GREAT BAY NATIONAL ESTUARINE RESEARCH RESERVE

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ECOLOGICAL TRENDS in the GREAT BAY ESTUARY

CELEBRATING 20 YEARS 1989 2009
GBNERR
Great Bay National Estuarine Research Reserve

20 Year Anniversary Report

Acknowledgements

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ECOLOGICAL TRENDS in the GREAT BAY ESTUARY

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GREAT BAY
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*Amidst a backdrop of ongoing ecological change,
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by generations yet to come.*

Introduction

The Great Bay Estuary: A Dynamic Meeting Place

The Great Bay Estuary is a multifaceted convergence zone—a place where the ocean and rivers, land and water, and people and nature meet. Great Bay lies at the confluence of tidally driven seawater from the Gulf of Maine and fresh water from seven major river systems—the Salmon Falls, Cocheco, Bellamy, Oyster, Lamprey, Squamscott, and Winnicut. Before reaching Great Bay, seawater travels 15 miles inland through the Piscataqua River and Little Bay. This geographic configuration makes Great Bay one of the nation's most recessed estuaries, and it is often referred to as New Hampshire's "hidden coast."

The oceanic connection to the Gulf of Maine substantially influences the physical setting and ecological dynamics of the Great Bay Estuary. When high tides flood the estuary, the water surface of Great Bay extends 8.9 square miles, whereas at low tide, over 50 percent of the bay is exposed as mudflat. The large quantities of water that move in and out of the estuary create some of the strongest tidal currents in North America. This tidal exchange structures the Great Bay ecosystem by affecting water quality, habitat extent, and species distributions.

The rivers that flow into the Great Bay Estuary drain a watershed that extends more than 1,000 square miles, and this convergence of land and water shapes features and uses of the ecosystem. Between the water's edge and the upper watershed, a rich mosaic of habitats sustains diverse species. For centuries, the watershed also has supported human societies and activities. Historically, communities developed around the abundant resources of the estuary, and today many people still choose to live, work, and recreate in the Great Bay area. As the population of the region grows, individual and community choices about how to use the land in the watershed take on greater importance because they affect streams, rivers, and ultimately the Great Bay Estuary.

Great Bay's position at the confluence of land, rivers, and the sea creates an ecosystem that is ever-changing over tidal, seasonal, annual, and historical time scales. Some of these changes are part of the natural dynamics of the ecosystem, while others are driven by human activities. But amidst this backdrop of ongoing ecological change, there is one constant—a strong commitment to protect Great Bay and ensure that it remains a natural treasure that can be enjoyed by generations to come.

The capacity to conserve Great Bay and steward it effectively stems from our ability to first detect and understand changes occurring within the ecosystem, then to apply this knowledge to improve management decisions. Monitoring and interpreting changes in natural dynamics and human-environment interactions require a concerted effort over many years. Applying these insights to support stewardship relies not only on good science but also on its interpretation in the context of pressing management issues. The Great Bay Estuary benefits from the efforts of multiple groups that seek to better understand how it functions and forward its protection.

Twenty Years of Stewarding Great Bay

The Great Bay National Estuarine Research Reserve (NERR) was established in 1989 with a mission to advance our understanding of Great Bay and promote stewardship of this complex ecosystem. It accomplishes this mission through integrated programs of research, education, and stewardship. The twentieth anniversary of the Reserve's inception provides an opportune time to reflect on both the ecological changes that have occurred in Great Bay and the roles that the NERR has played in understanding and addressing these changes.

This report focuses specifically on three management-relevant themes—land use and habitat change, water quality, and biological communities—that align with the Great Bay NERR's priorities. Data that have been collected by the Great Bay NERR and its partners are presented to document major changes in the ecosystem and interpreted to contextualize associated management issues. In addition, examples highlight how the Great Bay NERR and other groups use the data to guide stewardship initiatives, support local decision-making, and advance public understanding of the ecosystem. Ultimately, the report outlines future plans for the Great Bay NERR that will continue to build its capacity to provide scientific information and support management of the Great Bay Estuary and its watershed.

Habitats within the Great Bay Estuary provide homes for a variety of species, including the marsh wren, a secretive bird that is often hidden in tall emergent marsh vegetation.

National Estuarine Research Reserve System

The Great Bay NERR is part of the National Estuarine Research Reserve System (NERRS)—a network of 27 protected and coordinated sites that promotes informed management of the nation's estuaries and coastal habitats through long-term research, monitoring, education, and stewardship. Established by the Coastal Zone Management Act of 1972, the NERRS operates as a partnership between the National Oceanic and Atmospheric Administration (NOAA) and the coastal states. Since its inception, the NERRS has protected more than 1.3 million acres of estuarine lands and waters that span diverse biogeographic regions in 21 states and Puerto Rico (Figure 1).

The NERRS advances a vision of healthy estuaries and watersheds where coastal communities and ecosystems thrive. It pursues this vision through three primary goals:

1. Strengthen the protection and management of representative estuarine ecosystems to advance conservation, research and education.

2. Increase the use of Reserve science and sites to address priority coastal management issues.

3. Enhance people's ability and willingness to make informed decisions and take responsible actions that affect coastal communities and ecosystems.

These goals are addressed through research, education, and stewardship programs that focus on land use patterns and population growth, habitat loss and alteration, water quality degradation, and biological community change. These priority issues need to be understood and managed at multiple scales. With its network of local sites distributed around the country, the NERRS has a unique capacity to address nationally relevant management issues and information needs, while also providing data and information for use by local and regional scientists and decision-makers.

Since its inception, a key goal of the NERRS has been to ensure stable environments for estuarine research. Reserves serve as platforms for long-term research and monitoring, with a focus on water quality and biological communities. Throughout the NERRS, 109 water quality monitoring stations collect high-frequency data that is used for real-time applications as well as for tracking long-term changes. Reserve sites also function as living laboratories for research staff, visiting scientists, and graduate students. Nationally, more than 300 graduate students doing research applicable to coastal management have been funded and mentored through the NERRS Graduate Research Fellowship program.

National Estuarine Research Reserves are also designated to provide educational opportunities that enhance public awareness and understanding of estuarine areas. Each reserve site conducts a variety of programming for key audiences, ranging from young children to adults. Within the NERRS, over 2,000 K-12 education programs are offered annually; these programs introduce approximately 100,000 students to estuaries near them and encourage them to explore these environments. Reserves also host educational presentations and hands-on workshops for adults.

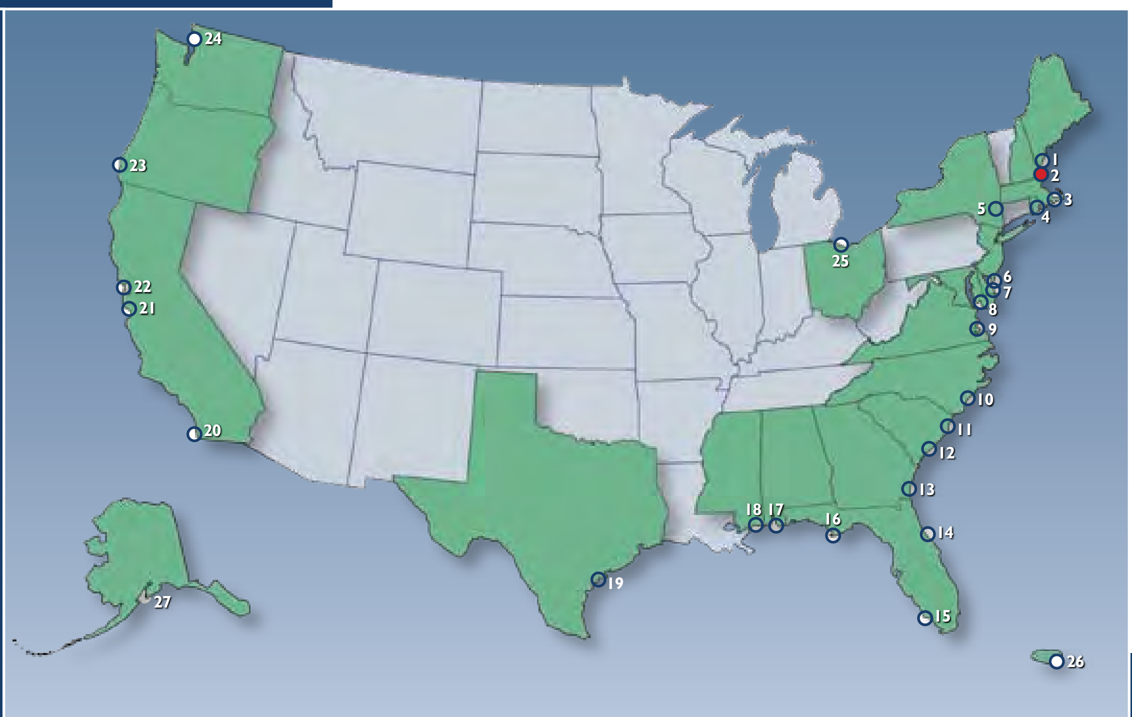
In addition, each reserve offers education and training opportunities specifically for professionals who make decisions that affect coastal ecosystems and resources. The Coastal Training Program provides science-based information and skill-building workshops to ensure that decision-makers have the knowledge and tools they need to address issues of concern to local communities. These training opportunities enable professionals to network across disciplines and develop new collaborative relationships to solve complex environmental problems.

Stewardship efforts at each reserve integrate aspects of research, monitoring, and education in the implementation of management actions to ensure the long-term protection of natural resources. Since resources are often affected by activities in adjacent waters and on watershed lands, effective stewardship requires close cooperation with diverse stakeholders. In addition, stewardship programs evaluate and model responsible management practices for coastal communities, assuring that the reserve-based programs address broader information needs.

While each of these program components—research, education, coastal training, and stewardship—strengthens local reserve sites as

1. Wells, ME.
2. Great Bay, NH.
3. Waquoit Bay, MA.
4. Narragansett Bay, RI.
5. Hudson River, NY.
6. Jacques Cousteau, NJ.
7. Delaware.
8. Chesapeake Bay, MD.
9. Chesapeake Bay, VA.
10. North Carolina.
11. North Inlet-Winyah Bay, SC.
12. ACE Basin, SC.
13. Sapelo Island, GA.
14. Guana Tolomato Matanzas, FL.
15. Rookery Bay, FL.
16. Apalachicola, FL.
17. Weeks Bay, AL.
18. Grand Bay, MS.
19. Mission-Aransas, TX.
20. Tijuana River, CA.
21. Elkhorn Slough, CA.
22. San Francisco Bay, CA.
23. South Slough, OR.
24. Padilla Bay, WA.
25. Old Woman Creek, OH.
26. Jobos Bay, PR.
27. Kachemak Bay, AK.

National Estuarine Research Reserve System



well as the NERRS, integration across the programs provides synergies necessary to accomplish the ultimate goals and mission. Strong science, engaged citizens, informed managers, and active stewardship are all needed to ensure that estuaries and watersheds throughout the country support healthy ecosystems and coastal communities. By capitalizing on these synergies, the NERRS can effectively address critical estuarine and coastal management issues at local, regional, and national scales.

Great Bay National Estuarine Research Reserve

When a citizens' group, Save Our Shores, mobilized to prevent the development of an oil refinery on Durham Point in 1973, it initiated a series of efforts to ensure the long-term protection of Great Bay. The process of designating Great Bay as a NERR was completed in 1989, and the site is currently managed as a partnership between the NOAA and the New Hampshire Fish and Game Department. The Reserve's boundary and aquisition zone encompass 20,172 acres of open water, wetlands, and uplands, including all of Great Bay and Little Bay, as well as tidal portions of the Winnicut, Squamscott, Lamprey, Bellamy, and Oyster rivers.

The Great Bay NERR's mission is to promote informed management of the Great Bay Estuary through linked programs of research, education, and stewardship. These programs enhance scientific understanding of the estuary and its watershed and communicate this information to interested citizens and decision-makers. The Reserve's programs focus on management-relevant issues aligned with four priority topics:

1. Land conservation and stewardship
2. Water quality
3. Habitat and biological communities
4. Climate change impacts and adaptation

The integration of research, education, and stewardship places the Great Bay NERR in a unique position to address these important issues.

Research. The Great Bay NERR implements monitoring programs to track water quality, habitat conditions, and species populations in the estuary and its watershed. These data provide a valuable long-term record of conditions that supports investigations of the factors that drive changes in the estuary as well as the ecological and social implications of observed changes. Research projects of the Great Bay NERR address information needs related to the four priority issues noted above; recent projects have focused on anadromous fish populations, invasive species, and climate change.

Education. Education programs of the Great Bay NERR convey scientific information to school groups, interested adults, public decision-makers, and others. These activities are typically conducted at the Great Bay Discovery Center in Greenland, where interpretive exhibits and interactive programs introduce visitors to the estuary and the creatures that call it home. The adjacent Hugh Gregg Coastal Conservation Center showcases exhibits on the upland habitats. It also serves as a training facility, where a variety of workshops for decision-makers are hosted through the Great Bay NERR's Coastal Training Program. These training opportunities provide science-based information and skill-building workshops to audiences that include municipal officials, volunteer board members, citizen groups, and business leaders.

Stewardship. The Great Bay NERR has a management interest in 3,740 acres of wetlands and uplands within the Reserve's boundary. As a founding member of the Great Bay Resource Protection Partnership, the Reserve has taken a lead in land protection to reduce the ecological impacts of habitat fragmentation caused by development in the Great Bay watershed. Properties are managed to sustain fish and wildlife populations in balance with human uses. In addition, stewardship interventions are structured experimentally when possible so that their outcomes can be evaluated and used to guide actions beyond Reserve properties.

All programs at the Great Bay NERR benefit from dynamic partnerships with academic institutions, government agencies, conservation organizations, and local businesses. The Great Bay Stewards formed in 1995 to support the Great Bay NERR and Great Bay Discovery Center. They are a key partner in the Reserve's efforts to advance education, land protection, research, and stewardship in the Great Bay Estuary. The Reserve also benefits from the dedication of volunteers who help with education programs, biological monitoring, and land stewardship.

Its integrated research, education, and stewardship programs as well as collaborations with other groups have enabled the Great Bay NERR to advance scientific understanding of the Great Bay ecosystem, provide diverse educational and outreach opportunities, and demonstrate effective land protection and stewardship approaches. This report summarizes some of these accomplishments and highlights future directions through which the Great Bay NERR will continue to promote informed management of the Great Bay Estuary and its watershed.

The Great Bay NERR's boundary (red outline) encompasses 10,235 acres of protected open water, wetlands and forests as well as an acquisition zone of an additional 9,937 acres of uplands. White lines indicate boundaries of towns located near the Reserve.

For centuries, Great Bay has evoked a strong sense of place among inhabitants, and its habitats and resources have been valued for sustenance, industry, transportation, and recreation.

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Human Use

An extensive and rich cultural history exists within the Great Bay region. For centuries, Great Bay has evoked a strong sense of place among local inhabitants, and its habitats and resources have been valued for sustenance, industry, transportation, and recreation. While the specific uses have changed over time, it is still through interactions with the estuary that societies and individuals establish a connection to the ecosystem and develop an appreciation of its utilitarian as well as intrinsic values. Sustaining diverse human uses within the Great Bay Estuary remains an important management goal today.

Historical uses

Human history of the Great Bay region extends back over 11,000 years, when Native Americans lived as hunter-gatherers on the natural resources available in and around Great Bay. By the time of the earliest European contact, several Native American tribes of the Abenaki nation inhabited the region. Europeans explored and fished in the Great Bay Estuary in the early 1600s, and the first permanent settlements were established in the 1620s.

Active fur, fish, waterfowl, and lumber trades developed around the plentiful and profitable resources in the region. As settlements increased in number and size, new industries developed in the area, including shipbuilding, textiles, brick making, and agriculture. To sustain these industries, the gundalow—a flat-bottomed sailing vessel—plied the waterways of the estuary, moving supplies from the Portsmouth Harbor into the bay and transporting finished goods from towns around Great Bay out to Portsmouth and beyond.

Over time, human settlements and activities brought about many changes. Timbering and agriculture changed the watershed's landscape. Plumes of sawdust and sediment choked the waterways, which deterred salmon from spawning in the rivers, buried eelgrass, and smothered oysters. Subsistence and commercial harvesting reduced the populations of living resources, including fish, shellfish, waterfowl, and mammals. Large mill complexes on the tidal rivers added industrial waste to the estuary, and the disposal of sewage and other pollutants contaminated the estuarine ecosystem. Resulting threats to human health eventually prompted measures to improve sanitation, and subsequent environmental regulations further promoted recovery of water quality and species populations. Although substantial ecological concerns remain, the Great Bay Estuary currently supports diverse human activities.

Current commercial activities

As it has been since Colonial times, Portsmouth remains an active port at the mouth of the Great Bay Estuary. The New Hampshire Port Authority reports that over five million metric tons of cargo is moved through the port each year. Imports include fuel oils, gasoline, coal, gypsum, and salt. These products are distributed to meet local fuel and road salt needs, used to run power plants along the Piscataqua River, and manufactured into various products such as drywall. Products exported through the port include undersea cable, scrap metal, tallow, drywall, and heavy machinery.

A commercial fish pier on Pierce Island in Portsmouth provides a base of operations for a portion of New Hampshire's fishing industry. Although many New Hampshire fishermen target offshore species, com-

Although substantial ecological concerns remain, the Great Bay Estuary currently supports diverse human activities.

FALL CULTURAL HISTORY PROGRAM AT GREAT BAY DISCOVERY CENTER

Connecting the natural resources of Great Bay to the cultural history of the region has been the goal of the Great Bay NERR's fall school program for over fifteen years. Since the program's inception, more than 25,000 students have traveled back in time to discover some of the ways the first inhabitants lived and worked on Great Bay.

During their three-hour experience, students visit a Native American fishing encampment, complete with birch bark wigwams, smoker and dugout canoe. Inside, they learn about the fishing, hunting and agriculture practices of native inhabitants. While at the site, the students get to sample smoked salmon and wild turkey. Important plants used by the Native Americans, as well as the salt marsh hay used by later colonists, are identified along the boardwalk.

At the "Great Bay Trading Post," students are introduced to the gundalow, the vessel used for centuries to transport goods throughout the estuary. They board a real gundalow, the Captain Edward H. Adams (shown at right), and learn how this unique vessel was constructed and its importance to the economy of the region.

The adventure ends with a simulated archaeological dig to uncover artifacts that represent different time periods of Great Bay's history. All program activities address New Hampshire curriculum frameworks for grade four and very successfully help the students picture life on Great Bay as it was centuries ago.

