Boston Harbor Water Quality Update 1995 - 2017

Massachusetts Water Resources Authority
Environmental Quality Department
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BOSTON HARBOR WATER QUALITY

UPDATE, 1995 - 2017

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EXECUTIVE SUMMARY

The Massachusetts Water Resources Authority has monitored water quality in Boston Harbor since the early to mid-1990's in support of its wastewater engineering projects, that have included among others, the Boston Harbor Project, the CSO Control Plan, TRAC pretreatment program, and programs to decrease infiltration into the sewer system. This report documents water quality in Boston Harbor during 2017, and compares it with water quality since 1994 to 2016. The aspects of water quality addressed in the report are relevant to public use of the harbor (microbial pathogen counts, water column transparency) and to the health of the harbor ecosystem (nutrients concentrations, amounts of algae, particulate organic matter in the water, transparency dissolved oxygen concentrations). In the late 1980's, the harbor ecosystem was severely degraded, and in many regions unsafe for human recreation use.

During 2017, many of the water quality changes that have followed the implementation of the wastewater projects continued. Water column total N and P concentrations were both lower than during years the harbor received wastewater discharges from Deer Island and Nut Island WWTF's or from DI WWTF alone. The proportion of the total N contributed by DIN remained lower, and the proportion of the DIN contributed by NO_{3+2} higher than during the wastewater discharges. Primary production, as in most post-diversion summers, was N relative to Si and P limited.

2017 summer phytoplankton biomass, as in all except one year since outfall diversion (2002 being the exception), was lower than during summers the harbor received the wastewater discharges. Annual biomass during 2017 was, however, the second highest since the discharges to the harbor were discontinued. Increases in biomass since ca. 2012-2013 have occurred in the Inner Harbor and the Dorchester Bay regions of the harbor, [perhaps caused by lower than average river inflows, and increased hydraulic residence times in these regions.

Total suspended solids (TSS) and particulate organic C concentrations too have been elevated since approximately 2012 or 2013. Consistent with this, the transparency of the water column too has been relatively low in recent years. Resuspension of inorganic bottom sediments or erosion of the shoreline in the east – southeastern portion of the harbor, perhaps caused by wind direction or intensity changes, have been responsible for the increases since 2012-2013. Bottom-water DO concentrations, which have shown a progressive increase since the mid-1990's, were the second highest since monitoring was started, and easily met the State Standard. *Enterococcus* counts averaged harbor-wide were low, and too easily met the State Standard.

Monitoring by the MWRA has provided valuable information on the changes, which in many cases have been improvements, the harbor has undergone since the early 1990's. The wastewater infrastructure improvements undertaken by the MWRA and others, in combination with differences in river discharge and long-term temperature increases, have likely contributed to these changes.

1. INTRODUCTION

During the past 20 years, and in support of its wastewater engineering projects, MWRA has monitored water quality in Boston Harbor (**Fig. 1**). The engineering projects have included, among others, the Boston Harbor Project (BHP), the combined sewer overflow (CSO) Control Plan (MWRA 2015), the TRAC pretreatment program, and programs to decrease infiltration into the sewer system. The BHP was implemented from 1991 through 2000, and the CSO Control Plan from 1996 to 2015. The TRAC pretreatment and the Infiltration and Inflow programs are ongoing.

This report addresses trends in three aspects of water quality pertinent to the health of the Boston Harbor ecosystem and to public using the harbor, specifically:

- system over-enrichment or eutrophication (measured as amounts of algae, nutrient concentrations and bottom-water dissolved oxygen),
- water transparency (measured as total suspended solids and irradiance or light attenuation coefficients), and
- microbial pathogen indicator counts (measured as counts of the enteric bacterium, *Enterococcus*).
- In this report, which is an update of Taylor (2016), we document Boston Harbor's water quality in 2017, and compare it with water quality since the monitoring started (1994 for certain variables and 1995 for others). The report takes a big-picture approach, focusing on annual and seasonal water quality, averaged for the Harbor as a whole, and for the two main regions of the Harbor, the Inner Harbor (IH) and Outer Harbor (OH).

Fig. 1. View into Boston Harbor from Massachusetts Bay, with Deer Island WWTF on the right, and Boston to the rear.

2. SAMPLING PROGRAM

Water quality was measured at 9 locations in the harbor as part of MWRA's Boston Harbor Water Quality Monitoring (BHWQM) project (**Fig. 1**). Three locations were sampled in the IH (137, 138 and 24), the other six locations were located in or at the mouth of the OH (106, 124, 139, 1409, 141 and 142). Station coordinates are shown in **Table 1.** Sampling was conducted at least once per every two weeks. Sampling and analytical procedures are described in Rex and Taylor (2000). All harbor-wide averages are volume-weighted by region (described in Taylor et al. 2011). Horizontal bars at the top of each graph show the 17 years since the discharges to the harbor were diverted offshore in Sept. 2000.

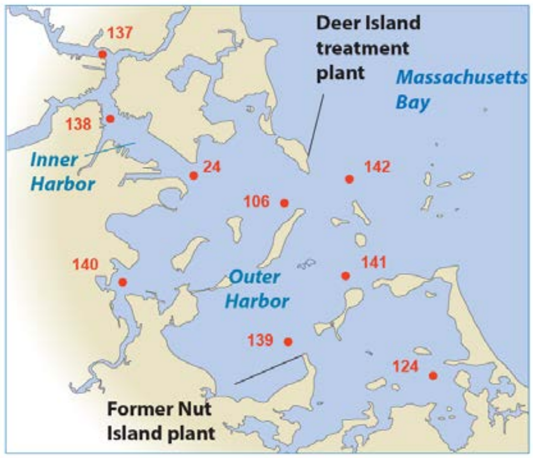

Fig. 2. Boston Harbor showing the nine water column sampling locations, and the Inner Harbor (IH) and Outer Harbor (OH) regions.

Table 1. Boston Harbor sampling locations

Station Id	Marine or freshwater[3]	Description	Coordinates	Monitoring years[1]
024	Marine;	Inner harbor mouth	42 20.66, 71 2.74	1993 – 2017
106	Marine;	Outer harbor, NE of Long Island	42 19.95, 70 57.54	1993 – 2017
124	Marine;	Hingham Bay, Crow Point flats	42 16.36, 70 53.86	1993 – 2017
137	Marine;	Mystic River mouth	42 23.21, 71 3.77	1993 – 2017
138	Marine;	Central inner harbor	42 21.56, 71 2.74	1993 – 2017
139	Marine;	Quincy Bay, SW of Hangman Island	42 17.20, 70 58.10	1993 – 2017
140	Marine;	Neponset River mouth/S. Dorchester Bay	42 18.35 71 2.43	1993 – 2017
141	Marine;	Outer harbor, NE of Peddocks Island	42 18.30, 70 55.85	1993 – 2017
142	Marine;	Outer harbor, President Roads, south channel	42 20.35, 70 55.89	1993 – 2017

3. RESULTS

Nitrogen (N) and phosphorus (P) concentrations

During 2017, as in all other years since the wastewater discharges to the harbor were diverted offshore (2000), harbor total nitrogen (N) and total phosphorus (P) concentrations were lower than during the years the harbor received the wastewater discharges (**Fig. 4 and 5**). 2017 total N and P concentrations were the highest since the discharges to the harbor were discontinued, but neither nutrient has shown an uptrend since 2000.

