STATE OF OUR ESTUARIES 2018

PREP

Piscataqua Region Estuaries Partnership

STATEOFOURESTUARIES.ORG

LETTER FROM THE EXECUTIVE DIRECTOR

Dear Friends and Partners,

It is with great pride that we present the ***2018 State of Our Estuaries*** report.

You will find that it builds on our previous status and trends reports to send a clear signal: our estuaries have declined due to stress and they are losing resilience to sustain themselves in the face of growing pressures. There are a number of contributing factors. Some of them are due to human activity; others are the result of natural processes beyond our immediate control. Combined, these factors are continually changing the ecosystem function and conditions in our region.

Every five years, the Piscataqua Region Estuaries Partnership (PREP) synthesizes and analyzes data regarding the health of our estuaries and communicates this information to you. We are deeply grateful to the many partners whose data, technical expertise, and practical experience have made this work possible. As one of 28 federally-designated National Estuary Programs established by the United States Environmental Protection Agency, developing this report was PREP's responsibility. Acting on the information it presents, however, is a task for all of us.

In a system as uniquely dynamic as ours, we will not reestablish estuarine health by focusing on one problem. Nor will we get there by allowing ourselves to be discouraged by what we observe or distracted by our differences. We must work collaboratively to make our estuaries more resilient to the changes they are experiencing now, and those to come. The good news is that we know we can do this; we are doing this. From improvements to wastewater treatment to significant increases in land conservation, we have demonstrated an increasing commitment to collaborating to build the resilience of our estuaries.

Since our program was founded 22 years ago, PREP has worked to protect and improve the water quality and health of our region's estuaries. We feel fortunate to be taking up this challenge as part of the University of New Hampshire's School of Marine Science and Ocean Engineering and with many other groups who willingly invest so much passion and dedication to help our ecosystems thrive. Our Comprehensive Conservation and Management Plan names more than 150 organizations and individuals across 52 communities as stakeholders in this effort; it also provides direction for reports like this one and our program overall.

Here is how PREP - your National Estuary Program - intends to act on the findings in this report:

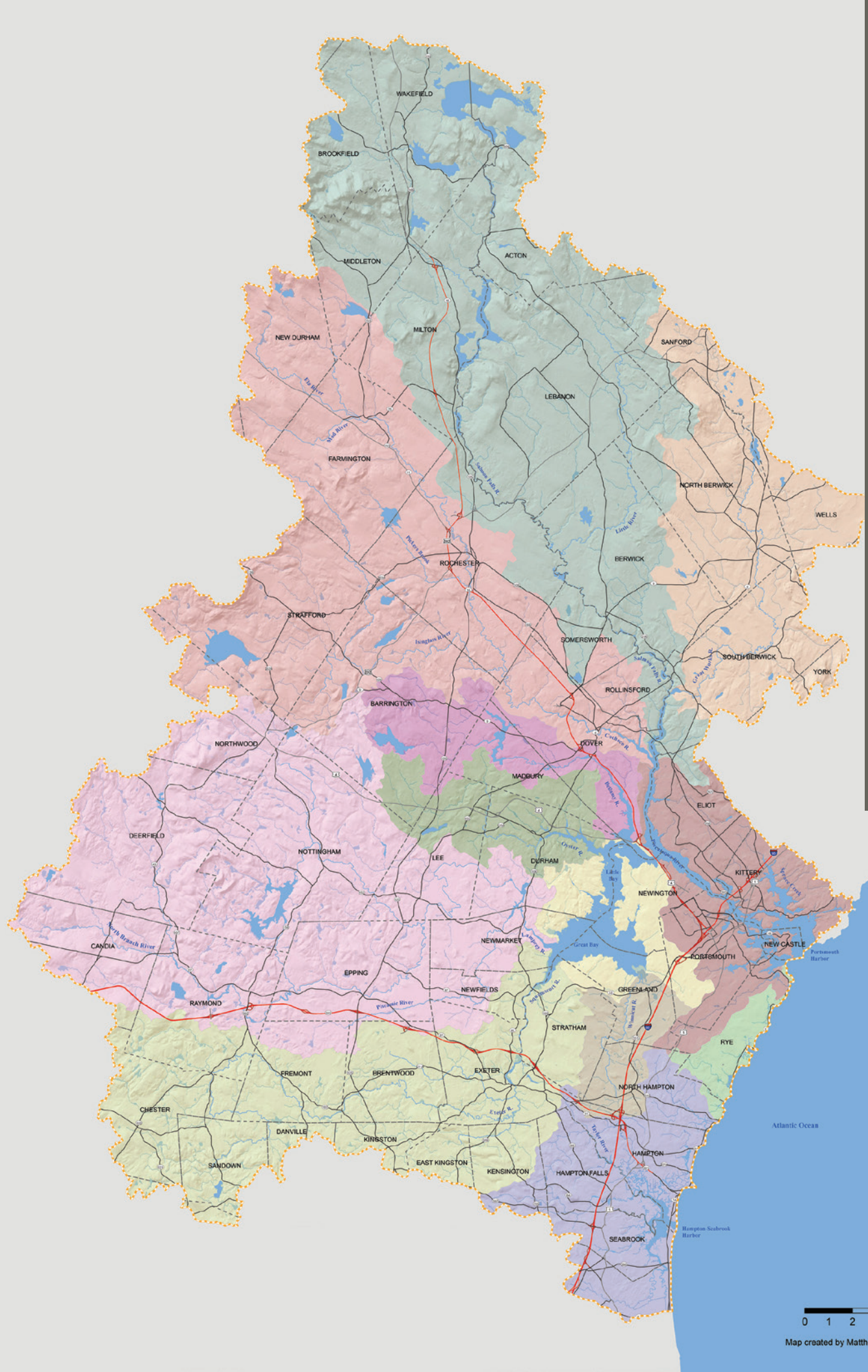
- **Continue to improve our capacity for stakeholder involvement**
- **Build a stronger, more transparent science program that provides the best possible data and science to assist our partners in decision-making for issues such as oyster restoration**
- **Engage our partners in bringing more resources to bear on critical work, such as gathering new data**
- **Leverage the National Estuary Program network to bring the technical expertise of nationally acknowledged experts to help us understand the Great Bay and Hampton-Seabrook estuaries**

Like our estuaries, our social fabric and community spirit need to be resilient in the face of changes to come. For the sake of our economy, quality of life, and public health, we must continue to find common ground and push forward together.

Warm regards,

Rachel Rouillard
Executive Director, Piscataqua Region Estuaries Partnership

For more information and to explore the full report interactively, visit the new www.StateofOurEstuaries.org



PISCATAQUA REGION WATERSHED

Rivers flowing from 52 communities in New Hampshire and Maine converge with the waters of the Atlantic Ocean to form the Great Bay and Hampton-Seabrook estuaries. The watershed covers 1,086 square miles. These bays provide critical wildlife habitat, nurseries for seafood production, buffering from coastal flooding, recreational enjoyment, and safe harbor for marine commerce. Our estuaries are part of the National Estuary Program and recognized broadly as exceptional natural areas in need of focused study and protection.

GREAT BAY ESTUARY

The entire Great Bay Estuary system including all seven tributaries, Great Bay, Little Bay, Piscataqua River, and Portsmouth Harbor.

GREAT BAY

Only the Great Bay portion of the Great Bay Estuary, south of Adams Point.

RYE, NH | PHOTO BY A. LYON

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2018 STATE OF OUR ESTUARIES EXECUTIVE SUMMARY

Every five years, the Piscataqua Region Estuaries Partnership (PREP) reports on the environmental condition of the Great Bay and Hampton-Seabrook Estuaries. Our goal is to provide an assessment that resource managers, residents, community leaders, scientists, policy makers, and others can use in their efforts to understand, manage, and protect our local estuaries of national significance.

The 2018 report presents a synthesis of 23 indicators of estuarine health that have been selected for their capacity to help us understand the dynamics and conditions of our estuaries. Some are biological, some are related to management activities, and this year, we are introducing three new indicators that explore the relationship between environmental conditions, social values, and human behavior.

Together, these indicators are sending a clear signal that our estuaries have declined and are under stress. Of the 16 environmental indicators, 12 are characterized as having cautionary or negative trends. The four indicators focused on management activities are split; two show positive progress toward management goals and two demonstrate only marginal headway. The new data we have begun to collect on social indicators will allow us to learn more about how human, economic, and social values influence the overall health of our estuaries. In general, it is clear that our estuaries, and the many benefits they provide for our communities, continue to experience significant stress.

Together, these indicators are sending a clear signal that our estuaries have declined and are under stress.

Where does the stress come from?

Estuaries are complex systems that respond to many compounding influences. Some of these are natural processes, largely beyond the control of citizens and decision makers. Others are byproducts of population growth and increased development. PREP monitors several indicators related to population growth including: housing permit approvals, impervious surfaces, and nutrient loading.

- **Demand for built infrastructure places increased pressure on our estuaries. This is reflected in the number of new housing unit permits approved each year (p. 41) and the growing expanse of impervious surfaces (p. 14) across the Piscataqua Region watershed.**
- **Nutrient loading is a critical stressor. Although we have been making impressive improvements since 2012, nutrients remain of high concern, particularly during rainy years where more runoff leads to increased loading (p. 16).**

How are our estuaries responding to stress?

Some indicators of estuarine health have been in decline for many years. As a consequence, our estuaries are becoming much less resilient to change and the stress it brings. This decline in their ability to bounce back is reflected in the changing condition of multiple indicators including the following:

- **Shellfish are at extremely low levels compared with populations in the 1980s and early 1990s. Critical habitats for clams in the Hampton-Seabrook Estuary and oysters in the Great Bay Estuary are close to being completely decimated (p. 32, 33).**
- **Eelgrass in the Great Bay Estuary shows an overall decline and, more importantly, a clear deterioration in its ability to recover from episodic stress (p. 23).**

What are we doing to help our estuaries be more resilient?

It is evident we value the importance of working together to protect our estuaries and natural resources across the Piscataqua Region. Since 2012, we have taken important steps together.

- **Land conservation efforts have increased across the region (p. 35), although more restoration efforts are needed to fully protect salt marshes (p. 25), eelgrass (p. 23), oysters (p. 32), and migratory fish (p. 34).**
- **Municipal efforts to reduce nutrient loading from point sources, such as wastewater treatment facilities, are an important step in the reduction of nutrient loading in the Great Bay Estuary (p. 16).**
- **Municipalities are being proactive with their stormwater regulations. Thirty communities in the Piscataqua Region have adopted, or are in the process of adopting, updated stormwater standards (p. 44).**
- **Piscataqua Region residents are stepping up to help. In 2016, stewardship volunteers donated more than 40,000 hours to protect water quality, wildlife, and natural resources (p. 46).**

Where do we go from here?

Our collective efforts to monitor, protect, and restore the health of our estuaries deserve celebration. We have shown innovation, diligence, and fortitude in our evolving approach to managing these precious resources. However, we cannot relax our diligence until we see clear evidence that our estuaries are recovering.

There is an urgent need for us to come together to make significant, strategic investments in increased monitoring and research, better shoreland protection policies, and infrastructure improvements. We cannot think in terms of a "silver bullet" action that will alleviate all of the stress on our estuaries. Instead, we must take cross-cutting steps that help our estuarine ecosystems be strong and healthy enough to rebound from the challenges we currently face and those we will encounter in the future (p. 48).

For more on what you can do to help make our estuaries more resilient, please see the companion pieces for this report: the *2018 State of Our Estuaries Municipal Guide* and the *2018 State of Our Estuaries Citizen Guide* at www.StateofOurEstuaries.org. In each you will find science-based actions you can take in your community and at home to protect water quality and the natural resources in our region.

ESTUARINE HEALTH: STRESS AND RESILIENCE

RESILIENCE: THE CAPACITY OF AN ECOSYSTEM TO ABSORB REPEATED DISTURBANCES OR SHOCKS AND ADAPT TO CHANGE WITHOUT CONTINUALLY DEGRADING AND FUNDAMENTALLY SWITCHING TO AN ALTERNATIVE STABLE STATE.[1]

PREP is one of many groups that work to protect and restore the estuaries in the Piscataqua Region. In our collective pursuit to understand what is driving the declining health of our estuaries, the debate has often centered on a single dynamic—the relationship between nitrogen and eelgrass loss. Nitrogen is an important factor that cannot be dismissed, but it is only one of many shocks and disturbances that impact our estuaries.[2] Some of these are slow-acting and chronic, others are episodic. Some are within our control, others much less so. All of these influences, however, act as stressors on estuarine health, and cannot be considered independently of one another. Some of the most significant include the following:

- ***Changing precipitation patterns:*** **Overall, our region is experiencing changing precipitation and more extreme storm events. Between 2004 and 2009, total annual precipitation levels remained above the 75th percentile (Figure 1). Since 2012, levels have been below the 25th percentile. Between 1996 and 2014, extreme precipitation (two inches or more in one day) in the Northeast was 53% higher than it was in the previous 94 years.[3] The 2006 Mother's Day Storm alone greatly increased levels of dissolved organic matter and brought salinity levels close to zero for five days.**

- ***Increasing colored dissolved organic matter (CDOM):*** **The entire Gulf of Maine is experiencing increases in CDOM from rivers as a result of the impacts of climate change, particularly increased precipitation.[4] CDOM, which is composed of decaying plant matter from the watershed, can significantly reduce light penetration and limit growth of eelgrass, phytoplankton, and seaweed.**

- ***Increased impacts of coastal acidification:*** **Coastal acidification has increased as a result of higher levels of carbon dioxide in the atmosphere. It is magnified by the increased frequency of extreme storms, which bring nutrient-rich freshwater into the coastal system. Nutrients can promote intense respiration (the digestion of dead algae by microbes), which consumes oxygen and produces carbon dioxide that leads to increased acidification. This negatively impacts many important species, from blue mussels and oysters to lobsters and flounder. It also has profound impacts on ecosystem health.[5]**

- ***Increasing sea-level rise and storm surge:*** **Since 1993, the rate of sea-level rise for New Hampshire has been 1.3 inches per decade, as compared with 0.7 inches per decade between 1900 and 1993. These higher sea-levels mean that current and future storm surge events will lead to much greater inundation, posing "significant risks to coastal systems by altering hydrology, sedimentation, and land-forming processes.[6]"**

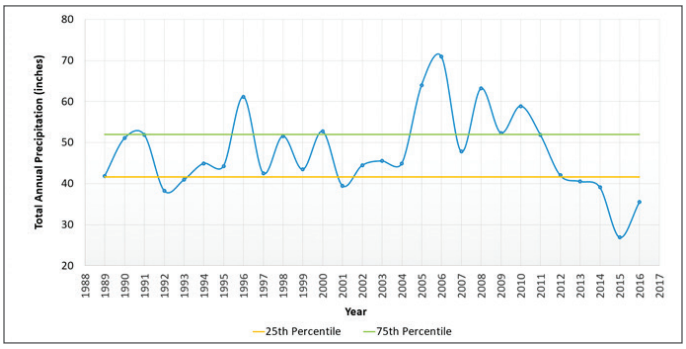


Figure 1 Precipitation in total inches from Greenland/Portsmouth Station. Data are averaged between Portsmouth (Pease) and Greenland weather stations.

Data Source: NOAA National Centers for Environmental Information

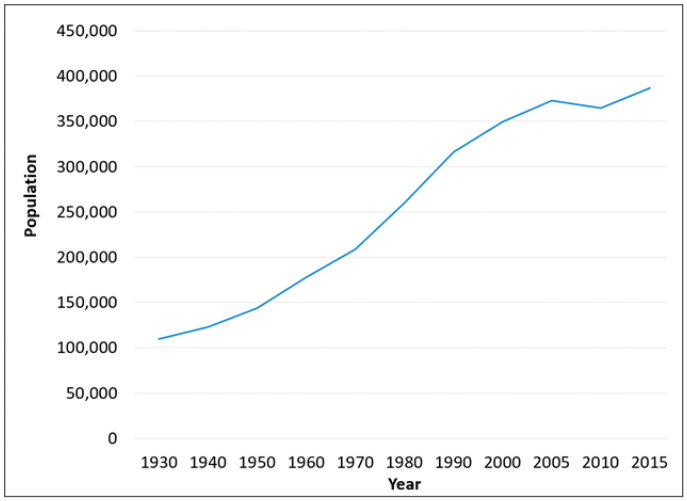


Figure 2 Human population of the 52 towns in the Piscataqua Region watershed; there are 42 communities in New Hampshire and 10 in Maine.

Data Source: U.S. Census Bureau

- ***Increasing human population:*** **Between 1990 and 2015, the combined population of the 52 towns in the Piscataqua Region watershed (10 in Maine and 42 in New Hampshire) grew by 38%, from 280,205 to 386,658 (Figure 2). A growing population can add stress to the environment through increased wastewater, fertilizers, toxic contaminants, and impervious surfaces.**

ESTUARINE HEALTH: STRESS AND RESILIENCE, CONT.

- ***Spread of impervious surfaces:*** **Between 1990 and 2010, impervious surfaces in our watershed increased by 120%[7] and have continued to increase over the last five years (p. 14). Combined with changes in precipitation, these impervious surfaces are sending more contaminants into our estuaries. During extreme storm events, they are delivered in large, disruptive pulses. Such rapid inflows of runoff not only add more nitrogen and toxics to the system, they also stir up estuarine sediments.**
- ***Increased nitrogen loading:*** **Before recent reductions from municipal wastewater treatment facilities (WWTFs), point source nitrogen loading levels had increased steadily between 1988 and 2012. In that time, non-point source (NPS) nitrogen loading also increased steadily, peaking between 2006 and 2008 due to the extreme precipitation that occurred during those years (p. 16).**

  At 43.6 tons per square mile (of tidal estuary surface area), nitrogen levels between 2012 and 2016 were much higher than the 14 tons per square mile threshold for eelgrass health indicated in a 2010 study of 62 New England estuaries.[8] While the Great Bay Estuary may have traits that make it more tolerant of high nutrient levels (such as high flushing rates), our system has three times the threshold level from that study, which is a concern.

  Nutrients fuel the growth of phytoplankton and seaweed and make it more difficult for light to reach eelgrass beds. In our system, monthly sampling of phytoplankton levels are most often in ranges considered "good" or "fair," though sometimes "poor" (p. 19). Seaweed percent cover at intertidal monitoring sites increased from 8% in 1980 to 19% in 2016 (p. 21).

  Excessive seaweed and phytoplankton growth also can lead to low dissolved oxygen levels. Low dissolved oxygen events continue to occur in our tributaries, but these are not necessarily caused by excess nitrogen (p. 22). Finally, excess nitrogen can lead to the organic enrichment of sediments, which limits abundance of benthic animals and shellfish and the growth of eelgrass.[9] It is unclear if this is happening in our system; we are still collecting and analyzing data on sediment conditions in the Great Bay Estuary.

Building estuary resilience in a time of change

There are many more stressors on estuarine health that need consideration, but we lack the data to track. These include disturbance by geese, green crabs, and other animals, and the cascading effects that come from the loss of large predatory fish, invasive species, and disease. It is critical to understand that all stressors—from extreme precipitation to disease—are additive and synergistic. Combined, they change each other's impacts in ways that make it very difficult to isolate the relationship between any one factor and a biological response.

Their collective impact, however, is evident in many of the indicators presented in this report. For example, oyster, clam, and eelgrass habitats decreased significantly over the last 25 years and do not show signs of rebounding (p. 32, 33 & 23). Without eelgrass and oyster habitat in the Great Bay Estuary, sediments and bits of plant and algal material (also known as "Total Suspended Solids" or "TSS") re-suspend more easily and may stay in suspension much longer (p. 15).

In the case of oysters (p. 32), it is acknowledged that disease (MSX and Dermo) has been the primary source of their deterioration. Resource managers locally—as well as in other parts of the world[10]—have recognized that we cannot limit our management actions to one primary stressor. However, we can help oysters become more resilient through restoration, providing more available substrate (shells) on which larvae can settle, or conducting oyster restoration (p. 38) in a way that encourages more vertical growth to help the oysters avoid being smothered by sediment.

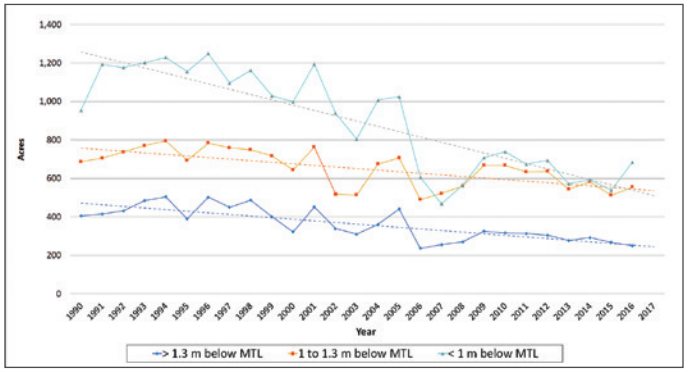


Figure 3 Acres of Eelgrass in Particular Depth Regimes in Great Bay. New Hampshire Department of Environmental Services analysis of loss of eelgrass by depth in Great Bay only. MTL = mean tide.

>1.3 m below MTL >1 to 1.3 m below MTL <1 m below MTL

Data Source: Eelgrass acres = Kappa Mapping, Inc. (for 2013 & 2016) and UNH Jackson Estuarine Laboratory (1990-2015). Bathymetry data from UNH Coastal & Ocean Mapping

In the Great Bay Estuary, eelgrass loss over time has been most pronounced in the deepest beds,[11] suggesting that lack of light is contributing to its decline (Figure 3). CDOM, TSS, and phytoplankton all combine to decrease water clarity and reduce the light that is available to eelgrass. In addition, precipitation and development influence the impact of all of these constituents on the health of our estuaries.

