2008
Outfall Monitoring Overview

Massachusetts Water Resources Authority

Environmental Quality Department

Report 2009-16

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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 sewage effluent outfall. The report includes data collected through effluent, water-column, sea-floor, and fish-and-shellfish monitoring. It presents 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. This year's outfall monitoring overview presents monitoring program results for effluent and field data from 2008, marking eight full years since discharge was diverted from the shallower, more confined, waters of Boston Harbor to the deeper waters of Massachusetts Bay, a period called post-diversion monitoring.

The year was relatively wet, and flow through the Deer Island Treatment Plant was higher than average. There was a corresponding increase in contaminant loads; however, concentrations of most contaminants in the effluent were very low. Most effluent contaminants are substantially lower than predicted during the planning and permitting process for the treatment plant and outfall. Nitrogen remains at levels that do not exceed Contingency Plan thresholds.

Overall, results of the monitoring were consistent with previous years, with no adverse impacts associated with the discharge. There were no exceedances of Contingency Plan thresholds for effluent, sea-floor, or winter-flounder monitoring in 2008. There was one exceedance of a water-column threshold, when concentrations of the red tide alga *Alexandrium fundyense* exceeded the caution level (Table 1). The *Alexandrium* bloom followed the historically typical pattern for red tides in the region, beginning off the coast of Maine and moving southward along the coast with winds from the northeast. The pattern suggests no effect of the outfall on the timing or region-wide magnitude of the bloom.

Special studies in 2008 included improvements to the methods of measuring chlorophyll in the water column, efforts to predict *Alexandrium fundyense* blooms, marine mammal observations, an analysis of nutrient loadings to Boston Harbor, and ongoing study of nutrient fluxes at the sediment-water interface.

As in other years, no effects of the outfall on the Stellwagen Bank National Marine Sanctuary were detected. No effects on the water column or sea floor in or near the sanctuary had been anticipated, and none have been measured.

Prior to constructing the Massachusetts Bay outfall, a series of questions was posed, aimed at assessing whether the relocated discharge would affect public health, the environment, or the aesthetics of the region. Baseline and post-diversion monitoring have answered those questions, and a final section of this report reviews the questions and answers.

Table 1. Contingency Plan thresholds and exceedances as of 2008. *(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
	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
	Oil and grease	✔	✔	✔	✔	✔	✔	✔	✔	✔

Table 1, continued. Contingency Plan thresholds and exceedances as of 2008. *(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
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
Farfield shellfish	PSP toxin extent	✔	✔	✔	✔	✔	✔	✔	✔	✔
Plume	Initial dilution	NA	✔	Complete						

Table 1, continued. Contingency Plan thresholds and exceedances as of 2008. *(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
Nearfield sediment contaminants	Acenaphthene	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Acenaphylene	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Anthracene	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Benzo(a)anthracene	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Benzo(a)pyrene	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Cadmium	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Chromium	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Chrysene	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Copper	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Dibenzo(a,h)anthracene	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Fluoranthene	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Fluorene	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Lead	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Mercury	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Naphthalene	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Nickel	NA	✓	✓	NA	NA	✓	NA	NA	✓
	p,p'-DDE	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Phenanthrene	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Pyrene	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Silver	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Total DDTs	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Total HMW PAH	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Total LMW PAH	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Total PAHs	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Total PCBs	NA	✓	✓	NA	NA	✓	NA	NA	✓
	Zinc	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	✓	✓	✓	✓	✓	✓	✓	✓
	Pielou's evenness	NA	✓	✓	✓	✓	✓	✓	✓	✓
Nearfield species composition	Percent opportunists	NA	✓	✓	✓	✓	✓	✓	✓	✓

Table 1, continued. Contingency Plan thresholds and exceedances as of 2008. *(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
Nearfield flounder tissue	Total PCBs	NA	✔	✔	✔	NA	NA	✔	NA	NA
	Mercury	NA	✔	✔	✔	✔	NA	✔	NA	NA
	Chlordane	NA	✔	✔	✔	NA	NA	✔	NA	NA
	Dieldrin	NA	✔	✔	✔	NA	NA	✔	NA	NA
	Total DDTs	NA	✔	✔	✔	NA	NA	✔	NA	NA
Nearfield flounder	Liver disease (CHV)	NA	✔	✔	✔	✔	✔	✔	✔	✔
Nearfield lobster tissue	Total PCBs	NA	✔	✔	✔	NA	NA	✔	NA	NA
	Mercury	NA	✔	✔	✔	NA	NA	✔	NA	NA
	Chlordane	NA	✔	✔	✔	NA	NA	✔	NA	NA
	Dieldrin	NA	✔	✔	✔	NA	NA	✔	NA	NA
	Total DDTs	NA	✔	✔	✔	NA	NA	✔	NA	NA
Nearfield mussel tissue	Total PCBs	NA	✔	✔	✔	NA	NA	✔	NA	NA
	Lead	NA	✔	✔	✔	NA	NA	✔	NA	NA
	Mercury	NA	✔	✔	✔	NA	NA	✔	NA	NA
	Chlordane	NA	**C**	**C**	✔	NA	NA	✔	NA	NA
	Dieldrin	NA	✔	✔	✔	NA	NA	✔	NA	NA
	Total DDTs	NA	✔	✔	✔	NA	NA	✔	NA	NA
	Total PAHs	NA	**C**	**C**	**C**	NA	NA	✔	NA	NA

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1. Introduction

For more than two decades, the Massachusetts Water Resources Authority (MWRA) has worked to minimize the effects of wastewater discharge on the marine environment. During most of those years, the efforts have included a monitoring program in Massachusetts Bay. The 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, 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 year since MWRA ended discharges into Boston Harbor and began to discharge treated effluent into Massachusetts Bay, 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 (MWRA 1991, 1997a, 2004), 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. With the Massachusetts Bay outfall operational as of September 2000, subsequent reports have included information relevant to the outfall permit, including Contingency Plan threshold exceedances, responses, and corrective actions.

This year's outfall monitoring overview presents monitoring program results for effluent and field data from 2008, marking eight full years since discharge was diverted from the shallower, more confined waters of Boston Harbor to the deeper waters of Massachusetts Bay, a period called post-diversion monitoring. The overview presents 2008 monitoring results for effluent, water column, sea floor, and winter flounder, and it compares relevant data to baseline conditions and Contingency Plan thresholds. It also includes sections on special studies and the Stellwagen Bank National Marine Sanctuary. A final section lists the monitoring questions that were posed at the beginning of the program and their answers to date. The questions have been answered by the years of monitoring data; the results from 2008 continue to verify those answers.

2. Effluent

2008 Characterization

Because 2008 was one of the wettest years on record in the Boston area, average flow to the DITP was somewhat greater than it had been in 2007, when flow reached a 25-year low. The year was the seventh wettest in 135 years of record-keeping (National Climate Data Center data). Annual precipitation for 2008 totaled 54.7 inches, while the ten-year average was 43.6 inches. Most of the post-diversion monitoring years have been relatively wet, while the period just before the diversion was variable and included several dry years.

Almost all of the DITP flow received primary and secondary treatment (Wu 2009a, in prep.). Only a small amount of effluent, about 2% of the total flow, received only primary treatment (Figures 2-1 and 2-2), which was blended with secondary-treated effluent prior to discharge. The blended flows met all NPDES permit conditions.

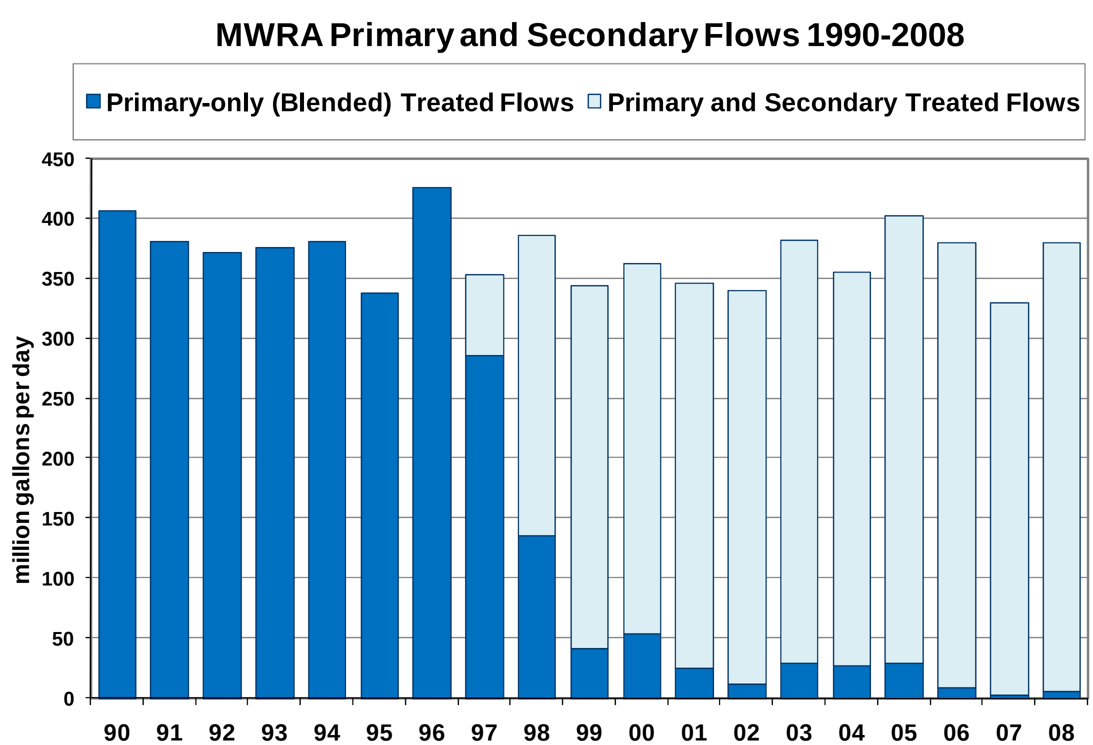


Figure 2-1. Annual effluent flows. *Average daily flow was relatively high in 2008. (Primary-only flows are blended with secondary flows, and the blended flows meet permit limits.)*

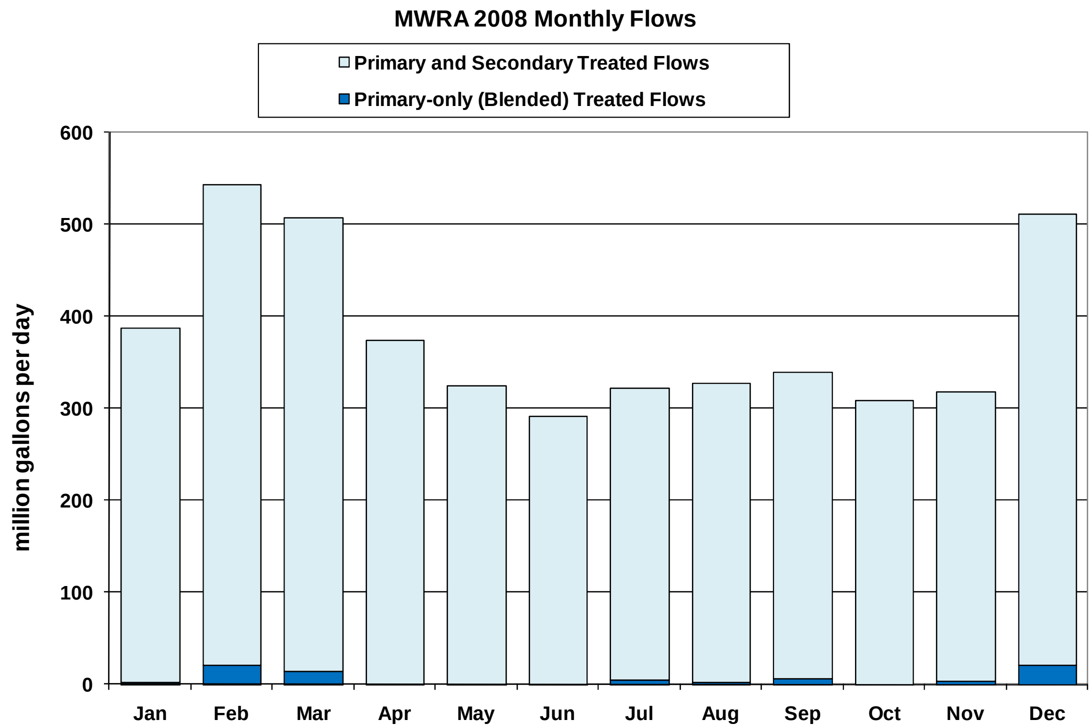


Figure 2-2. Monthly primary and secondary flows in 2008. *A small amount of primary-only treated effluent was blended with secondary flows and released during storms. (Blended flows meet all permit limits.)*

With the increased annual flow, contaminant loads also increased slightly in 2008 compared to 2007 but remained far below historic levels. Solids discharges were slightly greater than in 2006 and 2007 (Figure 2-3). Metals discharges were also slightly greater than in 2007 but much lower than they had been prior to the introduction of secondary treatment in 1997–2001 (Figure 2-4). Among the metals, only copper and zinc remain in significant quantities, with other metals present in only trace amounts. Mercury is now only rarely detected in effluent samples. About ten pounds of mercury were discharged during 2008, slightly more than was discharged in 2007, but well below the 50 pounds (0.14 pounds per day) that were discharged to Boston Harbor in 1999 (Figure 2-5).

Loads of organic contaminants were similarly low, with 3–4 pounds of polychlorinated biphenyls (PCBs) and 0.5–0.75 pounds of chlorinated pesticides discharged in 2008. These results reflect substantial, continuing reductions in contaminant levels throughout the post-diversion period (Delaney and Rex 2007, Delaney 2009). The current loadings are significantly lower than had been predicted during planning and permitting of the Massachusetts Bay outfall.

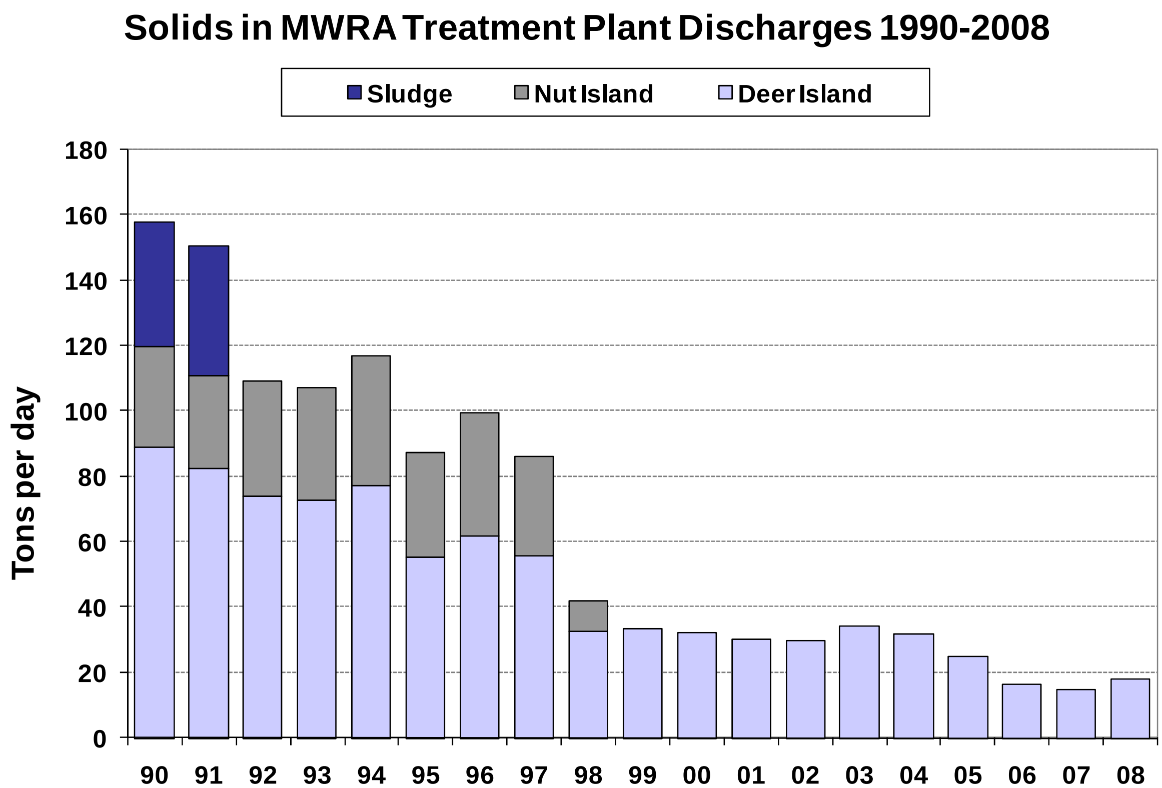


Figure 2-3. Annual solids discharges*. Solids discharges were slightly greater than the record low in 2007.*

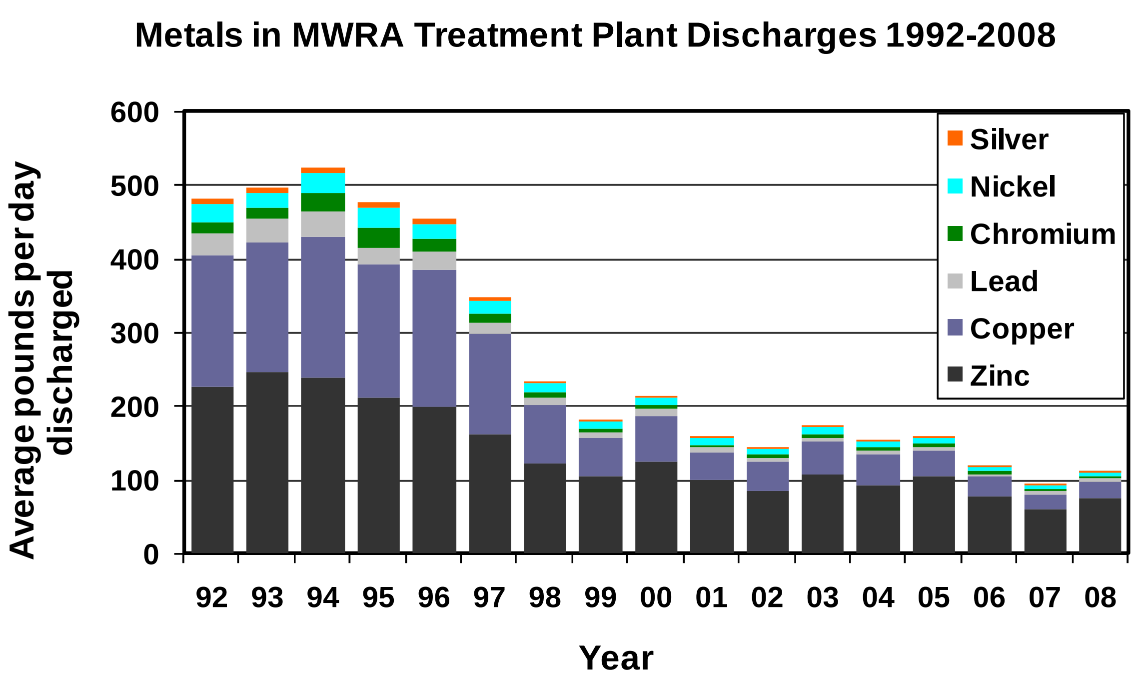


Figure 2-4. Annual metals discharges*. Total metals discharges remained low in 2008.*

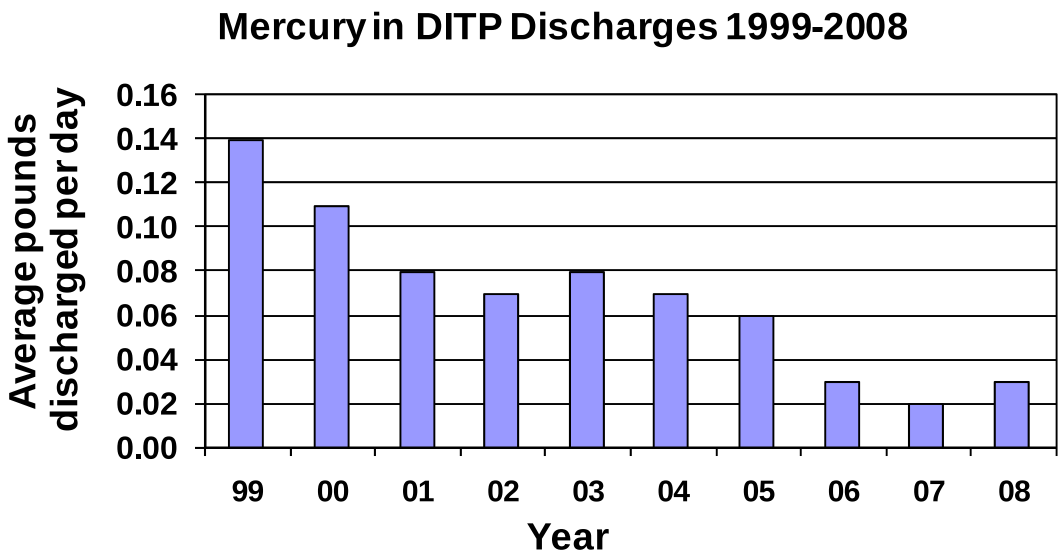


Figure 2-5. Annual mercury discharges*. Mercury is now only rarely detected in the effluent.*

Total nitrogen loads were also slightly higher in 2008 than in 2007, and the proportion of the load made up of ammonium remained high (Figure 2-6). About 10% of the ammonium in the sewage influent is removed by secondary treatment, and the biological treatment process converts some nitrate/nitrite and other forms of nitrogen to ammonium. MWRA continually evaluates nitrogen-removal technologies, so that nitrogen removal could be implemented at DITP (Bigornia-Vitale and Wu 2008). These evaluations meet a permit requirement that MWRA be able to swiftly implement such technologies, if the need arises. Nitrogen loadings remain below the Contingency Plan threshold.

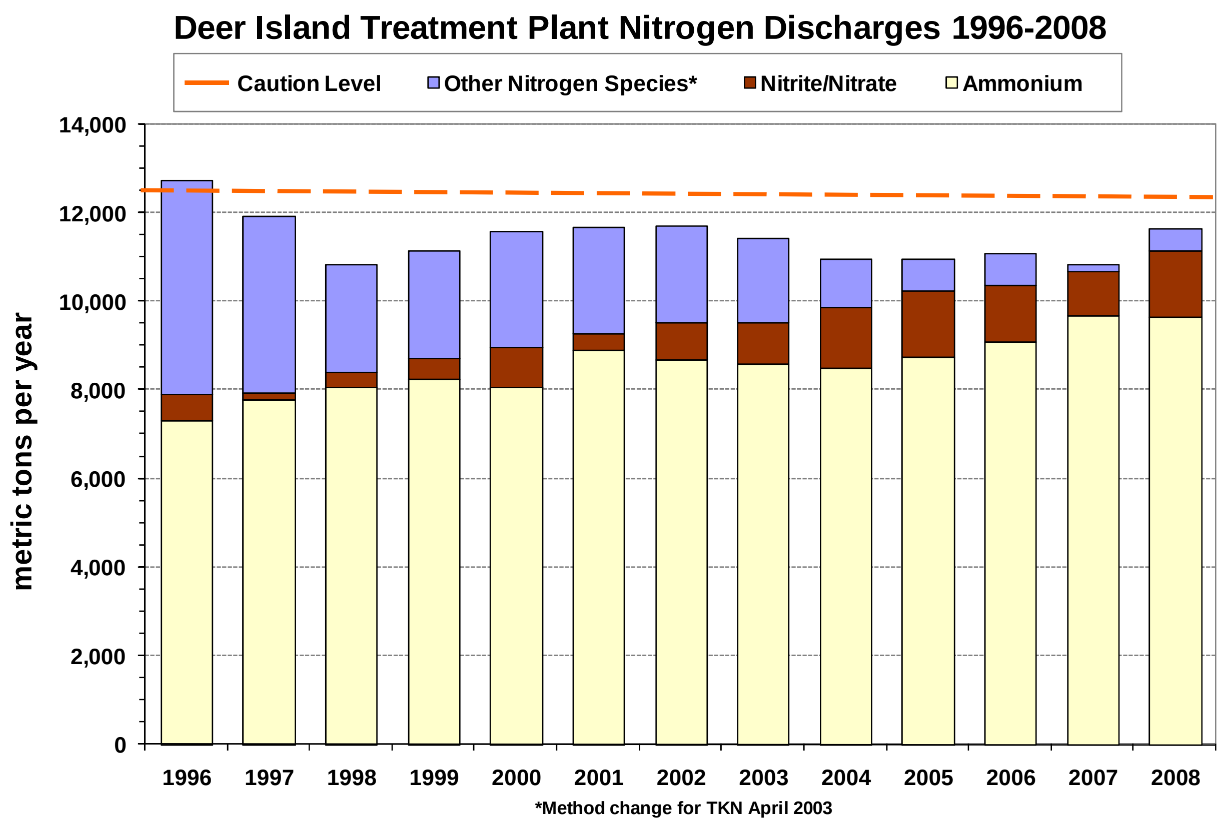


Figure 2-6. Annual nitrogen discharges. *Discharges of ammonium remained relatively high, a result of the secondary treatment process. (TKN = total Kjeldahl nitrogen, a measure of total nitrogen in the effluent)*

Biochemical oxygen demand (BOD), measured as carbonaceous BOD, also increased slightly in 2008, to about the same level as was measured in 2006 (Figure 2-7). This increase from a record low in 2007 reflected the increase in flow, but remained well below levels that might be expected to affect ambient waters at the discharge. Nitrogenous BOD, which is a result of the biological processes in secondary treatment and not a permit limit or Contingency Plan parameter, remained higher than historic levels but decreased slightly in 2008.

