2010
Outfall Monitoring Overview

Environmental Quality Department
Report 2011-16

Massachusetts Water Resources Authority

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Outfall Monitoring Overview

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Summary

Each year, the Massachusetts Water Resources Authority (MWRA) prepares this report, an overview of environmental monitoring related to the Massachusetts Bay municipal effluent outfall. It presents monitoring results and information relevant to the MWRA Contingency Plan, including threshold exceedances, responses, and corrective actions. The overview also includes sections on special studies and on the Stellwagen Bank National Marine Sanctuary. Special studies in 2010 included floatable materials study, a comparison of modeling results to field data, information from instrumented buoys, marine mammal observations, an update on nutrients in Boston Harbor, and the final results from nutrient flux studies.

This year's outfall monitoring overview marks eight years of baseline monitoring and more than ten years since discharge was diverted from the shallower, more confined, waters of Boston Harbor to the deeper waters of Massachusetts Bay. Results continue to confirm the predictions that the outfall would have only limited and localized effects on the Massachusetts Bay ecosystem, while greatly benefiting Boston Harbor.

Throughout 2010, monitoring results were consistent with previous years, with no unanticipated effects associated with the outfall. Despite record spring rains and record-breaking pumping and treatment levels at Deer Island Treatment Plant, there were no permit violations. There were no exceedances of Contingency Plan thresholds for water column, or fish and shellfish (Table 1). There were two exceedances of sea-floor thresholds, the first time that sea floor thresholds had ever been exceeded. However, these exceedances did not suggest a decline in community condition. Rather, they suggested that the soft-bottom community is somewhat more diverse than it was during the baseline period. Increased diversity is not generally an indication of a deteriorating environment; in this case, it probably resulted from normal population fluctuations.

Although there was no expectation that there would be adverse consequences from changing the location of the discharge, questions were developed during the planning process to focus on plausible impacts of the diverted effluent discharge on the Massachusetts Bay and Cape Cod Bay ecosystems. These questions formed the basis of the monitoring program and have now been answered (Table 2). Monitoring has confirmed predictions that any effects of the discharge would be small and localized. Compliance with effluent permit limits has proven to be the key to ensuring that there are no unanticipated effects.

With those monitoring questions answered, MWRA, in consultation with its advisory groups and regulatory authorities, has revised the monitoring plan for future years. The new plan is summarized in a final section of this report. It shifts the focus and scale of monitoring to a less geographically dispersed design but increases the frequency of sampling at reference stations. The new design is more efficient and consistent.

Table 1. Contingency Plan thresholds and exceedances as of 2010. (NA = not applicable, ✓ = no exceedance, C = caution level exceedance, W = warning level exceedance)

Effluent												
Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	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
	Oil and grease	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 1. Contingency Plan thresholds and exceedances as of 2010, continued. (NA = not applicable, ✓ = no exceedance, **C** = caution level exceedance, **W** = warning level exceedance)

Water Column												
Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Nearfield bottom water	Dissolved oxygen concentration	C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Dissolved oxygen saturation	C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Stellwagen Basin bottom water	Dissolved oxygen concentration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Dissolved oxygen saturation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nearfield bottom water	Dissolved oxygen depletion rate (June–October)	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
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*	Winter/spring	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Summer	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Autumn	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nearfield nuisance algae *Alexandrium*	Any sample	✓	✓	✓	✓	✓	C	C	✓	C	C	✓
Farfield shellfish	PSP toxin extent	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Plume	Initial dilution	NA	✓	Complete								

Table 1. Contingency Plan thresholds and exceedances as of 2010, continued. (NA = not applicable, ✔ = no exceedance, C = caution level exceedance, W = warning level exceedance)

Sea Floor												
Location/ Parameter Type	**Parameter**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Nearfield sediment contaminants	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
Nearfield sediment	RPD depth	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Nearfield benthic diversity	Species per sample	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Fisher's log-series alpha	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	Shannon diversity	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔	C
	Pielou's evenness	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔	C
Nearfield species composition	Percent opportunists	NA	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

Table 1. Contingency Plan thresholds and exceedances as of 2010, continued. (NA = not applicable, ✓ = no exceedance, **C** = caution level exceedance, **W** = warning level exceedance)

Fish and Shellfish

Location/ Parameter Type	Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Nearfield flounder tissue	Total PCBs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
	Mercury	NA	✓	✓	✓	✓	NA	✓	NA	NA	✓	NA
	Chlordane	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
	Dieldrin	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
	Total DDTs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
Nearfield flounder	Liver disease (CHV)	NA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Nearfield lobster tissue	Total PCBs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
	Mercury	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
	Chlordane	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
	Dieldrin	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
	Total DDTs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
Nearfield mussel tissue	Total PCBs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
	Lead	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
	Mercury	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
	Chlordane	NA	**C**	**C**	✓	NA	NA	✓	NA	NA	✓	NA
	Dieldrin	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
	Total DDTs	NA	✓	✓	✓	NA	NA	✓	NA	NA	✓	NA
	Total PAHs	NA	**C**	**C**	**C**	NA	NA	✓	NA	NA	✓	NA

Table 2. Answers to the monitoring questions.

Monitoring Question	Answer
Do effluent pathogens exceed the permit limits?	No. Secondary treatment and disinfection effectively remove pathogens. In thousands of tests, daily fecal coliform limits have been exceeded twice, both times during storms.
Does acute or chronic toxicity of effluent exceed the permit limit?	No. In more than 600 tests, there have been four exceedances of permit limits.
Do effluent contaminant concentrations exceed permit limits?	No. Discharges of priority pollutants are well below predictions and in most cases meet receiving water quality criteria even before dilution.
Do conventional pollutants in the effluent exceed permit limits?	No. Discharges of solids and BOD have decreased by 87% compared to the old treatment plant. In more than 600 tests, there have been three exceedances of suspended solids limits, which occurred during an upset of the secondary treatment process by an industrial discharge.
What are the concentrations of contaminants in the influent and effluent and their associated variability?	There has been great success in reducing contaminants in the influent and a high degree of removal of contaminants by the treatment system, with consistently low concentrations since secondary treatment was implemented.
Do levels of contaminants in water outside the mixing zone exceed water quality standards?	No. Water quality standards are not exceeded. The projected degree of mixing was confirmed by plume studies conducted in 2001. Ongoing effluent monitoring assures that standards are not violated.
Are pathogens transported to shellfish beds at levels that might affect shellfish consumer health?	No. Dilution is sufficient for pathogens to reach background concentrations before reaching shellfish beds. Dilution rates were confirmed by plume studies conducted in 2001.
Are pathogens transported to beaches at levels that might affect swimmer health?	No. Dilution is sufficient for pathogens to reach background concentrations before reaching beaches. Dilution rates were confirmed by plume studies conducted in 2001.
Has the clarity and/or color of the water around the outfall changed?	No. Although clarity and color have not changed, there are occasional observations of tiny bits of fat, similar to samples collected at the treatment plant.
Has the amount of floatable debris around the outfall changed?	Floatable debris of concern is rare in the effluent. Signs of effluent can occasionally be detected in the field.
Are the model estimates of short-term (less than one day) effluent dilution and transport accurate?	Yes. Model estimates were confirmed by plume studies conducted in 2001.
What are the nearfield and farfield water circulation patterns?	Flow is controlled by general circulation in the Gulf of Maine and influenced by tides and local wind. Bottom currents around the outfall can flow in any direction with no mean flow direction.

Monitoring Question	Answer
What is the farfield fate of dissolved, conservative, or long-lived effluent constituents?	There have been no detectable changes in the farfield. Changes in salinity and dissolved components of the effluent are not detected within tens of meters of outfall and not observed in farfield water or sediments.
Have nutrient concentrations changed in the water near the outfall; have they changed at farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, are they correlated with changes in the nearfield?	Changes have been consistent with model predictions. The effluent signature is observed in the vicinity of the outfall but is quickly diluted.
Do the concentrations (or percent saturation) of dissolved oxygen in the water column meet the state water quality standards?	Yes. Conditions are unchanged from the baseline.
Have the concentrations (or percent saturation) of dissolved oxygen in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay changed relative to pre-discharge baseline or a reference area? If so, can changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	No. Conditions have not changed from the baseline.
Has the phytoplankton biomass changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay, and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	No substantial change has been detected.
Have the phytoplankton production rates changed in the vicinity of the outfall or at selected farfield stations, and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	Productivity patterns in Boston Harbor may be changing, as the area transitions from eutrophic conditions to a more typical coastal regime. There has been no concurrent increase in productivity in Massachusetts Bay.
Has the abundance of nuisance or noxious phytoplankton changed in the vicinity of the outfall?	The frequency of *Phaeocystis* blooms has increased, but the phenomenon is regional in nature. *Alexandrium* blooms, which have occurred since 2005, are regional and have not been attributed to the outfall.
Has the species composition of phytoplankton or zooplankton changed in the vicinity of the outfall or at selected farfield stations in Massachusetts Bay or Cape Cod Bay? If so, can these changes be correlated with effluent of ambient water nutrient concentrations, or can farfield changes be correlated with nearfield changes?	The increase in frequency of *Phaeocystis* blooms is the most marked change in the phytoplankton community, and the region appears to be entering a period of frequent red tides. Those changes have not been attributed to the outfall. There have been no changes in the zooplankton community beyond normal ecological fluctuations.
What is the level of sewage contamination and its spatial distribution in Massachusetts and Cape Cod bays sediments before discharge through the new outfall?	The effects of historic inputs from Boston Harbor and other sources can be detected, particularly in coastal stations.

Monitoring Question	Answer
Has the level of sewage contamination or its spatial distribution in Massachusetts and Cape Cod bays sediments changed after discharge through the new outfall?	An effluent signal can be detected only in *Clostridium perfringens* spores, the most sensitive sewage tracer, and is only detectable within a few kilometers of the outfall.
Has the concentration of contaminants in sediments changed?	There has been no general increase in contaminants. An effluent signal can be detected as *Clostridium perfringens* spores within 2 km of the diffuser.
Has the soft-bottom community changed?	Changes have occurred but are the result of natural variation. The changes are not significant and are not attributed to the outfall.
Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased?	No. The sediment RPD has been deeper during post-diversion years rather than shallower; that is, the sediments are more rather than less oxic.
Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments?	There have been no changes detected, even within 2 km of the outfall.
Has the hard-bottom community changed?	There have been no changes that can be attributed to the outfall. There have been decreases in coralline algae at some stations, but the geographic pattern does not suggest an outfall effect.
How do the sediment oxygen demand, the flux of nutrients from the sediment to the water column, and denitrification influence the levels of oxygen and nitrogen in the water near the outfall? Have the rates of these processes changed?	These conditions were described by baseline monitoring. Conditions have improved in Boston Harbor and have not changed in Massachusetts Bay.
Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began?	There has been no substantial change in flounder or lobster contaminant body burdens, with concentrations remaining very low. There have been detectable increases in concentrations of some contaminants in mussel arrays deployed within the mixing zone at the outfall.
Do the levels of contaminants in the edible tissue of fish and shellfish around the outfall represent a risk to human health?	There have been no changes that would pose a threat to human health. Regional patterns have persisted since the baseline period, and there appears to be a general long-term downward trend for most contaminant levels.
Are the contaminant levels in fish and shellfish different between the outfall, Boston Harbor, and a reference site?	Differences were documented during baseline monitoring. Regional patterns have persisted since the diversion, with concentrations being highest in Boston Harbor and lowest in Cape Cod Bay.
Has the incidence of disease and/or abnormalities in fish or shellfish changed?	There have been no increases in disease or abnormalities in response to the outfall; there has been a long-term downward trend in liver disease in fish from near Deer Island and near the outfall.

1. Introduction

Since its creation in 1985, the Massachusetts Water Resources Authority (MWRA) has worked to minimize the effects of wastewater discharge on the marine environment. One important part of that mission has been a diversion of the municipal wastewater discharge from Boston Harbor to the deeper, less confined waters of Massachusetts Bay. A monitoring program assesses compliance with the National Pollutant Discharge Elimination System (NPDES) permit to discharge effluent from the Deer Island Treatment Plant (DITP) into Massachusetts Bay. Monitoring also assures that there are no unanticipated environmental effects of the discharge and provides information for management of the outfall.

Results from most of the baseline-monitoring years and each post-diversion year have been documented in annual reports such as this one, the **Outfall Monitoring Overview**. Background information for these overviews and a complete description of the monitoring program can be found in Werme and Hunt (2008). That document, the monitoring plans and revisions (MWRA 1991, 1997a, 2004, 2010), the Contingency Plan (MWRA 1997b, 2001), area-specific technical reports, and past outfall monitoring overviews are available on the technical report list at MWRA's website, www.mwra.com/harbor/enquad/trlist.html.

Overviews for 1994 through 1999 included only baseline information. After the Massachusetts Bay outfall became operational in September 2000, reports have included post-diversion data relevant to the outfall permit, including Contingency Plan threshold exceedances, responses, and corrective actions. This year's overview presents monitoring results for effluent, water column, sea floor, winter flounder, and special studies conducted to meet specific permit requirements, scientific questions, or public concerns. It also includes a section on the Stellwagen Bank National Marine Sanctuary, meeting a permit requirement that MWRA report on monitoring results that relate to the sanctuary.

Eight years of baseline monitoring and more than ten years of post-diversion monitoring have confirmed the predictions that the outfall would have only limited and localized effects on the Massachusetts Bay ecosystem, while the benefits to Boston Harbor have been dramatic. Consequently, MWRA, in consultation with its advisory groups and regulatory authorities, has revised the monitoring plan for future years. The new plan is summarized in a final section of this report. It shifts the focus and scale of monitoring to a less intensive, less geographically dispersed design, but increases the frequency of sampling at reference stations. The new design is more efficient and consistent.

2. Effluent

2010 Characterization

Throughout 2010, DITP continued to operate as designed, and contaminant loads remained low. It was a relatively wet year in the Boston area, with rainfall about 15% above average. Rainfall has been relatively high in the decade since the outfall discharge was diverted from Boston Harbor to Massachusetts Bay. The wet year in 2010 resulted in relatively high effluent flows, slightly higher than in 2009, with a small increase in the percentage of primary-blended flow (Figure 2-1).

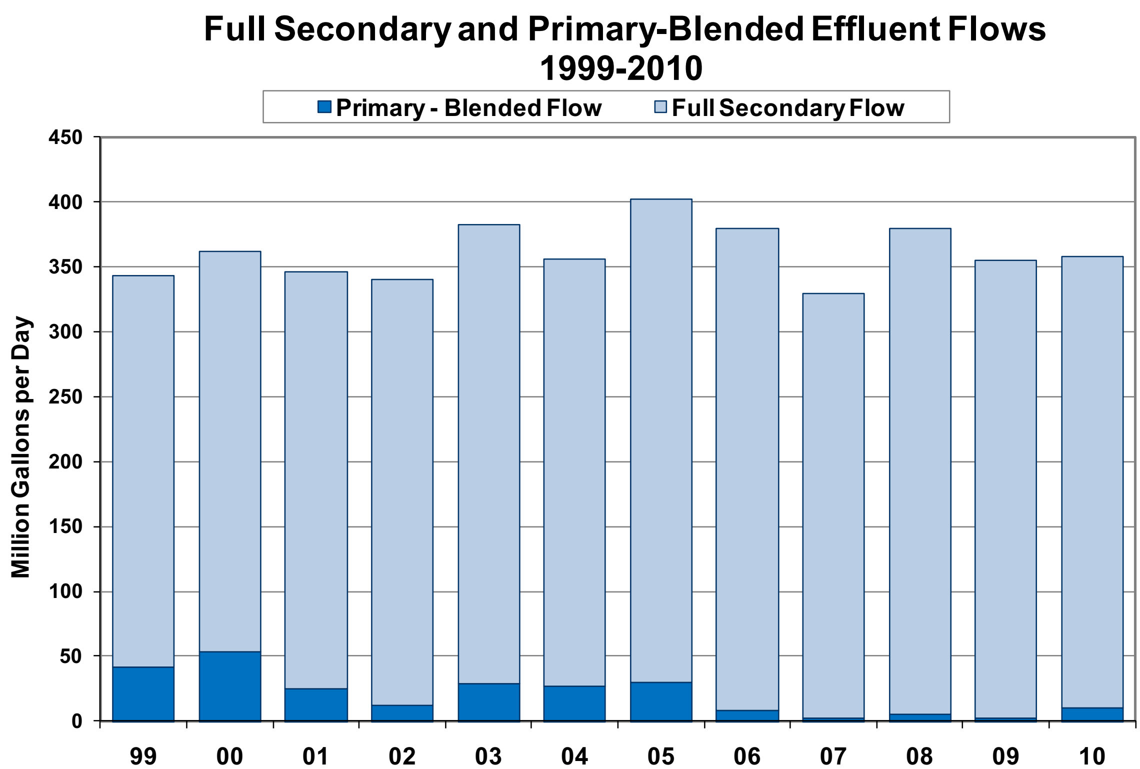


Figure 2-1. MWRA primary-blended and full secondary effluent flows. Almost all the flow from the treatment plant has received full secondary treatment since the completion of the secondary facilities in 2001. During large storms, flow exceeding the secondary capacity of the plant is diverted around the 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 effluent flows meet permit limits.

March was particularly stormy, receiving 15 inches of rain and breaking the previous record 11 inches that had been set in 1953. Average flow for March from DITP reached 726 mgd (Figure 2-2), much higher than the previous one-month record of 620 mgd. One March storm forced two controlled releases of wastewater from the Nut Island Headworks into Quincy Bay in the southern part of Boston Harbor. These releases, estimated at between 5 and 10 million gallons, were necessary to prevent sewage backups into homes and streets.

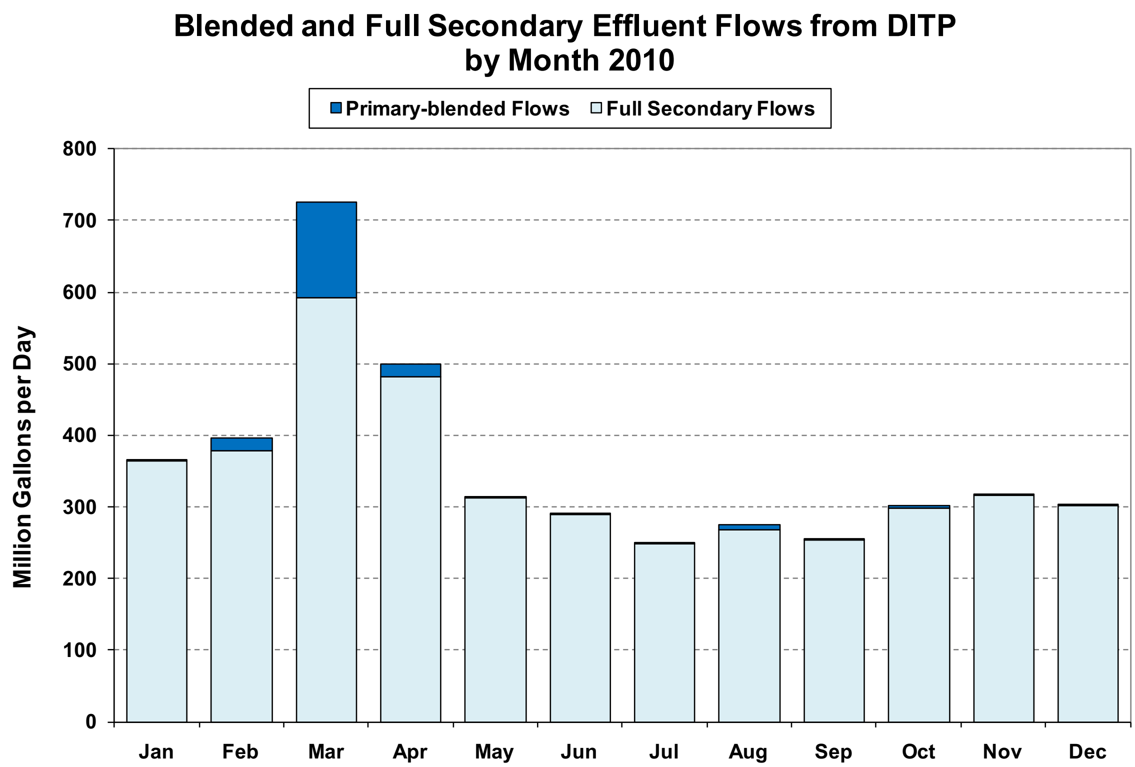


Figure 2-2. MWRA primary-blended and full secondary effluent flows during 2010. Blending mostly occurred during March storms.

The increased flows in 2010 resulted in slight increases in contaminant loads compared to record lows, but overall, contaminant loads in the effluent remained very low. Solids loads were the highest measured since 2005 but lower than any year before then (Figure 2-3). Biochemical oxygen demand (BOD), regulated as carbonaceous BOD, was also slightly higher in 2010 than in 2009, but lower than 2008 and 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, continued to decrease from a peak in 2005.

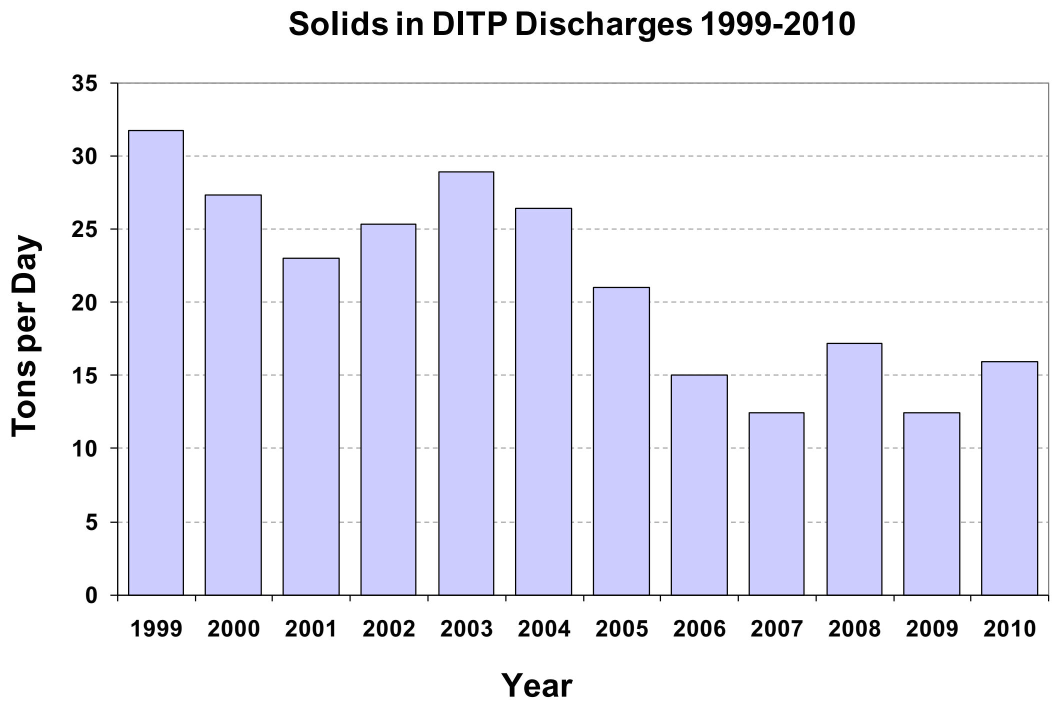


Figure 2-3. Solids in MWRA treatment plant discharges. Solids discharges remained low in 2010.

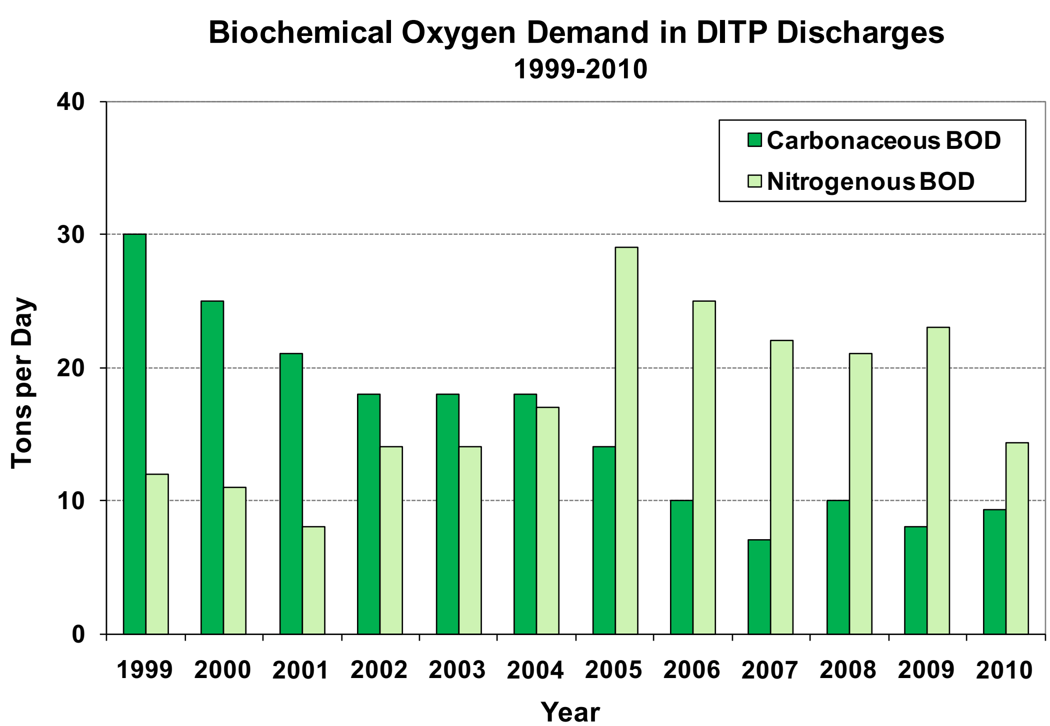


Figure 2-4. Biochemical oxygen demand in MWRA discharges. MWRA's permit limits carbonaceous BOD, which remained low in 2010. Nitrogenous BOD is the result of microbiological breakdown that occurs as a result of secondary treatment.

Total nitrogen loads were approximately the same in 2010 as in 2009 (Figure 2-5). The proportion of the load made up of ammonium continued to slightly increase, as it has each year since 2005. About 10% of the ammonium in the sewage influent is removed by secondary treatment, but the MWRA biological treatment process converts some organic forms of nitrogen to ammonium. Ammonium-rich liquids from the biosolids pelletizing (fertilizer) plant are also reintroduced to DITP for treatment. MWRA continually evaluates nitrogen-removal technologies, so that nitrogen removal could be implemented at DITP if the need arose (Bigornia-Vitale and Wu 2011). However, nitrogen loads have remained below the Contingency Plan threshold, and nitrogen removal has not been implemented.

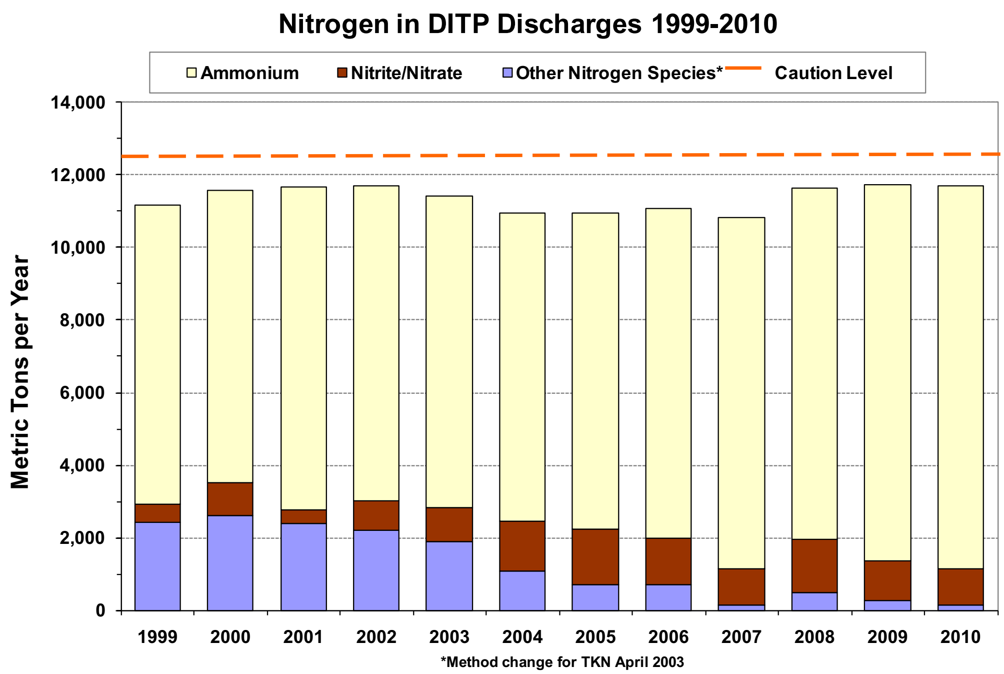


Figure 2-5. Deer Island Treatment Plant nitrogen discharges. Most of the nitrogen in the effluent is in the form of ammonium, a result of the treatment process. (TKN = total Kjeldahl nitrogen, a measure of total nitrogen in the effluent)

Metals loads increased very slightly in 2010 compared to 2009, but remained low (Figure 2-6). Among the metals that have been of concern, only copper and zinc remain in notable, though low, quantities, with other metals present in only trace amounts. In fact, except for copper, the metals meet receiving water quality criteria in the effluent prior to outfall dilution. Mercury levels increased slightly in 2010, but remained at low levels (Figure 2-7). Although extremely sensitive methods are used in 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 to reduce mercury use, handle workplace spills, and discourage disposal practices that introduce mercury into the sewer system.