During 2017, as in other post-diversion years, dissolved inorganic N (DIN) contributed a smaller proportion the harbor's total N (**Fig. 6**). (DIN contributed most of the wastewater N that used to be discharged to the harbor). As in other post-diversion years, 2017 nitrate + nitrite: ammonium (or NO_{3+2}: NH_4) concentration ratios were greater than during years the harbor received the wastewater discharges.

Not only have the amounts of N in the harbor water column been lowered, but the composition of this smaller N pool too has been changed. All nine locations have seen decreased total N and ammonium concentration since 1996 (**Fig. 7**). From the Mystic River arm of the IH (Stn. 137) south to the Hingham Bay region of the Outer Harbor (Stn. 124), the N and ammonium declines brought about by the Boston Harbor Project have been sustained into 2017.

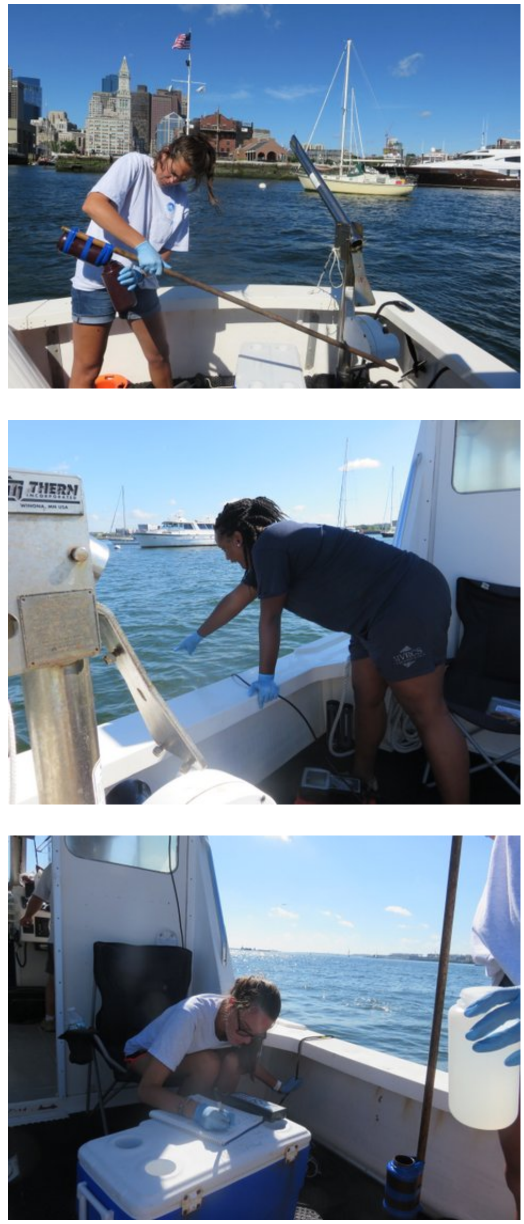

Fig. 3. Technical staff taking water samples and measurements of water quality in Boston Harbor.

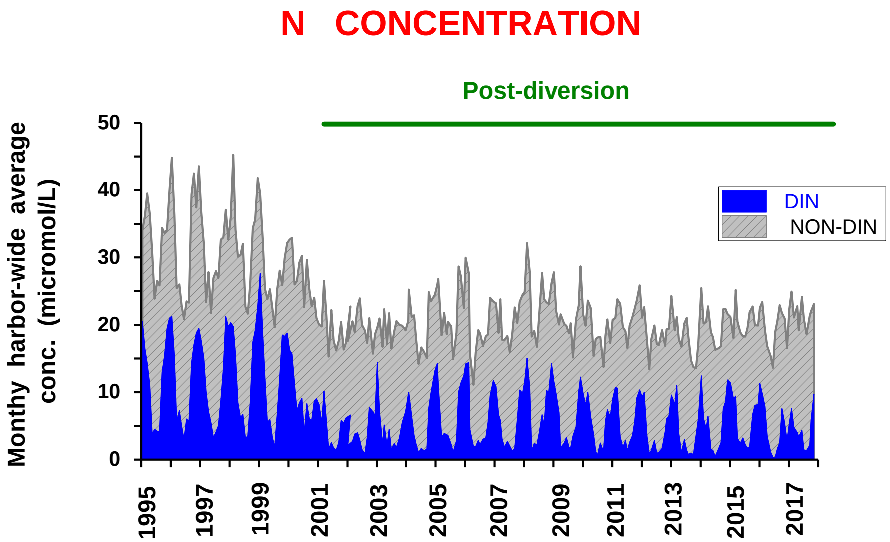

Fig. 4. Time series plot of monthly harbor-wide average total N concentrations partitioned into the dissolved inorganic N (DIN) and non-DIN fractions, 1995-2017.

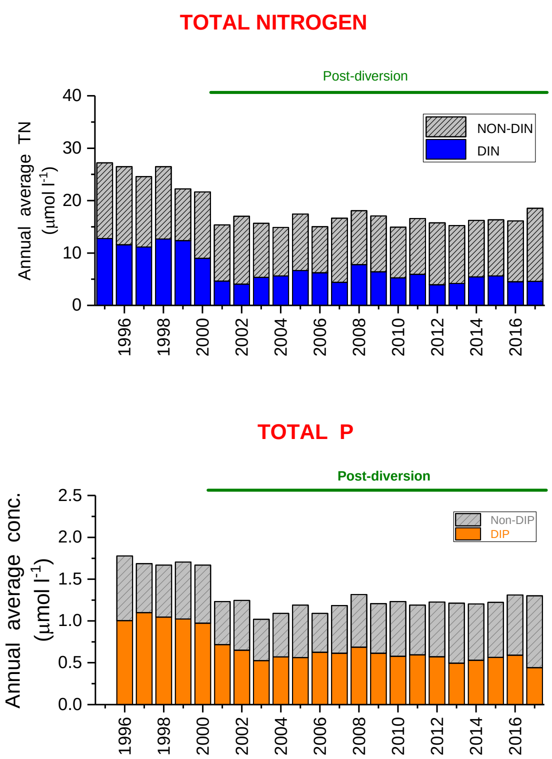

Fig. 5. Annual average total N (top) and total P concentrations (bottom).

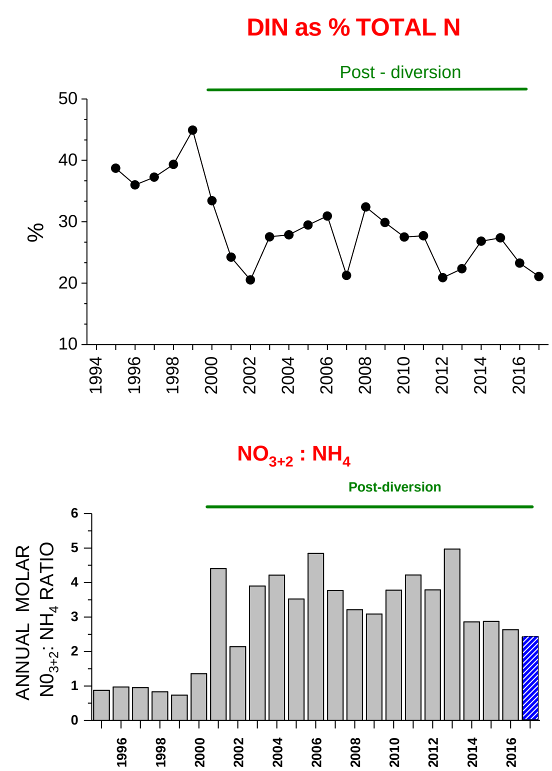

Fig. 6. Annual DIN expressed as percent total N (top), and NO_{3+2}: NH_4 molar ratios (bottom).

