ENVIRONMENTAL DATA REPORT

December 2017

Technical Support Document for the
2018 State of Our Estuaries Report

PREP
Piscataqua Region Estuaries Partnership

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Table of Contents

PREP
Piscataqua Region Estuaries Partnership

I. Introduction

Background

The Piscataqua Region Estuaries Partnership (PREP) is part of the U.S. Environmental Protection Agency's National Estuary Program, which is a joint local/state/federal program established under the Clean Water Act with the goal of protecting and enhancing nationally significant estuarine resources. PREP is funded by the EPA and is administered by the University of New Hampshire.

PREP's Comprehensive Conservation and Management Plan for the estuaries of the Piscataqua Region (PREP 2010) was updated in 2010 and implementation is ongoing. The Management Plan addresses current and emerging issues impacting the water quality and environmental health of estuaries in the Piscataqua Region. Priority action plans were developed for water resources, land use and habitat protection, living resources and habitat restoration, and watershed stewardship. Projects addressing these priorities are undertaken throughout the watershed, which includes 42 communities in New Hampshire and 10 in Maine.

Every five years, PREP prepares a State of Our Estuaries (SOOE) report with extensive data and information on the status and trends of environmental indicators from the Piscataqua Region watershed and estuaries. (See stateofourestuaries.org for previous reports.) The SOOE report is a suite of products of varying levels of detail for the diverse audiences who rely on our work. The Environmental Data Report (henceforth, "Data Report") provides a detailed analysis of the data collected over the period, and is intended to be used by technical and policy level audiences. The SOOE Summary Report, the more commonly used report, targets a broader audience and provides an overall assessment of the health of our estuaries using 23 water quality, biological and social/management indicators. The Citizens Guide and Municipal Guide are handbooks for very specific audiences that translate science into action towards the goals of water quality improvement.

Data Report Organization

This Data Report follows the same basic organizational structure as the shorter SOOE report, with the indicators organized in terms of "Pressure," "Condition," and "Response." Pressure indicators measure some of the key human stresses on our environment; condition indicators measure the state of conditions in our estuaries; and response indicators track some of the key actions managers are taking to protect and restore our estuarine ecosystems. Finally, this year, PREP introduced newly developed "Social Indicators," which cross these organizational categories.

Each section begins by presenting the same information that was presented in the Summary Report, using the same headings, including:

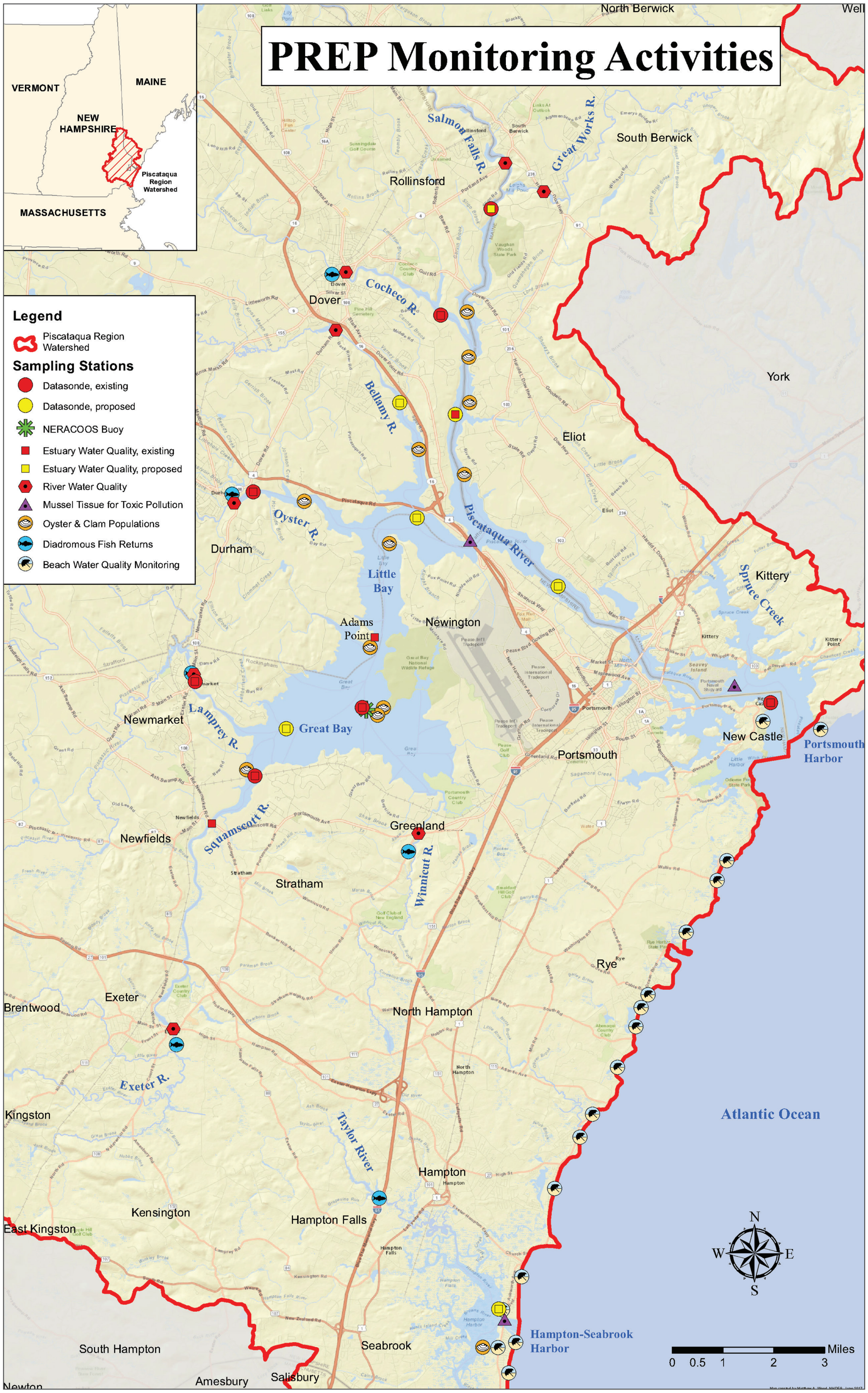
- Question (e.g., What is the current population of clams in Hampton-Seabrook Harbor?)
- Short Answer
- PREP Goal
- Why This Matters
- Explanation (from the SOOE Report)

The remaining sections (see below) are only found in the Data Report.

- Methods and Data Sources
- Additional Results (Beyond What Was Reported in the SOOE)*
- Technical Advisory Committee (TAC) Discussion Highlights*
- References Cited

Acknowledgements

Please see the "Acknowledgements and Credits" section (page 50) of the 2018 State of Our Estuaries Summary Report. (http://stateofourestuaries.org/2018-reports/sooe-full-report)



Map created by Matthew A. Wood, NHDES, July 2017

Indicator: Impervious Surfaces

Question

How much of the Piscataqua Region watershed is currently covered by impervious surfaces and how has it changed over time?

Short Answer

In 2015, 5.6% of the land area of the Piscataqua Region watershed was covered by impervious surfaces. This is an increase of 1,257 acres of impervious cover or 0.2% of the land area since 2010.

PREP Goal

No increase in the number of watersheds and towns with greater than 10% impervious cover and no decrease in the number of watersheds and towns with less than 5% impervious cover (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

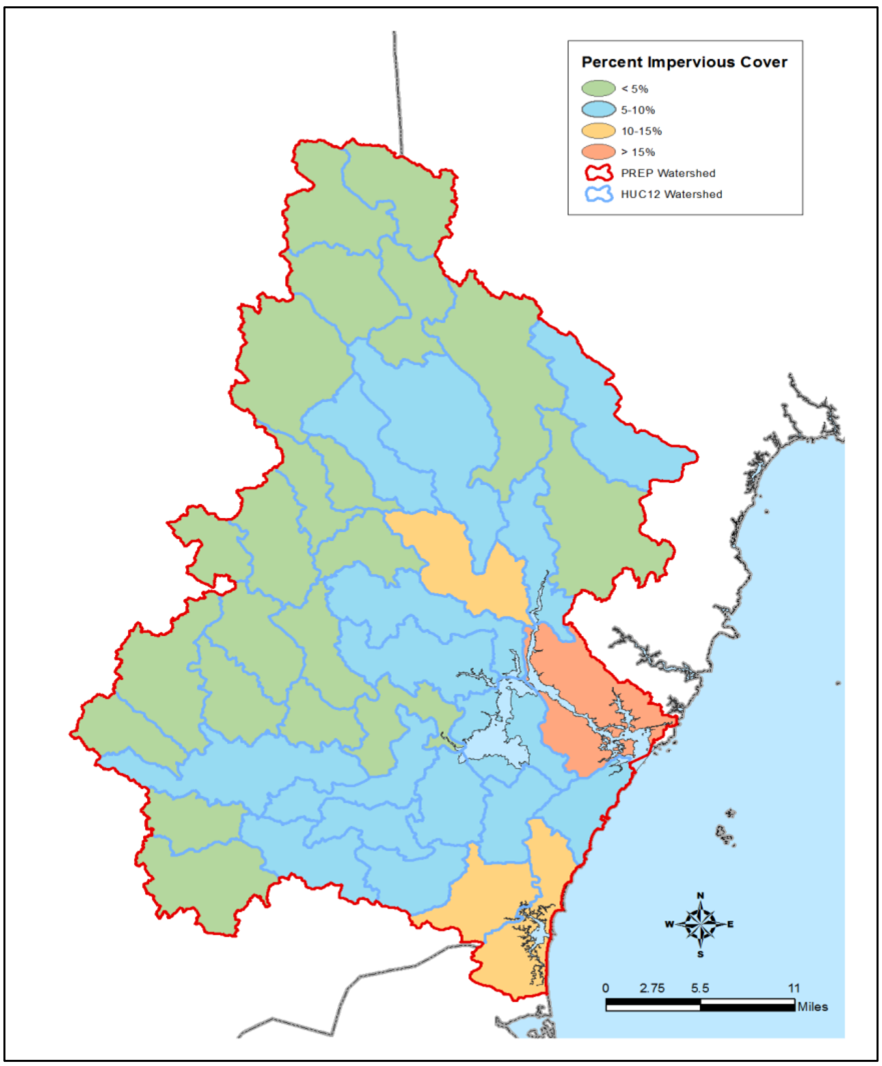


Figure IS-1. Percent impervious cover by subwatershed (HUC-12) as of 2015. Data Source: UNH Earth Systems Research Center.

Why This Matters

Impervious surfaces are man-made features, such as parking lots, roads, and buildings, that do not allow precipitation to infiltrate into the ground. When precipitation falls on impervious surfaces, it runs off those surfaces carrying pollutants and sediments into nearby waterways. Watersheds reach a tipping point around 10% impervious cover (Mallin et al. 2000), beyond which water quality impacts become increasingly severe.

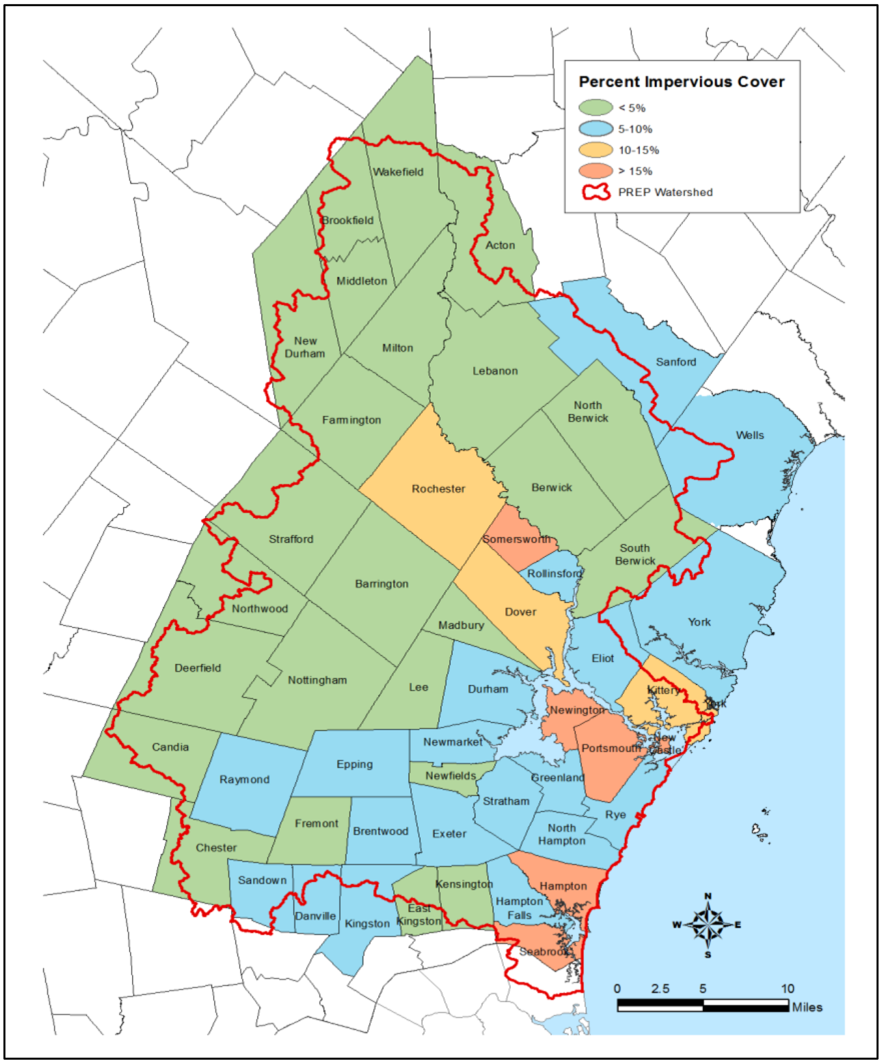


Figure IS-2. Percent impervious cover by town as of 2015. Data Source: UNH Earth Systems Research Center.

Explanation (from 2018 State of Our Estuaries Report)

The 2015 update to this dataset represents a new, improved baseline for impervious surface estimates across the region due to the use of higher resolution imagery and different processing methodology. Impervious surface values listed in the *2013 State of Our Estuaries* report using 30-meter satellite imagery (63,214 acres) were greater than those reported using 1-foot orthoimagery (45,377 acres) in this report. In 2015, 46,634 acres (5.6% of the land area) of impervious surface were mapped representing an increase of 1,257 acres (0.2% of the land area) since 2010 (45,377 acres). Watersheds with greater than 10% impervious surface coverage of land area are around the Hampton-Seabrook estuary, the Piscataqua River and the Route 16 corridor along the Cocheco

River. Impervious surfaces in 2015 in each of the Piscataqua Region subwatersheds are shown as a percentage of land area in Figure IS-1.

Communities with the highest reported impervious surface percentages included Portsmouth (26.7%), New Castle (20%), and Seabrook (20%), while the largest increase of impervious surfaces between 2010 and 2015 occurred in Rochester (122 acres), Wells (64 acres), Seabrook (64 acres), Dover (56 acres), York (42 acres), and Sanford (39 acres). Communities with the smallest increases in impervious surfaces included Madbury (4 acres), New Castle (2 acres), and Brookfield (2 acres). Small increases in impervious surfaces may be a result of limited availability of buildable lots. Town-by-town information on impervious surfaces in 2015 is shown in Figure IS-2.

Between 2010 and 2015 population in the Piscataqua Region watershed increased 6% (21,760 people), and impervious surfaces increased 2.7% (1,257 acres). For every one person increase in population, impervious surface increased 0.06 acres. However, as shown in Figures IS-1 and IS-2, the amount of impervious cover is not evenly spread across the watershed. For more discussion on population and housing trends in the watershed refer to the Housing Permits indicator section of the 2017 PREP Technical Report (PREP 2017).

Methods and Data Sources

A more comprehensive description of methods can be found in Justice and Rubin (2017).

Data sets for the 52-town PREP footprint (see Figure IS-2) were assembled from the NH GRANIT Clearinghouse (granit.unh.edu) and the Maine Office of GIS (maine.gov/megis). The updated IC coverage was derived by displaying the 2010 IC datasets for the project area over the 2015 source imagery, and manually digitizing new IC features visible in the imagery. Data were initially displayed at a minimum scale of 1:2,000 to identify features to be digitized. The scale was typically increased to 1:1,000 (or greater) when actively digitizing features.

In addition to mapping 2015 features, updates were made to the 2010 features to capture or delete IC as appropriate. Most of the updates addressed prior errors of omission (i.e., missing features). Typically, these errors occurred because features on the ground were at least partially obscured by tree canopy in the 2010 imagery but became visible in the 2015 imagery. The errors were addressed by confirming their presence in the 2010 imagery, and then digitizing the features from the 2015 imagery. Errors of commission (i.e., adding features not actually present) from the 2010 data were also updated as appropriate.

After a comprehensive review of the data, the IC polygons were processed to derive the final data set for distribution. First, the vector polygons were converted to a 1-foot resolution raster. To fill any small gaps between features, the raster data set was expanded by 2 pixels and then contracted back by 2 pixels. Lastly, the raster was converted back to vector format, the IC polygons were generalized (using a maximum offset of 2 feet), and small features (less than 20 sq. ft.) were eliminated.

Data Sources

Data for this indicator derived from geographic data layers of impervious surfaces in the Piscataqua Region watershed produced by the UNH Earth Systems Research Center. The data are available for download from NH GRANIT. The primary source data for the project comprised 2015 1-foot resolution, 4-band orthophotography in New Hampshire; 2015 1-meter resolution, 3-band orthophotography in Maine; and existing 2010 impervious cover (IC) feature data sets. Older vintage orthophotography (2010 and 2005) was also used for reference.

Additional Results (Beyond the Data Reported in the SOOE)

The primary result of this project is a high resolution (HR) impervious cover data set capturing features for the year 2015 within the 52 town PREP footprint. Figure IS-3 displays the distribution of impervious cover mapped throughout the study area. Figure IS-4 graphically shows impervious cover by town. Tables LS-1 and LS-2 summarize the impervious cover by town and subwatershed.

PREP goals were earlier stated as: "No increase in the number of watersheds and towns with greater than 10% impervious cover and no decrease in the number of watersheds and towns with less than 5% impervious cover." One additional municipality (Rochester, at 10.1% impervious cover) has been added to the list of towns with impervious cover over 10% (Table LS-1). One sub-watershed (Taylor River, at 10.3%) has been added to the list of sub-watersheds with impervious cover over 10% (Table LS-2).

There was no decrease in the number of towns with impervious cover less than 5% (Table LS-1). However, there was a decrease in the number of sub-watersheds at less than 5% impervious cover; the Bauneg Beg Pond/Great Works River sub-watershed went from 4.9% in 2010 to 5.0% in 2015 (Table LS-2).

Of the 52 towns, 48 saw slight increases (e.g., 1 – 2%) in impervious cover; four municipalities stayed the same. Of the 40 sub-watersheds, 33 saw slight increases in impervious cover; seven sub-watersheds remained at 2010 levels.

There were no decreases in impervious cover for any town or sub-watershed.

References Cited

Justice D, Rubin F. 2017. Developing 2015 High-Resolution Impervious Cover Estimates for the 52 Towns in the Piscataqua Region Estuaries Partnership: Final Report. *PREP Publications*. 395. http://scholars.unh.edu/prep/395

Mallin MA, Williams KE, Esham EC, Lowe RP. 2000. Effect of Human Development on Bacteriological Water Quality in Coastal Watersheds. *Ecological Applications*, Vol. 10, No. 4 (Aug., 2000), pp. 1047-1056 Published by: Wiley on behalf of the Ecological Society. Stable URL: http://www.jstor.org/stable/2641016.

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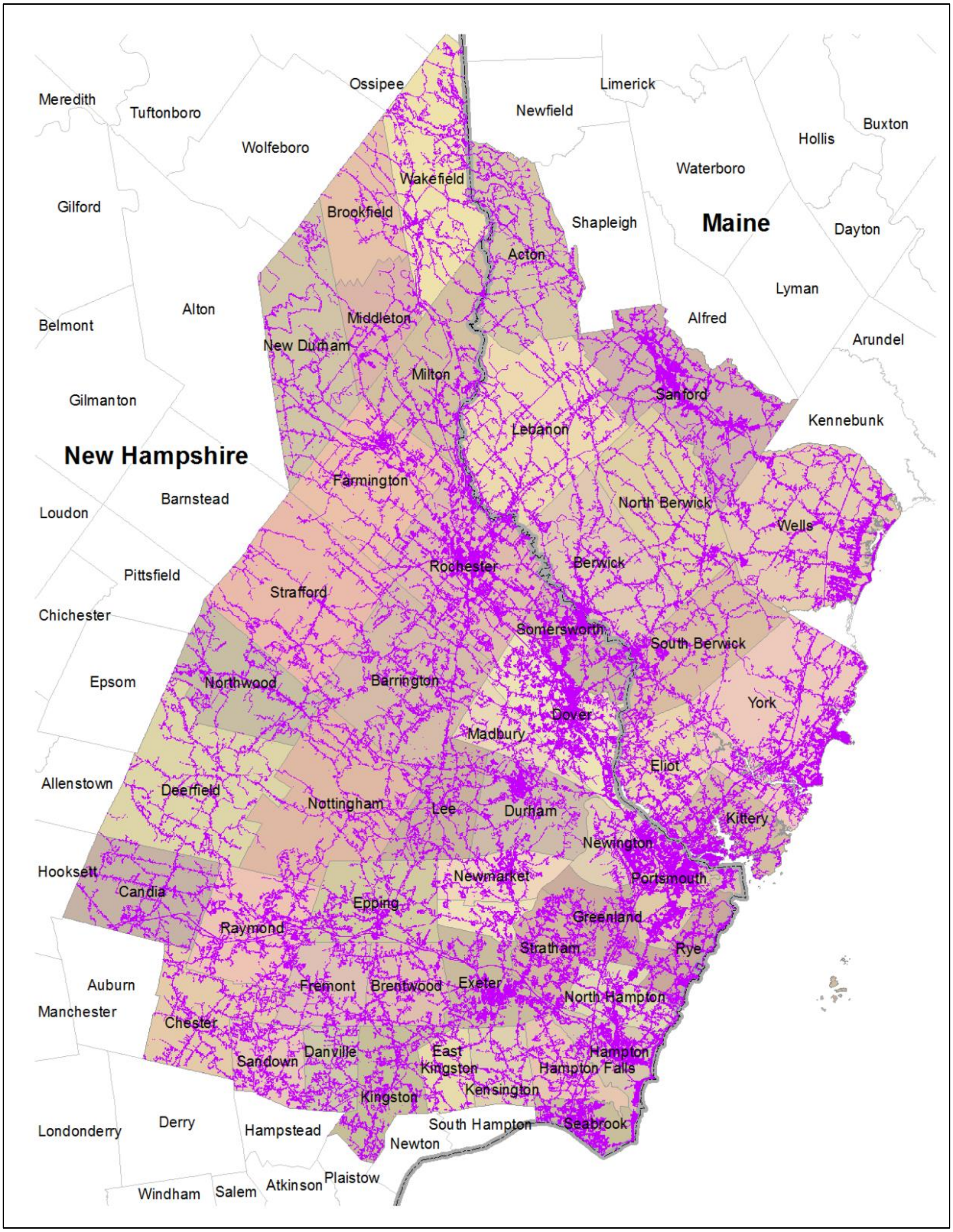

Figure IS-3. Distribution of 2015 impervious cover in the project study area. Impervious features displayed in purple.

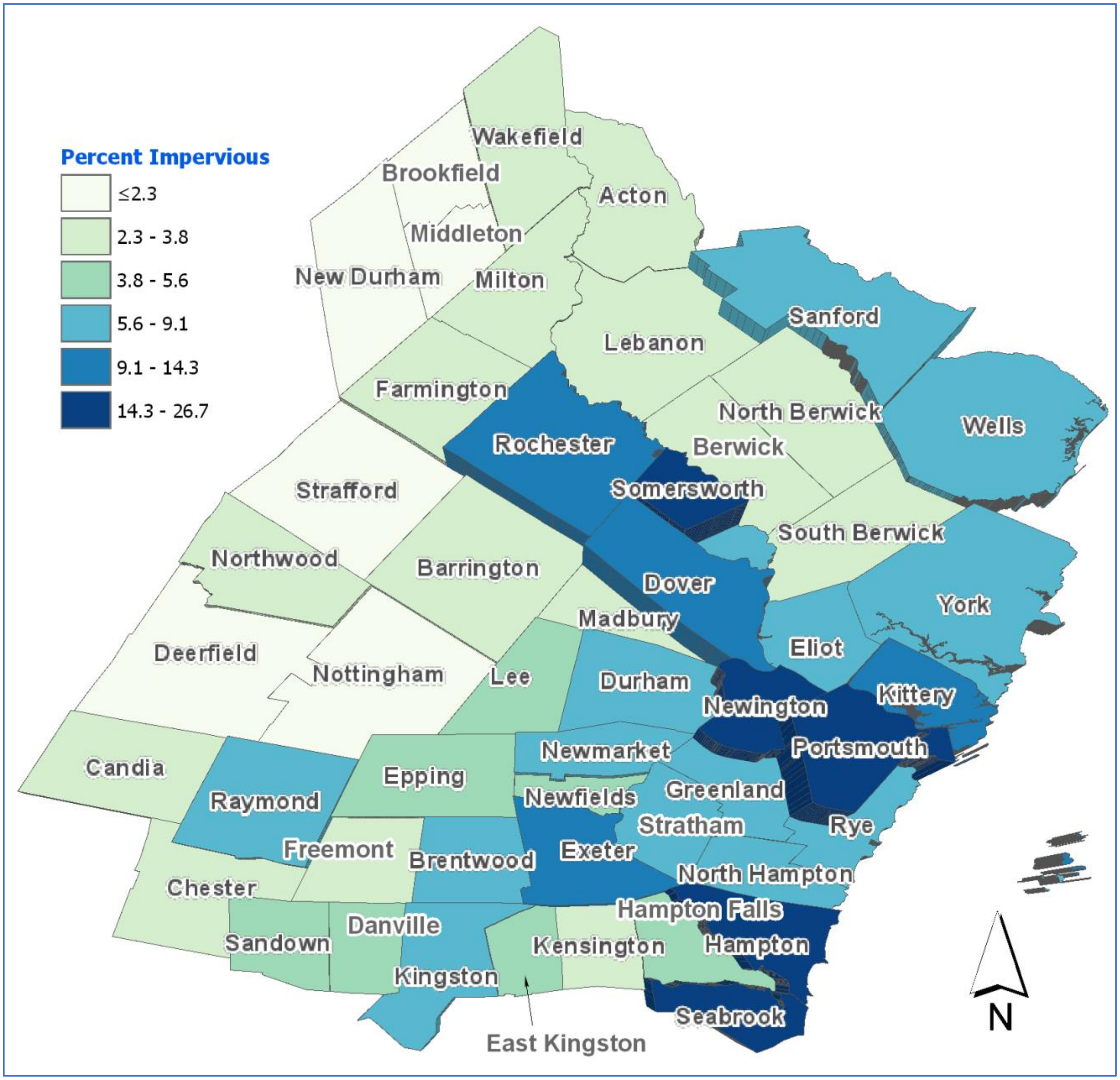

Figure IS-4. Percent impervious cover by town, 2015.

State	Town	Total Area (acres)			IC (acres)			Percent IC (Land Area)	
		Land	Inland Water	Total	2010	2015	Change	2010	2015
Maine	Acton	24,216.3	2,191.7	26,408.0	745.0	754.8	9.8	3.1%	3.1%
	Berwick	23,779.6	447.1	24,226.7	877.5	895.3	17.8	3.7%	3.8%
	Eliot	12,609.4	150.6	12,759.9	874.1	895.7	21.6	6.9%	7.1%
	Kittery[1]	11,548.0	168.2	11,716.1	1,304.2	1,315.8	11.5	11.3%	11.4%
	Lebanon	34,957.8	675.8	35,633.6	998.6	1,031.4	32.8	2.9%	3.0%
	North Berwick	24,265.1	157.6	24,422.7	737.8	765.1	27.3	3.0%	3.2%
	Sanford	30,314.8	890.3	31,205.1	2,427.9	2,466.7	38.7	8.0%	8.1%
	South Berwick	20,468.8	243.1	20,711.8	750.5	762.3	11.8	3.7%	3.7%
	Wells	36,427.3	125.1	36,552.3	2,134.3	2,198.4	64.1	5.9%	6.0%
	York	34,913.8	685.0	35,598.8	2,167.2	2,209.1	42.0	6.2%	6.3%
	Total	253,500.6	5,734.4	259,235.0	13,017.2	13,294.6	277.5	5.1%	5.2%
New Hampshire	Barrington	29,719.0	1,398.3	31,117.3	967.0	1,004.3	37.3	3.3%	3.4%
	Brentwood	10,728.1	134.9	10,863.0	636.8	672.6	35.8	5.9%	6.3%
	Brookfield	14,593.0	287.3	14,880.4	132.6	134.3	1.7	0.9%	0.9%
	Candia	19,328.9	228.2	19,557.2	621.6	642.9	21.3	3.2%	3.3%
	Chester	16,606.2	111.6	16,717.8	537.5	566.7	29.2	3.2%	3.4%
	Danville	7,438.7	130.7	7,569.4	390.8	402.0	11.2	5.3%	5.4%
	Deerfield	32,575.7	772.1	33,347.8	660.1	697.3	37.2	2.0%	2.1%
	Dover	17,036.9	1,555.2	18,592.1	2,388.9	2,445.4	56.5	14.0%	14.4%
	Durham	14,251.1	1,601.2	15,852.3	890.3	923.9	33.5	6.2%	6.5%
	East Kingston	6,318.0	62.8	6,380.8	265.8	274.1	8.3	4.2%	4.3%
	Epping	16,476.6	299.1	16,775.7	879.9	932.6	52.7	5.3%	5.7%
	Exeter	12,540.6	272.3	12,812.9	1,205.8	1,227.0	21.3	9.6%	9.8%
	Farmington	23,213.0	427.0	23,640.0	771.0	782.6	11.6	3.3%	3.4%
	Fremont	11,033.1	109.3	11,142.4	406.9	425.6	18.7	3.7%	3.9%
	Greenland	6,722.5	1,801.4	8,523.9	560.0	586.2	26.2	8.3%	8.7%
	Hampton	8,287.3	785.5	9,072.8	1,380.0	1,403.9	23.9	16.7%	16.9%
	Hampton Falls	7,719.6	358.4	8,078.0	395.2	402.9	7.7	5.1%	5.2%
	Kensington	7,616.4	51.4	7,667.8	279.8	288.1	8.2	3.7%	3.8%
	Kingston	12,494.3	955.9	13,450.3	764.5	784.5	20.0	6.1%	6.3%
	Lee	12,685.0	242.2	12,927.3	581.7	600.4	18.8	4.6%	4.7%
	Madbury	7,383.6	415.5	7,799.1	272.1	276.4	4.3	3.7%	3.7%
	Middleton	11,559.0	284.0	11,843.0	254.7	269.7	15.0	2.2%	2.3%
	Milton	21,088.6	847.3	21,935.9	670.1	694.8	24.6	3.2%	3.3%
	New Castle	506.2	841.4	1,347.6	99.9	101.5	1.6	19.7%	20.0%
	New Durham	26,345.5	1,708.5	28,054.0	524.1	533.7	9.6	2.0%	2.0%
	Newfields	4,540.8	105.9	4,646.7	208.8	213.6	4.7	4.6%	4.7%
	Newington	5,214.5	2,702.2	7,916.8	851.2	886.7	35.5	16.3%	17.0%
	Newmarket	8,034.5	1,045.8	9,080.3	571.1	579.3	8.3	7.1%	7.2%
	North Hampton	8,861.8	61.0	8,922.8	717.7	732.8	15.1	8.1%	8.3%
	Northwood	17,965.0	1,391.9	19,357.0	601.5	611.8	10.3	3.3%	3.4%
	Nottingham	29,839.7	1,157.0	30,996.7	640.3	657.0	16.7	2.1%	2.2%
	Portsmouth	10,003.5	759.9	10,763.4	2,657.8	2,674.4	16.6	26.6%	26.7%
	Raymond	18,438.3	505.2	18,943.6	1,121.2	1,142.5	21.3	6.1%	6.2%
	Rochester	28,329.2	751.5	29,080.7	2,736.8	2,858.5	121.7	9.7%	10.1%
	Rollinsford	4,681.3	161.5	4,842.8	275.7	281.3	5.6	5.9%	6.0%
	Rye[1]	8,464.7	411.3	8,876.0	650.3	663.4	13.0	7.7%	7.8%
	Sandown	8,888.5	343.3	9,231.8	475.0	500.1	25.0	5.3%	5.6%
	Seabrook	5,664.7	496.6	6,161.3	1,069.7	1,133.6	63.9	18.9%	20.0%
	Somersworth	6,219.2	179.1	6,398.3	996.9	1,015.6	18.7	16.0%	16.3%
	Strafford	31,151.8	1,627.1	32,778.9	545.2	563.3	18.1	1.8%	1.8%
	Stratham	9,655.1	246.5	9,901.6	849.0	874.4	25.4	8.8%	9.1%
	Wakefield	25,264.0	3,453.2	28,717.2	854.3	877.3	23.0	3.4%	3.5%
	Total	560,219.6	27,627.7	587,847.3	31,505.5	32,461.8	956.3	5.6%	5.8%
Study Total		838,984.2	36,815.3	875,799.5	45,376.9	46,633.7	1,256.8	5.4%	5.6%

[1]Acreage values for the towns of Kittery, ME and Rye, NH include the Isles of Shoals.

HUC 12 ID	HUC 12 Name	**Total Area** (acres)			**Mapped Area** (acres)			**IC** (acres)			**Percent IC** (Mapped Land Area)	
		Land	**Inland Water**	**Total**	**Land**	**Inland Water**	**Total**	**2010**	**2015**	**Change**	**2010**	**2015**
010600030602	Axe Handle Brook	7,028	369	7,397	7,028	369	7,397	246	256	11	3.5%	3.6%
010600030401	Bauneg Beg Pond-Great Works River	23,128	393	23,520	23,127	393	23,520	1,126	1,156	30	4.9%	5.0%
010600030705	Bean River-North River	14,796	276	15,072	14,796	276	15,072	368	371	4	2.5%	2.5%
010600030903	Bellamy River	20,335	1,277	21,612	20,335	1,277	21,612	1,423	1,455	33	7.0%	7.2%
010600031002	Berrys Brook-Frontal Rye Harbor	10,285	333	10,618	10,282	332	10,613	935	948	13	9.1%	9.2%
010600030505	Bog Brook-Little River	34,702	170	34,872	34,363	169	34,532	777	799	22	2.3%	2.3%
010600030604	Bow Lake	7,885	1,240	9,125	7,882	1,240	9,121	200	206	6	2.5%	2.6%
010600030502	Branch River	17,268	235	17,504	17,268	235	17,504	333	358	25	1.9%	2.1%
010600030805	Exeter River-Squamscott River	12,189	174	12,363	12,189	174	12,363	607	618	11	5.0%	5.1%
010600030904	Great Bay	13,103	6,121	19,224	13,103	6,121	19,224	1,083	1,112	28	8.3%	8.5%
010600031005	Hampton River	18,059	1,341	19,400	12,931	1,229	14,160	1,862	1,935	73	14.4%	15.0%
010600030501	Headwaters Branch River	17,543	840	18,383	17,101	840	17,941	391	398	8	2.3%	2.3%
010600030801	Headwaters Exeter River	20,209	202	20,411	18,875	197	19,072	796	844	49	4.2%	4.5%
010600030701	Headwaters Lamprey River	21,718	209	21,927	21,718	209	21,927	460	486	27	2.1%	2.2%
010600030503	Headwaters Salmon Falls River	15,178	2,556	17,734	15,179	2,556	17,735	424	432	9	2.8%	2.8%
010600030607	Isinglass River	10,289	438	10,727	10,289	438	10,727	483	498	15	4.7%	4.8%
010600030709	Lamprey River	12,789	402	13,191	12,788	402	13,191	610	614	4	4.8%	4.8%
010600030402	Leighs Mill Pond-Great Works River	31,670	270	31,940	31,670	270	31,940	1,020	1,050	30	3.2%	3.3%
010600030707	Little River	12,585	359	12,944	12,585	359	12,944	367	377	11	2.9%	3.0%
010600030606	Long Pond	9,801	351	10,153	9,801	351	10,153	173	179	6	1.8%	1.8%
010600030608	Lower Cocheco River	19,479	583	20,063	19,479	583	20,063	2,270	2,331	62	11.7%	12.0%
010600030507	Lower Salmon Falls River	13,299	567	13,866	13,299	380	13,679	955	968	13	7.2%	7.3%
010600030603	Middle Cocheco River	16,025	276	16,301	16,025	276	16,301	1,525	1,585	60	9.5%	9.9%
010600030506	Middle Salmon Falls River	37,430	790	38,220	37,430	787	38,217	2,083	2,155	72	5.6%	5.8%
010600030605	Nippo Brook-Isinglass River	17,116	273	17,389	17,116	273	17,389	330	342	12	1.9%	2.0%
010600030702	North Branch River	10,901	146	11,047	10,901	146	11,047	323	334	11	3.0%	3.1%
010600030706	North River	8,786	65	8,851	8,786	65	8,851	240	251	11	2.7%	2.9%
010600030902	Oyster River	19,317	542	19,860	19,317	542	19,860	1,305	1,358	53	6.8%	7.0%
010600030704	Pawtuckaway Pond	12,107	945	13,052	12,107	945	13,052	180	187	6	1.5%	1.5%
010600030703	Pawtuckaway River-Lamprey River	25,584	638	26,222	25,584	638	26,222	1,478	1,528	49	5.8%	6.0%
010600030708	Piscassic River	14,407	103	14,510	14,407	103	14,510	750	783	33	5.2%	5.4%
010600031001	Piscataqua R.-Frontal Portsmouth Harbor	25,020	5,383	30,404	25,018	2,652	27,670	4,660	4,736	76	18.6%	18.9%
010600030804	Scamen Brook-Little River	10,109	38	10,147	10,109	38	10,147	671	699	29	6.6%	6.9%
010600030803	Spruce Swamp-Exeter River	14,999	182	15,181	14,999	182	15,181	783	816	33	5.2%	5.4%
010600030806	Squamscott River	12,445	544	12,989	12,445	544	12,989	1,161	1,188	26	9.3%	9.5%
010600031003	Taylor River	14,374	282	14,655	14,374	282	14,655	1,444	1,475	30	10.0%	10.3%
010600030601	Upper Cocheco River	27,143	515	27,657	26,787	514	27,302	806	822	16	3.0%	3.1%
010600030504	Upper Salmon Falls River	13,692	1,174	14,866	13,693	1,177	14,869	416	422	6	3.0%	3.1%
010600030802	Watson Brook-Exeter River	10,452	123	10,575	10,452	123	10,575	396	404	9	3.8%	3.9%
010600030901	Winnicut River	11,052	99	11,151	11,052	99	11,151	908	942	34	8.2%	8.5%
Total		664,298	30,824	695,122	656,692	27,785	684,477	36,366	37,419	1,053	5.5%	5.7%

PREP
Piscataqua Region Estuaries Partnership

Indicator: Total Suspended Solids Concentrations in the Great Bay Estuary

Question

How have total suspended solids (TSS) in the Great Bay Estuary changed over time?

Short Answer

Suspended solids at Adams Point show a statistically significant trend since 1989. At the Great Bay Station, there is no statistically significant trend in the data going back to 2002.

(See Table TSS-1 for more results from the other six trend stations.)

PREP Goal
No increasing trends for total suspended solids (from the PREP Comprehensive Conservation and Management Plan PREP 2010).

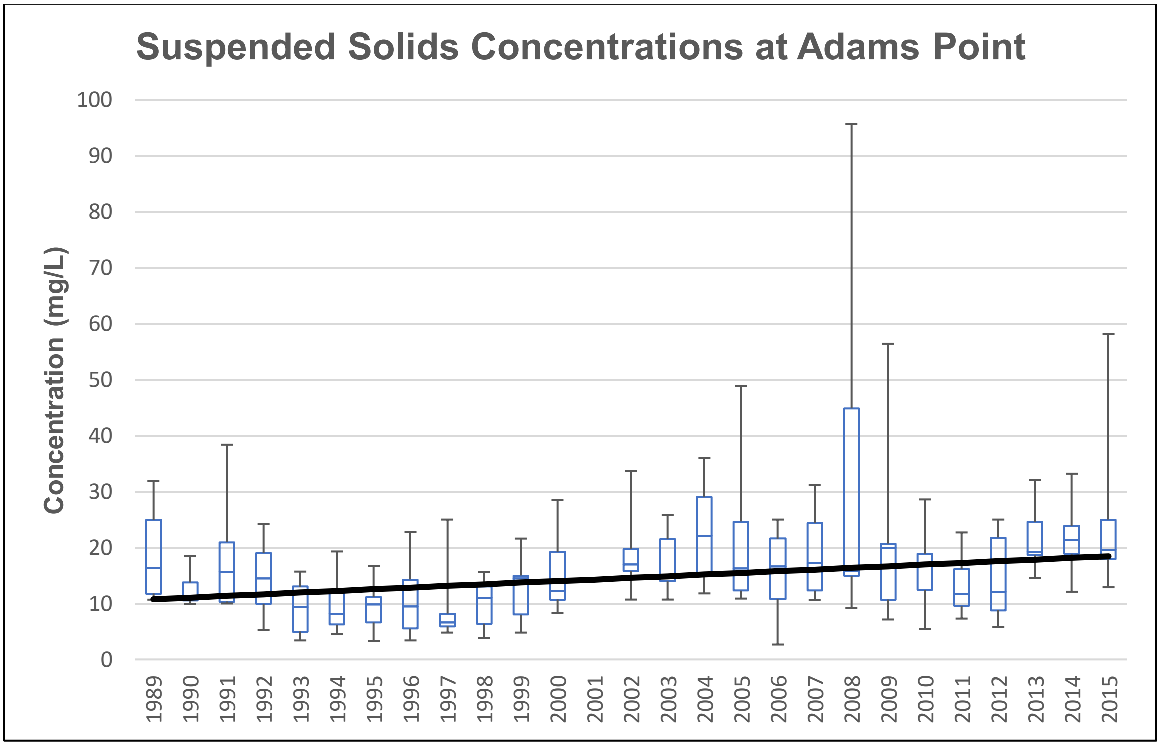

Figure TSS-1. Total Suspended Solids at Adams Point Station. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Year 2001 not included due to missing data. The black trendline indicates a statistically significant trend. Data Source: Great Bay National Estuarine Research Reserve and the UNH Jackson Estuarine Laboratory.

Why This Matters

Total suspended solids (TSS) are what is left over when a water sample is filtered and dried. While a small percentage of phytoplankton or pieces of plant matter remain, most of TSS is made up of sediment. Suspended solids come from resuspension within the estuary as well as erosion from streambanks, salt marshes and the upland portion of the watershed. This material is then delivered to the estuary via tributaries. Increasing suspended sediments reduce water clarity, and impact primary producers such as eelgrass, seaweeds and phytoplankton.

Explanation (from 2018 State of Our Estuaries Report)

Total suspended solids have increased at Adams Point since 1989 (Figure TSS-1). The average median value for the first 13 years of the dataset (1989-2002) was 12.0 mg/L. For the second half of the data set (2003-2015), the average median value increased to 22.9 mg/L, an increase of 90%. In contrast, suspended solids have remained relatively stable at the Great Bay station since 2002. In 2015, the median concentration was 14.1 mg/L (Figure TSS-2).

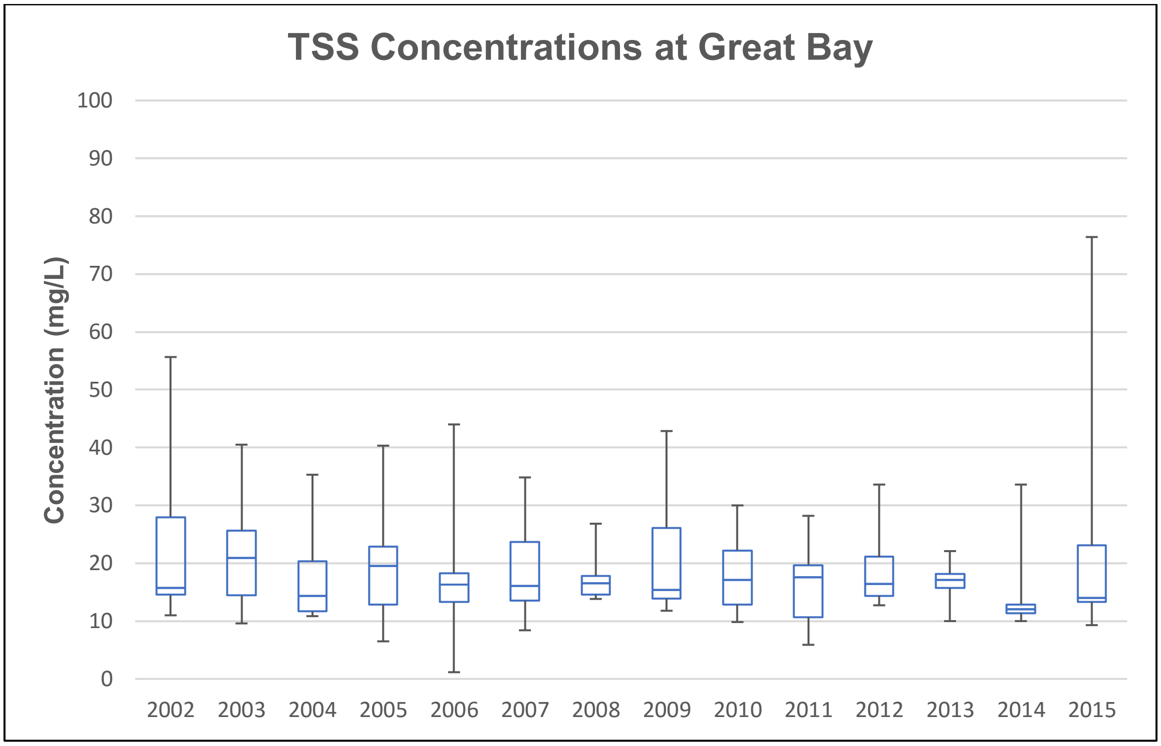

Figure TSS-2. Total Suspended Solids at Great Bay Station. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Data Source: Great Bay National Estuarine Research Reserve and the UNH Jackson Estuarine Laboratory.

Methods and Data Sources

Trend analysis for chlorophyll-a was performed at the following stations (Figure TSS-3):

- GRBAP (Adams Point between Great Bay and Little Bay)
- GRBGB (Great Bay)
- GRBCL (Chapmans Landing in the Squamscott River)
- GRBSQ (Squamscott River at the railroad trestle)
- GRBLR (Lamprey River)
- GRBOR (Oyster River)
- GRBUPR (Upper Piscataqua River)
- GRBCML (Portsmouth Harbor)

Samples collected at low-tide at the trend stations were identified. Low-tide samples were used for the trend analysis to control for the effects of tides. The data for each station were averaged by month (there was rarely more than one sample in the same month) and then the number of months with data in each year was counted. Only data from the months April through December were used. (The station at Adams Point is monitored 12 months per year.) If three consecutive

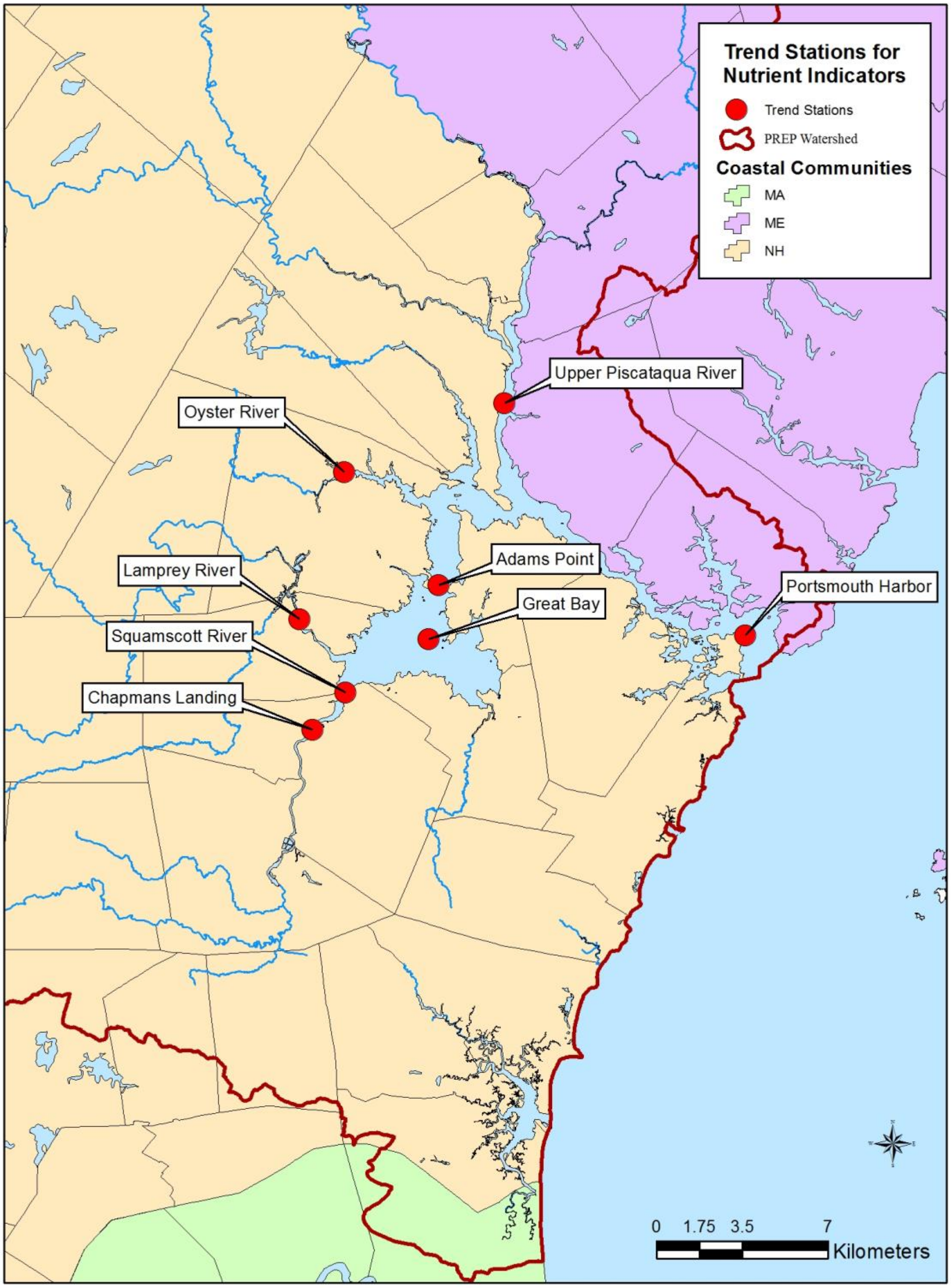

Figure TSS-3: Map of trend stations for total suspended solids.

months were missed in any year, that year was not included in the analysis. This was done in order to minimize bias from years for which the data do not reflect the full range of seasons.

Linear regression was used to test for long-term trends. The annual median values were regressed against the year variable. Trends were considered significant if the slope coefficient of the year variable was significant at the $p<0.05$ level.

Data Sources
Data for this indicator were provided by the UNH and Great Bay NERR Tidal Water Quality Monitoring Programs.

Additional trend monitoring stations have been added recently in the Bellamy, Cocheco, Salmon Falls, and Piscataqua Rivers and in Hampton-Seabrook Harbor; data from these stations will be included in the next Technical Report, scheduled for 2022.

<u>Additional Results (Beyond What Was Reported in the SOOE)</u>

The results of the trend analysis for TSS are summarized in Table TSS-1. Plots for each station are shown on Figure TSS-4. Two of the eight stations (Adams Point and Upper Piscataqua River) showed significant increasing trends for TSS. No other statistically significant temporal trends were evident at any of the other stations.

One of the primary reasons TSS is considered important is because it attenuates light and impacts primary producers such as eelgrass, seaweeds and phytoplankton. With regard to eelgrass, a range of thresholds at other estuaries have been established as being critical for the presence of eelgrass. For example, Kemp et al. (2004) noted that TSS levels less than 15 mg/L were required for eelgrass in Chesapeake Bay. Kenworthy et al. (2013), using a bio-optical model in Massachusetts coastal bays, asserted that TSS levels less than 6.4 mg/L were required for eelgrass to grow at a depth of 1.5 meters. These thresholds differ from system to system and are dependent on other light-attenuating substances such as colored dissolved organic matter (CDOM) and phytoplankton levels (measured via chlorophyll-a concentrations).

Table TSS-1 indicates the range of median and maximum values at each of the eight stations from 2012 to 2015. The highest median values were found at Squamscott River, Chapmans Landing, Oyster River and the Coastal Marine Laboratory. It is notable that the entire range of median values at these four sites was above 15 mg/L, the threshold noted by Kemp (2004). The lowest values were found at the Lamprey River and Upper Piscataqua River. Only the Lamprey River had median values (between 2012 and 2015) that were consistently below 15 mg/L. The highest maximum values were seen at the Squamscott River, Oyster River and Coastal Marine Laboratory stations.

It is also important to review Figure TSS-4 to understand the range of values seen at each station, since the ecosystem integrates the full range of values, not just the median or the mean. For example, TSS levels for single measurements frequently exceed 50 mg/L and, less frequently, are over 100 mg/L.

<u>Technical Advisory Committee (TAC) Discussion Highlights</u>
The Relationship Between TSS and Eelgrass
This topic was discussed as part of two consecutive TAC meetings on May 9-10, 2017; notes and presentations are available (PREP 2017). Of the 26 participants at the meeting, 23 rated TSS as a 3 or higher (on a scale of 1 to 5, 5 being highest) in terms of the probability that TSS is an important stressor on eelgrass habitat health. Of those 23 participants, 20 rated TSS 4 or higher.

At the meeting, there was little disagreement that turbidity is a very important factor for eelgrass health in the Great Bay Estuary. Turbidity is related to TSS; TSS is a measurement of the weight of particles larger than 2 microns while turbidity is measures how much light is scattered by particles in the water. Therefore, turbidity also includes particles that are smaller than 2 microns and are considered “dissolved,” such as CDOM.

At the May 9-10, 2017 meeting, the three external advisors to the TAC advocated that all light-attenuating components (e.g., seaweeds, TSS, colored dissolved organic matter (CDOM) and phytoplankton) be considered together, not separately, because these components act in an additive fashion. This approach to considering light attenuating substances and broader considerations relating to management options for increasing the resilience of the Great Bay Estuary are articulated more fully in the “Stress and Resilience” section of the 2018 State of Our Estuaries Report (PREP 2017b) as well as the “Statement Regarding Eelgrass Stressors” (Kenworthy et al. 2017).

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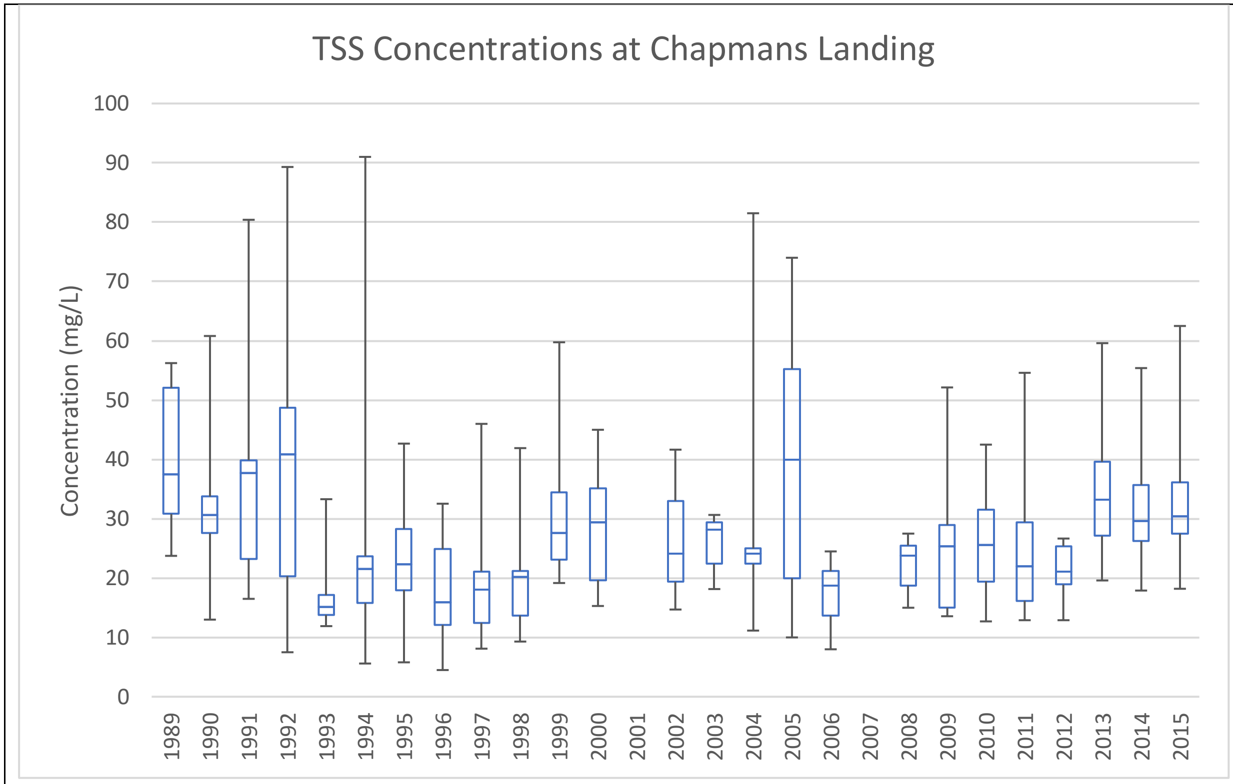
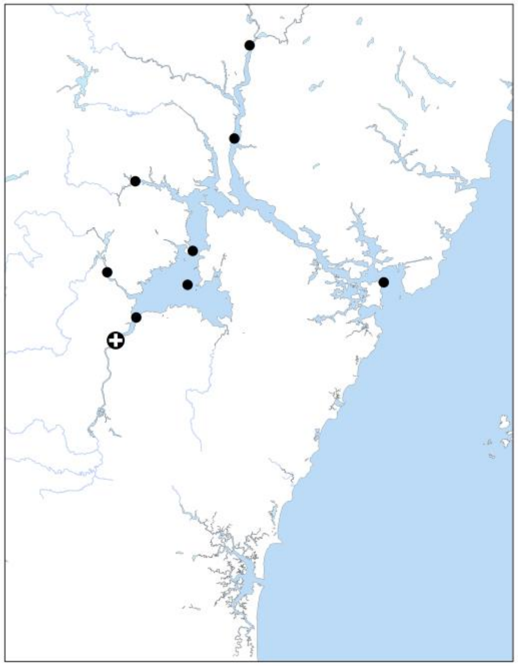
Table TSS-1: Trends for Total Suspended Solids in the Great Bay Estuary.

Station	Period	Range of Recent (Median Values) & Maximum Values 2012 -2015, mg/L	Long Term Trend
GRBAP (Adams Point)	1989-2015	(12.1 to 21.4) 25.0 to 58.2	Significant increasing trend
GRBCL (Chapmans Landing)	1989-2015	(21.1 to 33.2) 26.7 to 62.5	No significant trend
GRBSQ (Squamscott River)	2002-2015	(29.6 to 33.2) 47.0 to 160.6	No significant trend
GRBLR (Lamprey River)	1992-2015	(4.0 to 6.7) 8.2 to 40.0	No significant trend
GRBGB (Great Bay)	2002-2015	(12.1 to 16.4) 10.0 to 12.7	No significant trend
GRBOR Oyster River	2002-2015	(18.6 to 24.1) 37.1 to 83.6	No significant trend
GRBUPR Upper Piscataqua River	2007-2015	(10.7 to 16.7) 17.9 to 60.0	Significant increasing trend
GRBCML Coastal Marine Laboratory Portsmouth Harbor	2002-2015	(16.1 to 19.3) 20.7 to 66.1	No significant trend

Figure TSS-4: Total Suspended Solids (TSS) Concentrations at Stations in the Great Bay Estuary



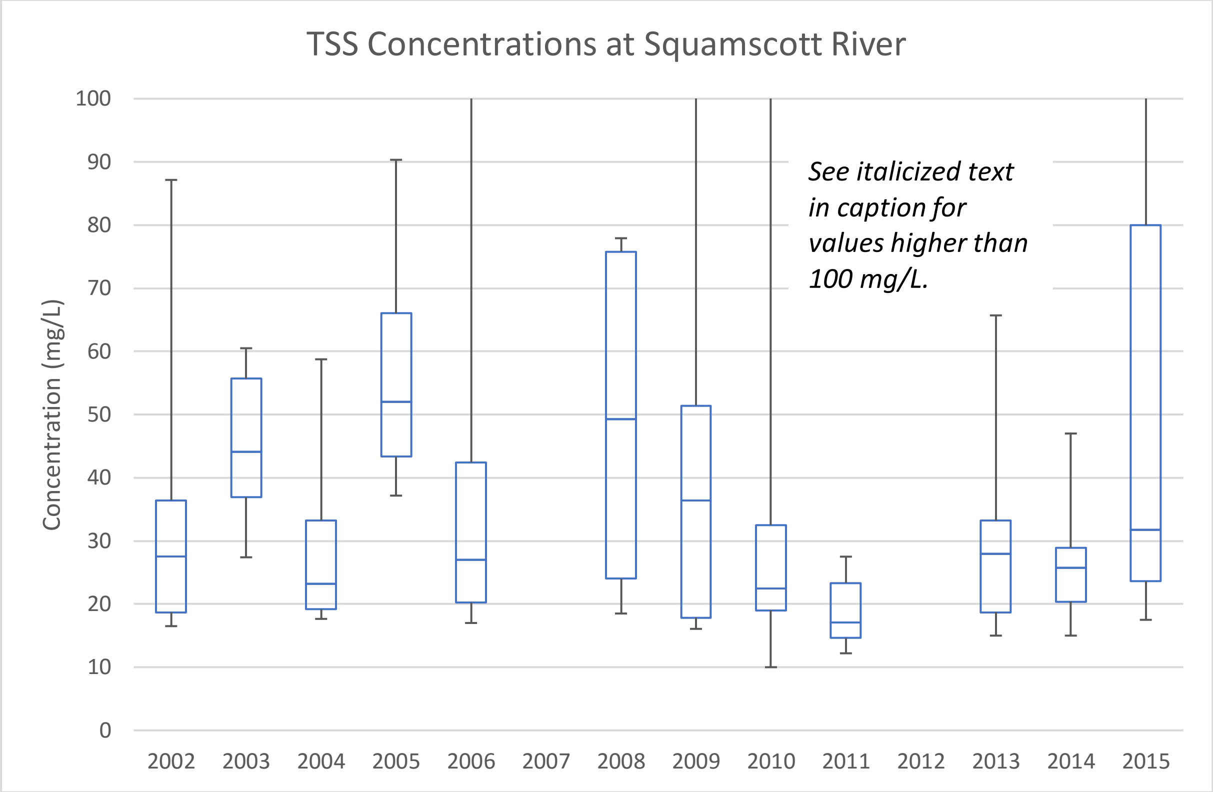
Monitoring Location (GRBCL)
Chapmans Landing
(black circle with white plus sign)



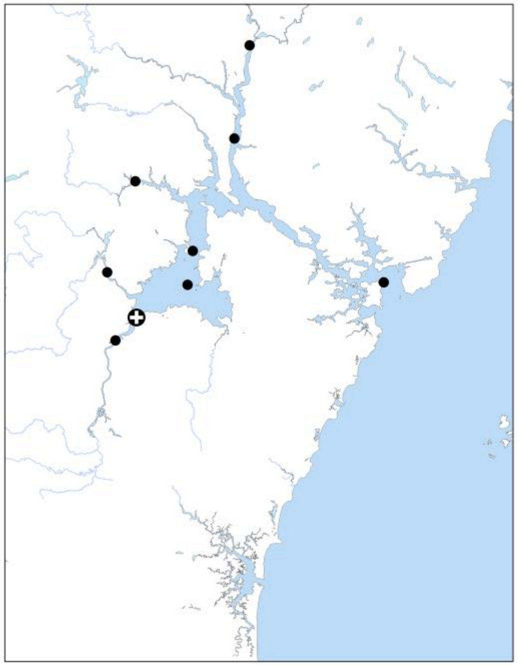
Station: GRBCL (Chapmans Landing in the Squamscott River)

Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



Monitoring Location (GRBSQ)
Squamscott River
(black circle with white plus sign)

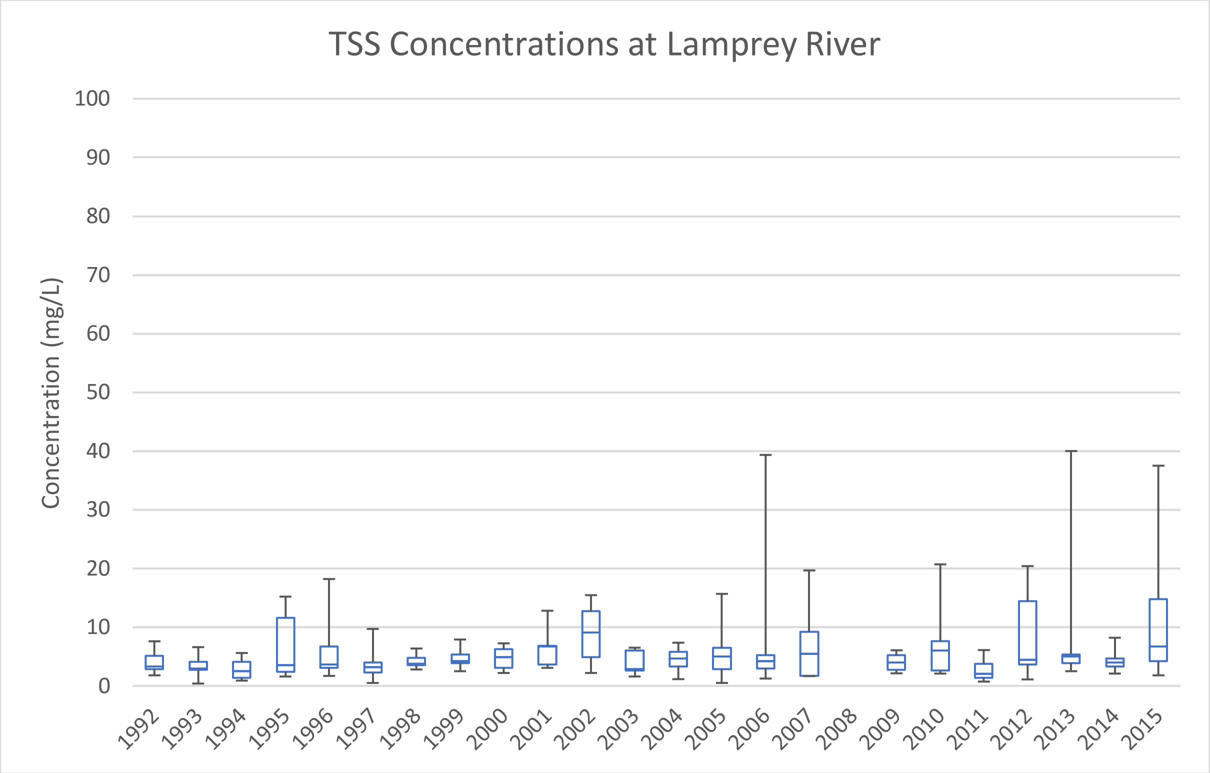


Station: GRBSQ (Squamscott River)

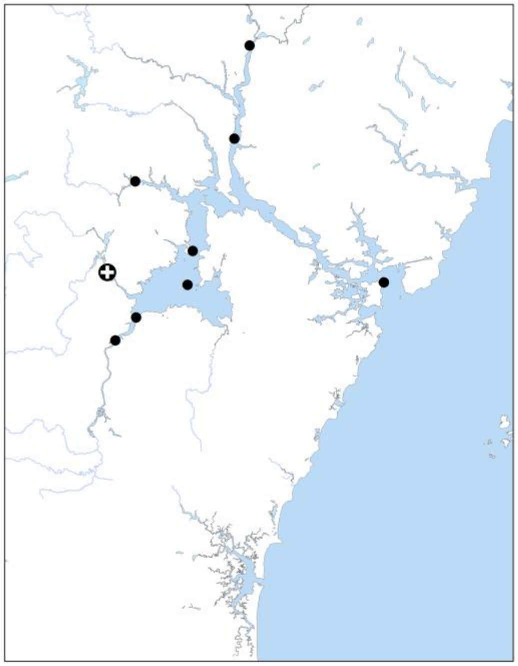
Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.

Values Higher Than 100 mg/L: 2006 = 159 mg/L; 2009 = 233 & 276 mg/L; 2010 = 121 mg/L; 2015 = 104 & 160 mg/L.



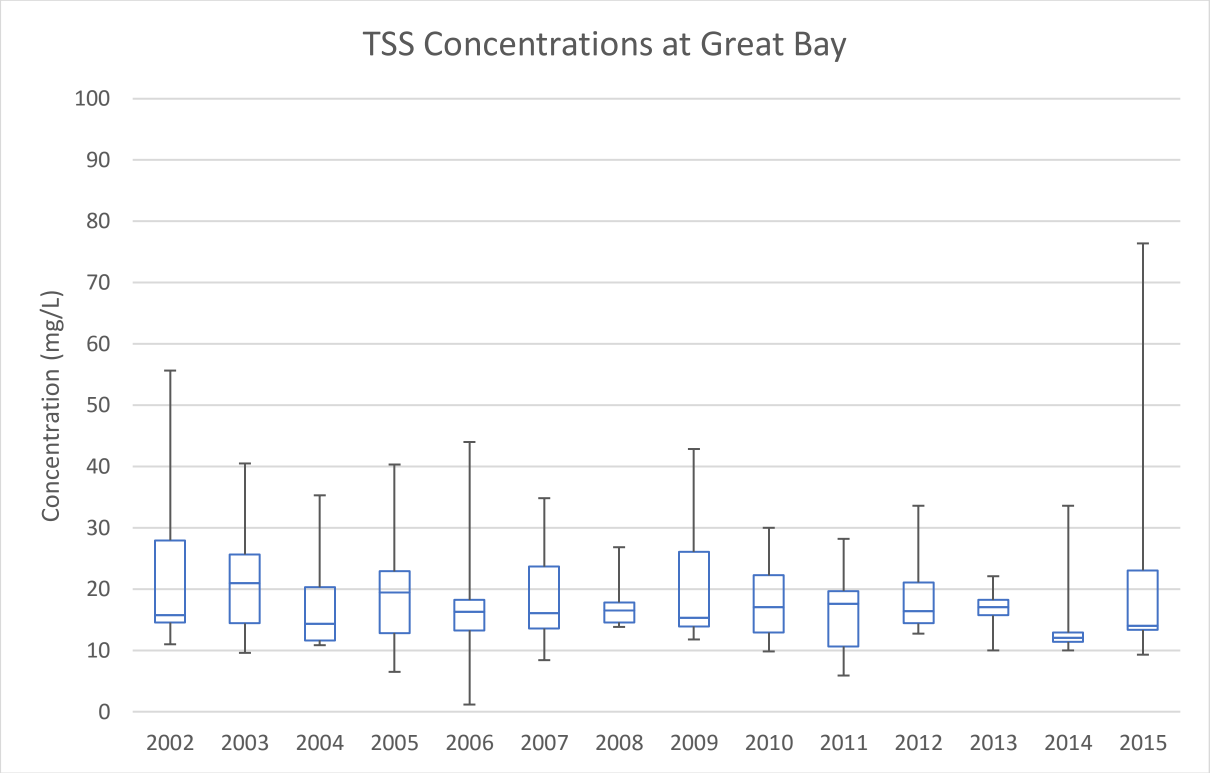
Monitoring Location (GRBLR)
Lamprey River
(black circle with white plus sign)



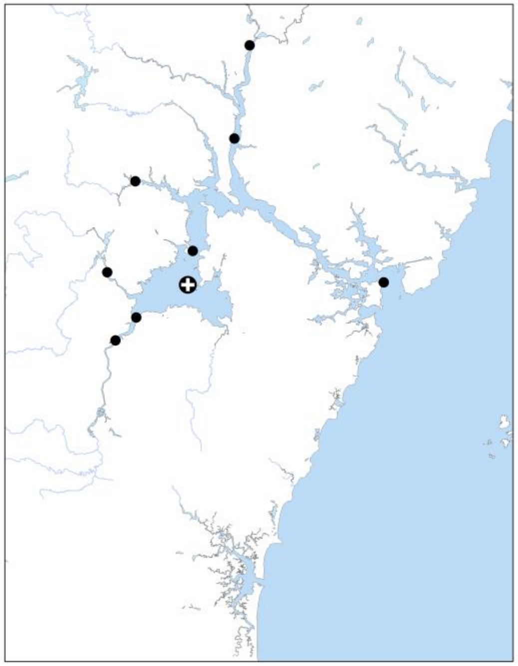
Station: GRBLR (Lamprey River)

Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



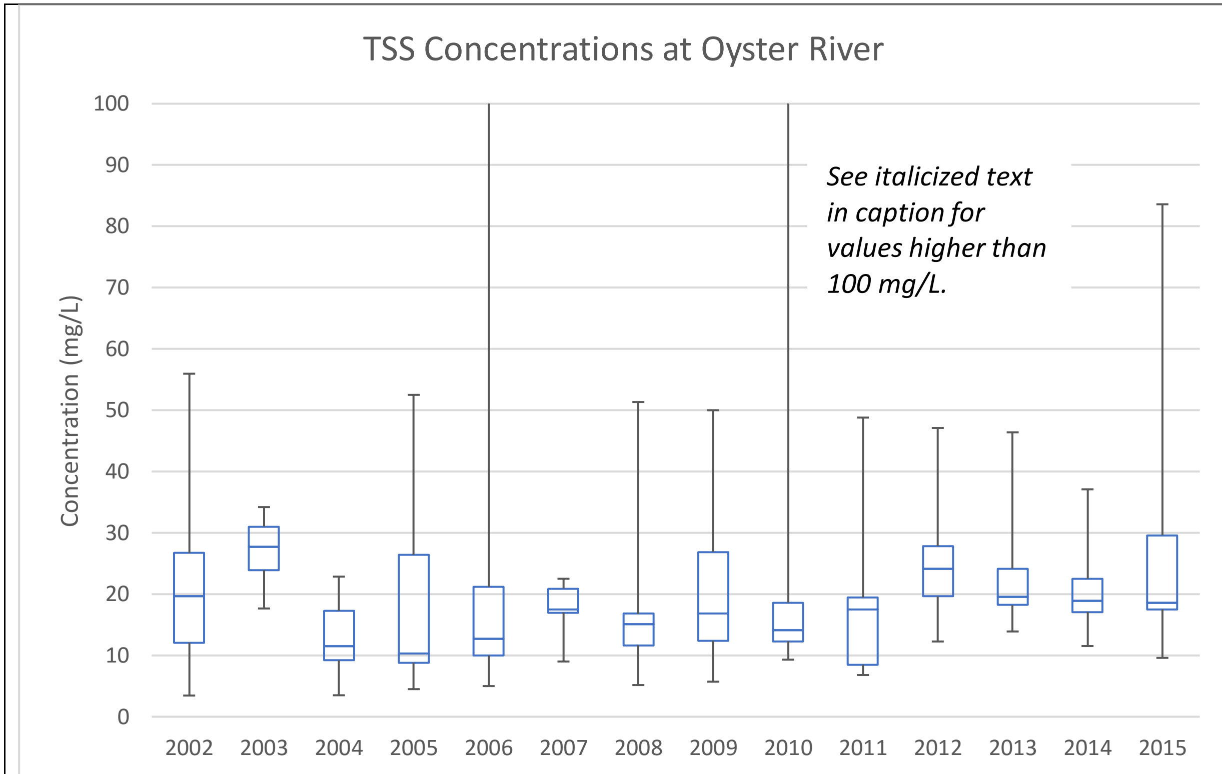
Monitoring Location (GRBGB)
Great Bay
(black circle with white plus sign)



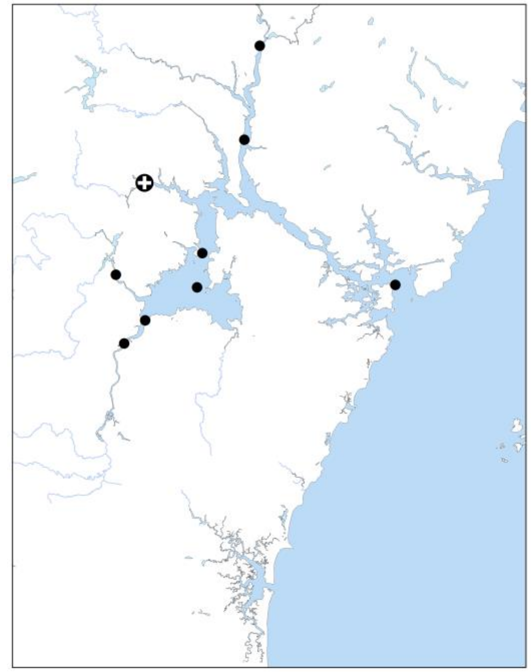
Station: GRBGB (Great Bay)

Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.



Monitoring Location (GRBOR)
Oyster River
(black circle with white plus sign)

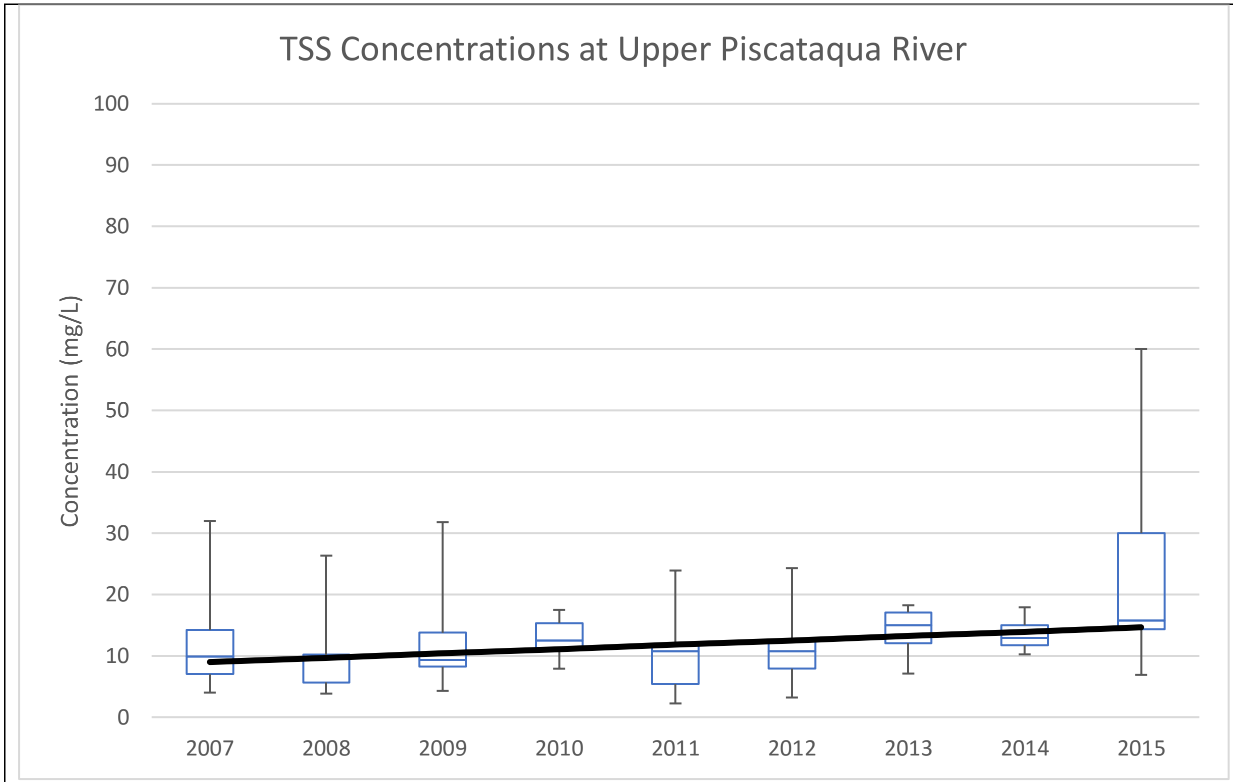


Station: GRBOR (Oyster River)

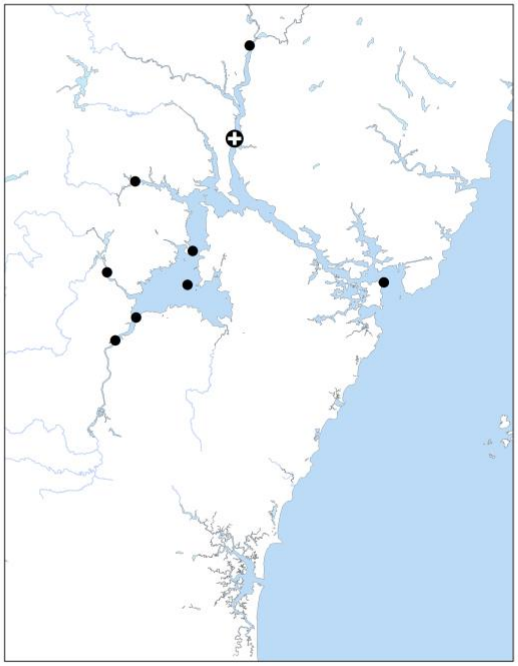
Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.

Values Higher Than 100 mg/L: 2006 = 130 mg/L; 2010 = 128 mg/L.



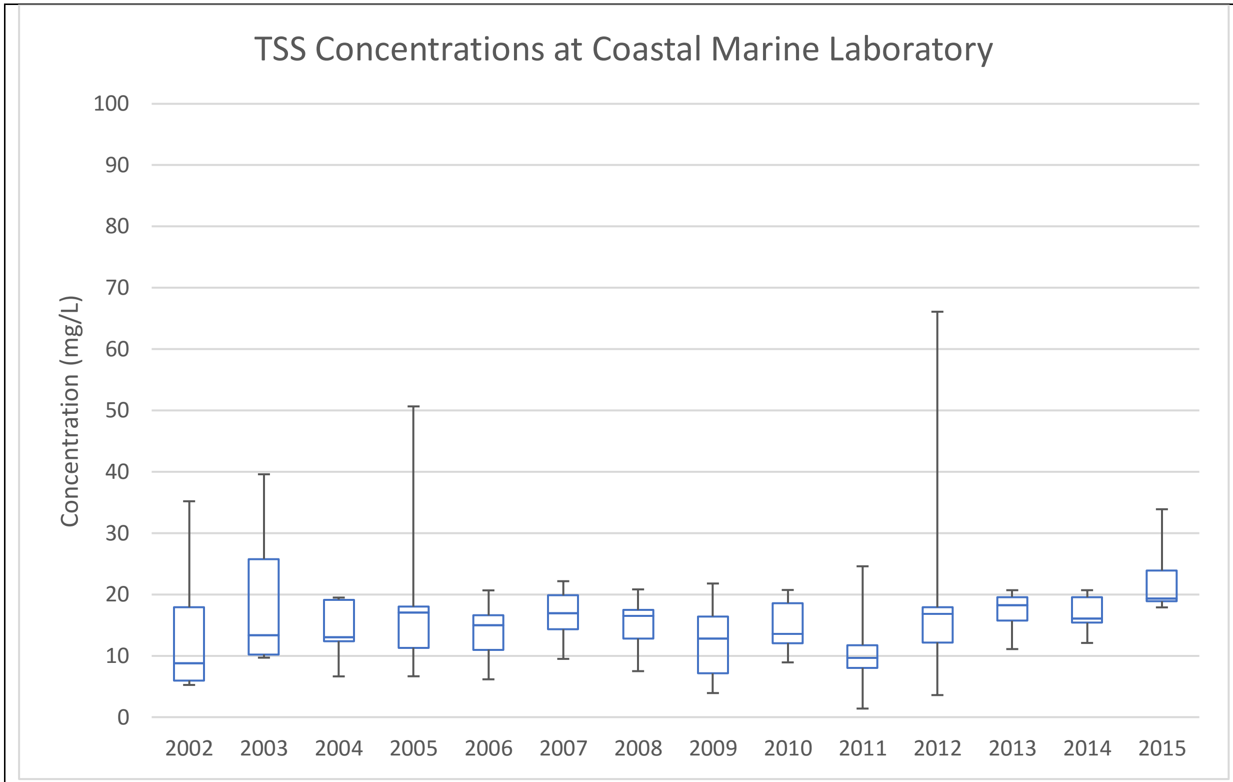
Monitoring Location (GRBUPR)
Upper Piscataqua River
(black circle with white plus sign)



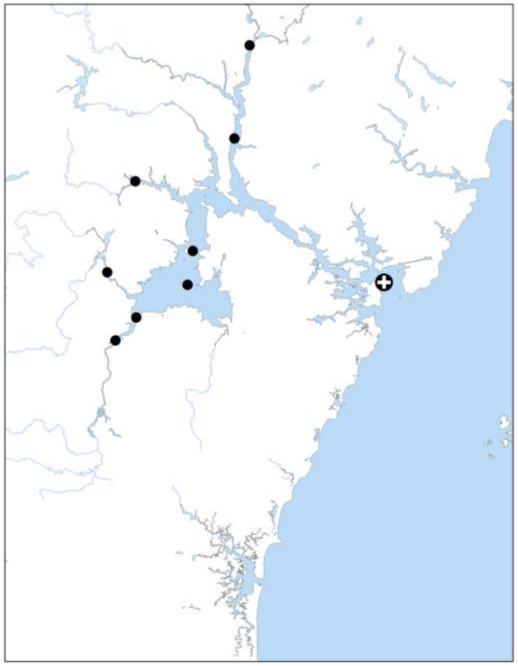
Station: GRBUPR (Upper Piscataqua River)

Long Term Trend: Significant increasing trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.



Monitoring Location (GRBCML)
Coastal Marine Laboratory
Portsmouth Harbor
(black circle with white plus sign)



Station: GRBCML (Coastal Marine Laboratory in Portsmouth Harbor)

Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.

Indicator: Nutrient loading to the Great Bay Estuary

Question
How much nitrogen is coming into the Great Bay Estuary?

(Currently, the only nutrient being quantified with regard to loading is nitrogen, although phosphorus may be added in the future. Therefore, this indicator may also be referred to as "nitrogen loading.")

Answer
Total nitrogen loading from 2012 to 2016 was 903 tons per year, which is 26% percent lower than the 2009 to 2011 levels (1224 tons per year). Low rainfall and corresponding stream flow during this period as well as significant reductions in nitrogen loading at municipal wastewater treatment facilities are the primary reasons for this decrease. Since the human population and impervious cover continue to increase, nitrogen management remains a high priority.

PREP Goal
Reduce nutrient loads to the estuaries and the ocean so that adverse, nutrient-related effects do not occur (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

Why This Matters
Nitrogen is one of many nutrients that are essential to life in the estuaries. However, high levels of nitrogen may cause problems like excessive growth of seaweed and phytoplankton. When these organisms die, bacteria and other decomposers use the available oxygen to break down the organic matter, decreasing oxygen availability for other organisms like fish. In addition, excessive algal growth can have negative impacts on sediment quality, seagrass, shellfish and benthic invertebrates.

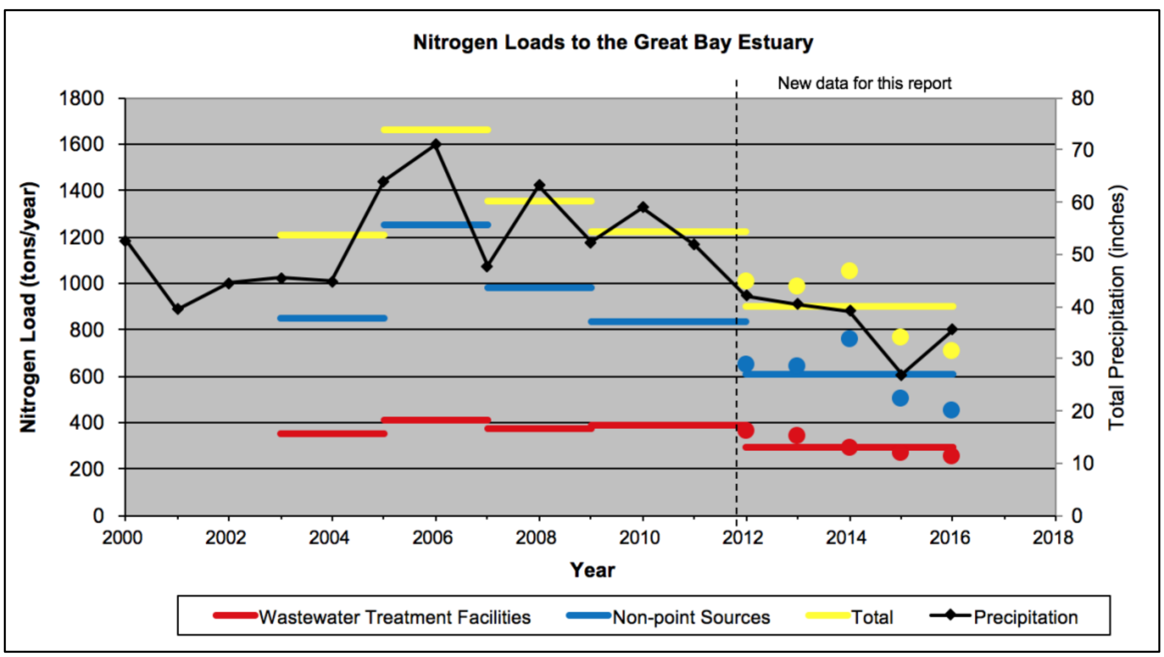


Figure NL-1. Nitrogen loads to the Great Bay Estuary. Precipitation data (indicated by the black line) are averaged between Portsmouth (Pease) and Greenland weather stations. Colored circles indicate annualized loads for 2012 through 2016. Data Source: NH Water Resources Research Center. Load estimates from 2003 - 2011 from NHDES (2010).

Explanation (from the 2018 State of Our Estuaries Report)
The average annual load of total nitrogen into the Great Bay Estuary from 2012 to 2016 was 903.1 tons per year (Figure NL-1). In 2016, the total nitrogen load was 707.8 tons per year, the lowest since consistent monitoring of loads began in 2003. Before 2003, there were three studies that assessed nitrogen loading to the Great Bay Estuary; they relied on data collected between 1987 and 1996

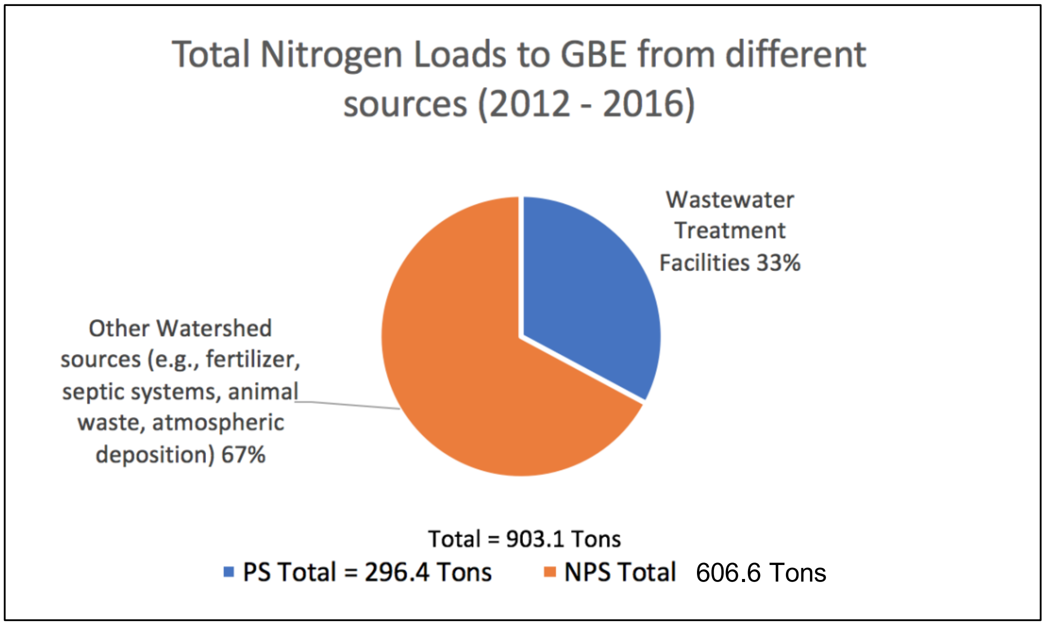


Figure NL-2. Total Nitrogen Loads from different sources (2012 to 2016). Data Source: NH Water Resources Research Center, UNH.

(NOAA/EPA 1988; Jones et al. 1992; Jones 2000) and estimated nutrient loading at approximately 715 tons per year. These three studies all used different methods from each other and from the current approach, but yielded very similar results (NOAA/EPA 1988; Jones et al., 1992; Jones 2000).

Figure NL-1 indicates that, since 2003, most of the variability relates to nitrogen from non-point sources. Non-point source nitrogen enters our estuaries in two major ways: 1) from stormwater runoff, which carries nitrogen from atmospheric deposition (including mobile transportation sources – cars, trucks, trains; and stationary stack emissions – smoke stacks), fertilizers, and animal waste to the estuaries; and 2) from groundwater contribution, which carries nitrogen from septic systems, sewer leakage and infiltrated stormwater runoff into streams, rivers and the estuary itself (NH DES 2014; Roseen et al. 2015). These non-point sources (NPS) accounted for 606.6 tons per year or 67% of the nitrogen load for 2012 – 2016 (Figure NL-2). It is important to understand that NPS loads are much more difficult to manage than point source loads because they come from a variety of sources, many of which are controlled by private land owners.

In addition, there are 17 municipal wastewater treatment facilities (WWTFs) that discharge treated wastewater into the bay or into rivers that flow into the bay. Point sources of nitrogen from these WWTFs account for 296.4 tons per year or 33% of the total nitrogen load for 2012-2016 (Figure NL-2). Of the 903.1 tons of total nitrogen entering the bay annually from 2012-2016, 506.0 tons were dissolved inorganic nitrogen (DIN), which is the most biologically available form of nitrogen. The DIN load was approximately evenly split between point and non-point sources (Figure NL-3). However, during the summer months when plant and algae growth is highest, point sources from WWTFs dominate DIN loading (Jones 2000; PREP 2012).

The highest loads since 2003 were seen in the 2005 to 2007 period (1,662.4 tons per year), a time that coincides with the highest total annual precipitation values (Figure NL-1). In comparison, the 2012 to 2016 period exhibited lower rainfall (Figure NL-1), a contributing factor to the 27% decrease in NPS loading since the 2009 – 2011 period. This underscores the association between nitrogen loading and run-off. Precipitation records (NH Climate Office 2014) and forecasts (Hayhoe et al. 2007) suggest that our region will continue to see periods of extreme highs and lows, which will continue to impact non-point source load.

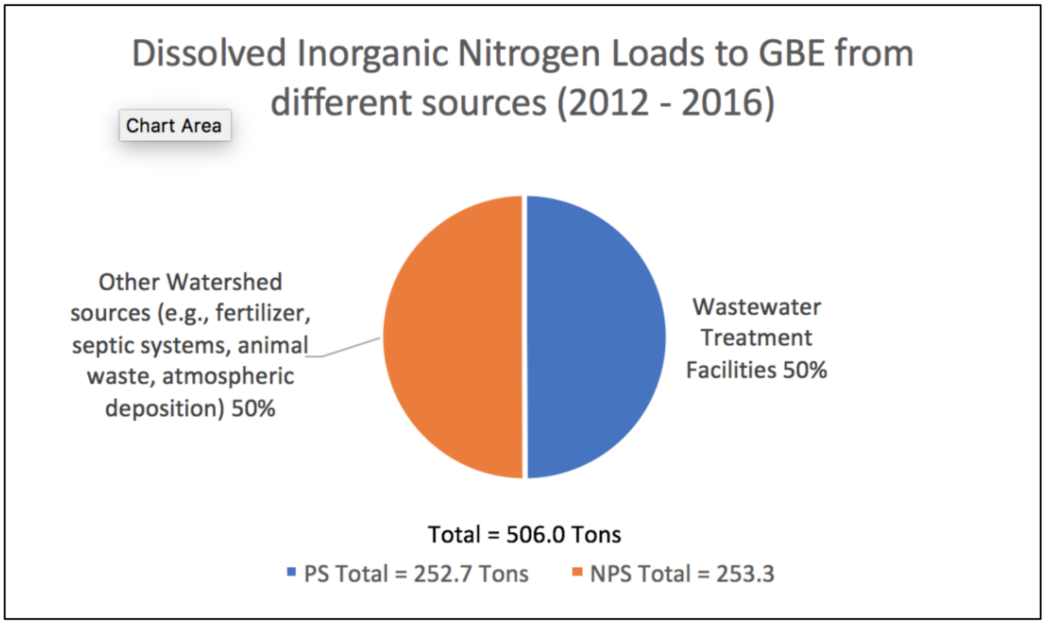


Figure NL-3. Dissolved Inorganic Nitrogen Loads from different sources (2012 to 2016). Data Source: NH Water Resources Research Center, UNH.

The nitrogen load from WWTFs for 2012 – 2016 was 296.4 tons, a decrease of 24% since the 2009 – 2011 period. In 2015 and 2016, the nitrogen load from WWTFs was 264.3 and 256.2 tons per year, respectively (Figure NL-1). Municipalities have made recent, substantial improvements to their WWTFs to reduce the amount of total nitrogen they discharge. Rochester, Dover, and Newmarket have recently completed major upgrades; Durham has reconfigured its facility and Portsmouth, Newington, and Exeter are in the process of upgrading their treatment plants. Each of these upgrades should result in less nutrients in wastewater effluent.

See the "*Estuary Health: Stress & Resilience*" section of the 2018 State of Our Estuaries Report (PREP 2017b) for more on how nitrogen loading relates to other indicators, such as phytoplankton, seaweed and eelgrass.

Methods and Data Sources

For the purposes of this analysis, the following sources were identified that contribute to the nitrogen load to the Great Bay Estuary (Figure NL-5). It is assumed that these represent a complete accounting of contributing sources.

- Municipal Wastewater Treatment Facilities (WWTFs)
- Non-Point Sources (NPS) in Watersheds
- Groundwater Discharge to the Estuary
- Atmospheric Deposition to the Estuary

Nitrogen loads were calculated for the portion of the Great Bay Estuary system north and west of Dover Point (Great Bay, Little Bay, and the Upper Piscataqua River – the "study area"). A complete analysis of nitrogen loads to the Lower Piscataqua River was not completed, although the delivered loads from WWTFs in the Lower Piscataqua River were included in the calculations. The methods for the nitrogen loading calculations follow the procedures in NHDES (2010, Appendix A). Brief summaries of the methods and any deviations from the procedures are described below.

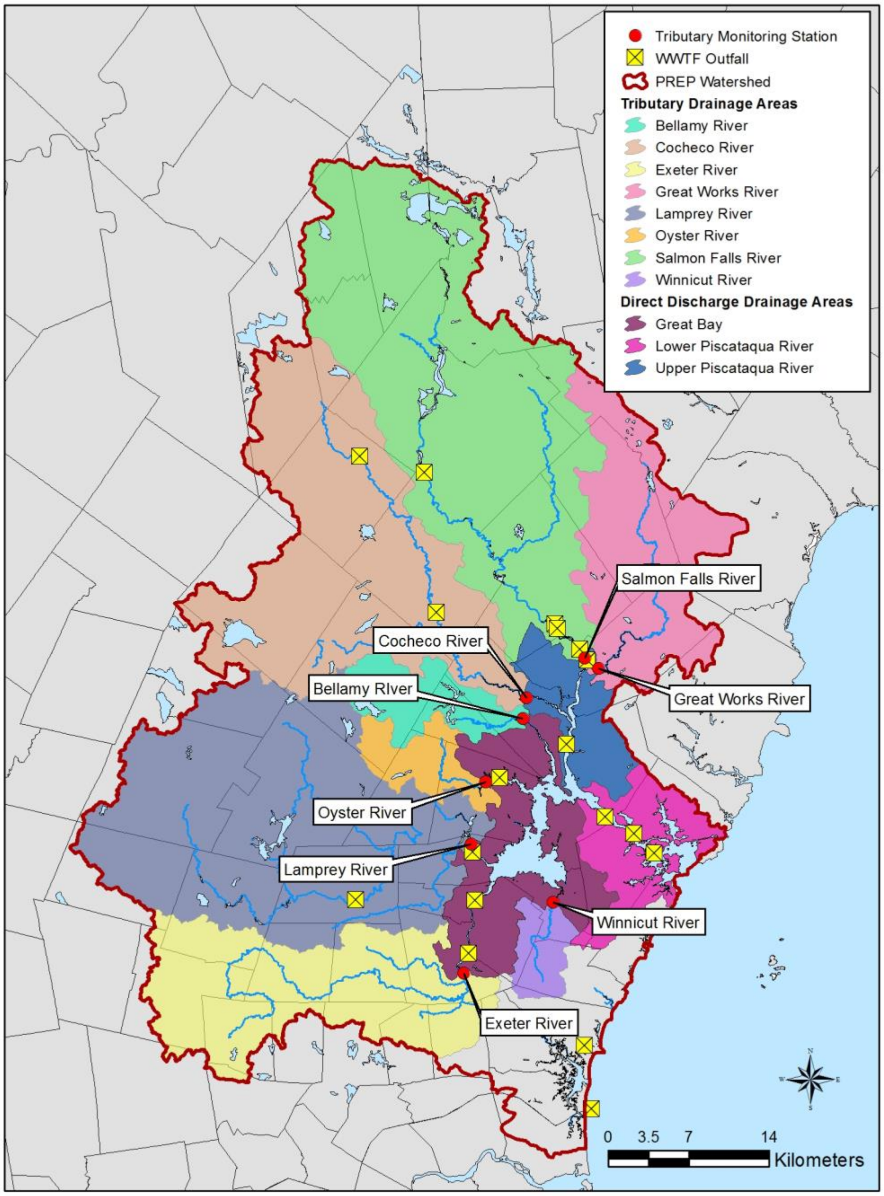


Figure NL-4. Watersheds draining to the Great Bay Estuary. Wastewater treatment plant facilities indicated with yellow markers.

Point Source Discharges from WWTFs

The annual and overall average TN and DIN load from each WWTF for 2012-2016 was estimated by multiplying the average concentration by the average effluent flow over the time period of interest (Table NL-2; Figure NL-7). If nitrogen data were not available for a WWTF, then the average TN and DIN concentrations from monitored WWTFs were used. Monthly average effluent flows from the WWTFs were compiled from facility operating reports and then averaged over the time period of interest. For WWTFs with intermittent discharges, the monthly average flow was calculated from the total volume of effluent discharged in the month, divided by the number of days in the month.

For WWTFs that discharge to rivers upstream of the estuary, some of the nitrogen discharged from the WWTF is lost during transit to the estuary. For WWTFs that discharge to the Lower Piscataqua River, some of the nitrogen discharged from the WWTF does not reach as far upstream as Dover Point due to the limits of the tidal water movement. For these WWTFs, the nitrogen load should be reported in terms of its “delivered load” to the Great Bay Estuary study area. The delivered load was calculated by multiplying the discharged load by a “delivery factor,” which represents the percent of the discharged load that is delivered to the study area (Table NL-2; Figure NL-8). The delivery factors for discharges to freshwater rivers were calculated based on travel time to the estuary following the methods of NHDES (2010). The delivery factors for WWTFs that discharge to the Lower Piscataqua River were calculated from particle tracking models used in NHDES (2010) or more recent models provided by Portsmouth and Kittery (ASA 2011a, ASA 2011b).