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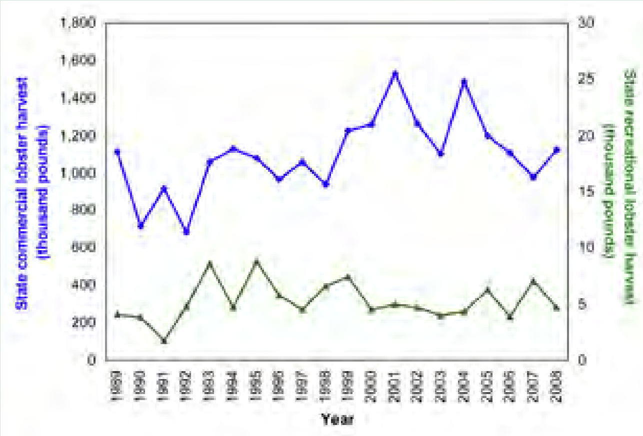


Figure 1. Commercial (blue line) and recreational (green line) harvest of lobsters in New Hampshire waters, including the Great Bay Estuary, from 1989 to present. Data provided by New Hampshire Fish and Game Department.

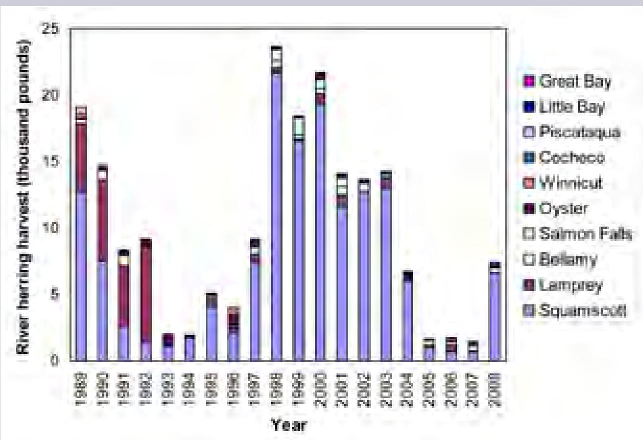


Figure 2. River herring harvest by coastal netters from Great Bay, Little Bay and tributary rivers from 1988 to 2008. Data provided by New Hampshire Fish and Game Department.

mercial fishing is also pursued in the Great Bay Estuary. Lobsters and river herring constitute the primary target species in the estuary. Lobster landings for state waters (extending to three miles offshore) have trended upward since 1989 (Figure 1), and the Great Bay catch has risen steeply since 2006, a year in which lobster abundance in the bay was anomalously low due to a major spring flood.

River herring are also harvested as bait for lobsters and striped bass. River herring catches within the Great Bay Estuary come primarily from the Squamscott River (Figure 2). Landings were high in the late-1990s and early-2000s; declines in landings in the mid-2000s coincide with a tightening of harvest regulations in the Squamscott River.

Current recreational activities

Local residents and visitors alike enjoy a variety of recreational activities in and around Great Bay. Visitors seeking to learn more about the Great Bay Estuary might start at the Great Bay Discovery Center, where the Great Bay NERR offers interpretive exhibits and educational programs about the natural and cultural resources of the area. Programs facilitate access to Great Bay through hands-on explorations of habitats near the Discovery Center and kayak trips that introduce participants to the bay.

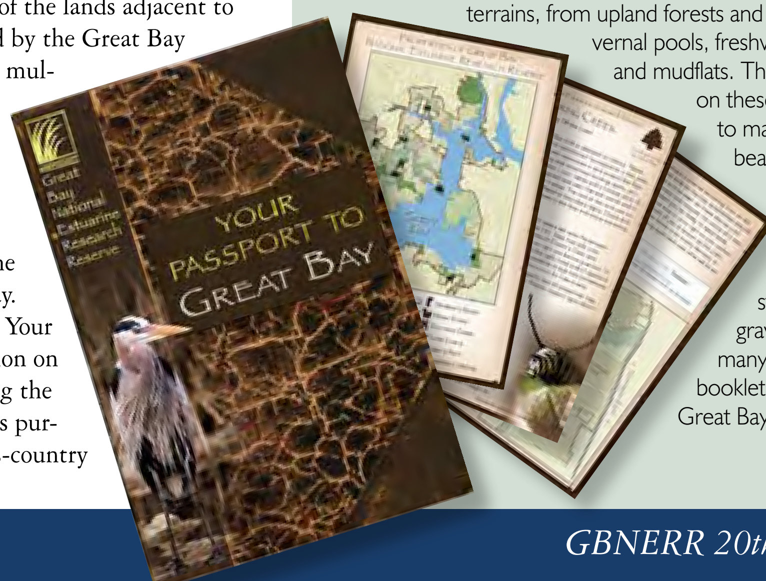
In addition, many of the lands adjacent to Great Bay are protected by the Great Bay NERR and are open for multiple uses, ensuring public access opportunities within a mosaic of changing land use and population growth. Hiking trails traverse the diverse habitats and provide scenic vistas of the bay. Some of the most popular trails are highlighted in Your Passport to Great Bay. Birdwatching is also common on these properties as well as in the marshes bordering the bay. During the fall, waterfowl and deer hunting is pursued on these multi-use lands, and in winter, cross-country skiing and showshoeing are popular activities.

© NHFG / VICTOR YOUNG PHOTO

Boating is one of the most popular recreational activities on Great Bay. Power boats, sailboats, canoes, kayaks, and rowing shells can all be seen on the bay and its tributary rivers. As interest in boating has increased, mooring areas and docks in the estuary have expanded. For example, in 1989 approximately 400 mooring permits were issued. This number has continuously increased over time, and the New Hampshire Port Authority estimates that 530 moorings will be permitted in the Great Bay Estuary in 2009. Public boat launches at Adams Point, Sandy Point (high tide only), and Hilton Park as well as on the Squamscott, Lamprey, and Oyster rivers facilitate access to Great Bay.

YOUR PASSPORT TO GREAT BAY

In one convenient booklet, Your Passport to Great Bay, the Great Bay NERR has compiled descriptions and trail guides to a dozen public lands surrounding Great Bay. Properties highlighted in the Passport span diverse terrains, from upland forests and granite outcrops, to ponds, vernal pools, freshwater and saltwater marshes and mudflats. The varied habitats represented on these properties provide homes to many species of wildlife; birds, beavers, turtles and tadpoles might all be spotted on these lands. In addition, reminders of earlier inhabitants—shell middens, stone walls, cellar holes and graveyards—are still present on many of the properties. Passport booklets can be obtained from the Great Bay Discovery Center.



Several boat launches provide public access to the Great Bay Estuary, including this New Hampshire Fish and Game Department launch at Chapman's Landing on the Squamscott River.

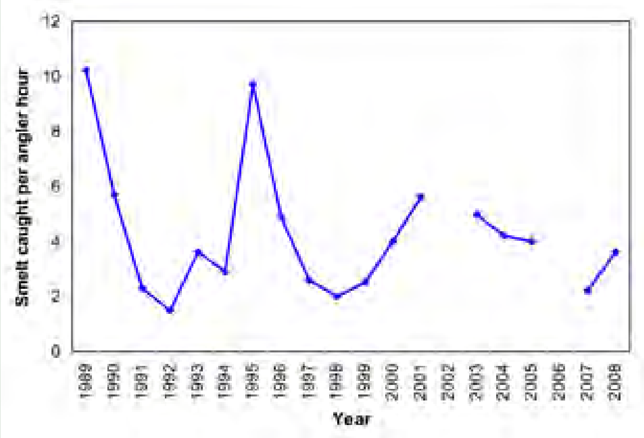


***Figure** 3. Average number of smelt caught per angler hour in the Great Bay ice fishery each year since 1989. No fishing occurred in 2002 and 2006 when ice did not form on the bay. Data provided by New Hampshire Fish and Game Department.*

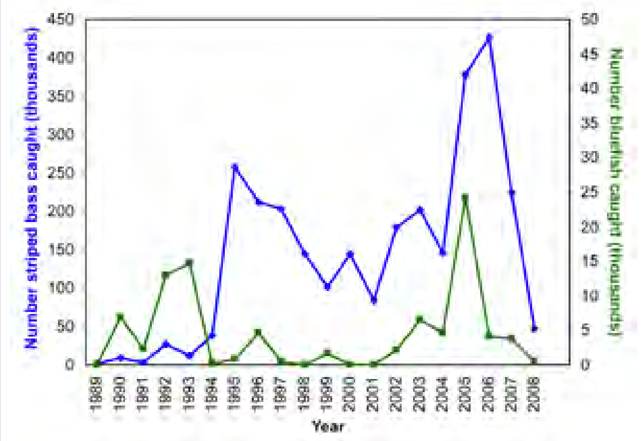


Figure 4. Estimated recreational catch of striped bass (blue line) and bluefish (green line) in inshore waters of New Hampshire since 1989. Data provided by New Hampshire Fish and Game Department.

Finfishing and shellfishing also attract many people to Great Bay. Anglers seek striped bass, bluefish, smelt, river herring, flounder, and a variety of other species in the estuary. In winter, smelt fishermen set up bobhouses, drill holes in the ice and wait patiently for smelt to nibble their lines. Catches in the ice fishery have fluctuated, with peaks in average catch per angler hour observed in 1989 and 1995 (Figure 3).

During warmer months, anglers primarily target striped bass and bluefish from boats, bridges, and the shoreline of Great Bay. Recreational anglers have taken an average of 130,000 trips each year since 1989 in the inshore waters of New Hampshire, which include the Great Bay Estuary. The number of trips has increased during the 1990s and 2000s, coinciding with a recovery of the striped bass population. Although the catch of striped bass fluctuates, it has risen substantially since the mid-1990s, with the exception of 2008 when the population largely stayed south of Cape Cod, perhaps due to high prey abundance or favorable water temperatures (Figure 4). The recreational catch of bluefish also fluctuates, but catches were particularly high in the early 1990s and mid-2000s (Figure 4).

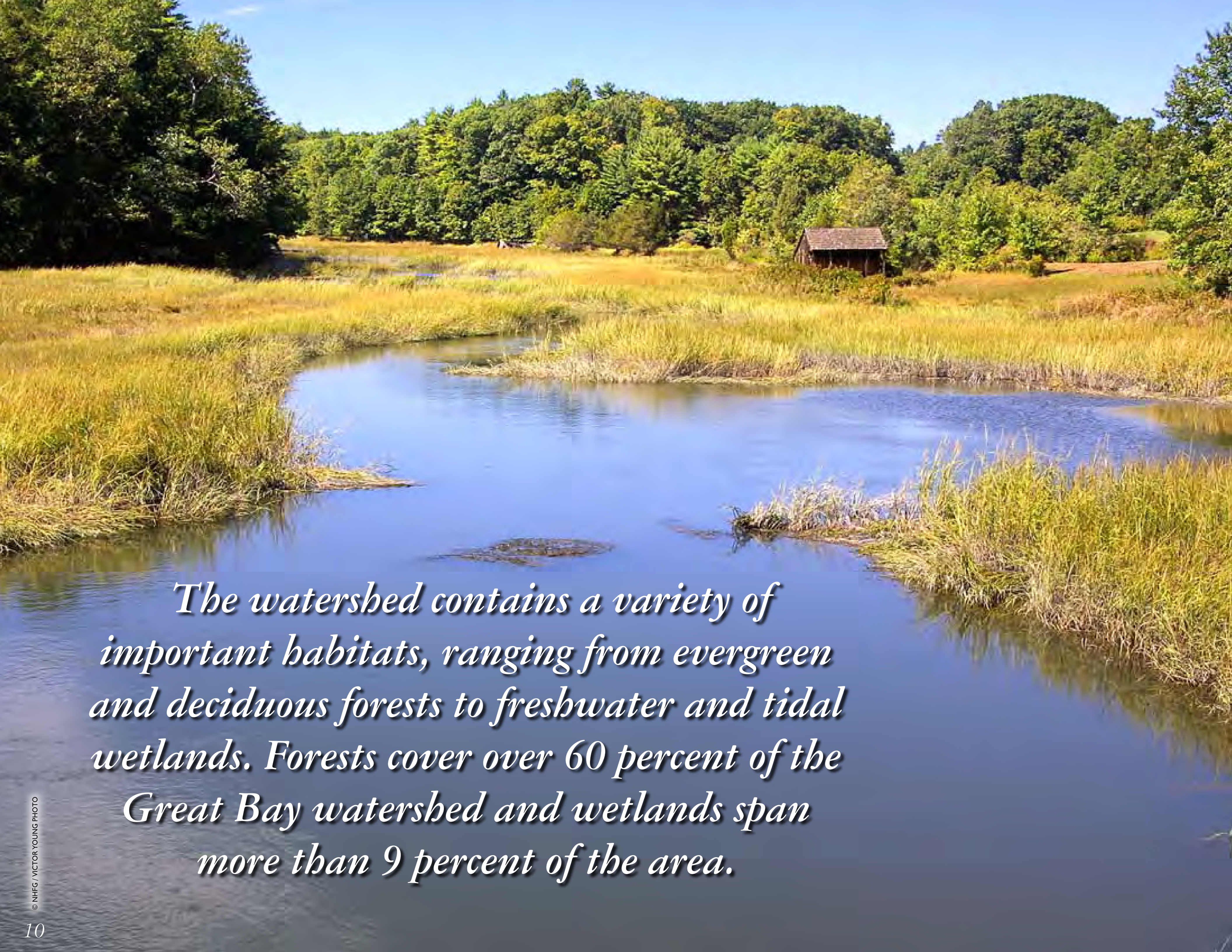
Lobstering and shellfishing are also important recreational activities in Great Bay. Recreational lobstermen have caught an average of around 5,000 pounds per year of lobsters in state waters since 1989 (Figure 1). Oysters are harvested recreationally in Great Bay by hand, rake, or tongs, but the number of licensees has dwindled in the past two decades as oyster abundance has declined. In 1989, oyster licenses were held by 771 individuals; in 2008, only 221 licenses were issued.

Sustaining diverse uses of Great Bay

Throughout history and still today, Great Bay has shaped the human communities living on its shores and in its watershed. The estuary instills a strong sense of place among residents who live near and recreate on Great Bay and its tributaries. Local citizens and visitors alike enjoy fishing and boating on its waters, exploring its marshes, and hiking through forests in its watershed. The bay, rivers, and watershed also support economic activities and provide tangible resources that are vital to local communities.

Sustaining existing and future human uses of the Great Bay Estuary requires thoughtful decision-making by individuals and communities to balance economic growth and resource protection. Challenges that may affect future use and enjoyment of the estuary are many. A few examples include: (1) water quality degradation that may compromise the estuary's aesthetic appeal; (2) habitat loss that may threaten species valued by anglers, birdwatchers, and hunters; and (3) region-wide increases in heavy metals and contaminants in fish tissue that reduce safe consumption levels.

The Great Bay NERR will continue working to sustain multiple human uses within the Reserve. Its stewardship efforts will ensure long-term protection of and public access to a diverse range of habitats, from the waters of the estuary to forests in the watershed. In addition, the Coastal Training Program will provide interested citizens, elected officials, and other public decision-makers with the information and skills they need to address challenges that may affect human uses of the estuary. As current uses continue and new uses are proposed, the Great Bay NERR will remain actively engaged in management to maintain healthy ecosystems and vibrant coastal communities.



The watershed contains a variety of important habitats, ranging from evergreen and deciduous forests to freshwater and tidal wetlands. Forests cover over 60 percent of the Great Bay watershed and wetlands span more than 9 percent of the area.

Land Use

The Great Bay Estuary drains a watershed that extends 1,084 square miles from the New Hampshire Lakes Region to the Seacoast. The watershed contains a variety of important habitats, ranging from evergreen and deciduous forests to freshwater and tidal wetlands. Forests cover over 60 percent of the Great Bay watershed and wetlands span more than nine percent of the area. The watershed's habitats support several species of concern and contain rare plant communities, such as Atlantic white cedar swamps.

The watershed also supports growing human communities in 55 municipalities--45 in New Hampshire and 10 in Maine. Human activities within these municipalities are reflected in the land cover of the watershed. The old growth forests that were cleared as Europeans settled in this area have been replaced by secondary forests and cultivated fields. More recently, suburban developments are expanding and replacing agricultural fields. At present, agricultural lands and developed areas each represent approximately nine percent of the watershed.

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As development increases and human activities change, the effects can be seen in the watershed's landscape as well as in the estuary itself. Development contributes to habitat loss and fragmentation. It also results in more runoff from the land, which pushes nutrients and sediments from agricultural fields, private lawns, and other sources into tributaries and the estuary. In addition, disturbance of soils and native vegetation creates opportunities for invasive species to move into the area. While development in the Great Bay watershed is likely to continue, it is critical to address its impacts on habitats and water quality.

These challenges are not unique to Great Bay. With over 53 percent of the nation's population living in counties bordering the coast, many regions are striving to preserve habitats and protect water quality in increasingly developed and utilized landscapes. What may be unique, however, is the commitment to meeting these challenges in the Great Bay area. Myriad efforts are underway to minimize local impacts of population growth and land use change with the goal of sustaining a healthy Great Bay watershed and estuary. Key strategies include conserving undeveloped land, implementing low impact development approaches, and controlling invasive species.

This section of the report describes land use and habitat characteristics of the Great Bay area and how these have changed in the past 20 years. In doing so, it focuses on land use change, impervious surfaces, and invasive plant species. Each major topic concludes with an overview of strategies and efforts of the Great Bay NERR to conserve lands, restore habitats, and promote sustainable development practices in the watershed and estuary.

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As development increases and human activities change, the effects can be seen in the watershed's landscape as well as in the estuary itself.

Land use change

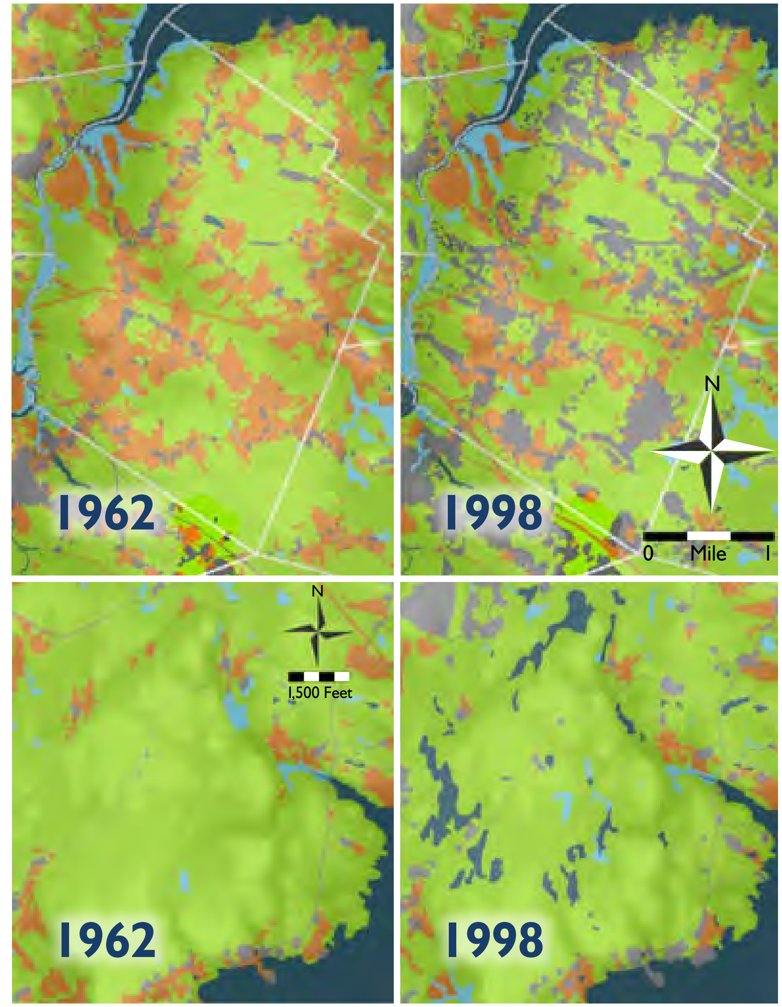
New Hampshire is the fastest growing state in the northeast, and much of this growth has been concentrated within the Great Bay watershed. Between 1980 and 2008, the average population size of the 45 New Hampshire municipalities in the watershed increased by 83 percent; in comparison, the statewide population rose by 43 percent. In some municipalities bordering the estuary, such as Newmarket and Stratham, populations have more than doubled. Population growth impacts natural ecological systems through the conversion of land from its original state to more intensive human uses.

