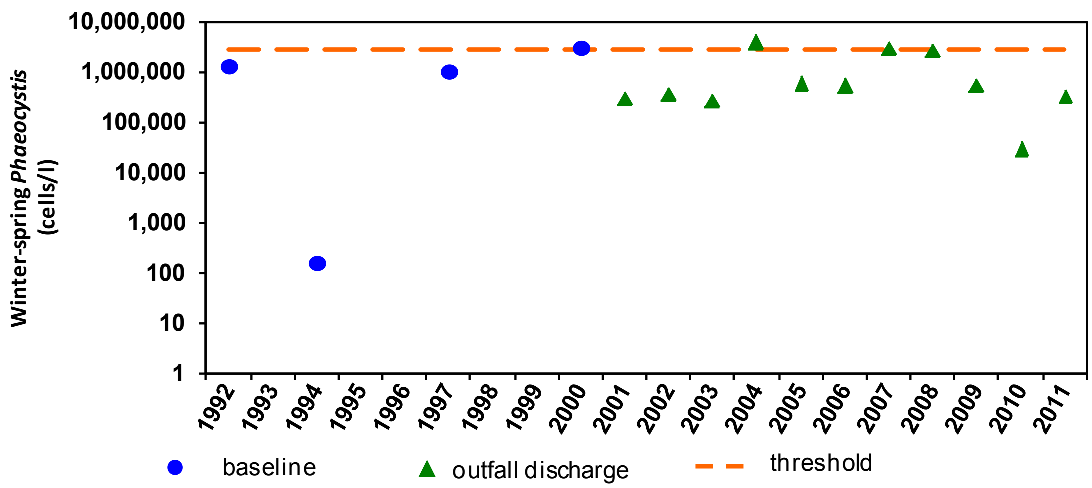

Figure 3-14. Winter/spring mean nearfield abundance of *Phaeocystis pouchetii*, 1992–2011. Years with no symbol had no detected *Phaeocystis.*

The phytoplankton population increases in Massachusetts Bay in May were dominated by centric diatoms and dinoflagellates. The dinoflagellate community included *Alexandrium fundyense* (Figure 3-15), with nearfield abundance peaking at about 2,500 cells/L at station N07. The *Alexandrium fundyense* abundance levels were above the 100 cells/L that trigger *Alexandrium* rapid-response surveys. Consequently, a three-week series of surveys was conducted in late May and early June, documenting a moderate bloom (Figure 3-16). The bloom was at levels sufficient to cause paralytic shellfish poisoning and impacted shellfishing across most of Massachusetts Bay. The bloom was, however, smaller than had been predicted from spore counts and weather patterns. *Alexandrium fundyense* blooms have occurred regularly in Massachusetts Bay since 2005.

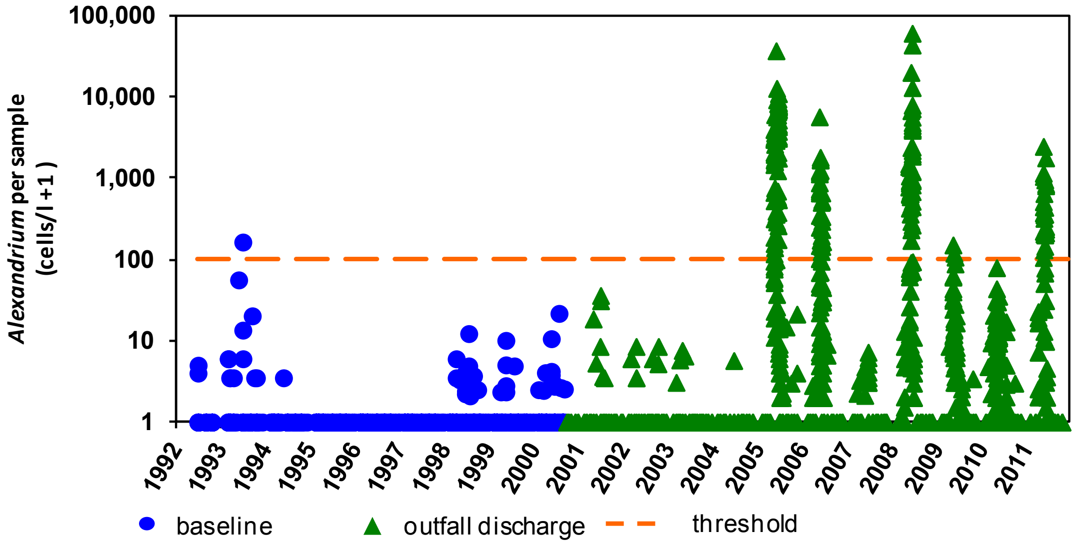

Figure 3-15. Nearfield abundance of *Alexandrium fundyense*, 1992–2011.

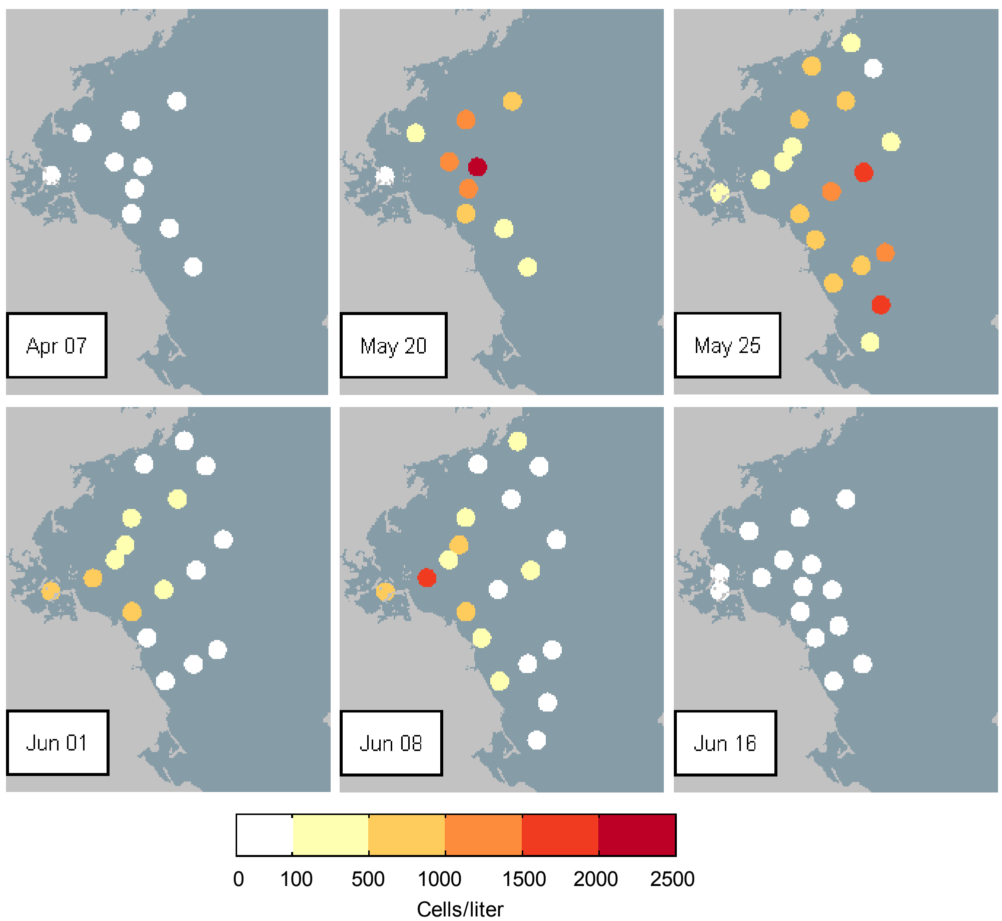

Figure 3-16. Surface *Alexandrium fundyense* abundance (cells/L) for individual samples during the April to June 2011 surveys.

Reports of "purple water" in Massachusetts Bay were received by MWRA from the U.S. Coast Guard in early August 2011. Targeted samples collected from what was described as "blood red water" off Nahant at the northern boundary between Boston Harbor and Massachusetts Bay found that the color was due to elevated abundance of a photosynthetic ciliate *Myrionecta rubra*. Elevated abundance of *Myrionecta rubra* had also been detected in the June 2011 survey samples. The observed abundances in June were about twice those of the long-term mean level for the bay and the highest abundances observed to date in the harbor and northern offshore stations. Presence of *Myrionecta rubra* is not a concern for environmental or human health, nor is it related to the outfall.

Zooplankton Communities

The 2011 abundances, species composition, and seasonal patterns of the zooplankton communities were typical of past years. Zooplankton abundance declined throughout the bays during 2001–2006 but has rebounded since that period. As is typical, total zooplankton abundance was dominated by copepod nauplii and copepodites and adults of the small species *Oithona similis*.

Total zooplankton abundance increased from the winter through the spring to peak in the summer, and declined in late summer except for an interesting peak in the fall after the late August passage of Hurricane Irene apparently spurred an increase in phytoplankton and subsequently zooplankton abundance (Figure 3-17). Overall, 2011 zooplankton levels were near the long-term means for most zooplankton groups in most regions of the bays.

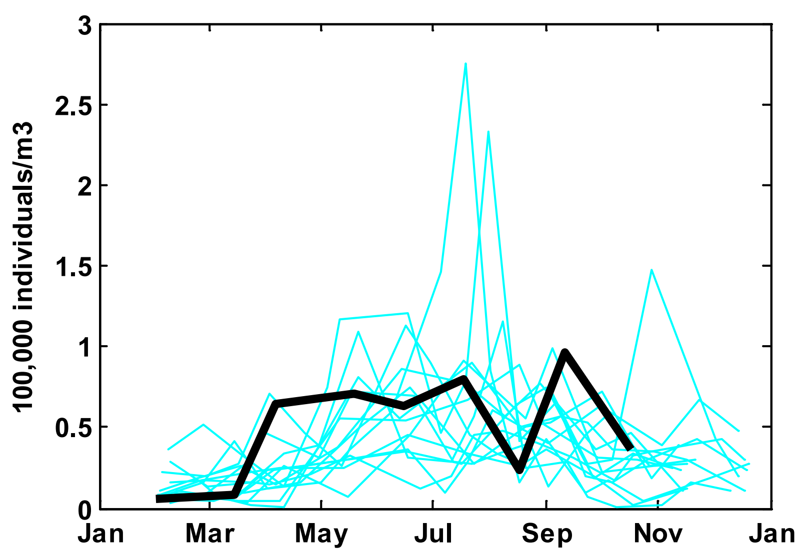

Figure 3-17. Nearfield abundance of total zooplankton in 2011 compared to past years.

Abundance of the large copepod *Calanus finmarchicus* peaked in April, with population abundances that were higher than in most years, making up more than 20% of total zooplankton population. In general, *Calanus finmarchicus* is most abundant at offshore stations.

Abundance of the more typically estuarine copepods *Acartia* spp. peaked in May at Station F23 in Boston Harbor and had similarly high counts at other inshore and nearfield stations. High *Acartia* spp. abundances in the nearfield area in May are unusual and may have been due to the large influx of fresher waters observed in May 2011.

Stellwagen Bank National Marine Sanctuary

The NPDES permit to discharge from DITP into Massachusetts Bay requires an annual report on results that are relevant to the Stellwagen Bank National Marine Sanctuary. Station F29 (Figure 3-1) is on the sanctuary's southern boundary, and Station F22 is in Stellwagen Basin. (The new monitoring plan eliminated the eastern boundary stations in the sanctuary.)

MWRA monitors dissolved oxygen concentration and saturation in Stellwagen Basin as Contingency Plan requirements. Bottom dissolved oxygen concentrations (Figure 3-18) and percent saturation (not shown) in 2011 remained within the baseline ranges.

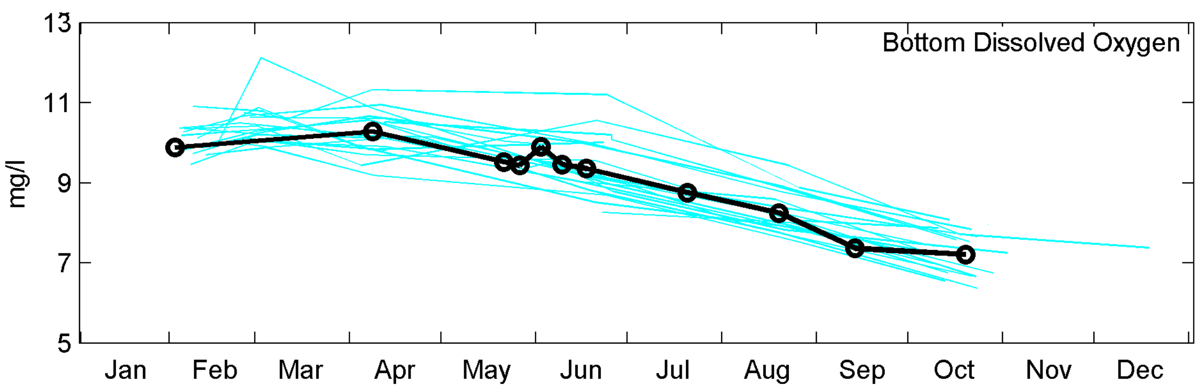

Figure 3-18. Bottom water dissolved oxygen concentrations in Stellwagen Basin in 2011 compared to the previous years of monitoring.

Besides survey data, buoy data and model outputs are useful in determining water quality conditions throughout Massachusetts Bay, including the sanctuary. Figure 3-19 shows the location of an east-west transect across the Massachusetts Bay outfall and Stellwagen Bank, and Figures 3-20 through 3-23 depict modeled water quality parameters along that transect. The model results confirmed predictions that there would be no indication of any effect of the outfall for most parameters, even in the nearfield.

Elevated levels of dissolved inorganic nitrogen can be detected but only in the immediate vicinity of the outfall, with no effect on the sanctuary. Dissolved oxygen concentration, dissolved oxygen saturation, and chlorophyll modeling show no effect of the outfall in any month.

