Barnegat Bay—Year 3

Benthic Invertebrate Community Monitoring and Indicator Development for the Barnegat Bay-Little Egg Harbor Estuary

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Project SR14-004: Benthic Invertebrate Community Monitoring and Indicator Development for Barnegat Bay-Little Egg Harbor Estuary: Year 3

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Introduction

The Barnegat Bay ecosystem is potentially under stress from human impacts, which appear to have increased over the past several decades. Benthic macroinvertebrates are commonly included in studies to monitor the effects of human and natural stresses on marine and estuarine ecosystems. There are several reasons for this. Macroinvertebrates (here defined as animals retained on a 0.5-mm-mesh sieve) are abundant in most coastal and estuarine sediments, typically on the order of 10^3 to 10^4 individuals per meter squared. Benthic communities are typically composed of many taxa from different phyla, and quantitative measures of community diversity (e.g., Rosenberg et al. 2004) and the relative abundance of animals with different feeding behaviors (e.g., Pelletier et al. 2010, Weisberg et al. 1997), can be used to evaluate ecosystem health. Because most benthic invertebrates are sedentary as adults, they function as integrators, over periods of months to years, of the properties of their environment.

The Barnegat Bay-Little Egg Harbor (BB-LEH) Estuary is heterogeneous with respect to environmental variables that are well known to affect benthic community composition. Salinity and sediment particle size vary throughout the system. Salinity varies locally along the main axis of the estuary in response to ocean water sources (notably at Barnegat Inlet, Little Egg Inlet, and the Point Pleasant Canal) and fresh-water sources (notably Toms River, Metedeconck River, and Cedar Creek). Long-term data collected by the New Jersey Department of Environmental Protection, Bureau of Marine Water Monitoring show that salinity tends to be lower in northern Barnegat Bay (range 0-20) than in central and southern Barnegat Bay and in Little Egg Harbor (range 20 to >28). Sediment particle size, and the inversely correlated sediment organic content, varies from east to west, with fine-grained sediments predominantly present in the western half and coarser sediments in the east. Sediment organic matter content is likely to also vary in response to variations in nutrient loadings throughout the system. Our objective is to develop quantitative measures to relate benthic community structure to variation in these and other environmental properties in BB-LEH Estuary.

Benthic invertebrates in the BB-LEH Estuary were sampled comprehensively in 2001 as part of the EPA REMAP and NCA efforts, when 96 stations were sampled. In July 2012 we sampled 100 stations throughout the bay in order to obtain a data set comparable to the sampling density in 2001. In July 2013, and again in July 2014, we re-sampled these stations, using the same methods in order to evaluate short-term temporal changes. In this report, we summarize the results from 2014. We also compare results among all three years. Finally, we analyze whether benthic community structure can be related to measures of water quality. We conclude that, as in 2012 and 2013, the benthic invertebrate community in BB-LEH in 2014 was healthy. We develop a simple index that relates the proportion of benthic animals that belong to ecologically sensitive species to total nitrogen concentration and the dissolved oxygen saturation level in the water.

Methods

Field sampling

One hundred stations were sampled between July 1 and 22, 2014. Surface and bottom water salinity, temperature, dissolved oxygen, and pH were measured at each station with a YSI hand-held meter (Yellow Springs Instruments, Yellow Springs OH). The data were stored in the instrument memory for later download to a computer, and were also hand-entered onto waterproof sheets, along with date and time of sampling, station coordinates, Secchi depth, weather, sea conditions, sediment visual characteristics, presence of submerged aquatic vegetation, and general notes about station characteristics.

Three sediment samples were taken at each station using a 0.044-m^2 Ted Young Modified Van Veen grab. Depth of sediment sampled was recorded. Two of the sediment samples were processed in their entirety for benthic invertebrate macrofauna. Sediment was sieved over a 0.5-mm-mesh screen, and material remaining on the screen was fixed in 3.7% formaldehyde solution in seawater buffered with Borax. Rose Bengal was added to stain organisms to facilitate sorting. Sieved samples were delivered to Cove Corporation (Lusby, MD) for sorting and identification of organisms to lowest possible taxonomic unit, usually species.

The third grab from each station was used for measurement of sediment properties. The top 2-cm layer of sediment was removed with a stainless steel spoon, transferred to a stainless steel bucket, and homogenized by stirring. Subsamples of the homogenized sediment were taken for total organic carbon, total nitrogen, and total phosphorus (~100 mL of sediment transferred to a glass 250 mL jar with a Teflon-lined cap), for grain size analysis (~250 mL of sediment transferred to a Whirl-Pak bag), organics (~250 mL of sediment transferred to a glass 500 mL jar with a Teflon-lined cap), and metals (~100 mL of sediment into a pre-cleaned plastic (HDPE) jar). All samples were stored on ice immediately after collection and during transport to the laboratory. The sediment samples for organics were transferred to a 4° refrigerator and those for metals were transferred to a -20° freezer for possible future analysis (US EPA 2001).

Laboratory analysis: sediment grain size

Sediment for grain size analysis was processed using methods described in detail in the EMAP-Estuaries Laboratory Methods Manual (US EPA 1995). Briefly, sediment was wet-sieved through a 63µm-mesh sieve in distilled water with dispersant to separate the silt and clay fraction from the sand-sized fraction. The sand fraction was dried and then sieved into the following size fractions: <4ϕ (<63 µm, silt), 4ϕ (63-125 µm, very fine sand), 3ϕ (125-250 µm, fine sand), 2ϕ (250-500 µm, medium sand), 1ϕ (500-1000 µm, coarse sand), and 0ϕ (1000-2000 µm, very coarse sand). Each fraction was weighed. The mass of the <4ϕ fraction was determined by drying a known volume of the water-particle mixture passing through the 63µm-mesh sieve.

Grain size statistics were computed using the program GSSTAT, developed by the United States Geological Service (Poppe et al. 2004).

Laboratory analysis: sediment organic carbon, nitrogen, and phosphorus

Sediment was freeze dried and then gently disaggregated. Large shell fragments, pieces of vegetation, or visible organic debris were removed, and then sediment was ground to a fine powder using a ceramic mortar and pestle.

Total organic carbon (TOC) and total nitrogen (TN) were measured using standard methods (elemental analysis EPA Method 440.0 for total C and N (US EPA 1992)). Aliquots were weighed into silver foil sample cups. Two replicates per station were prepared. The silver foil cups with sediment were placed into a sealed chamber with concentrated hydrochloric acid fumes to remove inorganic carbonate. Samples were analyzed using a Carlo Erba NA1500 Elemental Analyzer. Internal standards of acetanilide or NIST Standard Reference Material 2702-Inorganics in Marine Sediment (National Institute of Standards and Technology, Gaithersburg MD) were run after every five unknowns to validate instrument performance. Data were accepted if the measured values for carbon of the standards differed by less than $\pm$10% from the expected values.

Total phosphorus (TP) was measured using standard methods (colorimetric analysis of total phosphate (US EPA 2010, chapter 6). A laboratory reagent blank and an internal standard (NIST Standard Reference Material 2702-Inorganics in Marine Sediment) were run after every 10 unknowns. Data were accepted if the measured value for phosphorus of the standard differed by less than $\pm$10% from the expected value.

Data analysis

Exploratory data analysis was conducted using Microsoft Excel 2007 or Statistix v10 (Analytical Software, Tallahassee FL). In most cases exploratory data analysis involved use of scatterplots to examine potential correlations among variables. <u>Lo</u>cally <u>we</u>ighted <u>s</u>catterplot <u>s</u>moothing (LOWESS), a robust locally weighted regression algorithm, was used to visualize trends in data (Cleveland 1979). Multivariate statistical analyses were conducted using Canoco v4.56 (Microcomputer Power, Ithaca NY) and Primer 6 (Clarke and Gorley 2006).

Results and Discussion

<u>Bottom water properties</u>

Temperature

Bottom water temperatures ranged from 21.5 to 28.8° with the coolest waters present in the central section of the bay near Barnegat Inlet and in the southern section near Little Egg Inlet (Figure 1). Warmest waters were in the northern half of the bay. The average bottom temperature in 2014 was 25.6°, the same as in 2013. Average bottom temperature in 2012 was 27°.

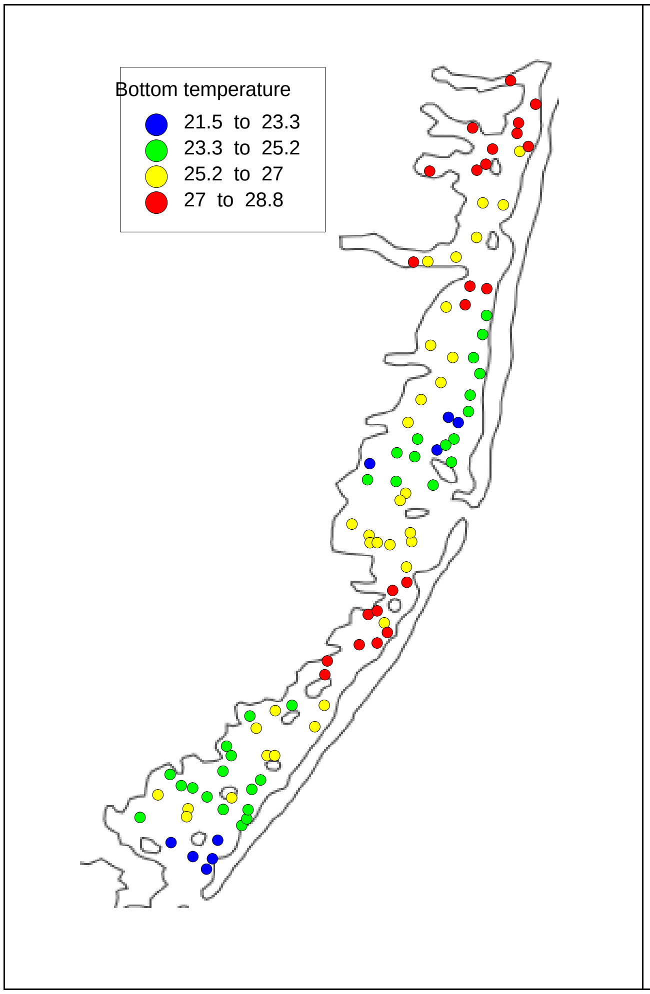
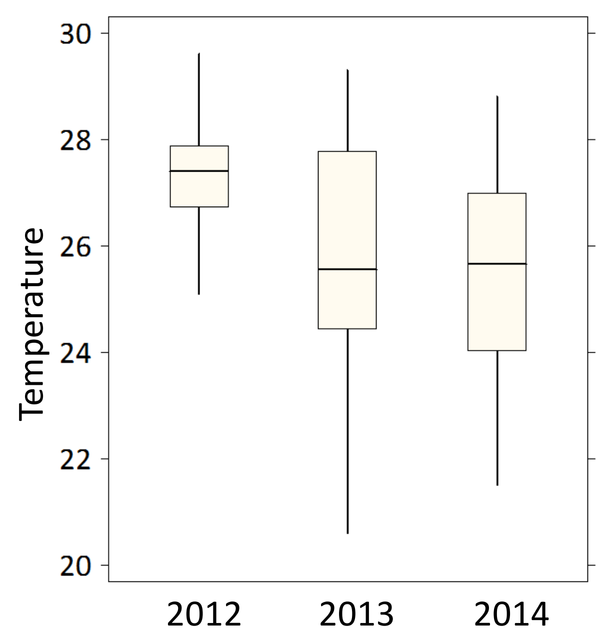


Figure 1. Bottom water temperatures in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	Mean	Minimum	Median	Maximum
Bottom temp 2012	27.1	21.0	27.4	29.6
Bottom temp 2013	25.6	15.1	25.6	29.3
Bottom temp 2014	25.6	21.5	25.6	28.8

Salinity

Bottom salinity ranged from 14.9 to 30.3 (Figure 2). Lowest values were in the northern section of the bay, while highest salinities occurred in the central section of the bay and in Little Egg Harbor.

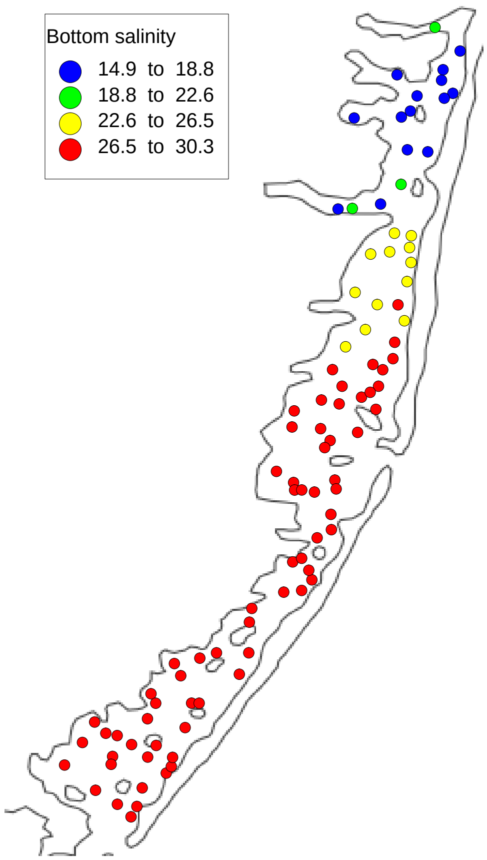
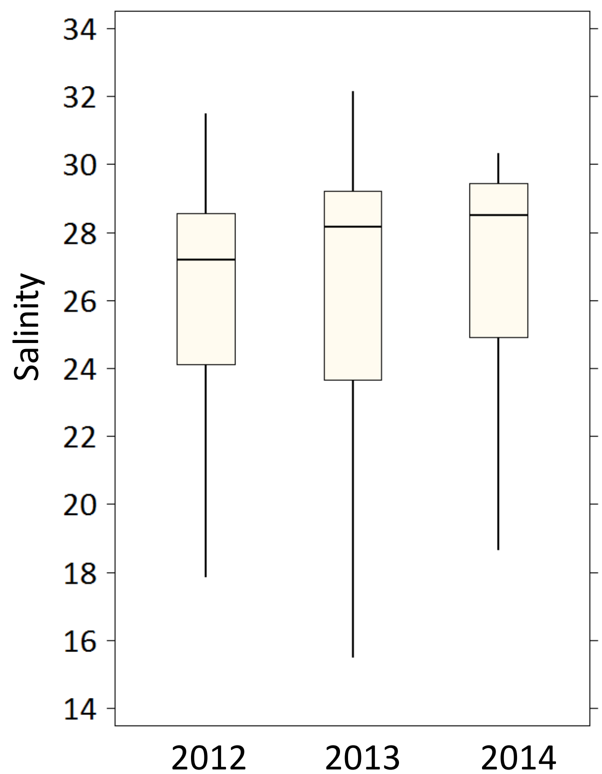


Figure 2. Bottom water salinity in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	Mean	Minimum	Median	Maximum
Bottom salinity 2012	25.4	11.3	27.2	31.5
Bottom salinity 2013	25.7	11.6	28.2	32.1
Bottom salinity 2014	26.0	10.1	28.5	30.3

There was little difference in salinity over the years 2012-2014 (Figure 3). The distribution with latitude is typical for BB-LEH, with three salinity ‘bands’: highest salinity at latitudes <=39.8, transitional salinity at 39.8 < latitude <=39.925, and lowest salinities at latitude >39.925.

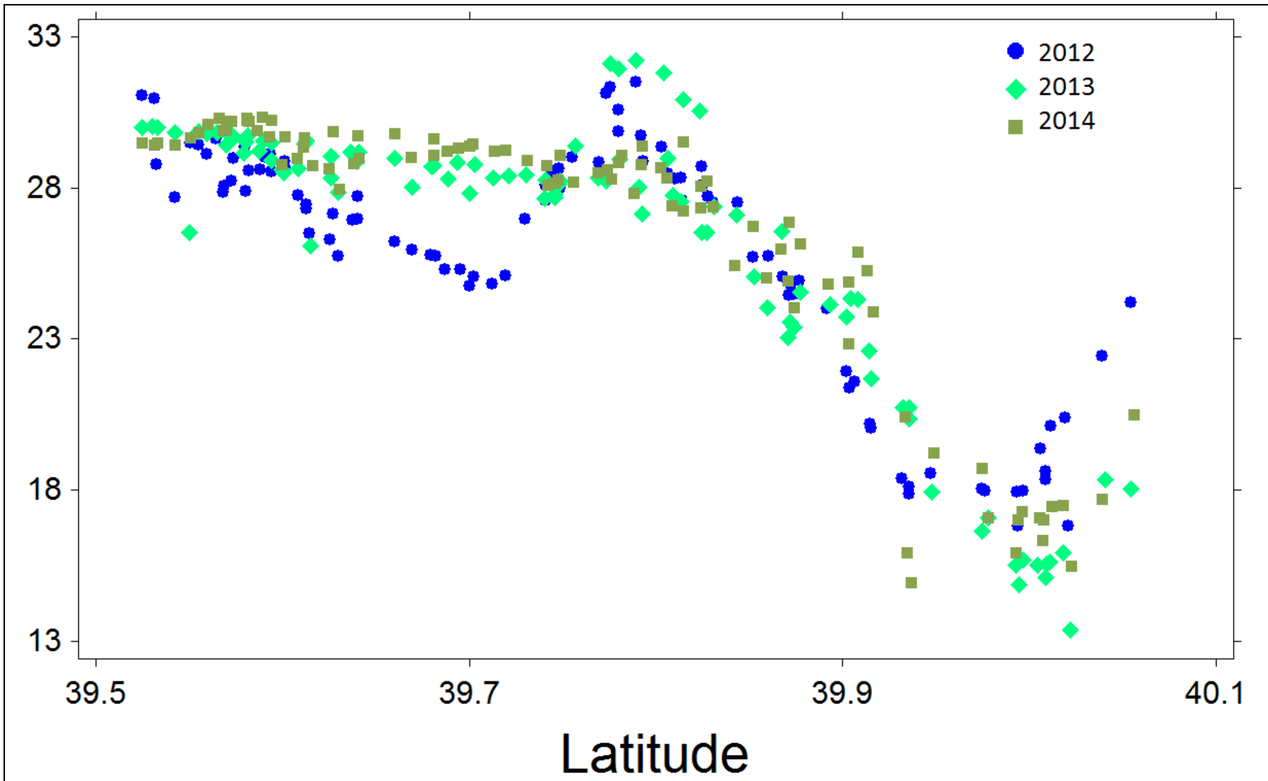


Figure 3. Bottom salinity along the south-north latitude gradient.

Dissolved oxygen

Dissolved oxygen concentrations in the bottom part of the water column ranged from 5 to 10.4 mg L^{-1} (Figure 4). There was no obvious spatial pattern in dissolved oxygen. Dissolved oxygen increased steadily from 2012 to 2013 to 2014.