Land use reflects human activities within an area. Land use change is not a recent phenomenon; it has occurred throughout human history. The densely forested watershed known to Native Americans was cleared by early European settlers as they developed a lumber industry and established settlements around Great Bay. Over time, some of the cleared areas returned to secondary forests, while others were used for agriculture. Later, paved roads crossed the landscape, facilitating the sprawl of residential and commercial activities. As more and more people have moved into the Great Bay area in recent years, the prevalence of homes, roads, and commercial areas on the landscape has increased.

The dominant landscape features within the Great Bay NERR are open water and mixed forests. Open water constitutes more than 7,500 acres within the Reserve, while mixed forests cover nearly 8,500 acres; together, these two important habitats represent approximately 80 percent of the area in the Reserve. Although the region is under substantial development pressure, large contiguous forest areas remain within the Reserve's boundary. Forest cover increased by nine percent between 1962 and 1998, due in large part to the re-forestation of abandoned agricultural fields.

Land use within the Reserve's boundary is changing in other ways as well. As the land area devoted to agriculture and farms declined by 40 percent from 1962 to 1998, the acreage used for residential and commercial purposes increased by 46 percent. In addition, the amount of land devoted to roads and other transportation infrastructure increased by 18 percent. These changes show that the human footprint within the Great Bay NERR is expanding, driven by the underlying increase in population within the Great Bay watershed.

The loss of agricultural land and the rise of residential development has been a common pattern of land use change in many towns within the Great Bay watershed – one that has broad social and ecological implications. As development removes rich crop and pasture land from agricultural uses, social and economic consequences include reduced local food production, a decline in the rural cultural heritage, and a loss of amenity value associated with open space and scenic views. Ecologi-



1. Top pair: Land use change in Stratham, NH showcases the conversion of agricultural lands (orange) to residential and commercial developments (grey). In 1962, agricultural lands were distributed throughout this town; by 1998, many of these lands and some forested areas (green) had been developed.
2. Bottom pair: In addition to human activities, beavers can also influence habitat patterns at the landscape scale. Land use change in the Crommet Creek watershed shows the effects that beavers can have on an ecosystem. Open water (dark blue) substantially increased from 1962 to 1998 as beaver dams flooded vegetated wetlands (light blue), forests (green), and agricultural lands (orange).

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UNDERSTANDING WATERSHED-SCALE LAND USE CHANGE

Many individual decisions and actions regarding land use have substantial cumulative effects at a landscape and watershed scale. Since 2007, Erika Washburn—a NOAA Social Science Fellow with the Great Bay NERR—has been working to understand how municipalities in the Great Bay watershed approach land use decisions and whether they consider the broader impacts of their choices. Her findings suggest that most decision-makers do not consider the watershed-scale effects of their actions and that little communication exists between towns that are facing similar decisions. Ultimately, her research will help identify challenges as well as opportunities for improving regional coordination on land use decisions that affect Great Bay and its tributaries.

cally, the development of agricultural land replaces porous soils with impervious surfaces, which increases the velocity of water flowing off the land, heightens the risk of flooding, and reduces groundwater recharge. To reduce these social and ecological impacts associated with land use change, the Great Bay NERR works to ensure the long-term protection of land and to encourage the adoption of smart growth management strategies in the Great Bay watershed.

Land protection

Recent population growth and development pressures have created significant threats to water quality, species diversity, and unfragmented natural habitats in the Great Bay watershed—an area that contains over 18 percent of the state's known rare species and exemplary natural communities. To sustain these valuable habitats, species, and ecological functions, land protection has been a key priority of the Great Bay NERR since its establishment. The Reserve achieves this goal through on-the-ground management of lands and by working with an extensive network of partners to protect new parcels of land with high ecological value.

Within the Great Bay NERR, 5,129 acres are conserved. Of this total, the Reserve has a management interest in 3,740 acres distributed over 71 parcels. In the upland areas of the Reserve, the protected lands include wetland and early successional habitats set in a matrix of Appalachian oak-pine forest, a type of forest that is rare statewide and is found only in the Seacoast region. Other protected parcels encompass intertidal habitats, including mudflats, rocky shores, and salt marshes. Land acquisition priorities have focused on protecting salt marshes and the upland buffer; these habitats support key species such as beaver and osprey, as well as species of concern such as the Blanding's turtle.

The Great Bay NERR actively stewards these lands to maintain key wildlife species, protect natural plant communities, and provide public recreational opportunities. Resource inventories of each property are used to shape regional management plans for ecologically distinct areas, such as sub-watersheds. These plans include guidelines related to the management and restoration of habitats, provision of recreational opportunities, and suitability of certain uses (e.g., agriculture) on the property.

Management prescriptions for Reserve lands within these areas are implemented by the Great Bay NERR's stewardship program. In addition, volunteer land stewards support management of the Reserve's protected lands by adopting properties and surveying them periodically for unique habitat features, wildlife use, invasive species, and recent recreational use. Creative partnerships with university faculty, students, and community members also advance land stewardship goals. Such partnerships have made possible three years of biological monitoring for upcoming wetland restorations, trail counters to track visitor use, construction and improvement of access trails, and monitoring of wildlife use on land parcels.

The Reserve also works closely with other partners through the Great Bay Resource Protection Partnership to advance land protection initiatives. The Nature Conservancy of NH serves as the lead acquisition organization for the Partnership, and other key partners in this effort include:

- Ducks Unlimited, Inc.
- New Hampshire Audubon
- New Hampshire Fish and Game Department
- Society for the Protection of New Hampshire Forests
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service, Great Bay National Wildlife Refuge
- U.S. Department of Agriculture, Natural Resources Conservation Service

Since 1995, the Partnership has invested over $65 million in land protection within the Great Bay watershed, including $56 million in funds from NOAA. Funding sources are diverse and include federal and state grants, municipal sources, foundation grants, and private donations.

Conservation lands within the Great Bay NERR's boundary (red outline). Reserve lands, shown in green, are held either in fee or as a conservation easement and are managed through the NH Fish and Game Department. Lands shown in grey are protected by other entities.

Proliferation of impervious surfaces

As residential and commercial developments displace agricultural uses, impervious surfaces replace natural land covers in the Great Bay watershed. Increasing impervious surfaces pose environmental concerns because they initiate a chain of events that impacts water resources. In natural landscapes, porous soils filter and absorb stormwater and recharge groundwater supplies. Impervious surfaces, such as building roofs, parking lots and roadways, do not allow water to infiltrate the soil. By sealing the soil's surface, they fundamentally alter the hydrology of an area, impeding rainwater infiltration and groundwater recharge. Stormwater accumulates on and runs directly across impervious surfaces, increasing flow volumes and velocities that can cause local flooding or stream erosion.

In addition to increasing the volume and velocity of water flows, impervious surfaces also increase the sediment, nutrient, and pollutant loads carried by these waters as they transport residues from developed areas into surface waters. Studies indicate that one acre of a typical commercial development generates 740 pounds of sediment and 20 pounds of nitrogen per year, and commercial streets can produce 4,600 pounds of sediment and 20 pounds of nitrogen. Stormwater runoff carries these pollutants to the streams and rivers that flow into the Great Bay Estuary and other coastal waters.

The increased sediment and nutrient loads carried by water flowing off of impervious surfaces have important ecological implications. Any impervious surface within a watershed can impact its hydrology and ecology, but deterioration of water quality and declines in sensitive species become noticeable when the impervious surface cover in the watershed reaches five percent. Substantial impacts are noted at impervious cover levels of 12 to 15 percent, and waters can become devoid of many aquatic species when imperviousness reaches 25 percent or more. Within the Great Bay watershed, streams draining small sub-watersheds with high impervious cover contain higher levels of bacteria, higher nutrient concentrations, and fewer macroinvertebrate species than sub-watersheds that are heavily forested.

Top: UNH Stormwater Center workshop participants observe a water infiltration demonstration on pervious concrete.
Bottom: Porous asphalt surface showing void space that allows water infiltration.

Concerns about the potential ecological implications are increasing as the amount of impervious surface in the Great Bay watershed continues to rise. An analysis by the UNH Complex Systems Research Center and Piscataqua Region Estuaries Partnership determined that the area of impervious surfaces in New Hampshire towns in the Great Bay watershed increased from 29,914 acres in 1990 to 50,934 acres in 2005. Impervious cover represented over seven percent of the combined land area in these towns by 2005, the most recent year for which data are available. In 15 of the 45 towns, impervious surfaces covered more than 10 percent of the watershed, with rates exceeding 30 percent in Portsmouth and 20 percent in Newington and Somersworth.

Reducing the impact of impervious surface cover

Reducing the extent and impacts of impervious surface cover requires concerted efforts at many scales, from residential lots to watersheds. Building codes, stormwater ordinances, land use planning, zoning ordinances, and transportation planning all affect the amount and distribution of impervious surfaces. Moreover, these regulatory and planning tools all offer the potential for reducing the extent and impact of impervious surface cover. With careful planning, new developments may leave a smaller footprint on the landscape and have less impact on water quality, habitats, and aquatic species.

Many of the water quality and ecological impacts of impervious surface cover can be minimized in residential, commercial, and industrial settings with the use of low impact development (LID), an innovative stormwater management approach that integrates natural site features with small-scale stormwater controls to more closely mimic natural hydrologic patterns. LID designs promote infiltration of runoff near its source, instead of managing stormwater at the end of a pipe. Some LID options include the use of rain gardens, bioretention systems, tree filters, and porous pavements to promote infiltration of water. These filtration systems reliably remove 90 percent of the solids, and vegetated filtration systems can remove 40 percent of the nitrogen in runoff. LID measures also slow the rate of runoff and reduce storm volumes, thereby minimizing hydrological changes and preventing many impacts associated with impervious surfaces.

Commercial and residential examples highlight the ecological and economic effectiveness of LID options.

Commercial implementation of LID. Because of its location next to waters that were considered impaired under the Clean Water Act, a commercial project in Greenland that will be home to two "big-box" stores and a grocery store was required to meet advanced stormwater standards. To satisfy this requirement, the 38-acre development with 76 percent impervious cover employed porous pavements, rooftop infiltration, and gravel wetlands that remove more than 90 percent of the nitrogen. The LID controls on this site will prevent 12,000 pounds of sediment and 440 pounds of nitrogen from entering nearby waters each year. Further, these LID options met the site's stormwater standards at a lower cost than a typical pipe-and-treat approach.

Residential application of LID. A Portsmouth City Counselor recently installed a porous asphalt driveway at his residence to prevent his garage from flooding during large storms. His home is located in a dense urban neighborhood, downhill from a massive parking lot. Typical approaches to solving his flooding problems would involve using regular pavement and catch basins with drainage. Instead, he chose to install pervious pavement with a stone subbase, an option that proved more cost effective than the standard approach. His small effort translates to a reduction of 34,000 gallons of runoff per year, thereby reducing the load to the municipal storm sewer system.

LID OPTIONS DEMONSTRATED AT THE GREAT BAY DISCOVERY CENTER

The Great Bay Discovery Center and Hugh Gregg Coastal Conservation Center now serve as a LID stormwater management demonstration site. The UNH Stormwater Center designed an integrated stormwater management strategy for the Reserve as part of a parking lot paving project. A comprehensive approach to reducing stormwater at the site relied on several LID technologies, all of which are available for visitors to view. In addition, the site is used for training purposes so that homeowners, decision-makers, and developers can see the LID options in practice.

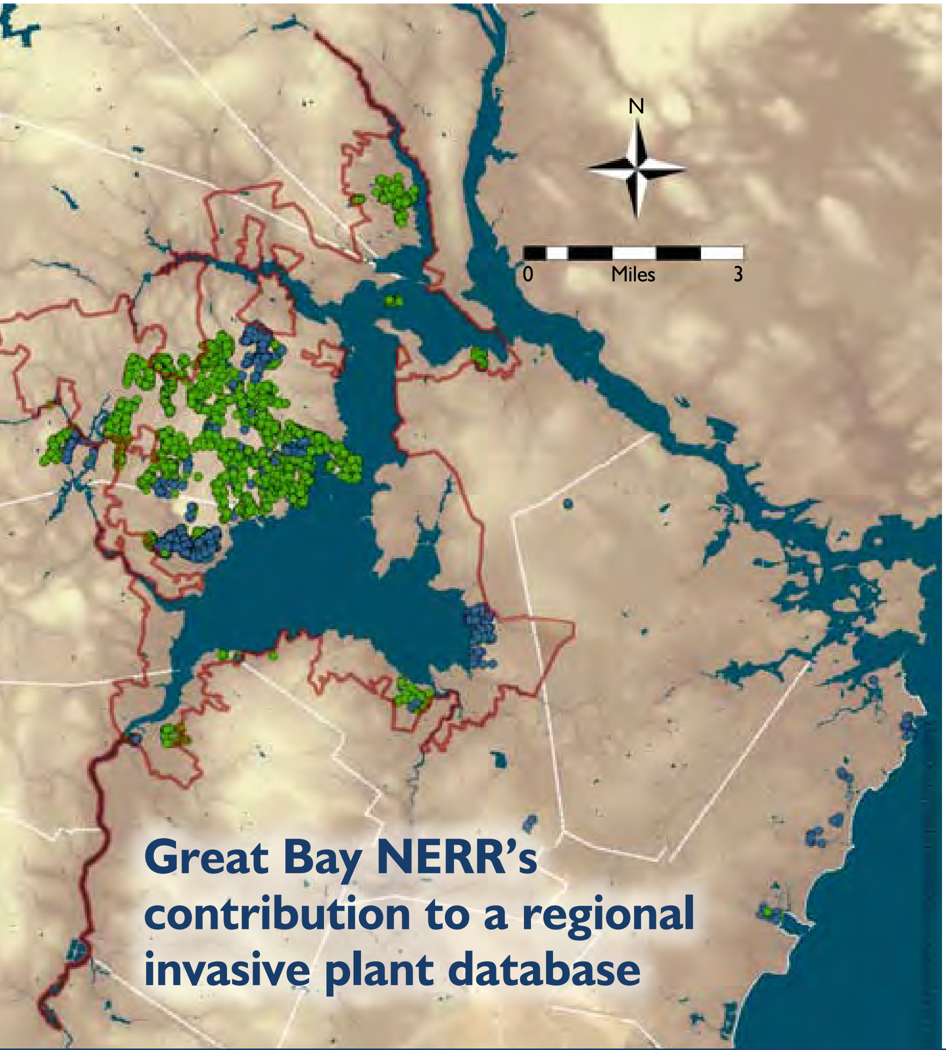
The parking lot and sidewalks use a combination of porous asphalt and pervious concrete. Both of these porous pavements infiltrate rain water into a stone sub-base, quickly eliminating the standing water on the surface after a major storm. In addition, the porous asphalt has reduced the amount of salt needed to keep the lot free of ice in the winter by 75%, and the porous concrete reflects light to keep the area cooler in the summer. An eco-paver walkway and a rain garden are also present on the site.

Left: Aerial view of the Great Bay NERR LID stormwater management demonstration site with porous asphalt, pervious concrete, and rain garden highlighted.
Right: Great Bay NERR rain garden workshop participants put the finishing touches to the rain garden installed at the Great Bay Discovery Center.

Invasive plant species

In addition to changes in the major land uses, invasive species can also substantially affect the structure and quality of habitats in the Great Bay watershed. Invasive species are not native to the region, and they can be introduced through a variety of activities. Clearing land or manipulating habitats creates disturbed conditions under which invasive species thrive. Once invasive species are introduced, they can trigger a series of ecological impacts by outcompeting and eventually replacing native plants. This loss of native species has direct implications for wildlife species that depend on them for food or habitat.

Since 2005, the Great Bay NERR has mapped twenty of the most ecologically damaging—those that spread rapidly and are the most persistent—invasive plant species on all Reserve properties. More than 4,000 stands of these species have been documented within the Reserve boundary. The most prevalent invasive species include Japanese barberry, common barberry, bush honeysuckle, glossy and common buckthorn, multiflora rose, and autumn olive. *Phragmites*, or common reed, is the major invasive species in salt marshes, although both native and invasive forms of this plant are present in marshes around Great Bay.



Populations of invasive plants that have been mapped within the Great Bay NERR (red outline). Green dots indicate populations that have been mapped by the Great Bay NERR, and blue dots show populations that have been mapped by other NH CWIPP partners.

In addition to documenting the location and size of invasive plant stands, the mapping effort documents ecological characteristics of each stand and the proximity to other natural and manmade features. Together this information points towards reasons for the spread of certain invasives around the landscape. First, invasive species are most commonly found along edges between distinct habitat types. The environmental changes that occur at habitat edges put species native to each habitat type at a competitive disadvantage and enable invasive species to thrive. Edge habitats are also travel corridors for humans and wildlife, and these movements can spread invasive species to new areas. In addition, invasive populations tend to be concentrated near disturbances and manmade features in the landscape. For example, cellar holes are the epicenter of many honeysuckle populations, indicating that early settlers planted these shrubs intentionally near their homes; unfortunately, they have subsequently spread throughout the landscape.

Controlling invasive species through local and regional efforts

Within the Great Bay NERR, mapping invasive populations has supported strategic prioritization of areas to focus control efforts. By overlaying locations of the most ecologically damaging invasive species and the most ecologically sensitive natural areas (e.g., NH Natural Heritage Program sites), priority areas for removing invasives can be identified. In addition, monitoring and mapping invasive populations enables their early detection before they become prevalent throughout the landscape. In 2008, the Great Bay NERR began control of Norway maple, purple loosestrife, and black swallowwort. These species were selected for initial control efforts because mapping efforts had determined that only small populations had recently become established within the Reserve. Thus, it was more likely these species could be eradicated without becoming re-established from other nearby populations, thereby increasing the chance they could be removed from within the Reserve for the long term.

In most cases, though, invasive species cannot be controlled through isolated efforts. Their aggressive colonization and growth potential requires a management approach that extends across property lines, as eradication on one property does not prevent re-establishment from a population on a neighboring property. For this reason, the Great Bay NERR works closely with local and regional partners to more effectively mitigate the spread of invasive species in the area.