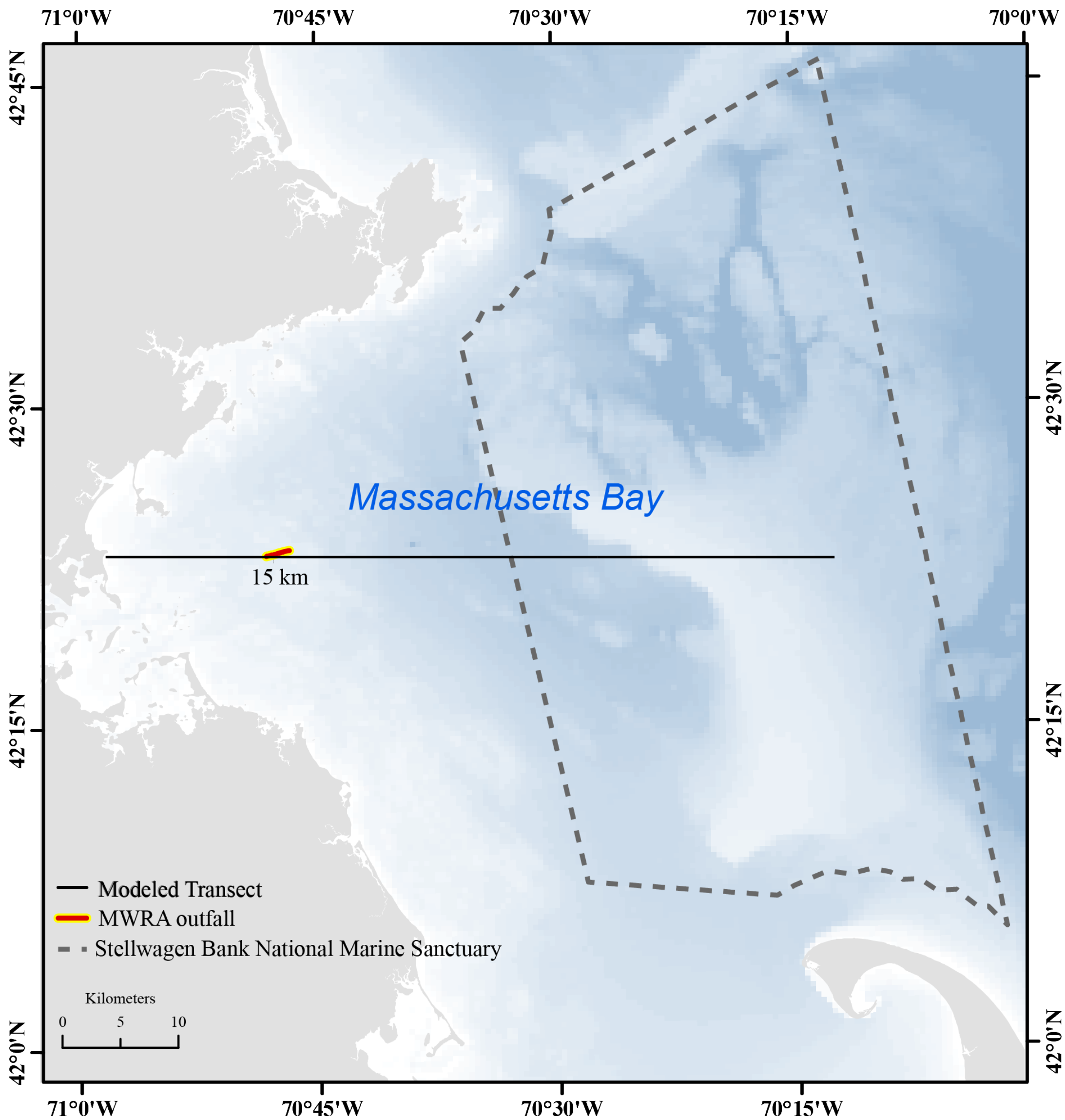

Figure 3-19. Location of east-west transect from Deer Island, across MWRA outfall, through Stellwagen Bank, for modeled water-quality parameters presented in Figures 3-20 through 3-23.

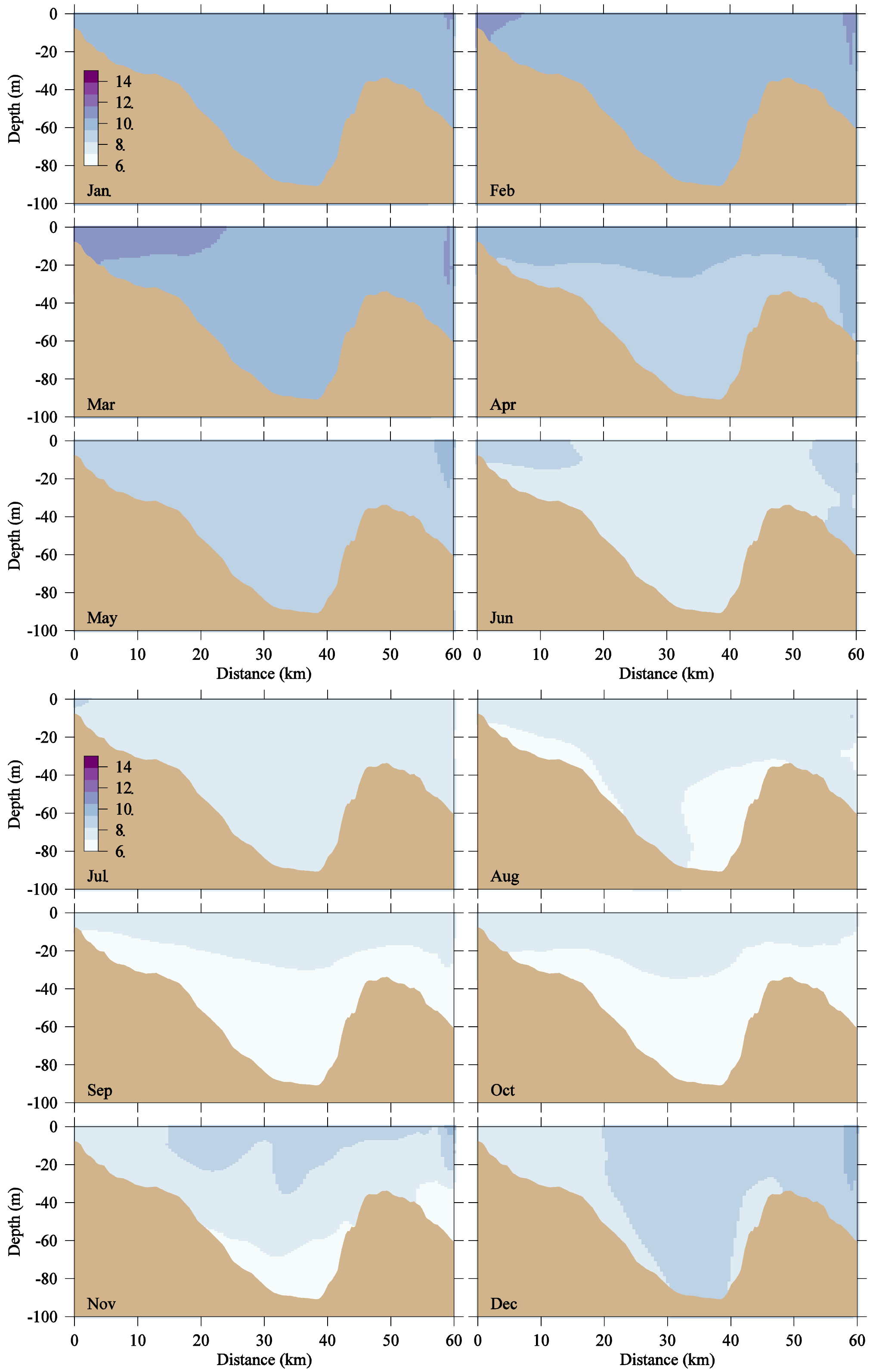

Figure 3-20. Modeled dissolved oxygen concentration (mg/L) on the east-west transect across the MWRA outfall and Stellwagen Bank National Marine Sanctuary at the end of each month from January through December 2011.

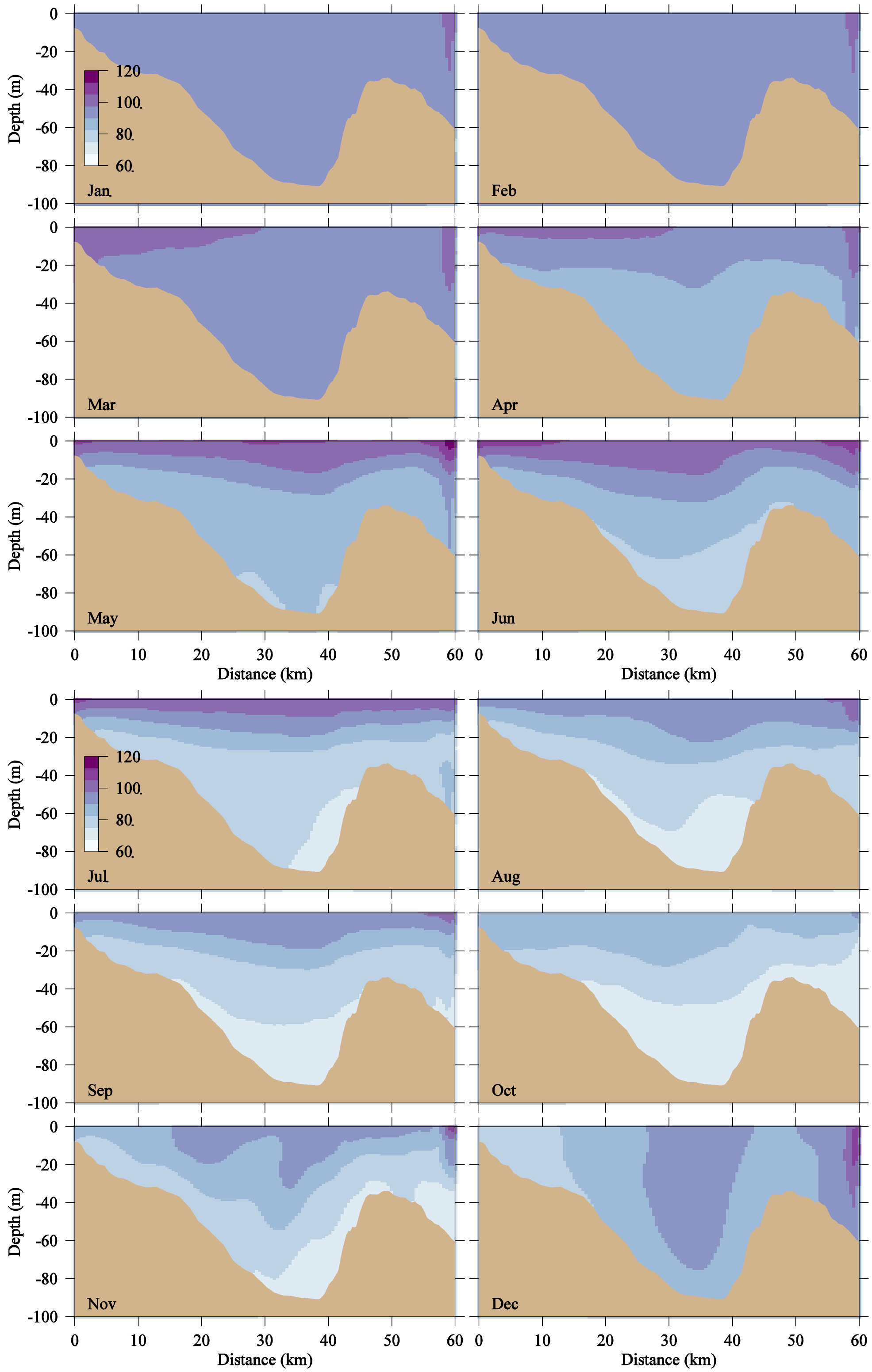

Figure 3-21. Modeled percent dissolved oxygen saturation on the east-west transect across the MWRA outfall and Stellwagen Bank National Marine Sanctuary at the end of each month from January through December in 2011.

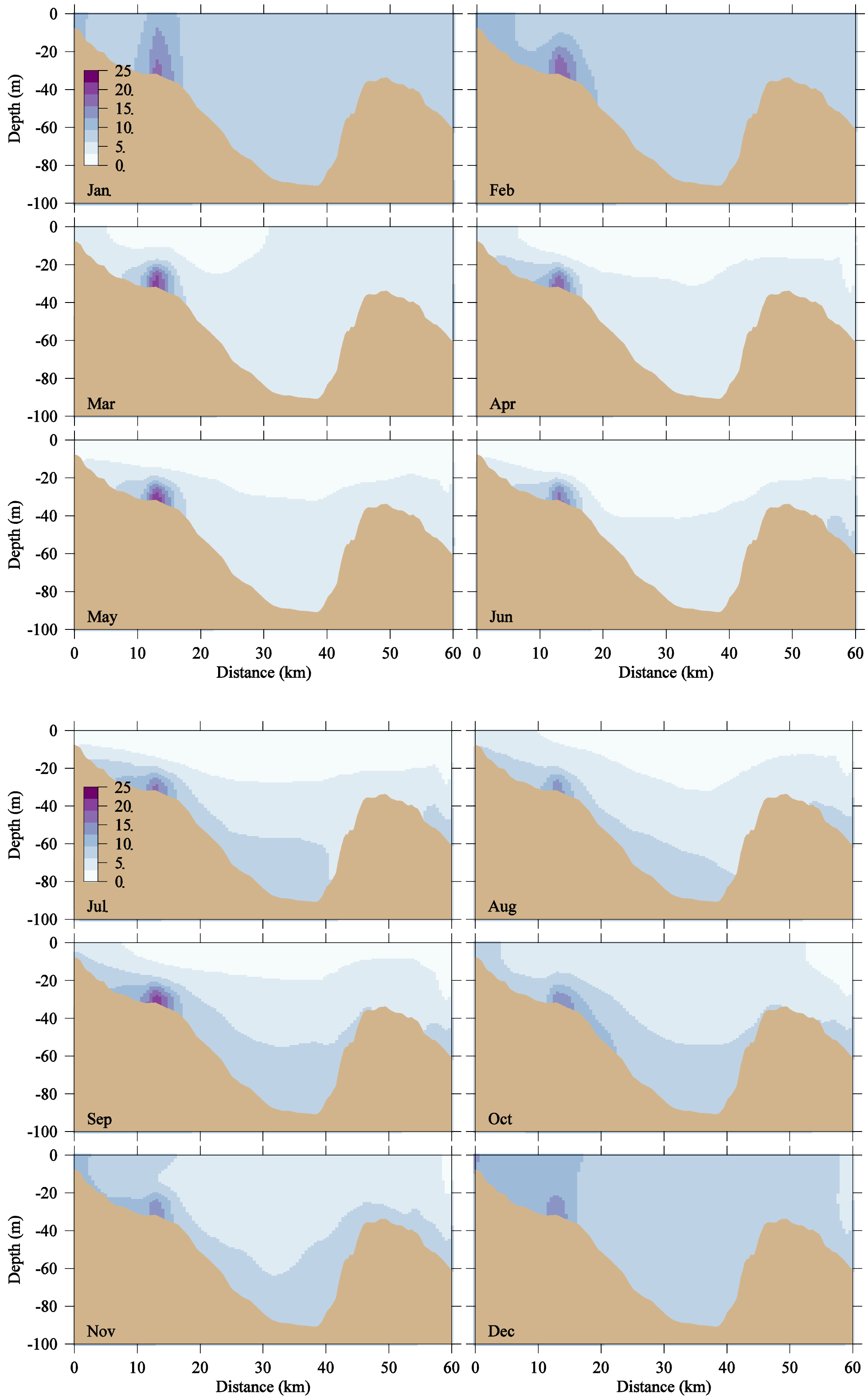

Figure 3-22. Modeled dissolved inorganic nitrogen concentrations (µM) on the east-west transect across the MWRA outfall and Stellwagen Bank National Marine Sanctuary at the end of each month from January through December in 2011.