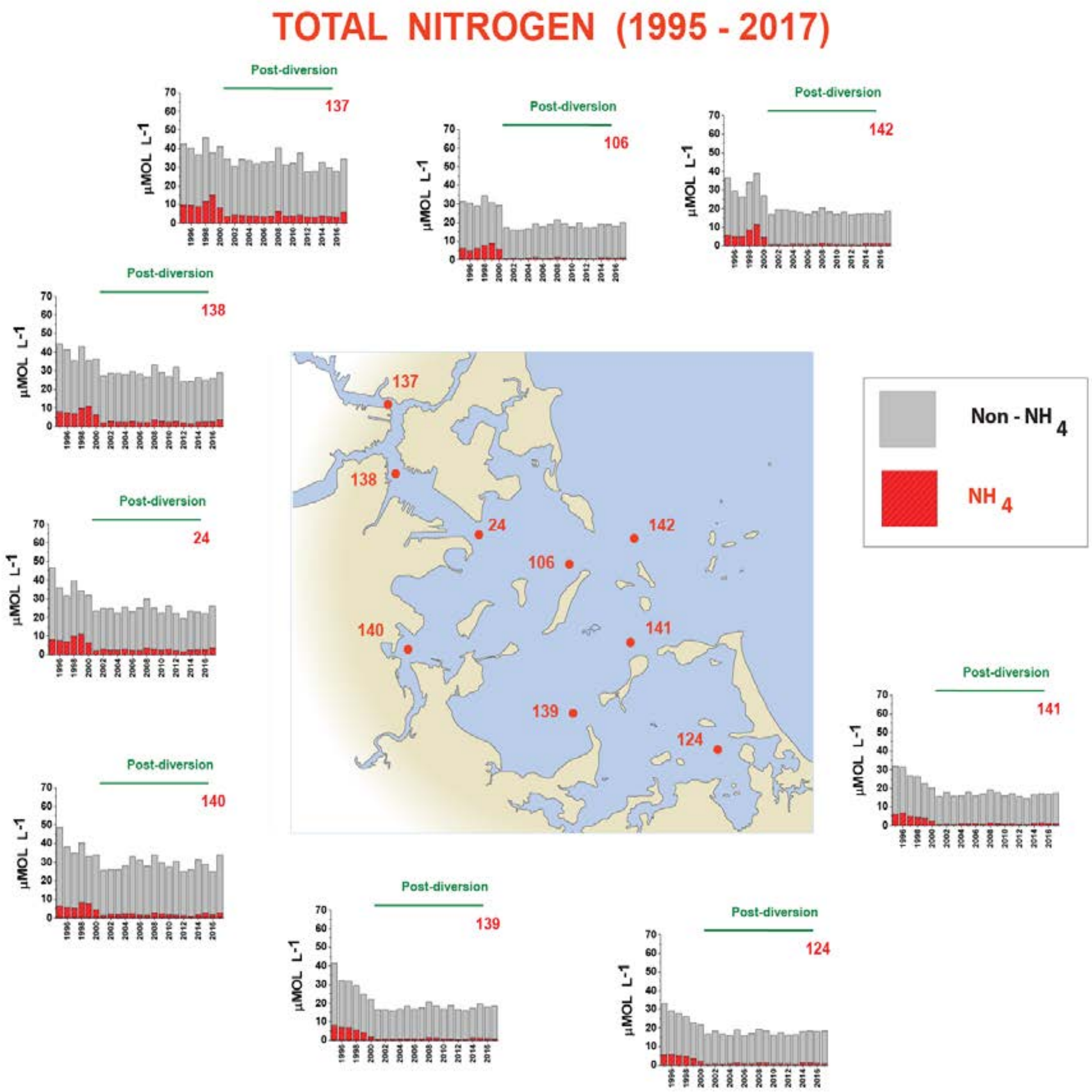

Fig. 7. Annual total N concentrations partitioned into the non-ammonium and ammonium fractions at the nine sampling locations, 1995-2015.

Nutrient concentration ratios

The implementation of the Boston Harbor Project also altered the DIN: DIP concentration ratios in the harbor **(Fig. 8).** DIN in the harbor tends to be drawn down relative to DIP during summers (when algae production is greatest and river inflows lowest), and during all except one of the summers since the discharges to the harbor were discontinued (2008 being the exception), DIN: DIP concentrations have been lower than during years the harbor received the discharges (**Fig. 9 left**).

Based on its summer DIN: DIP and DIN: DISi ratios relative to Redfield (N:P = 16:1 and N:Si = 1.07, blue dashed lines), during years the harbor received the wastewater discharges, its summer primary production was Si relative to N and P limited (**Fig. 9 right**). The diversion of the discharges to the harbor caused the primary nutrient liming production to shift from Si to N .

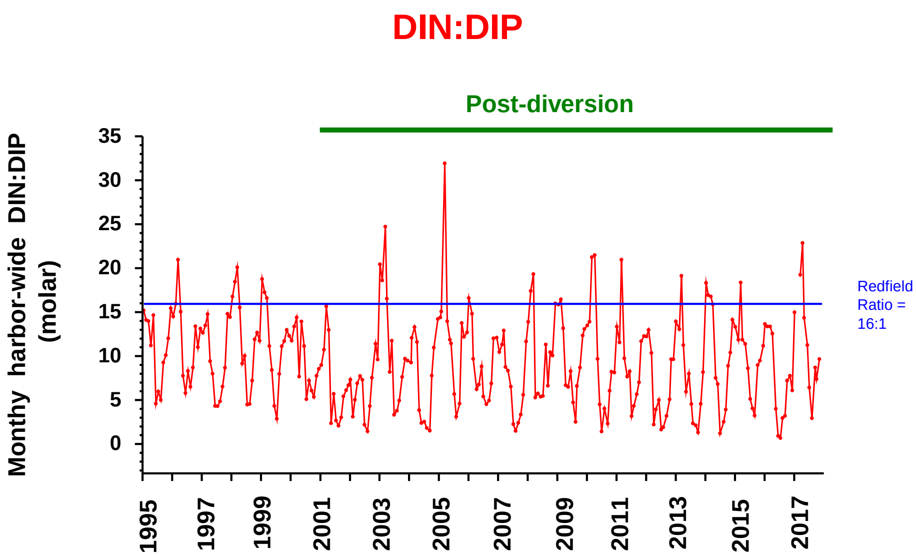

Fig. 8. Annual total N concentrations partitioned into the non-ammonium and ammonium fractions at the nine sampling locations, 1995-2015.