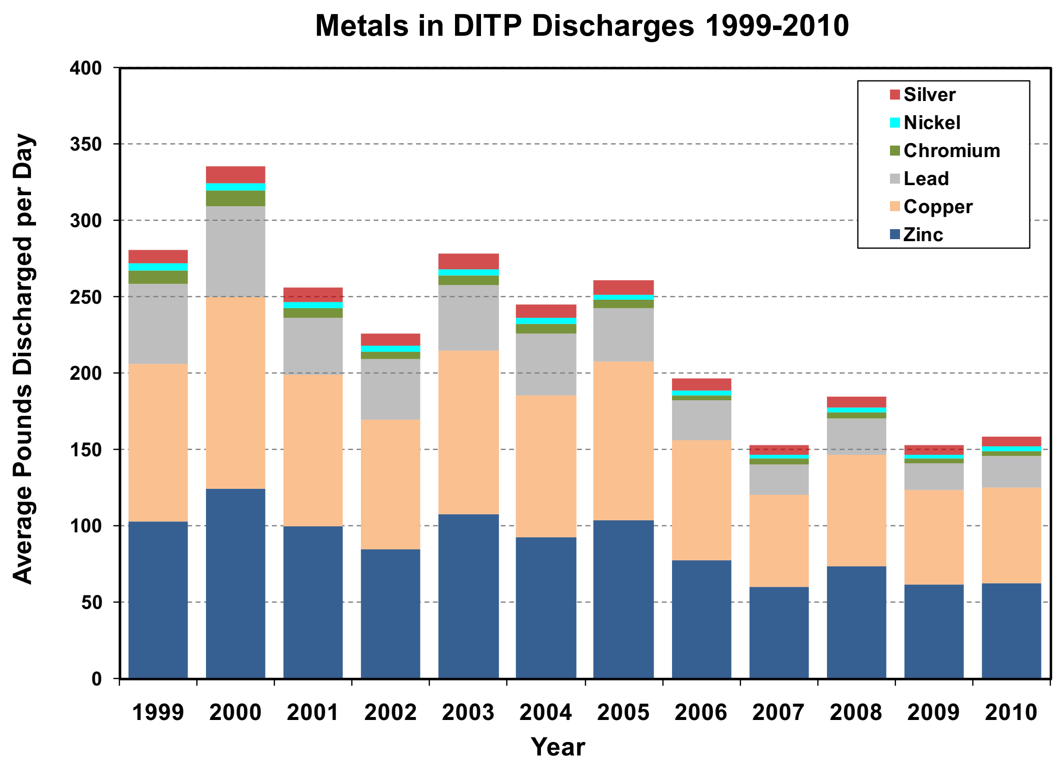


Figure 2-6. Deer Island Treatment Plant metals discharges. Except for copper, the metals meet receiving water quality criteria in the effluent, prior to outfall dilution.

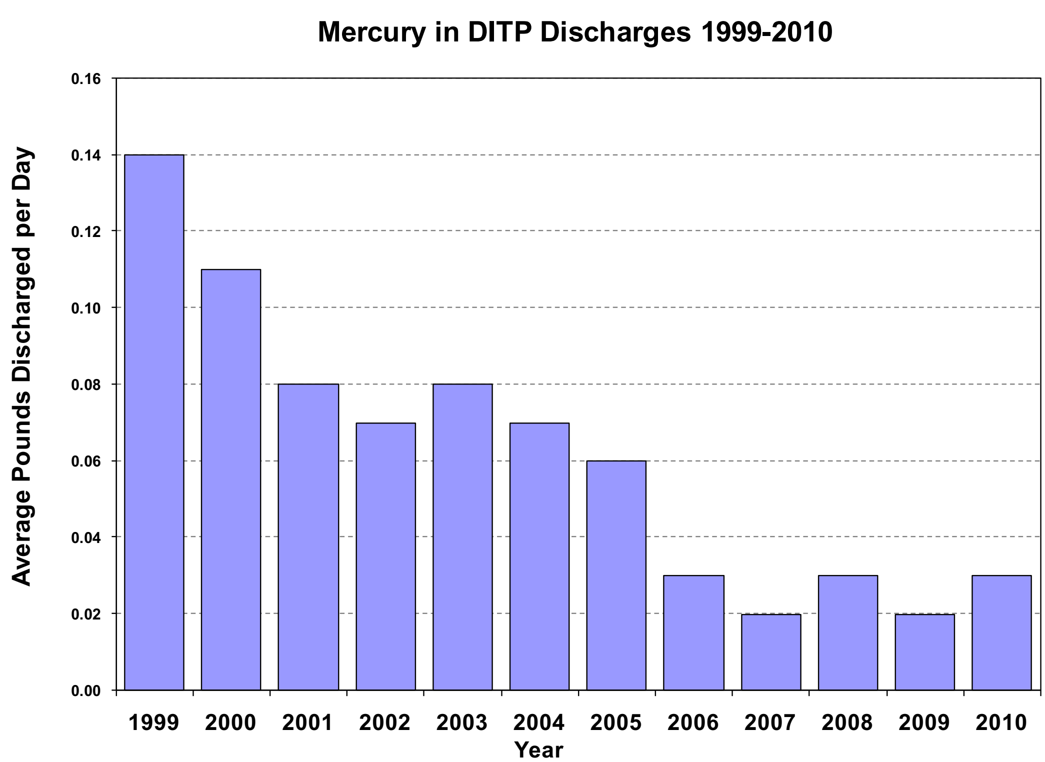


Figure 2-7. Mercury in Deer Island Treatment Plant discharges. Mercury is only rarely detected in the effluent.

Loads of pesticides and polychlorinated biphenyls (PCBs) also increased slightly in 2010 but remained low, also requiring sensitive detection methods (Figure 2-8). Annual loadings of PCBs, of which seven congeners are routinely detected, totaled about two pounds per year. Loads of the only breakdown product of the pesticide DDT that is found, 4-4' DDE, were about one half pound. Loads of another organochlorine pesticide, chlordane, detected as alpha chlordane and trans nonachlor, totaled about two pounds per year. These values were well below those that had been anticipated during the planning process for the relocated outfall, when anticipated loads of total PCBs were more than 100 pounds and projected loads of 4-4' DDE were more than 60 pounds per year.

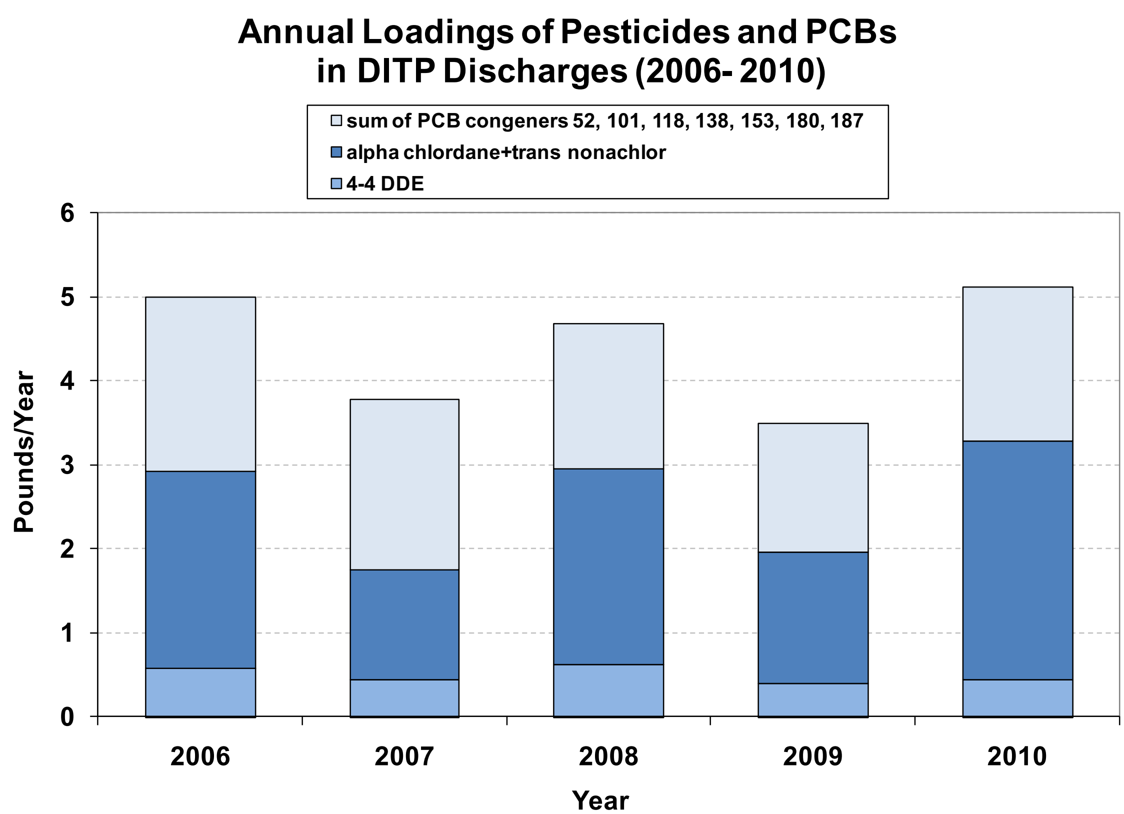


Figure 2-8. Organic compounds in Deer Island Treatment Plant discharges. New methods were implemented in 2006 to detect these compounds, which are present at very low levels.

Contingency Plan Thresholds

As in 2007–2009, DITP had no permit violations and no exceedances of the Contingency Plan thresholds in 2010 (Table 2-1). Of thousands of measurements, there have been only eleven effluent Contingency Plan exceedances since the permit went into effect and no exceedances of thresholds for overall plant performance, total nitrogen load, or oil and grease. Floatables, for which there are no caution or warning levels, are present at extremely low amounts at the end of the treatment process, measured in parts per billion (see Section 6, Special Studies, for results from sampling, characterizing, and quantifying floatables).

Table 2-1. Contingency Plan threshold values and 2010 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	2010 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 monitoring program measures water quality and studies phytoplankton and zooplankton at stations in Boston Harbor, Massachusetts Bay, and Cape Cod Bay (Figures 3-1, 3-2).

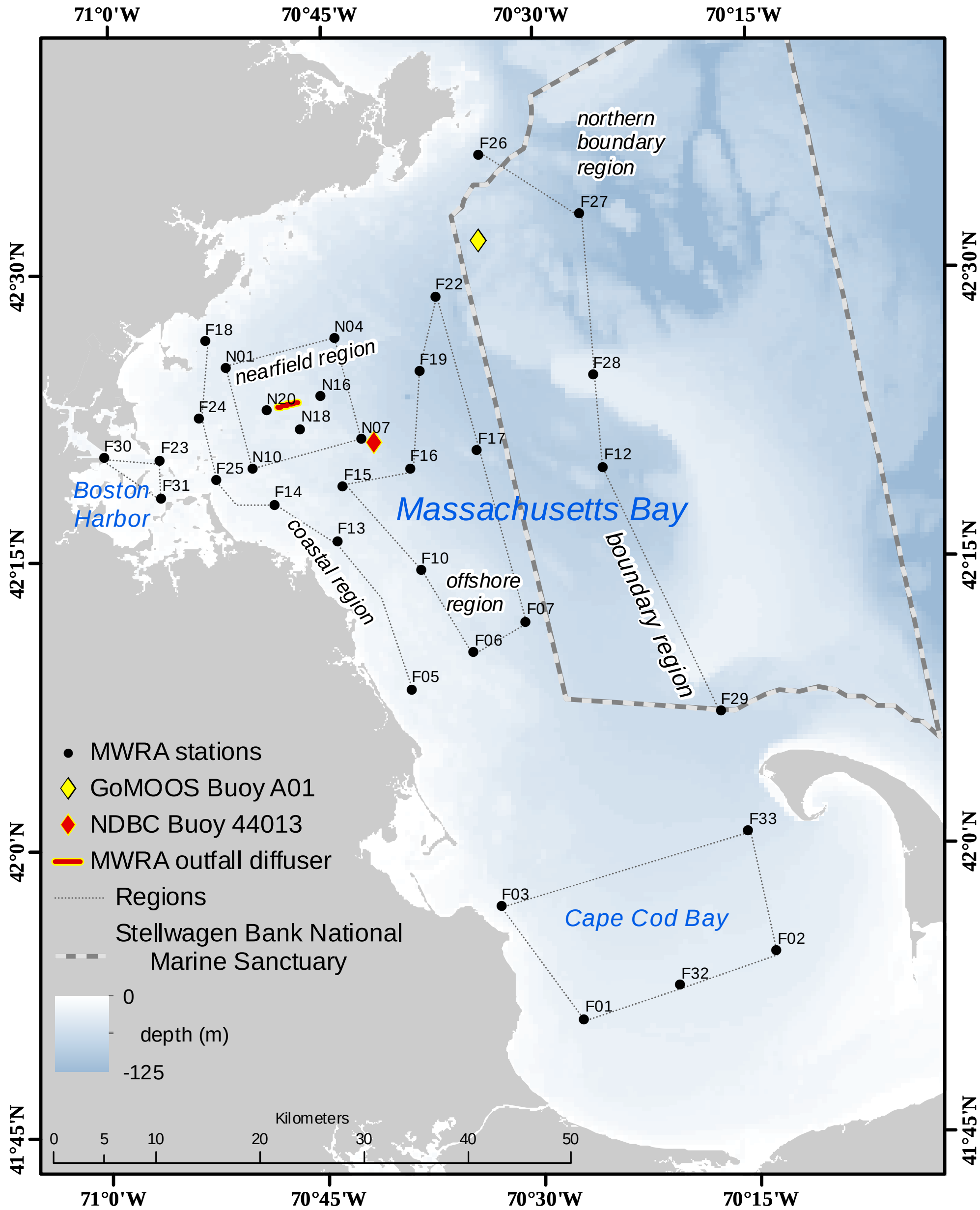


Figure 3-1. MWRA Bay water quality monitoring stations and regional groupings. "Farfield" stations include all stations in Boston Harbor; the coastal, offshore, and northern boundary regions; and Cape Cod Bay. Also shown are the MWRA outfall; instrumented buoys operated by the Gulf of Maine Ocean Observing System (GoMOOS Buoy A01) and the National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC Buoy 44013); and the Stellwagen Bank National Marine Sanctuary.

The Massachusetts Bay stations located within seven kilometers of the outfall diffusers are called nearfield stations. Those beyond are grouped into regions, which together are called farfield stations. Twelve surveys of seven nearfield stations and six surveys of 27 farfield stations were completed in 2010. Sampling was augmented by two instrumented buoys, the Gulf of Main Ocean Observing System (GoMOOS) Buoy A01 and the National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC) Buoy 44013, and remote sensing.

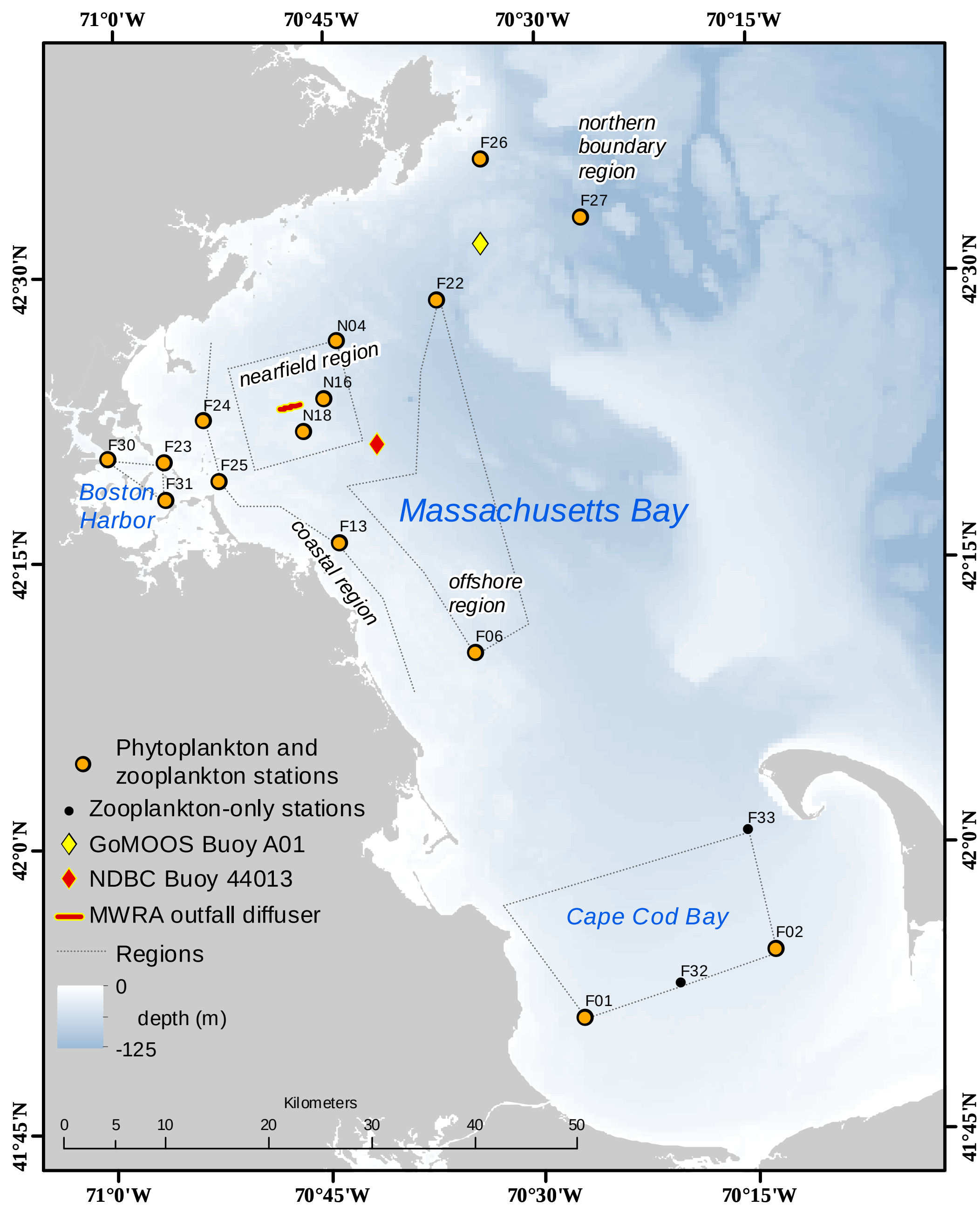


Figure 3-2. MWRA plankton stations. The stations are a subset of those included in water quality monitoring. Regional groupings, the instrumented buoys, and the MWRA outfall are also shown.

Physical Conditions

Monitoring baseline and post-diversion conditions 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.

Record-setting rains occurred in the Boston area during March 2010. They were followed by a dry summer and an average, slightly stormy fall. Three large March storms produced record high flows from the Merrimack and Charles rivers (Figures 3-3, Libby et al. 2011). Summer flows from the Merrimack River reached a record low for the monitoring program years, 1992–2010.

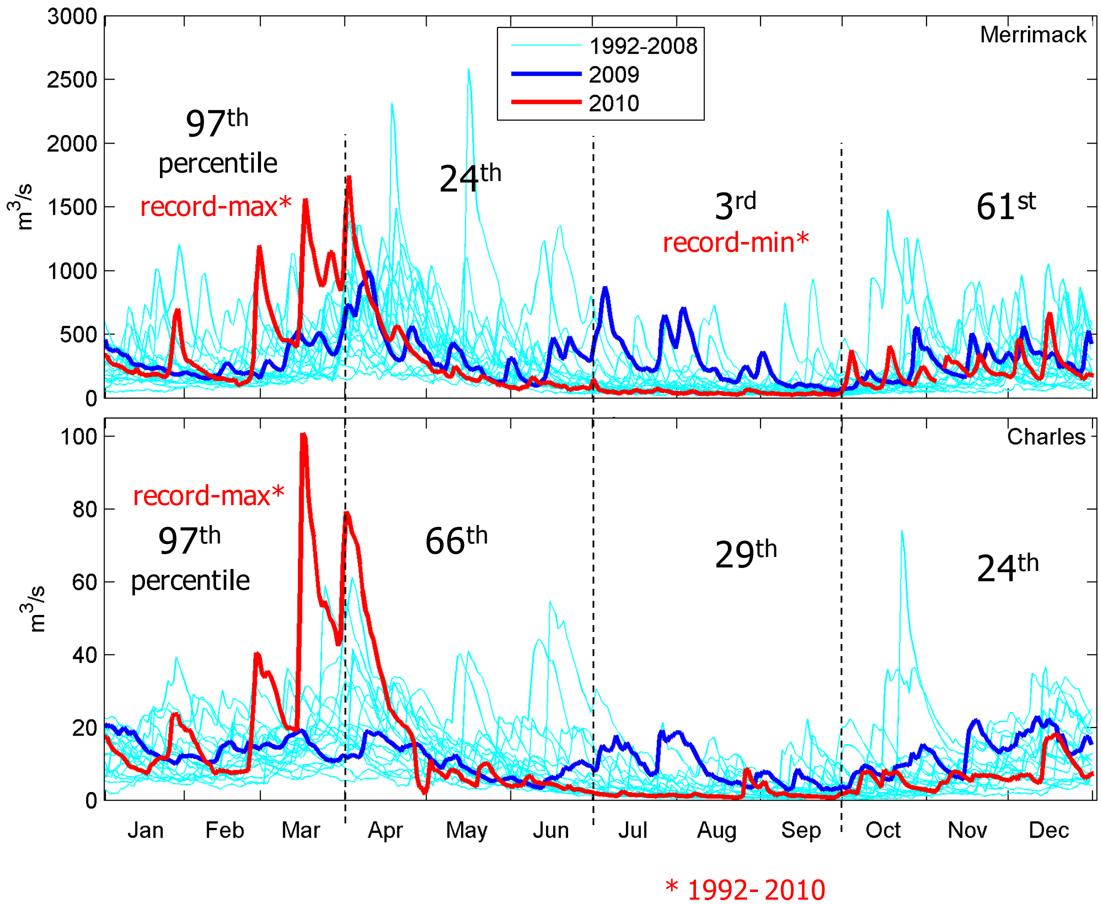


Figure 3-3. Flows of the Merrimack (top) and Charles (bottom) rivers reached record high levels during the first months of 2010. The average January–March flows in both rivers were the greatest measured during the monitoring program, translating to the 97th percentile. The previous record flows for that period were reached during 2008. Flows were low during the summer, particularly from the Merrimack River, where flows reached a record minimum for the monitoring program. Flows during 2009, shown for contrast, reached record highs for July–September.

The wind-forcing conditions in 2010 created moderate upwelling conditions throughout the summer, as winds pushed water away from the coast (Figure 3-4). This pattern was similar to that of most years, when spring is a transitional period between winter downwelling and spring/summer upwelling conditions. In contrast, a stormy summer in 2009 forced downwelling conditions during June. Wave heights in 2010 were higher than normal during the March storms, and there were also rough conditions during September through December. Only one weak storm occurred in May, the time period during which winds from the northeast sometimes bring *Alexandrium fundyense*, the phytoplankton species that causes red tides, into Massachusetts Bay.

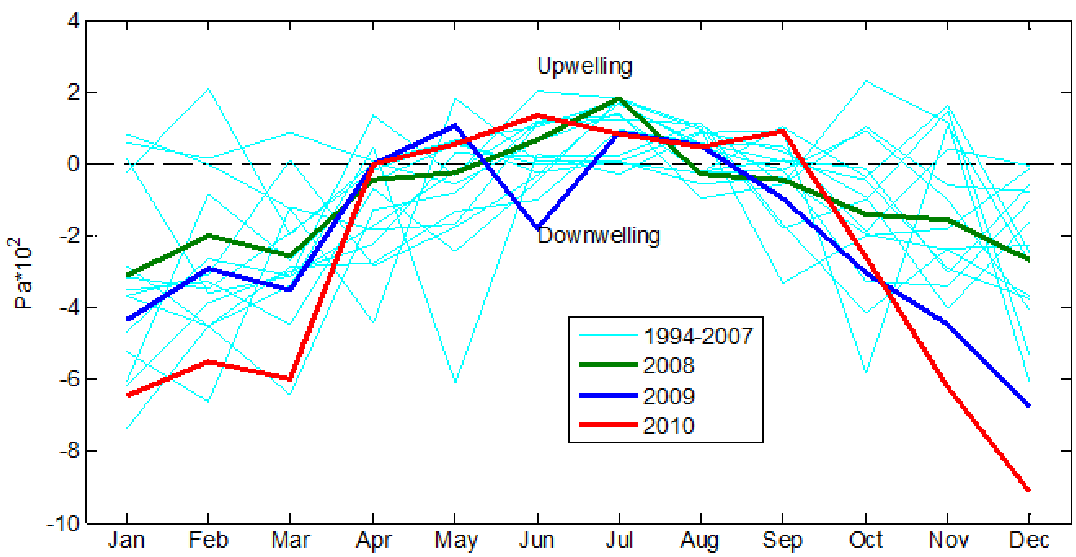


Figure 3-4. Monthly average wind stress at NDBC Buoy 44013. Positive values indicate winds from the south or southwest, which result in upwelling-favorable wind stress; negative values indicate winds from the north or northeast, which favor downwelling. There was moderate upwelling throughout the summer. Data from 2008 and 2009 are shown for comparison.

Despite the summer upwelling conditions, surface and bottom water temperatures (Figure 3-5) were warmer than average, particularly at the end of the stratified period, that summertime condition in which differences in water temperatures and salinities effectively separate surface and bottom waters. Near-bottom water temperatures were the highest ever recorded by the monitoring program. Continuous data from the NDBC Buoy 44013 also showed warmer than average water temperatures during the spring, with large variability during and after storms.

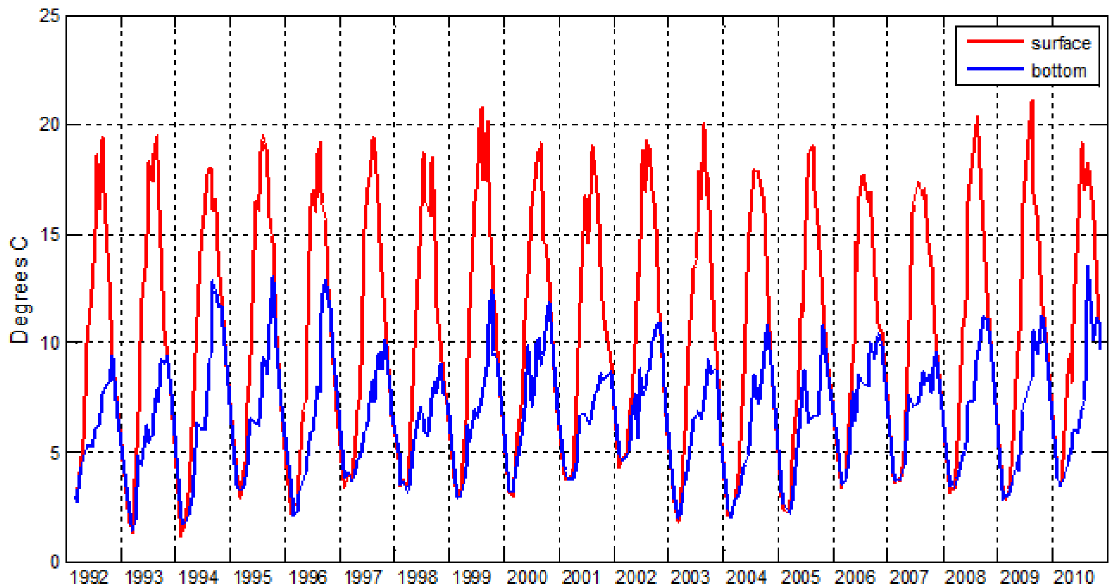


Figure 3-5. Nearfield surface and bottom water temperature. Surface measurements are the upper line. Summer surface temperatures were warm, despite the upwelling conditions.

Salinity was affected by the wet March conditions and was relatively low in spring, as it has been in most years since 2005 (Figure 3-6). Surface salinity did not, however, approach the extreme low that was recorded in May 1998, a year that was disrupted by many storms and record rainfall. The March rainfall also contributed to early and strong stratification, which broke down during a storm with winds from the northeast at the end of August.

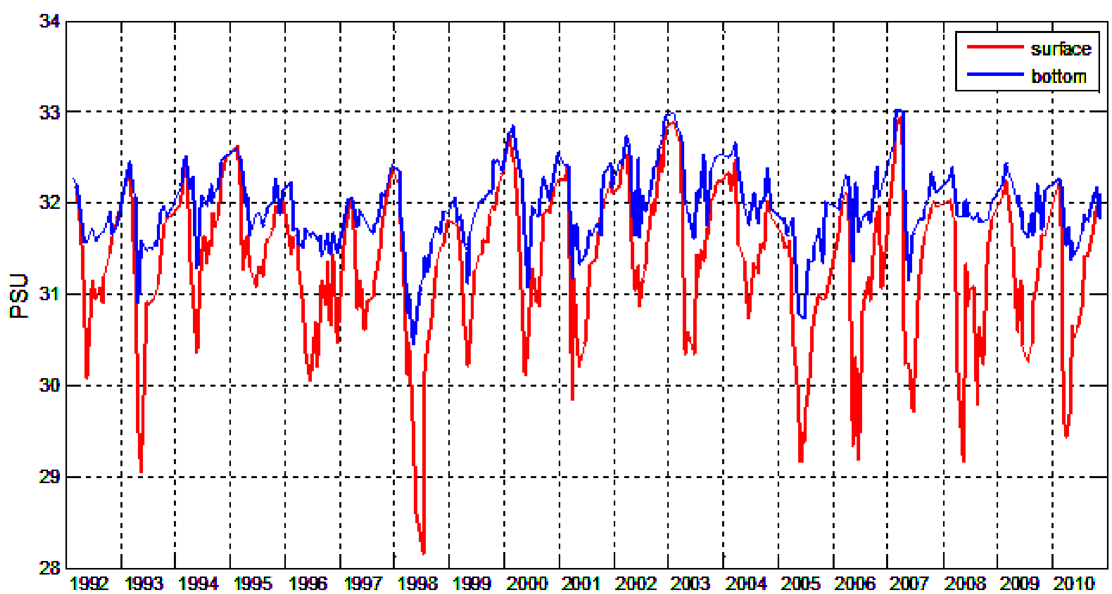


Figure 3-6. Nearfield surface and bottom water salinity. Surface measurements are the lower line. Surface salinity has been low in 2005–2010, reflecting a period of wet years.

Water Quality

Water quality measurements for 2010, including measurements of nutrients, phytoplankton biomass (measured as chlorophyll), and dissolved oxygen, followed typical annual cycles and continued to confirm predictions that there would be detectable localized effects of the discharge for certain parameters, no detectable adverse effects for other parameters, and no detectable effects for any measurements outside the immediate vicinity of the discharge (Libby et al. 2011). Water quality measurements in Boston Harbor continued to reflect the improvements of the post-diversion period.

Ammonium is the major component of total inorganic nitrogen in the effluent, and dilution models had suggested that, following the diversion, increased concentrations of ammonium would be detectable in the nearfield. Ammonium in the nearfield increased to about one micromole above background when the outfall came on-line and has remained so for ten years. Decreases in background ammonium (measured at the northern boundary) since 2005 have decreased the nearfield concentrations to levels typical of pre-diversion years (Figure 3-7). Meanwhile, the dramatic decrease in annual ammonium levels in Boston Harbor following the discharge diversion has persisted.