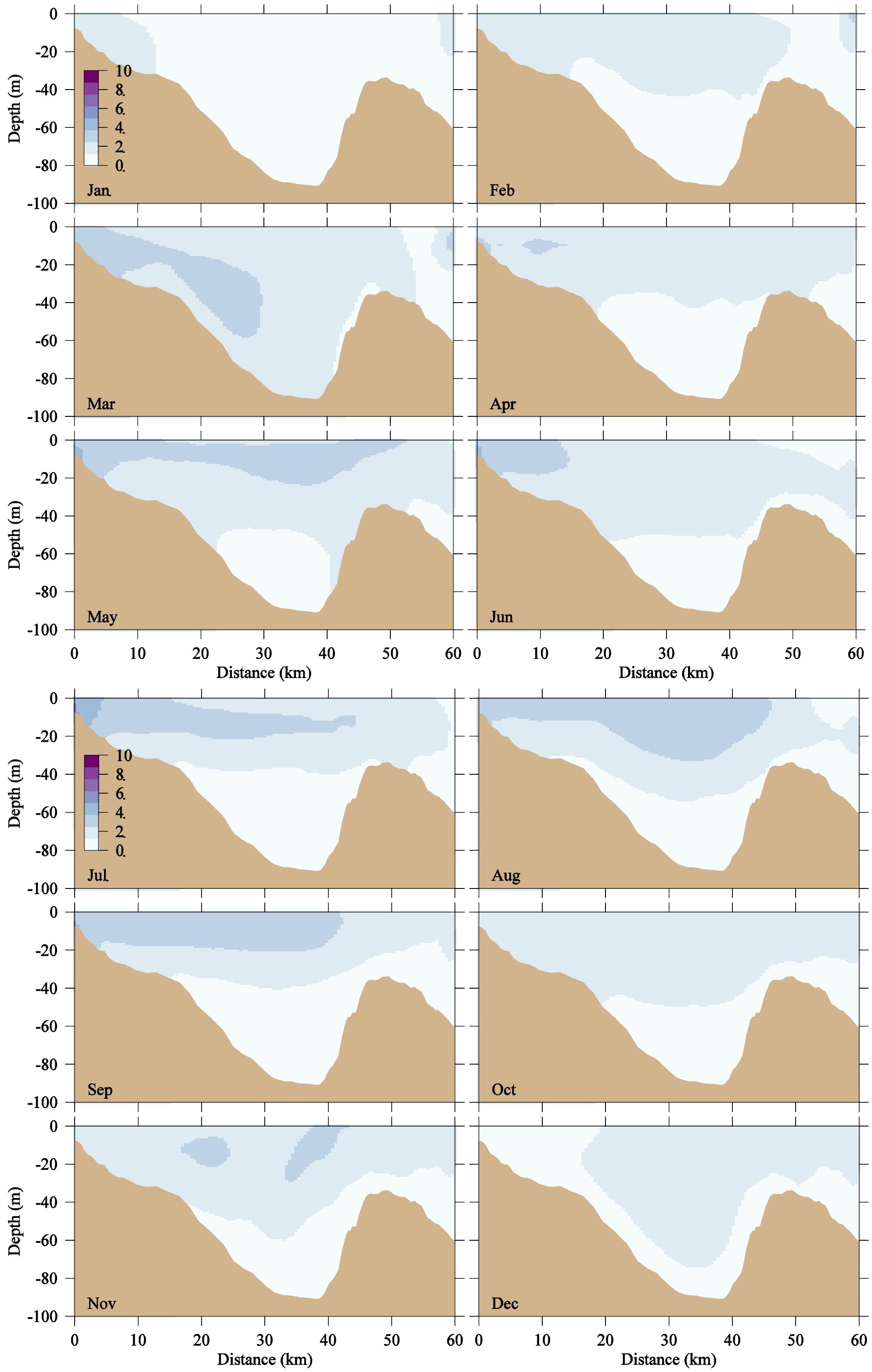

Figure 3-23. Modeled chlorophyll concentrations (µg/L) on the east-west transect across the MWRA outfall and Stellwagen Bank National Marine Sanctuary at the end of each month from January through December in 2011.

The Provincetown Center for Coastal Studies monitoring program in Cape Cod Bay includes MWRA Station F29, on the southern boundary of the sanctuary as well as other MWRA stations in Cape Cod Bay, F01 and F02. Major groups of phytoplankton and zooplankton followed similar abundance patterns at all of three stations throughout the year (Figures 3-24 and 3-25). Phytoplankton communities at all three stations were predominantly diatoms in the late winter and in June, while dinoflagellates peaked in May, and microflagellates were present throughout the year. Zooplankton communities were dominated by copepods, with the large species *Calanus finmarchicus* peaking in April, the time in which right whale abundance typically peaks in Cape Cod Bay.

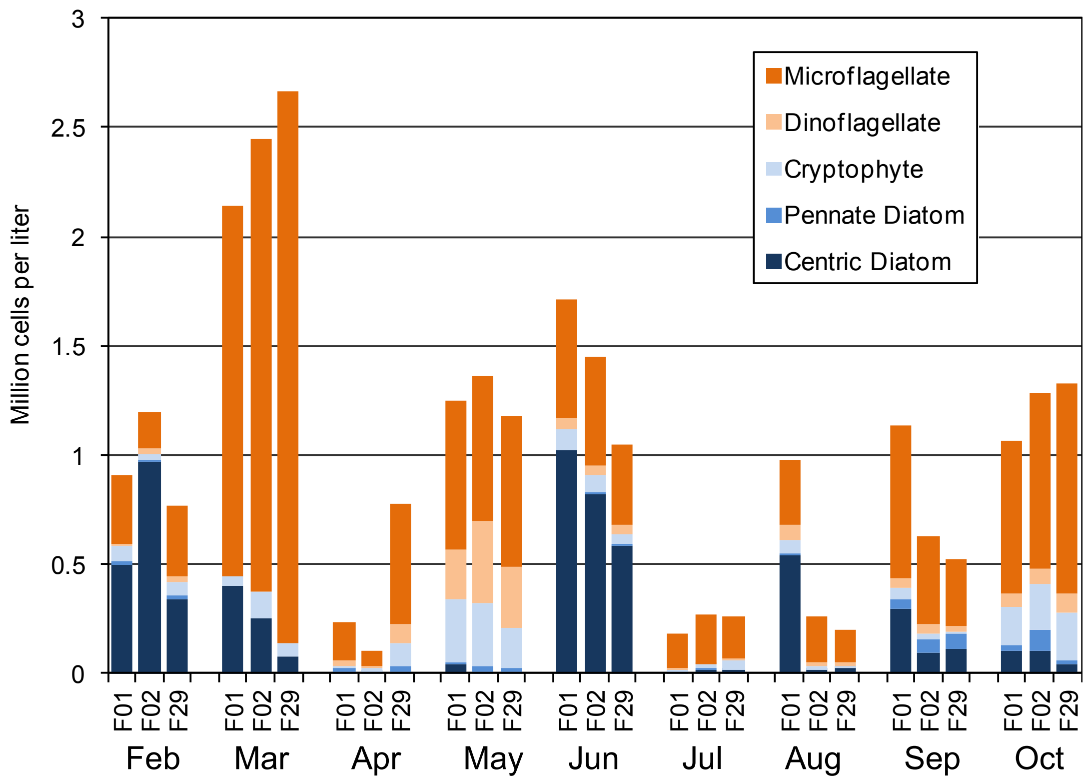

Figure 3-24. Surface-water phytoplankton abundance and composition at MWRA Cape Cod Bay stations, including Station F29 near Stellwagen Bank National Marine Sanctuary. (Data from the Provincetown Center for Coastal Studies)

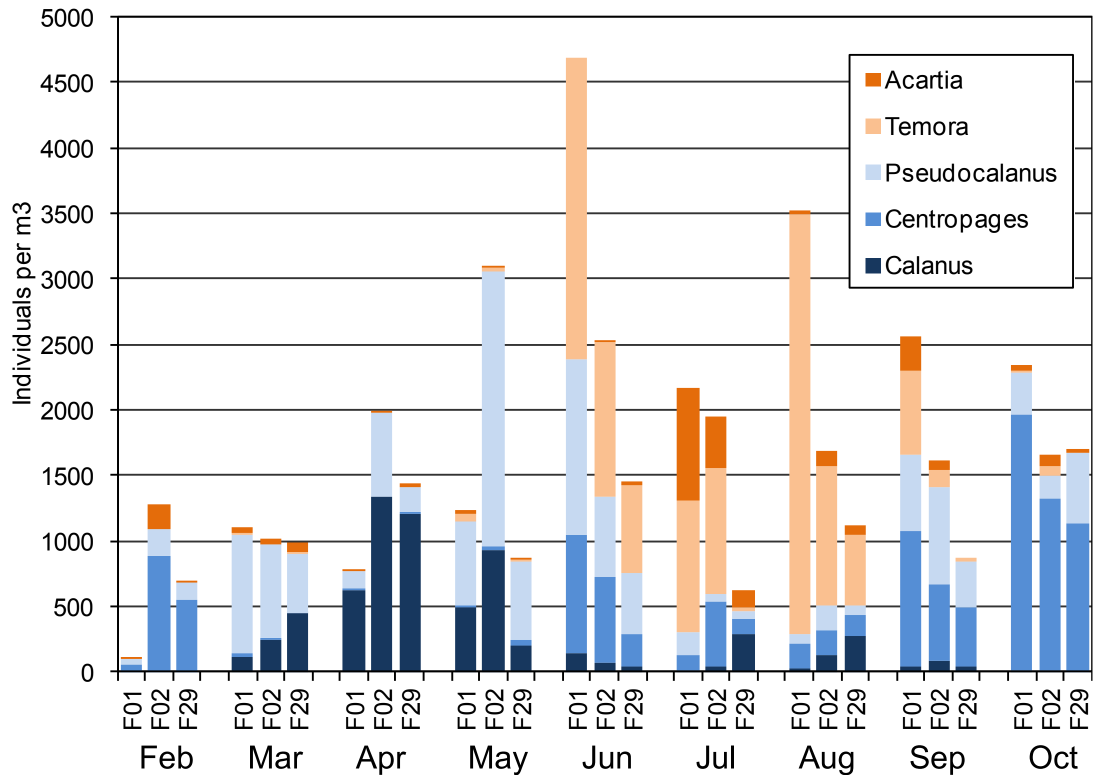

Figure 3-25. Zooplankton abundance and composition at MWRA Cape Cod Bay Stations, including Station F29 near Stellwagen Bank National Marine Sanctuary. Data from the Provincetown Center for Coastal Studies (PCCS). PCCS uses a different method to collect zooplankton than MWRA; the PCCS method collects larger species, which are favored whale prey. Therefore, PCCS data are not directly comparable to MWRA's zooplankton data.

Contingency Plan Thresholds

Water-quality parameters were within normal ranges throughout 2011. There was one exceedance of a nuisance phytoplankton species Contingency Plan threshold (Table 3-1), when samples collected in May exceeded the *Alexandrium fundyense* caution level. This 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 consistent with historic progressions and that the outfall discharge did not affect its intensity, timing, or duration.

Table 3-1. Contingency Plan threshold values and 2011 results for water-column monitoring. DO = dissolved oxygen

Location/ Parameter	Specific Parameter	Baseline	Caution Level	Warning Level	2011 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 = 6.78 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 = 74.4%
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 = 7.21 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 = 76.5%
Bottom water nearfield	DO depletion rate (June-October)	0.024 mg/L/d	0.037 mg/L/d	0.049 mg/L/d	0.021 mg/L/d
Chlorophyll nearfield	Annual	72 mg/m^2	108 mg/m^2	144 mg/m^2	49 mg/m^2
	Winter/spring	50 mgml^2	199 mg/m^2	None	44 mg/m^2
	Summer	51 mg/m^2	89 mg/m^2	None	48 mg/m^2
	Autumn	90 mg/m^2	239 mg/m^2	None	56 mg/m^2
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	622,000 cells/L	2,860,000 cells/L	None	338,000 cells/L
	Summer	72 cells/L	357 cells/L	None	Absent
	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	Absent
	Summer	14,635 cells/L	43,100 cells/L	None	660 cells/L
	Autumn	10,050 cells/L	27,500 cells/L	None	1,240 cells/L
Nuisance algae nearfield *Alexandrium fundyense*	Any nearfield sample	Baseline maximum = 163 cells/L	100 cells/L	None	2,453 cells/L, caution level exceedance
Farfield	PSP toxin extent	Not applicable	New incidence	None	No new incidence

4. Sea Floor

Sea-floor monitoring analyzes soft-bottom sediments and communities, sediment-profile imagery, and hard-bottom communities (Figures 4-1 through 4-3).

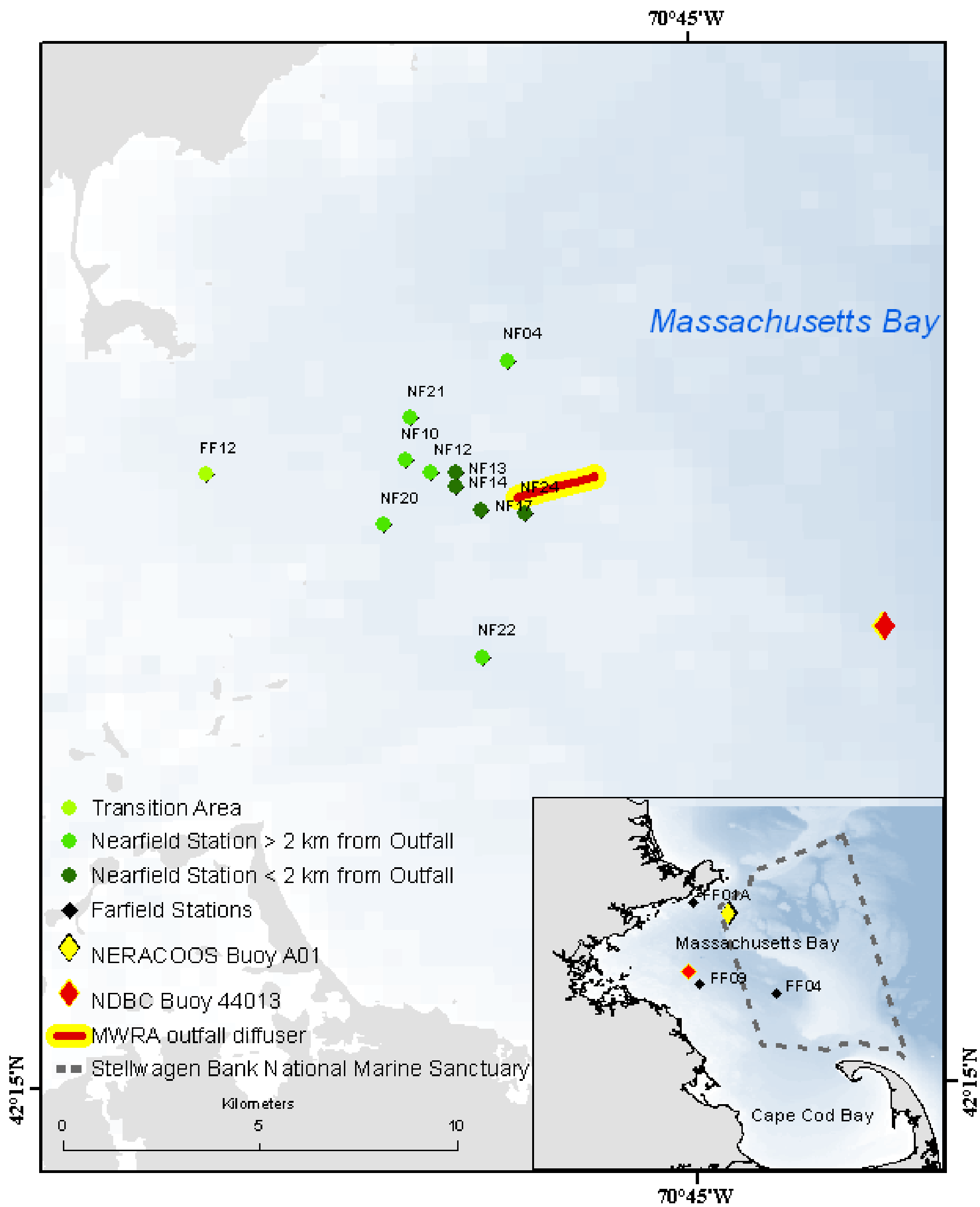

Figure 4-1. Soft-bottom monitoring stations. Fourteen stations were sampled for benthic community parameters and sediment characteristics and contaminants. Also shown are two instrumented buoys, one operated by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the other by the National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC); the MWRA outfall diffuser; and the Stellwagen Bank National Marine Sanctuary.