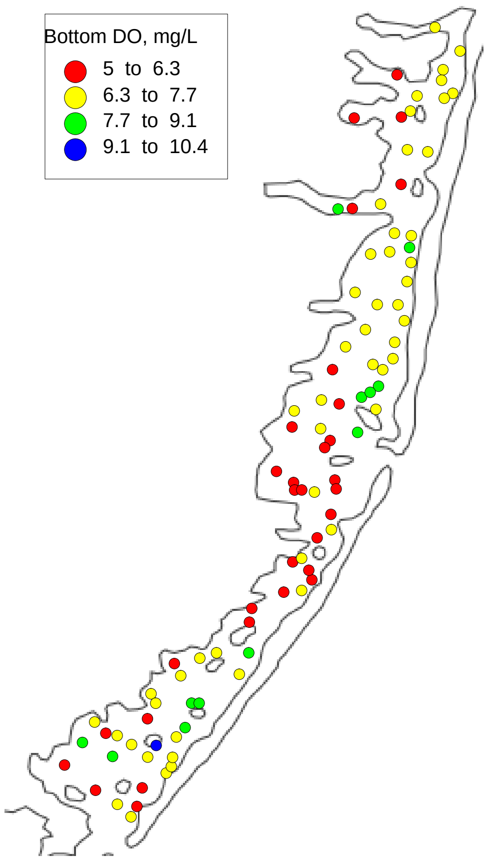
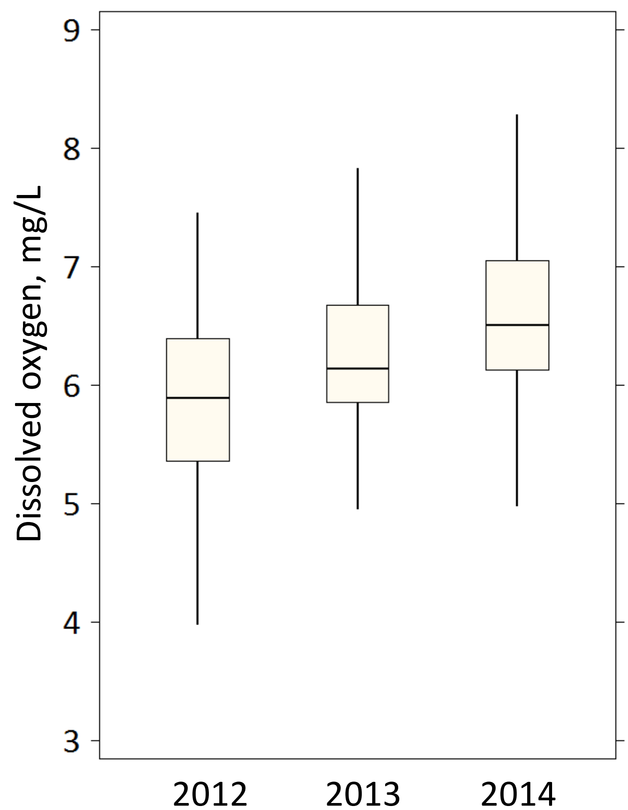


Figure 4. Bottom water dissolved oxygen in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	Mean	Minimum	Median	Maximum
Dissolved oxygen 2012	5.8	4.0	5.9	7.4
Dissolved oxygen 2013	6.2	2.1	6.1	8.4
Dissolved oxygen 2014	6.7	4.6	6.5	10.4

pH

Bottom water pH varied from 7.5 to 8.3 (Figure 5). Aside from the highest values occurring in southern Little Egg Harbor, there was no strong spatial pattern. pH varied little over the period 2012-2014.

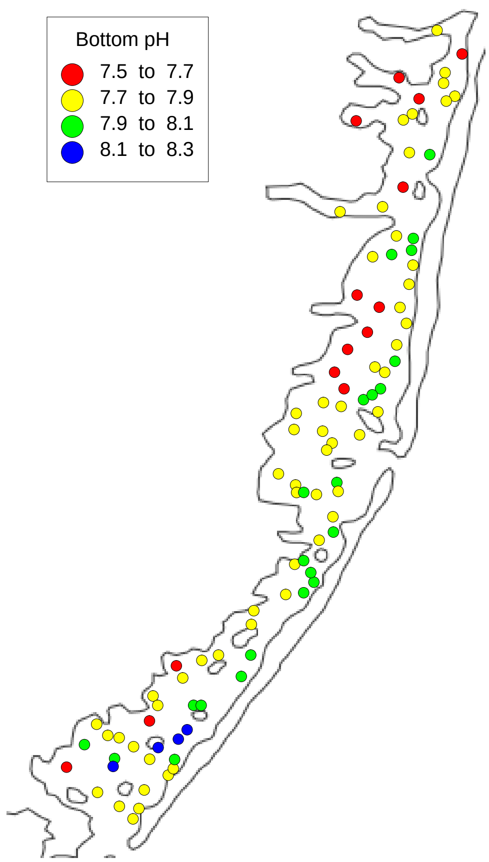
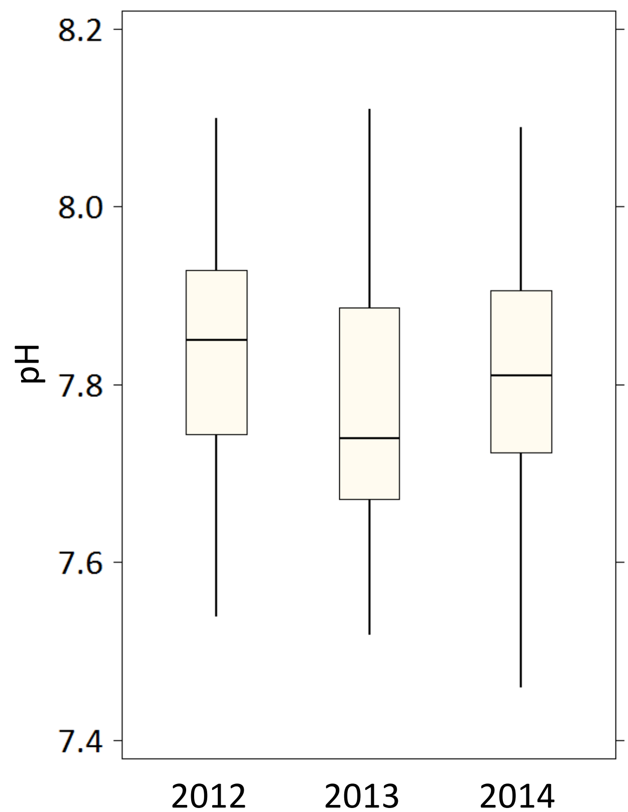


Figure 5. Bottom water pH in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	Mean	Minimum	Median	Maximum
Bottom pH 2012	7.83	7.40	7.85	8.10
Bottom pH 2013	7.76	7.02	7.74	8.11
Bottom pH 2014	7.82	7.15	7.81	8.27

<u>Sediment properties</u>

Sediment grain size

Sediments ranged from medium sands to coarse silts (Figure 6). Fine-to-medium sands tended to occur along the eastern boundary of BB-LEH and coarse silt tended to occur on the western side, but there was considerable heterogeneity in the distribution of particle sizes. There was a slight trend to coarser sediments over the period 2012-2014.

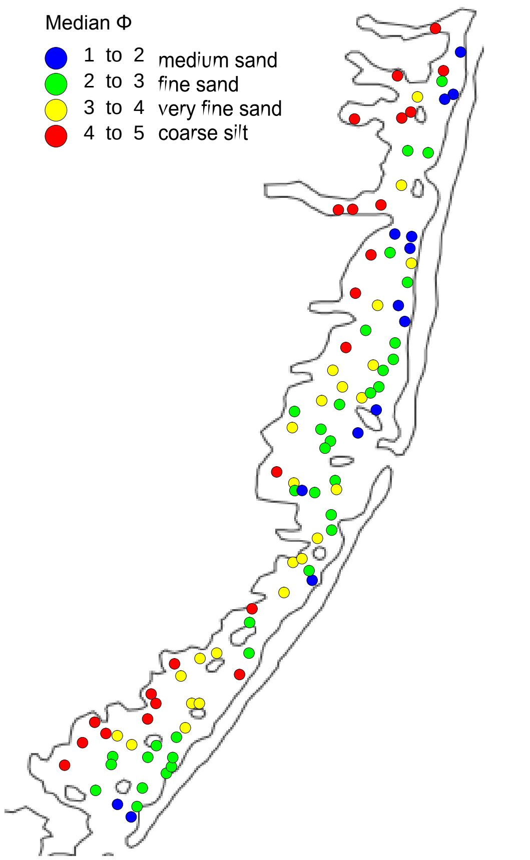
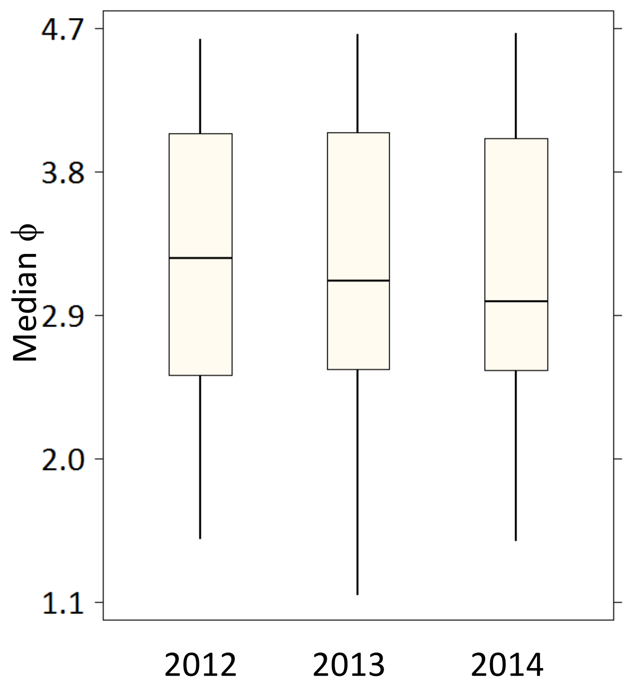


Figure 6. Median sediment phi size in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	**Mean**	**Minimum**	**Median**	**Maximum**
Median phi 2012	3.21	1.50	3.26	4.63
Median phi 2013	3.17	1.15	3.12	4.66
Median phi 2014	3.16	-0.46	2.98	4.67

Sediment sorting

The sediment sorting coefficient (Inclusive Graphic Standard Deviation, a measure of the variability of sediment particle sizes) varied from very well sorted to poorly sorted (Figure 7). At most locations, sediments were moderately sorted or moderately well sorted and these stations were spread throughout the bay. The four stations with very well sorted sediments were on the western side of the bay. There was a trend for sediments, baywide, to become better sorted over the three years of sampling.

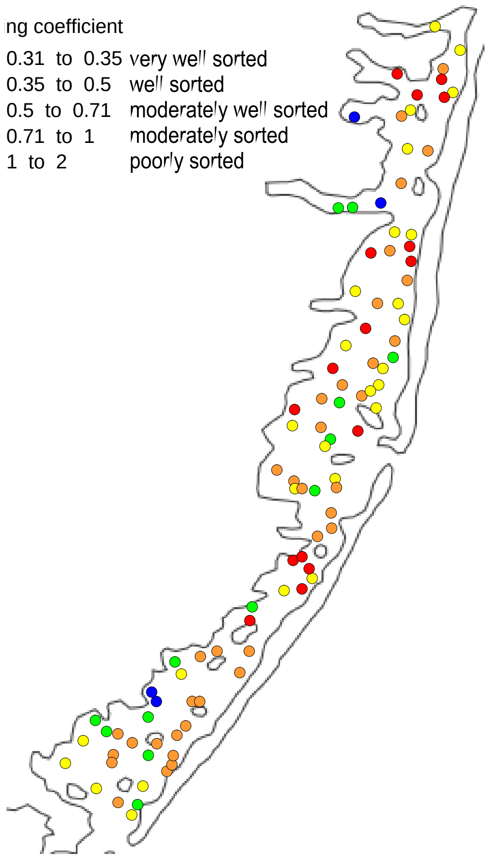
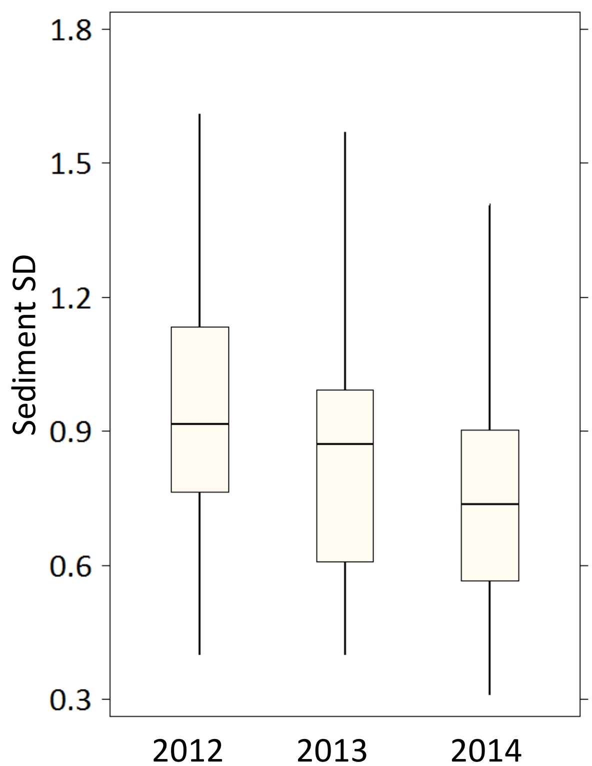


Figure 7. Sediment sorting coefficient in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	Mean	Minimum	Median	Maximum
Sorting coefficient 2012	0.96	0.40	0.92	1.96
Sorting coefficient 2013	0.87	0.40	0.87	2.06
Sorting coefficient 2014	0.76	0.31	0.74	1.71

Sediment carbon, nitrogen, and phosphorus

Sediment carbon concentration ranged from 0.03 to 6% by weight for 97 of the 100 stations sampled (Figure 8; three stations farther up the Toms River had sediment %C values of 10.4, 10.6, and 12.2 and are not included on the map). Most stations, 66 out of 100, had ≤1% carbon. The 2014 data are similar to previous years; the median sediment organic carbon concentration in BB-LEH is less than 0.8%.

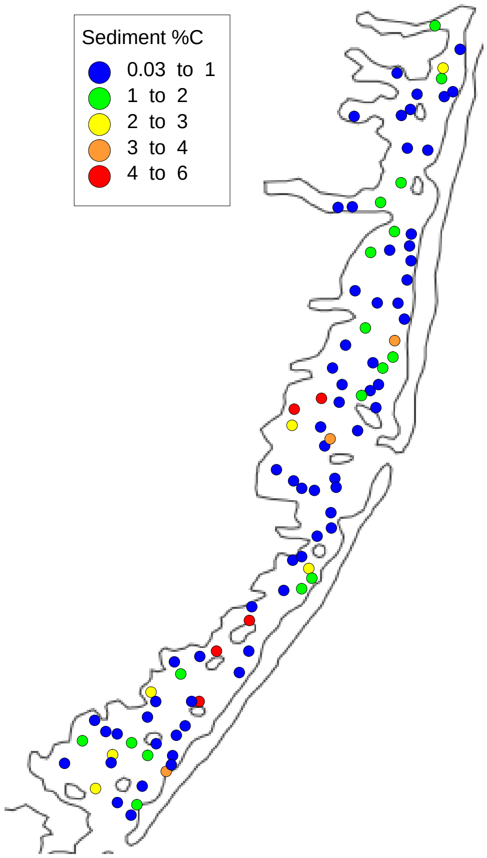
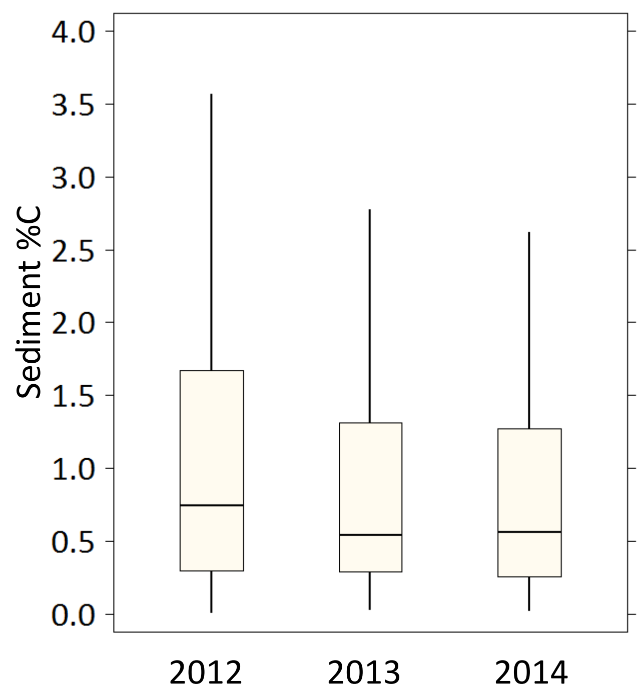


Figure 8. Sediment %C in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	Mean	Minimum	Median	Maximum
Sediment %C 2012	1.37	0.01	0.75	12.21
Sediment %C 2013	1.26	0.03	0.54	13.36
Sediment %C 2014	1.31	0.03	0.56	12.16

Total nitrogen concentration of sediments ranged from 0.002 to 0.51% for 97 of the 100 stations sampled (Figure 9; three stations farther up the Toms River had sediment %N values of 0.70, 0.77, and 0.85 and are not included on the map). Most stations (69) had nitrogen concentrations ≤0.1%. Sediment total nitrogen was slightly lower in 2013 and 2014 than in 2012.