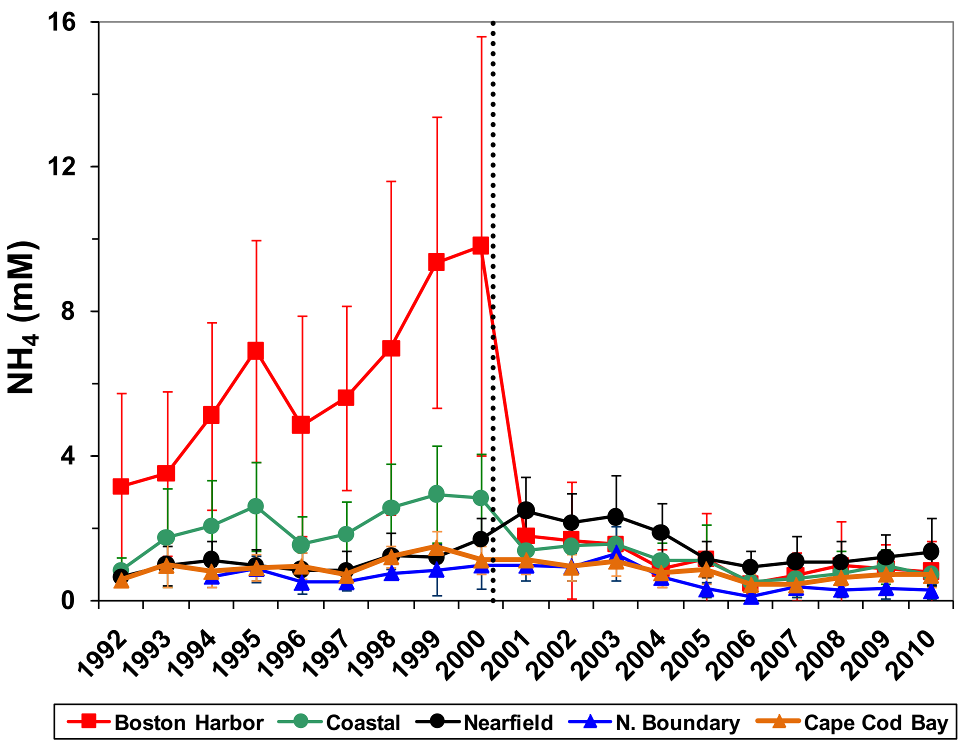


Figure 3-7. Annual mean ammonium concentrations. Levels greatly decreased in Boston Harbor after the outfall diversion, but have not greatly increased in the nearfield or other regions. Data represent all depths and all stations sampled within each region. Dotted vertical line shows the diversion of the discharge from Boston Harbor to Massachusetts Bay. Error bars represent ±1 standard deviation.

The localized increases in ammonium concentrations are apparent at the nearfield stations closest to the discharge compared to baseline conditions and relative to regional background conditions in every season (Figure 3-8). Much greater decreases in ammonium concentrations have been measured in Boston Harbor, and decreased ammonium concentrations have also been observed during the winter and spring at the coastal stations.

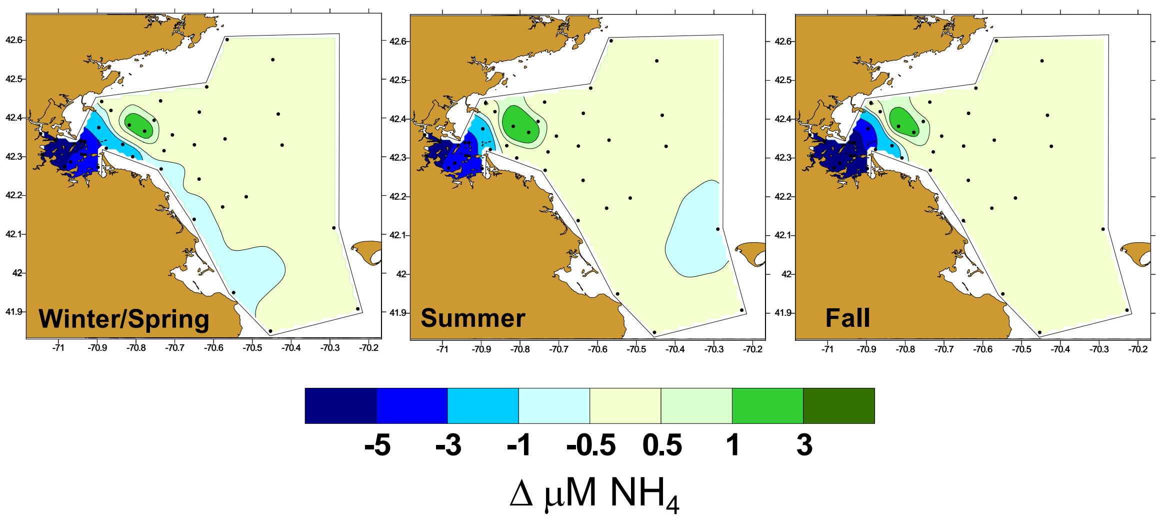


Figure 3-8. Changes in seasonal ammonium concentrations (μM NH_4) from the baseline to the post-diversion period. There have been localized increases in ammonium concentrations near the outfall (shown by the green area indicating a change of 1–3 μM NH_4), with concurrent decreases in ammonium concentrations in Boston Harbor.

There have also been region-wide changes in seasonal chlorophyll (Figure 3-9) and particulate organic carbon levels. Region-wide increases in spring chlorophyll levels reflect blooms of one phytoplankton species, *Phaeocystis pouchetii*. *Phaeocystis* blooms have occurred more frequently in recent years, although not strongly in 2010. Summer concentrations of chlorophyll have remained close to what they were during the baseline period, and fall concentrations have declined, particularly at the offshore and northern boundary stations. These changes have occurred across broad regional areas and are not induced by the discharge. Changes due to the outfall relocation are minor, local, and not adverse.

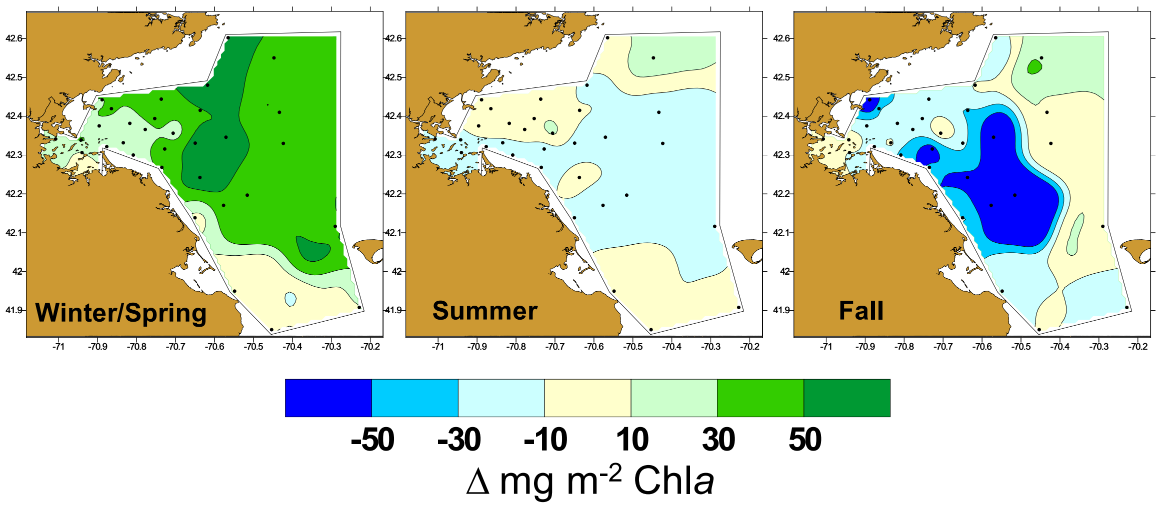


Figure 3-9. Changes in phytoplankton biomass, measured as areal chlorophyll (mg m^{-2} Chla), from the baseline to the post-diversion period. The changes reflect an increase in the *Phaeocystis* blooms in the spring and relative lack of fall blooms. These changes have occurred across the broad region and are not attributed to the relocated discharge. No large *Phaeocystis* bloom occurred during 2010.

The possibility that the outfall would cause lower dissolved oxygen levels in bottom waters was one important public concern prior to the diversion. However, measurements of concentrations and percent saturation of dissolved oxygen in bottom waters have shown no response to the outfall (Figure 3-10). There has been no change in levels or the seasonal pattern in any year. Summer and fall bottom water dissolved oxygen levels were somewhat lower in 2010 than in most other years, almost reaching 6 mg/L in the nearfield at the end of September, but these lower-than-usual levels have not been attributed to the discharge.

The data from the baseline and post-diversion years have shown that temperature and salinity, rather than effluent inputs, are the important factors controlling bottom-water dissolved oxygen concentrations and percent saturation in the nearfield (Figure 3-11). The relatively low dissolved oxygen minimum in 2010 is partly explained by warm, high salinity waters. Other factors, including differences in currents and water mass movements, may also have contributed. Lower levels of dissolved oxygen than were measured in 2010 were recorded in 1999, prior to the outfall diversion.

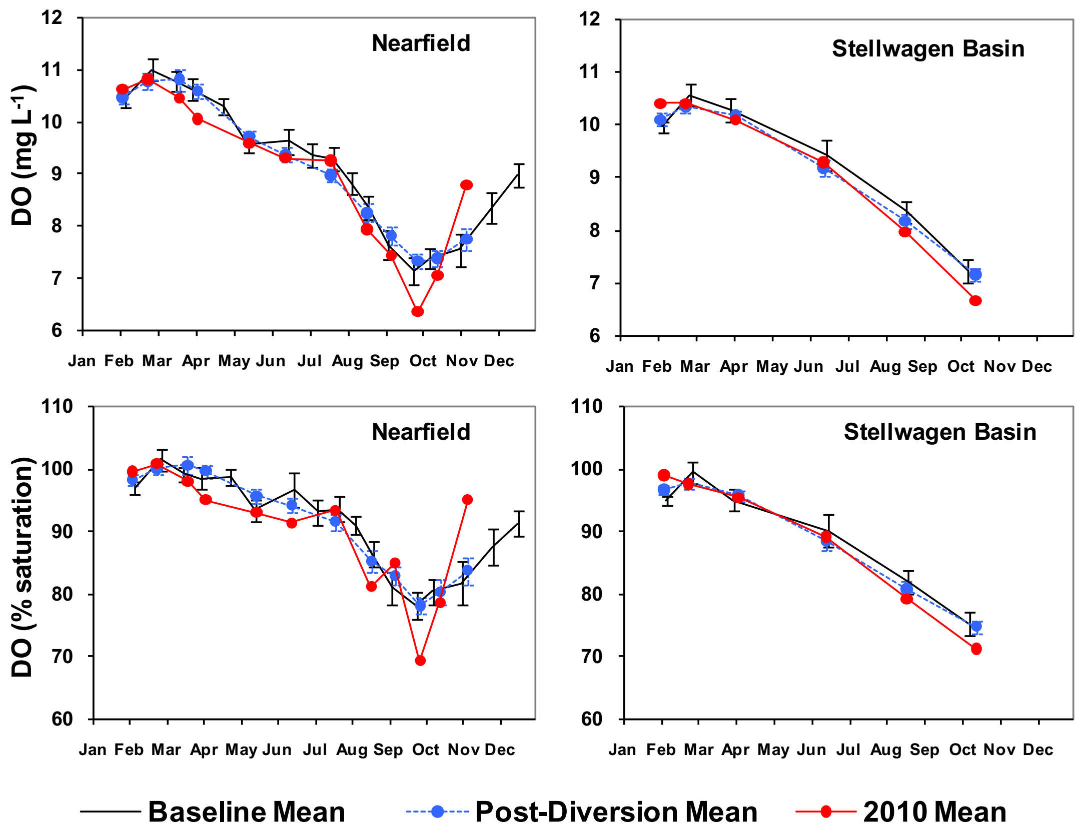


Figure 3-10. Survey-mean dissolved oxygen levels (top graphs) and percent saturation (bottom graphs) in nearfield and Stellwagen Basin bottom waters. There has been no change between the baseline period and the post-diversion years. The low levels detected in the nearfield in October have not been linked to any effect of the relocated sewage discharge. (Data for Stellwagen Basin collected from stations F12, F17, F19, and F22. Error bars represent ± one standard error.)

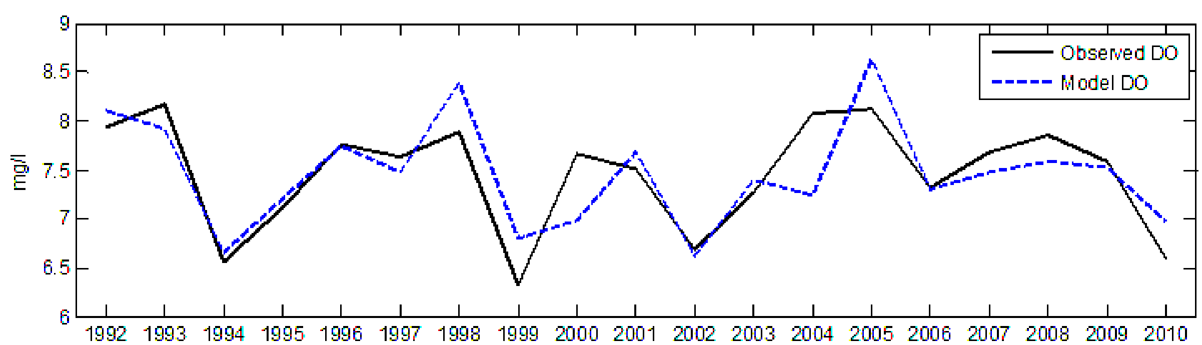


Figure 3-11. A simple model predicting nearfield dissolved oxygen (DO) minima from temperature and salinity variations in the boundary areas matches observations most years. The lower observed dissolved oxygen level in 2010 was probably a result of an older, more saline water mass in the region.

Phytoplankton Communities

Nearfield abundance of total phytoplankton was within the baseline range throughout 2010 (Figure 3-12), although regional changes in phytoplankton biomass, measured as chlorophyll concentrations (see Figure 3-9) reflect some of the long-term patterns in the phytoplankton populations (Libby et al. 2011). Annual total phytoplankton numbers have been below the long-term average since 2008, with an increase in 2010 to near-average levels. The abundance of one phytoplankton group, the diatoms, has fluctuated over the years of the monitoring program, with long-term declines since the late 1990s. In 2010, there were prolonged diatom blooms during the winter/spring and again in the summer, bringing the total numbers back to near the long-term average. Another group, the dinoflagellates, has been relatively abundant since 2006 and remained numerous in 2010 with small dinoflagellates very abundant in fall.

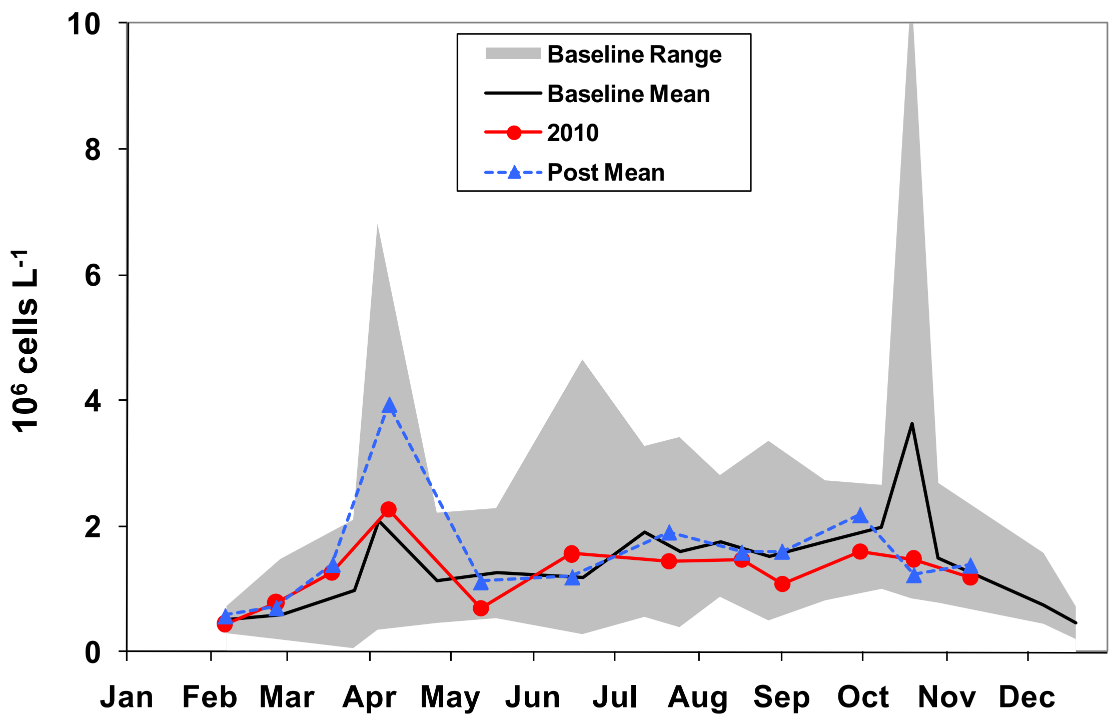


Figure 3-12. Nearfield abundance of total phytoplankton compared to baseline range and mean and post-diversion mean.

The general region-wide increase in phytoplankton biomass during the winter/spring can be attributed to annual blooms of the colonial species *Phaeocystis pouchetii*, which has bloomed each year since 2000 but occurred only modestly in 2010 (Figure 3-13). The 2010 bloom was confined mostly to the offshore and Cape Cod Bay regions. *Phaeocystis* is not toxic but is considered a nuisance species, because at high densities it forms gelatinous aggregates that may provide insufficient nutrition for zooplankton egg production (Turner et al.

2002). The timing and geographical extents of the blooms have not suggested any effect of the outfall. Rather, it appears that physical conditions, such as water temperature, are the most important factors affecting the timing and duration of *Phaeocystis* blooms. The monitoring data also show that abundance of *Phaeocystis* is inversely correlated with diatom abundance. This broad pattern appears to be related to wide regional patterns in the Gulf of Maine.

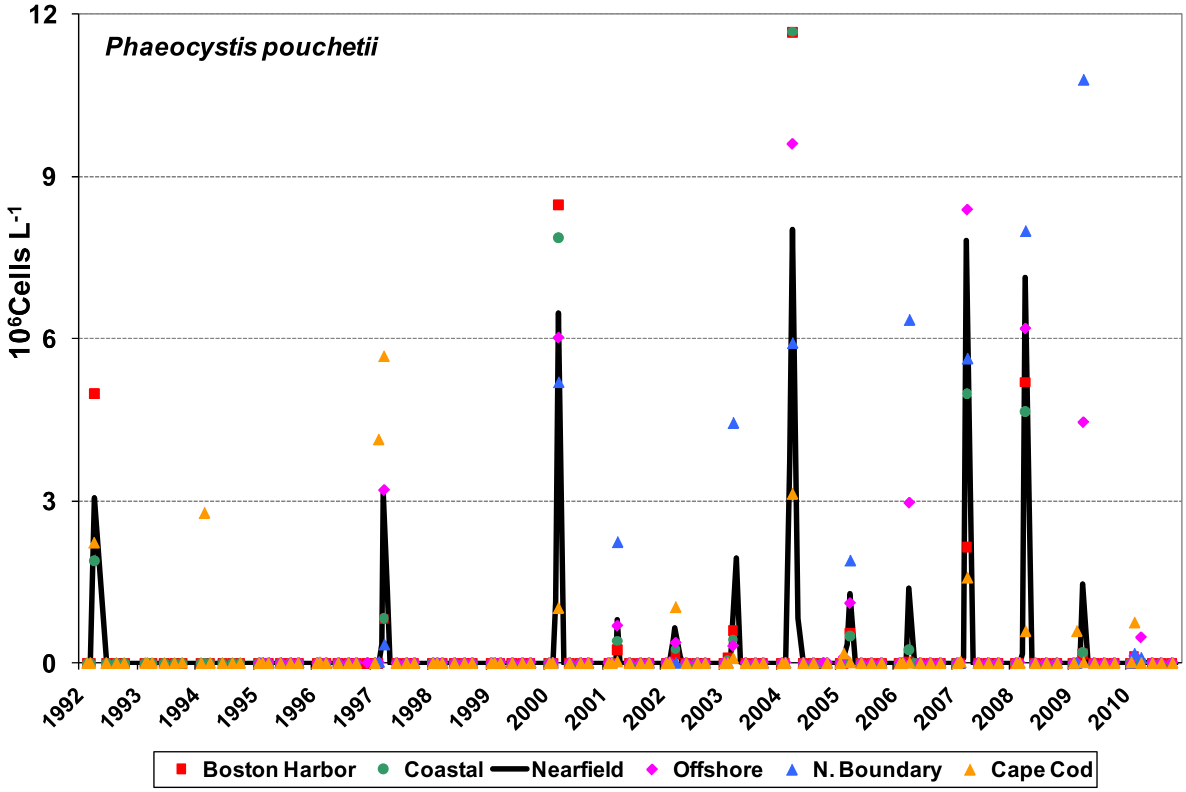


Figure 3-13. Abundance of *Phaeocystis pouchetii* since 1992. Blooms have occurred every year since 2000, although the 2010 bloom was modest.

Another general change has been an increase in the frequency of *Alexandrium fundyense* red tide blooms (Figure 3-14), which produce a toxin that causes paralytic shellfish poisoning (PSP). The abundance and geographic distribution of *Alexandrium* cysts in coastal sediments in 2009 had suggested that there would be a large bloom in 2010. Instead, while *Alexandrium* was observed in April and May 2010, the bloom was modest, with a maximum abundance of 78 cells/L in the nearfield. The bloom was of short duration and did not lead to closure of shellfish beds in Massachusetts Bay. A small number of cells was detected in September, marking the third consecutive year that some cells have been detected in the fall. Frequency of red tides with elevated PSP toxicity has increased throughout the Gulf of Maine since 2006, suggesting that the broad region is entering a period of frequent toxic blooms, similar to conditions during the 1970s. Why the 2010 bloom was unexpectedly mild has not yet been determined but is thought to be related to conditions within the Gulf of Maine water mass.

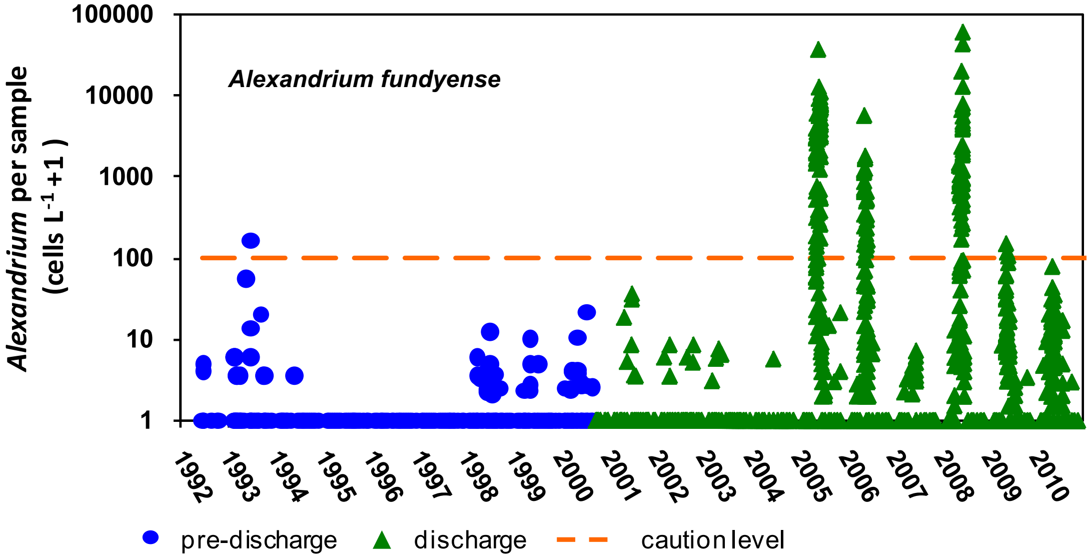


Figure 3-14. Nearfield abundance of *Alexandrium fundyense* since 1992. Blooms have occurred with greater intensity since 2006. The 2010 bloom was smaller than had been predicted from 2009 cyst distribution and abundance.

A third nuisance species group *Pseudo-nitzschia* spp. has been rare throughout most of the monitoring program and particularly during the post-diversion years (Figure 3-15). The 2010 peak of 13,300 cells/L occurred in October at the coastal stations. This abundance was much lower than has been detected in some other years and continues a general pattern of low abundance in Massachusetts Bay.

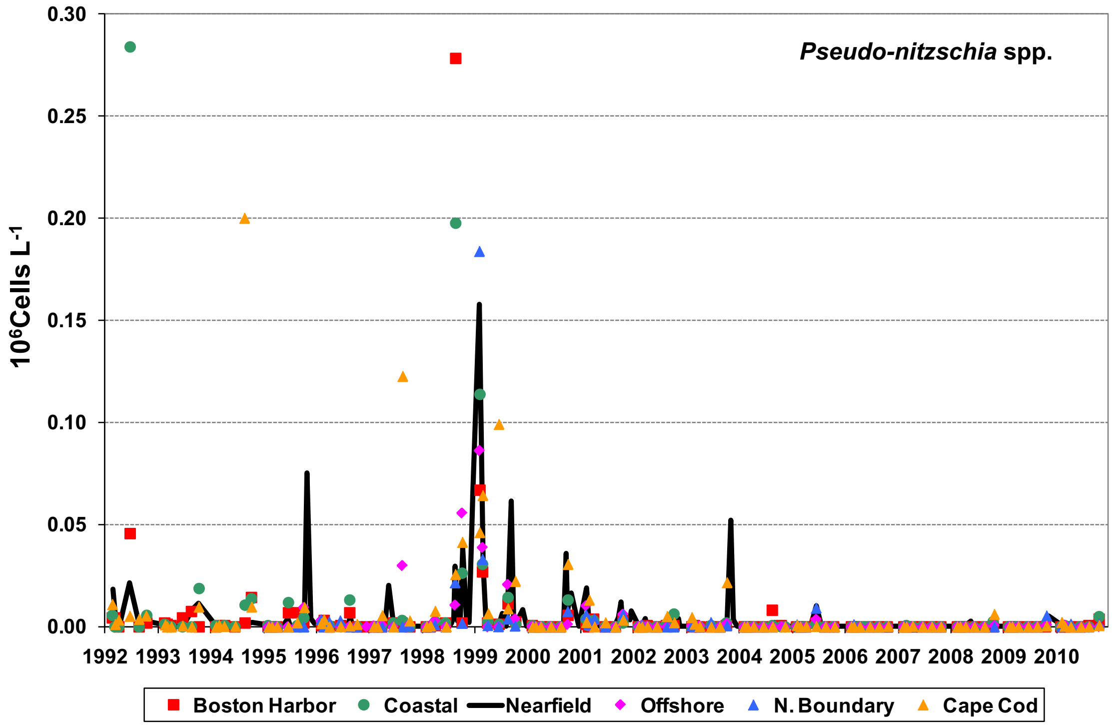


Figure 3-15. Abundance of *Pseudo-nitzschia* spp. since 1992. Abundance has been low throughout most of the monitoring program.

Zooplankton Communities

The total abundance of zooplankton in the nearfield and other regions in 2010 was similar to that of many earlier years, with abundance during most surveys falling within the baseline range and generally approximating the baseline mean (Figure 3-16). Total zooplankton abundance was relatively low during much of 2001–2006 but has rebounded somewhat (Figure 3-17), largely a reflection of the abundance of the dominant copepod, *Oithona similis* (a species so small that it is not detected by methods used in many other monitoring programs). The very high abundances recorded in 1999 and 2000 and shown in Figure 3-17 resulted from pulses of larval stages of polychaete worms and bivalve mollusks.

As is typical, overall zooplankton abundance was relatively low during the winter and peaked in the summer. The dominant species group continued to be copepods, as in most years, accounting for 90% of the animals. *Calanus finmarchicus*, a large copepod, which is considered an important food for right whales, peaked earlier than usual, with levels above the baseline range in March but low numbers during the rest of the year.

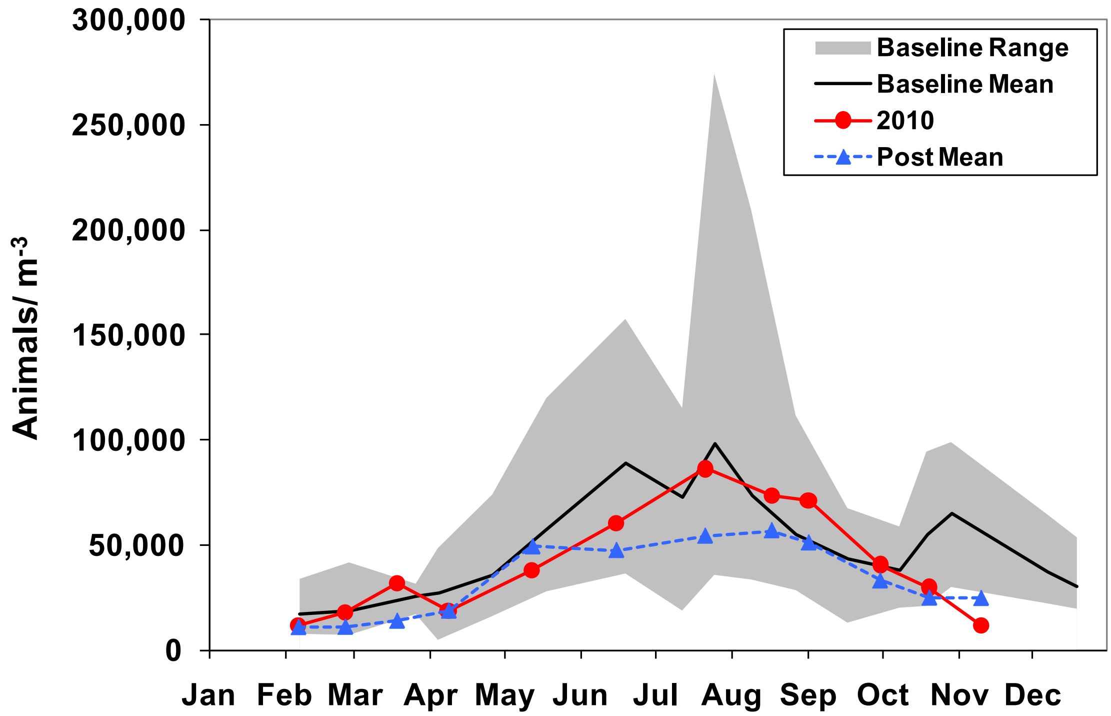


Figure 3-16. Nearfield abundance of total zooplankton compared to baseline range and mean and post-diversion mean. Abundance during many surveys was close to the baseline mean.

