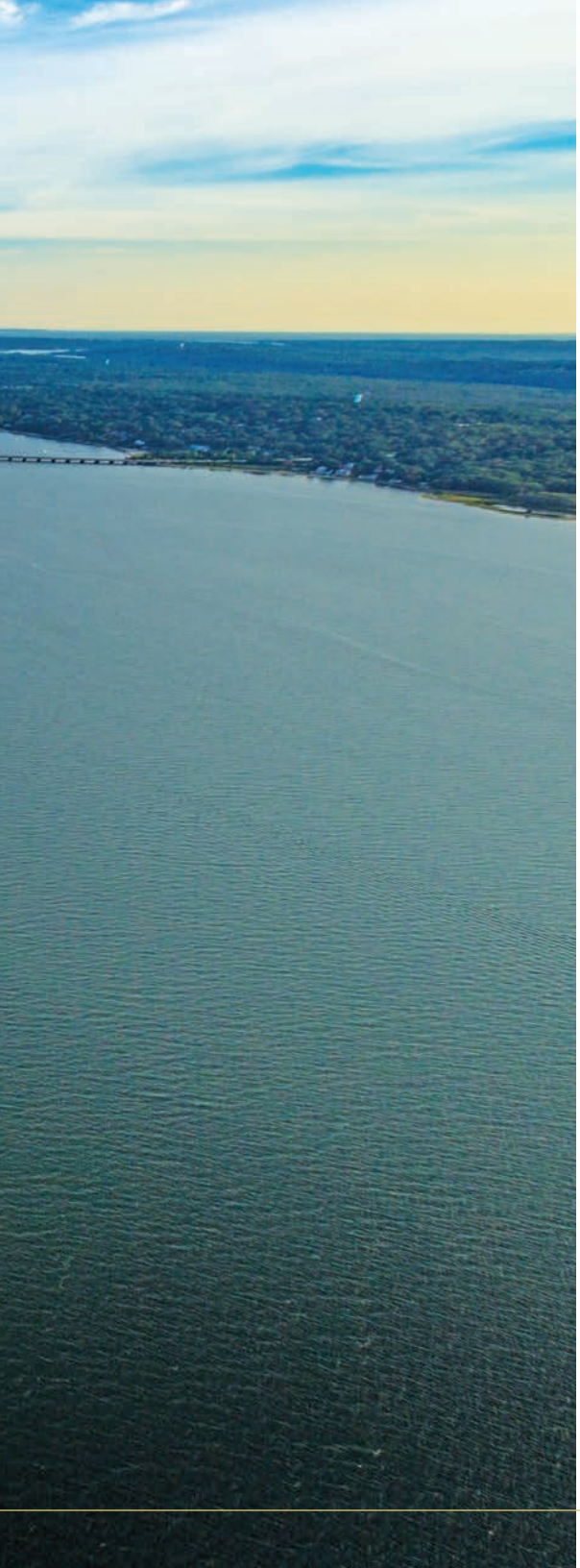
State of Narragansett Bay and Its Watershed

Summary Report

Narragansett Bay
Estuary Program
2017



State of Narragansett Bay and Its Watershed: Summary Report
Narragansett Bay Estuary Program, 2017

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Cover Photo: West Passage of Narragansett Bay looking south towards Jamestown, RI.

NARRAGANSETT BAY ESTUARY PROGRAM

EPA

NEIWPCC
New England Interstate Water Pollution Control Commission

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INTRODUCTION

Narragansett Bay and its watershed define the identity of Rhode Island and adjacent areas of Massachusetts. Covering 196 square miles, the bay spans the border of the two states and supports highly valued economic, recreation, and tourism activities. The land area, or watershed, that drains into the bay encompasses 1,705 square miles with over one hundred towns and cities that are home to 1.95 million people. While most of the bay itself is in Rhode Island, 60 percent of the Narragansett Bay watershed lies within Massachusetts. The watershed is composed of four major basins (see map) with over 3,500 miles of streams and rivers that carry water into the bay, linking land and sea.

In the 1800s, the Blackstone River Valley became the birthplace of the American Industrial Revolution, and the resulting development greatly altered the bay and watershed through damming of rivers, construction of mills and canals, urbanization, and pollution. Today, the watershed's three major population centers are located in Providence, Rhode Island, and in Fall River and Worcester, Massachusetts, but the population has spread far beyond the urban cores.

For some 40 years, state, federal, and local government agencies have undertaken major initiatives to improve water quality, including upgrades to wastewater treatment facilities and improvements to stormwater infrastructure, supported by years of water quality monitoring by agencies, researchers, citizens, and other environmental stewards. Many people have worked to preserve over 170,000 acres of natural open space lands in the watershed and to manage land use to reduce and mitigate pollution.

Map: Topography and hydrography of the four basins in the Narragansett Bay watershed.

While some forms of pollution have been reduced significantly, other pollution sources and the escalating impacts of climate change influence the bay's ecosystem and public health conditions, and are the focus of intensive efforts by many agencies and organizations.

The Narragansett Bay Estuary Program was established in 1985 to support these collaborative efforts. An estuary is a place where rivers meet the sea, and the Estuary Program works with numerous partners to protect, restore, and preserve the integrity of the Narragansett Bay estuary, focusing on both the bay and the watershed.

Beginning in 2014, the Estuary Program brought together practitioners from universities, organizations, and agencies in Massachusetts and Rhode Island to collaboratively produce the 2017 *State of Narragansett Bay and Its Watershed* report through gathering and analyzing the best available data. The comprehensive, 500-page technical report presents findings on the status and trends of 24 indicators of stressors and conditions in the bay and watershed.

The findings of the 2017 *State of Narragansett Bay and Its Watershed* report offer a new and unprecedented understanding of the changing conditions in this important region. Agencies, organizations, and individuals can use this information in their decision-making to ensure that the benefits provided by the bay and watershed are sustained and enhanced for future generations.

Key findings drawn from the technical report highlight five themes:

- **The water in the bay is getting cleaner.**
- **Scientists are tracking changes in the ecosystem after recent reductions in pollution from wastewater treatment facilities.**
- **Conditions vary greatly among places in the bay and watershed, generally improving with distance from urban areas–but urbanized areas are expanding.**
- **Climate change is affecting air and water temperatures, precipitation, sea level, and fish in the Narragansett Bay region.**
- **More research and monitoring are needed to understand the major changes occurring in the bay and watershed in order to enable well-informed adaptation and mitigation.**

To download the 2017 *State of Narragansett Bay and Its Watershed* technical report and related resources, go to: http://nbep.org/the-state-of-our-watershed

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CLEANER WATER

Overview: Bay Water Is Getting Cleaner

Not all that long ago, tremendous volumes of minimally treated sewage and toxic contaminants flowed into Narragansett Bay every day, leading to fish kills, contaminated shellfish, unhealthy swimming conditions, and an array of other problems. Over the past several decades, major investments in wastewater facilities and restrictions on harmful chemicals paid off in a dramatic drop in pollution. Discharges of pathogens, excessive nutrients, and toxic pollutants have declined. Now bay water is cleaner.

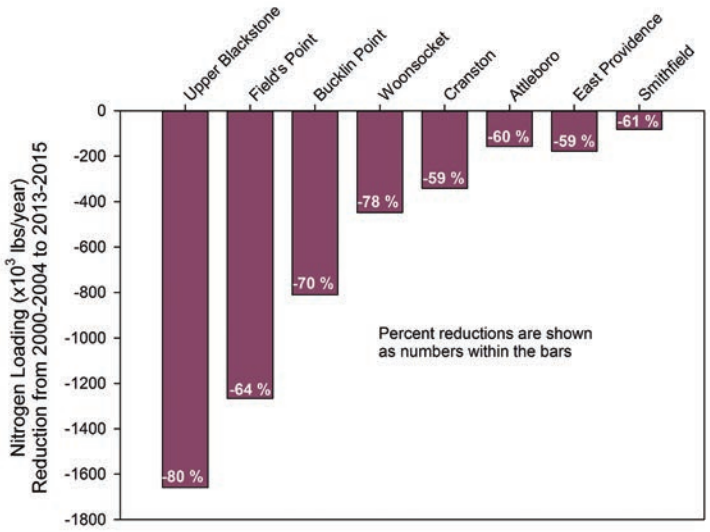
While major successes have been achieved, important challenges remain. State assessments continue to find poor water conditions in some areas due to stormwater runoff, failing septic systems, and cesspools. Certain historical contaminants persist at levels that pose health risks to people, such as mercury contained in fish caught in the bay. New types of contaminants from pharmaceuticals, personal care products, and industrial processes are entering the ecosystem with unknown impacts. Poorly managed stormwater from existing urbanized areas and rapidly expanding development of land outside urban cores are causing greater volumes of pollutant-laden waters to enter the river basins as well as the eleven estuarine sections of the bay (see map).

Map: Water depth in Narragansett Bay with names indicating sections of the bay. Photo: Beavertail State Park, Jamestown, RI.

Investments in Wastewater Treatment Facilities Have Significantly Reduced Nutrients

Over the last fifteen years, management policies and significant investments in many of the 37 wastewater treatment facilities have made huge strides in reducing the amount of nitrogen and phosphorus discharged from the facilities. Excessive amounts of nutrients can harm aquatic life by stimulating algae growth, which leads to low levels of dissolved oxygen as the algae die and decompose. A comparison of nutrient budgets from 2000–2004 and 2013–2015 revealed a 55 percent decrease in total nitrogen from wastewater treatment facility loadings throughout the watershed and a 45 percent decrease in total phosphorus.

Reductions in Nitrogen Loading



Map: Percent contribution to nitrogen loading and reduction in nitrogen loading for each of the 37 wastewater treatment facilities. Graph: Nitrogen loading reductions at eight of the wastewater treatment facilities from 2000-2004 to 2013-2015.

