# 2008 Annual Benthic Nutrient Flux Monitoring: Summary Report

Massachusetts Water Resources Authority

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# 2008 Annual
# Benthic Nutrient Flux
# Monitoring: Summary Report

**Submitted to**

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## INTRODUCTION

The Benthic Nutrient Cycling portion of the Massachusetts Water Resources Authority's (MWRA) Outfall Monitoring Program was designed to monitor biogeochemical processes in depositional sediments of Boston Harbor and Massachusetts Bay. These data have been used to assess changes in parameters relevant to eutrophication (eg.: organic carbon loading, sediment oxygen demand, nutrient flux, denitrification), particularly in the context of changing wastewater disposal practices. These data have also been used to examine benthic-pelagic coupling, specifically by providing data for the Bays Eutrophication Model. This summary report presents the status of both systems through the 2008 sampling season, with data from 2008 highlighted as appropriate. It includes as Appendix I a PowerPoint file that was presented at the Monitoring Program's Annual Technical Meeting for 2008, held May 8, 2009. Slides from the presentation "2008 Benthic Nutrient Cycling_MWRA Workshop 2009.ppt" are referred to in the report. For a more in-depth discussion of these studies, see Tucker et al., 2008 and references therein (http://www.mwra.state.ma.us/harbor/enquad/pdf/2008-14.pdf ).

The benthic flux component of the monitoring program began in its current design in 1993. From 1993 through 2000, the focus was on monitoring recovery of Boston Harbor as significant improvements in wastewater treatment and discharge were being implemented. Monitoring was also conducted in Massachusetts Bay and Stellwagen Basin in order to establish a baseline dataset for those environments. In September, 2000, a new outfall became operational, diverting wastewater from the historical outfall sites within Boston Harbor to a deepwater site 9 miles offshore in Massachusetts Bay. At this point, the focus shifted to Massachusetts Bay, and to watching for signs of any unexpected or significant impacts in the area near or even "downstream" of the new outfall. Monitoring of Boston Harbor continued in order to document further changes after the removal of effluent discharge.

Data presented in this report are from sediment samples collected four times a year: in May, to capture the deposition of the spring phytoplankton bloom; in July and August, to capture the warmest part of the season; and in October, before the breakdown of thermal stratification in Massachusetts Bay. Sediment cores were collected by box corer from three stations in Massachusetts Bay near the location of the ocean outfall and one station in Stellwagen Basin, which serves as a reference station (Appendix I: Slide 2) and by SCUBA from four stations in Boston Harbor (Appendix I: Slide 12). Survey dates, site coordinates, and field data for 2008 may be found in Appendix II. Details of field and laboratory protocols may be found in Tucker and Giblin, 2008 (http://www.mwra.state.ma.us/harbor/enquad/pdf/2008-06.pdf).

## MASSACHUSETTS BAY

A primary driver of benthic metabolism is organic matter (OM) supply to the sediments. A concern of the monitoring program has been that OM inputs might increase near the outfall, either directly from effluent, or indirectly via enhancement of primary production. We have measured total organic carbon and chlorophyll *a* content in surface sediments (collected in 2.5 cm dia. core tubes) to assess changes of organic matter content that might be attributed to wastewater. After eight years, there has been no discernable change in either measure (Table 1 and Appendix I: Slide 3).

| Location | Period | Period Averages | | | |
|---|---|---|---|---|---|
| | | TOC %dry wt | *S.E.* | Chl *a* μg $cm^{-2}$ | *S.E.* |
| Nearfield | Pre-Diversion | 1.2 | *0.1* | 7.5 | *0.5* |
| | Post- Diversion | 1.3 | *0.0* | 7.1 | *0.6* |
| Farfield | Pre-Diversion | 1.4 | *0.1* | 7.9 | |
| | Post- Diversion | 1.6 | *0.0* | 5.1 | |

**Table 1. Averages of total organic carbon (TOC; top two cm of sediment) and chlorophyll *a* (Chl *a*) inventories (top 5 cm) for the pre- and post-diversion periods. Values for the Nearfield combine Stations MB01, MB02, and MB03; the Farfield is the single station MB05. The pre-diversion period used in this table is 1994-2000. The post-diversion period is 2001-2008. For TOC all four surveys per year were included and for chl a inventories, only May and October data are included, with the following data gaps: 1.) no samples were collected in 1998; 2.) for MB01, data were not collected in October 1996 for TOC or October 1997 for either parameter; 3.) For MB02, no samples were collected in 1997; 4.) For MB05, no samples were collected in July 1998.**

Consequences of increased OM loading to sediments typically include increased sediment respiration, or sediment oxygen demand (SOD), as well as increased nutrient fluxes from the sediments. We have monitored these processes by incubating large sediment cores (15 cm dia.) under near ambient conditions and measuring respiratory gas ($O_2$ and $CO_2$) and nutrient [Dissolved inorganic nitrogen (DIN = $NH_4^+$ plus $NO_3^-$+$NO_2^-$), $PO_4^-$, dissolved Si (dSi)] exchange across the sediment water interface. We have not observed an increase in any of these measures since the ocean outfall became operational (Table 2). In fact, larger fluxes and greater variability were observed in the pre-diversion period, and may have been associated with regional influences such as large storms (Bothner and Butman, 2007). Fluxes averaged over the four surveys in 2008 were among the lowest in the entire dataset, and variability across the three nearfield stations (MB01, MB02, MB03) was quite low. There has been little interannual variability at the farfield station (MB05) over all years of the monitoring program. Average fluxes in 2008 for the nearfield and farfield, respectively, in mmol $m^{-2}$ $d^{-1}$, were: SOD = 12.8, 9.7; DIN flux = 0.1, 0.2; $PO_4^-$ flux = < 0.01, 0.02; dSi flux = 3.4, 3.1. These rates compare to the rest of the post-diversion period and the pre-diversion period as shown in Appendix I: Slides 4-7.

Although there has been no change in the nearfield DIN flux, there has been a subtle shift in the relative proportions of the components of that flux in recent years (Appendix I: Slide 6), with $NH_4^+$ flux trending down and $NO_3^-$ flux trending up. Fluxes of $NH_4^+$ have decreased such that in some years, the seasonal average was negative; that is, there was an overall uptake of $NH_4^+$ by the sediments rather than an efflux. This shift was first noticed at Station MB03 in 2002, and then in 2005 at Stations MB01 and MB02. In 2008, there was overall uptake of $NH_4^+$ at MB01 and MB02 and only a small efflux at MB03. Accordingly, $NO_3^-$ made up 100% of the average efflux at MB01 and MB02, and 80% at MB03. At MB05, a similar trend is suggested but is harder to discern given the very small fluxes. In 2008, there was essentially no $NH_4^+$ flux, in or out, at this station. A decline in $NH_4^+$ fluxes is generally considered an indication of improved sediment conditions; were these sites being adversely impacted by the outfall, the opposite trend would be expected.

| Location | Period | Flux Averages per Period (mmol $m^{-2}$ $d^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **SOD** | *S.E.* | **DIN** | *S.E.* | **$PO_4^-$** | *S.E.* | **dSi** | *S.E.* |
| **Nearfield** | **Pre-Diversion** | 17.3 | *0.98* | 0.9 | *0.18* | 0.1 | *0.03* | 5.0 | *0.61* |
| | **Post-Diversion** | 14.9 | *0.72* | 0.5 | *0.07* | 0.0 | *0.01* | 3.3 | *0.19* |
| **Farfield** | **Pre-Diversion** | 11.6 | *1.01* | 0.3 | *0.09* | 0.0 | *0.02* | 4.3 | *0.63* |
| | **Post-Diversion** | 11.5 | *0.38* | 0.2 | *0.04* | 0.0 | *0.01* | 3.6 | *0.22* |

**Table 2. Averages sediment oxygen demand (SOD) and fluxes of dissolved inorganic carbon (DIN), phosphate (PO4-) and dissolved silica (dSi) for the pre- and post-diversion periods. Nearfield values = the averages and standard error (*S.E.*) for Stations MB01, MB02, and MB03, for seven (MB01 and MB03) or six (MB02) years from 1993 thru 2000 for the Pre-Diversion period. Farfield = Station MB05; data are from 4 surveys per year for 6 years from 1994 thru 2000. Post-diversion averages are from 8 years (2001-2008). Averages include data from May, July, August, and October surveys.**

Another biogeochemical process that has been monitored is denitrification (Appendix I: Slide 8). Denitrification typically increases with eutrophication up to a point, after which hypoxic or anoxic conditions (including high sulfide concentrations) inhibit the process. Our observations have not shown such a trend. Instead, denitrification rates have shown considerable variability, but seemed to be higher in earlier years, and have decreased in recent years, in a trend consistent with the other fluxes. (We must note that denitrification measurements were not made at all stations or during all surveys until 2004, when a methods change allowed for more comprehensive measurements.) Denitrification in 2008 was typical of recent years, and among the lower rates observed. The nearfield average was 1.2 mmol N $m^{-2}$ $d^{-1}$, with little variability across the three stations (S.E. = 0.05). At MB05, the average was 0.9 mmol N $m^{-2}$ $d^{-1}$.

