STATE OF OUR ESTUARIES 2023

EXTENDED REPORT

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PREP™
Piscataqua Region Estuaries Partnership

State of Our Estuaries 2023 – Extended Version

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PREP, the Piscataqua Region Estuaries Partnership, is part of the University of New Hampshire and the School of Marine Science and Ocean Engineering.

To learn more about PREP, visit **PREPestuaries.org** and for more information and to explore the State of Our Estuaries Report interactively, visit **StateOfOurEstuaries.org**.

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Table of Contents

Introduction

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 receives its foundational funding from the EPA and is administered by the University of New Hampshire. Funding also comes from partners at the national and state level and from a growing number of the 52 municipalities in the Piscataqua Region Watershed.

Every five years, PREP prepares a State of Our Estuaries 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 Report is limited in length because it is also printed and offered to partners throughout the Region. The Extended Version (online only) serves as a companion to the State of Our Estuaries Report, including a "Special Features" section as well as expanded results, discussion, methods and data source details for all sections of the Report.

> *Please note that the State of Our Estuaries Report and the Extended Version do not have overlapping information. The main content about the health of the estuaries is found in the State of Our Estuaries Report, while the Extended Version has additional information on methods and other ecosystem variables not described in the Report.*

<u>Special Features, Supporting Variables, Potential Indicators and Indicators</u>

Special Features include important information that could not be included in the Summary Report due to space limitations. Special Features include "Potential Indicators" and "Supporting Variables."

Horseshoe crabs, lobsters, green crabs and saltmarsh sparrows are all potential indicators but have yet to be officially designated as an indicator through a Technical Advisory Committee process. This could happen in the future, however.

In contrast, Supporting Variables are variables that meet the first three of the "Indicator Criteria" (see below) but cannot be used to interpret environmental or ecological quality independently. Examples include temperature, wind speed and pH. While extremely important, these variables on their own have limited descriptive power regarding the health of estuarine ecosystems.

Established indicators, including those in the State of Our Estuaries Report*, have been reviewed and judged to meet the four criteria for an indicator, as established by EPA (EPA 1999).

- Conceptual Relevance – Relevance to both the ecological condition and a management question.
- Feasibility of Implementation – Feasibility of methods, logistics, cost, and other issues of implementation.
- Response Variability – Exhibition of significantly different responses at distinct points along a condition gradient.
- Interpretation and Utility – Ability to define the ecological condition as acceptable, marginal, or unacceptable in relation to the indicator results.

*Social indicators (such as Housing, Stormwater Management and Stewardship Behavior) are not subject to these criteria, which were developed for environmental indicators.

Acknowledgements

Please see the "Acknowledgements and Credits" section (pages 104-105) of the 2023 State of Our Estuaries Report. (StateOfOurEstuaries.org/2023-reports/sooe-report)

In addition, thanks to Maria Florencia Fahnestock for her help organizing and editing the Extended Version. Thanks also to extensive help from Sierra Kehoe for copy editing as well as content and web development. Thanks to Trevor Mattera for additional copy editing and to Abigail Lyon for project management.

References

EPA (1999) Evaluation Guidelines for Ecological Indicators. US Environmental Protection Agency, Office of Research and Development, Washington DC. EPA/620/R-00/005g. October 1999.

Impervious Cover

Methods & Data Sources

Data for the 52 town PREP footprint (see Figure 1.1) retrieved from the NH GRANIT Clearinghouse (granit.unh.edu) were used as the basis for mapping the 2021 impervious cover (IC). The primary data source used to update the 2015 IC consisted of 2021 60-cm resolution, 4-band National Agriculture Imagery Program (NAIP) orthophotography for both New Hampshire and Maine. Older vintage orthophotography (2015) was used for reference.

The updated IC coverage was derived by displaying the 2015 impervious cover data set for the project area, visually interpreting the 2021 source imagery, and manually digitizing changes to 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. Processing was conducted on a town-by-town basis to expedite the editing process and make the overall control of the task more efficient and manageable. Changes to the digitized features included adding new IC features, identifying features that were removed since 2015, and correcting any previous errors of omission or commission (e.g., missing features and false positives). Occasional errors were identified due to differences in tree canopy or lighting in the imagery; comparison of multiple imagery collections allowed for more accurate digitizing.

After a comprehensive review of the data, the IC polygons were processed to derive the final data set for distribution. This involved merging individual town-based datasets into the final, region-wide layer that was used to derive acreage summaries by town and HUC 12 watershed units.

The primary source data for the project comprised 2021 60-centimeter resolution, 4-band orthophotography acquired from the National Agricultural Imagery Program (NAIP) and existing 2015 impervious cover (IC) feature data sets. Older vintage orthophotography (2015) was also used for reference.

Additional Discussion

In some locations, there was a visible shift of the roadways and angle of building lean (as well as other features) between the 2015 high resolution imagery and the 2021 iteration. This is not unexpected, given the 6-year gap in the image collection cycle, the different sensors that were used, the different processing techniques, etc. As a result, there are instances of 2015 IC features that do not appear to overlay precisely on the 2021 imagery. In these cases, the 2015 data was left intact for the 2021 iteration. In general, for the New Hampshire data, where misalignments or questionable features occurred, the 2015 data was presumed correct because it was derived from a higher resolution data source. Conversely, this presumption was not necessarily used for the Maine features, since both the 2015 and 2021 features were derived from NAIP orthophotography.

This project represents the second iteration of mapping the entire 52-town PREP footprint using high resolution (HR), 1-foot/60-cm orthoimagery. Prior to 2015, the PREP IC mapping relied on medium resolution (MR), 30-meter satellite imagery (Justice and Rubin, 2011) As noted in an earlier report (Justice and Rubin, 2017), there are marked differences between impervious cover estimates generated by the two approaches. This is in part due to the significant difference in the spatial resolution of the source data (1-foot vs. 30-meter, respectively), and in part due to the different processing methodologies used (screen interpretation vs. subpixel automated classification, respectively).

As mentioned in our previous report (Justice and Rubin, 2015), we found that HR impervious cover can be derived using orthophotography at resolutions of 1-meter and greater. It should be noted however that using leaf-on data (i.e., NAIP, 60-centimeter resolution) makes processing slower and less refined. In addition, it should be realized that only major changes in the landscape will be recognized. Despite the shortcomings of the coarser resolution NAIP orthophotography, we feel that this data source is suitably resolved to identify IC at the mapping scales from which these were derived. It is clear, however, that leaf-off photography is preferred and that the NAIP imagery should only be used as a substitute when higher resolution, leaf-off data are not available. It is anticipated that orthophoto data sources such as regularly acquired NAIP imagery can be used as base data from which to delineate significant changes in IC.

Additional Data, Tables, and Graphs

The primary result of this project is a high resolution (HR) impervious cover data set capturing features for the year 2021 within the 52 town PREP footprint. Figure 1.3 displays the distribution of impervious cover mapped throughout the study area. Figure 1.4 presents a large-scale example of the mapping for a small subdivision in the study area. Figures 1.5 and 1.6 graphically show percent impervious cover by town and subwatershed. Tables 1.1 and 1.2 summarize the impervious cover by town and subwatershed.

Note that Figure numbers have been continued from the State of Our Estuaries Report, which contains Figures 1.1 and 1.2.

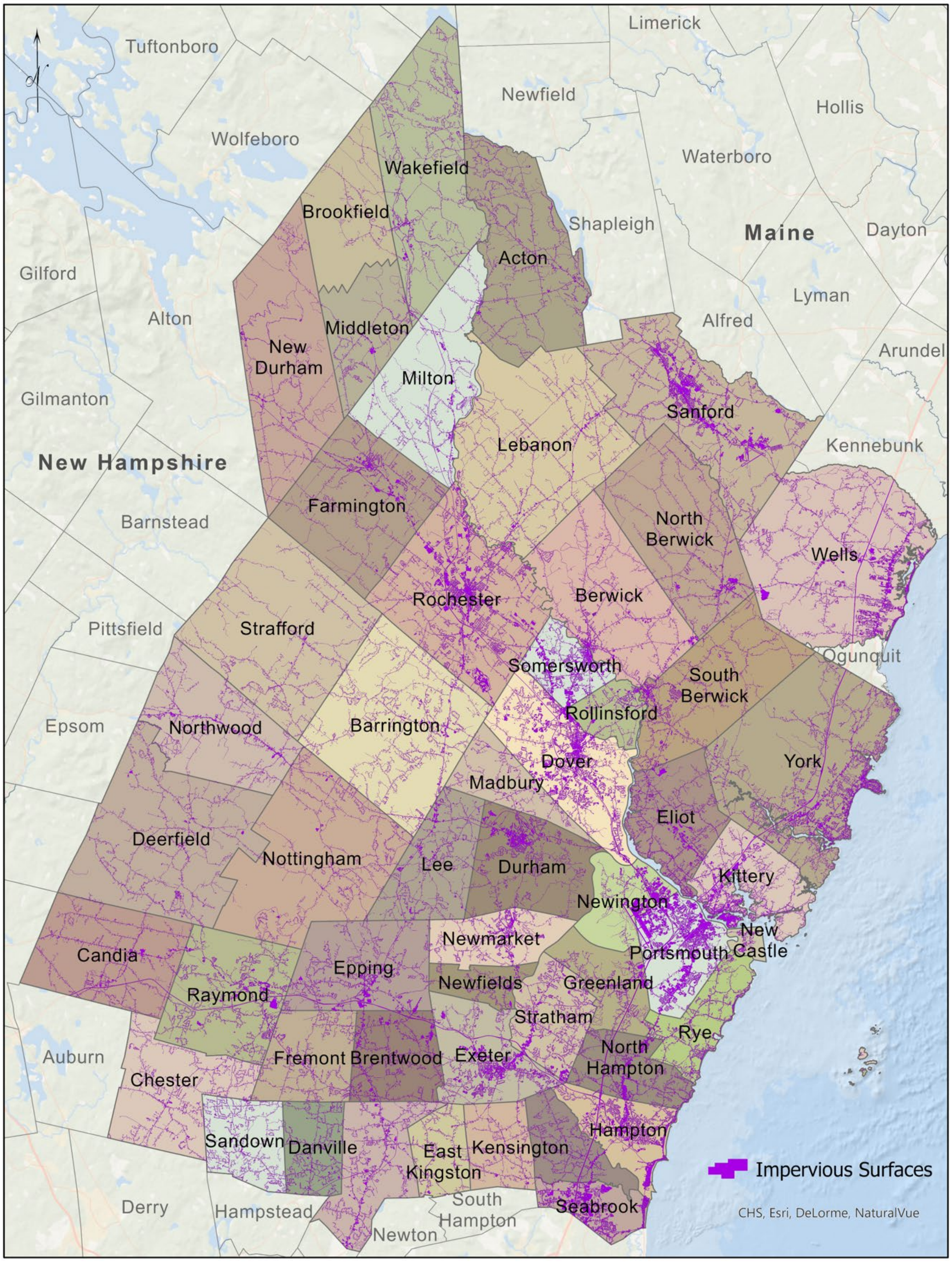


Figure 1.3. Distribution of 2021 impervious cover (purple features) in the project study area.

Figure 1.4. Large-scale example showing impervious cover features.

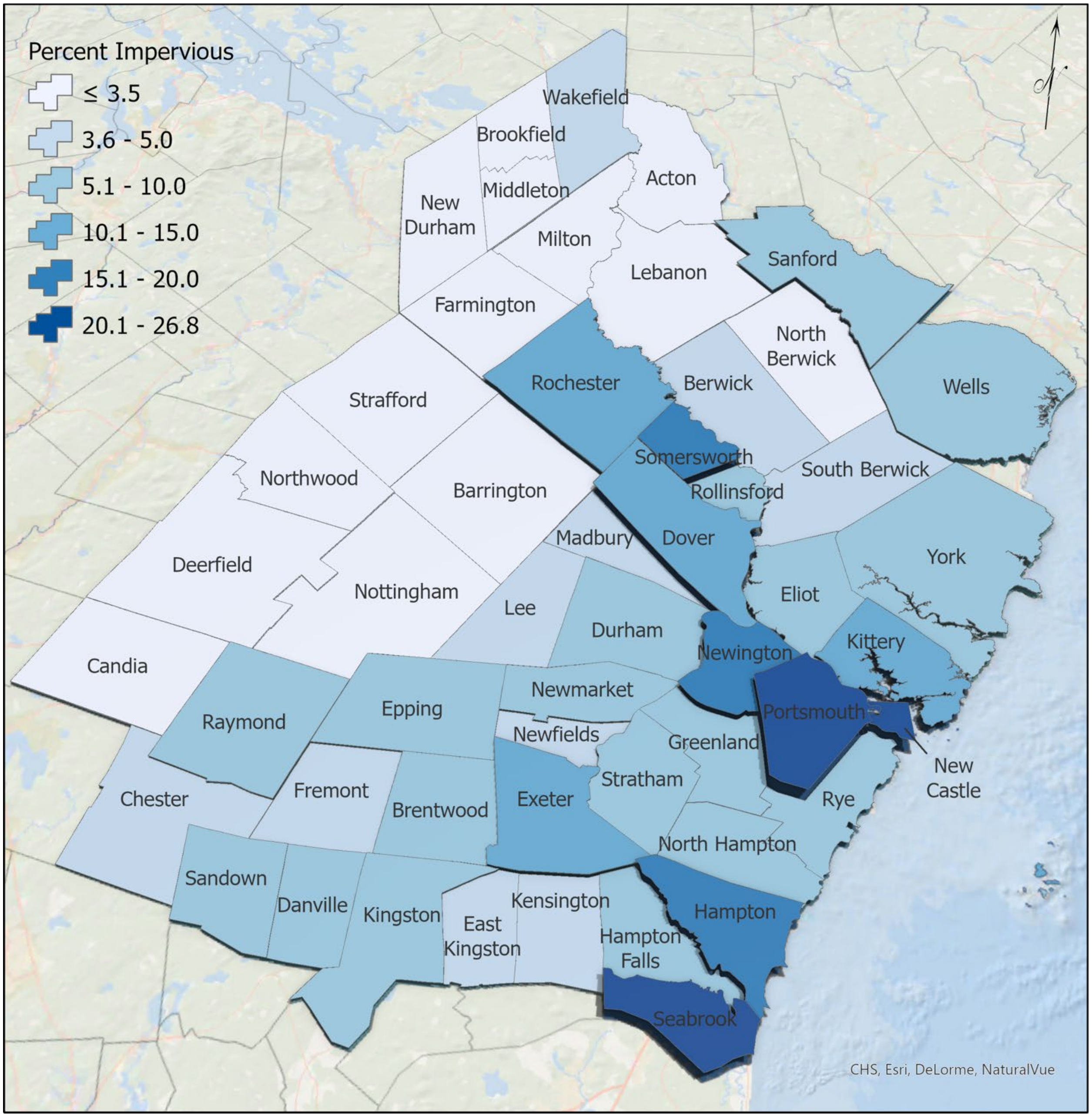


Figure 1.5. Percent impervious cover by town, 2021.

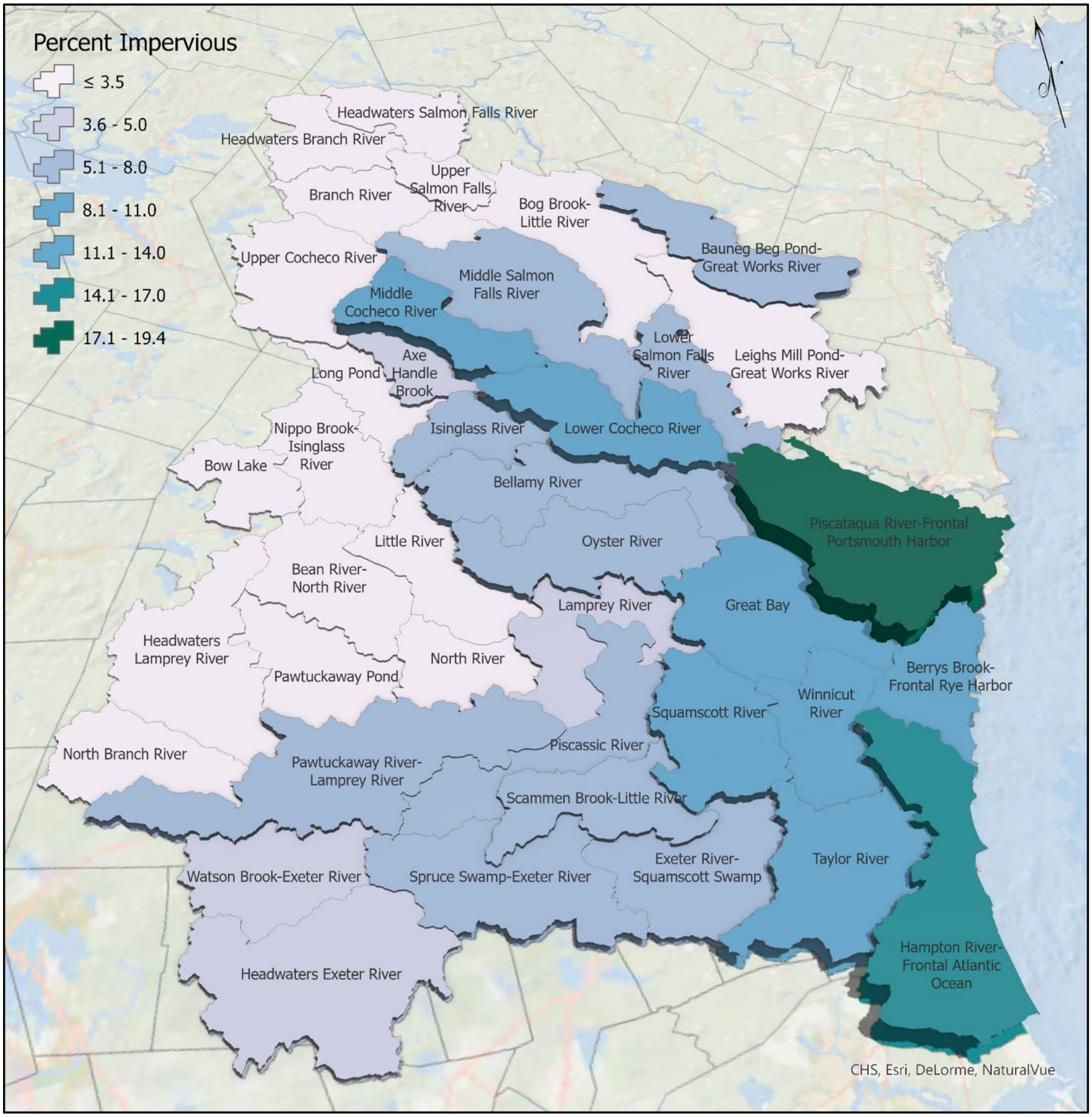


Figure 1.6. Impervious cover by HUC watershed.

State	Town	Total Area (acres)			IC (acres)			Percent IC (Land Area)	
		Land	Inland Water	Total	2015	2021	Change	2015	2021
Maine	Acton	24,216.3	2,191.7	26,408.0	747.0	781.4	34.4	3.1%	3.2%
	Berwick	23,779.6	447.1	24,226.7	893.8	946.0	52.2	3.8%	4.0%
	Eliot	12,609.4	150.6	12,759.9	894.0	957.8	63.8	7.1%	7.6%
	Kittery[1]	11,548.0	168.2	11,716.1	1,325.8	1,358.8	33.0	11.5%	11.8%
	Lebanon	34,957.8	675.8	35,633.6	1,018.0	1,050.5	32.5	2.9%	3.0%
	North Berwick	24,265.1	157.6	24,422.7	759.2	792.6	33.4	3.1%	3.3%
	Sanford	30,314.8	890.3	31,205.1	2,453.9	2,521.0	67.1	8.1%	8.3%
	South Berwick	20,468.8	243.1	20,711.8	761.7	802.3	40.6	3.7%	3.9%
	Wells	36,427.3	125.1	36,552.3	2,195.8	2,355.9	160.1	6.0%	6.5%
	York	34,913.8	685.0	35,598.8	2,204.7	2,295.6	90.9	6.3%	6.6%
	Total	253,500.6	5,734.4	259,235.0	13,253.9	13,861.9	608.0	5.2%	5.5%
New Hampshire	Barrington	29,719.0	1,398.3	31,117.3	1,003.8	1,037.1	33.3	3.4%	3.5%
	Brentwood	10,728.1	134.9	10,863.0	688.1	722.0	33.9	6.4%	6.7%
	Brookfield	14,593.0	287.3	14,880.4	133.7	138.3	4.6	0.9%	0.9%
	Candia	19,328.9	228.2	19,557.2	645.0	679.8	34.8	3.3%	3.5%
	Chester	16,606.2	111.6	16,717.8	566.1	604.4	38.3	3.4%	3.6%
	Danville	7,438.7	130.7	7,569.4	400.5	421.5	21.0	5.4%	5.7%
	Deerfield	32,575.7	772.1	33,347.8	697.1	723.4	26.3	2.1%	2.2%
	Dover	17,036.9	1,555.2	18,592.1	2,441.7	2,551.0	109.3	14.3%	15.0%
	Durham	14,251.1	1,601.2	15,852.3	922.7	952.6	29.9	6.5%	6.7%
	East Kingston	6,318.0	62.8	6,380.8	274.2	278.2	4.0	4.3%	4.4%
	Epping	16,476.6	299.1	16,775.7	929.7	996.9	67.2	5.6%	6.1%
	Exeter	12,540.6	272.3	12,812.9	1,226.6	1,272.7	46.1	9.8%	10.1%
	Farmington	23,213.0	427.0	23,640.0	781.2	798.2	17.0	3.4%	3.4%
	Fremont	11,033.1	109.3	11,142.4	425.6	446.6	21.0	3.9%	4.0%
	Greenland	6,722.5	1,801.4	8,523.9	586.1	613.0	26.9	8.7%	9.1%
	Hampton	8,287.3	785.5	9,072.8	1,404.9	1,437.5	32.6	17.0%	17.3%
	Hampton Falls	7,719.6	358.4	8,078.0	402.9	415.0	12.1	5.2%	5.4%
	Kensington	7,616.4	51.4	7,667.8	287.6	298.0	10.4	3.8%	3.9%
	Kingston	12,494.3	955.9	13,450.3	784.6	814.6	30.0	6.3%	6.5%
	Lee	12,685.0	242.2	12,927.3	597.8	633.0	35.2	4.7%	5.0%
	Madbury	7,383.6	415.5	7,799.1	266.6	274.4	7.8	3.6%	3.7%
	Middleton	11,559.0	284.0	11,843.0	269.4	277.5	8.1	2.3%	2.4%
	Milton	21,088.6	847.3	21,935.9	694.9	704.6	9.7	3.3%	3.3%
	New Castle	506.2	841.4	1,347.6	101.5	103.7	2.2	20.0%	20.5%
	New Durham	26,345.5	1,708.5	28,054.0	534.4	549.6	15.2	2.0%	2.1%
	Newfields	4,540.8	105.9	4,646.7	213.6	219.5	5.9	4.7%	4.8%

	Newington	5,214.5	2,702.2	7,916.8	886.5	903.7	17.2	17.0%	17.3%
	Newmarket	8,034.5	1,045.8	9,080.3	579.4	597.4	18.0	7.2%	7.4%
	North Hampton	8,861.8	61.0	8,922.8	732.6	759.2	26.6	8.3%	8.6%
	Northwood	17,965.0	1,391.9	19,357.0	611.0	629.3	18.3	3.4%	3.5%
	Nottingham	29,839.7	1,157.0	30,996.7	657.0	687.6	30.6	2.2%	2.3%
	Portsmouth	10,003.5	759.9	10,763.4	2,674.8	2,679.1	4.3	26.7%	26.8%
	Raymond	18,438.3	505.2	18,943.6	1,147.5	1,208.2	60.7	6.2%	6.6%
	Rochester	28,329.2	751.5	29,080.7	2,858.9	3,013.8	154.9	10.1%	10.6%
	Rollinsford	4,681.3	161.5	4,842.8	281.6	291.3	9.7	6.0%	6.2%
	Rye[1]	8,464.7	411.3	8,876.0	666.0	682.2	16.2	7.9%	8.1%
	Sandown	8,888.5	343.3	9,231.8	500.4	522.4	22.0	5.6%	5.9%
	Seabrook	5,664.7	496.6	6,161.3	1,133.8	1,177.3	43.5	20.0%	20.8%
	Somersworth	6,219.2	179.1	6,398.3	1,015.4	1,032.8	17.4	16.3%	16.6%
	Strafford	31,151.8	1,627.1	32,778.9	562.5	582.6	20.1	1.8%	1.9%
	Stratham	9,655.1	246.5	9,901.6	874.2	926.7	52.5	9.1%	9.6%
	Wakefield	25,264.0	3,453.2	28,717.2	878.5	908.7	30.2	3.5%	3.6%
	Total	585,483.6	31,080.9	616,564.5	33,340.4	34,565.4	1,225.0	5.7%	5.9%
Study Total		838,984.2	36,815.3	875,799.5	46,594.3	48,427.3	1,833.0	5.6%	5.8%

Table 1.1. Acreage and percent impervious cover by town.

[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**	**2015**	**2021**	**Change**	**2015**	**2021**
010600030602	Axe Handle Brook	7,028.2	368.8	7,397.0	7,028.2	368.8	7,396.9	256.5	267.1	10.6	3.6%	3.8%
010600030401	Bauneg Beg Pond-Great Works River	23,127.6	392.6	23,520.1	23,127.5	392.6	23,520.0	1,152.1	1,188.1	36.0	5.0%	5.1%
010600030705	Bean River-North River	14,795.8	276.0	15,071.8	14,795.7	276.0	15,071.7	371.3	378.9	7.6	2.5%	2.6%
010600030903	Bellamy River	20,335.0	1,276.8	21,611.8	20,334.9	1,276.8	21,611.7	1,443.8	1,514.0	70.2	7.1%	7.4%
010600031002	Berrys Brook-Frontal Rye Harbor	10,284.6	333.4	10,618.0	10,281.8	331.6	10,613.4	948.0	963.7	15.7	9.2%	9.4%
010600030505	Bog Brook-Little River	34,702.3	169.6	34,871.9	34,362.6	169.1	34,531.7	788.1	813.4	25.3	2.3%	2.4%
010600030604	Bow Lake	7,885.2	1,239.6	9,124.9	7,881.6	1,239.6	9,121.2	205.4	217.2	11.8	2.6%	2.8%
010600030502	Branch River	17,268.4	235.4	17,503.7	17,268.3	235.4	17,503.7	358.1	361.5	3.4	2.1%	2.1%

010600030805	Exeter River-Squamscott River	12,188.8	174.3	12,363.2	12,188.8	174.3	12,363.1	618.1	634.3	16.2	5.1%	5.2%
010600030904	Great Bay	13,102.6	6,121.2	19,223.8	13,102.5	6,121.2	19,223.7	1,111.0	1,125.0	14.0	8.5%	8.6%
010600031005	Hampton River-Frontal Atlantic Ocean	18,059.2	1,341.2	19,400.4	12,930.9	1,229.3	14,160.2	1,935.0	1,999.2	64.2	15.0%	15.5%
010600030501	Headwaters Branch River	17,542.9	839.9	18,382.8	17,101.4	839.9	17,941.4	397.4	411.6	14.2	2.3%	2.4%
010600030801	Headwaters Exeter River	20,208.8	202.1	20,410.9	18,875.1	197.0	19,072.1	842.7	900.1	57.4	4.5%	4.8%
010600030701	Headwaters Lamprey River	21,718.4	208.6	21,927.0	21,718.3	208.6	21,926.9	486.8	508.4	21.6	2.2%	2.3%
010600030503	Headwaters Salmon Falls River	15,178.3	2,555.7	17,734.0	15,179.1	2,555.6	17,734.7	432.3	449.4	17.1	2.8%	3.0%
010600030607	Isinglass River	10,288.6	438.5	10,727.1	10,288.6	438.5	10,727.0	498.5	527.6	29.1	4.8%	5.1%
010600030709	Lamprey River	12,788.5	402.4	13,191.0	12,788.5	402.4	13,190.9	613.3	630.1	16.8	4.8%	4.9%
010600030402	Leighs Mill Pond-Great Works River	31,670.4	269.8	31,940.2	31,670.2	269.8	31,940.0	1,044.5	1,116.5	72.0	3.3%	3.5%
010600030707	Little River	12,585.2	358.7	12,943.9	12,585.1	358.7	12,943.8	375.4	397.7	22.3	3.0%	3.2%
010600030606	Long Pond	9,801.4	351.3	10,152.6	9,801.3	351.3	10,152.6	178.6	188.1	9.5	1.8%	1.9%
010600030608	Lower Cocheco River	19,479.4	583.3	20,062.7	19,479.3	583.3	20,062.6	2,328.4	2,418.8	90.4	12.0%	12.4%
010600030507	Lower Salmon Falls River	13,299.2	567.2	13,866.5	13,299.2	379.6	13,678.7	968.4	1,007.9	39.5	7.3%	7.6%
010600030603	Middle Cocheco River	16,025.2	275.5	16,300.7	16,025.1	275.5	16,300.6	1,585.5	1,657.6	72.1	9.9%	10.3%
010600030506	Middle Salmon Falls River	37,430.2	789.6	38,219.8	37,430.2	787.2	38,217.5	2,152.4	2,213.6	61.2	5.8%	5.9%
010600030605	Nippo Brook-Isinglass River	17,115.9	272.9	17,388.9	17,115.9	272.9	17,388.8	341.9	356.3	14.4	2.0%	2.1%
010600030702	North Branch River	10,900.9	146.2	11,047.0	10,900.8	146.2	11,047.0	334.3	358.2	23.9	3.1%	3.3%
010600030706	North River	8,785.7	65.5	8,851.1	8,785.6	65.5	8,851.1	250.3	273.5	23.2	2.8%	3.1%
010600030902	Oyster River	19,317.5	542.4	19,859.8	19,317.4	542.3	19,859.7	1,357.1	1,412.2	55.1	7.0%	7.3%
010600030704	Pawtuckaway Pond	12,107.0	945.4	13,052.4	12,107.0	945.4	13,052.3	186.8	190.0	3.2	1.5%	1.6%
010600030703	Pawtuckaway River-Lamprey River	25,584.1	637.6	26,221.7	25,584.0	637.6	26,221.6	1,529.8	1,607.3	77.5	6.0%	6.3%
010600030708	Piscassic River	14,407.3	102.9	14,510.1	14,407.2	102.9	14,510.1	783.7	813.6	29.9	5.4%	5.6%
010600031001	Piscataqua River-Frontal Portsmouth Harbor	25,020.4	5,383.2	30,403.6	25,018.5	2,651.8	27,670.2	4,742.0	4,841.5	99.5	19.0%	19.4%
010600030804	Scamen Brook-Little River	10,109.1	38.3	10,147.3	10,109.0	38.3	10,147.3	715.1	758.9	43.8	7.1%	7.5%
010600030803	Spruce Swamp-Exeter River	14,998.9	182.0	15,180.9	14,998.8	182.0	15,180.8	815.8	858.4	42.6	5.4%	5.7%
010600030806	Squamscott River	12,445.2	543.6	12,988.8	12,445.1	543.6	12,988.7	1,186.9	1,245.5	58.6	9.5%	10.0%
010600031003	Taylor River	14,373.8	281.7	14,655.4	14,373.7	281.7	14,655.3	1,475.2	1,520.7	45.5	10.3%	10.6%
010600030601	Upper Cocheco River	27,142.7	514.6	27,657.3	26,787.3	514.3	27,301.6	820.2	838.1	17.9	3.1%	3.1%

010600030504	Upper Salmon Falls River	13,691.6	1,174.3	14,865.9	13,692.7	1,176.7	14,869.4	419.0	434.4	15.4	3.1%	3.2%
010600030802	Watson Brook-Exeter River	10,452.0	122.9	10,574.8	10,451.9	122.9	10,574.8	404.8	434.8	30.0	3.9%	4.2%
010600030901	Winnicut River	11,052.5	99.0	11,151.5	11,052.4	99.0	11,151.4	941.9	990.2	48.3	8.5%	9.0%
Total		664,298.3	30,823.9	695,122.1	656,691.6	27,785.0	684,476.6	37,396.4	38,823.4	1,427.0	5.7%	5.9%

Table 1.2. Acreage and percent impervious cover by HUC 12 subwatershed.

Acknowledgements and Credit
Rebecca Bannon, David Justice, and Chris Phaneuf (NH GRANIT), with contributions from Abigail Lyon (PREP) and Kalle Matso (PREP). Graphics from NH GRANIT.

References

Justice, David G. and Rubin, Fay A. 2011. Developing 2010 Impervious Surface Estimates for the Piscataqua Region Estuaries Partnership Towns. *PREP Reports & Publications*. 13. https://scholars.unh.edu/prep/13

Justice, David and Rubin, Fay A. 2017. Developing 2015 High-Resolution Impervious Cover Estimates for the 52 Towns in the Piscataqua Region Estuaries Partnership: Final Report. *PREP Reports & Publications*. 395. https://scholars.unh.edu/prep/395

Conserved Lands

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 5.1).

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 5.2). 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.

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.

Additional Data, Tables, and Graphs

Town Name	Conservation Lands 2022 (acres)	Town Area (acres)	Percent Conservation 2022
Barrington, NH	6,446.1	29,719.0	21.7%
Brentwood, NH	3,246.7	10,726.0	30.3%
Brookfield, NH	3,845.4	14,593.0	26.4%
Candia, NH	2,708.8	19,328.9	14.0%
Chester, NH	3,084.1	16,606.2	18.6%
Danville, NH	747.4	7,438.7	10.0%
Deerfield, NH	7,205.6	32,575.7	22.1%
Dover, NH*	3,643.1	17,036.9	21.4%
Durham, NH*	6,713.0	14,251.1	47.1%
East Kingston, NH	1,066.6	6,318.0	16.9%
Epping, NH	4,918.4	16,476.6	29.9%
Exeter, NH*	4,151.6	12,540.6	33.1%
Farmington, NH	2,804.8	23,213.0	12.1%
Fremont, NH	1,489.8	11,033.1	13.5%
Greenland, NH*	1,488.2	6,722.5	22.1%
Hampton, NH*	829.7	8,287.3	10.0%
Hampton Falls, NH*	1,195.3	7,719.6	15.5%
Kensington, NH	2,155.6	7,616.4	28.3%
Kingston, NH	2,665.9	12,494.3	21.3%
Lee, NH	3,336.8	12,685.0	26.3%
Madbury, NH*	2,110.1	7,383.6	28.6%
Middleton, NH	2,545.2	11,559.0	22.0%
Milton, NH	5,271.7	21,088.6	25.0%
New Castle, NH*	110.1	506.2	21.7%
New Durham, NH	4,258.3	26,337.9	16.2%
Newfields, NH*	1,324.0	4,540.8	29.2%
Newington, NH*	1,487.5	5,214.5	28.5%
Newmarket, NH*	2,184.3	8,034.5	27.2%
North Hampton, NH*	2,016.1	8,861.8	22.8%
Northwood, NH	3,141.6	17,965.0	17.5%
Nottingham, NH	9,942.9	29,839.7	33.3%
Portsmouth, NH*	1,491.4	9,995.0	14.9%
Raymond, NH	2,358.4	18,438.3	12.8%
Rochester, NH	2,458.4	28,329.2	8.7%
Rollinsford, NH*	919.2	4,681.3	19.6%
Rye, NH*	1,940.7	8,042.4	24.1%
Sandown, NH	1,138.5	8,888.5	12.8%

Seabrook, NH*	537.6	5,664.7	9.5%
Somersworth, NH	729.1	6,219.2	11.7%
Strafford, NH	8,669.4	31,151.8	27.8%
Stratham, NH*	1,928.5	9,655.1	20.0%
Wakefield, NH	1,414.7	25,264.0	5.6%
Acton, ME	834.3	24,216.3	3.4%
Berwick, ME	1,663.9	23,775.4	7.0%
Eliot, ME*	900.3	12,576.4	7.2%
Kittery, ME*	2,050.8	11,377.9	18.0%
Lebanon, ME	1,068.7	34,955.9	3.1%
North Berwick, ME	1,200.5	24,249.9	5.0%
Sanford, ME	2,653.0	30,289.8	8.8%
South Berwick, ME*	4,431.0	20,446.9	21.7%
Wells, ME*	5,968.7	36,427.3	16.4%
York, ME*	9,486.1	34,901.9	27.2%
TOTAL:	**151,978.0**	**838,260.8**	**18.1%**
Coastal Community TOTAL:	**56,907.4**	**254,868.3**	**22.3%**

Table 5.1. Conserved land in the Piscataqua Region communities (municipalities).
* = 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.

Protection Type	**New Hampshire**	**Maine**	**Total**	**% of Total**
Permanent	102,677.0	27,794.5	130,471.5	85.9%
Unofficial	18,017.7	1,954.8	19,972.5	13.1%
Unknown	1,030.3	508.9	1,539.2	1.0%
Total	121,725.0	30,258.2	151,983.2	100%
% of Total	80.1%	19.9%	100%	

Table 5.2. Conservation lands in the Piscataqua Region 2022.

Acknowledgements and Credit
Chris Phaneuf (NH GRANIT)

Conserved Lands Focus Areas

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. The most recent dataset of conservation lands from NH GRANIT was the primary data source for this indicator. Conservation focus area boundaries from Steckler and Ormiston (2021) and the analysis of the data for this indicator were provided by The Nature Conservancy in New Hampshire.

Additional information regarding the development of the updated conservation focus areas and additional methods can be found in the 2021 New Hampshire's Coastal Watershed Conservation Plan at connect-protect.org/the-plan/

Date Sources

The Nature Conservancy in New Hampshire, the Maine Office of GIS, and NH GRANIT provided conserved lands data for this indicator.

Additional Data, Tables, and Graphs

Table 6.1: Total acreage and percentage of Conservation Focus Areas protected among the 52 communities of the Piscataqua Region Watershed.

Town	State	CFA Acreage	Protected CFA Acreage	% CFA Protected
Acton	ME	6,629	306	5
Barrington	NH	13,206	5,153	39
Berwick	ME	5,793	485	8
Brentwood	NH	3,555	1,684	47
Brookfield	NH	7,208	2,066	29
Candia	NH	2,700	451	17
Chester	NH	4,599	832	18
Danville	NH	968	137	14
Deerfield	NH	16,291	4,373	27
Dover	NH	3,093	1,597	52
Durham	NH	8,236	4,074	49
East Kingston	NH	1,129	295	26
Eliot	ME	968	177	18
Epping	NH	7,587	4,026	53
Exeter	NH	5,753	2,737	48
Farmington	NH	9,225	1,352	15
Fremont	NH	4,542	1,195	26
Greenland	NH	2,639	1,043	40
Hampton	NH	3,707	517	14
Hampton Falls	NH	4,530	956	21

Kensington	NH	3,768	1,105	29
Kingston	NH	1,408	621	44
Kittery	ME	628	383	61
Lebanon	ME	9,278	431	5
Lee	NH	5,523	1,913	35
Madbury	NH	3,491	775	22
Middleton	NH	6,625	2,263	34
Milton	NH	7,637	1,970	26
New Castle	NH	76	32	43
New Durham	NH	6,327	1,427	23
Newfields	NH	3,105	1,195	38
Newington	NH	1,490	1,173	79
Newmarket	NH	4,531	1,855	41
North Berwick	ME	7,815	391	5
North Hampton	NH	3,431	1,168	34
Northwood	NH	5,563	2,003	36
Nottingham	NH	18,644	8,972	48
Portsmouth	NH	2,637	1,177	45
Raymond	NH	7,720	1,597	21
Rochester	NH	4,532	808	18
Rollinsford	NH	638	83	13
Rye	NH	4,472	1,640	37
Sandown	NH	1,809	496	27
Sanford	ME	1,618	27	2
Seabrook	NH	2,383	161	7
Somersworth	NH	559	148	27
South Berwick	ME	9,224	2,562	28
Strafford	NH	10,730	3,357	31
Stratham	NH	3,342	1,255	38
Wakefield	NH	6,482	866	13
Wells	ME	2,698	200	7
York	ME	1,939	1,700	88

Acknowledgements and Credit
Trevor Mattera (PREP), with contributions from Anna Ormiston and Peter Steckler (TNC) and David Justice and Chris Phaneuf (NH GRANIT). Graphics from Anna Ormiston and Peter Steckler.

References
Steckler P and Ormiston A. 2021. *New Hampshire's Coastal Watershed Conservation Plan, 2021 Update*. The Nature Conservancy. Concord, NH.

Nitrogen Loading

Please note that this section contains both "Methods and Data Sources" as well as "Additional Discussion" and over 15 additional tables and figures.

Methods and Data Sources
Nitrogen loads were estimated based on monthly wastewater treatment facility discharge and concentration data, monthly tributary concentration data, weekly nitrogen deposition in precipitation, and daily streamflow (using Loadest[30]). The methods used to estimate 2017-2020 nitrogen loads and a further breakdown of the point and non-point source loads are described below. For the purposes of this analysis, the following sources were identified that contribute to the nitrogen (N) load to the Great Bay Estuary (Figure 7.4; Figures 7.1 through 7.3 can be found in the State of Our Estuaries Report). It is assumed that these represent a complete accounting of contributing sources.

- Point Source (PS) N Loads from Wastewater Treatment Facilities (WWTFs)
- Non-Point Sources (NPS) N Loads from Major Tributary Watersheds
- NPS N Loads from Drainage Areas Adjacent to the Estuary
- Groundwater Discharge of N to the Estuary
- Atmospheric Deposition of N 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"; estuarine surface area of 13.4 square miles). 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. Load estimates from 2003-2016 are from previous reports (2003-2008 loads are from NHDES 2010; 2009-2011 loads are from PREP 2012; 2012-2016 loads are from PREP 2018).

Point Source Nitrogen Loads from WWTFs

The annual and overall average TN and DIN loads from each WWTF for 2017-2020 were estimated by multiplying the average monthly effluent concentration by the average monthly effluent flow over the time period of interest (Table 7.1; Figure 7.5a). Monthly average effluent flows from the WWTFs were obtained from the EPA's Enforcement and Compliance History Online (ECHO) database (https://echo.epa.gov/trends/loading-tool/get-data/monitoring-data-download) for national pollutant discharge elimination system (NPDES) monitoring data using individual NPDES permit numbers (Table 7.2). Monthly average effluent flows were then averaged over the time period of interest. Monthly average effluent nitrogen concentration data were either obtained from the EPA's ECHO database using individual NPDES permit numbers or general permit tracking numbers (Table 7.2) or directly from the WWTF operators (Table 7.1). Monthly average effluent nitrogen concentration data were then averaged over the time period of interest. If nitrogen concentration data were not available for a WWTF during the 2017-2020 reporting period, then either more recent (2021-2022) or historical (NHEP 2008 or

PREP 2018) data were used. If nitrogen concentration data were not available for a WWTF during any time period, then the average TN concentrations and average fraction of TN as DIN from monitored WWTFs were used to estimate TN and DIN.

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 7.1; Figure 7.5b). 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 models provided by Portsmouth and Kittery (ASA 2011a, ASA 2011b). These delivery factors were the same delivery factors used in PREP 2012 and PREP 2018.

Non-Point Sources from Major Tributary 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. The U.S. Geological Survey (USGS) LOADEST model (Runkel et al. 2004) was used to develop a calibrated model relating TN and DIN concentrations and daily average stream flow. The LOADEST model was set to select the optimal model based on the calibration dataset (Table 7.3) and all the parameters in the chosen model were included. The inputs to the LOADEST model were monthly (March-December) measurements of TN and DIN concentrations and daily average stream flow at each major tributary monitoring station. Samples were collected from head of tide stations on the Winnicut, Exeter, Lamprey, Oyster, Bellamy, Cocheco, Salmon Falls and Great Works Rivers and analyzed according to the Great Bay Estuary Tidal Tributary Monitoring Program (GBETTMP) Quality Assurance Project Plan (QAPP; Matso and Potter 2018). For TN and DIN concentrations, non-detected nitrogen in samples samples were represented by one-half of the reporting detection limit. Stream flows at the eight monitoring stations were estimated from USGS stream gages in five (Winnicut, Exeter, Lamprey, Oyster and Cocheco Rivers) of the watersheds and drainage area transposition factors (Table 7.4). 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 the 2017-2020 time period. The NPS delivered load from watersheds was calculated by subtracting the delivered PS nitrogen load from upstream WWTFs from the total modeled load at each of the eight major tributary monitoring stations (Table 7.5 and Figure 7.7).

Non-Point Sources from Drainage Areas Adjacent to the Estuary

Runoff from land adjacent to the estuary was not captured in the load measurements at the major tributary monitoring stations. Therefore, TN and DIN loads from these areas were estimated. Using the data from the major tributary watersheds, linear regression relationships were developed between the percent land use (2019 National Land Cover Database (NLCD); Dewitz, J. and U.S. Geological Survey 2021) and the 2017-2020 TN and DIN NPS area normalized loads (tons per year per square mile). These regressions spanned a range of developed land use (10.4 to 29.0%) and developed or agricultural land use (14.5 to 37.4%). The 2017-2020 TN and DIN NPS area normalized loads from drainage areas adjacent to the estuary were estimated using the percent of agricultural and/or developed land in the adjacent watershed and the corresponding regression equations (Figure 7.6). The adjacent Great Bay drainage area was slightly more developed (30.3%), and both the Great Bay and upper Piscataqua River drainage areas contained slightly more agricultural and developed land (39.9 to 40.7%) than the range among major tributary watersheds. The use of these regressions is an extrapolation of a linear model outside the calibration range, but the extrapolation is only 5% for developed and 9% for agricultural and developed land uses. A similar approach (using annual TN and DIN NPS area normalized loads from the major tributary watersheds) was used to estimate annual NPS loads from drainage areas adjacent to the estuary.

Groundwater Discharge of Nitrogen to the Estuary

Nitrogen loading from groundwater sources was partially accounted for in the NPS loading estimates from major watersheds. However, regional groundwater flow was also expected to contribute nitrogen loading directly to the estuary. Ballestero et al. (2004) measured the nitrogen loading rate from groundwater seeps to be 0.13 tons DIN/yr per mile of tidal shoreline. This loading rate was applied to the length of tidal shoreline in the estuary (111.9 miles) to estimate the groundwater loading rate of 14.55 tons DIN/yr. The groundwater loading rate was assumed to be constant over time because no other information was available. All of the nitrogen contributed by this source was assumed to be in the form of DIN (Table 7.6 and 7.7; Figure 7.8).

Atmospheric Deposition of Nitrogen to the Estuary

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 (as an area normalized load). Dry deposition was estimated as 58% of wet DIN deposition (ClimCalc ratio of 0.58 dry to wet DIN deposition for TF, Ollinger et al. 2001). Wet and dry deposition were summed to determine the total deposition of TN and inorganic N. For 2017-2020, this resulted in a wet deposition rate of 0.89 tons TN/sq mi/yr (0.75 tons DIN/sq mi/yr), a dry deposition rate of 0.44 tons TN/sq mi/yr (assumed to be 100% DIN) and a total deposition rate of 1.32 tons TN/sq mi /yr (1.19 tons DIN/sq mi/yr). This loading rate was assumed to be constant over the 13.4 sq mi estuary resulting in 17.8 tons of TN and 15.9 tons of DIN load to the estuary per year. Atmospheric deposition of nitrogen to the land surface is accounted for in the NPS load contribution from the major tributary watersheds and the land areas adjacent to the estuary. For annual estimates of deposition see Table 7.7a.

Nitrogen Load Summary

The 2017-2020 and annual TN and DIN loads were calculated by summing the individual components of the nitrogen load: Delivered PS loads from WWTFs, NPS loads from major tributary watersheds, NPS loads from drainage areas adjacent to the estuary, groundwater discharge to the estuary, and atmospheric deposition to the estuary (Table 7.6 and 7.7). Subtotals for PS (WWTFs) and NPS were also calculated.

Additional Discussion

The TN and DIN loads from the 17 WWTFs in the Great Bay Estuary watershed are shown in Table 7.1. The WWTF with the largest delivered nitrogen load was Exeter followed by Rochester and Dover. These three WWTFs accounted for 57% of the nitrogen delivered to the estuary by all WWTFs combined. Following these three WWTFs, Somersworth, Portsmouth, Durham, Berwick and Newmarket have the highest delivered nitrogen loads. It should be noted that these rankings do not account for the size of the population or the number of connections these municipalities serve. Over the years, several municipalities have made substantial improvements to their WWTFs to reduce the amount of nitrogen they discharge. From 2017 to 2020, WWTF delivered total nitrogen load decreased by 48% and delivered DIN load decreased by 40%. Please see Table 7.7 to see changes by each year in this period in the amount of N delivered from WWTFs to the Great Bay Estuary.

The TN and DIN loads from the eight major tributaries are shown in Table 7.5 and Figure 7.7. The Lamprey, Salmon Falls and Cocheco 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 second 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 has the second lowest level of developed or agricultural area (Table 7.5). On an area-normalized basis, the Winnicut, Oyster, and Bellamy watersheds deliver the most total nitrogen to the estuary area (Table 7.5).

The EPA has recommended a total nitrogen loading threshold of 100 kilograms per hectare per year in the Great Bay Total Nitrogen General Permit (TNGP; NPDES General Permit No. NHG58A000), issued in 2020. This equates to 384 tons TN per year for the tidal area of Great Bay, Little Bay, and the Upper Piscataqua River (13.4 square miles). To meet that long-term goal, the TN load for 2017-2020 (895 tons TN per year) would need to be reduced by 511 tons per year, or 57% and reductions in both point source (197 tons TN per year for 2017-2020) and non-point source (699 tons TN per year for 2017-2020) nitrogen loads would be required.

Additional Data, Tables, and Figures

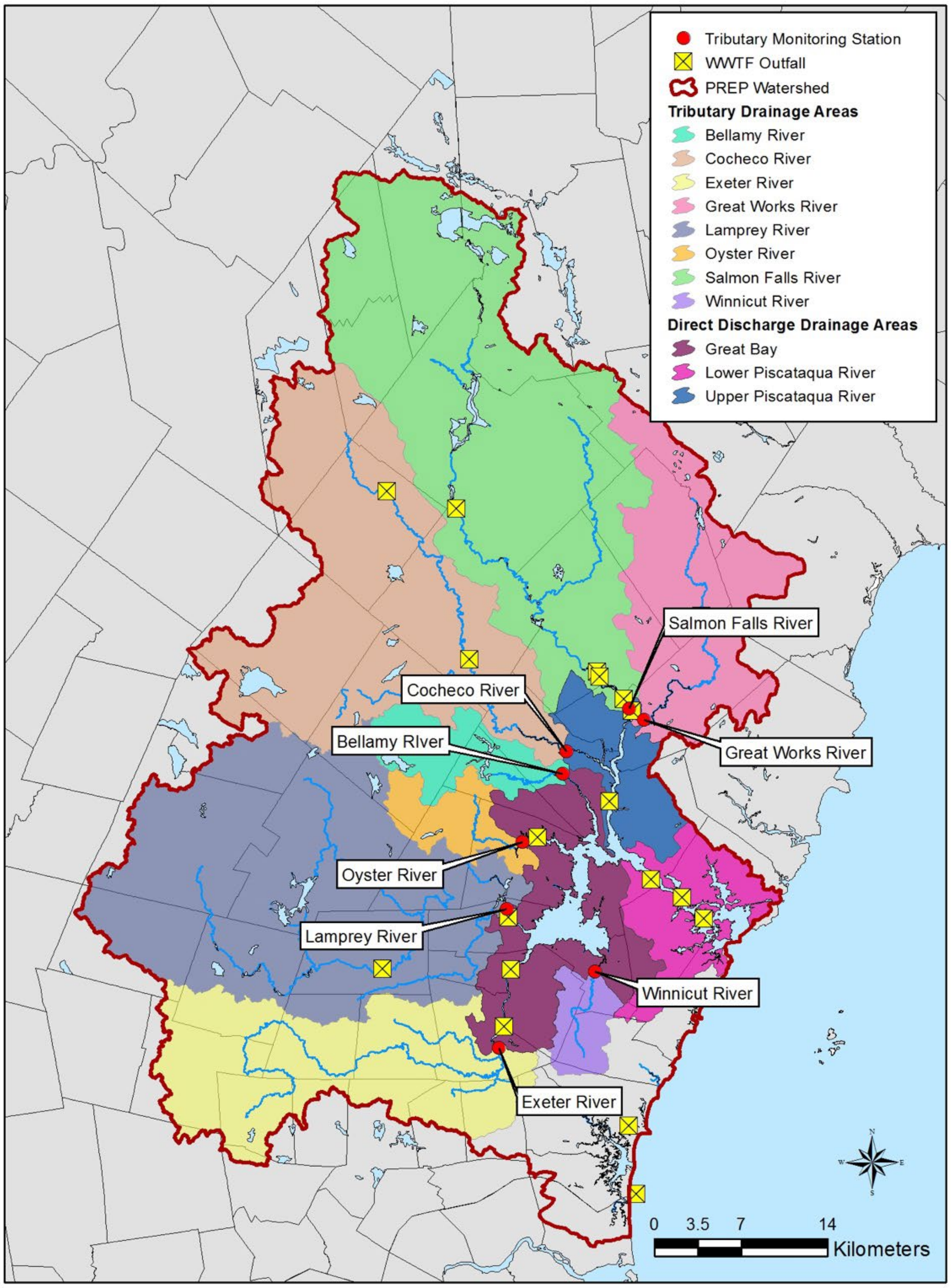
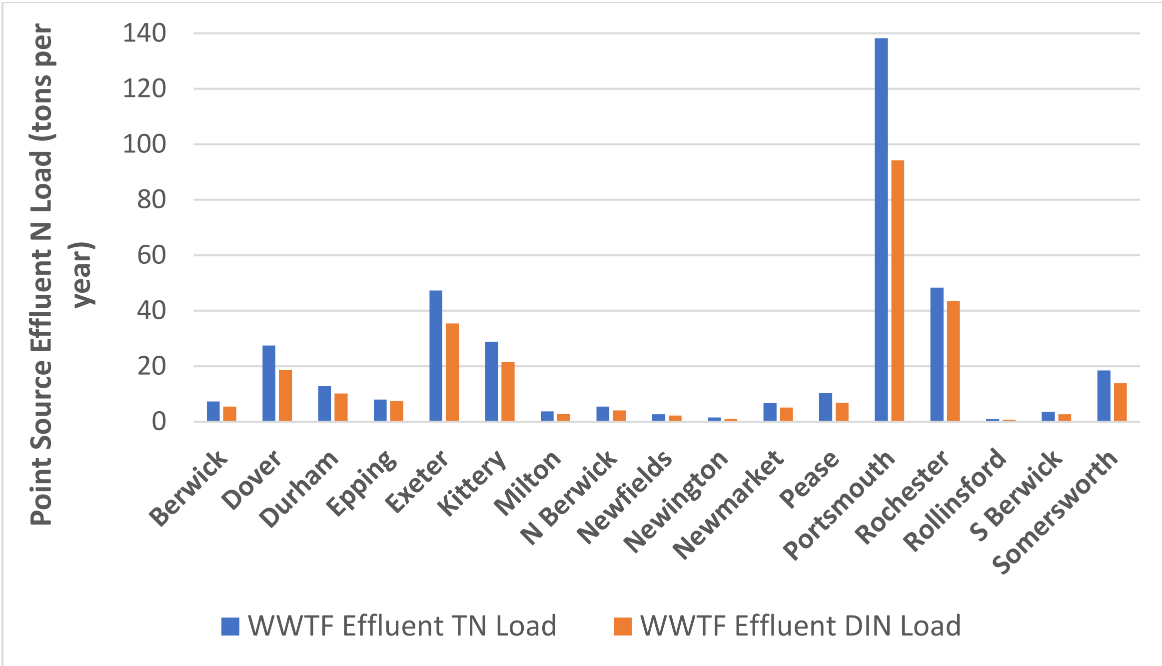


Figure 7.4. Watersheds draining to the Great Bay Estuary. Wastewater treatment plant facilities indicated with yellow markers. Major tributary monitoring stations indicated with red circles.