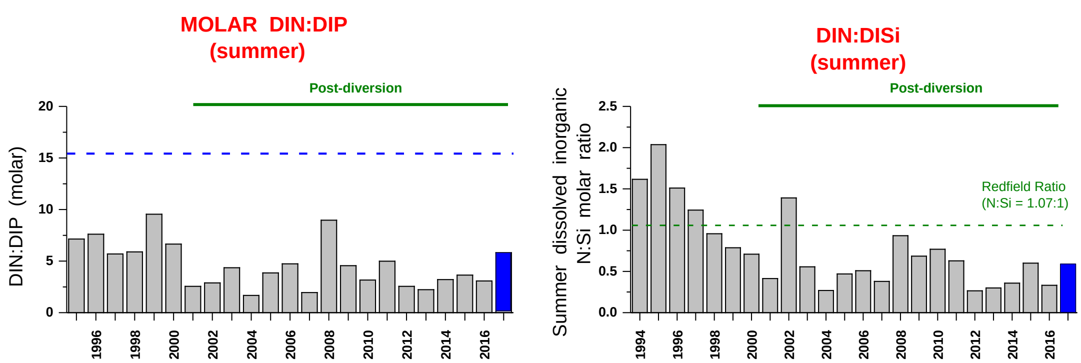

Fig. 9. Summer DIN: DIP and DIN: DISi concentration ratios, 1995-2017. **Summer = J, J, A and S**

Phytoplankton (floating microalgae) biomass

During most years since the discharges to the harbor were discontinued, and especially during summers, harbor phytoplankton biomass has been lower than during the discharges (**Fig. 10, 11**). Biomass during 2017 was in the upper range for years since the final wastewater diversion. During years since the diversion biomass variability year to year has been greater than for instance, nutrients. Elevated biomass during this post-diversion period was observed in 2002-2003, and then again in from 2012 or 2013 through 2017.

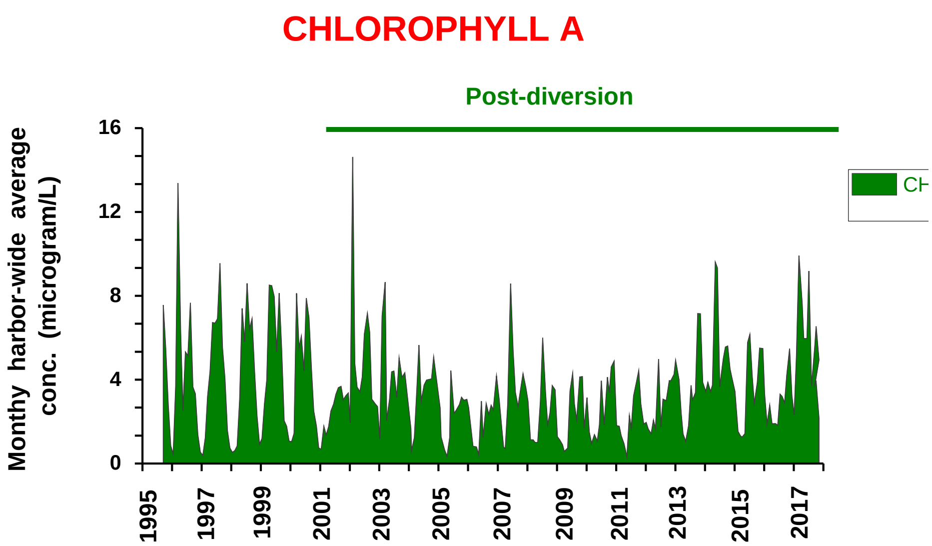

Fig. 10. Time series plot of monthly average phytoplankton biomass (measured as chlorophyll-a), 1995-2017.

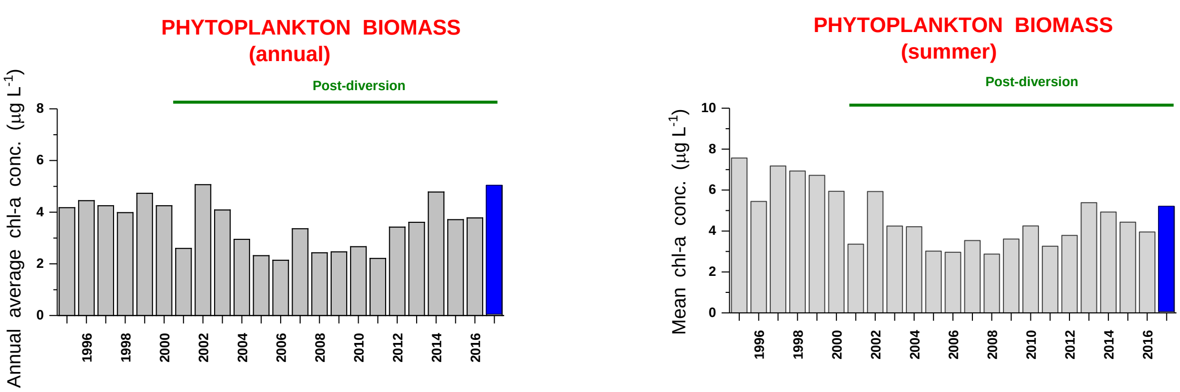

Fig. 11. Annual and summer (J,J,A,S) average phytoplankton biomass, 1995-2017

The summer biomass increases since 2012 have been observed at all nine locations, but especially at the three Inner Harbor stations (137, 138 and 24) and the single Dorchester Bay station (140) in the Outer Harbor (**Fig. 12**).