Non-Point Sources in Major Watersheds

The TN and DIN loads to the estuary from the eight major watersheds were calculated using measurements of TN and DIN concentrations and stream flow (Table NL-4). The U.S. Geological Survey (USGS) LOADEST model was used to develop a calibrated model relating TN and DIN concentrations and daily average stream flow (Runkel et al. 2004). The LOADEST model was set to select the optimal model based on the calibration dataset (Table NL-3) and all the parameters in the chosen model were included. The inputs to the LOADEST model were monthly measurements of TN and DIN concentrations and daily average stream flow at the tidal dam for each river. For TN and DIN concentrations, non-detected samples were represented by one-half of the reporting detection limit. Stream flow at the tidal dams was estimated from USGS stream gages in the watersheds and drainage area transposition factors (Table NL-1). The output of the LOADEST model was both the average load for the study period and the monthly loads during the study period. Monthly loads were summed to determine the annual loads during

Table NL-1: USGS stream gages and drainage area transposition factors for estimating stream flow at the tributary monitoring stations.

Tributary Monitoring Station	Watershed Area for Station (sq miles)	USGS Streamgage Number	Flow Multiplier for Transpositions	USGS Watershed Area for Stream Gage (sq miles)
Bellamy River[1]	27.26	Cocheco 01072800	0.341227	79.9
		Oyster 01073000	2.253228	12.1
Cocheco River	175.28	Cocheco 01072800	2.193704	79.9
Exeter River	106.90	Exeter 01073587	1.683529	63.5
Great Works River	86.69	Cocheco 01072800	1.085013	79.9
Lamprey River	211.91	Lamprey 01073500	1.145435	185
Oyster River	19.85	Oyster 01073000	1.640625	12.1
Salmon Falls River	235.00	Lamprey 01073500	1.270258	185
Winnicut River	14.18	Winnicut 1073785	1.005443	14.1

1. Flow in the Bellamy River was estimated by averaging cubic feet per square mile (cfsm) transpositions from the Cocheco and Oyster River gages.

the 2012-2016 time period. The NPS delivered load from watersheds was calculated by subtracting the delivered nitrogen load due to upstream WWTFs from the total measured load at each of the tidal dams (Table NL-4).

Non-Point Sources from Small Watersheds Adjacent to the Estuary

Runoff from land adjacent to the estuary was not captured in the load measurements at the tidal dams. Therefore, TN and DIN loads from these areas had to be estimated. Using the data from the major watersheds, relationships were developed between the percent of developed land and the TN and DIN yields (load per unit drainage area) after correcting for upstream WWTF discharges. The NPS loads from the small adjacent watersheds were estimated using the percent of developed land in the watershed and the corresponding regression equations (Figure NL-5). The regressions were developed for a range of land use from 9.6 to 27.5% developed. These small adjacent watersheds typically were more developed than this range (14.6 to 42.6%). Therefore, the use of these regressions is an extrapolation of a linear model outside the calibration range. For annual loading estimates from land adjacent to the estuary, annual NPS loading from the major watersheds was used in regression equations with % developed land use.

Groundwater Discharge

Some groundwater flow and nitrogen loading was accounted for in the NPS loading estimates for watersheds. However, regional groundwater flow was also expected to contribute some nitrogen to the estuaries. Ballestero et al. (2004) measured the nitrogen loading rate from groundwater seeps to be 0.13 tons N/yr per mile of tidal shoreline. This loading rate was applied to the length of tidal shoreline in the estuary to estimate the groundwater loading rate. The groundwater loading rate was assumed to be constant because no other information was available. All of the nitrogen contributed by this source was assumed to be in the DIN form (Table NL-5; Figure NL-7).

Atmospheric Deposition

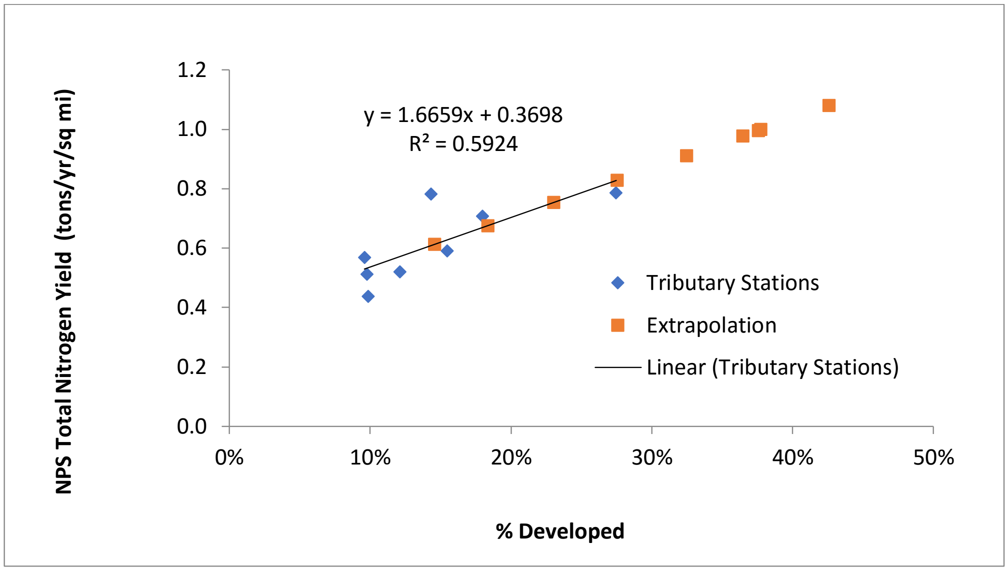
Atmospheric deposition of nitrogen directly to the estuary surface was estimated using wet deposition data provided by the University of New Hampshire Water Quality Analysis Laboratory (UNH WQAL). The UNH WQAL collected wet deposition (rain and snow) on a weekly basis at Thompson Farm (TF) in Durham, NH and analyzed the samples for total dissolved nitrogen (TDN) and DIN. Particulate nitrogen was assumed to be negligible in the wet deposition samples and therefore TDN in wet deposition was assumed to equal wet deposition TN. Volume weighted mean concentrations of TN and DIN in TF wet deposition were determined for the time period of interest and multiplied by the rainfall amount as recorded by the climate reference network (CRN) at TF (CRN station NH_Durham_2_SSW) over the same time period to determine wet deposition. Dry deposition was estimated as 58% of wet TN deposition (ClimCalc ratio of 0.58 dry to wet deposition for TF, Ollinger et al. 2001). Wet and dry deposition were summed to determine the total deposition of TN and inorganic N. For 2012-2016, this resulted in a wet deposition rate of 1.01 tons TN/sq mi/yr, a dry deposition rate of 0.60 tons TN/sq mi/yr and a total deposition rate of 1.63 tons TN/sq mi /yr. This loading rate was assumed to be constant over the 13.6 sq mi estuary resulting in 22.13 tons of TN load to the estuary per year. Atmospheric deposition of nitrogen to the land surface is accounted for in the NPS load contribution from the tributary watersheds and the land areas adjacent to the estuary. For annual estimates of deposition see Table NL-5.

Nitrogen Load Summary

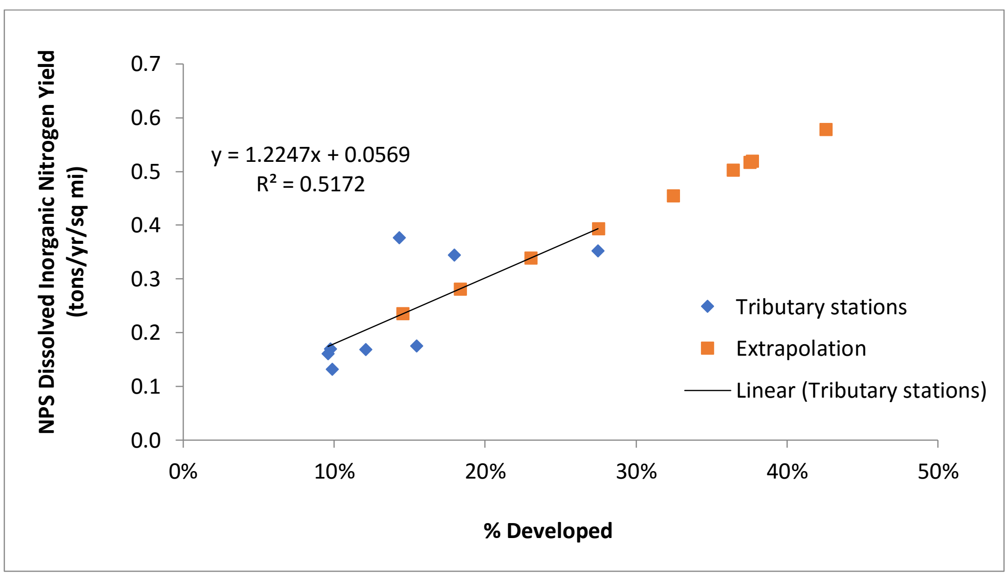
The 2012-2016 and annual TN and DIN loads were calculated by summing the individual components of the nitrogen load: Delivered WWTF loads, NPS loads from watersheds above the tidal dams, NPS loads from the land area below the tidal dams, groundwater loads, and atmospheric deposition to the estuary (Table NL-5). Subtotals for WWTFs and NPS were also calculated.

Figure NL-5. Relationship between non-point source nitrogen yields (2012-2016) and developed land use in major watersheds and extrapolations to small watersheds downstream of dams.

(A) Total Nitrogen



(B) Dissolved Inorganic Nitrogen



Data Sources
For the nitrogen load from WWTFs, flow data were obtained from monthly operating reports filed by the WWTFs. Nitrogen concentrations in WWTF effluent were obtained from the WWTFs and NHEP (2008).

The loading from the tidal tributaries was estimated from monthly (March-December) nutrient concentrations collected by the PREP Tidal Tributary Monitoring Program at the head of tide stations on the Winnicut, Exeter, Lamprey, Oyster, Bellamy, Cocheco, Salmon Falls and Great Works Rivers. Flow data for the Winnicut, Exeter, Lamprey, Oyster and Cocheco Rivers were obtained from the USGS Streamflow Monitoring Program.

Additional Results (Beyond What Was Reported in the SOOE)

The TN and DIN loads from the 17 WWTFs in the Great Bay Estuary watershed are shown in Table NL-2. The WWTF with the largest delivered nitrogen load was Dover followed by Rochester and Exeter. These three WWTFs accounted for 61% of the nitrogen delivered to the estuary by all WWTFs combined. Following these three WWTFs, Newmarket, Portsmouth, Durham and Somersworth have the highest delivered nitrogen loads. From 2012 to 2016, total nitrogen and DIN from WWTFs upstream of dams decreased by over 50% and 60%, respectively (Table NL-5).

The TN and DIN loads from the eight major tributaries are shown in Table NL-4 and Figure NL-8. The Cocheco, Salmon Falls and Lamprey River watersheds delivered the most NPS total nitrogen, but this is in part due to watershed size and the extent to which the watershed is developed. For example, the Salmon Falls watershed has the third highest delivery of total nitrogen, but it has the lowest level of "area-normalized" total nitrogen loading; at 235 sq mi, it is the largest watershed, and less than 10% of the watershed is developed (Table NL-4). On an area-normalized basis, the Winnicut, Cocheco and Oyster watersheds deliver the most total nitrogen to the estuary.

Technical Advisory Committee (TAC) Discussion Highlights
The Relationship Between Nitrogen Loading and Eelgrass Habitat Health
This topic was the focus of two consecutive TAC meetings on May 9-10, 2017; notes and presentations are available (PREP 2017). No votes were taken after the discussion but participants were asked to fill out a "matrix," which rated the probability of different stressors exerting negative pressure on eelgrass health. Figure NL-6 indicates that, of the 26 participants at the meeting, 22 rated nitrogen as a 3 or higher (on a scale of 1 to 5, 5 being highest) in terms of the probability that nitrogen is an important stressor on eelgrass habitat health in the Great Bay Estuary; four participants rated nitrogen lower than "2" as a stressor on eelgrass in the Great Bay Estuary.

One of the concerns about nitrogen is that it can fuel excessive blooms of phytoplankton and seaweeds (see individual "Phytoplankton" and "Seaweed" sections in this report.) At the May 9-10, 2017 meeting, the three external advisors to the TAC advocated that all light-attenuating components (e.g., seaweeds, TSS, colored dissolved organic matter (CDOM) and phytoplankton) be considered together, not separately, because these components act in an additive fashion.

Another concern about nitrogen is that it can lead to degraded sediment quality, which has impacts for eelgrass as well as benthic invertebrates such as shellfish. For more on the relationship between nitrogen loading and overall ecosystem health and resilience, see the "Stress and Resilience" section of the State of Our Estuaries Report (PREP 2017b) and the "External Advisors Statement Regarding Eelgrass Stressors in Great Bay Estuary" (Kenworthy et al. 2017).

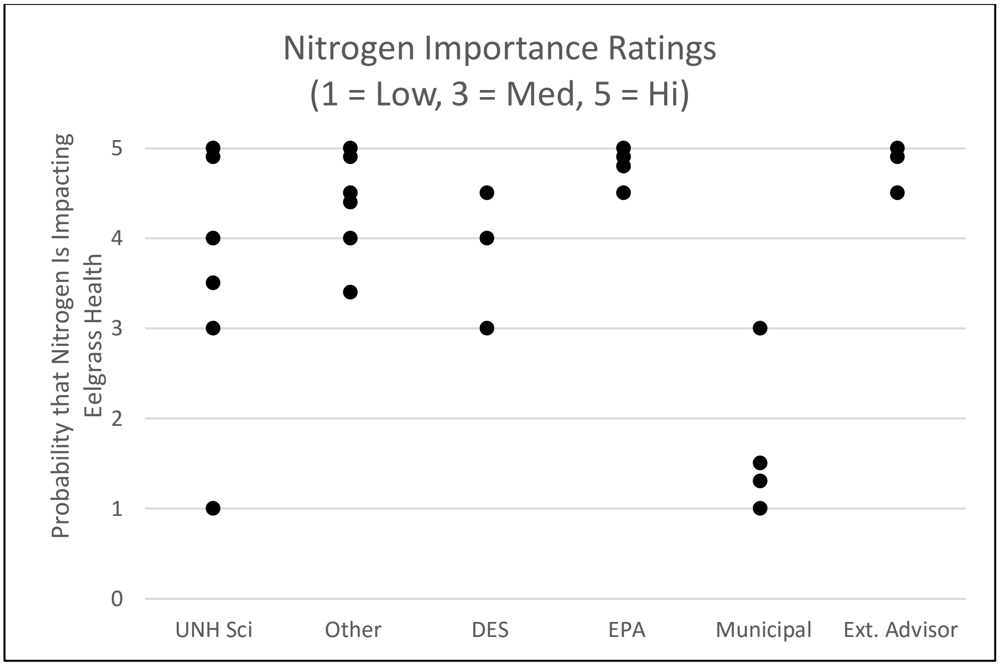


Figure NL-6. Results of "matrix" activity asking participants to rate the importance of nitrogen as a stressor on eelgrass. Results are categorized by segments of the community, from left to right: UNH Scientists, Other (e.g., non-profit organizations), NH DES, US EPA, Municipal Representatives, and External Advisors. Dots that are touching represent the same numeric rating, but are separated for visual clarity.

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Table NL-2: Estimated nitrogen loads from wastewater treatment facilities in 2012-2016

WWTF	Discharge Location (river)	Average Monthly Flow (mgd)	Data Source	Average TN (mg/L)	Average DIN (mg/L)	TN load (tons/yr)	DIN load (tons/yr)	Delivery Factor	Delivered TN load (tons/yr)	Delivered DIN load (tons/yr)
Rochester	Cocheco	3.0	City of Rochester Data	16.9	16.3	76.4	73.9	75.56%	57.7	55.9
Exeter	Exeter (tidal)	1.6	Town of Exeter Data for TN	22.6	19.0	55.5	46.6	100.00%	55.5	46.6
Newfields	Exeter (tidal)	0.1	2011 Town of Newfield Data for TN; 2002 data from Bolster et al. (2003) for DIN	21.5	19.0	2.9	2.6	100.00%	2.9	2.6
N Berwick	Great Works	0.2	Estimated	18.2	15.3	5.7	4.8	51.56%	2.9	2.5
Epping	Lamprey	0.2	Estimated	18.2	15.3	6.8	5.7	58.20%	4.0	3.3
Newmarket	Lamprey (tidal)	0.5	Town of Newmarket Data for TN	39.1	32.9	31.1	26.2	100.00%	31.1	26.2
Newington	Lower Piscataqua	0.1	Town of Newington Data	17.6	16.1	2.8	2.6	26.34%	0.8	0.7
Portsmouth	Lower Piscataqua	4.3	City of Portsmouth Data	30.0	21.7	194.9	141.0	12.50%	24.4	17.6
Kittery	Lower Piscataqua	0.9	NHEP 2008 and Kittery 2015 for TN	19.4	16.3	26.6	22.4	14.20%	3.8	3.2
Pease	Lower Piscataqua	0.6	2008 City of Portsmouth Data for TN	8.7	7.4	8.5	7.2	26.34%	2.2	1.9
Durham	Oyster (tidal)	0.9	Town of Durham Data	12.8	10.0	17.5	13.7	100.00%	17.5	13.7
Somersworth	Salmon Falls	1.4	City of Somersworth NH for TN Data	6.8	5.7	14.8	12.5	94.94%	14.1	11.8
Berwick	Salmon Falls	0.2	NHEP (2008) for TN Data	16.7	14.0	5.3	4.4	94.55%	5.0	4.2
Milton	Salmon Falls	0.1	Estimated	18.2	15.3	2.0	1.6	65.70%	1.3	1.1
Rollinsford	Salmon Falls	0.1	Estimated	18.2	15.3	2.1	1.8	98.96%	2.1	1.7
S Berwick	Salmon Falls (tidal)	0.3	2010 S Berwick Sewer District Data for TN; DIN Estimated using measured TN and DIN:TN at S Berwick in 2008	5.9	4.6	2.5	2.0	100.00%	2.5	2.0
Dover	Upper Piscataqua (tidal)	2.5	City of Dover Data	18.2	15.3	68.7	57.8	100.00%	68.7	57.8

1. Light grey cells: no data were available for this WWTF. For these WWTFs, TN was assumed to be the average TN concentration in monitored WWTFs (18.2 mg/L) and DIN was assumed based on the average TN and the average ratio of DIN to TN in monitored WWTFs (84.1%).
2. Dark grey cells: no DIN data were available and DIN was estimated as 84.1 % of TN for that WWTF.
3. The flows in this table are annual averages. The monthly average flows from NPDES discharge monitoring reports were averaged over the 60 months in the 5-year study period.
4. Delivery factor is the percent of the discharged load that is delivered to the GB/UPR estuary. For WWTFs in the watersheds, attenuation loss was estimated using the travel time for water between the WWTF outfall and the estuary and a first order loss coefficient. For the Lower Piscataqua River WWTFs, the delivery factor was estimated from the percent of particles in GB, LB, and Upper Piscataqua River at steady state in the Dartmouth particle tracking model (NHDES 2010) or particle tracking models provided by Portsmouth and Kittery (ASA 2011a, 2011b).
5. Italicized WWTFs are in Maine.

Table NL-3: LOADEST total nitrogen (TN) and Dissolved Inorganic Nitrogen (DIN) models for major tributaries in 2012-2016.

	LOADEST TN (tons/yr) Model			LOADEST DIN (tons/yr) Model		
Tributary	**R^2 (%)**	**PPCC**	**Model**	**R^2 (%)**	**PPCC**	**Model**
Bellamy	96.1	0.9921	1	86.4	0.9867	4
Cocheco	90.1	0.9839	9	83.1	0.9881	7
Exeter	99.0	0.9827	2	93.1	0.9822	6
Great Works	96.0	0.9892	2	89.2	0.9670	6
Lamprey	97.8	0.9934	3	91.4	0.9927	6
Oyster	98.2	0.9850	9	94.7	0.9667	9
Salmon Falls	97.2	0.9584	1	94.0	0.9874	8
Winnicut	98.8	0.9858	5	94.5	0.9936	9

1. TN loads estimated using USGS software "LOADEST" with water quality data from the PREP Tidal Tributary Monitoring Program and streamflow data from USGS.
2. R^2 is a measure of the quality of the loading regression model (0=worst, 1=best).
3. PPCC (probability plot correlation coefficient) is a measure of the normality of the residuals (0=worst, 1=best).
4. The model number refers to the specific model chosen. The models are defined in the LOADEST user's manual (Runkel et al. 2004).

Table NL-4: LOADEST, point (WWTFs) and non-point source nitrogen loads and yields from Great Bay Estuary watersheds 2012-2016.

Site	Area (mi^2)	TN Load (tons/yr)	DIN Load (tons/yr)	Area-Normalized TN Load (tons/yr/mi^2)	Area-Normalized DIN Load (tons/yr/mi^2)	Upstream WWTF Delivered TN (tons/yr)	Upstream WWTF Delivered DIN (tons/yr)	NPS TN Load (tons/yr)	NPS DIN Load (tons/yr)	Area-Normalized NPS TN Load (tons/yr/mi^2)	Area-Normalized NPS DIN Load (tons/yr/mi^2)	% Developed
Bellamy	27.26	16.10	4.79	0.59	0.18	0.00	0.00	16.10	4.79	0.59	0.18	15.46%
Cocheco	175.28	194.67	121.97	1.11	0.70	57.75	55.87	136.92	66.09	0.78	0.38	14.32%
Exeter	106.90	55.52	18.01	0.52	0.17	0.00	0.00	55.52	18.01	0.52	0.17	12.10%
Great Works	86.69	53.64	17.68	0.62	0.20	2.91	2.45	50.73	15.23	0.59	0.18	9.59%
Lamprey	211.91	112.51	39.39	0.53	0.19	3.97	3.34	108.55	36.05	0.51	0.17	9.77%
Oyster	19.85	14.05	6.84	0.71	0.34	0.00	0.00	14.05	6.84	0.71	0.34	17.98%
Salmon Falls	235.00	124.91	50.05	0.53	0.21	22.43	18.86	102.48	31.19	0.44	0.13	9.86%
Winnicut	14.18	11.13	5.00	0.79	0.35	0.00	0.00	11.13	5.00	0.79	0.35	27.48%
Total	**877**	**582.5**	**263.7**			**87.1**	**80.5**	**495.5**	**183.2**			

1. TN and DIN loads estimated using USGS software "LOADEST" with water quality data from the PREP Tidal Tributary Monitoring Program and streamflow data from USGS.
2. The following WWTFs are located upstream of the tributary monitoring stations. The Epping WWTF is upstream of the Lamprey River station. The Rochester and Farmington WWTFs are upstream of the Cocheco River station. The Milton, Berwick, Somersworth and Rollinsford WWTFs are upstream of the Salmon Falls River station. The North Berwick WWTF is upstream of the Great Works River station.
3. Upstream WWTF loads were reduced using an attenuation loss model to estimate the delivered load to the estuary.
4. Percent of watershed in developed land use classes are from the 2011 National Land Cover Dataset.

Table NL-5: Summary of nitrogen loads to the Great Bay Estuary from 2012-2016.

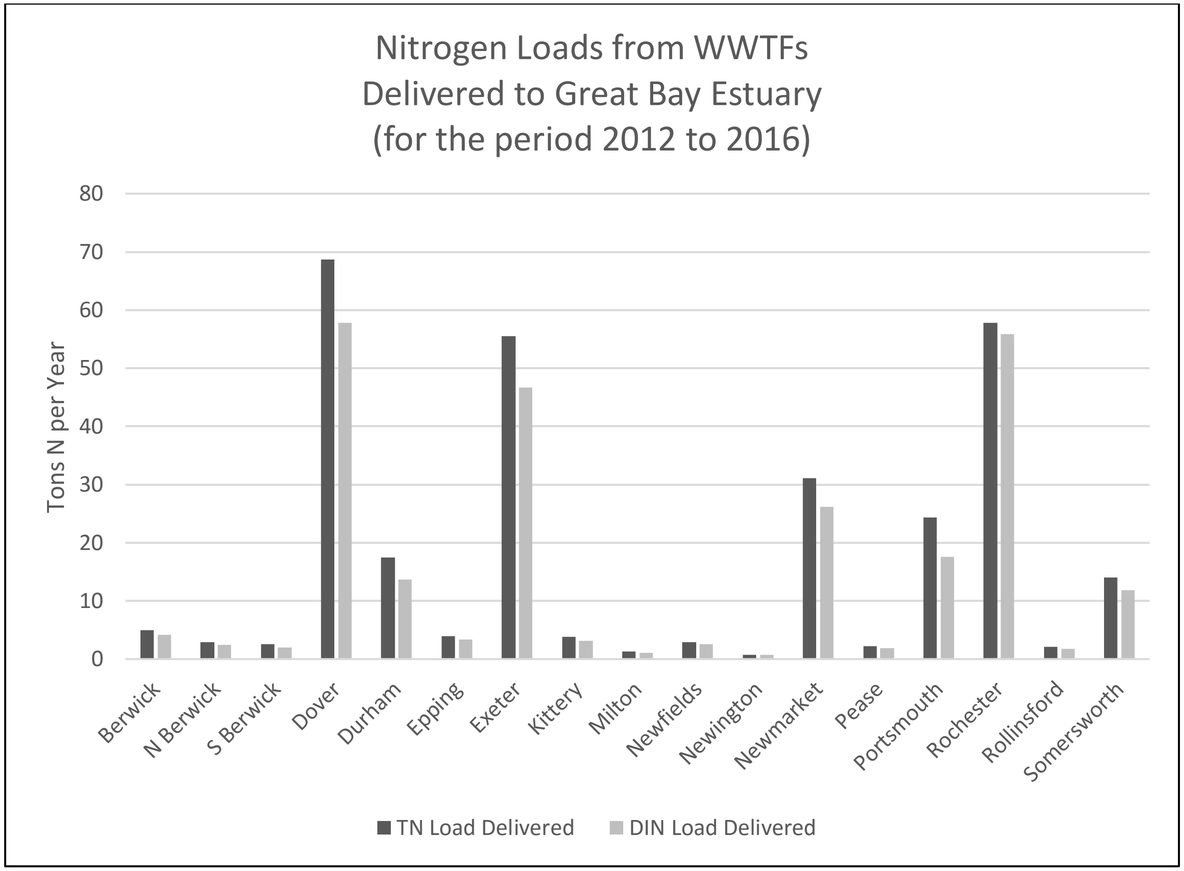
	2012-2016		2012		2013		2014		2015		2016	
Source	TN Load (tons/year)	DIN Load (tons/year)	TN Load (tons/year)	DIN Load (tons/year)	TN Load (tons/year)	DIN Load (tons/year)	TN Load (tons/year)	DIN Load (tons/year)	TN Load (tons/year)	DIN Load (tons/year)	TN Load (tons/year)	DIN Load (tons/year)
WWTFs in Lower Piscataqua	31.1	23.4	33.1	25.5	34.0	22.8	26.7	21.3	27.0	21.7	35.3	25.6
WWTFs Downstream of Dam	178.2	148.8	177.7	150.4	174.3	148.3	208.9	174.3	176.8	149.8	151.7	120.8
WWTFs Upstream of Dam	87.1	80.5	153.2	154.6	133.0	127.1	53.3	44.8	60.5	52.6	69.2	61.9
NPS Upstream of Dam	495.5	183.2	535.1	162.4	528.7	172.9	628.9	249.6	394.8	158.8	355.8	133.9
NPS Downstream of Dam	74.51	35.36	74.5	35.4	71.6	28.3	94.3	46.4	67.3	36.3	63.8	39.5
NPS Groundwater	14.55	14.55	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
NPS Atmospheric Deposition to Tidal Waters	22.13	20.19	21.1	19.6	27.1	23.1	23.1	20.1	21.8	21.2	17.5	16.8
Subtotal - WWTF	**296.4**	**252.7**	364.0	330.4	341.3	298.2	288.9	240.4	264.3	224.1	256.2	208.3
Subtotal - Non-point sources	**606.6**	**253.3**	645.2	231.9	641.9	238.9	760.8	330.7	498.5	230.8	451.6	204.7
Total	**903.1**	**506.0**	1009.2	562.4	983.3	537.1	1049.7	571.1	762.8	455.0	707.8	413.1

1. WWTF = Wastewater Treatment Facility.
2. NPS = Non-Point Source.
3. Light grey highlighted values in 2012 – Regressions for TN and DIN NPS load vs. % developed for 2012 were not statistically significant. The average NPS downstream of dams for the entire 2012-2016 time period was used for 2012 instead.
4. Dark grey values in 2013 - Regressions for TN and DIN NPS load vs. % developed for 2013 approached significance ($p=0.060$, $R^2=0.47$ for both TN and DIN) and were used to estimate NPS load for 2013.
5. Dark grey value in 2014 - Regression for DIN NPS load vs. % developed for 2014 approached significance (p=0.116, R2=0.36) and was used to estimate NPS load for 2014. Other annual regressions for TN and DIN NPS load vs. % developed were significant at the $p<0.05$ level and model R^2 ranged from 0.69-0.86.

Table NL-6: Summary of nitrogen loads as percentages to the Great Bay Estuary from 2012-2016.

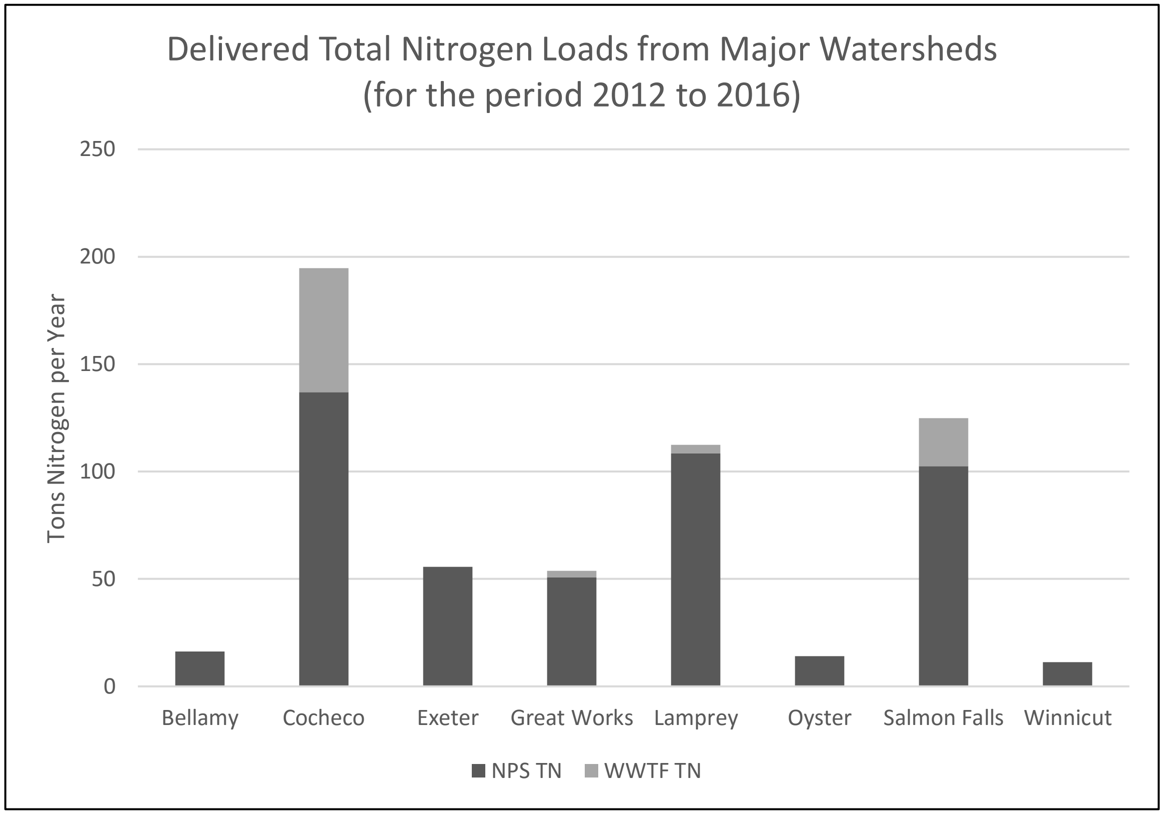
	2012-2016		2012		2013		2014		2015		2016	
Source	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**	**TN Load (tons/year)**	**DIN Load (tons/year)**
WWTFs in Lower Piscataqua	3.4%	4.6%	3.3%	4.5%	3.5%	4.3%	2.5%	3.7%	3.5%	4.8%	5.0%	6.2%
WWTFs Downstream of Dam	19.7%	29.4%	17.6%	26.7%	17.7%	27.6%	19.9%	30.5%	23.2%	32.9%	21.4%	29.2%
WWTFs Upstream of Dam	9.6%	15.9%	15.2%	27.5%	13.5%	23.7%	5.1%	7.9%	7.9%	11.6%	9.8%	15.0%
NPS Upstream of Dam	54.9%	36.2%	53.0%	28.9%	53.8%	32.2%	59.9%	43.7%	51.8%	34.9%	50.3%	32.4%
NPS Downstream of Dam	8.3%	7.0%	7.4%	6.3%	7.3%	5.3%	9.0%	8.1%	8.8%	8.0%	9.0%	9.6%
NPS Groundwater	1.6%	2.9%	1.4%	2.6%	1.5%	2.7%	1.4%	2.5%	1.9%	3.2%	2.1%	3.5%
NPS Atmospheric Deposition to Tidal Waters	2.5%	4.0%	2.1%	3.5%	2.8%	4.3%	2.2%	3.5%	2.9%	4.7%	2.5%	4.1%
Subtotal - WWTF	**32.8%**	**49.9%**	**36.1%**	**58.8%**	**34.7%**	**55.5%**	**27.5%**	**42.1%**	**34.7%**	**49.3%**	**36.2%**	**50.4%**
Subtotal - Non-point sources	**67.2%**	**50.1%**	**63.9%**	**41.2%**	**65.3%**	**44.5%**	**72.5%**	**57.9%**	**65.3%**	**50.7%**	**63.8%**	**49.6%**

Figure NL-7: Estimated total nitrogen and dissolved inorganic nitrogen loads from wastewater treatment facilities in 2012-2016.



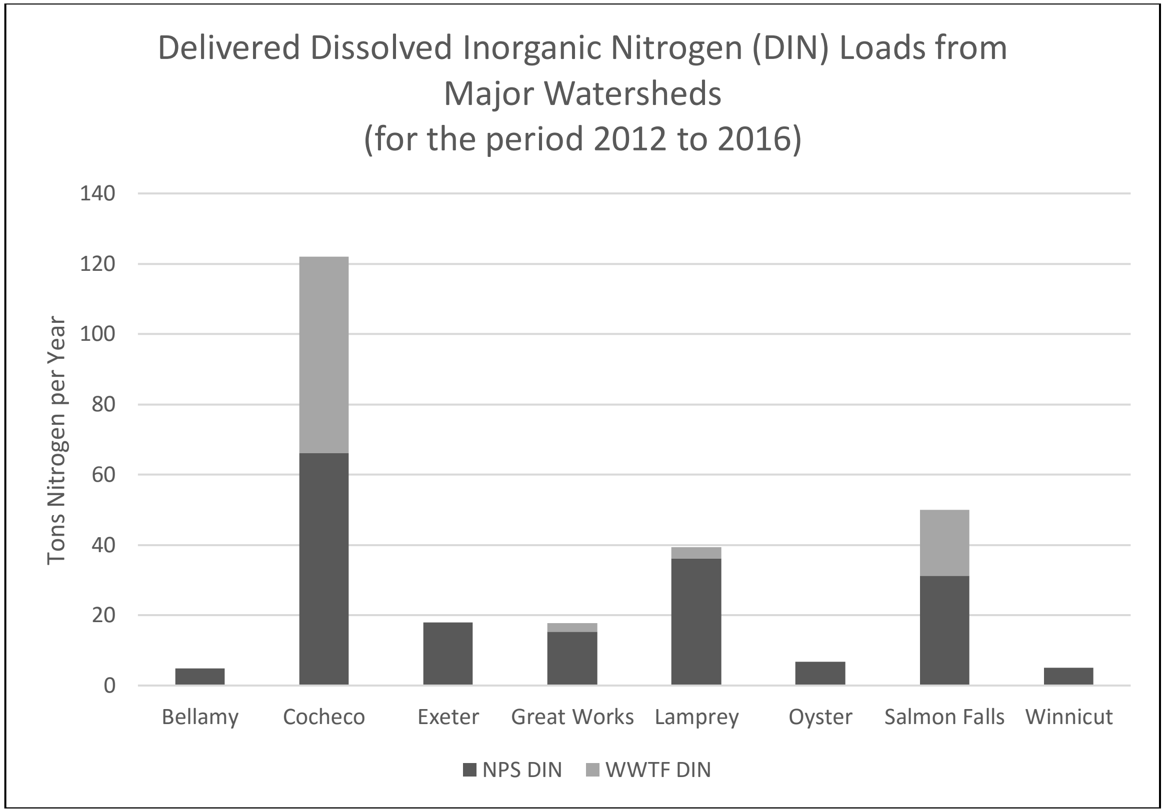
1. Values reported above combine data from 2012 through 2016, which does not reveal improvements made by WWTFs in the latter part of this period (e.g., for example, at Dover, Rochester and Durham.) Please see Table NL-5 to see changes by each year in this period in the amount of N delivered from WWTFs to the Great Bay Estuary.
2. Newmarket, in the summer of 2017, completed a major upgrade of their WWTF. Portsmouth, in 2017, broke ground on a major upgrade that should be completed by 2020. Also in 2017, Exeter broke ground on a major upgrade, slated for completion by the end of 2018. Newington, in 2016, broke ground on an upgrade of their system, which should be complete by early 2018.
3. Farmington's WWTF is not listed because the plant discharges to rapid infiltration basins so that the effluent does not reach the Cocheco River.

Figure NL-8a: Estimated total nitrogen loads from major tributaries in 2012-2016



1. Values reported above combine data from 2012 through 2016, which does not reveal improvements made by WWTFs in the latter part of this period (e.g., for example, at Dover, Rochester and Durham.) Please see Table NL-5 to see changes by each year in this period in the amount of N delivered from WWTFs to the Great Bay Estuary.
2. Newmarket, in the summer of 2017, completed a major upgrade of their WWTF. Portsmouth, in 2017, broke ground on a major upgrade that should be completed by 2020. Also in 2017, Exeter broke ground on a major upgrade, slated for completion by the end of 2018. Newington, in 2016, broke ground on an upgrade of their system, which should be complete by early 2018.

Figure NL-8b: Estimated total dissolved inorganic nitrogen (DIN) loads from major tributaries in 2012-2016



1. Values reported above combine data from 2012 through 2016, which does not reveal improvements made by WWTFs in the latter part of this period (e.g., for example, at Dover, Rochester and Durham.) Please see Table NL-5 to see changes by each year in this period in the amount of N delivered from WWTFs to the Great Bay Estuary.
2. Newmarket, in the summer of 2017, completed a major upgrade of their WWTF. Portsmouth, in 2017, broke ground on a major upgrade that should be completed by 2020. Also in 2017, Exeter broke ground on a major upgrade, slated for completion by the end of 2018. Newington, in 2016, broke ground on an upgrade of their system, which should be complete by early 2018.

PREP
Piscataqua Region Estuaries Partnership

Figure NL-9a: Total nitrogen loads to the Great Bay Estuary from different sources in 2012-2016. Total = 903.1 tons/year.

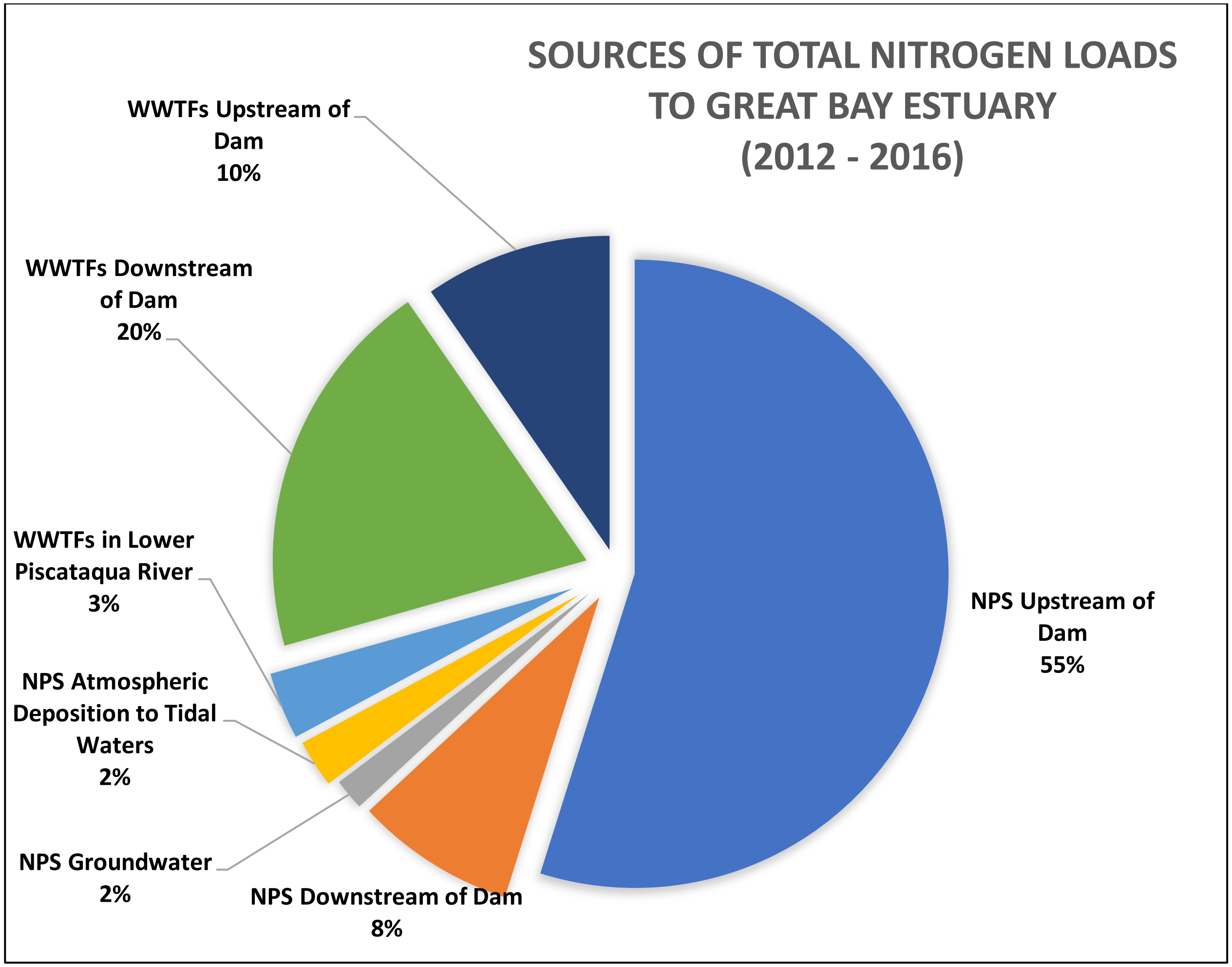
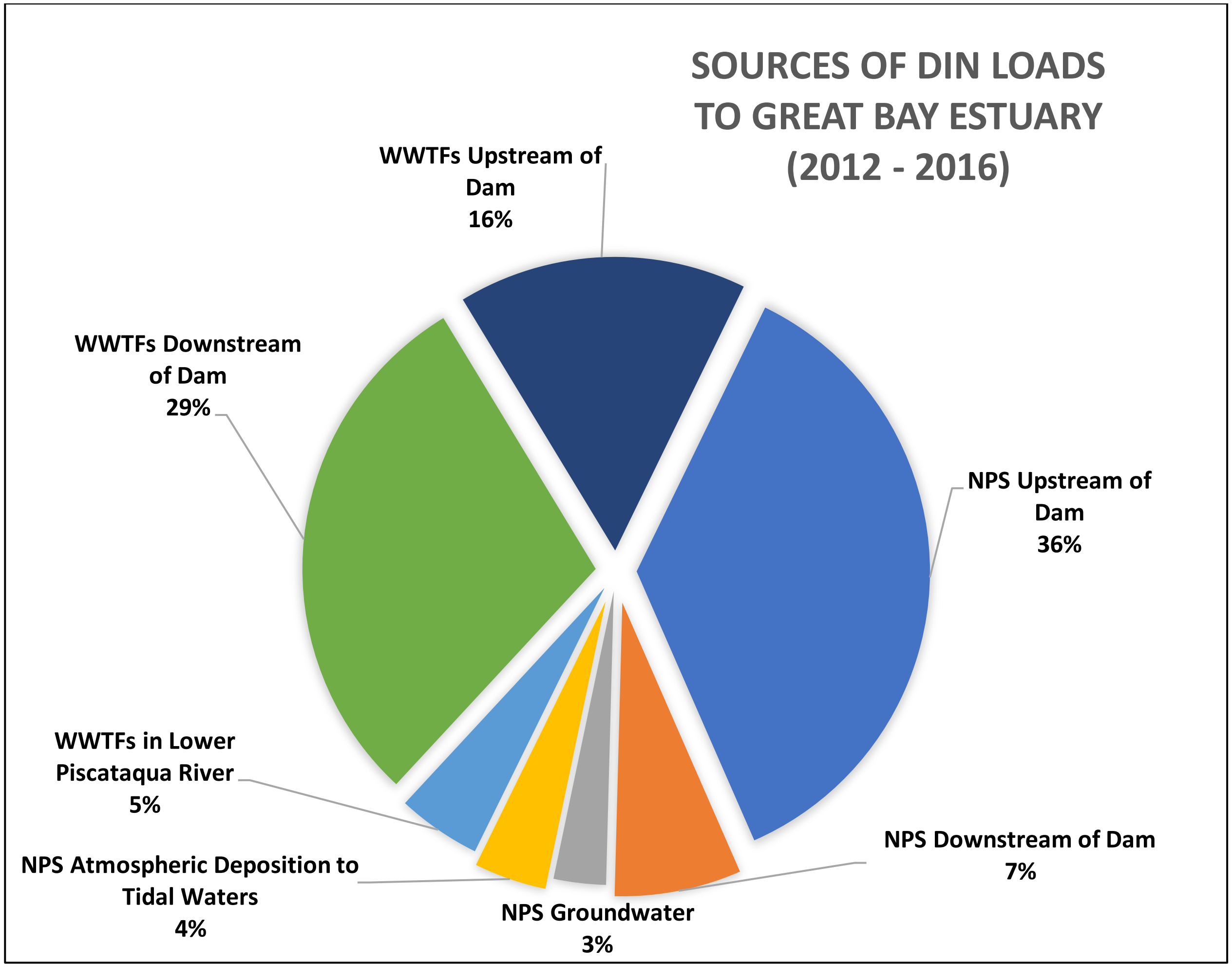


Figure NL-9b: Total dissolved inorganic nitrogen loads to the Great Bay Estuary from different sources in 2012-2016. Total = 506.0 tons/year.



Indicator: Nutrient Concentrations in the Great Bay Estuary

Question

How has the concentration of nitrogen and phosphorus in the waters of the Great Bay Estuary changed over time?

Short Answer

Nitrogen concentration varies by location and type of nitrogen. Total nitrogen (TN), which is less variable in space and time than dissolved inorganic nitrogen (DIN), shows a statistically significant decreasing trend at Adams Point. TN shows a statistically significant increasing trend at the Chapmans Landing and Lamprey River stations. No other stations indicate TN trends. For DIN, the Oyster River and Upper Piscataqua River stations indicate statistically significant decreasing trends while Chapmans Landing indicates a statistically significant increasing trend. (See “Additional Results” for discussion of phosphorus.)

PREP Goal
No increasing trends for any nitrogen or phosphorus species (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

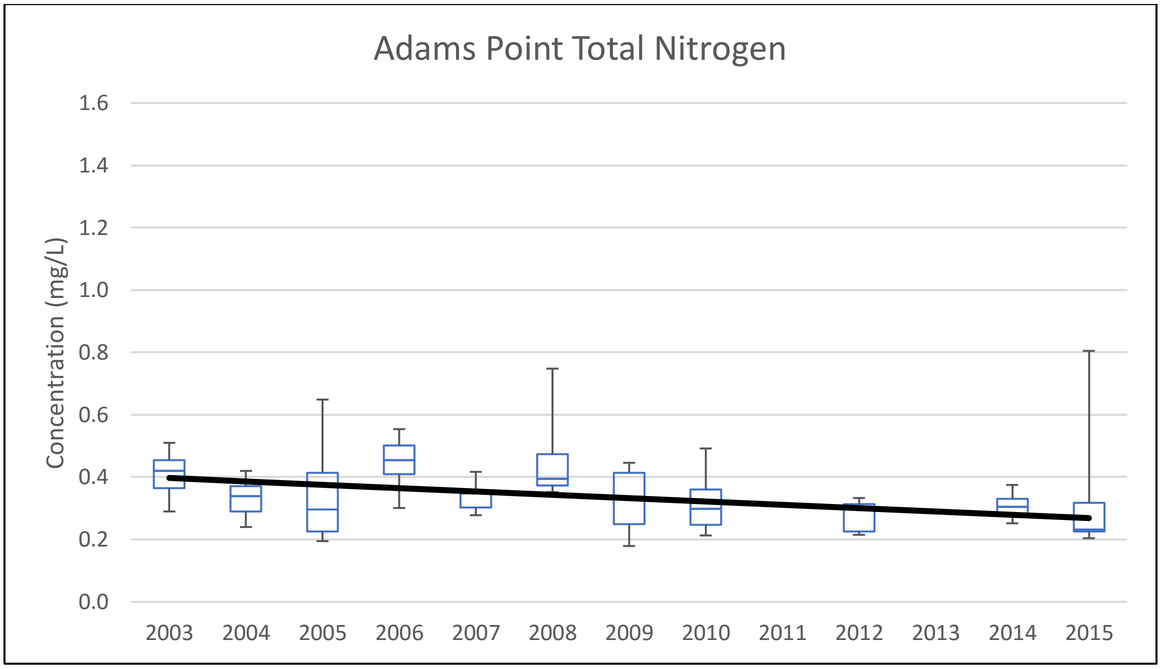


Figure NC-1. Total nitrogen at Adams Point. Box and whisker plots of Total Nitrogen concentrations (collected monthly, April through December, at low tide) between 2003 and 2015. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Years 2011 and 2013 not included due to missing data. Data Source: Great Bay National Estuarine Research Reserve and the UNH Jackson Estuarine Laboratory.

Why This Matters

Nitrogen is a critical nutrient for estuarine ecosystems; some is needed, but too much leads to problems. While nutrient loading measures how much nitrogen is being added to the system from the land and air, nutrient concentration measures the amount of nitrogen present in the water as a result of continual processing, at time of sampling. Measuring the concentration of nitrogen adds insight into the impact of nitrogen loading on the ecosystem. This report discusses two forms of nitrogen: total nitrogen (TN) and dissolved inorganic nitrogen (DIN). It is important to note that both forms – but especially DIN – are taken up quickly by plants and algae, so the concentration of DIN does not necessarily reflect the potential effects of nitrogen on the estuarine ecosystem.

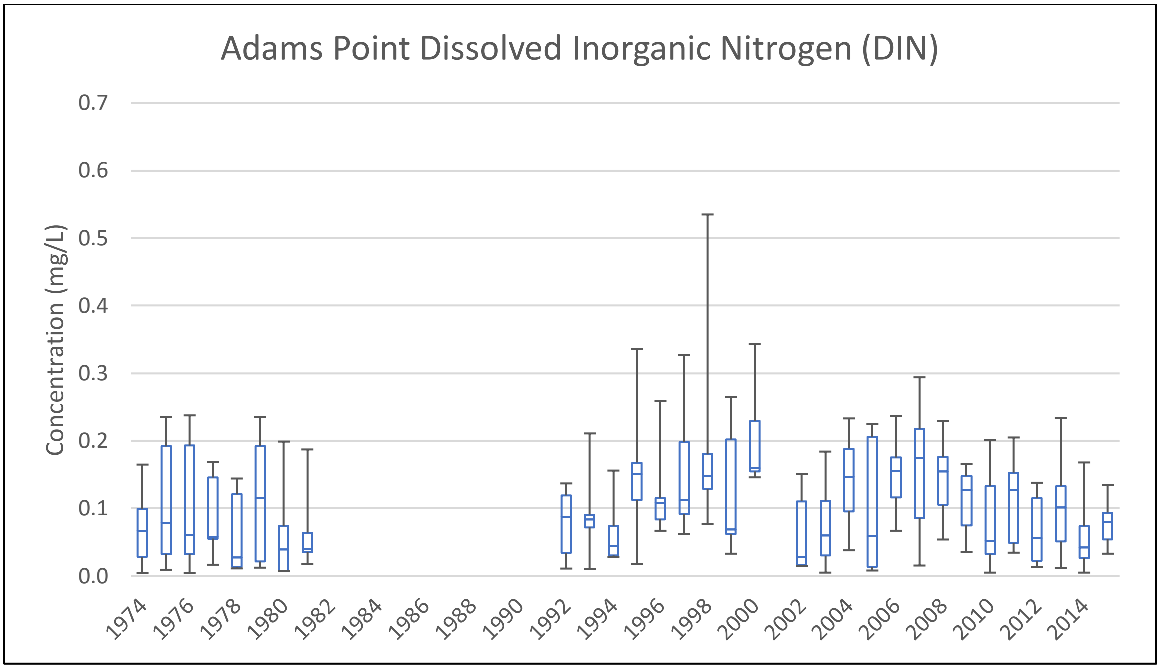


Figure NC-2. Dissolved inorganic nitrogen (DIN) at Adams Point. Box and whisker plots of concentrations (collected monthly, April through December, at low tide) between 1974 and 2015. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data. Data Source: Great Bay National Estuarine Research Reserve and the UNH Jackson Estuarine Laboratory.

<u>Explanation (from 2018 State of Our Estuaries Report)</u>

Total Nitrogen (TN): Includes both dissolved inorganic nitrogen (DIN) and nitrogen contained in particulate and dissolved organic matter, and is considered to be a more accurate measure of the nitrogen status of an estuary than DIN alone. TN at Adams Point shows a significant decreasing trend (Figure NC-1), but it is important to note that the time series begins relatively recently, in 2003. Since 2012, median values ranged from 0.23 mg/L to 0.30 mg/L over the sample season for TN at Adams Point. Figure NC-1 indicates that the years 2005, 2008 and 2015 experienced TN concentrations above 0.6 mg/L.

TN values at the Lamprey River and Chapmans Landing stations (Figure NC-3) show a significantly increasing trend, with average values over the last reporting period (2012 – 2015) of 0.52 and 0.90 mg/L, respectively. Average values for other stations were: 0.77 mg/L (Squamscott River), 0.35 mg/L (Great Bay), 0.52 mg/L (Oyster River), 0.44 mg/L (Upper Piscataqua) and 0.24 mg/L (the Coastal Marine Laboratory in Portsmouth Harbor).

Dissolved Inorganic Nitrogen (DIN): At Adams Point, median values for DIN for 2012 to 2015 ranged from 0.04 to 0.1 mg/L comparable to median values for the years 1974 to 1981 (Figure TC-2). For reference, the EPA National Coastal Assessment Condition Report categorizes values less than 0.1 as “Good.” Other categories include “Fair” (0.1 to 0.5 mg/L) and “Poor” (greater than 0.5 mg/L), (Bricker et al. 2003; US EPA 2012).

The Oyster River and Upper Piscataqua River stations both showed statistically significant decreasing trends for DIN, with average values since 2012 at 0.18 and 0.04 mg/L, respectively. In contrast, Chapmans Landing showed a statistically significant increasing trend with average values since 2012 at 0.48 mg/L. Average values for other stations were: 0.37 mg/L (Squamscott River), 0.21 mg/L (Lamprey River), 0.08 mg/L (Great Bay) and 0.09 mg/L (Coastal Marine Lab). Nutrient concentrations in the water are affected by nutrient loading from the watershed. As noted in the Nutrient Loading Indicator report, loadings since 2012 have been reduced in part due to reductions at municipal wastewater treatment facilities. Additionally, loading has been reduced due to consecutive years of low annual rainfall amounts and low occurrence of extreme rainfall events, which equates to less non-point source loading from run-off.

Methods and Data Sources

Trend analysis for nitrogen and phosphorus species was performed at the following stations (Figure NC-3):

- GRBAP (Adams Point between Great Bay and Little Bay)
- GRBGB (Great Bay)
- GRBCL (Chapmans Landing in the Squamscott River)
- GRBSQ (Squamscott River at the railroad trestle)
- GRBLR (Lamprey River)
- GRBOR (Oyster River)
- GRBUPR (Upper Piscataqua River)
- GRBCML (Portsmouth Harbor)

With regard to nitrogen species, this report focuses on total nitrogen and dissolved inorganic nitrogen (Table NC-1 and Figures NC-4 and NC-5); data are also available for ammonia, nitrate+nitrite, total dissolved nitrogen and particulate nitrogen and can be obtained by querying the NH DES Environmental Monitoring Database or by contacting PREP staff.

The phosphorus parameter for trend analysis was orthophosphate and is included in this report (Table NC-1 and Figure NC-6.)

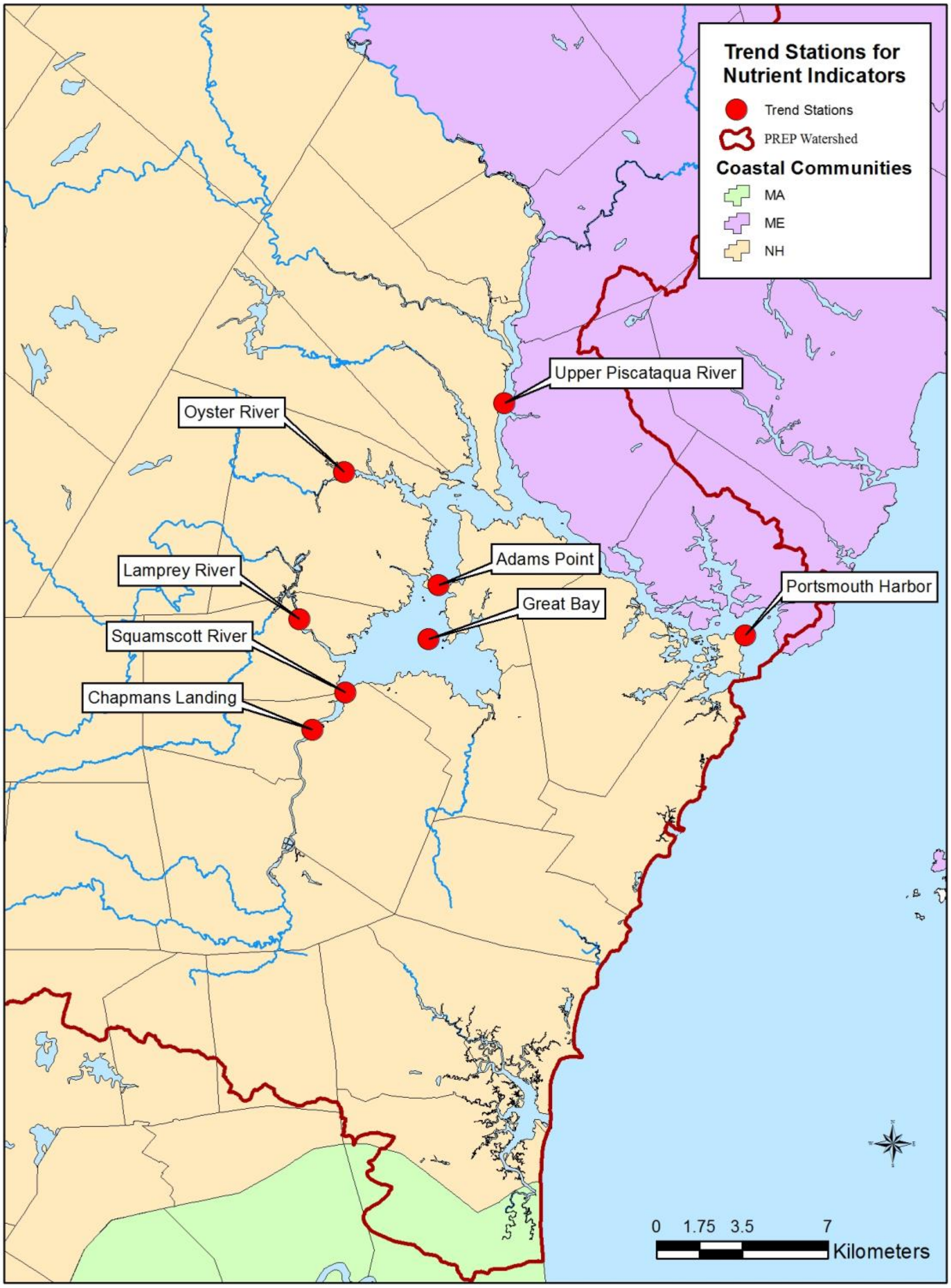
Samples collected at low-tide at the trend stations were identified. Low-tide samples were used for the trend analysis to control for the effects of tides and because historic datasets were collected exclusively at low tide. The data for each station were averaged by month (there was rarely more than one sample in the same month) and then the number of months with data in each year was counted. Only data from the months April through December were used. (The station at Adams Point is monitored 12 months per year.) If three consecutive months were missed in any year, that year was not included in the analysis. This was done in order to minimize bias from years for which the data do not reflect the full range of seasons.

Linear regression was used to test for long-term trends. The annual median values were regressed against the year variable. Trends were considered significant if the slope coefficient of the year variable was significant at the $p<0.05$ level.

Data Sources
Data for this indicator were provided by the UNH and Great Bay NERR Tidal Water Quality Monitoring Programs for years 1992 to present. Historic datasets from 1974 to 1981 (Norall et al. 1982; Loder et al. 1983) were also included in the trend analysis for station GRBAP.

Additional trend monitoring stations were added in 2017 in the Bellamy, Cocheco, Salmon Falls, and Piscataqua Rivers and in Hampton-Seabrook Harbor; data from these stations will be included in the next Technical Report, scheduled for 2022.

Figure NC-3. Map of trend stations for nutrient concentrations.



Additional Results (Beyond What Was Reported in the SOOE)

The results of the trend analysis for nitrogen and phosphorus compounds are summarized in Table NC-1. Plots of each nitrogen (TN and DIN) and phosphorus (orthophosphate) compound at each station are shown on Figures NC-4 through NC-6.

For DIN, the Chapmans Landing and Squamscott River stations both showed significant increasing trends. The Oyster River and Upper Piscataqua River stations, on the other hand, demonstrated significant decreasing trends. No significant trends were found at the other stations.

For total nitrogen, only the Chapmans Landing station showed a significant increasing trend. Adams Point, Great Bay and Oyster River all demonstrated significant decreasing trends. The other stations did not have significant trends in either direction.

Finally, for orthophosphate, none of the stations indicated any trends.

Table NC-1 indicates the range of median values seen at each station between the years 2012 and 2015. It is also important to review Figures NC-4 through NC-6 to understand the range of values seen at each station since the ecosystem integrates the full range of values, not just the median or the mean.

EPA (2012) provides general category ranges (poor, fair, good) for both DIN and dissolved phosphorus (orthophosphate), but not for total nitrogen. For DIN, less than 0.1 mg/L is "good;" between 0.1 mg/L and 0.5 mg/L is "fair;" and more than 0.5 mg/L is "poor." Figures NC-2 (Adams Point) and NC-4 indicate that results at most stations tend to fall into the "fair" category, with Adams Point, Great Bay, Upper Piscataqua River and the Coastal Marine Laboratory also seeing results in the "good" category as well. Chapmans Landing and Squamscott River both show results in the "fair" and "poor" category.

For orthophosphate, the EPA (2012) categories are: less than 0.01 mg/L is "good;" between 0.01 and 0.05 is "fair;" and above 0.05 mg/L is "poor." Figure NC-5 indicates that results at most stations can be categorized as "fair." Great Bay, relative to other stations, shows more results in the "good" category. Chapmans Landing, Lamprey River and Oyster River show results in both the "fair" and "poor" category.

The above EPA thresholds are general values for the entire Northeast region of the country (EPA 2012). More data is required to set nutrient thresholds that are specific to various zones of the Great Bay Estuary (Bierman et al. 2014; Kenworthy et al. 2017).

For more on the relationship between nutrient concentrations and other indicators (e.g., nitrogen loading, eelgrass, seaweed, and phytoplankton, please see those indicator sections.)

For more on the relationship between nitrogen loading and overall ecosystem health and resilience, see the "Stress and Resilience" section of the State of Our Estuaries Report (PREP 2017b) and the "External Advisors Statement Regarding Eelgrass Stressors in Great Bay Estuary" (Kenworthy et al. 2014).

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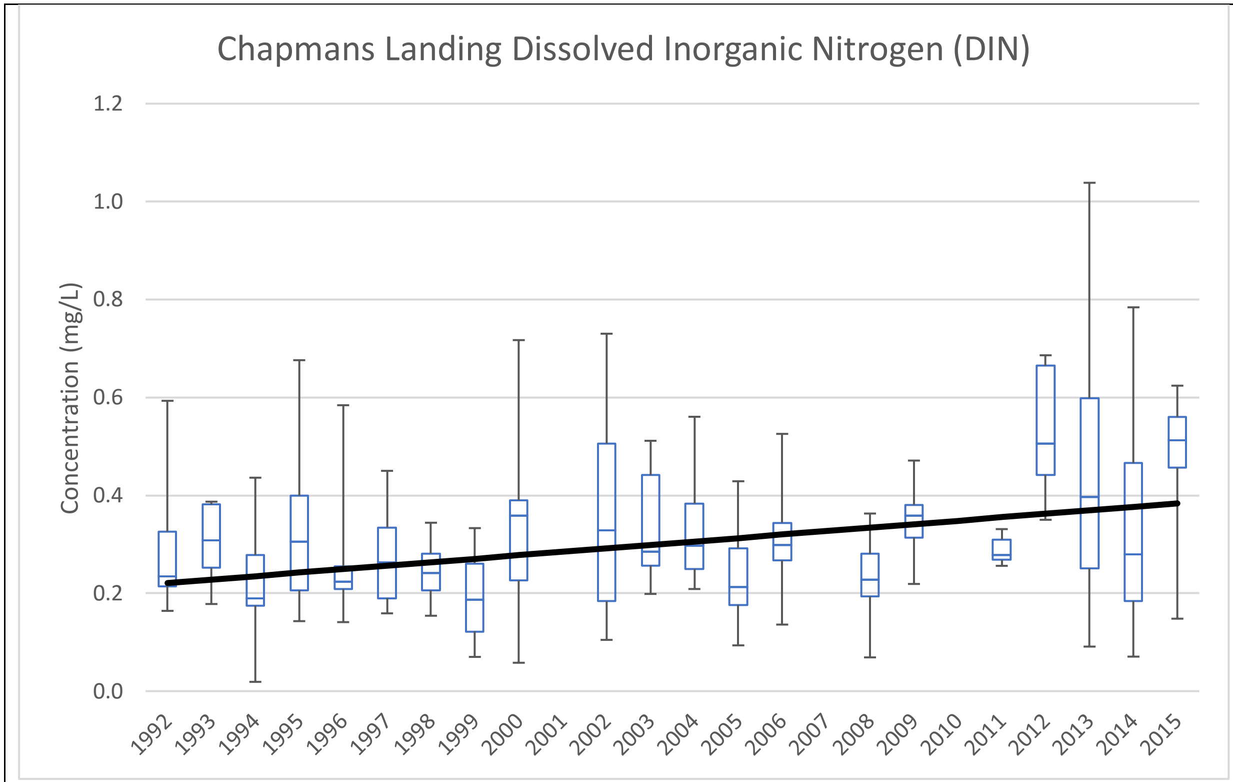
US EPA. 2012. National Coastal Condition Report IV. https://www.epa.gov/national-aquatic-resource-surveys/national-coastal-condition-report-iv-2012

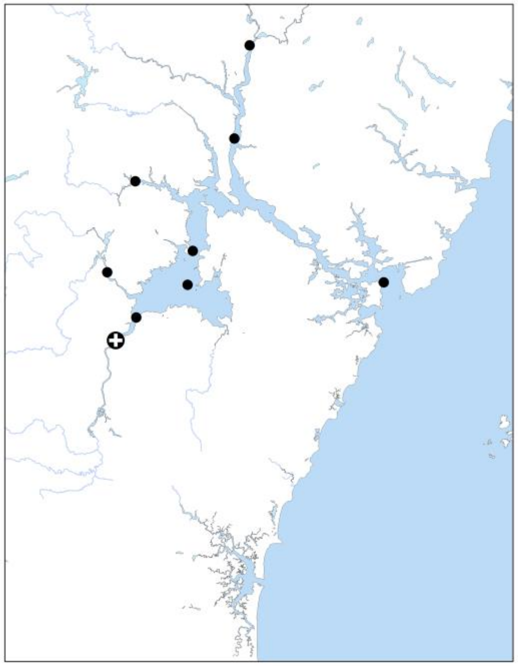
Table NC-1: Trends for nutrient compounds in the Great Bay Estuary

Station	Parameter	Period	Range of Recent Median Values (2012 -2015, mg/L)	Long Term Trend
GRBAP (Adams Point)	Dissolved Inorganic Nitrogen	1974-2015	0.04 to 0.1	No significant trend
	Total Nitrogen	2003-2015	0.23 to 0.30	Significant decreasing trend
	Orthophosphate	1992-2015	0.02 to 0.03	No significant trend
GRBCL (Chapmans Landing)	Dissolved Inorganic Nitrogen	1992-2015	0.28 to 0.51	Significant increasing trend
	Total Nitrogen	2003-2015	0.81 to 0.92	Significant increasing trend
	Orthophosphate	1992-2015	0.03 to 0.04	No significant trend
GRBSQ (Squamscott River)	Dissolved Inorganic Nitrogen	2002-2015	0.38 to 0.44	Significant increasing trend
	Total Nitrogen	2003-2015	0.71 to 0.77	No significant trend
	Orthophosphate	2002-2015	0.04 to 0.04	No significant trend
GRBLR (Lamprey River)	Dissolved Inorganic Nitrogen	1992-2015	0.14 to 0.22	No significant trend
	Total Nitrogen	2003-2015	0.41 to 0.49	No significant trend
	Orthophosphate	1992-2015	0.01 to 0.01	No significant trend
GRBGB (Great Bay)	Dissolved Inorganic Nitrogen	2002-2015	0.03 to 0.11	No significant trend
	Total Nitrogen	2003-2015	0.30 to 0.35	Significant decreasing trend
	Orthophosphate	2002-2015	0.02 to 0.02	No significant trend
GRBOR Oyster River	Dissolved Inorganic Nitrogen	2002-2015	0.11 to 0.23	Significant decreasing trend
	Total Nitrogen	2004-2015	0.40 to 0.53	Significant decreasing trend
	Orthophosphate	2002-2015	0.04 to 0.06	No significant trend
GRBUPR Upper Piscataqua River	Dissolved Inorganic Nitrogen	2007-2015	0.13 to 0.21	Significant decreasing trend
	Total Nitrogen	2009-2015	0.36 to 0.55	No significant trend
	Orthophosphate	2007-2015	0.02 to 0.02	No significant trend
GRBCML Coastal Marine Laboratory Portsmouth Harbor	Dissolved Inorganic Nitrogen	2001-2015	0.05 to 0.19	No significant trend
	Total Nitrogen	2003-2015	0.21 to 0.25	No significant trend
	Orthophosphate	2001-2015	0.02 to 0.02	No significant trend

Figure NC-4: Dissolved inorganic nitrogen (DIN) concentration trends at stations in the Great Bay Estuary



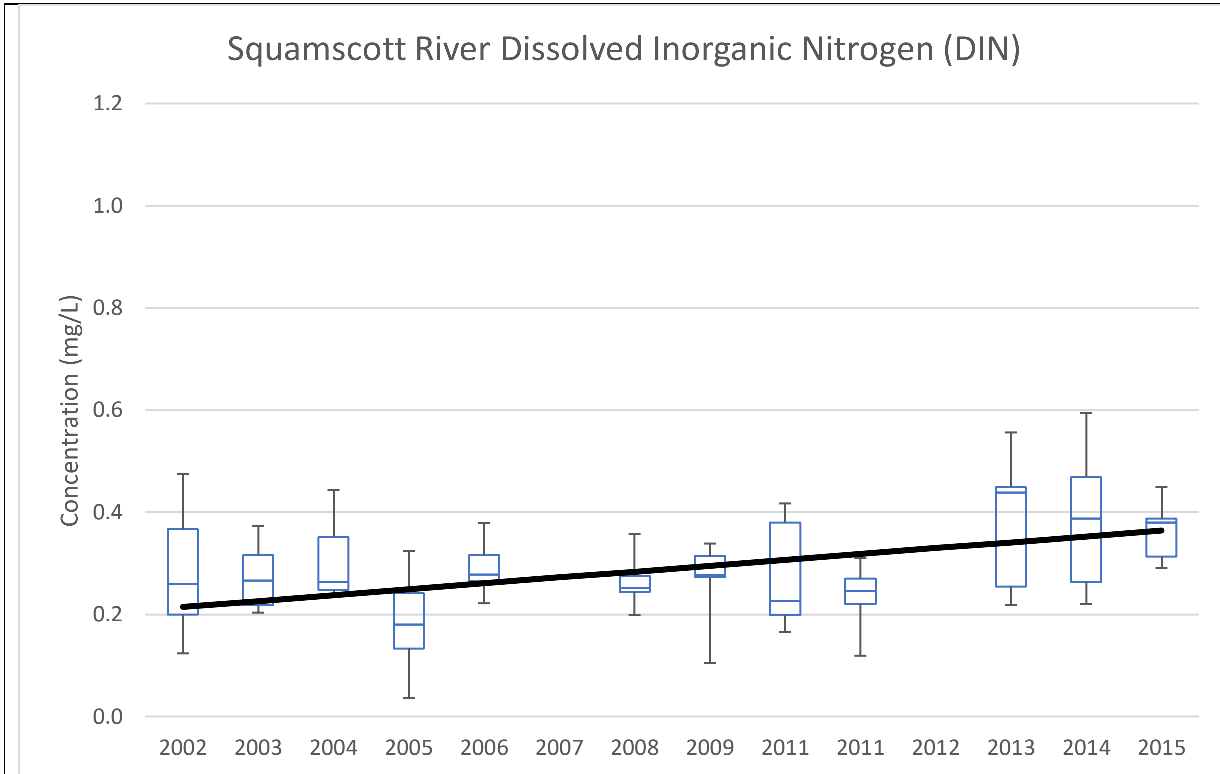
Monitoring Location (GRBCL)
Chapmans Landing
(black circle with white plus sign)



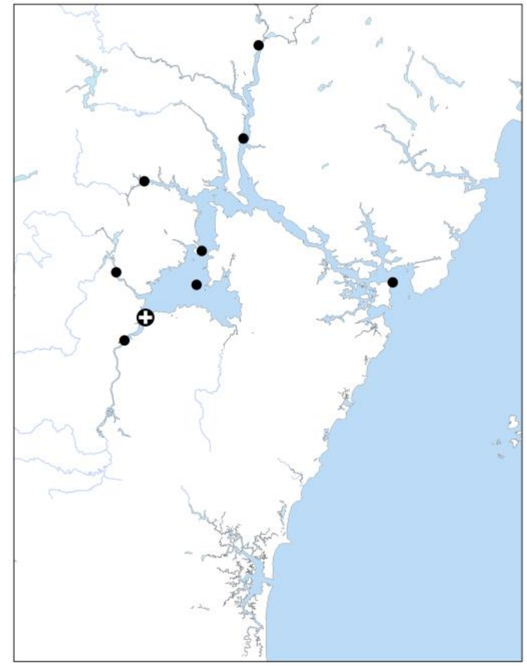
Station: GRBCL (Chapmans Landing in the Squamscott River)

Long Term Trend: Significant increasing trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



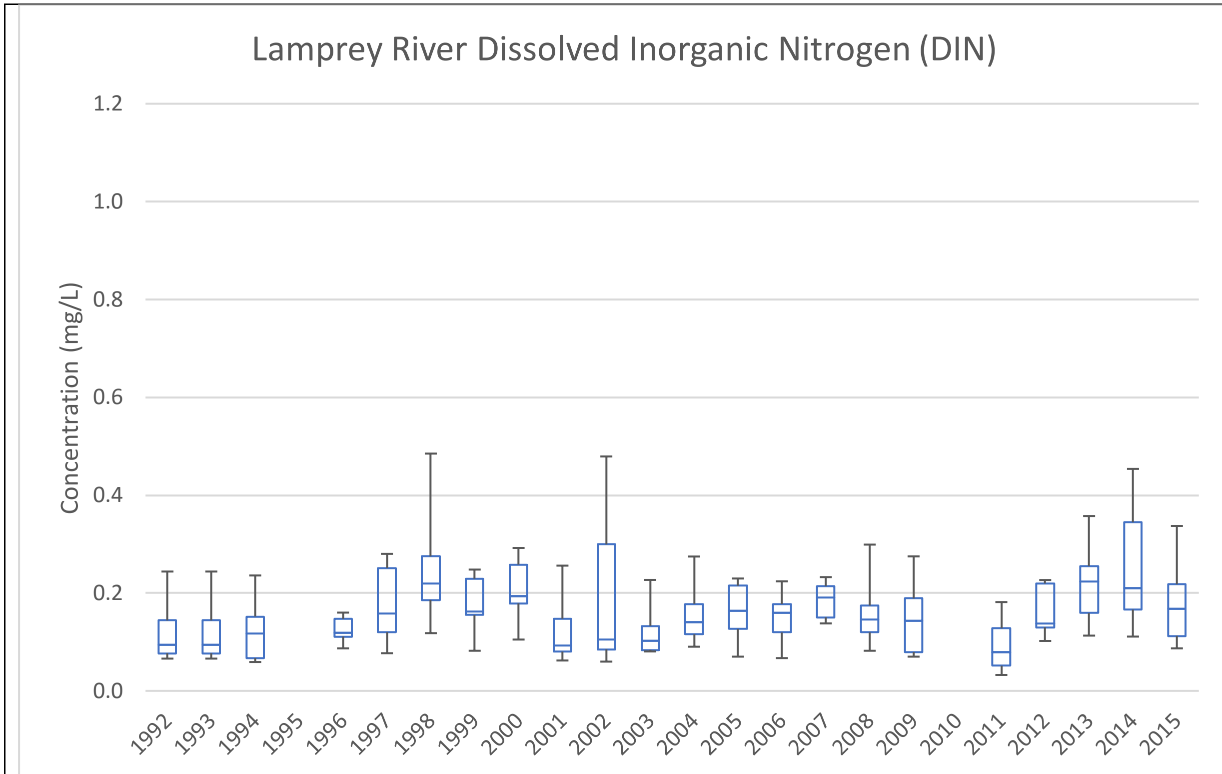
Monitoring Location (GRBSQ)
Squamscott River
(black circle with white plus sign)



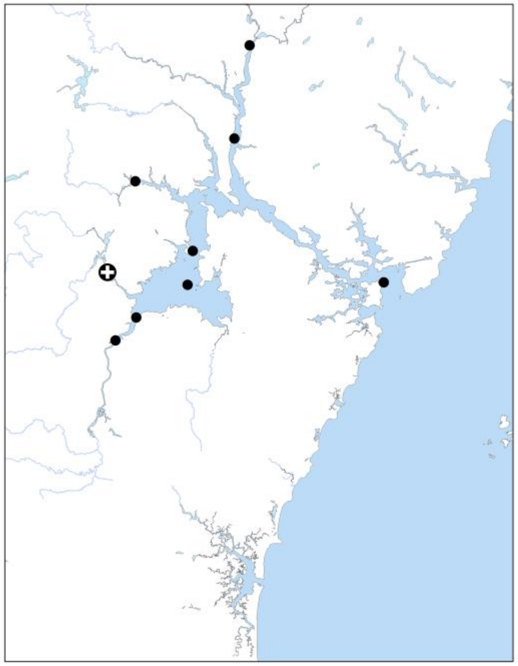
Station: GRBSQ (Squamscott River)

Long Term Trend: Significant increasing trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



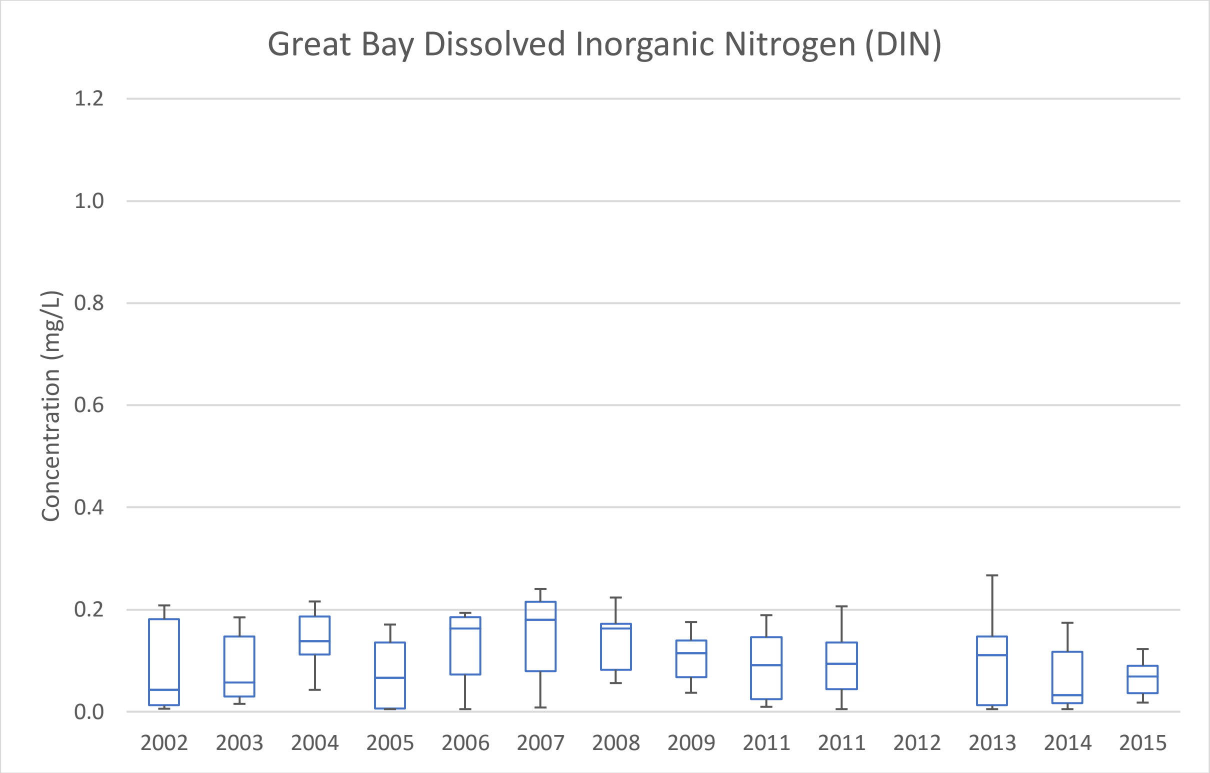
Monitoring Location (GRBLR)
Lamprey River
(black circle with white plus sign)



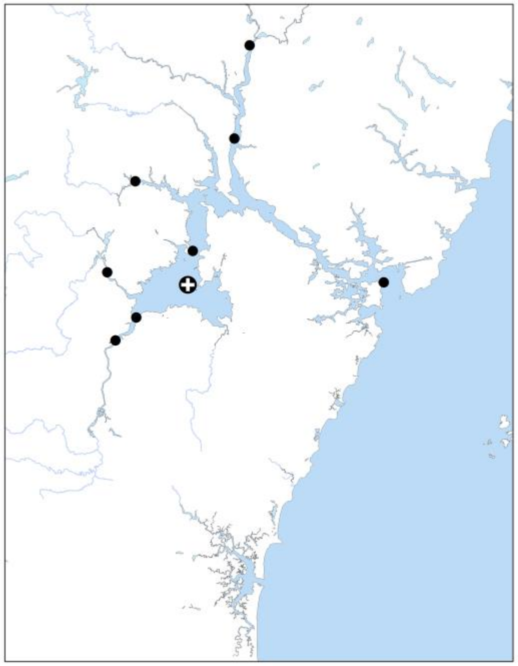
Station: GRBLR (Lamprey River)

Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



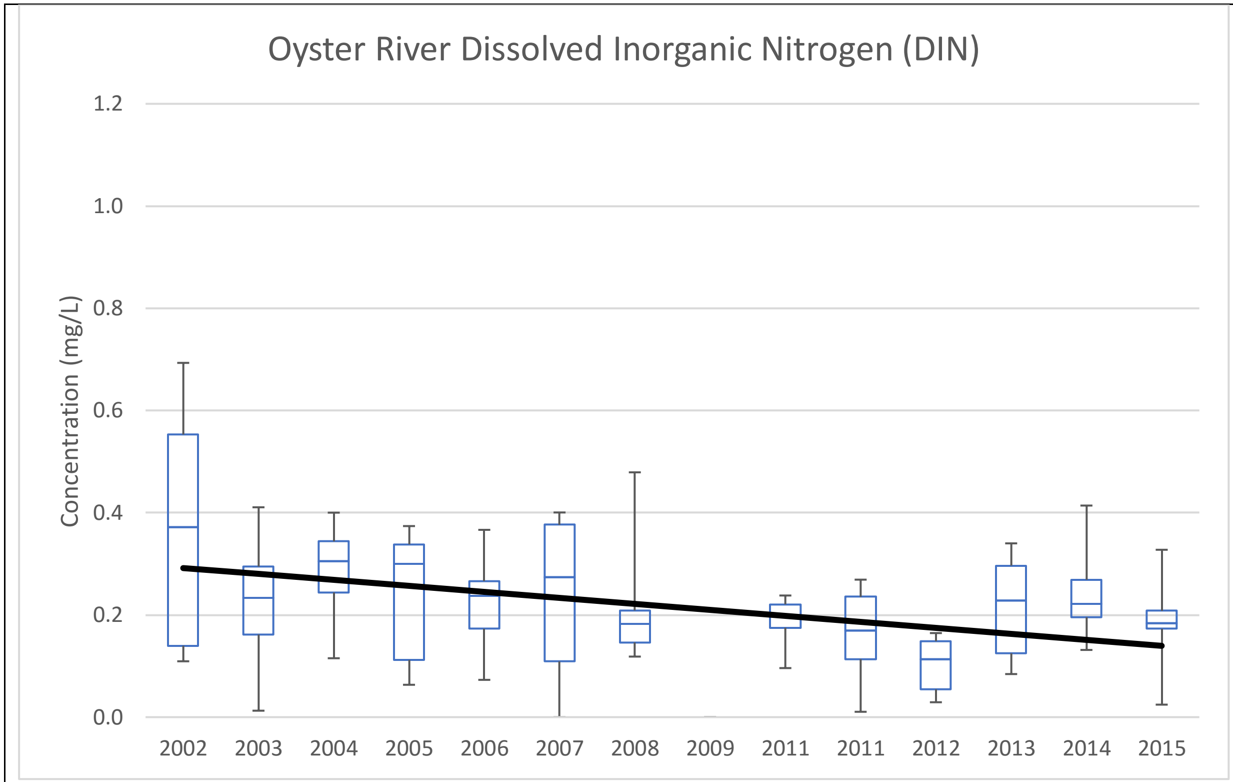
Monitoring Location (GRBGB)
Great Bay
(black circle with white plus sign)



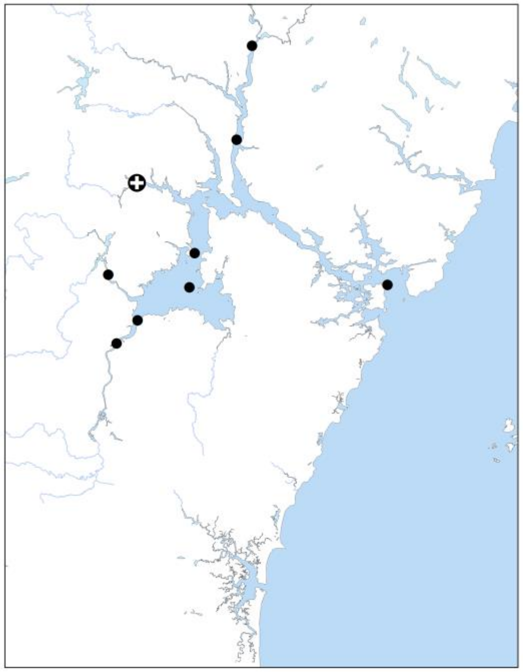
Station: GRBGB (Great Bay)

Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



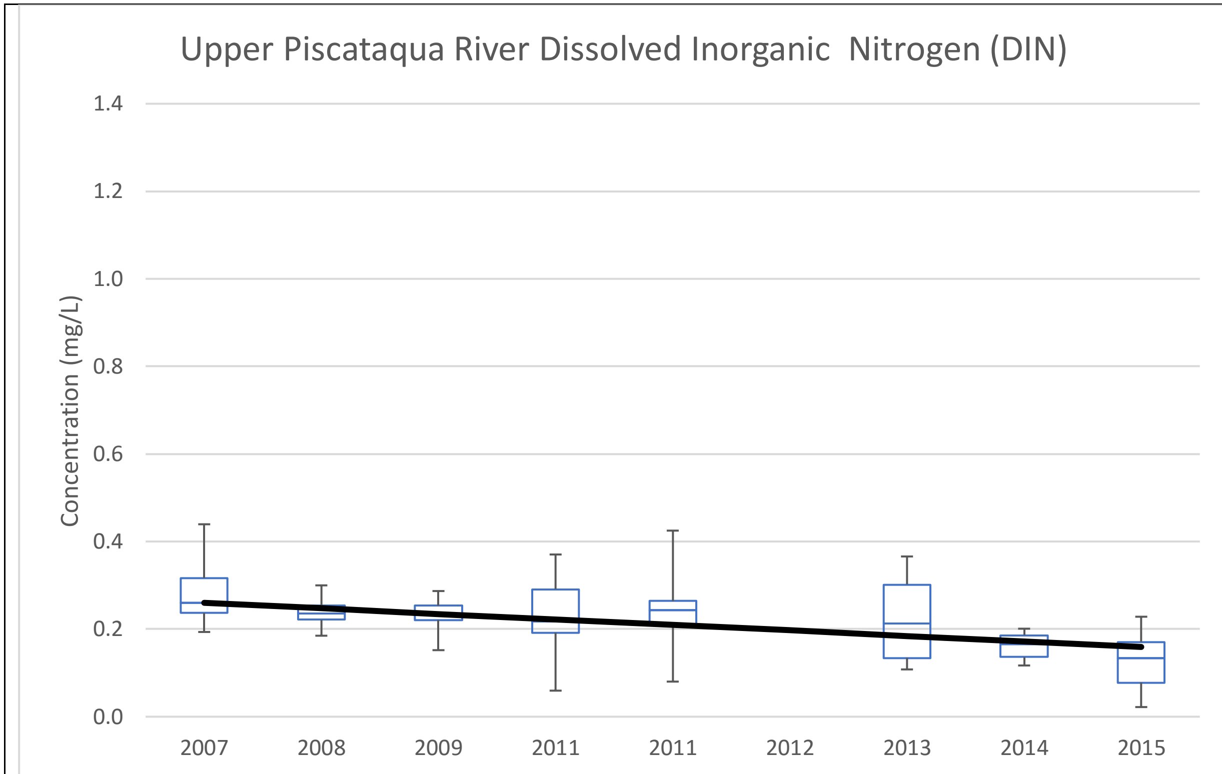
Monitoring Location (GRBOR)
Oyster River
(black circle with white plus sign)



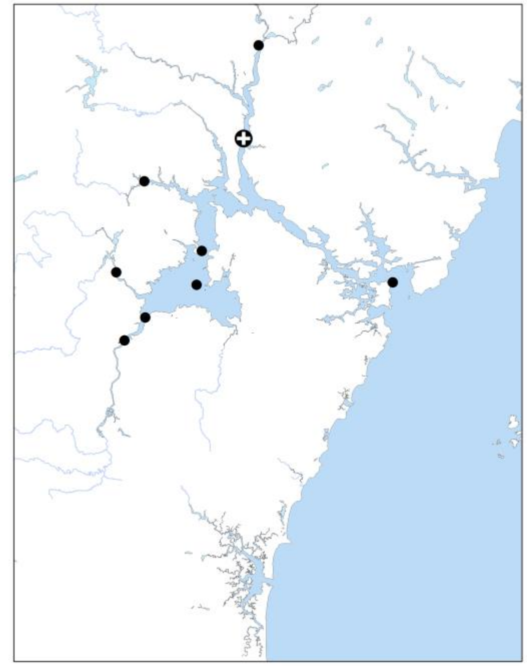
Station: GRBOR (Oyster River)

Long Term Trend: Significant decreasing trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



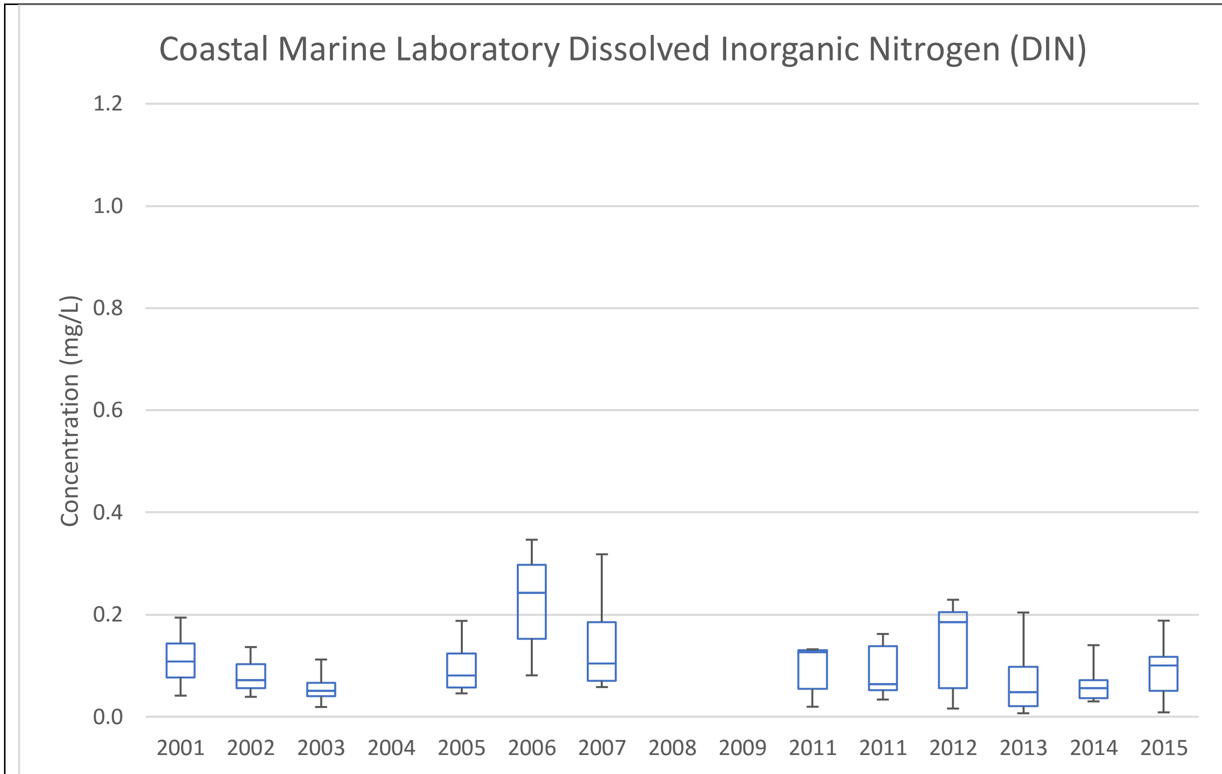
Monitoring Location (GRBUPR)
Upper Piscataqua River
(black circle with white plus sign)



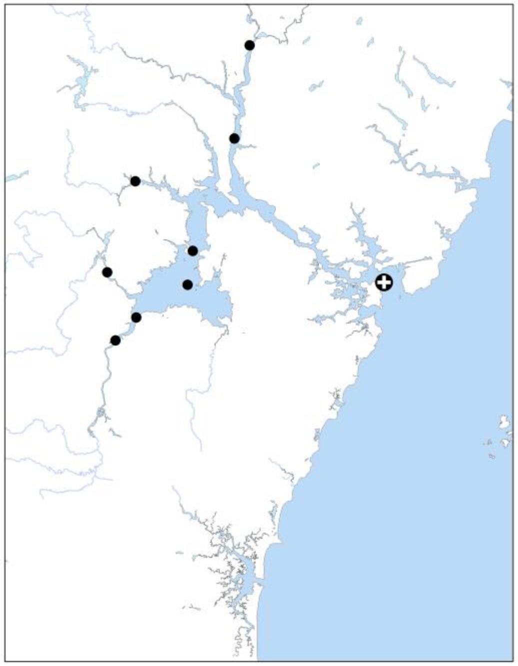
Station: GRBUPR (Upper Piscataqua River)

Long Term Trend: Significant decreasing trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



Monitoring Location (GRBCML)
Coastal Marine Laboratory
Portsmouth Harbor
(black circle with white plus sign)

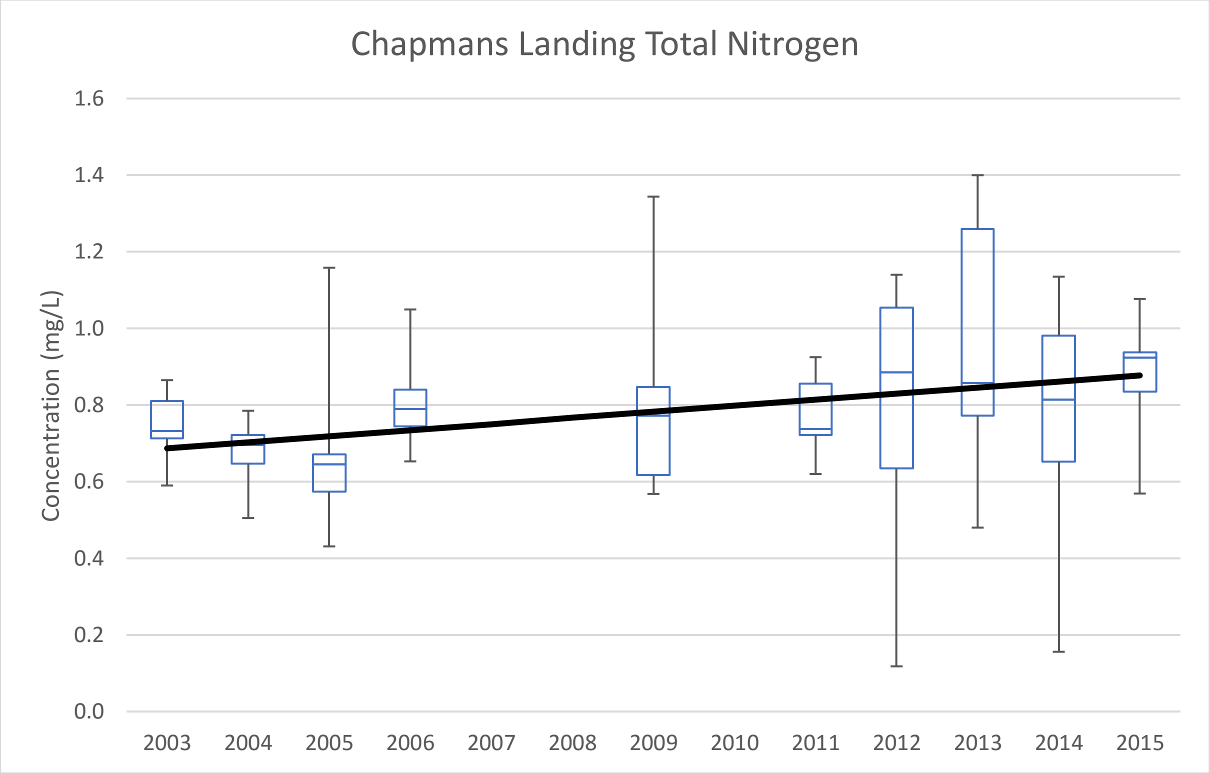


Station: GRBCML (Coastal Marine Laboratory in Portsmouth Harbor)

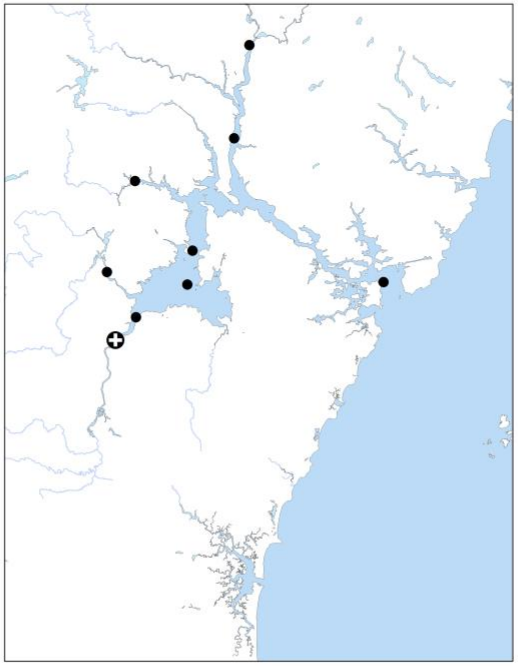
Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.

Figure NC-5: Total nitrogen (TN) concentration trends at stations in the Great Bay Estuary.



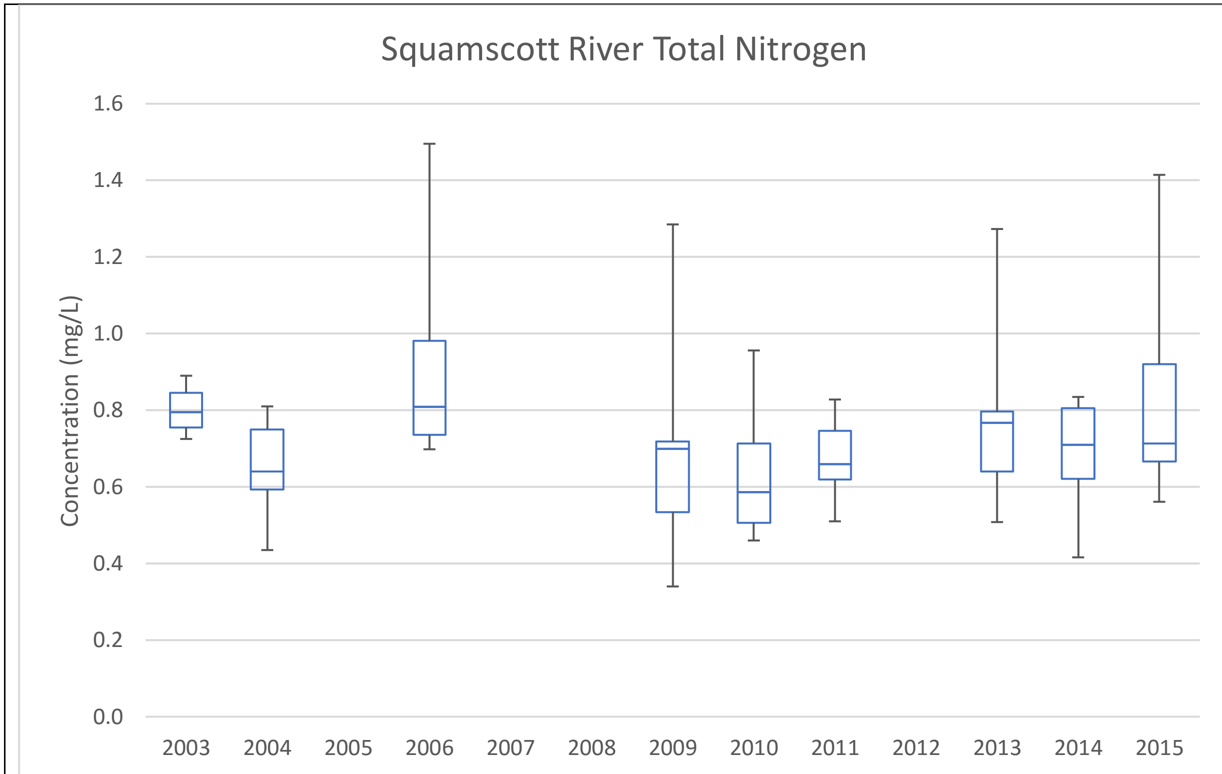
Monitoring Location (GRBCL)
Chapmans Landing
(black circle with white plus sign)



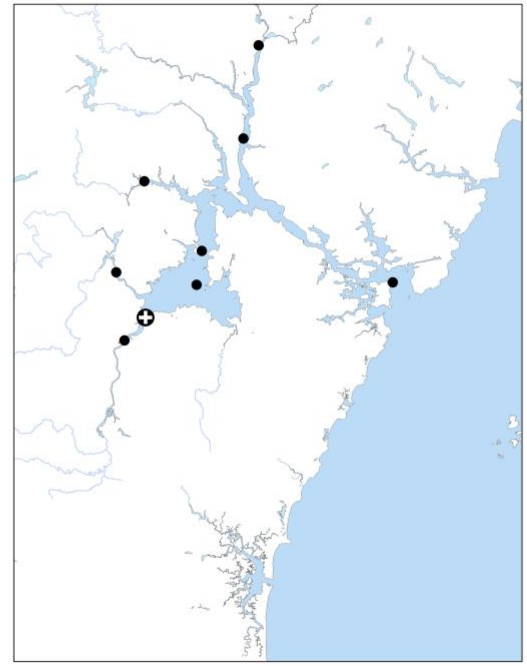
Station: GRBCL (Chapmans Landing in the Squamscott River)

Long Term Trend: Significant increasing trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



Monitoring Location (GRBSQ)
Squamscott River
(black circle with white plus sign)



Station: GRBSQ (Squamscott River)

Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.