(A) WWTF effluent N Load



(B) WWTF Delivered N Load

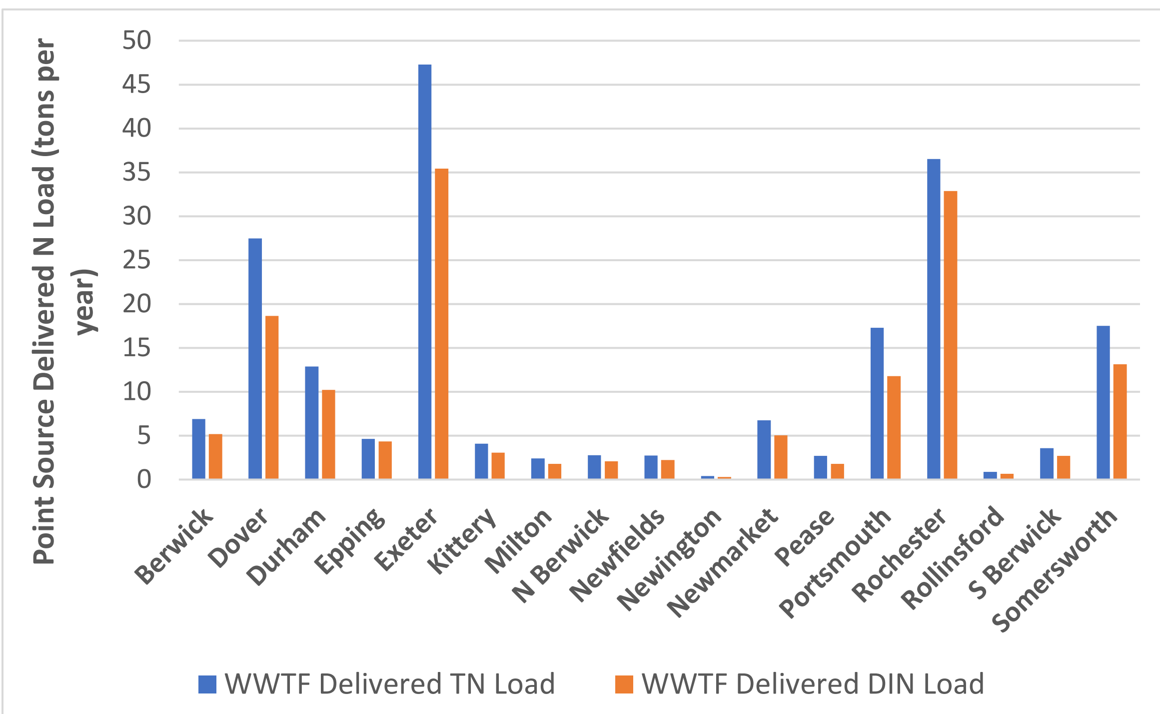
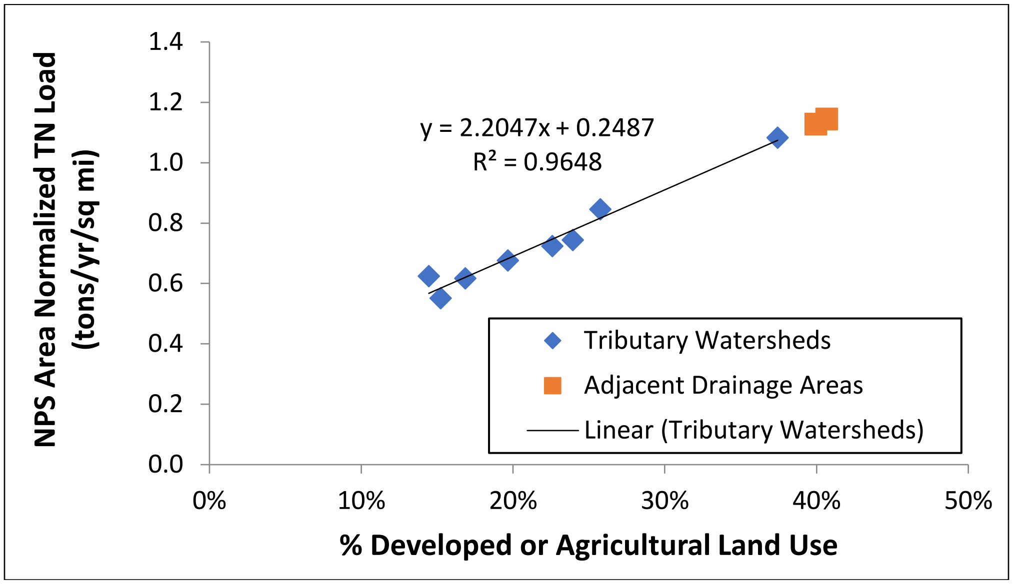


Figure 7.5: Estimated average total nitrogen (TN) and dissolved inorganic nitrogen (DIN) loads from wastewater treatment facility (WWTF) (A) effluent and (B) loads delivered to the Great Bay, Little Bay and Upper Piscataqua River Estuaries 2017-2020. Note the different scales on the vertical axes.

1. **Farmington's WWTF is not listed because this WWTF discharges to rapid infiltration basins and thus the effluent is considered to be a non-point source, rather than a point source, to the Cocheco River.**

(A) Total Nitrogen



(B) Dissolved Inorganic Nitrogen

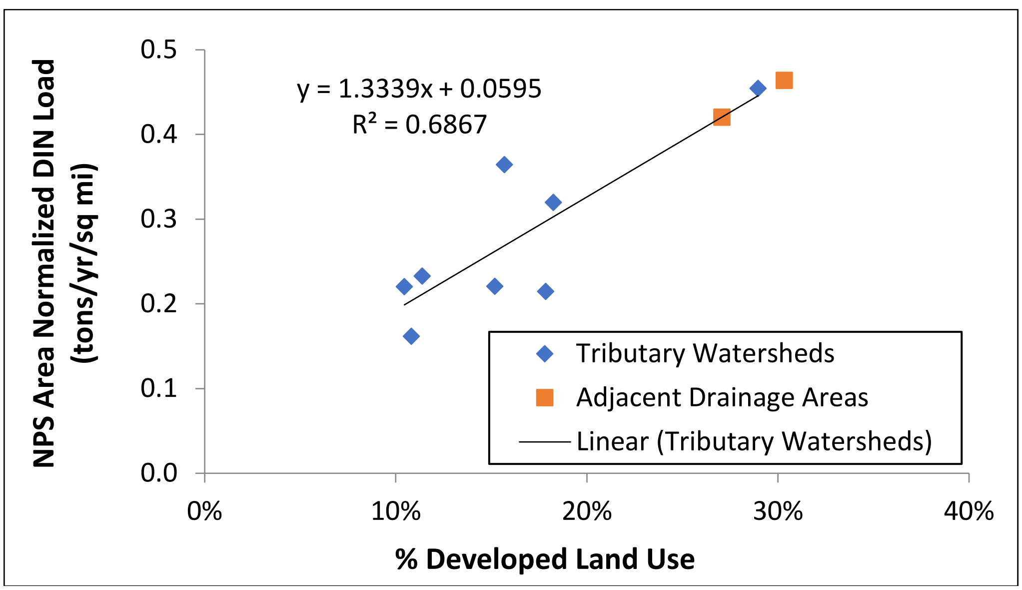
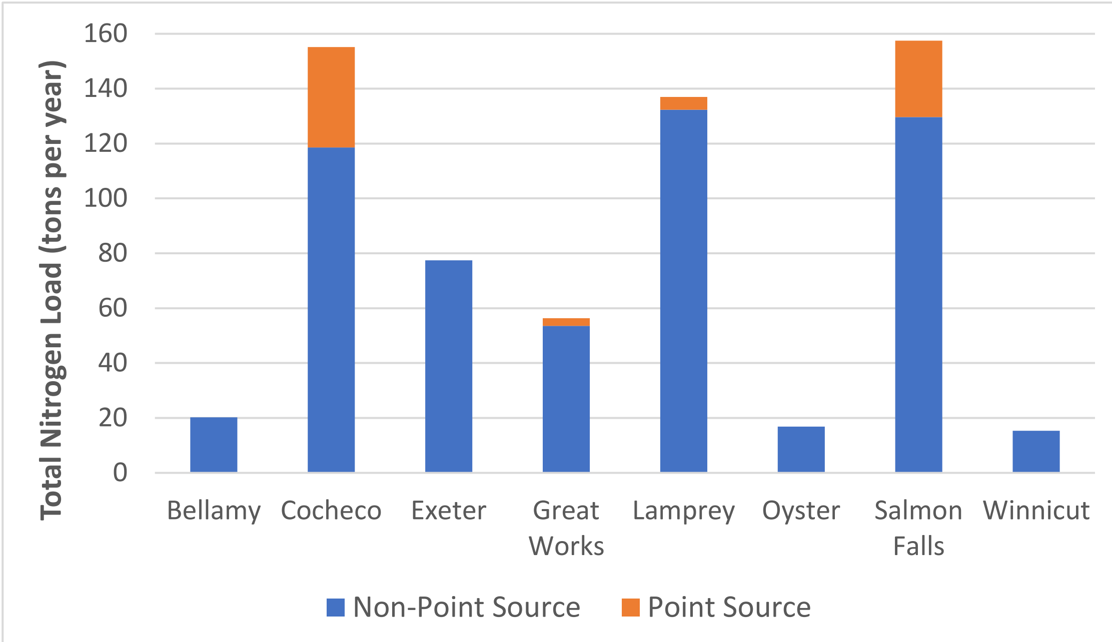


Figure 7.6. Relationship between non-point source (NPS) area normalized nitrogen loads (2017-2020) and land use in major tributary watersheds and extrapolations to drainage areas adjacent to the estuary for (A) Total Nitrogen (TN) and (B) Dissolved Inorganic Nitrogen (DIN). Note the different scales on the vertical axes.

 Table of Contents

(A) Total Nitrogen



(B) Dissolved Inorganic Nitrogen

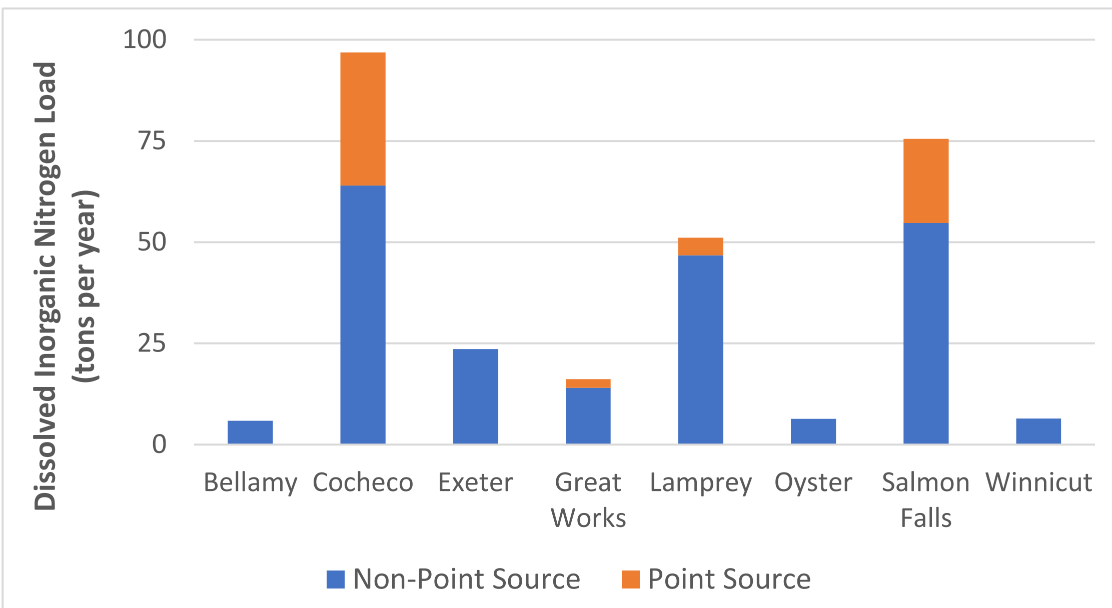


Figure 7.7. Estimated nitrogen loads from major tributaries in 2017-2020 for (A) total nitrogen and (B) dissolved organic nitrogen. Note the different scales on the vertical axes.

1. **Values reported above combine data from 2017 through 2020, which does not reveal improvements made by WWTFs during this period. Please see Table 7.7a to see changes by each year during this period in the amount of N delivered from WWTFs to the Great Bay Estuary.**

(A) Total Nitrogen Load = 895.4 tons per year (22.0% Point Source (PS); 78.0% Non-Point Source (NPS))

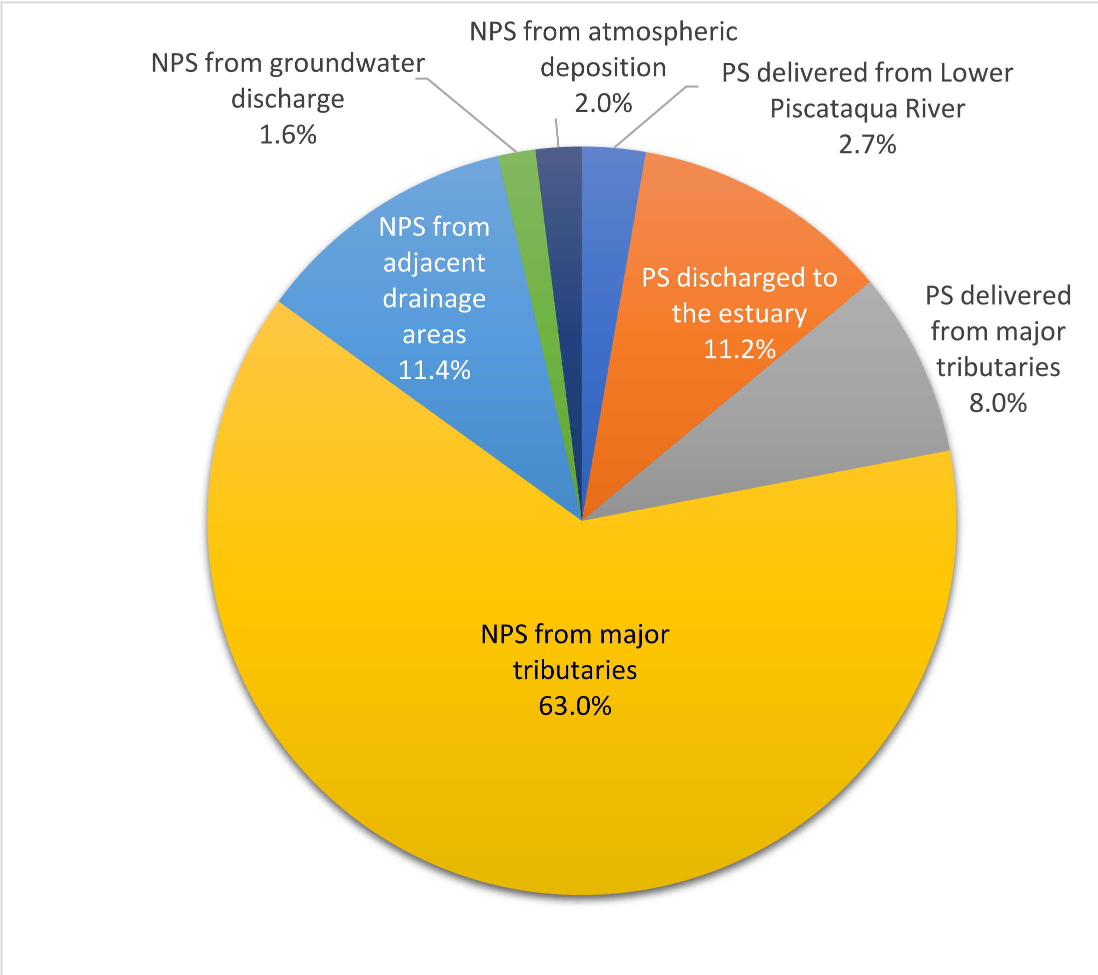


Figure 7.8. Sources of nitrogen loads to the Great Bay Estuary from 2017-2020 for (A) Total Nitrogen and (B) Dissolved Inorganic Nitrogen.

(C) Dissolved Inorganic Nitrogen Load = 443.9 tons per year (34.1% Point Source (PS); 65.9% Non-Point Source (NPS))

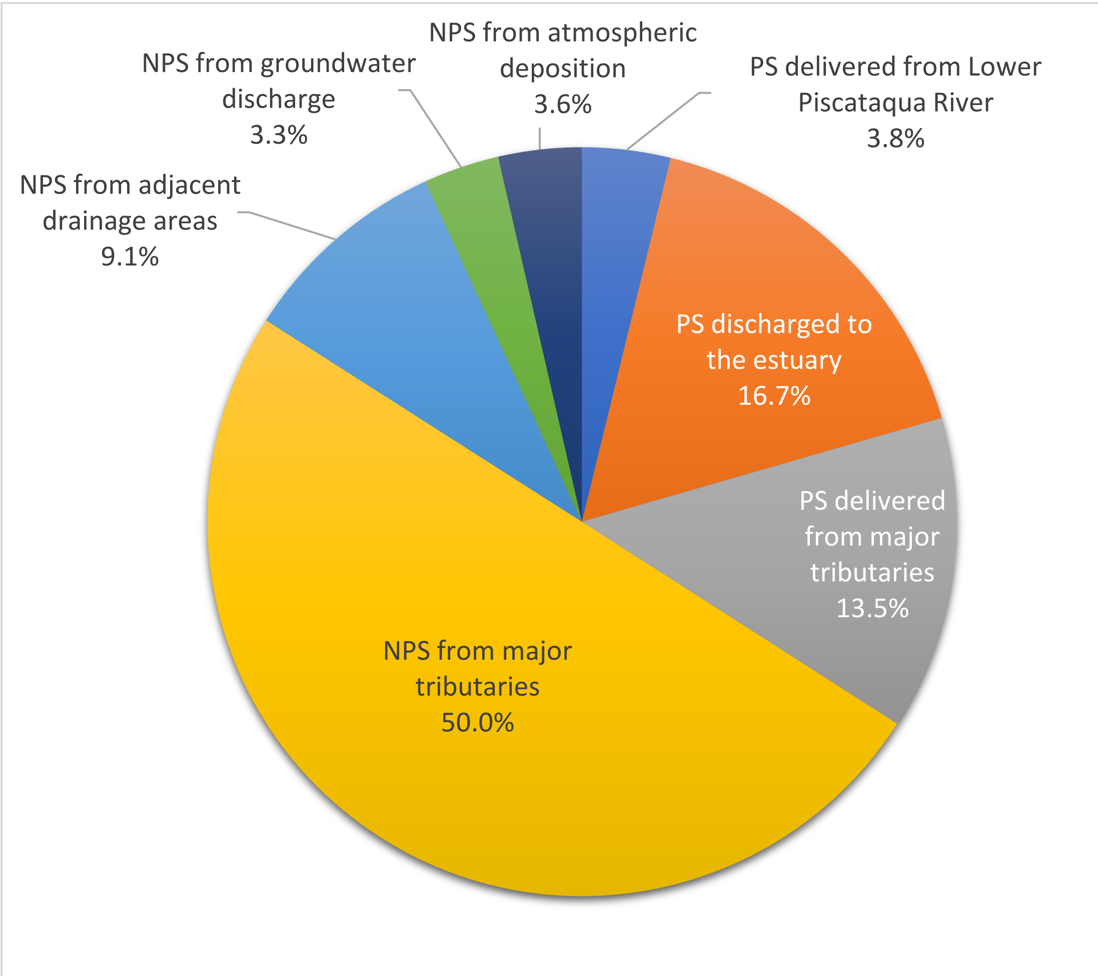


Figure 7.8. Sources of nitrogen loads to the Great Bay Estuary from 2017-2020 for (A) Total Nitrogen and (B) Dissolved Inorganic Nitrogen.

Table 7.1: Estimated average nitrogen loads from wastewater treatment facilities (WWTF) in 2017-2020.

WWTF	Discharge Location (River)	Ave. monthly effluent flow (mgd)	N Data Source	# of months with TN data	Ave. monthly TN (mg/L)	# of months with DIN data	Ave. monthly 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	3.20	City of Rochester	48	9.9	48	8.9	48.4	43.5	75.6%	36.5	32.9
Somersworth	Salmon Falls	1.56	City of Somersworth (TN)	48	7.8	0	5.8	18.5	13.8	94.9%	17.5	13.1
N Berwick	Great Works	0.30	Estimated	0	11.8	0	8.8	5.4	4.0	51.6%	2.8	2.1
Berwick	Salmon Falls	0.29	NHEP (2008) for TN	0	16.7	0	12.5	7.3	5.5	94.5%	6.9	5.2
Epping	Lamprey	0.28	Epping GBTNGP (2021-2022)	12	18.8	11	17.6	8.0	7.5	58.2%	4.6	4.3
Rollinsford	Salmon Falls	0.08	Rollinsford GBTNGP (2021-2022; TN)	12	7.4	0	5.5	0.9	0.7	99.0%	0.9	0.7
Milton	Salmon Falls	0.08	Milton GBTNGP (2021-2022; TN)	12	30.8	0	23.1	3.7	2.8	65.7%	2.4	1.8
Dover	Upper Piscataqua	2.64	City of Dover	47	6.8	47	4.6	27.5	18.6	100.0%	27.5	18.6
Exeter	Exeter (tidal)	1.73	Exeter NPDES permit (TN)	48	18.0	0	13.5	47.3	35.4	100.0%	47.3	35.4
Durham	Oyster (tidal)	0.91	Town of Durham	48	9.2	48	7.3	12.9	10.2	100.0%	12.9	10.2
Newmarket	Lamprey (tidal)	0.47	Newmarket NPDES permit (TN)	48	9.4	0	7.0	6.7	5.1	100.0%	6.7	5.1
S Berwick	Salmon Falls (tidal)	0.32	S Berwick Sewer District	44	7.3	18	5.4	3.6	2.7	100.0%	3.6	2.7
Newfields	Exeter (tidal)	0.09	Town of Newfield (2020)	4	20.0	3	16.3	2.7	2.2	100.0%	2.7	2.2
Portsmouth	Lower Piscataqua	4.16	City of Portsmouth	48	21.8	48	14.8	138.2	94.2	12.5%	17.3	11.8
Kittery	Lower Piscataqua	0.98	NHEP 2008 and Kittery 2015 (TN)	0	19.4	0	14.5	28.9	21.6	14.2%	4.1	3.1
Pease	Lower Piscataqua	0.71	City of Portsmouth	34	9.5	34	6.3	10.2	6.8	26.3%	2.7	1.8
Newington	Lower Piscataqua	0.10	Town of Newington	47	9.7	47	6.9	1.5	1.1	26.3%	0.4	0.3
								371.6	275.7	Total Load	196.9	151.2

1. Italicized WWTFs (N Berwick, Berwick, S Berwick and Kittery) are located in Maine. The other 13 WWTFs are located in New Hampshire.
2. Average (Ave.) monthly WWTF effluent flows are reported in million gallons per day (mgd). The monthly average effluent flows from NPDES discharge monitoring reports were averaged over the 48 months in the 4-year study period (2017-2020).
3. North (N) Berwick WWTF does not discharge June 1-Sept 30, thus 0 mgd was assigned to those 4 months of each year. A few months of effluent flow were not reported for N Berwick (3-5 mo/yr) and were excluded from the average effluent flow at this WWTF (32 total months with flow data, including June-Sept months with 0 mgd). All other WWTFs reported 48 months of effluent flow data.
4. Data are sorted by average monthly effluent flow (from highest to lowest) within each of the following groupings: WWTFs discharging to major tributaries, WWTFs discharging to the estuary and WWTFs discharging to the lower Piscataqua River.
5. National pollutant discharge elimination system (NPDES) 2020 Great Bay Total Nitrogen General Permit (GBTNGP; NHG58A000) N data were obtained for Epping, Rollinsford and Milton WWTFs from May 2021 to April 2022.
6. Light grey cells: a) No TN data were available. TN was estimated as the average of TN concentrations among WWTFs monitored during 2017-2020 (11.8 mg/L).
b) No DIN data were available. DIN was estimated based on the average ratio of DIN to TN in WWTFs monitored during 2017-2020 (74.9%).
7. Delivery factor is the percent of the discharged load that is delivered to the Great Bay (GB), Little Bay (LB), and Upper Piscataqua River (UPR) estuaries. For WWTFs in the major tributary 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 UPR at steady state in the Dartmouth particle tracking model (NHDES 2010) or particle tracking models provided by Portsmouth and Kittery (ASA 2011a, 2011b). These delivery factors were the same delivery factors used in PREP 2012 and PREP 2018.

Table of Contents

Table 7.2. Wastewater treatment facility (WWTF) total nitrogen general permit tracking numbers and individual NPDES permit numbers.

WWTF	General Permit Tracking Number	Individual NPDES Permit Number
Rochester	NHG58A001	NH0100668
Portsmouth	NHG58A002	NH0100234
Dover	NHG58A003	NH0101311
Exeter	NHG58A004	NH0100871
Durham	NHG58A005	NH0100455
Somersworth	NHG58A006	NH0100277
Pease ITP	NHG58A007	NH0090000
Newmarket	NHG58A008	NH0100196
Epping	NHG58A009	NH0100692
Newington	NHG58A010	NHG581141
Rollinsford	NHG58A011	NH0100251
Newfields	NHG58A012	NH0101192
Milton	NHG58A013	NH0100676
Berwick		ME0101397
Kittery		ME0100285
N Berwick		ME0101885
S Berwick		ME0100820

Table 7.3. LOADEST models for total nitrogen (TN) and dissolved inorganic nitrogen (DIN) loads from major tributary watersheds in 2017-2020.

	Loadest TN (tons/yr) Model			Loadest DIN (tons/yr) Model		
Tributary	**R^2 (%)**	**PPCC**	**Model**	**R^2 (%)**	**PPCC**	**Model**
Lamprey	98.5	0.972	8	92.5	0.991	6
Bellamy	98.1	0.927	6	89.7	0.993	6
Cocheco	97.6	0.981	8	90.3	0.933	5
Exeter	98.9	0.990	7	92.7	0.984	2
Great Works	99.0	0.990	6	92.4	0.958	2
Oyster	98.6	0.985	8	94.4	0.987	5
Salmon Falls	98.3	0.985	4	95.4	0.982	3
Winnicut	99.2	0.988	2	96.5	0.994	8

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. **R^2 is a measure of the quality of the loadest 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 7.4. 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 Streamgage (sq miles)
Bellamy River[1]	27.26	Cocheco 01072800	0.341176	79.9
		Oyster 01073000	2.252893	12.1
Cocheco River	175.28	Cocheco 01072800	2.193742	79.9
Exeter River	106.9	Exeter 01073587	1.683465	63.5
Great Works River	86.69	Cocheco 01072800	1.084981	79.9
Lamprey River	211.91	Lamprey 01073500	1.145459	185
Oyster River	19.85	Oyster 01073000	1.640496	12.1
Salmon Falls River	235	Lamprey 01073500	1.27027	185
Winnicut River	14.18	Winnicut 1073785	1.005674	14.1

1. **Stream flow in the Bellamy River was estimated by averaging cubic feet per second (cfs) transposition estimates from the Cocheco and Oyster Rivers.**

Table 7.5. LOADEST, point (WWTFs) and non-point source nitrogen loads and area normalized loads from major tributary watersheds 2017-2020.

Site	Area (mi²)	LOADEST TN Load (tons/yr)	LOADEST DIN Load (tons/yr)	Area Normalized TN Load (tons/yr/mi²)	Area Normalized DIN Load (tons/yr/mi²)	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/mi²)	Area Normalized NPS DIN Load (tons/yr/mi²)	% Developed Land	% Developed or Agricultural Land
Bellamy	27.26	20.28	5.86	0.74	0.21	0.00	0.00	20.28	5.86	0.74	0.21	17.9%	23.9%
Cocheco	175.28	155.13	96.82	0.89	0.55	36.53	32.88	118.60	63.94	0.68	0.36	15.7%	19.7%
Exeter	106.90	77.40	23.63	0.72	0.22	0.00	0.00	77.40	23.63	0.72	0.22	15.2%	22.6%
Great Works	86.69	56.35	16.14	0.65	0.19	2.78	2.08	53.57	14.05	0.62	0.16	10.8%	16.9%
Lamprey	211.91	136.93	51.09	0.65	0.24	4.65	4.34	132.29	46.75	0.62	0.22	10.4%	14.5%
Oyster	19.85	16.80	6.35	0.85	0.32	0.00	0.00	16.80	6.35	0.85	0.32	18.2%	25.8%
Salmon Falls	235.00	157.43	75.55	0.67	0.32	27.74	20.78	129.69	54.77	0.55	0.23	11.4%	15.2%
Winnicut	14.18	15.36	6.45	1.08	0.45	0.00	0.00	15.36	6.45	1.08	0.45	29.0%	37.4%
Total	**877.07**	**635.70**	**281.87**			**71.71**	**60.08**	**563.99**	**221.79**				

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. **Seven WWTFs discharge upstream of major tributary monitoring stations. The Epping WWTF is upstream of the Lamprey River station. The Rochester WWTF is 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. The Farmington WWTF is also upstream of the Cocheco River station, but Farmington discharges to the groundwater and thus is considered a NPS within the Cocheco watershed.**
3. **Upstream WWTF loads were reduced using an attenuation loss model to estimate the delivered load to the estuary.**
4. **Percent of watershed land area (excluding open water) in developed and agricultural land use classes are from the 2019 National Land Cover Dataset.**

Table of Contents

Table 7.6: Summary of average nitrogen loads (tons per year) to the Great Bay (GB), Little Bay (LB) and Upper Piscataqua River (UPR) Estuaries (2017-2020). Percentages by source are also included.

Source	TN Load (tons/yr)	DIN Load (tons/yr)	% TN load	% DIN load
PS delivered from Lower Piscataqua River	24.5	16.9	2.7%	3.8%
PS discharged to GB, LB and UPR Estuaries	100.7	74.2	11.2%	16.7%
PS delivered from major tributaries	71.7	60.1	8.0%	13.5%
NPS from major tributaries	564.0	221.8	63.0%	50.0%
NPS from drainage areas adjacent to the estuaries	102.2	40.4	11.4%	9.1%
NPS from groundwater discharge to the estuaries	14.6	14.6	1.6%	3.3%
NPS from atmospheric deposition to the estuaries	17.8	15.9	2.0%	3.6%
Subtotal - Point Sources (WWTFs)	**197**	**151**	22.0%	34.1%
Subtotal - Non-point sources	**699**	**293**	78.0%	65.9%
Grand Total	**895**	**444**	**100.0%**	**100.0%**

1. **PS = Point Source.**
2. **WWTF = Wastewater Treatment Facility.**
3. **NPS = Non-Point Source.**

Table of Contents

Table 7.7: Annual average nitrogen loads to the Great Bay (GB), Little Bay (LB) and Upper Piscataqua River (UPR) Estuaries (2017-2020) reported as (A) tons per year and (B) as percentages.

(A) average nitrogen loads as tons per year

Source	2017 TN Load (tons/yr)	2017 DIN Load (tons/yr)	2018 TN Load (tons/yr)	2018 DIN Load (tons/yr)	2019 TN Load (tons/yr)	2019 DIN Load (tons/yr)	2020 TN Load (tons/yr)	2020 DIN Load (tons/yr)
PS delivered from Lower Piscataqua River	32.7	20.3	30.2	19.7	24.0	17.4	12.2	10.2
PS discharged to GB, LB and UPR Estuaries	149.4	99.5	117.8	78.9	84.4	62.3	56.4	43.5
PS delivered from major tributaries	73.0	59.2	80.4	63.7	69.6	58.8	63.2	53.5
NPS from major tributaries	573.5	245.3	760.5	288.6	533.4	209.3	385.8	149.1
NPS from drainage areas adjacent to the estuaries	99.7	45.2	108.4	47.3	101.6	38.7	81.3	30.0
NPS from groundwater discharge to the estuaries	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
NPS from atmospheric deposition to the estuaries	18.6	17.6	20.5	17.4	18.5	17.3	13.5	11.4
Subtotal - Point Sources (WWTFs)	255	179	228	162	178	138	132	107
Subtotal - Non-point sources	706	323	904	368	668	280	495	205
Grand Total	961	502	1132	530	846	418	627	312

(B) average nitrogen loads as percentages

Source	2017 % TN load	2017 % DIN load	2018 % TN load	2018 % DIN load	2019 % TN load	2019 % DIN load	2020 % TN load	2020 % DIN load
PS delivered from Lower Piscataqua River	3.4%	4.0%	2.7%	3.7%	2.8%	4.2%	1.9%	3.3%
PS discharged to GB, LB and UPR Estuaries	15.5%	19.8%	10.4%	14.9%	10.0%	14.9%	9.0%	13.9%
PS delivered from major tributaries	7.6%	11.8%	7.1%	12.0%	8.2%	14.1%	10.1%	17.1%
NPS from major tributaries	59.7%	48.9%	67.2%	54.4%	63.0%	50.0%	61.5%	47.8%
NPS from drainage areas adjacent to the estuaries	10.4%	9.0%	9.6%	8.9%	12.0%	9.2%	13.0%	9.6%
NPS from groundwater discharge to the estuaries	1.5%	2.9%	1.3%	2.7%	1.7%	3.5%	2.3%	4.7%
NPS from atmospheric deposition to the estuaries	1.9%	3.5%	1.8%	3.3%	2.2%	4.1%	2.1%	3.6%
Subtotal - Point Sources (WWTFs)	26.5%	35.7%	20.2%	30.6%	21.0%	33.1%	21.0%	34.3%
Subtotal - Non-point sources	73.5%	64.3%	79.8%	69.4%	79.0%	66.9%	79.0%	65.7%
Grand Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table of Contents

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Nutrient Concentrations

Please note that this section contains both "Methods and Data Sources" as well as "Additional Discussion" and over 15 additional tables and figures.

Methods and Data Sources

Trend analysis for nitrogen and phosphorus species was performed at the following stations:

- 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)
- HHHR (Hampton River)
- GRBBR (Bellamy River)
- GRBCR (Cocheco River)

With regard to nitrogen species, this report focuses on total nitrogen and dissolved inorganic nitrogen; data are also available for ammonia, nitrate+nitrite, total dissolved nitrogen, and particulate nitrogen and can be obtained by querying the NHDES Environmental Monitoring Database or by contacting PREP staff. Total nitrogen is a calculated variable resulting from the summation of total dissolved nitrogen and particulate nitrogen. The phosphorus parameter for trend analysis was orthophosphate and is included in this report. Samples collected at low tide at the trend stations were identified and 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 only exception was the Adams Point station, which is monitored 12 months per year. Only years with at least seven data points were included in the analysis. This was done to minimize bias from years for which the data do not reflect at least half of the year. Linear regression was used to test for long-term trends between measured concentration and year of measurement. Trends were considered significant if the slope coefficient of the year variable was significant at the $p < 0.05$.

Data Sources

Data for this indicator were provided by the UNH and Great Bay NERR Tidal Water Quality Monitoring Programs for the 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 and Cocheco Rivers and in Hampton-Seabrook Harbor by the PREP Tidal Water Quality Monitoring Program.

Additional Discussion
Trend analysis results for nitrogen species and orthophosphate showed varied responses across monitoring stations (Table 8.3). Concentrations of dissolved inorganic nitrogen (DIN) for individual monitoring stations are shown in Figures 8.2 through 8.12. Figures 8.13 through 8.23 display total nitrogen (TN) concentrations for individual monitoring stations and Figures 8.24 through 8.34 depict orthophosphate concentrations over time. *(Note that figure and table numbers are continued from the Printed Report.)*

For DIN, only two monitoring stations had a significant decreasing trend in concentrations over time, the Oyster River (Figure 8.8) and the Upper Piscataqua River (Figure 8.3, found in State of Our Estuaries Report). Recent (2016 – 2021) annual median concentrations at these two stations were comparable. The annual median concentration in 2021 was the highest of the last six years for both of these stations. One station exhibited a significant increasing trend in DIN concentrations, Chapman's Landing on the Squamscott River (Figure 8.4). The range in recent annual median concentrations was the highest at Chapman's Landing, spanning from 0.42 to 0.47 mg-N/L (Table 8.3).

The remaining monitoring stations did not have significant linear trends in DIN concentrations over time. At the Squamscott River monitoring station, annual median concentrations from 2019 to 2021 were lower than the previous six years (Figure 8.5). Both Great Bay Estuary and Hampton-Seabrook Estuary appear comparable in DIN concentrations with both the GRBGB (Figure 8.7) and HHHR (Figure 8.10) stations showing similar concentrations over time. Neither of those monitoring stations had annual median concentrations exceeding 0.20 mg-N/L. While there was no trend in DIN for the Cocheco River between 2016 and 2018 (Figure 8.12), median annual concentrations were higher than other nearby stations (Bellamy and Upper Piscataqua Rivers).

The Adams Point and Coastal Marine Lab stations were the only monitoring stations to exhibit a significant decrease in TN concentration over time (Figures 8.13 and 8.20). At Adams Point, TN concentrations were high in the early 2000s. From 2004 – 2010, only one year had annual median total nitrogen concentration below the EPA definition of low total nitrogen (0.31 mg-N/L). Between 2011 and 2021, five different years had annual medians of 0.31 mg-N/L or lower at the Adams Point station. Recent (2016-2017) annual median concentrations ranged from 0.21 to 0.24 mg-N/L at the Coastal Marine Lab station. Additionally, only 3 of the 15 monitoring years had annual medians in excess of 0.31 mg-N/L. Both monitoring stations on the Squamscott River (Chapman's Landing and Squamscott River) had increasing trends in total nitrogen concentration over time (Figures 8.14 and 8.15). These stations had the highest annual median concentrations out of all the monitoring stations, ranging from 0.63 to 1.04 mg-N/L across the two stations (Table 8.3).

The remaining monitoring stations did not exhibit trends in total nitrogen over time. Annual median total nitrogen concentrations at the Great Bay station exhibited a wider range (0.29 – 0.52 mg-N/L) than those at the Hampton River Station (0.38 – 0.47 mg-N/L) (Table 8.3). At the Lamprey River station, total nitrogen peaked in 2016 with an annual median of 0.63 mg-N/L (Figure 8.16). Following that peak, concentrations have ranged between 0.39 and 0.48 mg-N/L.

The Oyster River station exhibited a different pattern, reaching an all-time low in 2016 with an annual median of 0.42 mg-N/L (Figure 8.18).

Although nitrogen tends to dominate nutrient discussions in estuarine systems, phosphorus is also important and can be the “limiting nutrient” at specific times in the year (usually in the spring and fall, when nitrogen loading is highest) and in specific areas (often in medium salinity parts of the estuary) where algae growth is quite high. The sources of phosphorus are similar to the sources of nitrogen: wastewater treatment plants, atmospheric deposition, fertilizer and stormwater.

Temporal trends in orthophosphate (the species of phosphorus most often measured) concentrations occurred at three out of the eleven monitoring stations. At the Adams Point station, orthophosphate has decreased over time since the early 1970s (Figure 8.24). Recent annual medians at Adams Point ranged from 0.01 to 0.02 mg-P/L. Both the Squamscott (Figure 8.26) and Lamprey (Figure 8.27) Rivers exhibited increasing trends in orthophosphate concentrations over time. Annual median concentrations between 2016 and 2021 were higher in the Squamscott than in the Lamprey, with the Lamprey ranging between 0.01 and 0.03 mg-P/L (Table 8.3). The Lamprey River had higher intra-annual variability in orthophosphate. For example, in 2016 concentrations of orthophosphate reached a high of 0.15 mg-P/L in October and a low of 0.01 mg-P/L in May.

No other monitoring stations had linear trends for orthophosphate over time. Overall, concentrations were low across all sites. The highest annual median between 2016 and 2021 was 0.06 mg-P/L in the Oyster River (Table 8.3). These low concentrations are comparable to other estuaries, with a reported median phosphate concentration of 0.05 mg-P/L in the Choptank River Estuary in Maryland (2005-2008) (Whitall et al., 2010).

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”. Based on annual median concentrations for each station’s entire monitoring record (Figures 8.24 through 8.34), the majority of stations classify as “fair”. The Lamprey River station oscillates the most between the “good” and “fair” categories with a number of individual observations falling well below the 0.01 mg-P/L threshold set by the EPA. 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).

Additional Data Tables and Figures

Table 8.3 Trends for nutrient species and recent annual median values for 10 stations in the Great Bay Estuary and one station in the Hampton-Seabrook Estuary.

Station	Parameter	Period	Range of Recent Median Values (2016-2021)	Long Term Trend
GRBAP (Adams Point)	Dissolved Inorganic Nitrogen	1974 – 2021	0.06 – 0.15	No
	Total Nitrogen	2004 – 2021	0.27 – 0.37	Yes (decreasing)
	Orthophosphate	1974 – 2021	0.01 – 0.02	Yes (decreasing)
GRBCL (Chapman's Landing)	Dissolved Inorganic Nitrogen	1992 – 2018	0.42 – 0.47	Yes (increasing)
	Total Nitrogen	2004 – 2018	0.90 – 1.04	Yes (increasing)
	Orthophosphate	1992 – 2018	0.04 – 0.05	No
GRBSQ (Squamscott River)	Dissolved Inorganic Nitrogen	2002 – 2021	0.19 – 0.42	No
	Total Nitrogen	2004 – 2021	0.63 – 1.04	Yes (increasing)
	Orthophosphate	2005 – 2021	0.04 – 0.05	Yes (increasing)
GRBLR (Lamprey River)	Dissolved Inorganic Nitrogen	1992 – 2021	0.12 – 0.21	No
	Total Nitrogen	2004 – 2021	0.39 – 0.63	No
	Orthophosphate	1992 – 2021	0.01 – 0.03	Yes (increasing)
GRBGB (Great Bay)	Dissolved Inorganic Nitrogen	2002 – 2021	0.06 – 0.15	No
	Total Nitrogen	2004 – 2021	0.29 – 0.52	No
	Orthophosphate	2002 – 2021	0.02 – 0.03	No
GRBOR (Oyster River)	Dissolved Inorganic Nitrogen	2005 – 2021	0.13 – 0.20	Yes (decreasing)
	Total Nitrogen	2004 – 2021	0.42 – 0.59	No
	Orthophosphate	2005 – 2021	0.02 – 0.06	No
GRBUPR (Upper Piscataqua River)	Dissolved Inorganic Nitrogen	2007 – 2021	0.14 – 0.20	Yes (decreasing)
	Total Nitrogen	2009 – 2021	0.37 – 0.48	No
	Orthophosphate	2007 – 2021	0.02 – 0.03	No
GRBCML (Coastal Marine Lab Portsmouth Harbor)	Dissolved Inorganic Nitrogen	2001 – 2017	0.07 – 0.12	No
	Total Nitrogen	2005 – 2017	0.21 – 0.24	Yes (decreasing)
	Orthophosphate	2002 – 2017	0.01 – 0.02	No
HHHR (Hampton River)	Dissolved Inorganic Nitrogen	2018 – 2021	0.09 – 0.12	No
	Total Nitrogen	2018 – 2021	0.38 – 0.47	No
	Orthophosphate	2018 – 2021	0.01 – 0.02	No
GRBBR (Bellamy River)	Dissolved Inorganic Nitrogen	2018	0.14	NA
	Total Nitrogen	2018	0.47	NA
	Orthophosphate	2018	0.02	NA
GRBCR (Cocheco River)	Dissolved Inorganic Nitrogen	2016 – 2020	0.22 – 0.25	No
	Total Nitrogen	2016 – 2020	0.50 – 0.57	No
	Orthophosphate	2016 – 2020	0.02 – 0.04	No

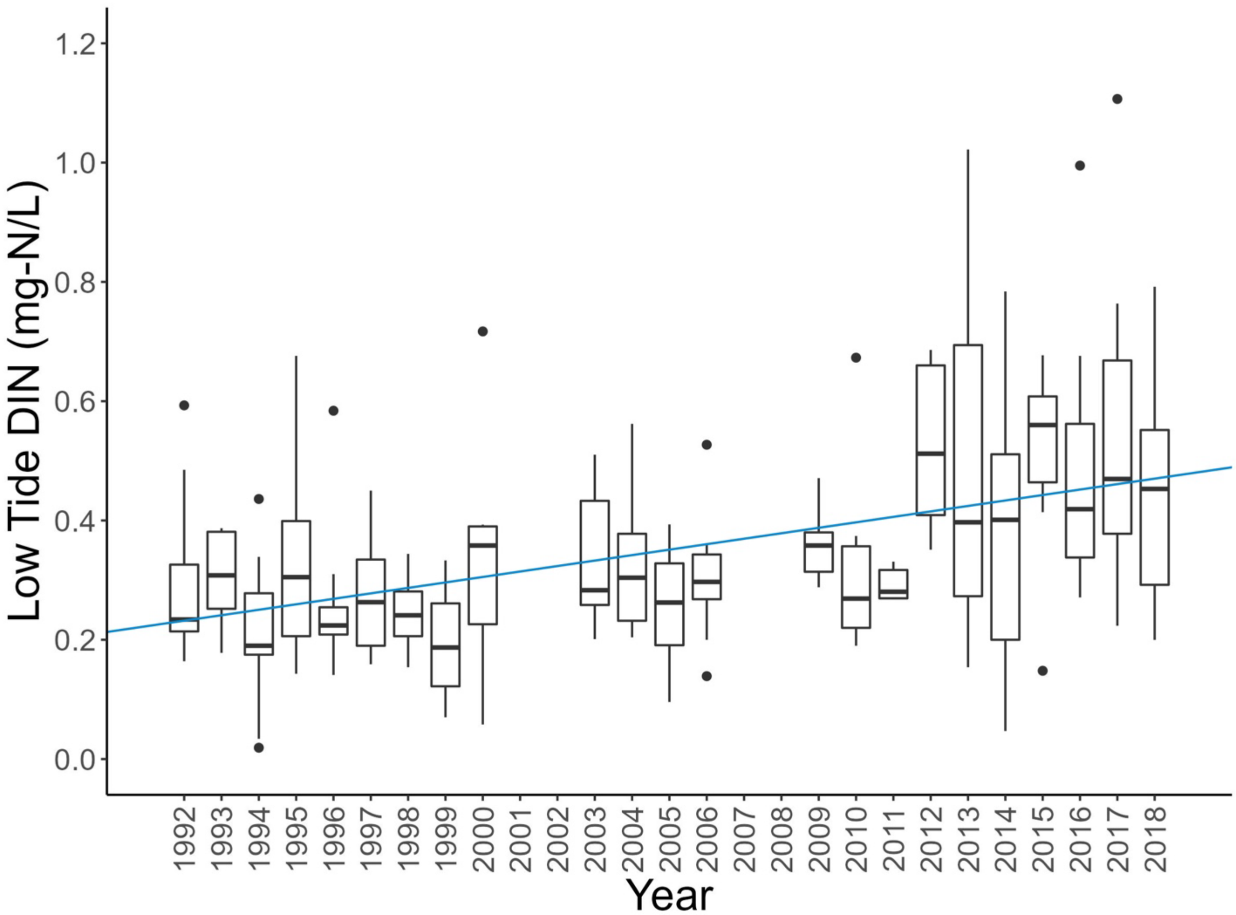

Figure 8.4: Dissolved inorganic nitrogen (DIN) at the Chapman's Landing Station (along the Squamscott River) shows an increasing trend based on data collected monthly at low tide between 1992 and 2018 and shown here as box and whisker plots. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. Blue line represents significant linear regression through all data points. *Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH*

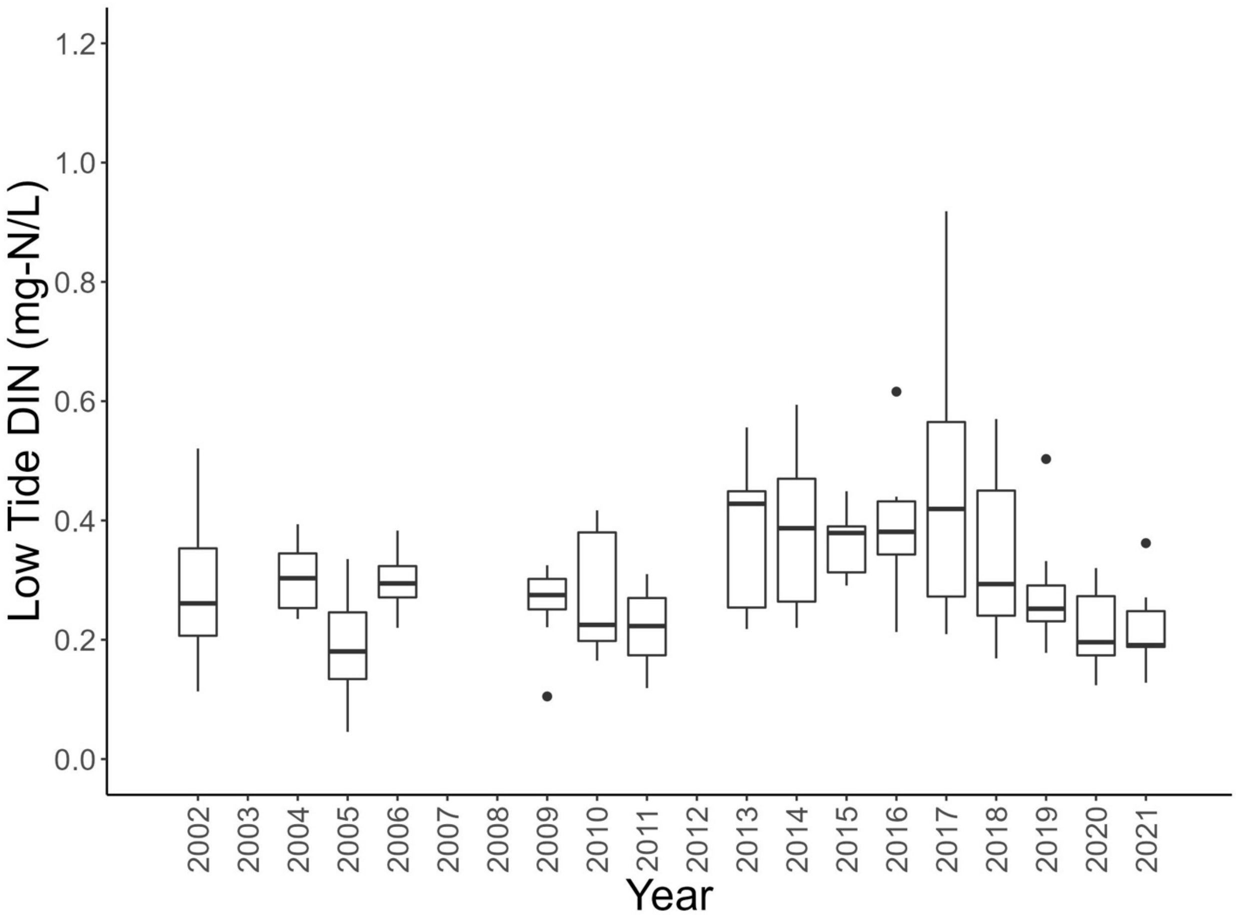

Figure 8.5: Dissolved inorganic nitrogen (DIN) at the Squamscott River Station. Box and whisker plots show DIN concentrations collected monthly at low tide between 2002 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

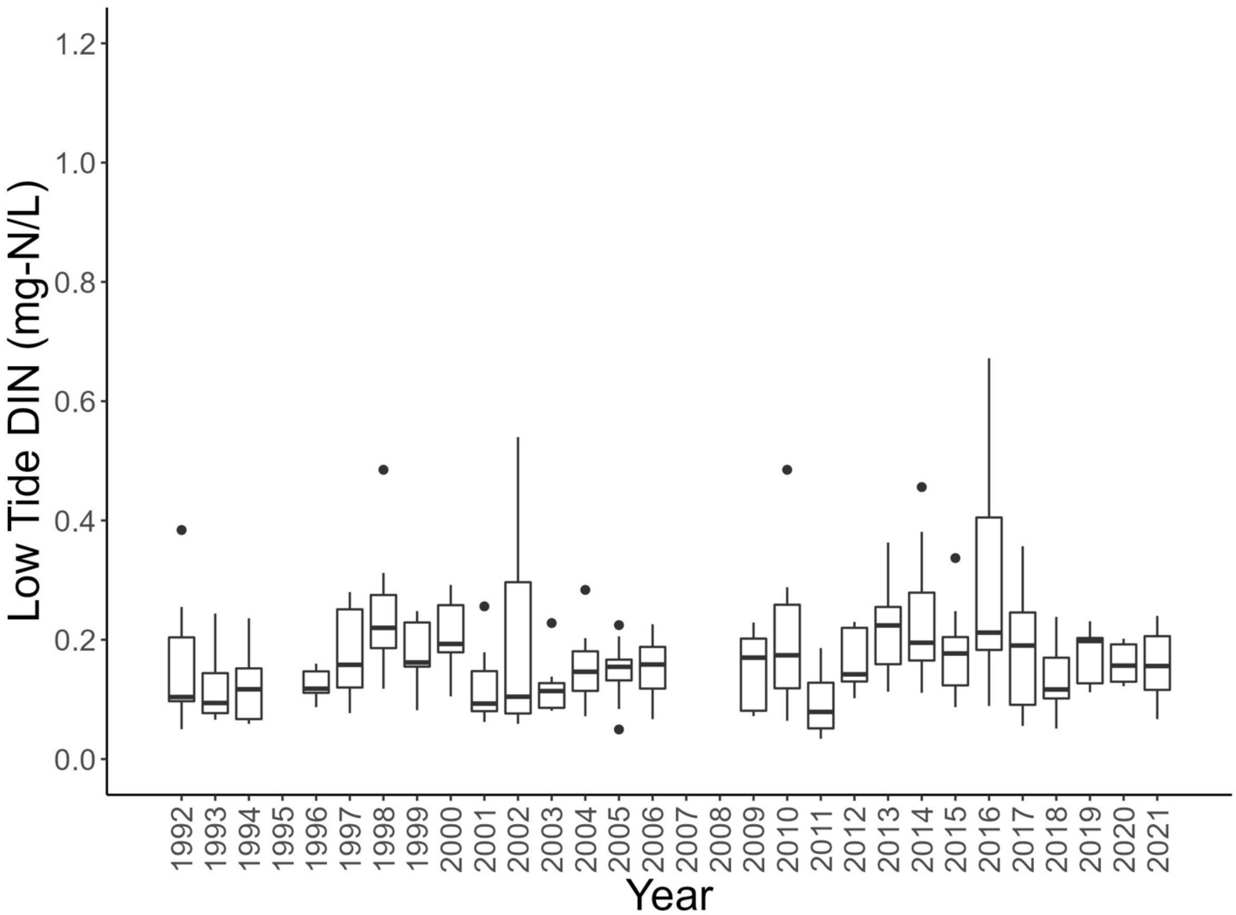

Figure 8.6: Dissolved inorganic nitrogen (DIN) at the Lamprey River Station. Box and whisker plots show DIN concentrations collected monthly at low tide between 1992 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

