Boston Harbor Water Quality
(1994-2015)

Massachusetts Water Resources Authority
Environmental Quality Department
Report 2016-08

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BOSTON HARBOR WATER QUALITY

(1994 - 2015)

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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 the Authority's 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 2015, and compares it with water quality during the preceding 20 years (1994-2014). The aspects of water quality that were selected for examination 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.

Water quality in the harbor during the past 20 years has undergone significant changes (many of them improvements), that have been the net result of the engineering projects plus background changes in meteorology and river discharges to the harbor. Changes have included declines in water column nutrient (nitrogen and phosphorus) concentrations, declines in pathogen indicator (*Enterococcus*) counts and the amounts of microalgae in the water, and increases in bottom-water dissolved oxygen (DO) concentrations. For certain aspects of water quality, specifically concentrations of nitrogen, improvements coincided with the final Deer Island wastewater discharge diversion offshore, and values since then have remained relatively constant.

For other variables, including concentrations of phosphorus, bottom-water DO concentrations, and *Enterococcus* counts, conditions have progressively improved since the early 1990's, with the improvements continuing well after the Deer Island and Nut Island discharges to harbor were discontinued. Annual average harbor salinity has shown a gradual increase, suggesting the marine influence on the harbor has increased slightly during the past 20 years. This increased marine influence may have contributed to the continued phosphorus, *Enterococcus* and DO improvements seen since the discharges to the harbor were discontinued.

Since 2011 the harbor has shown increases in phytoplankton biomass, total suspended solids and particulate organic carbon concentrations, and s a light decrease in transparency. River discharges to the harbor during three of the past four years during this period have been lower than average. The increased hydraulic residence time caused by the lowered river inflows may have contributed to these recent natural short-term changes.

INTRODUCTION

MWRA has monitored water quality in Boston Harbor during the past 20 years in support of the Authority's wastewater engineering projects. The 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 Deer Island treatment facility, the cornerstone of the BHP is shown in **Figure 1.**

Fig. 1. Deer Island wastewater treatment facility at the mouth of Boston Harbor

In the late 1980's Boston Harbor was viewed as one of the most degraded coastal bays in the USA. **Figure 2** shows a conceptual model of the changes that occur to coastal aquatic ecosystems during degradation. Following the large decreases in wastewater nutrient, organic matter and microbial inputs brought about by the BHP and CSO Control Plan, this historic degradation of the harbor has been reversed.

Nutrient (nitrogen and phosphorus) concentrations and the amounts of algae (and organic matter) in the water have decreased. Bottom-water dissolved oxygen concentrations have increased, and microbial pathogen indicator counts have declined. The harbor's soft-sediments (and associated invertebrate communities) have improved (Pembroke et al. 2015), and north harbor seagrass beds have expanded (Costello and Kenworthy 2011).

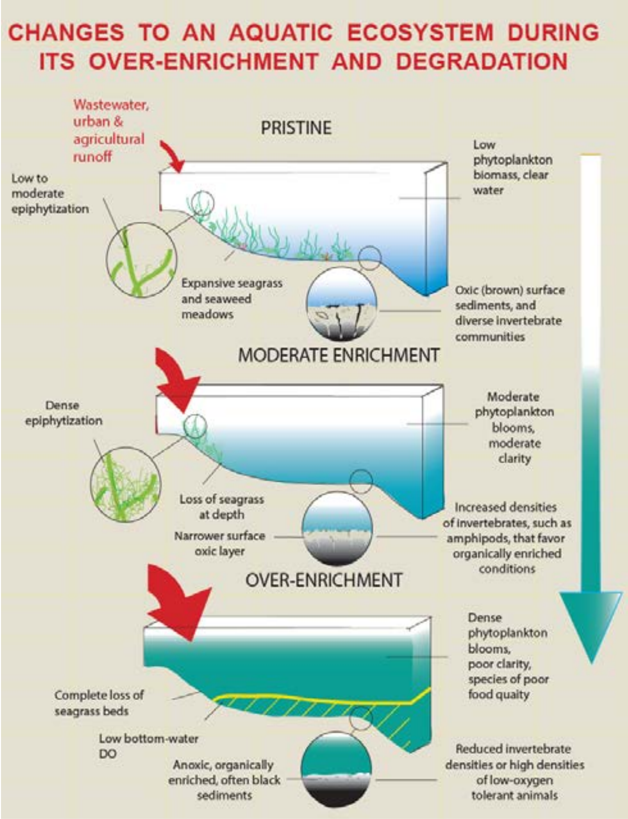

Fig. 2. Conceptual model of the changes that occur to coastal aquatic ecosystems during their degradation and specifically over-enrichment.

This report documents harbor water quality in 2015, and compares it with water quality trends during prior years. It addresses three water quality aspects pertinent to harbor ecosystem health and to the health of the 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*).

This report focuses on the main body of the harbor, where the effects of the input changes from multiple upstream sources are integrated. Changes to specific locations along the periphery of the harbor have been documented elsewhere (MWRA 2015).

The data we present here were collected at 9 locations as part of MWRA's Boston Harbor Water Quality Monitoring (BHWQM) project (**Fig. 3**). Three locations were sampled in the Inner Harbor (137, 138 and 24), the other six locations were located in or at the mouth of the Outer Harbor (106, 124, 139, 1409, 141 and 142). Station coordinates are shown in **Table A-1.**

Most locations were sampled weekly or every two weeks. Sampling and analytical procedures have been described in Rex and Taylor (2000). All water samples collected from MWRA's sampling vessel, the *Merganser* (**Fig. 4**). All harbor-wide averages reported here are volume-weighted by region, as described in Taylor et al. (2011). Horizontal bars at the top of each graph show the 15 years since the discharges to the harbor were diverted offshore.