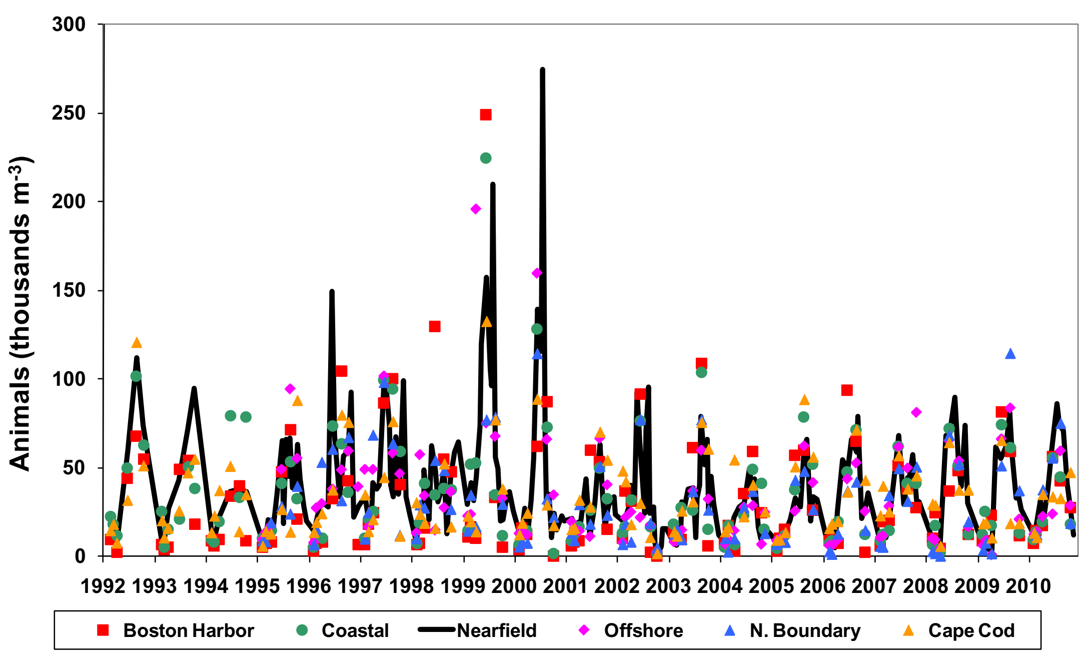


Figure 3-17. Zooplankton abundance by area, 1992–2010.

Barnacle nauplii (free-swimming larvae), one of the many zooplankton groups that occur sporadically, were very abundant during March, exceeding the baseline range (Figure 3-18). Elevated abundance of barnacle nauplii was observed in February–April in the nearfield and coastal regions and in Boston Harbor.

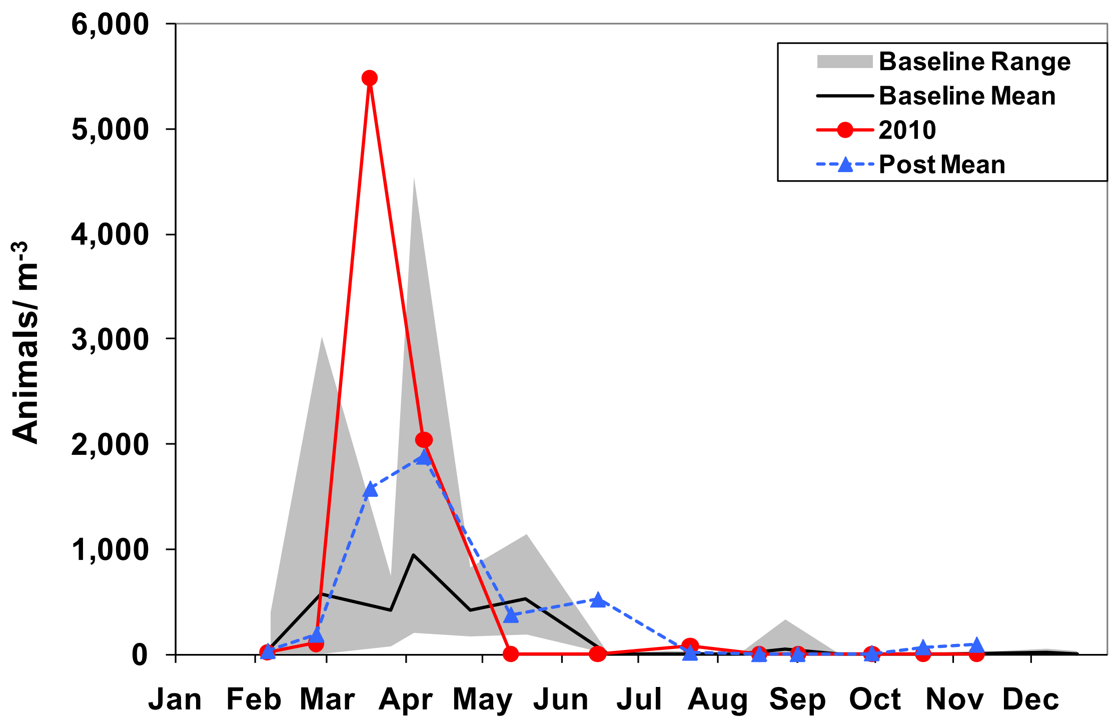


Figure 3-18. Nearfield abundance of barnacle nauplii compared to baseline range and mean and post-diversion mean.

Contingency Plan Thresholds

Water quality parameters were within normal ranges throughout 2010. There were no Contingency Plan exceedances for any water-column monitoring parameters throughout the year (Table 3-1).

Table 3-1. Contingency Plan threshold values and 2010 results for water-column monitoring. (DO=dissolved oxygen)

<table>
<tr><th>Location/ Parameter</th><th>Specific Parameter</th><th>Baseline</th><th>Caution Level</th><th>Warning Level</th><th>2010 Results</th></tr>
<tr><td rowspan="2">Bottom water nearfield</td><td>Dissolved oxygen concentration</td><td>Background 5th percentile 5.75 mg/L</td><td>Lower than 6.5 mg/L for any survey (June-October) unless background conditions are lower</td><td>Lower than 6.0 mg/L for any survey (June-October) unless background conditions are lower</td><td>Lowest survey mean = 6.36 mg/L</td></tr>
<tr><td>Dissolved oxygen percent saturation</td><td>Background 5th percentile 64.3%</td><td>Lower than 80% for any survey (June-October) unless background conditions are lower</td><td>Lower than 75% for any survey (June-October) unless background conditions are lower</td><td>Lowest survey mean = 69.3%</td></tr>
<tr><td rowspan="2">Bottom water Stellwagen Basin</td><td>Dissolved oxygen concentration</td><td>Background 5th percentile 6.2 mg/L</td><td>6.5 mg/L for any survey (June-October) unless background conditions lower</td><td>Lower than 6.0 mg/L for any survey (June-October) unless background conditions are lower</td><td>Lowest survey mean = 6.67 mg/L</td></tr>
<tr><td>Dissolved oxygen percent saturation</td><td>Background 5th percentile 66.3%</td><td>Lower than 80% for any survey (June-October) unless background conditions</td><td>Lower than 75% for any survey (June-October) unless background conditions are lower</td><td>Lowest survey mean = 71.2%</td></tr>
<tr><td>Bottom water nearfield</td><td>DO depletion rate (June-October)</td><td>0.024 mg/L/d</td><td>0.037 mg/L/d</td><td>0.049 mg/L/d</td><td>0.024 mg/L/d</td></tr>
<tr><td rowspan="4">Chlorophyll nearfield</td><td>Annual</td><td>79 mg/m^2</td><td>118 mg/m^2</td><td>158 mg/m^2</td><td>74 mg/m^2</td></tr>
<tr><td>Winter/spring</td><td>62 mgml^2</td><td>238 mg/m^2</td><td>None</td><td>81 mg/m^2</td></tr>
<tr><td>Summer</td><td>51 mg/m^2</td><td>93 mg/m^2</td><td>None</td><td>53 mg/m^2</td></tr>
<tr><td>Autumn</td><td>97 mg/m^2</td><td>212 mg/m^2</td><td>None</td><td>99 mg/m^2</td></tr>
<tr><td rowspan="3">Nuisance algae nearfield Phaeocystis pouchetii</td><td>Winter/spring</td><td>468,000 cells/L</td><td>2,020,000 cells/L</td><td>None</td><td>53,300 cells/L,</td></tr>
<tr><td>Summer</td><td>72 cells/L</td><td>357 cells/L</td><td>None</td><td>Absent</td></tr>
<tr><td>Autumn</td><td>317 cells/L</td><td>2,540 cells/L</td><td>None</td><td>Absent</td></tr>
<tr><td rowspan="3">Nuisance algae nearfield Pseudo-nitzschia</td><td>Winter/spring</td><td>6,200 cells/L</td><td>21,000 cells/L</td><td>None</td><td>610 cells/L</td></tr>
<tr><td>Summer</td><td>14,600 cells/L</td><td>43,100 cells/L</td><td>None</td><td>54 cells/L</td></tr>
<tr><td>Autumn</td><td>9,940 cells/L</td><td>24,700 cells/L</td><td>None</td><td>1,160 cells/L</td></tr>
<tr><td>Nuisance algae nearfield Alexandrium fundyense</td><td>Any nearfield sample</td><td>Baseline maximum = 163 cells/L</td><td>100 cells/L</td><td>None</td><td>78 cells/L</td></tr>
<tr><td>Farfield</td><td>PSP toxin extent</td><td>Not applicable</td><td>New incidence</td><td>None</td><td>No new incidence</td></tr>
</table>

4. Sea Floor

Sea-floor monitoring in 2010 was conducted at soft-bottom stations in the nearfield (Figure 4-1) and farfield (Figure 4-2) and through a video and photographic survey of rocky habitats in the vicinity of the outfall and at reference locations to the north and south (Figure 4-3).

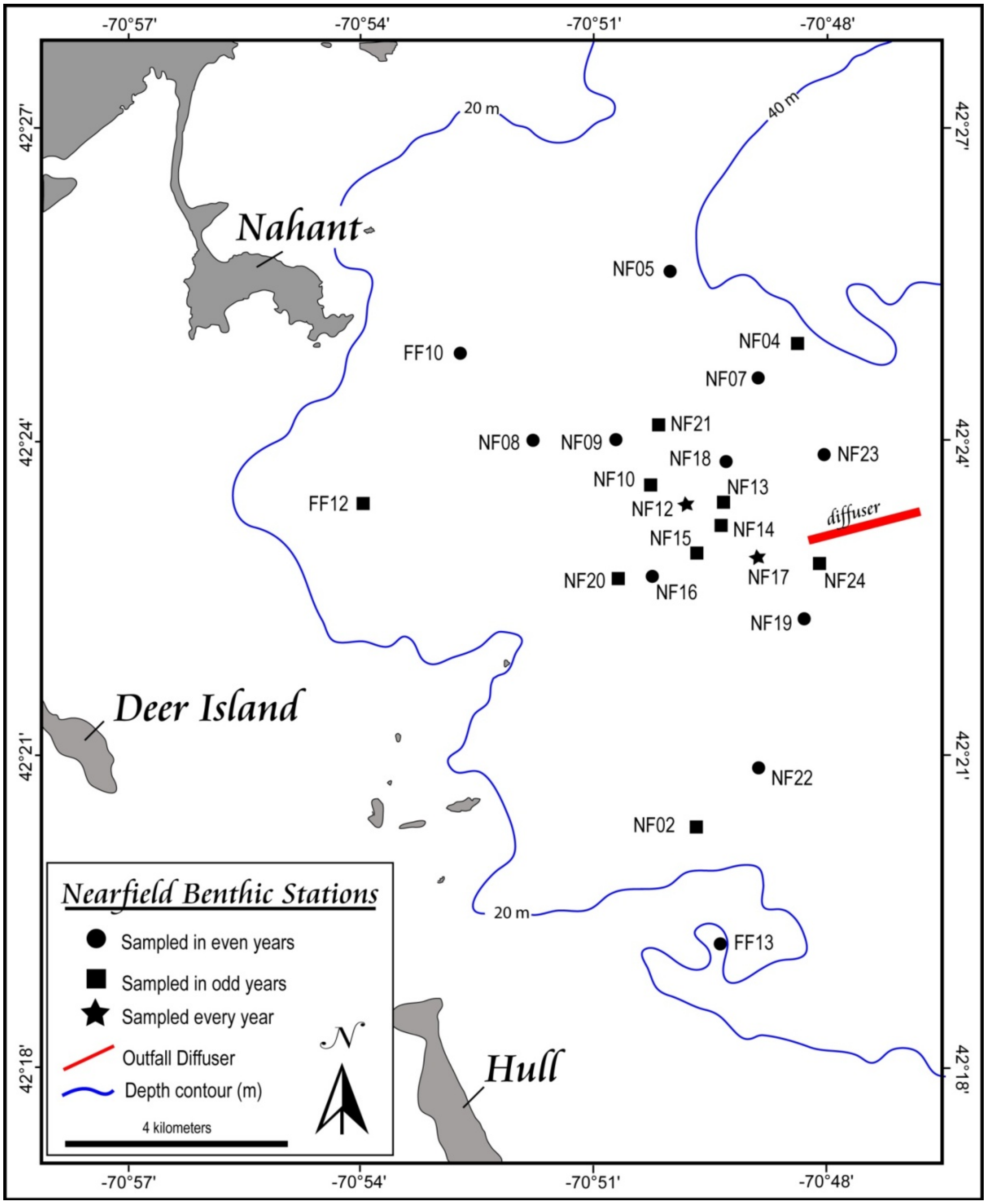


Figure 4-1. Locations of nearfield soft-bottom stations for chemical parameters, sediment-profile imaging, and community parameters. Sediment-profile imaging is conducted at all stations every year.

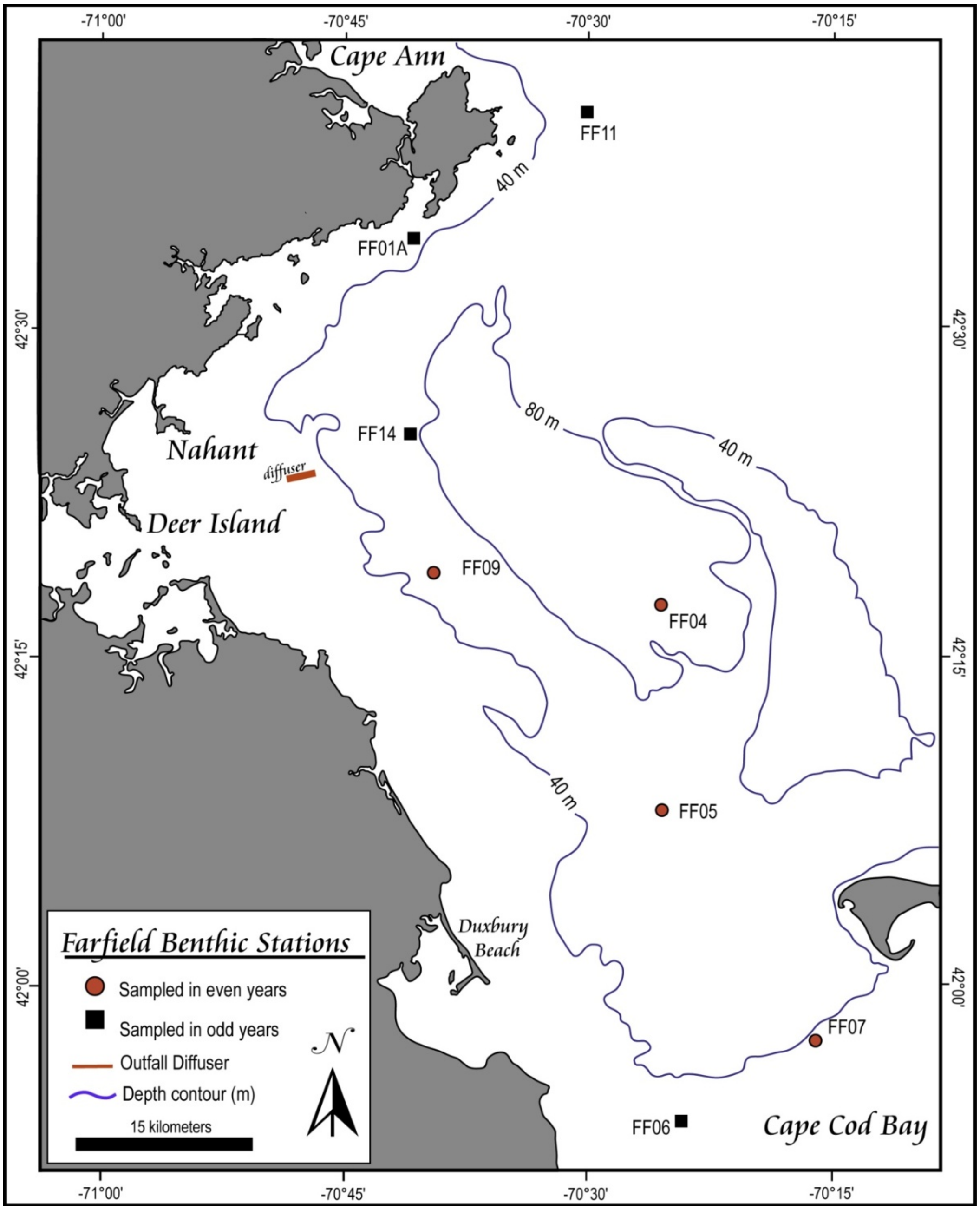


Figure 4-2. Locations of farfield soft-bottom stations for chemical and community parameters.

The soft-bottom studies included measurements of sediment grain-size distribution, total organic carbon, the sewage-bacteria tracer *Clostridium perfringens* spores, chemical contaminants, and community parameters at stations labeled as "sampled in even years" or "sampled every year." Sediment-profile imaging measurements were made at all nearfield Massachusetts Bay stations shown on Figure 4-1, including those denoted as being sampled in odd years.

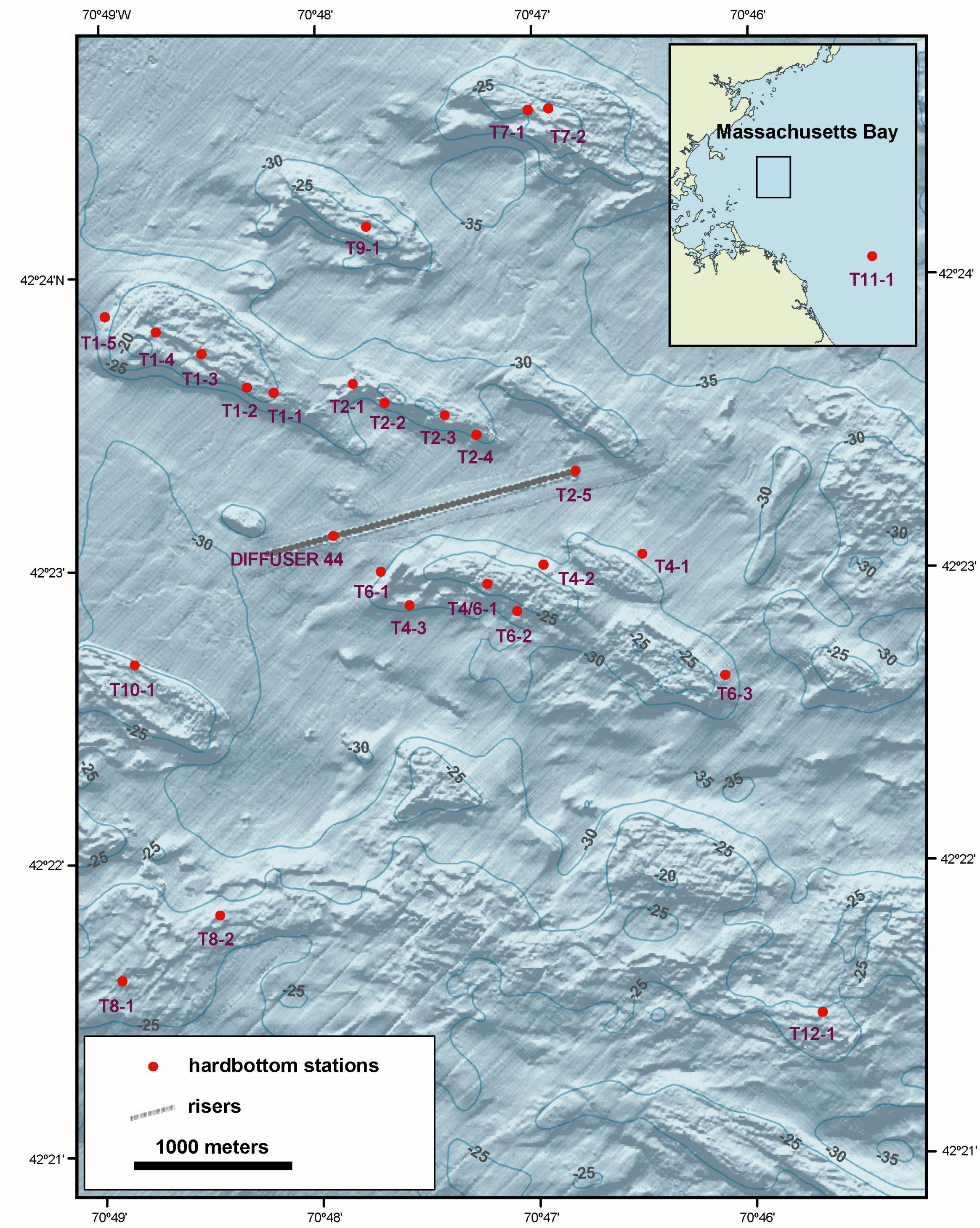


Figure 4-3. Locations of hard-bottom stations. Video and still photographs are collected at 17 stations distributed among six transects and at six additional waypoints, including one active diffuser and one diffuser that has not been opened.

Sediment Characteristics and Tracers

Grain-size distributions in 2010 remained within the historic ranges of the monitoring program, ranging from coarse to fine sediments (Maciolek et al. 2011). Total organic carbon concentrations were relatively low at most stations, generally at the low end of the baseline range or below the baseline mean. There has been no increase in mean concentrations of total organic carbon at stations located near the outfall since the diversion. Rather, there has been a slight decrease in the nearfield and at stations located between the nearfield and Boston Harbor, suggesting the continued importance of physical factors rather than the outfall discharge in structuring the bottom.

As in other post-diversion years (except 2006), it was possible to detect elevated levels of *Clostridium perfringens* spores in sediments collected at some stations located within two kilometers of the outfall, a smaller region than what is defined as the nearfield. The signal was especially apparent when comparing the data to those from late baseline years, 1999–2000 (Figure 4-4).

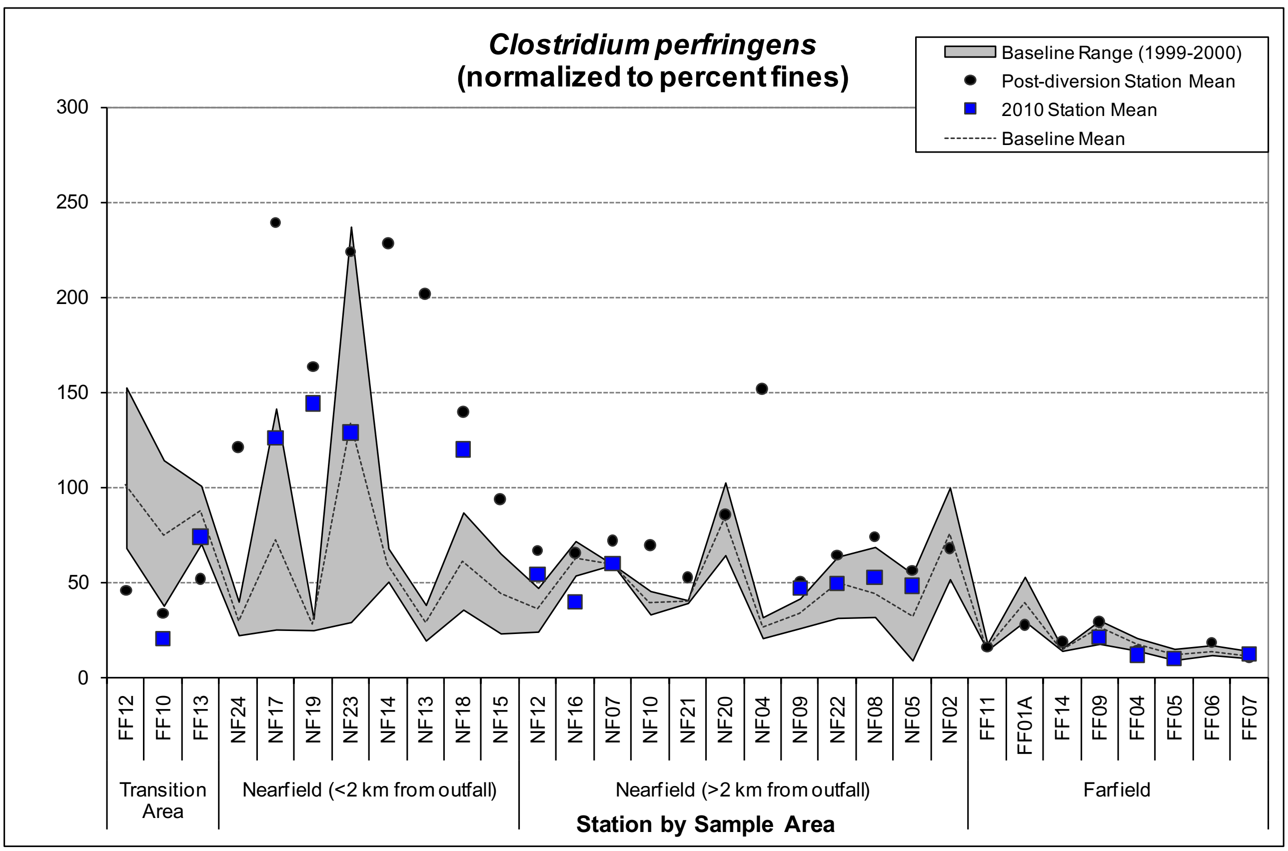


Figure 4-4. *Clostridium perfringens* spores normalized to percent fine fraction in the sediments compared to the late baseline range and post-diversion mean. "Transition area" denotes stations located between Boston Harbor and the outfall; "Farfield" denotes stations offshore from the outfall.

These findings were consistent with predictions that it would be possible to detect sewage tracers such as *Clostridium* spores in the immediate vicinity of the outfall. There has been a decline in spore counts at stations located in the transition area, located between Boston Harbor and the outfall, where 2010 spore counts were at the bottom or below the baseline range.

There has been no indication of accumulation of toxic compounds in the region surrounding the relocated outfall. Concentrations of chemical contaminants in the sediments were measured at two stations in 2010 (NF12 and NF17) and were generally at the low ends of the ranges measured throughout the monitoring program. Concentrations of PCBs and chlorinated pesticides have decreased at both nearfield and farfield stations, probably reflecting the slow declines in those contaminants since they were banned in the 1970s and 1980s. There have also been small decreases in silver, cadmium, and mercury concentrations. No similar region-wide declines in polycyclic aromatic hydrocarbons (PAHs) have been observed.

Concentrations of aluminum have increased in the nearfield and at transition stations since the outfall diversion, and in 2010, aluminum concentrations remained above the baseline range. Reasons for the increase have not been determined, but aluminum in sediments is more typically the result of natural processes than human activities.

In Boston Harbor, where monitoring has also been conducted since 1991, data continued to show a decline in concentrations of total organic carbon throughout the harbor, but especially at some stations, including those closest to the former harbor outfall near DITP. The large harbor-wide decline in concentrations of *Clostridium perfringens* spores also continued in 2010.

Sediment-Profile Imaging

Sediment-profile imaging measurements continued to show no adverse effects of the outfall (Maciolek et al. 2011). The number of animals and burrows recorded in each image has been lower during 2005–2010 since a high in 2004, continuing to suggest that physical rather than biological processes have been the primary forces structuring the sediments in recent years. Storms and storm-induced sediment transport and deposition remain the primary stresses on the sea-floor communities in Massachusetts Bay.

One concern about the relocated outfall was that an increase in the amount of organic matter deposited on the sea floor would result in a shallower apparent redox potential discontinuity (RPD), the depth at which sediment color shifts, an indication of the shift from oxidized to anoxic conditions. That concern has not been realized, as the mean RPD has been deeper than the baseline average in most post-discharge years (Figure 4-5). The mean RPD was shallower in 2010 than in most other post-diversion years, similar to 2003 and just shallower than the baseline mean, but there continues to be no suggestion of adverse effects. No other measure made from the sediment-profile images, including the habitat indicator organism sediment index (OSI) and accumulation of fine sediments and organic material, has suggested any adverse effects of the outfall diversion.

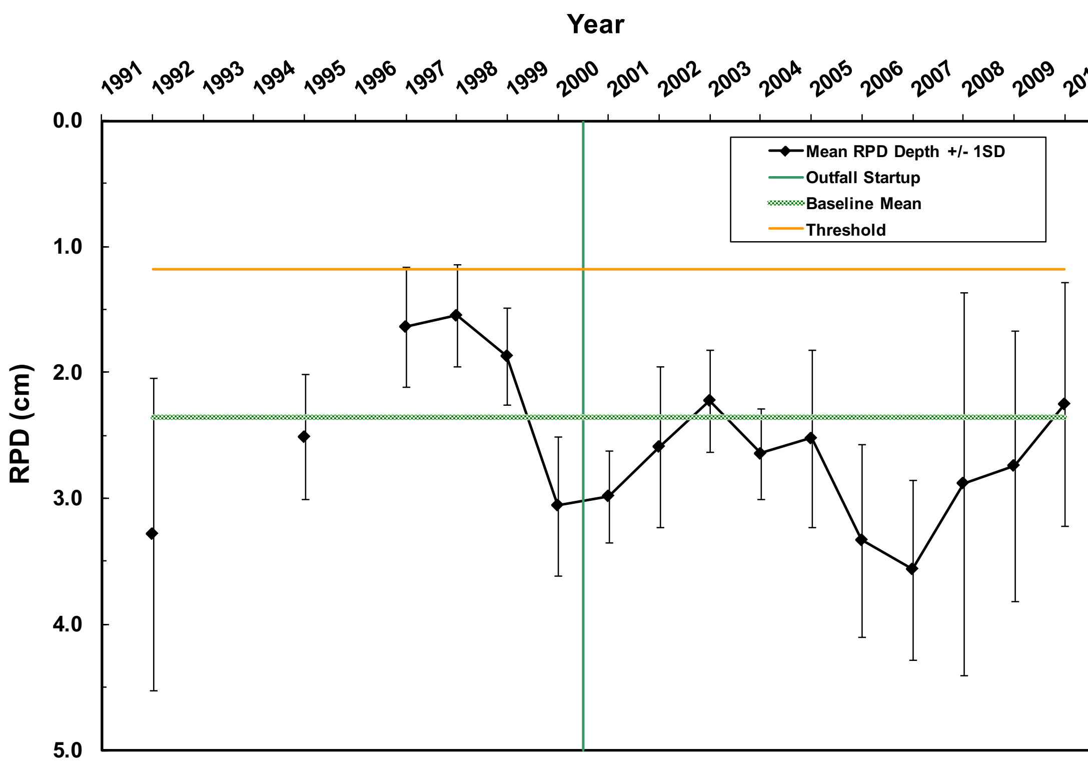


Figure 4-5. Annual apparent color RPD for data from nearfield stations. The average RPD post-diversion mean has been deeper than the baseline mean, indicating that there has been no adverse effect from the discharge. Data are mean +1 standard error.