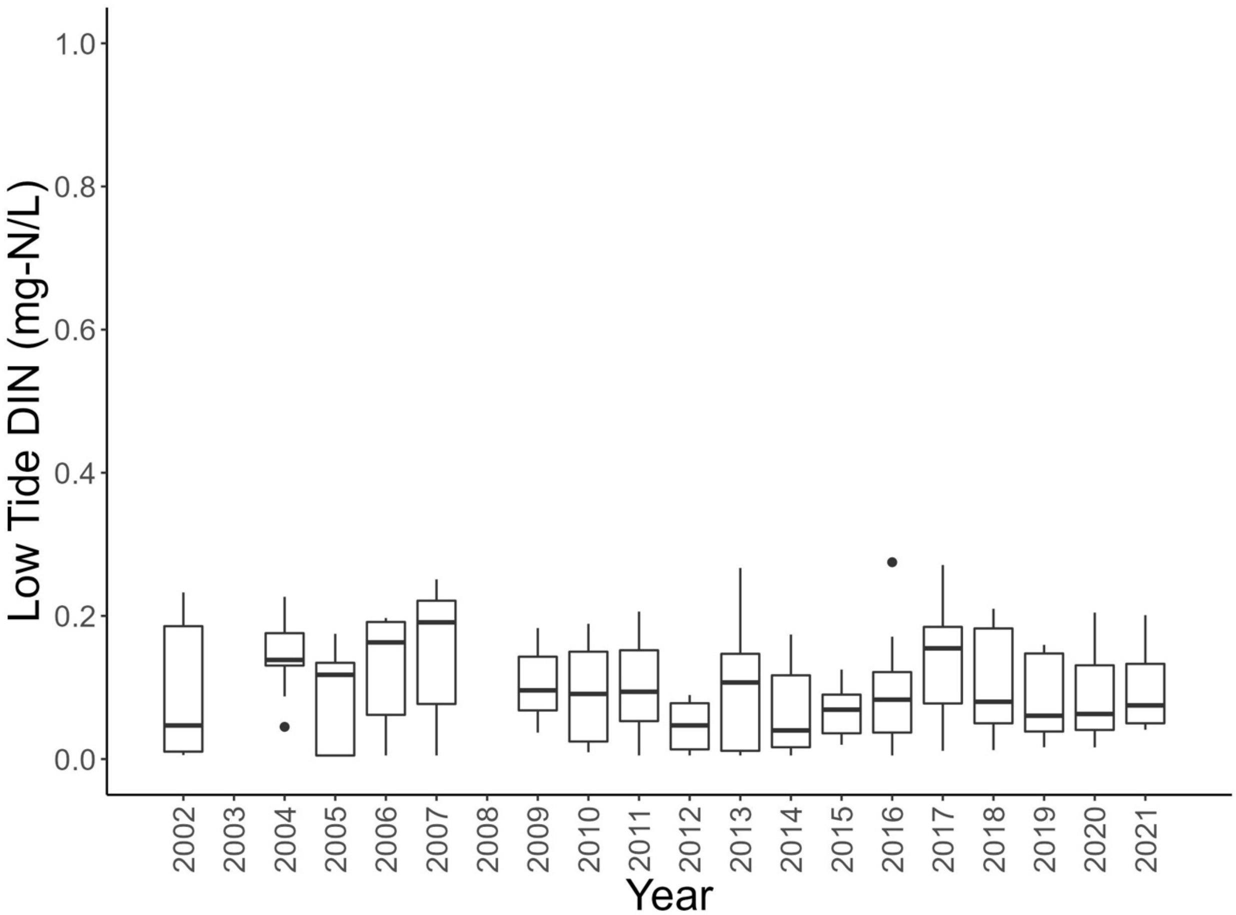

Figure 8.7: Dissolved inorganic nitrogen (DIN) at the Great Bay Station. Box and whisker plots show DIN concentrations collected monthly at low tide between 2002 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

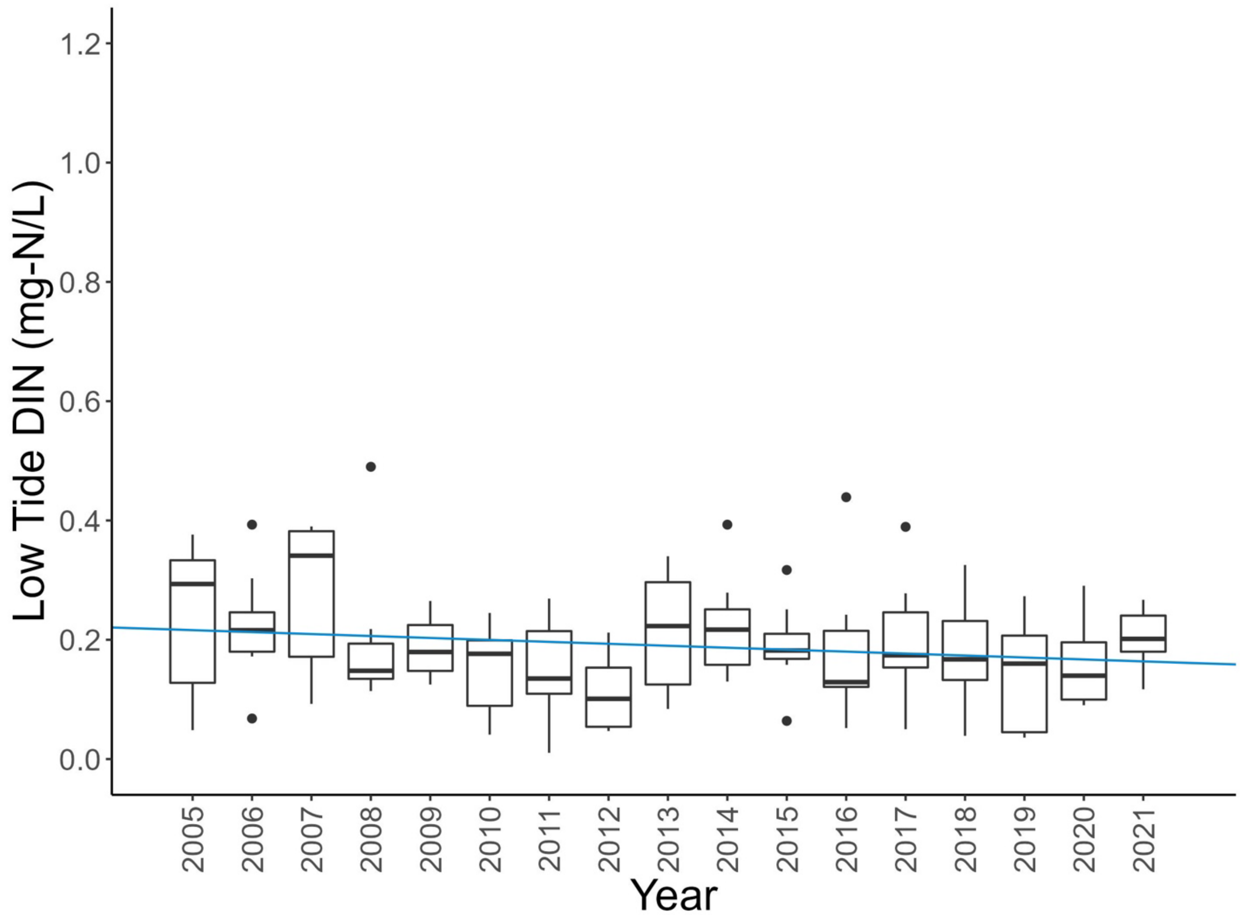

Figure 8.8: Dissolved inorganic nitrogen (DIN) at the Oyster River Station shows a decreasing trend based on data collected monthly at low tide between 2005 and 2021 and shown here as box and whisker plots. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. Blue line represents significant linear regression through all data points. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

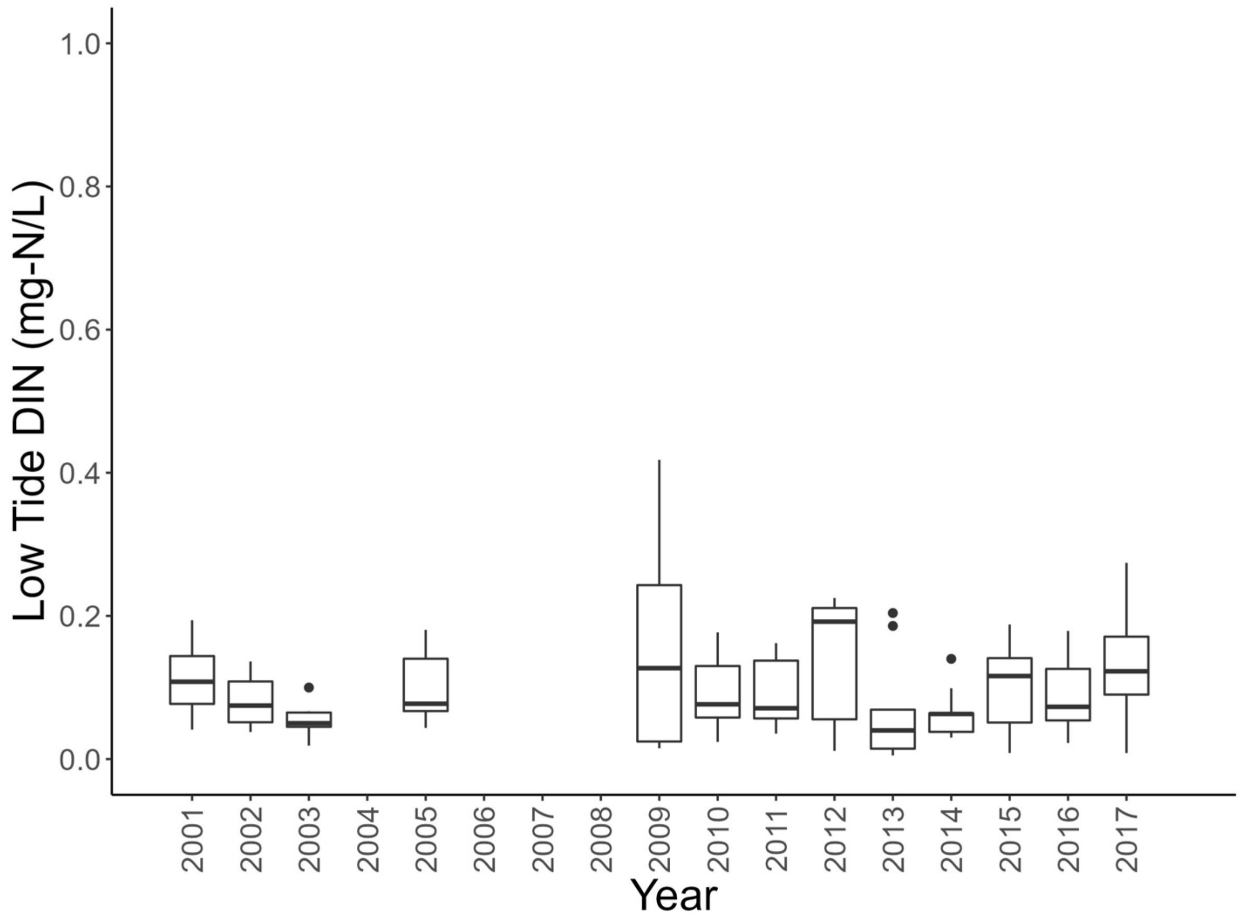

Figure 8.9: Dissolved inorganic nitrogen (DIN) at the Coastal Marine Lab (Portsmouth Harbor) Station. Box and whisker plots show DIN concentrations (ollected monthly at low tide between 2001 and 2017. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. *Data Source: Jackson Estuarine Laboratory, UNH*

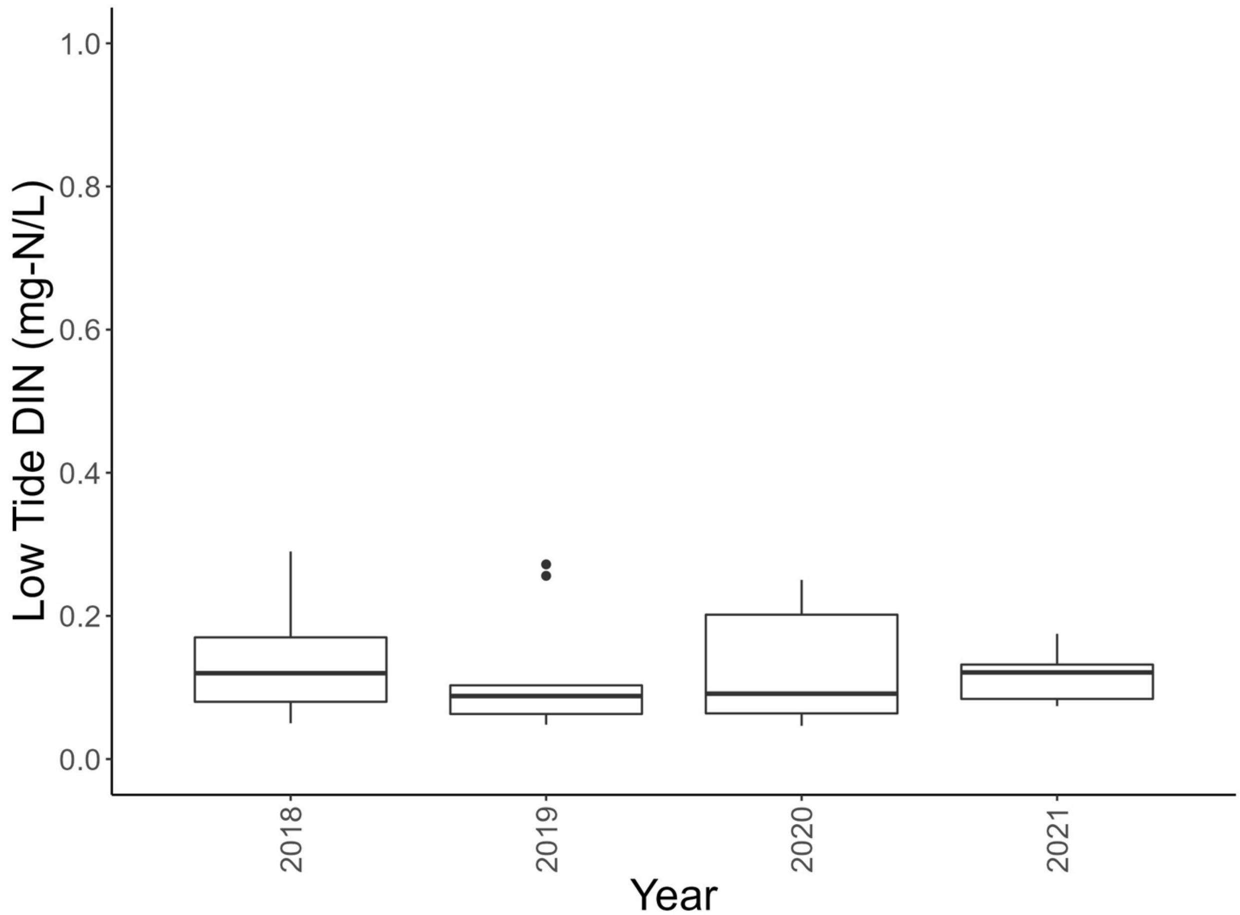

Figure 8.10: Dissolved inorganic nitrogen (DIN) at the Hampton River Station in the Hampton-Seabrook Estuary. Box and whisker plots show DIN concentrations collected monthly at low tide between 2018 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. ***Data Source: Jackson Estuarine Laboratory, UNH***

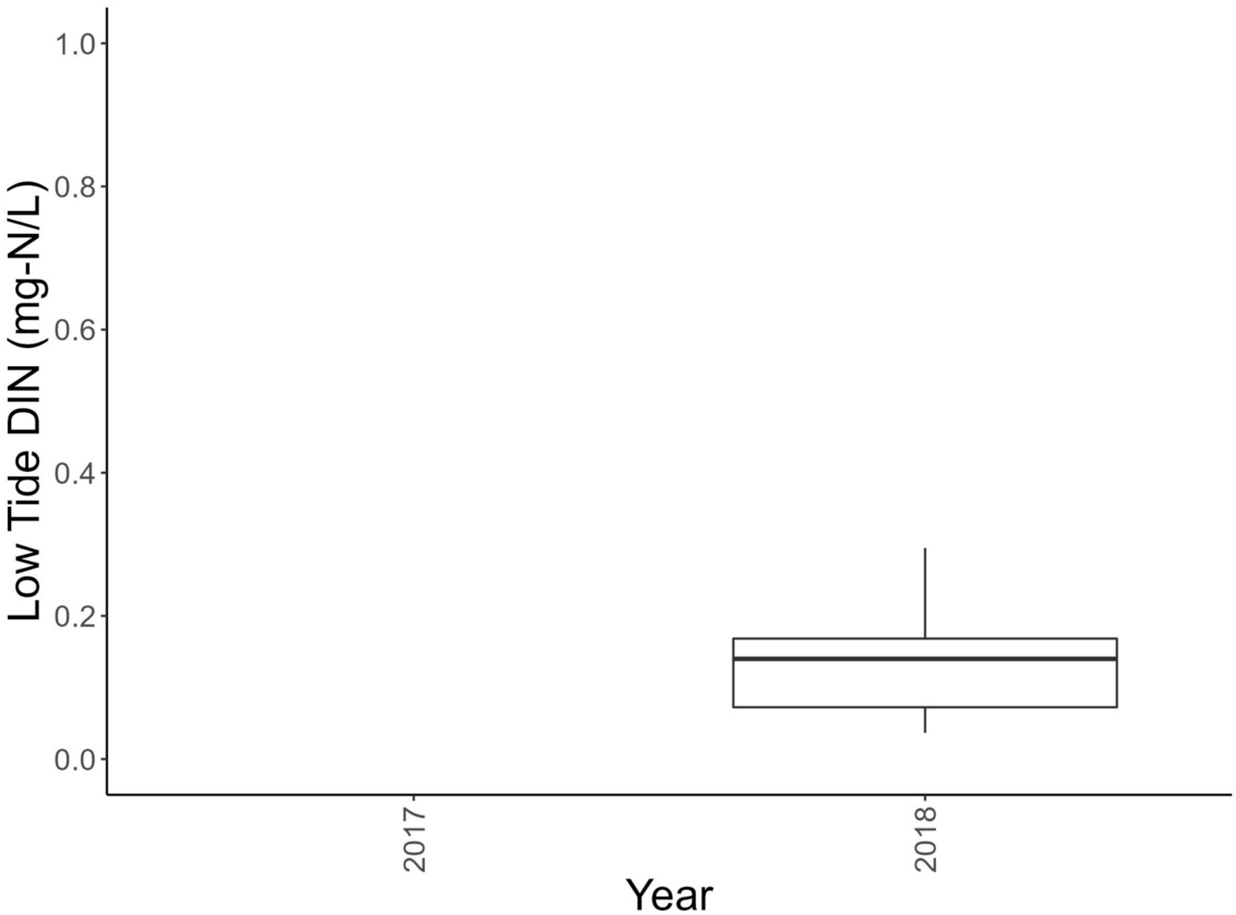

Figure 8.11: Dissolved inorganic nitrogen (DIN) at the Bellamy River Station. Box and whisker plots show DIN concentrations collected monthly at low tide in 2018. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Jackson Estuarine Laboratory, UNH***

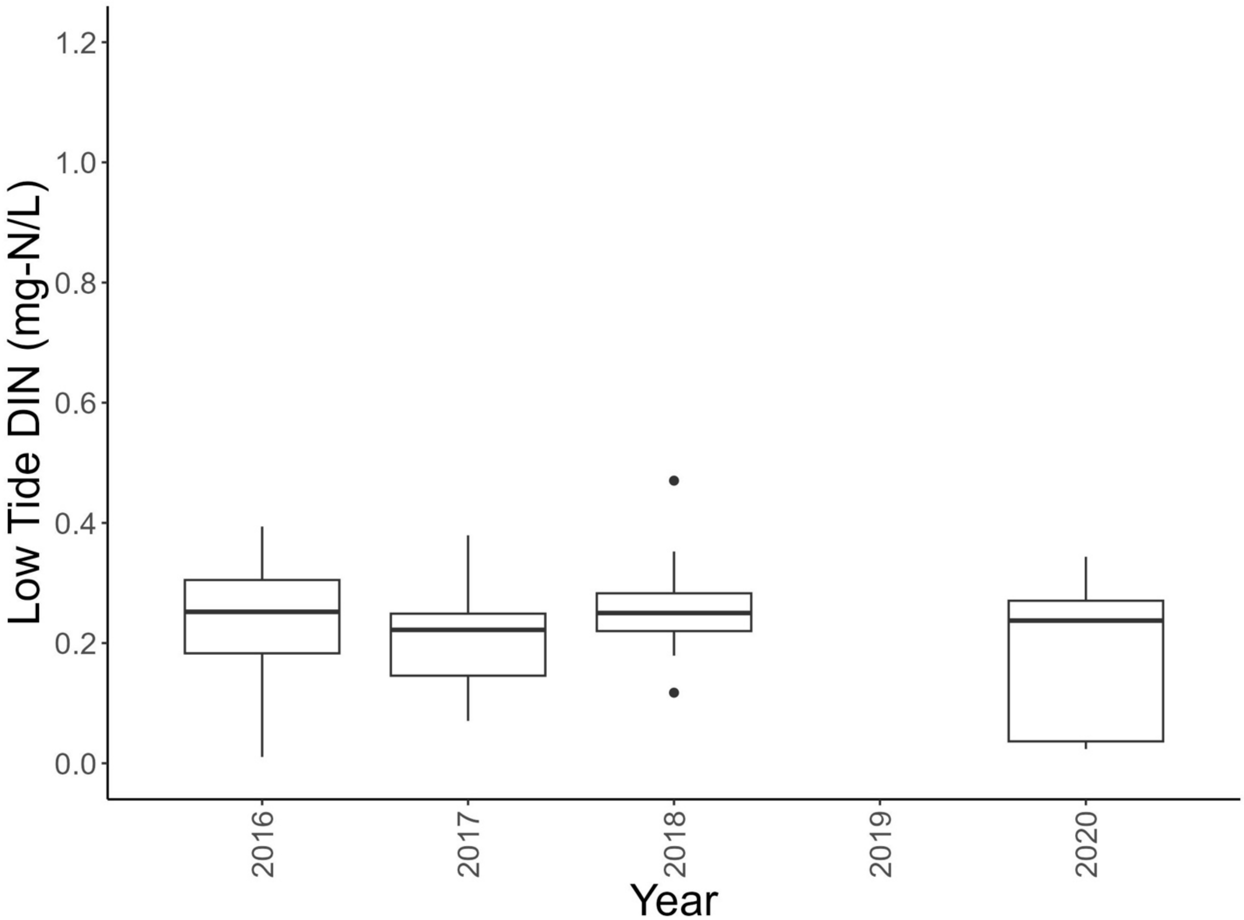

Figure 8.12: Dissolved inorganic nitrogen (DIN) at the Cocheco River Station. Box and whisker plots show DIN concentrations collected monthly at low tide between 2016 and 2020. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. *Data Source: Jackson Estuarine Laboratory, UNH*

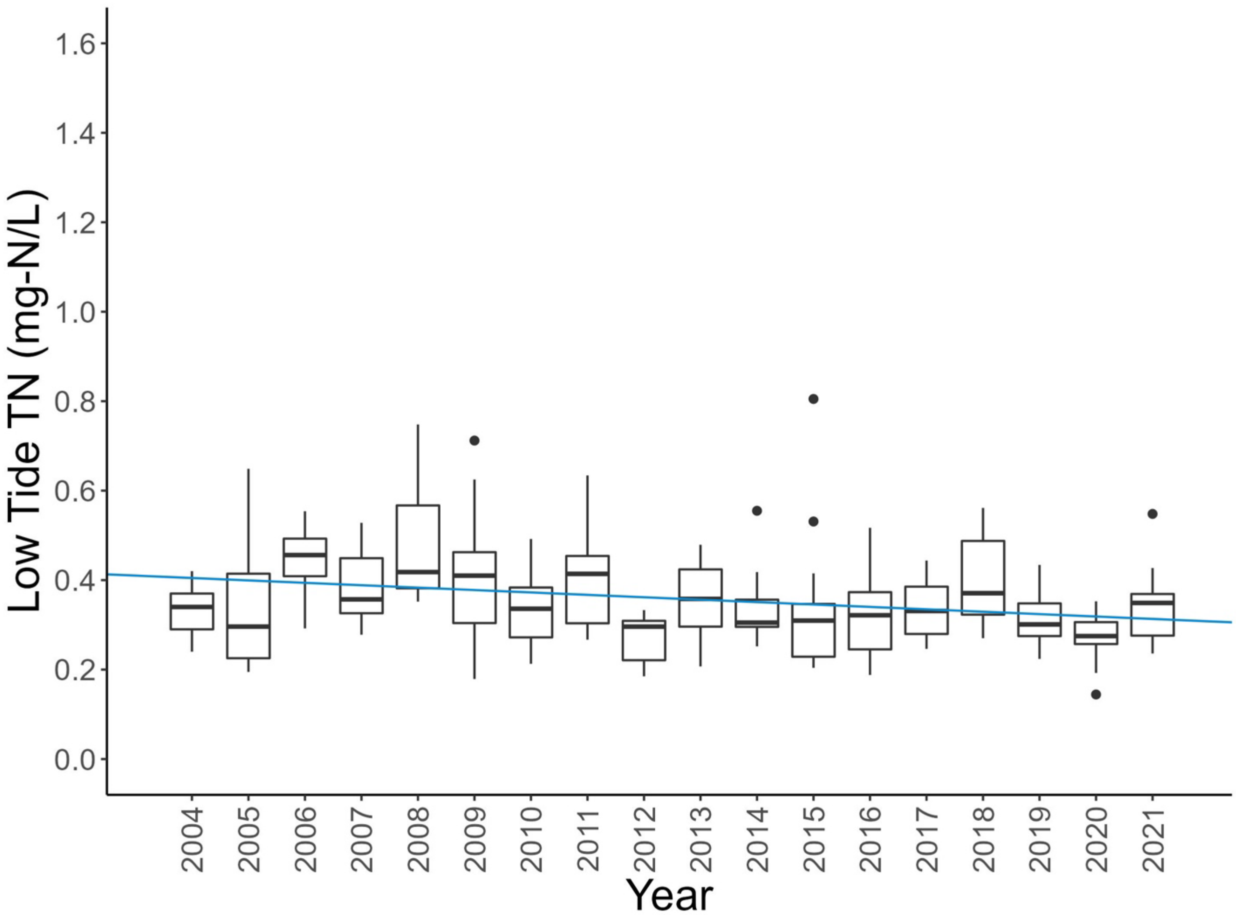

Figure 8.13: Total nitrogen (TN) at the Adams Point Station shows a decreasing trend based on data collected monthly at low tide between 2004 and 2021 and shown here as box and whisker plots. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. Blue line represents significant linear regression through all data points. ***Data Source: Jackson Estuarine Laboratory, UNH***

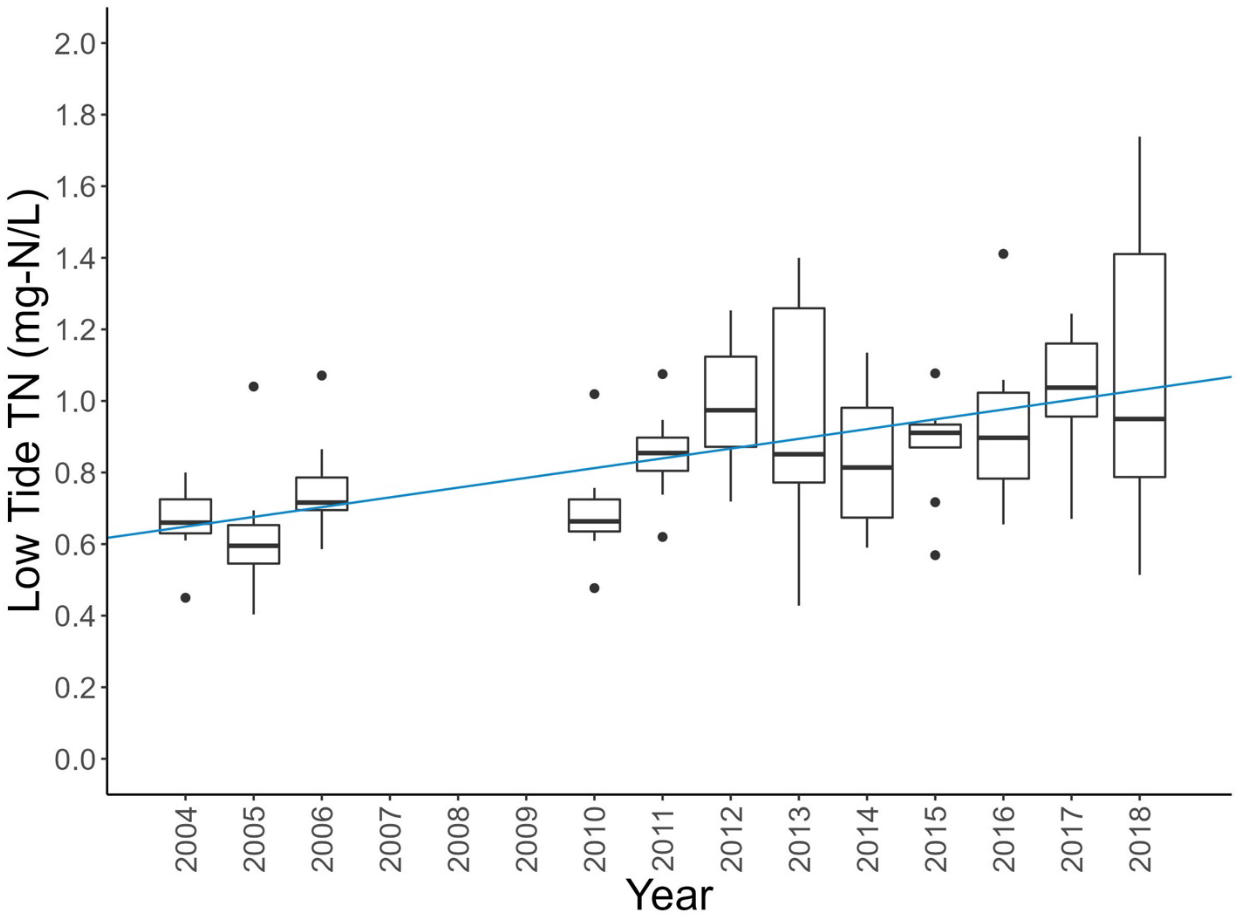

Figure 8.14: Total nitrogen (TN) at the Chapman's Landing Station (along the Squamscott River) shows an increasing trend based on data collected monthly at low tide between 2004 and 2021 and shown here as box and whisker plots. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. Blue line represents significant linear regression through all data points. *Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH*

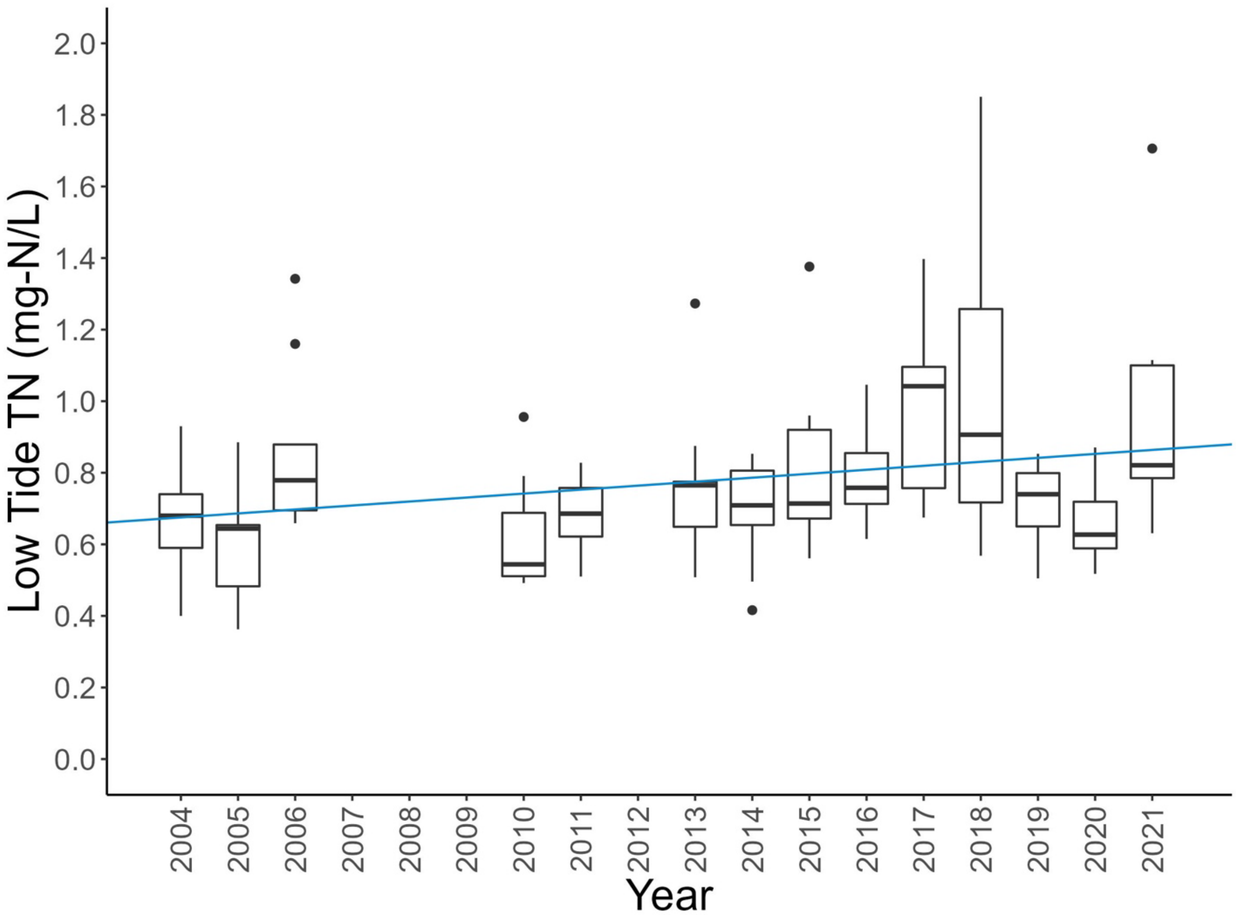

Figure 8.15: Total nitrogen (TN) at the Squamscott River Station shows an increasing trend based on data collected monthly at low tide between 2004 and 2021 and shown here as box and whisker plots. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. Blue line represents significant linear regression through all data points. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

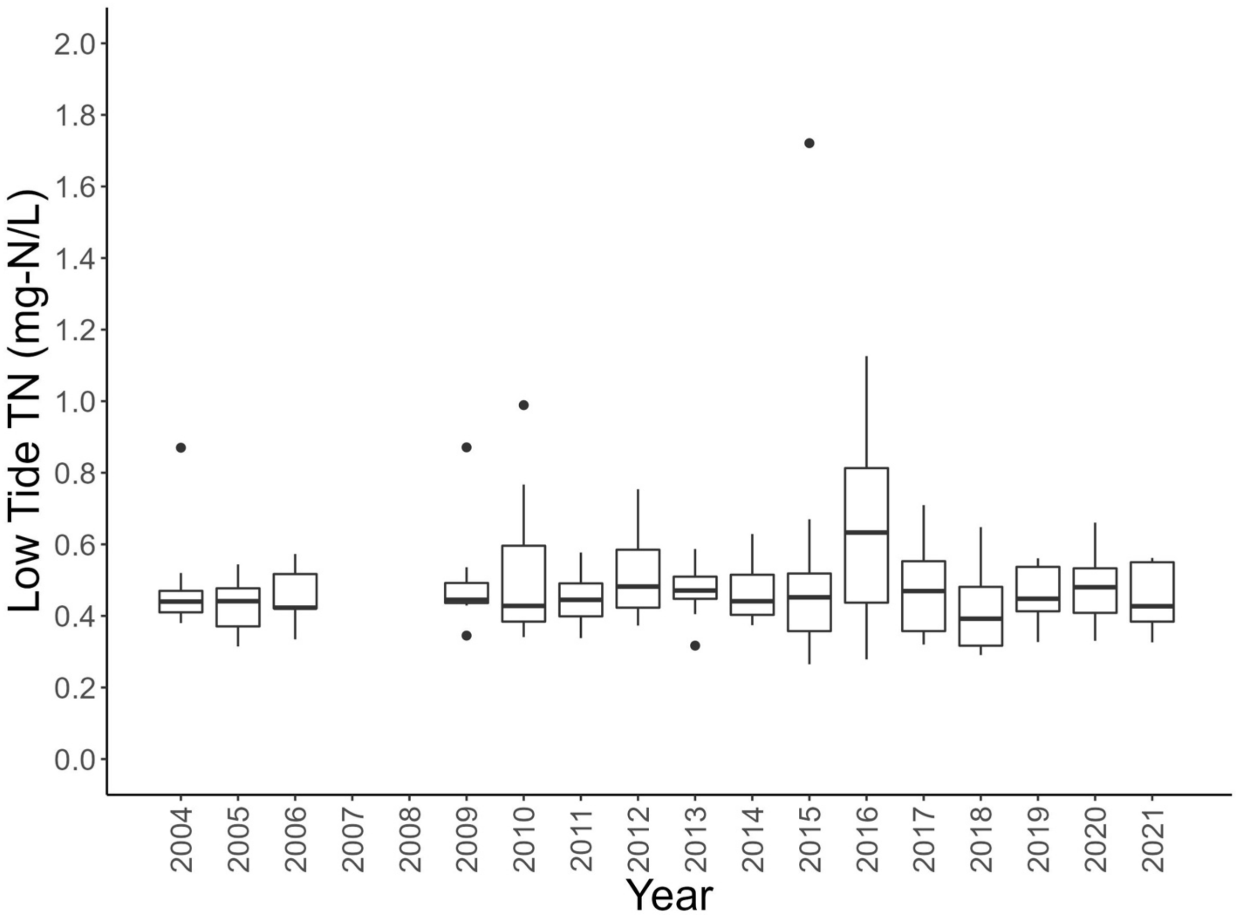

Figure 8.16: Total nitrogen (TN) at the Lamprey River Station. Box and whisker plots show TN concentrations collected monthly at low tide between 2004 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

Table of Contents

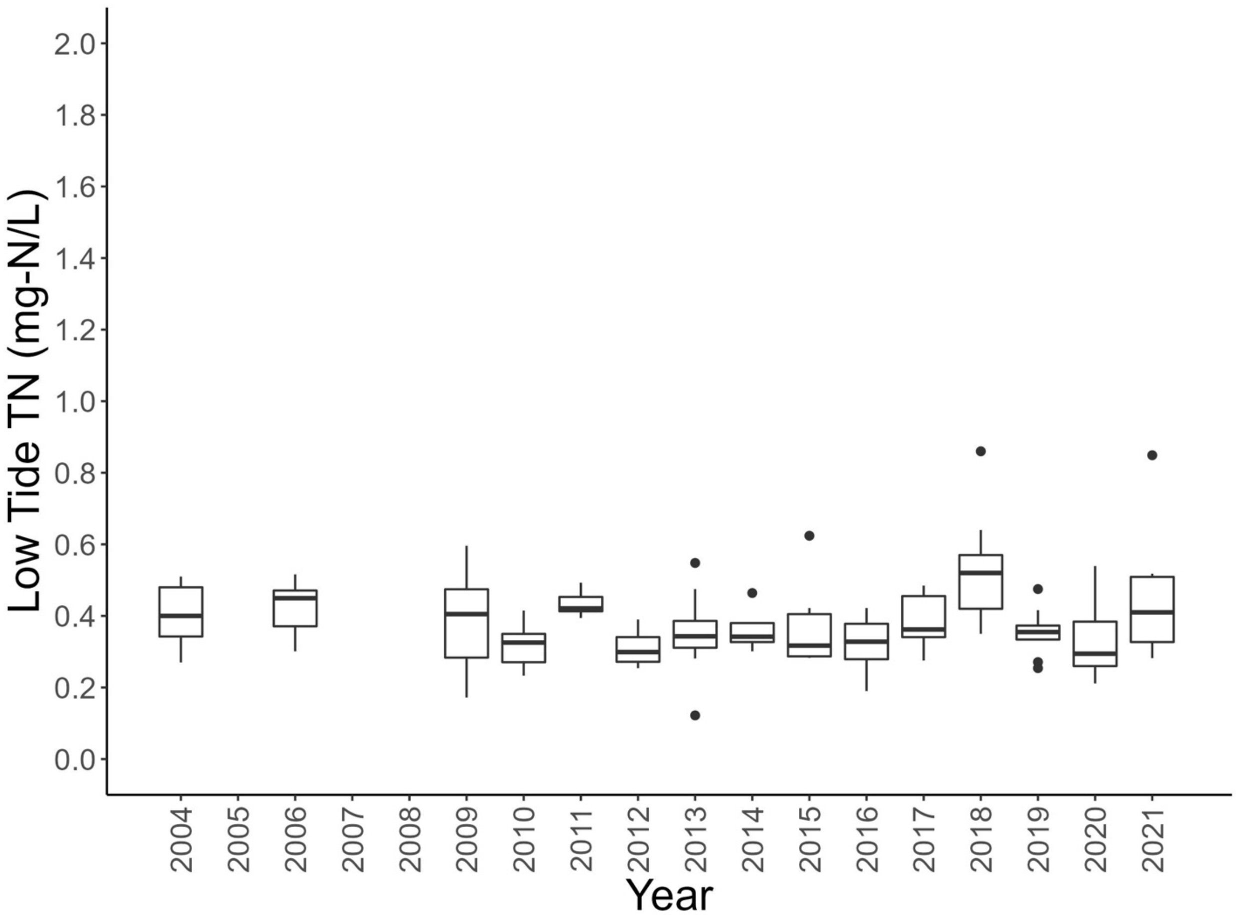

Figure 8.17: Total nitrogen (TN) at the Great Bay Station. Box and whisker plots show TN concentrations collected monthly at low tide between 2004 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

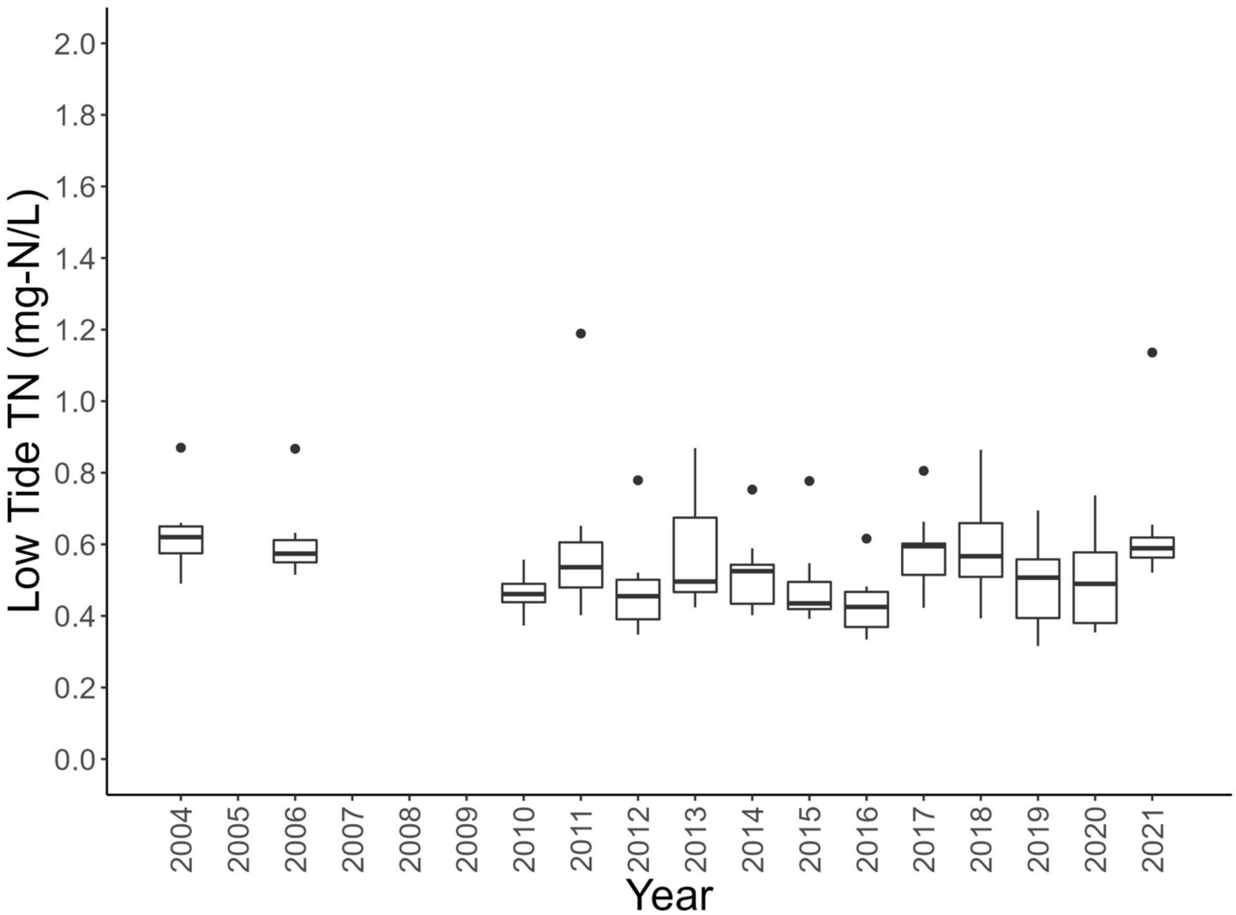

Figure 8.18: Total nitrogen (TN) at the Oyster River Station. Box and whisker plots show TN concentrations collected monthly at low tide between 2004 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

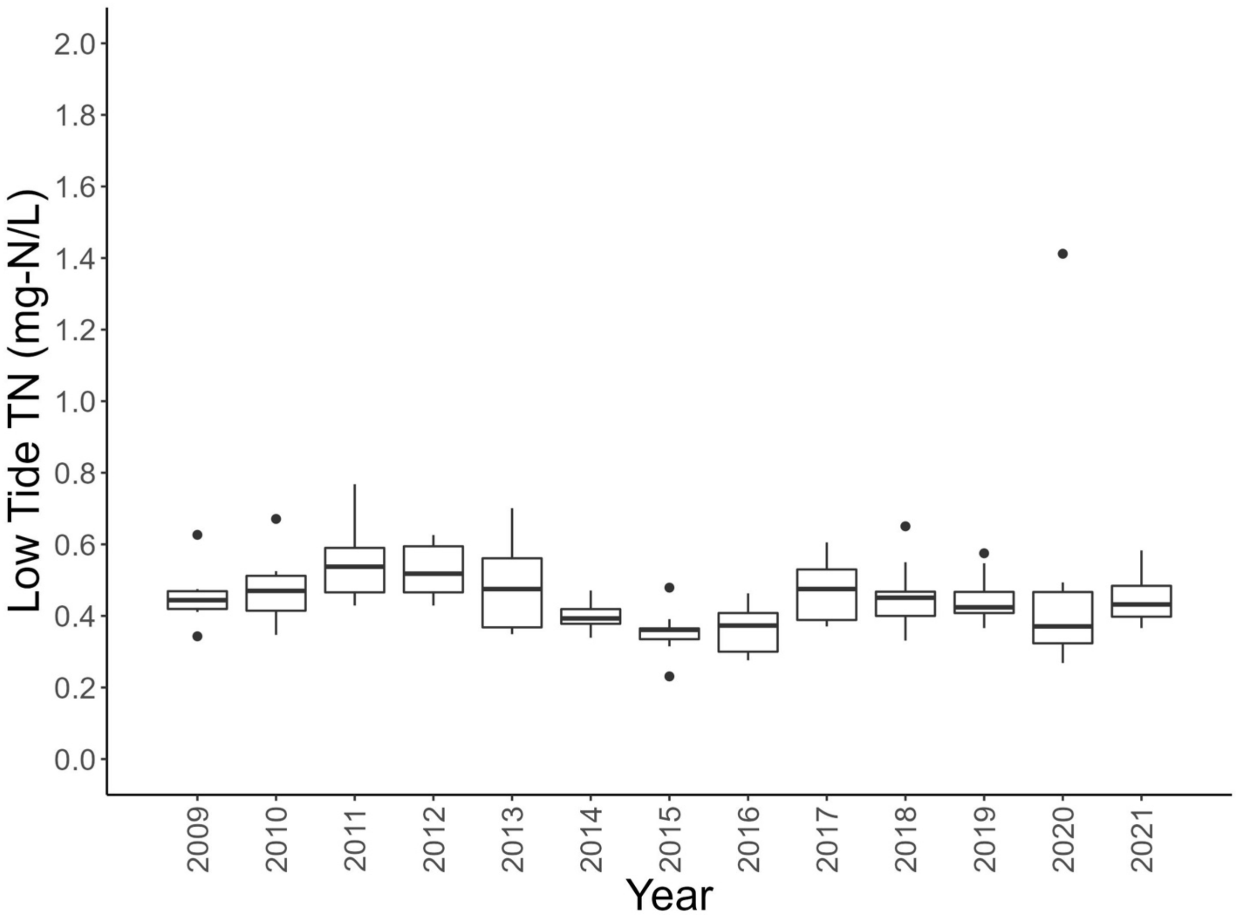

Figure 8.19: Total nitrogen (TN) at the Upper Piscataqua River Station. Box and whisker plots show TN concentrations collected monthly at low tide between 2009 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: the Jackson Estuarine Laboratory, UNH***

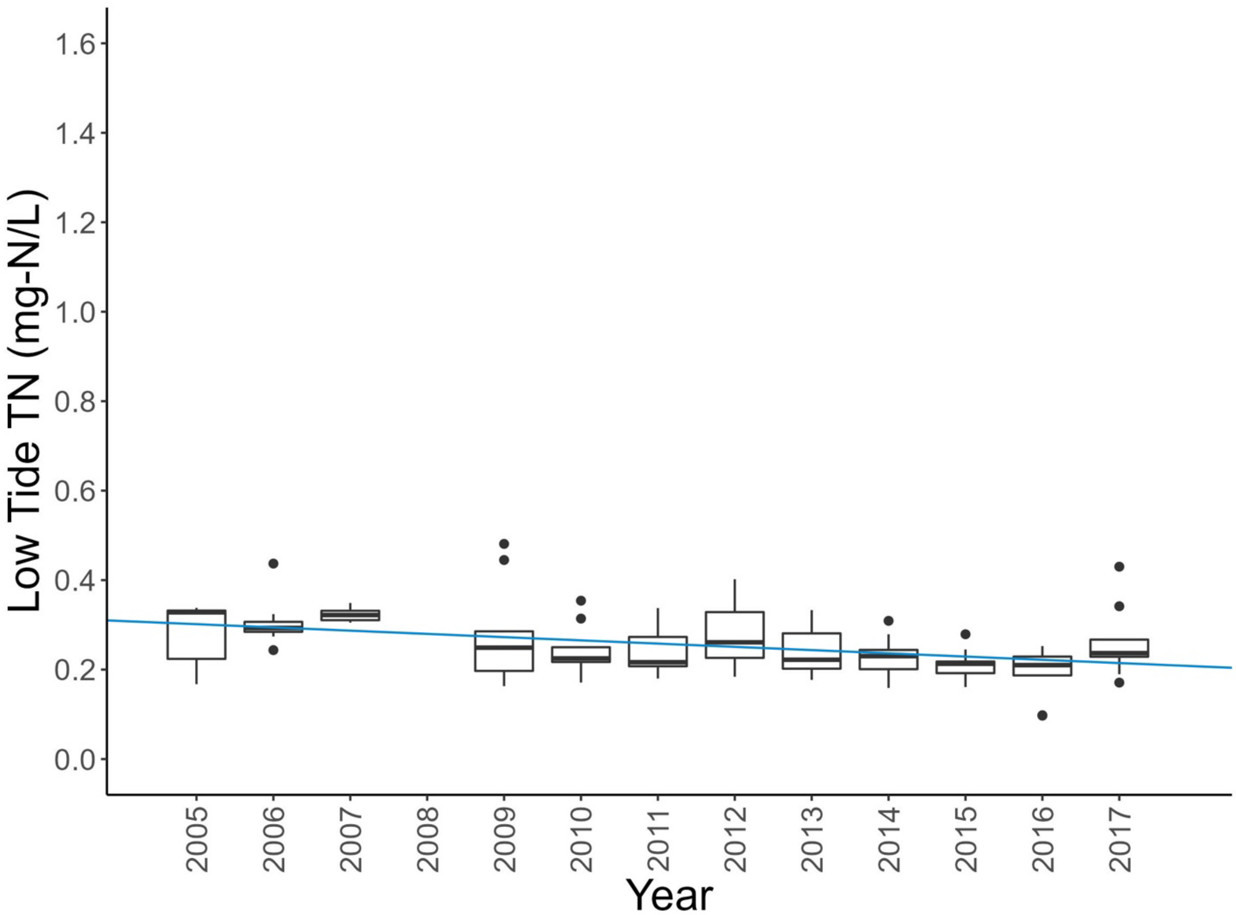

Figure 8.20: Total nitrogen (TN) at the Coastal Marine Lab (Portsmouth Harbor) Station shows a decreasing trend over time based on data collected monthly at low tide between 2005 and 2017 and shown here as box and whisker plots. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. Blue line represents significant linear regression through all data points. *Data Source: Jackson Estuarine Laboratory, UNH*