RELATIVE CONTRIBUTION (%) OF NITROGEN LOADINGS FROM WASTEWATER TREATMENT FACILITIES
0% - 1%
2% - 5%
6% - 10%
11% - 15%
> 15%

REDUCTION OF NITROGEN (N) LOADINGS [2000 - 2004 TO 2013 - 2015]
N DECREASED > 50%
25% - 50%
< 5% - 25%
NO CHANGE
N INCREASED 5% - 25%
> 25%
UNKNOWN

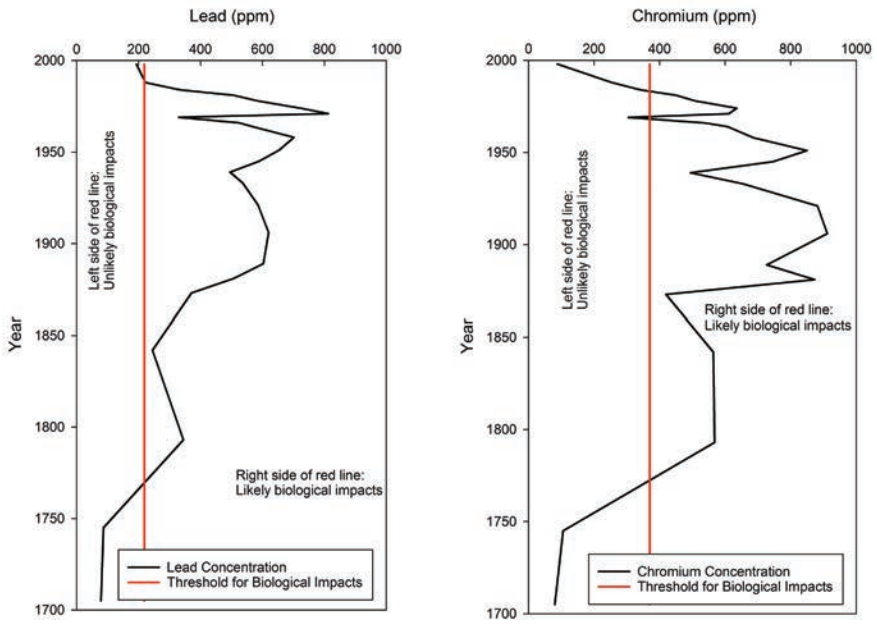
AREAS CONNECTED TO SEWER SYSTEM

BOSTON
WORCESTER
Upper Blackstone (Worcester)
Blackstone River
MASSACHUSETTS
BROCKTON
Woonsocket
Attleboro
Smithfield
Bucklin Point
PROVIDENCE
Field's Point
East Providence
Cranston
Pawtuxet River
TAUNTON
Taunton River
Taunton
FALL RIVER
Fall River
Bristol
CONNECTICUT
RHODE ISLAND
NEWPORT
NARRAGANSETT BAY
SAKONNET POINT
POINT JUDITH
0 5 10 Kilometers
0 2.5 5 Miles

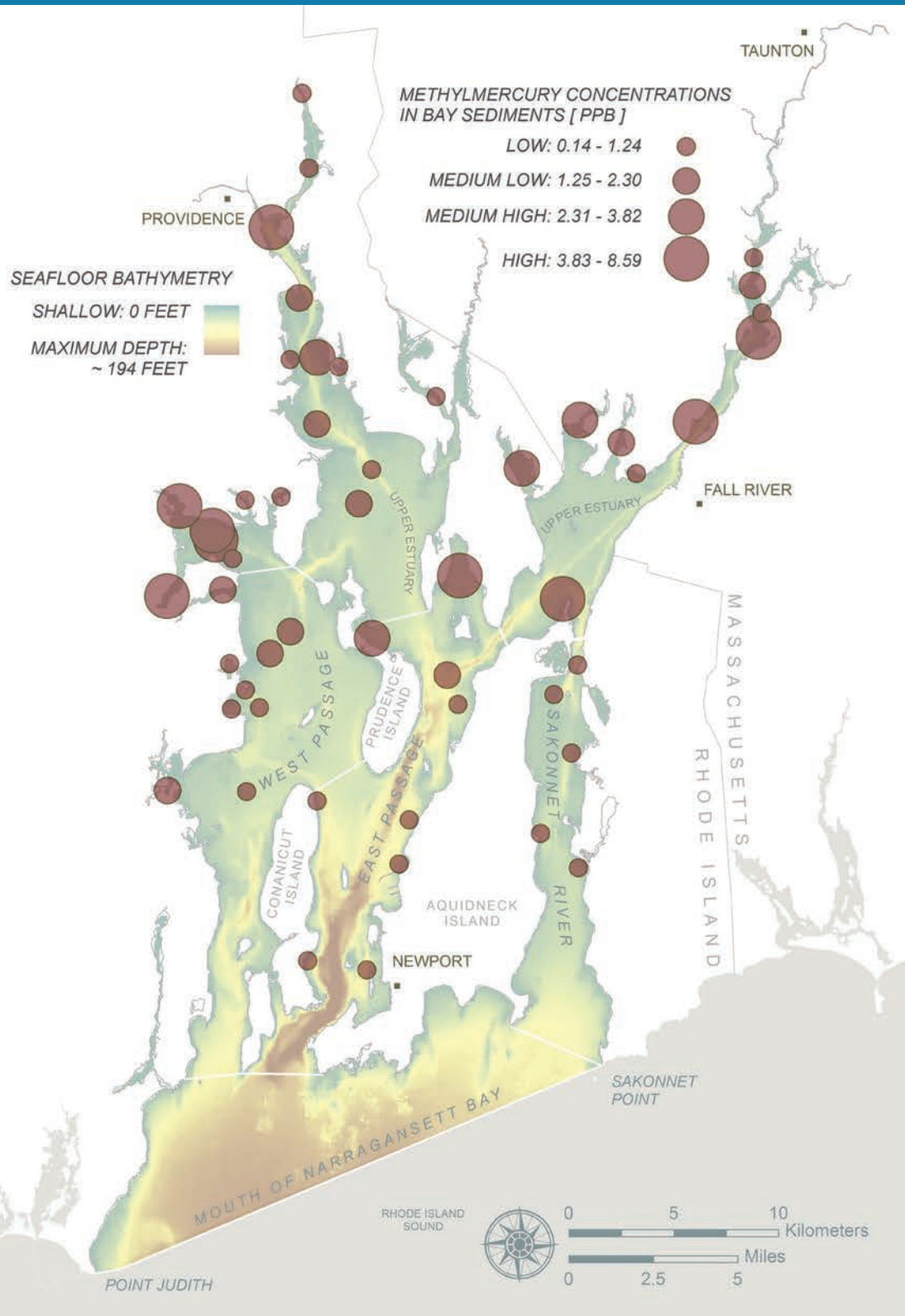
Legacy Contaminants Have Declined Substantially, but Some Still Pose Hazards

Exposure to metals, polychlorinated biphenyls (PCBs), and pesticides causes a variety of human health issues, particularly through consumption of contaminated fish and shellfish. These substances are called legacy contaminants because they remain in the environment even though their use has declined or come to an end. Concentrations of legacy contaminants, such as lead and chromium (see graphs below), have decreased dramatically in the last 50 years due to changes in the manufacturing community and in regulation and removal programs, including pre-treatment and upgrades at wastewater treatment facilities. However, the sediments of the upper estuary (including the Providence River, the Taunton River, and Greenwich Bay) still have high concentrations of many legacy contaminants, particularly mercury (shown as methylmercury on the map), that may pose a human health risk through bioaccumulation in locally harvested seafood.

Historical Trends in Two Legacy Contaminants



Map: Methylmercury concentrations in sediments of Narragansett Bay.
Graphs: Changes in lead and chromium concentrations from approximately 1700 to 2000 based on data from a Seekonk River sediment core near Providence. Red lines indicate the threshold concentration for likely biological impacts.



More Shellfish Harvesting Areas Are Open in the Upper Estuary, Reflecting Reduced Pathogens

To protect public health from contaminated shellfish, primarily due to harmful pathogens, state agencies regulate where shellfish can and cannot be harvested for direct human consumption. Contaminants enter the bay primarily in discharges from wastewater treatment infrastructure (combined sewer systems, failing septic systems, and cesspools) and in runoff of precipitation from land. In recent years, the number of acres opened to shellfish harvesting has increased, reflecting reduced combined sewer overflows in Providence and Fall River.

Timeline of Water Quality Changes

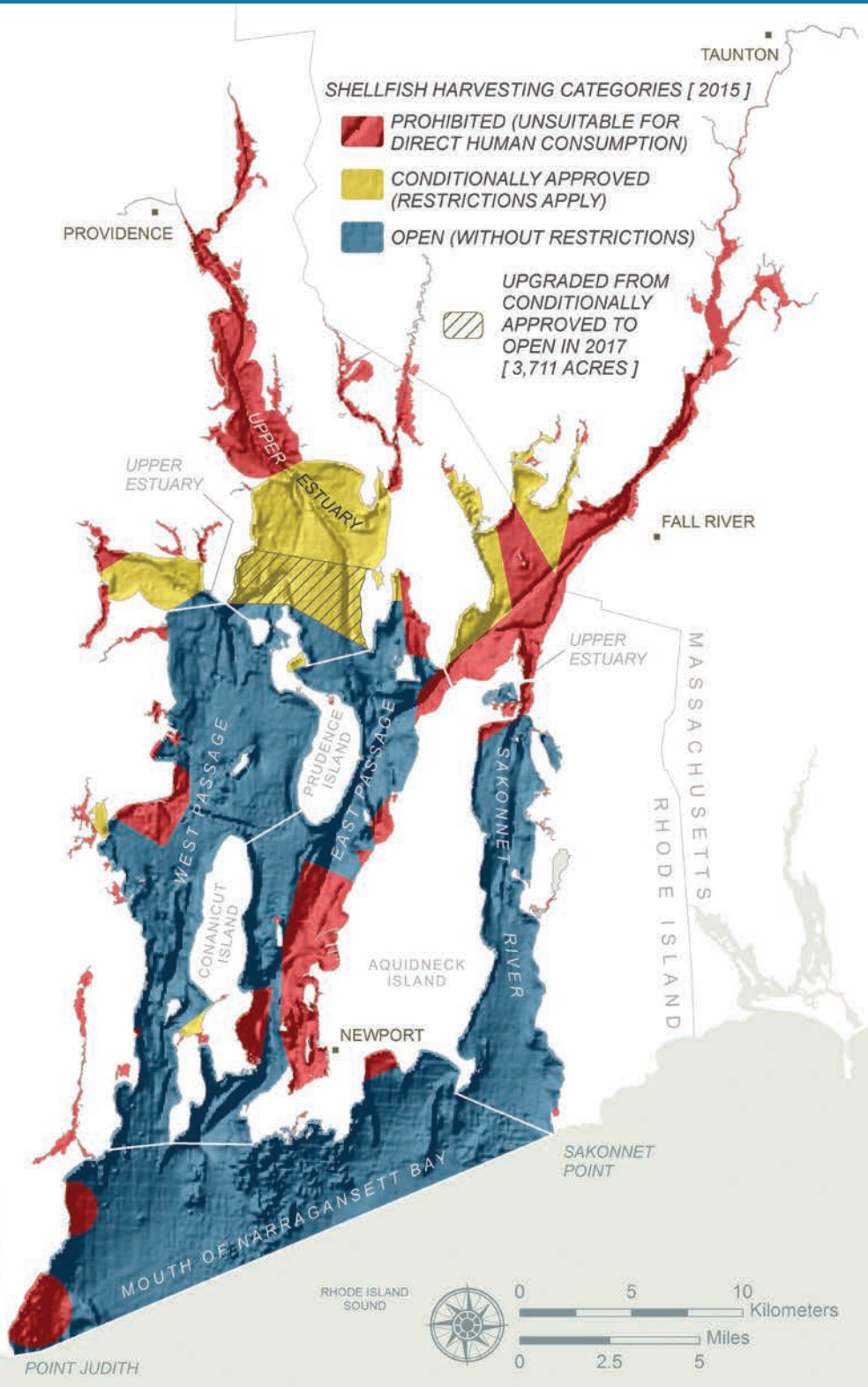
1995–2000: Declining water quality and other factors triggered a 400-acre increase in prohibited shellfish harvesting areas, while reducing conditionally approved areas.

2000–2005: Some conditionally approved areas recovered (200 acres), but there was also an increase in prohibited areas.

2005–2010: A reversal of the 1995–2000 trend occurred, with a dramatic decline in prohibited areas and increase in conditionally approved waters (600 acres), reflecting the reduction in pathogen contamination.

2010–2015: Rate of recovery increased by more than 1,000 acres, and major improvement in water quality occurred in Mount Hope Bay.

2017: 3,711 acres in the upper estuary in Rhode Island were converted from conditionally approved to open, without restrictions.



Map: Shellfish growing areas.
Photo: Shellfishing in the upper estuary.