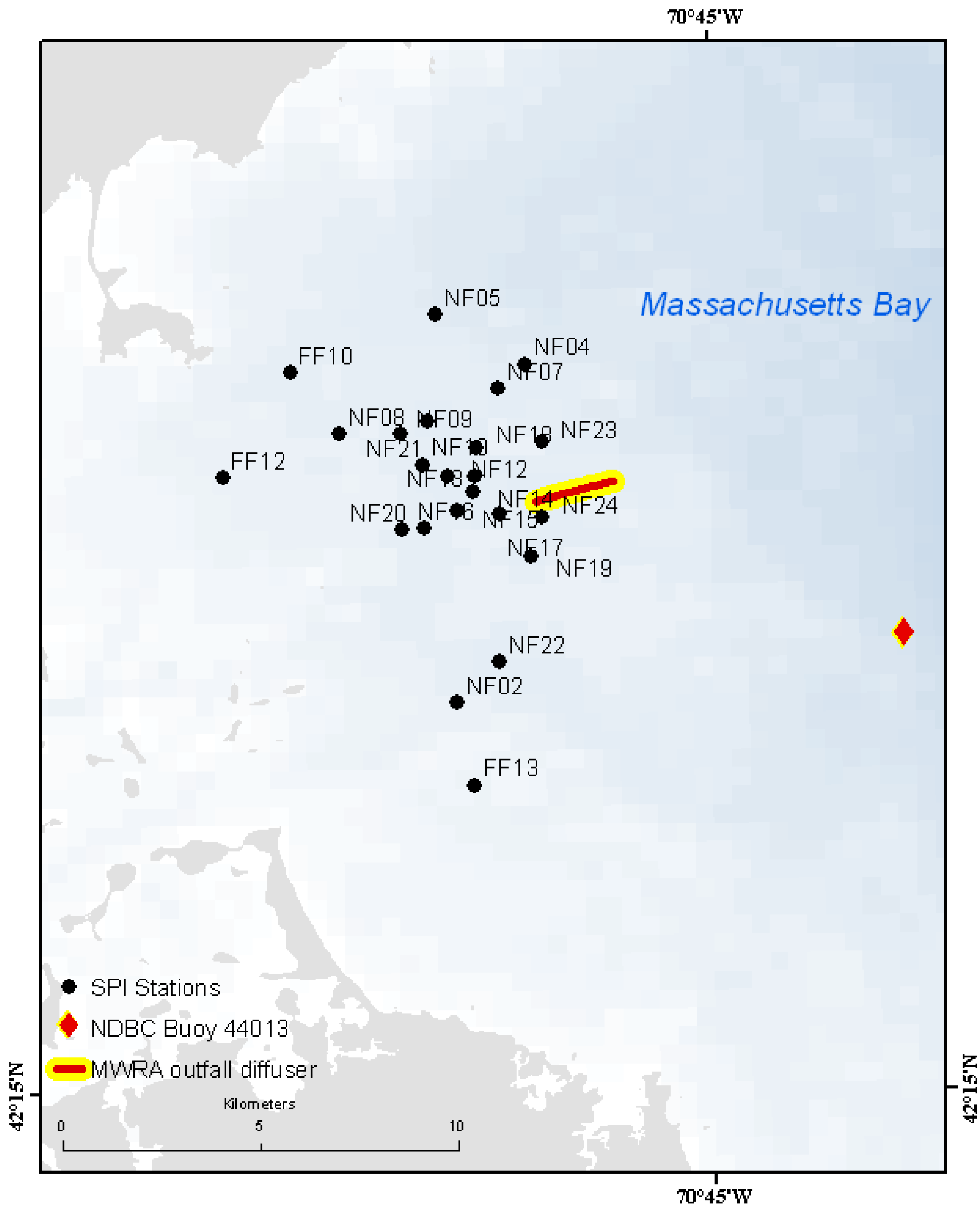

Figure 4-2. Sediment-profile imaging stations. Twenty-three stations are monitored. Also shown is an instrumented buoy operated by the National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC), and the MWRA outfall diffuser.

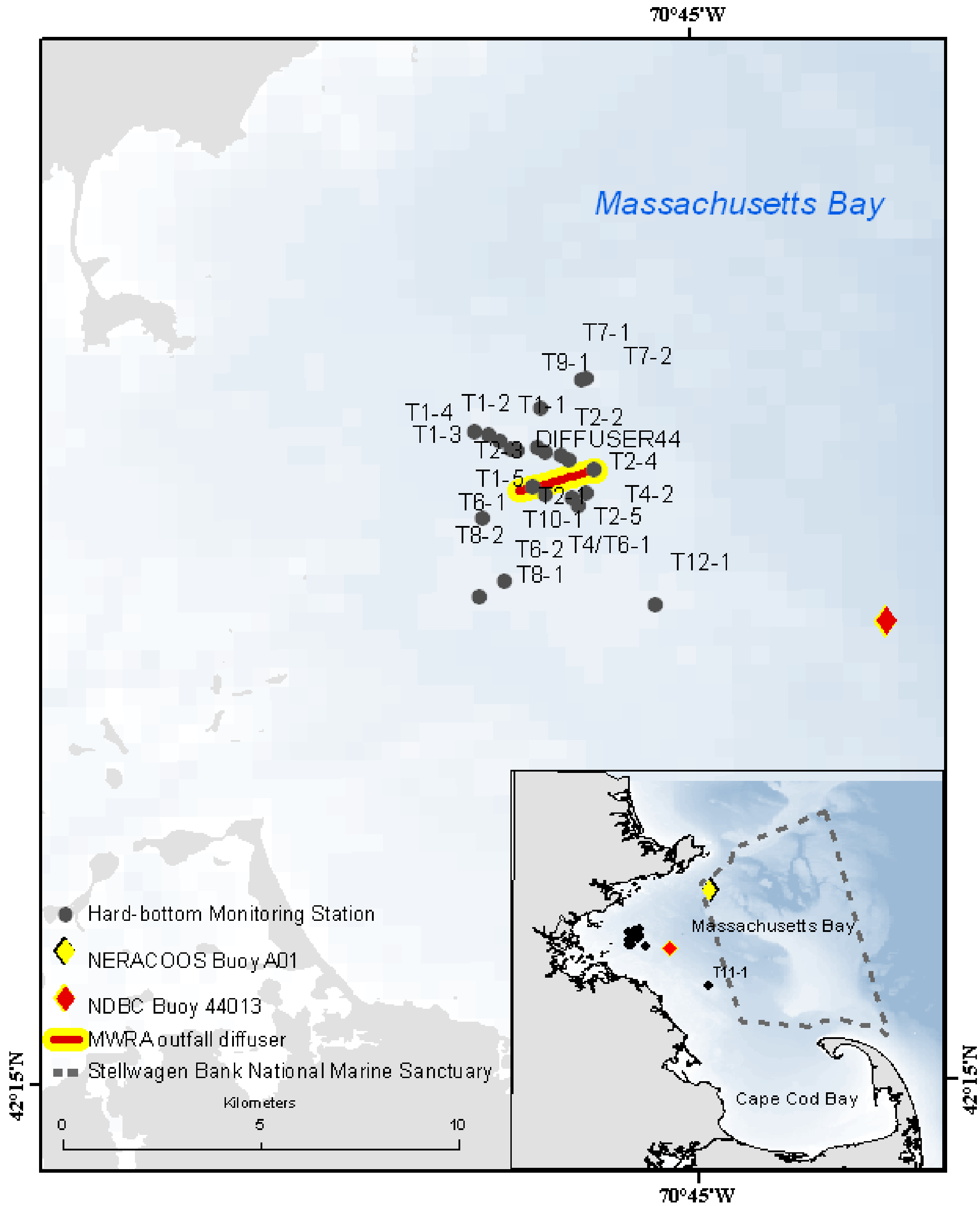

Figure 4-3. Hard-bottom stations. Video and still photographs are collected at 23 stations, including one active diffuser and one diffuser that has not been opened.

A new sea-floor monitoring plan was implemented in 2011 (MWRA 2010, Werme et al. 2012). Sediment and infauna sampling was conducted in August at 14 stations, including one station in the "transition" area, located between Boston Harbor and the outfall (FF12); four nearfield stations located in close proximity, within two kilometers, to 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 in August at 23 stations. This portion of the sea-floor program remained unchanged from earlier years.

Hard-bottom surveys by camera transects were performed in June and surveyed 23 waypoints, including an actively discharging diffuser head at the eastern end of the outfall. The general program remained unchanged, but its frequency has been decreased from annually to once every three years.

Sediment Characteristics and Tracers

Grain-size distributions of sediment samples in 2011 remained consistent with results from past years, ranging from silt and clay at some stations to mostly sand at others (Nestler et al. 2012). 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. One exception was Station NF12, located west of the outfall, the nearfield station with the finest-grain sediments, which had record low organic carbon content, with values more comparable to offshore, sandier sediments.

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 (Figures 4-4, 4-5). Concentrations of *Clostridium perfringens* spores were highest at Stations NF14 and NF21, both located within two kilometers of the outfall. Conversely, there has been a decline in *Clostridium perfringens* spores at the transition station FF12, with spore counts falling within the range of the reference stations.

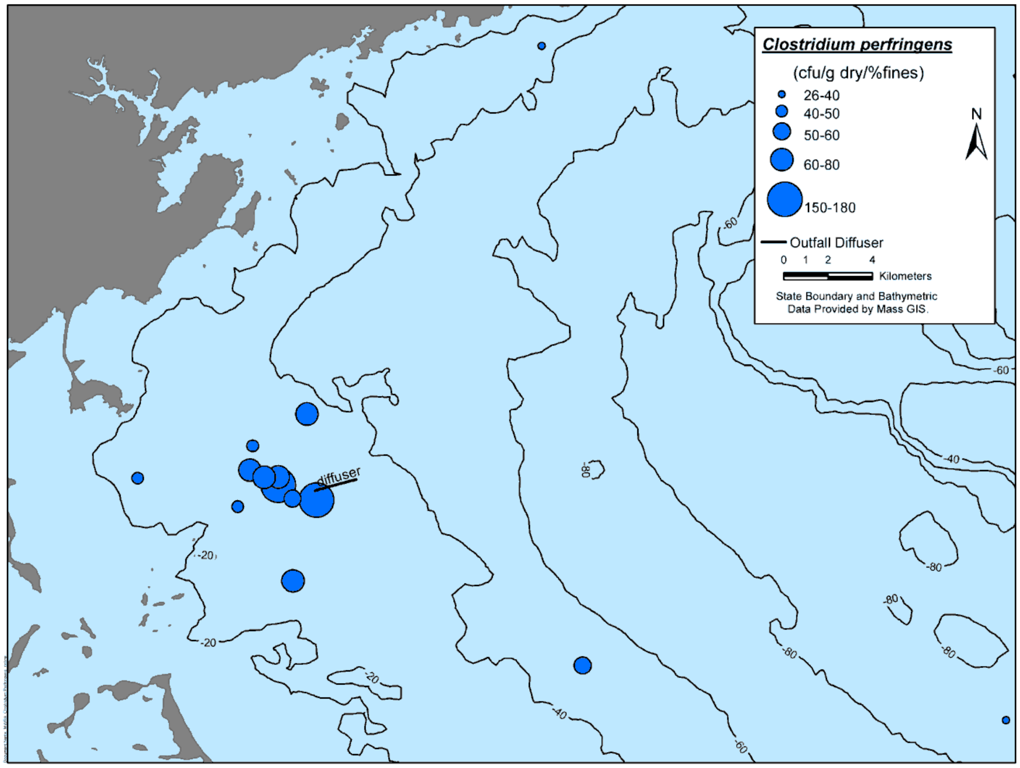

Figure 4-4. Concentrations of *Clostridium perfringens* spores, corrected for sediment grain size, in 2011.

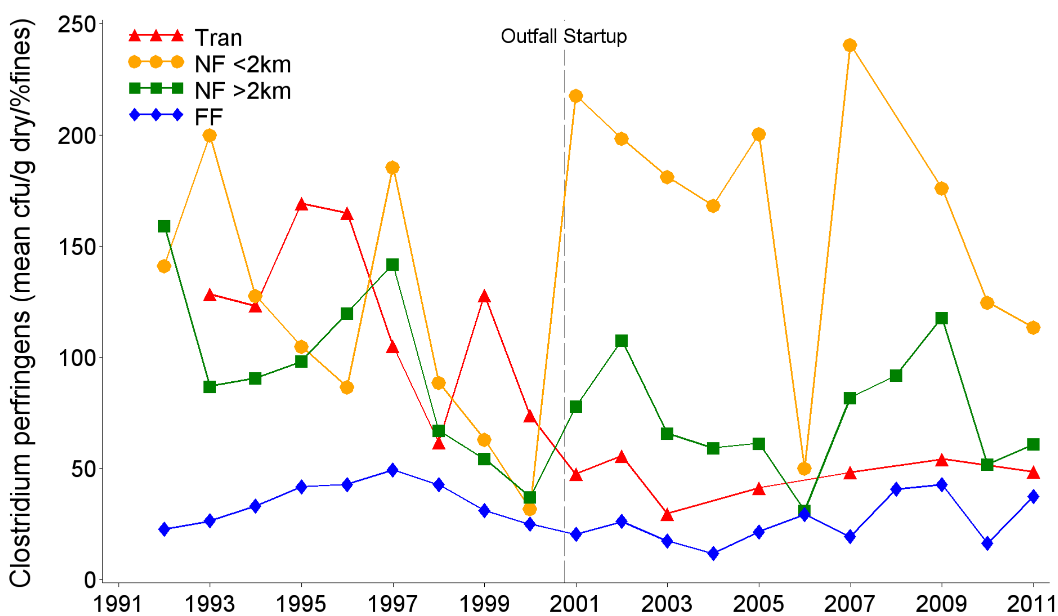

Figure 4-5. Mean concentrations of *Clostridium perfringens* spores, 1992–2011. Tran = transition station located between Boston Harbor and the outfall; NF<2km = nearfield stations located within 2 km of the outfall diffusers; NF>2km = nearfield stations located farther than 2 km from the diffusers; FF = farfield reference stations offshore from the outfall.

Sediment contaminants are measured every three years at the 14 soft-bottom stations. Concentrations of organic compounds and metals in sediments remained within or below the baseline range in 2011, and measurements continued to confirm that sediments with finer sediments have higher concentrations of chemical contaminants.

In general, the distribution of contaminants in nearfield sediments is related to how fine-grained the sediments are. Coarse sandy sediments, like those at NF17 tend to contain very low concentrations of toxic contaminants, while fine-grained, silty sediments like those found at stations NF12, NF21, and NF24 tend to contain, on average, much higher concentrations of contaminants.

PCB levels continued to be low at Station NF17 near the outfall (with sandy sediments), and it is possible that slow, long-term decreases are occurring at some other stations (Figure 4-6). Total DDT concentrations have also slowly declined throughout the region. Total PAH concentrations have slightly declined or remained stable throughout the monitoring program.

