STATE OF OUR ESTUARIES 2023

Great Bay Estuary

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STATEOFOURESTUARIES.ORG

PREP™
Piscataqua Region Estuaries Partnership

A Letter From PREP

DEAR FRIENDS AND PARTNERS,

Welcome to the 2023 State of Our Estuaries report.

Over the last few years, we have all been acutely aware of how things can change and of how those changes — both big and small — alter the way we live. In a way, this report is also about change. It tells a story of how our shared home — the Piscataqua Region Watershed — is changing and of how those trends are affecting our estuaries and the countless species that live there. It tells of stress and recognizes that while the challenges we face are significant, so too is our ability to bring about positive change. That is a critical part of this report: we can make a difference. Toward the end of this letter, you will learn about our commitment to protecting and restoring our estuaries and how YOU can help!

This State of Our Estuaries report demonstrates our ability to collaborate over 100 partners, with dozens of experts authoring indicator sections, and PREP staff serving as both contributors and editors. It would not be possible without the collected data, technical expertise, and inexhaustible effort from all those who contribute, and we at PREP are truly grateful to all of you.

Finally, speaking of changes, PREP staff have seen many since our last State of Our Estuaries report. In October of 2021, after 11 years of inspirational leadership as Director, Rachel Rouillard departed PREP to join the New Hampshire chapter of The Nature Conservancy. Fay Rubin, the former Director of NH GRANIT at UNH, joined us as Interim Director and has remained as our Special Projects Manager. Kalle Matso, previously the Coastal Scientist, was named Director in May of 2022. Abigail Lyon is now Manager of our Community Engagement Program and Trevor Mattera manages the Habitat Program. Lastly, we're very excited to welcome Sierra Kehoe as PREP's new Communications Coordinator!

Always feel free to reach out to us personally to chat about these systems that are so critical to our lives. You can find out more about each of us at PREP by visiting our website. There you will also find links to other excellent resources, such as our Eelgrass Dashboard and the Piscataqua Watershed Data Explorer. These sites give you the ability to access and quickly graph the data most interesting to you.

We have a separate website (StateOfOurEstuaries.org) that houses our State of Our Estuaries reports as well as the much longer "Extended Report" that includes more details on data and methods for each indicator. In addition, you will find special features not included in this printed report, such as new information related to Green Crabs. As you read through the State of Our Estuaries report, you will see plenty of reminders in the indicators about extra information found in the Extended Report.

In addition, StateOfOurEstuaries.org contains our latest "Municipal Guide" with information specific to municipal volunteers and staff. This site also houses our "Residential Guide" for people seeking ways to keep our estuaries healthy.

In order to bring about the positive change we want to see in our Great Bay and Hampton-Seabrook Estuaries, PREP — your National Estuary Program — intends to act on the findings in this report through:

- Expanding our resources and support to all interested parties across the Piscataqua Region Watershed
- Maintaining a transparent science and monitoring program and improving access to existing and future data
- Supporting our habitats and partners in restoration and conservation efforts across the Piscataqua Region Watershed

From all of us at PREP, thank you for caring about our shared estuaries!

Kalle, Abigail, Trevor, Fay, and Sierra

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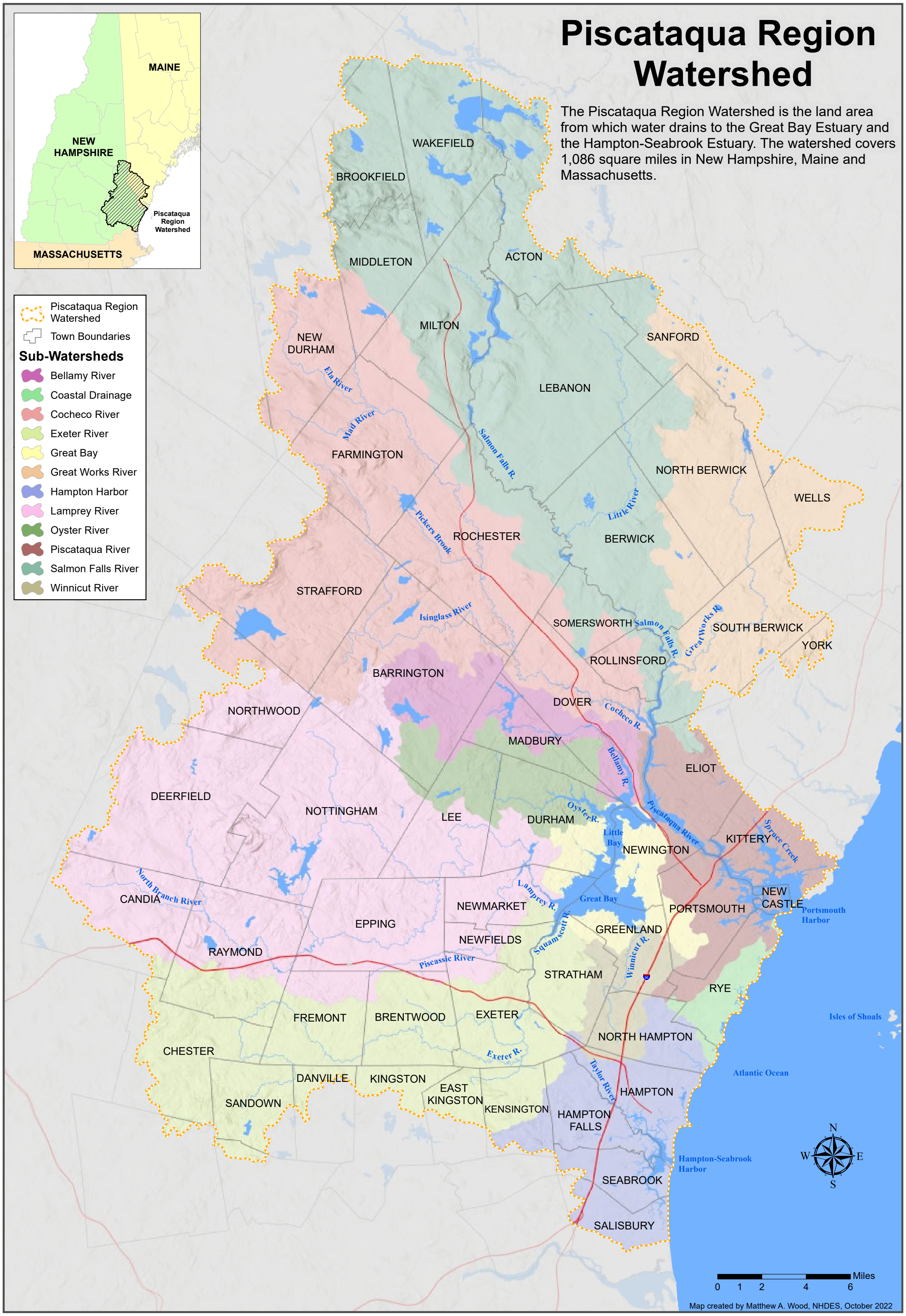
To learn more about PREP, visit **PREPestuaries.org** and for more information and to explore the State of Our Estuaries report interactively, visit **StateOfOurEstuaries.org**.

Table of Contents

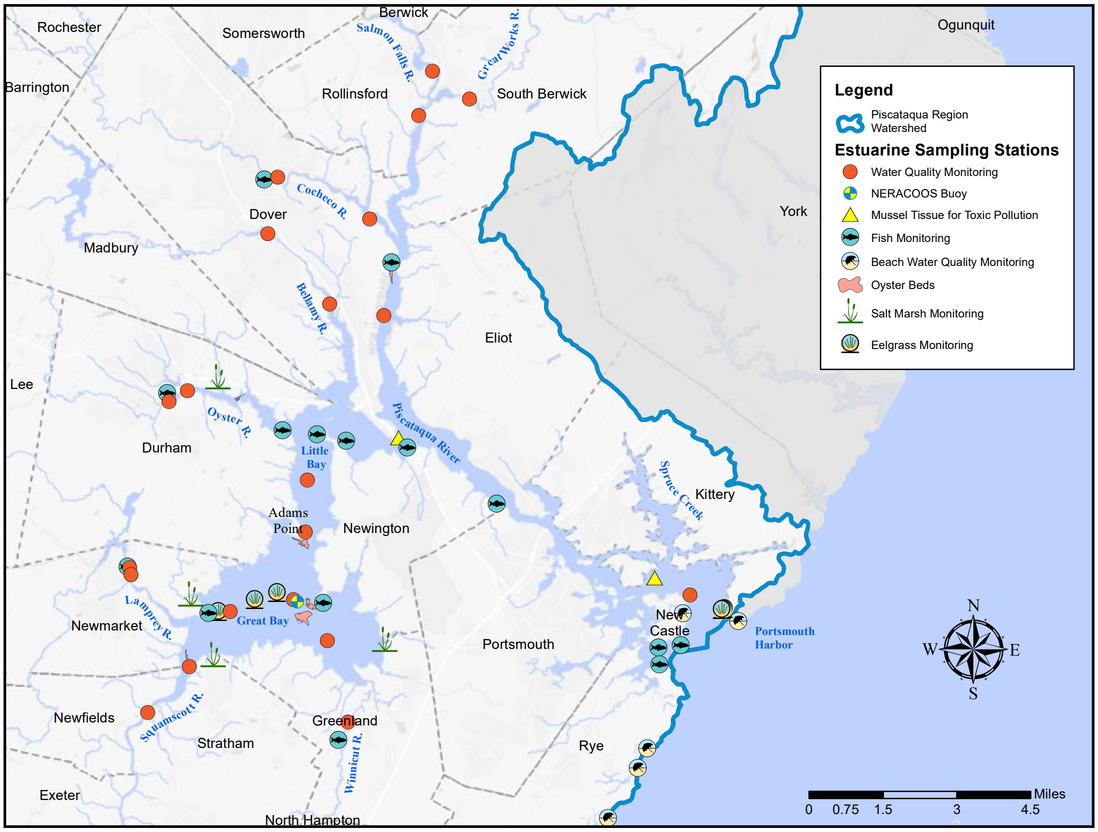
INDICATORS

Watershed Map

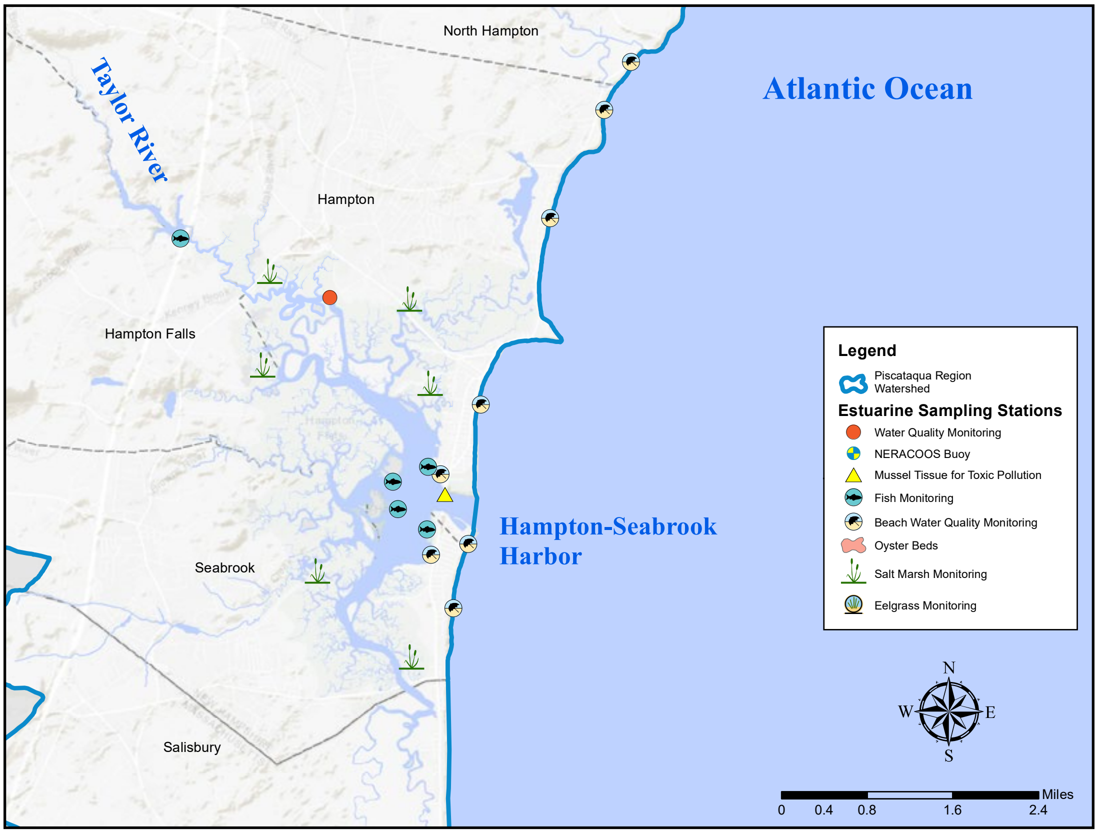


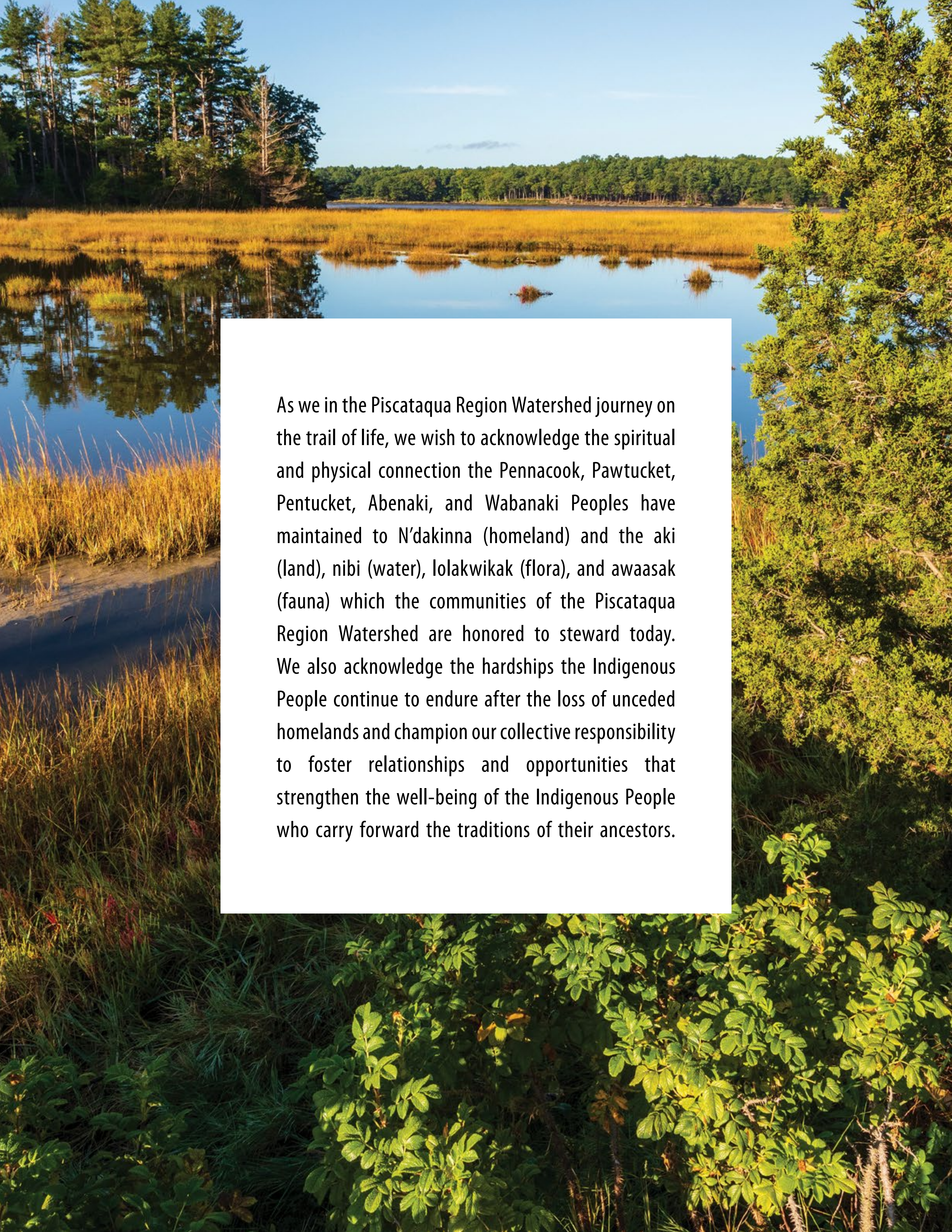
Monitoring Maps

GREAT BAY ESTUARY



HAMPTON-SEABROOK ESTUARY





As we in the Piscataqua Region Watershed journey on the trail of life, we wish to acknowledge the spiritual and physical connection the Pennacook, Pawtucket, Pentucket, Abenaki, and Wabanaki Peoples have maintained to N'dakinna (homeland) and the aki (land), nibi (water), lolakwikak (flora), and awaasak (fauna) which the communities of the Piscataqua Region Watershed are honored to steward today. We also acknowledge the hardships the Indigenous People continue to endure after the loss of unceded homelands and champion our collective responsibility to foster relationships and opportunities that strengthen the well-being of the Indigenous People who carry forward the traditions of their ancestors.

Executive Summary

The 2023 State of Our Estuaries report documents the magnitude of the challenges that face our Great Bay and Hampton-Seabrook Estuaries as well as the Piscataqua Region Watershed. At the same time, it reflects the notable increase in effective collaboration among Piscataqua Region partners over the last five years. Throughout these pages, you will encounter these two themes: the challenges we face are significant, AND so is our power to bring about positive change. To protect and restore our estuaries, we must continue working together toward positive change.

In the following pages, join us for a journey from the perspective of a juvenile river herring to learn about the stressors facing our estuaries. This is a new way to experience what the data tell us about habitats like seagrasses, shellfish, and salt marshes, which continue to struggle with warming waters, extreme weather, and rising seas.

After reading about the herring's journey, you will notice other additions to this report, such as the "Gulf of Maine Regional Perspective." These regional trends remind us that our estuaries are part of and interact with a larger system. For example, monitoring in the Gulf of Maine indicates that warmer waters are impacting a copepod, a type of plankton, that provides food for everything from right whales to herring. Conversely, what we do in the Piscataqua Region Watershed affects our estuaries and in turn the Gulf of Maine.

Also new to this report is a long overdue analysis of changes in water clarity, or light, as it relates to eelgrass health. This analysis is an important complement to studies of Total Suspended Solids and Phytoplankton, two indicators with a significant influence on light penetration. The critical message here is that if we can promote light penetration in deeper waters, perhaps we can compensate for shallower waters getting warmer and more stressful for eelgrass.

In this report, as we review the status and trends of our indicators, the story that develops is both concerning and encouraging. Examples of concerning trends include:

- **Nitrogen loading from non-point sources increased from the previous period by 15%, influenced in part by increased precipitation in 2017 and 2018. Given forecasts for continued extreme weather, this emphasizes the need to continue improving stormwater management.**
- **New contaminants of emerging concern are being found in blue mussel tissue at multiple sites in our estuaries; impacts on ecosystem and human health are currently being investigated.**

Examples of encouraging developments include:

- **Since 2017, 16 more NH communities have adopted more protective stormwater management standards; overall 35 out of 52 communities in the Piscataqua Region Watershed have some level of stormwater standards.**
- **Nitrogen loading from point sources such as wastewater treatment facilities is at its lowest level since we began regular reporting of this metric in 2003.**
- **Starting in 2014, eelgrass acreage in the Portsmouth Harbor region has continued to increase.**
- **There were 5 million oysters at six natural reefs in the Great Bay Estuary in 2020 and 2021. The last time we had more than 5 million oysters was 1998. The region's oyster aquaculture industry has never been more vibrant; it produced nearly a million oysters in 2021, and 30% of those were used for restoration efforts.**
- **Finally, propelled by the dam removal in Exeter, total migratory fish returns in the watershed are the highest we've seen since 1992!**

In our 2018 Executive Summary, PREP made the case that we needed to work together more effectively. That has certainly happened. For example, the Municipal Alliance for Adaptive Management has improved permit-related decisions between multiple municipalities, the Conservation Law Foundation, U.S. Environmental Protection Agency, and New Hampshire Department of Environmental Services. Now, in 2023, our challenge is to remain vigilant and continue to push the boundaries: both in terms of effective resource management and in terms of effective science to track and understand our changing estuaries.

Indicator Summary

POSITIVE

The trend or status of the indicator demonstrates improving conditions, generally good conditions, or substantial progress relative to the management goal.

TOTAL: 6

CAUTIONARY

The trend or status of the indicator demonstrates possibly deteriorating conditions, a mixture of positive and negative trends, or moderate progress relative to the management goal.

TOTAL: 13

NEGATIVE

The trend or status of the indicator demonstrates deteriorating conditions, generally poor conditions, or minimal progress relative to the management goal.

TOTAL: 3

SEAWEEDS

CONSERVED LANDS (GENERAL)

SHELLFISH HARVEST OPPORTUNITIES

NITROGEN LOADING (POINT SOURCES)

NUTRIENT CONCENTRATIONS

BACTERIA

HOUSING

EELGRASS

PHYTOPLANKTON

IMPERVIOUS COVER

NITROGEN LOADING (NON-POINT SOURCES)

TOTAL SUSPENDED SOLIDS

STORMWATER MANAGEMENT STANDARDS AND FUNDING

STEWARDSHIP BEHAVIOR

TOXIC CONTAMINANTS

DISSOLVED OXYGEN

MIGRATORY FISHES

CONSERVED LANDS (FOCUS AREAS)

OYSTERS

SALT MARSH

BEACH ADVISORIES

SOFTSHELL CLAMS

INDICATOR	STATUS/TREND	STATE OF THE INDICATOR
Impervious Cover		Five subwatersheds and ten towns across the Piscataqua Region Watershed have greater than 10% impervious surfaces. There was no decrease in the number of towns with less than 5% impervious surfaces but the Bauneg Beg Pond-Great Works River and Isinglass River subwatersheds increased from 5% to 5.1% and from 4.8% to 5.1% respectively.
Housing		Since 2015, average housing permit approvals were 515 for multi-units and 549 for single-family units per year. In 2020 multi-units housing permits fell to 361 while single-family permits increased to 628. Housing stock increased by 20% between 2000 and 2020, with 50,446 new units built.
Stormwater Management Standards and Funding		As of 2022, 25 of 42 New Hampshire communities have adopted some level of stormwater standards while the 10 Maine communities continue to follow a state standard. Currently no communities have adopted a stormwater utility.
Salt Marsh		There are currently 5,711 acres of salt marsh in the Piscataqua Region Watershed. While there has been little change in acreage since 2017, marshes are being impacted by sea-level rise and the spread of the invasive common reed (*Phragmites australis*).
Conserved Lands (General)		As of April 2022, 18.1% of the total land area in the Piscataqua Region Watershed is under conservation. For the 22 coastal communities in the Piscataqua Region Watershed, 22.3% is conserved, surpassing the PREP goal of 20%.
Conserved Lands (Focus Areas)		As of 2022, 29.3% of Conservation Focus Areas (CFAs) are conserved in the Piscataqua Region Watershed based on the 2021 New Hampshire Coastal Watershed Conservation Plan. More progress is needed to achieve our goal of 75% of total acres in the CFAs.
Nitrogen Loading (Point Sources)		Nitrogen loading from point sources for the period from 2017 through 2020 was the lowest (196.9 tons N per year) it has been since consistent monitoring began in 2003.
Nitrogen Loading (Non-Point Sources)		Nitrogen loading from non-point sources increased from the previous period, of 2013 – 2017, by 15%, influenced in part by increased precipitation in 2017 and 2018; further reductions are needed to meet management goals. On the other hand, this is the second lowest level since 2003 and the overall trend is improving.
Nutrient Concentrations		Nitrogen concentrations at most stations are comparable to the lowest measurements on record. Although the Squamscott and Lamprey Stations show increasing concentrations overall, the wastewater treatment facilities in those rivers were recently upgraded, which should have a positive impact going forward.
Dissolved Oxygen		Trends for dissolved oxygen are neither increasing nor decreasing in the Great Bay and Hampton-Seabrook Estuaries. In the bays, dissolved oxygen generally remains above the threshold of 5 mg/L; however, some tributaries experience many days with dissolved oxygen below 5 mg/L.
Seaweed		Although nuisance species of seaweeds continue to compete with eelgrass, especially in the Great Bay, overall trends show that seaweeds seem to be decreasing, especially relative to eelgrass.
Eelgrass		Eelgrass acreage and biomass in the Great Bay Estuary remain low in comparison to historical values; however, the Portsmouth Harbor region has been on a generally positive trend since 2014.
Phytoplankton		Chlorophyll-a levels are mixed, with increasing trends at some stations and decreasing trends at others. Most data show decreasing concentrations in recent years, even at the stations with increasing long-term trends.
Total Suspended Solids		Levels of total suspended solids in both the Great Bay and Hampton-Seabrook Estuaries are high relative to other estuaries, and the data at Adams Point indicate a statistically increasing long-term trend despite some signs of recent decreases.
Bacteria		With the exception of *Vibrio* spp. increasing due to warmer water temperatures, fecal-indicating bacteria show a statistically significant decreasing trend.
Shellfish Harvest Opportunities		The percentage of possible acre-days has been on a statistically significant upward trend for the period 2006 to 2021 due to wastewater treatment facility upgrades and expanded testing programs.
Oysters		Although restoration activities and commercial aquaculture are both increasing, natural oyster reefs remain approximately 80% down from 1993 levels, despite some improvements in recent years.
Softshell Clams		Clam populations in the Hampton-Seabrook Estuary remain below management goals even during relatively good years, a consistent declining trend since the peak in 1997.
Beach Advisories		Between 2017 and 2021 there was a significant increase in the number of beach advisories, switching this indicator from "positive" in 2018 to "negative" in 2023.
Migratory Fishes		In 2021, total migratory river herring returns in both estuaries were at their highest since 1992. However, three of the six tributaries monitored continue to have negligible counts.
Toxic Contaminants		While some contaminants are declining, some (e.g., mercury and PCBs) remain high enough to warrant concern. Also, many contaminants of emerging concern (e.g., PFAS) are impacting our communities and have yet to be monitored sufficiently.
Stewardship Behavior		Total volunteer hours decreased in 2020 likely due to COVID-19 to 6,810 hours, a 76% decrease compared to 2019 average, and the total number of volunteers decreased by 64%. However, in 2021, volunteer hours increased to 15,088, from 582 volunteers across 63 events.

The Journey Through Our Watershed: A Fish Story

INTRODUCTION

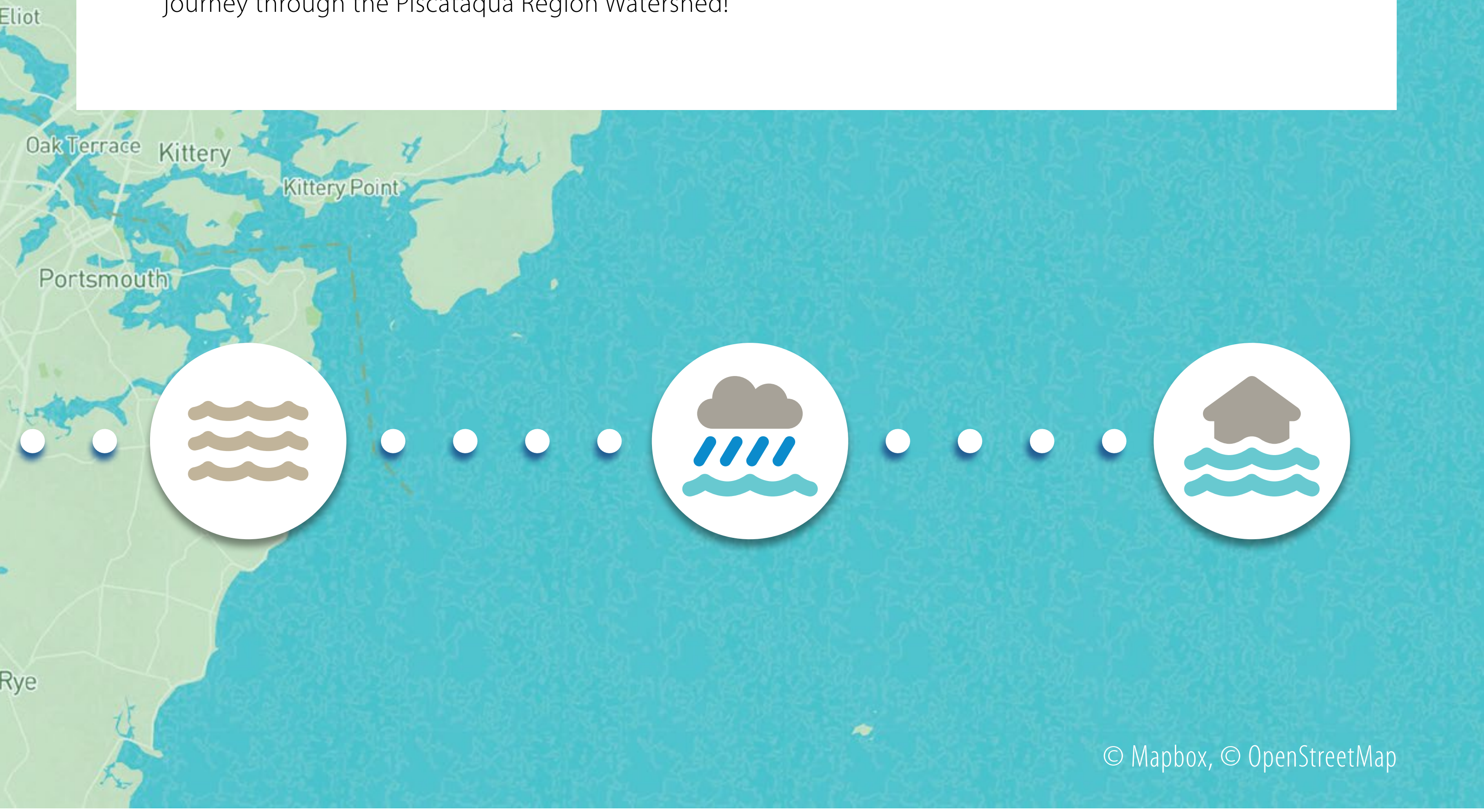
In this story, you are invited to follow along with a juvenile river herring during its first few months of life from hatching in a freshwater river through its journey in the Great Bay and out to the Atlantic Ocean. This section is also a journey through the many challenges that threaten our watershed and two estuaries of national significance: Great Bay Estuary and Hampton-Seabrook Estuary. Be forewarned: the list of stressors is long! We list these stressors because we can not solve a problem if we do not accurately define what's happening. Given the magnitude of these stressors, it's the view of the Piscataqua Region scientific community that we must improve habitat quality using **every** tool we **can** control to compensate for factors we **cannot** control.

Science indicates that we *can* make a difference; indeed, we *are* making a difference. You will read about how nitrogen loading from point sources — "point source" refers to pollution that comes from an identifiable localized source, such as a wastewater treatment plant — is lower than at any other time in our data record. You will see that in some places, oysters are making a modest comeback. Data also indicate that migratory fish returns are higher than they've been since 1992. This is what it means to make a difference!

Help us continue to make a difference for our estuaries. Let your local government know you are concerned about the resilience of the Great Bay and Hampton-Seabrook Estuaries. This is the single most important thing you can do to protect these critical ecosystems! More specifically, here are some primary actions we can take together to build their resilience.

- Conserve land to preserve open space
- Maintain, adopt, and enforce riparian buffers (vegetated areas near streams and rivers)
- Manage stormwater to reduce pollution and flooding
- Better manage nutrient pollution from septic systems and wastewater treatment facilities
- Reduce your own contributions to pollution

More information on how to support these efforts is available in the State of Our Estuaries sub-publications: “Municipal Guide” and “Residential Guide.” With that, please take a deep breath and plunge into a journey through the Piscataqua Region Watershed!



The Journey Through Our Watershed: A Fish Story

FOLLOWING THE HERRING

It's spring and a new generation of river herring has hatched in the upper reaches of the Exeter River **(1)**, the freshwater portion of what becomes the Squamscott River before it empties into the Great Bay. Only a few years ago, this leg of the journey would have been impossible, but with the removal of the Great Dam **(2)** in 2016, herring now have free run of the lower Exeter River for the first time in 400 years.

These herring are actually two species of migratory fish: the blueback herring (*Clupea aestivalis*) and the alewife (*Clupea pseudoharengus*) (Figure 1). Later in the summer, the juvenile fish will swim toward the saltier waters of Great Bay, where they will seek cover and food in its salt marshes, intertidal rocky areas, eelgrass meadows, and oyster reefs. Those that survive will migrate to the Gulf of Maine, where they will live for approximately four years before returning to freshwater rivers like the Exeter to spawn and restart the cycle.

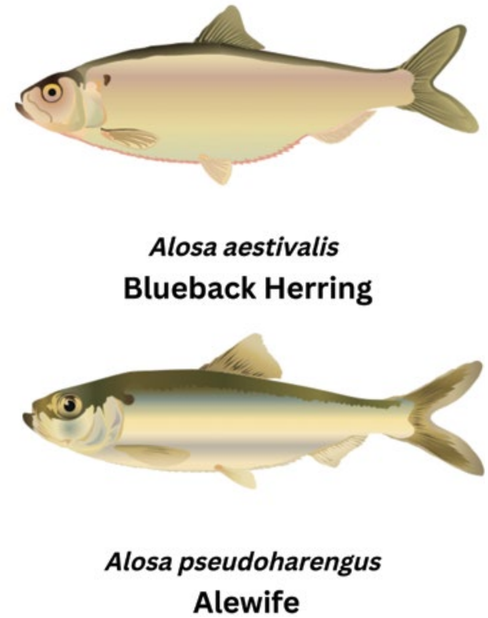
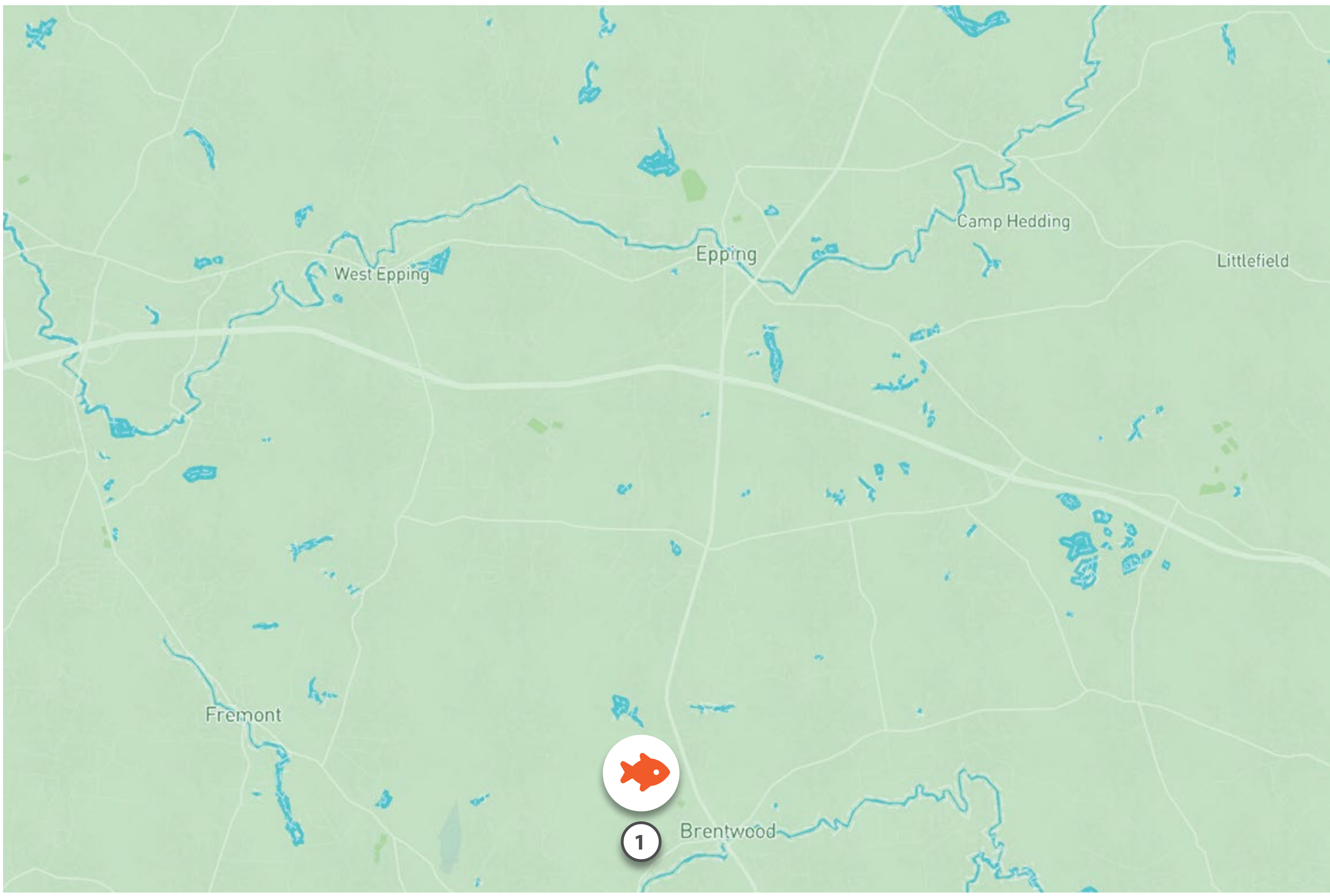


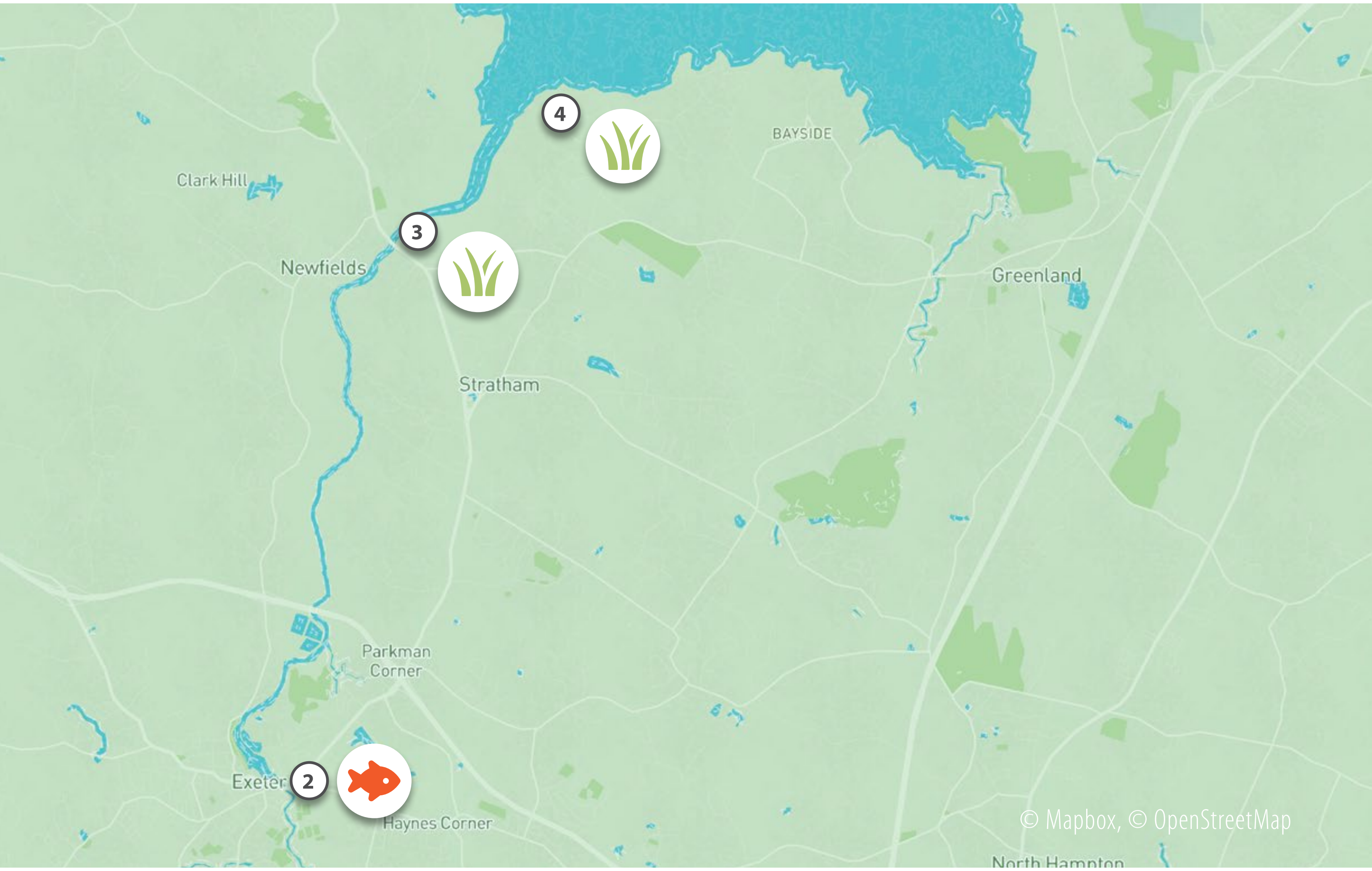
Figure 1: Two herring species utilize the Great Bay Estuary as they move throughout their life cycles.
Data source: Integration and Application Network, University of Maryland, Center for Environmental Science



FEWER HABITATS

As the juvenile fishes make their way to the ocean where they will spend the next four to five years, they might encounter the beautiful and extensive salt marsh at Chapman's Landing **(3)**, where small mysid shrimp — one of their favorite foods — thrive. Before they enter Great Bay, they may spend some time in the Estuary's largest oyster bed at the mouth of the Squamscott River, where there were over 4 million oysters in 2021! These shellfish provide safe places to hide from predators and plenty of food, such as barnacle larvae. From there, the young herring swim into Great Bay, where, at high tide, they take refuge in smaller fringing marshes, such as those in front of the Great Bay Discovery Center in Greenland, New Hampshire **(4)**. At low tide, they leave the marsh edges in search of deeper water habitats, such as eelgrass beds, where shrimp are also plentiful, or they may venture to oyster beds near Nannie Island and Woodman Point in western Great Bay. The herring continue this tidal dance among habitats as they move through the estuary.

In the mid-1990s, young herring would have had a lot more habitat to use for food and shelter during their journey. While oysters and eelgrass still exist in the Great Bay Estuary, particularly south of Adams Point, they are far less abundant and healthy than they were 30 years ago. These days, the juvenile herring must spend more time moving across much larger stretches of bare estuary bottom where they are more vulnerable to predation. The story is the same for Little Bay and the Piscataqua River. Only 25 years ago, a young herring could travel from the eastern shores of Little Bay to the Piscataqua River and under the I-95 bridge in Portsmouth/Kittery, all the while remaining mostly under the cover of either eelgrass or oysters. Today, those habitats are greatly diminished and there are more extensive stretches of bare mud.



The Journey Through Our Watershed: A Fish Story

WARMER WATERS

Throughout their journey, herring today are also swimming in warmer waters. An analysis of water temperatures taken in August at the Adams Point Station in Great Bay (5), where the time series goes back to 1988, shows a statistically significant warming trend through 2021. This is concerning since the warmest waters occur in August and September, which are the months when juvenile herring are beginning to move downstream. Warmer waters speed up the fishes' metabolism, so they need more food to stay alive, increasing their reliance on food sources found in marshes, eelgrass beds, and oyster reefs.

Higher water temperatures also adversely affect water quality. For example, certain harmful bacteria such as *Vibrio* species — which cause gastroenteritis and wound infections — are on the rise (see "Bacteria"). Warmer waters also nourish parasites that are reducing the lifespan of oysters in our estuaries. Finally, warmer waters impact eelgrass, another habitat on which juvenile river herring depend. In the warmest months, water temperatures in the shallow regions of Great Bay and Little Bay can rise above 25° C — that's equal to 77° F — the threshold at which temperatures become harmful to eelgrass (Figure 2).

In general, science shows that temperatures higher than 23° C are less than optimal for eelgrass; temperatures as high as 25° C lead to considerable stress, and 28° C is lethal. Some research has found that six consecutive days over 25° C is enough to lead to eelgrass die-off. More data and discussion on water temperature and eelgrass can be found in the "Eelgrass" section of the report.

Even in the deeper waters of the Gulf of Maine, river herring will encounter waters warming faster than any place on the planet (see "Regional Perspective"). Herring population declines in the Gulf of Maine have been attributed to these warmer temperatures and shrinking populations of an important copepod, *Calanus finmarchicus*

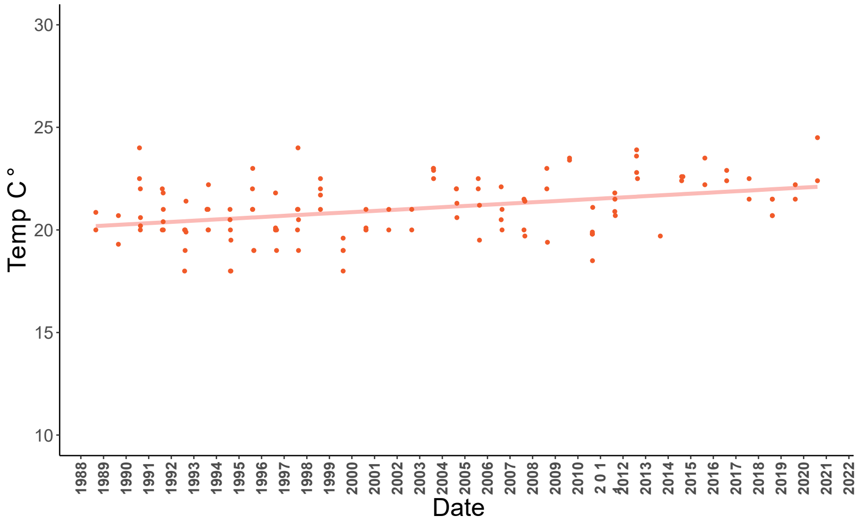


Figure 2: Water temperature taken at various tide stages at Adams Point Station during August, from 1988 to 2020. The increasing trend is statistically significant. Although the temperatures in this graph are below 25° C, temperatures in shallower areas, where eelgrass grows, are frequently above 25° C (see "Eelgrass").
Data source: Jackson Estuarine Laboratory, UNH

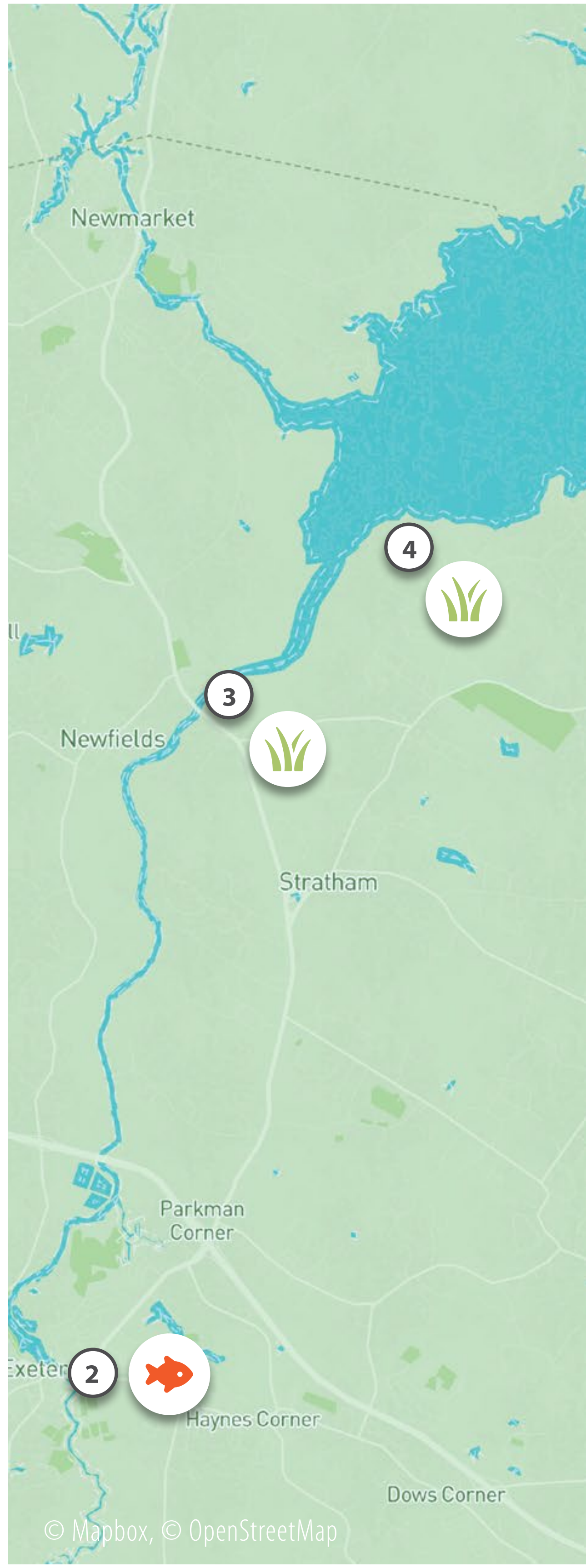


Figure 3: *Calanus finmarchicus* (body about 2 mm long).

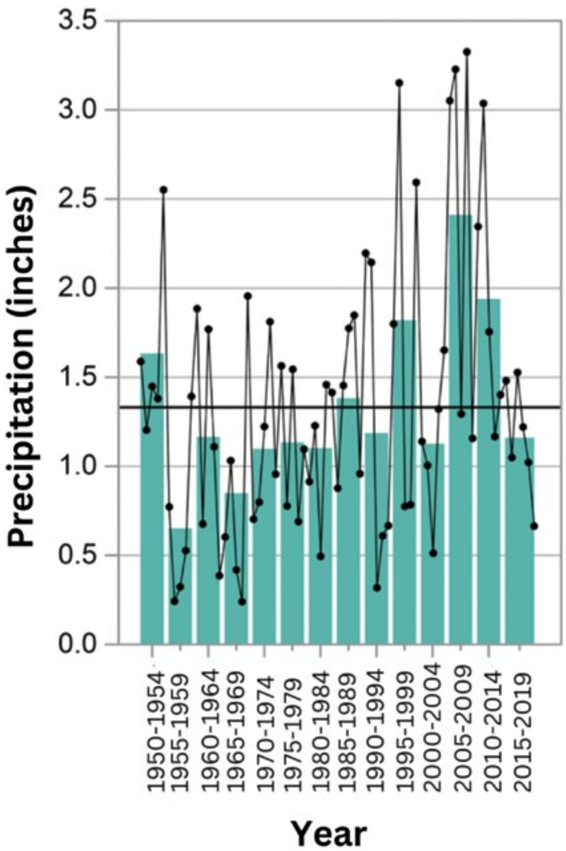


Figure 4: Extreme precipitation events. Black dots represent annual values, in some cases averaged over multiple stations. Green bars indicate averages for 5-year periods.
Data source: adapted from NOAA Climate Summaries

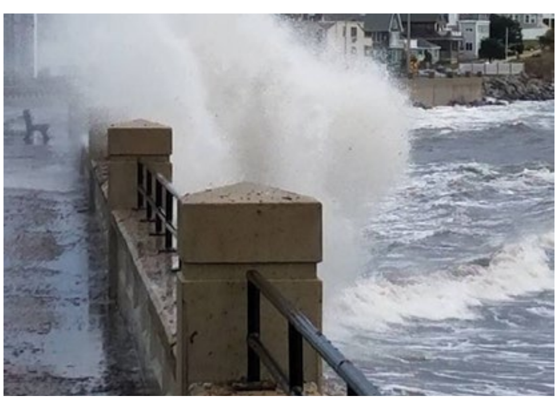


Photo by Vicki Thompson

(Figure 3), a significant prey species for everything from herring to whales.

But the story does not end when herring reach the Gulf of Maine. Their journey runs in reverse when herring reenter the Great Bay Estuary and make their way up the rivers to spawn. Once again, they are dependent on healthy waters and available habitat in order to create the next generation

MURKIER WATERS

The herrings' journey is not only warmer, with fewer places of refuge, it's also murkier. At Adams Point, on the border of Little Bay and Great Bay, data collected since 1988 show that concentrations of both total suspended solids and phytoplankton began to increase after the 1990s. It isn't surprising then to see that light conditions have worsened over time (see "Light") since total suspended solids and phytoplankton are the main factors that determine water clarity.

Lower light is a problem for many organisms but especially for eelgrass. This problem becomes worse under higher water temperatures, which increases eelgrass' metabolic rate. This means eelgrass plants require more photosynthesis and thus, more light when the water is warmer. Given that we have few tools, if any, to reduce water temperature, keeping waters clear takes on a greater importance.

STORMIER WATERS

The young herring — and their habitats — will most likely experience a stormier estuary. If we look at extreme precipitation events since 1960 (Figure 4), we see that the Piscataqua Region is experiencing more of these events, a trend forecasters agree will continue.

More storms generate more runoff, washing more nutrients, sediments, and toxic contaminants off impervious surfaces and lawns into our estuaries — all of which negatively impact herring. As we consider our stormwater management strategies for the future, precipitation increases need to be part of our calculations.

RISING WATERS

Since 1998, sea levels have risen by over 2 mm a year and the rate is increasing. In our region, salt marsh is the habitat most impacted by sea-level rise (see "Salt Marsh"). But rising seas are eroding stream banks as well as marshes, increasing total suspended solids, and worsening light attenuation. This creates problems for herring, and also creates problems for humans who depend on salt marshes and other buffers for protection of their property from wave erosion and storm surge.