2. NITROGEN (N) AND PHOSPHORUS (P) CONCENTRATIONS

The BHP completed in 2001 caused harbor total nitrogen (N) and total phosphorus (P) concentrations to decrease (**Fig. 5**). The bulk of the N declines occurred between 1997/1998 and 2001, the three to four years that spanned the two wastewater diversions, first to the harbor mouth and then offshore. Nitrogen concentrations since then have ranged between 18 and 22 µmol l^{-1}, about two thirds of what they were during the discharges. Total nitrogen (N) concentrations in 2015 averaged 20 µmol l^{-1}.

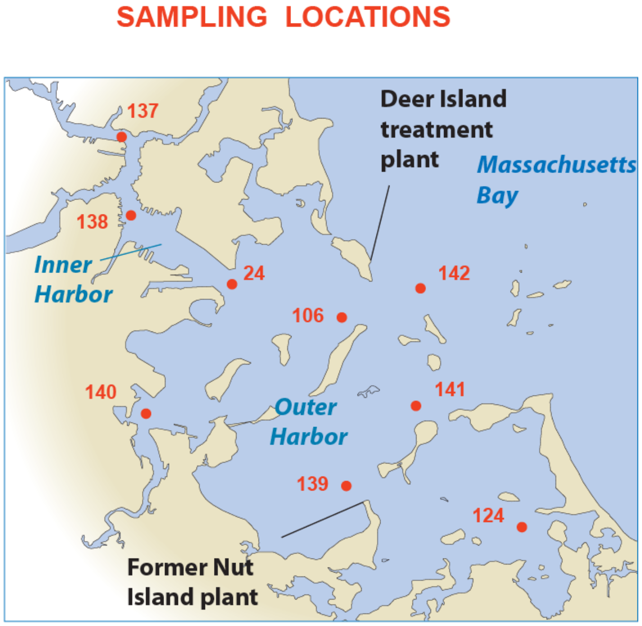

Fig. 3. Boston Harbor showing the 9 sampling locations, and the Inner and Outer Harbor regions of the harbor.

Fig. 4. MWRA's sampling vessel, the *Merganser*.

Total phosphorus concentrations have shown a progressive decline since 1995, continuing to decline after the wastewater discharges to the harbor were diverted offshore. Total P concentrations in 2015 (1.2 µmol l^{-1}) were the third lowest since monitoring started. N:P concentration ratios declined when the discharges were diverted offshore, but have progressively increased since then. The 2015 N:P ratios averaged 16.5:1, similar to the Redfield Ratio (16:1), and only slightly greater than the average for the 15 post-diversion years.

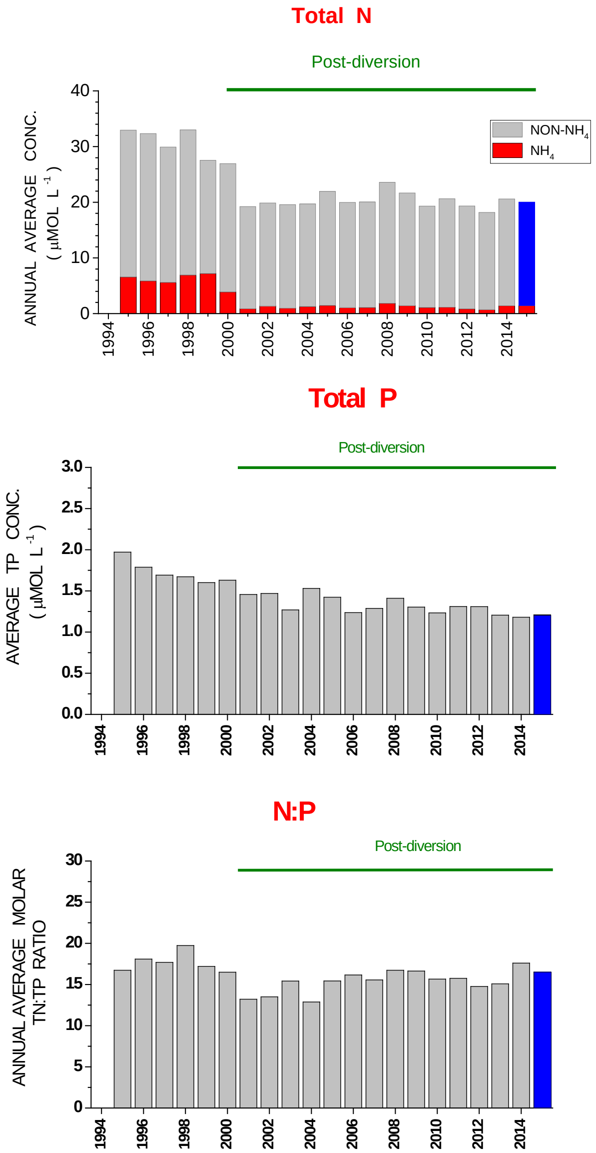

Fig. 5. Annual average total N and total P concentrations and total N:total P concentration ratios, 1995-2015.

Approximately 90% of the total N concentration decline brought about by the BHP was contributed by an ammonium (NH_4) concentration decline. Ammonium was the N fraction that made up most of the wastewater total nitrogen discharged to the harbor pre-2001. After the final wastewater diversion accounted for 6% of the lowered total N. During the discharges, ammonium contributed 21% of water column total N.

Declines in total N concentrations at all nine locations in **Figure A-1** (Appendix A) were responsible for the overall harbor-wide average N concentration decline. Ammonium concentrations were also decreased at all nine locations. At the three Inner Harbor locations (137, 138 and 024), N concentrations have continued to decline post-diversion; the lowered concentrations at the Outer Harbor locations during the same period have shown no trend.