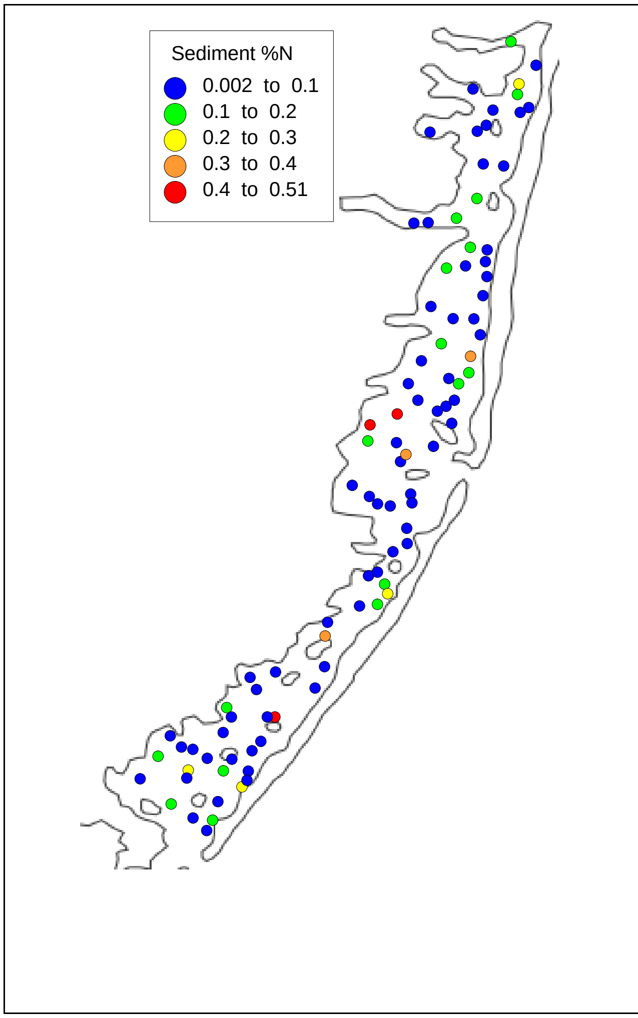
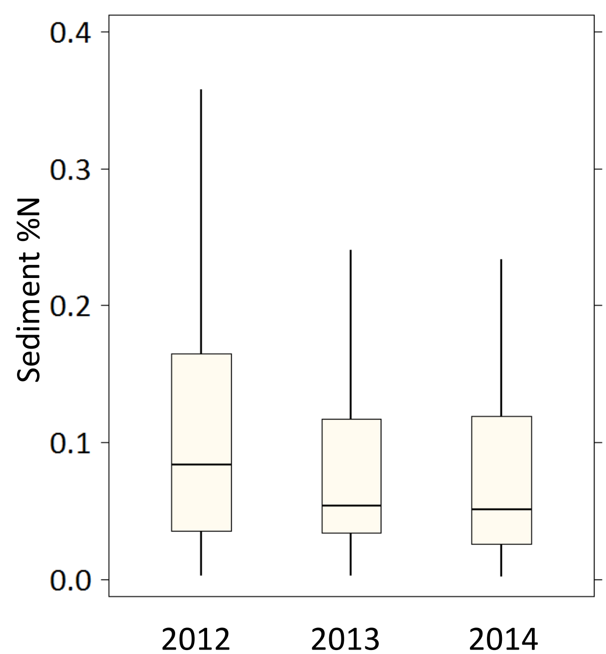


Figure 9. Sediment %N in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	Mean	Minimum	Median	Maximum
Sediment %N 2012	0.13	0.0035	0.084	0.78
Sediment %N 2013	0.11	0.0032	0.054	0.94
Sediment %N 2014	0.11	0.0027	0.051	0.85

Sediment total phosphorus concentrations ranged from 0.002 to 0.11% for 97 of the 100 stations sampled (Figure 10; three stations farther up the Toms River had sediment %P values of 0.08, 0.10, and 0.12 and are not included on the map). Most stations (76) had phosphorus concentrations ≤0.06%. Locations with higher concentrations were spread throughout the bay with no obvious pattern. Sediment total phosphorus did not vary over the three years.

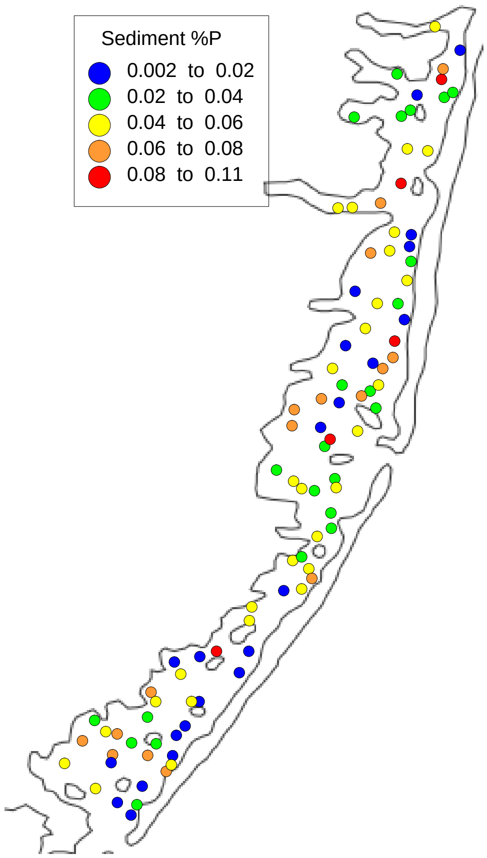
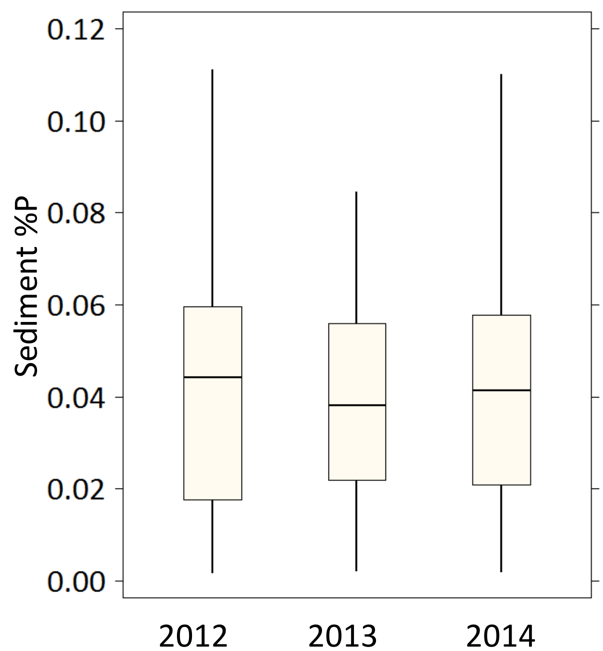


Figure 10. Sediment %P in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	Mean	Minimum	Median	Maximum
Sediment %P 2012	0.041	0.0018	0.044	0.11
Sediment %P 2013	0.040	0.0023	0.038	0.12
Sediment %P 2014	0.042	0.0019	0.042	0.12

Sediment C:N:P ratios

Sediment C:N ratio varied from 8 to 34 (Figure 11). These C:N ratios are greater than the Redfield C:N ratio of 6.6. This is common for marine sediments and is probably due to preferential breakdown of nitrogen-rich organic matter by benthic organisms. Interestingly, the C:N ratio increased over the 2012-2014 period, suggesting that sediment organic matter became increasingly nitrogen-depleted over this period.

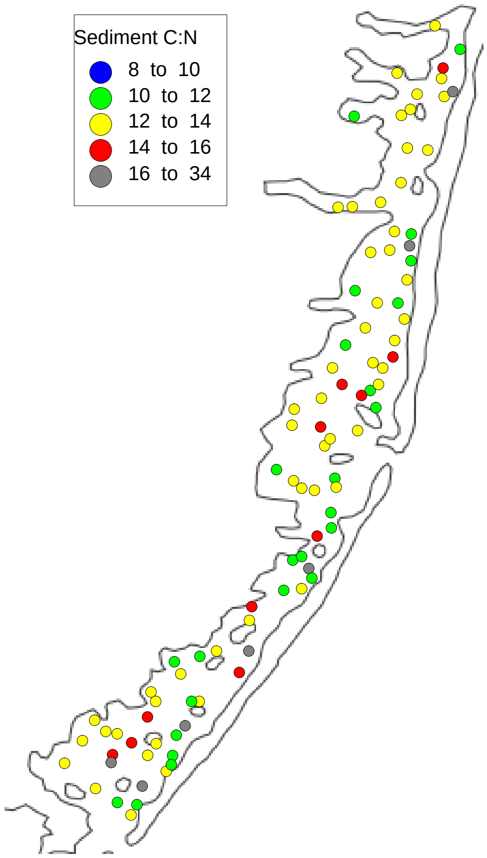
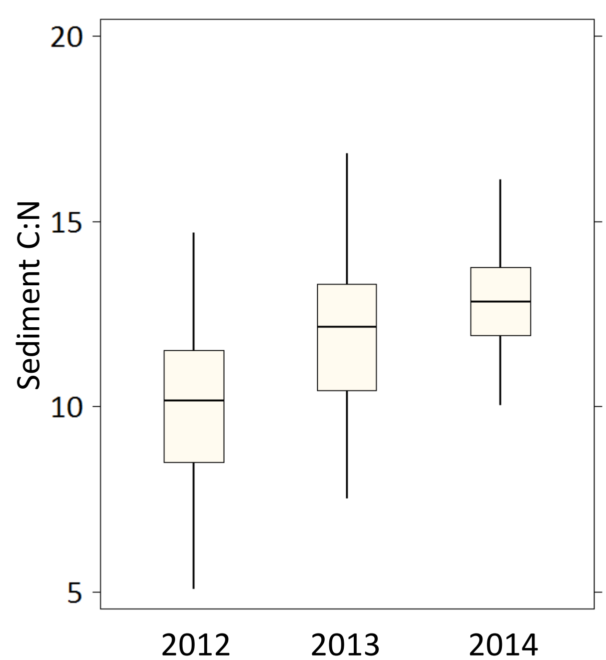


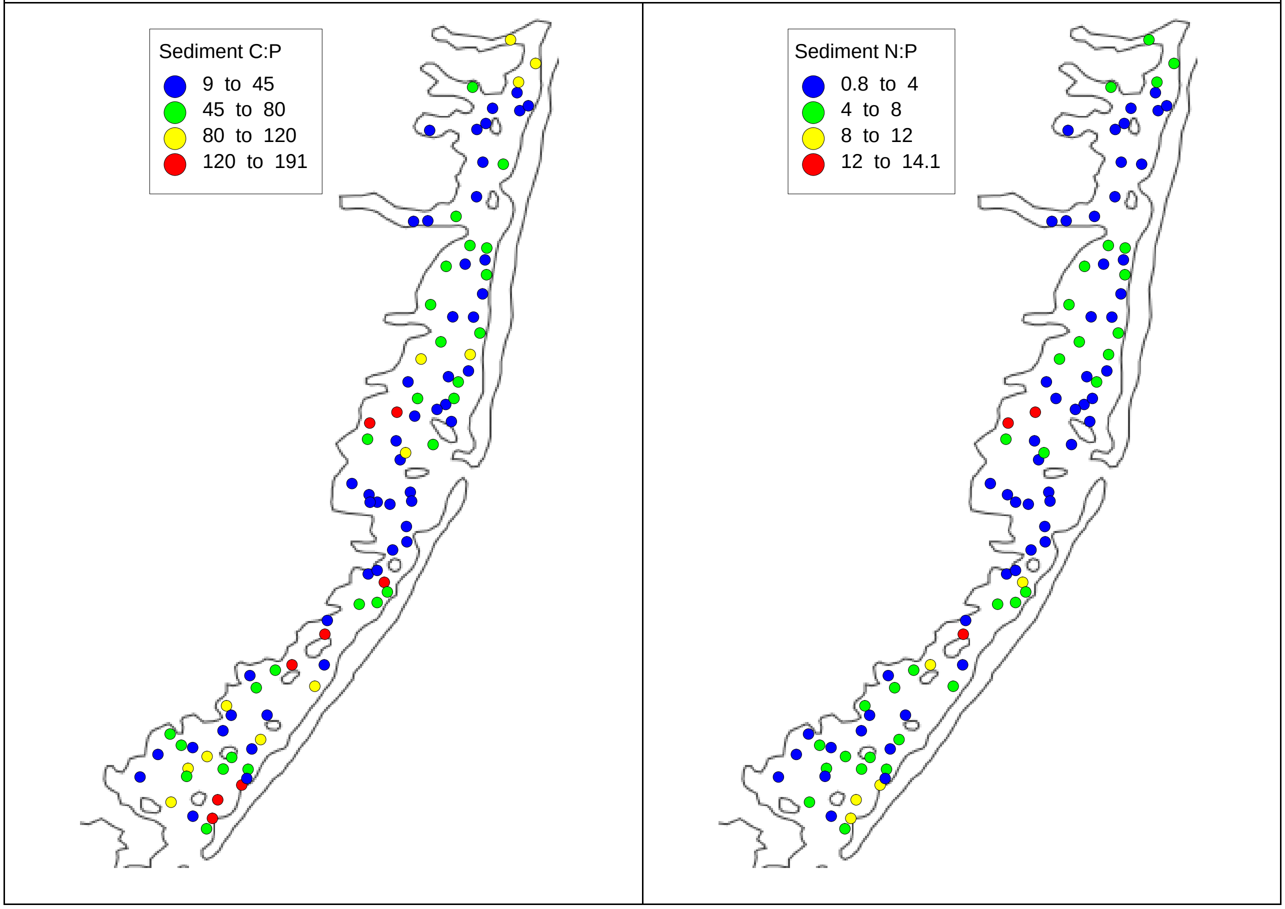
Figure 11. Sediment C:N ratio in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.

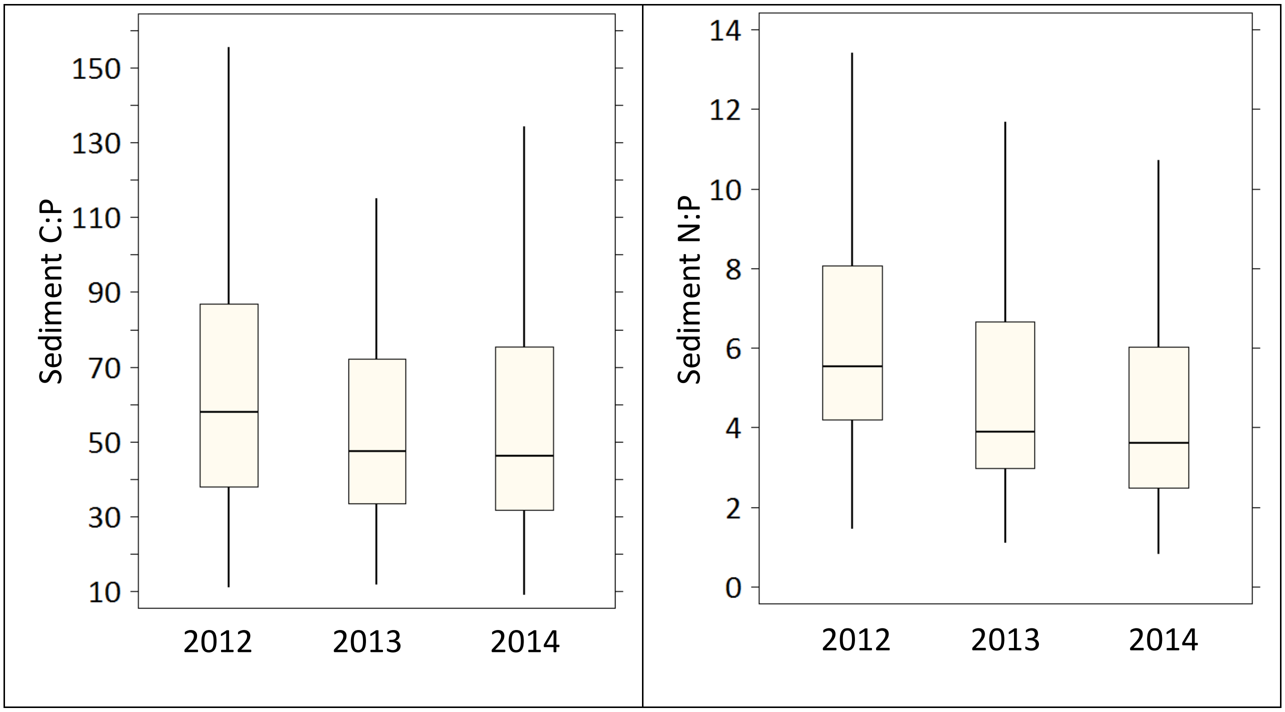


Variable	Mean	Minimum	Median	Maximum
C:N 2012	10.2	5.1	10.2	18.2
C:N 2013	11.9	7.5	12.2	22.3
C:N 2014	13.5	10.0	12.8	33.5

Sediment C:P and N:P ratios at most stations were less than the putative Redfield ratio of 106:1 and 16:1, respectively (Figure 12). This contrasts with the C:N ratios and indicates that sediments in BB-LEH may be a sink for phosphorus. This would only be the case if the C:P and N:P ratios of water column particulates are greater than the ratios in the sediments. We are unaware of any contemporary, direct measures of particulate C, N, and P.

Figure 12. Sediment C:P and N:P ratio in 2014 (top) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.





Variable	Mean	Minimum	Median	Maximum
C:P 2012	70.6	11.3	57.9	283.5
C:P 2013	64.2	12.0	47.6	282.2
C:P 2014	63.2	9.4	46.1	311.3

Variable	Mean	Minimum	Median	Maximum
N:P 2012	6.5	1.5	5.5	16.8
N:P 2013	5.2	1.1	3.9	17.0
N:P 2014	4.7	0.8	3.6	18.0

<u>Benthic macroinvertebrate community composition</u>

A total of 276 taxa were collected in 2014. A subset of 220 of these taxa was used for further analyses. Taxa were not included in analyses if they were epifaunal (for example, encrusting on *Zostera* or *Ruppia* blades), since such taxa are not indicative of conditions in sediments. We consulted the list of taxa omitted in calculations of the Chesapeake Bay Benthic Index of Biotic Integrity (see below and Table 1 in Llansó 2002) when making these decisions since the species lists in BB-LEH and the Chesapeake Bay are similar. We also omitted highly motile species since they are unlikely to be sampled quantitatively by a Van Veen grab. We omitted all taxonomic designations at the generic, familial, and higher taxonomic levels if there were two or more valid lower-level designations for that group (Gallagher and Grassle 1997). This usually occurred with unidentified specimens that were likely to belong to an already identified species. For consistency when comparing the values for the various indices (see below), omitted taxa were not used in calculations of any index. Most of the omitted taxa were rare or only occurred at a few stations, therefore our conclusions were not affected by these omissions. Finally, we also omitted three stations at the head of Toms River (stations, 18, 19, 25) because they contained only 9, 10, and 11 individuals, respectively.

As is common in estuarine environments, the benthic community in BB-LEH is dominated by relatively few species. Five taxa accounted for 50% of all individuals collected in 2014, and 48 taxa accounted for 90% of all individuals (Figure 13). The most abundant species, *Mediomastus ambiseta*, accounted for 25.8% of all individuals (Table 1). At the other end of the spectrum, 78 taxa had 10 or fewer individuals.

Figure 13. Species rank (1 = most abundant) vs. cumulative abundance at all stations. Some taxa were tied in abundance.