Some stakeholders tend to analyze these light-attenuating components separately, asking which of the three is the stressor on eelgrass. To help eelgrass recover, however, we cannot focus our management strategies on reducing the one factor that limits light the most as these stressors impact the system in an additive way;[12] a more comprehensive approach will be required.

It is also important to consider how eelgrass, seaweed, and phytoplankton compete for light and nutrients. Algae do not have roots like eelgrass and so they are dependent on nutrients in the water column. When algae are not limited by nutrients, as was indicated in a study of the green seaweed *Ulva* in 2010,[13] providing more light by reducing TSS or CDOM may not help eelgrass and instead lead to increases in seaweed and phytoplankton.

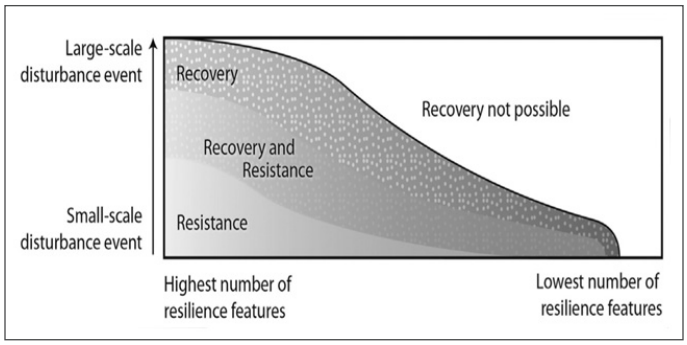


Figure 4 Resilience in Response to Disturbances. Resilience is comprised of resistance (light grey shade) and recovery (spotted fill) processes. Habitats with the highest number of resilience features (x axis) can resist and/or recover from large-scale disturbance events. As the number of resilience features declines, so does the capacity of the habitat to resist or recover from such disturbances.[16]

Given that our goal is healthy estuaries, we should consider taking actions to improve the overall resilience (Figure 4) of these systems. We may have little control over episodic events like extreme storms, but we can reduce the short-term and chronic impacts of these events by continuing to improve stormwater practices, conserve land, and better manage the buffer lands along the edges of our rivers, bays, and coast.[14]

We also can continue to work together to reduce nitrogen loading to increase resilience. The external reviewers (engaged by PREP's Technical Advisory Committee to analyze eelgrass stressors for the Great Bay Estuary) have indicated we should build on the significant reductions from municipal wastewater sources and focus on reducing non-point source (NPS) nitrogen, which accounts for 68% of the nitrogen load. (For a synthesis of this external expert review,[15] see sidebar).

As we work together on solutions, it is important that we recognize that the path back to healthy estuaries may not be the reverse of how we got here. Our estuarine resources and their stressors are different than they were 30 years ago. The impacts we have experienced are significant and recovery may be slow and unpredictable.[17] In light of this, we need to be prepared to invest in data collection and analysis that will allow us to better understand the impacts of the many stressors influencing the health of our estuaries, track the impacts of past management actions, and modify future strategies so they are as effective as possible.

EXTERNAL ADVISOR REVIEW OF STRESSORS IN GREAT BAY

In 2016 and 2017, external advisors were asked to provide input on which stressors to prioritize when managing for improved ecosystem health, with an emphasis on eelgrass. Using 44 different sources of information on the ecology of the Great Bay and Hampton-Seabrook estuaries, the external advisors made the following observations:

- **Eelgrass continues to recover partially, but it has not returned to its previous abundance. While returning to historic conditions may be possible, it will be challenging and it may require stressors to decrease to levels that are lower than those observed before eelgrass began to decline.**
- **Narrowly focusing on single stressors does not reflect the complexity of our estuarine systems.**
- **Despite encouraging reductions from wastewater treatment facilities, nitrogen loading levels are high enough that they should be considered an important stressor.**
- **To decide how much nitrogen reduction is enough, a thorough, quantitative ecosystem based model would be required.**
- **Based on available information, it is evident that a large fraction of the nitrogen entering the system comes from non-point sources. Given that only 2.6% of its watershed is occupied by wetlands, which buffer non-point sources of pollution, the Great Bay Estuary is extremely vulnerable to non-point source loadings.**
- **Eelgrass decline may relate to episodic stressors, such as storms, but it is equally plausible that chronic stressors, such as decreased water quality, may have limited the resilience of eelgrass to episodic disturbances. More comprehensive data is needed to better understand the interactive effects of these stressors.**

To read the complete external advisor report, please visit: http://scholars.unh.edu/prep/377 [18]

INDICATOR TABLE

Indicators are things we measure to characterize pressures on our estuaries, the conditions in our estuaries, and the steps we are taking to respond to challenges in our estuaries. The indicators PREP monitors are tied with PREP's Comprehensive Conservation and Management Plan (CCMP) and many include goals for management associated with them. Indicators do not stand alone, and many impact each other. To learn more about these important interactions refer to the *Estuarine Health: Stress and Resilience* section on p. 7. This report is organized with pressure indicators first, then condition indicators, followed by response indicators, and for the first time, it now includes social indicators. This list of indicators is not exhaustive and does not reflect every pressure, condition, response, or social factor that does or could exist for our estuaries. However, the list of indicators covers the major issues and provides a reasonably complete picture of the State of Our Estuaries.

PRESSURE INDICATORS — These measure some of the key human stresses on our estuaries.

CONDITION INDICATORS — These measure the current state of conditions in our estuaries.

RESPONSE INDICATORS — These track some key actions we are taking to restore our estuaries.

SOCIAL INDICATORS — These measure the social landscape that could impact environmental indicators.

TRENDS

Trends and their associated color drops are based on the entire data set for the indicator, and will vary by indicator.

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

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.

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

NO TREND — Demonstrates indicators that are too new to establish trends of any kind.

INDICATOR	STATUS	STATE OF THE INDICATOR	PAGE
Impervious Surfaces		In 2015, 5.6% of the land area of the Piscataqua Region watershed was covered by impervious surfaces. This is an increase of 1,257 acres of impervious cover or 0.2% of the land area since 2010.	14
Total Suspended Solids		Suspended solids at Adams Point have increased since 1989, but they have decreased at the Great Bay Station since 2002.	15
Nutrient Loading (Point-Sources)		Significant reductions in point source nitrogen loading have and are continuing to occurr at municipal wastewater treatment facilities.	16
Nutrient Loading (Non-Point Sources)		Non-point source loading has decreased, but low rainfall is a contributing factor.	16
Nutrient Concentration		Total nitrogen decreased at Adams Point but increased at the Chapman's Landing and Lamprey River stations. DIN decreased at the Oyster River and Upper Piscataqua stations while Chapman's Landing indicates an increasing trend.	18
Phytoplankton		Based on monthly sampling at low tide, four of the eight stations periodically—though infrequently—exhibit high (>20 ug/L) levels for chlorophyll-a. There are no statistically significant trends.	19
Seaweeds		At limited intertidal sampling sites, green and red seaweeds increased from 8% percent cover to 19% between 1980 and 2016. Two new invasive species are now the dominant red seaweeds.	21
Dissolved Oxygen		In 2015, at the Great Bay and Coastal Marine Laboratory datasondes, dissolved oxygen levels never fell below 6 mg/L. Low dissolved oxygen events occur in all the tidal rivers. There are no clear trends.	22
Eelgrass		Eelgrass acreage in the Great Bay is 31% less than when first mapped in 1981.	23
Salt Marsh		Between the early 1900s and 2010, over a thousand acres of salt marsh area was lost in the Piscataqua Region watershed. As of 2017, approximately 5,521 acres of salt marsh habitat remain.	25
Bacteria		Between 1989 and 2016, dry weather concentrations of bacterial indicators of fecal pollution in the Great Bay Estuary have typically fallen 67% to 93% due to pollution control efforts in most, but not all areas.	27
Shellfish Harvest Opportunities		The percentage of possible acre-days between 2012 and 2016 was 80% and 66% for the Great Bay and Hampton-Seabrook estuaries, respectively, continuing the long-term trend of gradual increase in acre-days.	28
Beach Advisories		Across the 17 tidal beaches in the Piscataqua Region watershed, beach advisory days occurred less than 1% of beach-days from 2012 to 2016. There are no statistically significant trends.	29
Toxic Contaminants		Most concentrations of measured metals and organic chemicals in blue mussel tissue from 1991-2016 are declining or not changing. Mercury and PCB levels remain high enough to merit continued concern. Many emerging contaminants are not yet monitored consistently.	30
Oysters		The number of adult oysters decreased from over 25 million in 1993 to 1.2 million in 2000. Since 2012, the population has averaged 2.1 million oysters, which is 28% of the PREP goal.	32
Clams		The clam population in 2015 was 1.4 million and the percentage of clams infected by disease has significantly increased.	33
Migratory Fish		Migratory river herring returns to the Great Bay Estuary increased 69% between 2012 and 2016; however, river herring returns have sharply declined for the Oyster and Taylor Rivers. No statistically significant trends.	34
Conservation Lands (General)		As of May 2017, 130,302 acres have been conserved (15.5% of the total land area) representing an increase of 5% in new land area coming under conservation (41,555 acres) since 2011.	35
Conservation Lands (Focus Areas)		In 2017, 34.4% of Conservation Focus Areas (CFAs) in New Hampshire and 14.2% of CFAs in Maine were conserved, for a combined impact of 40.9% of progress toward the PREP goal.	37
Oyster Restoration		More than 26 acres of oyster restoration efforts have taken place since 2011. For recent efforts, the actual area covered by oyster shell has decreased by an average of 63%, while one site increased by 30%.	38
Migratory Fish Restoration		In 2016, 42% of the historical distribution for river herring in the Piscataqua Region has been restored. Additionally, removal of the Great Dam in Exeter in July 2016 has improved/enhanced river herring passage on the Exeter River.	39
Housing Permit Approvals		There were a total of 19,483 multi-family and single-family permits issued between 2000-2015 for the 42 New Hampshire watershed towns. There were 331 permits issued for the 10 Maine watershed towns in 2015.	41
Stormwater Management Effort		As of July 2017, of the 42 NH watershed towns - 8 have adopted the complete set of standards, 7 are in the process of adoption, 5 have partial or different, and 22 have not adopted. The 10 ME towns adhere to a state-level standard.	44
Stewardship Behavior		In 2016 there were 38,878 volunteer hours logged in the watershed through the work of six selected New Hampshire-based groups. In 2016, there were 524 people who signed up for 96 events through the Stewardship Network New England.	46

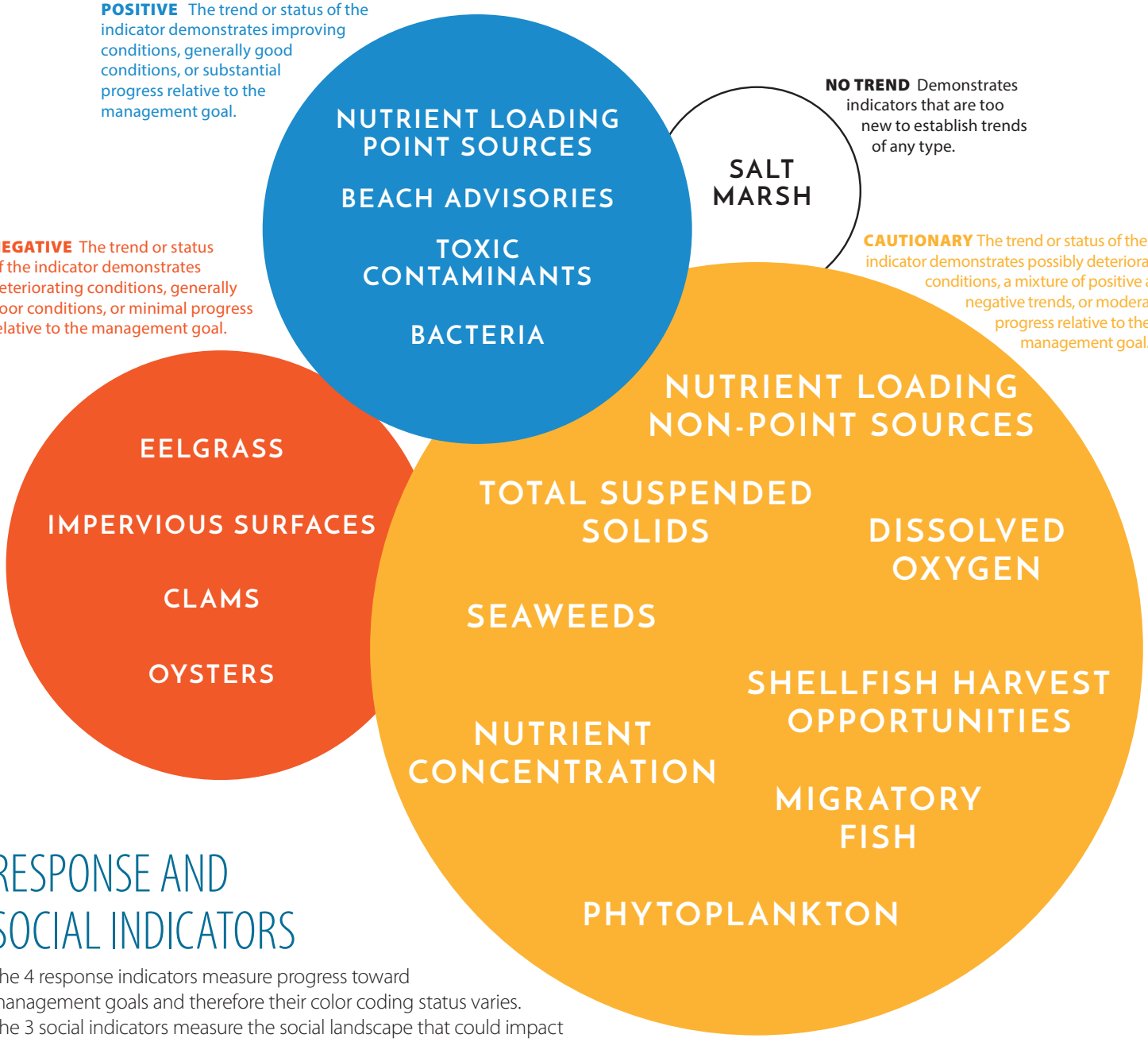
INDICATOR SUMMARY

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

NO TREND Demonstrates indicators that are too new to establish trends of any type.

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

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.



RESPONSE AND SOCIAL INDICATORS

The 4 response indicators measure progress toward management goals and therefore their color coding status varies. The 3 social indicators measure the social landscape that could impact environmental indicators.

- CONSERVATION LANDS (GENERAL)
- CONSERVATION LANDS (FOCUS AREA)
- OYSTER RESTORATION
- MIGRATORY FISH RESTORATION
- HOUSING PERMIT APPROVALS
- STORMWATER MANAGEMENT EFFORT
- STEWARDSHIP BEHAVIOR

HAMPTON BEACH, NH | PHOTO BY A. LYON

IMPERVIOUS SURFACES

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

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

WHY THIS MATTERS Impervious surfaces are man-made features, such as parking lots, roads, and buildings, that do not allow precipitation to infiltrate into the ground. When precipitation falls on impervious surfaces, it runs off those surfaces carrying pollutants and sediments into nearby waterways. Watersheds reach a tipping point around 10% impervious cover[19], beyond which water quality impacts become increasingly severe.

PREP GOAL: NO INCREASE IN THE NUMBER OF WATERSHEDS AND TOWNS WITH GREATER THAN 10% IMPERVIOUS COVER AND NO DECREASE IN THE NUMBER OF WATERSHEDS AND TOWNS WITH LESS THAN 5% IMPERVIOUS COVER.

EXPLANATION The 2015 update to this dataset represents a new, improved baseline for impervious surface across the region due to the use of higher resolution imagery and different processing methodology. Impervious surface values reported in the *2013 State of Our Estuaries* report using 30-meter satellite imagery (63,214 acres) were greater than those reported using the improved and more accurate 1-foot orthoimagery (45,377 acres) in this report. In 2015, 46,634 acres (5.6% of the land area) of impervious surface were mapped representing an increase of 1,257 acres (0.2% of the land area) since 2010 (45,377 acres).

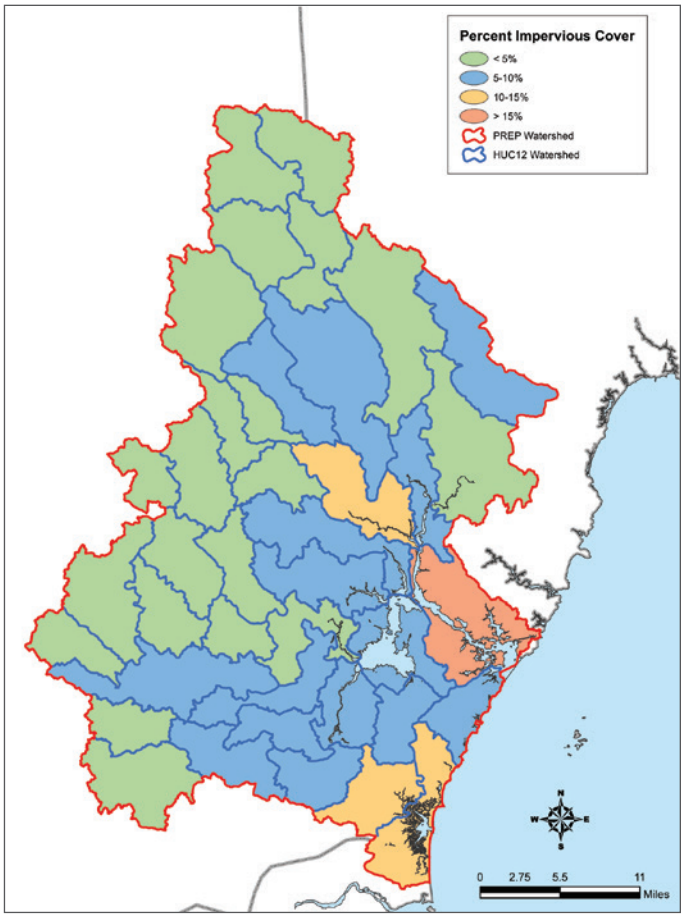


Figure 1.1 Percent impervious cover by subwatershed (HUC-12) as of 2015.
Data Source: UNH Complex Systems Research Center

Watersheds with greater than 10% impervious surface coverage of land area are around the Hampton-Seabrook Estuary, the Piscataqua River, and the Route 16 corridor along the Cocheco River. Impervious surfaces in 2015 in each of the Piscataqua Region subwatersheds are shown as a percentage of land area in Figure 1.1.

Communities with the highest reported impervious surface percentages were found in Portsmouth (26.7%), New Castle (20%), and Seabrook (20%), while the largest increase of impervious surfaces between 2010 and 2015 occurred in Rochester (122 acres), Wells (64 acres), Seabrook (64 acres), Dover (56 acres), York (42 acres), and Sanford (39 acres). Communities with the smallest increases in impervious surfaces occurred in Madbury (4 acres), New Castle (2 acres), and Brookfield (2 acres). Small increases in impervious surfaces may be a result of limited availability of buildable lots. Town-by-town information on impervious surfaces in 2015 is shown in Figure 1.2.

Between 2010 and 2015 population in the Piscataqua Region watershed increased 6% (21,760 people), and impervious surfaces increased 2.7% (1,257 acres). For every one person increase in population, impervious surface increased by .06 acres. However, as shown in Figures 1.1 and 1.2, the amount of impervious cover is not evenly spread across the watershed. For more discussion on population and housing trends in the watershed refer to the Housing Permit Approvals section p. 41.

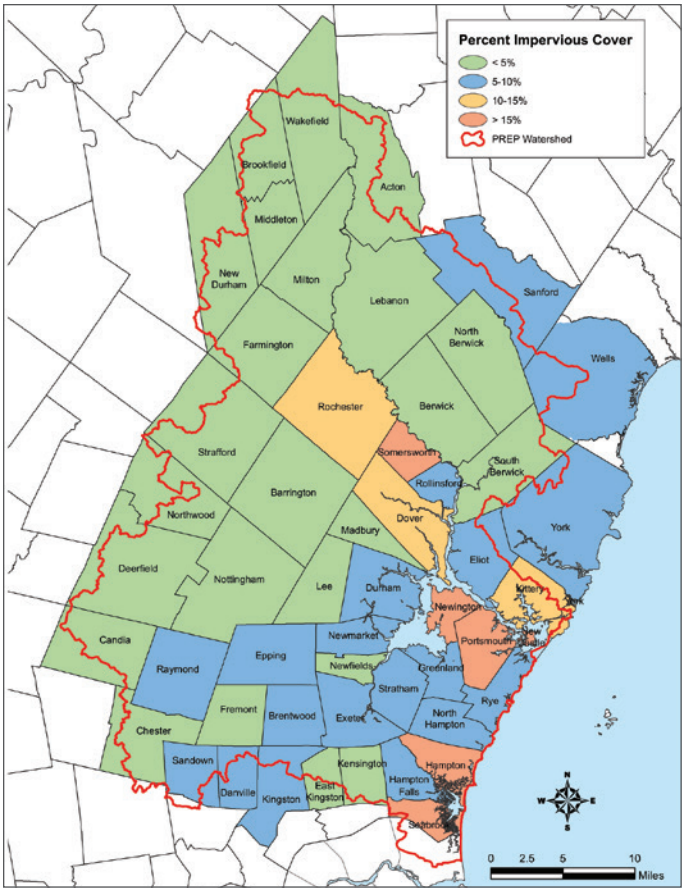


Figure 1.2 Percent impervious cover by town as of 2015.

Data Source: UNH Complex Systems Research Center

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

PLOWED SNOW PILE ON THE PIERCE ISLAND SALT MARSH, PORTSMOUTH, NH
PHOTO BY: J. FARRELL

TOTAL SUSPENDED SOLIDS

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

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

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

PREP GOAL: NO INCREASING TRENDS FOR TOTAL SUSPENDED SOLIDS.