PREP
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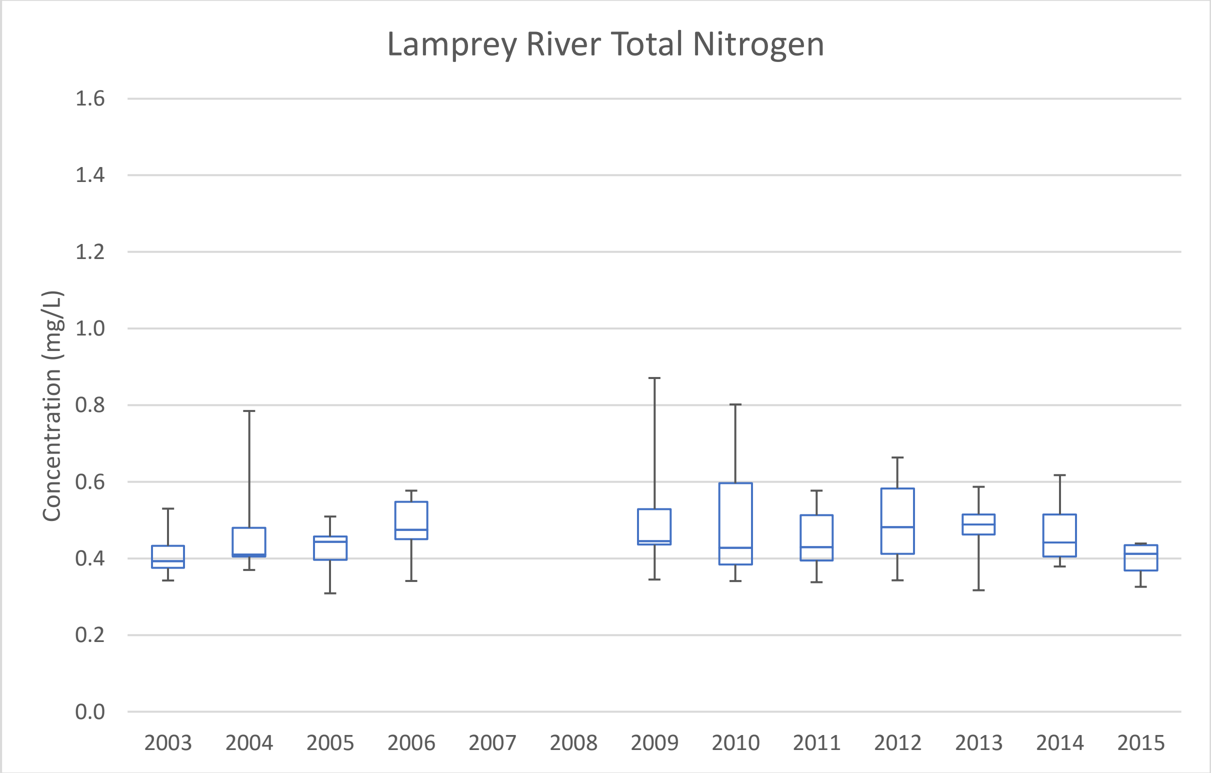
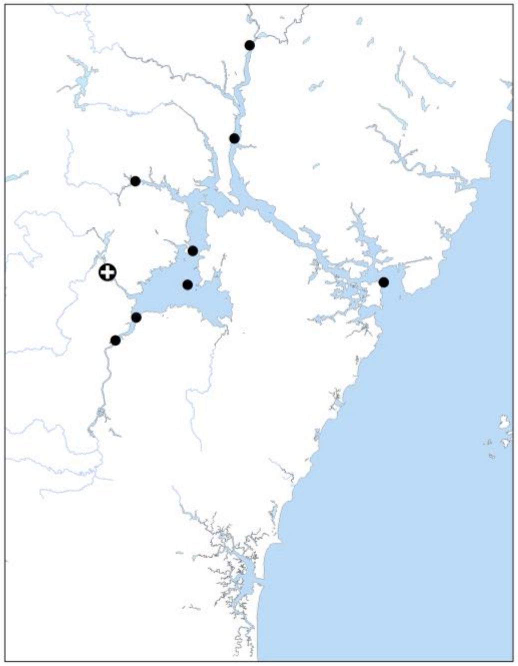


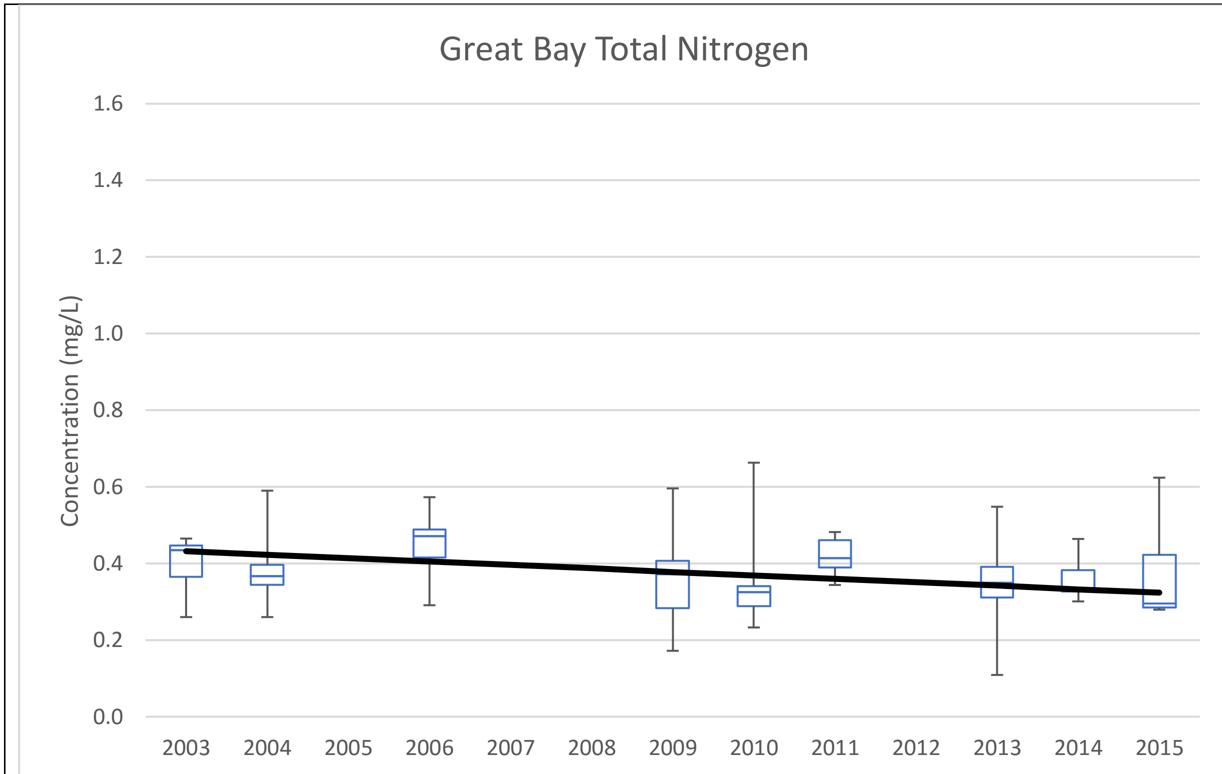
Monitoring Location (GRBLR)
Lamprey River
(black circle with white plus sign)



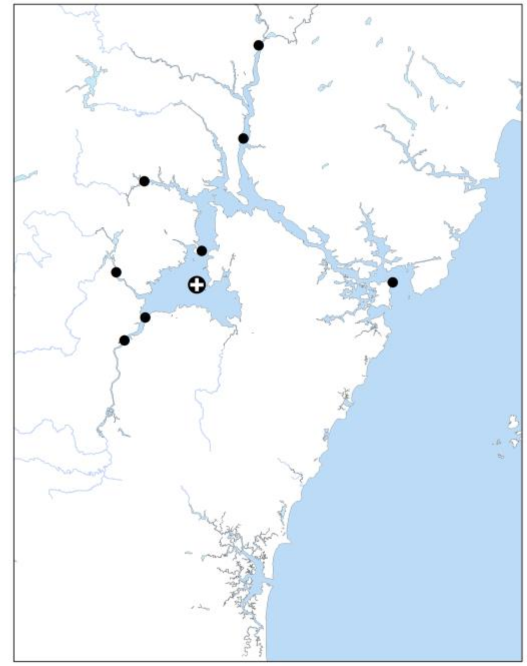
Station: GRBLR (Lamprey River)

Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



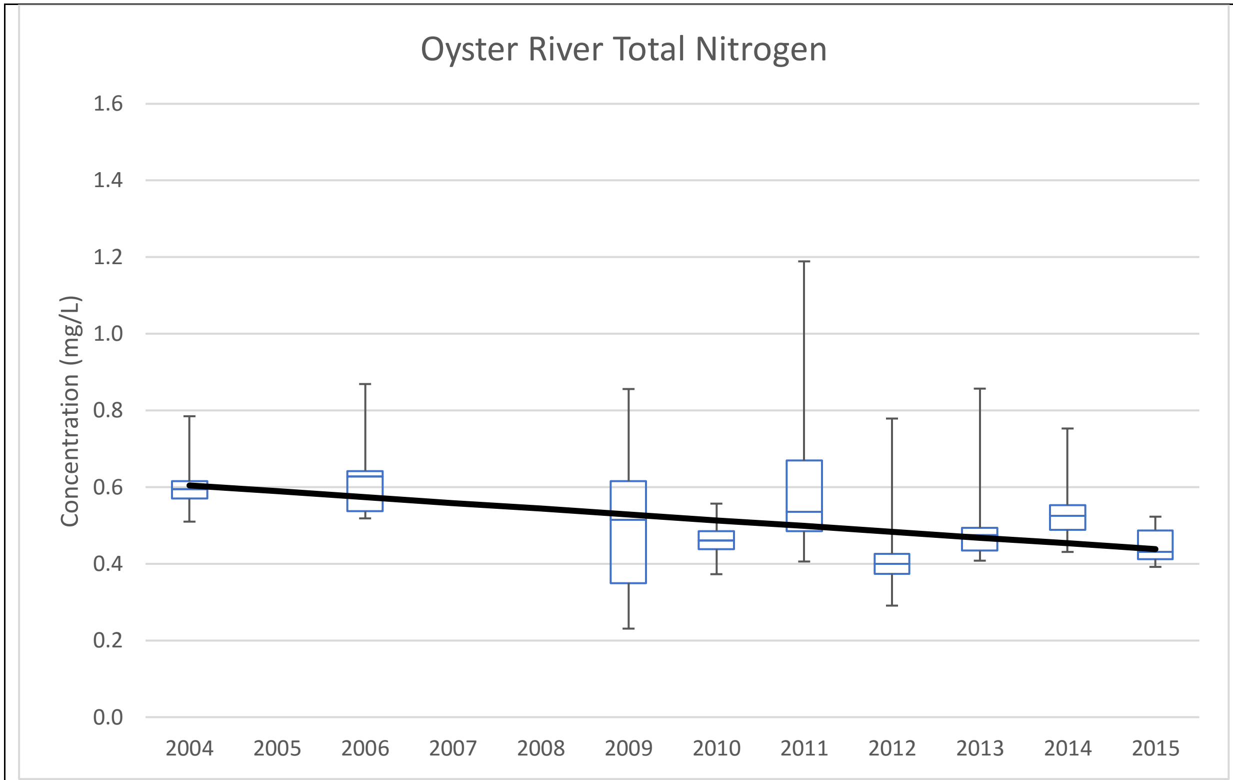
Monitoring Location (GRBGB)
Great Bay
(black circle with white plus sign)



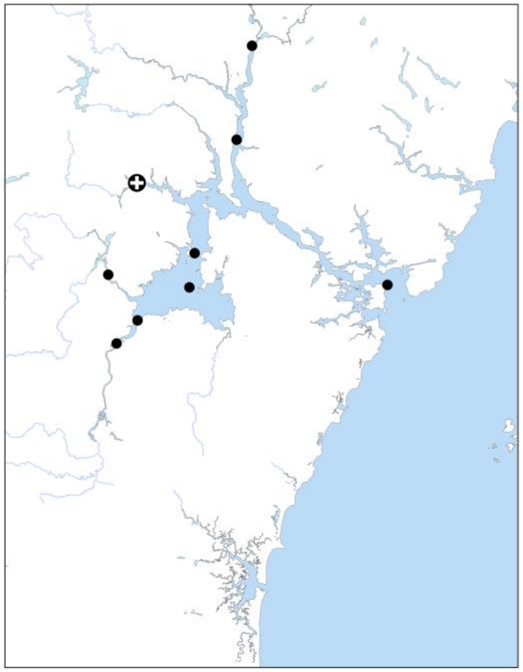
Station: GRBGB (Great Bay)

Long Term Trend: Significant decreasing trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



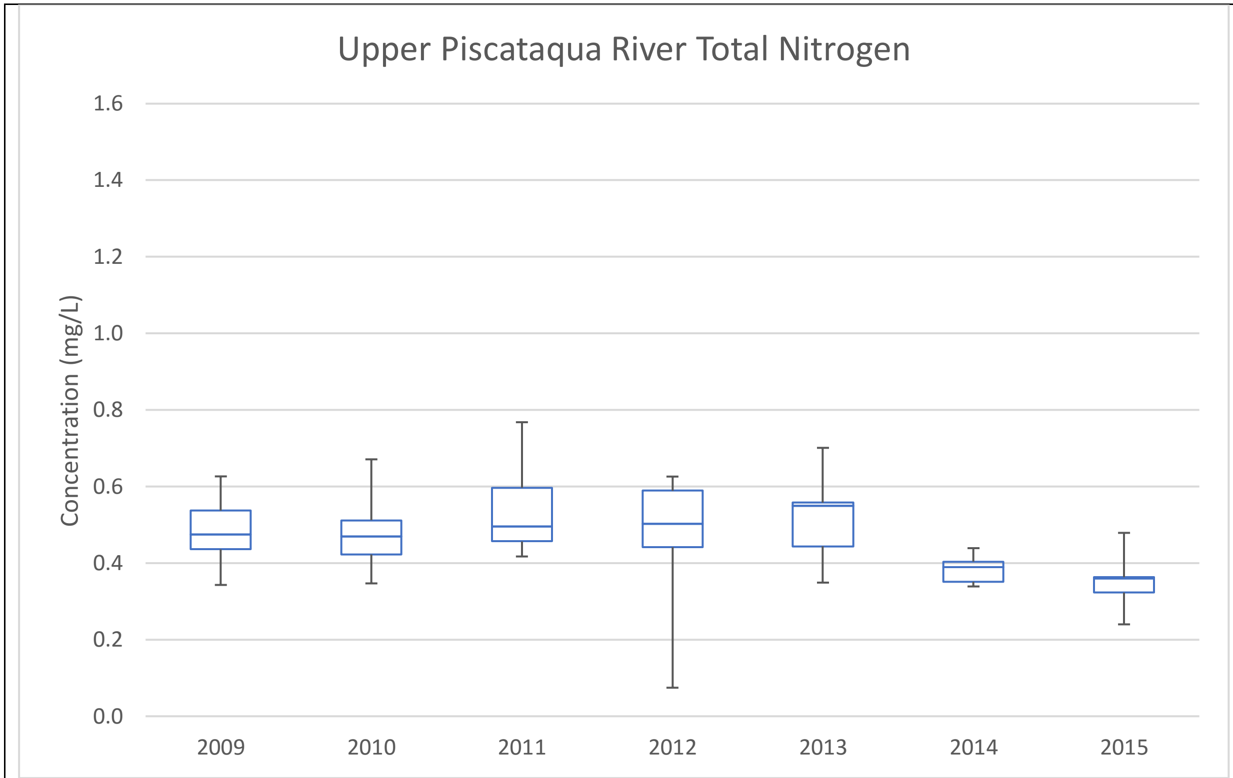
Monitoring Location (GRBOR)
Oyster River
(black circle with white plus sign)



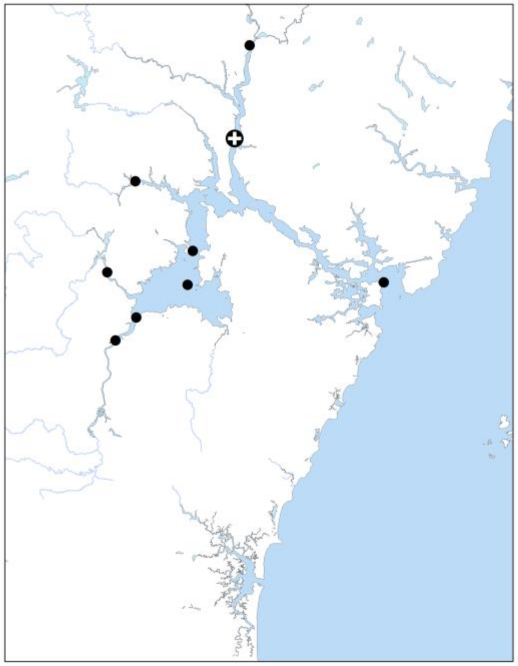
Station: GRBOR (Oyster River)

Long Term Trend: Significant decreasing trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



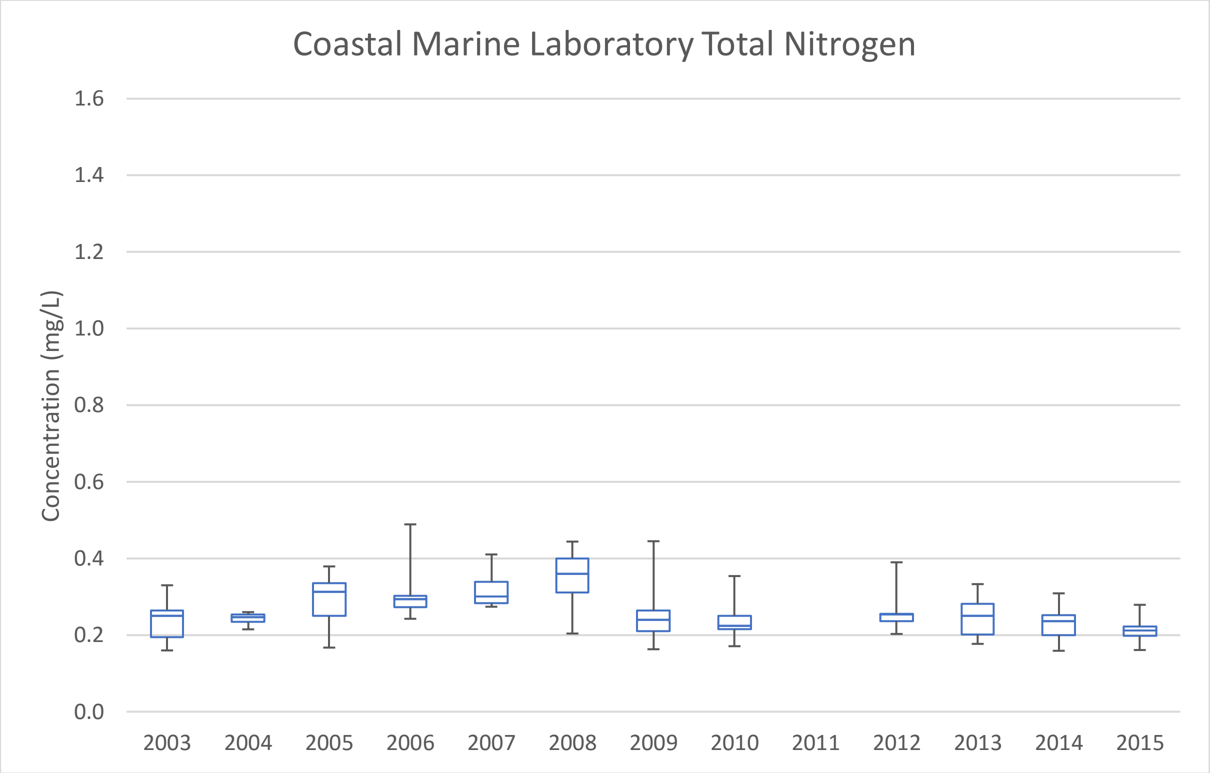
Monitoring Location (GRBUPR)
Upper Piscataqua River
(black circle with white plus sign)



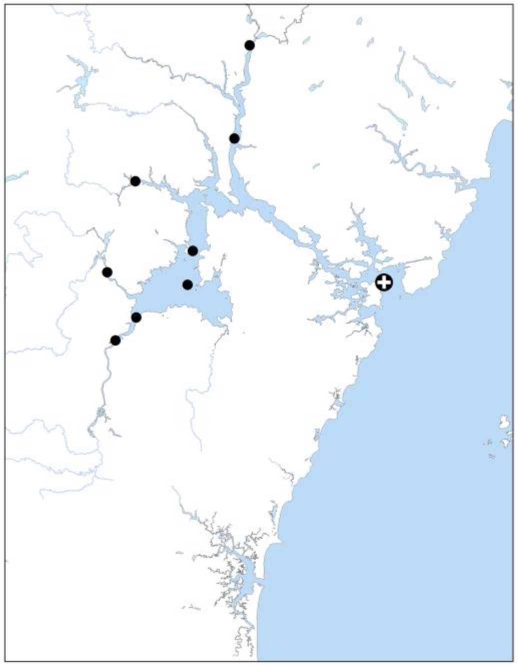
Station: GRBUPR (Upper Piscataqua River)

Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.



Monitoring Location (GRBCML)
Coastal Marine Laboratory
Portsmouth Harbor
(black circle with white plus sign)

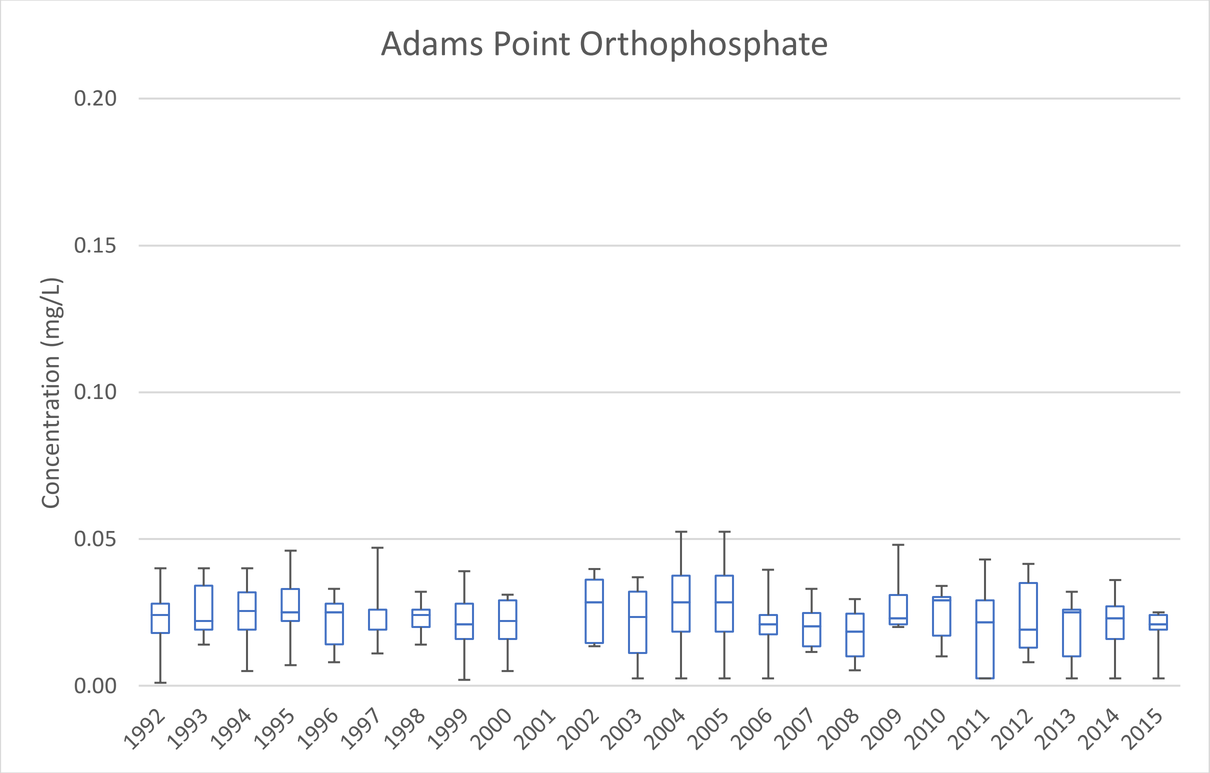


Station: GRBCML (Coastal Marine Laboratory in Portsmouth Harbor)

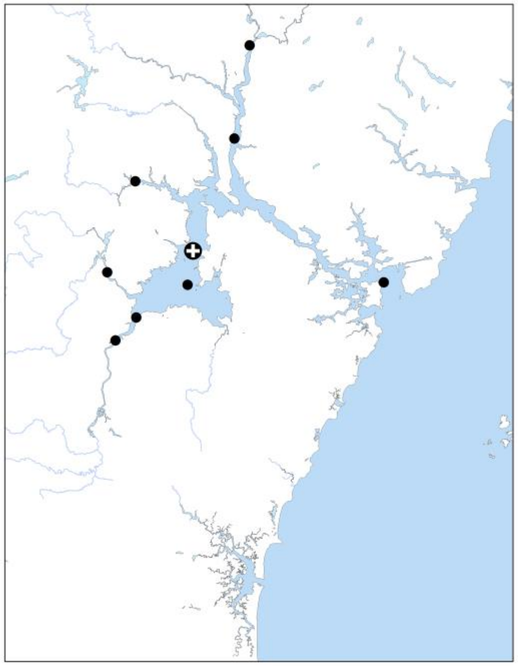
Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.

Figure NC-6: Orthophosphate concentration trends at stations in the Great Bay Estuary.



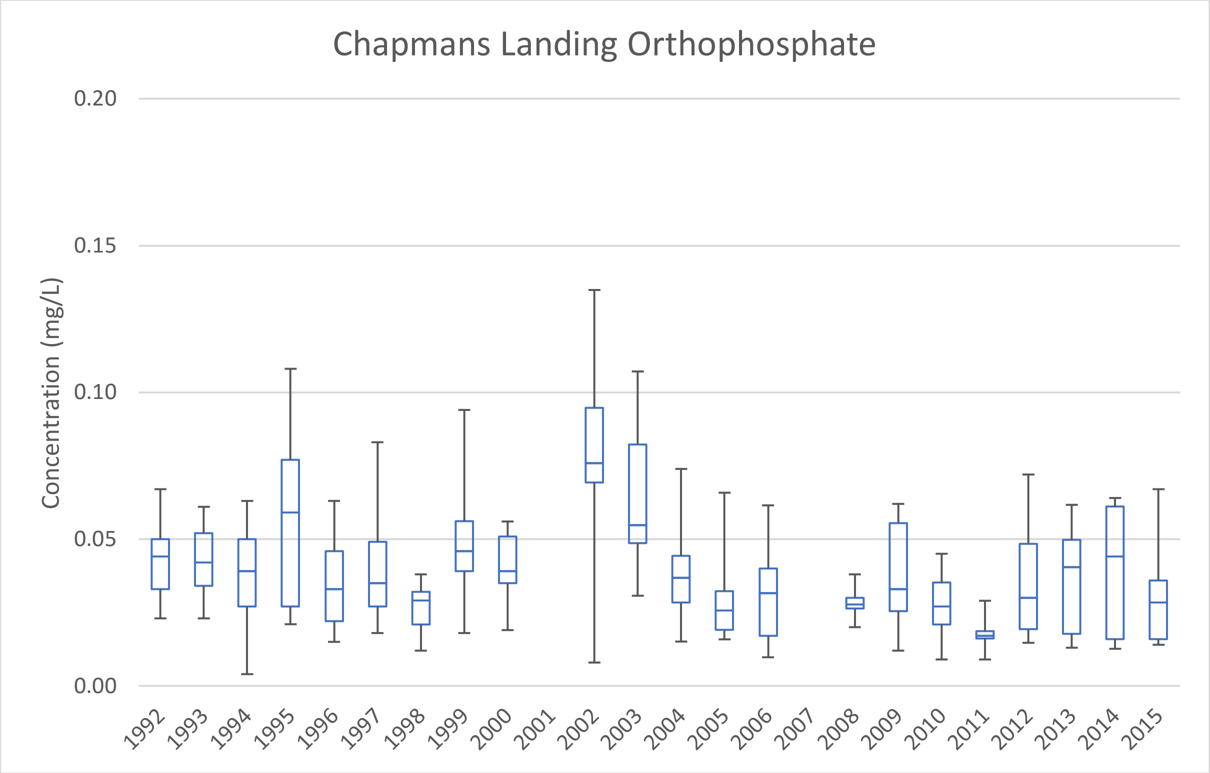
Monitoring Location (GRBAP)
Adams Point
(black circle with white plus sign)



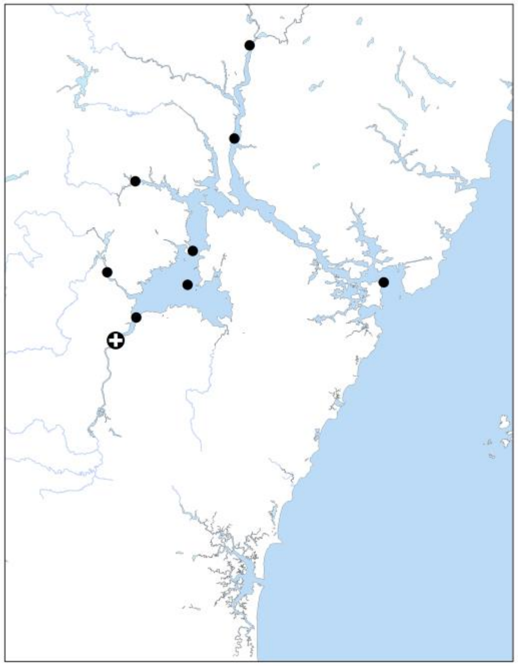
Station: GRBAP (Adams Point)

Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



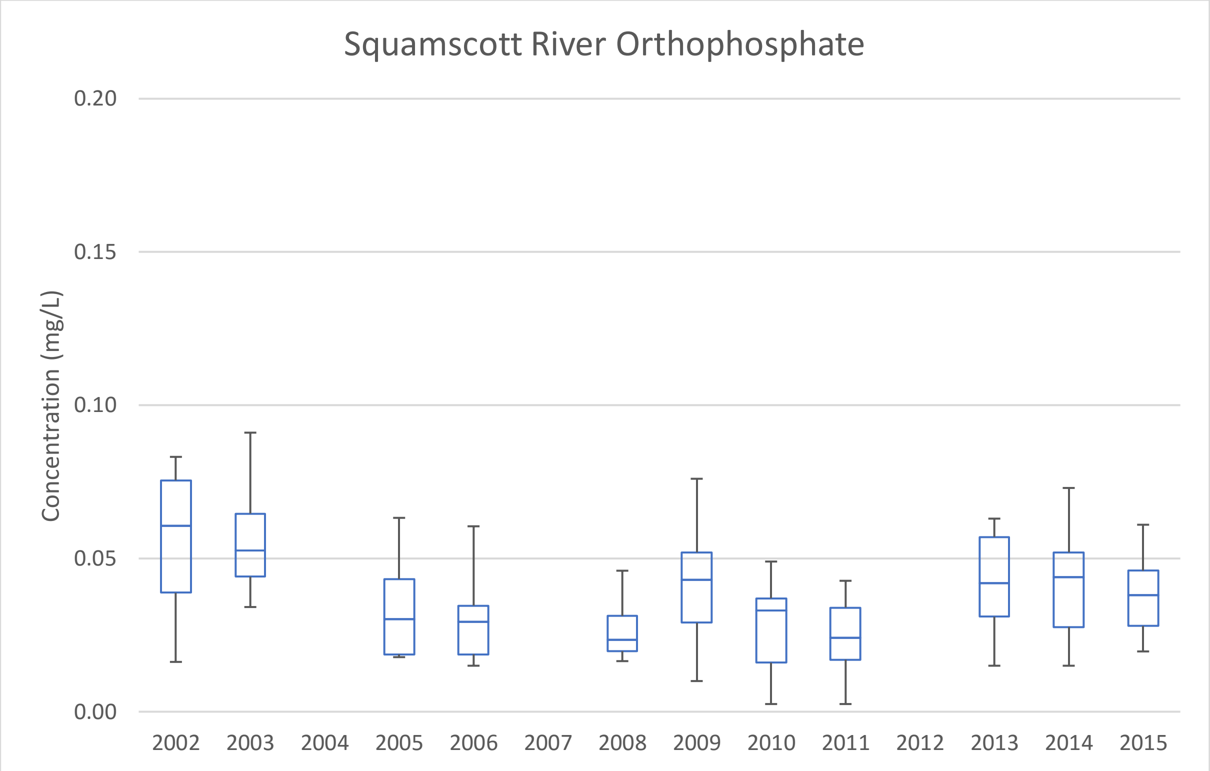
Monitoring Location (GRBCL)
Chapmans Landing
(black circle with white plus sign)



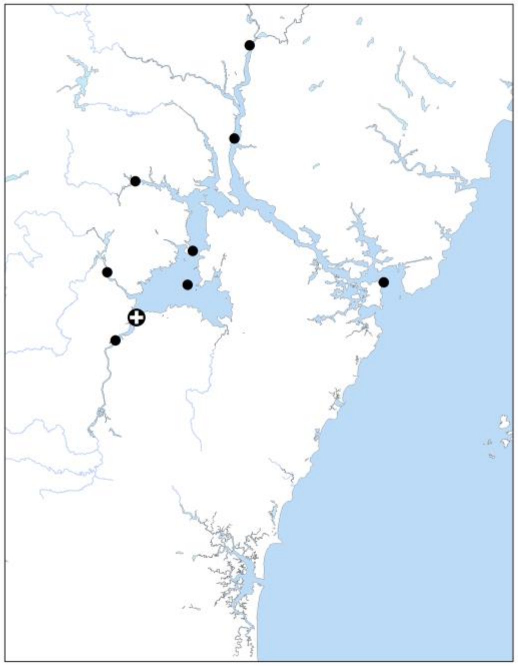
Station: GRBCL (Chapmans Landing in the Squamscott River)

Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



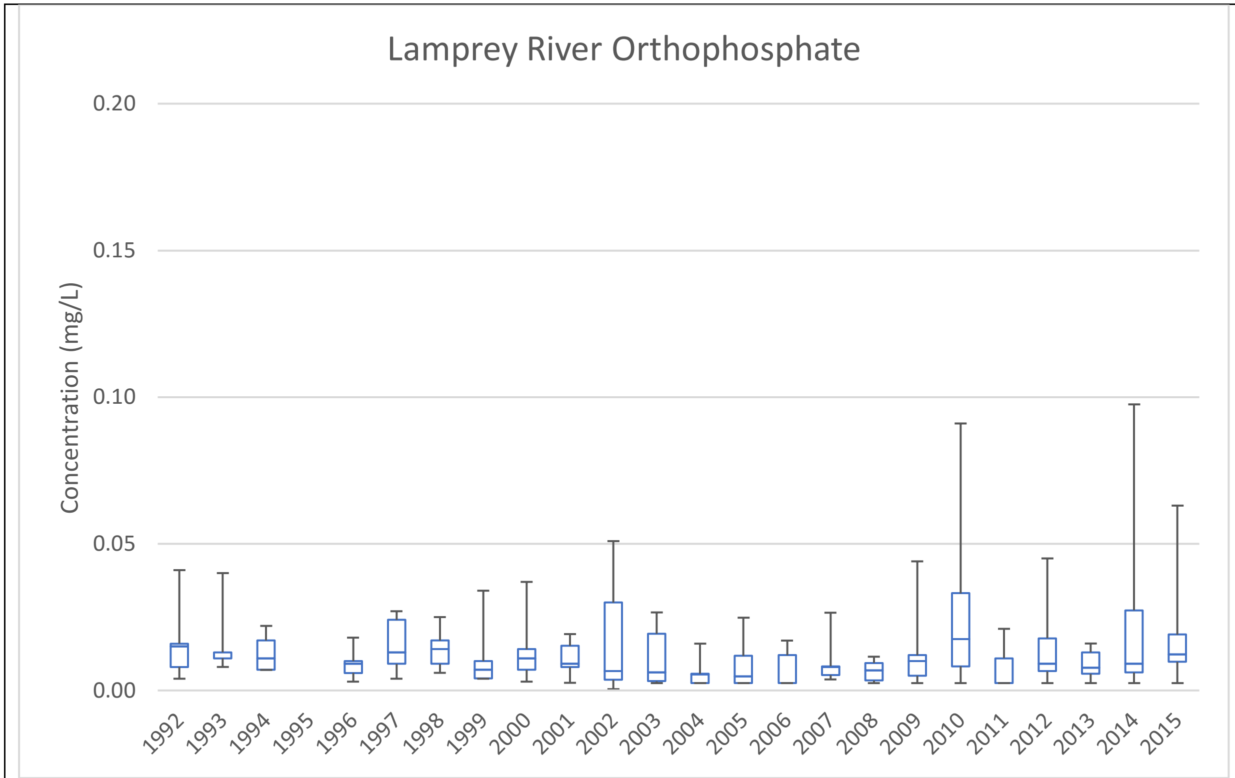
Monitoring Location (GRBSQ)
Squamscott River
(black circle with white plus sign)



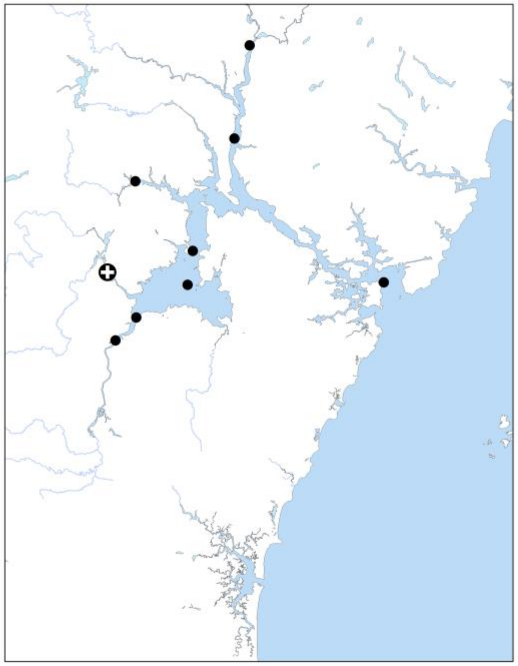
Station: GRBSQ (Squamscott River)

Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



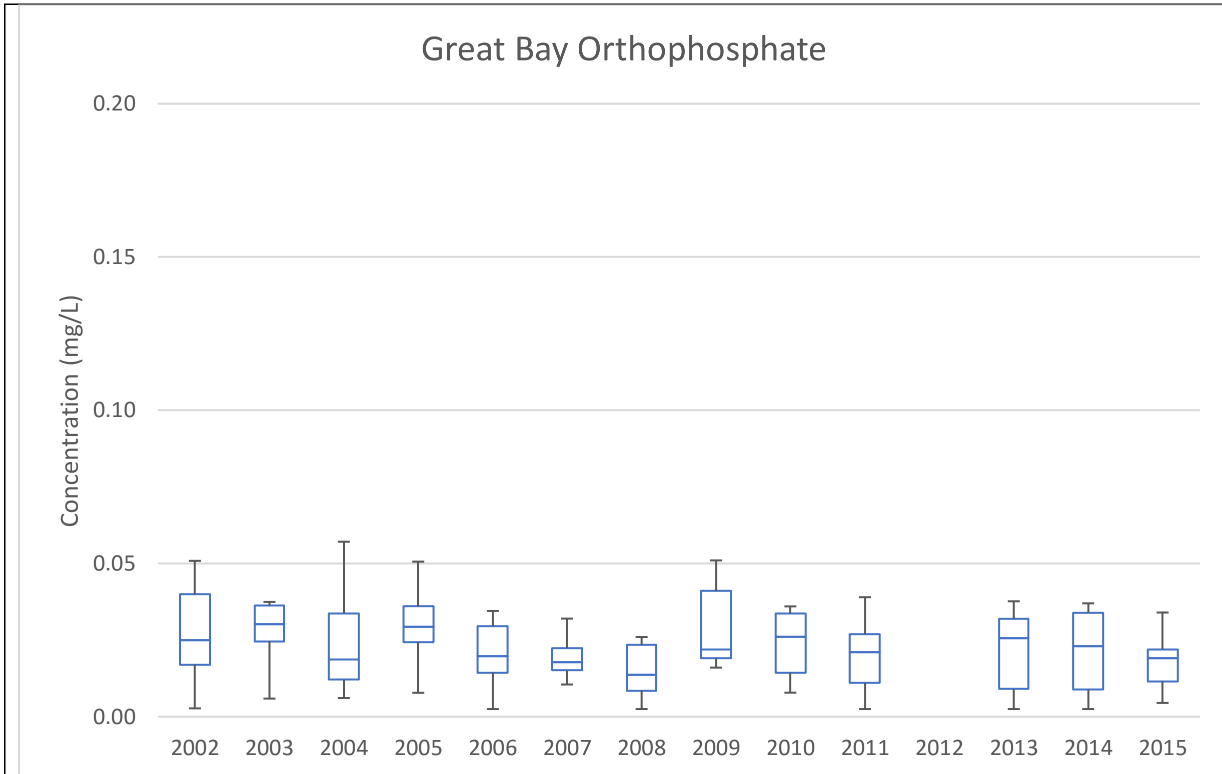
Monitoring Location (GRBLR)
Lamprey River
(black circle with white plus sign)



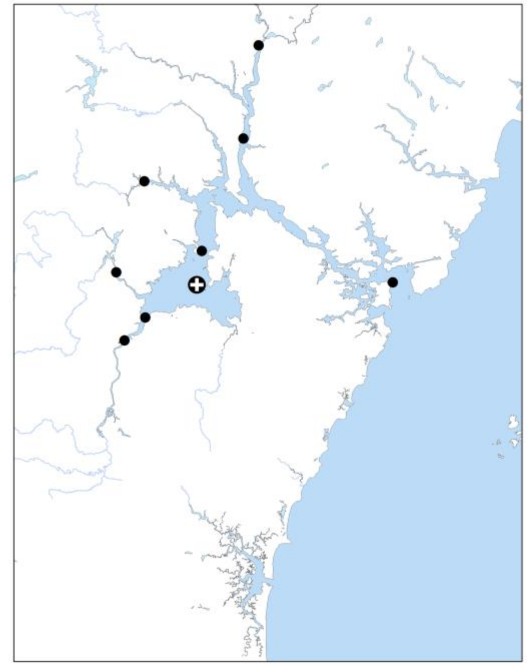
Station: GRBLR (Lamprey River)

Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



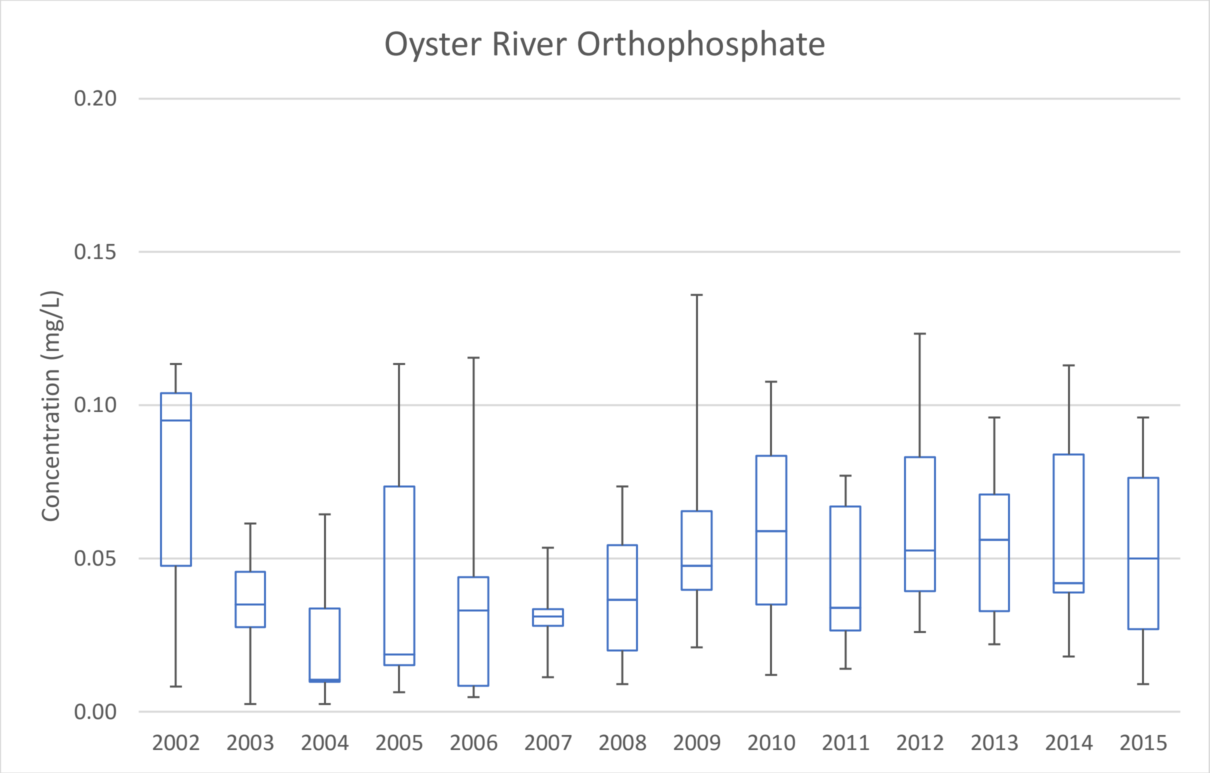
Monitoring Location (GRBGB)
Great Bay
(black circle with white plus sign)



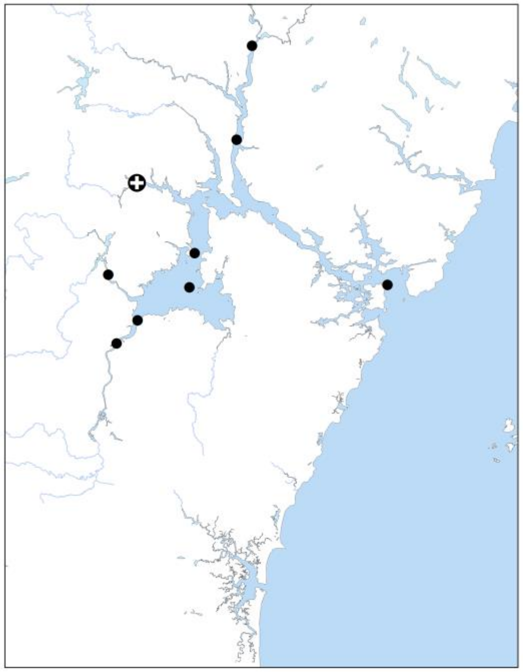
Station: GRBGB (Great Bay)

Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



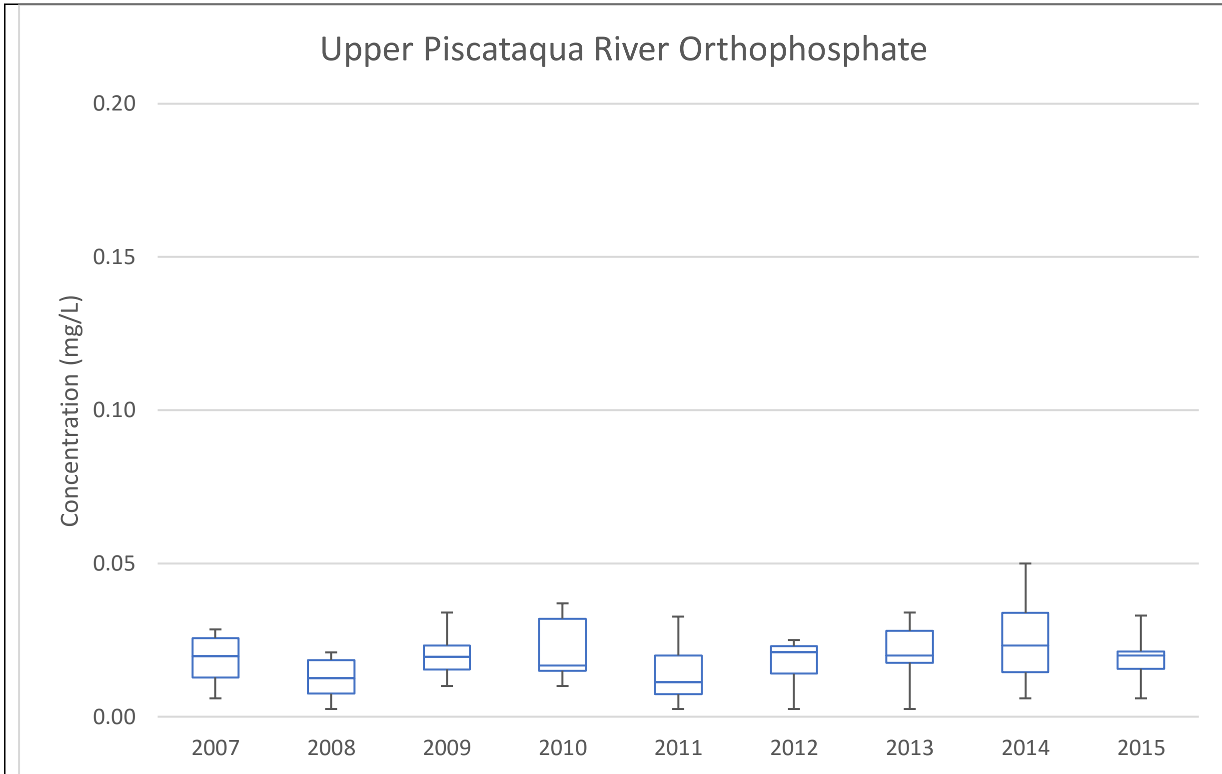
Monitoring Location (GRBOR)
Oyster River
(black circle with white plus sign)



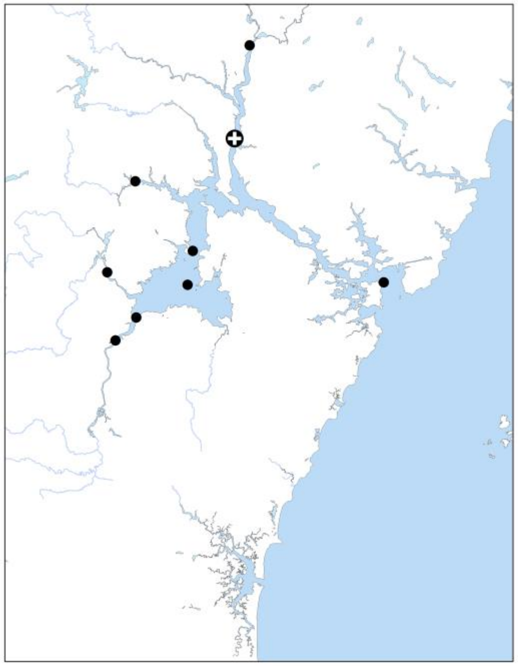
Station: GRBOR (Oyster River)

Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.



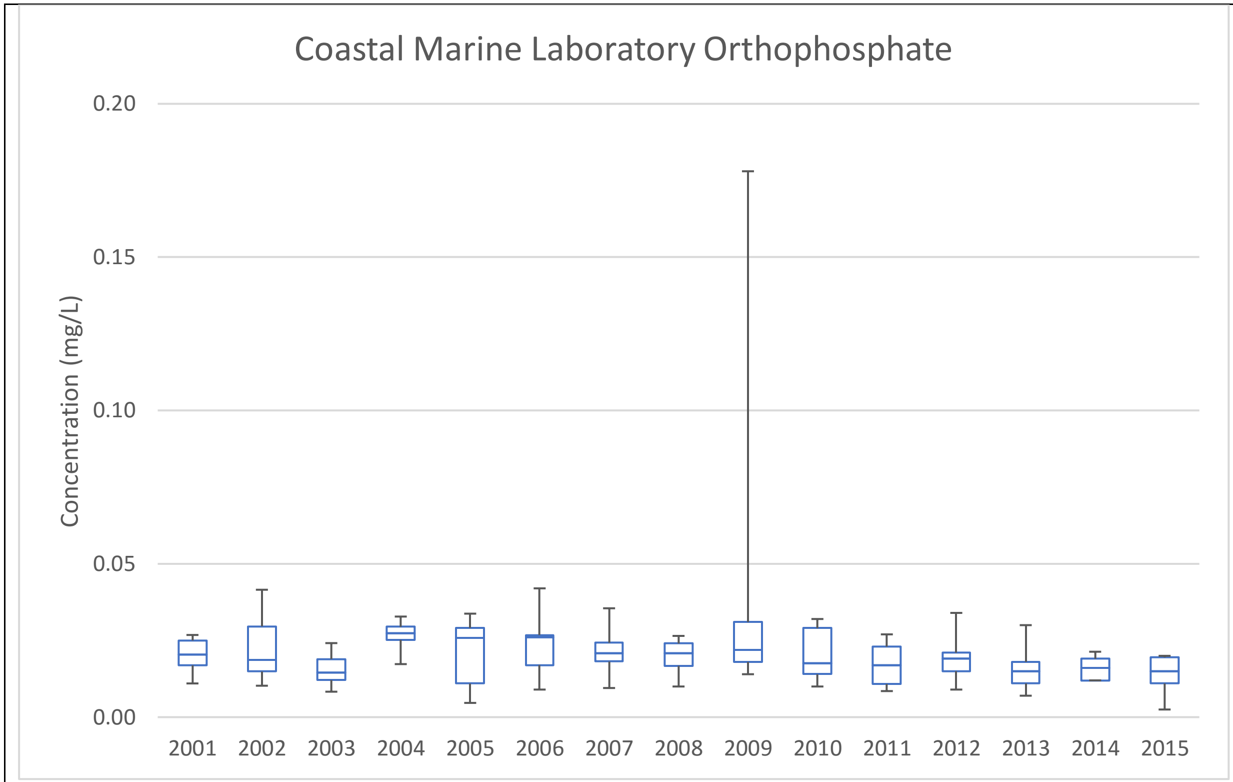
Monitoring Location (GRBUPR)
Upper Piscataqua River
(black circle with white plus sign)



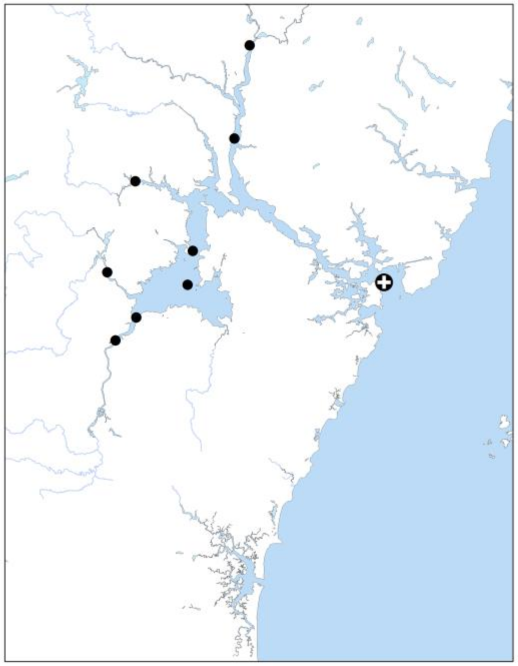
Station: GRBUPR (Upper Piscataqua River)

Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.



Monitoring Location (GRBCML)
Coastal Marine Laboratory
Portsmouth Harbor
(black circle with white plus sign)



Station: GRBCML (Coastal Marine Laboratory in Portsmouth Harbor)

Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.

Indicator: Phytoplankton populations in the Great Bay Estuary

<u>Question</u>

How have phytoplankton concentrations changed over time?

<u>Short Answer</u>

Chlorophyll-a concentrations—an accepted proxy for phytoplankton biomass—show no statistically significant trends at the eight stations sampled in the Great Bay Estuary. The Chlorophyll-a (Chl *a*) levels recorded in the Great Bay Estuary are often within ranges considered “good” or “fair” in the peer-reviewed literature. Periodically, however, Chl *a* levels increase to levels considered “poor.”

<u>PREP Goal</u>
No increasing trends for phytoplankton (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

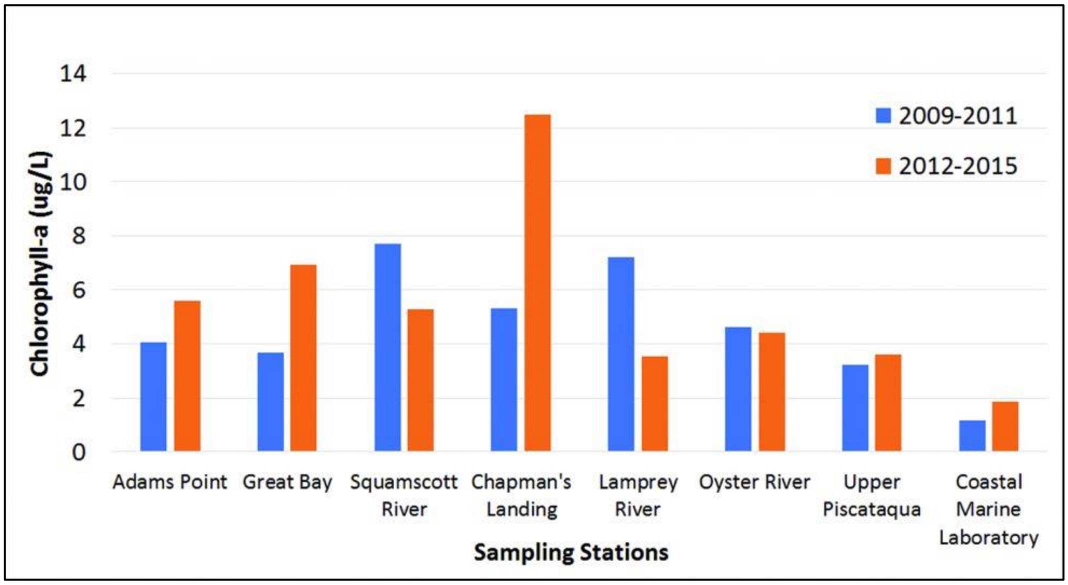


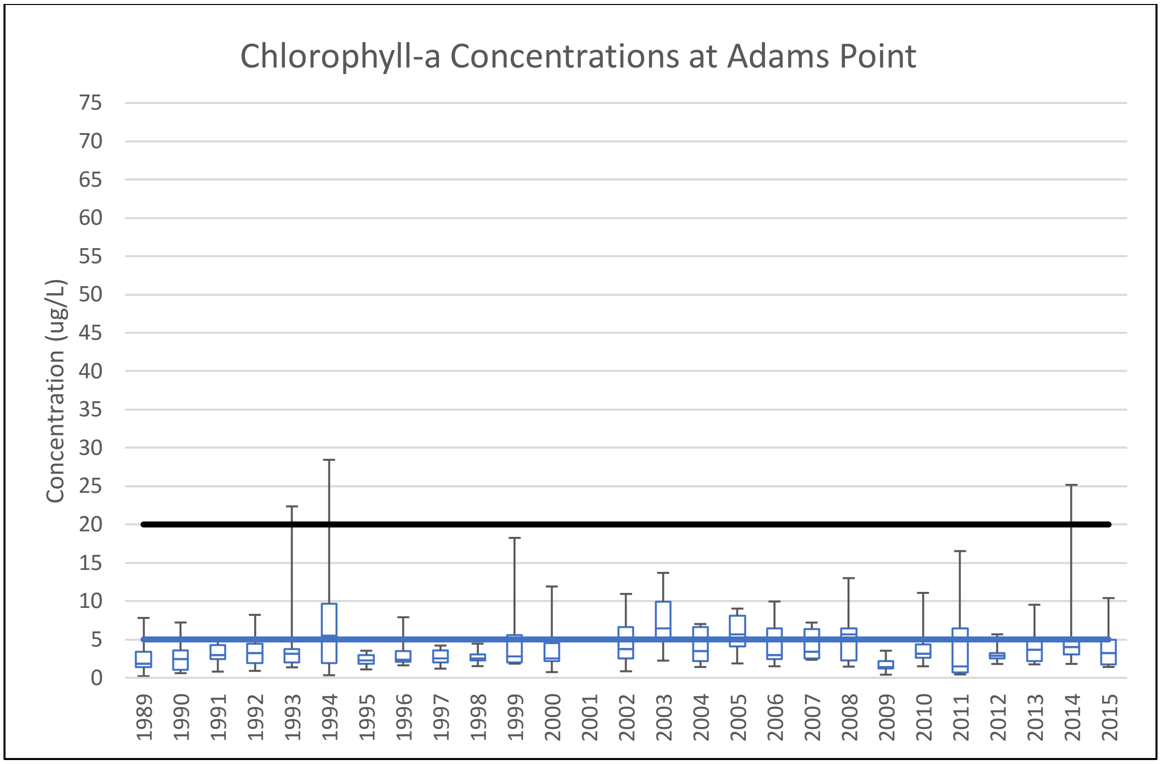
Figure P-1. Reporting average concentrations by sampling station. Data Source: Great Bay National Estuarine Research Reserve and the UNH Jackson Estuarine Laboratory.

<u>Why This Matters</u>

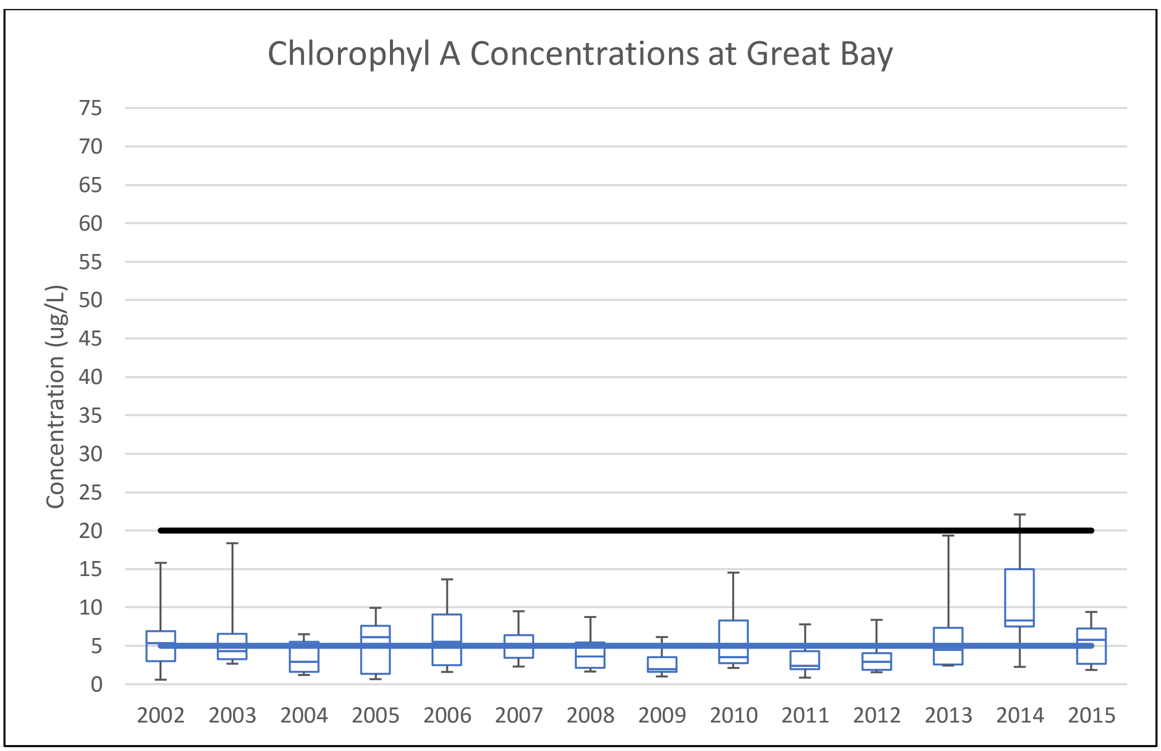
Phytoplankton convert the sun’s energy into biomass and are a key part of the food web. Phytoplankton can impact water clarity and compete with eelgrass and seaweeds for available light. Additionally, when large populations of phytoplankton die, their decomposition consumes the dissolved oxygen needed by fish and benthic invertebrates.

<u>Explanation (from 2018 State of Our Estuaries Report)</u>

National assessments note that less than 5 ug/L chlorophyll-a (Chl *a*) is considered “good;” between 5 and 20 ug/L is considered “fair” and above 20 ug/L is considered “poor” (Bricker et al. 2003; US EPA 2012). For the years 2012 to 2015, monthly sampling results suggest that, much of the time, Chl *a* levels in the Great Bay Estuary were within ranges regarded as “good” or “fair,” but that they sometimes exceeded 20 ug/L. As noted in Figure P-1, changes since the last reporting period (2009–2011) vary, depending on the sampling station.



Figures P-2 (above) and P-3 (below). Chlorophyll-a concentrations at Adams Point and Great Bay. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Levels between the blue and the black line are considered "fair." Levels above the black line are considered "poor." Data Source: Great Bay National Estuarine Research Reserve and the UNH Jackson Estuarine Laboratory.



All of the data were collected at low tide, when daily concentrations of Chl *a* tend to be highest. None of the eight stations sampled on a monthly basis show a statistically significant trend (Figure P-1). At Adams Point (Figure P-2), between 2012 and 2015, median Chl *a* levels ranged from 2.9 to 4.0 ug/L and maximum values ranged from 5.7 to 25.2 ug/L. At the Great Bay station (Figure P-3), between 2012 and 2015, median levels ranged from 2.9 to 8.3 ug/L and maximum values ranged from 8.4 to 22.1 ug/L.

The Chapman's Landing station indicated the highest levels of Chl *a*. Since 2012, median levels ranged from 4.8 to 6.9 ug/L and maximum levels ranged from 18.3 to 71.7 ug/L. At the Lamprey River station, median levels ranged from 1.4 to 4.6 ug/L and maximum levels ranged from 2.1 to 21.0 ug/L. At the Upper Piscataqua River Station, median levels ranged from 2.1 to 3.2 ug/L with maximum levels from 4.1 to 24.5 ug/L. Note that 2012 was the only year that levels rose above 20 ug/L for this station. Chl *a* levels at the remaining three stations (Squamscott River, Oyster River and Coastal Marine Laboratory) did not exceed 12 ug/L between 2012 and 2015.

(See Table P-1 and Figure P-5.)

Other parts of the Great Bay Estuary—in addition to the eight stations reported here—also show counts in excess of 20 ug/L. For example, Little Bay registered 25.2 ug/L in 2014 and the Cocheco River indicated a maximum of 28.9 ug/L in 2015 (NH DES 2017).

Methods and Data Sources

Trend analysis for chlorophyll-a was performed at the following stations (Figure P-4):

- GRBAP (Adams Point between Great Bay and Little Bay)
- GRBGB (Great Bay)
- GRBCL (Chapmans Landing in the Squamscott River)
- GRBSQ (Squamscott River at the railroad trestle)
- GRBLR (Lamprey River)
- GRBOR (Oyster River)
- GRBUPR (Upper Piscataqua River)
- GRBCML (Portsmouth Harbor)

Samples collected at low-tide at the trend stations were identified. Low-tide samples were used for the trend analysis to control for the effects of tides and because historic datasets were collected exclusively at low tide. The data for each station were averaged by month (there was rarely more than one sample in the same month) and then the number of months with data in each year was counted. Only data from the months April through December were used. (The station at Adams Point is monitored 12 months per year.) If three consecutive months were missed in any year, that year was not included in the analysis. This was done in order to minimize bias from years for which the data do not reflect the full range of seasons.

Linear regression was used to test for long-term trends. The annual median values were regressed against the year variable. Trends were considered significant if the slope coefficient of the year variable was significant at the $p<0.05$ level.

Data Sources

Data for this indicator were provided by the UNH and Great Bay NERR Tidal Water Quality Monitoring Programs.

Additional trend monitoring stations have been added recently in the Bellamy, Cocheco, Salmon Falls, and Piscataqua Rivers and in Hampton-Seabrook Harbor; data from these stations will be included in the next Technical Report, scheduled for 2022.

Additional Results (Beyond What Was Reported in the SOOE)

The results of the trend analysis for chlorophyll-a compounds are summarized in Table P-1. Plots for each station are shown on Figure P-5. Table P-1 indicates the range of median values straddle the 0.5 ug/L boundary separating “good” conditions from “fair” conditions, using EPA’s (2012) thresholds. However, it is also important to review the maximum values (Table P-1 and Figure P-5) to understand the range of values seen at each station, since the ecosystem integrates the full range of values, not just the median or the mean. Table P-1 and Figure P-5 indicate that only one of the eight stations (at the Coastal Marine Laboratory in Portsmouth Harbor) consistently registers chl-a levels below 5 ug/L.

Technical Advisory Committee (TAC) Discussion Highlights
The Relationship Between Phytoplankton and Eelgrass
This topic was discussed as part of two consecutive TAC meetings on May 9-10, 2017; notes and presentations are available (PREP 2017). While many of the TAC participants expressed concerns about episodic blooms (levels higher than 20ug/L) of phytoplankton (Figure P-5), a smaller group of UNH scientists and stakeholder point out that phytoplankton levels are frequently low; moreover, the data do not demonstrate any change over time in phytoplankton levels, leading some to conclude that phytoplankton cannot be implicated in the loss of eelgrass habitat.

Others TAC participants—including all three external advisors to the TAC—encourage a more holistic perspective. Specifically, they advocate that all light-attenuating components (e.g., seaweeds, total suspended solids, colored dissolved organic matter (CDOM) and phytoplankton) be considered together, not separately, because these components act in an additive fashion. This approach to considering light attenuating substances and broader considerations relating to management options for increasing the resilience of the Great Bay Estuary are articulated more fully in the “Stress and Resilience” section of the 2018 State of Our Estuaries Report (PREP 2017b) as well as the “Statement Regarding Eelgrass Stressors” (Kenworthy et al. 2017).

References Cited

Bricker SB, Ferreira JG, and Simas T. 2003. An integrated methodology for assessment of estuarine trophic status. *Ecological Modelling*. 169 (2003) 39 - 60.

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US EPA. 2012. National Coastal Condition Report IV. https://www.epa.gov/national-aquatic-resource-surveys/national-coastal-condition-report-iv-2012

Table P-1: Trends for chlorophyll-a in the Great Bay Estuary.

Station	Period	Range of Recent (Median Values) & Maximum Values 2012 -2015, ug/L	Long Term Trend
GRBAP (Adams Point)	1989-2015	(2.9 to 4.0) 5.7 to 25.2	No significant trend
GRBCL (Chapmans Landing)	1989-2015	(4.8 to 6.9) 18.3 to 71.7	No significant trend
GRBSQ (Squamscott River)	2002-2015	(4.3 to 6.1) 8.5 to 10.9	No significant trend
GRBLR (Lamprey River)	1992-2015	(1.4 to 4.6) 2.1 to 21.0	No significant trend
GRBGB (Great Bay)	2002-2015	(2.8 to 8.3) 8.4 to 22.1	No significant trend
GRBOR Oyster River	2002-2015	(2.8 to 5.6) 6.8 to 11.8	No significant trend
GRBUPR Upper Piscataqua River	2007-2015	(2.1 to 3.2) 4.1 to 24.5	No significant trend
GRBCML Coastal Marine Laboratory Portsmouth Harbor	2002-2015	(1.3 to 2.3) 2.5 to 4.7	No significant trend

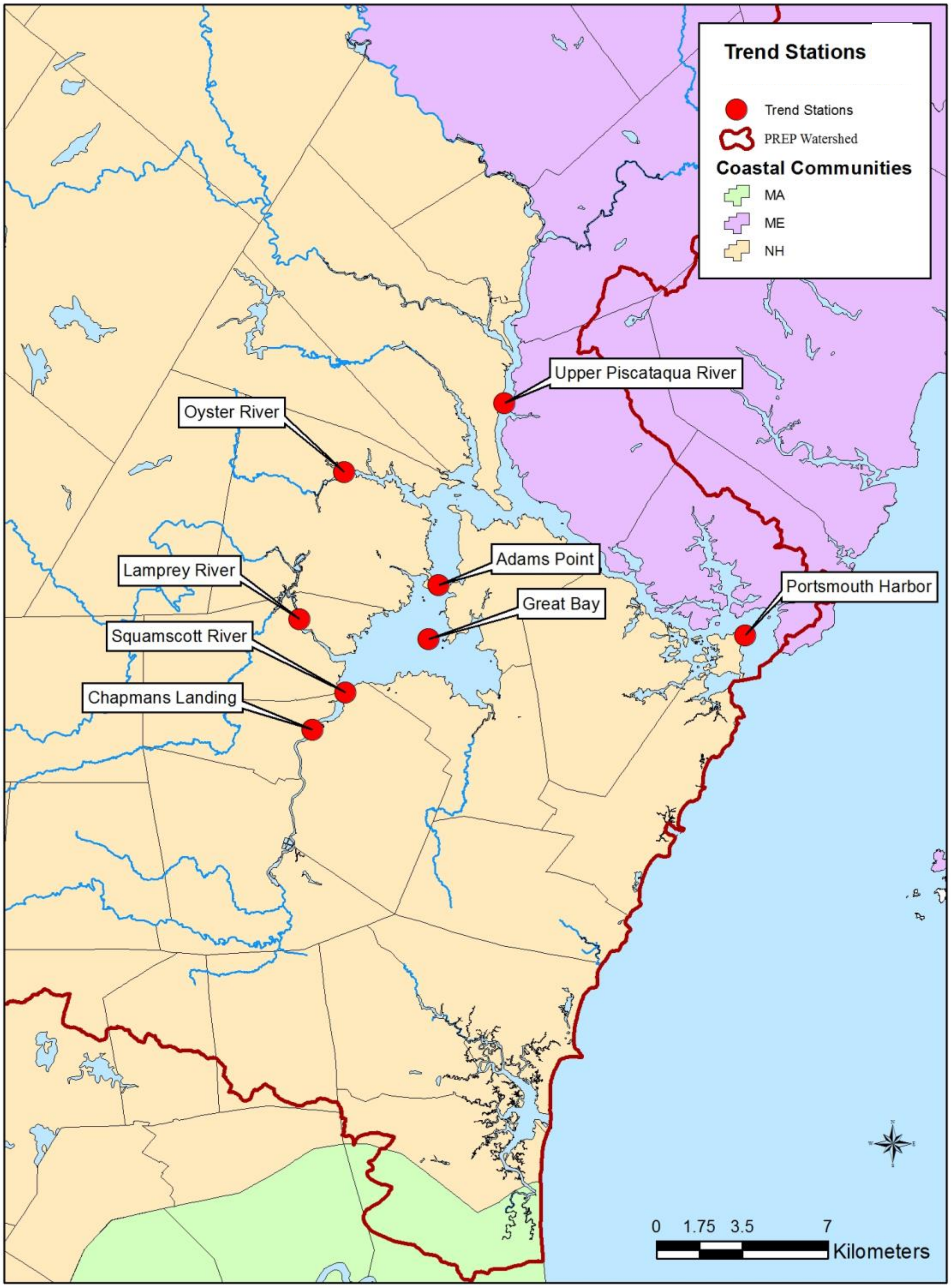
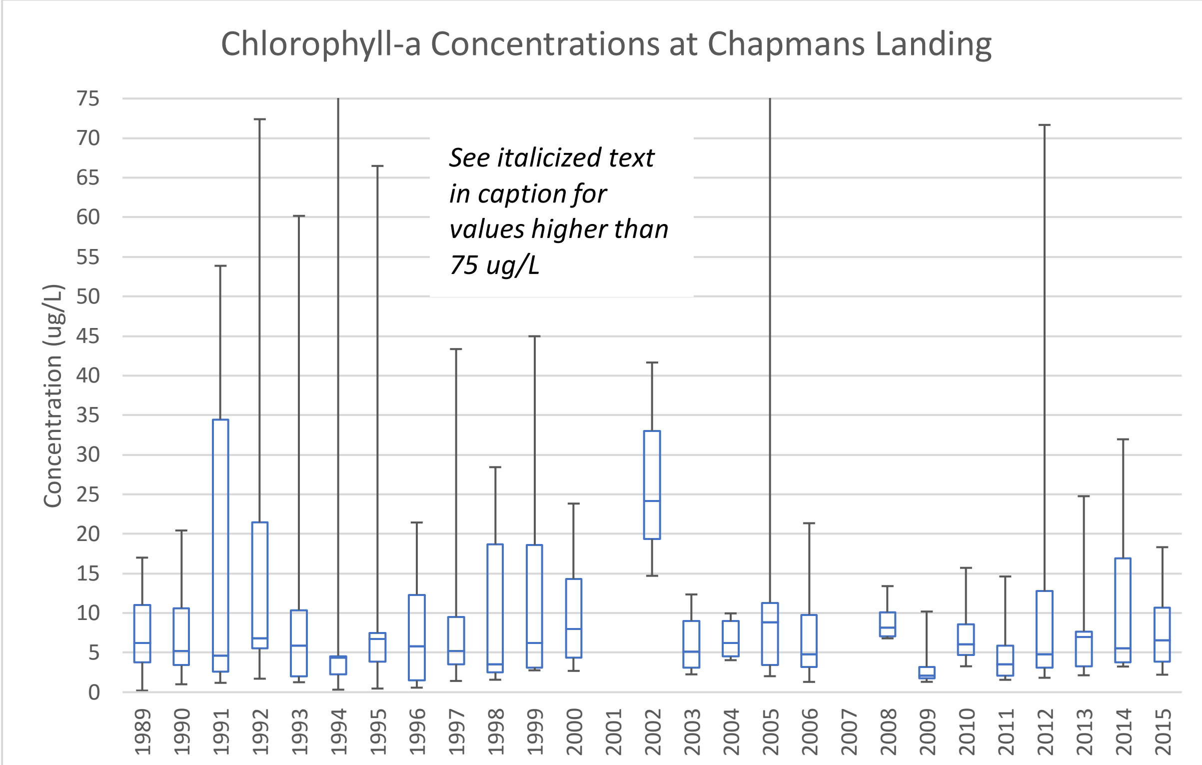
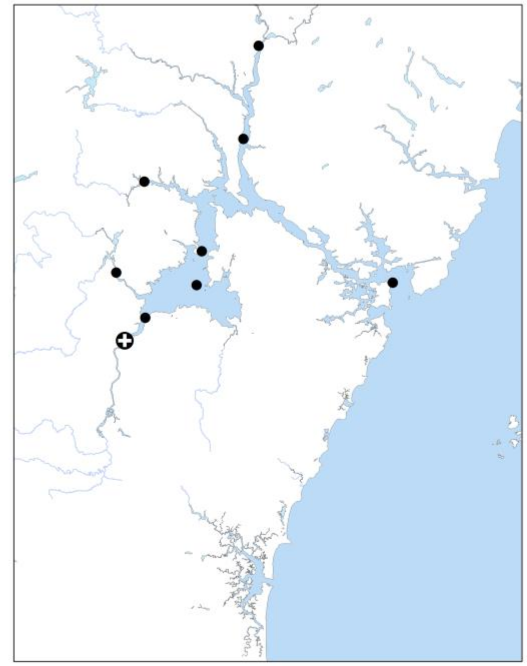


Figure P-4: Map of trend stations for chlorophyll-a.

Figure P-5: Chlorophyll-a concentrations at Stations in the Great Bay Estuary.



Monitoring Location (GRBCL)
Chapmans Landing
(black circle with white plus sign)

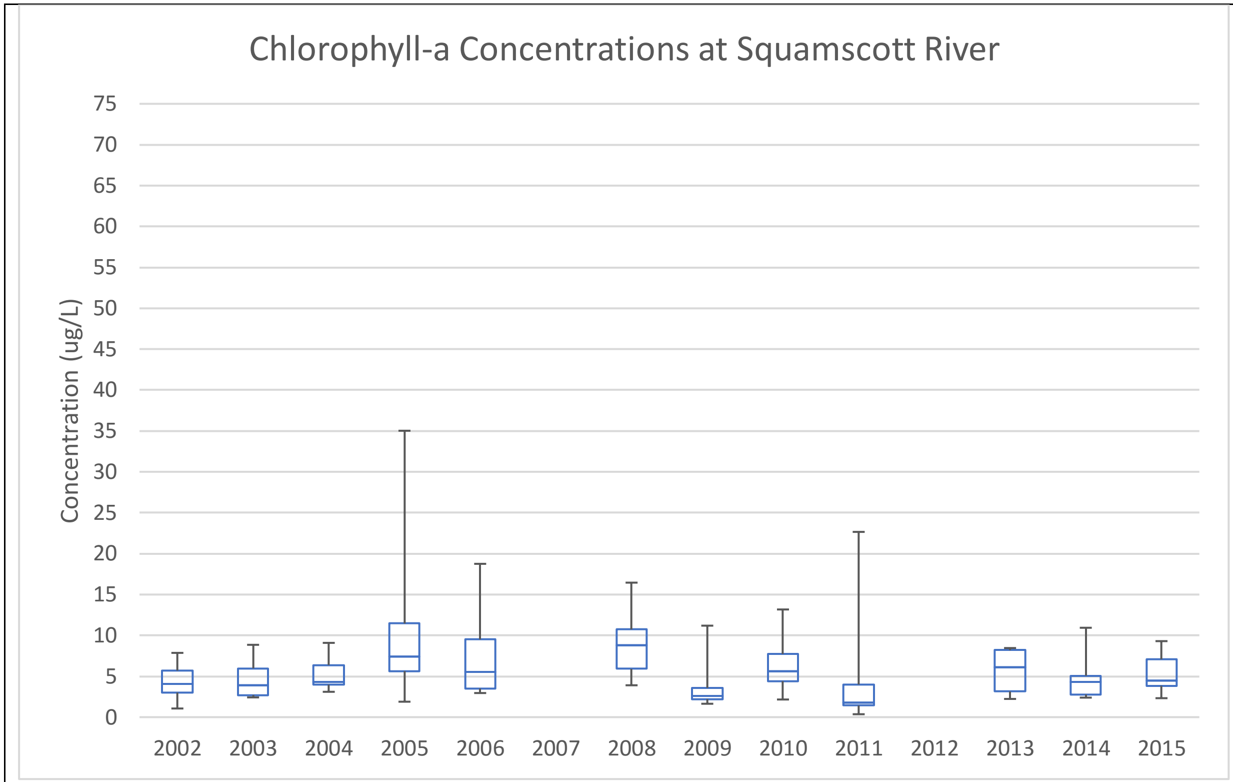


Station: GRBCL (Chapmans Landing in the Squamscott River)

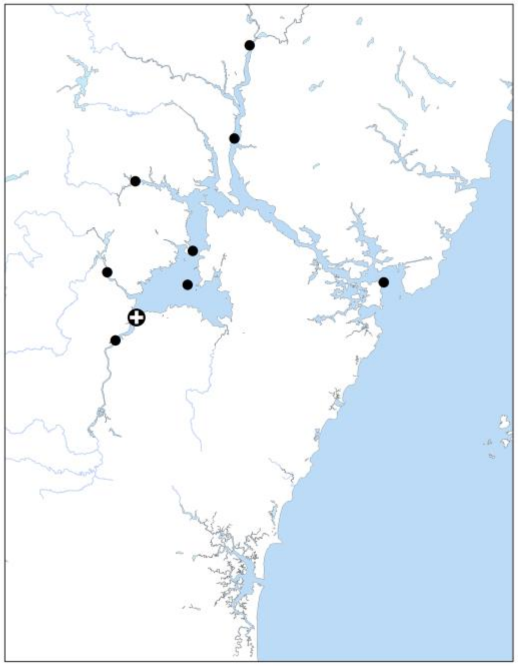
Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.

Values Higher Than 75 ug/L: 1994 = 160 ug/L; 2005 = 106 ug/L



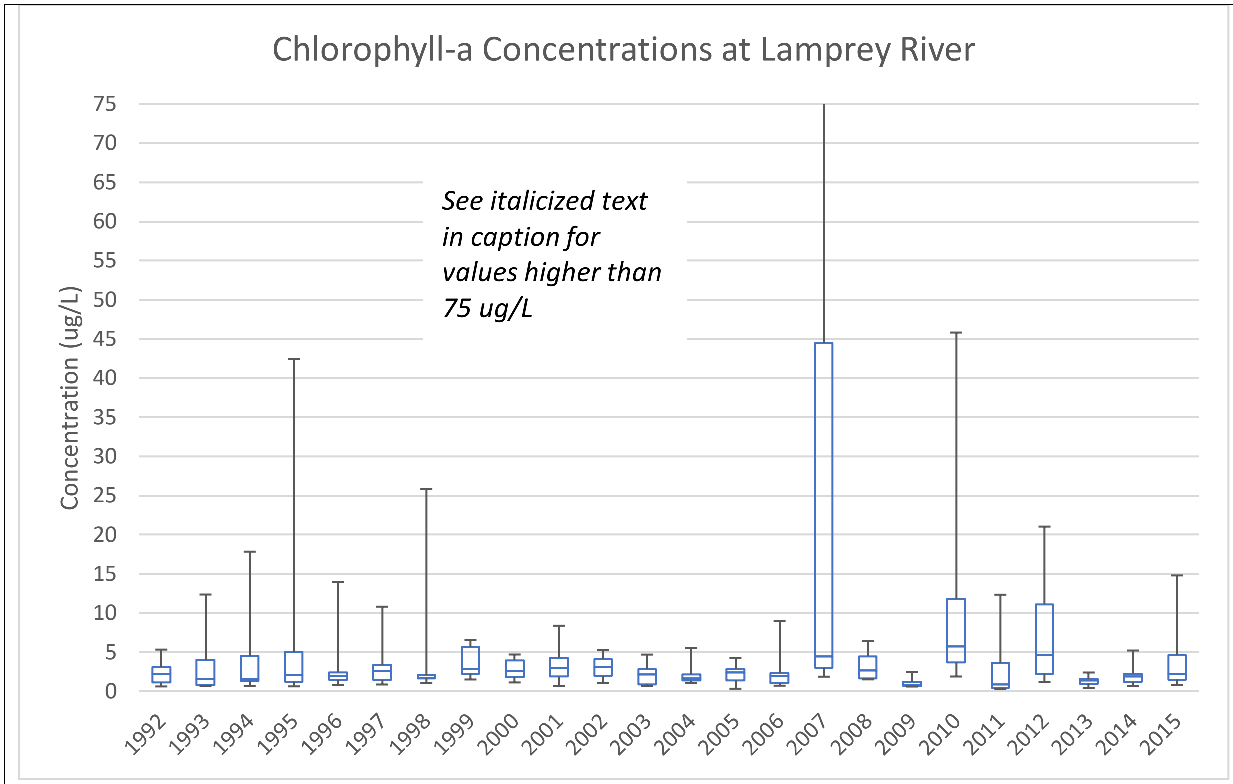
Monitoring Location (GRBSQ)
Squamscott River
(black circle with white plus sign)



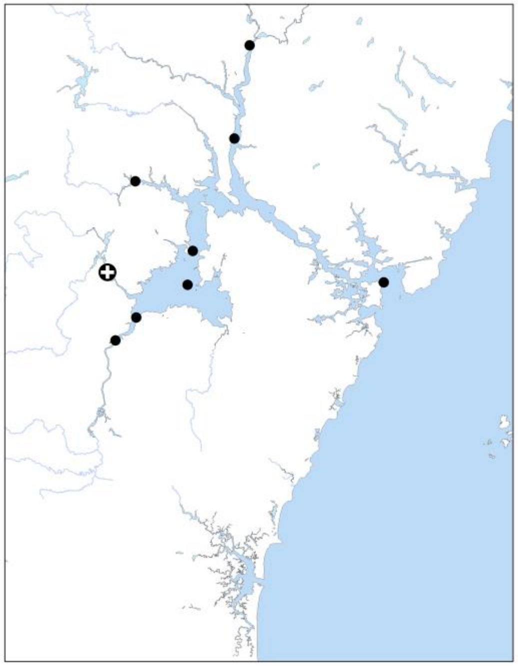
Station: GRBSQ (Squamscott River)

Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.



Monitoring Location (GRBLR)
Lamprey River
(black circle with white plus sign)

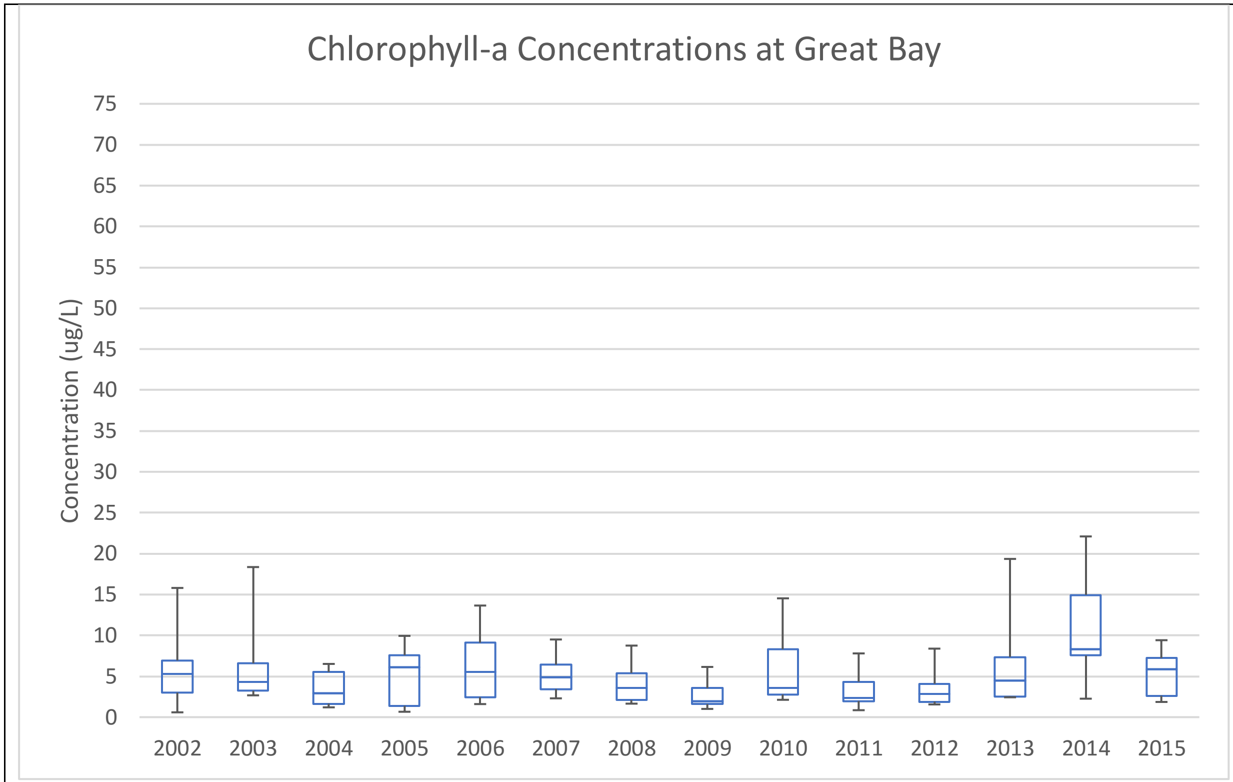


Station: GRBLR (Lamprey River)

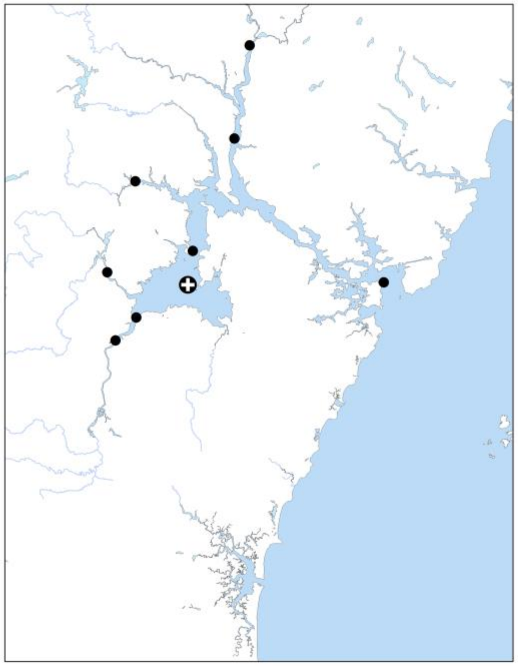
Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.

Values Higher Than 75 ug/L: 2007 = 145 ug/L



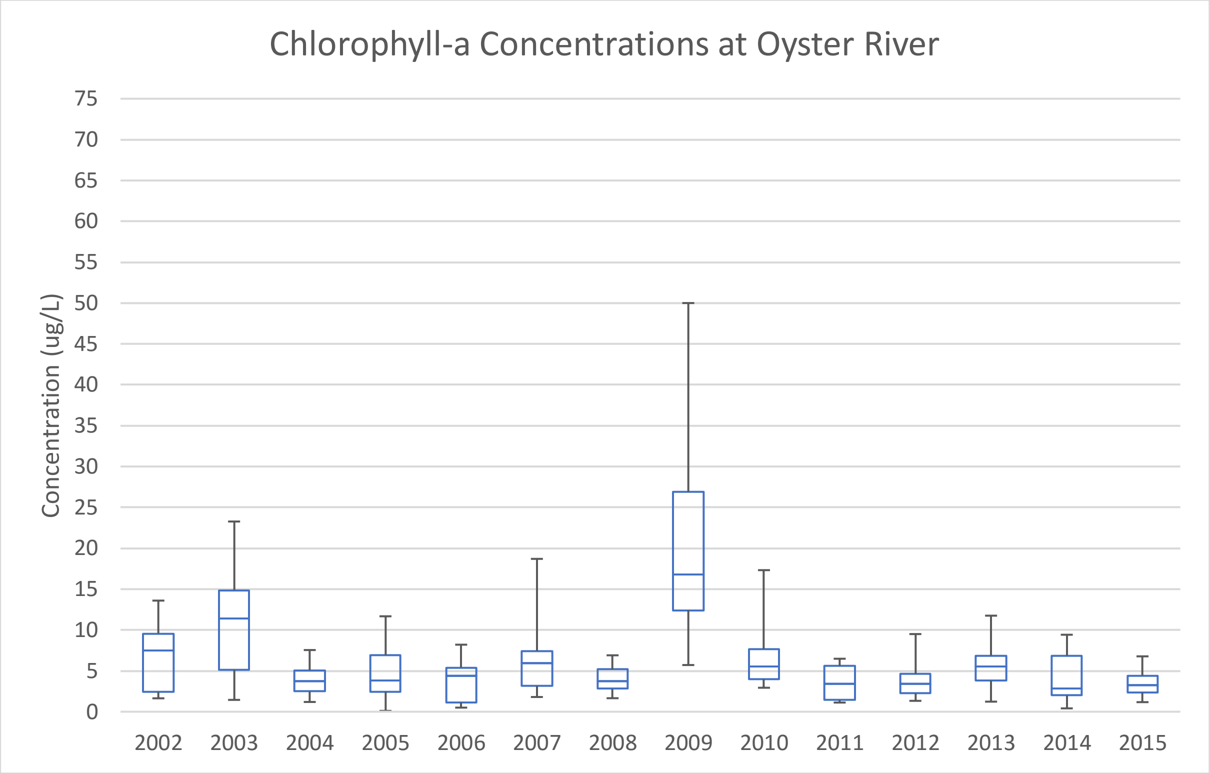
Monitoring Location (GRBGB)
Great Bay
(black circle with white plus sign)



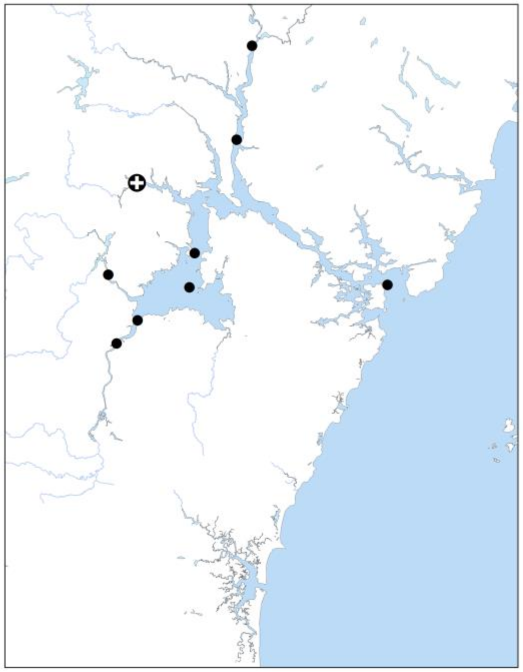
Station: GRBGB (Great Bay)

Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.



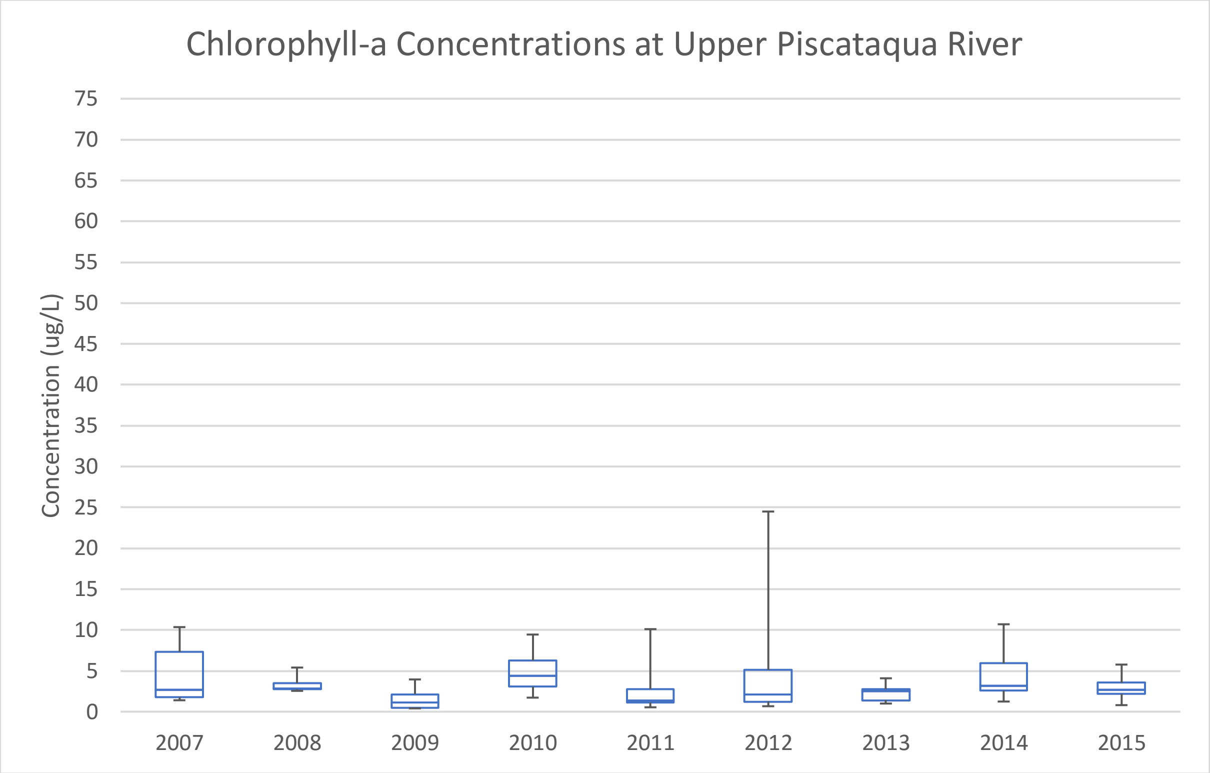
Monitoring Location (GRBOR)
Oyster River
(black circle with white plus sign)



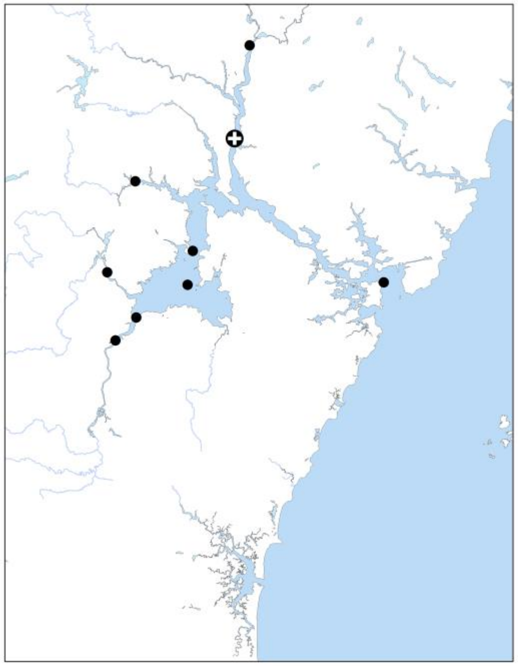
Station: GRBOR (Oyster River)

Long Term Trend: No significant trend.

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.