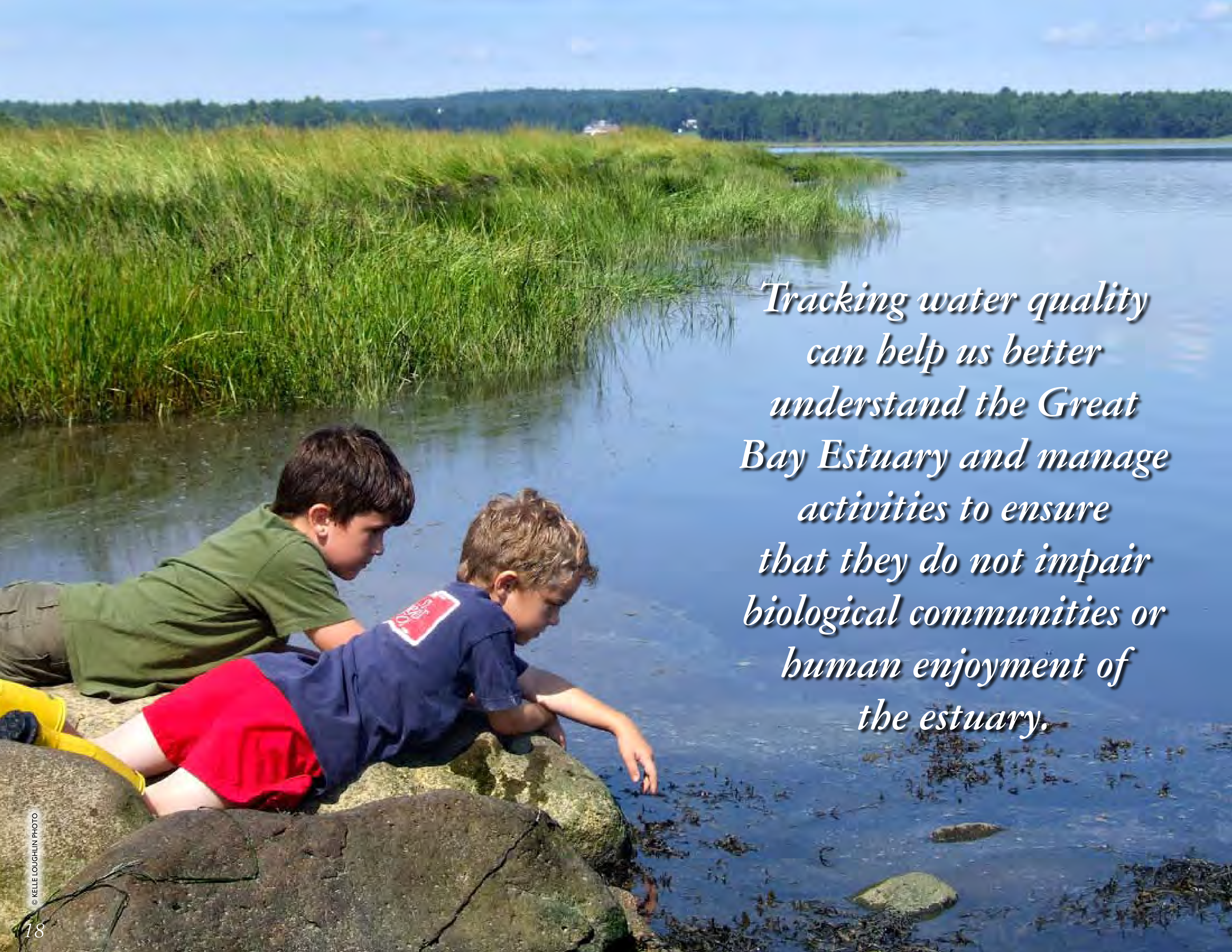
The Great Bay NERR is a key partner in the New Hampshire Coastal Watershed Invasive Plant Partnership (NH CWIPP), which brings together eleven agencies and organizations to assess the extent

and control the spread of invasive species in New Hampshire's coastal watershed. Partners in the NH CWIPP work collaboratively to inventory, monitor, and prevent the spread of invasive plants across jurisdictional boundaries. It also works with municipalities, private landowners, and state and federal land managers to control native species and restore native habitats.

In addition, the Reserve promotes and facilitates cooperative invasive species control efforts within its boundary. As an example, the Crommet Creek sub-watershed contains a mix of conservation lands and private properties. Within this watershed, the Great Bay NERR has worked closely with local landowners to document invasive species and build awareness of control options. Through hands-on workshops and demonstration projects, homeowners have learned to identify invasive species and practiced effective ways of removing them.

As the Great Bay NERR's efforts to control invasive species proceed, treatments are being applied using experimental designs that will allow for statistical comparisons of the effectiveness of different control options. By rigorously evaluating the effectiveness of control techniques and tracking conditions that may influence treatment outcomes, efforts by the Great Bay NERR to control invasive species on Reserve properties will provide lessons that are useful beyond its boundary. Ultimately, these experiences will be shared with landowners and management agencies to guide their future decisions about controlling invasive species on private and public lands.

Phragmites, or the common reed (left), and purple loosestrife (right) are prevalent invasive species within the Great Bay NERR. In the center photo, a Great Bay NERR volunteer cuts Japanese knotweed at the Chapman's Landing boat launch. After clearing the Japanese knotweed, the area was restored with a native species, Impatiens canadensis, and natural vegetation now dominates this site.


Tracking water quality can help us better understand the Great Bay Estuary and manage activities to ensure that they do not impair biological communities or human enjoyment of the estuary.

Water Quality

The Great Bay Estuary contains more than 60 billion gallons of water at high tide and more than 40 billion gallons at low tide. The physical dynamics and chemical properties of this vast volume of water control the ecological processes of the estuary. The salinity of the water, the amount of oxygen it contains, and its sediment and nutrient loads all influence the distribution of plants and animals in the estuary, as well as their ability to survive and thrive in its waters.

Changes in water quality are driven by natural dynamics and by the direct and secondary effects of human activities. By monitoring a variety of water quality parameters, short-term variability and long-term changes in estuarine processes can be detected, and the factors that influence these processes can be understood. Such baseline data provides important contextual information on the physical and chemical dynamics of an estuary, and monitoring changes from that baseline can guide management of estuarine ecosystems.

The Great Bay NERR tracks water quality in Great Bay and its tributaries as part of the NERRS's System-Wide Monitoring Program (SWMP). Through the SWMP, nationally consistent monitoring programs are implemented in multiple estuaries around the United States. The standardization of sampling protocols and data management procedures facilitates comparisons among the sites that comprise the NERRS. By participating in this program, the Great Bay NERR is able to develop and maintain a record of water quality conditions in the Great Bay Estuary, as well as compare these changes to those observed in other estuaries.

The Great Bay NERR established its first water quality monitoring station in the middle of Great Bay in 1995. Since that time, stations have been added in the Squamscott River (1997), Lamprey River (1998), and Oyster River (2002). At each station, a multi-parameter monitoring device called a datasonde measures temperature, depth, salinity, turbidity, pH, and dissolved oxygen every 15 minutes. In addition to the measurements collected with the datasondes, water samples have been collected monthly at each site since 2002. Concentrations of dissolved inorganic nutrients, particulate organic matter, suspended sediments, and chlorophyll in each sample are analyzed. To complement the monthly samples, high-frequency water samples are collected over a full lunar cycle at the Lamprey River location to track the tidally-driven temporal variability in nutrient concentrations. The SWMP also supports a meteorological station that collects data on weather conditions at 15-minute intervals; this contextual information aids interpretation of the water quality data.

The Great Bay NERR's water quality monitoring program benefits from partnerships with other local groups. The SWMP is collaboratively implemented with the Jackson Estuarine Laboratory (JEL) at the University of New Hampshire. This arrangement has helped ensure that data from the current monitoring program are comparable to those collected decades ago by university scientists. The Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) supports sensor testing and upgrades to enhance data collection as well as data distribution infrastructure to ensure that Great Bay water quality observations are accessible to users. In addition, the New Hampshire Department of Environmental Services has compiled and analyzed the data to set water quality criteria and track compliance with those standards. Both the Piscataqua Region Estuaries Partnership and CICEET have supported local and regional syntheses of the data, respectively.

This report highlights some of the water quality data gathered by the Great Bay NERR since the inception of its monitoring program. The parameters presented in this section were chosen to demonstrate how water quality conditions provide insights into natural dynamics and anthropogenic changes in the estuary. Tracking water quality can help us better understand the Great Bay Estuary and manage activities to ensure that they do not impair biological communities or human enjoyment of the estuary.

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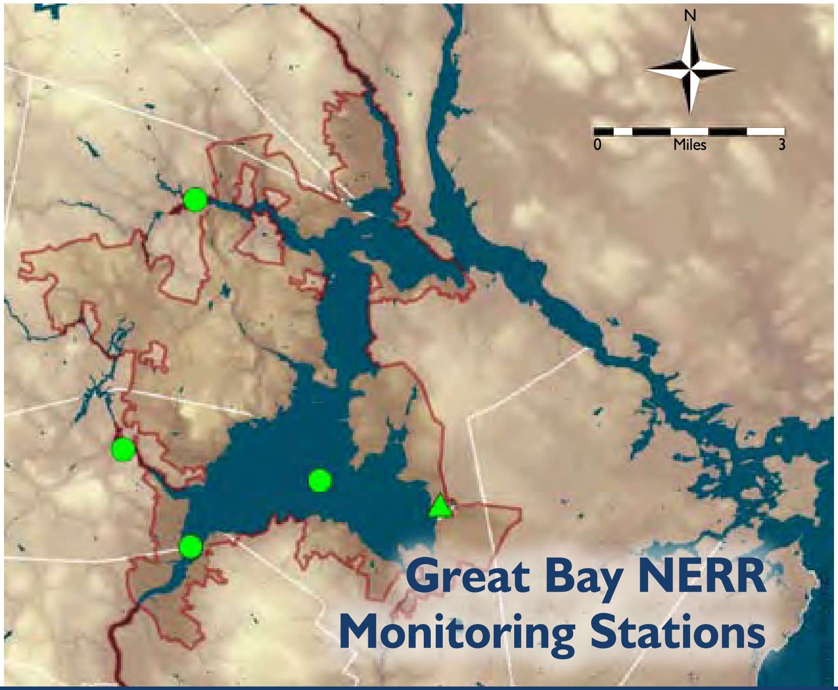
A research technician deploys a datasonde to collect water quality data in the Great Bay NERR.



Locations of water quality (circles) and weather (triangle) stations monitored by the Great Bay NERR as part of the System-Wide Monitoring Program.

Salinity

In connecting Great Bay to the Gulf of Maine, tides move salty ocean water up the estuary and back out to the sea twice a day. The higher salinity seawater mixes with fresh water entering from tributaries, resulting in an intermediate salinity in the estuarine waters. Compared to seawater's salinity of around 35 parts per thousand (ppt), salinity in Great Bay averages approximately 23 ppt. The salinity is lower at the monitoring stations in the Squamscott, Lamprey, and Oyster rivers due to a stronger freshwater influence in these tributaries (Figure 5).

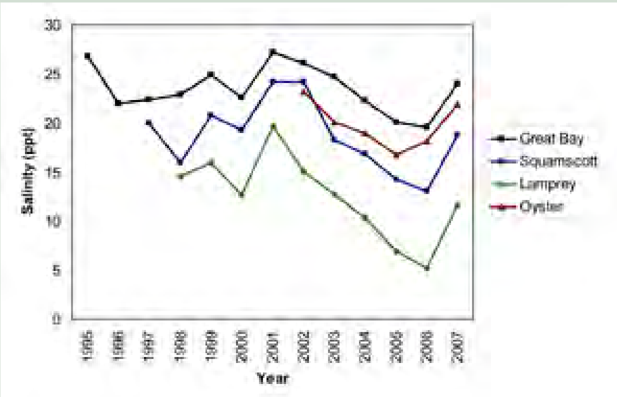


Figure 5. Average annual salinity at four monitoring sites in Great Bay and three tributary rivers.

While an average salinity can be computed for different locations, salinity in the estuary is dynamic and ever-changing. It rises and falls over the course of each tidal cycle (Figure 6, inset) as seawater enters and leaves the estuary. Salinity also changes with the seasons; it is generally lower in the spring when snowmelt and rainfall increase freshwater runoff, and highest during dry summer months when freshwater inputs are minimal (Figure 6).

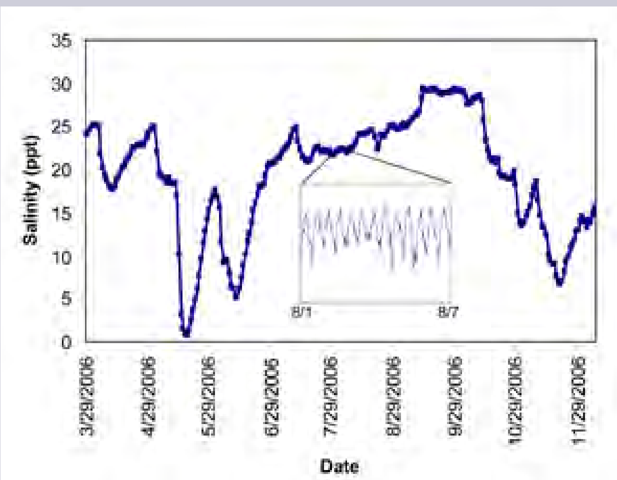


Figure 6. Daily average salinity at mid-Great Bay monitoring station during 2006. The inset shows one week of salinity measurements taken at 30-minute intervals to show changes that occur during each tidal cycle. The effects of several major rain events are noted in May (Mother's Day flood), June, and November.

The fluctuating salinity poses physiological challenges to organisms living in the Great Bay Estuary, as they must regulate the balance of water and salts in their bodies. Estuarine organisms need to tolerate a wider range of salinities than strictly freshwater or marine species, and they must be physiologically capable of enduring frequent salinity changes. The species that thrive in the Great Bay Estuary have adapted to the routine salinity dynamics that occur on tidal, daily, and seasonal schedules.

Occasionally, salinity fluctuations in the estuary exceed those experienced on a routine basis. The 2006 Mother's Day flood deluged Great Bay with fresh water from upland rivers and streams, and salinity in the bay plummeted to below five ppt for a week (Figure 6). The long duration of these near-freshwater conditions imposed severe stresses on organisms in the estuary. Some organisms have mechanisms for enduring such dramatic and sustained changes; for example, oysters close their shells and isolate themselves from external environmental conditions. However, other organisms cannot tolerate rapid shifts in salinity. Following the Mother's Day flood, surveys in the Great Bay Estuary found many dead lobsters, crabs, and clams that did not survive the influx of low-salinity water.

Salinity substantially influences the ecology of the Great Bay Estuary. As salinity varies in space and time, it affects the distribution and health of species in the estuary. Within the estuary, changes in salinity are largely driven by tidal cycles and riverine flows, which shift the balance of seawater and fresh water in the estuary. In the freshwater tributaries of the watershed, though, human activities such as road salting can alter salinity concentrations, a situation that has important implications for ecological conditions and human use of the water.

RISING SALINITY IN FRESHWATER STREAMS

Salt concentrations in freshwater streams are becoming a persistent year-round problem in many areas of New Hampshire. Road salt and de-icer use in the winter introduces salt to freshwater ecosystems, thereby degrading habitats for aquatic organisms and impacting drinking water supplies. Data from a 2007 study by the NH Department of Environmental Services in areas along the I-93 corridor showed that 50% of the salt entering freshwater streams comes from parking lots, and an additional 36% runs off from municipal and state roadways.

Salt dissolves in water and travels through the watershed; once it is dissolved, there is no easy way to remove it from the water. Hence, reducing impervious surface cover and the amount of salt used to de-ice parking lots and roads are critical steps to curbing salt inputs to freshwater systems. Recent studies in the northeast United States show that if salinity in streams continues increasing at its present rate, many surface waters will not be potable for human consumption and will become toxic to aquatic organisms within the next century.

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Turbidity

Just as the merging of seawater and fresh water affects salinity throughout the Great Bay Estuary, turbidity is influenced by the estuary's position at the confluence of land and water. Turbidity is a measure of the cloudiness of water due to particles suspended in it; clear waters have low turbidity, while turbidity is high in murky waters. In the Great Bay Estuary, the water's turbidity varies with natural processes, such as rainfall, that affect the load of suspended particles washed off the land and carried by tributaries to the estuary. In addition, wind and tidal action resuspends sediments on Great Bay's extensive mudflats, and wind-driven waves and boat wakes can erode shoreline sediments. Further, human activities on land can cause soil erosion, nonpoint source runoff and in-stream sediment suspension—all of which can increase turbidity in the estuary.

In Great Bay and its tributaries, the average annual turbidity has increased in recent years, but long-term changes in turbidity are highly variable (Figure 7). Spatial distinctions are noted in turbidity levels within the estuary. Conditions at the Squamscott River monitoring station are consistently more turbid than those observed in other tributaries or in Great Bay. The Oyster River site typically shows intermediate levels of turbidity, while the Lamprey River and mid-Great Bay monitoring stations track each other closely at lower turbidity values during most years. These spatial patterns are consistent with results observed by scientists at Jackson Estuarine Laboratory from 1988 to 1996, indicating persistent turbidity patterns in different portions of the estuary.

Major rainfall events also strongly influence turbidity in the Great Bay Estuary. A portion of the rain that falls on land in the Great Bay watershed runs off into the estuary. This runoff sweeps soil particles, decaying plant matter and other materials into the estuary, and the suspension of these particles increases turbidity in the water column. Observations during May and June 2006 show how turbidity responds after rain events (Figure 8). During the Mother's Day flood on May 13 and 14, heavy rains produced spikes in turbidity in Great Bay as runoff from the land washed loose particles into the estuary.

Turbidity shapes physical conditions and influences biological processes that occur in the Great Bay Estuary. High concentrations of suspended particles reduce light penetration, which hinders the growth of phytoplankton, benthic macroalgae and seagrass, thereby impacting organisms that depend on these aquatic plants for food and shelter. Fine particles in the water column can also damage fish gills and interfere with filter feeding by shellfish. Biological processes observed in fish change in relation to the level of turbidity and its persistence over time (Figure 9). As suspended particles settle out of the water column, they can smother fish eggs before they hatch, or cover important habitats. Sedimentation has contributed to the loss of oyster beds in the Great Bay Estuary, such as one at the mouth of the Lamprey River.

In addition to its potential ecological consequences, turbidity has several implications for human use and enjoyment of the Great Bay Estuary. Aesthetically, some people associate murky water with "dirty" water. Although this association is not always accurate, the appearance of murky water may deter some people from pursuing activities in Great Bay. Suspended particles can also transport microbes, nutrients, heavy metals and toxic contaminants into the estuary, and these pollutants create further aesthetic and human health concerns.