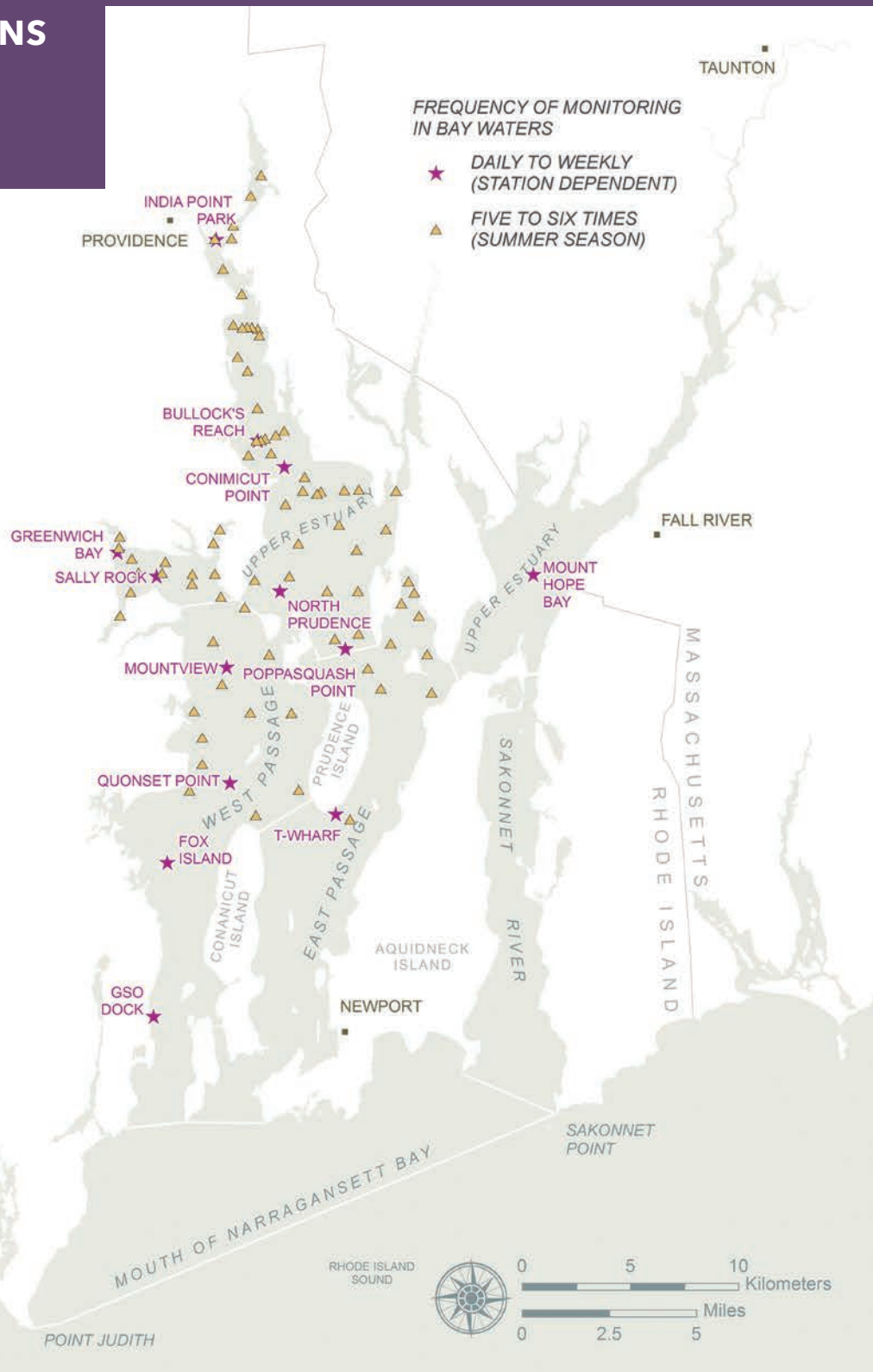
A CHANGING BAY & UNANSWERED QUESTIONS

Overview: Scientists Investigating Effects of Reduced Pollution

The amount of pollution entering Narragansett Bay from wastewater treatment facilities has declined dramatically in recent decades. The question of how the reduction in pollution is affecting the ecosystem is of great interest to resource managers, scientists, commercial and recreational fishermen, and many others. For the *State of Narragansett Bay and Its Watershed* report, the Estuary Program analyzed data on several indicators of ecosystem condition that may be expected to change in response to decreased pollution. Data on seafloor habitats in the bay showed improvement between 1988 and 2008.

However, for other indicators such as chlorophyll, dissolved oxygen, and water clarity, any long-term trends over decades are not yet possible to discern. One reason is that these parameters normally vary greatly from year to year because of many factors such as changes in precipitation and temperatures. Potential changes because of pollution reduction have not yet been identified due to this yearly variability and the relatively short time of monitoring since the infrastructure upgrades. Comprehensive monitoring over a number of years is necessary to identify how the bay changes in response to climate change and the reduction of nitrogen discharges from wastewater treatment facilities (see map).

Map: Locations of water quality sampling.
Photo: Monitoring by the Narragansett Bay Commission.

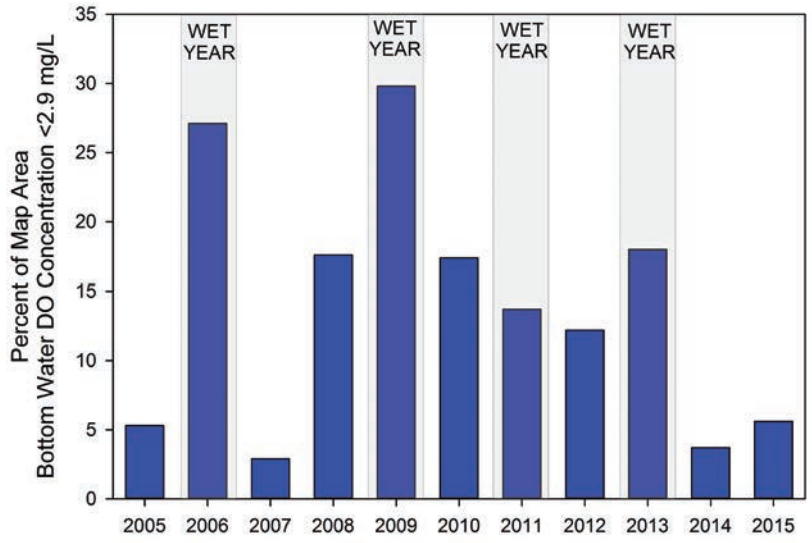


Large Annual Fluctuations in Bay Water Conditions

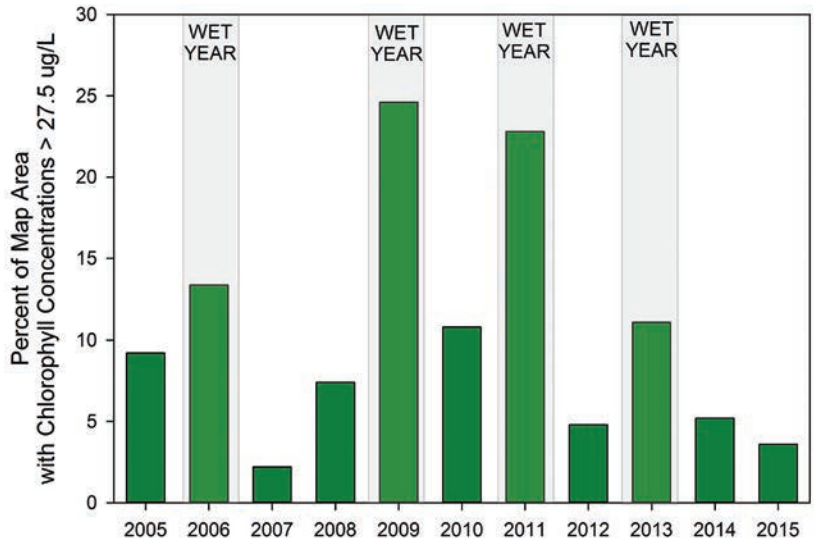
For shellfish and fish to thrive in Narragansett Bay, the water must contain sufficient amounts of dissolved oxygen, and the water must be clear enough for seagrasses, phytoplankton, and seaweeds to obtain energy from the sun. To understand trends in those two parameters, several Estuary Program partners routinely measure dissolved oxygen and water clarity, as well as chlorophyll (an indicator of the amount of phytoplankton in the water). High chlorophyll or phytoplankton bloom levels can indicate excessive nutrient pollution that potentially leads to harmful, low-oxygen conditions. The monitoring data showed that dissolved oxygen and chlorophyll varied greatly from year to year, and thus long-term trends, which might be expected following the recent upgrades to wastewater treatment facilities, have been difficult to discern. Many factors such as precipitation, winds, and temperature also affect these parameters and cause seasonal and annual variations. In the Estuary Program's analysis, each year was characterized as wet or dry based on amount of precipitation and freshwater flow from major rivers. Enhanced monitoring efforts are needed to identify long-term trends within the year-to-year variations and to assess the effects of nutrient pollution reductions.

Graphs: Left: Percentage of Narragansett Bay with low dissolved oxygen (below 2.9 mg/L) in bottom waters from 2005 to 2015. Right: Percentage of the bay with high chlorophyll concentrations (above 27.5 ug/L) from 2005 to 2015. On both graphs, "Wet Year" indicates years with high precipitation and river flow, and the percentage is based on stations represented by yellow triangles on map on page 9.

Dissolved Oxygen



Chlorophyll

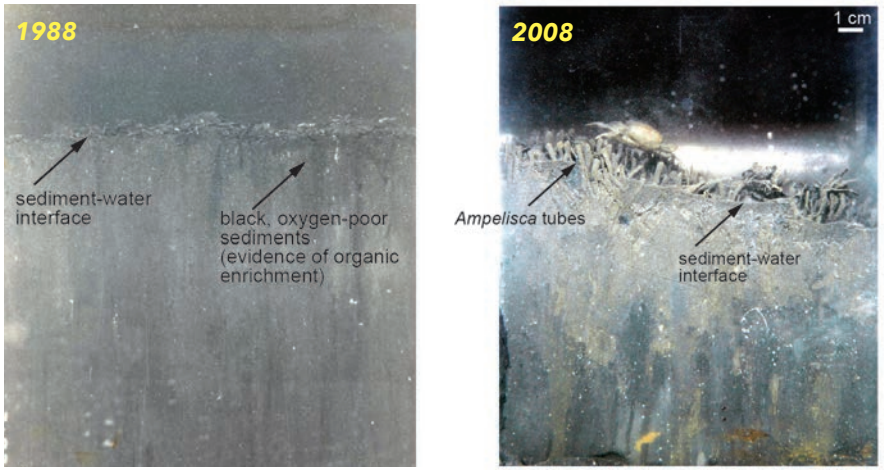


Improved Condition of Seafloor Habitats

The seafloor in the bay is a mosaic of muddy and sandy habitats that supports shellfish, fish, and a wide range of other species. In 1988, scientists found that seafloor species known to tolerate pollution were common in the bay, indicating poor conditions. In contrast, the most recent study, conducted in 2008, showed that beds of small, tube-building crustaceans called *Ampelisca* dominated the seafloor in much of the upper and middle bay. This change was good news because the presence of *Ampelisca* suggests the early stages of improvement.