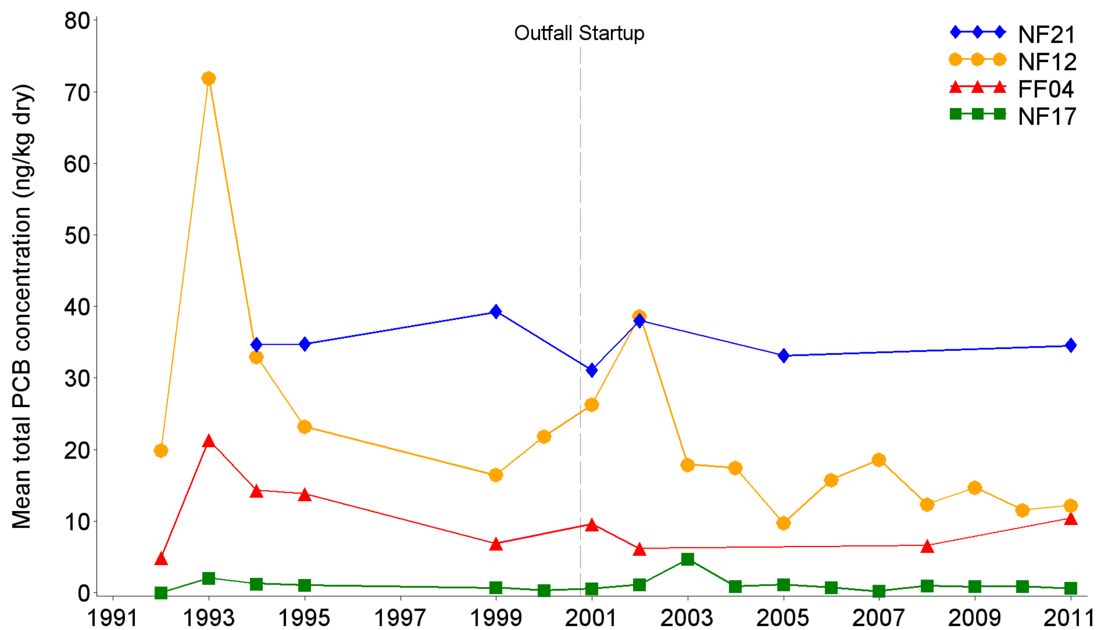

Figure 4-6. Mean concentrations of total PCBs at individual stations, 1992–2011. NF21 and NF12 are located shoreward and more than 2 km from the diffuser; FF04 is more than 20 km offshore from the outfall, in Stellwagen Basin; NF17 is within 2 km from the diffuser.

Mercury concentrations (data not shown) were higher at Station NF21 than in other outfall-discharge years. At other stations, mercury concentrations continued to be stable or reflect a very slow decline. Concentrations at Station NF17, the sandy station close to the outfall, were at a record low. All results can be explained by shifts in sediment grain-size distributions.

Sediment-profile Imaging

Sediment-profile imaging measurements continued to show no adverse effects of the outfall (Nestler et al. 2012). 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 sited in high-energy areas that promote rapid dispersion.

The apparent reduction-oxidation (redox) potential discontinuity (RPD) depth remained deeper than the baseline mean (Figure 4-7), the opposite of what had been an environmental concern before discharge began. The mean RPD depth since the outfall came on line has been slightly deeper than the baseline mean, continuing to indicate that there has been no adverse effect from the discharge. The sediment-profile images found no indication of organic carbon accumulation and no adverse effects on the types of organisms inhabiting the sediments.

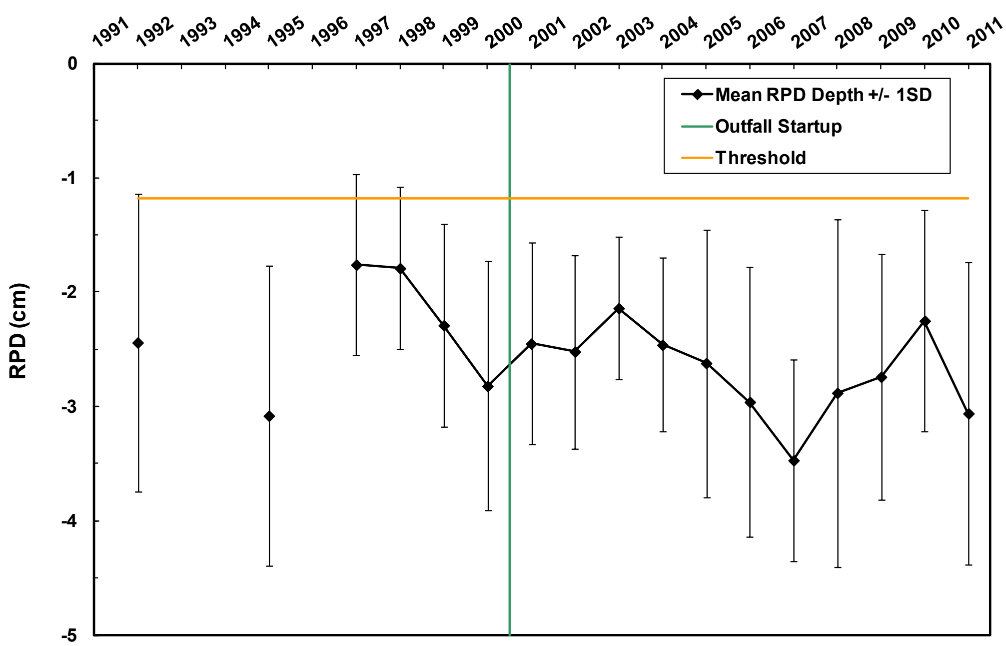

Figure 4-7. Annual apparent color RPD for data from nearfield stations. The average RPD has not become shallower during the outfall-discharge period (2001–2011). Data are mean ±1 standard error. Data are from all available stations in each year.

Soft-bottom Communities

The soft-bottom communities continued to show no response to the outfall relocation to the bay (Nestler et al. 2012). Community structure is determined primarily by grain-size distribution of the sediments and by natural fluctuations in populations.

Sampling and analysis of the 14 samples taken in 2011 yielded 15,067 organisms, classified into 199 species and 30 other taxonomic groups. The number of organisms per sample was similar to that in 2010, but continued to be lower than abundance peaks in 2002–2004 (Figure 4-8).

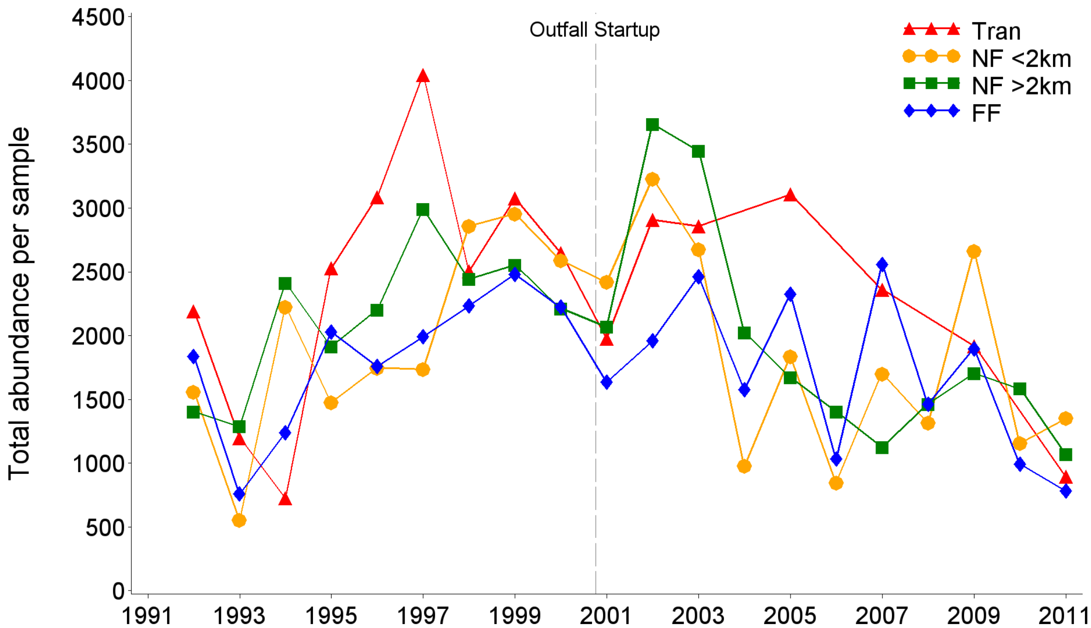

Figure 4-8. Mean infaunal abundance per sample in four areas of Massachusetts Bay, 1992–2011. Tran = transition station located between Boston Harbor and Massachusetts Bay; NF<2km = stations within 2 km of the outfall; NF>2km = nearfield stations greater than 2 km from the outfall; FF = farfield reference stations offshore from the outfall.

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. One analysis of similarity between samples identified three major types of communities, each of which was found both near and farther from the outfall and each dominated by polychaete worms. 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. The species assemblage for one station located just off the coast from Cape Ann, FF01A, was similar to that at Station NF14, located in close proximity to the outfall. These analyses provide further evidence that sediment grain size is the major determinant of the composition of soft-bottom communities.

Hard-bottom Communities

Photographic coverage in 2011 included 20–26 minutes of video at each waypoint, with occasional pauses to obtain screen captures (Nestler et al. 2012). Analyses of these survey data showed that the rocky habitats in the vicinity of the outfall and at reference locations continued to support robust communities of algae, invertebrates, and fishes (Figure 4-9).

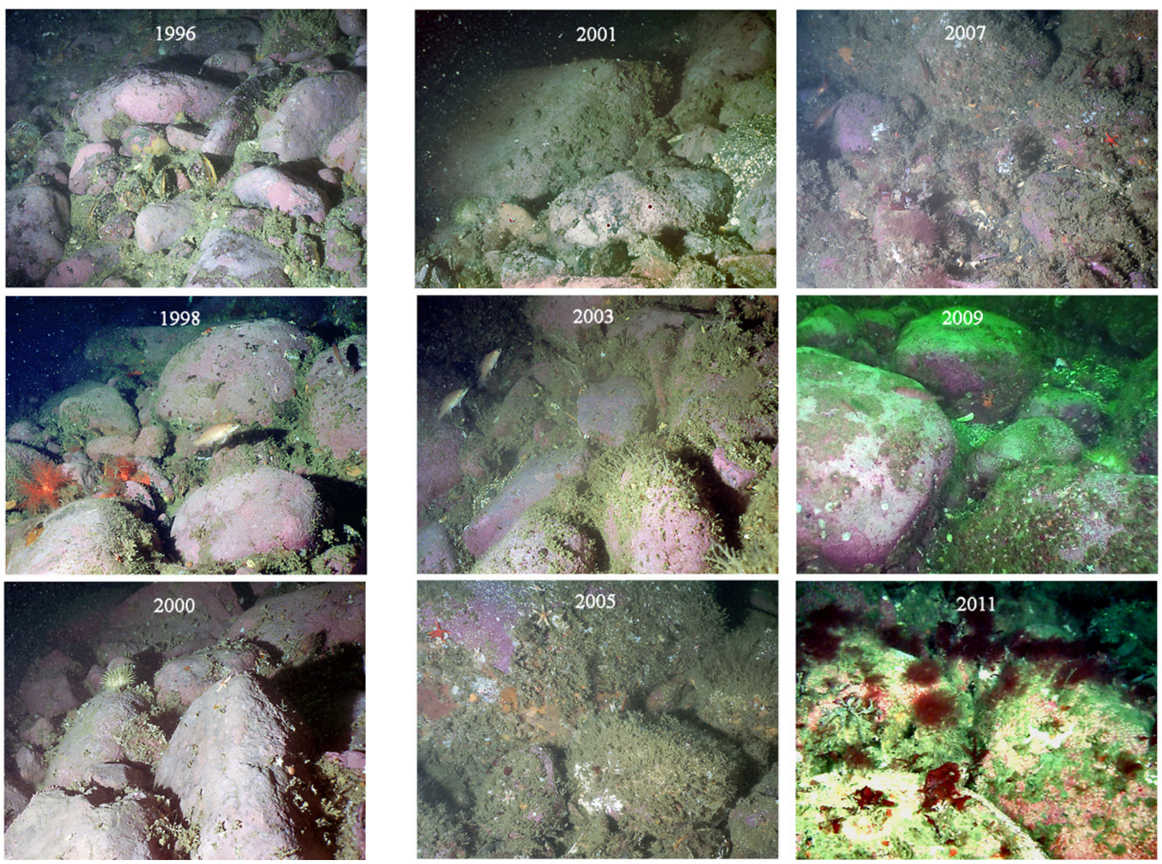

Figure 4-9. Screen captures from Waypoint T1-3, located north of the diffusers, 1996–2011. The photographs in the left-most column are from baseline years, and the photographs on the right are from 2001–2011, the period since the outfall came on line.

Conditions remained generally similar to those observed in past years. A total of 58 taxonomic groups, 4 algal species, 9 fish species, and 4 general groups could be identified from the footage, numbers that have remained relatively constant throughout the monitoring program. Coralline algae continued to be the most common and widespread species group. Three other algal species, *Palmaria palmata* (dulse), *Ptilota serrata* (filamentous red algae), and *Agarum cribrosum* (shot-gun kelp) were also seen in numbers similar to those observed in previous years. Many of the dulse fronds were encrusted with *Membanipora* sp. tunicates. Common invertebrates seen in 2011, as in other years, included the horse mussel *Modiolus modiolus*, juvenile and adult northern sea stars *Asterias vulgaris*, the blood star *Henricia sanguinolenta*, white and cream encrusting tunicates *Aplidium*/*Didemnum* spp., an encrusting yellow sponge *Polymastia* sp., the sea peach tunicate *Halocynthia pyriformis*, and the brachiopod *Terebratulina septentrionalis*. Fish abundances were also similar to previous years, with cunner *Tautogolabrus adspersus* the most abundant and widely distributed fish encountered within the study area.

Diffuser head #44, which has never been active, continued to support a stable community of the sea peach tunicate *Halocynthia pyriformis* and the sea anemone *Metridium senile.* Diffuser head #2, which is active, also supported a dense population of *Metridium senile*.

Stellwagen Bank National Marine Sanctuary

No large or unexpected changes in bottom community parameters have been measured within or near the sanctuary since the outfall came on line. With the new monitoring design implemented in 2011, one MWRA sea-floor station lies within the sanctuary, in Stellwagen Basin (FF04, see Figure 4-1). Station FF09 is adjacent to the basin, southeast of the diffuser. A third sea-floor station (FF01A) is just northwest of the sanctuary boundary.

Sediment chemistry has not changed at Station FF04, located within the depositional area of Stellwagen Basin, in response to the outfall. As at other stations, there are some indications of very slow declines in concentrations of contaminants that have been banned (see, for example, Figure 4-6).

Those deep-water stations continued to support infaunal communities typical of the monitoring program, but as would be expected, with some differences from the shallower communities in the nearfield and Cape Cod Bay. Dominant species at Station FF09 included the polychaetes *Spio limicola* and *Anobothrus gracilis*. Total abundance of organisms was relatively low in 2011, as it was in nearfield stations.

Multivariate analyses of soft-bottom fauna showed that Station FF04 tends to be an outlier in that its deepwater sediments are very silty, whereas many shallower stations are sandier. Its benthic community more closely matches some of the siltier nearfield stations than it does the community at the very sandy nearfield Station NF17 (Figure 4-10). Communities at Station FF04 were somewhat different in 2010 and 2011 than other monitoring years, probably because of the large decline in the population of the numerically dominant polychaete *Prionospio steenstrupi*. Decreases in the *Prionospio steenstrupi* are thought to be the result of natural population cycles.