Although rates of denitrification are not very high, $N_2$ flux (as N) comprises the largest component of the inorganic N flux from the sediments; it is nearly always larger than the DIN flux (Appendix I: Slide 9). As a fraction of the total, the $N_2$ flux is often over 70% of the average efflux at the nearfield stations, and 80% at the farfield. In 2008, denitrification accounted for about 80% of the total at all four stations.

We have looked at the balance between aerobic and anaerobic respiration as one indicator of change in the oxidation status of the sediments. The ratio of $CO_2$ release to $O_2$ uptake, known as the respiratory quotient (RQ), equals 1.0 for aerobic respiration, but becomes greater than 1.0 as the importance of anaerobic processes increases, and the endproducts of these processes are stored (not reoxidized). RQ values near 1.0 are consistent with highly oxidized, high habitat-quality sediments. To be used to characterize a system, the RQ is best considered as an annual average (in our case, a seasonal average since we do not have winter data) rather than from a single time-point measurement. Since 1999, the average RQs for our stations have been very close to 1.0; only in 1993 and 1994 did we observed higher values ($CO_2$ data not available for 1995-1998); we have seen no increase in RQ values. In 2008, RQs at all stations were slightly lower than 1.0 (about 0.9), suggesting that there was some reoxidation of previously stored endproducts of anaerobic respiration, possibly facilitated by deep-burrowing infauna. We often observe burrowing anemones (*Ceriantheopsis*), mud shrimp (*Upogebia?*), large polychaetes (*Nereis*) or clams (*Thracia*) in our cores.

The oxidation state of the sediments has also been monitored by direct measurement of oxidation-reduction potential (Eh) in small cores (6 cm diameter). Values of Eh, measured to a sediment depth of 18 cm, have always been quite positive throughout the depth of the cores, indicating the absence of strongly reducing conditions. Profiles continued to show highly oxidizing conditions in 2008 (Appendix I: Slide 10).

## BOSTON HARBOR

Boston Harbor has experienced substantial change related to wastewater treatment improvements, many of which occurred before the relocation of the outfall. Reductions in solids loading to the harbor, which were among the first steps implemented in the cleanup process, were of primary importance to the benthos. In particular, the cessation of sludge disposal and other early reductions were soon followed by the colonization of the sediments by an infaunal community, dominated by mat-forming amphipods *Ampelisca sp*., that quickly spread through much of the harbor. The infaunal community has played a major role in benthic nutrient cycling in the harbor. In 2008, this was again the case, as a different amphipod community, dominated by *Leptocheirus pingus*, was responsible for some significant changes at Stations BH02 and BH08A.

While it is important to look at the average changes across our sites as an indication of the harborwide response to improvements, it is also informative to look at the details from each site, as each has progressed along its own trajectory of recovery.

Much of the difference we have observed in the biogeochemistry of these sites has been related to the timing and extent of colonization by infaunal communities. Very briefly, the most dynamic changes began in 1993 at Station BH03 with the colonization of that station by the *Ampelisca* community. Soon after, Station BH08A was similarly colonized, with a harbor-wide peak in mat distribution in 1995. During these peak *Ampelisca* years benthic respiration, for example, was highest at these two stations, then declined as the mats declined into the early

2000s. In summer 2007, the *Leptocheirus* community appeared at Station BH02, at which point dramatic changes began to be seen at this site. This community was present again in 2008 at BH02 and also at BH08A (Appendix I: Slide 13). Neither of these amphipod communities has been present at Station QB01, and fluxes at this station have typically been the lowest and least variable of the four stations.

Reductions in solids loading were reflected in decreasing organic carbon content of the depositional sediments at our sites. Much of this change occurred well before the diversion of the outfall, coinciding with several periods of treatment upgrades (described by Taylor, 2006), although not in synchrony at our four sites. High rates of benthic respiration, enhanced by the mat communities, contributed to the decrease. By 1998, TOC (as average of 4 surveys/year) showed an overall decrease at all four stations, and variability across stations was less (Table 3 and Appendix I: Slide 15). After 1998, decreases in TOC continued, albeit at a slower rate. In 2008, average TOC ranged only from 1.8% to 2.1% across the four stations. In 1992, average TOC at Stations BH02 and BH03 had been 3.0% and 4.1%, respectively.

| | Average TOC per Period per Station (% dry wt) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Period** | **BH02** | *S.E.* | **BH03** | *S.E.* | **BH08A** | *S.E.* | **QB01** | *S.E.* |
| **1992-1994** | 1.9 | *0.5* | 3.7 | *0.3* | | | | |
| **1995-1997** | 2.5 | *0.5* | 3.8 | *0.2* | 3.3 | *0.3* | 3.2 | *0.2* |
| **1998-2000** | 2.2 | *0.4* | 2.8 | *0.2* | 2.6 | *0.1* | 2.4 | *0.3* |
| **2001-2008** | 2.0 | *0.1* | 2.2 | *0.2* | 1.9 | *0.1* | 2.3 | *0.1* |

**Table 3. Average TOC (and standard error S.E.) for each treatment period and each station, including data from May, July, August, and October sample collections. Data are not available for Stations BH089A and QB01 before 1995.**

The connection between benthic chlorophyll and treatment upgrades is more complex in Boston Harbor than in Massachusetts Bay. In contrast to Massachusetts Bay, benthic chlorophyll in sediments of Boston Harbor may come from *in situ* as well as water column production since the bottom depths are well within the photic zone. Therefore, benthic chlorophyll may be derived from the deposition of phytoplankton, whose growth was largely supported by effluent nutrients until the effluent was diverted offshore, and by benthic microalgae, whose nutrients come largely from sediment pore waters. Pore water nutrient concentrations in some Boston Harbor sediments may be enriched due to remineralization of large amounts of organic matter, some of which is also sewage derived. However, porewater nutrients from unimpacted sediments are usually sufficient to support substantial benthic production. Historically, benthic production in Boston Harbor has more likely been light-limited due to high water column turbidity, also related to effluent. In addition, grazing pressure has been high at sites of dense infaunal colonization; these sites have typically been those with highest OM loads.

Temporal patterns of sediment chlorophyll *a* (measured as the total inventory over the top 5 cm of sediment, µg $cm^{-2}$) have varied depending on site and the interplay of the various drivers noted above (Appendix I: Slides 16 and 17). At BH03 and BH08A, average inventories have not shown much interannual variability, although there seems to have been a slow decline over the last 3 years. These two stations typically supported dense populations of the tube building amphipod, *Ampelisca*, and associated infauna, and so have been subject to intense grazing pressure. In recent years, grazing pressure has relaxed at Station BH03 as the amphipod community declined, but physical disturbance, as suggested by a change in grain-size to much coarser sediments, has increased and currently seems to be the mechanism preventing chlorophyll accumulation.