Researchers plan to secure funding to conduct new studies to determine if seafloor conditions have continued to improve since 2008, when only about half or less of the total nitrogen reductions from wastewater treatment facilities had occurred. Moreover, researchers are near completion of a comprehensive analysis of long-term trends in the seafloor biodiversity of Narragansett Bay, dating back to data sets collected in the 1800s. This study will add to our knowledge of how benthic communities have changed under different pollution or water quality regimes.

Seafloor Images

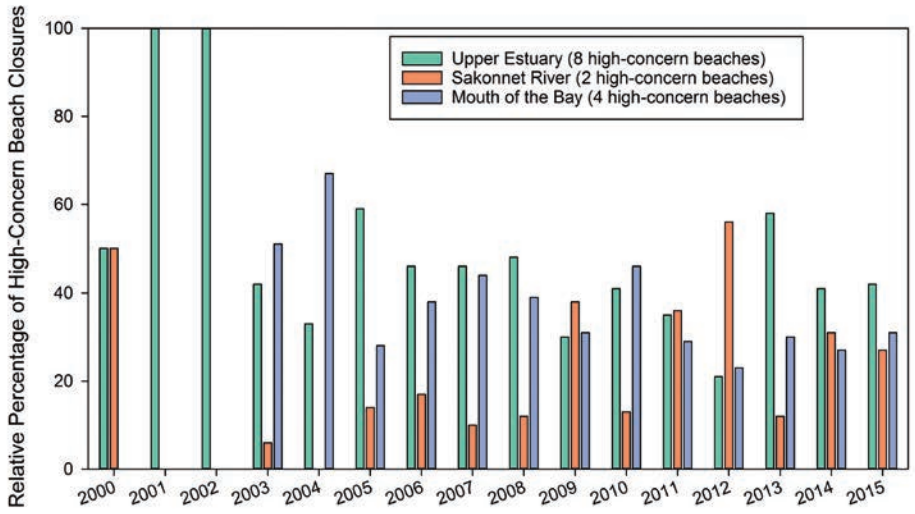


Map: Seafloor habitat change between the 1988 and 2008 surveys.
Photos: Cross-section views of seafloor habitat at site PR-3 (indicated on map) in the Providence River, showing change from organic-rich mud with pollution-tolerant species in 1988 (left) to Ampelisca *beds in 2008 (right).*

Many Factors Influence Frequency of Beach Closures

Narragansett Bay's beaches are a major draw for residents and visitors and have a considerable impact on the economy. State and local agencies monitor the 37 licensed beaches and close individual beaches when water tests show high counts of bacteria that indicate contamination from wastewater or stormwater. However, not all beaches are monitored with the same frequency, and localized impacts vary across the bay. From 2000 to 2015, beaches were closed more consistently in the upper estuary than in the Sakonnet River or mouth of the bay. Before 2009, the upper estuary had more beach closure events during wet summers than dry summers, but this pattern did not continue after 2009 (see map). Taking action to mitigate localized sources of pollution such as stormwater runoff is important to keeping beaches open. Changes in climate such as increased rainfall, warmer water temperatures, and sea level rise are likely to exacerbate conditions leading to beach closures.

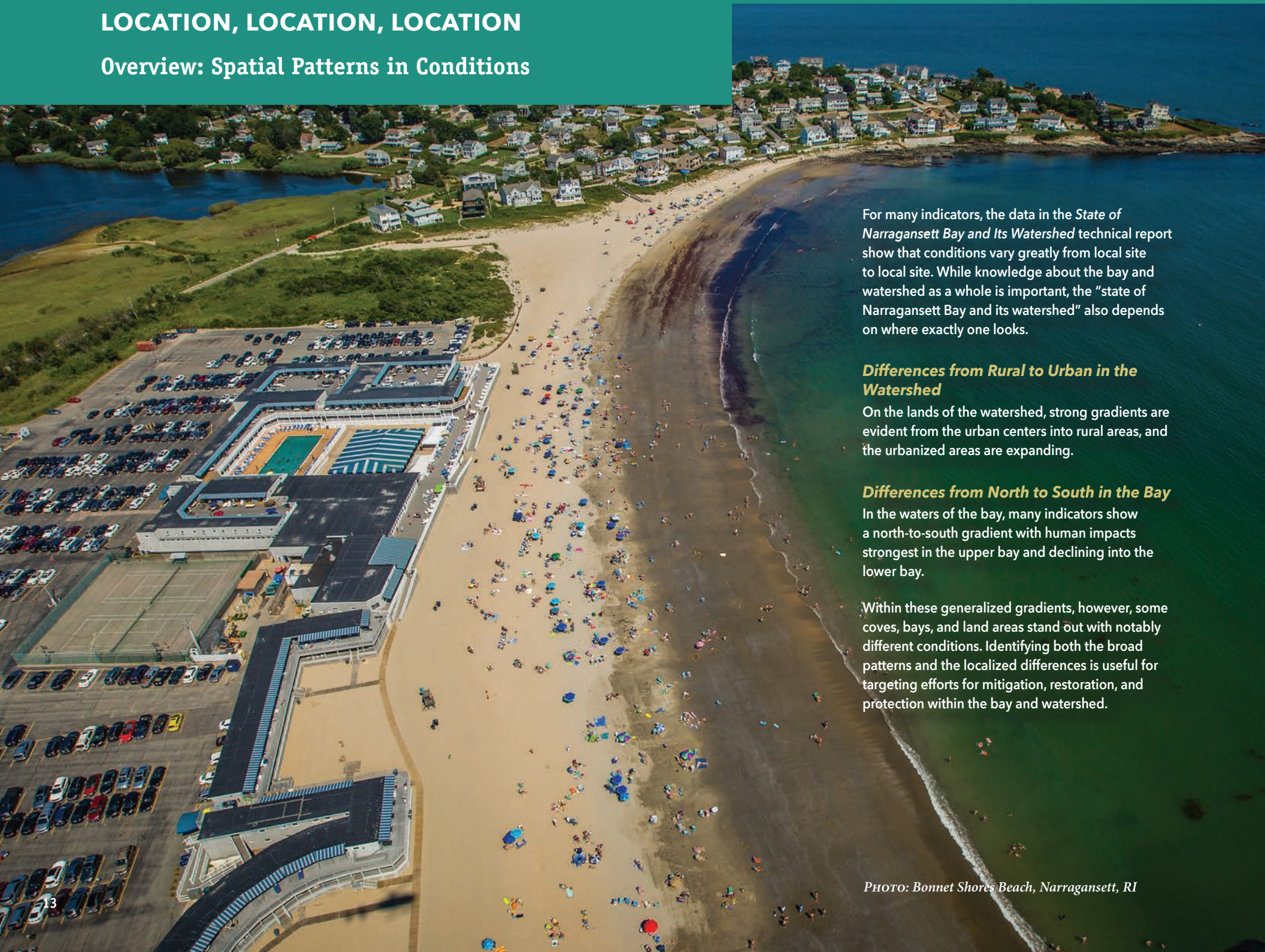
Marine Beach Closures



Map: Locations of high- and low-concern beaches with graphs showing closure events at high-concern beaches in bay regions. Graph: Relative percent of high-concern beach closure events among bay regions.

LOCATION, LOCATION, LOCATION

Overview: Spatial Patterns in Conditions



For many indicators, the data in the *State of Narragansett Bay and Its Watershed* technical report show that conditions vary greatly from local site to local site. While knowledge about the bay and watershed as a whole is important, the "state of Narragansett Bay and its watershed" also depends on where exactly one looks.

Differences from Rural to Urban in the Watershed

On the lands of the watershed, strong gradients are evident from the urban centers into rural areas, and the urbanized areas are expanding.

Differences from North to South in the Bay

In the waters of the bay, many indicators show a north-to-south gradient with human impacts strongest in the upper bay and declining into the lower bay.

Within these generalized gradients, however, some coves, bays, and land areas stand out with notably different conditions. Identifying both the broad patterns and the localized differences is useful for targeting efforts for mitigation, restoration, and protection within the bay and watershed.

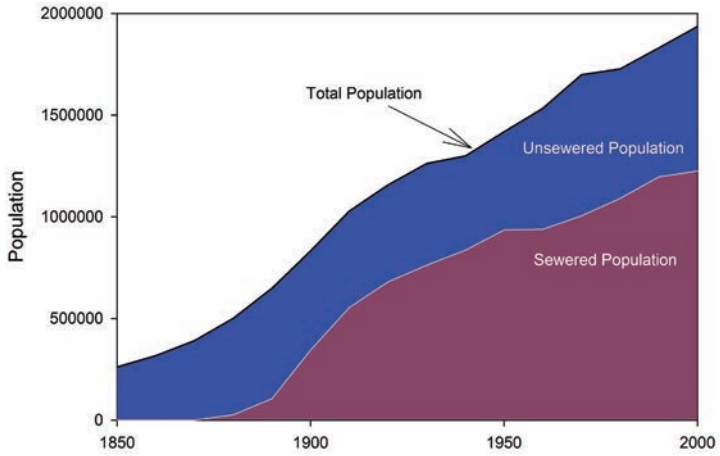
PHOTO: Bonnet Shores Beach, Narragansett, RI

Population Sprawling into Rural Areas

The population of the Narragansett Bay watershed increased by eight percent from 1990 to 2010, and the population was estimated to be approximately 1.9 million in 2014, split nearly equally between Massachusetts and Rhode Island. Most of the recent growth occurred in rural and less-developed areas, such as the Taunton River and Pawtuxet River basins, outside the traditional urban centers, where in many cases population actually declined. This spreading of the human population has spurred changes in land use, including loss of forests, that negatively affect rivers and the bay.

The result is that each person in the watershed uses more land now than ever before. On average, the watershed had 1.8 acres of developed land for every person in 1990 and 2.1 acres in 2010–an increase of sixteen percent. Because of "sprawl," some areas had as many as 3.9 acres of developed land per capita in 2010. While 62 percent of the watershed's residents are served by sewer systems, 38 percent use septic systems and cesspools, some of which are thought to be important sources of excessive nutrients and contaminants entering rivers and the bay.

Human Population



Map: Population change from 1990 to 2010 showing population gains in rural areas and declines in urban areas. Graph: Estimated total population from 1850 to 2000 with the portion of population connected to sewer systems.