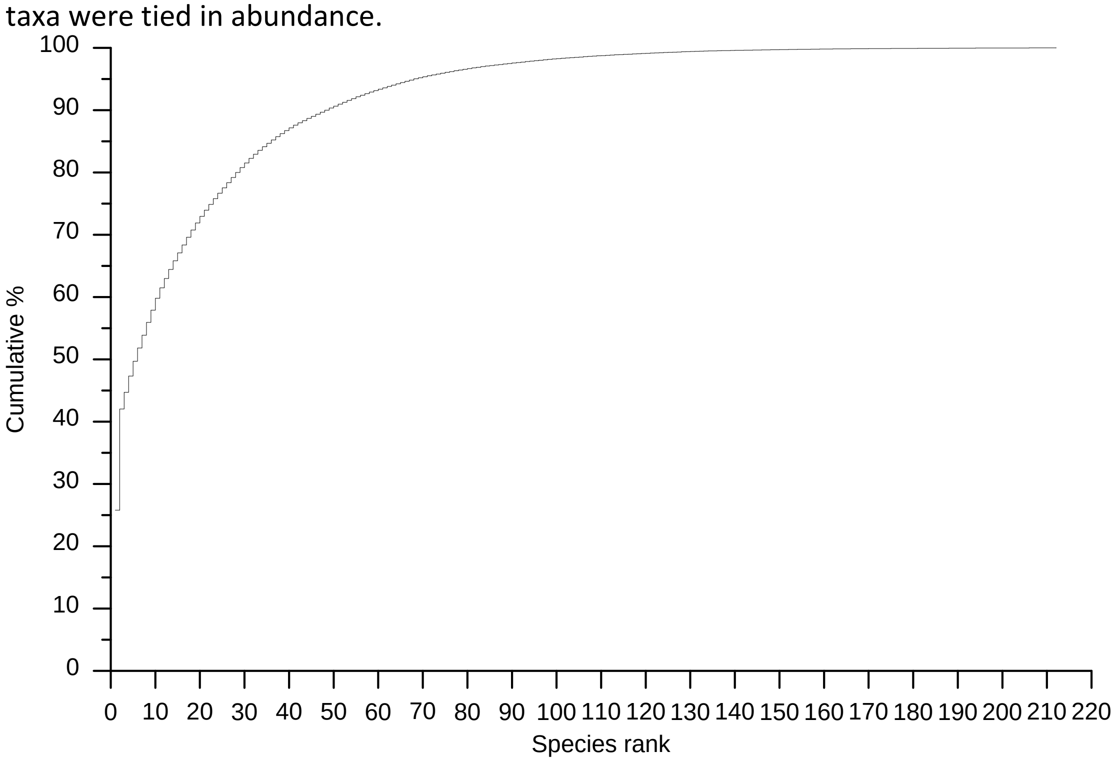


Table 1. Most abundant 48 taxa that made up 90% of all individuals collected.

Taxon	Rank	Total	cumulative %
Mediomastus ambiseta	1	15178	25.79
Ampelisca abdita	2	9550	42.03
Oligochaeta sp.	3	1583	44.72
Ampelisca verrilli	4	1531	47.32
Streblospio benedicti	5	1397	49.69
Elasmopus levis	6	1256	51.83
Heteromastus filiformis	7	1215	53.89
Notomastus sp. A Ewing	8	1206	55.94
Ampelisca vadorum	9	1156	57.91
Microdeutopus gryllotalpa	10	1121	59.81
Japonactaeon punctostriatus	11	988	61.49
Exogone (Exogone) dispar	12	873	62.97
Tharyx sp. A (MWRA)	13	857	64.43
Glycinde multidens	14	817	65.82
Clymenella torquata	15	754	67.10
Polycirrus eximius	16	741	68.36
Spiochaetopterus costarum oculatus	17	731	69.60
Haminoea solitaria	18	684	70.76
Oxyurostylis smithi	19	663	71.89
Leitoscoloplos robustus	20	632	72.96
Clymenella zonalis	21	575	73.94
Mulinia lateralis	22	549	74.87
Idunella barnardi	23	544	75.80
Acteocina canaliculata	24	517	76.68
Eobrolgus spinosus	25	502	77.53
Aricidea (Acmira) catherinae	26	493	78.37
Tubificoides sp.	27	486	79.19
Solemya velum	28	480	80.01
Rhepoxynius hudsoni	29	450	80.78
Ampithoe longimana	30	446	81.53
Scoletoma tenuis	31	424	82.25
Nucula proxima	32	406	82.94
Sabaco elongatus	33	359	83.55
Tellina agilis	34	348	84.15
Pygospio elegans	35	325	84.70
Capitella sp.	36	313	85.23
Leucon americanus	37	305	85.75
Turbonilla interrupta	38	293	86.25
Alitta succinea	39	284	86.73
Rudilemboides naglei	40	260	87.17
Cymadusa compta	41	257	87.61
Lysianopsis alba	42	213	87.97
Polydora cornuta	43	208	88.32
Leptosynapta tenuis	44	206	88.67
Ameroculodes spp. complex	45	197	89.01
Bostrichobranchus pilularis	46	197	89.34
Melinna maculata	47	196	89.68
Amphiporus bioculatus	48	195	90.01

Total abundance per 0.04 m^2 varied from 25 to 1909 individuals (Fig. 14). Stations just north of Barnegat Inlet and in southern Little Egg Harbor had the greatest abundances. Overall, the average abundance was slightly greater in 2014 than 2012 or 2013.

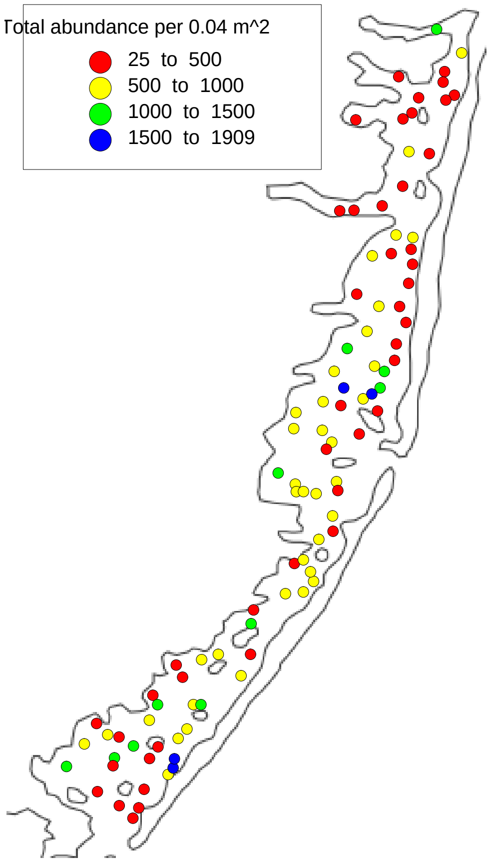
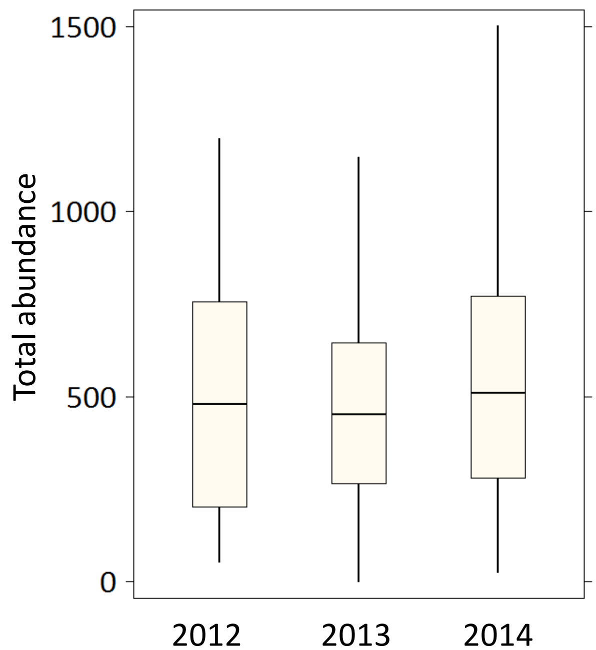


Figure 14. Total abundance of benthic invertebrates per 0.04 m^2 in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	Mean	Minimum	Median	Maximum
Total abundance 2012	517	54	479	1953
Total abundance 2013	462	1	450	1148
Total abundance 2014	587	25	508	1908

The number of species per 0.04 m^2 ranged from 9 to 80. Locations in northern Barnegat Bay tended to have lower species richness, while stations in central and southern parts of BB-LEH had greatest richness (Fig. 15). Species richness was similar among all three years.

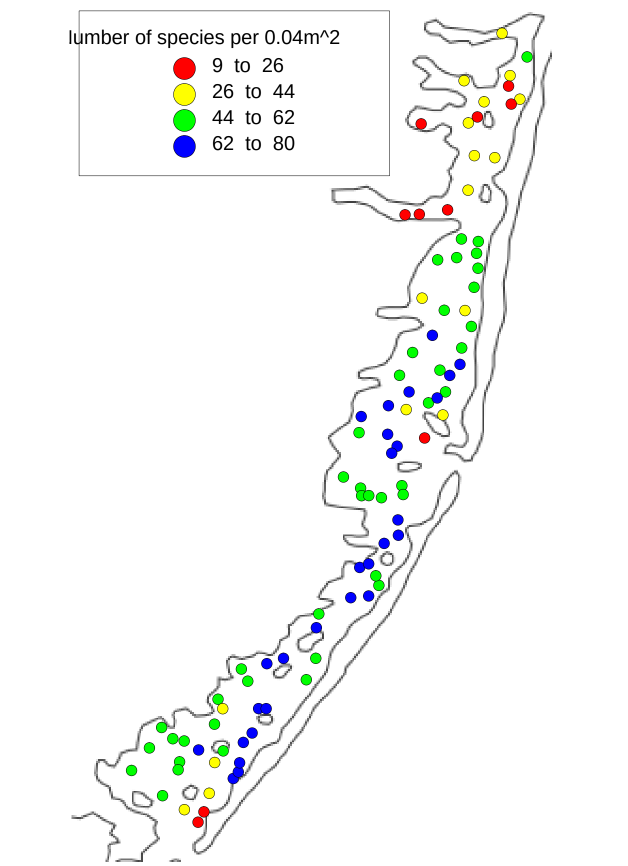
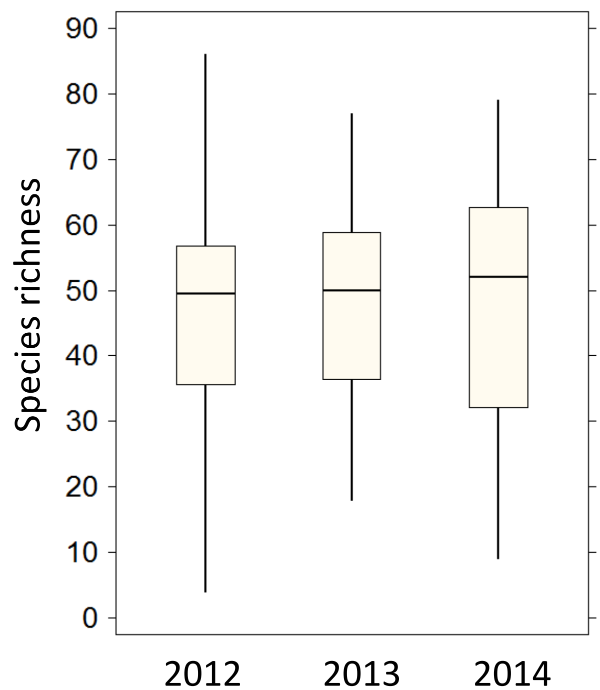


Figure 15. Species richness in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	Mean	Minimum	Median	Maximum
Species richness 2012	46	4	49	86
Species richness 2013	46	1	50	77
Species richness 2014	48	9	52	79

Species diversity is a measure of both species richness and the distribution of individuals among the species present. There are many indices for quantifying species diversity. We prefer Hurlbert's index, $E(S_n)$, which represents the expected number of species in a random subsample of *n* individuals from all those collected at a given station (Hurlbert 1971). A sample size of 50 individuals was chosen, common practice in studies attempting to relate benthic community structure to environmental stressors (Leonardsson et al. 2009, Rosenberg et al. 2004). $E(S_{50})$ ranged from 7 to 25 (Figure 16). Species diversity was lower in northern section of the bay. Average diversity was slightly lower in 2014 than in prior years.

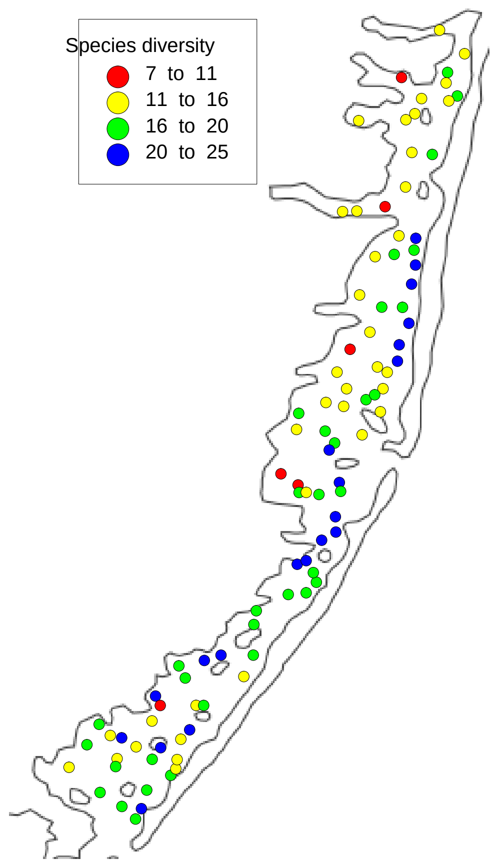
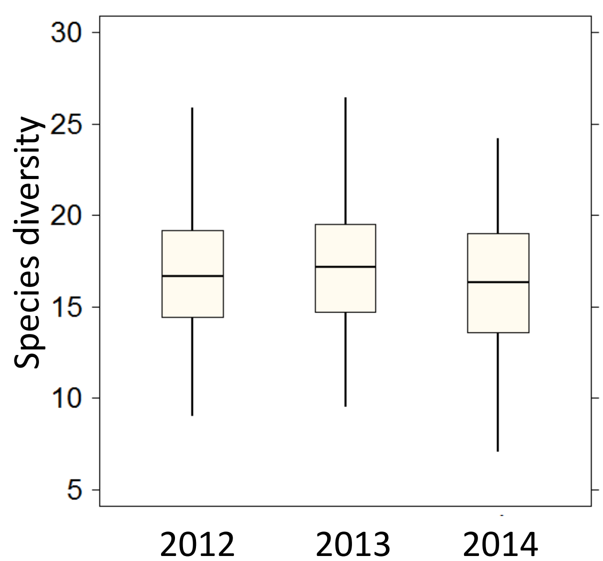


Figure 16. Species diversity in 2014 (left) expressed as $E(S_{50})$ and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	Mean	Minimum	Median	Maximum
$E(S_{50})$ 2012	16.6	3.8	16.6	27.0
$E(S_{50})$ 2013	17.4	9.6	17.1	26.4
$E(S_{50})$ 2014	16.4	7.1	16.4	24.2

<u>Multimetric analysis of community structure</u>

In our Final Reports for 2012 and 2013, we evaluated four multimetric indices of benthic community condition: the Benthic Index of Biotic Integrity (Llansó 2002, Weisberg et al. 1997), the Multivariate AZTI Marine Biotic Index (M-AMBI) (Borja et al. 2012, Muxika et al. 2007), the Virginian Province Index (Paul et al. 2001), and the Benthic Quality Index (Rosenberg et al. 2004). There was good agreement among these indices. For several reasons, we have selected the M-AMBI as our index of choice for analysis of the 2014 data. This index is based on the proportions of benthic macroinvertebrates that fall into one of five Ecological Groups, based on their tolerance or response to organic enrichment: sensitive, indifferent, tolerant, second-order opportunists, and first-order opportunists. These Ecological Groups are described by Grall and Glémarec (1997):

> *"Group 1: Species very sensitive to organic enrichment and present in normal conditions.*
> *Group 2: Species indifferent to enrichment, always present in low densities with non-significant variations in time.*
> *Group 3: Species tolerant of excess organic matter enrichment. These species may occur in normal conditions but their populations are stimulated by organic enrichment.*
> *Group 4: Second-order opportunistic species. These are the small species with a short life cycle, adapted to a life in reduced sediment where they can proliferate.*
> *Group 5: First-order opportunistic species. These are the deposit feeders that proliferate in sediments reduced up to the surface."*

While originally developed for European waters, taxa from North America have since been added to the database (Borja et al. 2008, Gillett et al. 2015). The index value is used to place a site into one of five categories: bad, poor, moderate, good, or high. In 2014, one station near the mouth of Toms River was classified as 'poor' and 10 stations, mostly in northern Barnegat bay, were classified as 'moderate' (Fig. 17). Eighty stations were classified as 'good' and six as 'high.' The average M-AMBI score was 'good' in all three years, although the average numerical value was lower in 2014.

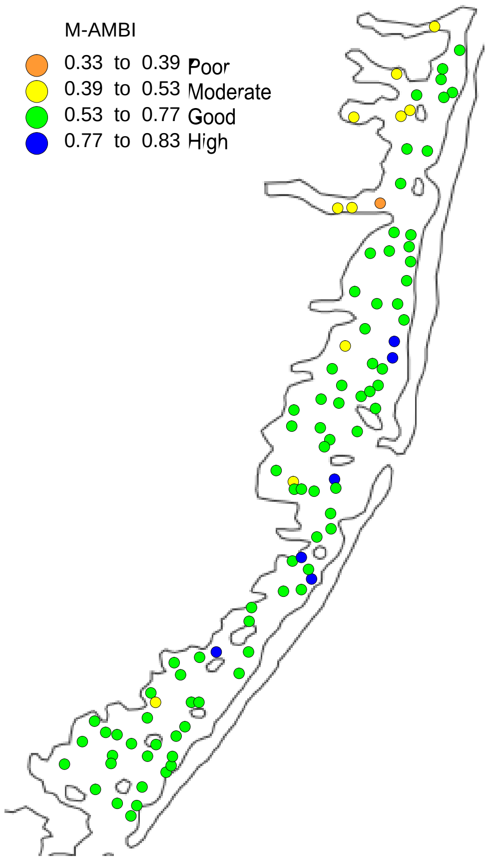
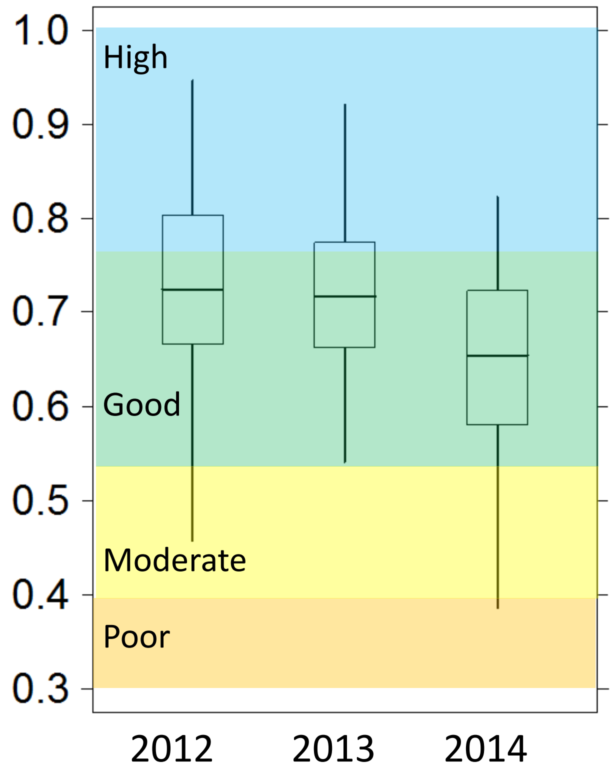


Figure 17. Classification of stations by M-AMBI in 2014 (left) and box and whisker plots of data for 2012-2014 (below). The box is bisected by a line at the value for the median; the bottom and top of the box are the 25th and 75th percentiles. The vertical lines at the top and the bottom of the box (the whiskers) indicate the range of typical data values.