Photo by Todd Selig

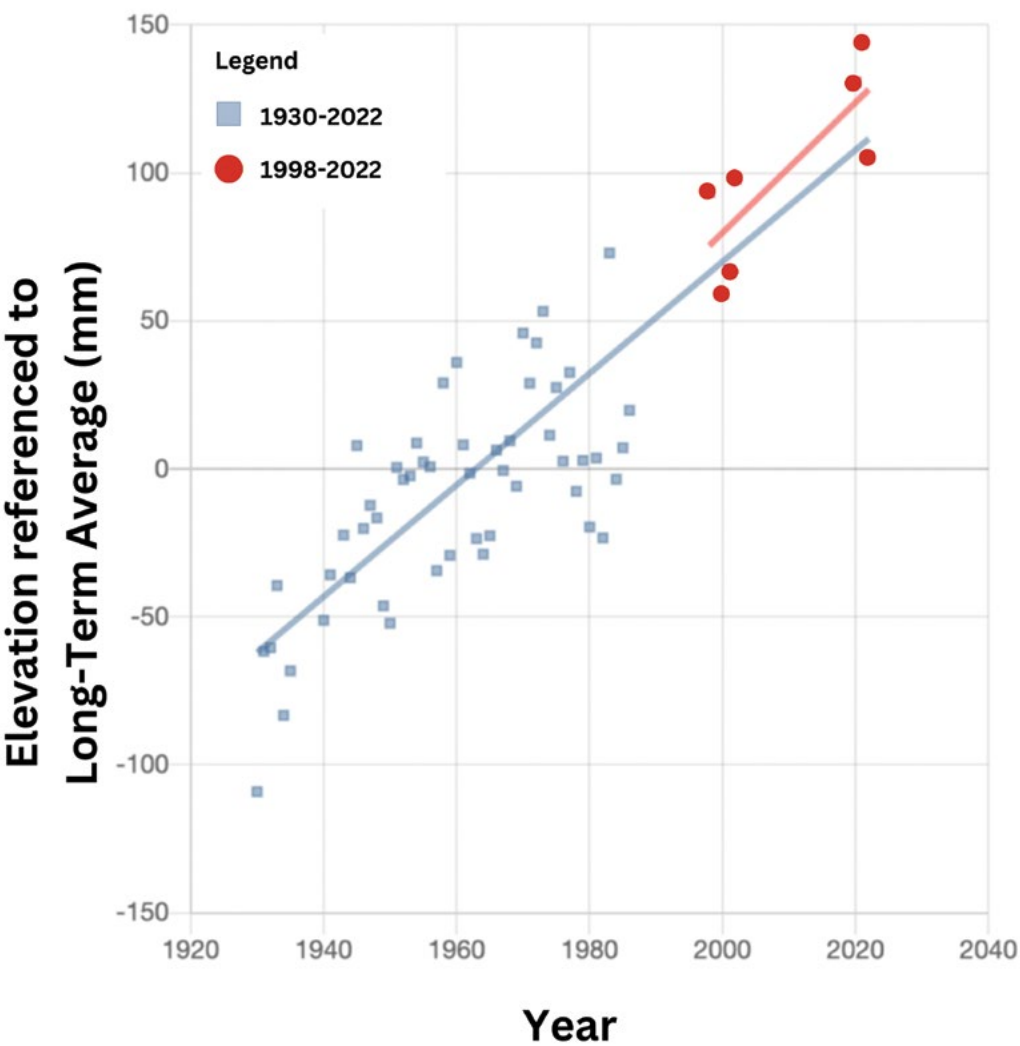


Figure 5: Sea-level rise measured at the NOAA Station located at the Portsmouth Naval Shipyard.
Data source: Maine Sea-Level Rise Dashboard

DOING WHAT WE CAN

With such significant physical changes occurring throughout our estuaries, protecting the herring of the future can seem like a daunting challenge. Stresses are increasing at a pace that could outstrip the slow recovery of estuarine habitats that support not only herring, but many other species and also our Piscataqua Region Watershed economy!

What can we do to protect the herring, their habitats, and the other benefits that healthy estuaries provide?

The solution is straightforward, though accomplishing it is difficult. **We must improve water and habitat quality using everything we can control to compensate for factors that we cannot control**. Things we can not control include the changes we've made to the landscape that are difficult to undo; they also include stressors related to climate change (Figure 6). But we can control future changes in the landscape by developing in a more low-impact manner, reducing pollution through stormwater management and redevelopment, and conserving open space.

Success will be easier if we use a proactive rather than reactive approach. This strategy recognizes that even if we can reduce chronic stresses (e.g., pollution), the future could have episodic stresses (e.g., storms) in store for us. A proactive approach will result in estuaries that are both more resistant and more resilient to stress. Healthy estuaries — those in Quadrant 4 — are so well balanced that when a stressful condition arises, the reaction is seamless and we may not even notice (high resistance). And when healthy estuaries do experience a challenge such as a hurricane, they are able to bounce back (high resilience) when the stress is alleviated (Figure 7).

We all want our estuaries to be in Quadrant 4 of Figure 6, which represents "Good" condition. But climate change and the region's increasing population are adding further stress

BEYOND THE FRONT PAGE HEADLINES

In this report, we focus on the big, clear stories. But there are also many important stories that are more nuanced; they require more space to discuss sufficiently. For example, we reviewed decades of data related to the wind, wind direction, sunlight, and pH. The results of these analyses are covered in detail in the Extended Report at StateOfOurEstuaries.org

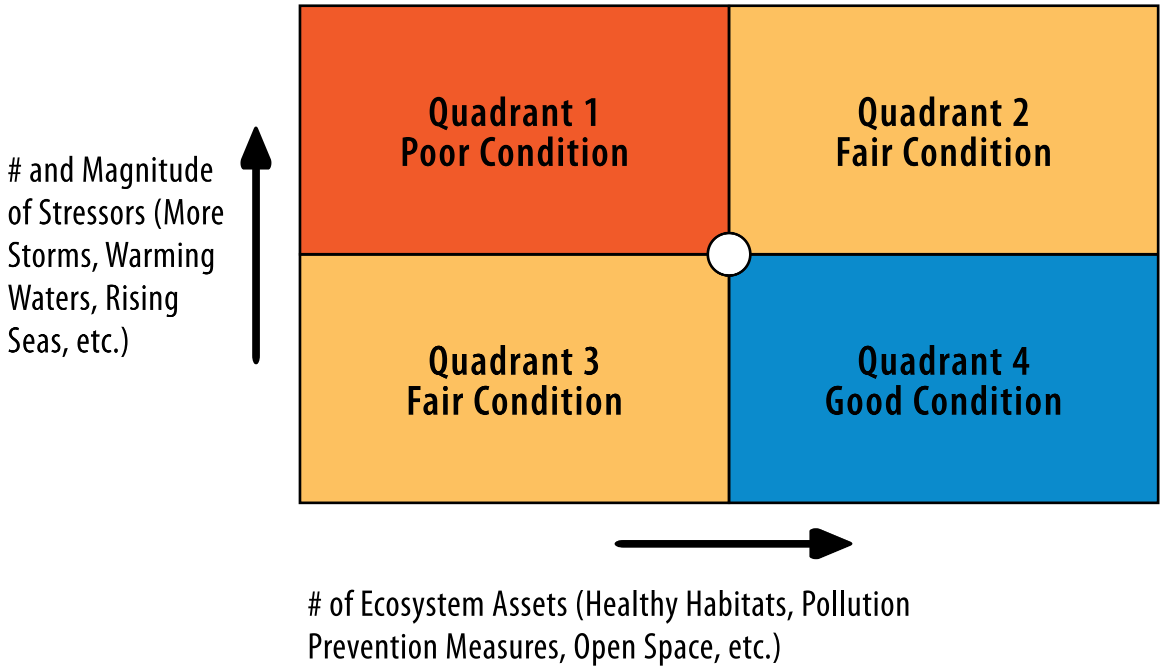


Figure 6: The Stressor - Asset Matrix breaks the condition of our estuaries into four quadrants based on the number and magnitude of stressors (vertical axis) and assets (horizontal axis). The white circle in the center is our hypothetical current position. To maintain our estuaries in "Fair" condition (Quadrant 2 or 3), we must either add to our assets or decrease stressors. The only way to reach Quadrant 4, which has "Good" condition, is to simultaneously increase assets and decrease stressors. Conceptual model: PREP

on the system. Likewise, impervious cover, which contributes to increased nutrient loads, continued to increase 0.2% since 2015 (see "Impervious Cover"). Using the knowledge presented in this report we can make decisions that address these trends and improve the condition of our estuaries.

Around the watershed, work to turn the tide is happening. The Exeter Dam removal in 2016 is an excellent example of how a community can wrestle with difficult decisions and ultimately take action to decrease stress and add ecosystem assets. There are also actions underway like the major culvert restoration project near Rye Harbor that restore hydrology to impacted wetlands (Figure 8). Many communities around the region are implementing more effective stormwater management programs in their efforts to reduce nutrient loading and mitigate flooding.

Figure 8: Surveyors plan a culvert restoration in Rye, NH, as part of the "Resilient Tidal Crossings" project. Designs call for this 3.5-ft wide culvert to be replaced in 2024 with a 15-ft wide structure, restoring natural hydrology to critical salt marsh habitat on the Seacoast. Photo by Kevin Lucey

Initiatives like these provide support to our struggling habitats. Though the latest eelgrass data are mixed, there are some signs of recent improvement, such as new acres of eelgrass in the Portsmouth Harbor region. For the 21 years between 1999 and 2019, we had less than 5 million oysters in the Great Bay Estuary; we've had more than 5 million for the last two years for which we have data (see "Oysters"). In 2021, over 260,000 river herring returned to Piscataqua Region tributaries (see "Migratory Fish"); that number of returns has not occurred since 1992!

Scientists are often criticized — occasionally for good reason — for emphasizing what they do not know instead of what they do know. So let's finish this story by emphasizing what we, the Piscataqua Region scientific community, do know. We know that our key habitats are struggling much more than we want them to be. We know that there are some signs that we could be having a positive impact on fish and shellfish and the habitats on which they rely. We know we have a long way to go to reach our goals, and we know that we have many continuing and newly emerging challenges. We know from attempts to restore other estuaries that recovery is possible and that it takes persistence and incredible effort.

The staff of PREP look forward to working with all of you to continue this huge but rewarding endeavor. For the river herring, for the other plants and animals in our estuaries, for our local economies, for all of us who enjoy clean water and abundant wildlife…let's make sure that, in five years when the next State of Our Estuaries Report is issued, we can reflect on the benefits of another half decade of impressive work!

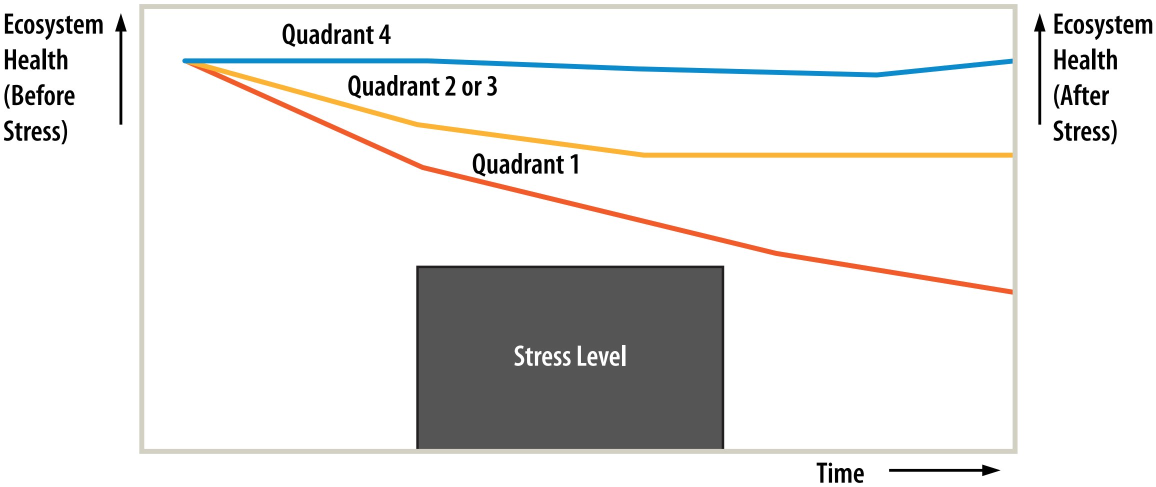


Figure 7: Conceptual model showing estuaries in different conditions reacting to stress. The Quadrant 4 Estuary (Good Condition) resists stress with very little change in health and returns to its original state when the stress is removed. Estuaries in Quadrants 2 or 3 (Fair Condition) are less able to resist stress and settle into a new, but less healthy, stable state when the stress stops. The Quadrant 1 Estuary (Poor Condition) is unable to resist stress, unable to improve its health, and experiences continued decline even when the stress is removed. Conceptual model: PREP

Gulf of Maine Regional Perspective

Conditions in our estuaries are shaped by local processes but are also influenced by ecosystem dynamics operating at larger scales such as the Gulf of Maine. The following is a brief overview of key changes detected by the regional ocean observing system managed by the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) as part of the U.S. Integrated Ocean Observing System (IOOS), the backbone of which is a network of buoys stationed along the Gulf of Maine coastline and at selected offshore locations (Figure 9). Data from the buoy network are supplemented by autonomous underwater gliders, land-based high-frequency radar stations, coastal sensors, ship-based surveys, and other tools. For more information, visit NERACOOS.org

Figure 9: The Great Bay Buoy has been in operation since 2005. The original buoy was replaced in 2022 through contributions from NHDES, PREP, UNH, the Alliance for Coastal Technologies, IOOS, and NERACOOS. The buoy and associated sensors collect critical data for understanding differences between estuarine dynamics and those of the Gulf of Maine ecosystem. Photo by Jackson Estuarine Lab, UNH

LONG-TERM REGIONAL TRENDS

It has long been documented that the Gulf of Maine is warming faster than almost any other ocean ecosystem on Earth. This trend continued in 2021 as the most significant marine heat wave since 2012 was felt across the Gulf. By mid-January 2021, daily average temperatures on the Eastern Maine Shelf began to reach or exceed the maximum values observed over the past 20 years, and temperatures did not fall below the 20-year average the entire year except for one brief instance (Figure 10). Air temperatures during the winter of 2020-2021 were not abnormally warm and the water

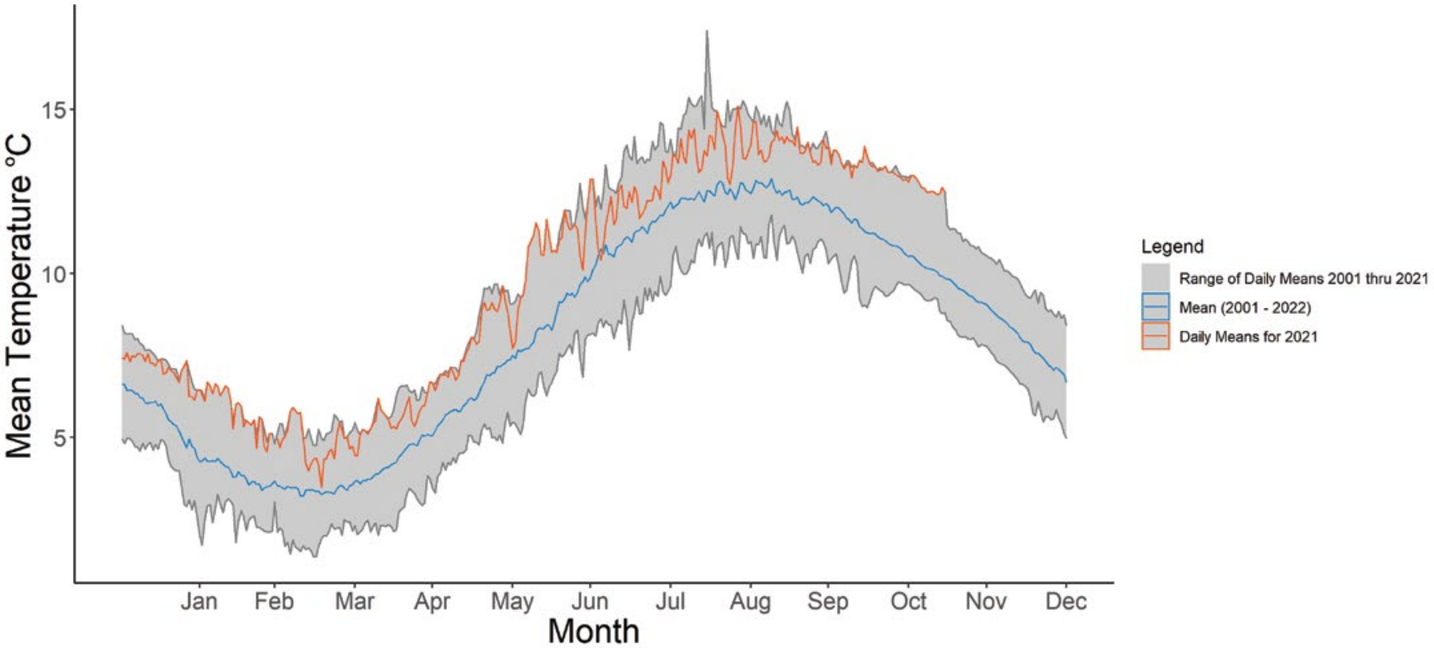


Figure 10: Daily average surface temperatures at NERACOOS Buoy I on the Eastern Maine Shelf in 2021 (orange line) relative to the daily 20-year average (blue line) and range (gray shaded area).
Data source: NERACOOS

temperature anomaly was observed throughout the water column rather than solely at the surface, suggesting that the marine heat wave was driven by oceanic rather than atmospheric influences. Furthermore, extreme temperatures were observed at stations progressively downstream along the Maine Coastal Current, following the dominant counterclockwise circulation trend in the Gulf.

Partly due to changes in temperature, an ecological change that is becoming increasingly clear in the Gulf of Maine is a fundamental restructuring at the base of the food web. In particular, the lipid-rich copepod, *Calanus finmarchicus,* has long been a dominant species of zooplankton that is responsible for vital trophic linkages between primary producers (e.g., phytoplankton) and higher-level predators. Calanus are the major prey for the critically endangered North Atlantic right whale as well as forage fishes such as Atlantic herring and sand lance. In turn, these fishes are important prey for humpback whales, Atlantic cod, and other economically important marine mammals and fishes. Monitoring reveals that Calanus abundance in the Gulf of Maine has been below average in recent years (Figure 11), corresponding to shifting temperatures, salinity, and other environmental conditions. If *Calanus* abundance declines to a level that is too low to consistently support fishes and whales, there are likely to be critical consequences for river herring and striped bass, as

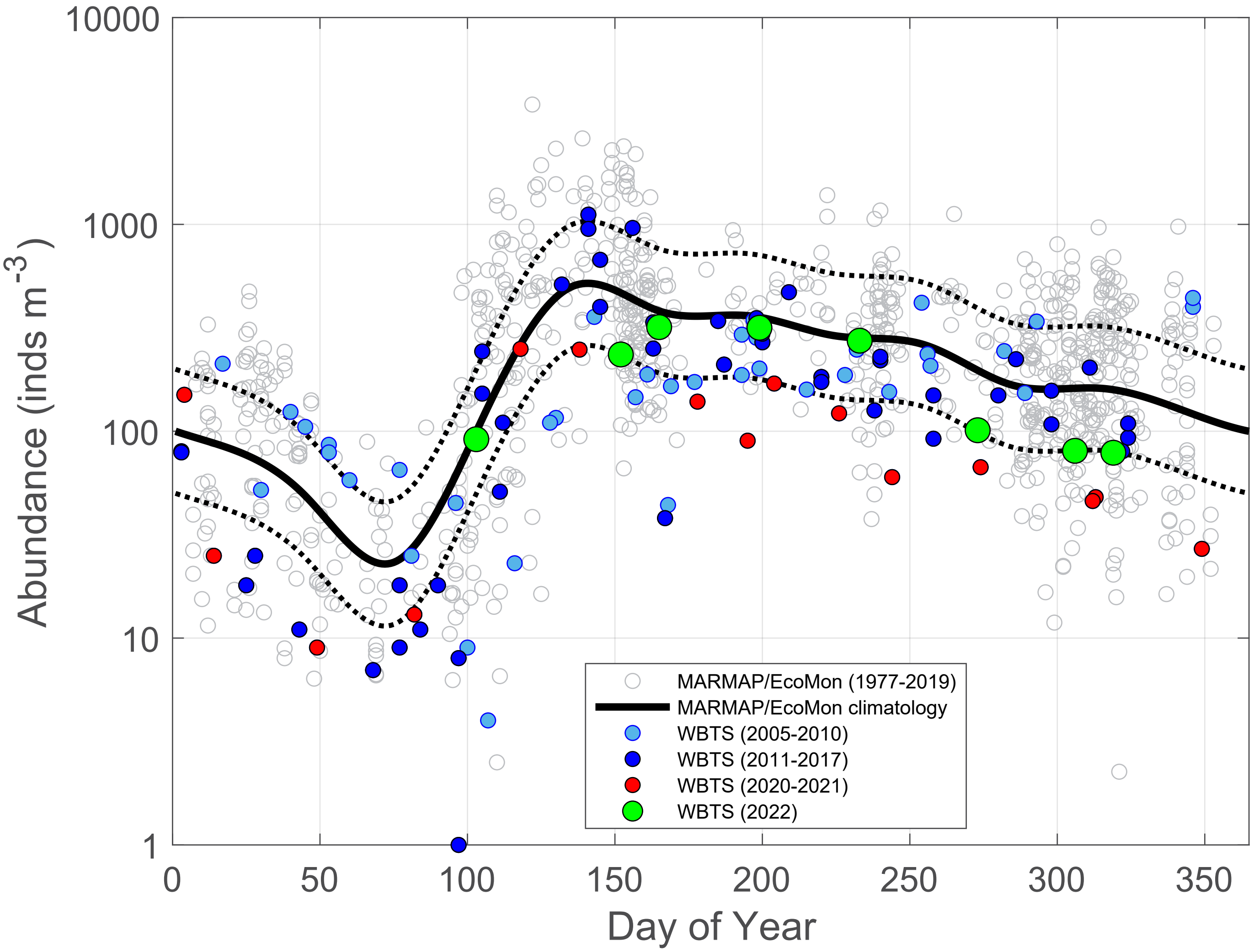


Figure 11: Long-term trends (top) in abundance of the copepod *Calanus finmarchicus* measured by the NOAA MARMAP and EcoMon programs, and at the Wilkinson Basin Time Series (WBTS) Station. Newer WBTS data points from the sampling program implemented by the Integrated Sentinel Monitoring Network, with support from the Marine Biodiversity Observation Network, are colored red (2021) and green (2022) to illustrate the low abundance observed in recent years. Note that this abundance is expressed on a logarithmic scale.
Data source: NOAA and Woods Hole Oceanographic Institution

well as industries that depend on these and other affected species (especially fisheries and ecotourism).

EMERGING ISSUES

Although Harmful Algal Blooms (HABs) are not a new phenomenon in the Gulf of Maine, there are signs that they are becoming more problematic. This is due to the emergence of new HAB species in the region, notably the first documentation of *Pseudo-nitzschia* in 2012, as well as changing conditions that can promote increased frequency and severity of blooms of all HAB species. Warmer water temperatures foster the development of HABs, as do increasing precipitation rates. Increases in temperature and precipitation also affect nutrient dynamics, which in turn drive HAB dynamics. More frequent and severe HABs have important implications for human health, recreation, and seafood production.

Another emerging issue is the rising concentration of CO_2 in the atmosphere and oceans, which is contributing to ocean and coastal acidification (OCA). Increased acidity in our coastal and ocean waters can pose a problem for shell-forming species (e.g., lobsters, oysters, clams, etc.), slowing the growth of new shell and, under extreme conditions, degrading existing shell. While the dynamics of OCA and its linkages to factors such as freshwater inputs and changing precipitation patterns are complex, understanding the impacts of OCA will be crucial given the high importance of these species to fishing communities and shellfish growers in the Northeast.

Finally, high-tide flooding constitutes another emerging issue warranting attention. An analysis of the first eight years of data from a tidal gauge at the mouth of the Hampton-Seabrook Estuary revealed that high tide flooding (greater than 10 ft above mean lower-low water) occurred on 36% of days monitored (Figure 12), with prospects for more frequent flooding as sea-level continues to rise. Sea-level rise interacts with long-term tidal cycles, making it harder to discern different signals and underscoring the importance of long-term time series.

Acknowledgment and Credit Jake Kritzer (NERACOOS)

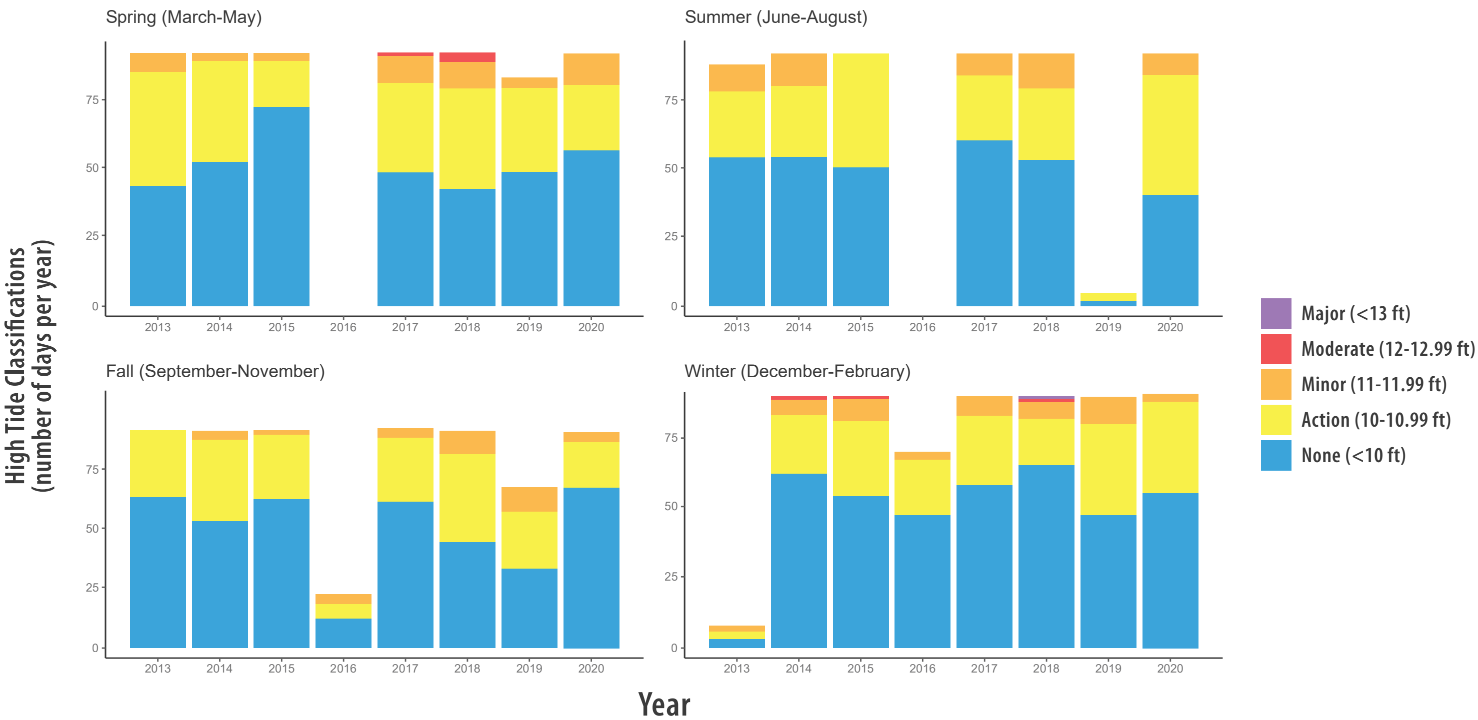


Figure 12: Number of days of each tide classification per season per year. There were large data gaps in 2016 and 2019 that resulted from equipment failure. The data record begins at the end of winter 2012, so there was incomplete data for this season of the year.
Data source: NHDES

Indicators

Impervious Cover

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

Five subwatersheds and 10 towns have greater than 10% impervious cover, including the Middle Cocheco River subwatershed which increased from 9.9% to 10.3% in 2021. Impervious cover in the Town of Exeter increased from 9.8% to 10.1%. There was no decrease in the number of towns with less than 5% impervious surfaces but the Bauneg Beg Pond-Great Works River and Isinglass River subwatersheds increased from 5% to 5.1% and from 4.8% to 5.1% respectively. As of 2021, 5.8% of the land area of the Piscataqua Region Watershed was covered by impervious surfaces. This is an increase of 1,834 acres of impervious cover or 0.2% of the watershed land area since 2015.

Goal

No increase in the number of subwatersheds and towns with greater than 10% impervious cover and no decrease in the number of subwatersheds and towns with less than 5% impervious cover.

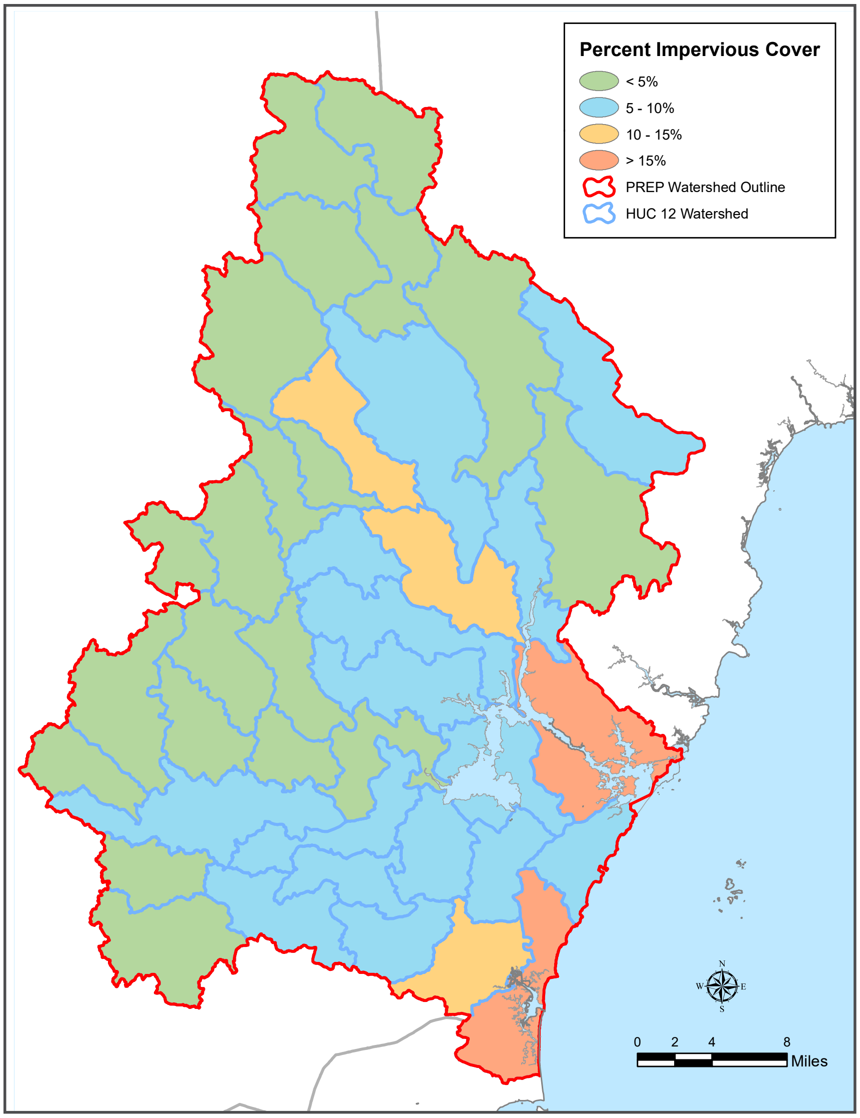


Figure 1.1: Percent impervious cover by subwatershed (HUC 12) in the Piscataqua Region Watershed as of 2021.
Data source: UNH Earth Systems Research Center

Why We Track This Indicator

Impervious surfaces are human-made features, such as parking lots, roads, and buildings, that do not allow precipitation to soak or infiltrate into the ground. When precipitation falls on impervious surfaces, a large proportion runs off into nearby waterways, carrying pollutants and sediments. More impervious surfaces also lead to higher peak flows and increased stream channel erosion. When watersheds have more than 10% impervious cover, water quality impacts become increasingly severe,[1] with some research showing impacts at less than 5% impervious cover.[2]

Explanation

The 2021 update to this dataset is the second iteration of mapping the entire 52-town Piscataqua Region Watershed using high resolution, 1-foot/60-cm

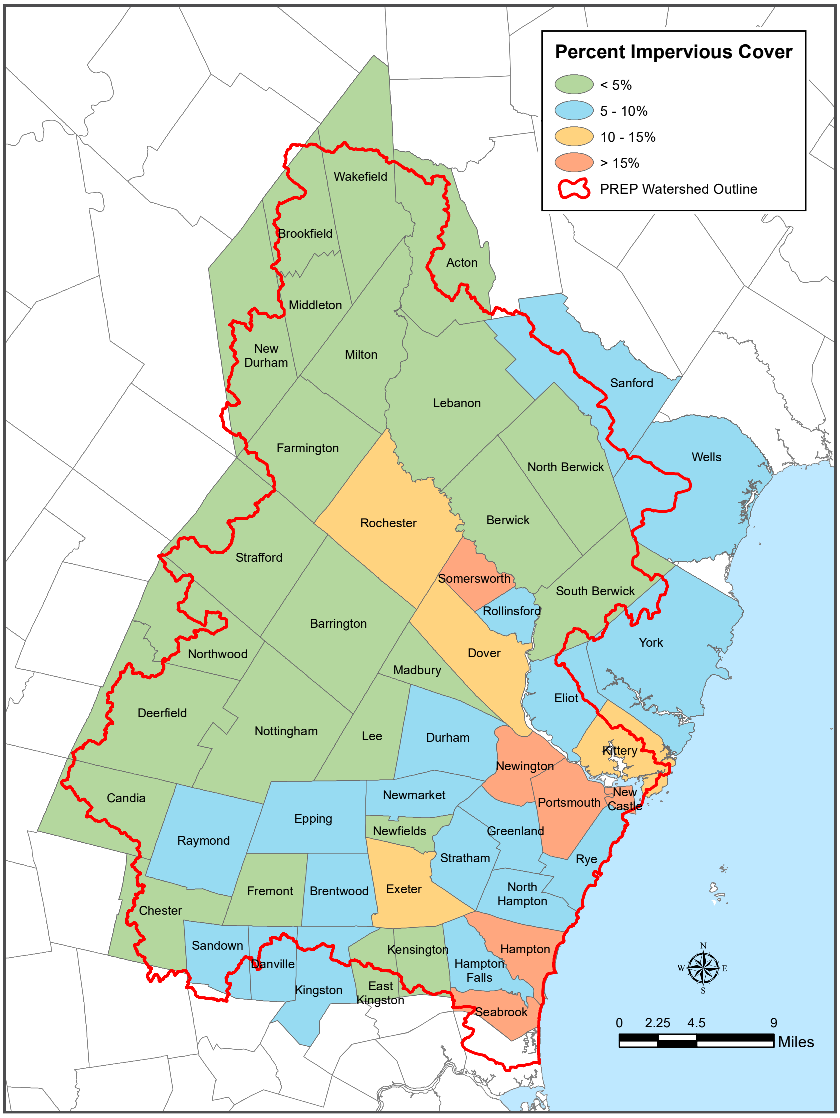


Figure 1.2: Percent impervious cover by town in the Piscataqua Region Watershed as of 2021.
Data source: UNH Earth Systems Research Center

orthoimagery. Impervious cover estimates using this approach represent 48,428 acres or 5.8% of the land area. This is an increase of 1,834 acres of impervious cover (0.2% of the Piscataqua Region) since 2015 (when there were 46,594 acres). Watersheds with greater than 10% impervious surface coverage of land area are concentrated in the vicinities of the Hampton-Seabrook Estuary, the Piscataqua River and the Route 16 corridor along the Cocheco River. Impervious surfaces in 2021 in each of the Piscataqua Region subwatersheds are shown as a percentage of land area in Figure 1.1.

Goals for impervious cover were not met. Two subwatersheds that previously had less than 5% went over the threshold (Bauneg Beg Pond-Great Works River and Isinglass River) and one subwatershed went over the 10% impervious threshold (Middle Cocheco River). Communities with the highest overall impervious cover percentages continue to be Portsmouth (27%), New Castle (21%), and Seabrook (21%), and the largest increases of impervious surfaces between 2015 and 2021 occurred in Wells (160 acres), Rochester (155 acres), Dover (109 acres), York (91 acres), Epping (72 acres), and Sanford (67 acres). Communities with the smallest increases in impervious surfaces included New Castle (2 acres), East Kingston (4 acres), and Portsmouth (4 acres) (Figure 1.2). Small increases in impervious cover in urbanized areas may be a result of limited availability of buildable lots. For information on housing trends in the watershed refer to the "Housing Permits" indicator section of this report. Town-by-town information on impervious surfaces in 2021 is shown in Figure 1.2.

Between 2015 and 2020 the population in the Piscataqua Region Watershed increased 3.9% (15,039 people), and impervious cover increased 4% (1,834 acres). This means that for every one person increase in population, impervious cover increased 0.13 acres or 5,663 square feet; however, impervious cover is not evenly distributed across the watershed. For more discussion on the relationship between municipal populations and impervious cover, see the Extended Report.

Acknowledgments and Credit

David Justice and Chris Phaneuf (NH GRANIT, Earth Systems Research Center), with contributions from Abigail Lyon (PREP) and Kalle Matso (PREP). Graphics from NH GRANIT.

Extended Report

These data were developed using 2021 National Agriculture Imagery Program (NAIP) orthophotography. See the Extended Report for a broader description of that data and how they differ from data used to generate previous impervious surface coverage estimates.

Housing

How many single and multi-family new housing permits were issued by communities in the Piscataqua Region Watershed from 2016 – 2020? How many new housing units were built from 2000 – 2020 in Rockingham, Strafford, and York Counties in the Piscataqua Region Watershed?

Since 2015, average annual housing permit approvals were 515 for multi-units and 549 for single-family units. In 2020 multi-unit housing permits fell to 361 while single-family permits increased to 628. Since 2000, there were 50,446 new housing units built, a 20% increase from 252,796 units in 2000 to 303,242 units in 2020. The expansion of the housing stock can lead to environmental consequences even if managed sustainably.

Why We Track This Indicator

Housing permit approvals and total housing offer context for tracking the impact of development on the watershed and estuaries. Development often increases impervious surfaces which can lead to more stormwater and sediment runoff and nutrient loading (see "Impervious Cover" and "Nutrient Loading").

Explanation

Those who live in the Piscataqua Region Watershed know that it is a desirable place to live. Since 2015, this region has experienced an increase in population of 3.9%. While there are substantial economic and cultural benefits of a growing community, increased population can lead to a variety of issues if not managed properly. New construction often increases impervious cover, leading to increased runoff and nutrient loading into the watershed. Improper fertilizer use on lawns, like applying more than is needed or before a rain event, can contribute to increased nutrient loading to our estuaries. Septic systems constructed too close to waterbodies, poorly maintained, or failing can also introduce harmful bacteria into local waterbodies and contribute to nutrient loading. Additionally, an increasing population and more housing results in more strain on municipal services and utilities.

In this section, the terms "housing units" and "housing permits" will be used frequently, and it is important to note the difference. "Housing permits" are permits issued by each municipality but do not indicate whether or not a structure was, in fact, built. "Housing units" refer to units that have been permitted and physically built.

The number of housing permits issued between 2000 and 2020 rose and fell reflecting economic trends (Figure 2.1). In the early 2000s, single family permits constituted the majority issued, with a high in the year 2000 of 1,513 permits. Since then, variables such as economic health and available land have shifted the metric. Following the 2008 recession, multi-unit permits have been rising from 216 permits issued in 2009 to a high of 727 permits issued in 2018. In the year 2020, coinciding with the pandemic, multi-unit permits fell to 361 and single-family permits increased to 628.

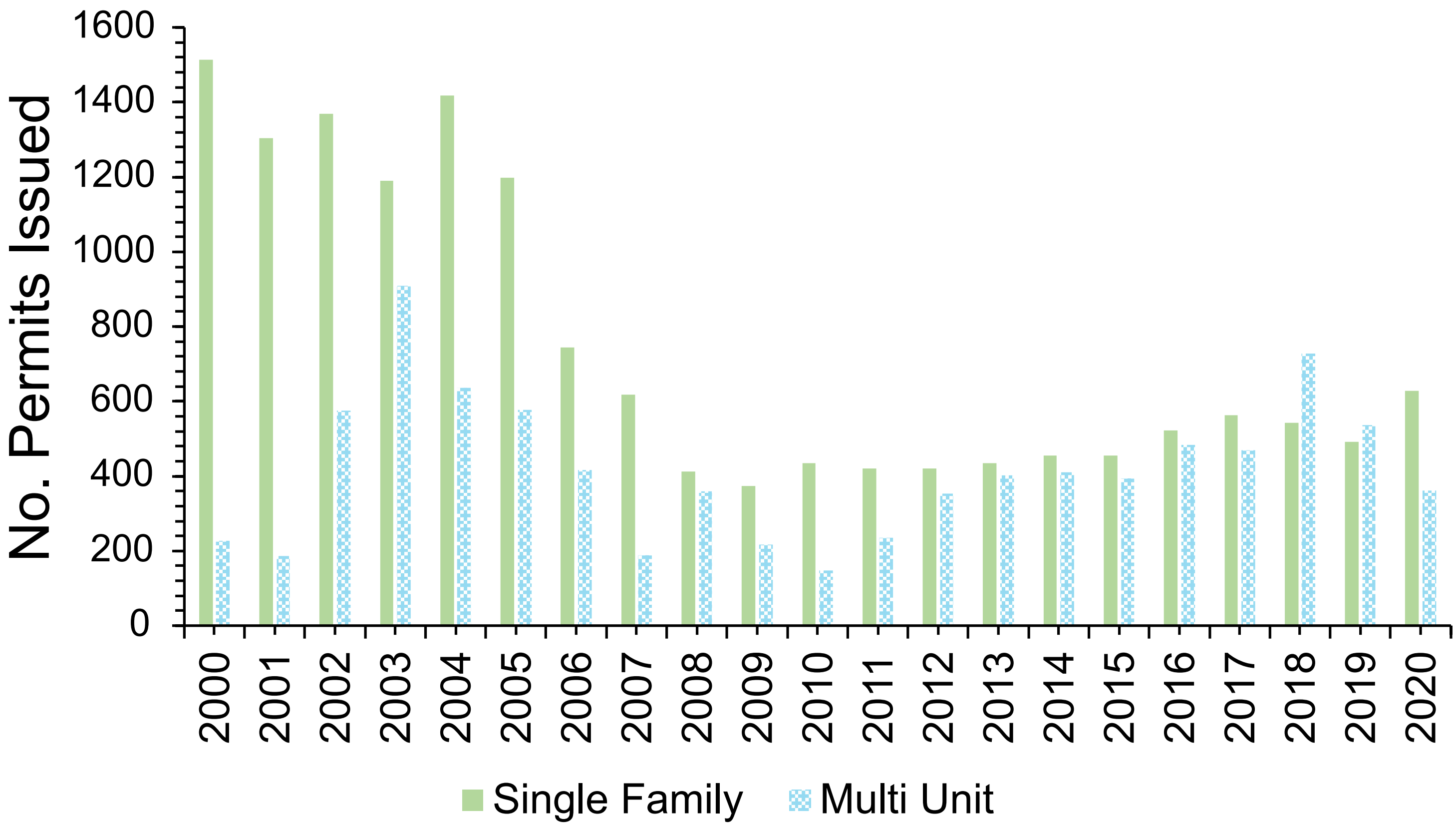


Figure 2.1: Housing permits issued in New Hampshire in the Piscataqua Region Watershed between 2000 and 2020, for both single and multi-family units.
Data source: NH Department of Business and Economic Affairs

Total housing units encompass all housing permitted and built from 2000 to 2020, including single-family, multi-unit, manufactured homes, and conversion of existing single units into condominiums and apartments. Currently there are a total of 303,242 housing units in the three counties (Rockingham, Strafford, and York) across the Piscataqua Region Watershed (Figure 2.2). This equates to a 20% increase in total units since 2000 and a 7% increase since 2010. Also included in these figures are unoccupied housing units, which are defined as units that are kept as second homes, vacant, condemned, or for sale with no current residents.

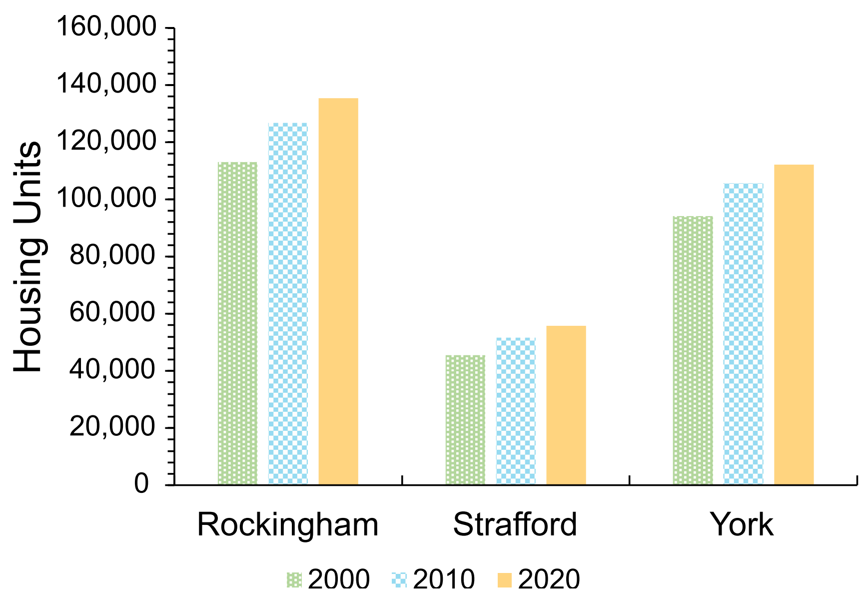


Figure 2.2: Total housing units in Piscataqua Region Watershed 2000 to 2020.
Data source: US Census, 2020, 2010, 2000

Single family homes make up most of the new and existing housing in the area (Figure 2.1). Rockingham, Strafford, and York Counties all have between 60 – 75% of their housing stock reported as single-family units. Multi-units make up 20 – 30%, and manufactured homes account for less than 10% in all three areas. "Manufactured" refers to

Housing

County	New Units (2000)	New Units (2020)	Annual Increase 2000 – 2020	Percent Increase 2000 – 2020
Rockingham	113,023	135,338	1,115	19.7%
Strafford	45,539	55,706	508	22.3%
York	94,234	112,198	898	16.0%

Table 2.1: Housing unit change in counties of the Piscataqua Region Watershed.
Data source: US Census, 2020

prefabricated homes (including but not limited to trailers) that are not built on site.

A 2021 report stated a goal to build 13,500 new housing units by 2024 to meet the current market demand in New Hampshire.[3] Although this includes the entire state, we know that the population density and economic centers fall disproportionately in the Rockingham and Strafford County areas, two of the three counties in the Piscataqua Region Watershed. Rockingham County has seen an increase in housing units of 1,116 units per year since the year 2000. Strafford County sits at about half of this with 508 units per year, and York County housing units have increased by an average of 898 units (Table 2.1).

In order to meet housing needs, it is also important to consider occupancy of existing housing stock. For example, in 2020 there were an estimated 37,077 unoccupied housing units in the Piscataqua Region Watershed (Figure 2.3). Unoccupied housing includes second or vacation homes, vacant properties, condemned properties, and for-sale units (with no current residents). Unoccupied housing reached a peak in 2010 and has decreased only slightly in the past decade.

In York County, 20.7% of all the housing units fall into the 'unoccupied' category, meaning more than 1 in 5 housing units has no permanent residents (Figure 2.4). This metric is lower in both New Hampshire counties where the percent unoccupied is 7.1% and 7.6% for Rockingham and Strafford, respectively.

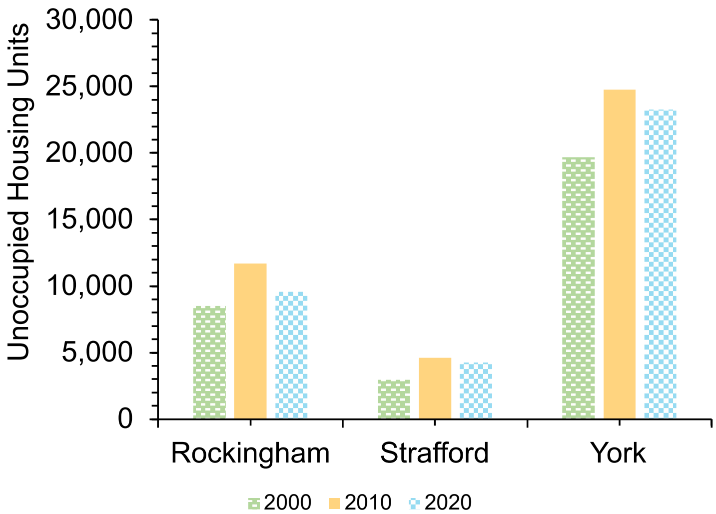


Figure 2.3: Unoccupied housing units in the Piscataqua Region Watershed by county.
Data source: US Census, 2020

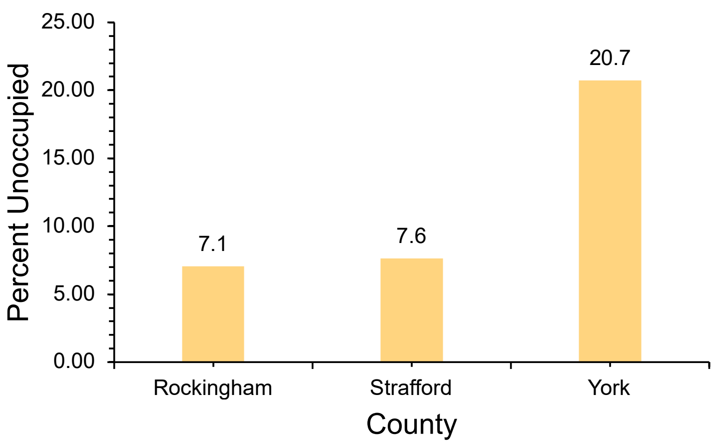


Figure 2.4: Percentage of unoccupied housing units in the Piscataqua Region Watershed by county.
Data source: US Census, 2020

Acknowledgments and Credit
Nathaniel Gruen (PREP/UNH), Abigail Lyon (PREP), and Kalle Matso (PREP).

Photo of Hampton Beach, by Jerry Monkman

Stormwater Management Standards and Funding

How many of the 52 communities in the Piscataqua Region Watershed have adopted the Southeast Watershed Alliance Model Stormwater Standards for Coastal Communities or similar standards? Additionally, how many communities in the watershed have adopted a stormwater utility?

As of May 2022, 24 of the 42 (57%) New Hampshire municipalities in the Piscataqua Region Watershed have adopted the complete set of the Southeast Watershed Alliance (SWA) model or similar stormwater management standards, two communities are in the process of adoption, one community has partial or a different set of standards, and 15 communities have not yet adopted stormwater standards. The 10 Maine communities in the watershed adhere to state-level stormwater management regulations. Although there is community interest in exploring alternate stormwater funding mechanisms, currently no communities have adopted or implemented a stormwater utility. Stormwater projects, operations, and maintenance remain funded by a combination of local taxes, property development costs, grants and loans, and fees.[4]

Why We Track This Indicator

Stormwater runoff is a significant source of non-point source pollution that contributes to water quality degradation. When rain falls and snow melts on impervious surfaces like roads, parking lots, and buildings, pollutants on the surface run off into groundwater and directly into local waterbodies. Also, undersized and aging stormwater infrastructure can worsen flooding. Adopting and enforcing up-to-date stormwater management standards to improve stormwater infrastructure can reduce both pollution and flooding. Additionally, establishing a dedicated funding mechanism, like a stormwater utility, can support stormwater operations and maintenance and help communities plan for necessary upgrades to existing infrastructure to support water quality goals.

Explanation

Successful stormwater infrastructure directs rainfall to a treatment area where water soaks or infiltrates into the soil or, in some cases, to an outfall on a local waterbody. Impervious cover has a negative impact on streams and groundwater supplies and contributes to nutrient loading and pollution runoff into surface waters. Improvements in stormwater infrastructure include approaches to reduce flow and pollution and to increase infiltration. This helps to recharge groundwater supplies, purify water, and slow the rate of water entering streams that might otherwise increase erosion and the risk of flooding.

Adopting local stormwater management standards helps communities balance development while improving existing site conditions and preventing or reducing future water quality impairments. There are also financial benefits and savings for adopting stormwater management regulations early to avoid higher future costs of installing stormwater retrofits to restore impaired waters.[5] New Hampshire state statute enables municipalities to adopt regulatory standards for stormwater management projects not captured under

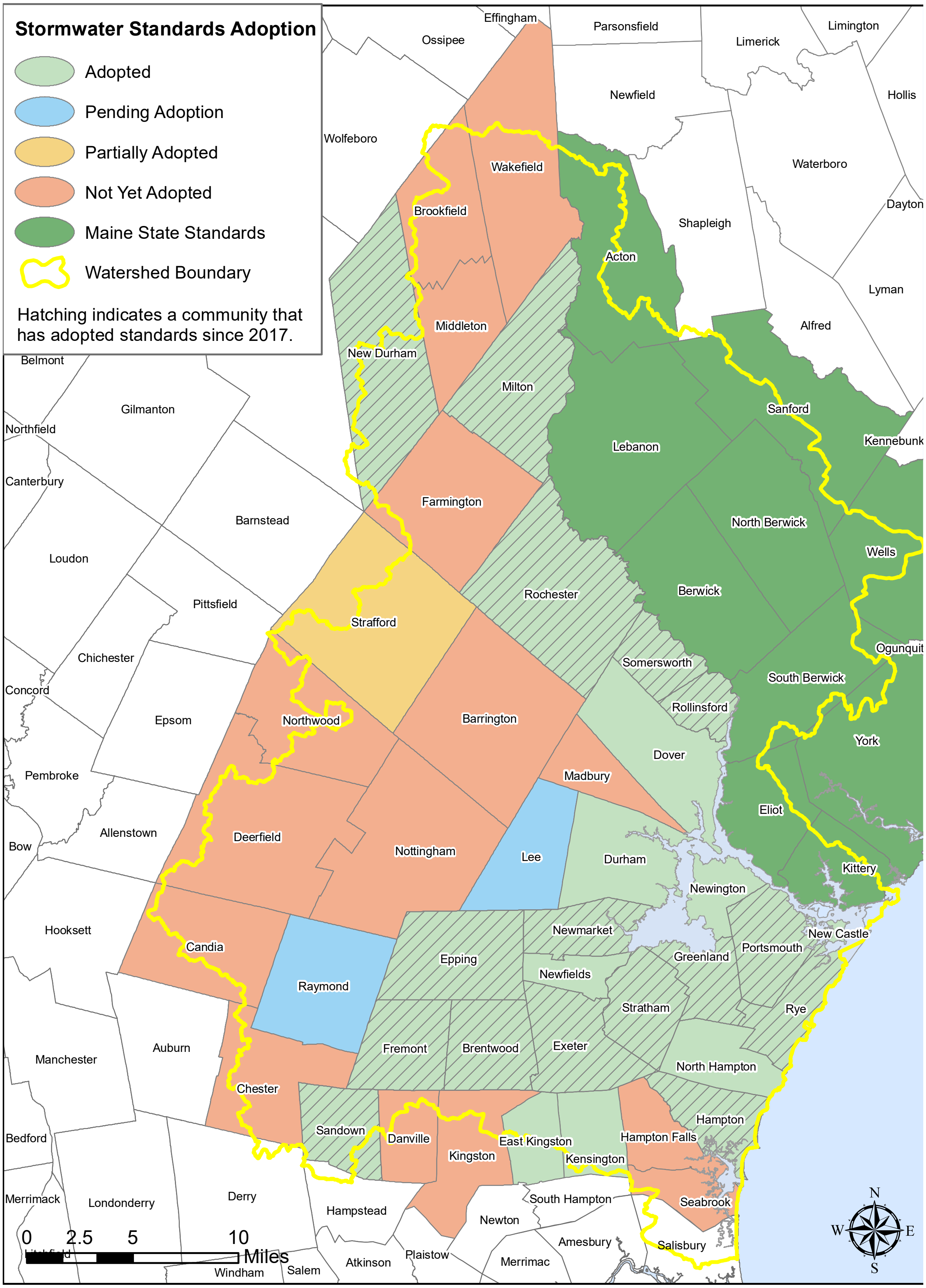


Figure 3.1: Status of stormwater management standards adopted in the Piscataqua Region Watershed.
Data source: Strafford Regional Planning Commission and Rockingham Regional Planning Commission, May 2022

Stormwater Management Standards and Funding

state Alteration of Terrain regulations.[6] Similarly in Maine, the state stormwater management law provides stormwater management standards for development that communities must implement for projects exceeding one acre of disturbance.[7]

The SWA model stormwater standards provide a comprehensive and tailorable approach that can be adopted as part of a community's zoning ordinance or land development regulations. The list below is a summarized version of key components of the SWA Model Stormwater Standards for Coastal Watershed Communities (elements B-D).[8] Including these four components in local regulations minimizes further water quality impairments, and in the case of redevelopment, can improve existing conditions.