At Station QB01, benthic chlorophyll inventories increased dramatically after 2001, and were quite high from 2003-2005. How this increase might be related to effluent diversion is unclear, but the western edge of the harbor was one of two areas that did improve in water clarity after offshore transfer (Taylor, 2006). We have often observed benthic diatoms at this site, and attribute elevated chlorophyll levels largely to *in situ* production. Inventories have declined since 2005, and were low for this station in 2008. We typically do not observe dense infaunal populations here, although in July, 2008 we were surprised to find a large *Mya* clam in one of our cores (Appendix I: Slide 14). If these clams have become more common, they may reduce benthic chlorophyll both by suspension feeding and by ingesting microflora associated with resuspended sediments (Lopez and Levinton, 1987).

Since 1998, largest benthic chlorophyll inventories have been found at Station BH02. We have often characterized this station as the slowest of our four stations to exhibit signs of recovery. Changes in TOC have not been appreciable, and, until recently, the ARPD (apparent redox potential discontinuity) had remained shallow. The combination of a rich supply of nutrients from the sediments with reducing conditions, which limit infaunal colonization, may have promoted the growth of benthic diatoms, often observed at this site. Over the last two years, chlorophyll levels at Station BH02 decreased sharply. This decline coincides with the colonization by the *Leptocheirus* amphipod community.

Sediment oxygen demand (SOD) in 2008 was highlighted by results from Stations BH02 and BH08A, the two stations with dense *Leptocheirus* communities (Appendix I: Slide 18 and 19). For Station BH02, the seasonal average (May-Oct) of 106 mmol $m^{-2}$ $d^{-1}$ was the highest rate yet observed at this station. The increase in SOD at Station BH02 started in 2007, with the first appearance of the *Leptocheirus* community there. At BH08A, the seasonal average was 102, nearly as high as this station's 1995 maximum of 106 mmol $m^{-2}$ $d^{-1}$, measured during the *Ampelisca* period. 2008 was the first year for *Leptocheirus* at Station BH08A. [For reference, the highest average SOD measured during the monitoring program was 205 mmol $m^{-2}$ $d^{-1}$, observed at Station BH03 in 1993.] SOD at Station QB01 was also the highest observed at this station (58 mmol $m^{-2}$ $d^{-1}$), but only about half the rate at BH02 and BH08A. There was no amphipod community observed at this station. At Station BH03, SOD was 42 mmol $m^{-2}$ $d^{-1}$, typical of the post-relocation period.

Nutrient fluxes were also elevated at Stations BH02 (for the second year) and BH08A in 2008 and were also related to the presence of animals. In contrast, fluxes at Stations BH03 and QB01 were typical of the post-relocation period.

Average fluxes of dissolved inorganic nitrogen (DIN) in 2008 (Appendix I: Slide 20) were equivalent at BH02 and BH08A at 6.6 and 6.8 mmol $m^{-2}$ $d^{-1}$, respectively. Increases in DIN fluxes were largely due to the $NO_3^-$ component, which was the highest recorded for these two stations and accounted for about 60% of the flux (Appendix I: Slide 21) as opposed to 30% or less at the other two stations. Nitrate fluxes (and consequently DIN fluxes) followed a seasonal pattern at these two stations, with largest fluxes occurring in the summer. In contrast, $NO_3^-$ fluxes at the other two stations were small and showed little seasonal change. Enhanced $NO_3^-$ fluxes are consistent with active bioturbation, which increases oxygen penetration into the sediments, thereby promoting nitrification, and in turn, denitrification.

Dissolved silica (dSi) fluxes were also high at Station BH02 and BH08A (17 and 14 mmol $m^{-2}$ $d^{-1}$, respectively: Appendix I: Slide 22). These fluxes were particularly striking at BH02, where animal effects had been minimal until 2007-2008, whereas at BH08A, where the *Ampelisca* mats had been present, similarly high rates had been observed before. The animals enhance the fluxes two ways: they flush Si-rich porewaters from the sediments as they irrigate their burrows and tunnels, and in so doing they promote further dissolution by lowering pore water Si concentrations (Aller, 2001).

Phosphate fluxes did not show as dramatic an increase over previous years as the other fluxes, but were higher at BH02 and BH08A than at the other two stations (Appendix I: Slide 22). They also followed the seasonal pattern, with highest rates occurring in the summer.
These fluxes are in keeping with overall increase in nutrient cycling and solute transport associated with bioturbation.

However, while the DIN fluxes had been nearly identical at the two high stations, this was not the case for the $PO_4^-$ fluxes: $PO_4^-$ fluxes at BH08A were only about half those at BH02 ( 0.3 vs. 0.6 mmol $m^{-2}$ $d^{-1}$, respectively). Phosphate fluxes may not be tightly coupled to DIN fluxes because they are controlled by interplay of biological and physicochemical processes, which are made more complex by redox fluctuations associated with bioturbation. At BH02, these elevated fluxes occurred for the second straight year. At BH08A, $PO_4^-$ fluxes were nearly twice those of the previous year.

In accordance with enhanced $NO_3^-$ fluxes, denitrification was high at BH02 (for the second year) and at BH08A (seasonal averages of 5.1 and 4.0 mmol N $m^{-2}$ $d^{-1}$), but within typical post-relocation ranges for BH03 and QB01 (1.9 and 2.2 mmol N $m^{-2}$ $d^{-1}$) (Appendix I: Slide 23). By converting biologically available DIN to unavailable $N_2$ gas, denitrification may function to mitigate the impacts of nitrogen loading. Before outfall relocation, even high rates of denitrification had only a small effect compared to total nitrogen inputs. With the diversion of the effluent offshore, however, denitrification has become an important sink, accounting for about 60% of remaining inputs (Appendix I: Slide 24).

In spite of the temporal and spatial variability, and the recent upticks at BH02 and BH08A, there has been a steady decline in SOD and nutrient fluxes from the benthos over the time frame of the monitoring period (Table 4). The decreases in the averages (May-October) across our stations follow the treatment improvement periods (see Taylor, 2006) especially as they related to changes in solids loading to the harbor.

| | Harbor Flux Averages per Period (mmol $m^{-2}$ $d^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Period** | **SOD** | *S.E.* | **DIN** | *S.E.* | **$PO_4^-$** | *S.E.* | **dSi** | *S.E.* |
| **1993-1994** | 90.2 | *38.5* | 8.0 | *2.1* | 1.0 | *0.5* | 11.4 | *3.7* |
| **1995-1997** | 73.0 | *13.3* | 5.5 | *0.8* | 0.2 | *0.0* | 5.6 | *0.8* |
| **1998-2000** | 51.9 | *6.1* | 4.5 | *0.7* | 0.5 | *0.1* | 8.0 | *1.1* |
| **2001-2008** | 41.2 | *3.8* | 3.1 | *0.3* | 0.2 | *0.3* | 6.1 | *0.7* |

**Table 4. SOD and nutrient fluxes as harbor-wide averages and standard error (*S.E.*) of four stations, May, july, August, and October surveys, and for each treatment period.**

The oxidation state of the sediments at our stations has improved over the monitoring period, although conditions at Station BH02 seemed to lag behind the other three stations. Respiratory quotients varied spatially and temporally, however values were often noticeably higher at Station BH02. This pattern changed in 2007 with the appearance of the amphipods; average RQs at all four stations were near 1.0. In 2008, average RQs were less than 1.0 at all stations, ranging from 0.9 at BH02 to 0 .7 at BH03. Such low RQs likely reflect the reoxidation of stored endproducts as oxygenated water enters the sediments via bioirrigation.

Profiles of redox potential (Eh) also showed highly oxidized sediments at all stations in 2008 (Appendix I: Slide 25), with the most dramatic change from typical at BH02. At this station, a deepening of the RPD corresponded to the depth of burrowing by infauna (Appendix I: Slide 26, and refer back to Slide 13). A similar feature was present at Station BH08A, but the change was less pronounced because this station has often had amphipod colonies.