EXPLANATION Total suspended solids have increased at Adams Point since 1989 (Figure 2.1). The average median value for the first 13 years of the dataset (1989-2002) was 12.0 mg/L. For the second half of the data set (2003-2015), the average median value increased to 22.9 mg/L, an increase of 90%. In contrast, suspended solids have remained relatively stable at the Great Bay station since 2002.

Continued

Total Suspended Solids, cont.

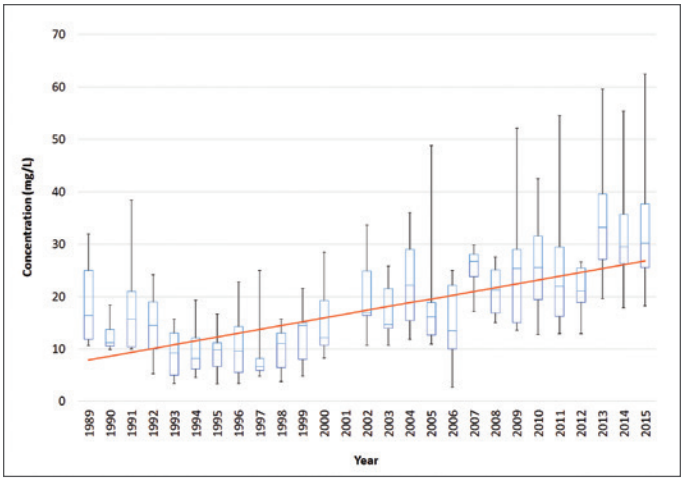


Figure 2.1 Total suspended solids at Adams Point Station. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Year 2001 not included due to missing data.

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

In 2015, the median concentration was 14.1 mg/L (Figure 2.2).

More research is necessary to understand the source and transport of sediments in the Great Bay Estuary. 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 tributaries or the estuary shores.

Higher suspended solids concentrations have the potential to harm eelgrass and oysters. Anything that reduces light to eelgrass leaves can add stress. In addition, sediment build-up on leaves can inhibit gas exchange. Oyster monitoring efforts show that oyster reefs that do not build high enough above the estuary floor can be smothered by sediment deposits.

It is important to acknowledge, however, that a certain amount of sediment supply is necessary to maintain salt marsh elevations, and sediment supply is a key factor in determining salt marsh resilience to rising sea-level and potential migration.

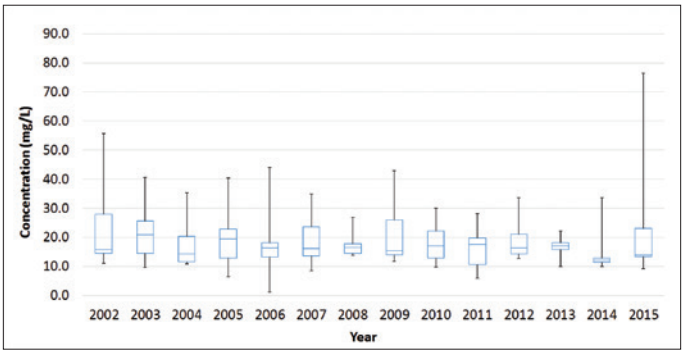


Figure 2.2 Total suspended solids at Great Bay Station. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values.

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

PRESSURE INDICATOR
CONDITION INDICATOR
RESPONSE INDICATOR
SOCIAL INDICATOR

NUTRIENT LOADING

How much nitrogen is coming into the Great Bay Estuary?

Total nitrogen loading from 2012 to 2016 was 903 tons per year, which is 26% percent lower than the 2009 to 2011 levels (1,224 tons per year). Low rainfall and corresponding streamflow during this period, as well as significant reductions in nitrogen loading at municipal wastewater treatment facilities, are the primary reasons for this decrease. Since the human population and impervious cover continue to increase, nitrogen management remains a high priority.

WHY THIS MATTERS Nitrogen is one of many nutrients that are essential to life in the estuaries. However, high levels of nitrogen may cause problems like excessive growth of seaweed and phytoplankton. When these organisms die, bacteria and other decomposers use the available oxygen to break down the organic matter, decreasing oxygen availability for other organisms like fish. In addition, excessive algal growth can have negative impacts on sediment quality, seagrass, shellfish, and benthic invertebrates. Other important nutrients, such as phosphorus, are addressed in the *State of Our Estuaries Environmental Data Report*.[20]

PREP GOAL: MANAGE NUTRIENT LOADS TO THE ESTUARIES AND THE OCEAN TO MINIMIZE ADVERSE, NUTRIENT-RELATED CONSEQUENCES.

EXPLANATION The average annual load of total nitrogen into the Great Bay Estuary from 2012 to 2016 was 903.1 tons per year (Figure 3.1). In 2016, the total nitrogen load was 707.8 tons per year, the lowest since consistent monitoring of loads began in 2003. Before 2003, there were three studies that assessed nitrogen loading to the Great

Bay Estuary; they relied on data collected between 1987 and 1996[21] and estimated nutrient loading at approximately 715 tons per year. These three studies all used different methods from each other and from the current approach, but yielded very similar results.

Figure 3.1 indicates that, since 2003, most of the variability relates to nitrogen from non-point sources. Non-point source nitrogen enters our estuaries in two major ways: 1) from stormwater runoff, which carries nitrogen from atmospheric deposition (including mobile transportation sources – cars, trucks, trains; and stationary stack emissions – smoke stacks), fertilizers, and animal waste to the estuaries; and 2) from groundwater contribution, which carries nitrogen from septic systems, sewer leakage, and infiltrated stormwater runoff into streams, rivers, and the estuary itself.[22, 23] These non-point sources (NPS) accounted for 606.6 tons per year or 67% of the nitrogen load for 2012-2016 (Figure 3.2). It is important to understand that NPS loads are much more difficult to manage than point source loads because they come from a variety of sources, many of which are controlled by private land owners.

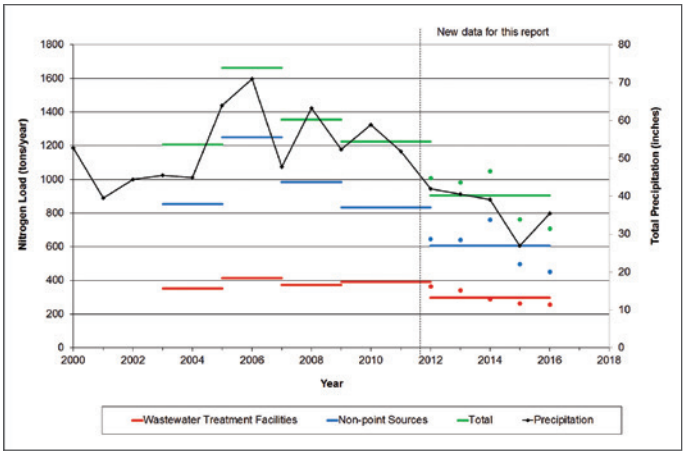


Figure 3.1 Nitrogen loads to the Great Bay Estuary, shown separated by source as well as the total nitrogen load. Precipitation data are averaged between Portsmouth (Pease) and Greenland weather stations. Colored circles indicate annualized loads for 2012 through 2016.

Data Source: NH Water Resources Research Center. Load estimates from 2003-2011 from NHDES (2010)

In addition, there are 17 municipal wastewater treatment facilities (WWTFs) that discharge treated wastewater into the bay or into rivers that flow into the bay. Point sources of nitrogen from these WWTFs account for 296.4 tons per year or 33% of the total nitrogen load for 2012-2016 (Figure 3.2). Of the 903.1 tons of total nitrogen entering the bay annually from 2012-2016, 506.0 tons were dissolved inorganic nitrogen (DIN), which is the most biologically available form of nitrogen. The DIN load was approximately evenly split between point and non-point sources (Figure 3.3). However, during the summer months when plant and algae growth is highest, point sources from WWTFs dominate DIN loading.[24, 25]

The highest loads since 2003 were seen in the 2005 to 2007 period (1,662.4 tons per year), a time that coincides with the highest total annual precipitation values (Figure 3.1). In comparison, the 2012 to 2016 period exhibited lower rainfall (Figure 3.3), a contributing factor to the 27% decrease in NPS loading since the 2009-2011 period. This underscores the association between nitrogen load-

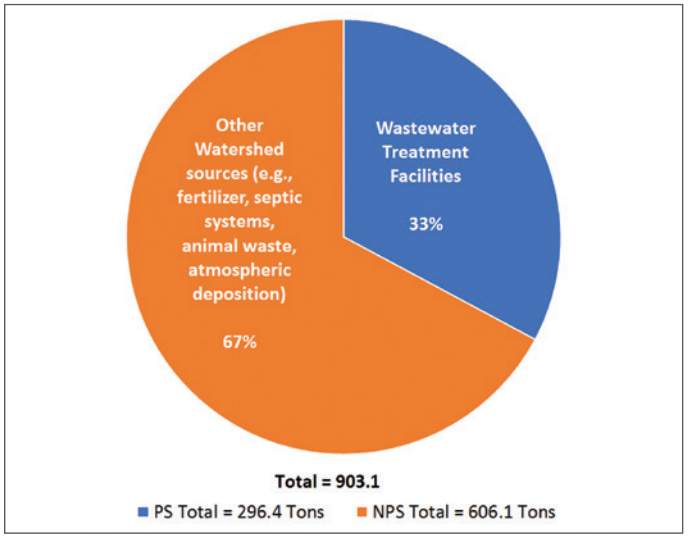


Figure 3.2 Total nitrogen loads from different sources (2012 to 2016).

Data Source: NH Water Resources Research Center

ing and run-off. Precipitation records[26] (see Figure 1, p. 7) and forecasts[27] suggest that our region will continue to see periods of extreme highs and lows, which will continue to impact non-point source load.

The nitrogen load from WWTFs for 2012-2016 was 296.4 tons, a decrease of 24% since the 2009-2011 period. In 2015 and 2016, the nitrogen load from WWTFs was 264.3 and 256.2 tons per year, respectively (Figure 3.1). Municipalities have made recent, substantial improvements to their WWTFs to reduce the amount of total nitrogen they discharge. Rochester, Dover, and Newmarket have recently completed major upgrades; Durham has reconfigured its facility; and Portsmouth, Newington, and Exeter are in the process of upgrading their treatment plants. Each of these upgrades should result in less nutrients in wastewater effluent.

See the *Estuary Health: Stress & Resilience* section, p. 7 for more on how nitrogen loading relates to other indicators, such as phytoplankton, seaweed, and eelgrass.

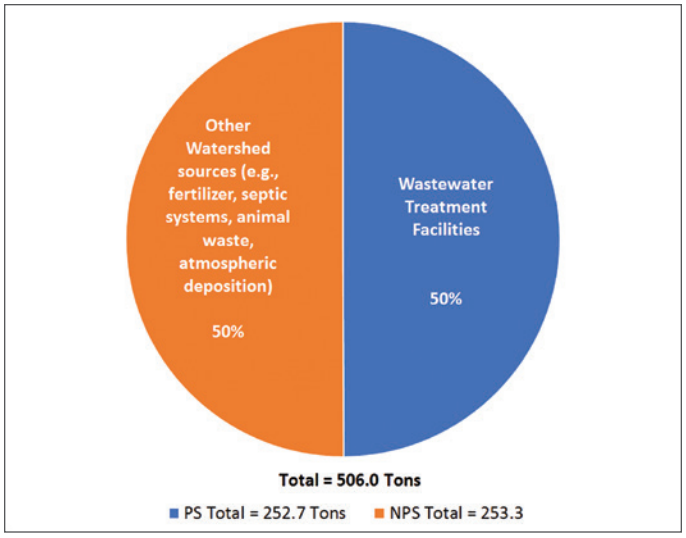


Figure 3.3 Dissolved inorganic nitrogen loads to Great Bay Estuary from different sources (2012-2016).

Data Source: NH Water Resources Research Center

NUTRIENT CONCENTRATION

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

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

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

PREP GOAL: NO INCREASING TRENDS FOR ANY NITROGEN SPECIES.

EXPLANATION ***Total Nitrogen (TN)***: Includes both dissolved inorganic nitrogen (DIN) and nitrogen contained in particulate and dissolved organic matter, and is considered to be a more accurate measure of the nitrogen status of an estuary than DIN alone. TN at Adams Point shows a significant decreasing trend (Figure 4.1), but it is important to note that the time series begins relatively recently, in 2003. Since 2012, median values ranged from 0.23mg/L to 0.30mg/L over the sample season for TN at Adams Point. Figure 4.1 indicates that the years 2005, 2008, and 2015 experienced TN concentrations above 0.6 mg/L.

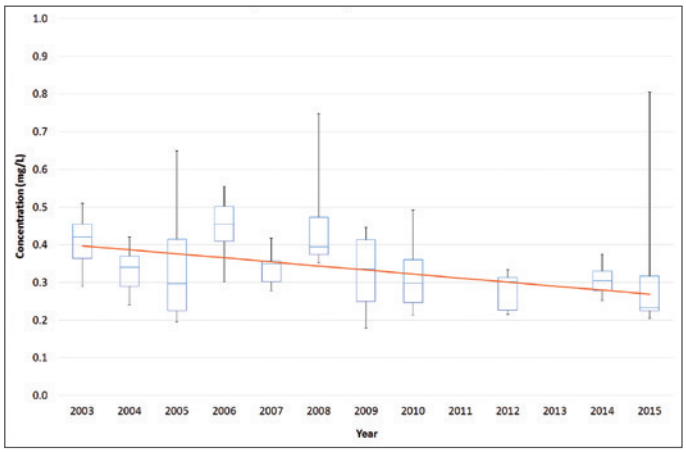


Figure 4.1 Total nitrogen at Adams Point. Box and whisker plots of total nitrogen concentrations (collected monthly, April through December, at low tide) between 2003 and 2015. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Years 2011 and 2013 not included due to missing data.

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

TN values at the Lamprey River and Chapman's Landing stations (see Monitoring Map p. 49) show a significantly increasing trend, with average values over the last reporting period (2009 - 2011) of 0.52 and 0.90 mg/L, respectively. Average values for other stations were: 0.77 mg/L (Squamscott River), 0.35 mg/L (Great Bay), 0.52 mg/L (Oyster River), 0.44 mg/L (Upper Piscataqua), and 0.24 mg/L (the Coastal Marine Laboratory in Portsmouth Harbor).

Dissolved Inorganic Nitrogen (DIN): At Adams Point, median values for DIN for 2012 to 2015 ranged from 0.04 to 0.1 mg/L comparable to median values for the years 1974 to 1981 (Figure 4.2). For reference, the *EPA National Coastal Assessment Condition Report* categorizes values less than 0.1 as "good." Other categories include "fair" (0.1 to 0.5 mg/L), and "poor" (greater than 0.5 mg/L).[28, 29]

The Oyster River and Upper Piscataqua River stations both showed statistically significant decreasing trends for DIN, with average values since 2012 at 0.18 and 0.04 mg/L, respectively. In contrast, Chapman's Landing showed a statistically significant increasing trend

with average values since 2012 at 0.48 mg/L. Average values for other stations were: 0.37 mg/L (Squamscott River), 0.21 mg/L (Lamprey River), 0.08 mg/L (Great Bay), and 0.09 mg/L (Coastal Marine Lab).

Nutrient concentrations in the water are affected by nutrient loading from the watershed. As noted in the Nutrient Loading Section (p. 16), loadings since 2012 have been reduced in part due to reductions at municipal wastewater treatment facilities. Additionally, loading has been reduced due to consecutive years of low annual rainfall amounts and low occurrence of extreme rainfall events, which equate to less non-point source loading from run-off.

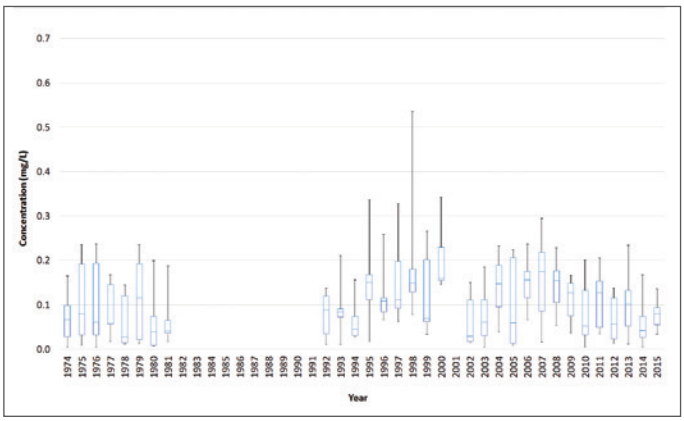
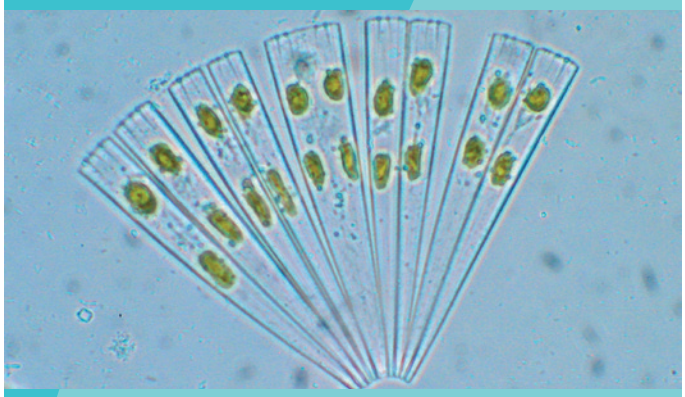


Figure 4.2 Dissolved inorganic nitrogen (DIN) at Adams Point. Box and whisker plots of dissolved inorganic nitrogen (DIN) concentrations (collected monthly, April through December, at low tide) between 1974 and 2015. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Some years omitted due to missing data.

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

ESTUARINE NUTRIENT CONCENTRATION DATA ARE COLLECTED IN THE FIELD BY UNH RESEARCHERS ON A MONTHLY BASIS | PHOTO BY E. LORD

PHYTOPLANKTON



How have phytoplankton concentrations changed over time?

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

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

PREP GOAL: NO INCREASING TRENDS FOR PHYTOPLANKTON.

EXPLANATION National assessments note that less than 5 ug/L chlorophyll-a (chl a) is considered "good," between 5 and 20 ug/L is considered "fair," and above 20 ug/L is considered "poor."[30, 31] For the years 2012 to 2015, monthly sampling results suggest that, much of the time, chl a levels in the Great Bay Estuary were within ranges regarded as "good" or "fair", but that they sometimes exceeded 20 ug/L. As noted in Figure 5.1, changes since the last reporting period (2009–2011) vary, depending on the sampling station.

All of the data reported below were collected at low tide, when daily concentrations of chl a tend to be highest. None of the eight stations sampled on a monthly basis show a statistically significant

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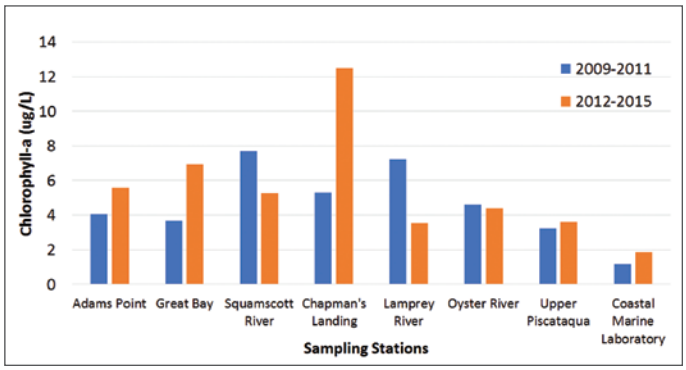


Figure 5.1 Reporting average concentrations by sampling station.

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

trend (Figure 5.1). At Adams Point (Figure 5.2), between 2012 and 2015, median chl a levels ranged from 2.9 to 4.0 ug/L and maximum values ranged from 5.7 to 25.2 ug/L. At the Great Bay station (Figure 5.3), between 2012 and 2015, median levels ranged from 2.9 to 8.3 ug/L and maximum values ranged from 8.4 to 22.1 ug/L.

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

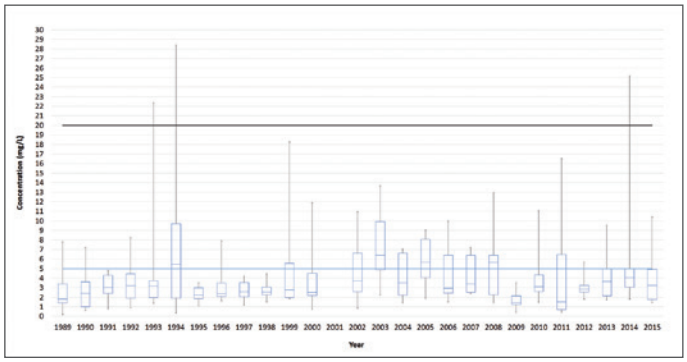


Figure 5.2 Chlorophyll-a concentrations at Adams Point. Box and whisker chart of data collected at low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Levels between the blue and the black line are considered "fair." Levels above the black line are considered "poor."