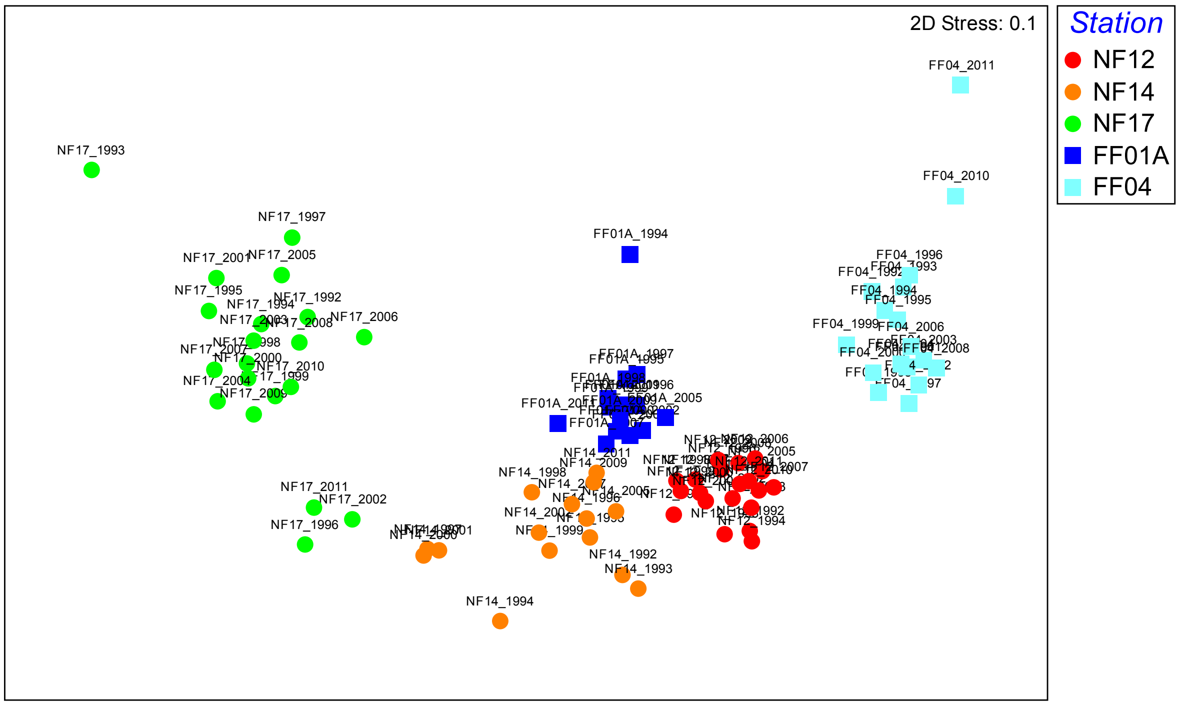

Figure 4-10. Stations superimposed on non-metric multidimensional scaling plots, a multivariate analyses tool. Station FF04, in Stellwagen Basin, consistently supports a unique community.

Contingency Plan Thresholds

For a second year in a row, there were Contingency Plan threshold exceedances for sea-floor monitoring (Table 4-1). All sediment contaminant concentrations were well below 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 or warning levels. However, two thresholds for community parameters, Shannon-Wiener diversity and Pielou's evenness were higher than the caution-level ranges (Figure 4-11). Two other community threshold parameters, total number of species per sample and log-series alpha, were within the caution level ranges.

Table 4-1. Contingency Plan threshold values and 2011 results for sea-floor monitoring.

Parameter Type	Parameter	Caution Level	Warning Level	2011 Results
Nearfield PAHs (ng/g or parts per billion, dry weight)	Acenaphthene	None	500	17.1
	Acenaphylene		640	18.3
	Anthracene		1,100	93.6
	Benzo(a)anthracene		1,600	186
	Benzo(a)pyrene		1,600	216
	Chrysene		2,800	181
	Dibenzo(a,h)anthracene		260	31.0
	Fluoranthene		5,100	400
	Fluorene		540	23.2
	Naphthalene		2,100	54.9
	Phenanthrene		1,500	214
	Pyrene		2,600	351
	Total HMW PAH		9,600	2,854
	Total LMW PAH		3,160	1,083
	Total PAHs		44,792	3,937
Nearfield other organics (ng/g dry weight)	p,p'-DDE	None	27	0.64
	Total DDTs		46.1	2.62
	Total PCBs		180	7.18
Nearfield metals (μg/g or parts per million, dry weight)	Cadmium	None	9.6	0.10
	Chromium		370	43.4
	Copper		270	15.4
	Lead		218	39.1
	Mercury		0.71	0.19
	Nickel		51.6	15.4
	Silver		3.7	0.19
	Zinc		410	49.8
Nearfield sediments	RPD depth	<1.18 cm	None	3.06
Nearfield benthic community parameters	Species per sample	<42.99 or >81.85	None	64.4
	Fisher's log-series alpha	<9.42 or >15.8	None	15.04
	Shannon diversity	<3.37 or >3.99	None	4.15, caution level exceedance
	Pielou's evenness	<0.57 or >0.67	None	0.69, caution level exceedance
	Percent opportunists	>10%	>25%	0.19%

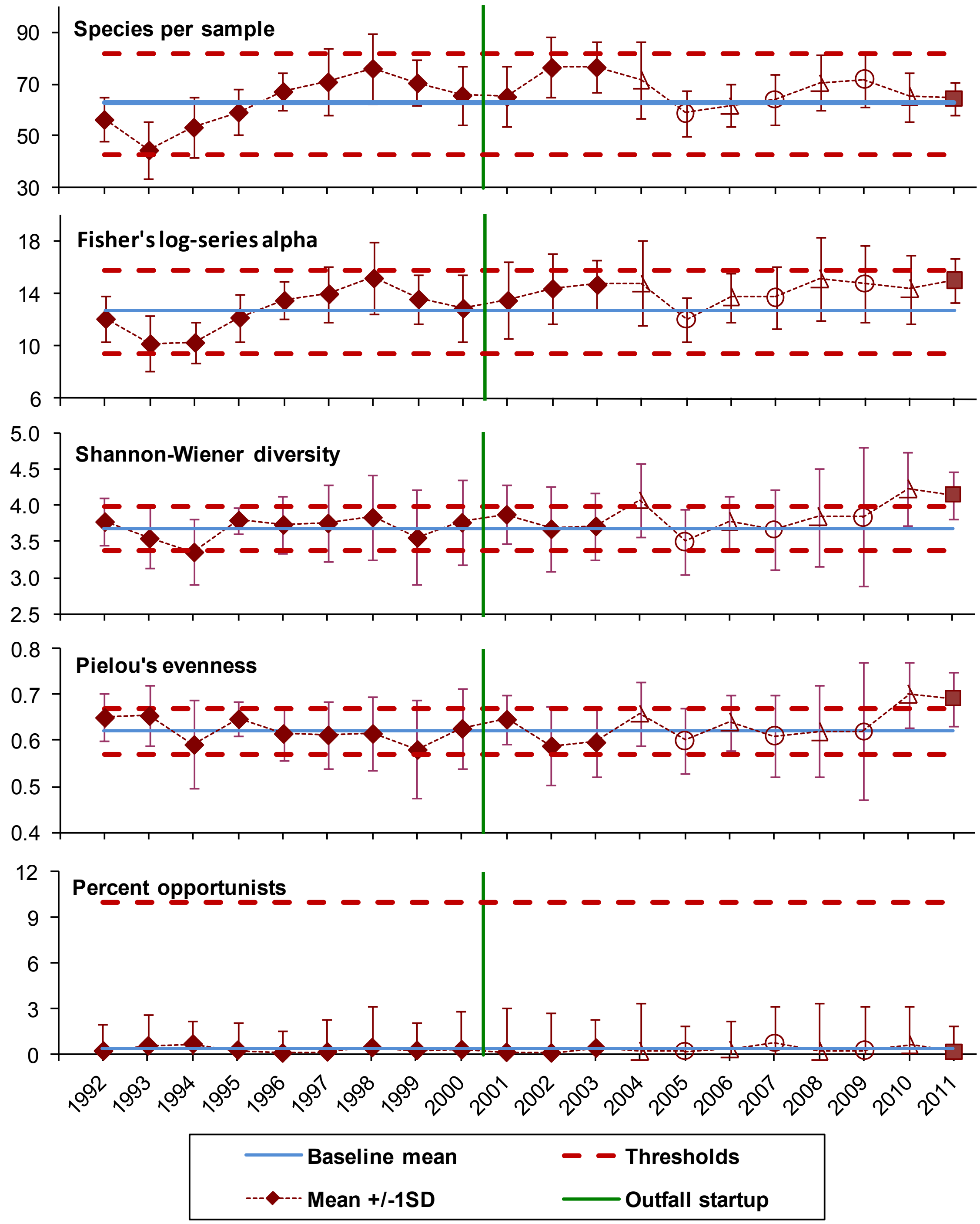

Figure 4-11. Annual community parameters with nearfield Contingency Plan. The varied symbols represent differences in the monitoring over the years of the program. Results from the different sampling designs were tested against thresholds calculated for each sampling design. Only the current threshold values are shown. Except for the percent opportunists threshold, which is based on levels in Boston Harbor, thresholds were selected to show potentially meaningful changes from the baseline, so have both upper and lower bounds.

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

Temporal comparisons of Contingency Plan threshold values showed no indication of increases in the community-parameter measurements during the outfall-discharge period compared to the baseline at stations closest to the outfall. Instead, the threshold exceedances were driven by nearfield stations that are farther away, more than two kilometers from the outfall and less likely to be influenced by the discharge. Shannon-Wiener diversity and Pielou's evenness have increased in both nearfield and farfield locations, suggesting region-wide changes, unrelated to the discharge. As reported by Maciolek et al. (2011), region-wide declines in the abundance of the spionid polychaete, *Prionospio steenstrupi*, are likely an important factor in the recent increases. This species has been the numerically dominant taxon in the Massachusetts Bay samples since the mid to late 1990s, but its populations have declined substantially in recent years.

Increases in Shannon-Wiener diversity and Pielou's evenness often signal 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 that is why they have upper as well as lower bounds.

5. Flounder Studies

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 (Figure 5-1).

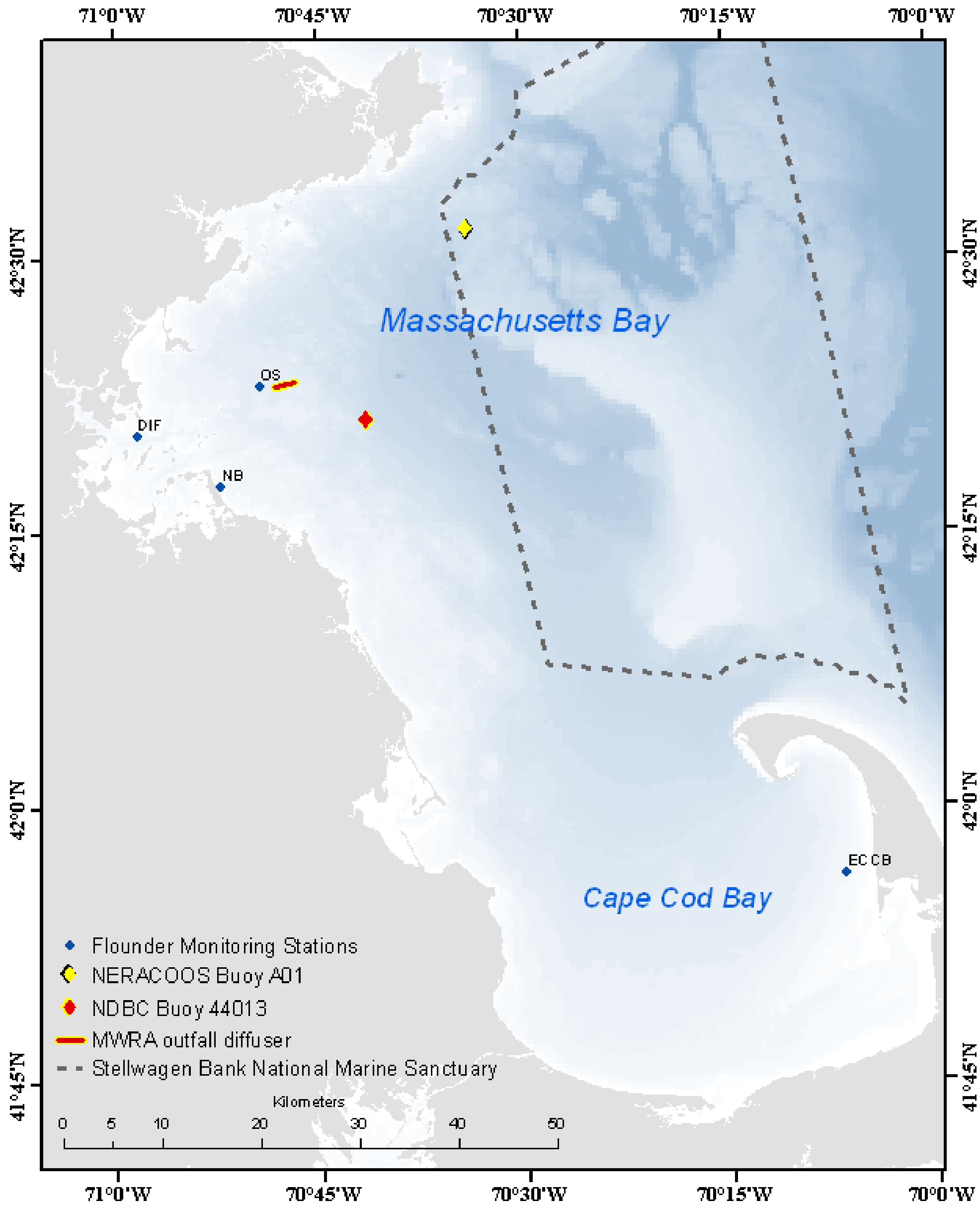

Figure 5-1. Flounder sampling sites. DIF=Deer Island Flats, NB=Nantasket Beach, OS=Outfall Site, ECCB=Eastern Cape Cod Bay. Also shown are two instrumented buoys, one operated by the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) and the other by the National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC); the MWRA outfall diffuser; and the Stellwagen Bank National Marine Sanctuary.

The fish-and-shellfish monitoring program was not changed for 2011. Annual flounder monitoring focuses on the presence of early liver disease and liver neoplasms (tumors). Other indications of health are also documented. Chemical contaminants are measured in flounder muscle and liver tissues every three years, and lobster and mussel studies are also conducted every three years. The next fish-and-shellfish chemistry studies will be carried out during the 2012 monitoring year.

In April 2011, 50 sexually mature flounder were collected from each site for field processing and shipment to the laboratory (Moore et al. 2011). Catch per unit effort was slightly higher near the outfall and off Nantasket Beach, and there was a decrease in eastern Cape Cod Bay, where catches had increased over the past three years. Catch per unit effort continued to be low at Deer Island Flats, where lost or abandoned fishing gear often interferes with sampling. This "ghost" gear appears to be an increasing problem at the outfall site as well as at Deer Island Flats, and the field crews have begun to document its presence and abundance in each tow.

Average ages, lengths, and weights of the winter flounder collected in 2011 were within the historic ranges. Average age continued an upward trend at most sites, evident since 2008, but declined slightly at Deer Island Flats. Average length and weight increased in fish from the outfall site compared to recent years but decreased slightly in fish from the other locations. As they have been throughout most of the monitoring program, the catches continued to be dominated by females. As in 2009 and 2010, approximately 76% of fish taken from near the outfall were female, down from values in 1998–2008 of 85–95%. About 95% of the fish from eastern Cape Cod Bay but only 64% of the Deer Island Flats catch were females, the smallest percentage at that site since 1995.