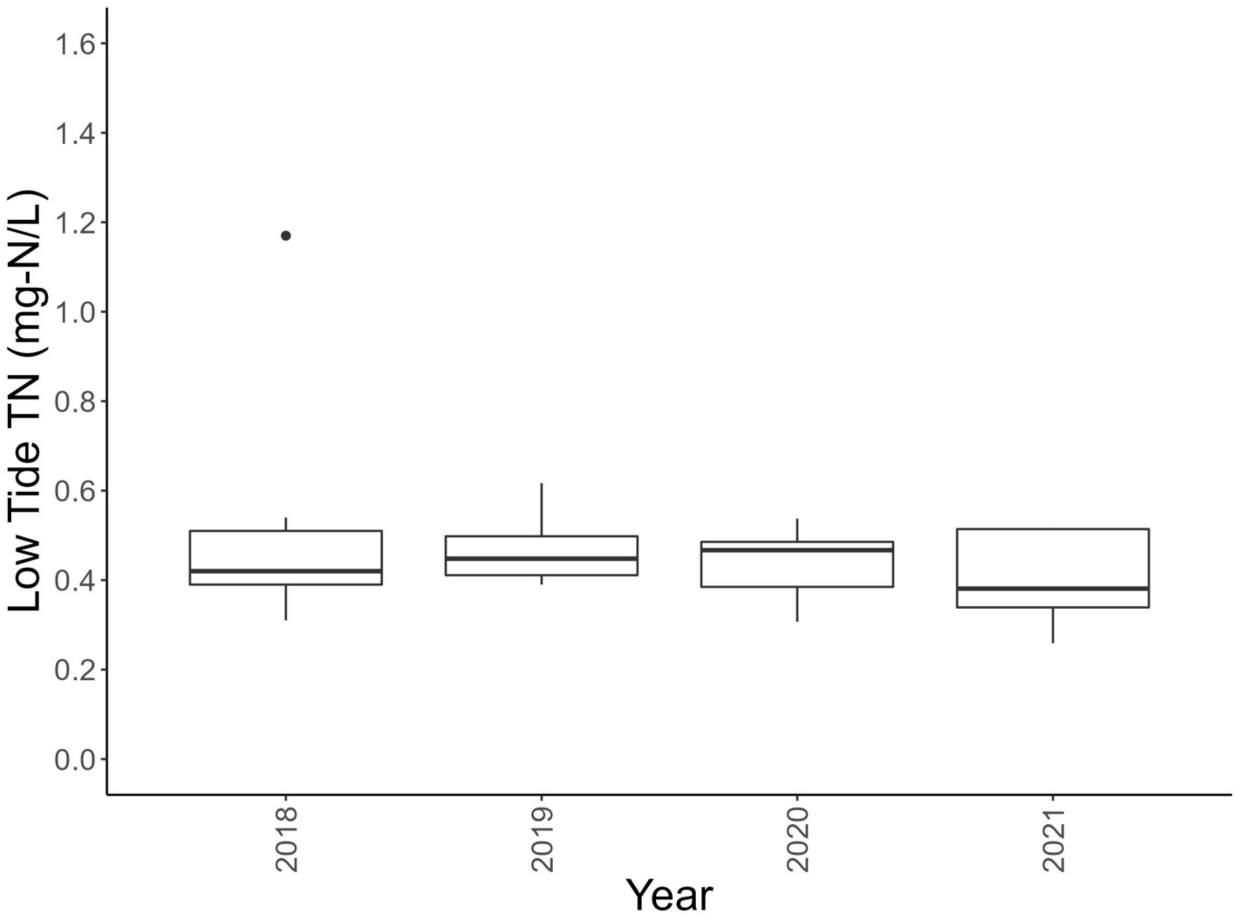

Figure 8.21: Total nitrogen (TN) at the Hampton River Station in the Hampton-Seabrook Estuary. Box and whisker plots show TN concentrations (collected monthly at low tide) between 2018 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Jackson Estuarine Laboratory, UNH***

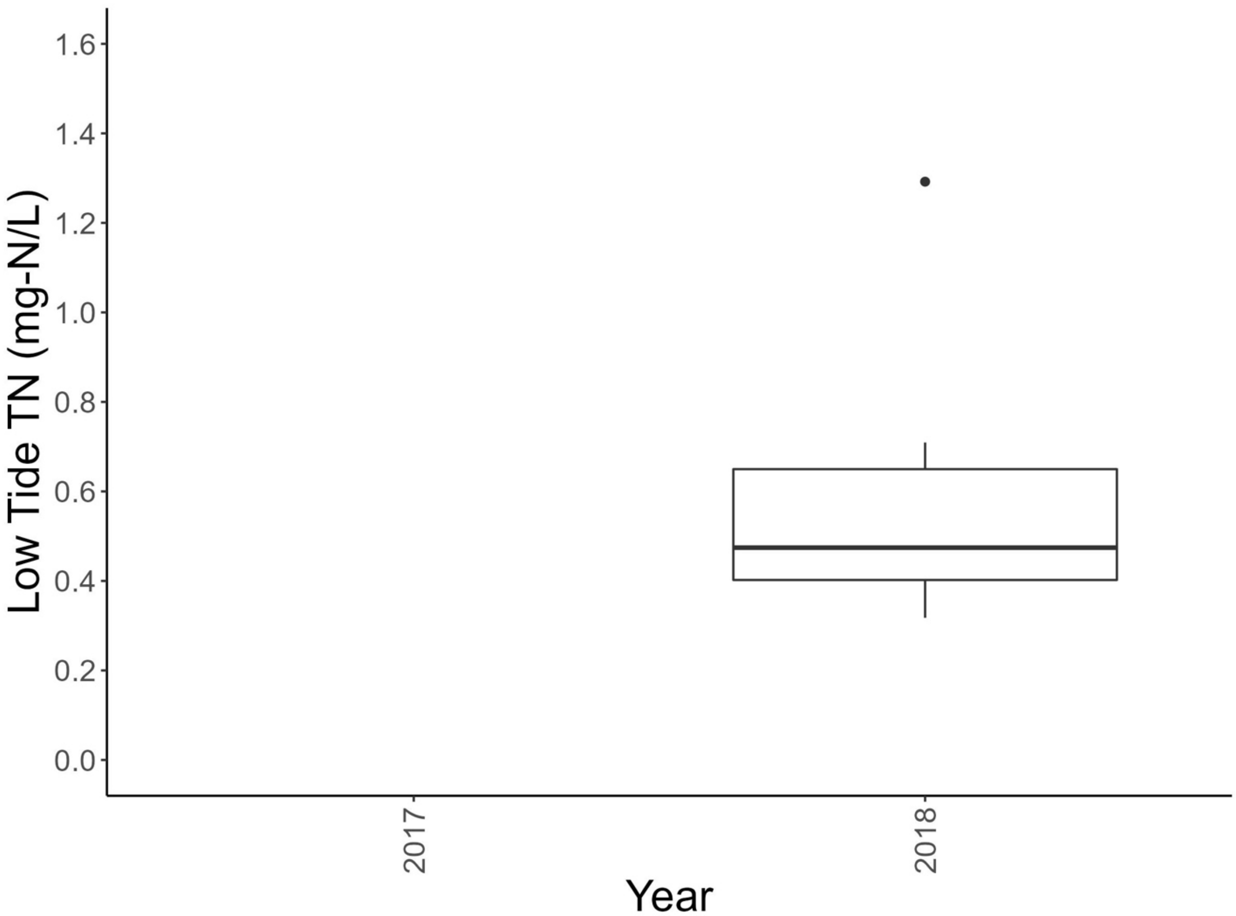

Figure 8.22: Total nitrogen (TN) at the Bellamy River Station. Box and whisker plots show TN concentrations collected monthly at low tide in 2018. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Jackson Estuarine Laboratory, UNH***

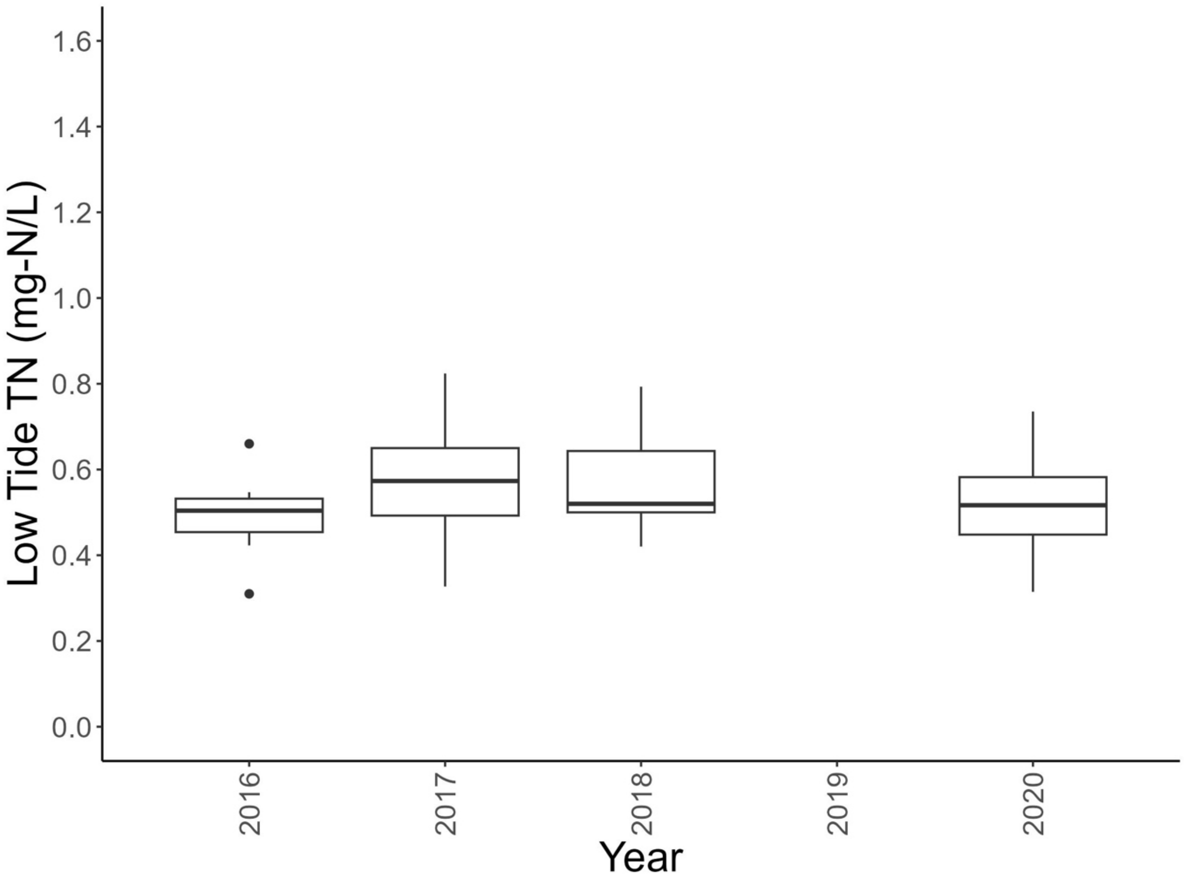

Figure 8.23: Total nitrogen (TN) at the Cocheco River Station. Box and whisker plots show TN concentrations collected monthly at low tide between 2016 and 2020. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. *Data Source: Jackson Estuarine Laboratory, UNH*

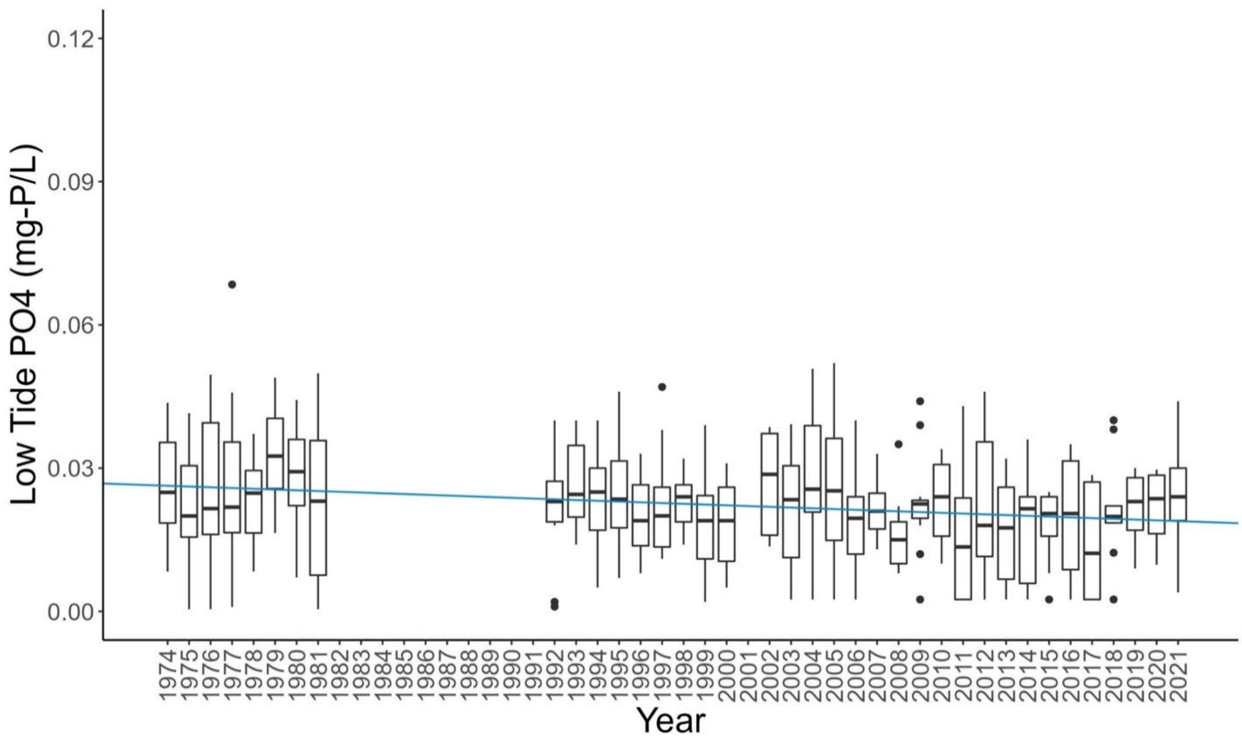

Figure 8.24: Orthophosphate (PO_4^{3-}) at the Adams Point Station shows a decreasing trend over time based on data collected at low tide between 1974 and 2021 and shown as box and whisker plots. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. Blue line represents significant linear regression through all data points. ***Data Source: Jackson Estuarine Laboratory, UNH***

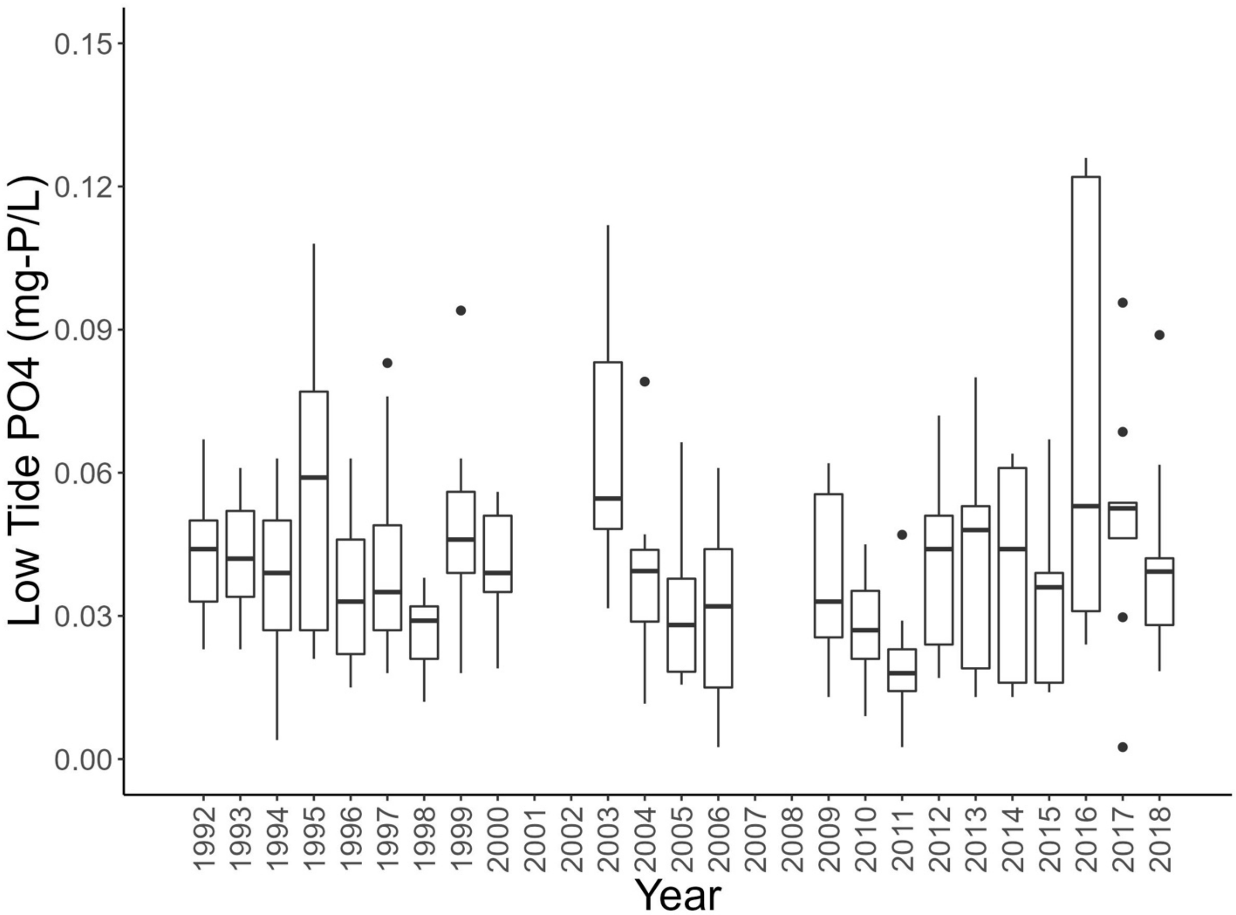

Figure 8.25: Orthophosphate (PO_4^{3-}) at the Chapman's Landing Station (along the Squamscott River). Box and whisker plots show concentrations based on data collected at low tide between 1992 and 2018. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

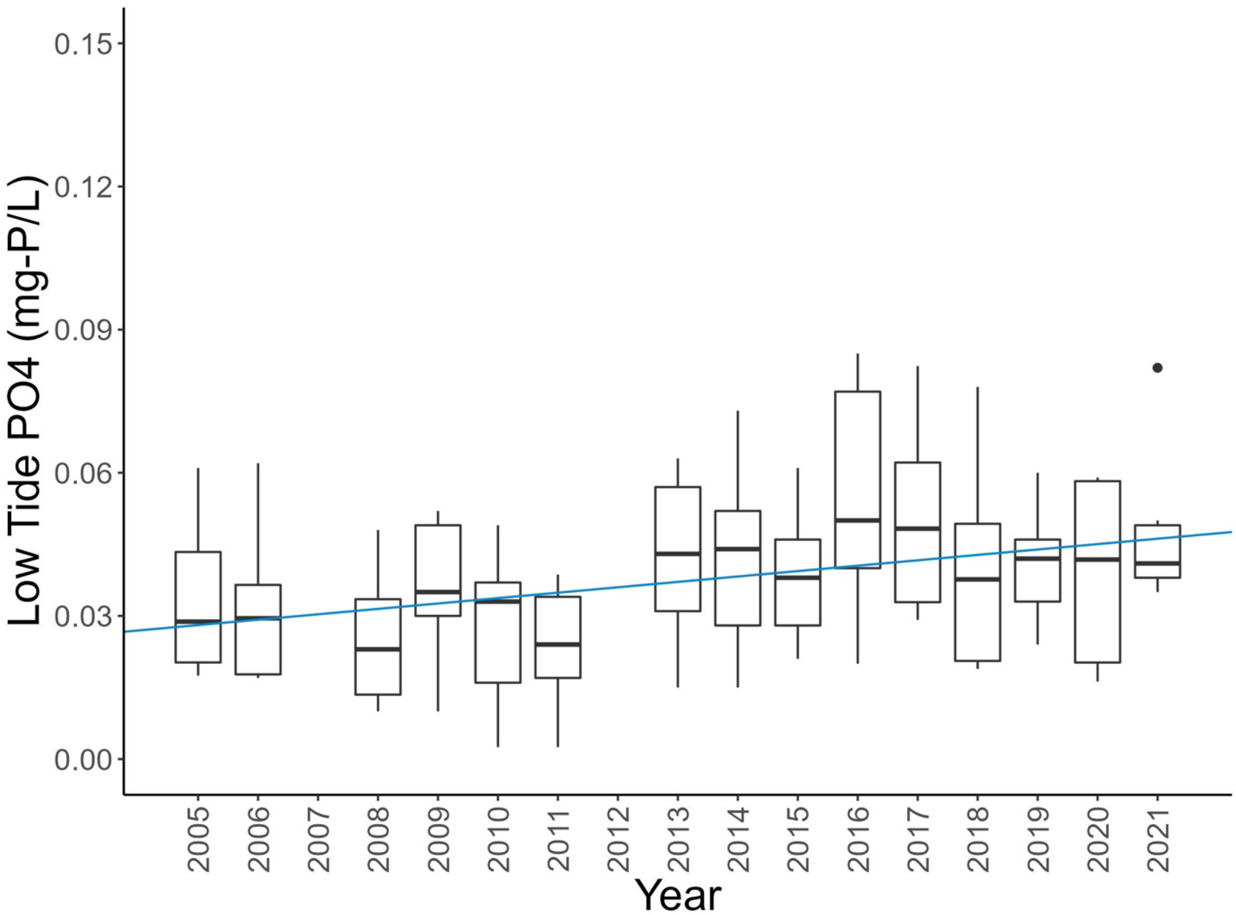

Figure 8.26: Orthophosphate (PO_4^{3-}) at the Squamscott River Station shows an increasing trend over time based on data collected at low tide between 2005 and 2021 and shown as box and whisker plots. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. Blue line represents significant linear regression through all data points. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

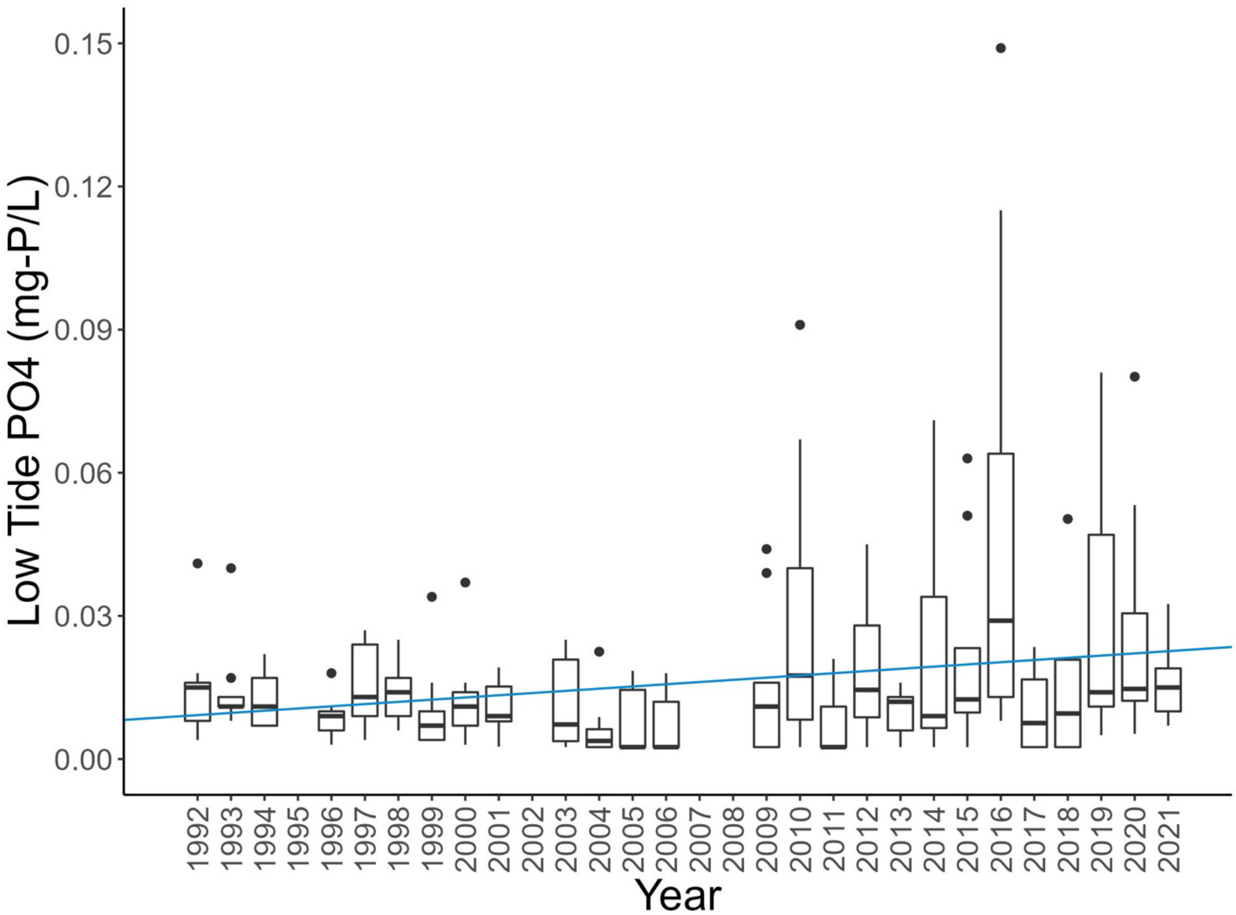

Figure 8.27: Orthophosphate (PO_4^{3-}) at the Lamprey River Station shows an increasing trend over time based on data collected at low tide between 1992 and 2021 and shown as box and whisker plots. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. Blue line represents significant linear regression through all data points. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

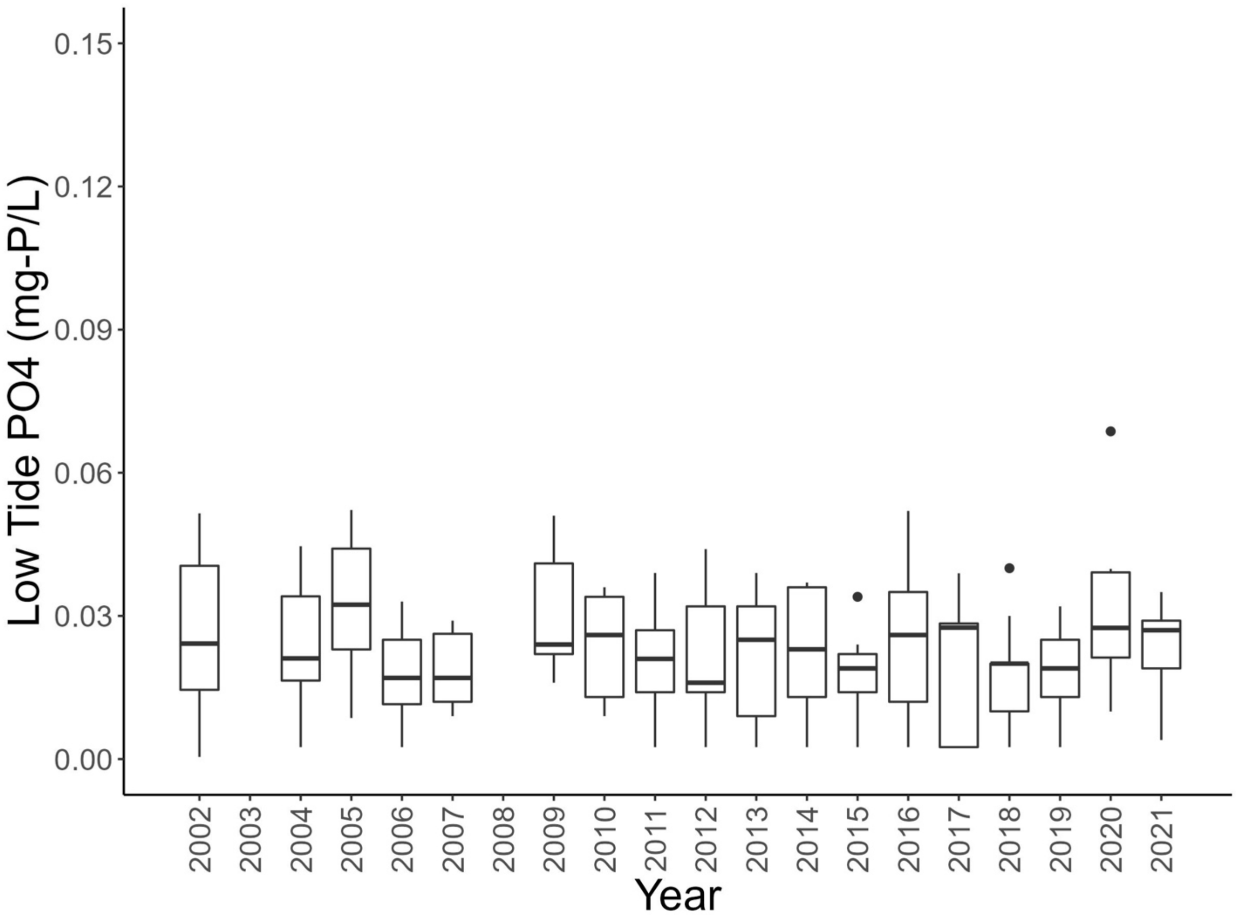

Figure 8.28: Orthophosphate (PO_4^{3-}) at the Great Bay Station. Box and whisker plots show PO_4 concentrations over time based on data collected at low tide between 2002 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. Blue line represents significant linear regression through all data points. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

Table of Contents

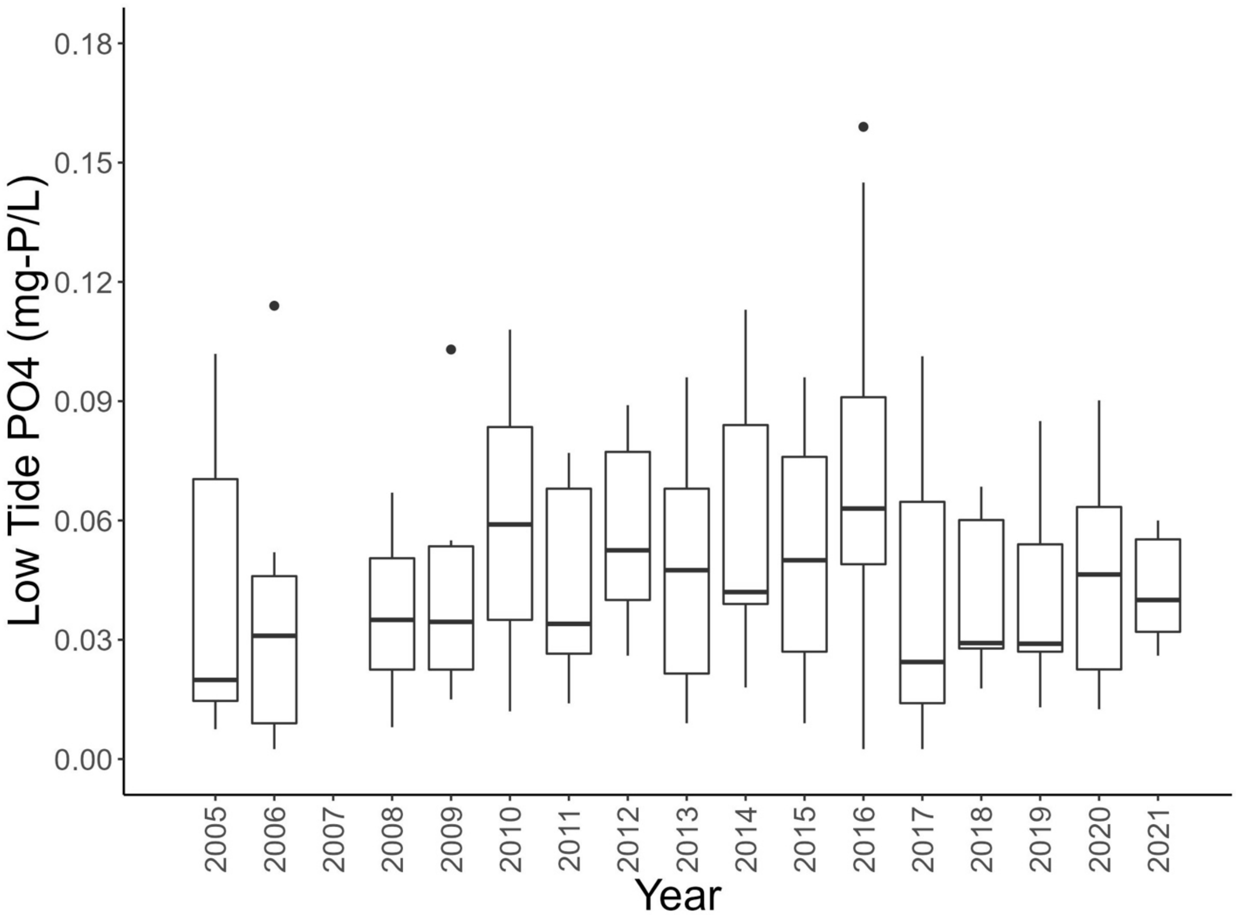

Figure 8.29: Orthophosphate (PO_4^{3-}) at the Oyster River Station. Box and whisker plots show PO_4 concentrations over time based on data collected at low tide between 2005 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH***

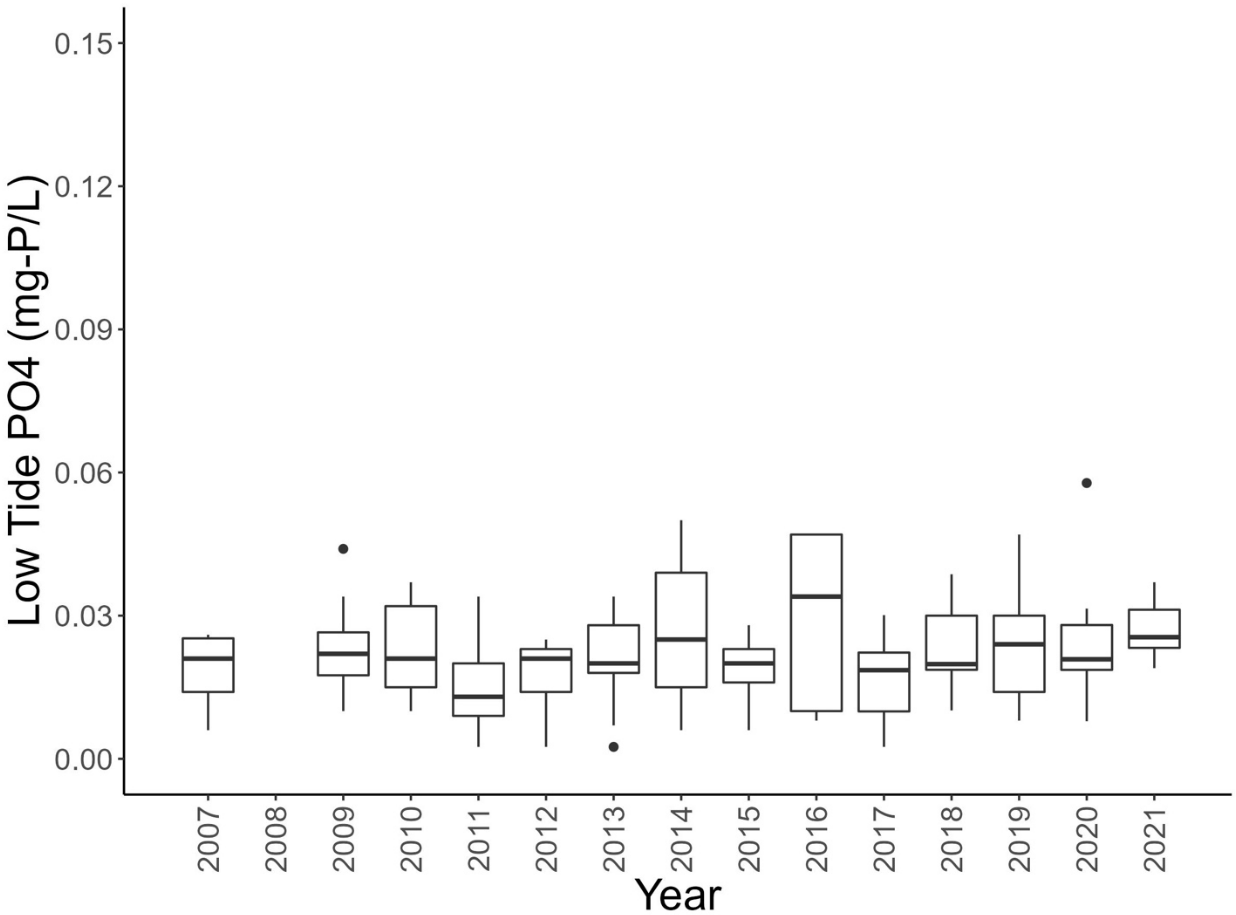

Figure 8.30: Orthophosphate (PO_4^{3-}) at the Upper Piscataqua River Station. Box and whisker plots show PO_4 concentrations over time based on data collected at low tide between 2007 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Jackson Estuarine Laboratory, UNH***

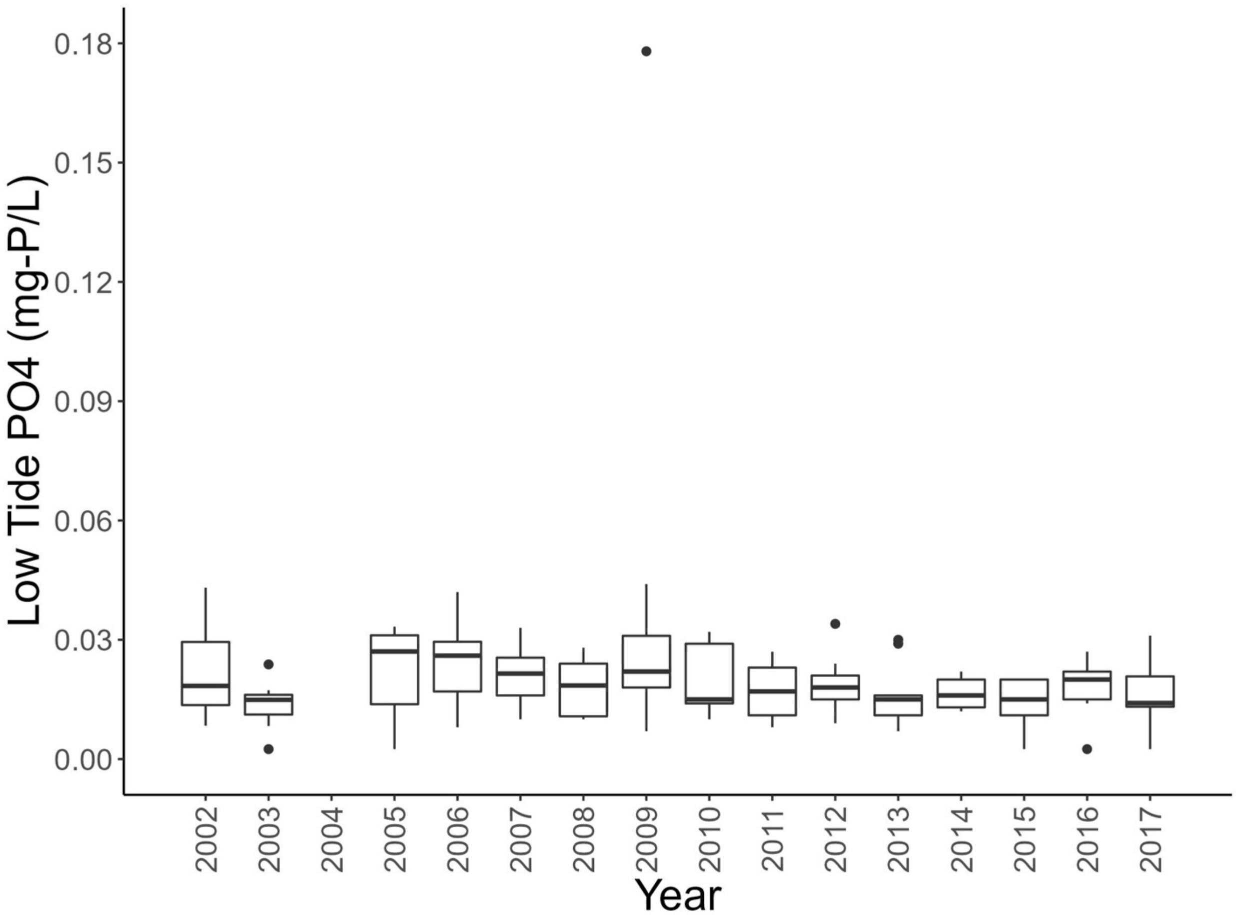

Figure 8.31: Orthophosphate (PO_4^{3-}) at the Coastal Marine Lab (Portsmouth Harbor) Station. Box and whisker plots show PO_4 concentrations over time based on data collected at low tide between 2002 and 2017. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Jackson Estuarine Laboratory, UNH***

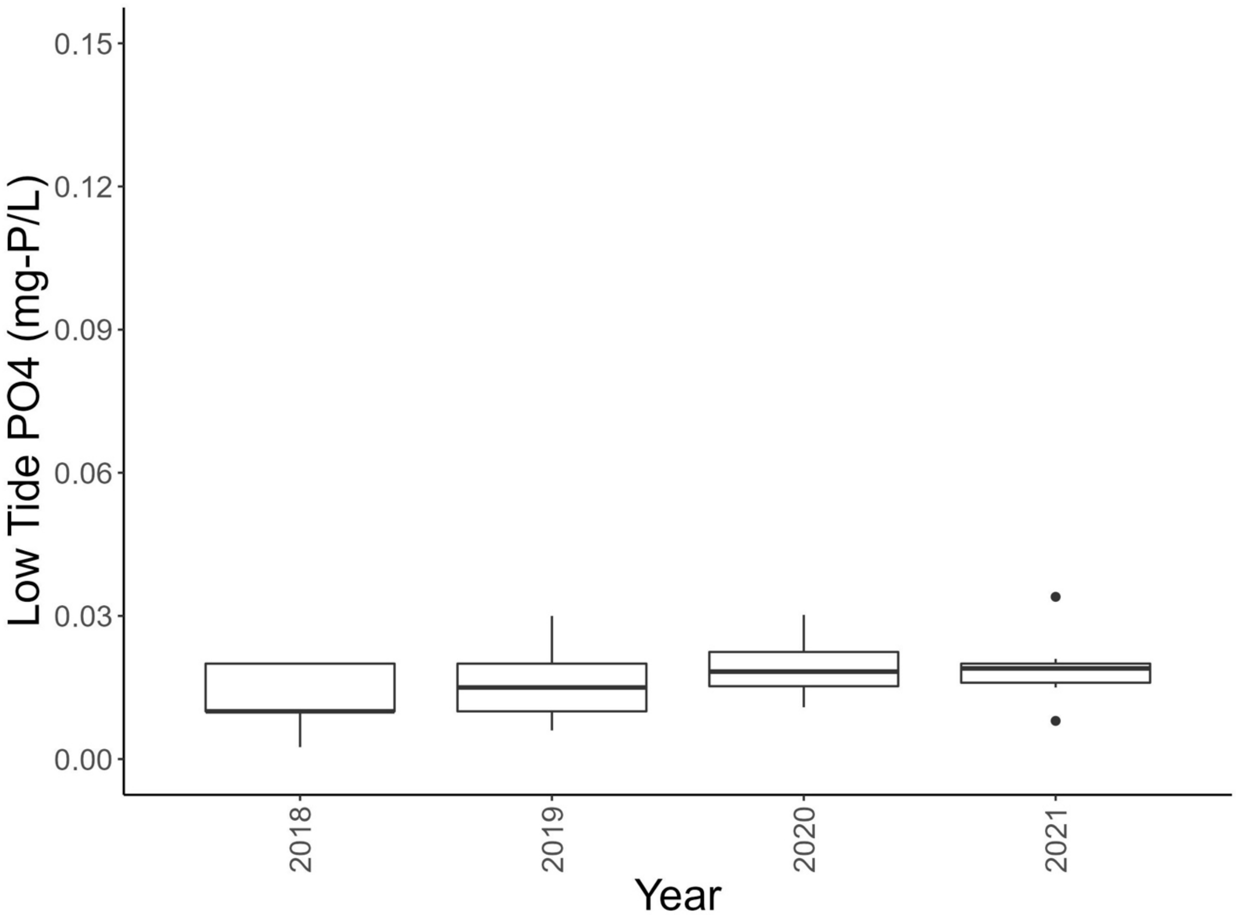

Figure 8.32: Orthophosphate (PO_4^{3-}) at the Hampton River Station in the Hampton-Seabrook Estuary. Box and whisker plots show PO_4 concentrations over time based on data collected at low tide between 2018 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Jackson Estuarine Laboratory, UNH***

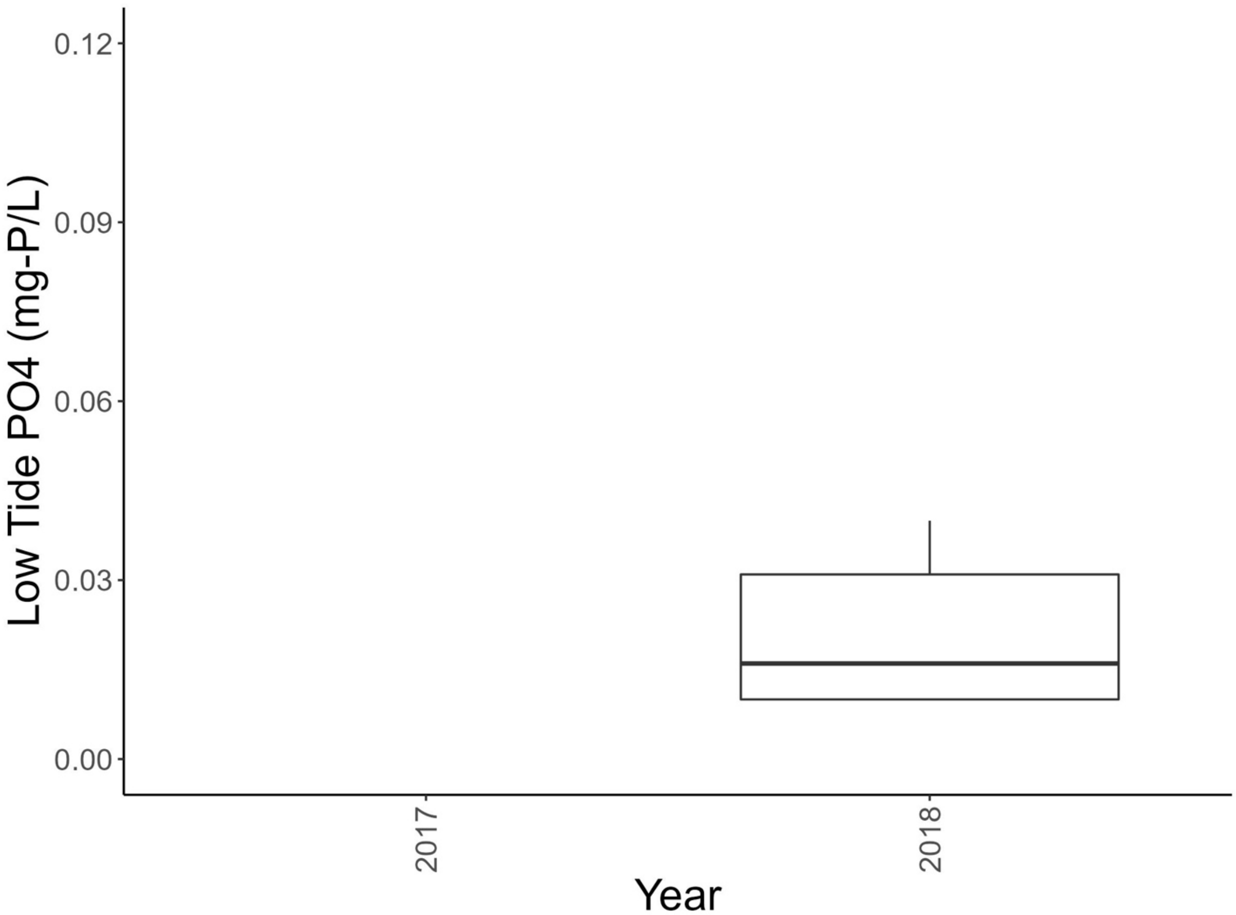

Figure 8.33: Orthophosphate (PO_4^{3-}) at the Bellamy River Station. Box and whisker plots show PO_4 concentrations over time based on data collected at low tide in 2018. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Jackson Estuarine Laboratory, UNH***

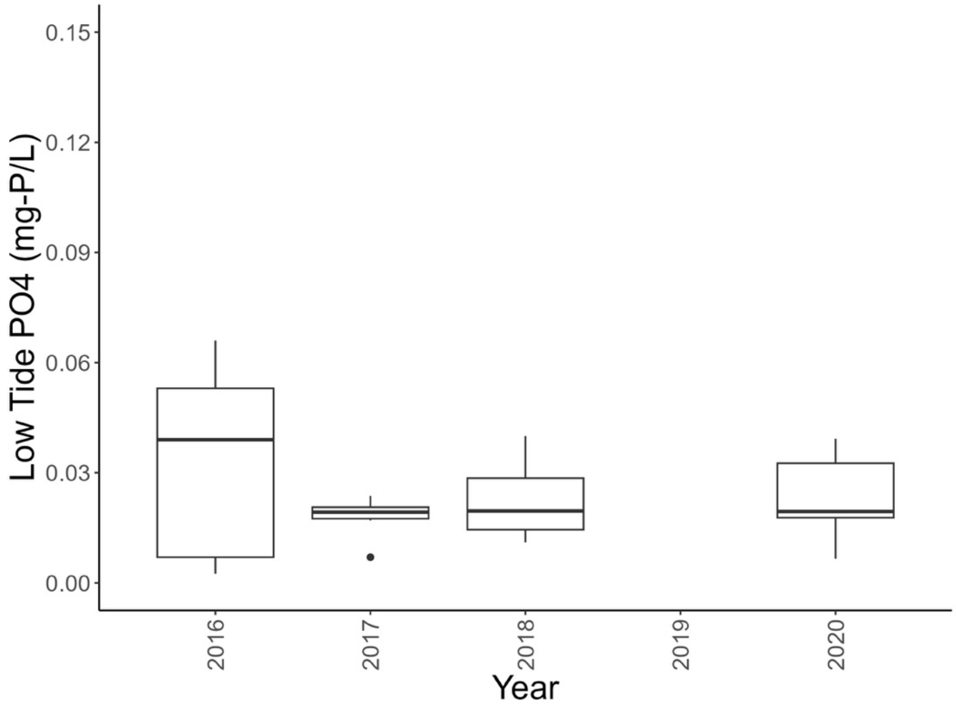

Figure 8.34: Orthophosphate (PO_4^{3-}) at the Cocheco River Station. Box and whisker plots show PO_4 concentrations over time based on data collected at low tide between 2016 and 2020. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years are omitted due to missing data or an insufficient number of measurements that year. ***Data Source: Jackson Estuarine Laboratory, UNH***

Acknowledgements and Credit

Anna Mikulis (UNH), with contributions from Kalle Matso (PREP) Easton White (UNH) and Jody Potter (UNH).

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Whitall D, Mason A, Pait A. Nutrient Dynamics in Coastal Lagoons and Marine Waters of Vieques, Puerto Rico. *Tropical Conservation Science*. 2012;5(4):495-509. doi:10.1177/194008291200500407

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Phytoplankton

Methods and Data Sources

Trend analysis for chlorophyll-a was performed at the following stations to understand changing chlorophyll trends over time:

- GRBAP (Adams Point)
- GRBGB (Great Bay)
- GRBSQ (Squamscott River)
- GRBLR (Lamprey River)
- GRBOR (Oyster River)
- GRBUPR (Upper Piscataqua River)
- HHHR (Hampton River)

The data was aggregated by sampling year and graphed as a box-and-whisker plot to examine the spread of data across the year. Linear regression of chlorophyll concentration over time was used to test for long-term trends at each geographic location. Trends were considered significant if the slope coefficient of the year variable was significant at the $p<0.05$ level.

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

Additional Discussion

Looking closer at data from Adams Point, which is experiencing significant increases in chlorophyll-a concentration over time, the annual maximum and minimum chlorophyll concentrations were examined (Figure 12.7). *(Note that figure numbers are continued from the State of Our Estuaries Report.)*

These values can provide some insight into how chlorophyll values are changing over time at this location (e.g., to discern whether only the minimum values increasing). Interestingly, both the annual maximum and minimum chlorophyll concentrations are trending significantly higher over time. Despite these significant trends, the mechanisms responsible for this increase are not clear, and the number of days of ‘poor’ chlorophyll concentrations experienced in this area on an annual basis are low.