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

Other parts of the Great Bay Estuary—in addition to the eight stations reported here—also show counts in excess of 20 ug/L. For example, Little Bay registered 25.2 ug/L in 2014 and the Cocheco River indicated a maximum of 28.9 ug/L in 2015.[32]

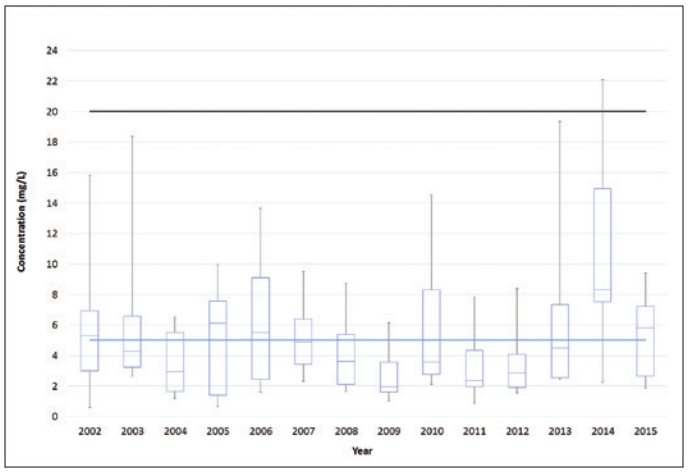


Figure 5.3 Chlorophyll-a concentrations at Great Bay. Box and whisker chart of low tide only. The horizontal line in each box is the median. Boxes encompass the middle 50% of the data points. Upper and lower vertical lines show the complete range of data values. Levels between the blue line and the black line are considered "fair." Levels above the black line are considered "poor."

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

PROCESSING WATER SAMPLES AT THE UNH JACKSON ESTUARINE LABORATORY
PHOTO BY E. LORD

SEAWEEDS

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

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

WHY THIS MATTERS Seaweeds are an important and critical group of estuarine primary producers, but many of the factors affecting estuaries globally (e.g., climate change, sedimentation, nutrient pollution) also accelerate the growth of some seaweeds.[33, 34] In these situations, seaweeds can grow so abundant that they shade eelgrass. Since they can "bloom"—that is, grow and die very quickly—they can also negatively impact sediment conditions by decomposing on the estuary floor.[35] This can negatively impact shellfish and benthic invertebrates as well as eelgrass.

PREP GOAL: NO INCREASING TRENDS FOR SEAWEEDS.

EXPLANATION Great Bay Estuary seaweeds can be categorized as brown, green, and red. This indicator focuses on changes in the red and green seaweeds, which are much more abundant in the subtidal areas (those areas always covered by water) and are more likely to compete with eelgrass. However, there are only a few data points in the subtidal areas of the Great Bay Estuary that allow for assessment of changes in the abundance of these seaweeds where impacts on eelgrass could also be assessed (Figure 6.2).

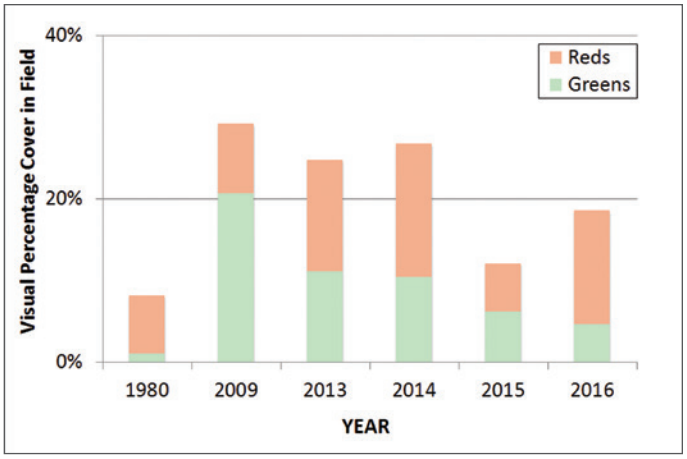


Figure 6.1 Percent cover of red and green seaweed at selected intertidal sites in the Great Bay Estuary.

Data Source: UNH Jackson Estuarine Laboratory

The mean percent cover of green and red seaweeds (combined) at a limited number of sampling sites in the Great Bay Estuary was 8% in 1980 but increased to 19% by 2016 (Figure 6.1). For green seaweeds, this increase includes the presence of both native and invasive species of *Ulva*. It is notable that no invasive species of *Gracilaria* (a red seaweed) were seen in 1980, but now two major invasive Asiatic red seaweeds (*Gracilaria vermiculophylla* and *Dasysiphonia japonica*) along with a native species (*Gracilaria tikvahiae*) dominate the red seaweeds.[36]

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

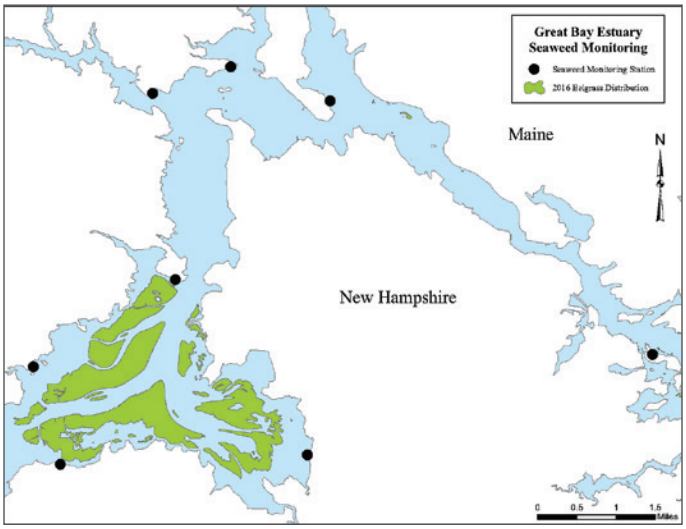


Figure 6.2 Locations of the eight intertidal seaweed monitoring sites are designated by the black circles. Green areas indicate mapped eelgrass habitat from 2016.

DISSOLVED OXYGEN

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

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

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

PREP GOAL: ZERO MEASUREMENTS BELOW 5 MG/L FOR DISSOLVED OXYGEN CONCENTRATION.

EXPLANATION National ecosystem health thresholds for dissolved oxygen (DO) concentrations range from 2 mg/L to 5 mg/L, depending on the region or state.[37] The threshold of 5 mg/L is considered protective of all organisms.[38] Dissolved oxygen levels in Great Bay at the central datasonde and in Portsmouth Harbor at the Coastal Marine Laboratory (See Monitoring Map p. 49) remain consistently above 5 mg/L. The most recently collected data from 2015 show that DO concentrations never fell below 6 mg/L at these two sites.

The tidal portions of the major tributary rivers continue to experience many days when the minimum DO concentration value is below 5 mg/L. No long-term trends are notable at any stations, as exemplified by the data from the Salmon Falls River and Squamscott River datasondes (Figures 7.1 and 7.2). These datasondes were used in this long-term trend analysis because they had complete datasets going back as far as 2004, and because they represent different parts of the estuary.

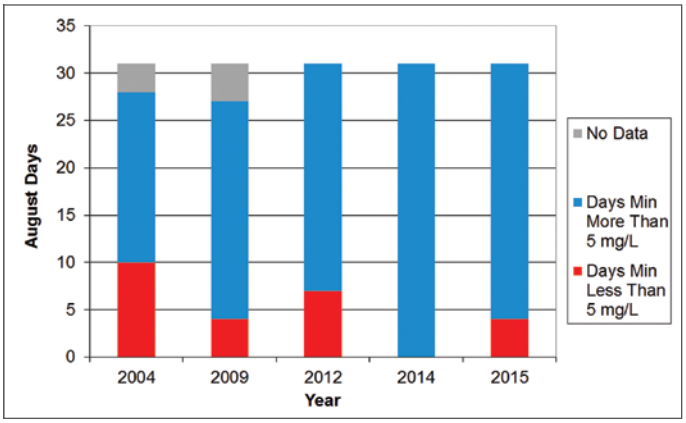


Figure 7.1 Number of days when minimum dissolved oxygen (DO) fell below 5 mg/L at the Salmon Falls datasonde. Particular years shown have the most complete datasets.

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

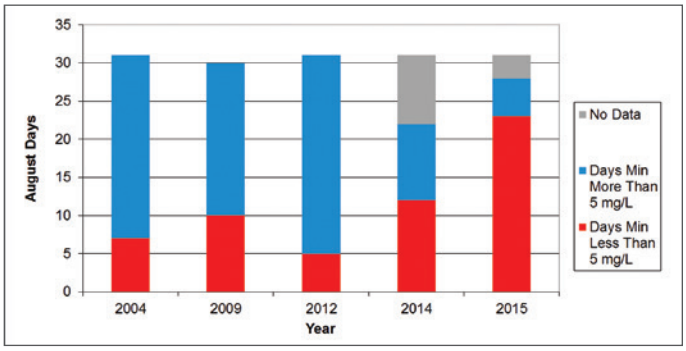


Figure 7.2 Number of days when minimum DO fell below 5 mg/L at the Squamscott River datasonde. Particular years shown have the most complete datasets.

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

It is important to note not only the number of low DO events but also the duration of those events because there are implications for organisms (such as small invertebrates in the sediment) that cannot move quickly to areas with higher DO levels. In 2015, the Lamprey and Squamscott Rivers had the highest number of low DO events, the majority of which took place in August and September. Figure 7.3 shows data taken every 15 minutes throughout August 2015 for the Squamscott River; this figure indicates that DO concentrations fell below 5 mg/L most days during the month, and that there was less than 5 mg/L for 12% of the month. These low DO events lasted anywhere from one to four hours.

In August 2015, 73% of the time Lamprey River DO levels were below 5 mg/L and stayed below the threshold for more than 24 hours on two occasions (Figure 7.4) with the second occasion lasting almost 168 hours (7 days). A 2005 study[39] of the Lamprey River concluded that the datasonde readings were reflective of river conditions, but that density stratification—when salt water and fresh water stack in layers without mixing—was a significant factor in the low DO conditions in the Lamprey River.

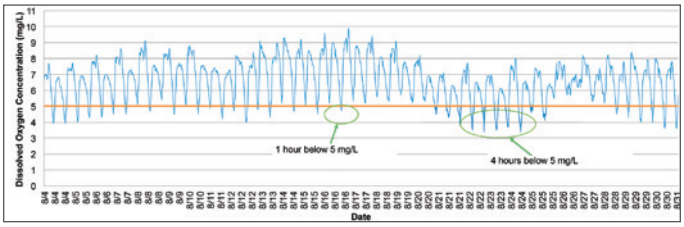


Figure 7.3 Dissolved oxygen concentration measurements at the Squamscott River datasonde, August 2015. Measurements were taken every 15 minutes. The orange line marks the 5 mg/L threshold.

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

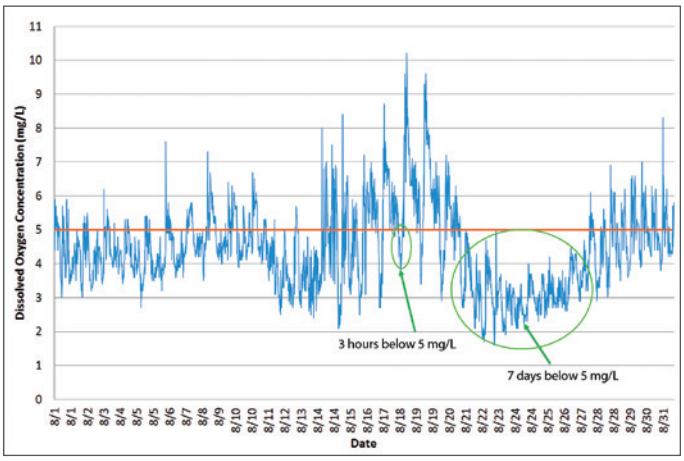


Figure 7.4 Dissolved oxygen concentration measurements at the Lamprey River datasonde, August 2015. Measurements were taken every 15 minutes. The orange line marks the 5 mg/L threshold.

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

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

Finally, this analysis does not include all DO data collected in the Great Bay Estuary. For information on other data, please see the *2017 Technical Support Document for Aquatic Life Use Support* from NH Department of Environmental Services.[40]

EELGRASS

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

The Great Bay Estuary, which includes seven tidal tributary rivers, the Piscataqua River, and Portsmouth Harbor, had 1,625 acres of eelgrass in 2016, which is 54% of the PREP goal of 2,900 acres. In Great Bay, there were 1,490 acres of eelgrass, which is a 31% reduction from 1981, the first year that data was collected. Over time, eelgrass habitat indicates a diminishing ability to recover from periodic disturbances, such as stress from extreme storms.

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

PREP GOAL: INCREASE EELGRASS DISTRIBUTION TO 2,900 ACRES AND RESTORE CONNECTIVITY OF EELGRASS BEDS THROUGHOUT THE GREAT BAY ESTUARY BY 2020.

Continued

EXPLANATION In 2016, there were 1,625 acres of eelgrass in the Great Bay Estuary. Figure 8.1 shows a statistically significant decreasing trend in eelgrass acreage since 1996 when the data became available for the entire estuary. The year 1996 also represents the highest amount of eelgrass on record for the Great Bay Estuary; this must be considered when evaluating the trend. Figure 8.2 compares 2016 eelgrass coverage with the acreage of eelgrass in 1996.

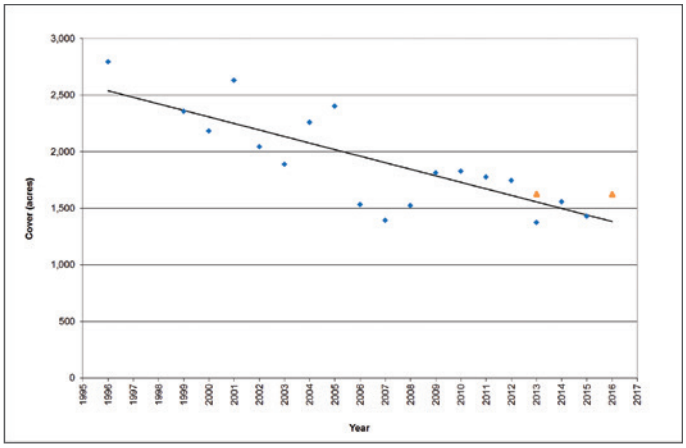


Figure 8.1 Eelgrass cover in the Great Bay Estuary.

Data Source: Kappa Mapping, Inc. (for years 2013 & 2016) and UNH Jackson Estuarine Laboratory (1996-2015). In 2013, the two data sources were averaged for the linear regression

For Great Bay only, in contrast, data exists going back to 1981 (Figure 8.3). In 2016, there were 1,490 acres of eelgrass in Great Bay. The trend is not statistically significant; however, there is broad scientific consensus that eelgrass in the Great Bay shows a consistent pattern of being less and less able to rebound from episodic stresses. Current levels of eelgrass in the Great Bay are 31% reduced from 1981 levels. Connectivity of the remaining eelgrass habitat in the Great Bay Estuary is critical for habitat health and expansion. See figure 8.2 for 2016 eelgrass distribution.

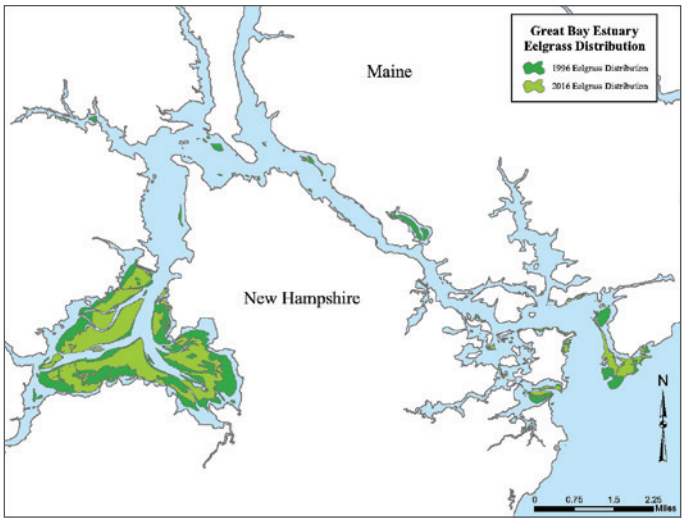


Figure 8.2 Map of eelgrass cover for 1996 and 2016. Map based on 2016 data from Kappa Mapping, Inc. and 1996 data provided by the UNH Jackson Estuarine Laboratory. To be counted as present, eelgrass must cover at least 10% of a given area. Therefore, this map does not distinguish between areas with dense versus sparse cover. With negligible exceptions, the 2016 areas also existed in 1996; the darker shade of green therefore represents areas that have been lost since 1996.

Data Source: Kappa Mapping, Inc. (for 2016) and UNH Jackson Estuarine Laboratory (for 1996)

In Portsmouth Harbor (Figure 8.4), there were 87.4 acres of eelgrass in 2016. The entire time series (1996-2016) shows a statistically significant decreasing trend. On a positive note, the number of acres in 2016 was higher than the previous eight years.

The causes of eelgrass decline in the Great Bay continue to be the subject of great interest. Worldwide, the main causes of temperate (between the tropics and the polar regions) seagrass loss are nutrient loading, sediment deposition, sea-level rise, high temperature, introduced species, biological disturbance (e.g., from crabs and geese), and wasting disease[41]. Toxic contaminants such as herbicides that are used on land can also stress eelgrass[42]. All of these causes are plausible in the Great Bay Estuary and many magnify each other to stress eelgrass and make habitats less resilient. Proactive actions to increase resilience for eelgrass habitat are critical as climate science predicts an increase of stressful events, such as extreme storms with increased rains and higher winds. Since the 1930s there have been three 100-year storms recorded by measurements of the river discharge at the Lamprey River: two of those storms occurred in 2006 and 2007; the third was in 1987. Increased rainfall during these events causes a large quantity of water flow to enter the estuary delivering increased sediments and nutrients as well as resuspending sediments throughout the water column. Since eelgrass relies on clear water to grow, these events are important to note.

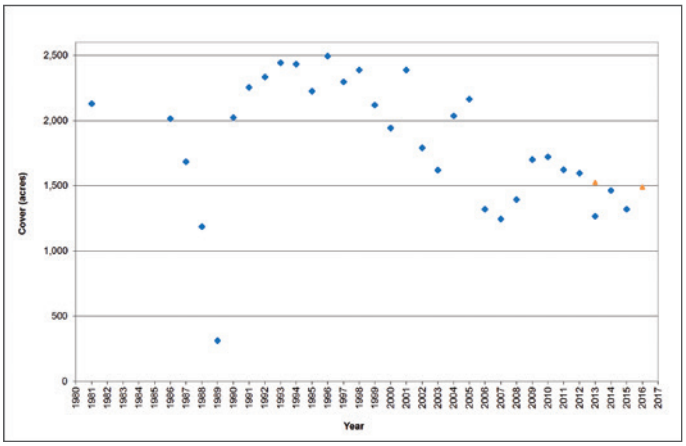


Figure 8.3 Eelgrass cover in the Great Bay only (not entire Great Bay Estuary). Missing data for years 1982-1985. Years 1988 and 1989 show very low values due to eelgrass wasting disease event. These data, however, are still included in linear regression calculations.

Data Source: NH Fish and Game (for 1981); Kappa Mapping, Inc. (for years 2013 & 2016) and UNH Jackson Estuarine Laboratory (1986-2015). In 2013, the two data sources were averaged for the linear regression

Research and discussions continue to focus on the type of recovery Great Bay Estuary can expect for eelgrass. In some cases, recovery requires only a decrease in the stressors that caused the problem. In other cases, conditions for recovery have to be better than conditions before the habitat loss began to occur.[43] Figure 8.3 shows that eelgrass recovered after the wasting disease event of 1988-1989. After a drop in 2002-2003, eelgrass rebounded, but not quite to previous levels. Another three year downturn during 2006-2008 was followed by a weaker recovery.

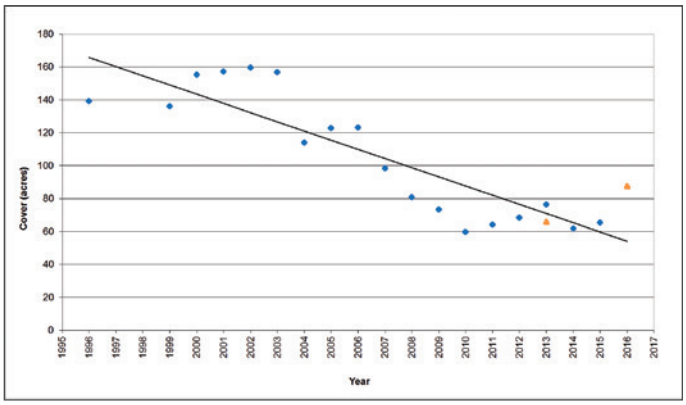


Figure 8.4 Eelgrass cover in Portsmouth Harbor. Linear regression showing a statistically significant trend.

Data Source: Kappa Mapping, Inc. (for year 2013 & 2016) and UNH Jackson Estuarine Laboratory (1996-2015). In 2013, the two data sets were averaged for the linear regression

SNAILS GRAZE ALGAE GROWING ON EELGRASS LEAVES, HELPING THE PLANT TO GET MORE LIGHT
PHOTO BY A. NORTON

SALT MARSH

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

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

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

PREP GOAL: UNDER DEVELOPMENT.

EXPLANATION As of 2017, there are 5,521 acres of salt marsh habitat in the Piscataqua Region watershed (Figure 9.1) with these acres distributed among 17 municipalities (Figure 9.2). The area surrounding the Hampton-Seabrook Estuary has the greatest amount of salt marsh habitat. Hampton had the most acres of salt marsh

Continued

(1,342 acres), followed closely by Seabrook (1,140 acres). Hampton Falls and Rye had 725 and 627 acres, respectively. Great Bay Estuary municipalities, such as Stratham, Greenland, and Dover, had less than half the salt marsh acreage of Rye (Figure 9.2).

Between the early 1900s and 2010, an estimated 431 acres of salt marsh area was lost in the Great Bay Estuary, and in the Hampton-Seabrook Estuary, 614 acres (or 12% of the historic salt marsh) was lost[44]. As these habitats experience continued pressures from development and impacts related to climate change, such as sea-level rise, it will be important to assess changes in marsh location, total acreage, and salt marsh structure. For example, one possible reaction to sea-level rise, forecasted to be between 6 and 11 mm/year, is that plant species that are less tolerant to flooding, such as high-marsh grass (*Spartina patens*) will be replaced by low-marsh grass (*Spartina alterniflora*) and the boundary between high and low will shift upslope. In addition, the lower edge of the marsh will migrate landward as the marshes literally drown, and pannes (depressions in the marsh that do not tend to retain water) and pools (which do retain water) are likely to expand.[45]

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

Figure 9.1 Map of salt marsh coverage, showing marsh habitat in New Hampshire only.