Minimizing turbidity impacts from human activities in the watershed and in tributary river systems is important for sustaining ecological functions and human uses of the Great Bay Estuary. Many steps may be taken to help to capture particles that run off into the estuary, including: maintaining vegetated buffers adjacent to waterbodies; cleaning out stormwater catchments; minimizing and carefully timing dredging activities; and using silt fences and sediment basins at construction sites. Actions such as these reduce the potential for turbidity to increase within the estuary, resulting in ecological as well as social benefits.

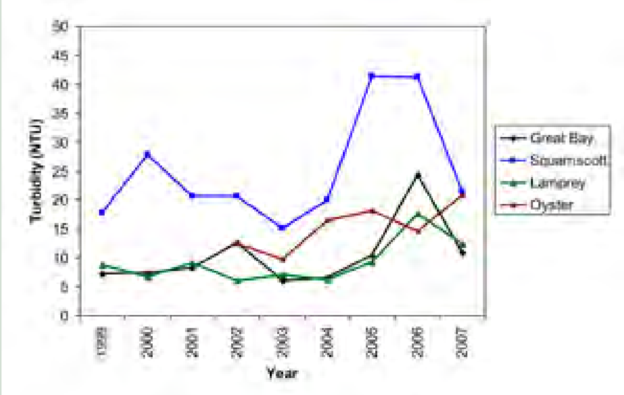

Figure 7. Annual average turbidity values for four monitoring stations in the Great Bay Estuary.

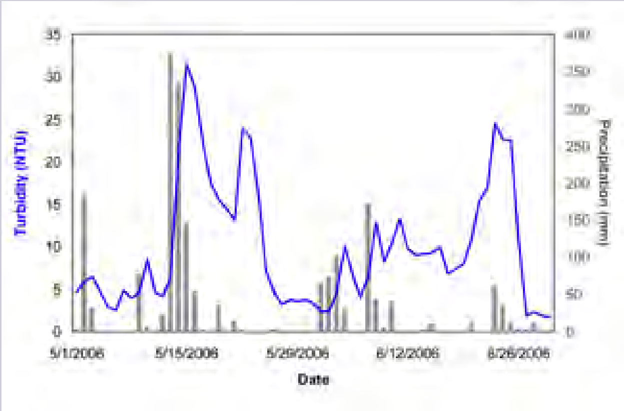

Figure 8. Turbidity values in mid-Great Bay during May and June 2006 overlaid on precipitation during each day.

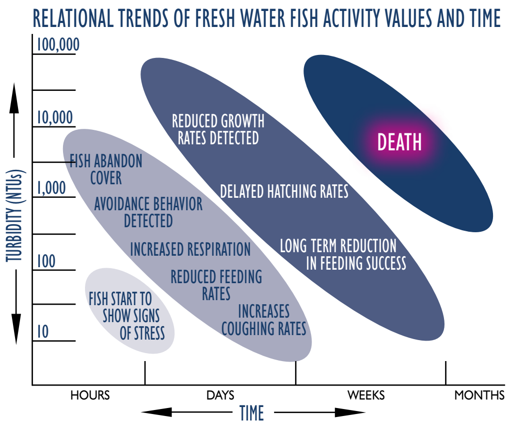

Figure 9. Generalized relationship of fish activity to turbidity levels and exposure time.

Based on Newcombe & Jensen, 1996: *www.waterontheweb.org/under/waterquality/turbidity.html*

Nutrients

Nutrients fuel the abundant life in estuaries. Nitrogen and phosphorus are essential for the growth of all plants—from tiny phytoplankton to eelgrass—that form the base of the food chain and provide important habitats within the Great Bay Estuary. While nutrients are vital for sustaining the Great Bay estuarine ecosystem, excessive nutrient levels can be harmful.

Nutrient loading of estuaries around the country has increased substantially in the past few decades, largely due to increasing development, a proliferation of impervious surfaces, and human activities in surrounding watersheds. Nitrogen is the nutrient of greatest concern in estuarine waters. Analyses by the Piscataqua Region Estuaries Partnership show that nonpoint source runoff from major tributaries and the watershed contributes 63 percent of the nitrogen entering the Great Bay Estuary. This nitrogen comes from sources as diverse as agricultural and lawn fertilizers, septic systems, animal wastes, and atmospheric deposition. In addition, 18 wastewater treatment facilities discharge into the Great Bay Estuary or its tributaries, contributing 34 percent of the estuary's nitrogen load.

The Great Bay NERR has monitored concentrations of nitrogen in the estuary since 2002. Coupled with data collected by scientists at the JEL as early as 1973, a valuable time series exists for evaluating changes in nutrients in the Great Bay Estuary. Data from the Great Bay NERR's monitoring program indicates that the median concentrations of dissolved inorganic nitrogen, the form most available to plants, have generally been higher in the Oyster and Squamscott rivers than in Great Bay or the Lamprey River (Figure 10). However, substantial variability in the data makes it difficult to discern trends since 2002. Comparing recent data (2001-2008) to historical data (1974-1981) gathered at Adams Point by scientists at the JEL indicates a 44 percent increase in median nitrogen concentrations. This large increase over a 35-year time period has substantial ecological implications.

High nutrient levels can trigger sudden blooms of phytoplankton and nuisance macroalgae, which have a variety of adverse impacts on water quality and aquatic life. When algae in a dense bloom die, they consume oxygen in the water as they decompose, thereby lowering the dissolved oxygen available to other organisms. Algal blooms and particles that transport nutrients in the water column also increase the turbidity of the water, which reduces the light that can penetrate to plants such as eelgrass. These diverse impacts of excessive nutrient inputs reduce habitat quality, destabilize food webs, and impair human uses of estuarine waters.

As a step towards ensuring that the Great Bay Estuary continues to support biological communities and human uses, nutrient data collected by the Great Bay NERR, the University of New Hampshire, and the US Environmental Protection Agency's National Coastal Assessment have recently been used by the NH Department of Environmental Services as a basis for developing quantitative water quality criteria for nitrogen, chlorophyll-a, and water clarity. The water quality criteria were based on the habitat requirements for eelgrass survival and the prevention of low dissolved oxygen concentrations. Assessing the ability of the estuary's waters to support aquatic life against these criteria indicates that the majority of the estuary, particularly its tributary rivers, is impaired due to excess nutrient loading. Mitigating these impairments and restoring the Great Bay Estuary's capacity to fully support aquatic life will require concerted public and private efforts to reduce the amount of nitrogen entering the estuary and its tributaries.

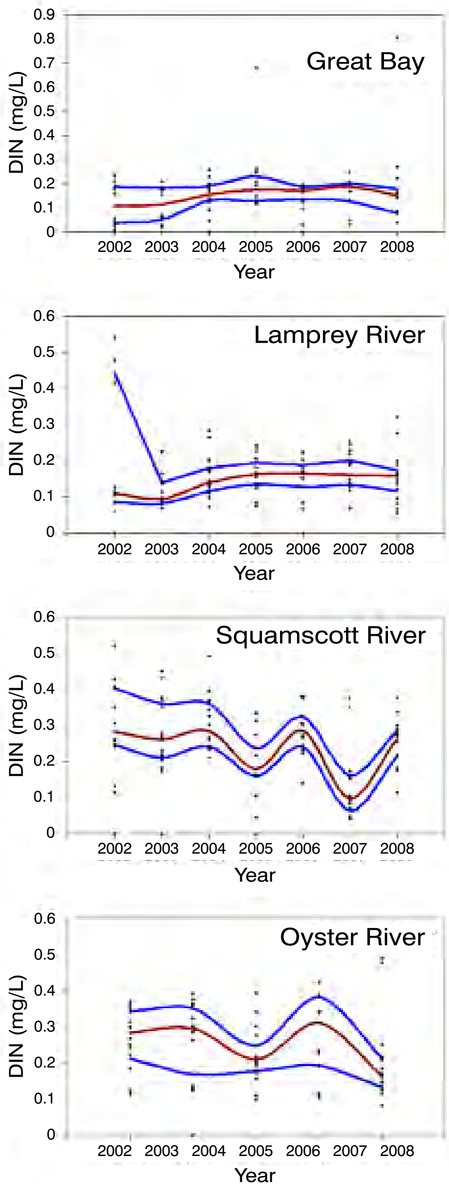

Figure 10. Concentrations of dissolved inorganic nitrogen at four monitoring sites in the Great Bay Estuary. The black dots show all data points. The red line shows the median, or midpoint, of the observations recorded in each year. The blue lines encapsulate 50% of the data points collected in each year.

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ECOSYSTEM IMPACTS OF NUTRIENTS IN GREAT BAY

To better understand the impacts of nutrients on the Great Bay ecosystem, Jeremy Nettleton—a Graduate Research Fellow with the Great Bay NERR—has been assessing the abundance of green macroalgae, *Ulva*, in the estuary. The genus *Ulva*, more commonly called sea lettuce (above), includes species that increase in abundance in nutrient-rich waters. Nettleton's comparisons of historical and present-day surveys of *Ulva* percent cover and biomass show that these bloom-forming species have increased dramatically in southern portions of Great Bay. In November 2008, *Ulva* cover exceeded 90% near the mouth of Lubberland Creek, more than 90 times greater than the abundance observed by researchers in 1979. Similarly, an *Ulva* bloom near the mouth of the Winnicut River resulted in greater than 65% cover. These high abundances of *Ulva* and the dramatic change from historical conditions provide further evidence that nutrient loading may substantially affect the ecology of the Great Bay Estuary.

Dissolved oxygen

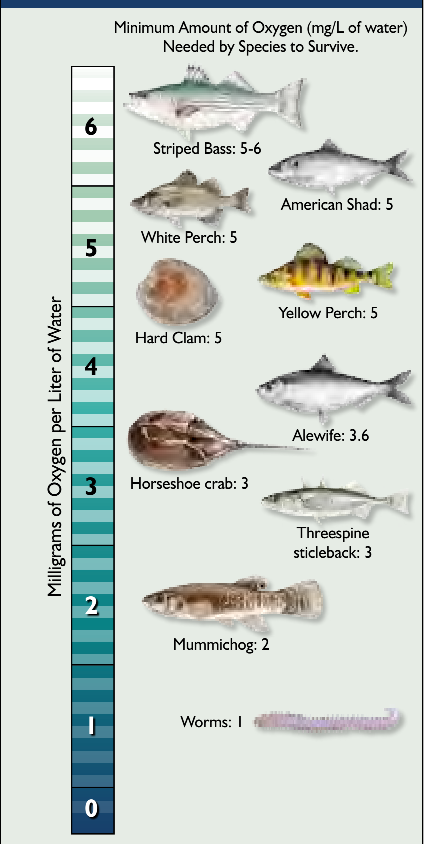
Just like humans, organisms that live in the waters of the Great Bay Estuary need oxygen to survive. As humans, we use our lungs to extract oxygen from the air we breathe. Similarly, fish, crabs, and many other aquatic organisms use gills to extract oxygen from the water. As water moves past their gills, oxygen gas in the water—called dissolved oxygen (DO)—is transferred to their blood. This process is only efficient if sufficient levels of oxygen are present in the water, so DO concentrations above certain thresholds are necessary to sustain aquatic life.

Oxygen enters Great Bay's waters in several ways. Physical mixing at the air-water interface moves oxygen from the atmosphere into surface waters. In addition, water entering the bay from the ocean or from faster-moving rivers tends to contain higher concentrations of DO. Biological processes also contribute oxygen to Great Bay's water; plants such as algae and seagrasses release oxygen as they photosynthesize.

Oxygen concentrations are affected by a combination of natural and human-influenced factors, the most important of which are the water's temperature, organic load, and nutrient load. The temperature of the water controls the amount of oxygen that can dissolve in it. Cold water can hold more oxygen than warm water, so low DO events tend to occur during the summer. As noted above, plants can contribute oxygen to the estuary's waters during photosynthesis, but as they respire and decompose, these same plants take up oxygen from the water. High loads of organic material can steadily deplete DO during nighttime hours when respiration is not counter-balanced by photosynthesis. Further, nutrient loading to the estuary can promote the growth of algae, thereby increasing the overall demand for oxygen and raising the risk of oxygen depletion in bottom waters.

Species vary in their DO requirements based on their habitat, evolutionary adaptations, and life history stage. Worms and clams that live in the mud, where DO levels are naturally low, can survive in waters that contain very little oxygen. Fish, crabs, and oysters that live or feed near the bottom need higher concentrations of DO. Migratory fish that enter the estuary for short periods of time have even higher DO requirements, particularly during their sensitive egg and larval life history stages. Generally, DO concentrations of 5 mg/L and greater are sufficient to allow aquatic organisms to live and thrive; concentrations below 3 mg/L pose threats to many aquatic species, a condition termed hypoxia.

DISSOLVED OXYGEN CRITERIA



To ensure that water bodies can continue to support aquatic life, the state of New Hampshire establishes water quality standards for DO concentrations. The standard requires that two conditions be satisfied: (1) the daily average concentration of DO remains above 75 percent saturation and (2) the instantaneous DO concentration remains above 5 mg/L. Evaluating summer oxygen observations against both standards shows that DO levels rarely fall below desired levels in Great Bay proper, but high rates of non-compliance occur in the tidal rivers (Figures 11 and 12).

The Lamprey River shows the highest portion of violations of both the daily average saturation and instantaneous concentration standards. In multiple years, the Lamprey River fails to meet the DO standards for more than 50 percent of the days in the summer. The Squamscott and Oyster River monitoring stations also show instantaneous DO concentrations falling below 5 mg/L during most years. In several years, the daily average saturation falls below 75 percent in the Oyster River, and occasional violations are noticed in the Squamscott River.

The strong tidal flushing within the main portion of the Great Bay Estuary appears to help maintain well-oxygenated waters in the large embayments of the estuary. However, DO concentrations in many of the tidal rivers that flow into the estuary fall below levels that are necessary to support certain organisms. Both anthropogenic stressors and natural phenomena may contribute to these impairments, and steps to reduce nutrient inputs to the estuary should also reduce the number of low DO events that occur in the tidal rivers.

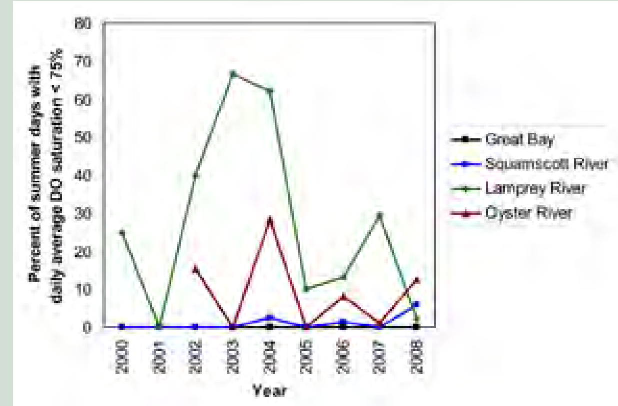


Figure 11. The percent of summer days (June, July, August) during which the average dissolved oxygen concentration falls below 75% saturation at four monitoring stations.

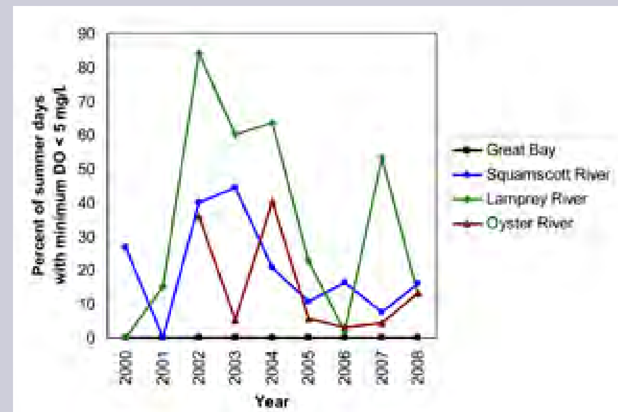


Figure 12. The percent of summer days (June, July, August) during which instantaneous dissolved oxygen concentrations fall below 5 mg/L at four monitoring stations.

Protecting water quality in the Great Bay Estuary

Good water quality ensures that light can penetrate through Great Bay's water to promote the growth of eelgrass. Protecting water quality is critical for sustaining eelgrass habitats and the species they support.

While the Great Bay Estuary is a resilient ecosystem, protecting its water quality is essential to retaining habitats and species within the estuary and sustaining our ability to enjoy activities on its water. Tides and rainfall cause water quality conditions in the Great Bay Estuary to fluctuate on short-term time scales, but longer-term changes in turbidity, nutrients, and dissolved oxygen are driven by human activities. The choices we make as individuals and as a society substantially influence water quality in the estuary.

Conserving the natural state of land and improving stormwater management are important steps towards protecting water quality in the Great Bay Estuary. Vegetation holds soil in place on the land and promotes slow infiltration of water into the ground. As forests and wetlands are cleared and replaced by residential and commercial developments, impervious surfaces cause water to flow quickly and dramatically increase in volume. At these higher velocities and volumes, it picks up sediment particles, pollutants, and nutrients from sources as diverse as parking lots, lawns, and farms. Some of this runoff flows directly into streams and rivers, but much of it enters storm drains which are directed to the nearest surface waters. Ultimately, runoff from any location in the

LEARN ABOUT WATER QUALITY AT GREAT BAY DISCOVERY CENTER

At the Great Bay Discovery Center, visitors can learn about the Great Bay NERR's water quality monitoring program through an interactive exhibit called A Measure of Change. A timeline of land use change since the early 1600s highlights the effects of different human activities on water quality in the estuary. The exhibit also explains why scientists measure water quality today and what they do with the data they collect.

Visitors can navigate their way through a computer touch screen to learn how changes in water quality affect species that live in the Great Bay Estuary, such as lobsters, eelgrass, mussels, and river herring. With this knowledge, visitors gain a better understanding of the challenges faced by a variety of plants and animals in the estuary, as well as some of the things the Reserve is doing to combat those challenges.

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Great Bay watershed will make its way to the estuary, where it increases turbidity, nutrient concentrations, and pollutant loads.

Private and public actions are necessary to enhance the infiltration capacity of lands and reduce runoff to the Great Bay Estuary. Private landowners can take a variety of steps on their own property that will protect water quality in the estuary. Some examples include:

- Avoiding use of lawn, garden, and agricultural chemicals, especially within 100 feet of all surface waters
- Using permeable pavement materials, such as gravel or modular pavers
- Installing rain gardens and using rain barrels
- Planting trees and shrubs and using mulches to slow water movement
- Protecting vegetated buffers adjacent to all surface waters, including streams and wetlands
- Composting yard wastes and using the compost in place of chemical fertilizers
- Keeping yard waste away from rivers, streams, and storm drains
- Properly siting and maintaining septic systems to avoid leaching bacteria or nutrients
- Complying with all aspects of the NH Comprehensive Shoreland Protection Act

Public organizations should also pursue a variety of efforts that benefit water quality in the Great Bay Estuary. The work of public agencies and non-profit organizations to preserve ecologically valuable land parcels in the watershed will help enhance the estuary's water quality, as these natural areas maintain the natural water cycle and promote infiltration of rainwater. In addition, municipal building regulations that protect wetlands, maintain vegetated buffers, require setbacks, and promote the use of low impact development techniques all help protect water quality. Finally, steps to upgrade wastewater treatment facilities from primary to higher levels of treatment will reduce nutrient and turbidity inputs and improve dissolved oxygen levels in the Great Bay Estuary.