Additional Data Figures

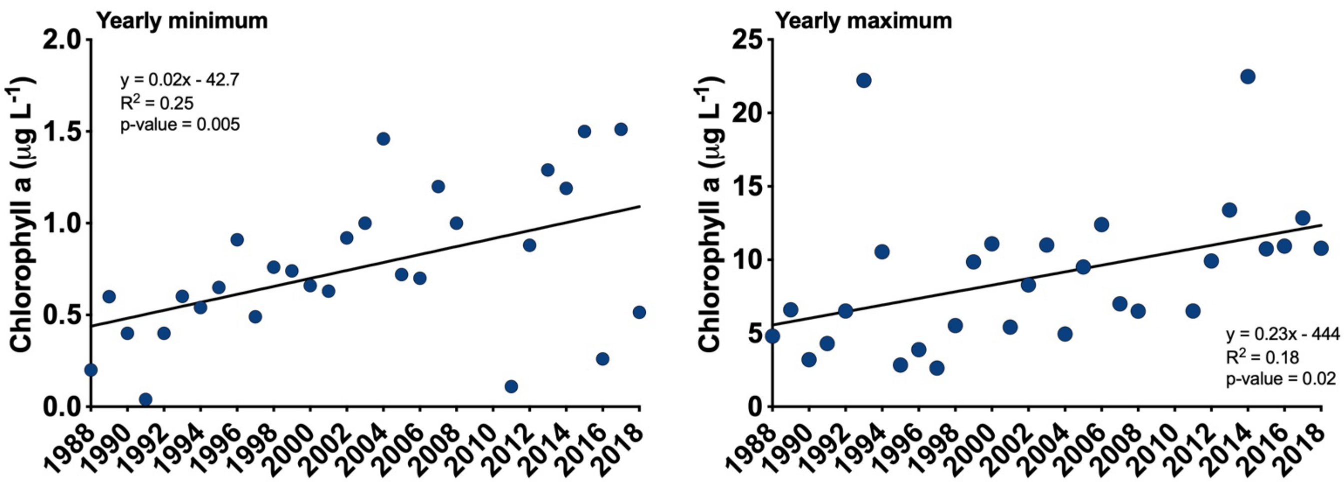

Figure 12.7 The annual minimum (left) and maximum (right) chlorophyll-a concentrations (ug L-1) measured at Adams Point during sampling that takes place primarily from April-October. The solid line on each graph is the line of best fit from a linear regression analysis. The equation, R^2, and p-value for that linear regression are found on each graph. Both minimum and maximum annual chlorophyll-a concentrations increase over time, suggesting at this location that overall chlorophyll concentrations are higher at present relative to the beginning of the time series in 1988.

Acknowledgements and Credit

Elizabeth Harvey (UNH).

Total Suspended Solids

Please note that this section contains both "Methods and Data Sources" as well as "Additional Discussion" and additional tables and figures.

Methods and Data Sources

Trend analysis for total suspended solids was performed at the following stations:

- 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)
- HHHR (Hampton River)
- GRBBR (Bellamy River)
- GRBCR (Cocheco River)

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). Only years with at least seven months of data were included in statistical 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. Both the full dataset and the annual median concentrations were regressed against the year variable. Trends were considered significant if the slope coefficient of the year variable was significant at a p-value of 0.05 or less. TSS concentrations greater than 100 mg/L were considered to be outliers and were excluded from analysis. The only exception was the Squamscott River (GRBSQ) station, where high TSS concentrations exceeding 100 mg/L have been observed throughout the 20-year monitoring period. Only 16 values across two stations had sampling events with high TSS concentrations, with 14 of those occurring at the Squamscott River Station.

For more information on sample collection and analysis methods, please see the most recent Quality Assurance Project Plan (https://scholars.unh.edu/prep/419).

Data for this indicator were provided by UNH and the Great Bay Estuary Water Quality Monitoring Program.

Additional Discussion

The full summary table for trends in suspended solids across 11 different monitoring stations demonstrates the large range in observed concentrations (Table 13.2). Annual median values between 2016 and 2021 ranged from 3.6 mg/L to as high as 54.1 mg/L. River monitoring stations exhibited larger variability year to year, especially in the Lamprey, Oyster, Squamscott, and Cocheco Rivers. No other statistically significant temporal trends were evident in any of the additional stations (Coastal Marine Lab, Cocheco River, Bellamy River, Chapmans Landing).

(Note that table and figure numbers are continued from the State of Our Estuaries Report.)

For the Lamprey River Station, suspended solids have shown an increasing trend since 1992 (Figure 13.6). Although in 2021, the annual median concentration decreased 4.5x from the decadal high of 16.1 mg/L in 2020. In the most recent 10 years, intra-annual variability in suspended solid concentrations appears larger than in the 1990s or early 2000s. This pattern may relate to increased climate variability observed in recent years, with two significant droughts occurring in 2016 and 2020 (*Rockingham County, NH | U.S. Drought Monitor*, 2023) and increasing annual precipitation totals in the early 2000s and 2010s (Kunkel 2022). The Oyster River Station shows a similar increasing linear trend in suspended solids over time (Figure 13.7).

For the Squamscott River Station, there were 14 separate suspended solids measurements that exceeded 100 mg/L (Figure 13.8). These values spanned a seasonal range from April to September and encompassed years from 2006 to 2021. Outlier concentrations reached a high of 275.7 mg/L in May of 2009 and a low of 103.6 mg/L in September of 2021. Due to the random dispersion of high suspended solids concentrations across the full range of the Squamscott River dataset, it was decided to leave the outliers in for analysis. It is worth noting that if the 14 outliers are removed, then there is a significant increasing trend in suspended solids concentrations over time ($p < 0.05$). The last three years of data (2019-2021) show a steady increase in suspended solids from an annual median of 29.0 mg/L to 54.1 mg/L. At Chapman's Landing (Figure 13.11), a site located upriver from the Squamscott River Station, suspended solids show no linear temporal trend over time but do exhibit high variability both within and between years.

Suspended solids at both the Bellamy (Figure 13.9) and Cocheco Rivers (Figure 13.10) showed no temporal trend over time, possibly due to the small sampling size of only a few years. Annual median suspended solids concentrations are comparable at these two stations, with the Cocheco exhibiting slightly lower annual values than the Bellamy. Comparison of the entire TSS monitoring period for these two rivers reveals a median concentration of 13.2 mg/L for the Cocheco and an almost doubled median concentration (21.7 mg/L) for the Bellamy River.

At the Coastal Marine Lab (Figure 13.12) in Portsmouth Harbor, concentrations of suspended solids are comparable to that of Adams Point and Great Bay Monitoring Stations. Between 2002 and 2016, the overall median concentration was 16.1 at the Coastal Marine Lab. This is only slightly larger than the overall median at Adams Point (15.0 mg/L) and slightly smaller than the median for the Great Bay Station (17.1 mg/L).

Additional Data, Tables, and Figures

Table 13.2: Total suspended solid (TSS) trends and median values at ten stations in the Great Bay Estuary and one station in the Hampton-Seabrook Estuary. Trends and values reflect low tide sampling only.

Location	Significant change in TSS concentration?	Dates for Trends in Column to Left	Range of Median Values 2016 -2021 (mg/L)	Range of Maximum Values 2016-2021 (mg/L)
Adams Point	Yes (increase)	1989-2021	15.7 – 21.6	25.2 – 50.4
Great Bay	Yes (increase)	2002-2021	16.1 – 23.2	24.6 – 96.9
Lamprey River	Yes (increase)	1992-2021	3.6 – 16.1	12.9 – 77.1
Oyster River	Yes (increase)	2004-2021	17.8 – 36.8	38.2 – 95.4
Squamscott River	No	2004-2021	29.0 – 54.1	96.9 – 217.9
Upper Piscataqua River	No	2007-2021	12.0 – 14.2	15.7 – 24.6
Hampton River	No	2018-2021	18.9 – 22.1	28.6 – 42.5
Coastal Marine Lab	No	2002-2016	20.7	25.4
Cocheco River	No	2016-2020*	8.6 – 18.7	22.1 – 33.6
Bellamy River	Insufficient data	2018	21.7	64.1
Chapmans Landing	No	1989-2018	31.2 – 37.0	52.1 – 65.0

*no sampling was done at this site in 2019

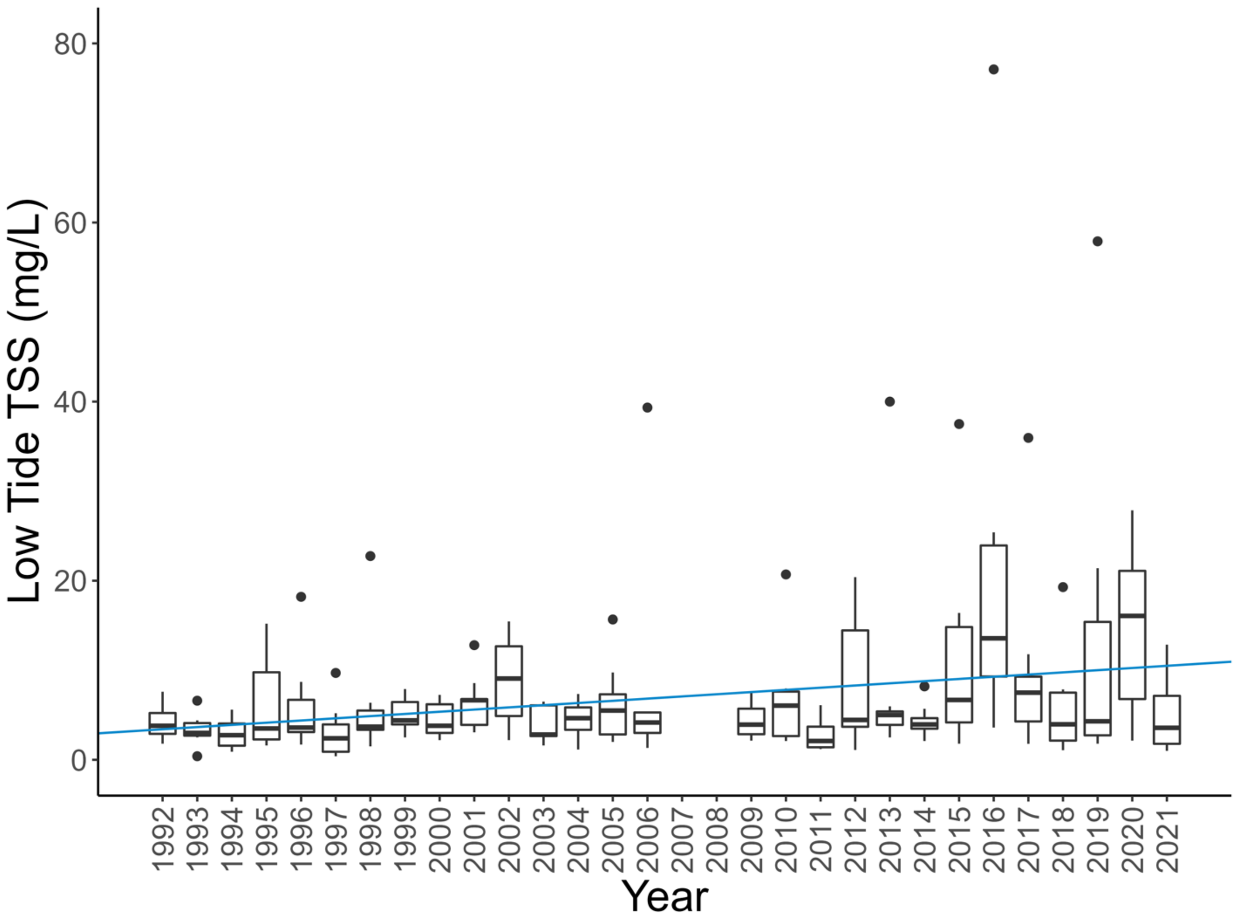

Figure 13.6: Total suspended solids at Lamprey River Station. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years omitted due to insufficient data.
Data Source: Jackson Estuarine Laboratory, UNH

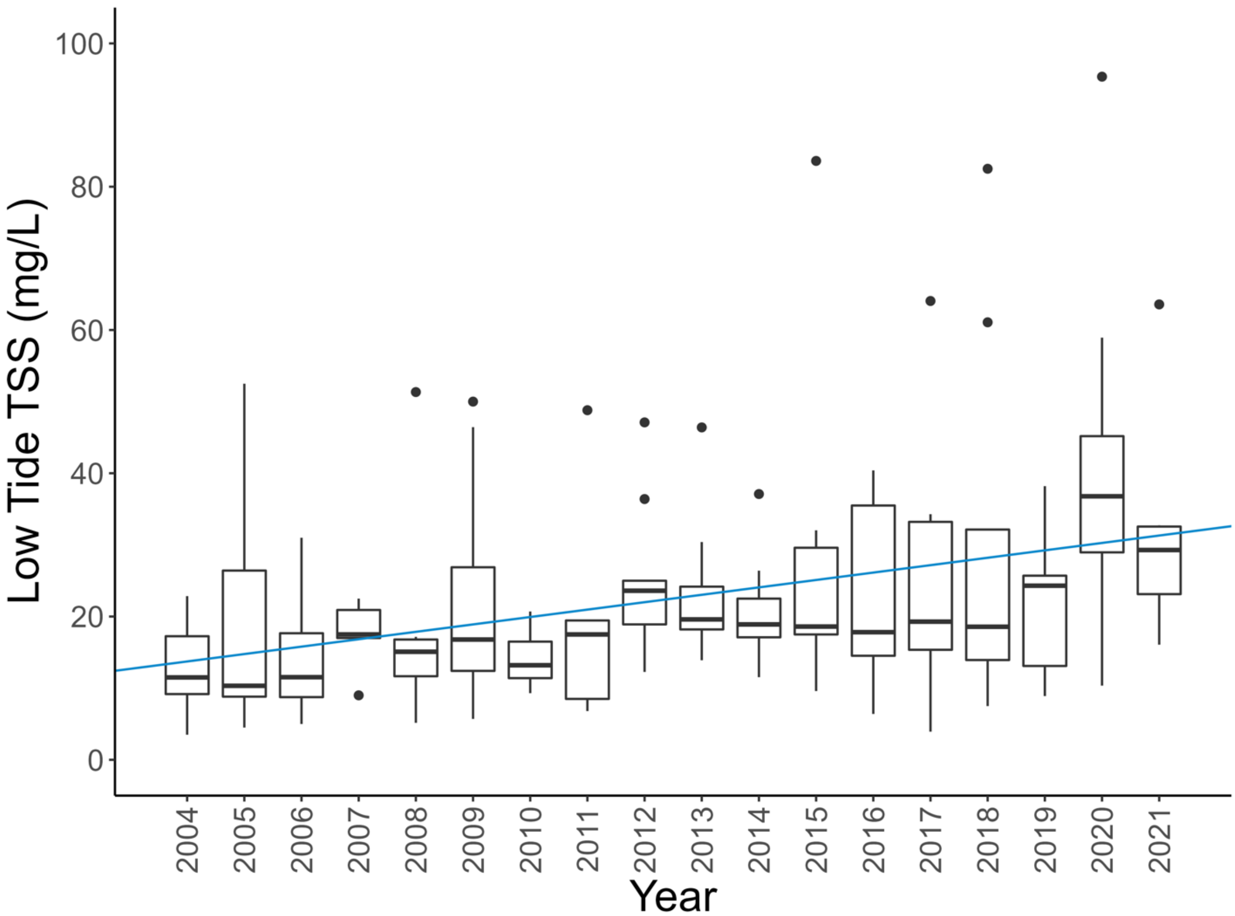

Figure 13.7: Total suspended solids at Oyster River Station. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points.
Data Source: Jackson Estuarine Laboratory, UNH

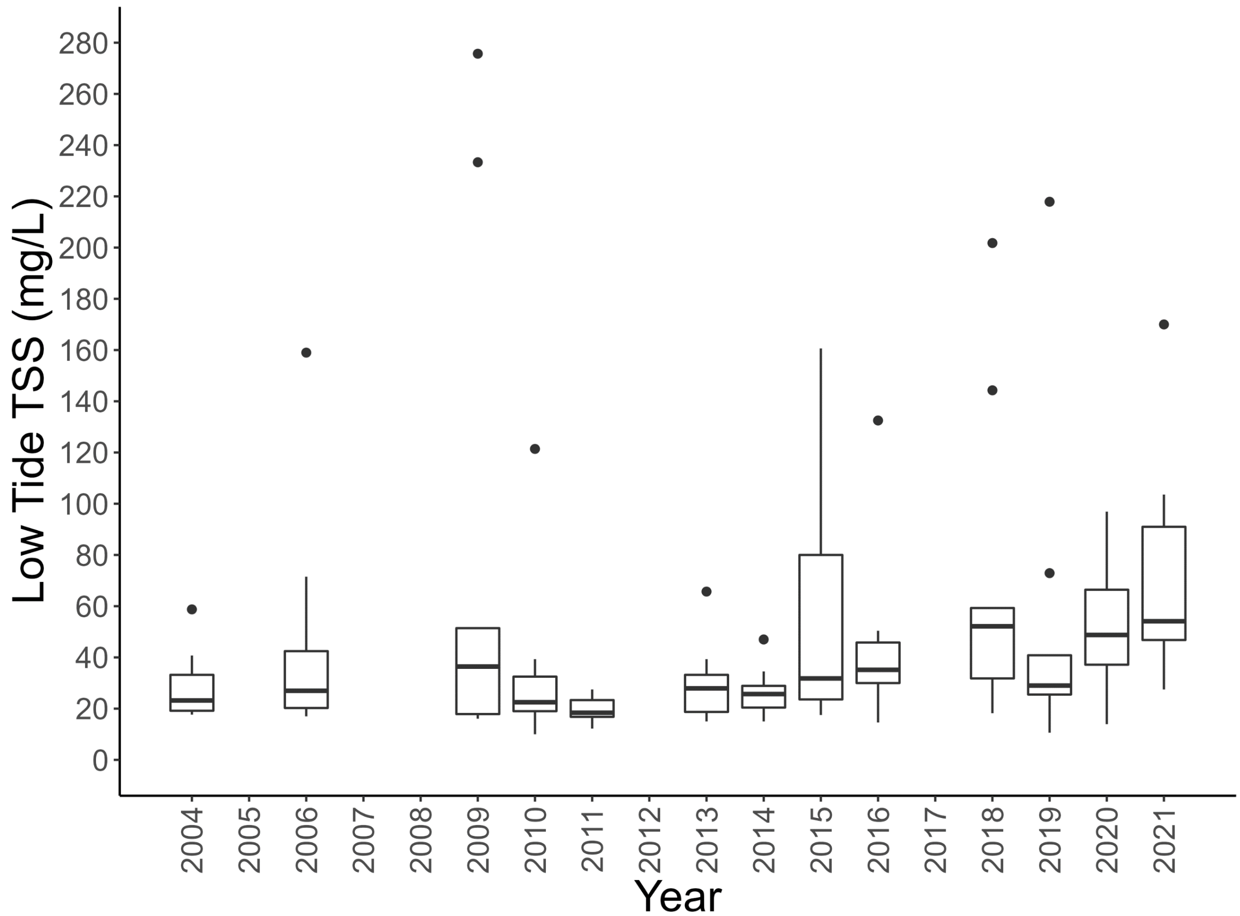

Figure 13.8: Total suspended solids at Squamscott River Station. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years were omitted due to insufficient or missing data.
Data Source: Jackson Estuarine Laboratory, UNH

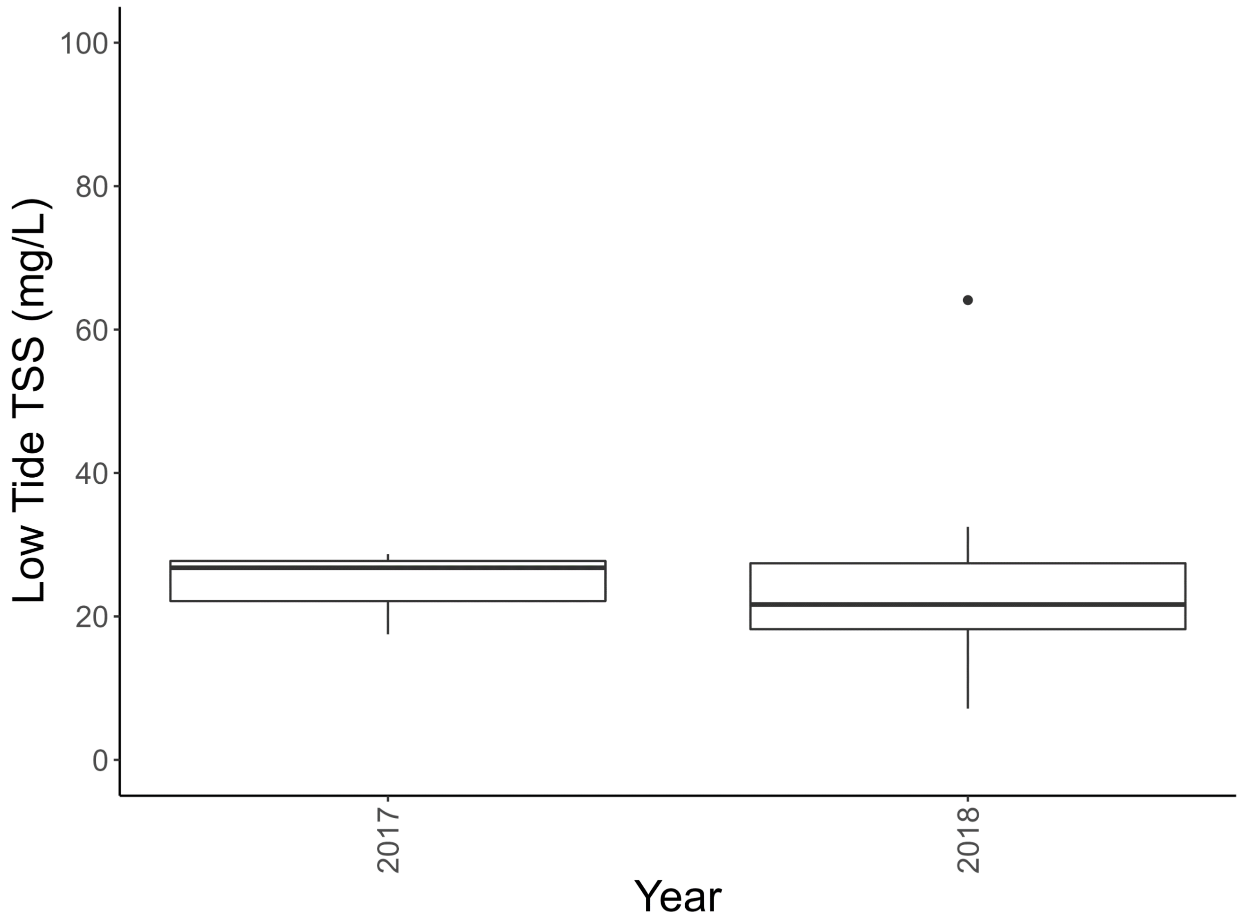

Figure 13.9: Total suspended solids at Bellamy River Station. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Note 2017 has only 3 data points.
Data Source: Jackson Estuarine Laboratory, UNH

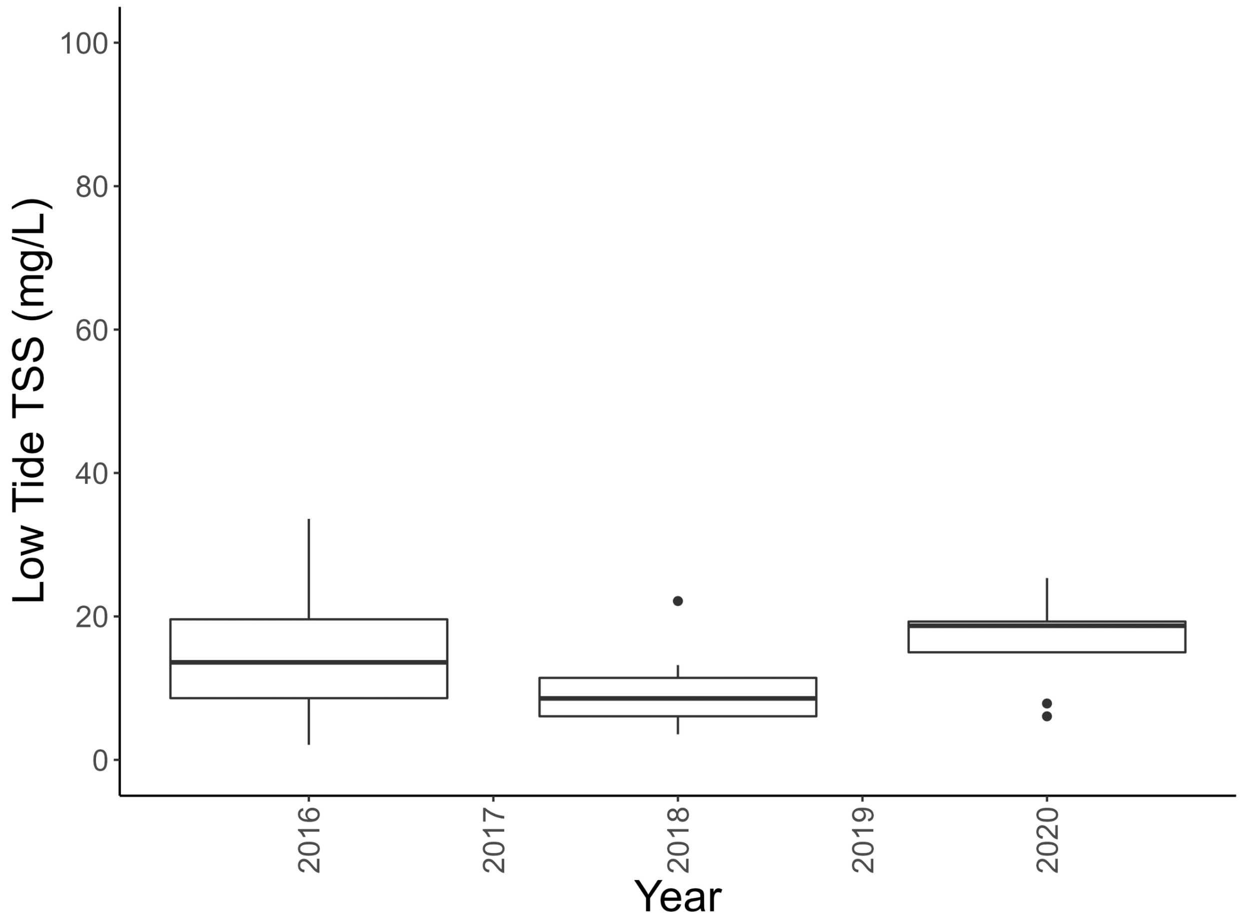

Figure 13.10: Total suspended solids at Cocheco River Station. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years omitted due to insufficient data.
Data Source: Jackson Estuarine Laboratory, UNH

Table of Contents

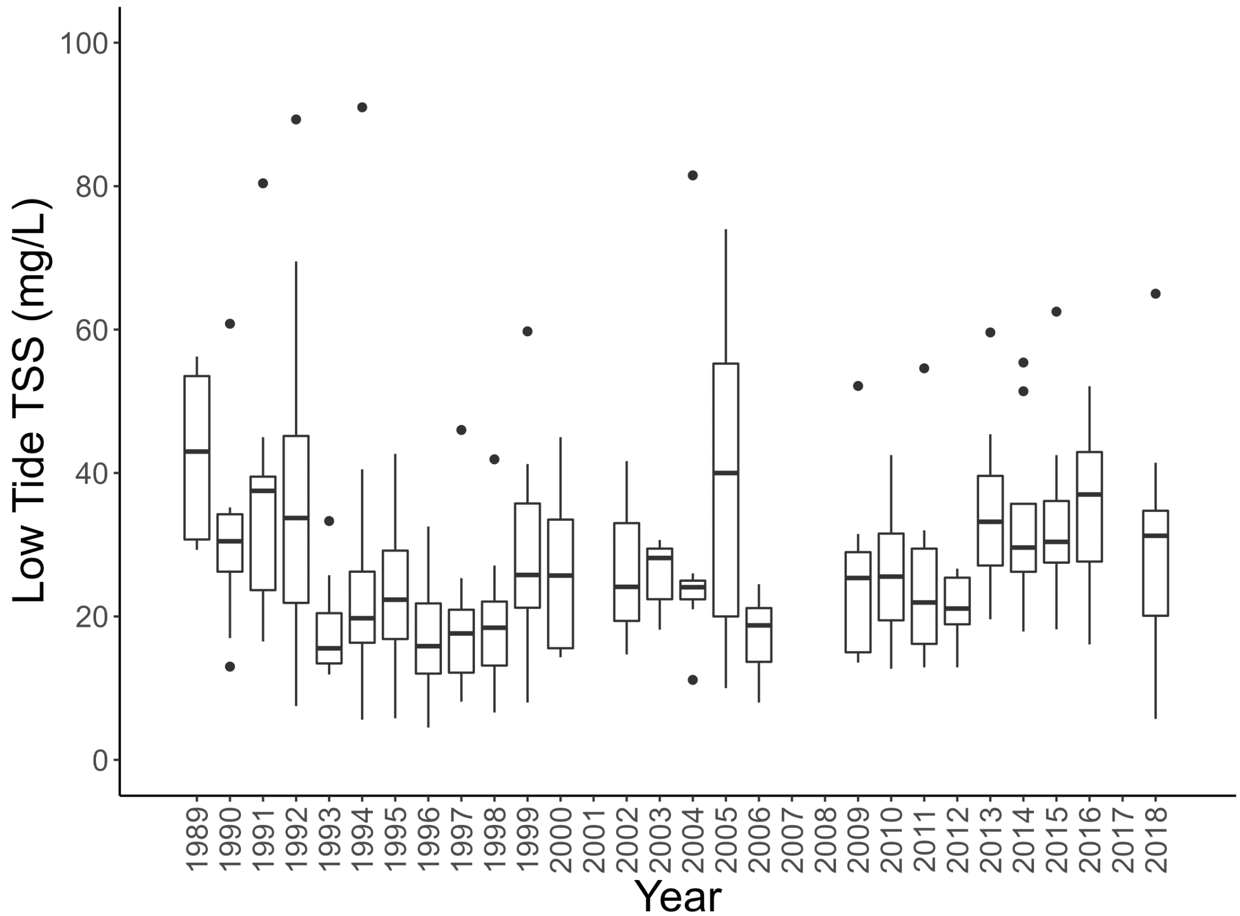

Figure 13.11: Total suspended solids at the Chapman's Landing Station. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years omitted due to insufficient data.
Data Source: Jackson Estuarine Laboratory, UNH

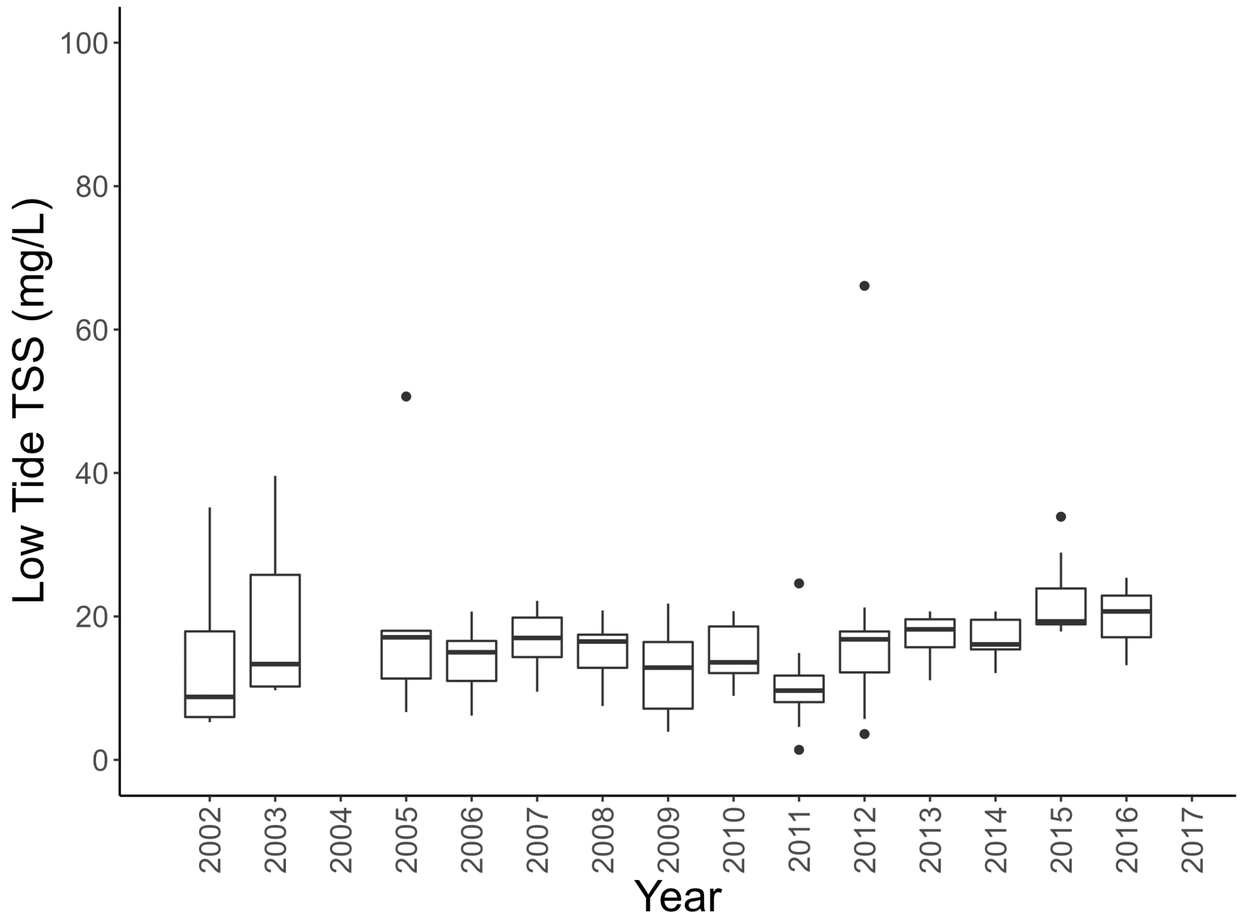

Figure 13.12: Total suspended solids at the Coastal Marine Lab (Portsmouth Harbor) Station. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass values within 1.5*inter-quartile range (99.7% of the data). "Outliers" are shown as individual points. Some years omitted due to insufficient data.
Data Source: Jackson Estuarine Laboratory, UNH

Acknowledgements and Credit
Anna Mikulis (UNH) with contributions from Miguel Leon (UNH), Kalle Matso (PREP), Easton White (UNH), Lara Martin (UNH), and Tom Gregory (UNH).

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Bacteria

Additional Discussion

In addition to the data in Figures 15.2 and 15.3 (found in State of Our Estuaries Report), three different fecal indicator bacteria were measured at both sites, including fecal coliforms, *E. coli*, and enterococci. The *E. coli* concentrations at Adams Point show very similar and slightly lower concentrations compared to fecal coliforms, with a similar decreasing trend (Figure 15.4). Enterococci concentrations at Adams Point were rarely above (1% of samples) the State standard of 104/100 ml but showed no temporal trend (Figure 15.5). Fecal coliform and *E. coli* concentrations in the Lamprey River were much higher than at Adams Point but also showed a decreasing trend from elevated concentrations through the 1990s (Figures 15.6 & 15.7). The annual geometric mean fecal indicator concentrations at low tide at these two sites and at sites in the Cocheco River (CR) and the upper Piscataqua River (UPR) showed wide differences between sites and years from 2020 to 2022 (Figure 15.5). CR and UPR were used to allow comparison of indicator levels at sites where sampling and analyses have occurred in the past three years, except that sampling did not occur in 2021 at CR. All three indicators were relatively low at Adams Point and at UPR, with levels increasing in 2022 at UPR. In comparison, indicator levels were substantially higher in the Lamprey and Cocheco rivers, and levels of all three indicators were higher at both of these tidal river sites during 2022 compared to 2020. These findings are consistent with the NH Shellfish Program classification for harvesting shellfish including proximity to wastewater treatment facility outfalls.

The use of bacterial indicators of fecal contamination has been a long-term and effective tool for managing public health risks for a variety of uses of surface waters. The levels of these indicators dictate shellfish harvest classifications and the basis for posting warnings to swimmers and other recreational users about potential health risks, but they provide no information about the source(s) of the detected contamination. An ongoing study involves the use of a commonly used Microbial Source Tracking (MST) method to show what types of fecal-borne bacteria sources are present in the Lamprey River watershed, from the tidal waters in Newmarket to Raymond, NH (Jones, 2021; 2022). MST is useful because it provides information on what is causing detected contamination, and thus allows for focusing resources to mitigate actual sources of pollution. In the ongoing study in the Lamprey River watershed, sources are identified using two methods for detecting source-specific genetic markers: one method, Polymerase Chain Reaction (PCR) detected presence/absence of 9 different sources: human, bird, mammal, dog, cow, horse, Canada goose, sea gull and ruminants. The second method, a semi-quantitative PCR (qPCR) detected relative levels of 3 sources: human, bird, and mammal.

Concentrations of fecal indicator bacteria (*E. coli*, enterococci) were generally low and below State water quality standard thresholds (Table 15.1). At the freshwater sites (Sites 2-6), the *E. coli* State standard was exceeded 7 times (17.5% of samples) at all but Site 6. *E. coli* concentrations exceeded the water quality standard in 7 of the 8 samples at Site 1 but this contamination had no effect on the upstream freshwater sites. The enterococci water quality standard for tidal water recreational use was exceeded 5 times (62.5%) at Site 1. Enterococci levels in the freshwater portion of the watershed were always below the water quality standard, suggesting that the higher level contamination at the tidal site was from nearby sources. These

Table of Contents

results are consistent with the long-term monitoring of fecal indicator bacteria in the upper tidal Lamprey River (Figures 15.3, 15.6, 15.7).

The MST analyses showed that all 9 different sources were detected at least once in the watershed (Figure 15.6). The mammal source marker was detected in all samples as it serves as a positive control for the analysis. Bird and dog sources were detected in 39 and 31 of the samples, respectively, with cow and human sources detected in 21 and 12 samples, respectively. The Canada goose, sea gull, other ruminant and horse sources were detected in only 5 or fewer samples. The average number of source types detected were relatively consistent although Site 1 had an average of 5.3 sources per sample date while other sites had between 2.9 and 3.6 sources detected (Table 15.2). Human contamination was detected at each site once, except for Site 1 where it was detected in 7 out of 8 samples (Table 15.2). Data for the human-specific genetic marker using qPCR were related to risk of unacceptable levels of human illness (Boehm et al. 2015). The threshold they reported, 4200 copies of the human marker/100 ml, was exceeded on 6 of the 8 samples dates at Site 1 and once at Site 3 (Table 15.2). These results suggest that human contamination source pollution is consistent and elevated in the vicinity of Site 1. Finally, there was a slight seasonal trend of increasing numbers of sources detected at all 6 sample sites from May to November (Figure 15.7), which is important to understand where contamination from different sources is coming from.

The leading cause of seafood-borne illnesses are *Vibrio* species. These bacteria are naturally occurring and tend to proliferate and persist in warm areas, or in the Northeast during warm summer months. Because of this, they require separate ongoing assessment and monitoring because their presence and concentrations do not correlate with fecal-borne indicator bacteria. *Vibrio parahaemolyticus* was first detected in Great Bay in 1970 (Bartley and Slanetz 1971), while *V. vulnificus* was first detected in 1989 (O'Neill et al. 1990) and *V. cholerae* in 2008 (Schuster et al. 2011).

More recent ongoing monitoring for all three of these most significant public health threats has resulted in relatively long-term (2007 to present) databases for levels of these *Vibrio* species in oysters, water, plankton and sediments in the Great Bay estuary (Hartwick et al. 2019; 2021). Each species occupies specific niches in the estuarine ecosystem of the NH Seacoast. Their average monthly occurrence over the past 5 years (2018-22) shows that *Vibrio parahaemolyticus* is detected earlier and later, and reaches higher concentrations compared to *V. vulnificus* and *V. cholerae* in the Oyster River and at Nannie Island in Great Bay, and the latter two are detected at much lower concentrations at Nannie Island compared to the Oyster River (Figures 15.8 & 9). The average monthly *Vibrio parahaemolyticus* concentrations at Nannie Island over 3-year time spans from 2014 to 2022 showed relatively similar patterns for both 2014-16 and 2020-22, while concentrations were higher during August and September during the middle period, 2017-19 (Figure 15.10).

The results show only the total concentrations of these potentially pathogenic *Vibrio* species, whereas local studies have shown that hypervirulent strains that are most commonly associated with human illness in the Northeast are not detectable or present only at extremely low levels in the NH Seacoast estuarine ecosystems (Xu et al. 2015). Total populations are critical monitoring targets as higher populations associated with warming of the Gulf of Maine and coastal New Hampshire will increase the potential for the emergence of virulent strains.

Methods and Data Sources

The methods used for detection and quantification of fecal indicator bacteria are summarized in the Great Bay Estuary Water Quality Monitoring Program Quality Assurance Project Plan 2018, specifically in Appendix F: Quality Assurance Plan: Microbiology Laboratory at UNH-Jackson Estuarine Laboratory, and Appendix G: SOPs for Detection of Total Coliforms, Fecal Coliforms, *Escherichia coli* and Enterococci from Environmental Samples. The general approach for detection and quantification of all three fecal indicator bacteria in the surface waters of the NH Seacoast is to filter measured volumes of water and collect target bacteria in membrane filters that are then placed on selective agar media plates that are incubated under conditions to select for growth of the different bacterial indicators and inhibit the growth of non-target bacteria. After a day of incubation, the individual bacterial indicator cells grow into visible colonies that are differentiated from other bacteria by color due to indicator-specific reactions that cause dyes to indicate a positive response. The number of colonies is recorded and expressed as colony-forming units per 100 ml.

In the ongoing Microbial Source Tracking study in the Lamprey River watershed (Jones 2022), sources are identified using two methods for detecting source-specific genetic markers (Rothenheber 2017; Rotheheber and Jones, 2018): one method (polymerase chain reaction; PCR) was used to detect the presence/absence of different sources and a semi-quantitative method (qPCR) was usedto detect relative levels, expressed as copy number of the target genes, of different sources.

The methods used for detection and quantification of potentially pathogenic *Vibrio* species are based on FDA protocols (Kaysner and DePaola 2004) and summarized in several more recent sources (Hartwick et al. 2019; Whistler et al. 2015).

Data Sources

The GBNERR SWMP and the PREP Monitoring Programs, along with UNH, provided data for the bacterial indicators of fecal contamination. The Jackson Estuarine Laboratory, the Center for Vibrio Disease and Ecology and the Cheryl Whistler laboratory at UNH provided data for the MST and Vibrio aspects of this report.

Additional Data Tables and Graphs

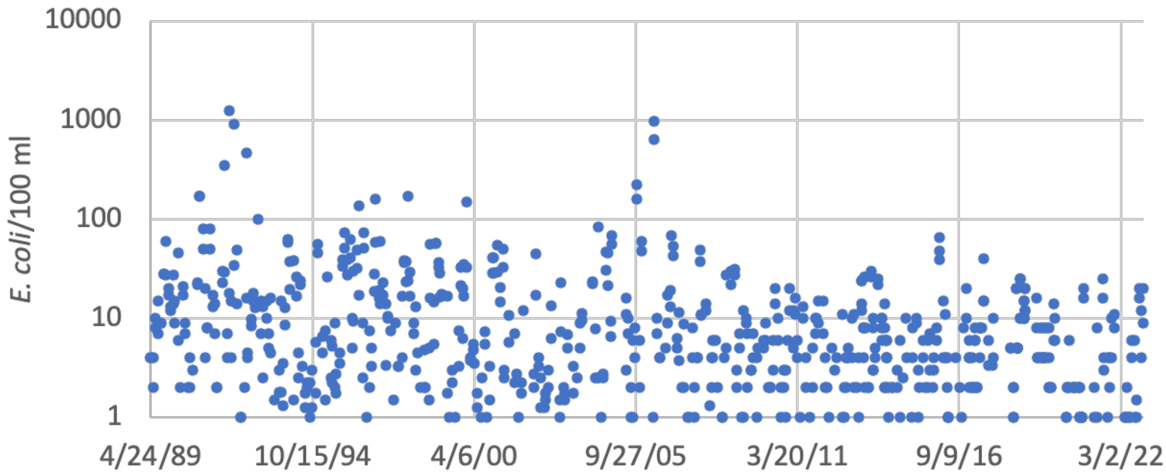

Figure 15.4. *E. coli* concentrations at Adams Point.

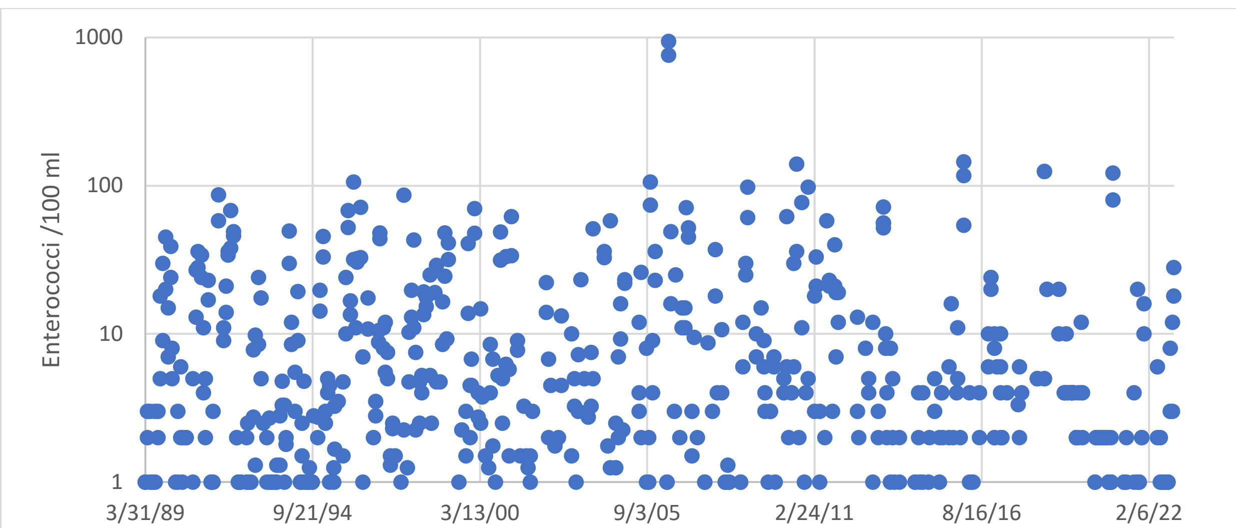

Figure 15.5. Enterococci concentrations at Adams Point.

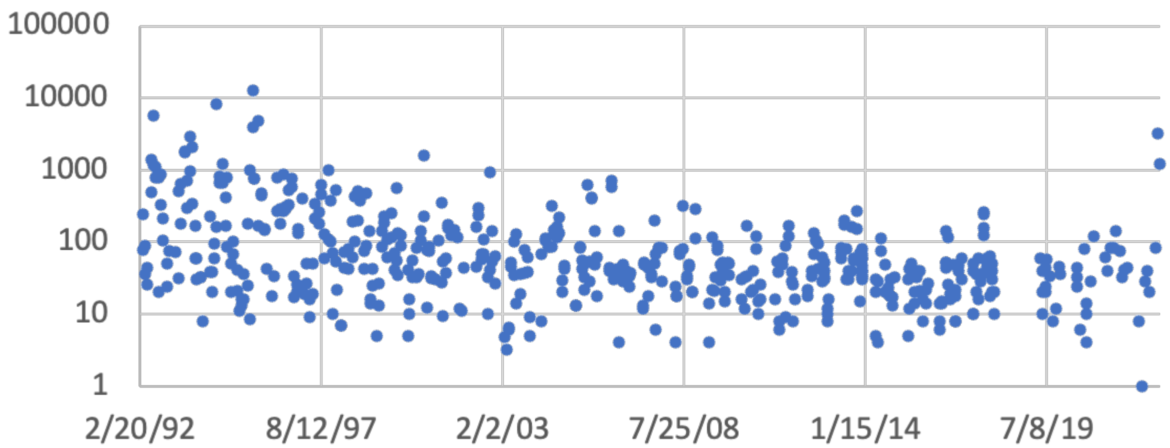

Figure 15.6. Fecal coliform concentrations in the Lamprey River.

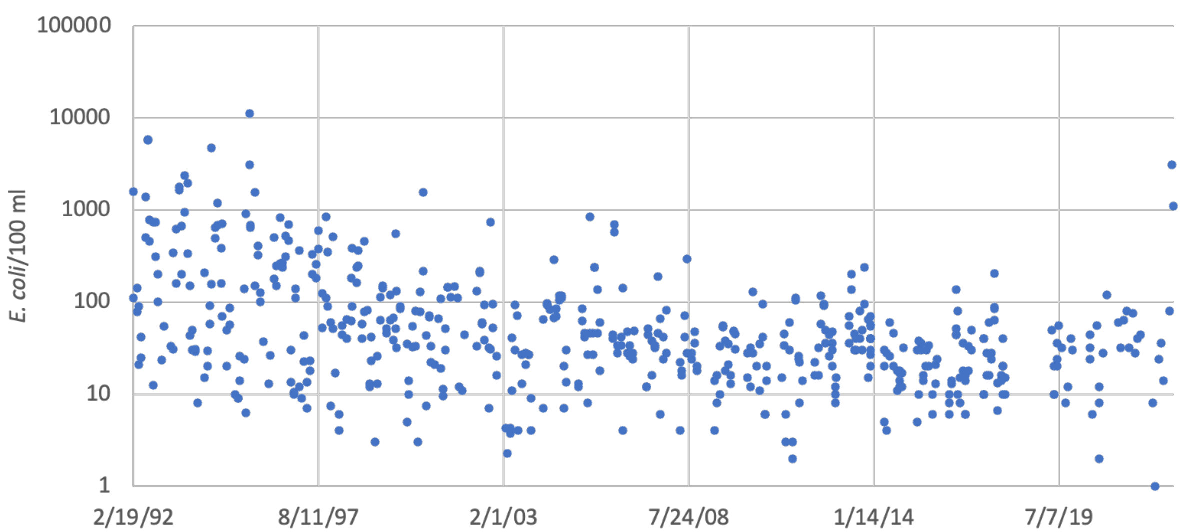

Figure 15.7. *E. coli* concentrations in the Lamprey River.

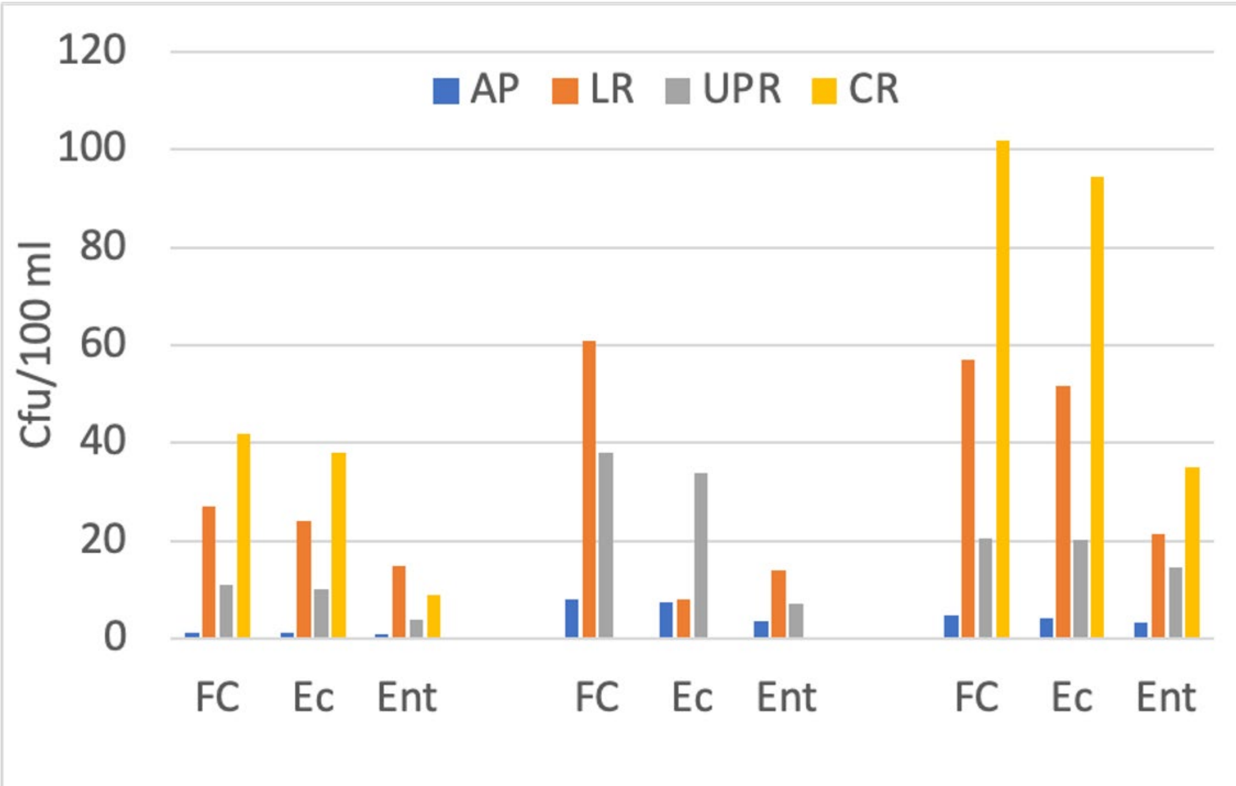

Figure 15.8. Annual geometric mean fecal coliform (FC), *E. coli* (Ec) and enterococci (Ent) concentrations at low tide at Adams Point (AP), Lamprey River (LR), upper Piscataqua River (UPR) and Cocheco River (CR): 2020 (left), 2021 (middle) and 2022 (right).

Site	Enterococci >104/100 ml	*E. coli* >158/100ml
1	5	7
2	0	2
3	0	1
4	0	2
5	0	2
6	0	0
Total	**5**	**7**
% samples	**63%**	**15%**

Table 15.1. Frequency of exceedance of State water quality standards at 6 sites in the Lamprey River watershed: 2022. Tidal water related data are highlighted in yellow, freshwater data are highlighted in blue.