- Threshold for applicability — Creates a minimum threshold area for disturbance for new development projects that requires full compliance with stormwater standards.
- Performance measures — Improves water quality by requiring the removal of an established percentage of Total Suspended Solids, Total Nitrogen, and Total Phosphorus.
- Groundwater recharge — Promotes use of infiltration practices (groundwater recharge) to reduce runoff caused by a project and replenish groundwater supply.
- Redevelopment criteria — Requires improvements in stormwater management and treatment for redevelopment projects on existing properties.

To assess stormwater management progress across the Piscataqua Region Watershed, PREP monitors which municipalities have adopted enhanced stormwater standards. As of May 2022, the SWA model or similar stormwater standards has been adopted by 24 communities, one community has adopted a partial set of the recommended regulations without redevelopment standards, two communities have regulations pending, and 15 communities have not yet adopted stormwater regulations (Figure 3.1). Overall, 35 out of 52 communities in the Piscataqua Region Watershed have adopted some level of stormwater standards including the 10 Maine communities in the watershed that adhere to Maine state standards. This represents an increase of 16 communities (31%) that have adopted enhanced stormwater management standards since 2017.

Local stormwater management standards are a step toward reducing non-point source pollution and better managing stormwater in a community. Regulations alone will not solve all water quality concerns and flooding, but enforcement of these standards is key to seeing improvements on the ground. The model stormwater standards also only address new and redevelopment and not existing impervious surfaces. Communities can begin to address existing impervious cover on both public and private land by establishing a dedicated stormwater funding mechanism like a stormwater utility.

Stormwater utilities generate dedicated funding for stormwater management through user fees that are often based on a property's impervious area.[9,10] Fees based on impervious surface area can incentivize green infrastructure and the reduction of impervious surfaces by property owners, further improving water quality and alleviating flooding. This dedicated funding can also be used to maintain or upgrade existing stormwater infrastructure like catch basins and outfalls, develop drainage plans, construct flood control measures, and enhance water quality programs. In addition to providing a dedicated funding source, stormwater utilities can improve the equity of funding stormwater management by basing the fee on impervious surface area rather than property value in cases where property taxes are used to generate stormwater funding.

More than 2,000 communities across the country implement a user or service-based fee program to fund stormwater management and flood resilience programs.[11] Currently, none of the 52 communities in the Piscataqua Region Watershed have adopted stormwater utilities; however, several communities are exploring the possibilities. In August 2020, the City of Dover established the Ad Hoc Committee to Study Stormwater and Flood Resilience Funding (Committee) to investigate, study, identify, and make recommendations to the City Council concerning various funding opportunities with respect to existing needs and future stormwater and flood resilience management planning. In January 2022, the Committee voted unanimously to recommend the City of Dover pursue establishment of a Stormwater and Flood Resilience Utility with considerations for crediting to offer rate payers the opportunity to reduce their fee by making site improvements that reduce stormwater runoff and/or improve the water quality of stormwater runoff from their property. Other communities, including Rochester and Portsmouth, have expressed interest in exploring stormwater funding mechanisms/utilities.

Acknowledgments and Credits
Nathaniel Gruen (PREP/UNH) and Abigail Lyon (PREP)
with contributions from Fay Rubin (PREP)

Salt Marsh

How many acres of salt marsh are there in the towns of the Piscataqua Region Watershed and how are the marshes responding to sea-level rise?

There are 5,711 acres of tidal marsh habitat in the New Hampshire portion of the Piscataqua Region Watershed. These acres are distributed among 16 towns, with the greatest amount in Hampton (1,429 acres) and Seabrook (1,189 acres). Between 1900 and 2010, an estimated 1,045 acres of salt marsh in New Hampshire was lost to development or inadequate tidal flow.[12] Although changes in overall acreage since the 2018 report are negligible, existing salt marshes are threatened by sea-level rise and the spread of the invasive common reed (*Phragmites australis*).

Why We Track This Indicator

Salt marshes are among the most productive ecosystems in the world. They support recreational and commercial fisheries, protect shorelines from erosion, provide long term carbon storage, reduce flooding, protect water quality, and provide essential wildlife habitat. While salt marsh extent and health are impacted by sea-level rise, they are also impacted by management decisions related to land use and water quality.

Explanation

The 2018 State of Our Estuaries report focused on acreage, and there has been little change in the number of acres of salt marsh in the Piscataqua Region Watershed. However, new data allowed for better assessment of marsh resilience to sea-level rise, which is the most immediate stressor for salt marshes. Not surprisingly, the areas with the most extensive marshes, such as Rye and the Hampton-Seabrook Estuary, are also the areas showing the most resilience to sea-level rise. On the other hand, marshes surrounding the Great Bay Estuary as well as marshes in the Portsmouth and Newington areas, are the least resilient to rising seas. This indicator focuses on salt marshes in New Hampshire as we do not have sufficient data for Maine at this time.

Metrics that indicate resilience to sea-level rise include: the relative proportion of high to low marsh; the ratio of unvegetated to vegetated areas; and the acreage of marsh migration pathways, which show potential for a marsh to move inland in the future.

Proportion of High to Low Marsh, by Region and Community

The boundary between high and low marsh is notable as a vegetative demarcation of local mean high-water level. Changes in the location of this boundary are one of the earliest ecological indicators of climate change. If there is enough suspended sediment available, salt marshes can build up peat and maintain their elevation relative to rising sea levels. Salt marshes can also migrate inland as sea-level rises. If barriers prevent migration and the marsh cannot accrete vertically at a rate that keeps up with sea-level rise, change will take place in two stages. First, the relative proportion of low marsh will increase and slowly take over the area occupied by high marsh. Second, eventually the entire marsh will become "squeezed" against the barrier and slowly convert to intertidal mudflat.

Regionally, the Great Bay Estuary has the highest proportion of low marsh. These systems could be starting to experience flooding and may not be able to keep up with sea-level rise (Figure 4.1). Thus, projects that aim to enhance marsh resilience in this Estuary are particularly important to pursue.

Extensive high marsh meadows can be found in Rye and the Hampton-Seabrook Estuary, in contrast to the mainly fringing marshes along many of the tidal rivers and Great Bay shorelines. Meadows in Exeter, Portsmouth, and Stratham have a greater proportion of high marsh and are currently keeping

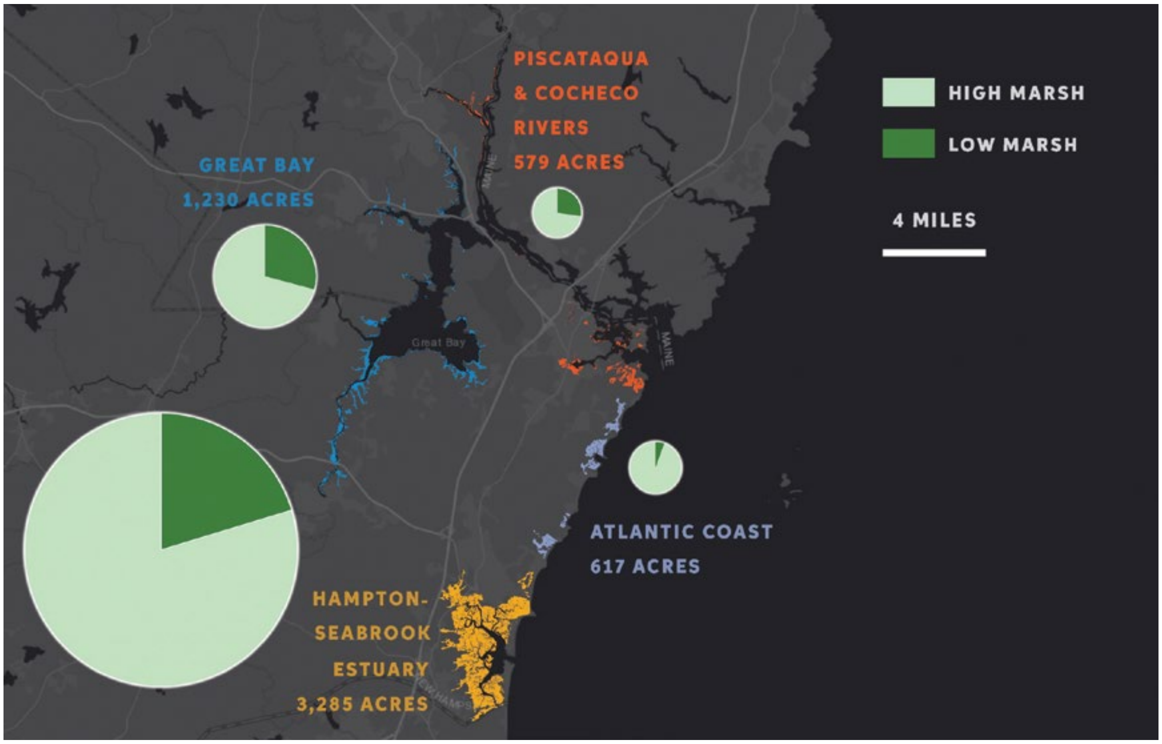


Figure 4.1: Overall acreage and proportion of high and low salt marsh in different regions of New Hampshire. Marshes in Great Bay have the highest proportion of low marsh showing they are least able to keep pace with sea-level rise.
Data source: Great Bay National Estuarine Research Reserve

A Detailed Look at Salt Marsh Response to Sea-Level Rise

Field data from three marshes encircling the Great Bay indicate that marshes are changing over time due to increased tidal flooding. As a result, they are becoming wetter, with low marsh plants dying off and high marsh looking more like low marsh. Evidence of this change is most notable at transition areas between low and high marsh because it is the lower limit of stress from tidal flooding for most plant species. The transition area at Great Bay Farms marsh (Figure 4.5), located on the eastern shore in Newington, shows a drastic change between 2010 and 2022 with the high marsh dominant salt hay (*Spartina patens*) being almost completely replaced by its more flood tolerant cousin, smooth cordgrass (*Spartina alterniflora*). Supporting these changes in plants, a local study found Great Bay marshes were not building up as fast as sea-level rise.[15] Finally, a recent regional study including data from Great Bay shows more extreme changes towards a wetter and less vegetated environment, as in southern New England marshes, which may be a sign of the future of Great Bay marshes.[16]




up with sea-level rise more effectively than those in Dover (Figure 4.2). An example of a marsh that is dominated by low marsh, demonstrating it is not keeping up with sea-level rise, can be seen when driving on Route 4 along Bunker Creek in Durham. Over 80% of this site is low marsh; it cannot migrate inland due to the high-sided natural topography of the surrounding upland.

The Unvegetated to Vegetated Ratio of a Marsh

The amount of plant coverage on a salt marsh in comparison to the amount of bare earth and standing water is an important indicator of its vulnerability to relative sea-level rise. This Unvegetated to Vegetated Ratio (UVVR), has been found to be highly correlated with net sediment budget and helps to determine if a marsh is building up vertically and laterally or eroding and starting to "drown." It has been found that marshes with a UVVR above 0.15 start to become unstable and are at a tipping point to drowning and/or lateral contraction.[13]

Over 89% of marshes in New Hampshire have a UVVR of 0.15 or less, so most New Hampshire marshes are not showing signs of vulnerability to sea-level rise according to this metric (Figure 4.3). Portsmouth and Newington have marshes with the highest average UVVR values of 0.38 and 0.32 respectively. The marsh that fringes the eastern portion of South Mill Pond in Portsmouth has the highest UVVR by far in the state of New Hampshire. It is bounded by roads, a parking lot, and a tennis court.

Marsh Migration Potential

If a marsh abuts low-lying topography, it has potential to migrate inland and keep up with relative sea-level rise. Consequently, these migration pathways are good places to target land protection projects.

Rye and Hampton have the largest acreage of migration pathway and, therefore, have the highest potential for new salt marsh formation (Figure 4.4). The largest unhindered area in New Hampshire is the low-lying forest surrounding Fairhill Marsh in Rye. In Great Bay, the largest migration pathways lie at the mouth of the Squamscott River.

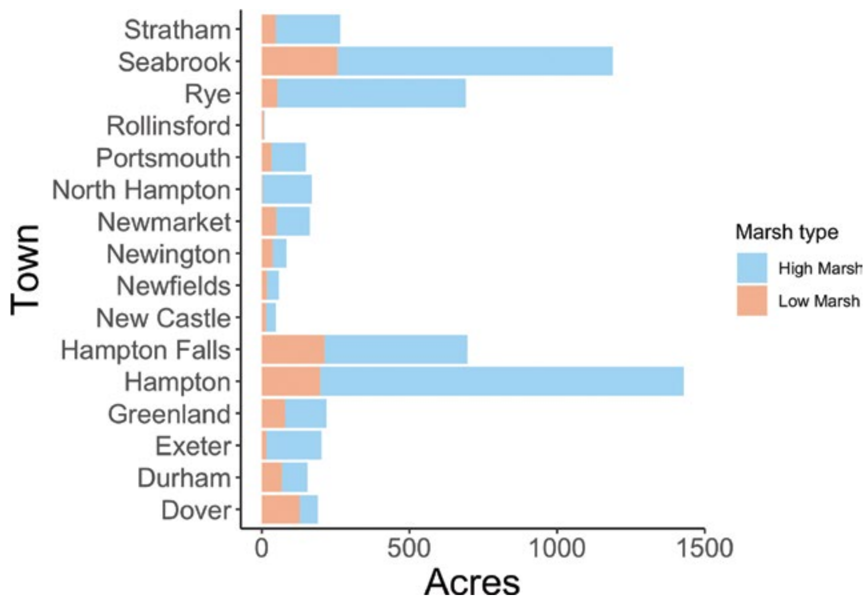


Figure 4.2: The acreage of salt marsh in coastal communities of New Hampshire.
Data source: Great Bay National Estuarine Research Reserve

Beyond the size of marsh migration space, land cover type within this low-lying upland edge determines how easily a tidal wetland can migrate inland.[14] For example, it is much easier for a salt marsh to spread into a neighboring brackish or freshwater marsh as sea-level rises than a low-lying developed area such as a paved parking lot.

Acknowledgments and Credits
Rachel Stevens (GBNERR/NHFG), with contributions from Katie Callahan (NHFG), Chris Peter (GBNERR/NHFG), David Burdick (UNH), Kevin Lucey (NHDES), Adrienne Kovach (UNH), Neil Ganju (USGS), and Alyson Eberhardt (NH Sea Grant/UNH Extension). Graphics by Rachel Stevens.

Extended Report

UNH researchers have been investigating nesting success and habitat of the saltmarsh sparrow, a species of special concern in New Hampshire. Read more about these results and other salt marsh monitoring in the Extended Report.

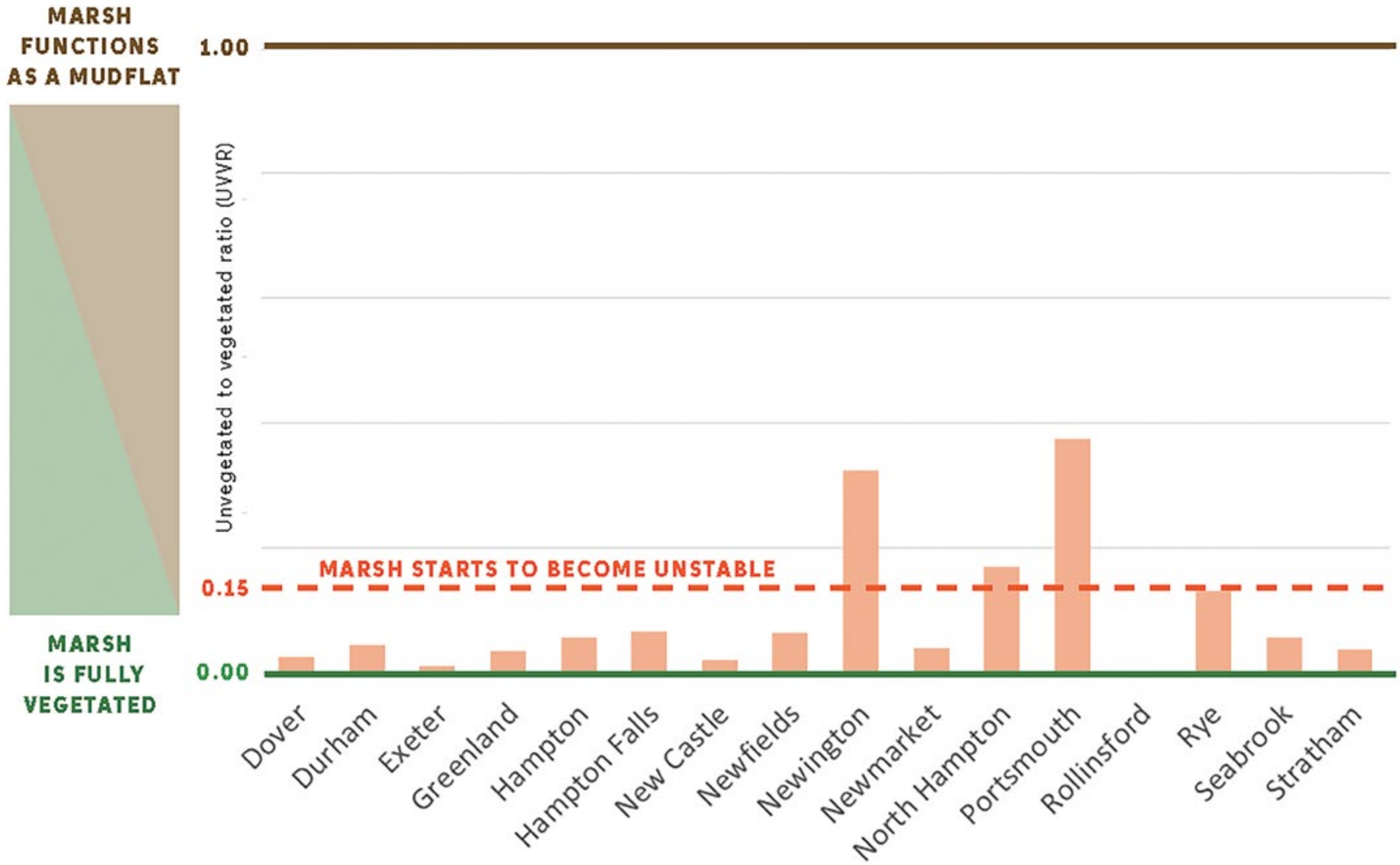


Figure 4.3: The unvegetated to vegetated ratio of marshes for communities in New Hampshire. A marsh with a UVVR of 0.0 is entirely covered by vegetation, while a marsh with a UVVR of 1.00 or more is so sparsely vegetated it is effectively functioning as a mudflat.
Data source: Great Bay National Estuarine Research Reserve

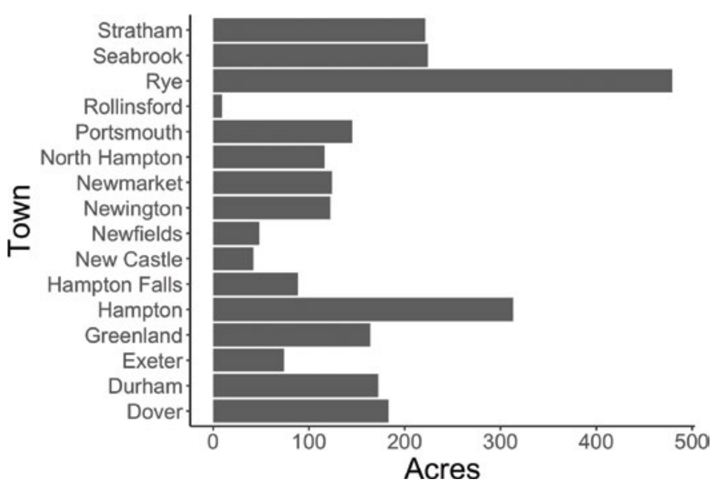


Figure 4.4: The acreage of potential salt marsh migration pathway in coastal communities of New Hampshire using a 2m (6.6ft) sea-level rise scenario at the year 2100.
Data source: Great Bay National Estuarine Research Reserve

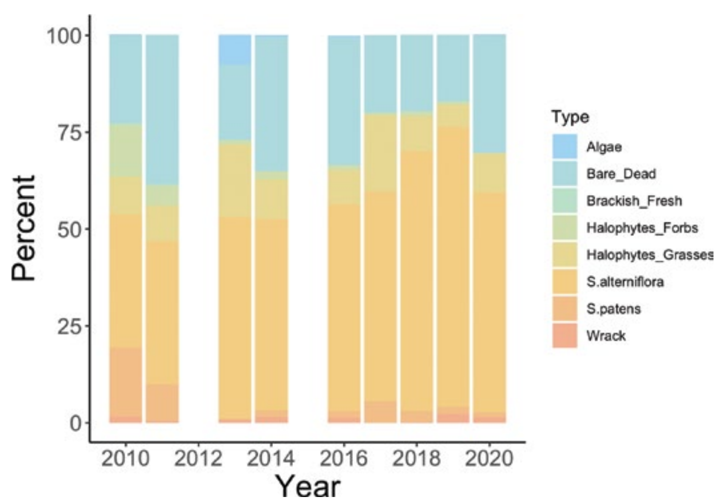


Figure 4.5: Field data collected from Great Bay Farms marsh in Newington, NH within transition plots (area between low and high marsh).
Data source: Great Bay National Estuarine Research Reserve

Conserved Lands (General)

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

As of April 2022, 18.1% of the total land area in the watershed (151,978 acres) was conserved, representing an increase of 2.6% in new land area coming under conservation (21,676 acres) since 2017. An additional 16,024 acres must be conserved in the watershed to meet the PREP goal of 20% of the total land area conserved.

Goal

Conserve 20% of the total land area in the Piscataqua Region Watershed.

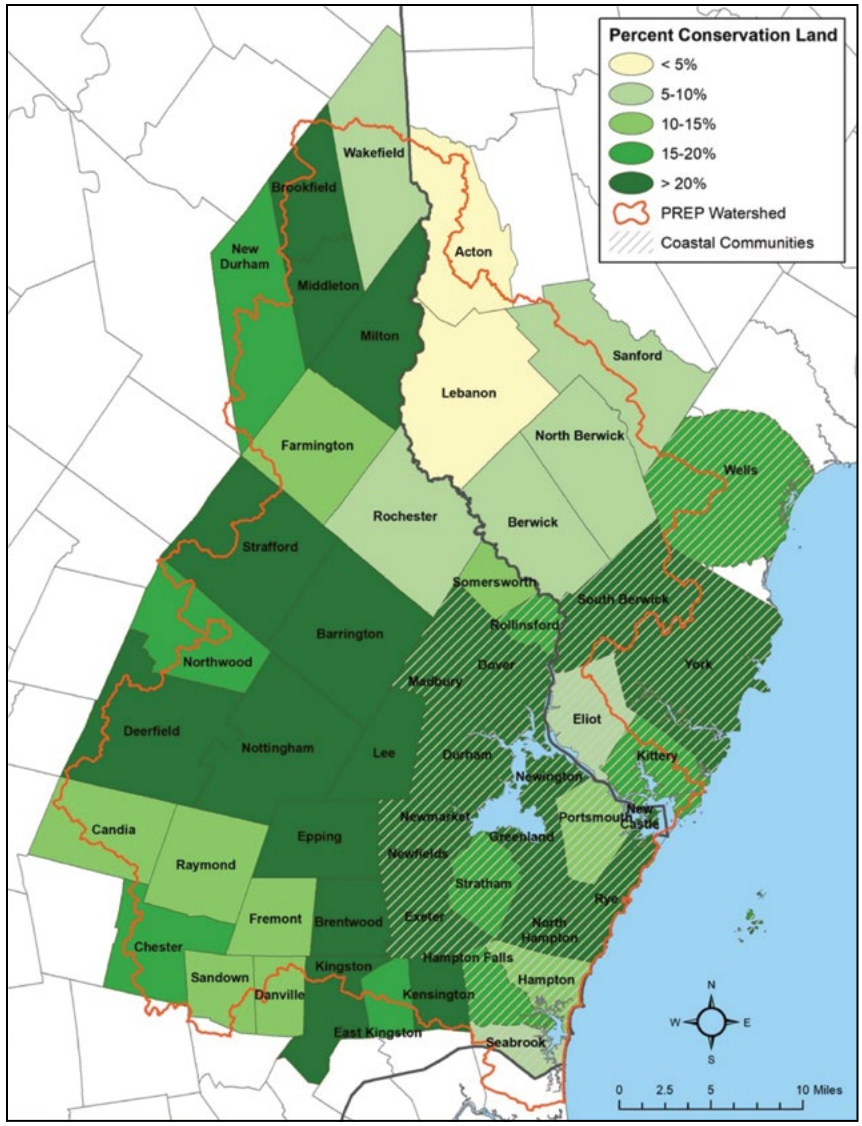


Figure 5.1: Land conservation percentages for each Piscataqua Region Watershed community.
Data source: NH GRANIT, Earth Systems Research Center

Why We Track This Indicator

The Piscataqua Region Watershed is under pressure from population growth and associated development. Conserving a network of natural lands across the region is the most effective action we can take to ensure clean water and healthy and abundant wildlife populations, minimize flood damages, and provide a diversity of quality recreational opportunities.

Explanation

As of April 2022, 18.1% of the total land area in the Piscataqua Region Watershed (151,978 acres) was conserved. This represents an increase of 2.6% in new land area coming under conservation (21,676 acres) since the last report in 2017. Of the acreage considered conserved, 86% is under permanent protection. Across

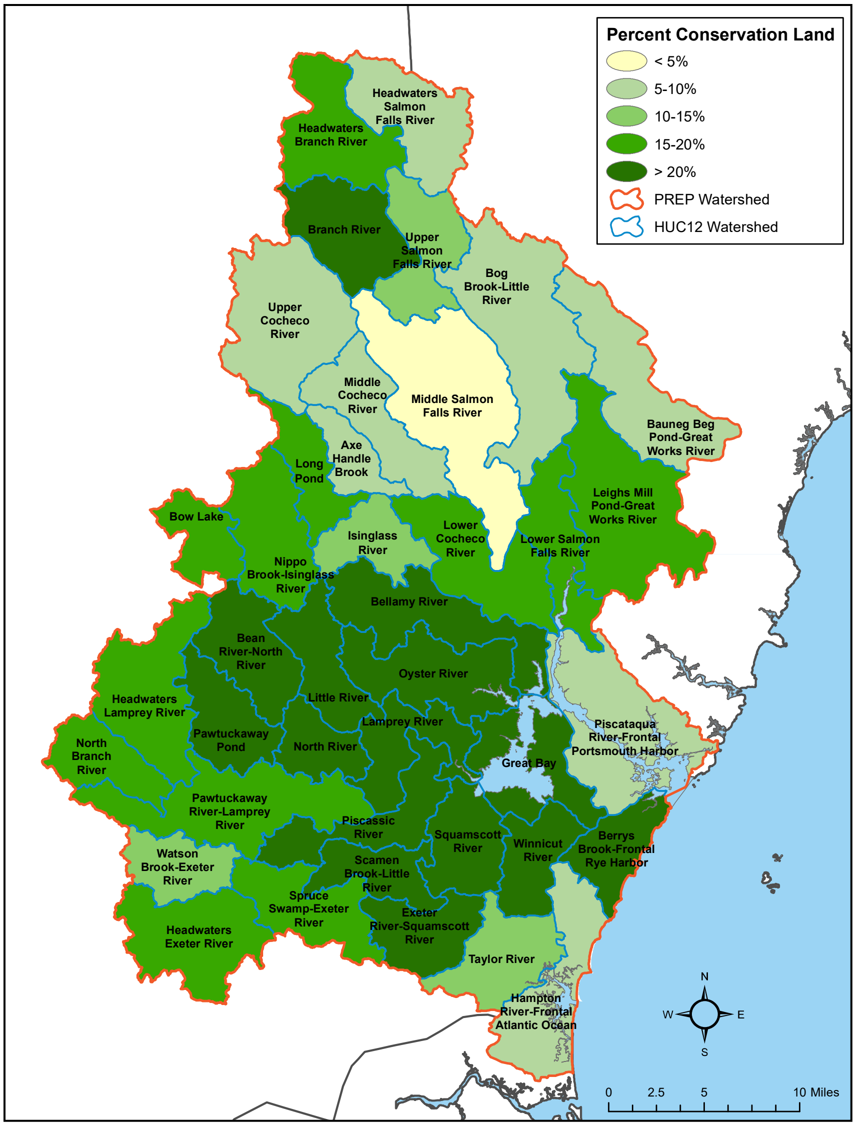


Figure 5.2: Land conservation by percentage of total area for each HUC-12 (sub-watershed level).
Data source: NH GRANIT, Earth Systems Research Center

the 22 coastal communities in the region (those adjacent to tidal waters), a total of 56,907 acres of land has been conserved. This represents 22.3% of the total land area in those 22 towns.

In 2017, 28 communities had achieved greater than 15% of their land in conservation. As of 2022, six additional communities have conserved greater than 15% of their land area for a new total of 34 communities (Figure 5.1). Of those, 26 communities have met or exceeded the PREP goal of 20% of total acreage conserved. Overall, conservation lands have increased across most of the region. But there remain places where conservation lands, as a total percentage of the community's land cover, are less than 5%. At the subwatershed level (HUC-12 analysis; Figure 5.2), areas where conservation efforts have been high (greater than 30% of total land area) include Branch River, Exeter-Squamscott, Great Bay,

Lamprey River, Oyster River, Pawtuckaway Pond, and Scamen Brook-Little River. Conversely, areas where conserved lands lag include Bauneg Beg Pond-Great Works River, Bog Brook-Little River, Middle Cocheco River, and Middle Salmon Falls River.

Although land protection continues to progress, there is work to do to reach the PREP goal of conserving 20% of the land area. Land protection for the 22 coastal communities in the aggregate has exceeded 20%, but an additional 16,024 acres must be conserved to meet the 20% level for the entire watershed.

Acknowledgments and Credit
Trevor Mattera (PREP), David Justice, and Chris Phaneuf (NH GRANIT, Earth Systems Research Center) with contributions from Abigail Lyon (PREP)

Conserved Lands (Focus Areas)

Photo by Jerry Monkman

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

As of 2022, 32.6% of Conservation Focus Areas (CFAs) in New Hampshire and 14.1% of CFAs in Maine were conserved. This represents a total of 29.3% of conserved CFA acreage in the watershed. Given the challenges associated with conserving these important lands, the PREP goal of conserving 75% of total acres in the CFAs will take additional effort to achieve.

Goal

Conserve 75% (199,026 acres) of lands identified as Conservation Focus Areas.

Photo by Jerry Monkman

Why We Track This Indicator

The Piscataqua Region Watershed is home to exceptional unfragmented natural areas and corridors supporting important wildlife populations, water filtration capacity, and protection against flooding and storms. CFAs represent highly prioritized areas for conservation that maximize these benefits. Due to development and growth pressures in our region, it is increasingly important to protect these areas to ensure they will continue to provide benefits for future generations.

Explanation

The 2021 New Hampshire's Coastal Watershed Conservation Plan (Plan) is a science-based, regional conservation master plan that identifies 265,368 acres of CFAs in the Piscataqua Region Watershed across New Hampshire, Maine, and Massachusetts.[17] These CFAs encompass conservation priorities for maintaining ecological function and integrity for wildlife and habitat, coastal water resource protection, coastal resilience, and climate adaptation. The Plan identified CFAs by synthesizing and weighting previous conservation datasets used to prioritize land conservation and protect the specific benefits and values mentioned.[18 – 23] The CFAs in the new Plan integrate, update, and replace the 166,212 acres of CFAs identified in The Land Conservation Plan for New Hampshire's Coastal Watersheds (2006)[24] and The Land Conservation Plan for Maine's Piscataqua Region Watersheds (2010)[25] and used for the 2018 State of Our Estuaries report.

Of the 265,368 acres that fall within designated CFAs, 29.3% (77,629 acres) has been permanently protected (Figure 6.1), representing progress toward the PREP goal of conserving 75% of total CFA acres in the region (199,026 acres) but still falling far short. As there have been incremental updates but no substantial, comprehensive updates to the conservation lands datasets since 2017, conserved acres may be underrepresented in the data after this point. Nonetheless, the data we have suggests the need for continued, focused efforts in protecting valuable lands in our region to meet our goal.

Acknowledgments and Credit

Trevor Mattera (PREP), with contributions from Anna Ormiston and Peter Steckler (TNC) and David Justice and Chris Phaneuf (NH GRANIT, Earth Systems Research Center). Graphics from Anna Ormiston and Peter Steckler.

Extended Report

See the Extended Report for a breakdown of total and protected CFA acreage across towns in the Piscataqua Region Watershed. Looking to take the next step protecting lands in your community? Check out www.Connect-Protect.org for more information.

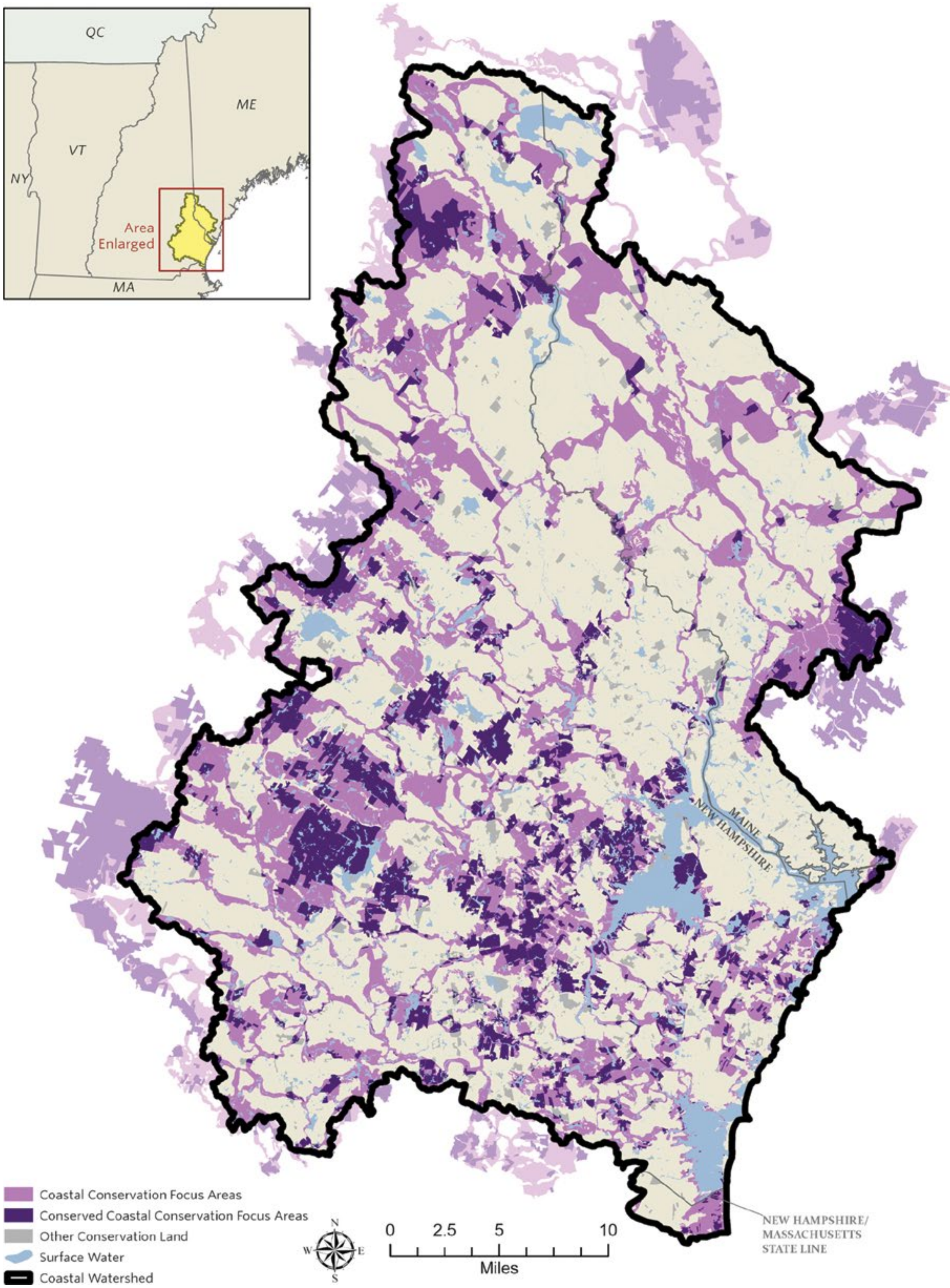
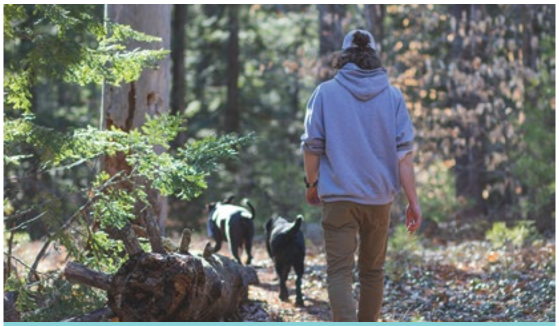


Figure 6.1: Conservation Focus Areas (CFAs) in the Piscataqua Region. CFAs that are conserved are shown in dark purple and CFAs that are not conserved are in light purple. Conserved land not identified as CFAs are in gray.
Data source: The Nature Conservancy

Nitrogen Loading



How much nitrogen is coming into the Great Bay Estuary and how has loading changed over time?

Estimated annual total nitrogen load from 2017 to 2020 averaged 895 U.S. tons, which is similar to the 2012 to 2016 average (903 tons per year), but lower than the high point from the mid-2000s. Comparing 2012 to 2020, there was a 64% decrease in overall point source nitrogen loading from wastewater treatment facilities. This resulted directly from the actions of several municipalities to make substantial improvements to their wastewater treatment facilities to reduce the amount of nitrogen they discharge. Non-point source nitrogen loading — nitrogen from diffuse sources that are difficult to pinpoint — in 2017 to 2020 averaged 699 tons per year, which is 15% higher than the 2012 to 2016 average (607 tons per year). Nitrogen loading data for Hampton-Seabrook Estuary are currently being developed and will be reported in future documents.

Goal

Manage nitrogen loads to minimize adverse consequences.

Why We Track This Indicator

Nitrogen is one of the primary nutrients that are essential to all life. Nitrogen "loading" involves measurement of the rate at which nitrogen is being added to estuarine water from various sources, such as the land and atmospheric deposition. This differs from nitrogen "concentration," which is simply a snapshot of the amount of nitrogen present in the water at any given time (see "Nutrient Concentrations"). Nitrogen loading levels that are too high can cause problems in an estuary such as excessive growth of phytoplankton, epiphytes, and nuisance seaweeds. When these organisms die, bacteria and other decomposers use the available dissolved oxygen to break down the dead organic matter, decreasing oxygen availability for other organisms, including fish and shellfish. In addition, excessive phytoplankton, epiphytes, and seaweed growth can have negative impacts on sediment quality, water clarity, eelgrass, and benthic invertebrates.

Explanation

Estimated annual total nitrogen load from 2017 to 2020 averaged 895 tons, which is similar to the 2012 to 2016 average (903 tons per year), but lower than the high point from the mid-2000s (Figure 7.1). In 2020, the most recent year that we have estimates for, the average annual load was 627 tons, which is the lowest on record. Figure 7.1 indicates a trend in nitrogen reductions, especially compared with the 2005 – 2007 period, when nitrogen loading peaked.

This section focuses on the Great Bay Estuary, where nitrogen loading has been estimated since 2003. Nitrogen loading protocols are currently being established for the Hampton-Seabrook Estuary and will be covered in future reports.

However, nitrogen loading remains higher than the amount recommended by the EPA in the Great Bay Total Nitrogen General Permit, issued in 2021. To meet that long-term goal, nitrogen loading would have to be further reduced by approximately 39% from the 2020 level. While reduction efforts continue, it is acknowledged that the goal in the permit is subject to change based on active research into the relationship between nitrogen loading and adverse effects on the ecosystem, such as seaweed blooms and loss of eelgrass. Results of this research could lead to adjustments (up or down) in the loading goal.

Figure 7.1 indicates a great deal of variation over the time series. This variation should be looked at in the context of the two types of loading: from point sources versus non-point sources. Point sources of nitrogen are predominantly from wastewater treatment facilities, while non-point source nitrogen enters into our streams, rivers, and estuaries in three main ways: 1) from stormwater runoff, which includes nitrogen from atmospheric deposition (including

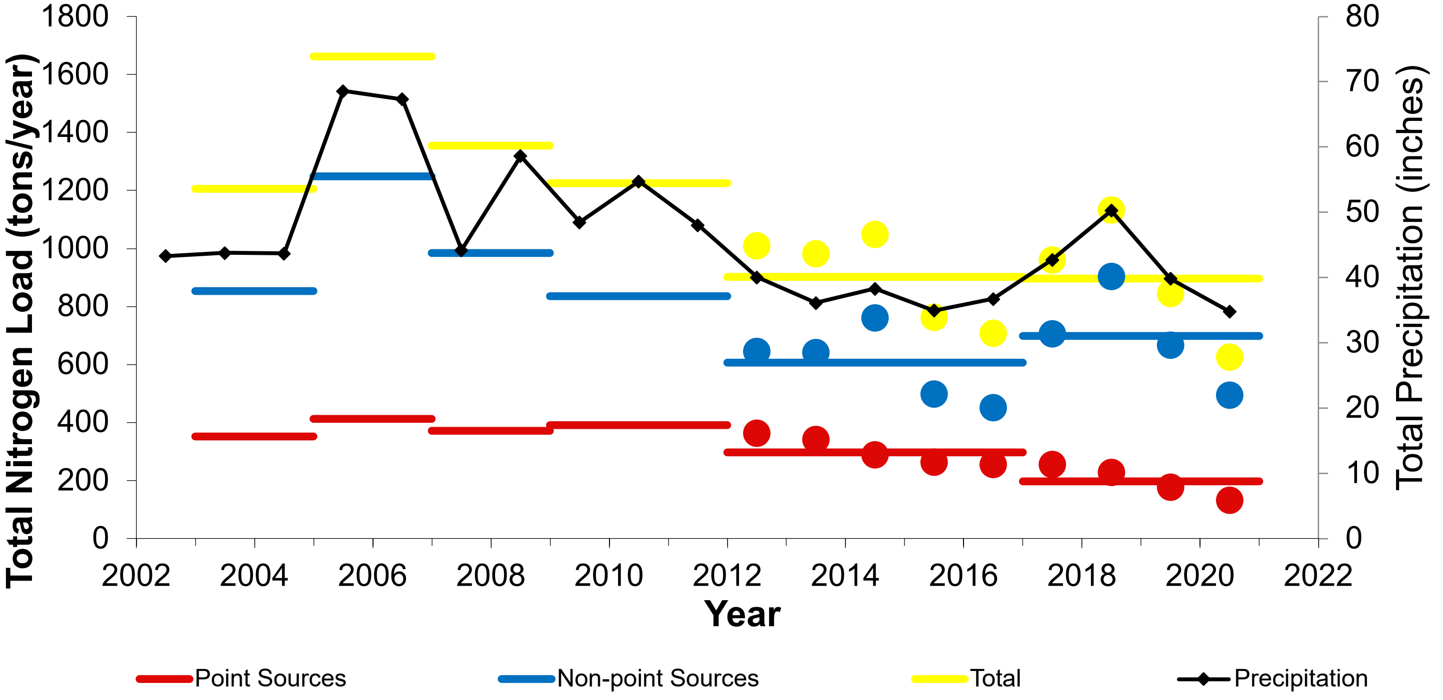


Figure 7.1: Nitrogen loads to the Great Bay Estuary, shown separated by source as well as the combined total nitrogen load. Loads are based on an estuarine surface area of 13.4 square miles. (Lower Piscataqua River not included. See the Extended Report for details.) Colored circles indicate annual loads for 2012 through 2020. Annualized data were not available for 2003 – 2011, thus multi-year averages are presented for the entire record. Precipitation data are from the Portsmouth (Pease/KPSM) weather station.

Data sources: EPA, Municipalities, USGS, PREP, and Water Quality Analysis Lab (WQAL)

transportation and industrial emissions), fertilizers, and animal waste; 2) from groundwater contribution, which carries nitrogen from septic systems, sewer leakage, infiltrated fertilizers, and animal waste;[26,27] and 3) from direct atmospheric deposition.

Between 2003 and 2011, most of the variability in nitrogen loading was related to non-point source inputs, while the contribution from point source inputs was relatively stable during that period (Figure 7.1). The highest loads since 2003 were in the 2005 to 2007 period (1,662 tons per year), a time that coincides with the highest total annual precipitation. In comparison, the lower rainfall during 2012 to 2020 contributed to the lower total and non-point source loading during this period.

Non-point sources of nitrogen in 2017 to 2020 accounted for 78% (Figure 7.2) of the total nitrogen load. During the fall seasons of 2016 and 2020, most of the watershed experienced extreme drought conditions.[28] This underscores the association between nitrogen loading and stormwater run-off. Precipitation records and forecasts[29] suggest that our region will continue to see periods of extreme high and low precipitation, which will continue to impact non-point source nitrogen loads.

In terms of point sources, the 17 municipal wastewater treatment facilities accounted for 22% of the total nitrogen load in 2017 to 2020 (Figure 7.2). The 2017 to 2020 point-source loads were lower than in any other reporting period since 2003 despite increased population. This is a result of substantial investment in upgraded wastewater treatment by several municipalities in the watershed to reduce the amount of total nitrogen they discharge. There has been a 64% decrease in overall point source nitrogen loading from wastewater treatment facilities between 2012 and 2020.

Total nitrogen load includes dissolved inorganic nitrogen, dissolved organic nitrogen, and particulate nitrogen (PN). Of the 895 tons of nitrogen entering the bay annually (on average) from 2017 – 2020, 50% (444 tons per year) was dissolved inorganic nitrogen, which is comprised of the most biologically available forms of nitrogen. The 2017 to 2020 dissolved inorganic nitrogen load was 12% lower than the average dissolved inorganic nitrogen load in 2012 to 2016 (506 tons per year). In earlier reporting periods, point source and non-point source dissolved inorganic nitrogen each accounted for approximately half of the dissolved inorganic nitrogen load (Figure 7.3). In 2017 to 2020, 34% of the DIN load was point source and 66% was non-point source (Figure 7.3). This reduction in point-source dissolved inorganic nitrogen loading could reduce the excessive biological activity of problematic seaweeds in Little Bay and Great Bay given that seaweeds generally uptake dissolved inorganic nitrogen preferentially over organic nitrogen.

Acknowledgments and Credit
Michelle D. Shattuck (UNH), with contributions from Aneliya Cox (UNH), Miguel Leon (UNH), and Kalle Matso (PREP).

Extended Report

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]). To read a detailed description of methods used to estimate 2017 – 2020 nitrogen loads and a further breakdown of the point and non-point source loads, see the Extended Report.

Photo by Jerry Monkman

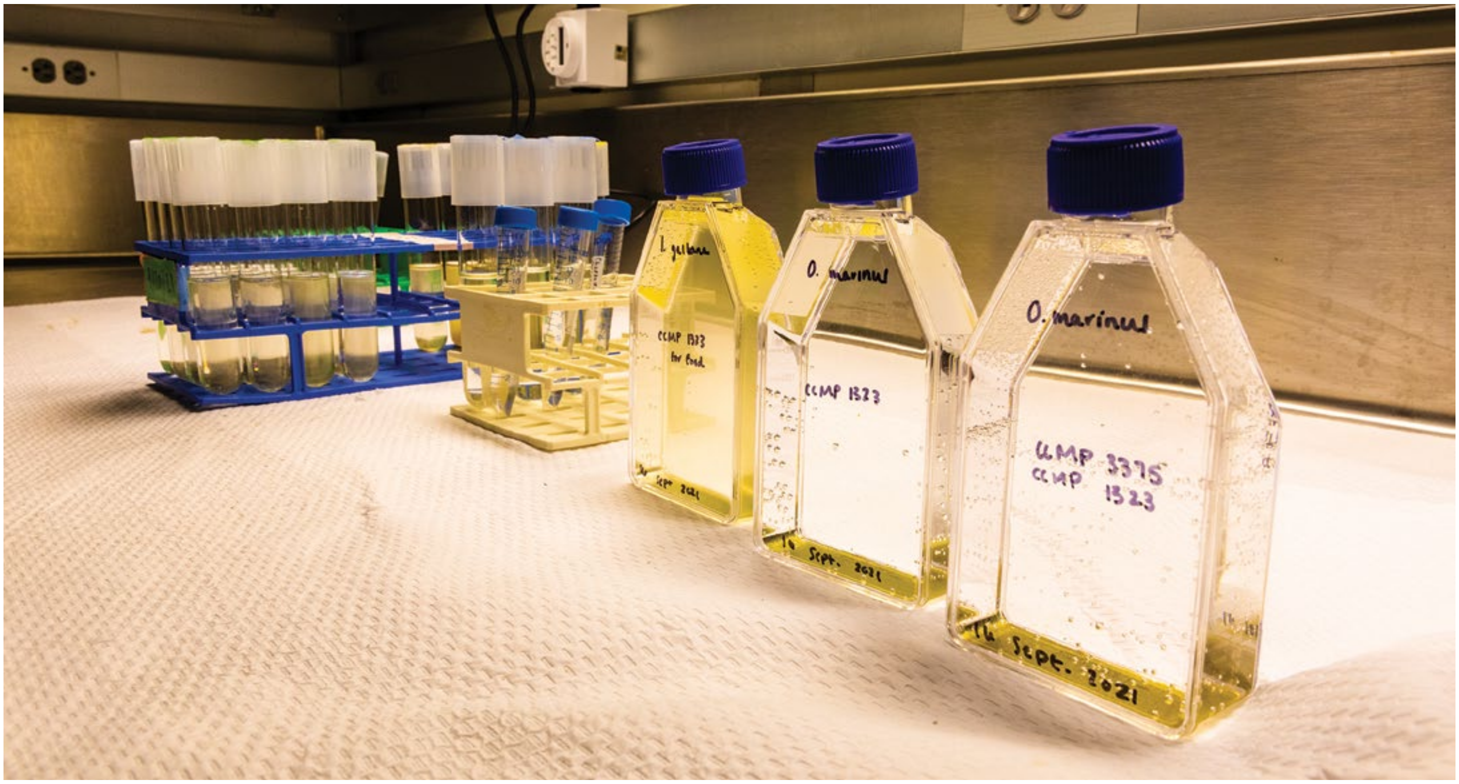


Photo by Jerry Monkman

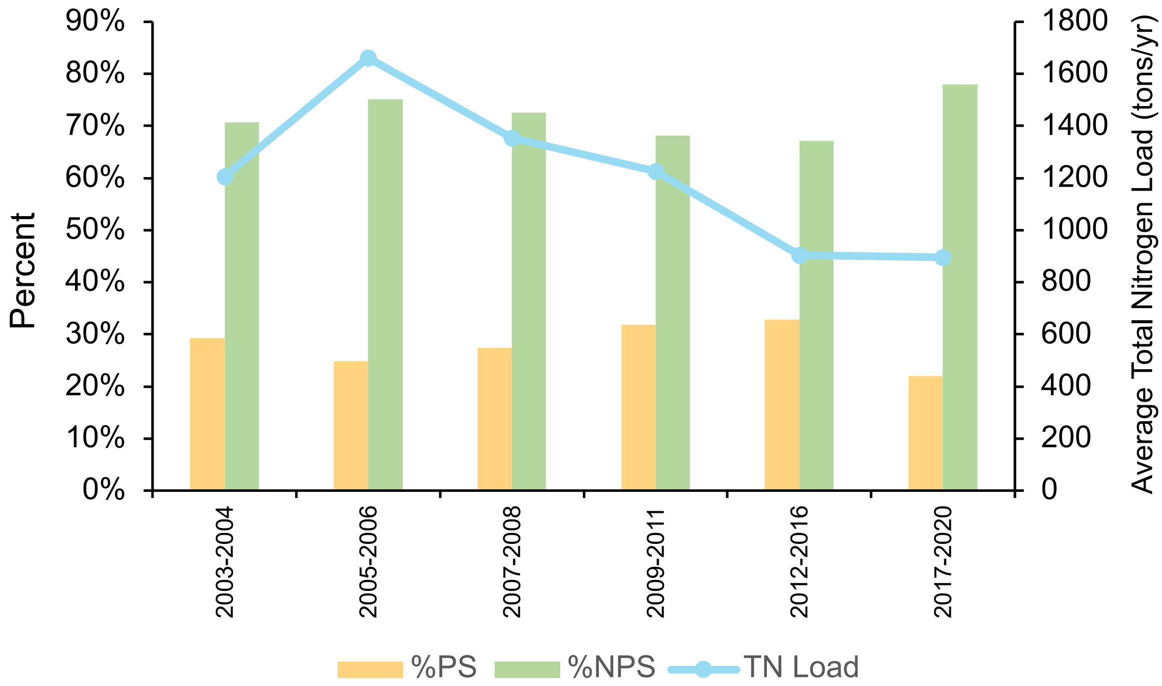


Figure 7.2: Estimated average for total nitrogen (TN) loads to the Great Bay Estuary point-sources (PS) and non-point sources (NPS). Loads are based on an estuarine surface area of 13.4 square miles. (Lower Piscataqua River not included. See the Extended Report for details.) PS and NPS values for each time period amount to 100% of total loading.