## CONCLUSIONS

Biogeochemical processes in depositional sediments of Massachusetts Bay have shown no discernable change during 8 years of post outfall relocation monitoring. We have observed no indication of increased organic matter loading to our nearfield stations, nor have we observed a change in redox conditions. Sediment oxygen demand and nutrient fluxes have not increased, and in fact are somewhat lower than in some years preceeding relocation. Denitrification continues to be the major component of remineralized nitrogen (Appendix I: Slide 11).

In Boston Harbor, the organic matter content of the sediments continues to decline as a result of earlier decreases in solids loading to the harbor and as the OM is respired away. SOD and fluxes in the post-relocation period continue to be lower and less variable overall than in the pre-relocation period, in spite of recent large fluxes at two of our stations. As was the case in the earlier period, enhanced fluxes are attributed to bioirrigation effects, most recently by a community dominated by the amphipod *Leptocheirus pinguis*. Macrofaunal effects also deepen the oxidized layer in the sediments thereby stimulating nitrification and denitrification. Due to the reduction in nitrogen loading to the harbor effected by the outfall relocation, denitrification has become a major sink, accounting for about 60% of the remaining total nitrogen inputs (Appendix I: Slide 28).

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# APPENDIX I

# 2008 Benthic Nutrient Cycling
# MWRA Workshop 2009

# Benthic Nutrient Cycling 2008

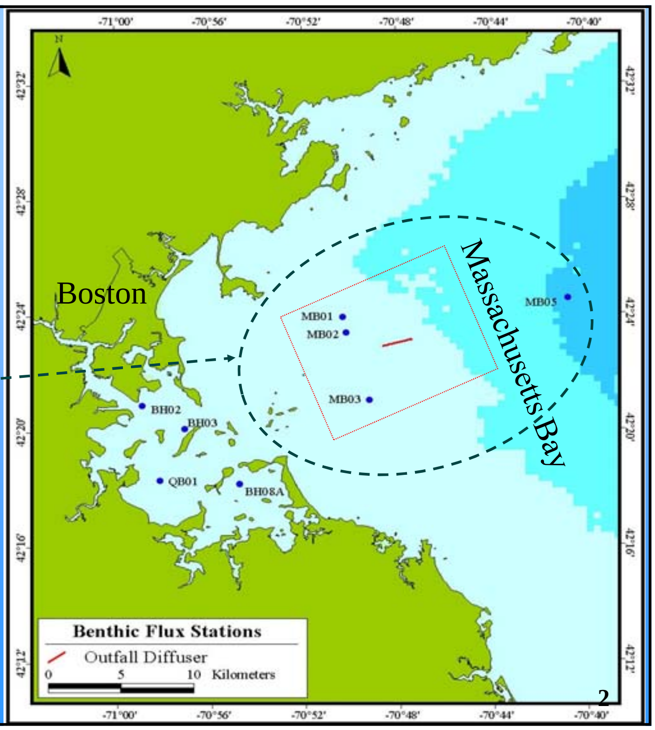
MWRA Annual Technical Meeting
May 8, 2009

Jane Tucker
Anne Giblin
Sam Kelsey

1

## Stations for Benthic Nutrient Flux

**In Massachusetts Bay:**
3 Nearfield
1 Farfield

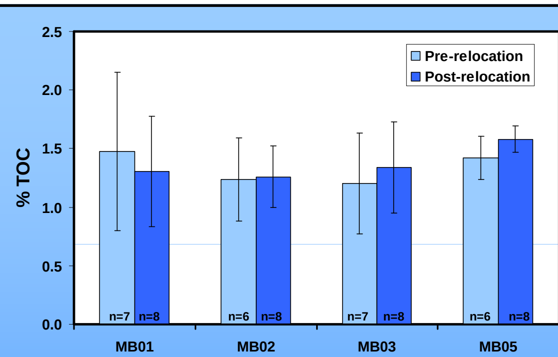


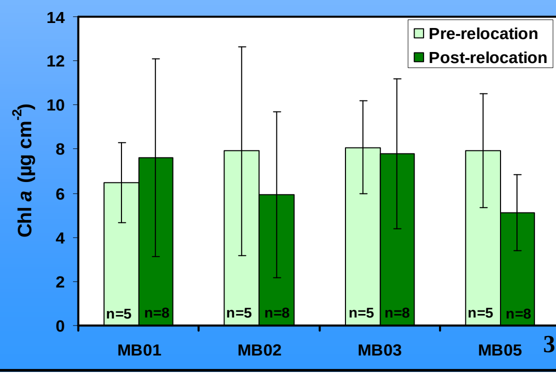

2

## Organic Carbon and Chlorophyll *a* content of surface sediments

**Means for the pre- (1993-2000) and post-relocation (2001-2008) periods show no change.**

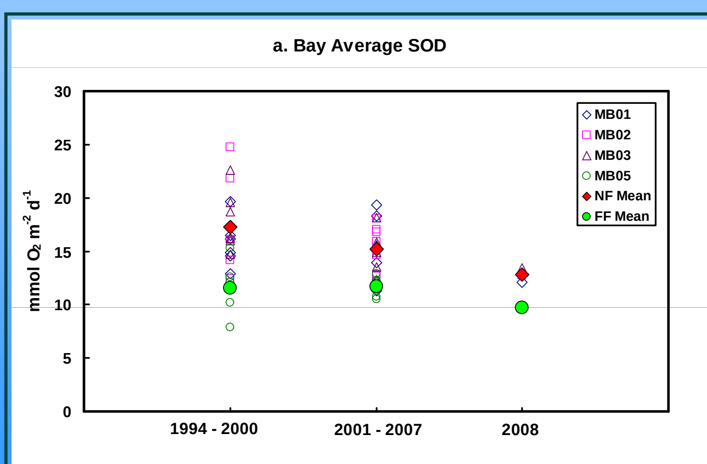
For TOC: May- Oct means and SD
For Chl *a*: May, Oct means and SD



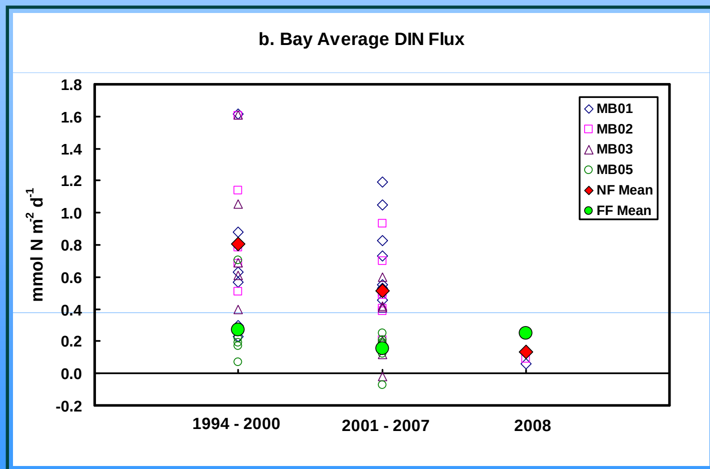

3

## Sediment Oxygen Demand for Nearfield and Farfield: 2008 compared to pre- and post-relocation of the MWRA outfall




4

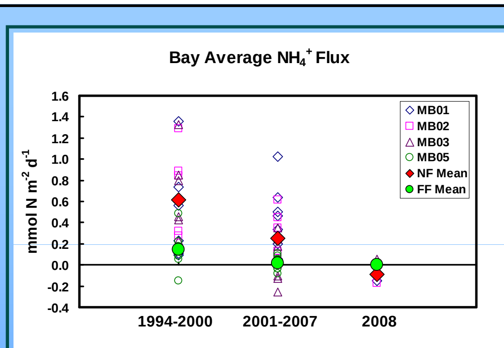
## DIN Flux for Nearfield and Farfield:
### 2008 compared to pre- and post-relocation of the MWRA outfall