3. PHYTOPLANKTON BIOMASS

Phytoplankton biomass in the harbor (measured here as concentrations of chl-a) has decreased during the past 20 years (**Fig. 6**). Biomass declined sharply when the wastewater discharges were diverted offshore in 2000. Biomass has shown a series of fluctuations since then, when concentrations have exceeded or fell within the biomass range during discharge years. The first of the increases occurred two to three years post-diversion, and the other, seven to eight years later. The 2015 biomass values fell on the ebb side of the latter increase.

The N input declines brought about by the BHP (Taylor 2010) were a major contributor to the biomass declines that followed the discharge diversion offshore. During neither of the post-diversion increases were harbor nitrogen or phosphorus concentrations greater than during discharge years, suggesting processes other than increased nutrient inputs were responsible for the background biomass increases observed post-diversion.

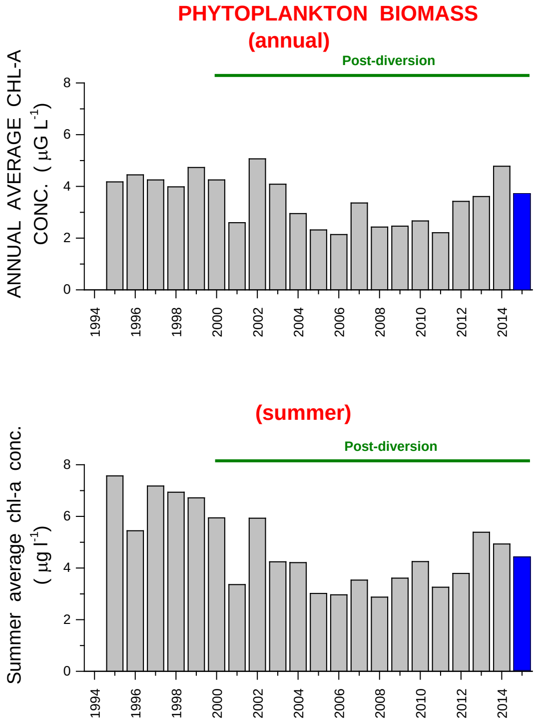

Fig. 6. Annual (top) and summer (bottom) average phytoplankton biomass measured as chl-a, 1995-2015. Summer = J,J,A and S.

The phytoplankton declines in the harbor were evident at all except one of the nine sampling locations (**Fig. A-2**). Station 137 in the uppermost Inner Harbor was the exception. The 2002-2003 phytoplankton increase was not consistent among stations, but the biomass increase later in the study was evident at all locations, including 137, in fact, it was the stations in the Inner Harbor (137, 138 and 24) and western harbor (140) where the more recent increases were observed.

4. SUSPENDED SOLIDS, PARTICULATE ORGANIC MATTER

Harbor total suspended solids (TSS) concentrations increased during the period spanned by this study (**Fig. 7**). TSS concentrations, which averaged 6.9 mg l^{-1}, were the second highest since monitoring started. The bulk of the increase started in 2007/2008, reaching a maximum in 2014. All nine locations showed the TSS concentration increases (**Fig. A-3**). Particulate organic C (POC) concentrations, like the TSS concentrations, increased during the second half of the study, but unlike for TSS, POC concentrations at the end of the study were lower than at the start. POC accounted for only a small fraction of harbor TSS. The percent POC content of TSS declined during the study, indicating the bulk of the TSS increase was caused by increased concentrations of suspended inorganic rather than organic material.

5. TRANSPARENCY

Transparency, which in the harbor is high compared to many other coastal systems, has shown no trend during the past 20 years (**Fig. 8**). Transparency is reported here as attenuation coefficients (k). These measure the rates at which light attenuates as it passes through the water column. The k values are presented as reciprocal values, meaning the greater the value, the greater the transparency. background elevated TSS, POC and chl-a values observed during these years (and shown earlier) may have been contributing factors.

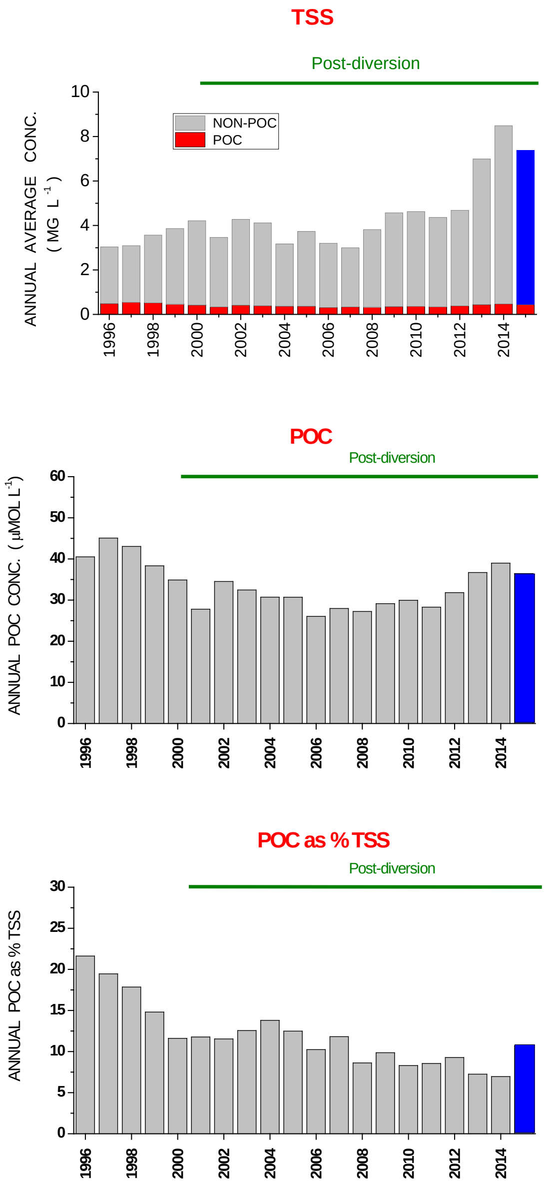

Fig. 7. POC, TSS and POC as % TSS (by weight), 1996-2015.