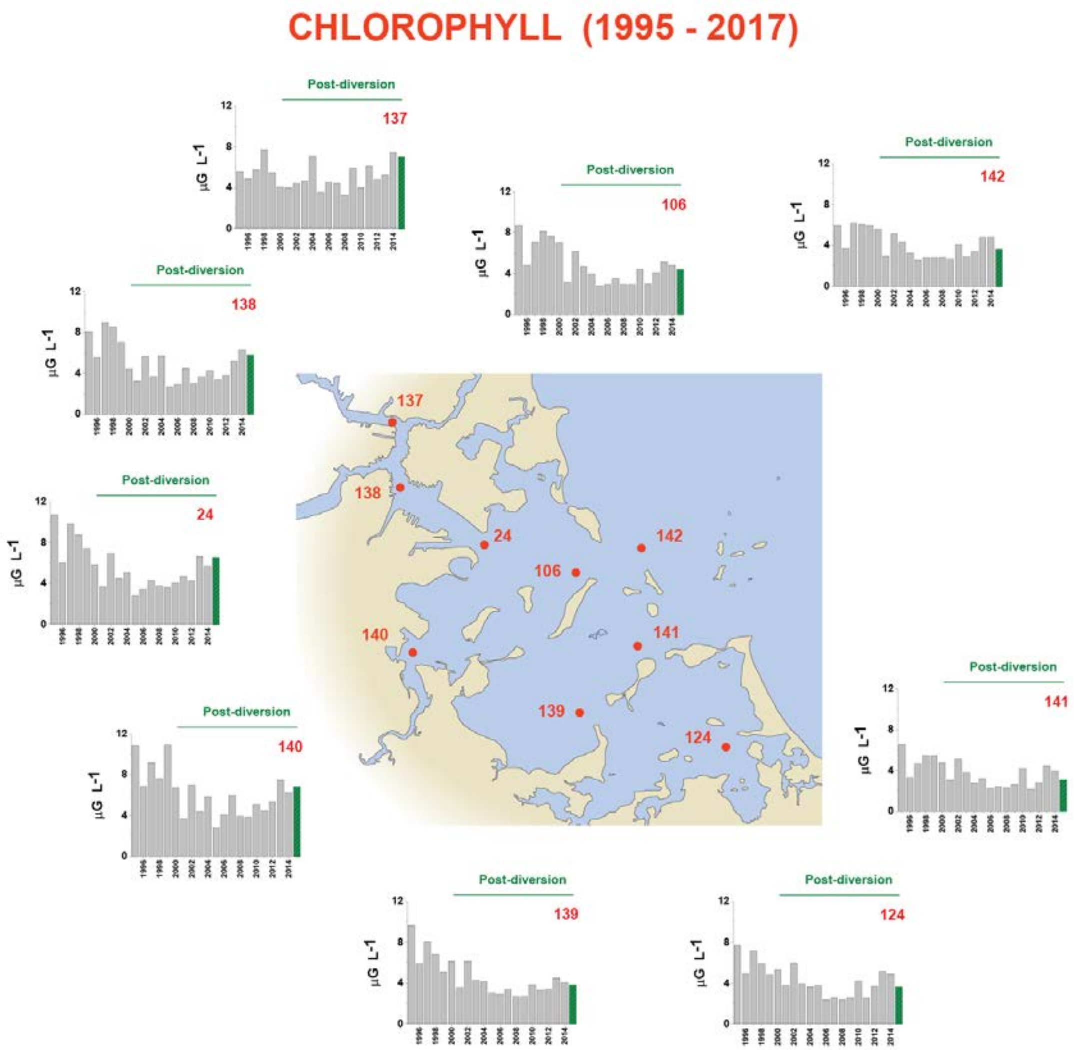

Fig. 12. Summer chl-a concentrations at the nine sampling locations, 1995-2017.

Suspended solids and particulate organic matter

Harbor total suspended solids (TSS) in 2017, unlike for nutrients, were greater than during years the harbor received the wastewater discharges (**Fig. 13**). 2017 particulate organic C (POC) concentrations were the highest since the discharges to the harbor were discontinued, but fell within the range seen during the discharges. Although both TSS and POC have increased during the 17 years since the discharges were diverted offshore, the percent POC content of the TSS has shown a progressive decrease, suggesting increased inorganic particle (silts or clays) concentrations have been largely responsible for the increases.

Unlike for chl-a, where the increases during recent years have been greatest in the Inner Harbor and Dorchester Bay, the TSS increases have been focused in Dorchester Bay (140) and the southeast portions of the Outer Harbor (139 and 141) (**Fig. 14**).

Transparency

2017 water column transparency, measured as rates of light attenuation through the water column, was the poorest since 1996 (**Fig. 13**) Note the greater the attenuation coefficients (k), the poorer the transparency. The slightly poorer transparency from 2012 to 2017 corresponds the elevated chl-a, TSS and POC concentrations observed during the same five years.

From 1996 through 2017, the potential 1% incident light penetration depth, which is the depth above which photosynthesis exceeds respiration, has averaged 7.3 m (**Fig. 15**). This is time the mid-tide water depth, suggesting algae production during the 22-year period has not been limited by light availability.

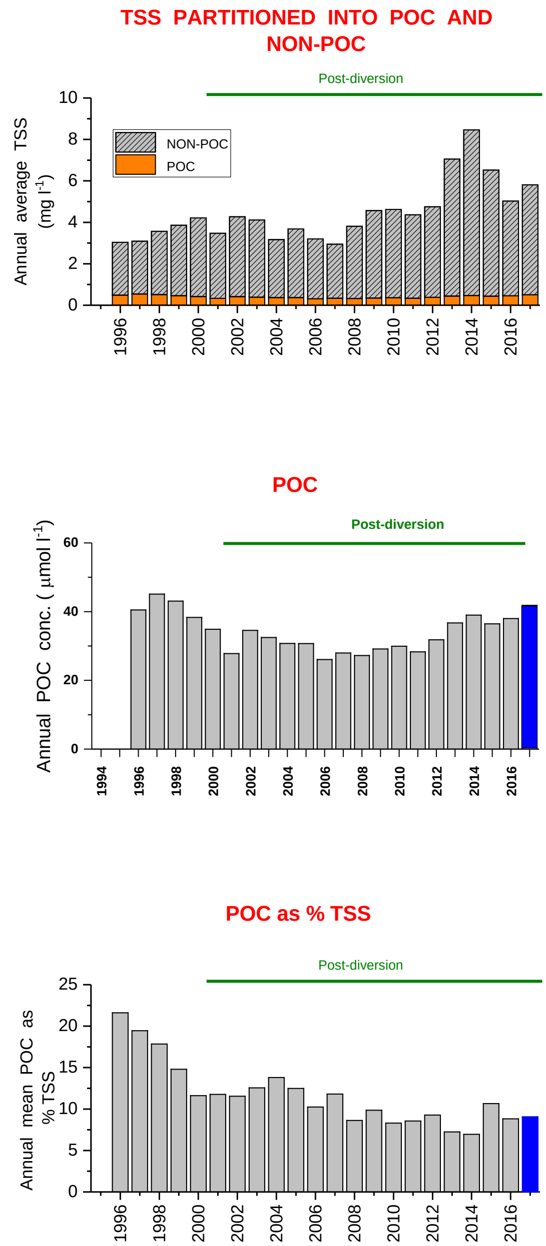

Fig. 13. TSS, POC and POC as % TSS (by weight), 1996-2017.