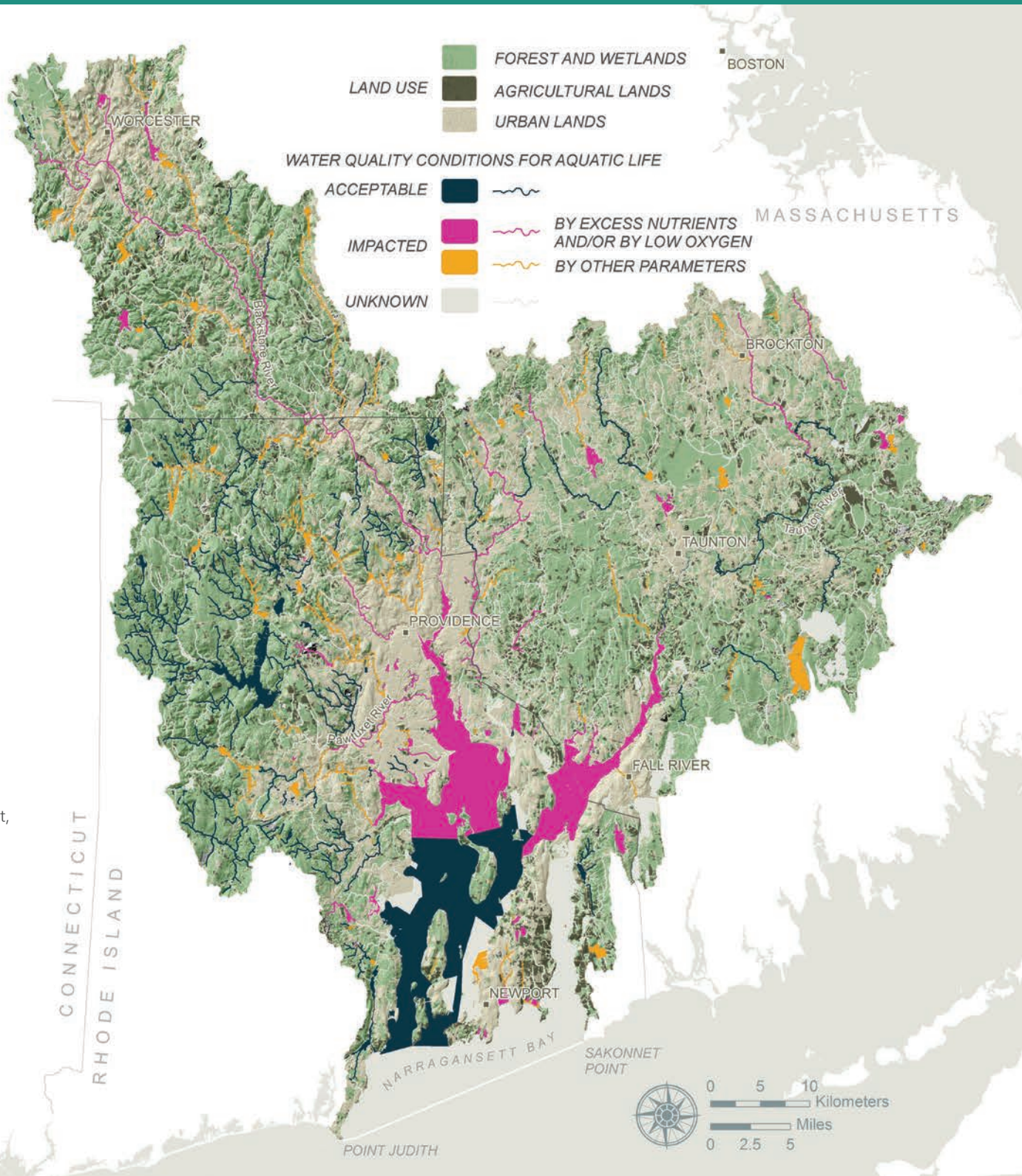
Urbanization of Forested Areas Has Implications for Bay and Watershed Condition

Land development affects how water flows across the land. Conversion of forest land to streets and buildings typically increases the amount of pollutants carried by stormwater into rivers and the bay. These changes in land use also affect wildlife and habitat conditions. State assessments found that water quality conditions in 162 miles of streams, 57 square miles of estuarine waters, and over 4,800 acres of ponds and lakes were unacceptable for aquatic life, such as fish communities, because of excess nutrients and/or low oxygen levels.

Conversion of Forest to Urban Lands

As of 2011, the watershed contained 35 percent urban and 39 percent forested lands. From 2001 to 2011, forest lands around Narragansett Bay decreased by four percent, lost primarily to urban lands, which increased by 8.5 percent. In 2011, coastal subwatersheds were 65 to 85 percent urban, whereas headwater subwatersheds were 70 percent forest. The Taunton River Basin experienced especially dramatic changes, with forest land decreasing by nine percent around the upper Taunton River and Ten Mile River, and urban lands increasing by 18 percent around the middle Taunton River.

Map: Land use and water quality conditions for aquatic life.
Photo: Brook trout, North Kingstown, RI.



Pavement Increases Pollution of Aquatic Ecosystems

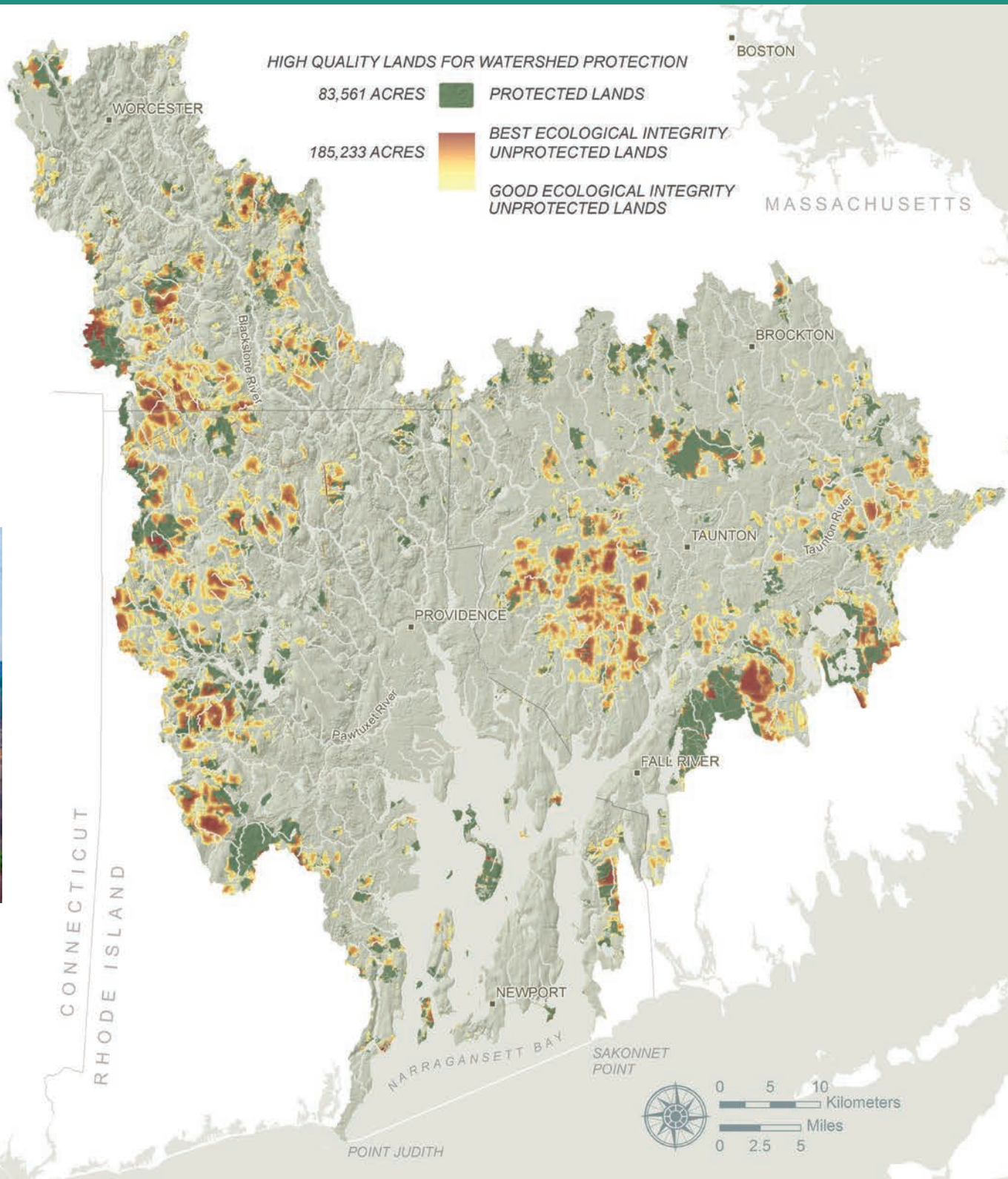
Precipitation falling on roads, buildings, and other impervious surfaces tends to flow quickly into rivers and coastal waters. In contrast, when water falls in natural areas it percolates into soil where ecological processes remove or store excess nutrients, pathogens, and other pollutants before they enter rivers and bay waters. These pollutants can have a significant impact on aquatic life such as stream invertebrates. Degraded aquatic habitats are most common in watersheds with greater than ten percent impervious cover. The entire Narragansett Bay watershed has an estimated fourteen percent impervious cover, and 36 of the 52 subwatersheds around the bay have more than the detrimental ten percent threshold.

Map: Extent of impervious cover and percentage of impervious cover in the subwatersheds. For each subwatershed, grey to dark red shading indicates percentage of its area that is covered with impervious surface. Photo: Stream invertebrate in the Flat River, Exeter, RI.

Opportunities to Protect Natural Lands as Open Space

Given the rate of development within the Narragansett Bay watershed and the multitude of landscape, climatic, and chemical stressors, it is increasingly important to protect natural lands. As of 2015, 171,244 acres of natural lands had been protected as open space, representing over fifteen percent of the watershed's land. Of that, 83,561 acres have high ecological integrity (see map). However, more than 450,000 acres of natural lands remain unprotected, covering 41 percent of the watershed, and 185,233 acres of those lands have high ecological integrity. The Mount Hope and Segreganset River portions of the Taunton River Basin had the highest ratios of unprotected to protected ecologically significant natural lands (20:1 and 18:1, respectively).

Map: Areas of protected and unprotected natural lands in the watershed. Brown areas indicate unprotected lands with high ecological significance. Photo: Blackstone River Valley, Uxbridge, MA.



North-to-South Gradient in Bay Conditions

Water Conditions

Data on chlorophyll, dissolved oxygen, and water clarity revealed strong geographic trends. Chlorophyll was highest in the upper bay and declined into the lower bay. Conversely, dissolved oxygen and water clarity tended to be lowest in the upper bay and increase southward into the lower bay. The gradient in water conditions reflects the concentration of urban centers, wastewater treatment facilities, and discharges from major rivers in the northern portion of the watershed.

Seafloor Habitat Conditions

Seafloor habitat conditions improve from north to south, as shown on the map on page 11.

Industrial Contaminants in Sediments

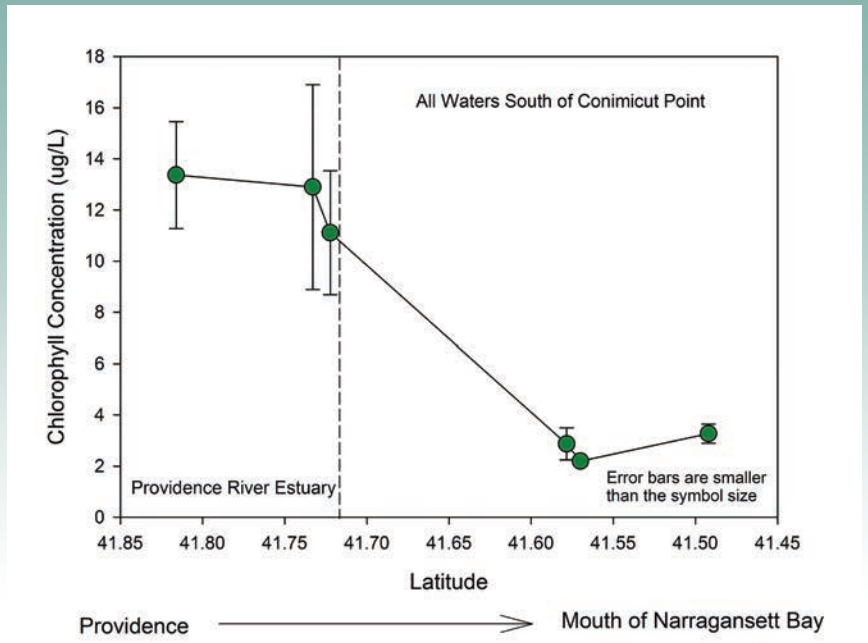
While decades of concerted pollution-control efforts have resulted in major declines in legacy contaminants, they are still present in sediments. Their levels are highest in the Seekonk River, Providence River, Taunton River, and upper bay, where industrial activity, human population, and wastewater treatment facilities have long been concentrated, and levels decrease into the lower bay. Mercury remains a significant concern in northern portions of the bay and in some coves, as shown on page 7.