Transparency during the past three years (and especially during 2013 and 2014) has been slightly poorer than during many of the other years since the discharges to the harbor were discontinued. The

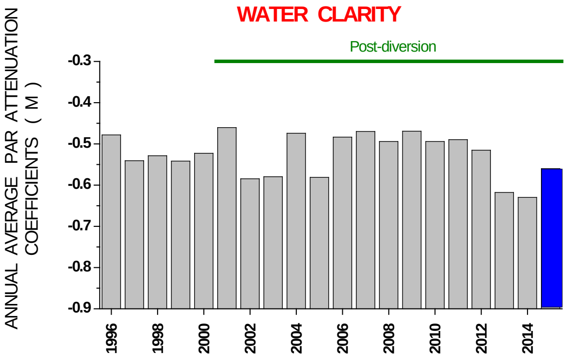

Fig. 8. Vertical light attenuation coefficients, a measure of transparency, 1996-2015.

6. BOTTOM-WATER DISSOLVED OXYGEN

Summer bottom-water dissolved oxygen (DO) concentrations in the harbor have increased since the early 1990's, and during 2015 the minimum monthly-average concentrations (7.6 mg l^{-1}) were the highest since monitoring started (**Fig. 9**). During the final six years the harbor received the discharges the minimum monthly average DO concentrations fell below or approached the State Standard of 6 mg l^{-1}. Since then, the values averaged harbor-wide have consistently met the standard.

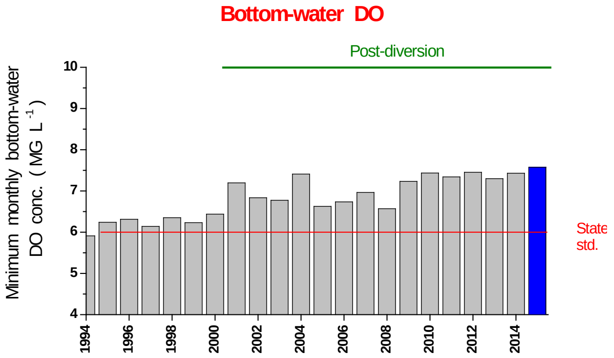

Fig. 9. Lowest monthly average bottom-water DO concentrations observed each year, 1994-2015.

The DO increase during the period spanned by the report was evident at all nine locations (**Fig. A-4**). The baseline concentrations from which the increases occurred differed among locations. At station 137, bottom-water DO concentrations failed to meet the Standard during all of the final six years the harbor received the discharges. Since then, the standard has been met at this location five of the 15 years. At four of the locations, the standard was not met during only one of the 15 years; at the remaining four locations (three of them in the south harbor), the standard was met during all fifteen post-diversion years.

7. PATHOGEN INDICATOR COUNTS

Harbor recreational use requires pathogen indicator bacteria be monitored (**Fig. 10**). *Enterococcus* counts in 2015 were the second lowest since 1994, and averaged 3 colony forming units 100 ml^{-1}. Counts <35 colony forming units 100 ml^{-1} meet the State Standard for recreational marine waters. 2015 counts at all nine locations were well below levels seen during the period the harbor received the wastewater discharges (**Fig. A-5**).

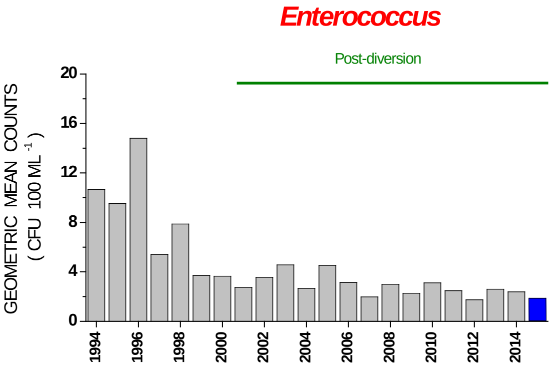

Fig. 10. Annual average *Enterococcus* counts by year, 1994-2015.

8. RIVER DISCHARGES AND HARBOR PHYSICAL CONDITIONS

Annual average river flows into the harbor during 2015 (1.5 x10^6 m^3 d^{-1}) were the third lowest since 1990 (**Fig. 11**). Flows during three of the past four years (2015 included), have been the lowest since 1990. Salinities during 2015 were the highest since 1990 (**Fig. 12**).

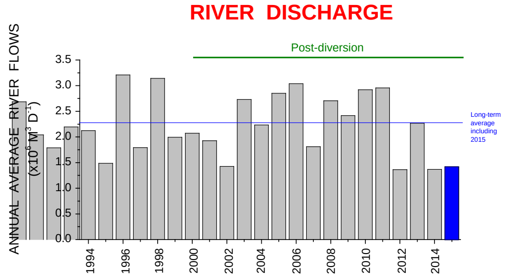

Fig. 11. Average river discharges, 1991-2015 (data from USGS).

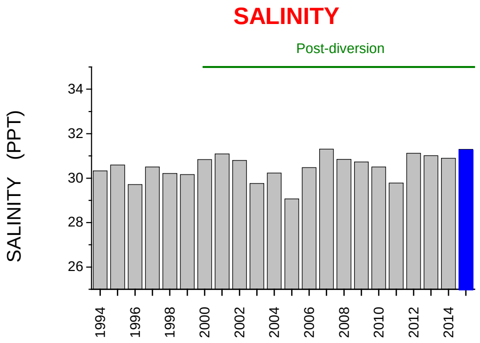

Fig. 12. Average harbor salinities, 1994-2015.