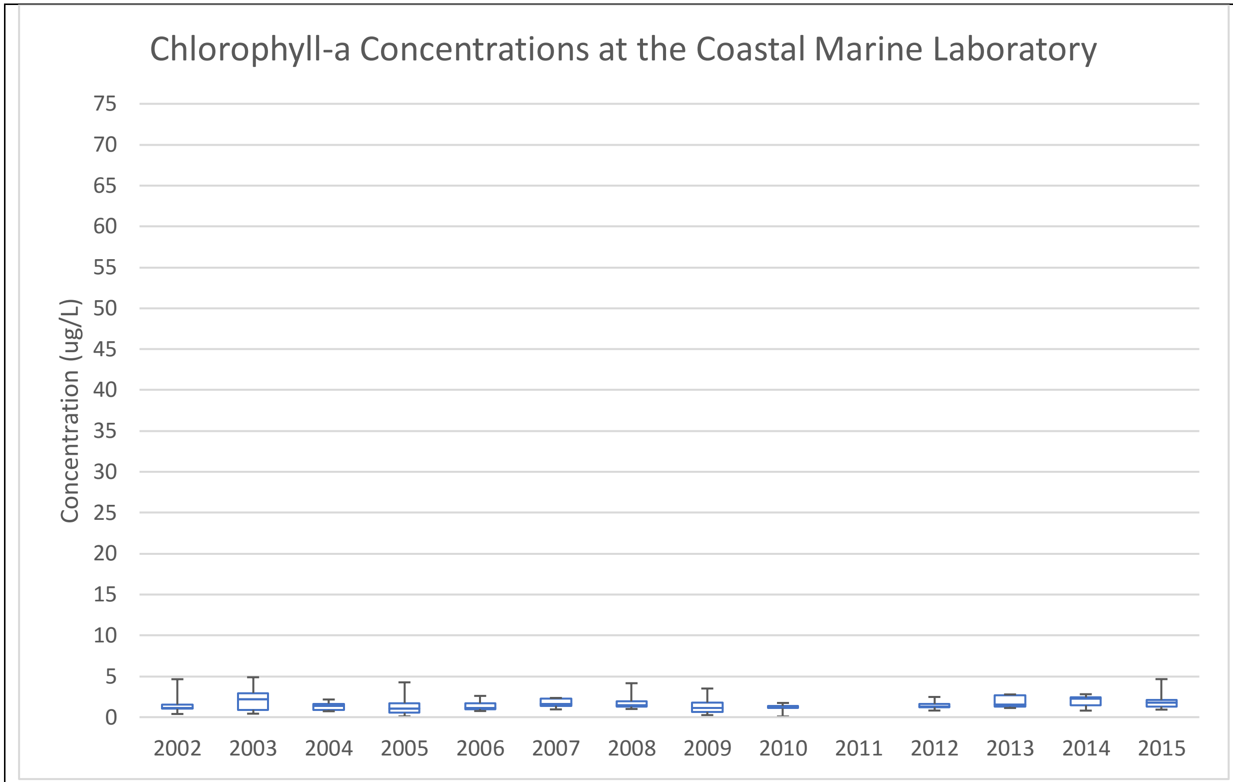
Monitoring Location (GRBUPR)
Upper Piscataqua River
(black circle with white plus sign)



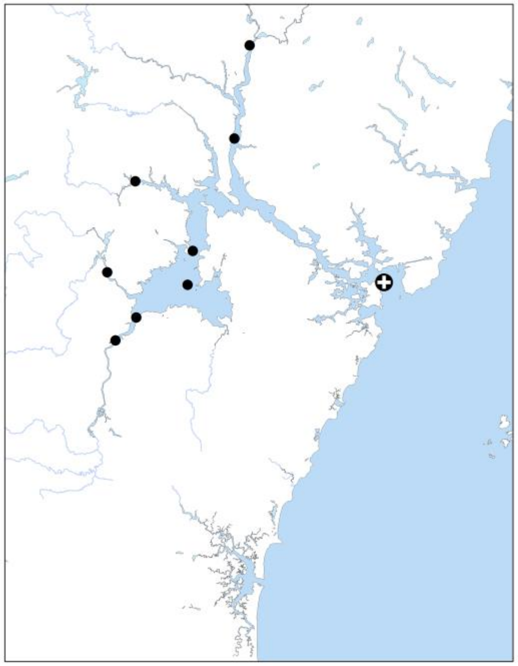
Station: GRBUPR (Upper Piscataqua River)

Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.



Monitoring Location (GRBCML)
Coastal Marine Laboratory
Portsmouth Harbor
(black circle with white plus sign)



Station: GRBCML (Coastal Marine Laboratory in Portsmouth Harbor)

Long Term Trend: No significant trend

Box and whisker plots of data collected at low tide. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.

Indicator: Seaweed

Question

How has the amount of seaweed in the Great Bay Estuary changed over time?

Short Answer

At intertidal sampling sites, green and red seaweeds (combined) increased from approximately 8% mean percent cover in 1980 to 19% cover in 2016. At these same sites, invasive species now dominate the red seaweed category, which comprised approximately 15% of all seaweeds in 2016.

PREP Goal
No increasing trends for seaweeds.

Why This Matters

Seaweeds are an important and critical group of estuarine primary producers, but many of the factors affecting estuaries globally (e.g., climate change, sedimentation, nutrient pollution) also accelerate the growth of some seaweeds (Thomsen et al. 2012; Mathieson and Dawes 2017). In these situations, seaweeds can grow so abundant that they shade eelgrass. Since they can "bloom"—that is, grow and die very quickly—they can also negatively impact sediment conditions by decomposing on the estuary floor (Hauxwell et al. 2001). This can negatively impact shellfish and benthic invertebrates as well as eelgrass.

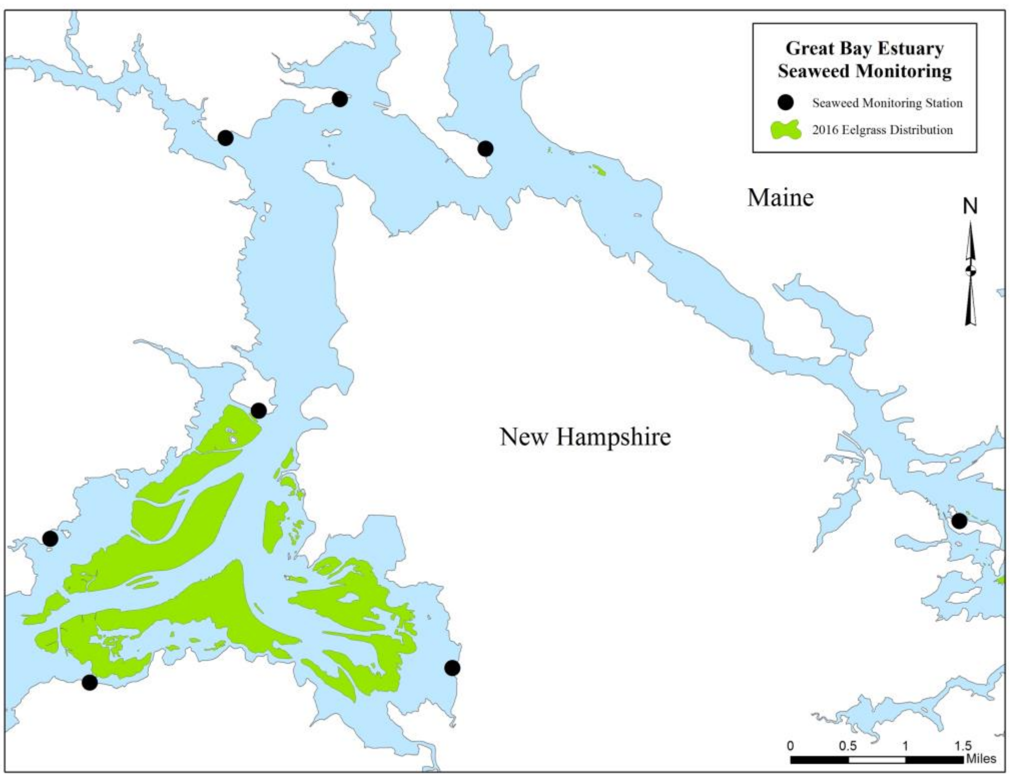


Figure S-1. Locations of the eight intertidal seaweed monitoring sites are designated by the black circles. Green areas indicate mapped eelgrass habitat from 2016.

Explanation (from 2018 State of Our Estuaries Report)

Great Bay Estuary seaweeds can be categorized as brown, green and red. This indicator (intertidal seaweeds) focuses on changes in the red and green seaweeds, which are much more abundant in the subtidal areas (those areas always covered by water) and are more likely to compete with eelgrass. However, there are only a few data points in the Great Bay Estuary that allow for assessment of changes in the abundance of these seaweeds where impacts on eelgrass could also be assessed (Figure S-1).

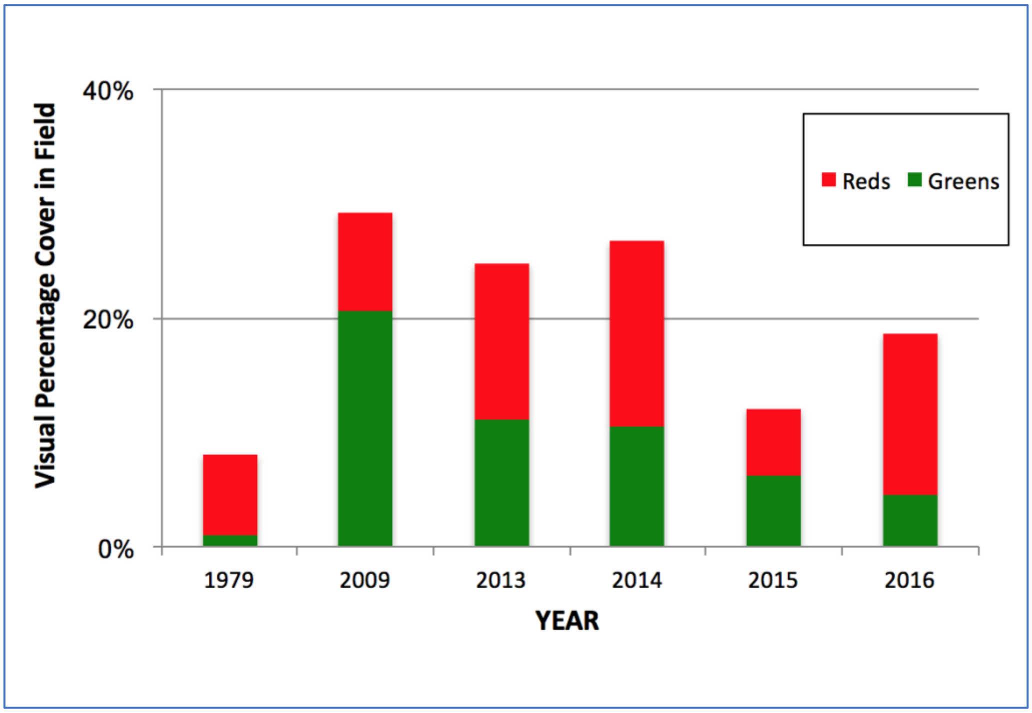


Figure S-2. Percent cover of red and green seaweed at selected intertidal sites in the Great Bay Estuary. Data Source: UNH Jackson Estuarine Laboratory.

The mean percent cover of green and red seaweeds (combined) at a limited number of sampling sites in the Great Bay Estuary was 8% in 1980 but increased to 19% by 2016 (Figure S-2). For green seaweeds, this increase includes the presence of both native and invasive species of *Ulva*. It is notable that no invasive species of *Gracilaria* (a red seaweed) were seen in 1980, but now two major invasive Asiatic red seaweeds (*Gracilaria vermiculophylla* and *Dasysiphonia japonica*) along with a native species (*Gracilaria tikvahiae*) dominate the red seaweeds (Burdick et al. 2017).

While the seaweed data are cause for concern, it is important to note that this dataset is not comprehensive in time and space; more research is required to verify these trends. In addition, these data are restricted to intertidal areas. While important steps to establish a baseline in the subtidal area have occurred, this work needs to be followed up by additional monitoring to better assess trends.

Methods and Data Sources

Seaweed populations have been researched extensively in the Great Bay Estuary and surrounding areas (e.g., Mathieson 1975; Short 1992; Jones 2000; Pe'eri et al. 2008). However, seaweed percent cover has not been monitored in a consistent fashion until recently (Cianciola and Burdick 2014), with the most recent report issued in 2017 (Burdick et al. 2017); this most recent report describes methods in detail and summarizes trends since 2013.

Figure S-2 also incorporates data collected from two earlier studies: the first occurred 1979-1980 (Hardwick-Witman and Mathieson 1983) and the second occurred 2008-2010 (Nettleton et al. 2011).

Seaweed trends were also discussed at two separate PREP Technical Advisory Committee meetings in 2016 and 2017 (PREP 2016; PREP 2017). At the 2017 meeting, data from a recent SeagrassNet report (Short 2017) noted an increase (since 2007) in subtidal seaweed within 12 replicate quadrats sampled along three permanent transects in Great Bay.

Technical Advisory Committee (TAC) Discussion Highlights

Seaweeds as Stressors on Eelgrass

The topic of eelgrass stressors was the focus of two consecutive TAC meetings on May 9-10, 2017; notes and presentations are available (PREP 2017). In the TAC discussions, there was agreement that, in general, seaweed blooms can degrade ecosystems and impact eelgrass as well as shellfish and other benthic invertebrates. The mechanisms by which seaweeds exert a negative influence are fairly well understood; seaweeds can shade eelgrass, rip eelgrass out of the sediment by getting tangled in the plants when the current is running high, and seaweeds can degrade water and sediment quality when they die and decay. One of the external advisors, Chris Gobler, summarized very recent research indicating that seaweeds also exhibit allelopathy. That is, they secrete chemicals that weaken competing plants, such as eelgrass (PREP 2017).

After two days of discussion, TAC participants were asked to fill out a “matrix,” which rated the probability of different stressors exerting negative pressure on eelgrass health. Figure S-3 indicates that, of the 26 participants, 18 participants felt that the evidence supports the assertion that seaweeds are currently exerting a negative influence on eelgrass habitat in the Great Bay Estuary. To read the rationale behind the ratings for some of the participants—not everyone offered their opinions verbally—see PREP (2017).

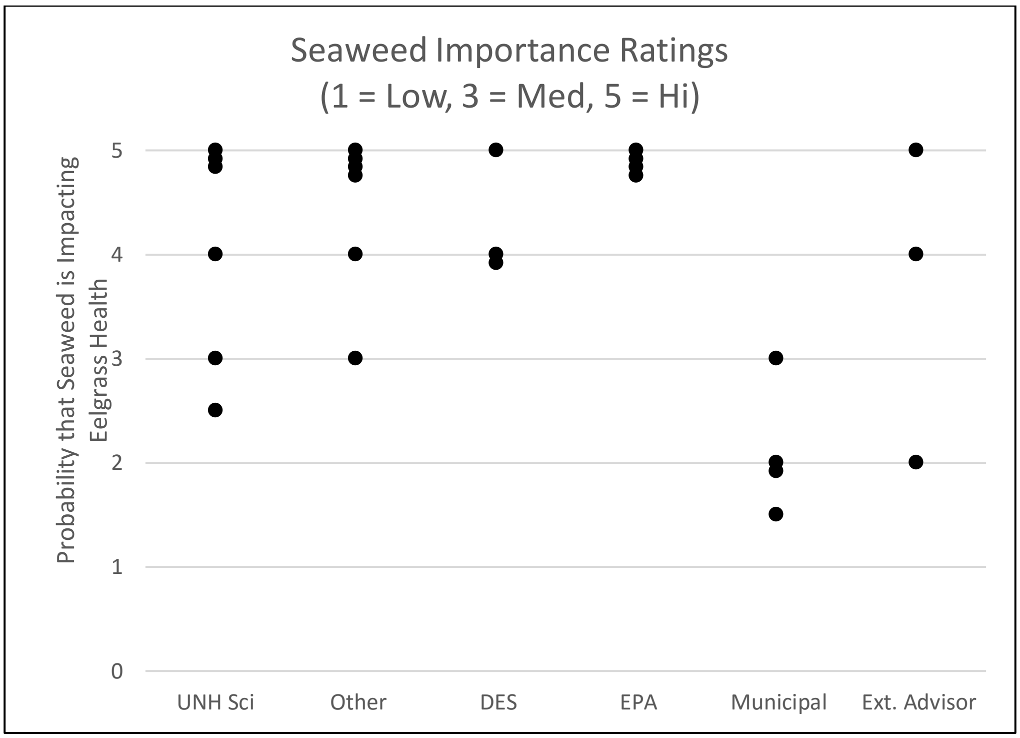


Figure S-3. Results of “matrix” activity asking participants to rate the importance of seaweeds as a stressor on eelgrass. Results are categorized by segments of the community, from left to right: UNH Scientists, Other (e.g., non-profit organizations), NH DES, US EPA, Municipal Representatives, and External Advisors. Dots that are touching represent the same numeric rating, but are separated for visual clarity.

At the May 2017 TAC meeting, the three external advisors advocated that all light-attenuating components (e.g., seaweeds, TSS, colored dissolved organic matter (CDOM) and phytoplankton) be considered together, not separately, because these components act in an additive fashion. This approach to considering light attenuating substances is articulated more fully in the “Stress and Resilience” section of the 2018 State of Our Estuaries Report (PREP 2017b) as well as the “Statement Regarding Eelgrass Stressors” (Kenworthy et al. 2017).

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Indicator: Dissolved oxygen in the Great Bay Estuary

Question

How often does dissolved oxygen (DO) in the estuary fall below 5 mg/L?

Short Answer

Datasondes, an automated water quality sensor or probe, in the bays and open waters located at the center of the Great Bay and in Portsmouth Harbor at the Coastal Marine Laboratory indicate dissolved oxygen levels well above 5 mg/L. Low dissolved oxygen events occur in all the tidal rivers. In August 2015–the most recent year we have data–most low dissolved oxygen events in the tidal rivers lasted between two and six hours.

PREP Goal
Reduce nutrient loads to the estuaries and the ocean so that adverse, nutrient-related effects do not occur (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

Why This Matters

Fish and many other organisms need dissolved oxygen in the water to survive. Dissolved oxygen levels can decrease due to various factors, including rapid changes in temperature and salinity, as well as respiration of organic matter. Dissolved oxygen levels can also decrease as a reaction to nutrient inputs. When nutrient loading is too high, phytoplankton and/or seaweed can bloom and then die. Bacteria and other decomposer organisms then use oxygen to break down the organic matter.

Explanation (from 2018 State of Our Estuaries Report)

National ecosystem health thresholds for dissolved oxygen (DO) concentrations range from 2 mg/L to 5 mg/L, depending on the region or state (US EPA 2012). The threshold of 5 mg/L is considered protective of all organisms (Bierman et al. 2014). Dissolved oxygen levels in Great Bay at the central datasonde and in Portsmouth Harbor at the Coastal Marine Laboratory (Table DO-1; Figure DO-6) remain consistently above 5 mg/L. The most recently collected data from 2015 show that DO concentrations never fell below 6 mg/L at these two sites.

The tidal portions of the major tributary rivers continue to experience many days when the minimum DO concentration value is below 5 mg/L. No long-term trends are notable at any stations, as exemplified by the data from the Squamscott River and Salmon Falls River datasondes (Figures DO-1 and DO-2). These datasondes were used in this long-term trend analysis because they had complete datasets going back as far as 2004, and because they represent different parts of the estuary.

It is important to note not only the number of low DO events but also the duration of those events because there are implications for organisms (such as small invertebrates in the sediment) that cannot move quickly to areas with higher DO levels. In 2015, the Lamprey and Squamscott Rivers had the highest number of low DO events, the majority of which took place in August and September. Figure DO-3 shows data taken every 15 minutes throughout August 2015 for the Squamscott River; this figure indicates that DO concentrations fell below 5 mg/L most days during the month, and that there was less than 5 mg/L for 12% of the month. These low DO events lasted anywhere from one to four hours.

In August 2015, 73% of the time Lamprey River DO levels were below 5 mg/L and stayed below the threshold for more than 24 hours on two occasions (Figure DO-4) with the second occasion

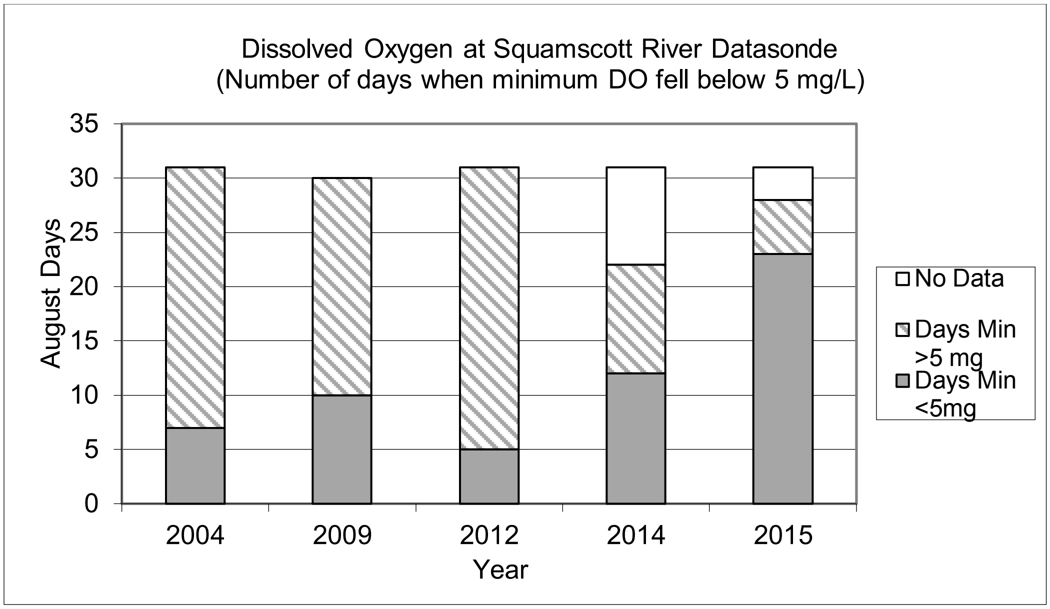

Figure DO-1. Number of days in August when minimum DO fell below 5 mg/L at the Squamscott River datasonde. Particular years shown have the most complete datasets.

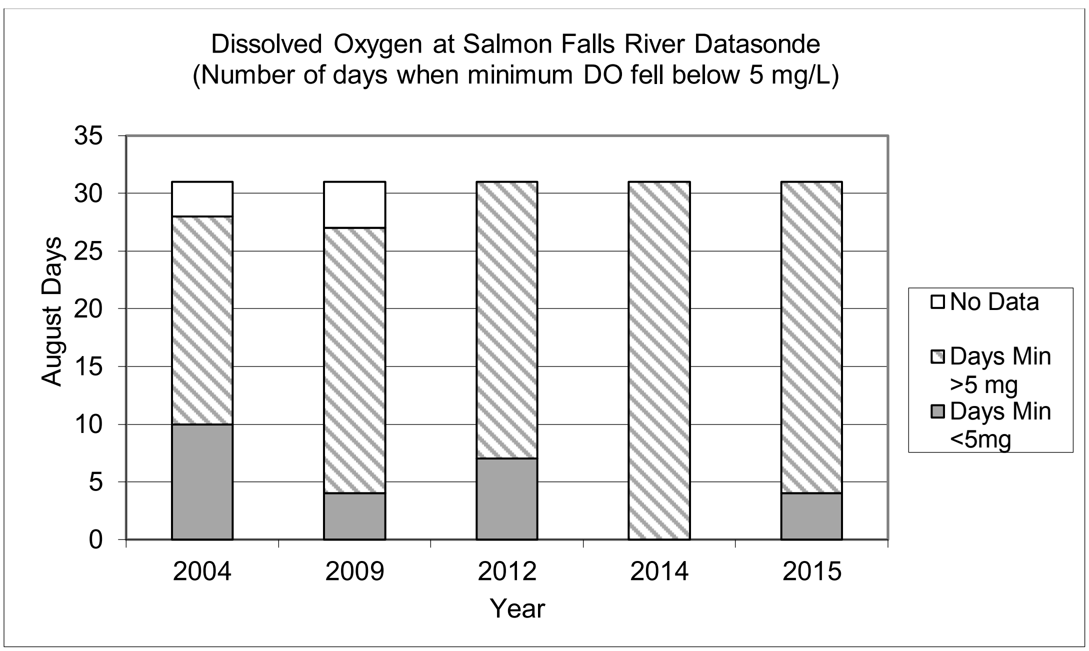

Figure DO-2. Number of August days when minimum DO fell below 5 mg/L at the Salmon Falls River datasonde. Particular years shown have the most complete datasets.

lasting almost 168 hours (7 days). A 2005 study (Pennock 2005) of the Lamprey River concluded that the datasonde readings were reflective of river conditions, but that density stratification—when salt water and fresh water stack in layers without mixing—was a significant factor in the low DO conditions in the Lamprey River.

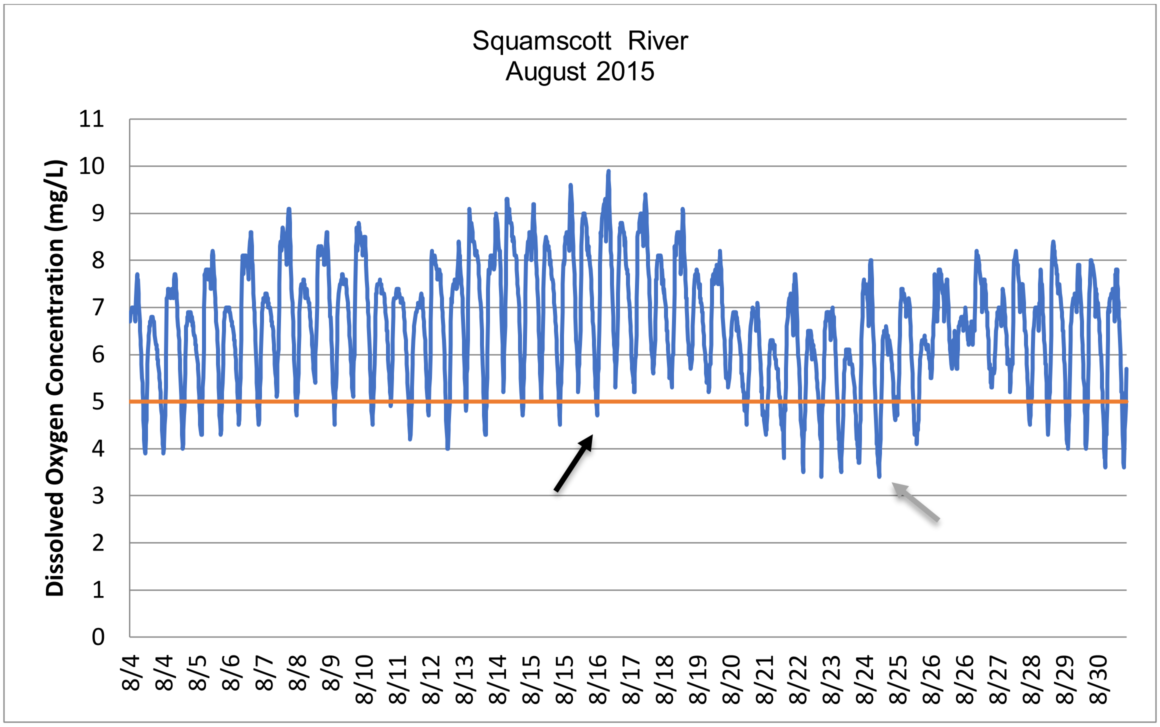

Figure DO-3. Dissolved oxygen concentration measurements at the Squamscott River datasonde, taken every 15 minutes during the month of August 2015. The red line marks the 5 mg/L value; levels below this line may present a danger to fish and benthic invertebrates. The black arrow points to an event that represents approximately 1 hour below 5 mg/L. The gray arrow indicates an event that represents approximately 4 hours below 5 mg/L.

In August 2015, the Oyster River experienced four low DO events, lasting between two and six hours each. The Salmon Falls River experienced two low DO events, each lasting approximately three hours. In the Cocheco River, data was only available for the month of September 2015. In that month, the datasonde indicates 12 low DO events, all lasting approximately two hours. More data and analysis is required to understand the relative importance of temperature, tidal stage, time of day, freshwater inputs, organic matter loading and nutrient loading as contributing factors to these low DO events.

Finally, this analysis does not include all DO data collected in the Great Bay Estuary. For information on other data, please see the 2017 Technical Support Document for Aquatic Life Use Support (NH DES 2017).

Methods and Data Sources

In a system as well mixed as the Great Bay Estuary, low DO events may occur rapidly. Therefore, DO measurements taken at a high frequency by in-situ datasondes deployed 1-2 meters above the sediments were used for this indicator.

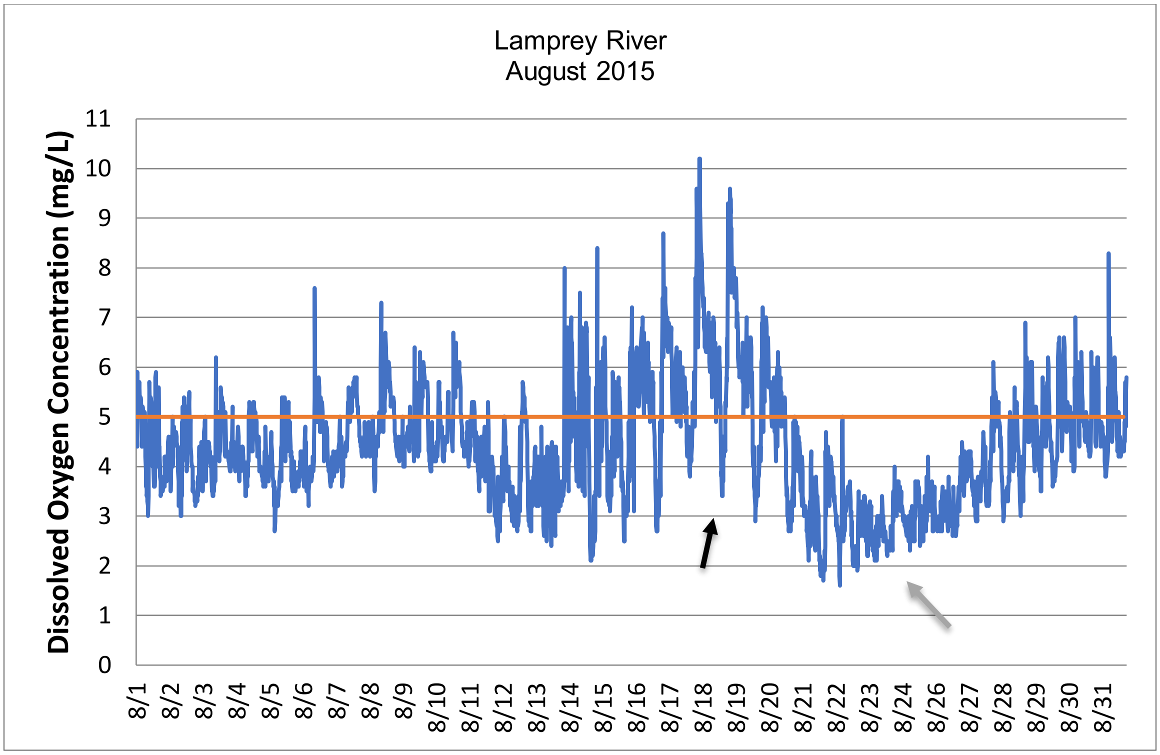

Figure DO-4. Dissolved oxygen concentration measurements at the Lamprey River datasonde, taken every 15 minutes during the month of August. The red line marks the 5 mg/L value; levels below this line may present a danger to fish and benthic invertebrates. The black arrow points to one event (August 18) that represents approximately 3 hours below 5 mg/L. The gray arrow represents a longer event of below 5 mg/L conditions, lasting approximately 7 days.

The daily minimum dissolved oxygen concentration were calculated at each station in the Great Bay Estuary (Figure DO-5). The number of days per year that the daily minimum DO fell below 5 mg/L was tabulated and is reported in Table DO-1. Inter-annual comparisons of that data are shown in Figure DO-6.

The Great Bay National Estuarine Research Reserve Datasonde Program and the UNH Datasonde Program provided data for this indicator. The data used for this indicator were quality assured by staff from the UNH Jackson Estuarine Lab and NHDES. For data from 2004 and later, the dissolved oxygen measurements were validated by pre- and post-deployment checks with an independently calibrated dissolved oxygen sensor or post-deployment calibration checks in the laboratory. For earlier years, for which quality control data were not available, only measurements from the first 96 hours of the sonde deployment were used. This is due to the fact that the older type of DO membrane-style probes had a tendency to drift over time.

Technical Advisory Committee (TAC) Discussion Highlights

For more information on the PREP TAC, please see:

http://prepestuaries.org/prep-technical-advisory-committee/

With regard to the low DO events in the tributaries, the committee was divided in terms of how to interpret the dissolved oxygen data. Some TAC members see the occurrence of low DO events as indicators of high productivity and potential water quality problems related to excess nutrients and point to supersaturation events as an indication of this. Others feel more caution is required in the interpretation of the data, noting that low DO events can relate to stratification, rainfall/runoff conditions, diurnal conditions, and changes in wind patterns. However, there is wider agreement that regardless of the cause of the low DO, these events are of concern to the resiliency of the system and may be of detriment to the organisms that live within it.

With regard to comparing DO conditions between different stations, most of the TAC members urged caution, noting that the locations of the datasondes are not consistent in terms of distance from the mouths of the river (Figure DO-5). For example, the Oyster and Lamprey River stations are located fairly far up river, while the Squamscott River station is located at the mouth of the river.

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Table DO-1: Measurements of dissolved oxygen concentrations less than 5 mg/L at datasondes in the Great Bay Estuary.

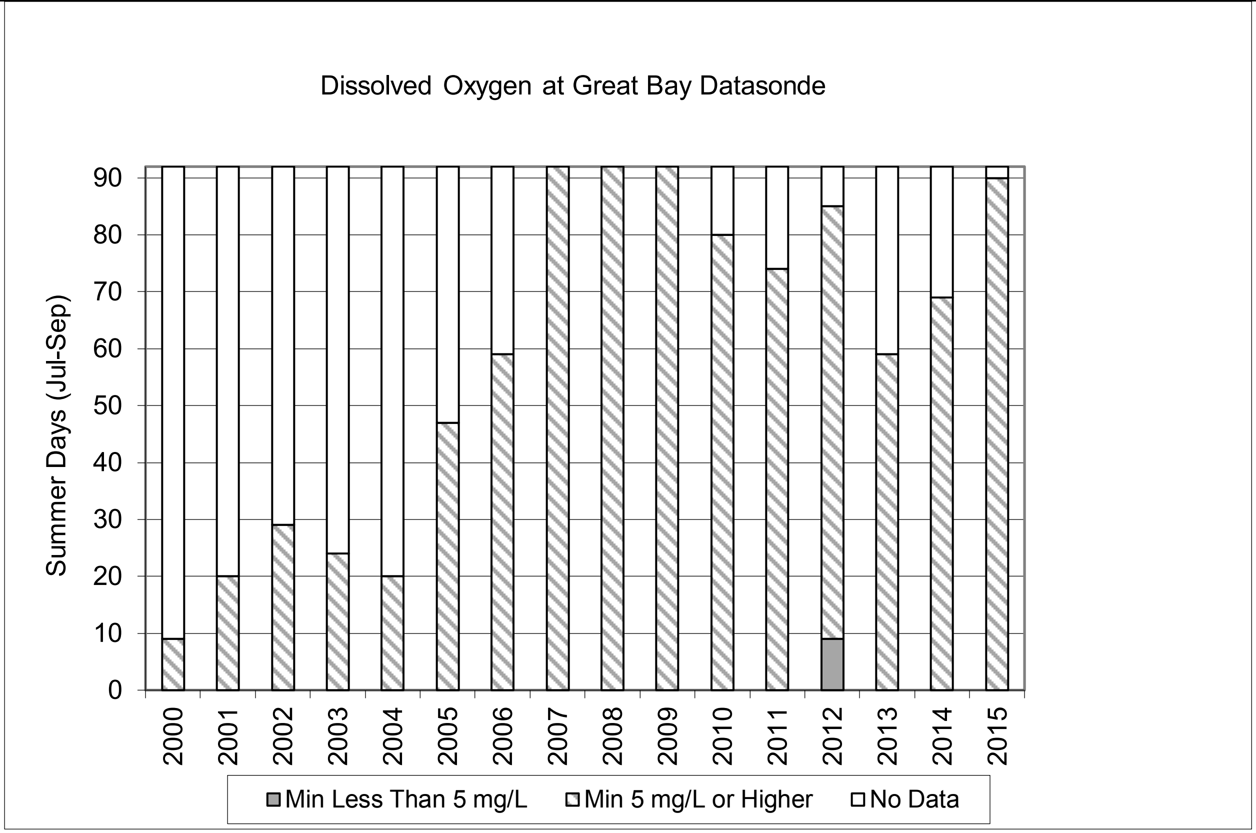
Station	Year	Number of Summer Days with Valid DO Data (Max of 92)	Number of Summer Days with Minimum DO <5 mg/L
Portsmouth Harbor	2002	16	0 (of 16)
Portsmouth Harbor	2003	20	0 (of 20)
Portsmouth Harbor	2004	21	0 (of 21)
Portsmouth Harbor	2005	49	0 (of 49)
Portsmouth Harbor	2006	51	0 (of 51)
Portsmouth Harbor	2007	15	0 (of 15)
Portsmouth Harbor	2008	92	0 (of 92)
Portsmouth Harbor	2009	92	0 (of 92)
Portsmouth Harbor	2010	88	1 (of 88)
Portsmouth Harbor	2011	92	0 (of 92)
Portsmouth Harbor	2012	92	0 (of 92)
Portsmouth Harbor	2013	27	0 (of 27)
Portsmouth Harbor	2014	81	0 (of 81)
Portsmouth Harbor	2015	92	0 (of 92)
Great Bay	2000	9	0 (of 9)
Great Bay	2001	20	0 (of 20)
Great Bay	2002	29	0 (of 29)
Great Bay	2003	24	0 (of 24)
Great Bay	2004	20	0 (of 20)
Great Bay	2005	47	0 (of 47)
Great Bay	2006	59	0 (of 59)
Great Bay	2007	92	0 (of 92)
Great Bay	2008	92	0 (of 92)
Great Bay	2009	92	0 (of 92)
Great Bay	2010	80	0 (of 80)
Great Bay	2011	74	0 (of 74)
Great Bay	2012	85	9 (of 85)
Great Bay	2013	59	0 (of 59)
Great Bay	2014	69	0 (of 69)
Great Bay	2015	90	0 (of 90)
Lamprey River	2000	7	0 (of 7)
Lamprey River	2001	20	3 (of 20)
Lamprey River	2002	25	21 (of 25)
Lamprey River	2003	15	9 (of 15)
Lamprey River	2004	52	33 (of 52)
Lamprey River	2005	44	10 (of 44)
Lamprey River	2006	55	1 (of 55)
Lamprey River	2007	92	49 (of 92)
Lamprey River	2008	92	12 (of 92)
Lamprey River	2009	77	1 (of 77)
Lamprey River	2010	92	87 (of 92)
Lamprey River	2011	92	51 (of 92)
Lamprey River	2012	92	55 (of 92)
Lamprey River	2013	92	20 (of 92)

Station	Year	Number of Summer Days with Valid DO Data (Max of 92)	Number of Summer Days with Minimum DO <5 mg/L
Lamprey River	2014	87	23 (of 87)
Lamprey River	2015	92	62 (of 92)
Oyster River	2002	25	9 (of 25)
Oyster River	2003	19	1 (of 19)
Oyster River	2004	52	21 (of 52)
Oyster River	2005	35	2 (of 35)
Oyster River	2006	30	1 (of 30)
Oyster River	2007	92	4 (of 92)
Oyster River	2008	53	7 (of 53)
Oyster River	2009	92	3 (of 92)
Oyster River	2010	12	2 (of 12)
Oyster River	2011	92	31 (of 92)
Oyster River	2012	86	9 (of 86)
Oyster River	2013	91	34 (of 91)
Oyster River	2014	91	10 (of 91)
Oyster River	2015	92	8 (of 92)
Salmon Falls River	2002	10	0 (of 10)
Salmon Falls River	2003	17	6 (of 17)
Salmon Falls River	2004	60	12 (of 60)
Salmon Falls River	2005	10	1 (of 10)
Salmon Falls River	2006	28	0 (of 28)
Salmon Falls River	2007	15	1 (of 15)
Salmon Falls River	2008	41	2 (of 41)
Salmon Falls River	2009	78	4 (of 78)
Salmon Falls River	2010	25	7 (of 25)
Salmon Falls River	2011	45	8 (of 45)
Salmon Falls River	2012	77	31 (of 77)
Salmon Falls River	2013	79	2 (of 79)
Salmon Falls River	2014	83	0 (of 83)
Salmon Falls River	2015	62	4 (of 62)
Squamscott River	2000	15	4 (of 15)
Squamscott River	2001	20	0 (of 20)
Squamscott River	2002	20	8 (of 20)
Squamscott River	2003	18	8 (of 18)
Squamscott River	2004	92	19 (of 92)
Squamscott River	2005	37	4 (of 37)
Squamscott River	2006	73	12 (of 73)
Squamscott River	2007	92	7 (of 92)
Squamscott River	2008	88	14 (of 88)
Squamscott River	2009	92	10 (of 92)
Squamscott River	2010	80	36 (of 80)
Squamscott River	2011	92	25 (of 92)
Squamscott River	2012	92	25 (of 92)
Squamscott River	2013	92	28 (of 92)
Squamscott River	2014	83	27 (of 83)
Squamscott River	2015	87	51 (of 87)

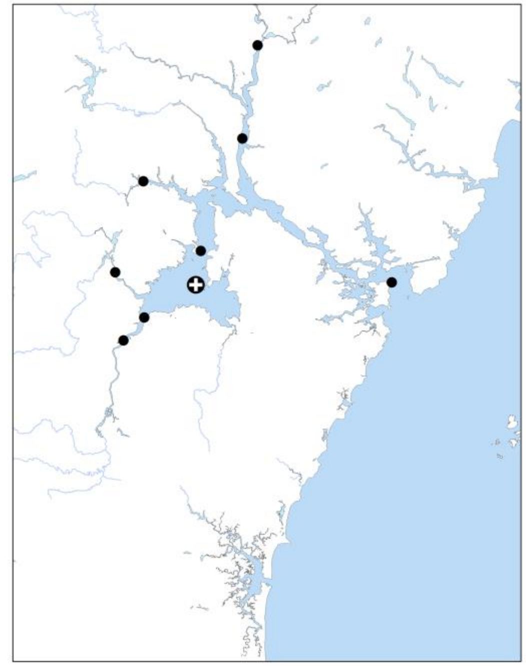
Note: Summer days are defined as days in the months of July, August, and September. Maximum is 92.

Figure DO-5: Map of datasonde station locations.

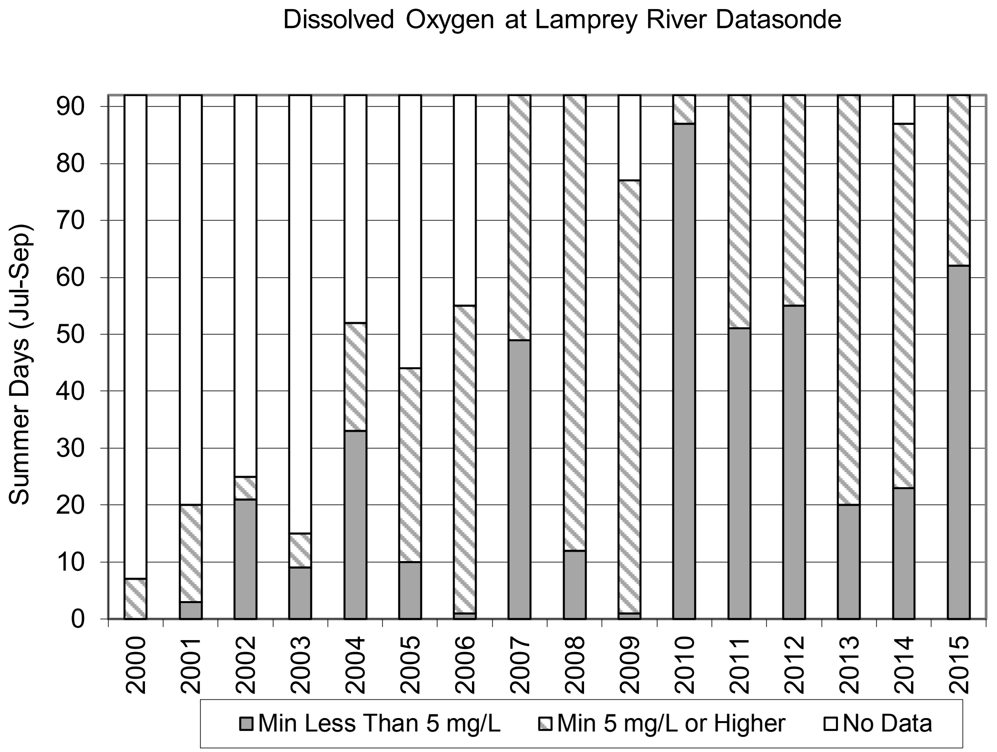
Figure DO-6: DO concentrations. Number of days in July, August, and September relative to 5 mg/L threshold.



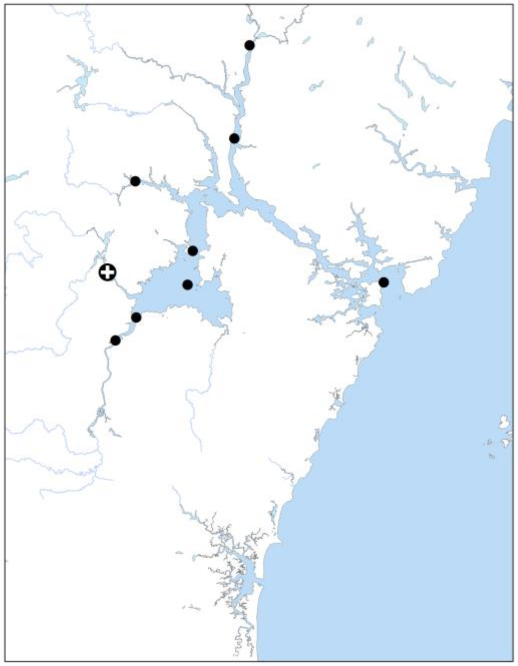
Monitoring Location (GRBGB)
(black circle with white plus sign)



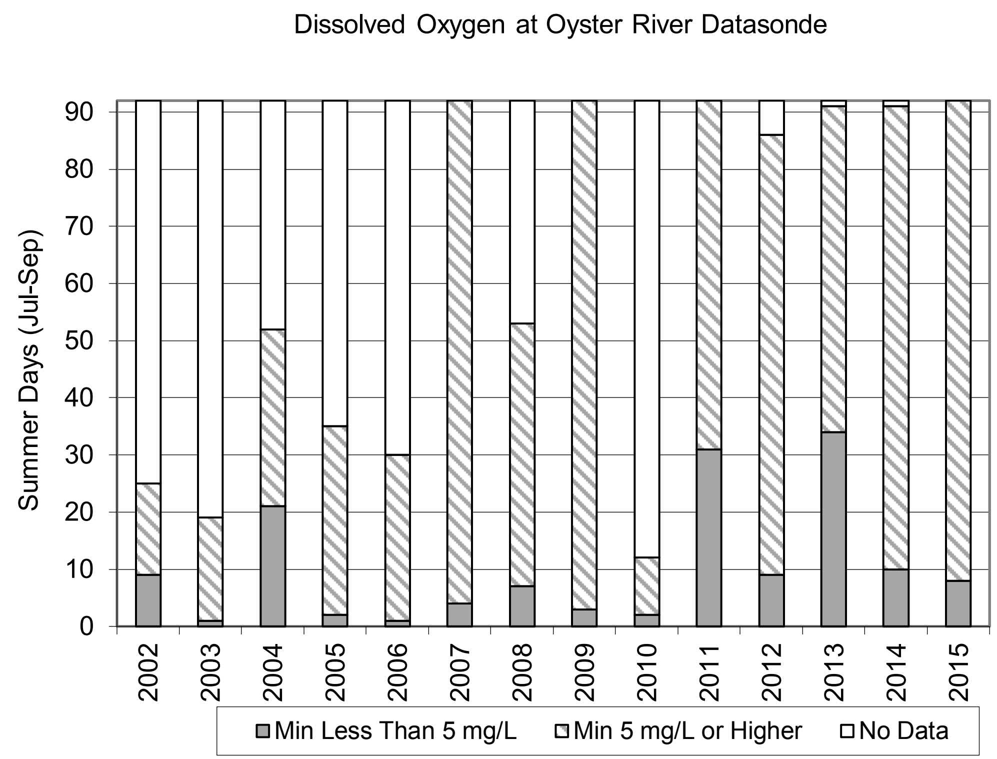
Station: GRBGB (Great Bay). Maximum number of days is 92.



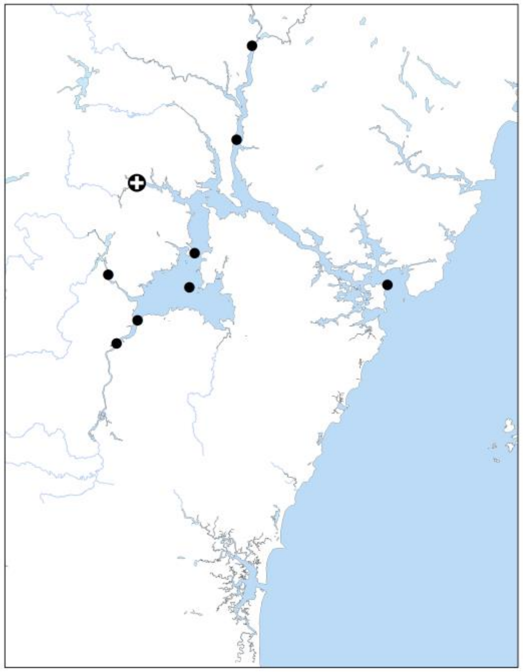
Monitoring Location (GRBLR)
(black circle with white plus sign)



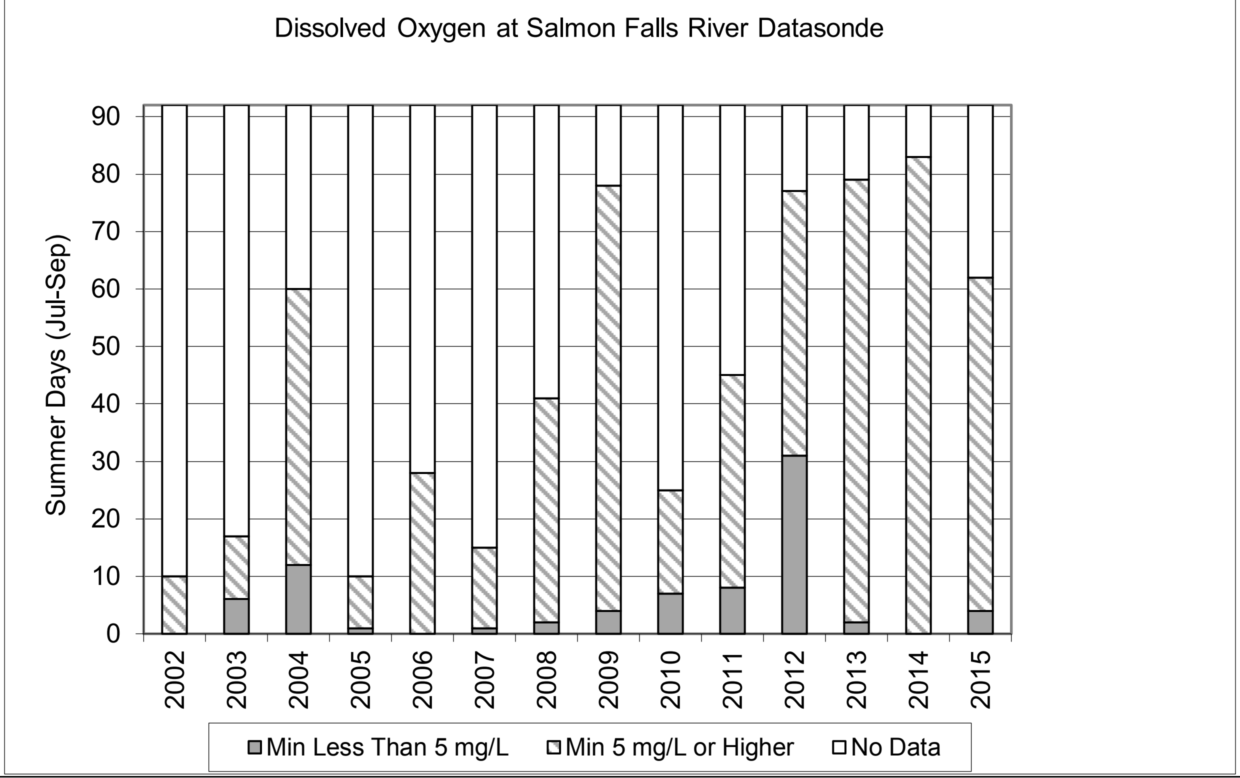
Station: GRBLR (Lamprey River). Maximum number of days is 92.



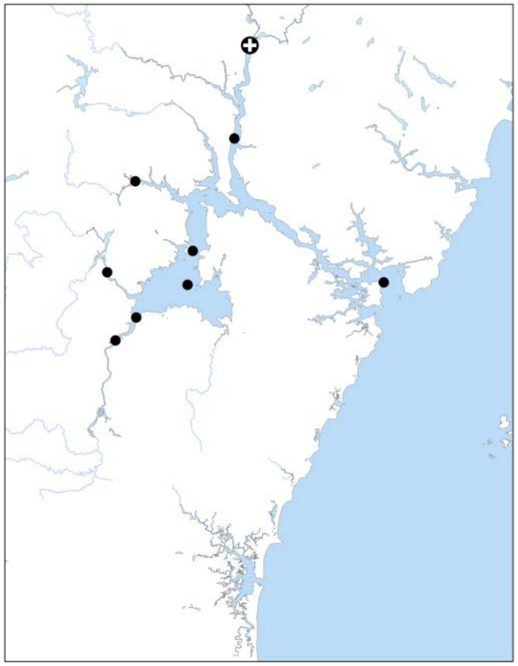
Monitoring Location (GRBOR)
(black circle with white plus sign)



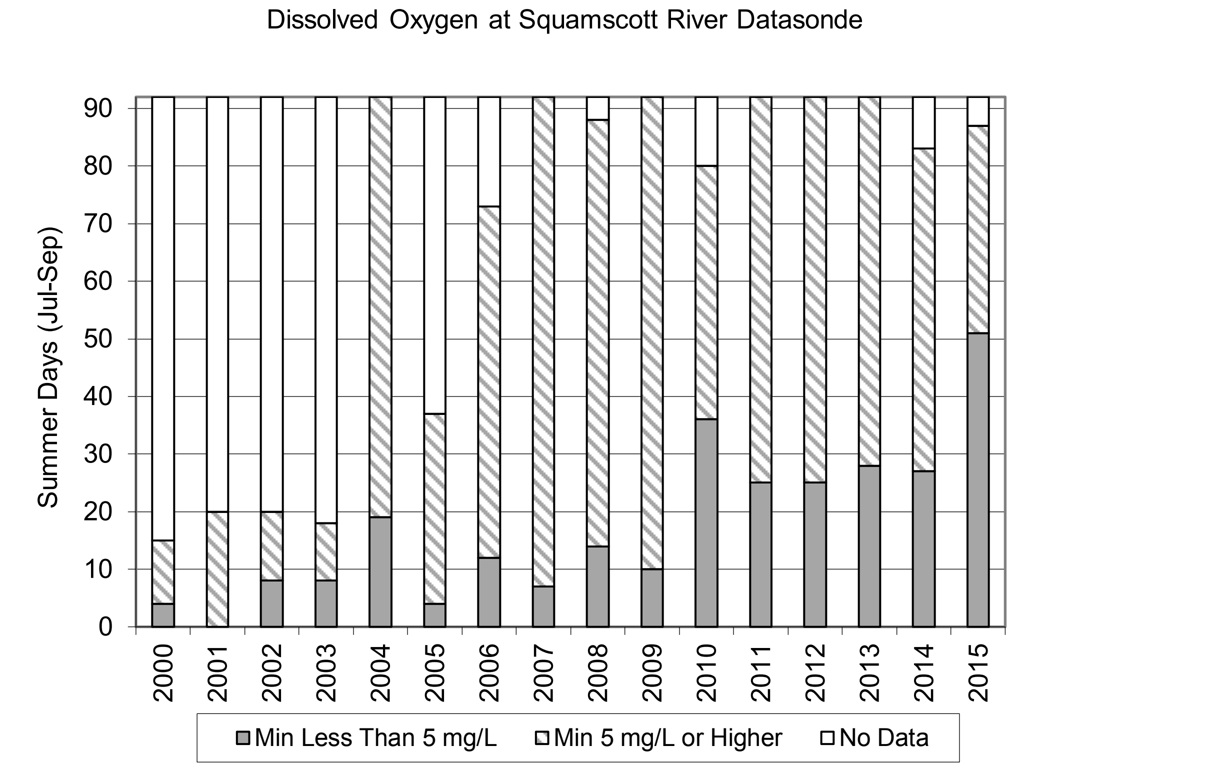
Station: GRBOR (Oyster River). Maximum number of days is 92.



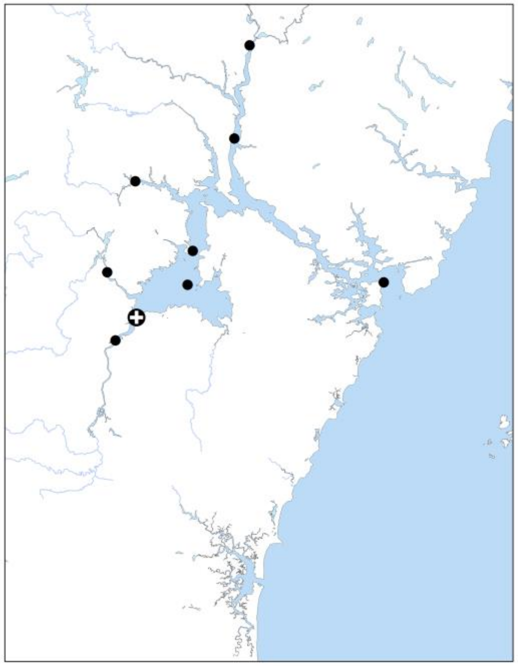
Monitoring Location (GRBSF)
(black circle with white plus sign)



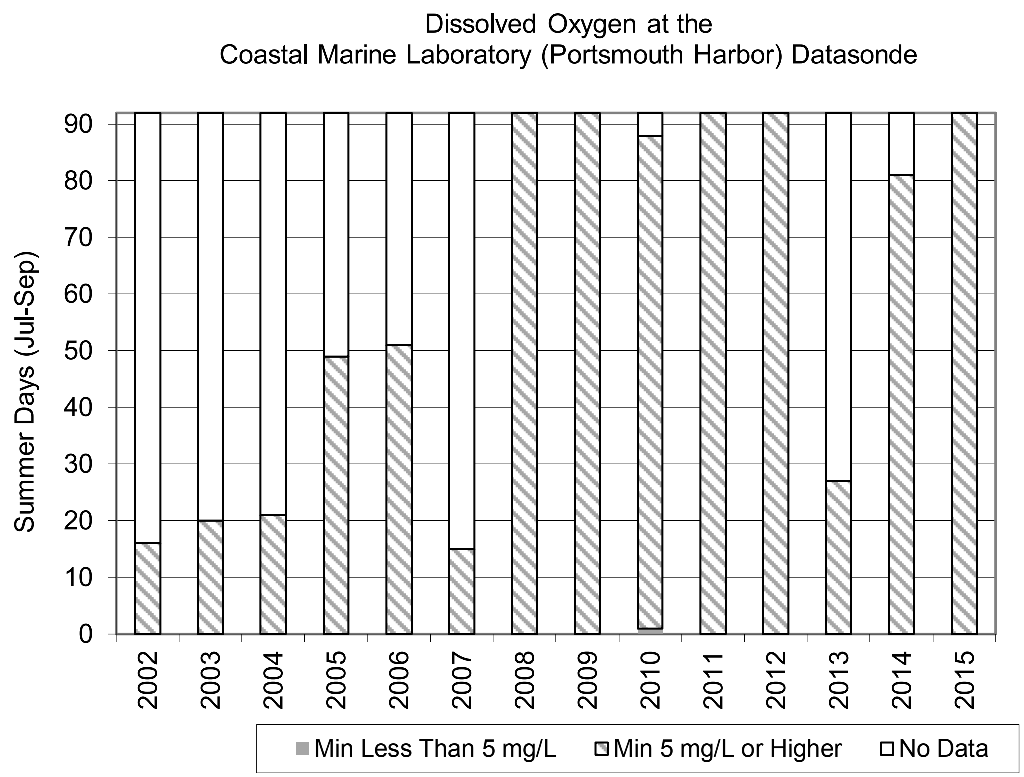
Station: GRBSF (Salmon Falls River). Maximum number of days is 92.



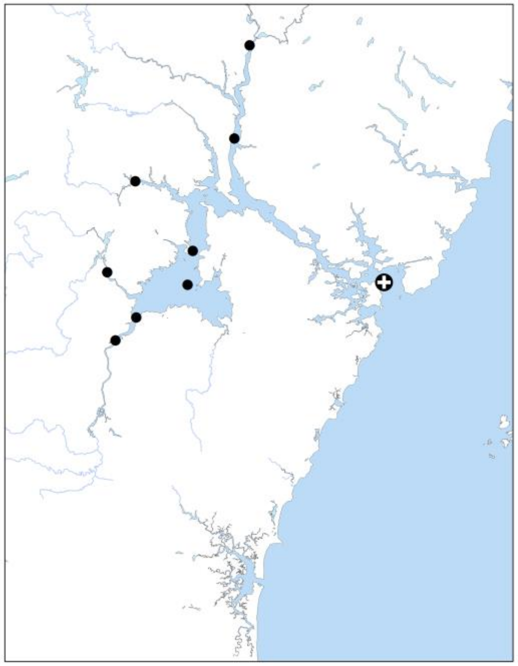
Monitoring Location (GRBSQ)
(black circle with white plus sign)



Station: GRBSQ (Squamscott River at the railroad trestle). Maximum number of days is 92.



Monitoring Location (GRBCML)
(black circle with white plus sign)



Station: GRBCML (Portsmouth Harbor at the Coastal Marine Laboratory). Maximum number of days is 92.

Indicator: Eelgrass habitat in the Great Bay Estuary

<u>Question</u>

How many acres of eelgrass are currently present in the Great Bay Estuary and how has it changed over time?

<u>Short Answer</u>

The Great Bay Estuary, which includes seven tidal tributary rivers, the Piscataqua River and Portsmouth Harbor, had 1,625 acres of eelgrass in 2016, which is 54% of the PREP goal of 2900 acres. In Great Bay proper, there were 1,490 acres of eelgrass, which is a 31% reduction from 1981, the first year that data was collected. Over time, eelgrass habitat indicates a diminishing ability to recover from periodic disturbances, such as stress from extreme storms.

<u>PREP Goal</u>
Increase the aerial extent of eelgrass cover to 2,900 acres and restore connectivity of eelgrass beds throughout the Great Bay Estuary by 2020 (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

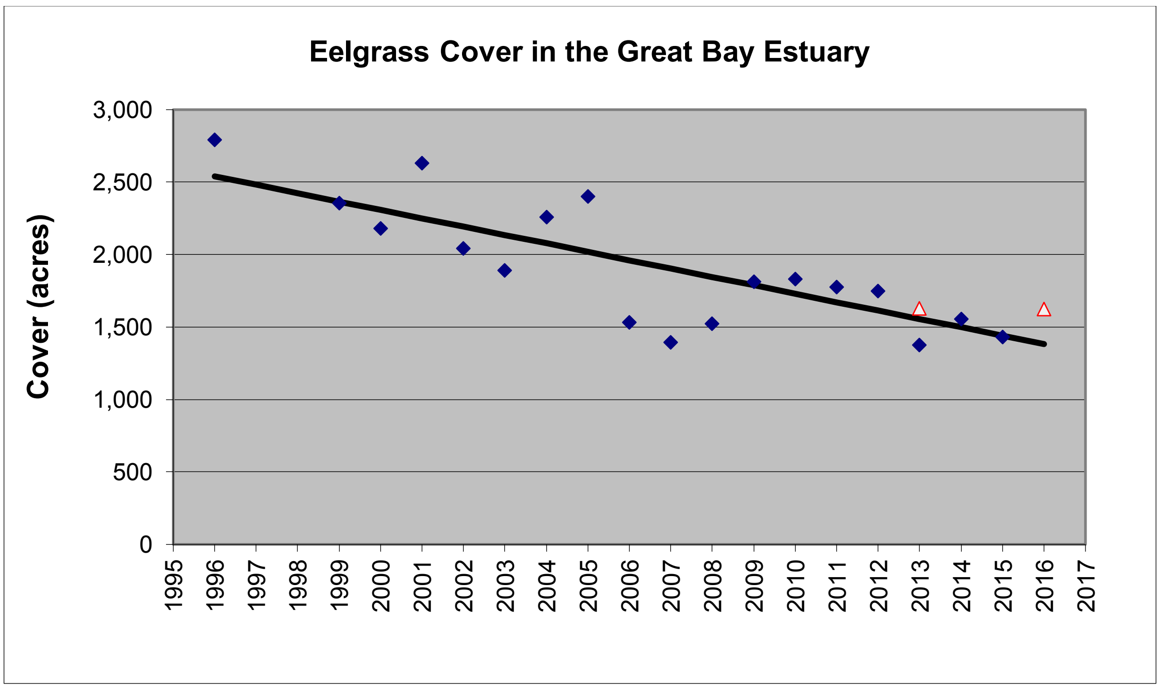


Figure E-1. Eelgrass cover in the Great Bay Estuary. Diamonds indicate UNH Jackson Laboratory as data source; triangles indicate Kappa Mapping, Inc. Data in 2013 were averaged for regression analysis.

<u>Why This Matters</u>

The long leaves of eelgrass (*Zostera marina*) slow the flow of water, encouraging suspended materials to settle, thereby promoting water clarity. Eelgrass roots stabilize sediments and both the roots and leaves take up nutrients from sediments and the water. Eelgrass provides habitat for fish and shellfish, and it produces significant amounts of organic matter for the larger food web.

Explanation (from 2018 State of Our Estuaries Report)

In 2016, there were 1,625 acres of eelgrass in the Great Bay Estuary. Figure E-1 (above) shows a statistically significant decreasing trend in eelgrass acreage since 1996 when the data became available for the entire estuary. The year 1996 also represents the highest amount of eelgrass on record for the Great Bay Estuary (see Table E-1); this must be considered when evaluating the trend. Figure E-2 compares 2016 eelgrass coverage with the acreage of eelgrass in 1996.

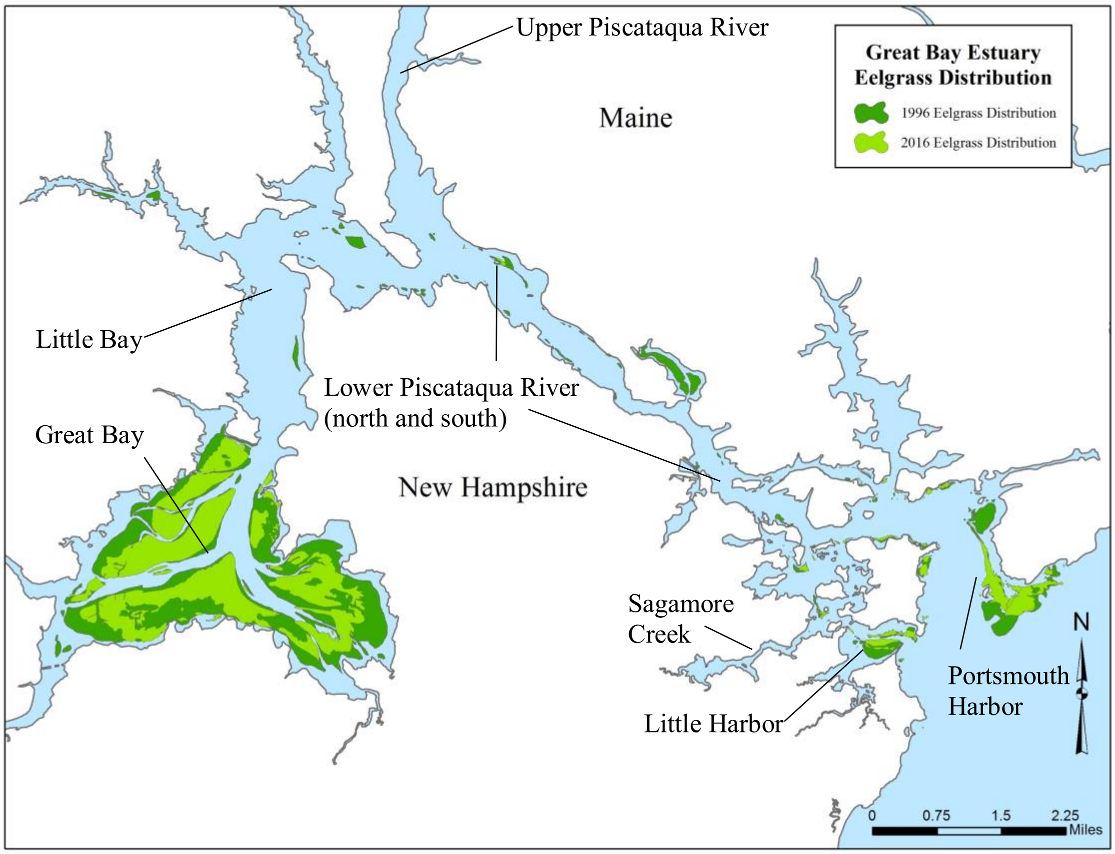


Figure E-2. Map of eelgrass cover for 1996 and 2016. Map based on 2016 data from Kappa Mapping, Inc., and 1996 data provided by UNH Jackson Estuarine Laboratory. To be counted as present, eelgrass must cover at least 10% of a given area. Therefore, this map does not distinguish between areas with dense versus sparse cover. With negligible exceptions, the 2016 areas also existed in 1996; the darker shade of green therefore represents areas that have been lost since 1996.

For Great Bay only, in contrast, data exists going back to 1981 (see Figure E-3). In 2016, there were 1,490 acres of eelgrass in Great Bay. The trend is not statistically significant; however, there is broad scientific consensus that eelgrass in the Great Bay shows a consistent pattern of being less and less able to rebound from episodic stresses. Current levels of eelgrass in the Great Bay are 31% reduced from 1981 levels. Connectivity of the remaining eelgrass habitat in the Great Bay Estuary is critical for habitat health and expansion. See Figure E-2 for 2016 eelgrass distribution.

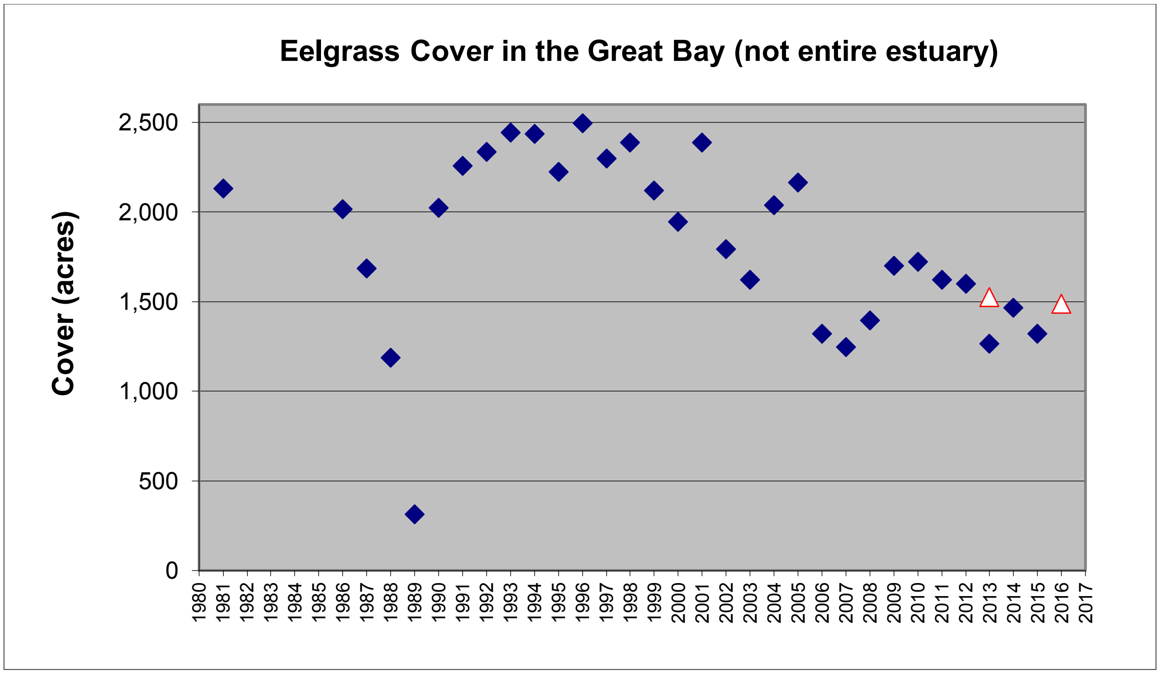


Figure E-3. Eelgrass cover in the Great Bay only. Missing data for years 1982-1985. Years 1988 and 1989 show very low values due to eelgrass "wasting disease" event. These data, however, are still included in linear regression calculations. Diamonds indicate UNH Jackson Laboratory as data source; triangles indicate Kappa Mapping, Inc. Data in 2013 were averaged for regression analysis.

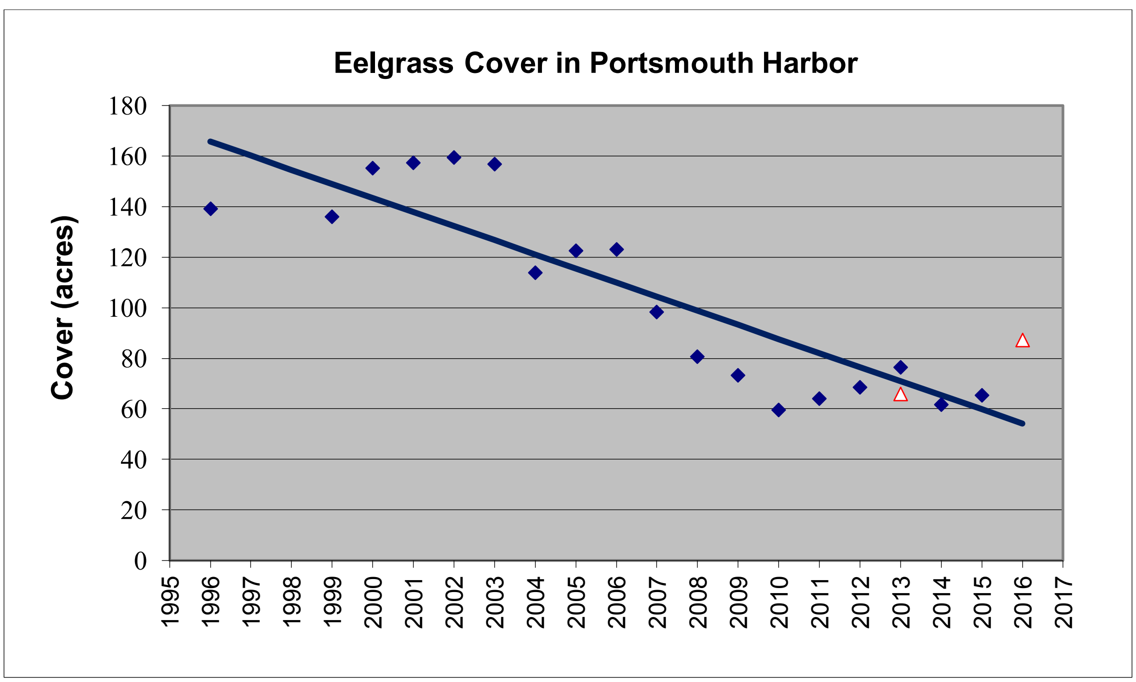


Figure E-4. Eelgrass cover in Portsmouth Harbor. Diamonds indicate UNH Jackson Laboratory as data source; triangles indicate Kappa Mapping, Inc. Data in 2013 were averaged for regression analysis.

In Portsmouth Harbor (Figure E-4), there were 87.4 acres of eelgrass in 2016. The entire time series (1996-2016) shows a statistically significant decreasing trend. On a positive note, the number of acres in 2016 was higher than the previous 8 years.

The causes of eelgrass decline in the Great Bay continue to be the subject of great interest. Worldwide, the main causes of temperate (between the tropics and the polar regions) seagrass loss are nutrient loading, sediment deposition, sea-level rise, high temperature, introduced species, biological disturbance (e.g., from crabs and geese), and wasting disease (Orth et al. 2006). Toxic contaminants such as herbicides that are used on land can also stress eelgrass (Unsworth et al. 2015). All of these causes are plausible in the Great Bay Estuary and many magnify each other to stress eelgrass and make habitats less resilient. Proactive actions to increase resilience for eelgrass habitat are critical as climate science predicts an increase of stressful events, such as extreme storms with increased rains and higher winds. Since the 1930's there have been three 100-year storms recorded by measurements of the river discharge at the Lamprey River – two of those storms occurred in 2006 and 2007, the third was in 1987. Increased rainfall during these events causes a large quantity of waterflow to enter the estuary delivering increased sediments and nutrients as well as resuspending sediments throughout the water column. Since eelgrass relies on clear water to grow these events are important to note.

Research and discussions continue to focus on the type of recovery the Great Bay Estuary can expect for eelgrass. In some cases, recovery requires only a decrease in the stressors that caused the problem. In other cases, conditions for recovery have to be better than conditions before the habitat loss began to occur (Kenworthy et al. 2013; Unsworth et al. 2015). Figure E-3 shows that eelgrass recovered after the wasting disease event of 1988-1989. After a drop in 2002-2003, eelgrass rebounded but not quite to previous levels. Another three-year downturn during 2006-2008 was followed by a weaker recovery.

Methods and Data Sources

For the Great Bay (only)—as opposed to the whole estuary—maps from the UNH Jackson Estuarine Laboratory (JEL) from 1986 to 2015 were used. Maps for the entire Great Bay Estuary (Great Bay, Little Bay, tidal tributaries, Piscataqua River, Little Harbor, and Portsmouth Harbor) were used from JEL from the year 1996, the first year JEL mapped the entire estuary, through 2015.

The assessment of 1981 coverage was also made by JEL, using imagery from the USDA and field verification from NH Fish & Game (Short 2009). Note that the 1981 values most likely underestimate actual eelgrass habitat in 1981, because the 1981 dataset was incomplete. Eelgrass in some portions of the estuary could not be mapped because the imagery had glare in some areas. The interference affected mapping in the Oyster River, Lower Piscataqua River, Portsmouth Harbor and Little Harbor (Short 2009).

In 2013, mapping was conducted by both JEL and Kappa Mapping, Inc. (now Cornerstone Energy Services), and an accuracy assessment for both approaches was implemented. The results of those assessments can be found at scholars.unh.edu (Wood 2014; Wood 2015). In 2016, the eelgrass mapping was performed by Kappa Mapping, Inc. only. Quality Assurance Project Plans (QAPPs) can be found at scholars.unh.edu. QAPPs were issued for JEL work in year 2003 (Short and Trowbridge 2003), and 2010 (Short and Trowbridge 2010). The QAPP for Kappa Mapping, Inc. was issued in 2013 (Trowbridge 2013). In addition, year by year reports on eelgrass distribution and mapping can also be found at scholars.unh.edu. Finally, NH DES created a user-friendly GIS application focused on eelgrass, which can be accessed at: http://nhdes.maps.arcgis.com/apps/webappviewer/index.html?id=2792e57da2704867b164c17ae e2dc43e

The area of eelgrass in each assessment zone of the estuary was calculated using the GIS files provided by JEL or Kappa Mapping, Inc. and the ArcGIS Identity tool. Trends in the area of eelgrass cover in each assessment zone versus year were identified using linear regression with $p<0.05$ defined as the level of significance.

Additional Results (Beyond What Was Reported in the SOOE)

Results for the entire Great Bay Estuary, the Great Bay and Portsmouth Harbor were reported earlier in this section (Figures E-1, E-3 and E-4). Below, six other components of the estuary are discussed. See Table E-1 and Figure E-5 for more information.

Four of the six zones discussed below indicate significantly decreasing trends. As noted earlier, the dataset begins at a period of time (1996) known to be a peak year for the system, which impacts the results of the regression. Three of the six zones (Sagamore Creek, Little Harbor, and Lower Piscataqua River - North), have shown slow but consistently increasing levels of eelgrass over the most recent reporting period (2012 to 2016).

Sagamore Creek (no significant trend since 1996): A very slow and consistent increase in acreage is evident since 2013 (from 0.3 acres to 1.9 acres.) Maximum acres of eelgrass on record was in the year 2005 (6.1 acres).

Little Harbor (significant decreasing trend since 1996): A very slow and consistent increase since 2014 to 39.2 acres. Maximum acres of eelgrass on record was in the year 2004 (65.8 acres).

Lower Piscataqua River (south) (significant decreasing trend since 1996): Little change during the 2012 to 2016 period. 2016 acreage = 3.6 acres. Maximum acres of eelgrass on record was in the year 2006 (11.6 acres).

Lower Piscataqua River (north) (significant decreasing trend since 1996): No eelgrass detected between 2008 and 2011. Since 2012, slight and consistent increases. 2016 acreage = 3.0 acres. Maximum acres of eelgrass on record was in the year 2003 (22.9 acres).

Upper Piscataqua River (significant decreasing trend since 1996): No eelgrass detected since 2007. Maximum acres of eelgrass on record was in the year 2003 (2.9 acres).

Little Bay (no significant trend since 1996): No eelgrass detected in the years 2008, 2009, 2014 and 2016. In 2011 and 2012, over 30 acres were present. Since 2012, acreage has not exceeded 1.7 acres. Maximum acres of eelgrass on record was in the year 2011 (48.2 acres).

Technical Advisory Committee (TAC) Discussion Highlights

Biomass

Previous PREP Data Reports (PREP 2012) as well as eelgrass distribution reports (e.g., Short 2016) have gone beyond the discussion of eelgrass cover—that is, the number of acres covered where there is at least 10% cover of eelgrass—to discuss eelgrass biomass. Biomass refers to the actual weight, in this case, of the aboveground (not including roots below the surface) eelgrass material.

At a TAC meeting in October 2017, the rationale for including biomass was discussed at length. For a primer and extensive notes on the discussion, see Matso (2016) and PREP (2016). Existing data (Short et al. 1993; Trowbridge 2006; Short 2016; Short 2017b) suggest that eelgrass in the Great Bay Estuary has decreased since the late 1990s in terms of acreage AND also in terms of density, which in turn decreases estimates of biomass. However, based on the discussion, there were many questions about how biomass is assessed and how error in the measurement is captured and articulated. Until PREP has the opportunity to better understand and assess the reliability of the measurement, biomass will not be included in the State of Our Estuaries reporting.

Wasting Disease
"Wasting Disease" is caused by a pathogenic slime mold, *Labyrinthula zosterae*, and can have a significant negative impact on eelgrass health and distribution (Groner et al. 2016). In the Great Bay Estuary, two wasting disease events had a particularly devastating impact: the first in the early 1930s and the second in the late 1980s (Muehlstein et al. 1991). For further published information specific to wasting disease in the Great Bay Estuary, see "Eelgrass Distribution" reports from years 2002, 2003 and 2004, as well as Trowbridge (2006) at scholars.unh.edu.

These reports and other published research (e.g., Kaldy 2014; Groner et al. 2016) indicate that wasting disease is always present in the eelgrass population, and its effects become more or less noticeable in response to other environmental conditions. For example, increased salinity may favor wasting disease (Burdick et al. 1993) as well as warming waters and high nitrate conditions (Kaldy 2014).

During PREP TAC discussions, some participants proposed that any year with a report of wasting disease be eliminated from regression analyses (PREP 2017), including various years in the 1990s and early 2000's. Also, in the past, PREP has eliminated the years 1988 and 1989 from regressions due to the significant losses of eelgrass to wasting disease in those two years. However, in this latest State of Our Estuaries Report, PREP has included all years in regression analyses for two reasons: 1) there has not been any clear criteria set for how much wasting disease constitutes a wasting disease "event," and 2) research clearly shows that the virulence of wasting disease is increased by other environmental factors. Until these factors are clearly separated, eliminating any years due to particularly significant losses runs counter to the entire point of monitoring eelgrass health over many years and regressing changing levels against the factor of time.

Stressors on Eelgrass
This topic was discussed as part of two consecutive TAC meetings on May 9-10, 2017; notes and presentations are available (PREP 2017). Many stressors were discussed, from ice scour and geese to warming waters to factors affecting the amount of light that reaches eelgrass blades. The three external advisors to the TAC advocated that all light-attenuating components (e.g., seaweeds, TSS, colored dissolved organic matter (CDOM) and phytoplankton) be considered together, not separately, because these components act in an additive fashion. This approach to considering light attenuating substances and broader considerations relating to management options for increasing the resilience of the Great Bay Estuary are articulated more fully in the "Stress and Resilience" section of the 2018 State of Our Estuaries Report (PREP 2017b) as well as the "Statement Regarding Eelgrass Stressors" (Kenworthy et al. 2017).

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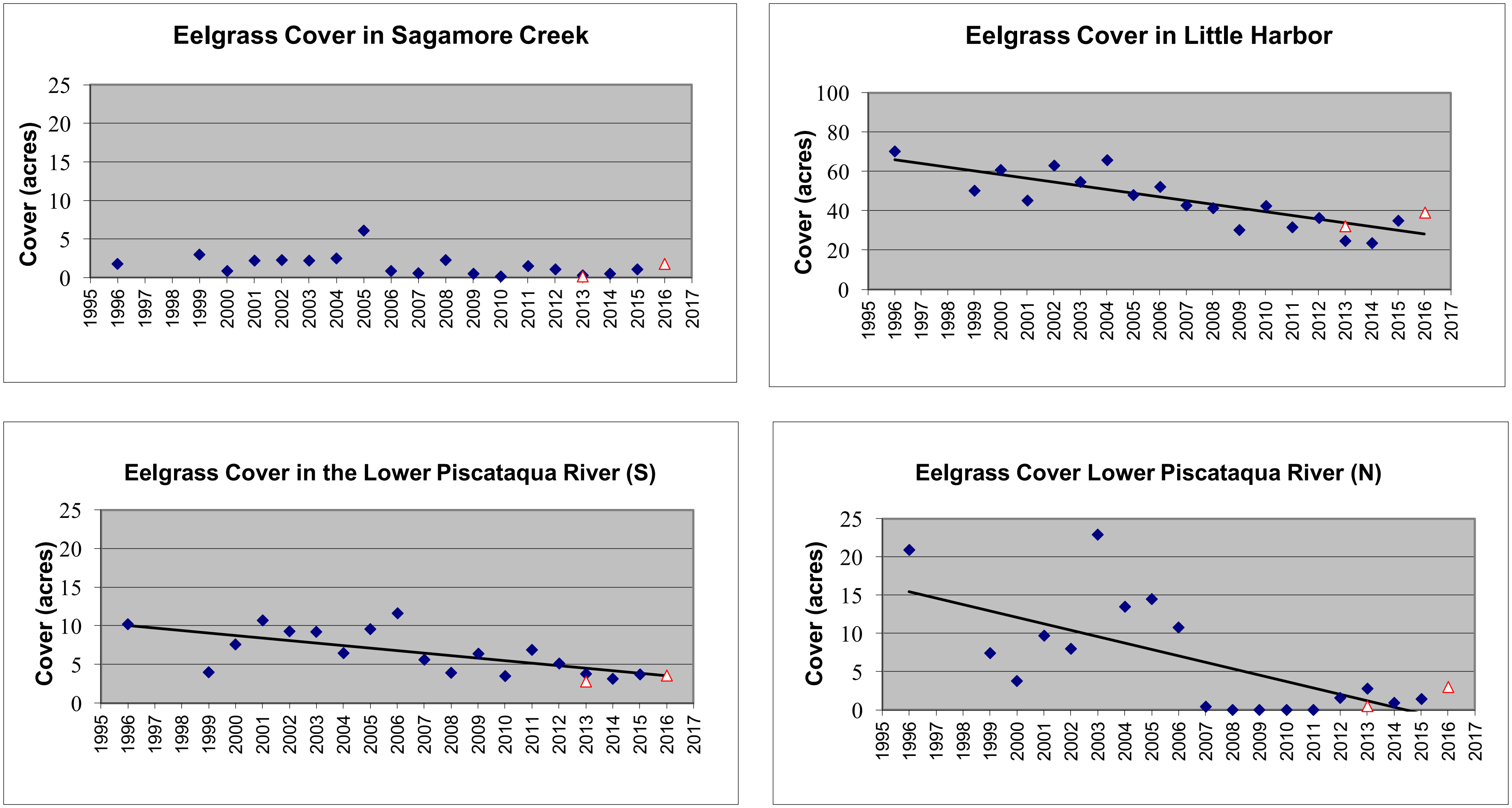
Table E-1: Eelgrass coverage in the Great Bay Estuary. Units = Acres; a = not mapped. * The acreages for 1981,1996-2008 include beds from both the NH and ME sides of the Piscataqua River but not the tidal creeks along the Maine shore.

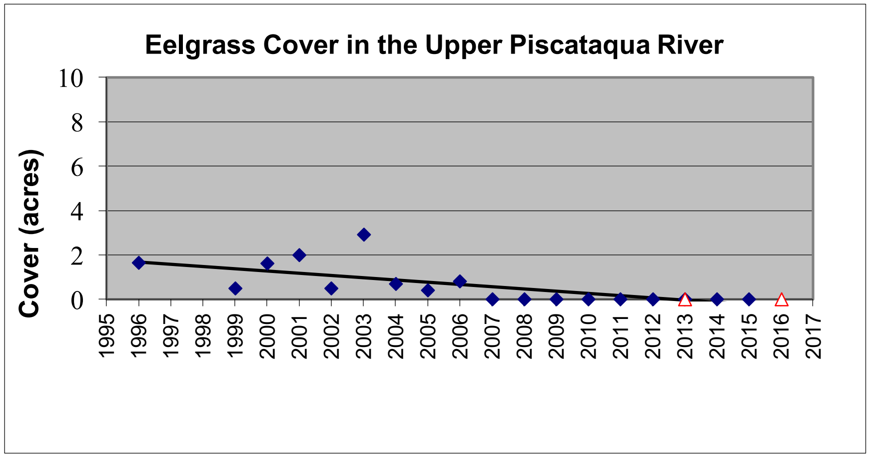
Year	Winnicut River	Squamscott River	Lamprey River	Oyster River	Bellamy River	Great Bay	Little Bay	Upper Pisc River*	Lower Pisc River North*	Lower Pisc River South*	Portsmouth Harbor*	Little Harbor	Sagamore Creek	Total
1981	0.0	0.0	0.0	a	3.4	2130.7	252.0	0.5	60.1	5.1	227.7	68.8	4.1	2752.3
1986	2.2	0.0	0.0	a	a	2015.2	a	a	a	a	a	a	a	
1987	2.2	0.0	0.0	a	a	1685.7	a	a	a	a	a	a	a	
1988	0.0	0.0	0.0	a	a	1187.5	a	a	a	a	a	a	a	
1989	0.0	0.0	0.0	a	a	312.6	a	a	a	a	a	a	a	
1990	15.9	0.0	0.0	a	a	2024.2	a	a	a	a	a	a	a	
1991	23.4	0.0	0.0	a	a	2255.8	a	a	a	a	a	a	a	
1992	7.3	0.0	0.0	a	a	2334.4	a	a	a	a	a	a	a	
1993	6.9	0.0	0.0	a	a	2444.9	a	a	a	a	a	a	a	
1994	13.8	0.0	0.0	a	a	2434.3	a	a	a	a	a	a	a	
1995	7.8	0.0	0.0	a	a	2224.9	a	a	a	a	a	a	a	
1996	7.6	0.0	0.0	14.0	0.0	2495.4	32.7	1.6	20.9	10.2	245.6	70.1	1.8	2900.0
1997	7.5	0.0	0.0	a	a	2297.8	a	a	a	a	a	a	a	
1998	10.0	0.0	0.0	a	a	2387.8	a	a	a	a	a	a	a	
1999	10.2	0.0	0.0	0.0	0.0	2119.5	26.2	0.5	7.4	4.0	244.0	50.1	3.0	2464.9
2000	0.0	0.0	0.0	0.0	0.0	1944.5	7.5	1.6	3.8	7.6	260.5	60.9	0.9	2287.3
2001	4.1	0.0	0.0	0.0	0.0	2388.2	10.9	2.0	9.7	10.7	274.2	45.3	2.2	2747.3
2002	3.5	0.0	0.0	0.0	0.0	1791.8	4.3	0.5	8.0	9.3	268.9	63.1	2.3	2151.7
2003	3.5	0.0	2.2	0.0	0.0	1620.9	14.2	2.9	22.9	9.2	270.1	54.7	2.2	2002.8
2004	4.2	0.0	0.0	0.0	0.8	2037.6	12.8	0.7	13.5	6.5	225.2	65.8	2.5	2369.8
2005	9.1	0.0	0.0	0.0	0.0	2165.7	25.8	0.4	14.5	9.6	232.5	47.9	6.1	2511.7
2006	0.8	0.0	0.0	0.0	0.0	1319.8	12.2	0.8	10.8	11.6	217.6	52.1	0.9	1626.5
2007	0.0	0.0	0.0	0.0	0.0	1245.3	0.1	0.0	0.4	5.6	201.3	42.7	0.6	1496.0
2008	0.0	0.0	0.0	0.0	0.0	1394.9	0.0	0.0	0.0	3.9	183.8	41.4	2.3	1626.4
2009	0.1	0.0	0.0	0.0	0.0	1700.6	0.0	0.0	0.0	6.4	155.0	30.2	0.5	1892.8
2010	0.0	0.0	0.0	0.0	0.0	1722.2	0.3	0.0	0.0	3.5	128.0	42.5	0.2	1896.8
2011	0.0	0.0	0.5	0.0	0.0	1623.2	48.2	0.0	0.0	6.9	178.8	31.6	1.5	1890.6
2012	0.3	0.0	0.0	0.0	0.0	1598.4	34.6	0.0	1.6	5.1	68.5	36.4	1.1	1817.1
2013	0.0	0.0	0.0	0.0	0.0	1395.4	0.2	0.0	1.6	3.3	71.1	28.5	0.3	1566.7
2014	2.4	0.0	0.0	0.0	0.0	1464.0	0.0	0.0	0.9	3.1	61.8	23.7	0.5	1621.4
2015	0.0	0.0	0.0	2.4	0.0	1319.3	1.7	0.0	1.4	3.7	65.4	34.9	1.1	1497.5
2016	0.0	0.0	0.0	0.0	0.0	1490.0	0.0	0.0	3.0	3.6	87.4	39.2	1.8	1689.1

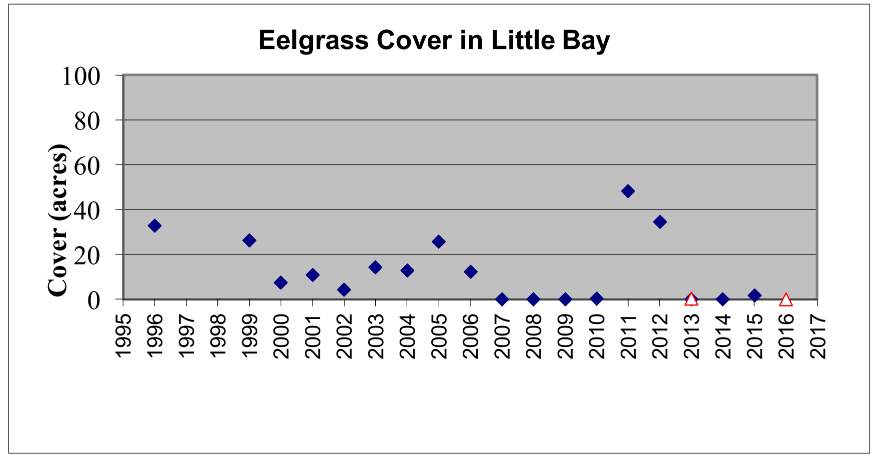
Figure E-5: Eelgrass coverage in segments of the Great Bay Estuary.



* Regression lines indicate a statistically significant trend. Diamonds are data collected by UNH-JEL; triangles indicate data from Kappa Mapping, Inc.

Figure E-5 (cont'd): Eelgrass coverage in segments of the Great Bay Estuary.





* Regression lines indicate a statistically significant trend. Diamonds are data collected by UNH-JEL; triangles indicate data from Kappa Mapping, Inc.

Indicator: Salt marsh habitat in the Great Bay and Hampton-Seabrook Estuaries

Question

How many acres of salt marsh habitat are there in the towns of the Piscataqua Region Watershed?

Short Answer

As of 2017, there are 5,521 acres of salt marsh habitat in the Piscataqua Region Watershed, with these acres distributed amongst 17 municipalities. Hampton and Seabrook have the most salt marsh habitat, with 1,342 and 1,140 acres, respectively. This baseline will be monitored in the future in order to track changes in the amount, location and characteristics of salt marsh habitat in the Piscataqua Region.

Figure SM-1. Map of salt marsh coverage, showing marsh habitat in New Hampshire only.

PREP Goal
Goal is under development.

Why This Matters

Salt marshes are among the most productive ecosystems in the world and provide many services, such as: habitat, food web support, and buffering from storms and pollution. Most salt marshes in the Piscataqua Region Watershed have been degraded over time due to development and past management activities. Also, as the rate of sea level rise increases, salt marshes will experience impacts that will change marsh composition, cause erosion or force these marshes to migrate landward.

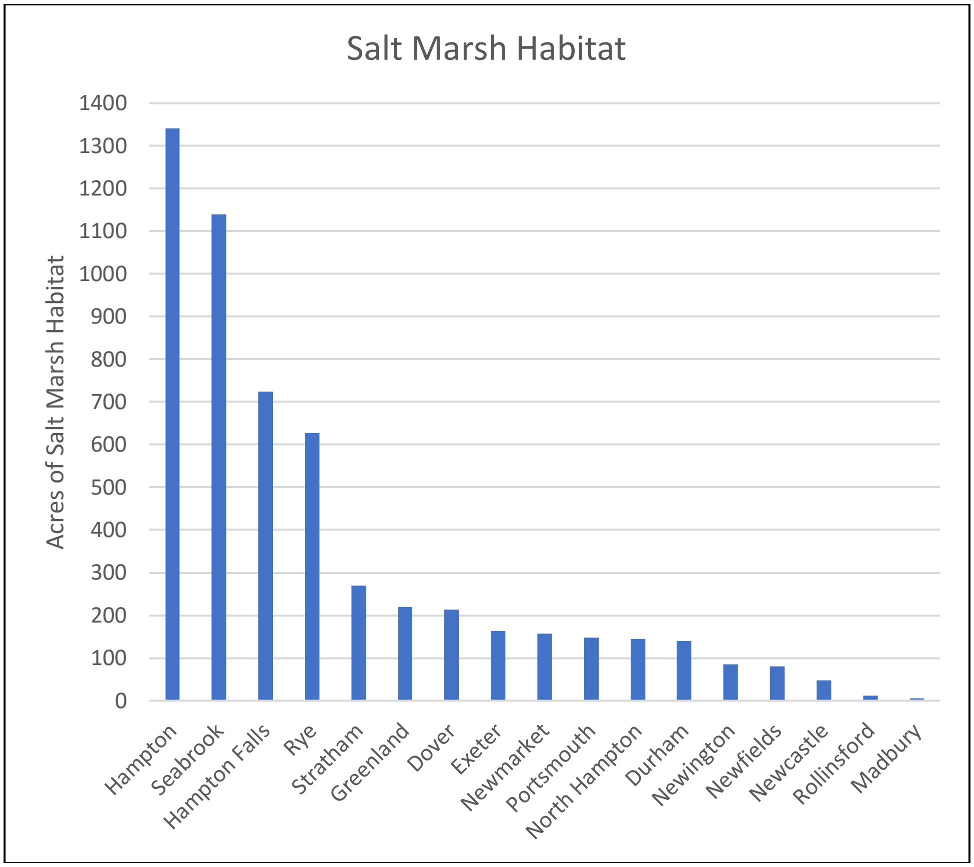


Figure SM-2. Number of acres of salt marsh habitat in 2017, by town/city within the Piscataqua Region Watershed. Data Source: Great Bay National Estuarine Research Reserve; Kappa Mapping, Inc. (2013 Flight); USGS LIDAR Data (2011 and 2014); NOAA Office of Coastal Management, and NHDES Coastal Program.

Explanation (from 2018 State of Our Estuaries Report)

As of 2017, there are 5,521 acres of salt marsh habitat in the Piscataqua Region Watershed (Figure SM-1) with these acres distributed amongst 17 municipalities (Figure SM-2). The area surrounding the Hampton-Seabrook Estuary has the greatest amount of salt marsh habitat. Hampton had the most acres of salt marsh (1,342 acres), followed closely by Seabrook (1,140 acres). Hampton Falls and Rye had 725 and 627 acres, respectively. Great Bay Estuary municipalities, such as Stratham, Greenland and Dover, had less than half the salt marsh acreage of Rye (Figure SM-2).

Between the early 1900s and 2010, an estimated 431 acres of salt marsh area was lost in the Great Bay Estuary, and in the Hampton-Seabrook Estuary, 614 acres (or 12% of the historic salt marsh) was lost (PREP

2010). As these habitats experience continued pressures from development and impacts related to climate change, such as sea level rise, it will be important to assess changes in marsh location, total acreage and salt marsh structure. For example, one possible reaction to sea level rise, forecasted to be between 6 and 11 mm/ year, is that plant species that are less tolerant to flooding, such as high-marsh grass (*Spartina patens*) will be replaced by low-marsh grass (*Spartina alterniflora*) and the boundary between high and low will shift upslope. In addition, the lower edge of the marsh will migrate landward as the marshes literally drown and pannes (depressions in the marsh that do not tend to retain water) and pools (which do retain water) are likely to expand (Smith et al. 2017).

Acreages presented in this report represent a new baseline that will be monitored consistently into the future. The 2017 baseline assessment is the first to use standardized digital methods, which are being employed across the nation by NOAA and the National Estuarine Research Reserve (NERR) system. Although this report focuses only on number of acres, future years will include other salt marsh categories, such as: acres of high marsh versus low marsh, pannes and pools, and amount of invasive species such as *Phragmites australis*. PREP anticipates that the new baseline will be used to track the area of marsh lost to sea level rise, the area of marsh gained by landward migration as well as the conversion of high marsh to low marsh.

Methods and Data Sources

The goal for this project, and this new indicator, was to create a new habitat mapping system, based on high resolution source data and semi-automated classification routines, calibrated through on-the-ground field verification. The specific objective of this new approach is to facilitate the development of finely detailed habitat delineations that will provide a baseline representation of salt marsh habitats in New Hampshire and will be suitable for change analysis in the future.

Data mining was initiated during the fall of 2015 and several critical input data sets were identified and acquired. Partners (Great Bay NERR, NOAA Office for Coastal Management and NH DES) worked together to create a standardized salt marsh classification system, which includes 24 unique classes that differentiate habitats (species, species assemblages, and physical environments) from the salt marsh terrestrial border to open water. Significant class types include tall form and short form *Spartina alterniflora*, lower and upper salt meadow, upper brackish meadow, pannes and pools, and *Phragmites australis*.

Initial field work was performed in 2016. Field calibration points were recorded at hundreds of reference sites covering most of the state's tidal wetlands. Georeferenced photographs were also acquired to support the ongoing quality control process. The initial classification phase produced draft maps and classifications. These were reviewed and merged with additional training data into a comprehensive database in order to improve the semi-automated classification routines.

NOAA OCM generated draft habitat layers and published them to NOAA's ArcGIS online account (NOAA GeoPlatform) for external reviewers to access and submit comments. Comments were incorporated and revised habitat maps were generated for a second round of review. This was followed by the second round of field verification to calibrate the semi-automated analysis and to perform an accuracy assessment for the final product.

Data Sources

NOAA OCM compiled existing 2004 and 2012 NH wetlands datasets, from Normandeau and US Fish and Wildlife Service, respectively. These datasets, along with a modeled mean higher high water tidal surface, were used to establish the project mapping boundary.

Primary mapping imagery was provided by PREP (Orthoimagery, 1- foot resolution, 4-band imagery collected on August 24, 2013 at low tide.) Ancillary elevation data included 2011 and 2014 USGS lidar data, which were downloaded from NOAA's Digital Coast and were processed to generate digital terrain models and digital surface models.

Ancillary water surface data included four different tidal surfaces; highest annual tide, mean higher high water, mean high water, and mean tide level were generated using model output from VDatum, the lidar data, and NOAA OCM's water surface mapping methods.

References Cited

PREP. 2010. Piscataqua Region Comprehensive Conservation and Management Plan, Piscataqua Region Estuaries Partnership: D.B.Truslow Associates, Mettee Planning Consultants, 2010, Durham, NH. scholars.unh.edu/prep/22/.