Variable	Mean	Minimum	Median	Maximum
M-AMBI 2012	0.72	0.46	0.72	0.95
M-AMBI 2013	0.71	0.54	0.72	0.92
M-AMBI 2014	0.65	0.39	0.65	0.82

Development of a benthic index of water quality

We previously (Final Report 2013) showed that no single species would be useful as an indicator species. Here, we take a different approach, based on the Ecological Groups (henceforth, EG) used in the M-AMBI to address the question: Is there a relationship between water quality and benthic community structure?

We assembled data for these water properties measured in BB-LEH: temperature, salinity, total nitrogen, total phosphorus, dissolved oxygen concentration, dissolved oxygen saturation, and chlorophyll *a*. Data from stations within BB-LEH covering the time period from 03/21/2011 to 12/16/2014 were downloaded from the EPA STORET Data Warehouse (http://www.epa.gov/storet/). If the data set contained multiple values for a variable for a given date, for example surface and bottom measurements or multiple samples collected throughout the day, the average value for that date was used.

There is a strong south to north trend of decreasing salinity (Fig. 18). This latitudinal trend is well known. Based on the salinity trends, we classify the bay into three zones: low salinity north of latitude 39.925, transitional salinity between 39.925 and 39.8, and high salinity south of 39.8 degrees (Fig. 19).

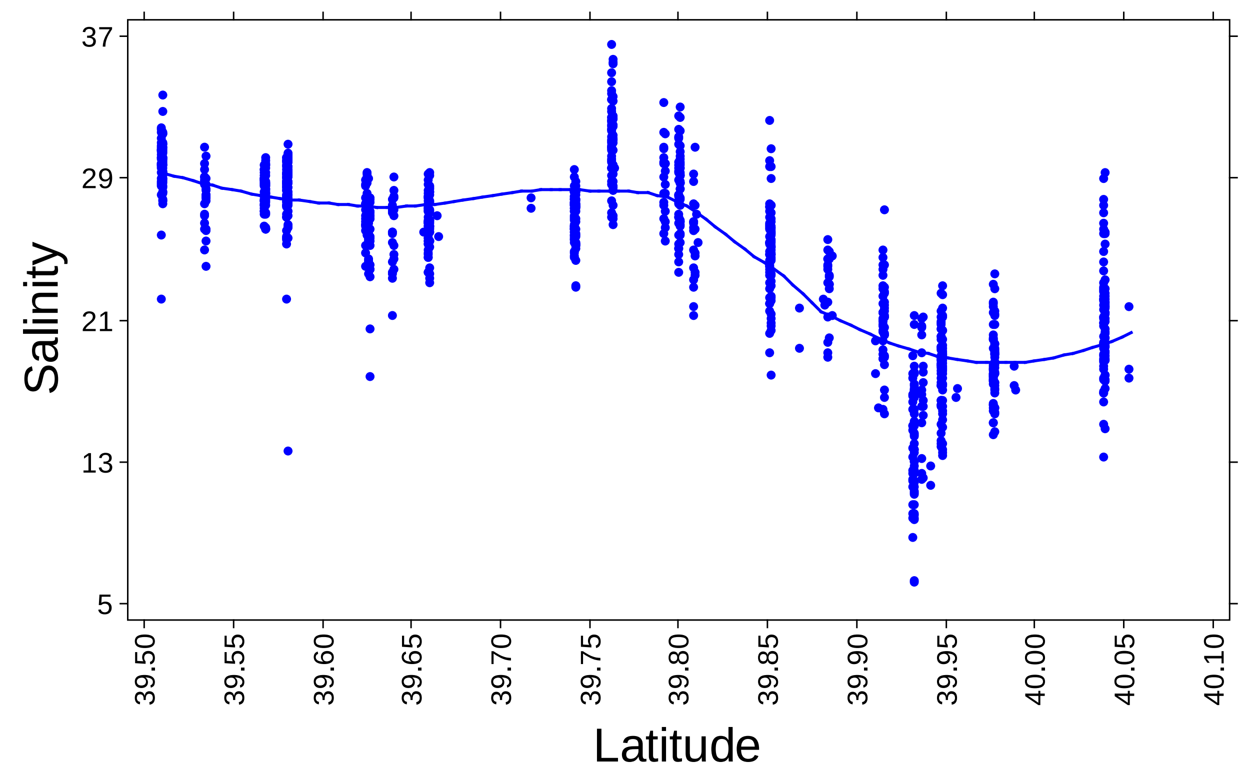


Figure 18. Salinity in BB-LEH along the S-N latitude gradient. Line is the LOWESS fit.

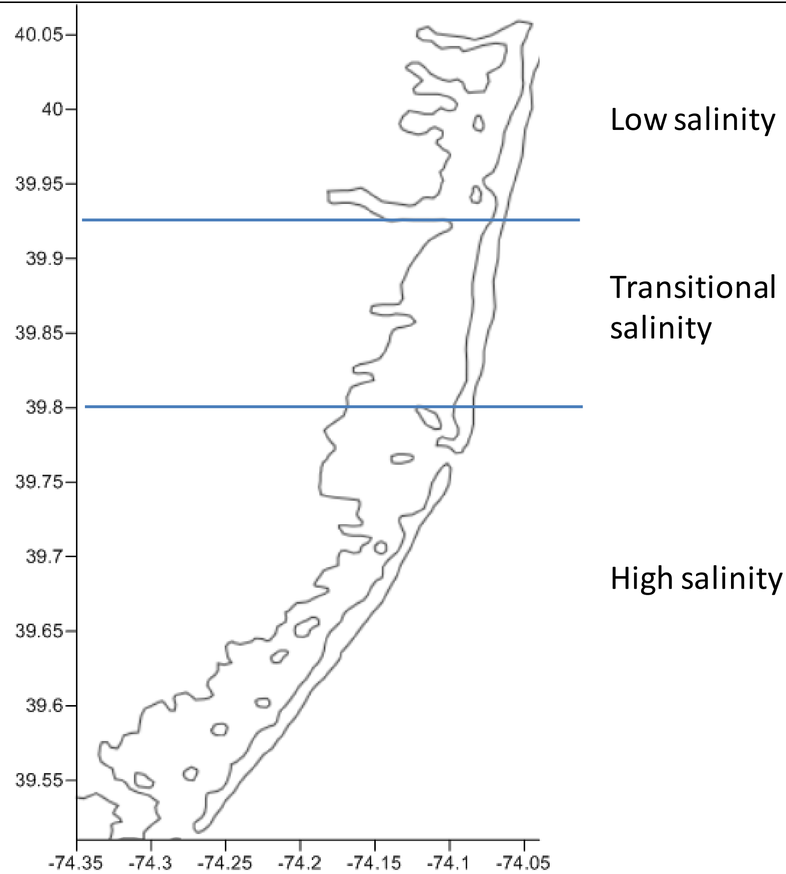


Figure 19. Classification of BB-LEH into three salinity zones.

In addition to the strong spatial gradient in salinity, and other potential stressors such as nutrient and chlorophyll concentrations, there are likely to be temporal differences. There are no seasonal trends in salinity, however; within each zone salinity is essentially constant for all months of the year (Fig. 20).

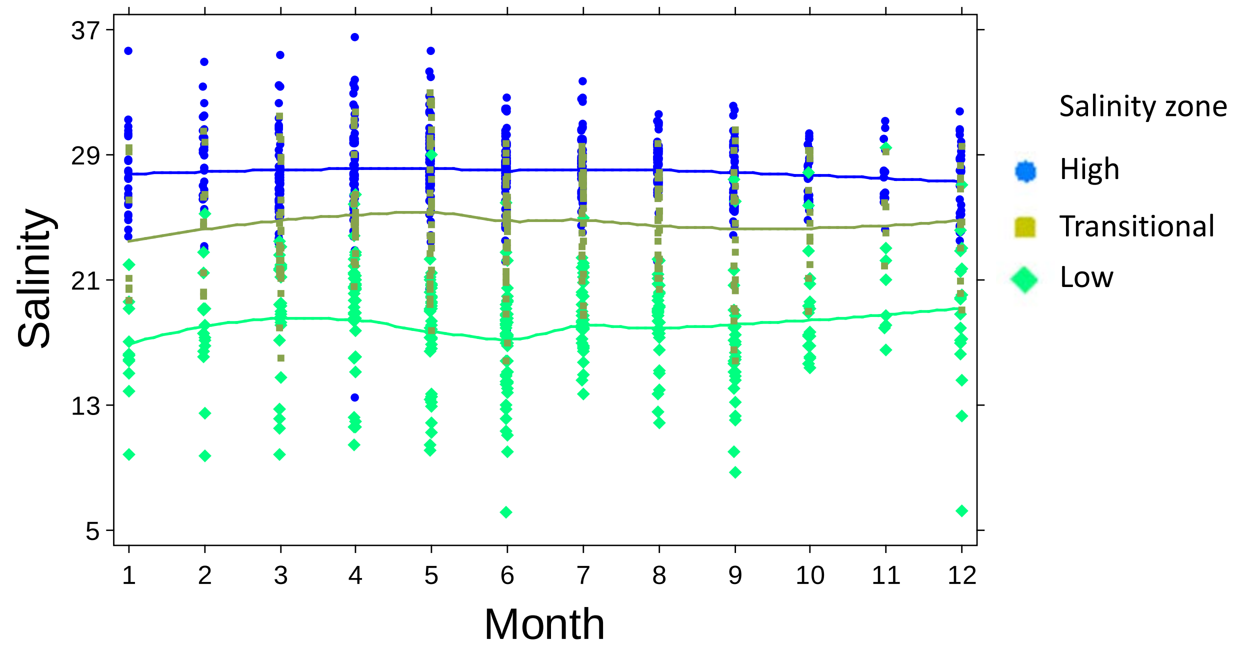


Figure 20. Monthly changes in average salinity in each of the salinity zones. Lines are LOWESS fits.

As expected, there is a strong seasonal pattern in water temperature (Fig. 21). Temperatures were highest, and most likely to be stressful to the benthos, from June to September. This temporal pattern was the same in all salinity zones.

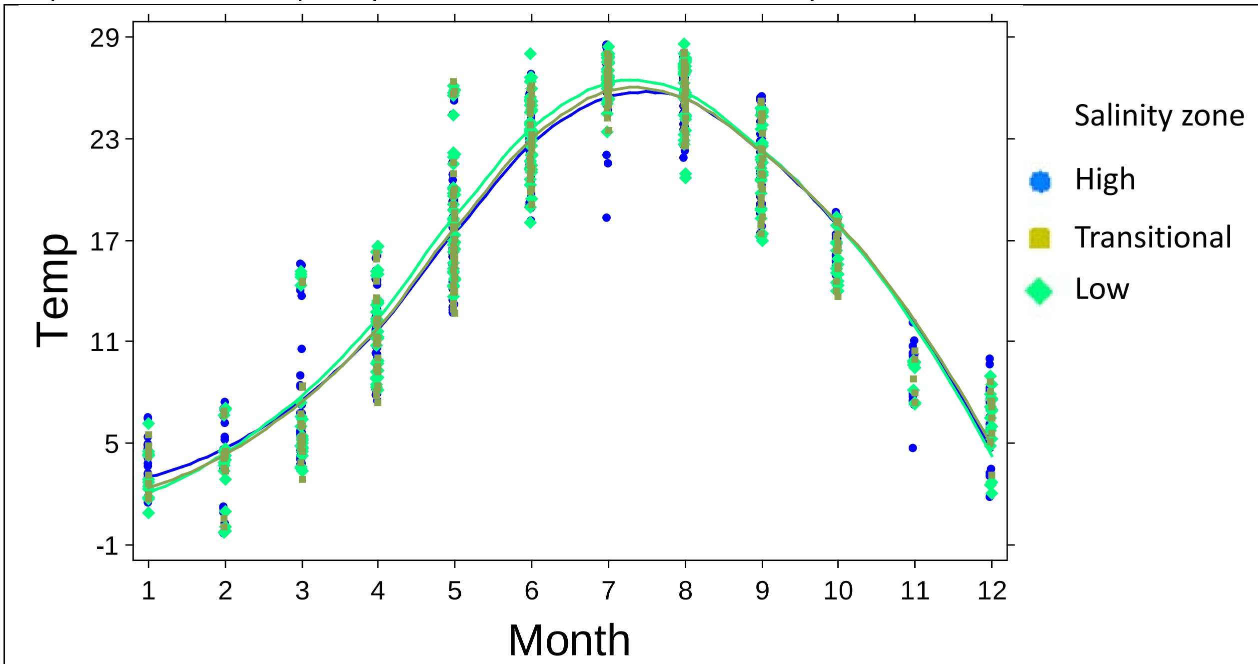


Figure 21. Monthly changes in average temperature in each of the salinity zones. Lines are LOWESS fits.

There were strong seasonal trends in dissolved oxygen concentration (Fig. 22). DO was lowest July through September and is likely to be most stressful then. DO was highest in the northern, low salinity zone and lowest in the central and southern low salinity zone.

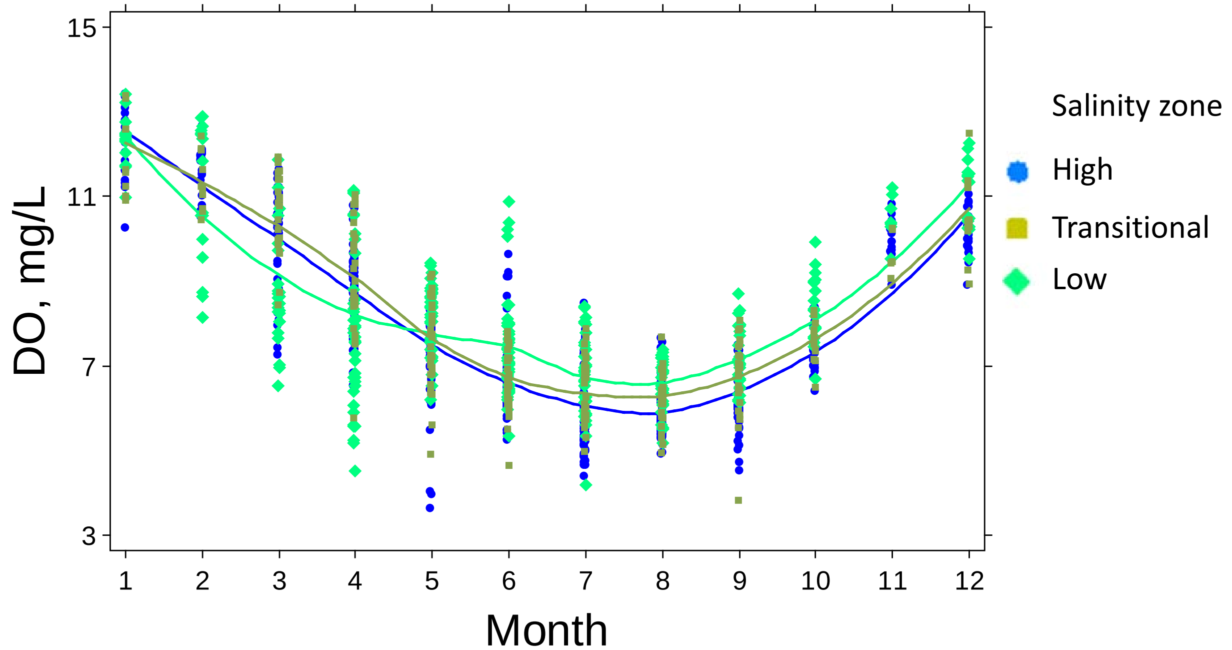


Figure 22. Monthly changes in dissolved oxygen concentration in each of the salinity zones. Lines are LOWESS fits.

DO saturation also varied seasonally, but due to the effect of temperature the variation was not as strong as DO concentration (Fig. 23). DO saturation was lowest in July-September and was higher in the low salinity zone.

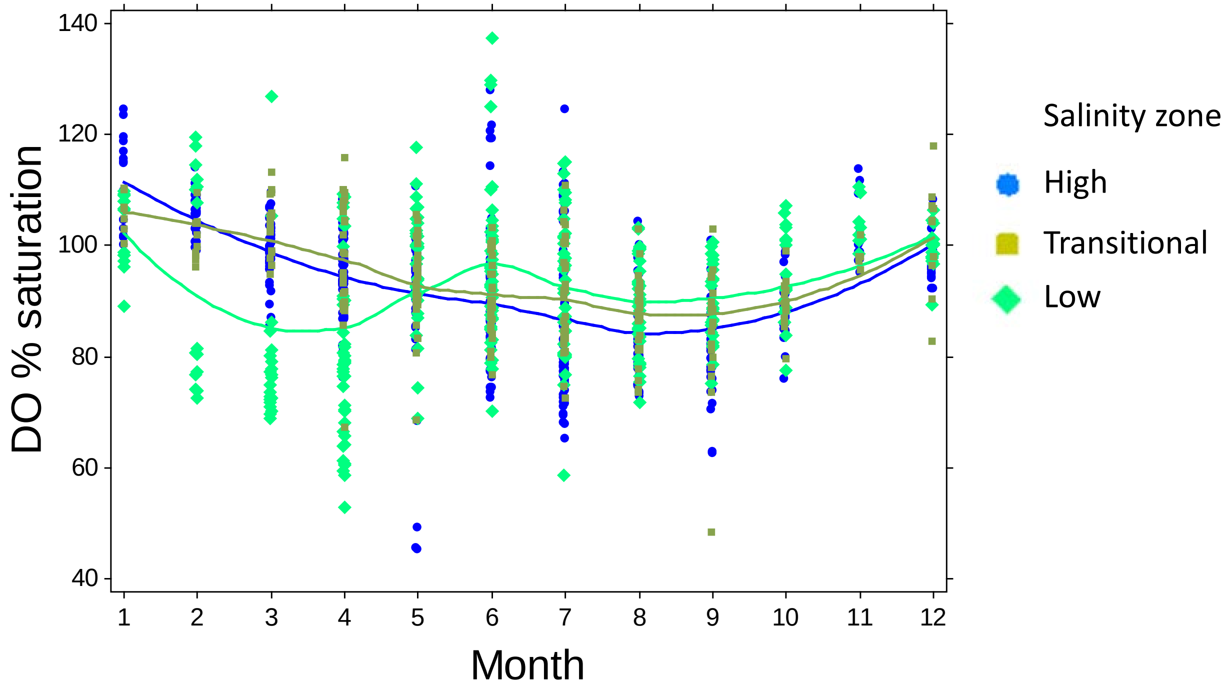


Figure 23. Monthly changes in dissolved oxygen saturation in each of the salinity zones. Lines are LOWESS fits.