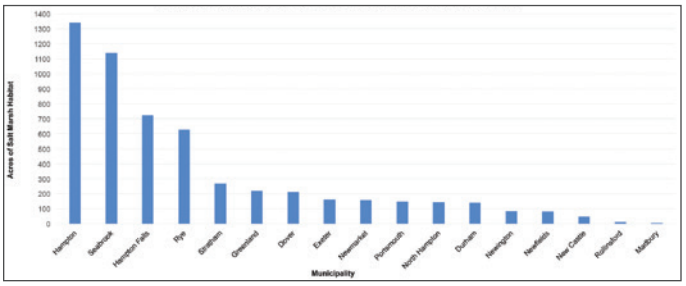


Figure 9.2 Number of acres of salt marsh habitat in 2017, by town/city within the Piscataqua Region watershed.

Data Source: Great Bay National Esturaine Research Reserve; Kappa Mapping, Inc. (2013 Flight); USGS LIDAR Data (2011 and 2014); NOAA Office of Coastal Management, and NHDES Coastal Program

VOLUNTEERS PLANTING SALT MARSH GRASSES AT CUTTS COVE RESTORATION SITE IN PORTSMOUTH, NH | PHOTO BY E. LORD

BACTERIA

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

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

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

PREP GOAL: NO INCREASING TRENDS FOR FECAL COLIFORM BACTERIA, ENTEROCOCCI, OR *E. COLI* IN THE GREAT BAY ESTUARY.

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

At all four long-term water pollution monitoring stations in the estuary (See Monitoring Map p.49), a decrease in fecal coliform bacteria during dry weather has been observed over the past 26 years. For example, at Adams Point, fecal coliform bacteria decreased by 67% between 1989 and 2016 (Figure 10.1). Upgrades to wastewater treatment facilities, improvements to stormwater and sewage infrastructure, and microbial source tracking studies that identify and address sources of bacterial pollution are all contributing factors to the long-term decreasing trend. It should be noted that not all trends were decreasing. Fecal coliform bacteria measurements in Portsmouth Harbor and enterococci at Adams Point, the Squamscott River, and Portsmouth Harbor showed no significant trends (not plotted in figure).

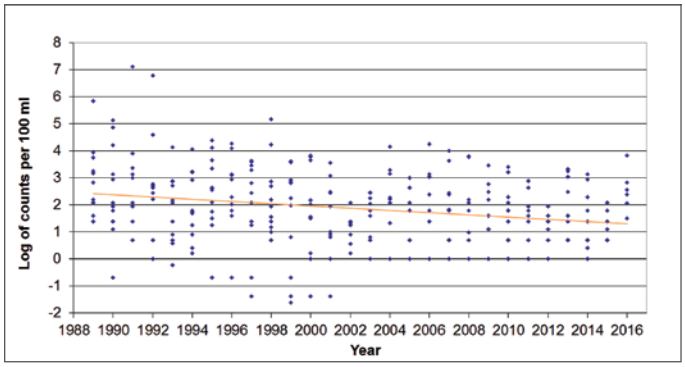


Figure 10.1 Fecal coliform bacteria concentrations at low tide during dry weather at Adams Point. Line shows a statistically significant trend.

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

POTENTIAL *VIBRIO* ON CHROMagar AT UNH JACKSON ESTUARINE LABORATORY | PHOTO BY E. LORD

SHELLFISH HARVEST OPPORTUNITIES

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

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

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

PREP GOAL: IMPROVE WATER QUALITY AND IDENTIFY AND MITIGATE POLLUTION SOURCES SO THAT ADDITIONAL ESTUARINE AREAS MEET WATER QUALITY STANDARDS FOR BACTERIA AND FOR SHELLFISH HARVESTING.

EXPLANATION Figure 11.1 indicates open and closed areas of the Great Bay and Hampton-Seabrook estuaries for recreational shellfish harvesting. (Note that open areas may become temporarily closed after large rain events due to water quality issues). The percentage of possible acre-days between 2012 and 2016 was 80% and 66% for the Great Bay and Hampton-Seabrook estuaries, respectively (Figure 11.2). The Great Bay acre-days open data exhibits a sawtooth profile between 2006 and 2009, which is most likely caused by major storms, such as the Mother's Day storm of 2006. The 2016 steep decrease in the Hampton-Seabrook acre-days open data was the result of a prolonged discharge of raw sewage from a broken 14-inch force main pipe under a salt marsh in the Town of Hampton. The pipe broke in late 2015 and was fixed in early 2016. The overall long-term trend of gradual improvements since the year 2000 may reflect improved pollution source management, such as efforts by NHDES and municipalities to identify and eliminate illicit discharges. Lower rainfall amounts in recent years may also have led to a decrease in the occurrence of bacterial pollution events related to stormwater runoff.

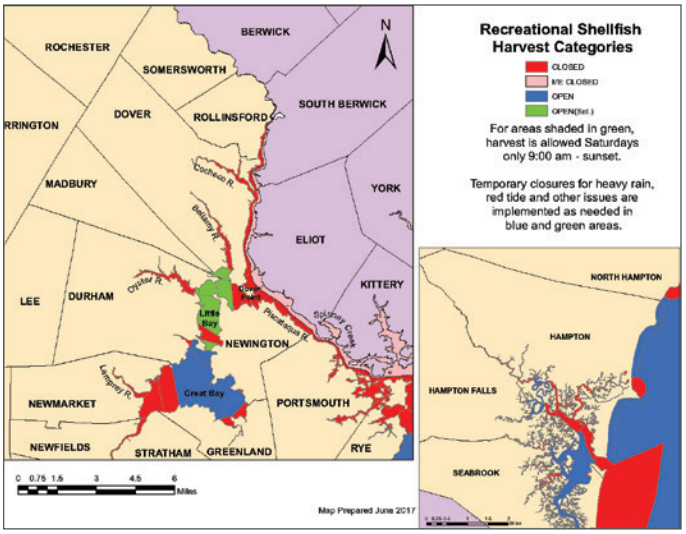


Figure 11.1 Map showing recreational shellfish harvest categories for the Great Bay and Hampton-Seabrook estuaries.

Courtesy of the NH DES Shellfish Program

The areas designated as "conditionally approved" (open but subject to temporary closures due to water quality issues), "restricted" (closed due to chronic water quality problems), and "prohibited" (closed due to water quality issues that require further investigation) have remained fairly constant since 2004 (Figure 11.3). The most notable change occurred in 2014 with the conversion of over 1,300 acres that was "prohibited/unclassified" area (closed because the water quality is unknown) to "prohibited/safety zone." This refers to areas closed due to pollution sources that may unpredictably affect the water quality of the area and create a potentially dangerous public health risk. These zones are most often related to WWTFs.

This 2014 conversion was a direct result of the December 2012 Portsmouth WWTF dye study[46], which examined how this primary WWTF affected water quality in the estuary, and how those effects might change once the facility upgrade is complete in 2019. The

dye study indicated effluent travels further up river and faster than previously determined; this resulted in the reduction of harvest opportunities at the Little Bay and Bellamy River shellfish beds (Figure 11.1). Specifically, harvest days were reduced from seven days/week to Saturdays only, from 9 a.m. to 5 p.m.; this approach gives wastewater operators and the NHDES Shellfish Program more time to react in the event of a WWTF problem that occurs overnight. (Note: aquaculture operators in Little Bay are mandated to call the NHDES Shellfish Program before harvesting and so are not impacted by the new rule).

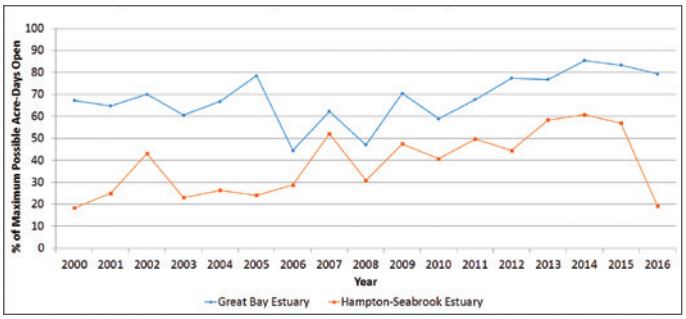


Figure 11.2 Shellfish harvest opportunities for Great Bay and Hampton-Seabrook estuaries. Percentage maximum possible "acre-days", which is the number of open acres multiplied by the number of days those acres were open for harvest.

Data Source: NH Department of Environmental Services, Shellfish Program

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

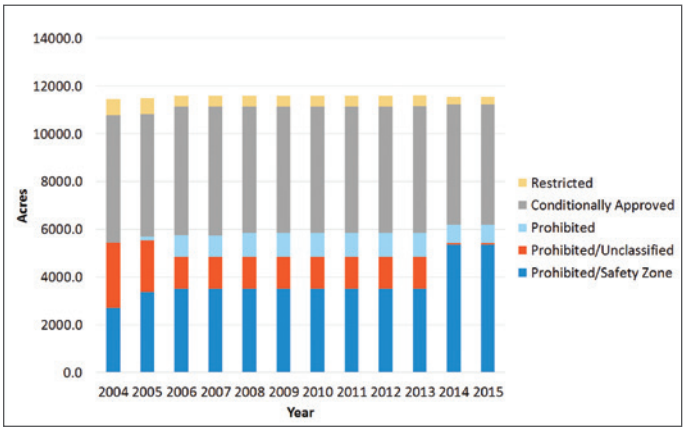


Figure 11.3 Shellfish closure acres by classification.

Data Source: NH Department of Environmental Services, Shellfish Program

BEACH ADVISORIES

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

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

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

PREP GOAL: LESS THAN 1% OF BEACH DAYS OVER THE SUMMER SEASON AFFECTED BY ADVISORIES DUE TO BACTERIA POLLUTION.

EXPLANATION The Atlantic coast is home to 17 public tidal beaches in the Piscataqua Region. At these beaches, between 1 and 11 advisories have been issued per year since 2003. Advisories between

Continued

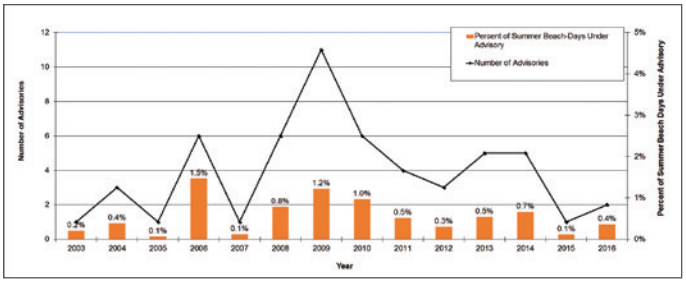
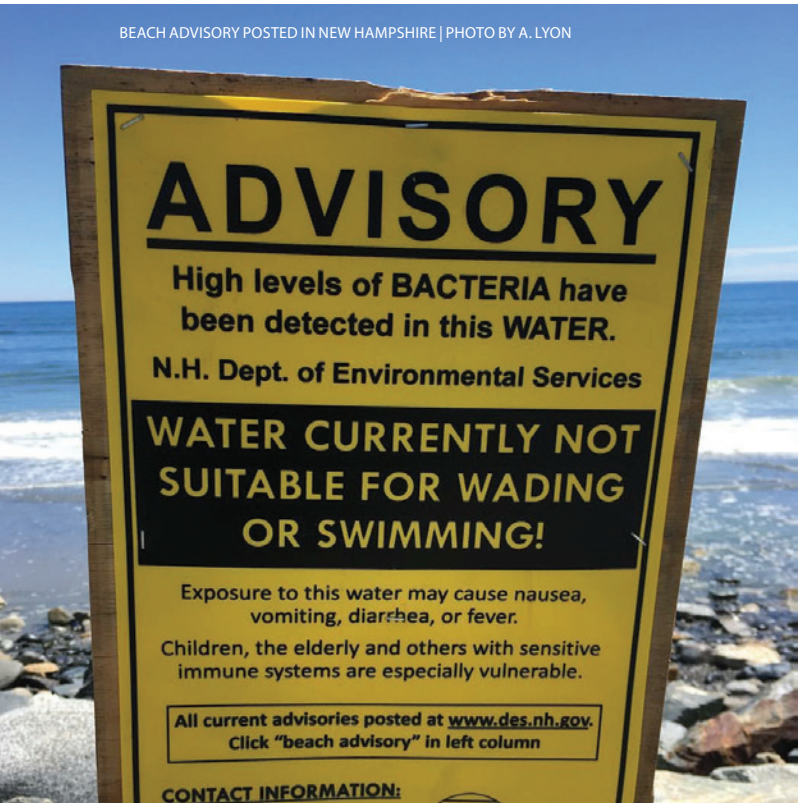


Figure 12.1 Advisories at tidal beaches in the Piscataqua Region 2003-2016. Beach days are calculated based on days between Memorial Day and Labor Day each year.

Data Source: NH Dept. of Environmental Services and Maine Dept. of Environmental Protection

2003 and 2016 have affected 130 of 23,373 beach summer days (0.06%). The most advisories occurred in 2009 with 11 advisories affecting six beaches for a total of 23 days (1.2% of total beach-days) (Figure 12.1). In 2016, North Hampton State Beach had two advisories for a total of six days (0.4% of beach-days). A 2014 report by the Natural Resources Defense Council ranked New Hampshire beaches as the second cleanest out of 30 states.[47] During 2012-2016, New Hampshire and Maine tidal beaches in the region continued to meet PREP's goal of beach advisories affecting <1% of beach-days each summer.

Poor water quality in 2016 resulted in two beach advisories (0.4% of summer days). There are no apparent trends.



BEACH ADVISORY POSTED IN NEW HAMPSHIRE | PHOTO BY A. LYON

PRESSURE INDICATOR
CONDITION INDICATOR
RESPONSE INDICATOR
SOCIAL INDICATOR

TOXIC CONTAMINANTS

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

Most concentrations of measured metals and organic chemicals in blue mussel tissue from 1991-2016 are declining or not changing. Mercury and PCB levels remain high enough to merit continued concern. Many new contaminants have been introduced to the estuary, such as pharmaceuticals, perfluorinated compounds, and brominated flame retardants, and they are not being consistently monitored.

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

PREP GOAL: ZERO PERCENT OF SAMPLING STATIONS IN THE ESTUARY HAVE SHELLFISH TISSUE CONCENTRATIONS THAT EXCEED LEVELS OF CONCERN AND NO INCREASING TRENDS FOR ANY CONTAMINANTS.

EXPLANATION The Gulfwatch Program uses blue mussels (*Mytilus edulis*) to better understand trends in the accumulation of toxic and persistent contaminants, including metals, pesticides, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). The use of many of these contaminants has been banned or is limited, so trends are expected to be stable or decreasing. At Dover Point, concentrations of DDT, an insecticide banned in the U.S. in 1972, are relatively low and gradually decreasing (Figure 13.1). Inputs of mercury, a heavy metal, have been reduced since the 1990s due to regulatory action taken on coal-fired power plants, medical waste, and municipal incinerators, but mercury continues to be deposited through wet and dry atmospheric deposition.[48] At most sites, including Clark's Cove in Portsmouth Harbor, mercury levels in shellfish have been fairly stable since 2003 (Figure 13.2); these levels are similar to those seen in other estuaries located close to urban centers[49]. PAHs, which mostly come from oils spills, the burning of fossil fuels, and some driveway sealants, have been stable across all stations, including Hampton-Seabrook. Only one value was above the national median level of 250 ug/kg (Figure 13.3). Other data collected at that time indicate a possible fuel spill.[50] Trend lines are not shown as there were no statistically significant results.

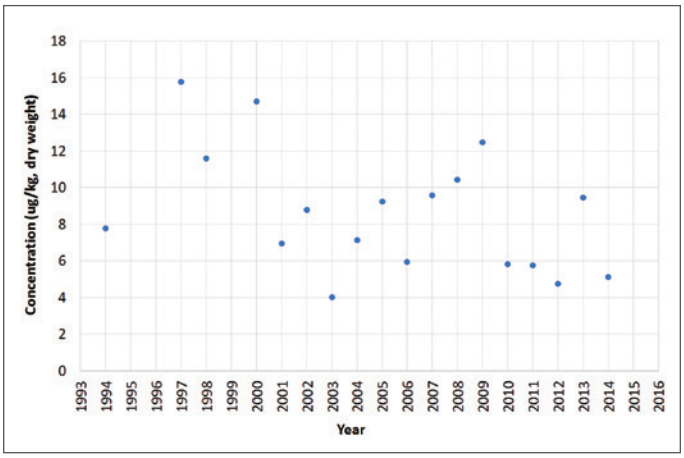


Figure 13.1 Concentrations of DDT in mussel tissue at Dover Point. The most recent national median for the Mussel Watch program was 30ug/kg.[51] The 85th percentile was 130ug/kg.

Data Source: Gulfwatch Contaminant Monitoring Program

PCBs, DDT, and mercury at these three stations—Dover Point, Clark's Cove, and Hampton-Seabrook (see Monitoring Map p. 49)—are generally representative of the trends in the more comprehensive dataset, which includes over 120 different specific contaminants. Focusing only on these three contaminants, however, does not provide a comprehensive picture of the level of toxic contamination in our estuaries. Many new contaminants have been introduced to the estuary, such as pharmaceuticals, perfluorinated compounds, and brominated flame retardants, and they are not being consistently monitored.

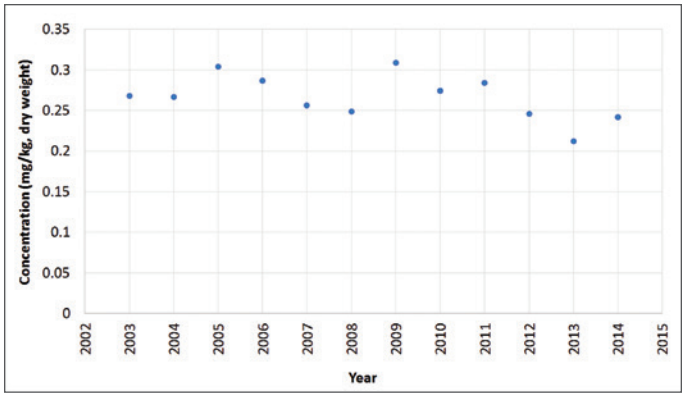


Figure 13.2 Concentrations of mercury in mussel tissue at Clark's Cove, Portsmouth Harbor. The most recent national median for the Mussel Watch program was 0.7mg/kg.[51] The 85th percentile was 0.13mg/kg.

Data Source: Gulfwatch Contaminant Monitoring Program

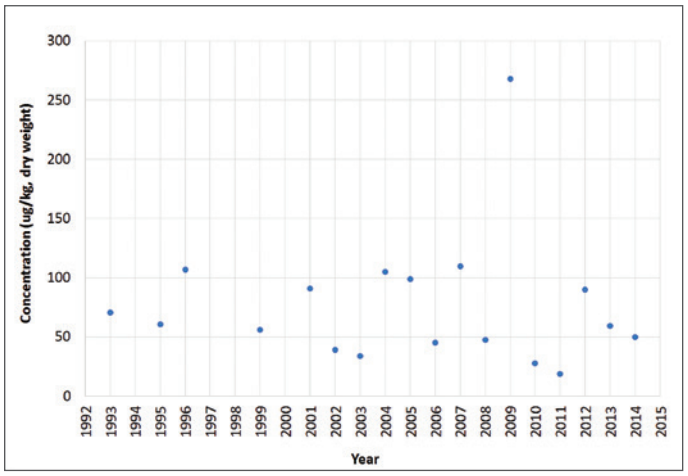


Figure 13.3 Concentration of PAHs at Hampton-Seabrook Harbor. In 2008, the national median for the Mussel Watch program was 250 ug/kg.[51] The 85th percentile was 1250 ug/kg.

Data Source: Gulfwatch Contaminant Monitoring Program

PAHs COME FROM A VARIETY OF SOURCES INCLUDING OIL SPILLS | PHOTO BY A. LYON

OYSTERS

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

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

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

PREP GOAL: INCREASE THE ABUNDANCE OF ADULT OYSTERS AT THE SIX DOCUMENTED BEDS IN THE GREAT BAY ESTUARY TO 10 MILLION OYSTERS BY 2020.

EXPLANATION From 2012 to 2016, the average standing stock of adult oysters (greater than 80 mm in shell height) at the six largest oyster habitat sites (Figure 14.1) was just over 2.1 million oysters. This shows a decline from the previous reporting period (2009-2011), which averaged just over 2.8 million oysters (Figure 14.2). In 2016, there were 2,766,314 oysters, a decrease of 89% from 1993, when 25,729,204 adult oysters were present. The 2016 oyster population is approximately 28% of the PREP goal.

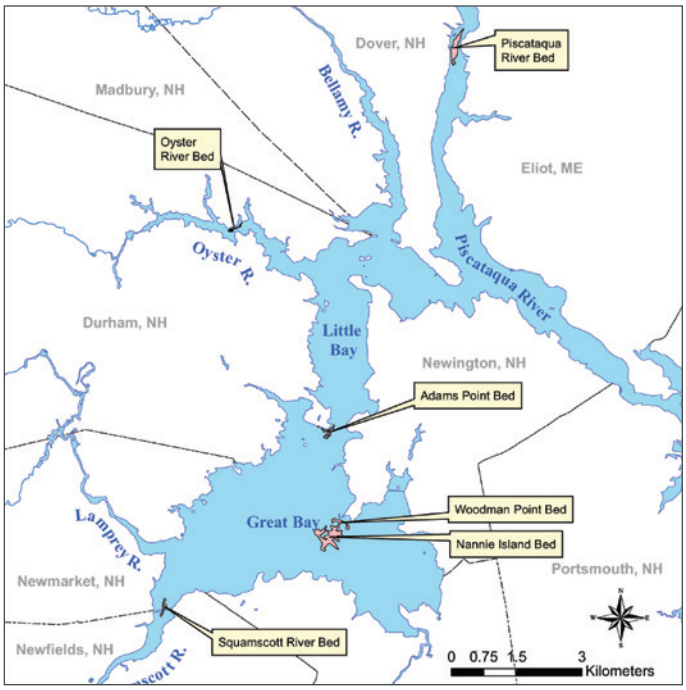


Figure 14.1 Map showing the locations of the six major oyster beds in the Great Bay Estuary.