Concerted public and private actions will be needed to protect and improve water quality in Great Bay, and expediting these actions is critical. The estuary is already showing signs of stress that appear to be triggered by water quality conditions. Noted declines in eelgrass, increases in macroalgae, and dissolved oxygen impairments in tidal rivers may be just the first warnings that the ecosystem is approaching a tipping point, which once crossed would negatively impact species and human activities in the estuary. Taking actions now to improve water quality is imperative for sustaining healthy biological communities and recreational opportunities in the estuary.

ADVANCING STORMWATER MANAGEMENT IN THE GREAT BAY WATERSHED

Stormwater management is a key issue of concern in the Great Bay watershed. As such, this topic has been a training priority for the Great Bay NERR's Coastal Training Program (CTP). Since 2004, the CTP has offered workshops and science-based training sessions on natural resource planning, wetland buffers, nutrient pollution, low impact development, watershed management, and stormwater issues. These training opportunities enable municipal board members in towns throughout the watershed to gain new knowledge and skills that they will be able to apply to enhance stormwater management approaches in their own towns. In 2008, the 29 trainings that were offered through the CTP reached 873 decision-makers. Participating decision-makers have used these new skills and insights to conduct assessments, improve planning, and update regulations as needed to address municipal challenges related to growth and stormwater management.

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The diverse habitats found in the estuary and its watershed sustain an impressive range of species… like horseshoe crabs… iconic symbols of the estuary itself.

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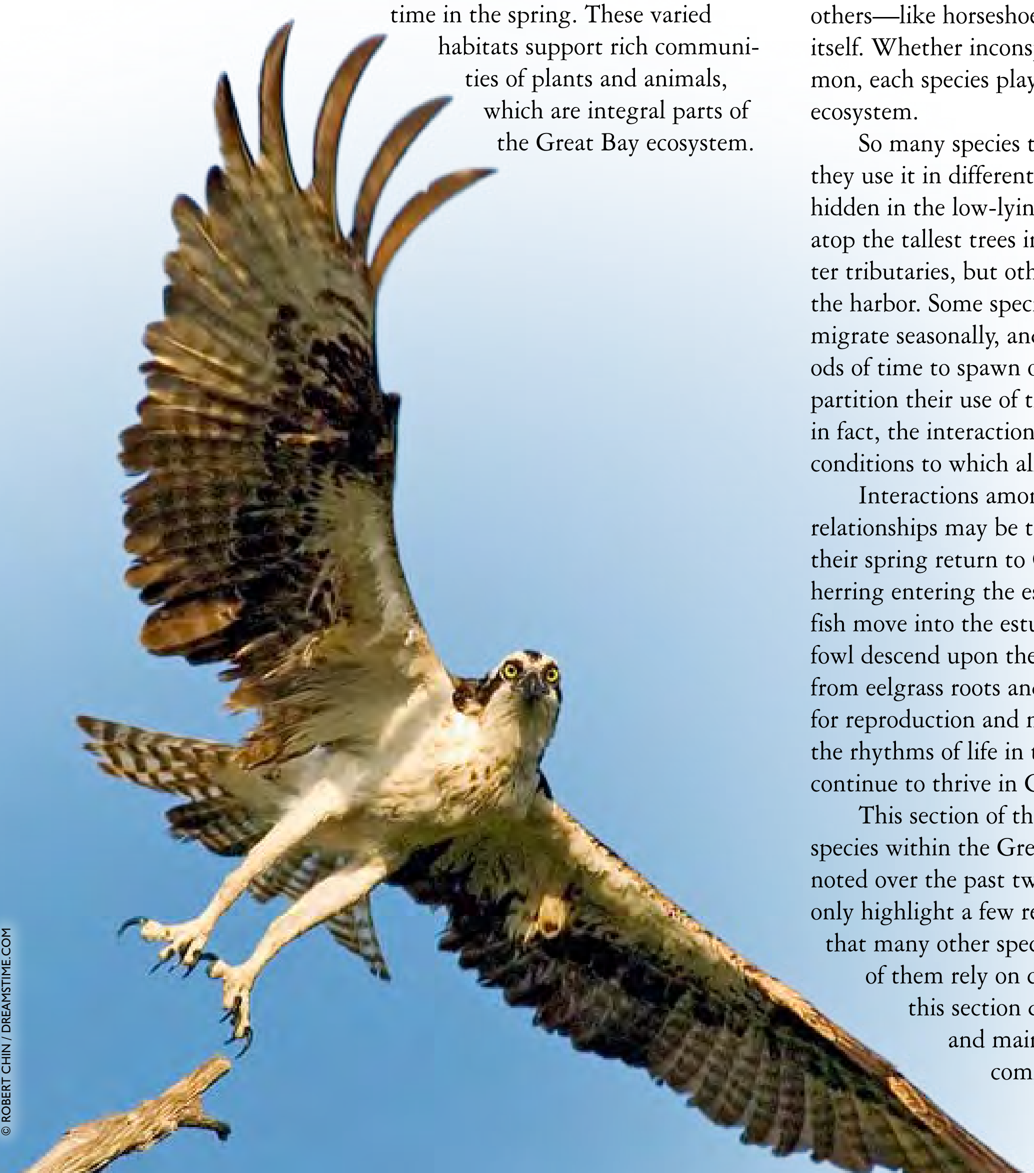
Biological Communities

The Great Bay Estuary and its watershed contain a wide array of habitats, from seagrass beds where the plants flow gently back and forth with the tides to oak-pine forests where sturdy trees tower above the forest floor. The smooth surfaces of the estuary's expansive mudflats contrast with the rough edges of its rocky beaches. Upland forests conceal distinct habitats, such as vernal pools that appear in low-lying areas for a short time in the spring. These varied habitats support rich communities of plants and animals, which are integral parts of the Great Bay ecosystem.

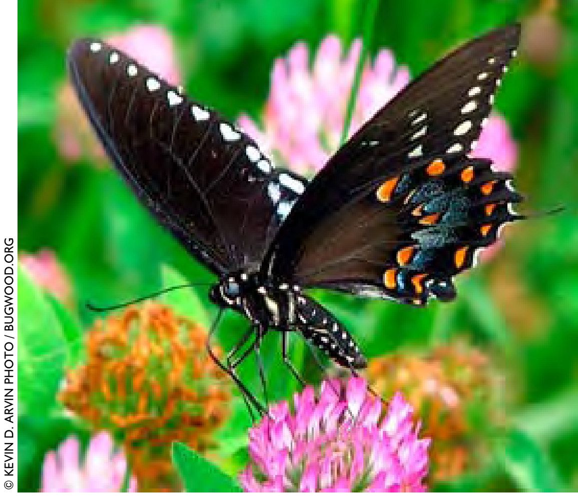


The diverse habitats found in the estuary and its watershed sustain an impressive range of species—from oysters that sit firmly attached to the underwater substrate, to fish that swim through the tidal waters, to migratory birds that arrive to feed for the winter. Some species may rarely be seen or noticed, like the small invertebrates that burrow in the mudflats, but others—like horseshoe crabs—are iconic symbols of the estuary itself. Whether inconspicuous or eye-catching, rare or common, each species plays an important role within the Great Bay ecosystem.

So many species thrive in the Great Bay Estuary because they use it in different ways and at different times. Some birds nest hidden in the low-lying vegetation of salt marshes, while others perch atop the tallest trees in the forest. Some fish can only live in the freshwater tributaries, but others can only survive in the most saline waters of the harbor. Some species live in the estuary for their entire lives, others migrate seasonally, and still others enter the estuary only for short periods of time to spawn or feed. Although the many fish and wildlife species partition their use of the estuary in space and time, they are not isolated; in fact, the interactions among species are as important as the physical conditions to which all of the species adapt and respond.

Interactions among species can take many forms, but feeding relationships may be the most widely recognized. Ospreys (left) time their spring return to Great Bay to coincide with strong runs of river herring entering the estuary to spawn. During the summer, predatory fish move into the estuary to feast on abundant prey. In winter, waterfowl descend upon the estuary to feed, and the calories they consume from eelgrass roots and mudflat invertebrates provide energy they need for reproduction and migration. These feeding interactions not only drive the rhythms of life in the estuary, but also ensure that familiar species continue to thrive in Great Bay.

This section of the report describes some of the key habitats and species within the Great Bay Estuary and the changes that have been noted over the past twenty years. While the pages of this report can only highlight a few representative species, it is important to recognize that many other species are part of the Great Bay ecosystem, and all of them rely on clean water and healthy habitats. The last part of this section discusses actions that are being pursued to improve and maintain the conditions that support diverse biological communities in Great Bay.



Spicebush swallowtail

Ospreys time their spring return to Great Bay to coincide with strong runs of river herring entering the estuary to spawn.

Habitats

Many different types of habitats are found within the boundary of the Great Bay NERR. This rich habitat mosaic supports numerous species, making the estuary and its watershed one of the most biologically diverse areas in the state. The dominant estuarine habitats include eelgrass beds, mudflats, rocky intertidal shores, and salt marshes. These habitats are structured along an elevation gradient that controls the frequency and extent of tidal inundation. Eelgrass beds grow in shallow subtidal and soft-bottom portions of the estuary. In intertidal zones, mudflats and rocky shores provide distinct habitats. Salt marshes sit slightly higher in the elevation gradient; while the low marsh is flooded by every high tide, the high marsh is submerged only during extreme tides. Landward of the salt marshes, upland habitats include hardwood forests, shrub-scrub wetlands, cattail marshes, vernal pools, and agricultural fields.

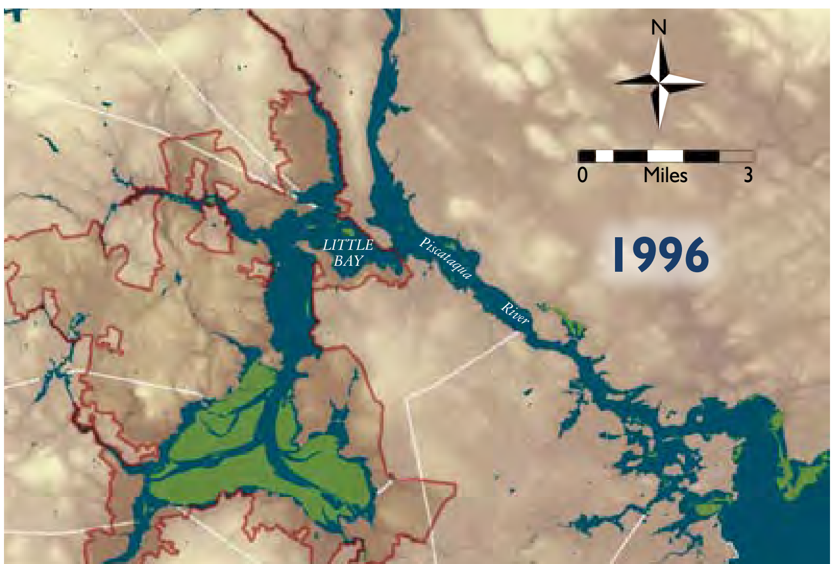
While a variety of habitats support the diversity of aquatic and terrestrial species in the Great Bay Estuary and its watershed, this report focuses on two of the key habitats—seagrass beds and salt marshes—to explain their ecological functions and current status.

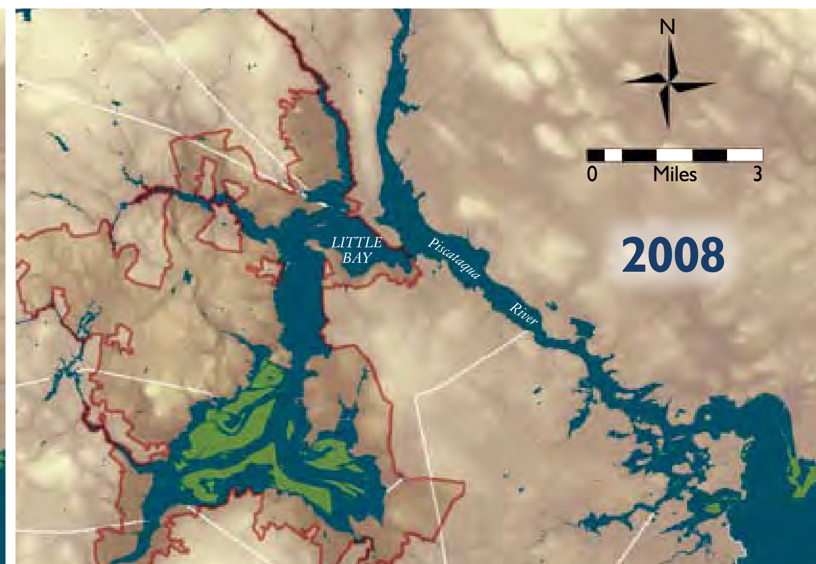
Seagrass beds

Seagrasses are flowering plants that grow submerged or partially floating in marine and estuarine environments. In the Great Bay Estuary, eelgrass (*Zostera marina*) is the dominant seagrass species. Another species, widgeon grass (*Ruppia maritima*), is found to a limited extent in some of the tributaries and shallow salt marsh pannes. These two species create different habitat conditions, as the long ribbon-like leaves of eelgrass provide more canopy cover than the short, thin widgeon grass leaves.

Eelgrass beds serve important biological and physical functions within the Great Bay Estuary. They offer protective spawning and nursery habitats for fish and shellfish, including many commercially, recreationally, and ecologically important species. They also provide feeding areas for larger fish and wading birds, which are attracted to the small fish concentrated within the eelgrass beds. In addition, some wintering waterfowl, such as geese and ducks, feed directly on the plants. Beyond their habitat value, eelgrass beds remove nutrients and trap suspended sediments in the water column, which improves water clarity within the estuary. Further, their dense network of roots and rhizomes stabilizes sediments and prevents erosion due to tidal currents or severe storms.

The distribution and biomass of eelgrass in the Great Bay Estuary has declined substantially in the past decade. Mapping conducted by the UNH Seagrass Ecology Lab shows that following a severe crash due to wasting disease that reduced eelgrass coverage to only 300 acres in 1989, the beds recovered and reached a maximum observed extent of 2,954 acres in 1996. Since then, the distribution of eelgrass in the estuary has been contracting, and wasting disease is not the culprit. From 1996 through 2008, the spatial coverage of eelgrass shrank by 45 percent within the estuary (maps below). The most severe declines have been observed in the Piscataqua River and Little Bay, where all of the eelgrass has died. Eelgrass beds have also been lost in some of the tributaries, such as the Oyster and Winnicut rivers. Eelgrass area has declined in Great Bay as well, but it still contains the largest eelgrass beds in the estuary as the bay's tidal range ensures that these plants receive a surge of sunlight at low tide to boost their photosynthesis. Although eelgrass





The distribution of eelgrass (shown in green) in the Great Bay Estuary declined by 45% between 1996 and 2008. Losses in the Piscataqua River and Little Bay were particularly severe, with all eelgrass beds disappearing from those areas. Data provided by Fred Short, UNH Seagrass Ecology Lab.

GRADUATE RESEARCH HIGHLIGHTS

The Great Bay NERR has supported four graduate students studying the ecology and restoration of habitats in Great Bay.

STUDENT	YEAR	PROJECT TITLE
Jordan Mora	2009	Berm impacts on salt marsh dynamics in New England
David Rivers	2004	Comparing water quality data and maximum depth of eelgrass, *Zostera marina*, beds: Can eelgrass depth be used as a water quality indicator?
Cathy Bozek	2002	The effects of seawalls and berms on salt marshes: Implications for marsh persistence and restoration of self-maintenance
Pamela Morgan	1997	Functions and values of salt marshes in Northern New England: A comparison of fringing marshes and back barrier marshes

restoration projects in the Piscataqua River, Portsmouth Harbor, and Little Bay were successful in the early 1990s, these transplanted beds have now experienced the same declines as natural eelgrass.

The eelgrass decline has severe ecological implications for the Great Bay Estuary. The complete loss of eelgrass beds in the Piscataqua River and Little Bay eliminates a vital corridor of shelter for estuarine species as they move between the Atlantic Ocean and Great Bay. Further, the contraction of eelgrass beds in Great Bay reduces their habitat value and their ability to provide ecological services, such as water filtration and sediment stabilization. These changes affect the survival and growth of many species that rely on the beds for feeding and nursery habitats. As such, they may have long-term ramifications for fish, invertebrate, and waterfowl populations in the estuary.

Recent losses of eelgrass are related to declining water clarity within the estuary due to nutrient loading and sedimentation. Reduced water clarity prevents light from penetrating the water column, which decreases photosynthesis in the eelgrass plants. Comprehensive actions to mitigate nutrient loading and reduce turbidity in the estuary are necessary to restore water clarity and reverse eelgrass losses.

Salt marshes

Salt marshes in the Great Bay Estuary exist both as expansive meadow marshes and narrow fringing marshes. Meadow marshes are concentrated in the mouths of tributary rivers and embayments along the shoreline, while fringing marshes line the edges of the bays and rivers. Smooth cordgrass (*Spartina alterniflora*) dominates the intertidal low marsh. In the high marsh, which lies above the extent of mean high tide, saltmeadow cordgrass (*Spartina patens*), spikegrass (*Distichlis spicata*), and black grass (*Juncus gerardii*) are the most common plant species.

Salt marshes provide habitat for a variety of species. They offer important breeding, refuge and forage habitats for fish, invertebrates and birds. Small prey fish such as mummichogs, silversides, sticklebacks, and juvenile white perch are particularly common in salt marshes. As these organisms move between salt marshes and other estuarine habitats, they help export energy to support coastal food webs. Salt marshes are also utilized by terrestrial species, including deer, mink, and otter.

Salt marshes in the Great Bay Estuary have been heavily altered and some have been destroyed by human actions. Historically, salt marshes were ditched and drained to farm hay and control mosquitoes; these ditches still remain common features of marshes within the estuary. More recently, coastal development activities have resulted in dredging and filling of salt marshes. As understanding of salt marsh functions has improved, regulations to prevent harm to these habitats have also advanced, but salt marshes continue to be directly and indirectly impacted by development.

Protecting the remaining salt marshes is important not only because of the habitat benefits they offer, but also because of other ecosystem functions they provide. Salt marshes stabilize shorelines and protect them against storm damage, a benefit that will become increasingly important as climate change impacts such as sea level rise and intense precipitation events increase the erosive potential of storms. In addition, salt marshes filter nutrients and pollutants, binding them in soil and plant material and breaking them down through chemical processes before they reach the tidal waters of the estuary.

Left: Jordan Mora helps plant Spartina pectinata for a salt marsh restoration project.
Right: Fringing and meadow salt marshes within the Great Bay NERR.