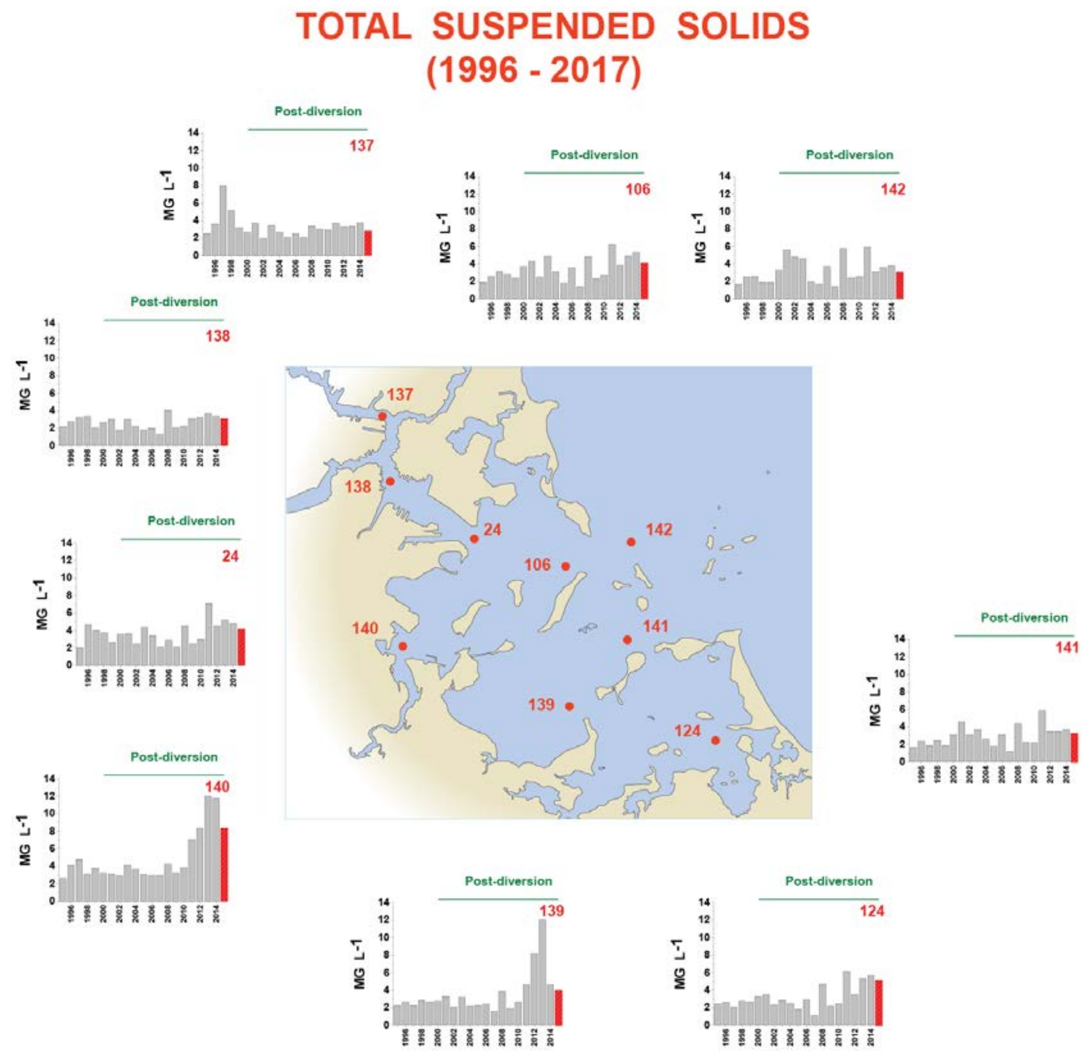

Fig. 14. Spatial patterns of TSS concentrations, 1995-2017.

Bottom-water dissolved oxygen (DO)

Bottom-water DO concentrations in the harbor each year are typically lowest during late summers. During 2017, as in every summer except 2009 since the discharges to the harbor were discontinued, harbor-wide average bottom-water DO concentrations were greater than during 1994 to 1999, when the harbor received the discharges (**Fig. 16**). Years in which summer DO concentrations were greater than during the discharges are indicated by circles in the Figure. The DO increase between 2000 and 2001, coincided with the final wastewater diversion offshore in 2000.

Minimum survey harbor-wide average bottom-water DO increased from 5.9 mg l^{-1} slightly below the State Standard of 6.0 mg l^{-1} in 1994 to 7.5 mg l^{-1} in 2017 (**Fig. 17**). Both the Inner Harbor and Outer Harbor regions showed the DO increases. values in 2017 were the third highest since 1994 (**Fig. 17 right**).

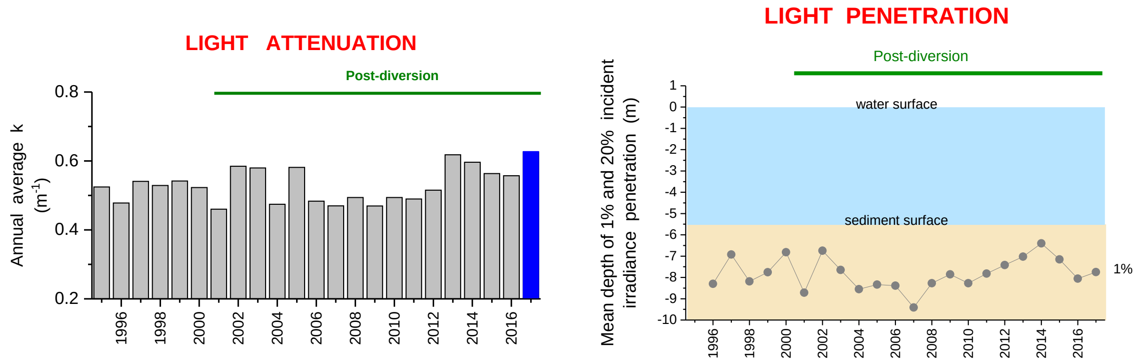

Fig. 15. Vertical light attenuation coefficients, a measure of transparency (left), and potential 1% incident irradiance penetration depths (right).

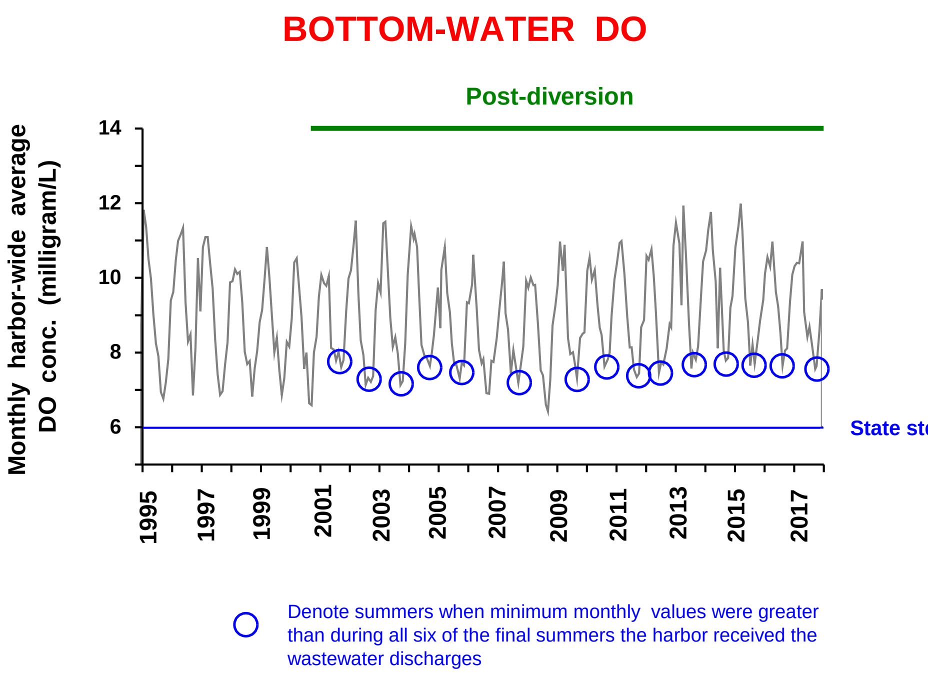

Fig. 16. Time-series monthly harbor-wide average bottom-water DO concentrations.

As can be seen from **Figure 18**, bottom-water DO concentrations have been increased at all nine locations, with the increases in the Inner Harbor occurring from lower initial values than in the Outer Harbor.