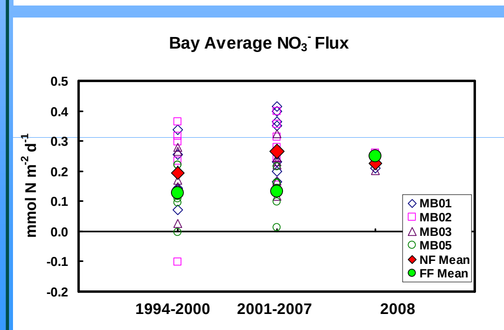



5

## Components of the DIN Flux

**Downward trend in $NH_4^+$ flux and upward trend in $NO_3^-$ flux are consistent with oxidizing conditions in sediments**

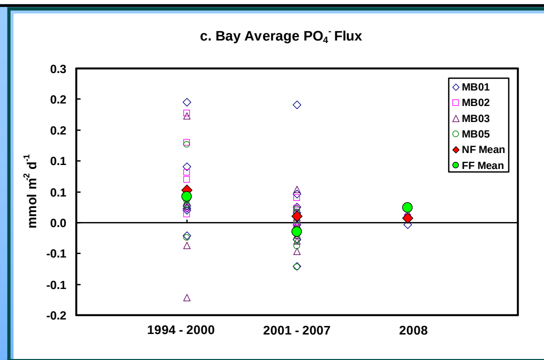


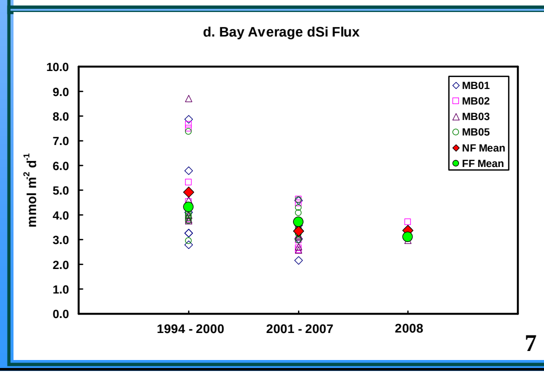




6

## $PO_4^-$ and Si Fluxes for Nearfield and Farfield:

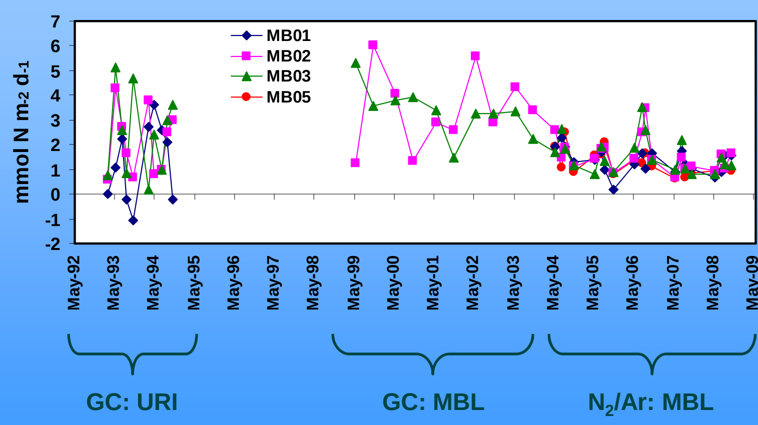
2008 compared to pre- and post-relocation of the MWRA outfall



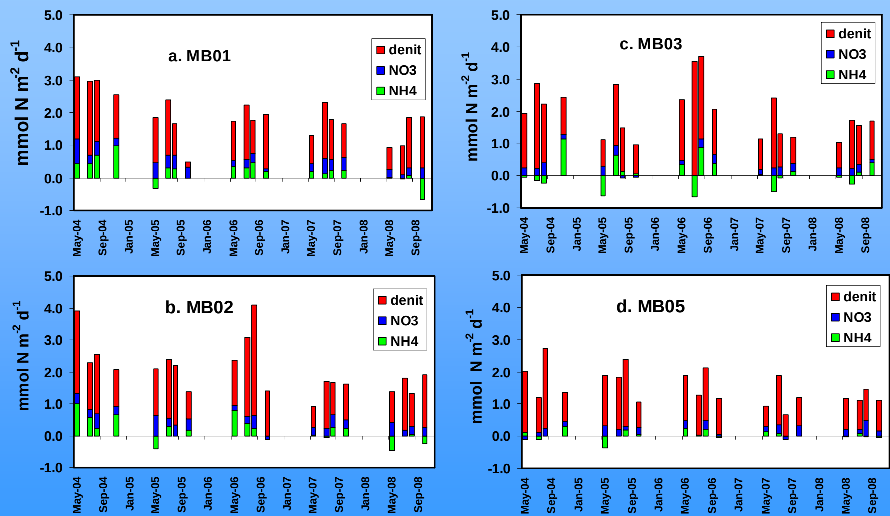

7

## Bay Denitrification 1993-2008



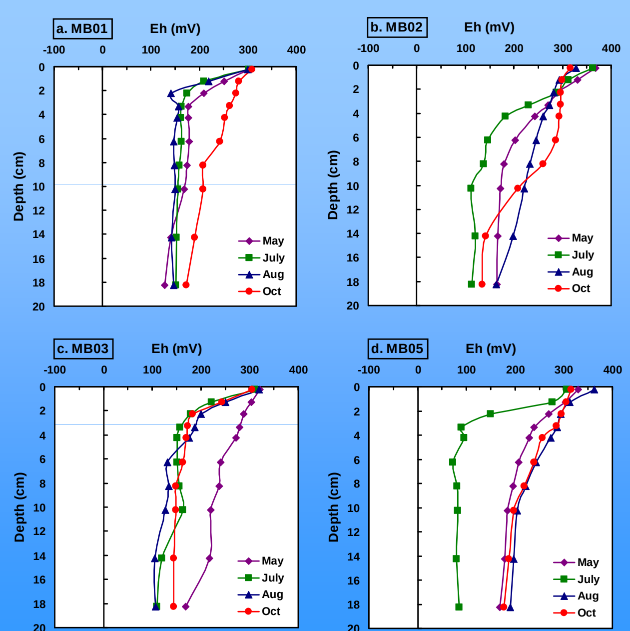

8

## Denitrification compared to DIN Flux; 2004-2008 at all four Bay stations




9

## Eh Profiles 2008

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## Conclusions for 2008

### Massachusetts Bay

No indication of increased OM loading to nearfield

No change in redox conditions

No increase in SOD or nutrient fluxes

No discernible change in denitrification, which remains the major component of remineralized N

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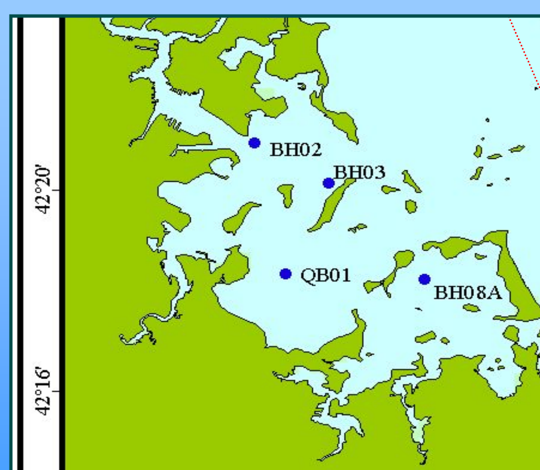
## Stations for Benthic Nutrient Flux

**In Boston Harbor:**
2 in North Harbor
1 in Quincy Bay
1 in Hingham Bay

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## Amphipods II: *Leptocheirus pinguis*




July 2008

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## Other Noteworthy Critters captured in cores during July survey

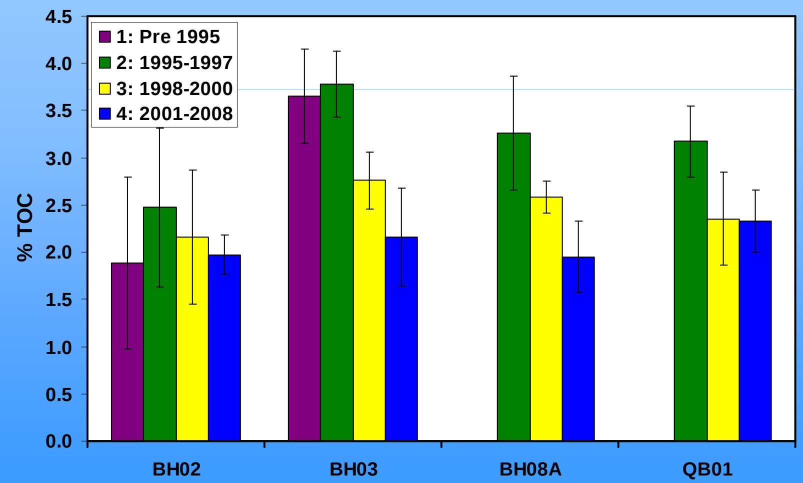

*Pherusa affinis*


*Mya arenaria* and ?