At Boston Harbor stations, where a separate monitoring program is conducted, the RPD, successional stage, and OSI remained about the same in 2010 as in earlier years. For the third consecutive year, eelgrass was detected near Deer Island Flats. Tube mats produced by the amphipods *Ampelisca* spp. were detected at about 25% of stations, more than had been seen since 2003. Individual amphipods were detected at about half the stations, a slight decrease from 2008 and 2009, and the incidence of biogenic features decreased. Fewer burrowing amphipods (*Leptocheirus pinguis*) were seen since the high density of 2008, when there had been a large increase. Overall, since 1993, there has been an increase in the number of animals and burrows per image and a functional shift, with animals that burrow deeper into the sediments becoming more prevalent. These changes indicate improvements to the bottom habitats in the harbor.

Soft-Bottom Communities

The soft-bottom communities continued to show no response to the outfall. Rather, post-diversion monitoring has continued to confirm the baseline finding that sediment grain size is the most important influence on the benthic infaunal communities (Maciolek et al. 2011).

Twenty-one samples from 12 nearfield stations taken in 2010 yielded fewer animals than in 2008, the last year that the same suite of stations were sampled, but about the same number of animals as were found in 2006 (Figure 4-6). Annual mean abundances have been lower than the baseline mean since 2004. The mean number of species per sample was slightly higher than the baseline. The mean value of one index of diversity, Fisher's log-series alpha, declined slightly. Two other indices, Shannon-Wiener diversity and Pielou's evenness, reached the highest values measured during the monitoring program, exceeding their upper Contingency Plan thresholds. The high diversity and high evenness largely resulted from a decline in the numerically dominant spionid polychaete *Prionospio steenstrupi*. *Prionospio* remained the numeric dominant, but its decrease in density in recent years has allowed other species to contribute to greater percentages of the total community. The list of species making up the community composition remained consistent with earlier years.

The farfield stations are more geographically widespread, with mostly finer sediments, and polychaetes dominate at most stations. The species compositions at those stations have always differed from those at nearfield stations. There were no unusual findings in the twelve samples from four farfield stations in 2010. The mean number of species was lower than in 2008, and the mean number of species per sample also declined. As in the nearfield, these changes were largely driven by a decline in the *Prionospio steenstrupi* population. Diversity and evenness indices were similar to those found in 2008.

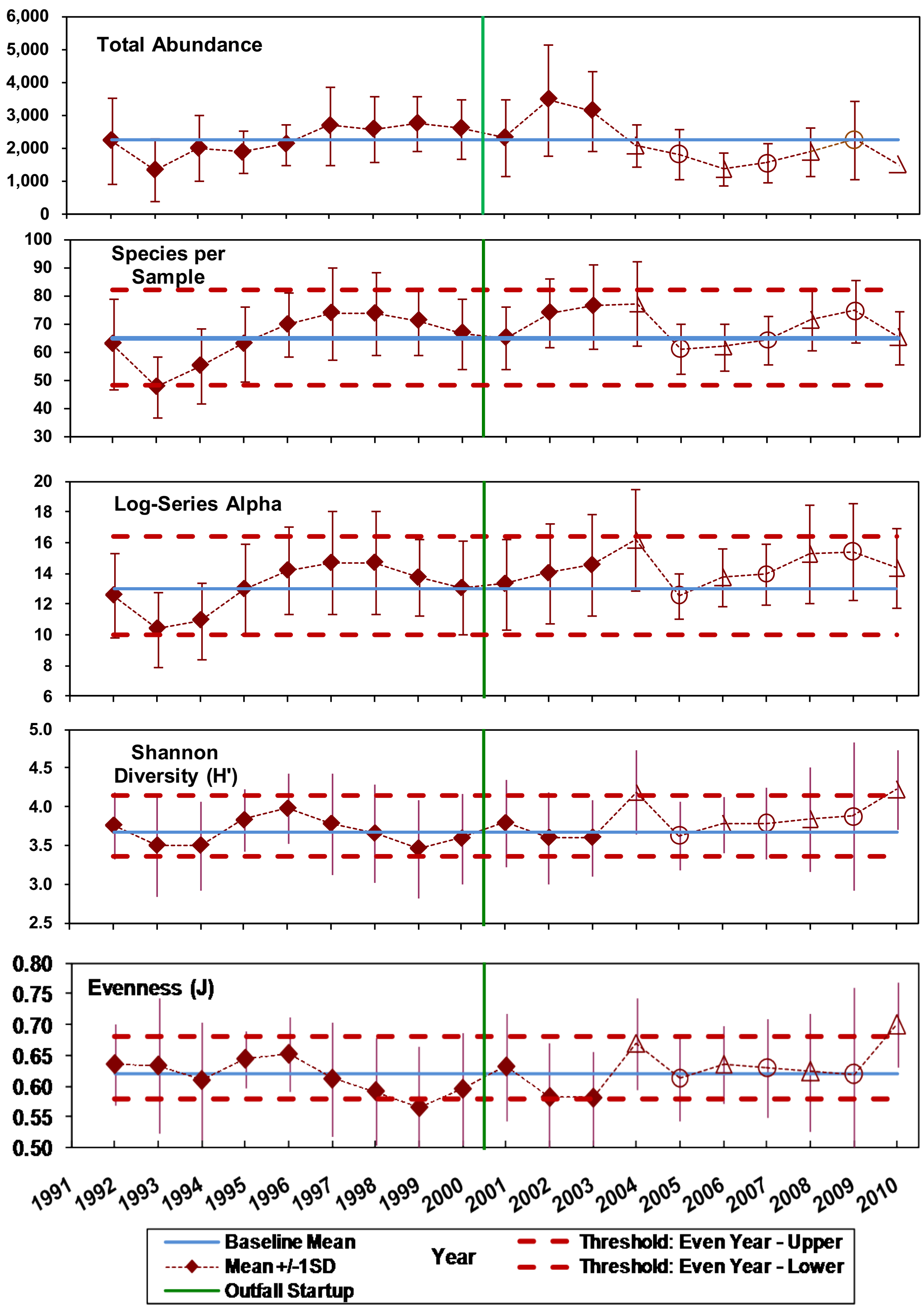


Figure 4-6. Annual community parameters in the nearfield. The open symbols denote the separate even- and odd-year sampling design initiated in 2004. Only the upper even-year Contingency Plan thresholds are shown, as those bounds were exceeded for two indices. Thresholds were selected to show deviations from the baseline, so have both upper and lower, as well as even and odd year, bounds.

Hard-Bottom Communities

The rocky habitats in the vicinity of the outfall and at reference locations continued to support robust communities of algae, invertebrates, and fish (Maciolek et al. 2011). Baseline and post-diversion monitoring has shown that the hard-bottom communities in the region are spatially diverse but temporally stable. While there have been some shifts in species composition and abundance, those changes have been modest. Lush epifaunal growth, particularly sea anemones, has thrived on the diffuser heads.

Some modest changes have been noted over time, including increases in the amount of "sediment drape," a visual assessment of the detritus deposited on hard surfaces, with a concurrent decrease in coralline algae at some stations, including northern reference sites. There has also been a general decrease in the number of upright algae. Changes at the northern reference stations may be attributed to disturbance of the sea floor by anchors, but decreases at southern stations point to more general, region-wide changes. One upright alga dulse, *Palmaria palmate*, increased at some stations in 2010, suggesting a cyclical pattern in abundance of that species. Another alga, *Ptilota serrata*, also increased in abundance in 2010. Sightings of cod and lobster have increased greatly since the baseline period, but these increases may be the result of quieter sampling equipment.

One interesting finding in 2010 was a massive barnacle settlement (Figure 4-7). This settlement was predicted from large number of barnacle nauplii in the water column in March (see Figure 3-18 in Section 3, Water Column). Similarly large settlements occurred in 2003.

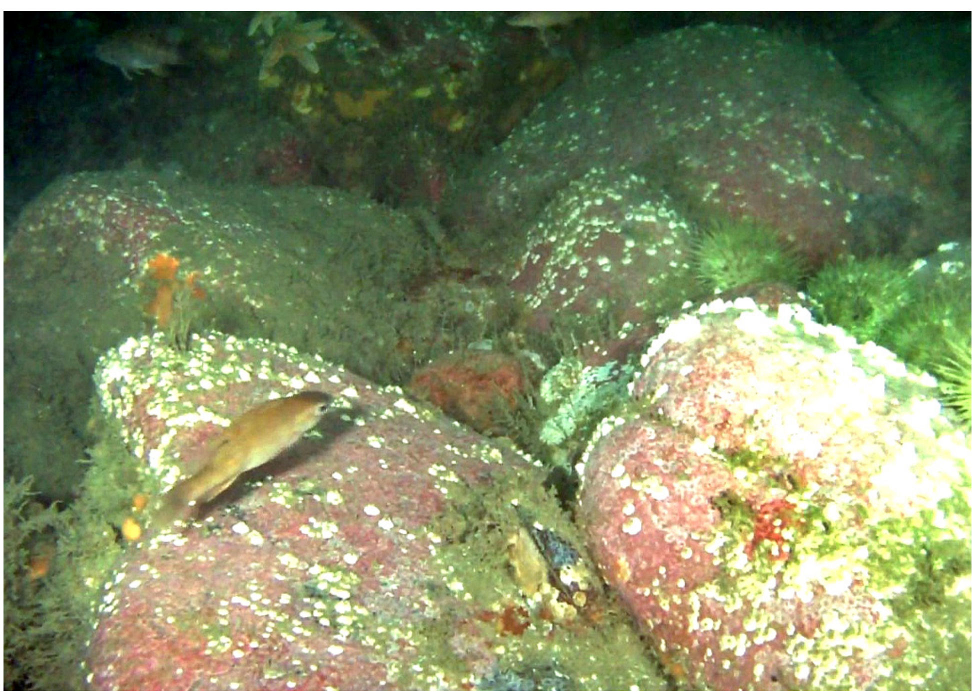


Figure 4-7. Screen capture showing barnacle settlement in 2010.

Contingency Plan Thresholds

For the first time in the monitoring program there were Contingency Plan threshold exceedances for sea-floor monitoring (Table 4-1). Two of the community parameters calculated, Shannon-Wiener diversity and Pielou's evenness, were slightly higher (more diverse) than their threshold ranges, triggering the exceedances. The other two Contingency Plan community measures, number of species per sample and Fisher's log-series alpha, were within threshold ranges. RPD depth also continued to be deeper than the threshold, and the six opportunistic species detected made up less than one percent of the total number of animals recorded, well below the thresholds of 10 and 25%.

Ironically, increases in Shannon-Wiener diversity and Pielou's evenness often signal an improvement rather than a 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. Evaluation of all available data from 2010 suggests there is no evidence that the threshold exceedance resulted from an impact of the outfall discharge on infaunal communities. Indications are that the exceedances resulted from natural variability in the benthic communities monitored in the vicinity of MWRA's outfall.

Table 4-1. Contingency Plan threshold values and 2010 results for sea-floor monitoring.

Location/ Parameter Type	Parameter	Caution Level	Warning Level	2010 Results
Nearfield	RPD depth	1.18 cm	None	2.25 cm
Even years, benthic diversity, nearfield	Species per sample	48.4< or >82	None	65.1
	Fisher's log-series alpha	<9.99 or >16.47	None	14.37
	Shannon diversity	<3.37 or >4.14	None	**4.23, caution level exceedance**
	Pielou's evenness	<0.58 or >0.68	None	**0.70, caution level exceedance**
Benthic opportunists	% opportunists	>10%	>25%	0.62 %

5. Winter Flounder

Each year MWRA monitors the health of winter flounder from Deer Island Flats in Boston Harbor, off Nantasket Beach, the outfall site, and eastern Cape Cod Bay (Figure 5-1). In 2010, 50 sexually mature flounder were collected from Deer Island Flats, Nantasket Beach, and Cape Cod Bay, but only 38 fish were taken from the outfall site (Moore et al. 2010).

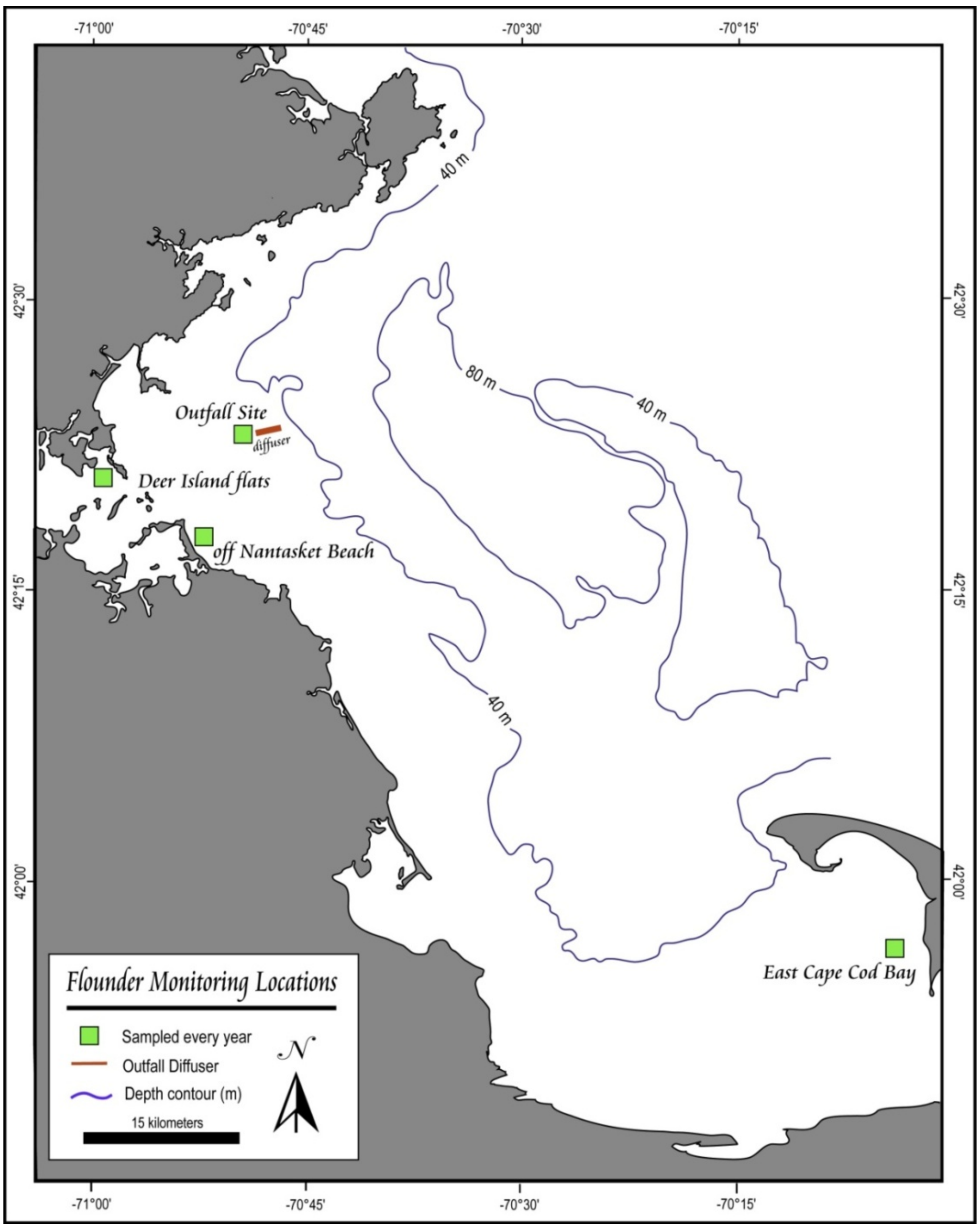


Figure 5-1. Flounder sampling sites.

The low catch per unit effort at the outfall site was largely due to risks of entangling the trawl nets with lobster-fishing gear. Large numbers of lobster traps also hampered fishing at Deer Island Flats. Catch per unit effort at Cape Cod Bay was the highest observed during the monitoring program for the second year in a row.

Average ages, lengths, and weights of the winter flounder collected in 2010 were within the historic ranges. Average age was about at the historic mean, while age and weight have increased somewhat since 2008. As they have been throughout most of the monitoring program, the catches continued to be dominated by females, although the percent of the catches made up by females decreased somewhat from levels approaching 100% in fish from Deer Island Flats and eastern Cape Cod Bay. Approximately 75% of fish taken from near the outfall were female.

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 lower than had been observed in the late 1970s and early 1980s. At Deer Island Flats, prevalence of fin erosion was close to the mean level for the monitoring program. The lowest incidence, 13%, was at the outfall site. The highest levels were in fish from eastern Cape Cod Bay, where incidence of fin erosion reached 38%, the highest level recorded for that site during the monitoring program.

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 monitoring programs 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 5-2). Incidence of CHV at Deer Island Flats was slightly less in 2010 than in 2009, continuing a gradual decline from baseline levels. A gradual increase in CHV has been detected in fish from the outfall site since 2005, but incidence remains below that observed during the baseline period. Average severity of CHV also remained lower than baseline levels (Figure 5-3).

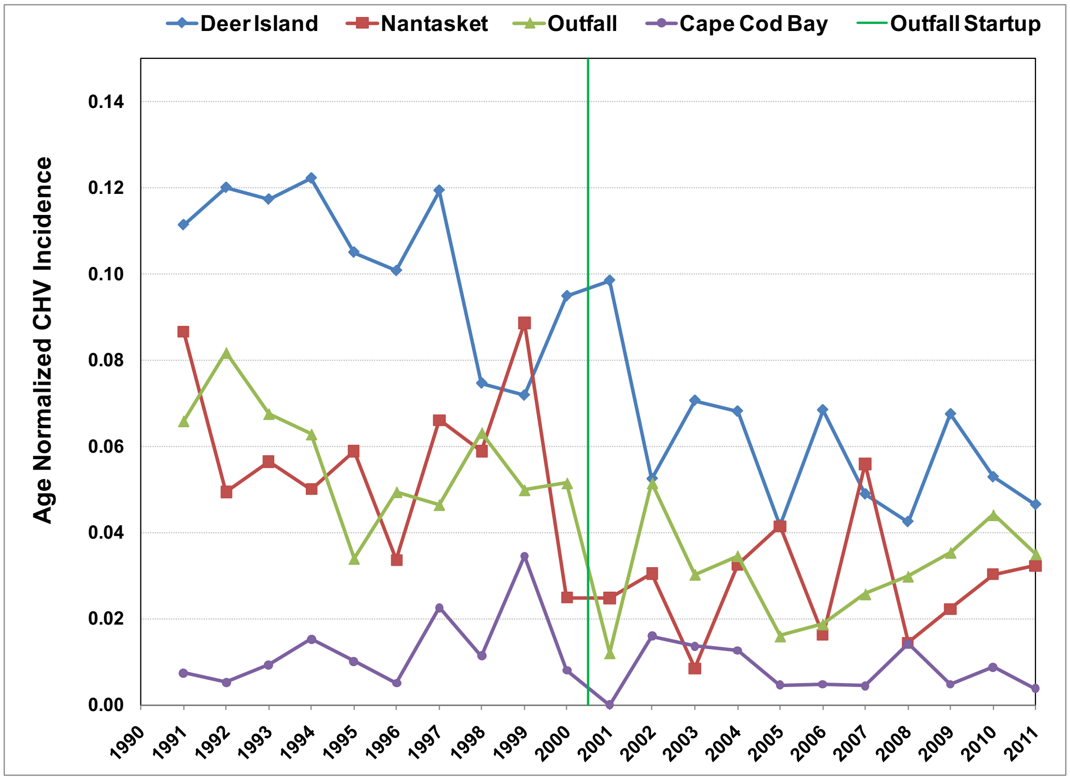


Figure 5-2. Annual prevalence of centrotubular hydropic vacuolation (CHV), corrected for age.

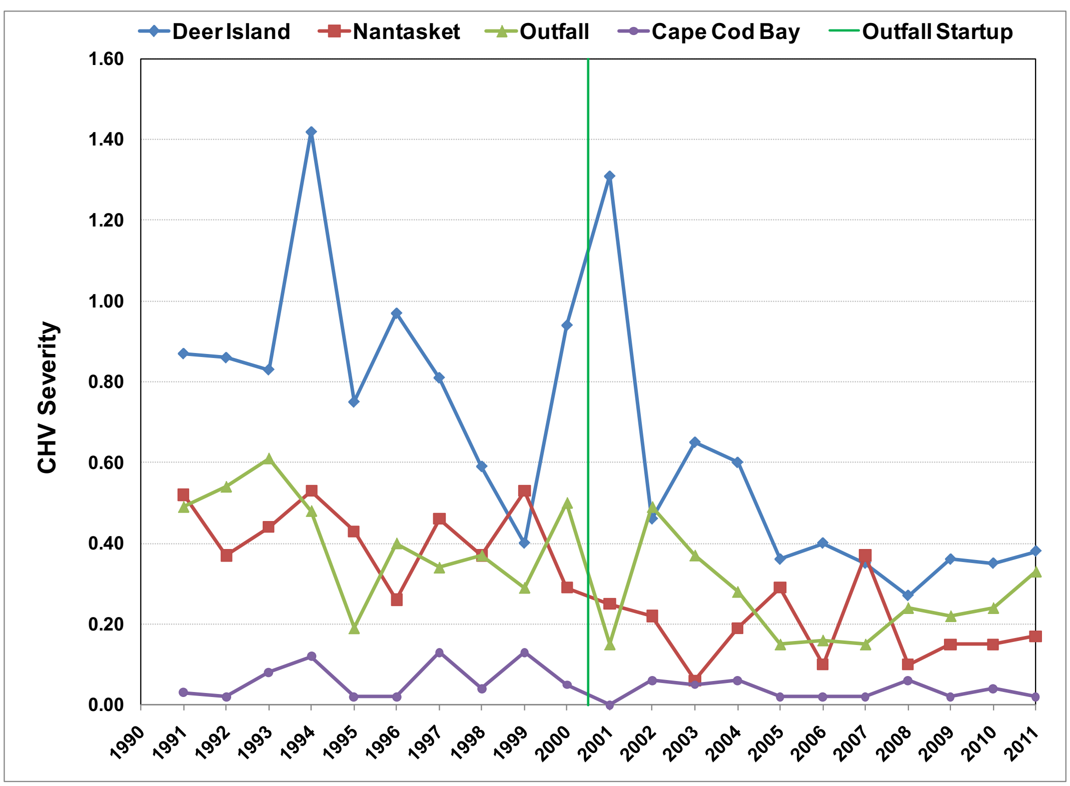


Figure 5-3. Annual severity of centrotubular hydropic vacuolation (CHV), corrected for age.

Contingency Plan Thresholds

There was no exceedance of the only threshold parameter for fish and shellfish in 2010, 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 21% in fish taken from the vicinity of the outfall site, lower than the caution threshold of 44.9% and also lower than the baseline average.

Table 5-1. Contingency Plan threshold values and 2010 results for winter flounder monitoring.

Parameter Type/ Location	Parameter	Baseline	Caution Level	Warning Level	2010 Results
Flounder nearfield	Liver disease (CHV)	24.4%	44.9%	None	21%

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. During 2010, MWRA continued several special studies. This section updates information on floatable debris in the DITP effluent, modeling in Massachusetts Bay, data from instrumented buoys, marine mammal observations, water quality monitoring in Boston Harbor, and nutrient flux at the sediment-water interface.

Floatables

During the planning stages for the treatment plant and relocated outfall, one concern was that the discharge should not contain sewage-related floatable debris, called floatables, which could be an aesthetic nuisance or harm marine life. Contingency Plan warning-level thresholds limited floatables to a volumetric measurement of 5 gallons/day in the final collections device and an oil-and-grease measurement of 15 mg/liter/week (MWRA 1997b). However, the final collection devices were inaccessible scum-removal tip tubes in the disinfection basins, which were logistically too difficult and dangerous to sample. In 2000, the Outfall Monitoring Science Advisory Panel (OMSAP) and the regulatory agencies reviewed and revised the requirement for monitoring floatables, deleting the Contingency Plan threshold, but requiring MWRA to “make regular observations of wastewater during treatment to determine whether floatables are removed as expected.”

Because there is no Environmental Protection Agency (EPA) -approved standardized method for sampling, characterizing, and quantifying floatables, MWRA staff designed an innovative sampling system for collection just prior to discharge (Figure 6-1). Final effluent was screened and the screened material collected in a hopper, dried, weighed, and the uncompressed volume estimated. Repeated sampling showed that the flow-paced, quantitative sampler and sampling methods were sensitive and reproducible (Rex et al. 2008).

Figure 6-1. Effluent floatables sampling device. Samples were collected at the end of the west disinfection basin, after the final tip tube and scum baffle, prior to discharge to the outfall.

The facilities improvements at DITP, particularly improvements to the secondary process beginning in 2005 and improved tip tubes, substantially decreased the volumes and weights of floatables in the effluent. During 2006–2010, volume and weight of floatables varied with total effluent flow, but remained consistently lower than during 2003–2005 (Figure 6-2, Rex and Tyler 2011).

Floatables sampling found both degradable and non-degradable debris in only very low levels. During 2006–2010, on average, non-degradable materials were present at an estimated 4.4 ppb by weight, a decrease from the previously measured 6 ppb. Materials of concern such as petroleum grease and plastics, which are aesthetically offensive or could harm wildlife, were rare. Much of the degradable material was bits of fat and plant matter. Most non-degradable material was found in small pieces, such as fruit labels and cellophane wrappers. Plastic bags were rare, while condoms and tampon applicators were sometimes found.

The total dry weight of floatables proved to be a good estimator of both degradable and non-degradable floatables, better than volume measure. Degradable floatables made up about 86% of the total by dry weight, and non-degradable floatables made up about 14%.

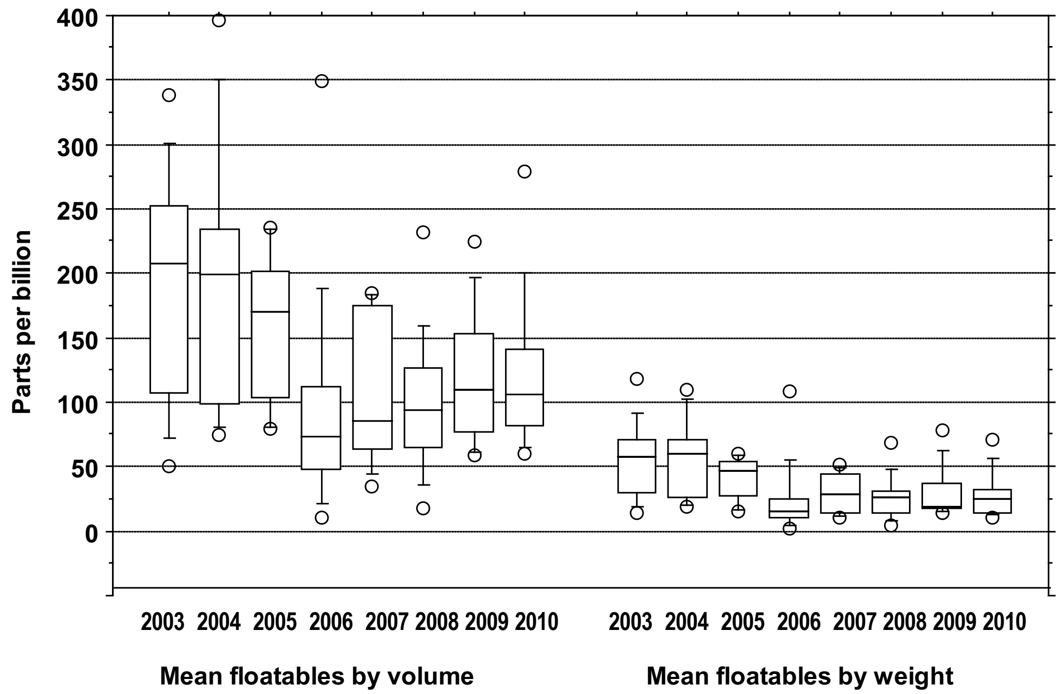


Figure 6-2. Percentile box plots of effluent floatables concentrations by volume and weight, 2003–2010. Horizontal lines are the mean, boxes indicate the upper and lower quartiles, error bars are ± one standard deviation, open circles are the upper and lower ranges.

The amount of floatable material varied with the flow rates through the plant (Figure 6-3). At higher flows, concentrations increased, possibly due to increased matter in the effluent from street runoff and probably also due to reduced removal efficiencies. However, even at the highest flows, floatable material was present at only low levels. As a result of these studies, the regulatory agencies agreed that sufficient floatables data had been collected and allowed MWRA to end the floatables sampling program at DITP in 2010 (MWRA 2010, Rex and Tyler 2011).

The effluent floatables monitoring has been complemented by field observations and net tows conducted during water-column monitoring surveys. Since the outfall came online, no petroleum grease and no sewage-derived plastics have been observed in the waters at the outfall. This ambient floatables sampling study at the outfall discharge will continue for a minimum of another two years, through 2012, with an objective of sampling after wet-weather-related blending events at DITP.

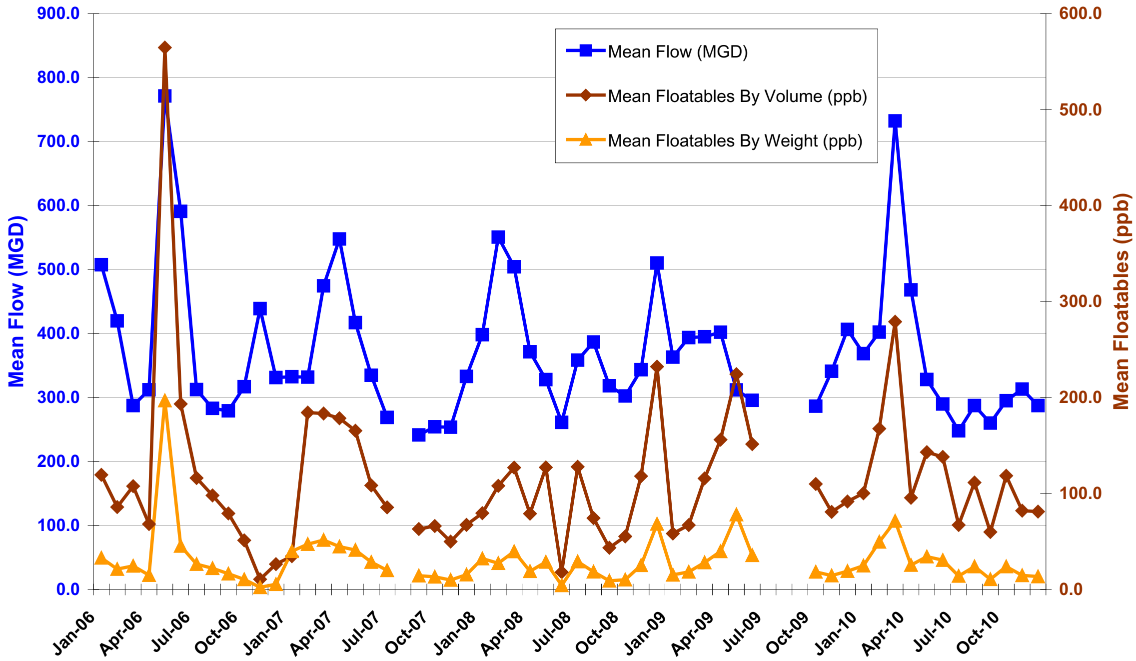


Figure 6-3. Average effluent flow and concentrations of floatables by volume and weight, 2006–2010.