A primary limitation on oyster health is disease, caused by two microscopic parasitic organisms, Dermo (*Parkinsus marinus*) and MSX (*Haplosporidium nelsoni*). Figure 14.3 shows that Dermo, a warmer water organism, has become more prevalent over time. The prevalence of both diseases increases with salinity.[52] Figure 14.3 also indicates that oysters no longer grow above 115 mm in shell height, which suggests that oysters are only living four or five years, rather than 10+ years as they did in the early 1990s.

Oyster habitat in the Great Bay Estuary also faces challenges due to a lack of available substrate for oyster larvae to settle. Oysters themselves can provide this substrate, but less and less oyster habitat diminishes the available substrate. This can be offset by

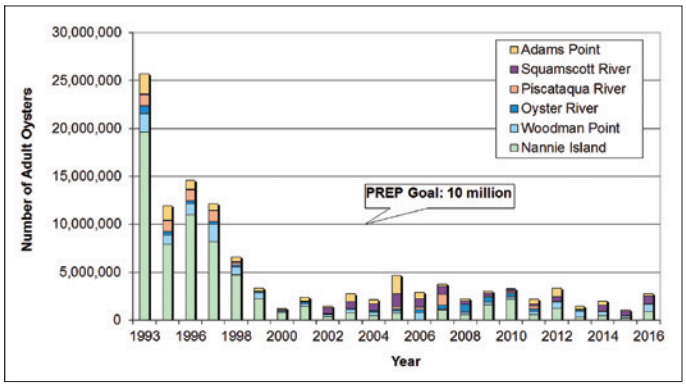


Figure 14.2 Standing stock of adult (>80 mm shell height) oysters in the Great Bay Estuary. Standing stock is estimated by multiplying adult densities by estimates of the acreage at each site.

Data Source: Oyster density data from NH Fish and Game; site acreages from UNH Jackson Estuarine Laboratory

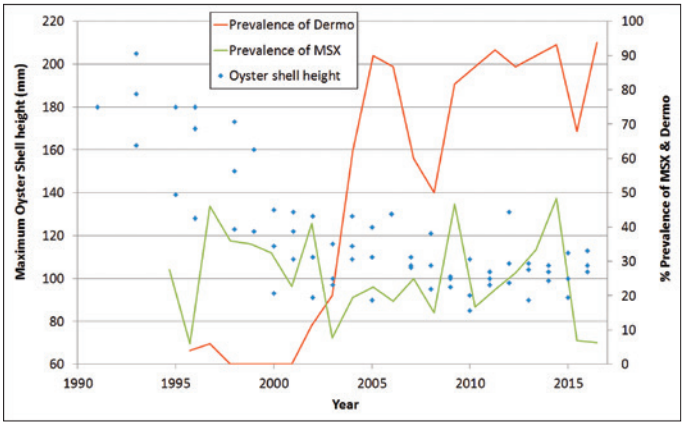


Figure 14.3 Maximum shell height of oysters from the Adams Point, Nannie Island, and Woodman Point reefs. Updated from the original graph, published in Eckert (2016), available at https://scholars.unh.edu/prep/371.

Data Source: NH Fish and Game

planting recycled oyster shell material—for example, from restaurants and other sources—in key locations in the estuary. (See "Oyster Restoration" p. 38).

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

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

SHUCKING OYSTERS ON THE CEDAR POINT SHELLFISH OYSTER FARM | PHOTO BY A. LYON

CLAMS

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

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

WHY THIS MATTERS Soft shell clams provide recreational opportunities to state residents as well as visitors from outside the region. Clams consume phytoplankton and other detrital material and therefore have a significant impact on coastal and estuarine ecosystems.

PREP GOAL: INCREASE THE NUMBER OF ADULT CLAMS IN HAMPTON-SEABROOK ESTUARY TO 5.5 MILLION CLAMS BY 2020.

EXPLANATION In 2015, there were 1.4 million clams in Hampton-Seabrook Harbor. Since 2012, clam populations have remained below the PREP goal of 5.5 million clams and below the average level (2.4 million) from 2009 to 2011 (Figure 15.1).

Clams may be limited by a type of cancer (*Hemic neoplasia*) that affects marine bivalves but is not dangerous to humans. Figure 15.2 shows that the percentage of clams infected with *Neoplasia* has increased since 2002. Research suggests there are several factors that make clams more susceptible to this disease, especially pollution (mainly heavy metals and hydrocarbons) and warming water temperatures.[53]

Green crabs eat clams and have also been shown to reduce clam populations. However, Figure 15.3 shows that green crab abundance in Hampton-Seabrook Harbor has steadily declined – for unknown reasons – between 2011 and 2015.

Continued

Clams, cont.

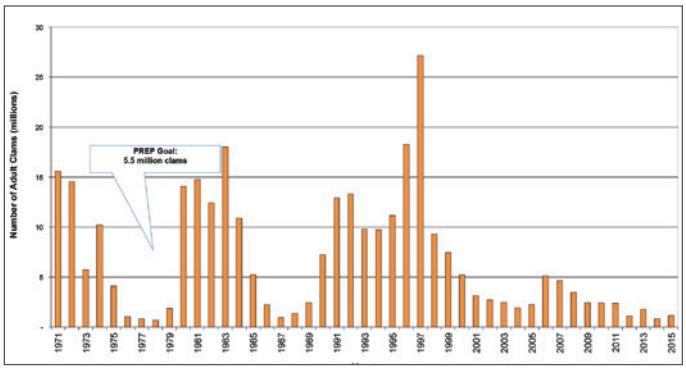


Figure 15.1 Standing stock of adult clams in Hampton-Seabrook Harbor. Number of adult clams is calculated by multiplying clam densities by the acreage of clam flats in Hampton-Seabrook Harbor.

Data Source: Normandeau Associates, with support from NextEra Energy

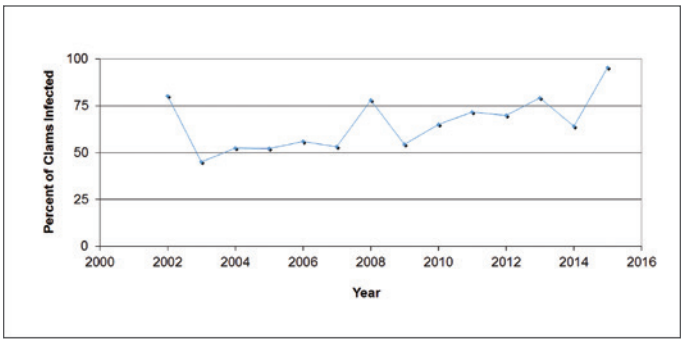


Figure 15.2 Percent of clams with any *Neoplasia* infection in Hampton-Seabrook Harbor.

Data Source: Normandeau Associates, with support from NextEra Energy

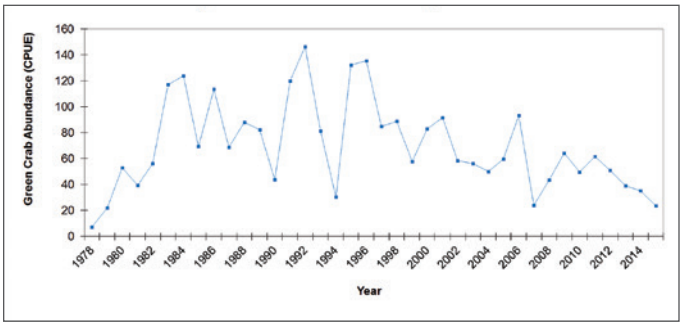


Figure 15.3 Green crab abundance in Hampton-Seabrook Harbor. CPUE = catch per unit effort. Crabs are caught in baited traps, twice a month year-round with the exception of February and March.

Data Source: Normandeau Associates, with support from NextEra Energy

In 2015, there were only 1.4 million clams in Hampton-Seabrook Harbor (only 25% of the PREP goal).

PRESSURE INDICATOR
CONDITION INDICATOR
RESPONSE INDICATOR
SOCIAL INDICATOR

MIGRATORY FISH

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

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

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

PREP GOAL: NO GOAL.

EXPLANATION Observed river herring returns to the coastal rivers of the Piscataqua Region watershed varied during the 1972-2016 period (Figure 16.1). Total river herring returning to fish ladders in 2016 reached 199,090. This is a 69% increase from 2012 that was driven by record river herring returns in the Lamprey and Cocheco

Rivers. Conversely, returns have sharply declined in two other rivers: the Taylor and the Oyster. Due to variability in the dataset there are no statistically significant trends. Declines in river herring returns in some rivers may be due to several factors including: limited freshwater habitat quantity and quality, difficulty navigating fish ladders, safe downstream passage over dams, fishing mortality, pollution, predation, and flood events during upstream migrations. To continue improving river herring returns, NH Fish and Game and the NH Coastal Program continue to work with state, federal, and local partners on dam removal and culvert replacement projects on the Cocheco River (Gonic dams in Rochester), Bellamy River (Sawyer Mill dams in Dover), and Exeter River (Great Dam in Exeter; completed in September 2016).[54, 55]

Despite increases in river herring returns for some rivers, the Oyster and Taylor River populations have declined dramatically in recent years most likely due to poor water quality in impoundments upstream.[56] Additionally the Winnicut River fish ladder has been declared ineffective and NH Fish and Game is working on a solution.[57] The 2016 river herring returns are almost exclusively from the Lamprey and Cocheco Rivers.

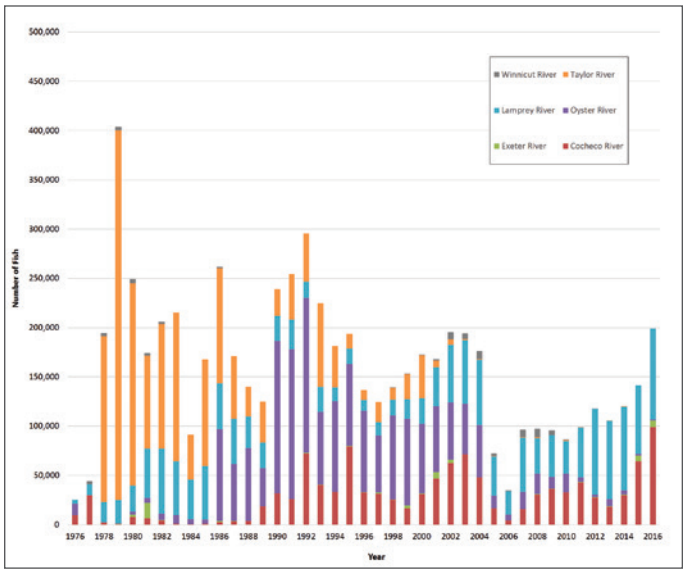


Figure 16.1 Returns of river herring to NH coastal tributaries 1976-2016. In 2016 river herring returns were almost exclusively from two rivers: the Lamprey and Cocheco.

Data Source: NH Fish and Game

NH FISH AND GAME SURVEYING ANADROMOUS RIVER HERRING
PHOTO BY I. MACLELLAN

CONSERVATION LANDS (GENERAL)

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

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

WHY THIS MATTERS Our region is under pressure from population growth and associated development (see Housing Permit Approvals p. 41). Conserving a network of natural lands across the region is the most effective action to take to ensure clean water and healthy and abundant wildlife populations, to minimize flood damages, and to provide a diversity of quality, recreational opportunities.

PREP GOAL: CONSERVE 20% OF THE WATERSHED BY 2020.

Continued

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

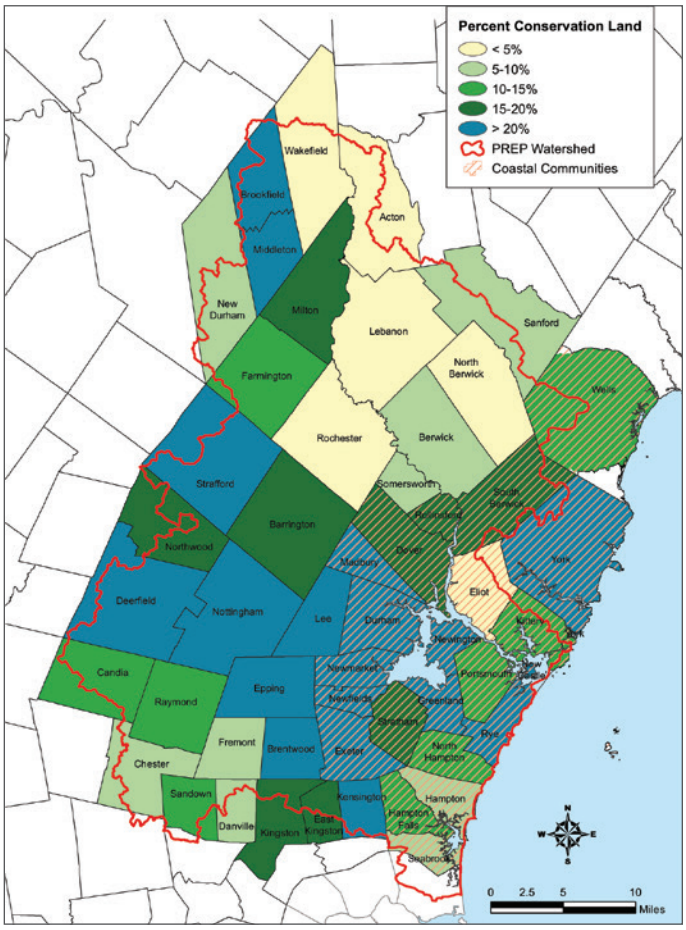


Figure 17.1 Land conservation by percent of total land area for each Piscataqua Region community.

Data Source: NH GRANIT

The percentage of conserved land area protected in each town is shown in Figure 17.1. As of 2017, 18 communities have greater than 20% conserved lands, and 9 communities have between 15 and 20% conserved lands. Overall, conservation lands have increased across most of the region, but there are still communities where conservation lands as a total percentage of the municipality's land area is below 5% (yellow). Figures 17.1 and 17.2 (HUC-12 analysis) highlight areas where conservation efforts have been significant (+30% of total land area) and these include Great Bay, Exeter-Squamscott, Lamprey River, Oyster River, Pawtuckaway Pond, and Scamen Brook-Little River. Conversely, areas where conserved lands are lower include the Cocheco, Salmon Falls, Bog Brook-Little River, and Great Works River.

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

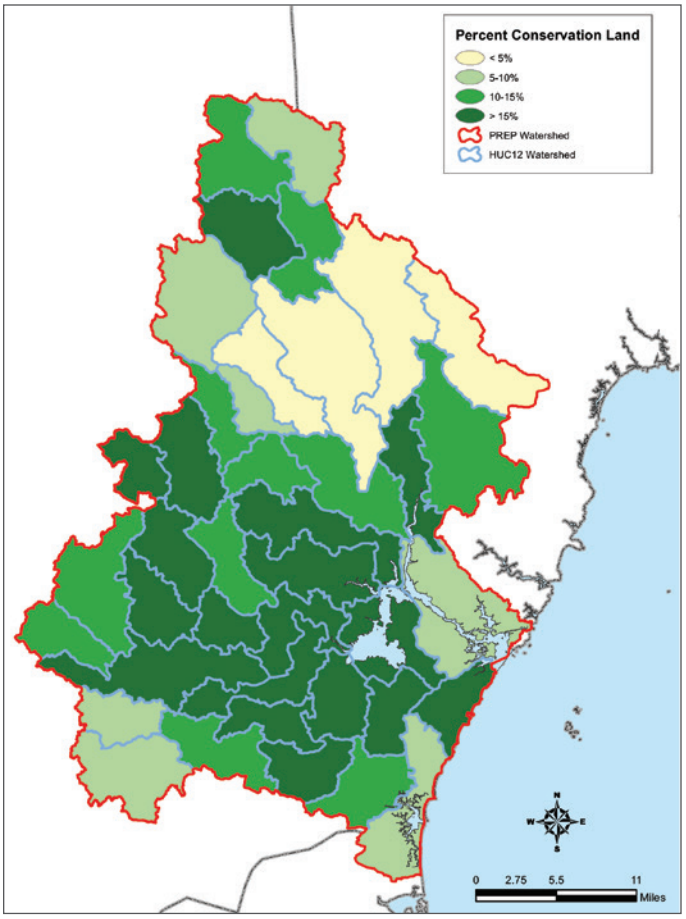


Figure 17.2 Land conservation by percent of total area for each subwatershed (HUC-12).

Data Source: NH GRANIT

PHOEBE'S NABLE MOUNTAIN, MIDDLETON, NH | PHOTO BY E. LORD

CONSERVATION LANDS (FOCUS AREAS)

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

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

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

PREP GOAL: CONSERVE 75% (124,659 ACRES) OF LANDS IDENTIFIED AS CONSERVATION FOCUS AREAS BY 2025.

EXPLANATION *The Land Conservation Plan for New Hampshire's Coastal Watersheds*[58] and *The Land Conservation Plan for Maine's Piscataqua Region Watersheds*[59] are two science-based regional conservation master plans developed by a range of municipal, regional, and technical partners to guide conservation efforts throughout the region. The plans identify 90 CFAs that have high conservation values associated with them (such as rare habitat for threatened or endangered species). Of the 166,212 acres that fall within these designated CFAs, a total of 51,062 acres have been permanently protected (40.9% of progress toward the PREP goal of 124,659 acres). This represents an increase of 3.7% since 2011 or 5,197 new conserved acres, with the majority of these increases being in New Hampshire. There are a few notable areas where gains have been significant (over 50% increases since 2011), including the Winnicut River, Isinglass River, Kennard Hill, and Birch Hill Lowlands. There are 16 CFAs where 50% or more of the acres have been protected (see Figure 18.1). CFAs where 70% or more have been protected include the Upper and Middle Winnicut, Creek Pond Marsh, Lower Lubberland Creek, Exeter River, Fabyan Point, and Laroche and Woodman Brooks. Continued, focused efforts are needed to meet the goal in protecting 75% of these CFAs by 2025.

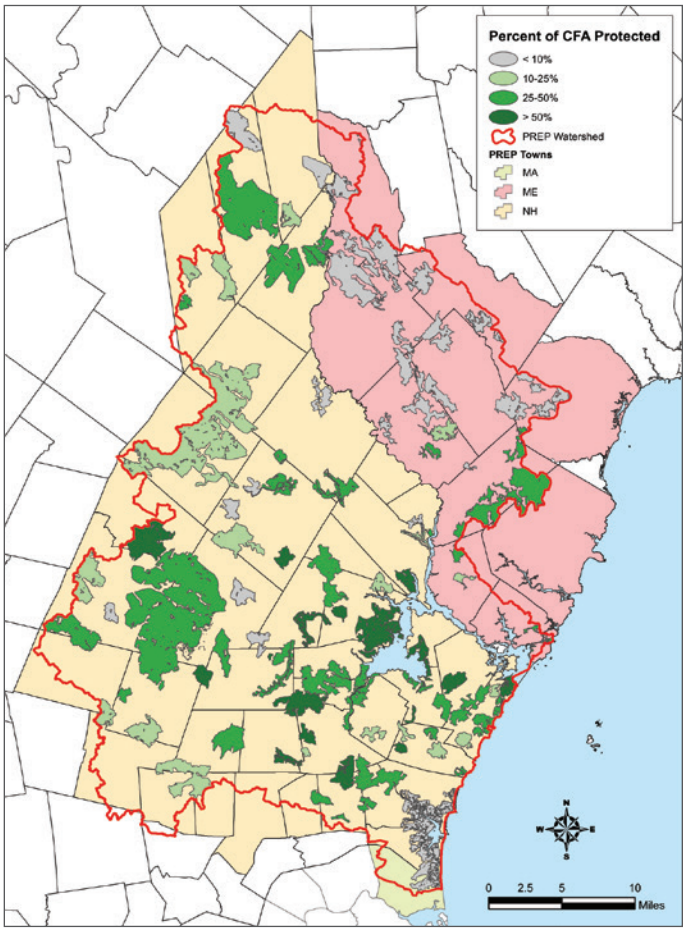


Figure 18.1 Percent of each Conservation Focus Area in the Piscataqua Region conserved.

Data Source: NH GRANIT

OYSTER RESTORATION

How many acres of oyster restoration have been initiated?