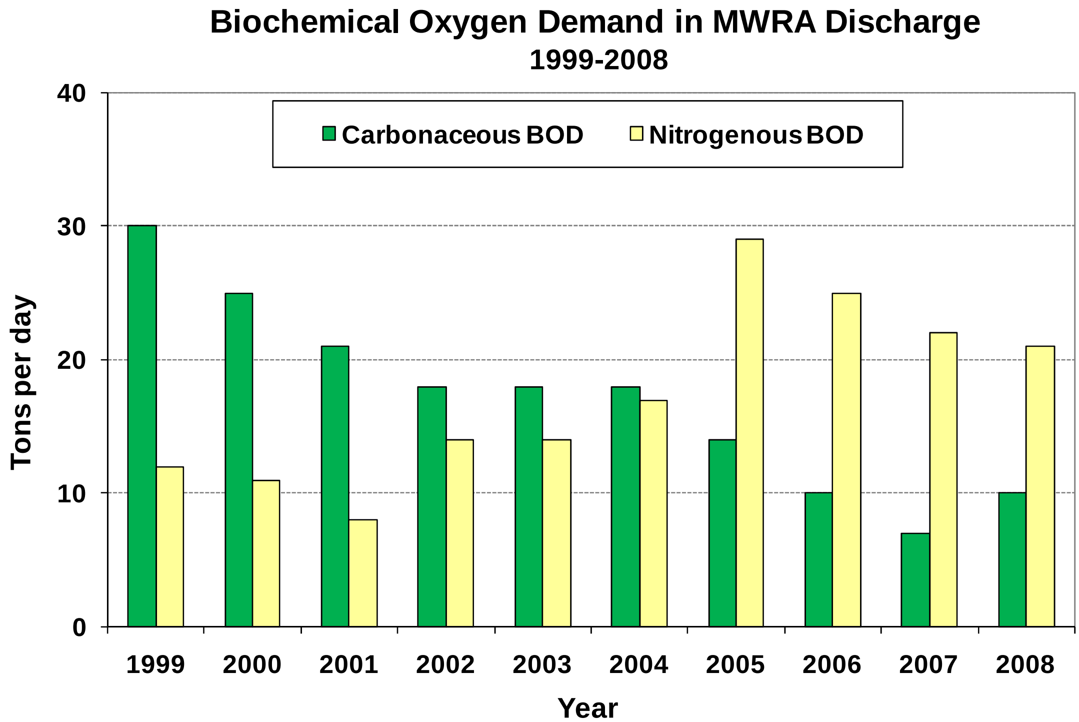


Figure 2-7. Average annual biochemical oxygen demand. *MWRA's permit limits carbonaceous BOD, which remained low in 2008. Nitrogenous BOD is the result of microbiological breakdown that occurs during secondary treatment. Ambient monitoring data show that the discharge has had no effect on dissolved oxygen in the environment.*

Contingency Plan Thresholds

As in 2007, DITP had no permit violations and no exceedances of the Contingency Plan thresholds in 2008 (Table 2-1). In acknowledgment of this record, MWRA was awarded a Gold Peak Performance award from the National Association of Clean Water Agencies. This award recognizes facilities that have achieved 100% compliance with their NPDES permits in a calendar year.

Table 2-1. Contingency Plan threshold values and 2008 results for effluent monitoring. *(cBOD=carbonaceous biological oxygen demand, NOEC=no observable effect concentration, LC50=50% mortality concentration, MGD=million gallons per day; NA=not applicable)*

Parameter	Caution Level	Warning Level	2008 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, phytoplankton, and zooplankton at stations in Boston Harbor, Massachusetts Bay, and Cape Cod Bay (Figures 3-1, 3-2).

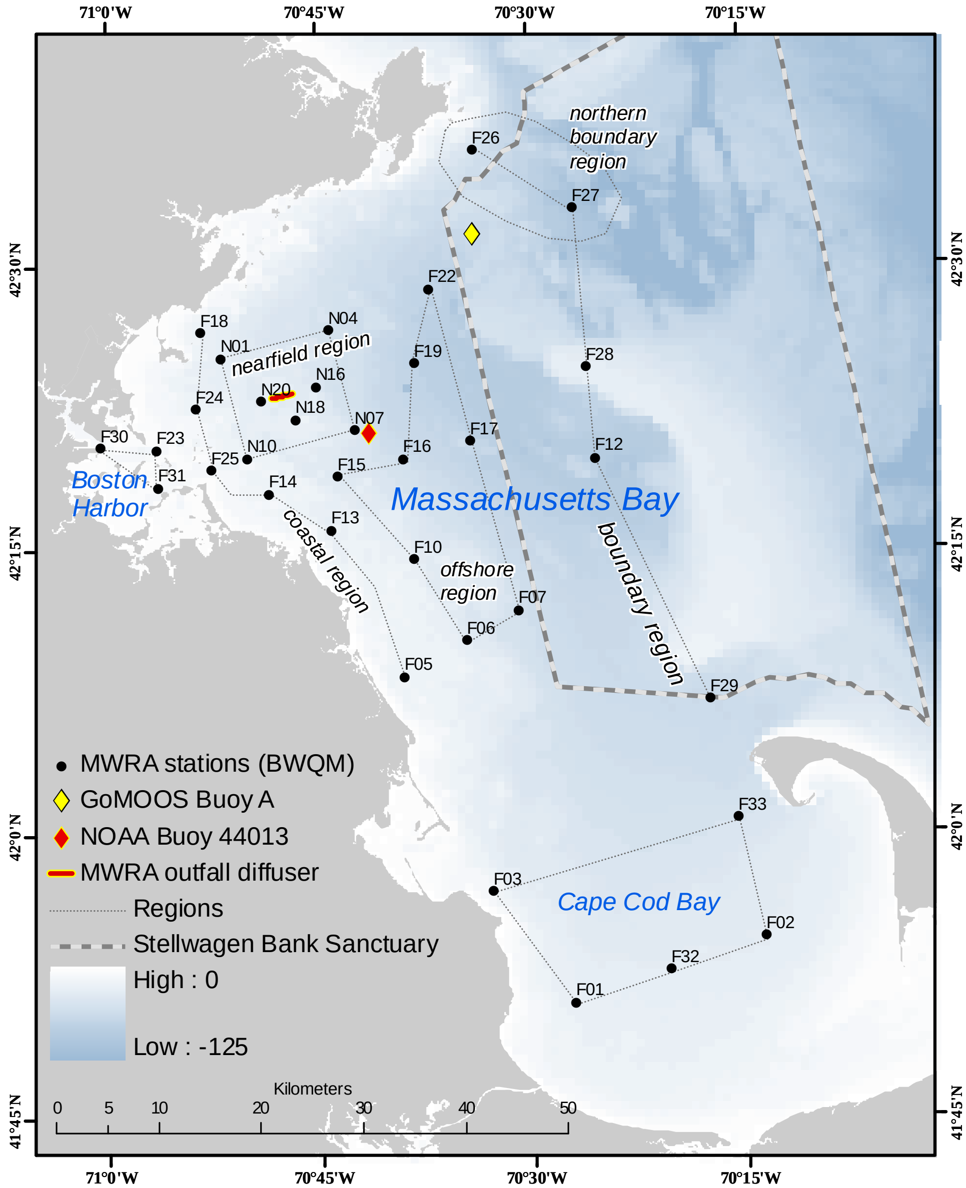


Figure 3-1. MWRA Bay Water Quality Monitoring (BWQM) stations and regional groupings. *"Farfield" stations include all stations in Boston Harbor; the coastal, offshore, and northern boundary regions; and Cape Cod Bay. Also shown are the MWRA outfall; two instrumented buoys, one operated by the Gulf of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

The Massachusetts Bay stations located within seven kilometers of the outfall diffuser are called nearfield stations. Those beyond are grouped into regions, which together are called farfield stations. Sampling is augmented by instrumented buoys and remote sensing. A separate Boston Harbor program contributes additional data.

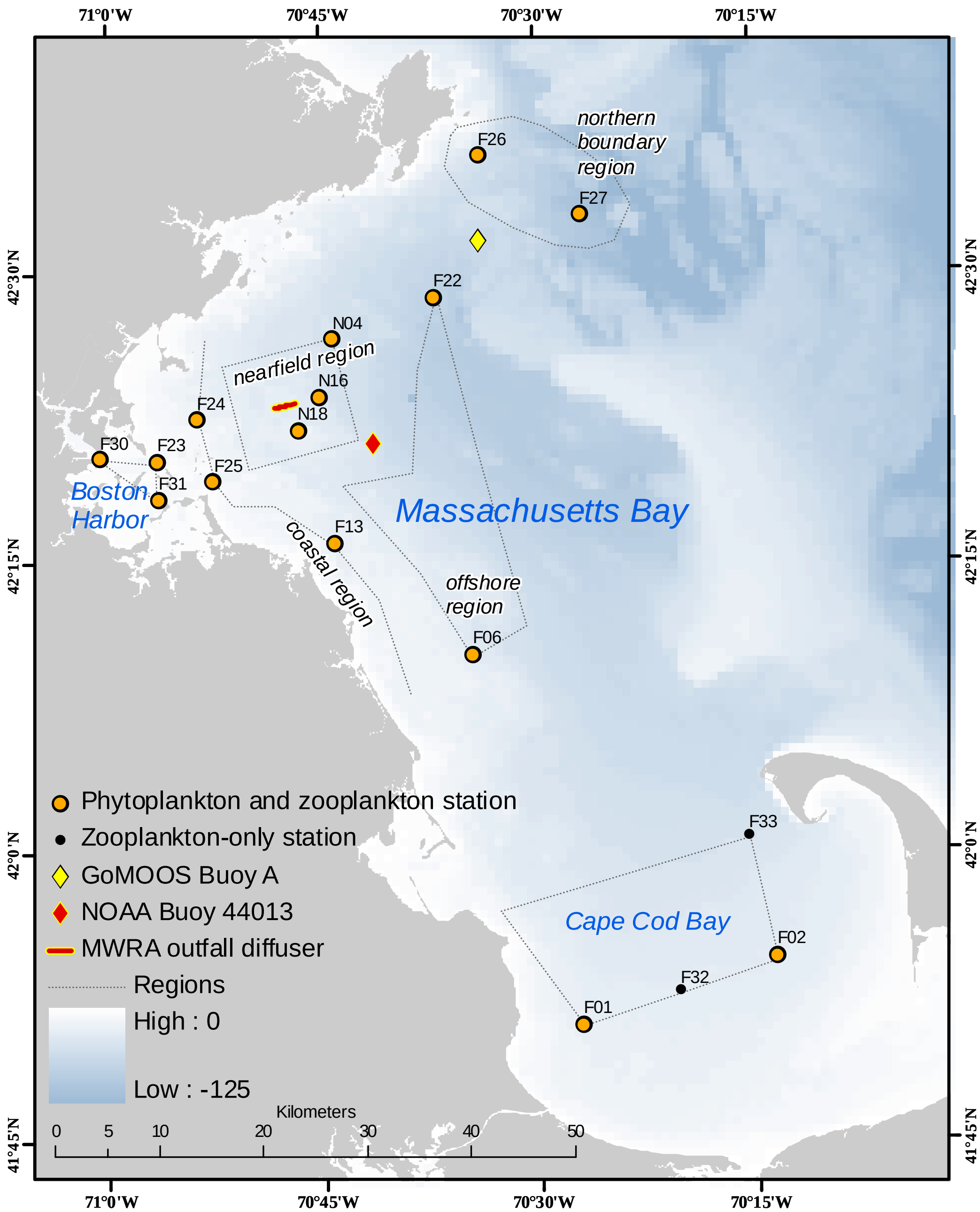


Figure 3-2. MWRA plankton stations. *The stations are a subset of those included in water quality monitoring. Regional groupings, the instrumented buoys, and the MWRA outfall are also shown.*

Physical Conditions

Baseline and post-diversion monitoring have found 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 provides a context for interpreting the annual monitoring data.

Because of the high precipitation throughout 2008, the year was also marked by greater than average flows from the Merrimack and Charles rivers (Figures 3-3 and 3-4). Flow from the Merrimack River tends to reflect regional conditions and affects the salinity of bottom waters. Flow from the Charles River reflects local conditions and may influence surface salinity.

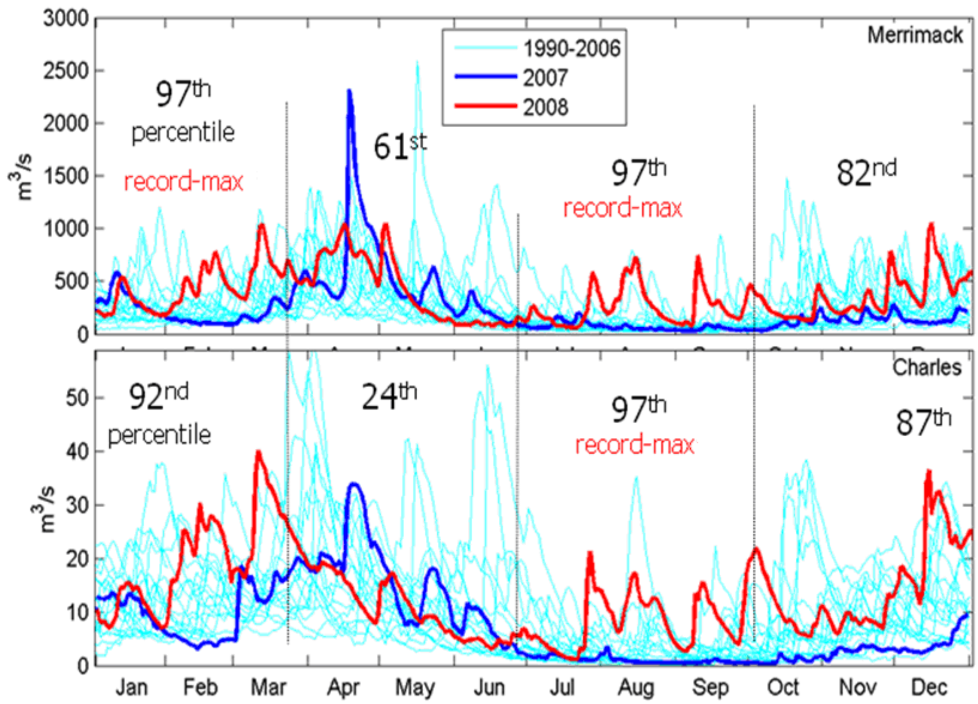


Figure 3-3. Flows of the Merrimack (top) and Charles (bottom) rivers during 2008 were relatively high over the course of the year*. In some cases, quarterly flows reached record highs for the monitoring program. For example, the average January–March flow in the Merrimack River was the greatest in 19 years of monitoring, translating to the 97th percentile. In July–September, flow from both rivers reached record highs. Flows during 2007, shown for contrast, were high in the spring, but very low in the summer and fall.*

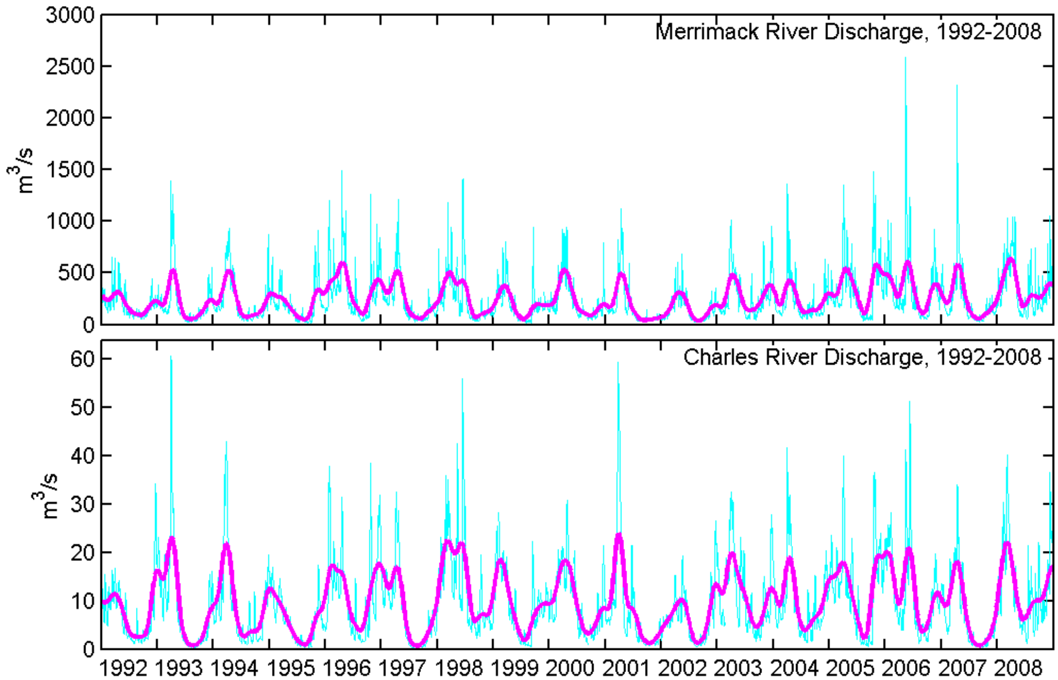


Figure 3-4. Merrimack River (top) and Charles River (bottom) discharges to the ocean. *(Data are from gauges at Lowell and Waltham, Massachusetts; smooth lines are 3-month moving averages; note the differences in scale for the rivers.)*

The wind-forcing conditions in 2008 were similar to 2006–2007 and within the range observed throughout the monitoring program (Figure 3-5). In most years, spring is a transitional period between winter downwelling and spring upwelling conditions. Peak upwelling, the condition in which winds from the south and southwest push surface waters away from the coast, occurred in July, but over the course of the year, downwelling conditions predominated, as they have in recent years. Wave heights were average, with no strong storms that would be expected to resuspend sediments.

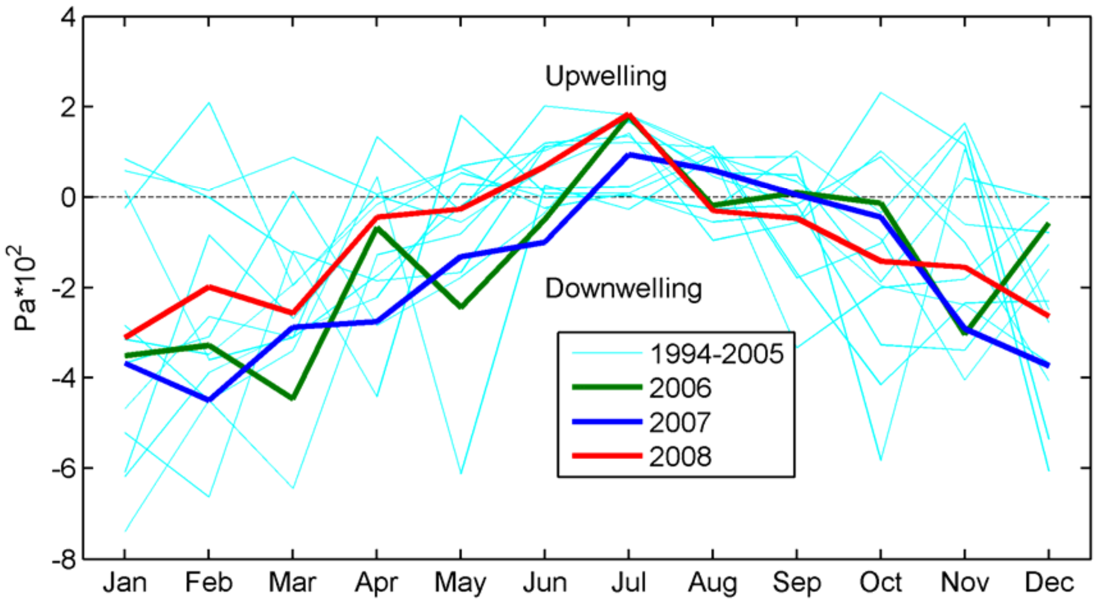


Figure 3-5. Monthly average wind stress at the Boston Buoy. *Positive values indicate winds from the south or southwest, which result in upwelling-favorable wind stress; negative values indicate winds from the north or northeast, which favor downwelling. Data from 2006, 2007, and 2008 show that downwelling conditions have predominated in recent years.*

Surface water temperatures were warmer than average, particularly during the summer months (Figure 3-6). In many other years, the summer has been marked by cooler waters brought to the surface through upwelling. Bottom waters were cooler than average during May, but were warm during the late summer and fall.

Salinity was affected by the wet year (Figure 3-7). Surface salinity was particularly low during the late fall, a period when in other years, the water has become more saline. The annual average nearfield surface-water salinity was the lowest measured since the monitoring program began in 1992.

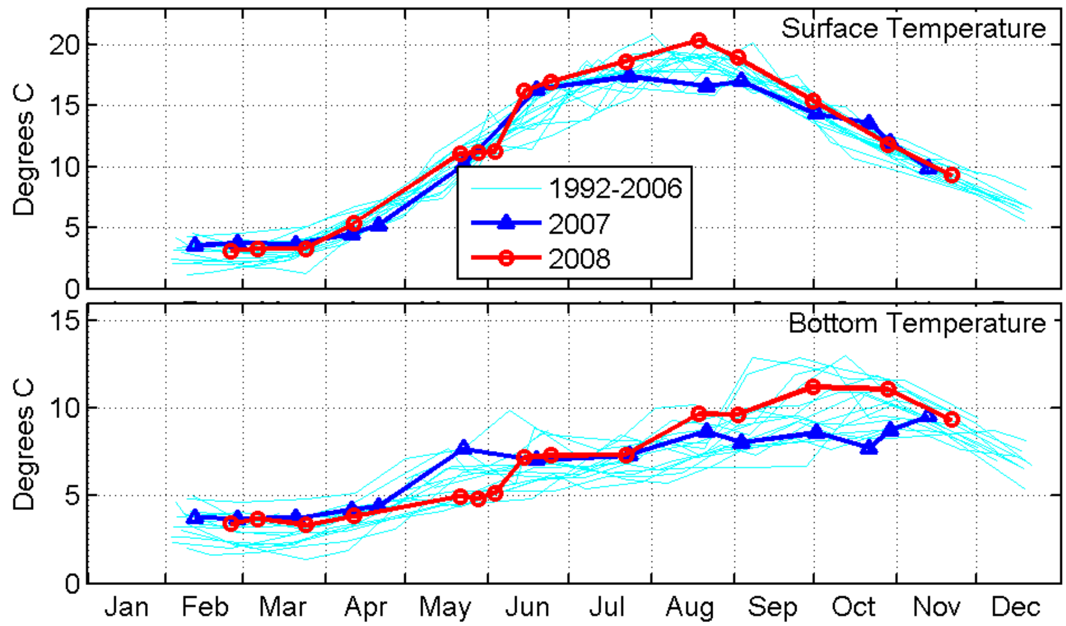


Figure 3-6. Nearfield surface and bottom water temperature. *Summer surface temperatures were warm. Bottom waters were warmer than average during the late summer and fall. (Data from 2007 are shown for comparison.)*

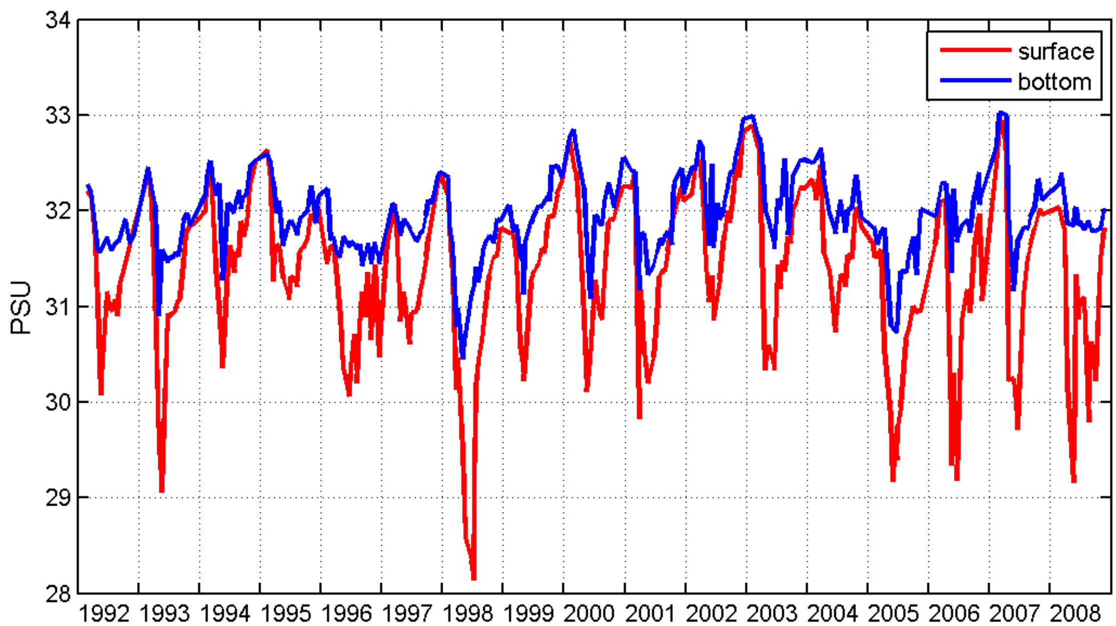


Figure 3-7. Nearfield surface and bottom water salinity. *Surface measurements are the lower line. Surface salinity in 2008 was markedly low in the late summer and fall (second sharp dip in 2008), reflecting the unusually wet year.*

Water Quality

Water quality measurements for 2008 continued to confirm predictions that there would be detectable local effects of the discharge for certain parameters and no detectable adverse effects for other parameters or for any measurements outside the immediate vicinity of the discharge (Libby *et al.* 2009). Measurements of nutrients, dissolved oxygen, phytoplankton biomass (measured as chlorophyll), and productivity in 2008 continued to show improvements in Boston Harbor.

The changes in the bay were evaluated using "Before-After, Control-Impact" (BACI) statistical analyses (Figure 3-8), which compared data from an "impact" area (the inner nearfield) with those from "control" regions (the outer nearfield, offshore Massachusetts Bay, and Cape Cod Bay). None of the measured changes have suggested large or unexpected effects of the discharge.