Smith SM, Tyrrell M, Medeiros K, Bayley H, Fox S, Adams M, Mejia C, Dijkstra A, Janson S, Tanis M. 2017. Hypsometry of Cape Cod Salt Marshes (Massachusetts, U.S.A.) and Predictions of Marsh Vegetation Responses to Sea-level Rise. *Journal of Coastal Research*. (33) 3: 537 – 547

Indicator: Bacterial indicators of fecal pollution in the Great Bay Estuary

Question

How have bacterial pollution concentrations changed over time in the Great Bay Estuary?

Short Answer

Between 1989 and 2016, dry weather concentrations of bacterial indicators of fecal pollution in the Great Bay Estuary have typically fallen 67% to 93% at four monitoring stations due to pollution control efforts in most, but not all, areas.

PREP Goal

No increasing trends for fecal coliform, enterococci, or *Escherichia coli* in the Great Bay Estuary (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

Why This Matters

Elevated concentrations of bacterial pollutants in estuarine waters can indicate the presence of pathogens from sewage and other fecal sources. Illness-causing microorganisms pose a public health risk, and are a primary reason why shellfish beds can be closed and beach advisories can be posted.

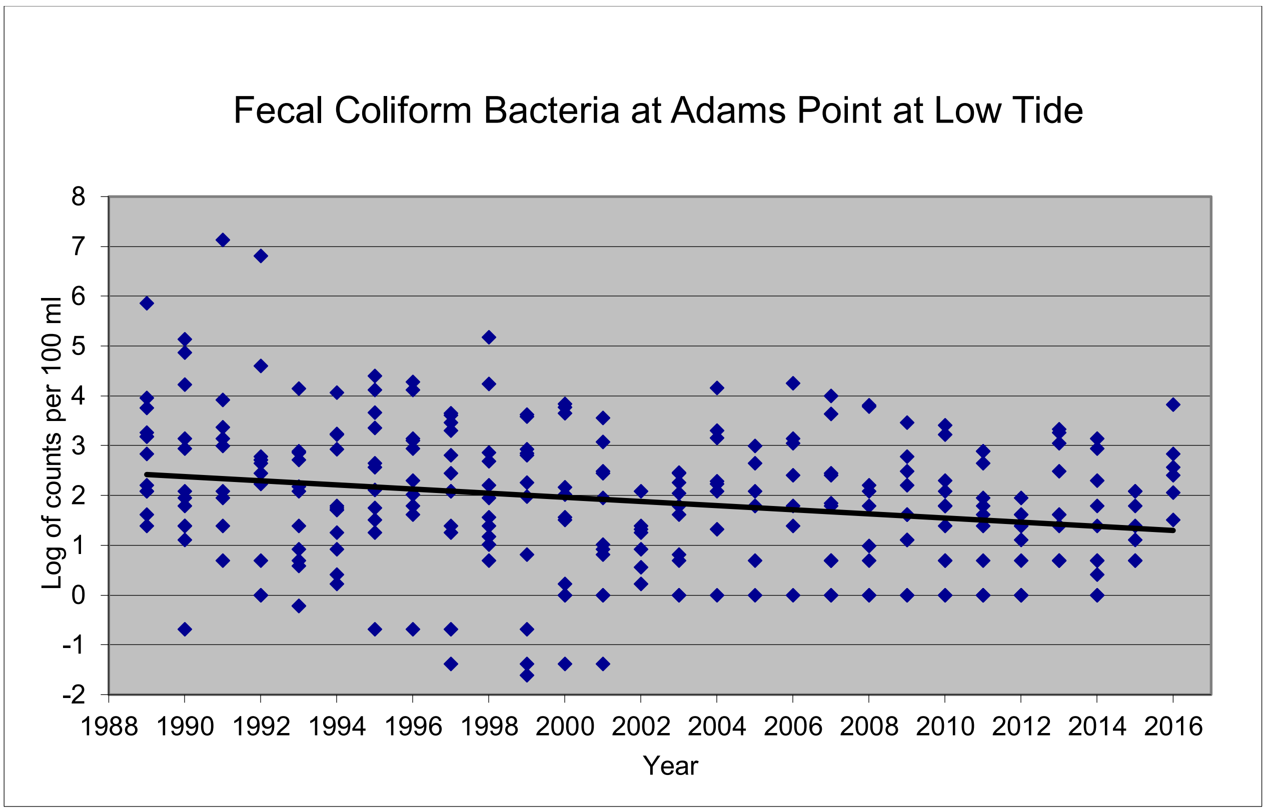


Figure B-1. Fecal coliform bacteria concentrations at low tide during dry weather at Adams Point. Line shows a statistically significant trend. Data are log-transformed for better visualization. "0" values translate to a count of "1" colony forming unit (CFU). Values less than "0" indicate an original value between "0" and "1." Data Source: Great Bay National Estuarine Research Reserve and the UNH Jackson Estuarine Laboratory.

PREP
Piscataqua Region Estuaries Partnership

Explanation (from 2018 State of Our Estuaries Report)

Elevated levels of fecal-borne indicator bacteria in our estuaries can indicate the presence of sewage pollution from failing septic systems, overboard marine toilet discharges, wastewater treatment facility overflows, illicit connections between sewers and storm drains, and sewer line failures, as well as livestock, pet, and wildlife waste that can run off impervious surfaces. Such indicator bacteria can also originate from polluted sediments that become resuspended in the estuary due to waves and tides. Increases in rainfall often cause increases in indicator bacteria concentrations because stormwater runoff can cause flushes of pollution into the estuary. PREP uses measurements from days without significant rainfall to reflect chronic contamination levels rather than include data from rainfall events that would cause runoff-induced peak levels of bacteria. Data for this indicator is only presented for the Great Bay Estuary.

At all four long-term water pollution-monitoring stations in the estuary, a decrease in fecal coliform bacteria during dry weather has been observed over the past 26 years. For example, at Adams Point, fecal coliform bacteria decreased by 67% between 1989 and 2016 (Figure B-1). Upgrades to wastewater treatment facilities, improvements to stormwater and sewage infrastructure, and microbial source tracking studies that identify and address sources of bacterial pollution are all contributing factors to the long-term decreasing trend. It should be noted that not all trends were decreasing. Fecal coliform bacteria measurements in Portsmouth Harbor and *enterococci* at Adams Point, the Squamscott River, and Portsmouth Harbor showed no significant trends.

Methods and Data Sources
Fecal coliforms, enterococci and *Escherichia coli* bacteria are referred to as fecal-indicating bacteria; they are themselves not harmful to humans, but rather indicate the potential presence of harmful pathogens associated with fecal matter from warm-blooded animals (US EPA 2012). Since the 1970s, recommendations regarding the usage of these three indicators have changed as a result of updated testing, development of new methods and implementation of epidemiology studies. The most recent recreational water quality criteria—that is, developed for protecting the health of swimmers—recommend that enterococci be used for marine or fresh water and that *E. coli* be used for freshwater only (US EPA 2012.) These recommendations no longer endorse using fecal coliforms for recreational water quality criteria; however, fecal coliforms are still used by the National Shellfish Sanitation Program (NSSP) for setting water quality levels for the harvest and consumption of shellfish (NSSP 2017).

Data for samples that were collected at low tide during dry weather were queried from the overall bacterial dataset. Measurements of bacteria concentrations (fecal coliforms, enterococci, and *E. coli*) at long-term trend stations in the estuary were compiled. Field duplicate and quality-assurance samples were excluded and results reported as non-detected (less than ten percent of the samples) were replaced with one-half the method detection limit. Each measurement was paired with the antecedent rainfall in Portsmouth in the preceding two days and the preceding four days. For sites in the middle of Great Bay/Little Bay, "dry weather" samples were defined as those collected when there had been less than 2 inches of rain in the previous 4 days. For all other sites, a sample was considered to be dry if there had been less than 0.5 inches of rain in the previous 2 days. The two different criteria are used to identify "dry weather" samples because water quality at stations in the middle of the bay responds slower to rainfall runoff than at stations in the tidal tributaries. The samples collected at low tide and under dry-weather conditions were extracted from this dataset for trend analysis. It is important to keep in mind that these data represent ideal conditions, since wet weather samples were excluded from the analysis.

Trends in low-tide dry weather samples were assessed using linear regression of natural log transformed concentrations versus year. Trends were considered significant if the slope coefficient of the year variable was significant at the $p<0.05$ level.

Data Sources
Data for this indicator was provided by the UNH and Great Bay NERR Tidal Water Quality Monitoring Program.

Additional Results (Beyond What Was Reported in the SOOE)

Eight out of 12 combinations of three indicators at four stations showed decreasing trends (Table B-1). There were no increasing trends. Of the four combinations that did not show trends, three of these were for enterococci; of the four stations, only enterococci at the Lamprey River station showed a decreasing trend. The only non-enterococci combination that did not show a trend was fecal coliforms at the Coastal Marine Laboratory station in Portsmouth Harbor.

Table B-1: Summary table of three fecal-indicating bacteria from four stations with long-term data.

Station	Parameter	Period of Record	Trend
GRBAP (Adams Point)	Fecal coliforms	1989-2016	**Decreasing**
	Enterococci		no significant trend
	E. coli		**Decreasing**
GRBLR (Lamprey River)	Fecal coliforms	1992-2016	**Decreasing**
	Enterococci		**Decreasing**
	E. coli		**Decreasing**
GRBCL (Squamscott River)	Fecal coliforms	1989-2016	**Decreasing**
	Enterococci		no significant trend
	E. coli		**Decreasing**
GRBCML (Portsmouth Harbor)	Fecal coliforms	1992-2016	no significant trend
	Enterococci		no significant trend
	E. coli		**Decreasing**

References Cited

NSSP. 2017. National Shellfish Sanitation Program Guide for the Control of Molluscan Shellfish 2017 Revision. Interstate Shellfish Sanitation Conference and U.S. Food and Drug Administration. Published online: https://www.fda.gov/Food/GuidanceRegulation/FederalStateFoodPrograms/ucm2006754.htm

PREP 2010. Piscataqua Region Comprehensive Conservation and Management Plan, Piscataqua Region Estuaries Partnership: D.B.Truslow Associates, Mettee Planning Consultants, 2010, Durham, NH. http://scholars.unh.edu/prep/22/. Accessed 14 September 2017.

US EPA. 2012. Recreational water quality criteria. Office of Water. 820-F-12-058. https://www.epa.gov/sites/production/files/2015-10/documents/rwqc2012.pdf

Figure B-2: Trend stations for bacteria indicator species.

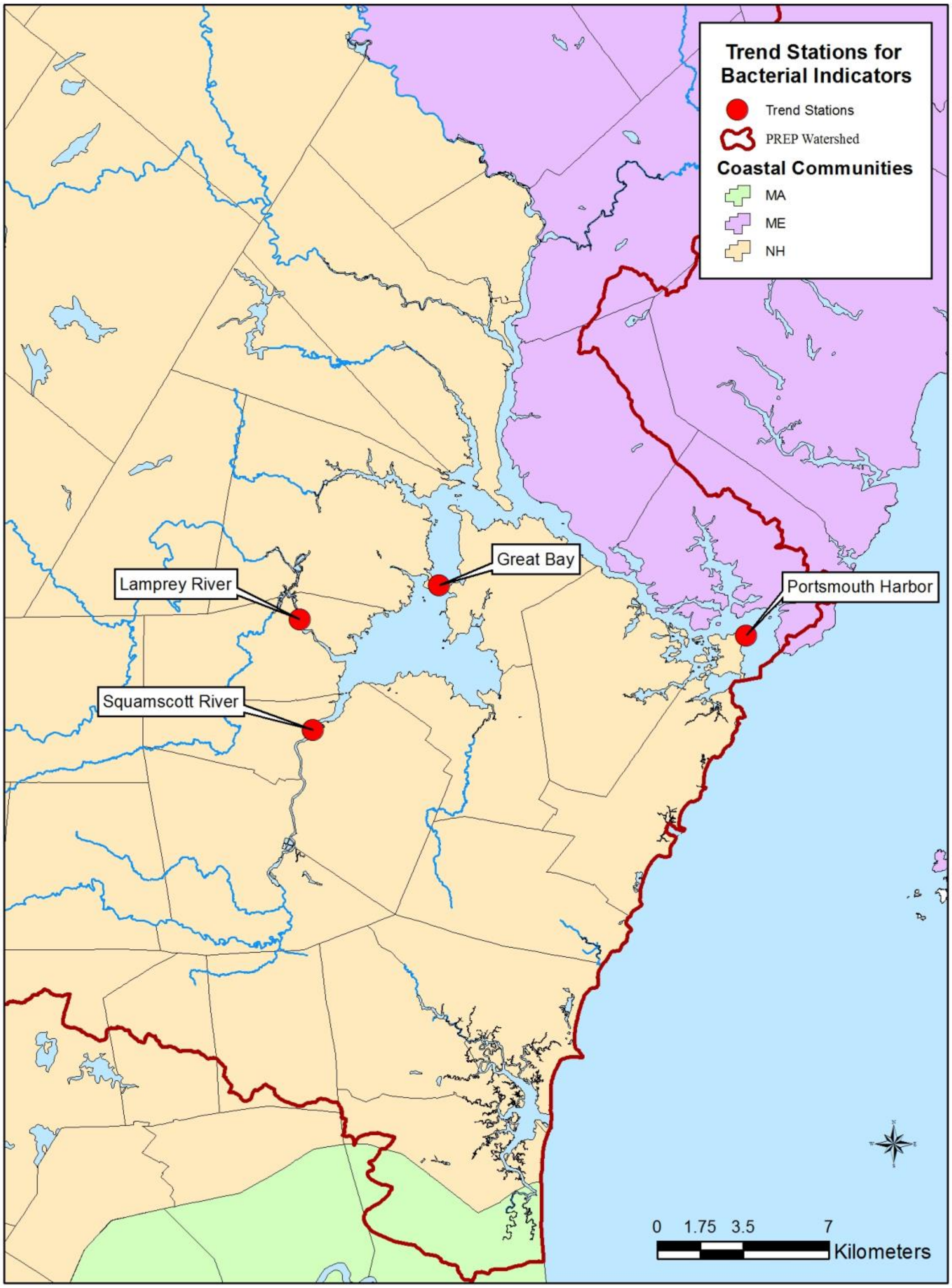
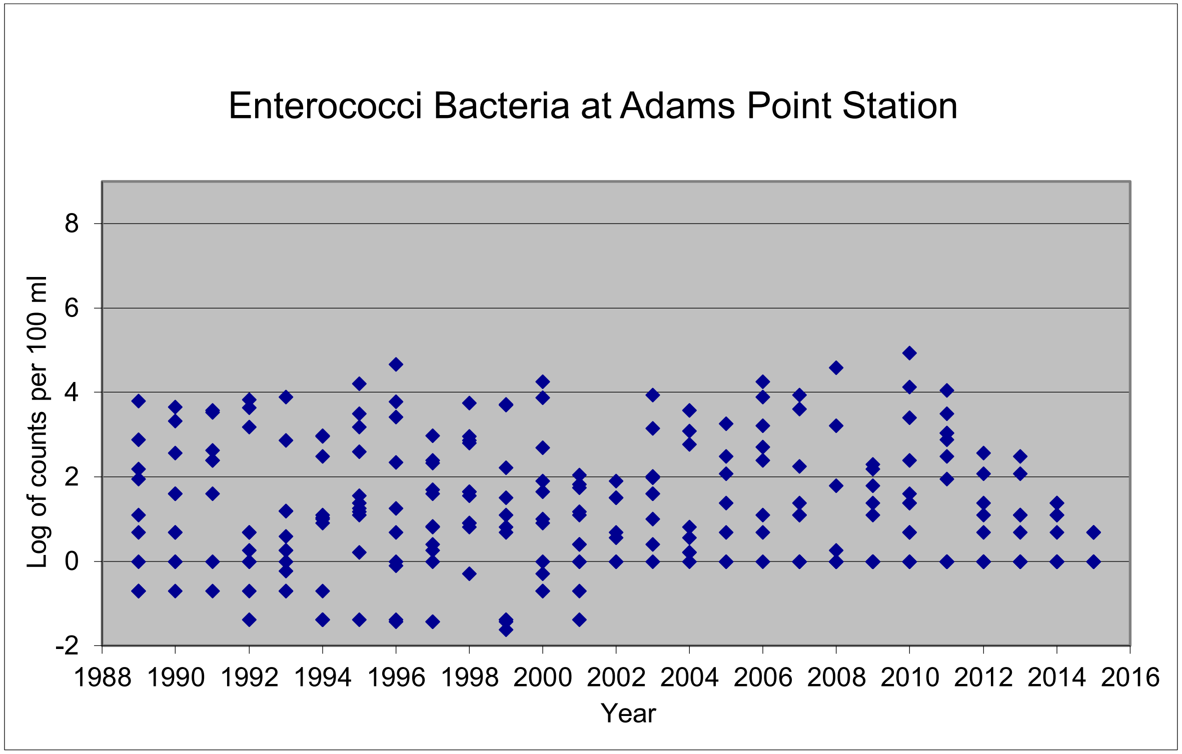


Figure B-3: Enterococci concentrations at the four trend stations in the Great Bay Estuary. Enterococci is recommended as an indicator for marine and/or fresh water. Trendline only shown when there is a statistically significant relationship. Data are log-transformed for better visualization. "0" values translate to a count of "1" colony forming unit (CFU). Values less than "0" indicate an original value between "0" and "1."



Monitoring Location (GRBAP)
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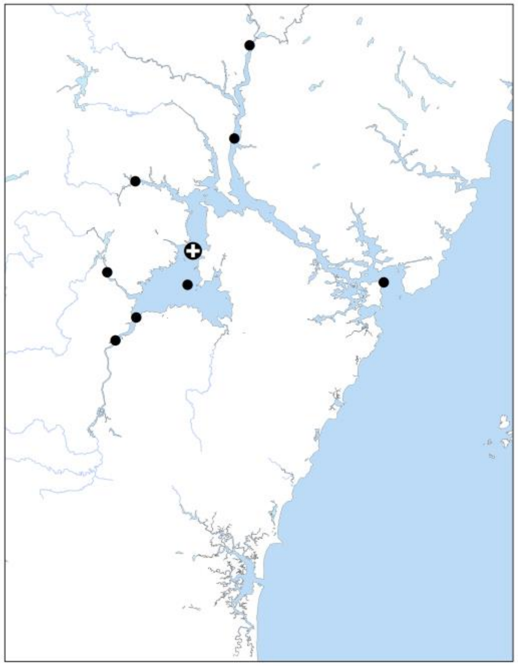

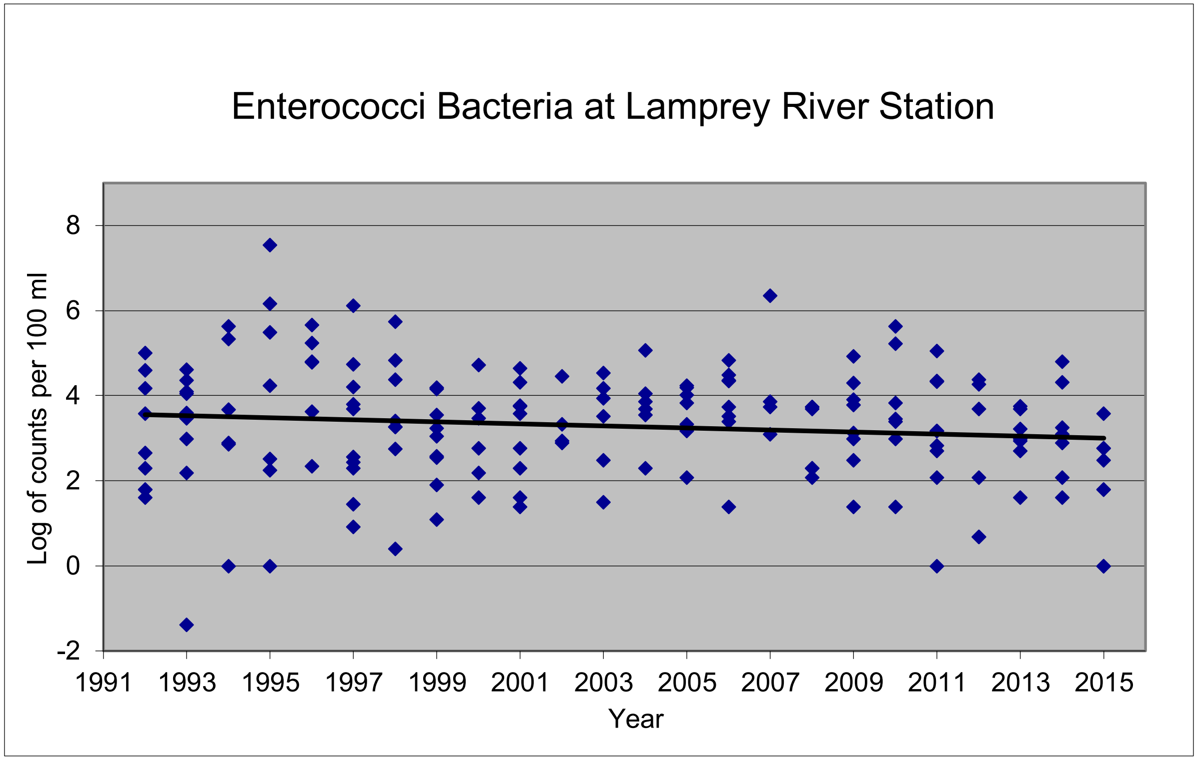

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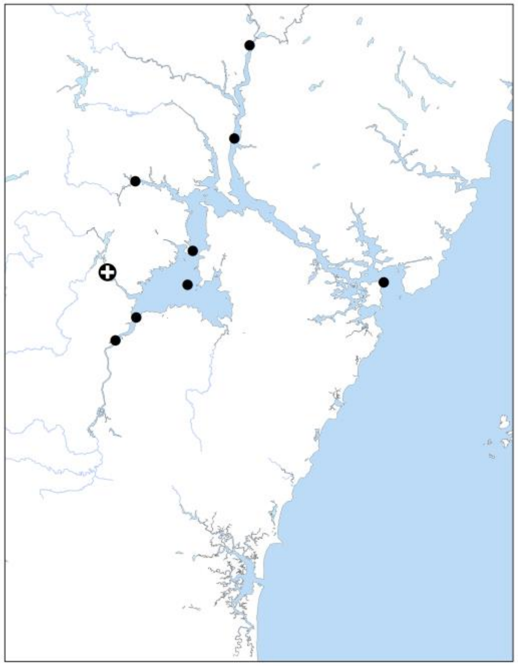

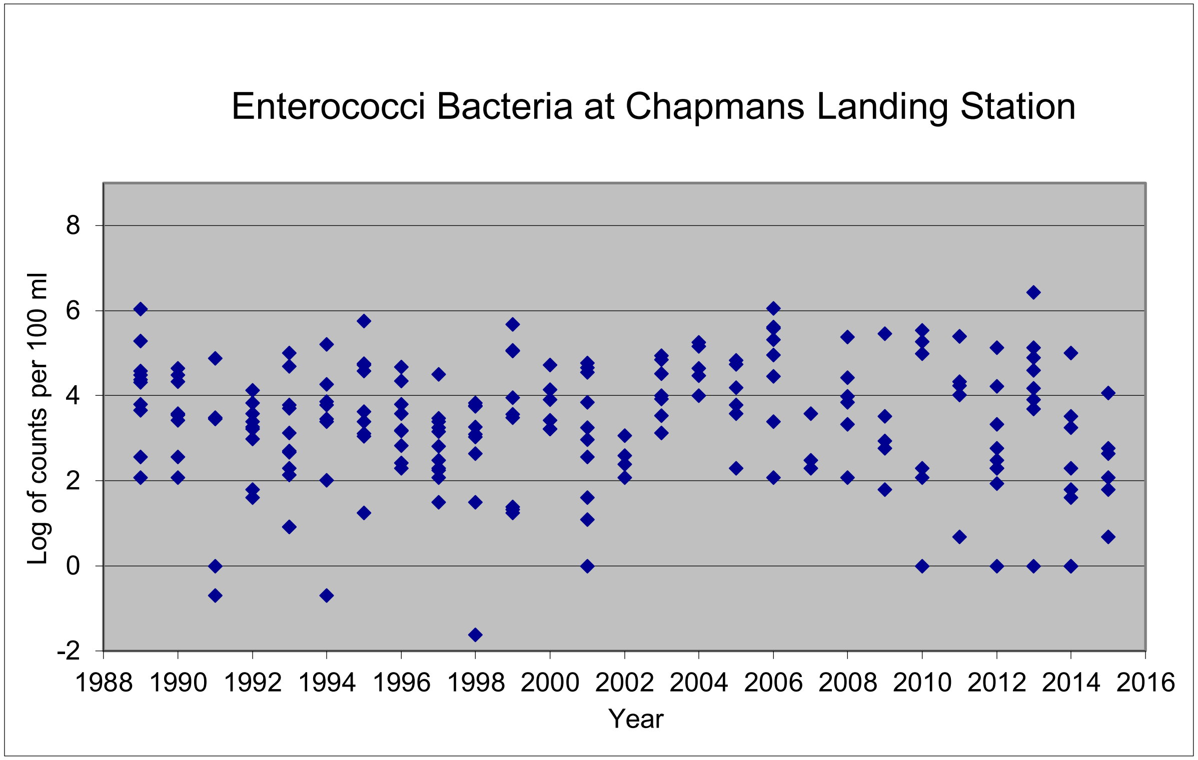

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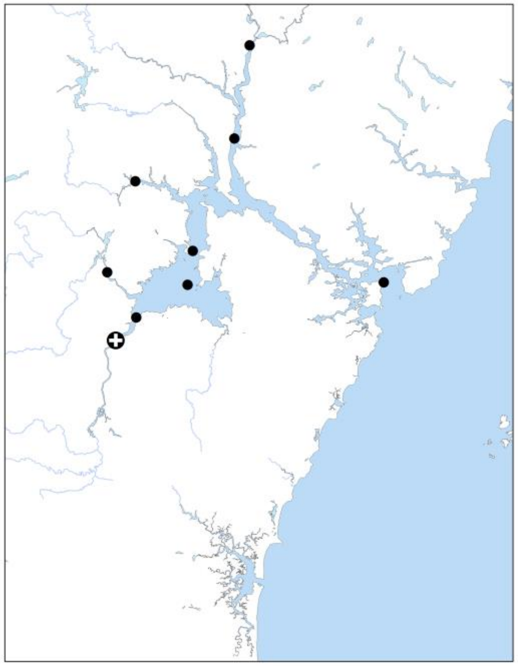

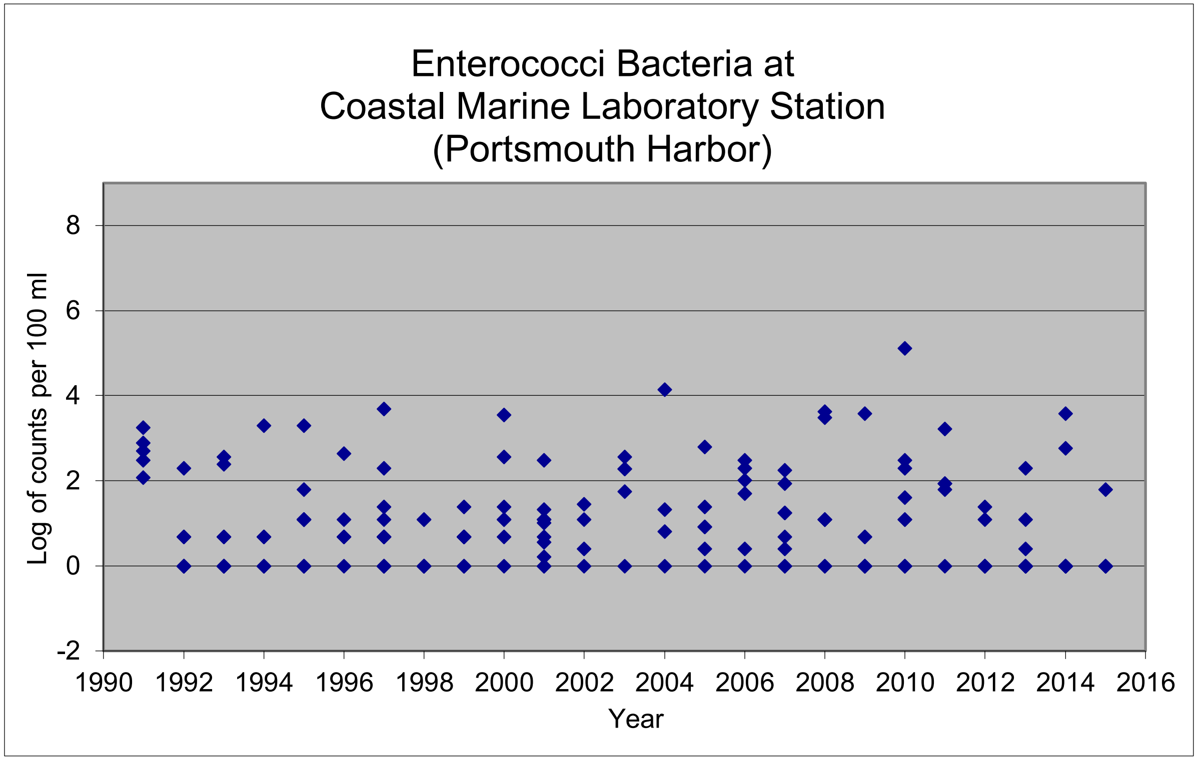

Monitoring Location (GRBCML)
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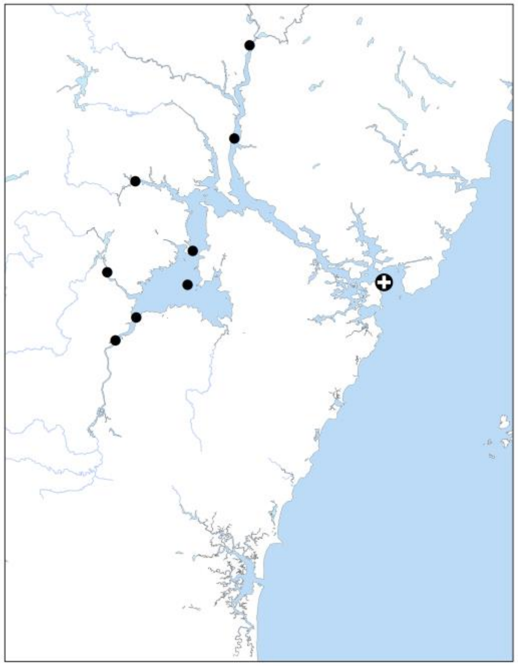
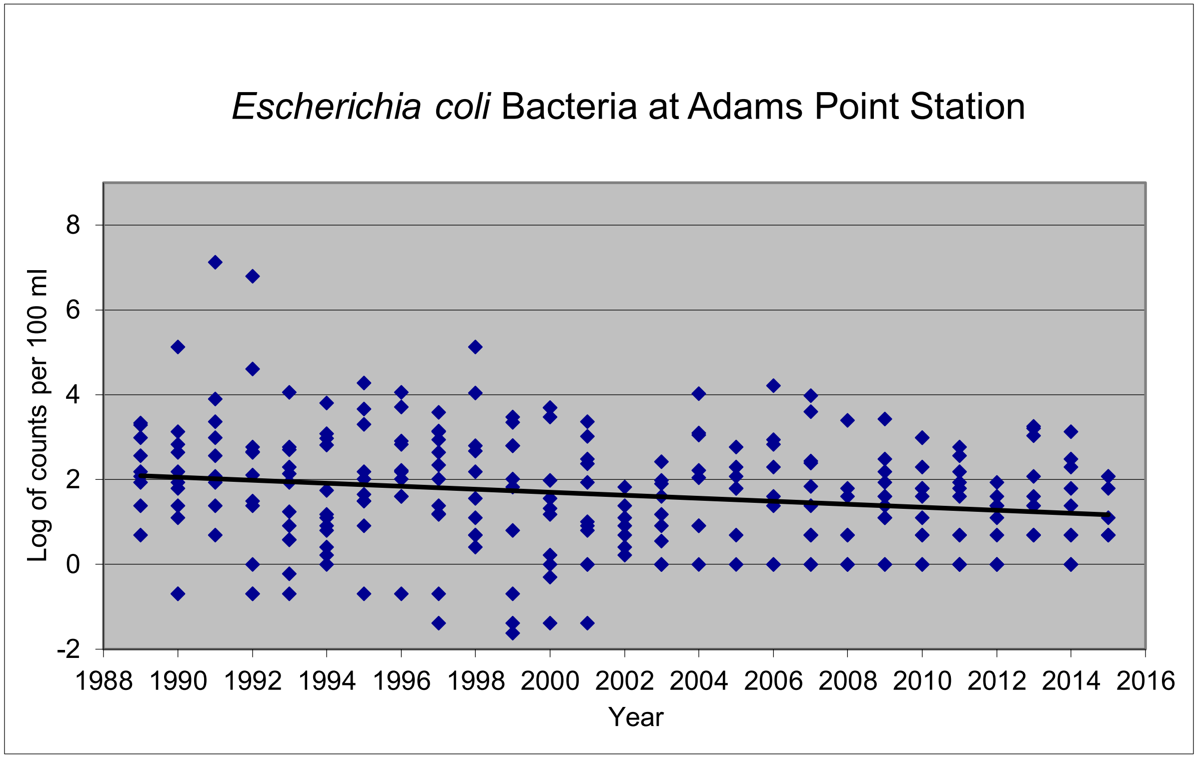


Figure B-4: *E. coli* concentrations at the four trend stations in the Great Bay Estuary. *E. coli* is recommended as a fecal indicator for fresh water only. Trendline only shown when there is a statistically significant relationship. "0" values translate to a count of "1" colony forming unit (CFU). Values less than "0" indicate an original value between "0" and "1."



Monitoring Location (GRBAP)
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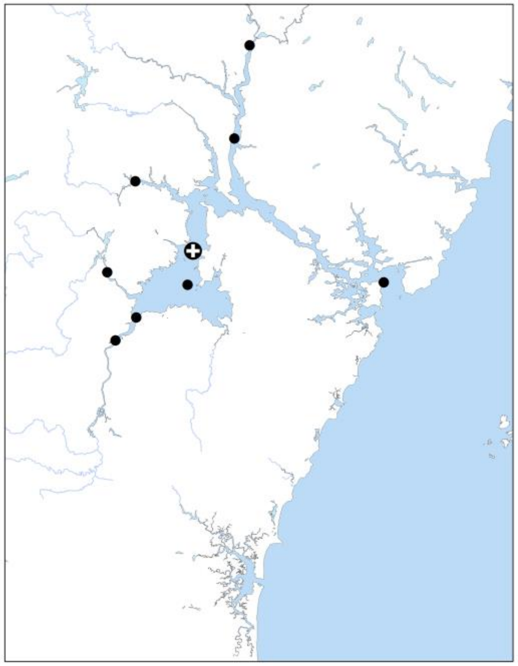

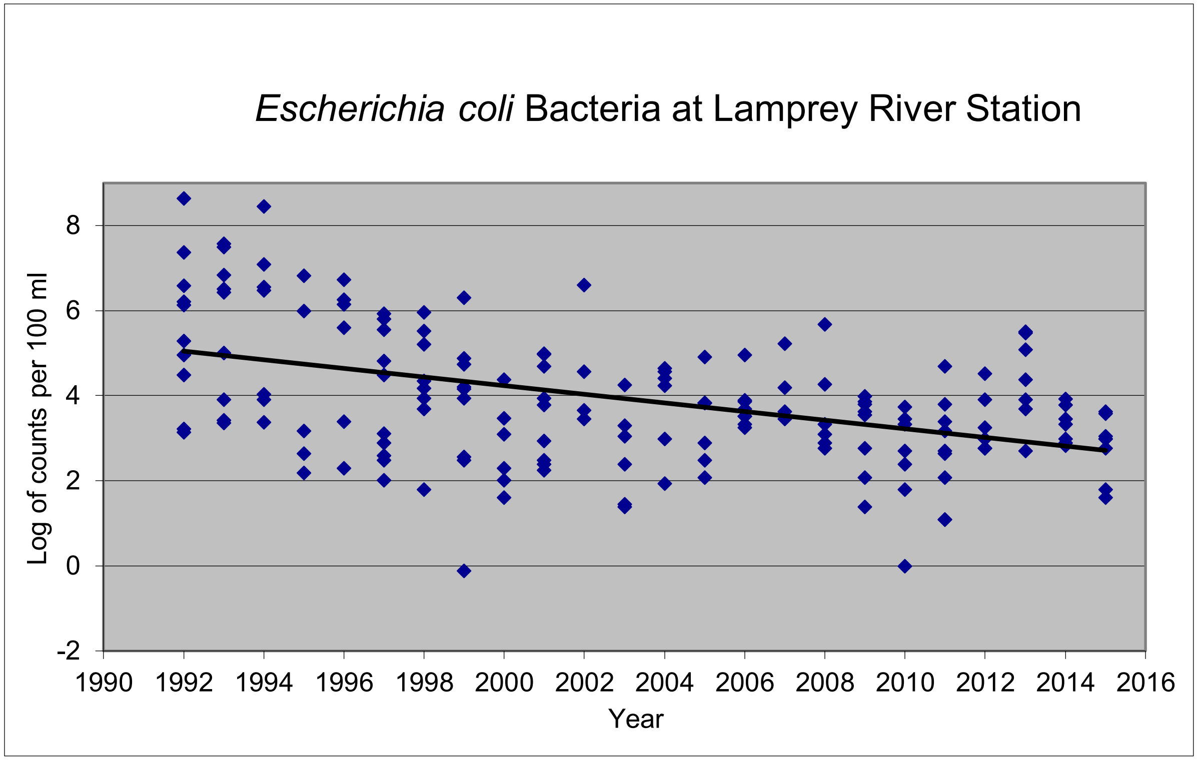

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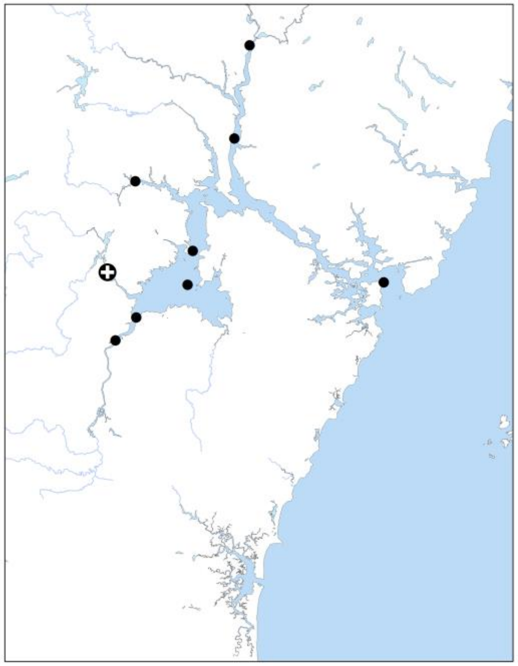

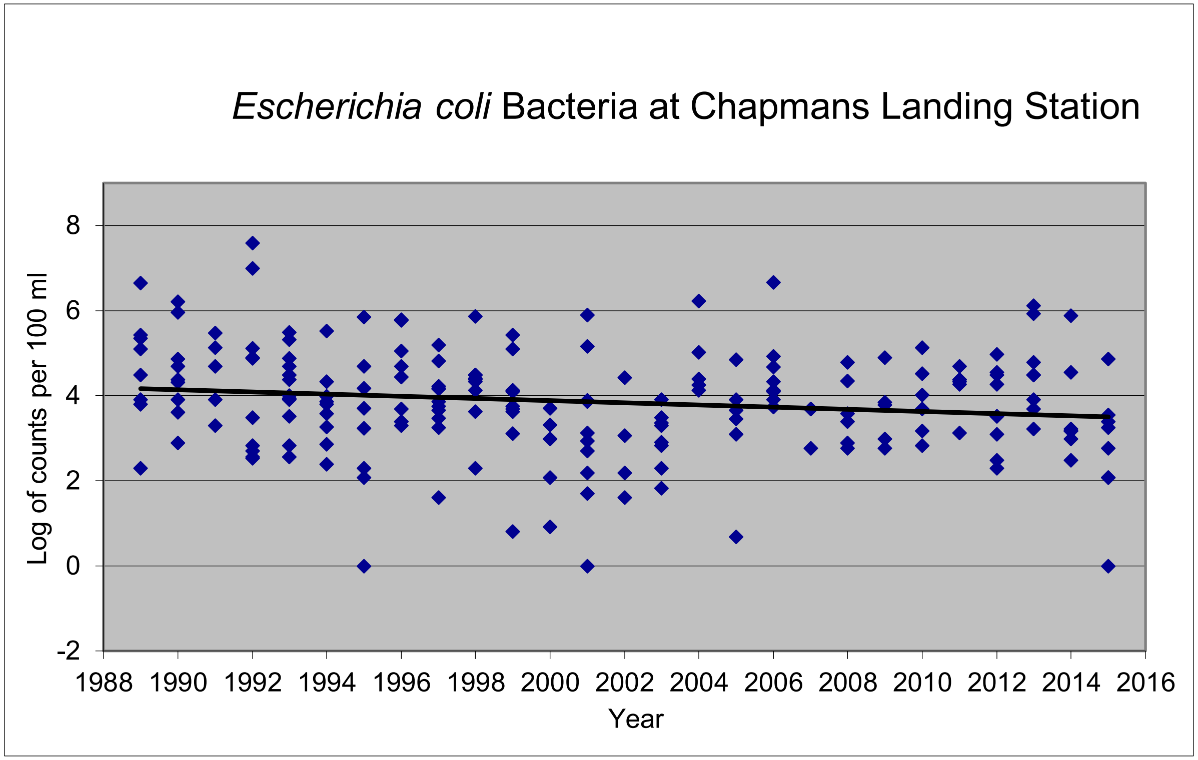

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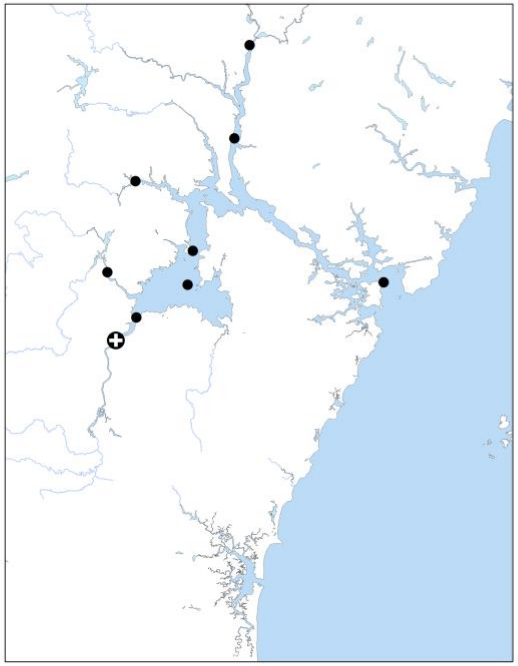

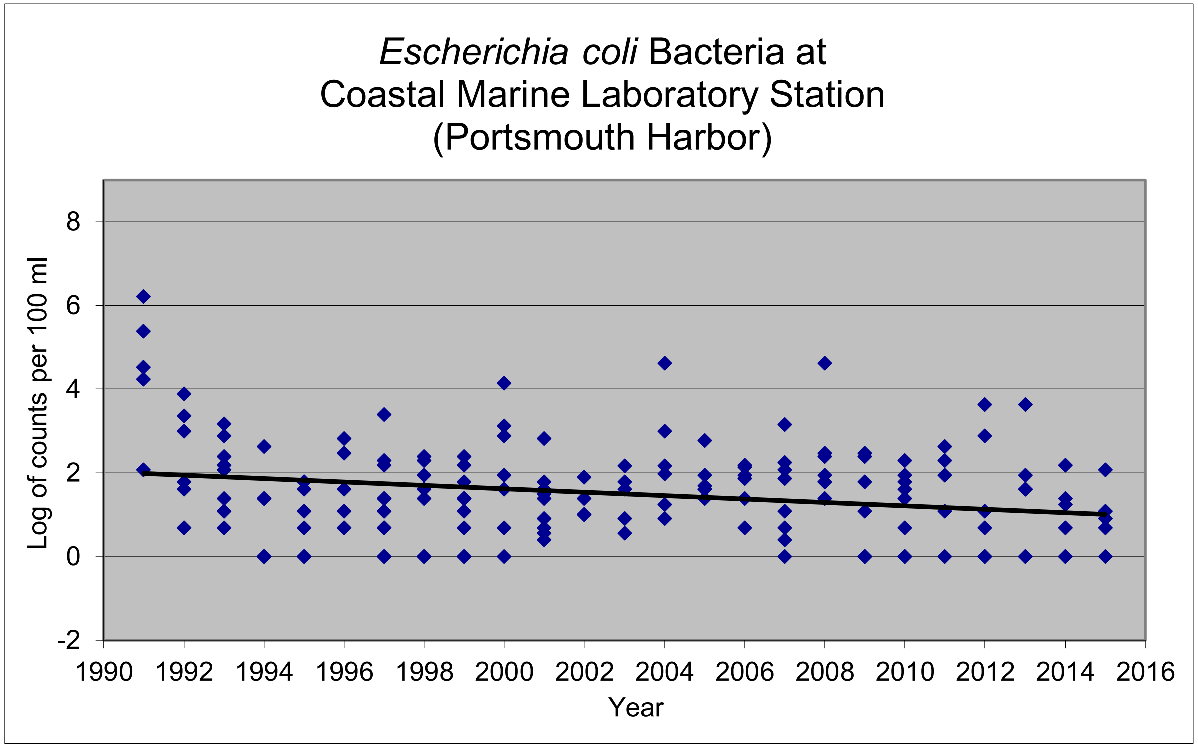

Monitoring Location (GRBCML)
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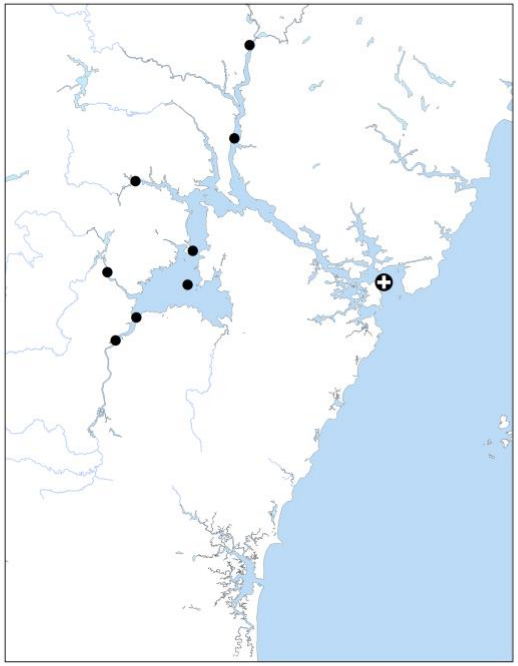
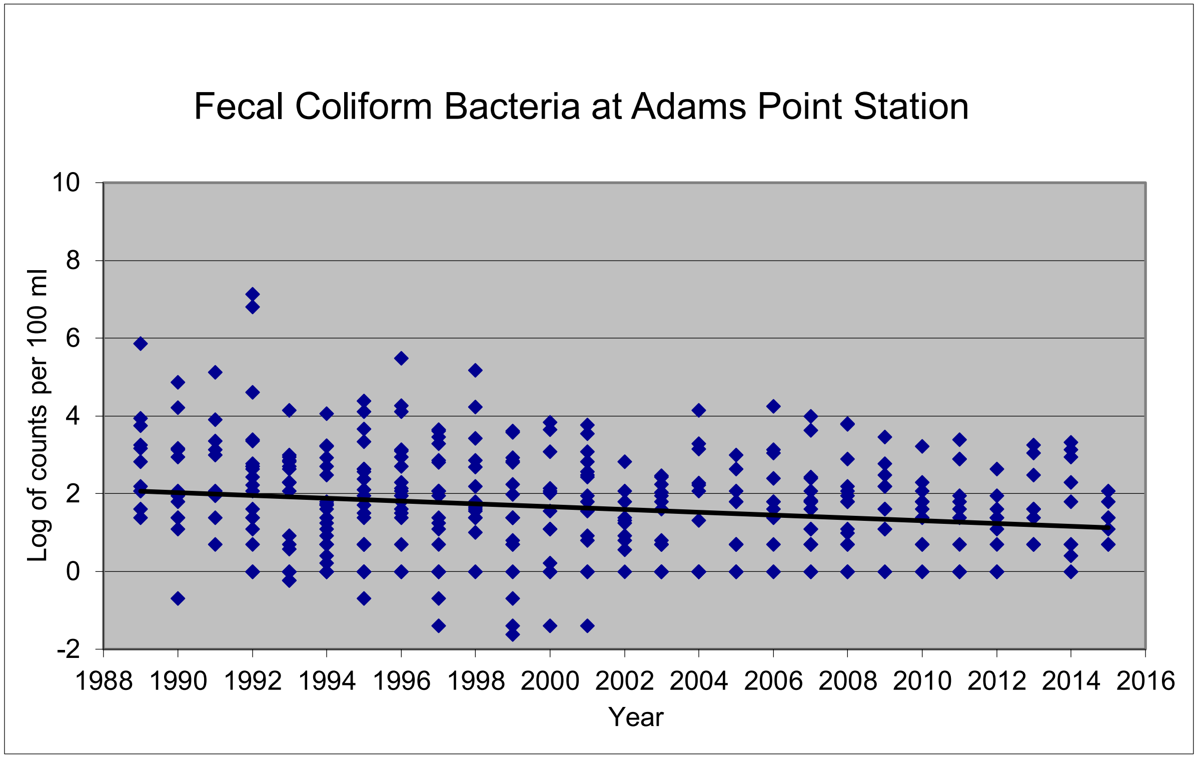


Figure B-5: Fecal coliform concentrations at the four trend stations in the Great Bay Estuary. Fecal coliform is recommended as a fecal indicator for shellfish purposes only. Trendline only shown when there is a statistically significant relationship. "0" values translate to a count of "1" colony forming unit (CFU). Values less than "0" indicate an original value between "0" and "1."



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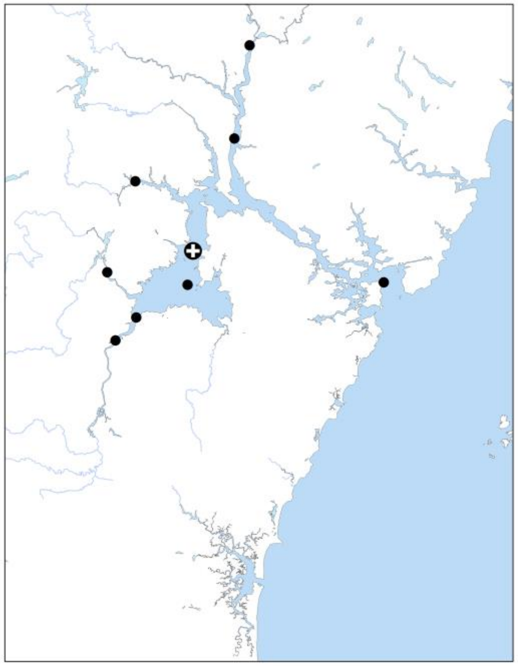

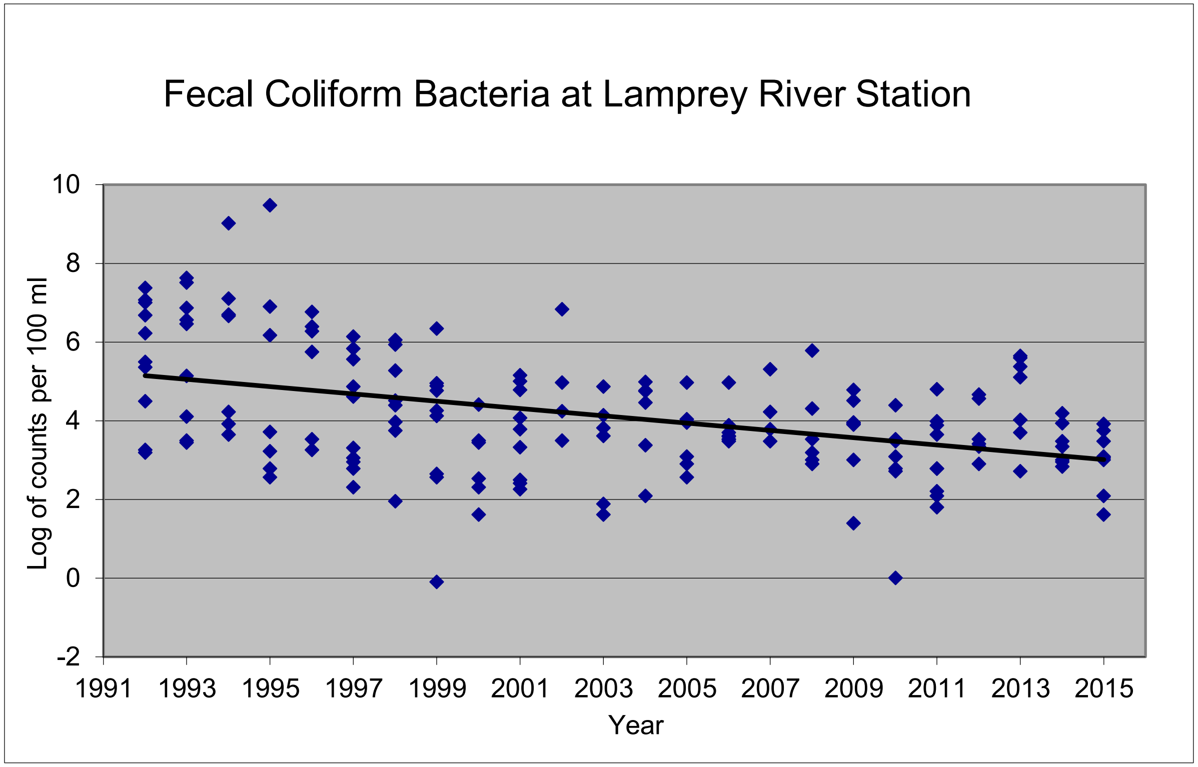

Monitoring Location (GRBLR)
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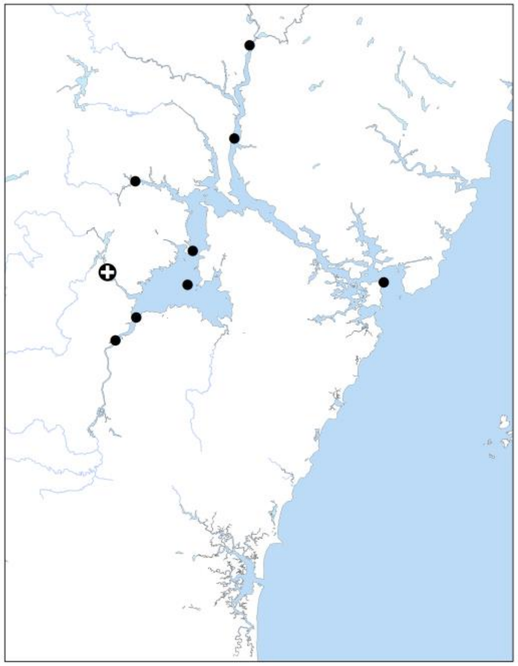

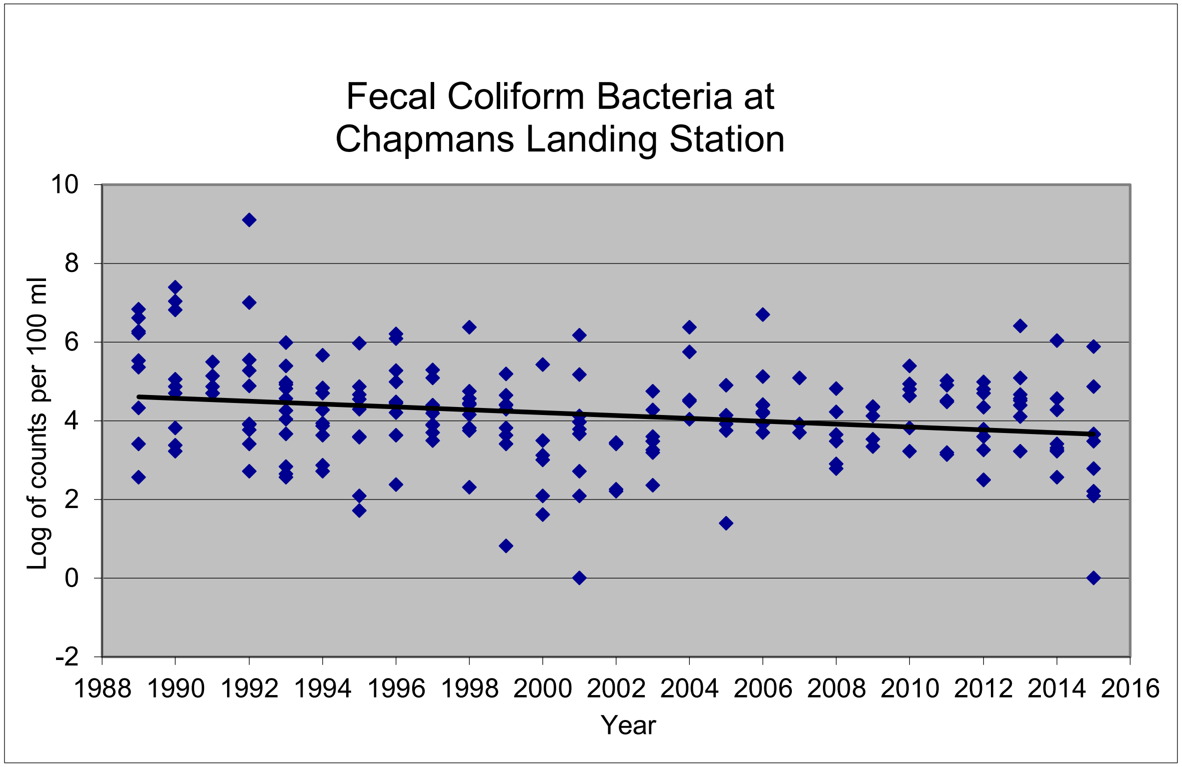

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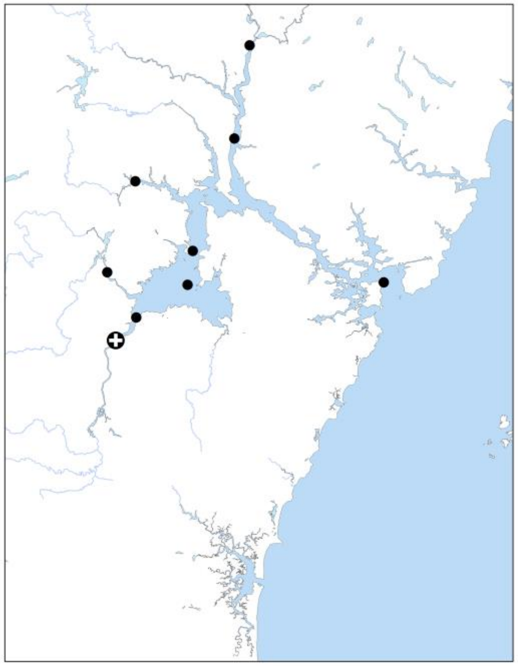

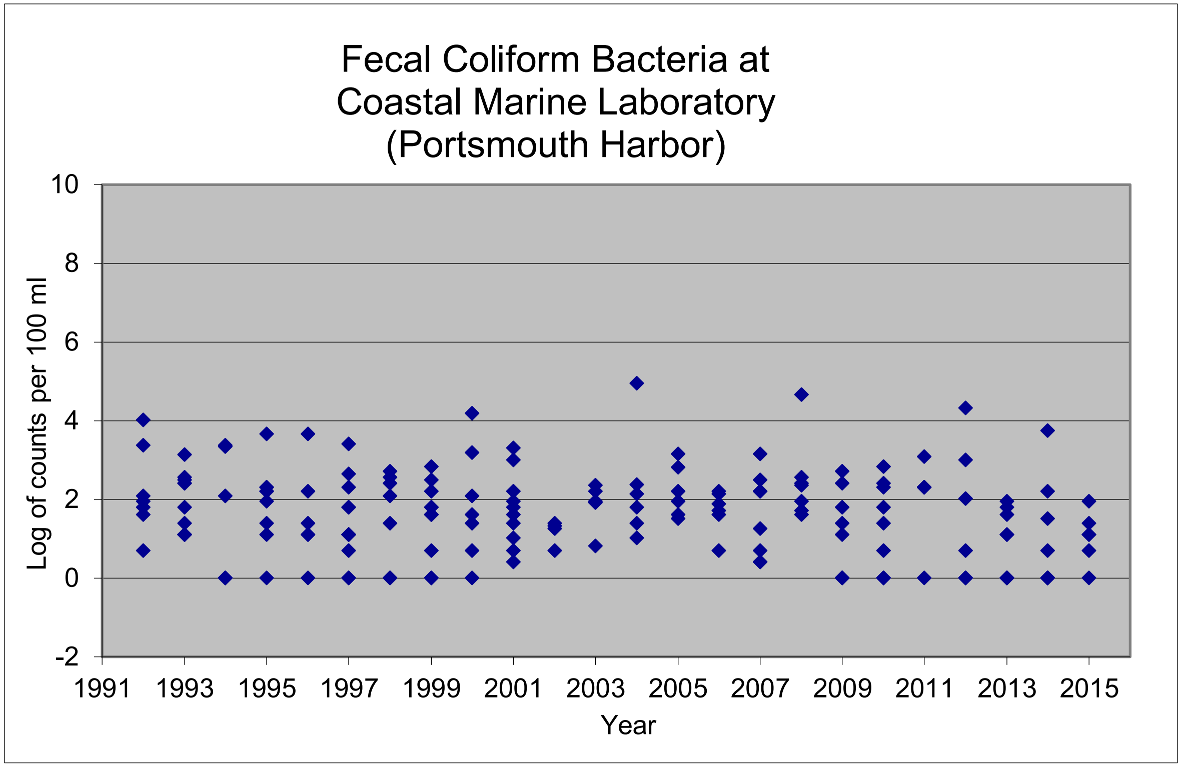

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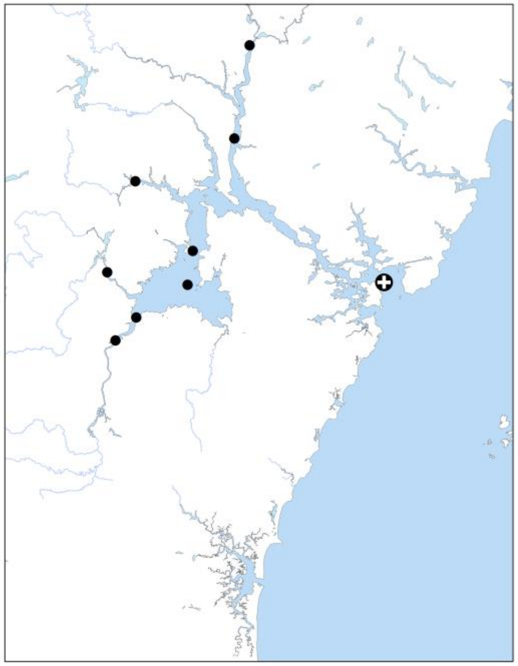

Indicator: Shellfish Harvesting Opportunities in the Great Bay and Hampton-Seabrook Estuaries

Question

How much of our estuaries are open for shellfish harvesting and how has it changed over time?

Short Answer

The percentage of possible acre-days (i.e., the number of open acres multiplied by the number of days those acres were open for harvest) between 2012 and 2016 was 80% and 66% for the Great Bay and Hampton-Seabrook Estuaries, respectively. This continues the long-term trend of a gradual increase in acre-days. The next reporting period may see continued increases as the Portsmouth wastewater treatment facility upgrade is completed in 2019-2020.

PREP Goal

Improve water quality and identify and mitigate pollution sources so that additional estuarine areas meet water quality standards for bacteria and for shellfish harvesting (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

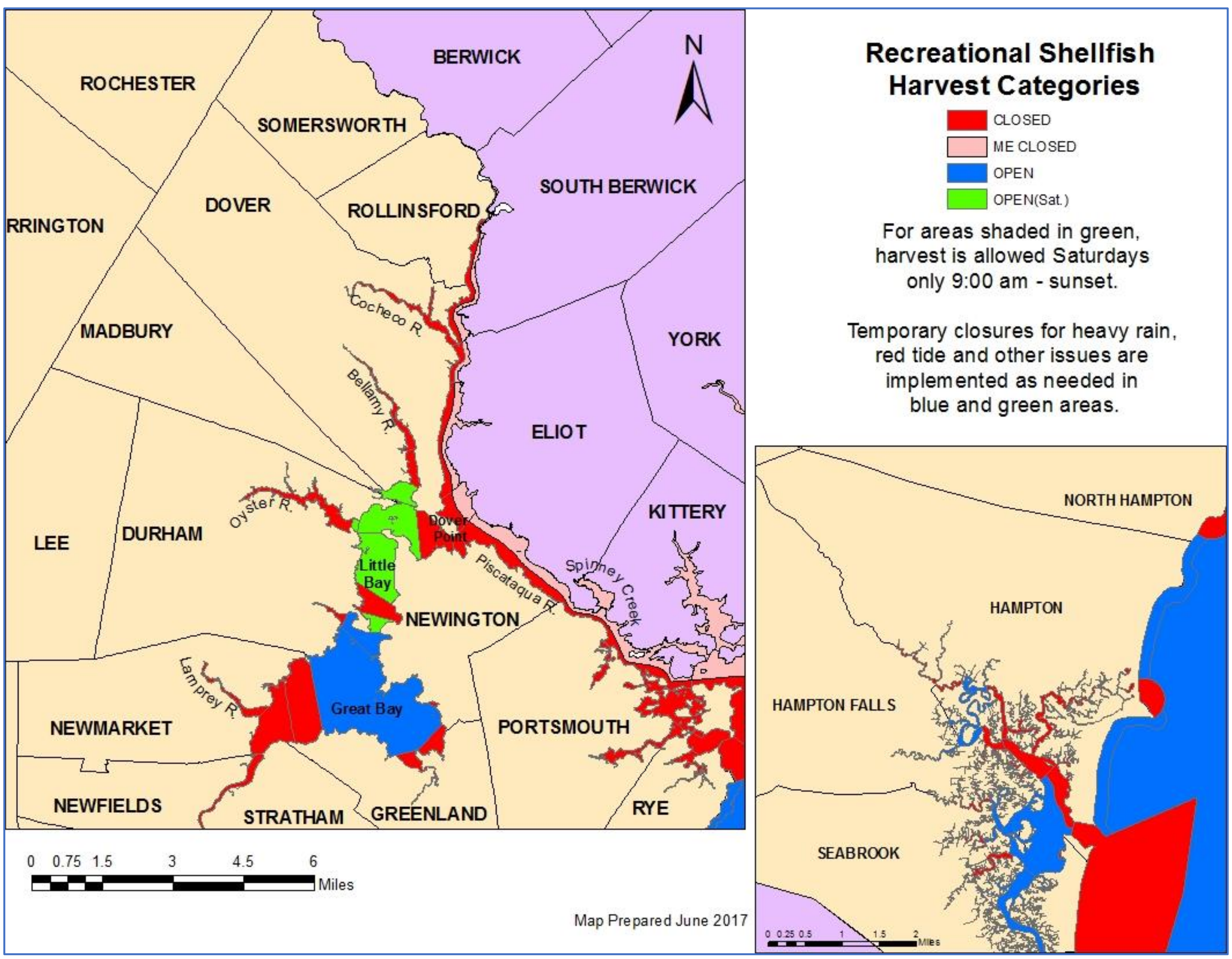

Figure SH-1. Map showing recreational shellfish harvest categories for the Great Bay and Hampton-Seabrook Estuaries. Courtesy of the NH DES Shellfish Program.

Why This Matters

Shellfish beds are closed—either temporarily or indefinitely—to commercial and recreational harvesting when there are high amounts of bacteria or other pollution in the water. Closures also occur for precautionary reasons related to wastewater treatment facilities (WWTFs). Therefore, the amount of time that shellfish beds are open for harvest can be used as an indicator of water quality.

Explanation (from 2018 State of Our Estuaries Report)

Figure SH-1 indicates open and closed areas of the Great Bay and Hampton-Seabrook Estuaries for recreational shellfish harvesting. (Note that open areas may become temporarily closed after large rain events due to water quality issues). The percentage of possible acre-days between 2012 and 2016 was 80% and 66% for the Great Bay Estuary and Hampton-Seabrook Estuaries, respectively (Figure SH-2). The Great Bay acre-days open data exhibits a saw tooth profile between 2006 and 2009, which is most likely caused by major storms, such as the Mother's Day storm of 2006. The 2016 steep decrease in the Hampton-Seabrook acre-days open data was the result of a prolonged discharge of raw sewage from a broken 14-inch force main pipe under a salt marsh in the Town of Hampton. The pipe broke in late 2015 and was fixed in early 2016. The overall long-term trend of gradual improvements since the year 2000 may reflect improved pollution source management, such as efforts by NHDES and municipalities to identify and eliminate illicit discharges. Lower rainfall amounts in recent years may also have led to a decrease in the occurrence of bacterial pollution events related to stormwater runoff.

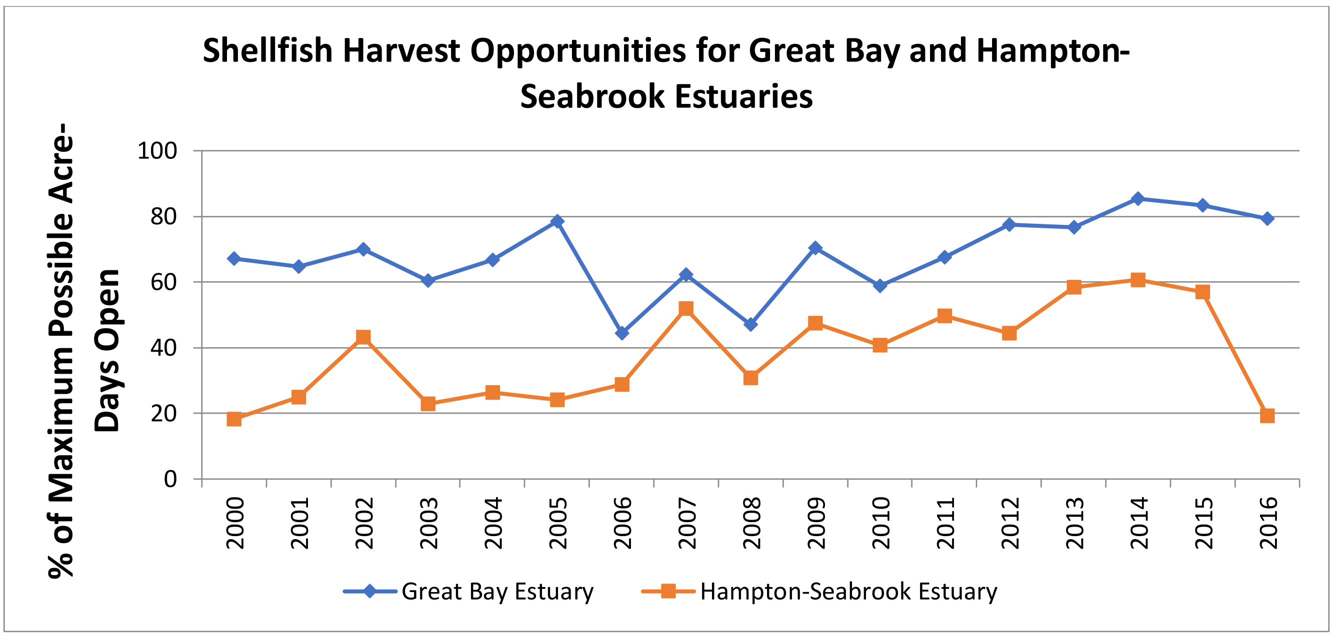

Figure SH-2. Shellfish harvest opportunities for Great Bay and Hampton-Seabrook Estuaries. The Y axis indicates the percentage of maximum possible "acre-days," which is the number of open acres multiplied by the number of days those acres were open for harvest. Data Source: NH Department of Environmental Services, Shellfish Program.

The areas designated as "conditionally approved" (open but subject to temporary closures due to water quality issues), "restricted" (closed due to chronic water quality problems) and "prohibited" (closed due to water quality issues that require further investigation) have remained fairly constant since 2004 (Figure SH-3). The most notable change occurred in 2014 with the conversion of over 1,300 acres that were "prohibited/unclassified" (closed because the water quality is unknown) to "prohibited/safety zone." This refers to areas closed due to pollution sources that may unpredictably affect the water quality of the area and create a potentially dangerous public health risk. These zones are most often related to wastewater treatment facilities.

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This 2014 conversion was a direct result of the December 2012 Portsmouth wastewater treatment facility (WWTF) dye study (Ao et al. 2017), which examined how this primary WWTF affected water quality in the estuary, and how those effects might change once the facility upgrade is complete in 2019. The dye study indicated effluent travels further up river and faster than previously determined; this resulted in the reduction of harvest opportunities at the Little Bay and Bellamy River shellfish beds (Figure SH-1). Specifically, harvest days were reduced from seven days/week to Saturdays only, from 9 a.m. to 5 p.m.; this approach gives wastewater operators and the NHDES Shellfish Program more time to react in the event of a WWTF problem that occurs overnight. (Note: aquaculture operators in Little Bay are mandated to call the NHDES Shellfish Program before harvesting and so are not impacted by the new rule).

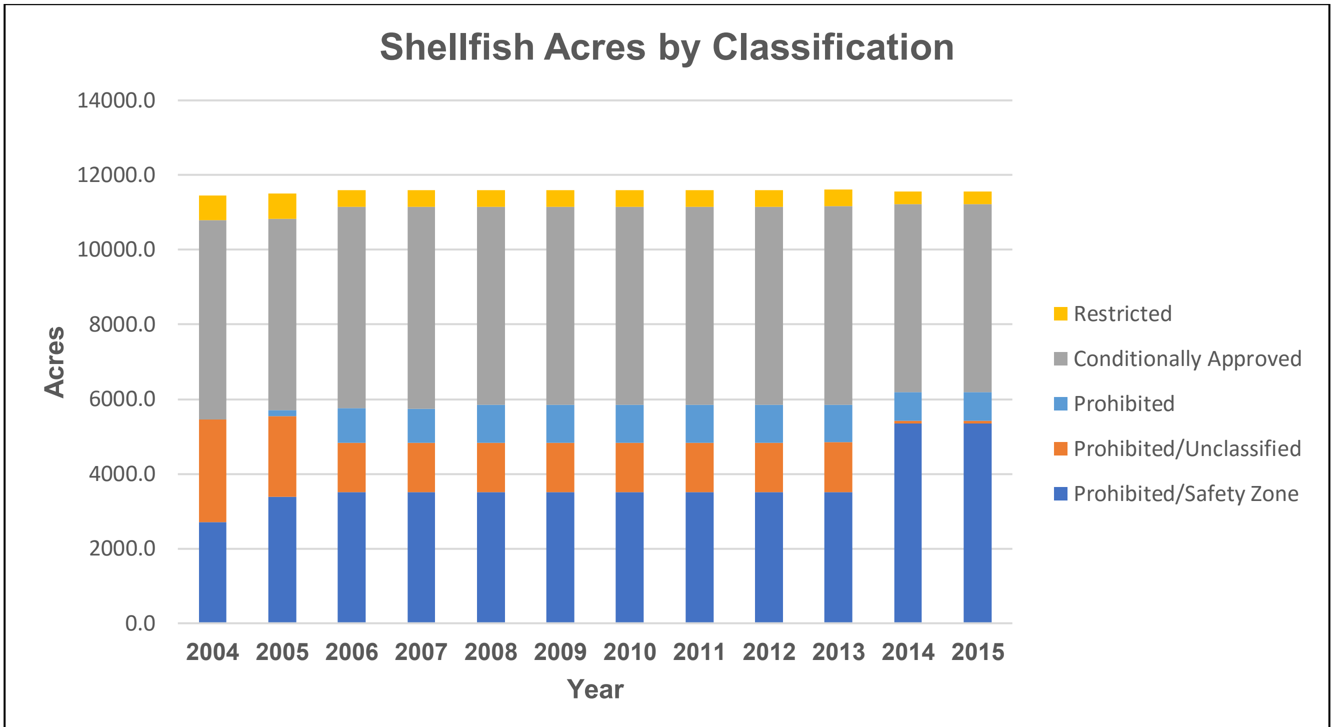

Figure SH-3: Shellfish closure acres by classification. Data Source: NH Department of Environmental Services, Shellfish Program.

Maine waters, including areas of the Piscataqua River and Spruce Creek, are also closed due to concerns about the Portsmouth WWTF. This facility is being upgraded from primary to secondary treatment, which should greatly reduce both the risk of bacterial/viral contamination during failure events as well as improve overall water quality. When the Portsmouth upgrade is complete, NHDES and Maine Department of Marine Resources will reassess the public health risks and modify harvesting classifications accordingly.

<u>Methods and Data Sources</u>
The areas of estuarine waters in each National Shellfish Sanitation Program (NSSP) classification category were compiled in a table showing the percentage of the estuarine waters in the “approved,” “conditionally approved,” “restricted,” “prohibited (unclassified),” or “prohibited (safety zone)” categories. All estuarine waters in both New Hampshire and Maine were included. Ocean waters were not included.

For areas that are classified as “approved” or “conditionally approved,” the percent of possible acre-days that were actually open for harvesting was calculated. The NHDES Shellfish Program measures the opportunities for shellfish harvesting using “acre-days,” which is the product of the acres of shellfish growing waters and the amount of time that these waters are open for harvest. The acre-days indicator is reported as a percentage of the total possible acre-days of harvesting for the year; (this total does not include days when harvesting is not allowed during the summer oyster reproductive season).

In the past, results for this indicator were reported for five regions: Great Bay, Upper Little Bay, Lower Little Bay, Little Harbor, and Hampton-Seabrook Harbor. For this reporting period, only Great Bay and Hampton Harbor are included, so that the indicator better represents actual water quality issues, rather than the risk of water quality issues. (See "Changes in Policy Versus Changes in Water Quality" section below.)

Data Sources
The acres of estuarine waters in each NSSP classification and the acre-days of harvesting potential for the estuary were taken from annual reports by the NHDES Shellfish Program (http://des.nh.gov/organization/divisions/water/wmb/shellfish/index.htm) and Maine Department of Marine Resources (http://www.maine.gov/dmr/rm/public_health/G_A_reports/index.htm). Shellfish growing area classifications and harvest closures are determined by NHDES and Maine DMR following protocols from NSSP (2017).

Technical Advisory Committee (TAC) Discussion Highlights

As part of the January 2017 TAC meeting, participants discussed some of the most salient issues related to shellfish harvesting opportunities (PREP 2017c). Complete notes are available at: http://prepestuaries.org/prep-technical-advisory-committee/

Changes in Policy Versus Changes in Water Quality
The TAC noted that this indicator is complex since it captures changes in both water quality as well as policy changes, usually around perceptions of risk related to unforeseen incidents at WWTFs. Several TAC members suggested modifications so that changes in perceptions of risk wouldn't be confused with changes in actual water quality.

For example, it was noted that the number of acre-days for Upper and Little Bay as well as Little Harbor decreased dramatically after the Portsmouth WWTF Dye Study (Ao et al. 2017). However, this does not indicate actual decreases in water quality, but rather a heightened understanding of potential public health dangers if a facility failure (in the disinfection system) should occur. Therefore, it was determined that the acre-day data and graph (Figure SH-2) should focus on areas where "safety zone" prohibitions were not in effect. In this way, the indicator would reflect water quality issues only. Moreover, by showing both SH-2—focused on acre-days related water quality issues—as well as SH-3, focused on changes in policy closures, the public can obtain a broader perspective on real and potential water quality issues.

Clarifications Regarding the Portsmouth Wastewater Treatment Plant
TAC discussions clarified current versus projected water quality issues as it relates to the Portsmouth WWTF. Construction on the facility upgrade began in 2017 and initial phases are scheduled to be finished in 2019, with all phases complete in 2020. Before the upgrade, the Portsmouth facility operated with a disinfection system that keeps bacteria concentrations very low (fecal coliform counts less than 14 colony forming units per 100 ml), when the system is working properly. Precautionary "safety zone" closures are related to potential disinfection failures; there have been only 2 failures in the last two decades.

After the upgrade, the Portsmouth WWTF will be a functioning advanced secondary facility and wastewater will receive more extensive treatment for longer periods of time. This will greatly diminish both bacteria and virus counts, regardless of the status of the disinfection system. As noted earlier, once the Portsmouth upgrade is complete, the Shellfish Program will re-evaluate its shellfish area designations.

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Indicator: Beach Advisories

Question

How many times did beach advisory days occur on public tidal beaches in the NH and Maine Piscataqua Region due to bacterial pollution, and have beach advisory days changed over time?

Short Answer

Across the 17 tidal beaches in the Piscataqua Region watershed, beach advisory days occurred less than 1% of beach-days from 2012 to 2016. There are no statistically significant trends.

PREP Goal

Less than 1% of beach-days over the summer season affected by advisories due to bacteria pollution (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

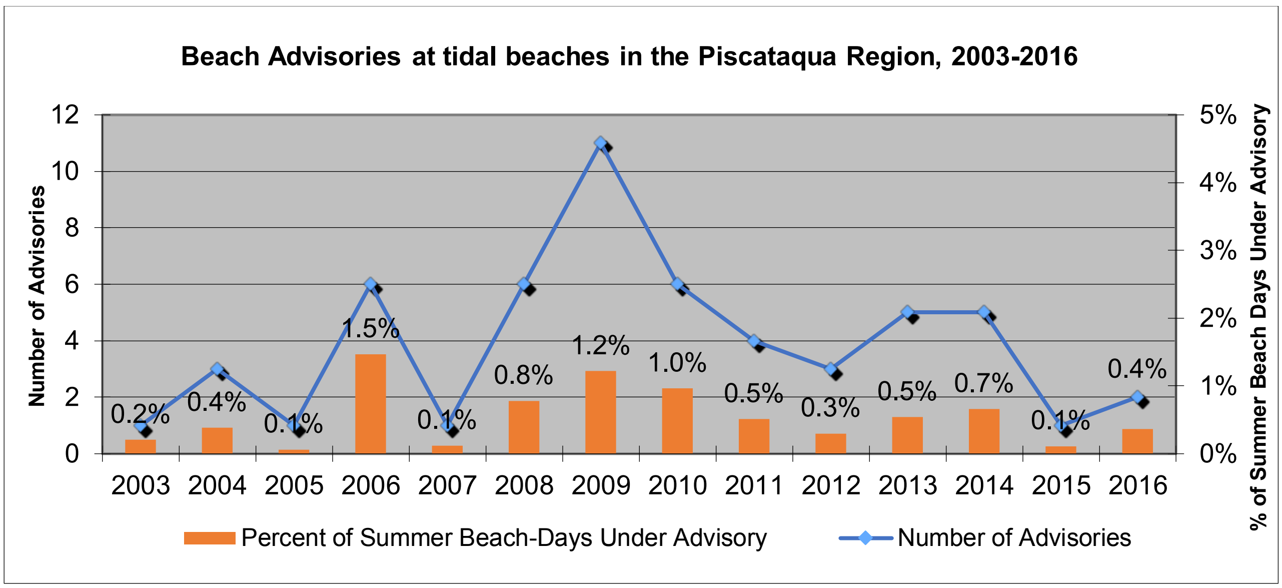

Figure BA-1. Advisories at tidal beaches in the Piscataqua Region 2003-2016. Beach days are calculated based on days between Memorial Day and Labor Day each year. Data Source: NH Dept. of Environmental Services and Maine Dept. of Environmental Protection.

Why This Matters

Beach advisories are an indicator of water quality overall and they are a particularly important measure of the health and safety of the region's popular recreational areas. Beach areas in the region supply vital economic benefits from the tourist economy. Advisories are issued by the New Hampshire Beach Inspection program and the Maine Healthy Beaches program when bacteria water quality samples do not meet state and federal standards for swimming.

Explanation (from the 2018 State of Our Estuaries Report)

The Atlantic coast is home to 17 public tidal beaches in the Piscataqua Region. At these beaches, between 1 and 11 advisories have been issued per year since 2003. Advisories between 2003 and 2016 have affected 130 of 23,373 beach summer days (0.06%). The most advisories occurred in 2009 with 11 advisories affecting six beaches for a total of 23 days (1.2% of total beach-days) (Figure BA-1). In 2016, North Hampton State Beach had two advisories for a total of six days (0.4% of beach-days). A 2014 report by the Natural Resource Defense

Council ranked New Hampshire beaches as the second cleanest out of 30 states (NRDC 2014). During 2012-2016, NH and ME tidal beaches in the region continue to meet PREP's goal of beach advisories affecting <1% of beach-days each summer.

Methods and Data Sources

The advisories at all tidal bathing beaches in New Hampshire and Maine that are within the Piscataqua Region watershed were compiled for each year. Currently, the list of beaches includes all tidal beaches monitored by NHDES and the Fort Foster beach monitored by Maine Healthy Beaches (Figure BA-2). Only advisories due to water quality contamination were included. For each advisory, the number of days that the advisory was in effect was calculated and then the total number of beach advisory days were calculated for the year. The number of advisories were summed for each year and then compared to the number of beach days between Memorial Day and Labor Day (number of days multiplied by the number of beaches monitored).

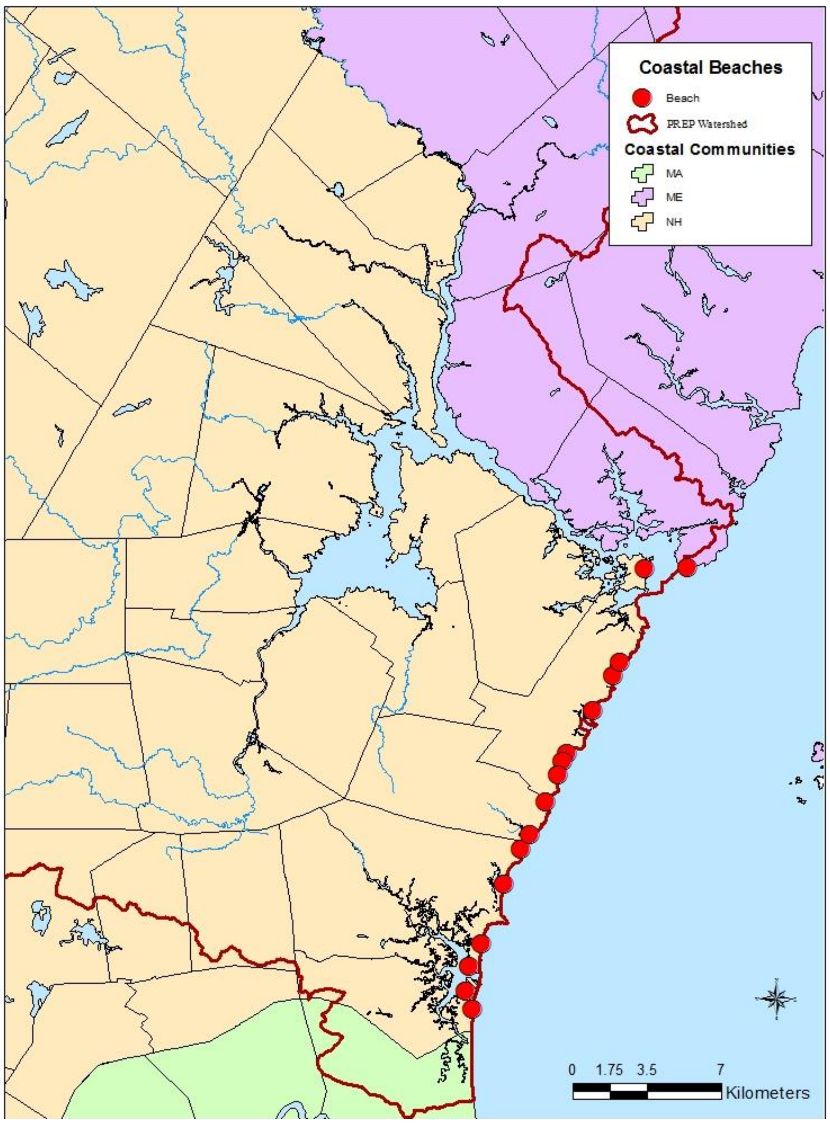

Figure BA-2. Map of Piscataqua Region watershed beaches that are monitored as part of the "Beach Advisories" indicator.

Data Sources
Records of beach postings are available from the NHDES Beach Program and from the Maine Healthy Beaches Program. The NHDES Beach Program and the Maine Healthy Beaches Program review the water quality results for each beach and make a determination whether or not to recommend posting.

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NRDC. 2014. Testing the Waters: A Guide to Water Quality at Vacation Beaches – Executive Summary. Natural Resources Defense Council. https://www.nrdc.org/sites/default/files/ttw2014_Executive_Summary.pdf

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Indicator: Toxic Contaminants in the Great Bay and Hampton-Seabrook Estuaries

Question

How much toxic contamination is in shellfish tissue and how has it changed over time?

Short Answer

Most concentrations of measured metals and organic chemicals in blue mussel tissue from 1991-2014 are declining or not changing. Mercury and PCB levels remain high enough to merit continued concern. Many new contaminants have been introduced to the estuary, such as pharmaceuticals, perfluorinated compounds and brominated flame retardants, and they are not being consistently monitored.

PREP Goal
Zero percent of sampling stations in the two estuaries have shellfish tissue concentrations that exceed levels of concern and no increasing trends for any contaminants (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

Why This Matters

Toxic and persistent contaminants such as PCBs (polychlorinated biphenyls), mercury, and DDT (dichloro-diphenyltrichloroethane) can accumulate in the tissue of filter-feeding mussels, clams, oysters and other marine biota and seafood. Tracking contamination in mussel tissue offers insight into changes in contaminant levels in our estuarine and coastal ecosystems.

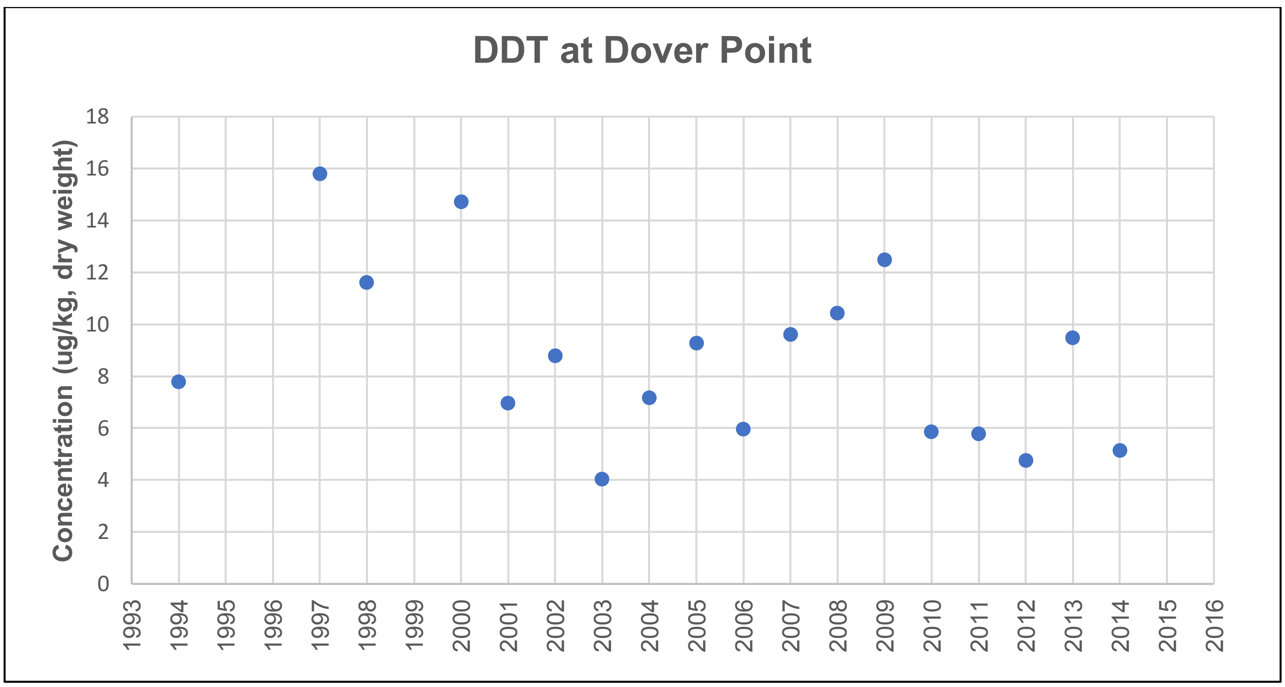

Figure TC-1. Concentrations of DDT in mussel tissue at Dover Point. The most recent national median for the Mussel Watch program was 30ug/kg. The 85th percentile was 130ug/kg. Data Source: Gulfwatch Program (LeBlanc et al. 2009).

Explanation (from 2018 State of Our Estuaries Report)

The Gulfwatch Program uses blue mussels (*Mytilus edulis*) to better understand trends in the accumulation of toxic and persistent contaminants, including metals, pesticides, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). The use of many of these contaminants has been banned or is limited, so

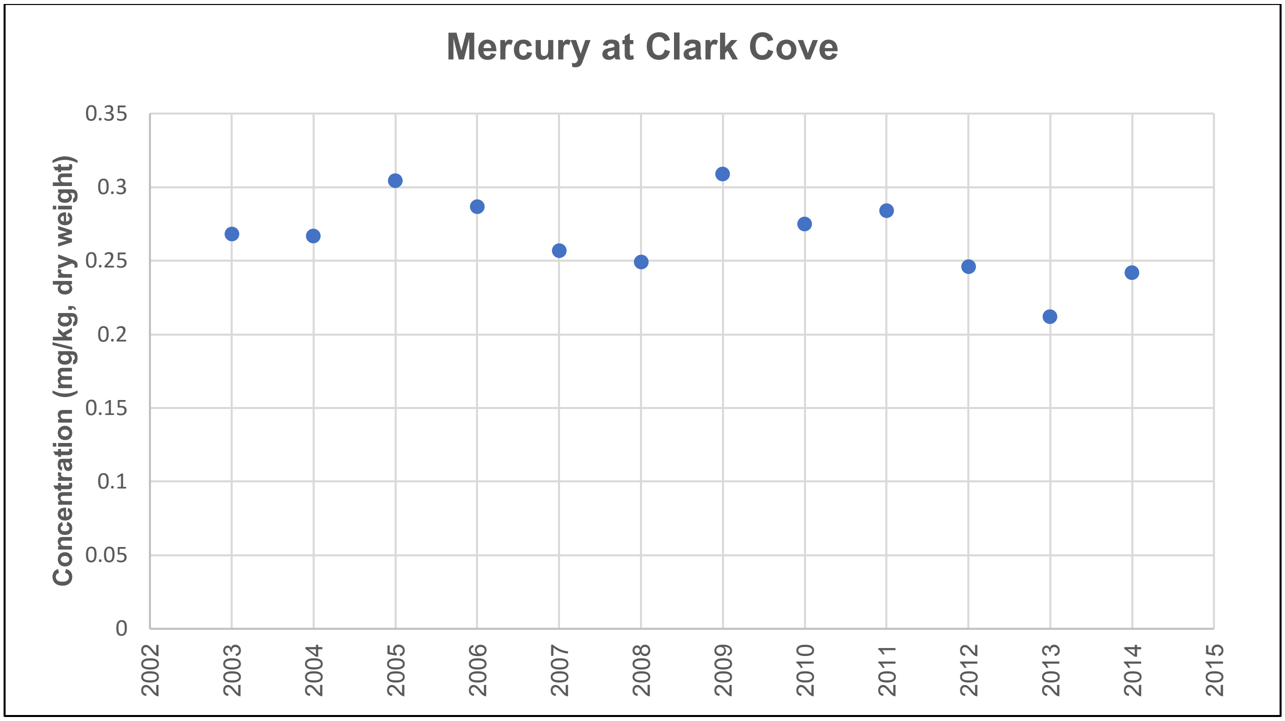

Figure TC-2. Concentrations of Mercury in mussel tissue at Clark Cove, Portsmouth Harbor. The most recent national median for the Mussel Watch program was 0.7mg/kg. The 85th percentile was 0.13mg/kg. Data Source: Gulfwatch Program (LeBlanc et al. 2009).

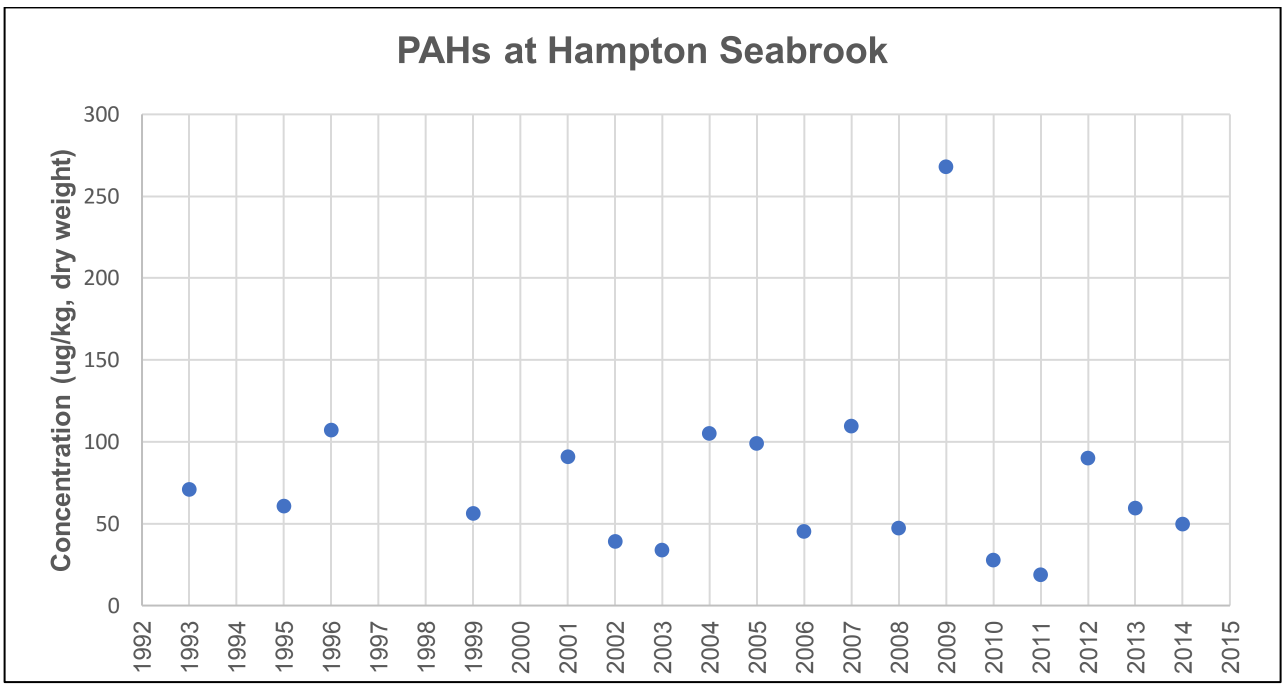

Figure TC-3. Concentration of PAHs at Hampton-Seabrook Harbor. In 2008, the national median for the Mussel Watch program was 250 ug/kg. The 85th percentile was 1250 ug/kg. Data Source: Gulfwatch Program (LeBlanc et al. 2009).

trends are expected to be stable or decreasing. At Dover Point, concentrations of DDT, an insecticide banned in the U.S. in 1972, are relatively low and gradually decreasing (Figure TC-1). Inputs of mercury, a heavy metal, have been reduced since the 1990s due to regulatory action taken on coal-fired power plants, medical waste and municipal incinerators, but mercury continues to be deposited through wet and dry atmospheric deposition (NEIWPCC 2007). At most sites, including Clark Cove in Portsmouth Harbor, mercury levels in shellfish have been fairly stable since 2003 (Figure TC-2), these levels are similar to those seen in other estuaries located close to urban centers (Sunderland et al. 2012). PAHs, which mostly come from oils spills, the burning of fossil fuels and some driveway sealants, have been stable across all stations, including Hampton- Seabrook. Only one value was above the national median level of 250 ug/kg (Figure TC-3). Other data collected at that time indicate a possible fuel spill (PREP 2009). Trend lines are not shown as there were no statistically significant results.

PAHs, DDT and mercury at these three stations—Dover Point, Clark Cove and Hampton-Seabrook— are generally representative of the trends in the more comprehensive dataset, which includes over 120 different specific contaminants. Even measuring these 120 contaminants, however, does not provide a comprehensive picture of the level of toxic contamination in our estuaries. Many new contaminants have been introduced to the estuary, such as pharmaceuticals, perfluorinated compounds and brominated flame retardants, and they are not being consistently monitored.

<u>Methods and Data Sources</u>

Each blue mussel tissue sample consisted of either four measurements from replicate subsamples and/or a composite sample from samples collected at four distinct areas at the sample site. Trends were evaluated at the three benchmark sites in the estuary: MECC (Clark Cove, Portsmouth Harbor), NHDP (Dover Point) and NHHS (Hampton-Seabrook Harbor). In 2008, the Gulfwatch program changed the sample design from collecting four replicates at each station to collecting three replicates plus one composite of the three replicates. Funding limitations in recent years only allowed for the analysis of composite samples and replicate samples at select sites. The averages from all results (replicates and composites) for each parameter were regressed against the year of collection using a linear model. Linear coefficients with a probability of <0.05 of being different from zero were considered statistically significant.

For details on data collection and lab analysis, see Wood (2015) at: http://scholars.unh.edu/prep/357/

Data Sources

Originally conducted by the Gulf of Maine Council on the Marine Environment from 1993 to 2011, the Gulfwatch Program examined trends in the water quality of the Gulf of Maine by monitoring toxic contaminant concentrations in the tissues of shellfish. In 2012, after the Gulfwatch program was discontinued, PREP and partners such as NOAA, NHDES and the UNH Jackson Estuarine Laboratory have worked to continue this program in the Piscataqua Region. For this report, data are only presented up to 2014. It is anticipated that data from 2015 and future years will be included in the 2023 State of Our Estuaries Report.

<u>Additional Results (Beyond the Data Reported in the SOOE)</u>

Table TC-1 indicates that of the 39 indicators (13 at each of three stations), 19 fell in the “no significant trend” category, 19 were in the “decreasing” category and only one was categorized as “increasing” (cadmium at Hampton Harbor). Compared with the last report (reporting on data through 2011, as opposed to 2014), 9 indicators were added to the “decreasing” category, changed from “no significant trend,” and one indicator (iron at Hampton Harbor) went from “increasing” to “no significant trend”). At Clark Cove, PCBs went from “decreasing” to “no significant trend” due to three years of elevated results. No indicators were added to the “increasing” category.

Figures TC-4 through TC-42 show individual plots of all 39 indicators.

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Table TC-1: Trends in contaminant concentrations in mussel tissue in Clark Cove, Portsmouth Harbor ("MECC"), Dover Point ("NHDP") and Hampton Harbor ("NHHS"), 1993-2014.