Data sources: See the Extended Report for nutrient loading

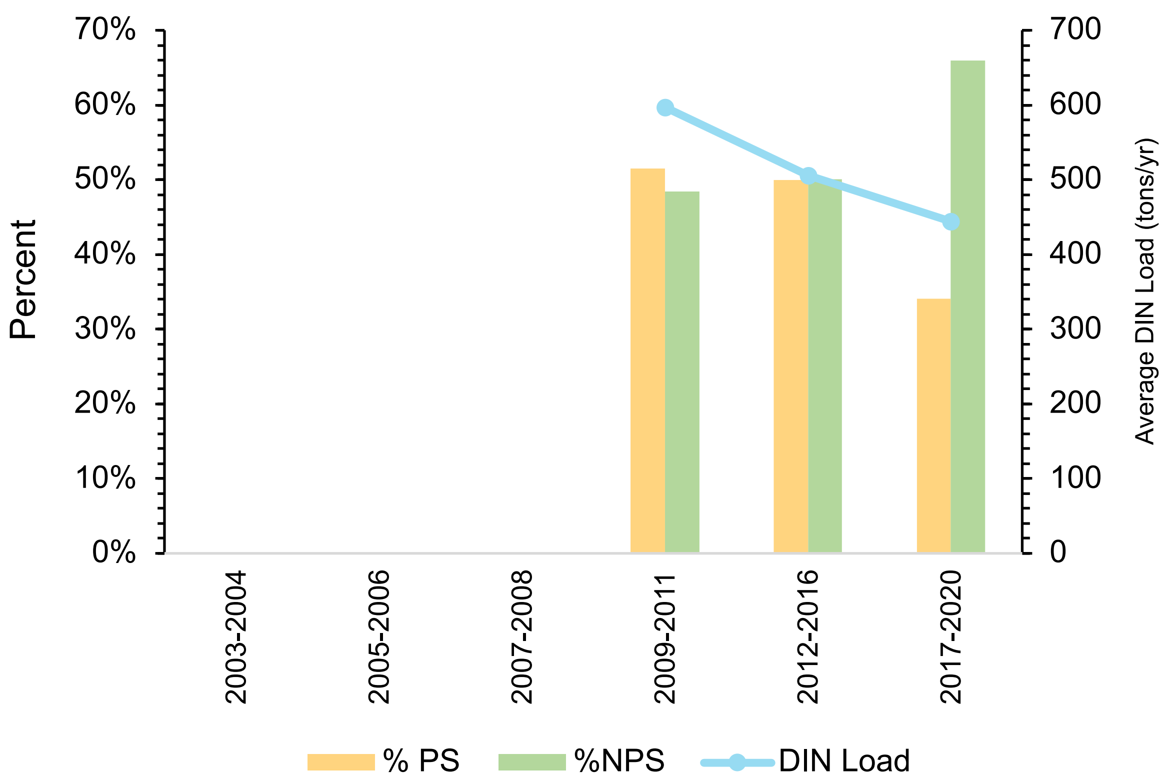


Figure 7.3: Estimated average for dissolved inorganic nitrogen (DIN) loads to the Great Bay Estuary from point sources (PS and non-point sources (NPS). Loads are based on an estuarine surface area of 13.4 square miles. (Lower Piscataqua River not included. See the Extended Report for details.) PS and NPS values for each time period amount to 100% of total loading. DIN loads were not available for 2003 – 2008.

Data sources: See the Extended Report for nutrient loading

Nutrient Concentrations

How have the concentrations of nutrients in the waters of the Great Bay and Hampton-Seabrook Estuaries changed over time?

Dissolved inorganic nitrogen concentrations have been trending lower over recent years, despite higher levels between 1998 and 2016 for several stations. As a result, there are no increasing trends in dissolved inorganic nitrogen, but three stations have decreasing trends. Dissolved inorganic nitrogen is an important form of nitrogen because it is most readily taken up by eelgrass, seaweed, and phytoplankton. Total nitrogen is another form of nitrogen that incorporates particulate and living matter. Total nitrogen concentrations at Adams Point have significantly decreased since 2004, while Squamscott River is the only monitoring station that had a statistically significant increasing trend between 2003 and 2021. However, given the recent upgrade of the Town of Exeter Wastewater Treatment Facility, this trend may change in the near future. The Hampton River Station has the shortest time series and the second lowest levels of the seven stations listed.

Goal

No increasing trends in nutrient concentrations.

Why We Track This Indicator

Nutrients, like nitrogen, are critical for estuarine ecosystems; some are needed, but an overabundance leads to problems. Nutrient "concentration" measures the amount of nutrients present in the water at the time of sampling and represents a snapshot of how much remains after eelgrass, seaweeds, plankton, and microbes use the nutrient for growth plus any released from estuarine sediments. This is compared to "loading" which measures the rate at which a nutrient is being added to the system from the land, air, and tributaries. Although all nutrients are important, nitrogen is emphasized here because it is most often the limiting nutrient in estuarine watersheds.

Explanation

Nutrient concentrations in the water are affected by nutrient loading from the watershed, hydrodynamic mixing, and all the complex uses and transformations by living resources. Although all nutrients are important, nitrogen is most often the limiting nutrient in estuarine watersheds, and therefore, is currently emphasized in our estuaries. As noted in "Nitrogen Loading," nitrogen inputs since 2012 have been reduced in the Great Bay Estuary in part due to consecutive years of low annual rainfall. In addition, since 2014, several municipalities have improved their wastewater treatment facilities. These changes are expected to have some influence on the concentrations of nitrogen, discussed below.

Although dissolved inorganic nitrogen is an important form of nitrogen because it is taken up most readily by plants and algae, total nitrogen is considered a more accurate measure of the nitrogen status of an estuary because it includes the portion in living biomass.

At the Adams Point Station (Figure 8.1) — the site with the longest time series — the earliest and most recent dissolved inorganic nitrogen data are low relative to the rest of the dataset, with the highest values between 1998 and 2016. Median values for dissolved inorganic nitrogen from 2016 to 2020 ranged from 0.10 to as high as 0.15mg/L and were comparable to median values for the years 1974 to 1981. For reference, the EPA National Coastal Assessment Condition Report categorizes values less than 0.1 as "good." Other categories include "fair"

Photo by Todd Selig

(0.1 to 0.5 mg-N/L), and "poor" (greater than 0.5 mg-N/L). Using this categorization, recent dissolved inorganic nitrogen concentrations at Adams Point vary between the "good" and "fair" categories.

At the Oyster River and Upper Piscataqua River Stations, dissolved inorganic nitrogen concentrations significantly decreased (Table 8.1). This pattern may be attributed to the shorter time series at these stations, which began collecting data between 2002 and 2007. For example, the data for Upper Piscataqua River (Figure 8.2) indicate elevated concentrations during a time period that overlaps with the periods of high values for Adams Point and Lamprey River (between 2007 and 2013).

The time series for the Hampton River Station only goes back to 2018, but the data from this site indicate that dissolved inorganic nitrogen concentrations straddle the "good" and "fair" threshold (Table 8.1). The Hampton River Station has the second lowest levels of nitrogen across the seven stations listed.

Since 2016, median annual total nitrogen values at Adams Point ranged from 0.27 mg-N/L to 0.37 mg-N/L over the sample season (Table 8.2). A total nitrogen concentration greater than 0.5 mg-N/L was only measured in three sampling months since 2016. For reference, the EPA National Coastal Assessment Condition Report categorizes values less than 0.31 mg-N/L as "low," values between 0.31 and 0.48 mg-N/L as "moderate," and values between 0.48 and 0.68 mg-N/L as "high."[31,32]

Table 8.2 shows that most values over the past five years fall in the "moderate" category, according to the National Coastal Assessment Condition Report, with the Squamscott River Station standing out as having higher concentrations. It is possible that these high values could come down, however, given the 2020 upgrade of the Town of Exeter Wastewater Treatment Facility.

Relationships between nitrogen concentrations and ecosystem health response vary from estuary to estuary. Currently, researchers are addressing this issue in order to clarify these relationships for our waters.

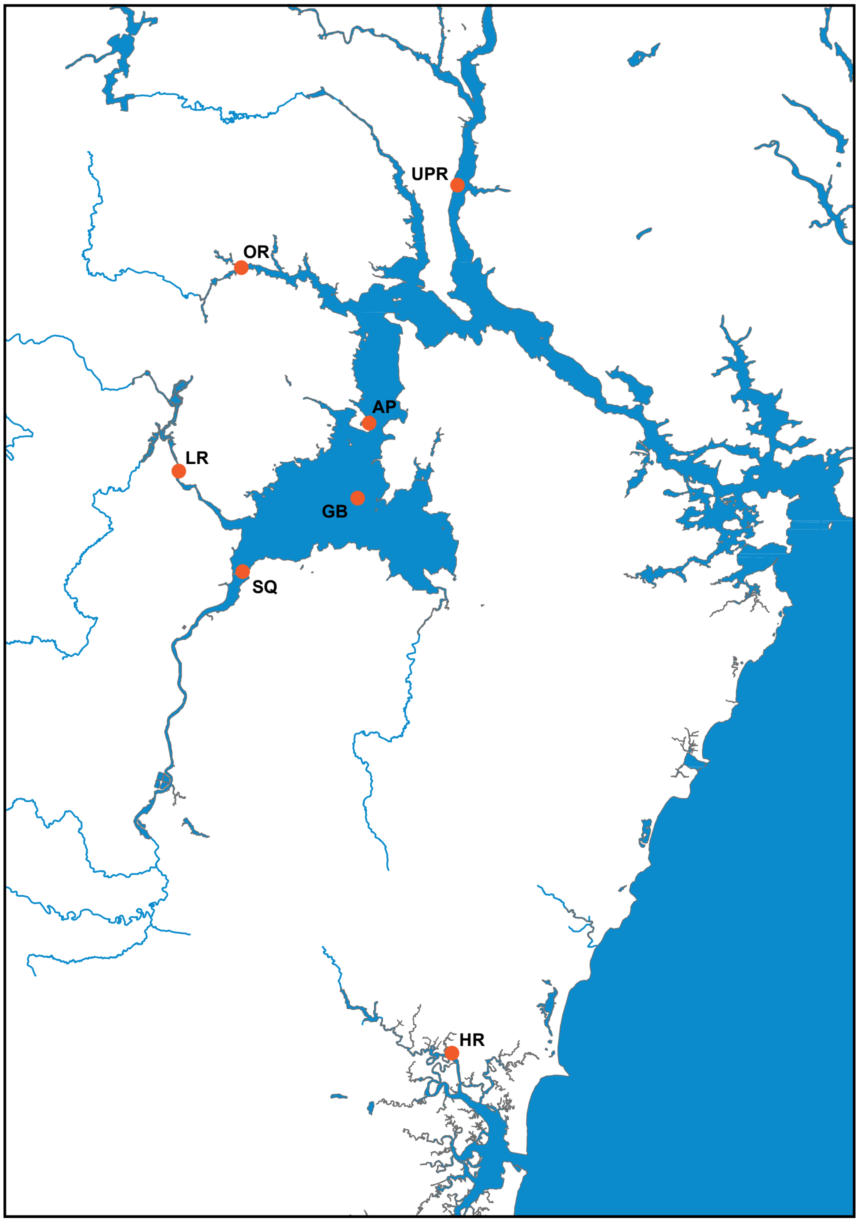


Figure 8.1: Monitoring stations for nutrient concentrations including Adams Point (AP), Great Bay (GB), Lamprey River (LR), Oyster River (OR), Squamscott River (SR), Upper Piscataqua River (UPR), and Hampton River (HR).
Data source: Jackson Estuarine Lab, UNH

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

Extended Report

The Extended Report includes information on other nutrients, such as phosphorus concentrations.

Nutrient Concentrations

Dissolved Inorganic Nitrogen

Location	Monitoring Period	Significant change in dissolved inorganic nitrogen concentration?	Range of Median Values 2016 – 2021 (mg-N/L)
Adams Point	1974 – 2021	No	0.06 – 0.15
Great Bay	2002 – 2021	No	0.06 – 0.15
Lamprey River	1992 – 2021	No	0.12 – 0.21
Oyster River	2005 – 2021	Yes ↓	0.13 – 0.20
Squamscott River	2002 – 2021	No	0.19 – 0.42
Upper Piscataqua River	2007 – 2021	Yes ↓	0.14 – 0.20
Hampton River	2018 – 2021	No	0.09 – 0.12*

*Range of Median Values for Hampton River include data from 2018-2021

Table 8.1. Dissolved inorganic nitrogen trends and median values at six stations in the Great Bay Estuary and one station in the Hampton-Seabrook Estuary.

Data source: Jackson Estuarine Laboratory, UNH

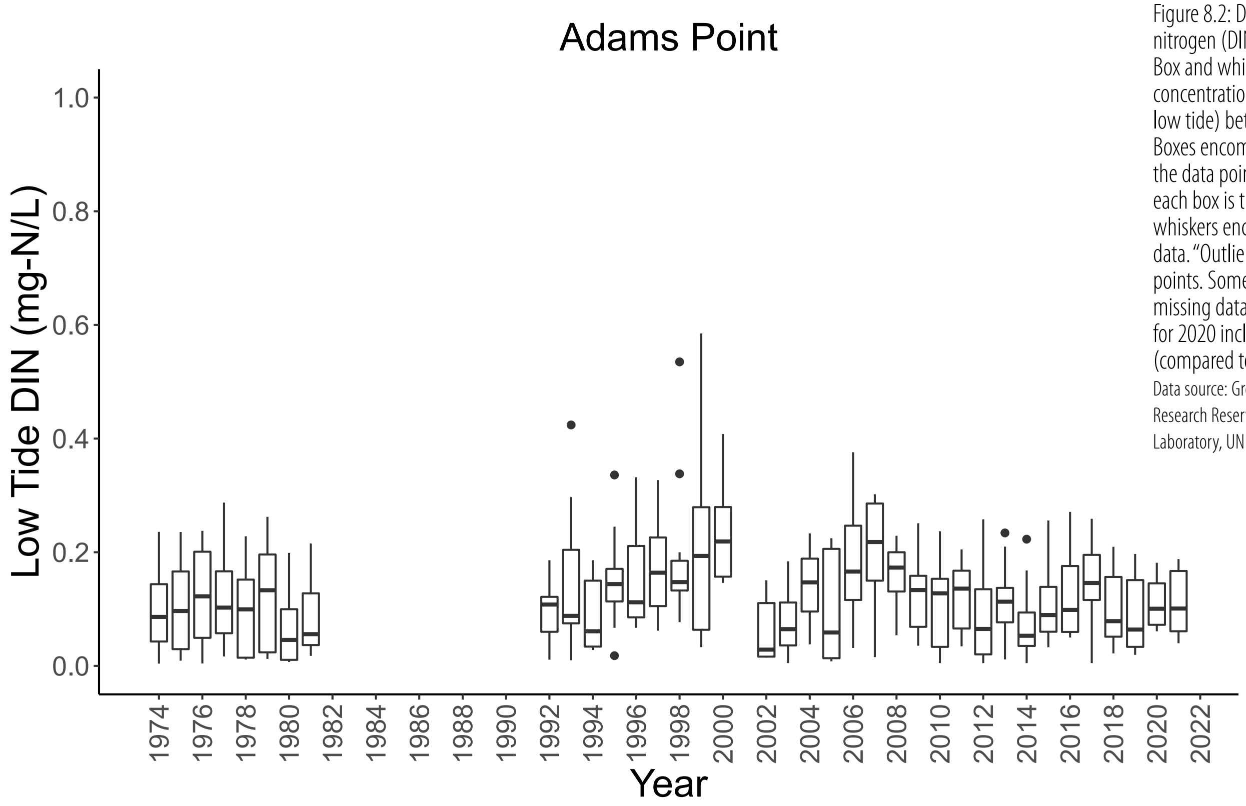


Figure 8.2: Dissolved inorganic nitrogen (DIN) at Adams Point. Box and whisker plots show DIN concentrations (collected monthly at low tide) between 1974 and 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass the remaining data. "Outliers" are shown as individual points. Some years are omitted due to missing data. The box and whisker plot for 2020 includes only six DIN values (compared to nine for other years).

Data source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH

Total Nitrogen

Location	Monitoring Period	Significant change in total nitrogen concentration?	Range of Median Values 2016 – 2021
Adams Point	2004 – 2021	Yes ↓	0.27 – 0.37
Great Bay	2004 – 2021	No	0.29 – 0.52
Lamprey River	2004 – 2021	No	0.39 – 0.63
Oyster River	2006 – 2021	No	0.43 – 0.60
Squamscott River	2005 – 2021	Yes ↑	0.63 – 1.04
Upper Piscataqua River	2009 – 2021	No	0.37 – 0.48
Hampton River	2018 – 2021	No	0.38 – 0.47*

*Range of Median Values for Hampton River include data from 2018-2021

Table 8.2. Total nitrogen trends and median values at six stations in the Great Bay Estuary and one station in the Hampton-Seabrook Estuary.

Data source: Jackson Estuarine Laboratory, UNH

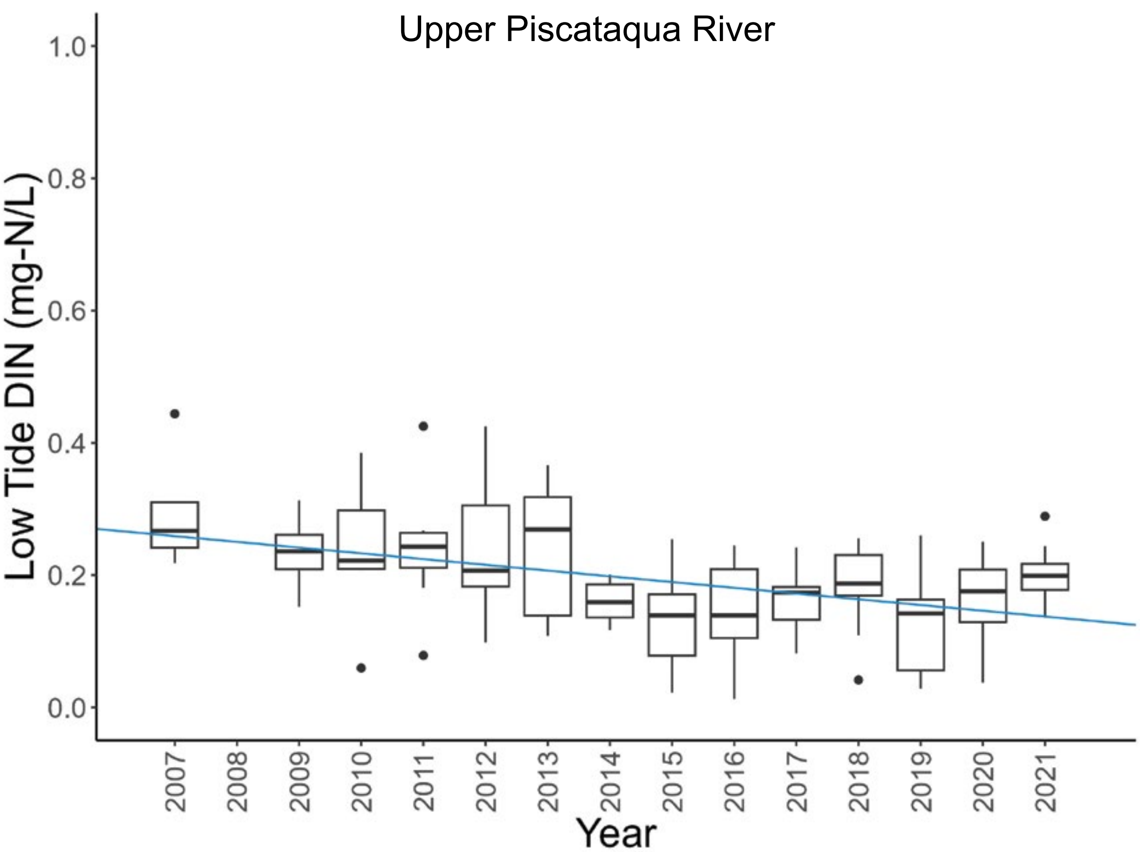


Figure 8.3: Dissolved inorganic nitrogen (DIN) at the Upper Piscataqua Station indicates a downward trend based on data collected monthly at low tide between 2007 and 2021 and shown here as box and whisker plots. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass the remaining data. "Outliers" are shown as individual points. Some years are omitted due to missing data. Blue line represents significant linear regression through annual median values.

Data source: Great Bay National Estuarine Research Reserve and the Jackson Estuarine Laboratory, UNH

Dissolved Oxygen

How often does dissolved oxygen in the Great Bay and Hampton-Seabrook Estuaries fall below 5 mg/L?

Most of the time, dissolved oxygen levels remain well above 5 mg/L in the bays and open waters located at the center of the Great Bay and in Portsmouth Harbor. However, low dissolved oxygen events do occur in the Upper Piscataqua River, all the Great Bay Estuary tidal rivers, and the Hampton River in the Hampton-Seabrook Estuary. In 2021, most low dissolved oxygen events in the tidal rivers lasted between two and four hours. If these events remain sporadic and of short duration, negative impacts on aquatic organisms will likely be limited.

Goal

No measurements below 5 mg/L for dissolved oxygen concentration.

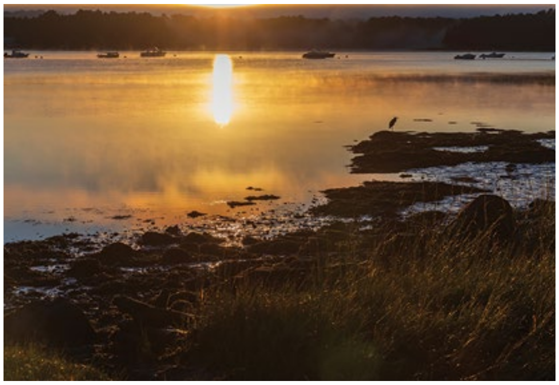


Photo by Jerry Monkman

Why We Track This Indicator

Fish and many other organisms need dissolved oxygen in the water to survive. Dissolved oxygen levels can decrease due to various factors, including rapid changes in wind, temperature, and salinity, as well as prolonged periods of dense cloud cover. Dissolved oxygen levels can also decrease as a consequence of nutrient inputs. When nutrient loading is too high, phytoplankton and seaweed can bloom and then die, after which bacteria and other decomposers use oxygen to break down the dead organic matter.

Explanation

There were no statistically significant trends for dissolved oxygen levels in either the Great Bay (from 2005 to 2021) or Hampton-Seabrook Estuaries (from 2017 to 2021). For the Great Bay Estuary, in general, the overall trend seems to be for fewer summer days with instances of dissolved oxygen dropping below 5 mg/L than in the previous report (see Figure 9.1). For example, in the Oyster River, since 2006, the number of low dissolved oxygen days has gradually fallen. In the Squamscott River, since peaking in 2017, conditions also seem to be improving. Though less consistent, Lamprey River low dissolved oxygen days seemed to peak in 2015 and have been gradually decreasing since then.

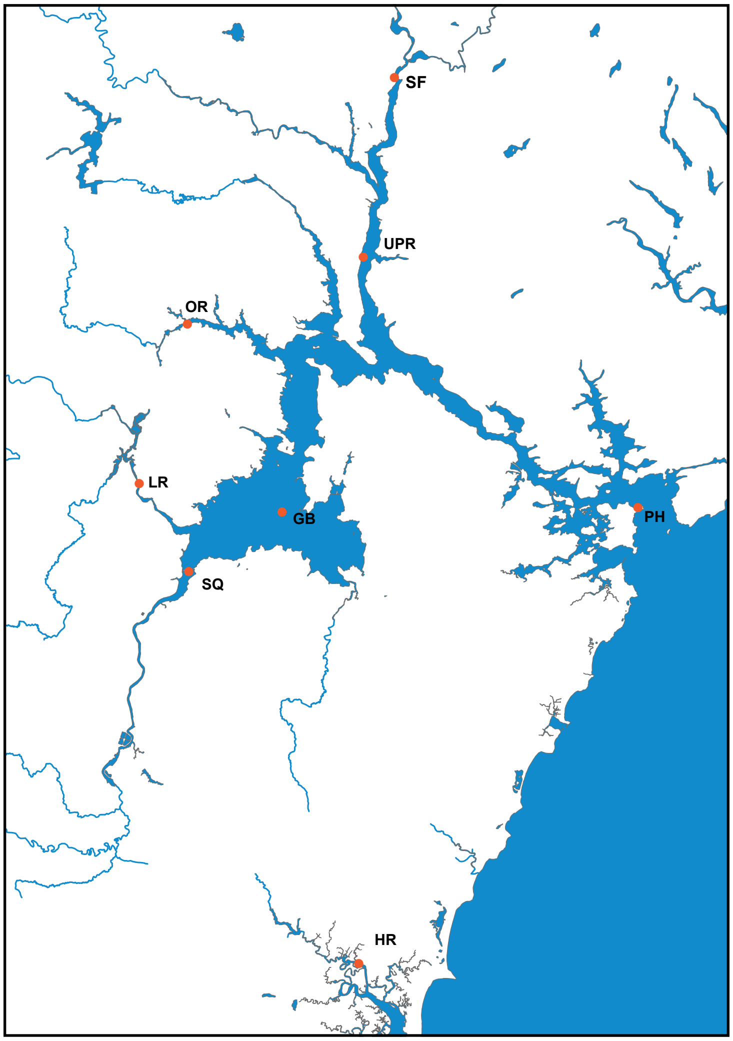
The exception to this overall trend is the Hampton River Station in the Hampton-Seabrook Estuary, where data have been collected since 2017, and in both 2020 and 2021, there were more low dissolved oxygen days than in the previous three years.

Recently, both the Great Bay and the Upper Piscataqua River Stations remain consistently above the 5 mg/L threshold.

Another important dimension to this indicator is the duration of low dissolved oxygen events. Most recently, in the Great Bay Estuary, low dissolved oxygen events have occurred infrequently and have not lasted longer than five hours. Data indicate that the Lamprey, Oyster and Squamscott Stations have the highest number of low dissolved oxygen days in this estuary. Considering sensor dissolved oxygen data from June through September, 2021, the majority of hourly measurements in all three rivers are above 5 mg/L, but there are low dissolved oxygen events for multiple hours (Figures 9.2 – 9.4).

The insets for these time series show how many hours the dissolved oxygen was less than 5 mg/L for the lowest day on record. In the Oyster River (Figure 9.2), this day occurred on July 2, 2021, and the data show that the low dissolved oxygen event lasted for a total of eight hours. In the Squamscott River (Figure 9.3), the lowest dissolved oxygen day occurred on August 20, 2021, with two low dissolved oxygen events within the 24-hour window, each lasting about four hours.

Previous reports have noted that the Lamprey River seems to have particular dissolved oxygen problems because the tributary is less vertically mixed than other tributaries, leading to low oxygen conditions on the bottom. Given the 2017 upgrade to the Newmarket Wastewater Treatment Facility, observers hoped that there would be fewer low dissolved oxygen events; this does, in fact, seem to be happening although the trend is not statistically significant (Figure 9.1).



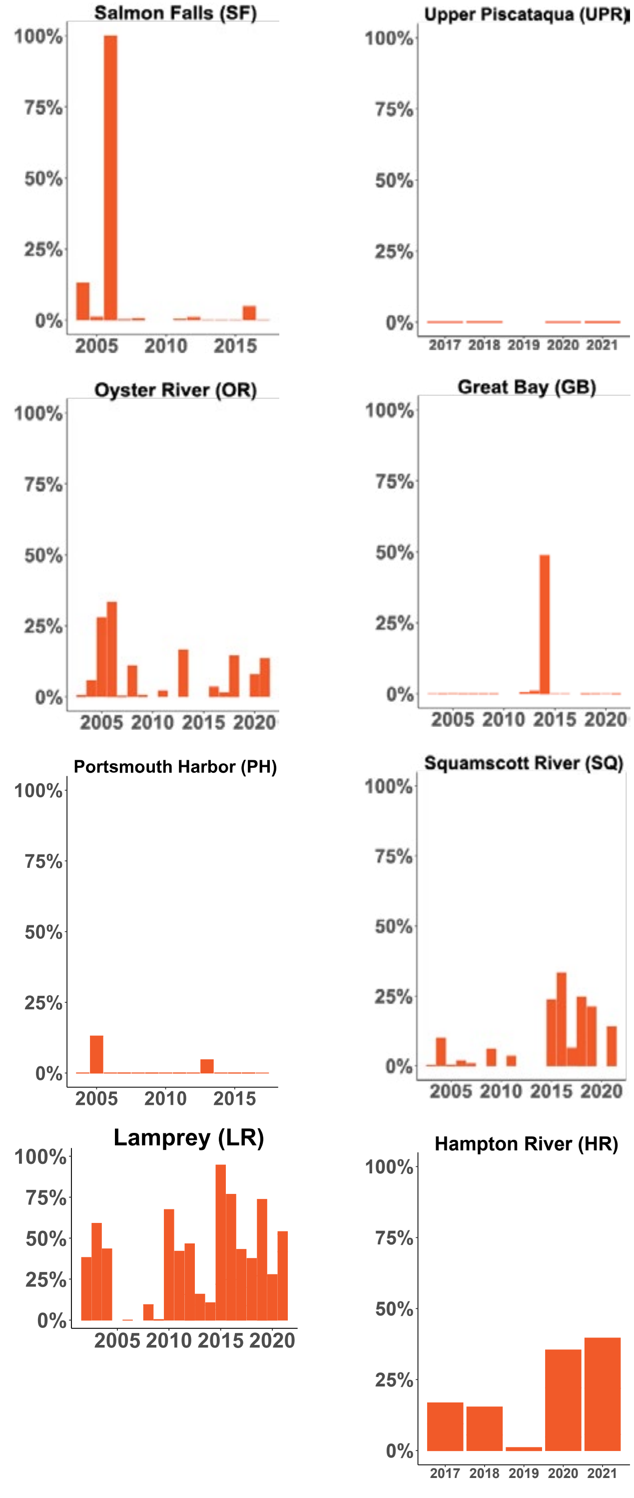


Figure 9.1: Number of summer days — the period when low dissolved oxygen (DO) events most commonly occur — when DO falls below 5 mg/L at eight sites in both the Great Bay and Hampton-Seabrook Estuaries. Data source: Jackson Estuarine Lab, UNH

In August of 2015, the Lamprey River experienced a low dissolved oxygen event that lasted seven days. In contrast, the longest lasting low dissolved oxygen event in 2021 was approximately 23 hours (Figure 9.4). This pattern of shorter periods of low dissolved oxygen could signal higher water quality. However, due to the occurrence of some low dissolved oxygen events, the average dissolved oxygen values over some period of time needs to be monitored. For example, in a 2009 Chesapeake Bay report, the recommendation was to set a 7-day average at 4 mg/L.[33] Experiments have shown that juvenile fishes experience increased mortality and decreased growth after as few as 8 hours of low dissolved oxygen situations.[34] The impact is worse when coupled with other stressors, such as low pH.

Data for Hampton River from 2021 are concerning because of the frequency of low dissolved oxygen events (Figure 9.5). Studies indicate that frequent low dissolved oxygen events can slowly build up stress in aquatic organisms, particularly for larval or juvenile fishes.[35]

Acknowledgments and Credit

Easton R. White (UNH) and Wilton Burns (UNH) with contributions from Kalle Matso (PREP), Lara Martin (UNH), and Miguel Leon (UNH).

Dissolved Oxygen

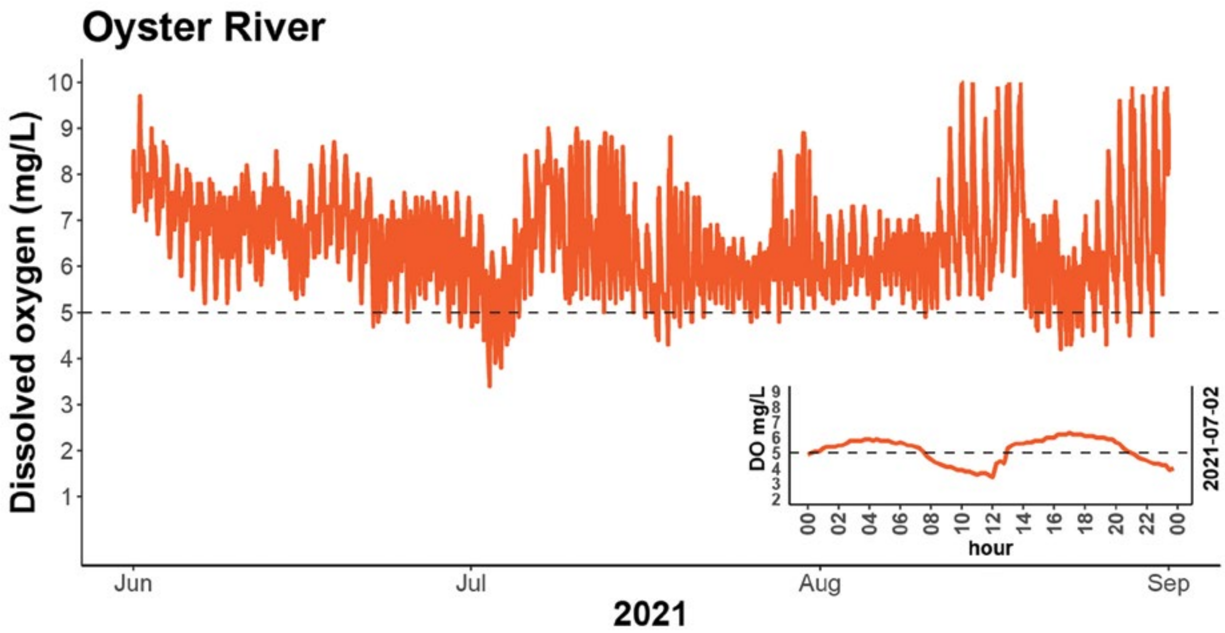


Figure 9.2: Dissolved oxygen measured every 15 minutes between June and September 2021 at Oyster River Station in the Great Bay Estuary. The smaller inset graph shows a 24-hour period on the lowest dissolved oxygen day of the Oyster River record: July 2, 2021.
Data source: Jackson Estuarine Lab, UNH

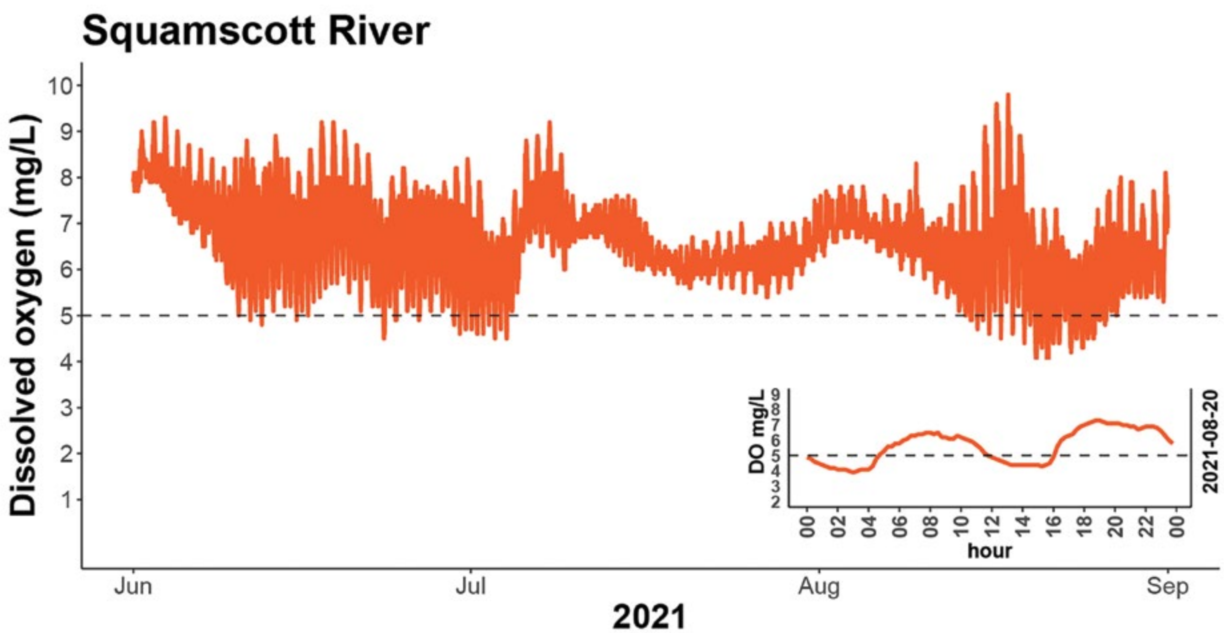


Figure 9.3: Dissolved oxygen measured every 15 minutes between June and September 2021 at the Squamscott River Station in the Great Bay Estuary. The smaller inset graph shows a 24-hour period on the lowest dissolved oxygen day of the Squamscott River record: August 20, 2021.
Data source: Jackson Estuarine Lab, UNH

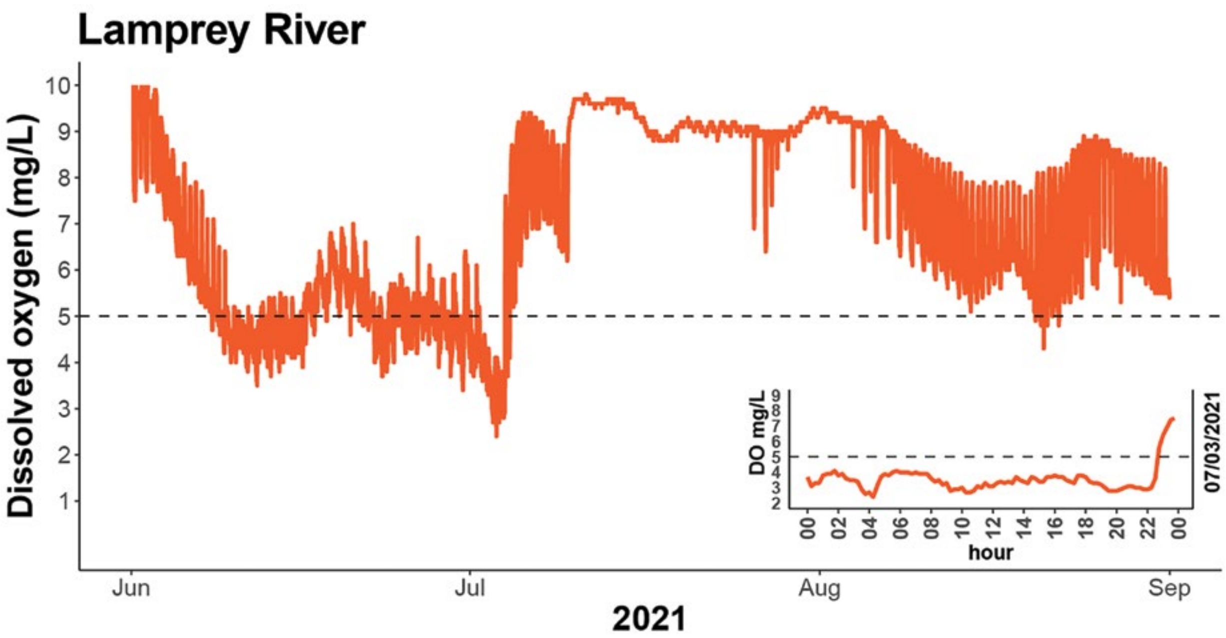


Figure 9.4: Dissolved oxygen measured every 15 minutes between June and September 2021 at the Lamprey River Station in the Great Bay Estuary. The smaller inset graph shows a 24-hour period on the lowest dissolved oxygen day of the Lamprey River record: July 3, 2021.
Data source: Jackson Estuarine Lab, UNH

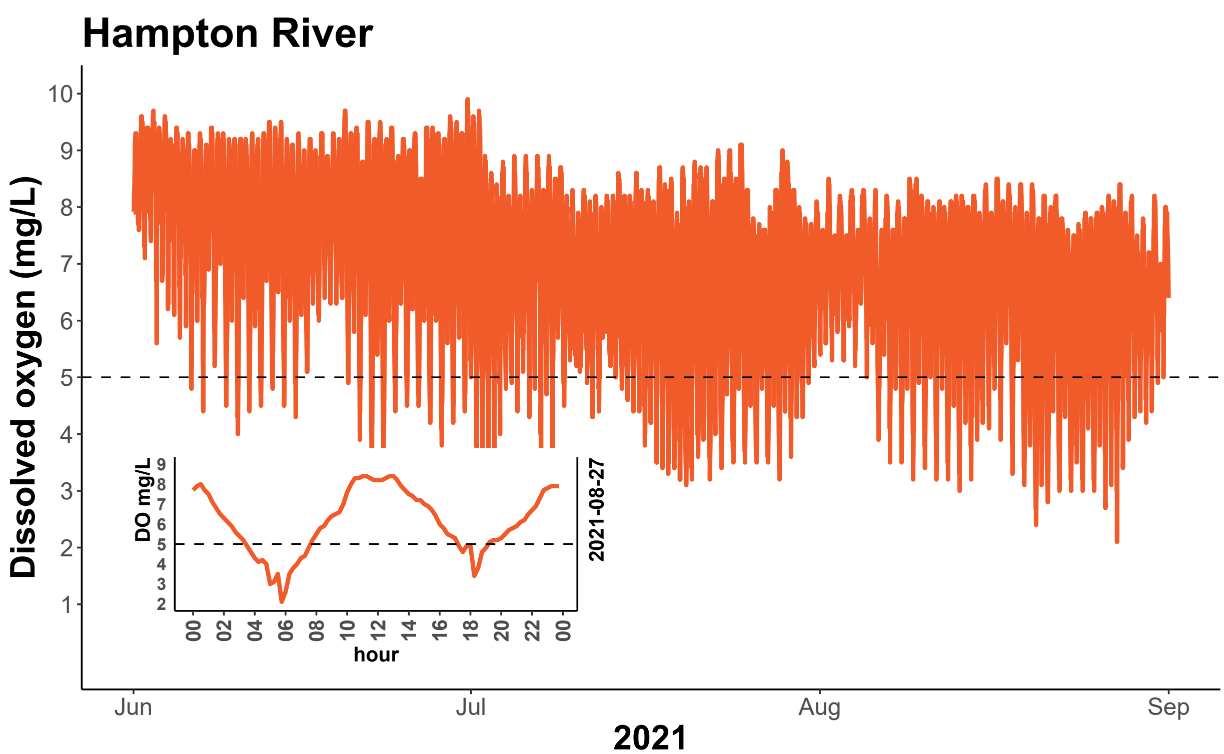


Figure 9.5: Dissolved oxygen measured every 15 minutes between June and September 2021 at the Hampton River Station in the Hampton-Seabrook Estuary. The smaller inset graph shows a 24-hour period on the lowest dissolved oxygen day of the Hampton River record: August 27, 2021.
Data source: Jackson Estuarine Lab, UNH

Seaweed

What are the dominant seaweeds that grow in the Great Bay Estuary? Are some seaweeds better for the ecosystem than others? How is seaweed abundance for different species changing over time?

Since 2013, green seaweeds at a majority of the intertidal monitoring sites in the Great Bay Estuary decreased, while there were no clear patterns for red seaweeds. A new subtidal monitoring effort, started in 2018, indicates that while red and green nuisance species still compete with eelgrass, especially in the southern and western portions of the Great Bay, the proportion of eelgrass is increasing.

Goal

No increasing trends for nuisance seaweeds.

Why We Track This Indicator

Many seaweeds, like brown intertidal "rockweed," provide important ecosystem services, such as habitat for many organisms, including juvenile oysters (see "Oysters"). However, eutrophication (i.e., excess nutrients loaded into our estuaries) can spur growth of nuisance seaweeds (usually red and green seaweeds) that in turn can block light and smother eelgrass. Too much of these unwanted seaweeds, like red *Gracilaria* or green *Ulva*, can also impact other desirable habitats such as oyster reefs. Because there is little or no eelgrass in the Hampton-Seabrook Estuary, seaweed is not actively monitored.

Explanation

Intertidal

In a healthy estuary, seaweeds are in balance with other estuarine life and are not a cause for concern. For example, attached brown seaweeds, like the image at the bottom, form important habitat and support overall productivity in the Great Bay Estuary. However, international shipping has allowed seaweeds to hitchhike from distant coasts to our estuaries and proliferate. In the Great Bay, south of Adams Point, we are seeing high abundances of these seaweeds competing with eelgrass.

Overall, data from eight stations in the Great Bay Estuary (Figure 10.1) suggest that red and green seaweeds expanded between 1980 and 2013 and since then, have decreased. The average cover of red and green seaweeds combined was generally less than 20% at Little Bay and Piscataqua River sites (Figure 10.2), and about twice as abundant in the Great Bay (Figure 10.2).

Nuisance red *Gracilaria* and green *Ulva* species composed nearly all the cover in intertidal areas. Both species can survive as drift or attached seaweed. Over the seven-year study period, only Depot Road and Adams Point had more than four years of data available for statistical analysis. Both red and green seaweeds declined significantly at the Depot Road site along the southern shore of Great Bay, but only greens were found to decline at Adams Point on the north shore of the Bay (Figure 10.3).

Clouds of nuisance green seaweed compete with eelgrass blades for light in the Great Bay near Newmarket, NH. Summer, 2022. Photo by Amanda Giacchetti.

Invasive red seaweed floats above eelgrass in the Piscataqua River, Eliot, ME. Photo by Kalle Matso.

Subtidal

The intertidal transects established earlier in the Great Bay Estuary were extended in 2018 into the subtidal regions to examine seaweed beds and directly assess eelgrass-seaweed competition (Figure 10.4). The attached browns that dominated some intertidal areas were mostly absent from subtidal sites. Despite high variability in the abundance of drift seaweeds from year-to-year, some trends are evident. The highest seaweed abundance (dominated by *Gracilaria* and *Ulva*) and lowest eelgrass abundance was at the Depot Road location, whereas eelgrass was most dominant at the Sunset Hill Farm site (lower East Great Bay) for all three years of sampling (Figure 10.4). Eelgrass cover was stable or increased at three of four sites.

Acknowledgments and Credits

David Burdick (UNH), with contributions from Gregg Moore (UNH), Art Mathieson (UNH), Andrew Payne (UNH), Chris Peter (GBNERR/NHFG), Lara Martin (UNH), Natalie White (UNH), Elizabeth Cianciola (UNH), Grant McKown (UNH), and a host of UNH students. We appreciate the assistance of volunteers organized by the Coastal Research Volunteers.

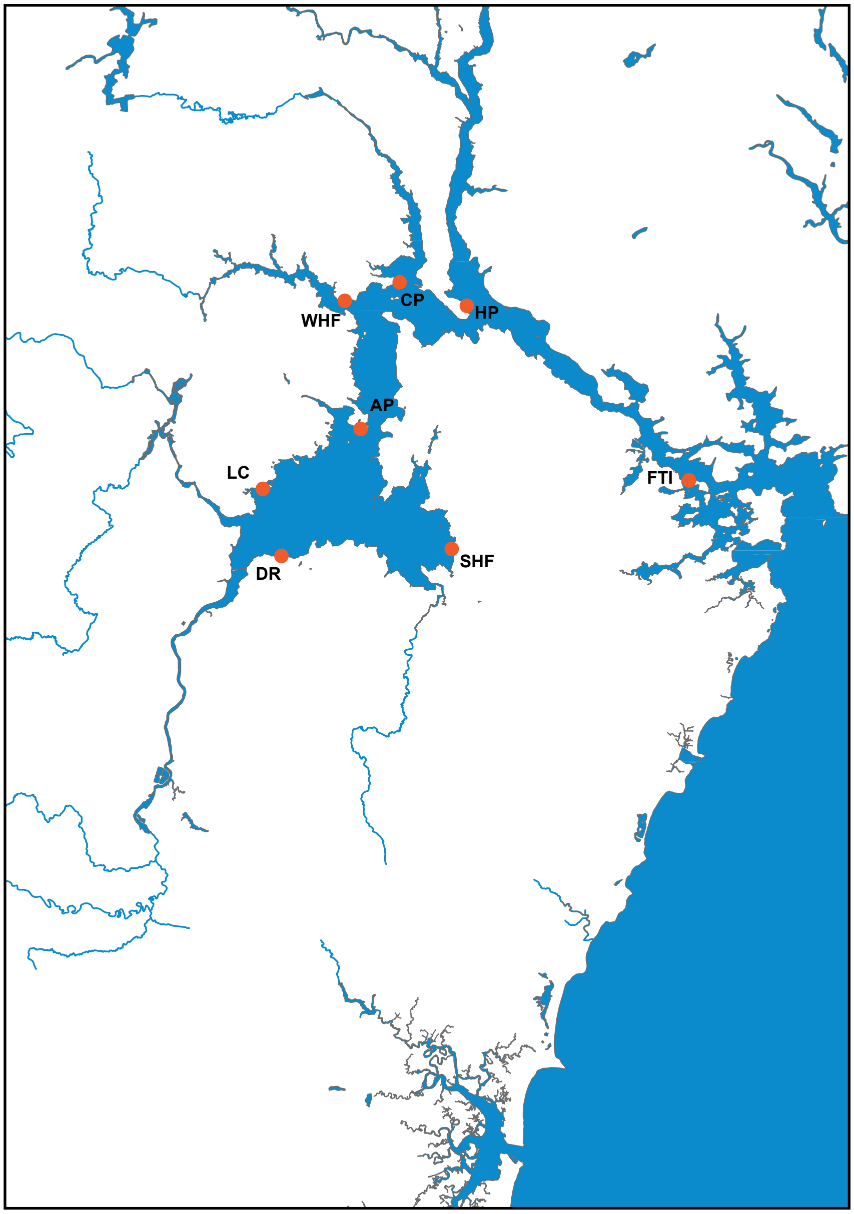


Figure 10.1: Seaweed monitoring sites in the Great Bay Estuary, which include intertidal and subtidal locations: Adams Point (AP), Sunset Hill Farm (SHF), Depot Road (DR), Lubberland Creek (LC). Sites in Little Bay and Portsmouth Harbor are intertidal only: Wagon Hill (WHF), Cedar Point (CP), Hilton Point (HP), and Four Tree Island (FTI).

Data source: Jackson Estuarine Laboratory, UNH

Aerial image of seaweed (reddish vegetation) patches within eelgrass beds in Portsmouth Harbor. Photo by Michael Routhier, UNH.

Seaweed

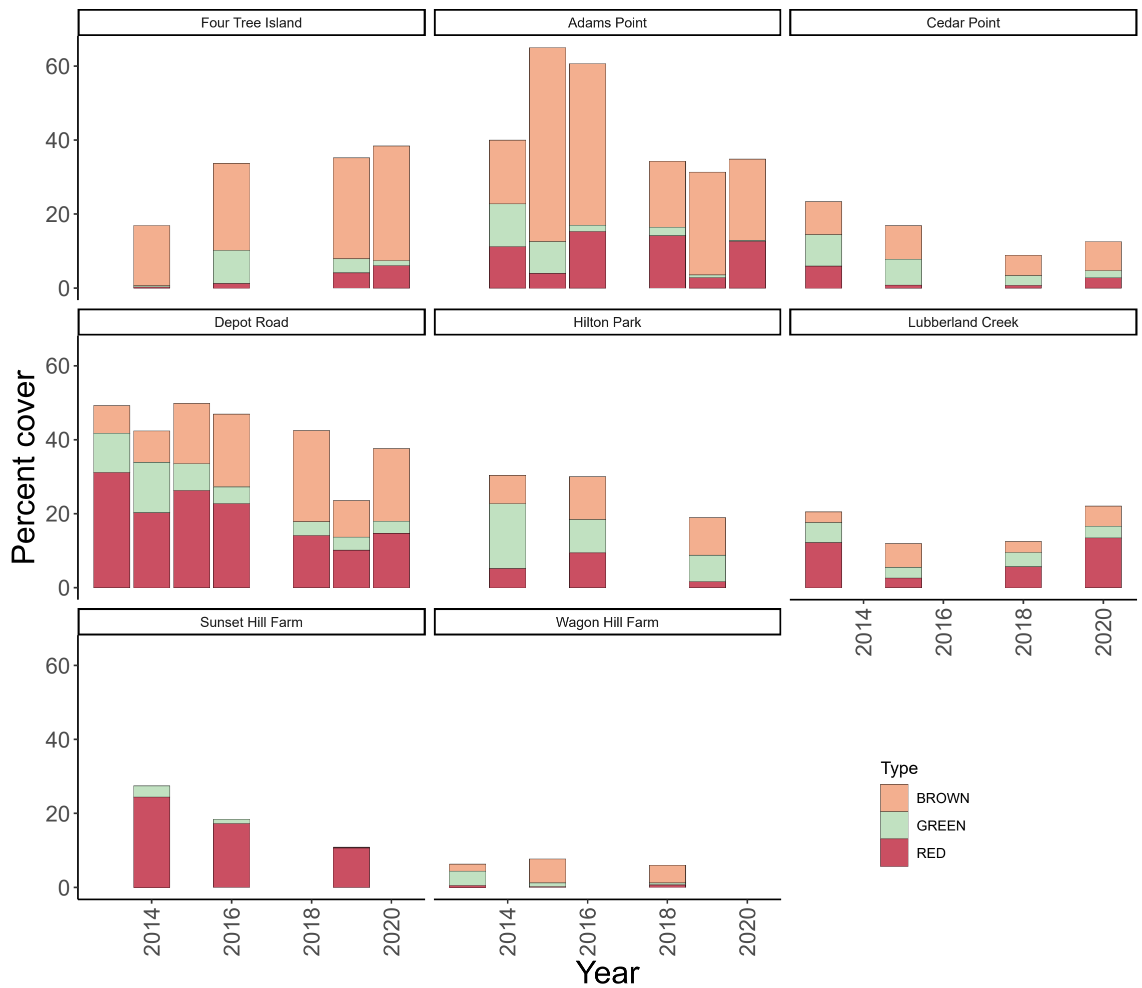


Figure 10.2: Abundance of intertidal green, red, and brown seaweeds assessed by percentage cover and averaged for three transects at depths of 0.5 to 2.5 m relative to mean low water in the Little Bay and Piscataqua River sites (Four Tree Island, Hilton Park, Cedar Point, Wagon Hill Farm) and Great Bay sites (Adams Point, Lubberland Creek, Depot Road, Sunset Hill Farm).

Data source: Jackson Estuarine Laboratory, UNH

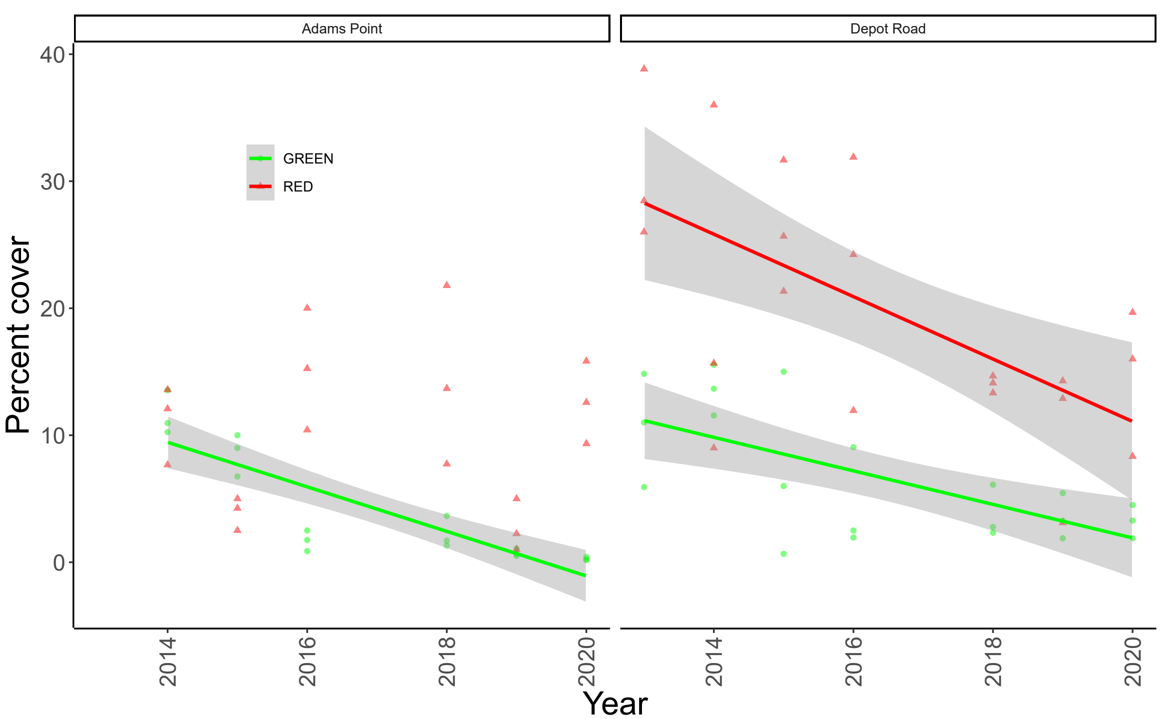


Figure 10.3: Linear regression showing red and green seaweed cover over time at Adams Point and Depot Road survey sites with best fit lines shown where change was statistically significant.