Model Results

MWRA uses the numerical Bays Eutrophication Model (BEM) to simulate and predict the physical and biological conditions in Massachusetts Bay. The BEM has two major components, the first a hydrodynamic model that simulates the movement of seawater throughout Massachusetts and Cape Cod bays. The second component is a water quality model, which uses the output from the hydrodynamic model as one of its inputs and simulates the uptake of nutrients, production of algal biomass, and impacts of those processes on dissolved oxygen as water moves through the bays system. During 2009, the hydrodynamic part of BEM was upgraded to a new model, the Finite Volume Coastal Ocean Model (FVCOM), which among other advantages, was in more widespread use among regional oceanographic researchers.

Use of FVCOM, which is integrated into a regional monitoring effort at the University of Massachusetts Dartmouth, and improvements in data flow have enabled the modeling team to make results available faster than had been possible in prior years. For 2010, MWRA was able to use both modeling and field results to evaluate physical conditions and possible outfall effects. The improved model was used to simulate currents, temperature, salinity, and water column variables, including inorganic nutrients and phytoplankton biomass, measured as chlorophyll. The simulations allowed assessment of horizontal and vertical dispersal of the effluent plume and an analysis of the possible influence of the outfall on water quality and ecosystem function.

In a comparison of 2010 model predictions with field data, the model accurately predicted oxygen levels, as it has for past years. For algal biomass, the model reproduced the seasonal cycle in general terms, but missed the highs and lows of chlorophyll concentrations, under-predicting the spring bloom.

Model simulations comparing conditions with and without the Massachusetts Bay outfall continued to confirm that there is little effect of the outfall on nutrients, dissolved oxygen, or chlorophyll levels. The model shows that without the discharge, dissolved inorganic nitrogen levels would be lower at stations in the immediate vicinity of the outfall (Figure 6-4), but that bottom dissolved oxygen concentrations would be unchanged (Figure 6-5). Chlorophyll concentrations appear to be similarly unaffected by the discharge (Figure 6-6) and more particularly sensitive to the flux conditions at the northern boundary.

These results are consistent with the predictions made during the outfall-siting process (EPA 1988) and field observations made throughout the monitoring program. Overall, the modeling has confirmed predictions that despite differing nutrient regimes, there would be no difference in dissolved oxygen minima in Massachusetts Bay. The nutrients discharged from the outfall during the summer, stratified season are trapped in deeper, dimly lit waters, where they are relatively unavailable to phytoplankton.

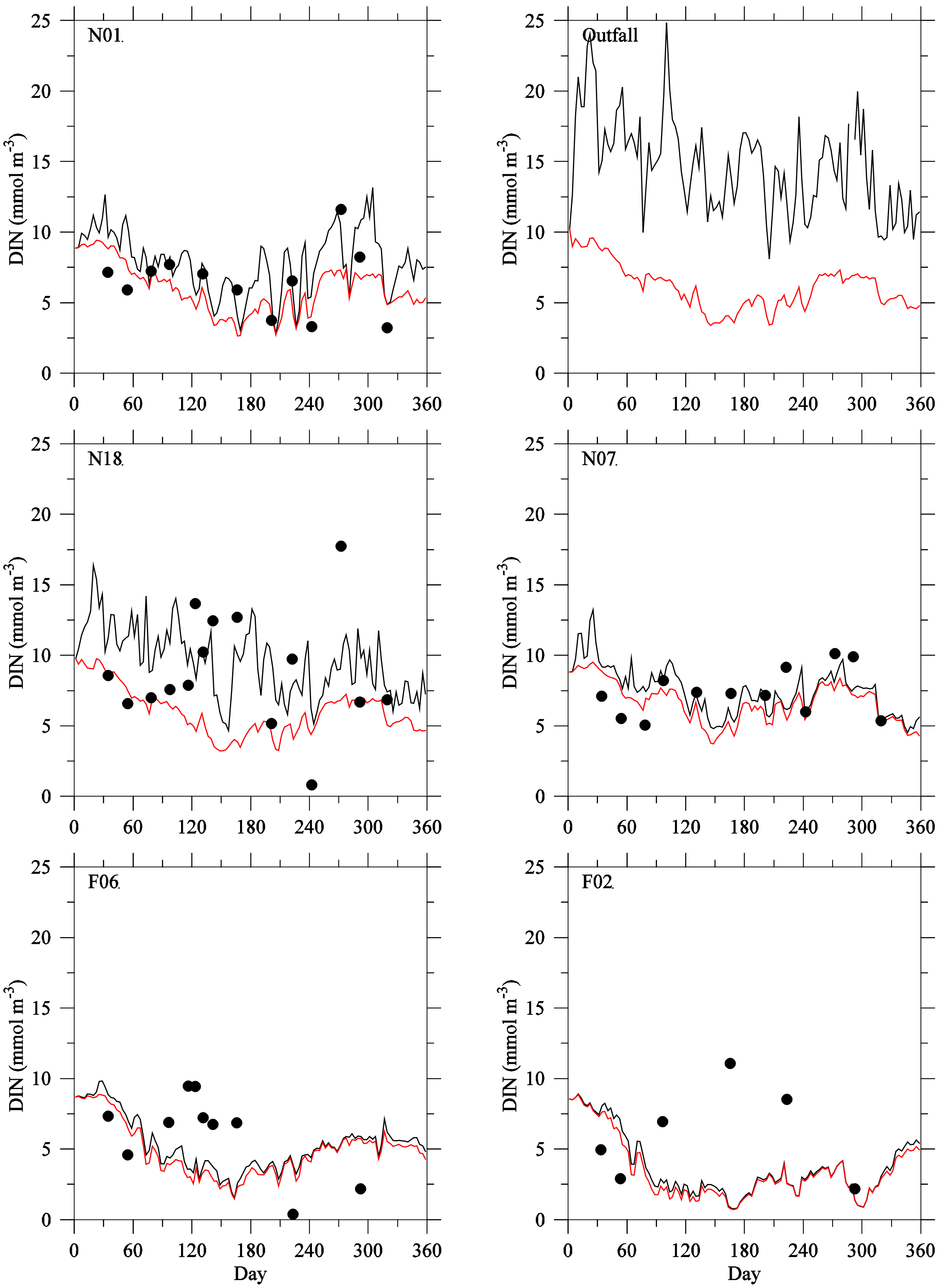


Figure 6-4. Comparison of bottom dissolved inorganic nitrogen concentrations at selected monitoring stations in 2010. Black line=modeled values with discharge; red line=modeled values without discharge; black dots=field observations. (See Figure 3-1 for station locations.)

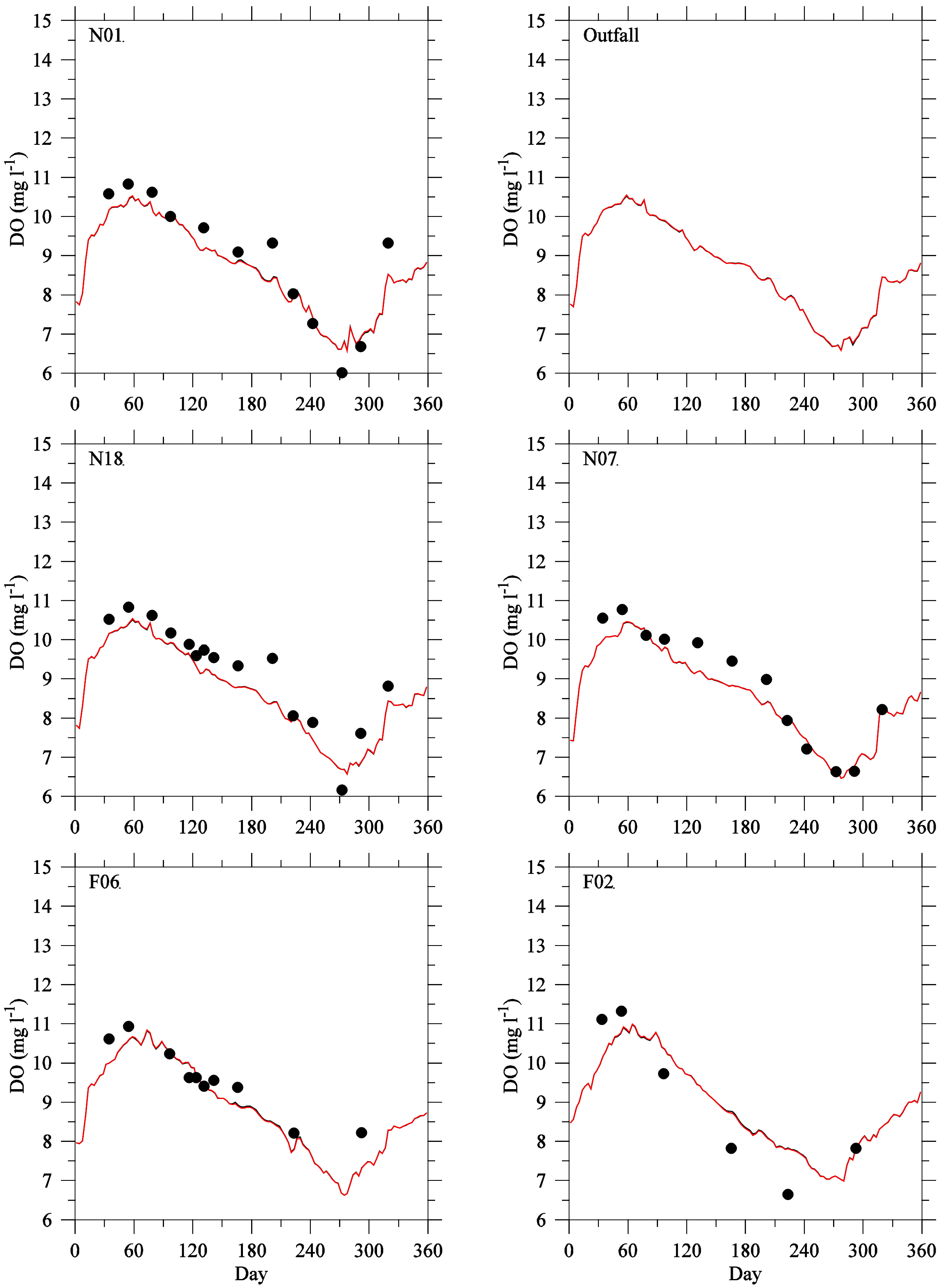


Figure 6-5. Comparison of bottom dissolved oxygen concentrations at selected monitoring stations in 2010. Black line=modeled values with discharge; red line=modeled values without discharge; black dots=field observations. (See Figure 3-1 for station locations.)

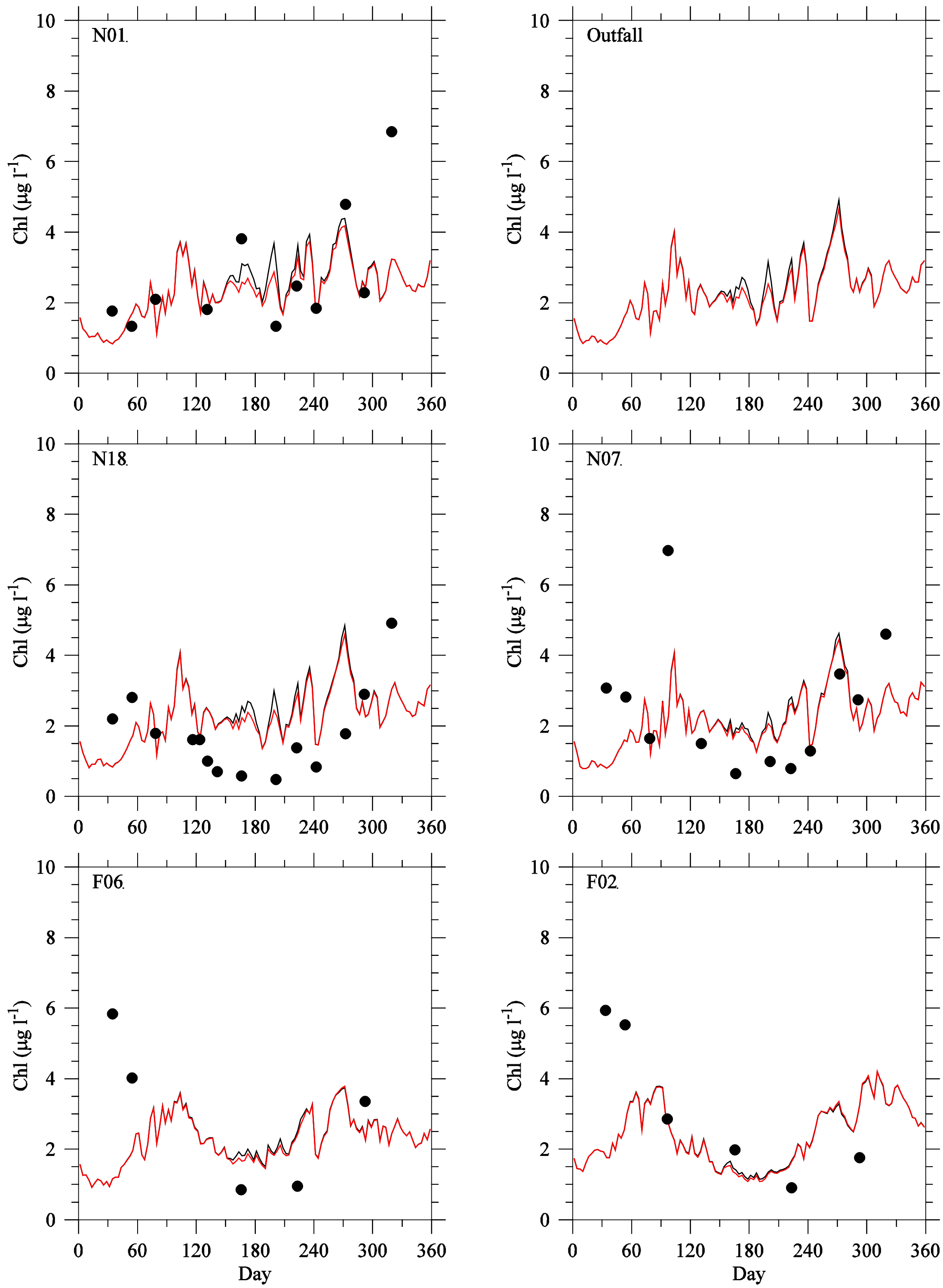


Figure 6-6. Comparison of surface chlorophyll concentrations at selected monitoring stations in 2010. Black line=modeled values with discharge; red line=modeled values without discharge; black dots=field observations. (See Figure 3-1 for station locations.)

Data from Instrumented Buoys

As part of water quality monitoring, MWRA collaborates with two agencies to maintain instrumented buoys, which measure water-column properties and transmit information to users in near real-time, often hourly, via the Internet. Continuous data from buoys offer the opportunity to observe temporal variations in the bay system, providing information on changes that occur between monitoring surveys. MWRA uses the data to help identify and interpret unusual events, for example phytoplankton blooms that are detected as abrupt spikes in algal mass, measured as chlorophyll. The buoy data are also used as input to water-transport and water-quality models.

MWRA works with the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS, www.neracoos.org) to maintain the Gulf of Maine Ocean Observing System (GoMOOS) Buoy A01, located south of Cape Ann. This buoy transmits near-real-time data on currents, water temperature, salinity, and dissolved oxygen at multiple depths, and measures algal biomass at the surface.

MWRA also has a jointly funded project with the National Oceanic and Atmospheric Administration NDBC, which has added oceanographic instrumentation to a weather buoy near MWRA's outfall (NDBC Buoy 44013, http://www.ndbc.noaa.gov/station_page.php?station=44013). The instruments measure ocean currents at many depths and temperature, salinity, dissolved oxygen, and algal biomass at the surface. Figures 3-1 and 3-2 in Section 3, Water Column, show the locations of both buoys.

Data from the buoys in 2010 reflected the major findings observed by MWRA's field water-column surveys. Both buoys documented the substantial decrease in surface salinity in March and April, caused by extreme runoff and rain events in March (Figure 6-7). Surface chlorophyll data from the GoMOOS Buoy A01 off Cape Ann were in reasonable agreement with the survey data, both methods documenting the strong spring bloom in April, lower chlorophyll levels through most of the summer, and increased chlorophyll during a fall bloom (Figure 6-8). Chlorophyll data from the NDBC Buoy 44013 near the outfall also documented the strong spring bloom but detected higher summer and fall chlorophyll levels than were measured during the surveys. The high chlorophyll measurements were probably due to a defective sensor; a steep drop in the chlorophyll measurements occurred when one sensor stopped reporting data in late October and was replaced in mid-November.

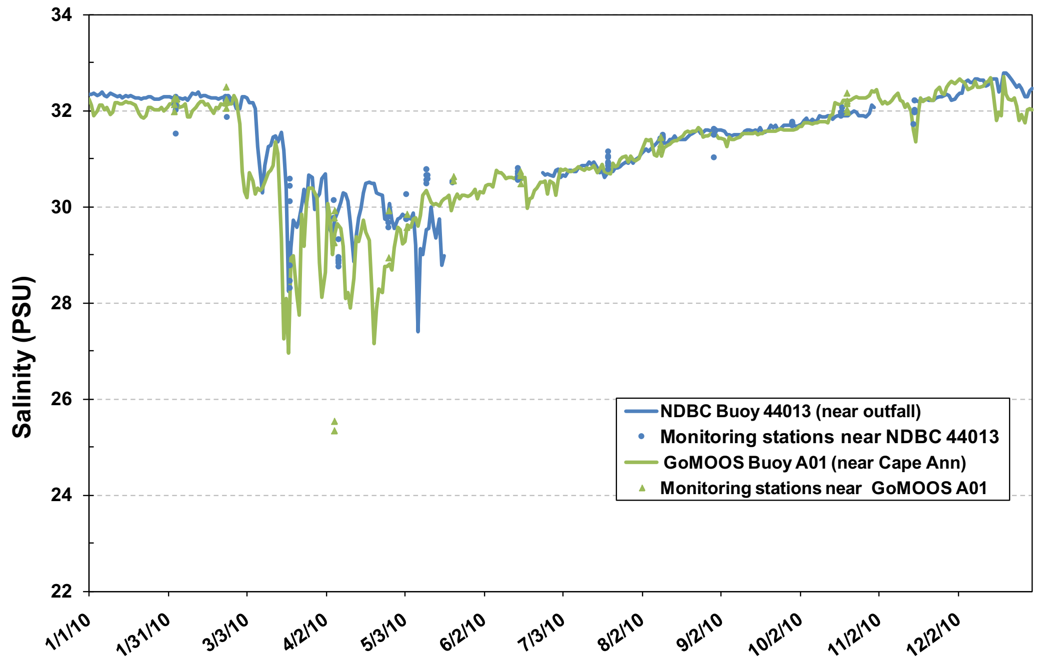


Figure 6-7. Surface salinity detected by instrumented buoys and during field surveys near Cape Ann and the outfall site in 2010 both showed large drops following spring runoff and large March storms.

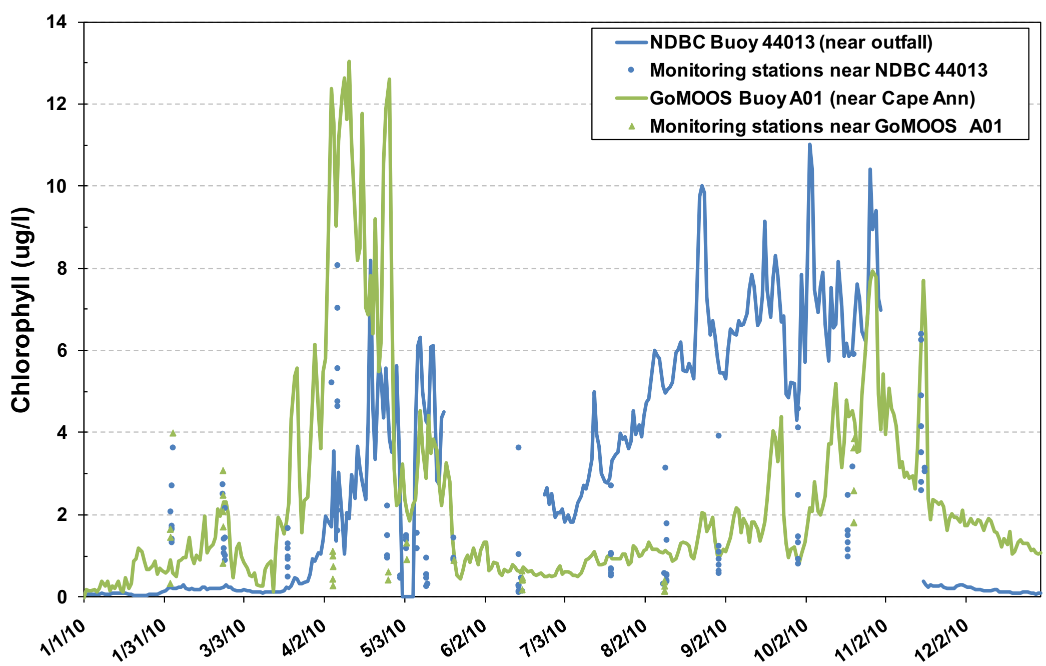


Figure 6-8. Chlorophyll concentrations detected by instrumented buoys and during field surveys near Cape Ann and the outfall site in 2010 were in agreement during the spring, but diverged in the summer and early fall, probably the result of a faulty sensor on the NDBC Buoy 44013 near the outfall.

Marine Mammal Observations

Several species of endangered or threatened whales and turtles visit Massachusetts and Cape Cod bays, including right, humpback, finback, sei, and, rarely, blue whales. Also seen are the protected, but not endangered, minke whale, harbor porpoise, gray seal, harbor seal, and several species of dolphins.

Since 1995, MWRA has included endangered species observers on monitoring surveys. In 2010, observers were included on all nearfield and farfield water quality surveys (Wu 2011). Besides providing observational data, the presence of trained marine mammal observers responds to the request by the National Marine Fisheries Service that MWRA actively minimize the chances of a collision of one of its survey vessels with a right whale.

During the 2010 surveys, the observers sighted more than 200 marine mammals, including five right whales, eight minke whales, four finback whales, nine humpback whales, and seven unidentified whales, six of which were baleen whales. They also sighted at least 112 Atlantic white-sided dolphins, one pilot whale, 24 harbor porpoises, two unidentified porpoises, 84 harbor seals, one grey seal, and five unidentified seals. Most of the whales were seen in the Stellwagen Bank National Marine Sanctuary and in Cape Cod Bay. Four whales were counted in the nearfield.

In an independent study, the Provincetown Center for Coastal Studies sighted 199 right whales in Cape Cod Bay and adjacent waters during 32 aerial surveys conducted during January through May 2010 (Stamieszkin et al. 2010). By comparing photographs of the whales seen during those surveys to those included in a comprehensive North Atlantic right whale catalog, they identified 163 individual whales, more than 45% of the known right whale population. Similar to other years of the study, which has been conducted since 1998, feeding behaviors suggested that the whales followed daily vertical migrations of the zooplankton and that the whales fed on *Calanus*, *Pseudocalanus*, and *Centropages* copepods.

Nutrient Inputs to Boston Harbor

Water quality monitoring in Boston Harbor continues to demonstrate improvements in response to decreased loadings of nutrients, total suspended solids, and organic material. The total nitrogen and total phosphorus loads to the harbor have decreased substantially (Taylor et al. 2010).

Prior to the Boston Harbor Project, loads of both nitrogen and phosphorus to the harbor were high, comparable to those to the highly urbanized Scheldt estuary in western Europe and Tokyo Bay in Japan (Figure 6-9). Loadings decreases to Boston Harbor have been dramatic, greater than decreases in other estuaries where improvement projects have been implemented, such as the Hillsborough

Bay portion of Tampa Bay and greater Tampa Bay in Florida, Kaneohe Bay in Hawaii, and the Danish Straits in northern Europe (Taylor et al. in preparation).

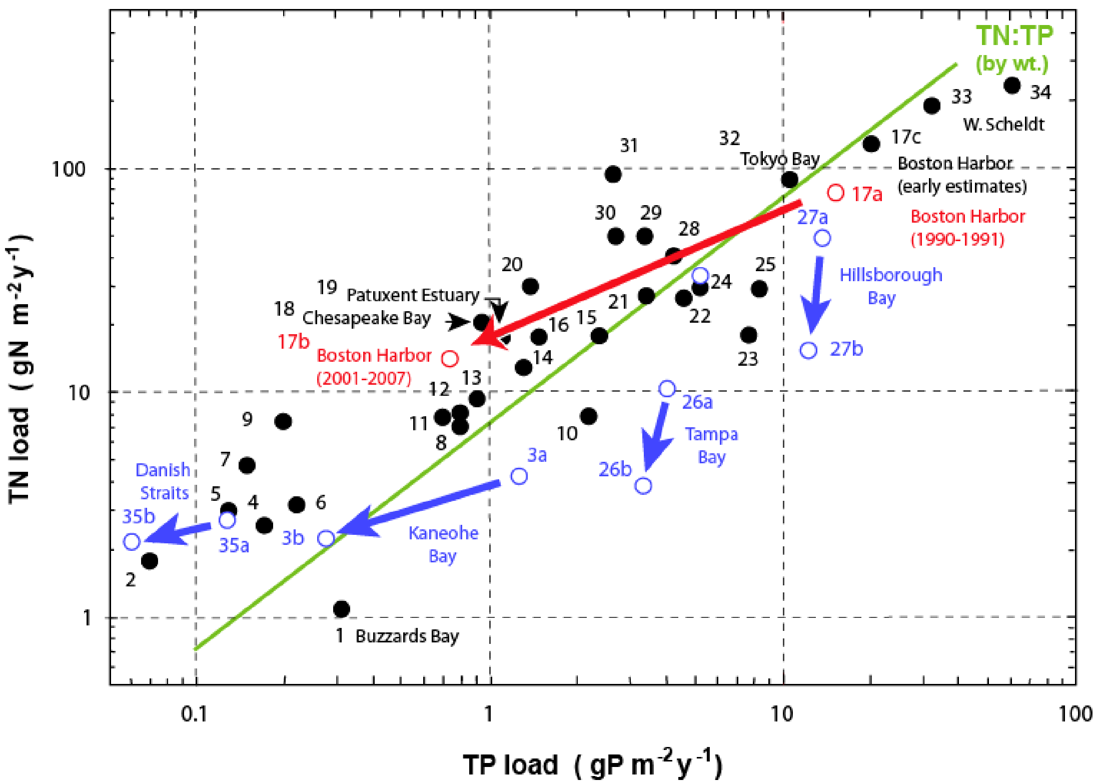


Figure 6-9. Average total nitrogen (TN) vs. total phosphorus (TP) loads in Boston Harbor and a selection of other coastal estuaries and lagoons. Figure adapted from Boynton 2008. Note especially points 17a, Boston Harbor 1990–1991; 17b, Boston Harbor, 2001–2007; 17c, earlier estimate for Boston Harbor; and 34, Charles River Basin, 1999–2000. The solid diagonal line represents the Redfield ratio for total nitrogen to total phosphorus, the ratio considered optimal for phytoplankton growth.

1=Buzzards Bay, NOAA/EPA 1989; 2=Sinepuxent Bay, Maryland, Boynton et al. 1996; 3a,b=Kaneohe Bay, Hawaii, Smith 1981; 4=Isle of Wight Bay, Maryland, Boynton et al. 1996; 5=Baltic Sea, Nixon et al. 1996; 6=Chincoteague Bay, Maryland, Boynton et al. 1982, 1996; 7=Gulf of Riga, Yurkovskis et al. 1993; 8=Albemarle Sound, North Carolina, Nixon et al. 1986; 9=Himmerfjarden Estuary, Sweden, Engquist 1996; 10=Guadalupe Bay, Texas, dry year, Nixon et al. 1996; 11=Buttermilk Bay, Massachusetts, Valiela and Costa 1988; 12=Moreton Bay, Australia, Eyre and McKee 2002; 13=Seto Inland Sea, Japan, Nixon et al. 1986; 14=Taylorville Creek, Maryland, Boynton et al. 1996; 15=Newport Bay, Rhode Island, Boynton et al. 1996;16=North Adriatic Sea, Degobbis and Gilmartin 1990; 17a,b,c=Boston Harbor, Taylor 2010, Alber and Chan 1994; 18=Chesapeake Bay, Maryland, Boynton et al. 1995; 19=Patuxent Estuary, Maryland, Boynton et al. 2008; 20=Potomac River, Maryland, Boynton et al. 1995; 21=Narragansett Bay, Rhode Island, modern conditions, Nixon et al. 1995; 22=Delaware Bay, Delaware, Nixon et al. 1996; 23=Mobile Bay, Alabama, NOAA/EPA 1989; 24=Guadalupe River, Texas, wet year, Nixon et al. 1996; 25=North San Francisco Bay, California, Hager and Schemel 1992; 26a,b=Tampa Bay, Florida, Zarbock et al. 1994, Poe et al. 2005; 27a,b=Hillsborough Bay, Tampa Bay, Florida, Poe et al. 2005; 28=St. Martins River, Maryland, Boynton et al. 1996; 29=Patapsco River, Maryland, Stammerjohn et al. 1991; 30=Apalachicola Bay, Florida, Mortazavi et al. 2000; 31= Back River, Maryland, Boynton et al. 1998; 32=Tokyo Bay, Japan, Nixon et al. 1986; 33=Western Scheldt, Netherlands, Nixon et al. 1996; 34=Charles River Basin, Boston, Breault et al. 2002; 35=Carstensen et al. 2006.

Total inputs of nitrogen to Boston Harbor during 2006–2009 were 77% lower than those in 1990–1992 (Taylor et al. 2011). Earlier estimates from Boston Harbor were even higher (Alber and Chan 1994). Because flushing rates from the harbor into Massachusetts Bay are very high, Boston Harbor had suffered from fewer noxious algal blooms than many other estuaries with high nutrient loads, even prior to the beginnings of the Boston Harbor Project. Consequently, it took substantial decreases in loads before a difference in chlorophyll levels was detected. With the diversion of effluent discharge from the harbor to Massachusetts Bay, there have been decreases in summer chlorophyll levels. Similarly, decreases in particulate carbon and increases in dissolved oxygen have been notable since the outfall diversion.

Benthic Flux

One concern about the outfall diversion was that increased loads of organic matter near the outfall (from either direct inputs of effluent or from stimulation of algal production) might increase benthic respiration and fluxes of nutrients between the sediments and the water column. The concern was that the resulting higher rates of benthic respiration or sediment oxygen demand might lead in turn to lower levels of oxygen in both the sediments and the water column. Beginning in 1993, MWRA has studied the sediment-water interface at stations in Massachusetts Bay and Boston Harbor (Figure 6-10) to learn whether the outfall discharge caused such changes. The study was completed in 2010.