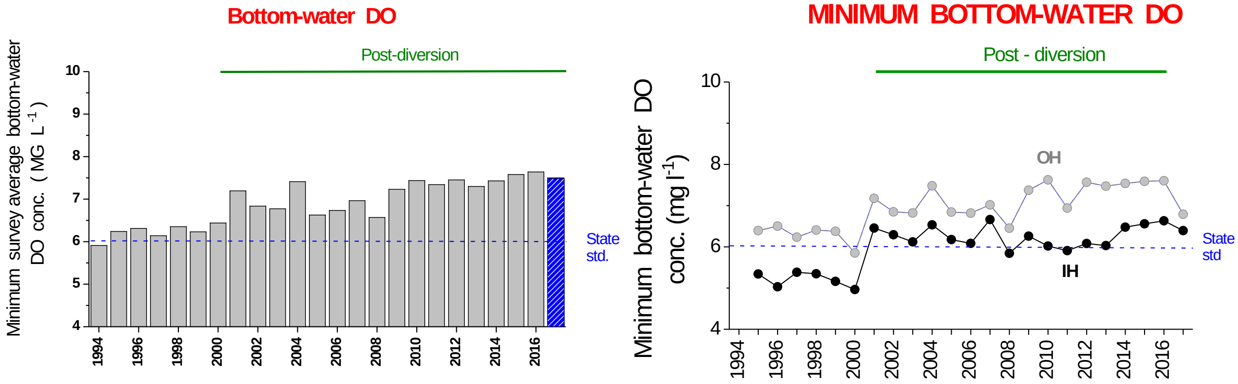

Fig. 17. Lowest survey-average bottom-water DO concentrations observed each year for the harbor as a whole (left) and for the Inner and Outer Harbor regions (right), 1994-2017.

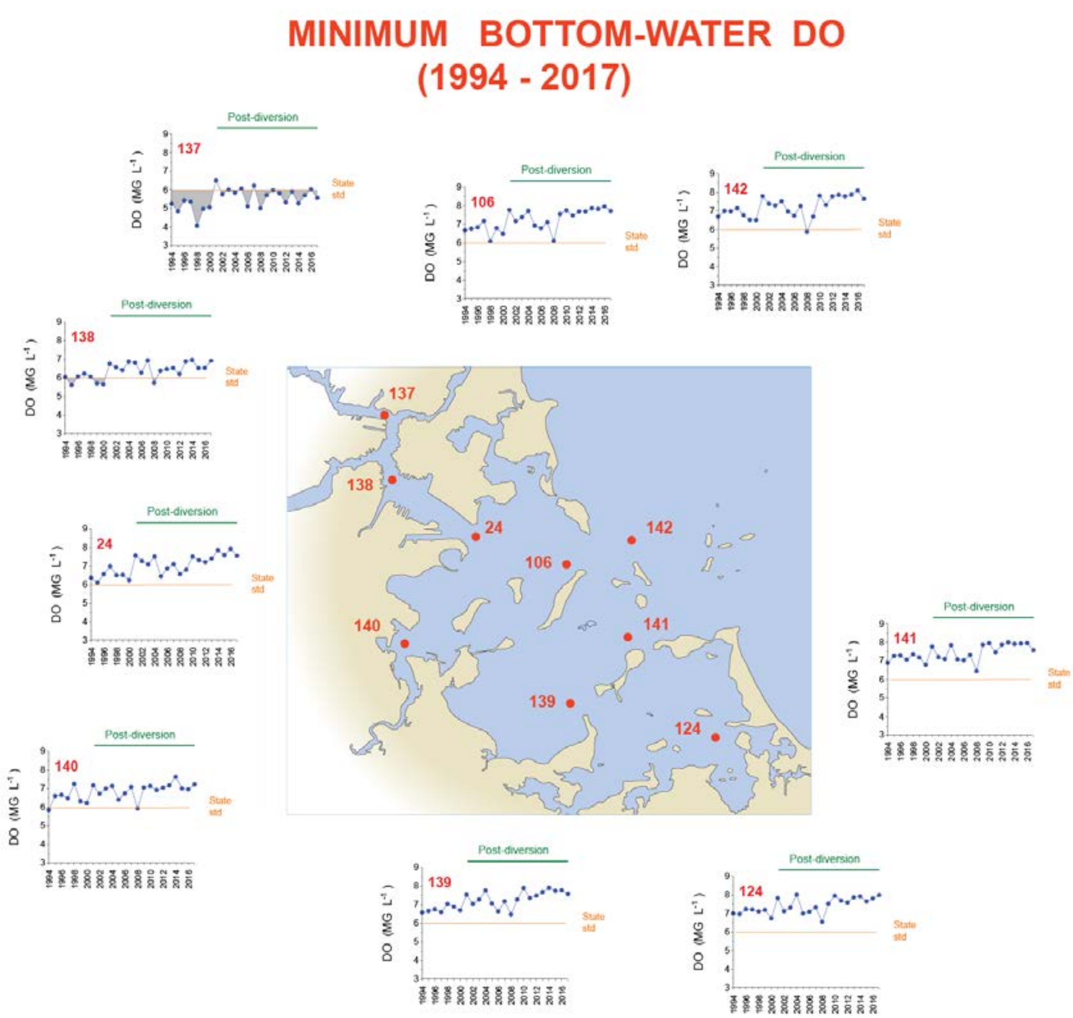

Fig. 18. Minimum monthly-average bottom-water DO concentrations, 1994-20170. Shaded areas show years the values failed to meet State Standard.

Pathogen indicator counts

Harbor-wide geometric mean counts of the pathogen indicator bacterium, *Enterococcus*, in 2017 were in the order of one third of what they were in the early to mid-1990s (**Fig. 19**). At all nine locations, 2017 counts were also lower than they were during the early to mid-1990s (**Fig. 20**). During all years, for the harbor as a whole and for all nine locations, geomean *Enterococcus* counts have been < 33 cfu 100 ml^{-1}, the State swimming standard.

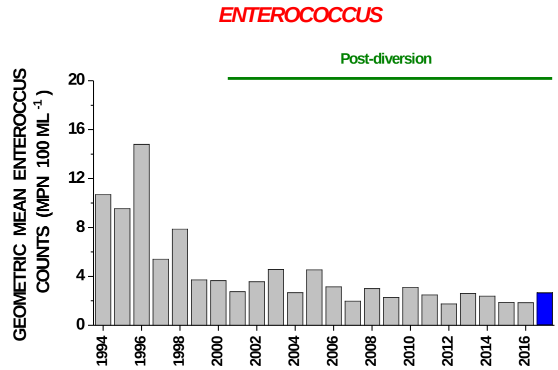

Fig. 19. Annual average *Enterococcus* counts.