Data source: Jackson Estuarine Laboratory, UNH

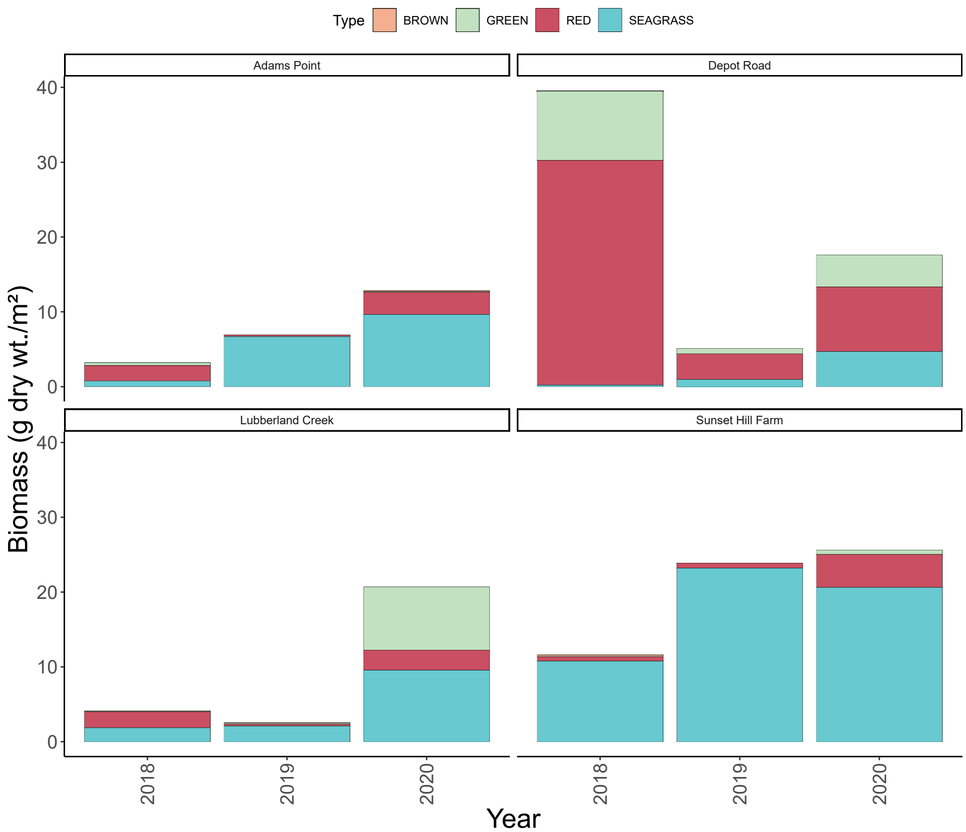


Figure 10.4: Abundance of drift seaweeds and rooted eelgrass using biomass estimates from summer sampling at four subtidal locations with three transect stations (12 stations total) in the Great Bay.
Data source: Jackson Estuarine Laboratory, UNH

Eelgrass

How many acres of eelgrass are present in the Great Bay Estuary and how has eelgrass cover changed over time? Has the total amount of eelgrass — measured as biomass — changed over time?

The Great Bay Estuary (including Kittery, ME to Odiorne State Park in Rye, NH) had 1,654 acres of eelgrass in 2021, slightly less than the 1,678 acres reported in 2019[36] (Figure 11.2). This is 43% below the peak in 1996 (2,900 acres) and 40% below the coverage in 1981 (2,752 acres), the first year that data were collected for the entire area. It is noteworthy that acreage in the Portsmouth Harbor region has been increasing steadily since 2014. Biomass, a measure of eelgrass health, at sites in Great Bay and Portsmouth Harbor are currently 214 g/m^2 and 139 g/m^2, respectively. These levels are much lower than the peaks, which were 454 g/m^2 for Great Bay in 1993[37] and 506 g/m^2 for Portsmouth Harbor in the late 1980s[38]. This means that, since peaking several decades ago, biomass decreased by 53% in Great Bay and 73% at Portsmouth Harbor. Given the importance of eelgrass to the estuarine ecosystem, efforts to improve eelgrass health continue to be a high priority. Whereas factors that are impossible to control — such as increasing water temperature — are also impacting eelgrass, land conservation, and better stormwater management to reduce nutrient and sediment loading to the Great Bay Estuary are effective actions we can take to improve eelgrass habitat.

Goal

Increase eelgrass distribution to 2,900 acres in the Great Bay Estuary. Goals related to the health of eelgrass (e.g., biomass) are in development. Note that eelgrass is not and has never been abundant in the Hampton-Seabrook Estuary and so this goal does not apply there.

Why We Track This Indicator

Eelgrass (*Zostera marina*) leaves slow the flow of water, encouraging suspended materials to settle, thereby promoting water clarity. Eelgrass roots stabilize sediments and both the roots and leaves take up nutrients from sediments and the water while providing habitat for fish, shellfish, and other small invertebrates, which in turn support other wildlife such as wading birds. Finally, eelgrass is sensitive to pollution — especially nutrients and sediments — and often indicates the status of an estuary's water quality.

Explanation

To assess eelgrass, we map the number of acres of habitat and then determine how much eelgrass is growing in those habitats, because eelgrass meadows can become less dense and have less biomass (weight of plant material per area) when they are struggling. When eelgrass biomass decreases, beneficial functions, such as habitat for fish and shellfish, wave dampening, etc., also decrease. Based on 2021 data, the total acreage of eelgrass (1,654 acres) in the Great Bay Estuary has not changed notably since 2017 (Figure 11.1, Figure 11.2). The biomass of eelgrass at the deepest SeagrassNet monitoring site in the Great Bay shows overall improvement from 2019 to 2021 before a decrease in 2022. Eelgrass at the deepest site In Portsmouth Harbor decreased between 2019 and 2021 before increasing in 2022, finishing with little net change when compared to 2019 (Figure 11.3).

Total acreage of eelgrass in 2021 represents losses in some parts of the Great Bay Estuary and gains in others. For example, roughly 100 acres of eelgrass were lost in the Great Bay since 2019, especially in shallow regions of the southern portion of the Great Bay. On the other hand, there were considerable gains in acres of eelgrass in the Portsmouth Harbor and Rye coastal areas, with the highest acreage of eelgrass near Odiorne Point since we began regular monitoring in 1981. In 2021, Portsmouth Harbor had 114 acres, up from 60 acres in 2010 (Figure 11.4).

These data tell a complex yet common story of eelgrass that occurs in many estuaries from North Carolina to Prince Edward Island, Canada. Eelgrass is a plant sensitive to several stressors including wasting disease, temperature, habitat disturbance, and predation. Most commonly, excessive nutrients and sediments contribute to eelgrass decline. Nutrients, such as nitrogen, spur the growth of seaweed, epiphytes (algae growing on eelgrass leaves), and phytoplankton, which then outcompete eelgrass for light. Suspended sediments, too, block light from eelgrass, which needs much more light than most algal competitors. The "Total Suspended Solids" and "Phytoplankton" sections

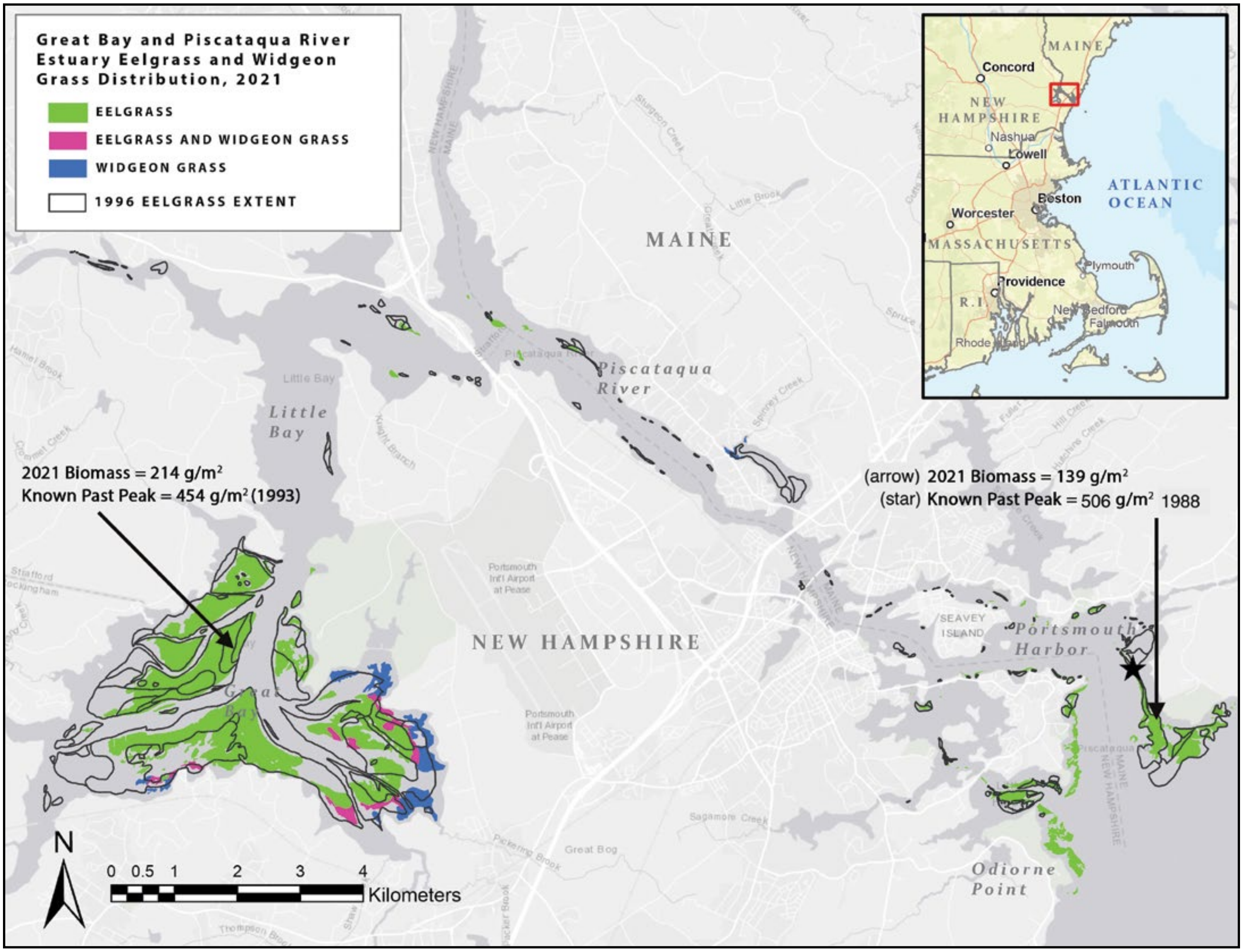


Figure 11.1: Seagrass distribution in the Great Bay Estuary in 2021, with biomass values for two sites. Black outlined polygons show the extent of eelgrass in 1996.
Data source: Michael Routhier, Ray Grizzle and Krystin Ward, UNH. 1996 data from Fred Short, UNH

review data indicating increasing trends in these light-blocking constituents over time.

Eelgrass is also sensitive to warming waters, a phenomenon that is occurring all along the US East Coast. This can create a "habitat pinch," where shallow waters can have good water clarity but are too warm, and the deeper waters are cooler but difficult for eelgrass because not enough light gets to the seafloor.

The relative role of different stressors on eelgrass in the Great Bay Estuary is a topic of ongoing research. The overall trend of eelgrass acres is inversely related to nitrogen loading and precipitation (Figure 11.2), at least through 2010, but does not necessarily indicate a cause-and-effect relationship. Nitrogen loading and precipitation track each other closely, because much more nitrogen enters the system when it rains, both from non-point and point sources. The same can be said for sediments and colored dissolved organic matter; large rain events wash material from the landscape into the tributaries and estuaries. Also, strong winds can stir up existing sediments, which also blocks light from reaching eelgrass. In rare cases, the salinity of the Great Bay Estuary can be greatly reduced, as happened during the Mother's Day Storm of 2006 (Figure 11.2). These conditions, along with the erosive force of extreme freshwater flow events, can cause significant stress to eelgrass habitats, which prefer salinity levels to be 15 ppt or higher. While the 2006 storm coincides with a notable decrease in the number of acres of eelgrass, Figure 11.2 also suggests that a downward trend in eelgrass acreage was underway before this storm.

Since the Mother's Day storm in 2006, the number of eelgrass acres in the estuary has remained relatively flat (Figure 11.2) even as nitrogen load continues to decrease and despite some years with low precipitation. On the other hand, over the same time period, eelgrass acreage in Portsmouth Harbor decreased in the years following the storm and then began to increase starting in 2010 (Figure 11.4).

The difference in eelgrass trends between Portsmouth Harbor and Great Bay is not completely understood, and might be related to hydrodynamic,

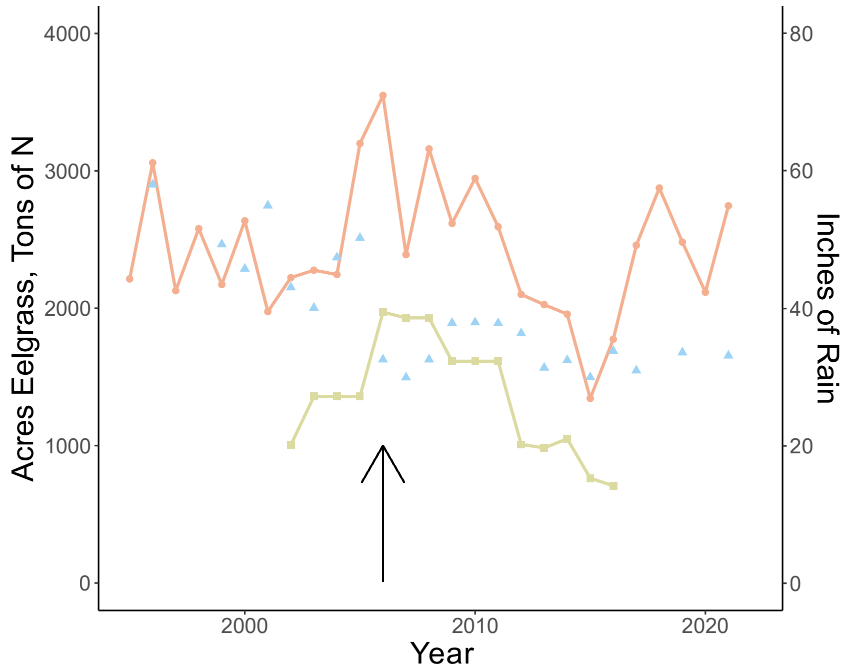


Figure 11.2: Eelgrass acres (light blue diamonds). The green line with squares indicate tons of nitrogen loading (per year). The orange line with circles represents total inches of rain. The arrow indicates the year of the Mother's Day Storm which qualified as a 1% chance annual flood event: 1 of 3 such storms since 1935. The second such event was in 2007 and the third was in 1987.
Data source: Eelgrass acres from 1996 to 2015, Fred Short (UNH); 2016 to 2019, Seth Barker; 2021, Michael Routhier, Ray Grizzle and Krystin Ward, UNH. Nitrogen loading data from the UNH Water Quality Analysis Lab, except for 1996 data point, which is from Jones 2001. Precipitation data from Greenland, NH weather station

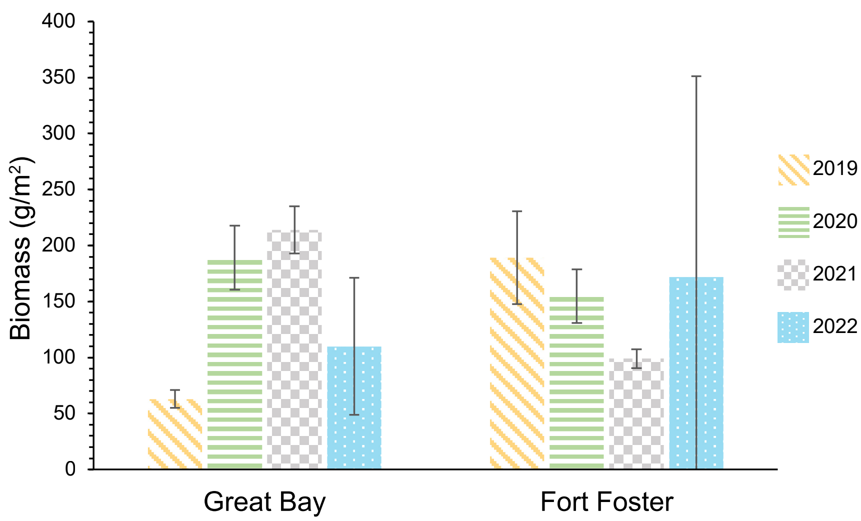


Figure 11.3: Biomass of eelgrass at deepest transect for two "SeagrassNet" monitoring stations: Great Bay and Portsmouth Harbor (Fort Foster). (See Figure 11.1 black arrows for locations on map.) Bars denote Standard Error.
Data source: Jackson Estuarine Laboratory, UNH

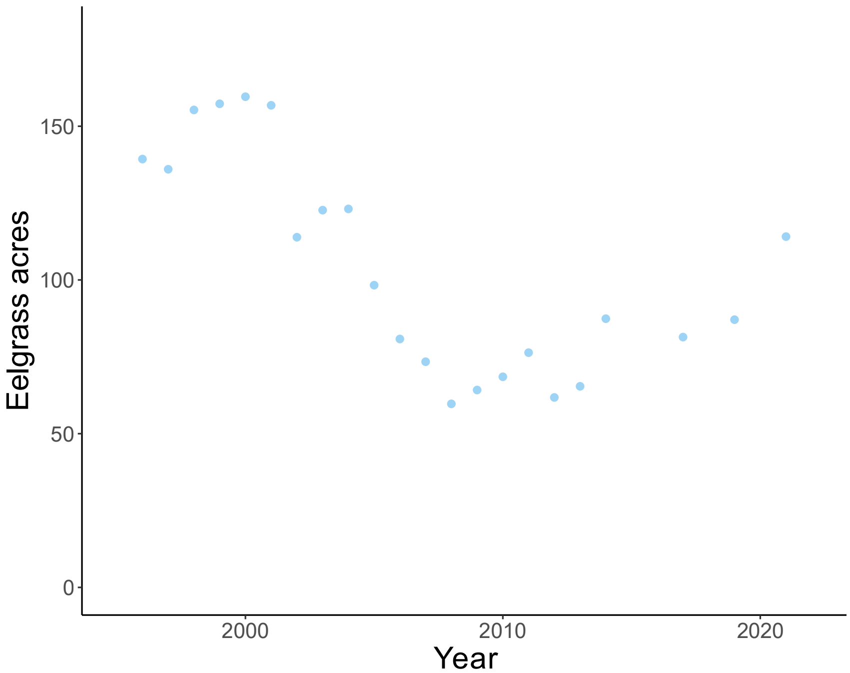


Figure 11.4: Number of acres of eelgrass in Portsmouth Harbor from 1995 to 2021.
Data source: Jackson Estuarine Laboratory, UNH

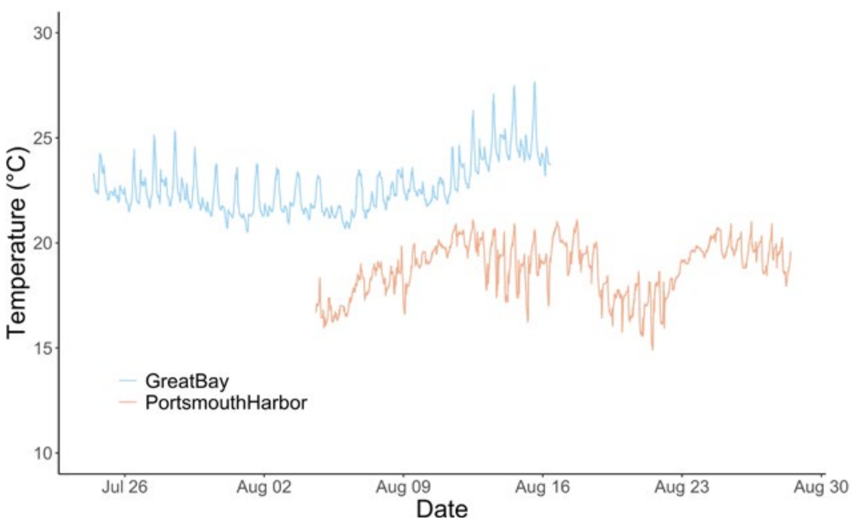


Figure 11.5: Temperature data collected by HOBO sensors (every 10 minutes, located close to the bottom) from August 3 to August 28, 2021, at an eelgrass bed in Portsmouth Harbor (see Figure 11.1 for location) at one of the shallower locations in the Harbor and July 4 to August 16, 2021, at an eelgrass bed in the Great Bay Estuary (see Figure 11.1 for location), at one of the deeper locations.
Data source: Jackson Estuarine Laboratory, UNH

sediment, temperature, and ecological differences between the two areas. In the Great Bay, water remains "in residence" much longer; it takes 10 days for 50% of the water particles to leave the Bay. At the mouth of the Estuary, in contrast, 90% of the water particles flow to the ocean or upriver (depending on the tide) within a day. Also, the Bay is much shallower than Portsmouth Harbor. In fact, much of the Bay turns into a mudflat at low tide. Therefore, the sediments in Great Bay are fine-grained organic muds, in comparison with the coarse sands found in Portsmouth Harbor. This means that the sediments in Great Bay are more easily resuspended. Fine sediments tend to also have higher nutrient concentrations than coarser sediments and can release them slowly — years and sometimes decades later.

In addition, much of the eelgrass in Great Bay is growing in very shallow water and, therefore, is more susceptible to temperature stress (Figure 11.5). In contrast, for the Portsmouth Harbor eelgrass beds — despite the Gulf of Maine experiencing rapidly warming water — temperatures do not rise above 25° C (the threshold stress point for eelgrass)[39] even at the shallow eelgrass beds (Figure 11.5). Finally, the two areas may host different types and proportions of fauna that can exert top-down effects on eelgrass or eelgrass habitat.

Acknowledgments and Credit
Kalle Matso and Trevor Mattera (PREP), with contributions from Michael Routhier (UNH), Ray Grizzle (UNH), Krystin Ward (UNH), Tom Gregory (UNH), Amanda Giacchetti (UNH), Lara Martin (UNH), and David Burdick (JEL/SMSOE/UNH).

Extended Report

A new seagrass and seaweed monitoring program was started in 2021, tracking seagrass and seaweed abundance at 25 sites throughout the Great Bay Estuary. See the Extended Report for results from the first year.

Phytoplankton

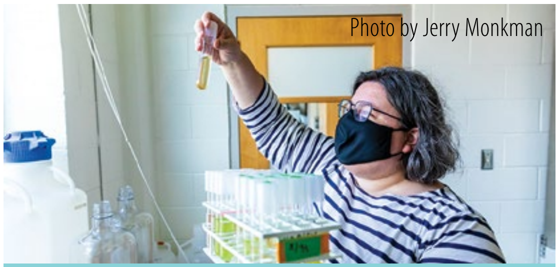


Photo by Jerry Monkman

How are phytoplankton concentrations changing over time?

Stations in Great Bay indicate an increase in chlorophyll-a (a proxy for phytoplankton) over time, peaking around 2010 through 2015, with levels dropping off in recent years. Other stations indicate either no trend or decreasing chlorophyll-a concentrations. Chlorophyll-a concentrations in Hampton River in recent years (2020 – 2021) are mostly at levels that indicate "good" water quality. Phytoplankton levels should be considered together with total suspended solids, because the two components combine to impact how much light gets to the bottom of our estuaries (see "Total Suspended Solids" and "Light").

Goal

No increasing trends in phytoplankton abundance.

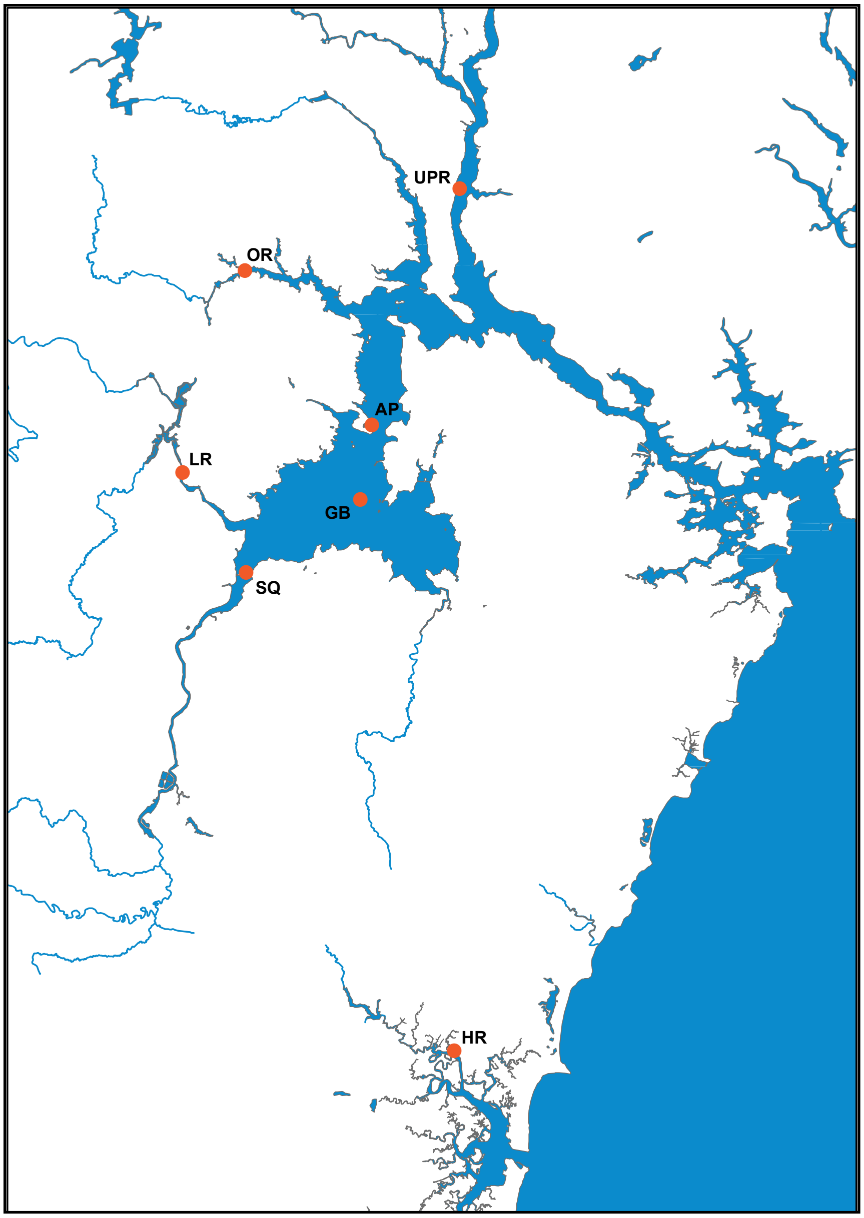


Figure 12.1: Monitoring stations for phytoplankton including Adams Point (AP), Great Bay (GB), Lamprey River (LR), Oyster River (OR), Squamscott River (SQ), Upper Piscataqua River (UPR), and Hampton River (HR)
Data source: Jackson Estuarine Lab, UNH

Why We Track This Indicator

Phytoplankton population dynamics are significant indicators of marine ecosystem health and marine food web structure. These single-cell algae impact water clarity, compete with eelgrass and seaweeds for available light and nutrients, and support biomass production in commercial fisheries. Additionally, when large populations of phytoplankton die, their decomposition decreases the dissolved oxygen available for fishes and benthic invertebrates, a problem that does occasionally occur in the tributaries that feed into both the Great Bay and Hampton-Seabrook Estuaries (see "Dissolved Oxygen").

Explanation

Extracted chlorophyll-a measurements were compared among six locations in the Great Bay Estuary (Figure 12.1). Both the Adams Point and Great Bay Stations (Figure 12.2; Table 12.1) indicate statistically significant increasing trends while the Squamscott River (Figure 12.3) and Oyster River Stations indicate statistically decreasing trends (Table 12.1). These differences could be due to when these various time series began. For example, only the Adams Point Station includes data from the late 1980s and early 1990s, a period when chlorophyll-a levels were low. The Upper Piscataqua River Station time series only extends back to 2007

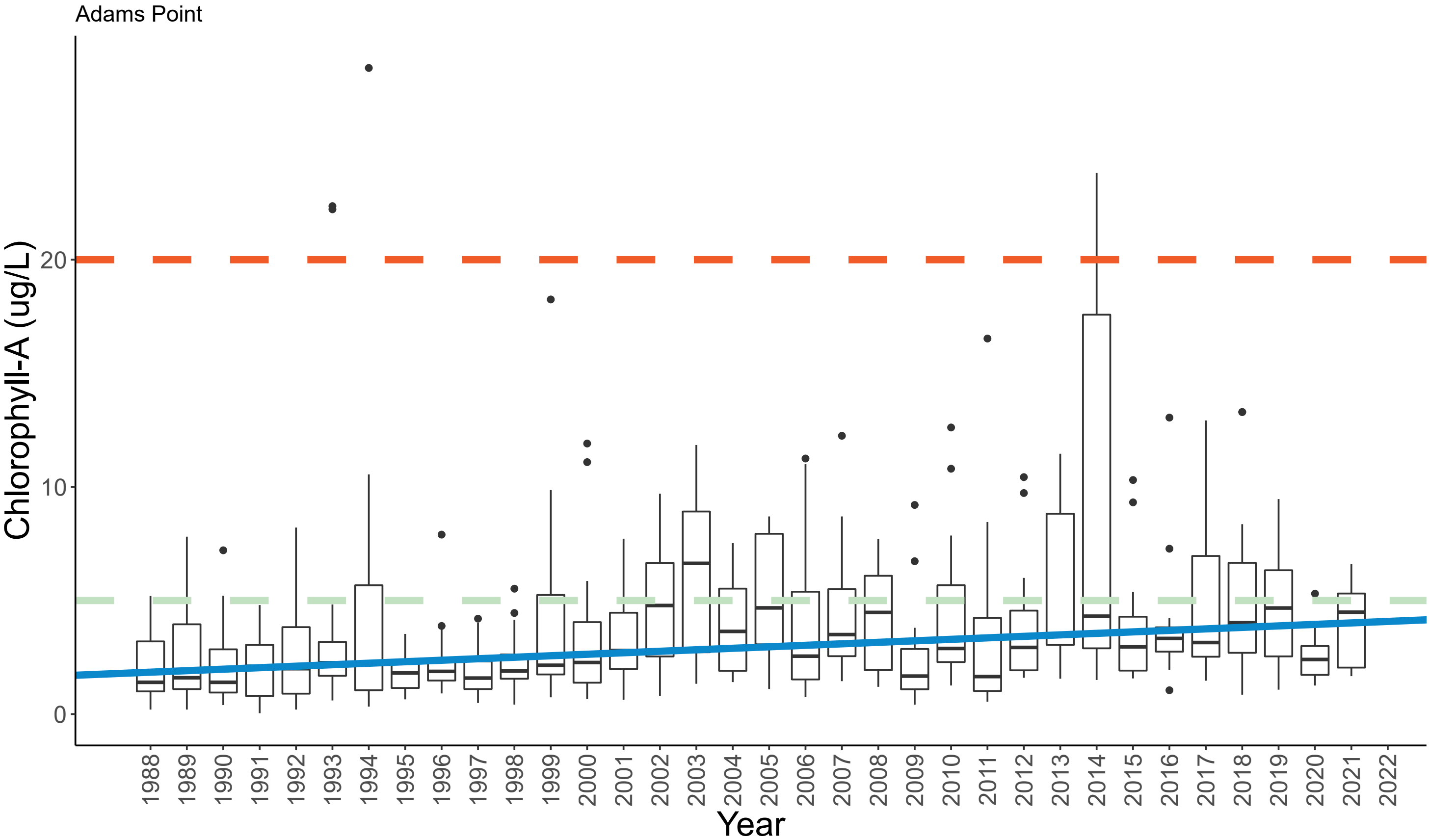


Figure 12.2: Box and whisker plot of chlorophyll-a data at the Adams Point Station (year-round, both low and high tide) from 1988 to 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass the remaining data. "Outliers" are shown as individual points. In general, measurements below the green dashed line at 5µg/L reflect better water quality. Measurements between 5 and 20µg/L are "moderate" and measurements above the red dashed line (20µg/L) indicate poorer water quality. The blue trend line indicates a statistically significant increase over time.

Data source: Jackson Estuarine Laboratory, UNH

Photo by Jerry Monkman

Location	Significant change in chlorophyll-a concentration?	Dates
Adams Point	Yes ↑	1988 – 2021
Great Bay	Yes ↑	2002 – 2021
Lamprey River	No	1992 – 2021
Oyster River	Yes ↓	2002 – 2021
Squamscott River	Yes ↓	2001 – 2021
Upper Piscataqua River	No	2007 – 2021
Hampton River	No	2018 – 2021

Table 12.1. Summary of analysis of annual change in chlorophyll-a concentrations.

Data source: Jackson Estuarine Laboratory, UNH

Phytoplankton

and there have been no detectable trends (Figure 12.4). Similarly, the time series for the Hampton River Station began very recently (2018) and does not exhibit a clear trend (Figure 12.5).

At all stations investigated, chlorophyll-a concentration ranged from less than 1 µg/L to approximately 40 µg/L and there were significant trends in chlorophyll-a at four of the seven stations (Table 12.1). The longest time series is for Adams Point and illustrates the pattern of low levels at the beginning of the record (1988 through 2002) with higher levels over the last two decades (Figure 12.2). Currently, this station shows a statistically significant increasing trend.

Chlorophyll-a concentrations are regularly used to assess an estuary's "eutrophication" status: that is, whether the estuary contains excess nutrients. There are no current thresholds specific to our estuaries, but general thresholds do exist for coastal regions of the United States.[40] For the Northeast, chlorophyll-a levels less than 5 µg/L are categorized as "low" with regard to eutrophic status, concentrations between 5 and 20 µg/L are "moderate," and concentrations above 20 µg/L are considered "high." In general, looking at Figures 12.1 through 12.4, most measurements fall in either the "low" or "moderate" category (encompassing from 0 to 20 µg/L) with some, but infrequent, measurements that are "high." It is encouraging that the vast majority of measurements are less than 10 µg/L in the most recent years.

Across all locations, chlorophyll-a concentrations were seasonally variable, with a primary peak in the spring (Figure 12.6). Although chlorophyll-a should continue to be tracked, efforts should be made to characterize the dominant phytoplankton communities in estuarine waters consistently over time. This would provide essential information regarding the health of our estuaries, as well as their potential to nutritionally support important fisheries such as oyster aquaculture.

Acknowledgments and Credit

Elizabeth Harvey (UNH), with contributions from Kalle Matso (PREP), Lara Martin (UNH), and Tom Gregory (UNH).

Extended Report

Another analysis of chlorophyll-a shows how both minimum and maximum levels at Adams Point have statistically increased since 1988.

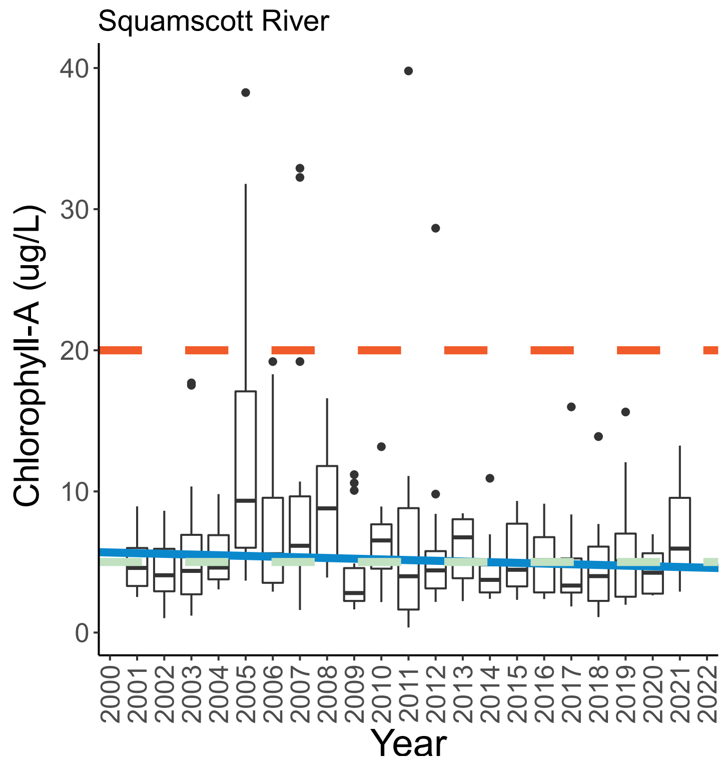


Figure 12.3: Box and whisker plot of chlorophyll-a data at the Squamscott River Station (low tide only) from 2001 to 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass the remaining data. "Outliers" are shown as individual points. In general, measurements below the green dashed line at 5µg/L reflect better water quality. Measurements between 5 and 20µg/L are "moderate" and measurements above the red dashed line (20µg/L) indicate poorer water quality. The blue trend line indicates a statistically significant decrease over time.

Data source: Jackson Estuarine Laboratory, UNH

Photo by Jerry Monkman

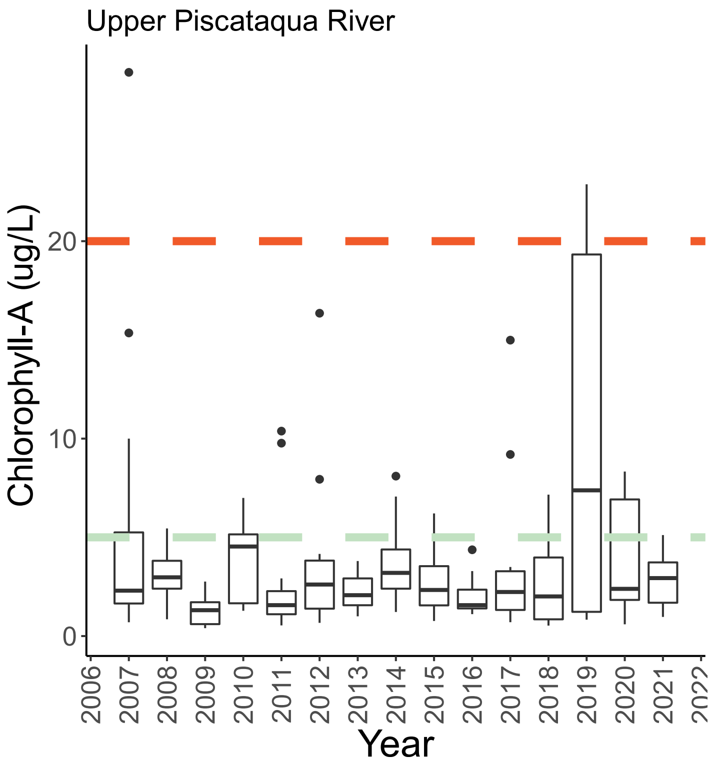


Figure 12.4: Box and whisker plot of chlorophyll-a data at the Upper Piscataqua River Station (low tide only) from 2007-2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass the remaining data. "Outliers" are shown as individual points. In general, measurements below the green dashed line at 5µg/L reflect better water quality. Measurements between 5 and 20µg/L are "moderate" and measurements above the red dashed line (20µg/L) indicate poorer water quality. There was no statistical trend.
Data source: Jackson Estuarine Laboratory, UNH

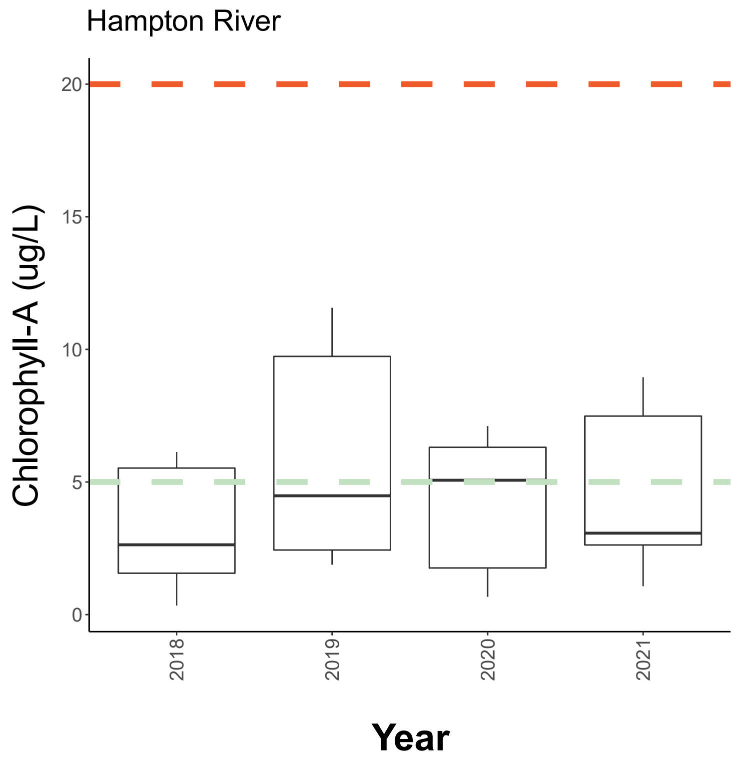
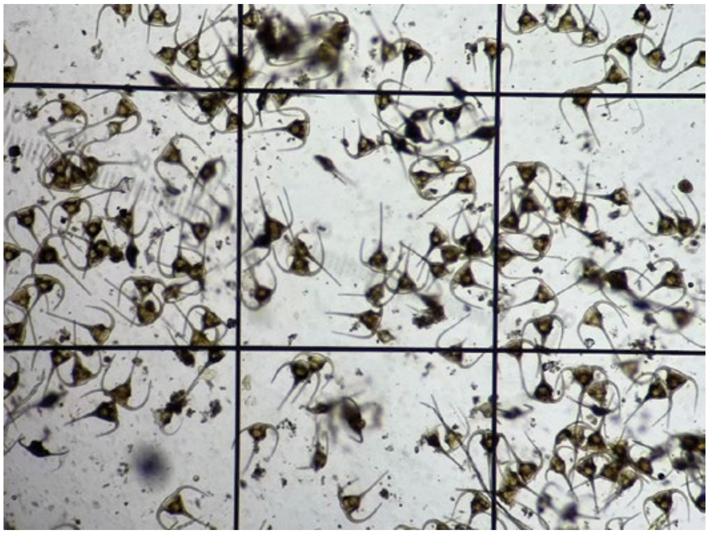


Figure 12.5: Box and whisker plot of chlorophyll-a data at the Hampton River Station (low tide only) from 2018 to 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass the remaining data. "Outliers" are shown as individual points. In general, measurements below the green dashed line at 5µg/L reflect better water quality. Measurements between 5 and 20µg/L are "moderate" and measurements above the red dashed line (20µg/L) indicate poorer water quality. There was no statistical trend.
Data source: Jackson Estuarine Laboratory, UNH



Cells of Ceratium longipes from water sampled in April of 2023 off the coast of New Castle, NH. Photo by Eric Schroeder, Shellfish Program Volunteer.

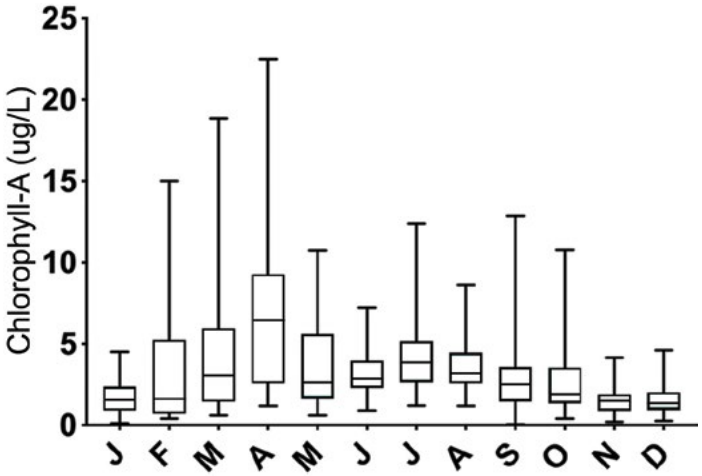


Figure 12.6: Monthly mean of chlorophyll-a concentration at the Adams Point Station (both low and high tide samples). This dataset runs from 1998 – 2020. The line within each box is the mean across all years examined, and whiskers encompass the minimum and maximum values.
Data source: Jackson Estuarine Laboratory, UNH

Total Suspended Solids

How have total suspended solids in both estuaries changed over time?

Total Suspended Solids (TSS) at Adams Point had a statistically significant increasing trend since monitoring began in 1989 across both high and low tide sampling. At the Great Bay Station, TSS concentrations had no temporal trend, remaining consistent since 2002. At low tide, both the Adams Point and Great Bay Stations had decreasing levels over 2019, 2020, and 2021. At the Hampton River Station in 2021, total suspended solids concentrations were at medium levels: higher than some Great Bay Estuary stations but lower than others. The level of suspended solids in an estuary, and thus the clarity of its waters, varies with the tides, rainfall, regional development, an increase or decrease in shoreline vegetative buffers, and a host of other factors.

Goal

No increasing trends for total suspended solids.

Why We Track This Indicator

Total suspended solids are particles suspended in the water column measured as the dry weight of particles filtered from a known volume of water. They can consist of phytoplankton or pieces of plant matter, but most total suspended solids are generally made up of inorganic particles, such as sediment. Sources of suspended solids include erosion from streambanks, salt marshes, and the upland portion of the watershed. Surface water inflows, stormwater runoff, and wastewater treatment effluent all can deliver total suspended solids to estuaries. In addition to external sources of suspended solids, they can also originate from resuspension within an estuary. Increasing suspended sediments reduces water clarity and light availability for primary producers such as eelgrass, seaweeds, and phytoplankton. High total suspended solid values can also negatively impact oyster feeding and the aesthetic value of our estuaries.

Explanation

The Adams Point Station has the longest time series dating back to 1989. Since that time, total suspended solids have statistically increased, but concentrations appear to be decreasing in recent years (Figure 13.2). Median annual low measurements at Adams Point over the last three years (2019 – 2021) are all lower than the six preceding years. The Upper Piscataqua River Station has a similar pattern, with recent years showing a plateau in total suspended solids concentrations (Figure 13.3).

Broadly, Table 13.1 demonstrates clearly that total suspended solid concentrations have increased around the Great Bay Estuary over the past two decades, with most of the stations indicating statistically increasing trends. For the Hampton-Seabrook Estuary, data on total suspended solids has only been collected for the period 2018 through 2021. During that time, values have been comparable to the Great Bay Station, ranging between 18.3 and 23.2 mg/L (Figure 13.4).

Location	Significant change in TSS concentration?	Dates for Trends in Column to Left	Range of Median Values 2016 – 2021 (mg/L)
Adams Point	Yes ↑	1989 – 2021	15.7 – 21.6
Great Bay	Yes ↑	2002 – 2021	16.1 – 23.2
Lamprey River	Yes ↑	1992 – 2021	3.6 – 16.1
Oyster River	Yes ↑	2004 – 2021	17.6 – 36.8
Squamscott River	No	2002 – 2021	29.0 – 54.1
Upper Piscataqua River	No	2007 – 2021	12.0 – 14.2
Hampton River	No	2018 – 2021	18.9 – 22.1

Table 13.1: Total suspended solids (TSS) trends and median values at six stations in the Great Bay Estuary and one station in the Hampton-Seabrook Estuary. Trends and values reflect low tide sampling only.

Data source: Jackson Estuarine Laboratory, UNH

At the Great Bay Station, since 2002, suspended solids have remained relatively stable, with a low tide median concentration of 17.1 mg/L for the entire record. The observed statistical increase in suspended solids at the Great Bay Station is likely driven by the eight measurements that exceed 50 mg/L since 2015. Despite the increasing trend, the median concentration decreased in 2021 to 18.3 mg/L (Figure 13.5). The median concentration in 2021 exceeded that of Adams Point (17.9 mg/L).

For context, consider that values over 15 mg/L are often cited as being very challenging for the health of eelgrass.[41] When concentrations are regularly above 15 mg/L, light is blocked and eelgrass cannot photosynthesize, while seaweeds and phytoplankton continue to thrive since they have lower photosynthesis requirements. For more on total suspended solids and eelgrass, see "Light."

High suspended solids concentrations also have the potential to harm oysters. Oyster monitoring efforts indicate that oyster reefs that are not built high enough above the estuary floor can be smothered by sediment deposits.

As is often the case with estuarine science, there is a range of conditions that are optimal for ecosystems. For example, some light scattering by total suspended solids helps phytoplankton suspended in the water column receive sufficient light to grow. On the other hand, if the water is clearer, more light reaches the bottom, which benefits eelgrass. Thus, there is a "sweet spot" that balances the light available to phytoplankton — critical food for oysters and fish — with the light for benthic primary producers like seagrass.

Chemists, ecologists, hydrologists, and oceanographers are working together to understand the connections between the source and transport of sediments in our estuaries. For example, decreases in eelgrass and oyster habitats lead to greater resuspension of sediments, but sediments may also be added to the estuary from the surface water inflows or the estuary shores. At the same time, hydrologic and hydrodynamic drivers (e.g., changing climate patterns such as drought or record rainfall) can influence the delivery of total suspended solids from the surrounding watershed and the flushing of total suspended solids from the estuary. Finally, it is important to acknowledge that a certain amount of sediment transport from the watershed is necessary to maintain salt marsh elevations, and so is a key factor in determining salt marsh resilience to rising sea-level.

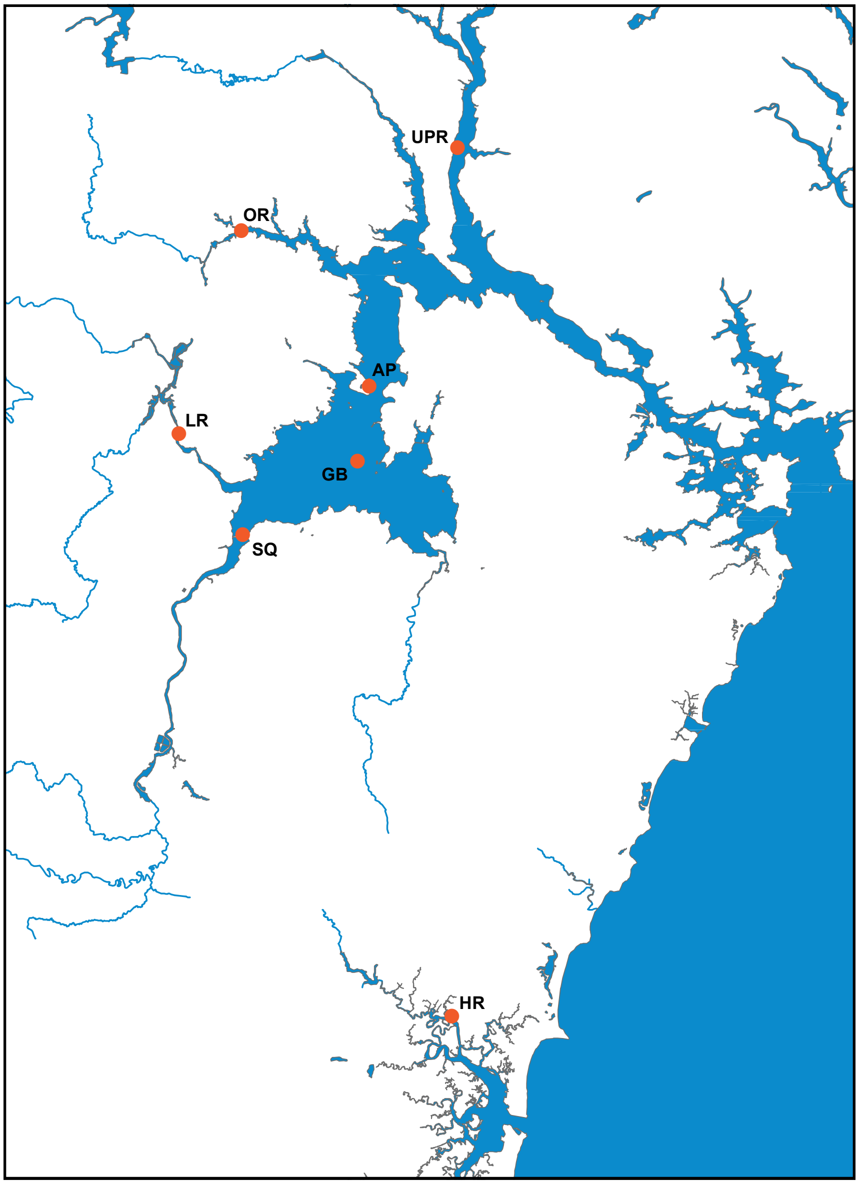


Figure 13.1: Monitoring stations for total suspended solids including Adams Point (AP), Great Bay (GB), Lamprey River (LR), Oyster River (OR), Squamscott River (SQ), Upper Piscataqua River (UPR), and Hampton River (HR).
Data source: Jackson Estuarine Lab, UNH

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

Extended Report

See the extended report for data on other stations.