Invertebrates

A diverse array of species is represented among the invertebrates that live in the Great Bay Estuary. Clam worms, gem clams, mud snails, and ribbed mussels inhabit the mudflats. Snails, barnacles, and oysters are found on rocky shores and hard bottoms. Crustaceans, such as lobster and sand shrimp, swim in the water column or move along the bottom. These invertebrates fill a variety of ecological niches and showcase a range of adaptations to life in the estuary. The diversity of invertebrates in the Great Bay Estuary is impressive, and this report focuses on three species that are routinely monitored and of particular interest—horseshoe crabs, oysters, and lobsters.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Horseshoe crabs

Horseshoe crabs are most visible in Great Bay during their spawning season in late spring and early summer. During the highest tides, males and females move onto the shores of the bay, where females lay up to 90,000 tiny eggs before returning to the water. Their behavior during other times of the year is less well understood. Recent studies have shown that horseshoe crabs remain in the shallow waters of Great Bay through the fall, where they forage in the muddy substrates. As they dig for shellfish and worms to eat, horseshoe crabs influence sediment characteristics and invertebrate species composition. These changes have important ecological implications that are being investigated in the Great Bay Estuary.

In 1998, the Great Bay NERR initiated a monitoring program to track horseshoe crab abundance and spawning habitat use. This effort identified shoreline spawning habitats and documented the abundance of horseshoe crabs in each location. Since 2001, the Marine Fisheries Division of the NH Fish and Game Department has continued this monitoring program, focusing on five highly-utilized spawning sites. The highest concentrations of horseshoe crabs have been found in the southern portion of Great Bay at Greenland Bay and Sandy Point, with intermittent years of high spawning densities at Chapman's Landing. In recent years, the average number of horseshoe crabs observed per foot of shoreline at these sites has declined by more than 60 percent from peaks between 2001 and 2004 (Figure 13).

The greatest human threat to horseshoe crabs in Great Bay is coastal development, which can eliminate or restrict access to spawning sites and nursery areas. Protecting gently sloping beaches along the Great Bay shoreline can help ensure that horseshoe crabs continue spawning in the estuary. In other portions of their range, commercial harvesting of horseshoe crabs is a major concern, but harvest in Great Bay is minimal.

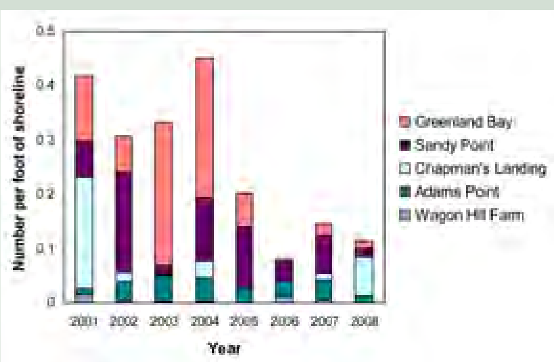

Figure 13. Number of horseshoe crabs observed per foot of shoreline at five spawning sites in Great Bay during May and June of 2001 to 2008. Data provided by the New Hampshire Fish and Game Department.

Oysters

Historical records indicate extensive beds of oysters in nearly all of the rivers and many channels in the Great Bay Estuary. Substantial reductions in the distribution of oysters and declines in their abundance

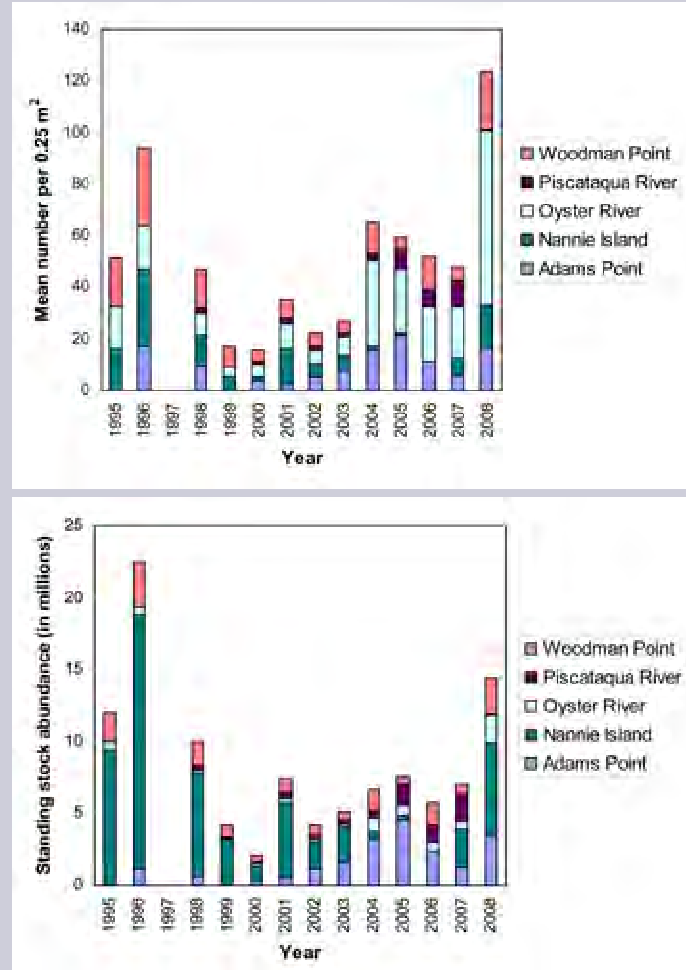

Figure 14. Density (a) and standing stock abundance (b) of oysters over 60 mm in shell length at five sites in Great Bay from 1995 to 2008. Standing stock combines measures of the size of each bed with the observed density of oysters recorded on each bed. Note that monitoring was not conducted at Adams Point in 1995 and 1999 or in the Piscataqua River in 1995 and 1996.

were documented in Jackson's 1944 survey of biological resources in Great Bay. Centuries of pollution, harvesting, and siltation had reduced oyster beds to a fraction of their historical size.

The current status of oysters can be evaluated based on changes in their spatial coverage, density, and standing stock. The spatial extent of oyster beds in Great Bay declined slightly overall between 1997 and 2000. The largest bed in Great Bay, which is located at Nannie Island, declined in area by 33 percent. In contrast, a much smaller bed at Adams Point expanded by over 200 percent during the same period.

The biological status of oysters in Great Bay has been monitored consistently by the NH Fish and Game Department since 1995. Following the initiation of this monitoring program, the density of spawning size oysters (>60 mm) declined in the early 2000s but has increased in more recent years (Figure 14a). An excellent "spat set" (young oysters) in 2006 contributed to high oyster densities in 2008. Scaling the densities up to the full spatial extent of each bed provides an indication of the standing stock of spawning oysters in Great Bay (Figure 14b). While densities peaked in 2008, the standing stock remains lower than in 1995 and 1996 due to the fact that many of the oyster beds are now smaller.

The spatial coverage and abundance of oysters in Great Bay have been affected by a variety of factors, including siltation and disease. In the mid-1990s, two parasitic protozoans, MSX and Dermo, infected and killed many adult oysters. MSX infection rates exceeded 40 percent in 1997 and 1998; in 2008, 27 percent of the oysters tested were infected with MSX. The prevalence of Dermo increased substantially in 2004, and since that time, infection rates have ranged between 63 percent and 76 percent.

The recovery of oysters has substantial ecological implications for the Great Bay Estuary. As oysters filter the water to feed on algae and other particles, they remove pollutants and nutrients, thereby improving water clarity. Assuming that adult oysters can each filter 20 gallons per day, the estimated oyster population in 1970 could filter the estuary's water in four days; today this feat is accomplished only every 100 days or so.

A variety of management measures and research efforts strive to sustain and restore oysters in Great Bay. Harvest regulations promote use of the resource while also protecting oyster populations. In addition, research and conservation programs led by the Jackson Estuarine Lab and The Nature Conservancy focus on improving oyster restoration techniques and developing hard-bottom sites suitable for settlement and growth of oysters in Great Bay. Some of these projects have been supported by the Great Bay NERR through research fellowships to graduate students.

Lobsters

The American lobster is the largest crustacean found in New Hampshire's coastal waters, where it is an important commercial and recreational species. In addition to their value to fisheries, lobsters play important ecological roles as intermediate links in marine food chains. Lobsters feed on bivalve shellfish, crabs, and other invertebrates; in turn, they are preyed upon by large predatory fish, such as cod and striped bass.

Since 1992, the Marine Fisheries Division has monitored the relative abundance of juvenile lobsters in the Great Bay Estuary. This survey is conducted by divers from April to November. The annual trends in juvenile lobster abundance observed in this survey are relatively stable until 2006 (Figure 15). In May of 2006, 11.5 inches of rain fell in three consecutive days, lowering the salinities in the estuary to 1.6 ppt. Many lobsters in the estuary died during this freshet, and others likely moved out to the harbor and coast. A similar storm in April 2007 may have kept lobsters from entering the estuary in typical numbers as well. Continuing the survey into future years will be critical for determining whether lobster abundance returns to levels observed before 2006.

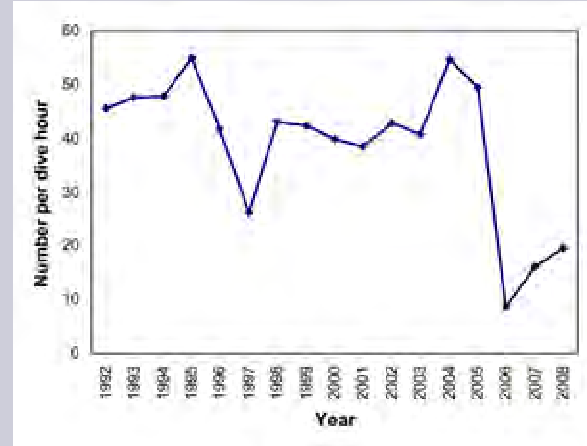

Figure 15. Catch per unit effort (number per dive hour) of lobsters observed in the upper Piscataqua River from 1992 to 2008. Data provided by New Hampshire Fish and Game Department.

A CHANCE TO DISCOVER

leven pairs of children's hands are held over the Discovery Tank as if to receive a bowl of soup. A creature with wriggling legs and a pointy tail is gently passed and eagerly received by all but one pair of hands. Not sure of what to expect, the youngster steps back as the horseshoe crab nears her. Encouraging words from classmates bring her forward again, and everyone can see her smile as she balances the animal on her fingertips.

This scene plays out often at the Discovery Tank during Spring Natural History field trips for elementary students at the Great Bay Discovery Center. Holding a horseshoe crab is a rare opportunity to appreciate and admire up close an animal that has lived on earth since before the age of the dinosaurs. Each spring over 2,000 children have a chance to touch an estuarine animal, explore the mudflats, and learn how the salt marsh keeps the estuary clean. These discoveries allow for a better understanding of life in the estuary and an increased likelihood of a stewardship connection to Great Bay in the future.

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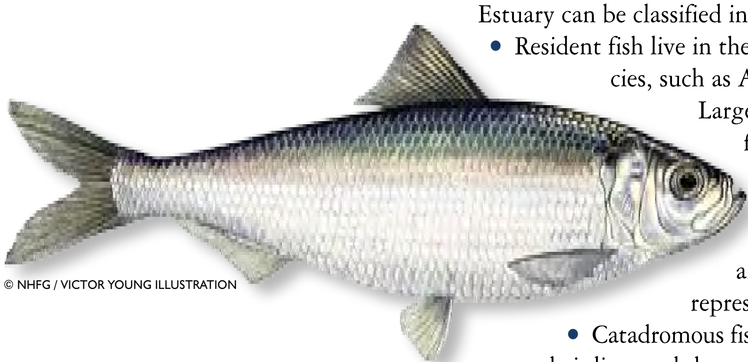
Fish

Many commercially and recreationally valued fish rely on estuaries during a portion of their life history. Estuaries provide sheltered habitats and rich food sources, serving as vital feeding grounds, spawning areas, and nursery habitats for a variety of species. The fish that use the Great Bay Estuary can be classified into five major categories:



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River herring

- Resident fish live in the estuary year round. Many are small prey species, such as Atlantic silverside, killifishes, and sticklebacks. Larger resident species in the estuary include winter flounder, Atlantic tomcod, and cunner.
- Anadromous fish spend most of their lives in the ocean but migrate into freshwater rivers to spawn. River herring (alewife and blueback herring) and rainbow smelt are representative species.
- Catadromous fish live in fresh and brackish waters for most of their lives and then migrate to the ocean to spawn. The American eel is the only catadromous species common in the Great Bay Estuary.
- Ocean migrants use the estuary as a nursery area for juveniles and feeding ground for adults. Species such as Atlantic cod, Atlantic herring, and pollock spawn offshore, but juveniles come into estuaries to take advantage of the protected habitats offered by seagrass beds and shallow tidal creeks. Other species such as striped bass and bluefish migrate into estuaries as adults in search of abundant forage.
- Freshwater fish, typically found in the freshwater tributaries to the estuary, are also a component of the estuarine fish community. Some species can live at the low salinity interface where the tributaries meet the brackish water of the estuary.

Since the establishment of the Great Bay NERR, research and monitoring efforts have focused on anadromous species in the Great Bay Estuary. Therefore, they are emphasized in the remainder of this section.

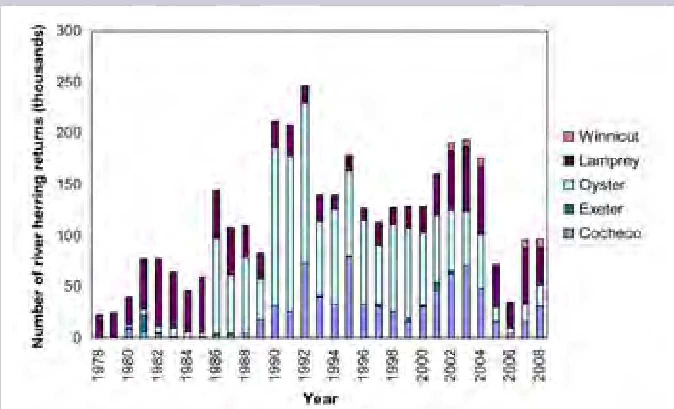

Figure 16. Numbers of river herring returning to fishways on rivers within the Great Bay Estuary from 1978 to 2008. No monitoring was conducted on the Exeter River fish ladder in 1984, 1985, and 1988-1991. In 1994, the Exeter fishway was operated as a swim-through system, and returning fish were not counted. The Winnicut River fish ladder did not effectively pass fish until 1998, so no values are reported for this river in earlier years. Data provided by the New Hampshire Fish and Game Department.

Anadromous fish

For centuries, anadromous fish surged into the rivers of the Great Bay Estuary each spring. Their predictable arrival provided a reliable food source for the Native Americans and early settlers. However, as early as the 1640s, European settlers began constructing obstacles that impeded the upstream migration of anadromous species, including weirs to catch the fish and industrial dams in towns around Great Bay. By the late 1800s, Atlantic salmon reportedly had become rare visitors to Great Bay's rivers. In more recent years, populations of American shad, river herring, and rainbow smelt have experienced declines locally and throughout their range.

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Fish ladder at

River herring

Since the advent of fish ladder construction in the early 1970s, the NH Fish and Game Department's Marine Division has monitored returns of river herring to five rivers in the Great Bay Estuary. A steady increase in the number of returning fish was observed until

GRADUATE RESEARCH HIGHLIGHTS

The Great Bay NERR has supported seven graduate students studying the ecology and restoration of species and biological communities in Great Bay.

STUDENT	YEAR	PROJECT TITLE
Wan-Jean Lee	2007	Engineering through disturbance: Role of horseshoe crabs on soft-sediment communities in Great Bay
Erica Westerman	2006	The effect of increasing primary production and artificial substrates on the success of invasive ascidians in the Great Bay Estuary
Mark Capone	2005	The effects of natural and restored oyster reefs on water quality
Jennifer Greene	2003	Oyster restoration studies in the Great Bay Estuary
Aaren Freeman	2002	The ecological significance of phenotypic plasticity in blue mussels
Gregory Shriver	2000	Distribution and abundance of salt marsh birds breeding in New England
Pamela Morgan	1998	Impacts of two introduced intertidal crab species in northern New England

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Oyster River.

the early 1990s as fish ladder construction or modifications and other restoration efforts proceeded (Figure 16). Returns plateaued in the late 1990s and early 2000s, when populations stabilized near the carrying capacity in certain rivers, particularly the Oyster and Cocheco. Declines of river herring have been noted since 2005 (Figure 16). This downturn can be associated with a variety of conditions: natural population fluctuations, flood events, water quality, or habitat degradation.

Over the entire time period, average river herring returns have been the highest on the Oyster River. Peaks in counts of fish returning to the estuary from 1990 to 1992 were largely attributable to exceptional runs on the Oyster River alone. Substantial returns have also been documented on the Lamprey and Cocheco rivers, with markedly fewer fish returning to the Exeter system. Modifications to the Winnicut River ladder in 1997 and 2002 have improved the returns to this river system.

Wan-Jean Lee collects a sediment core to investigate how infaunal invertebrates are affected by horseshoe crab digging activities.

River herring are harvested as bait for commercial and recreational fisheries, but fishing activities are not considered primary threats due to harvest regulations. The lack of access to upstream spawning habitats, downstream migration pathways, and water quality impairments constitute the greatest threats to these populations. Allowing river herring upriver to spawning habitats is only one part of restoration efforts—pathways for out-migration after spawning or as juveniles are also necessary in some impoundments. Water quality conditions, particularly oxygen concentrations, fall below levels that are needed for the survival of juveniles. Improving water quality in impoundments, maintaining or improving fishways, constructing new upstream and downstream fishways, and removing dams on coastal rivers are critical activities to improve riverine connectivity and habitat.

Rainbow smelt

Rainbow smelt move into the Great Bay Estuary and its tributaries during the winter to feed. In the early spring, smelt move to head of tide areas of the tributaries on nighttime high tides to lay eggs over gravel substrate. Migration of rainbow smelt is restricted completely by dams; due to their small size, they cannot pass through fishways. Instead, they spawn at the base of the dams in Great Bay, although habitat conditions below the dams may be less than ideal for spawning and egg development.

Rainbow smelt

Surveys conducted during the winter ice fishery in Great Bay indicate that the relative abundance of smelt in the estuary follows a cyclical pattern with a downward trend since 1989. Similar declines have been noted throughout the range of the species. As a result, the National Marine Fisheries Service listed rainbow smelt as a "species of concern" in 2004, indicating a need for conservation attention.

Dams are often cited as a key factor in declines of anadromous species, such as smelt. But the recent declines in smelt spawning populations are not likely due to habitat restrictions alone. Instead, water quality and habitat degradation may affect smelt spawning success. In addition, smelt are important prey for a variety of larger fish and birds, and increasing predator populations may influence smelt abundance. Overfishing is not a primary concern in New Hampshire, as fishing effort has decreased in tandem with population declines and is controlled through regulations.