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 within the historic range of the monitoring program and much lower than had been observed in other studies in the late 1970s and early 1980s. The greatest percentage of fin erosion, 28%, occurred in fish from eastern Cape Cod Bay. The greatest percentage of another common condition, bent fin ray, occurred at Deer Island Flats and off Nantasket Beach. Other external conditions noted in 2011 were blind-side hemorrhages, which result from net trauma, and blind-side ulcers (Figure 5-2). Ulcers, which were first noted in 2003, were present at all locations in 2011 except for Nantasket Beach after four years of very low occurrence. Ulcers occurred in elevated levels in 2003–2006 but in lower numbers in 2007–2010. No cause for the ulcers has been found.

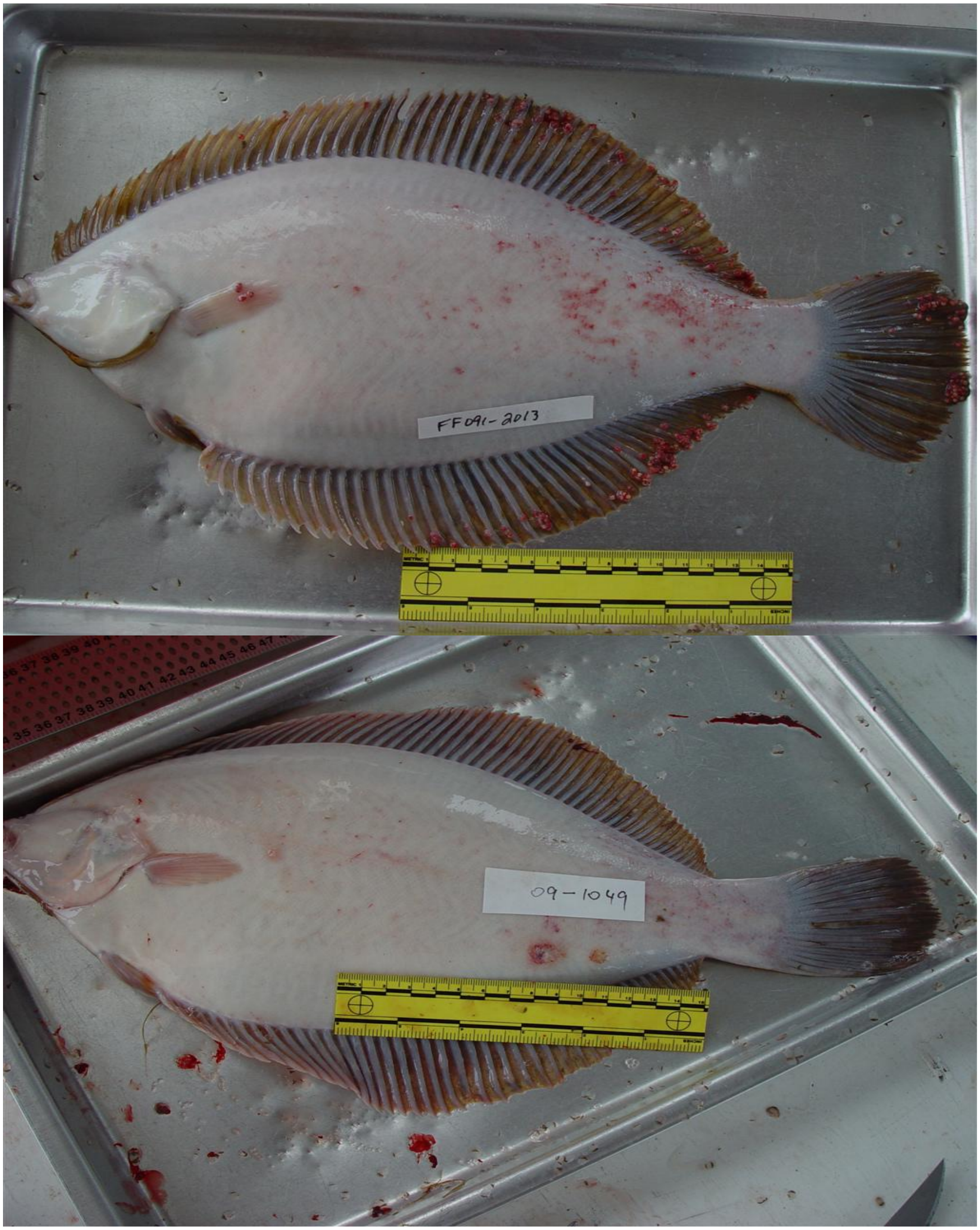

Figure 5-2. External conditions noted during the 2011 field program. Top: External blind-side hemorrhage resulting from net trauma. Bottom: Blind-side ulcers.

.

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 other 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 (Figure 5-3). Incidence of CHV at Deer Island Flats continued a gradual decline from the relatively high baseline levels. A gradual increase in CHV had been detected in fish from the outfall site since 2005, with a slight decline in 2011, but incidence remains below that observed during most baseline years. Average severity of CHV also remained lower than baseline levels.

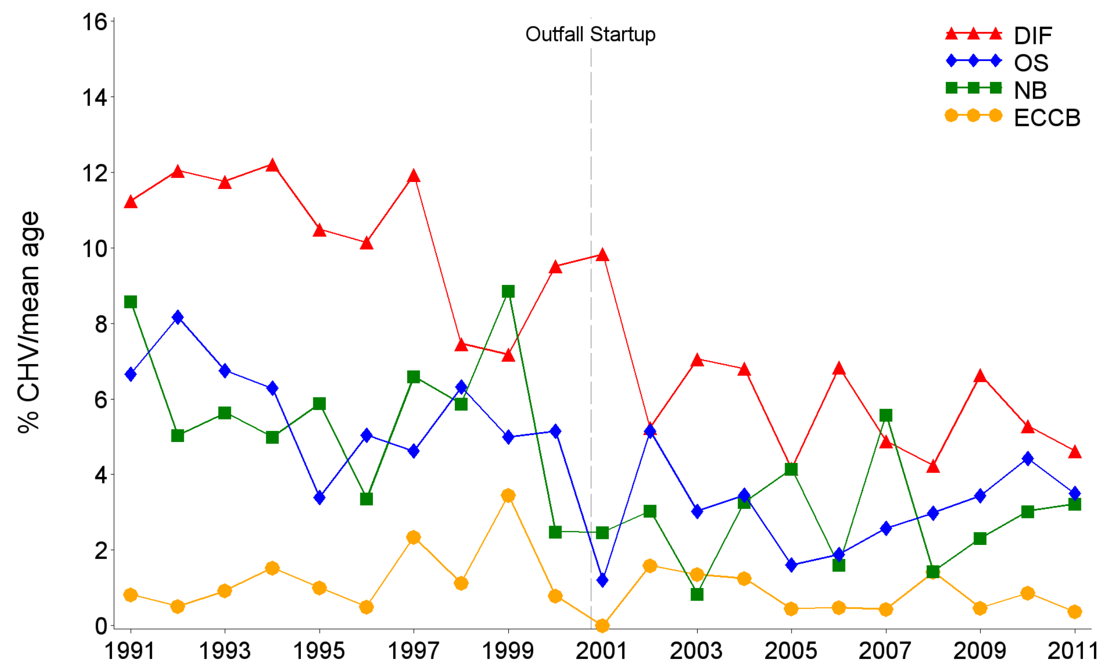

Figure 5-3. Annual prevalence of centrotubular hydropic vacuolation (CHV), corrected for age. (DIF = Deer Island Flats, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, OS = Outfall Site)

Contingency Plan Thresholds

There was only one Contingency Plan threshold for fish and shellfish applicable in 2011: the incidence of CHV at the outfall site (Table 5-1). Incidence of CHV, the most common indicator of liver disease in the winter flounder of the region, was 20% in fish taken from the vicinity of the outfall site, lower than the caution threshold of 44.9% and lower than the baseline average.

Table 5-1. Contingency Plan threshold values and 2011 results for winter flounder monitoring.

Parameter Type/ Location	Parameter	Baseline	Caution Level	Warning Level	2011 Results
Flounder nearfield	Liver disease (CHV)	24.4%	44.9%	None	20%

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 2011 included completion of a study to improve field chlorophyll measurements, a report on productivity, continued analysis of sediment-profile imagery in Boston Harbor, and MWRA collaboration with the Provincetown Center for Coastal Studies in monitoring Cape Cod Bay. Also, as part of the monitoring plan revision, MWRA recalculated Contingency Plan threshold values, using appropriate subsets of baseline data to match the new stations and sampling schedules.

Chlorophyll Measurements

For several years, MWRA has been working to improve field chlorophyll measurements, which are faster and less costly than laboratory analysis of field samples. Field measurements use data from a fluorometer, which measures chlorophyll fluorescence in living cells, while laboratory analysis requires sampling, extraction, and analysis. However, the ratio of the field fluorescence measurement to the laboratory results is not always consistent. It decreases with increasing phytoplankton cell size, increasing temperature, and increasing solar irradiance. MWRA has developed a method to correct for one of these factors, solar irradiance (Hersh and Leo 2012).

The effect of light levels on fluorescence is called "non-photochemical quenching," and its consequence for daylight measurements taken near the surface can be quite pronounced. This quenching forced MWRA to exclude many surface chlorophyll measurements from past calibrations, which were calculated by simple linear regressions. The new method uses a multiple regression model that includes terms for light as well as extracted chlorophyll and allows for use of these previously excluded data. The resulting multivariate regression has shown that the effect of light can be important for individual hydrocasts, especially at mid-day during the darker months, but does not greatly change the depth-integrated, averaged seasonal values.

MWRA has also corrected an error that occurred in the regression calculations in some of the early baseline surveys. The new multivariate regression model and the corrections to the baseline survey regressions have been used to recalculate chlorophyll Contingency Plan thresholds (see Contingency Plan Threshold Changes, below).

Productivity Measurements

MWRA's special study of water-column primary productivity, the rate of phytoplankton growth, was completed in 2010. MWRA has completed a related report, which compares field measurements with model predictions using the MWRA Bays Eutrophication Model (BEM) (Keay et al. 2012).

Throughout the special study, annual field productivity measurements were made at two nearfield stations and at one station at the mouth of Boston Harbor. The BEM and the hydrodynamic model that feeds it have evolved throughout the monitoring program, including improvements to productivity estimates and to the modeled factors that may affect them. Early BEM runs reproduced the seasonal productivity patterns that were measured in the field, but predicted productivity tended to be lower and less variable than the field measurements. In later years, modeled productivity was similar to field results for the Boston Harbor station but higher than field data from Massachusetts Bay. In no case did the field or modeled productivity data suggest any effect of the outfall relocation on productivity in Massachusetts Bay.

A second report, evaluating comparisons between productivity estimates and light-biomass models, is in preparation.

Boston Harbor Sediment-profile Images

While monitoring in Massachusetts Bay has detected no changes in sediment-profile images with the relocated discharge (see Section 4, Sea Floor), there have been great changes in Boston Harbor (Figure 6-1). Habitat conditions in the harbor have improved in response to decreased loads of organic material in sewage biosolids and effluent. As in Massachusetts Bay, physical processes also remain important to structuring the surface sediments.

Since 1992, there have been steady increases in the depths at which bioturbating species are found, an indication of habitat improvements and more complex animal communities. An eelgrass bed, another sign of healthy habitat, has been present near Deer Island Flats since 2008.

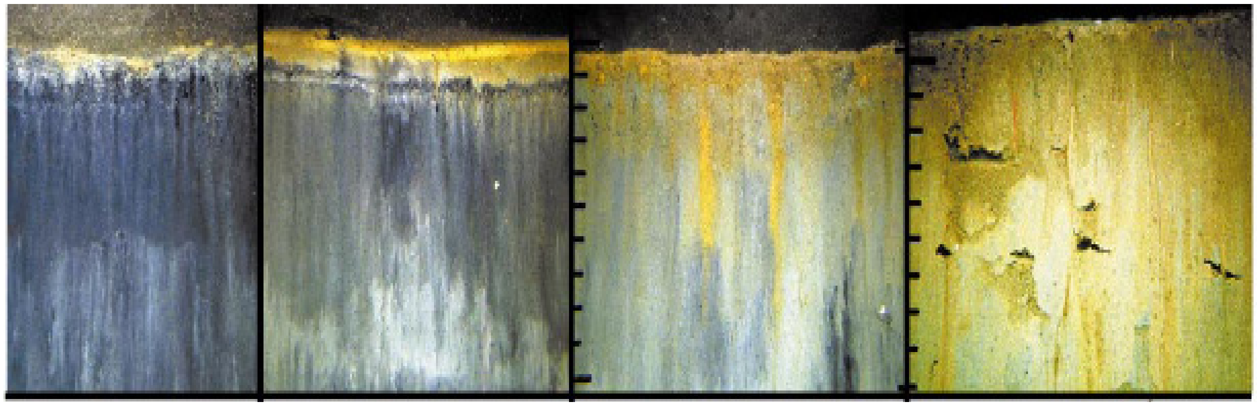

Figure 6-1. Boston Harbor sediments and environmental conditions. In the early days of the Boston Harbor project, some inner and middle harbor stations were unhealthy, with very shallow RPD depths, as demonstrated by the left-most picture. With improvements, sediments from those stations now have deeper RPD depths, similar to those shown in the intermediate pictures. Sediments from the outer harbor have consistently been healthy, similar to the right side-most photograph. Lighter, yellow colors indicate oxygenated sediments, while dark gray or black sediments are anoxic, lacking in oxygen.

One interesting measure for examining changes in Boston Harbor has been the presence or absence of amphipod tube mats. Presence of mats rose dramatically during the early 1990s, after sewage biosolids were no longer disposed of in the harbor, then declined in the late 1990s and through 2005. Since 2005, tube mats have become more common, occurring at a third of the stations. The rebound has occurred primarily in the outer and southern portions of the harbor. Mats were never common in the inner harbor. Fluctuations are expected to continue with continued recovery.

Boston Harbor Beach Monitoring

MWRA provides technical support and laboratory services to the Department of Conservation and Recreation (DCR) in its Boston Harbor beach monitoring program to enable DCR to monitor beach water quality every day during the swimming season. Figure 6-2 shows that South Boston beaches have seen a significant decrease in the number of days the beaches were posted after the North Dorchester Bay Combined Sewage Overflow (CSO) Storage Tunnel came on-line in May 2011, even though the summers of 2011 and 2012 were quite rainy.

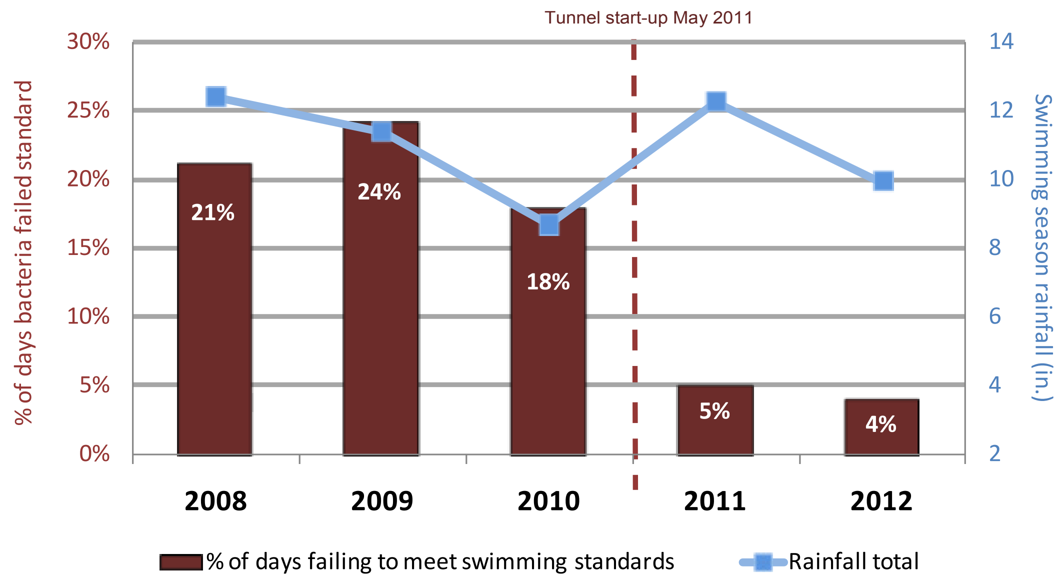

Figure 6-2. Percent of days beaches in South Boston failed swimming standards, before and after the CSO storage tunnel came on-line in 2011.