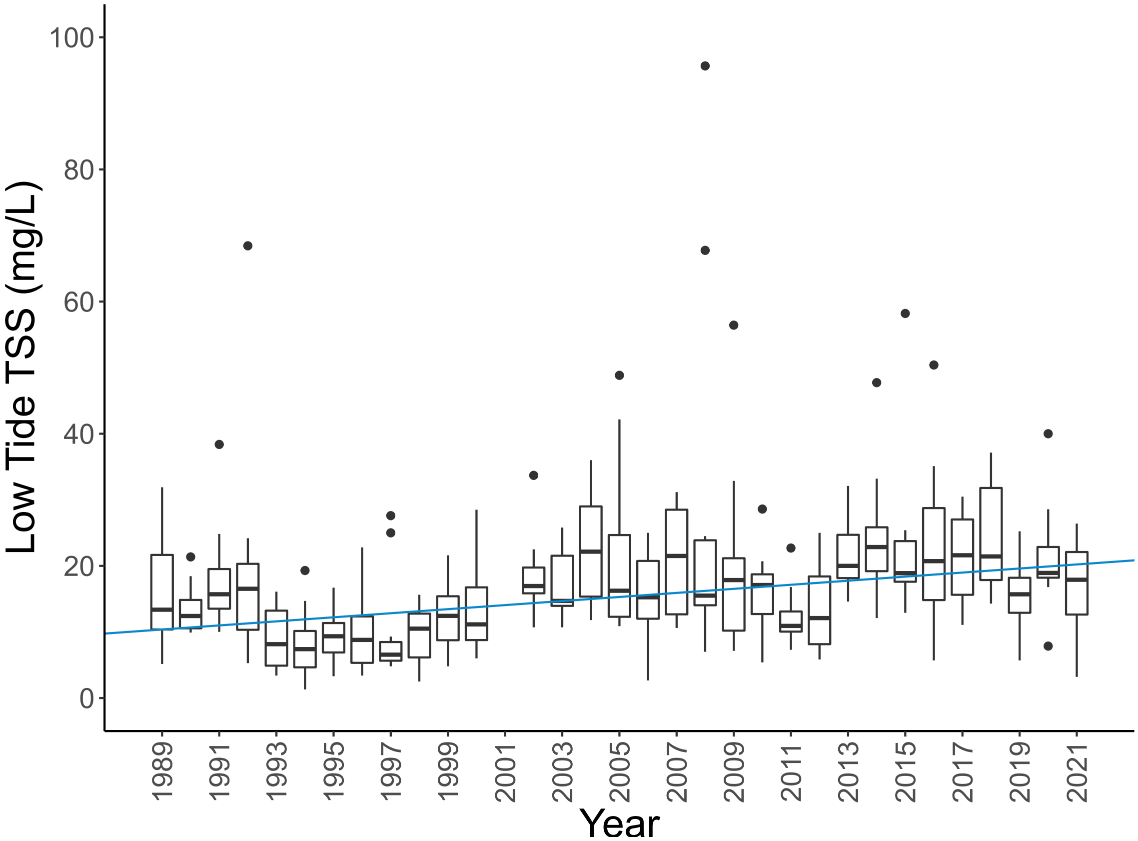


Figure 13.2: Total suspended solids (TSS) at Adams Point Station (low tide only). Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass the remaining data. "Outliers" are shown as individual points. Year 2001 not included due to missing data. The linear regression represented by the blue line shows the statistically significant increasing trend in annual median TSS concentrations.

Data source: Jackson Estuarine Laboratory, UNH

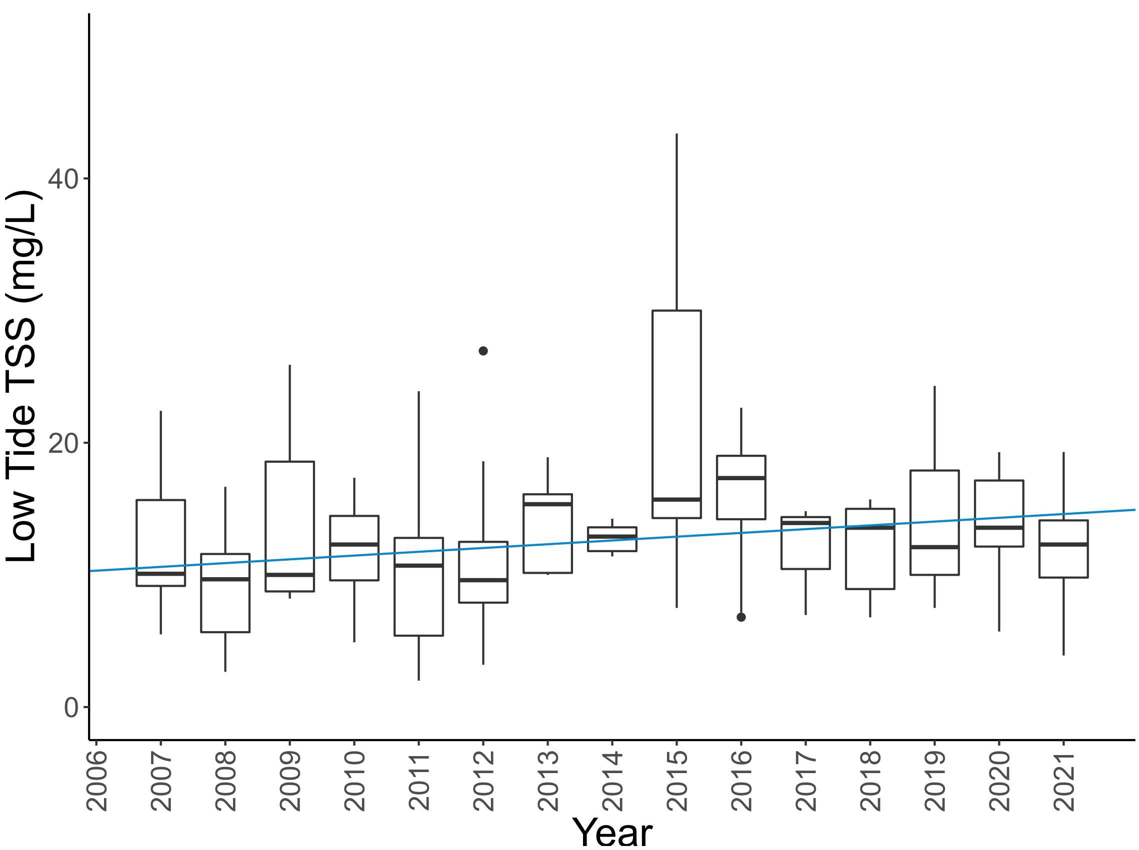


Figure 13.3: Total suspended solids (TSS) at Upper Piscataqua River Station. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass the remaining data. "Outliers" are shown as individual points. The linear regression represented by the blue line shows the statistically significant increasing trend in annual mean TSS concentrations.

Data source: Jackson Estuarine Laboratory, UNH

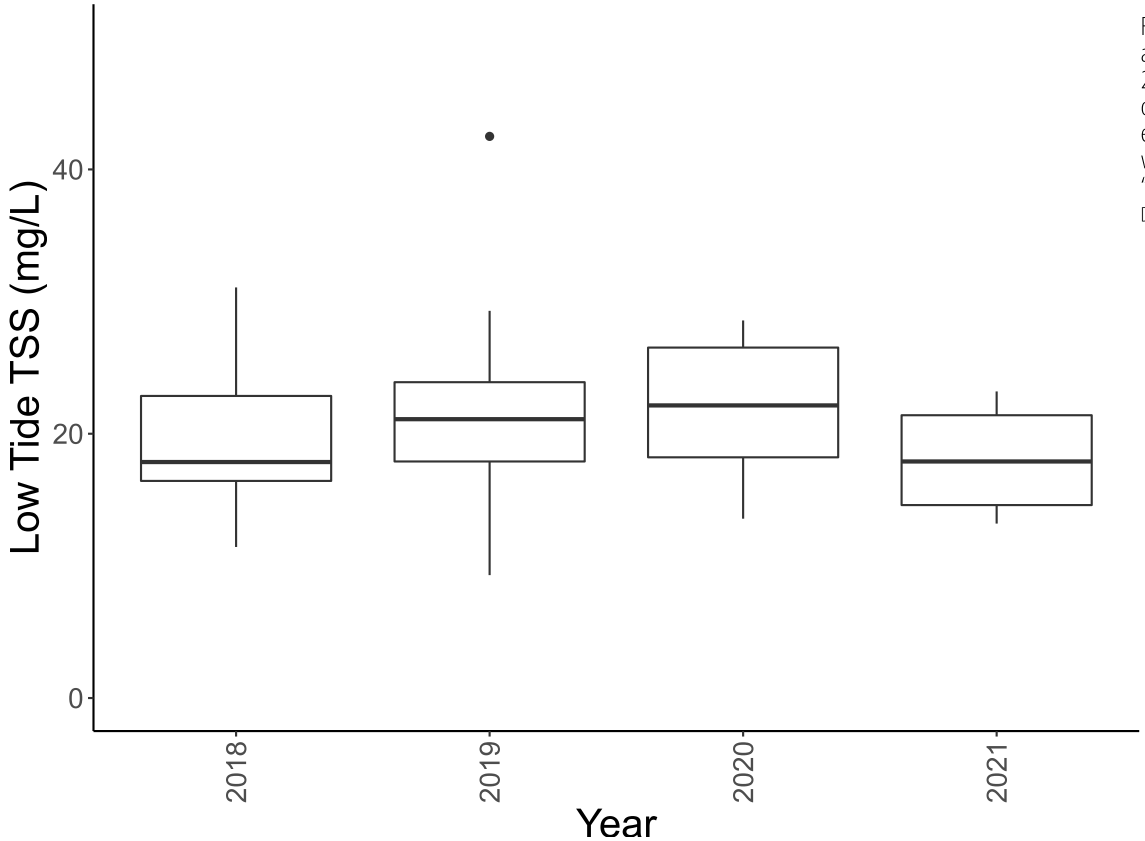


Figure 13.4: Total suspended solids (TSS) at Hampton River Station from 2018 to 2021. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass the remaining data. “Outliers” are shown as individual points.
Data source: Jackson Estuarine Laboratory, UNH

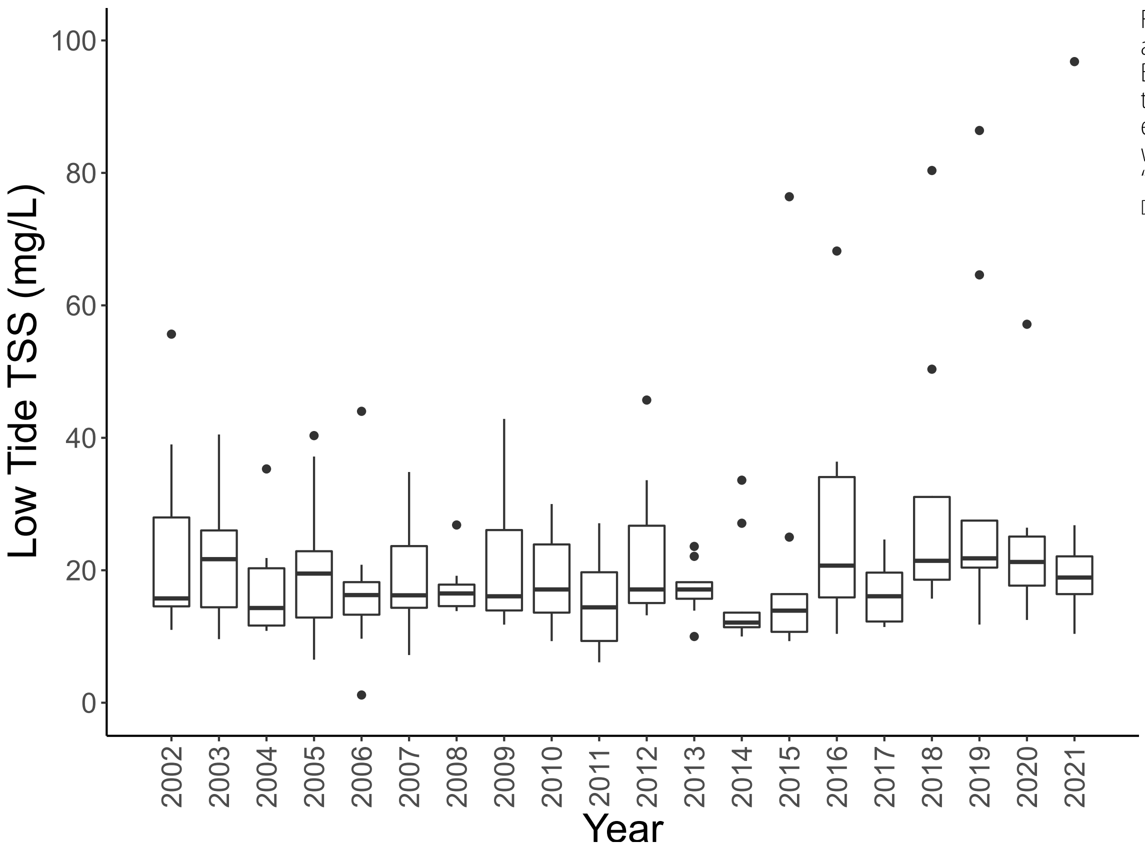


Figure 13.5: Total suspended solids (TSS) at Great Bay Station (low tide only). Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass the remaining data. “Outliers” are shown as individual points.
Data source: Jackson Estuarine Laboratory, UNH

Light

What are the underwater light conditions and how have they changed over time?

As often happens in estuaries, light penetration is greater at the mouth of the Great Bay Estuary than in the upper portions of the estuary, where light frequently does not meet eelgrass requirements. At Adams Point, where data collection began in 2003, there is a statistically significant increasing trend in light attenuation (reduction) pointing to worsening light conditions. The two main constituents that attenuate light — total suspended solids and phytoplankton — have increased since 1988 at Adams Point, with total suspended solids decreasing in recent years. In the Hampton-Seabrook Estuary, light attenuation data has been collected since 2018, and values are comparable to Adams Point.

Why We Track Light

Underwater light conditions impact primary producers like eelgrass, seaweed, and phytoplankton. When the water has high concentrations of suspended material (e.g., plankton or sediments) and/or dissolved substances (e.g., colored dissolved organic matter, a.k.a. CDOM), light is "attenuated" (i.e., reduced), making survival more difficult for plants like eelgrass that need higher light levels than seaweeds and phytoplankton.

Explanation

This section focuses on the Great Bay Estuary due to the connection between light and eelgrass. Eelgrass habitat is not present in the Hampton-Seabrook Estuary, but light attenuation data has been collected there since 2018. Currently, light attenuation values at the Hampton River Station are comparable to the values in the Great Bay Estuary, described below.

It is well known that eelgrass in the Great Bay Estuary has struggled since its peak in 1996. Very often, eelgrass disappears because light conditions have degraded. This is worrisome because it could lead to an undesirable feedback loop, where less eelgrass leads to less stable sediments and reduced filtering of nutrients, which leads to worsening light conditions and the loop continues.

In the Great Bay Estuary, our longest time series of light data starts in 2003 at the Adams Point Station (Figure 14.1), and these data indicate a statistically significant increasing trend for light attenuation (Figure 14.2). "Light attenuation" or "Kd" refers to the loss of light as water gets deeper. So, low values indicate more light is penetrating deeper. There are no trends in light attenuation at other stations, possibly due to not having as many years of data. Unfortunately, none of our light attenuation data extend back to the time when eelgrass was more abundant (1996).

Eelgrass monitoring off of New Castle, NH in 2022, at approximately 17 feet of depth. The water is clearer near the coast when compared with Great Bay so eelgrass can grow at greater depths. Photo by Kalle Matso.

In 2009, the NHDES report, *Numeric Nutrient Criteria for the Great Bay Estuary* suggested a range of light attenuation values (0.5/m to 0.75/m) for the maintenance of existing eelgrass beds, depending on how deep the beds are.[42] A peer review of this document noted that these attenuation targets could actually be too high — i.e., light attenuation needs to be less, so more light penetrates the water column — given that eelgrass loss has already occurred, and that better conditions are required for recovery as compared with "maintenance."[43] For the deeper beds (~3 m) in Portsmouth Harbor, lower light attenuation (i.e., higher penetration) is necessary because the light has to travel through more water to reach the eelgrass. For the meadows in Great Bay proper, light attenuation values as high as 0.75/m were deemed acceptable because the plants are only expected to grow in water 2 m deep.

In Portsmouth Harbor, between 2004 and 2017, the median light attenuation value is 0.61/m. In the Upper Piscataqua River, between 2007 and 2020, the median value is 1.30/m. At Adams Point (Figure 14.2), between 2003 and 2021, the median light attenuation value is 1.2/m, and very few data points in recent years are below the threshold of 0.75/m. The high number of data points above 1.0/m and approaching 2.0/m suggests that light is a serious concern in terms of eelgrass recovery and perhaps even for basic maintenance of current levels.

Given the concern about light, the next step is to look at the things that can attenuate light in the Great Bay Estuary. The three main controls of light in estuaries are total suspended solids, chlorophyll-a (a proxy for phytoplankton), and colored dissolved organic matter. By looking closely at the levels of these constituents at various places in the Great Bay Estuary, managers can see what changes they will need to make to improve light conditions for eelgrass. Usually, phytoplankton is the most amenable to change through control of nutrients, even if it is not the highest attenuator of light. Colored dissolved organic matter is more difficult to manage as it is mostly derived from decomposing leaves and other plant material delivered by rivers. For these reasons, phytoplankton management thresholds are often lower for systems with higher total suspended solids values.

Adding more complications to an already complex topic, it is important to understand that light can be attenuated in other ways (Figure 14.3). "Epiphytes" — algae or plant matter that grow on other plants — often grow on the eelgrass blades, especially when grazers are not abundant or nutrients (e.g., nitrogen) are high. Also, seaweeds can grow inside, around, and on top of eelgrass beds, blocking light and adding organic matter to the sediments. In the estuaries around Prince Edward Island, Canada, for example, scientists found that eelgrass was impacted by seaweed proliferation, fueled by nitrogen from agricultural runoff. However, light attenuation measured in the water column never changed.

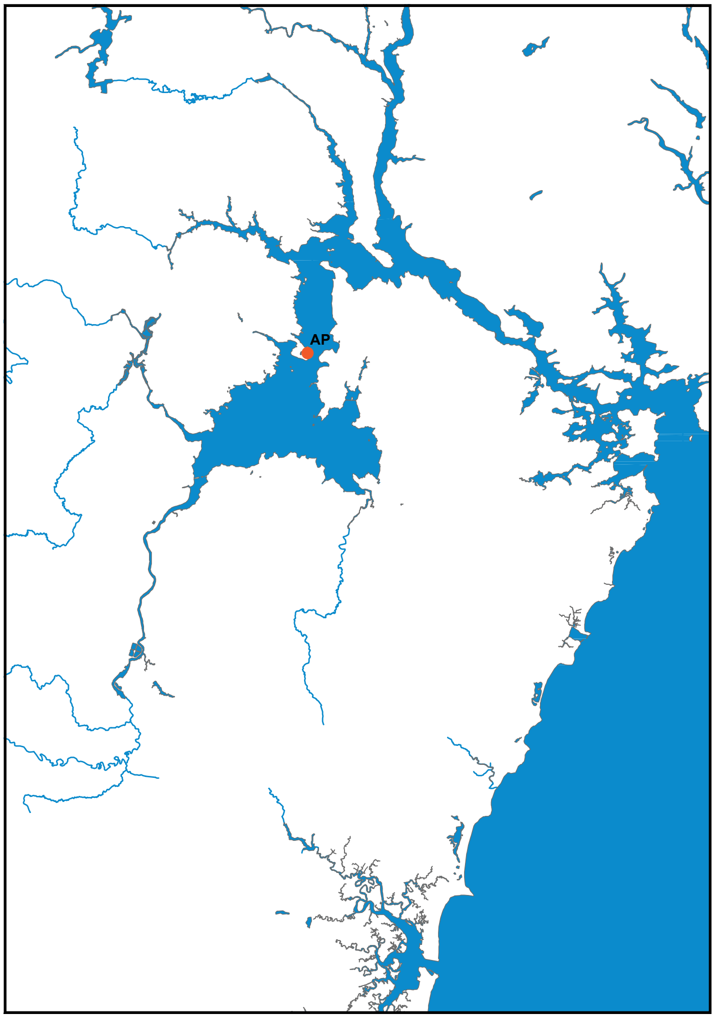


Figure 14.1: Monitoring station for light at Adams Point (AP)
Data source: Jackson Estuarine Lab, UNH

Total suspended solid levels have been declining in recent years while there was no clear pattern in phytoplankton levels (see "Total Suspended Solids" and "Phytoplankton"). In 2021, a 3-year project began with the goal of better understanding the relationship between nutrients and sediments and how these constituents relate to light, eelgrass, seaweeds, phytoplankton, and epiphytes.

Acknowledgments and Credit
Kalle Matso (PREP) with contributions from Lara Martin (UNH).

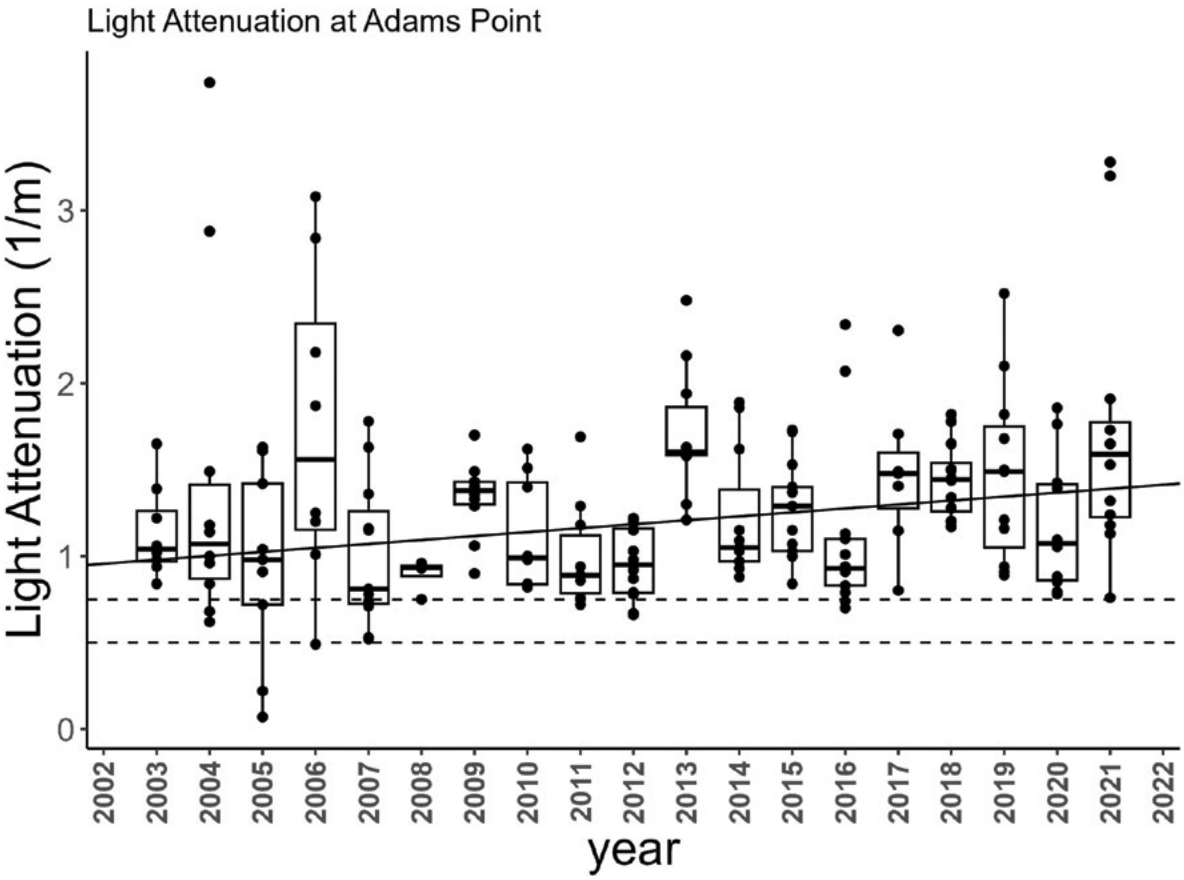


Figure 14.2: Light attenuation (Kd) data at Adams Point, 2003 through 2021. Data are log-transformed and include a mix of high and low tide samples, with all samples taken between April 1 and August 30 of the given year. Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass the remaining data. "Outliers" are shown as individual points. Lines at 0.5/m and 0.75/m refer to suggested range of light attenuation values for the maintenance of existing eelgrass beds. The trend line indicates a statistically significant increasing relationship over time.

Data source: Jackson Estuarine Lab, UNH

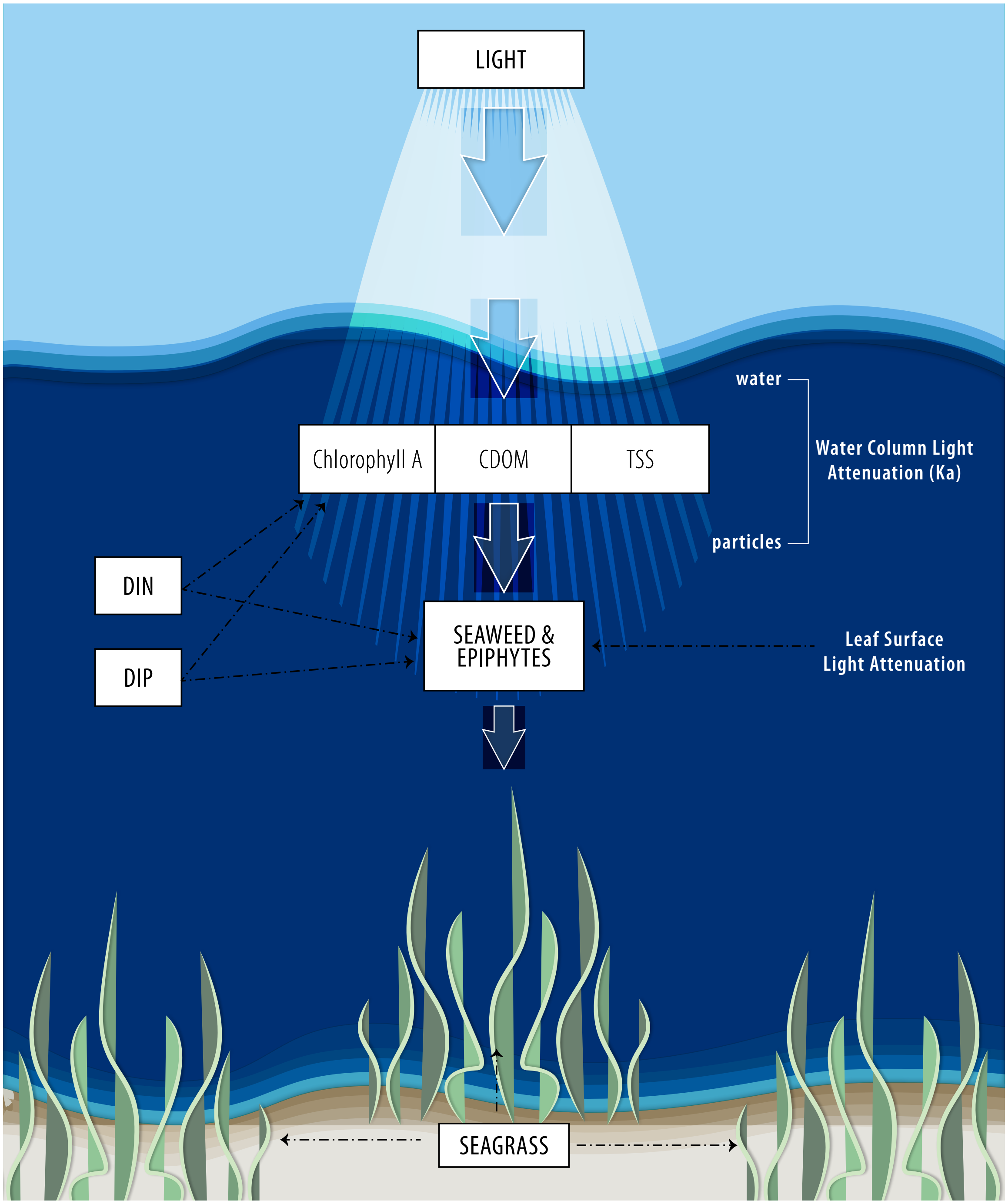


Figure 14.3: This image, adapted from the Long Island Sound Study, "Habitat Restoration Initiative," illustrates the interactive effects of nutrients and living resources on light penetration including Dissolved Inorganic Nitrogen (DIN) and Dissolved Inorganic Phosphorus (DIP), Colored Dissolved Organic Matter (CDOM), and Total Suspended Solids (TSS). Grazers include fishes and invertebrates that feed on the algae that can grow on eelgrass leaves.
Data source: Long Island Sound Study

Bacteria

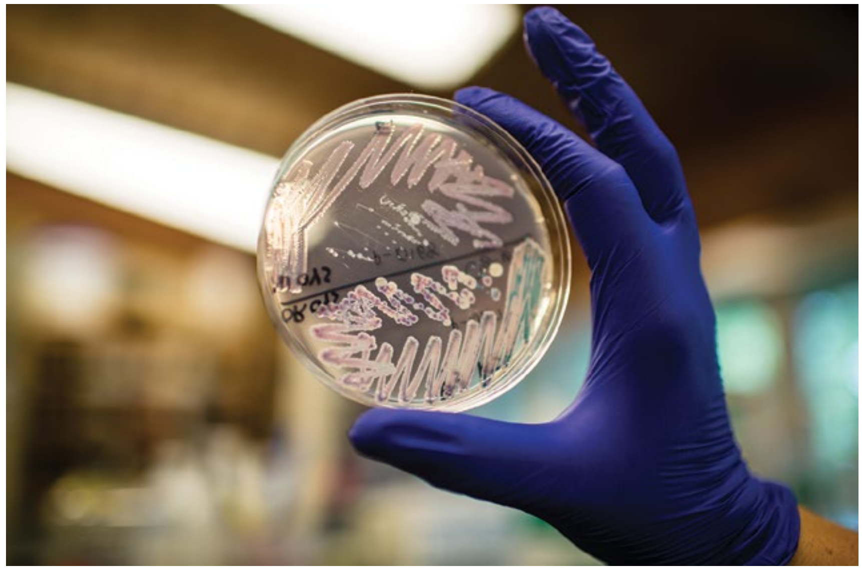
Photo by John Carroll

How have concentrations of bacterial indicators of fecal contamination changed over time in the Great Bay Estuary?

Tracking data from bacterial indicators suggest that ongoing management actions within the watershed have reduced levels of fecal contamination. Over the long-term (1988 to present), bacterial indicator levels have decreased estuary-wide; however, there have been no significant trends at the routinely monitored sites over the past six years. Monitoring for bacteria in the Hampton-Seabrook Estuary is currently being developed and will be included in future reports.

Goal

No increasing trends for fecal coliforms, enterococci or *Escherichia coli* bacteria.



Why We Track This Indicator

Activities such as shellfish harvesting and swimming depend on safe water quality, which is tracked by measuring concentrations of bacterial indicators of fecal contamination. These water quality indicators are affected by point and non-point pollution, human (sewage) and non-human (animal) sources of pollution, environmental conditions, and climate change. Tracking these indicator organisms allows for evaluation of water quality relative to potential risks for human illness.

Explanation

Long-term data for tracking baseline (dry weather) trends in fecal indicator bacteria are only available for two currently monitored sites, Adams Point and the Lamprey River (Figure 15.1). At both sites, the long-term trends for enterococci, fecal coliforms, and *E. coli* have decreased since the last report, issued in 2018. This can be attributed, in part, to improved stormwater infrastructure and wastewater treatment at all facilities in the watershed. There was a significantly decreasing trend in the annual average concentration data

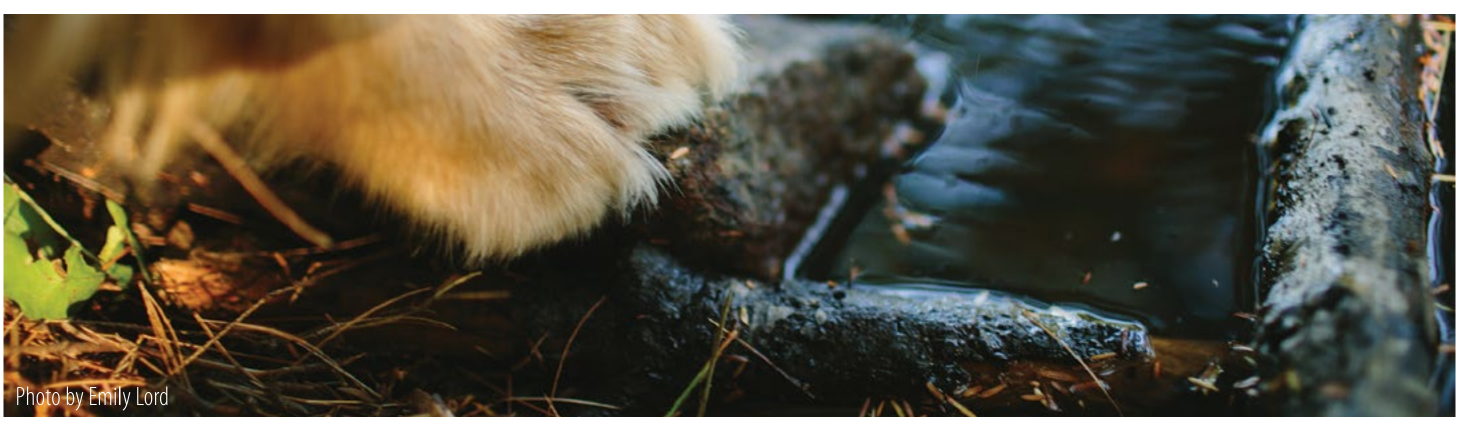


Photo by Emily Lord

(1988 – 2021) of fecal coliforms at Adams Point (Figure 15.2). Enterococci concentrations in the Lamprey River have significantly decreased from 1990 – 2021 (Figure 15.3).

The monitoring protocol is set up to assess baseline conditions and so it avoids wet weather, known to cause elevated contamination levels in the Great Bay Estuary.[44] However, since our region is forecast to receive more extreme precipitation events, these data do not reflect typical conditions, but rather, dry conditions.

State standard concentrations are included for each graph in Figures 15.2 and 15.3 as a reference, though the analysis procedures used for these data are slightly different than those required for assessing water quality classifications. Recent (2016 – 2021) levels of fecal coliforms at Adams Point (less than 5 colony forming units/100 mL) and enterococci levels in the Lamprey River (less than or equal to 24 colony forming units/100 mL) have, on average, remained below these reference concentrations, indicating acceptable quality. Generally, fecal indicator bacteria are present at elevated levels in estuarine tributaries that include urban centers at the head-of-tide, where there are more non-point sources, making the origin of pollution difficult to pinpoint. Head-of-tide urban centers may also have wastewater treatment facility discharges and significant impervious surfaces that cause runoff and increased stormwater-related contamination.

Excessive fecal indicator bacteria levels can be managed in various ways, informed by additional laboratory tests — microbial source tracking — that can identify the sources of the contaminating bacteria (e.g., humans, dogs, wildlife). This tracking tool can help managers identify a specific source so that the problem can be effectively addressed (e.g., replacement of a failed septic tank, education to manage pet waste). An ongoing study in the Lamprey River is using this tool to inform how best to ensure that river water quality is safe for recreational uses.[45]

Other bacteria of public health concern include *Vibro* and some other naturally occurring bacterial species that are not a result of fecal pollution. The dramatic increasing trend in illnesses over the past 15 years, including gastroenteritis and wound infections, caused by *Vibro* species in the Northeast[46] is a regionally significant concern as coastal waters continue to warm.[47] *Vibrio parahaemolyticus* populations are increasing in the Northeast and in the Great Bay Estuary;[48] however, there have been only rare illnesses to date from exposure to New Hampshire coastal waters and shellfish.

Acknowledgments and Credit

Stephen Jones (NH Sea Grant/UNH).

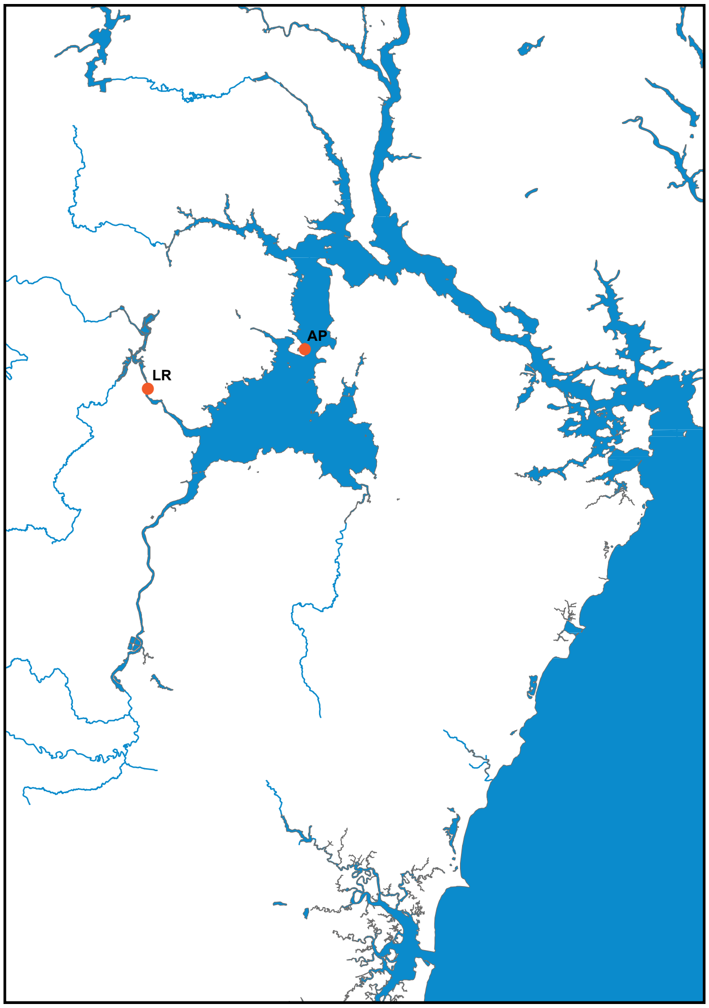


Figure 15.1: Monitoring stations for bacteria at Adams Point (AP) and Lamprey River (LR)
Data source: Jackson Estuarine Lab, UNH

Extended Report

Ongoing monitoring for Vibrio species has resulted in relatively long-term (2007 to present) databases for levels of *V. parahaemolyticus*, *V. vulnificus* and *V. cholerae* in oysters, water, plankton and sediments of the Great Bay Estuary. In addition, ongoing studies show what types of fecal-borne bacteria sources are present in the Lamprey River and in other coastal watersheds. See the Extended Report for summaries of both types of studies.

Bacteria

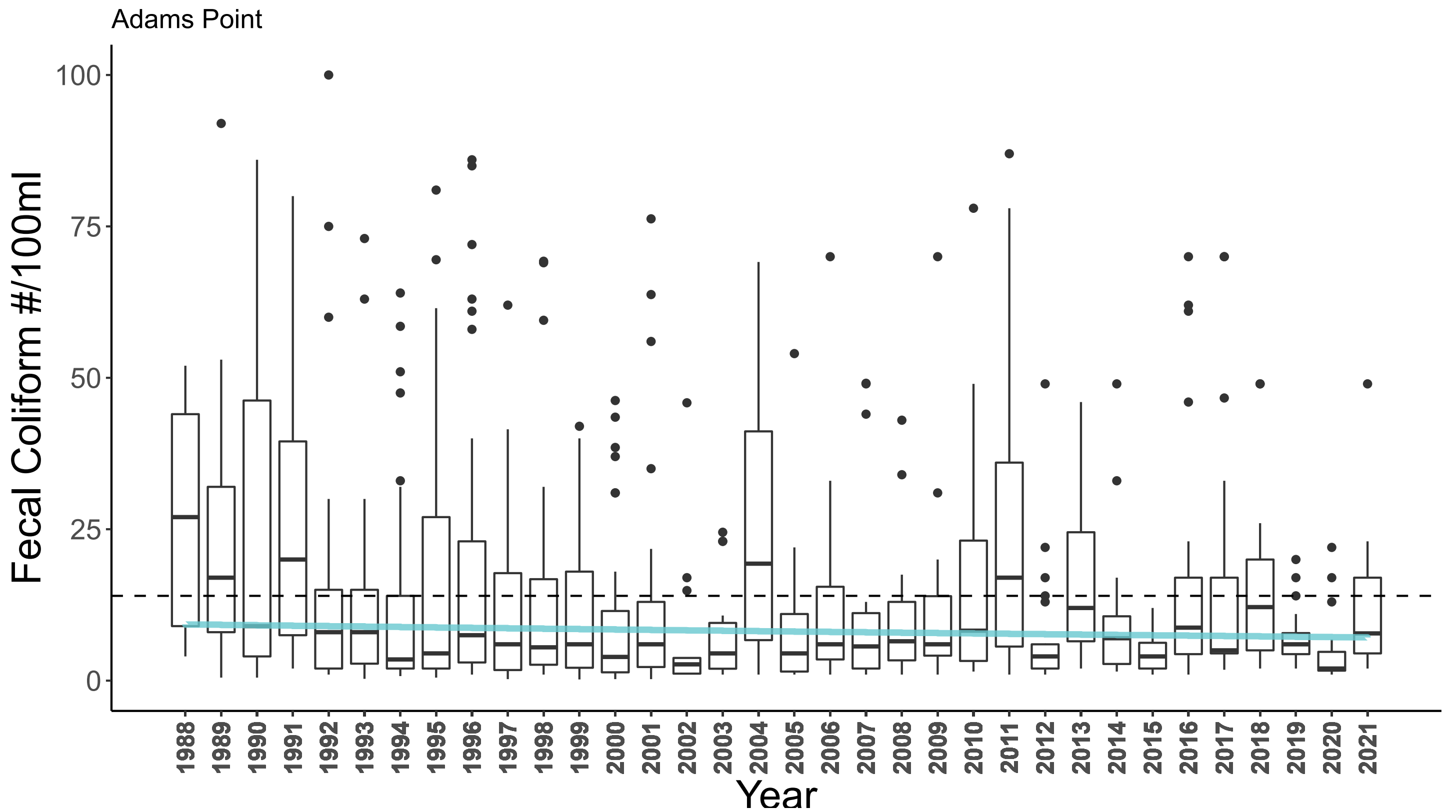
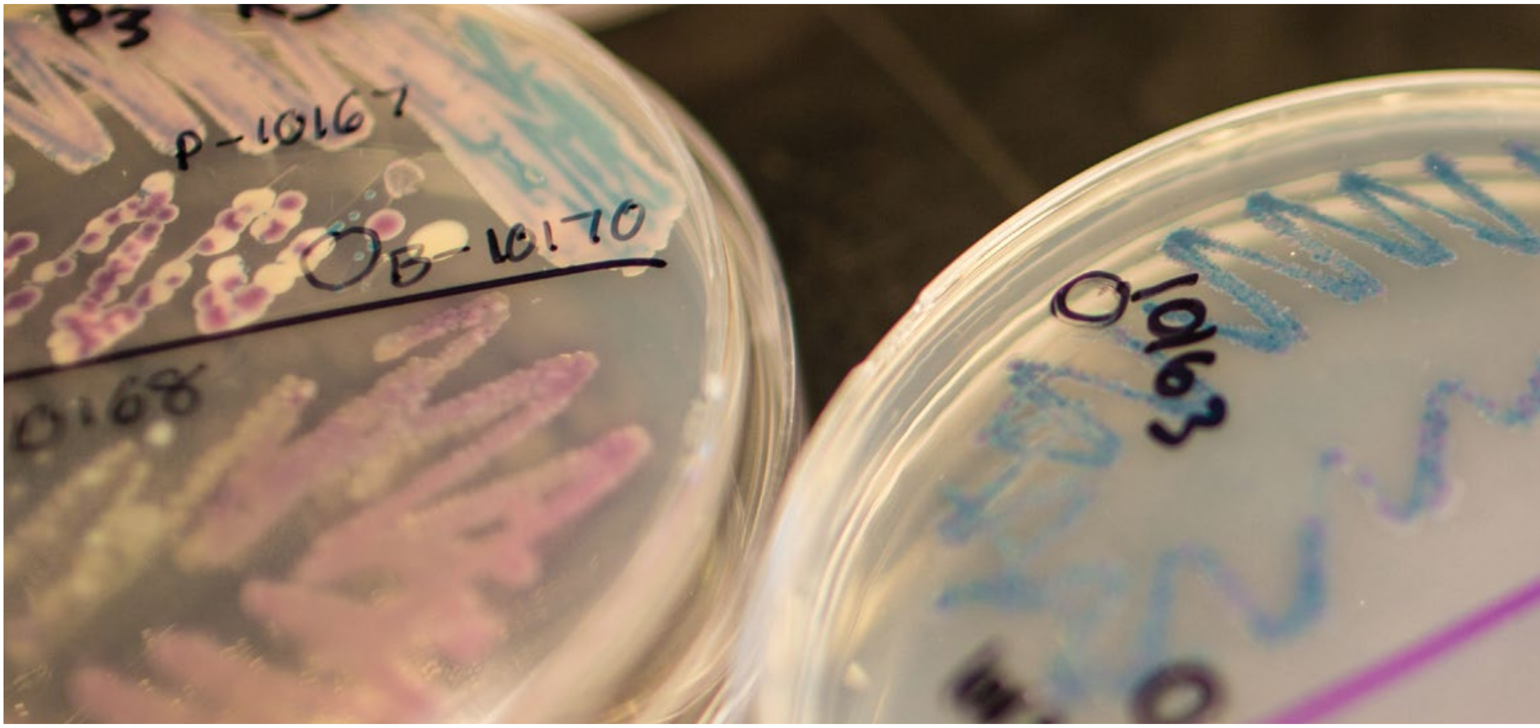


Figure 15.2: Long-term trends for monthly fecal coliform concentrations at Adams Point grouped by year. The dashed line shows the New Hampshire State standard for fecal coliforms (14/100 mL). Boxes encompass the middle 50% of the data points. The horizontal line in each box is the median and the vertical whiskers encompass the remaining data. "Outliers" are shown as individual points. The solid blue line indicates a statistically significant trend. The fecal coliform indicator, the standard for shellfish regulation, is used at this location due to the prevalence of shellfish harvesting in the area. Typically, nine samples are taken per year, from April through December.

Data source: Jackson Estuarine Laboratory, UNH



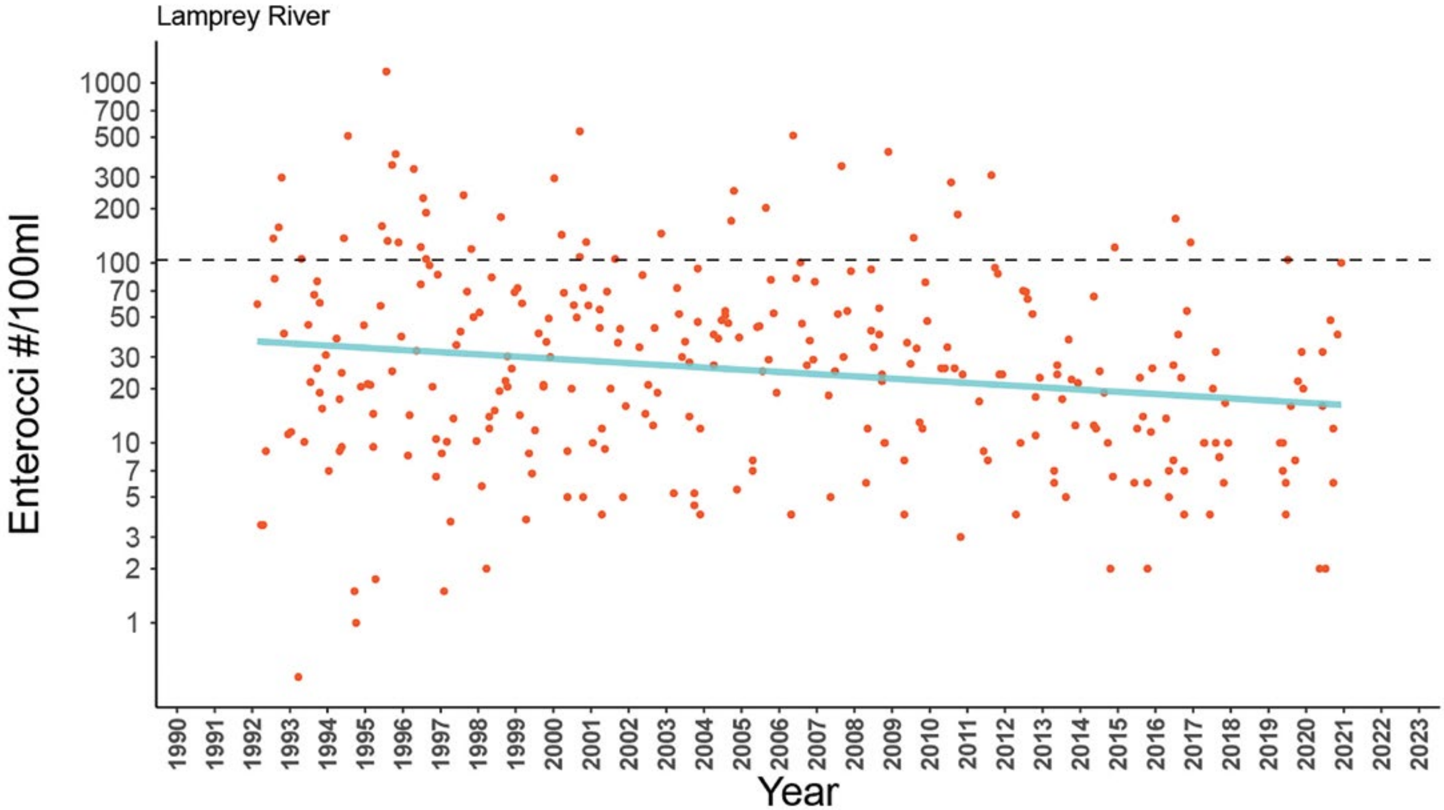


Figure 15.3: Long-term trends for monthly enterococci concentrations at the Lamprey River plotted on a log-scale, grouped by year. The dashed line shows the New Hampshire State standard for enterococci (104/100 mL). The blue line indicates a statistically significant trend. The enterococci indicator, the standard for marine recreation, is used at this location due to the prevalence of boaters, stand-up paddlers, etc. on the Lamprey River. Typically, nine samples are taken per year, from April through December.

Data source: Jackson Estuarine Laboratory, UNH

Shellfish Harvest Opportunities

What percentage of our estuaries are open for shellfish harvesting and how has this changed over time?

The percentage of possible acre-days when shellfish beds are open has been on a statistically significant, gradual upward trend from 2006 to 2021. Factors driving the upward trend in harvest opportunities in our estuaries include wastewater treatment facility upgrades, the opening of new harvest areas in Little Bay and the Oyster River due to expanded testing programs, better understanding of pollution dispersion by tidal currents, and improved management of risk related to potential boat sewage contamination. Increased harvest opportunities coincide with decreasing bacteria concentrations (see "Bacteria"), underscoring the effectiveness of management efforts.

Goal

Improve water quality and identify and mitigate pollution sources so that additional estuarine areas meet water quality standards for bacteria and for shellfish harvesting.

Why We Track This Indicator

Shellfish beds are closed — either temporarily or indefinitely — to commercial and recreational harvesting due to high amounts of bacteria or other pollutants in the water, as often occurs after heavy rainfall or accidental discharge of improperly treated sewage. Closures also occur for precautionary reasons related to wastewater treatment facilities. Therefore, the amount of time that shellfish beds are open for harvest can be used as an indicator of water quality as it relates to human health.

Explanation

Figure 16.1 indicates open and closed areas of the Great Bay and Hampton-Seabrook Estuaries for shellfish harvesting in 2021. The percentage of possible acre-days (i.e., the number of open acres multiplied by the number of days those acres were open for harvest) in 2021 was 82% for the Great Bay Estuary and 55% for the Hampton-Seabrook Estuary (Figure 16.2).

Shellfish areas often are closed as a safety measure, especially after heavy rainfall, because significant rain events often lead to increased pollution. In addition, operational problems, either at wastewater treatment facilities or in the sewer infrastructure, can lead to closures because of improper discharge of treated sewage. To re-open a shellfish area in these instances, New Hampshire Shellfish Program staff analyze water samples to ensure the number of fecal coliform bacteria meet established safety standards (see "Bacteria"). Samples of shellfish tissue also are analyzed for certain types of pollution events.

Less often, areas are closed due to the occurrence of harmful algae blooms, commonly known as "red tide." Since 2000, red tides have been responsible for multiple day closures in nine different years. In some years, red tides may have occurred at times when the beds were already closed for conservation purposes; in those cases, they are not recorded as contributing to more closures.

Much of the Great Bay Estuary and Hampton-Seabrook Estuary data reflects the interannual variability of weather, with wet years leading to more numerous temporary harvest closures. The large number of closures in 2016 in the Hampton-Seabrook Estuary was the result of a significant discharge of raw sewage from a broken 14-inch sewer pipe under a salt marsh in the Town of Hampton. The long-term trend of gradual improvements since 2000 might reflect improved data collection and pollution source management by New Hampshire Department of Environmental Services, U.S. Environmental Protection Agency, and seacoast municipalities. Such efforts include programs to identify and eliminate illicit discharges, upgrade or build new wastewater treatment facilities, reduce wet-weather "combined sewer overflows" by expanding and upgrading sewer collection lines and pump-station capacity, and develop a more detailed understanding of individual wastewater treatment facility operations, effluent quality, and distribution patterns of pollutants in the receiving waters.