The Massachusetts Bay portion of the study, at stations located within depositional areas, has shown no significant changes from baseline conditions (Tucker et al. 2011). Sediment cores from the stations in 2010 showed that they remained similar to each other at the surface (Figure 6-11) and at depth, with no visible changes in the color of the sediments throughout the lengths of the cores, indicating that the sediments were oxidized throughout their lengths.

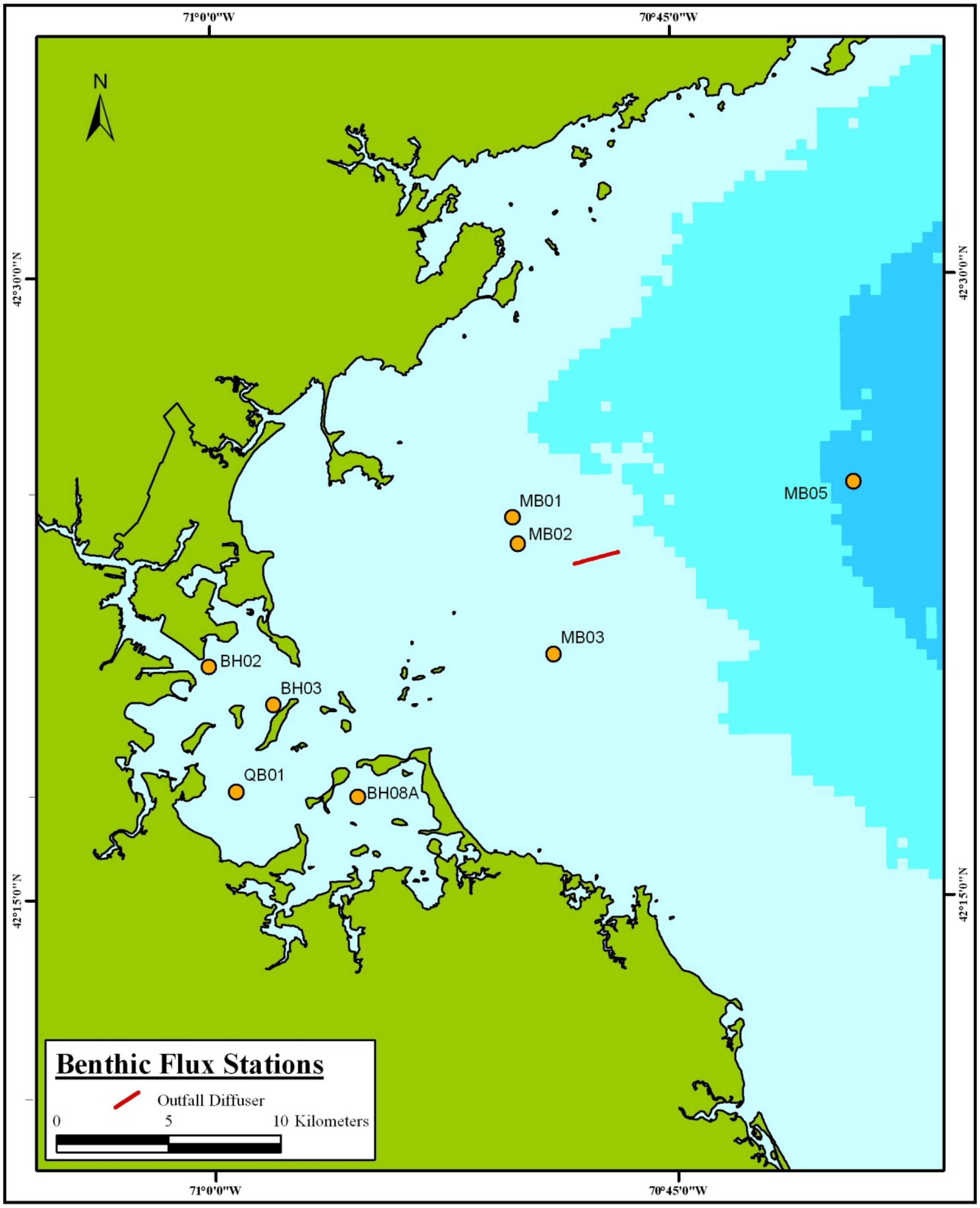


Figure 6-10. Benthic flux stations in Massachusetts Bay and Boston Harbor.

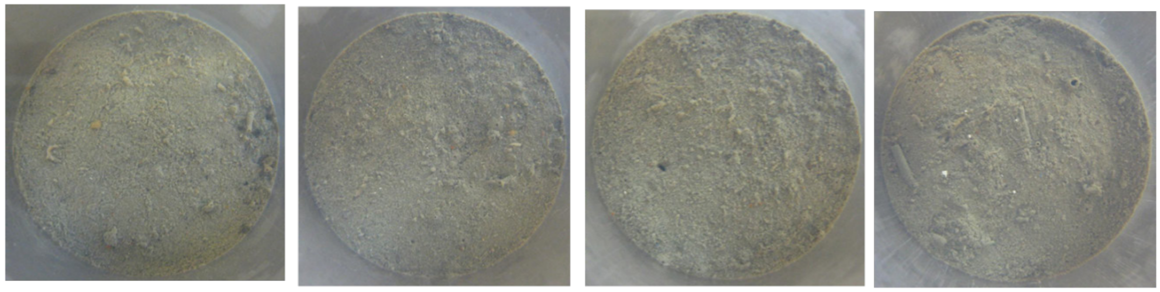


Figure 6-11. Surfaces of sediment cores from Massachusetts Bay stations in May 2010 (from left to right: MB01 and MB02 north of the outfall, MB03 south of the outfall, and MB05, in the farfield to the east of the outfall).

There has been little or no indication of increased deposition of organic matter, measured as organic carbon and as chlorophyll, to the sea floor and no change in the oxidation of the bottom waters or sediments at the Massachusetts Bay stations. There have been no increases in sediment oxygen demand (Figures 6-12) and no changes in nutrient fluxes. In fact, the overall average nearfield sediment oxygen demand has been slightly lower in the post-diversion period than in the baseline period. In 2010, the rate of oxygen consumption by the sediments in the nearfield was close to the mean for the entire span of the monitoring program.

Figure 6-12. Sediment oxygen demand in Massachusetts Bay surface sediments in 2010, compared with baseline (1994–2000) and other post-diversion (2001–2009) years (NF=nearfield, FF=farfield).

Most of the variability in inorganic nutrient fluxes appears to be in the ammonium component of the measurement. Average ammonium flux was 0.6 mmol per m^2 per day during the baseline period and declined to as low as -0.1 mmol per m^2 per day in 2008. Ammonium flux in 2010 averaged 0.3 mmol per m^2 per day.

Meanwhile, monitoring at the sediment-water interface has documented great improvements at the four stations in Boston Harbor, beginning prior to the 2000 outfall diversion (Tucker et al. 2011). Biosolids discharges into the harbor ended in 1991, and improvements to primary treatment at DITP during 1991–1997 also contributed to improved conditions within the harbor. Changes during the pre-diversion period were particularly obvious at two stations, BH03, which is adjacent to the former biosolids disposal site, and BH08A, in Hingham Harbor. Both BH08A and QB01 are located in the southern portions of the harbor, where effluent discharges ended in 1998 when flow was directed to DITP for secondary treatment.

Numerous tube-building amphipods, *Ampelisca* spp., appeared throughout the harbor after the end of biosolids discharge, accelerating the removal of organic matter from the sediments. The presence or absence of *Ampelisca* tube mats and other dense assemblages, such as colonies of another amphipod *Leptocheirus pinguis* in 2007 and 2008, have continued to affect sediment processes in the harbor. Sediment cores in May 2010 showed a continued presence of *Ampelisca*, occurring as scattered individuals in some samples and as dense or degrading mats in others (Figure 6-13). Benthic diatoms were abundant at the Quincy Bay station QB01. The changing communities over the seasons and years exert strong effects on sediment oxygen demand, nutrient fluxes, and other processes.

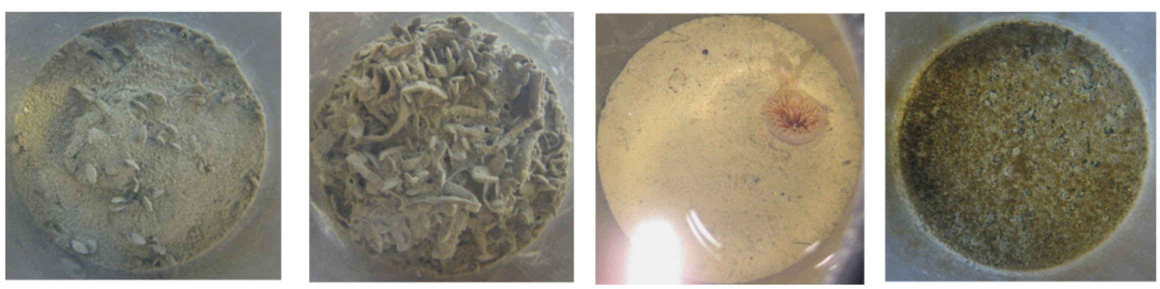


Figure 6-13. Surfaces of sediment cores from Boston Harbor stations in May 2010 (from left to right: BH02 near the Inner Harbor, BH03 near the former biosolids disposal site, BH08A in Hingham Harbor, QB01 in Quincy Bay). Scattered tube mats were present at BH02, dense mats were found at BH03, a few tubes and a burrowing anemone were found at BH08A, and diatoms covered the surface at QB01.

Sediment oxygen demand in 2010 (Figure 6-14) and nutrient fluxes continued to be lower than pre-diversion rates. There has been year-to-year variability in response to specific, episodic events, but the variation now occurs around lower values, more typical of natural shallow coastal systems.

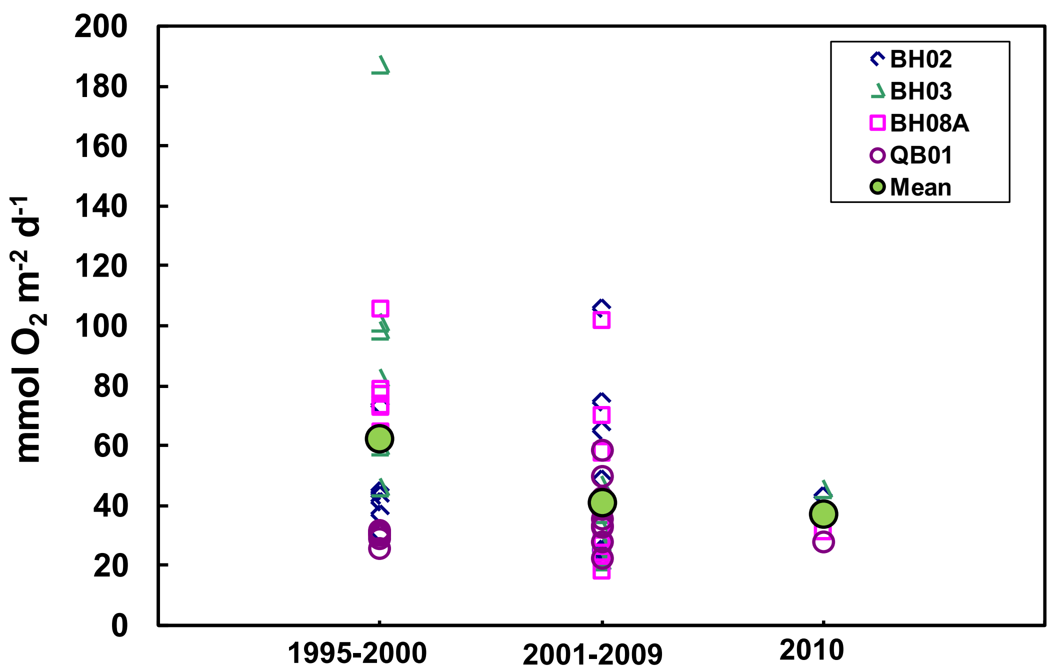
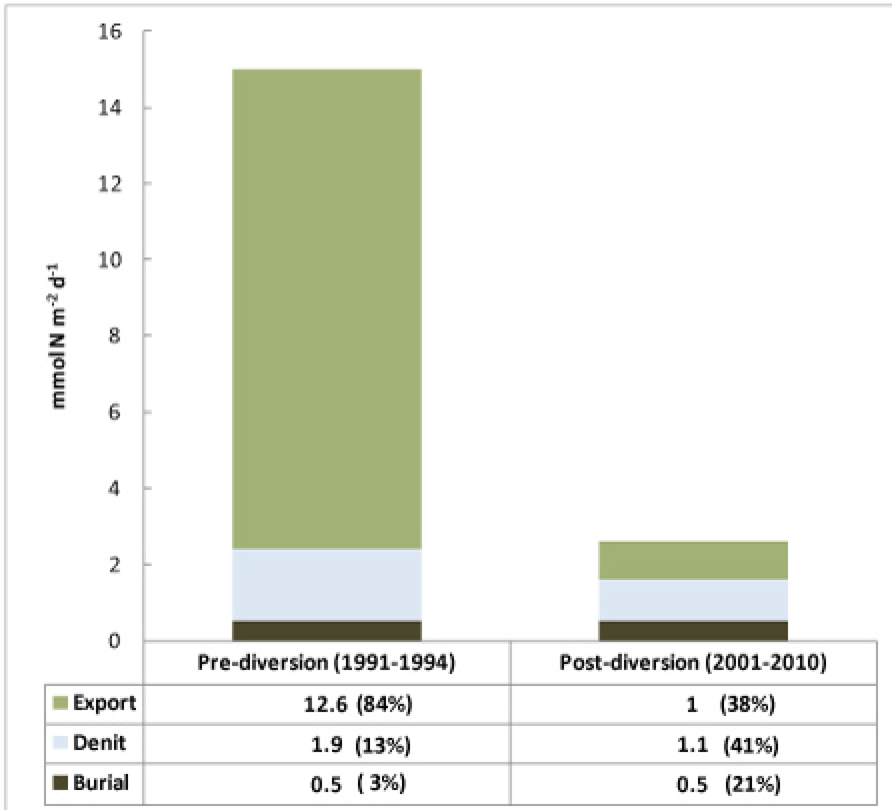


Figure 6-14. Sediment oxygen demand in Boston Harbor surface sediments in 2010, compared to baseline (1995–2000), and other post-diversion (2001–2009) years. Sediment oxygen in demand in Boston Harbor had already begun to fall during the baseline period.

For example, during the first stages of the Boston Harbor Project, sediment oxygen demand measurements at some stations were among the highest reported in the literature. Sediment oxygen demand began to decrease as soon as biosolids discharges ended. Declines continued during 2001–2006, then oxygen demand increased in 2007 and 2008, coinciding with increased colonization by the amphipod *Leptocheirus pinguis*. The activities of these animals were likely promoting faster oxygenation of the remaining organic matter in the sediment. Some high rates of sediment oxygen demand were also recorded in 2010, but none were as high as those during the *Leptocheirus* peaks of 2007 and 2008. Similar fluctuations are likely as the harbor continues to recover.

The total nitrogen budget for Boston Harbor has changed considerably between the early pre-diversion and the post-diversion periods (Figure 6-15). During the early years of monitoring, 1991–1994, Kelly (1997) found that about 14% of the total nitrogen load to the harbor was lost to denitrification, and 2% was lost to burial; the bulk of the nitrogen was exported to Massachusetts Bay. During the years since the outfall came on-line, total loading has decreased to about 14% of the earlier estimate. Denitrification now removes about 60% of that reduced load, and export to Massachusetts Bay from Boston Harbor has been greatly reduced. The results of the studies have confirmed predictions that the outfall diversion would have no adverse effect on sediment respiration or nutrient flux in Massachusetts Bay, while greatly benefiting Boston Harbor.



	Pre-diversion (1991-1994)	Post-diversion (2001-2010)
Export	12.6 (84%)	1 (38%)
Denit	1.9 (13%)	1.1 (41%)
Burial	0.5 (3%)	0.5 (21%)

Figure 6-15. Pre-diversion and post-diversion nitrogen budgets for Boston Harbor.

7. Stellwagen Bank National Marine Sanctuary

The Gerry E. Studds Stellwagen Bank National Marine Sanctuary protects 842 square miles of open water at the boundary between Massachusetts Bay and the rest of the Gulf of Maine. It includes a part of Stellwagen Basin, which is the deepest part of Massachusetts Bay and a long-term sediment sink. Stellwagen Bank rises to the east of Stellwagen Basin and provides a rich habitat for marine life.

The MWRA outfall is located about nine miles from the sanctuary border, a greater distance than any effects of the discharge were expected or have been recorded. Other wastewater treatment plants discharge to the north and south of the sanctuary, and the area receives pollutant inputs from aerial deposition, discharges from commercial and private vessels, dredged material disposal at the Massachusetts Bay Disposal Site, and other sources.

The management plan for the sanctuary (U.S. Department of Commerce 2010) focuses on issues including alteration of ecosystems by cables, pipelines, and fishing gear; introduction of pollutants from sea- and shore-based sources; and disturbance of marine mammals by ship vessels, aircraft, noise, and fishing gear. Another recent report prepared for the sanctuary documents historic declines in the fisheries resources of Stellwagen Bank (Claesson et al. 2010). The NPDES permit to discharge effluent from DITP into Massachusetts Bay requires an annual report on possible effects of the discharge on the sanctuary. This section of the Outfall Monitoring Overview meets that requirement.

Water Column

The water quality in the sanctuary remains good. The 2010 MWRA water-quality monitoring measurements at the stations in and near the sanctuary (Figure 7-1) continued to find that dissolved oxygen, nutrient concentrations, and plankton abundances and community measures were within the expected ranges for this region of Massachusetts Bay.

Concentrations of dissolved oxygen and percent saturation have remained unchanged in Stellwagen Basin, as they have in the nearfield (Figure 7-2; see also Figure 3-10 in Section 3, Water Column). Potential decreases in dissolved oxygen concentrations or percent saturation had been a concern before the outfall diversion, but those concerns have not been realized. The 2010 bottom water oxygen concentrations remained within the baseline range.

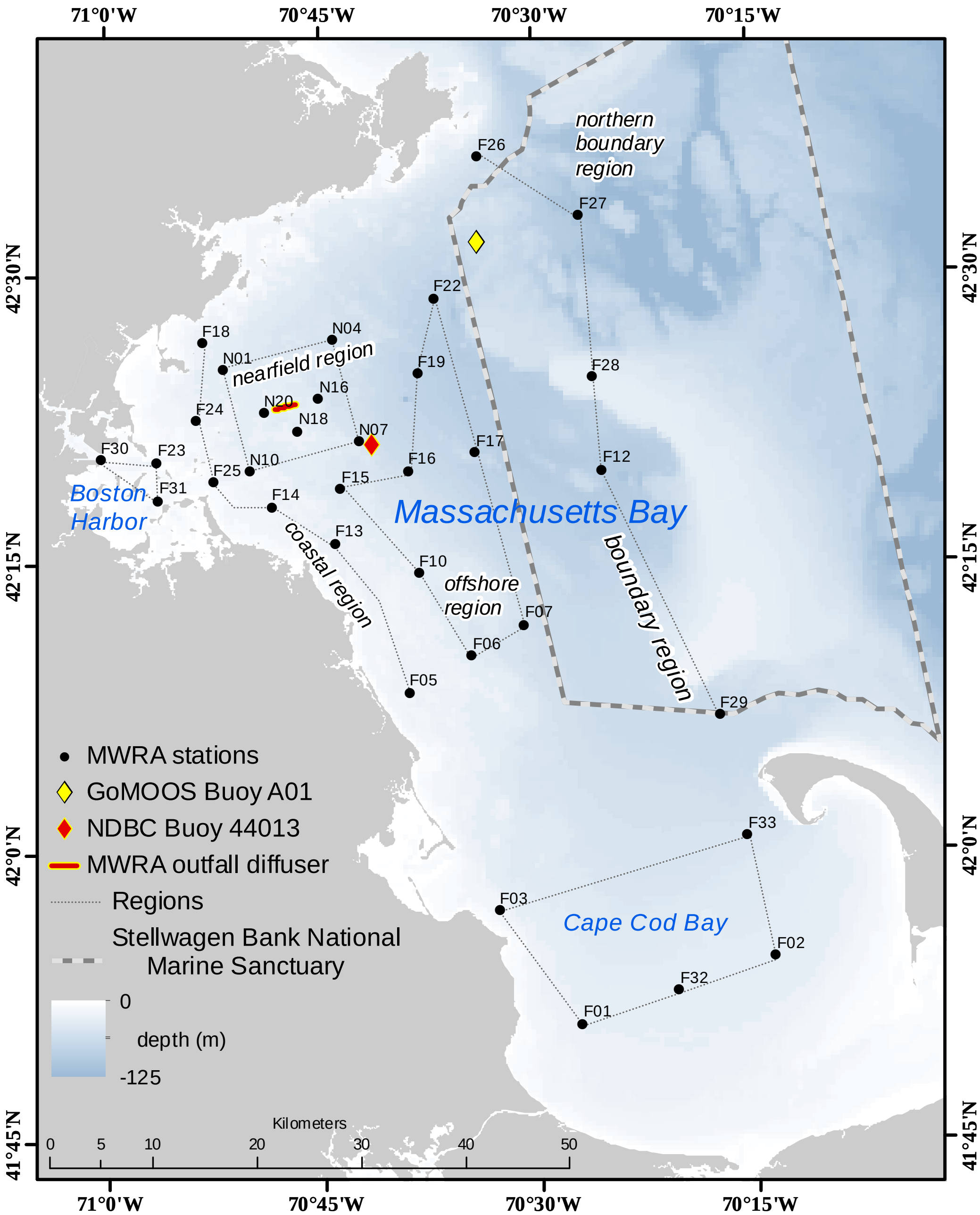


Figure 7-1. Water column stations, including those in and near the Stellwagen Bank National Marine Sanctuary. (F27, F28, and F12 are within the sanctuary borders.)

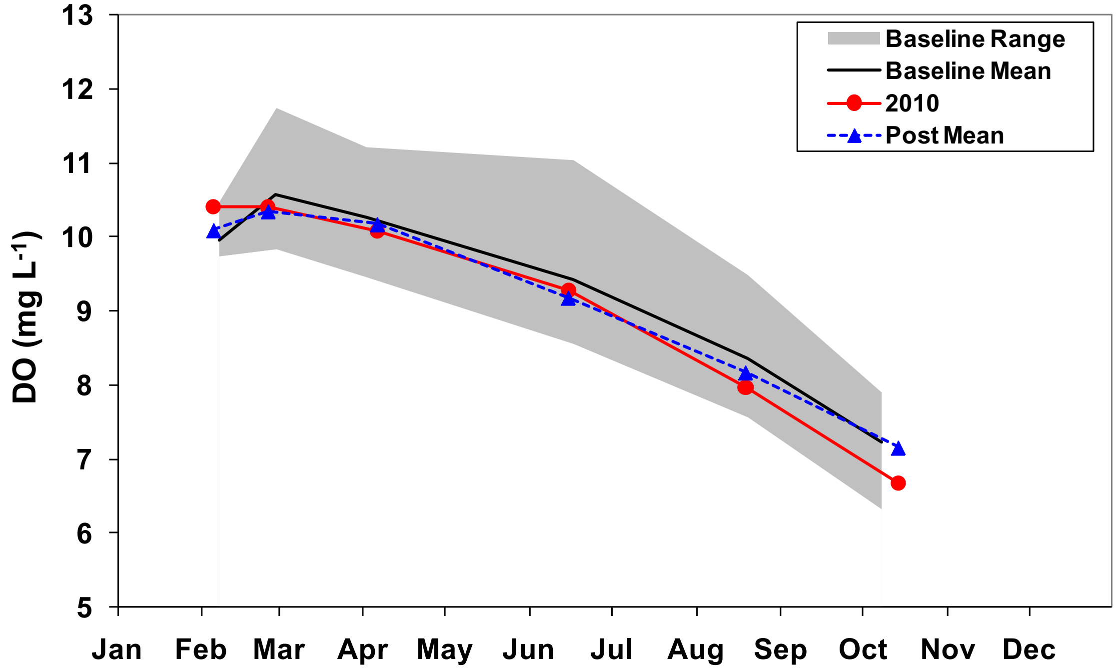


Figure 7-2. 2010 bottom water dissolved oxygen concentrations in Stellwagen Basin compared to baseline range, baseline mean, and post-diversion mean. There has been no change in patterns of dissolved oxygen concentrations (or saturation, data not shown) since the outfall diversion.

Annual mean concentrations of nutrients in water samples have varied somewhat over the years, but the changes have not been substantial, and no changes at stations in and near the sanctuary have been attributed to the outfall diversion. Similar patterns have been observed in and near the sanctuary, in the nearfield, and in Cape Cod Bay.

Annual mean concentrations of total nitrogen have varied across the study area from year to year, but the pattern is similar across regions (Figure 7-3). Although ammonium levels (Figure 7-4) rose in the nearfield when the outfall first went on line, ammonium concentrations in and near the sanctuary were not similarly affected and have been lower than baseline levels since 2004.

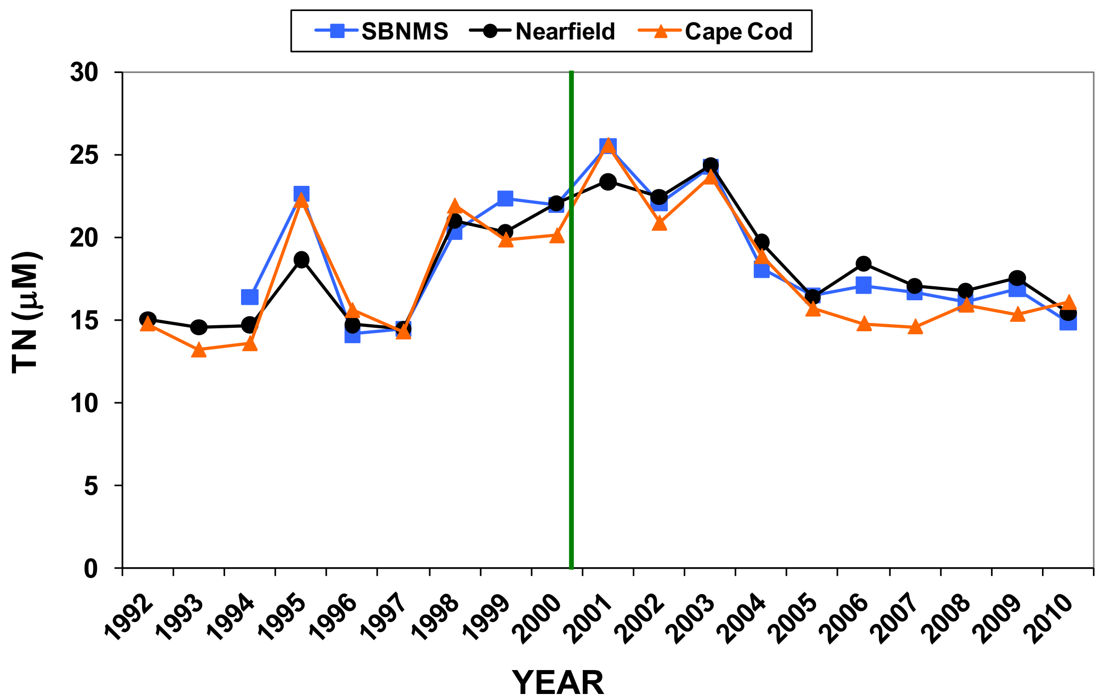


Figure 7-3. Annual mean total nitrogen (TN) at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. Concentrations have varied by year but have been similar across regions. Vertical line indicates when the outfall came on-line.

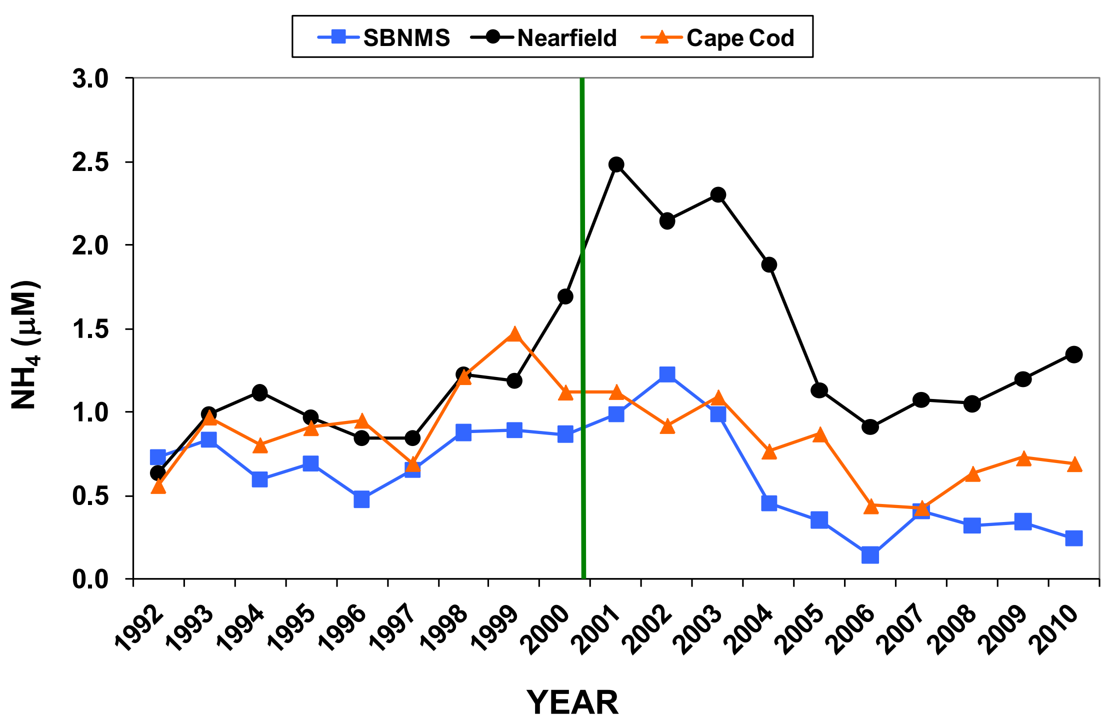


Figure 7-4. Annual mean ammonium at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. There has been no increase in ammonium concentrations in SBNMS with the outfall diversion. Vertical line indicates when the outfall came on-line.

Nitrate concentrations (Figure 7-5) have varied from year to year across all regions. In general, concentrations of nitrate, as well as silicate and phosphate (not shown), have been consistently higher at stations in and near the sanctuary than at stations in the nearfield and lowest in Cape Cod Bay. These higher levels are associated with deeper offshore waters. It is these nutrient-rich bottom waters that feed plankton and small fishes and make Stellwagen Bank a thriving habitat for commercial fishes and whales.