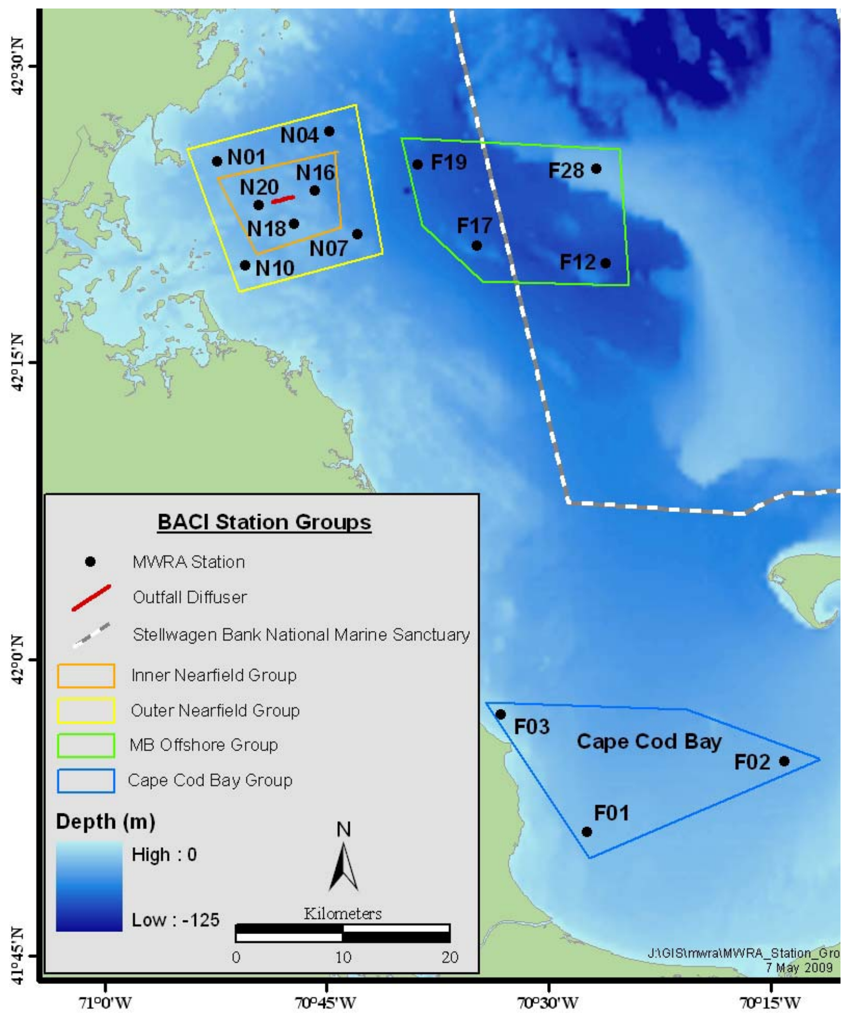


Figure 3-8. Before-After, Control-Impact (BACI) station groups. *The BACI analyses were used to evaluate effects of the outfall in comparison to regional changes.*

Ammonium is the major component of total inorganic nitrogen in the effluent, and simple dilution models suggested that, following the diversion, increased concentrations of ammonium would be detectable in the nearfield. As anticipated during planning and permitting, there have been increases in ammonium at the stations closest to the discharge compared to baseline conditions and relative to regional background conditions (Figure 3-9). At the same time, much greater decreases in ammonium concentrations have been measured in Boston Harbor and in the coastal area.

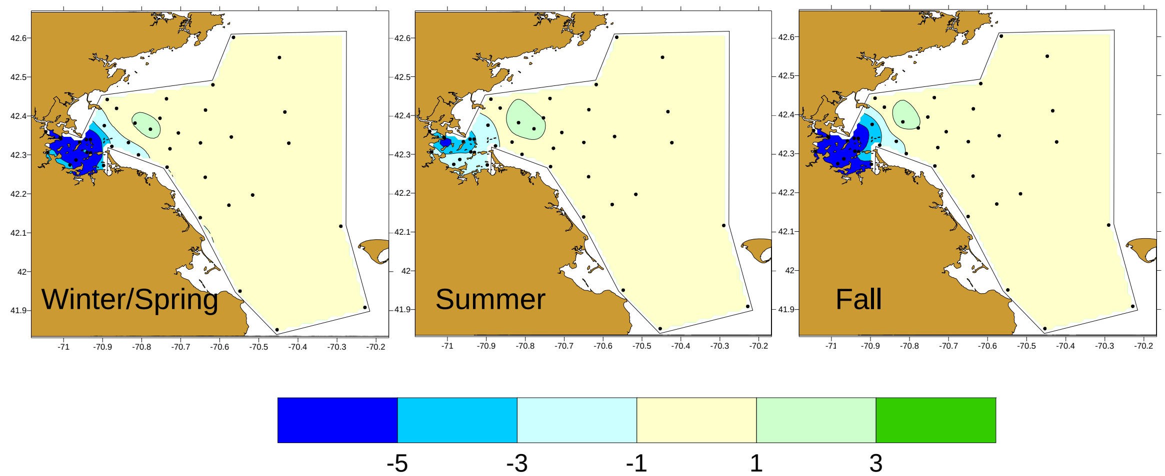


Figure 3-9. Changes in seasonal ammonium concentrations (µM) from the baseline to the post-diversion period. *There have been localized increases in ammonium concentrations near the outfall with concurrent decreases in ammonium concentrations in Boston Harbor.*

The increased ammonium concentrations in the nearfield have become less apparent in 2005–2008 (Figure 3-10). It seems that ammonium concentrations have also decreased in the coastal and northern boundary regions. Increases in nitrate levels have occurred throughout the region, including the nearfield, but this change is not thought to be outfall-related.

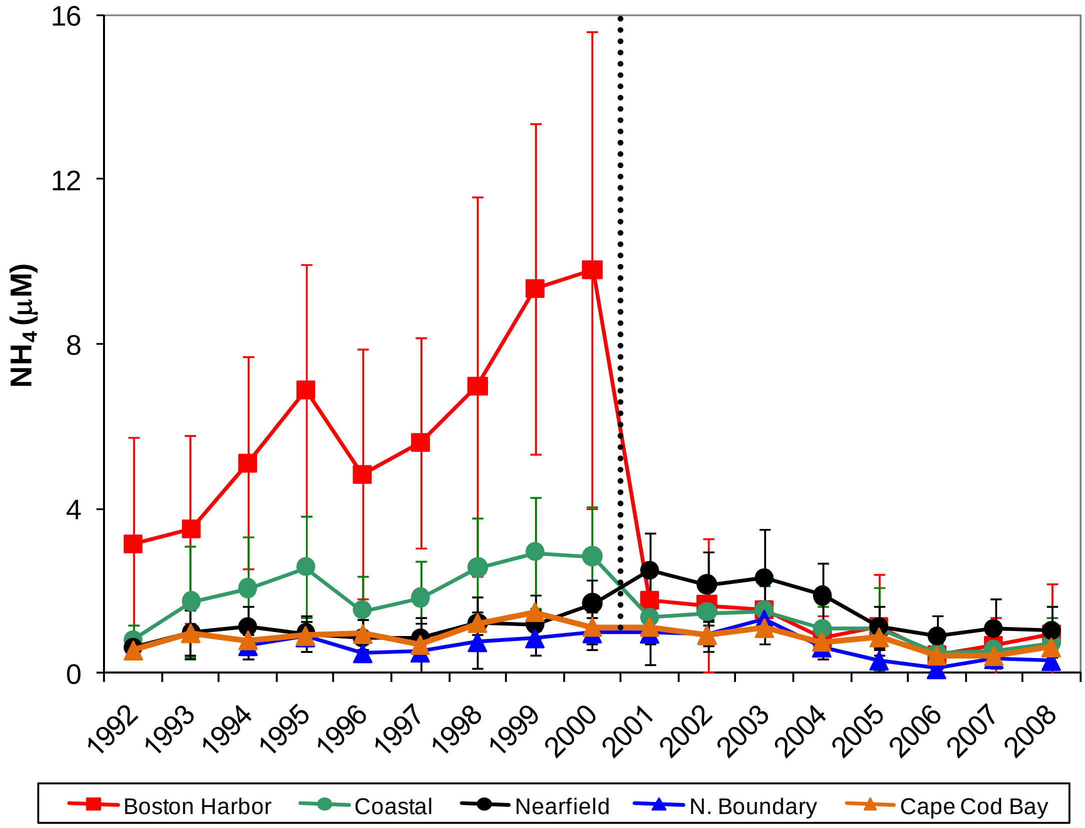


Figure 3-10. Annual mean ammonium concentrations. *Data represent all depths and all stations sampled within each region. Vertical dotted line shows when the bay outfall came on-line. Error bars represent ±1 standard deviation.*

Similarly, there have been region-wide changes in chlorophyll (Figure 3-11) and particulate organic carbon (not shown). Summer concentrations of chlorophyll have decreased in Boston Harbor, while there has been a trend towards higher winter/spring concentrations throughout Massachusetts Bay and lower fall concentrations at the offshore and northern boundary stations. *Phaeocystis pouchetii* blooms, which have occurred over much of the bay during each of the years since 2000, have caused the increased spring chlorophyll levels. Regional processes have been responsible for the increased *Phaeocystis pouchetii* counts.

Decreases in concentrations of chlorophyll in Boston Harbor are evident in the summer. During the years prior to the diversion, when effluent was discharged into the harbor, higher levels persisted from the spring through fall (Figure 3-12).

Primary production rates have been lower in recent years (Figure 3-13). Investigators hypothesize that this change is related to lower than average winds.

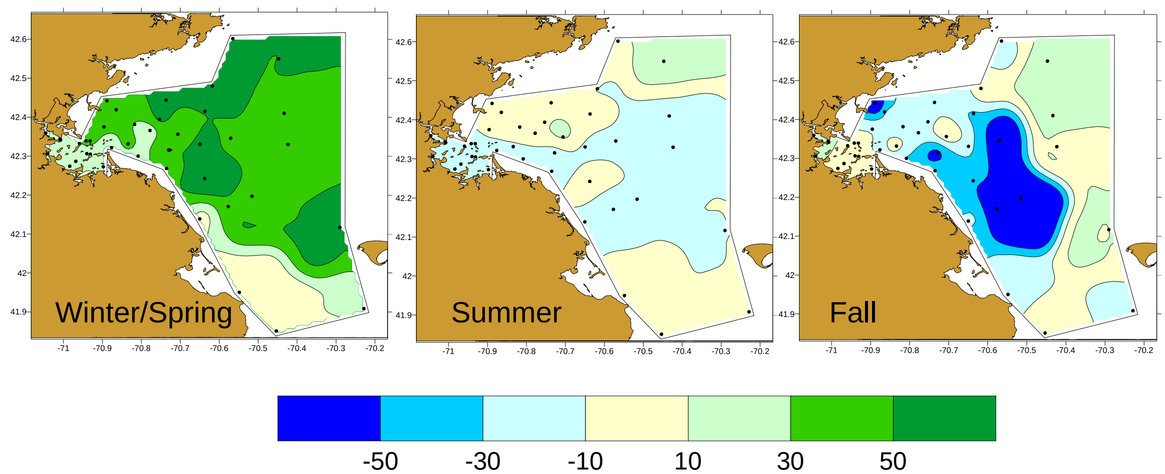


Figure 3-11. Changes in seasonal chlorophyll concentrations (mg m^{-2}) from the baseline to the post-diversion period. *(Post-diversion minus baseline values.) Changes in Massachusetts Bay have reflected regional conditions and are not indicative of any effect from the relocated outfall.*

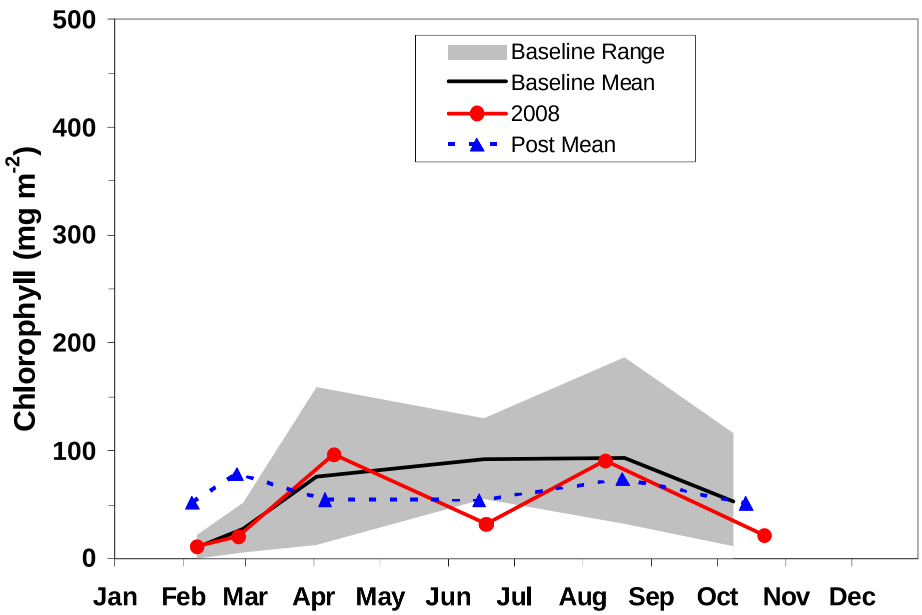


Figure 3-12. 2008 Boston Harbor chlorophyll levels compared to the baseline range, baseline mean, and post-diversion mean. *Decreases in summer chlorophyll levels show a change to a bimodal pattern of spring and fall phytoplankton blooms, which is characteristic of temperate coastal waters.*

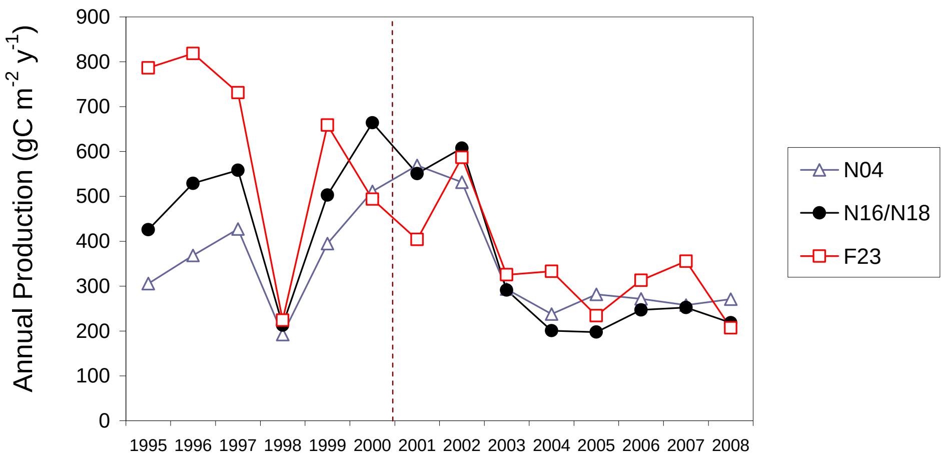


Figure 3-13. Potential annual production. *There has been a significant decrease in production in Boston Harbor (Station F23) and no significant change in the nearfield (Stations N04 and N18) since the 2000 outfall diversion. Vertical dotted line represents when the bay outfall came on-line.*

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 the nearfield bottom waters have shown no response to the outfall. There has been no change in levels or the seasonal pattern in any year. Summer and fall bottom water dissolved oxygen levels were relatively high in 2008 (Figure 3-14).

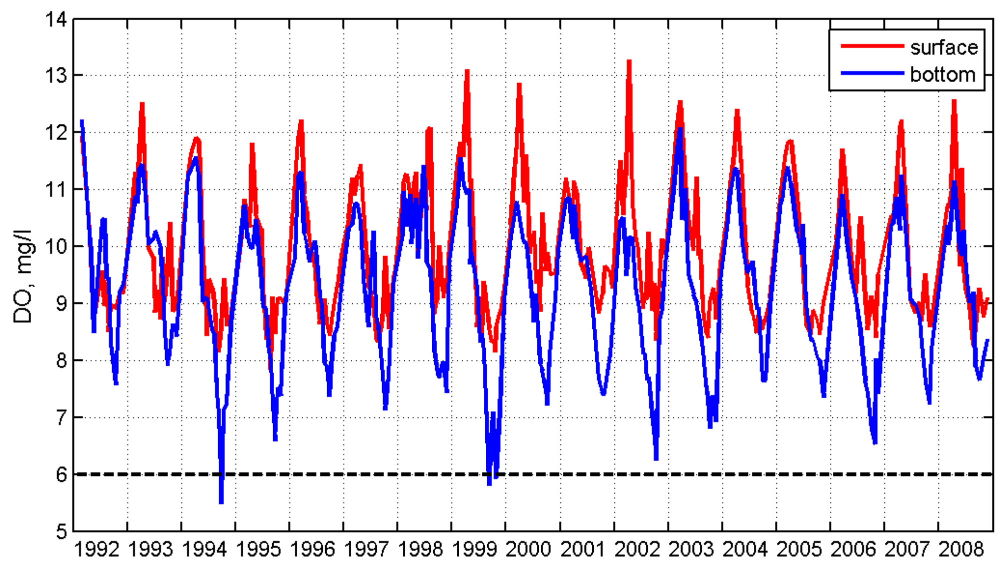


Figure 3-14. Nearfield surface and bottom dissolved oxygen concentrations. *Bottom measurements are the lower line. Minimum levels were relatively high in 2008. Dotted line shows the state water quality criterion.*

Phytoplankton Communities

Several long-term patterns in phytoplankton abundance continued in 2008. There have been increased numbers of microflagellates (although this apparent increase may reflect a methodological underestimate for 1992–1995) and decreased abundance of diatoms during the post-diversion years (Libby *et al.* 2009). These changes are region-wide, not related to the outfall.

A bloom of the colonial nuisance species *Phaeocystis pouchetii* (Figure 3-15) and a major *Alexandrium fundyense* red tide with high toxicity were the most notable events for the phytoplankton community in 2008. The *Phaeocystis* bloom was one of the largest in terms of cell abundance that has been recorded during the monitoring program (Figure 3-16), but was of short duration. The bloom was recorded throughout the monitoring area in April, ending by the May (nearfield-only) sampling survey (Figure 3-17). Satellite images suggest that the bloom started in the western Gulf of Maine in April.

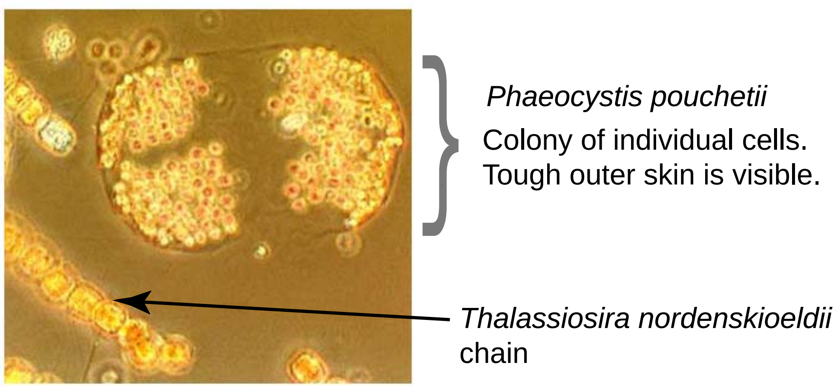


Figure 3-15.* Phaeocystis pouchetii *colony from Massachusetts Bay*, *ca. 250um long by 150 um wide (Station N18, March 14, 2000, abundance 1.3 million cells/L; photograph by D. Borkman, University of Rhode Island).

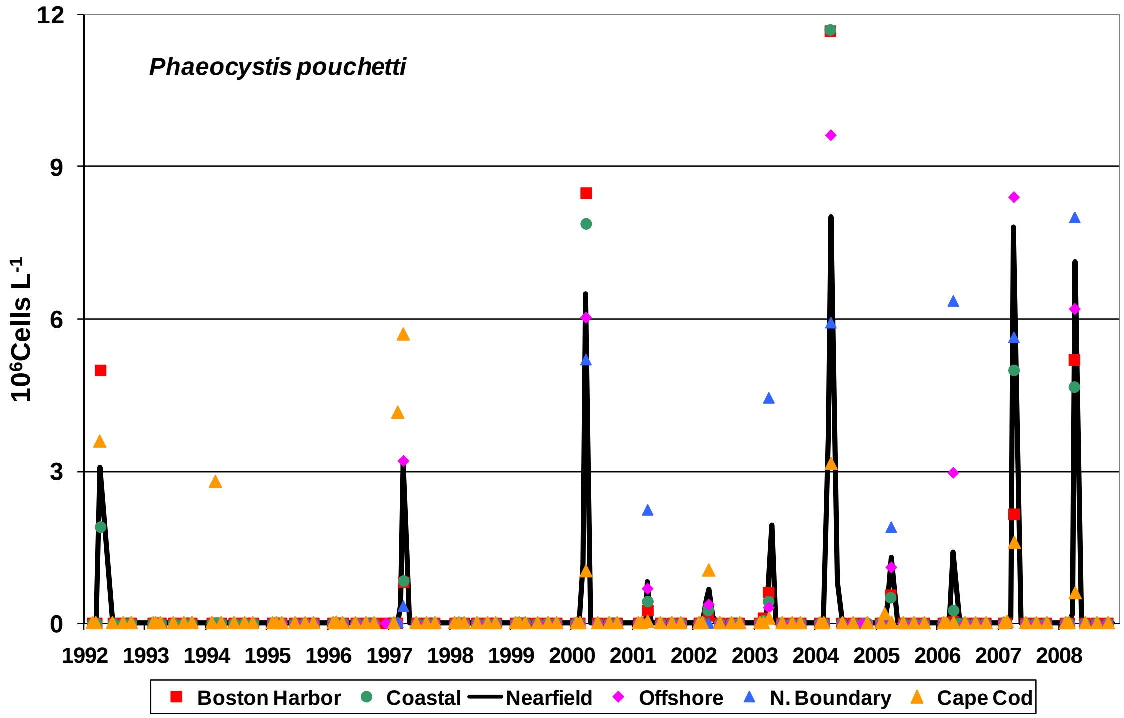


***Figure 3-16. Abundance of* Phaeocystis pouchetii *since 1992.** The 2008 bloom was large in terms of cell abundance but of short duration.*

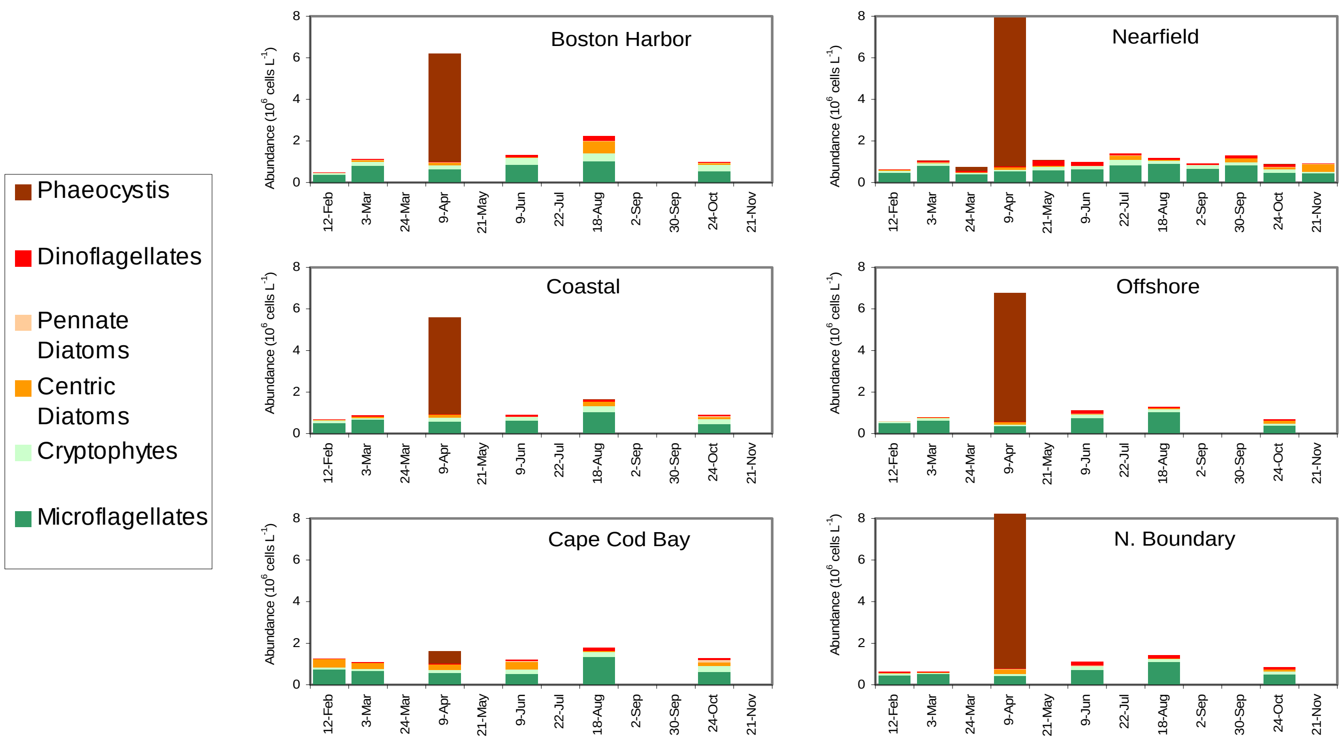


Figure 3-17. Nearfield abundance of dominant phytoplankton groups in 2008.

Similar to 2005 and 2006, there was a large bloom of the toxic dinoflagellate *Alexandrium fundyense* (red tide) (Figure 3-18), which produces a toxin that causes paralytic shellfish poisoning (PSP). The 2008 red tide event began in April, in the coastal waters of Maine, and was transported to Massachusetts Bay by winds from the northeast. MWRA and the Woods Hole Oceanographic Institution (WHOI) mobilized surveys to track the progress of the red tide. MWRA completed seven surveys in April–June and WHOI conducted six surveys in April–July. MWRA surveyed Boston Harbor in early June (Figure 3-19).