14

## Average TOC during periods of treatment improvements

(% dry wt, top 2 cm of sediment)

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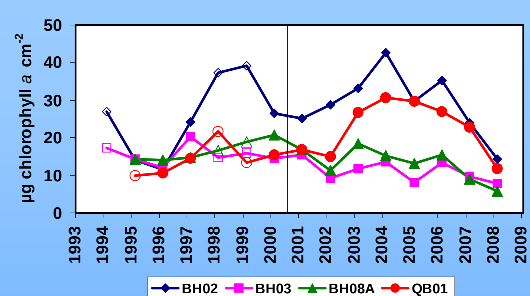
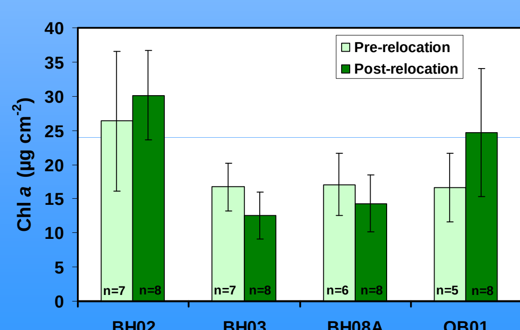
## Sediment chlorophyll *a* inventory (top 5 cm) before and after outfall relocation




**Includes both deposition and *in situ* production; benthic diatoms are often observed at BH02 and QB01**




Averages include May and October only

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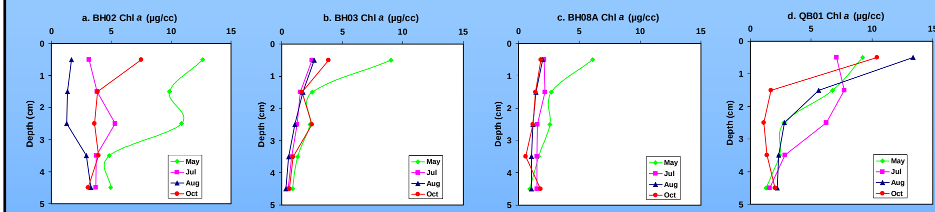
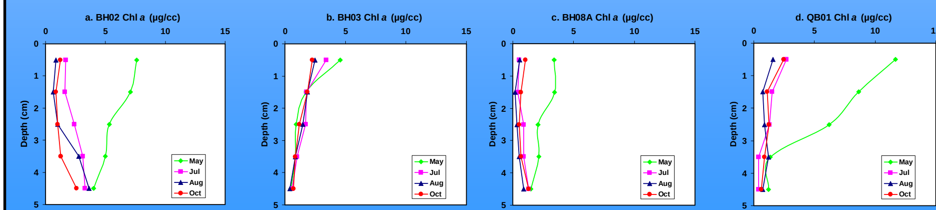
## Harbor Chlorophyll *a* Profiles

2007




2008

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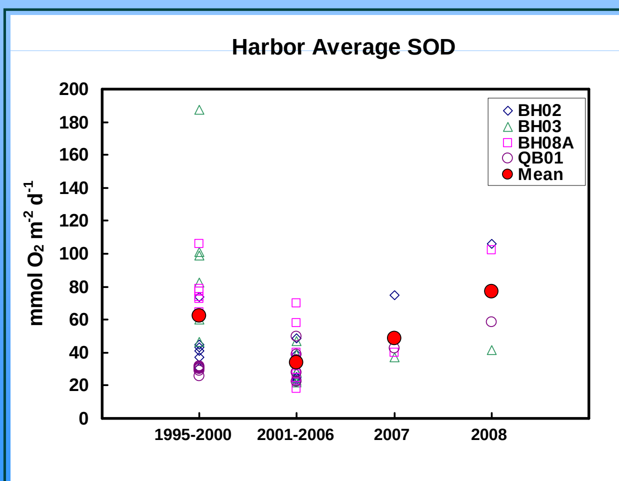
## Sediment Oxygen Demand for Boston Harbor

**2008 compared to 2007and to pre- and post-relocation of the MWRA outfall**

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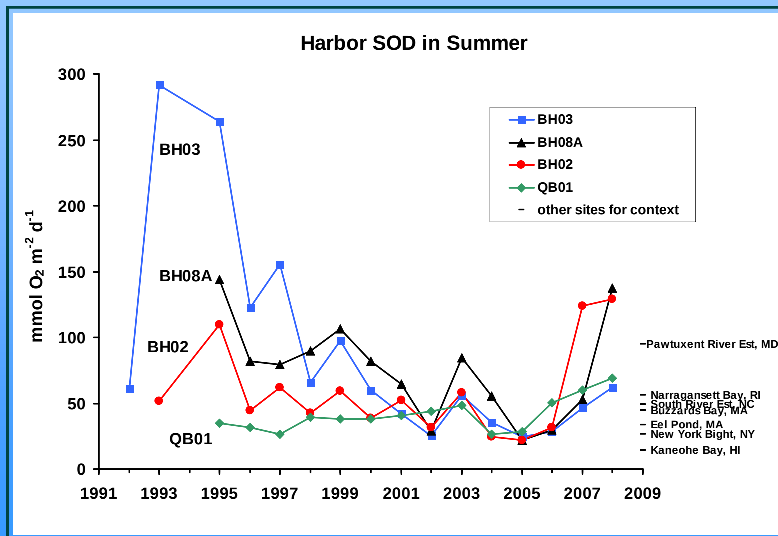
## July-August Average SOD for Boston Harbor

**2008 compared to pre-relocation highs and with summer rates from other estuaries (Nixon, 1981) as benchmarks.**

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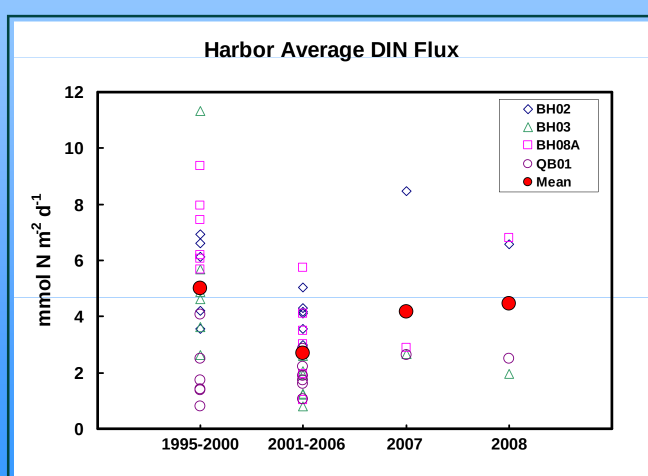
## DIN Flux for Boston Harbor