From February through June water temperatures during 2015 were 2°C to 5°C lower than during the same months during all years since the discharges were discontinued (**Fig. 13**), though October temperatures were the warmest ever observed.

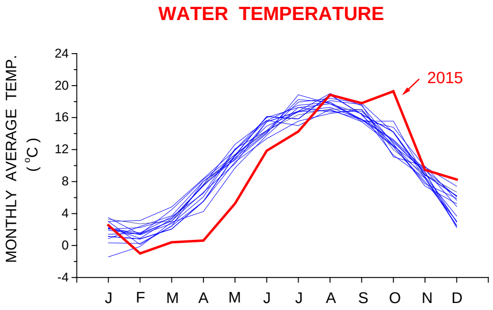

Fig. 13. Average water temperatures by month. Red line shows 2015 data; blue lines shown 2001 to 2014.

9. CONCLUSIONS

Many of the harbor water quality improvements observed during the implementation of the BHP and the CSO Control Plan have been sustained into 2015. The ending of the wastewater discharges in 2000 caused harbor total nitrogen, total phosphorus, and particulate organic C concentrations, and phytoplankton biomass and *Enterococcus* counts to decline.

During the 16 years since the discharges were discontinued, total P concentrations and *Enterococcus* counts have continued to decline. DO concentrations too have continued to increase post-discharge. 2015 total P concentrations and *Enterococcus* counts were the lowest seen since 1994, and DO concentrations the highest.

Certain variables have shown fluctuations during the years since the discharges were discontinued. Phytoplankton biomass, POC and TSS concentrations have all increase between about 1995/1996 (five to six years after the discharges to the harbor were discontinued) to 2013 or 2014.

Biomass, POC and TSS concentrations during 2015 were all higher than during most years since the discharges to the harbor were discontinued. 2015 TSS concentrations were the second highest since monitoring started. 2015 chl-a and POC concentrations were elevated, but lower than during most post-diversion years.

10. REFERENCES

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APPENDIX

Table A-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 – 2015+
106	Marine;	Outer harbor, NE of Long Island	42 19.95, 70 57.54	1993 – 2015+
124	Marine;	Hingham Bay, Crow Point flats	42 16.36, 70 53.86	1993 – 2015[3]
137	Marine;	Mystic River mouth	42 23.21, 71 3.77	1993 – 2015+
138	Marine;	Central inner harbor	42 21.56, 71 2.74	1993 – 2015+
139	Marine;	Quincy Bay, SW of Hangman Island	42 17.20, 70 58.10	1993 – 2015+
140[2]	Marine;	Neponset River mouth/S. Dorchester Bay	42 18.35 71 2.43	1993 – 2015+
141	Marine;	Outer harbor, NE of Peddocks Island	42 18.30, 70 55.85	1993 – 2015+
142	Marine;	Outer harbor, President Roads, south channel	42 20.35, 70 55.89	1993 – 2015+