Total N concentration was greatest July-September, and was higher in the low salinity zone (Fig. 24).

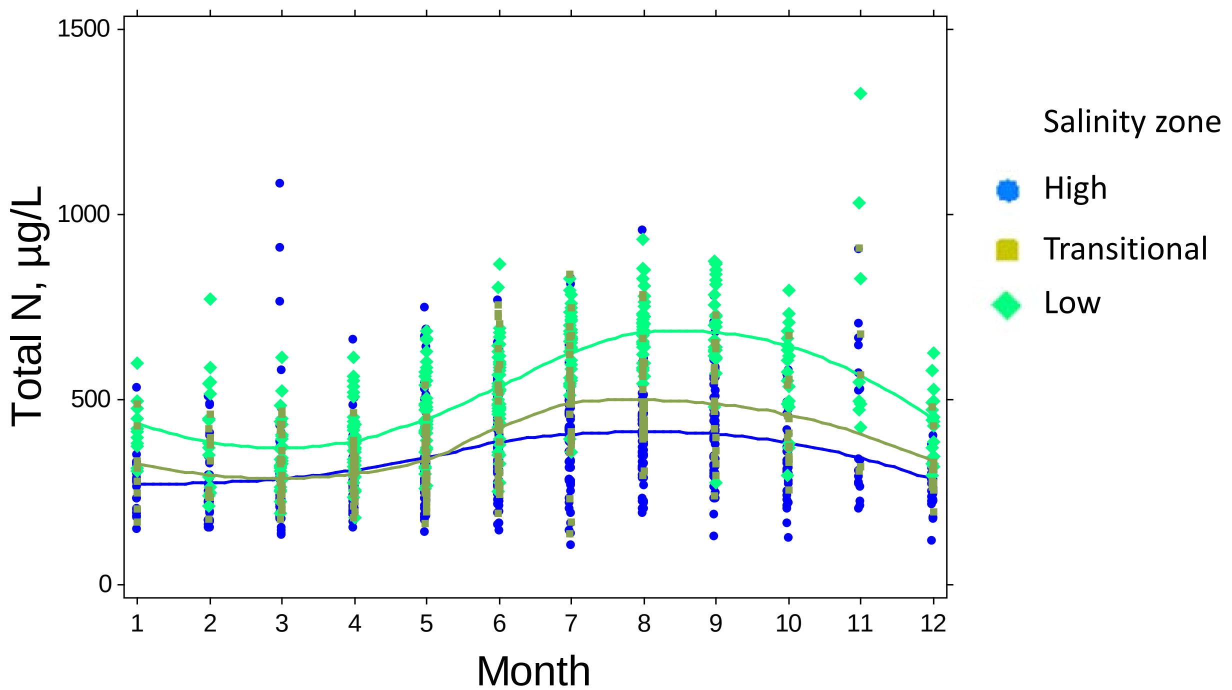


Figure 24. Monthly changes in total nitrogen concentration in each of the salinity zones. Lines are LOWESS fits.

Total P concentration also peaked July-September, but was greatest in the high salinity zone (Fig. 25).

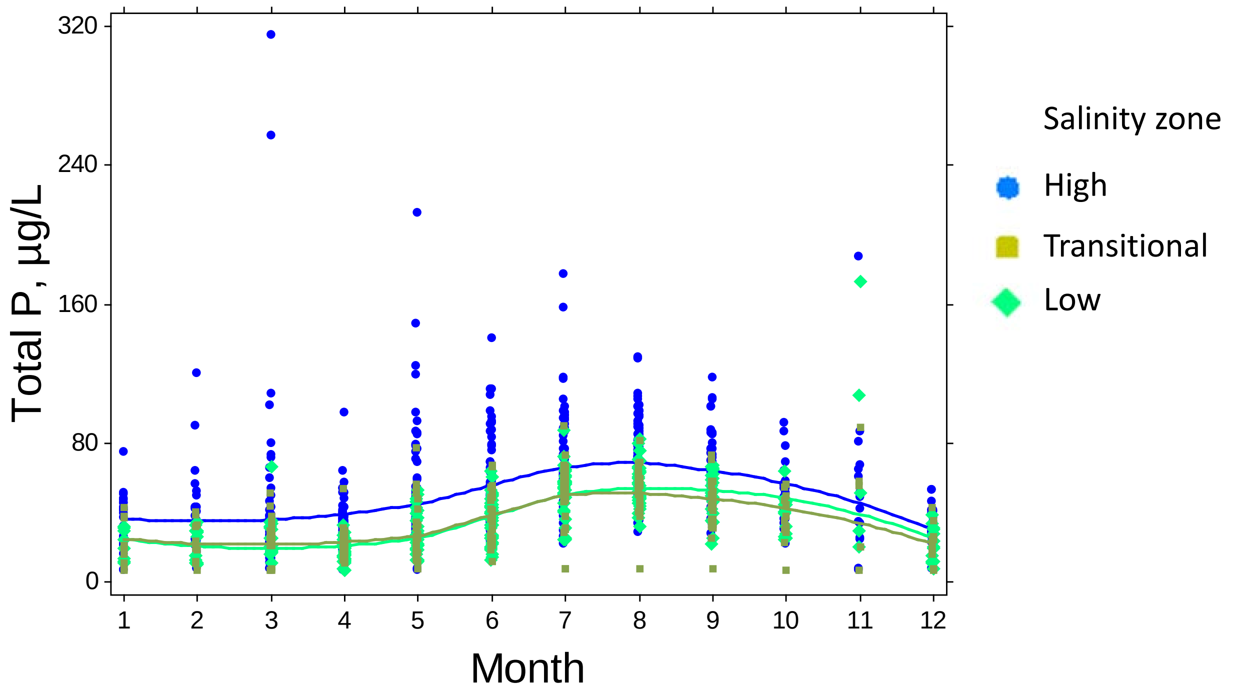


Figure 25. Monthly changes in total phosphorus concentration in each of the salinity zones. Lines are LOWESS fits.

Chlorophyll *a* concentration peaked July-September (Fig. 26). There was considerable scatter in the data, but the trend was highest concentrationin the low salinity zone, intermediate in the transitional salinity zone, and lowest in the high salinity zone.

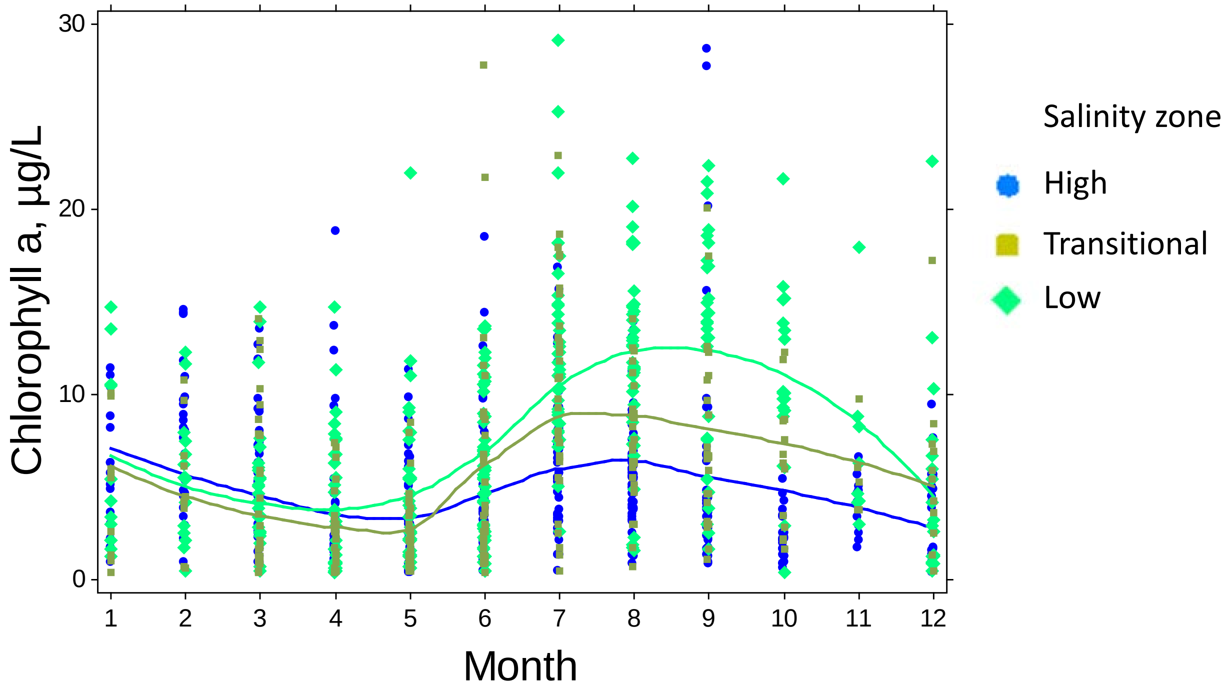


Figure 26. Monthly changes in chlorophyll *a* concentration in each of the salinity zones. Lines are LOWESS fits.

Attempting to relate water quality to benthic community structure is complicated by the spatial relationship between sampling locations. In the three years of this project, we sampled at 100 locations, while water quality data are available for 24 locations. This means that the distance between benthic and water quality stations will vary considerably. We chose a cutoff distance of 2 km for associating a benthic location with a water quality location. This resulted in 17 groups consisting of benthic stations within 2 km of water stations (Table 2; Fig. 27).

Because potential stressors were at their most extreme values in July, August, and September we calculated their average values for this three month period. We used only data for 2011, 2012, and 2013 in these calculations, because we assume that water conditions in those years affected the benthic community as sampled in July of 2012, 2013, and 2014, respectively. The average values of the water quality parameters and the number of dates included in calculating the average values are in Appendix 1.

Table 2.

Group #	Water quality stations	Benthic stations
1	1826A	93, 95, 97, 98
2	BB13	83, 84
3	1834A, BB12	79, 88, 91, 94, 96
4	BB11, BB11a	74, 75, 85, 89
5	1707C	62, 68, 69, 73
6	BB10	59 (2013-2014), 60
7	1674B, BB09	37, 39, 42, 51, 52, 56, 59 (2012), 63

8	1691A, BB07, BB07a	40, 43, 45, 48, 50
9	1661F	49, 53, 54, 58
10	BB06	26, 34, 36
11	BB05	21, 28, 29, 30, 33
12	BB05a	16, 17, 22, 31, 32
13	BB04	20
14	BB04a	15, 24
15	1629B, BB03	1
16	BB02	2, 4, 6, 8
17	1605A, BB01	11

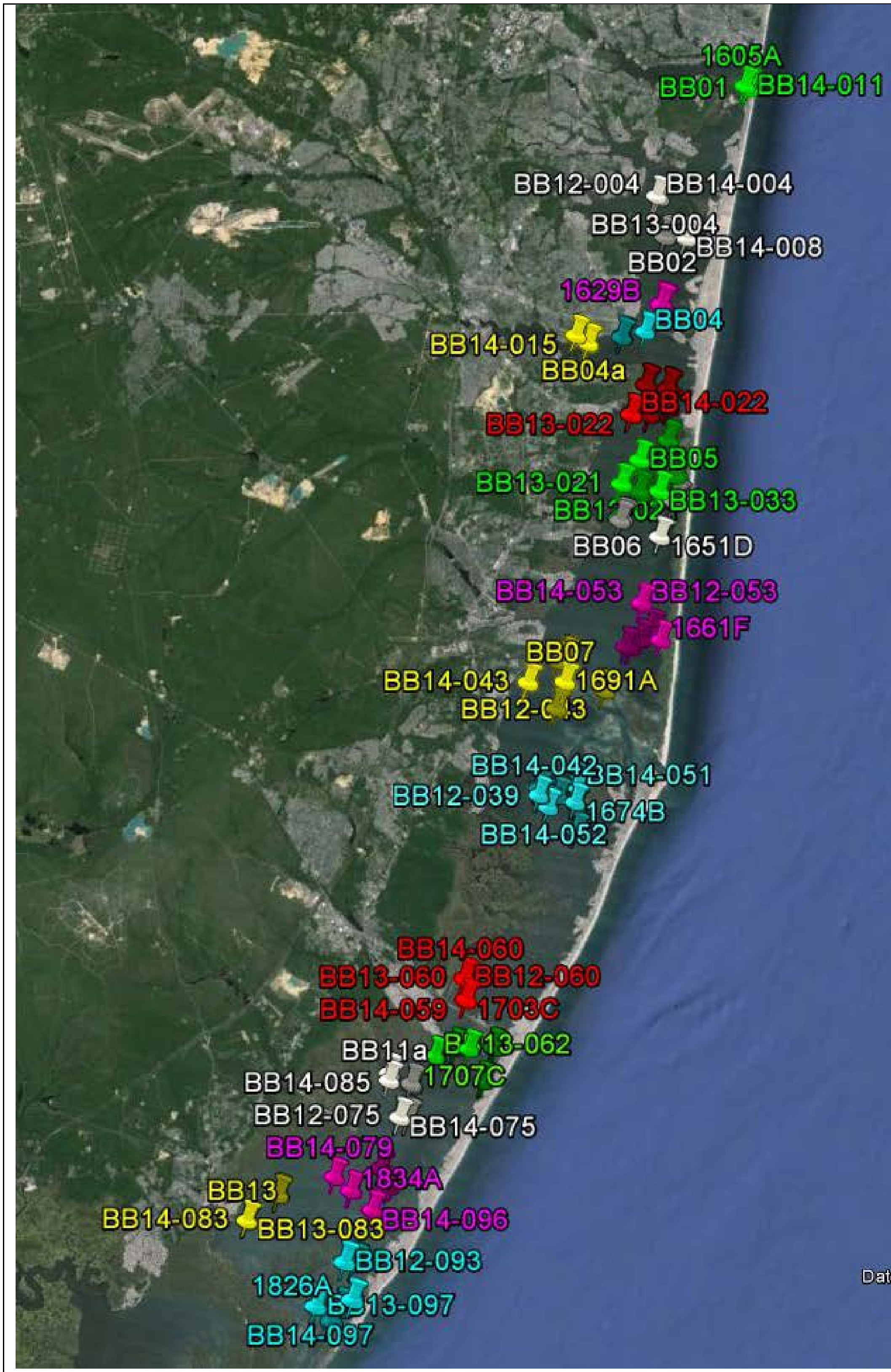


Figure 27. The 17 groups of water quality and benthic stations. Groups are color coded, group 1 is southern-most, group 17 is northern-most.

Next, the average proportion of individuals in each of the five Ecological Groups were calculated for each water station-benthic station group (the assignments of taxa to the EG is given in Appendix 2). Scatterplots of the data suggest that the proportion of Ecological Group 1 taxa, the sensitive species, decreased as temperature, total N concentration, and chlorophyll concentration increased (Fig. 28). A robust locally weighted regression analysis (Cleveland 1979) indicates that the trend is essentially linear.

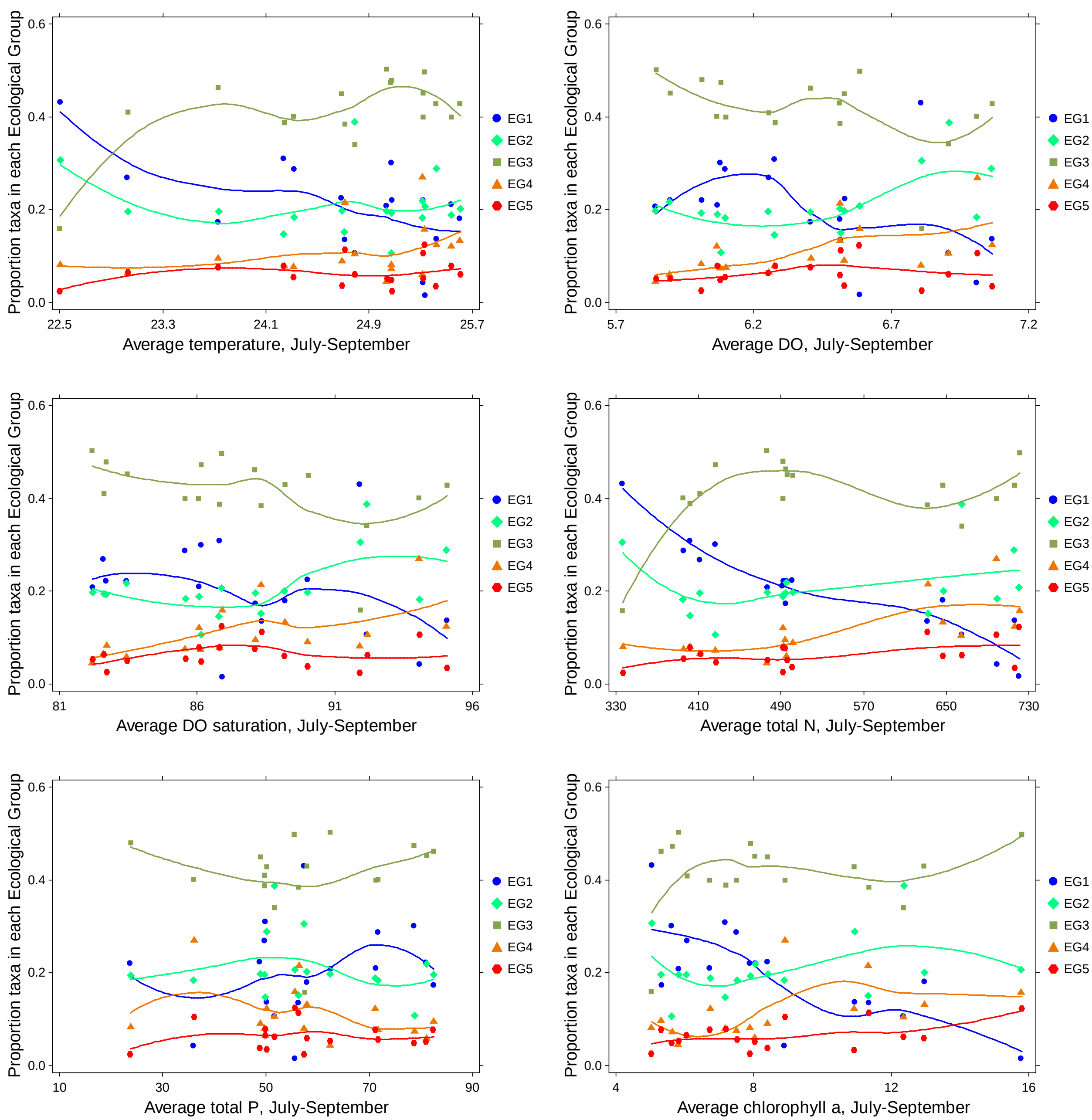


Figure 28. Relationships between the relative abundances of taxa in the five Ecological Groups to water properties. Solid lines are LOWESS fits (f = 0.85).