**2008 compared to 2007 and to pre- and post-relocation of the MWRA outfall**

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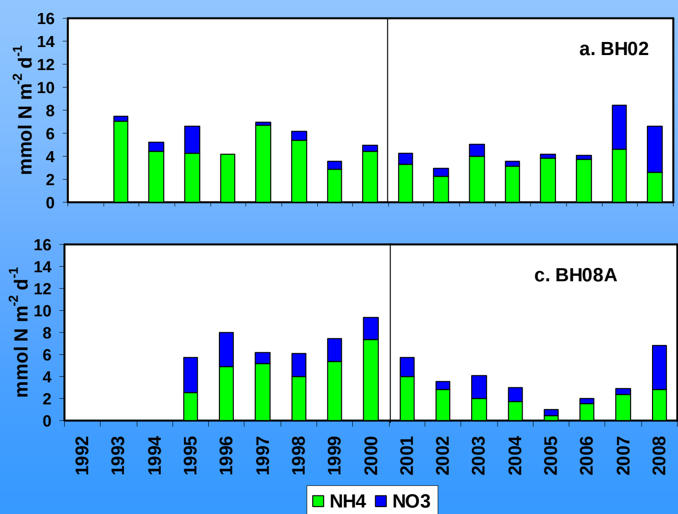
## DIN Flux Components at Stations BH02 and BH08A

**Increase in 2007-2008 due to $NO_3^-$**

**Enhanced $NO_3^-$ fluxes consistent with presence of amphipod mat**

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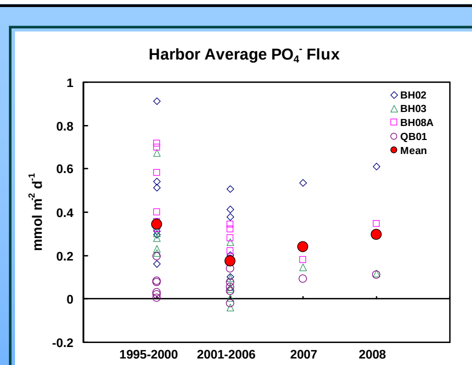
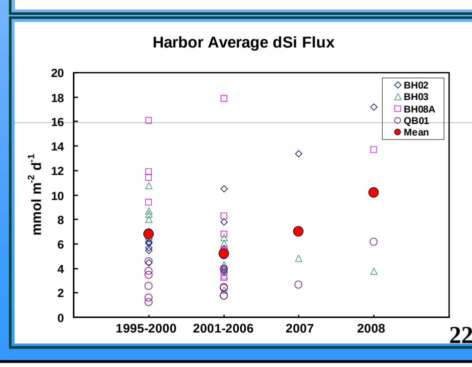
## $PO_4^-$ and dSi Fluxes

**2008 compared to 2007 and to pre- and post-relocation of the MWRA outfall**

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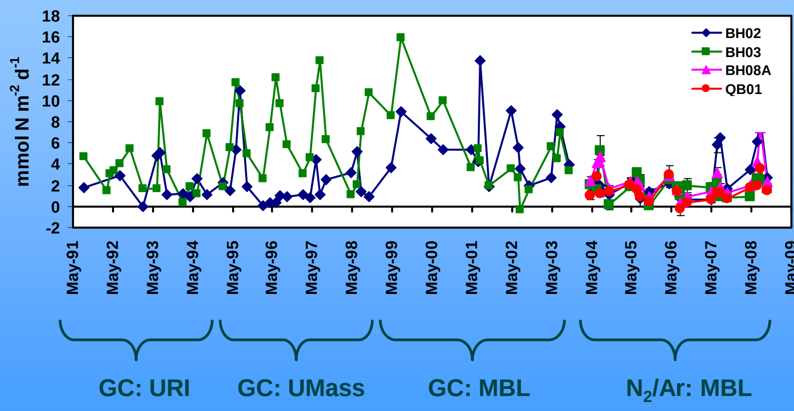
## Harbor Denitrification 1991-2008

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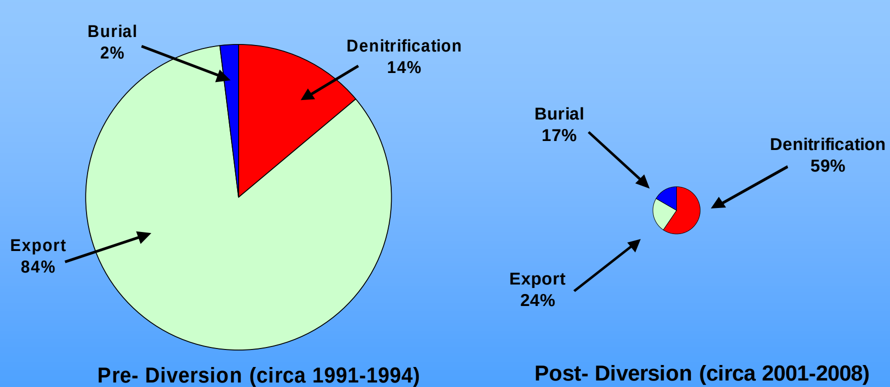
## Harbor Annual Nitrogen Budget

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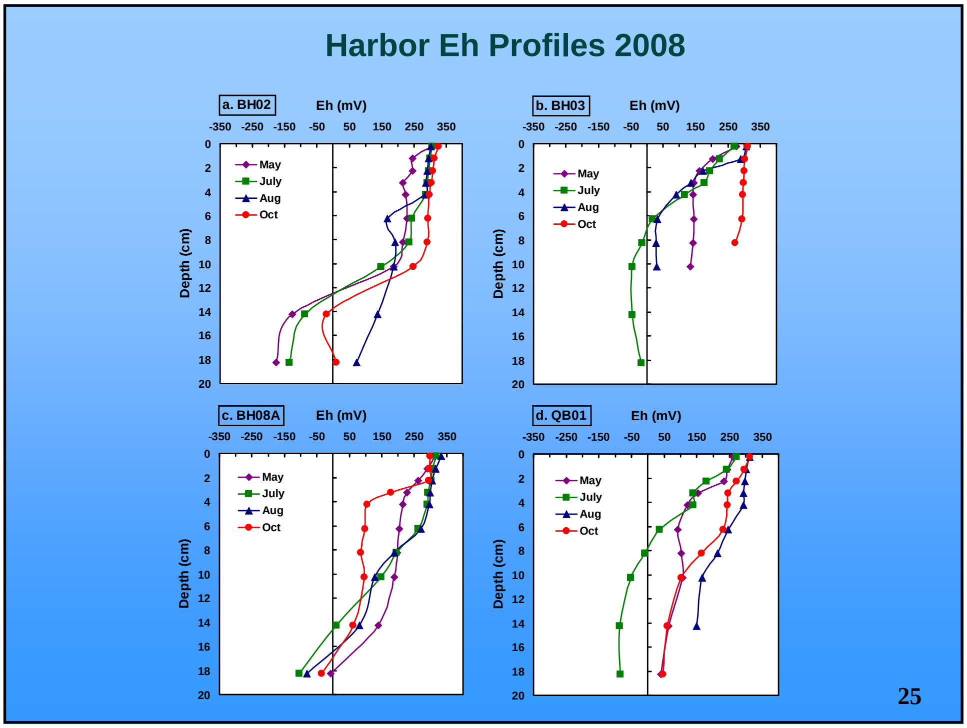
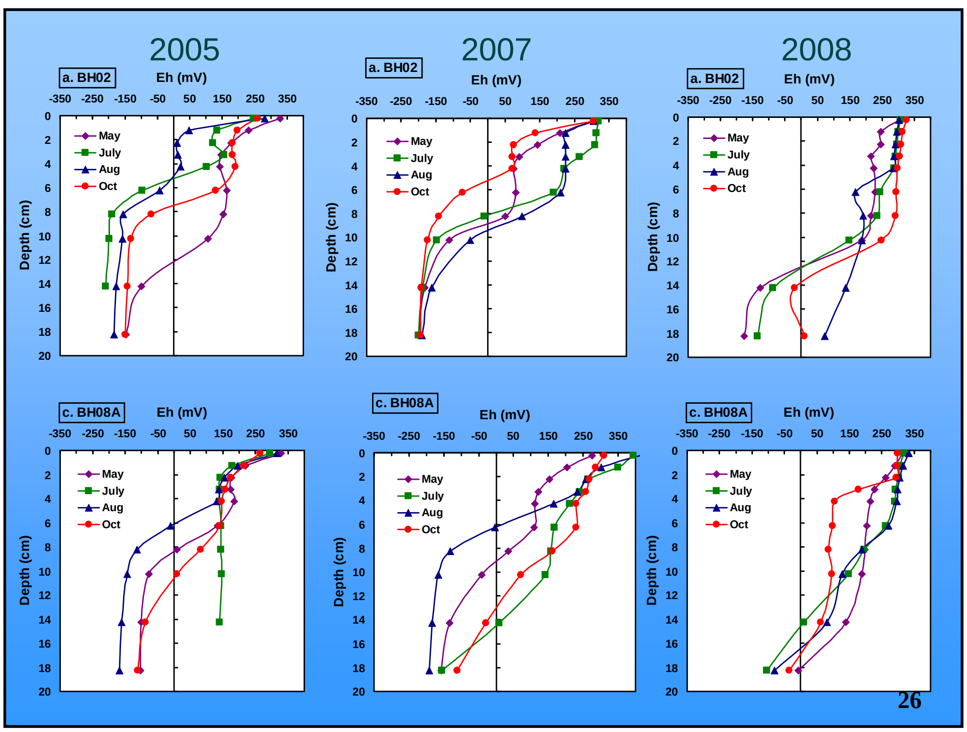
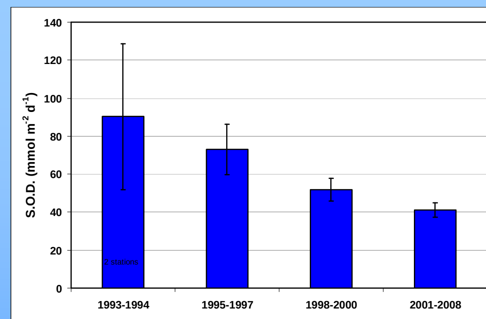