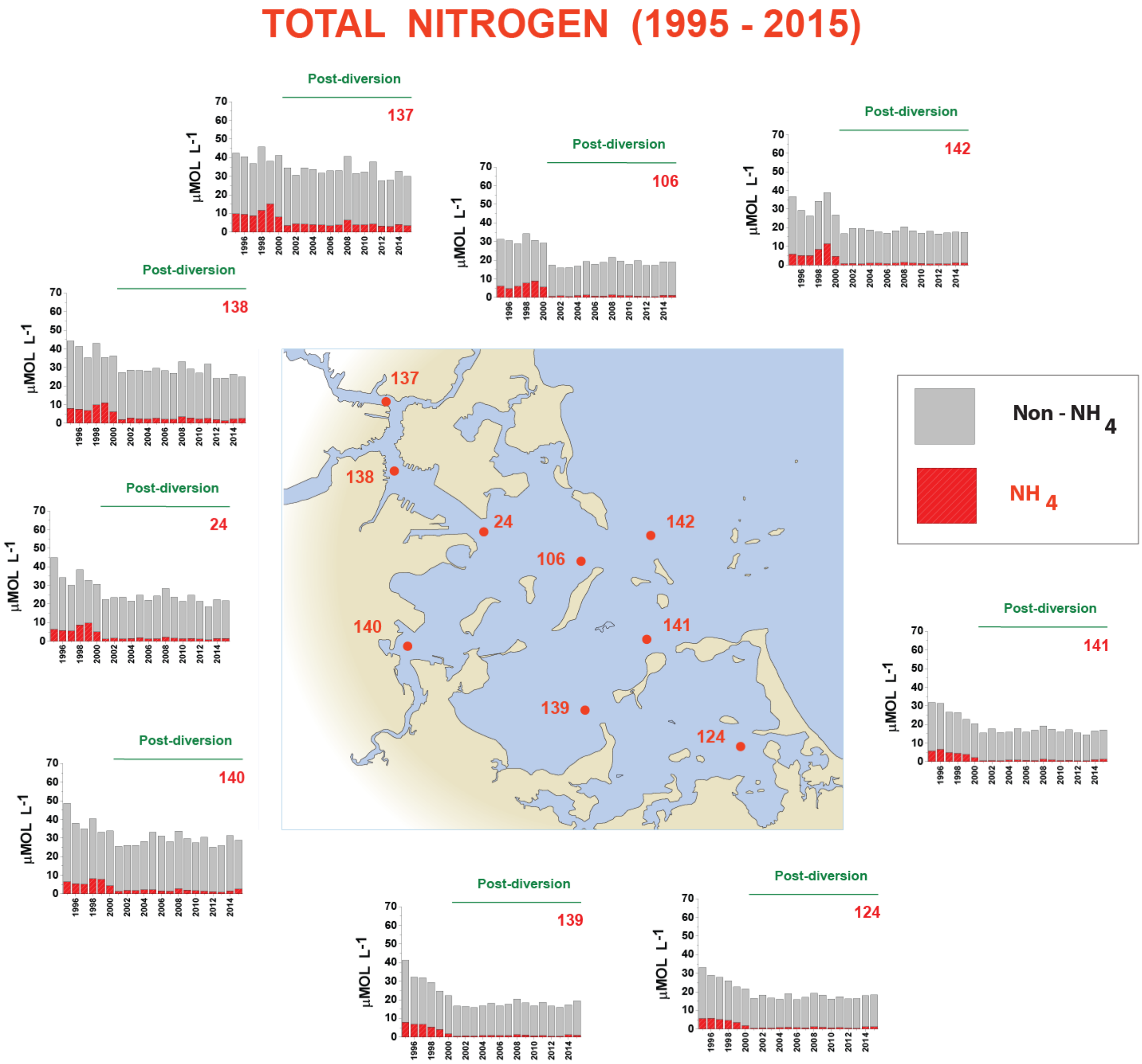

Fig. A-1. Annual total N concentrations partitioned into the non-ammonium and ammonium fractions at the nine sampling locations, 1995-2015.

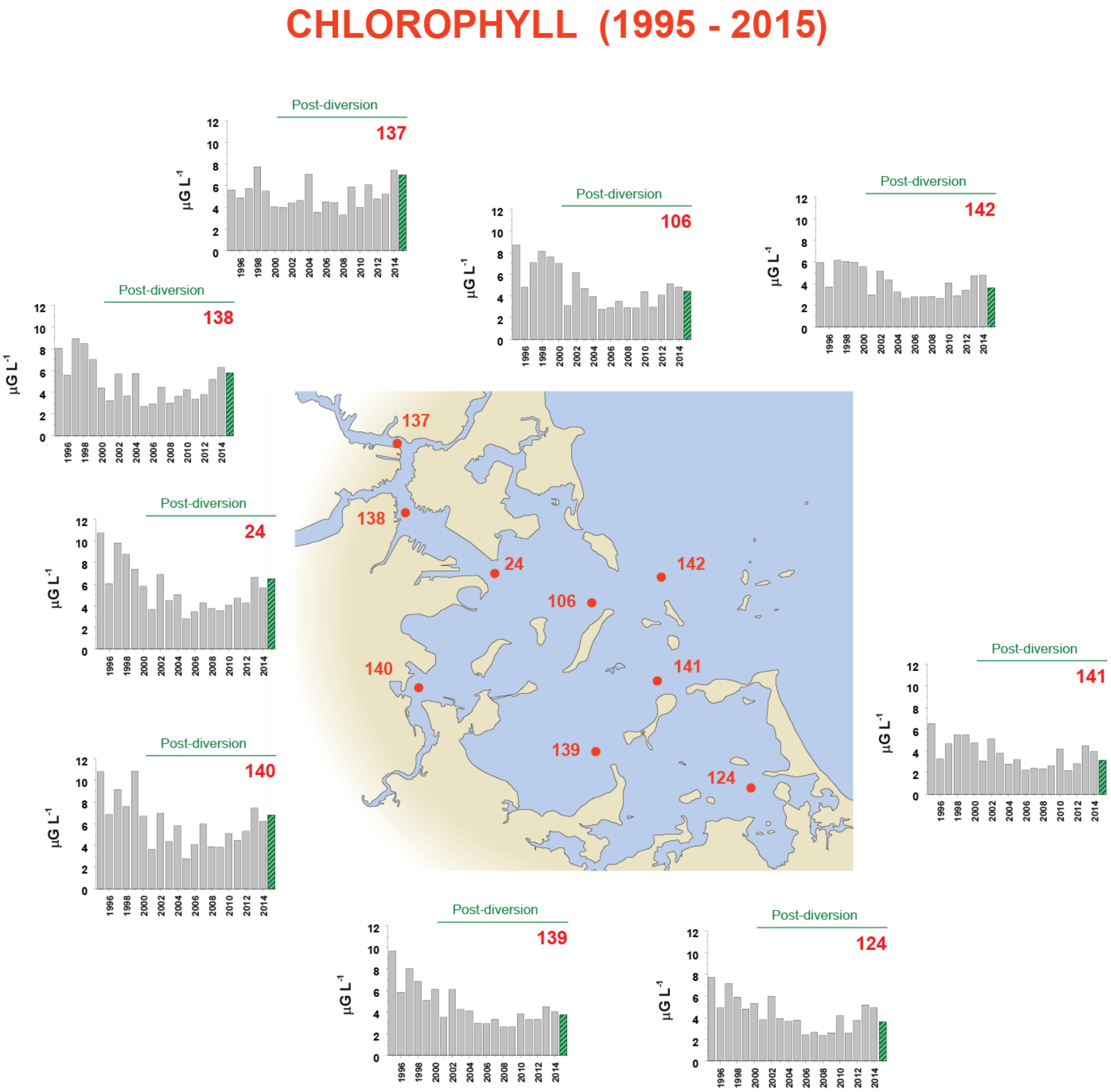

Fig. A-2. Summer average phytoplankton biomass (measured as chlorophyll-a) at nine harbor sampling locations, 1995-2015, Summer = J, J, A and S.