Toxicity spread throughout Massachusetts Bay and Boston Harbor but did not result in closing shellfish beds in Cape Cod Bay. Local weather may have been the primary factor in transporting the bloom into Boston Harbor, while sparing Cape Cod Bay. The bloom ended in June. More about red tides is presented in Section 6, Special Studies.

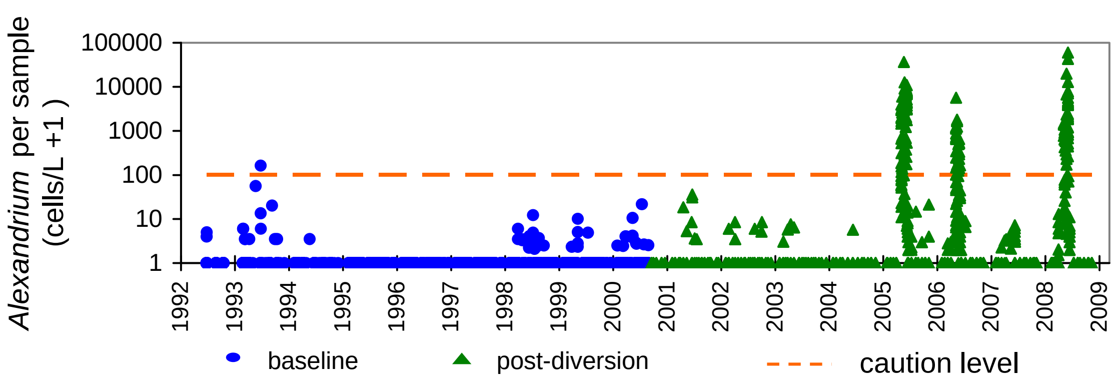


Figure 3-18. Nearfield abundance of* Alexandrium fundyense *since 1992. *The 2008 bloom was similar to blooms in 2005 and 2006.*

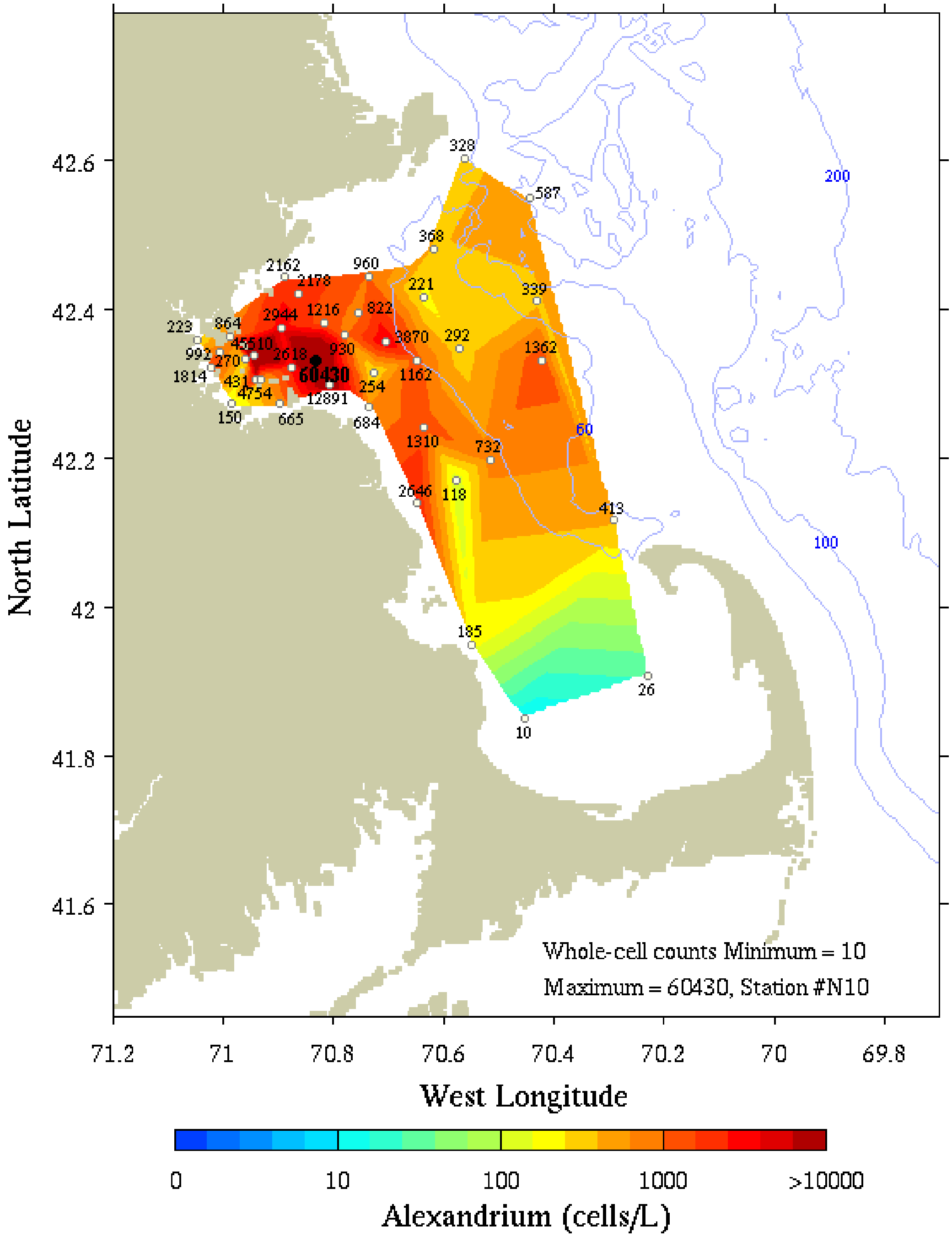


Figure 3-19.* Alexandrium fundyense *cell concentrations in Massachusetts Bay and Boston Harbor in June 2008. *The 2008 bloom did not result in closures in Cape Cod Bay.*

Zooplankton Communities

The structure of the zooplankton community in the nearfield in 2008 was similar to that of many earlier years, with abundance approximating the baseline mean for several surveys (Figure 3-20). Similar to 2007, monitoring did not show the decline in total annual abundance of zooplankton that had been observed during 2001–2006. A rebound in the abundance of the copepods and especially the small species *Oithona similis* was responsible for this recovery. The reasons for the lower copepod abundance during 2001–2006 are not clear but appear to be related to large-scale climatic conditions. In Boston Harbor, annual zooplankton abundance has been slightly lower since the outfall diversion, and mean abundance continued to be relatively low in 2008. There have been no changes in zooplankton abundance in Cape Cod Bay.

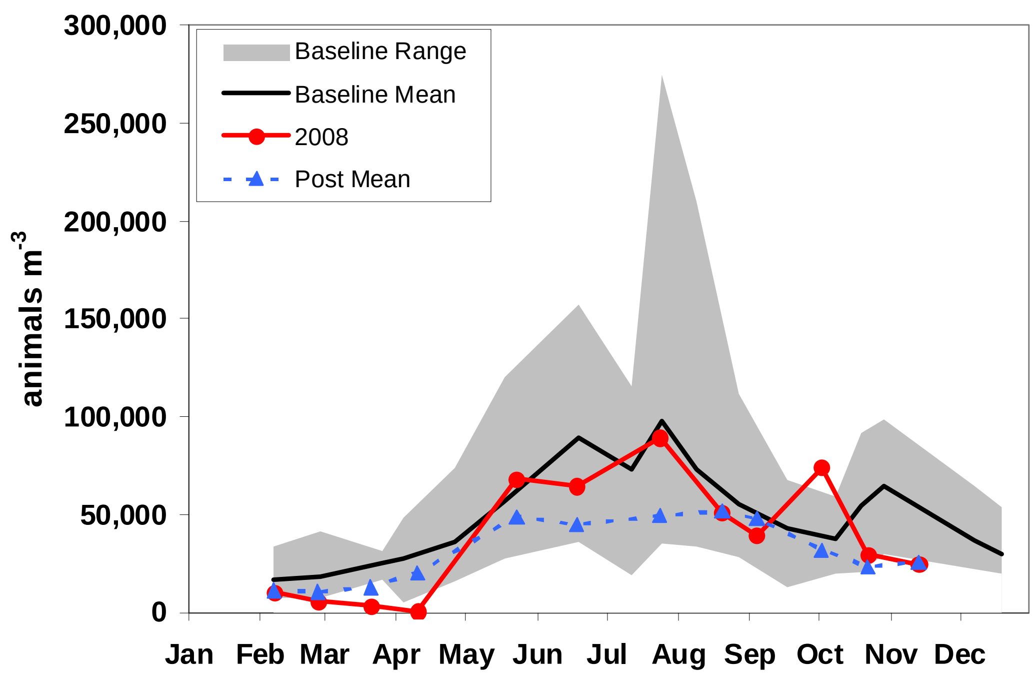


Figure 3-20. 2008 nearfield survey mean total zooplankton abundance compared to baseline range, baseline mean, and post-diversion mean. *For much of the year, abundance approximated the baseline mean.*

Contingency Plan Thresholds

Water quality parameters were within normal ranges throughout 2008. There was one exceedance of a nuisance algae threshold (Table 3-1), when samples collected in May exceeded the *Alexandrium fundyense* caution level. This exceedance had been anticipated, based on information on overwintering *Alexandrium* cysts in the sediments off the coast of Maine (see Section 6, Special Studies) and spring measurements of *Alexandrium* cells in coastal waters of Maine and New Hampshire. In response to the exceedance, MWRA, in cooperation with WHOI and the Massachusetts Division of Marine Fisheries, implemented its rapid-response *Alexandrium* survey plan (Libby 2006), which provides for assessment of rapidly developing and potentially large blooms. Results from those surveys indicated that the bloom proceeded in a pattern that was consistent with historic progressions and that the outfall discharge did not affect its intensity, timing, or duration.

Table 3-1. Contingency Plan threshold values and 2008 results for water-column monitoring. *(DO=dissolved oxygen)*

Location/ Parameter	Specific Parameter	Baseline	Caution Level	Warning Level	2008 Results
Bottom water nearfield	Dissolved oxygen concentration	Background 5th percentile 5.75 mg/L	Lower than 6.5 mg/L for any survey (June-October) unless background conditions are lower	Lower than 6.0 mg/L for any survey (June-October) unless background conditions are lower	Lowest survey mean = 7.71 mg/L
	Dissolved oxygen percent saturation	Background 5th percentile 64.3%	Lower than 80% for any survey (June-October) unless background conditions are lower	Lower than 75% for any survey (June-October) unless background conditions are lower	Lowest survey mean = 85.7%
Bottom water Stellwagen Basin	Dissolved oxygen concentration	Background 5th percentile 6.2 mg/L	6.5 mg/L for any survey (June-October) unless background conditions lower	Lower than 6.0 mg/L for any survey (June-October) unless background conditions are lower	Lowest survey mean = 7.06 mg/L
	Dissolved oxygen percent saturation	Background 5th percentile 66.3%	Lower than 80% for any survey (June-October) unless background conditions	Lower than 75% for any survey (June-October) unless background conditions are lower	Lowest survey mean = 74.8%
Bottom water nearfield	DO depletion rate (June-October)	0.024 mg/L/d	0.037 mg/L/d	0.049 mg/L/d	0.017 mg/L/d
Chlorophyll nearfield	Annual	79 mg/m^2	118 mg/m^2	158 mg/m^2	67 mg/m^2
	Winter/spring	62 mgml^2	238 mg/m^2	None	96 mg/m^2
	Summer	51 mg/m^2	93 mg/m^2	None	42 mg/m^2
	Autumn	97 mg/m^2	212 mg/m^2	None	64 mg/m^2
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	468,000 cells/L	2,020,000 cells/L	None	1,980,000 cells/L
	Summer	72 cells/L	357 cells/L	None	Absent
	Autumn	317 cells/L	2,540 cells/L	None	Absent
Nuisance algae nearfield *Pseudo-nitzschia*	Winter/spring	6,200 cells/L	21,000 cells/L	None	Absent
	Summer	14,600 cells/L	43,100 cells/L	None	540 cells/L
	Autumn	9,940 cells/L	24,700 cells/L	None	171 cells/L
Nuisance algae nearfield *Alexandrium fundyense*	Any nearfield sample	Baseline maximum = 163 cells/L	100 cells/L	None	60,430 cells/L. caution level exceedance
Farfield	PSP toxin extent	Not applicable	New incidence	None	No new incidence

4. Sea Floor

Sea-floor monitoring in 2008 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).

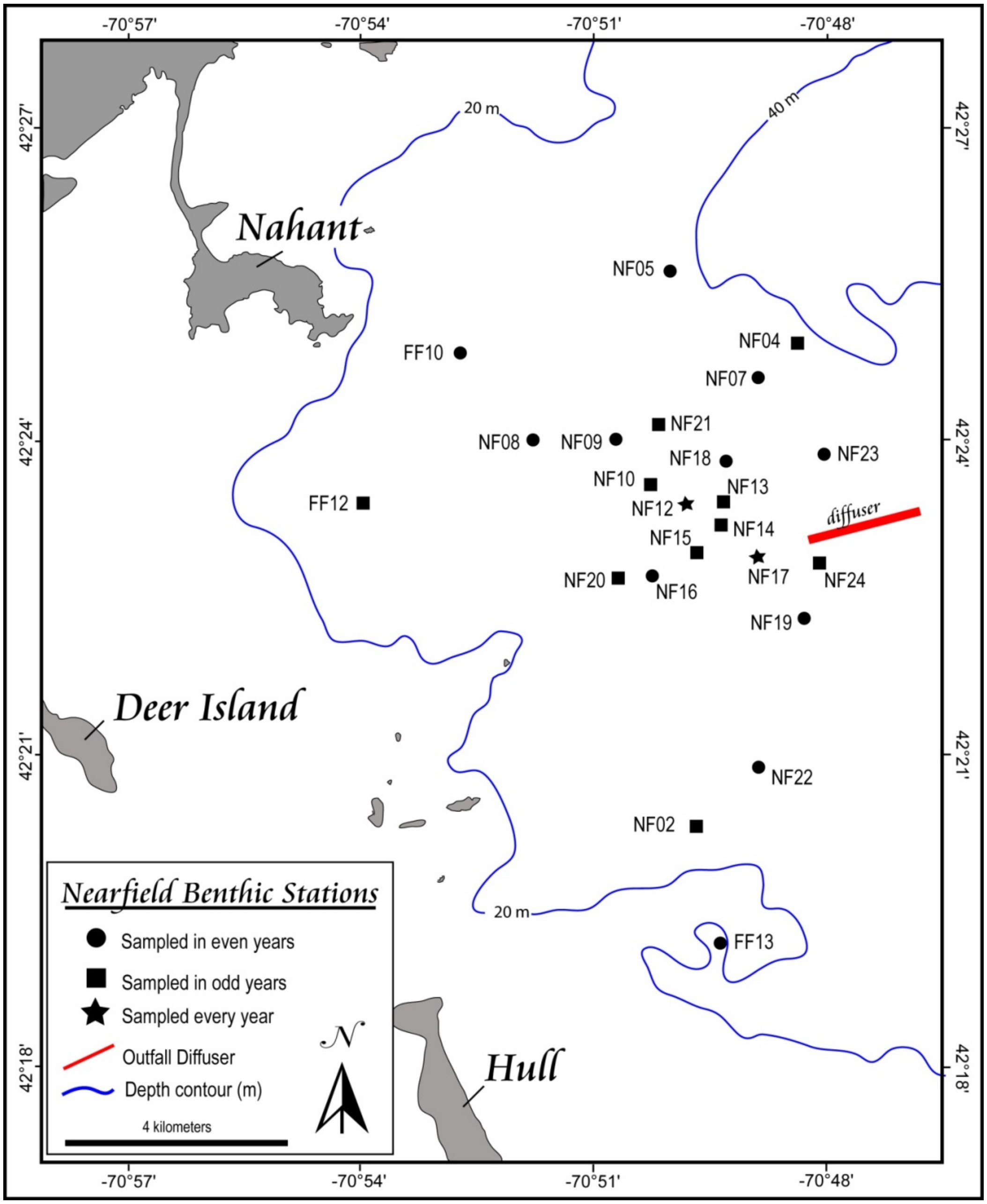


Figure 4-1. Locations of nearfield soft-bottom stations for chemical parameters, sediment-profile imaging, and community parameters.

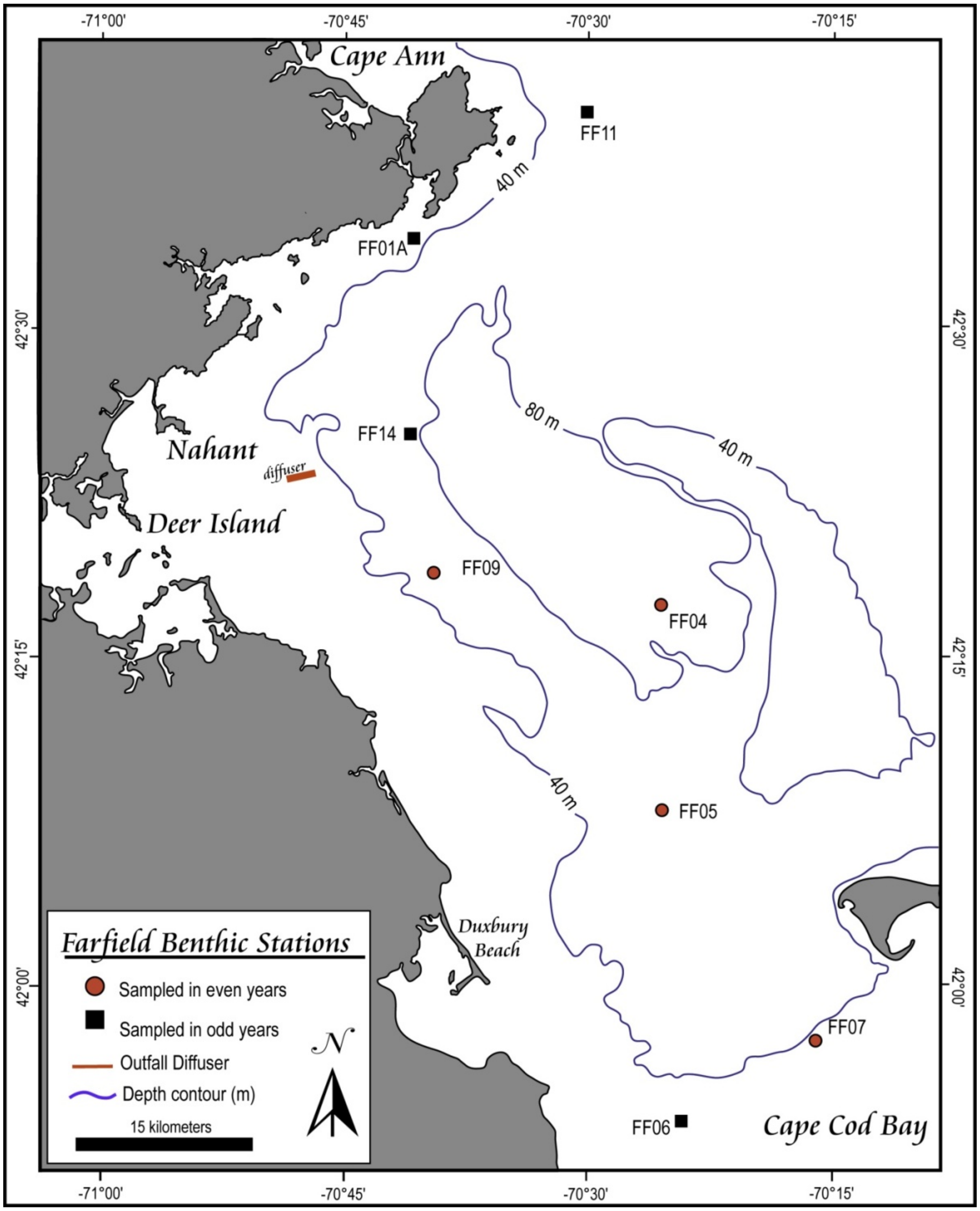


Figure 4-2. Locations of farfield soft-bottom stations for chemical and community parameters.

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.

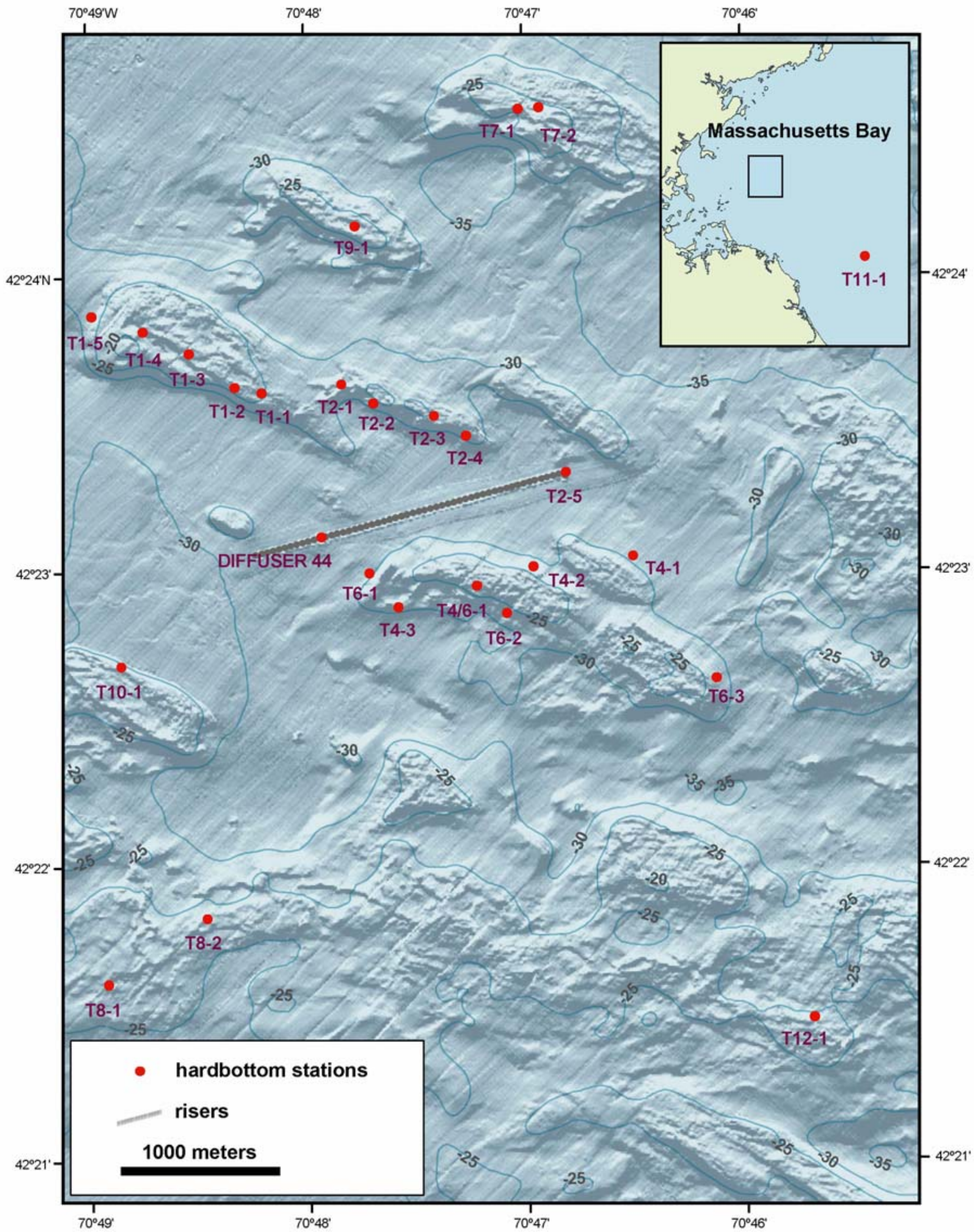


Figure 4-3. Locations of hard-bottom stations. *Video and still photographs are collected at 17 stations distributed among six transects and at six additional waypoints, including one active diffuser and one diffuser that is not in use.*

Sediment Characteristics and Tracers

Grain-size distributions in 2008 remained within the historic ranges of the monitoring program, with no indication of the coarse sediments that can result from large storms (Maciolek *et al.* 2009). Total organic carbon concentrations were relatively low, especially at nearfield stations, where at some stations, the percent total organic carbon fell below the baseline range.

As in other post-diversion years (except 2006), it was possible to detect elevated levels of *Clostridium perfringens* spores in sediments collected within two kilometers of the outfall (Figure 4-4). 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.