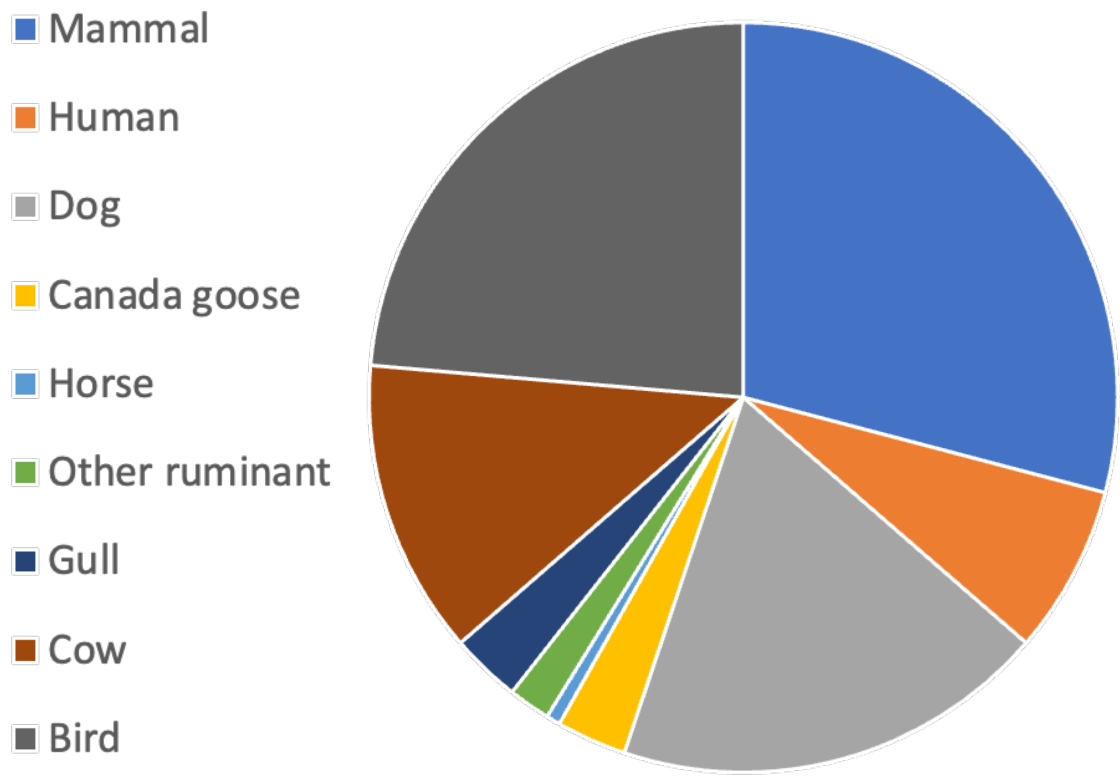

Figure 15.8. Relative frequency of identified fecal contamination sources in the Lamprey River watershed: May-November 2022.

Site #	Ave. # of source types detected	Human source detection	Human source >threshold
1	**5.3**	**7**	**6**
2	3.1	1	0
3	3.6	1	1
4	3.4	1	0
5	2.9	1	0
6	3.6	1	0

Table 15.2. Average fecal source types detected, total times the Human source was detected and when a public health safety threshold concentration (copy number/100 ml sample) was exceeded at 6 sites in the Lamprey River watershed. May-November 2022.

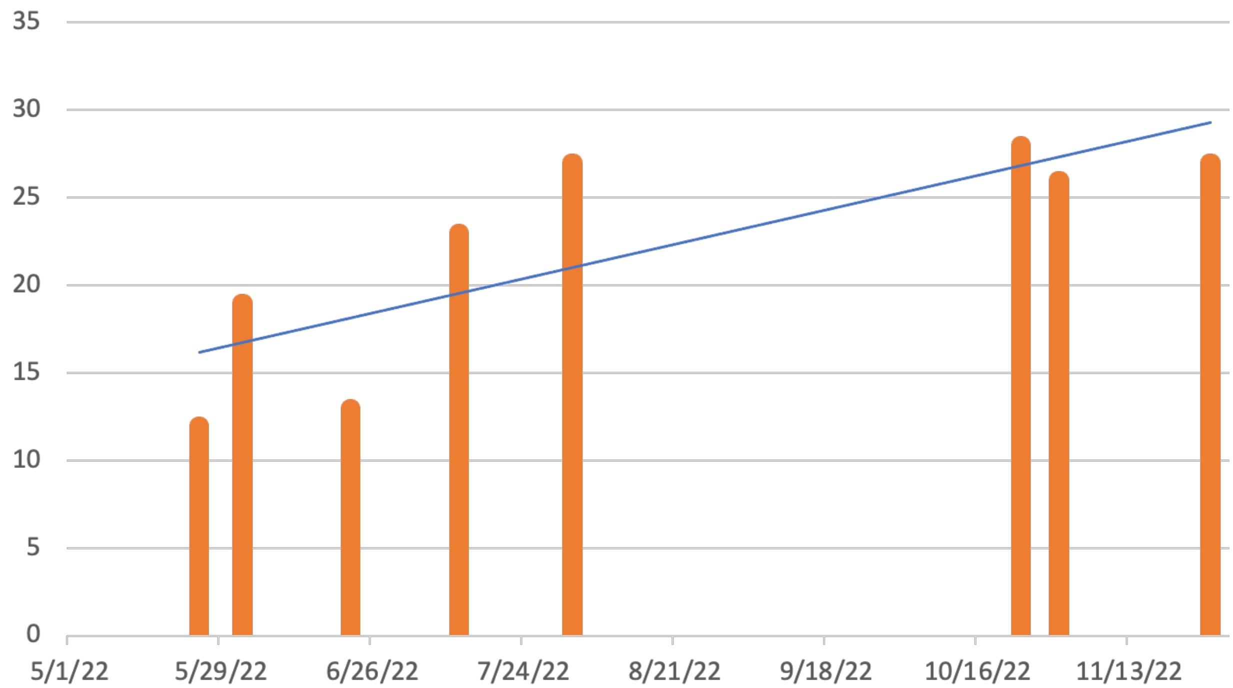

Figure 15.9. The number of fecal contamination sources at all 6 sample sites in the Lamprey River watershed: May-November 2022.

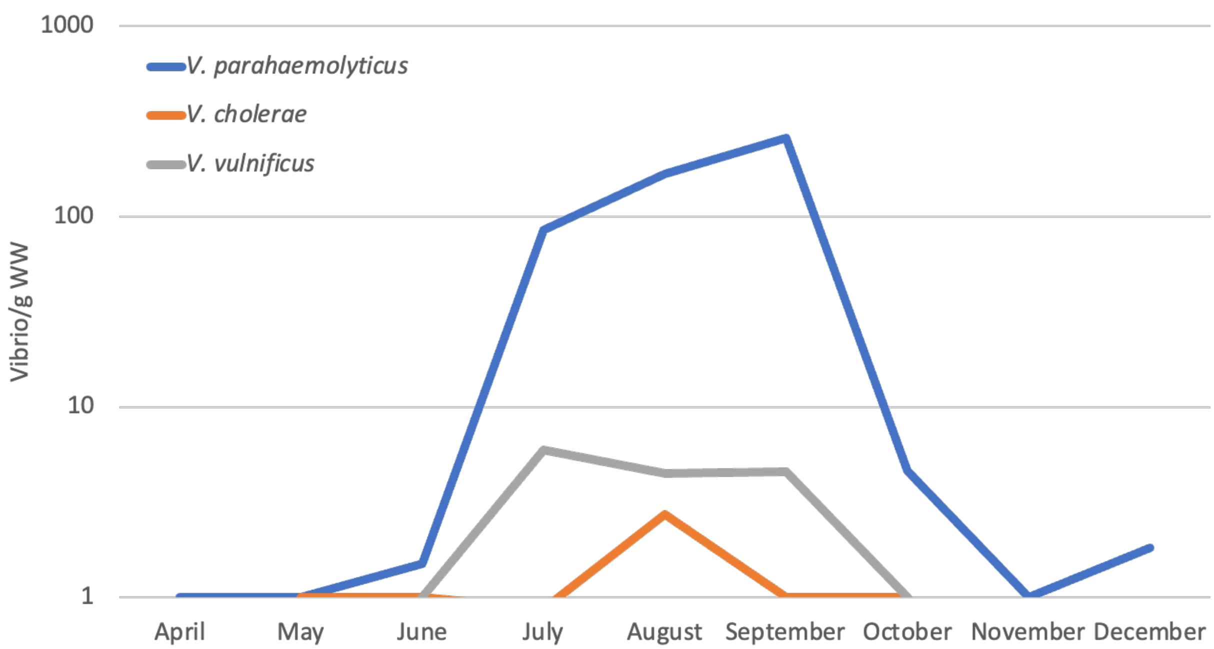

Figure 15.10. Average monthly concentrations of *Vibrio* species in Oyster River oysters: 2018-2022.

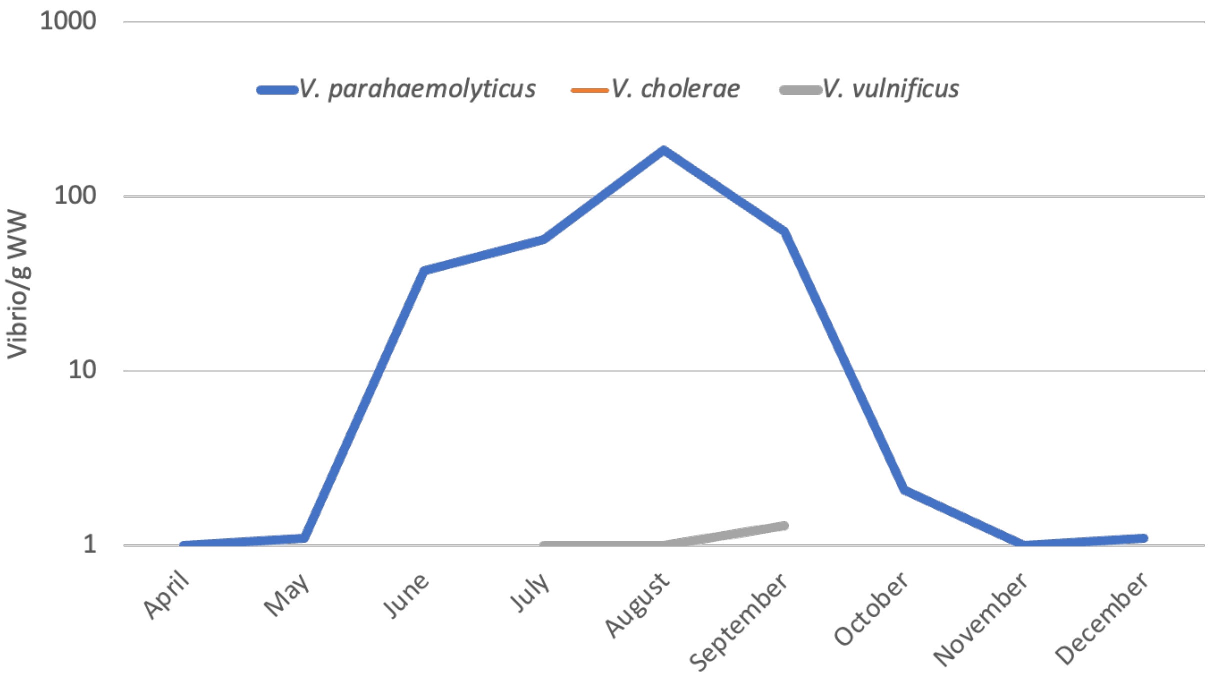

Figure 15.11. Average monthly concentrations of *Vibrio* species in Nannie Island oysters: 2018-2022.

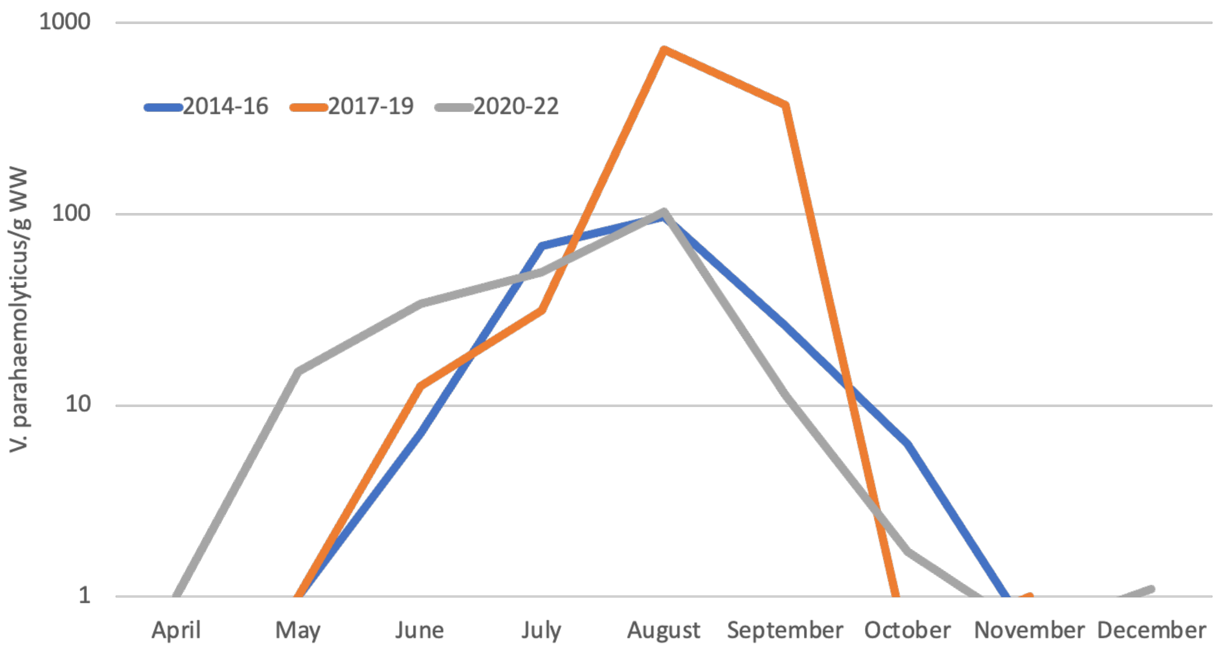

Figure 15.12. Average monthly concentrations of *Vibrio parahaemolyticus* species in Nannie Island oysters over 3 consecutive 3-year time spans: 2014-2022.

Acknowledgements and Credit
Stephen Jones (NH Sea Grant/UNH*)*. Funds for freshwater bacterial tracking in the Lamprey River were provided by the National Park Service under CFDA 15.962 – National Wild and Scenic Rivers System. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. Government. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government.

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Softshell Clams

Methods and Data Sources

Data for softshell clams, neoplasia, and green crab abundance are from the annual Seabrook Station Environmental Monitoring Reports funded by NextEra Energy (Normandeau 2021). These reports present softshell clam data as a density (#/m^2) rather than standing stock. Future PREP reports should use density rather than standing stock because density is less likely to be affected by changes in the areas of the flats. Furthermore, the areas of the flats are not assessed every year. Density is a metric that is less likely to be affected by extraneous variables such as erosion or accretion to the clam flats.

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Normandeau 2021. Seabrook Station 2020 Environmental Monitoring in the Hampton-Seabrook Area. A Characterization of Environmental Conditions, Chapter 7.0 Softshell Clam. Prepared for NextEra Energy Seabrook.

Beach Advisories

Methods and Data Sources

Beach advisories at New Hampshire and Maine tidal bathing beaches within the Piscataqua Region Watershed were compiled for each year from 2003 to 2021 (Figure 19.2, found in State of Our Estuaries Report. The list of beaches currently includes 16 public tidal beaches monitored by NHDES, and one public tidal beach, Fort Foster, monitored by Maine Healthy Beaches. Beach advisories per year from 2003 to 2021 were compiled by each tidal beach within the Piscataqua Region Watershed (Figure 19.3). Only advisories due to water quality contamination were included.

For each advisory, the number of days that the advisory was in effect was calculated. The total number of beach advisory days for the year was then calculated. Beach advisories per year was compared to the number of beach days between Memorial Day and Labor Day (number of days multiplied by the number of beaches monitored) (Figure 19.4).

Additional information regarding monitoring can be found on NHDES and Maine DEP websites.

NHDES Public Beach Inspection Program and Maine DEP Healthy Beaches Program provided records of beach advisories data for this indicator.

Additional Discussion

Beaches in New Hampshire and Maine are routinely monitored during the swim season, between Memorial Day and Labor Day, for fecal bacteria called enterococci. In New Hampshire, NHDES Public Beach Inspection Program will issue a beach advisory to the public when any one bacterial water quality sample exceeds the state standard of 104 counts/100ml. In Maine, when a bacterial sample goes over 104 counts/100ml, Maine DEP Healthy Beaches Program will provide this data to local beach managers, who will typically issue an advisory based on the exceedance. Resampling will occur at the affected beach/beaches, and once bacteria levels have lowered, the advisory will be lifted.

When an advisory is put into effect, it does not necessarily mean that the beach is closed. A beach advisory cautions against swimming, but ultimately lets the public decide whether they'd like to risk going in the water. A beach closure will come into effect if the state or local government decides that water conditions are unsafe for the public.

A number of factors can contribute to the elevated fecal bacteria levels at North Hampton State Beach and New Castle Town Beach. However, it is difficult to pinpoint one specific source of pollution. Heavy rainfall events prior to the bacterial sampling may have caused runoff from nearby saltmarshes or neighboring towns that could have led to the higher levels of fecal bacteria.

Additional Data Tables and Graphs

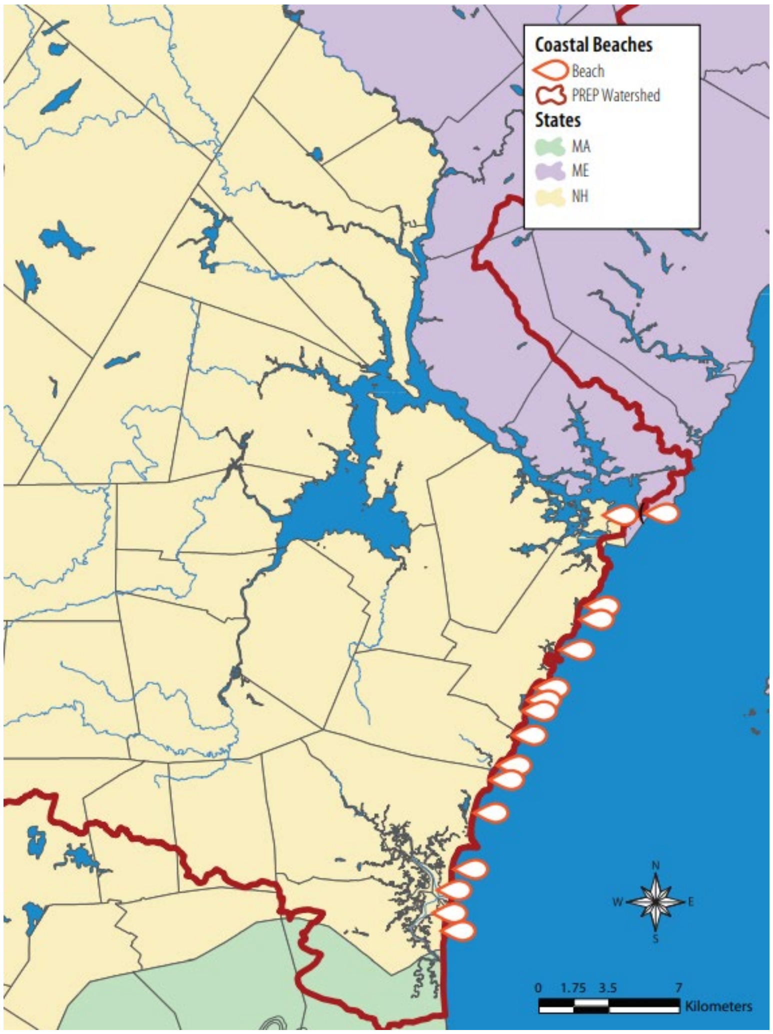

Figure 19.3 Map of Piscataqua Region watershed beaches that are monitored as part of the "Beach Advisories" indicator (State of Our Estuaries 2013).

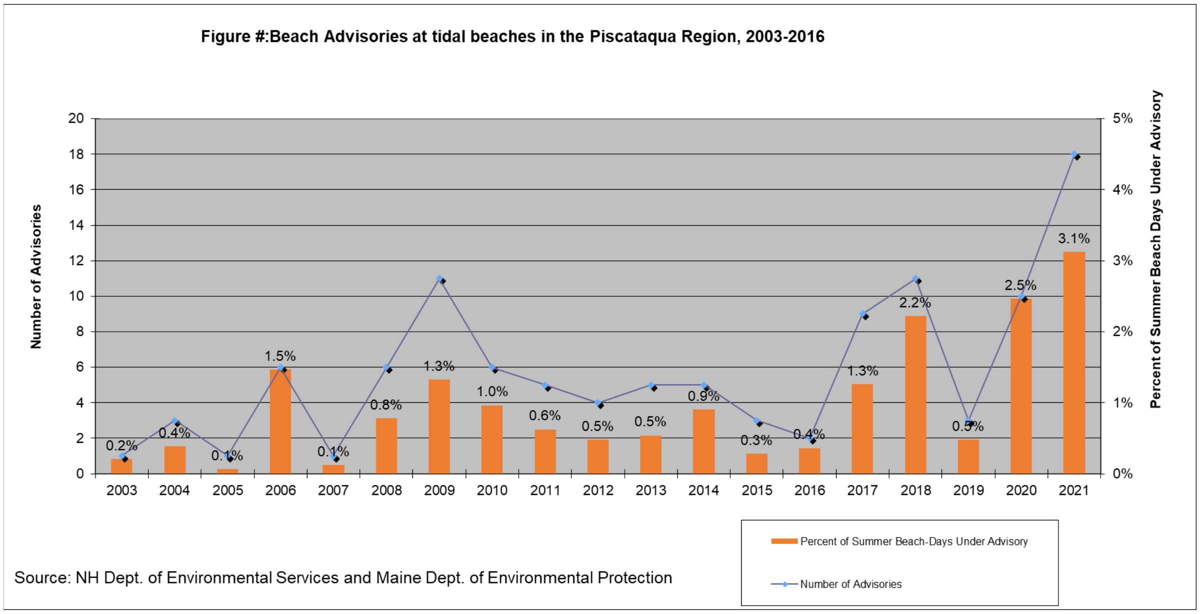

Figure 19.4: Percent of Piscataqua Region Watershed summer beach days under advisory, 2003 - 2021.
Data source: NH Department of Environmental Services and Maine Department of Environmental Protection.

Acknowledgements and Credit

Amanda Giacchetti (UNH) with contributions from Abigail Lyon (PREP).

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Migratory Fish

Methods and Data Sources

Measurements of abundance for three diadromous fish species were tracked for each year using data from the NH Fish and Game Department (NHFG). Abundance was measured by counts of fish passing through fish ladders or via visual counts in the spring.

NHFG 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. NHFG 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 NHFG staff. (Note: NHFG 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 NHFG since 1978.

NH Fish and Game Anadromous Fish Monitoring Programs provided data for this indicator. Research on rainbow smelt by UNH was funded by New Hampshire Sea Grant and NHFG.

Additional Discussion

In 2021, a research partnership between NHFG and UNH began to investigate the migrations of rainbow smelt in Great Bay using acoustic telemetry. Acoustic telemetry tags emit unique signals at specific intervals, and these unique signals are heard and decoded by hydrophones or receivers placed throughout the Great Bay system. A total of 44 adult rainbow smelt captured in the Winnicut, Squamscott, Oyster, and Bellamy Rivers received acoustic telemetry tags and their movements recorded by 22 telemetry receivers placed in Great Bay, its tributaries, and the mouth to the coastal Gulf of Maine. This process was aided by NH Sea Grant's Coastal Research Volunteer (CRV) program. A total of 14,142 detections of rainbow smelt occurred between March 23 (first date of tagging) through mid-May, when the final tagged fish exited Great Bay via the Piscataqua River. Rainbow smelt spent longer in Great Bay than expected (on average for ~39 days among the tributaries and estuary, prior to exiting the system), and several fish used multiple tributaries. Survival from release to the Piscataqua River mainstem (enroute to exit) was estimated (via mark-recapture Cormack-Jolly-Seber models) to be 74%. Although movements among individual rainbow smelt were diverse and complex, in general, movements downstream in the system (towards the Gulf of Maine) occurred disproportionately during ebb tides, while upstream movements (towards tributaries) occurred disproportionately during flood tides, suggesting rainbow smelt may use tides to aid in larger-scale movements. More information on this project can be found at https://storymaps.arcgis.com/stories/1ac83acd0f104e1781ab6cbc01d02276.

UNH and NHFG continue to work together on rainbow smelt, with a new project initiated in 2022 and continuing in 2023 to better estimate interannual survival of the local rainbow smelt population. This project uses passive integrative transponder (PIT) tags, the same technology as microchips used in household pets. Rainbow smelt will be PIT-tagged each spring during the

NHFG fyke net surveys, and the number of recaptures identified each year will allow for estimating annual survival. In addition, the locations of tagging and any recaptures will provide further insight into what rivers rainbow smelt use during the spawning season.

Acknowledgements and Credit
Nathan B. Furey (UNH), with contributions from Kevin Sullivan (NHFG) and Robert Atwood (NHFG).

Toxic Contaminants

Methods and Data Sources

The methods used for detection and quantification of toxic organic chemicals and trace metals are summarized in Apeti et al. (2021) for CECs. The methods and data for toxic contaminants in sediments are from the U.S. Environmental Protection Agency. *National Aquatic Resource Surveys. National Coastal Condition Assessment 2000-2006, 2010, and 2015 (data and metadata files)*. Available from U.S. EPA website: https://archive.epa.gov/emap/archive-emap/web/html/index-124.html; https://www.epa.gov/national-aquatic-resource-surveys/data-national-aquatic-resource-surveys. The sediment data discussed in this report are included in Table 21.4. PAH, PCB, and Pesticide data are reported as sum totals. *(Note that table and figure numbers are continued from the State of Our Estuaries Report.)*

Additional Discussion

Contaminants of Emerging Concern (CECs)

There are many chemical contaminants that are rarely monitored and that are polluting US surface and drinking waters with potential impacts to both aquatic ecosystems and human health. There are many ways that exposure to these chemicals can be deleterious to health, and many of these chemicals are endocrine disruptors that can cause deleterious and altering effects on reproduction in nontarget species at low concentrations. States in the Northeast are responding by increasing efforts to determine the presence and concentrations of these chemicals in coastal ecosystems while simultaneously understanding potential health risks.

There has been an increase in research and monitoring of CECs in New Hampshire and the Gulf of Maine region over the past few years. In 2016, the NOAA Mussel Watch Program, in collaboration with the Gulf of Maine Council Gulfwatch Program, supported sampling and analysis of many of these compounds in blue mussels as part of a Gulf of Maine-wide project that covered 41 monitoring sites from Nova Scotia south to Cape Cod Bay in Massachusetts (Apeti et al. 2021). The following section of this report provides data from 8 sampling sites in the NH Seacoast area, including Clark Cove on Seavey Island (Portsmouth Naval Shipyard; MECC), and a regional context relating NH results to those in the rest of the Gulf of Maine.

The PFAS (PFOSA) found in mussels at the eight NH sample sites (Figure 21.3), can be compared to PFAS levels in mussels from around the Gulf of Maine (Apeti et al. 2021). The frequency of detection at sites in NH (62.5%) was higher than in MA (47.1%), ME (30.8%), and NS (0%). The concentrations detected in the NH samples show that the concentration (2.79 ng/g ww) at NHNM was the second highest in the Gulf of Maine, only lower than the concentration (5.46 ng/g ww) at MEPH in Portland Harbor (Figure 21.4).

Analysis of mussel tissue targeted a wide range of other CEC contaminants. Mussel samples from the eight local sampling sites were analyzed for a total of 240 to 249 individual CEC compounds, including four alkylphenols (APs), nine alternative flame retardants (AFRs), 33 current-use pesticides (CUPs), 12 per- and polyfluoralkyl substances (PFASs), 121 pharmaceuticals and personal care products (PPCPs), and 70 brominated flame retardants (BFRs). At least one CEC chemical was detected at all Gulf of Maine sites, including those in NH. Some of the contaminant types were not detected in NH (Table 21.2), including AFRs, CUPs, and polybrominated biphenyls (PBBs; a type of BFR). The other types of CECs, including APs, PFAS, PPCPs, and PBDEs (also a type of BFR) were detected. The frequencies of detection of all targeted chemicals at the eight different sites were relatively low, ranging from 2.4% at NHLH to 5.2% at NHHS.

The detection frequencies for APs, PFAS, PPCPs, and PBDEs at NH sites were relatively high, with 75, 62.5, 100, and 100% detection of at least one individual compound from these four types of CECs at the eight NH sites (Table 21.3). The most frequently detected alkylphenol compound (AP) was NP1EO (Apeti et al. 2021). In NH, NP1EO was detected at six of the eight sampling sites, with 4-n-OP and NP2EO detected at only one site each (Table 21.2).

Alkylphenols (APs) were found most prominently and at the highest concentrations at NH sites compared to the other three jurisdictions. APs are chemicals used in detergents, including household detergents, and surfactants used mostly in industrial processes and are typically transported to surface waters from wastewater treatment and on-site septic systems. They tend to persist in the environment, especially attached to particles and in sediments, and can have endocrine disrupting effects on aquatic species and humans. APs were detected at six of eight NH Seacoast area sites (Table 21.2), and the highest concentrations of each of the individual AP contaminants were detected at NH sites (Figure 21.5), including 16.6 ng NP1EO/g ww and 6.88 ng NP2EO/g ww at NHSM, and 1.44 ng 4-n-OP/g ww at NHHS.

At least one PPCP contaminant was detected in all but one site (NS) in the Gulf of Maine (Apeti et al. 2021), with higher frequencies of detection and concentrations of more than one PPCP in harbor areas and near wastewater treatment facility outfalls. The most commonly detected PPCP in the Gulf of Maine was the insect repellant DEET (87.5% detection), including detection at all eight NH sites (Table 21.3). Several other PPCPs were detected at more than one NH site, including sertraline (six sites), diphenylhydramine and triamterene (five sites), and propranolol (two sites; the only detection in the Gulf of Maine), all of which are various kinds of drugs for managing human health. Seven other PPCPs were detected at one site in NH, with all but miconazole and hydrocortisone not detected anywhere else in the Gulf of Maine.

Even though DEET was detected at all eight sites in the NH Seacoast area, the concentrations were relatively low (highest concentration = 3.47 ng/g ww at NHNM) compared to sites across Maine and at MBNR in Massachusetts where the highest concentration (31.0 ng/g ww) was recorded (Figure 21.6).

At least one individual BFR was also detected in all eight of the NH sites, with 100% detection of PBDE-47 and detection of four other PBDEs at six or more sites (Table 21.3). Only 12 of the measured 51 (23.6%) PBDE congeners were detected in Gulf of Maine mussels (Apeti et al. 2021), and of these only eight were detected at five or more sites. The maximum PBDE concentrations were measured for the congener PBDE-77 and the highest detected concentration (0.67 ng/g ww) was in mussels from NHHS.

Apeti et al. (2021) also stated that developed land-use and land with high percent impervious cover were positively correlated with AP, PFAS, and PPCP detection frequencies, and the concentrations of several individual compounds (NP1EO, PFOSA, diphenhydramine, sertraline, PBDE-47, PBDE-71/49, and PBDE-99). Higher detection frequencies were also located at the mouths of major rivers, like the Merrimack and Kennebec rivers, and near wastewater treatment plants and combined sewer outfalls.

In summary, many CECs were present in blue mussels at sites all around the Gulf of Maine and throughout the NH Seacoast area. These results suggest widespread sources, but also questions about the toxicity of different levels of these chemicals to aquatic ecosystems and human health. More recent studies have identified many more chemicals of emerging concern, raising the alarm for more monitoring to inform management strategies for identifying and eliminating different sources of these chemicals to coastal ecosystems, and for mitigating potential health risks.

Toxic Contaminants in Sediments

Estuarine sediments are ultimately where many contaminants end up being deposited and accumulated over time. However, the ability of sediments to store various constituents is largely dependent on their chemical and physical composition. The NCCA sediment chemistry data for 2000-2015 includes 15 metals, 26 PAHs, 44 PCBs, and 30 pesticides as well as total organic carbon (TOC) and percent grain size distribution that help us understand important characteristics about sediments (e.g., the kind of hydrological environment) they were sampled from, which in turn helps provide important context for understanding the fate of contaminants in our estuaries. When we consider both TOC and grain size, we see that, as expected, finer (high % silt/clay) particles and organic rich particles are associated with higher concentrations of heavy metals (e.g., Hg, Pb and As in Figure 21.7 and 21.8). However, the same trends are not observed in more complex organic molecules such as PAHs, PCBs, and pesticides (Figures 21.7 and 21.8).

When considering the spatial distribution of sediment, PAHs we can target areas for future monitoring (Figure 21.9). Most of the sites sampled in Great Bay and Hampton-Seabrook fall below the lowest effect level of 4000 ppb for freshwater sediments (Persaud et al. 1993). Levels above 22,800 ppb dry wt. are considered probable effect concentrations (MacDonald et al. 2020); the Piscataqua River and Portsmouth Harbor, notably, have the highest values.

The spatial distribution of sediment PCBs is shown in Figure 21.10 with data ranging from 2000-2010. Most of the locations sampled across the watershed were below the lowest effect level of 70 ppb (Persaud et al. 1993). The three highest levels were measured in the Piscataqua and Cocheco rivers.

These data allow us to understand the spatial distribution of contaminants of concern and to target future areas of concern for higher resolution and higher temporal frequency monitoring to better understand both the sources of the contaminants and the time scales over which they persist in the environment.

Additional Data Tables and Graphs

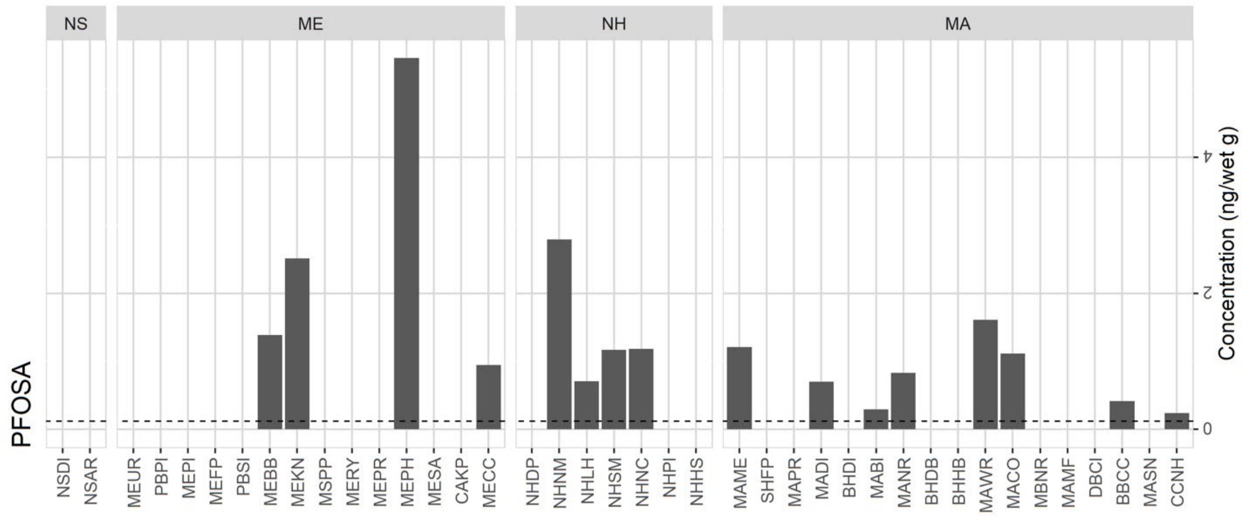

Figure 21.4. The magnitude of PFAS contaminants detected in the Gulf of Maine. The dotted line represents the minimum weight corrected detection limit. Sites are listed geographically from north to south, following the coastline. (From: Apeti et al. 2021).

Site	Number compounds analyzed	Number compounds detected	Detection frequency (%)	Alkylphenols	Alternnative flame retardants	Current use pesticides	PFAS	Pharmaceuticals & personal care products	Polybrominated biphenols	Polybrominated diphenyl ethers
NHHS	249	13	5.2	2	0	0	0	5	0	6
NHNM	240	11	4.6	1	NA	0	1	4	0	5
NHSM	249	11	4.4	2	0	0	1	5	0	3
NHDP	249	11	4.4	1	0	0	0	5	0	5
MECC	249	11	4.4	1	0	0	1	5	0	4
NHNC	248	10	4	1	0	0	1	3	0	5
NHPI	248	8	3.2	0	0	0	0	4	0	4
NHLH	248	6	2.4	0	0	0	1	1	0	4
From Apeti et al. 2021; Table 37										

Table 21.4. Total detection frequency of types of CEC contaminants in mussels from sampling sites in the NH Seacoast area.

CEC type	Compound	Number of Detects	Sample Sites	Frequency (%)
AP	NP1EO	6	8	75
	4-n-OP	1	8	12.5
	NP2EO	1	8	12.5
PFAS	PFSOA	5	8	62.5
PPCP	DEET	8	8	100
	Sertaline	6	8	75
	Diphenhydramine	5	8	62.5
	Triamterene	4	8	50
	Propranolol	2	8	25
	Amitriptyline	1	8	12.5
	Atenolol	1	8	12.5
	Cocaine	1	8	12.5
	Fluoxetine	1	8	12.5
	Hydrocortisone	1	8	12.5
	Miconazole	1	8	12.5
BFR	PBDE-47	8	8	100
	PBDE-119	7	8	87.5
	PBDE-71/49	7	8	87.5
	PBDE-99	6	8	75
	PBDE-77	6	8	75
	PBDE-126	1	8	12.5
	PBDE-118	1	8	12.5

Table 21.3. The frequency of detection of CEC contaminants in mussels from sampling sites in the NH Seacoast.

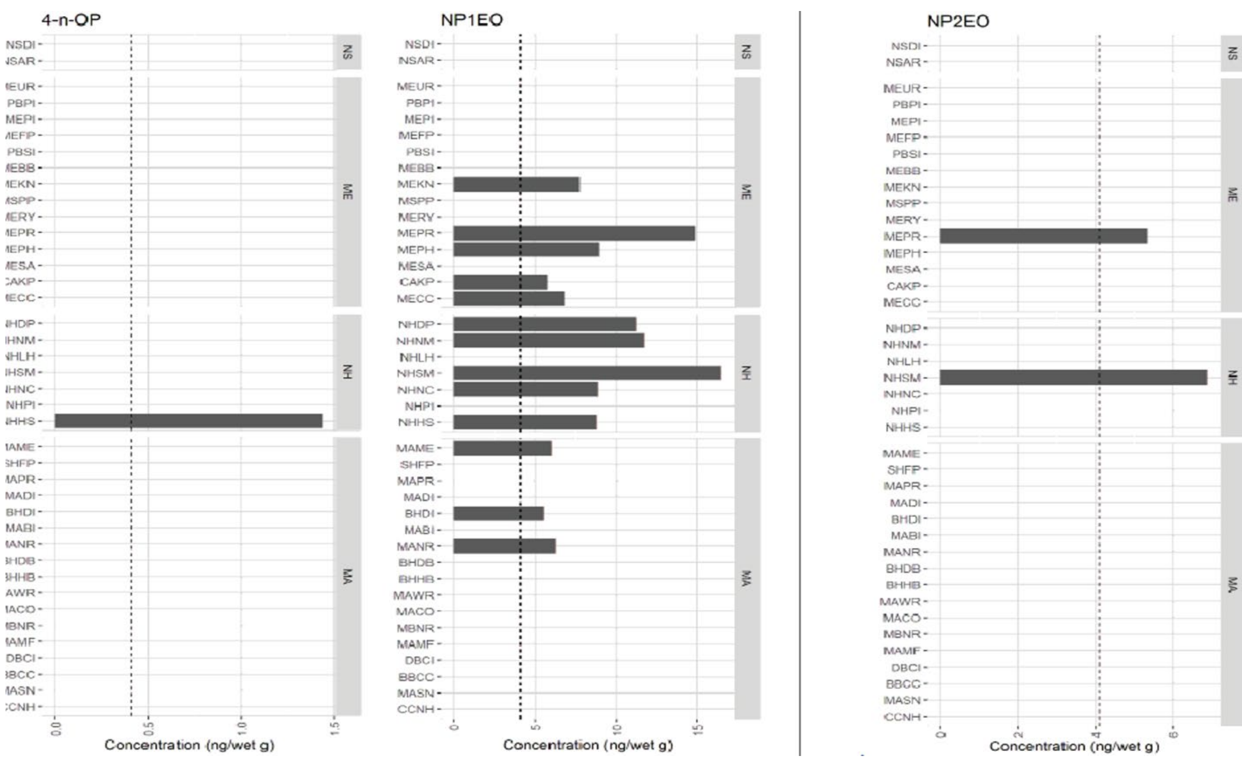

Figure 21.5. Concentrations of alkylphenols at sites in the Gulf of Maine. Sites are listed geographically from north to south, following the coastline. (From: Apeti et al. 2021).

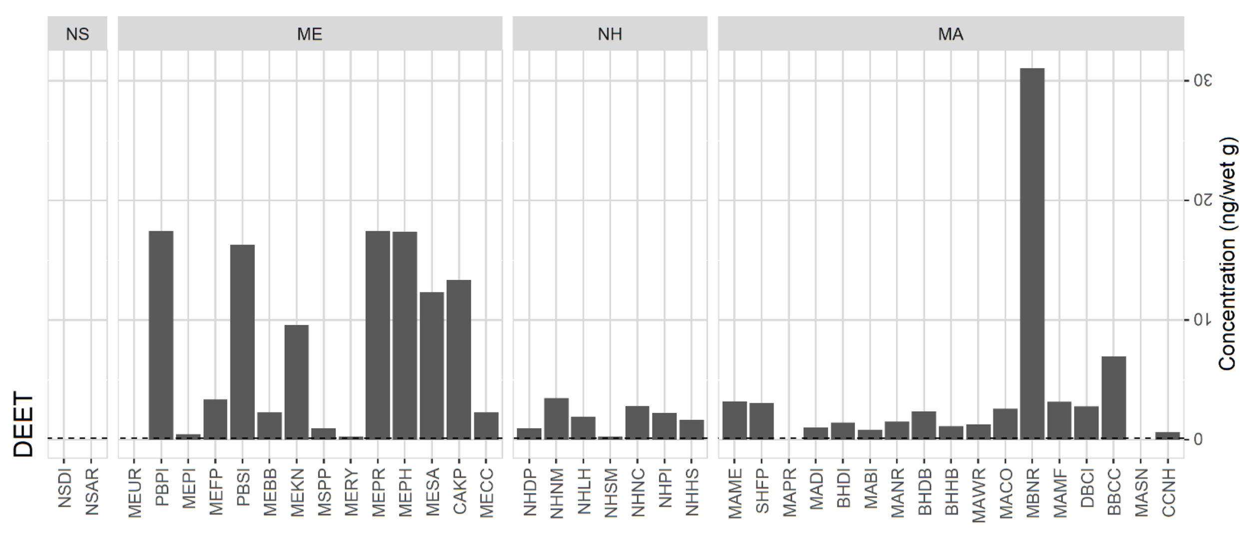

Figure 21.6. Concentrations of DEET at sites in the Gulf of Maine. Sites are listed geographically from north to south, following the coastline. (From: Apeti et al. 2021).

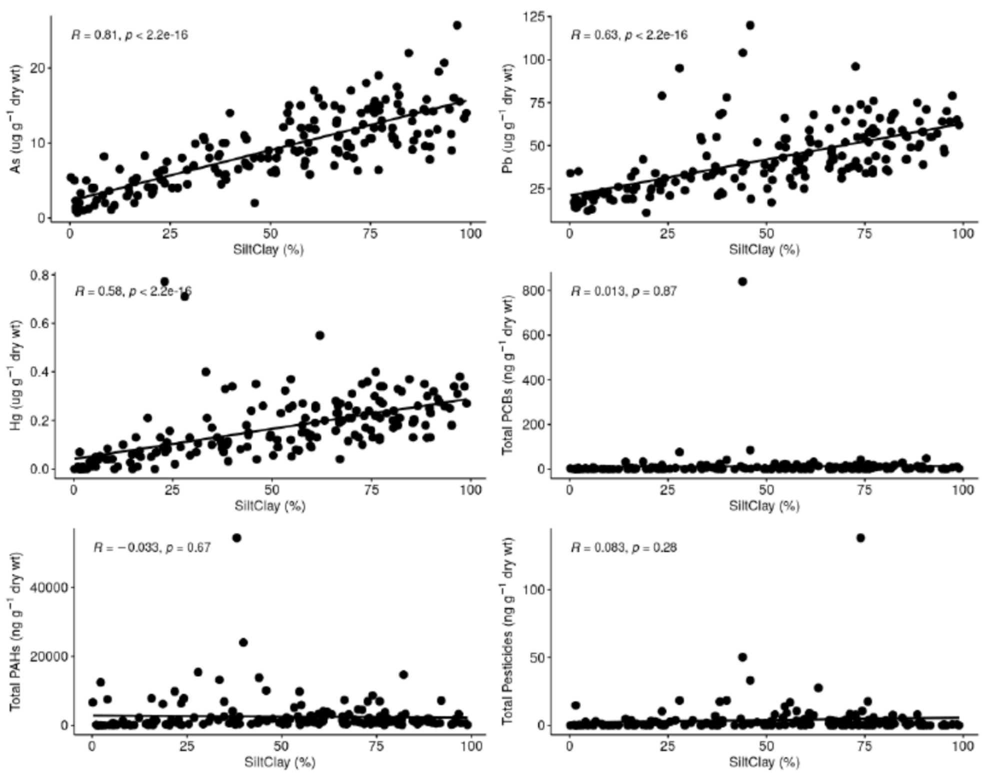

Figure 21.7 Contaminants of concern (As, Pb, Hg, PAHs, PCBs, and pesticides) vs. percent silt/clay grain size fraction.

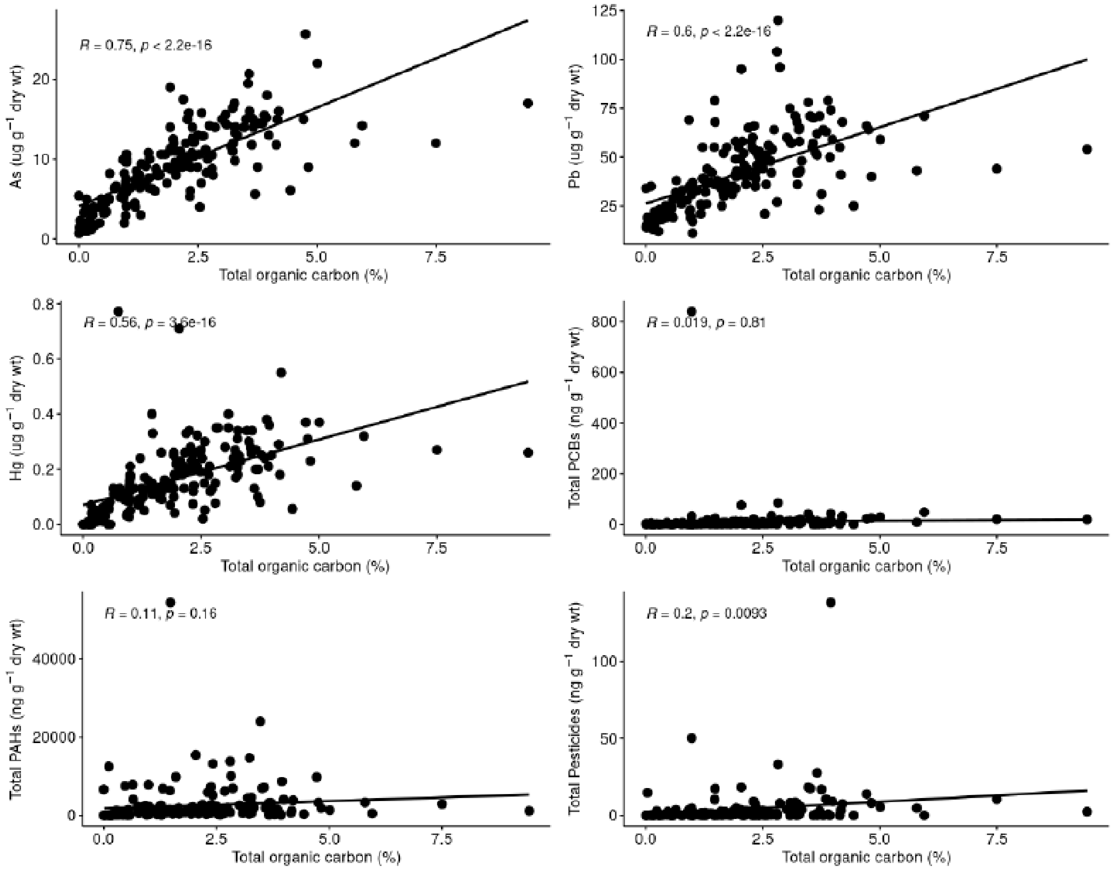

Figure 21.8 Contaminants of concern (As, Pb, Hg, PAHs, PCBs and Pesticides) vs. percent total organic carbon (TOC).

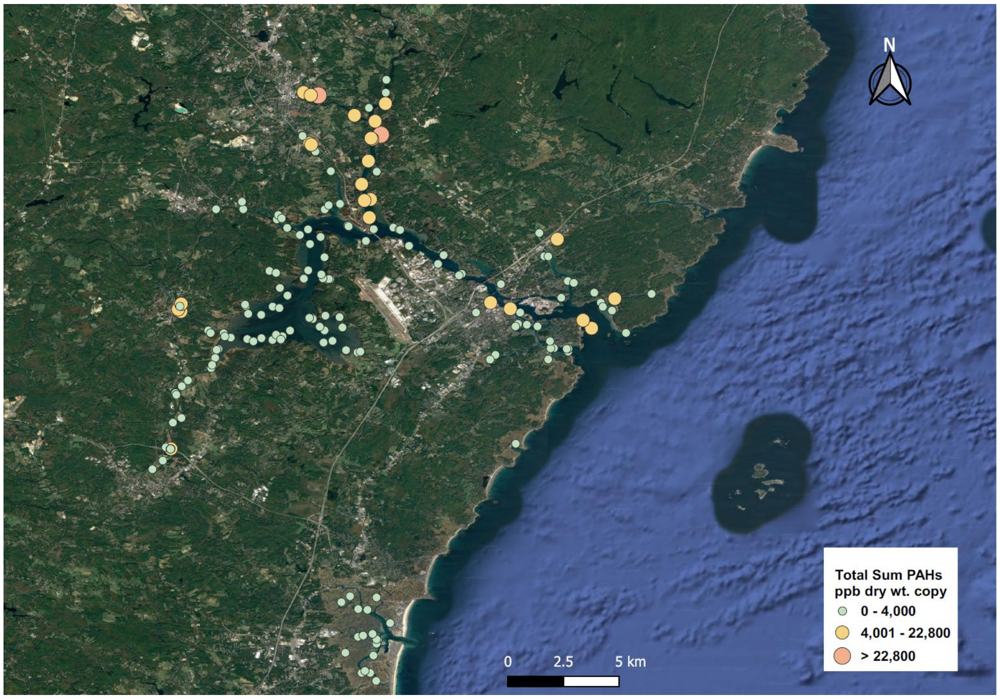

Figure 21.9 Distribution of sediment total sum PAH concentrations in Piscataqua Region Watershed Estuaries and tributaries from NCCA surveys 2000-2006, 2010, and 2015. Concentrations greater than 22,800 ppb (red) are considered probable effect concentrations (MacDonald et al. 2020). At concentrations < 4,000 ppb (green), effects are not expected. Intermediate concentrations with less defined risk are shown in orange. ***Data source: National Coastal Condition Assessment, EPA.***

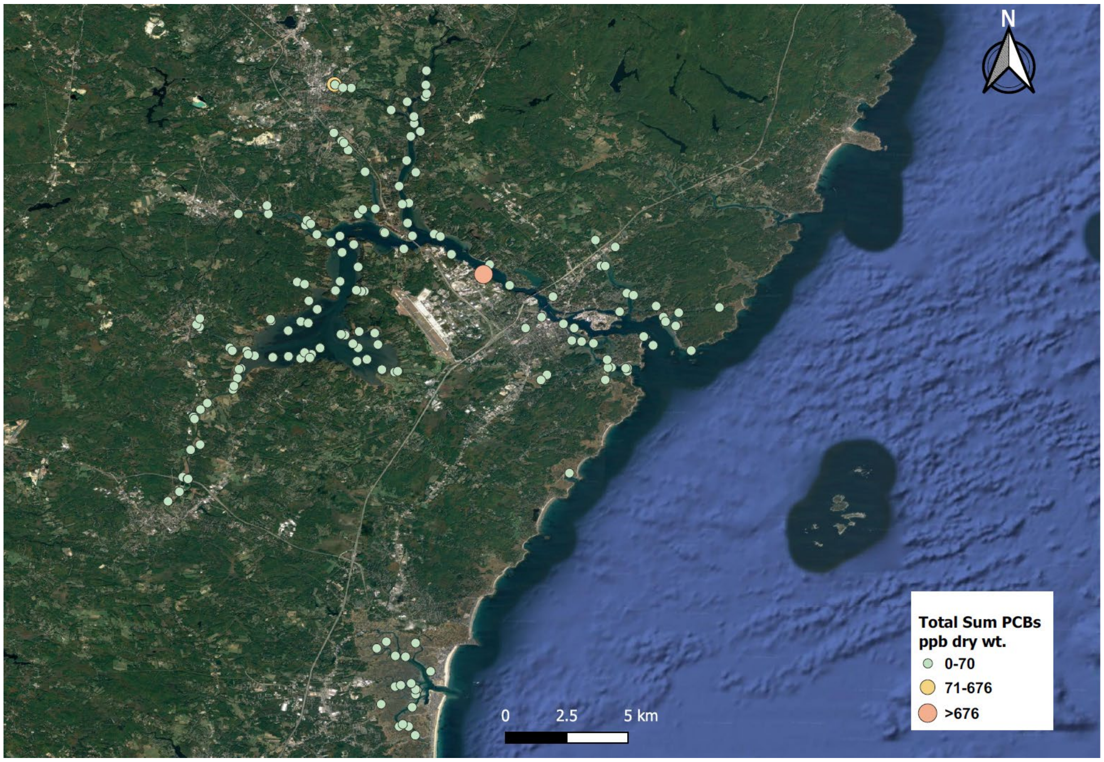

Figure 21.10 Distribution of sediment total sum PCB concentrations in Piscataqua Region Watershed Estuaries and tributaries from NCCA surveys 2000-2006 and 2010. Concentrations greater than 676 ppb (red) are considered probable effect concentrations (MacDonald et al. 2020). At concentrations < 70 ppb (green), effects are not expected. Intermediate concentrations with less defined risk are shown in orange. *Data source: National Coastal Condition Assessment, EPA.*

Acknowledgements and Credit

Stephen Jones (UNH/NH Sea Grant Program), Maria Florencia Fahnestock (UNH) and NOAA Mussel Watch Program. The New Hampshire NCCA 2000-2015 data were a result of the collective efforts of dedicated field crews working out of the UNH Jackson Estuarine Lab, plus laboratory staff, data management and quality control staff, analysts and many others from EPA, states, tribes, federal agencies, universities, and other organizations. Please contact nars-hq@epa.gov with any questions.