New Contaminants in Bay Waters

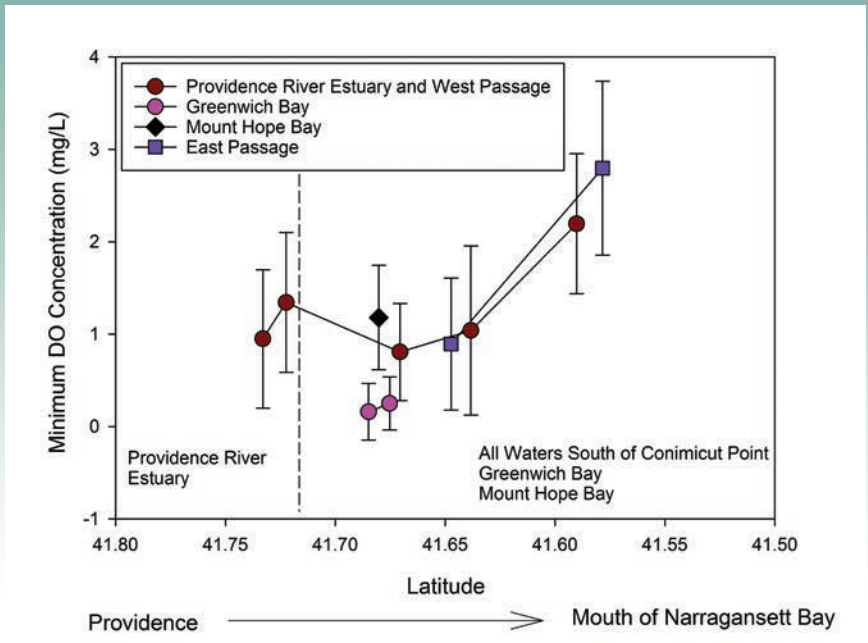
Now new types of contaminants are increasingly a concern. The term "chemical contaminants of emerging concern" (CECs) refers to chemicals with unknown ecological effects and no associated regulatory standards. Many CECs are associated with personal care products, pharmaceuticals, or industrial chemicals and have been identified as being present at low levels in natural waters such as Narragansett Bay. Historical trends measured in sediment cores from Narragansett Bay show the recent appearance of CECs, contrasting with legacy contaminants that show sustained decline due to strict regulatory standards. Like legacy contaminants, CECs appear to be concentrated in the upper bay. Hotspots of legacy and emerging contaminants also exist in other localized areas of the bay.

Graphs: Decrease in chlorophyll (below left) and increase in minimum dissolved oxygen (below right) from north to south in the bay.

Chlorophyll

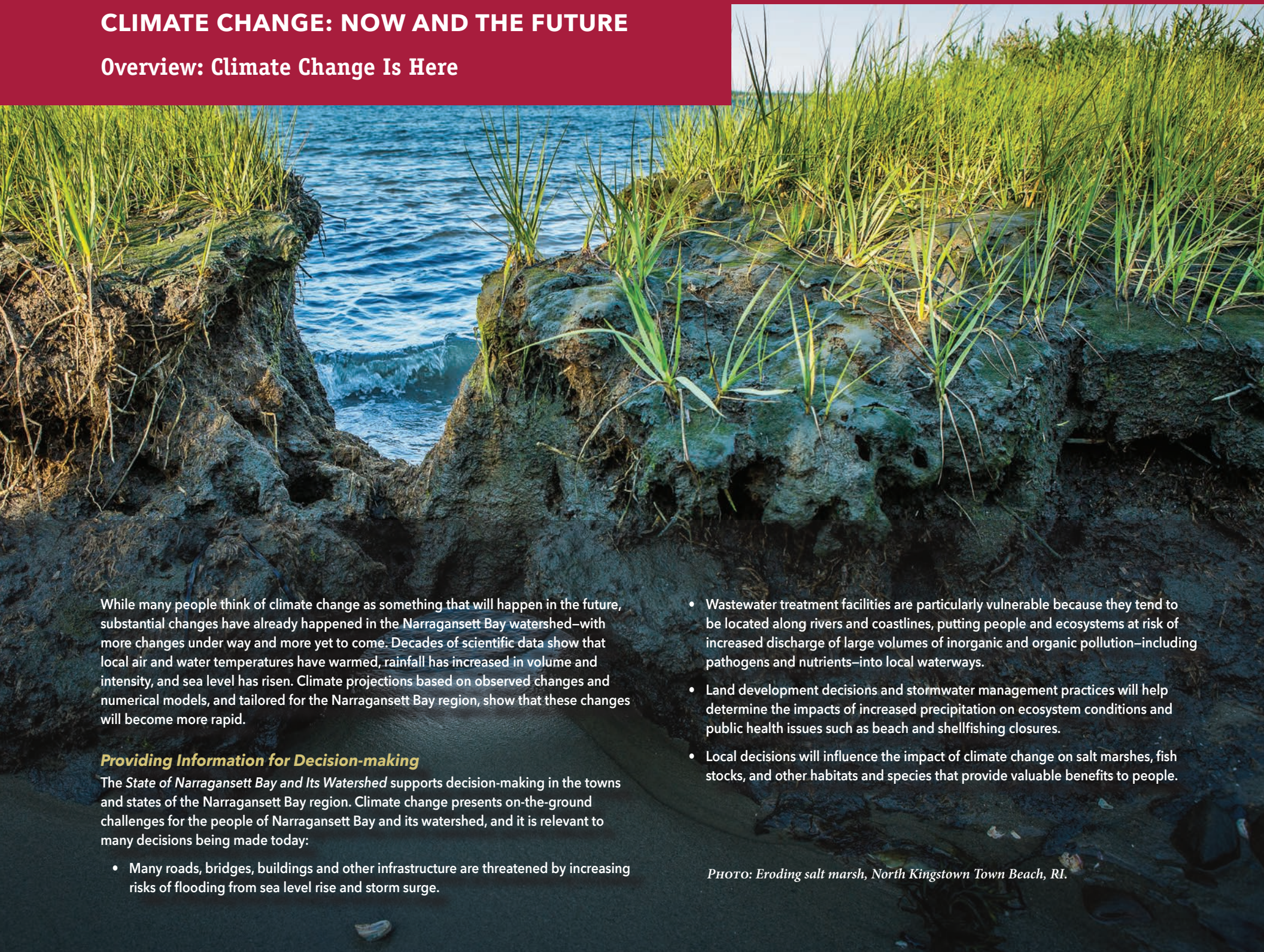


Dissolved Oxygen



CLIMATE CHANGE: NOW AND THE FUTURE

Overview: Climate Change Is Here



While many people think of climate change as something that will happen in the future, substantial changes have already happened in the Narragansett Bay watershed–with more changes under way and more yet to come. Decades of scientific data show that local air and water temperatures have warmed, rainfall has increased in volume and intensity, and sea level has risen. Climate projections based on observed changes and numerical models, and tailored for the Narragansett Bay region, show that these changes will become more rapid.

Providing Information for Decision-making

The *State of Narragansett Bay and Its Watershed* supports decision-making in the towns and states of the Narragansett Bay region. Climate change presents on-the-ground challenges for the people of Narragansett Bay and its watershed, and it is relevant to many decisions being made today:

- Many roads, bridges, buildings and other infrastructure are threatened by increasing risks of flooding from sea level rise and storm surge.
- Wastewater treatment facilities are particularly vulnerable because they tend to be located along rivers and coastlines, putting people and ecosystems at risk of increased discharge of large volumes of inorganic and organic pollution–including pathogens and nutrients–into local waterways.
- Land development decisions and stormwater management practices will help determine the impacts of increased precipitation on ecosystem conditions and public health issues such as beach and shellfishing closures.
- Local decisions will influence the impact of climate change on salt marshes, fish stocks, and other habitats and species that provide valuable benefits to people.

Photo: Eroding salt marsh, North Kingstown Town Beach, RI.

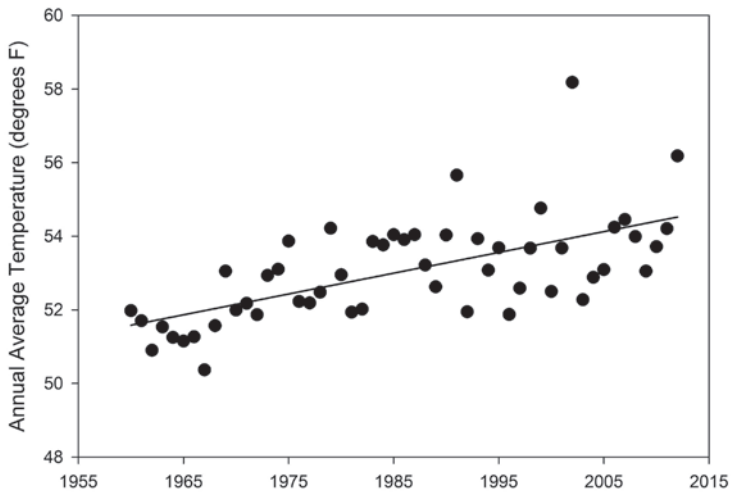
Warming Temperatures Trigger Ecological Changes

Temperature strongly influences public health and environmental conditions in many ways. Decades of temperature measurements in Narragansett Bay and the watershed show that air and water temperatures are increasing. Air temperature increased approximately 2.7°F (1.5°C) from 1960 to 2015, while the increase in bay water temperature was slightly greater at 2.9°F (1.6°C). Climate projections suggest that air temperature in the region will increase another 5 to 10°F (2 to 6°C) by 2100 under various scenarios of greenhouse gas emissions. Two models are shown in the graphs below: a lower-emission model (blue line) representing heavy mitigation of greenhouse gases (such as carbon dioxide) and a higher-emission model (red line) representing a continuation of the release of greenhouse gases with little mitigation.

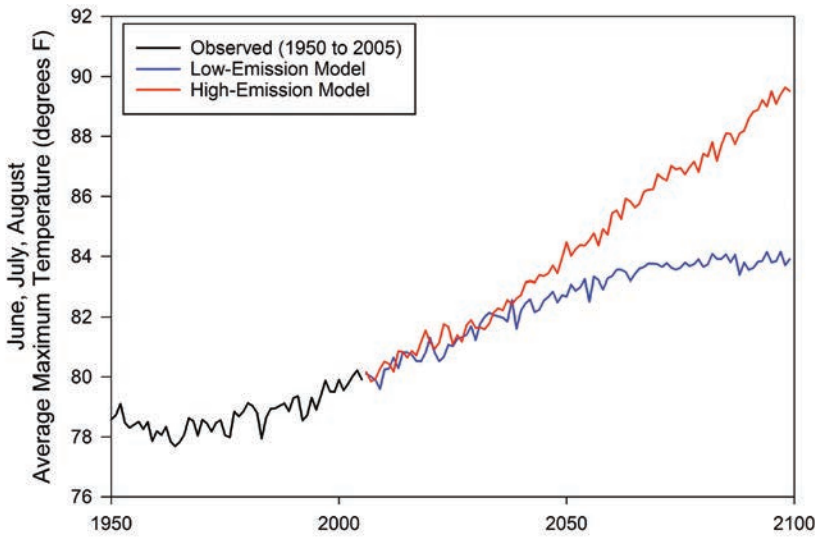
The warming temperatures are already causing warm-water fish species to increase in the bay as cold-water species seek cooler waters. More ecological and public health-related changes are expected as temperatures continue to rise. For example, beach closures may become more frequent as bacteria grow more quickly in warmer water, the abundance and diversity of phytoplankton could change with ripple effects on the food web, and growth and survival of seagrass could be reduced.