Complicating a straightforward relationship between abundance of sensitive taxa and water quality is the effect of salinity. For example the proportion of EG 1 taxa decreases as salinity decreases, and salinity and total N concentration are inversely correlated. Thus, the problem becomes determining which environmental factor or salinity correlates best with the abundance of sensitive taxa. Because in most cases the relationship between potential stressors and the proportion of taxa in the ecological groups is approximately linear, we ran stepwise linear regression with backwards selection. The analysis used the proportion of sensitive taxa (EG1) as dependent variable, with the average July-September values of salinity, temperature, DO concentration, DO saturation, total N, total P, and chlorophyll *a* as independent variables. With all variables in the model, 91.7% of the variation in the proportion of EG1 taxa was explained (Table 3). The effects of DO concentration and salinity were minor, and both were eliminated after the third step with no change in explanatory power. In subsequent steps, total P, temperature, and chlorophyll *a* were eliminated. In the end, only a constant, the total N concentration, and DO saturation were included in the model, accounting for 89.2% of the variation in proportion of EG1 taxa (87.7% using coefficient of determination adjusted for the number of variables in the model). Because two variables are in the model, predicted values will depend on both total N and dissolved oxygen saturation. Predicted values over the range of total N concentrations and over the range of DO saturation levels compare well with observed values (Fig. 29).

Proportion EG1 species = 0.074 – 8.62E-4*Total N +6.68E-3*DO saturation

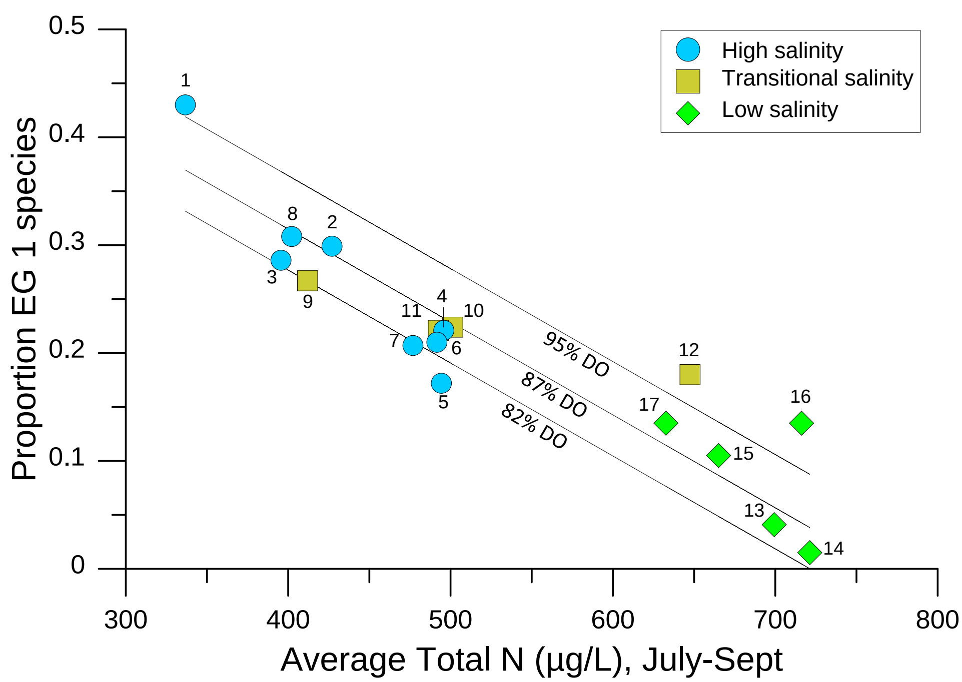


Figure 29. The least-squares linear model for relationship between average total N in July-September and proportion of taxa in Ecological group 1, at three values for DO saturation (minimum, median, maximum for all data). Symbols indicate station groups located in different salinity zones; number next to each symbol refers to station group (see Table 2).

Table 3. **Stepwise Linear Regression of EG1 (Mean proportion EG1 taxa)**

Unforced Variables: Salinity, Temperature, DO, DO sat, Total N, Total P, Chlor a

P to Enter 0.0500

P to Exit 0.0500

Step	**Variable**	**Coefficient**	**T**	**P**	**R^2**	**MSE**
1	Constant	-0.37533	-0.20		0.9173	1.523E-03
	Total N	-1.150E-03	-2.71	0.0240		
	Salinity	2.230E-04	0.01	0.9904		
	Total P	-2.511E-04	-0.23	0.8270		
	DO	1.372E-03	0.00	0.9974		
	DO sat	8.646E-03	0.31	0.7673		
	Temperature	0.01430	0.24	0.8126		
	Chlor a	8.944E-03	1.23	0.2487		
2	Constant	-0.36938	-0.71		0.9173	1.371E-03
	Total N	-1.150E-03	-2.90	0.0159		
	Salinity	1.786E-04	0.02	0.9881		
	Total P	-2.517E-04	-0.24	0.8145		
	DO sat	8.742E-03	2.77	0.0199		
	Temperature	0.01411	0.73	0.4801		
	Chlor a	8.944E-03	1.30	0.2227		
3	Constant	-0.36735	-0.76		0.9173	1.246E-03
	Total N	-1.155E-03	-6.29	0.0001		
	Total P	-2.390E-04	-0.40	0.6996		
	DO sat	8.747E-03	2.92	0.0140		
	Temperature	0.01428	0.96	0.3556		
	Chlor a	8.887E-03	1.61	0.1349		
4	Constant	-0.36402	-0.79		0.9162	1.159E-03
	Total N	-1.144E-03	-6.54	0.0000		
	DO sat	8.760E-03	3.03	0.0104		
	Temperature	0.01326	0.94	0.3643		
	Chlor a	9.000E-03	1.70	0.1154		
5	Constant	0.02848	0.14		0.9099	1.149E-03
	Total N	-1.048E-03	-7.37	0.0000		
	DO sat	7.512E-03	2.94	0.0115		
	Chlor a	8.296E-03	1.59	0.1366		
6	Constant	0.07400	0.35		0.8925	1.273E-03
	Total N	-8.615E-04	-10.27	0.0000		
	DO sat	6.677E-03	2.53	0.0238		

Resulting Stepwise Model

Variable	**Coefficient**	**Std Error**	**T**	**P**	**VIF**
Constant	0.07400	0.21167	0.35	0.7318	
Total N	-8.615E-04	8.387E-05	-10.27	0.0000	1.4
DO sat	6.677E-03	2.634E-03	2.53	0.0238	1.4

Cases Included	17	R^2	0.8925	MSE	1.273E-03
Missing Cases	0	Adjusted R^2	0.8771	SD	0.03569

Variables Not in the Model	**Correlations**			
Variable	**Multiple**	**Partial**	**T**	**P**
Salinity	0.9314	-0.1172	-0.43	0.6773
Total P	0.3121	-0.0918	-0.33	0.7448
DO	0.9453	-0.0655	-0.24	0.8166
Temperature	0.7226	0.1813	0.66	0.5179
Chlor a	0.8504	0.4028	1.59	0.1366

Based on the linear model, predicted values of the proportion of EG 1 taxa, the most sensitive group, at different total N concentrations and DO saturation levels can be readily calculated (Table 4). This may be of use from a management perspective. For example, if the target is to have sensitive taxa represent at least 25% of the benthos, then the target for average total N concentration in July-September should be <450 µg N/L for the typical range of DO saturation levels.

Table 4. Predicted vales for the proportion of sensitive species at various total N and DO saturation values.

Total N	DO saturation	Proportion EG 1 taxa
400	82	0.28
400	87	0.31
400	95	0.36
450	82	0.23
450	87	0.27
450	95	0.32
500	82	0.19
500	87	0.22
500	95	0.28
550	82	0.15
550	87	0.18
550	95	0.23

Conclusions

Based on the data collected in July 2014, the benthic environment and macrofaunal communities in Barnegat Bay-Little Egg Harbor were in good condition. For the most part, surface sediments had low concentrations of total organic carbon (the majority of stations <1%), total nitrogen (<0.1%), and total phosphorus (<0.06%). Exceptions were several stations in the northern section of the bay, especially sites near major sources of freshwater input, such as the Toms River. Although neither organic contaminants nor heavy metals were measured in this study, it would be surprising if there were elevated levels of these substances in the sediments given the generally low concentrations of organic carbon, except possibly in localized areas as noted above. Bottom water dissolved oxygen concentrations were above 5 mg/L at all sites during the sampling period, again except for stations in the Toms River and several stations on the western side, central section of Barnegat Bay. Sediment TOC concentrations below 2% and bottom water dissolved oxygen concentrations above 5 mg/L are usually considered characteristics of reference, non-impacted habitats (Pelletier et al. 2012, Pelletier et al. 2010).

Benthic macroinvertebrates were abundant and diverse. Taxa typical of reference, non-impacted estuarine habitats in the Virginian Biogeographic Province dominated the fauna, again with a few exceptions as noted for sediment chemical properties. Over 80% of sites were classified as in Good or High condition by the Multivariate AZTI Marine Biotic Index.

Both the physical and biological properties of the benthic environment showed little difference in 2014 with the measurements made in 2012 and 2013. Notably, there were no detectable effects of Hurricane Sandy over this time period.

Combining data on the abundance of benthic invertebrates from three years of sampling (2012-2014) with archived data on water quality, we found a strong relationship between the proportion of benthic taxa that are considered to be sensitive to organic enrichment and the total N concentration and dissolved oxygen saturation levels in the water. Total N has a negative effect but DO saturation has a positive effect on the proportion of sensitive benthic species. The model is based on average values of water properties during the months of July, August, and September, which are typically the months when nutrients are at their highest levels. This model may be of use from a management perspective. We note that this model should be tested further with additional data. The data coverage used to develop the model is not uniform across all of the 17 water quality-benthic infauna station groups. In particular, values of water quality measures are in some cases based on as few as five days over the July-September, 2011-2013 time period (see Appendix 1), a 'temporal coverage' of only 5.5%. Variability about the average values is often quite high. We recommend that monitoring of both water quality and benthic infauna continue at selected sites to further evaluate and refine the model.

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APPENDIX 1. Water properties for the station groups. N is the number of dates used to calculate the mean value.

Breakdown for Salinity

		N	Mean	Minimum	Maximum
Group	1	6	27.382	23.940	30.230
Group	2	22	27.829	26.030	29.270
Group	3	28	28.470	22.020	30.900
Group	4	23	26.915	23.700	29.240
Group	5	6	27.122	25.740	27.950
Group	6	23	26.738	24.600	29.170
Group	7	29	26.903	24.390	29.440
Group	8	27	27.696	24.140	29.800
Group	9	6	25.272	21.750	30.580
Group	10	27	24.910	20.200	27.400
Group	11	6	22.283	18.900	25.400
Group	12	17	20.217	15.700	22.600
Group	13	5	16.946	12.000	21.110
Group	14	21	14.576	8.6000	17.840
Group	15	25	18.190	14.010	22.360
Group	16	22	17.671	14.550	21.230
Group	17	28	20.531	16.740	27.310

Breakdown for Temperature

		N	Mean	Minimum	Maximum
Group	1	6	22.508	17.300	26.900
Group	2	22	25.072	19.100	28.000
Group	3	28	24.321	17.400	27.800
Group	4	23	25.319	19.000	27.900
Group	5	6	23.733	17.100	28.300
Group	6	23	25.540	18.500	28.500
Group	7	29	25.038	17.800	28.300
Group	8	28	24.241	17.900	28.100
Group	9	7	23.029	17.900	27.500
Group	10	28	24.689	17.300	27.750
Group	11	6	25.078	22.300	27.200
Group	12	17	25.606	19.500	28.000
Group	13	5	25.320	22.500	27.800
Group	14	22	25.332	17.400	28.600
Group	15	26	24.792	16.900	28.000
Group	16	22	25.423	18.800	27.900
Group	17	32	24.713	17.200	27.800

Breakdown for Total N µg/L

		N	Mean	Minimum	Maximum
Group	1	6	336.63	225.22	516.49
Group	2	22	426.99	281.80	705.60
Group	3	28	395.56	215.37	951.20
Group	4	23	495.85	272.40	703.50
Group	5	6	494.37	383.40	809.40
Group	6	23	491.58	291.70	780.50
Group	7	29	476.83	334.80	826.70
Group	8	28	402.20	229.26	837.10
Group	9	7	411.90	241.80	484.48

		N	Mean	Minimum	Maximum
Group	10	28	501.36	321.39	671.56
Group	11	6	492.47	401.20	633.00
Group	12	17	647.54	500.80	781.20
Group	13	5	699.30	556.20	847.20
Group	14	22	721.22	578.60	928.80
Group	15	26	665.08	534.60	849.70
Group	16	22	716.13	551.90	868.00
Group	17	28	632.65	275.60	820.40

Breakdown for Total P µg/L

		N	Mean	Minimum	Maximum
Group	1	6	57.443	32.400	94.540
Group	2	22	78.745	47.600	127.90
Group	3	28	71.678	32.900	117.00
Group	4	22	81.173	33.200	128.70
Group	5	6	82.547	54.810	176.36
Group	6	23	71.353	25.010	101.10
Group	7	29	62.613	28.700	157.10
Group	8	28	49.876	22.400	89.000
Group	9	7	49.829	34.880	66.660
Group	10	28	48.867	7.0000	90.010
Group	11	6	23.783	7.0000	42.600
Group	12	17	58.082	43.300	81.200
Group	13	3	36.133	24.300	47.500
Group	14	22	55.555	34.400	79.900
Group	15	25	51.671	23.800	87.160
Group	16	22	50.105	21.500	65.600
Group	17	27	56.440	31.100	74.400

Breakdown for Dissolved Oxygen mg/L

		N	Mean	Minimum	Maximum
Group	1	6	6.8100	5.6700	7.3900
Group	2	22	6.0823	4.6100	7.6000
Group	3	28	6.0996	4.6400	8.4600
Group	4	23	5.8965	4.4900	7.8500
Group	5	6	6.4100	5.2000	7.5200
Group	6	23	6.0683	4.6900	7.7400
Group	7	29	5.8471	4.3800	7.6400
Group	8	28	6.2779	4.7000	7.8800
Group	9	7	6.2543	3.8000	7.4400
Group	10	28	6.5314	4.9800	8.0800
Group	11	6	6.0133	5.5000	6.3800
Group	12	17	6.5141	5.1000	7.6400
Group	13	5	7.0140	6.8500	7.2100
Group	14	22	6.5864	4.1700	8.6800
Group	15	26	6.9112	5.5600	8.2200
Group	16	22	7.0668	5.5200	8.3500
Group	17	28	6.5160	5.4950	7.7700

Breakdown for Dissolved Oxygen % saturation

		N	Mean	Minimum	Maximum
Group	1	6	91.927	79.941	99.987
Group	2	22	86.143	67.599	110.52
Group	3	28	85.579	69.317	124.26
Group	4	23	83.463	62.555	112.86
Group	5	6	88.111	77.053	104.21
Group	6	23	86.061	68.129	111.24
Group	7	29	82.207	65.065	104.18
Group	8	27	86.814	62.276	110.54
Group	9	6	82.617	48.031	96.708
Group	10	27	90.027	72.221	103.99
Group	11	6	82.715	73.410	88.568
Group	12	17	89.193	73.235	106.10
Group	13	5	94.083	88.532	102.90
Group	14	21	86.903	58.739	114.77
Group	15	25	92.190	78.637	112.68
Group	16	22	95.072	78.233	114.80
Group	17	28	88.334	77.748	108.30

Breakdown for Chlorophyll a µg/L

		N	Mean	Minimum	Maximum
Group	1	6	5.0450	3.3600	7.9900
Group	2	22	5.6400	2.7300	13.880
Group	3	28	7.5339	2.1000	20.180
Group	4	23	8.0561	2.3100	28.590
Group	5	6	5.3267	2.1000	7.5700
Group	6	23	6.7548	1.2600	16.820
Group	7	29	5.8182	1.2600	27.750
Group	8	28	7.1919	0.6300	17.450
Group	9	7	6.0671	2.7300	9.2500
Group	10	28	8.4294	1.6800	17.450
Group	11	6	7.9200	4.6300	12.190
Group	12	17	12.955	2.9400	22.914
Group	13	5	8.9140	1.6800	15.560
Group	14	22	15.792	1.6800	29.082
Group	15	26	12.375	2.3100	22.280
Group	16	22	10.947	1.4700	20.810
Group	17	32	11.357	1.8900	21.440

APPENDIX 2. Assignment of benthic taxa to Ecological Groups.