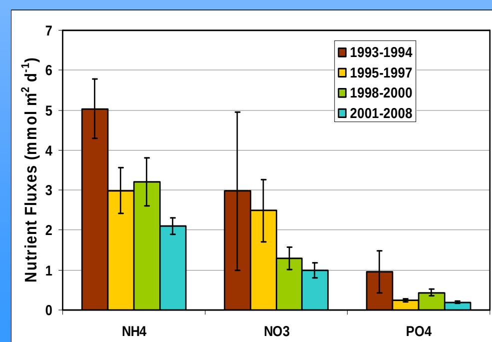
Harbor Eh Profiles 2008
a. BH02
b. BH03
c. BH08A
d. QB01
Eh (mV)
Depth (cm)
May
July
Aug
Oct
25

2005
2007
2008
a. BH02
c. BH08A
Eh (mV)
Depth (cm)
May
July
Aug
Oct
26

Despite recent upticks at BH02 and BH08A, harbor-wide averages of SOD and nutrient fluxes continue to be much lower than they were at the beginning of the harbor cleanup.

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## Conclusions for 2008
## Boston Harbor

Station BH02 (for the second year) and Station BH08A showing elevated SOD and nutrient fluxes consistent with colonization by amphipods in July and August and with higher oxidation state of sediments at these sites

In spite of the above, harbor average SOD and fluxes maintaining the downward trend associated with each treatment period, being lowest and least variable in the post-relocation period

Although denitrification appears to have decreased during the period since outfall relocation, its significance as an N sink in the harbor TN budget has increased due to the reduction in loading.

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Sending the box corer over during NC081; photo by C. Maki

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# APPENDIX II

# Field Results

**Appendix II.** Station names, survey IDs, date of survey, station locations, near-bottom water sampling depth, temperature, dissolved oxygen (D.O.) and salinity for Boston Harbor and Massachusetts Bay stations visited in 2008.

| Station | Survey | Date | Latitude | Longitude | Depth (m) | Temp. ($^oC$) | D.O. (mg/L) | Salinity (psu) |
|---|---|---|---|---|---|---|---|---|
| BH02 | NC081 | 5/14/2008 | 42.34350 | -71.00218 | 11 | 10.9 | 9.20 | 29.7 |
| | NC082 | 7/15/2008 | 42.34378 | -71.00210 | 9 | 15.4 | 7.66 | 32.0 |
| | NC083 | 8/12/2008 | 42.34375 | -71.00211 | 10 | 18.6 | 7.03 | 30.6 |
| | NC084 | 10/15/2008 | 42.34358 | -71.00235 | 12 | 13.4 | 8.36 | 31.3 |
| BH03 | NC081 | 5/14/2008 | 42.33053 | -70.96208 | 10 | 10.8 | 9.47 | 29.8 |
| | NC082 | 7/15/2008 | 42.33068 | -70.96201 | 8 | 14.4 | 8.23 | 32.1 |
| | NC083 | 8/12/2008 | 42.33064 | -70.96183 | 9 | 19.0 | 7.36 | 30.3 |
| | NC084 | 10/15/2008 | 42.33053 | -70.96204 | 11 | 13.4 | 8.25 | 33.2 |
| BH08A | NC081 | 5/14/2008 | 42.29113 | -70.92235 | 8 | 10.7 | 9.40 | 29.2 |
| | NC082 | 7/15/2008 | 42.29113 | -70.92208 | 9 | 16.9 | 7.66 | 31.9 |
| | NC083 | 8/12/2008 | 42.29108 | -70.92202 | 9 | 19.1 | 6.90 | 30.9 |
| | NC084 | 10/15/2008 | 42.29093 | -70.92212 | 8 | 13.7 | 8.13 | 32.1 |
| QB01 | NC081 | 5/14/2008 | 42.29348 | -70.98785 | 5 | 11.7 | 8.45 | 30.3 |
| | NC082 | 7/15/2008 | 42.29340 | -70.98797 | 5 | 16.7 | 7.49 | 32.0 |
| | NC083 | 8/12/2008 | 42.29348 | -70.98782 | 5 | 19.8 | 5.99 | 30.1 |
| | NC084 | 10/15/2008 | 42.29333 | -70.98797 | 4 | 14.1 | 8.50 | 31.4 |
| MB01 | NC081 | 5/16/2008 | 42.40307 | -70.83707 | 30 | 4.6 | 9.59 | 32.4 |
| | NC082 | 7/14/2008 | 42.40283 | -70.83725 | 33 | 7.6 | 8.60 | 32.9 |
| | NC083 | 8/11/2008 | 42.40312 | -70.83730 | 27 | 10.0 | 8.54 | 32.0 |
| | NC084 | 10/13/2008 | 42.40300 | -70.83732 | 33 | 9.7 | 7.00 | 33.1 |
| MB02 | NC081 | 5/16/2008 | 42.39243 | -70.83421 | 31 | 4.7 | 9.48 | 32.9 |
| | NC082 | 7/14/2008 | 42.39242 | -70.83442 | 32 | 7.7 | 8.60 | 33.1 |
| | NC083 | 8/11/2008 | 42.39255 | -70.83437 | 27 | 9.8 | 8.72 | 32.0 |
| | NC084 | 10/13/2008 | 42.39255 | -70.83425 | 34 | 9.8 | 6.69 | 33.0 |
| MB03 | NC081 | 5/16/2008 | 42.34783 | -70.81595 | 35 | 5.0 | 10.22 | 33.4 |
| | NC082 | 7/14/2008 | 42.34797 | -70.81602 | 33 | 7.7 | 8.01 | 33.0 |
| | NC083 | 8/11/2008 | 42.34765 | -70.81613 | 22 | 10.2 | 9.00 | 31.6 |
| | NC084 | 10/13/2008 | 42.34787 | -70.81613 | 32 | 10.1 | 6.62 | 32.8 |
| MB05 | NC081 | 5/16/2008 | 42.41658 | -70.65215 | 23 | 8.1 | 10.14 | 31.8 |
| | NC082 | 7/14/2008 | 42.41640 | -70.65179 | 42 | 6.5 | 8.82 | 33.5 |
| | NC083 | 8/11/2008 | 42.41658 | -70.65213 | 43 | 8.3 | 9.56 | 33.2 |
| | NC084 | 10/13/2008 | 42.41653 | -70.65195 | 44 | 9.5 | 7.51 | 33.5 |

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