Right: Increase in water temperature at Newport, RI. Dots represent temperature measurements, and line indicates the statistically significant trend. Below: Increases in Massachusetts and Rhode Island air temperature in summer (left) and winter (right). Black line represents temperature measurements, and colored lines show model projections of future changes under scenarios of high (red) or low (blue) greenhouse gas emissions.

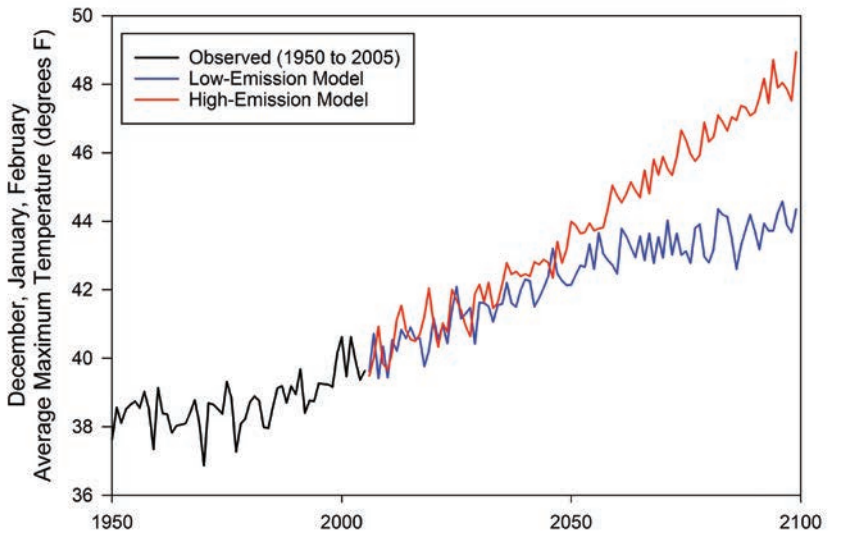
Water Temperature in the Bay (Newport)



Summer Air Temperature



Winter Air Temperature



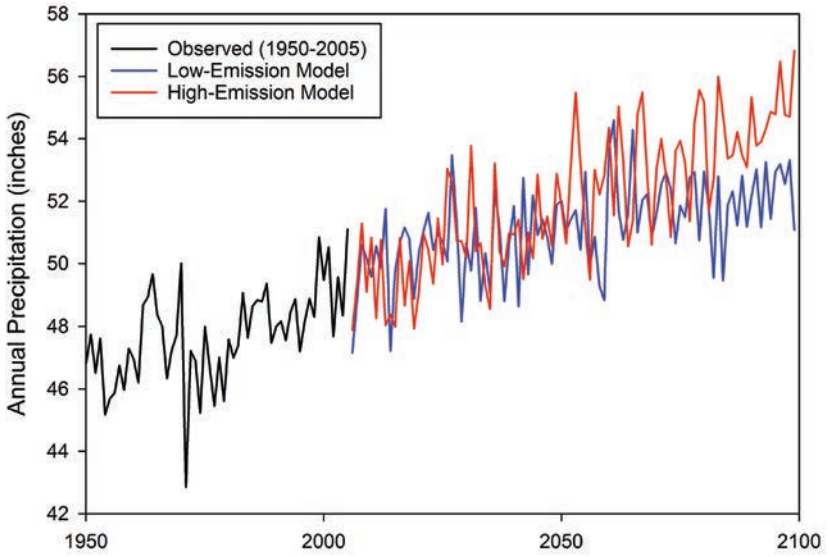
Increasing Precipitation and More Intense Storms

Precipitation patterns are changing in the Narragansett Bay region. Average annual precipitation at Providence, Rhode Island, has increased by 0.4 inches per decade since 1895. Climate models project that annual precipitation will continue to increase by up to three inches per decade locally and that more precipitation will fall during intense storms, giving the ever-reducing areas of natural soils little opportunity to filter stormwaters. Seasonality of precipitation will shift so that more precipitation occurs during winter, as rain, and less during summer.

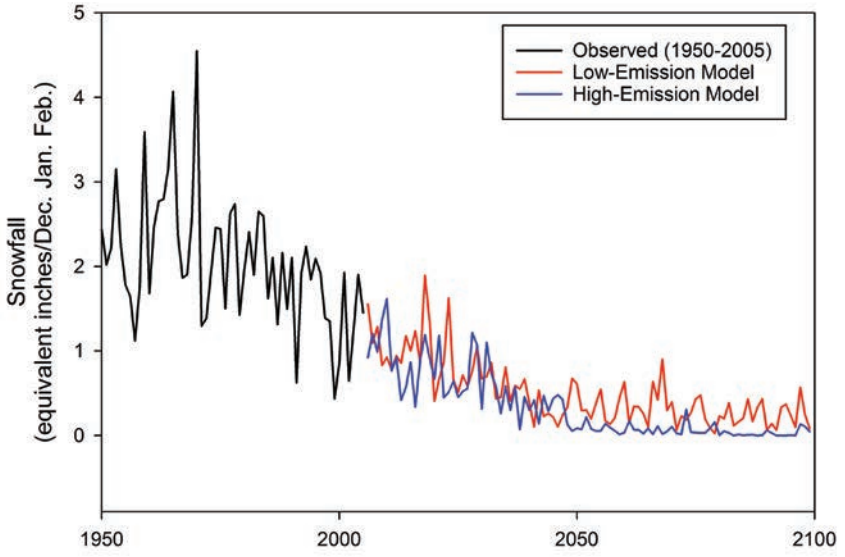
The impacts of changing precipitation patterns will be magnified by the rapid sprawl of urbanization in the watershed, as pavement and other impervious surfaces lead to greater amounts of pollutant-laden stormwater runoff into waterways without allowing sufficient replenishment of groundwater supplies. With the change in both amount and pattern of precipitation, communities may experience more flooding and more droughts, which can harm both built infrastructure and concentration of pollutants in waterways. In turn, these changes in precipitation influence many aspects of the Narragansett Bay ecosystem such as nutrient pollution, dissolved oxygen, chlorophyll, and water clarity. From a public health standpoint, the increasingly intense precipitation could carry more pathogens into coastal waters, leading to more frequent closures of beaches and shellfishing areas.

Photo: Upper Wood River, Exeter, RI. Right: Measurements (1950–2005) and projections of annual precipitation (top) and snowfall from December through February (bottom) in Massachusetts and Rhode Island.

Annual Precipitation



Snowfall (December-February)

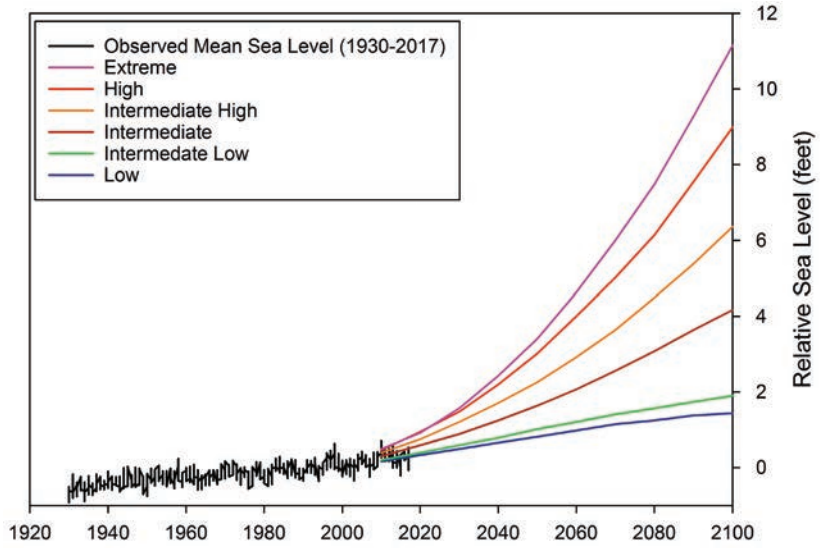


Rising Sea Level Will Bring More Flooding

Measurements taken from 1930 to 2015 at a tide gauge at Newport, Rhode Island, show that sea level rose by nine inches during that 85-year period. Now the pace of sea level rise is increasing, carrying major implications for people, infrastructure, and habitats around Narragansett Bay. The National Oceanic and Atmospheric Administration (NOAA) projects that sea level could rise as much as nine feet or even eleven feet at Newport by 2100, accounting for rapid melting of polar ice sheets and other geological and oceanographic factors such as thermal expansion of ocean waters. Along Rhode Island's coastline in Narragansett Bay, approximately seventeen square miles of land, 3,765 buildings, and the homes of over 10,000 people would be inundated under a seven-feet sea level rise scenario (http://www.beachsamp.org/stormtools). The impacts will not be spread evenly around the bay. For example, the lower Taunton River watershed is especially vulnerable to sea level rise because of its shallow slopes.

While the exact amount of sea level rise is uncertain, sea level will continue to rise substantially and coastal flooding may become more frequent into the future. Today's storm flood level is projected to be tomorrow's high tide. Many decisions being made today related to bridges, roads, buildings, and coastal habitats will be most successful by taking sea level rise into account.

Sea Level Rise (Newport, Rhode Island)



Graph: Observed sea level in Newport from 1930-2015 and NOAA projections to 2100.
Photo: High tide in Barrington, RI.

An Uncertain Future for Seagrass and Salt Marshes

Salt marshes and beds of seagrasses play important roles in the ecosystem by providing shelter, nurseries, and feeding grounds for many types of fish and shellfish. Salt marshes also provide coastal communities with some protection from storms and flooding, serve as feeding and breeding habitat for birds, and filter pollution from stormwater runoff. While many efforts have been made to protect and restore salt marshes and seagrass beds in Narragansett Bay, climate change poses an increasing threat.

Between the 1800s and the 1970s, over 50 percent of Narragansett Bay's salt marshes were lost to development and other factors. A recent analysis of aerial photographs found that 3,321 acres of salt marsh remained in the bay, with approximately one-third in the Warren, Palmer, and Barrington Rivers. Recent observations and future projections suggest that a large percentage of existing marshes will be lost under accelerating sea level rise, affecting fish, birds, and wildlife of the Narragansett Bay region. Protection of natural, open lands next to salt marshes is one strategy that may allow some marshes to migrate landward as sea level rises.

Because seagrasses require sunlight, they thrive in clear, clean waters, and they are useful indicators of ecosystem health. Prior to the 1930s, seagrasses were prevalent throughout Narragansett Bay, including the Providence River estuary and Mount Hope Bay. They declined precipitously because of a combination of nutrient pollution, disease, and physical damage or destruction by human activities, and now seagrasses are found only in southern areas of the bay. In recent decades, the status of seagrass beds in Narragansett Bay generally appears to have been improving. Surveys found approximately 357 acres in 2006 and 513 acres in 2012. In 2016, a new survey estimated that there had been a slight decline to 479 acres. While the increase from 2006 to 2016 is encouraging, warmer water temperatures and sea level rise associated with climate change may increasingly imperil seagrasses by reducing their growth and survival.