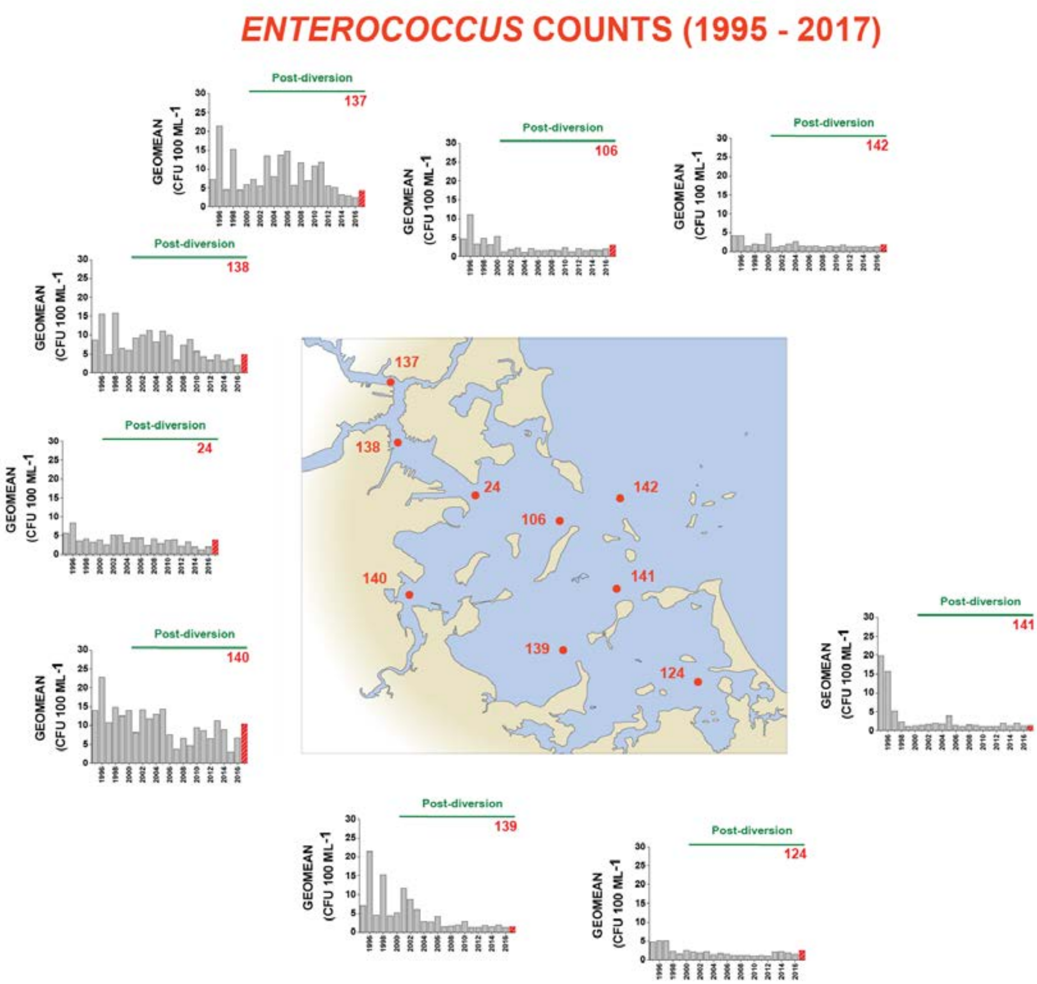

Fig. 20. Annual geomean *Enterococcus* counts, 1994-2017.

Water temperature and salinities

Harbor-wide average water temperatures during 2017 were the third highest since 1994, and above the long-term average (**Fig. 21**). Average salinities approximated the long-term average (30.6 psu). Water temperatures in the Inner Harbor (Stations 137, 138 and 24) have shown no trend since 1993, but in the outermost Outer Harbor (stations 106, 142, 139 and 141), and both in the near-surface and near-bottom-waters) have increased **(Fig. 22).**

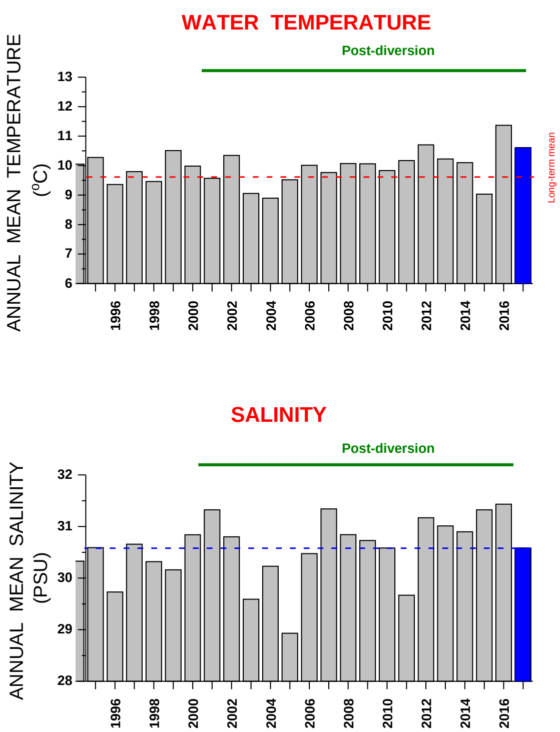

Fig. 21. Average harbor water temperatures and salinities, 1994-2017. Dashed lines show long term averages for the period 1995 through 2017.

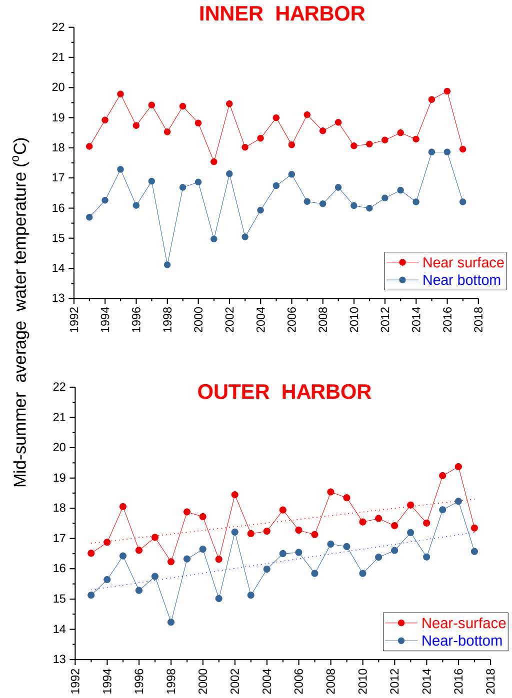

Fig. 22. Near-surface and near-bottom, mid-summer (J, A, S) average water temperatures in the Inner Harbor and outermost Outer Harbor regions, 1994-2017.

River discharges to the harbor

Annual river discharges, which vary widely, and from between 1.4 $x10^6$ m^3 d^{-1} to 3.2 $x10^6$ m^3 d^{-1} year to year, has shown no trend since 1990 (**Fig. 23**). Discharges during five of the last six years of this study, were well below the long-term average of 2.2 $x10^6$ m^3 d^{-1}. Discharges during previous years have fallen to levels seen in 2012-2013 to 2017, but not for the extended period seen at the end of this study.

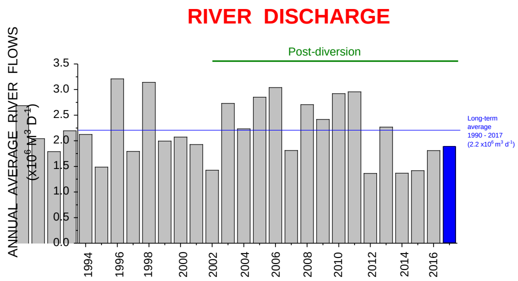

Fig. 23. Annual average river flows (Charles, Mystic, Neponset, Weymouth-Weir) to Boston Harbor (data from USGS).

4. CONCLUSIONS

Many of the harbor water quality improvements that followed the implementation of the BHP and CSO Control Plan continued into 2017. Total N, total P, POC as %TSS, and *Enterococcus* counts during 2017 were among the lowest since the study started. Mid-summer bottom-water DO concentrations during 2017 were the third highest since 1994.

For a number of variables, including phytoplankton biomass, TSS, POC and light attenuation coefficients, values have increased from 2012 or 2013 into 2017. These increases were perhaps related to the low river inflows the harbor received during all except one of these final six years.

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