TOTAL SUSPENDED SOLIDS
(1996 - 2015)

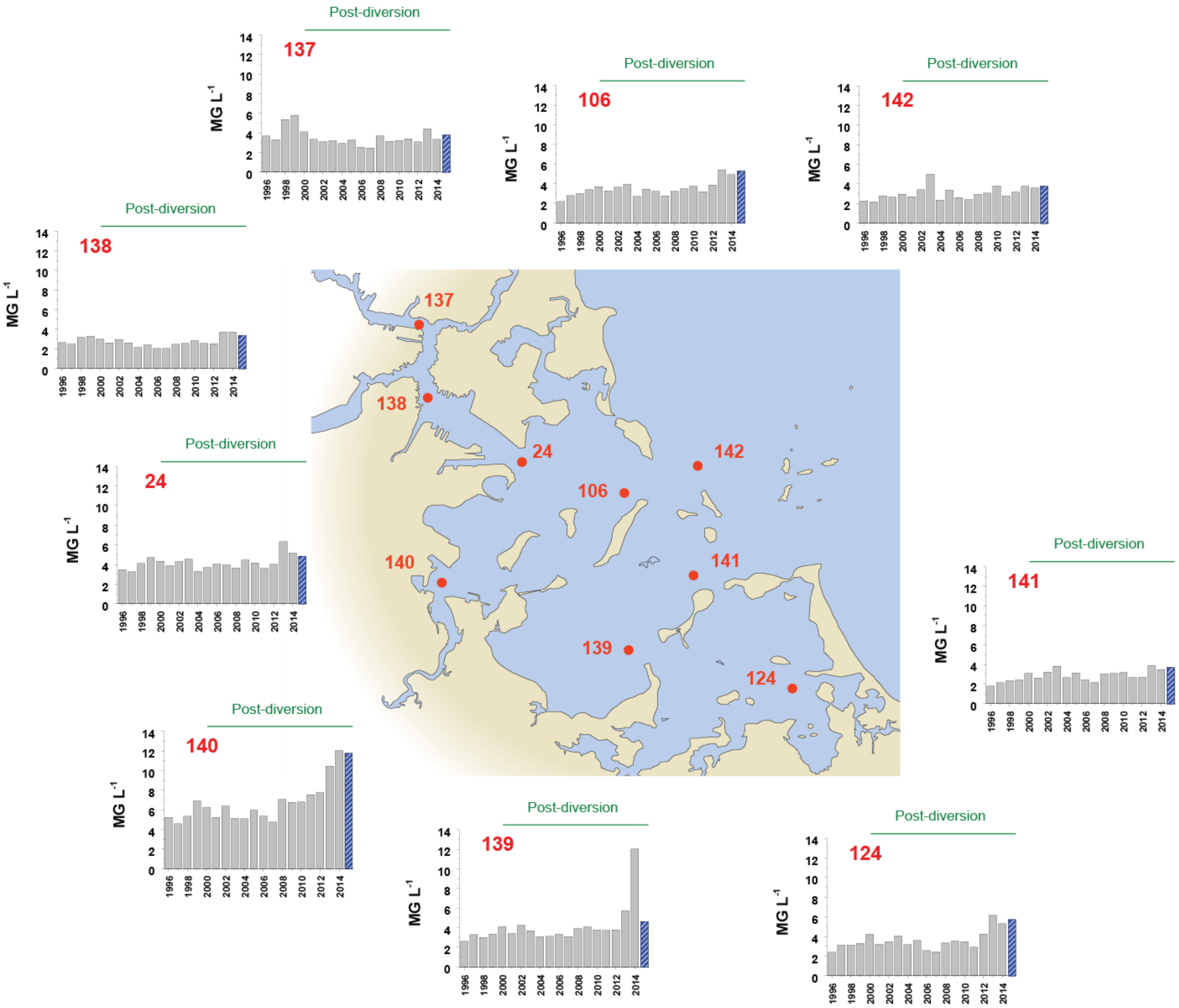

Fig. A-3. Annual total suspended solids (TSS) concentrations, 1995-2015.

MINIMUM BOTTOM-WATER DO *
(1994 - 2015)