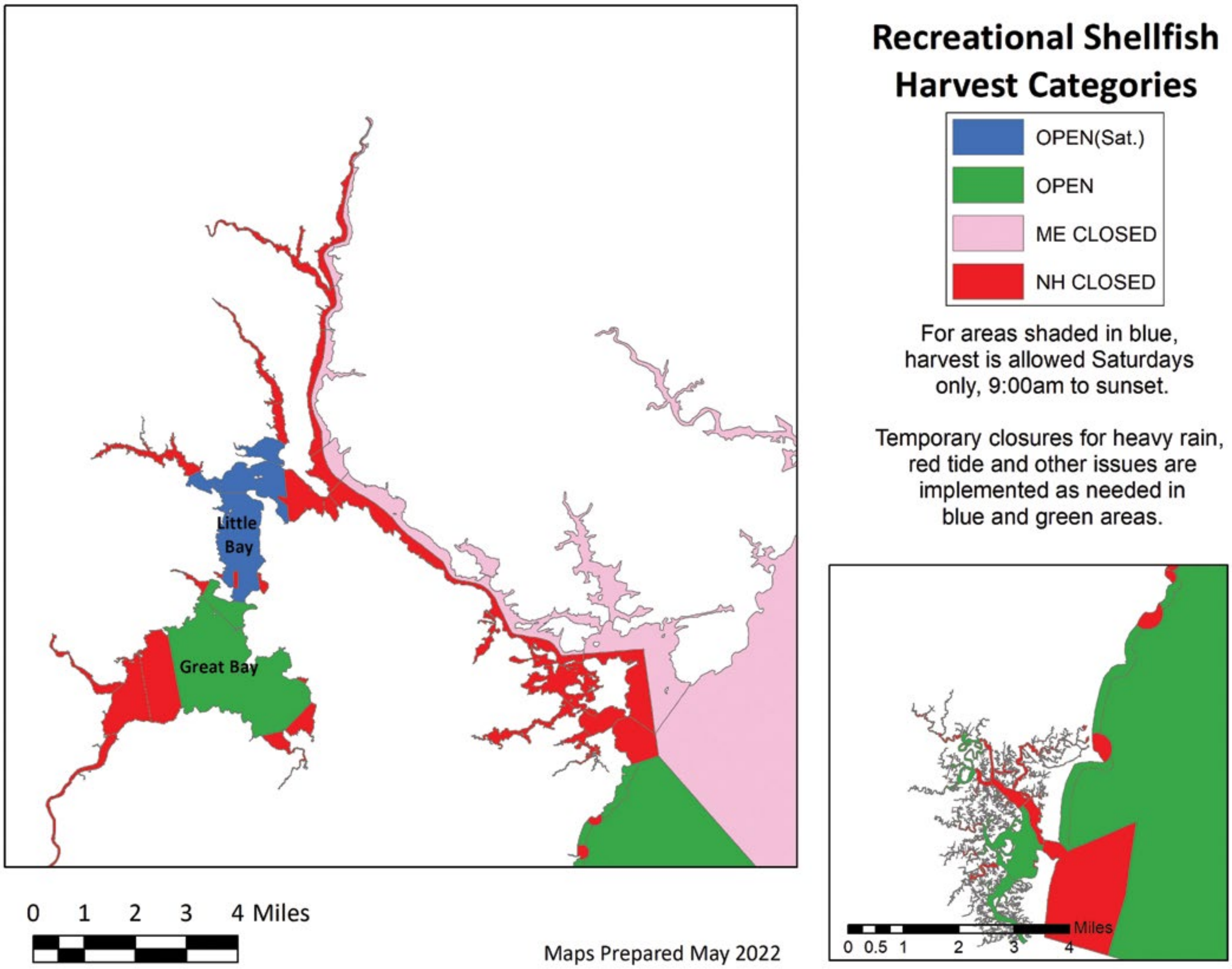


Figure 16.1: Map showing recreational shellfish harvest categories for both the Great Bay and Hampton-Seabrook Estuaries.
Data source: NH Department of Environmental Services, Shellfish Program

Photo by Jerry Monkman

Shellfish Harvest Opportunities

The amount of area designated as conditionally approved — open but subject to temporary closures due to water quality issues — has remained relatively steady at around 5,300 acres in recent years (Figure 16.3). The drop in acres during 2014 – 2017 was based on results of the December 2012 Portsmouth Wastewater Treatment Facility Dye Study, which examined how the former treatment facility affected water quality in the estuary.[49] The earlier version of the facility employed a relatively simple sewage treatment process. At a total cost of over $90 million, the new facility uses more modern sewage treatment technologies and treatment, resulting in more thoroughly treated effluent. Subsequent studies of effluent quality and seawater/shellfish microbiological indicators have allowed for some of the previous harvesting restrictions to be relaxed. In addition to the Portsmouth improvements, Exeter upgraded its wastewater treatment facility and significantly upgraded its sewage collection system — completed in 2020 at a total cost of $53.5 million. As post-upgrade monitoring of water quality continues, shellfishing areas might be opened more frequently.

For the Hampton-Seabrook area, most of the closed areas (red areas in Figure 16.1) are safety closures due to the proximity to the outfalls for the Hampton and Seabrook Wastewater Treatment Facilities. The Town of Hampton facility relates to the red area within Hampton Harbor and the Town of Seabrook facility relates to the area in the Atlantic Ocean, offshore of Seabrook Beach. The Seabrook facility releases its effluent 1,500 feet offshore via an underground pipe. Both facilities are modern systems that are functioning effectively with regard to effluent disinfection. However, the New Hampshire Shellfish Program maintains safety closures due to the contingency of a temporary system breakdown.

The two smaller red areas in Hampton and North Hampton are related to unexplained but occasional occurrences of very high fecal coliform bacteria, possibly caused by owners not picking up pet waste.

Maine waters, including areas of the Piscataqua River and Spruce Creek, are closed for harvest, partly due to concerns about the Portsmouth facility. The exception to this is Spinney Creek Shellfish in Eliot, Maine, which has a specialized facility for removing potential pathogens from shellfish. As ongoing studies document the positive water quality effects of the Portsmouth facility upgrade, the New Hampshire Department of Environmental Services and Maine Department of Marine Resources will reassess the public health risks and modify harvesting classifications in the areas under their jurisdictions.

Acknowledgments and Credit

Chris Nash (NH Department of Environmental Services, Shellfish Program)

Oysters in the Great Bay open up to filter phytoplankton from the water. Photo by Kalle Matso.

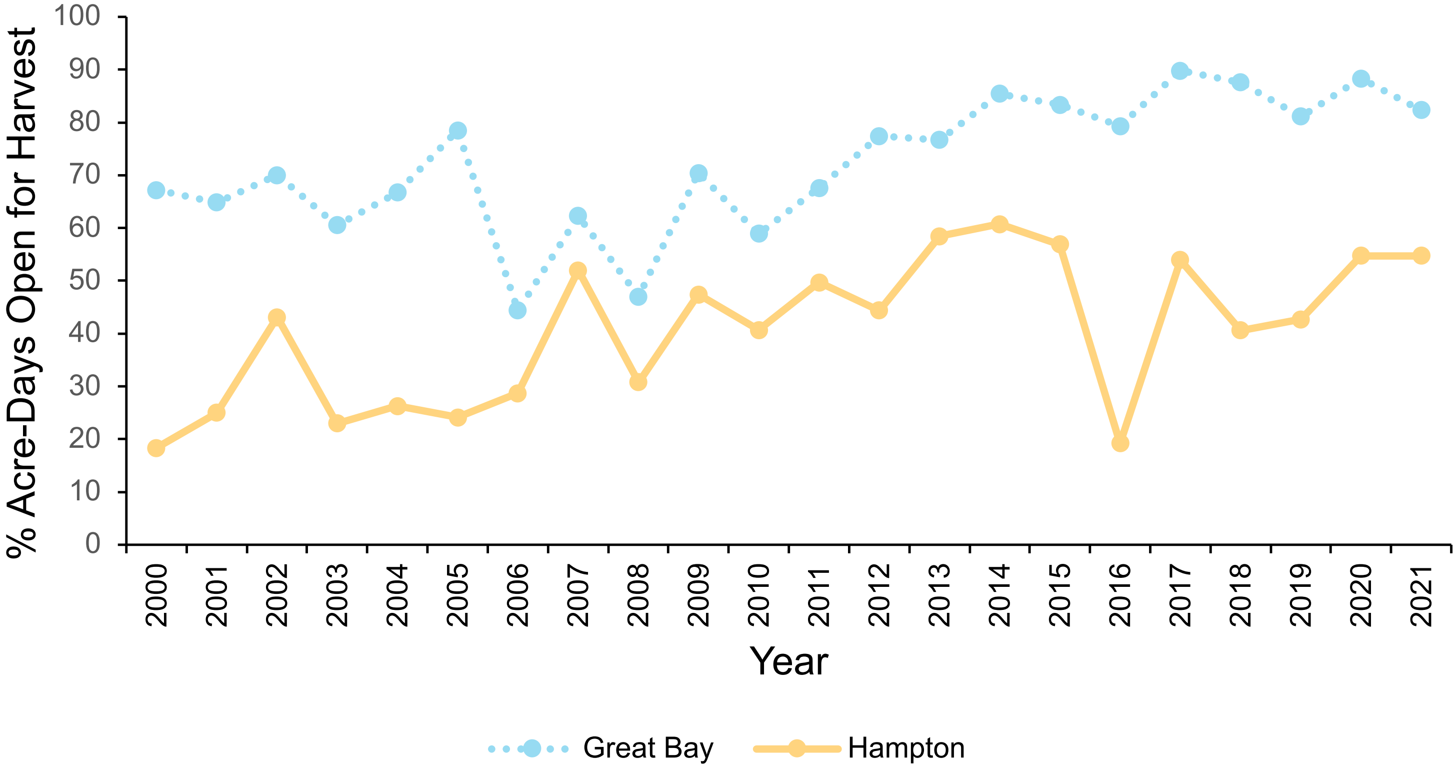


Figure 16.2: Shellfish harvest opportunities for Great Bay and Hampton-Seabrook Estuaries. Graph displays percentage maximum possible "acre-days," which is the number of open acres multiplied by the number of days those acres were open for harvest.
Data source: NH Department of Environmental Services, Shellfish Program

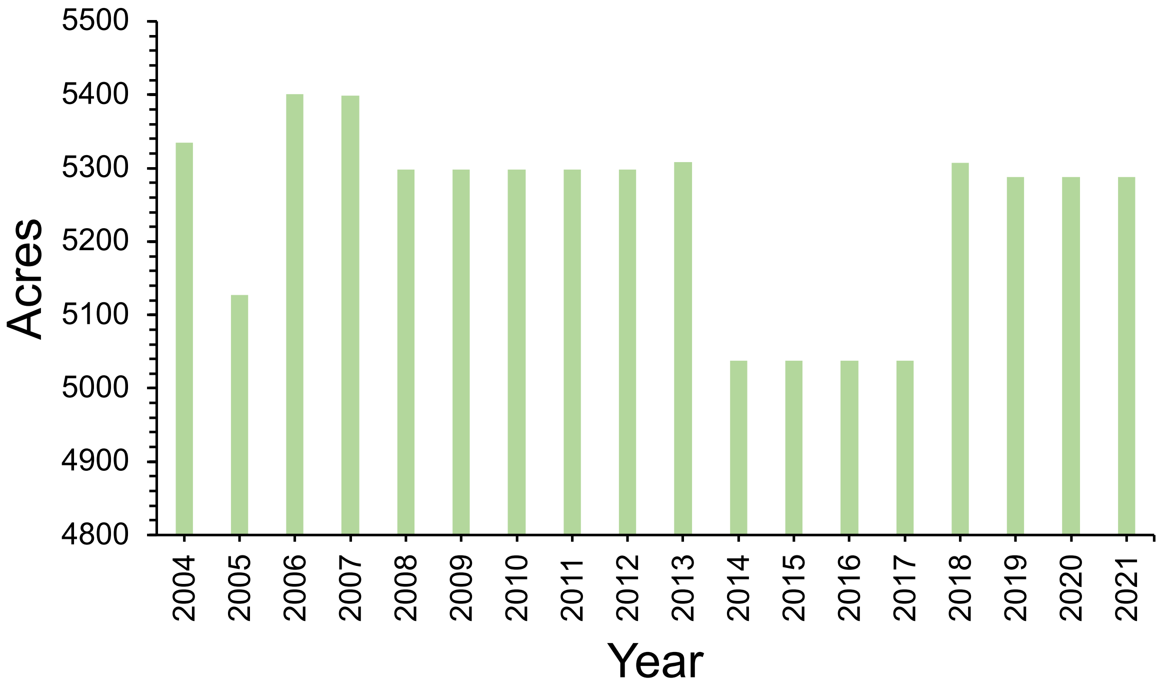


Figure 16.3: Trends in the acres of estuarine waters conditionally approved for shellfish harvest for years 2004 – 2021.
Data source: NH Department of Environmental Services, Shellfish Program

Oysters, Oyster Restoration, and Oyster Aquaculture

OYSTERS

How many adult oysters are present on natural reefs in the Great Bay Estuary and how has the number changed over time?

The number of adult native oysters (*Crassostrea virginica*, the eastern or American oyster) decreased from >25 million in 1993 to ~1.2 million in 2000, a 95% loss (Figure 17.1). Annual sampling since 2000 had indicated <5 million were present each year until 2020 when oysters rebounded to 7.4 million on natural reefs. Additionally, oyster aquaculture has dramatically increased in the past several years and in 2021 there were nearly as many live oysters on aquaculture facilities as adult oysters on the natural reefs (see below).

Oysters Goal

Increase the abundance of adult oysters (that are greater than 80 mm in shell height) at the six regularly monitored oyster reefs in the Great Bay Estuary to 10 million by 2030. The previous goal was to reach 10 million by 2020; this was not met.

Why We Track This Indicator

Oysters support a recreational fishery and a rapidly growing aquaculture (farming) industry, and provide important ecosystem services. As filter feeders, they reduce phytoplankton biomass and other suspended particles, thereby increasing light penetration to benthic plants such as eelgrass. They also provide habitat for resident and migratory fishes and many other species. Since the early 1990s, as oyster populations in the Great Bay Estuary declined, the functions and services they provided also declined. However, substantial efforts are underway to restore oyster populations and the multiple roles they play in the estuary.

Explanation

Wild oysters mainly occur on subtidal reefs in the Great Bay Estuary but have been found in intertidal waters in recent years. The six major subtidal reefs are monitored annually providing abundant data for long-term assessments. Underwater video surveys in 2020 by UNH scientists indicated that the total area covered by live reefs was ~80 acres,[51] compared to historical (1970s) estimates of "live oyster bottom" coverage ranging from 900 to 1,300 acres.[52]

A major limitation on oyster health for the past 20 years has been disease caused by two microscopic parasitic organisms: Dermo (*Perkinsus marinus*) and MSX (*Haplosporidium nelsoni*). Both parasites are present in both wild and aquacultured oysters in the Great Bay Estuary.[53] Whereas MSX is in decline in the Estuary, Dermo, a warmer water parasite, has become more prevalent in the last decade, and is expected to be favored by warmer winters as climate change continues.[54,55] In recent years, oysters have rarely grown past 115 mm in shell height. This suggests average longevity is now only 4 or 5 years rather than 10+ years as in the early 1990s, when oysters greater than 200 mm were common.

Oyster populations in the Great Bay Estuary also face challenges due to a lack of suitable substrate on which oyster larvae can settle. Oysters themselves provide hard substrate as they grow and increase in shell size, but less and less oyster habitat diminishes the available hard substrate for new recruits. This has been offset to some extent by deploying oyster and other mollusk shell — from restaurants and other sources — in key locations in the Great Bay Estuary (see "Oyster Restoration").

Sedimentation is another stressor related to the issue of available substrate for new oysters to set. Sediments enter the estuary from run-off, eroding salt marshes and stream banks, and can be resuspended from the bottom sediments during storm events. With eelgrass and oyster habitats decreased from historic levels, sediments may be more easily resuspended following storms and high-flow periods. Oyster restoration monitoring has indicated that young reefs can be rapidly smothered by sediment in many areas.

Recreational harvesting of oysters also may be stressing the population. Although studies from other areas have shown that restricted harvesting can

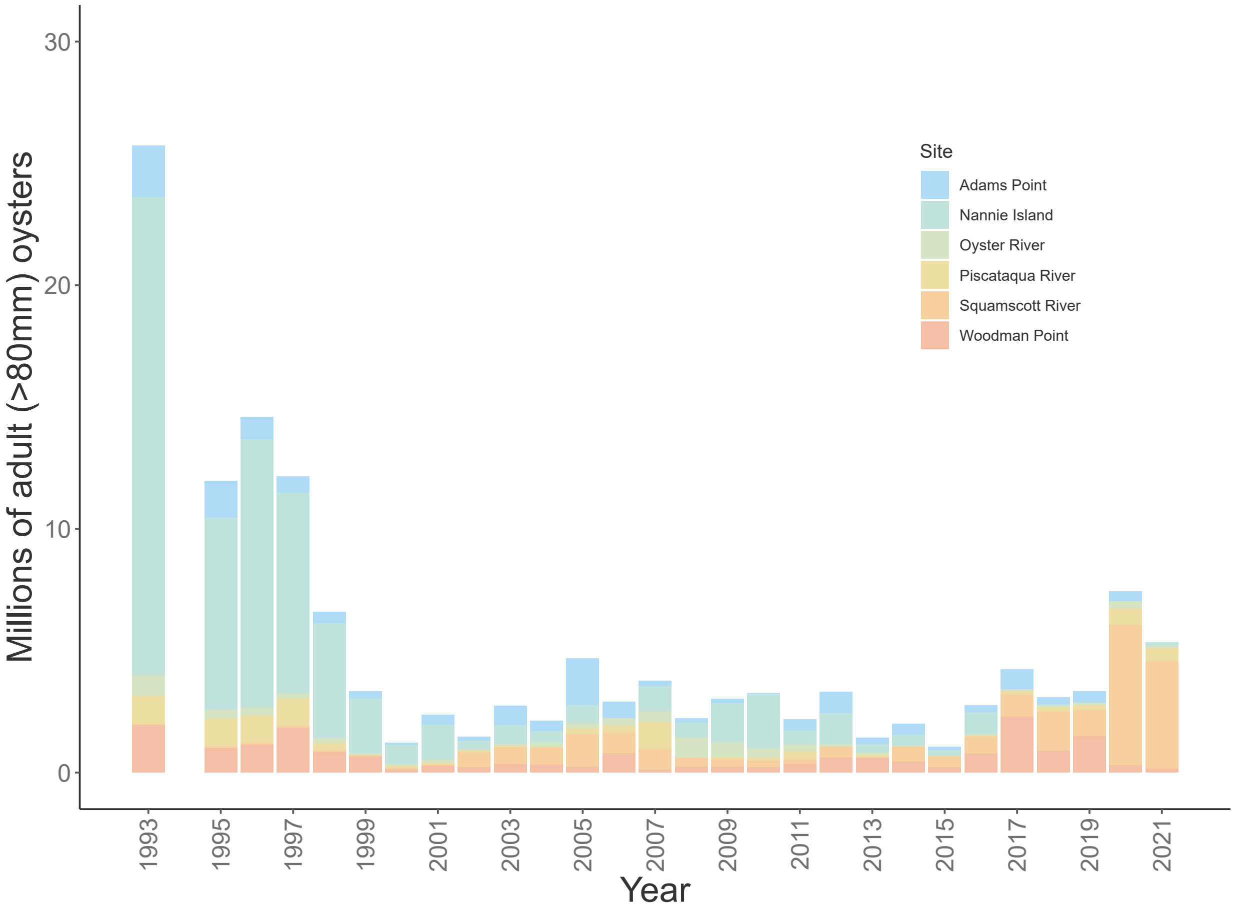
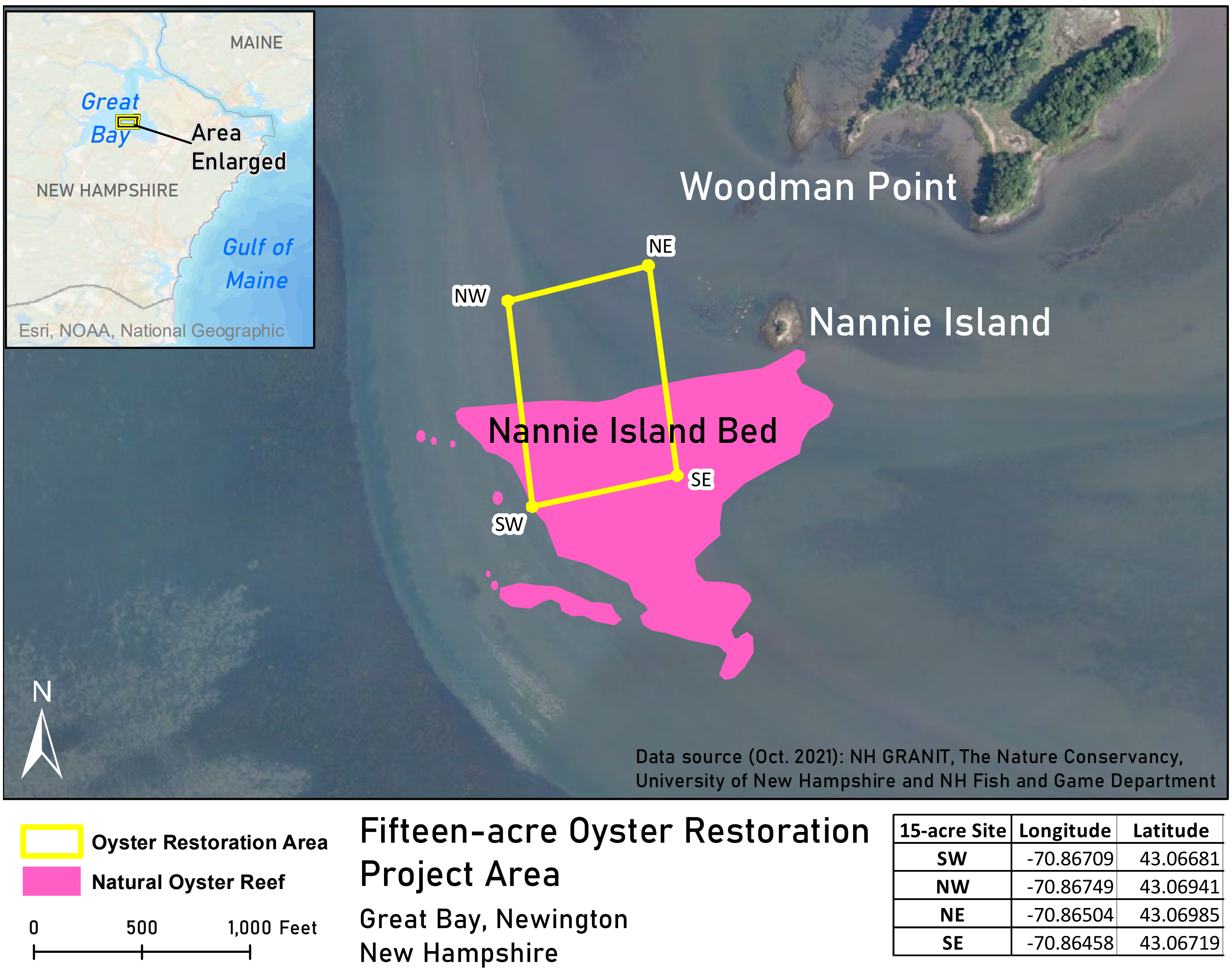


Figure. 17.1: Number of adult oysters (>80 mm shell height) at the six regularly monitored natural reefs from 1993 – 2021.
Data source: NH Fish and Game

Photo by Jerry Monkman

provide benefits through the resuspension and removal of sediment on reefs that are regularly harvested, there are no data that quantify the relationship between oyster harvest and sediment removal. In reaction to the Nannie Island oyster reef population decline (shown in Figure 17.1), the New Hampshire Fish and Game Department implemented a five-year harvest closure (2022 – 2026) of a 15-acre area covering a substantial portion of the Nannie Island oyster reef to encourage oyster growth and provide an opportunity for new restoration projects (Figure 17.2; see more discussion in "Oyster Restoration").

In the past 10 or so years, eastern oysters have been documented in the intertidal zone in New Hampshire and Maine, and anecdotal evidence indicates this is a recent phenomenon likely related to climate change.[56] Rock outcrops and other hard substrata in the intertidal zone of the Great Bay Estuary are typically covered by two fucoid brown seaweeds: *Ascophyllum nodosum* and *Fucus* spp., collectively called rockweed. Oysters in the intertidal zone of the Great Bay Estuary only occur under the rockweed canopy. These intertidal oysters have not been quantified, but available data indicate the total intertidal population could be as much as the subtidal reef population.



Fifteen-acre Oyster Restoration Project Area

Great Bay, Newington New Hampshire

15-acre Site	Longitude	Latitude
SW	-70.86709	43.06681
NW	-70.86749	43.06941
NE	-70.86504	43.06985
SE	-70.86458	43.06719

Figure 17.2: 15-acre area covering a portion of the degraded Nannie Island natural reef where shellfish harvest will be prohibited through October 31, 2026.
Data source: NH GRANIT, The Nature Conservancy, University of New Hampshire, and NH Fish and Game Department

OYSTER RESTORATION

How many acres of oyster reef restoration projects have been initiated since 2000?

Although there are insufficient data to fully evaluate the PREP goal, oyster reef restoration projects totaling about 75 acres have been initiated since 2000. Sedimentation and other mortality factors hampered success at most sites, but methods have been developed recently that show good promise. Moreover, the process has become highly collaborative in recent years. Planned projects for 2023 and future years involve collaborations between New Hampshire Fish and Game Department, The Nature Conservancy, the USDA's Natural Resources Conservation Service, and the University of New Hampshire. Restoration projects are focused on the Great Bay Estuary since there is no historical record of oysters in the Hampton-Seabrook Estuary.

Oyster Restoration Goal

Restore 20 acres of oyster reef habitat by 2030. The previous goal was to be met by 2020. Although more than 20 acres of restoration were initiated, it is not clear that 20 acres of sustained habitat survived.

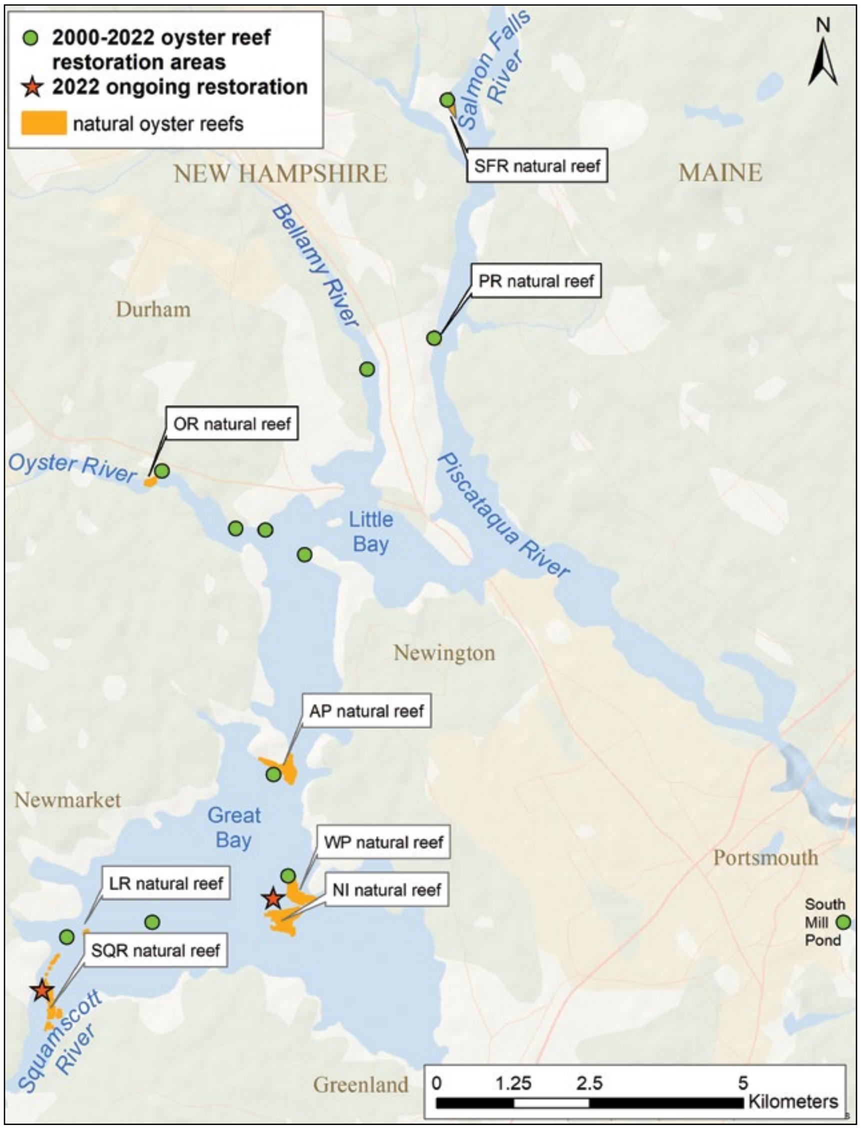


Figure 17.3: Locations of major oyster restoration projects (green dots) since 2000 and remaining natural oyster reefs (orange polygons). Note that there were multiple projects in five of the areas in the Squamscott River (SQR) and Lamprey River (LR), Adams Point (AP), and near Nannie Island (NI). Also shown are Woodman Point (WP), Oyster River (OR), and Salmon Falls River (SFR).

Data source: University of New Hampshire

Why We Track This Indicator

This indicator quantifies the results of activities aimed at restoring reefs, and it provides a metric of success at achieving two oyster-related goals (10 million oysters and 20 acres of restored reef). Historically, oyster management was mainly concerned with oysters as a recreational fishery. In recent years, the focus has been on restoring reefs that oysters naturally form rather than just numbers of oysters; this is because the reefs provide habitat for other species as well.

Oysters, Oyster Restoration, and Oyster Aquaculture

Explanation

There is no widely accepted method for determining when an oyster reef has been "restored." Current research includes efforts to determine metrics that will allow assessment of this goal.

Between 2000 and 2021, 75 acres of oyster reef restoration projects were initiated (Figure 17.3), but the success of most projects was not quantified beyond one or two years. Recent assessments of restoration sites up to 13 years post-construction indicated most sites had a reduction in base shell cover compared to initial restored reef base, and constructed reefs located near native reefs had the highest live oyster densities.[57] However, there are insufficient data on live oyster density, recruitment to the area (new oyster larvae settling), and reef areal coverage at most sites to allow a current quantitative assessment of "restored" reefs.

Disease, lack of hard substrate, and sedimentation explain the major constraints on reef restoration. Long-term development of the constructed reef is largely dependent on two factors: the shell base remaining above the soft sediment surface so that oyster larvae can settle, and an adequate level of natural recruitment from wild oyster larvae. Unfortunately, the recent long-term assessments discussed above found substantial losses (burial and/or subsidence) of the shell base at many sites and lack of natural recruitment at most. These findings resulted in two new design criteria for most projects since ~2018.

First, reef restoration sites are positioned as close as possible to a natural reef, since recent research showed that recruitment decreased significantly as distance from a native natural reef increased.[58] Second, reef bases are designed to consist of multiple

Oyster Aquaculture

Although oyster aquaculture is usually thought of in terms of economic metrics and currently there are no management goals, this activity is directly related to oyster abundance and oyster restoration goals.

Shellfish aquaculture (primarily eastern oysters) in New Hampshire has grown from six acres in 2010 (two businesses) to 80.4 acres in 2021 (16 businesses; Figure 17.4). The average annual oyster harvest was 581,749 for the past five years (2017 to 2021), a dramatic increase from 2012 – 2016 when the average harvest was 129,045 oysters. Nearly a million oysters were harvested from New Hampshire's oyster farms in 2021, including ~30% sold for use on oyster restoration sites (see "Oyster Restoration"). Oyster aquaculture in New Hampshire is an economically and ecologically important industry that is rapidly growing.

In 2021, there were ~7 million oysters (20 – 100 mm shell height) on 74 acres of licensed aquaculture sites in Little Bay — roughly the same number as the ~7.4 million adult (greater than 80 mm) oysters on natural reefs in 2020. Although not directly comparable, the numbers clearly indicate that the total population of farmed oysters (all size classes) is similar to that for adult oysters on natural reefs in recent years. Additionally, if farmed oysters and wild oysters were counted in the context of the aforementioned goal of 10 million adult oysters in the Great Bay Estuary by 2030, then that goal may have been met in 2021.

Four key facts explain how farmed oysters are important to PREP's goal of more abundant wild oysters. First, farmed oysters in New Hampshire are from "seed" (juvenile oysters) produced by brood stock maintained in hatcheries, mostly in Maine. In other words, they are not from wild New Hampshire or Maine oysters. The brood stock oysters in most cases have been selected for fast growth and disease tolerance. Recent data have indicated that farmed oysters >3 years old have less disease and they generally are larger in size than wild oysters of similar age. Second, although there are important differences, oysters on farms do provide water filtration. Third, oyster farms also provide habitat for a wide range of organisms. Recent research in the Great Bay Estuary found that farm gear supported invertebrate and macroalgal communities similar to adjacent eelgrass and oyster reef habitats.[59,60] Fourth, the larvae produced by oysters on farms can disperse away from the farm sites and may produce recruits for wild reefs.

mounds of mollusk shell projecting less than 0.5 m above the sediment surface and arranged randomly across as much of the restoration site as funds will allow (typically ~25% coverage).

Acknowledgments and Credit

Ray Grizzle (UNH), Krystin Ward (UNH), and Robert Atwood (NHFG).

Restoration by Design

Learn more about recommended approaches for restoring oysters in the Great Bay Estuary in the Restoration by Design report from the NH chapter of The Nature Conservancy, PREP, and the USDA Natural Resources Conservation Services, published in January 2021. Download the report at: scholars.unh.edu/PREP/449/

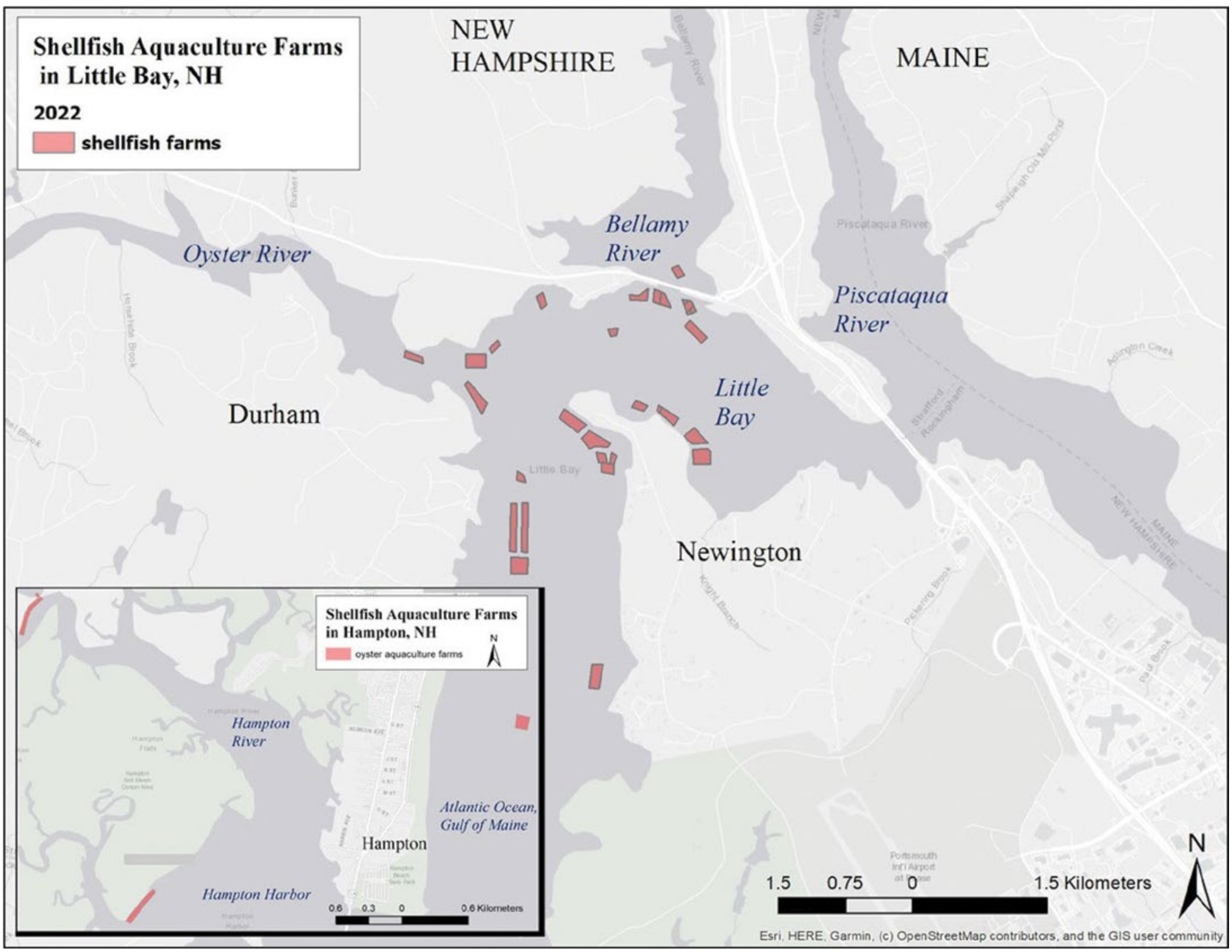


Figure 17.4: Locations and sizes (total areal coverage = 80.4 acres) of licensed shellfish (mostly oysters) farms in New Hampshire in 2022.
Data source: University of New Hampshire and NH Fish and Game Department

Softshell Clams

What is the current population of adult softshell clams in Hampton-Seabrook Harbor? How has the habitat changed over time?

In 2020, the estimated population of adult softshell clams in Hampton-Seabrook Harbor was 5.1 million. Before 1998, the population size was variable, with peaks usually of more than 15 million clams. However, since 1998, the population has remained below 10 million and, most often, below 5 million.

Goal

Increase the number of adult softshell clams in the Hampton-Seabrook Estuary to 5.5 million clams.

Photo by Jerry Monkman

Why We Track This Indicator

Clams consume phytoplankton and detritus to form an important link between food webs in the water column and the sediments. Clamming also provides recreational opportunities and food. Finally, softshell clam condition and abundance can offer insight into the environmental health of a system.

Explanation

In 2020, the estimated population of adult (>50 mm, or almost 2 inches, in shell length) softshell clams (*Mya arenaria*) in Hampton-Seabrook Harbor was 5.1 million, below the PREP goal of 5.5 million. Softshell clams are present in the Great Bay Estuary although recreational clamming is not as prevalent. Softshell clams are only monitored in the Hampton-Seabrook Estuary at this time. The standing stock of softshell clams at the Hampton-Seabrook Estuary clam flats (Figure 18.1) has fluctuated over the years (Figure 18.2). In some cases, the stock increases were most likely caused by the closure of the flats to harvesting. For example, the clam flats were closed to recreational harvesting from 1989 through 1993 due to a lack of sanitary surveys of the growing areas. The Common Island and Browns River flats were reopened intermittently beginning in 1994. The Confluence and Middle Ground flats were reopened in 1994 and 1998. All flats were and still are periodically closed due to coliform pollution following heavy rains and paralytic shellfish poisoning (red tide) outbreaks. Since the reopening of the flats in 1993 – 1997 and the resulting increase in harvesting, the standing stock of clams has generally declined. Since 2012, it has remained below the PREP goal of 5.5 million (Figure 18.2; Table 18.1).

Standing stock is estimated as the density (number per square meter) of adult clams multiplied by the acreage of the flats. As a result, standing stock is affected by changes in the density of clams as well as the acreage of the flats themselves. Clam flats are an extremely dynamic environment due to sediment erosion and accretion, both driven by storms and human activities such as dredging. PREP and partners are considering changing the metric from standing stock to density of softshell clams to avoid variability caused by changes in the acreage of the flats.

Softshell clams might also be limited by a type of contagious cancer (hemic neoplasia) that affects marine bivalves but is not dangerous to humans. The disease is transmitted directly among softshell clams through the transfer of cells called neoplastic hemocytes.[60,61,62] There are several factors that make softshell clams more susceptible to this disease, including pollution (mainly heavy metals and hydrocarbons) and warming water temperatures.[63] The percentage of softshell clams infected with neoplasia increased from 2002 through 2015 and has averaged between 60% and 79% since 2015 (Figure 18.3). A review of data collected from 2002 – 2018 indicates that the advanced forms of neoplasia are significantly increasing in the Hampton-Seabrook Estuary.[64]

Green crabs prey on softshell clams, especially newly settled individuals, reducing softshell clam population size; therefore, studies have noted a significant negative relationship between green crab abundance and density of newly settled

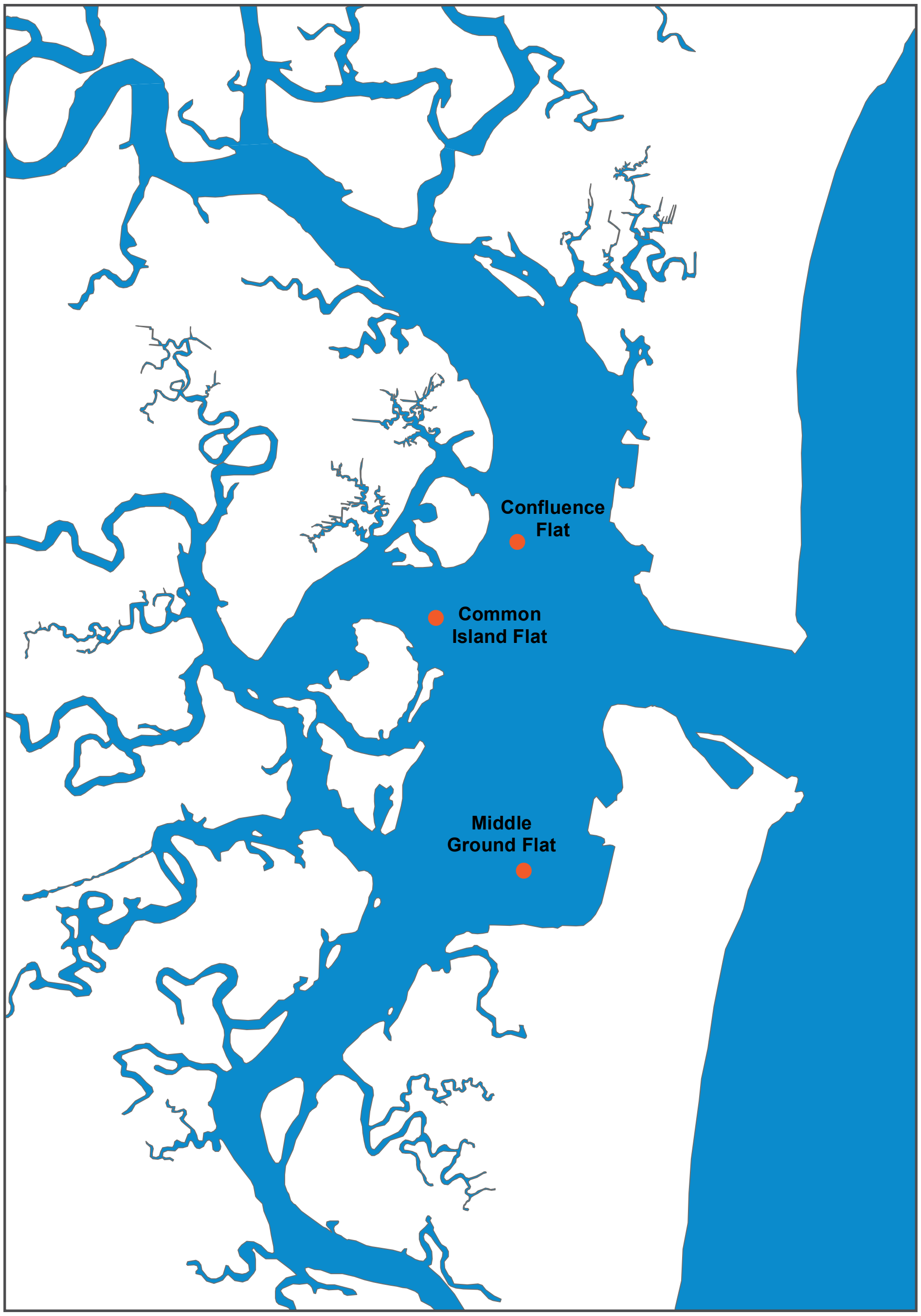


Figure 18.1: Location and names of the three major softshell clam flats in Hampton-Seabrook Harbor: Confluence Flat, Common Island Flat, and Middle Ground Flat.

Data source: Normandeau Associates, with support from NextEra Energy.

softshell clams.[65] Green crab abundance in Hampton-Seabrook Harbor was highest in 1992 and 1996 and has generally declined since then (Figure 18.4). Cold winter water temperatures often limit green crab abundance. Given the trend of warming waters in our region, one concern is that green crab abundance will increase as we look towards the future, negatively impacting softshell clams.

Acknowledgments and Credit

Paul Geoghegan (Nomandeau Associates) with contributions from Kalle Matso (PREP) and Trevor Mattera (PREP).

Photo by Jerry Monkman

Softshell Clams

Year	Common Island Flat	Confluence Flat	Middle Ground Flat	Total
1977	54.9	27.2	49.7	131.8
1979	54.8	26.7	53.5	135.0
1981	54	24.7	50.8	129.5
1983	52.7	26.4	49.9	129.0
1984	50	21.7	47.9	119.6
1995	45.7	26.4	47.3	119.4
2002	36.9	23.4	57.8	118.1
2013	32.3	21.9	48.7	102.9
2016	25.3	21.9	31.8	79.0
2021	25.3	21.9	29.5	76.7

Table 18.1. Acres of the major clam flats used in this report: Common Island Flat, Confluence Flat, and Middle Ground Flat. Data source: Normandeau Associates, with support from NextEra Energy

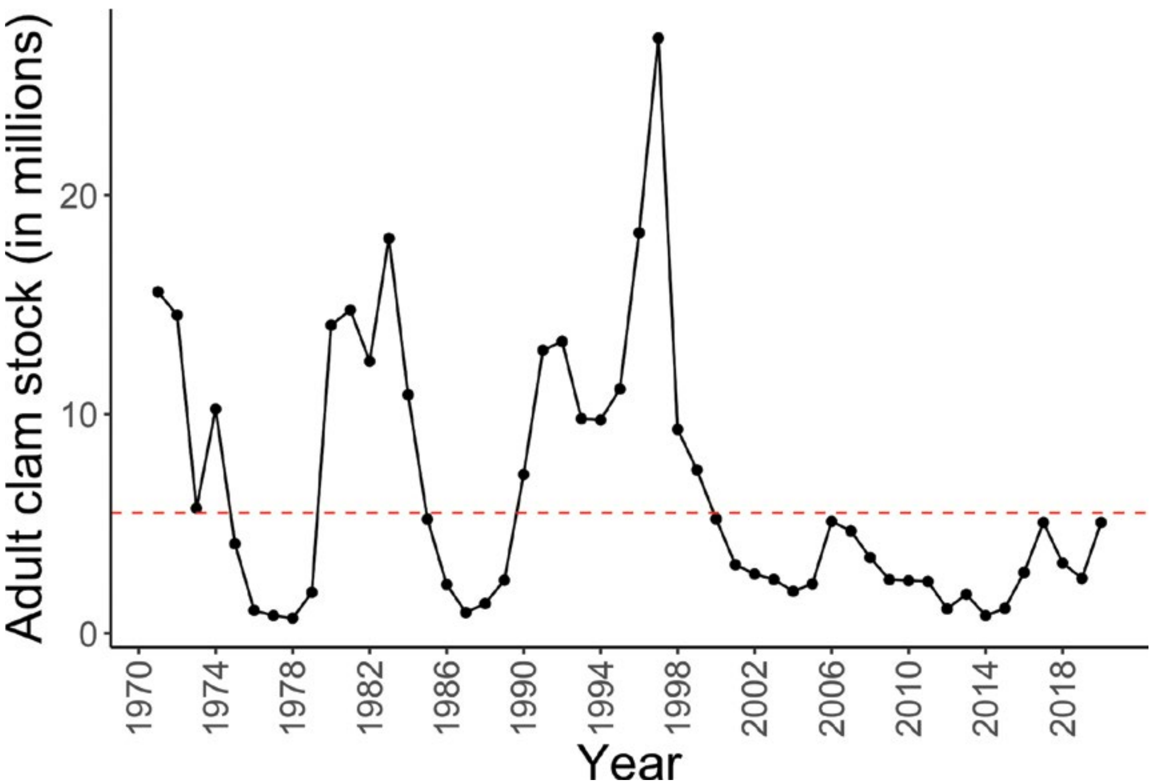


Figure 18.2: Standing stock of adult softshell clams in Hampton-Seabrook Harbor. Red dashed line indicates PREP goal of 5.5 million clams. Data source: Normandeau Associates, with support from NextEra Energy

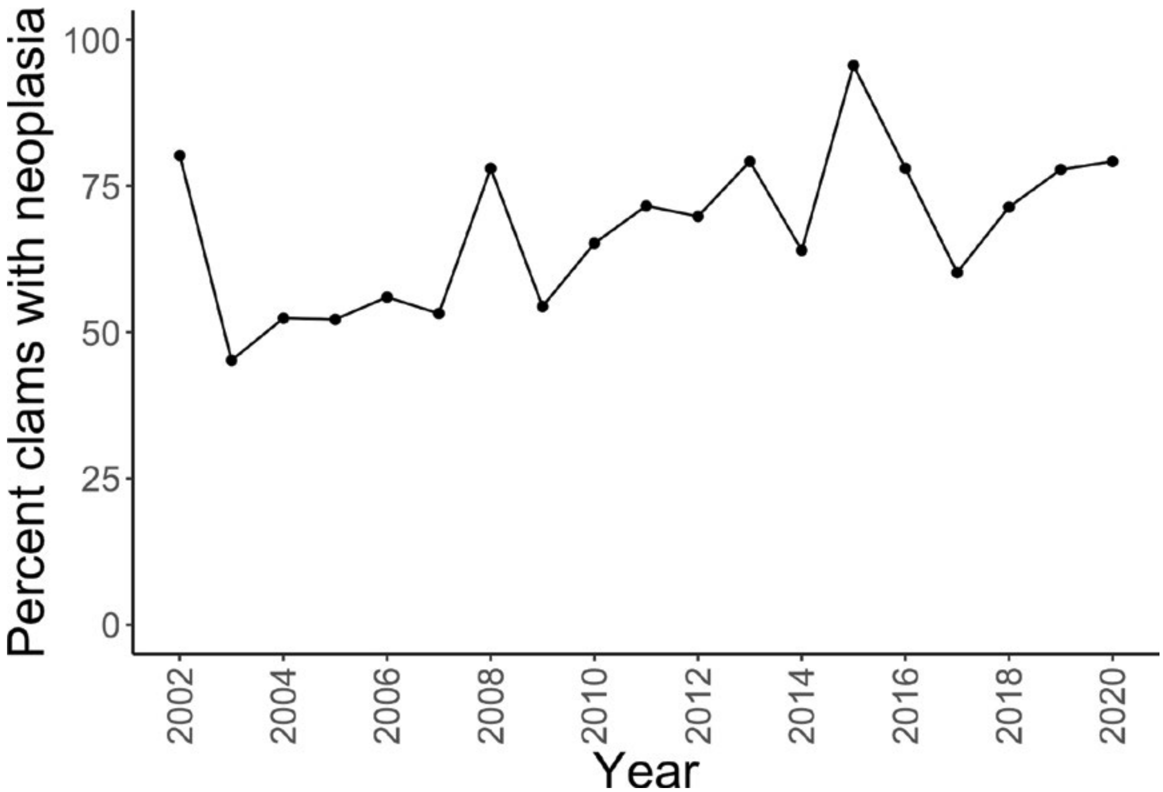


Figure 18.3: Percent of softshell clams with any amount of neoplasia in Hampton-Seabrook Harbor.
Data source: Normandeau Associates, with support from NextEra Energy

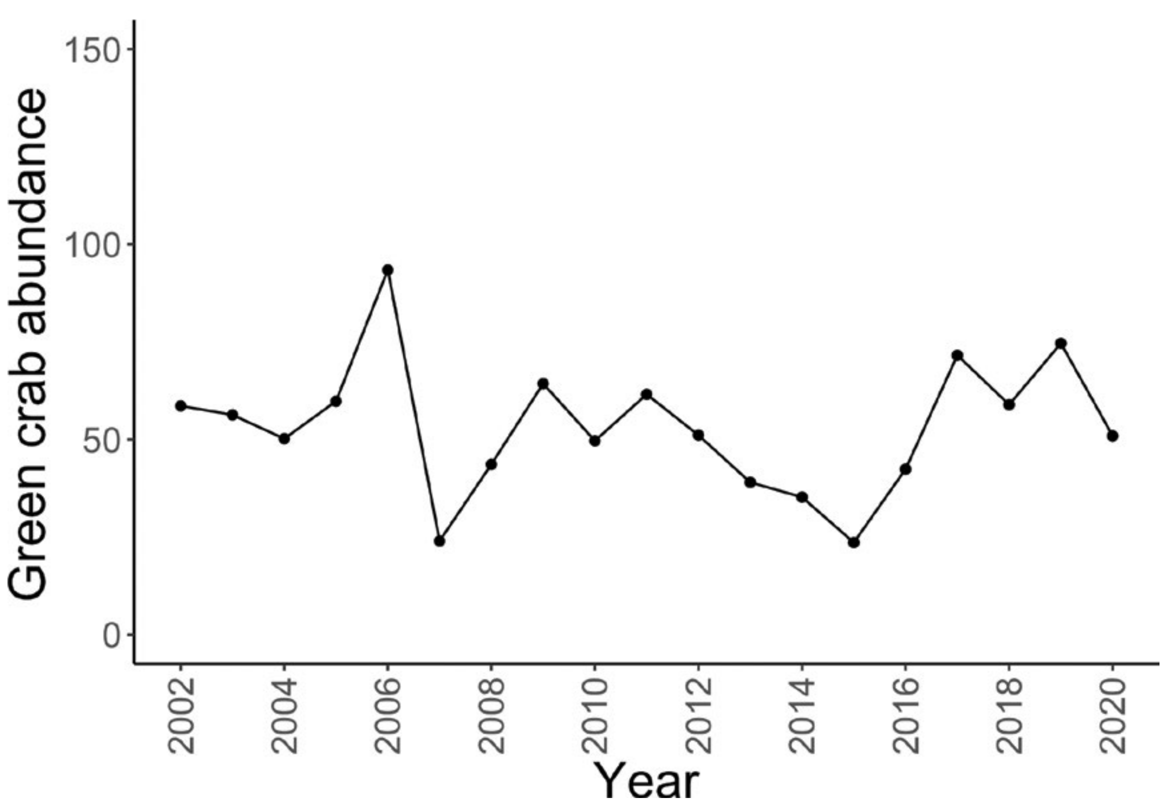


Figure 18.4: Green crab abundance in Hampton-Seabrook Harbor as measured by CPUE (catch per unit effort). Green crabs are caught in baited traps, twice a month year-round with the exception of February and March.
Data source: Normandeau Associates with support from NextEra Energy

Beach Advisories

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

Across the Piscataqua Region's 16 public tidal beaches in New Hampshire and one public tidal beach in Maine, beach advisory days occurred more than the PREP goal of 1% of beach-days from 2017 to 2021. There was a significant increase in New Hampshire beach advisory days since 2003.

Goal

Less than 1% of beach days over the summer season are affected by advisories due to bacteria pollution.

Why We Track This Indicator

Beach advisories measure the health and safety of the region's popular recreational areas and serve as an indicator of overall water quality. More specifically, this indicator reflects issues related to fecal pollution from humans, livestock, pets, or wildlife. Related indicators include "Bacteria," which looks at similar indicating bacteria, but at different sites, and only during dry-weather periods. Also, this report features the indicator, "Shellfish Harvest Opportunities;" New Hampshire's Shellfish Program uses a combination of bacteria concentrations, rainy weather monitoring, and assessment of harmful algal blooms to open or close certain areas to shellfish harvesting.

Explanation

The Piscataqua Region Watershed is home to 16 public tidal beaches in New Hampshire, as well as Fort Foster in Kittery, Maine. Since 2003, between one and 18 advisories have been issued per year across these beaches due to elevated counts of enterococci — a type of bacteria in our guts that aid in digestion and are used as an indicator of fecal bacteria. Sun Valley Beach, one of the sixteen New Hampshire beaches, is the only beach that never had an advisory. Maine's Fort Foster has had between one and four advisories issued per year since 2003 (Figure 19.1).

Advisories between 2003 and 2021 have affected 306 of 31,822 summer beach days (1.0%) between Memorial Day and Labor Day (Figure 19.2). Within the last five summers (2017 – 2021), there have been 162 affected summer beach days out of 8,449 total (1.9% of beach-days). In 2021, New Hampshire saw the highest number of beach advisories and the highest number of beach advisory days since 2003, with 18 advisories affecting seven beaches for a total of 52 days (3.1% of total beach-days). At Fort Foster, there have been no beach advisories since 2016. The highest number of advisories Fort Foster has seen (four) was back in 2009.

Most advisories reported in 2020 and 2021 impacted North Hampton State Beach and New Castle Town Beach. These two beaches are historically known for having issues with elevated enterococci levels. Together, they have accounted for nearly half of all posted beach advisories since 2003, having a combined total of 51 advisories out of 110.