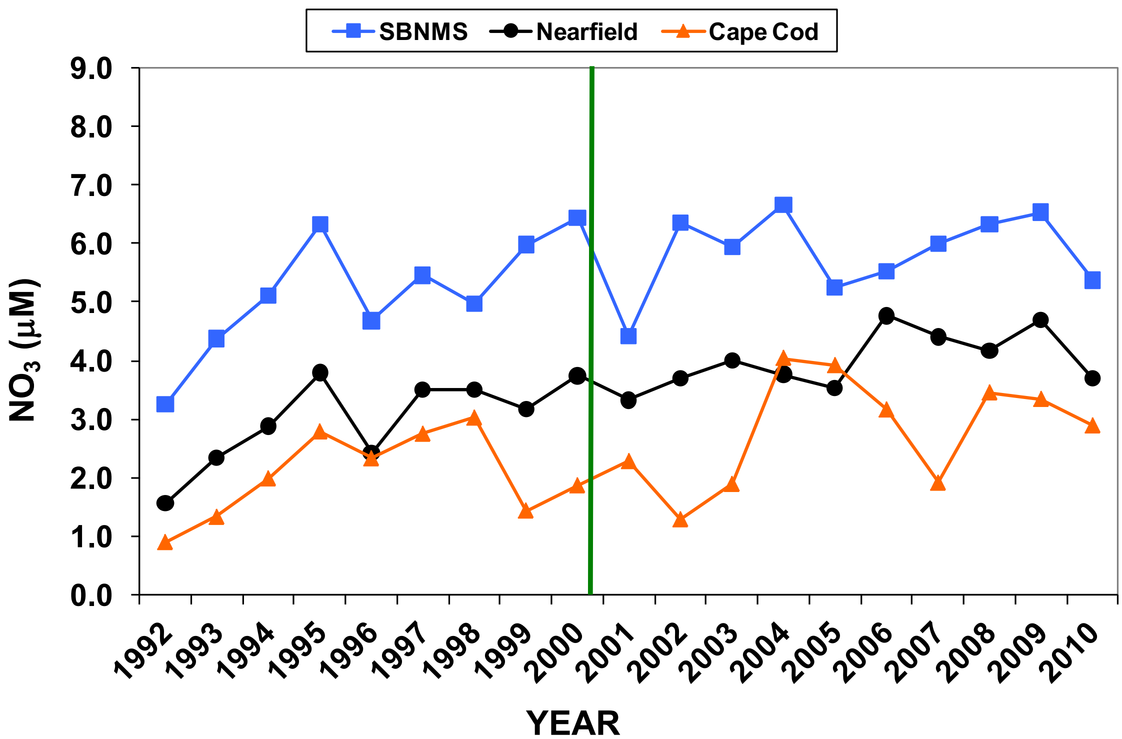


Figure 7-5. Annual mean nitrate at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. Nitrate concentrations are variable, but there have been no changes attributed to the outfall. Vertical line indicates when the outfall came on-line.

The annual mean areal chlorophyll levels have varied at the sanctuary stations, the nearfield, and in Cape Cod Bay throughout the monitoring program, but post-diversion levels are not significantly different from the baseline (Figure 7-6). Chlorophyll levels do not correlate with nitrogen and have not changed in response to changes in nutrient inputs. In 2010, levels in all regions were approximately at the long-term mean.

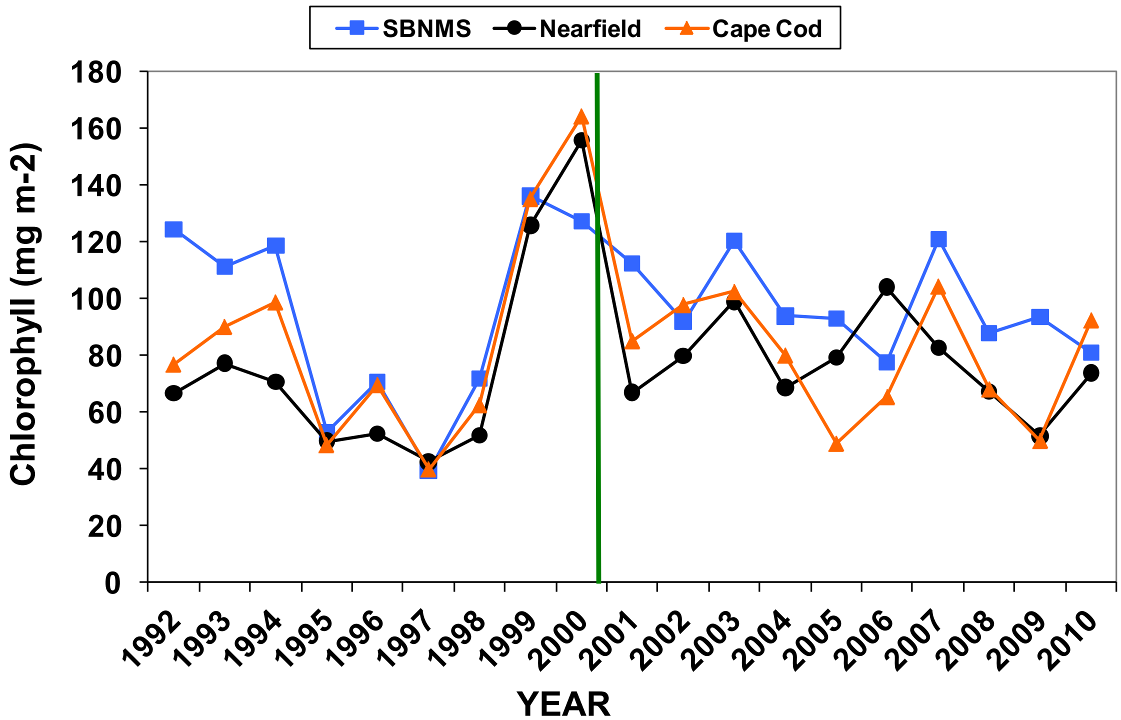


Figure 7-6. Annual chlorophyll at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. Over the course of monitoring, annual chlorophyll levels have varied, but similar patterns have been seen in samples from every region. Vertical line indicates when outfall came on-line.

Sea Floor

No changes in bottom community parameters have been measured within or near the sanctuary since the outfall diversion. Stations FF04 and FF05 were sampled in 2010 (Figure 7-7, Maciolek et al. 2011).

Those deep-water stations continued to support a distinct infaunal community, with recognizable differences from communities in the nearfield and Cape Cod Bay. Benthic community parameters at individual stations showed no pattern of change following the outfall diversion in 2000 (Figure 7-8). The total number of individual organisms per sample has varied widely and decreased at both stations in 2010, compared to when they were last sampled in 2008. This decrease was the result of fluctuations in the population of *Prionospio steenstrupi*, the polychaete that has been the numerically dominant species throughout the region. The number of species per sample and the diversity of organisms within the samples decreased at Station FF04, which is located within Stellwagen Basin. These changes are attributed to normal cycles in the populations of benthic animals in the community. No patterns that relate to the outfall diversion have been found.

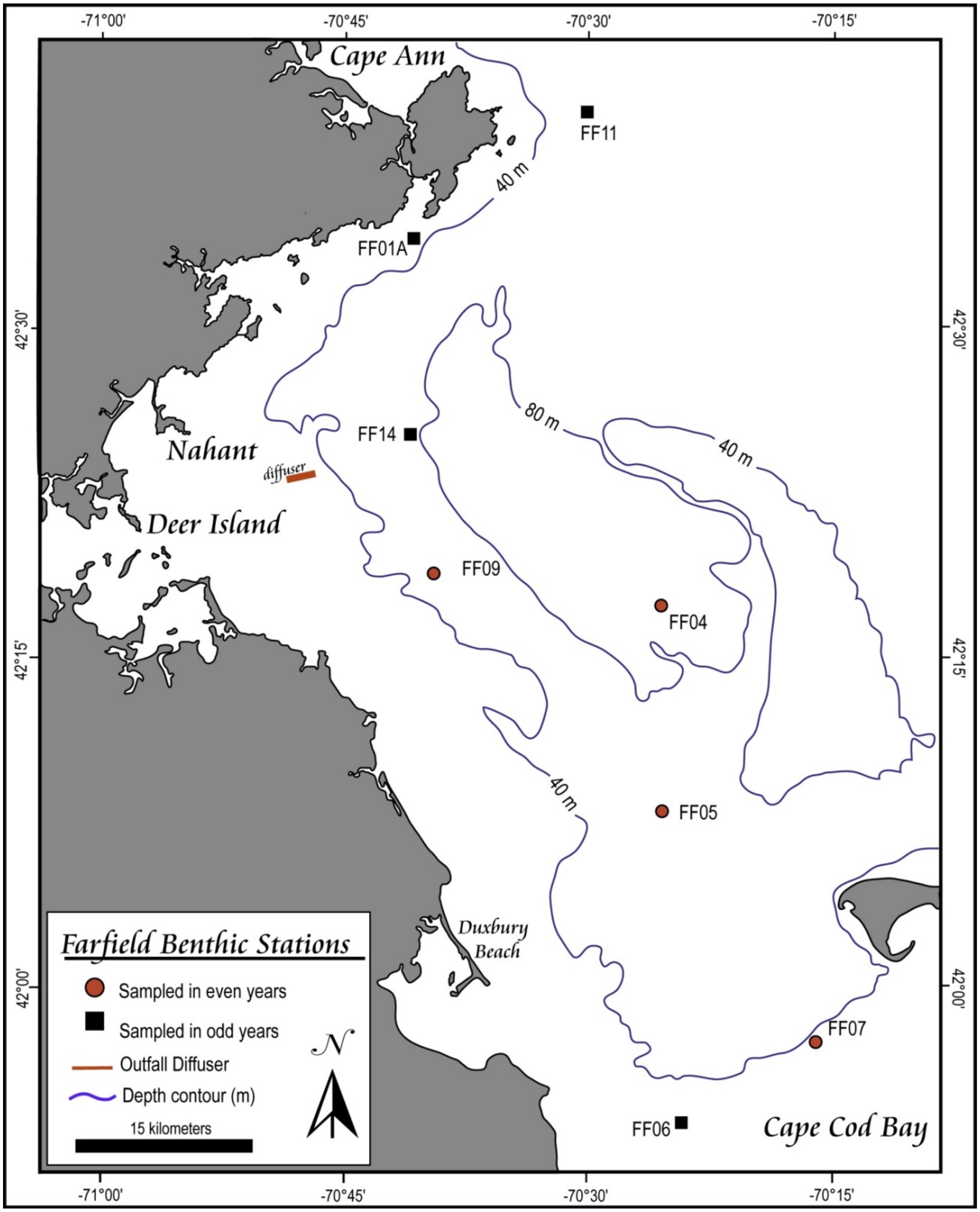


Figure 7-7. Farfield benthic stations. Stations FF04, FF05, FF11, and FF14 are in or near the Stellwagen Bank National Marine Sanctuary. FF04 and FF05 were sampled in 2010.

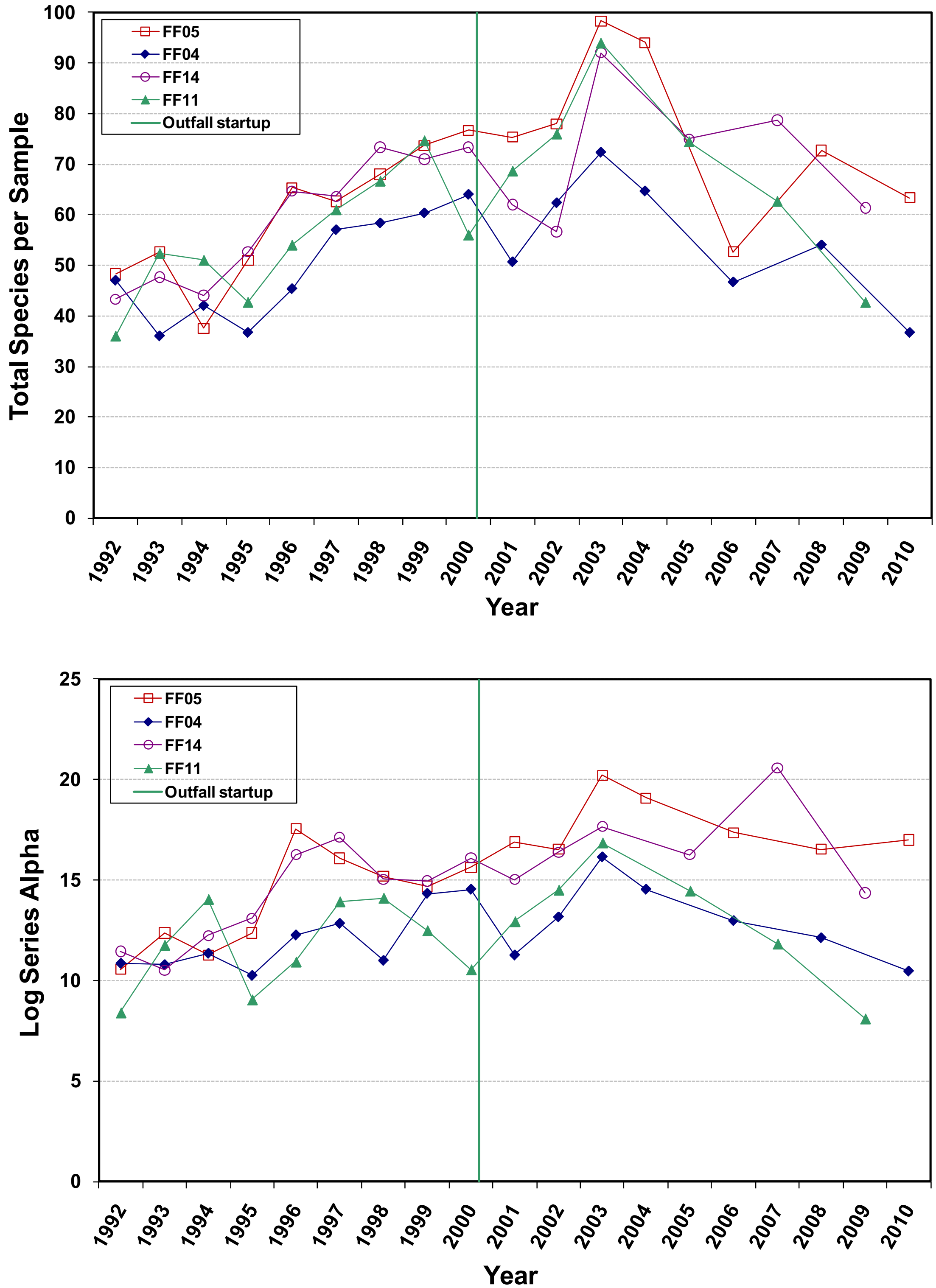


Figure 7-8. Community parameters at stations in or near the Stellwagen Bank National Marine Sanctuary. Top: species richness or number of species per sample; Bottom: Log-series alpha, a measure of diversity.

8. Monitoring Plan Revisions

Eight years of baseline monitoring and more than ten years of post-diversion monitoring have greatly increased the scientific understanding of Massachusetts Bay and demonstrated that the outfall relocation has had only limited, localized effects, while Boston Harbor continues to improve. These results suggested that it was appropriate to shift the focus and scale of monitoring. Therefore, MWRA, in consultation with OMSAP; its permanent committees (the Public Interest Advisory Committee and the Inter-Agency Advisory Committee), EPA, and the Massachusetts Department of Environmental Protection, developed a revised monitoring plan (MWRA 2010), which was implemented in 2011.

Effluent

Discharging effluent that meets all permit conditions is the best way of ensuring that Massachusetts Bay is protected from possible adverse effects of effluent discharge. MWRA will continue its robust effluent monitoring. The new monitoring plan ends a special study, which measured effluent floatables. The study began because of early concerns that the effluent might contain plastics or other floating material that would be aesthetically displeasing or could harm marine life. The effluent floatables study (see Section 6, Special Studies) found that the discharges of floatable debris were minimal; therefore, the study has been completed. Field assessment of floatable debris continues as part of the water quality monitoring program.

Water Column

The major change in the water column monitoring sampling design reduces the spatial redundancy inherent in the previous design and increases the sampling frequency of reference stations. Decreasing the number of stations allows sampling of all stations for all parameters, replacing the complex measurement plan that monitored several subsets of those stations for a variety of parameters.

Another advantage is that all the stations can be sampled within a reasonably short period of time. The previous design was 12 nearfield surveys of 7 stations and 6 farfield surveys of 28 stations each year. A number of the farfield stations were quite remote from the outfall; farfield surveys took a minimum of 3–4 days, which could stretch over periods of weeks because of foul weather.

The new plan calls for 9 surveys annually of 14 stations: five nearfield stations, six reference stations, and three stations in Cape Cod Bay and Stellwagen Bank National Marine Sanctuary (Figure 8-1). This change focuses the monitoring on the area with the greatest potential for being affected by sewage effluent and enough reference areas for comparison. All stations are sampled during every survey, and all physical, chemical, and biological parameters are measured at each station, enabling better data interpretation across the region.

The special study on productivity has ended, as the measurements were costly and, after ten years, did not detect substantial increases in productivity related to the outfall. Post-diversion data have shown decreases in productivity in Boston Harbor without changes in the nearfield.

The frequency of net tows to sample for floatable debris has been reduced. The new plan is for two wet-weather tows following wet-weather primary-blending events each year. Fat particles taken in those tows are analyzed for PCBs, PAHs, pesticides, and mercury. Visual monitoring for floatable debris continues during each survey.

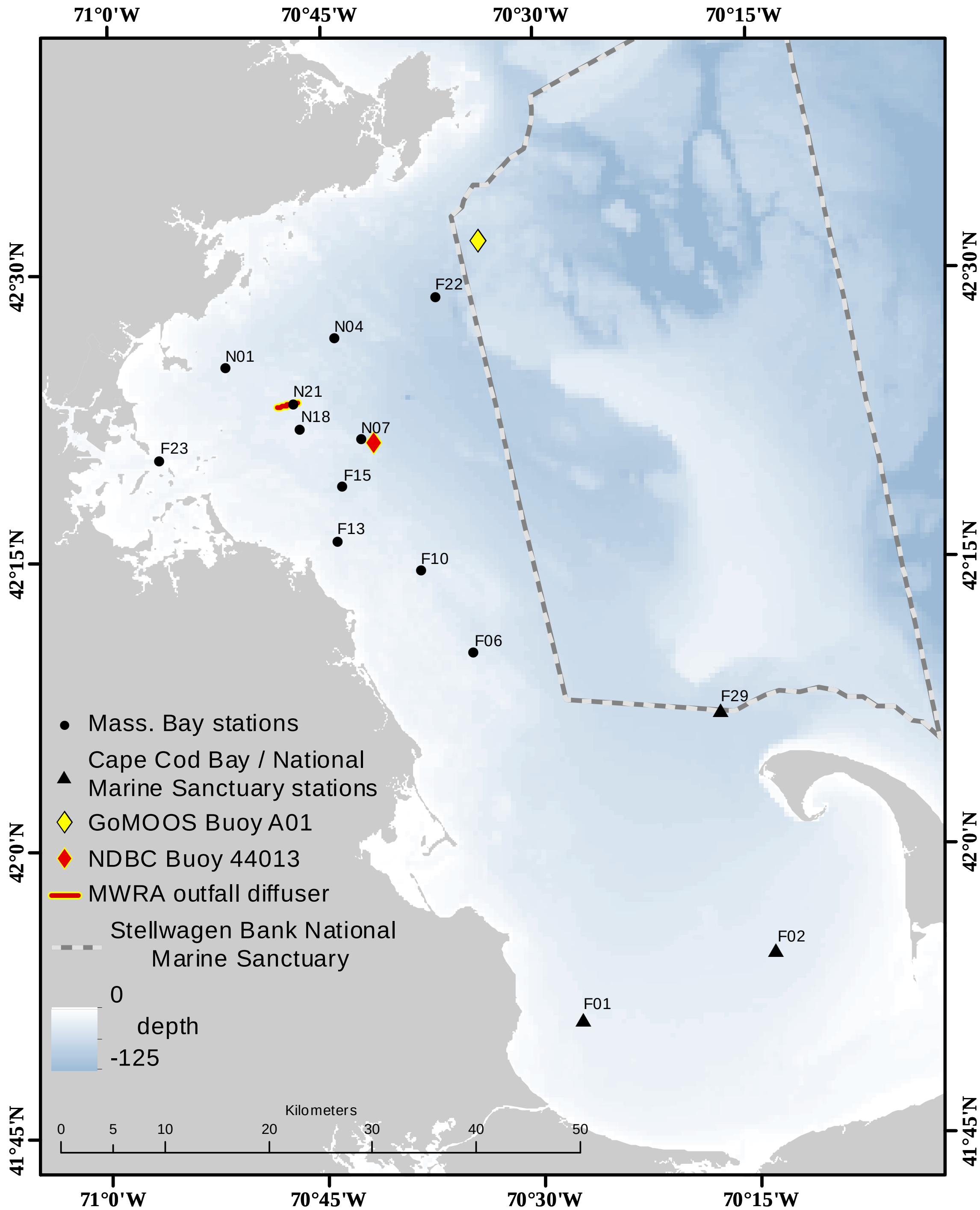


Figure 8-1. Map of water-column monitoring stations.

Sea Floor

Changes to sea-floor monitoring include a decrease in the number of soft-bottom stations to ten stations in the nearfield (Figure 8-2) and three in the farfield (Figure 8-3) and a change to monitoring the same set of stations every year. The former plan called for monitoring two sets of stations in alternate years, a design that complicated data interpretation. Sediment-contaminant monitoring will be conducted every third year at those same 13 stations, but annual monitoring of sediment contaminants at two stations has ended. Sediment-profile imaging remains unchanged, visiting 23 nearfield soft-bottom stations each year.

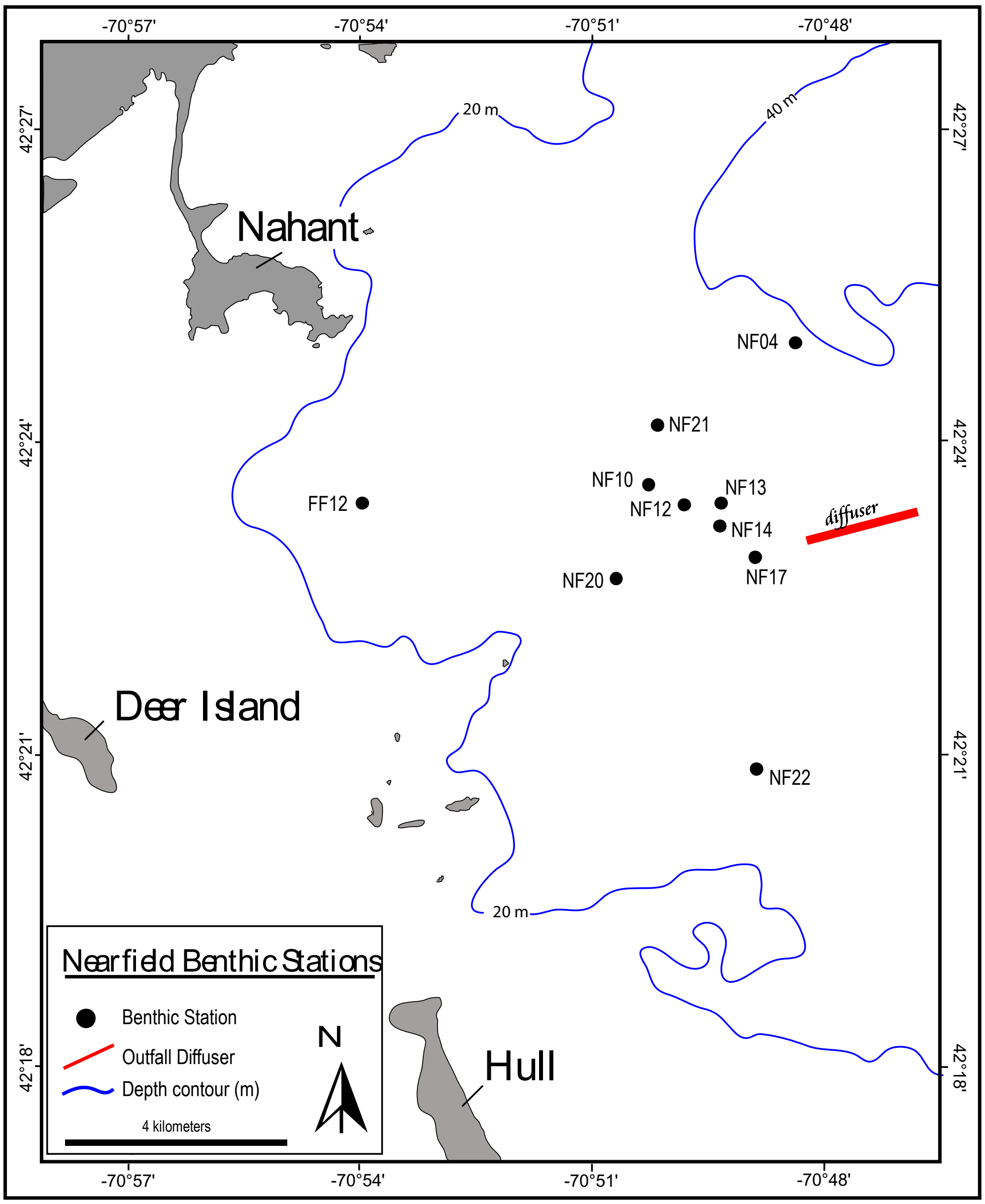


Figure 8-2. Map of nearfield soft-bottom monitoring stations.

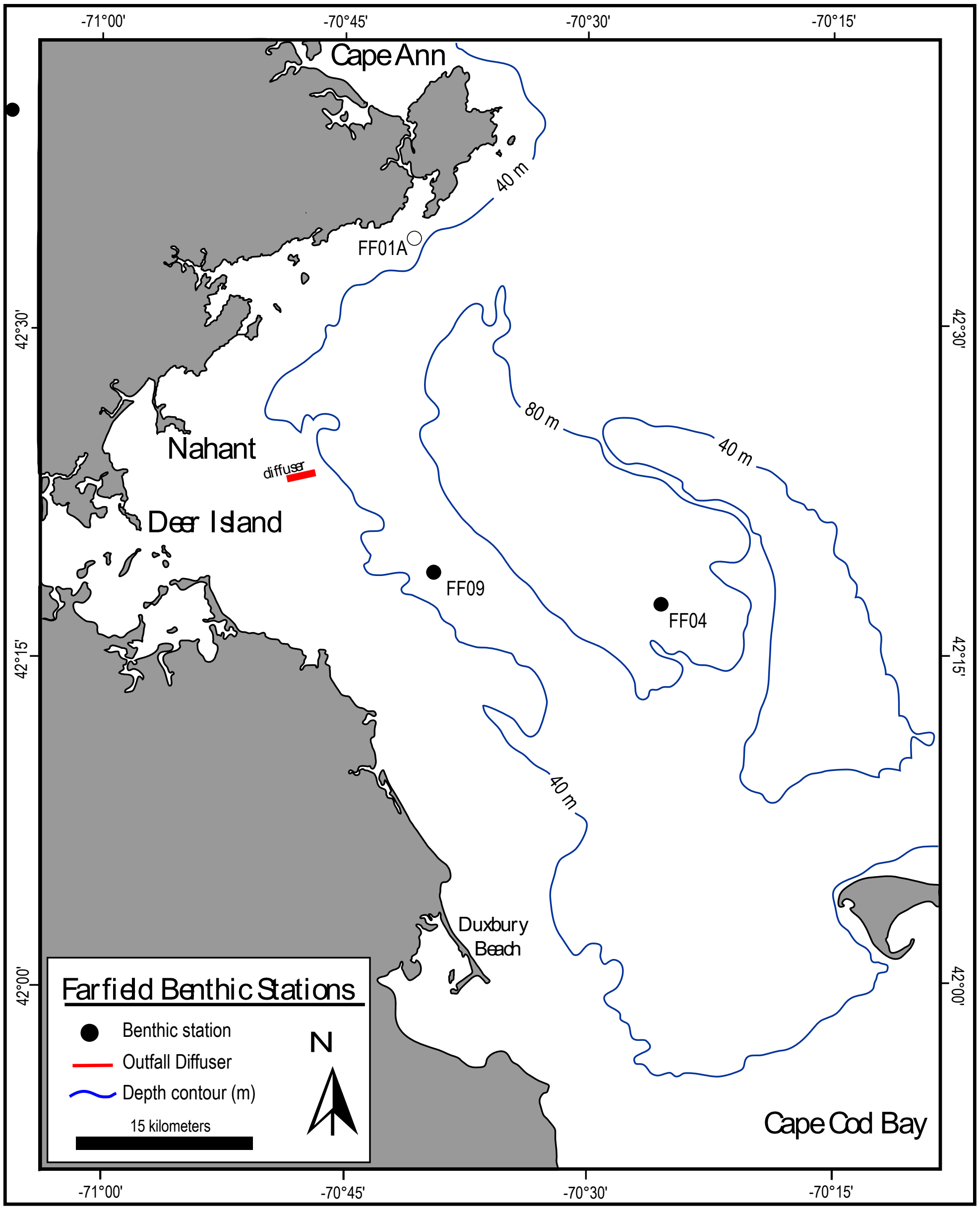


Figure 8-3. Map of farfield soft-bottom monitoring stations.

Video surveys of the hard bottom have decreased in frequency to once every three years, conducted in the same year as sediment-contaminant monitoring. However, a treatment plant upset that caused the release of more than 180,000 pounds of suspended solids per day over seven consecutive days would trigger an unscheduled hard-bottom survey. The design and timing of the survey would depend on the exact nature of the discharge.

The special study on nutrient flux from the sediment to the water column and denitrification has ended. The potential for changes in these processes was of concern prior to construction of the outfall, but monitoring has shown that conditions in Massachusetts Bay remain unchanged, while those in Boston Harbor have improved (see Section 6, Special Studies).

Fish and Shellfish

No changes have been implemented for fish and shellfish monitoring.

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List of Acronyms

BEM	Bays Eutrophication Model
BOD	Biochemical oxygen demand
cBOD	Carbonaceous biochemical oxygen demand
CHV	Centrotubular hydropic vacuolation
DITP	Deer Island Treatment Plant
DO	Dissolved oxygen
EPA	U.S. Environmental Protection Agency
FF	Farfield
FVCOM	Finite Volume Coastal Ocean Model
GoMOOS	Gulf of Maine Ocean Observing System
HMW	High molecular weight
IAAC	Inter-Agency Advisory Committee
LC50	50% mortality concentration
LMW	Low molecular weight
MWRA	Massachusetts Water Resources Authority
NA	Not analyzed/not applicable
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
OSI	Organism sediment index
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
PSP	Paralytic shellfish poisoning
RPD	Redox potential discontinuity
SBNMS	Stellwagen Bank National Marine Sanctuary
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen

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