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Saltmarsh Sparrow – Special Feature

Question:
Where do Saltmarsh Sparrows occur in the Piscataqua Watershed and why are the Watershed's estuaries important for supporting the Saltmarsh Sparrow?

Short Answer

Estuaries and adjacent coastal areas provide key reproductive habitat for the vulnerable Saltmarsh Sparrow – a unique, salt marsh obligate bird that breeds only in tidal salt marshes along the Atlantic coast, from Maine to Virginia (Greenlaw et al. 2020). The reproductive behavior of Saltmarsh Sparrows is shaped by the selective pressures and harsh environmental conditions of the salt marsh, and their reproduction, therefore, is closely tied to the tidal cycle (Shriver et al. 2007; Benvenuti et al. 2018). Increases in marsh flooding and high marsh habitat loss due to sea-level rise are threatening the long-term persistence of this species. In New Hampshire, two marshes in the Great Bay Estuary, Chapman's Landing and Lubberland Creek Preserve, provide critical high marsh habitat that supports breeding populations of Saltmarsh Sparrow and are among the most productive habitats across the species range. Saltmarsh Sparrows also breed in the expansive marshes of the Hampton-Seabrook Estuary. These sites are vital for saltmarsh sparrow conservation and research examining how to restore salt marshes to ensure persistence of robust Saltmarsh Sparrow populations in New Hampshire.

What We Know and Need to Know to Conserve Saltmarsh Sparrows

Female Saltmarsh Sparrows (Figure SS-1) construct ground nests in high marsh vegetation, with a nest cup raised centimeters above the marsh surface (Figure SS-2). They nest primarily in *Spartina patens* and *Juncus gerardii*, although they may also use *Spartina alterniflora* or a mixture of *S. alterniflora* and *S. patens* in higher elevation areas of the marsh, which typically flood monthly, rather than daily (Gjerdrum et al. 2005). Female Saltmarsh Sparrows are adapted for laying a clutch of eggs, incubating, and fledging their young (Figures SS-3 and SS-4) within a 23-26 day window, which must fit between two lunar spring tide events (28 days apart) that inundate the marsh and flood nests. While females can renest quickly after losing a nest to a spring tide flooding event, the window of flood-free days on the marsh is decreasing with increasing tide heights and duration, as is their ability to nest successfully, putting them at great risk for long-term persistence (Field et al. 2017).

Figure SS-1: Banded Saltmarsh Sparrow held by a researcher during monitoring activities. Photo credit: Grace McCulloch

Figure SS-2: Saltmarsh Sparrow nest with four eggs. Photo Credit: Talia Kuras

Another tidal marsh sparrow co-exists

In New Hampshire, Saltmarsh Sparrows overlap in occurrence with their sister species, the Nelson's Sparrow; the two species interbreed within this hybrid zone that spans from Thomaston, Maine to Newburyport, Massachusetts (Hodgman et al. 2002; Walsh et al. 2015). Although Nelson's Sparrows are infrequent and most of the tidal marsh sparrows in New Hampshire are Saltmarsh Sparrows, many of them may be hybrids or have some amount of genetic admixture between the two species. It is often difficult to distinguish the two species in the field. For this reason, surveys typically record them as "Sharp-tailed Sparrows", meaning that they may be either species or hybrids.

Threats to Saltmarsh Sparrows

Populations of Saltmarsh Sparrow and other tidal marsh specialist birds (Nelson's Sparrow, Great Blue Heron, Marsh Wren, Goldfinch, Yellowthroat, Cranes) are experiencing steep declines, at a rate of 9% annually range-wide and 12% annually in New England (Correll et al. 2017). As a result, since 1998, they have lost 87% of their population range-wide (Hartley and Weldon 2020). Primary threats to Saltmarsh Sparrows are habitat degradation and loss and increased rates of marsh flooding due to sea-level rise. More than 50% of U.S. tidal marshes have been lost since colonial times, including in New Hampshire, primarily due to development (Benoit and Askins 2002; Bromberg and Bertness 2005). Humans have modified marshes for centuries, including through filling, ditching, and tidal restriction. The resulting alterations in natural hydrology impact the biogeochemistry, plant communities, and accretion rates, thereby decreasing resiliency (Bromberg et al. 2009). Many marshes today are subsided, drowning with increased inundation and pooling of water on the marsh surface, and therefore poor quality for supporting vulnerable, ground-nesting Saltmarsh Sparrows.

Where to find Saltmarsh Sparrows in New Hampshire

University of New Hampshire researchers, who are members of the Saltmarsh Habitat and Avian Research Program (SHARP, www.tidalmarshbirds.org), have monitored the reproduction of Saltmarsh and Nelson's Sparrows on Chapman's Landing (a 13-ha site along the Squamscott River) and Lubberland Creek Preserve (a 11-ha site on The Nature Conservancy property) since 2011 to track long-term trends in productivity. Due to the slightly dampened tidal regime relative to coastal marshes, these two marshes support sparrow nesting with lower flooding rates and higher success than nearby coastal marshes in the Great Marsh complex, including Hampton-Seabrook Estuary. Among 24 marshes monitored by SHARP across the species range in 2011-2015, Chapman's Landing was one of the two marshes with the highest nest survival rates (Ruskin et al. 2017). Of 115 nests monitored at Chapman's Landing during the 2021 and 2022 breeding seasons, 42% (49 nests) successfully fledged one or more offspring. Nesting Saltmarsh Sparrows also are found in Hampton-Seabrook Estuary, around Tide Mill Creek and Drake's River, near Philbrick Pond in North Hampton, and in Rye at the marshes near Wallis Sands and Odiorne Point (Fairhill).

Figure SS-3: Saltmarsh Sparrow nestlings in a nest. Photo credit: Talia Kuras

Figure SS-4: Three banded Saltmarsh Sparrow nestlings, nearing the age when they are ready to fledge the nest. Photo Credit: Talia Kuras

In addition to the key breeding sites described above, Sharp-tailed Sparrows also are found in smaller numbers around Great Bay on small areas of marsh north of Chapman's Landing, along both sides of the mouth of the Squamscott River, including near the Great Bay National Estuarine Research Reserve Discovery Center, and near the Portsmouth Country Club. Along the coast, they also occur in smaller numbers throughout other areas of the Hampton-Seabrook Estuary, North Hampton, and Rye (Figure SS-5).

Continued, systematic monitoring of the occurrence and demographics of Saltmarsh Sparrows in New Hampshire is necessary to understand how they respond to ongoing and planned marsh restoration. Marsh restoration is critical to ensure resilience, to provide critical ecosystem services, and support endemic wildlife. We do not yet know which specific restoration methods – such as microtopography (sediment) mounds, runneling, and ditch remediation – will best support breeding populations of Saltmarsh Sparrow. Future work will help us understand which restoration methods provide the most protection of the Saltmarsh Sparrow.

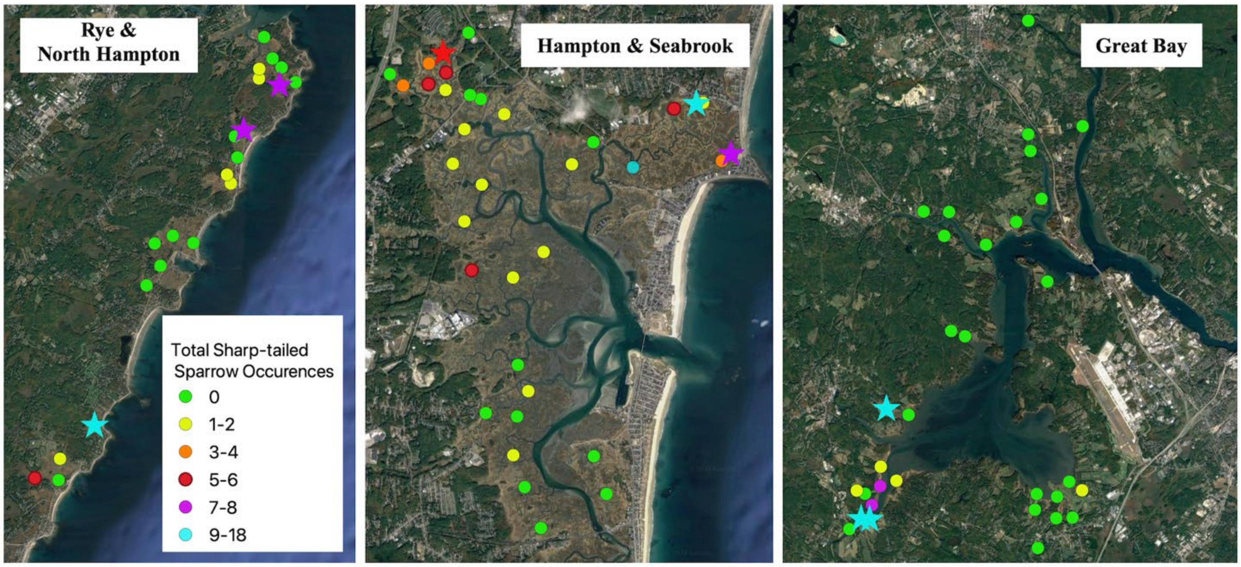

Figure SS-5. Locations where Saltmarsh and Nelson's Sparrows, and their hybrids (collectively referred to as "Sharp-tailed Sparrows"), were detected in three main areas in New Hampshire – coastal marshes in Rye and North Hampton, Hampton-Seabrook Estuary and Great Bay Estuary. Colors indicate the total number of detections during two rounds of point count surveys in 2022. Stars indicate sites where nesting sparrows have been documented.

Methods and Data Sources

Since 2011, SHARP partners have been monitoring Saltmarsh Sparrow occupancy, abundance, and demographic parameters, using systematic survey protocols on marshes from Maine – Virginia. Survey results, protocols, and numerous publications by SHARP researchers can be found at www.tidalmarshbirds.org.

Additional information for this document came from published and unpublished work of UNH graduate students in Adrienne Kovach's lab. Current ongoing research on Saltmarsh Sparrows in Great Bay and Hampton Seabrook Estuaries and other New Hampshire marshes is conducted by UNH researchers in partnership with Great Bay National Estuarine Research Reserve.

Marshes are surveyed for sparrow occupancy using standard avian point count surveys, by which all birds seen and heard are recorded during 10-minute survey windows, conducted twice per season at each survey point. To document reproduction, marshes are searched systematically for nests, and found nests are monitored every 3-5 days to determine their fate – fledged, flooded, or predated.

Acknowledgements and Credit

Talia Kuras (UNH), Grace McCulloch (UNH), and Adrienne Kovach (UNH).

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Green Crabs – Special Feature

In June 2024, pages 120-124 were updated with corrected information

Question:
What is the abundance and distribution of green crabs in Great Bay Estuary temporally and spatially?

Short Answer
Green crabs, *Carcinus maenas*, are a non-indigenous, highly adaptable (Monteiro et al. 2021) and naturalized member of the Great Bay and Hampton Estuary ecosystems (Figure GC-1). They are considered a nuisance to the oyster aquaculture industry and a detriment to eelgrass beds (Garbary et al., 2014) and wild oysters (Pickering et al. 2017). Periodic monitoring through trapping helps us to understand the current situation of this invasive species and keep track of any increases or decreases in their abundance. Warmer waters associated with climate change have made it easier for green crab populations to grow and thrive nearly year-round (Monteiro et al. 2021). Consequently, it is increasingly more difficult for the habitats where they occur and the industries that they affect to remain healthy and sustainable.

Why We Track This Indicator
Spatial and temporal tracking of green crabs in the Great Bay Estuary helps us determine their densities, reproduction cycles, and molting periods, and sheds light on population expansion and how this species is changing the ecosystem. Green crab foraging behavior can affect the health of the Bay by altering important habitats, which in turn can negatively impact fish and wildlife, water quality, and recreational/commercial fisheries. Crab monitoring also provides critical information for seagrass restoration teams, oyster farmers, oyster restoration teams, living shoreline projects, residents, and management teams. For example, an oyster farmer may not want to apply for a new farm in an area that is heavily infested with green crabs year-round.

Figure GC-1. Green crabs captured in the Great Bay Estuary.

Explanation

Green crab trapping studies have been conducted in the past (Fulton et al. 2013, Goldstein et al. 2017) but not for almost 10 years and never investigating wild versus farmed oyster areas. From April through November in 2021 and 2022, replicates of three trapezoidal green crab traps (Figure GC-2) were set out at four sites throughout Great Bay Estuary (Figure GC-3, Kahle and Wickham, 2013); two wild reef sites, Nannie Island and Lamprey River, and two farmed sites, Fox Point and Cedar Point. Green crabs collected each week were weighed, measured, and sexed. Abundance of green crabs was converted into catch per unit effort (CPUE), which is the number of green crabs divided by how many hours the trap was submerged in the water (Figure GC-4).

Figure GC-2. Redeploying a trapezoidal green crab trap. Photo credit: Tim Briggs

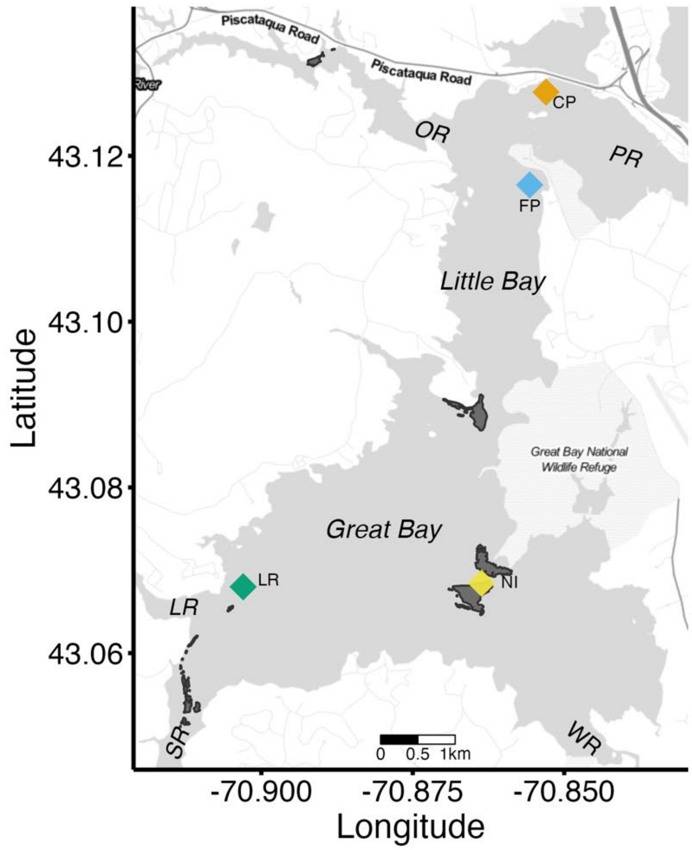

Figure GC-3. Map of Great Bay Estuary showing four sites (diamonds) where trapezoidal crab traps are deployed. Areas shaded in dark gray are natural reefs. There are two oyster farm sites, Cedar Point (CP, orange diamond) and Fox Point (FP, blue diamond), and two native oyster reef sites, Nannie Island (NI, yellow diamond) and Lamprey River (LR, green diamond). Squamscott River (SR), Lamprey River mouth (LR), Oyster River (OR), Piscataqua River (PR), and Winnicut River (WR) are shown on the map for reference.

In both years, male green crabs were captured in much greater numbers than female green crabs (Figures GC-4 and GC-5). The highest CPUE observed in 2021 (Figure GC-4) was at the farm near Cedar Point between late July to mid-August. Nannie Island, a reef site in the Great Bay proper, had the second highest CPUE. At Lamprey River, few green crabs were observed, and the first appearance did not occur until August. In 2022, Nannie Island had the highest CPUE throughout the season and Lamprey River exhibited crabs in April and yielded more green crabs compared to 2021 at that site (Figure GC-5). The low numbers of females captured appears to be due to a narrower range of movement than for male green crabs; better access to females will require deployment of more traps in many other locations around the Bay. The differences that occurred between 2021-2022 could be due to record differences in precipitation that could greatly affect the salinity gradient in Great Bay Estuary. Studies have shown salinity influences both catch (Monteiro et al. 2021) and range of male and female green crabs (Fulton et al. 2013). Interestingly, beginning in September 2022, blue crabs (*Callinectes sapidus*) were found either exclusively in the traps or together with green crabs on many occasions throughout the remainder of the season.

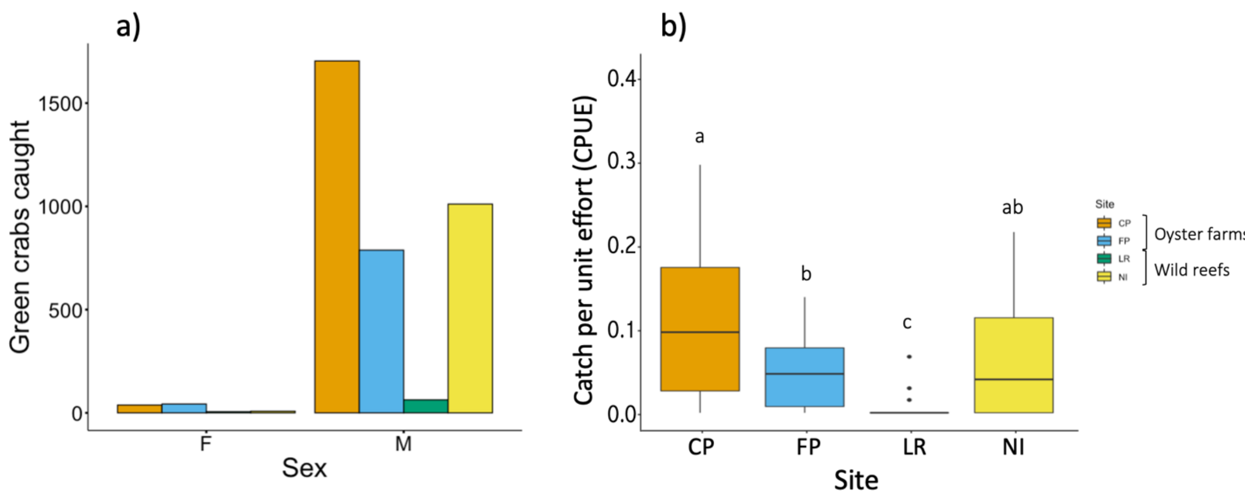

Figure GC-4. Plots showing a) the total numbers and b) the average CPUE of green crabs caught in GBE in 2021.Significant differences are denoted by different letters above each box. Site abbreviations as in Figure GC-1.

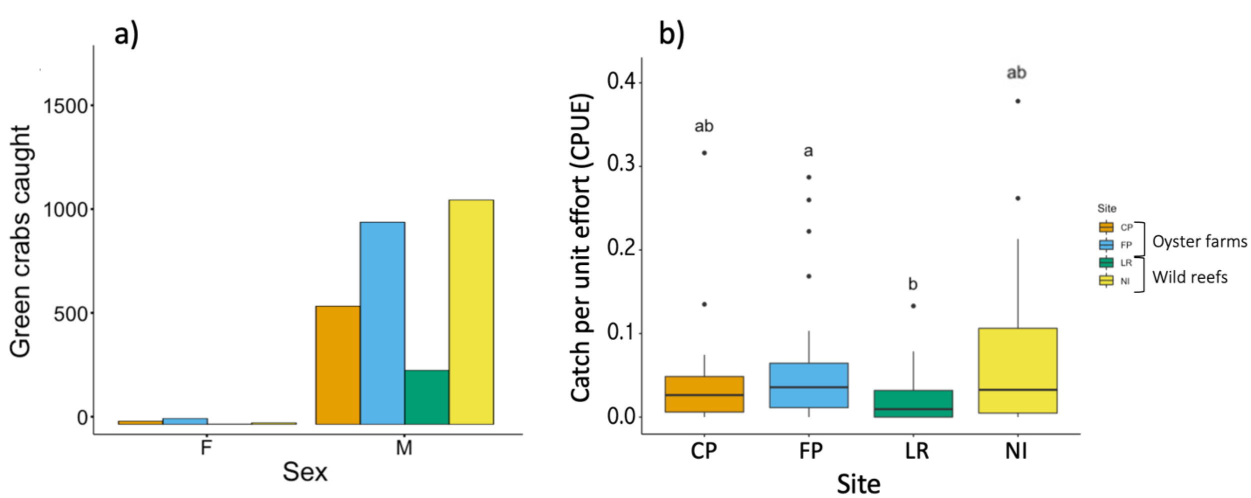

Figure GC-5. Plots showing a) the total numbers and b) the average CPUE of green crabs caught in GBE in 2022. Significant differences are denoted by different letters above each box. Site abbreviations as in Figure 1.

Work on this topic is relevant currently due to the lack of mitigation and population control methods of green crabs in this ecosystem. Modeling the abundance and distribution of green crabs will provide information of where these green crabs are, what time of year and where they congregate, differences between male and female crabs, and their activities and interactions at oyster farms, wild oyster reefs, and eelgrass beds (e.g., at Nannie Island).

Acknowledgements and Credit
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Horseshoe Crabs – Special Feature

Question:
Where and when do horseshoe crabs spawn in the Great Bay Estuary? How have numbers of crabs changed over time?

Short Answer
Since 2012, the number of horseshoe crabs counted in spring surveys has remained stable with notable increase in 2022. The ratio of male to females has increased steadily since 2012, though the reasons for this are not known. Recent spawning surveys indicate that spawning usually peaks in May with a smaller peak approximately two weeks later. Spawning takes place primarily on small beaches in the Great Bay Estuary but also on marshes and in tributaries.

Why Monitor Horseshoe Crabs?
Horseshoe crabs (Figure HC-1) are important for a number of reasons ranging from economic to ecological. While they are not fished in New Hampshire, more than 600,000 of them are captured and bled to obtain *Limulus* amoebocyte lysate, a valuable substance used by the biomedical industry to detect contamination of medicines. A large number of horseshoe crabs are also captured and used as bait by the whelk fishery. As a result of harvesting for both these purposes their population has declined, and there is concern for the survival of this species. Ecologically, horseshoe crabs are considered a keystone estuarine species primarily because they are key "bioturbators" as they forage in the marine mud for prey, they "turn-over" nearly all of the intertidal mud and bring nutrients to the surface (Lee 2010).

Figure HC-1. Female (larger, at left) and male horseshoe crab during spawning season in Great Bay Estuary. (Photo credit: Elizabeth Carroll)

In addition, horseshoe crabs, like many other species, might also be impacted by climate change. There is concern that warming waters and rising sea levels might impact both when and where these crabs are able to spawn. In locations like estuaries, these impacts might occur even sooner than along the coastline, and thus serve as early indicators that steps need to be taken to protect this species.

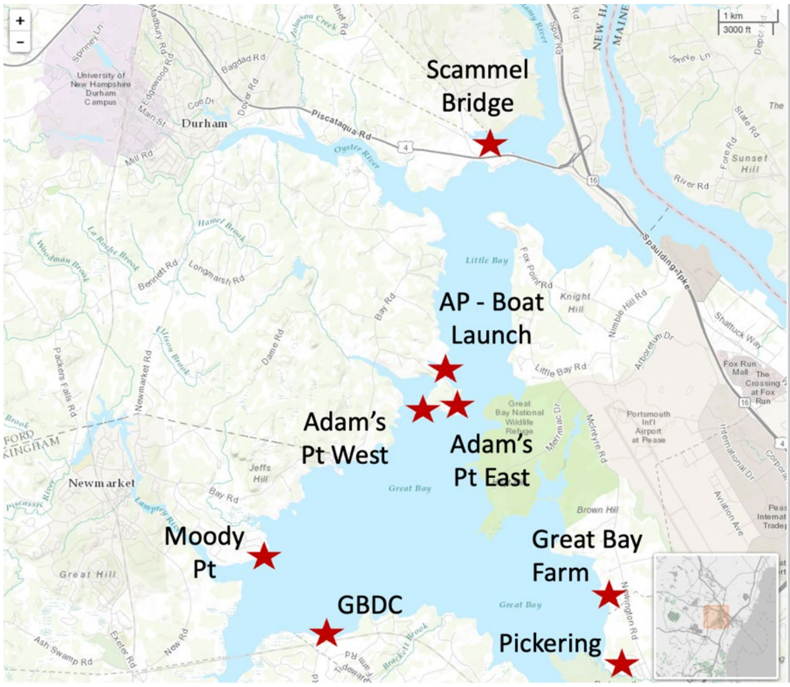

Figure HC-2. Map showing locations of horseshoe crab monitoring sites in the Great Bay Estuary.

Results

Horseshoe crab abundance and spawning is tracked at sites shown in Figure HC-2. Male to female ratios and abundance counts from 2012 to 2022 are shown in Figures HC-3 and HC-4. The ratio of males to females has increased steadily since 2012 while overall abundances have remained somewhat stable with a notable uptick in 2022. It is unclear why the male to female ratio is increasing. In states such as Massachusetts, females are preferentially harvested, which would impact the ratio, but harvesting is not allowed in New Hampshire.

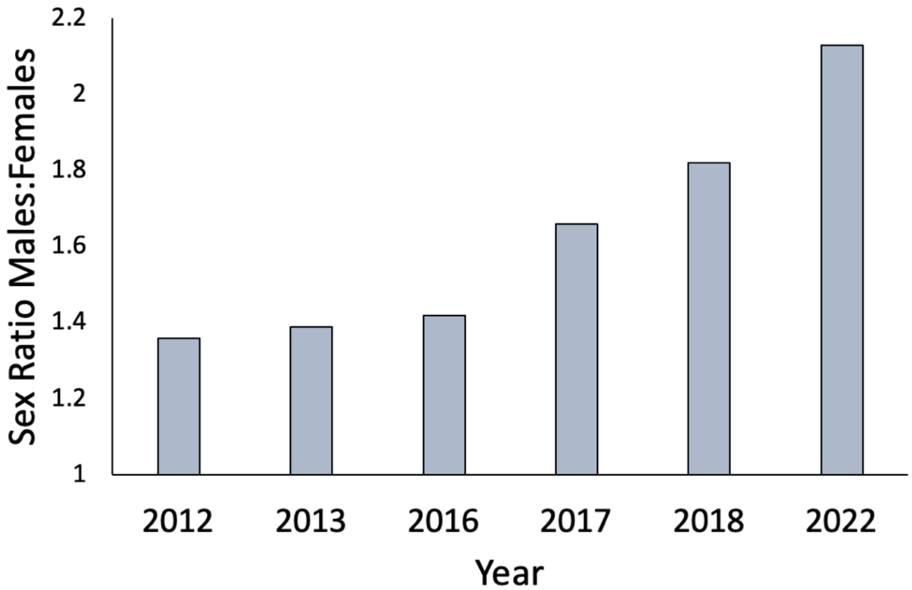

Figure HC-3. Male to female ratios of horseshoe crabs in the Great Bay Estuary.

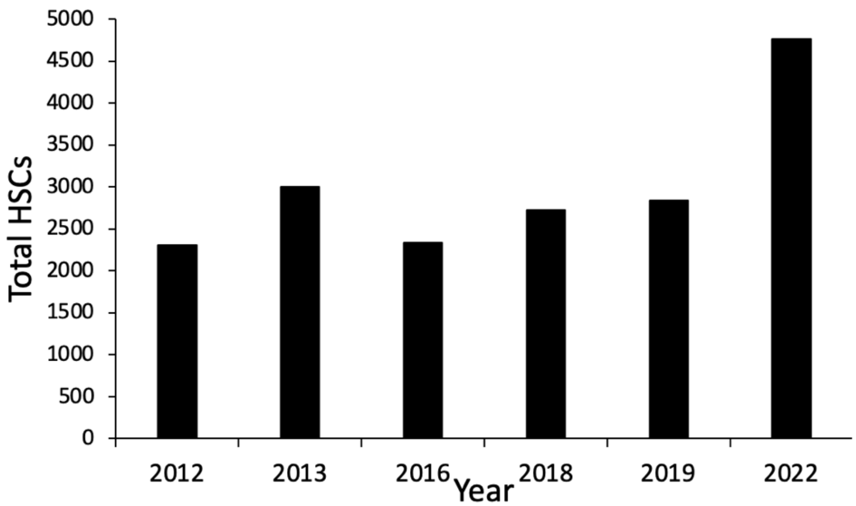

Figure HC-4. Total numbers of horseshoe crabs counted during Great Bay Estuary spring surveys.

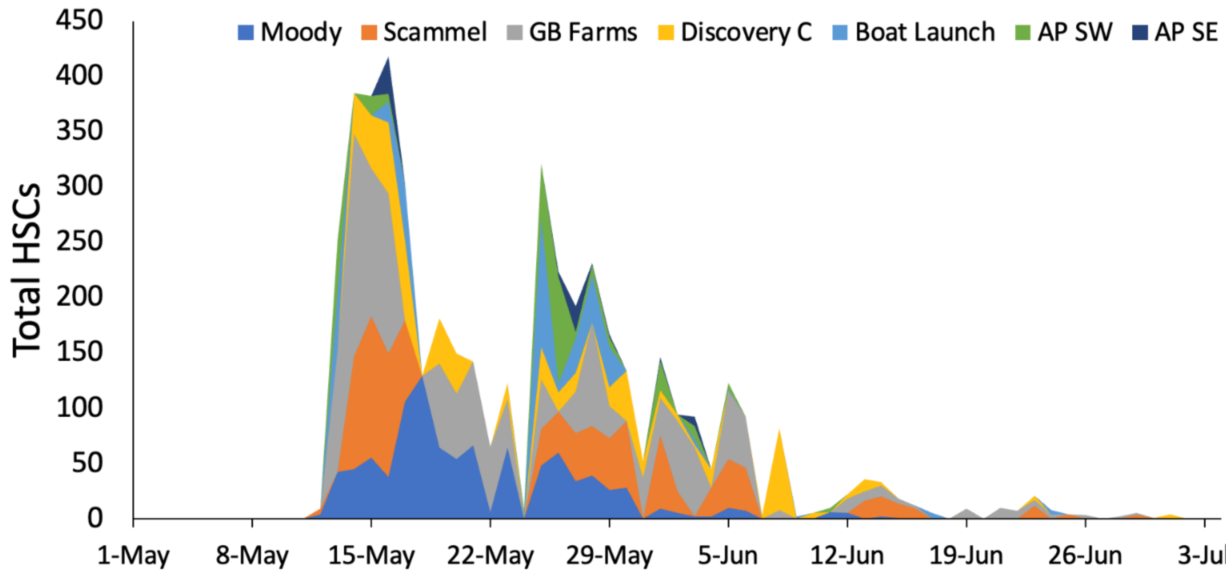

Figure HC-5. Horseshoe crab spawning survey results from 2022 in the Great Bay Estuary.

Volunteer-aided annual horseshoe crab spawning surveys have been conducted since 2016 (Figure HC-5). The goals of the survey are to determine: 1) What factors might coincide with the initiation of *Limulus* mating; 2) How long the mating season lasted and whether mating behavior coincided with the phases of the moon; 3) Where most of the spawning took place and if these locations coincided with the abundance of juvenile horseshoe crabs. Last year, scientists also began to map "alternative" mating locations (marsh grass) throughout the estuary to determine if eggs were laid in these areas and if the eggs survive as well as they do in traditional beaches.

Many of the horseshoe crabs that are present in Great Bay in the summer overwinter in the deeper channels found in Little Bay (Schaller et al. 2010; Watson et al. 2010). Then in the spring, when the water temperature exceeds ~12ºC, they move up into Great Bay in preparation for spawning (Watson et al. 2016). Typically, in May, when there are a series of warm days and the water temperature increases rapidly, spawning begins, leading to the first large surge in mating activity (Cheng et al. 2015, 2016). While lunar phase appears to be important in some horseshoe crab populations, breeding in Great Bay horseshoe crabs doesn't necessarily coincide with new or full moons. A given individual female typically spawns about 2-4 times in a week during the ~6-8 week breeding season (Owings et al. 2019; Watson et al. 2022). A second peak of breeding activity generally occurs 10-14 days after the first one and it is not clear what factors give rise to this second peak. While females often return to the same beach to spawn, they will also mate in several other locations in a given spring/summer. Some of the "most popular" locations in Great Bay appear to be: 1) Moody Point; 2) Great Bay Farm; 3) Pickering Creek and; 4) Adams Point (see Figure 2). While the greatest abundance of mating horseshoe crabs is usually observed on a handful of beaches in the Great Bay proper, mating has also been observed, and now confirmed, in a number of marshes and tributaries as well.

Horseshoe crab eggs hatch after about 3-4 weeks and the trilobite larvae stay in the water column for about 14 days. During this time the combination of currents and their movements up and down in the water column (Chabot et al. 2021), cause many of them to be carried up into Great Bay proper, and into various tributaries, where they settle to the bottom in the soft mud and metamorphose into 2nd instar juveniles. Thus, the greatest abundance of juvenile horseshoe crabs does not necessarily coincide with where spawning takes place (Cheng et al. 2021).

Methods and Data Sources

Spawning surveys were conducted by students, faculty, and volunteers during each daytime high tide in May and June. In one year, surveys were carried out during night high tides to test the hypothesis that more mating takes place during the night than the day. This turned out to be false and there are similar numbers of animals breeding during the day and the night tides in Great Bay. In most years, surveys were done at: The Great Bay Discovery Center, Moody Point, Adams Point, and the boat launch near JEL. At these locations, 50-100 meter transects were established and people walked the transect at high tide and counted all the horseshoe crabs seen from the edge of the water out to 2m from the edge. They also quantified the number of single males, single females, and pairs, with males attached to females. In 2022, the number of study sites was expanded to six and volunteers were also asked to note the number of male/female pairs that were buried and apparently actively mating.

Additional data outlined above were also obtained using a variety of acoustic telemetry methods and SCUBA diving was employed to survey juveniles throughout Great Bay and Little Bay. These methods are provided in the papers cited below.

Acknowledgements and Credit

Win Watson (UNH). Reviewers: Bonnie Brown (UNH), Jason Goldstein (Wells National Estuarine Research Reserve), Chris Chabot (Plymouth State University) and Chris Peter (Great Bay National Estuarine Research Reserve).

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Lobsters – Special Feature

Question:
To what extent do American lobsters use Great Bay Estuary as habitat?

Short Answer
Although lobsters (Figure L-1) are not as abundant in Great Bay Estuary as they are along the ocean coast of New Hampshire and Maine, they are abundant enough to support a significant fishery. Some lobsters migrate into and out of the estuary on a seasonal basis (Howell et al. 1999; Watson et al. 1999; Jury et al. 2018) and in response to storms that create a large freshwater runoff (Jury et al. 1995). There also is a resident population that reproduces, overwinters, and releases larvae in the Estuary (Goldstein 2012; Moore et al. 2020). Given the recent and large increase in the European green crab population, and signs that blue crabs might be expanding their range into northern New England estuaries as well (Stasse et al. 2023), it is important to understand how these invasive species might impact the commercially and ecologically important lobsters.

Figure L-1. An American lobster (*Homarus americanus*) in the Piscataqua River. (Photo credit: Ben Gutzler)

Why Monitor Lobsters in Great Bay Estuary?
American lobsters are the most valuable single species fishery in the USA and still support a viable fishery within Great Bay Estuary. Data collected over the past 40 years have demonstrated that, although there is exchange of adults and larvae with New Hampshire coastal habitats (Goldstein 2012; Moore et al. 2020) there also are lobsters in Great Bay Estuary that reproduce

and likely contribute new recruits (Figure L-2, Moore et al. 2020). Furthermore, a certain portion of these new recruits might also be transported to, and settle along, the coast. Therefore, Great Bay Estuary is an important overall component of the New Hampshire lobster habitat.

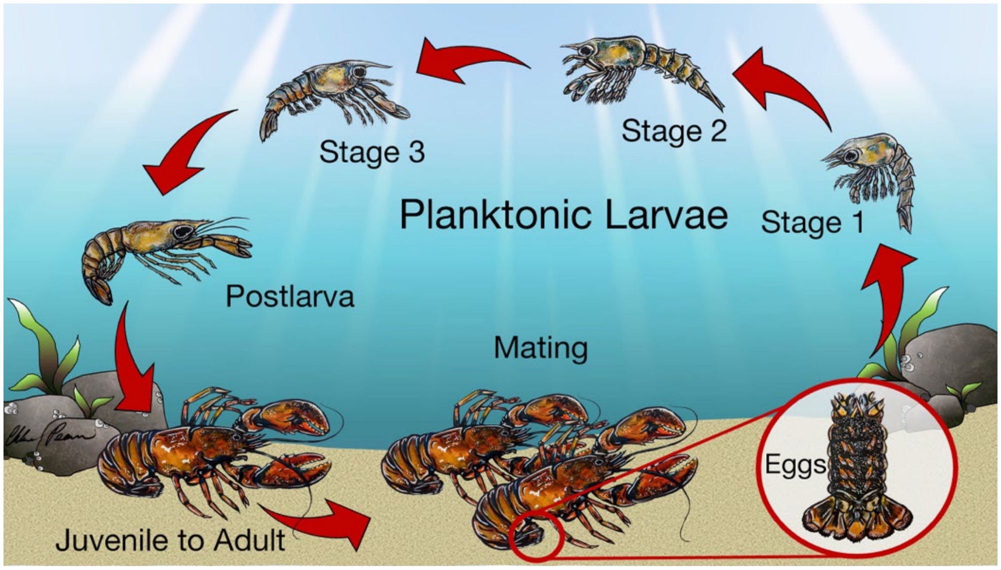

Figure L-2. The life cycle of an American lobster. It takes roughly one month for the planktonic larvae to develop through all four stages and settle to the bottom. It then takes juveniles about 5-7 years to reach sexual maturity. As adults, they can live for more than 10 years. (Artwork used with permission of Chloe Pearson).

In the last 10+ years, the population of the invasive European green crab (*Carcinus maenas*) has steadily increased in Great Bay Estuary (Fulton et al. 2013; Goldstein et al. 2017) and it would not be surprising if they outnumber all the other crustaceans (Figure L-3). When comparing Little Bay sites (Goat Island and Fox Pont) to Great Bay sites (Adams Point and Nannie Island), there are significantly more lobsters in Little Bay during both years ($W = 56.36$, $P < 0.0001$). During 2014 (but not in 2013), more green crabs were captured at Great Bay sites than Little Bay ($W = 33.734$, $P = 0.0001$). Generally, there was a higher relative abundance of crab than lobster.

Whether green crabs impact lobsters is uncertain at the present time, but it is worth investigating. In addition, there are also sporadic reports of blue crabs (*Callinectes sapidus*) in the estuary, and their sustained presence may have interesting impacts on lobsters and green crabs. To maintain a sustainable lobster population in Great Bay Estuary, it will be important to learn more about how these three large crustaceans interact with each other and how they impact the overall estuary system.

The first studies of lobsters in Great Bay Estuary were published in the 1990's. These investigations documented their seasonal migrations and environmental factors, such as water temperature and salinity, that likely influence their movements (Jury et al. 1994a, b; Jury and Watson 1995; Crossin et al. 1998; Howell et al. 1999; Watson et al. 1999; Jury and Watson 2000; Dufort et al. 2001). More recently, studies of mature females carrying eggs (a.k.a. ovigerous or "berried" lobsters) showed that they overwinter in the Estuary and, because the Estuary warms up faster than the coast, their eggs hatch in the spring (Figure L-4), about a month earlier than the eggs from coastal lobsters (Moore et al. 2020). Some of these larvae are likely retained in the Estuary, but some probably make their way to the New Hampshire coast as well.

Given that female lobsters in Great Bay Estuary reach sexual maturity at a smaller size than those along the coast (Little and Watson 2003), more of them are able to reproduce before they can be taken by the fishery, and thus the Estuary may be an important source of recruits to New Hampshire waters.

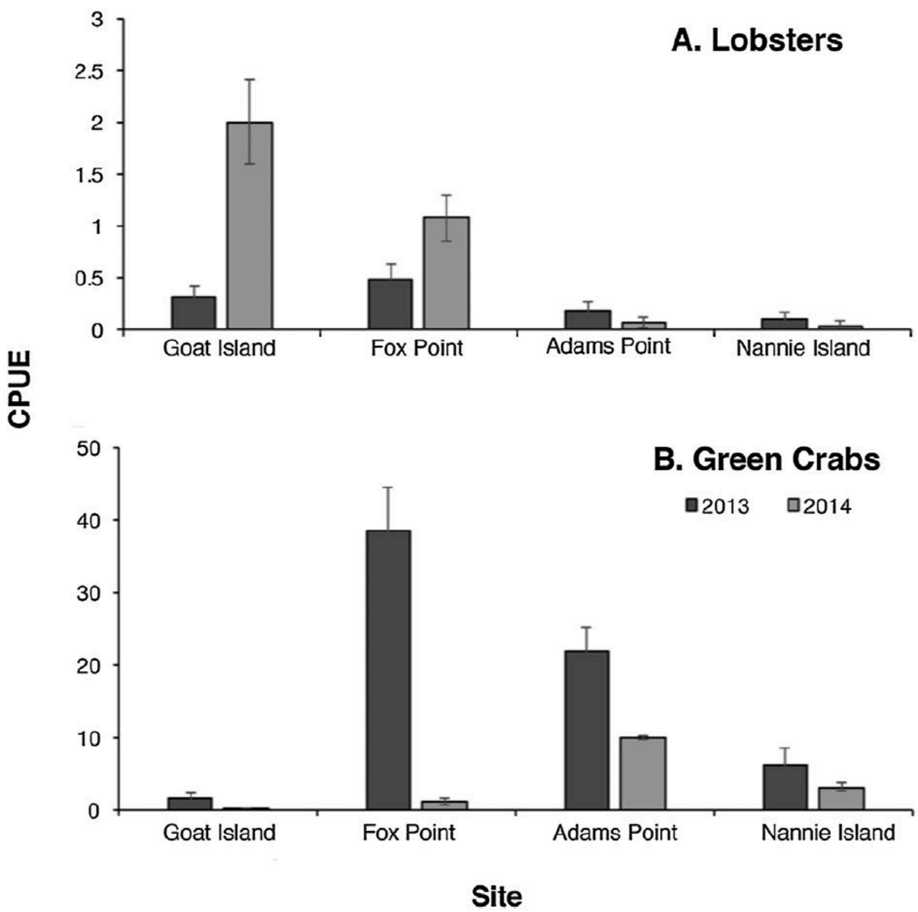

Figure L-3. Catch-per-unit-effort (CPUE) for lobster (top graph) and green crab (bottom graph) in each of two surveyed years (2013 and 2014); here, CPUE refers to the numbers of animals present in a pulled trap. Note difference in scale between Lobsters and Green Crabs figures. Data from Goldstein et al. 2017.

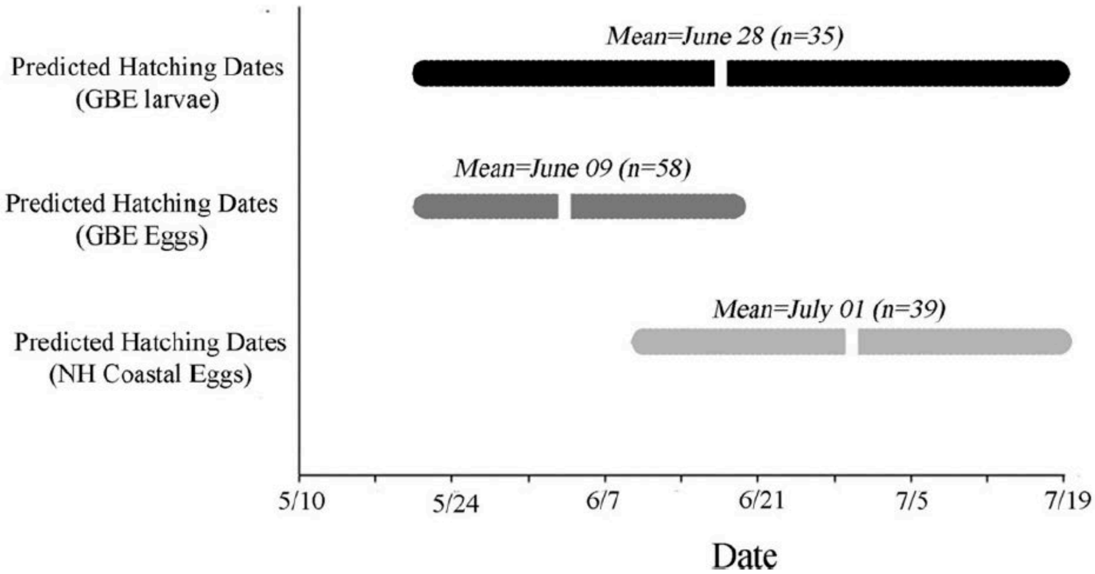

Figure L-4. The predicted hatch dates of eggs collected in 2015 from ovigerous lobsters (black bars) captured during sea sampling trips in Great Bay Estuary (black bars) and the coast (light gray bars), compared with the predicted hatch dates of larvae captured in plankton tows in the Estuary (dark gray bar). Data from Moore et al. 2020.

Data Sources

The dominant sources of information for this summary were publications by UNH faculty members and their graduate and undergraduate students (Watson, Howell, Fairchild, Brown). The work was funded primarily by NH Sea Grant and NHAES.

Acknowledgements and Credit

Win Watson (UNH). Reviewers: Bonnie Brown (UNH), Jason Goldstein (Wells National Estuarine Research Reserve), and Chris Peter (Great Bay National Estuarine Research Reserve).

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pH, Salinity, Wind, PAR – Supporting Variables

Question:
How have estuarine pH, salinity, wind speed, wind direction, and photosynthetically active radiation (from sunlight) changed over time in the Great Bay Estuary and Hampton-Seabrook Estuary?

Short Answer
The statistical significance of trends is impacted by the particular duration (start and end points) of the time series. For most of the supporting variables' data, the data collection ends in 2021 and begins in 2003, just as an increase in precipitation was beginning; this period of greater rainfall ended after 2010. Precipitation patterns will impact or correlate with all the variables examined here. In examining these data, it can be enlightening to consider how trends would change if the time series began in either 1990 or 2011, as opposed to a lengthy period of higher than normal precipitation.

The examined period has seen increases in pH, salinity, and photosynthetically active radiation from sunlight (PAR). An increase in pH is contrary to the trend for oceans in New England, but this reflects a broader pattern of well-mixed estuaries seeing increased alkalinity due to minerals being loaded into waters from the watershed. Also, atmospheric pH has increased (gotten less acidic) due to Clean Air Act regulations decreasing acid rain.

Wind speed has increased in April and decreased in September; otherwise, no trends are evident. Wind direction shows no clear pattern with wind coming out of the south-southwest most often; the record also shows some anomalous years in 2012 when the direction shifted to the south and recent years as the wind has shifted to the west.

Why We Track these Variables
pH indicates the concentration of hydrogen ions in water and is impacted by natural processes and human pollution. Estuaries are interesting with regard to pH because oceans have been experiencing decreasing pH levels (more acidic water) while estuarine waters are becoming less acidic due to lower pH in rain and watershed runoff.

Regardless of the causes of fluctuations, pH is important for both animals and plants. Most organisms in estuaries are adapted to a specific range of pH and significant shifts in that range can cause stress. Decreasing pH poses challenges for organisms like clams, blue mussels and lobsters, which require higher pH to build their calcium carbonate skeletons. Regarding eelgrass, some studies have indicated that carbon limitation, especially in high pH and warm water, could be a cause for eelgrass loss.

Salinity in an estuary reflects the mixing of freshwater (salinity = 0 parts per thousand or ppt) and oceanic water (salinity = 33 ppt), with salinity generally trending lower as one proceeds upstream away from the ocean. While some estuarine plants and animals are tolerant of broad swings in salinity, other organisms can be quite sensitive to salinity shifts. Salinity is an important variable for understanding hydrodynamics in estuaries because salt water is heavier than fresh water.

Wind speed and direction impact currents and mixing in estuaries, which in turn impacts indicators such as dissolved oxygen, turbidity, total suspended solids and light attenuation. Therefore, changes in wind can have a significant impact on ecosystem health. In general, wind speed has more of an influence on water quality than wind direction; wind direction becomes more important in estuaries as tidal velocity decreases, such as in the areas in the Great Bay that are far from the channel.

Photosynthetically active radiation (PAR) from sunlight drives photosynthesis in estuaries, which determines how productive an ecosystem is. PAR is not to be confused with light attenuation and turbidity, which are other ways of measuring how light is lost or scattered underwater. Even with increasing PAR, for example, a system could have increased turbidity and reduced light at depth, and reduced light at depth if there are increases in total suspended solids, plankton or colored dissolved organic matter.

Explanation: pH

pH: Data Results

Monitoring in the ocean zone of the Gulf of Maine shows a decreasing trend for pH with most recent values averaging pH 8.1. In Hampton-Seabrook Estuary, the average pH since data collection began in 2018 is 7.8 (Figure pH-1). Despite the short time series, the trend shows a significant decrease.

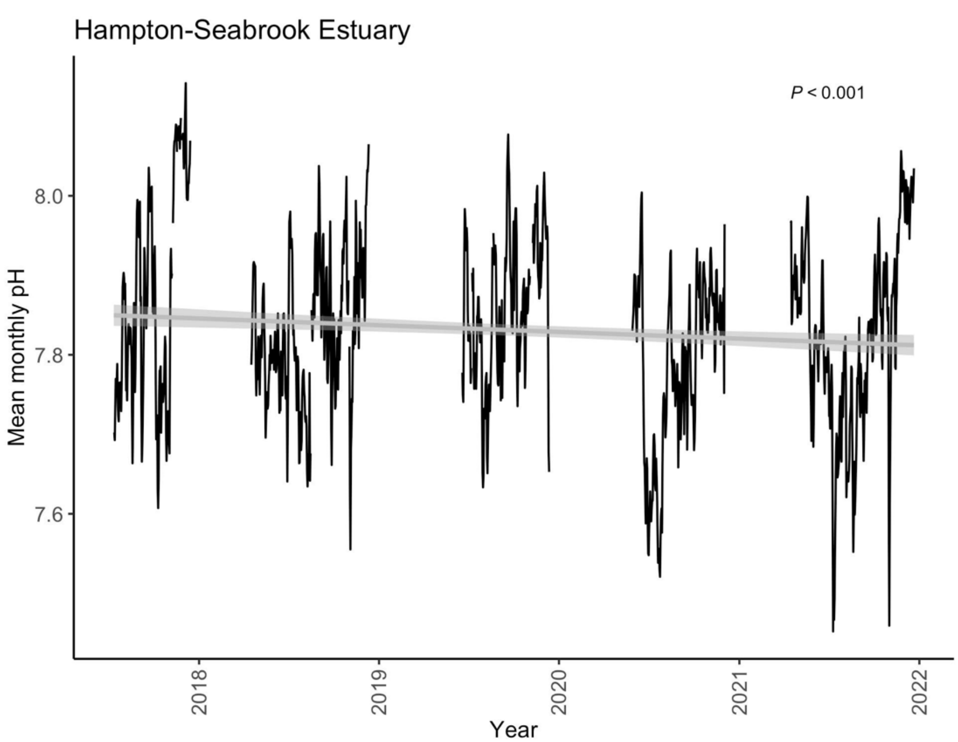

Figure pH-1. pH at the Hampton River station in the Hampton-Seabrook Estuary. Data collection at this station began in 2018. The curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model.

In the Great Bay Estuary, mean annual pH data collected since 2003 show statistically increasing trends in pH at four sites (Figure pH-2): Great Bay, Lamprey River, Oyster River, and Squamscott River. Three of the sites show recent pH values between pH 7.5 - 8.0, whereas Lamprey River is below pH 7.5. Drilling in by month at two sites (Great Bay and Oyster River, Figure pH-3), we see significant increases over time.

pH: Discussion

In general, pH 6.5 to 8.5 is the optimum healthy range for estuarine organisms. For oysters, pH 6.7 is considered severely acidic and associated with increased mortality. For the American Lobster, between 7.6 - 8.1 is considered a healthy range. In experiments at UNH's Coastal Marine Laboratory, it was found that lobsters reacted to food more slowly when pH was less than 7.5, suggesting their senses were negatively affected by acidified conditions (Gutzler 2019).

Since 2005, pH levels throughout the Great Bay Estuary are higher than 7.5, with the exception of the tidal Lamprey River station. Trends in the Great Bay Estuary show increasing pH levels—at least since 2005—which is the opposite of what is seen in the ocean where pH levels have decreased over the past decades. These data a reflect a broader trend seen throughout estuarine and river systems along the North American East Coast. Many estuaries heavily influenced by land use and watershed processes show an increase in pH and alkalinity. In addition to recovery from acid rain (Kaushai et al. 2013), climate patterns are increasing the amount of minerals washing into the estuary, which in turn increases alkalinity, defined as the ability of a system to resist acidification or reduced pH (Kaushai et al. 2013).

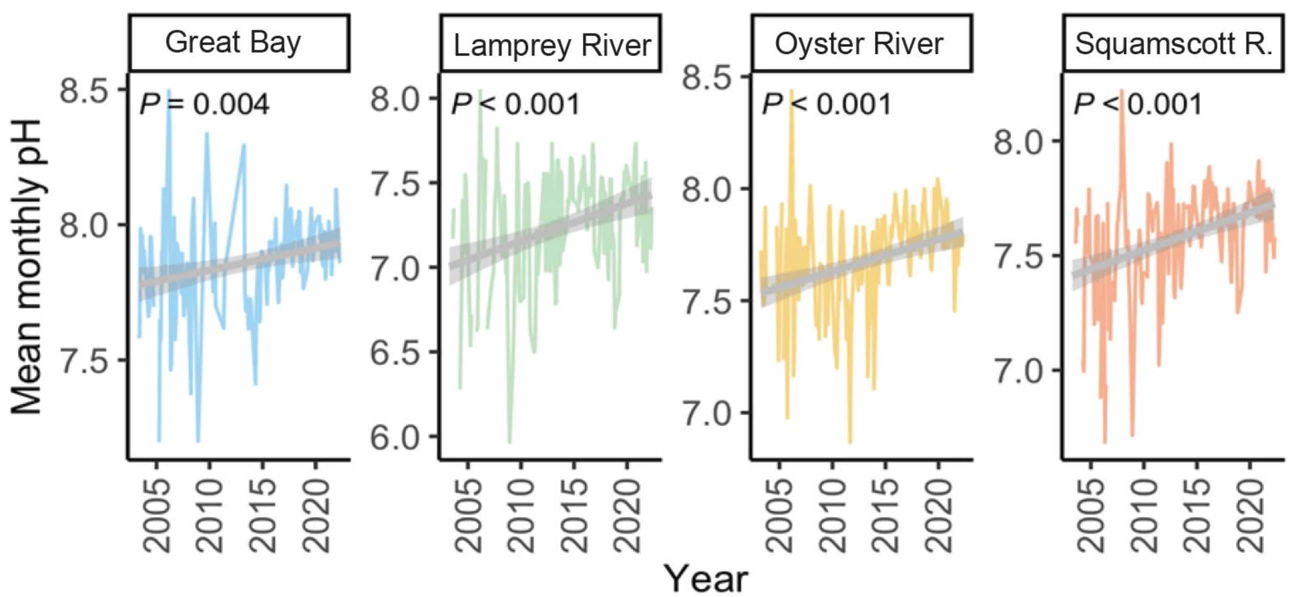

Figure pH-2. Mean monthly pH at four representative sites in the Great Bay Estuary. Each curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model. Each P value indicates whether the slope of the curve is significantly different from zero.
Data Source: UNH Jackson Estuarine Laboratory.