WORKING REGIONALLY TO INVESTIGATE POTENTIAL CAUSES OF RAINBOW SMELT DECLINES

Since 2007, the Great Bay NERR and NH Fish and Game Department have participated in a research initiative with agencies from Maine and Massachusetts to evaluate factors that may contribute to declines in rainbow smelt. The five-year project will provide state and regional baseline data on smelt distribution and abundance, habitat quality, and threats. Field surveys document smelt spawning in rivers of the Great Bay Estuary, including their genetic distinctness and the contaminant and pathogen loads in their body tissues. Smelt abundance, sex ratios, and size distributions are more directed evaluated in the Winnicut and Squamscott rivers. Habitat conditions in each river are assessed by monitoring water quality, algal growth rates, and in-stream habitat parameters. The results will identify conditions that support smelt spawning, threats to spawning habitats and populations, and strategies for protecting smelt in Great Bay and other Northeast rivers.

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Birds

A diverse community of birds exists within the Great Bay Estuary, where over 100 bird species (excluding upland birds) have been observed. Seabirds, shorebirds, wading birds, diving birds, waterfowl, predatory birds, and salt marsh birds are found throughout the estuary during the course of a year. The estuary is also an important migratory stopover along the Atlantic flyway as well as a wintering area for waterfowl and eagles. Due to its significant habitats and diverse bird community, Great Bay has been recognized as an Important Bird Area by N.H. Audubon.

Seabirds, such as gulls and cormorants, are year-round residents of Great Bay. The great blue heron is the most common wading bird, but snowy egrets, green herons, glossy ibis and a variety of other species can all be seen foraging on the mudflats and in shallow waters of the estuary. Sandpipers, plovers, yellowlegs, and killdeer are found along the shores of the Great Bay Estuary, while the Virginia rail, red-winged blackbird, sora, and sharp-tailed sparrow live in the marshes.

Wintering waterfowl

The Great Bay Estuary is particularly important as a wintering area for waterfowl. Aerial surveys indicate that approximately 5,000 birds winter in New Hampshire's coastal waters. Of these birds, 75 percent gather on Great Bay, including almost all of the Canada geese and greater scaup. The total abundance of the five most common species of waterfowl observed in the Great Bay Estuary has increased slightly over the past five decades, but different trends are noted for individual species (Figure 17). While more Canada geese, greater scaup, and mallards have been wintering on Great Bay, the numbers of goldeneye and black ducks have declined. In addition to these five species, at least ten others are typically sighted in small numbers.

The Great Bay Estuary provides a variety of food options to help these birds build energy for reproduction and long migratory flights. Canada geese feed on grain in fields bordering the estuary and on eelgrass when it is exposed at low tide. Diving ducks, such as scaup and goldeneye, consume several species of clams. Dabbling ducks, such as black ducks and mallards, forage for seeds, stems, and leaves in salt marshes as well as for snails, clams, and crustaceans on the mudflats. Protecting eelgrass, salt marsh, and mudflat habitats is important for ensuring that the Great Bay Estuary can continue to support waterfowl wintering in the region.

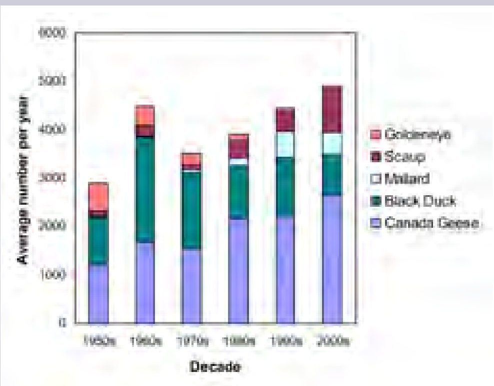
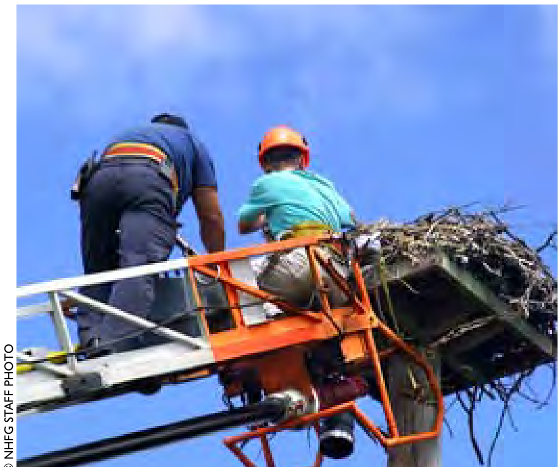


Figure 17. Average number of five most common species of wintering waterfowl observed during aerial surveys of the Great Bay Estuary and coastal New Hampshire. Data provided by the New Hampshire Fish and Game Department.

Protected species

Several endangered and threatened bird species, including bald eagles, common terns, upland sandpipers, Northern harriers, and common loons utilize habitats in the Great Bay Estuary. The estuary supports one of the largest winter populations of bald eagles in New England, and properties managed by the Great Bay NERR provide critical roosting habitat.

Ospreys are also thriving in the Great Bay Estuary and statewide, and they represent a conservation success story. In 1981, only three pairs of ospreys were observed nesting in New Hampshire, all near Lake Umbagog. The construction of nesting platforms and protection of breeding pairs and young offspring enabled ospreys to reproduce successfully and expand their distribution throughout the state. In the Great Bay Estuary and coastal New Hampshire, breeding pairs and young have steadily increased since the late 1980s (Figure 18). In 2008, a record 30 young fledged from nests in this area. Similar successes have been noted throughout the state, with 87 total young fledged in 2008. The scope and speed of the osprey's recovery allowed the NH Fish and Game Department to remove it from the state's list of threatened species in 2008.



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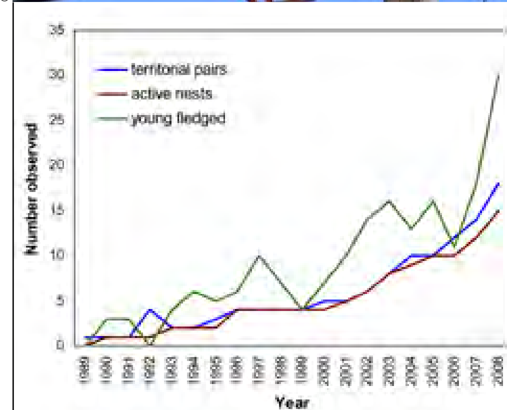

Figure 18. Number of osprey observed in the Great Bay Estuary and coastal New Hampshire since 1989. Data provided by NH Audubon.

Protecting biological communities in the Great Bay Estuary

Maintaining the diverse and productive biological communities in the Great Bay Estuary is a key goal of the Great Bay NERR. In partnership with other agencies and organizations, the Reserve helps advance multifaceted efforts to protect and restore habitats and species within the estuary and throughout its watershed.

Protecting and restoring habitats

The diverse habitats in the Great Bay Estuary provide the foundation that supports aquatic and terrestrial communities. Fish and wildlife need healthy places to live, feed, and reproduce. They also need corridors of suitable habitat so that they can move from place to place. Further, many habitats offer services that humans value—from water filtration provided by salt marshes to the recreational enjoyment of exploring riparian forests. The Great Bay NERR strives to protect critical habitats primarily through its land conservation efforts, which are focused on salt marshes and upland habitats. In addition, the Great Bay NERR works with other organizations to help advance understanding, protection, and restoration of estuarine habitats, such as seagrass beds and salt marshes.

Ensuring habitat access

While protecting habitats is important for sustaining species in Great Bay, ensuring that species can access the habitats they need is also critical. Species that migrate through waterways or the landscape are threatened by barriers that impede their movements. Anadromous fish encounter dams in all of the major tributary rivers of the Great Bay Estuary. The construction and maintenance of fish ladders is essential to ensure that these fish can get above the dams to spawning habitats in freshwater portions of rivers. In addition, removing dams will further support migrations of anadromous fish. Removal of a head-of-tide dam in the Bellamy River allowed fish access to one-half mile of freshwater spawning habitat before the next mill dam. The removal of the head-of-tide dam in the Winnicut River is underway (fall 2009) and will allow anadromous fish access to over 30 additional miles of river habitat.

For terrestrial species, the construction of roads and developments that fragment habitats can impede their movement through the landscape. Connecting fragmented habitats to one another enhances migration and movement pathways for these species. To help accomplish this goal, the Great Bay NERR and its partner conservation organizations prioritize the acquisition and protection of land parcels that fill gaps between other conserved lands and improve habitat connectivity.

Managing harvest

Hunting and fishing are important recreational and commercial activities within the Great Bay Estuary and its watershed. The New Hampshire Fish and Game Department regulates these activities to ensure that species populations and their harvest can be sustained. Harvest of upland game birds, waterfowl, and mammals is controlled by season length and bag limits. Fisheries are managed through similar methods, with the additional use of size limits to ensure that fish survive to reproductive ages. Managing harvest of fish and game species is critical for supporting on-going commercial and recreational uses while ensuring that the harvested species are sustained over the long term.

PARTNERING WITH PROJECT OSPREY

From 2000 to 2005, the NH Fish and Game Department joined forces with Public Service of New Hampshire (PSNH) and New Hampshire Audubon to promote recovery of osprey. Through this effort—termed Project Osprey—PSNH established nesting platforms in potential osprey habitats, including one in the Great Bay NERR on the Squamscott River. The Squamscott platform was constructed in 1992 and has been actively used by breeding pairs of ospreys since 1993.

The Great Bay NERR was involved in Project Osprey in a variety of ways. Staff members assisted in developing a teaching curriculum focused on osprey biology and ecology: The Return of the Fish Hawk. A travelling trunk of materials is available from the Great Bay Discovery Center for teachers interested in implementing this curriculum. In addition, Great Bay NERR staff created and trained the Great Bay Osprey Stewards, a team of volunteers who monitor osprey nesting sites and behavior. Data collected by the Osprey Stewards is critical for tracking osprey abundance in the Great Bay Estuary. Since 2005, the Great Bay Osprey Stewards have been coordinated by New Hampshire Audubon, and their diligent work of observing and reporting on osprey populations continues today.

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LAND CONSERVATION PROTECTS ENDANGERED SPECIES

Conserving land near Great Bay has important implications for rare and endangered species. The Blanding's turtle (above), an endangered species in New Hampshire, needs large undeveloped landscapes with a diversity of habitat types, including freshwater wetlands and vernal pools. In the Great Bay area, large swaths of suitable habitat for Blanding's turtles are concentrated on lands protected and managed by the Great Bay NERR. Active management of certain protected properties also benefits other species. Several protected areas within the Great Bay NERR are managed to protect and create early successional habitat, which is required by another endangered species in the state—the New England cottontail. Post-agricultural forest regeneration has resulted in this habitat type becoming relatively rare. Efforts to protect and restore early successional conditions have direct benefits for New England cottontails as well as for a wide variety of other species that use this habitat.

The future directions of the Great Bay NERR will help sustain a healthy Great Bay ecosystem and thriving human communities.

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Future Directions

In the 20 years since its inception, the Great Bay NERR has established research, education, and stewardship programs to advance understanding and protection of the Great Bay Estuary and its watershed. During those same 20 years, the Great Bay ecosystem has experienced many changes in its land use, water quality, habitats, and biological communities. In the face of these changes and new concerns about how climate change may affect local ecosystems and communities, the multifaceted efforts of the Great Bay NERR will become even more important.

As the Reserve looks toward the future, it is building and expanding programs that will anticipate the implications of these challenges and effectively respond to them. By integrating research, education, and stewardship elements, these programs will develop, apply, and disseminate information needed to address pressing issues facing the ecosystem. These efforts will be strengthened and their relevance broadened through collaborations with other partners and the involvement of committed citizens. As a whole, the future directions of the Great Bay NERR will help sustain a healthy Great Bay ecosystem and thriving human communities.

Focus themes

Moving forward, the Great Bay NERR will continue to focus on four themes—(1) land conservation and stewardship, (2) water quality, (3) habitats and biological communities, and (4) climate change impacts and adaptation. Within each of these themes, the Reserve's research, stewardship, and education programs will work together to develop scientific information needed to understand an issue and its implications, apply this information to guide stewardship within the Reserve, and transmit this information to local citizens and public decision-makers who shape management directions affecting the estuary. Some examples of the Reserve's plans associated with each theme are provided below.

Land Conservation and Stewardship

As the human population around Great Bay continues to grow, the development and expansion of residential areas, transportation corridors, and other infrastructure will continue to change the landscape of the Great Bay watershed. Protecting lands in the watershed offers one mechanism for mitigating some of the impacts of development. Other impacts can be minimized through effective planning and the use of low impact development approaches. Land protection and stewardship efforts provide a range of benefits to the ecosystem and human communities, including: (1) supporting habitats for diverse species, (2) preserving water quality, (3) enhancing resilience to the impacts of climate change, and (4) ensuring public access to multi-use areas.

In the coming years, the Reserve will continue to play a key role in protecting and stewarding lands around Great Bay. In addition, the Great Bay NERR will work with local communities to assess how land use changes may affect them and how they can effectively address some of the impacts associated with development. Stewardship efforts on Reserve-managed lands will be structured to provide lessons and insights that may be useful to other land managers in the Great Bay watershed and beyond.

Some specific efforts that the Great Bay NERR will pursue related to land conservation and stewardship include:

- Continuing conservation efforts and management of lands within the Great Bay NERR boundary.
- Implementing the New Hampshire Wildlife Action Plan through protection and restoration of critical habitats on Reserve-managed lands and outreach to private landowners.
- Monitoring and treating invasive species, using experimental designs so that the effectiveness of multiple approaches can be compared and applied to guide future control efforts within and beyond the Reserve.
- Expanding the types of low impact development approaches demonstrated at the Great Bay Discovery Center and continue providing training opportunities for homeowners and decision-makers who want to implement low impact development options.
- Assisting towns in the Great Bay watershed seeking to protect natural resources through land use ordinances and planning.

In the coming years, the Reserve will continue to play a key role in protecting and stewarding lands around Great Bay.

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Water Quality

Rising nutrient concentrations and turbidity levels, coupled with more frequent incidents of low dissolved oxygen, signal concerns about declining water quality in the Great Bay Estuary. In addition, ecological impacts associated with these changes in water quality are being noted; perhaps the most compelling example is seen in recent declines of eelgrass in the estuary. Improving water quality in the Great Bay Estuary is not a simple or straightforward challenge, and accomplishing this goal will require concerted public and private initiatives. However, neglecting this challenge could have significant ecological and social consequences.

The Great Bay NERR will remain centrally involved in efforts to better understand and address water quality in the estuary. The Reserve will continue monitoring the estuary's water quality as part of the NERRS' System-Wide Monitoring Program and working with the Piscataqua Region Estuaries Partnership and NH Department of Environmental Services to use the data to assess water quality trends and standards compliance in the Great Bay Estuary. Additional future initiatives focused on water quality will include:

- Advancing scientific research to understand and quantify the ecological implications of water quality degradation.
- Working regionally within the Gulf of Maine in conjunction with the Northeastern Regional Association of Coastal Ocean Observing Systems to understand links between inshore and offshore water quality conditions.
- Enhancing citizens' awareness of the hydrologic cycle, the effects of runoff, and actions they can take to improve water quality.
- Building awareness of stormwater management issues and providing decision-relevant scientific information needed by towns to improve stormwater management approaches.
- Supporting regional watershed approaches that will advance collaborative learning and coordinated municipal actions to improve water quality.

Habitats and Biological Communities

Diverse habitats support rich biological communities in the Great Bay Estuary and its watershed. Healthy habitats and species not only are fundamental for sustaining the Great Bay ecosystem, but they also enhance people's appreciation and enjoyment of it—from birdwatching in the marshes to hiking in the forests. Stewarding Great Bay's biological communities requires good information about their status and changes as well as effective management approaches to protect habitats and species.

The Great Bay NERR's future efforts will build on current programs and develop new initiatives to better understand, manage, and enhance public awareness of biological communities in the Great Bay ecosystem. Its land conservation efforts will directly protect key habitats and indirectly benefit a wide range of species. In addition, other efforts will entail:

- Expanding monitoring of seagrass and salt marsh habitats as part of the NERRS' System-Wide Monitoring Program.
- Completing and periodically updating habitat classification and mapping within the Great Bay NERR.
- Monitoring populations of key species within the Great Bay Estuary, in conjunction with the NH Fish and Game Department's Marine Fisheries Division when appropriate.
- Advancing restoration science by monitoring and assessing the outcomes of different types of habitat restoration approaches.
- Conducting research on anadromous fish species and factors associated with recent population declines and using the information gained to develop conservation strategies to protect these species.
- Educating school groups and the public about the biology and ecology of Great Bay.

Climate Change

Throughout the Northeast, signs of a rapidly changing climate are becoming more pronounced each year. As climate change proceeds, coastal New Hampshire is likely to experience increasing temperatures, rising sea levels, and more storms. These changes have substantial implications for the Great Bay ecosystem, as species and habitats may shift in response to changes in temperature and sea level rise. In addition, human communities in the Great Bay watershed will be affected by increases in the magnitude and frequency of flood events due both to sea level rise and increased precipitation.

Future efforts of the Great Bay NERR related to climate change will focus on anticipating and assessing local ecological and socio-economic impacts and providing decision-relevant information to resource managers and community decision-makers. In addition, the Reserve will actively work with local communities to ensure that they can apply this information to support effective adaptation planning. Specific activities will include:

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- Establishing vertical control points and tide gauges within the Reserve and acquiring LIDAR data (topographic data collected with remote sensing equipment) for the region to develop the high-resolution elevation data sets necessary to understand the impacts of sea level rise and freshwater flooding on natural habitats and human communities.

- Implementing long-term programs to monitor changes in key habitats and species in response to climate change. Examples include seagrass beds, salt marshes, juvenile fish and marsh birds, as well as invasive species such as the woolly adelgid and Asian longhorn beetle.

- Working with communities through the Coastal Training Program to identify and address their needs for climate-related information, then supporting their efforts to use this information for infrastructure decisions, climate change adaptation planning, and coastal hazard mitigation.

- Collaborating with university scientists to assess the risk of 100-year floods in the context of changes in climate and land use and providing decision-relevant products to enable local communities to understand how future flooding may affect them. With support from the Cooperative Institute for Coastal and Estuarine Environmental Technology, this assessment will be conducted in the Lamprey watershed from 2009 to 2011; later efforts will expand to other parts of the Great Bay watershed.

- Developing partnerships to assess how climate change impacts, particularly changes in precipitation patterns, may affect water quality in the Great Bay Estuary.

Addressing these four priorities has substantial implications for the Great Bay ecosystem and local communities. While the challenges of effectively addressing each issue are substantial, so too are the capacities brought to bear on them by the Great Bay NERR. Its combined focus on research, education, and stewardship enables the Reserve to approach and address key issues in an integrated, site-based manner. In addition, the Reserve's partners and many dedicated citizens contribute additional resources and capacities needed to comprehensively address these issues. These individual and organizational partners will remain critical as the Reserve seeks to advance watershed-scale approaches to address important issues facing Great Bay in coming years.

Healthy habitats and species not only are fundamental for sustaining the Great Bay ecosystem, but they also enhance people's appreciation and enjoyment of it.

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While the challenges of effectively addressing each issue are substantial, so too are the capacities brought to bear on them by the Great Bay NERR.

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Notes:

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