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

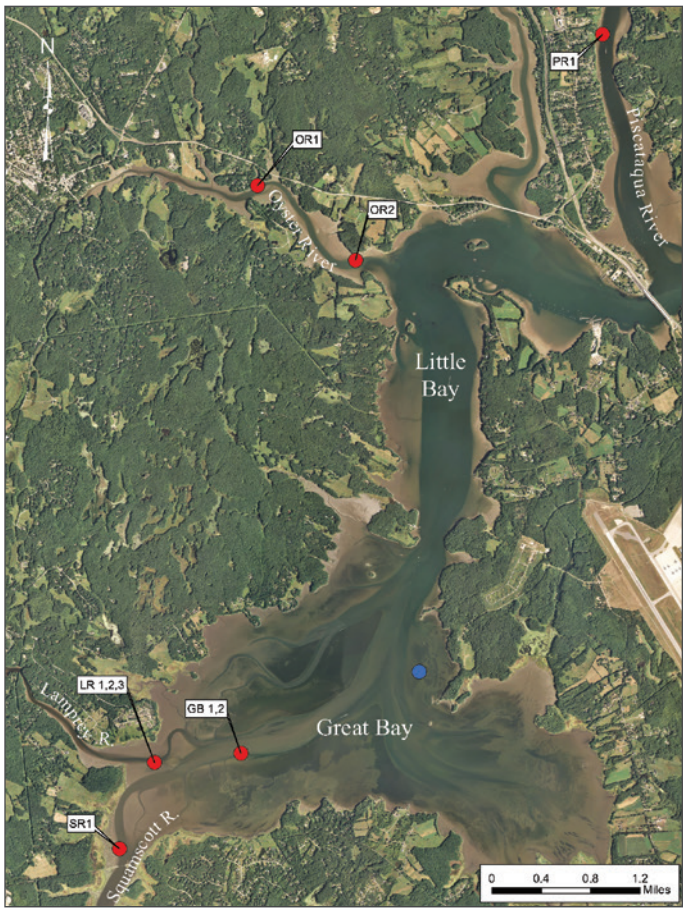


Figure 19.1 Map showing major oyster restoration activity. The red dots show general location of sites that have been monitored. Note that two of the red dots show the location of multiple sites (in the Lamprey River and in Great Bay). The blue dot shows the most recent restoration site in the Great Bay.

Data Source: Grizzle and Ward (2016) and Grizzle and Ward (2017)

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

PREP GOAL: RESTORE 20 ACRES OF OYSTER REEF HABITAT BY 2020.

EXPLANATION Between 2000 and 2012, 10.8 acres of oyster restoration were initiated. Between 2012 and 2016, an additional 15.5 acres of oyster restoration were established in the Great Bay Estuary (Figures 19.1 and 19.2) through collaborations between the University of New Hampshire (UNH) and The Nature Conservancy (TNC). The cumulative total for oyster restoration sites is now over 26 acres, above the PREP goal of 20 acres. Although 26 acres of restoration area exist, each site is only partially covered by oyster shell. For example, a common design is to establish multiple small circles of shell on which oysters can settle.

Unfortunately, in many cases, these restoration sites have struggled to remain viable, primarily due to burial by fine sediments (sedimentation)[60]. Table 19.1 shows monitoring results for seven different restoration sites; in four of the seven sites, shell cover has decreased since initial construction. Only one site showed an increase in shell cover.

Monitoring of these sites suggests several keys to successful future restoration, including: 1) build reefs to achieve greater vertical height to guard against burial by sediments and 2) select sites as close as possible to a natural reef. Recent UNH research showed that recruitment (new oyster larvae settling) decreased significantly as distance from a native natural reef increased[61].

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

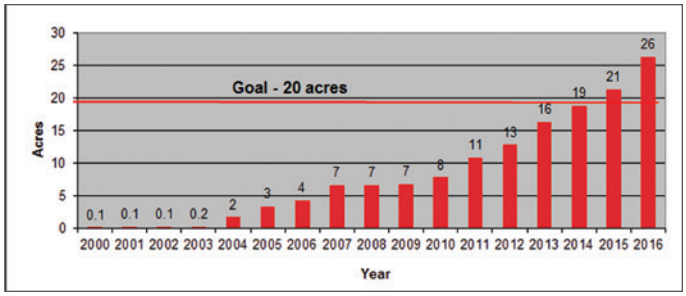


Figure 19.2 Cumulative acres of oyster restoration projects 2000-2016. Data pertain to the total areas of a restoration site, not necessarily the area covered by oysters.

Data Source: UNH Jackson Estuarine Laboratory

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

Table19.1 Change in shell cover after initial construction.

Data Source: UNH Jackson Estuarine Laboratory

CEDAR POINT SHELLFISH OYSTER AQUACULTURE ON GREAT BAY ESTUARY | PHOTO BY A. LYON

MIGRATORY FISH RESTORATION

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

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

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

PREP GOAL: RESTORE NATIVE MIGRATORY (DIADROMOUS) FISH ACCESS TO 50% OF THEIR HISTORICAL MAINSTEM RIVER DISTRIBUTION RANGE BY 2020.

EXPLANATION Coastal rivers of the Great Bay Estuary historically supported abundant fish returns for river herring (alewife and blueback herring) and American shad. However, during the 19th century the construction of dams along coastal rivers limited access to freshwater spawning habitats[62]. To support recovery of river herring populations in the 1950s, NH Fish and Game began efforts to restore access to historically accessible freshwater streams and

Continued

ponds. Figure 20.1 shows the historically accessible miles of freshwater in the main stem of each major river, and how many miles of freshwater habitat are currently accessible. For this indicator, fish ladders are considered to provide limited access for migratory fish; however, fish ladders on the Winnicut Dam in Greenland and former Great Dam in Exeter are inefficient at passing river herring to upstream spawning habitat.

For the Exeter, Cocheco, and Winnicut Rivers, 100% of freshwater miles historically accessible are once again open for fish passage as of 2017, assuming fish ladders provide limited access. Less than 30% access is open for the remaining mainstem rivers. Overall, freshwater access for river herring has been restored to 42% of historical distribution within the main stems of the region's major rivers (Figure 20.2).

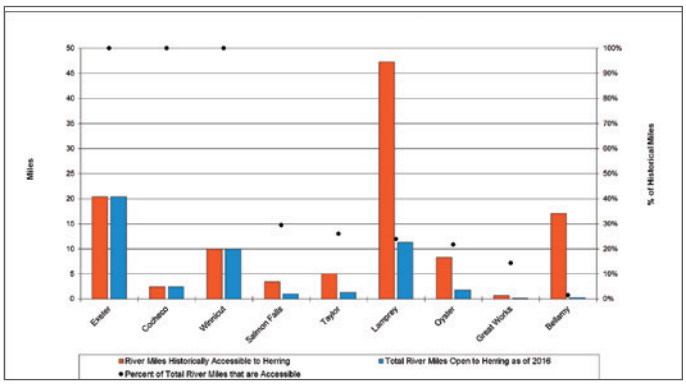


Figure 20.1 Mainstem stream miles accessible to river herring in major rivers of the Piscataqua Region. River miles historically accessible to river herring and total river miles open to river herring as of 2016.

Data Source: NH Fish and Game

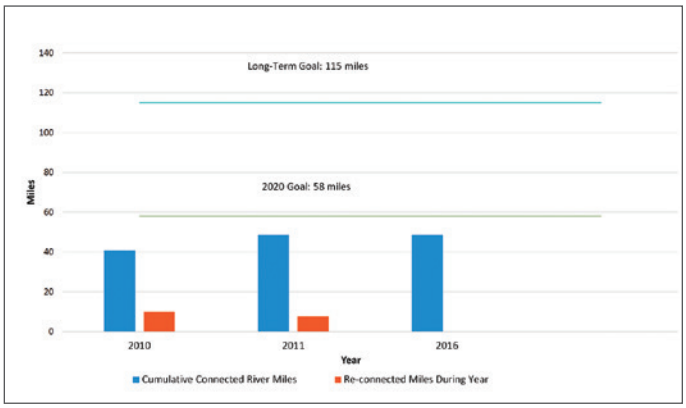


Figure 20.2 Upstream river miles re-connected for migratory herring on the mainstems of major rivers.

Data Source: NH Fish and Game

SOCIAL INDICATORS

Since the first *The State of New Hampshire's Estuaries* report in 2000[62], PREP has been committed to reporting on a suite of ecological and biological indicators of health in the Great Bay and Hampton-Seabrook Estuaries. These estuaries are not just places of biological value; they also provide social value, economic benefits, and many other quality of life assets such as recreational opportunities and community character. They are where rivers meet the sea, where land meets the water, and where people meet the water.

In 2015, PREP partnered with the NH Department of Environmental Services Coastal Program (NHCP), Great Bay National Estuarine Research Reserve (GBNERR), the National Oceanic and Atmospheric Administration (NOAA), and Plymouth State University (PSU) to kick off the *Social Indicators Project**. This two-year initiative is our region's first attempt to gather, understand, and link social and behavioral data to regional environmental indicators. The project team conducted an extensive assessment of values through almost 40 one-on-one interviews with watershed stakeholders that included resource managers, business owners, regional planners, community organizers, and state policy makers (Figures 21.1 and 21.2). Following the interviews, a technical advisory process was used to find existing data and/or indicators that reflected the stakeholder values that were identified in the interviews (Figure 21.2). After a broad review of existing data sources, a list of 31 potential indicators was shared with the advisory board for input, refining, and ranking. This input was used to categorize and narrow 31 indicators to 15 indicators that fit into seven categories. PREP staff evaluated and chose the final three indicators: housing permit approvals, stormwater management effort, and stewardship behavior, for their relevance to environmental trends, how rigorously they were collected, geographic scale, and applicability to management actions. Additional detail on the indicator selection process is outlined in the full *2018 State of Our Estuaries Environmental Data Report*[20].

At their core, these social indicators are meant to strike up conversation, prime questions, and encourage more research.

GREAT BAY GUNNERS REMOVING DEBRIS ALONG THE SHORES OF THE GREAT BAY ESTUARY
PHOTO BY E. LORD

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

Each social indicator has a strong connection to several environmental indicators that PREP monitors and reports on (Table 21.1). They represent the beginning of PREP's ongoing commitment to robust social-ecological indicator monitoring.

Figure 21.1 Sectors represented across 38 stakeholder interviews.

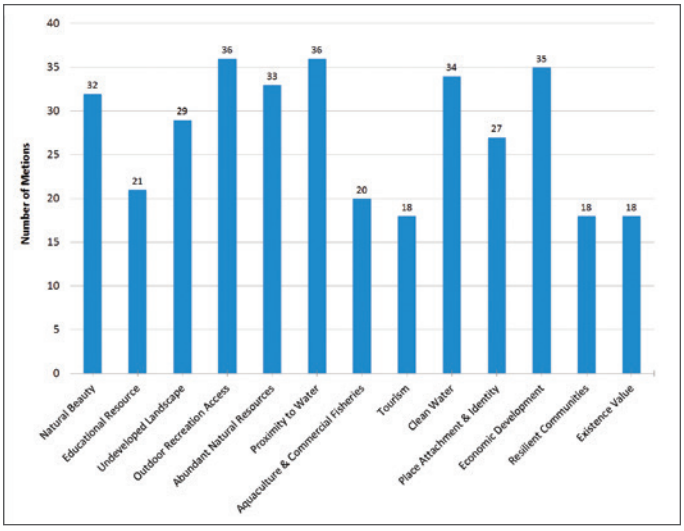


Figure 21.2 Social ecological values expressed across 38 stakeholder interviews. Bars represent number of times that concept was mentioned or referenced in interviews.

Social Indicator	Housing Permits	Stormwater Effort	Stewardship Behavior
Environmental indicators that this social indicator could relate to or affect	• Impervious Surfaces • Total Suspended Solids • Nutrient Load / Concentration • Bacteria • Toxic Contaminants • Conservation Lands • Stormwater Effort	• Impervious Surfaces • Total Suspended Solids • Nutrient Load / Concentration • Conservation Lands • Bacteria • Eelgrass • Phytoplankton	• Conservation Lands • Oyster Restoration • Migratory Fish Restoration

Table 21.1 Connecting social indicators to PREP's environmental indicators.

HOUSING PERMIT APPROVALS

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

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

WHY THIS MATTERS The Piscataqua Region is a desirable place to live, and as the population increases, so too do pressures. The number of housing permit approvals in the Piscataqua Region provides good context for considering an increase in population and the commensurate disturbance of the land to support that population. If not properly mitigated and planned for, construction can change the hydrology of the land and can lead to short-term soil erosion. New housing units increase impervious cover, which can lead to more stormwater and sediment runoff and nutrient loading. Since the U.S. Census is run every ten years, monitoring housing permit approvals gives us a more frequent indicator of increase in population, demand for development, and conversion of land to housing. Additionally, monitoring new housing permit approvals can shed light on economic development trends, migration patterns, shifting demographics, and overall pressure on our coastal and

Continued

recreational resources. Furthermore, as development trends shift geographically, it can also help communities understand where development pressure is occurring and can prime conversations about smart growth and low-impact development practices that allow for an increase in population and economic development and the protection of sensitive, natural areas.

PREP GOAL: NO GOAL.

EXPLANATION Population pressure on the nation's 452 coastal shoreline counties has been continually on the rise. In 2010, 123.3 million people, or 39% of the nation's population, lived in counties directly on the shoreline (called coastal shoreline counties) and 52% resided in coastal watershed counties (upriver and on tributaries from the shore). This population is expected to increase by 8%, or 10 million people, by 2020. Not only are there more people living on the coast, the population density far outweighs the rest of the U.S. There are 446 persons per square mile in coastal shoreline counties and 319 persons per square mile in coastal watershed counties nationwide. This is in stark contrast to the rest of the U.S., which averages 105 persons per square mile. Nationwide, there were 1,355 building permits issued per day in coastal shoreline counties from 2000–2010.[63]

This trend rings true in the Piscataqua Region. There were 386,658 people living in our three coastal and estuarine counties in 2015—an increase of 126,453 people since 1980.[64] There is also close alignment to the national density numbers, with 317 persons per square mile in New Hampshire watershed towns and 216 persons per square mile in Maine watershed towns in 2015 (Figure 21.3). In 2015 more people moved into New Hampshire than moved out of it; ~53,000 residents moved into New Hampshire, and 42,000 left the state[65].

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

- **Increase in the tax base**
- **Enhanced tourist economy**
- **Additional people to enjoy and steward our lands (see Stewardship Behavior p. 46)**
- **Growth of local business and commerce**
- **Diversificiation of our socio-economic structure**

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

Historically, New Hampshire's population is among the most mobile in the nation. Only a third of New Hampshire residents age 25 and older were born in the state (Figure 21.4)[66]. This is an important consideration as this kind of demographic shift can mark how policy is made at the town level and can help inform outreach partners on the best engagement tactics for reaching a different type of taxpayer and resident who are more accustomed to state-level environmental policies.

As pressure on existing housing stock increases, so does the need for new units. An accepted indicator for new development is the number of approved new housing unit permits in each town. It is important to note that an approved permit does not always equate to the actual construction of the unit; permits are often pulled but development can stall due to various factors. The construction sector in the 42 New Hampshire watershed towns experienced an all-time high in 2000 and an all-time low in 2009. Since then, it has been rising incrementally (Figure 21.5). There are confounding factors as to why the construction sector has not bounced back as robustly since 2009, including loss of construction workers, limitations of local regulations, and lack of buildable lots.[68]

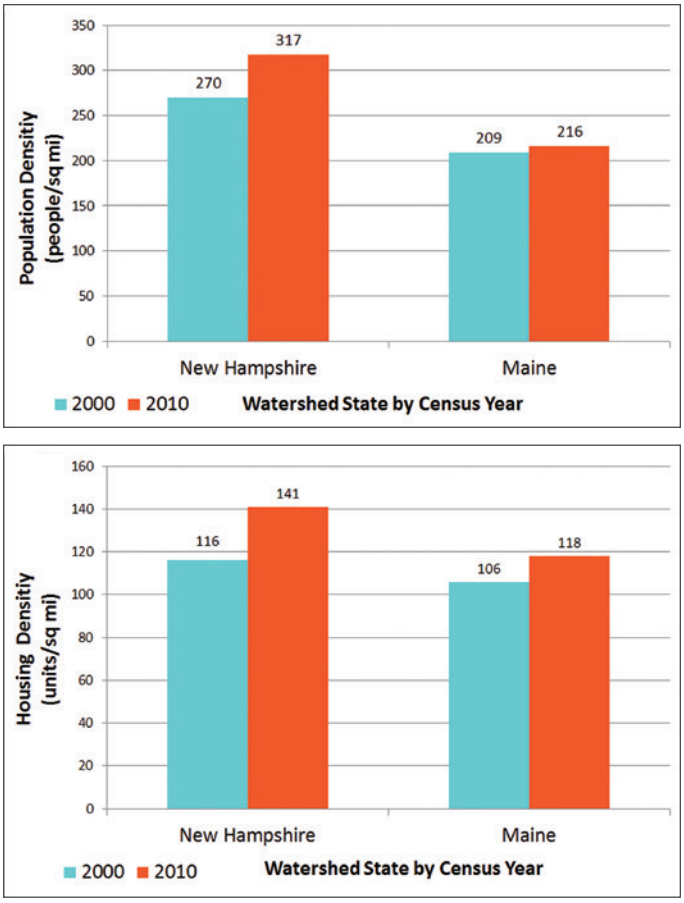


Figure 21.3 Population and housing densities in the Piscataqua Region: census years 2000 and 2010.

Data Source: US Census Bureau

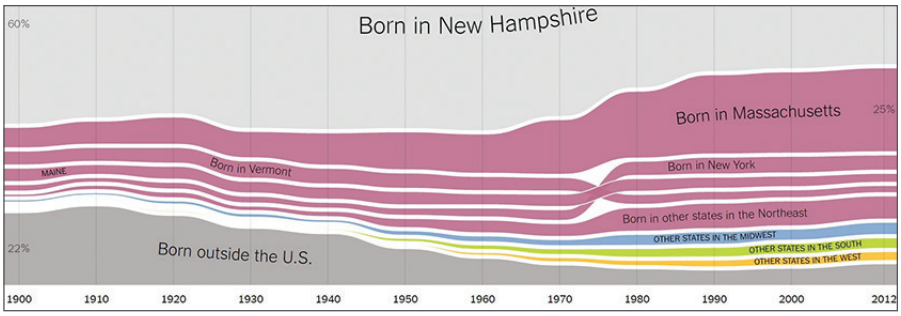


Figure 21.4 Created by *The New York Times*, this graphic shows the make-up of New Hampshire residents living in the state as of 2012.

Data Source: New York Times: The Upshot, Aug. 19, 2014[67]

Of particular note is the recent increase in multi-family unit permit approvals (dark blue bars in Figure 21.5). In the last six years, these have steadily kept pace with single-family units. From a land use perspective this is encouraging, as multi-family units often have an overall smaller lot size per person than typical, single-family, one-acre lot zoning.

The NH Office of Energy and Planning provides a very useful statewide data clearinghouse for all New Hampshire housing data. Table 21.2 shows the percent change, which gives a relative sense of growth as compared to the baseline of 2000. Absolute changes in housing units from 2000 to 2015 provide another interesting perspective. Table 21.3 displays the 10 New Hampshire Piscataqua Region towns that have seen the largest absolute changes in housing units. Additionally, when looking at where the newest development is occurring (Tables 21.2 and 21.3), it is important to note that it is increasing in towns that are upwatershed from Great Bay and in communities that have been more traditionally rural. There can be negative impacts when converting land from open space to development, especially along smaller tributaries. Engaging the tenets of low impact development should become increasingly more important in these communities.

For the Piscataqua Region municipalities in Maine, data on new single family housing permit approvals is available on a town-by-town basis (Table 21.4). Each municipality publishes an annual Town Report that includes a chapter from the town code enforcement officer. PREP extracted the number of new single-family housing permits reported in each of the 10 Maine watershed communities from 2015 (the latest year all 10 communities had publically available data at the time of publication). PREP anticipates continuing to collect Maine municipalities' data year to year and developing trend analyses for the next *State of Our Estuaries* report.

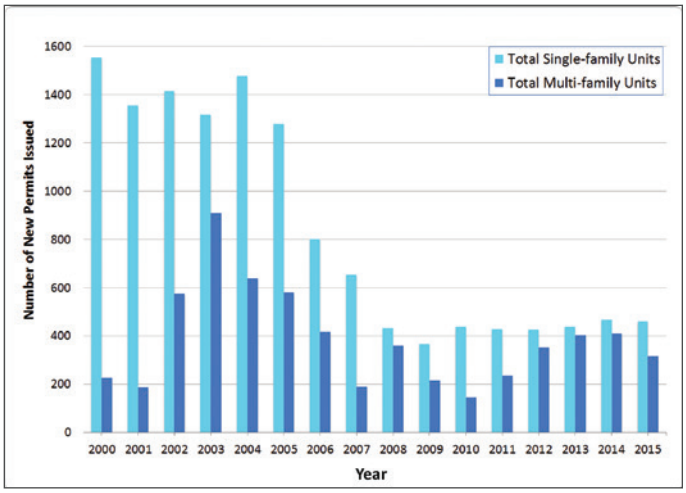


Figure 21.5 New building permits in the Piscataqua Region watershed communities in New Hampshire.

Data Source: NHOEP State Data Center

NH Municipality	Total Housing Units, 2000 (from Census)	Total Units, 2015 (from 2010 Census and new permits)**	Change from 2000-2015	% change (change/ total housing units in 2000)
Brentwood	920	1,446	526	57.17%
Fremont	1,201	1,735	534	44.46%
East Kingston	648	935	287	44.29%
Chester	1,247	1,725	478	38.33%
Epping	2,215	2,959	744	33.59%
Sandown	1,777	2,345	568	31.96%
Deerfield	1,406	1,851	445	31.65%
Nottingham	1,592	2,093	501	31.47%
Greenland	1,245	1,603	358	28.76%
Hampton Falls	729	912	183	25.10%

Table 21.2 Top 10 New Hampshire Piscataqua Region watershed communities with the largest percent change in units from 2000-2015.

Data Source: NHOEP State Data Center & US Census Bureau

NH Municipality	Absolute change in housing units from 2000-2015
Dover	**2,252**
Rochester	**1,845**
Hampton	**847**
Newmarket	**844**
Portsmouth	**770**
Epping	**744**
Durham	**738**
Exeter	**707**
Barrington	**670**
Raymond	**663**

Table 21.3 Top 10 New Hampshire Piscataqua Region watershed communities with the largest absolute changes in housing units.

Data Source: NHOEP State Data Center & US Census Bureau

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

Housing Permit Approvals, cont.