The number and duration of advisories varies from year to year depending on different environmental conditions, especially due to excessive rainfall events and other severe weather. Such events can facilitate stormwater runoff, which can transport fecal matter into coastal waters. Unfortunately, due to the increase in number of beach advisories between 2017 and 2021, New Hampshire tidal beaches in the region did not continue to meet PREP's goal of beach advisories affecting fewer than 1% of summer beach-days.

Acknowledgments and Credit

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

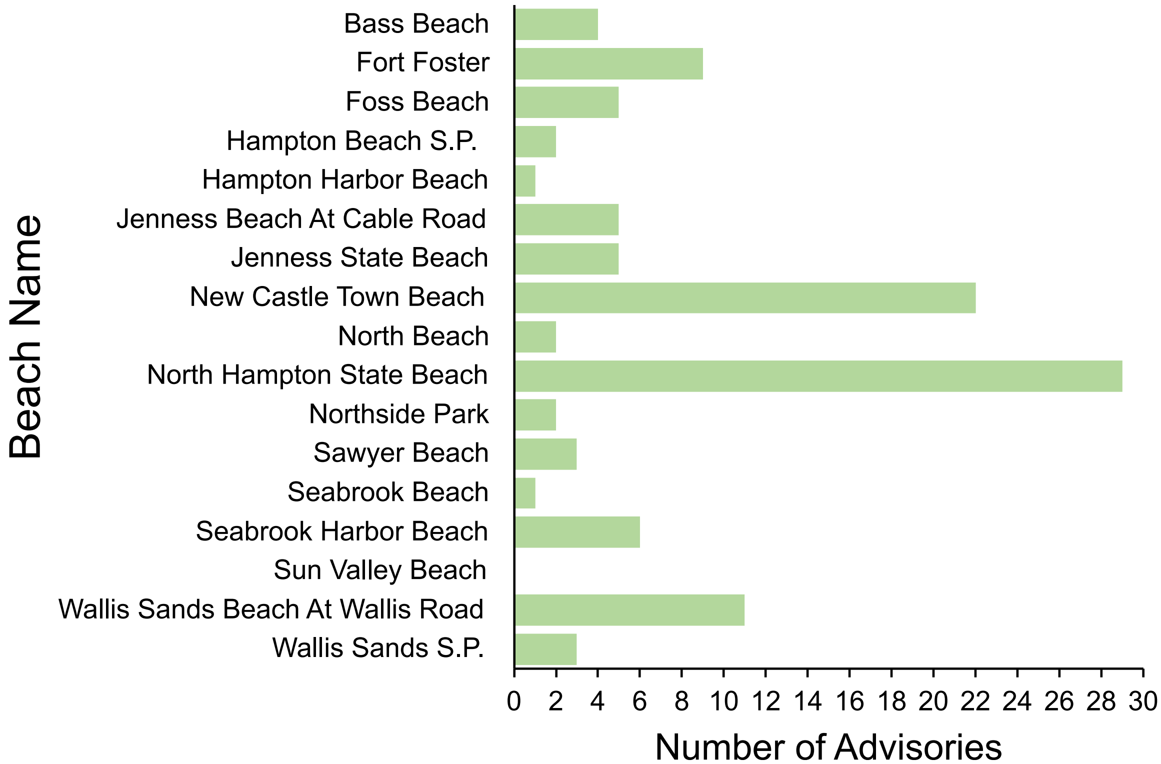


Figure 19.1: Beach advisories per tidal beach in the Piscataqua Region Watershed, 2003 – 2021.
Data source: NH Department of Environmental Services and Maine Department of Environmental Protection

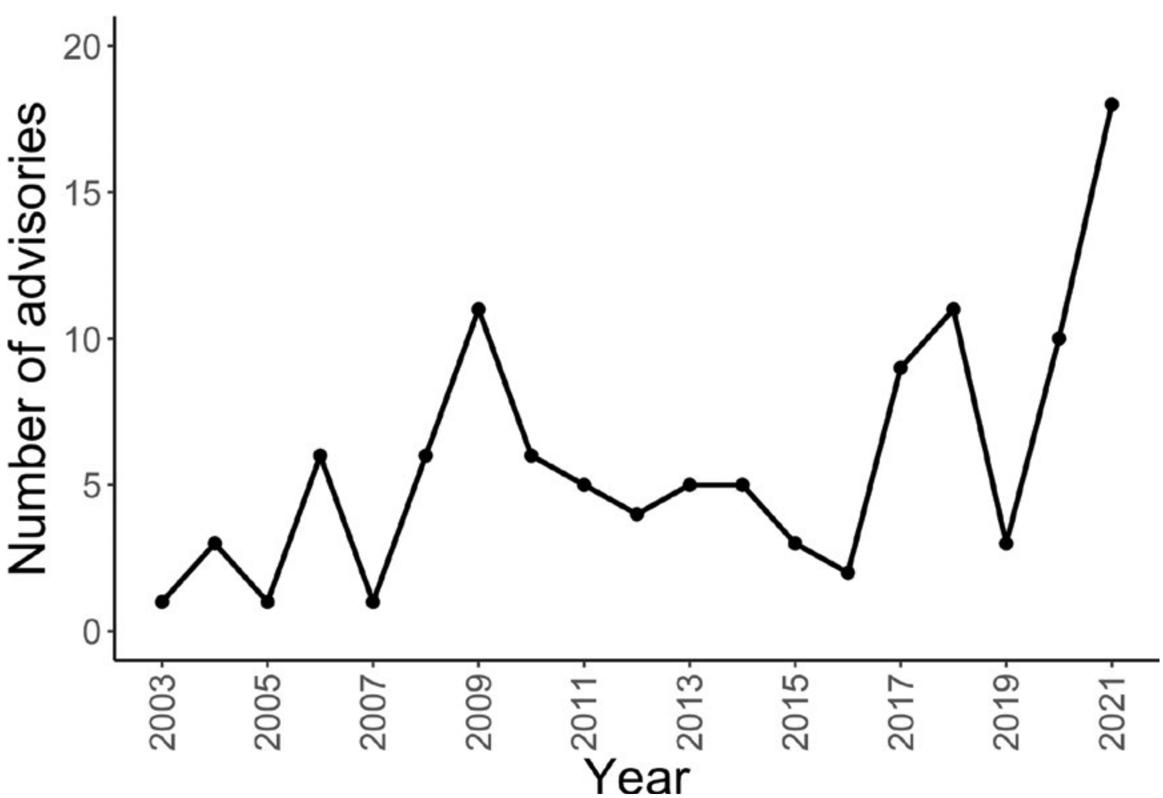


Figure 19.2: Number of advisories in the Piscataqua Region Watershed, 2003 – 2021.
Data source: NH Department of Environmental Services and Maine Department of Environmental Protection

Migratory Fishes

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

Estimates of more than 260,000 river herring returned to Piscataqua Region tributaries in 2021, a ~30% increase from 2016. This increase was driven by high returns to the Exeter River, likely due to a combination of the removal of the Great Dam in 2016 and to changes in counting methods. However, the average returns over the past two decades (2000s and 2010s) are ~30% lower than those observed in the 1980s and 1990s. Given the importance of river herring in linking freshwater, estuarine, and marine ecosystems, efforts to restore rivers and improve herring passage and health continue to be high priorities.

River restoration continues to be a priority in the region, with two dams removed from the Bellamy River since the last report in 2018. Additionally, in March 2022 the Town of Durham, NH voted to remove the Mill Pond Dam, which will improve accessibility for river herring.

Rainbow smelt have been monitored by the New Hampshire Fish and Game Department since 2010. They spawn in freshwater rivers downstream of river herring in early spring at head-of-tide. Removal of head-of-tide dams has resulted in increases in the relative abundance of spawning rainbow smelt on the Winnicut and Squamscott Rivers.

Why We Track This Indicator

Diadromous fish such as river herring and rainbow smelt migrate from the rivers of their birth to ocean waters and back again to freshwater habitats to reproduce. These fishes are important sources of nutrients for upstream systems and food for wildlife in freshwater habitats (birds, turtles, fishes, and mammals). They are also prey for important coastal fisheries including striped bass, bluefish, and groundfish. River herring are considered "forage fish" and are prey for numerous predators in marine food webs.

Explanation

Diadromous fish are those that migrate between freshwater and marine ecosystems to complete their life cycles. These fish require estuarine habitat that effectively links coastal ecosystems to bays and their freshwater tributaries. Across North America, diadromous fish have experienced dramatic population declines over the past century due in part to dams, overfishing, loss of habitat resulting from coastal development, and decreases in water quality.

In the Gulf of Maine, migratory species that use the Hampton-Seabrook and Great Bay Estuaries, such as river herring, have similarly experienced declines. The term "river herring" is actually a common name that refers to two different species: blueback herring (*Clupea aestivalis*) and alewife (*Clupea pseudoharengus*). Since 2008, the New Hampshire Fish and Game Department has estimated the numbers of each species returning to each river. Most tributaries of

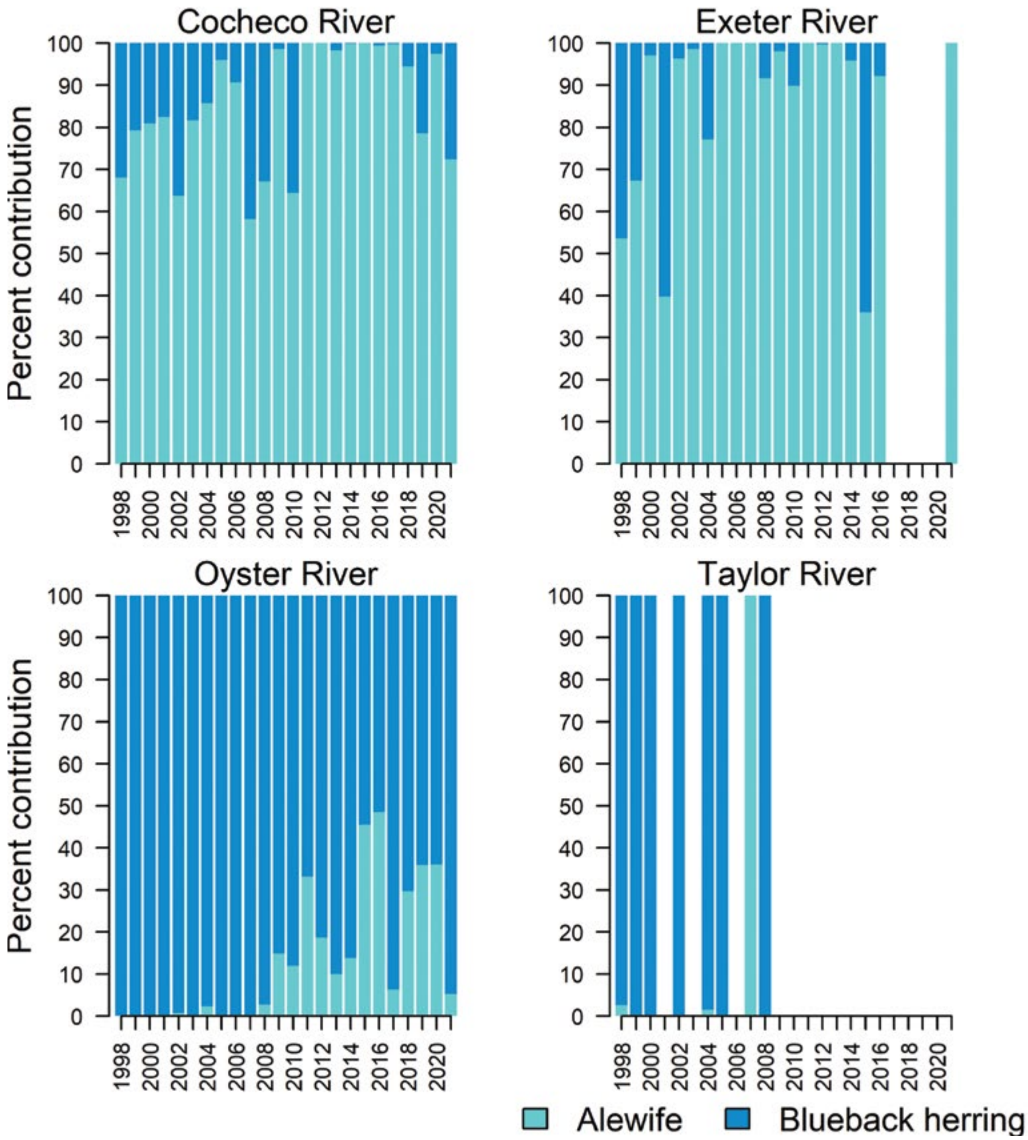


Figure 20.1: Percent contribution of alewife (dark) and blueback herring (light) to total river herring returns to New Hampshire coastal tributaries 1998 – 2021. Years with no data or insufficient data are presented as white.
Data source: NH Fish and Game Department

the Great Bay are dominated by one species or the other. For example, most river herring returning to the Cocheco River, Exeter River, and Lamprey River are alewife (Figure 20.1). In contrast, most river herring returning to the Oyster River are blueback herring, but the relative contribution of alewife to this river has increased over the past decade.

Observed river herring returns to the coastal rivers of the Piscataqua Region Watershed varied during the 1972 – 2021 period (Figure 20.2). From ~1975 – 1985, returns were dominated by the Taylor River and, to a lesser degree, the Lamprey River. From the mid-1980s to the early 2000s, returns on the Oyster River and Cocheco River dominated total returns. In the early 2000s, the Taylor River run collapsed and returns to the Oyster River dropped considerably, leaving returns to be driven by the Lamprey River and Cocheco River through 2020. Total river herring returning in 2021 reached 260,065 (30.6% increase from 2016), but this was driven by the highest returns recorded on the Exeter River (167,400); note that the Exeter River is the freshwater portion of the Squamscott River. This increase was likely in response to the removal of the Great Dam in 2016.

Fewer than 10 fish were reported for the Taylor and Winnicut Rivers in 2021, and returns have decreased in the Oyster River over the past ~20 years. Overall, the mean annual river herring returns among all monitored rivers over the past two decades (118,222 in 2011 – 2021 and 121,590 in 2001 – 2010), are lower than those observed in the 1980s (179,076) and 1990s (188,386).

Rainbow smelt (*Osmerus mordax*) are also migratory and monitored by the New Hampshire Fish and Game Department (NHFG). Removal of head-of-tide dams on the Winnicut (completed in 2012) and Squamscott (2016) Rivers resulted in time-series highs in rainbow smelt catches within approximately three years after restoration of each respective river (Figure 20.3). Whereas rainbow smelt spawn in the Squamscott River, river herring continue upstream into the Exeter River, and they all share the same migratory pathway to the Great Bay. The catches of rainbow smelt on these rivers have continued to be considerably higher than they were during the time period before dam removal. In addition, in the most recent years, the catches are composed of a higher proportion of 2-year-old fish relative to 1-year-olds (Figure 20.4). There are many possible explanations for this, such as poor spawning effort or poor survival of juveniles. More data will be necessary to understand these dynamics.

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

Extended Report

In 2019, a research partnership between NHFG and UNH began to investigate the migrations of rainbow smelt in Great Bay. See the Extended Report for preliminary results, and for more details on river herring and rainbow smelt returns.

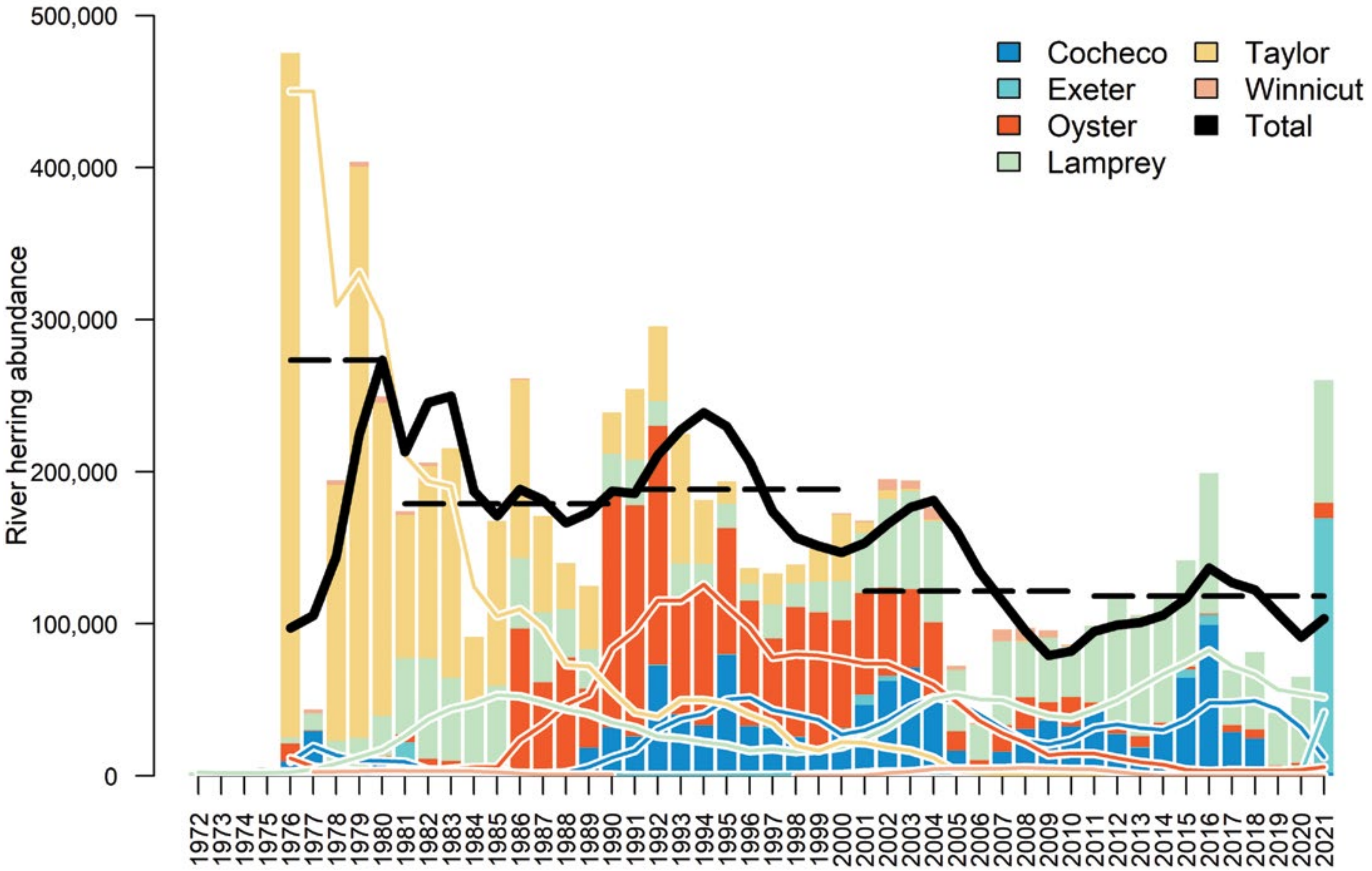


Figure 20.2: Returns of river herring to New Hampshire coastal tributaries 1972 – 2021. Bars indicate estimated abundance of returning river herring. The solid black line indicates 5-year rolling averages of total abundance (of the previous four years and current year) and the dashed lines represent means of total abundance for 1975 – 1980, 1981 – 2000, and 2000 – 2021. The colored solid lines are rolling averages for each of the tributaries. Note than in 2017 – 2020, abundance was not estimated on the Exeter River after removal of the Great Dam.

Data source: NH Fish and Game Department

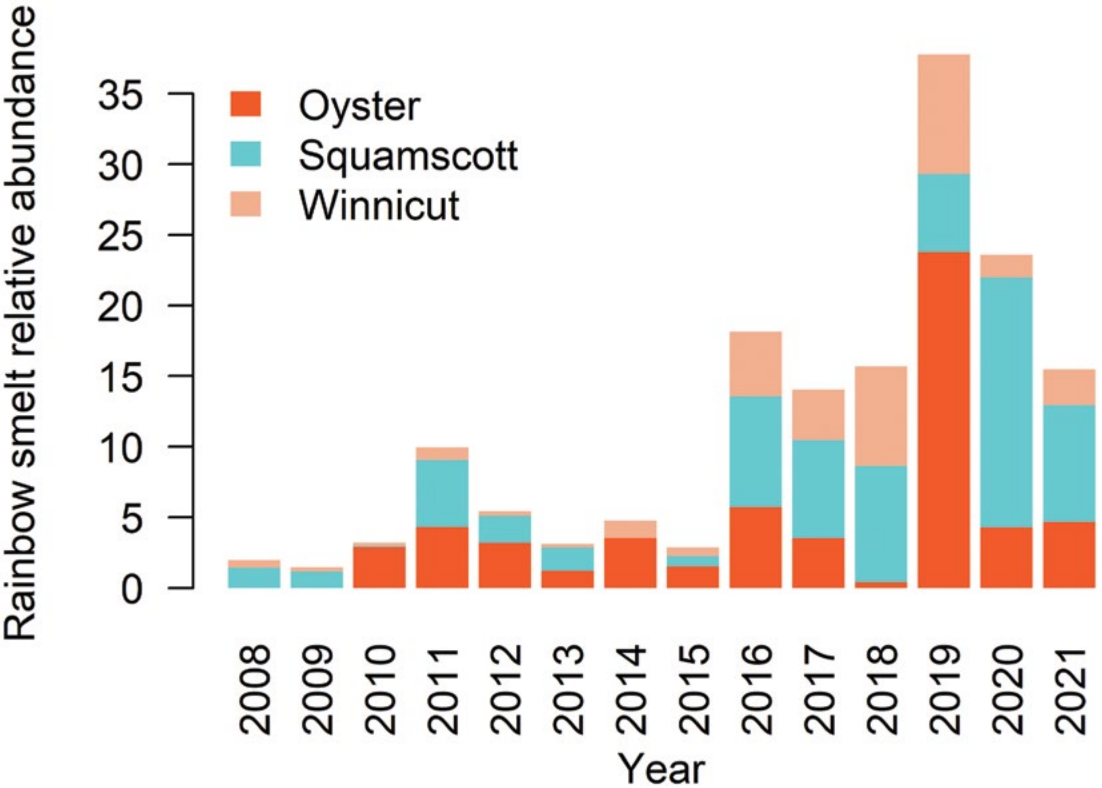


Figure 20.3: Relative abundance of rainbow smelt observed by New Hampshire Fish and Game Department spring spawning surveys 2008 – 2021.
Data source: NH Fish and Game Department

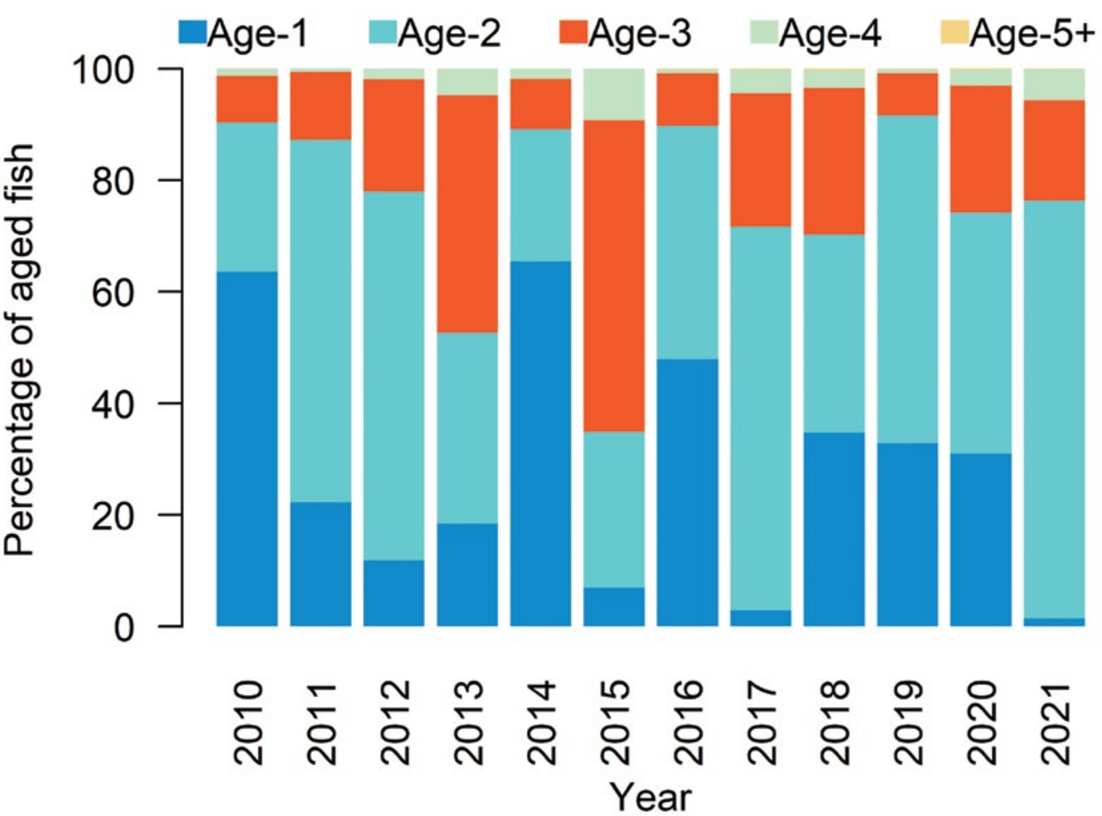


Figure 20.4: Percent contribution of each age class of rainbow smelt to the total of those aged via scales among the three rivers collectively (Oyster, Squamscott, and Winnicut Rivers) 2010 – 2021. Please note this figure aggregates data across all three rivers.
Data source: NH Fish and Game Department

Toxic Contaminants

How much toxic contamination is in blue mussel tissue and how has it changed over time? What is the status of mercury in sediments? What are contaminants of emerging concern and what do we know about their impacts on ecosystems and human health?

In blue mussel tissue, most concentrations of inorganic (e.g., heavy metals such as mercury and lead) and organic (e.g., polychlorinated byphenyls (PCBs)) chemicals from 1993 – 2016 were declining or not changing. Mercury concentrations in sediments were highest in Great Bay, the Piscataqua River, and Portsmouth Harbor; lowest values were found in Hampton Harbor. No trends were detected in time series beginning in 2000. Contaminants of emerging concern, per- and poly-fluoroalkyl substances (PFAS), pharmaceuticals, and personal care products, were widely detected. There are no regulatory advisories for these chemicals currently, but research and monitoring are ongoing.

Goal

All sampling stations in the Hampton-Seabrook and Great Bay Estuaries show shellfish tissue concentrations below stated levels of concern and for there to be no increasing trends for any contaminants.

Why We Track This Indicator

Toxic and persistent contaminants, such as PCBs, mercury, and contaminants of emerging concern, can accumulate in the tissue of filter-feeding bivalves (e.g., mussels, clams, and oysters) and other marine organisms, posing health risks to people and non-human organisms when consumed.[66] Tracking contamination in blue mussel tissue over time offers insight into temporal and spatial changes in distributions and contaminant levels in estuarine and coastal ecosystems that reflect direct (e.g., runoff) and indirect (e.g., sediments) sources of these contaminants.

Explanation

The 2018 State of Our Estuaries report noted that most legacy contaminants — metals, pesticides, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) — showed either decreasing or no overall trends from 1993 through the year 2014. Two additional years of data from 2015 and 2016 resulted in no change for 26 contaminants, five changed from no trend to decreasing, and five contaminants changed from decreasing to no trend (Table 21.1). No contaminants were added to the "increasing" category. In addition, none of the recent data have exceeded US Food and Drug Administration "tolerance" or "action" levels for mercury or PCBs in shellfish and seafood (Figure 21.1).

Determining concentrations of contaminants in sediment is another useful way to track where contaminants end up in the Piscataqua Region Watershed. The EPA conducted surveys throughout the United States as part of the National Coastal Condition Assessment, collecting data in 2000 – 2006, 2010, and 2015 on toxic contaminants in sediments and fish tissue. In sediments, mercury concentrations ≥ 0.7 µg/g are considered likely to cause adverse health effects, while levels ≤ 0.13 µg/g are not.[67] Results indicate that the possibility for

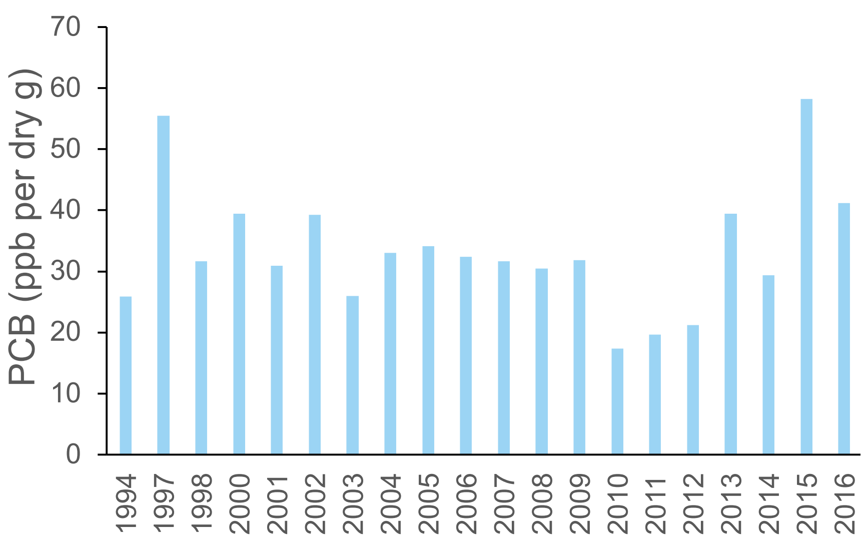


Figure 21.1: Average concentrations (parts per billion dry wt.) of PCBs in blue mussel samples from Dover Point (NHDP) from 1994 to 2016.

Data source: NOAA Mussel Watch Program /Jackson Estuarine Laboratory, UNH

Station	Parameter	Period	Trend at 2014	Change with 2015 – 16 data
MECC	Aluminum	1993 – 2014	No significant trend	No change
	Cadmium	1993 – 2014	No significant trend	No change
	Chromium	1993 – 2014	Decreasing	Change to no trend
	Copper	1993 – 2014	No significant trend	No change
	Iron	1993 – 2014	No significant trend	Change to decreasing
	Lead	1993 – 2014	Decreasing	No change
	Mercury	2003 – 2014	No significant trend	Change to decreasing
	Nickel	1993 – 2014	Decreasing	No change
	Silver	2003 – 2014	Decreasing	No change
	Zinc	1993 – 2014	No significant trend	No change
	PAH-Total	1993 – 2014	No significant trend	No change
	PCB-Total	1993 – 2014	No significant trend	Change to decreasing
NHDP	Aluminum	1994 – 2014	No significant trend	No change
	Cadmium	1994 – 2014	Decreasing	No change
	Chromium	1994 – 2014	Decreasing	Change to no trend
	Copper	1994 – 2014	No significant trend	No change
	Iron	1994 – 2014	Decreasing	No change
	Lead	1994 – 2014	Decreasing	No change
	Mercury	2003 – 2014	No significant trend	Change to decreasing
	Nickel	1994 – 2014	Decreasing	Change to no trend
	Silver	2003 – 2014	Decreasing	No change
	Zinc	1993 – 2014	Decreasing	No change
	PAH-Total	1993 – 2014	No significant trend	No change
	PCB-Total	1993 – 2014	No significant trend	No change
NHHS	Aluminum	1993 – 2014	No significant trend	No change
	Cadmium	1993 – 2014	Increasing	No change
	Chromium	1993 – 2014	Decreasing	Change to no trend
	Copper	1993 – 2014	No significant trend	No change
	Iron	1993 – 2014	No significant trend	No change
	Lead	1993 – 2014	Decreasing	No change
	Mercury	2003 – 2014	No significant trend	Change to decreasing
	Nickel	1994 – 2014	Decreasing	Change to no trend
	Silver	2003 – 2014	Decreasing	No change
	Zinc	1993 – 2014	Decreasing	No change
	PAH-Total	1993 – 2014	No significant trend	No change
	PCB-Total	1993 – 2014	Decreasing	No change

Table 21.1. Trends in contaminant concentrations in mussel tissue in Clark Cove, Portsmouth Harbor (MECC), Dover Point (NHDP), and Hampton Harbor (NHHS), 1993 – 2016.
Data source: Jackson Estuarine Laboratory, UNH

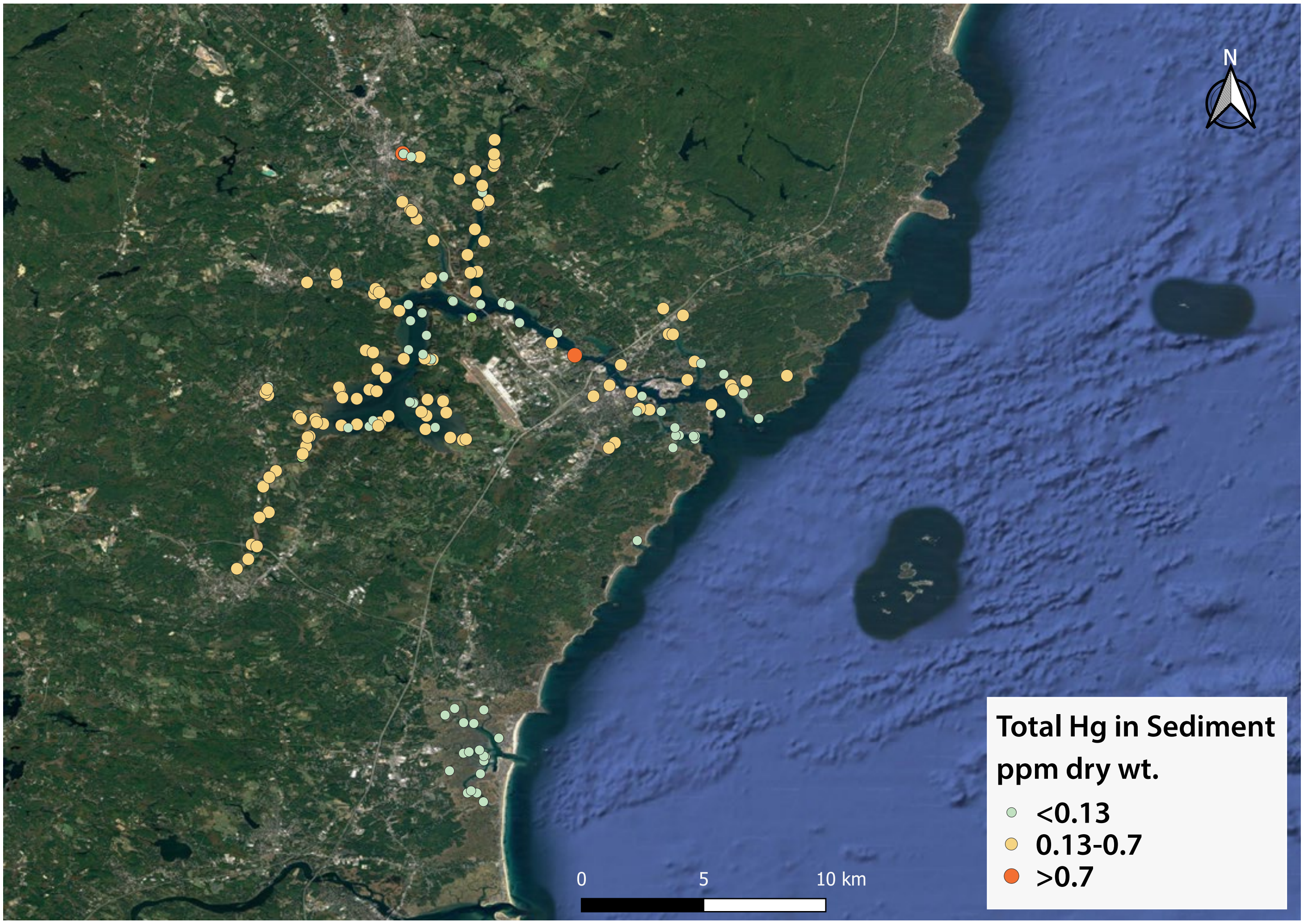


Figure 21.2: Distribution of sediment mercury concentrations in Piscataqua Region Watershed estuaries and tributaries from National Coastal Condition Assessment surveys 2000 – 2006, 2010, and 2015. Concentrations >0.7 µg/g (orange) are considered likely to cause adverse effects; at levels <0.13 µg/g (light green), effects are not expected[67]. Intermediate concentrations between 0.13 – 0.7 with less defined risk are shown in yellow.
Data source: National Coastal Condition Assessment, EPA

adverse effects exist throughout the Great Bay Estuary, whereas the Hampton-Seabrook Estuary's levels of mercury are lower and therefore less likely to cause adverse effects (Figure 21.2).

Apart from legacy contaminants, researchers are working to understand the presence and potential ecosystem and human health impacts of contaminants of emerging concern, including the family of chemicals referred to as PFAS. PFAS can be released from wastewater treatments facilities, current and former military sites due to firefighting foam use, and other runoff sources due to widespread use of these chemicals. In blue mussel tissue, PFAS (as PFOSA) were detected at five of eight sites in the Piscataqua Region Watershed, including Little Harbor (NHLH), New Castle (NHNC), North Mill Pond (NHNM), South Mill Pond (NHSM), and Clark Cove (MECC; Seavey Island, Portsmouth Naval Shipyard) sites, but not at Hampton-Seabrook Harbor (NHHS), Dover Point (NHDP), or Peirce Island (NHPI) (Figure 21.3).[68]

Currently, there are no published PFAS thresholds for ecosystem health, but there are thresholds for human health in terms of consuming shellfish and finfish. Based on recent sampling efforts, NHDES concluded that a shellfish consumption advisory for PFAS was not warranted[69] but advisories for finfish may be necessary in the future as state and academic partners investigate further. This is because PFAS tends to accumulate as they travel up the food chain to bigger organisms, especially in finfish. PFAS toxicity, their regulation, and their occurrence across New Hampshire is an evolving situation so people with concerns should check the latest news at the NHDES PFAS Response website (https://www.pfas.des.nh.gov/).

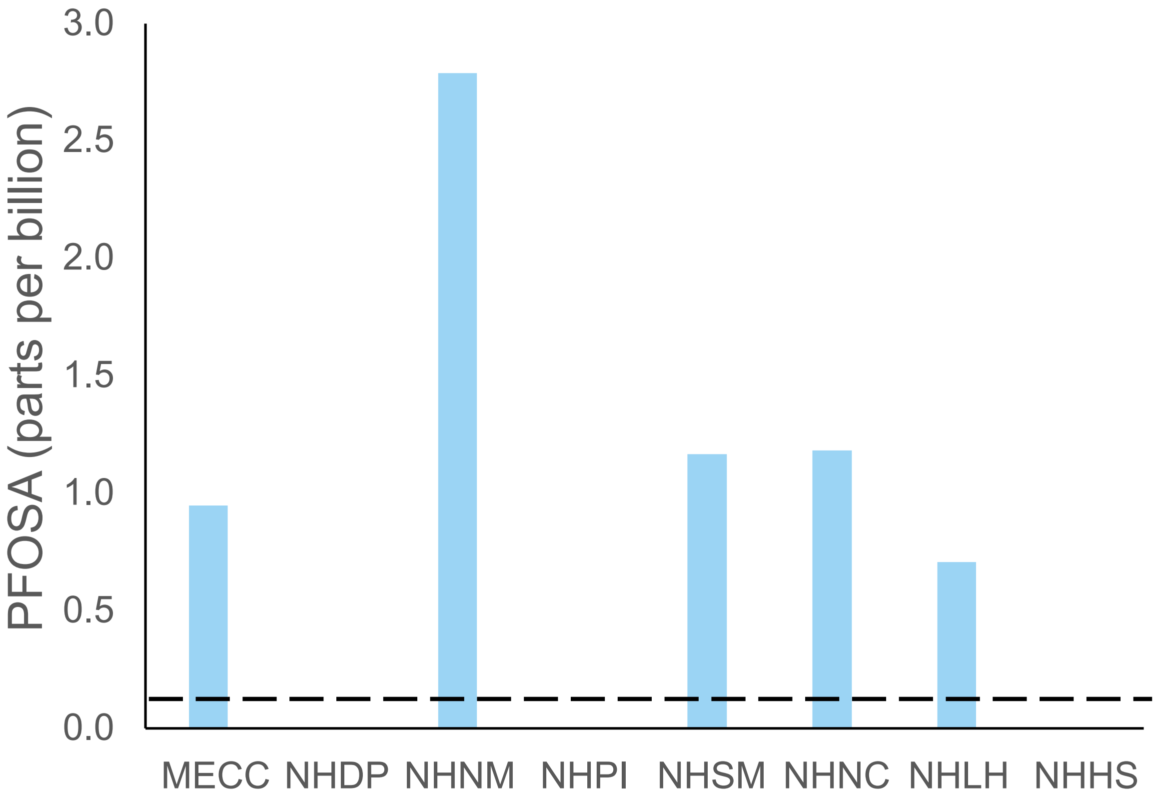


Figure 21.3: PFOSA concentrations (parts per billion, wet weight) in blue mussel tissue detected at monitoring sites in the Piscataqua Region Estuaries (see narrative on page 101 for site names). Dotted line represents the minimum weight corrected detection limit. Perfluorooctane sulfonamide (PFOSA) was the most frequently detected of the PFAS contaminants in this study, which used samples collected in 2015 and 2016 throughout the Gulf of Maine.[71]
Data source: NOAA Mussel Watch Program/ Jackson Estuarine Laboratory, UNH

In addition to PFAS, blue mussel samples were analyzed for many other potentially harmful contaminants of emerging concern compounds, including current-use pesticides, pharmaceuticals, personal care products, and flame retardants. Many of these contaminants of emerging concern were not detected at the eight Piscataqua Region Watershed sites. However, a number of pharmaceuticals and personal care products were detected. DEET, a common insect repellent, was found at all eight sites, although concentrations were well below levels associated with adverse effects.[70]

Future reports will contain more information on trends over time as well as potential impacts on ecosystem and human health.

Acknowledgment and Credits
Stephen Jones (NH Sea Grant/UNH) and Maria Florencia Fahnestock (UNH), with contributions from Kalle Matso (PREP).

Extended Report

The Extended Report includes more detailed data and analysis of legacy heavy metal and toxic organic contaminants in blue mussel tissue, and more sediment data with assessments of 15 metals, 26 PAHs, 44 PCBs, and 30 pesticides. The Extended Report also contains more contaminants of emerging concern data, including 249 chemicals at eight Piscataqua Region Watershed sites compared to 34 other sites around the Gulf of Maine.

Stewardship Behavior

How many volunteer hours were logged in the Piscataqua Region Watershed through the work of five New Hampshire stewardship groups between 2017 – 2021? How many sign-ups and events were completed in this timeframe?

From 2017 – 2021 there were 109,063 volunteer hours logged from five major organizations in the Piscataqua Region Watershed: Blue Ocean Society, NH Sea Grant, Great Bay National Estuarine Research Reserve (GBNERR), Gundalow Company, and the Seacoast Science Center. There were 458 volunteering events and 3,783 sign-ups from local individuals. These efforts amount to a total economic benefit of over $2.5M, based on the current calculated value of volunteer time. The pandemic affected stewardship rates in 2020, but 2021 could indicate the beginning of a resurgence of environmental volunteering.

Why We Track This Indicator

Volunteer efforts are a critical component in the stewardship of our region; by tracking stewardship hours, we obtain a sense of how engaged the people of the Piscataqua Region are in the health of their estuaries.

Explanation

Stewardship can be defined as the careful and responsible management of something entrusted to one's care, and is a vital component of our community. Since data reporting began in 2015, stewardship activity showed a modest increase until the pandemic. Not surprisingly, there was a substantial decrease in stewardship hours in response to the COVID-19 outbreak (Figure 22.1, Table 22.1). Total volunteer hours in 2020 were 6,810, a 76% decrease compared to previous year's average, and the total number of volunteers decreased by 64%. However, with the distribution of the vaccine in 2021, stewardship efforts are seeing a resurgence. Most recently, in 2021, our region saw a total of 15,088 volunteer hours, from 582 volunteers across 63 events, and 2022 is looking even more promising (Table 22.2).

As human populations grow and greater strain is placed on natural resources, stewardship in our communities becomes more and more critical. Not only does volunteer stewardship have a positive impact on the ecosystem, but it also benefits the region economically. The Bureau of Labor Statistics calculates the value of volunteer work in New Hampshire at $30.75 per hour. With a total of 109,063 hours logged from 2017 – 2021, the total economic value of these efforts was $3,353,676 in just these 5 years.

Those who are passionate about the environment and feel compelled to get involved in local efforts can access a list of upcoming events at NatureGroupie.org. This website is a hub for volunteer events and citizen scientist opportunities in New England. The site connects volunteers with various organizations and individuals and identifies projects that fit volunteer interests. From 2017 to 2021, there were 458 events made possible from the contributions of 3,783 volunteers. This is likely an underestimation as there are countless groups and citizens who volunteer that go unreported.

Acknowledgments and Credits

Nathaniel Gruen (UNH) with contribution from Abigail Lyon (PREP).

Organization	2015	2016	2017	2018	2019	2020	2021
Gundalow Company	2,500	2,779	3,622	3,384	2,704	1,173	1,748
GBNERR	3,883	2,963	2,978	3,986	4,536	465	3,007
Seacoast Science Center	13,075	11,978	11,978	17,284	16,245	3,718	6,547
NH Sea Grant (Coastal Research Volunteers)	1,764	1,602	1,060	2,863	2,023	910	1,185
Blue Ocean Society	3,080	3,765	4,811	4,042	5,651	544	2,601
Grand Total	**24,302**	**23,087**	**24,449**	**31,558**	**31,158**	**6,810**	**15,088**

Table 22.1. Volunteer hours by selected stewardship groups by year. Volunteer Hours by Year (2015 – 2021)
Data source: Blue Ocean Society; NH Sea Grant; GBNERR; Gundalow Company; Seacoast Science Center. NHDRED data not reported due to reorganization of the agency. These organizations were chosen according to criteria established by PREP.[72]

Year	Number of Events	Number of Volunteers
2017	134	872
2018	120	1018
2019	117	968
2020	24**	343
2021	63	582

Table 22.2. Number of stewardship events among chosen organizations.
**In 2020, uncertainties related to the COVID-19 pandemic led to a drop in events; only 38 total events were scheduled, and of those 14 were canceled resulting in a total of 24 events. Data source: Blue Ocean Society; NH Sea Grant; GBNERR; Gundalow Company; Seacoast Science Center. NHDRED data not reported due to reorganization of the agency. These organizations were chosen according to criteria established by PREP.[72]

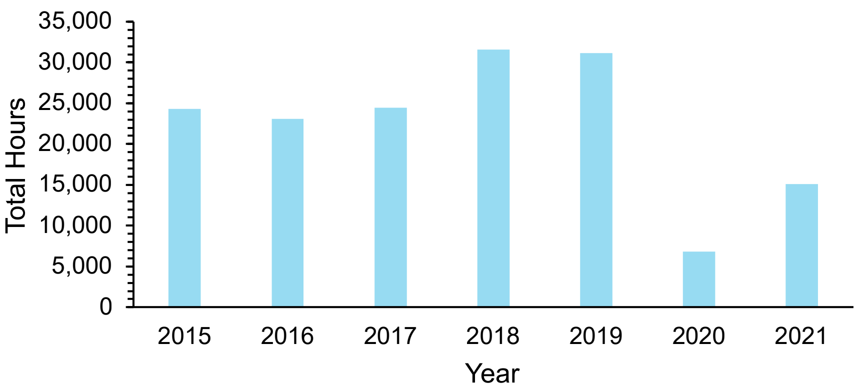


Figure 22.1: Total Volunteer Hours in the Piscataqua Region Watershed during 2015 – 2021.
Data source: Blue Ocean Society; NH Sea Grant; GBNERR; Gundalow Company; Seacoast Science Center. NHDRED data not reported due to reorganization of the agency. These organizations were chosen according to criteria established by PREP.[72]

Acknowledgments and Credits

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Moral Support

Spouses, Partners, Families, and Friends for emotional support

End Notes

1. See Mallin et al. (2000)
2. See Brabec et al. (2002)
3. See NH Department of Business and Economic Affairs (2021)
4. See U.S. EPA (2009)
5. See UNH Stormwater Center and Vanasse Hangen Brustlin, Inc. (2015)
6. See NHDES (2022)
7. Title 38, §420-D
8. See SWA (2012)
9. See U.S. EPA Office of Wastewater Management (2015)
10. See NHDES (2020)
11. See Western Kentucky University (2021)
12. See PREP (2010)
13. See Wasson et al. (2019)
14. See Anderson and Barnett (2017)
15. See Payne et al. (2019)
16. See Burdick et al. (2020)
17. See Steckler and Ormiston (2021)
18. See Anderson et al. (2020)
19. See ME Department of Inland Fisheries and Wildlife (2017)
20. See NH Fish and Game Department (2020a)
21. See NH Fish and Game Department (2020b)
22. See Steckler and Brickner-Wood (2019)
23. See Steckler et al. (2016)
24. See Zankel et al. (2006)
25. See Walker et al. (2010)
26. See Jones et al. (1992)
27. See Jones (2000)
28. See Lemcke-Stampone et al. (2022)
29. See Jayhoe et al. (2007)
30. See Runkel et al. (2004)
31. See U.S. EPA (2012)
32. See Bricker et al. (2003)
33. See Batiuk et al. (2009)
34. See Morrell and Gobler (2020)
35. See Batiuk et al. (2009)
36. See Barker (2019)
37. See Jones (2000)
38. See Short et al. (1993)
39. See Moore et al. (2014)
40. See U.S. EPA (2012)
41. See Kemp (2004)
42. See Trowbridge (2009)
43. See Bierman (2014)
44. See NH Estuaries Project and Jones (2000)
45. See Jones (2021)
46. See Urquhart et al. (2016)
47. See Xu et al. (2015)
48. See Hartwick et al. (2021)
49. See Ao et al. (2017)
50. See Grizzle and Ward (2020)
51. See Odell et al. (2006)
52. See Stasse et al. (2021)
53. See NH Fish and Game Department (2013)
54. See Grizzle et al. (2021)
55. See Capone et al. (2008)
56. See Grizzle et al. (2021)
57. See Atwood and Grizzle (2020)
58. See Glenn (2016)
59. See Glenn et al. (2020)
60. See Metzger et al. (2015)
61. See Metzger et al. (2016)
62. See Metzger et al. (2018)
63. See Carballal et al. (2015)
64. See Geoghegan et al. (2021)
65. See Normandeau (2021)
66. See NHDES (2017)
67. See Canadian Council of Ministries of the Environment (2023)
68. See Apeti et al. (2021)
69. See NHDES (2021)
70. See Weeks et al. (2011)
71. See Apeti et al. (2021)
72. See Barley-Greenfield (2017)

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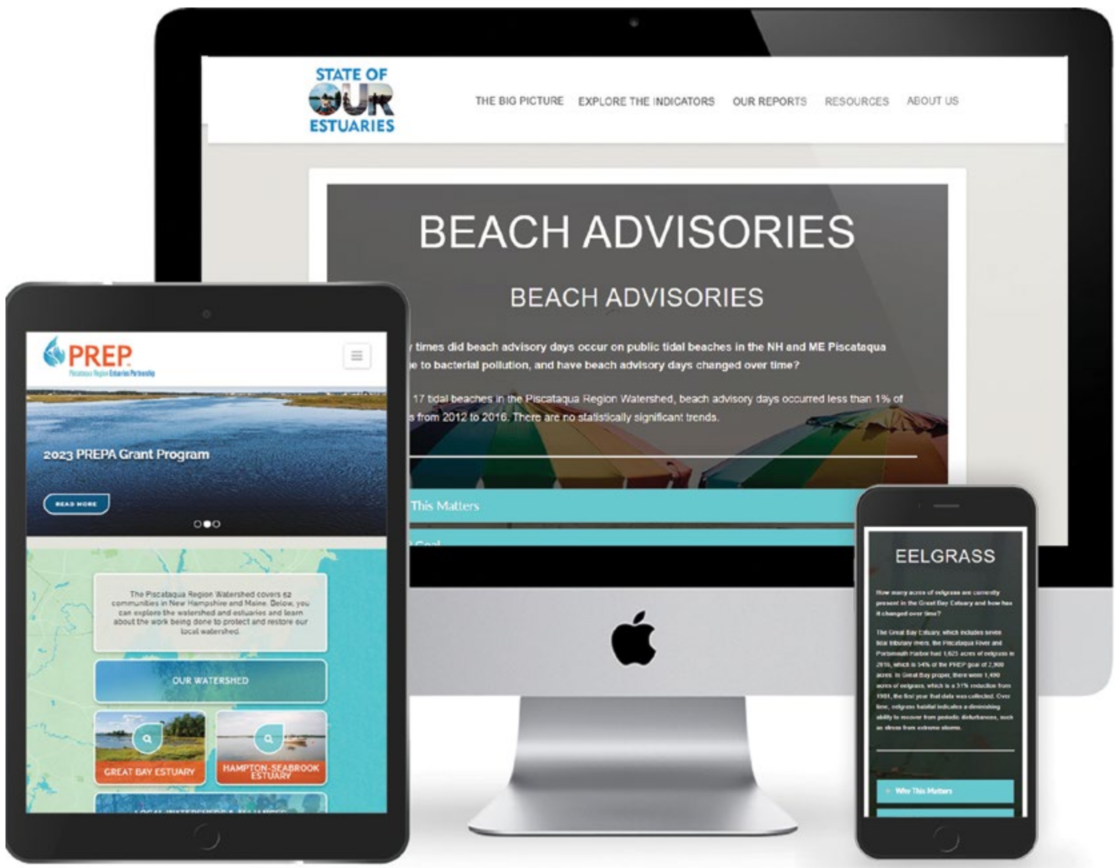

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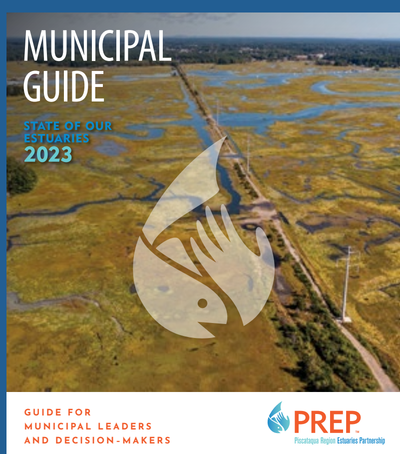

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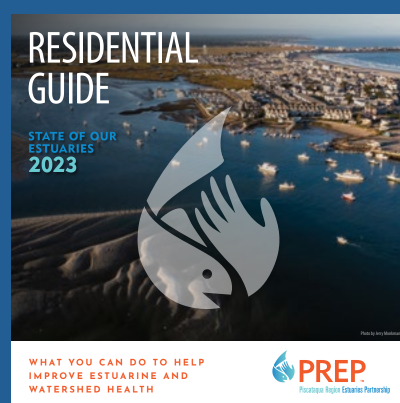

A short guide for residents that has examples and tips on simple things everyone can do to help prevent pollution and protect the places we love.

Hampton-Seabrook Estuary