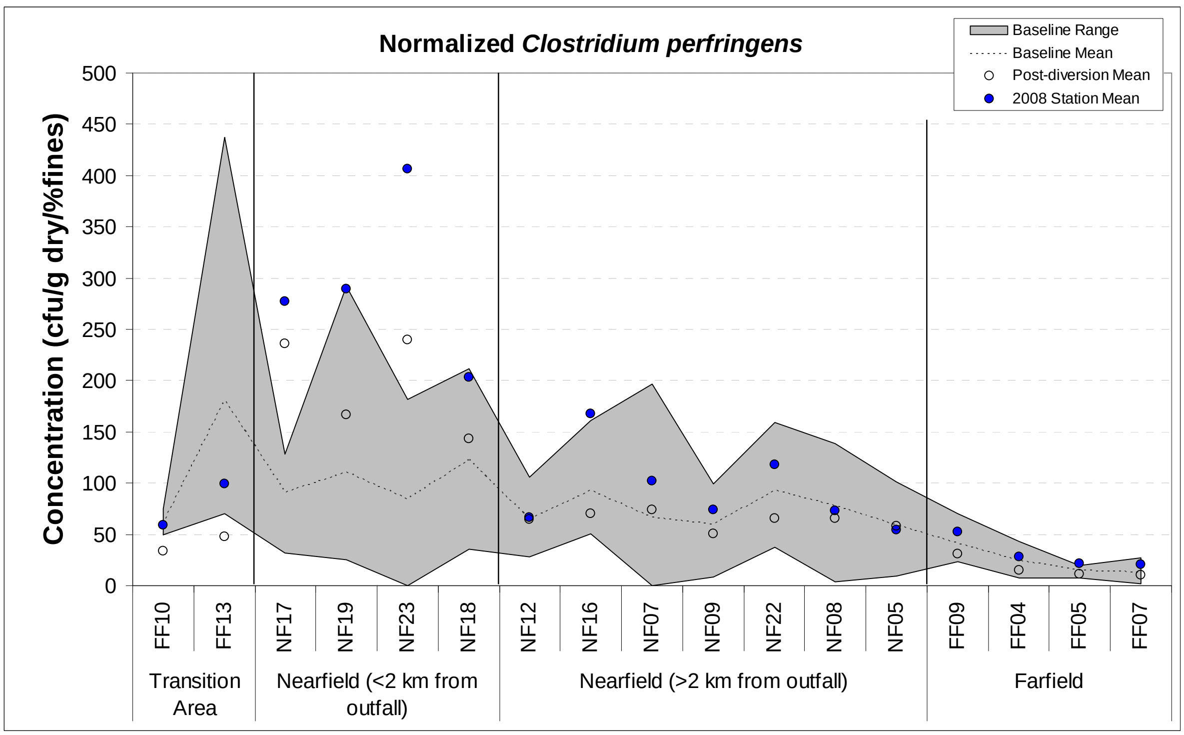


Figure 4-4.* Clostridium perfringens *spores normalized to percent fine fraction in the sediments. *"Transition area" denotes stations located between Boston Harbor and the outfall; "Farfield" denotes stations offshore from the outfall.*

Concentrations of chemical contaminants in the sediments were generally within the ranges measured throughout the monitoring program, but somewhat low, probably reflecting the relatively low levels of total organic carbon. Concentrations of PCBs (Figure 4-5) and DDT (not shown) were significantly lower than the baseline mean, reflecting the slow decline in those contaminants since they were banned in the 1970s and 1980s.

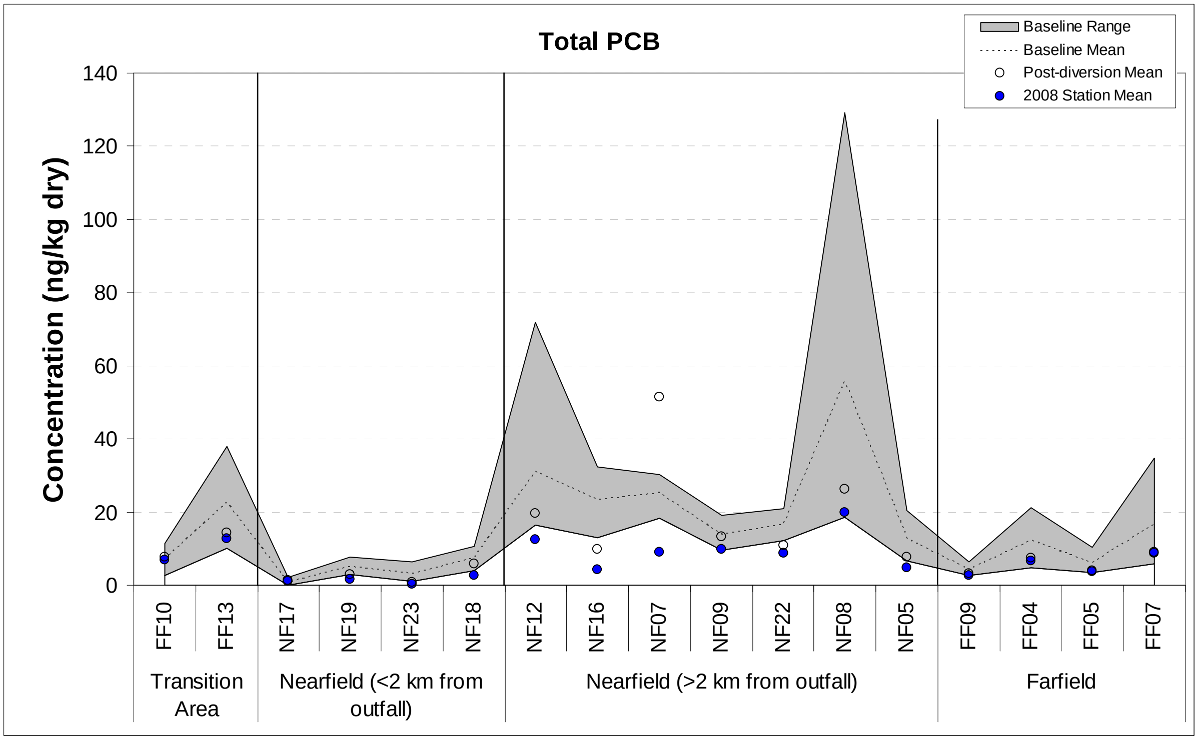


Figure 4-5. Total PCB concentrations in sediments. *"Transition area" denotes stations located between Boston Harbor and the outfall; "Farfield" denotes stations offshore from the outfall.*

Throughout Massachusetts Bay, the data continued to confirm that sediment grain-size distribution and proximity to historic inputs are the main indicators of contaminant concentrations. In the nearfield, contaminant concentrations are typically correlated with grain size, with the muddier stations having more organic carbon and correspondingly higher concentrations of contaminants. Sediments from farfield stations are typically finer-grained than those from the nearfield but also have lower concentrations of some contaminants, a pattern that has persisted throughout the monitoring program.

In Boston Harbor, where monitoring has also been conducted since 1991, concentrations of total organic carbon have fallen at some stations, including those closest to the former harbor outfall near DITP. There has also been a significant harbor-wide decline in concentrations of *Clostridium perfringens* spores.

Sediment-Profile Imaging

Sediment-profile imaging measurements continued to show no effects of the outfall (Maciolek *et al.* 2009). Concerns that an increase in the amount of organic matter deposited on the sea floor would result in a shallower apparent redox potential discontinuity (RPD) have not been realized (Figure 4-6). The mean RPD was somewhat shallower and the data were more variable in 2008 compared to 2007, but the RPD remained deeper than the baseline mean.

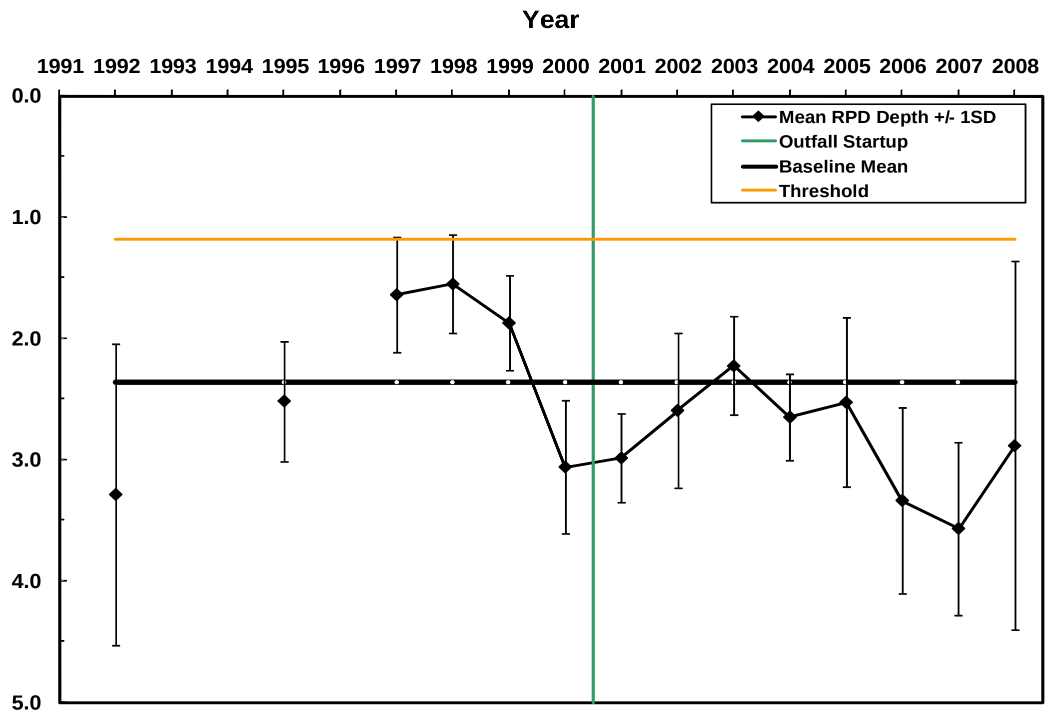


Figure 4-6. Annual apparent color RPD for data from nearfield stations sampled in 2008. *The average RPD depth in 2008 remained deeper than the baseline mean, continuing to indicate that there has been no adverse effect from the discharge.*

Two other measures from the sediment-profile images, successional stage and the organism sediment index (OSI), have provided further evidence that the outfall has not adversely affected the sea floor. The 2008 OSI remained similar to the level measured in 2007. Biogenic structures, such as amphipod tubes were more abundant in 2008, but, as in prior years, physical processes continued to be the dominant force in structuring the surface sediments. Storms and storm-induced sediment transport and deposition remain the primary stress on the sea-floor communities in Massachusetts Bay.

At Boston Harbor stations, where a separate monitoring program is conducted, the RPD has also deepened, while successional stage, OSI, and the incidence of biogenic features have increased. The camera recorded eelgrass at a station at Deer Island Flats, an area that might have been thought to be too degraded for colonization and restoration of eelgrass beds. The sediment-profile images also recorded abundant *Leptocheirus pinguis*, a burrowing amphipod, at many harbor stations. Tube mats constructed by the amphipods *Ampelisca* spp. returned to several stations after an absence of several years.

Ampelisca mats had provided an early demonstration of the improvements in Boston Harbor, greatly increasing in abundance in 1992 and subsequent years. By 2005, however, the mats had declined in abundance, presumably because of the reduction in inputs of organic material following the diversion of sewage inputs from Boston Harbor (Diaz *et al.* 2008). The return of *Ampelisca* tube mats may compel some modification to that hypothesis, placing a greater emphasis on the role of storms, but it remains clear that there have been major improvements to the soft-bottom habitats of Boston 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. The number of species per sample, total abundance of animals per sample, and a measure of diversity log-series alpha all remained within the baseline ranges (Figure 4-7).

Over the course of monitoring, some community parameters have fluctuated in sine-wave-like patterns. These patterns appear to be driven by annual fluctuations in several dominant species, particularly polychaete worms that inhabit fine-grained sediments. The results have held constant through both even and odd years, when since 2003, separate subsets of stations have been sampled.

Baseline and post-diversion monitoring has shown that the nearfield stations fall into two major groups, those that are characterized by fine sediments dominated by polychaete worms and those that are sandier, supporting amphipod crustaceans as well as polychaetes. Most of the numerically dominant species in the nearfield in 2008 were the same as those in 2007, with the addition of the polychaetes *Leitoscoloplos acutus* and *Monticellina baptisteae*.

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 farfield samples for 2008.

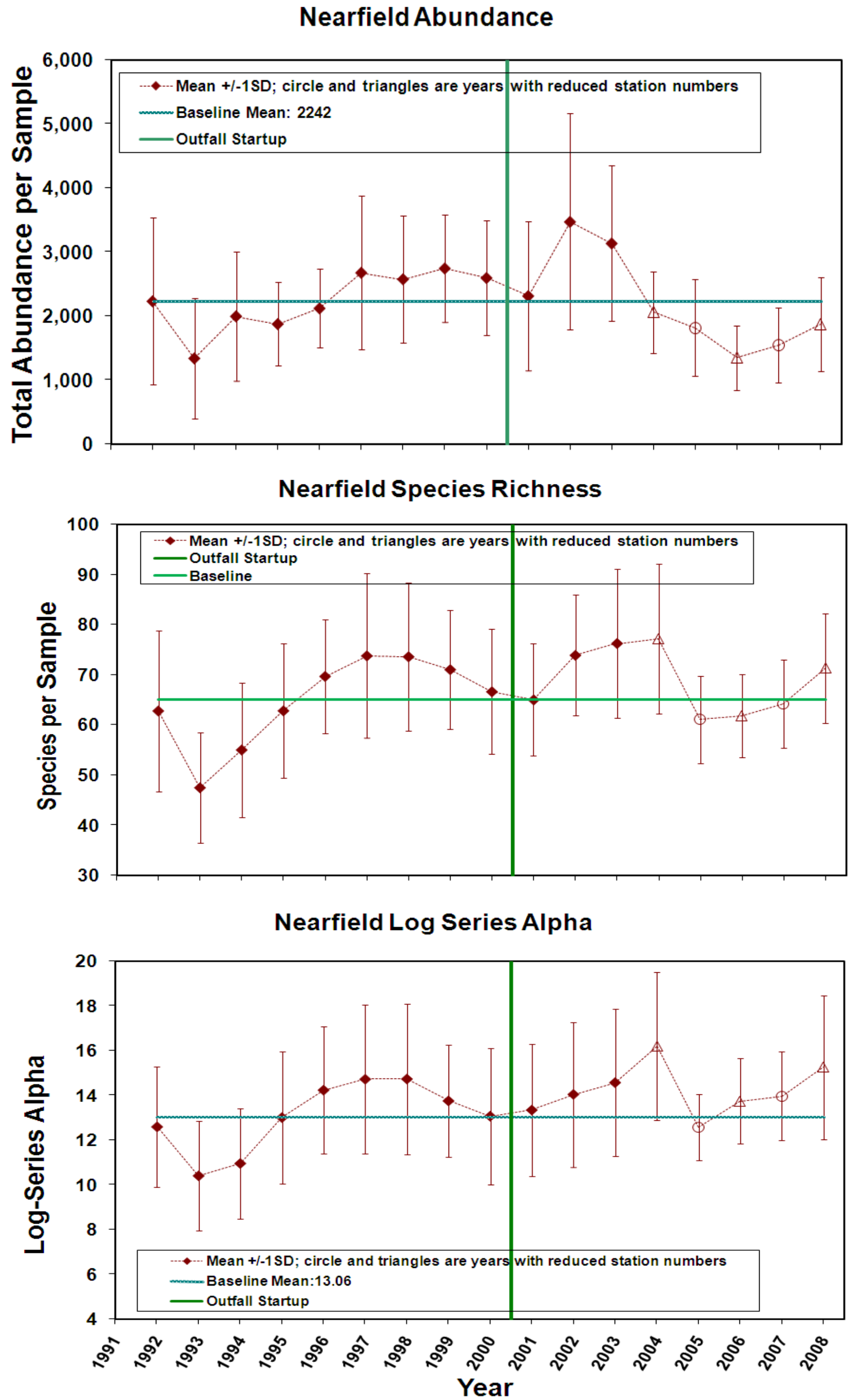


Figure 4-7. Annual community parameters in the nearfield.

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. 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, a condition unchanged since the Massachusetts Bay outfall began to discharge.

One measure of interest has been the amount of "sediment drape," a visual assessment of the detritus deposited on hard surfaces (Figure 4-8). During the post-diversion years, there have been modest increases in the amount of sediment drape at some stations, particularly north of the outfall, including the northern reference sites.

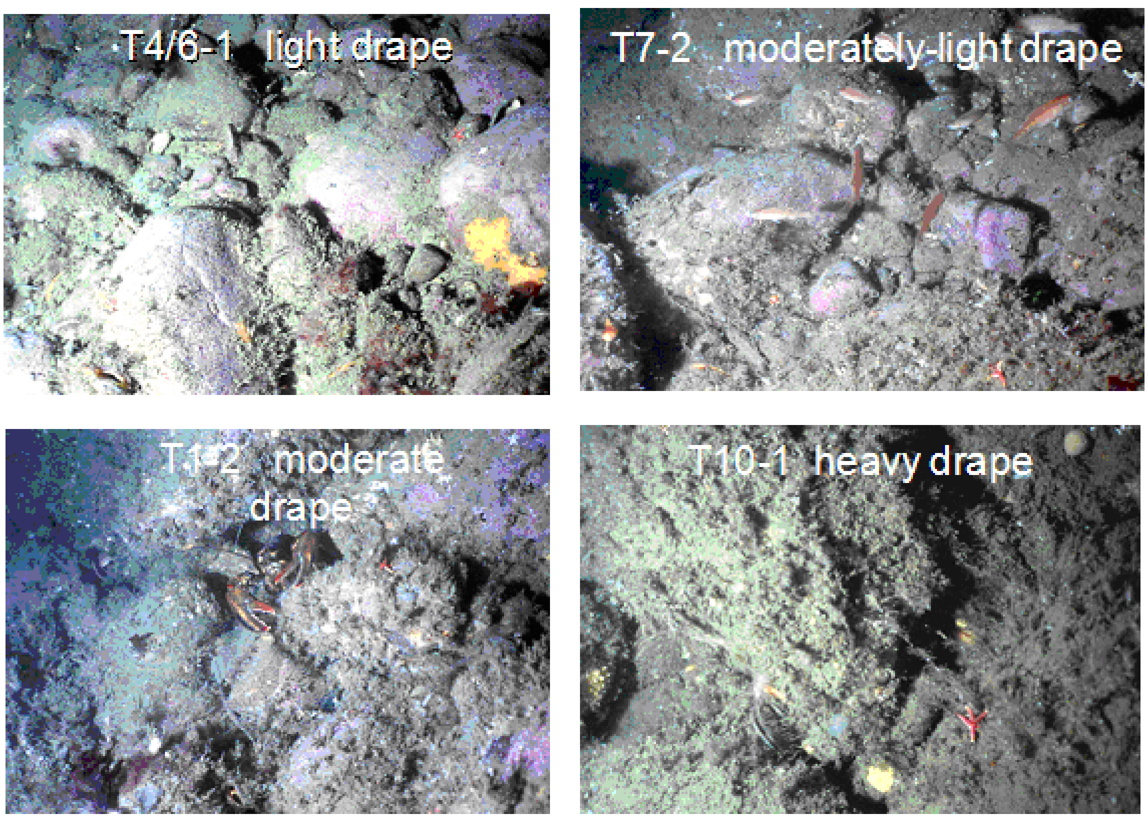


Figure 4-8. Examples of levels of sediment drape from 2008 photographs. *Upper left: light drape at T4/6-1 south of the outfall; upper right: moderately light drape at T7-2 a northern reference site; lower left: moderate drape at T1-2 north of the outfall; lower right: heavy drape at T10-1 southwest of the outfall.*

There has been some evidence that the northern reference stations are being adversely affected by tanker traffic. Tankers have frequently been seen to be anchored in the area, sometimes affecting MWRA survey schedules. Anchor scars and overturned boulders were recorded during the 2007 and 2008 surveys; the physical disturbances may be compromising the effectiveness of these sites as reference stations.

Contingency Plan Thresholds

No Contingency Plan thresholds for sea-floor monitoring were exceeded in 2008 (Table 4-1). There have been no threshold exceedances for any sea-floor parameter during the course of the monitoring program. Contaminant concentrations were well below warning levels, RPD depth continued to be deeper than the baseline mean, and the soft-bottom community parameters were within normal ranges. The percent of the soft-bottom community composed of opportunistic species remained low, about two orders of magnitude below the warning threshold.

Table 4-1. Contingency Plan threshold values and 2008 results for sea-floor monitoring. *(HMW=high molecular weight, LMW=low molecular weight, PAH=polycyclic aromatic hydrocarbon)*

Location	Parameter	Caution Level	Warning Level	2008 Results
Sediments, nearfield	Acenaphthene	None	500 ppb dry wt	27.3 ppb dry wt
	Acenaphylene	None	640 ppb dry wt	35.6 ppb dry wt
	Anthracene	None	1100 ppb dry wt	127.9 ppb dry wt
	Benzo(a)anthracene	None	1600 ppb dry wt	236.7 ppb dry wt
	Benzo(a)pyrene	None	1600 ppb dry wt	272.0 ppb dry wt
	Cadmium	None	9.6 ppm dry wt	0.13 ppm dry wt
	Chromium	None	370 ppm dry wt	71.9 ppm dry wt
	Chrysene	None	2800 ppb dry wt	212.2 ppb dry wt
	Copper	None	270 ppm dry wt	14.7 ppm dry wt
	Dibenzo(a,h)anthracene	None	260 ppb dry wt	35.8 ppb dry wt
	Fluoranthene	None	5100 ppb dry wt	470 ppb dry wt
	Fluorene	None	540 ppb dry wt	40.3 ppb dry wt
	Lead	None	218 ppm dry wt	40.2 ppm dry wt
	Mercury	None	0.71 ppm dry wt	0.13 ppm dry wt
	Naphthalene	None	2100 ppb dry wt	56.8 ppb dry wt
	Nickel	None	51.6 ppm dry wt	14.9 ppm dry wt
	p,p'-DDE	None	27 ppb dry wt	0.39 ppb dry wt
	Phenanthrene	None	1500 ppb dry wt	287.8 ppb dry wt
	Pyrene	None	2600 ppb dry wt	380.3 ppb dry wt
	Silver	None	3.7 ppm dry wt	0.32 ppm dry wt
	Total DDTs	None	46.1 ppb dry wt	5.59 ppb dry wt
	Total HMW PAH	None	9600 ppb dry wt	3712.7 ppb dry wt
	Total LMW PAH	None	3160 ppb dry wt	1579.5 ppb dry wt
	Total PAHs	None	44792 ppb dry wt	5292.1 ppb dry wt
	Total PCBs	None	180 ppb dry wt	7.5 ppb dry wt
	Zinc	None	410 ppm dry wt	57.8 ppm dry wt
	RPD depth	1.18 cm	None	2.88 cm
Even years, benthic diversity, nearfield	Species per sample	<48.41 or >82.00	None	70.6
	Fisher's log-series alpha	<9.99 or >16.47	None	15.1
	Shannon diversity	<3.37 or >4.14	None	3.84
	Pielou's evenness	<0.58 or >0.68	None	0.624
Benthic opportunists	% opportunists	>10%	>25%	0.254%

5. Winter Flounder

MWRA's fish-and-shellfish monitoring includes annual study of winter flounder. Fifty sexually mature winter flounder were taken from each of four sampling sites (Figure 5-1) during April 2008 for assessment of external condition and examination of liver histology (Moore *et al.* 2009).

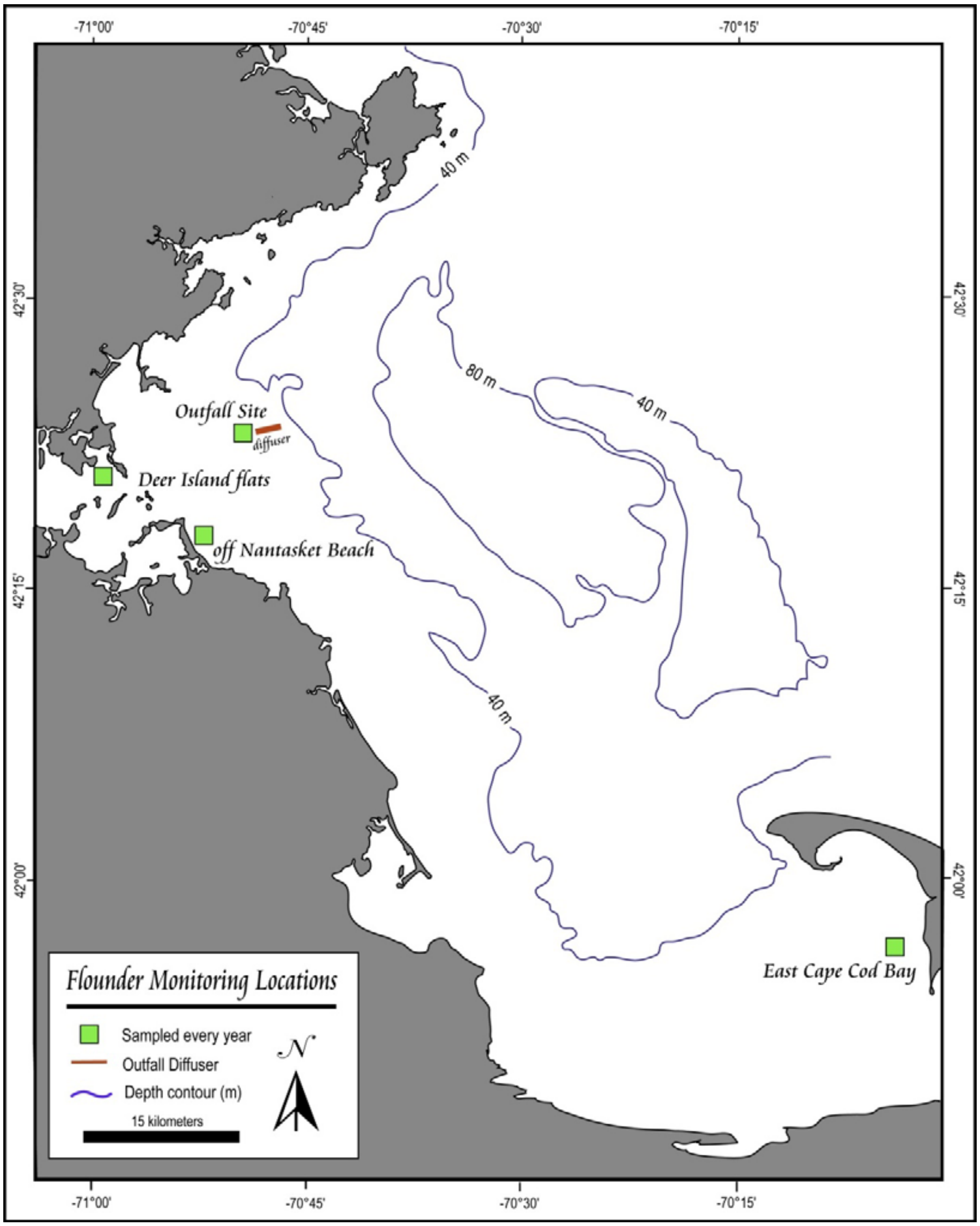


Figure 5-1. Winter flounder sampling sites.

Catch per unit effort remained low compared to 2001–2004 but was similar to 2006, 2007, and the years before the outfall diversion (Figure 5-2). The Northeast Fisheries Science Center (NFSC) has noted similar fluctuations in abundance and suggests that the Gulf of Maine stock, of which Massachusetts Bay is a part, may be in an overfished condition, as are other flatfish populations in New England (NFSC 2008).