Ecosystem metabolism also affects pH levels. Increased photosynthesis from more seagrass, plankton or seaweed biomass tends to drive pH up, especially in well-mixed systems like the Great Bay Estuary. When not well-mixed, plant and animal respiration and microbial processing of organic matter can lower dissolved oxygen and pH, especially in bottom waters (Van Dam and Wang 2019). Note that the Lamprey River, less well-mixed than others and often seeing low dissolved oxygen levels, has the lowest pH.

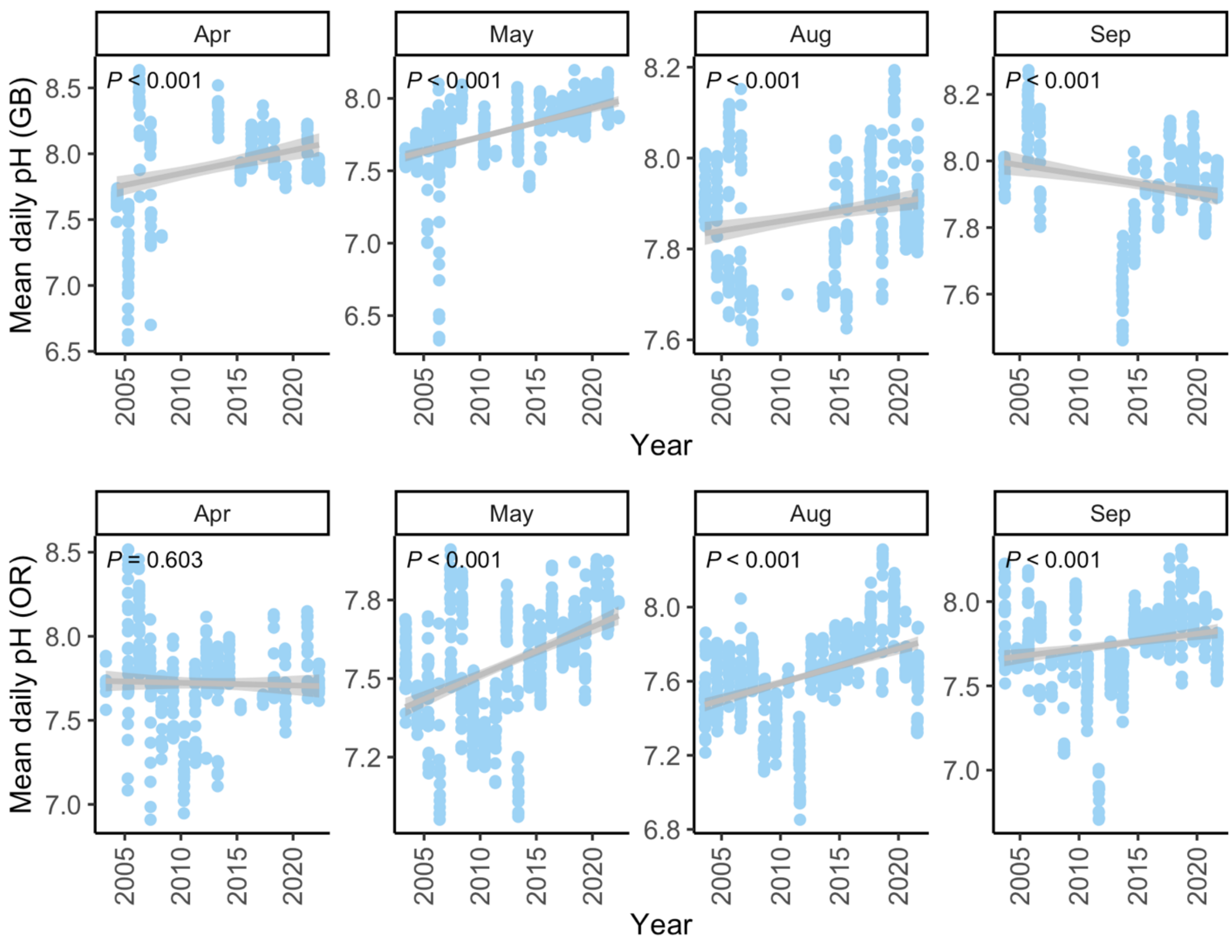

Figure pH-3. Mean daily pH at two representative sites in the Great Bay Estuary: OR = Oyster River and GB = Great Bay, for 4 months spanning the growing season seagrass and seaweed. Each curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model. Each P value indicates whether the slope of the curve is significantly different from zero.
Data Source: UNH Jackson Estuarine Laboratory.

Explanation: Salinity

Salinity: Data Results/Discussion

At Adams Point, where the time series begins in the late 1980s, the data indicates a decrease in salinity beginning around 2006, with some higher values in recent years (Figure S-1). Notice that until 2006, coincident with a lengthy period of high precipitation and watershed runoff between 2005 and 2010, with a few higher values in recent years (Figure S-1). Prior to 2006, only three data points were lower than 22 ppt whereas after 2006, there are eight instances of annual mean salinity lower than 22 ppt. The other three sites shown in Figure S-1 (from Great Bay, Upper Piscataqua River and Coastal Marine Laboratory) also show a significant increase in salinity for the time series beginning in 2003.

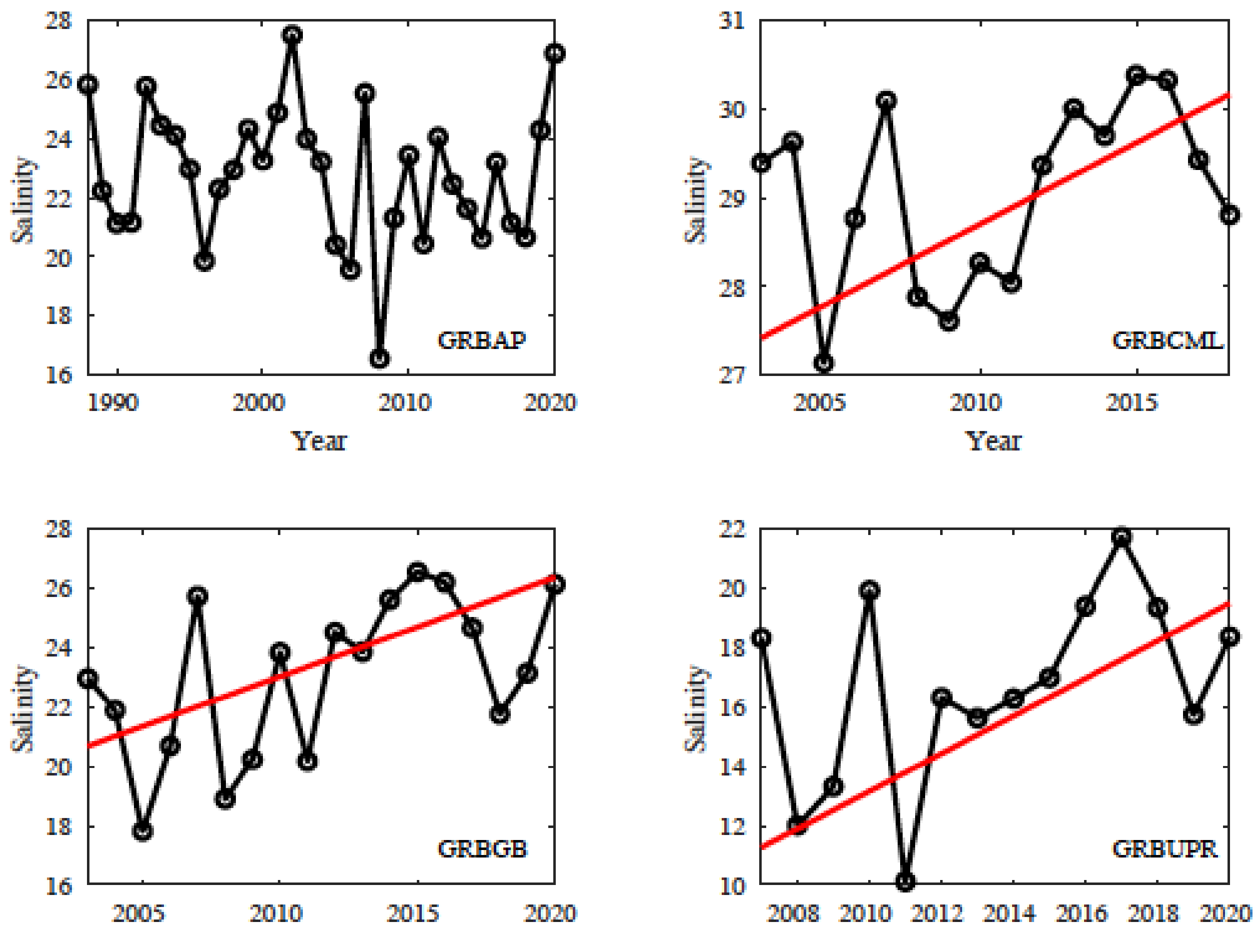

Figure S-1. Annual mean of salinity measured at 4 representative stations in the Great Bay Estuary during sampling that took place on a monthly basis primarily from April to October. GRBCML = Coastal Marine Laboratory at the mouth of Portsmouth Harbor; GRBGB = Great Bay in the middle of Great Bay, south of Adams Point; GRBUPR = Upper Piscataqua River, located between Dover, NH and Eliot, ME north of the General Sullivan Bridge. Trends ($p < 0.05$) are shown using Kendal-Theil robust lines (red). No trend for GRBAP was detected.
Data Source: UNH Jackson Estuarine Laboratory.

Explanation: Wind Speed

Wind Speed: Data Results/Discussion

Monthly mean wind speed shows no clear trend since 2003 (Figure WS-1). Data analysis on a finer monthly scale, however, Figure WS-2 shows that wind speed in September has decreased significantly over the last 20 years, and wind speed in April has increased, though not significantly so at the *P*<0.05 significance threshold.

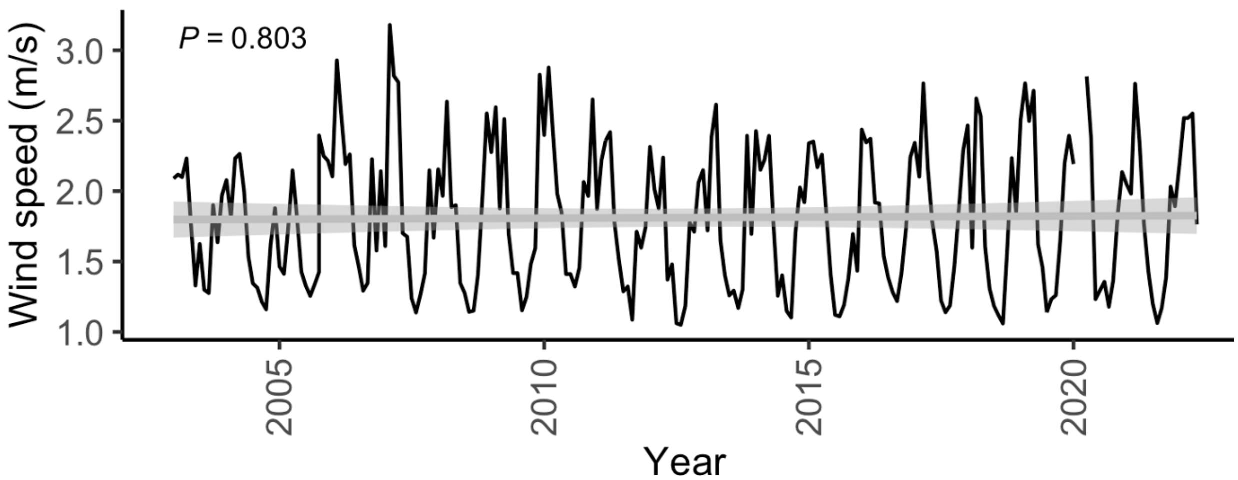

Figure WS-1. Wind speed measured at the Greenland, NH weather station. The curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model. The P value indicates whether the slope of the curve is significantly different from zero.

Data Source: Centralized Data Management Office, National Estuarine Research Reserve System.

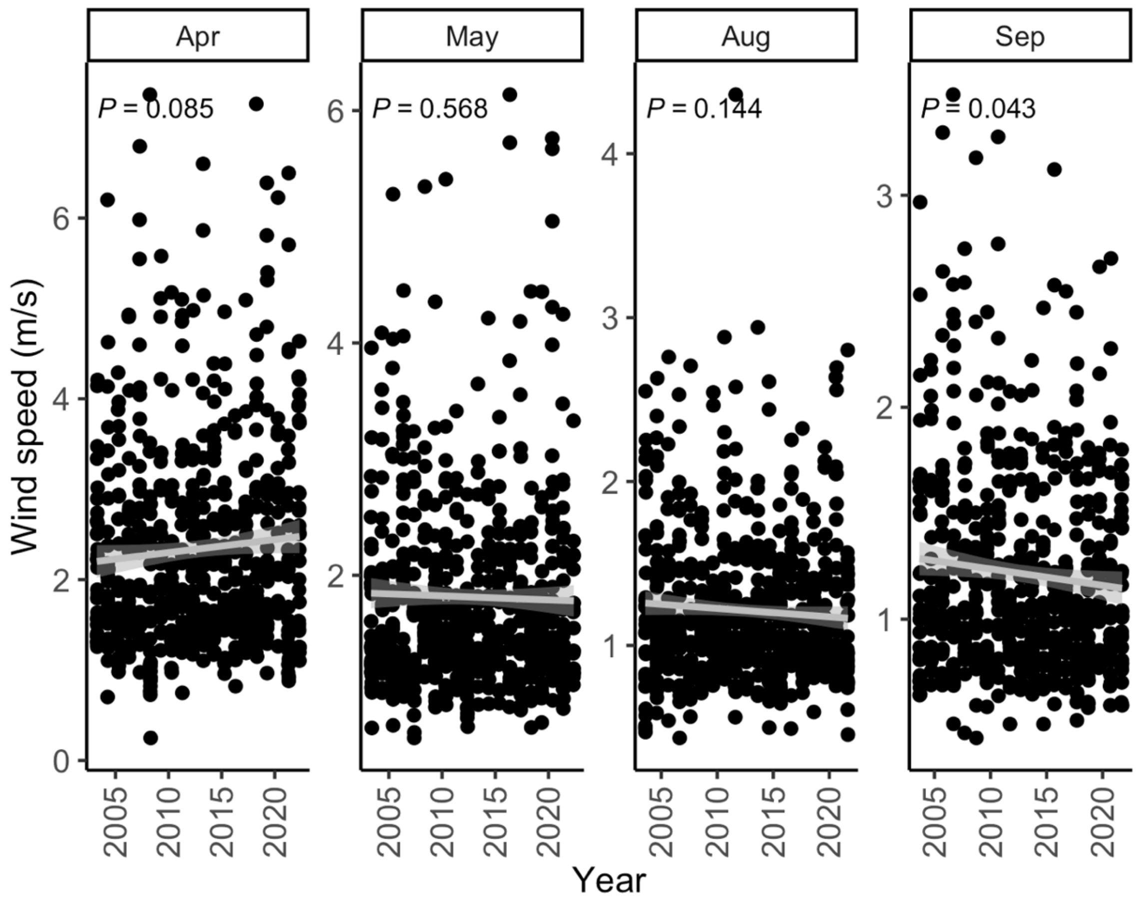

Figure WS-2. Wind speed by month from the Greenland, NH weather station. Each curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model. Each P value indicates whether the slope of the curve is significantly different from zero.

Data Source: Centralized Data Management Office, National Estuarine Research Reserve System.

Explanation: Wind Direction

Wind Direction: Data Results

Data from the Great Bay meteorological station in Greenland, NH indicate that the dominating wind direction in Spring and Summer—considered the main part of the growing season for seagrass—is between 180 and 200 degrees, corresponding to wind coming out of the south-southwest (Figure WD-1). In recent years, during the spring, wind direction has shifted from the west. It is also notable that between 2011 and 2013 there was a dramatic shift in wind direction when the wind blew primarily from the southeast.

Wind Direction: Discussion

If it were to be observed, a significant change in direction could impact fetch, which in turn could cause significant changes in flow and erosion. Global atmospheric patterns, including the

El Niño and La Niña cycles, impact wind direction and speed. Much more data would be necessary to discern clear trends.

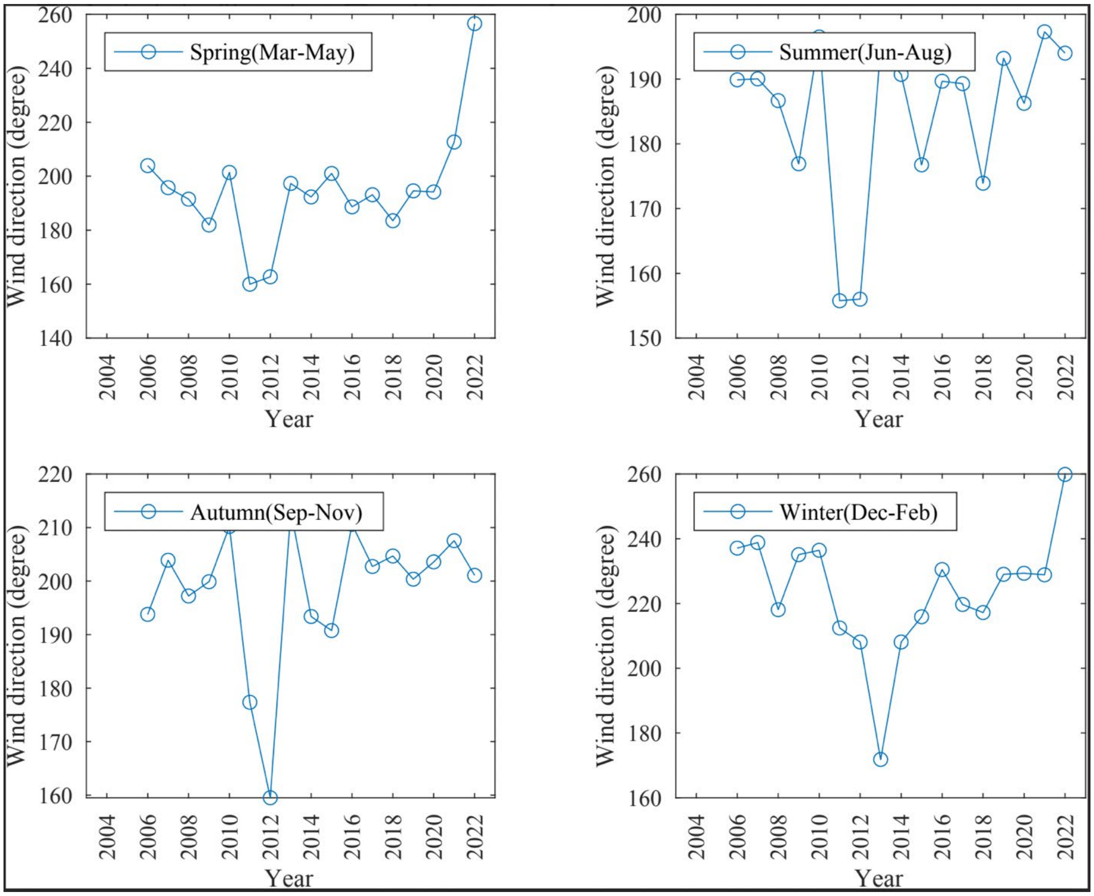

Figure WD-1. Wind direction by season using data collected from the Greenland, NH weather station. The original data with 15-minute intervals within a month were first used for generating monthly mean data. Given that an internannual variability is not necessarily represented by data in a single month, seasonal data with three months were instead calculated. No significant trends were detected.*Data Source: Centralized Data Management Office, National Estuarine Research Reserve System.*

Explanation: Photosynthetically Active Radiation (PAR)

PAR: Data Results/Discussion

Since 2003, monthly mean PAR levels have increased, *albeit* not significantly so (Figure PAR-1). Looking at means on a finer monthly scale, however, shows that PAR in May, August, and September have increased significantly (Figure PAR-2). As for other supporting variables, the increase in PAR over this time period must be examined in the context of when the time series began: in this case, during a time of elevated precipitation levels, which would correspond with more clouds and less sunlight.

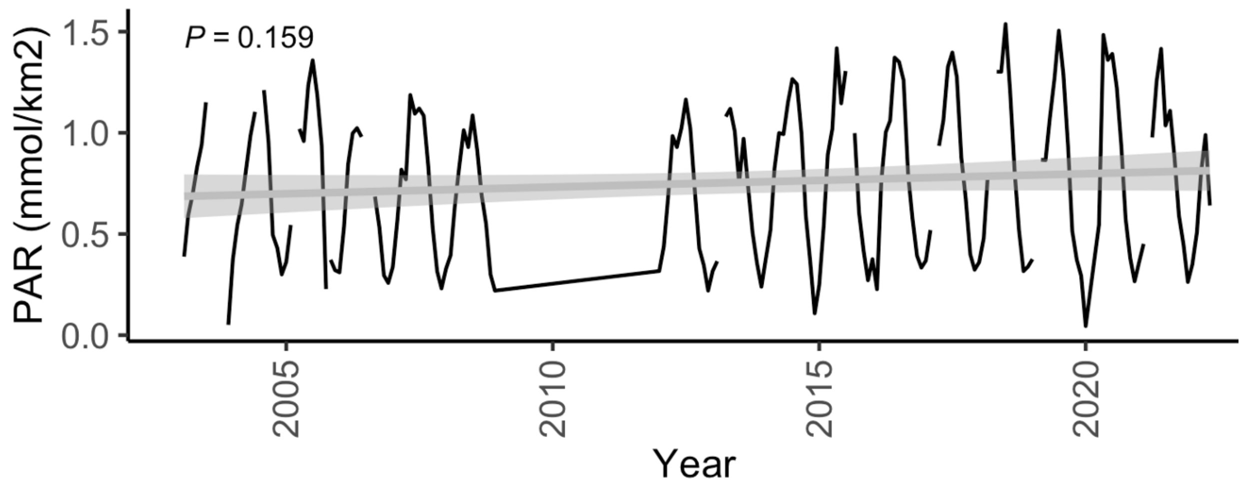

Figure PAR-1. Monthly photosynthetically active radiation (PAR). Data collected from the Greenland, NH weather station. The curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model. The P value indicates whether the slope of the curve is significantly different from zero.
Data Source: Centralized Data Management Office, National Estuarine Research Reserve System.

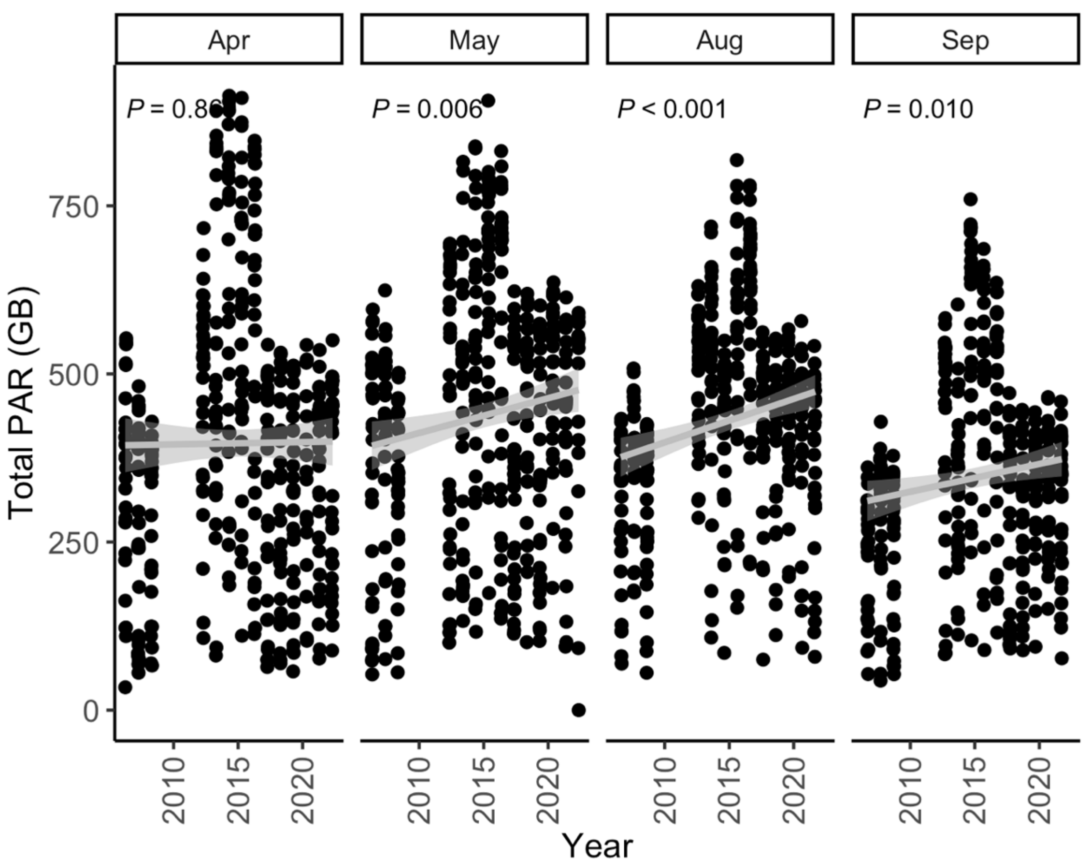

Figure PAR-2. PAR data collected from the Greenland, NH weather station. Each curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model. Each P value indicates whether the slope of the curve is significantly different from zero.
Data Source: Centralized Data Management Office, National Estuarine Research Reserve System.

Acknowledgements and Credit
Kalle Matso (PREP). Figures and analysis contributions from Florencia Fahnestock (UNH), Easton White (UNH), Wilton Burns (UNH), and Atsushi Matsuoka (UNH). Reviewed by: Bonnie Brown (UNH), Wil Wollheim (UNH), and Chris Hunt (UNH). Also reviewed by Simon Courtenay (University of Waterloo, Canada).

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Precipitation – Supporting Variable

Question:
How has precipitation in the Piscataqua Region Watershed changed over time?

Why We Track Precipitation

Precipitation has a significant impact on the health of our watershed and our estuaries. Precipitation directly affects what is "loaded" into our tributaries and, thus, our estuaries. For example, light penetration in estuaries is significantly influenced by precipitation levels because rainfall impacts the three main components that attenuate (i.e., decrease) light penetration: algae, total suspended solids, and colored dissolved organic matter. Therefore, increased precipitation decreases photosynthesis underwater due to the decreased light penetration. In addition, precipitation affects salinity and temperature, which in turn impacts the health of a host of organisms, including shellfish and migratory fish.

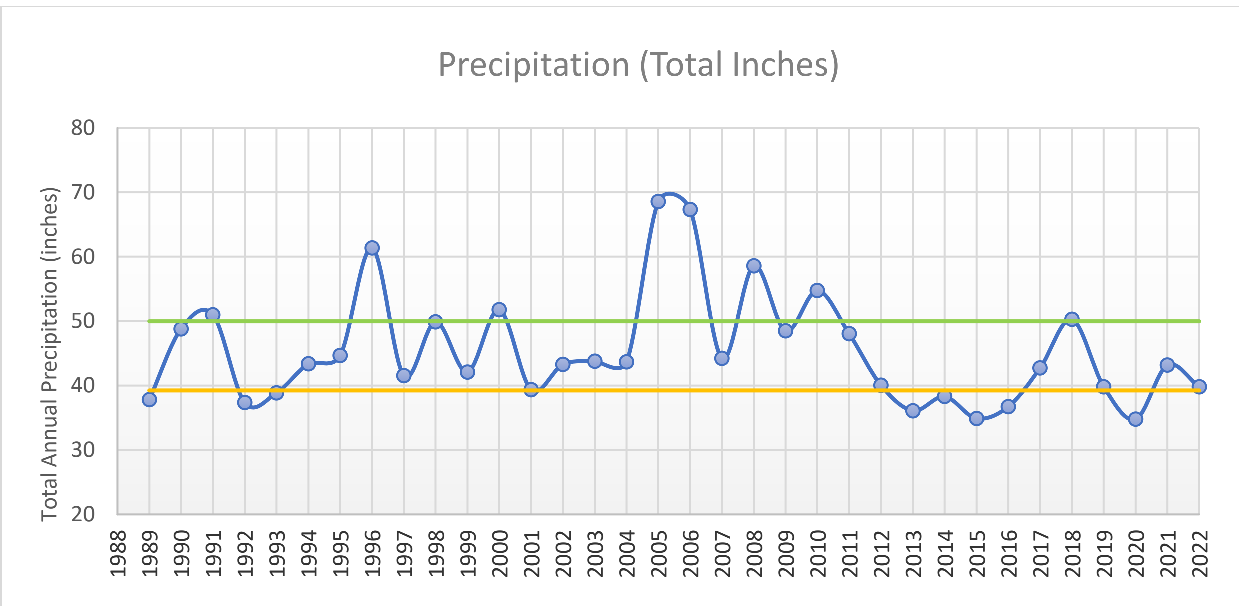

Figure P-1. Total annual Precipitation measured in inches at the Pease Airport station in Portsmouth, NH. The green line represents the 75th percentile of the data while the yellow line shows the 25th percentile. Thus, the area between the lines depicts the middle 50% of the measurements.

Explanation/Discussion

The precipitation record (Figure P-1) shows increased variability beginning in 2005, which began a 5-year period of much higher precipitation than the previous 15 years, except for 1996. Since 2012, precipitation levels have been lower and slightly less variable, except for 2018. Lower amounts of precipitation have contributed to two extreme droughts in our region, one in 2016 and one in 2020 (Source: https://droughtmonitor.unl.edu/). Drought is determined by looking not only at precipitation but also streamflow, temperature, evaporative demand, water content in the soil, and vegetation health.

Variability in annual precipitation also affects the variability of non-point source nitrogen loading. During the previous 5-year reporting period (2012 to 2016), annual precipitation was at or below the bottom 25th percentile in all 5 years, which has never happened at any other time in this data record. This consistently low annual precipitation was a primary factor in non-point source nitrogen loading being at its lowest level on record during the 2012 to 2016 period. During the 2017 to 2020 period, precipitation was at or below the bottom 25th percentile in 2 of the 4 years, but at the 75th percentile in 2018. The combination of low precipitation in 2012 to 2016 and low to moderate precipitation in 2017 to 2020 resulted in the 2017 to 2020 average non-point source nitrogen loading increasing by 15% when compared with the previous five years (2012 to 2016).

Methods

In the figure above, the data are from one source only: the Pease Airport (Portsmouth) weather station. However, precipitation has been quantified in various ways over the years and even within the 2023 State of Our Estuaries Report. For example, in previous years and in the "Eelgrass" section of this report, data from the Pease and Greenland stations were combined into an average. The most notable result of averaging the data is a much lower amount of precipitation reported for 2015 (mainly due to missing data at the Greenland station). Therefore, as of May 2023, PREP staff now believe it is more accurate to show this time series with only the Pease station data, as shown above and in the nitrogen loading sections of the Report, but not the Eelgrass section.

Acknowledgements and Credit

Written by Kalle Matso (PREP), with contributions from Michelle Shattuck (UNH) and Miguel Leon (UNH).

Eelgrass and Seaweed Biomass (from Tier 2 Monitoring) – Supporting Variable

Question:
How does total eelgrass biomass (above and belowground) and seaweed biomass vary at 25 sites throughout the Great Bay Estuary?

Short Answer
Biomass (the dry weight of above and belowground eelgrass plant material per unit area) assessments are based on sampling within randomly chosen eelgrass meadows, throughout the Great Bay Estuary. In 2021 and 2022, the eelgrass meadows in Portsmouth Harbor tended to have more biomass than those in other locations. However, there may still be more biomass total in Great Bay due to the abundance of shallow habitat where eelgrass can grow.

Seaweed biomass (dry weight per unit area; seaweed grows only aboveground) is slightly higher in Portsmouth Harbor than in Great Bay and Little Bay/Piscataqua River sites, though the differences are small in the context of the variability.

Why We Track Eelgrass and Seaweed Biomass
Eelgrass, *Zostera marina*, is an aquatic vascular flowering plant. It is considered critical estuarine habitat and an excellent indicator of overall ecosystem health, due to its sensitivity to light, which is strongly influenced by loadings of nutrients and sediments. Although many eelgrass metrics are possible (e.g., percent cover, density), biomass (the mass of eelgrass above and below the sediment) per unit area is considered one of the most accurate and direct indicators of habitat health (Krause-Jensen et al. 2004).

Some seaweeds (e.g., *Fucus vesiculosis* and *Ascophyllum nodosum*, both often referred to as "rockweed") also provide excellent habitat for juvenile shellfish and other organisms. Rockweed are generally associated with rocky substrates, to which they attach, while eelgrass is generally found on sandy or silty substrates. Some green seaweeds (such as *Ulva lactuca* or sea lettuce) and red seaweeds (such as *Gracilaria vermiculo*phylum) can be anywhere because they can be attached or free-floating. (In the analysis below, the brown seaweeds have been taken out since most brown seaweeds are not indicative of poor ecosystem health.) However, proliferation of other species of seaweeds in the sub-tidal estuarine zone is often an indication of an ecosystem out of balance, frequently because of excessive nutrient and sediment loading and exacerbated by warming water temperatures. (Warming water is also a concern because it impacts eelgrass health regardless of seaweed abundance.)

Therefore, the Tier 2 Monitoring protocol was introduced in 2021 to better track the condition of subtidal eelgrass and the green and red seaweeds, which are often indicative of ecosystem problems, at 25 sites in the Estuary (Figure T-1). There are now three tiers to eelgrass/seaweed monitoring: Tier 1 assesses the distribution of habitat throughout the Estuary; Tier 2 assesses the abundance of eelgrass and seaweed by sub-sampling throughout the Estuary; and Tier 3 examines a host of detailed health metrics at the exact same location at two sites: one in Portsmouth Harbor and the other in Great Bay. More details on Tiers 1, 2, and 3 can be found at: https://scholars.unh.edu/prep/

Explanation

Data Results

The median eelgrass biomass within identified beds (Figure T-2) was highest overall in Portsmouth Harbor, but variation in the dataset is quite high. Median biomass of eelgrass was the least in Great Bay. Seaweed biomass (Figure T-3) between Great Bay and Little Bay/Piscataqua River was similar, and seaweed was more abundant at Portsmouth Harbor. The differences in seaweed abundance are small and given the variability across sites, not significant.

Median eelgrass biomass in Great Bay doubled from 2021 to 2022 but decreased by approximately 50% in the other two areas. Meanwhile, median seaweed biomass increased at all three sites from 2021 to 2022.

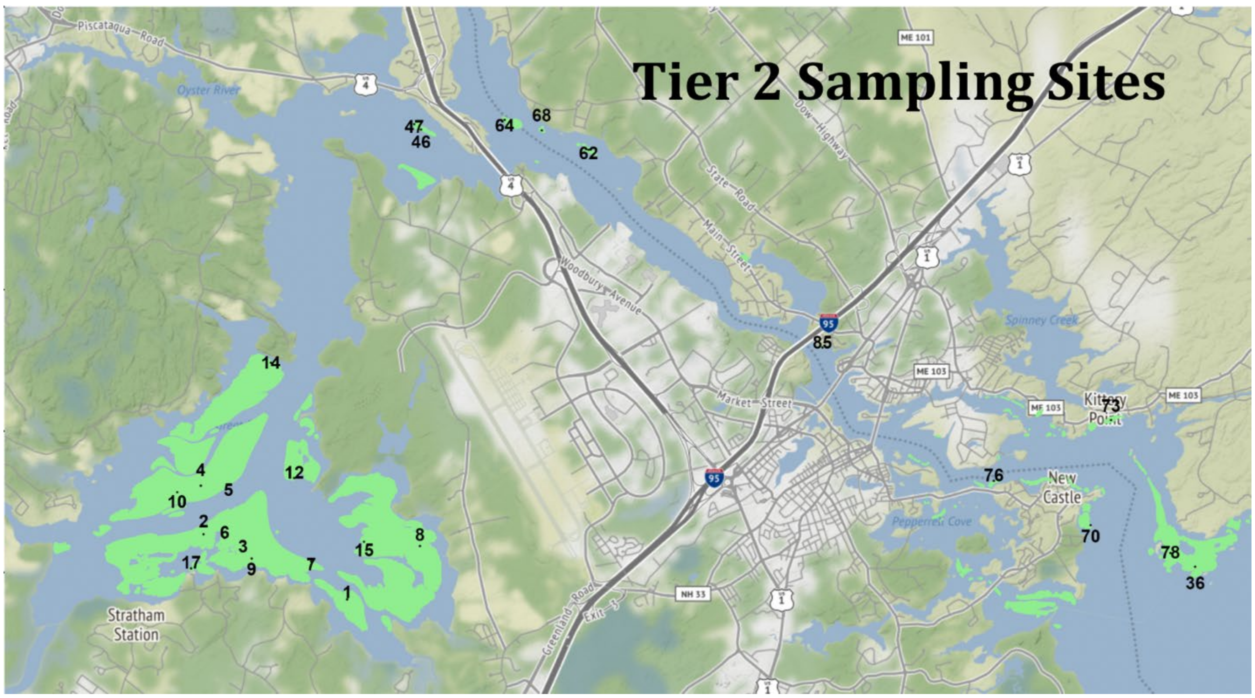

Figure T-1. A map of Tier 2 sampling sites in the Great Bay Estuary. Numbers indicate the locations of the 25 sites and were chosen from a random sample of 100 sites based on locations that had eelgrass in 2019. Great Bay is located south of site 14; the Little Bay/Piscataqua River group is at the top of the map, and Portsmouth Harbor sites are bottom right. (Map credit: Anna Mikulis)

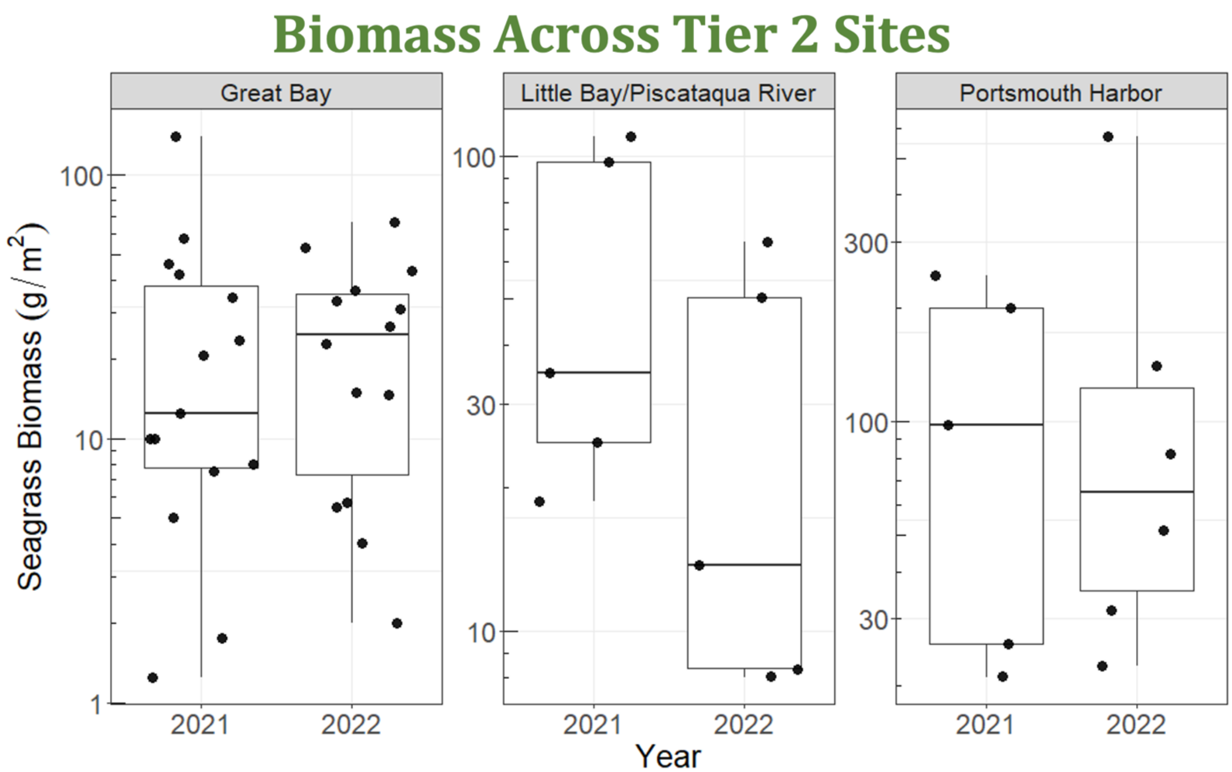

Figure T-2. Seagrass biomass from 25 sites, partitioned into three main areas in the Estuary for years 2021 and 2022. The vertical axis is on a logarithmic scale to prevent the low and high ends of the data range from being overly condensed on the graph. Use the tick marks on the vertical axis to estimate the biomass. Notice that the Portsmouth Harbor axis maximum is 300 g/m^2 versus 100 g/m^2 for the other two areas.
Data Source: UNH Jackson Estuarine Laboratory.

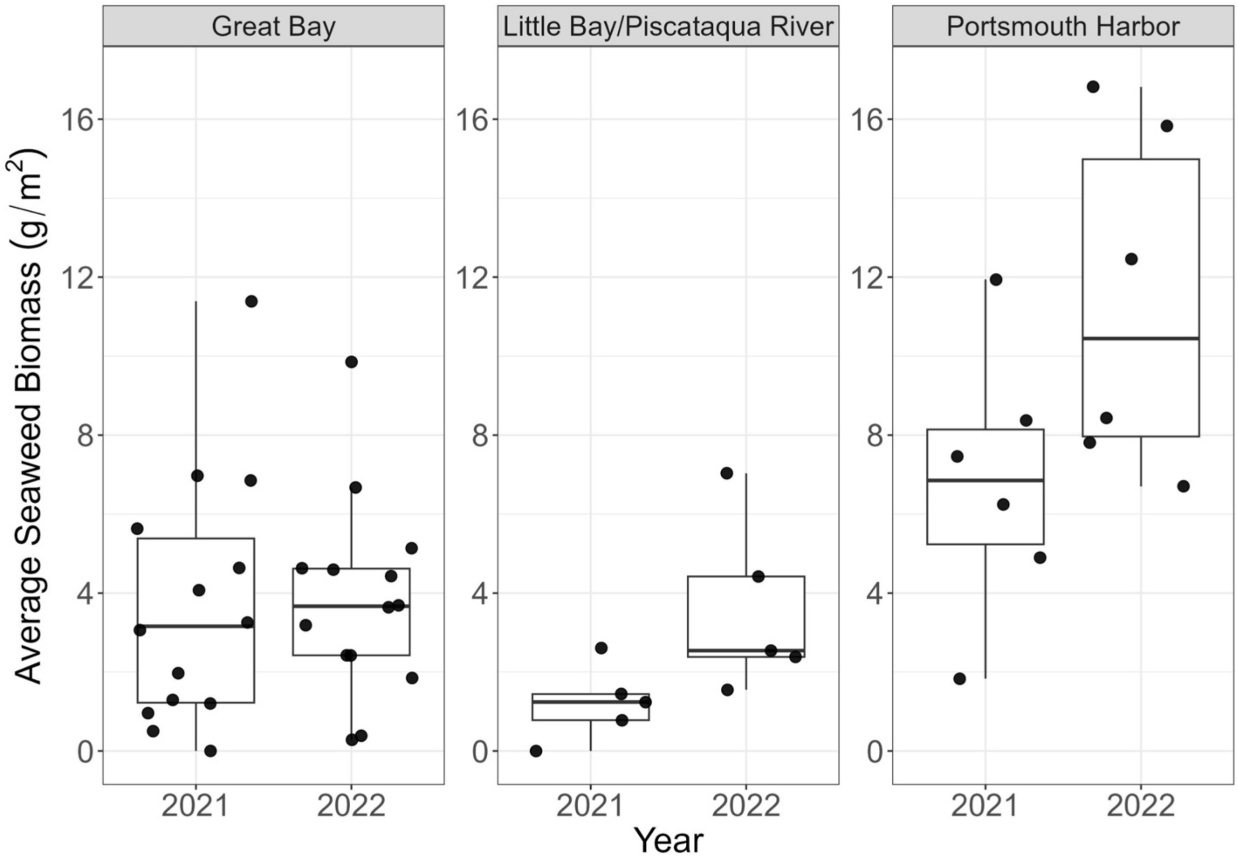

Figure T-3. Seaweed biomass from three main areas in the Estuary for years 2021 and 2022. The vertical axis is on a logarithmic scale to prevent the low and high ends of the data range from being overly condensed on the graph. Use the tick marks on the vertical axis to estimate the biomass.
Data Source: UNH Jackson Estuarine Laboratory.

Discussion

Overall, the increase in median eelgrass biomass may emphasize the more stressful conditions affecting Great Bay eelgrass versus locations in and near Portsmouth Harbor. Great Bay experiences greater fluctuations in light, temperature, and salinity than experienced at the Portsmouth Harbor locations. Although eelgrass can tolerate a range of conditions, the range experienced in Great Bay is most likely stressful relative to Portsmouth Harbor.

It is unexpected that red and green seaweed biomass is greater in Portsmouth Harbor than in Great Bay. The species making up the red/green contingent are different across the two locations and the Portsmouth Harbor consortia may weigh more than the species in Great Bay; this has yet to be verified. Also, the seaweed in Great Bay, especially the species *Gracilaria vermiculophyla,* has a tendency to accumulate in large clumps that are variable in time and space and do not always appear in the random quadrats being sampled.

Comparisons of eelgrass and seaweed health between zones and between years are complicated by many confounding factors. Over time, after more years of collecting data, the signal versus noise should become easier to detect.

Acknowledgements and Credit
Kalle Matso (PREP),Flor Fahnestock (UNH), Anna Mikulis (UNH), and Lara Martin (UNH). Reviewed by Bonnie Brown (UNH), Wil Wollheim (UNH), and Simon Courtenay (University of Waterloo, Canada).

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Krause-Jensen D, Queresma, AL, Cunha AH and TM Greve. 2004. How are seagrass distribution and abundance monitored? In, "European seagrasses: an introduction to monitoring and management," eds. Borum, Duarte, Krause-Jensen, and Greve. A publication by the EU project Monitoring and Managing of European Seagrasses (M&MS) EVK3-CT-2000-00044.

Human Population (for Piscataqua Region Watershed) – Supporting Variable

Question:
How has the population of the Piscataqua Region Watershed changed over time?

Why We Track Population
A growing population often brings with it increased stress on natural resources. This is due to the addition of impervious cover, the loss of open space, and the loading of additional pollutants. Although it is possible to increase the watershed population without stressing the environment, it does require resources and planning.

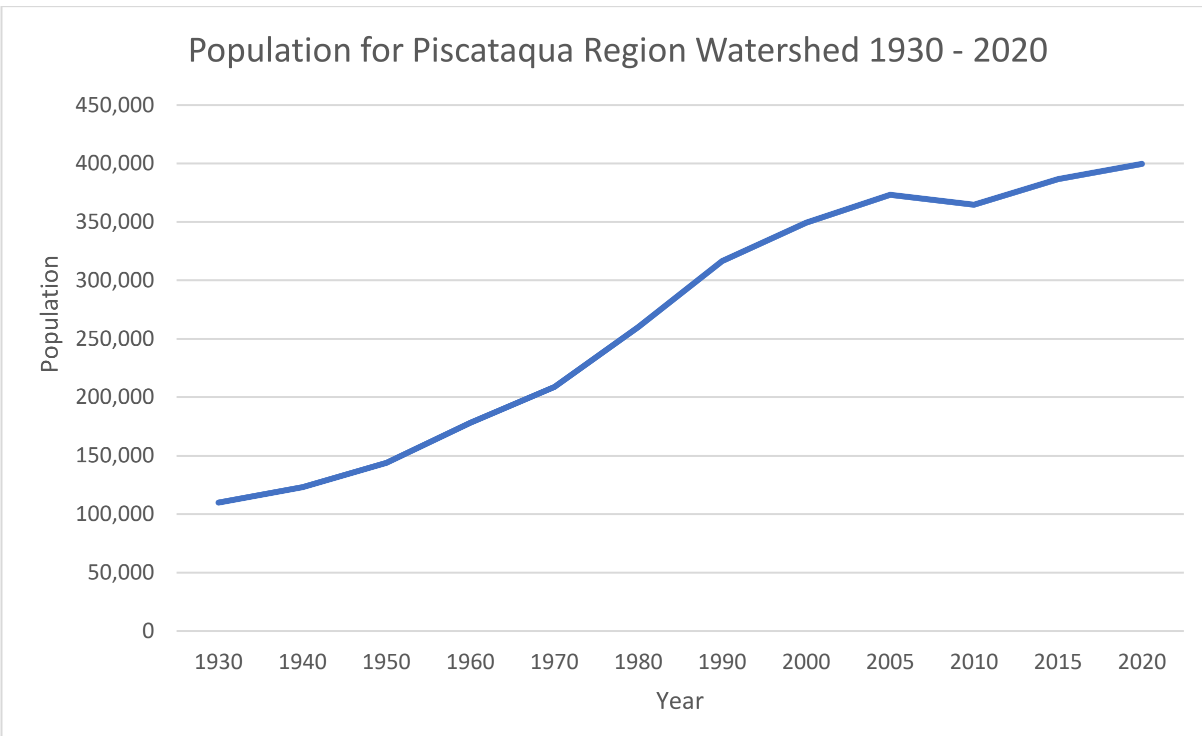

Figure HP-1. Population of the Piscataqua Region Watershed, based on 2020 census data of the 52 individual municipalities.

Explanation
In 2020, the population of the Piscataqua Region Watershed was approximately 399,704, based on adding up the individual populations of the 52 municipalities that make up the Watershed: 42 in New Hampshire and 10 in Maine. In 2015, the population was 386,658, which means that the population increased by 3.3% over five years. In 1990, a time when many of our biological indicators (e.g., migratory fish, oysters, clams) were more abundant, the population of the Watershed was 316,404. The population has grown 21.1% over that 30-year period (Figure HP-1).

The small but steady increase in the Watershed population is reflective of state trends as well (Figure HP-2), with both states adding to their population in 2015 and again in 2020. The decrease in overall population between 2005 and 2010 was more impacted by Maine decreases more than changes in New Hampshire, which saw continued increases during that period.

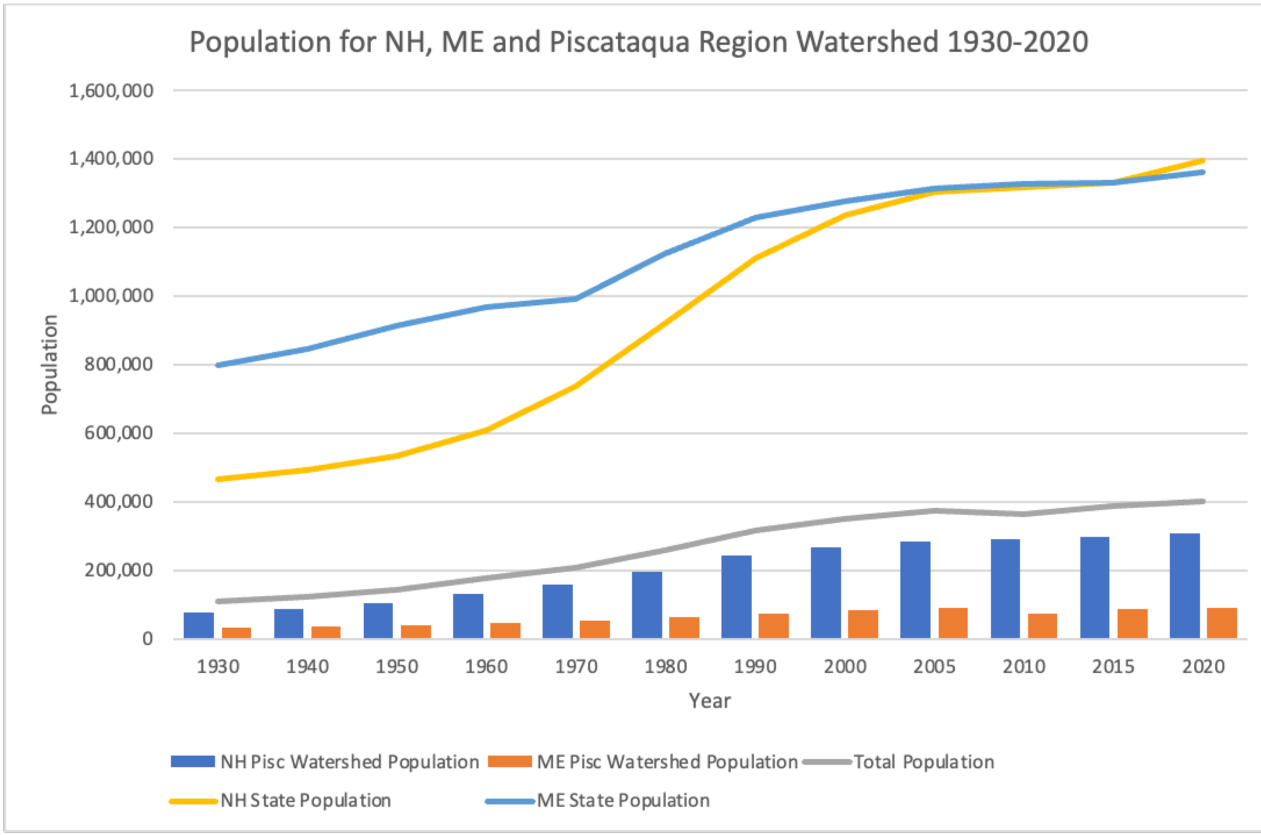

Figure HP-2. Population of the Piscataqua Region Watershed and overall population of New Hampshire and Maine.

Acknowledgements and Credit
Kalle Matso (PREP).