Station	Parameter	Period	Trend
MECC (Portsmouth Harbor)	ALUMINUM	1993 - 2014	No significant trend
	CADMIUM	1993 - 2014	No significant trend
	CHROMIUM	1993 - 2014	**Decreasing**
	COPPER	1993 - 2014	No significant trend
	IRON	1993 - 2014	No significant trend
	LEAD	1993 - 2014	**Decreasing**
	MERCURY	2003 - 2014	No significant trend
	NICKEL	1993 - 2014	**Decreasing**
	SILVER	2003 - 2014	**Decreasing**
	ZINC	1993 - 2014	No significant trend
	DDT, TOTAL	1993 - 2014	**Decreasing**
	PAH, TOTAL	1993 - 2014	No significant trend
	PCB, TOTAL	1993 - 2014	No significant trend
NHDP Dover Point	ALUMINUM	1994 - 2014	No significant trend
	CADMIUM	1994 - 2014	**Decreasing**
	CHROMIUM	1994 - 2014	**Decreasing**
	COPPER	1994 - 2014	No significant trend
	IRON	1994 - 2014	**Decreasing**
	LEAD	1994 - 2014	**Decreasing**
	MERCURY	2003 - 2014	No significant trend
	NICKEL	1994 - 2014	**Decreasing**
	SILVER	2003 - 2014	**Decreasing**
	ZINC	1993 - 2014	**Decreasing**
	DDT, TOTAL	1993 - 2014	No significant trend
	PAH, TOTAL	1993 - 2014	No significant trend
	PCB, TOTAL	1993 - 2014	No significant trend
NHHS (Hampton Harbor)	ALUMINUM	1993 - 2014	No significant trend
	CADMIUM	1993 - 2014	**Increasing**
	CHROMIUM	1993 - 2014	**Decreasing**
	COPPER	1993 - 2014	No significant trend
	IRON	1993 - 2014	No significant trend
	LEAD	1993 - 2014	**Decreasing**
	MERCURY	2003 - 2014	No significant trend
	NICKEL	1993 - 2014	**Decreasing**
	SILVER	2003 - 2014	**Decreasing**
	ZINC	1993 - 2014	**Decreasing**
	DDT, TOTAL	1993 - 2014	**Decreasing**
	PAH, TOTAL	1993 - 2014	No significant trend
	PCB, TOTAL	1993 - 2014	**Decreasing**

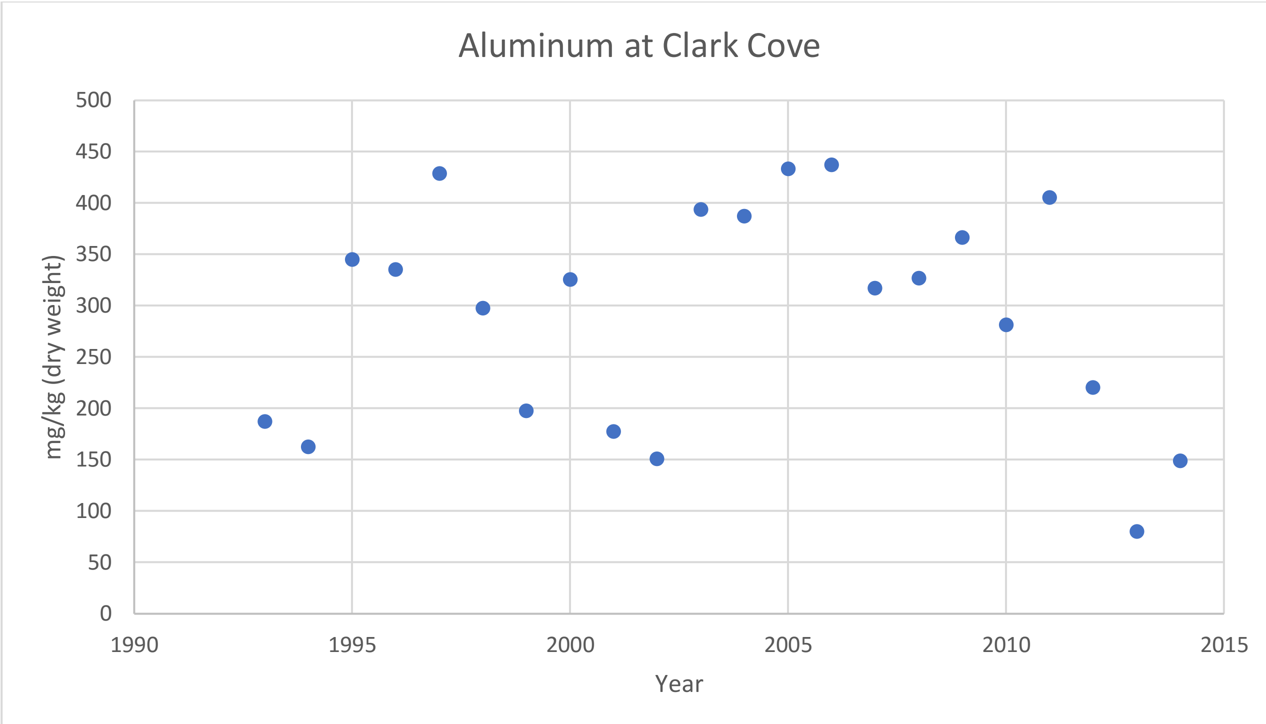

Figure TC-4: Aluminum concentrations in mussel tissue at Clark Cove, Portsmouth Harbor.

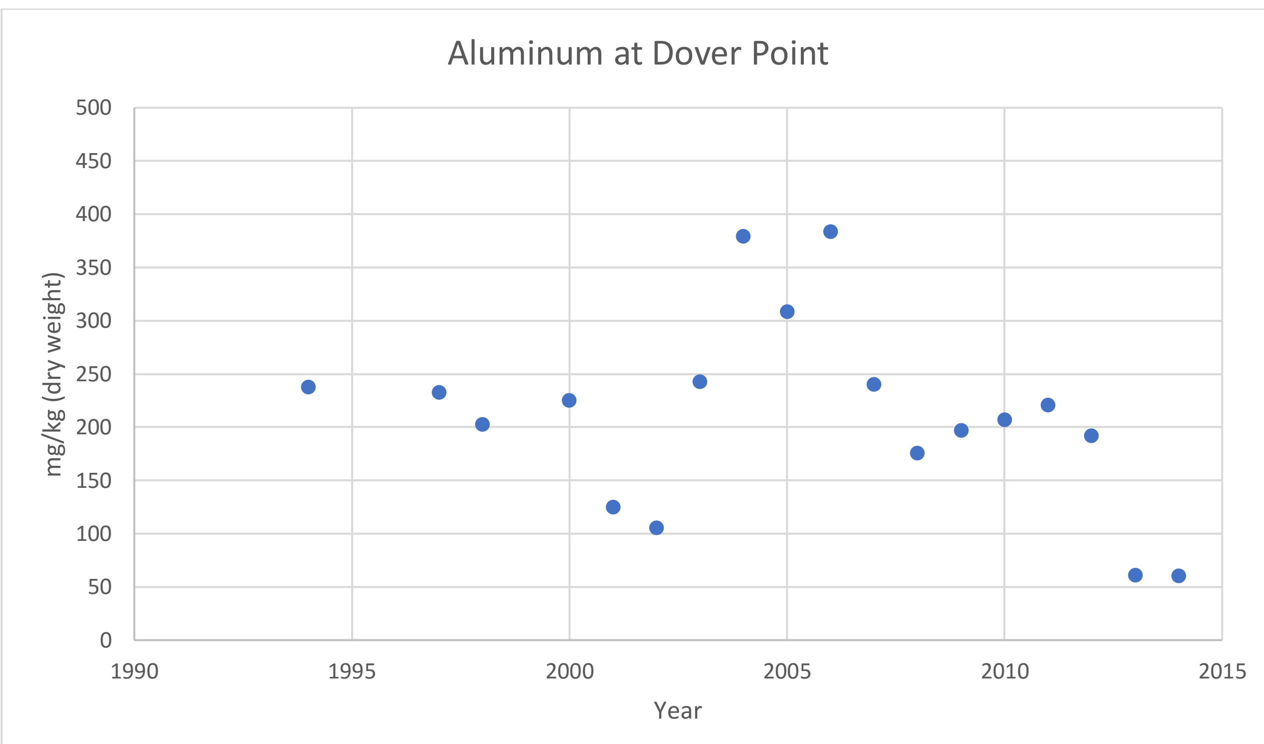

Figure TC-5: Aluminum concentrations in mussel tissue at the Dover Point station.

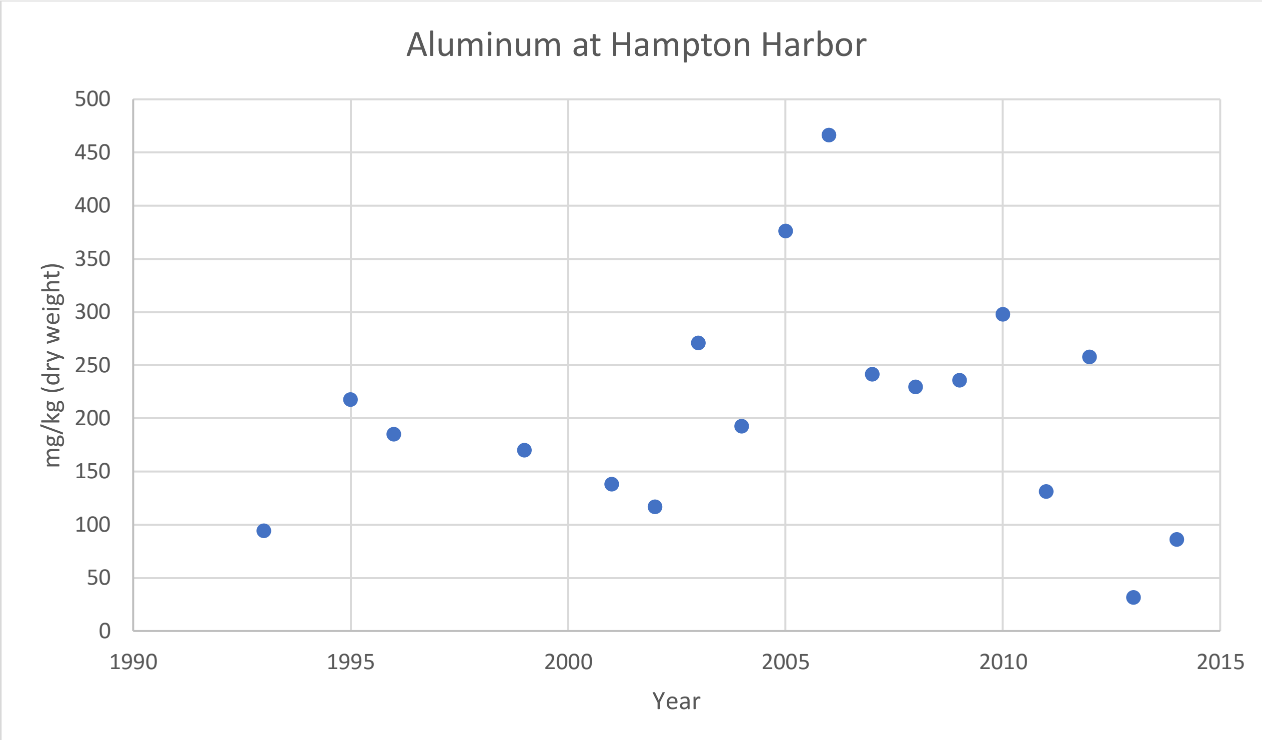

Figure TC-6: Aluminum concentrations in mussel tissue at the Hampton Harbor station.

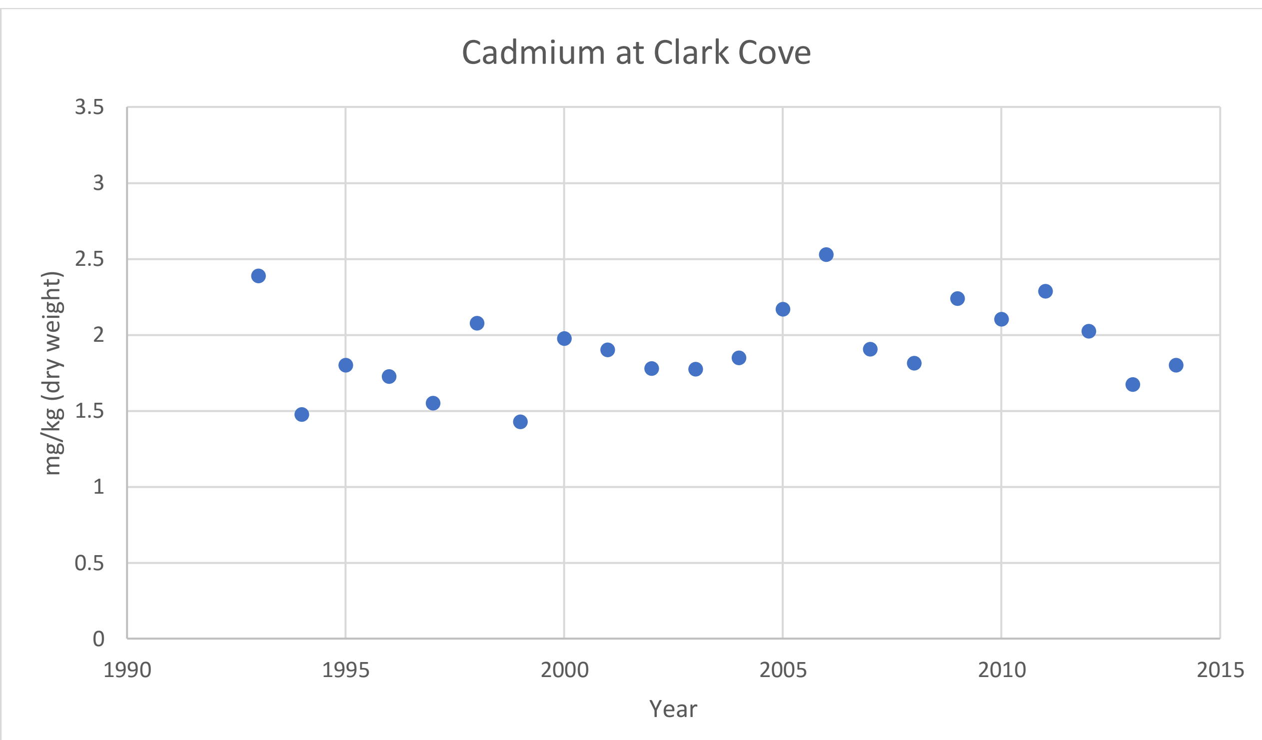

Figure TC-7: Cadmium concentrations in mussel tissue at the Clark Cove station, Portsmouth Harbor.

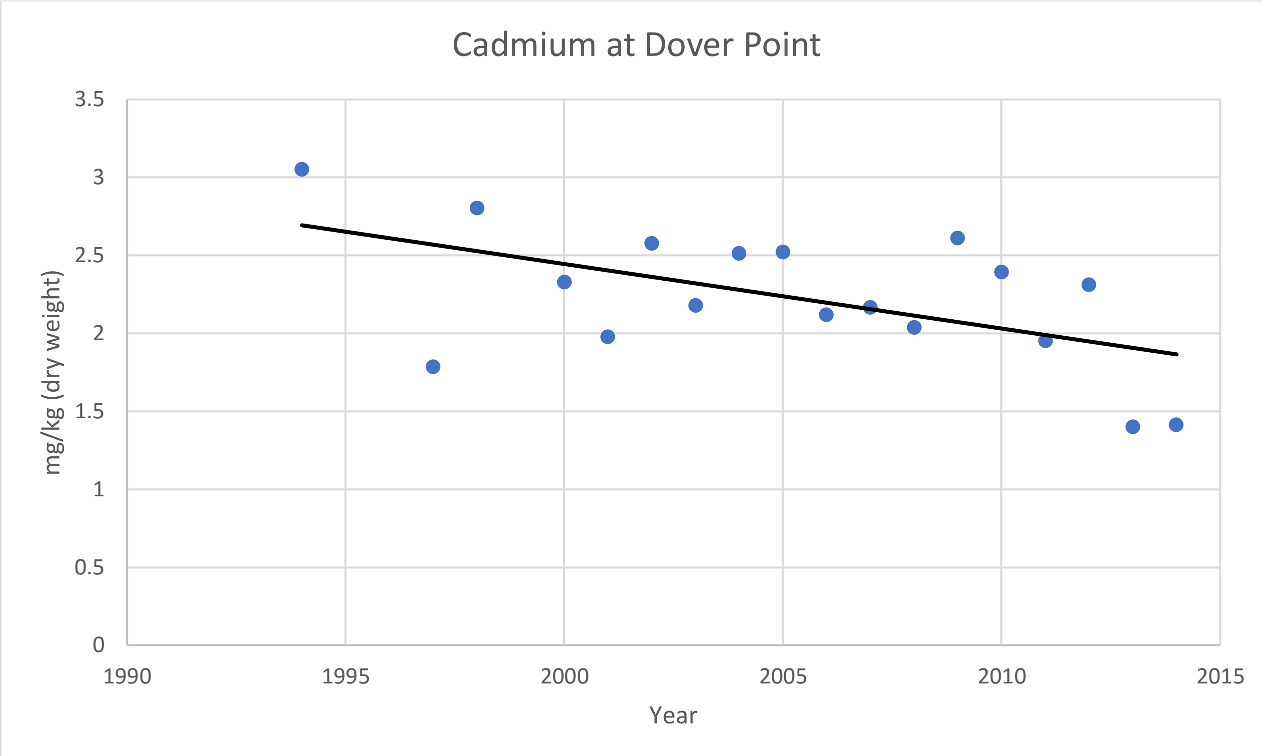

Figure TC-8: Cadmium concentrations in mussel tissue at the Dover Point station. Trendline indicates statistically significant trend.

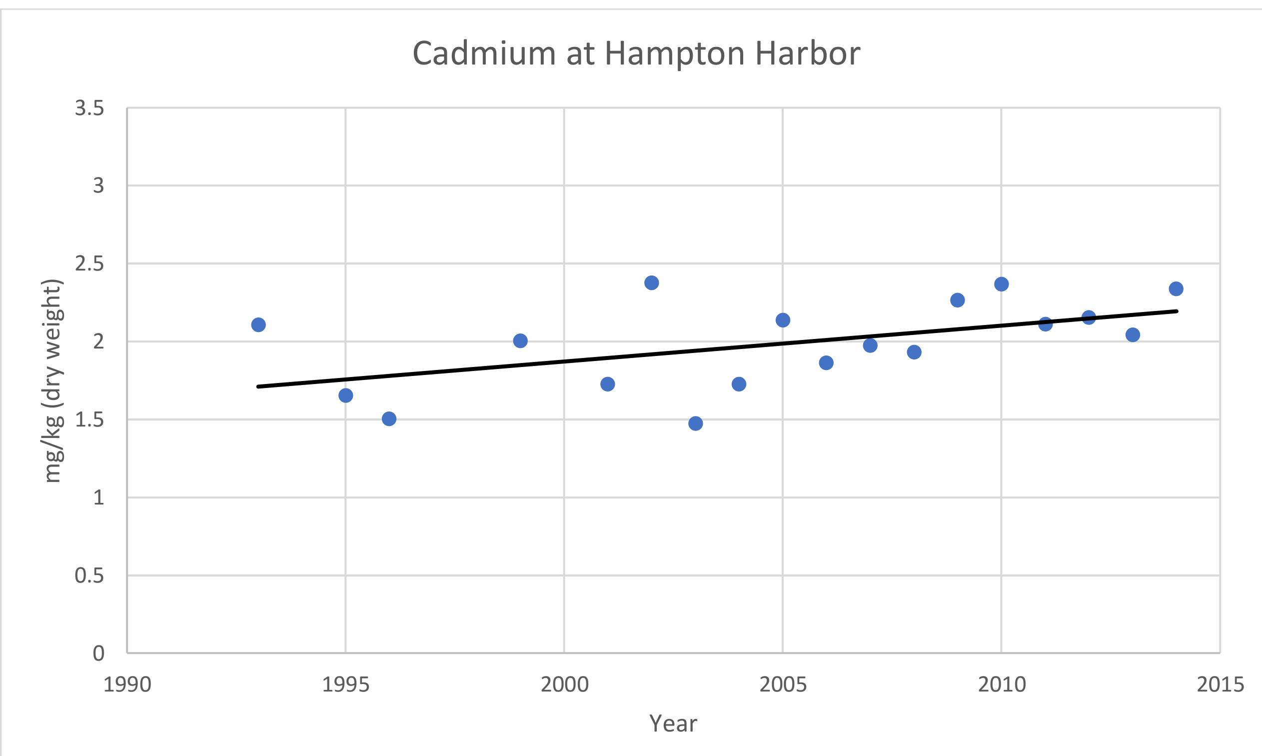

Figure TC-9: Cadmium concentrations in mussel tissue at the Hampton Harbor station. Trendline indicates statistically significant trend.

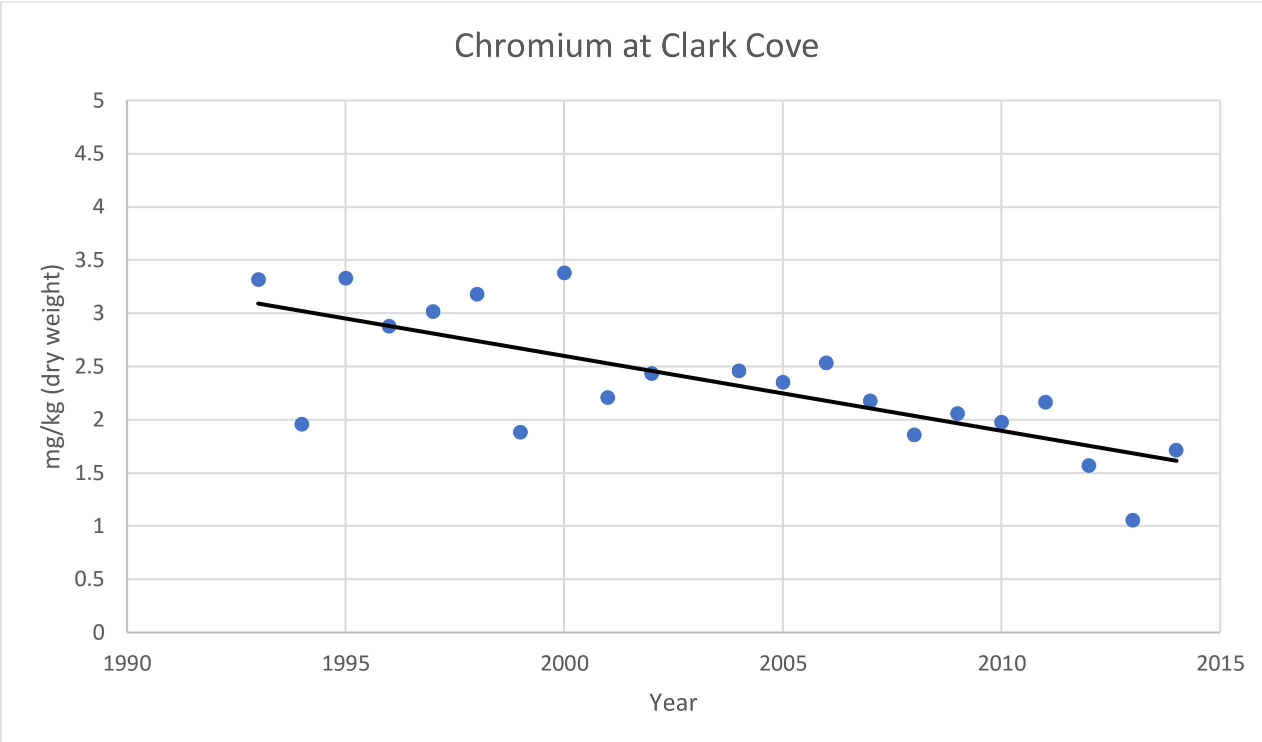

Figure TC-10: Chromium concentrations in mussel tissue at the Clark Cove station, Portsmouth Harbor. Trendline indicates statistically significant trend.

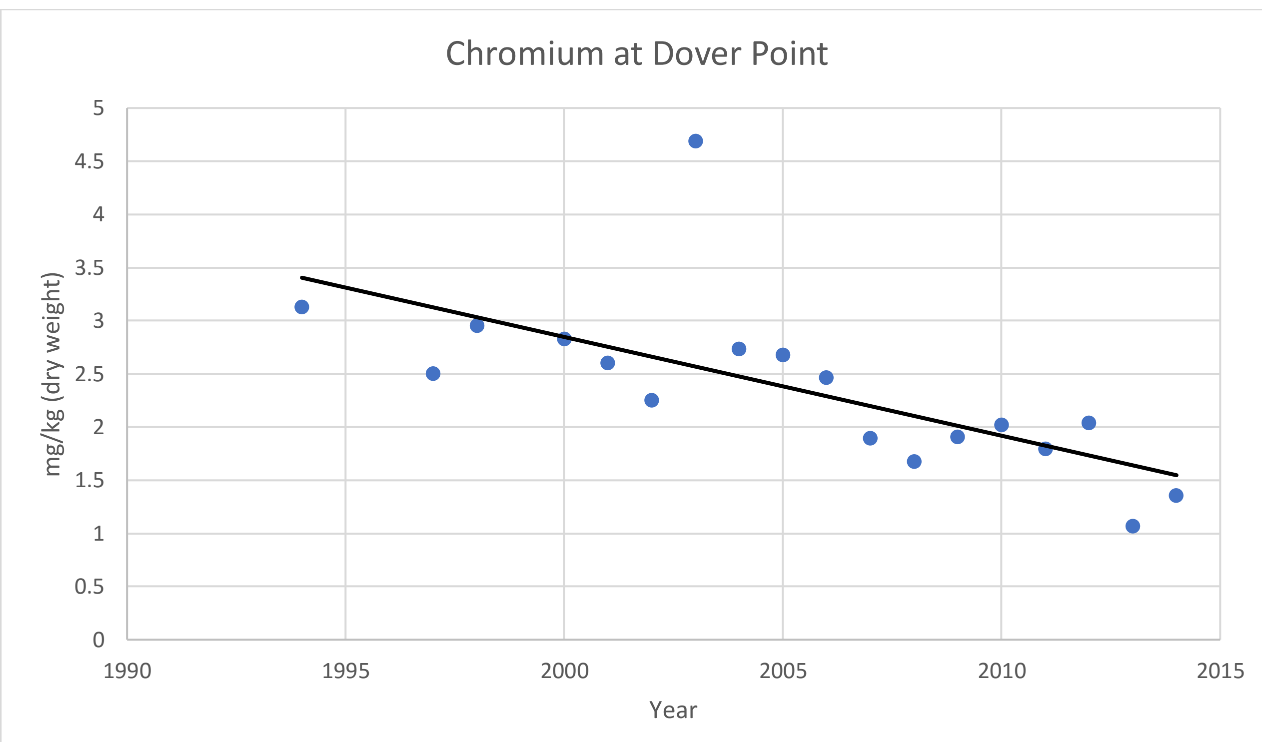

Figure TC-11: Chromium concentrations in mussel tissue at the Dover Point station. Trendline indicates statistically significant trend.

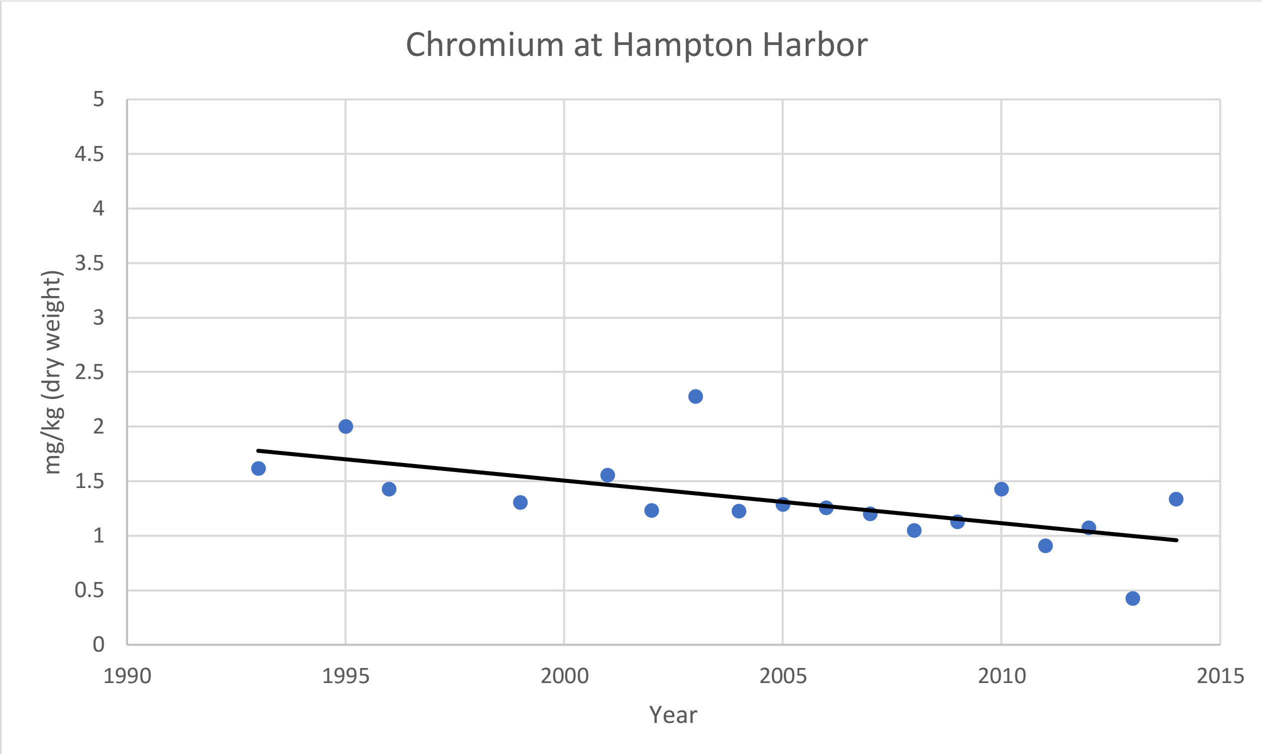

Figure TC-12: Chromium concentrations in mussel tissue at the Hampton Harbor station. Trendline indicates statistically significant trend.

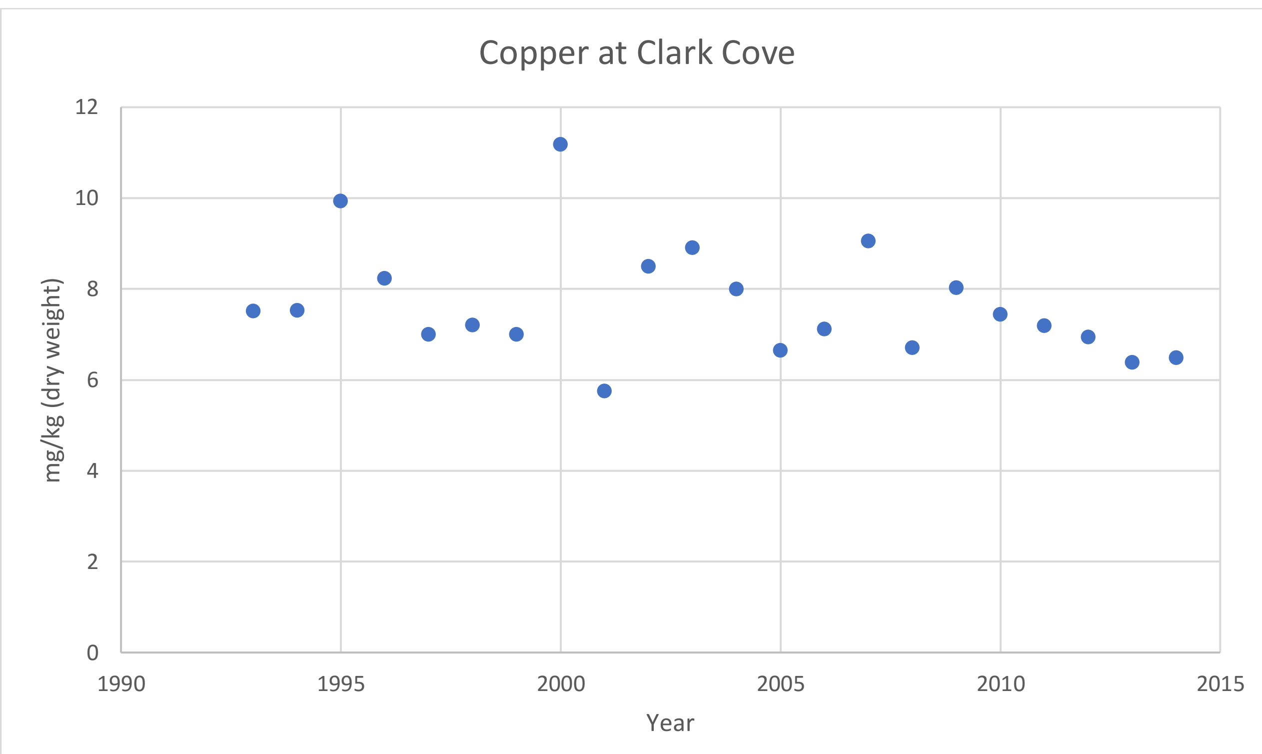

Figure TC-13: Copper concentrations in mussel tissue at the Clark Cove station, Portsmouth Harbor.

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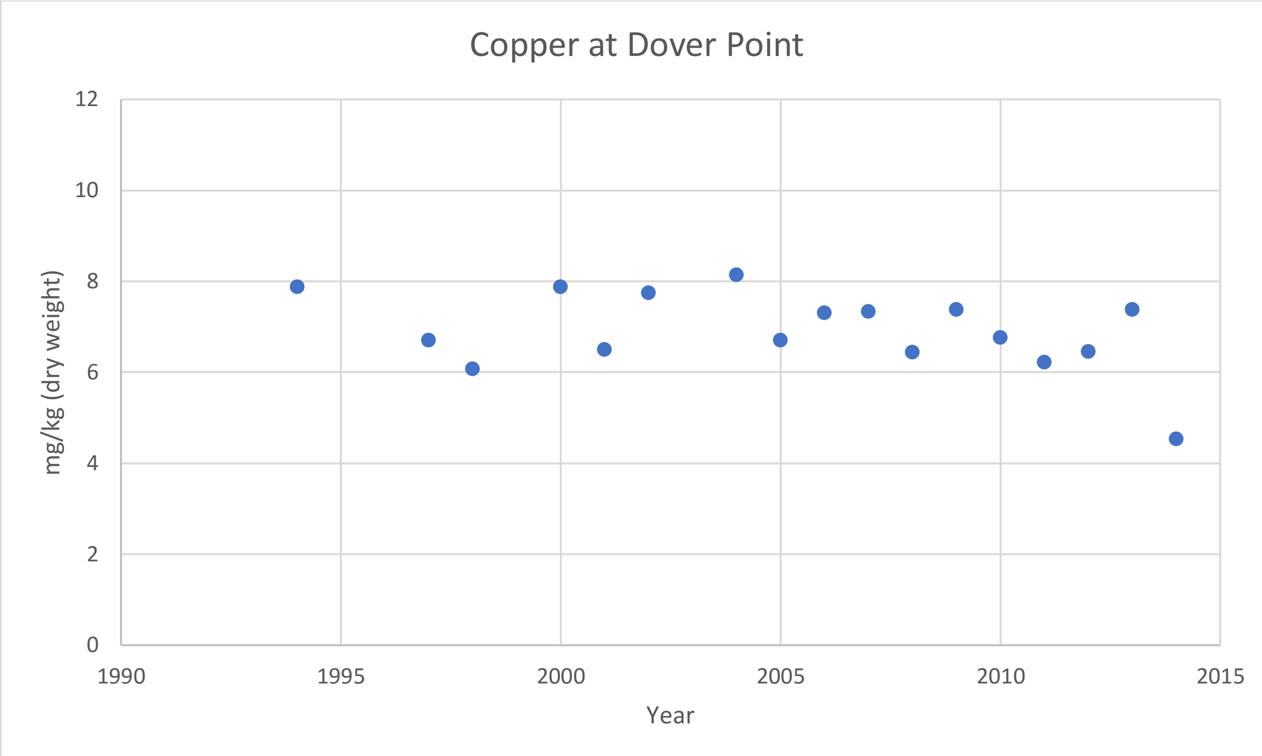

Figure TC-14: Copper concentrations in mussel tissue at the Dover Point station.

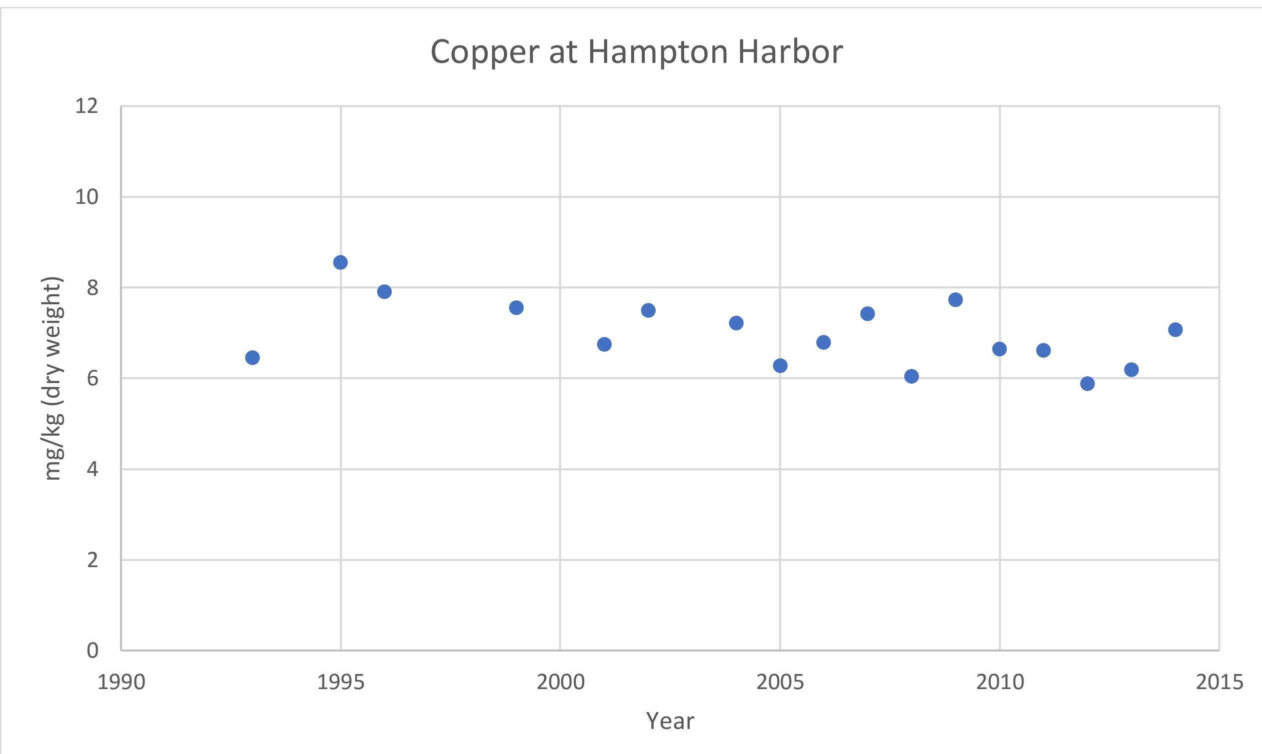

Figure TC-15: Copper concentrations in mussel tissue at the Hampton Harbor station.

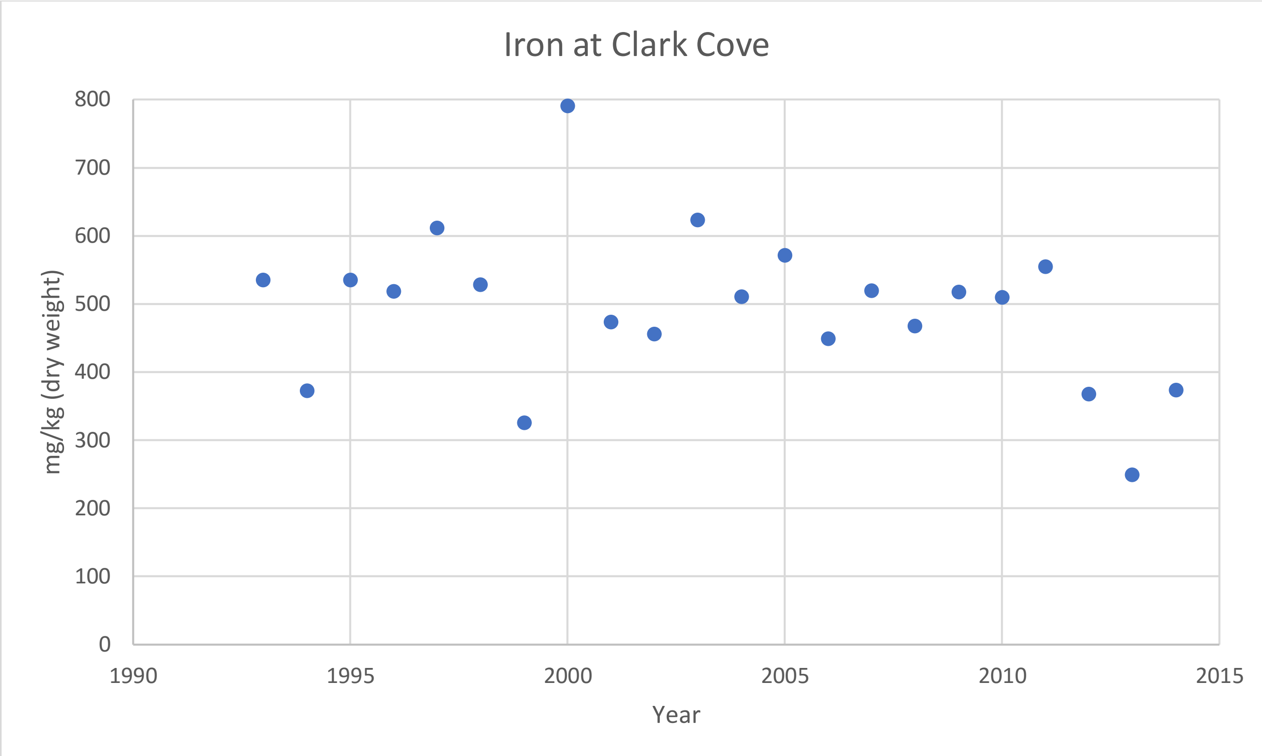

Figure TC-16: Iron concentrations in mussel tissue at the Clark Cove station, Portsmouth Harbor.

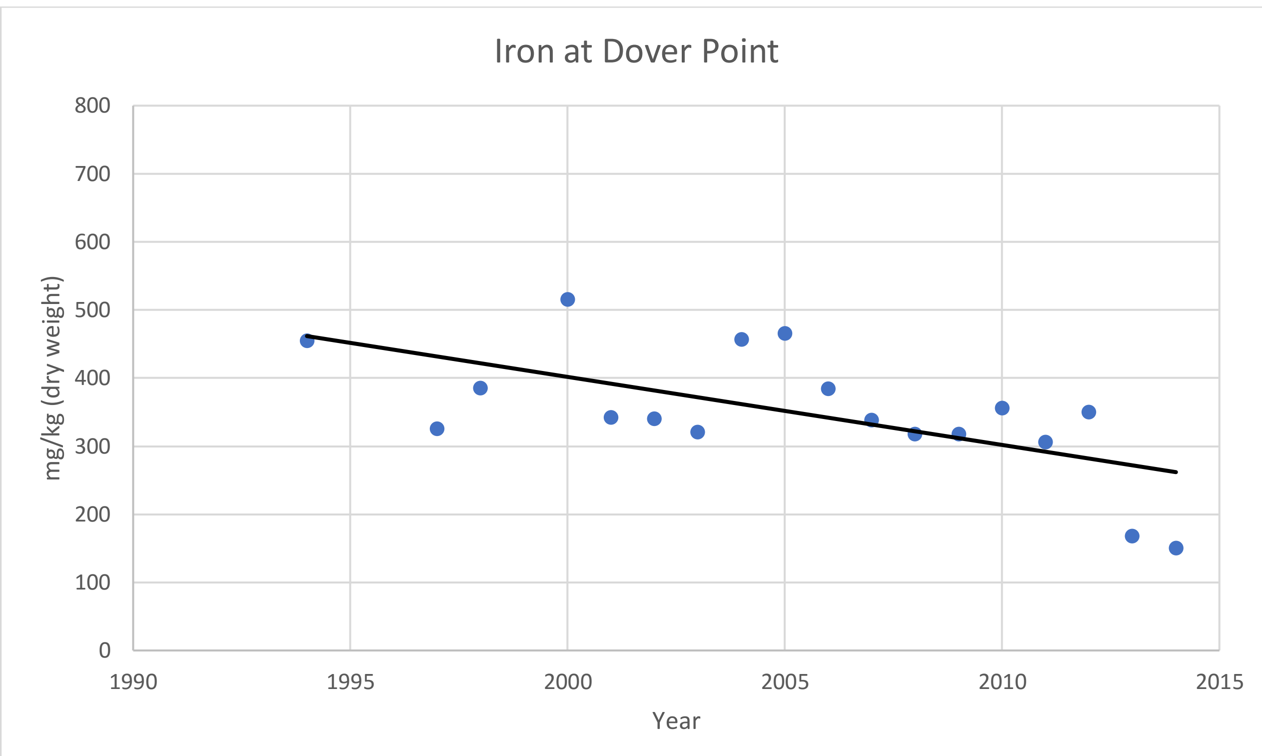

Figure TC-17: Iron concentrations in mussel tissue at the Dover Point station. Trendline indicates statistically significant trend.

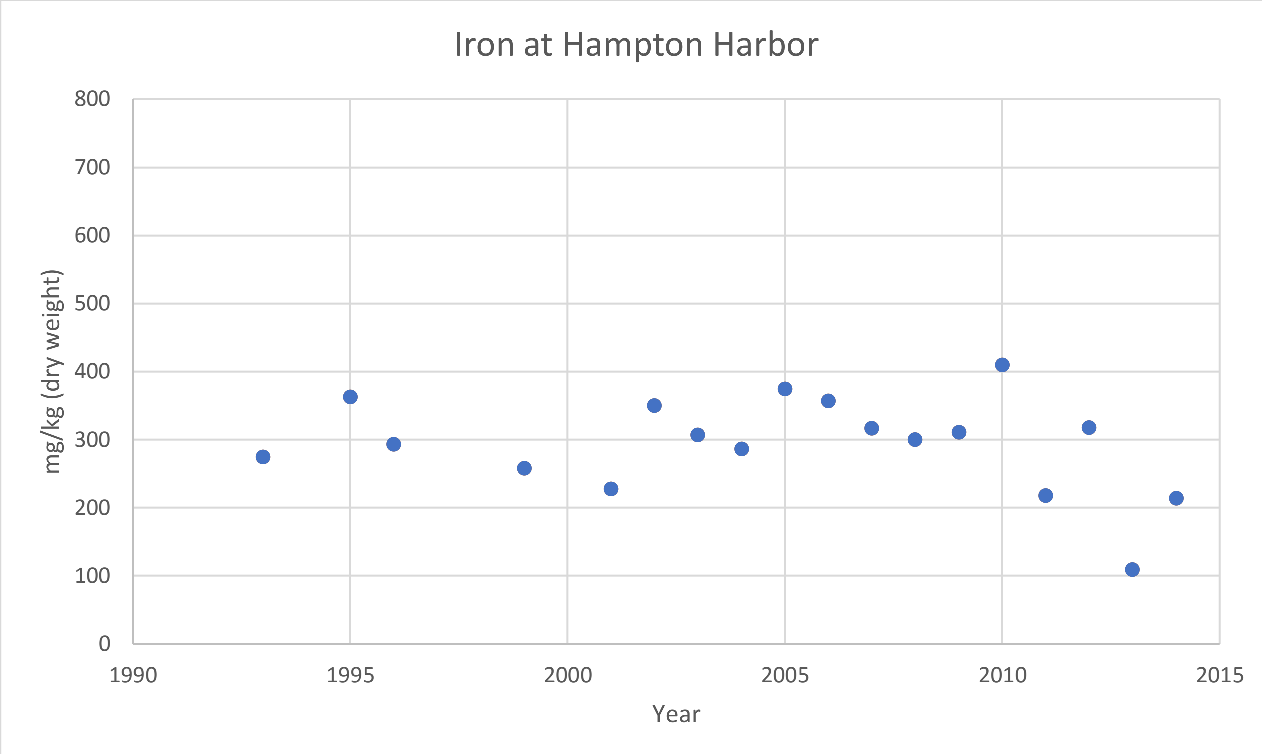

Figure TC-18: Iron concentrations in mussel tissue at the Hampton Harbor station.

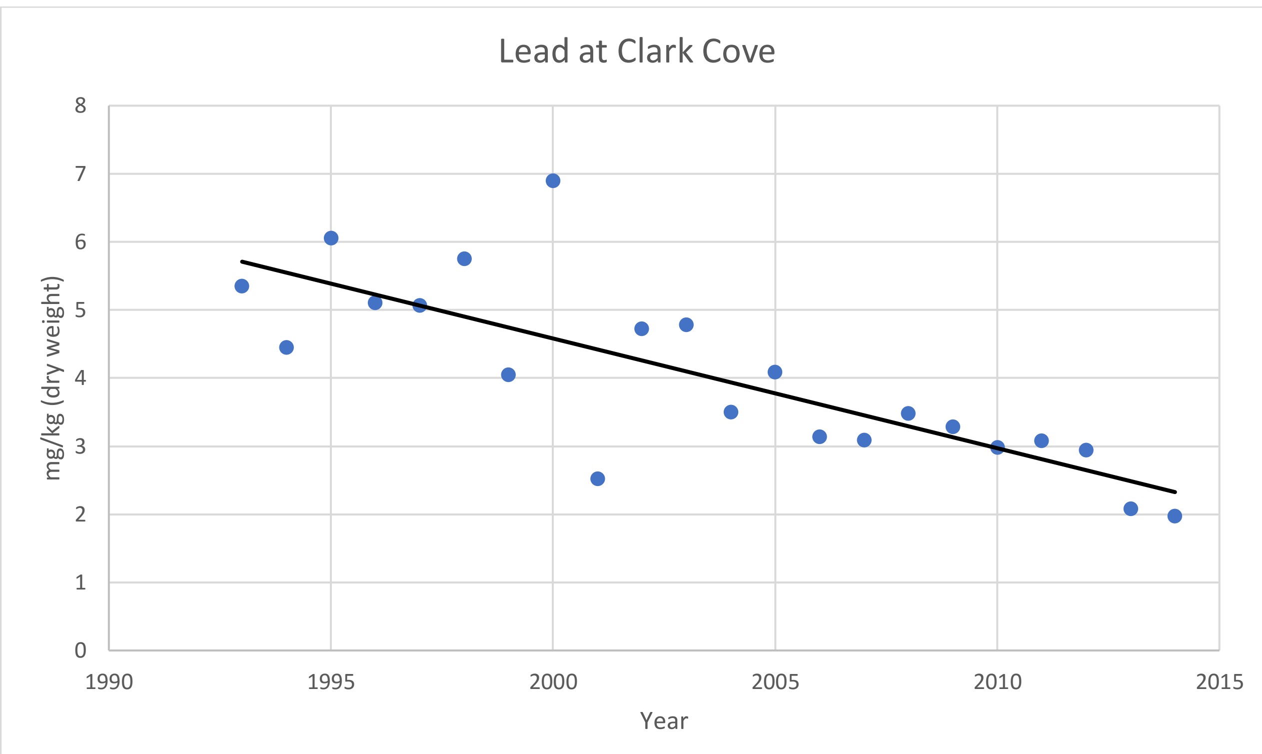

Figure TC-19: Lead concentrations in mussel tissue at the Clark Cove station, Portsmouth Harbor. Trendline indicates statistically significant trend.

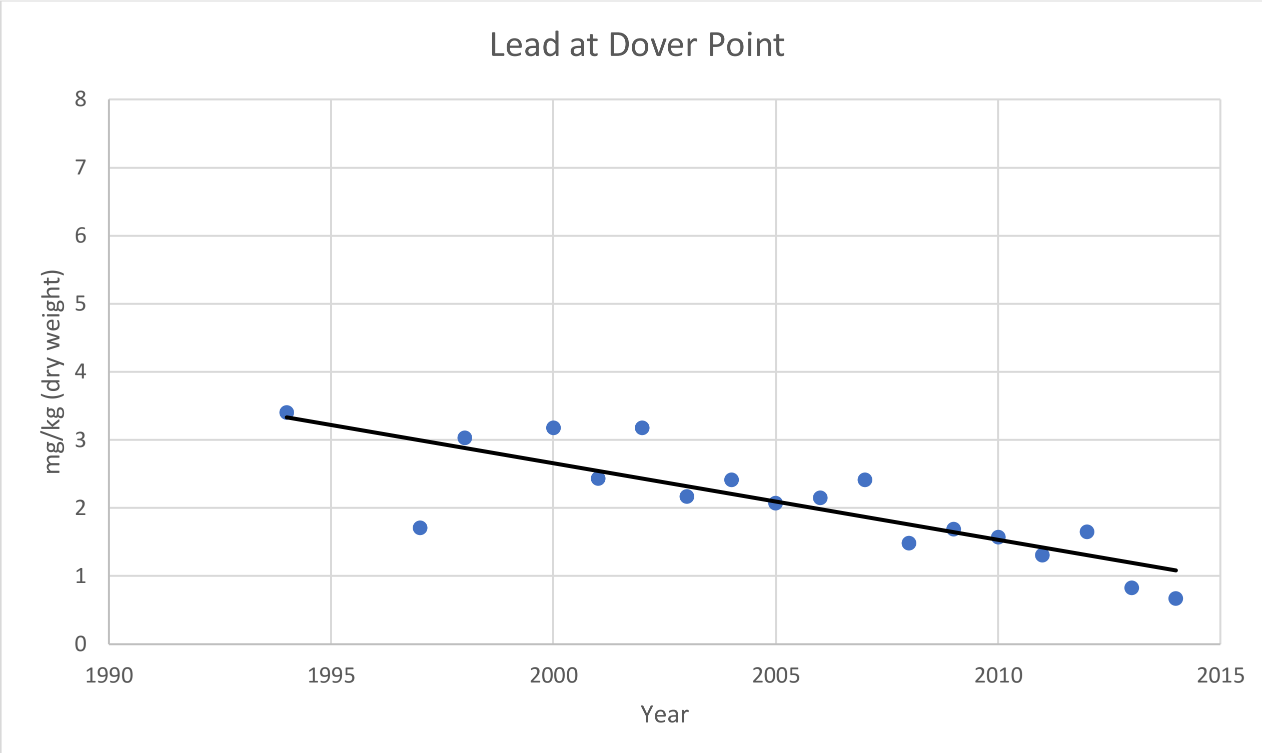

Figure TC-20: Lead concentrations in mussel tissue at the Dover Point station. Trendline indicates statistically significant trend.

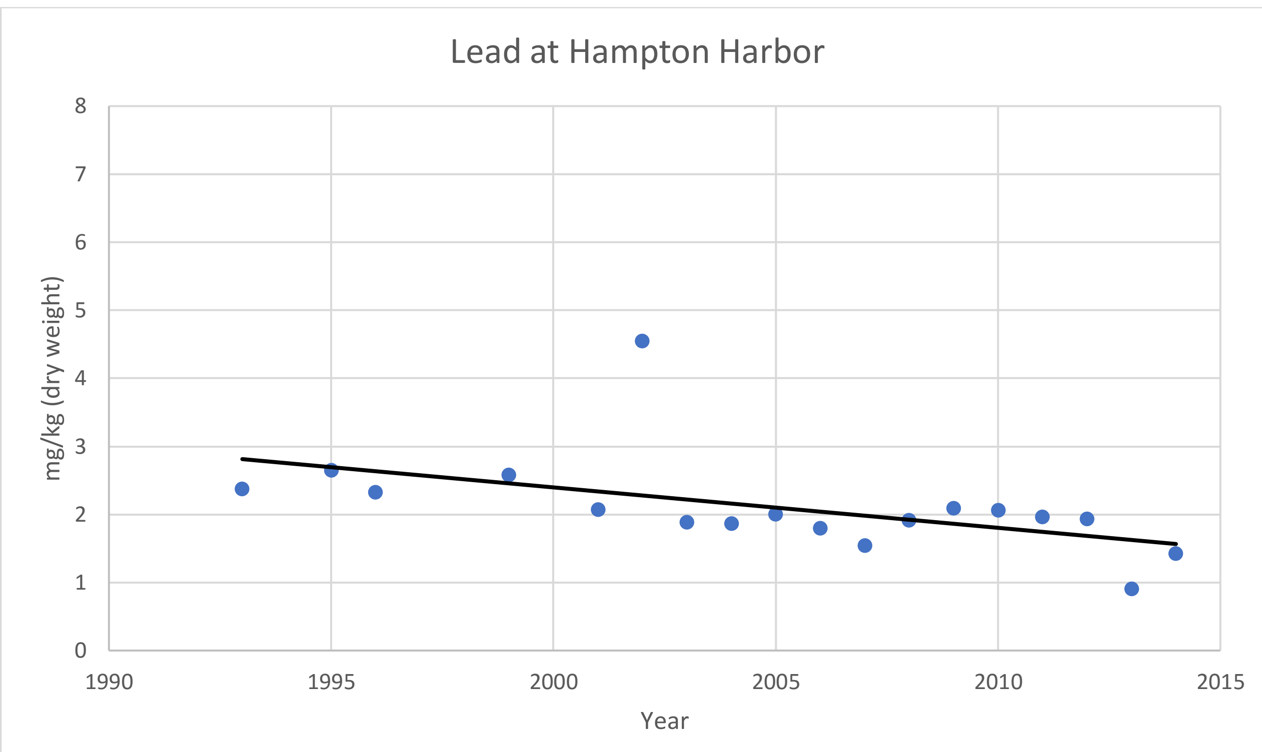

Figure TC-21: Lead concentrations in mussel tissue at the Hampton Harbor station. Trendline indicates statistically significant trend.

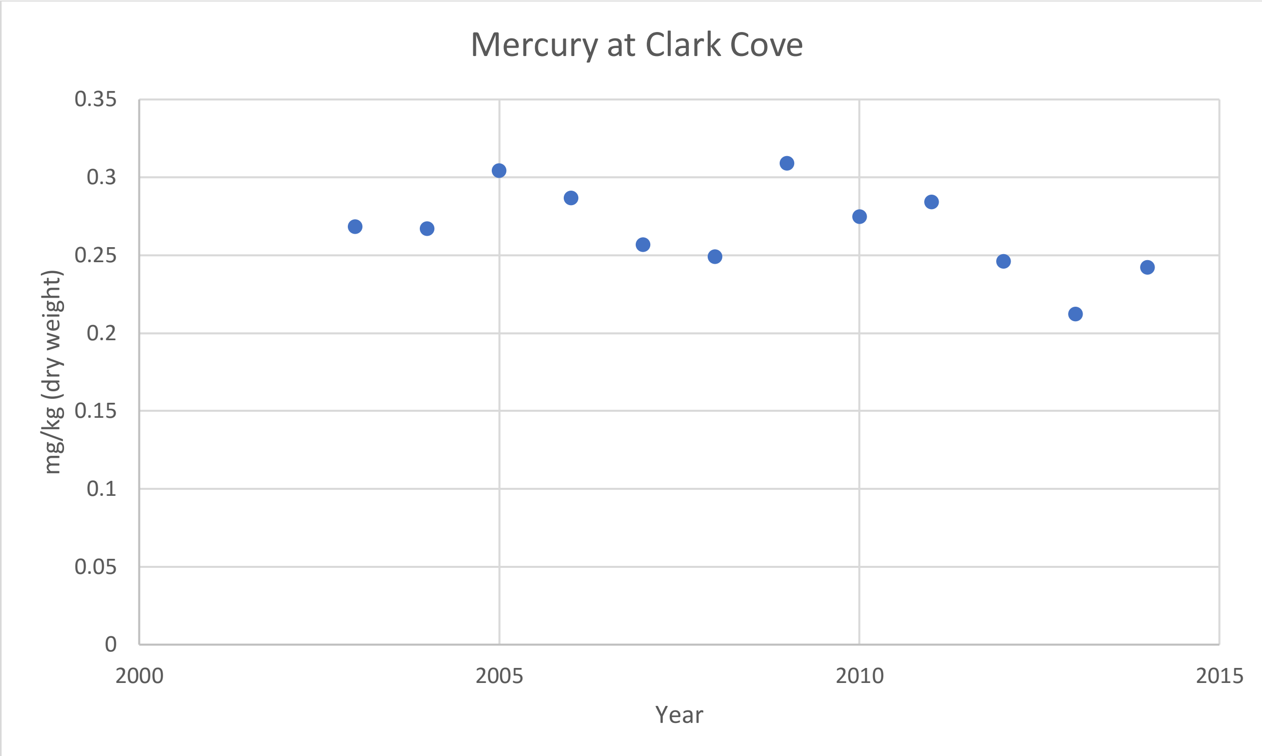

Figure TC-22: Mercury concentrations in mussel tissue at the Clark Cove station, Portsmouth Harbor.

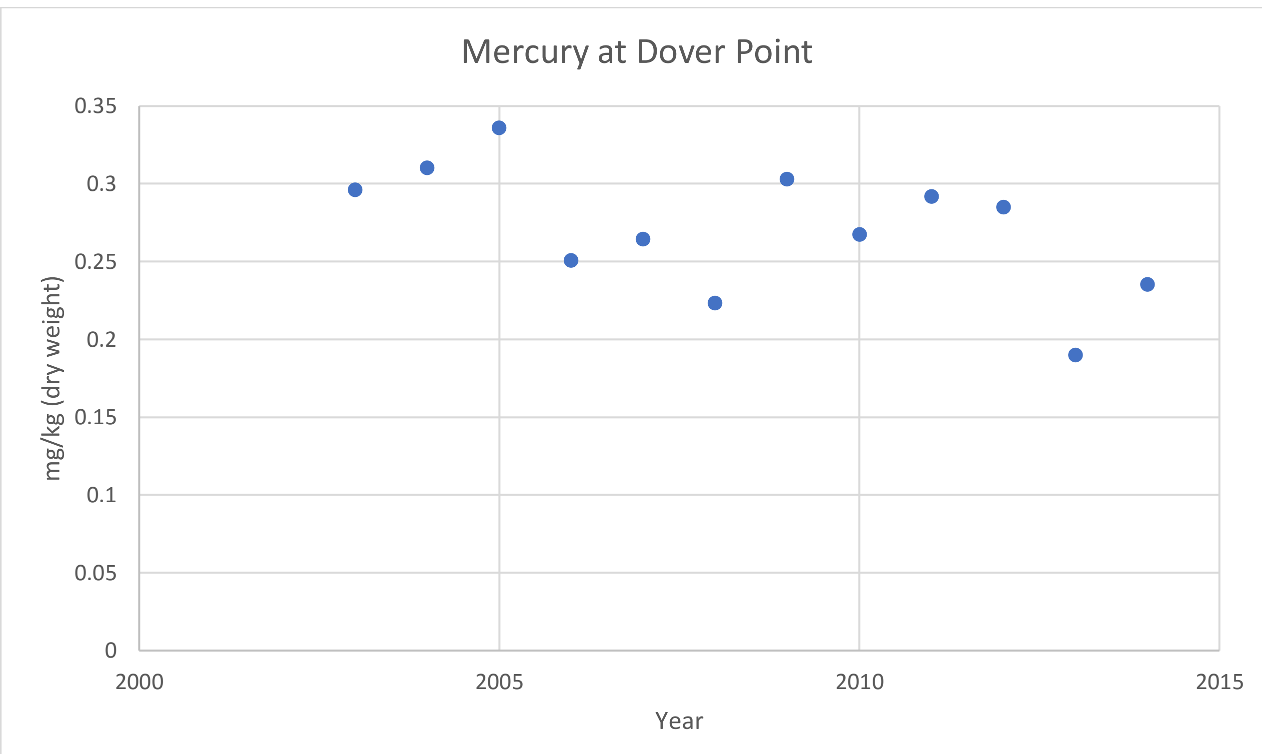

Figure TC-23: Mercury concentrations in mussel tissue at the Dover Point station.

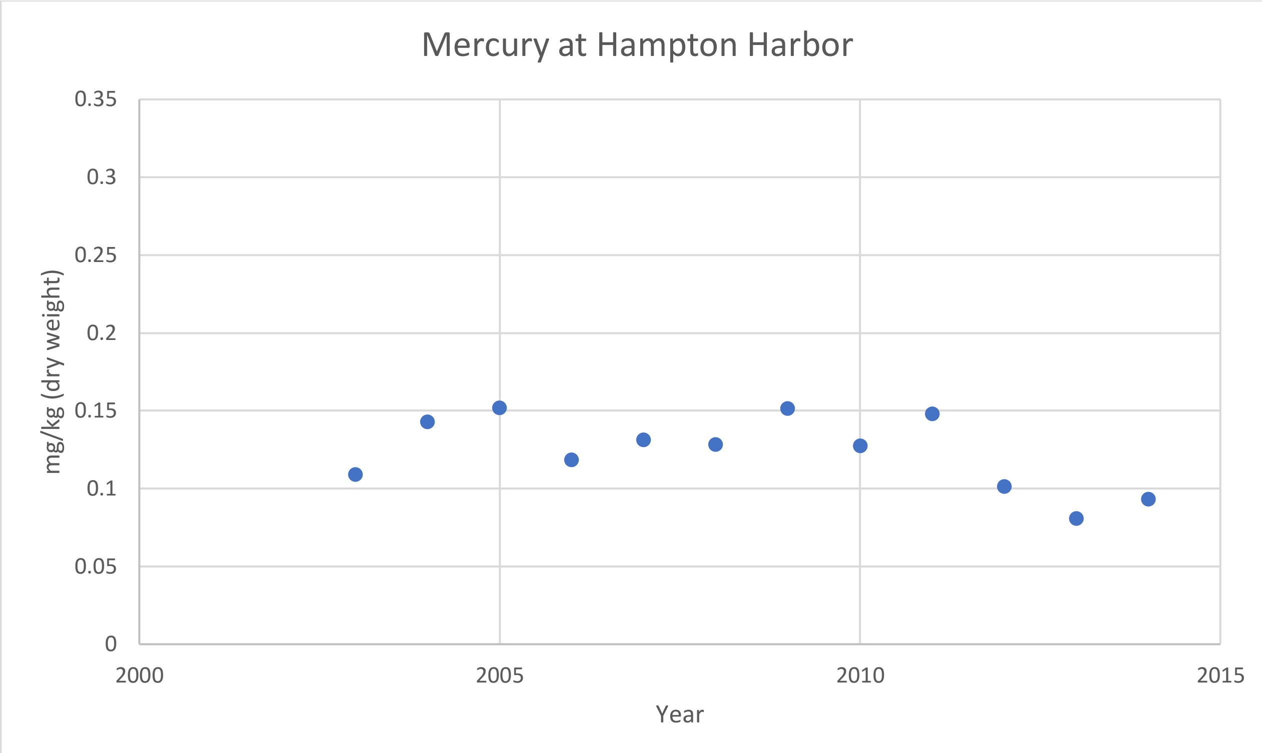

Figure TC-24: Mercury concentrations in mussel tissue at the Hampton Harbor station.

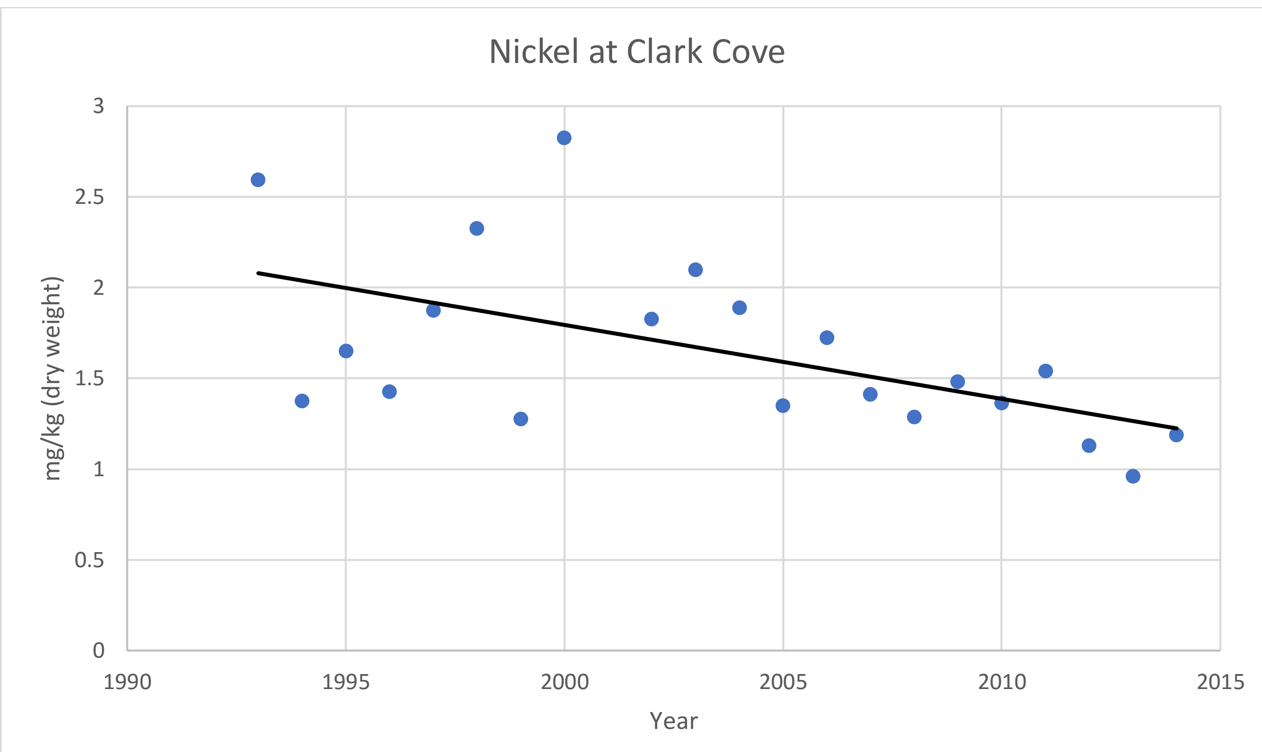

Figure TC-25: Nickel concentrations in mussel tissue at the Clark Cove station, Portsmouth Harbor. Trendline indicates statistically significant trend.

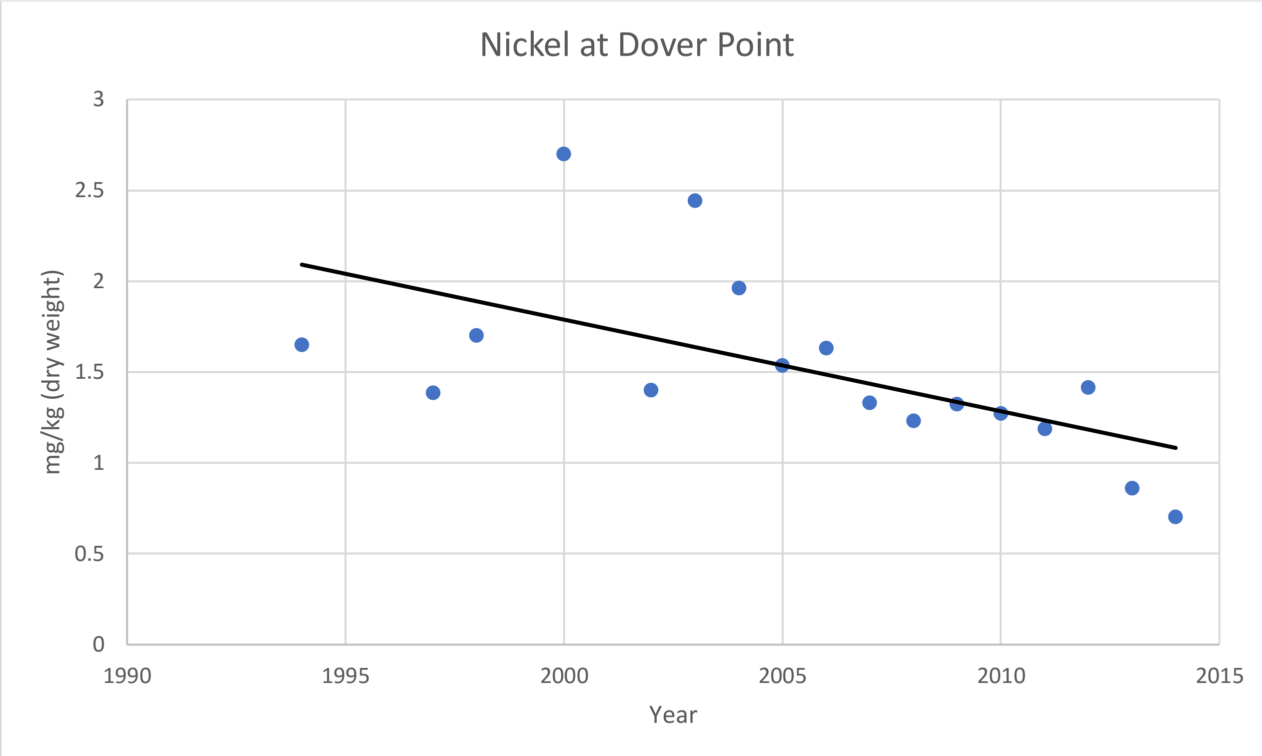

Figure TC-26: Nickel concentrations in mussel tissue at the Dover Point station. Trendline indicates statistically significant trend.

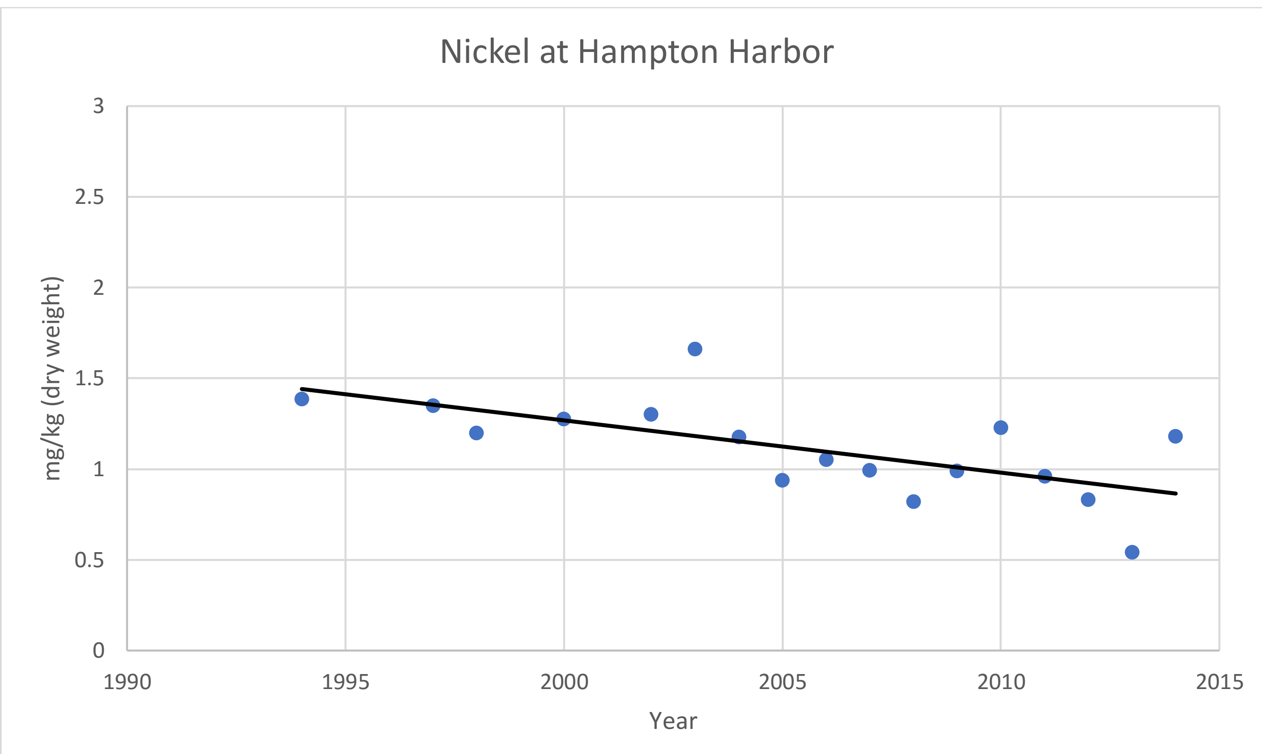

Figure TC-27: Nickel concentrations in mussel tissue at the Hampton Harbor station. Trendline indicates statistically significant trend.

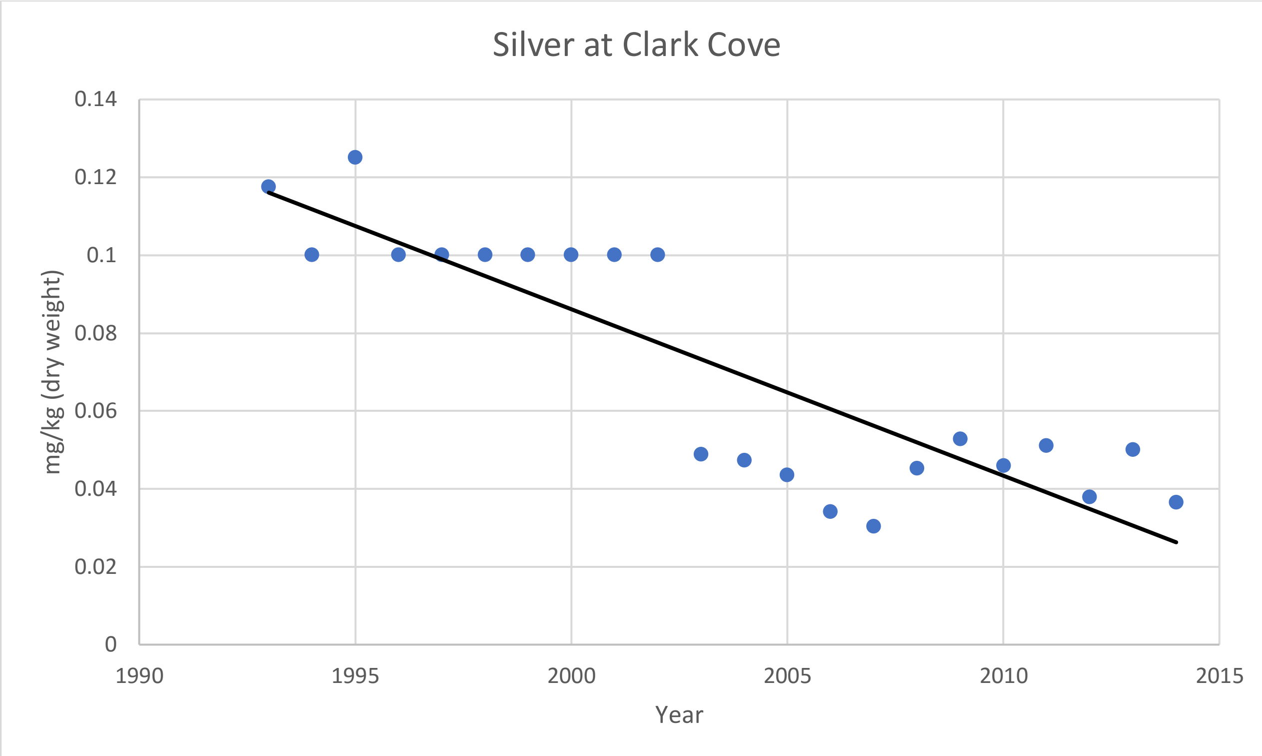

Figure TC-28: Silver concentrations in mussel tissue at the Clark Cove station, Portsmouth Harbor. Trendline indicates statistically significant trend. Multiple 0.1 results are due to minimum detection limits, which were changed in 2003.

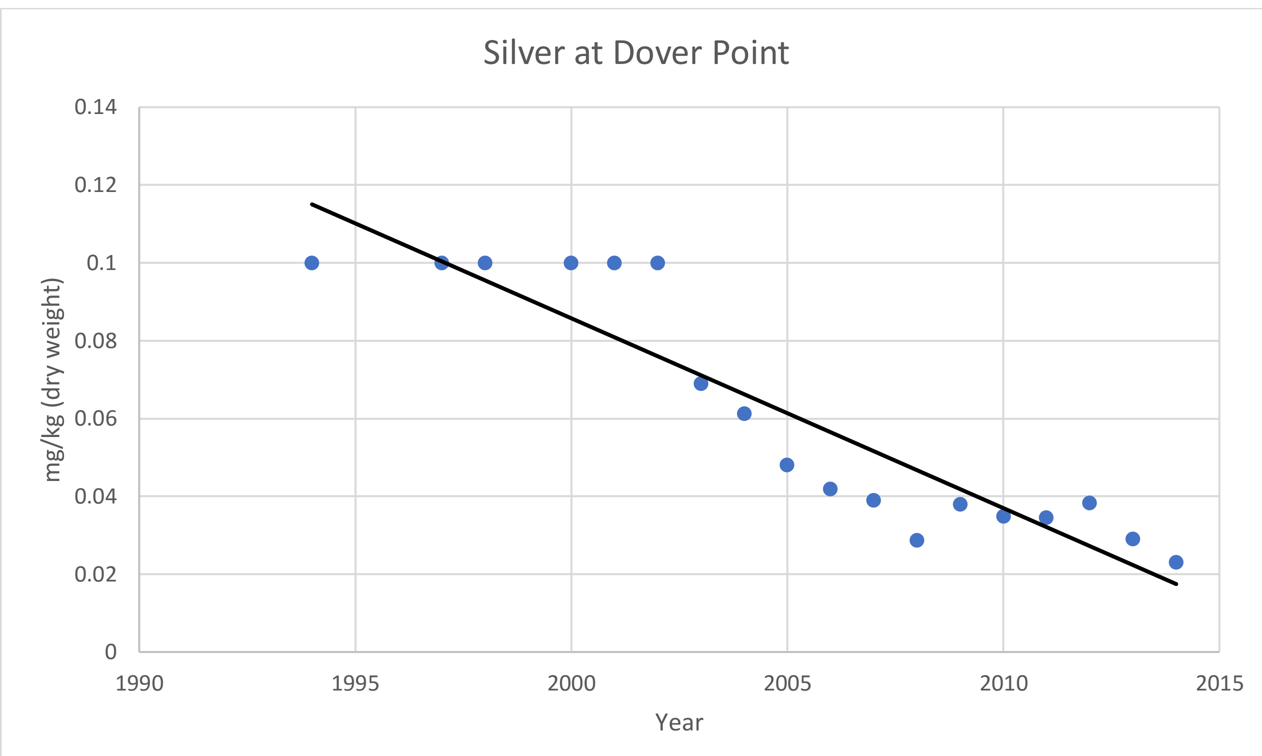

Figure TC-29: Silver concentrations in mussel tissue at the Dover Point station. Trendline indicates statistically significant trend. Multiple 0.1 results are due to minimum detection limits, which were changed in 2003.

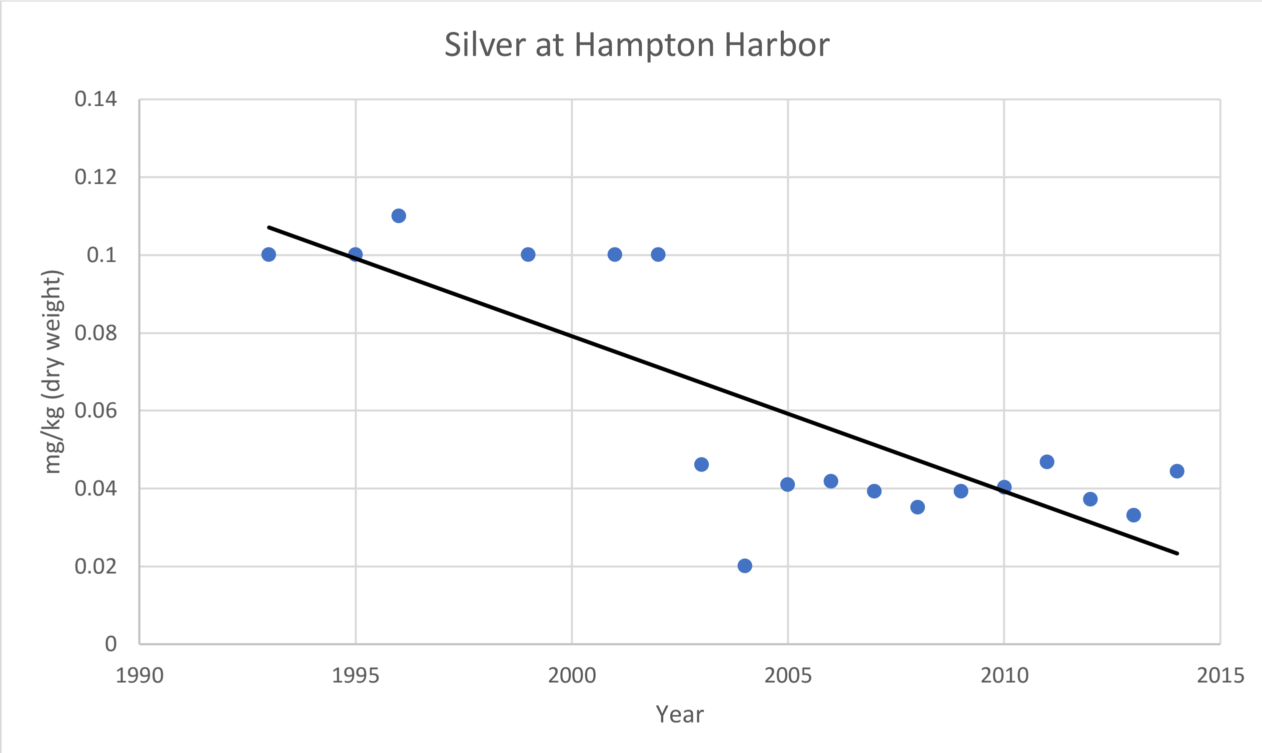

Figure TC-30: Silver concentrations in mussel tissue at the Hampton Harbor station. Trendline indicates statistically significant trend. Multiple 0.1 results are due to minimum detection limits, which were changed in 2003.

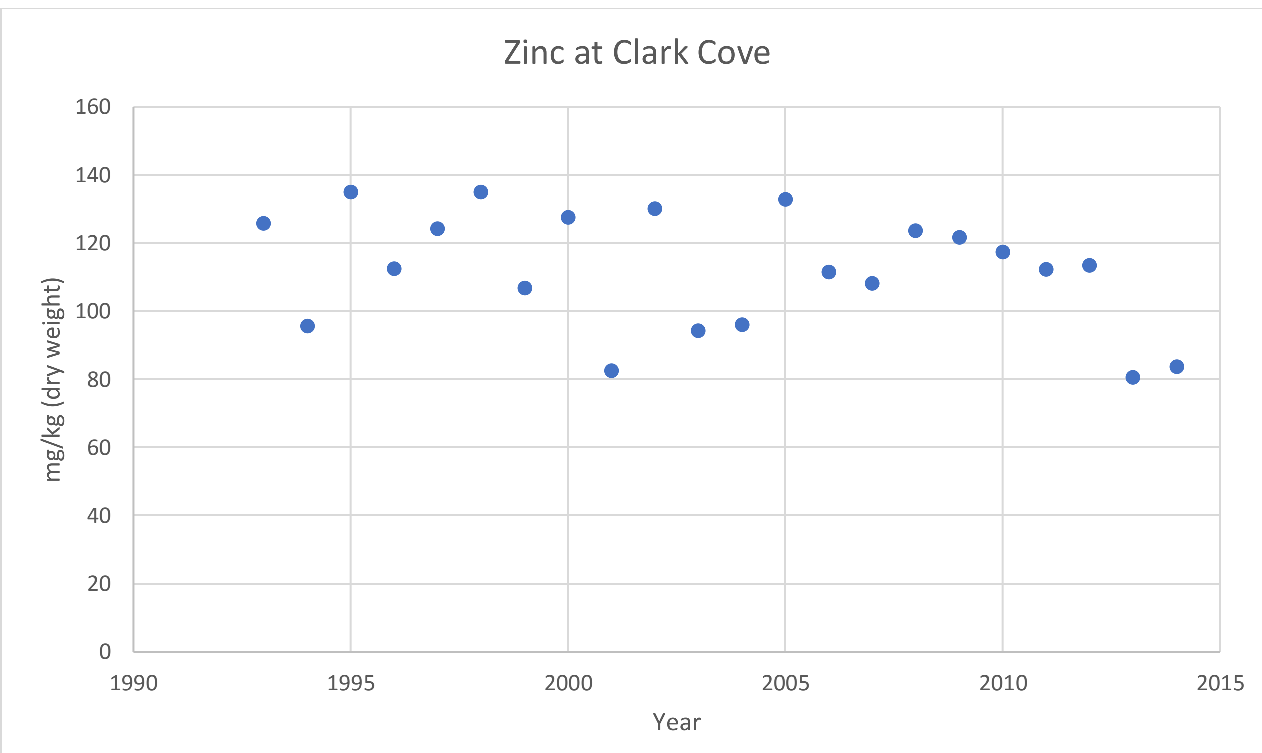

Figure TC-31: Zinc concentrations in mussel tissue at the Clark Cove station, Portsmouth Harbor.

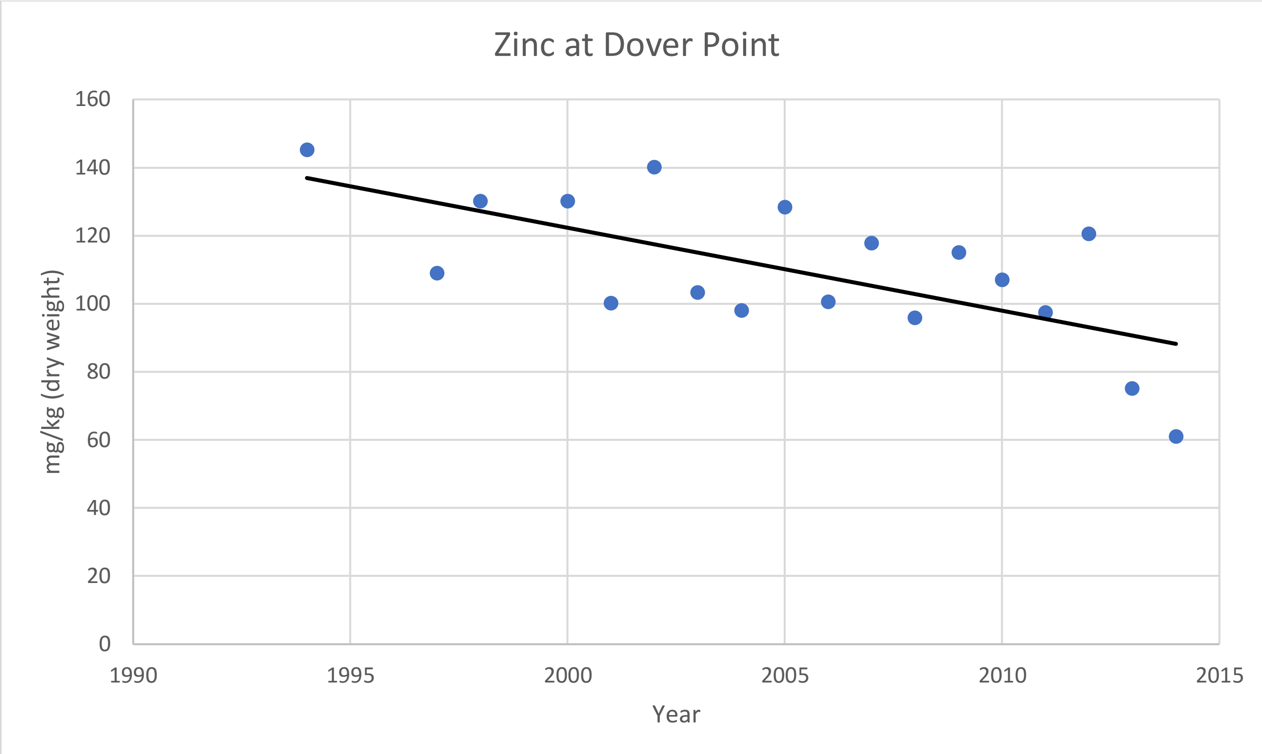

Figure TC-32: Zinc concentrations in mussel tissue at the Dover Point station. Trendline indicates statistically significant trend.

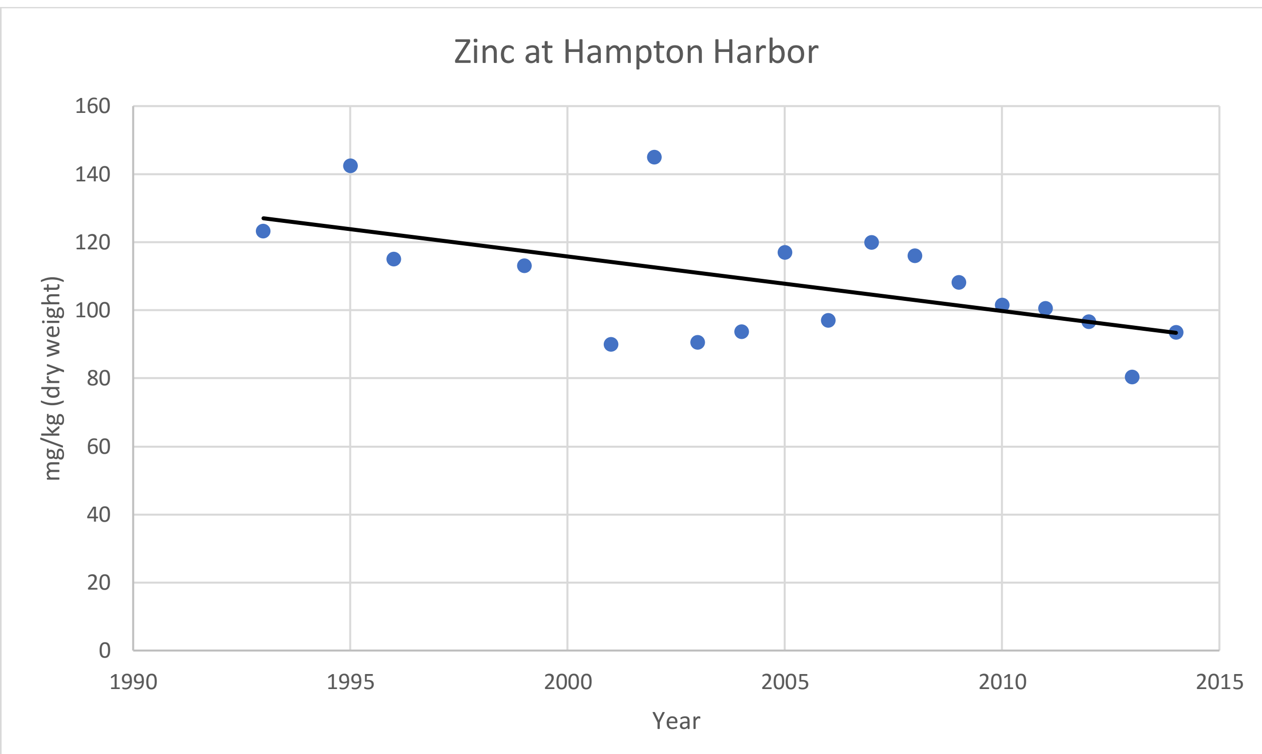

Figure TC-33: Zinc concentrations in mussel tissue at the Hampton Harbor station. Trendline indicates statistically significant trend.

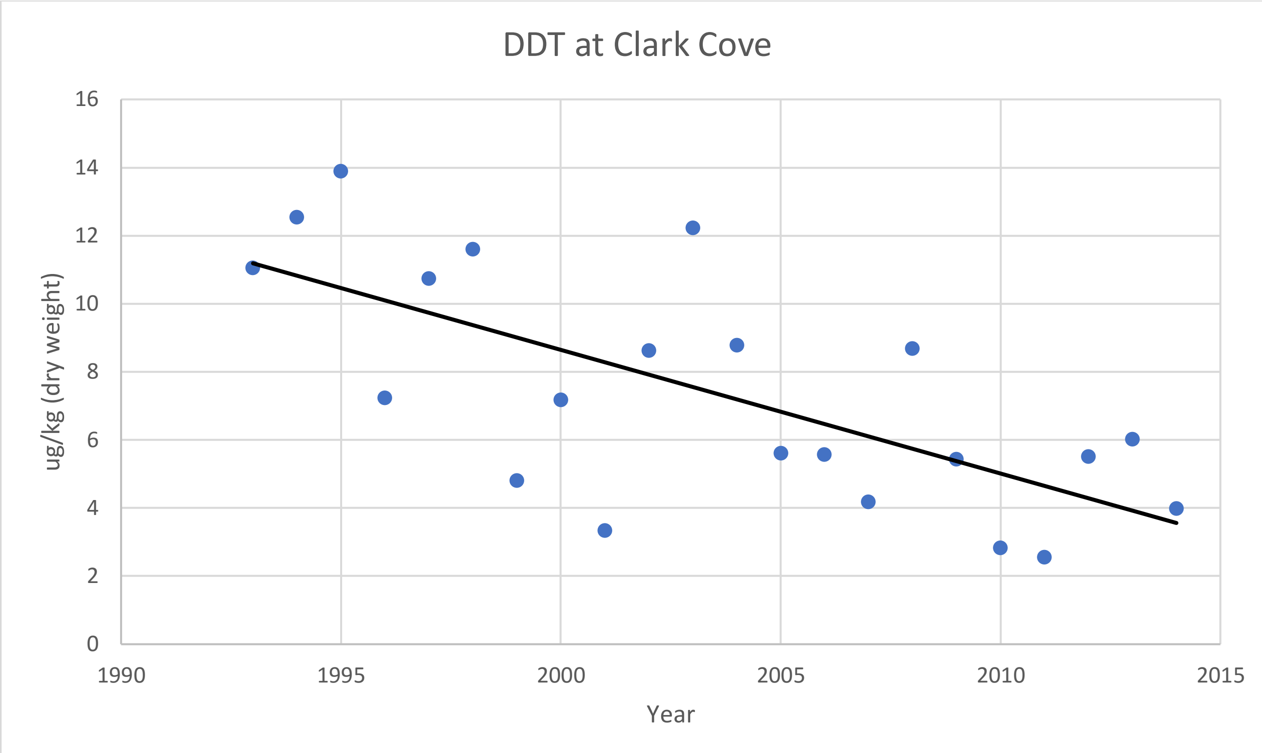

Figure TC-34: Total DDT concentrations in mussel tissue at the Clark Cove station, Portsmouth Harbor. Trendline indicates statistically significant trend.

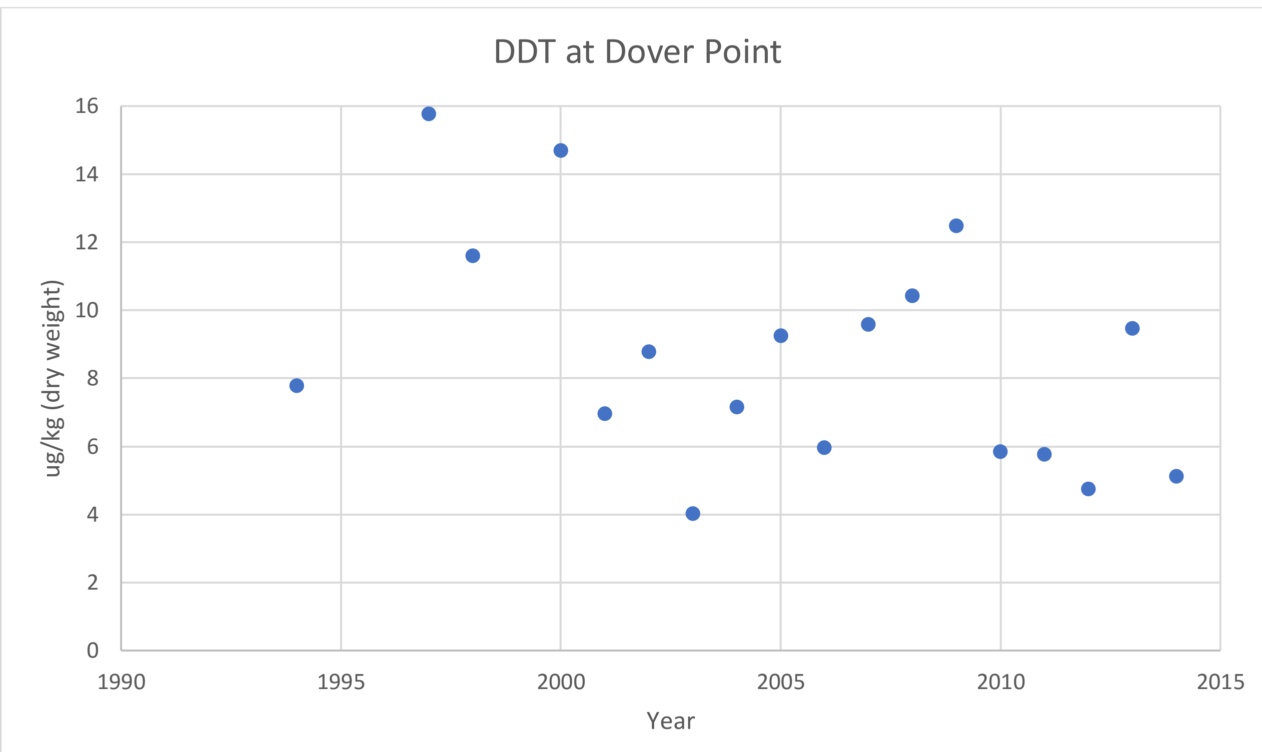

Figure TC-35: Total DDT concentrations in mussel tissue at the Dover Point station.

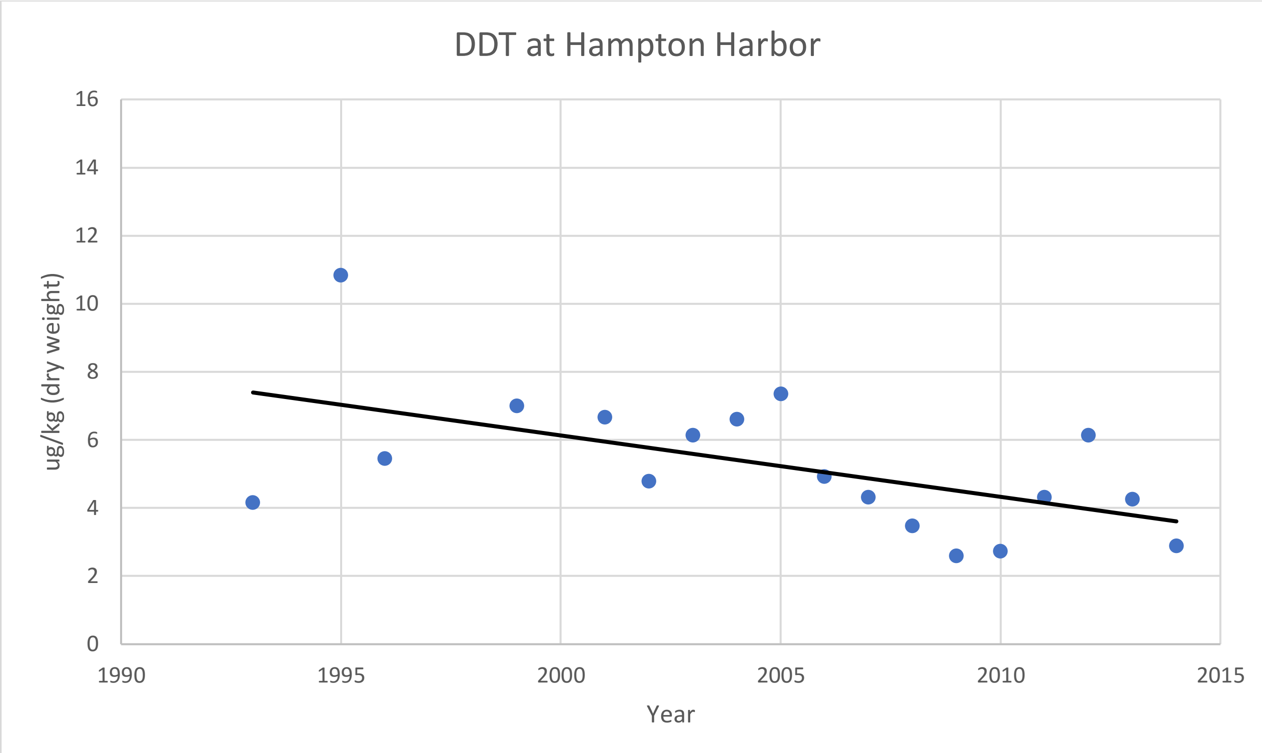

Figure TC-36: Total DDT concentrations in mussel tissue at the Hampton Harbor station. Trendline indicates statistically significant trend.