Cape Cod Bay Studies

As part of their commitment to marine conservation, the Provincetown Center for Coastal Studies has an extensive program to monitor Cape Cod Bay and its shorelines. In 2011, MWRA teamed with the Center for a portion of the program, including water quality and plankton measurements. The program provides additional detail for the region, with a focus on information relevant to the whale populations that visit the area each year. Some of the program results have been reported on in Section 3, Water Column.

In 2011, the Provincetown 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 6-3). Those surveys found typical hydrographic and water quality patterns. Dissolved nutrient concentrations were high in the spring, when the water column was well-mixed. These nutrient levels fueled spring blooms, and fall blooms also occurred. Phytoplankton communities were dominated by microflagellates, with diatoms occurring in large numbers in the spring. The zooplankton community was dominated by the copepods *Centropages* spp. during the winter and *Pseudocalanus* spp. and *Calanus finmarchicus* during the spring. Cladocerans and the copepod *Temora longicornis* predominated in the summer, and radiolarians and *Centropages* spp. occurred in the fall.

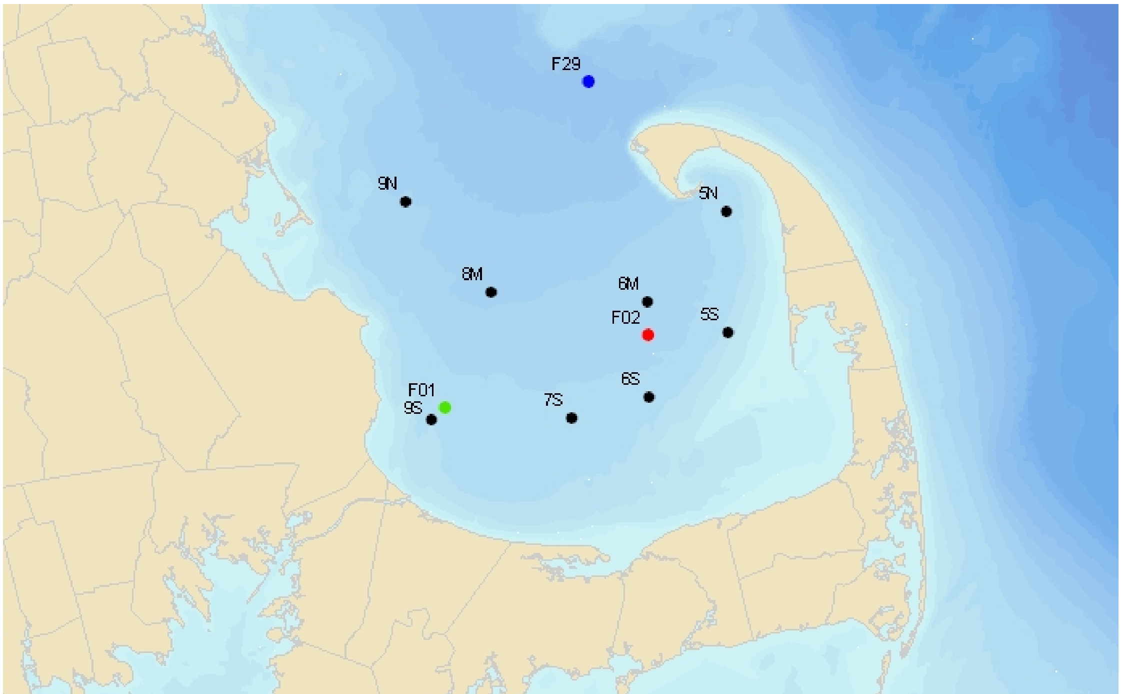

Figure 6-3. The Provincetown Center for Coastal Studies monitors its own eight stations and three MWRA stations (F01, F02, and F29) in and near Cape Cod Bay.

During the winter and spring, much of the sampling effort for zooplankton in Cape Cod Bay is focused around right whales. The Provincetown Center for Coastal Studies also makes observations of whales in the region, including aerial surveys and shipboard observations (Figure 6-4). During 2011, both zooplankton and whale abundances were high, with peak abundances occurring slightly later in the season than observed in previous years. Numbers of whale sightings have been relatively high over the past five years of study.

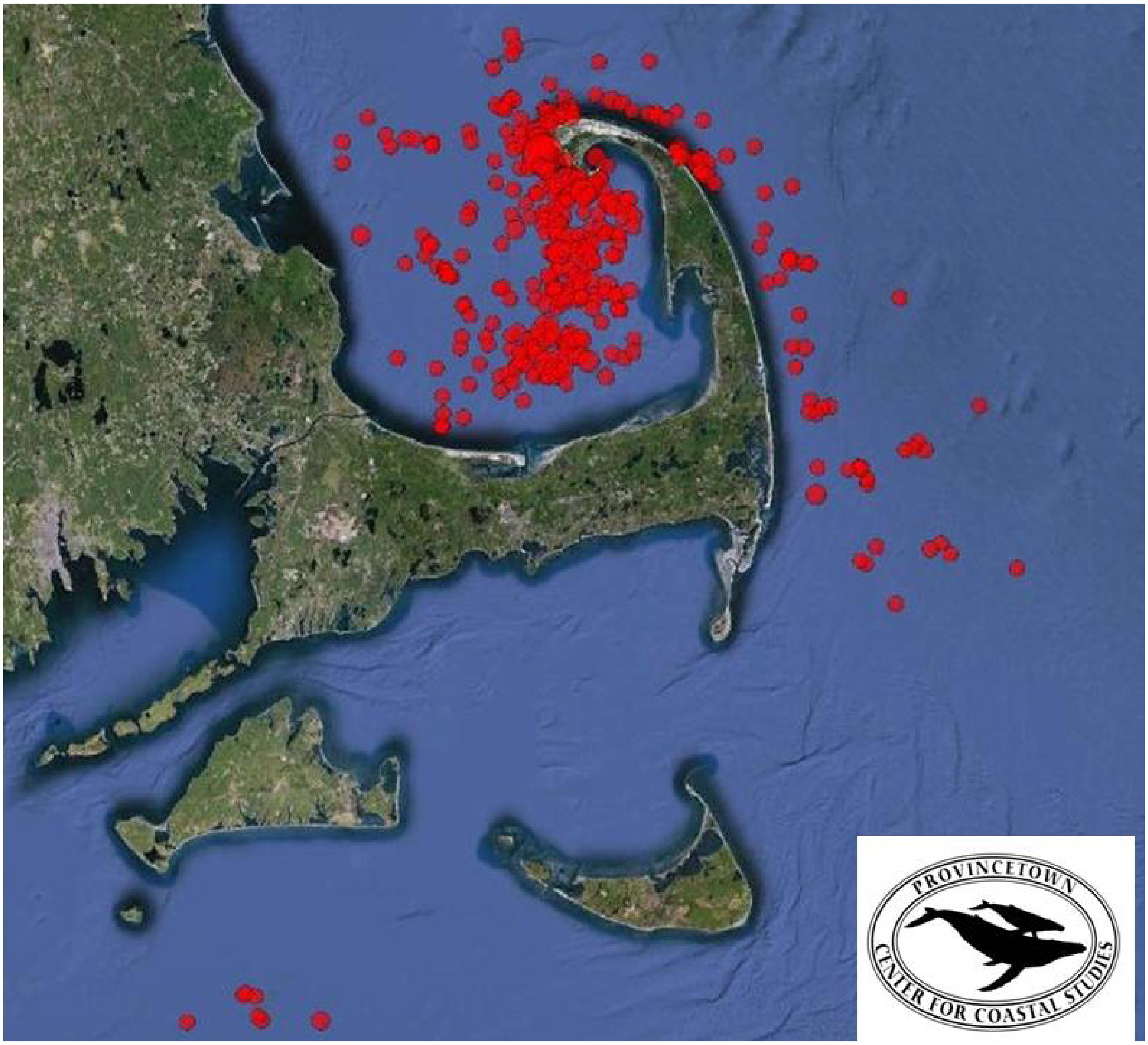

Figure 6-4. Provincetown Center for Coastal Studies whale sightings in 2011. Sightings are made from aircraft and ships.

Contingency Plan Threshold Recalculations

With the changes to the monitoring program that were implemented in 2011, it was necessary to recalculate Contingency Plan thresholds that were derived from baseline data. Changes were made in water-column and sea-floor threshold values. No changes were made to effluent or fish-and-shellfish threshold values. The changes did not affect the likelihood of any threshold exceedance.

Water Column Thresholds

The changes to the sampling schedule and design required recalculation of dissolved oxygen, chlorophyll, and two of three nuisance algae thresholds.

The changes to the monitoring plan resulted in the elimination of one survey used to calculate **dissolved oxygen** thresholds in Stellwagen Basin. There is now only one station in Stellwagen Basin, but that station is sampled more frequently than in the past. Recalculated baseline means and "background" values, the 5th percentile of the baseline survey means, resulted in slightly higher threshold values. The summer oxygen depletion rates did not change.

Chlorophyll thresholds were recalculated to account for the change in schedule; because chlorophyll concentrations do not vary much across the nearfield during a given survey, the change in number of stations was not a factor. The baseline means and the thresholds (the 95th percentile of the baseline mean for the seasonal thresholds; 1.5 and 2 times the baseline mean for the annual thresholds) were recalculated by mathematically deleting baseline data corresponding to the one spring and two autumn surveys that were dropped in the revised study design. The recalculated winter/spring threshold for chlorophyll is slightly lower than the old threshold, the recalculated autumn threshold is very slightly higher than the old threshold, and the recalculated annual thresholds are very close to the old values. There was no change in the summer survey schedule, but there were corrections to baseline data that resulted in the summer chlorophyll threshold being recalculated to be very slightly lower than the old threshold. Additional recalculations were completed in 2012 to reflect the recalibration of chlorophyll fluorescence data (see Chlorophyll Measurements, above).

The threshold for one **nuisance algal species** *Alexandrium fundyense* is based on a single high baseline sample and was not modified. The thresholds for *Pseudo-nitzschia* spp. and *Phaeocystis pouchetii* were recalculated based on the new survey schedule, also reflecting a small increase in the number of nearfield stations sampled for plankton. All available nearfield data are included in the seasonal means. These calculations resulted in slight changes, both increases and decreases, to winter/spring and fall thresholds.

Sea Floor Thresholds

In a change from the sampling design for 2004–2010, which called for different sets of stations sampled in even or odd years and the results tested against "even-year" and "odd-year" thresholds, the revised monitoring plan calls for eleven nearfield stations to be sampled each year. The benthic-community thresholds were recalculated using the baseline data from just these stations, resulting in very slightly different threshold values. The threshold for opportunists was not based on baseline data but on historical values measured in Boston Harbor, so it was not affected by the redesign and was not modified. The sampling design for sediment-profile imaging was not changed.

References

Bigornia-Vitale G, Wu D. 2012. Technical survey of nitrogen removal alternatives of the Deer Island Treatment Plant. Boston: Massachusetts Water Resources Authority. Report 2012-01. 35p.

Hersh D, Leo WS. 2012. A new calibration method for *in situ* fluorescence. Boston: Massachusetts Water Resources Authority. Report 2012-06. 11p.

Keay KE, Leo WS, Libby PS. 2012. Comparisons of model-predicted and measured productivity in Massachusetts Bay. Boston: Massachusetts Water Resources Authority. Report 2012-03. 9p.

Libby PS, Borkman D, Geyer WR, Turner JT, Costa A. 2012. 2011 water column monitoring results. Boston: Massachusetts Water Resources Authority. Report 2012-09. Draft.

Maciolek NJ, Dahlen DT, Diaz RJ, Hecker B. 2011. Outfall benthic monitoring report: 2010 results. Boston: Massachusetts Water Resources Authority. Report 2011-14. 43p.

Moore MJ, Nestler EC, Pembroke AE. 2011. Flounder monitoring report: 2011 results. Boston: Massachusetts Water Resources Authority. Report 2011-19. 17p.

MWRA. 1991. Massachusetts Water Resources Authority effluent outfall monitoring plan: Phase I baseline studies. Boston: Massachusetts Water Resources Authority. Report 1991-ms-02. 95p.

MWRA. 1997a. Massachusetts Water Resources Authority effluent outfall monitoring plan: Phase II post discharge monitoring. Boston: Massachusetts Water Resources Authority. Report 1997-ms-44. 61p.

MWRA. 1997b. Massachusetts Water Resources Authority Contingency Plan. Boston: Massachusetts Water Resources Authority. Report 1997-ms-069. 41p.

MWRA. 2001. Massachusetts Water Resources Authority Contingency Plan revision 1. Boston: Massachusetts Water Resources Authority. Report 2001-ms-071. 47p.

MWRA. 2004. Massachusetts Water Resources Authority effluent outfall ambient monitoring plan Revision 1, March 2004. Boston: Massachusetts Water Resources Authority. Report 2004-ms-092. 65p.

MWRA. 2010. Ambient monitoring plan for the Massachusetts Water Resources Authority effluent outfall Revision 2, July 2010. Boston: Massachusetts Water Resources Authority. Report 2010-04. 107p.

Nestler EC, Diaz RJ, Hecker B, Pembroke AE. 2012. Outfall benthic monitoring report: 2011 results. Boston: Massachusetts Water Resources Authority. Report 2012-08. 38 pages plus appendices..

Werme C, Rex AC, Hunt, C. 2012. Background outfall monitoring overview. Boston: Massachusetts Water Resources Authority. Report 2012-02. 58p.

List of Acronyms

BEM	Bays Eutrophication Model
BOD	Biochemical oxygen demand
cBOD	Carbonaceous biochemical oxygen demand
CHV	Centrotubular hydropic vacuolation
CSO	Combined Sewer Overflow
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DIF	Deer Island Flats
DITP	Deer Island Treatment Plant
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
ER-L	Effects Range-Low sediment guideline
FF	Farfield
HMW	High molecular weight
IAAC	Inter-Agency Advisory Committee
LC50	50% mortality concentration
LMW	Low molecular weight
MADEP	Massachusetts Department of Environmental Protection
MWRA	Massachusetts Water Resources Authority
NA	Not analyzed/not applicable
NB	Nantasket Beach
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
NDBC	National Data Buoy Center
NF	Nearfield
NOAA	National Oceanic and Atmospheric Administration
NOEC	No observed effects concentration
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OS	Outfall site
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
PCCS	Provincetown Center for Coastal Studies
PSP	Paralytic shellfish poisoning
RPD	Redox potential discontinuity
SD	Standard deviation

Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Boston, MA 02129
(617) 242-6000