Map: Extent of seagrass and salt marshes.

Warmer-Water Fish Moving into the Bay

Estuarine fish such as striped bass play important roles in Narragansett Bay's food web, offer sustenance and recreation to humans, and serve as links between the estuary and the open ocean. Many factors can cause changes in the abundance and mix of fish species living in estuaries, such as fishing pressure, weather patterns, water quality, pollution, loss of habitat, and disease. In Narragansett Bay, warming of coastal waters–which has been documented here over the last 60 years and is projected to continue into the future–is an increasingly important factor. Since the 1980s, warmer-water species such as scup and black sea bass have displaced the resident species such as winter flounder and red hake, partly due to increasing temperatures. The survival rate of American lobster may also be reduced. As time goes by, the fish community in Narragansett Bay is expected to increasingly resemble that of a more southerly, mid-Atlantic estuary with associated shifts in species that are iconic in southern New England's culture.

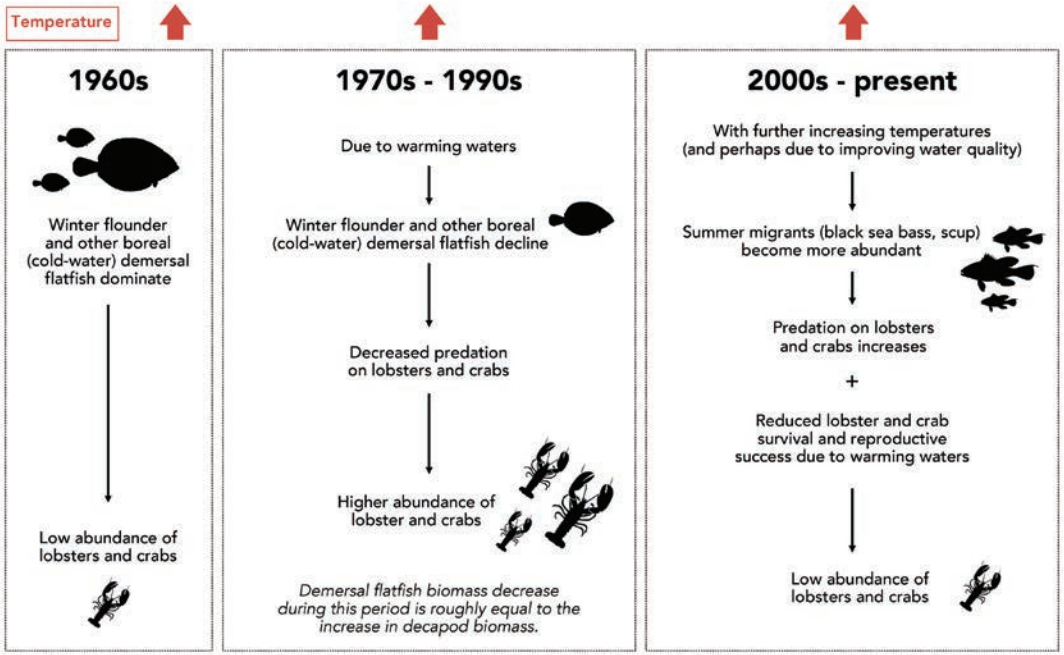
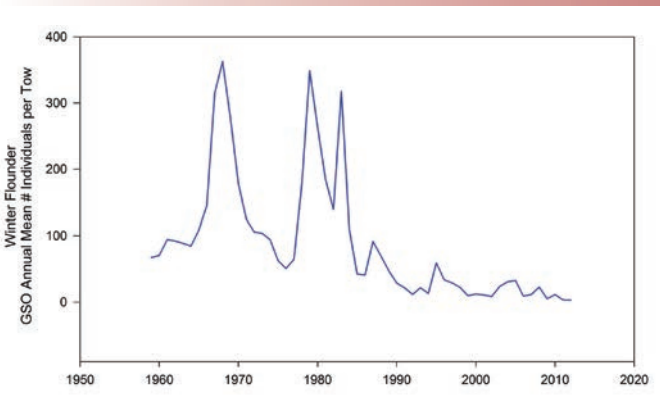
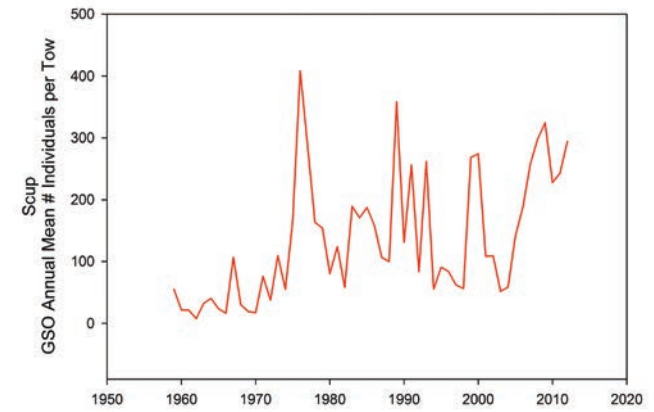


Illustration: A timeline and description of changes in the Narragansett Bay fish community. Abundances of cold-water demersal species such as winter flounder, lobsters, and crabs, as well as summer migrants like black sea bass and scup, have been linked with increases in temperature and shifts in predation. Graphs: Changes in abundance of winter flounder (top), scup (middle), and lobster (bottom).

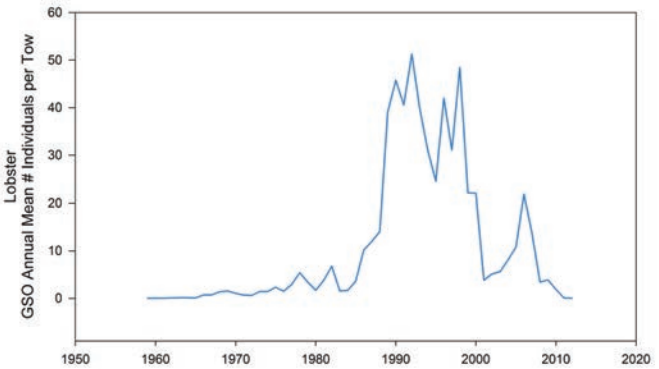
Winter Flounder



Scup



Lobster



MOVING FORWARD

Enhanced Data Collection Is Needed to Improve Understanding of the Bay and Watershed

Many organizations and individuals are engaged in monitoring and research focused on Narragansett Bay and the watershed, and their efforts generate important data and scientific insights. However, the process of developing the 2017 *State of Narragansett Bay and Its Watershed* report revealed that many of the existing monitoring and research programs are not sufficient.

Substantial gaps in data and information made it challenging to document and evaluate critical indicators of ecological conditions, climate change, and public health concerns. For many of the indicators in the report, the best available data had been collected so infrequently and at so few locations that it was impossible to accurately characterize present-day conditions, much less determine how conditions had changed over time.

Some fairly extensive data exist for basic parameters such as dissolved oxygen, water clarity, and chlorophyll, which are fundamental for understanding the bay ecosystem and for assessing human impacts, but because these parameters vary spatially and temporally throughout the bay it was difficult to elucidate trends; enhanced data collection is required. Similarly, data were not readily available for analysis on the number, types, and locations of septic systems and cesspools in the watershed, meaning the report was limited to analyzing only proxy data to estimate the scale and extent of this important source of pollution. For some increasingly serious issues, such as emerging contaminants, available data were too limited to assess status and trends.

The bay and watershed ecosystems are complex, with driving processes and responses varying from place to place, day by day, season by season, and year to year. It is challenging to design monitoring and research programs that are cost effective and can account for this variability so that trends can be detected. The 2017 *State of Narragansett Bay and Its Watershed* has demonstrated that it is certainly possible to design and implement informative monitoring and research programs, but there are gaps and improvements that are necessary for a more comprehensive assessment of status and trends to inform management and policy decision-making.

Photo: Conimicut Lighthouse, Warwick, RI.

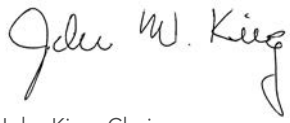
Statement from the Narragansett Bay Estuary Program's Chair of the Executive Committee and the Chair of the Science Advisory Committee

The 2017 *State of Narragansett Bay and Its Watershed* report documents some major accomplishments that have been achieved through the collaboration of many organizations over the past several decades, including significant improvements to wastewater treatment facilities with reductions in nutrients, toxic contaminants, and pathogens introduced into the bay and rivers. These accomplishments resulted from substantial financial investment, primarily by ratepayers and taxpayers, and the regulatory efforts of government agencies and private-sector partners. But there is more to do regarding two interrelated issues with important ramifications for the environment, and the economic and social wellbeing of the people who live, work, and recreate in this region.

The data are incontrovertible that climate change is here. Air and water temperatures are increasing; sea level is rising; storms are intensifying; extreme weather events are more frequent; winter and spring precipitation is increasing along with summer and fall droughts. How these changes affect the bay and the watershed is observable, and the implications for people are substantial—even potentially catastrophic. Looking ahead, for example, flooding and droughts will become more frequent and severe, salt marshes, seagrass beds and other vital habitats are changing or disappearing, pathogens and toxins may increasingly threaten public health through degrading water quality, and warming waters have been fundamentally altering fisheries. Substantial and swift actions to reduce greenhouse gases along with implementation of local adaptation strategies are essential if we hope to mitigate climate change. Our watershed experienced unparalleled flooding in April 2010, and Superstorm Sandy devastated coastal communities in fall 2012. These kinds of events will continue to impact our region with increasing force and frequency, mirroring recent events such as Hurricanes Harvey, Irma, and Maria.

We as a society are not prepared for climate change. Significant investments in local infrastructure are needed to enhance the resiliency and the socioeconomic vitality of the Narragansett Bay region. Such investments will pay long-term dividends as a cleaner, more-resilient bay and watershed results in stronger economic prosperity. Future investments in coastal infrastructure must take into account the predicted effects of climate change such as sea level rise, changing patterns of precipitation, and more severe storm surge flooding. To enhance coastal management efforts, investments in expanded research and monitoring are critical to understand the changing conditions in the bay and watershed, to identify priorities and solutions, and to evaluate the effectiveness of these actions.

The future of Narragansett Bay and its watershed as well as the welfare of those natural and social systems that depend upon this ecological treasure are inextricably bound with the implementation of actions identified in this report.



John King, Chair
Science Advisory Committee

Judith Swift, Chair
Executive Committee

Photo: Assonet River, Freetown, MA.

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References and Partner Support

The *State of Narragansett Bay and Its Watershed* technical report includes supporting references and technical information as well as a complete list of the partners that assisted with this project. The primary authors of the technical report include: James Boyd, Mark Cantwell, Michael Charpentier, Dan Codiga, Christine Comeau, Karen Cortes, Jessica Cressman, Katie DeGoosh-DiMarzio, Jason Grear, Susan Kiernan, John King, Anne Kuhn, Eivy Monroy, David Murray, Candace Oviatt, Sherry Poucher, Warren Prell, Brenda Rashleigh, Miranda Rayner, Charles Roman, Courtney Schmidt, Emily Shumchenia, Heather Stoffel, Juliet Swigor, Peter Taylor, James Tobey, and Julia Twichell.

Back Cover Photo: Blackstone River Gorge.

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