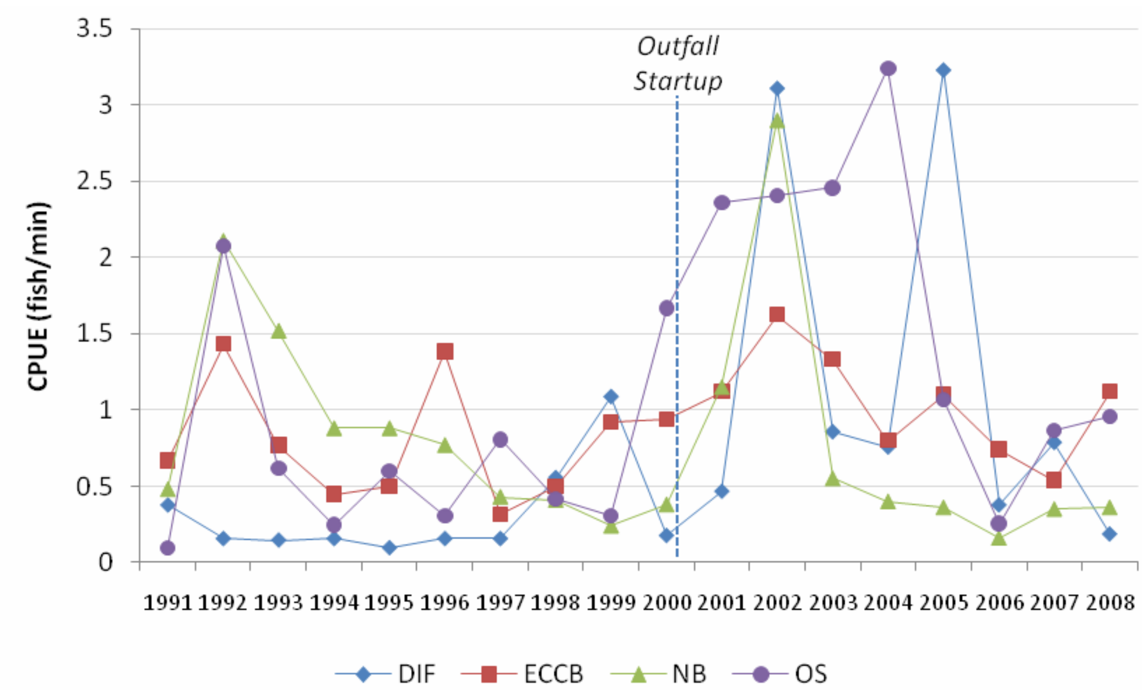


Figure 5-2. Annual catch per unit effort. *(DIF = Deer Island Flats, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, OS = Outfall Site)*

Mean age was lower, and fish weighed less and were shorter in length than fish sampled in 2007, but the values for each of these physical characteristics remained within the historic ranges. The percentage of female fish in the catch has increased since the beginning of the monitoring program, and almost every fish sampled was female (Figure 5-3). Skewed sex ratios are not unusual in flounder, and the region-wide incidence suggests that the outfall does not play a role in the imbalance.

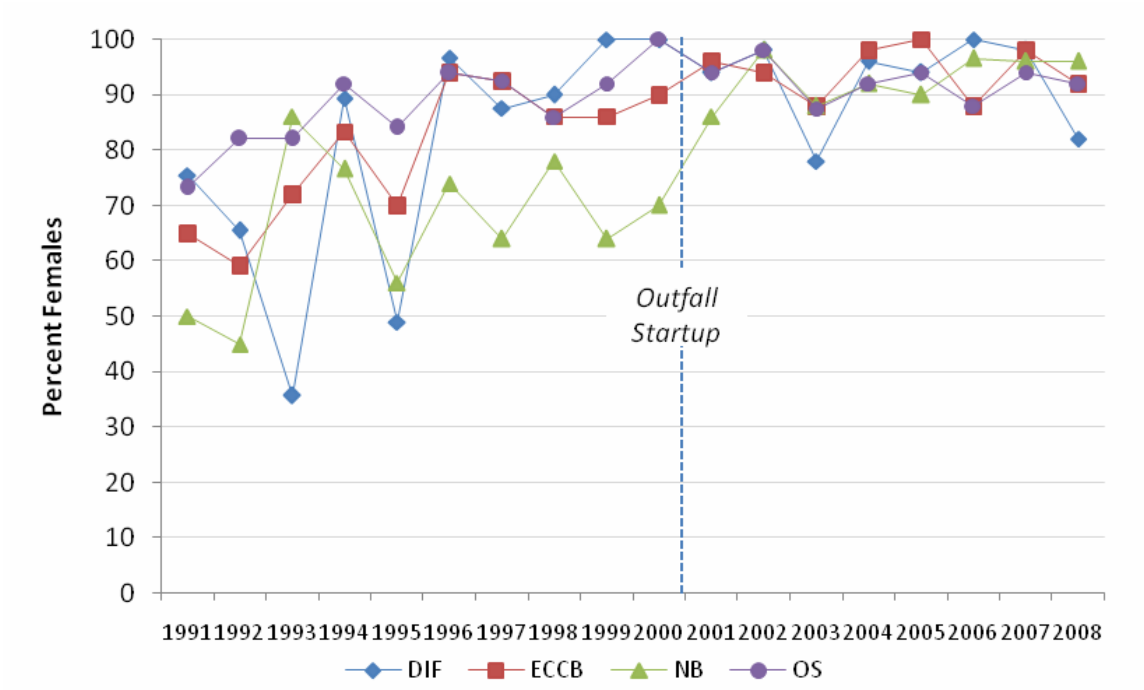


Figure 5-3. Annual percent females in winter flounder samples. *(DIF = Deer Island Flats, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, OS = Outfall Site)*

At most stations, incidence of fin erosion, a condition that can be indicative of elevated concentrations of ammonium and other pollutants, was lower than was observed in 2007. Prevalence of fin erosion has varied in recent years, with no clear evidence of short-term trends. Over a longer period, since the late 1970s and early 1980s, the incidence and severity of fin erosion has lessened considerably.

Blind-side ulcers, which were first detected in 2003, were uncommon, continuing an ongoing decline. Ulcers were present in only 2% of fish sampled near the outfall; at the peak of the infection in 2004, 36% of the fish had ulcers.

No neoplasms were observed in any fish from any site. Incidence of neoplasia has been rare throughout the area since routine monitoring started in 1991. 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 fish taken from the outfall site. The incidence of centrotubular hydropic vacuolation (CHV), a mild condition associated with exposure to contaminants, remained low (Figure 5-4). Incidence of CHV in fish from the outfall site continued to be lower than it had been in the years before the Massachusetts Bay outfall began to discharge. Incidence of CHV at Deer Island Flats has also declined since the outfall diversion.

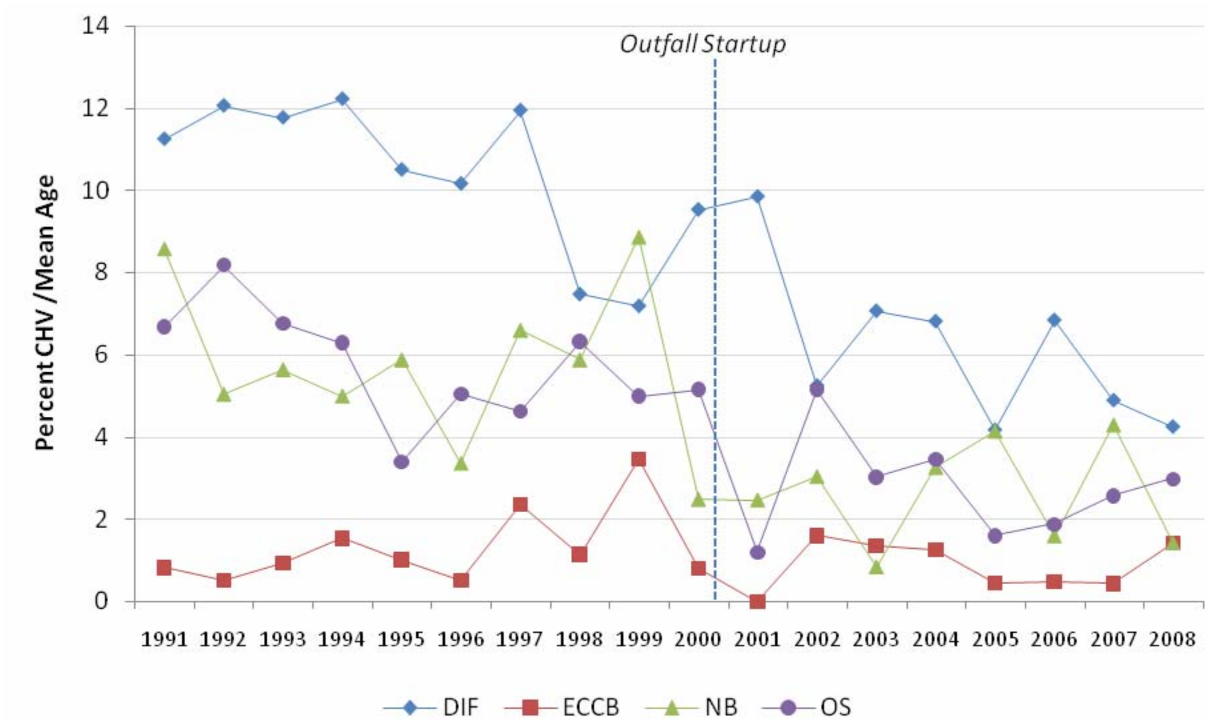


Figure 5-4. Annual prevalence of centrotubular hydropic vacuolation (CHV), corrected for age. *(DIF = Deer Island Flats, , ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, OS = Outfall Site)*

Contingency Plan Thresholds

Only one threshold parameter for fish and shellfish was measured in 2008 (Table 5-1). Incidence of CHV, the most common indicator of liver disease in the winter flounder of the region, was 12% in fish taken from the vicinity of the outfall site, unchanged from 2007. This value was less than half the 24.4% observed during the baseline period and well below the caution level.

Table 5-1. Contingency Plan threshold values and 2008 results for flounder monitoring.

Parameter Type/ Location	Parameter	Baseline	Caution Level	Warning Level	2008 Results
Flounder nearfield	Liver disease (CHV)	24.4%	44.9%	None	12%

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 2008, MWRA continued or initiated several special studies:

- Calibration of chlorophyll measurements in the water column.
- Prediction of red tides.
- Marine mammal observations.
- Analysis of nutrient loads to Boston Harbor.
- Nutrient flux at the sediment-water interface.

Chlorophyll Measurements

MWRA uses two types of measurements of water column chlorophyll: laboratory and field (*in situ*) measurements. The laboratory chemistry method is relatively expensive and labor-intensive. The *in situ* method is faster, allowing more measurements, but can be affected by field conditions. MWRA is developing an improved method to calibrate the field measurements. Multiple regression methods are used to account for factors including temperature and solar irradiance (Hersh 2009).

Predicting Red Tides

Since 2005, when the worst bloom of the red tide dinoflagellate *Alexandrium fundyense* occurred in New England, MWRA has conducted targeted research aimed at understanding and predicting these blooms. The studies have been conducted in coordination with the WHOI Gulf of Maine Toxicity (GOMTOX) program, a cooperative observation and modeling effort focused on the Gulf of Maine and the adjacent southern New England coastal region. The GOMTOX studies have identified the abundance of cysts in seed beds off the coast of Maine, coupled with a population-dynamics model, as the best predictor of the magnitude of blooms in the following year.

In 2008, these studies resulted in the first-ever forecast advisory for a red tide with significant PSP toxicity (WHOI 2008). Data from fall 2007 surveys of the seed beds (Figure 6-1, top) were used in a model simulating weather and oceanographic conditions of past years to predict cell abundance for 2008 (Figure 6-1, bottom). Those model results suggested a high likelihood of a significant red tide in 2008, a prediction that proved accurate (Figure 6-2). Similar correct predictions were made for 2009 (WHOI 2009).

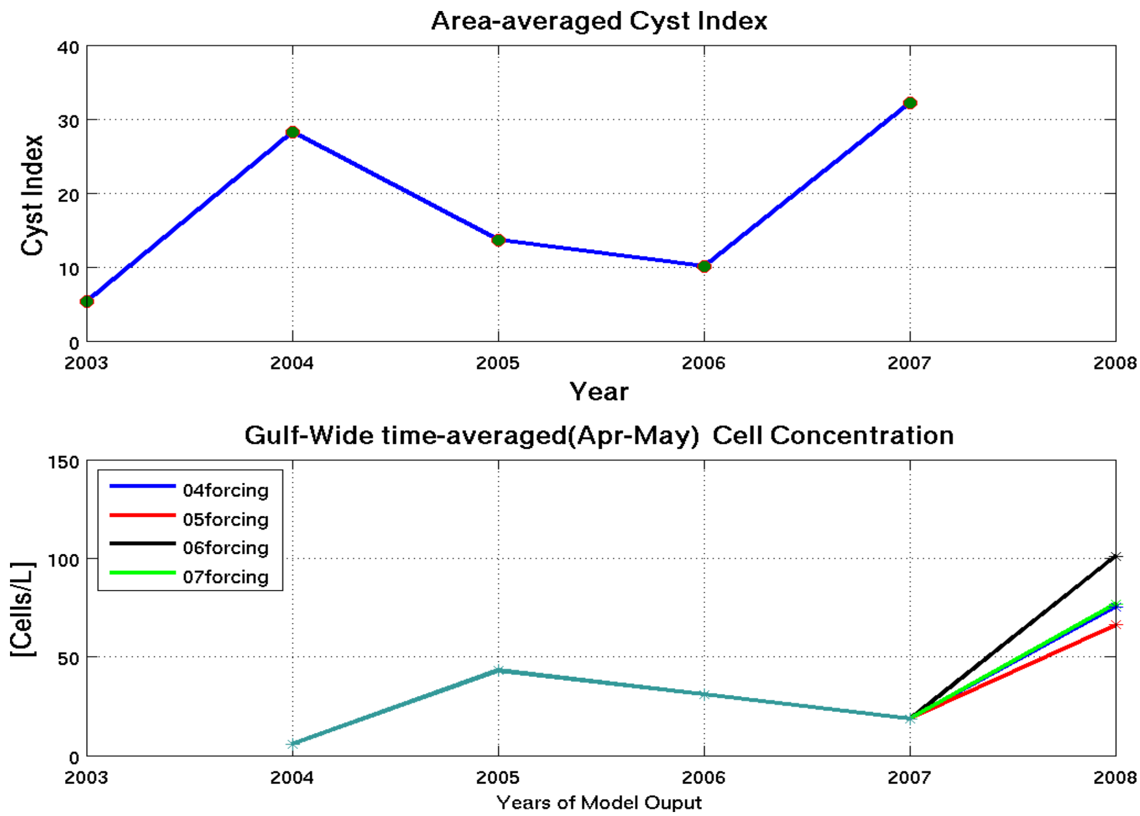


Figure 6-1. Top: Annual abundance of* Alexandrium *cysts in Maine seed beds. Bottom: Annual modeled concentrations of* Alexandrium *cells. *Values for 2008 were predicted from 2007 cyst abundance and weather forcing conditions from 2004–2007. Each model run predicted a large red tide for 2008.*

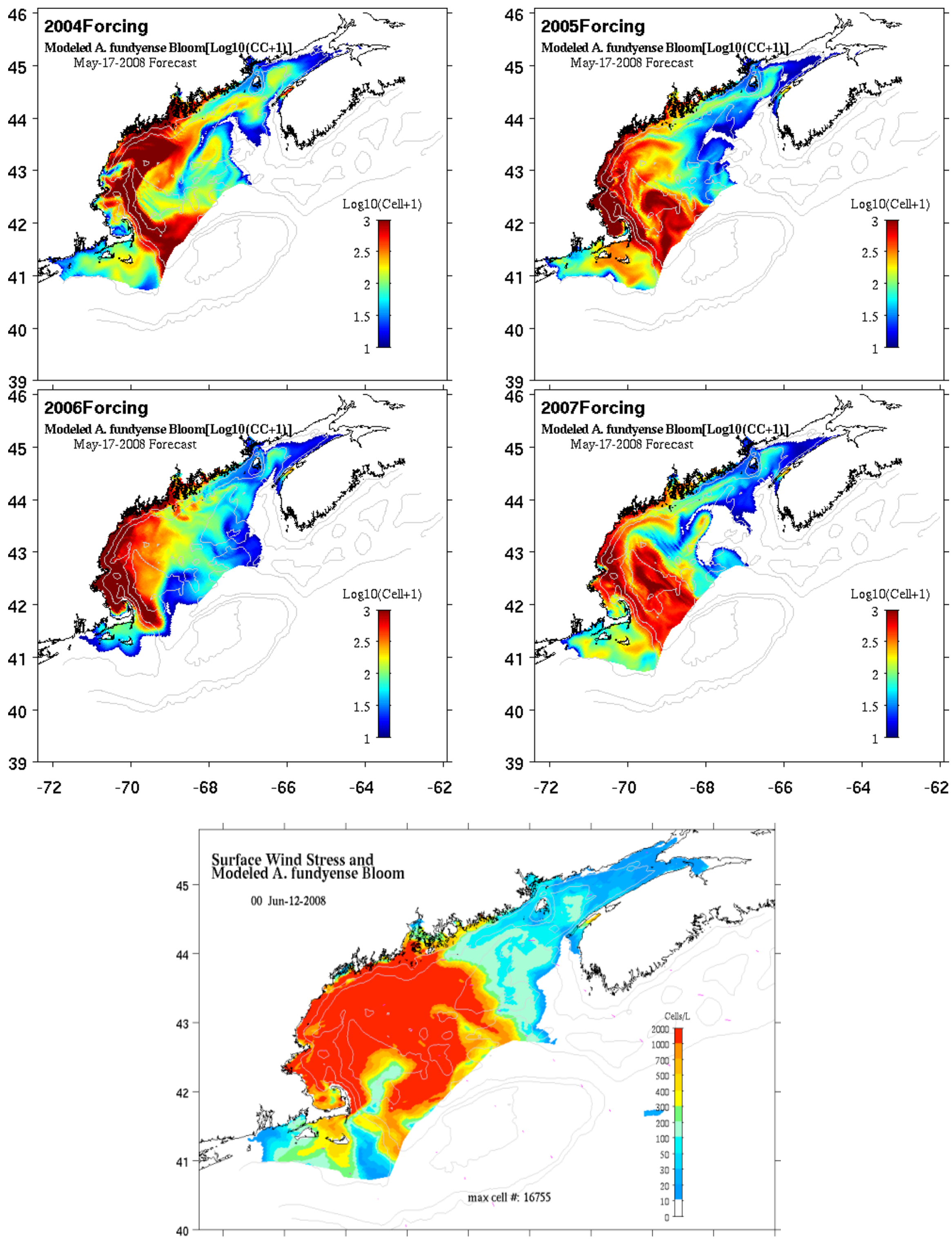


Figure 6-2. Modeled abundance of* Alexandrium *cells for 2008. *Upper maps show modeled results for 2008 using weather forcing conditions from 2004–2007. Lower map shows the modeled results using actual 2008 weather conditions.*

The research and modeling have suggested that the western Gulf of Maine has entered an era of frequent and high-intensity red tides. Prior to 1972, it appears that *Alexandrium* cysts were abundant in the Bay of Fundy but not in the western Gulf of Maine. From 1972, when a large red tide occurred, through the early 1990s, cysts began to accumulate in the western Gulf of Maine, but abundance then waned. During the early years of the MWRA monitoring program, there were few cysts in the Gulf of Maine, and PSP toxicity resulting from blooms was rare. Since the mid 2000s, cysts have again become abundant in the Gulf of Maine, and significant red tides have occurred.

To date, it does not appear that cyst seed beds have been established in Massachusetts, and the timing and geographic progression of the blooms has not been associated with any stimulating effect from the nutrients in the Massachusetts Bay discharge. Additional field and modeling studies are continuing.

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 2008, observers were included on all nearfield and farfield water quality surveys (Wu 2009b). Besides providing observational data, the presence of trained marine mammal observers addresses a request by the National Marine Fisheries Service that MWRA take active steps to minimize the chances of a collision of one of its survey vessels with a right whale.

During the 2008 surveys, 44–45 individual whales, one Atlantic white-sided dolphin, four harbor porpoises, ten humpback whales, five finback whales, four minke whales, and 12–13 unidentified whales were directly observed by the trained observers and other members of the monitoring team (Figure 6-3). The total number of whales sighted was the highest since 2006, a year that saw increases after a period of relatively sparse sightings. Several whales were sighted in the vicinity of the outfall, 17–18 were within the Stellwagen Bank National Marine Sanctuary, and 18 were sighted in Cape Cod Bay.

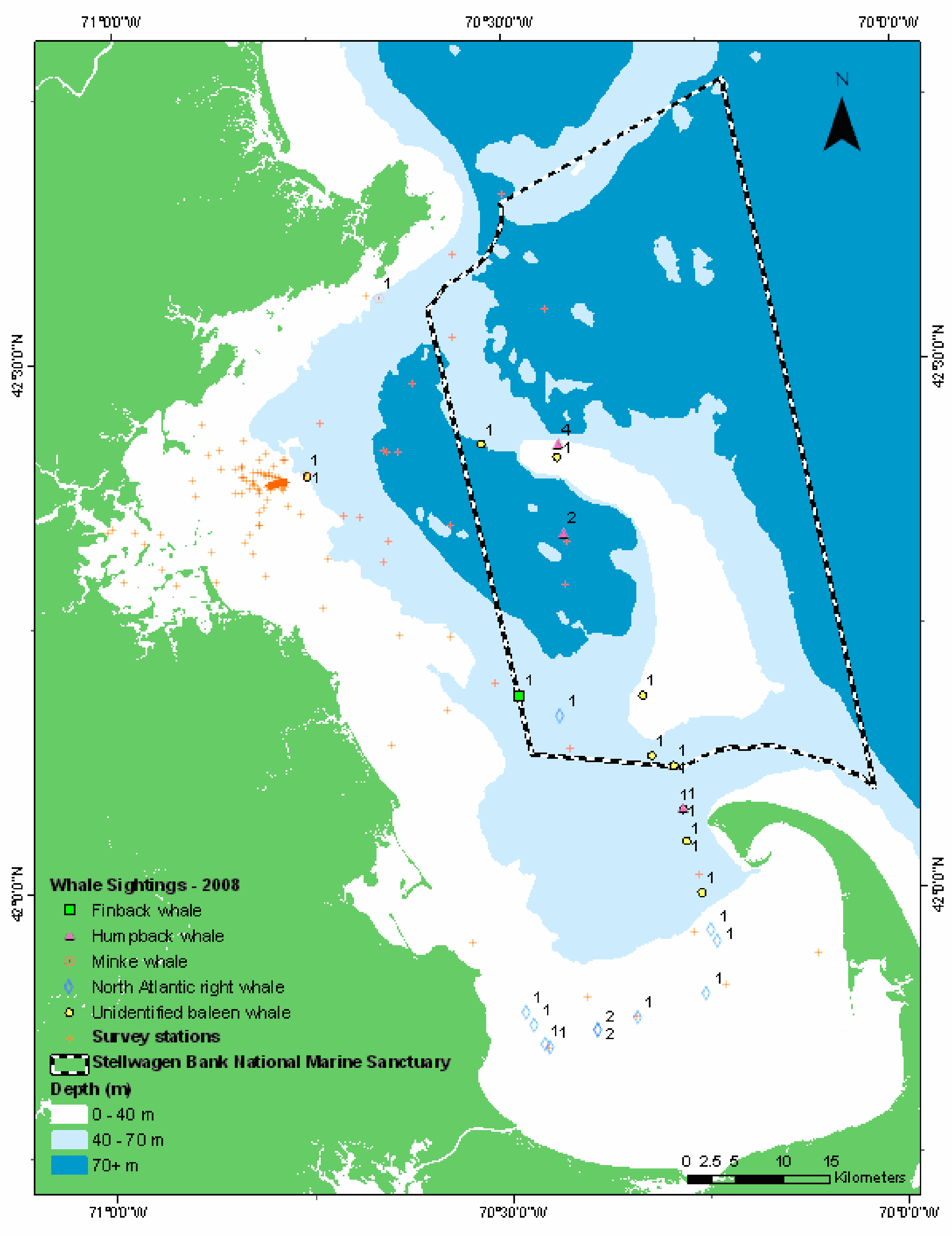


Figure 6-3. Approximate locations of whale sightings during 2008 nearfield and farfield water quality surveys.

The Provincetown Center for Coastal Studies (www.coastalstudies.org), which conducts systematic surveys of Cape Cod Bay, reported that twice the usual number of right whales visited the area in 2007 and 2008 as had been sighted during 1998–2006. The length of time that individual whales remained in or near Cape Cod Bay was also longer in 2007 and 2008 than had been typical in recent years.

Nutrient Loads to Boston Harbor

Estimates of contaminant loads to Boston Harbor have been completed by MWRA in 1991 (Menzie *et al.* 1991) and 1994 (Alber and Chan 1994). The 1994 study reported that loads of many contaminants had decreased in response to the ending of biosolids discharges in 1991. The earlier estimates lacked accurate estimates of loadings from rivers. Since then, MWRA has been compiling an updated inventory of the loadings to the harbor and the changes over the course of the Boston Harbor Project (Taylor 2009).

Loadings of total nitrogen, total phosphorus, total suspended solids, and particulate organic carbon have declined by 82–95% since 1990–1991 (Figure 6-4). Almost all those decreases can be accounted for by reductions in wastewater-associated discharges. Increases in the ratios of total nitrogen to total phosphorus and total suspended solids to particulate organic carbon show a shift in the dominant input away from sewage sources to rivers and other sources (Figure 6-5). Now, riverine inputs contribute most of the loadings of all the contaminants associated with eutrophication. Total nitrogen loadings to Boston Harbor are now lower than those in many other urban estuaries.