Phylum	Class	Order	Family	Taxon	Ecological Group
Annelida	Polychaeta	"unassigned"	Capitellidae	*Amastigos caperatus*	1
Annelida	Polychaeta	"unassigned"	Maldanidae	*Clymenella torquata*	1
Annelida	Polychaeta	"unassigned"	Maldanidae	*Clymenella zonalis*	1
Annelida	Polychaeta	"unassigned"	Maldanidae	*Sabaco elongatus*	1
Annelida	Polychaeta	"unassigned"	Orbiniidae	*Scoloplos (Leodamas) rubra*	1
Annelida	Polychaeta	"unassigned"	Paraonidae	*Aricidea (Aricidea) wassi*	1
Annelida	Polychaeta	"unassigned"	Polygordiidae	*Polygordius jouinae*	1
Annelida	Polychaeta	"unassigned"	Protodriloididae	*Protodriloides chaetifer*	1
Annelida	Polychaeta	Eunicida	Oenonidae	*Arabella iricolor*	1
Annelida	Polychaeta	Eunicida	Onuphidae	*Diopatra cuprea*	1
Annelida	Polychaeta	Phyllodocida	Hesionidae	*Oxydromus obscurus*	1
Annelida	Polychaeta	Phyllodocida	Hesionidae	*Podarke obscura*	1
Annelida	Polychaeta	Sabellida	Sabellidae	*Parasabella microphthalma*	1
Annelida	Polychaeta	Spionida	Magelonidae	*Magelona sp. A Jones, 1968*	1
Annelida	Polychaeta	Spionida	Magelonidae	*Magelona sp. B Day, 1973*	1
Annelida	Polychaeta	Spionida	Spionidae	*Carazziella hobsonae*	1
Annelida	Polychaeta	Terebellida	Ampharetidae	*Ampharete finmarchica*	1
Annelida	Polychaeta	Terebellida	Ampharetidae	*Ampharete oculata*	1
Annelida	Polychaeta	Terebellida	Pectinariidae	*Pectinaria gouldii*	1
Annelida	Polychaeta	Terebellida	Terebellidae	*Loimia viridis*	1
Annelida	Polychaeta	Terebellida	Terebellidae	*Pista cristata*	1
Annelida	Polychaeta	Terebellida	Terebellidae	*Pista palmata*	1
Arthropoda	Malacostraca	Amphipoda	Ampeliscidae	*Ampelisca vadorum*	1
Arthropoda	Malacostraca	Amphipoda	Ampeliscidae	*Ampelisca verrilli*	1
Arthropoda	Malacostraca	Amphipoda	Ampithoidae	*Cymadusa compta*	1
Arthropoda	Malacostraca	Amphipoda	Aoridae	*Globosolembos smithi*	1
Arthropoda	Malacostraca	Amphipoda	Bateidae	*Batea catharinensis*	1
Arthropoda	Malacostraca	Amphipoda	Bathyporeiidae	*Bathyporeia quoddyensis*	1
Arthropoda	Malacostraca	Amphipoda	Gammaridae	*Gammarus mucronatus*	1
Arthropoda	Malacostraca	Amphipoda	Gammaridae	*Gammarus palustris*	1
Arthropoda	Malacostraca	Amphipoda	Haustoriidae	*Acanthohaustorius intermedius*	1
Arthropoda	Malacostraca	Amphipoda	Haustoriidae	*Acanthohaustorius millsi*	1
Arthropoda	Malacostraca	Amphipoda	Haustoriidae	*Parahaustorius attenuatus*	1
Arthropoda	Malacostraca	Amphipoda	Haustoriidae	*Parahaustorius longimerus*	1
Arthropoda	Malacostraca	Amphipoda	Haustoriidae	*Protohaustorius cf. deichmannae*	1
Arthropoda	Malacostraca	Amphipoda	Maeridae	*Elasmopus levis*	1
Arthropoda	Malacostraca	Amphipoda	Melitidae	*Melita nitida*	1
Arthropoda	Malacostraca	Amphipoda	Oedicerotidae	*Ameroculodes spp. complex*	1
Arthropoda	Malacostraca	Amphipoda	Phoxocephalidae	*Eobrolgus spinosus*	1
Arthropoda	Malacostraca	Amphipoda	Phoxocephalidae	*Rhepoxynius hudsoni*	1
Arthropoda	Malacostraca	Amphipoda	Unciolidae	*Rudilemboides naglei*	1
Arthropoda	Malacostraca	Amphipoda	Unciolidae	*Unciola dissimilis*	1
Arthropoda	Malacostraca	Amphipoda	Unciolidae	*Unciola irrorata*	1
Arthropoda	Malacostraca	Amphipoda	Unciolidae	*Unciola serrata*	1

Arthropoda	Malacostraca	Cumacea	Diastylidae	*Oxyurostylis smithi*	1
Arthropoda	Malacostraca	Decapoda	Upogebiidae	*Upogebia affinis*	1
Arthropoda	Malacostraca	Isopoda	Ancinidae	*Ancinus depressus*	1
Arthropoda	Malacostraca	Isopoda	Anthuridae	*Ptilanthura tenuis*	1
Arthropoda	Malacostraca	Isopoda	Janiridae	*Janira alta*	1
Arthropoda	Pycnogonida	Pantopoda	Callipallenidae	*Callipallene brevirostris*	1
Chordata	Ascidiacea	Stolidobranchia	Molgulidae	*Molgula manhattensis*	1
Cnidaria	Anthozoa	Ceriantharia	Cerianthidae	*Ceriantheopsis americanus*	1
Echinodermata	Holothuroidea	Apodida	Synaptidae	*Leptosynapta tenuis*	1
Echinodermata	Holothuroidea	Dendrochirotida	Phyllophoridae	*Havelockia scabra*	1
Hemichordata	Enteropneusta	Enteropneusta	Harrimaniidae	*Saccoglossus kowalevskii*	1
Mollusca	Bivalvia	Anomalodesmata	Lyonsiidae	*Lyonsia hyalina*	1
Mollusca	Bivalvia	Euheterodonta	Pharidae	*Ensis directus*	1
Mollusca	Bivalvia	Nuculida	Nuculanoida	*Yoldia limatula*	1
Mollusca	Bivalvia	Nuculida	Nuculidae	*Nucula proxima*	1
Mollusca	Bivalvia	Solemyoida	Solemyidae	*Solemya velum*	1
Mollusca	Bivalvia	Veneroida	Donacidae	*Donax variabilis*	1
Mollusca	Bivalvia	Veneroida	Lasaeidae	*Aligena elevata*	1
Mollusca	Bivalvia	Veneroida	Mactridae	*Spisula solidissima*	1
Mollusca	Bivalvia	Veneroida	Veneridae	*Petricolaria pholadiformis*	1
Mollusca	Gastropoda	"unassigned"	Acteonidae	*Japonactaeon punctostriatus*	1
Mollusca	Gastropoda	"unassigned"	Pyramidellidae	*Turbonilla interrupta*	1
Mollusca	Gastropoda	Caenogastropoda	Cerithiidae	*Bittiolum alternatum*	1
Mollusca	Gastropoda	Caenogastropoda	Epitoniidae	*Epitonium rupicola*	1
Mollusca	Gastropoda	Cephalaspidea	Cylichnidae	*Acteocina canaliculata*	1
Mollusca	Gastropoda	Littorinimorpha	Hydrobiidae	*Littoridinops tenuipes*	1
Mollusca	Gastropoda	Littorinimorpha	Naticidae	*Neverita duplicata*	1
Mollusca	Gastropoda	Neogastropoda	Columbellidae	*Costoanachis avara*	1
Mollusca	Gastropoda	Neogastropoda	Mangeliidae	*Pyrgocythara plicosa*	1
Nemertea	Anopla	"unassigned"	Carinomidae	*Carinomella lactea*	1
Annelida	Polychaeta	"unassigned"	Paraonidae	*Aricidea (Acmira) catherinae*	2
Annelida	Polychaeta	Eunicida	Eunicidae	*Marphysa bellii*	2
Annelida	Polychaeta	Eunicida	Lumbrinereidae	*Scoletoma tenuis*	2
Annelida	Polychaeta	Eunicida	Oenonidae	*Drilonereis longa*	2
Annelida	Polychaeta	Eunicida	Oenonidae	*Notocirrus spinifera*	2
Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycera americana*	2
Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycera dibranchiata*	2
Annelida	Polychaeta	Phyllodocida	Goniadidae	*Glycinde multidens*	2
Annelida	Polychaeta	Phyllodocida	Hesionidae	*Microphthalmus aggregatus*	2
Annelida	Polychaeta	Phyllodocida	Hesionidae	*Microphthalmus sczelkowii*	2
Annelida	Polychaeta	Phyllodocida	Hesionidae	*Parahesione luteola*	2
Annelida	Polychaeta	Phyllodocida	Hesionidae	*Podarkeopsis levifuscina*	2
Annelida	Polychaeta	Phyllodocida	Nephtyidae	*Aglaophamus circinata*	2
Annelida	Polychaeta	Phyllodocida	Nephtyidae	*Nephtys bucera*	2
Annelida	Polychaeta	Phyllodocida	Nephtyidae	*Nephtys incisa*	2
Annelida	Polychaeta	Phyllodocida	Nephtyidae	*Nephtys picta*	2
Annelida	Polychaeta	Phyllodocida	Pholoidae	*Pholoe minuta*	2
Annelida	Polychaeta	Phyllodocida	Phyllodocidae	*Eumida sanguinea*	2
Annelida	Polychaeta	Phyllodocida	Phyllodocidae	*Paranaitis speciosa*	2

Annelida	Polychaeta	Phyllodocida	Phyllodocidae	*Phyllodoce arenae*	2
Annelida	Polychaeta	Phyllodocida	Polynoidae	*Harmothoe extenuata*	2
Annelida	Polychaeta	Phyllodocida	Polynoidae	*Lepidonotus sublevis*	2
Annelida	Polychaeta	Phyllodocida	Sigalionidae	*Sthenelais boa*	2
Annelida	Polychaeta	Phyllodocida	Sphaerodoridae	*Sphaerodoropsis sp. A Maciolek*	2
Annelida	Polychaeta	Phyllodocida	Syllidae	*Brania wellfleetensis*	2
Annelida	Polychaeta	Phyllodocida	Syllidae	*Erinaceusyllis erinaceus*	2
Annelida	Polychaeta	Phyllodocida	Syllidae	*Exogone (Exogone) dispar*	2
Annelida	Polychaeta	Phyllodocida	Syllidae	*Pionosyllis longocirrata*	2
Annelida	Polychaeta	Phyllodocida	Syllidae	*Proceraea cornuta*	2
Annelida	Polychaeta	Phyllodocida	Syllidae	*Salvatoria clavata*	2
Annelida	Polychaeta	Phyllodocida	Syllidae	*Sphaerosyllis brevidentata*	2
Annelida	Polychaeta	Phyllodocida	Syllidae	*Syllides convolutus*	2
Annelida	Polychaeta	Phyllodocida	Syllidae	*Syllides verrilli*	2
Annelida	Polychaeta	Phyllodocida	Syllidae	*Syllis alternata*	2
Annelida	Polychaeta	Sabellida	Oweniidae	*Owenia fusiformis*	2
Annelida	Polychaeta	Spionida	Chaetopteridae	*Spiochaetopterus costarum oculatus*	2
Annelida	Polychaeta	Spionida	Spionidae	*Marenzelleria viridis*	2
Annelida	Polychaeta	Spionida	Spionidae	*Prionospio pygmaeus*	2
Annelida	Polychaeta	Spionida	Spionidae	*Scolelepis (Parascolelepis) texana*	2
Annelida	Polychaeta	Terebellida	Ampharetidae	*Melinna maculata*	2
Annelida	Polychaeta	Terebellida	Terebellidae	*Lysilla alba*	2
Arthropoda	Malacostraca	Amphipoda	Ampithoidae	*Ampithoe longimana*	2
Arthropoda	Malacostraca	Amphipoda	Liljeborgiidae	*Idunella barnardi*	2
Arthropoda	Malacostraca	Amphipoda	Lysianassidae	*Lysianopsis alba*	2
Arthropoda	Malacostraca	Amphipoda	Oedicerotidae	*Americhelidium americanum*	2
Arthropoda	Malacostraca	Amphipoda	Stenothoidae	*Stenothoe minuta*	2
Arthropoda	Malacostraca	Cumacea	Bodotriidae	*Cyclaspis varians*	2
Arthropoda	Malacostraca	Cumacea	Leuconidae	*Leucon americanus*	2
Arthropoda	Malacostraca	Decapoda	Cancridae	*Cancer irroratus*	2
Arthropoda	Malacostraca	Decapoda	Paguridae	*Pagurus longicarpus*	2
Arthropoda	Malacostraca	Isopoda	Anthuridae	*Cyathura burbancki*	2
Arthropoda	Malacostraca	Isopoda	Chaetiliidae	*Chiridotea coeca*	2
Arthropoda	Malacostraca	Isopoda	Idoteidae	*Edotia triloba*	2
Arthropoda	Malacostraca	Isopoda	Idoteidae	*Idotea balthica*	2
Arthropoda	Malacostraca	Tanaidacea	Leptocheliidae	*Hargeria rapax*	2
Arthropoda	Malacostraca	Tanaidacea	Tanaissuidae	*Tanaissus psammophilus*	2
Arthropoda	Pycnogonida	Pantopoda	Phoxichilidiidae	*Anoplodactylus petiolatus*	2
Cnidaria	Anthozoa	Actiniaria	Edwardsiidae	*Edwardsia elegans*	2
Mollusca	Bivalvia	Myoida	Myidae	*Mya arenaria*	2
Mollusca	Bivalvia	Veneroida	Solencurtidae	*Tagelus divisus*	2
Mollusca	Bivalvia	Veneroida	Tellinidae	*Tellina agilis*	2
Mollusca	Bivalvia	Veneroida	Veneridae	*Gemma gemma*	2
Mollusca	Bivalvia	Veneroida	Veneridae	*Mercenaria mercenaria*	2
Mollusca	Gastropoda	"unassigned"	Pyramidellidae	*Eulimastoma engonium*	2
Mollusca	Gastropoda	Cephalaspidea	Haminoeidae	*Haminoea solitaria*	2
Mollusca	Gastropoda	Neogastropoda	Columbellidae	*Astyris lunata*	2

Mollusca	Gastropoda	Neogastropoda	Nassariidae	*Ilyanassa trivittata*	2
Mollusca	Gastropoda	Neogastropoda	Nassariidae	*Nassarius vibex*	2
Nemertea	Anopla	"unassigned"	Lineidae	*Cerebratulus lacteus*	2
Nemertea	Enopla	Monostilifera	Amphipoidae	*Zygonemertes virescens*	2
Phoronida				*Phoronis psammophila*	2
Platyhelminthes	Rhabditophora	Polycladida	Stylochidae	*Stylochus ellipticus*	2
Platyhelminthes	Turbellaria			*Turbellaria sp. A (LTBA)*	2
Sipuncula	Spunculidea	Golfingiida	Phascolionidae	*Phascolion (Phascolion) strombus*	2
Annelida	Polychaeta	"unassigned"	Arenicolidae	*Arenicola cristata*	3
Annelida	Polychaeta	"unassigned"	Capitellidae	*Mediomastus ambiseta*	3
Annelida	Polychaeta	"unassigned"	Capitellidae	*Notomastus sp. A Ewing*	3
Annelida	Polychaeta	"unassigned"	Paraonidae	*Cirrophorus sp. B*	3
Annelida	Polychaeta	"unassigned"	Paraonidae	*Paraonis fulgens*	3
Annelida	Polychaeta	Phyllodocida	Nereididae	*Alitta succinea*	3
Annelida	Polychaeta	Phyllodocida	Nereididae	*Alitta virens*	3
Annelida	Polychaeta	Phyllodocida	Nereididae	*Neanthes arenaceodentata*	3
Annelida	Polychaeta	Phyllodocida	Nereididae	*Platynereis dumerilii*	3
Annelida	Polychaeta	Phyllodocida	Phyllodocidae	*Hypereteone foliosa*	3
Annelida	Polychaeta	Phyllodocida	Pilargidae	*Ancistrosyllis hartmanae*	3
Annelida	Polychaeta	Phyllodocida	Syllidae	*Streptosyllis arenae*	3
Annelida	Polychaeta	Phyllodocida	Syllidae	*Streptosyllis websteri*	3
Annelida	Polychaeta	Spionida	Spionidae	*Boccardiella hamata*	3
Annelida	Polychaeta	Spionida	Spionidae	*Polydora websteri*	3
Annelida	Polychaeta	Spionida	Spionidae	*Prionospio heterobranchia*	3
Annelida	Polychaeta	Spionida	Spionidae	*Pygospio elegans*	3
Annelida	Polychaeta	Spionida	Spionidae	*Spio setosa*	3
Annelida	Polychaeta	Spionida	Spionidae	*Spiophanes bombyx*	3
Annelida	Polychaeta	Spionida	Spionidae	*Streblospio benedicti*	3
Annelida	Polychaeta	Terebellida	Ampharetidae	*Hobsonia florida*	3
Annelida	Polychaeta	Terebellida	Cirratulidae	*Caulleriella venefica*	3
Annelida	Polychaeta	Terebellida	Cirratulidae	*Cirratulus grandis*	3
Annelida	Polychaeta	Terebellida	Terebellidae	*Loimia medusa*	3
Arthropoda	Malacostraca	Amphipoda	Ampeliscidae	*Ampelisca abdita*	3
Arthropoda	Malacostraca	Amphipoda	Aoridae	*Microdeutopus gryllotalpa*	3
Arthropoda	Malacostraca	Amphipoda	Corophiidae	*Apocorophium acutum*	3
Arthropoda	Malacostraca	Amphipoda	Corophiidae	*Leptocheirus plumulosus*	3
Arthropoda	Malacostraca	Amphipoda	Corophiidae	*Monocorophium acherusicum*	3
Arthropoda	Malacostraca	Amphipoda	Corophiidae	*Monocorophium tuberculatum*	3
Arthropoda	Malacostraca	Amphipoda	Gammaridae	*Gammarus daiberi*	3
Arthropoda	Malacostraca	Decapoda	Callianassidae	*Gilvossius setimanus*	3
Arthropoda	Malacostraca	Isopoda	Idoteidae	*Erichsonella attenuata*	3
Arthropoda	Malacostraca	Isopoda	Idoteidae	*Erichsonella filiformis*	3
Mollusca	Bivalvia	Veneroida	Arcticidae	*Arctica islandica*	3
Mollusca	Bivalvia	Veneroida	Montacutidae	*Mysella planulata*	3
Mollusca	Bivalvia	Veneroida	Tellinidae	*Macoma tenta*	3
Mollusca	Gastropoda	Neogastropoda	Nassariidae	*Ilyanassa obsoleta*	3
Nemertea	Anopla	"unassigned"	Carinomidae	*Carinoma tremaphoros*	3
Nemertea	Anopla	"unassigned"	Lineidae	*Lineus pallidus*	3

Nemertea	Anopla	"unassigned"	Lineidae	*Lineus ruber*	3
Nemertea	Enopla	Monostilifera	Amphipoidae	*Amphiporus bioculatus*	3
Nemertea	Enopla	Monostilifera	Tetrastemmatidae	*Tetrastemma elegans*	3
Nemertea	Enopla	Monostilifera	Tetrastemmatidae	*Tetrastemma sp. A*	3
Nemertea	Enopla	Monostilifera	Tetrastemmatidae	*Tetrastemma vermiculus*	3
Nemertea	Palaeonemertea	"unassigned"	Cephalothricidae	*Cephalothrix spiralis*	3
Nemertea				*Nemertea sp. 2 (MWRA)*	3
Annelida	Polychaeta	"unassigned"	Capitellidae	*Heteromastus filiformis*	4
Annelida	Polychaeta	"unassigned"	Cossuridae	*Cossura sp. A Maciolek*	4
Annelida	Polychaeta	"unassigned"	Orbiniidae	*Leitoscoloplos robustus*	4
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Parougia caeca*	4
Annelida	Polychaeta	Eunicida	Dorvilleidae	*Schistomeringos rudolphii*	4
Annelida	Polychaeta	Phyllodocida	Phyllodocidae	*Hypereteone heteropoda*	4
Annelida	Polychaeta	Phyllodocida	Pilargidae	*Sigambra bassi*	4
Annelida	Polychaeta	Spionida	Spionidae	*Dipolydora commensalis*	4
Annelida	Polychaeta	Spionida	Spionidae	*Dipolydora socialis*	4
Annelida	Polychaeta	Spionida	Spionidae	*Paraprionospio alata*	4
Annelida	Polychaeta	Spionida	Spionidae	*Polydora cornuta*	4
Annelida	Polychaeta	Terebellida	Cirratulidae	*Monticellina cf. dorsobranchialis*	4
Annelida	Polychaeta	Terebellida	Cirratulidae	*Tharyx sp. A (MWRA)*	4
Annelida	Polychaeta	Terebellida	Terebellidae	*Polycirrus eximius*	4
Mollusca	Bivalvia	Arcoida	Arcidae	*Anadara transversa*	4
Mollusca	Bivalvia	Veneroida	Mactridae	*Mulinia lateralis*	4
Annelida	Clitellata	Haplotaxida	Tubificidae	*Tubificoides sp.*	5
Annelida	Clitellata			*Oligochaeta sp.*	5
Annelida	Polychaeta	"unassigned"	Capitellidae	*Capitella sp.*	5