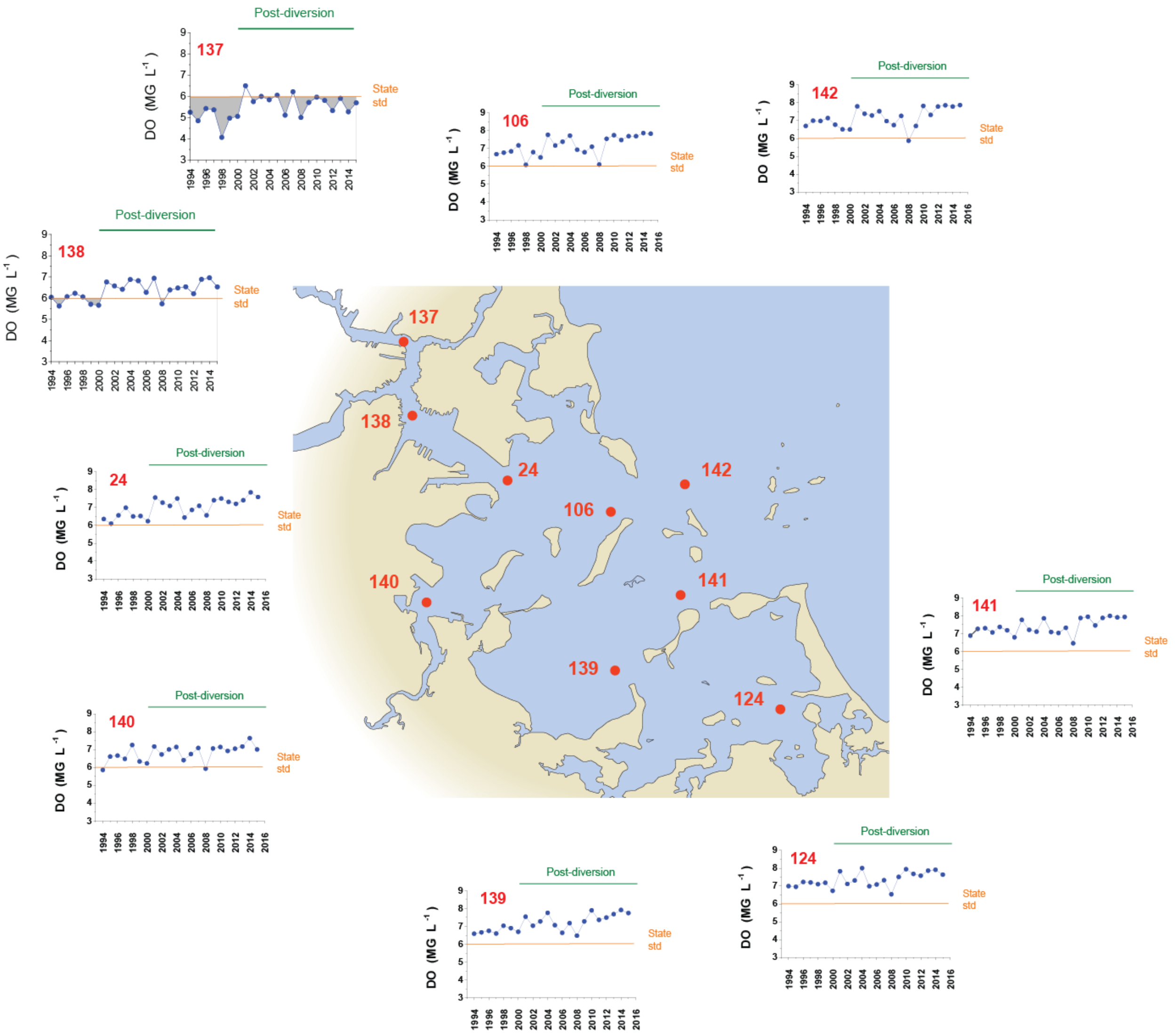

Fig. A-4. Lowest monthly average bottom-water DO concentrations, 1994-2015. Shaded areas show years values failed to meet state Standard.

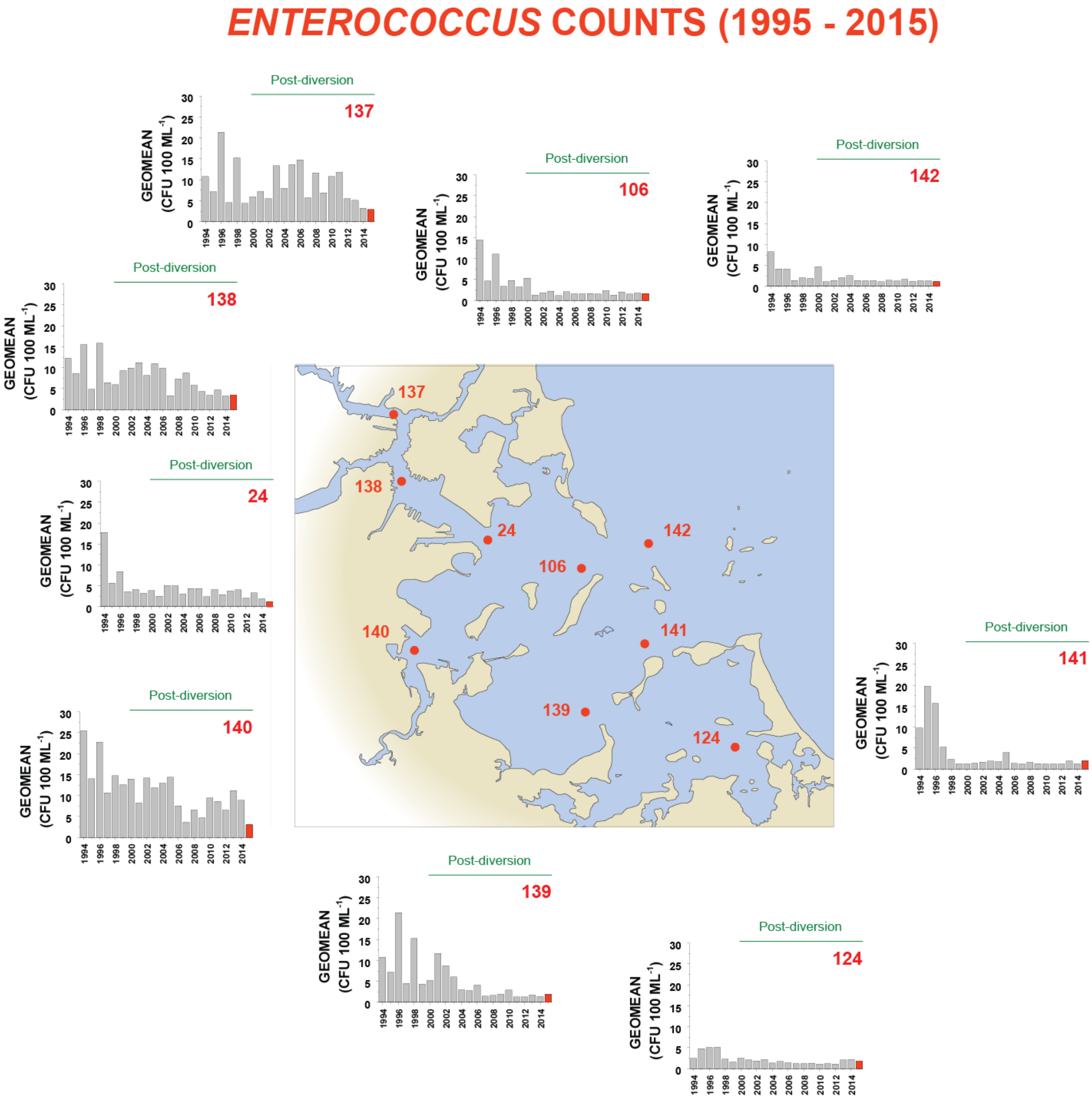

Fig. A-5. Annual mean *Enterococcus* counts, 1994-2015.

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