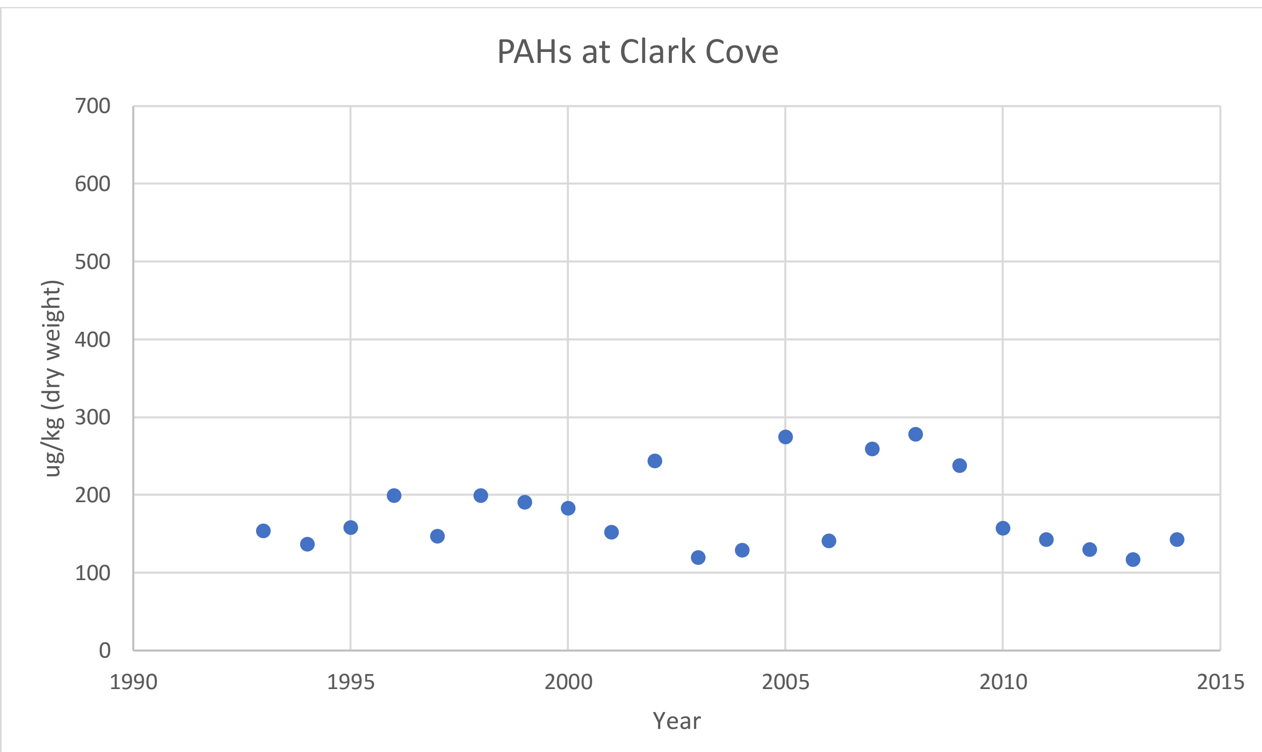

Figure TC-37: Total PAH concentrations in mussel tissue at the Clark Cove station, Portsmouth Harbor.

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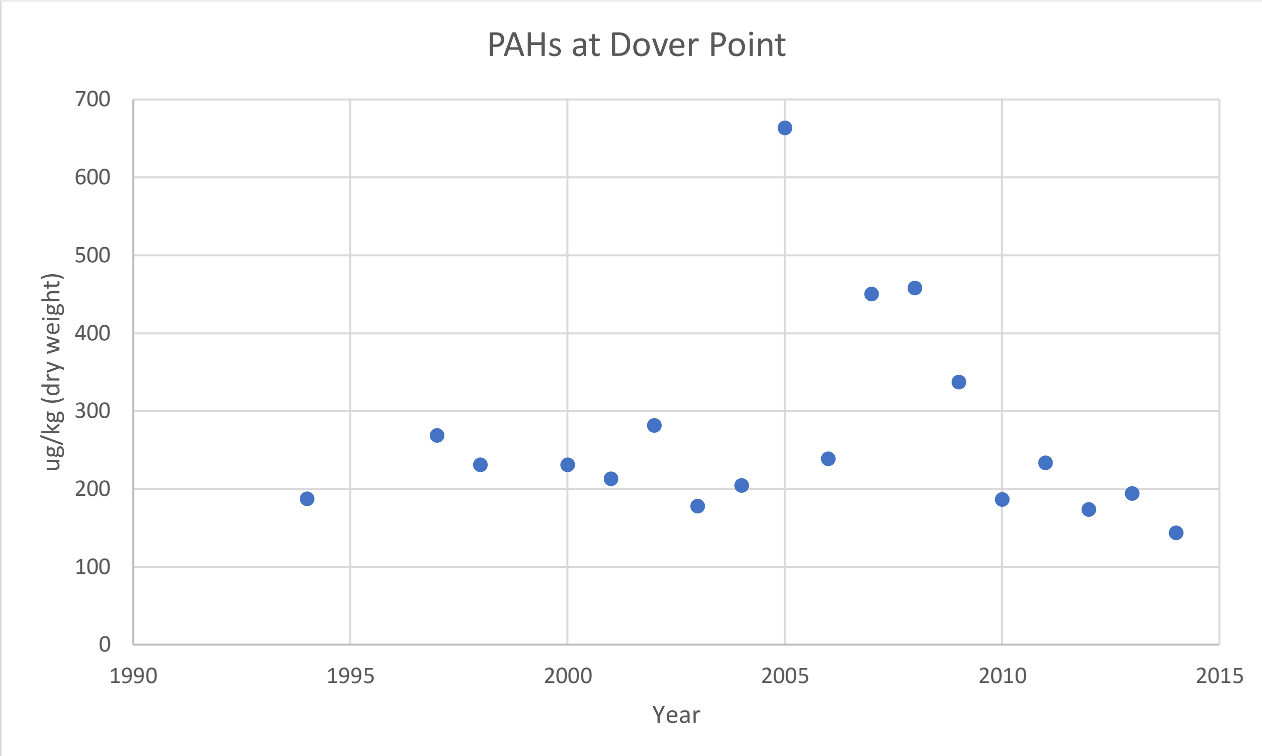

Figure TC-38: Total PAH concentrations in mussel tissue at the Dover Point station.

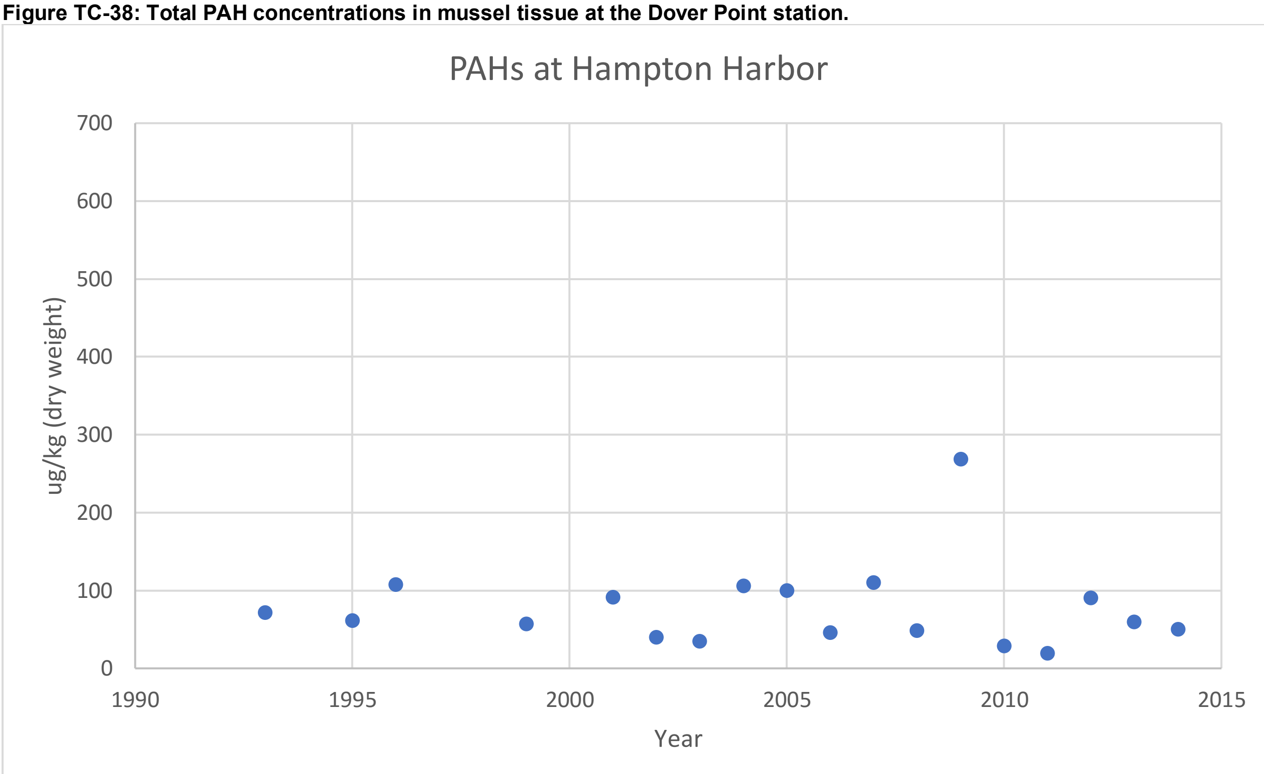

Figure TC-39: Total PAH concentrations in mussel tissue at the Hampton Harbor station.

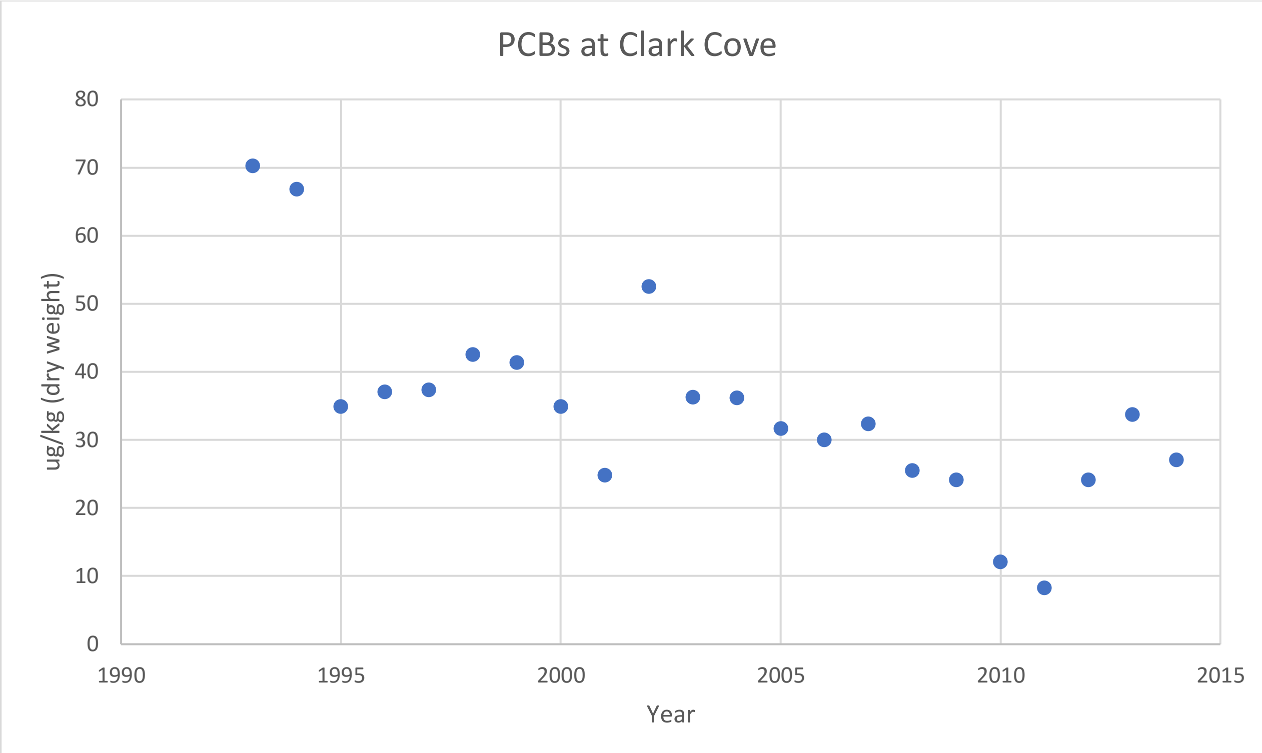

Figure TC-40: Total PCB concentrations in mussel tissue at the Clark Cove station, Portsmouth Harbor.

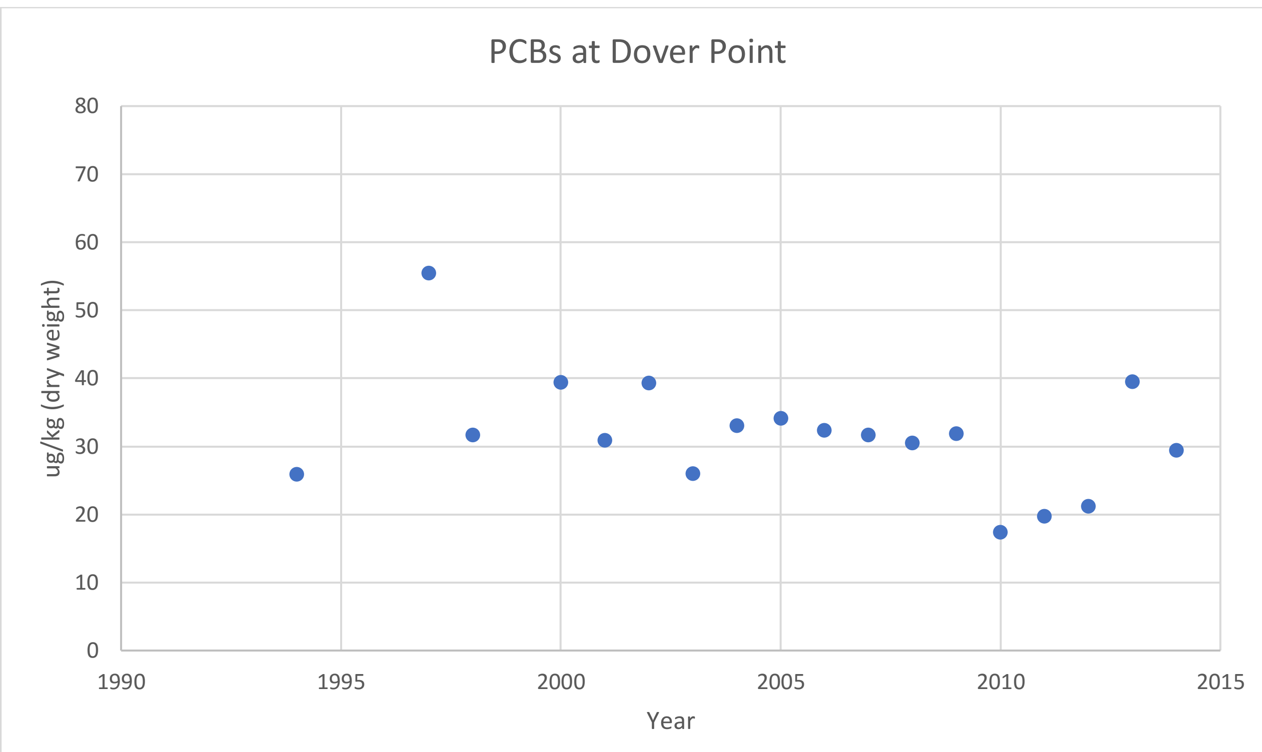

Figure TC-41: Total PCB concentrations in mussel tissue at the Dover Point station.

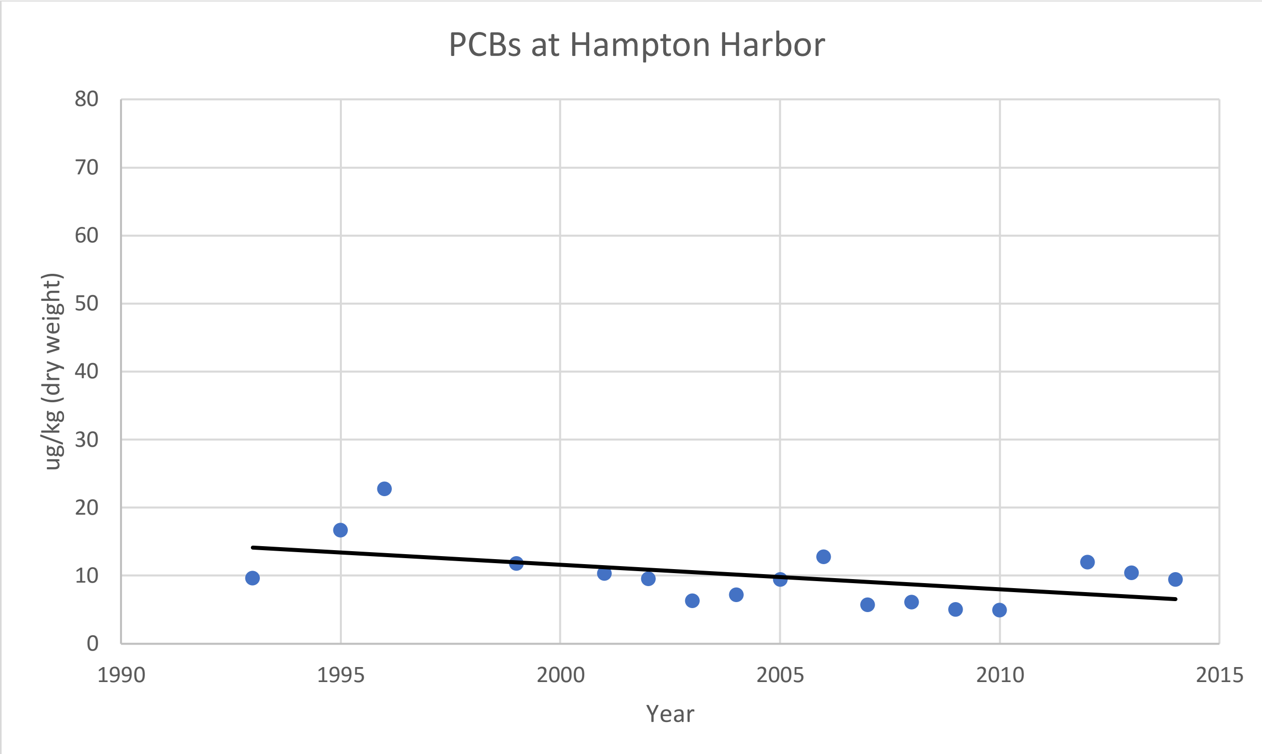

Figure TC-42: Total PCB concentrations in mussel tissue at the Hampton Harbor station. Trendline indicates statistically significant trend.

Indicator: Oysters in the Great Bay Estuary

Question

How many adult oysters are in the Great Bay Estuary and how has it changed over time?

Short Answer

The number of adult oysters decreased from over 25 million in 1993 to 1.2 million in 2000. Since 2012, the population has averaged 2.1 million oysters, which is 28% of the PREP goal for oyster recovery by 2020. This shows a decline from the previous reporting period (2009-2011) which averaged just over 2.8 million oysters.

PREP Goal

Increase the abundance of adult oysters at the six documented beds in the Great Bay Estuary to 10 million oysters by 2020 (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

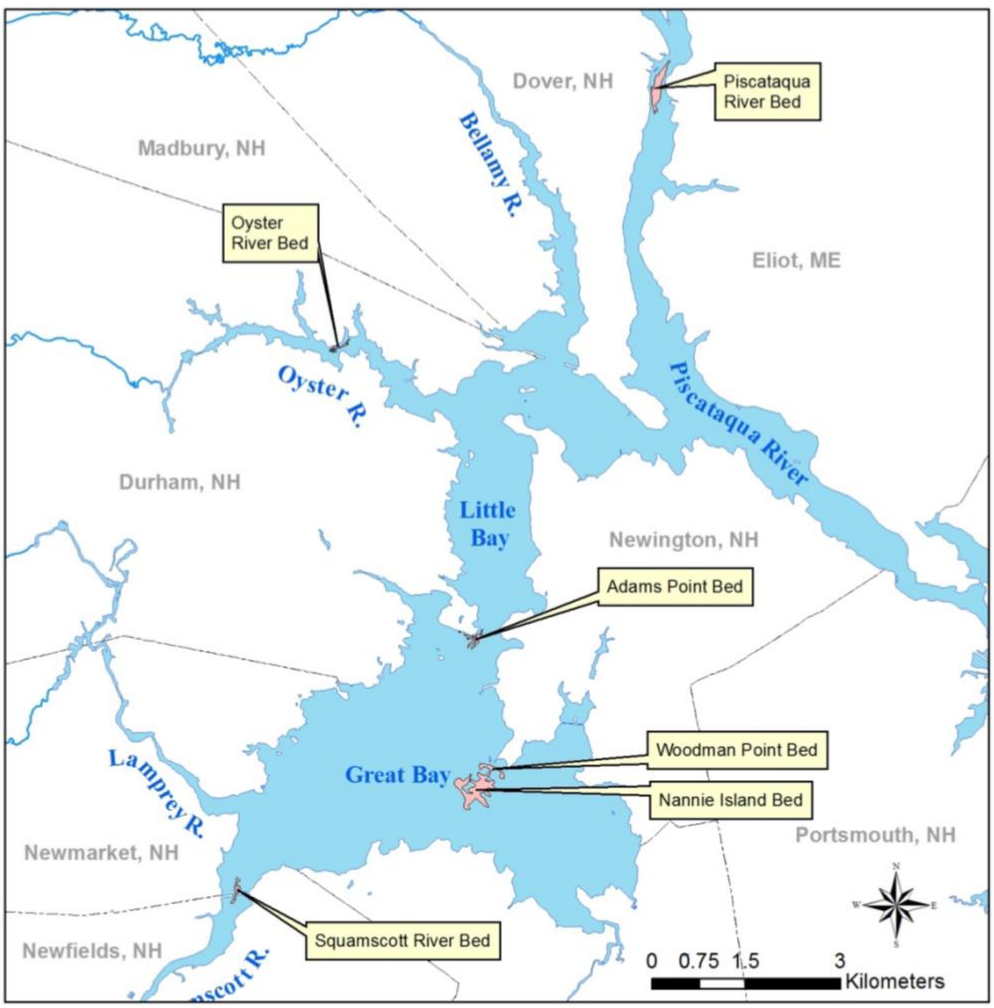

Figure O-1. Map showing the locations of the six major oyster beds in the Great Bay Estuary.

Why This Matters

Filter-feeding oysters are both a fisheries resource and a provider of key ecosystem services and functions. For example, they can reduce phytoplankton biomass and other suspended particles; this increases the ability for light to penetrate through the water which helps benthic plants, like eelgrass, to grow. They also provide important habitat for many invertebrate species and enhance biodiversity. Since the early 1990's as oyster populations in the Great Bay Estuary have declined, it is likely these important functions and services that oysters provide, may have also declined.

Explanation (from 2018 State of Our Estuaries Report)

From 2012 to 2016, the average standing stock of adult oysters (greater than 80 mm in shell height) at the six largest oyster habitat sites (Figure O-1) was just over 2.1 million oysters. This shows a decline from the previous reporting period (2009- 2011) which averaged just over 2.8 million oysters (Figure O-2). In 2016, there were 2,766,314 oysters, a decrease of 89% from 1993, when 25,729,204 adult oysters were present. The 2016 oyster population is approximately 28% of the PREP goal.

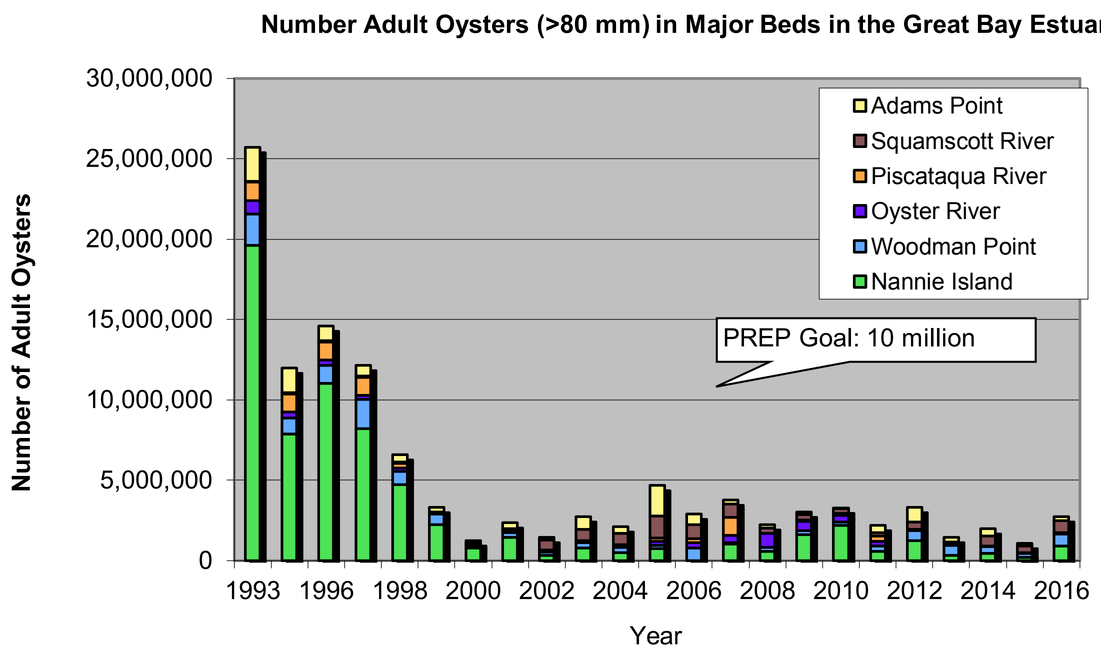

Figure O-2. Standing stock of adult (>80 mm shell height) oysters in the Great Bay Estuary. Standing stock is estimated by multiplying adult densities by estimates of the acreage at each site. Data Source: Oyster density data from NH Fish and Game; site acreages from UNH Jackson Estuarine Laboratory.

A primary limitation on oyster health is disease, caused by two microscopic parasitic organisms, Dermo (*Parkinsus marinus*) and MSX (*Haplosporidium nelsoni*). Figure O-3 shows that Dermo, a warmer water organism, has become more prevalent over time. The prevalence of both diseases increases with salinity (Ewart and Ford 1993). Figure O-3 also indicates that oysters no longer grow above 115 mm in shell height, which suggests that oysters are only living four or five years, rather than 10+ years as they did in the early 1990s.

Oyster habitat in the Great Bay Estuary also faces challenges due to available substrate for oyster larvae to settle. Oysters themselves can provide this substrate, but less and less oyster habitat diminishes the available substrate. This can be offset by planting recycled oyster shell material—for example, from restaurants and other sources—in key locations in the estuary. (See "Oyster Restoration" Indicator).

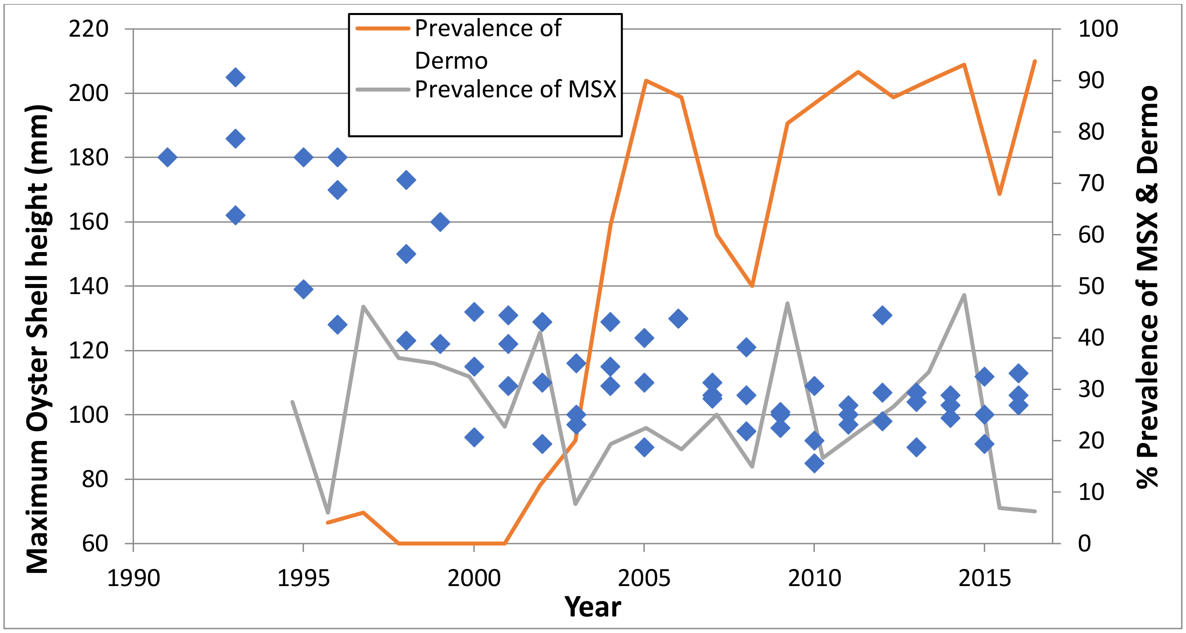

Figure 0-3: Blue diamonds indicate maximum shell height of oysters from the Adams Point, Nannie Island and Woodman Point reefs. Updated from the original graph, published in Eckert (2016). Data Source: NH Fish and Game.

Sedimentation is another stressor on oysters and it relates to the issue of available substrate. Sediments occur in the watershed from run-off, from stream and river erosion, and they get resuspended from the substrate in the estuary. With eelgrass and oyster habitats decreased from historic levels, sediments may be more easily resuspended following storms and high-flow periods. Oyster restoration monitoring has indicated that young reefs can easily be smothered by sediment.

Recreational harvesting of oysters may also be stressing the population. However, studies from other areas have shown that some restricted harvesting can provide benefit, through the removal of sediment.

<u>Methods and Data Sources</u>
For each of the major oyster beds, the average density of adult oysters (>80 mm shell height) was calculated and compared to 1997 levels (Langan 1997). For each oyster bed in each year, the mean of the number of oysters per quadrat with >80mm shell height was calculated. Only quadrats where oysters were found were included in the average density calculation. The number of adult oysters in each bed was estimated by multiplying the average density of oysters for each bed by the most recent estimate of the bed size. If data on density or area was missing for a bed for a particular year, the closest other available data for that bed was used in the calculation. The number of adult oysters was summed for beds in areas open for harvesting and for all beds.

Data Sources
Baseline data from 1997 on the six major oyster beds in Great Bay was provided in Langan (1997). The baseline data were compared to more recent mapping (Grizzle and Ward 2013). The monitoring programs for this indicator should have an accuracy of ± 10% in the area estimate for each bed.

The NHF&G Oyster Resource Monitoring Program conducts a survey of the major oyster beds in the Great Bay Estuary every year to measure oyster density with quadrats and to collect samples for disease testing.

Maps of open and closed areas for shellfishing were provided by the DES Shellfish Program.

Technical Advisory Committee (TAC) Discussion Highlights

As part of the January 2017 TAC meeting, participants discussed some of the most salient stressors on oyster habitats (PREP 2017c). Complete notes are available at: http://prepestuaries.org/prep-technical-advisory-committee/

Table O-1. TAC participants collaboratively rated salient stressors on oyster habitat in terms of the impact of the stressor as well as the ability of managers to affect the situation. Choices were "high," "medium," and "low." * indicates that the rating was unanimous. ** indicates that the rating was close to unanimous (2 or less opposing.) * indicates that there was a majority but the feedback was mixed.**

Stressor	Impact on Oysters	Ability to Manage
Disease	High*	Low**
Available Substrate	High*	High**
Sedimentation	High*	??
Harvest	Medium***	High*

The four stressors in Table O-1 are discussed in greater detail below. Other stressors discussed in the notes (PREP 2017c) include spawning stock biomass and predation from green crabs and other animals.

Disease and Natural Resistance
The TAC was in agreement regarding the impacts of disease (MSX and Dermo) on oyster habitat (Figure O-3). However, there was some disagreement about the potential to improve the situation through selective breeding. While some members felt that using disease-resistant oysters holds promise, others were less supportive of this idea, noting that results have not been extremely impressive in other locations, and asserted that research indicates that the natural adaptation of oysters to disease holds more promise, although this is a very slow process.

Available Substrate
It was agreed that there is significant unrealized potential to add available substrate by expanding past/current activities, such as working with local restaurants to collect oyster shell and then placing that shell in the estuary. However, several participants cautioned that decisions regarding the placement of shell need to be made very strategically. Recent research on oyster larvae settling patterns in the Great Bay Estuary (Eckert 2016) indicate that there is more recruitment—settling of larvae onto available substrate—on restored reefs that are close to native reefs.

Finally, there was agreement that increased understanding of larval transport in the estuary would be helpful to ensure that resources spent on adding additional substrate were most effective.

Sedimentation
Most participants agreed that sedimentation—the movement and settling of sediment within the estuary—has a negative impact on native and restored reefs. Monitoring efforts (e.g., Grizzle and Ward 2016) indicate that young oysters are often covered by sediment. There was also general agreement that sediments are more mobile now than in the past, at least partially due to the loss of oyster and eelgrass habitat, both of which baffle water and encourage the settlling of sediments. A more thorough sediment budget was proposed as a research need to better understand where sediments are coming from—i.e., how much is coming from internal sources and how much is being supplied from the tributaries—and how sediments are transported within the system.

Harvest
There was disagreement about whether current recreational harvesting levels are adding stress to oyster habitat. Current regulations allow recreational harvesters to take a half bushel of unshucked oysters using either hands, rakes or tongs. Some participants felt that rakes and tongs are harmful to reefs, especially as these reefs try to build up a vertical profile to defend against sedimentation. Other participants asserted that current harvest levels have a negligible negative impact.

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Table O-2: Area (in acres) of the major oyster beds in the Great Bay Estuary.

Year	Bed Area (acres)							Source	Comments
	Adams Point	Nannie Island	Oyster River	Piscataqua River	Squamscott River	Woodman Point	Total area		
1997	4	37.3	1.8	12.8	1.7	6.6	64.2	Langan (1997)	
2001	13.1	24.7	1.7			7.3	61.2	NHF&G (2002)	Total calculated using 2003 areas for the PR & SR
2003				12.5	1.9			Grizzle and Brodeur (2004) - high density area	
2004		41.8				6.1		Grizzle et al. (2008)	
2006	5.7		2.5				70.5	Grizzle et al. (2008)	Total calculated using 2003 areas for PR & SR, 2004 areas for NI & WP
2012	15.9	32.4	1.4	7	7.7	15.4	79.8	Grizzle and Ward (2013)	
Difference	11.9	-4.9	-0.4	-5.8	6	8.8	15.6	Acreage change 1997 to 2012	
	298%	-13%	-22%	-45%	12%	353%	24%	% change 1997 to 2012	

*** Note that changes in acreages can be caused by actual changes in bed area as well as changes in mapping approaches. In some cases, newer mapping efforts extended the area mapped and new habitat was found (Grizzle and Ward 2013). No mapping of natural oyster reefs has occurred since the report by Grizzle and Ward (2013).**

Table O-3: Average density (# per m^2) of adult oysters (>80 mm shell height) in the major Great Bay Estuary beds.

Year	Adams Point	Nannie Island	Oyster River	Piscataqua River	Squamscott River	Woodman Point	Source
1993	120.0	119.3	109.5			66.4*	NHF&G
1995		48.0	46.7			34.3	NHF&G
1996	52.7	67.0	40.8			39.0	NHF&G
1997	38.0	50.0	29.0	20.0		63.0	Langan (1997)
1998	27.5	28.7	26.0	5.1	9.3	28.7	NHF&G
1999		13.6	10.4	0.0		22.4	NHF&G
2000	5.3	4.8	12.0	1.3		4.0	NHF&G
2001	7.0	13.3	17.6	1.0	8.0	8.6	NHF&G
2002	2.8	3.2	9.6	0.8		6.4	NHF&G
2003	13.6	7.2	10.4	0.8		10.4	NHF&G
2004	7.2	2.7	24.8	0.0		12.0	NHF&G
2005	33.6	4.0	28.8	4.0	**161.3**	8.8	NHF&G
2006	26.4	0.0	**29.6**	4.8		29.6	NHF&G
2007	8.8	5.6	**40.8**	20.0		4.0	NHF&G
2008	7.2	3.2	**79.2**	0.0	**44.0**	8.8	NHF&G
2009	7.2	8.8	**56.0**			8.8	NHF&G
2010	1.6	12.0	**36.0***	2.4	**32.0**	8.0	NHF&G
2011	18.4	3.2	23.2	6.0	**24.8**	12.8	NHF&G
2012	12.8	8.8	17.6	0.0	**13.6**	8.8	NHF&G
2013	4.0	2.4	16.0	4.0		8.8	NHF&G
2014	6.4	3.2	6.4	0.0	**18.4**	6.4	NHF&G
2015	2.0	1.6	2.4	0.8	**12.8**	3.2	NHF&G
2016	4.0	6.4	7.2	0.8	**21.6**	11.2	NHF&G

1. Green cells are the PREP Management Goals for adult oyster density from Langan (1997). The density at the Squamscott River bed was not measured in 1997 so the 1998 value from NHF&G is the goal for this bed.

2. Bold values indicate an increase above 1997 density

* Value for Woodman Pt in 1993 is from NHF&G summary reports. Raw data from quadrats were not available for this survey. Value for Oyster River in 2009 was measured using tongs, not quadrats.

Table O-4: Standing stock of adult oysters (>80 mm) in the Great Bay Estuary.

Year	Adams Point	Nannie Island	Oyster River	Piscataqua River	Squamscott River	Woodman Point	Total open beds	Total all beds
1993	2,115,360	19,616,145	868,259	1,128,192	69,924	1,931,324	23,662,828	25,729,204
1995	1,521,884	7,890,293	370,188	1,128,192	69,924	997,241	10,409,418	11,977,722
1996	928,408	11,013,534	323,650	1,128,192	69,924	1,134,362	13,076,304	14,598,070
1997	669,864	8,219,055	230,045	1,128,192	69,924	1,832,431	10,721,350	12,149,511
1998	484,770	4,724,435	206,248	290,107	69,924	833,804	6,043,009	6,609,287
1999	289,393	2,235,583	82,499	0	64,930	651,531	3,176,507	3,323,936
2000	94,016	789,029	95,191	75,213	64,930	116,345	999,390	1,234,724
2001	404,122	1,451,372	131,857	56,410	59,935	275,752	2,131,246	2,379,448
2002	161,649	348,329	71,922	45,128	634,314	205,895	715,873	1,467,237
2003	785,151	783,741	77,916	44,070	708,939	334,579	1,903,471	2,734,397
2004	415,668	491,563	185,799	0	708,939	322,910	1,230,141	2,124,879
2005	1,939,785	737,344	215,767	220,350	1,350,892	236,800	2,913,930	4,700,939
2006	658,163	0	320,378	264,420	859,659	796,511	1,454,673	2,899,130
2007	219,388	1,032,282	441,603	1,101,750	859,659	107,637	1,359,306	3,762,317
2008	179,499	589,875	857,228	0	368,425	236,800	1,006,175	2,231,828
2009	179,499	1,622,157	606,121	66,105	318,185	236,800	2,038,456	3,028,868
2010	39,889	2,212,032	389,649	132,210	267,946	215,273	2,467,194	3,256,999
2011	458,719	589,875	251,107	330,525	207,658	344,437	1,393,032	2,182,322
2012	896,913	1,256,524	108,588	0	461,501	597,237	2,750,673	3,320,763
2013	280,285	342,688	98,717	123,396		597,237	1,220,210	1,442,323
2014	448,456	456,918	39,487	0	624,384	434,354	1,339,728	2,003,598
2015	140,143	228,459	14,808	24,679	434,354	217,177	585,778	1,059,619
2016	280,285	913,836	44,423	24,679	732,972	760,119	1,954,240	2,756,314

Sources: Langan (1997) for 1997 values and NHF&G for all other years.

Most of the values on this table are approximate because the oyster density and oyster bed boundary were not measured in the same year. In 1997, the density and boundary were mapped by Langan (1997) for all the beds except for the Squamscott River bed. In 2001, the density and boundary were mapped for the Adams Point, Nannie Island, Oyster River and Woodman Point beds. In 2003, only the boundaries were mapped for the Piscataqua River and Squamscott River beds. Boundaries from 1997 were used up until the year that the beds were remapped (2003 for the Squamscott and Piscataqua beds and 2001 for all others). For 2002 onwards, the most recent area for a bed was used starting with the year that the new map was made. This simplification requires the assumption that the bed sizes have not changed over 4-6 years, which may not be justified. The average adult oyster density for Woodman Point in 1993 was taken from NHF&G reports because raw data were not available to calculate this value independently.

Yellow cells indicate that oyster density measurements were not taken at that bed in that year and an assumption regarding the density of oysters was needed for the calculation. Either the closest value from another year or an average of two bracketing years was used.

Open beds include Adams Point, Nannie Island and Woodman Point. Closed beds are: Oyster River, Piscataqua River and Squamscott River.

Indicator: Clams in the Hampton-Seabrook Estuary

Question

What is the current population of clams in Hampton-Seabrook Harbor and how has it changed over time?

Short Answer

The most recent clam population in Hampton-Seabrook Harbor (in 2015) was 1.4 million clams. The population has declined most years since 1997.

PREP Goal

Increase the number of adult clams in Hampton-Seabrook Estuary to 5.5 million clams by 2020 (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

Why This Matters

Soft shell clams provide recreational opportunities to state residents. Clams consume phytoplankton and other detrital material and therefore have a significant impact on coastal and estuarine ecosystems.

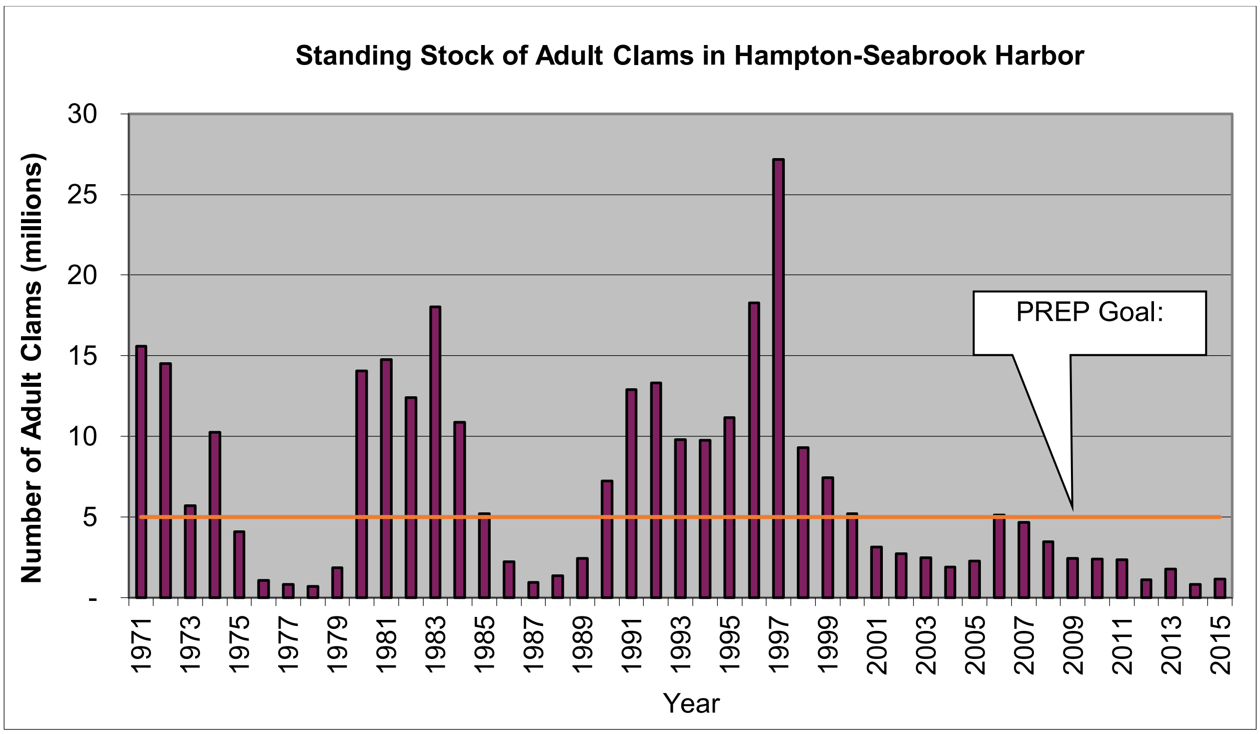

Figure C-1. Standing Stock of Adult Clams in Hampton-Seabrook Harbor. Number of adult clams is calculated by multiplying clam densities by the acreage of clam flats in Hampton-Seabrook Harbor. Data Source: Normandeau Associates, with support from NextEra Energy.

Explanation (from 2018 State of Our Estuaries Report)

In 2015, there were 1.4 million clams in Hampton-Seabrook Harbor. Since 2012, clam populations have remained below the PREP goal of 5.5 million clams and below the average level (2.4 million) from 2009 to 2011 (Figure C-1).

Clams may be limited by a type of cancer (*Hemic neoplasia*) that affects marine bivalves but is not dangerous to humans. Figure C-2 shows that the percentage of clams infected with *Neoplasia* has increased since 2002. Research suggests there are several factors that make clams more susceptible to this disease, especially pollution (mainly heavy metals and hydrocarbons) and warming water temperatures (Carballal et al. 2015).

Green crabs eat clams and have also been shown to reduce clam populations. However, Figure C-3 shows that green crab abundance in Hampton-Seabrook Harbor has steadily declined – for unknown reasons – between 2011 and 2015.

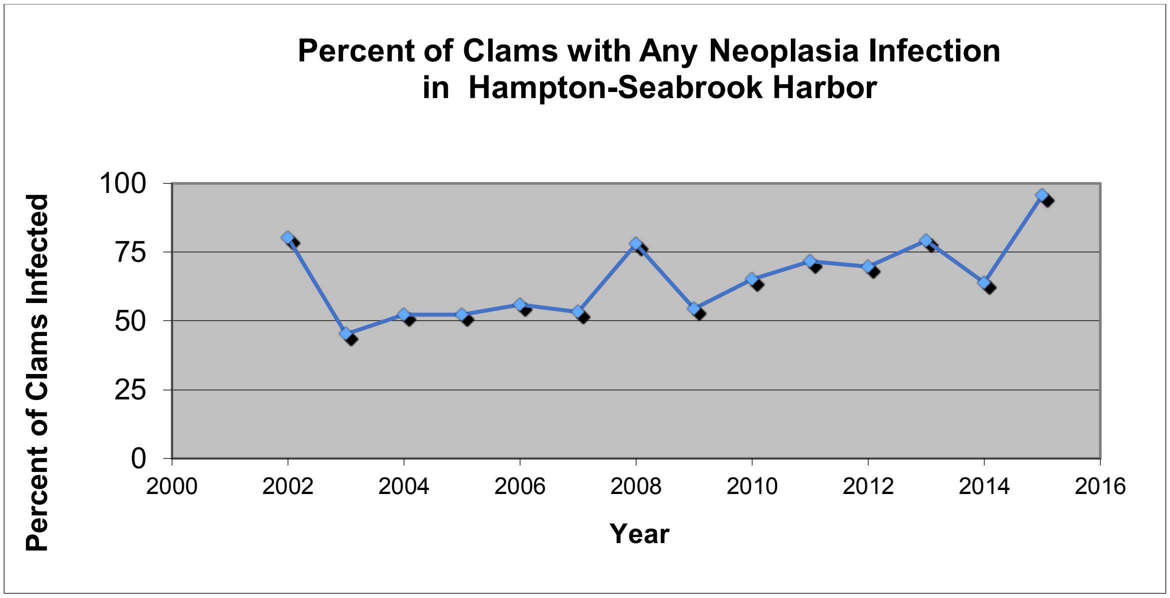

Figure C-2. Percent of clams with any neoplasia infection in Hampton- Seabrook Harbor. Data Source: Normandeau Associates, with support from NextEra Energy.

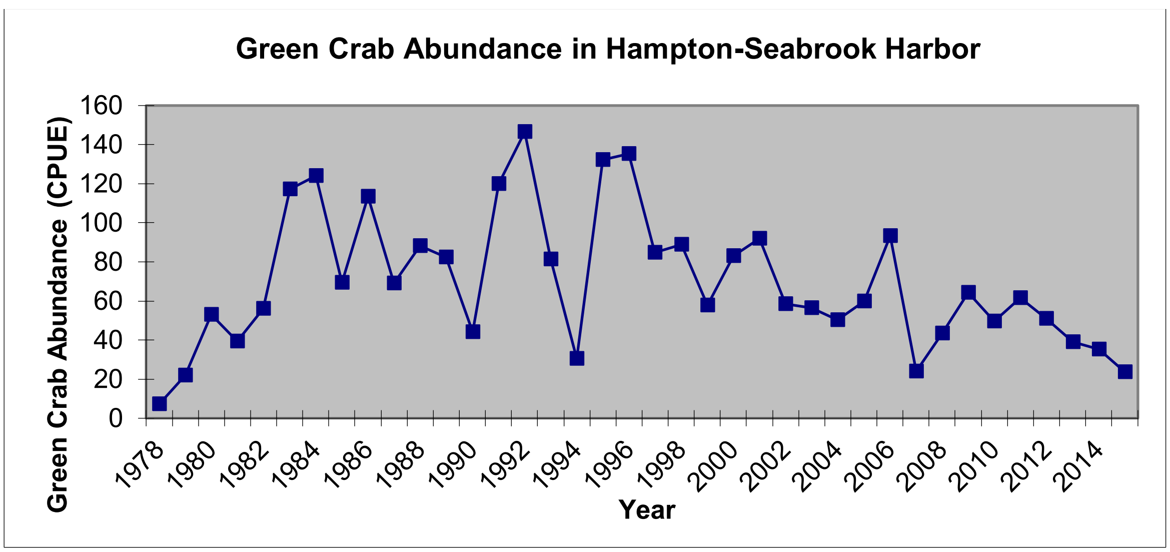

Figure C-3: Green crab abundance in Hampton-Seabrook Harbor. CPUE = catch per unit effort. Crabs are caught in baited traps, twice a month year-round with the exception of February and March. Data Source: Normandeau Associates, with support from NextEra Energy.

<u>Methods and Data Sources</u>
The location of each flat is shown in Figure C-4. For each flat, the mean densities for adults were calculated by summing the mean densities for the >50mm size class using data in the Seabrook Station Annual Data Reports.

The standing stock of adult clams was calculated by multiplying the average density of adult clams in each flat in each year by the most recent estimate of the size of the flat. Clam densities have been measured annually since 1971 but flat boundaries have only been monitored seven times between 1977 and 2015 (Table C-1). For the years when the flat boundaries were not surveyed, it was assumed that the most recent boundary for that flat was still accurate. This assumption introduces some uncertainty into the estimates for these years. The standing stock in the three major flats was summed to estimate the total standing stock in Hampton-Seabrook Harbor.

Looking at adult clam densities (per square meter) is one way to eliminate the uncertainty associated with changes in clam flat area. Figure C-5 shows that densities have been low—relative to previous peaks—for the last 15 years.

Figure C-4. Map of Hampton-Seabrook Estuary, showing location of the three major clam flats.

Table C-1. Acres of the three major clam flats used in this report.

Year	Common Island Flat	Confluence Flat	Middle Ground Flat	Total
1977	54.9	27.2	49.7	131.8
1979	54.8	26.7	53.5	135.0
1981	54	24.7	50.8	129.5
1983	52.7	26.4	49.9	129.0
1984	50	21.7	47.9	119.6
1995	45.7	26.4	47.3	119.4
2002	36.9	23.4	57.8	118.1
2013	32.3	21.9	48.7	102.9

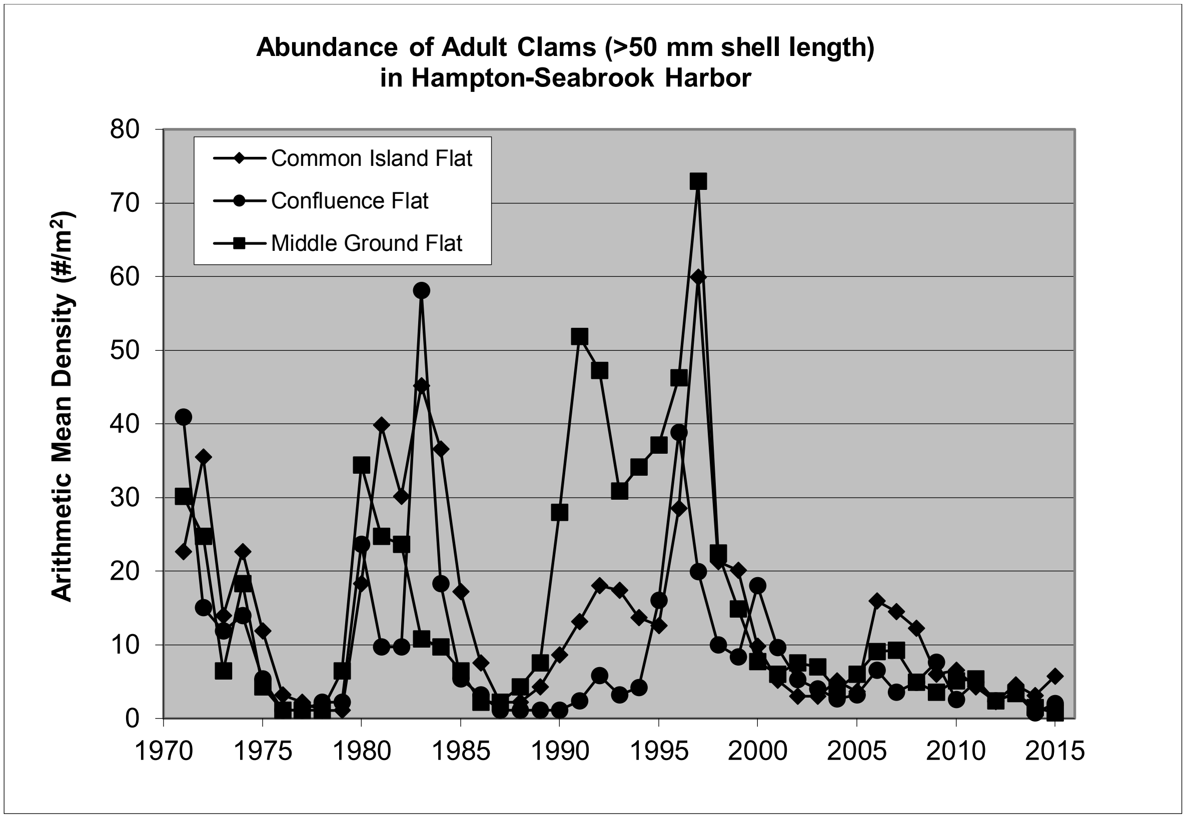

Figure C-5. Abundance of adult clams, measured by number of clams per square meter, for three clam flats. Data Source: Normandeau Associates, with support from NextEra Energy.

Data Sources
The Seabrook Station Soft Shell Clam Monitoring Program, implemented by Normandeau Associates, conducts annual surveys of clam densities in the three major flats in Hampton-Seabrook Harbor.

<u>Technical Advisory Committee (TAC) Discussion Highlights</u>

As part of the January 2017 TAC meeting, participants discussed in detail the methods and results for the clam indicator (PREP 2017c). Complete notes are available at: http://prepestuaries.org/prep-technical-advisory-committee/

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Indicator: Migratory Fish

Question

How have migratory fish returns to the Piscataqua Region changed over time?

Short Answer

Overall migratory river herring returns to the Piscataqua Region increased 69% between 2012 and 2016, however river herring returns have sharply declined for the Oyster and Taylor Rivers. Returns for American shad have been consistently fewer than five since 2011 and zero were reported in 2016. There are no statistically significant trends. A lack of fishable ice resulted in insufficient data for Rainbow Smelt in 2012, 2013, and 2016.

PREP Goal

No goal.

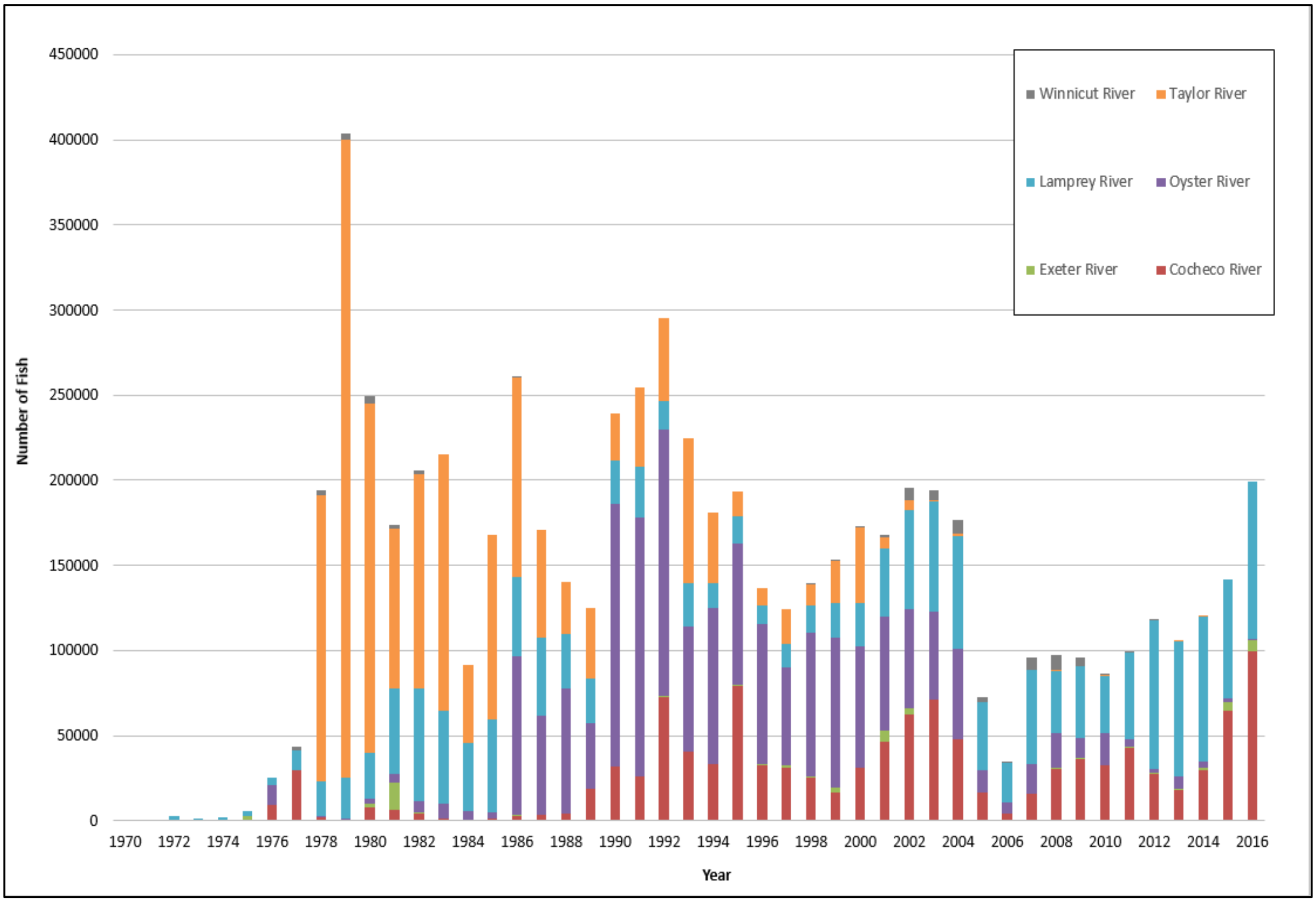

Figure MF-1. Returns of River Herring to NH Coastal Tributaries 1976 – 2016. In 2016 river herring returns are almost exclusively from two rivers: Lamprey River and Cocheco River. Data Source: NH Fish and Game.

Why This Matters

Migratory fish – such as river herring and American Shad – travel from ocean waters to freshwater streams, marshes, and ponds to reproduce. River herring are an important source of food for wildlife and bait for commercial and recreational fisheries.

Explanation (from the 2018 State of Our Estuaries Report)

Observed river herring returns to the coastal rivers of the Piscataqua Region varied during the 1972 - 2016 period (Figure MF-1). Total river herring returning to fish ladders in 2016 reached 199,090. This is a 69% increase from 2012 that was driven by record river herring returns in the Lamprey and Cocheco rivers. Conversely, returns have sharply declined in two other rivers: the Taylor and the Oyster. Due to variability in the dataset there are no statistically significant trends. Declines in river herring returns in some rivers may be due to several factors including: limited freshwater habitat quantity and quality, difficulty navigating fish ladders, safe downstream passage over dams, fishing mortality, pollution, predation, and flood events during upstream migrations. To continue improving river herring returns, NH Fish and Game and the NH Coastal Program continue to work with state, federal, and local partners on dam removal and culvert replacement projects on the Cocheco River (Gonic dams – Rochester), Bellamy River (Sawyer Mill dams – Dover), and Exeter River (Great Dam – Exeter), which was completed in September 2016 (TNC 2009; NHF&G 2017).

Despite increases in river herring returns for some rivers, the Oyster and Taylor River populations have declined dramatically in recent years. Additionally, the Winnicut River fish ladder has been declared ineffective and NH Fish and Game is working on a solution (Dionne 2017). The 2016 river herring returns are almost exclusively from the Lamprey and Cocheco Rivers.

Methods and Data Sources

Measurements of abundance for three diadromous fish species (Table MF-1) were tracked for each year using data from the NH Fish and Game Department (NHF&G). Abundance was measured by counts of fish passing through fish ladders in the spring. Abundance was plotted versus year to illustrate the trend in returns over time.

Table MF-1: Species, Measure and Location for Migratory Fish Counts*

Species	Abundance Measure	Location
Herring, Alewife and Blueback Herring (*Alosa pseudoharengus* and *Alosa aestivalis)*	Passage through fish ladders (# of fish/yr)	Exeter, Lamprey, Oyster, Cocheco, Winnicut, and Taylor Rivers
American Shad (*Alosa sapidissima*)	Passage through fish ladders (# of fish/yr)	Exeter, Lamprey, and Cocheco Rivers

* Extensive information on methods and results can be found in NHF&G 2017.

NHF&G also has tracked abundance of five other diadromous fish: Atlantic salmon, sea lamprey, American eel (young-of-year), brown trout, and striped bass. Very few Atlantic salmon have returned to rivers in the Piscataqua River in the past decade, making this species an insensitive indicator. Between 1992 and 2003, only 44 fish were recorded in fish ladders. NHF&G discontinued the Atlantic salmon stocking and monitoring programs in 2003. The abundance of brown trout and striped bass were tracked by voluntary reports from anglers rather than designed surveys implemented by NHF&G staff. (Note: NHF&G discontinued the sea run brown trout program in 2015.) Therefore, the abundance results for these species were not included in this indicator.

The number of rainbow smelt (*Osmerus mordax*) caught by fisherman (per year) has also been tracked by NHF&G since 1978. Rainbow smelt are primarily fished in the winter months by cutting a hole in the ice. However, 3 of the last five years have not seen a smelt fishery due to a lack of ice over the winter months. Therefore, this species was not included as an indicator.

Data Sources

NH Fish and Game Anadromous Fish Monitoring Programs provided data for this indicator.

Additional Results (Beyond the Data Reported in the 2018 SOOE)
Many factors influence the returns of diadromous fish. Each species has its own life cycle history and has different habitat needs as larvae, juvenile and adults. The following comments summarize major patterns in the data. For a more detailed discussion, please see NHF&G (2017): http://scholars.unh.edu/prep/396/

New Hampshire's coastal rivers once supported abundant runs of anadromous fish, but these and other diadromous species were unable to reach historical, freshwater spawning habitat due to the construction of dams to support the explosion of the textile industry. During the late 1950’s through the early 1970’s, NHF&G addressed this issue by installing “fishways” on the Cocheco, Exeter, Oyster, Lamprey, Taylor, and Winnicut rivers. Herring and shad are discussed separately below. In general, herring have adapted to dams much better than shad. While dams eliminated shad returns, herring were able to find pockets of habitat for spawning at the base of dams (NHF&G 2017).

Table MF-2 analyzes trends over different periods of time. For the entire time period (1976-2016), the Cocheco and the Lamprey show a statistically significant increase in river herring returns. The Taylor and Winnicut Rivers show a statistically significant decrease in returns, while the Exeter and Oyster Rivers show no trends.

Over the last 10 years, however, the Exeter River shows a significant increase while the Oyster River shows a significant decrease. Over the last five years, the only significant trend is an increase at the Exeter River.

Table MF-2. Statistical trends analysis for river herring returns for the entire period, last 10 years and last 5 years. Results based on Mann-Kendall Trend Test performed by NH Fish and Game.

	1976-2016	2007-2016	2012-2016
Cocheco	Significant Increase	No Trend	No Trend
Exeter	No Trend	Significant Increase	Significant Increase
Oyster	No Trend	Significant Decrease	No Trend
Lamprey	Significant Increase	Significant Increase	No Trend
Taylor	Significant Decrease	Significant Decrease	No Trend
Winnicut	Significant Decrease	Significant Decrease	No Trend

Individual data plots for each river for herring returns are shown in Figure MF-2. One of the most important observations regarding river herring returns is that high water conditions during the spawning runs affect fish ladder efficiency thereby dramatically reducing the number of returns as noted in all rivers from 2005 through 2007. Once the river herring population in the Cocheco River became established after construction of a fish ladder, herring returns have improved but are subjected to lows likely due to high water conditions and availability of effective downstream passage over dams. Returns on the Cocheco have steadily increased since 2013 (Figure MF-2). In 2016, 99,241 river herring were counted as returning, representing the highest return in 41 years of operation (NHF&G 2017).

Since 2012, herring returns to the Lamprey River have been at the highest levels since the fishways were introduced in the 1970s (Figure MF-2). Lamprey River returns have been increasing since 1997. NHF&G (2017) point out that stock enhancement at Pawtuckaway Lake may be providing some benefit.

Following the modification of a fish ladder in the Exeter River in 1999, herring runs increased for a few years (Figure MF-2) but then subsided. A 2005 NHF&G report attributed the low returns to harvest pressure, inadequate downstream passage over dams, and water quality issues such as low dissolved oxygen in the upstream impoundment (NHF&G 2006). In the years 2012 through 2014, the number of returns increased but at a slow rate in the Exeter River. In contrast, in 2015 and 2016, the returns increased more dramatically. In 2016, 6,622 river herring returned to the Exeter fish ladder: the third highest return since 1975 and the highest return since 2001. Increases have been attributed to changes in how water flows were controlled below the fishway to widen the attraction area of the fishway (NHF&G 2017). In the summer of 2016, just after the spawning season, the Great Dam on the Exeter River was removed; however, NHF&G will continue to monitor returns to the

Exeter River despite the removal of the dam. NHF&G modified the fishway at the next dam upriver (Pickpocket Dam) to allow for counting and biological sampling of herring to maintain the time series for the Exeter River.

Herring returns to the Oyster River continued to decline throughout this period (Figure MF-2). In 2016, only 863 river herring returned to the Oyster River; this is the lowest return since 1979 and is far below the average of 43,597 fish over the previous 40 years (NHF&G 2017). Over the last 20 years, one of the most dramatic changes occurred in 2005 (Figure MF-2), which could be attributed to several years of unusually wet summers. These high-flow conditions decrease the effectiveness of the fishways and could decrease returns.

The Taylor River history has similarities with Oyster River. Very high returns in the 1970s have been followed by steady losses with returns essentially absent in most recent years. In 2005, most likely due to very wet years, the returns dramatically decreased and have not recovered (Figure MF-2). NHF&G (2017) also point to eutrophication of the upstream impoundment as an important factor. Daily monitoring of fish runs during spawning has been discontinued by NHF&G. Instead, the Taylor River will only be monitored on a weekly basis, although daily monitoring may be re-implemented if there is evidence of a renewed spawning run. Finally, state and federal agencies are considering whether to remove or replace the Taylor River dam complex. In the summer of 2016, modifications to the fishway were begun. This work is being completed in conjunction with bridge construction just below the dam and fish ladder (NHF&G 2017).

At the Winnicut River, the period of 2002 through 2009 saw some modest runs (between 5,000 and 10,000 returns). However, since that period, returns have dropped off and no fish were observed passing through the fishway in 2016 (Figure MF-2). This is most likely due to modifications to the dam and fishway. In the fall of 2009, the head-of-tide dam on the Winnicut River was removed and a pool-and-weir fish passage was constructed in the fall of 2011. The passage was located approximately 100 m upstream of the former dam site; the plan was for fish to pass through a constricted channel under a bridge created after the impoundment was lowered. However, each year since 2012, river herring have been observed in small quantities below the fishway but never observed passing through. NHF&G staff have concluded that the velocity of the water prevents herring from passing through. A solution is currently being explored.

In the absence of restoration efforts, no American Shad returned to NH fishways in 2016 (Figure MF-3). There were no shad returns to Exeter or Lamprey since 2011. The Cocheco River saw less than five returns per year in this latest period, and only one fish per year in 2013, 2014 and 2015. As noted earlier, shad are far less able to adapt to barriers to spawning habitat than river herring. As with river herring, the declines in shad returns are likely compounded by flood waters, impoundment water quality degradation, and lack of supplemental stocking since 2009. Returns to the Lamprey and Cocheco Rivers have been minimal as well, largely because restoration efforts (supplemental stocking) have focused on the Exeter River since 1989, leaving only a small residual returning spawning stock.

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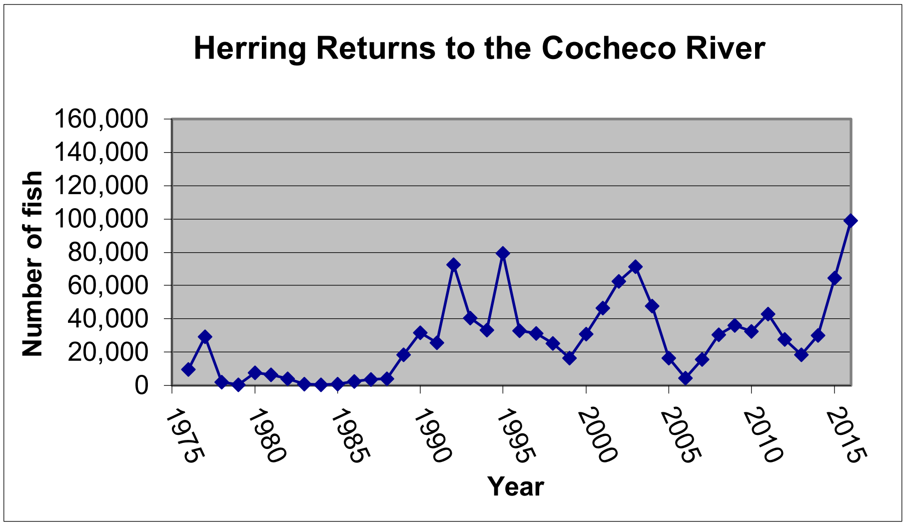
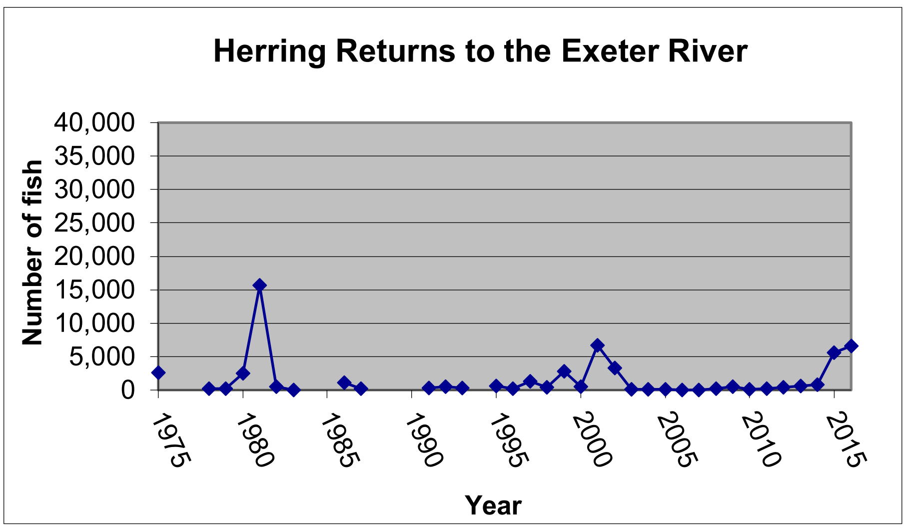
TNC. 2009. Assessment of Road Crossings for Improving Migratory Fish Passage in the Winnicut River Watershed. The Nature Conservancy. http://scholars.unh.edu/prep/397/

Figure MF-2. Returns of river herring to fish ladders on Piscataqua Region rivers. Plots include data from 2016. Note that the Y-axis scale is not uniform from plot to plot.





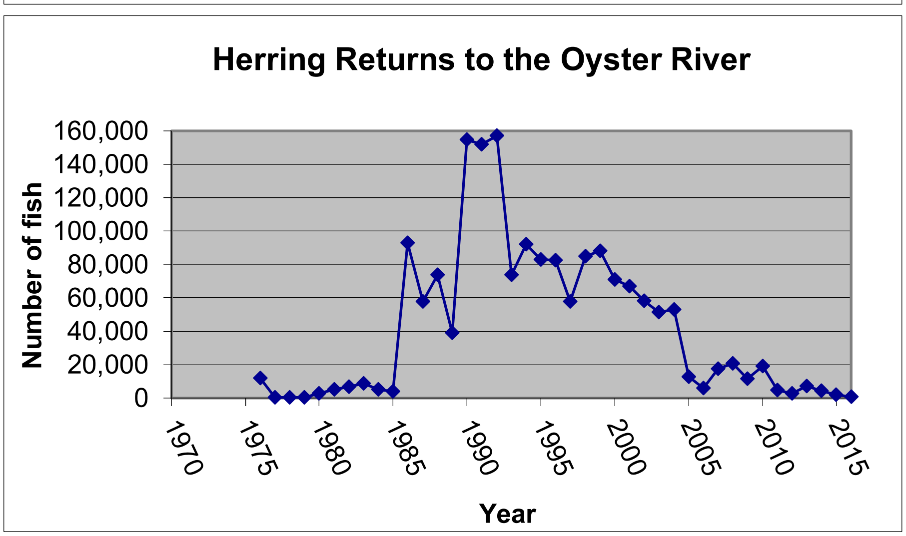
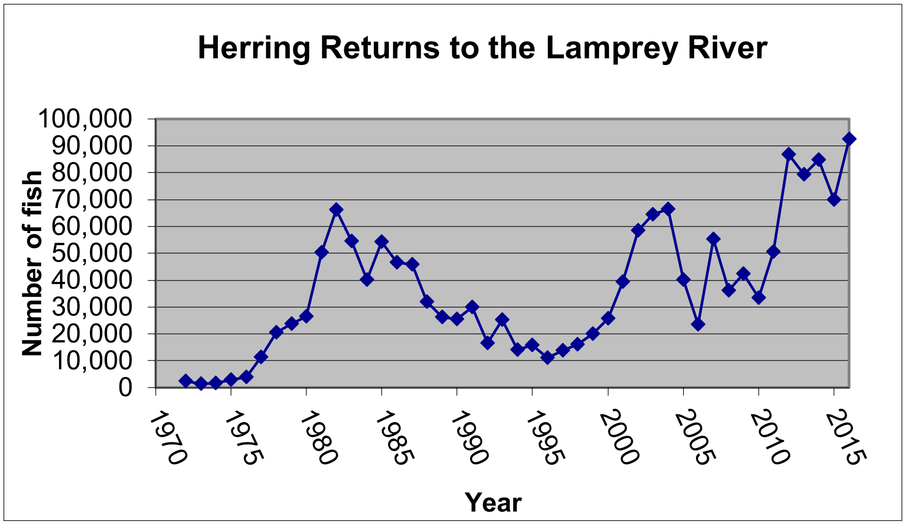
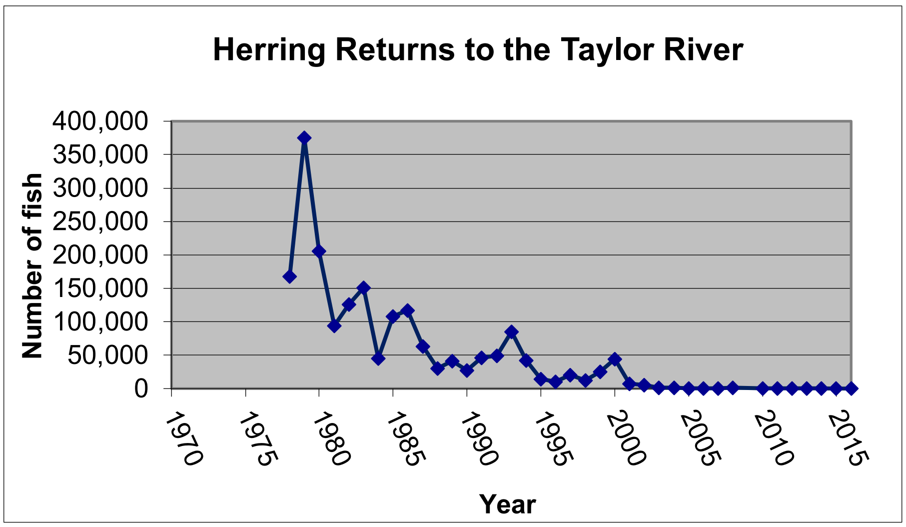


Figure MF-2 (continued). Returns of river herring to fish ladders on Piscataqua Region rivers. Plots include data from 2016. Note that the Y-axis scale is not uniform from plot to plot.





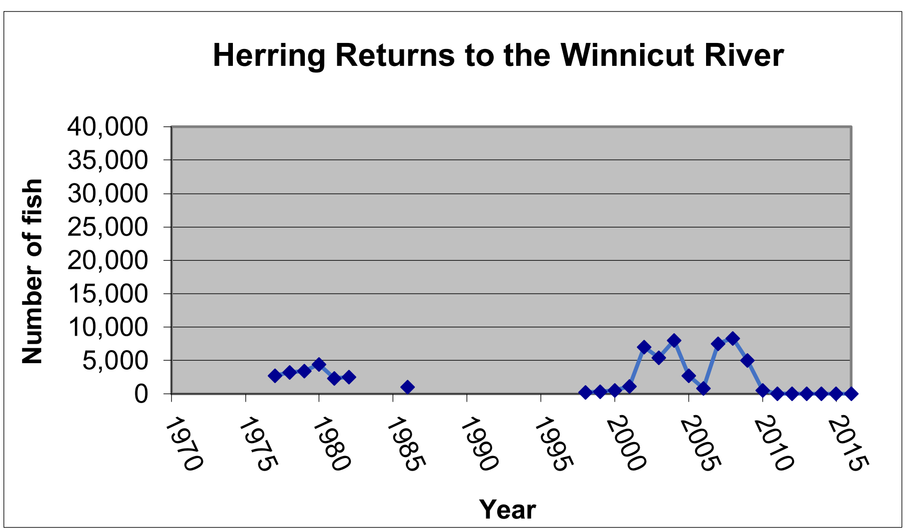


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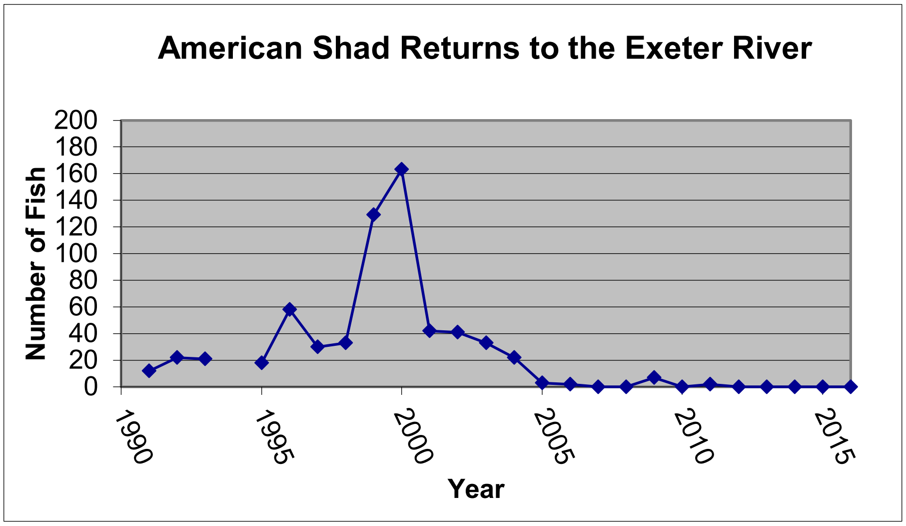
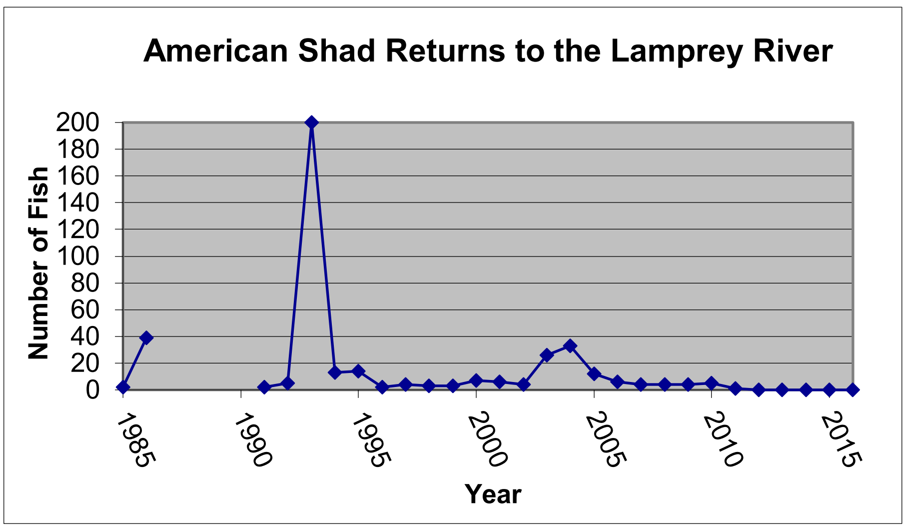
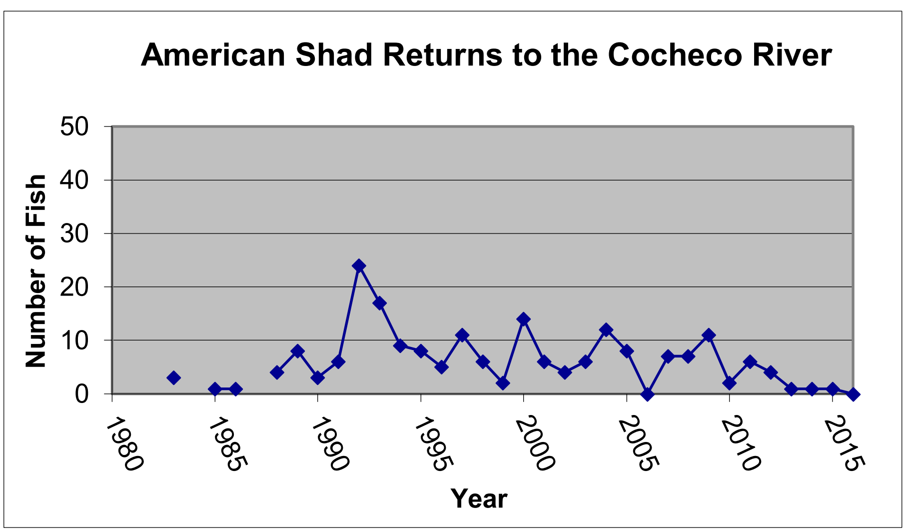
Figure MF-3. Returns of American Shad to fish ladders on Piscataqua Region rivers. Plots include data from 2016. Note that the Y-axis scale is not uniform from plot to plot.







Indicator: Conservation Lands (general)

Question

How much of the land in the 52 communities that make up the Piscataqua Region is permanently conserved or considered public lands?

Short Answer

There has been 130,302 acres conserved as of May 2017; that is 15.5% of the total land area in the 52-town Piscataqua Region. This represents an increase of 5% (41,555 acres) in new land area coming under conservation since 2011. Focusing on the 22 coastal communities in the Piscataqua Region, 49,918 acres of land have been conserved to date. That represents 19.6% of the land area in those 22 towns, and is approaching the PREP goal of 20%.

PREP Goal

Conserve 20% of the watershed by 2020 (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

Why This Matters

Our region is under pressure from population growth and associated development (see Housing Permits Indicator). Conserving a network of natural lands across the region is the most effective action to take to ensure clean water, healthy and abundant wildlife populations, to minimize flood damages and to provide a diversity of quality recreational opportunities.

Explanation (from the 2018 State of Our Estuaries Report)

In the full 52-town Piscataqua Region there has been 130,302 acres conserved as of May 2017. This amounts to 15.5% of the total land area in the region and represents an increase of 5% in new land area coming under conservation (41,555 acres) since 2011. Of all the acres considered conserved, 82% of them are under permanent protection. An additional focus for this data is on the 22 coastal communities in the region. These are the communities that are tidally influenced in the coastal zone and together are seeing the greatest development pressures. There has been a total of 49,918 acres of land conserved in these communities. This represents 19.6% of the land area in the 22 towns, and is very close to the PREP goal of 20%.

The percentage of conserved land area protected in each town is shown in Figure CG-1. As of 2017, 18 communities have greater than 20% conserved lands, and 9 communities have between 15- 20% conserved lands. Overall, conservation lands have increased across most of the region, but there are still communities where conservation lands as a total percentage of the municipality's land area are below 5% (yellow). Figures CG-1 and CG-2 (HUC-12 analysis) highlight areas where conservation efforts have been significant (+30% of total land area) and these include Great Bay, Exeter-Squamscott, Lamprey River, Oyster River, Pawtuckaway Pond and Scamen Brook-Little River. Conversely, areas where conserved lands are lower include the Cocheco, Salmon Falls, Bog Brook-Little River and Great Works River.

Recent progress suggests the region can meet PREP's goal of 20% of the watershed conserved. Although the 22 coastal communities are very close at 19.6%, region-wide an additional 37,700 acres will need to be conserved in order to achieve the goal.

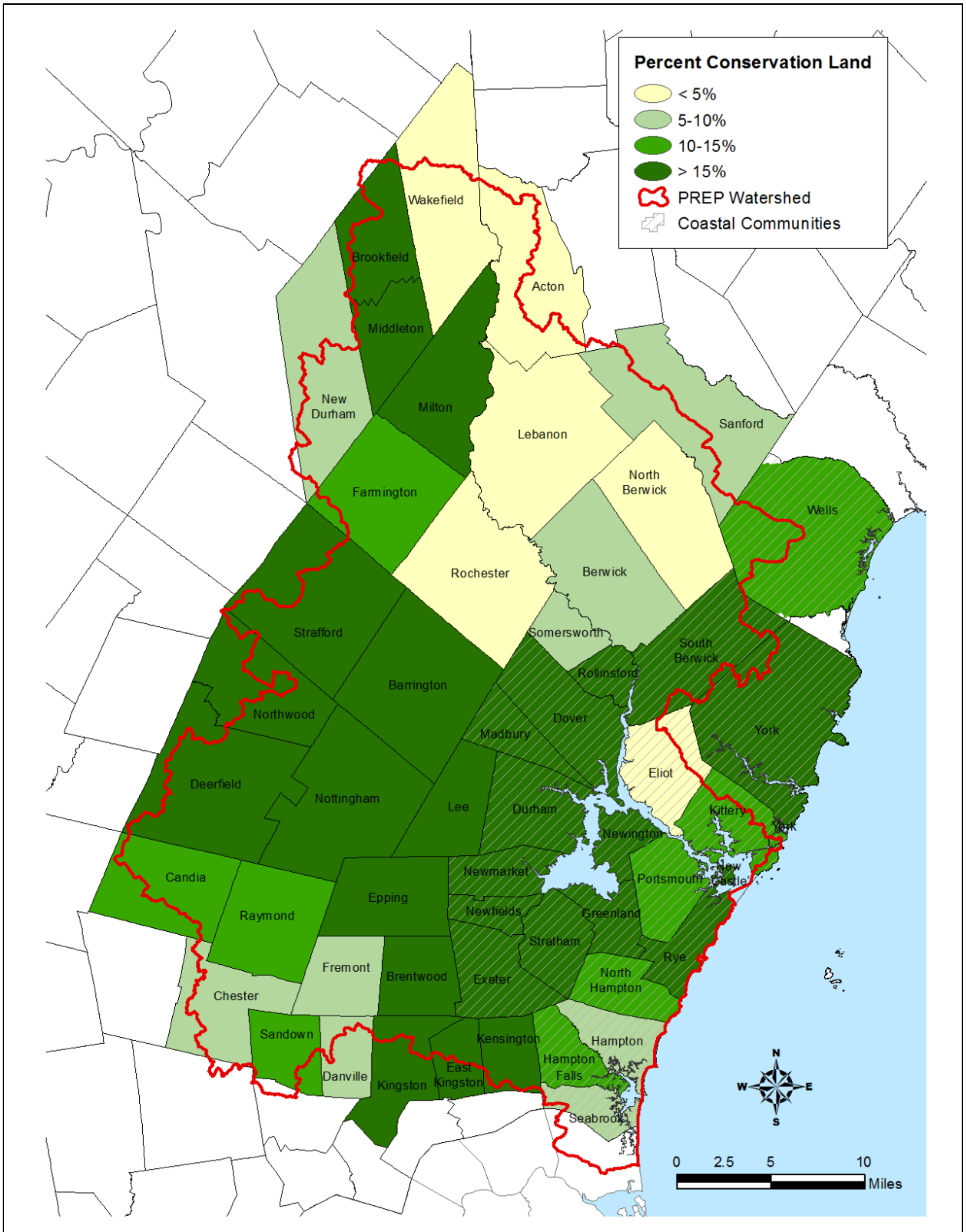


Figure CG-1. Land conservation by percent of total land area for each Piscataqua Region community. Data Source: NH GRANIT.

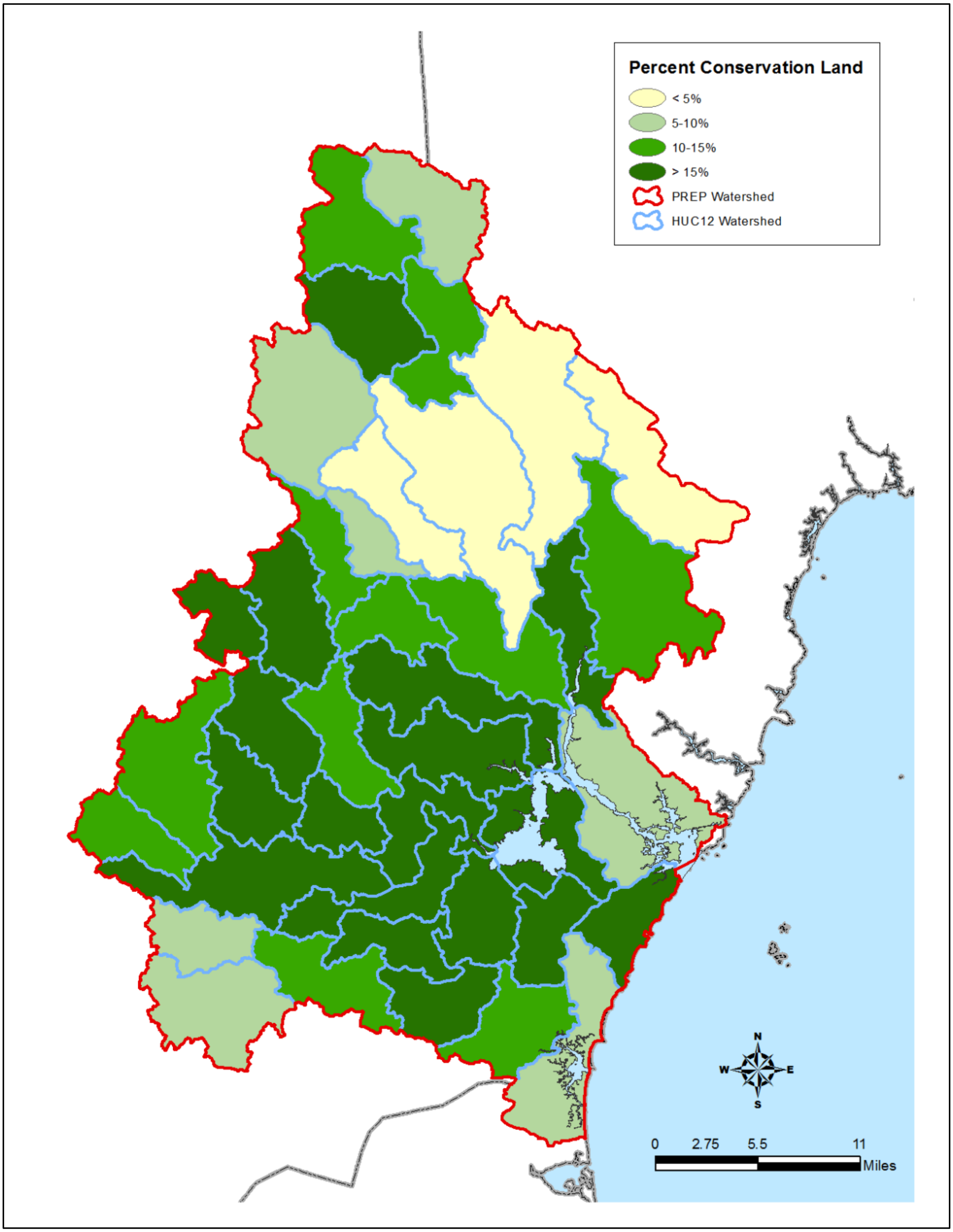


Figure CG-2. Land conservation by percent of total area for each subwatershed (HUC-12). Data Source: NH GRANIT.

Methods and Data Sources

The Maine and New Hampshire databases were queried to identify the conservation lands within the Piscataqua Region watershed (HUC8 01060003). The total acres of public and private conservation lands in the watershed, and the 22 coastal communities in the watershed, were calculated by summing the land area of individual conservation polygons (Table CG-1).

The land area was calculated by subtracting the areas of surface waters from the town boundary polygons. To determine the area of surface waters, GRANIT combined the relevant National Hydrography Dataset Waterbody features (with FType = 390 "LakePond," 436 "Reservoir," and 493 "Estuary") and Area features (with FType = 336 "CanalDitch," 364 "Foreshore," 403 "Inundation Area," 431 "Rapids," 445 "SeaOcean," 455 "Spillway," and 460 "StreamRiver.") The percentage of the Piscataqua Region watershed that is conserved was calculated by dividing the total acres of conservation land by the total land area of the watershed. The same method was used to determine the percent of conservation lands in the 22 coastal communities.

Conservation lands were grouped into "permanent," "unofficial," and "unknown" categories using the protection level fields in each state database (Table CG-2). Permanent conservation lands are protected from development through legally enforceable mechanisms, such as conservation easements, deed restrictions or ownership by an organization or agency whose mission emphasizes land protection. Unofficial conservation lands are not permanently protected; rather, they are owned by a public agency or private organization with the stated intent of protecting the land. The "unknown" designation is self-explanatory.

Data Sources

The most recent dataset of conservation lands from the Maine Office of GIS for the Maine towns and NH GRANIT for the New Hampshire towns were the primary data sources for this indicator.

References Cited

PREP 2010. Piscataqua Region Comprehensive Conservation and Management Plan, Piscataqua Region Estuaries Partnership: D.B. Truslow Associates, Mettee Planning Consultants, 2010, Durham, NH. http://scholars.unh.edu/prep/22/

Table CG-1: Conserved land in the Piscataqua Region communities (municipalities).

Town Name	Conservation Lands 2017 (acres)	Town Area (acres)	Percent Conservation 2017
Barrington, NH	4,705.8	29,719.0	15.8
Brentwood, NH	3,107.1	10,728.1	29.0
Brookfield, NH	3,231.4	14,593.0	22.1
Candia, NH	2,400.4	19,328.9	12.4
Chester, NH	1,310.7	16,606.2	7.9
Danville, NH	679.9	7,438.7	9.1
Deerfield, NH	6,953.2	32,575.7	21.3
Dover, NH*	3,271.3	17,036.9	19.2
Durham, NH*	6,486.3	14,251.1	45.5
East Kingston, NH	1,054.1	6,318.0	16.7
Epping, NH	4,570.0	16,476.6	27.7
Exeter, NH*	4,095.6	12,540.6	32.7
Farmington, NH	2,406.9	23,213.0	10.4
Fremont, NH	1,055.8	11,033.1	9.6
Greenland, NH*	1,451.9	6,722.5	21.6
Hampton, NH*	760.6	8,287.3	9.2
Hampton Falls, NH*	1,139.6	7,719.6	14.8
Kensington, NH	1,871.0	7,616.4	24.6
Kingston, NH	2,471.3	12,494.3	19.8
Lee, NH	3,208.7	12,685.0	25.3
Madbury, NH*	1,804.4	7,383.6	24.4
Middleton, NH	2,449.7	11,559.0	21.2
Milton, NH	3,813.2	21,088.6	18.1
New Castle, NH*	106.9	506.2	21.1
New Durham, NH	2,000.5	26,345.5	7.6
Newfields, NH*	1,321.7	4,540.8	29.1
Newington, NH*	1,349.6	5,214.5	25.9
Newmarket, NH*	1,973.8	8,034.5	24.6
North Hampton, NH*	1,308.9	8,861.8	14.8
Northwood, NH	3,021.9	17,965.0	16.8
Nottingham, NH	9,241.7	29,839.7	31.0
Portsmouth, NH*	1,417.1	10,003.5	14.2
Raymond, NH	1,936.9	18,438.3	10.5
Rochester, NH	1,415.3	28,329.2	5.0
Rollinsford, NH*	763.5	4,681.3	16.3
Rye, NH*	1,693.4	8,053.4	21.0
Sandown, NH	1,052.3	8,888.5	11.8

Table CG-1 (cont'd)

Town Name	Conservation Lands 2017 (acres)	Town Area (acres)	Percent Conservation 2017
Seabrook, NH*	508.8	5,664.7	9.0
Somersworth, NH	406.2	6,219.2	6.5
Strafford, NH	8,915.2	31,151.8	28.6
Stratham, NH*	1,692.0	9,655.1	17.5
Wakefield, NH	1,021.7	25,264.0	4.0
Acton, ME	570.8	24,216.3	2.4
Berwick, ME	1,304.4	23,779.6	5.5
Eliot, ME*	619.2	12,609.4	4.9
Kittery, ME*	1,695.6	11,378.2	14.9
Lebanon, ME	958.6	34,957.8	2.7
North Berwick, ME	847.2	24,265.1	3.5
Sanford, ME	2,401.9	30,314.8	7.9
South Berwick, ME*	3,987.5	20,468.8	19.5
Wells, ME*	4,588.7	36,427.3	12.6
York, ME*	7,882.1	34,913.8	22.6
TOTAL:	**283,623.4**	**1,935,631.4**	**15.5%**
Coastal Community TOTAL:	**63,349.4**	**399,539.3**	**19.6%**

*** = Coastal Community**
All reported acreages refer to land area only; surface water areas not included.
Acreages are reported for entire town; several towns are only partially within the Piscataqua Region watershed.

Table CG-2: Conservation lands in the Piscataqua Region Watershed 2017

Protection Type	New Hampshire	Maine	Total	% of Total
Permanent	83,100.3	23,156.6	106,256.9	81.5%
Unofficial	16,088.9	1,675.1	17,764.0	13.6%
Unknown	6,257.2	24.2	6,281.4	4.8%
Total	105,446.4	24,855.9	130,302.3	100.0%
% of Total	80.9%	19.1%	100.0%	

Indicator: Conservation Lands (focus areas)

Question

How much of the Conservation Focus Areas in the Piscataqua Region are permanently conserved or considered conserved public lands?

Short Answer

In 2017, 34.4% of Conservation Focus Areas (CFAs) in New Hampshire and 14.2% of CFAs in Maine were conserved. This represents a combined impact of 40.9% of progress towards the PREP goal of conserving 75% of all total acres in the CFAs. Given the challenges associated with conserving these important lands, the goal of conserving 75% (or 124,659 acres) of these core focus areas in both ME and NH by 2025 will take significant additional effort to achieve.

PREP Goal

Conserve 75% (124,659 acres) of lands identified as conservation focus areas by 2025 (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

Why This Matters

The Piscataqua Region is home to exceptional, unfragmented natural areas and corridors supporting important wildlife populations, water filtration capacity and storm buffering. Due to the infrastructure and growth pressures in our region, there is limited time to protect these areas in order to ensure they will continue to provide benefits for future generations.

Explanation (from 2018 State of Our Estuaries Report)

T*he Land Conservation Plan for New Hampshire's Coastal Watersheds* (Zankel et al. 2006) and *The Land Conservation Plan for Maine's Piscataqua Region Watersheds* (Walker et al. 2010) are two science-based regional conservation master plans developed by a range of municipal, regional, and technical partners to guide conservation efforts throughout the region. The plans identify 90 CFAs that have high conservation values associated with them (such as rare habitat for threatened or endangered species). Of the 166,212 acres that fall within these designated CFAs, a total of 51,062 acres have been permanently protected (40.9% of progress towards the PREP goal of 124,659 acres). That represents an increase of 3.7% since 2011 or 5,197 new conserved acres, with the majority of these increases being in NH. There are a few notable areas where gains have been significant (over 50% increases since 2011), including the Winnicut River, Isinglass River, Kennard Hill and Birch Hill Lowlands. There are 16 CFAs where 50% or more of the acres have been protected (see Figure CF-1). CFAs where 70% or more have been protected include the Upper and Middle Winnicut, Creek Pond Marsh, Lower Lubberland Creek, Exeter River, Fabyan Point and Laroche and Woodman Brooks. Continued, focused efforts are needed to meet the goal in protecting 75% of these CFAs by 2025.

Methods and Data Sources

The general conservation lands database was queried to identify the intersection of the conservation lands data and conservation focus areas data within the Piscataqua Region watershed (HUC8 01060003). Only core areas for conservation focus areas were used for this analysis (Table CF-1, CF-2.)

Data Sources

The most recent dataset of conservation lands from the Maine Office of GIS for the Maine towns and NH GRANIT for the New Hampshire towns were the primary data source for this indicator. Conservation focus area boundaries were obtained from Zankel et al. (2006) and Walker et al. (2010).