Maine Municipality	New Single-Family Housing Permits Issued in 2015
Wells	113
York	68
Berwick	28
Kittery	27
Acton	22
Lebanon	18
Elliot	18
Sanford	17
South Berwick	10
North Berwick	10
Total:	331

Table 21.4 Maine Piscataqua Region watershed communities housing permit data in 2015.

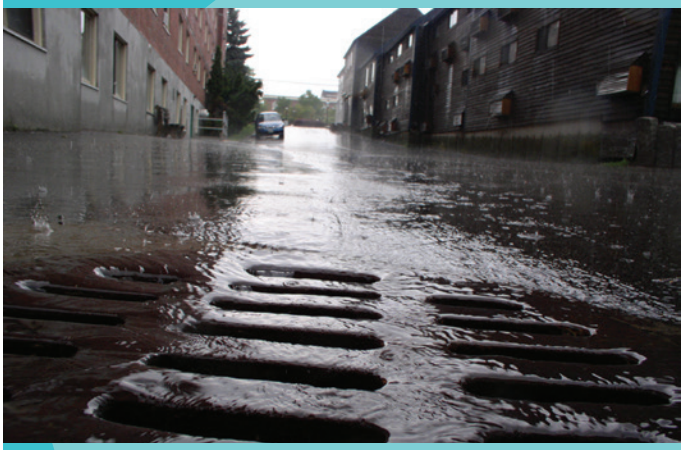
Data Source: ME 2015 Town Reports***

PORTSMOUTH, NH, FROM THE AIR | PHOTO BY A. LYON

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

PRESSURE INDICATOR
CONDITION INDICATOR
RESPONSE INDICATOR
SOCIAL INDICATOR

STORMWATER MANAGEMENT EFFORT



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

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

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

PREP GOAL: NO GOAL.

EXPLANATION Adopting local stormwater management standards allows a community to grow in a resilient manner, while improving existing conditions and preventing future water quality impairments. In New Hampshire, state statute enables municipalities to adopt regulatory standards for stormwater management for projects not captured under state Alteration of Terrain regulations (projects smaller than 100,000 sq. ft. of terrain or 50,000 sq. ft. of protected shoreland).[69] In Maine, the state stormwater management law provides stormwater management standards for development that municipalities must adhere to (if projects exceed one acre of disturbance).

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

Local stormwater standards empower communities to guide development and protect natural resources while providing developers with consistent, equitable guidelines for managing impervious cover. These standards can be adopted in the zoning ordinance or as land development regulations. While any improvement to existing stormwater standards is a beneficial first step, the SWA model represents a comprehensive approach. Below is a summarized version of what is contained in the Southeast Watershed Alliance's Model Stormwater Standards for Coastal Watershed Communities: Elements B-D[70]. Stormwater experts encourage municipalities to include the following four components to minimize further water quality impairment and improve present conditions.

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

A 2015 UNHSC study of the Oyster River watershed found early adoption of enhanced stormwater standards could reduce average annual pollutant loads by up to 70% and save towns an estimated $14 million in avoided costs over the next 30 years.[71] If other municipalities in the Piscataqua Region watershed adopt such regulations, future cost savings could increase dramatically. To track stormwater management progress across the watershed, PREP and its partners monitor which municipalities have adopted enhanced stormwater standards. Figure 22.1 reflects which communities have adopted the SWA model stormwater standards or something similar (8), which communities have adopted a partial set of the recommended regulations without redevelopment standards (5), and which communities have regulations pending (7). Overall, 30 out of 52 communities in the Piscataqua Region watershed have adopted some level of stormwater standards; this includes the 10 Maine communities that adhere to Maine state standards.

In addition to adopting new regulations, communities are exploring creative options for funding sustainable stormwater management. One option is adoption of a stormwater utility designed to generate funding through user fees that are often based on a property's collective amount of impervious cover within the utility district. A stormwater utility provides a stable revenue source to support long-term operation and implementation of a municipal stormwater program that addresses flooding, water quality, and aging infrastructure. These utilities require equitable cost distributions (charging owners with the most impervious cover their fair share), incentivize reduction of stormwater volumes through lower fees, and help communities comply with federal regulations. Many communities in Maine, Vermont, and Massachusetts have successfully adopted stormwater utilities. While no such utilities currently exist in New Hampshire (Table 22.1), the cities of Dover and Portsmouth have conducted feasibility studies.[72, 73]

For more information:

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

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

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

Number of Piscataqua Region watershed communities that have adopted a stormwater utility	**0**

Table 22.1 Number of watershed communities that have adopted a stormwater utility.

Data Source: Rockingham Planning Commission & Strafford Regional Planning Commission, July 2017

Continued

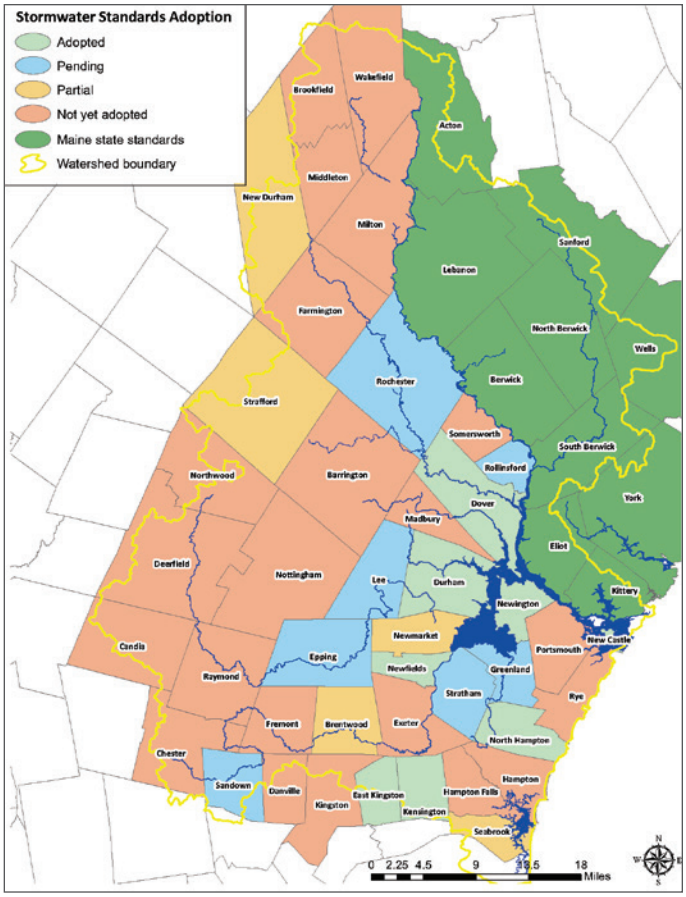


Figure 22.1 Map depicting adoption status of SWA model stormwater standards across 42 New Hampshire communities and 10 Maine communities.

Data Source: Rockingham Planning Commission & Strafford Regional Planning Commission, July 2017. Mapping and GIS technical assistance provided by the University of New Hampshire Cooperative Extension

AN EXAMPLE OF STORMWATER BEST MANAGEMENT PRACTICES ON SITE AT THE UNH JACKSON ESTUARINE LABORATORY | PHOTO BY PREP

PRESSURE INDICATOR
CONDITION INDICATOR
RESPONSE INDICATOR
SOCIAL INDICATOR

STEWARDSHIP BEHAVIOR

How many volunteer hours were logged in the watershed through the work of six New Hampshire stewardship groups in 2015 and 2016?

Additionally, how many signups and events for stewardship-related activities were completed through The Stewardship Network: New England from 2015 to 2016?

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

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

WHY THIS MATTERS Stewardship of local ecosystems improves environmental conditions and fosters and sustains a sense of investment in, and value for, the long-term wellbeing of those systems. No matter how stringent local environmental regulations are or how advanced wastewater and stormwater technology becomes, local communities cannot be truly sustainable without an engaged citizenry that takes action to care for and protect local natural resources. Environmental stewardship in communities has been shown to create personal connections to the landscape and improve local quality of life, and its role in strengthening the social resilience of communities is being studied[74]. Many organizations, groups, and individuals in the Piscataqua Region are already working to ensure that stewardship culture is ingrained in the identity of local residents. The health of this region depends on this stewardship culture's capacity to reach and engage new demographics of residents, including newcomers to the region and the growing millennial population.

PREP GOAL: NO GOAL.

EXPLANATION Stewardship can be defined as the careful and responsible management of something entrusted to one's care.[75] While there are many active organizations working on stewardship and conservation across the region, PREP developed criteria for which groups' data would be used for this indicator. These include 1) regular collection of volunteer data; 2) opportunities for engagement offered for a majority of the year; 3) stewardship activities that occurred within the PREP watershed boundary, and 4) a focus on coastal resources. The entities selected were the Blue Ocean Society for Marine Conservation, Great Bay National Estuarine Research Reserve (GBNERR), the Gundalow Company, the Seacoast Science Center, the New Hampshire Department of Resources and Economic Development (NHDRED), and the Coastal Research Volunteer (CRV) Program at University of New Hampshire Sea Grant.

These organizations have dedicated volunteer bases that combined to donate 44,174 hours in 2015 in the Piscataqua Region and 39,788 hours in 2016 (Table 23.1). Using the latest Bureau of Labor Statistics volunteer rate for New Hampshire ($24.90 per hour), the estimated economic value of this contribution is $1,099,993 in 2015 and $990,721 in 2016[76]. These volunteers work tirelessly to care for the local landscape, be it through cleaning up litter on a beach, restoring eroded dunes, counting glass eels, or teaching students about the historical significance of Great Bay and its tributaries. The work of these passionate volunteers improves environmental conditions and lays the foundation for increased understanding of, and appreciation for, local natural resources. By tracking the hours donated by volunteers from these well-established groups, PREP can track the activity of a dedicated group of stewards in the region. PREP hopes to expand the number of organizations contributing to this indicator in the future, with a particular focus on those that work in Maine.

It is crucial that this spirit of stewardship and understanding of local ecosystems continue in the region, especially as populations increase and our natural resources are more heavily utilized. The University of New Hampshire Cooperative Extension launched The Stewardship Network: New England in 2013 to address New Hampshire's growing need for increased stewardship capacity and volunteer coordination. The Network's mission is to mobilize volunteers to care for and study the lands and waters in New England. In keeping with this mission, the Network cultivates an online hub for stewardship and citizen science volunteer opportunities and trainings. Their website (http://newengland.stewardshipnetwork.org/citizen-science) and weekly e-bulletin are utilized by hundreds of organizations to promote hundreds of stewardship opportunities and events. There are thousands of subscribers interested in taking part in these activities, and The Stewardship Network tracks how many people sign up and how many hours are spent on each event. Additonally, The Stewardship Network can select data by zip code, including the coastal region. In 2015, 422 people signed up for 122 events, and in 2016, 524 people signed up for 96 events (Table 23.2).

Organization	2015	2016
Blue Ocean Society for Marine Conservation	3,080	3,765
NH Dept. of Resources & Economic Development	19,872	19,791
NH Sea Grant Dune & Coastal Research Volunteers	1,764	1,602
Great Bay National Estuarine Research Reserve	3,883	2,963
Gundalow Company	2,500	2,779
Seacoast Science Center	13,075	11,978
Combined Total Hours	**44,174**	**39,878**

Table 23.1 Volunteer hours by selected stewardship groups by year.

Data Source: Blue Ocean Society; NHDRED; NH Sea Grant; GBNERR; Gundalow Company; Seacoast Science Center

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

Table 23.2 The Stewardship Network: New England volunteer event data in the Piscataqua Region by year.

Data Source: UNH Cooperative Extension, The Stewardship Network: New England

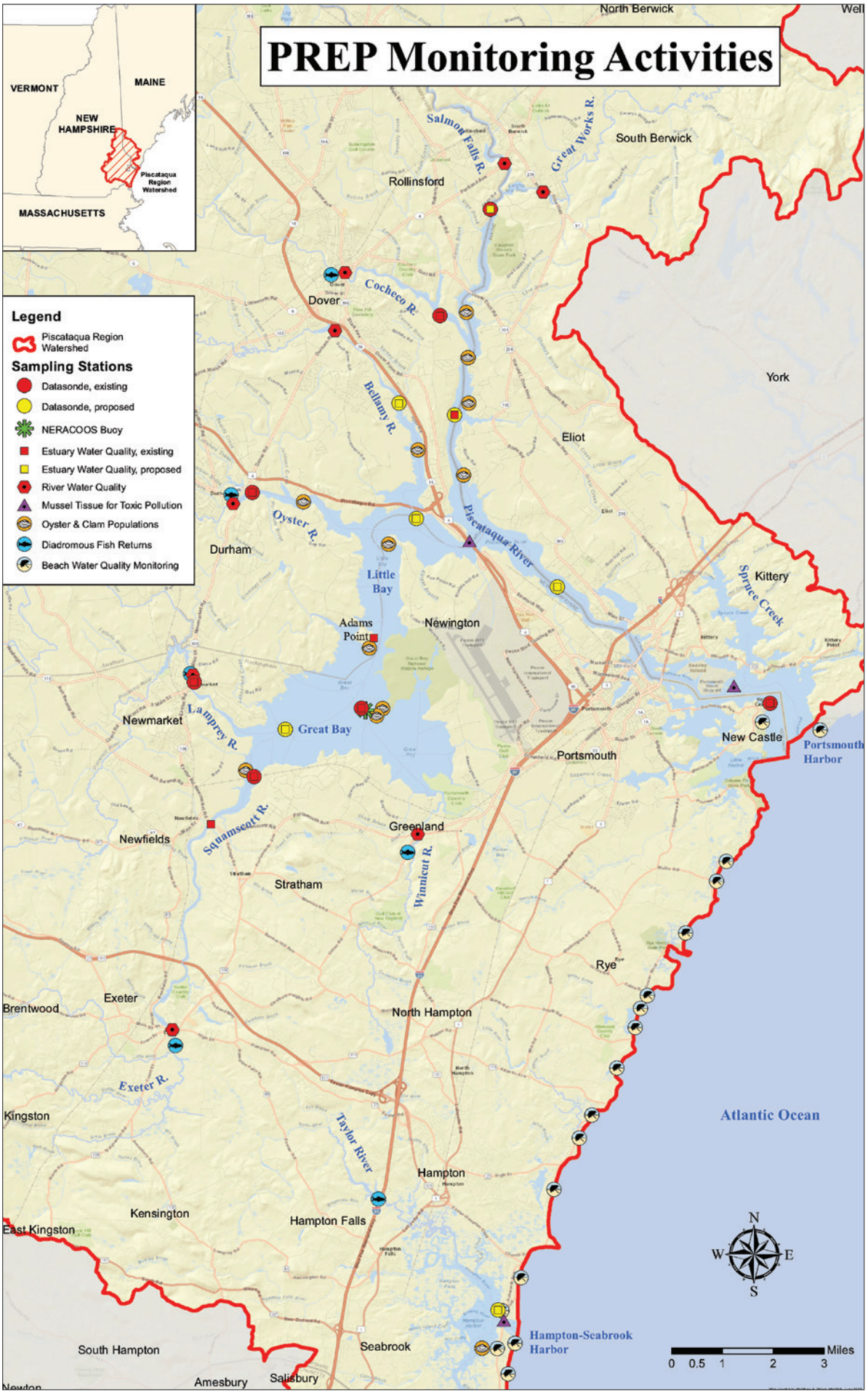
LOOKING AHEAD: 2018 & BEYOND

The Technical Advisory Committee (TAC) process helped to identify the following specific areas of needed research:

- **Continue to Increase Monitoring** Expand sites and parameters in the Hampton-Seabrook Estuary, building on the 2017 addition of an automated datasonde located in the Hampton River.
- **Macroalgae/Seaweed Monitoring** Invest in a more comprehensive monitoring plan looking at subtidal environments in addition to the existing intertidal sites.
- **Bio-optical Modeling** Invest in more highly resolved (time and space) measurements of suspended sediments, CDOM, phytoplankton, seaweed, and epiphytes to develop a data-driven model focused on what is limiting light at different locations in the estuary. Ideally, this would be followed by ground truth monitoring across the estuary to correct the model for accuracy.
- **Sediment Transport** Develop a better understanding of the sources and movement of sediment within the estuary.
- **Benthic Community Health** Augment the resolution (time and space) of our understanding of invertebrate population in the sediments. Key parameters will include–but are not limited to–distribution of species and the overall population density as well as key community indices such as diversity and evenness.
- **Increase Frequency of Nitrogen Sampling** Collect loading data before, during, and after storm events to improve and understand best management practices (BMP's) such as buffers or porous pavements.
- **Sediment Sampling** Invest in high-resolution (time and space) sediment sampling to better understand benthic flux of nitrogen and nitrogen regeneration areas.
- **Improved Mass-Balance Assessment** Incorporate estuarine hydrodynamics and nitrogen cycling in both the water column and sediments to better understand how nutrient loading impacts ecosystem health.
- **Toxic Contaminants Monitoring** Continue and expand mussel tissue analysis for tracking concentration of contaminants. Also, consider methods for better understanding prevalence and impact of emerging contaminants.
- **Clam Research** Better understand the accuracy of current age groupings for clams. Current estimates use clam flat data from Gloucester. Local length versus age is key for soft shell clams and is a research need.
- **SeagrassNet** Look at archived data paying attention to light attenuation and sediment quality, and continue SeagrassNet into the future.
- **Long-term Monitoring** Further develop datasets for additional parameters such as: air/water temperature, storm frequency/intensity, CDOM, and light attenuation.
- **Social Indicators** Continue to monitor and expand the data for the three selected social indicators as well as explore indicator monitoring into recreation, quality of life, and behavior arenas.

It is important to remember that research of this type is costly and therefore prioritization is essential so that PREP together with our partners can seek out appropriate resources for conducting this vital work. As noted in the *Estuary Health: Stress and Resilience* section (p. 7), there are many pieces of the estuary story that we have yet to understand, and expanding our knowledge and understanding of these systems is essential. Asking questions, reviewing our methods, expanding our expertise, and humbly accepting that we may never know it all is a key balance to strike as we move forward.

HAMPTON-SEABROOK ESTUARY | PHOTO BY E. LORD



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

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Tom Morgan, Town of Seabrook, NH
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NH Department of Environmental Services
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HAMPTON-SEABROOK HARBOR | PHOTO BY E. LORD

END NOTES

1. See Holling (1973)
2. See Bierman et. al. (2014)
3. See Huang et. al. (2017)
4. See Balch et. al. (2016)
5. See Gledhill et. al. (2015)
6. See New Hampshire Coastal Risk and Hazards Commission (2016)
7. See PREP (2012)
8. See Latimer and Rego (2010)
9. See Burkholder et. al. (2007)
10. See Guillotreau et. al. (2017)
11. See NH DES (2017a)
12. See Kemp et. al. (2004)
13. See Nettleton et. al. (2011)
14. See Flanagan et. al. (2017)
15. See Kenworthy et. al. (2017)
16. See Unsworth et. al. (2015)
17. See Unsworth et. al. (2015)
18. See Kenworthy et. al. (2017)
19. See Mallin et. al. (2000)
20. See PREP (2017)
21. See NOAA/EPA (1988), Jones et. al. (1992), and Jones (2000)

** Note: of the three above studies, only the 2000 study incorporated atmospheric deposition into estimates of total nitrogen load. Atmospheric deposition from the 2000 study was combined with nitrogen load estimates from 1988 and 1992 studies to obtain earlier estimates of total nitrogen load.*

22. See NH DES (2014)
23. See Roseen et. al (2015)
24. See PREP (2012)
25. See Jones (2000)
26. See NH State Climate Office (2014)
27. See Hayhoe et. al. (2007)
28. See US EPA (2012)
29. See Bricker et. al. (2003)
30. See US EPA (2012)
31. See NH DES (2017b)
32. See NH DES (2017b)
33. See Mathieson and Dawes (2017)
34. See Thomsen et. al. (2001)
35. See Hauxwell et. al. (2001)
36. See Burdick et. al. (2017)
37. See US EPA (2012)
38. See Bierman et. al. (2014)
39. See Pennock (2005)
40. See NH DES (2017b)
41. See Orth et. al. (2006)
42. See Unsworth et. al. (2015)
43. See Kenworthy et. al. (2013)
44. See PREP (2010)
45. See Smith et. al. (2017)
46. See Ao et. al. (2017)
47. See NRDC (2014)
48. See NEIWPCC (2007)
49. See Sunderland et. al. (2012)
50. See PREP (2009)
51. See LeBlanc et. al. (2011)
52. See Ewart and Ford (1993)
53. See Carballal et. al. (2015)
54. See NHFG (2017)
55. See TNC (2009)
56. See Grout (2017)
57. See Dionne (2017)
58. See Zankel et. al. (2006)
59. See Walker et. al. (2010)
60. See Grizzle and Ward (2016)
61. See Eckert (2016)
62. See New Hampshire Estuaries Project (2000)
63. See NOAA (2013)
64. See US Census Bureau (2015)
65. See NH Employment Security (2016)
66. See Johnson et. al. (2016)
67. See Aisch et. al. (2016)
68. See New Hampshire Public Radio (2017)
69. See NH DES Alteration of Terrain Bureau (2017)
70. See Southeast Watershed Alliance et. al. (2012)
71. See University of New Hampshire Stormwater Center and Vanasse Hangen Brustlin, Inc. (2015)
72. See NHDES (2011a)
73. See NHDES (2011b)
74. See McMillen et. al. (2016)
75. See Merriam Webster (2017)
76. See 2016 Bureau of Labor Statistics (2017)

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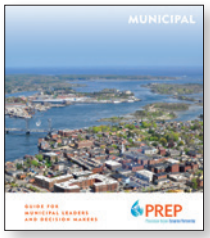

A short guide for municipal leaders and decision makers that provides a list of priority policy options for consideration and model efforts from our own communities.

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

PREP
Piscataqua Region Estuaries Partnership

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