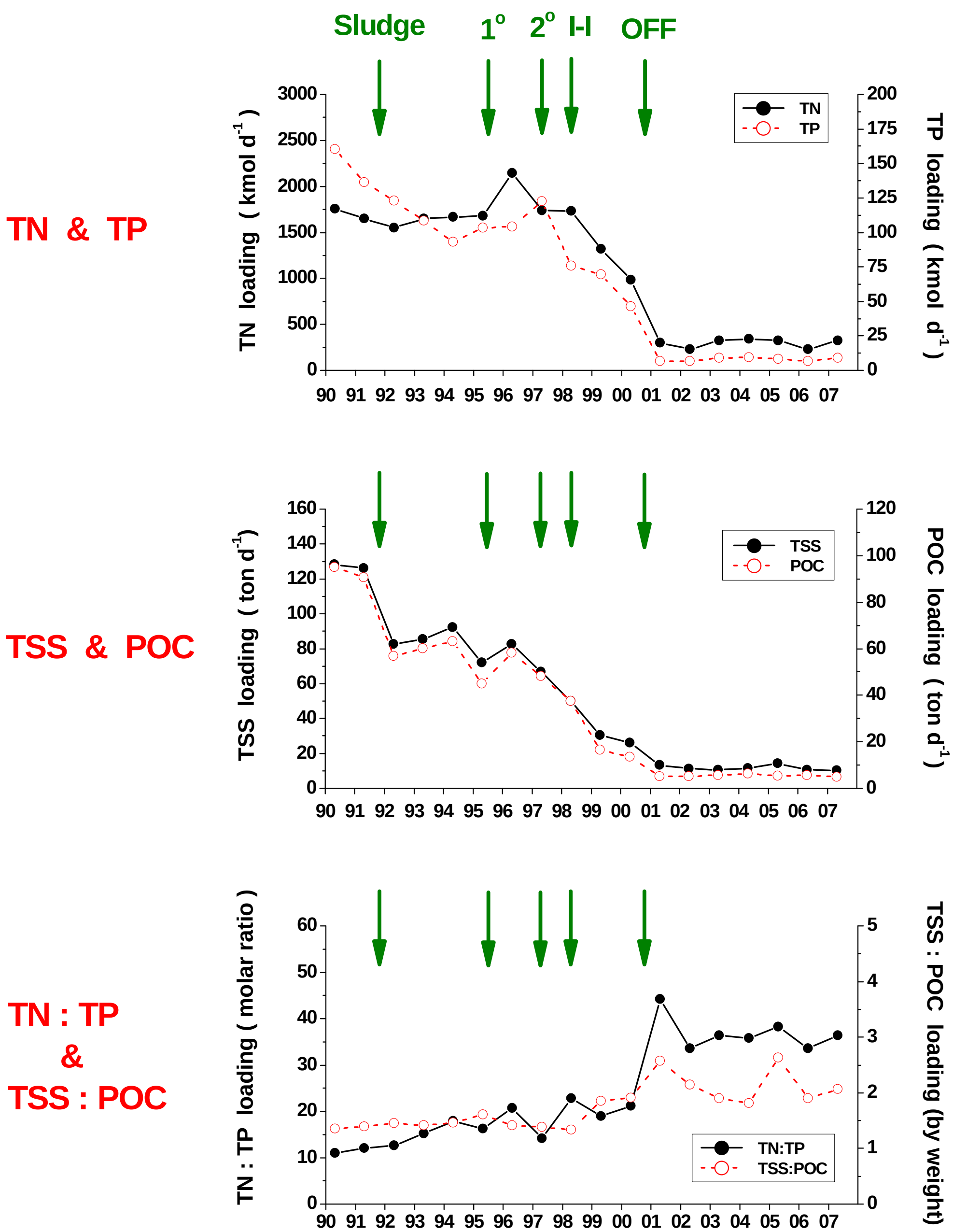


Figure 6-4. Total loadings of nutrients and solids to Boston Harbor, 1990–2007. *TN=total nitrogen, TP=total phosphorus, TSS=total suspended solids, POC=particulate organic carbon, Sludge=end of biosolids discharge, 1°=upgrade of primary treatment plant, 2°=implementation of secondary treatment, I-I=ending of discharge to the southern harbor with construction of the inter-island tunnel, OFF=ending of effluent discharge to the harbor with the commissioning of the new outfall.*

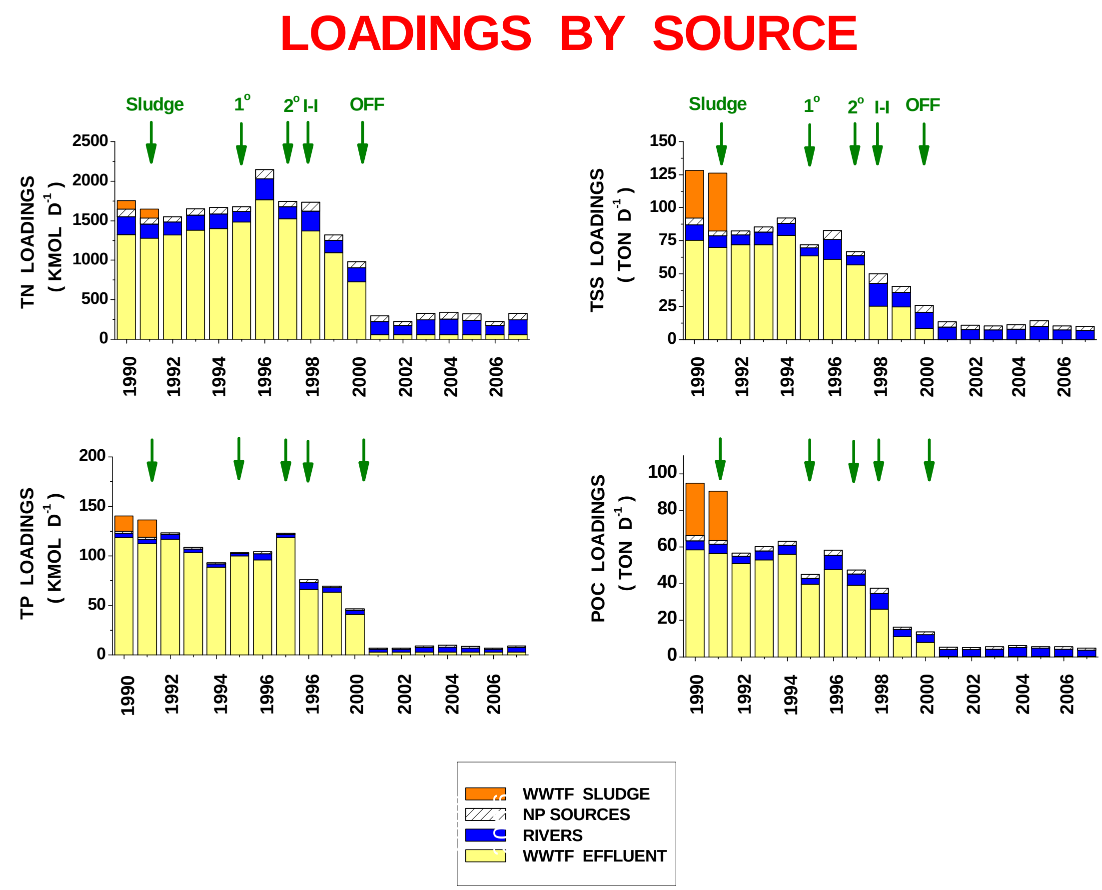


Figure 6-5. Nutrient loadings to Boston Harbor by source. *TN=total nitrogen, TP=total phosphorus, TSS=total suspended solids, POC=particulate organic carbon, Sludge=end of biosolids discharge, 1°=upgrade of primary treatment plant, 2°=implementation of secondary treatment, I-I=ending of discharge to the southern harbor with construction of the inter-island tunnel, OFF=ending of effluent discharge to the harbor, WWTF SLUDGE=biosolids, NP SOURCES=nonpoint sources, RIVERS=rivers, WWTF EFFLUENT=wastewater effluent.*

Benthic Flux

One concern about the outfall diversion was that increased loads of organic matter might enhance benthic respiration and increase fluxes of nutrients between the sediments and the water column. 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. In response to these concerns, MWRA has conducted studies of the sediment-water interface in Massachusetts Bay and in Boston Harbor since 1993 (Figure 6-6).

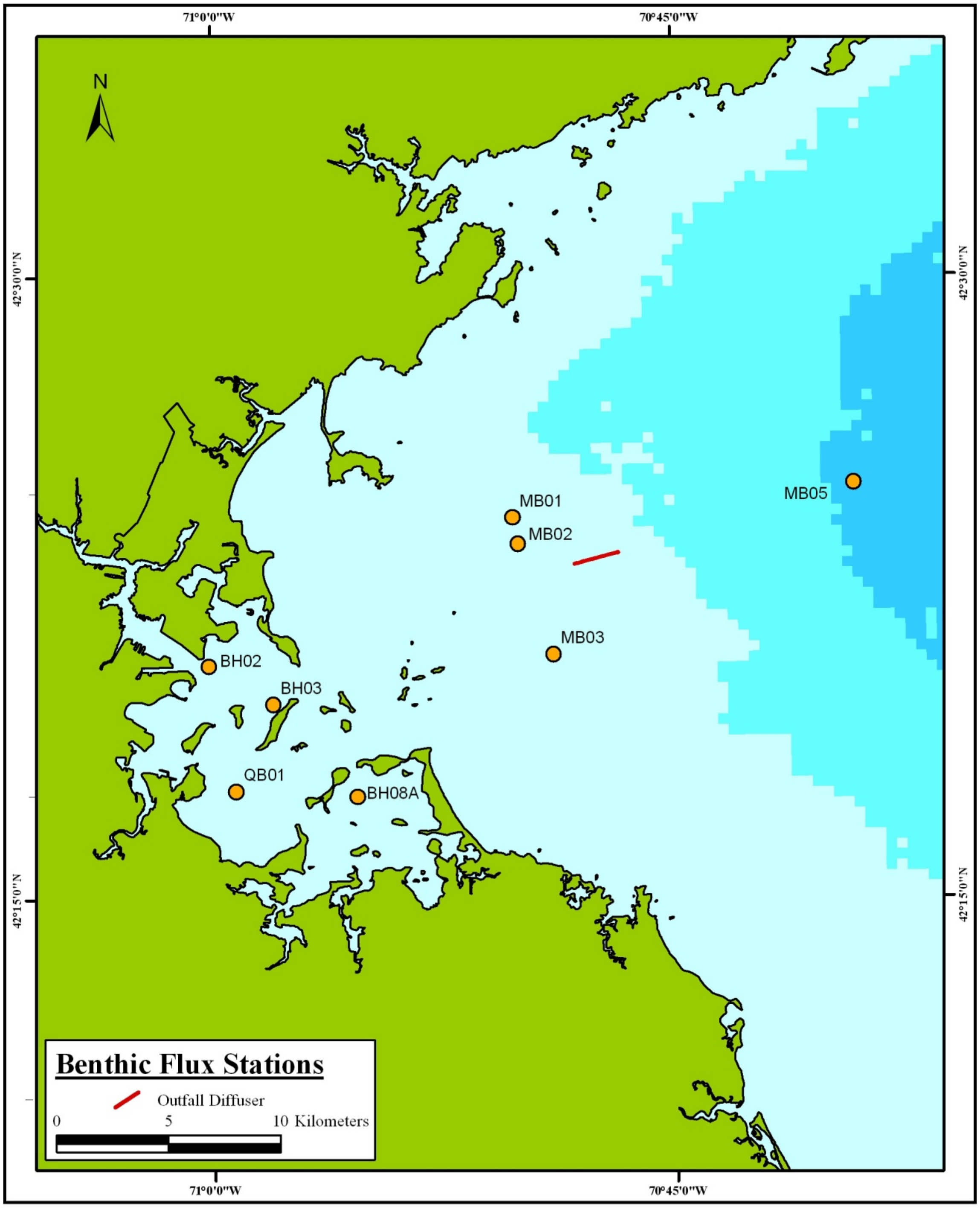


Figure 6-6. Benthic flux stations in Massachusetts Bay and Boston Harbor.

The Massachusetts Bay studies have shown no significant changes from baseline conditions (Tucker *et al.* 2009). There has been little or no indication of increased deposition of organic matter to the sea floor (Figure 6-7) and no change in the oxidation of the bottom waters or sediments. There have been no increases in sediment oxygen demand and no changes in nutrient fluxes at the Massachusetts Bay stations.

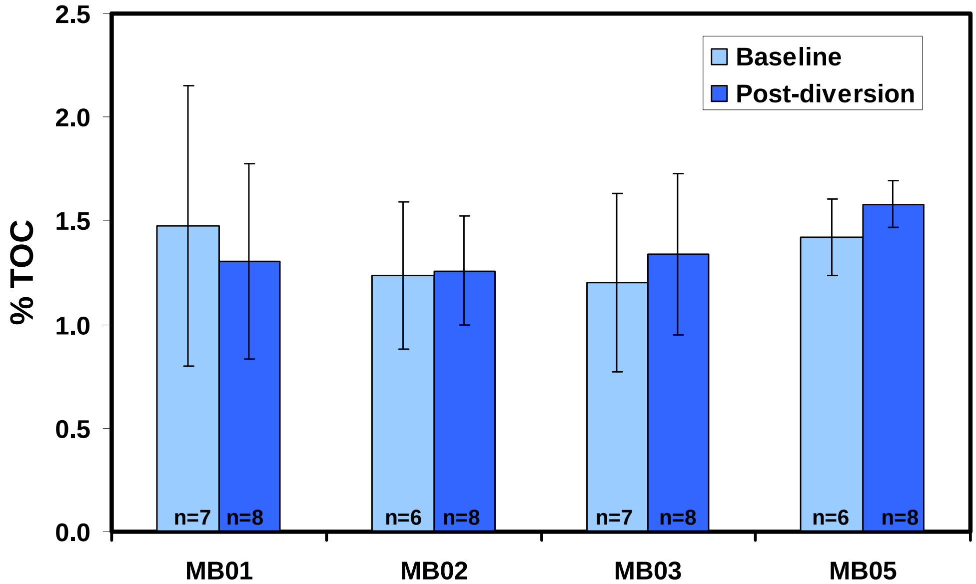


Figure 6-7. Percent total organic carbon in surface sediments from Massachusetts Bay. *There has been no increase in organic matter deposition to the bottom.*

Meanwhile, there have been significant decreases in fluxes at the four stations in Boston Harbor, reflecting improvements to the benthic environment during those same time periods that are considered important in the evaluation of nutrient loading (see preceding special study, Nutrient Loads to Boston Harbor). The percent organic carbon has decreased at all Boston Harbor stations except for the one nearest to the former discharge site near DITP (Figure 6-8), and nutrient fluxes have declined at every station (Figure 6-9). In 2008, there was an increase in sediment oxygen demand at two stations, BH02 near Deer Island and BH08A in Hingham Harbor. This condition had also been observed at the BH02 in 2007. It resulted from increased colonization of the sites by amphipods and is not considered to be an indication of any decline in environmental quality.

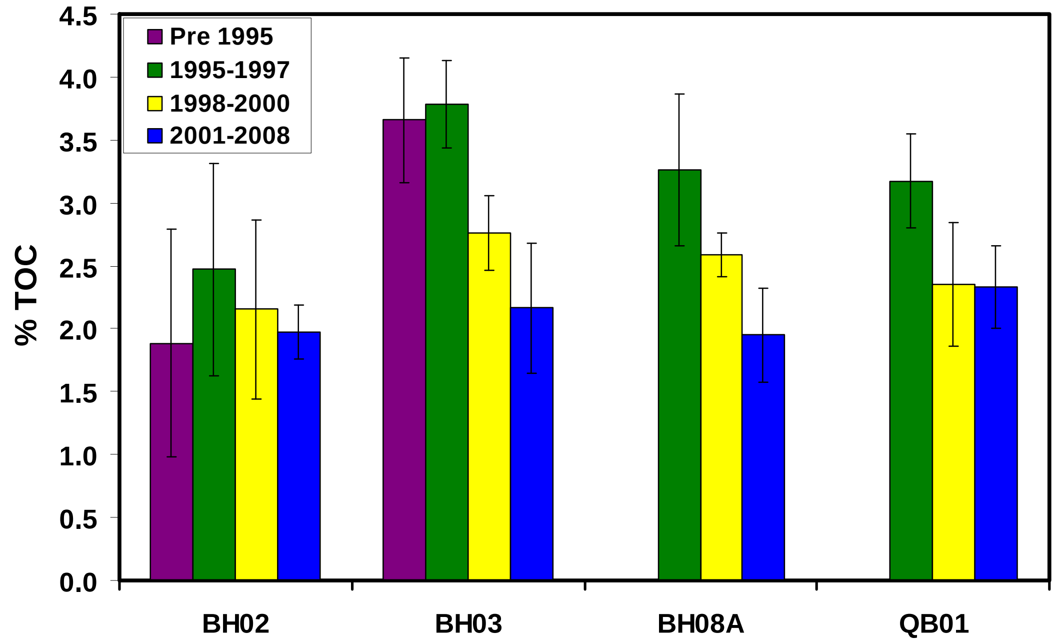


Figure 6-8. Percent total organic carbon in surface sediments from Boston Harbor. *Percent total organic carbon has significantly declined at all stations except BH02, which is close to the former Deer Island outfall.*

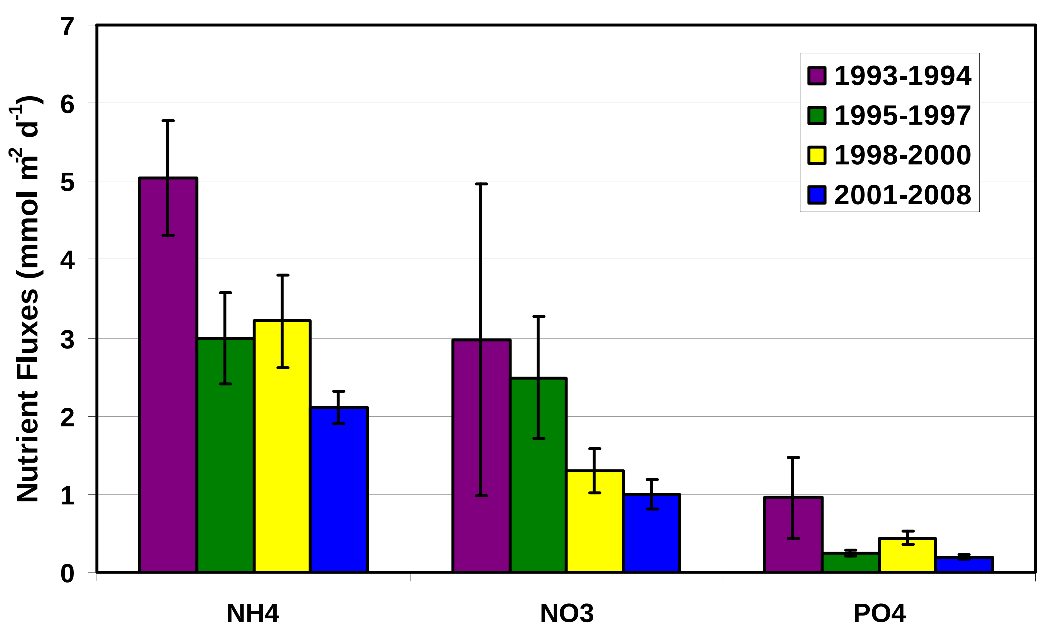


Figure 6-9. Nutrient fluxes in surface sediments from Boston Harbor. *Nutrient fluxes have significantly declined at all Boston Harbor stations.*

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 NPDES permit to discharge effluent into Massachusetts Bay requires this annual report on possible effects of the discharge on the sanctuary.

In 2008, the sanctuary issued a draft management plan and environmental assessment (U.S. Department of Commerce 2008) finding diverse and rich habitats and varied marine life, including 80 fish species, 34 bird species, and 22 species of marine mammals. It describes the major threats to the sanctuary as overfishing, increasing speeds of whale-watch vessels, invasion by exotic species, harmful algal blooms, and the potential for degraded water quality resulting from coastal development and urbanization.

Water Column

Despite the concerns about the effects of coastal development on the sanctuary, the overall water quality remains good. The 2008 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. There has been no indication of any effect of the Massachusetts Bay outfall.

Concentrations of dissolved oxygen (Figure 7-2) and percent saturation (not shown) have remained unchanged in Stellwagen Basin, as they have in the nearfield. Potential decreases in dissolved oxygen concentrations or percent saturation had been a concern before the outfall began to discharge, but those concerns have not been realized. The 2008 bottom water concentrations were slightly below the baseline mean, but were higher than would be predicted from the year’s temperature and salinity regime.

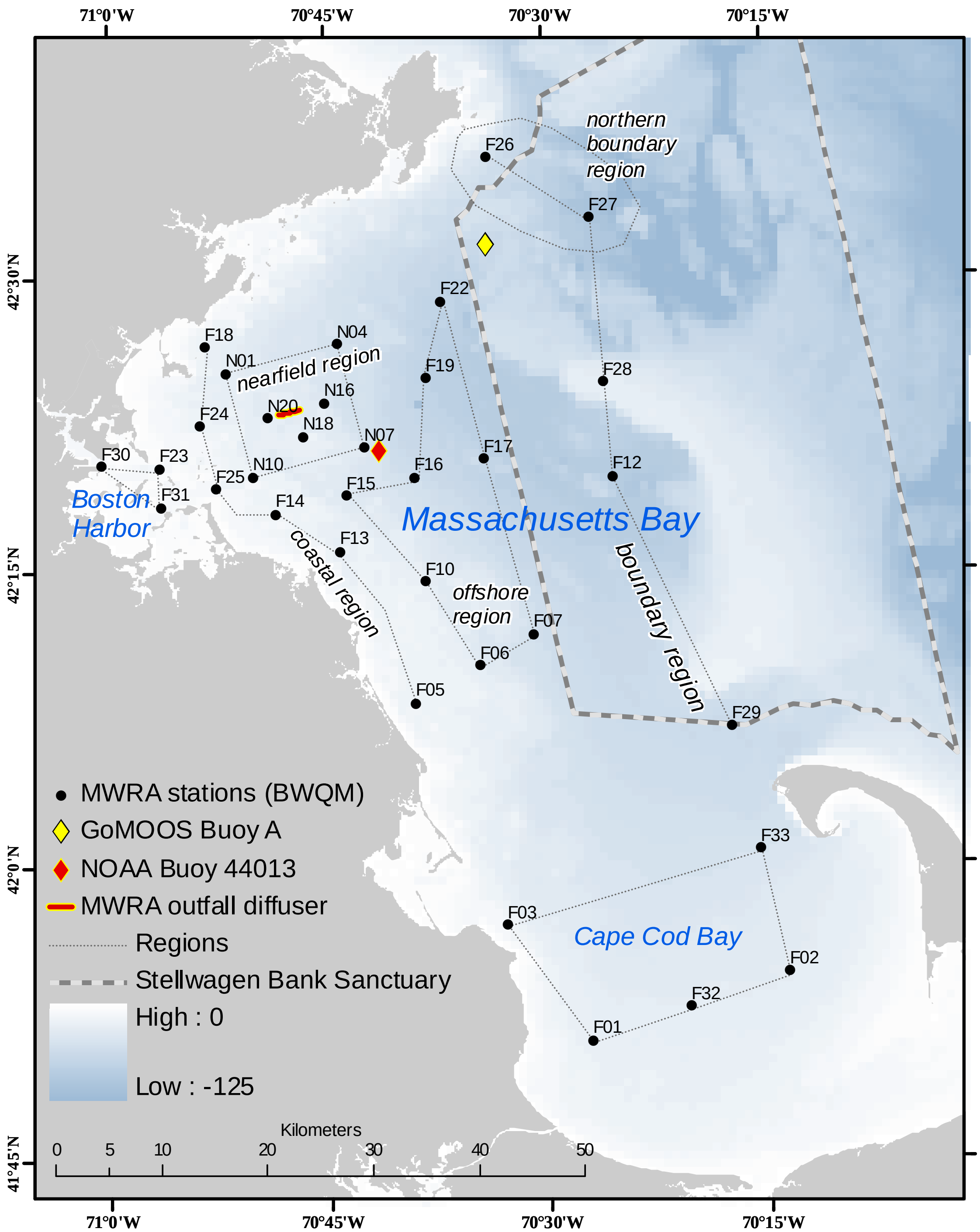


Figure 7-1. Water column stations, including those in and near the Stellwagen Bank National Marine Sanctuary (F27, F28, F12).