References Cited

PREP 2010. Piscataqua Region Comprehensive Conservation and Management Plan, Piscataqua Region Estuaries Partnership: D.B.Truslow Associates, Mettee Planning Consultants, 2010, Durham, NH. http://scholars.unh.edu/prep/22/

Walker S, Smith T, Schumacher P, Czapiga J, Sowers D, Oman-Saltmarsh J, Dest P. 2010. The Land Conservation Plan for Maine's Piscataqua Region Watersheds. Maine Beginning with Habitat, Wells National Estuarine Research Reserve, Southern Maine Regional Planning Commission, and Piscataqua Region Estuaries Partnership. Published by the Piscataqua Region Estuaries Partnership, Durham, NH. http://scholars.unh.edu/prep/32/

Zankel M, Copeland C, Ingraham P, Robinson J, Sinnott C, Sundquist D, Walker T, Alford J. 2006. The Land Conservation Plan for New Hampshire's Coastal Watershed. PREP Publications. 174. http://scholars.unh.edu/prep/174

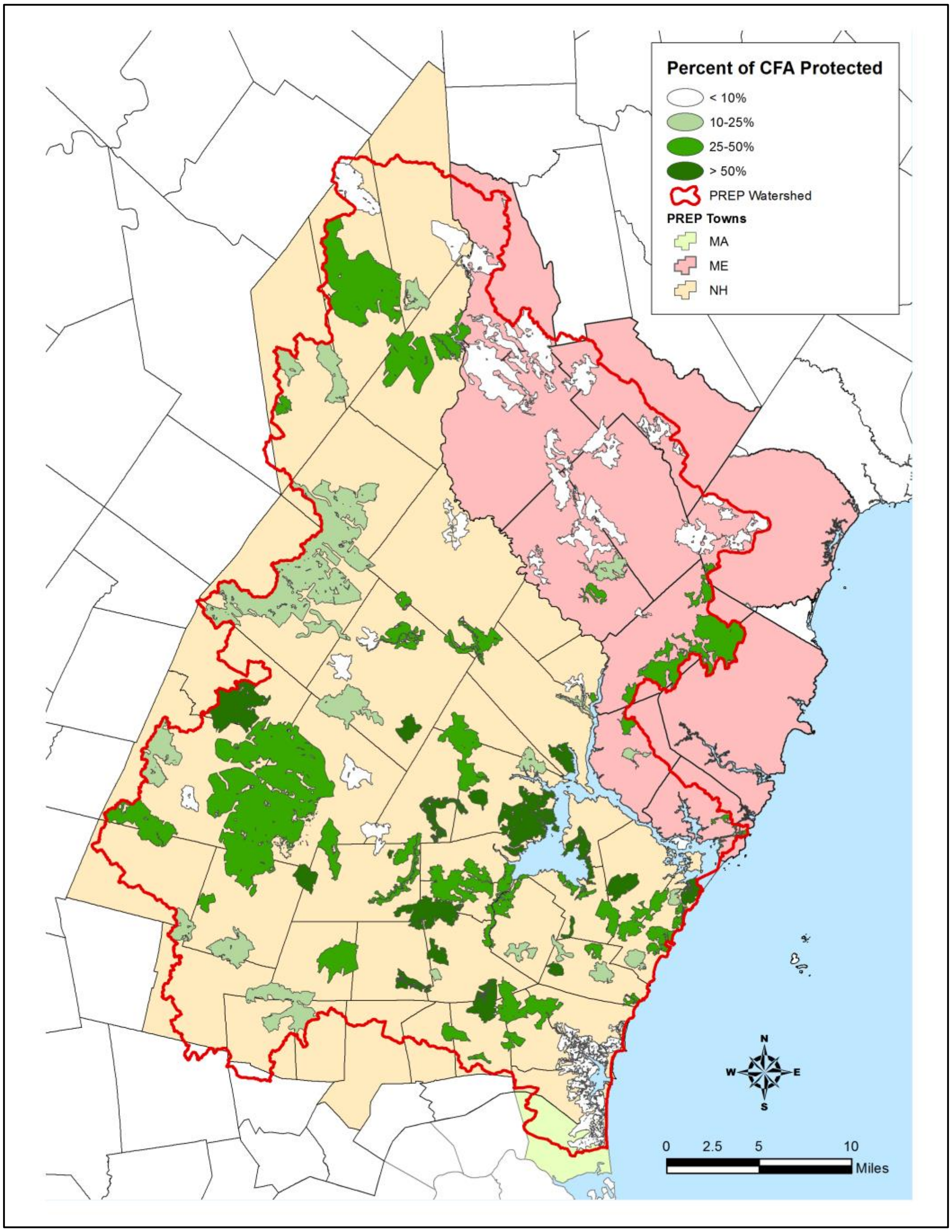


Figure CF-1. Percent of each Conservation Focus Area in the Piscataqua Region conserved. Data Source: NH GRANIT.

Table CF-1: Conservation lands in individual conservation focus areas in New Hampshire in 2017.

Core Focus Area Name	Conservation Lands 2017 (acres)	Area of Core CFA (acres)	Percent of Core CFA Area (2017)	Conservation Lands 2011 (acres)	Percent of Core CFA area (2011)	Acreage Change	Percentage Change
Awcomin Marsh	346.4	885.0	39.1%	334.1	37.7%	12.3	1.4%
Bailey Brook	138.5	564.2	24.6%	115.7	20.5%	22.8	4.1%
Bayside Point	120.7	333.1	36.2%	120.7	36.2%	0.0	0.0%
Bellamy River	529.4	796.0	66.5%	529.4	66.5%	0.0	0.0%
Birch Hill Road Lowlands	30.2	57.7	52.2%	0.0	0.0%	30.2	52.2%
Bloody and Dudley Brooks	357.2	552.8	64.6%	361.2	65.3%	-3.9	-0.7%
Blue Hills	3,708.2	16,879.0	22.0%	2,894.7	17.2%	813.5	4.8%
Bumfagging Hill	465.0	2,361.1	19.7%	478.9	20.3%	-13.8	-0.6%
Candia Road	0.0	549.2	0.0%	0.0	0.0%	0.0	0.0%
Cocheco Headwaters	173.5	1,691.1	10.3%	173.5	10.3%	0.0	0.0%
Coldrain Pond	129.5	906.3	14.3%	129.5	14.3%	0.0	0.0%
Cooper Cedar Woods	169.2	379.5	44.6%	130.9	34.5%	38.3	10.1%
Creek Pond Marsh	632.6	671.2	94.2%	632.6	94.2%	0.0	0.0%
Crommet/Lubberland Creeks	2,312.0	3,798.7	60.9%	2,201.5	58.0%	110.5	2.9%
Davis and Oak Hill	38.8	1,337.3	2.9%	38.8	2.9%	0.0	0.0%
Dogtown Swamp	40.5	164.1	24.7%	35.8	21.8%	4.7	2.9%
Dumplingtown Hill	118.7	364.9	32.5%	118.7	32.5%	0.0	0.0%
Exeter River	480.8	620.3	77.5%	436.5	70.4%	44.3	7.1%
Fabyan Point	799.1	1,071.6	74.6%	797.8	74.4%	1.3	0.2%
Fordway Brook Headwaters	125.5	941.4	13.3%	118.3	12.6%	7.2	0.7%
Fresh Creek	0.0	325.9	0.0%	0.0	0.0%	0.0	0.0%
Garvin Brook	37.0	82.8	44.7%	37.0	44.7%	0.0	0.0%
Great Bog	661.4	989.2	66.9%	645.4	65.2%	16.0	1.7%
Great Meadows	816.6	1,400.2	58.3%	816.7	58.3%	-0.1	0.0%
Hampton Marsh	645.6	7,437.6	8.7%	669.5	9.0%	-24.0	-0.3%
Hart Brook / Mt. Tenneriffe	1,121.8	3,503.0	32.0%	764.7	21.8%	357.1	10.2%
Johnson and Bunker Creeks	178.0	747.6	23.8%	178.0	23.8%	0.0	0.0%

Kennard Hill	575.2	1,294.6	44.4%	0.0	0.0%	575.2	44.4%
Lamprey River	627.8	1,722.2	36.5%	536.6	31.2%	91.2	5.3%
Langley and Cyrus Ponds	0.0	1,027.8	0.0%	0.0	0.0%	0.0	0.0%
LaRoche and Woodman Brooks	350.5	444.1	78.9%	350.6	78.9%	0.0	0.0%
Lower Berry's Brook	58.4	270.2	21.6%	58.4	21.6%	0.0	0.0%
Lower Cocheco River	107.2	485.5	22.1%	107.2	22.1%	0.0	0.0%
Lower Fordway Brook	214.0	1,679.1	12.7%	201.5	12.0%	12.5	0.7%
Lower Isinglass River	518.2	1,260.9	41.1%	224.3	17.8%	293.8	23.3%
Lower Lamprey River	616.6	1,228.1	50.2%	535.7	43.6%	80.8	6.6%
Lower Little River	76.8	195.9	39.2%	76.8	39.2%	0.0	0.0%
Lower Lubberland Creek	170.7	239.1	71.4%	189.1	79.1%	-18.4	-7.7%
Lower Piscassic River	1,280.1	3,027.2	42.3%	1,208.3	39.9%	71.9	2.4%
Lower Winnicut River	61.4	229.0	26.8%	61.4	26.8%	0.0	0.0%
Middle Isinglass River	0.0	504.4	0.0%	0.0	0.0%	0.0	0.0%
Middle Little River	102.0	595.2	17.1%	95.5	16.0%	6.6	1.1%
Middle Piscassic River	1,218.4	2,281.3	53.4%	1,215.6	53.3%	2.8	0.1%
Middle Winnicut River	118.6	163.9	72.4%	36.8	22.4%	81.9	50.0%
Moose Mountains	3,960.5	8,788.7	45.1%	3,638.4	41.4%	322.1	3.7%
Muddy Pond	61.4	156.3	39.3%	61.4	39.3%	0.0	0.0%
North River / Rollins Brook	61.8	813.9	7.6%	33.7	4.1%	28.1	3.5%
Northeast Pond	733.9	1,803.3	40.7%	703.0	50.8%	30.9	-10.1%
Oyster River	1,006.6	2,691.1	37.4%	749.9	27.9%	256.6	9.5%
Packer Bog	394.1	815.1	48.4%	394.1	48.4%	0.0	0.0%
Parkman Brook	74.5	547.2	13.6%	74.5	13.6%	0.0	0.0%
Pawtuckaway Mountains	10,914.1	23,142.6	47.2%	10,293.5	44.5%	620.5	2.7%
Pawtuckaway River	424.9	749.0	56.7%	424.9	56.7%	0.0	0.0%
Pike Brook	57.4	2,338.7	2.5%	57.4	2.5%	0.0	0.0%
Preston Pond	110.2	342.5	32.2%	110.2	32.2%	0.0	0.0%
Rochester Heath Bog	49.2	1,024.0	4.8%	49.2	4.8%	0.0	0.0%
Rochester Neck	446.6	1,605.2	27.8%	354.5	22.1%	92.0	5.7%

Saddleback Mountain	1,841.3	3,342.9	55.1%	1,658.3	49.6%	183.0	5.5%
Seavey Creek / Fairhill Swamp	439.0	633.2	69.3%	439.8	69.4%	-0.7	-0.1%
Spruce Swamp	759.1	1,854.5	40.9%	452.8	24.4%	306.3	16.5%
Squamscott River	648.4	2,023.6	32.0%	638.1	31.5%	10.3	0.5%
Stonehouse Brook	0.0	726.5	0.0%	0.0	0.0%	0.0	0.0%
Taylor River and The Cove	767.5	2,421.9	31.7%	693.0	28.6%	74.4	3.1%
Thurston Pond / Hartford Brook	347.4	2,474.7	14.0%	382.9	15.5%	-35.5	-1.5%
Union Meadows	165.8	985.9	16.8%	43.9	4.5%	121.9	12.3%
Upper Berry's Brook	389.5	1,460.6	26.7%	326.9	22.4%	62.6	4.3%
Upper Exeter River	539.0	3,011.2	17.9%	395.3	13.1%	143.7	4.8%
Upper Great Brook	223.7	543.5	41.2%	185.9	34.2%	37.8	7.0%
Upper Isinglass River	203.5	853.8	23.8%	203.6	23.8%	0.0	0.0%
Upper Little River	86.7	326.6	26.5%	86.7	26.5%	0.0	0.0%
Upper North Branch River	1,227.3	2,879.9	42.6%	1,025.7	35.6%	201.6	7.0%
Upper Taylor River	122.5	439.0	27.9%	107.8	24.6%	14.6	3.3%
Upper Winnicut River	221.2	289.6	76.4%	49.3	17.0%	171.9	59.4%
Wallis Marsh	137.0	310.9	44.1%	137.6	44.3%	-0.6	-0.2%
Winnicut River / Cornelius Brook	50.4	329.4	15.3%	50.4	15.3%	0.0	0.0%
TOTAL:	46,737.0	135,784.6	34.4%	41,480.5	30.6%	5,256.5	3.8%

All reported acreages reflect ONLY those areas within the Piscataqua Region watershed.
2011 CFAs also included "Northeast Pond," however 2017 analysis does not include this CFA.

Table CF-2: Conservation lands in individual conservation focus areas in Maine in 2017.

Core Focus Area Name	Conservation Lands 2017 (acres)	Area of Core CFA (acres)	Percent of Core CFA Area (2017)	Conservation Lands 2011 (acres)	Percent of Core CFA area (2011)	Acreage Change	Percentage Change
Bauneg Beg Mountain	0.0	1571.7	0.0	0.0	0.0	0.0	0.0
Beaver Dam Heath	155.6	1051.4	0.1	120.9	0.1	34.7	0.0
Brave Boat Harbor/Gerrish Island	91.3	339.8	0.3	82.4	0.2	8.9	0.0
Cranberry Meadow	181.4	426.6	0.4	126.7	0.3	54.7	0.1
Gerrish Mountain	0.0	1282.9	0.0	32.8	0.0	-32.8	0.0
Knights Pond	0.0	113.5	0.0	0.0	0.0	0.0	0.0
Little River East	0.0	4372.2	0.0	0.0	0.0	0.0	0.0
Little River West	32.7	476.8	0.1	32.7	0.1	0.0	0.0
Merriland River Wetlands	294.3	3231.1	0.1	341.4	0.1	-47.1	0.0
Mt Agamenticus and	3009.7	6845.7	0.4	3098.3	0.5	-88.6	0.0
York River Headwaters							
Sanford Ponds	62.7	907.4	0.1	62.5	0.6	0.1	-0.6
Shapleigh Pond	0.0	77.2	0.0	0.0	0.0	0.0	0.0
South Acton Swamps	436.0	8179.9	0.1	424.8	0.1	11.2	0.0
Sturgeon Creek	49.3	295.9	0.2	49.3	0.2	0.0	0.0
West Sanford Swamps	12.5	1256.2	0.0	12.6	0.0	0.0	0.0
TOTAL:	4325.4	30428.3	0.1	4384.2	0.1	-58.8	0.0

All reported acreages reflect ONLY those areas within the Piscataqua Region watershed.
2011 CFAs also included "Northeast Pond," however 2017 analysis does not include this CFA.

Indicator: Oyster Restoration

Question

How many acres of oyster restoration have been initiated?

Short Answer

More than 26 acres of oyster restoration have taken place since 2000—15.5 of those acres since 2011. Sedimentation hampers success at most but not all sites.

PREP Goal

Restore 20 acres of oyster reef habitat by 2020 (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

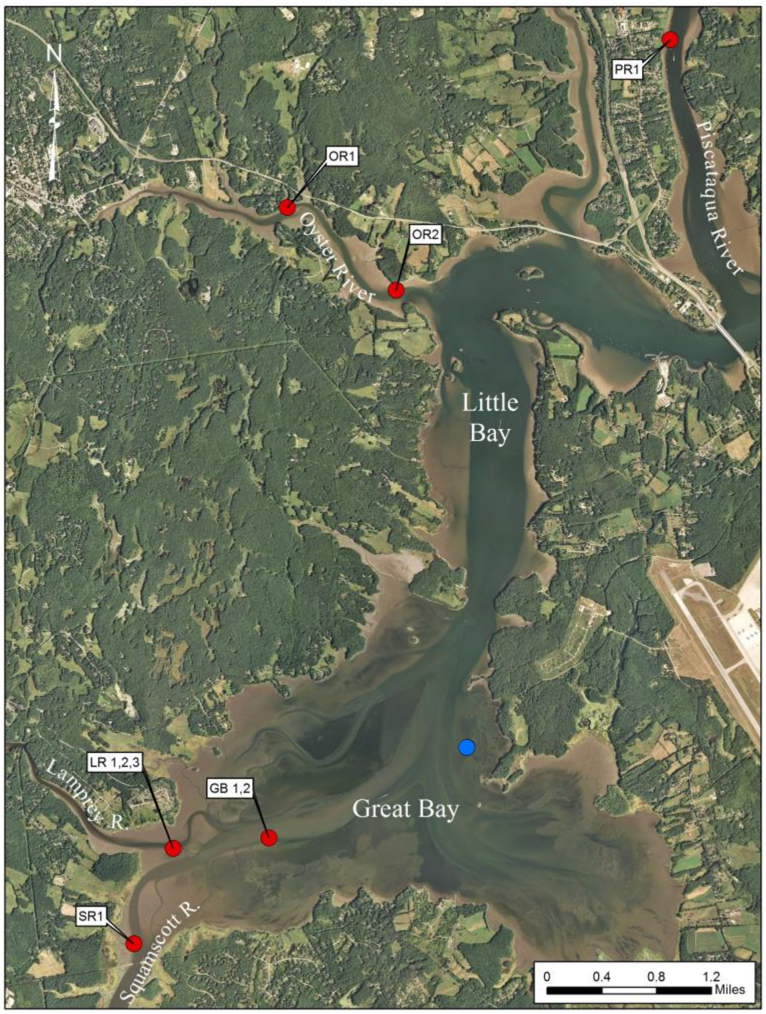


Figure OR-1. Map showing major oyster restoration activity. The red dots show general location of sites that have been monitored. Note that two of the red dots show the location of multiple sites (in the Lamprey River and in Great Bay). The blue dot shows the most recent restoration site in the Great Bay. Data Source: Grizzle and Ward (2016) and Grizzle and Ward (2017).

Why This Matters

The oyster fishery and commercial oyster aquaculture industry support the local economy through jobs and sales. Filter feeding oysters can improve light penetration through the water; they provide critical habitat for many species of invertebrates and juvenile fish and they can sequester nitrogen and carbon. Unfortunately, the Great Bay Estuary has lost 89% of its wild oysters since 1993, which results in less available substrate and, in turn, less available area for juvenile oyster spat to settle.

Explanation (from the 2018 State of Our Estuaries Report)

10.8 acres of oyster restoration was initiated between 2000 and 2012. Between 2012 and 2016, an additional 15.5 acres of oyster restoration were established in the Great Bay Estuary (Figure OR-1 and OR-2) through collaborations between the University of New Hampshire (UNH) and The Nature Conservancy (TNC). The cumulative total for oyster restoration sites is now over 26 acres, above the PREP goal of 20 acres. Although 26 acres of restoration area exists, each site is only partially covered by oyster shell. For example, a common design is to establish multiple small circles of shell for oysters to settle on.

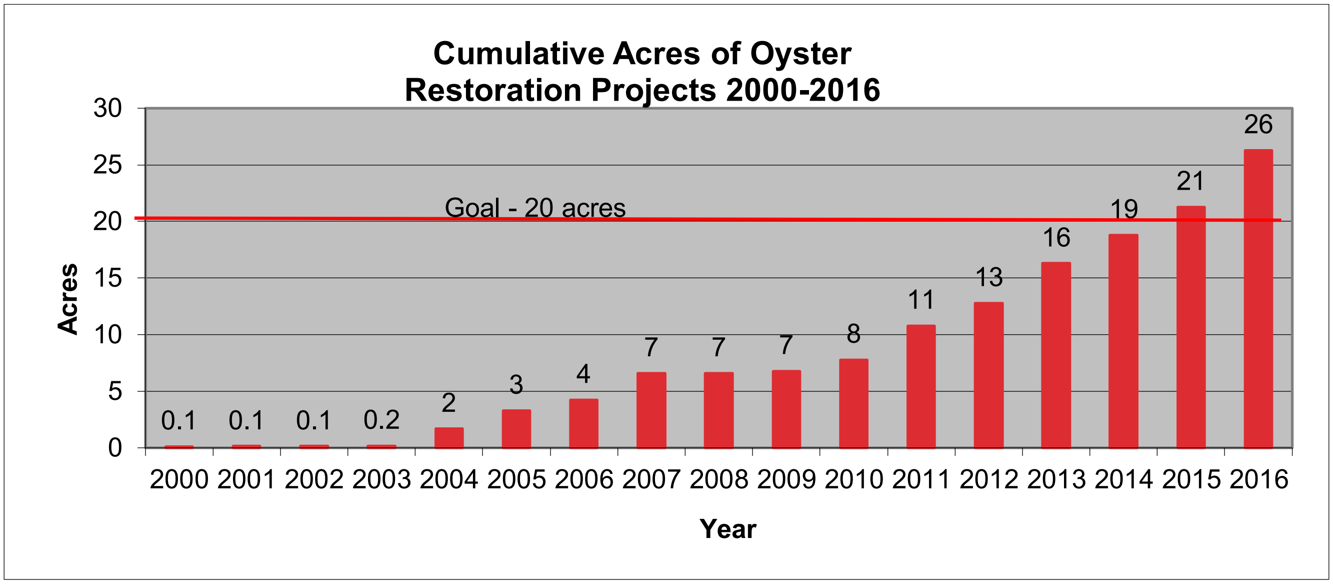


Figure OR-2. Cumulative Acres of Oyster Restoration Projects 2000-2016. Data pertain to the total areas of a restoration site, not necessarily the area covered by oysters. Data Source: UNH Jackson Estuarine Laboratory.

Unfortunately, in many cases, these restoration sites have struggled to remain viable, primarily due to burial by fine sediments (Grizzle and Ward 2016). Table OR-1 shows monitoring results for seven different restoration sites; in four of the seven sites, shell cover has decreased since initial construction. Only one site (Lamprey River #2) showed an increase in shell cover.

Monitoring of these sites suggests several keys to successful future restoration, including: 1) build reefs to achieve greater vertical height to guard against burial by sediments and 2) select sites as close as possible to a natural reef. Recent NH Fish and Game/UNH research showed that recruitment (new oyster larvae settling) decreased significantly as distance from a native natural reef increased (Eckert 2016).

Oyster aquaculture (i.e., oyster farms) in the Great Bay Estuary has increased steadily since 2011, with 22 aquaculture harvest licenses issued in 2016, as compared to only five in 2011. In 2016, NH Fish and Game estimates that over 180,000 oysters were harvested from aquaculture activities.

Table OR-1: Change in shell cover after initial construction. Data Source: UNH Jackson Estuarine Laboratory.

	Date Constructed	Shell Cover Initial (% of total area)	Shell Cover 2015 (% of total area)
Lamprey River #1	2011	60	3
Lamprey River #2	2011	20	26
Squamscott River	2012	20	5
Lamprey River #3	2013	38	25
Piscataqua River	2013	54	23
Great Bay #1	2014	25	1
Great Bay #2	2015	21	4

Methods and Data Sources

The total acres of oyster beds that have been restored since January 1, 2000 was recalculated each year and compared to the goal. The oyster beds were considered "restored" at the conclusion of the restoration project. Only projects that actively transplant oysters to reefs or otherwise enhance oyster populations were considered restoration projects. The total area of each restored oyster bed was determined by the restoration project manager.

For more on methods and data collection, please see the following reports:

"2016 Oyster Reef Restoration Project Funded by the Aquatic Resources Mitigation Program" by Grizzle and Ward. (http://scholars.unh.edu/prep/368/)

"Assessment of recent eastern oyster (Crassostrea virginica) reef restoration projects in the Great Bay Estuary, New Hampshire: Planning for the future" by Grizzle and Ward (http://scholars.unh.edu/prep/353/)

Data Sources

Data on oyster restoration projects was gathered from The Nature Conservancy and the UNH Jackson Estuarine Laboratory staff leading oyster restoration work in the Great Bay Estuary.

Technical Advisory Committee (TAC) Discussion Highlights

As part of the January 2017 TAC meeting, participants discussed oyster restoration (PREP 2017c). Complete notes are available at: http://prepestuaries.org/prep-technical-advisory-committee/

One of the most salient issues brought up at the meeting was a need for more strategic and explicit long-term monitoring plan. This long-term plan would, ideally, include mapping of both natural and restored beds every 5 years. In addition, as part of this plan, more nuanced metrics would be introduced. Currently, the number of "acres restored" is tracked; however, acres restored actually combines and confuses two separate metrics: 1) the two-dimensional footprint of the restoration site (measured in acres) and 2) the amount of area within the greater footprint that has actual oyster habitat.

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Indicator: Migratory Fish Restoration

Question

How many miles of main stem freshwater rivers are accessible to river herring in the Piscataqua Region?

Short Answer

As of 2016, 42% of the historical distribution for river herring in the rivers of the Piscataqua Region has been restored. Additionally, removal of the Great Dam in Exeter in July 2016 has improved/enhanced river herring passage on the Exeter River.

PREP Goal

Restore native migratory (diadromous) fish access to 50% of their historical main stem river distribution range by 2020 (from the PREP Comprehensive Conservation and Management Plan, PREP 2010).

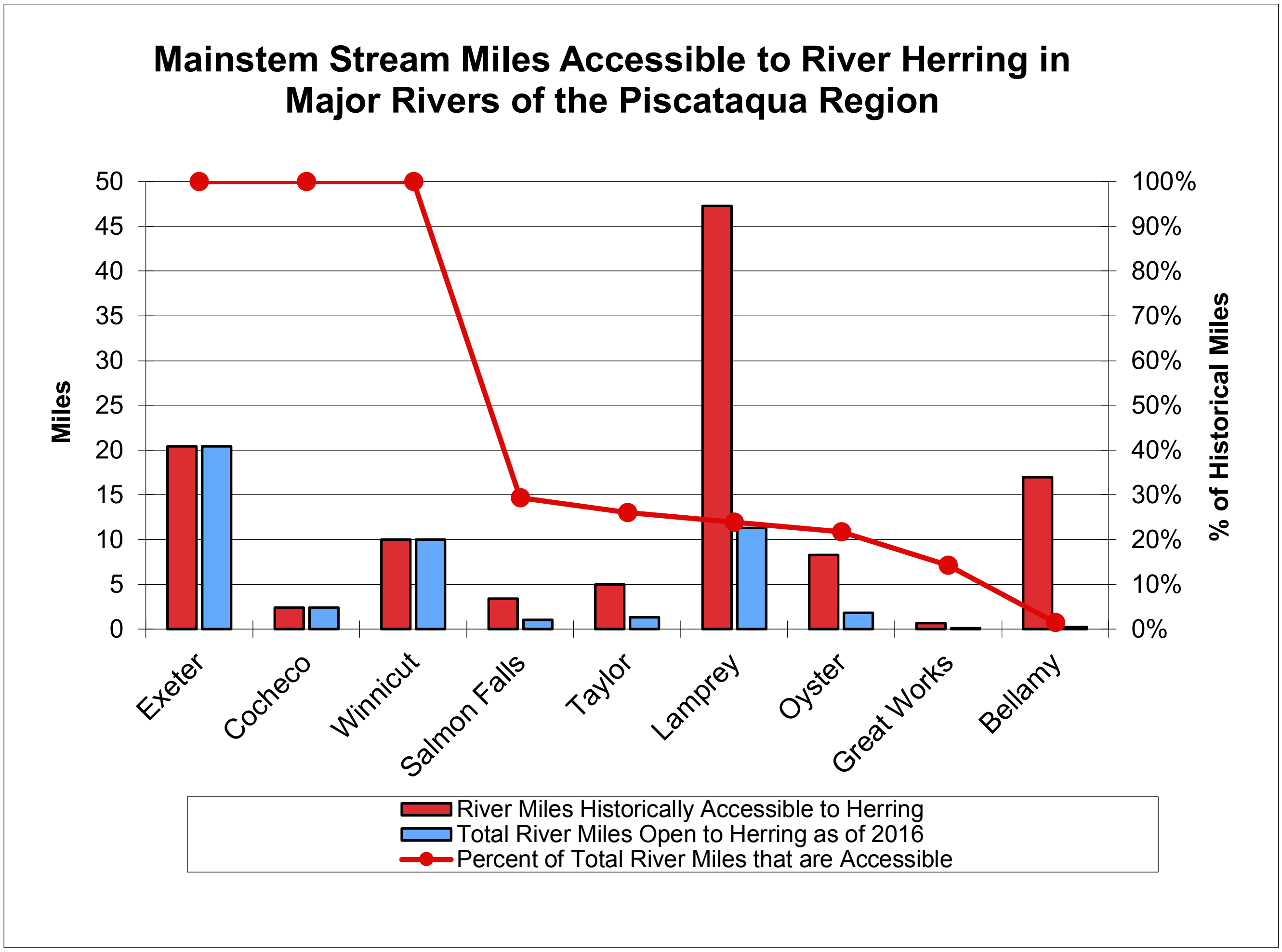

Figure MFR-1. Mainstem Stream Miles Accessible to River Herring in Major Rivers of the Piscataqua Region. River miles historically accessible to river herring and total river miles open to river herring as of 2016. Data Source: NH Fish and Game.

Why This Matters

Physical barriers such as dams and culverts can prohibit the movement of migratory fish between up-stream and downstream areas. Migratory fish – such as river herring – live mostly in saltwater, but travel upstream to freshwater to reproduce. Limiting passage to freshwater upstream can limit populations.

Explanation (from the 2018 State of Our Estuaries Report)

Coastal rivers of the Piscataqua Region historically supported abundant fish returns for river herring (alewife and blueback herring) and American shad. However, during the 19th century the construction of dams along coastal rivers limited access to freshwater spawning habitats (NHEP 2000). To support recovery of river herring populations in the 1950s, NH Fish and Game began efforts to restore access to historically accessible freshwater streams and ponds. Figure MFR-1 shows the historically accessible miles of freshwater in the main stem of each major river, and how many miles of freshwater habitat are currently accessible. For this indicator, fish ladders are considered to provide limited access for migratory fish, however, fish ladders on the Winnicut Dam in Greenland and former Great Dam in Exeter are inefficient at passing river herring to upstream spawning habitat.

For the Exeter, Cocheco, and Winnicut Rivers, 100% of freshwater miles historically accessible are once again open for fish passage as of 2017, assuming fish ladders provide limited access. Less than 30% access is open for the remaining main stem rivers. Overall, freshwater access for river herring has been restored to 42% of historical distribution within the main stems of the region's major rivers (Figure MFR-2).

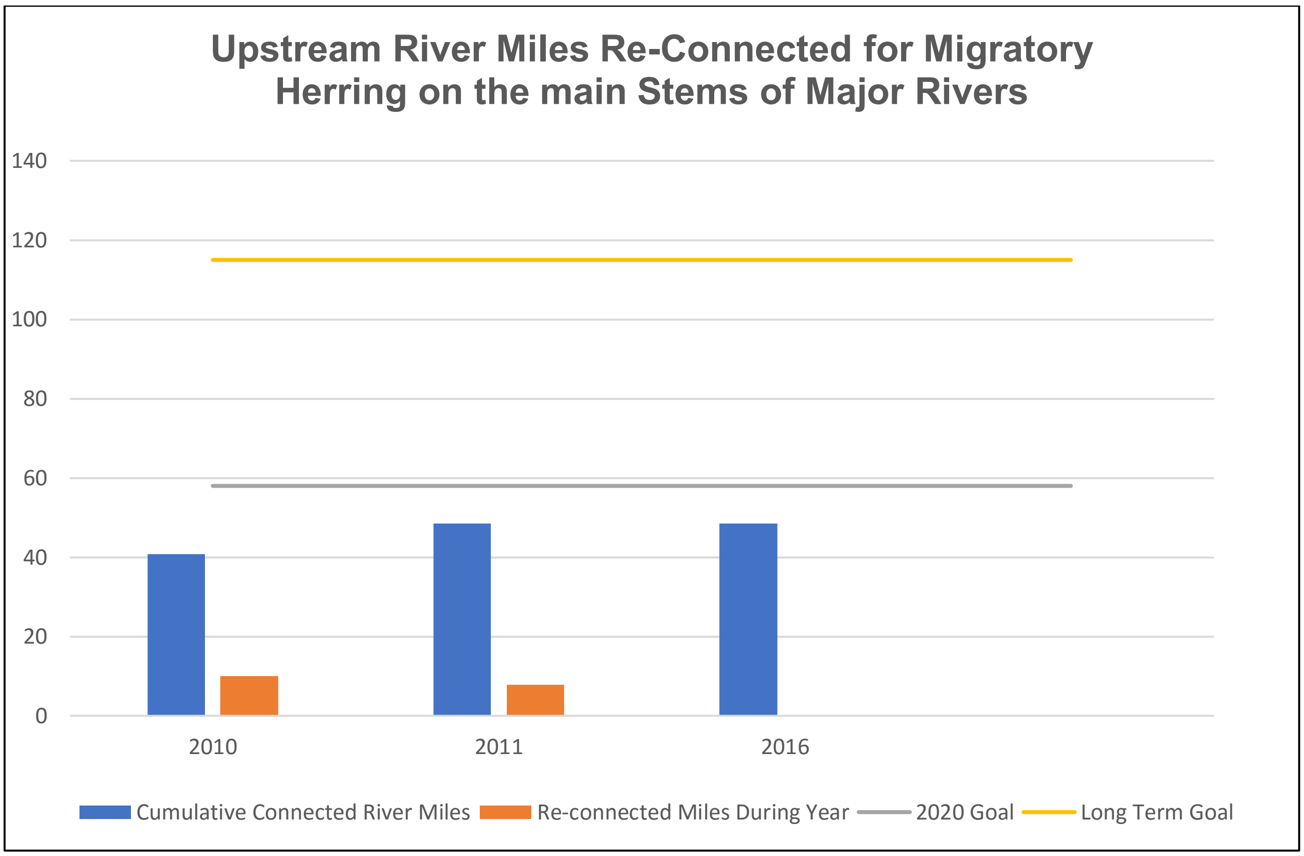

Figure MFR-2. Upstream river miles re-connected for migratory herring on the main stems of major rivers. The 2020 Goal is 58 miles: 50% of the historical extent, which is the long-term goal of 115 miles. Data Source: NH Fish and Game.

<u>Methods and Data Sources</u>
The cumulative mainstem river miles restored to date was calculated and compared to the historical river mileage baseline estimate of 114.5 miles. Restored river miles within the mainstem were divided by the historic mileage and reported as a percent completed.

Historical distribution of river herring along the mainstem portions of the region's major rivers was estimated and reported in the Great Bay Estuary Restoration Compendium (Odell et al. 2006) and Hampton-Seabrook Estuary Restoration Compendium (Eberhardt and Burdick 2009). These reports summarized data about the location of mainstem dams and the status of fish passage at these dams. Estimates of mainstem river miles were adjusted such that the location of head-of-tide was treated as river mile zero. This was done to acknowledge that herring have unobstructed access to the tidal portions of the rivers (which are part of the estuary), and to ensure that "upstream" river miles are reported as strictly the freshwater portions of the major rivers above head-of-tide. The historical distribution estimates are treated as the baseline mileage against which future improvements in fish passage around dams will be measured against. This indicator does not tally stream miles opened along tributary streams and does not account for obstructions to passage from dams and culverts located along tributaries or non-major river segments. This indicator considers dams with fish ladders to provide access for migratory fish although access is limited by the presence of the dam.

Data Sources
Data on upstream mainstem river miles restored for river herring access are obtained by PREP from NHF&G, the NH Coastal Program, and other fish passage restoration practitioners in the coastal watershed that have completed work on the mainstem segments of the major rivers.

The quality of the information for this indicator depends on the accuracy of the river mileage estimates reported for both historical distribution extent of river herring as well as the estimate for river mileage restored for upstream passage of river herring. The historical distribution estimates from Odell et al. (2006) and Eberhardt and Burdick (2009) are considered the best available estimates. These estimates are likely conservative in some cases, especially with regard to the historical extent of river herring within the Salmon Falls and Great Works river systems.

<u>Additional Results (Beyond the Data Reported in the SOOE)</u>
Major efforts are underway to restore river herring access to their historical freshwater ranges in order to support recovery of their populations. The Great Dam on the Exeter River was removed in the summer of 2016. In 2011, on the Lamprey River, a dam in Epping was removed. However, a partially breached dam at Wadleigh Falls between Wiswall and the former Bunker Dam site is not passable by river herring. Therefore, improvements at the Wadleigh Falls location are necessary for fish to take advantage of the passage opportunities in Epping. In 2012 on the Lamprey River, a new fishway was built at the Wiswall Dam, which is the next barrier upstream from the NHF&G owned fishway at the head-of-tide dam in Newmarket, NH. The Town of Durham built, maintains and operates the new fishway with technical assistance and monitoring provided by NHF&G.

Improvements to the fishway trap on the Cocheco may have increased returns for that river. In addition, NHF&G staff have been working with state, federal and other partners to initiate the removal of the Gonic Dam (in Rochester, NH) on the Cocheco River. New strategies are also currently being developed to address problems at the Taylor and Winnicut Rivers. In 2016, on the Taylor River, modifications to the existing fishway were implemented. At the same time, partners are determining whether to remove or modify the existing dam complex. On the Winnicut River, the dam was removed in 2009 in an attempt to restore access to 10 miles of upstream habitat. However, the resulting fish passage is now considered too narrow, creating water velocities that prevent fish from accessing upstream habitat. Solutions are in the process of being developed to address this issue.

For additional information, see the indicator "Migratory Fish" in this report as well as the 2016 NHF&G "Diadromous Fish Investigation" report (NHF&G 2017).

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Introduction to Social Indicators

Since the first *State of New Hampshire's Estuaries* Report in 2000 (NHEP 2000), PREP has been committed to reporting on a suite of ecological and biological indicators of health in the Great Bay and Hampton-Seabrook estuaries. These estuaries are not just places of biological value; they also provide social value, economic benefits, and many other quality of life assets such as recreational opportunities and community character. They are where rivers meet the sea, where land meets the water, and where people meet the water.

In 2015, PREP partnered with the NH Department of Environmental Services Coastal Program (NHCP), Great Bay National Estuarine Research Reserve (GBNERR), NOAA, and Plymouth State University (PSU) to kick off the *Social Indicators Project**. This two-year initiative is our region's first attempt to gather, understand, and link social and behavioral data to regional environmental indicators. The project team conducted an extensive assessment of values through almost 40 one-on-one interviews with watershed stakeholders that included resource managers, business owners, regional planners, community organizers, and state policymakers (Figures SI-1 and SI-2). Following the interviews, a technical advisory process was used to find existing data and/or indicators that reflected the stakeholder values that were identified in the interviews (Figure SI-2). After a broad review of existing data sources, a list of 31 potential indicators was shared with the advisory board for input, refining, and ranking. This input was used to categorize and narrow 31 indicators to 15 indicators that fit into seven categories. PREP staff evaluated and chose the final three indicators: housing permits, stormwater effort, and stewardship behavior, for their relevance to environmental trends, how rigorously they were collected, geographic scale, and applicability to management actions. Additional detail on the indicator selection process is outlined in the "Final Environmental Data Report December 2017: Technical Support Document for the 2018 State of Our Estuaries Report" (PREP 2017).

Figure SI-1. Sectors represented across 38 stakeholder interviews.

The Social Indicators Project was funded using a combination of federal funds coordinated by the NOAA Office for Coastal Management and $15,000 of nonfederal funding provided by PREP. This funding supported a NOAA Coastal Management Fellow for two years working on the project, and the NH Department of Environmental Services Coastal Program provided in-kind support and office space for the fellow during this period.

At their core, these social indicators are meant to strike up conversation, prime questions, and encourage more research. Each social indicator has a strong connection to several environmental indicators that PREP monitors and reports on (Table SI-1). They represent the beginning of PREP's ongoing commitment to robust social-ecological indicator monitoring.

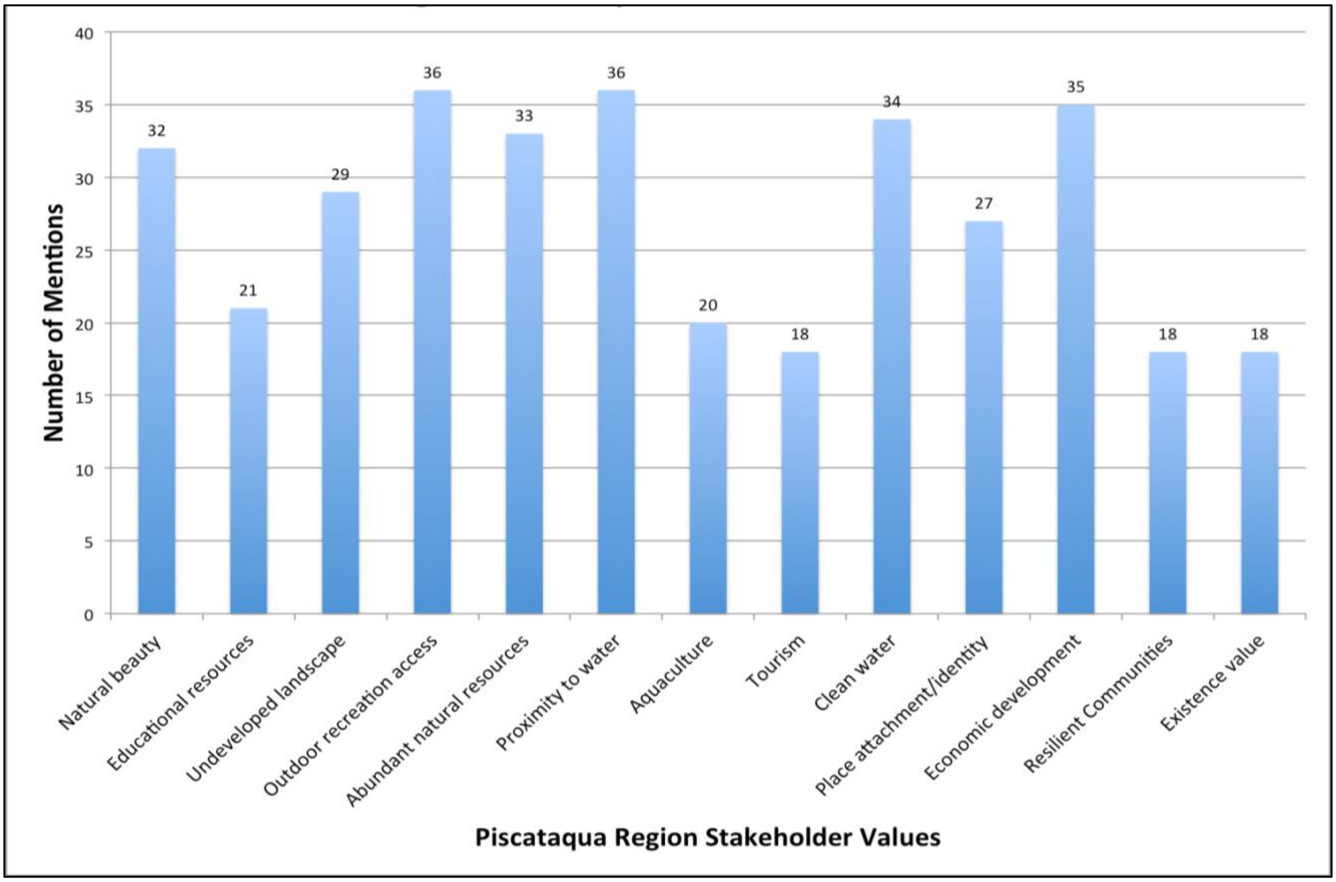


Figure SI-2. Social ecological values expressed across 38 stakeholder interviews. Bars represent number of times that concept was mentioned or referenced in interviews.

Table SI-1. Connecting social indicators to PREP's environmental indicators.

Indicator	*Environmental Indicator Connection 1*	*Environmental Indicator Connection 2*	*Environmental Indicator Connection 3*	*Environmental Indicator Connection 4*	*Environmental Indicator Connection 5*
Housing Permits	Impervious Surfaces	Total suspended solids	Nutrient Load	Conservation Land	Stewardship Behavior
Stormwater Effort	Impervious Surfaces	Conservation Land	Nutrient Load	Total suspended solids	Bacteria
Stewardship Behavior	Conservation Land	Stormwater Effort	Housing Permits	Oyster restoration	Migratory Fish Restoration

<u>References Cited</u>

NHEP. 2000. State of New Hampshire's Estuaries. PREP Publications. 263. http://scholars.unh.edu/prep/263

PREP. 2017. Final Environmental Data Report December 2017: Technical Support Document for the 2018 State of Our Estuaries Report. PREP. http://stateofourestuaries.org/2018-reports/data-report

Indicator: Housing Permit Approvals

Question

How many single and multi-family new housing permits were issued by communities in the Piscataqua Region from 2000 to 2015?

Short Answer

There were 19,483 multi-family and single-family new housing permits issued in the 42 New Hampshire towns in the watershed from 2000 to 2015. There were 331 new housing permits issued in the ten Maine towns in the watershed in 2015.

PREP Goal

No goal established yet.

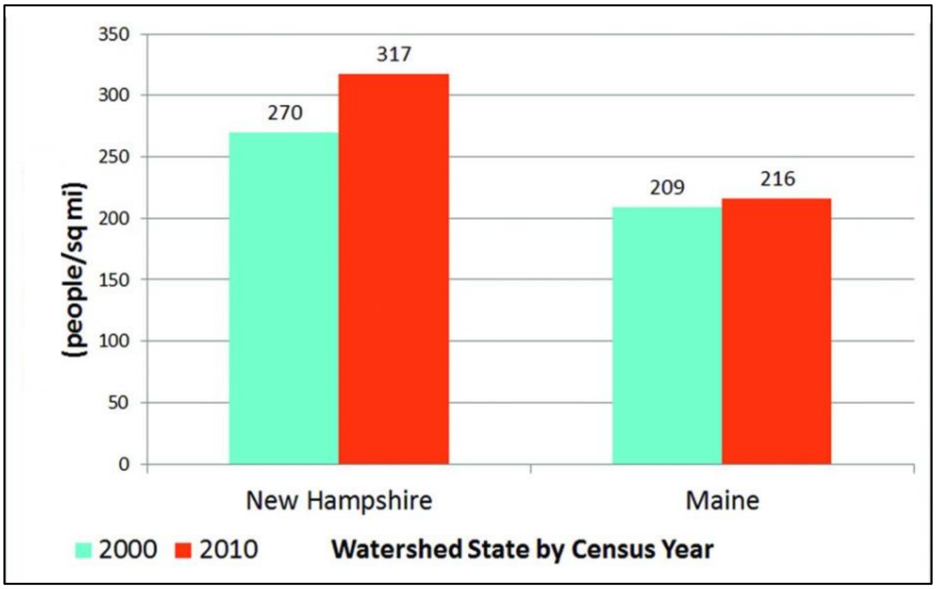
Why This Matters

The Piscataqua Region is a desirable place to live, and as the population increases, so too do pressures. The number of housing permit approvals in the Piscataqua Region provides good context for considering an increase in population and the commensurate disturbance of the land to support that population. If not properly mitigated and planned for, construction can change the hydrology of the land and can lead to short-term soil erosion. New housing units increase impervious cover, which can lead to more stormwater and sediment runoff and nutrient loading. Since the U.S. Census is run every ten years, monitoring housing permit approvals gives us a more frequent indicator of increase in population, demand for development, and conversion of land to housing. Additionally, monitoring new housing permit approvals can shed light on economic development trends, migration patterns, shifting demographics, and overall pressure on our coastal and recreational resources. Furthermore, as development trends shift geographically, it can also help communities understand where development pressure is occurring and can prime conversations about smart growth and low-impact development practices that allow for an increase in population and economic development and the protection of sensitive, natural areas.

Explanation (from 2018 State of Our Estuaries Report)

Population pressure on the nation's 452 coastal shoreline counties has been continually on the rise. In 2010, 123.3 million people, or 39% of the nation's population lived in counties directly on the shoreline (called coastal shoreline counties) and 52% reside in coastal watershed counties (upriver and on tributaries from the shore). This population is expected to increase by 8%, or 10 million more people, by 2020. Not only are there more people living on the coast, the population density far outweighs the rest of the U.S. There are 446 persons per square mile in coastal shoreline counties and 319 persons per square mile in coastal watershed counties nationwide. This is in stark contrast to the rest of the U.S., which averages 105 persons per square mile. Nationwide, there were 1,355 building permits issued per day in coastal shoreline counties from 2000–2010 (NOAA 2013).

This trend rings true in the Piscataqua Region. There were 386,658 people living in our three coastal and estuarine counties in 2015—an increase of 126,453 people since 1980 (US Census Bureau 2015). There is also close alignment to the national density numbers, with 317 persons per square mile in NH watershed towns and 216 persons per square mile in Maine watershed towns in 2015 (Figure H-1). In 2015 more people moved into New Hampshire then moved out of it; ~53,000 residents moved into New Hampshire, and 42,000 left the state (NH Employment Security 2016).



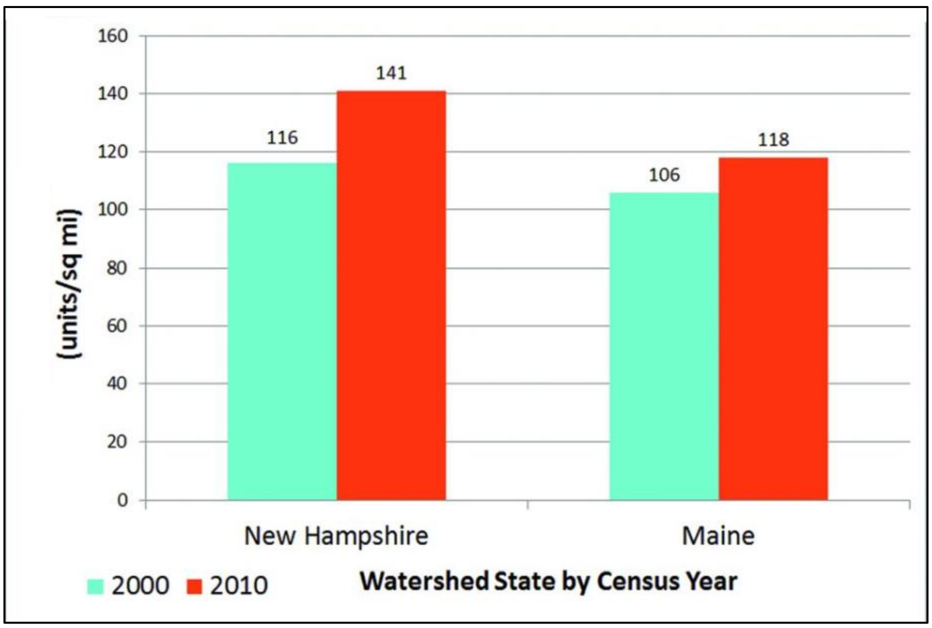


Figure H-1. Population & Housing Densities in the Piscataqua Region: Census Year 2000 & 2010. Data Source: US Census Bureau.

Population increases can bring many positive benefits to communities and the region, including:

- Increase in the tax base
- Enhanced tourist economy
- Additional people to enjoy and steward our lands (see "Stewardship Behavior" Indicator)
- Growth of local business and commerce
- Diversification of our socio-economic structure

However, more housing development also means more services for communities to provide such as schools, road maintenance, police, fire, public services, etc., all requiring more pull on already strained municipal budgets.

Historically, New Hampshire's population is among the most mobile in the nation (Johnson et al. 2016). Only a third of New Hampshire residents age 25 and older were born in the state (Figure H-2). This is an important consideration to reflect as this kind of demographic shift can mark how policy is made at the town level and can help inform outreach partners on the best engagement tactics for reaching a different type of taxpayer and resident who are more accustomed to state-level environmental policies.

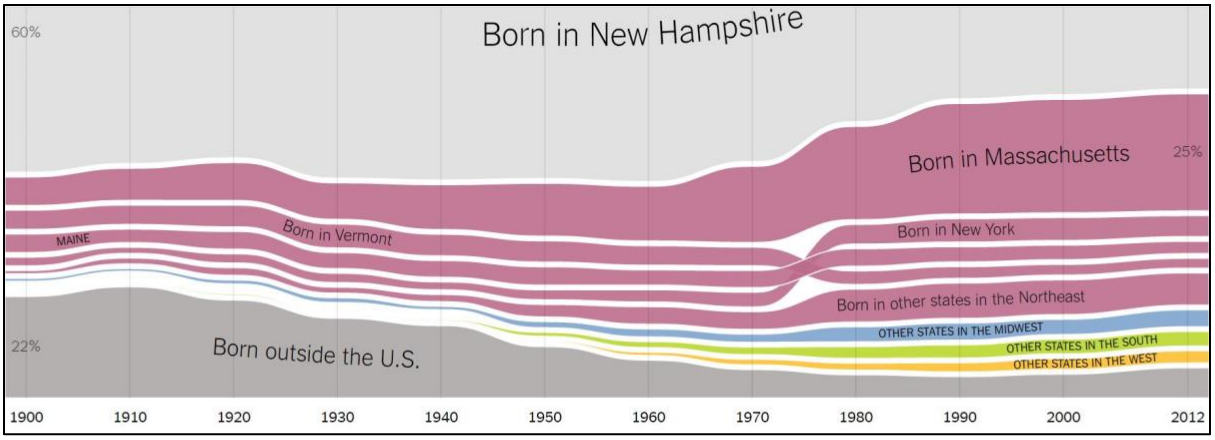


Figure H-2. Make-up of New Hampshire residents living in the state as of 2012. Graphic and Data Source: New York Times (Aisch et al. 2014).

As pressure on existing housing stock increases, so does the need for new units. An accepted indicator for new development is the number of approved new housing unit permits in each town. It is important to note that an approved permit does not always equate to the actual construction of the unit. Permits are often pulled but development can stall due to various factors. The construction sector in the 42 New Hampshire watershed towns experienced an all-time high in 2000 and an all-time low in 2009. Since then, it has been rising incrementally (Figure H-3). There are confounding factors as to why the construction sector has not bounced back as robustly since 2009, including loss of construction workers, limitations of local regulations and lack of buildable lots (NH Public Radio 2017).

Of particular note is the recent increase in multi-family unit permit approvals (dark blue bars in Figure H-3). In the last six years, these have steadily kept pace with single-family units. From a land use perspective this is encouraging, as multi-family units often have an overall smaller lot size per person than typical, single-family, one-acre lot zoning.

The NH Office of Energy and Planning provides a very useful statewide data clearinghouse for all NH housing data. Table H-1 shows the percent change, which gives a relative sense of growth as compared to the baseline of 2000. Absolute changes in housing units from 2000 to 2015 provide another interesting perspective. Table H-2 displays the 10 New Hampshire Piscataqua Region towns that have seen the largest absolute changes in housing units. Additionally, when looking at where the newest development is occurring (Tables H-1 and H-2), it is important to note that it is increasing in towns that are upwatershed from Great Bay and in communities that have been more traditionally rural. There can be negative impacts when converting land from open space to development, especially along smaller tributaries. Engaging the tenets of low impact development should become increasingly more important in these communities.

For the Piscataqua Region municipalities in Maine, data on new single-family housing permit approvals is available on a town-by-town basis (Table H-3). Each municipality publishes an annual Town Report that includes a chapter from the Town Code Enforcement Officer. PREP extracted the number of new single-family housing permits reported in each of the 10 Maine watershed communities from 2015 (the latest year all 10 communities had publically available data at the time of publication). PREP anticipates continuing to collect Maine municipalities data year-to-year and developing trend analyses for the next *State of Our Estuaries* Report.

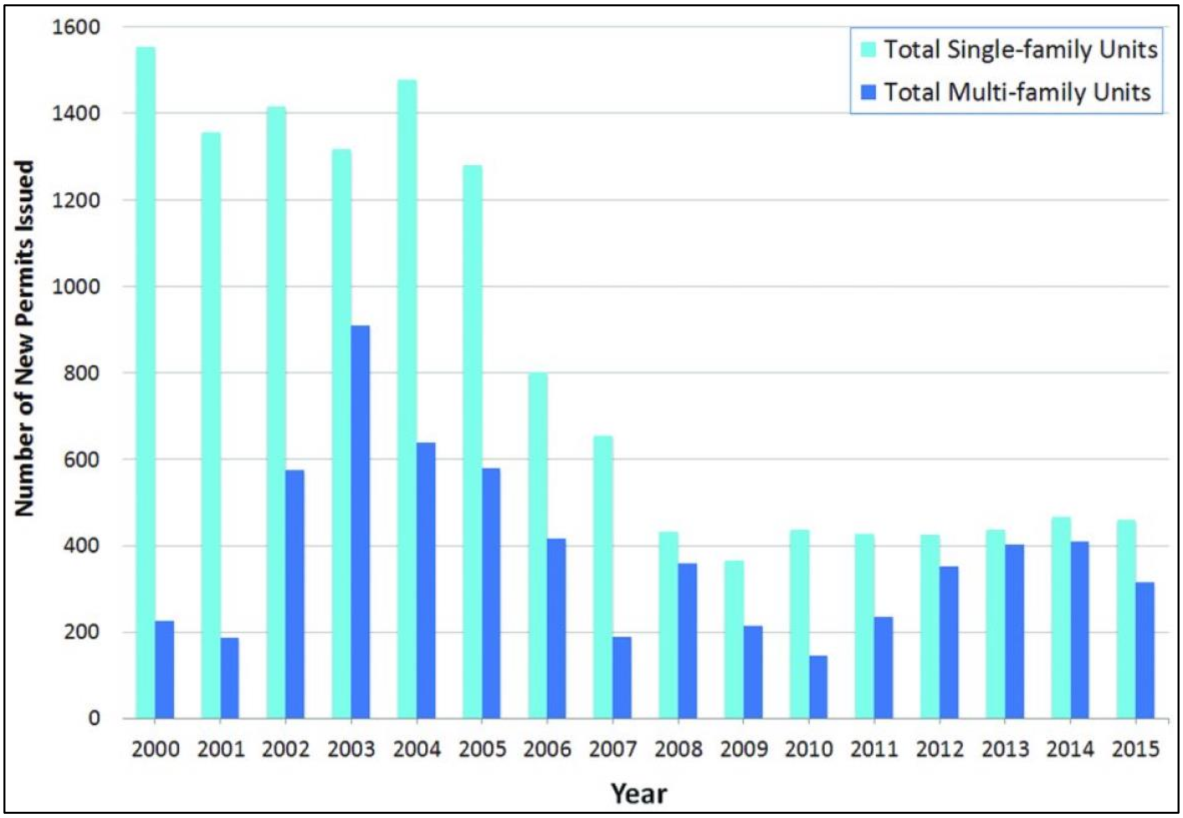


Figure H-3. New Building Permits in the Piscataqua Region watershed communities in New Hampshire. Data Source: NHOEP State Data Center.

Table H-1. Top 10 NH Piscataqua Region watershed communities with the largest % change in units (2000-2015). Data Source: NHOEP State Data Center & US Census Bureau.

Town	Total Housing Units 2000 (from Census)	Total Units 2015 (from 2010 Census & new permits)**	Change from 2000-2015	% change (change/total housing units in 2000)
Brentwood	920	1446	526	57.17%
Fremont	1201	1735	534	44.46%
East Kingston	648	935	287	44.29%
Chester	1247	1725	478	38.33%
Epping	2215	2959	744	33.59%
Sandown	1777	2345	568	31.96%
Deerfield	1406	1851	445	31.65%
Nottingham	1592	2093	501	31.47%
Greenland	1245	1603	358	28.76%
Hampton Falls	729	912	183	25.10%

****Because Census data is only collected every decade, the 2015 data from the NH Office of Energy and Planning is based on census data and the total number of permits issued from 2010-2015. Permits are not an exact measure of housing units as some permits issued never materialize into a new housing unit but this is the closest estimate available. This section has been reviewed by the NHOEP.**

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Table H-2: Top 10 NH Piscataqua Region watershed communities with the largest absolute changes in housing units. Data Source: NHOEP State Data Center & US Census Bureau.

Town	Absolute change in housing units from 2000-2015
Dover	2075
Rochester	1702
Hampton	795
Newmarket	763
Portsmouth	732
Exeter	698
Durham	683
Epping	645
Barrington	595
Raymond	582

While we have data for a longer time period for the NH Towns in the Watershed (2000-2015), we only have one year of housing permit data, 2015, for the Maine towns that are in the Great Bay Watershed. Both datasets are helpful for beginning to understand trends and we anticipate including more data on the Maine communities as it becomes available in future years.

Table H-3. Maine Piscataqua Region watershed communities housing permit data in 2015. Data Source: ME 2015 Town Reports***

Maine Municipality	New Single-Family Housing Permits Issued in 2015
Wells	113
York	68
Berwick	28
Kittery	27
Acton	22
Lebanon	18
Eliot	18
Sanford	17
South Berwick	10
North Berwick	10

*****Maine municipalities record the number of new single-family housing permits issued annually on either a Fiscal Year or Calendar Year basis. This data can be found in each municipality's Annual Town Report under the Code Enforcement section.**

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Methods and Data Sources

The number of permits approved for new housing units for each New Hampshire municipality in the Piscataqua Region watershed was aggregated watershed-wide for both single and multi-family units. This aggregation was conducted year by year for the entire New Hampshire portion of the watershed using data from 2000 through 2015. Separate from the total number of permits issued annually across the entire New Hampshire portion of the watershed, the total number of new single and multi-family housing permits issued from 2000 through 2015 was calculated for each New Hampshire municipality using data collected by the New Hampshire Office of Energy and Planning (NHOEP). These 15-year total values were compared to the total number of housing units in each town calculated by the US Census Bureau during the 2000 Census. Data from each New Hampshire municipality was analyzed to determine percent change in total housing units from 2000 to 2015 and absolute change in total housing units from 2000 to 2015 (Tables H-4 and H-5).

The data necessary to perform the analyses conducted for each New Hampshire municipality were not readily available for the 10 Maine municipalities in the Piscataqua Region watershed. Each Maine municipality does keep records of new single family housing permits issued in the Code Enforcement section of each annual Town Report, however, these records were not uniformly accessible and did not span the 2000 to 2015 timeframe. Given these discrepancies in access and availability, PREP collected the latest available data on new single family housing permits from each Maine municipality's Town Report and reached out to each municipality to verify these values. Since each town collects its own data through its Code Enforcement Office, some towns report their data by Calendar Year while others report it based on Fiscal Year. Correspondence with individual Maine municipalities who report by Calendar Year indicated that re-calculating those data to fit into the Fiscal Year timeframe would not be feasible in the necessary timeframe for publication. Therefore, the data represented for 2015, while mostly by Fiscal Year, does contain two data points from a Calendar Year perspective.

Population and housing densities for each municipality in the watershed were readily accessible using the United States Census Bureau American FactFinder online data portal. Using the aggregation features available on the American FactFinder portal, data for each watershed municipality in both New Hampshire and Maine were extracted from the comprehensive state datasets and aggregated by state to calculate total watershed population and total number of housing units in both Census Year 2000 and Census Year 2010. These state totals were then divided by the total land area calculated by the Census Bureau during those Census Years to produce both population and housing density totals in both the New Hampshire and Maine portions of the Piscataqua Region watershed in 2000 and 2010.

Data Sources

For New Hampshire, data on new single and multi-family housing permits is collected, collated, and made available for download by the NHOEP. The State Data Center at NHOEP has been issuing a series of annual reports that show short- and long-term trends in housing construction and total housing supply in New Hampshire since the mid-1970s, and these records are available for outside analysis. According to NHOEP, the permit data in these reports update the 2010 Census and American Community Survey data and are collected via an annual mail survey of municipalities, which achieves a 100% response rate. Additionally, NHOEP devotes considerable time to checking and refining survey returns to ensure consistency. NHOEP does not conduct any field checks as part of the quality control process. The source data for these reports was refined to only include data for the 42 Piscataqua Region watershed municipalities from the year 2000 through 2015.

For the Piscataqua Region municipalities in Maine, data on new single family housing permit approvals is only available on a town-by-town basis.

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Table H-4: Percent Change in Total Housing Units 2000-2015 Piscataqua Region watershed. The10 New Hampshire Municipalities with the greatest % change are highlighted.

New Hampshire Municipality	Total Housing Units in 2000 (from Census)	Total Units 2015 (from 2010 Census & new permits)	Change in Total Units from 2000-2015	% change (change/total housing units in 2000)
Brentwood	920	1446	526	**57.17%**
Fremont	1201	1735	534	**44.46%**
East Kingston	648	935	287	**44.29%**
Chester	1247	1725	478	**38.33%**
Epping	2215	2959	744	**33.59%**
Sandown	1777	2345	568	**31.96%**
Deerfield	1406	1851	445	**31.65%**
Nottingham	1592	2093	501	**31.47%**
Greenland	1244	1603	359	**28.86%**
Hampton Falls	729	912	183	**25.10%**
Newmarket	3457	4301	844	24.41%
Stratham	2371	2949	578	24.38%
Durham	2923	3630	707	24.19%
Madbury	543	671	128	23.57%
Farmington	2337	2867	530	22.68%
Middleton	706	864	158	22.38%
Brookfield	280	340	60	21.43%
Barrington	3147	3817	670	21.29%
Kensington	672	814	142	21.13%
Milton	1815	2193	378	20.83%
Dover	11924	14176	2252	18.89%
Raymond	3710	4373	663	17.87%
Strafford	1564	1843	279	17.84%
Danville	1479	1734	255	17.24%
New Durham	1309	1528	219	16.73%
Lee	1534	1788	254	16.56%
Wakefield	3331	3866	535	16.06%
Seabrook	4066	4712	646	15.89%
Rochester	11836	13681	1845	15.59%
North Hampton	1782	2039	257	14.42%
Newfields	532	604	72	13.53%
Northwood	1905	2144	239	12.55%
Exeter	6107	6845	738	12.08%
Kingston	2265	2537	272	12.01%
Newington	305	339	34	11.15%
New Castle	488	541	53	10.86%
Rye	2645	2915	270	10.21%
Hampton	9349	10196	847	9.06%
Candia	1384	1509	125	9.03%
Somersworth	4841	5231	390	8.06%
Portsmouth	10186	10956	770	7.56%
Rollinsford	1060	1114	54	5.09%

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Table H-5: Absolute Change in Total Housing Units 2000-2015 Piscataqua Region watershed. The10 New Hampshire Municipalities with the greatest amount of change are highlighted.

New Hampshire Municipality	Total Housing Units in 2000 (from Census)	Total Units 2015 (from 2010 Census & new permits)	% change (change/total housing units in 2000)	Change in Total Units from 2000-2015
Dover	11924	14176	18.89%	2252
Rochester	11836	13681	15.59%	1845
Hampton	9349	10196	9.06%	847
Newmarket	3457	4301	24.41%	844
Portsmouth	10186	10956	7.56%	770
Epping	2215	2959	33.59%	744
Exeter	6107	6845	12.08%	738
Durham	2923	3630	24.19%	707
Barrington	3147	3817	21.29%	670
Raymond	3710	4373	17.87%	663
Seabrook	4066	4712	15.89%	646
Stratham	2371	2949	24.38%	578
Sandown	1777	2345	31.96%	568
Wakefield	3331	3866	16.06%	535
Fremont	1201	1735	44.46%	534
Farmington	2337	2867	22.68%	530
Brentwood	920	1446	57.17%	526
Nottingham	1592	2093	31.47%	501
Chester	1247	1725	38.33%	478
Deerfield	1406	1851	31.65%	445
Somersworth	4841	5231	8.06%	390
Milton	1815	2193	20.83%	378
Greenland	1244	1603	28.86%	359
East Kingston	648	935	44.29%	287
Strafford	1564	1843	17.84%	279
Kingston	2265	2537	12.01%	272
Rye	2645	2915	10.21%	270
North Hampton	1782	2039	14.42%	257
Danville	1479	1734	17.24%	255
Lee	1534	1788	16.56%	254
Northwood	1905	2144	12.55%	239
New Durham	1309	1528	16.73%	219
Hampton Falls	729	912	25.10%	183
Middleton	706	864	22.38%	158
Kensington	672	814	21.13%	142
Madbury	543	671	23.57%	128
Candia	1384	1509	9.03%	125
Newfields	532	604	13.53%	72
Brookfield	280	340	21.43%	60
Rollinsford	1060	1114	5.09%	54
New Castle	488	541	10.86%	53
Newington	305	339	11.15%	34

PREP Piscataqua Region Estuaries Partnership

Indicator: Stormwater Management Effort

Question

How many communities in the Piscataqua Region watershed have adopted the Southeast Watershed Alliance Model Stormwater Standards for Coastal Communities and how many communities have other regulations in place? Additionally, how many communities in the watershed have a stormwater utility?

Short Answer

As of July 2017, in the 42 New Hampshire municipalities, 8 communities have adopted the complete set of stormwater standards; 7 communities are in the process of adoption; 5 communities have partial or a different set of standards, and 22 communities have not adopted standards. The 10 Maine communities are required to adhere to state-level stormwater management regulations. Zero communities have adopted a stormwater utility.

PREP Goal

No goal at this time.

Why This Matters

Stormwater runoff is a main driver of declining water quality in local waterways and leads to increased flooding. One way communities can reduce pollution and alleviate flooding is adopting up-to-date stormwater management standards. This action will increase the resilience of each community and the region as a whole in the face of climate change and increasingly severe storm events and flooding.

Explanation (from 2018 State of Our Estuaries Report)

Adopting local stormwater management standards allows a community to grow in a resilient manner, while improving existing conditions and preventing future water quality impairments. In New Hampshire, state statute enables municipalities to adopt regulatory standards for stormwater management for projects not captured under state Alteration of Terrain regulations: projects smaller than 100,000 sq. ft. of terrain or 50,000 sq. ft. of protected shoreland (NH DES Alteration of Terrain Bureau 2017). In Maine, the state Stormwater Management Law provides stormwater management standards for development that municipalities must adhere to (if projects exceed one acre of disturbance).

Communities in New Hampshire have already achieved many stormwater management successes through partnerships with the Southeast Watershed Alliance (SWA), the University of New Hampshire Stormwater Center (UNHSC), Soak Up the Rain, and other regional resources. Adopting enhanced standards allows communities to build on the great progress they have already made and continue to strengthen the culture of stormwater management leadership throughout the Piscataqua Region.

Local stormwater standards empower communities to guide development and protect natural resources while providing developers with consistent, equitable guidelines for managing impervious cover. These standards can be adopted in the zoning ordinance or as land development regulations. While any improvement to existing stormwater standards is a beneficial first step, the SWA model represents a comprehensive approach. Below is a summarized version of what is contained in the SWA Model Stormwater Standards for Coastal Watershed Communities: Elements B-D (SWA et al. 2012). Stormwater experts encourage municipalities to include the following four components to minimize further water quality impairment and improve present conditions.

- Threshold for Applicability: Creates a minimum threshold area of disturbance for new development projects that requires full compliance with stormwater standards.

- Performance Measures: Improves water quality by requiring the removal of an established percentage of Total Suspended Solids, Total Nitrogen, and Total Phosphorous.

- Groundwater Recharge: Promotes use of infiltration practices (groundwater recharge) to reduce runoff caused by a project and replenish groundwater supply.

- Redevelopment Criteria: Requires improvements in stormwater management and treatment for redevelopment projects on existing properties. By capturing redevelopment projects this addresses existing stormwater runoff.

A 2015 UNHSC study of the Oyster River watershed found early adoption of enhanced stormwater standards could reduce average annual pollutant loads by up to 70% and save towns an estimated $14 million in avoided costs over the next 30 years (UNHSC and VHB 2015). If other municipalities in the Piscataqua Region watershed adopt such regulations, future cost savings could increase dramatically. To track stormwater management progress across the watershed, PREP and its partners monitor which municipalities have adopted enhanced stormwater standards. Figure SM-1 reflects which communities have adopted the SWA model stormwater standards or something similar (8), which communities have adopted a partial set of the recommended regulations without redevelopment standards (5), and which communities have regulations pending (7). Overall, 30 out of 52 communities in the Piscataqua Region watershed have adopted some level of stormwater standards; this includes the 10 Maine communities that adhere to Maine state standards.

In addition to adopting new regulations, communities are exploring creative options for funding sustainable stormwater management. One option is adoption of a stormwater utility designed to generate funding through user fees that are often based on a property's collective amount of impervious cover within the utility district. A stormwater utility provides a stable revenue source to support long-term operation and implementation of a municipal stormwater program that addresses flooding, water quality, and aging infrastructure. These utilities require equitable cost distributions (charging owners with the most impervious cover their fair share), incentivize reduction of stormwater volumes through lower fees, and help communities comply with federal regulations. Many communities in Maine, Vermont, and Massachusetts have successfully adopted stormwater utilities. While no such utilities currently exist in New Hampshire, the cities of Dover and Portsmouth have conducted feasibility studies (Peschel 2011; Allen 2011).

For More Information

Model Standards

https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/Final_SWA_SWStandards_Dec_20121_0.pdf

Durham Study Fact Sheet

https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/FactSheet%20-%20P2%20ModelingRV_WEB.pdf

Stormwater Manual

https://www.des.nh.gov/organization/divisions/water/stormwater/manual.htm

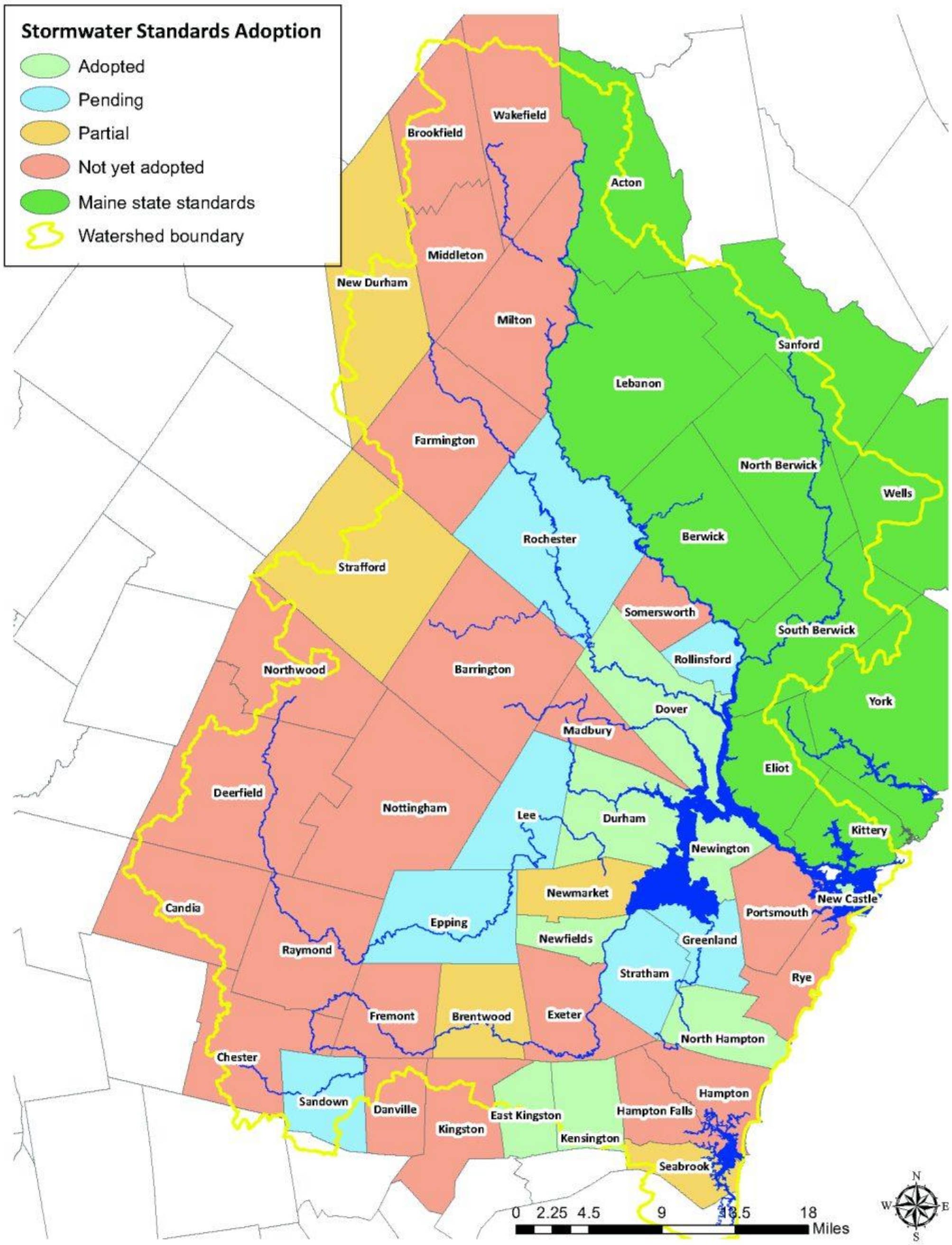

Figure SM-1. Map depicting adoption status of SWA model stormwater standards across 42 New Hampshire communities and 10 Maine communities. Data Source: Rockingham Planning Commission and Strafford Regional Planning Commission. Mapping and GIS technical assistance provided by the University of New Hampshire Cooperative Extension.

Methods and Data Sources

The borders of each municipality in the Piscataqua Region watershed were mapped using spatial data from NH GRANIT. The area of each municipality was then filled with a color corresponding to its status in adopting the recommended standards outlined in the SWA *Model Stormwater Standards for Coastal Watershed Communities.* Communities were assigned one of five status categories: Adopted, Pending, Partial, Not Yet Adopted, and Maine State Standards (Table SM-1). "Adopted" communities have adopted the recommended standards in their entirety and the changes have been incorporated into the municipality's regulations. Municipalities classified as "Adopted" may not have the same or any specific threshold for applicability standard outlined in their regulations, though a threshold of 5000 square feet is recommended by stormwater experts in New Hampshire. "Pending" communities are those who are still in the process of changing their local regulations (as of July 2017) to reflect the recommended standards and will be assigned either "Partial" or "Adopted" once the changes are finalized and approved. "Partial" is assigned to those communities who have successfully adopted some of the regulatory changes recommended in the model stormwater standards, but those changes did not include important criteria such as Redevelopment Standards or other performance measures. "Not Yet Adopted" communities have not changed their local stormwater regulations to reflect the recommended standards.

The 10 Maine communities in the Piscataqua Region watershed are required to adhere to Maine Stormwater Management Law (38 MRSA § 420-D) and its associated Chapter 500 Rules, as well as the Maine State General Permit requirements (Maine Legislature 2017; Maine Dept. of Environmental Protection 2017). Maine guidance provides stormwater standards required for projects located in organized areas that include one acre or more of disturbed area. This one-acre threshold, equal to approximately 43,560 square feet, is significantly smaller, and thus, more restrictive, than the Alteration of Terrain permit threshold for non-protected land in New Hampshire, and it captures a larger portion of development projects in Maine communities. As a result, many Maine municipalities rely solely on the State's stormwater management standards and have not adopted more restrictive stormwater management regulations. Additionally, many development projects in Maine communities that are less than 1 acre are required to comply with stormwater standards found in the Maine Construction General Permit or in Chapter 500 Rules if they are subdivision, redevelopment, or shoreland projects. Given these additional restrictions and requirements at the state level in Maine, the 10 Maine communities in the Piscataqua Region watershed were assigned their own category.

It is important to note that because the Maine Stormwater Management Law and its associate rules and resources provide more restrictive standards than state level stormwater regulations in New Hampshire, the lack of enhanced stormwater standards at the local level in Maine does not necessarily reflect a lack of recommended stormwater management. For more information on the Maine Stormwater Management Law and Rules, visit the Stormwater Program webpage on the Maine Department of Environmental Protection website.

For more information on recommended performance standards and best management practices for stormwater management in Maine, Maine DEP provides publically accessible guides and manuals online, including the *Maine Stormwater Management Design Manual* and the *Maine Erosion and Sediment Control Practices Field Guide for Contractors* (Maine Dept. of Environmental Protection 2016, 2017).

Data Sources

For NH, the data source for this indicator was information from the Rockingham Planning Commission and the Strafford Regional Planning Commission regarding the adoption of model stormwater standards recommended for New Hampshire municipalities in the coastal watershed by the SWA, the UNHSC, and The Rockingham Planning Commission. The Rockingham Planning Commission and the Strafford Regional Planning Commission assisted with data collection and provided details on which New Hampshire municipalities have adopted all the recommended components of the SWA's *Model Stormwater Standards* as well as which communities have adopted only a portion of the recommended components.

The data source for Maine stormwater management regulations and statistics was the Maine Department of Environmental Protection website.

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Table SM-1. Status of enhanced stormwater standards for Piscataqua Region watershed communities.

Municipality	Stormwater Status	MS4 Status	Stormwater Utility
Dover	Adopted	Yes	No
Durham	Adopted	Yes	No
East Kingston	Adopted	Waiver	No
Kensington	Adopted	No	No
New Castle	Adopted	Yes	No
Newfields	Adopted	Waiver	No
Newington	Adopted	Waiver	No
North Hampton	Adopted	Yes	No
Barrington	Not yet adopted	Waiver	No
Brookfield	Not yet adopted	No	No
Candia	Not yet adopted	Waiver	No
Chester	Not yet adopted	Waiver	No
Danville	Not yet adopted	Yes	No
Deerfield	Not yet adopted	No	No
Exeter	Not yet adopted	Yes	No
Farmington	Not yet adopted	No	No
Fremont	Not yet adopted	Waiver	No
Hampton	Not yet adopted	Yes	No
Hampton Falls	Not yet adopted	Waiver	No
Kingston	Not yet adopted	Yes	No
Madbury	Not yet adopted	Waiver	No
Middleton	Not yet adopted	No	No
Milton	Not yet adopted	Yes	No
Northwood	Not yet adopted	No	No
Nottingham	Not yet adopted	No	No
Portsmouth	Not yet adopted	Yes	No
Raymond	Not yet adopted	Yes	No
Rye	Not yet adopted	Yes	No
Somersworth	Not yet adopted	Yes	No
Wakefield	Not yet adopted	No	No
Strafford	Partial	No	No
New Durham	Partial	No	No
Brentwood	Partial	Waiver	No
Newmarket	Partial	Yes	No

Municipality	Stormwater Status	MS4 Status	Stormwater Utility
Seabrook	Partial	Yes	No
Epping	Pending	Waiver	No
Lee	Pending	Waiver	No
Rochester	Pending	Yes	No
Rollinsford	Pending	Yes	No
Sandown	Pending	Yes	No
Stratham	Pending	Yes	No
Greenland	Pending	Yes	No
Acton, ME	ME State Standards	No	No
Berwick, ME	ME State Standards	Yes	No
Eliot, ME	ME State Standards	Yes	No
Kittery, ME	ME State Standards	Yes	No
Lebanon, ME	ME State Standards	No	No
North Berwick, ME	ME State Standards	No	No
Sanford, ME	ME State Standards	No	No
South Berwick, ME	ME State Standards	Yes	No
Wells, ME	ME State Standards	No	No
York, ME	ME State Standards	Yes	No

Indicator: Stewardship Behavior

Question

How many volunteer hours were logged in the watershed through the work of six NH stewardship groups in 2015 and 2016? Additionally, how many signups and events for stewardship-related activities were completed through The Stewardship Network: New England from 2015 to 2016?

Short Answer

In 2015, there were 44,174 volunteer hours logged in the watershed through the work of six selected New Hampshire-based stewardship groups. In 2016, there were 39,788 volunteer hours logged in the watershed through those same six selected groups.

In 2015, there were 422 people who signed up for 122 events in the watershed, and, in 2016, there were 524 people who signed up for 96 events in the watershed through the Stewardship Network: New England.

PREP Goal

No goal yet determined.

Why This Matters

Stewardship of local ecosystems improves environmental conditions and fosters and sustains a sense of investment in, and value for, the long-term wellbeing of those systems. No matter how stringent local environmental regulations are or how advanced wastewater and stormwater technology becomes, local communities cannot be truly sustainable without an engaged citizenry that takes action to care for and protect local natural resources. Environmental stewardship in communities has been shown to create personal connections to the landscape and improve local quality of life, and its role in strengthening the social resilience of communities is being studied (McMillen et al. 2016). Many organizations, groups, and individuals in the Piscataqua Region are already working to ensure that stewardship culture is ingrained in the identity of local residents. The health of this region depends on this stewardship culture’s capacity to reach and engage new demographics of residents, including newcomers to the region and the growing millennial population.

Explanation (from 2018 State of Our Estuaries Report)

Stewardship can be defined as the careful and responsible management of something entrusted to one’s care (Merriam-Webster.com). While there are many active organizations working on stewardship and conservation across the region, PREP developed criteria to determine which groups would be used for this indicator. These include 1) regular collection of volunteer data; 2) opportunities for engagement offered for a majority of the year; 3) stewardship activities occurred within the PREP watershed boundary and 4) a focus on coastal resources. The entities selected were the Blue Ocean Society for Marine Conservation, Great Bay National Estuarine Research Reserve (GBNERR), the Gundalow Company, the Seacoast Science Center, the New Hampshire Department of Resources and Economic Development (NHDRED), and the Coastal Research Volunteer (CRV) Program at University of New Hampshire Sea Grant.

These organizations have dedicated volunteer bases that combined to donate 44,174 hours in 2015 in the Piscataqua Region and 39,788 hours in 2016 (Table SB-1). Using the latest Bureau of Labor Statistics volunteer rate for New Hampshire ($24.90 per hour), the estimated economic value of this contribution is $1,099,993 in 2015 and $990,721 in 2016 (Bureau of Labor Statistics 2017). These volunteers work tirelessly to care for the local landscape, be it through cleaning up litter on a beach, restoring eroded dunes, counting glass eels, or teaching students about the historical significance of Great Bay and its tributaries. The work of these passionate volunteers improves environmental conditions and lays the foundation for increased understanding of, and appreciation for, local natural resources. By tracking the hours donated by volunteers from these well-established groups, PREP can track the activity of a dedicated group of stewards in the region. PREP hopes to expand the number of organizations contributing to this indicator in the future, with a particular focus on those that work in Maine.

It is crucial that this spirit of stewardship and understanding of local ecosystems continue in the region, especially as populations increase and our natural resources are more heavily utilized. The University of New Hampshire Cooperative Extension launched The Stewardship Network: New England in 2013 to address New Hampshire's growing need for increased stewardship capacity and volunteer coordination. The Network's mission is to mobilize volunteers to care for and study the lands and waters in New England. In keeping with this mission, the Network cultivates an online hub for stewardship and citizen science volunteer opportunities and trainings. Their Events Calendar (http://newengland.stewardshipnetwork.org/events-training) and weekly e-bulletin are utilized by hundreds of organizations to promote hundreds of stewardship opportunities and events. There are thousands of subscribers interested in taking part in these activities, and The Stewardship Network tracks how many people sign up and how many hours were spent on each event. Additionally, The Stewardship Network can select data by zip code, including the coastal region. In 2015, 422 people signed up for 122 events, and in 2016, 524 people signed up for 96 events (Table SB-2).

Table SB-1. Volunteer Hours by Selected Stewardship Groups by Year. Data Source: Blue Ocean Society for Marine Conservation; NHDRED; NH Sea Grant; GBNERR; Gundalow Company; Seacoast Science Center.

Organization	2015	2016
Blue Ocean Society for Marine Conservation	3,080	3,765
Dept. of Resources & Economic Development	19,872	16,791
Dune & Coastal Research Volunteers	1,764	1,602
Great Bay National Estuarine Research Reserve	3,883	2,963
Gundalow Company	2,500	2,779
Seacoast Science Center	13,075	11,978
TOTAL	**31,099**	**40,975**

Table SB-2. The Stewardship Network: New England Volunteer Event Data in the Piscataqua Region by Year. Data Source: UNH Cooperative Extension, The Stewardship Network: New England.

Year	Number of Signups	Number of Events
2015	422	122
2016	524	96

Methods and Data Sources

Data from six prominent organizations and entities who organize and facilitate stewardship events in the Piscataqua Region watershed were combined to create a regional summation of volunteer hours donated to stewardship activities. These data were compared from 2015 to 2016 and will continue to be monitored in future years. Signup and event data from The Stewardship Network: New England was extracted from the Network's

Salesforce database based on events located in the zip codes that fall within the boundaries of the Piscataqua Region watershed. Total signups were calculated by adding up the number of signups across all the events in the region for each year, and total events were calculated by adding up the number of distinct events posted on the Stewardship Network website in the relevant zip codes for each year.

Data Sources
The data sources selected for this indicator were the records kept by the six organizations and groups studied. The organizations and groups who contributed data to this indicator were as follows: Blue Ocean Society for Marine Conservation, the New Hampshire Department of Resources and Economic Development, the UNH Dune and Coastal Research Volunteers, Great Bay National Estuarine Research Reserve, The Gundalow Company, and The Seacoast Science Center.

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Appendix A - Technical Advisory Committee/External Advisor Process

Key Technical Advisory Committee Process Steps:

- Public TAC Meetings were held in September 2016, October 2016, January 2017, March 2017, and May 2017.
    - Meetings were open to all interested participants and invitations were sent to over 700 people four weeks before the date of each meeting.
    - 69 different participants overall and an average of 26 came to each meeting.
    - Meetings were facilitated by the PREP Coastal Scientist to ensure that the interactions met professional standards for public participation.
    - The May 2017 TAC event was a 2-day meeting focused on looking at the relationships between key indicators, with an emphasis on better understanding the decline in eelgrass habitat. These interactions consisted of two 4-hour meetings conducted on two consecutive days.
        - This event was also attended by the three external advisors (see "External Advisors" below for more information). These advisors subsequently developed a "Statement Regarding Eelgrass Stressors," which is an appendix to this report.

Presentations and notes for all of these meetings can be found at:

http://prepestuaries.org/prep-technical-advisory-committee/

- In late April 2017, drafts of the water quality and biological indicators of the Summary Report were shared with TAC participants for comment. The invitation to review indicator drafts was sent to all 69 people who attended any TAC meeting from September 2016 forward. 54 people asked to be included as TAC Reviewers. These reviewers included a broad range of stakeholders, including: federal, regional, state and municipal staff as well as non-governmental agency staff, academic scientists and citizens of the Piscataqua Region.
- Indicator drafts were edited, when appropriate, in response to the above feedback and then shared in full draft manuscript form with the PREP Management Committee. The purpose of this review was to ensure that the content corresponded to PREP's mission as a National Estuary Program. For more information on the PREP Management Committee, please see: http://prepestuaries.org/prep-management-committee/
- Beginning in September 2017, the sections of the Data Report were finalized. Much of the data had already been analyzed and presented as part of the TAC process; however, graphs and figures needed to be checked for accuracy and finalized.
- As Data Report sections were developed, they were sent back to subject matter experts for a final technical review before being finalized.

External Advisors

Three external advisors were brought on to the Technical Advisory Committee (TAC). The advisors brought additional knowledge and perspectives to the already rich diversity represented in the TAC process. The advisors also reviewed drafts of certain SOOE indicator sections, including: Estuarine Stress and Resilience; Nutrient Loading; Nutrient Concentrations; Dissolved Oxygen; Total Suspended Solids, Eelgrass, Phytoplankton; and Seaweed.

The advisors were selected by the PREP Coastal Scientist after consulting with a variety of stakeholders in the region. With regard to expertise, advisors were sought based on their deep experience dealing with eelgrass in a variety of estuarine conditions. As a secondary criterion, PREP sought advisors who had experience dealing with related habitats such as seaweed, phytoplankton and shellfish. Finally, each advisor had to have a reputation for meeting standards for objectivity and professionalism.

Read more about the process for working with the external advisors as well as their “Statement Regarding Eelgrass Stressors” in Appendix B of this Report.

Appendix B External Advisors to PREP Technical Advisory Committee Statement Regarding Eelgrass Stressors in the Great Bay Estuary

External Advisors to PREP Technical Advisory Committee

Statement Regarding Eelgrass Stressors in the Great Bay Estuary

Background for this Statement

Three external advisors were invited to participate in PREP's Technical Advisory Committee (TAC) process during the 2016-2017 meetings. Dr. Jud Kenworthy has been advising PREP since the spring of 2016 and he served on the 2014 Peer Review Panel for the Numeric Nutrient Criteria for the Great Bay Estuary. Dr. Ken Moore was one of the scientists approached to be on the the Peer Review Panel by NH Department of Environmental Services (DES) and the Great Bay Municipal Coalition. Dr. Moore joined the process in February 2017. Dr. Chris Gobler began offering advice on issues related to seaweeds, shellfish, and general water and sediment quality in December 2016. Dr. Gobler was chosen because of his unique combination and depth of background in issues pertaining to phytoplankton, seagrass and bivalves.

In early 2017, several conference calls involving the PREP coastal scientist and all three advisors were held. The primary task for the advisors was articulated as: "Provide feedback on what stressors should be considered and prioritized (relative to each other) when trying to manage for improved ecosystem condition, in particular, as measured by the distribution and abundance of eelgrass in the Great Bay estuarine ecosystem, but also considering health of shellfish habitats." The advisors were asked to focus on data collected specific to the Great Bay Estuary and to bring to bear knowledge gained from experience and studies in other coastal ecosystems. The advisors were given access to 44 different sources of environmental information on eelgrass, oysters and water quality in the Great Bay Estuary. These sources included data from PREP, EPA, NH DES, the Municipal Coalition and individual researchers. All three advisors attended the May 9th and 10th (2017) TAC meetings and continue to offer advice on the development of the State of Our Estuaries Report.

The charge for this statement was to offer overarching views on the question of eelgrass stressors, based on science, but in a way that builds a foundation for future management discussions. In addition, Dr. Kenworthy, who also served on the 2014 Peer Review of 2009 proposed numeric nutrient criteria, was asked to write a paragraph relating the Peer Review to the 2017 TAC Process.

In the statement below, the pronoun "we" refers to the three external advisors only.

Statement Regarding Eelgrass Stressors in the Great Bay Estuary

Many previous discussions have focused on very specific stressors (e.g., nitrogen, major storms) in an attempt to determine what are the main drivers of ecosystem changes in the Great Bay Estuary. We suggest that these narrowly focused debates do not reflect the complexity of estuarine ecosystems. Rather, management actions should be considered in the context of multiple stressors having both additive, cumulative, and potentially synergistic impacts on the resilience of the system. For example, rather than focus on what is stressing eelgrass and oysters, the charge is to focus on what is stressing these habitats' ability to respond to chronic and acute stressors (Unsworth et al. 2015). This gets to the core of "resilience," which is defined as "the capacity of an ecosystem to absorb repeated disturbances or shocks and adapt to change without fundamentally switching to an alternative and sometimes undesirable stable state" (Holling 1973). It is believed that the preponderance of evidence indicates that multiple stressors have acted and interacted to weaken the resilience of the Great Bay ecosystem.

We agreed that there is evidence the Great Bay Estuary has become de-stabilized with regard to eelgrass and oyster abundance. We note that eelgrass continues to partially recover from stress but has not returned to levels of abundance previously recorded. Three things are important in acknowledging that the ecosystem has been de-stabilized. 1) It is possible to regain a previous state (Greening et al. 2014); 2) It is challenging to regain the previous state because of new or modified conditions in the current state (Duarte et al. 2009; Kenworthy et al. 2013; Kuusemae et al. 2016). For example, with 89% of oysters and 30% of eelgrass gone, the ability of the system to filter and stabilize sediments is greatly decreased. Also, eelgrass cannot recover through vegetative reproduction alone; it must rely on sexual reproduction (through seed production and dispersal). But given the plant's two-year life cycle, complex life history, sensitive life stages and decreasing number of plants, there are multiple pathways for stressors to affect eelgrass and inherent limits to how much eelgrass can respond unless conditions significantly improve (Kenworthy et al. 2013); 3) regaining past levels of resilience may require environmental conditions to improve initially to levels better than before the declines were observed (Biber et al. 2008; Jarvis and Moore 2010; Jarvis et al. 2014). This follows on point #2; due to the current lack of resilience, improving conditions to previous levels may only allow habitats to remain at the current state or slow the decline and not regain the previous one (Bostrom et al. 2014; Duarte et al. 2015).

Regarding the suite of stressors affecting eelgrass, we believe it is important to not consider individual stressors separately, but rather consider their interactive and additive effects. Any one stressor—warming waters, major storms, excessive nutrient loading, the overgrowth of seaweeds, organically-enriched sediments, episodes of high phytoplankton concentrations, continually increasing suspended sediments—can make eelgrass less resilient to the other stressors (Orth et al. 2006; Kenworthy et al. 2013; del Barrio et al. 2014).

Some might argue that the decrease in eelgrass is related to a "pulse" stressor like major storms, but it is equally plausible that a slow "press" stressor chronically applied, such as decreased water quality in response to increases in population and impervious cover, created conditions limiting eelgrass recovery from a pulse disturbance (Orth et al. 2006; Bostrom et al. 2014). Further, the interactions of stressors can create feedback loops that can promote rapid ecosystem degradation. For example, the overgrowth of seaweeds may lead to the progressive organic enrichment of sediments that have high levels of sulfide and low levels of oxygen, depressing both the abundance of benthic animals and the growth of eelgrass. Since eelgrass and benthic animals promote oxygen levels in sediments and since high oxygen in sediments degrade organic matter, the loss of eelgrass and benthos could lead to continually declining sediment oxygen and high sulfide levels that in turn will further decrease the abundance of eelgrass and the benthos. This feedback loop has been documented in several coastal ecosystems where eelgrass and shellfish were considered foundation species (Burkholder et al. 2007; Viaroli et al. 2008).

We appreciate that there are many stressors affecting eelgrass, such as ice scour, bioturbation and consumption by geese and green crabs as well as the light attenuating components of phytoplankton, CDOM, total suspended solids, epiphytes and drift seaweed. More spatially and temporally comprehensive data needs to be collected to better understand the interactive effects of these stressors, especially so that the community can track the response of the ecosystem to the many interventions that are already taking place and determine if they are sufficient or others need to be implemented. We strongly recommend that: 1) the Great Bay Estuary system develops a comprehensive, frequent and coordinated environmental quality monitoring program; 2) the monitoring program should be designed to capture the fundamental conditions in the different geographic zones of the Great Bay Estuary, and 3) seek a means of funding and cooperation between the scientific community, the resource managers and the municipalities to integrate the existing data to develop a set of verifiable conclusions about the state of the system as can be known from the existing data. This will help remove quite a bit of the present uncertainty and will also help inform the design and interpretation of a long-term monitoring program.

Despite encouraging reductions in nitrogen from wastewater treatment plants, loading levels are still well above levels found to be related to environmental degradation and reduced estuarine ecosystem resiliency in many other systems (Latimer and Rego 2010). The most recent physiological measurements of Ulva (a green seaweed) that is abundant in the estuary indicate complete nitrogen saturation (Nettleton et al. 2011). Episodic phytoplankton blooms reach levels that both NOAA and EPA consider high and potentially damaging to eelgrass (Bricker et al. 2003; US EPA 2012; NH DES 2017). Low nitrogen levels will reduce the number and impact of phytoplankton and seaweed blooms. In fact, if nitrogen isn't low enough, reducing sediment loadings will allow more light to phytoplankton and seaweed which could cause a further decrease in eelgrass abundance. Both stressors need to be addressed.

Parts of Great Bay Estuary are well flushed, but this characteristic comes with stress. Much of the estuary is extremely shallow, especially at low tide, so any nitrogen in the system is more concentrated and sediments are more easily resuspended. A large tidal range may allow more light to temporarily reach eelgrass in the intertidal zone during ebb, but associated shifts in light levels are stressful to eelgrass as well. It is energetically costlier and less efficient for the plants to have to continually shift their photosynthetic apparatus to deal with highly varying light conditions associated with high tidal ranges in areas with relatively shallow water depths. Additionally, much of the hydrodynamic flushing comes from substantial riverine inputs, but these inputs also bring in light-attenuating substances (like CDOM) as well as other contaminants.

How much nitrogen reduction is enough or too much? The data to answer this question do not currently exist. To help answer that question, a thorough quantitative ecosystem based model as recommended by the 2014 Peer Review (Bierman et al. 2014) would be required. And this model would need to be specific to different assessment zones within the estuary. It is not likely that one model would work for the entire system.

The fact that municipalities have significantly reduced nitrogen from wastewater treatment facilities is an excellent foundation to build upon. Based on the reports given to the advisors, it is evident that a large fraction of the nitrogen entering the system comes from non-point sources (NH DES 2014). Given that only 2.6% of the estuarine watershed area is occupied by the mitigating effects of wetlands, the Great Bay estuary is extremely vulnerable to non-point source loadings. This is typical of northeastern estuaries, which have much less wetland buffering capacity compared to estuaries in the southeast and Gulf of Mexico (Bricker et al. 1999; Bricker et al. 2003). Addressing these non-point source loads is a natural next source for managers to consider, especially as non-point source reduction can also mitigate other run-off related pollutants, such as toxic contaminants, including herbicides and petrochemicals, both of which have been linked with eelgrass stress.

In summary, the opinions expressed here with respect to the status of eelgrass in the Great Bay Estuary are consistent with the general conclusions of the 2014 Peer Review Panel Joint Report (Bierman et al. 2014), which reviewed the NHDES proposed Numeric Nutrient Criteria for the Great Bay Estuary (NH DES 2009). Empirically derived evidence from experimental studies and monitoring programs indicate that eelgrass distribution and abundance in an estuary results from the complex interaction of several physical, biological and process based factors and no two estuaries or sub-embayments of an estuary are identical in all of these factors. To determine if one or more factors are the primary controlling factor it is necessary to either consider all the factors and their interactions or be able to definitively rule out factors as insignificant. The multivariate factors, the linkages between factors and the processes by which they can be evaluated that was identified in the Panel's report provide a basis for developing a comprehensive monitoring and modelling program that could be used to improve our understanding of which physical and biological variables in the system are having the greatest effect on eelgrass distribution and abundance.

We are grateful for the opportunity to offer our perspectives on estuarine ecosystem issues as they pertain to the Great Bay Estuary. Readers should know that all three advisors agreed without question on the above statement.

With regards and best hopes for the Great Bay and Hampton-Seabrook Estuaries,

Chris Gobler

Jud Kenworthy

W. Judson Kenworthy

Ken Moore

Kenneth A. Moore

External Advisors: Brief Biographies

Dr. Chris Gobler
Christopher J. Gobler is a Professor and Associate Dean of Research within the School of Marine and Atmospheric Sciences (SoMAS) at Stony Brook University. He received his M.S. and Ph.D. from Stony Brook University in the 1990s. He is also co-Director of the New York State Center for Clean Water Technology and co-Editor of the international, peer-reviewed journal, *Harmful Algae*. The major research focus within his group is investigating how anthropogenic activities and climate change combine to alter the ecological functioning of coastal ecosystems. Past research has emphasized interactions and feedbacks among nutrient delivery pathways, pelagic phytoplankton communities, benthic filter feeders, and benthic autotrophs such as seagrass. His research group also strives to understand how co-occurring stressors related to both climate change and shallow coastal ecosystems (hypoxia, thermal stress, algal blooms) may act and interact to affect the performance of marine animals. Finally, Dr. Gobler's lab specializes in studying harmful algal blooms (HABs) and how nutrients, CO_2 levels, zooplankton grazing and bivalve grazing influence the dynamics of HABS. His work has resulted in more than 150 manuscripts in peer-reviewed journals.

Dr. Jud Kenworthy
Dr. Kenworthy holds a BSc from the University of Rhode Island, a M.S. in Environmental Sciences from the University of Virginia and a PhD in Zoology at N.C. State University. Dr. Kenworthy is recently retired from the Center for Coastal Fisheries and Habitat Research, NCCOS, NOS, NOAA after 33 years of federal service. As a student and NOAA research scientist Dr. Kenworthy has over 40 years of experience in coastal ecology with emphasis on seagrasses and the effects of natural and anthropogenic disturbance on coastal environments. Dr. Kenworthy's areas of expertise in applied science include research on water quality impacts on seagrasses, seagrass restoration, disturbance ecology, designing and implementing environmental assessments and resource monitoring programs and assisting State, Federal and International Resource Management Agencies in planning and implementing conservation and restoration programs.

Dr. Ken Moore
Dr. Moore holds a B.S. from the Pennsylvania State University in Zoology, a M.S from the University of Virginia in Marine Science and a Ph.D. for the University of Virginia in Marine and Environmental Sciences. Dr. Moore is a Professor of Marine Science and past Chairman of the Department of Biological Sciences at the College of William and Mary, School of Marine Science. He is also the Research Coordinator of the National Estuarine Research Reserve in the Chesapeake Bay. His research studies, which have been conducted world-wide, have focused on the ecology of estuarine and coastal shallow water environments, especially those vegetated with marshes, seagrasses and other submersed aquatic vegetation. Specifically, he has studied the relationships between these aquatic macrophyte systems and their interactions with environmental factors including water quality and sediment conditions, as well as climate stressors that can limit their growth, reproduction, survival and restoration. These studies have been hierarchal in nature, ranging from laboratory studies of the physiological responses of individual organisms, to field studies of seagrass restoration, to ecosystem-level responses of these systems to management actions. He has worked to develop and implement new, enhanced shallow water monitoring and measuring technologies to evaluate and quantify the highly variable conditions in space and time that are found there, and to connect these integrated conditions to seagrass bed and other community responses.

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