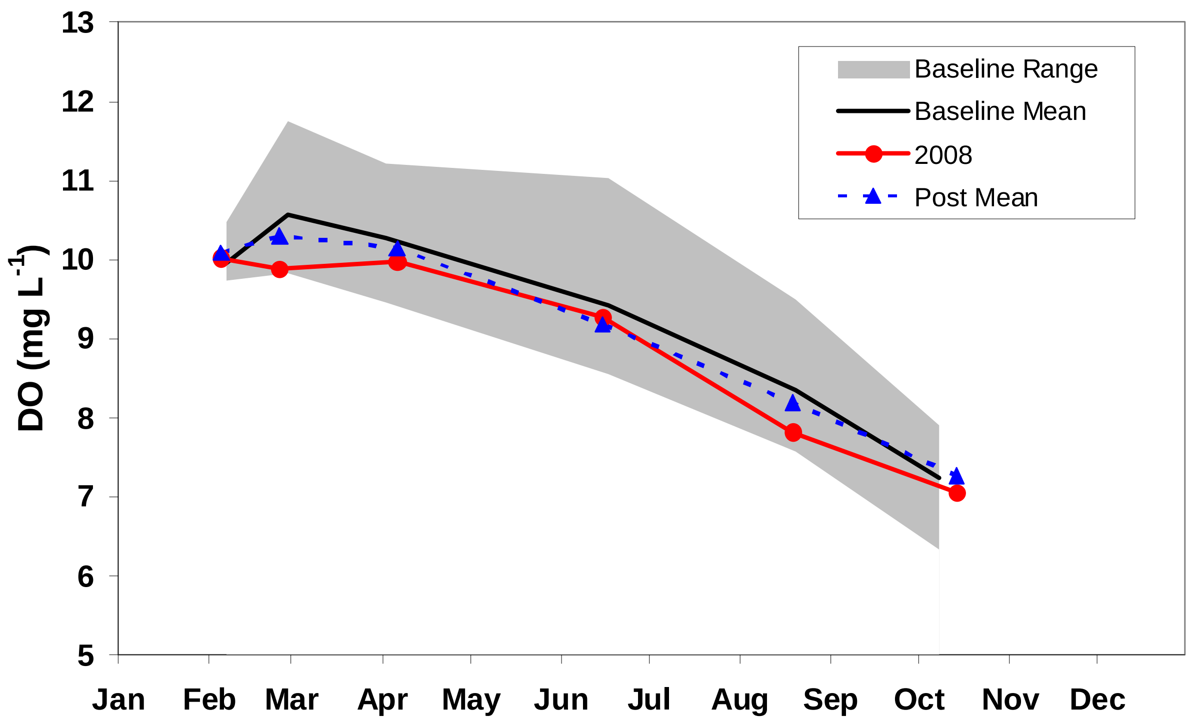


Figure 7-2. 2008 bottom water dissolved oxygen (DO) concentrations in Stellwagen Basin compared to baseline range, baseline mean, and post-diversion mean. *There has been no change in patterns of dissolved oxygen concentrations (or saturation) since the outfall began to discharge.*

Annual mean concentrations of nutrients in water samples have varied somewhat over the years, but the changes have not been substantial, and changes at stations in and near the sanctuary have not been attributed to the outfall diversion. These variations have been observed in and near the sanctuary, and also in the nearfield and in Cape Cod Bay, which are shown for comparison. Annual mean concentrations of total nitrogen vary across the study area from year to year, but the pattern is similar among areas (Figure 7-3). Although ammonium levels (Figure 7-4) rose in the nearfield when the outfall first went on line, ammonium in and near the sanctuary was not affected. Changes in ammonium levels at the boundary of Massachusetts Bay now appear to be lowering the concentrations found in the nearfield.

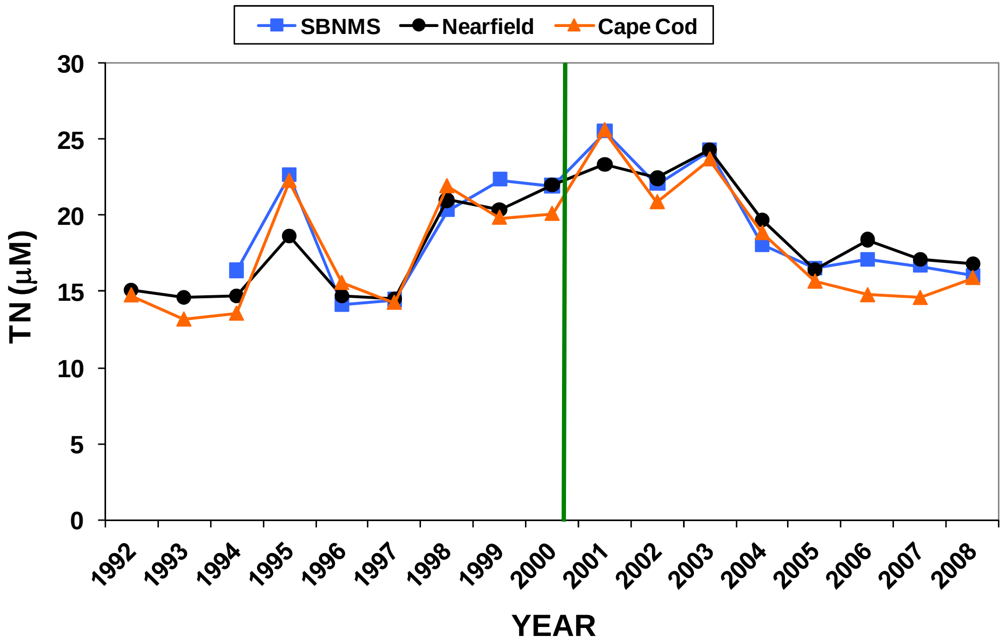


Figure 7-3. Annual mean total nitrogen (TN) at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. *Concentrations have varied by year but have been similar across regions. Vertical line indicates when outfall came on-line.*

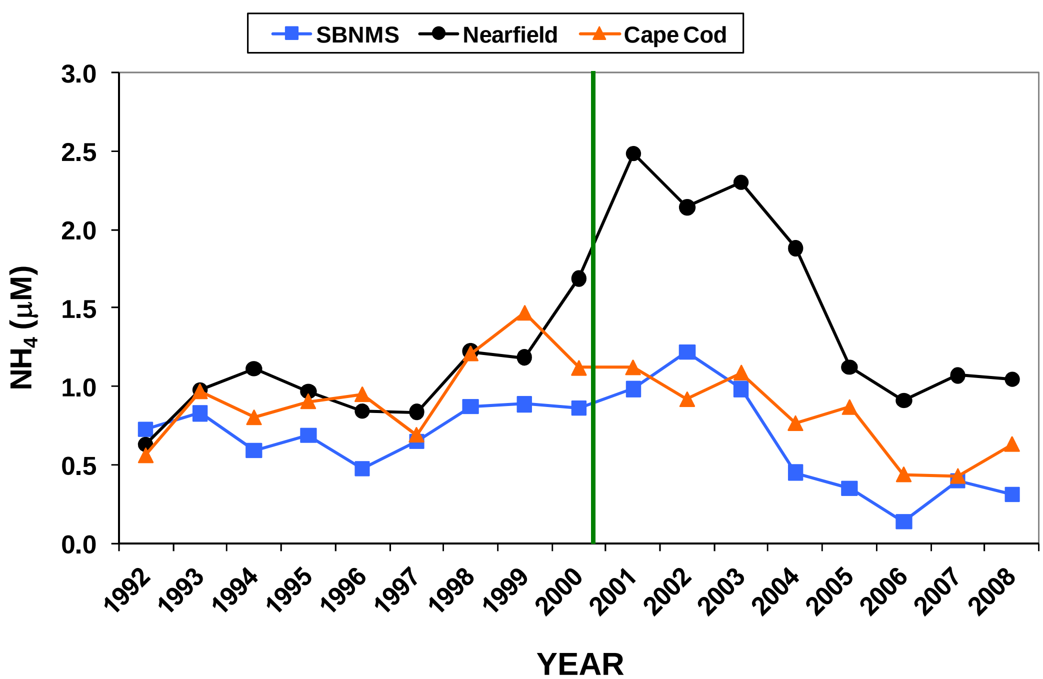


Figure 7-4. Annual mean ammonium at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. *Ammonium levels have declined in the past four years. Vertical line indicates when outfall came on-line.*

Nitrate concentrations (Figure 7-5) continue to be quite variable across all regions. Concentrations of nitrate, as well as silicate and phosphate, have been consistently higher at stations in and near the sanctuary than at stations in the nearfield and Cape Cod Bay. These higher levels are associated with deeper offshore waters, such as are found within the sanctuary. 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. There has been a long-term, slight, upward trend in nitrate levels across the regions.

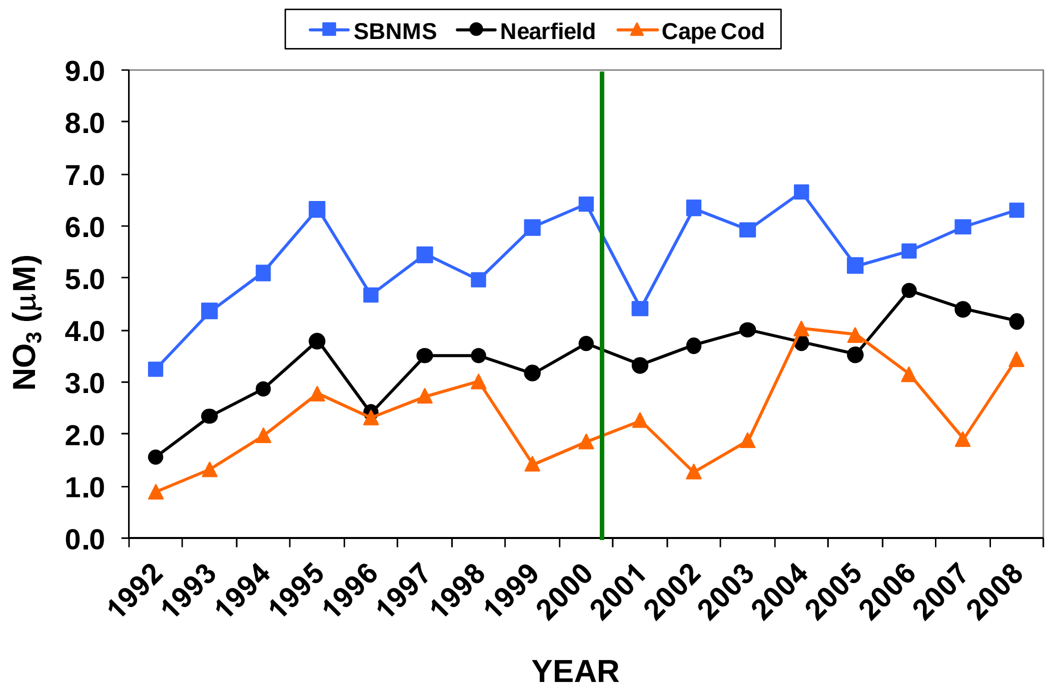


Figure 7-5. Annual mean nitrate at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. *Nitrate concentrations are variable, but there have been no changes that can be attributed to the outfall. Vertical line indicates when outfall came on-line.*

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.

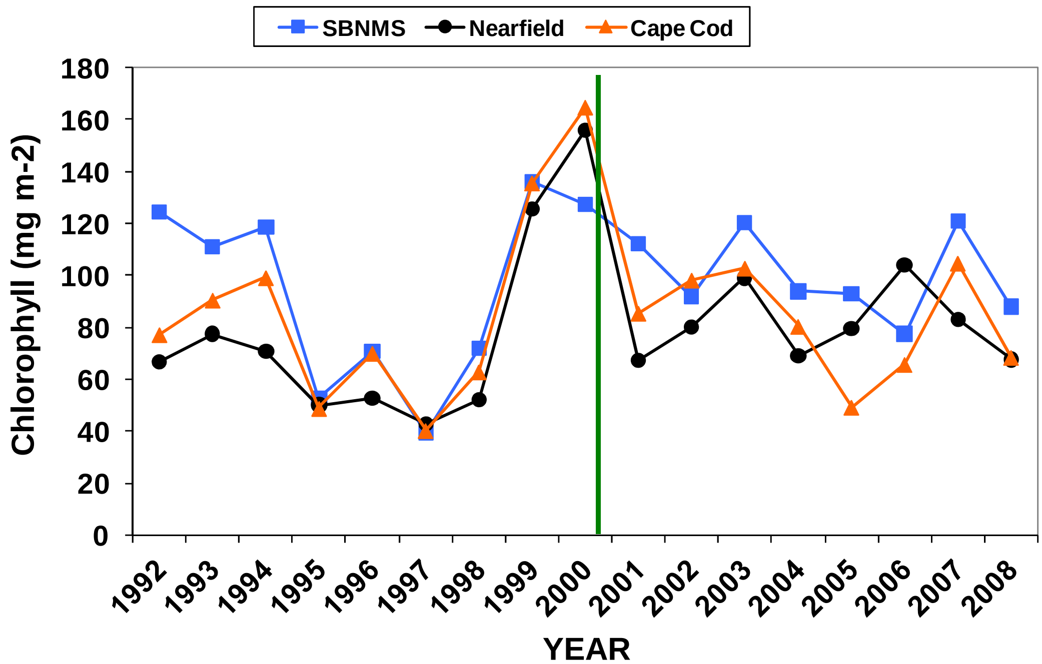


Figure 7-6. Annual chlorophyll at the Stellwagen Bank National Marine Sanctuary (SBNMS), the outfall nearfield, and Cape Cod Bay. *Over the course of monitoring, annual chlorophyll levels have varied, but similar patterns have been seen in samples from every region. Vertical line indicates when outfall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

Sea Floor

No changes in concentrations of sewage tracers or sewage-related contaminants were observed in the sediment samples from stations (FF04 and FF05) sampled in 2008 within or near the sanctuary (Figure 7-7), and there have been no changes in community parameters since the outfall began to discharge (Maciolek *et al.* 2009).

The deep-water stations sampled in 2008 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. The total number of individual organisms per sample has varied widely, but remained within the baseline range for stations in or near the sanctuary in 2008. The numbers of species per sample and the diversity of organisms within the samples were also within the baseline ranges (Figure 7-8). A general increase in number of species, which began during the baseline period and peaked in 2003, is considered to be a result of normal cycles. No patterns that relate to the outfall diversion have been found.

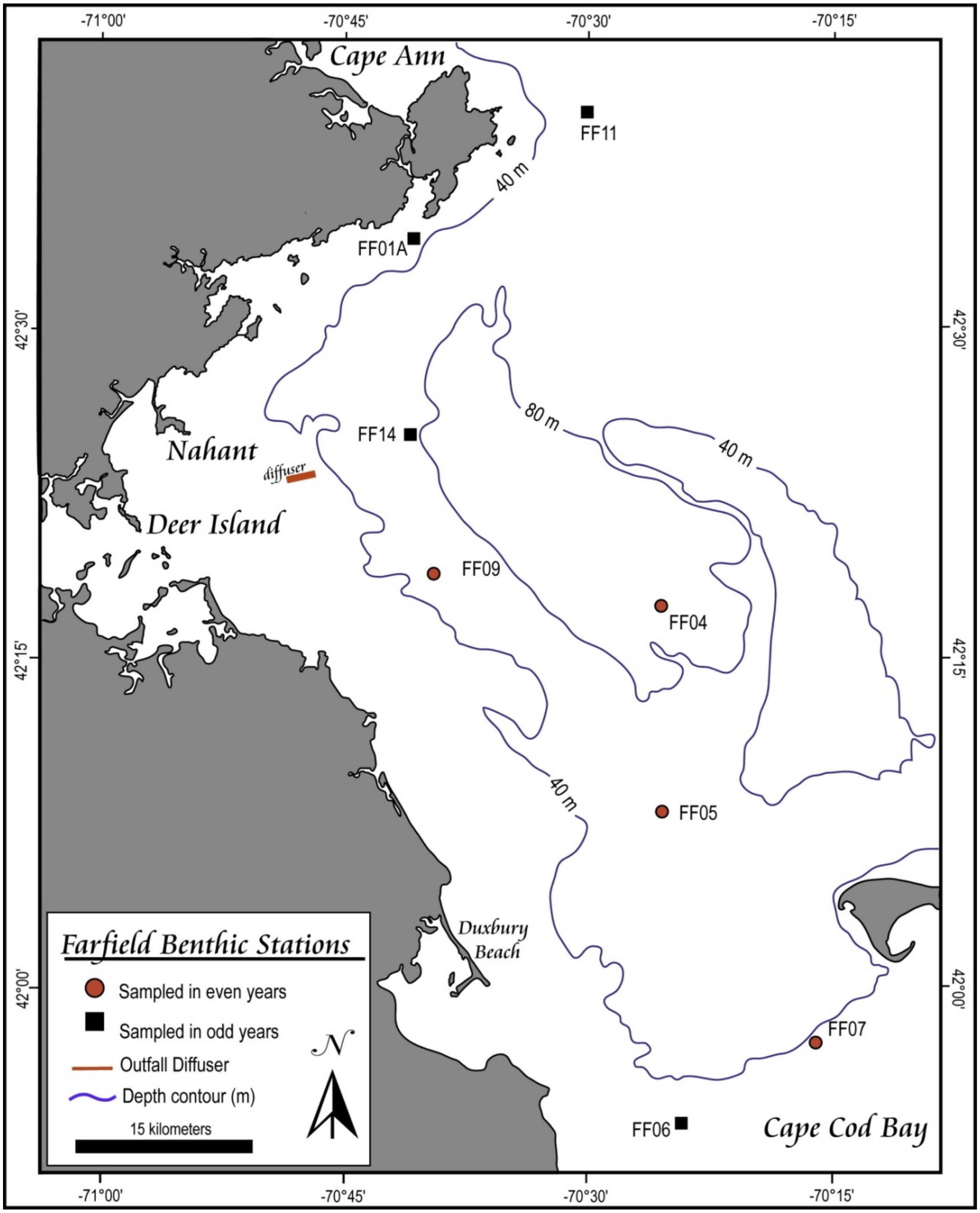
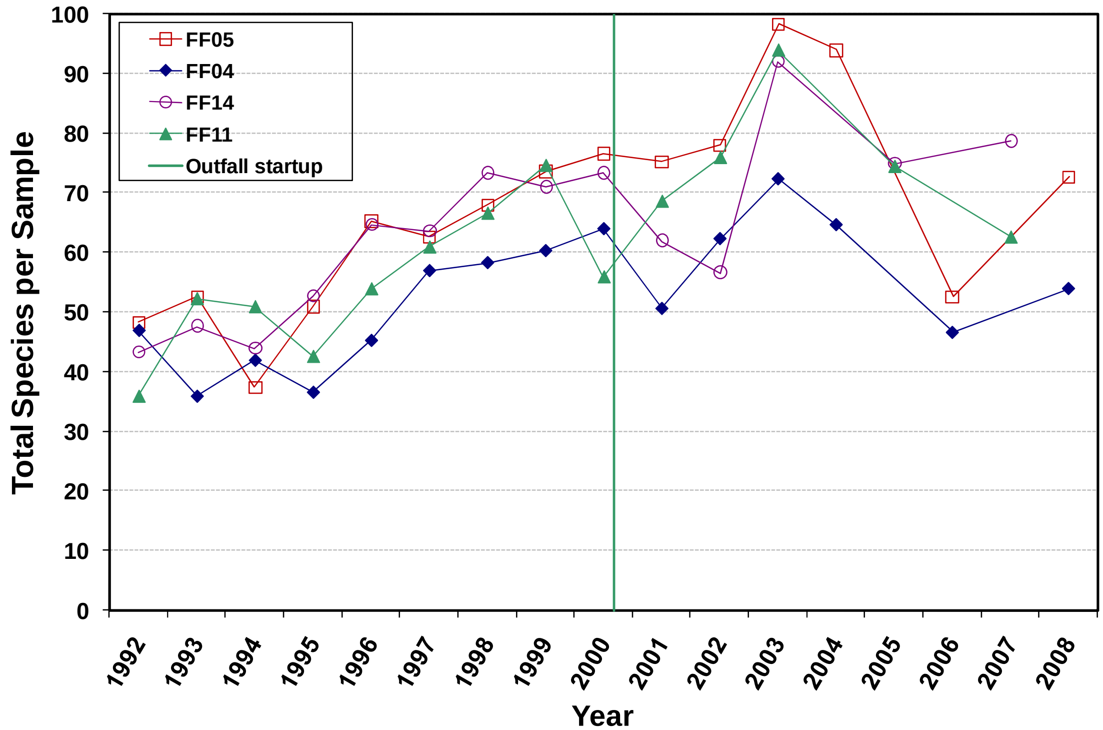


Figure 7-7. Farfield benthic stations. *Stations FF04, FF05, FF11, and FF14 are in or near the Stellwagen Bank National Marine Sanctuary. FF04 and FF05 were sampled in 2008.*



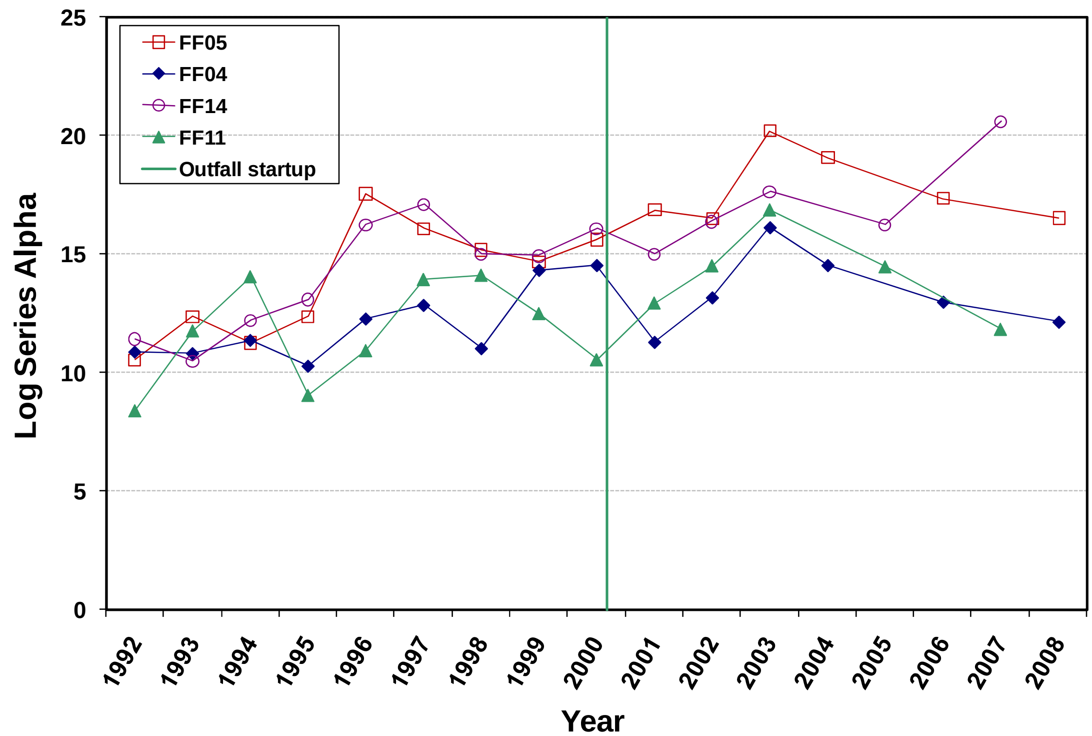


Figure 7-8. Community parameters at stations in or near the Stellwagen Bank National Marine Sanctuary. *Top: species richness (number of species per sample); Bottom: Log-series alpha, a measure of diversity.*

8. Monitoring Questions and Answers: 2008

Prior to beginning the monitoring program, an Outfall Monitoring Task Force formulated a series of questions that focused on plausible unanticipated consequences of the diverted effluent discharge. Monitoring has answered those questions (Table 8-1).

Compliance with effluent permit limits has been the key to ensuring that there are no unanticipated effects on Massachusetts Bay. Out of the tens of thousands of measurements that have been made since the Massachusetts Bay outfall began to discharge, there have been only eleven violations of permit limits (which are Contingency Plan threshold exceedances) including failures of four toxicity tests, none of which were attributed to toxic constituents of the effluent; an exceedance of the total suspended solids limits after an industrial discharge caused a disruption of the secondary treatment process; and exceedances of fecal coliform limits during storms.

As expected, water-column monitoring has confirmed that it is possible to detect sewage tracers at stations in the immediate vicinity of the outfall, but there have been no unexpected changes resulting from the relocated discharge. Late summer and fall levels of dissolved oxygen in bottom waters have not been affected by the outfall. Incidence of nuisance algal blooms has increased, but those changes have not been attributed to any stimulation from the discharge.

Similarly, there have been no unanticipated changes on the sea floor. Elevated concentrations of the sewage tracer *Clostridium perfringens* spores are detected at stations within the immediate vicinity of the outfall, but there are no elevated concentrations of toxic contaminants. The soft- and hard-bottom communities of Massachusetts and Cape Cod bays remain healthy.

There have been no effects on fish or shellfish. Some contaminant levels are elevated in mussels deployed in the immediate vicinity of the outfall, within the mixing zone. There have been no increases in contaminant levels or disease in the flounder and lobsters included in the monitoring program or in mussels deployed at any distance from the discharge.

Table 8-1. Answers to the monitoring questions as of the end of 2008.

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 500 tests, there have been four exceedances of permit limits.
Do effluent contaminant concentrations exceed permit limits?	No. Discharges of priority pollutants are well below SEIS 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 80% compared to the old treatment plant. In more than 500 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 grease, 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. 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 marked changes in the zooplankton community.
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?	These conditions were described by baseline monitoring.
Have the rates of these processes changed?	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.

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List of Acronyms

BACI	Before-After, Control-Impact analysis
BOD	Biochemical oxygen demand
cBOD	Carbonaceous biochemical oxygen demand
BWQM	Bay Water Quality Monitoring
CHV	Centrotubular hydropic vacuolation
CSO	Combined sewer overflow
DDE	Dichlorodiphenylethylene
DDT	Dichlorodiphenyltrichloroethane
DIF	Deer Island Flats
DITP	Deer Island Treatment Plant
DO	Dissolved oxygen
ECCB	Eastern Cape Cod Bay
GoMOOS	Gulf of Maine Ocean Observation System
GOMTOX	Gulf of Maine Toxicity
HMW	High molecular weight
IAAC	Inter-Agency Advisory Committee
LC50	50% mortality concentration
LMW	Low molecular weight
MB	Massachusetts Bay
MGD	Million gallons per day
MWRA	Massachusetts Water Resources Authority
NA	Not analyzed/not applicable
NB	Nantasket Beach
NDBC	National Data Buoy Center
NFSC	Northeast Fisheries Science Center
NOAA	National Oceanic and Atmospheric Administration
NOEC	No observed effects concentration
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OS	Outfall site
OSI	Organism sediment index
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
POC	Particulate organic carbon
PSP	Paralytic shellfish poisoning
RPD	Redox potential discontinuity
SBNMS	Stellwagen Bank National Marine Sanctuary
SEIS	Supplemental Environmental Impact Statement
TKN	Total Kjeldahl nitrogen
TP	Total phosphate
TSS	Total suspended solids
WHOI	Woods Hole Oceanographic Institution
WWTF	Wastewater treatment facility

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